Baryon Spectroscopy in (π, 2π) Reactions with 10^6 Hz Beams at J-PARC

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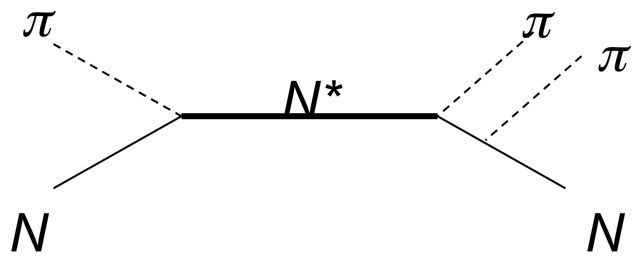
for J-PARC E45 Collaboration
INPC2016, 13 Sep 2016, Adelaide

1. Introduction
2. J-PARC E45 design
3. Detector status
5. Summary

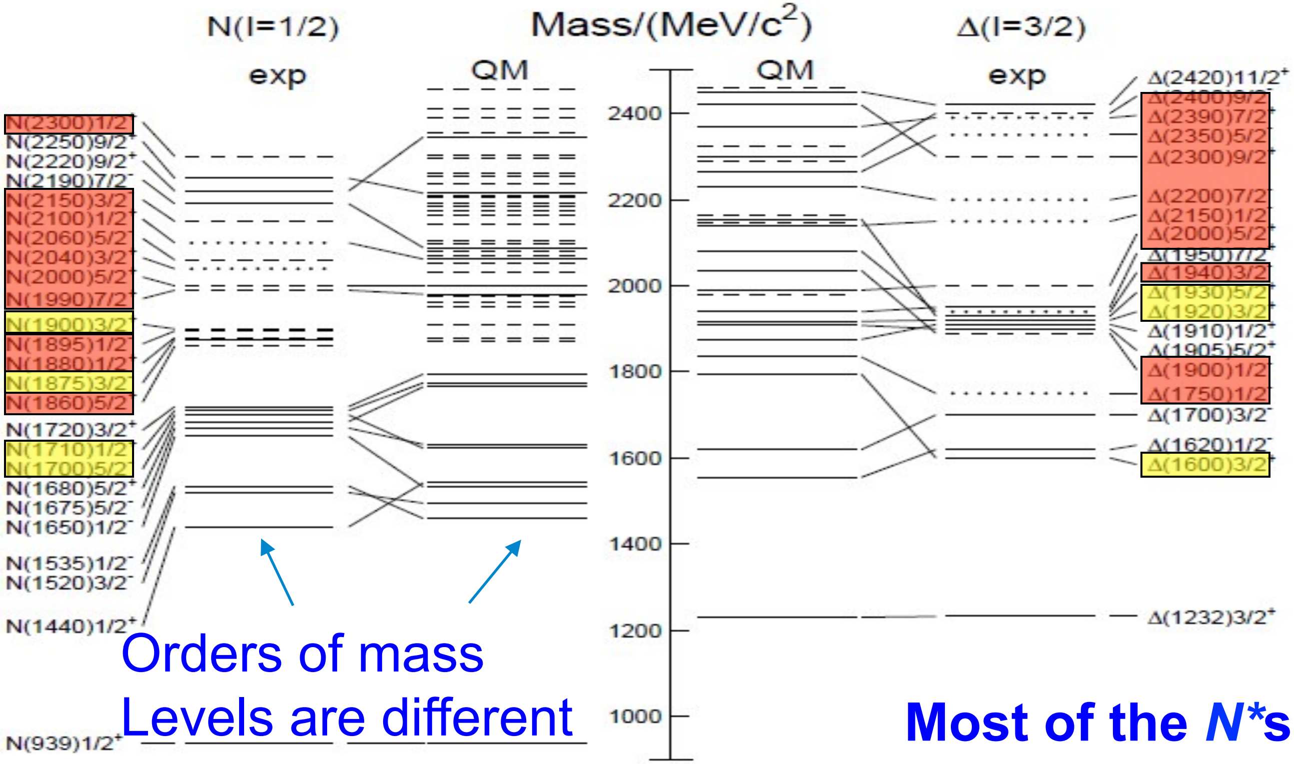
J-PARC E45

Proposed to study baryon resonances in (π,2π) reactions.

- Precise measurements of baryon resonance properties
- Deeper understanding of non-perturbative QCD
- Search for new baryon states
  - *e.g.* hybrid baryons (*qqqg*)



Baryon mass: Experiment vs Quark Model



Many baryon resonances have not been established experimentally.

**** established

***

* **

Orders of mass Levels are different

PDG 2014

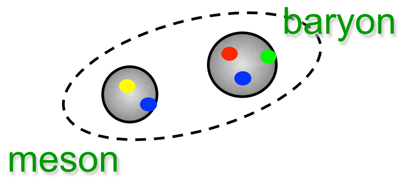
Most of the *Ns so far were measured from**

$$\pi N \to \pi N\,,\quad \gamma N \to \pi N$$

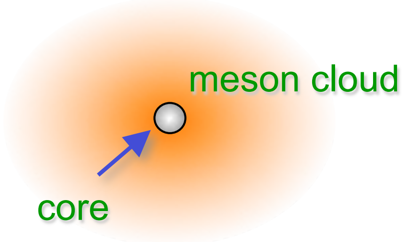
Dynamical Coupled-Channels model (ANL-Osaka)

Matsuyama, Sato, Lee, Phys. Rep. 439,193 (2007)

Physical N^*s will be a "mixture" of the two pictures:



$$|N^*\rangle = |MB\rangle$$



$$|N^*\rangle = |qqq\rangle + |\mathrm{m.c.}\rangle$$

$$V_{a,b} = v_{a,b} + \sum_{N^*} \frac{\Gamma^\dagger_{N^*,a}\Gamma_{N^*,b}}{E - M_{N^*}}$$

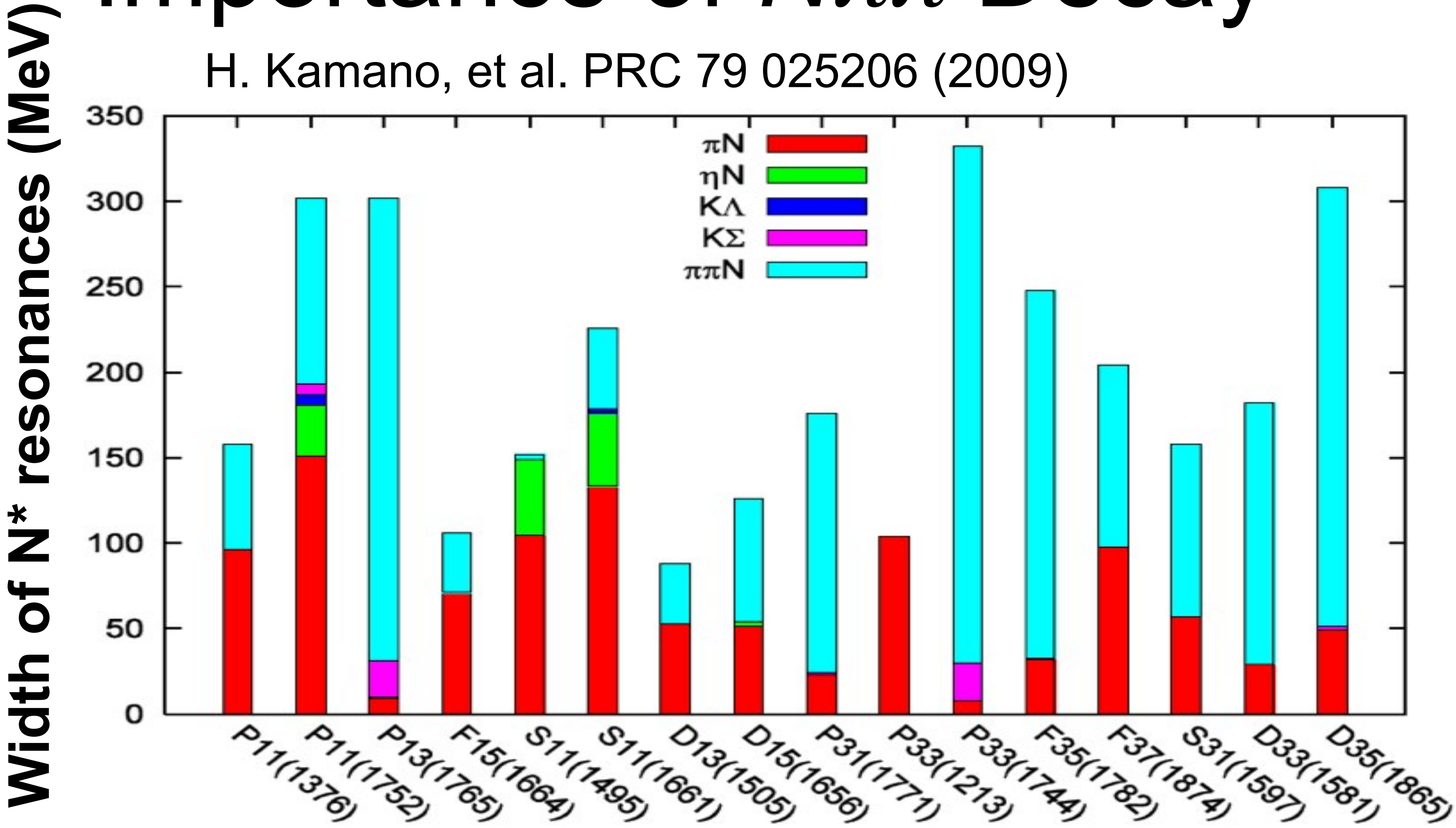
✓ Transition potentials:

exchange potentials of ground state mesons and baryons

bare N^* states

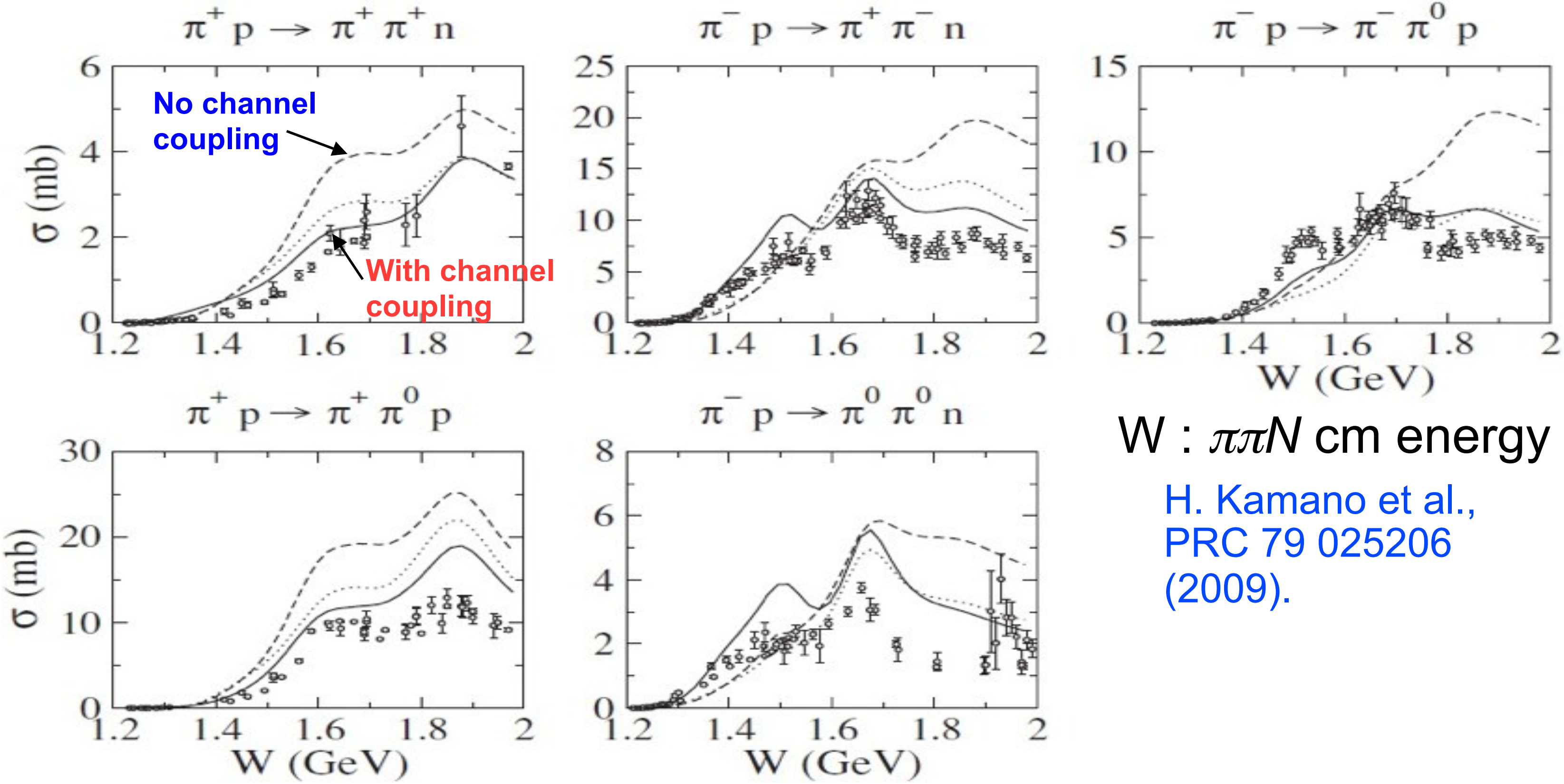
Importance of $N\pi\pi$ Decay

H. Kamano, et al. PRC 79 025206 (2009)



World's $\pi N \rightarrow \pi\pi N$ data

Only 240K events measured in 1970's

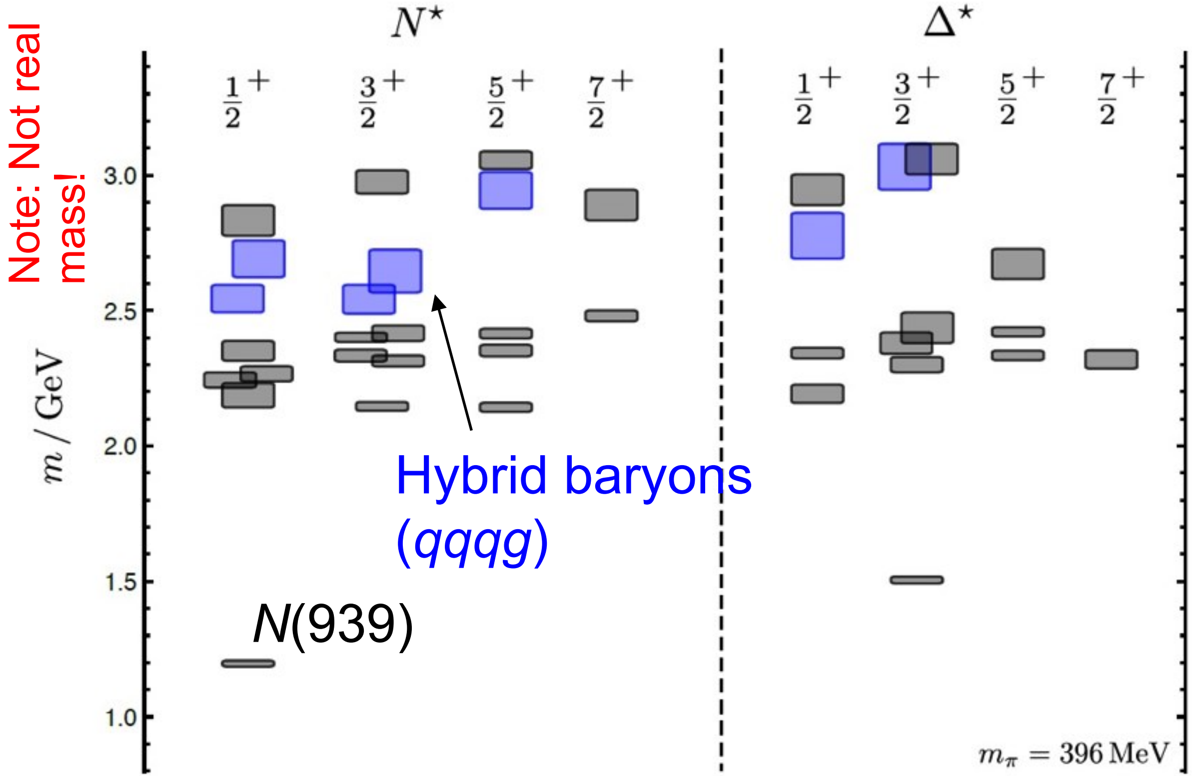


W : $\pi\pi N$ cm energy

H. Kamano et al., PRC 79 025206 (2009).

Recent Lattice QCD calculations

J. Dudek et al., PRD85 (2012) 054016



J-PARC E45 spectrometer

Measuring $(\pi,2\pi)$ in large acceptance TPC (HypTPC)

$\pi^- p \rightarrow \pi^+\pi^- n,\ \pi^0\pi^- p$ *2 charged particles* + *1 neutral particle*

$\pi^+ p \rightarrow \pi^0\pi^+ p,\ \pi^+\pi^+ n$ *→missing mass technique*

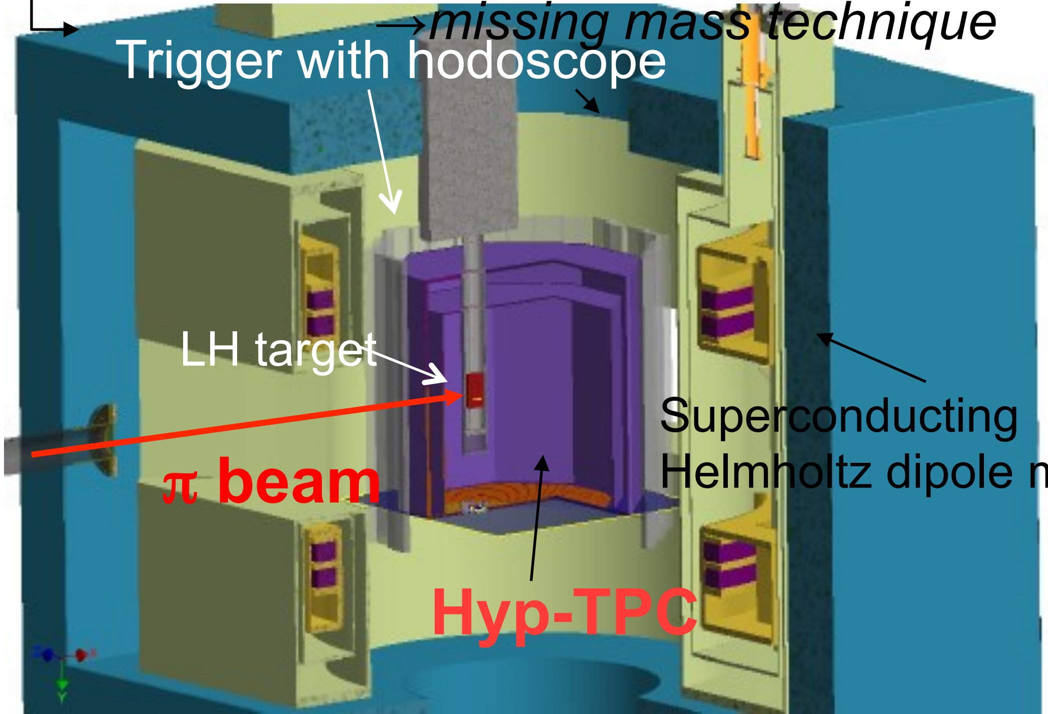
$\pi N \rightarrow KY$ *(2-body reaction)*

$\pi^- p \rightarrow K^0 \Lambda,$

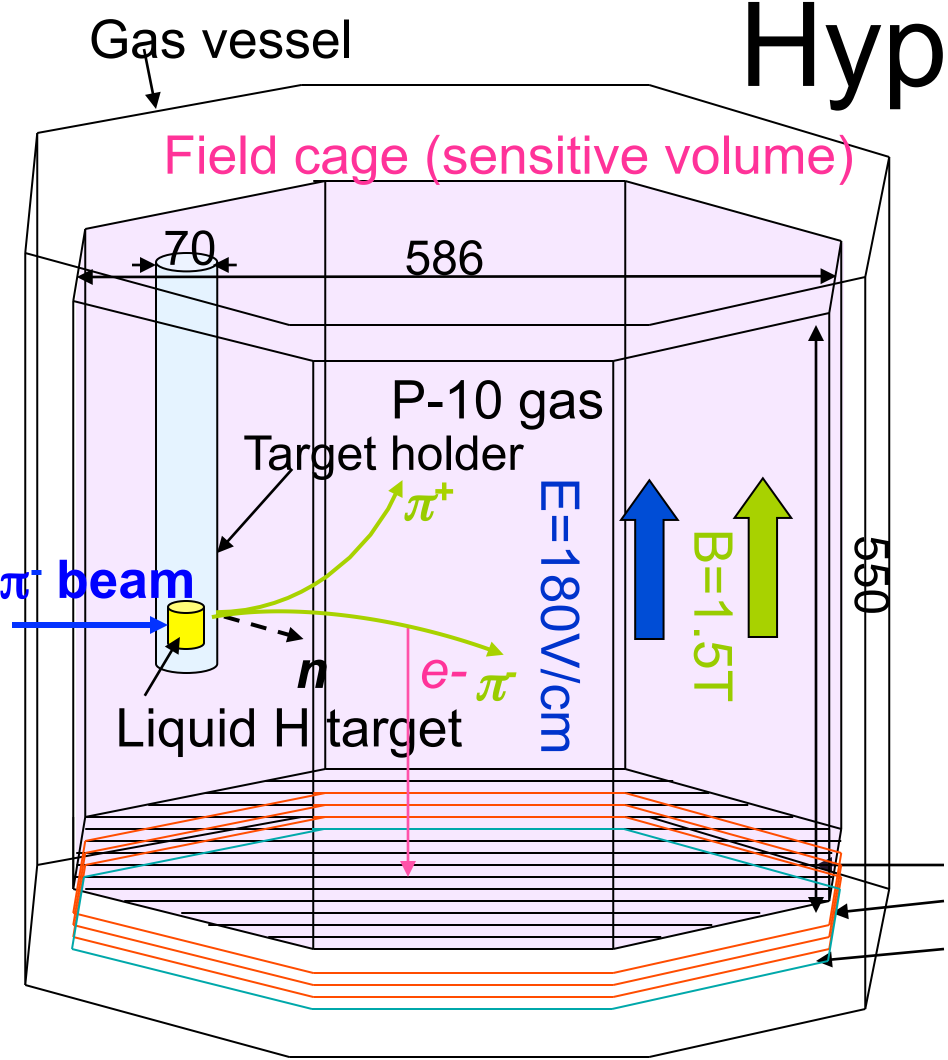
$\pi^+ p \rightarrow K^+ \Sigma^+$ $(I=3/2,\ \Delta^*)$

π^{+-} beam on liquid-H target

p= 0.73 – 2.0 GeV/c



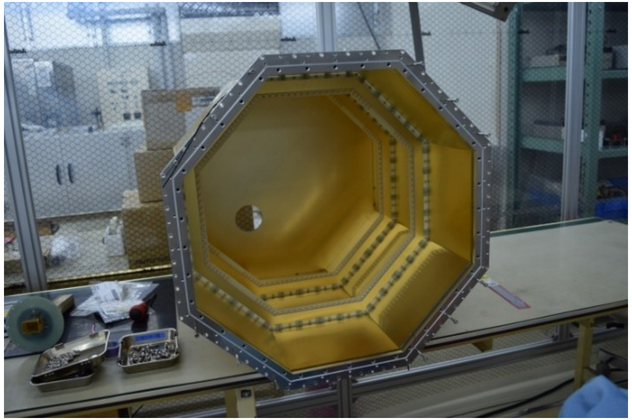
HypTPC

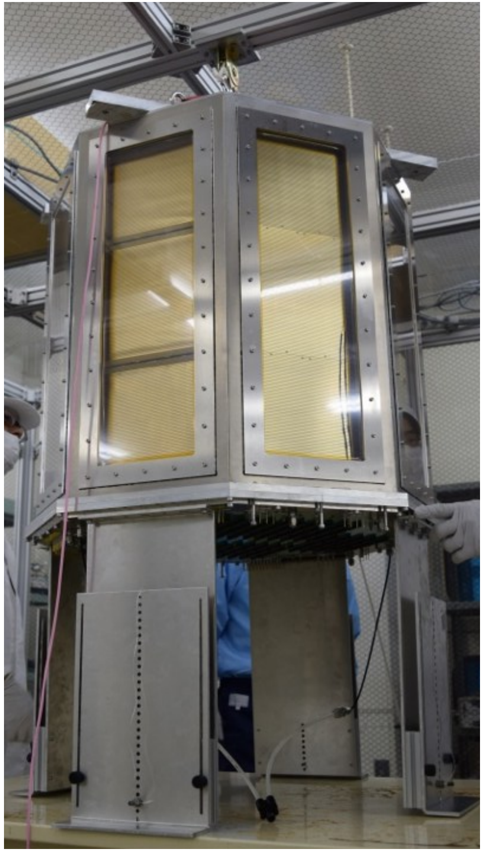


- Large acceptance
  - Liquid-Hydrogen target inside
- High-rate capability with suppression of positive-ion backflow causing distortion of trajectories
  - Gating Grid
  - GEM (Gas Electron Multiplier)
- Good momentum resolution (1-3%) with B-field and fine-segmented pads
  - 2.5 mm x 10 mm pad
  - No. of pads = 5800

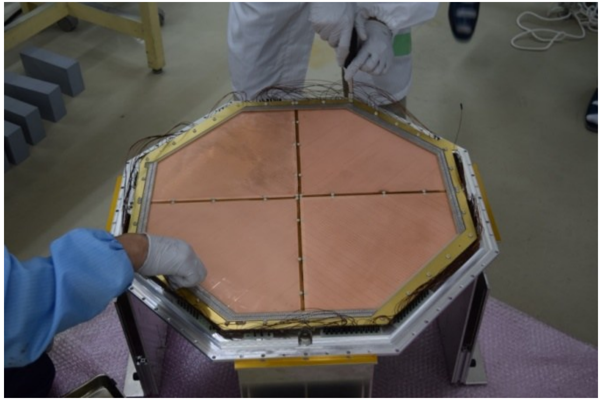
HypTPC

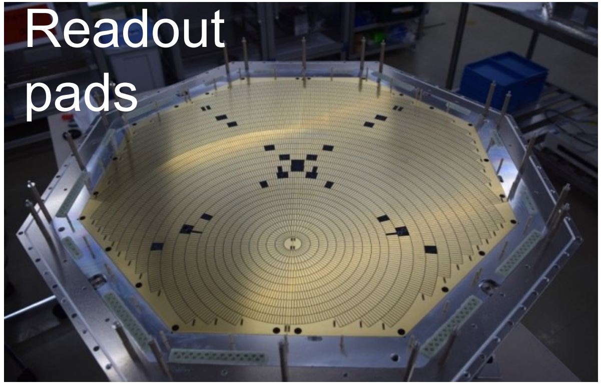
Field cage





GEM



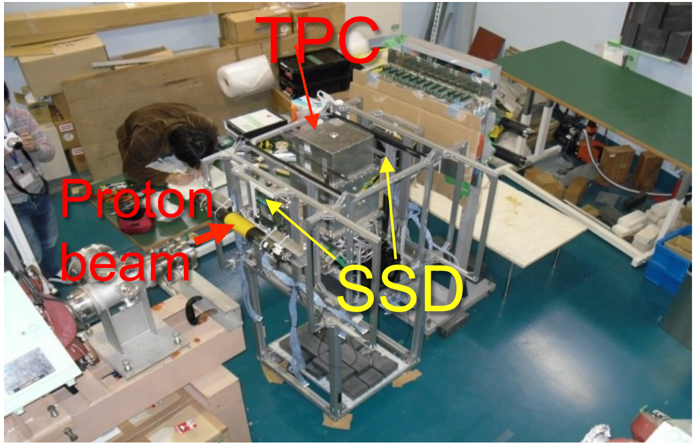


Completed
Beam test at ELPH in
Nov 2016

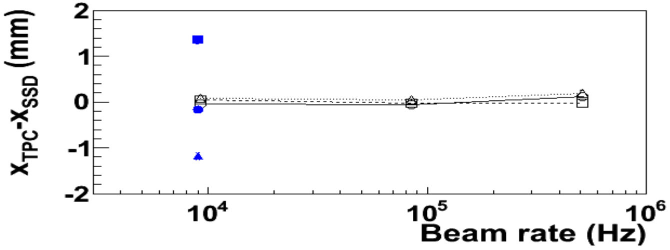
Prototype TPC test

- Beam test at RCNP (Osaka Univ.)
  - Proton beam at 400 MeV
  - Beam rate up to 10^6 Hz/cm^2

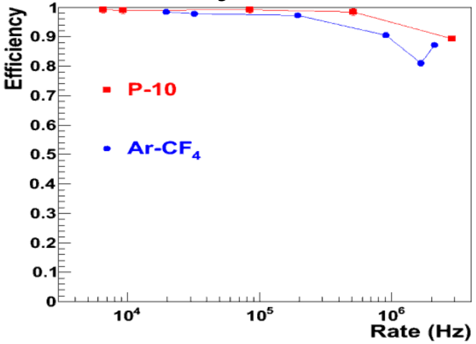
NIMA763(2014)65-81



Hit position distortion <0.1mm

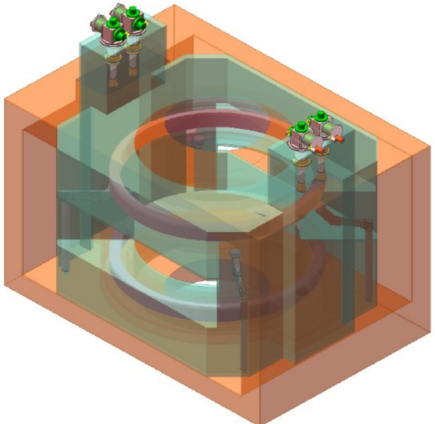


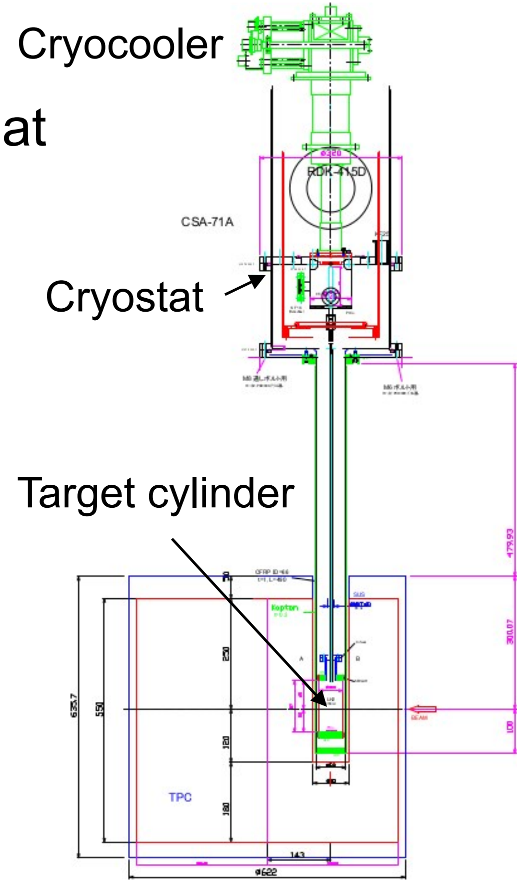
Efficiency>95% at 10^6Hz



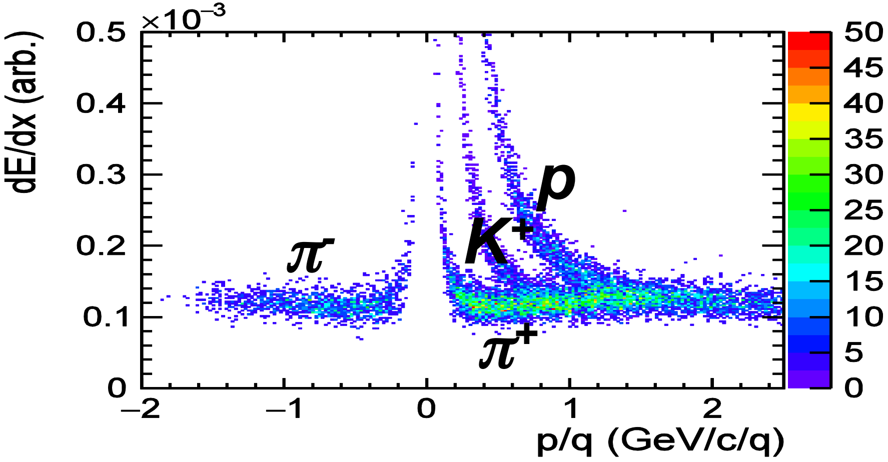
Helmholtz magnet and Liq-H target

- Excitation test of the magnet at KEK from Nov. 2016
  - B<=1.5T
  - Transverse field < 3%
- Target construction in 2017

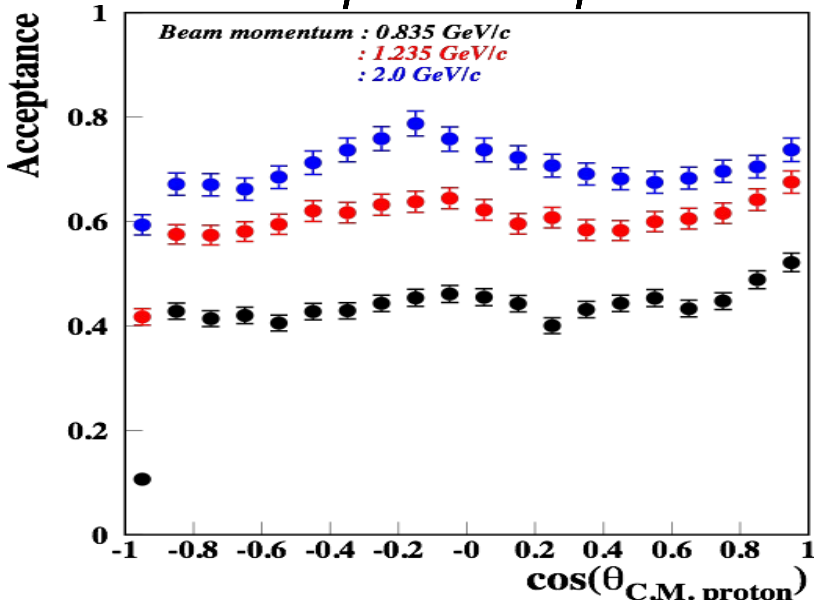




Simulated PID and acceptance



$\pi^+ p \rightarrow \pi^+ \pi^0 p$



π/K : p<=0.5 GeV/c
π/p : p<=1.1 GeV/c

p_p > 300 MeV/c

Expected statistics

- π beam rate : ~10^6 / cycle (6s)
- Liquid H target : 5 cm thickness
- TPC acceptance : 40%
- $(\pi,2\pi)$ cross section : ~2 mb
- ⇨ 160 events / cycle (6 s)
- Background : elastic scattering
  3200 events / cycle

・Energy range : 1.50 – 2.15 GeV
・No. of bins : π^- beam : 24 (energy) x 20 (angle)
  π^+ beam : 23 (energy) x 20 (angle)
・No. of events / bin : 32 K

⇨ 30M events in 15 days

Increase world's $\pi\pi N$ data (240K) by a factor of 130

Summary

- We proposed J-PARC E45 to resolve baryon excited states up to 2 GeV/c^2 in $(\pi,2\pi)$ reactions, which will improve previous data statistics by two-orders of magnitude.
- The E45 spectrometer will measure $(\pi,2\pi)$ reactions with 10^6 Hz pion beams in a large acceptance TPC with 2-charged particle trigger.
- The spectrometer will be ready in 2017.

J-PARC E45 collaboration list

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J.K. Ahn	(Korea Univ)
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K. Ozawa	(KEK)
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R. Schumacher	(Carnegie Melon Univ)
D. M. Manley	(Kent State Univ)
L. Guo	(Florida International Univ)
P. Cole , A. Forest, D. McNulty	(Idaho State Univ)
T.S.-H. Lee	(Argonne National Lab)
T. Sato, H. Kamano	(Osaka Univ)
Y. Azimov	(Petersburg Nuclear Physics Institute)
V. Shklyar	(Univ Giessen)
A. Svarc	(Ruder Boskovic Institute)
S. Ceci	(RBI-Zagreb)
M. Hadzimehmedovic, H. Osmanovic	(Univ Tulza)

Backup

N* states and PDG *'s

Particle	$L_{2I\cdot 2J}$	status	$N\pi$	$N\eta$	ΛK	ΣK	$\Delta\pi$	$N\rho$	$N\gamma$
$N(939)$	P_{11}	****							
$N(1440)$	P_{11}	****	****	*			***	*	***
$N(1520)$	D_{13}	****	****	***			****	****	****
$N(1535)$	S_{11}	****	****	****			*	**	***
$N(1650)$	S_{11}	****	****	*	***	**	***	**	***
$N(1675)$	D_{15}	****	****	*	*		****	*	****
$N(1680)$	F_{15}	****	****	*			****	****	****
$N(1700)$	D_{13}	***	***	*	**	*	**	*	**
$N(1710)$	P_{11}	***	***	**	**	*	**	*	***
$N(1720)$	P_{13}	****	****	*	**	*	*	**	**
$N(1900)$	P_{13}	**	**					*	
$N(1990)$	F_{17}	**	**	*	*	*			*
$\Delta(1232)$	P_{33}	****	****	F					****
$\Delta(1600)$	P_{33}	***	***	o			***	*	**
$\Delta(1620)$	S_{31}	****	****	r			****	****	***
$\Delta(1700)$	D_{33}	****	****	b		*	***	**	***
$\Delta(1750)$	P_{31}	*	*	i					
$\Delta(1900)$	S_{31}	**	**	d		*	*	**	*
$\Delta(1905)$	F_{35}	****	****	d		*	**	**	***
$\Delta(1910)$	P_{31}	****	****	e		*	*	*	*
$\Delta(1920)$	P_{33}	***	***	n		*	**		*
$\Delta(1930)$	D_{35}	***	***			*			**
$\Delta(1940)$	D_{33}	*	*	F					
$\Delta(1950)$	F_{37}	****	****	o		*	****	*	****

**** : existence is certain, and properties are at least fairly well explored.

***: Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, etc. are not well determined.

Most of the N*s so far were extracted from

$$\pi N \to \pi N \ , \quad \gamma N \to \pi N$$

Octet Assignments (PDG)

$L(\pi N)_{2I2J}$

		J^P	(D, L_N^P)	S	Octet members				Singlets
L=0	P_{11}	$1/2^+$	$(56,0_0^+)$	1/2	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
	P_{11}	$1/2^+$	$(56,0_2^+)$	1/2	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(?)$	
L=1	S_{11}	$1/2^-$	$(70,1_1^-)$	1/2	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(?)$	$\Lambda(1405)$
	D_{13}	$3/2^-$	$(70,1_1^-)$	1/2	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
	S_{11}	$1/2^-$	$(70,1_1^-)$	3/2	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$	$\Xi(?)$	
	D_{13}	$3/2^-$	$(70,1_1^-)$	3/2	$N(1700)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
	D_{15}	$5/2^-$	$(70,1_1^-)$	3/2	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$	$\Xi(?)$	
L=0	P_{11}	$1/2^+$	$(70,0_2^+)$	1/2	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Xi(?)$	$\Lambda(?)$
L=2	P_{13}	$3/2^+$	$(56,2_2^+)$	1/2	$N(1720)$	$\Lambda(1890)$	$\Sigma(?)$	$\Xi(?)$	
	F_{15}	$5/2^+$	$(56,2_2^+)$	1/2	$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$	$\Xi(2030)$	

Mass hierarchy problem with L=1, S=3/2 !!

Here, there are more assignments, but are they correct?? (Maybe)

Decuplet Assignments (PDG)

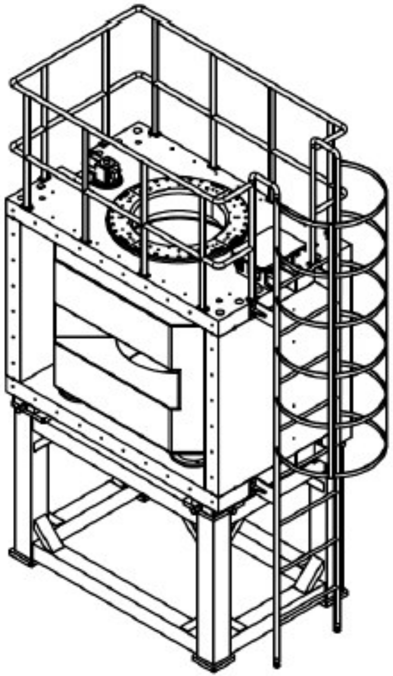
		J^P	(D, L^P_N)	S				
L=0	P_{33}	$3/2^+$	$(56,0_0^+)$	$3/2$	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$
	P_{33}	$3/2^+$	$(56,0_2^+)$	$3/2$	$\boxed{\Delta(1600)}$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
L=1	S_{31}	$1/2^-$	$(70,1_1^-)$	$1/2$	$\Delta(1620)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
	D_{33}	$3/2^-$	$(70,1_1^-)$	$1/2$	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
L=2	F_{35}	$5/2^+$	$(56,2_2^+)$	$3/2$	$\Delta(1905)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$
	F_{37}	$7/2^+$	$(56,2_2^+)$	$3/2$	$\Delta(1950)$	$\Sigma(2030)$	$\Xi(?)$	$\Omega(?)$
L=4		$11/2^+$	$(56,4_4^+)$	$3/2$	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$

From π-scatt. database: all **** rated.

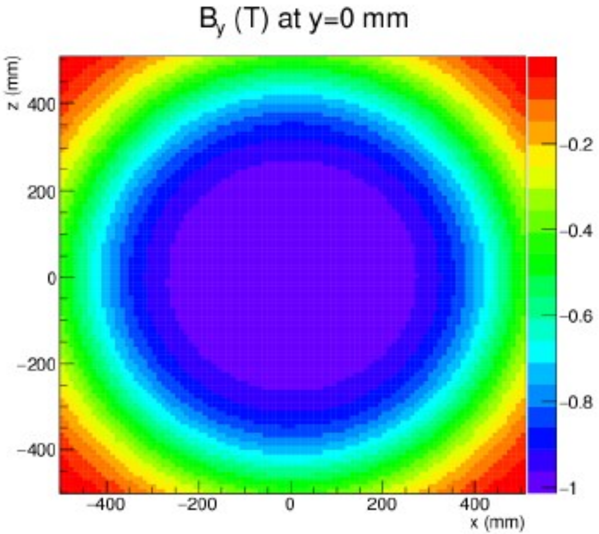
Lots of missing states! Lack of K-scatt. data or photoproduction data.

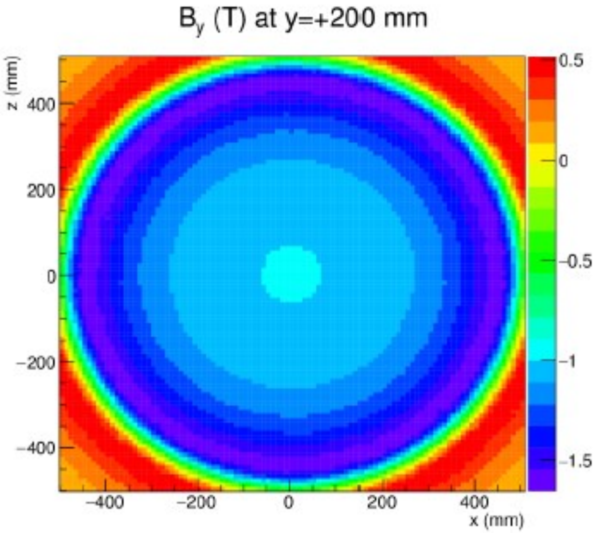
Superconducting Dipole Magnet

- Magnetic field at center : 1.5 T
- Conduction cooling with two GM refrigerators
- Coil diameter : 1000 mm
- Conductor : ϕ 0.77 mm, Cu/SC=2.4, PVA insulation
- Number of turns : $7259.5/$ coil (78×96) and 23.4 km per coil
- Operation current : 99.9 A
- Total inductance : 251 H with yoke
- Weight : 10 ton (the yoke thickness of 125 mm)
- Field uniformity $B_r/B_y < 1\%$ over the inner volume of $r = 250$ mm



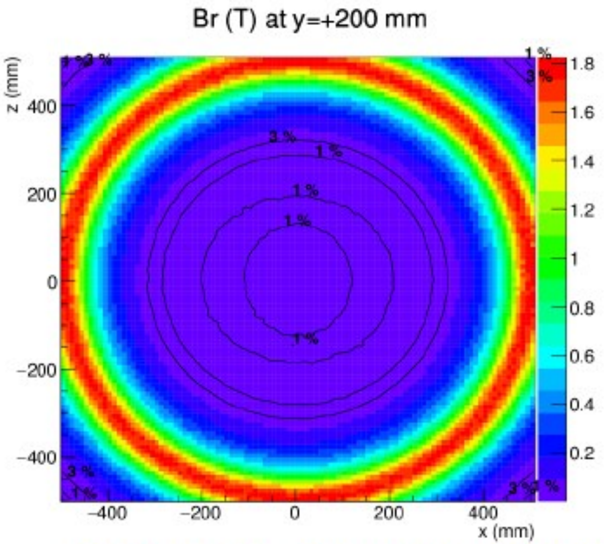
Vertical Magnetic Field Distributions

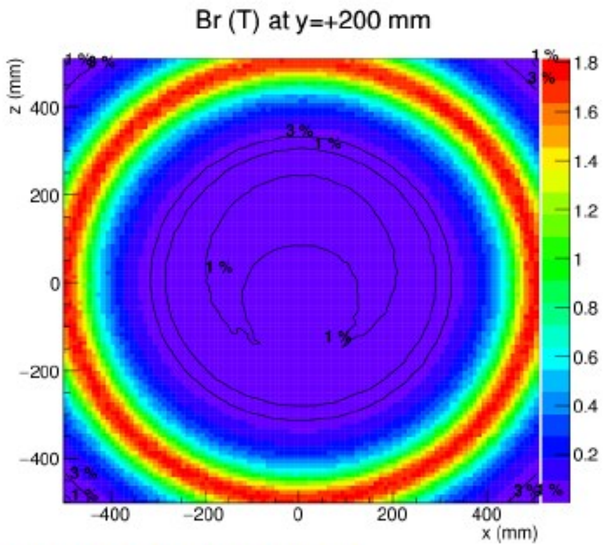




- Maxwell3D calculation results for vertical components ($B_y(x,z)$) of the magnetic field distributions at (left) $y=0$ and (right) $+200$ mm.

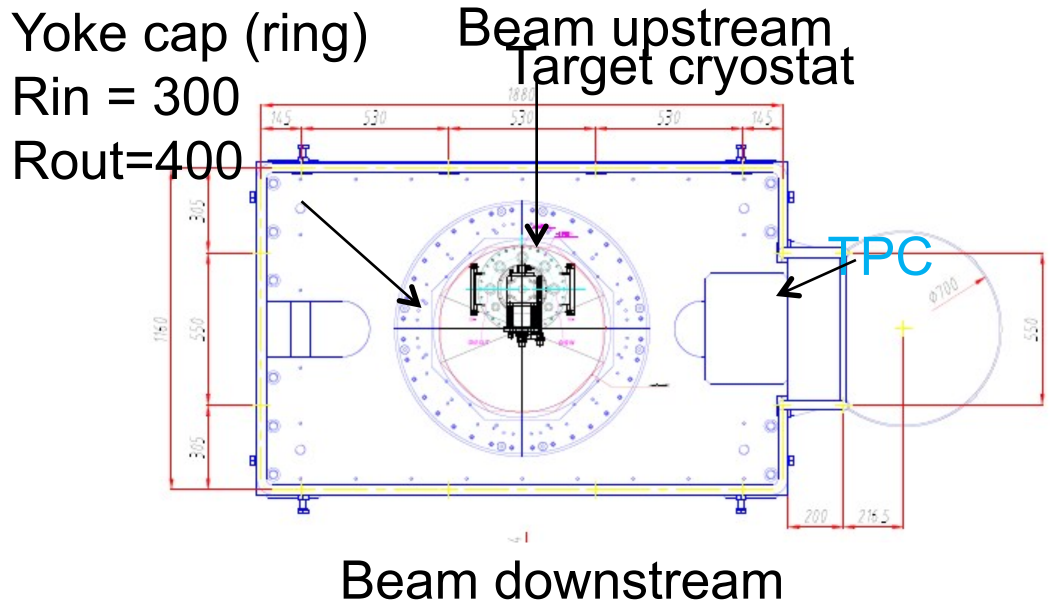
Radial Magnetic Field Distributions





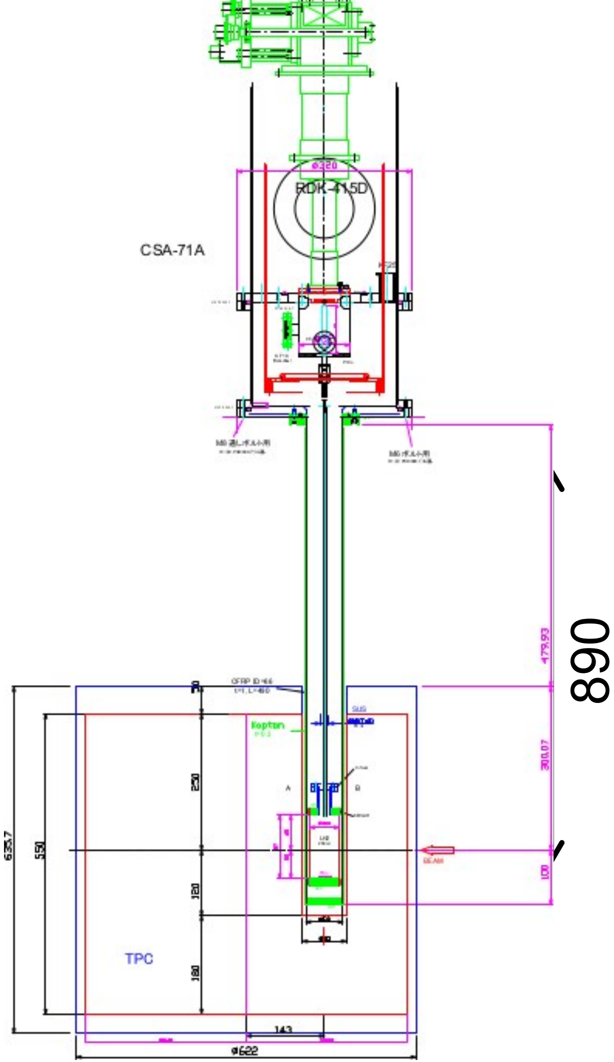
- Maxwell3D calculation results for radial (transverse) components ($B_r(x,z)$) of the magnetic field distributions at a vertical coordinate $y = +200$ mm when the KURAMA magnet is (left) on and (right) off.

Liq-H target



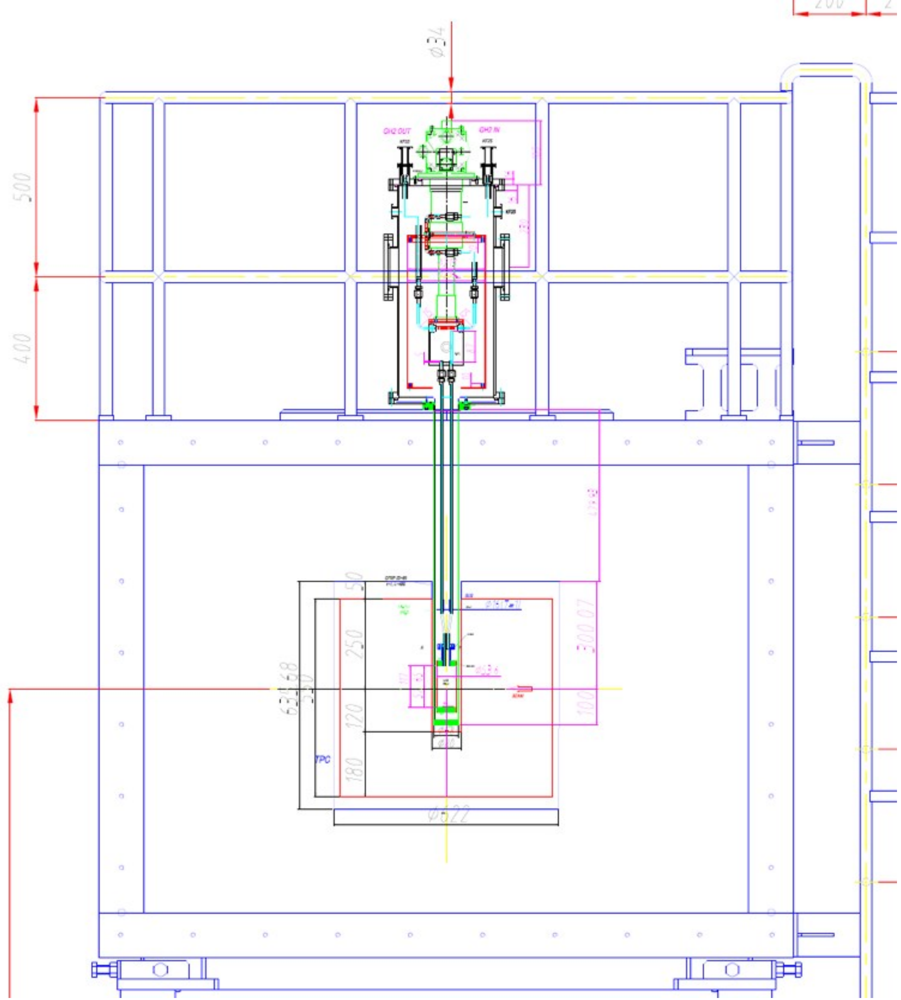
Installation order

1. Magnet without the yoke cap
2. Hodoscope around the TPC
3. TPC
4. Yoke cap
5. target



Liq-H target

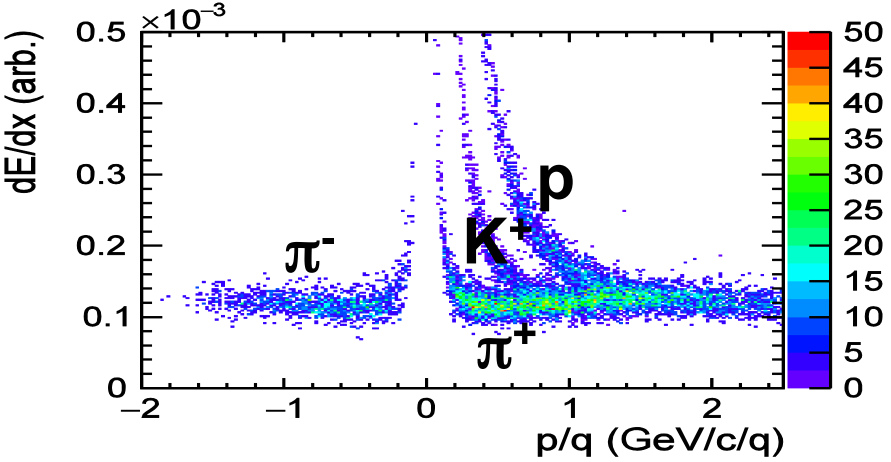
- Long cylinder to avoid interference
  - 490→890mm
  - Possible?

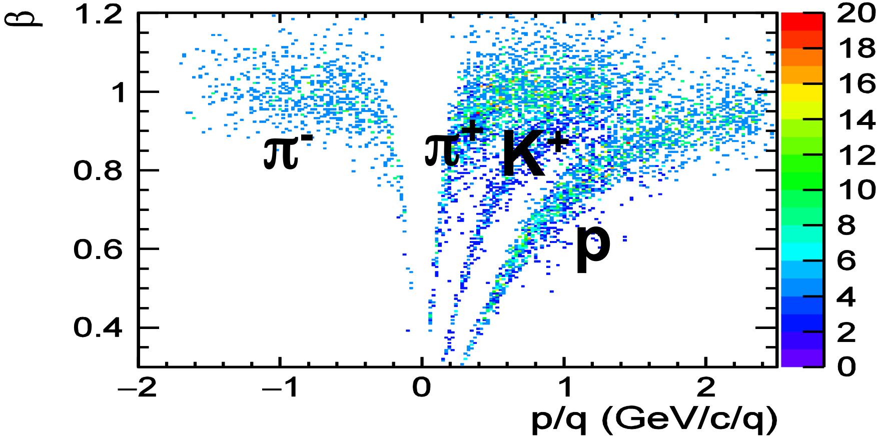


Issues

- Support of the cryostat and the target cylinder.
- Installation procedure of the target =67cylinder into the TPC

Particle identification (GEANT)





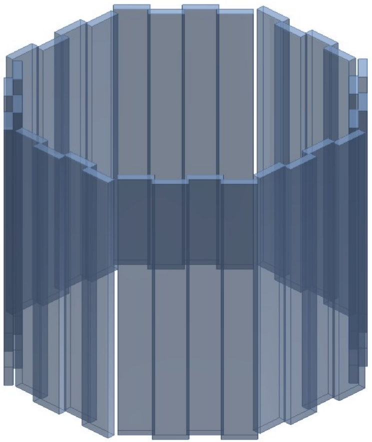
π/K : p<=0.5 GeV/c
π/p : p<=1.1 GeV/c

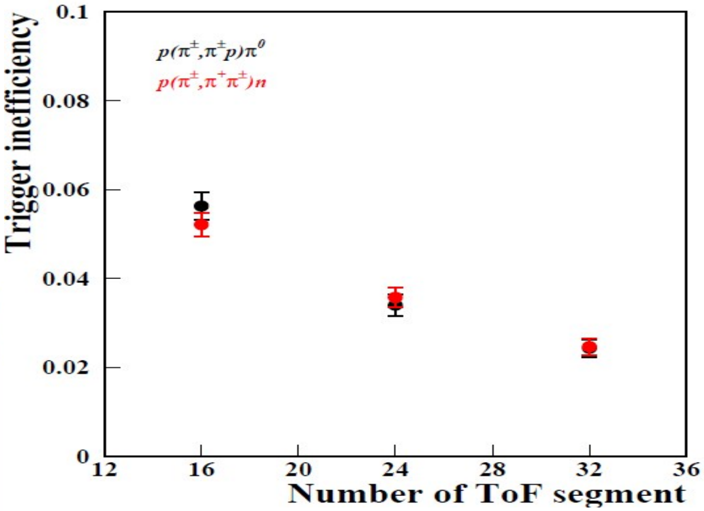
w/ Hodoscope TOF
σ_T = 100ps

Trigger efficiency and acceptance

2-charged particle trigger
(inefficiency due to double hit)

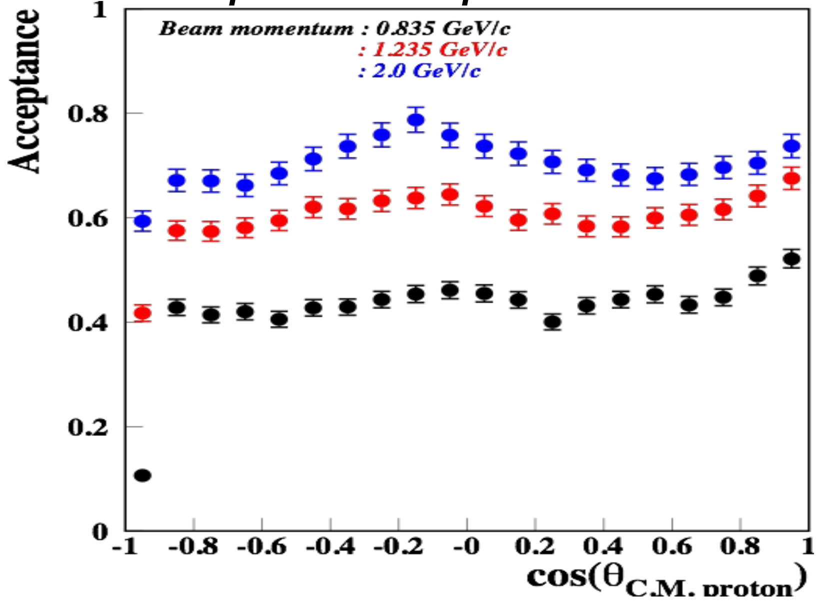
hodoscope





Proton momentum > 300 MeV/c

$\pi^+p \rightarrow \pi^+\pi^0p$ reaction



Readout pads

Pad size

2.4 x 9 mm^2 (inner layer)

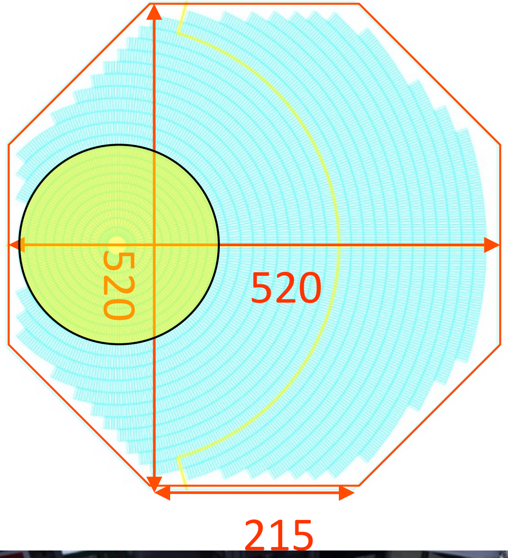
2.4 x 13 mm^2 (outer layer)

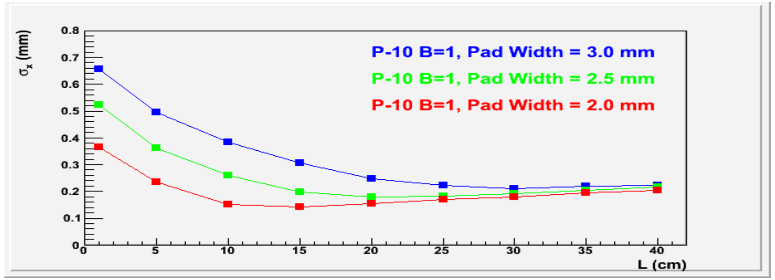
32 pad rows (rings)

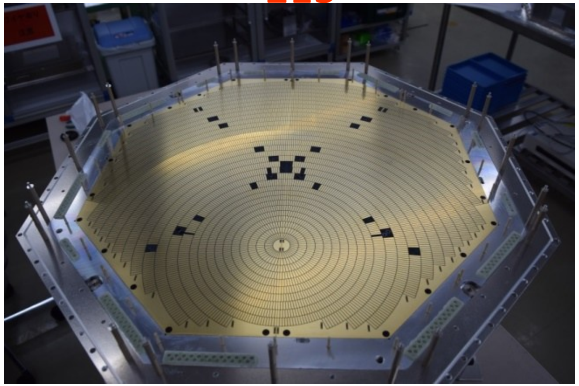
No. of pads = 5768

Position resolution <300μm (L>10cm) at B=1 T

$\Delta p/p$=1-3% (π,p)



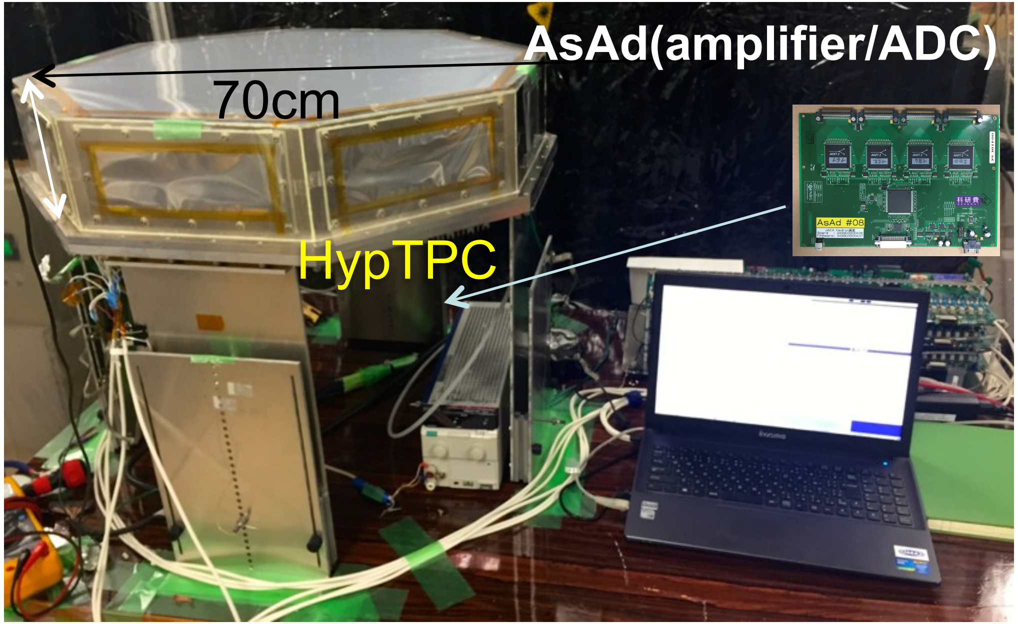




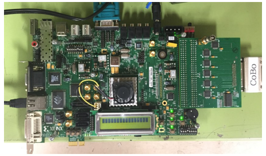
HypTPC test

GET(General Electronics for TPC) readout system

10cm



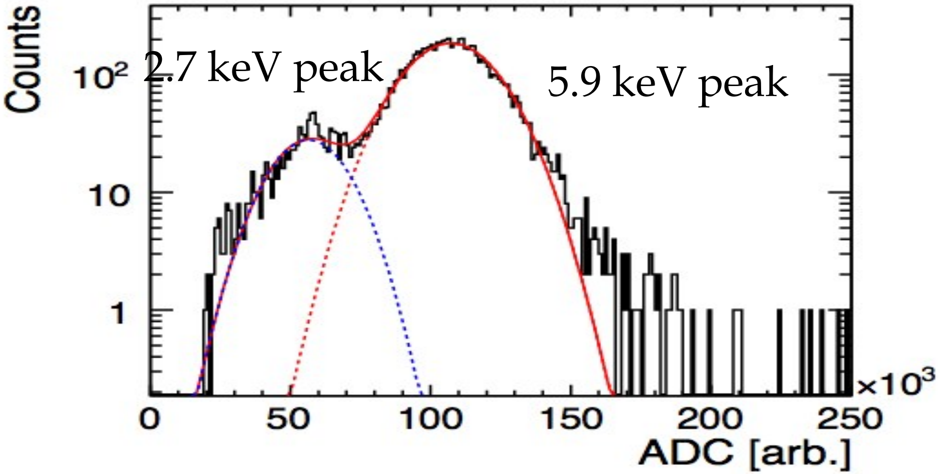
r-CoBo
(data collector)

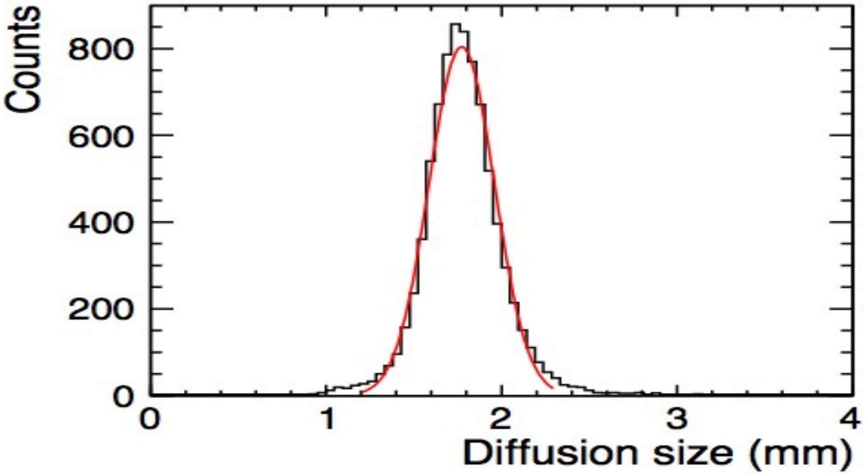


Mar 2015

HypTPC test with ^{55}Fe (x-ray) source

Gain : 120fC, Shap T: 70ns, GEM Curr.: 315 μA





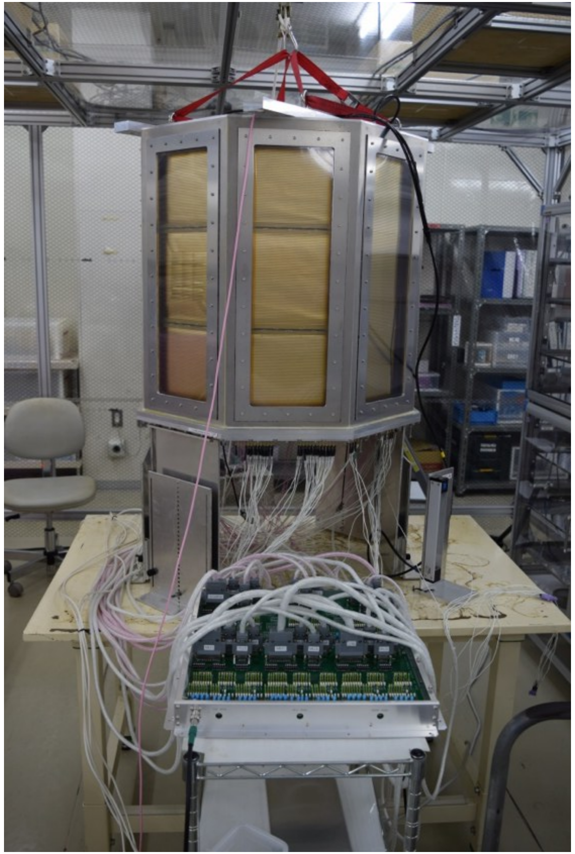
$\Delta E/E$:14.3 ± 0.2 %

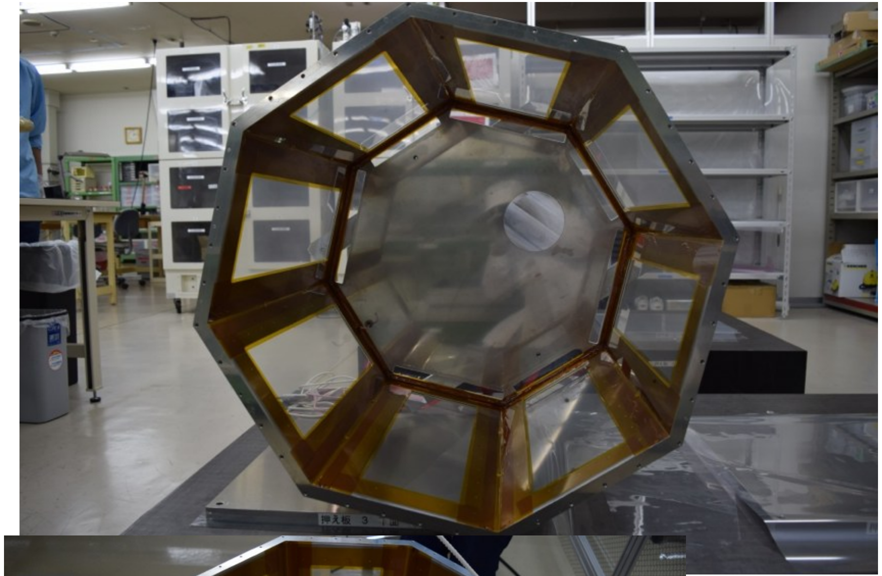
(Peak)/(Esp. Peak): 0.52 ± 0.01

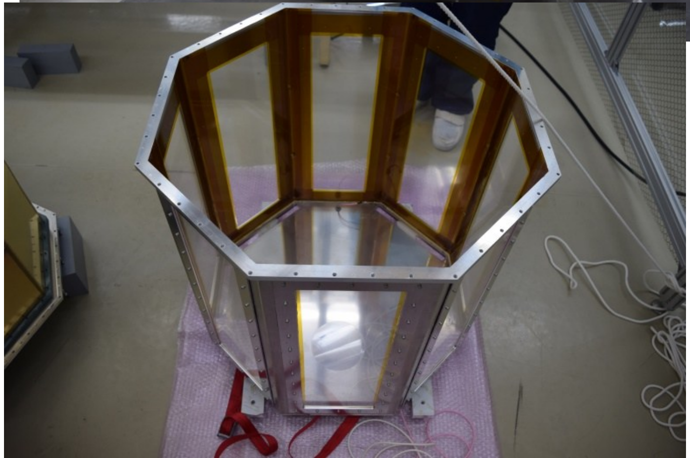
Diffusion size : 1.87 ± 0.02 mm

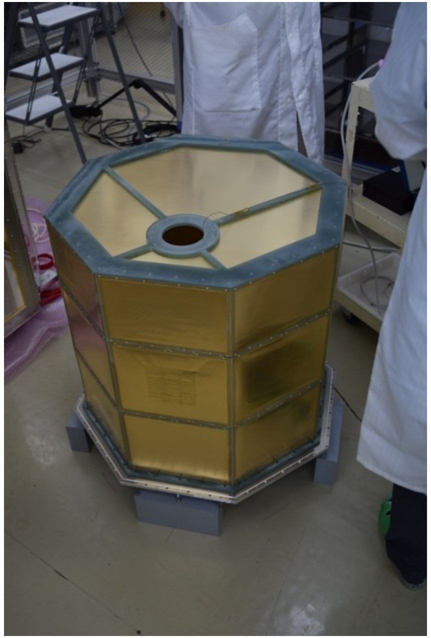
cf. prototype TPC(5 cm to 10 cm)
: 1.7 ~ 2.0 mm

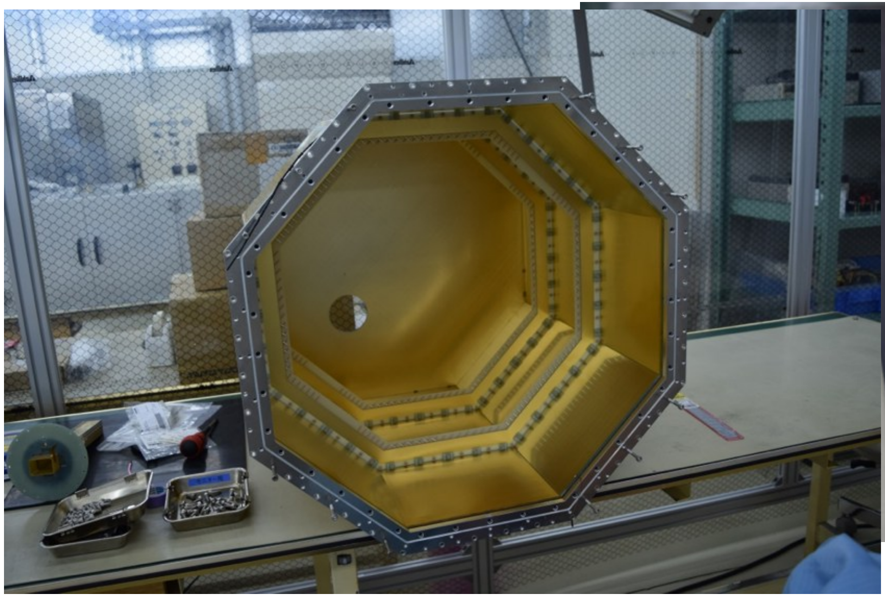
The TPC operation is consistent with the prototype TPC!!

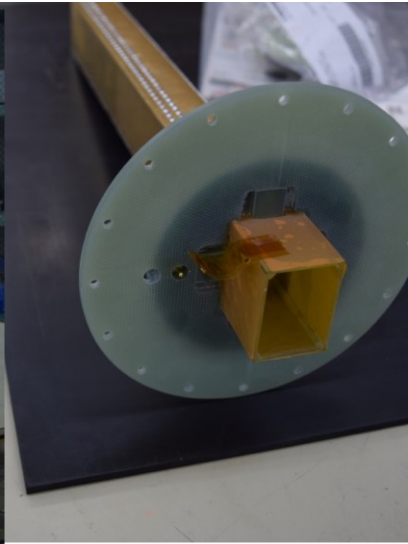


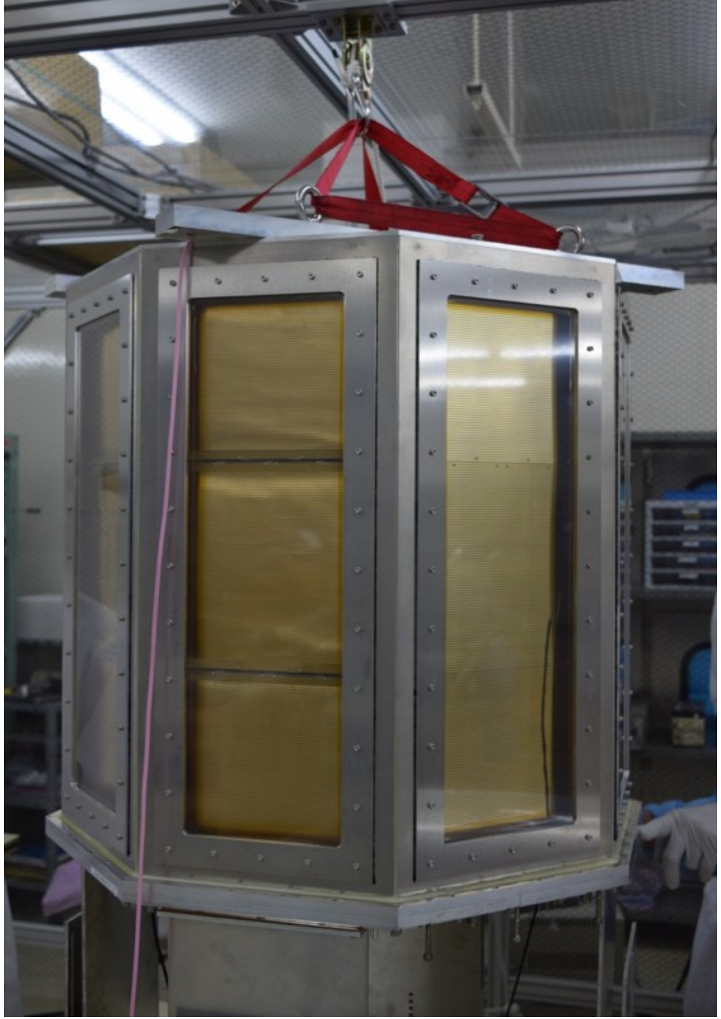


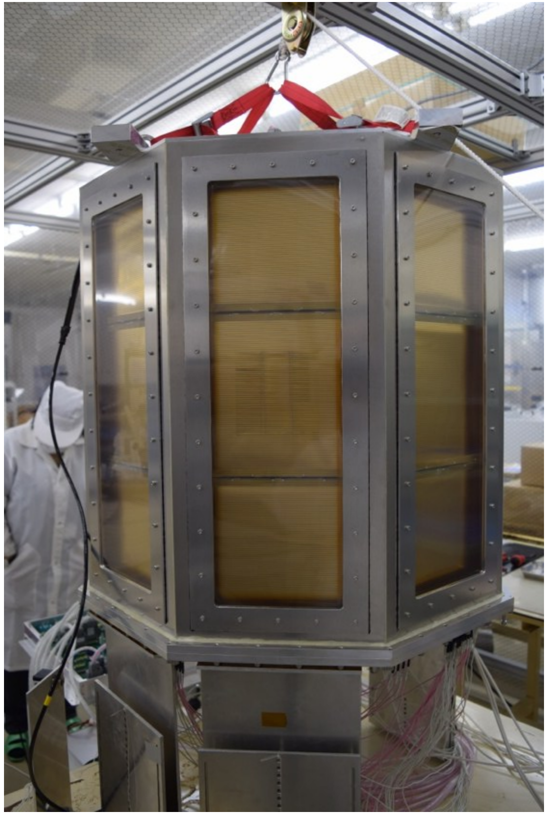












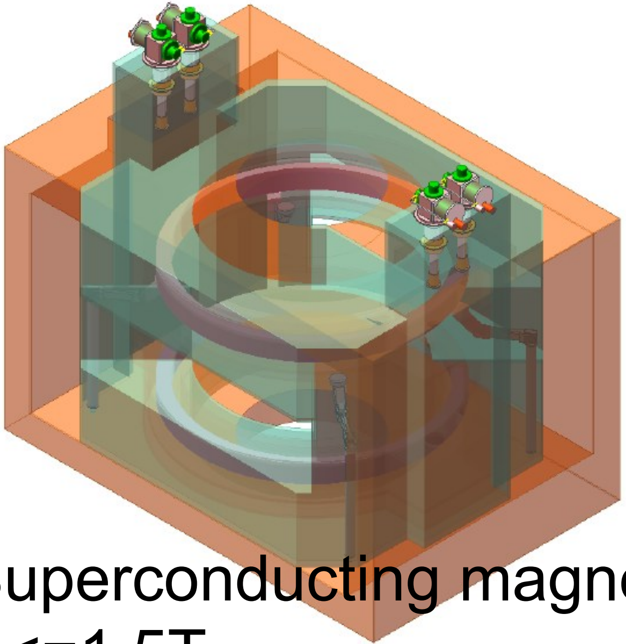
Helmholtz magnet

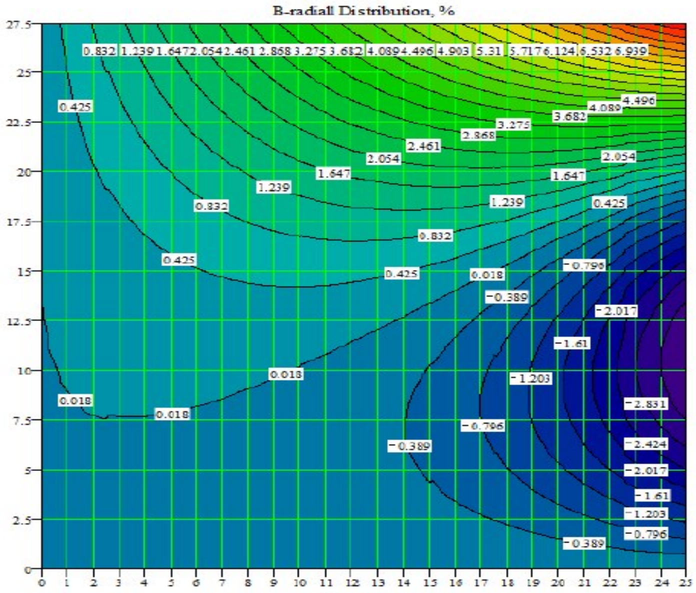
Helmholtz magnet

at KEK East Counter Hall

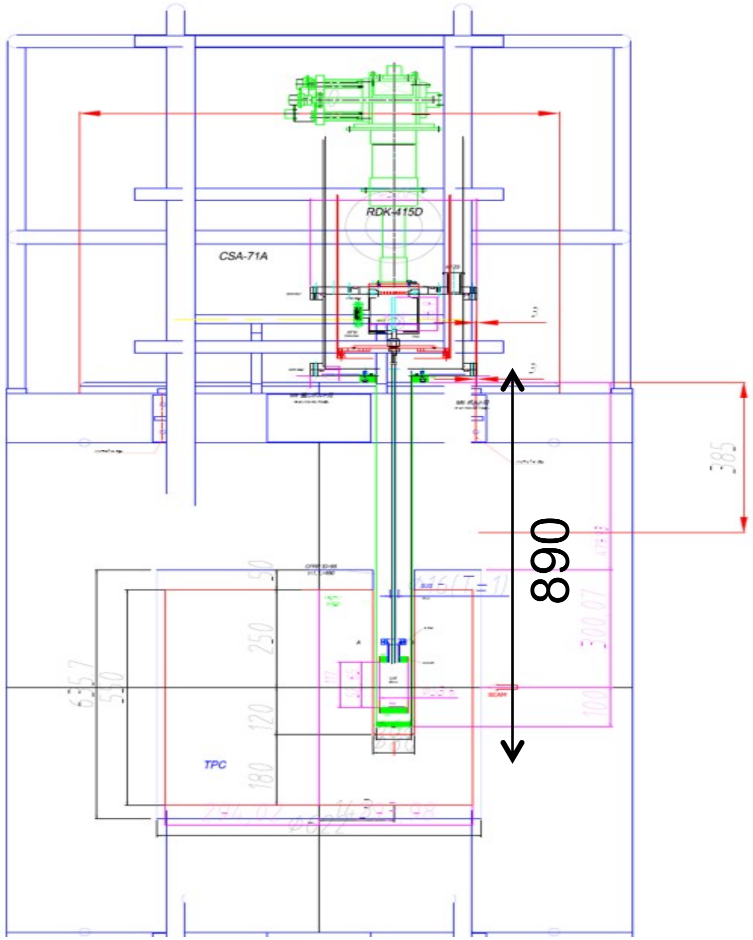
Excitation Test from Nov. 2017

Helmholtz magnet



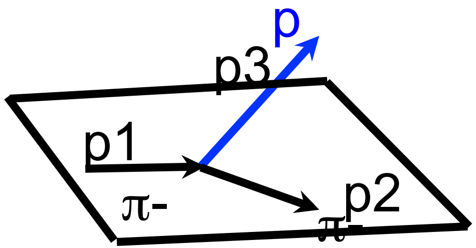


Superconducting magnet
B<=1.5T
Field non-uniformity < 6%
Construction in 2015-2016



- Long cylinder to avoid interference
  - 490→890mm
  - Possible?

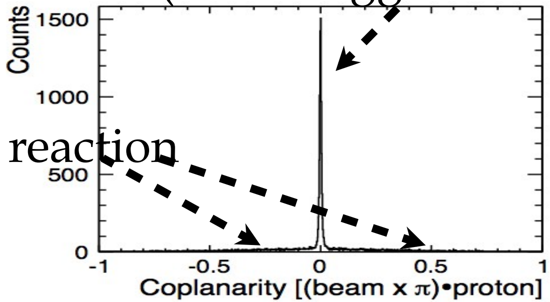
Rejection of elastic scattering



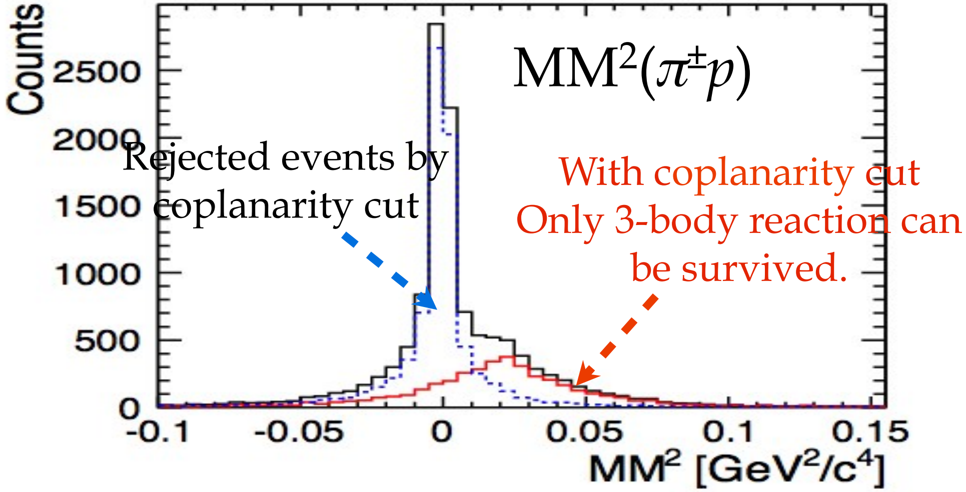
coplanarity
=cosine of angle
Between p1 and
(p2xp3)

Elastic scattering
(Same trigger condition)

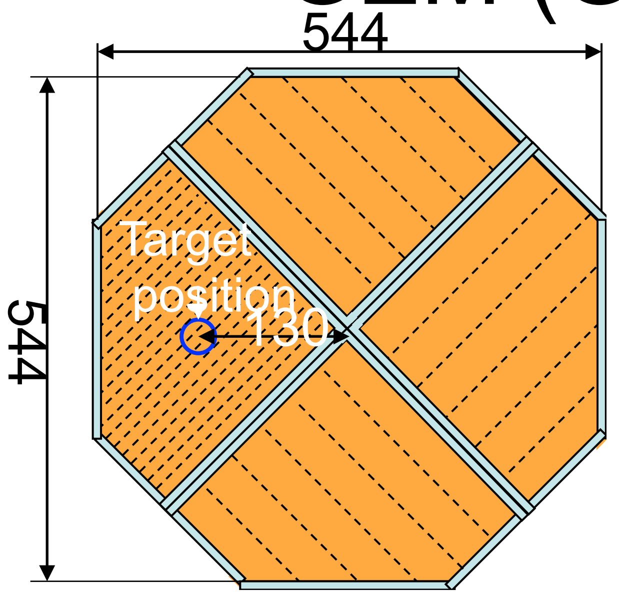
3-body reaction

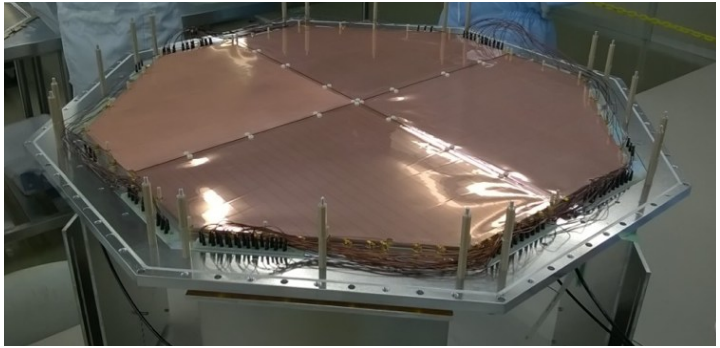


$\pi^- p \rightarrow \pi^- \pi^0 p$ reaction



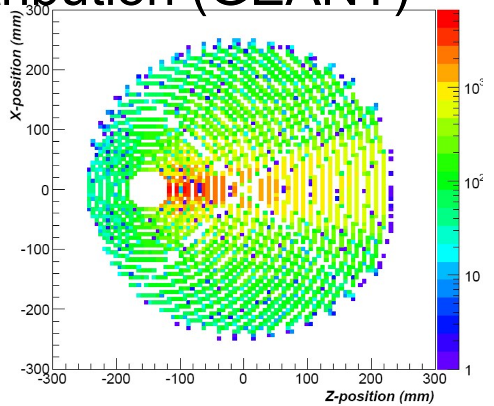
GEM (Gas Electron Multiplier)





▪4 GEM (250mmx250mm) sheets
▪3-GEM layers
50μm + 50μm +100μm thick
Gain ~ 10^4

Hit distribution (GEANT)

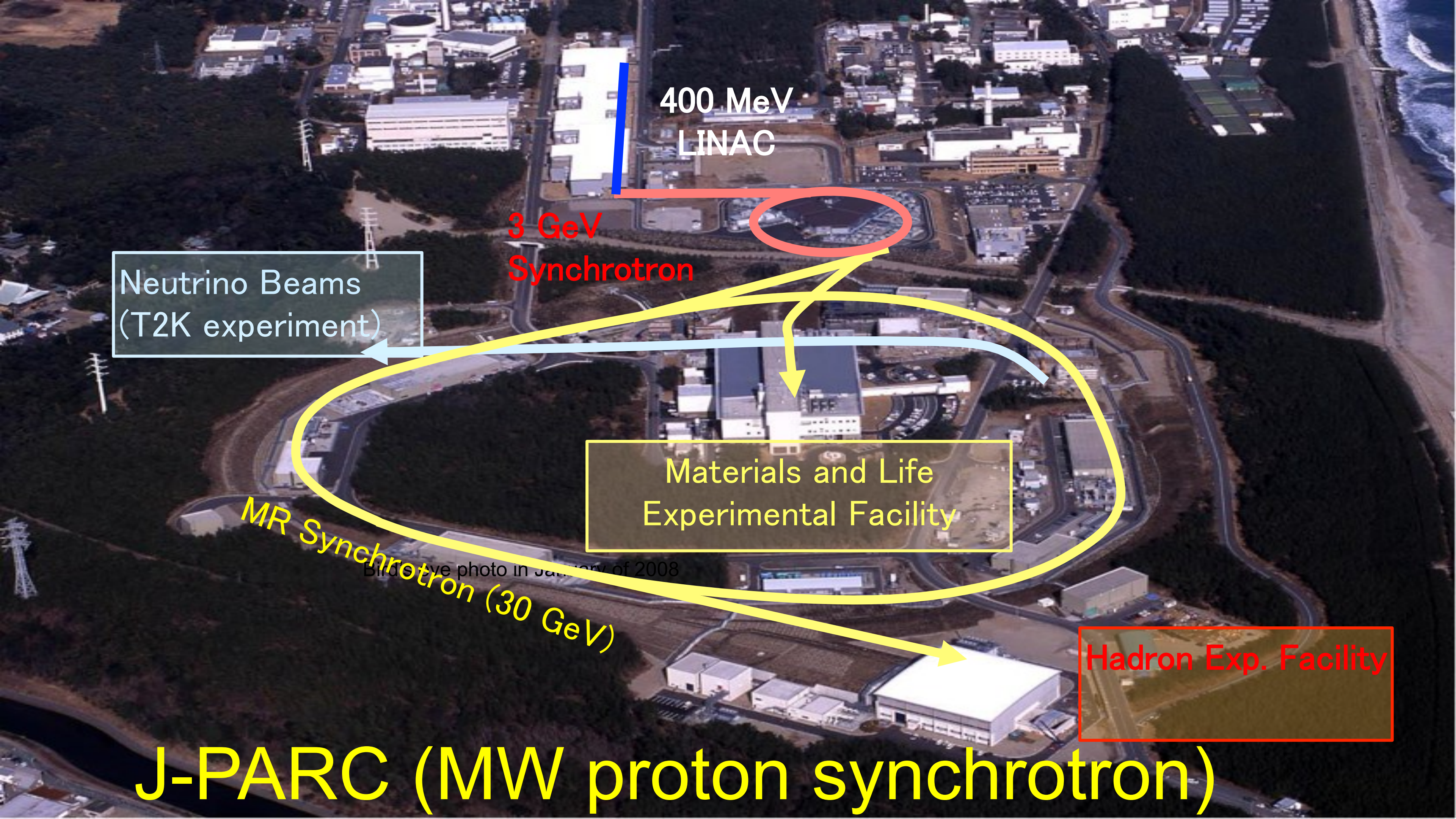


Segmented electrodes

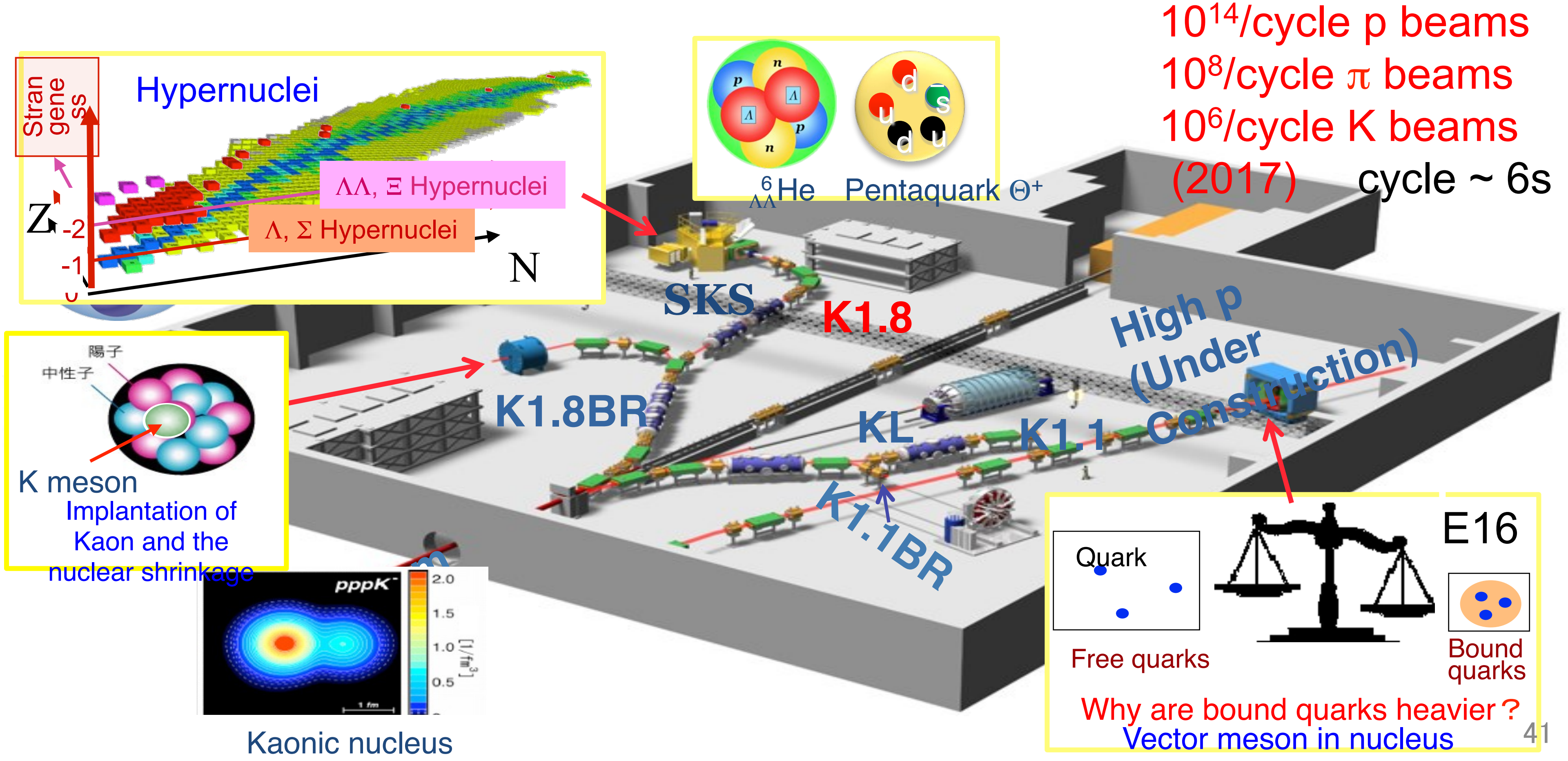
▪to reduce spark rate / electrode

▪to minimize acceptance loss when an electrode is broken due to discharge

J-PARC (MW proton synchrotron)

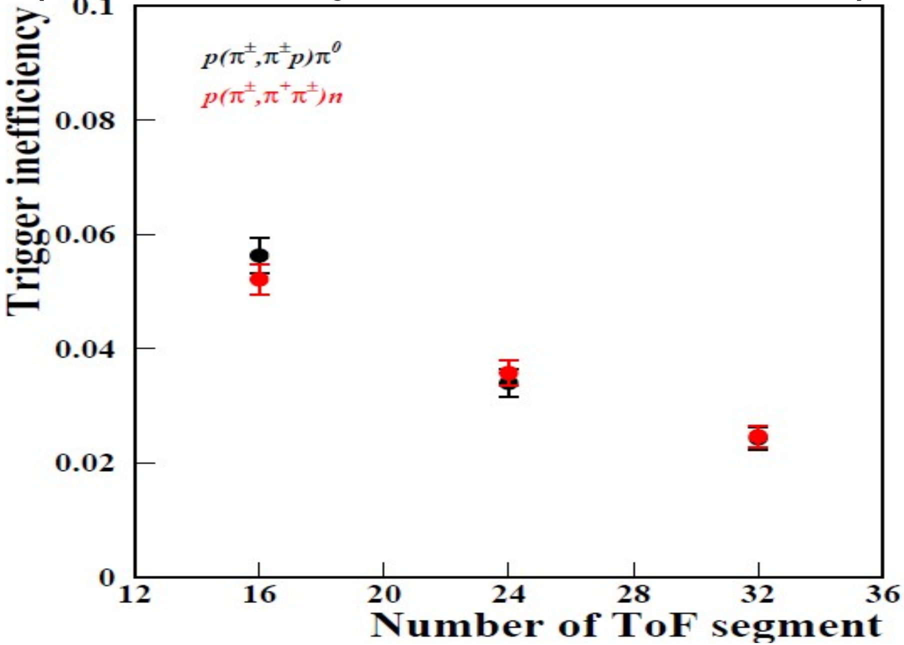


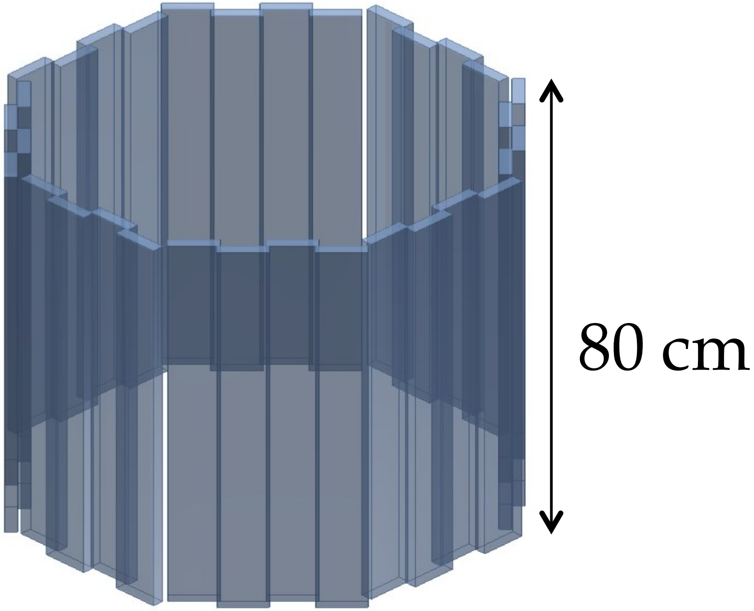
Hadron Experimental Facility



Trigger efficiency

2-charged particle trigger
(inefficiency due to double hit)

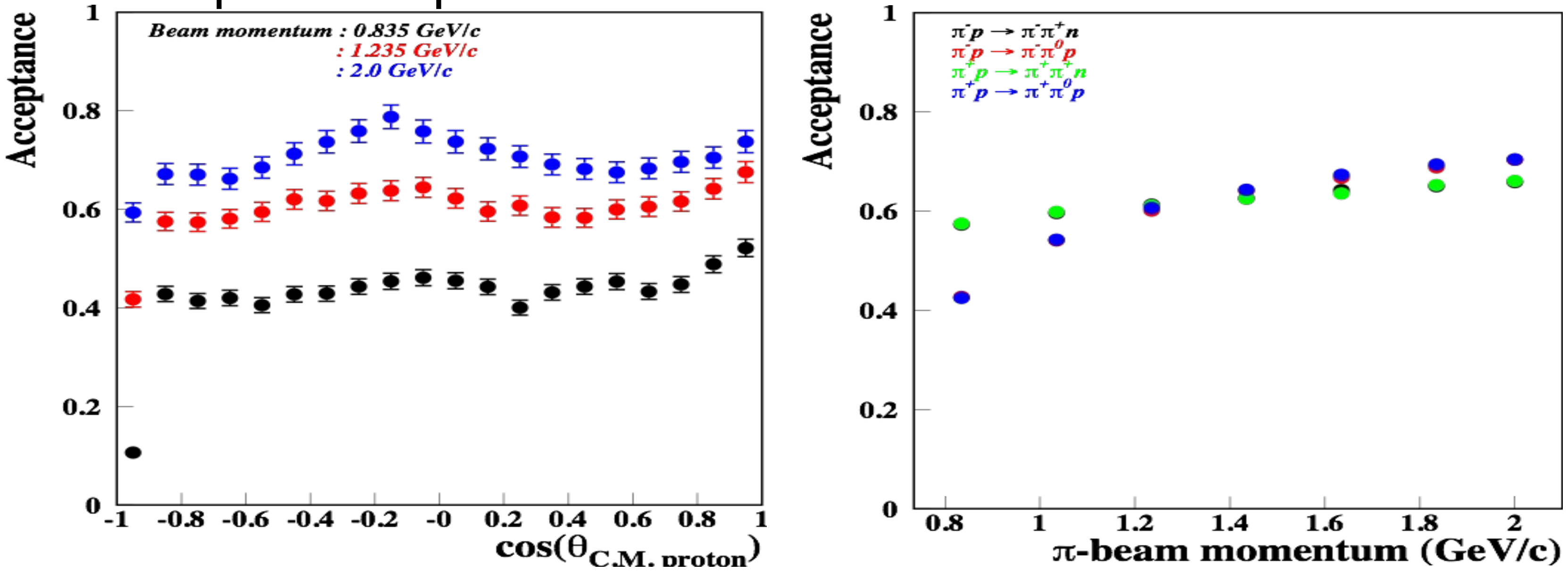




Proposed hodoscope with 32 segments.

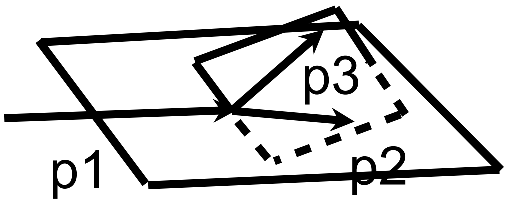
Acceptance

$\pi^+ p \rightarrow \pi^+ \pi^0 p$ reaction



Momentum of Proton > 300 MeV/c (large energy loss in target)

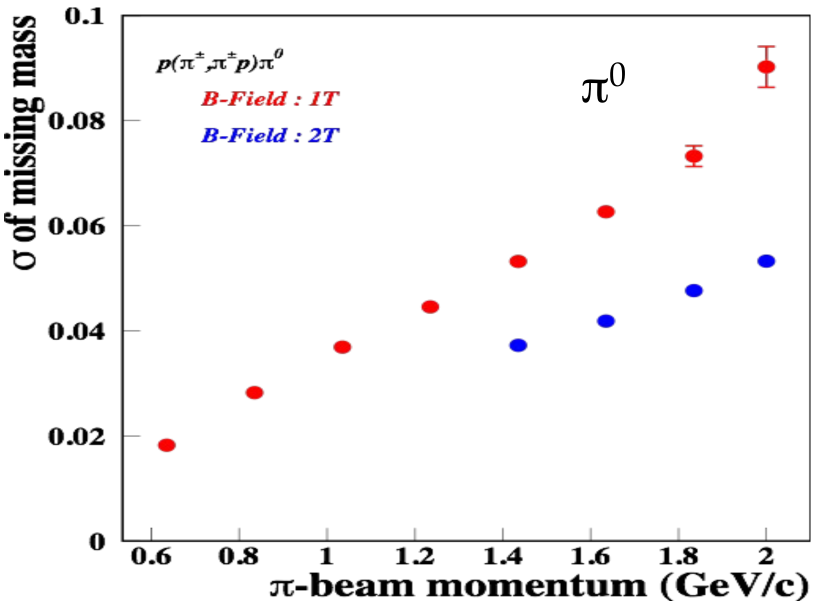
Coplanarity

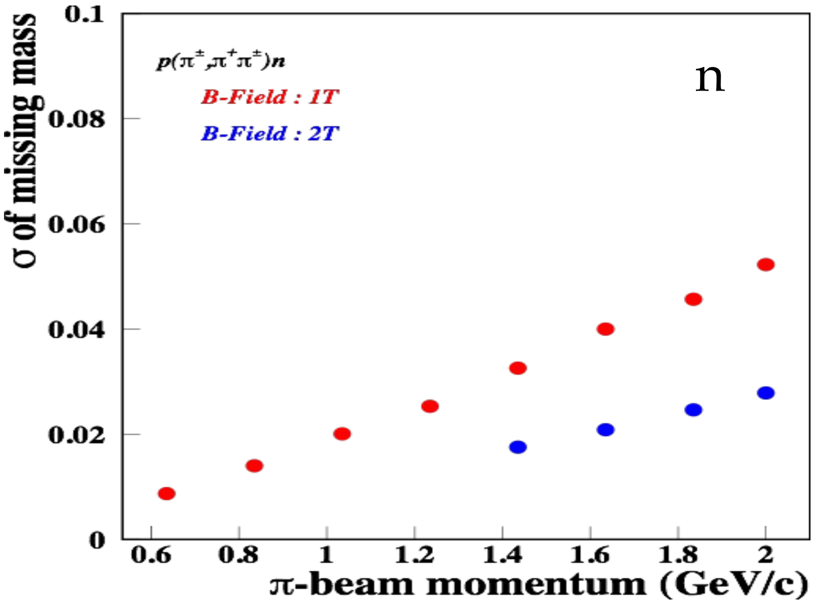


coplanarity
=cosine of angle
between p1 and (p2xp3)

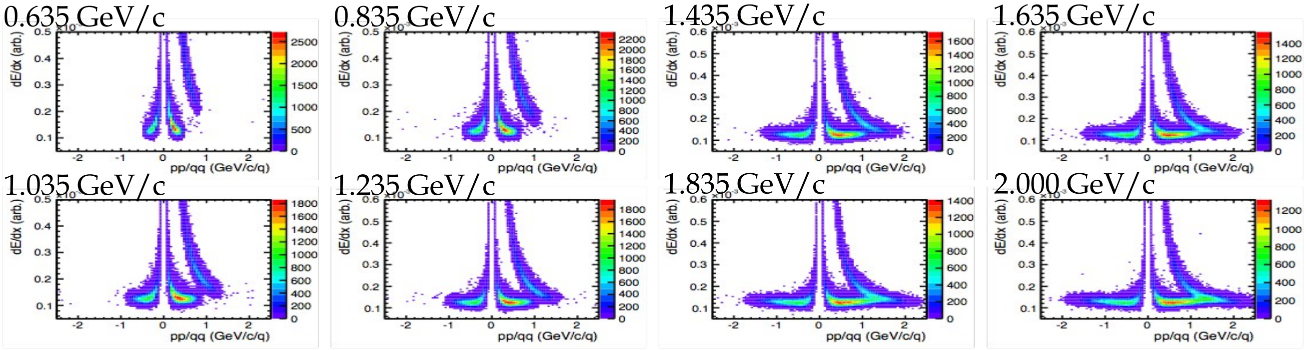
0 : p1,p2,p3 are in the
common plane

Missing mass resolution





Missing mass technique and coplanarity can identify neutral particles.


0.635 GeV/c
0.835 GeV/c
1.435 GeV/c
1.635 GeV/c
1.035 GeV/c
1.235 GeV/c
1.835 GeV/c
2.000 GeV/c
dE/dx (arb.)
pp/qq (GeV/c/q)

Trigger efficiency

$$\epsilon_B = \frac{1}{1 + 1\text{k} \cdot 250\,\mu\text{sec}} = 0.80$$

Quark Model (PDG2014)

Table 15.5: N and Δ states in the N=0,1,2 harmonic oscillator bands. L^P denotes angular momentum and parity, S the three-quark spin and 'sym'=A,S,M the symmetry of the spatial wave function. Only dominant components indicated. Assignments in the N=2 band are partly tentative.

N	sym	L^P	S	$N(I=1/2)$				$\Delta(I=3/2)$			
2	A	1^+	1/2	$1/2^+$	$3/2^+$						
2	M	2^+	3/2	$1/2^+$	$3/2^+$	$5/2^+$	$7/2^+$				
2	M	2^+	1/2		$3/2^+$	$5/2^+$			$3/2^+$	$5/2^+$	
2	M	0^+	3/2		$3/2^+$						
2	M	0^+	1/2	$1/2^+$				$1/2^+$			
				$N(1710)$				$\Delta(1750)$			
2	S	2^+	3/2					$1/2^+$	$3/2^+$	$5/2^+$	$7/2^+$
								$\Delta(1910)$	$\Delta(1920)$	$\Delta(1905)$	$\Delta(1950)$
2	S	2^+	1/2		$3/2^+$	$5/2^+$					
					$N(1720)$	$N(1680)$					
2	S	0^+	3/2						$3/2^+$		
									$\Delta(1600)$		
2	S	0^+	1/2	$1/2^+$							
				$N(1440)$							
1	M	1^-	3/2	$1/2^-$	$3/2^-$	$5/2^-$					
				$N(1650)$	$N(1700)$	$N(1675)$					
1	M	1^-	1/2	$1/2^-$	$3/2^-$			$1/2^-$	$3/2^-$		
				$N(1535)$	$N(1520)$			$\Delta(1620)$	$\Delta(1700)$		
0	S	0^+	3/2						$3/2^+$		
									$\Delta(1232)$		
0	S	0^+	1/2	$1/2^+$							
				$N(938)$							

Cross Sections (mb) for pi- beam

W (MeV)	p_{beam} (MeV/c)	$Tot_{Reaction}$(p pi-)	pi0 pi0 n	pi+ pi- n	pi0 pi- p	Hours	Shifts
1340	487.7	2.90	0.59	1.27	0.12		
1375	538.3	5.27	1.18	2.77	0.39		
1400	575.3	6.91	1.45	3.87	0.76		
1440	635.8	9.34	1.71	5.09	1.72		
1460	666.7	10.94	1.53	5.49	2.43		
1480	698.1	13.06	2.10	5.74	3.33		
1500	729.8	16.81	2.29	5.96	4.22		
1520	762.0	18.39	2.47	6.10	4.83	2.76	.60
1540	794.6	17.83	2.64	6.39	4.82	2.77	.60
1565	836.0	17.10	2.69	6.92	4.67	2.86	.61
1595	886.5	18.29	2.96	8.17	4.88	2.73	.59
1620	929.3	20.86	3.07	9.32	5.30	2.52	.56
1640	964.1	23.63	3.17	10.47	5.71	2.34	.54
1660	999.3	26.10	3.21	10.86	6.07	2.20	.52
1680	1034.8	26.69	2.79	10.68	6.28	2.12	.52
1700	1070.9	25.26	3.04	10.16	6.17	2.16	.52
1725	1116.5	22.91	2.53	9.12	5.89	2.26	.53
1755	1172.1	21.29	2.54	8.04	5.25	2.54	.57
1790	1238.2	20.90	1.68	7.21	4.50	2.96	.62
1830	1315.4	21.32	1.30	7.20	4.24	3.14	.64
1870	1394.3	21.90	1.80	7.74	4.54	2.94	.62
1910	1474.8	22.21	2.05	7.76	4.84	2.75	.59
1940	1536.4	22.00	2.00	7.75	4.50	2.96	.62
1970	1598.9	22.00	2.00	7.75	4.50	2.96	.62
2000	1662.4	22.00	2.00	7.75	4.50	2.96	.62
2025	1716.0	22.00	2.00	7.75	4.50	2.96	.62
2050	1770.3	22.00	2.00	7.75	4.50	2.96	.62
2075	1825.2	22.00	2.00	7.75	4.50	2.96	.62
2100	1880.8	22.00	2.00	7.75	4.50	2.96	.62
2125	1937.1	22.00	2.00	7.75	4.50	2.96	.62
2150	1994.1	22.00	2.00	7.75	4.50	2.96	.62
						Total	14.2

		Cross Sections (mb) for pi+ beam				
W (MeV)	p_{beam} (MeV/c)	$Tot_{Reaction}$(p pi+)	pi0 pi+ p	pi+ pi+ n	Hours	Shifts
1340	487.7	0.74	0.01	0.00		
1375	538.3	1.03	0.52	0.10		
1400	575.3	1.40	0.70	0.16		
1440	635.8	2.33	1.20	0.25		
1460	666.7	2.98	1.48	0.29		
1480	698.1	3.78	1.99	0.35		
1500	729.8	4.73	2.57	0.44		
1520	762.0	5.87	3.32	0.56		
1540	794.6	7.26	4.54	0.72	18.52	2.6
1565	836.0	9.32	6.33	1.04	12.82	1.9
1595	886.5	11.64	8.57	1.51	8.83	1.4
1620	929.3	12.57	9.55	1.77	7.53	1.2
1640	964.1	12.74	9.81	1.77	7.53	1.2
1660	999.3	12.74	9.76	1.84	7.25	1.2
1680	1034.8	12.78	9.47	1.79	7.45	1.2
1700	1070.9	12.97	8.91	1.55	8.60	1.3
1725	1116.5	13.54	8.34	1.31	10.18	1.5
1755	1172.1	14.81	8.24	1.49	8.95	1.4
1790	1238.2	17.04	9.54	1.48	9.01	1.4
1830	1315.4	20.10	10.67	2.17	6.14	1.0
1870	1394.3	22.70	11.39	2.84	4.69	0.8
1910	1474.8	23.55	10.95	3.16	4.22	0.8
1940	1536.4	23.00	11.00	3.33	4.00	0.8
1970	1598.9	23.00	11.00	3.33	4.00	0.8
2000	1662.4	23.00	11.00	3.33	4.00	0.8
2025	1716.0	23.00	11.00	3.33	4.00	0.8
2050	1770.3	23.00	11.00	3.33	4.00	0.8
2075	1825.2	23.00	11.00	3.33	4.00	0.8
2100	1880.8	23.00	11.00	3.33	4.00	0.8
2125	1937.1	23.00	11.00	3.33	4.00	0.8
2150	1994.1	23.00	11.00	3.33	4.00	0.8
					Total	25

Baker (1978)		Cross Section (mb)	(error)		J-PARC
W (GeV)	p_{beam} (MeV/c)	pi- p → K0 Λ		Hours	Counts
1.633	951.9	0.13	(0.02)	5.5	40,950
1.661	1001.0	0.46	(0.05)	4.9	128,340
1.683	1040.2	0.69	(0.07)	4.8	188,370
1.694	1060.0	0.92	(0.09)	4.8	251,160
1.724	1114.7	0.68	(0.10)	5.1	197,880
1.758	1177.7	0.48	(0.05)	5.7	156,960
1.792	1242.1	0.46	(0.05)	6.6	175,260
1.825	1305.7	0.25	(0.03)	7.1	102,750
1.847	1348.7	0.32	(0.03)	7.0	129,600

Saxon (1980)		Cross Section (mb)	(error)		
W (GeV)	p_{beam} (MeV/c)	pi- p → K0 Λ			
1.870	1395	0.25	(0.05)	6.6	95,250
1.900	1455	0.29	(0.06)	6.4	107,010
1.930	1515	0.22	(0.05)	6.2	78,540
1.959	1575	0.21	(0.04)	6.5	78,750
1.992	1645	0.16	(0.03)	6.6	60,960
2.020	1705	0.14	(0.03)	6.6	53,340
2.052	1775	0.13	(0.03)	6.6	49,530
2.097	1875	0.16	(0.03)	6.6	60,960
2.153	2000	0.15	(0.03)	6.6	57,150

Candlin (1983)		Cross Section (mb)	(error)		J-PARC
W (GeV)	p_{beam} (MeV/c)	pi+ p → K+ Σ+		Hours	Counts
1.813	1282	0.37	(0.02)	7	149,850
1.836	1328	0.41	(0.02)	6	141,450
1.861	1377	0.47	(0.03)	6	162,150
1.882	1419	0.52	(0.03)	5	148,200
1.917	1490	0.53	(0.03)	9	278,250
1.931	1518	0.55	(0.03)	9	288,750
1.962	1582	0.47	(0.03)	9	246,750
1.977	1614	0.49	(0.03)	9	257,250
2.012	1687	0.43	(0.02)	9	225,750
2.023	1712	0.44	(0.02)	9	231,000
2.052	1775	0.42	(0.02)	9	220,500
2.067	1808	0.39	(0.02)	9	204,750
2.099	1879	0.33	(0.02)	9	173,250
2.111	1906	0.37	(0.02)	9	194,250
2.140	1971	0.34	(0.02)	9	178,500
2.151	1997	0.30	(0.02)	9	157,500

The Primary Data Source of (π,2π)

Nuclear Physics B78 (1974) 233–250. North-Holland Publishing Company

EXPERIMENTAL RESULTS ON π^-p INTERACTIONS IN THE CM ENERGY RANGE 1.50 – 1.74 GeV

J. DOLBEAU, M. NEVEU, F.A. TRIANTIS * and C. COUTURES
Departement de Physique des Particules Elementaires, CEN, Saclay

Received 21 March 1974

Abstract: Channel cross sections, elastic differential cross sections and single pion production mass spectra and angular distributions are presented for π^-p interactions, based on 139 000 events observed at six energies in the center of mass region 1.50 – 1.74 GeV.

Existing (π,2π) Database

M. Manley, Phys. Rev. D 30, 904 (1984).

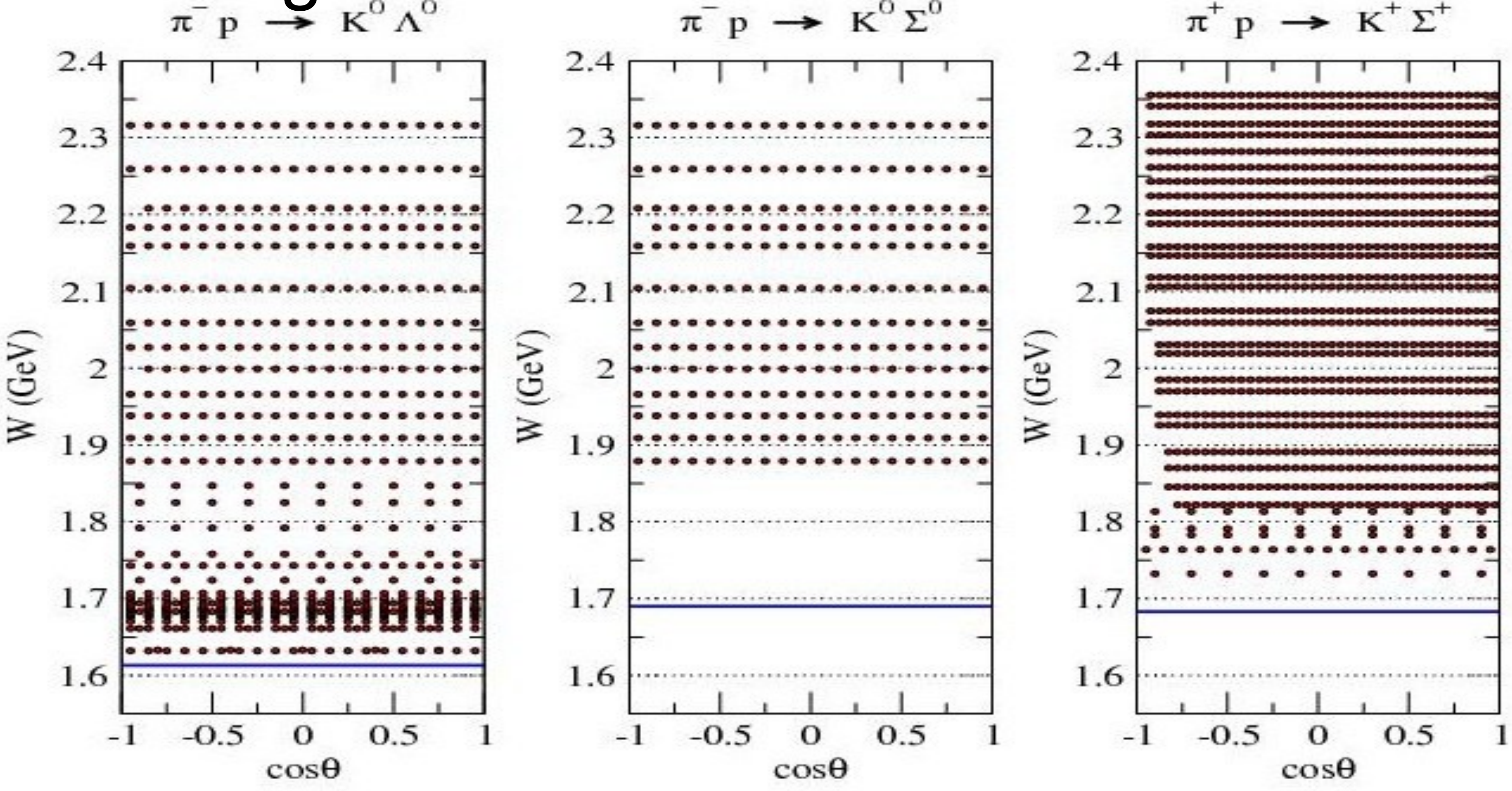
TABLE I. Summary of the number of events analyzed at each energy.

W (MeV)	$\pi^+\pi^-n$	$\pi^0\pi^-p$	$\pi^0\pi^+p$	$\pi^+\pi^+n$	Total
1340±20	1664	11	0	0	1675
1375±15	3893	145	15	2	4055
1400±10	3646	826	63	15	4550
1440±10	3790	1339	207	48	5384
1460±10	2074	971	152	36	3233
1480±10	7246	3776	537	128	11 687
1500±10	6224	4055	1160	250	11 689
1520±10	5650	4671	795	143	11 259
1540±10	6230	5320	1115	183	12 848
1565±15	2237	1598	2704	481	7020
1595±15	3065	1962	2864	483	8374
1620±10	0	0	4203	621	4824
1640±10	7437	4177	7939	1013	20 566
1660±10	7411	4273	4071	752	16 507
1680±10	8784	5340	4999	847	19 970
1700±10	8377	5394	5375	1007	20 153
1725±15	6265	4594	5679	524	17 062
1755±15	5442	4200	1316	18	10 976
1790±20	1966	1352	4715	228	8261
1830±20	3543	2223	2322	0	8088
1870±20	4342	3382	8190	557	16 471
1910±20	6036	4081	6445	0	16 562
Total	105 322	63 690	64 866	7336	241 214

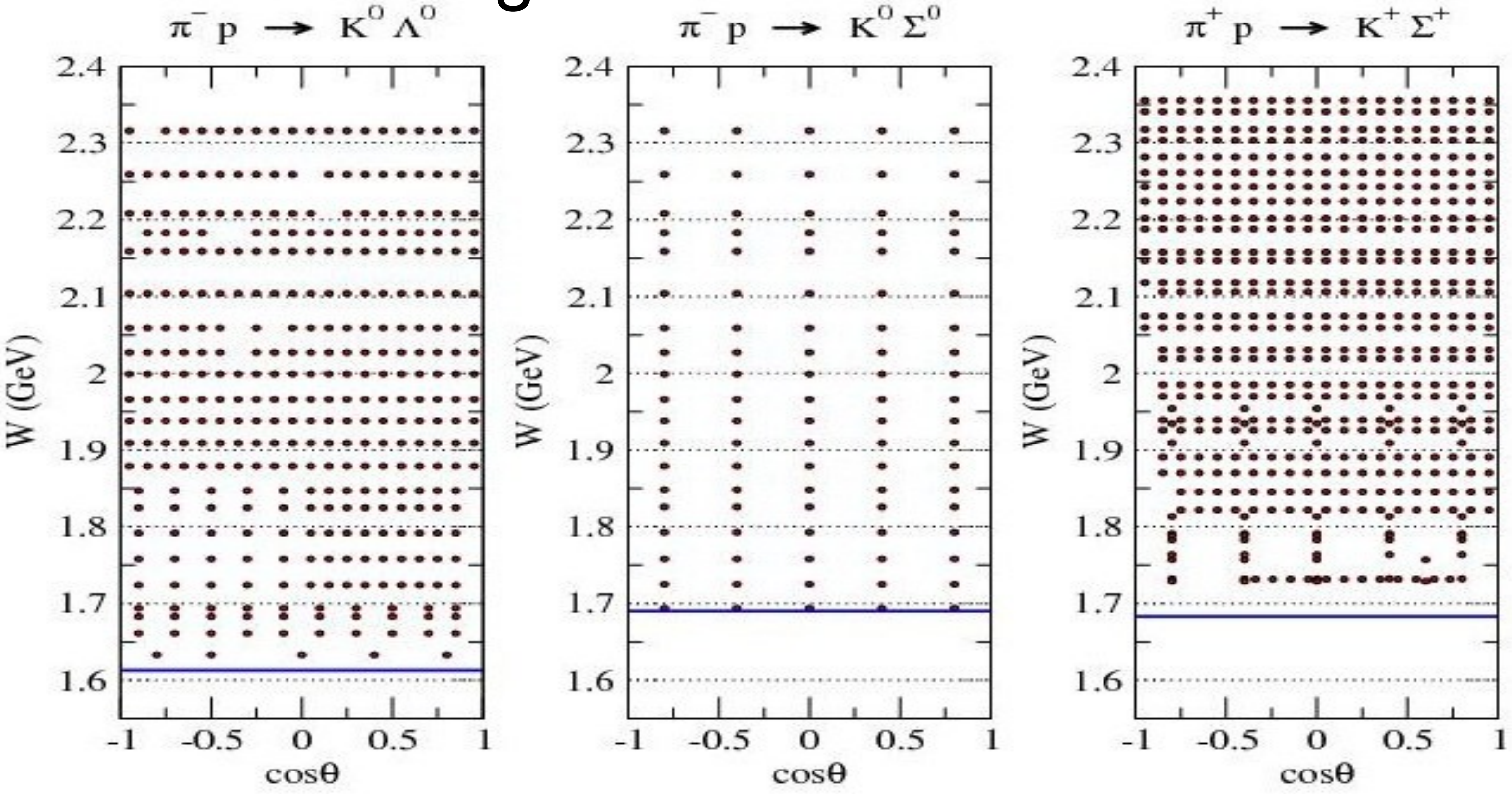
1960's-1970's bubble chamber data

Total number of events!

Coverage for Measurements of Cross Section



Coverage for Measurements of P

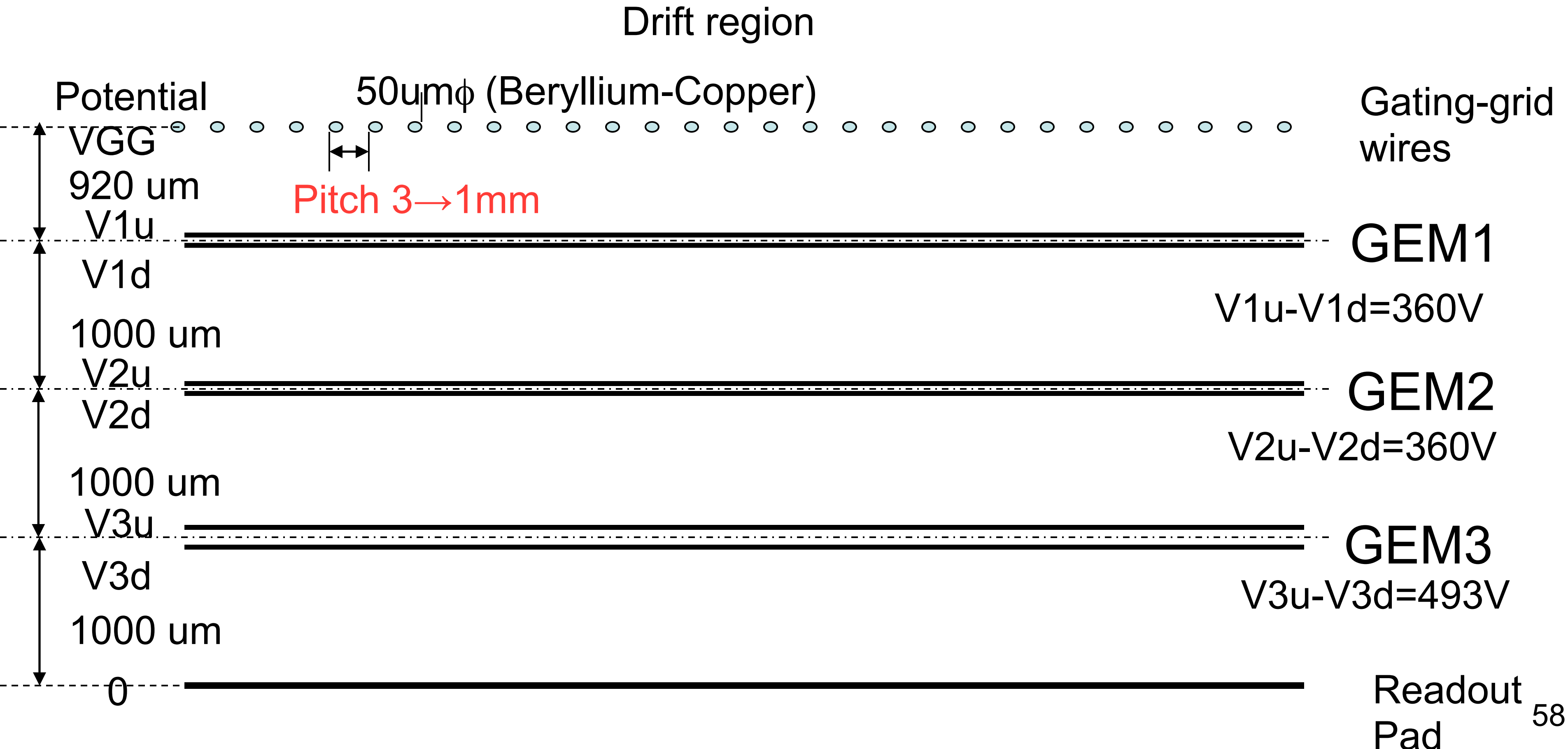


Capstick & Roberts (1993)

Model state	$\lvert A_{N\pi} \rvert$ ($\mathrm{MeV}^{\frac{1}{2}}$)	$N\pi$ state assignment	Rating	$\sqrt{\Gamma_{tot}}(BR)_{N\pi}$ ($\mathrm{MeV}^{\frac{1}{2}}$)
$[N\frac{1}{2}^-]_1(1460)$	14.7 ± 0.5	$N\frac{1}{2}^-(1535)$	****	8.0 ± 2.8
$[N\frac{1}{2}^-]_2(1535)$	12.2 ± 0.8	$N\frac{1}{2}^-(1650)$	****	8.7 ± 1.9
$[N\frac{3}{2}^-]_1(1495)$	8.6 ± 0.3	$N\frac{3}{2}^-(1520)$	****	8.3 ± 0.9
$[N\frac{3}{2}^-]_2(1625)$	5.8 ± 0.6	$N\frac{3}{2}^-(1700)$	***	3.2 ± 1.3
$[N\frac{5}{2}^-]_1(1630)$	5.3 ± 0.1	$N\frac{5}{2}^-(1675)$	****	7.7 ± 0.7
$[N\frac{1}{2}^+]_2(1540)$	$20.3^{+0.8}_{-0.9}$	$N\frac{1}{2}^+(1440)$	****	19.9 ± 3.0
$[N\frac{1}{2}^+]_3(1770)$	4.2 ± 0.1	$N\frac{1}{2}^+(1710)$	***	4.7 ± 1.2
$[N\frac{1}{2}^+]_4(1880)$	$2.7^{+0.6}_{-0.9}$			
$[N\frac{1}{2}^+]_5(1975)$	$2.0^{+0.2}_{-0.3}$			
$[N\frac{3}{2}^+]_1(1795)$	14.1 ± 0.1	$N\frac{3}{2}^+(1720)$	****	5.5 ± 1.6
$[N\frac{3}{2}^+]_2(1870)$	$6.1^{+0.6}_{-1.2}$			
$[N\frac{3}{2}^+]_3(1910)$	$1.0^{+0.1}_{-0.2}$			
$[N\frac{3}{2}^+]_4(1950)$	$4.1^{+0.4}_{-0.7}$			
$[N\frac{3}{2}^+]_5(2030)$	1.8 ± 0.2			

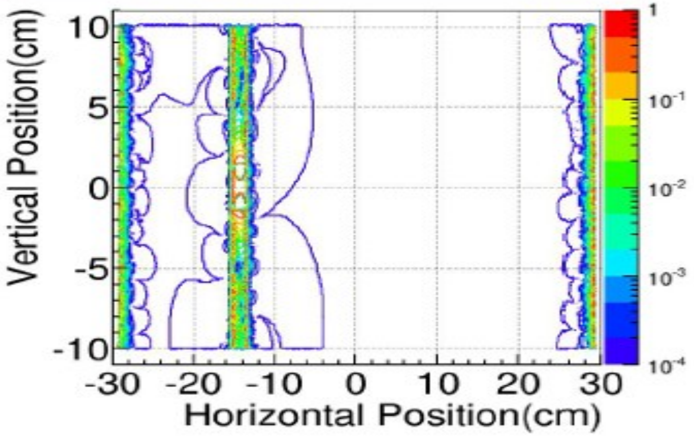
Even 20 years ago, this problem was known!
(Note: just $N\pi$ PWA.)

3-layer GEM configuration

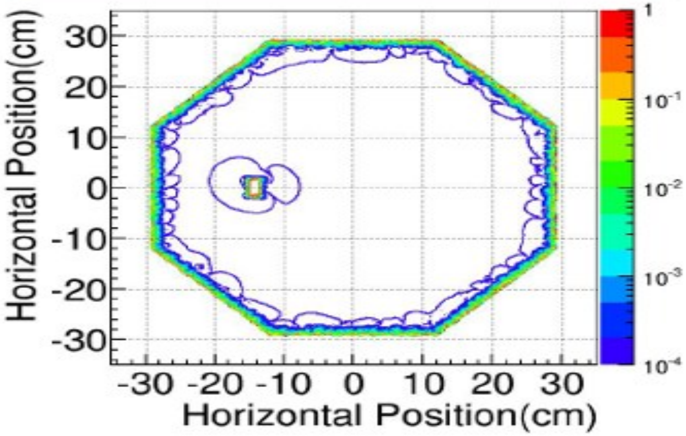


Tipical Emag distribution

Verical plane cross target



Horizontal plane via center



Refer to asumed E_0=180 V/cm: $(E-E_0)/E_0$
Target holder from bottom (z=-10 cm)

TPC Prototype

High-rate capable TPC

Track position distortion (expected)

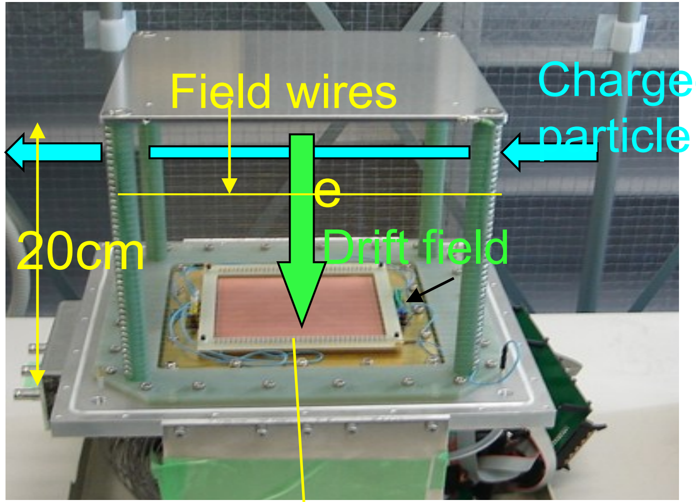
< 1 mm up to 10^8 cps

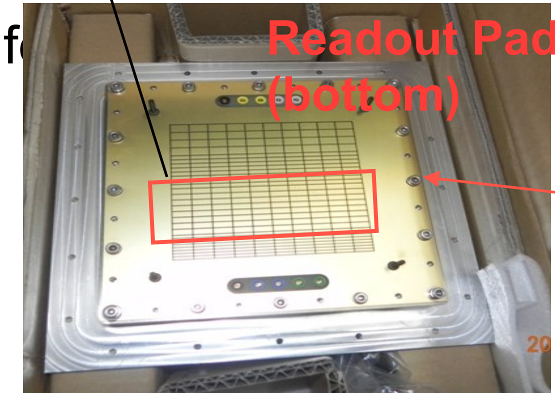
- Gating grid wires
  - Minimize positive-ion feedback
- GEM (50μm,50μm,100μm)
  - Low positive-ion f
- Readout pads
- Gas

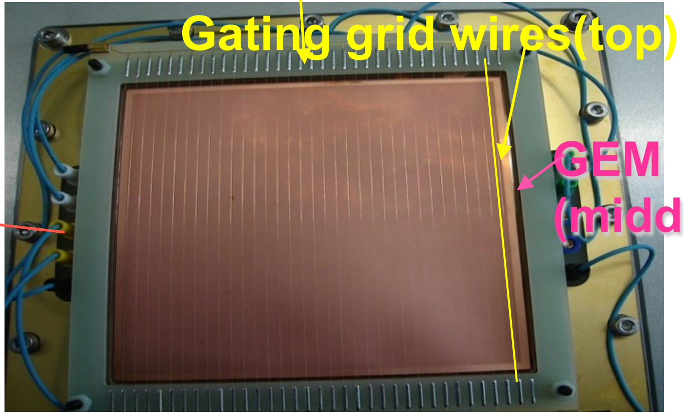
Ar-CH_4 (90:10)

5cm/μs,310μm /√cm

Pad size 4mm x 10mm

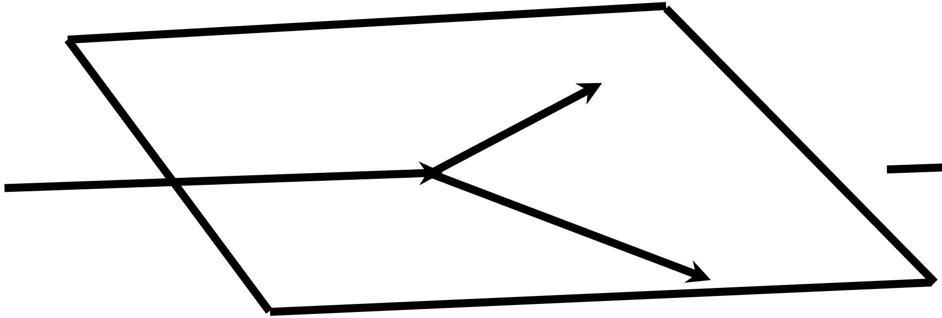




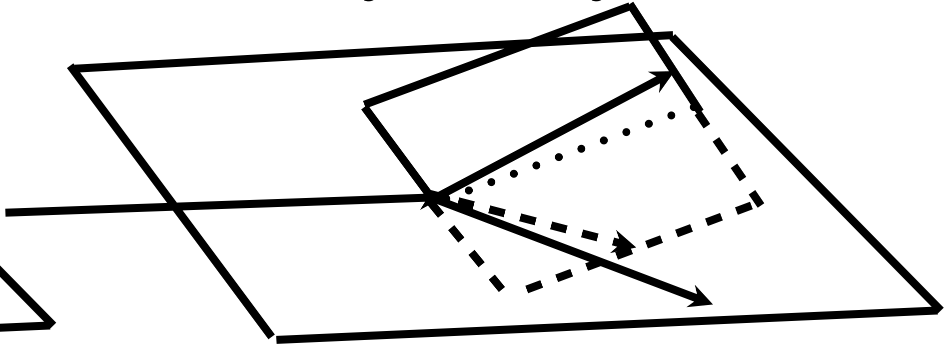


Coplanarity

Elastic scattering

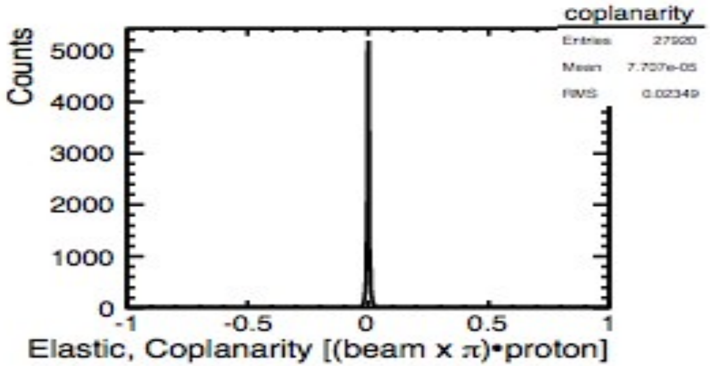


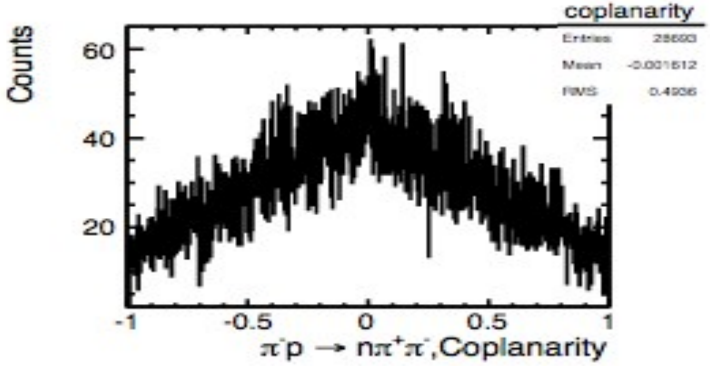
3-body decay

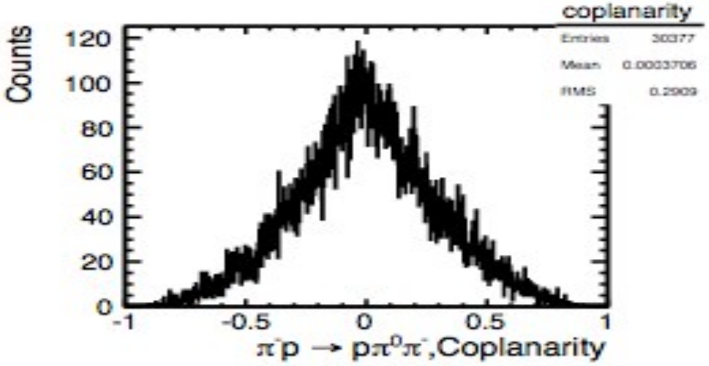


Coplanarity

Beam momentum : 1.435 GeV/c

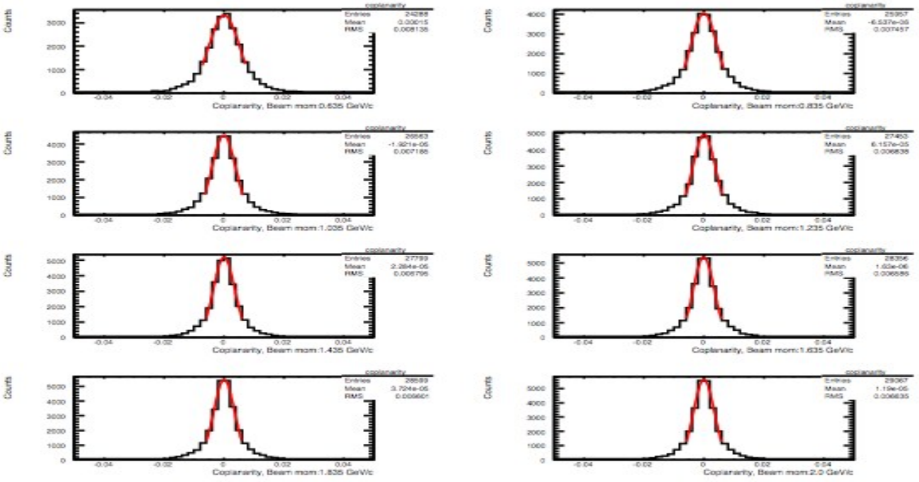


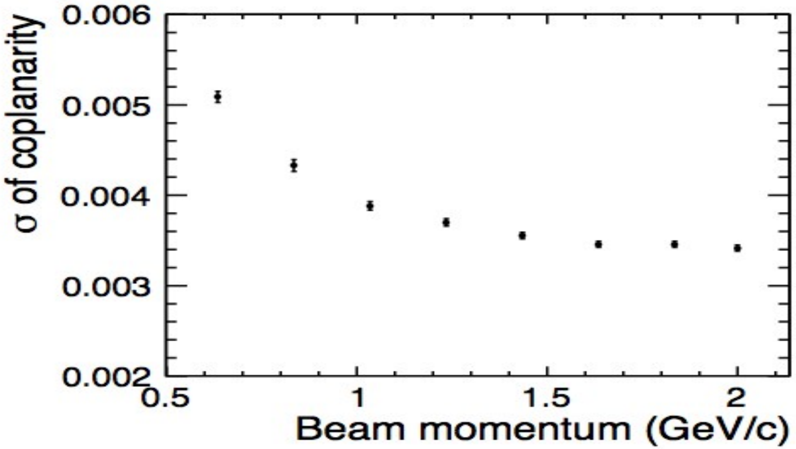




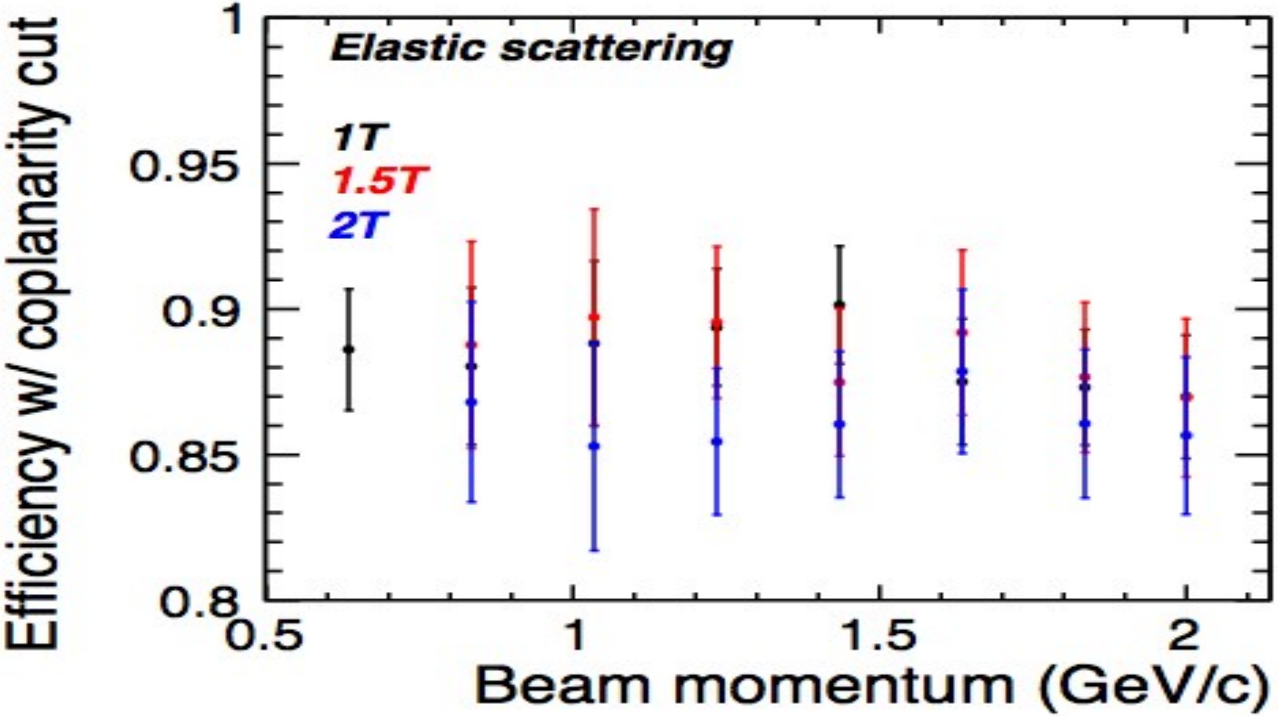
Sigma of coplanarity

Elastic scattering



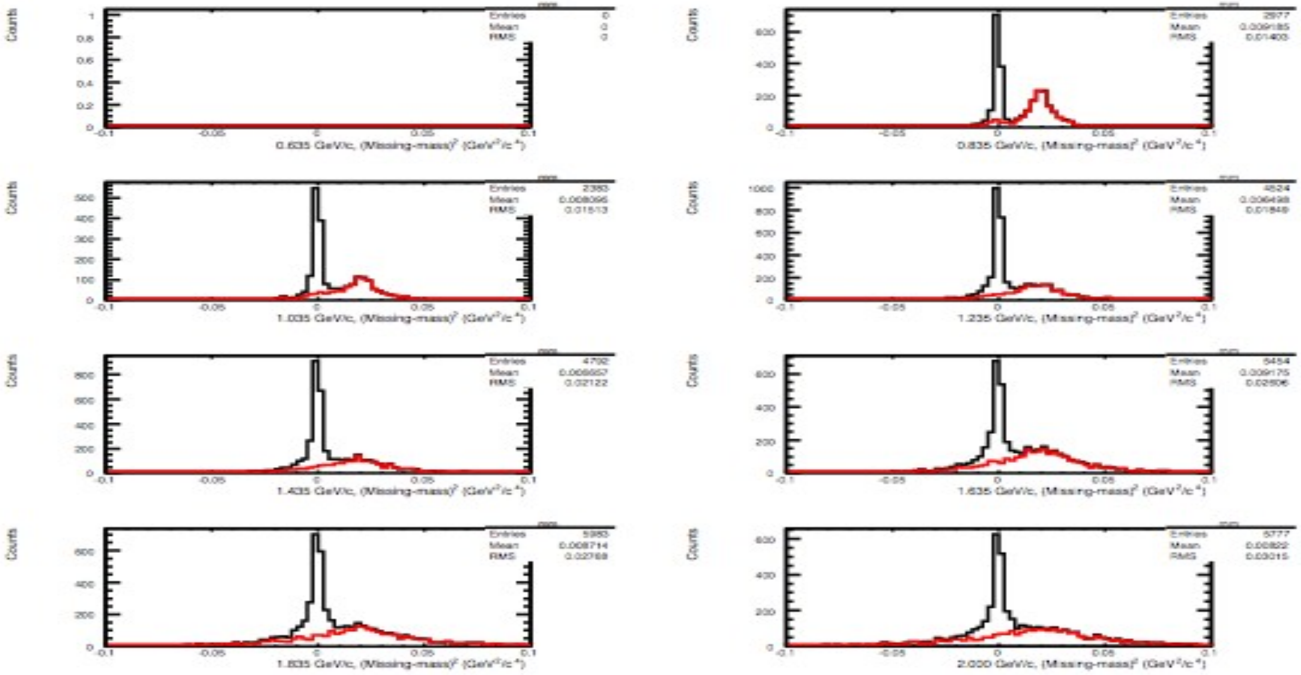


Rejection efficiency w/ coplanarity cut



MM distribution w/ cop. cut

1.5T



PWA

$$\frac{d\sigma}{d\varphi d\cos\theta} = \frac{1}{k^2}\left|\sum_l (2l+1)T(l)P_l(\cos\theta)\right|^2$$

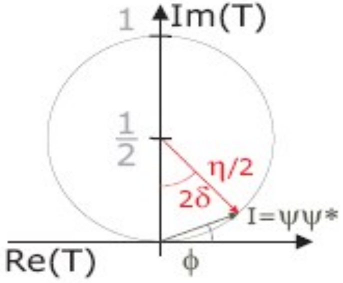
$$T(l) = \frac{\eta_l e^{2i\delta_l} - 1}{2i} = \frac{i}{2} - \frac{i\eta_l}{2}e^{2i\delta_l}$$

$$\sigma_T = \frac{4\pi}{k}\sum_l (2l+1)2(1-\eta_l\cos 2\delta_l)$$

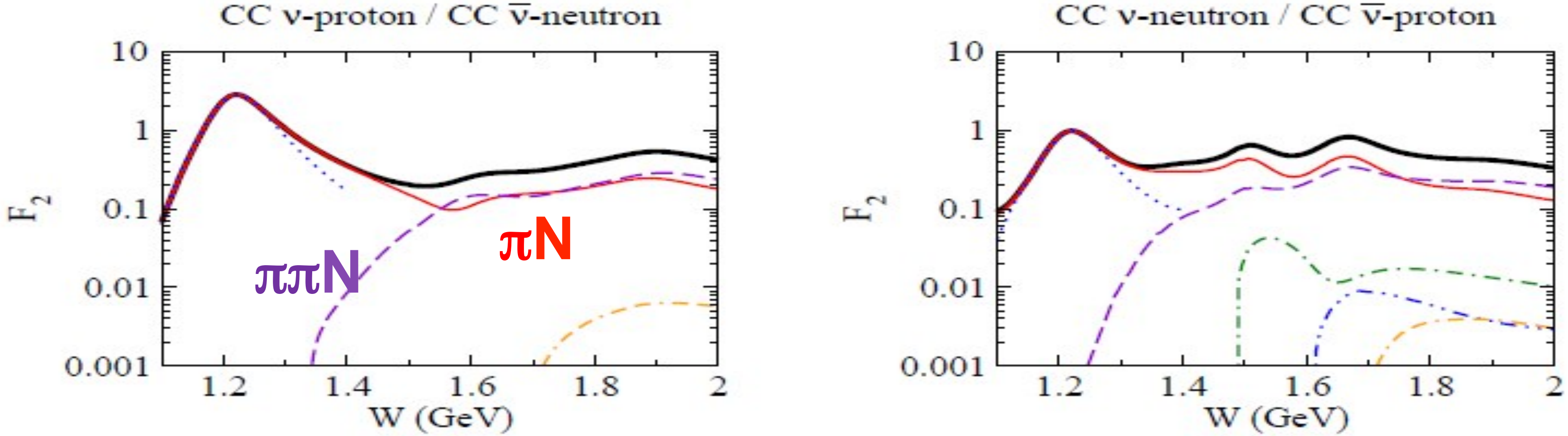
$$\text{elastic scattering}(\eta_l = 1),\ \text{spin0 particle}$$

$$T_l = \frac{1}{\cot\delta - i} = \frac{\Gamma/2}{(E_R - E) - i\Gamma/2}$$

Scattering amplitude

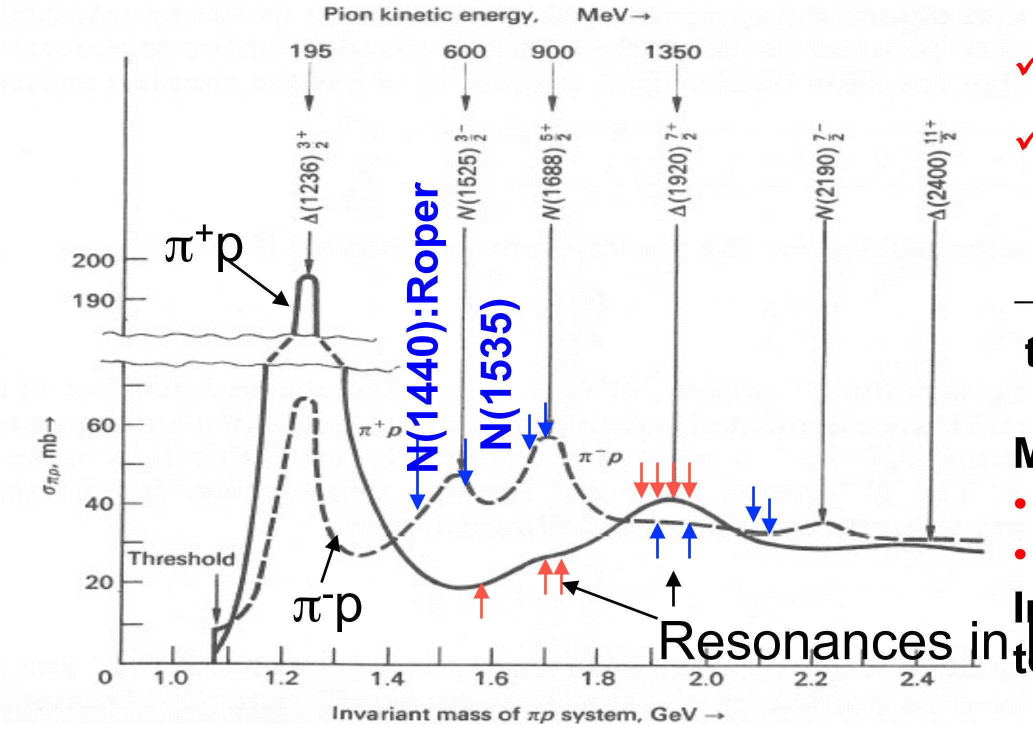


Importance of πN→ππN for long baseline neutrino experiments



Charged Current neutrino scattering structure functions. For W>1.5 GeV, about half of the cross section is for the ππN final state. Knowledge of the N* resonances at higher mass is important to precise understanding of the detector response of neutrino detectors.

Baryon spectroscopy :
Physics of broad and overlapping resonances



- ✓ Width: a few hundred MeV.
- ✓ Resonances are highly overlapped in energy except Δ(1232).

→Complicated Partial Wave Analysis to extract hidden resonances

Measure cross sections as a function of
- incident pion energy
- Scattering angle

In broad range (with fine bins) to extract resonance poles

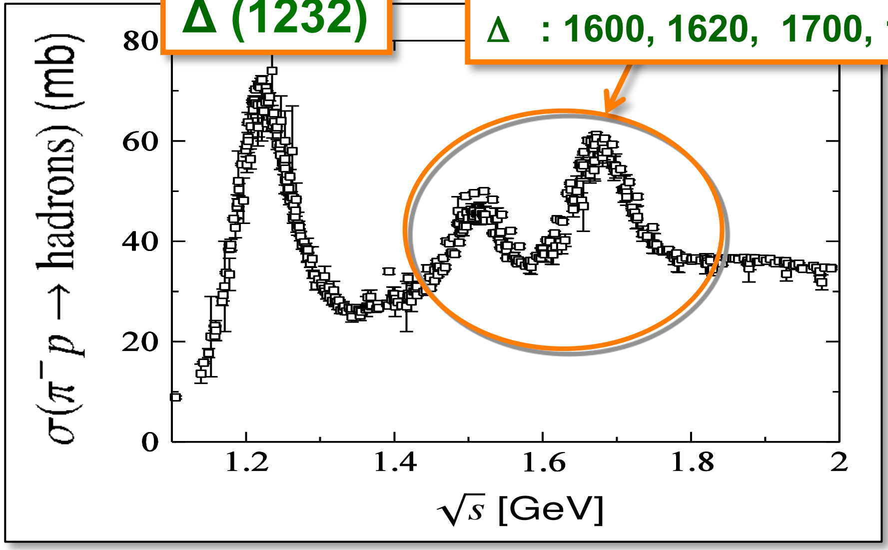
D.H.Perkins, Introduction to High Energy Physics

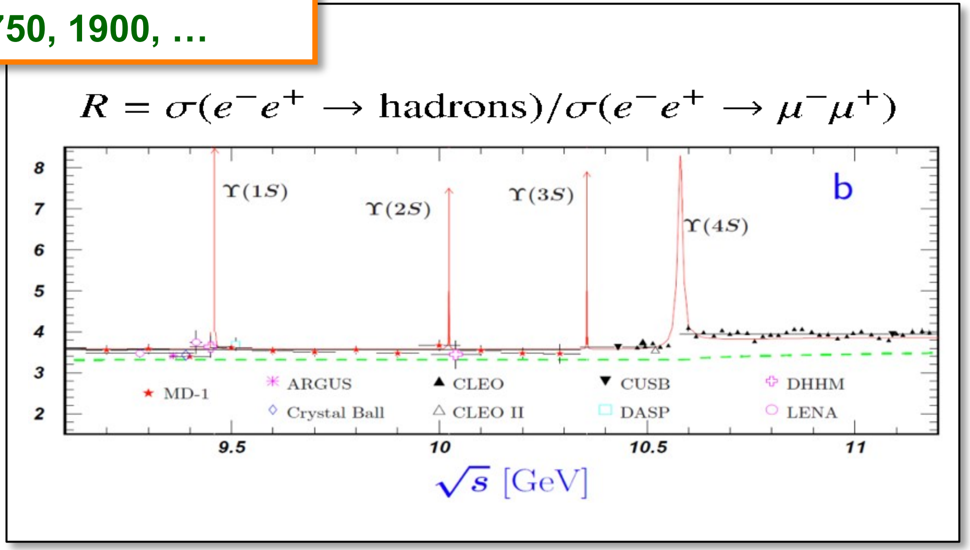
N* spectroscopy :
Physics of broad and overlapping resonances

Δ (1232)

N* : 1440, 1520, 1535, 1650, 1675, 1680, ...

Δ : 1600, 1620, 1700, 1750, 1900, …





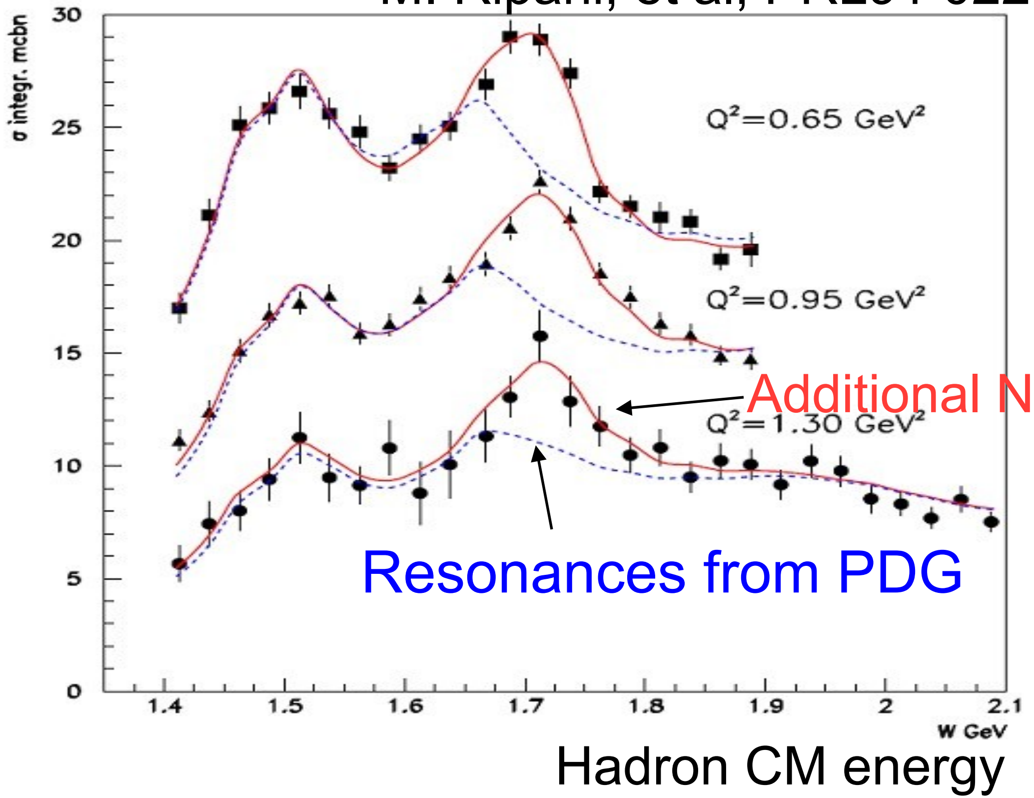
- ✓ **Width: a few hundred MeV.**
- ✓ **Resonances are highly overlapped in energy except Δ(1232).**

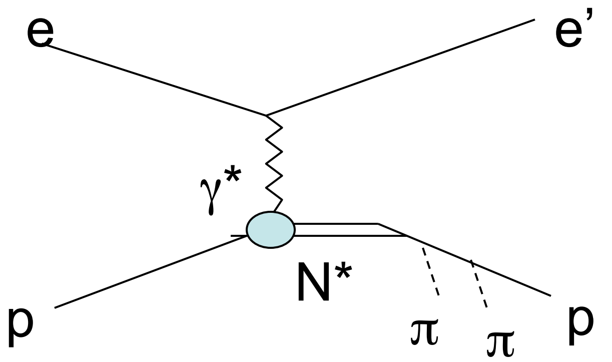
→Complex PWA is necessary

- ✓ **Width: ~10 keV to ~10 MeV**
- ✓ **Each resonance peak is clearly separated.**

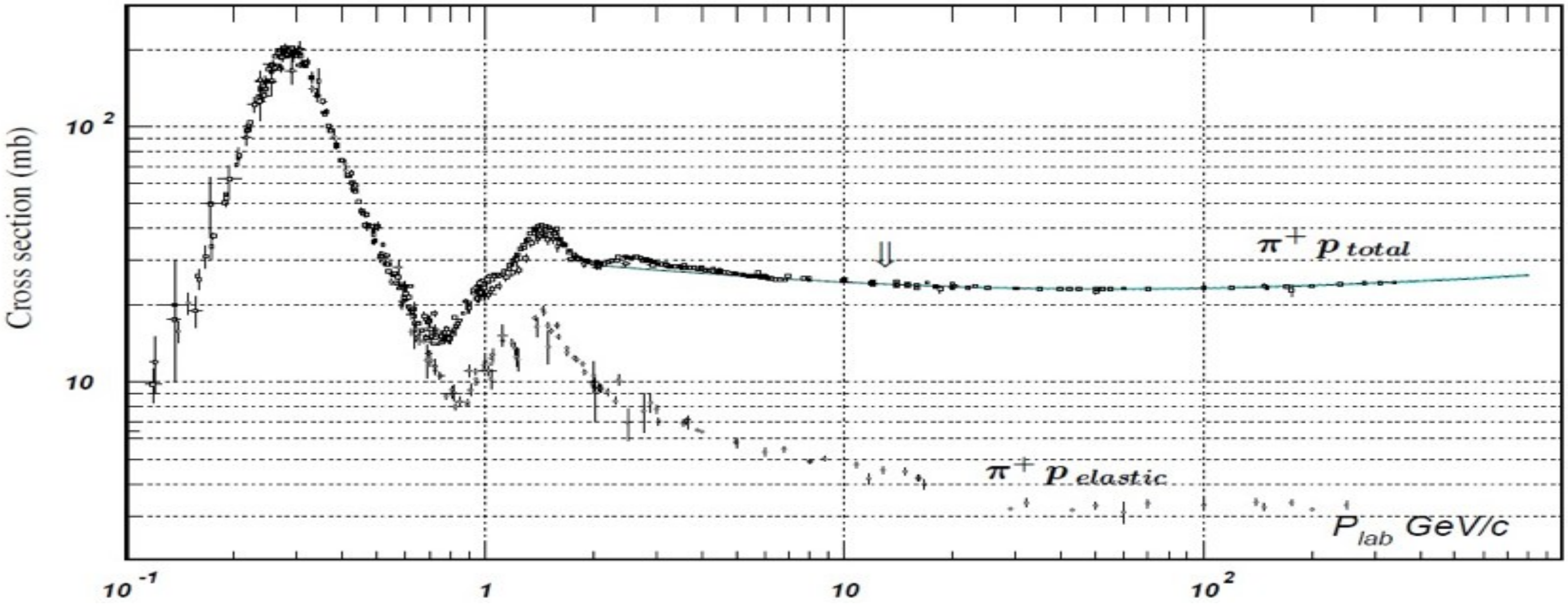
New results from CLAS: $e\,p \rightarrow e'\,p\,\pi^+\,\pi^-$

M. Ripani, et al, PRL91 022002 (2003)



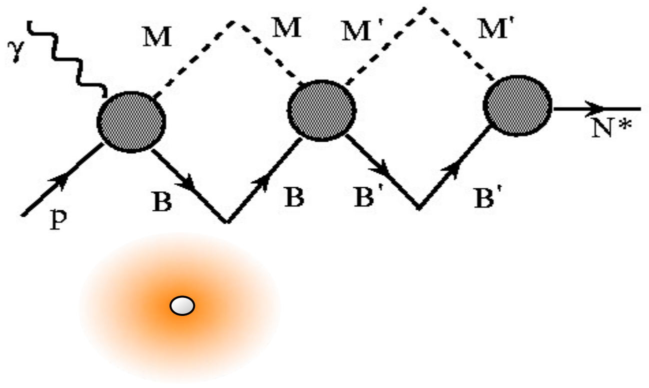


π-N Total Cross Sections



Example: Meson cloud effects in γ N → N* form factors

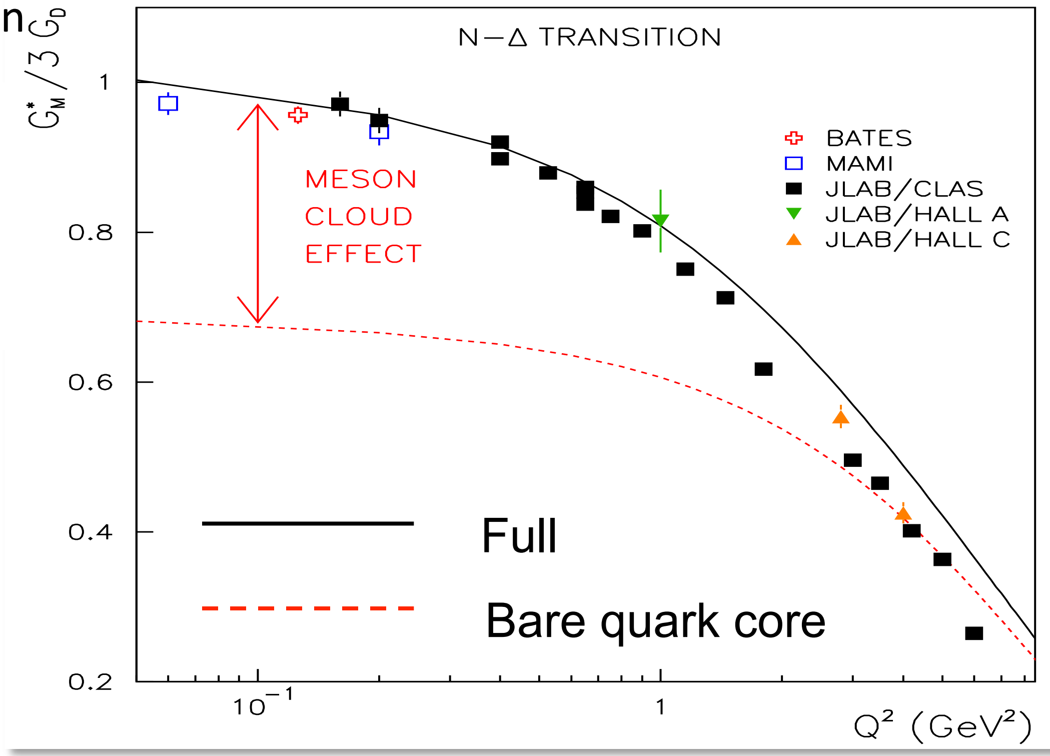
- One third of G*M at low Q^2 is due to contributions from meson–baryon (MB) dressing:



N, N*

In the relativistic QM framework, the bare-core contribution is well described by the three-quark component of the wave function at high Q^2.

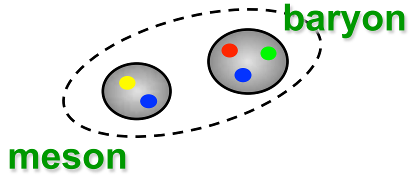
$G_M(Q^2)$ for γ N → Δ (1232) transition



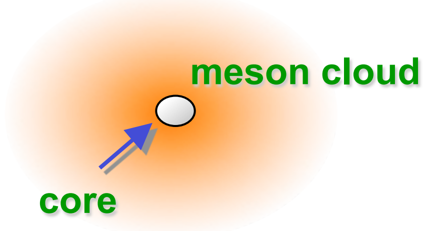
B.Julia-Diaz *et al.*, PRC 69, 035212 (2004)

Dynamical coupled-channels (DCC) model for

Physical N*s will be a “mixture” of the two pictures:

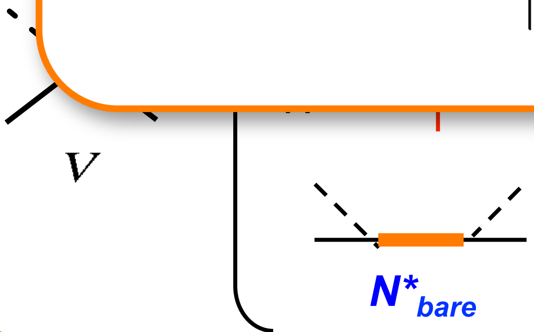


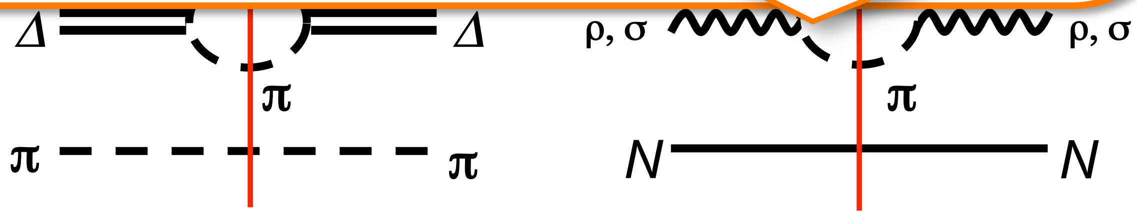
$$|N^*\rangle = |MB\rangle$$



$$|N^*\rangle = |qqq\rangle + |\mathrm{m.c.}\rangle$$

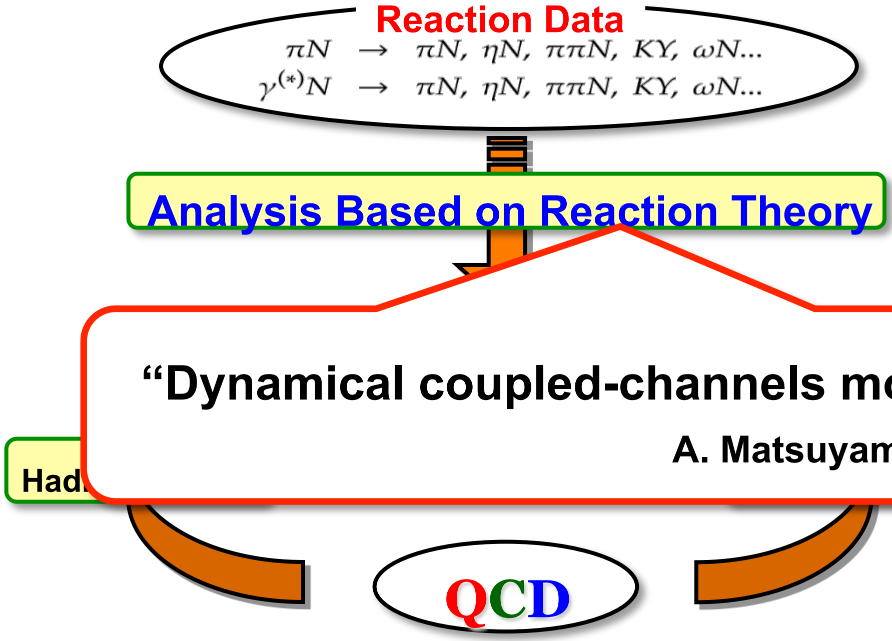
Can be related to hadron states of the static hadron models (quark models, DSE, etc.) excluding meson-baryon continuum.





Collaboration at Excited Baryon Analysis Center (EBAC) of Jefferson Lab

Founded in January 2006 http://ebac-theory.jlab.org/



"Dynamical coupled-channels model of meson production reactions"

A. Matsuyama, T. Sato, T.-S.H. Lee Phys. Rep. 439 (2007) 193

Objectives and goals:

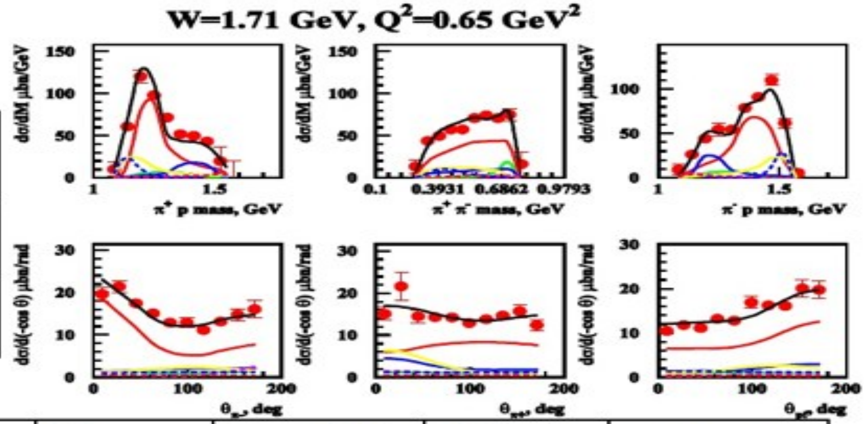
Through the comprehensive analysis of world data of πN, γN, N(e,e') reactions,

- ✓ **Determine N* spectrum (pole masses)**
- ✓ **Provide reaction mechanism information necessary for interpreting N* spectrum, structures and dynamical origins**

CLAS: Partial Wave Analysis

$P_{13}(1720)$ state with hadronic decays fit to the CLAS data - $2.94<\chi^2/d.p.<3.15$

	M, GeV	Γ_{tot}, MeV	BF($\pi\Delta$) %	BF(ρp) %
$P_{13}(1720)$ CLAS	1.728± 0.005	133±19	66±26	16±11
$P_{13}(1720)$ PDG	1.70 - 1.75	150-300	comp. with 0.	70-85



hadronic parameters of $3/2^+(1725)$ candidate state as well as of others N*'s were varied within PDG uncertainties - $2.78<\chi^2/d.p.<2.9$

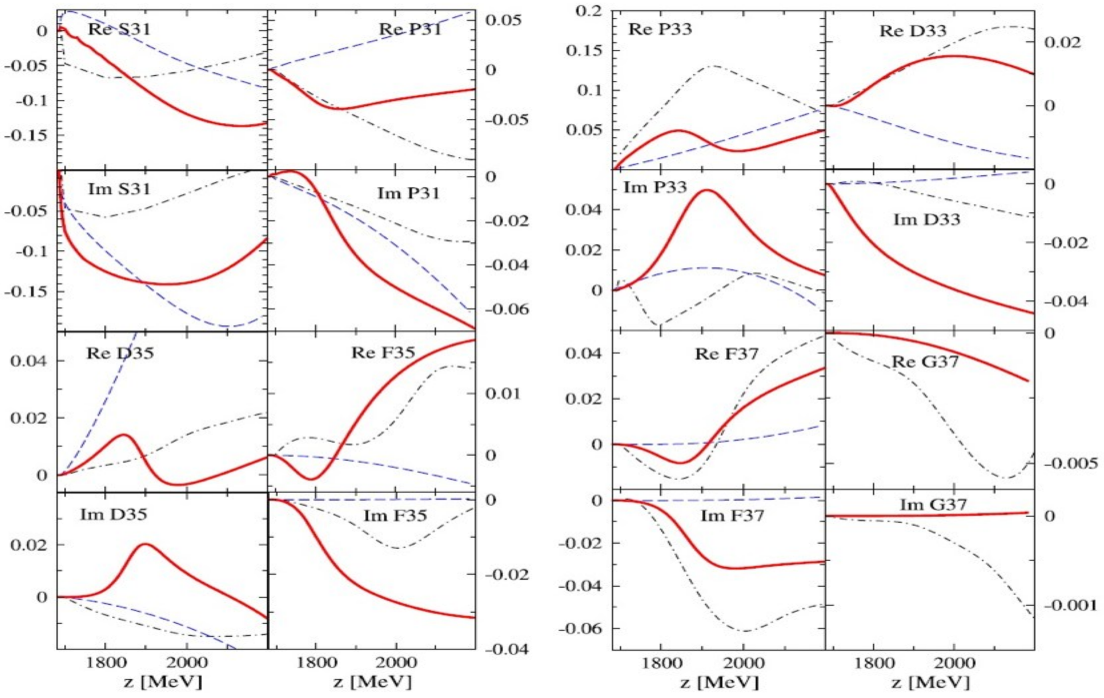
	M, GeV	Γ_{tot}, MeV	BF($\pi\Delta$) %	BF(ρp) %
3/2+(1725)	1.725± 0.004	80±6.0	48±10	7.7±2.2
$P_{13}(1720)$	1.747± 0.004	161±31	comp. with 0.	60-100

A new P_{13} resonance, much lower in mass than the quark model prediction, is necessary to fit the data.

Additional final state: KY data

- Data for KΛ and KΣ come for free
  - Cross sections are smaller, but the final state is two-body, so less data are needed.
  - These final states have two charged particles and hence will be part of the trigger.
- Data on $\pi^+ p \rightarrow K^+ \Sigma^+$ are especially useful
  - Only isospin 3/2 contributes: Δ resonances.
  - Is the Δ(1600) the I=3/2 partner of the Roper?

Partial wave solutions: KY data



We need better quality data to resolve the PWA ambiguities.

Connection to Hypernuclei

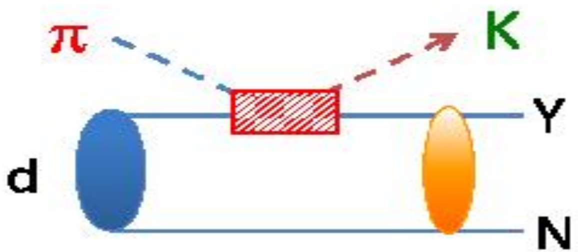
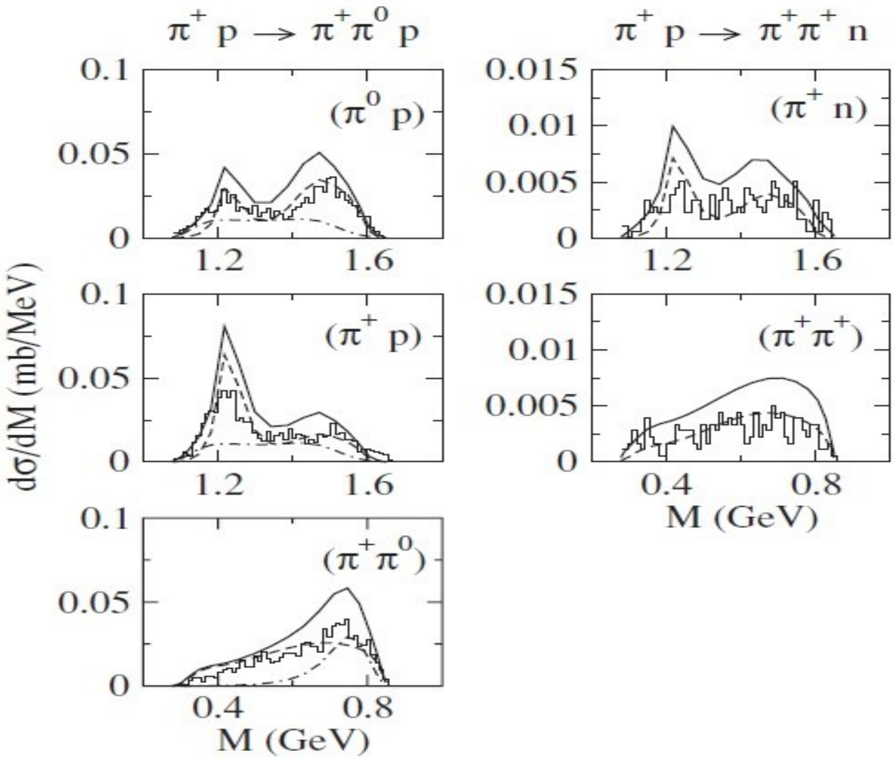


Diagram showing the YN interaction studied through FSI of the (π,K) reaction on the deuteron.
To calculate this, one first needs better data for the basic (π,K) reaction on the nucleon.

Studies of hypernuclei have provided potentials for the YN force in nuclei, and now Lattice calculations have made predictions for free YN scattering. The data from this proposal will provide the (π,K) data over a broad range of kinematics needed to constrain the first part of the calculation.

Mass Projections of existing data

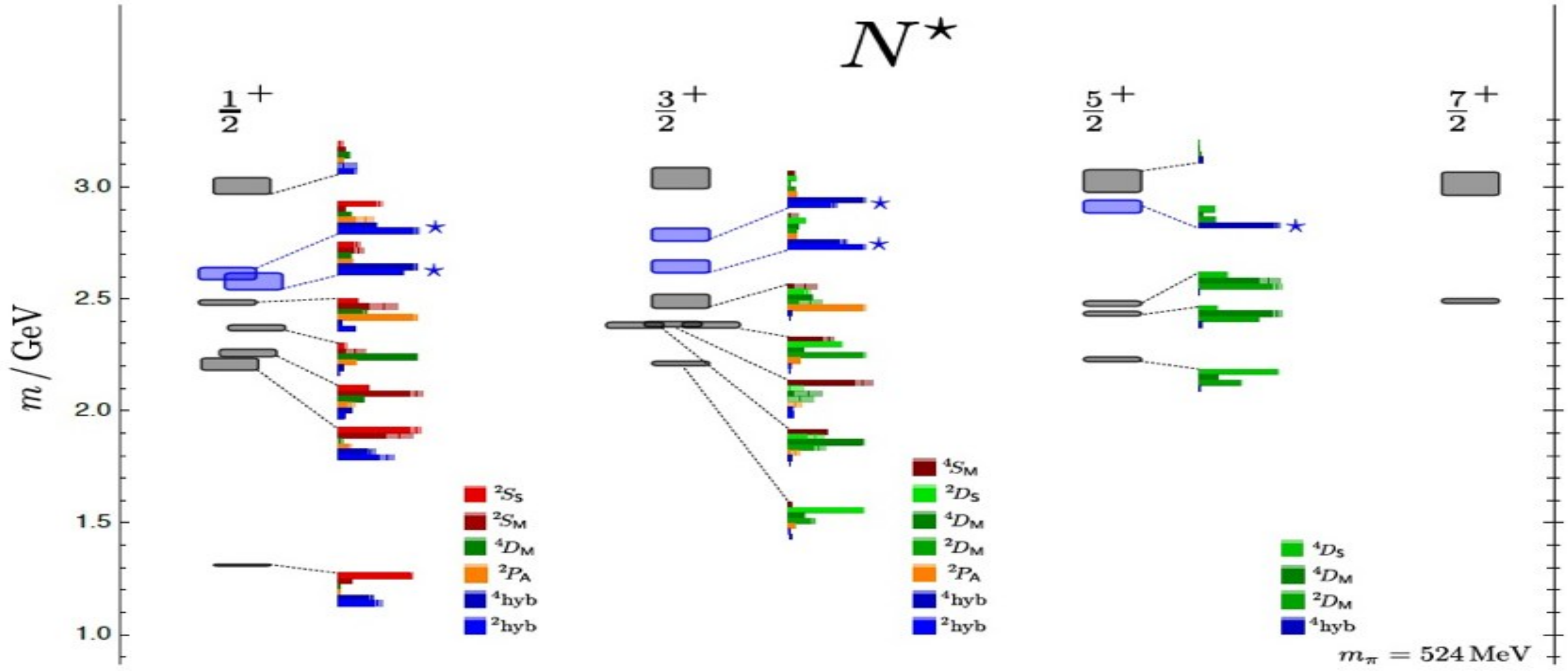


Problem: the normalization of these data is unknown.

The total cross sections were used to set the vertical scale.

The solid curves are the full calculation using only πN elastic data. The other curves do not include some coupled-channels effects.

Projection of N* to $^{S}L_{I}$



P45: 3-Body Reactions for New Aspects of Baryon Spectroscopy

K. Hicks (Ohio) and H. Sako (JAEA)

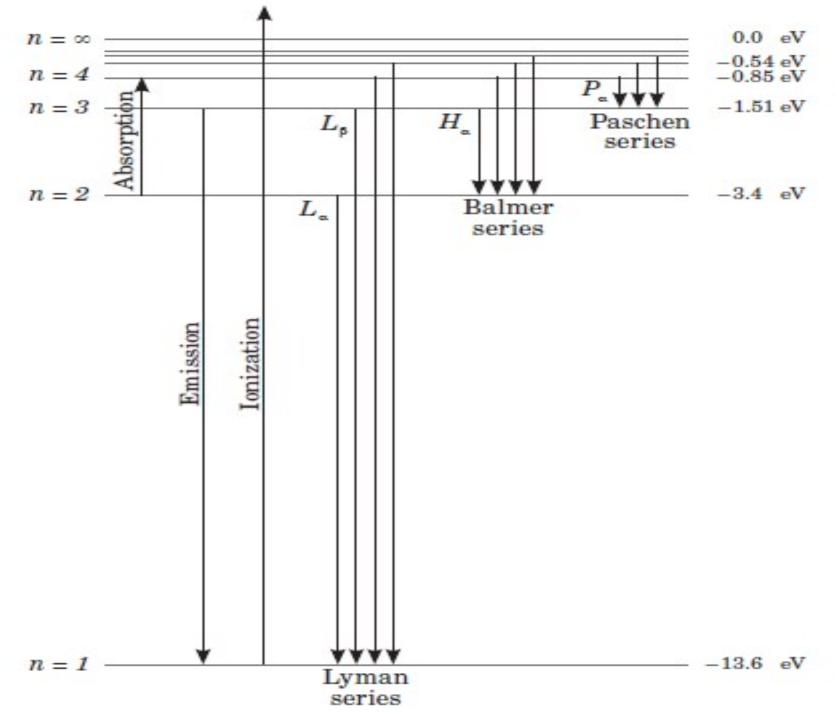
J-PARC PAC Meeting

10 January 2013

Physics Goals

- QCD is believed to be the fundamental theory of the strong force
  - At high energies, the force becomes weaker and perturbation theory can be used for calculations.
  - In the real world, energies are lower.
    - Perturbation theory fails
    - Phenomenological quark models are inadequate
    - Lattice gauge theory can now make predictions due to advances in computers and calculation

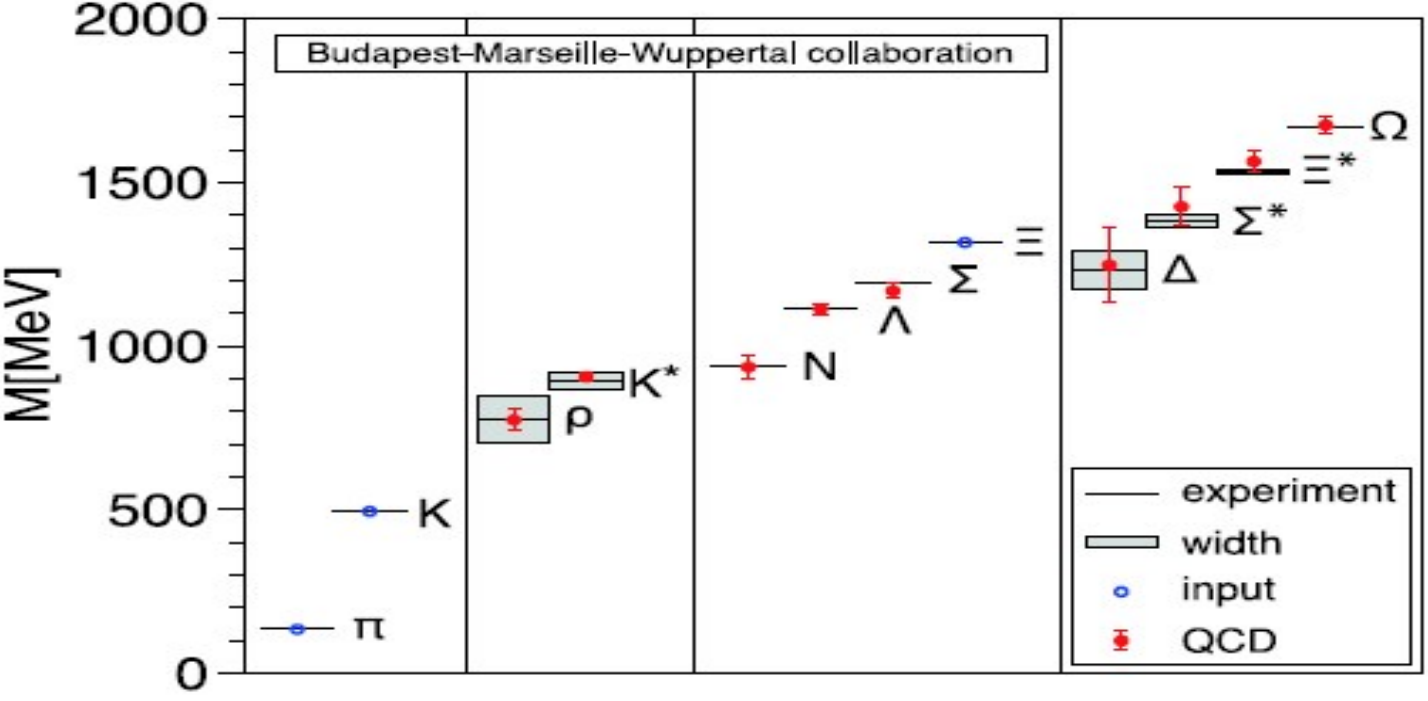
An Analogy



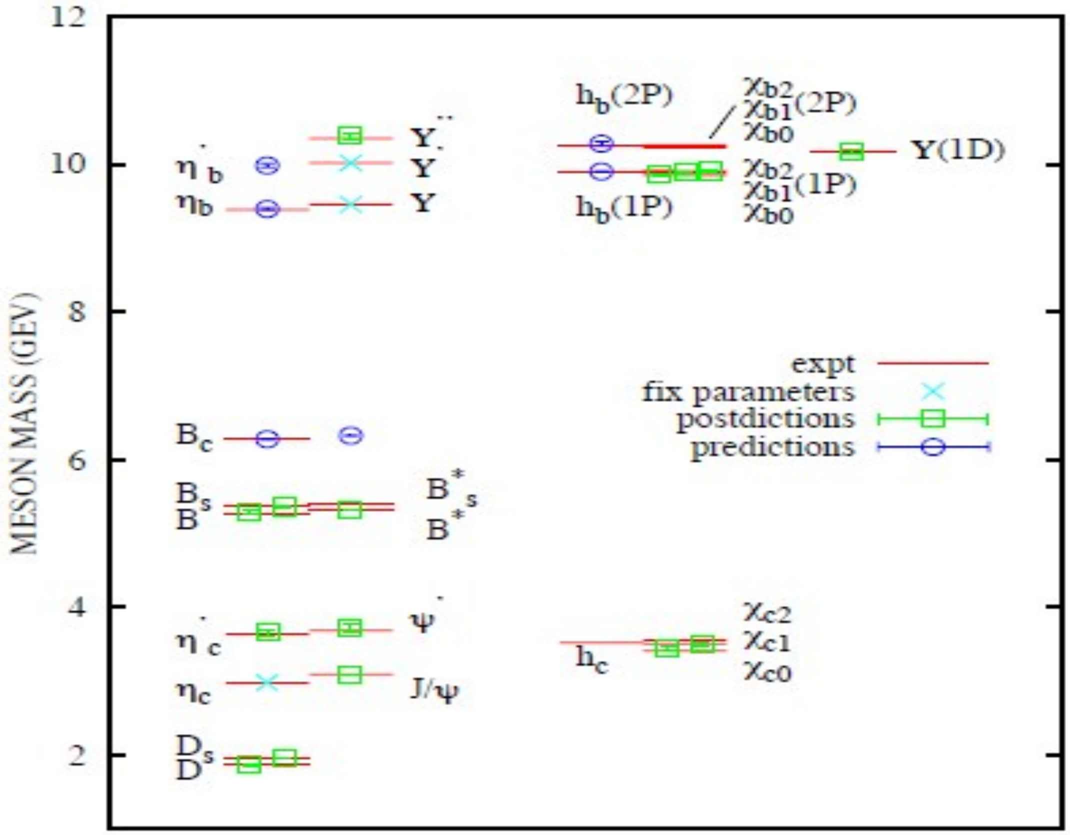
The spectrum of energy levels of the hydrogen atom provided insights into the structure of the atom from Bohr and later, with more precise data, to the theory of quantum mechanics.

Even today, the spectrum of hydrogen continues to give surprises (*e.g.* proton radius)

Lattice Gauge: Ground States



Lattice: heavy meson spectrum



Experimental Tests: N* Spectrum

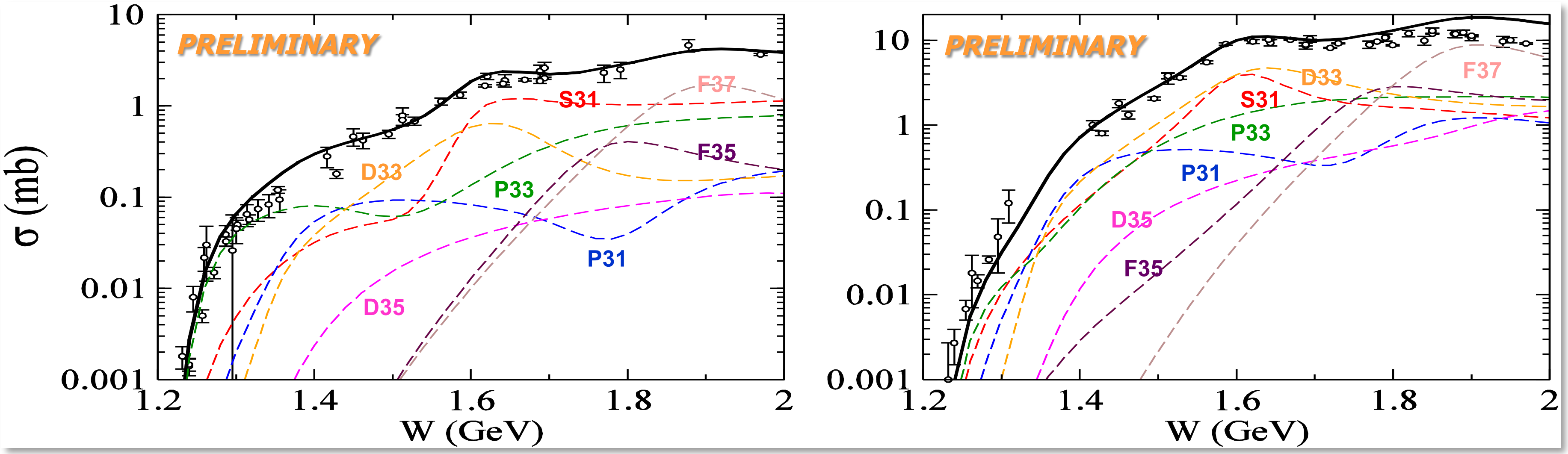
- Extracting the spectrum of nucleon resonances is not an easy task.
  - The resonances have natural widths 100-200 MeV
  - The resonances are overlapping
- However, resonances have distinct values of spin, parity and isospin.
  - Using the techniques of Partial Wave Analysis (PWA), the resonances can be separated.
  - This requires high-statistics, high-quality data.

Question 1

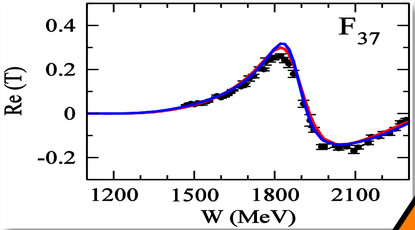
- The proponents should provide a more quantitative argument to show how the data of expected precision will contribute to the analysis of nucleon resonances.

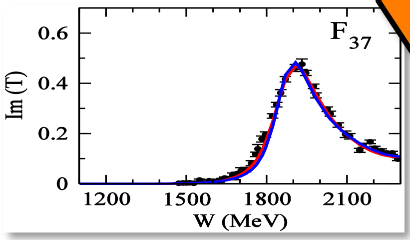
Total Cross Sections

$\pi^+ p \rightarrow \pi^+ \pi^+ n$ $\pi^+ p \rightarrow \pi^+ \pi^0 p$



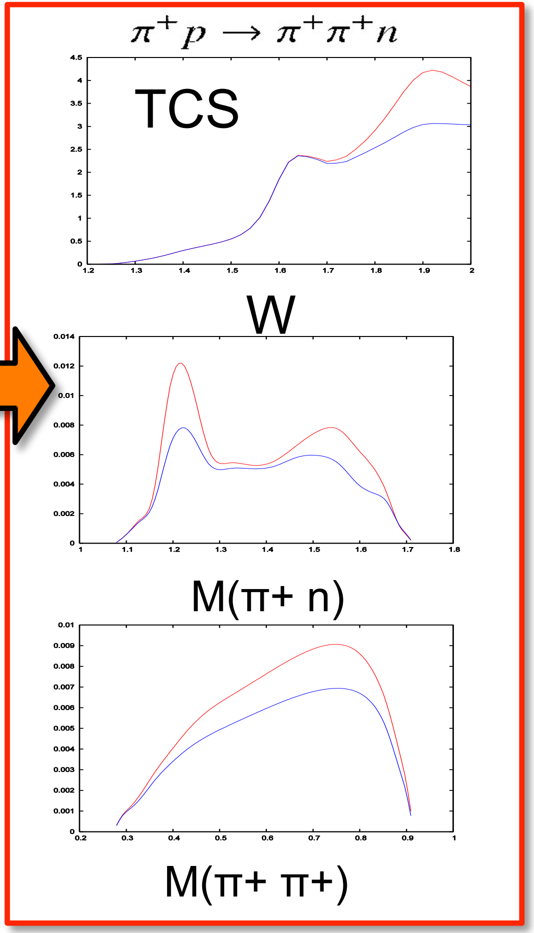
PRELIMINARY

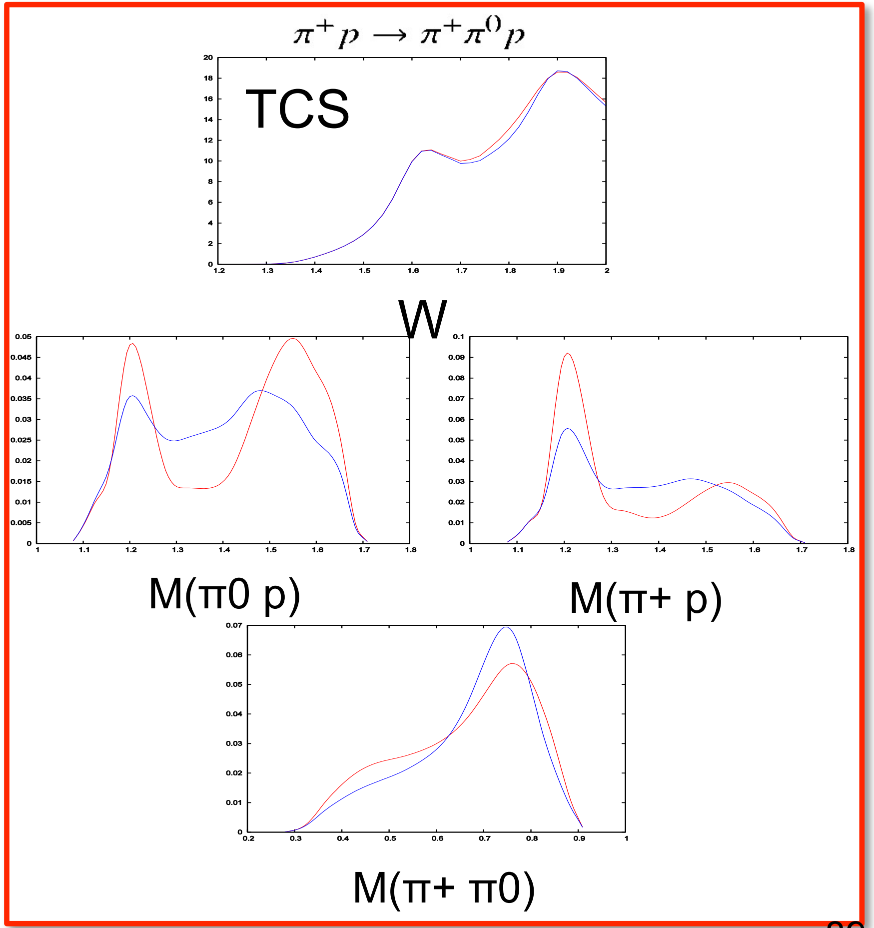




Current model

Refit F37 PWA keeping N* → πΔ off

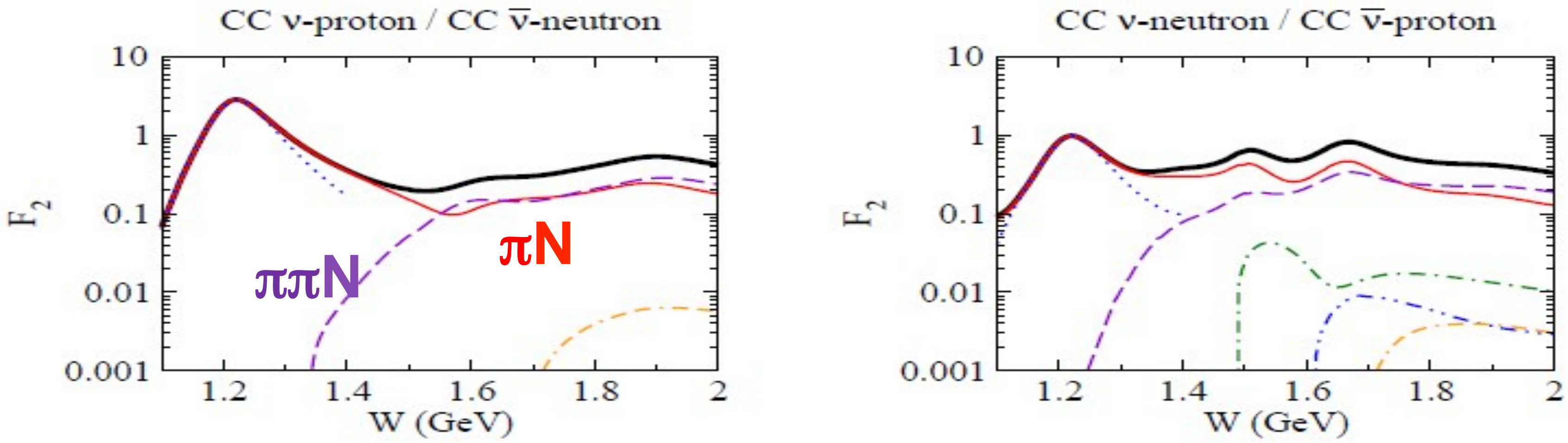




Answer 1-a

- The previous data for the $\pi N \rightarrow \pi\pi N$ reaction is not sufficient to isolate the N* properties.
  - Ambiguities exist in the $\pi N \rightarrow \pi N$ elastic data
  - Coupled channels calculations (simultaneous fits to all πN reactions) are necessary
  - The theoretical tools now exist to do this!
- In a small amount of beam time, J-PARC can completely re-write the $\pi N \rightarrow \pi\pi N$ database.

Answer 1-b



Charged Current neutrino scattering structure functions. For W>1.5 GeV, about half of the cross section is for the ππN final state. Knowledge of the N* resonances at higher mass helps to calculate the detector response of neutrino detectors.

New Theoretical Collaboration

- Neutrino-nucleus reactions from MeV to GeV
  - Spokespersons S. Kumano and T. Sato
  - Goal: to study the effect of deep-inelastic scattering of neutrinos from nuclei leading to specific final states.
  - The leading-order effect is the πN final state, and the next-to-leading effect is the $\pi\pi$N final state.
  - Quantitative results are not yet available, but will be studied in the near future.

DCC for $\pi N \rightarrow \pi N$

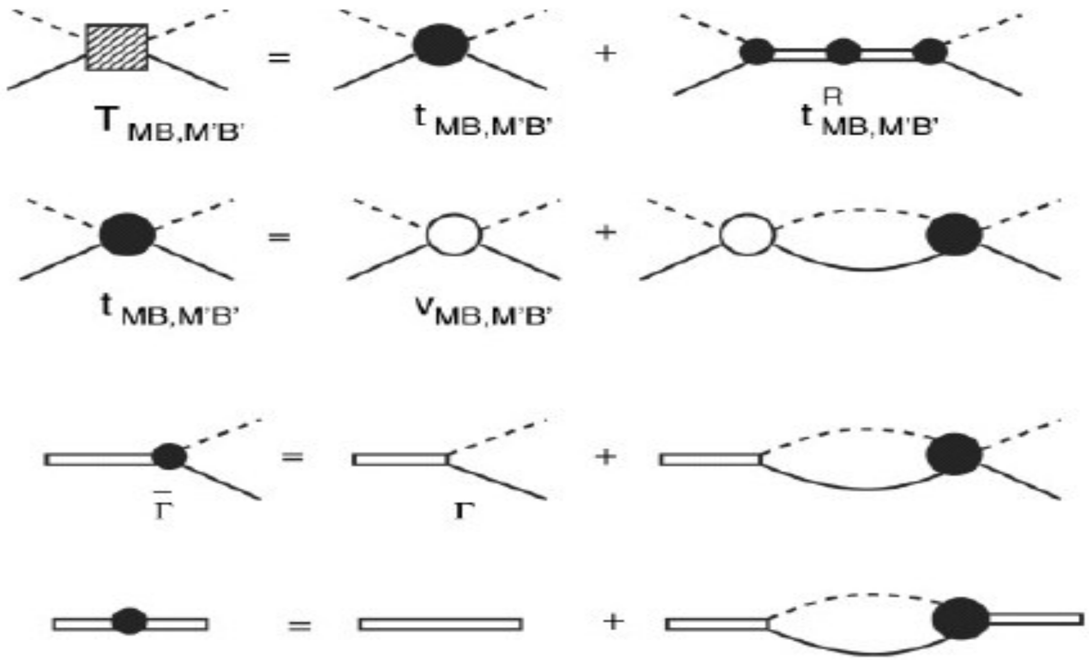
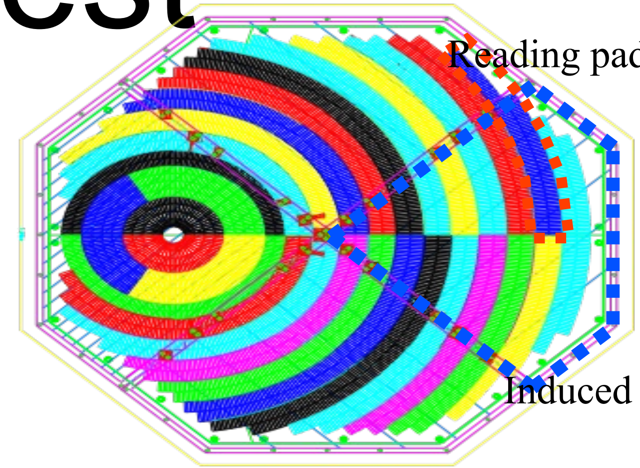
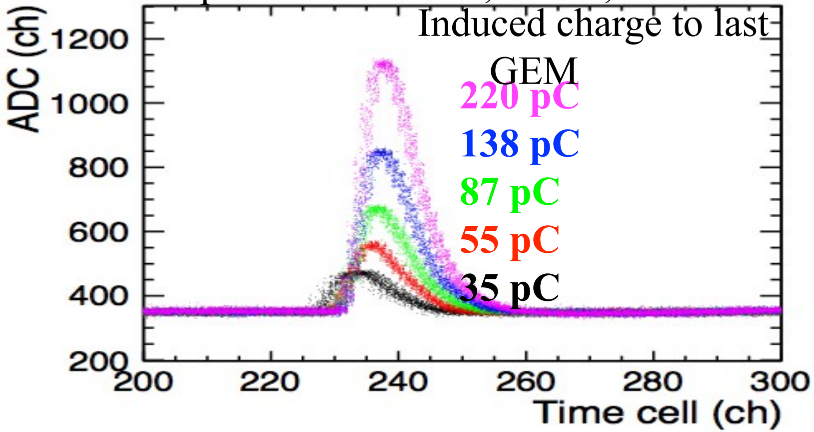


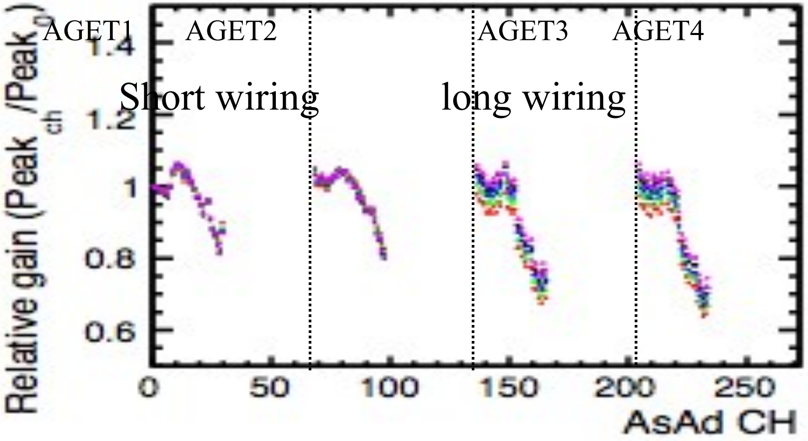
FIG. 1. Graphical representation of Eqs. (5)–(21).

Gain test



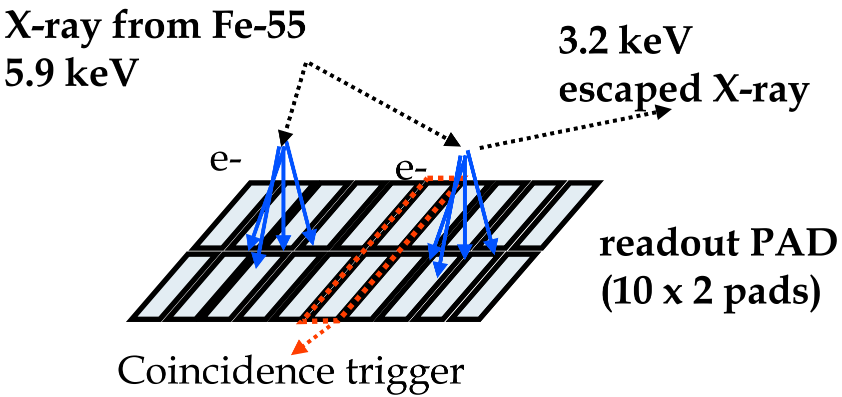
Pulse shape of AsAd board, 120fC, 232ns

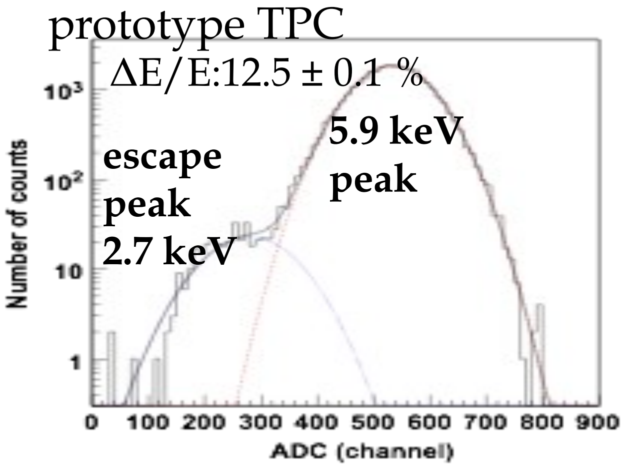




Gain uniformity is good.

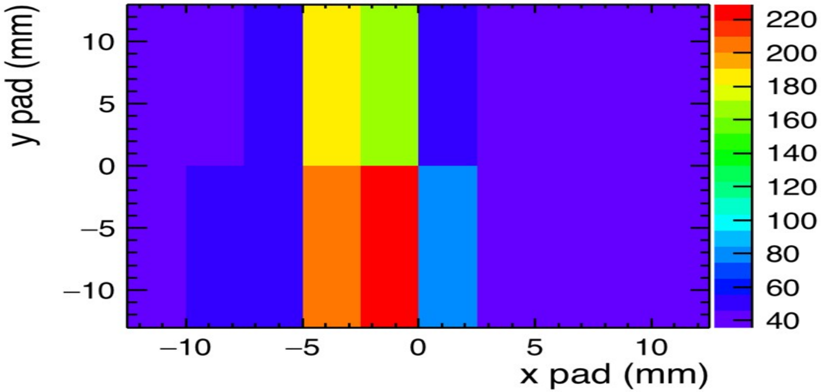
X-ray measurement



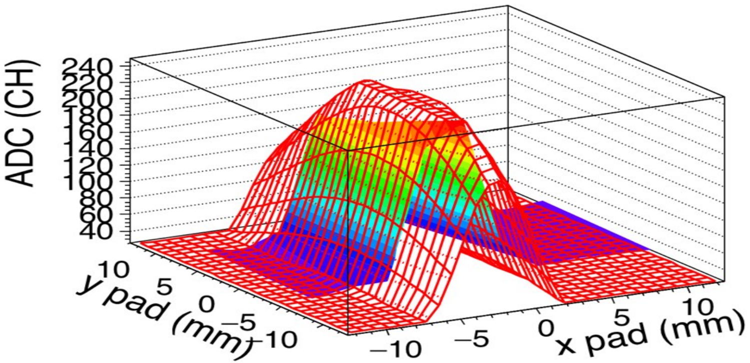


Analysis

ADC distribution

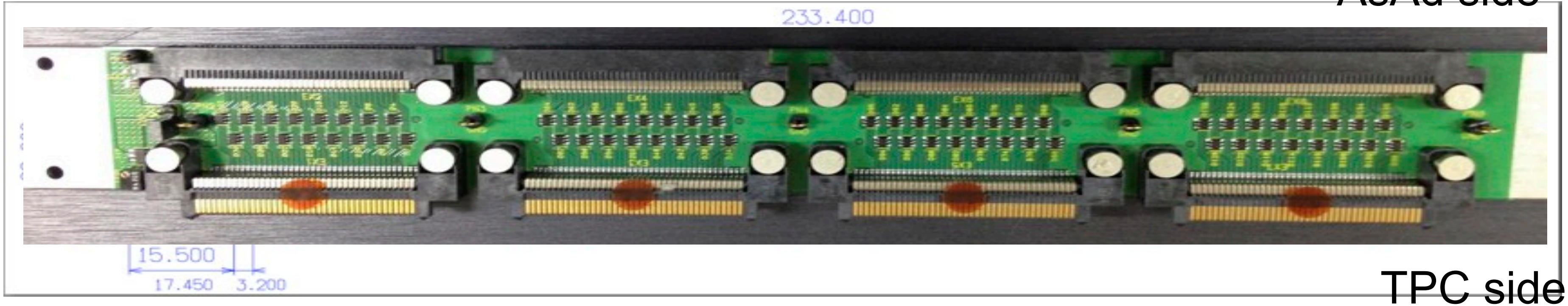


2D-gaussian fitting



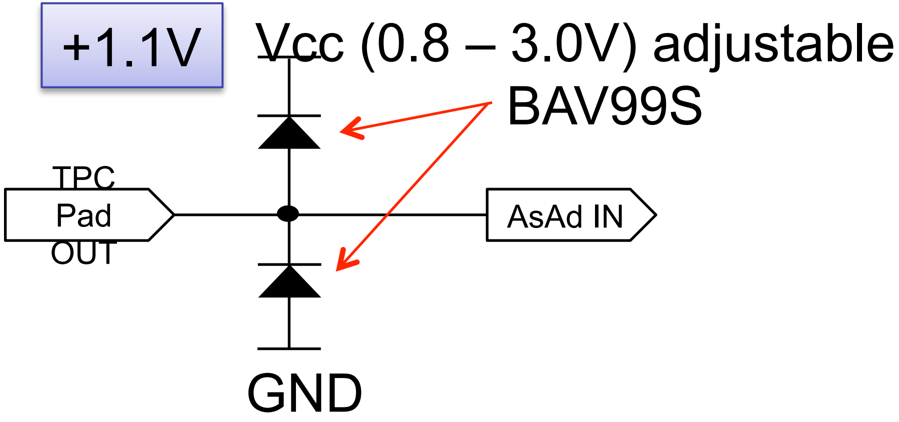
ZAP for HypTPC

AsAd side



TPC side

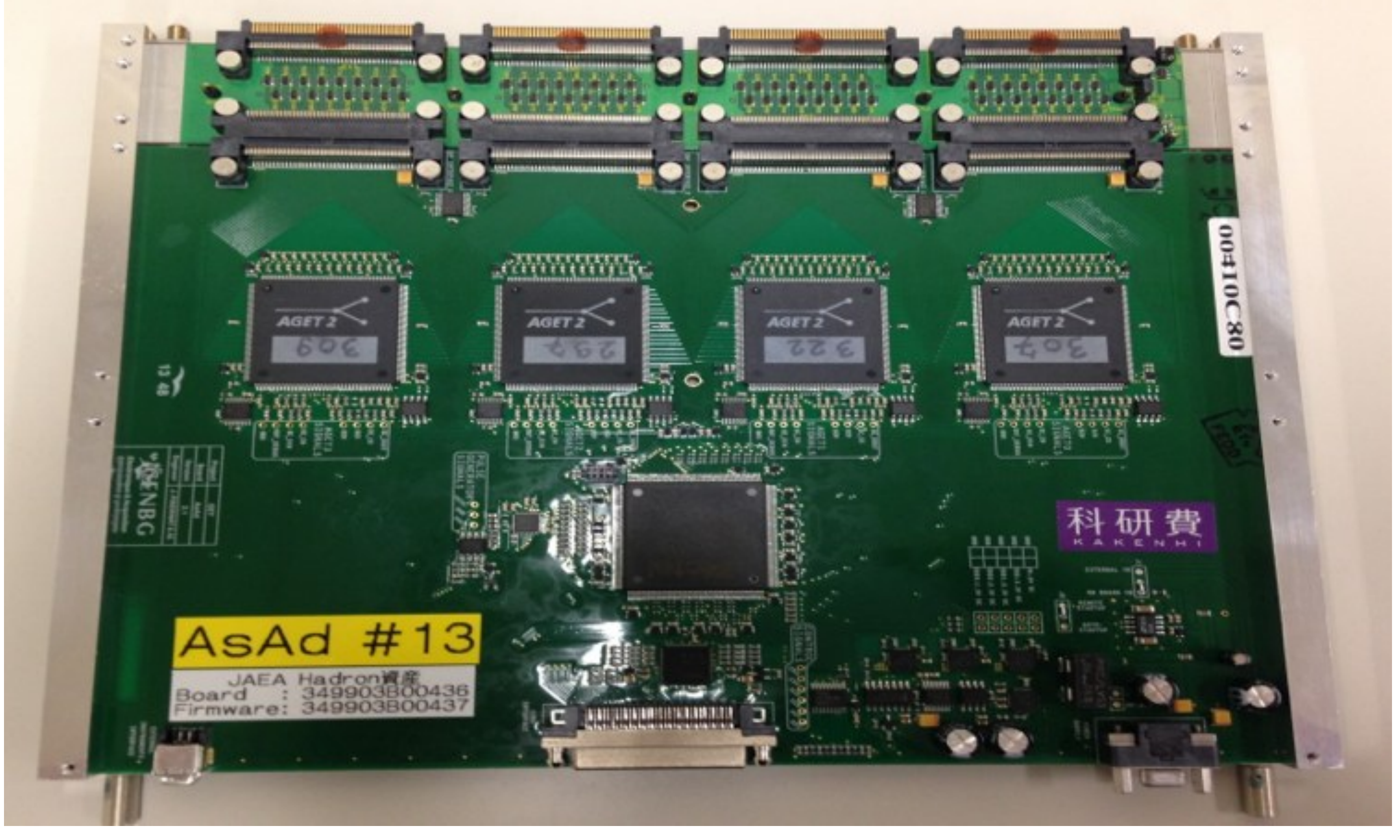
+1.1V



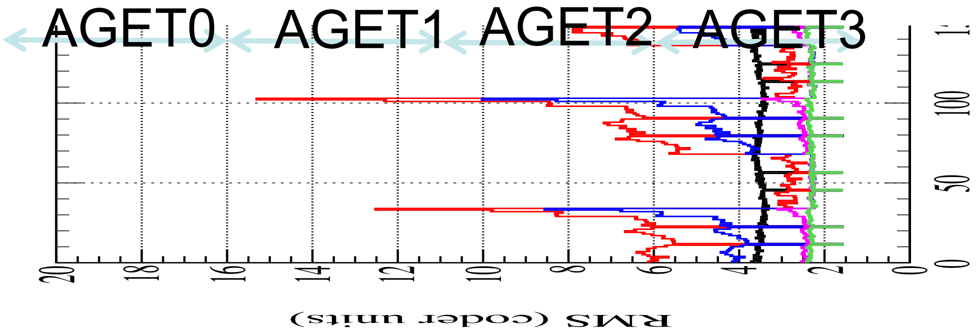
Layers

L1 : Signal (even ch)
L2 : GND
L3 : Vin = 3.6V (AsAd)
L4 : Vcc = 1.1 V (regulator out)
L5 : GND

Shield for AsAd + ZAP (front)

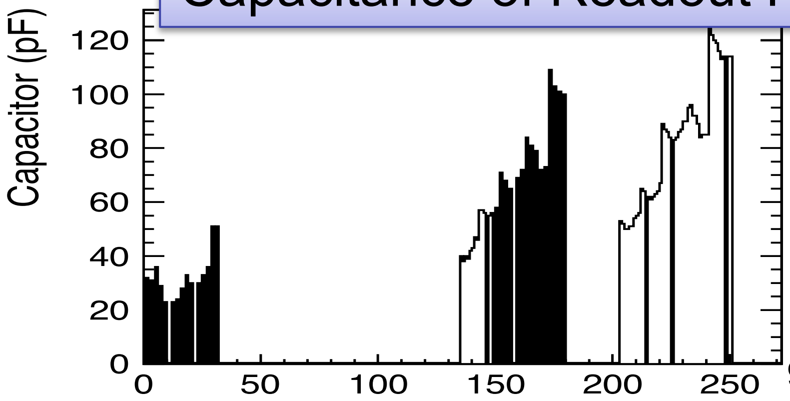


Noise level measurement



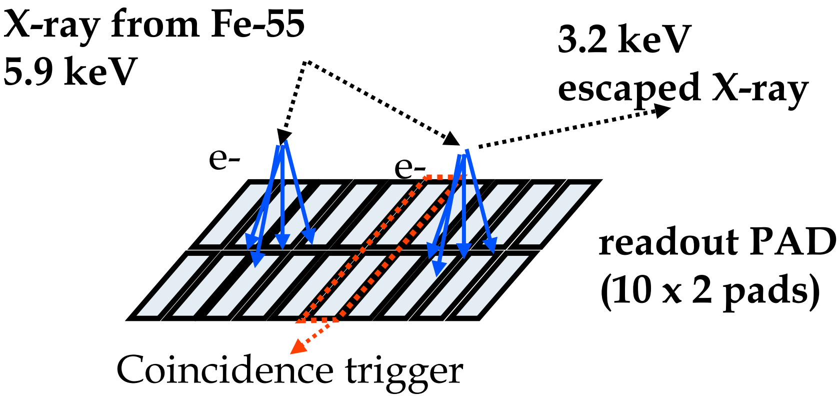
Black : AsAd + ZAP (120fF)
Red : + TPC (120fF)
Blue : + TPC (240fF)
Pink : + TPC (1pF)
Green : + TPC (10pF)

Capacitance of Readout Pad

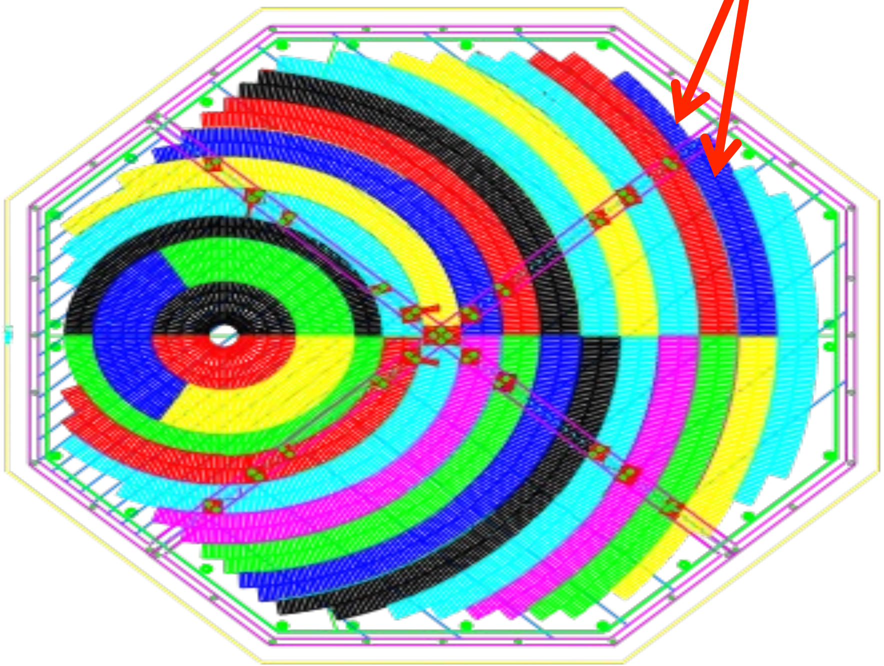


AGET ch ID + offset

X-ray measurement

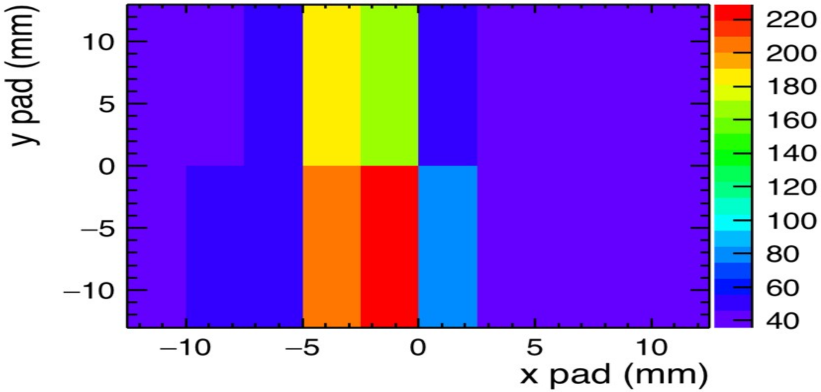


Only these two blue rings were u
(AsAd + R-Cobo)

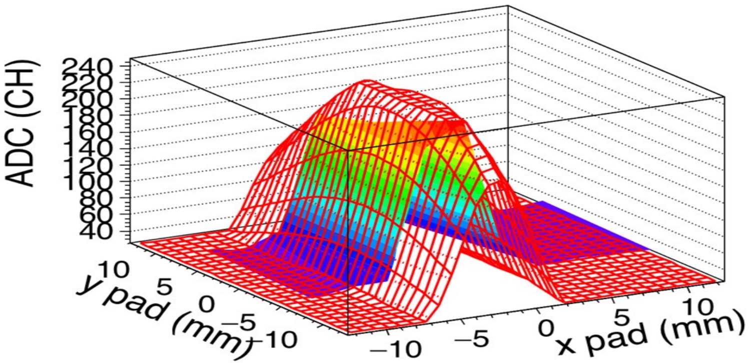


Analysis

ADC distribution



2D-gaussian fitting

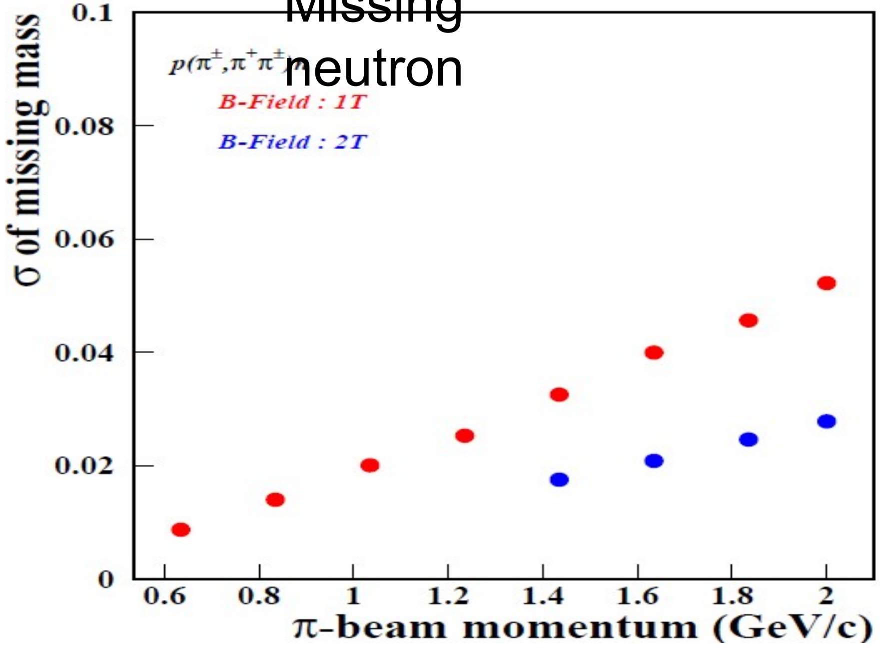


Question 2

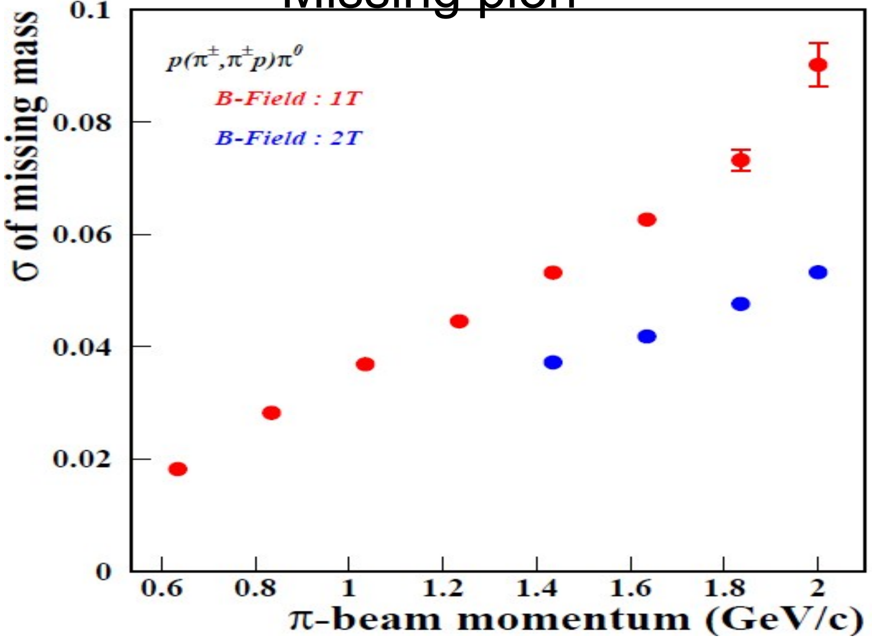
- The proponents should show how well the measurements of proposed reactions can be made in a full simulation.

Missing Mass Resolution

Missing neutron

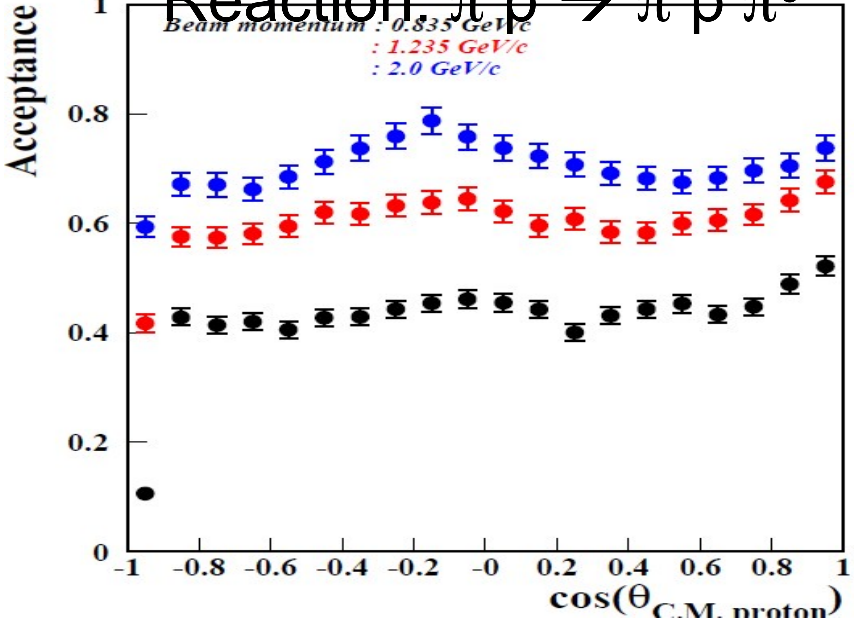


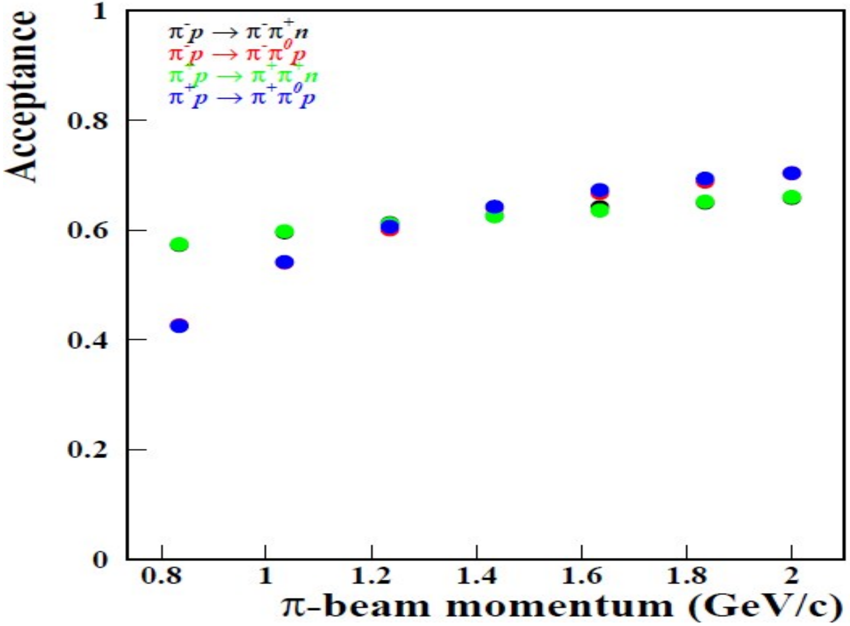
Missing pion



Acceptance

Reaction: $\pi\, p \rightarrow \pi\, p\, \pi^0$

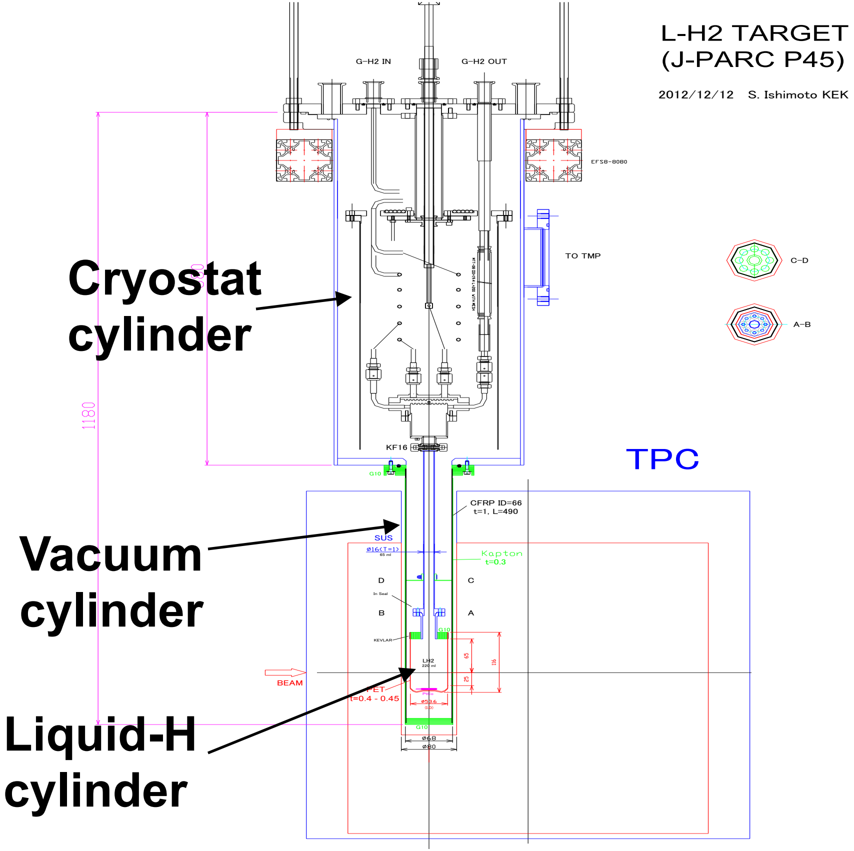




Note: for these plots, protons with momentum p < 300 MeV/c were cut out (due to energy-loss in the target).

3-1. Liquid Hydrogen Target

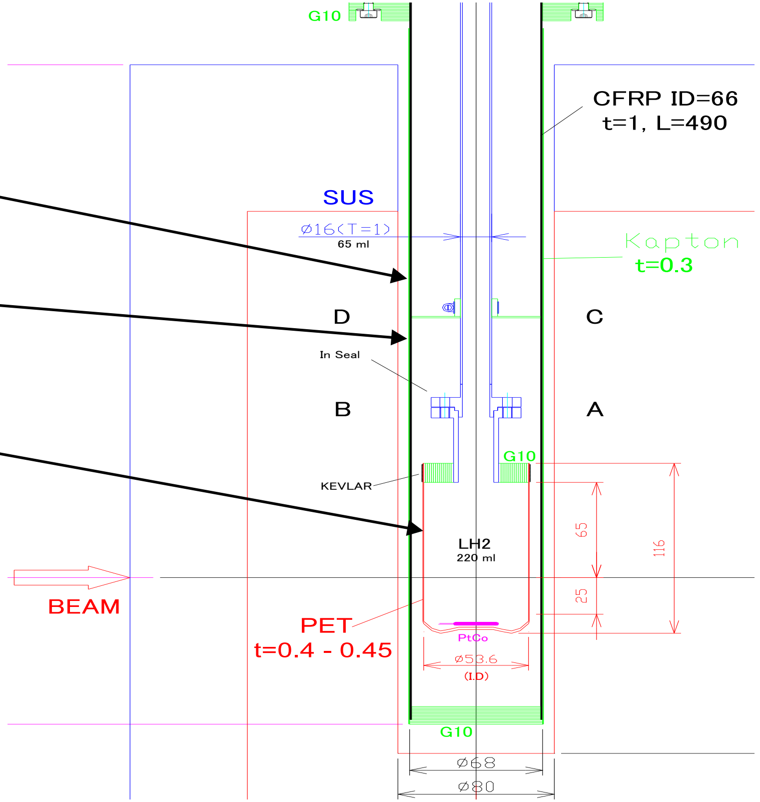
- Basic design done with S. Ishimoto (KEK)
  - Fit to the TPC target holder of 8cm ϕ cylinder
- Reuse cryostat system of liquid-H target for E19 (penta-quark search)
- Need to construct newly
  - Cryostat cylinder
  - Vacuum cylinder
  - Liquid-H cylinder



Liquid Hydrogen Target

Minimize material

- Vacuum cylinder
  - t=1mm CFRP (carbon fiber)
    - conductor
  - t=0.3mm Kapton
    - Insulation to field strips
- Liquid-H cylinder
  - t=0.4 mm PET(polyethylene terephthalate)
    - used in E19 successfully
- Total thickness
  - 0.28 g/cm^2



3-2. TPC Modifications

Modifications for target diameter

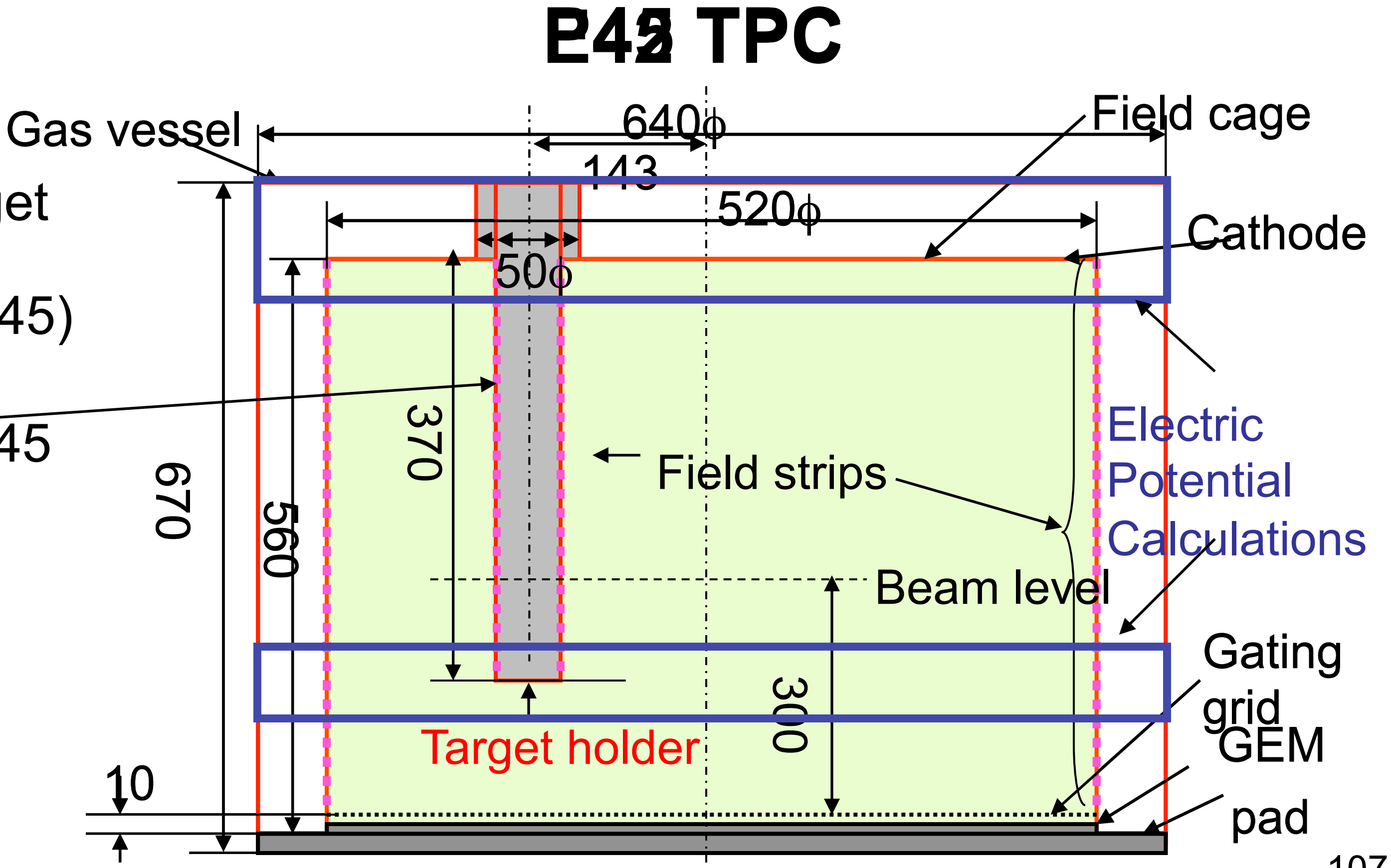
50(E42)→80mmφ (P45)

To be replaced for P45

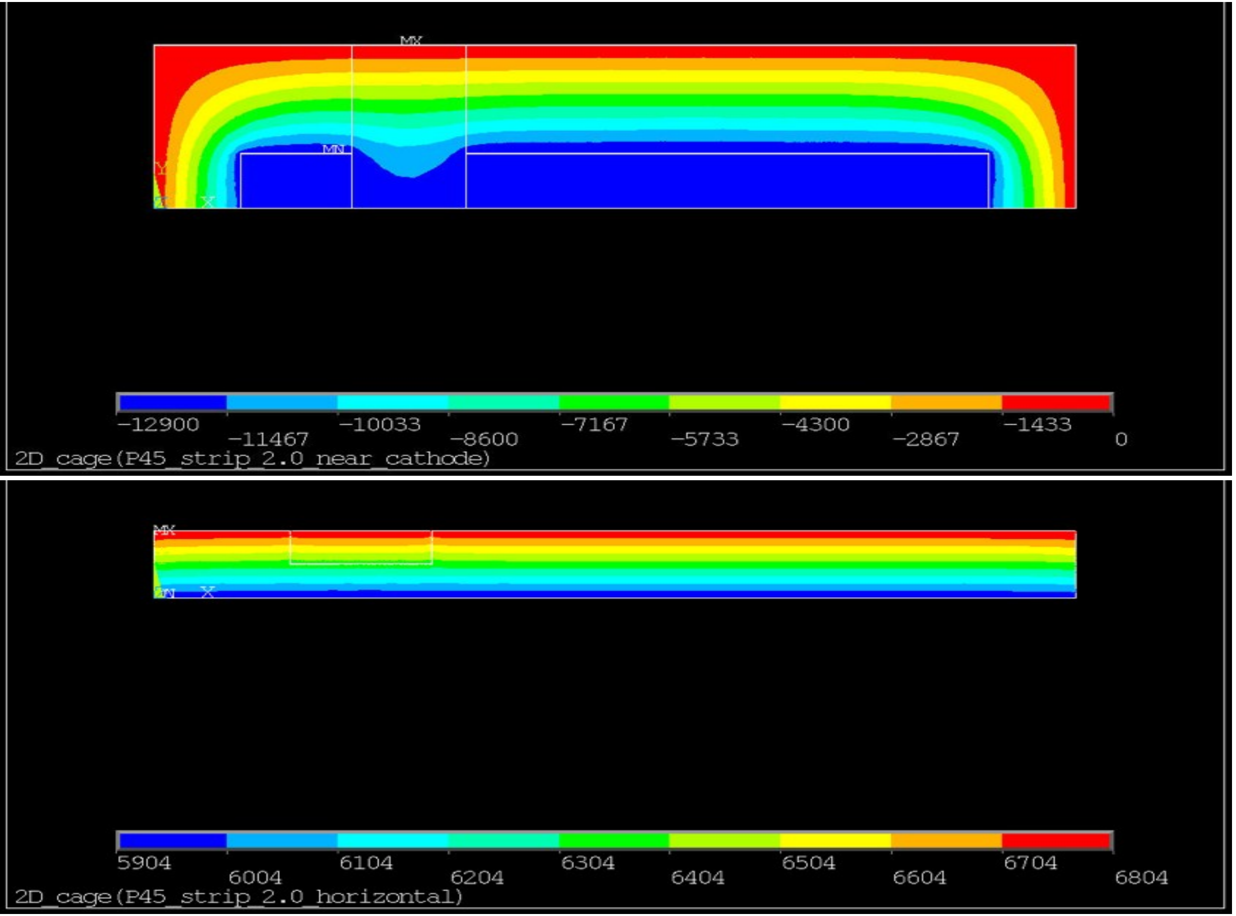
- Target holder

Share with E42

- Gas vessel
- Field cage
- Gating Grid
- GEM
- Pad plane

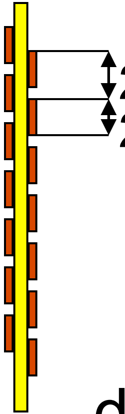


Electric potential calculations



2-d calculation

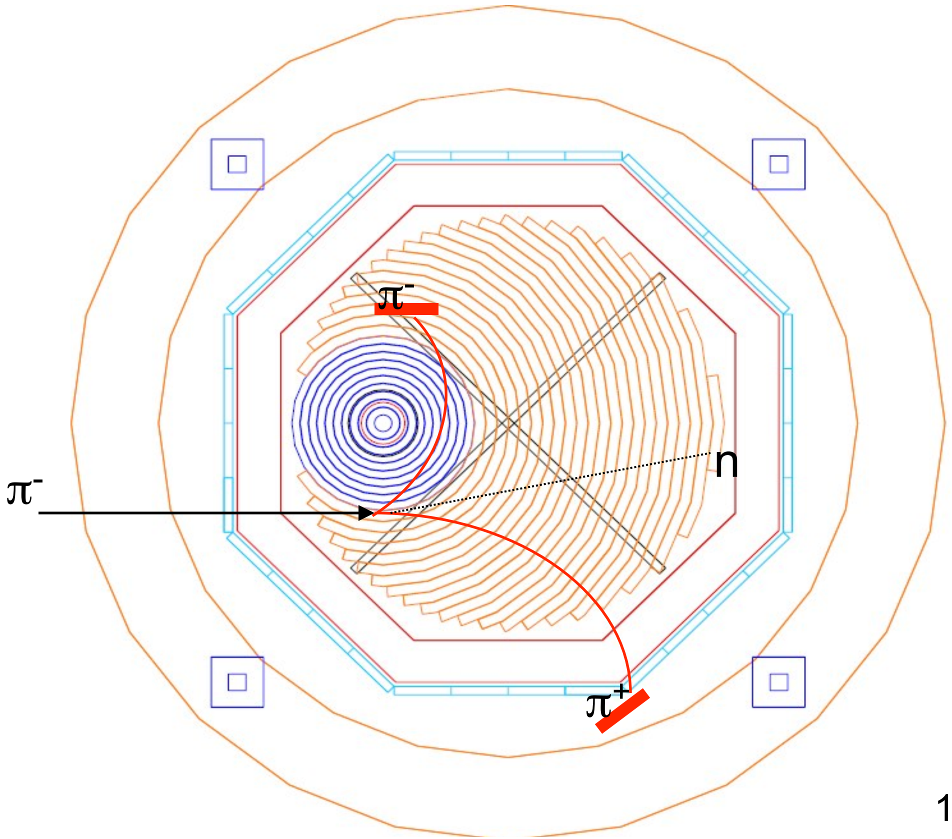
- Gas vessel
- Field cage
  - -13kV at maximum
- Target holder
- Double layer field strips



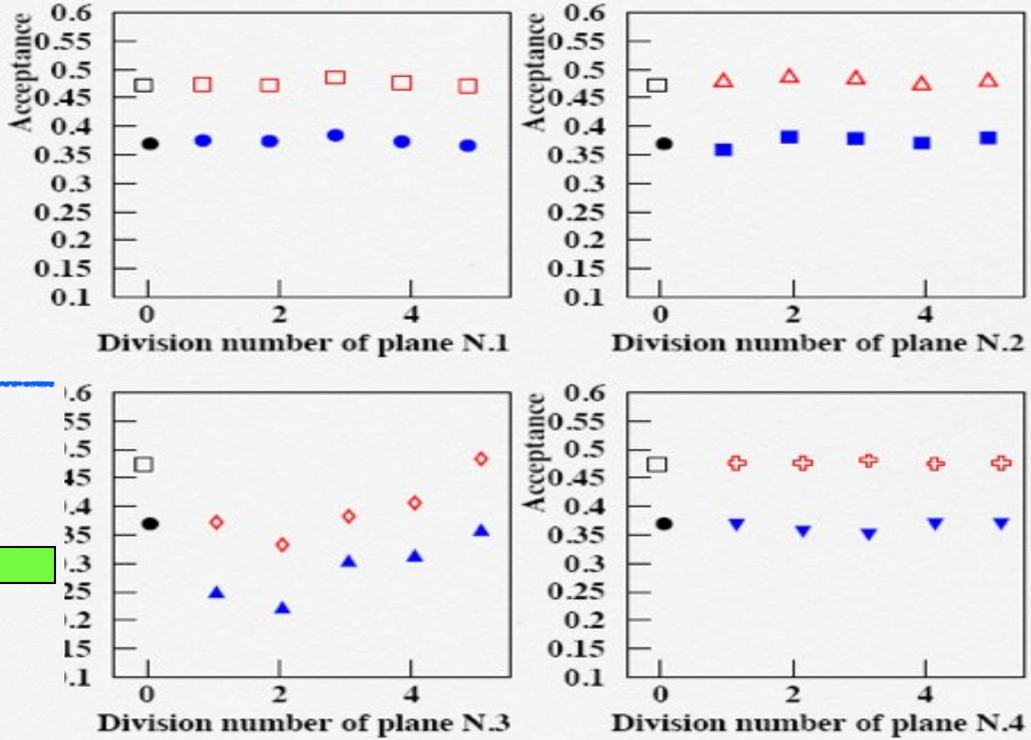
dE/E < 0.1% in the almost whole active volume

3-3. Two-Particle Trigger

- Details are shown in answers to Questions 2 and 4
- A pion (π^+ or π^-) beam with hits in 2 of 32 scintillators
- No K^+ spectrometer trigger in E42 is required

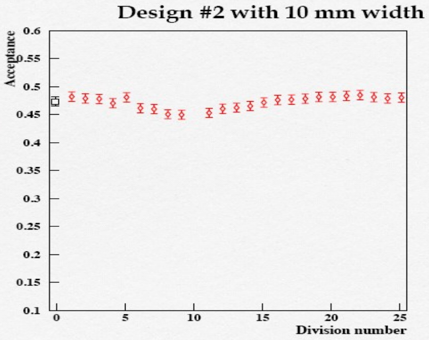


Results (width 50 mm)



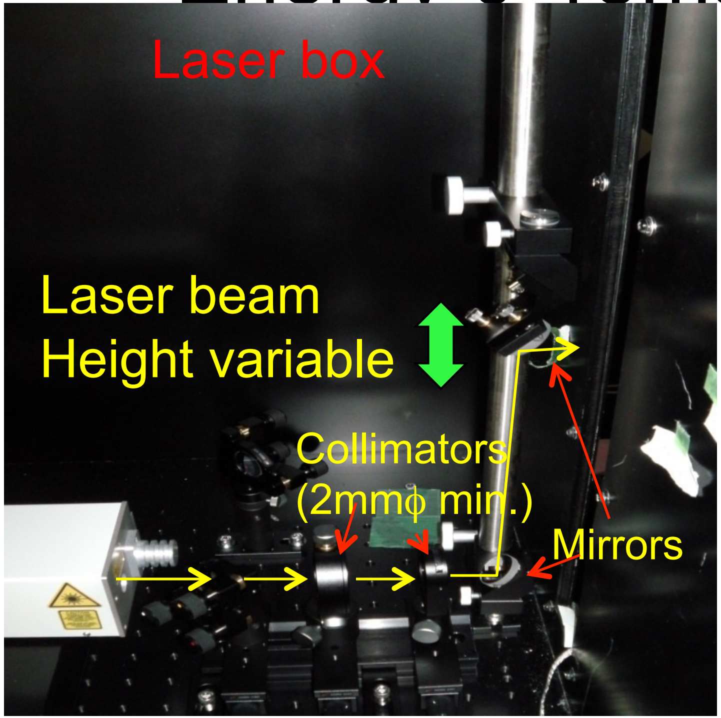
Blue : Laytpc>7
Red : Laytpc>5

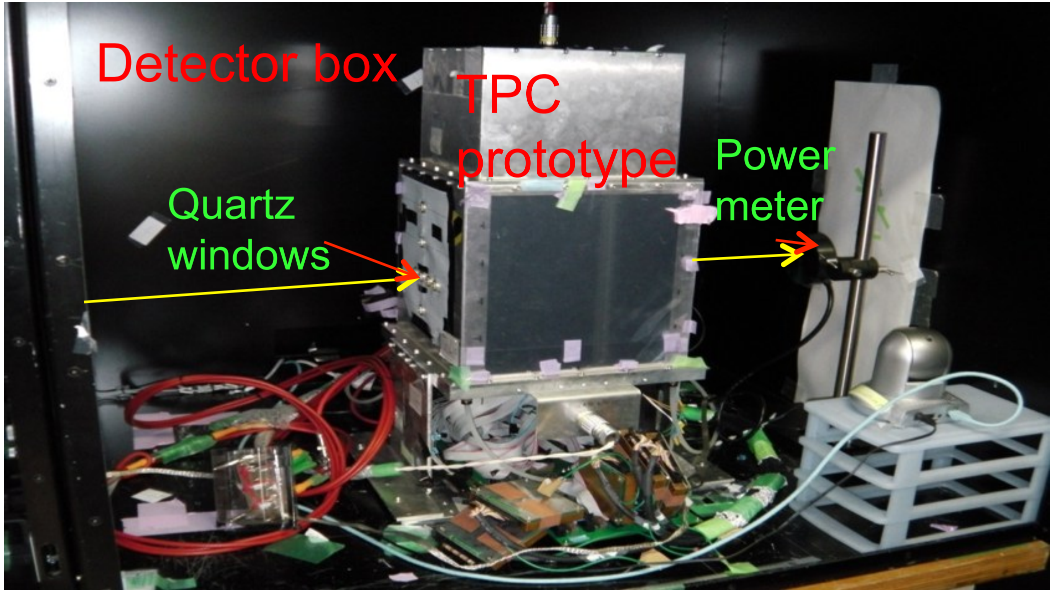
Result (width 10 mm)



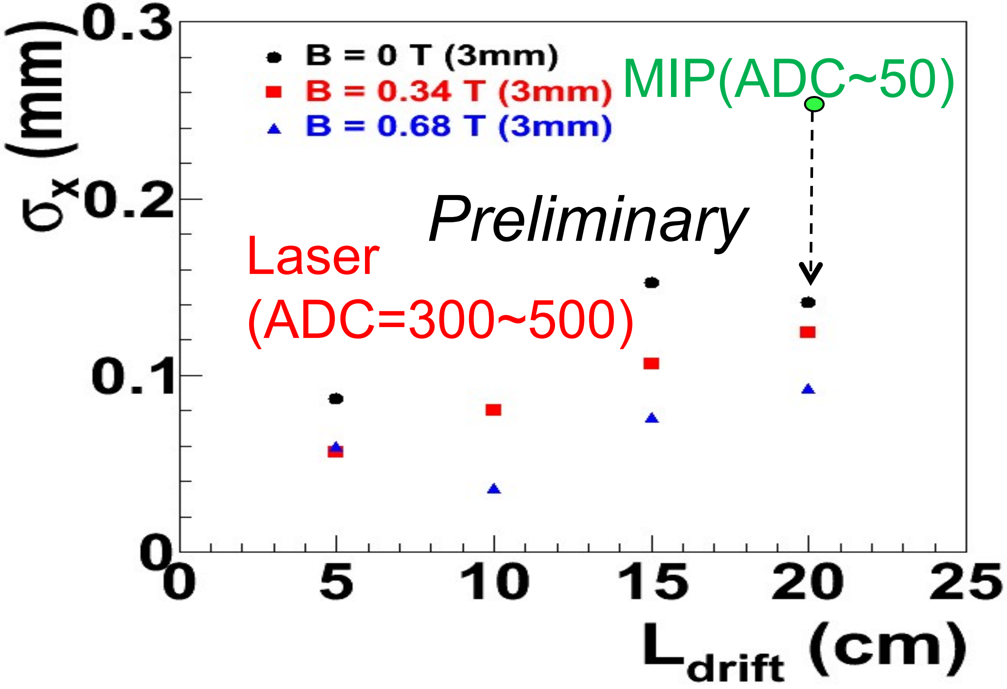
Laser optics

- YAG laser 266nm
- Energy 0-15mJ/pulse, 10Hz



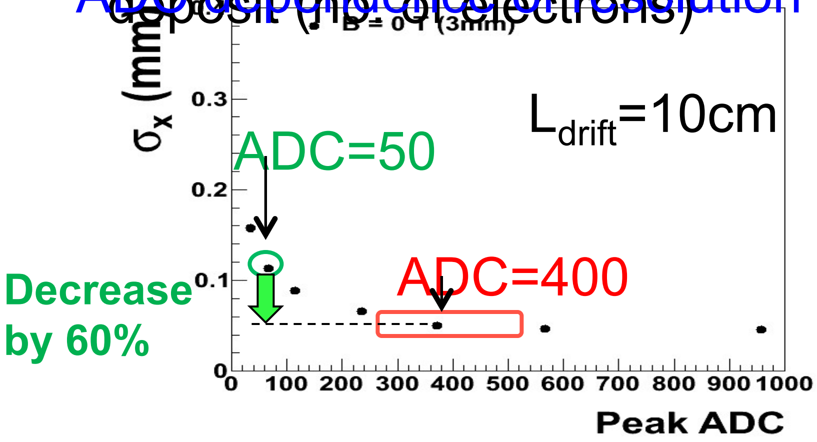


Horizontal resolutions with B-field



- Resolutions improve by 40-50% B=0 → 0.7 T
- Resolutions are 60% smaller than expected for MIP
  may be due to higher energy deposit (no. of electrons)

ADC dependence of resolution



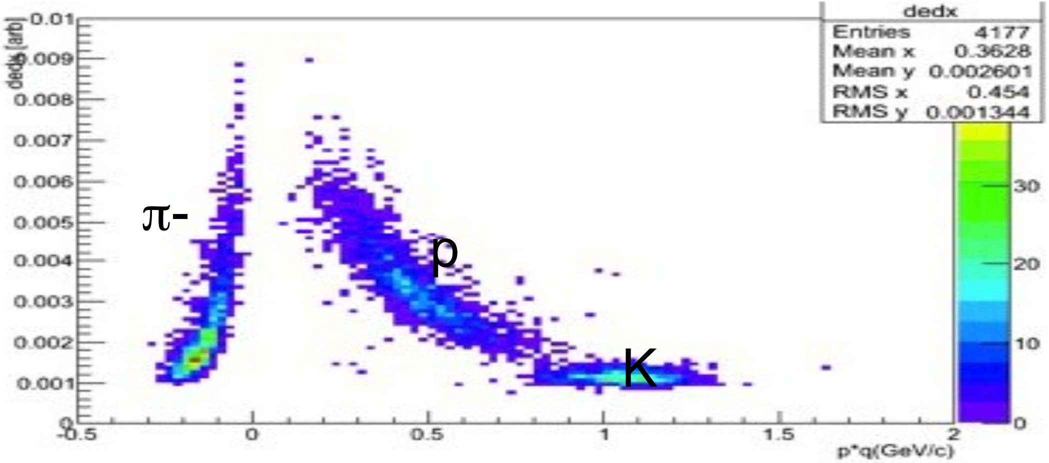
K1.8

- Momentum bite (window)
  - Typically ±2%
  - Mean p = 1.36 GeV/c
  - 4% of mean p = 54.4 MeV/c
  - Momentum resolution ~ 0.1%→1.4 MeV/c
  - Run proposal
    - Energy range 650 MeV / 26 = 25 MeV / bin
    - W=1.5-2.15 GeV
    - p=0.73-1.99 GeV/c
    - Δp=1.26 GeV/c / 26 = 48 MeV/c / bin

ADC dynamic range

- Requirement
  - dE/dx range (pi,p,K) ~ 10
  - Need dynamic range of 100 for pad charge sharing to pick up a few % pulse height of adjacent pad hits
  - At least 1000 dynamic range

- INC gen.

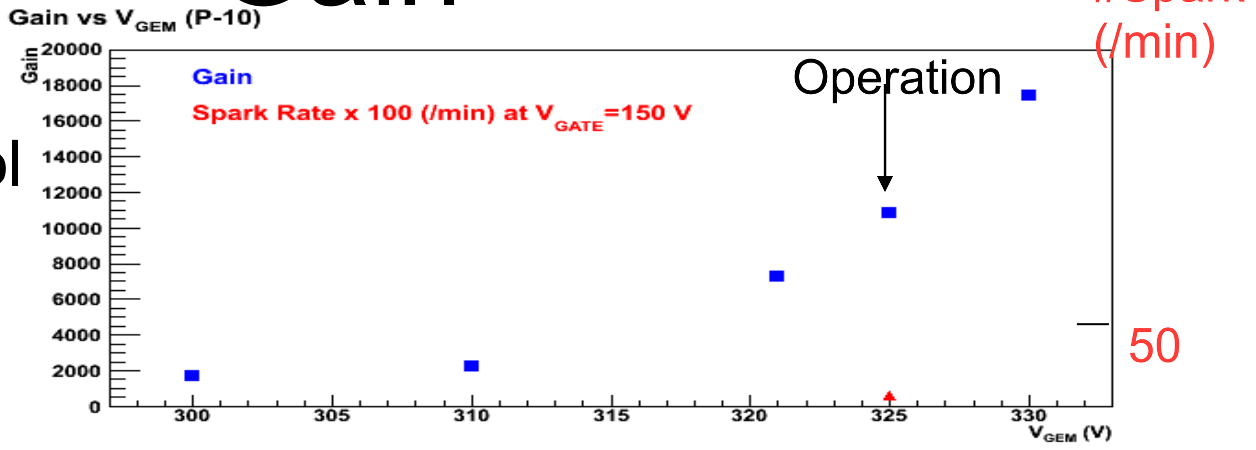


- H mass : 2.24 ~ 2.26 GeV/c2
- Beam momentum ~ 1.66 GeV/c
- K+ momentum cut > 0.9 GeV/c
- K+ angle < 15 Deg

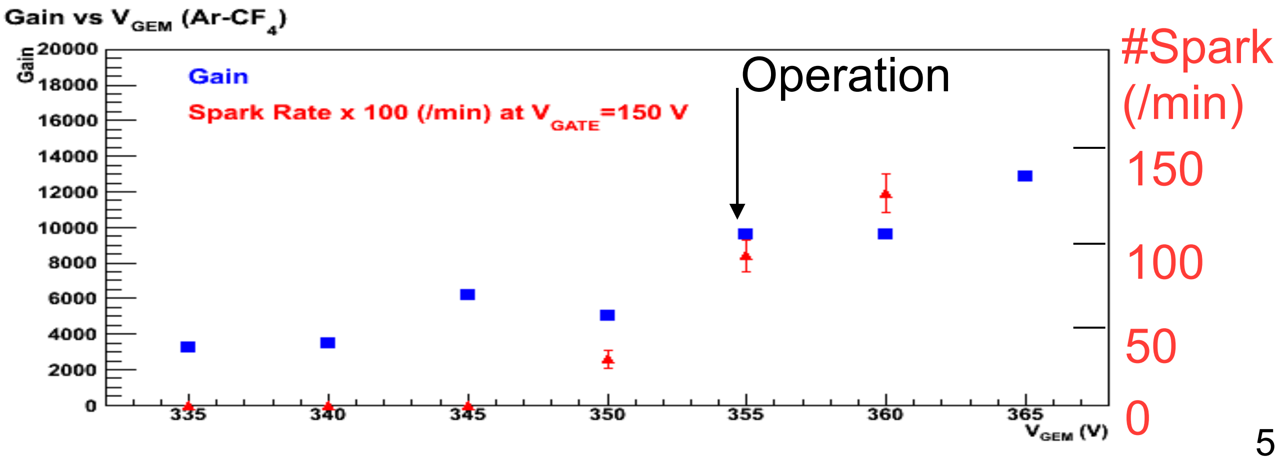
Gain

- Gain ~1x10^4(P10)
- We need to control spark rate to

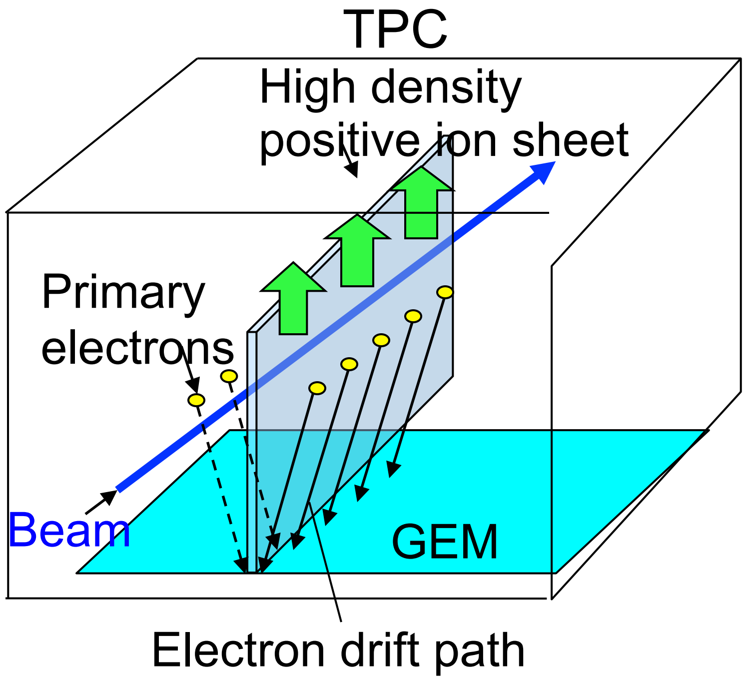
< a few sparks / min



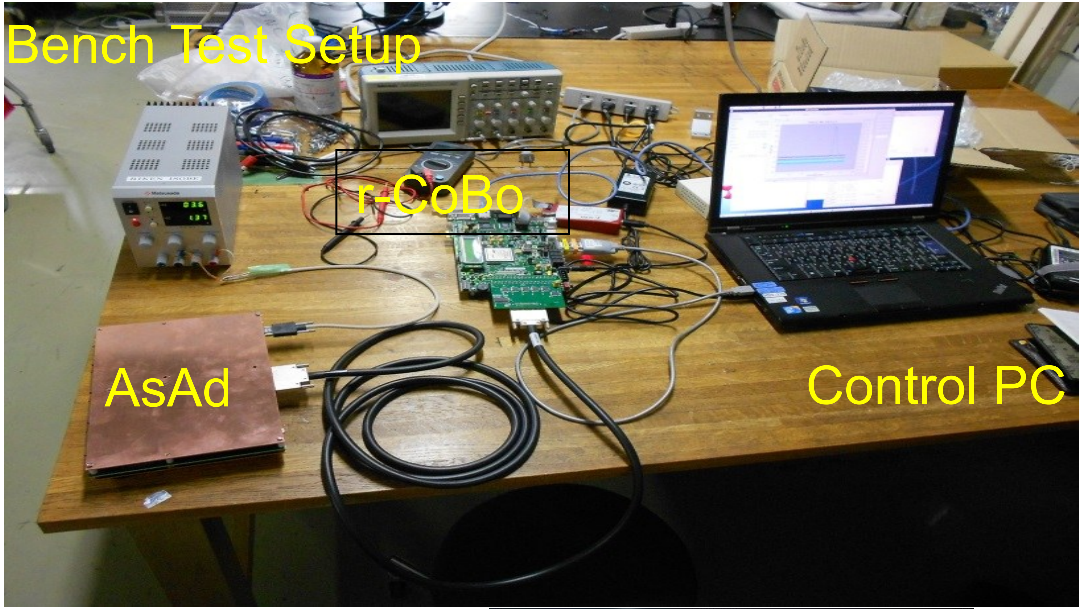
- For Ar-CF_4, operation GEM voltage must be less than 345V (gain<5x10^3) at low spark rate

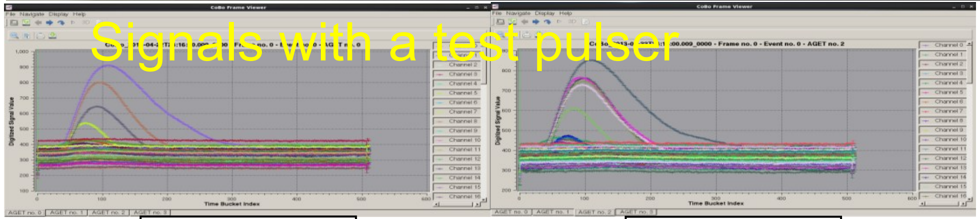


TPC hit distortions



Test of TPC Electronics
GET (General Electronics for TPC)





AGET0

AGET2

- Developed by Saclay, GANIL, MSU, IRFU, CENBG …
- Optimized for TPC
  - Variable gain/polarity, FADC frequency
- Adopted by Samurai-TPC,ACTAR TPC,ATTPC,MINOS

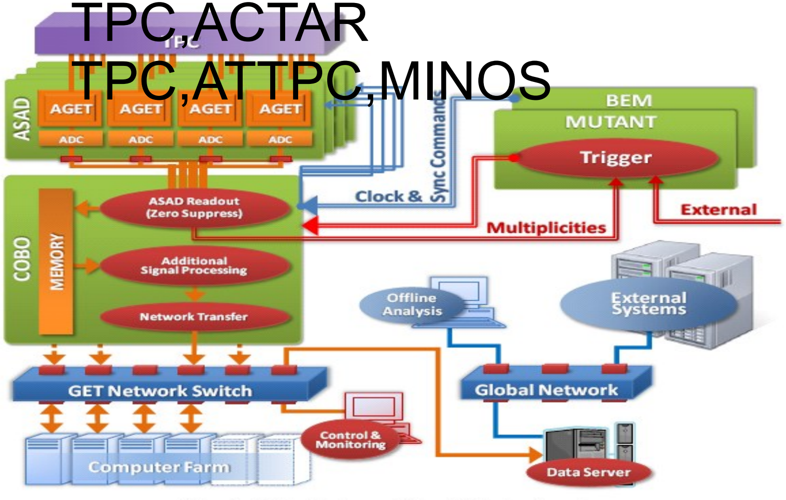


Fig. 1: Global view of the GET electronic.

Physics possibilities with HypTPC

- *H*-dibaryon (E42) : $K^{-}C \rightarrow K^{+} H X$, $H \rightarrow \Lambda\Lambda, \Lambda\pi^{-}p$
- $\Lambda(1405)$: $\pi^{-}p \rightarrow K^{0}\Lambda(1405)$

  $\Lambda(1405) \rightarrow \Lambda\gamma$ ($\bar{K}$N compositeness, T. Sekihara, *PR*C89 (2014) 025202)
- $K^{-}pp$: $\pi^{+}d \rightarrow K^{+}K^{-}pp$

  $K^{-}pp \rightarrow \Lambda p, \Sigma^{0}p, \Lambda\pi^{0}p, \Sigma^{0}\pi^{0}p$
- Ξ excited states:

  $K^{-}p \rightarrow K^{+}\Xi^{-*}$, $\Xi^{-*} \lozenge \Lambda K^{-}, \Sigma^{0}K^{-}, \Sigma^{-}K^{0}, \Xi^{-}\pi^{0}, \Xi^{0}\pi^{-}, \Xi^{-}\gamma$

  $K^{-}p \rightarrow K^{0}\Xi^{0*}$, $\Xi^{0*} \lozenge \Lambda K^{0}, \Sigma^{0}K^{0}, \Sigma^{+}K^{-}, \Xi^{-}\pi^{+}$

Physics possibilities with HypTPC

- H-dibaryon (E42) : $K^-C \rightarrow K^+ H X$ 1440 (1mon)

  $H \rightarrow \Lambda\Lambda$, $\Lambda\pi^-p$
- Ξ-C atom (E42) : $K^-C \rightarrow K^+\Xi^-X$, Ξ^- capture in C

  X-ray detection in TPC (Ar gas) 150
- Λ(1405) : $\pi^-p \rightarrow K^0\Lambda(1405)$ 1M

$\Lambda(1405) \rightarrow \Lambda\gamma$ (KN compositeness, T. Sekihara, *PR*C89 (2014) 025202)

- K^-pp : $\pi^+d \rightarrow K^+K^-pp$

  $K^-pp \rightarrow \Lambda p, \Sigma^0 p, \Lambda\pi^0 p, \Sigma^0\pi^0 p$

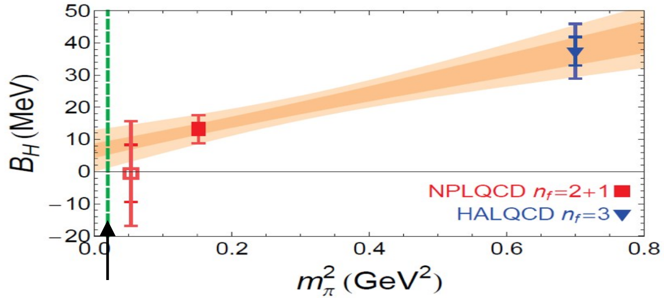
Search for H-dibaryon

Most stable and compact 6-quark state (*uuddss*)

Lattice-QCD calculations

Binding energy：-13 ~ +7 MeV

H may be slightly bound or unbound



Physical p mass

Experimental search

- Peaks observed

by KEK-E224, E522

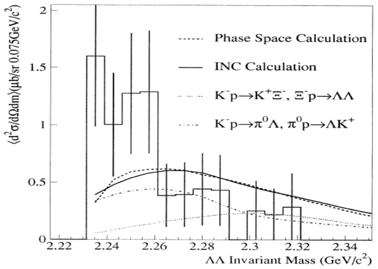
around LL mass threshold

– Indication of H?

– Statistics not enough

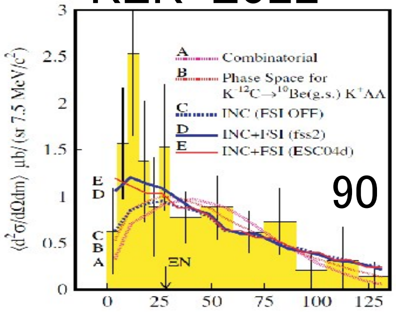
High statistics experiment

KEK−E224



m−2m$_L$(MeV/c^2)

KEK−E522

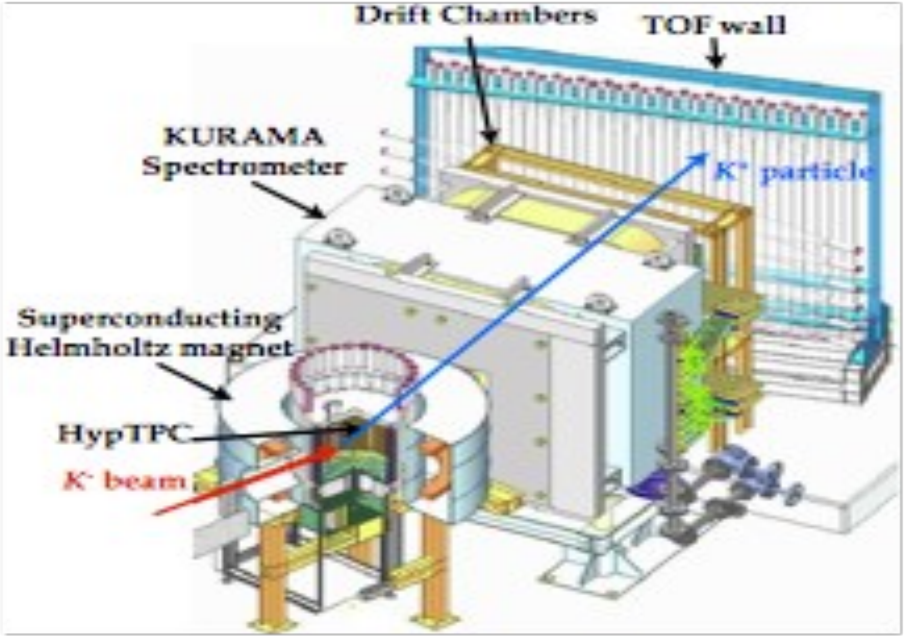


90 LL

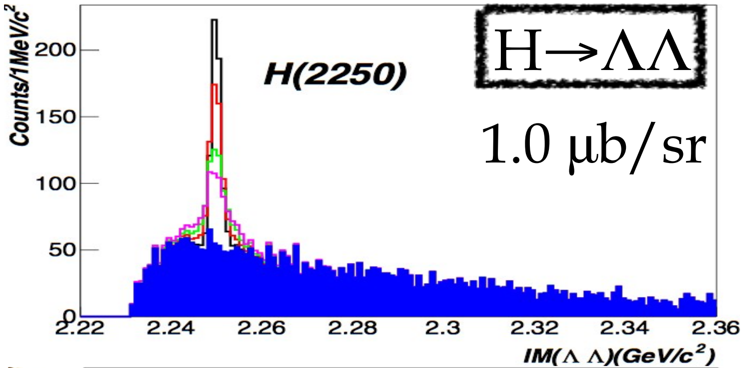
m−2m$_L$(MeV/c^2)

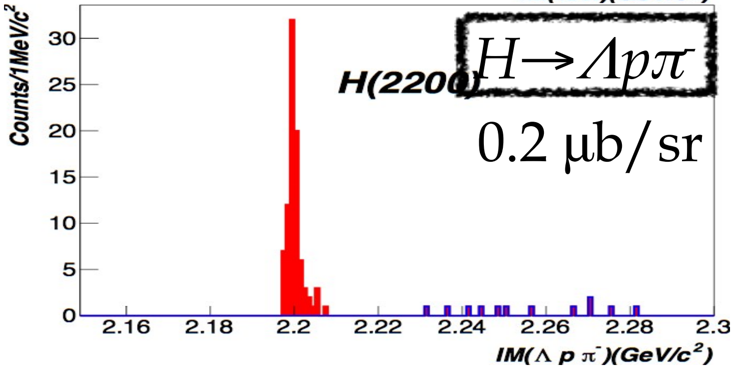
E42 experiment: H-dibaryon search

Most stable spin and isospin singlet with 6-quarks (uuddss) compose was predicted by R. L. Jaffe. We search for H→ΛΛ→π⁻π⁻pp and H→Λπ⁻p→π⁻π⁻pp with Hyperon Time-Projection-Chamber (HypTPC)

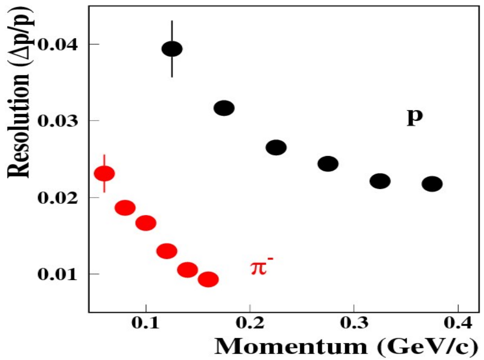


Drawn by S.H. Kim





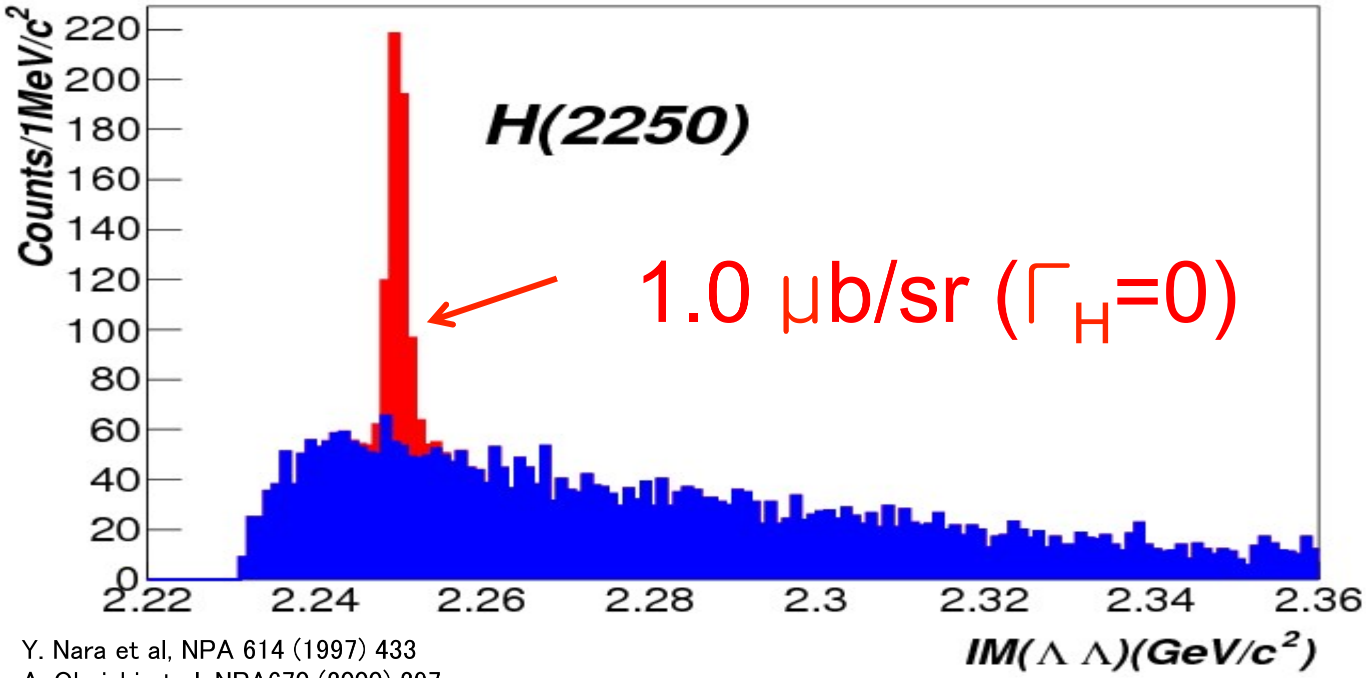
Simulated H-dibaryon mass spectrum



Momentum resolution
π : 0.8-2.3%
p : 2.2-4.0%

Invariant mass resolution
~1.5 MeV/c^2

11000 LL events and 1440 H–dibaryons in 33–day experiment



Y. Nara et al, NPA 614 (1997) 433
A. Ohnishi et al, NPA670 (2000) 297c;
Few-body Syst. Suppl. 12 (2000) 367;

J.K. Ahn PAC meeting, Jul. 2012

How can we measure Ξ excited states with HypTPC at K1.8

- Spin-parity and branching ratio to ΛK, ΣK, Ξπ, Ξγ
- $K^-p \rightarrow K^+\Xi^{-*}$, Ξ^{-*} ◊ ΛK^-, $\Sigma^0 K^-$, $\Sigma^- K^0$, $\Xi^-\pi^0$, $\Xi^0\pi^-$, $\Xi^-\gamma$
- $K^-p \rightarrow K^0\Xi^{0*}$, Ξ^{0*} ◊ ΛK^0, $\Sigma^0 K^0$, $\Sigma^+ K^-$, $\Xi^-\pi^+$
- K^0◊$\pi^+\pi^-$, Ξ^0◊$\Lambda\pi^0$, Ξ^-◊$\Lambda\pi^-$

Most of decay channels can be measured. (one neutral particle is allowed to reconstruct the decays)

Yield estimation: (5cm LH, 10^6 K^-/spill, 100 shifts)

$4\mu b \rightarrow 5\times10^5$ $\Xi^*(1690)$

if $1\mu b$ is assumed for each channel

ΛK^-, $\Sigma^0 K^-$, $\Xi\pi$: $0.6(\varepsilon_{TPC})\times0.64(BR(\Lambda\rightarrow\pi^- p))=0.38$ → $5X10^4$ events

$\Sigma^- K^0$: $0.35(50\% K_s^0/K^0, 70\% BR(K_s^0\rightarrow\pi^+\pi))\times0.64\times0.6=0.13$

→ 1.6×10^4 events

for $K^0\Xi^{0*}$ channels, multiply $0.35\times0.6=0.2$

How to determine spin-parity of Ξ^*

Angular distribution of decay particles !!

3/2 → ½ +0 $\Delta \to \pi$+N L=1 → cosθ

But it is not so simple.

for parity determination of ½ state.

interference with background

(p(s)-wave resonance on s(p)-wave background)

polarization of daughter hyperon (Λ,Σ) if Ξ^* is polarized

(Λ(1405) Moriya et al.)

Ξ-atom measurement with HypTPC

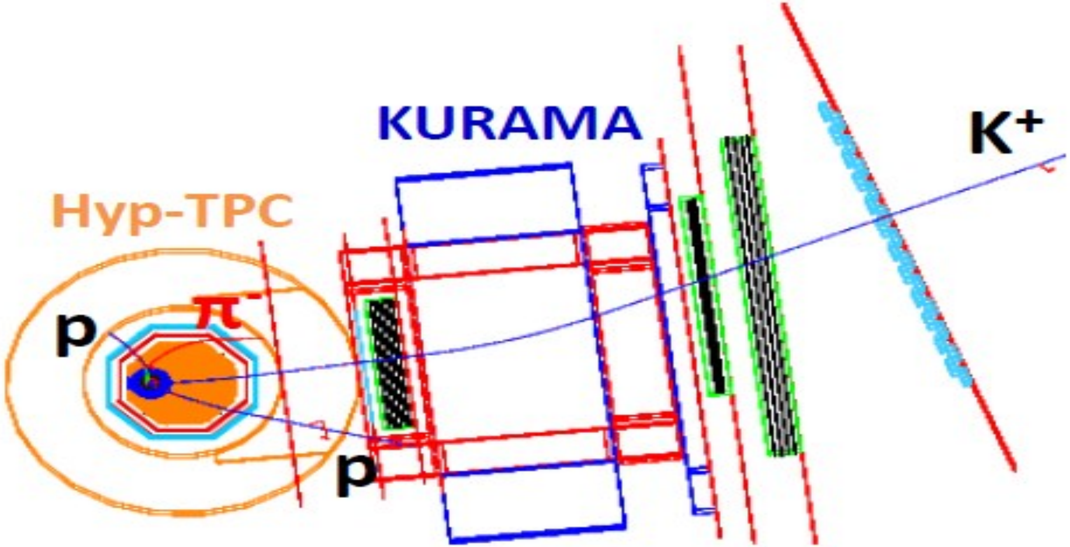
In E42, more than 10^4 Ξ-C atoms are produced in C target. We can detect X-rays from these atoms with HypTPC.

- X-rays from Ξ-C atom (C.J.Batty, E.Friedman and A.Gal, PRC 59 (1999) 295.)
- 5 – 4 transition 25 keV l(Ar): 0.2 g/cm^2 l(C): 2.5 g/cm^2 eff: 0.073 s: 3.2%
- 4 – 3 transition 55 keV l(Ar): 1.5 g/cm^2 l(C): 4 g/cm^2 eff: 0.015 s: 2.2%
- 5 – 3 transition 80 keV l(Ar): 2 g/cm^2 l(C): 6 g/cm^2 eff: 0.014 s: 1.8%
- 3 – 2 transition 157 keV l(Ar): 7 g/cm^2 l(C): 7 g/cm^2 eff: 0.004

- Assume 25 cm Ar (0.043 g/cm^2 at 1 atm) for detection efficiency and 0.7 cm diamond (density: 3.4 g/cc) for X-ray absorption.
  - Eff = $(1- e^{-t/l(Ar)})(e^{-t/l(C)})$
- The radius of photo-electrons is less than the pad width (2.5 mm) of HypTPC. The number of ion pairs are X-ray-energy/26 eV. With more than 10000 Ξ-C atoms, we can surely measure 5 – 4 transition X-rays. By tagging this X-ray, one can study the final states of the atom with HypTPC.
- If we have 10000 X-rays for 4-3 transition, we can detect 150 events with 2.2%

d(π^+, K^+) measurement with E42 setup

The d(π^+, K^+) reaction at 1.69 GeV/c which is same as E27 will be measured by using K1.8beamline spectrometer and KURAMA. Charged decay particle will be measured by using Hyp-TPC. Today, I have studied the resolution and identification method of each final state of $\pi^+ d \rightarrow K^+$ "K^-pp", "K-pp"→ Λp or $\Sigma^0 p$ or $\Lambda \pi^0 p$ or $\Sigma^0 \pi^0 p$ mode.
In these final states, we can measure the p, p, π^- particles by Hyp-TPC.
Acceptance will be improved about factor 10 comparing E27 setup.



Radiative decay of Λ(1405)

Table 3. The radiative decay widths of the $\Lambda(1405)$ predicted by different theoretical models, in units of keV. The values denoted by "UχPT" are the results obtained in the present study. The widths calculated for the low-energy pole and high-energy pole are separated by a comma.

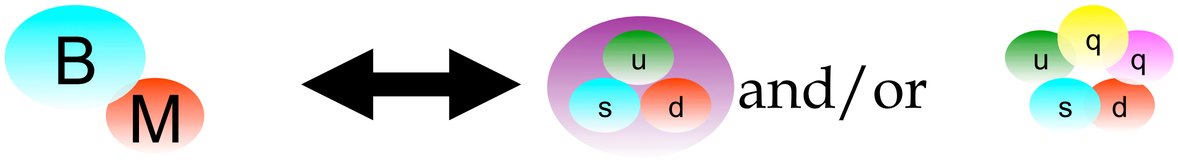
Decay channel	UχPT	χQM [35]	BonnCQM [36]	NRQM	RCQM [39]
$\gamma\Lambda$	16.1, 64.8	168	912	143 [37], 200, 154 [38]	118
$\gamma\Sigma^0$	73.5, 33.5	103	233	91 [37], 72, 72 [38]	46
Decay channel	**MIT bag [38]**	**Chiral bag [40]**	**Soliton [41]**	**Algebraic model [42]**	**Isobar fit [23]**
$\gamma\Lambda$	60, 17	75	44,40	116.9	27 ± 8
$\gamma\Sigma^0$	18, 2.7	1.9	13,17	155.7	10 ± 4 or 23 ± 7

- Several theoretical calculations were done with varying theoretical frames.
- Only one experimental data (based on an isobar model fitting of K-p atom data) is available.

Compositeness

$$\Lambda(1405) = C_{uds}\,|uds\rangle + C_{KN}\,|K\rangle \otimes |N\rangle + C_{uudus}\,|uudu\,s\rangle + \dots$$

- Compositeness : amount of the two-body components in a resonance as well as a bound state.



- Compositeness can be defined as the contribution of the two-body component to the normalization of the total wave function.

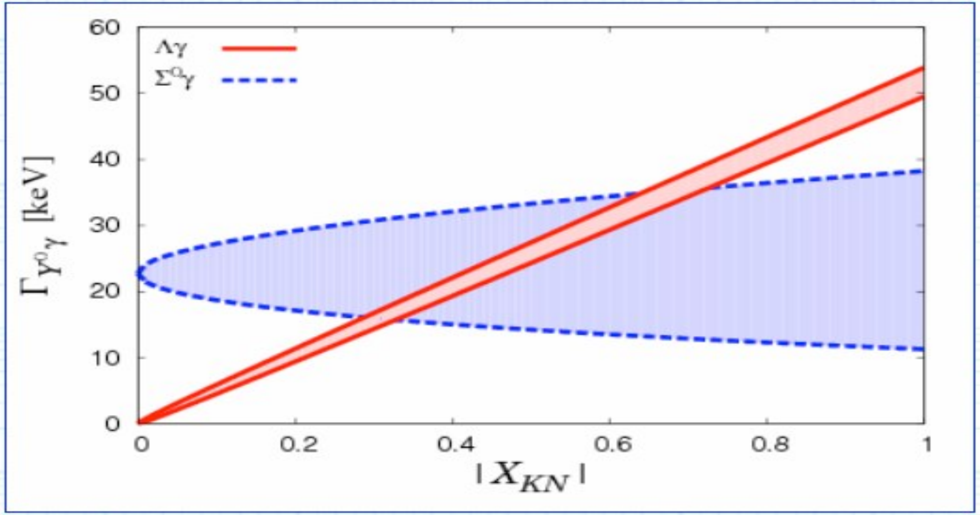
$$< \Lambda(1405)|\Lambda(1405) >= X_{\bar{K}N} + X_{\pi\Sigma} + \cdots + Z = 1$$

Decay width of Λ(1405) radiative decay

PHYSICAL REVIEW C 89, 025202 (2014)

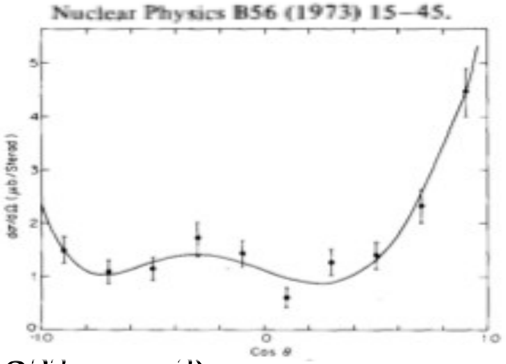
Determination of compositeness of the Λ(1405) resonance from its radiative decay

T. Sekihara[1,*] and S. Kumano[1,2]



- Λγ decay mode : dominated by the KbarN component
- Allowed region for Λγ is very small and is almost proportional to compositeness
- Large Λγ width = large $|X_{KN}|$

- The Λ(1405) → Λγ is suitable to measure the KbarN component inside of Λ(1405)



Yield estimation

- Total cross section σ_{tot} : 20.67 μb
- Pion beam rate N_{beam} : 10^6 per (6 second) spill-cyc
- Liquid hydrogen target length : 5 cm (N_{tgt} : 2.1 x 10^{23} cm^{-2})
- Charged decay mode for K^0_S $<Br(K^0_S \rightarrow \pi^+\pi^-)>$: 0.692
- Charged decay mode for Λ $<Br(\Lambda \rightarrow p\pi^-)>$: 0.639
- Detector acceptance : A_{det}

$$\text{Yield} = \sigma_{tot}\ N_{tgt}\ N_{beam} <Br(K^0_S \rightarrow \pi^+\pi^-)> <Br(\Lambda1405 \rightarrow \Lambda\gamma)> A_{det}$$

$$= 2.98\ events/spill \times <Br(\Lambda \rightarrow p\pi^-)> <Br(\Lambda1405 \rightarrow \Lambda\gamma)> A_{det}$$

one month beam time (in missing mass spectra of K^0_S):
1.3 M events $<Br(\Lambda \rightarrow p\pi^-)> <Br(\Lambda1405 \rightarrow \Lambda\gamma)> A_{det}$

E31 (Noumi et al.,)

$K^- d \rightarrow \pi^- p\, \Lambda(1405)$ ~10^4 Λ(1405)

Background yield

$\Sigma(1385) \rightarrow \Lambda\pi^0$ (87%)
$\rightarrow \Sigma^{\pm}\pi^{\mp}$ (11.7%)
$\rightarrow \Lambda\gamma$ (1.3 %)

$\Lambda(1405) \rightarrow \Sigma^{+}\pi^{-}$ (33.3%)
$\rightarrow \Sigma^0\pi^0$ (33.3%) $\rightarrow \Lambda\gamma\pi^0$
$\rightarrow \Sigma^{+}\pi^{-}$ (33.3%)

- Total cross section of $\Sigma(1385)$: 76.7 μb (3.7 $\sigma_{tot,\Lambda 1405}$)
  - Within one month beam time
- $\Lambda\pi^0$ yield : 2.67 M events x A_{det}
- $\Lambda\gamma$ yield : 0.04 M events x A_{det}
- $\Lambda\gamma\pi^0$ yield : 0.28 M events x A_{det}

Missing particle

Nuclear Physics B56 (1973) 15–45.

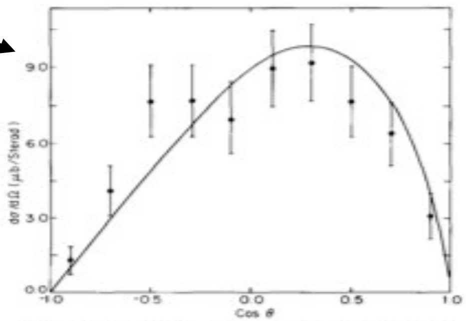


Fig. 8. Differential cross section for $\pi^- p \rightarrow \Sigma(1385)^0 K^0$.

Summary

- Radiative decay of Λ(1405) is strongly related with structure of Λ(1405), especially a compositeness of KbarN.

- Total yield is estimated to be 1 M (5 M) events with 10^6 (10^7) pion beam per 6 second spill in one month beam time
  - ✓ It is suitable to measure the radiative decay of Λ(1405) with 0.3 % branching ratio (1000 events).
  - ✓ $\Sigma^+\pi^-$, $\Sigma^-\pi^+$ line shapes and angular distribution

- We are preparing a LoI of the radiative decay of Λ(1405) and we would like to submit at the coming J-PARC PAC meeting.

$\pi N \to \pi \eta N$

Jido, Oka, Hosaka, PTP 106 (2001) 823

N(1535) (S_{11}) strongly couples to η

Sign of coupling constant $g_{N^*N^*}$ different bet.

- Naïve model
- Mirror model

→N(1535) : chiral partner of N(938)

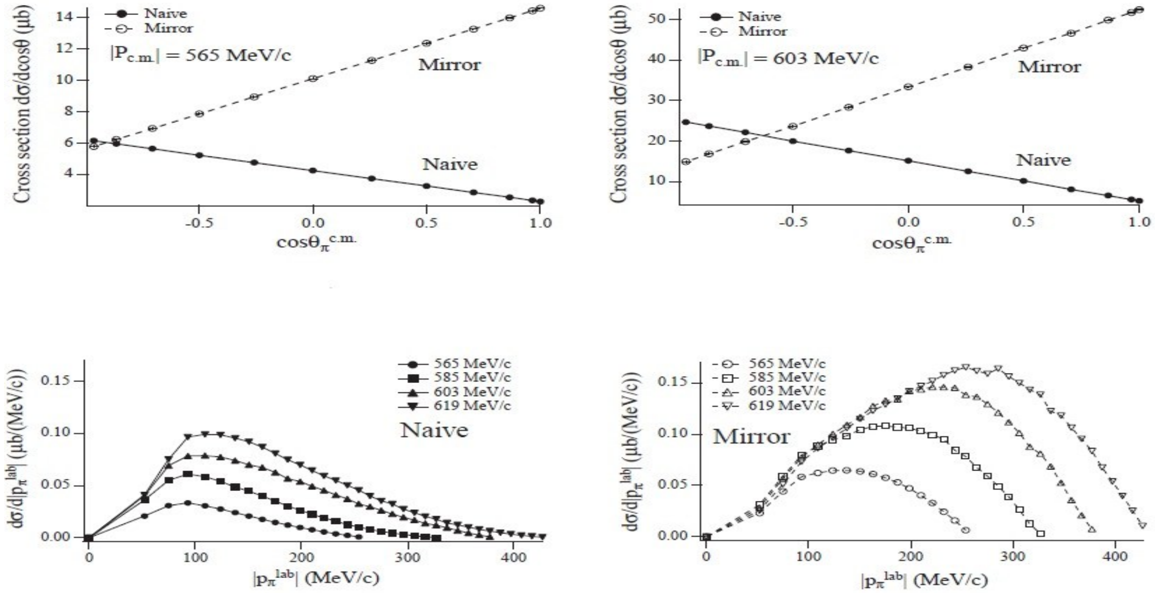
Difference in angular dist.

of produced pions and p_{lab}

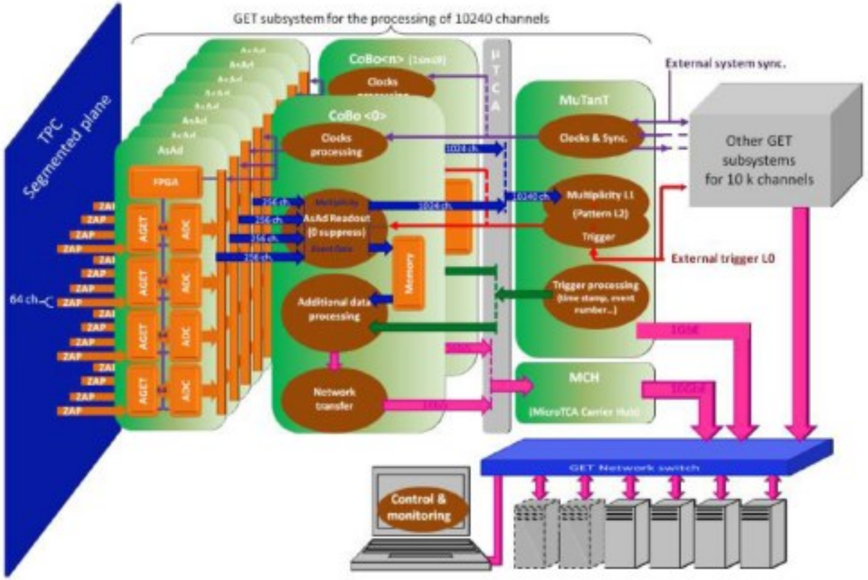
p_{CM}=0.6 GeV/c

(p_{lab}=0.96 GeV/c)

→10 events/min



Generic Electronics for TPC (GET)



- Variable gain, polarity and sampling frequency.
- Developed in CEA-Saclay, GANIL, CENBG, MSU.
- Adopted by ACTAR (Saclay, GANIL), AT-TPC (MSU), 2π-TPC (CENBG), and SπRIT (RIBF).

Generic Electronics for TPC (GET)

31 AsAds (ASIC and ADC boards)

- 256 ch / board
- 4 AGETs (ASIC) with amplifier/shaper circuits
- 512 cell Switched Capacitor Arrays
- 12-bit ADCs

CoBo (Coordination Board)

- Digital data from AsAds
- Zero suppression
- Network transfer to PC's

MUTANT

- Trigger module