INPC2016
Adelaide
Australia

Re-Opening of Research Activities of Hypernuclear & Hadron Physics at J-PARC Hadron Hall

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High Energy Accelerator Research Organization

KEK

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J-PARC
Japan Proton Accelerator Research Complex
J-PARC at Tokai-mura, Ibaraki-ken

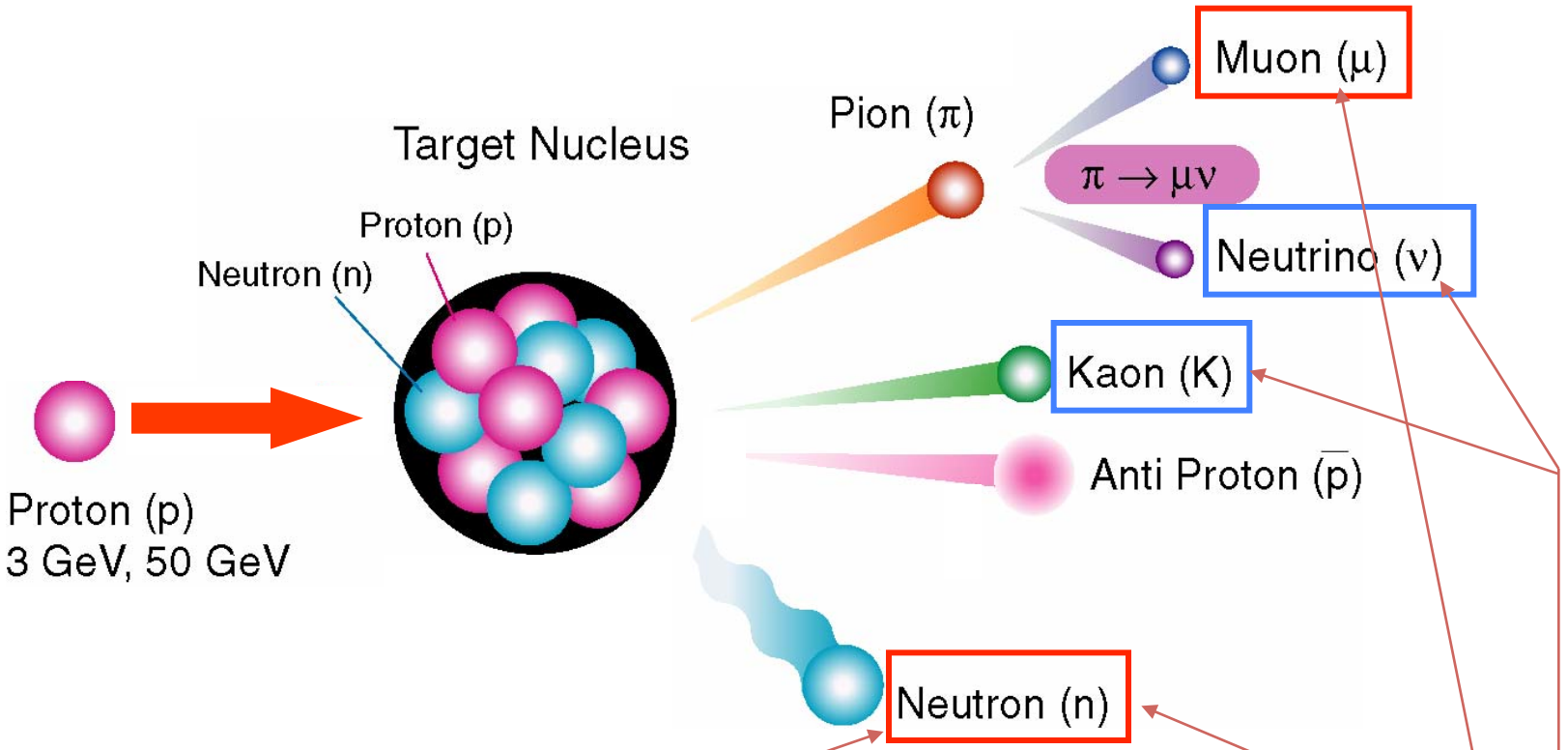
J-PARC

Japan Proton Accelerator Research Complex

Bird's eye photo
in January 2016


Bird's eye photo
in January 2016
400MeV
LINAC
J-PARC
Japan Proton Accelerator Research Complex
3GeV333μA
RCS
ν to
SK
750kW Fast
Ext.
MLF
50GeV-MR
Hadron Hall
for Counter experiments
100kW Slow Extraction

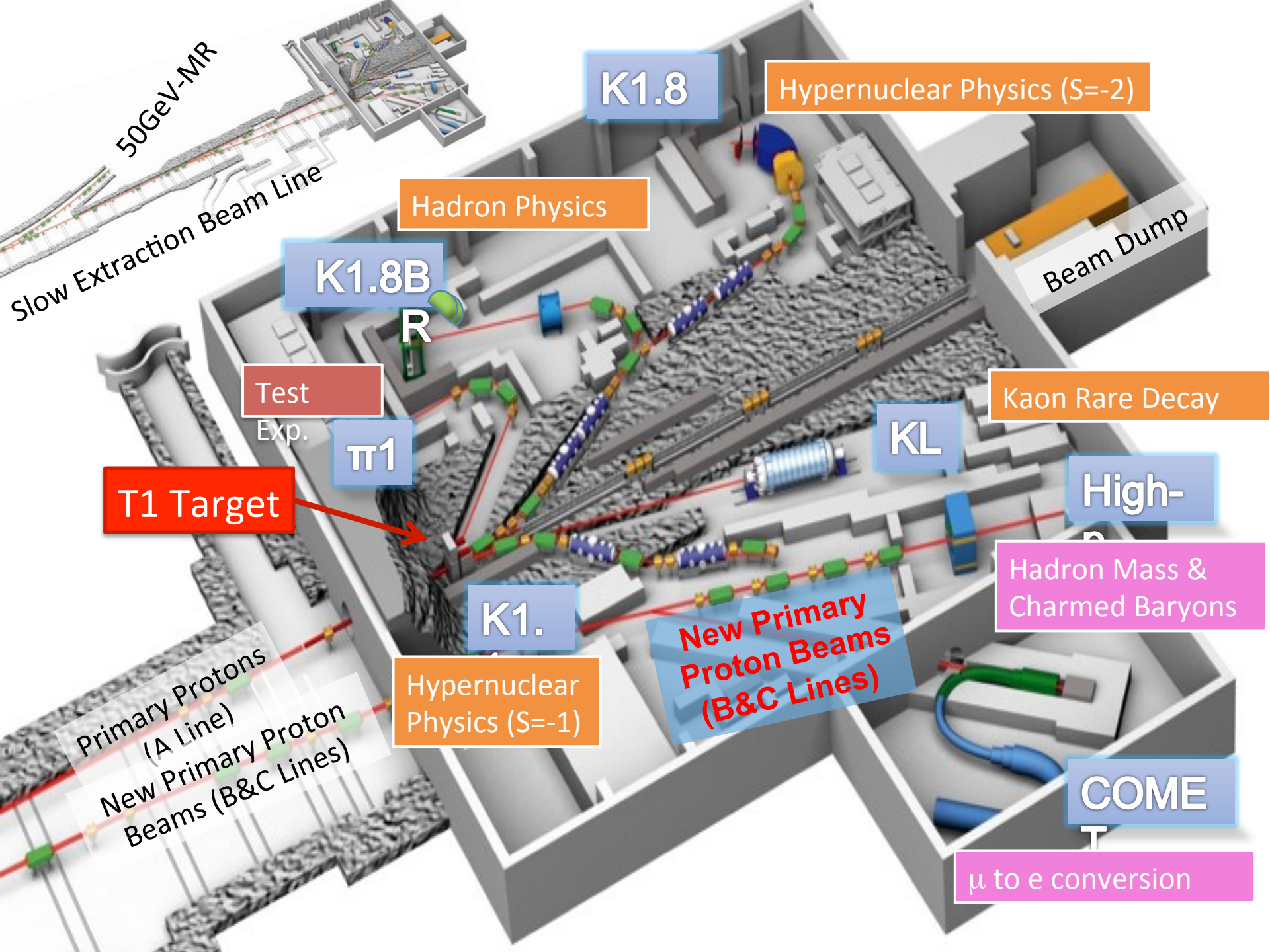
Goals at J-PARC



Need to have high-power proton beams

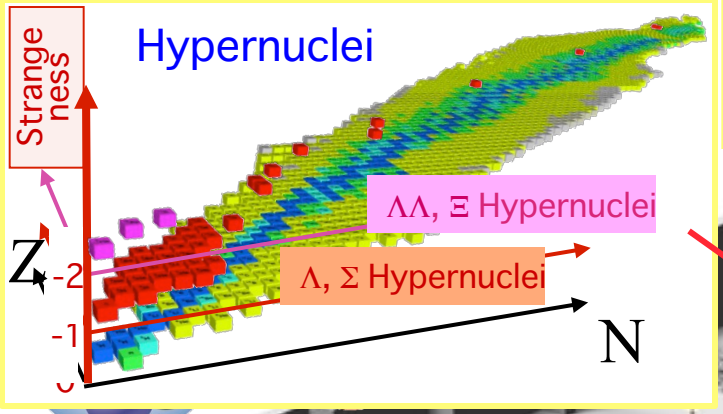
→ MW-class proton accelerator (current frontier is about 0.1 MW)

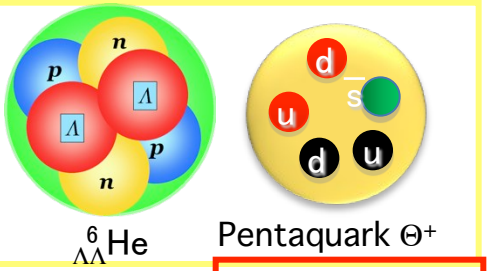
Materials & Life Sciences at 3 GeV
Nuclear & Particle Physics at 50 GeV
R&D toward Transmutation at 0.6 GeV


50GeV-MR
Slow Extraction Beam Line
K1.8
Hypernuclear Physics (S=-2)
Hadron Physics
K1.8B
R
Beam Dump
Test
Exp.
π1
KL
Kaon Rare Decay
T1 Target
High-
Hadron Mass &
Charmed Baryons
K1.
New Primary
Proton Beams
(B&C Lines)
Hypernuclear
Physics (S=-1)
Primary Protons
(A Line)
New Primary Proton
Beams (B&C Lines)
COME
T
μ to e conversion

Nuclear, Hadron, & Particle Physics at Hadron Hall

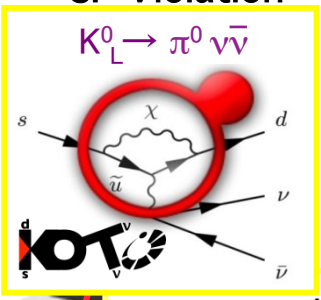
High Density Nuclear Matter, Nucelar Force



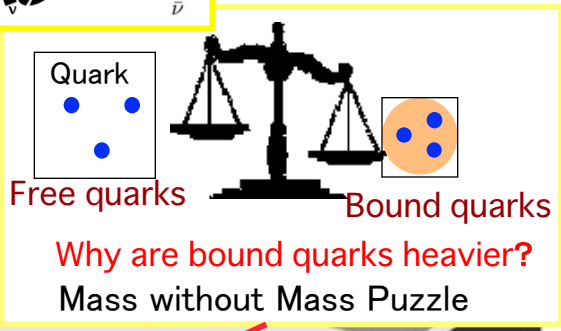


$^{6}_{\Lambda\Lambda}$He Pentaquark Θ+

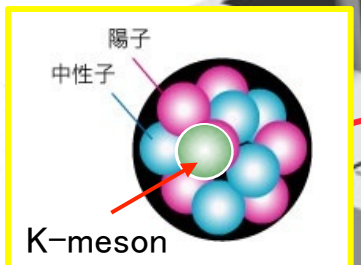
CP-Violation



Origin of Mass



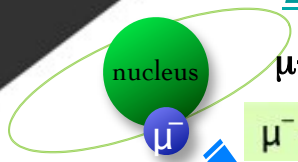
Confinement



Implantation of Kaon and the nuclear shrinkage

High Density Nuclear Matter, Nucelar Force

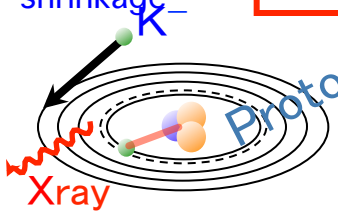
COMET Beam line



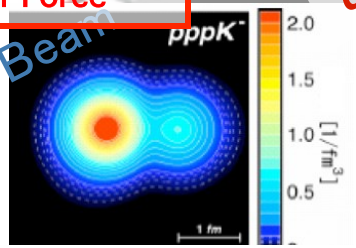
μ-e conversion

$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$

e^-

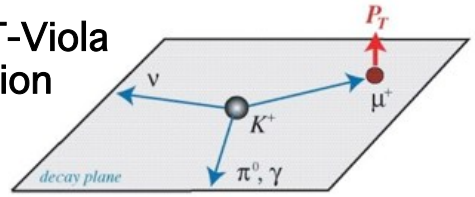


Kaonic atom

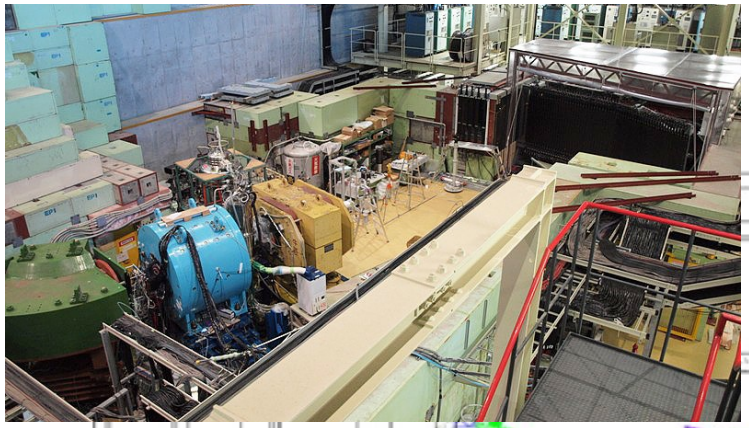


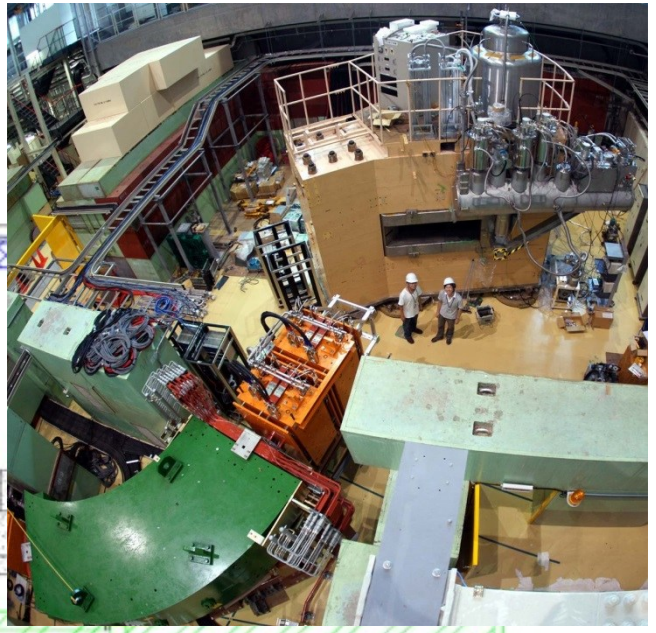
Kaonic nucleus

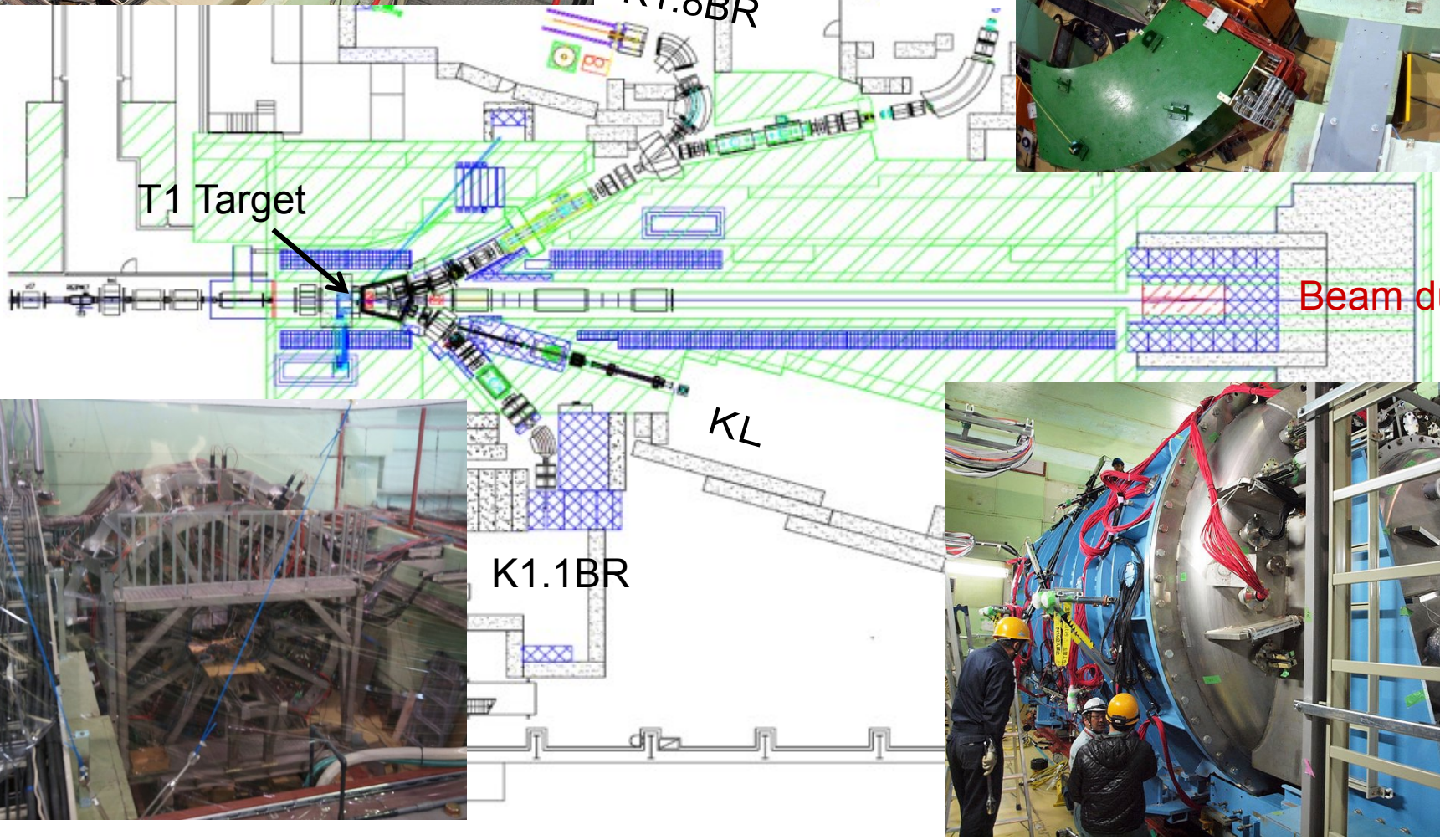
T-Violation



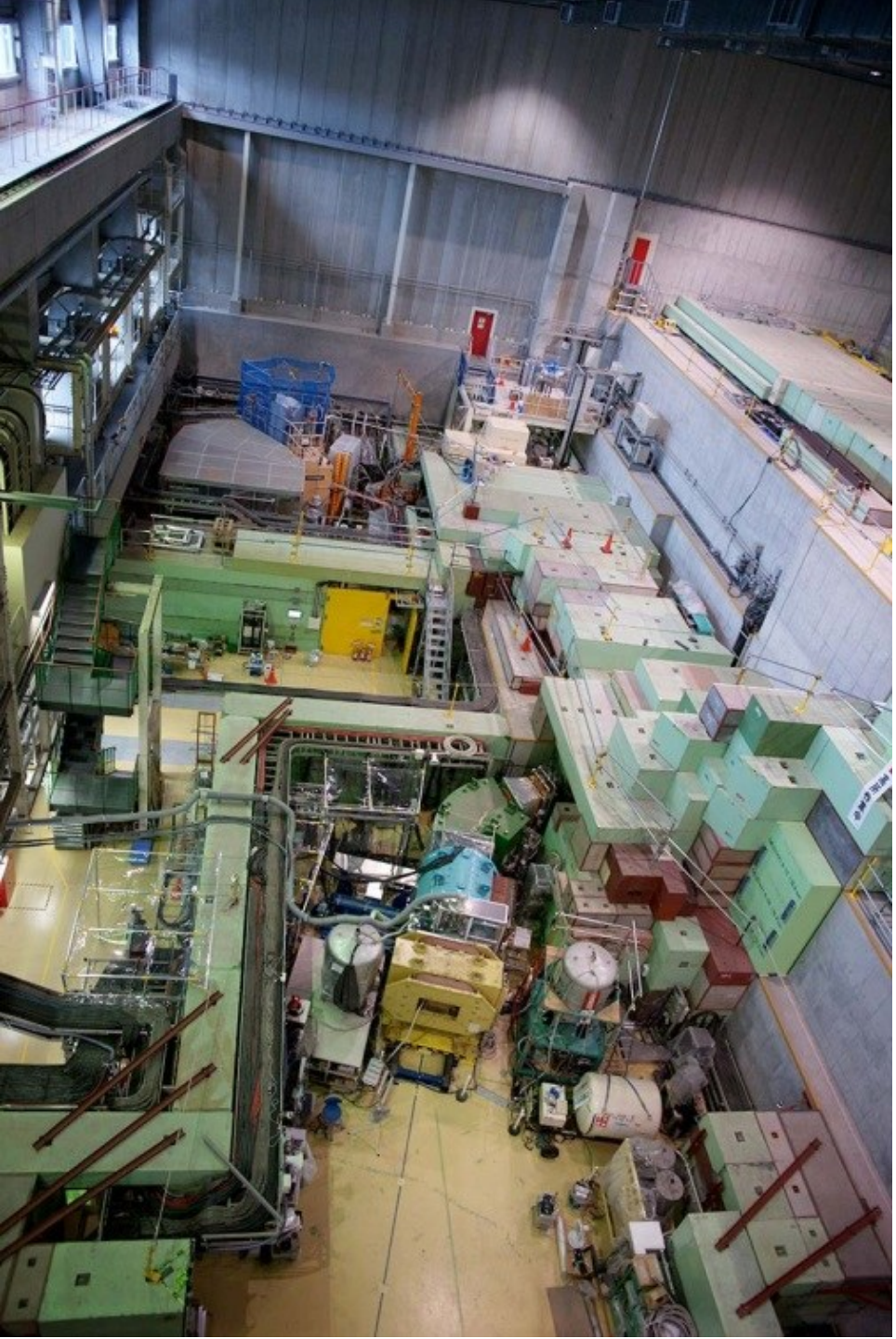
Hadron Exp. Hall & Experimental Setup December 2015

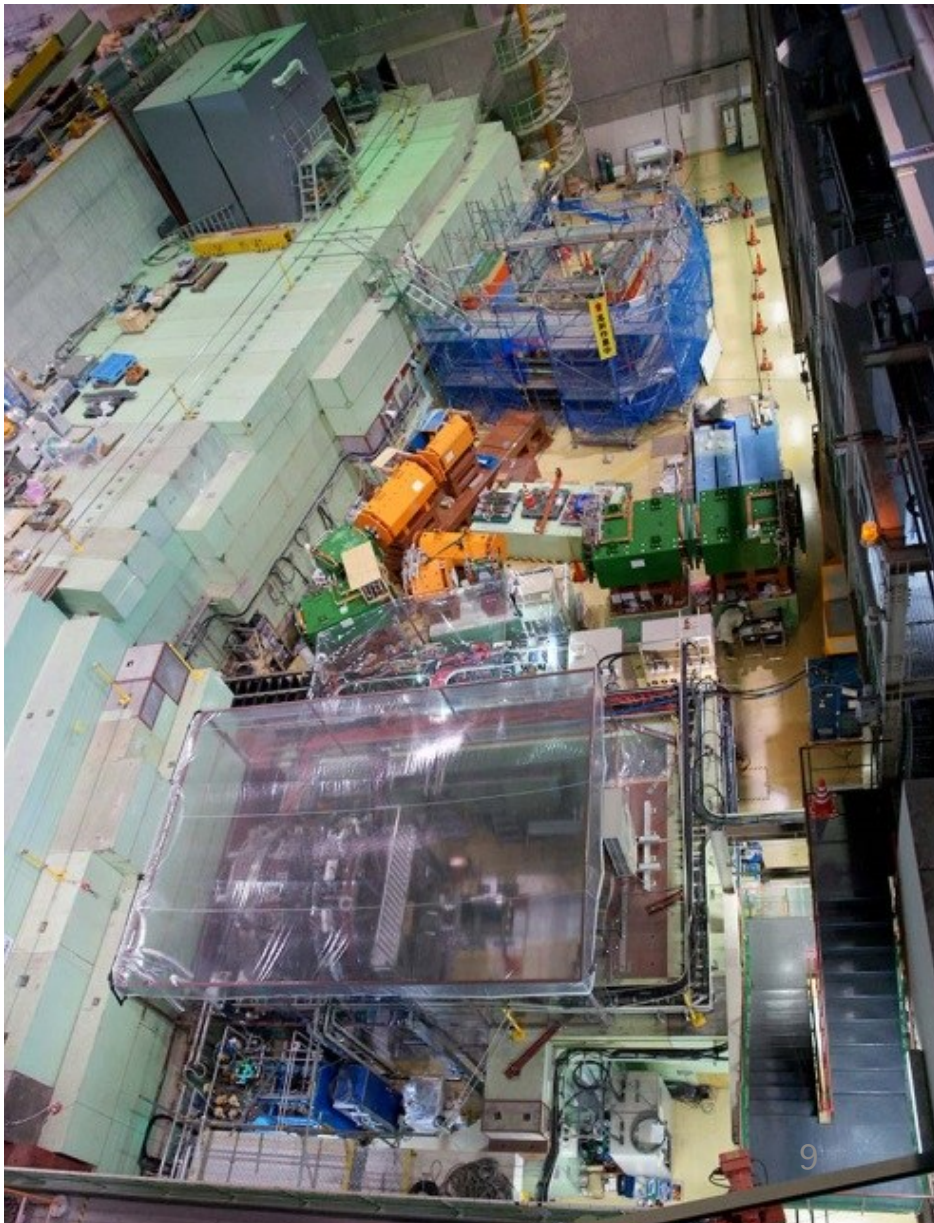






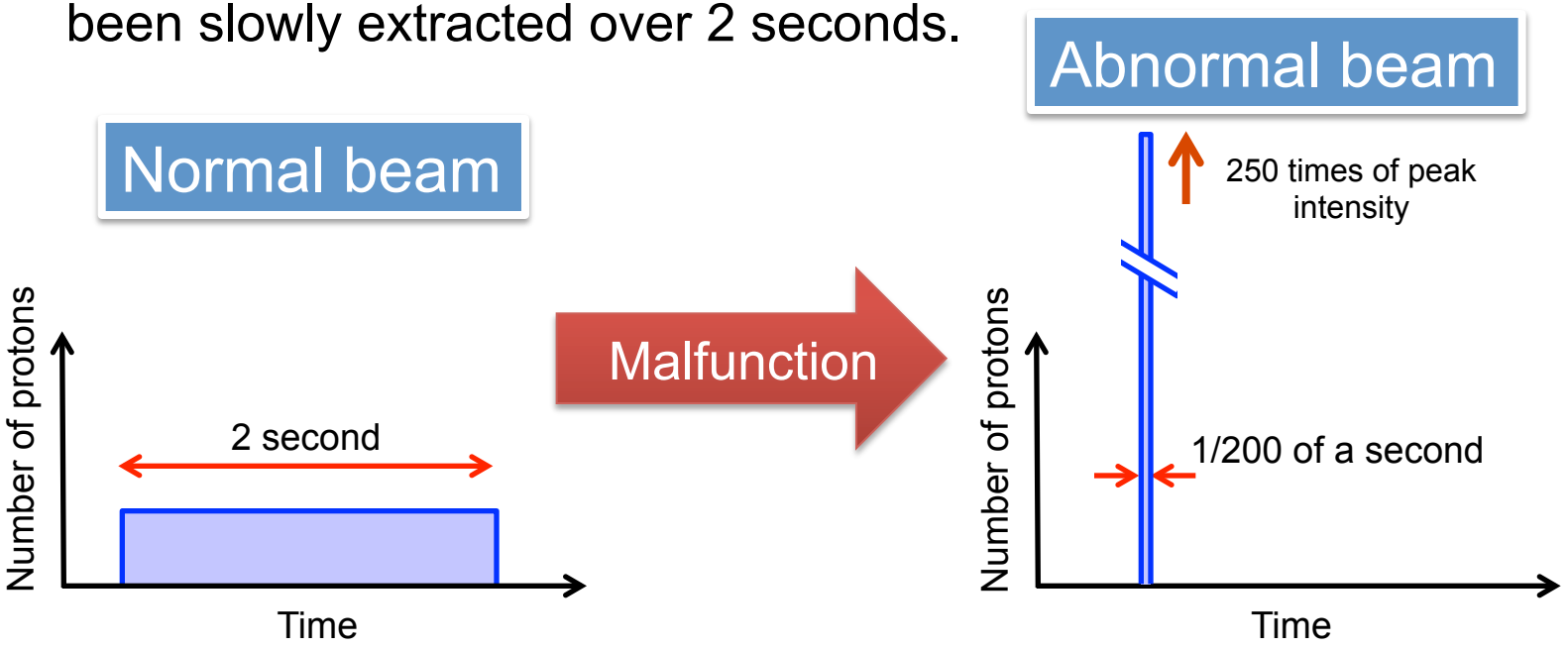
Hadron Hall 2015 Dec.



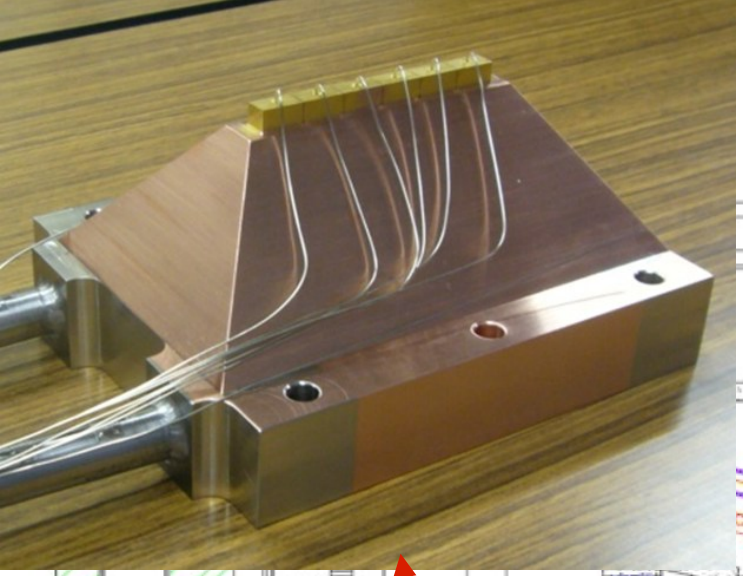


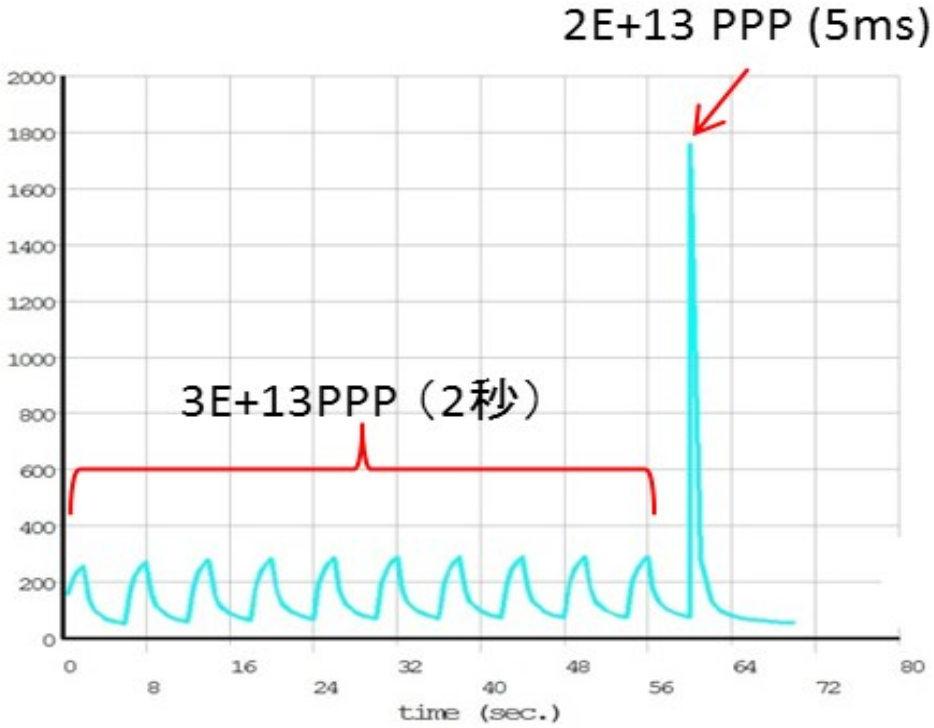
Hadron Hall Incident
Abnormal Shot Pulse Beam

- At around **11:55 on May 23 in 2013,** the power supply system of a special magnet in the 50 GeV Synchrotron malfunctioned.
  → 2×10^{13} protons were extracted in a very short period of 5 milliseconds, while in normal operation 3×10^{13} protons should have been slowly extracted over 2 seconds.

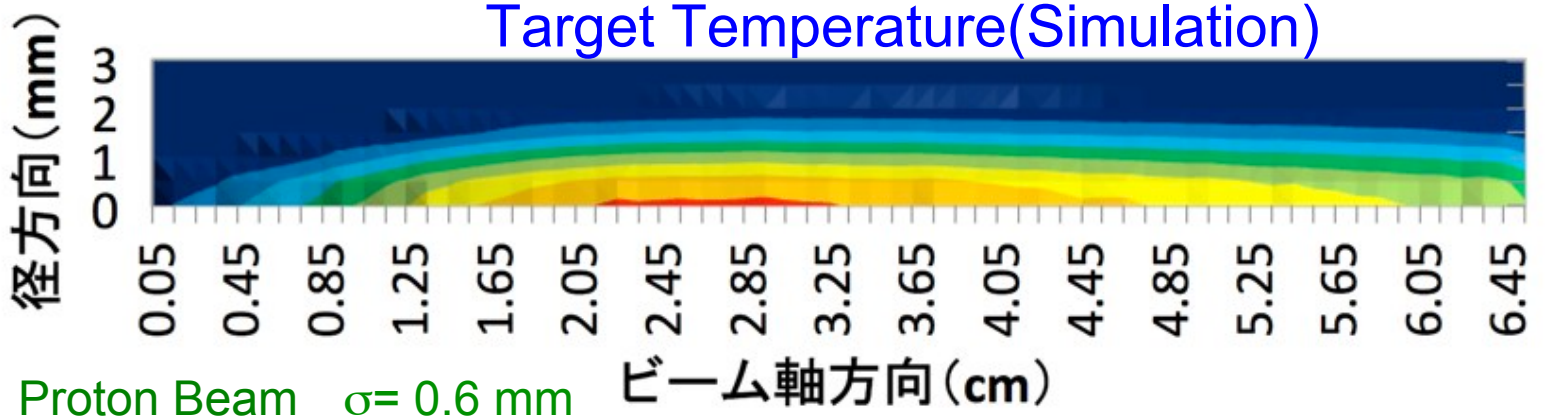


Target Heat Up



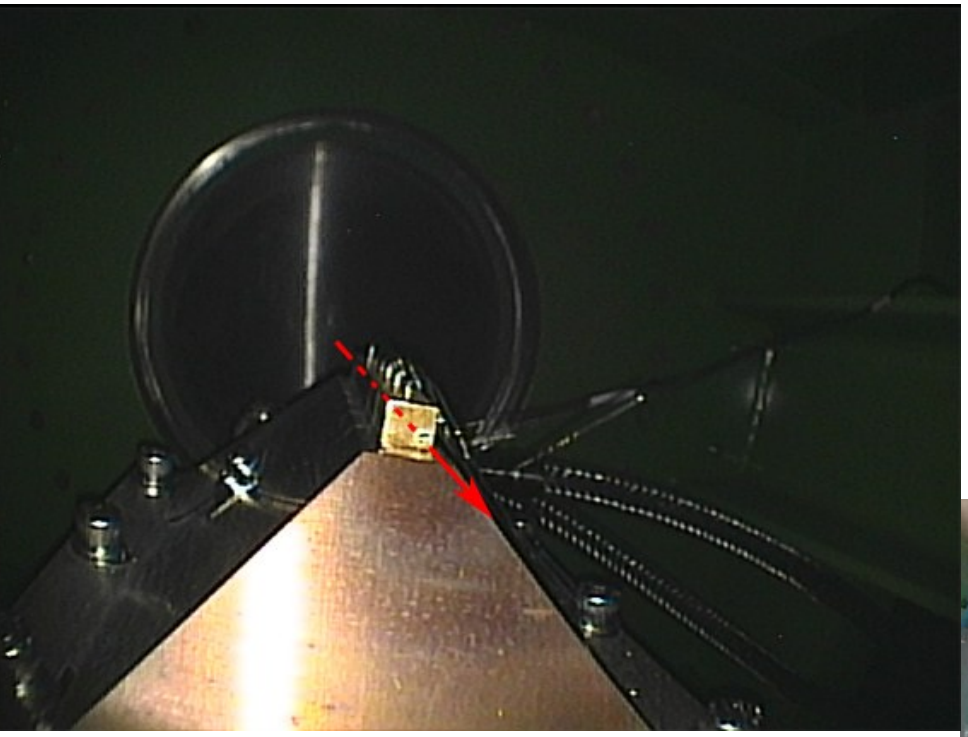


Target Temperature(Simulation)



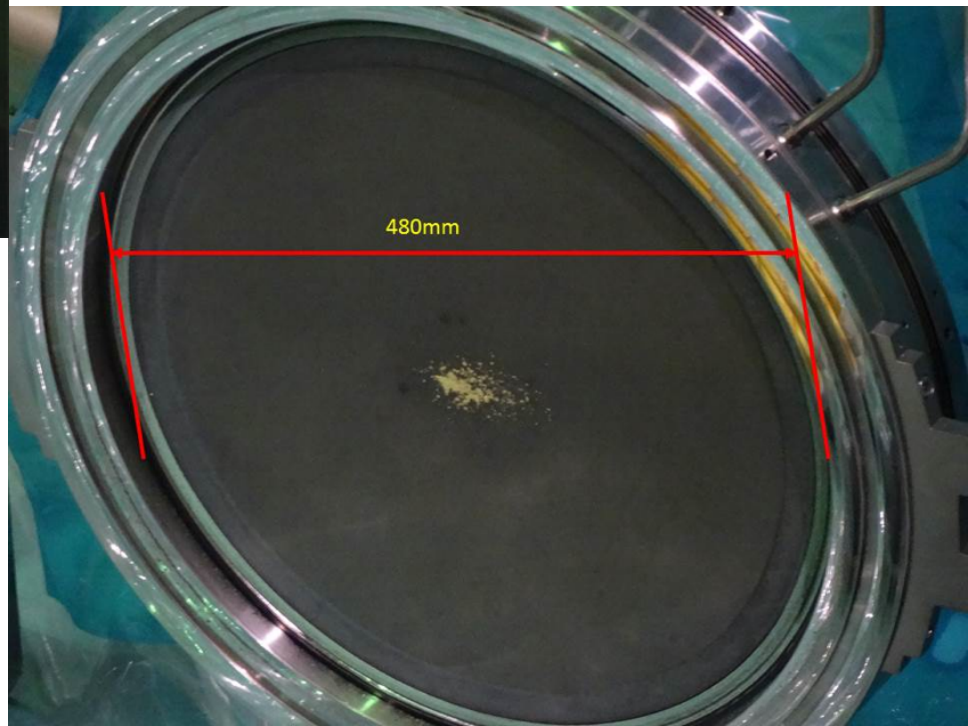
Proton Beam　σ= 0.6 mm

Observed Gold Target



← Gold target observed from the downstream: a 1mm in diameter hole was seen at the downstream end.

Traces of sprayed-out melting Gold at the Be window at the downstream →



These observations well match with our simulation results.

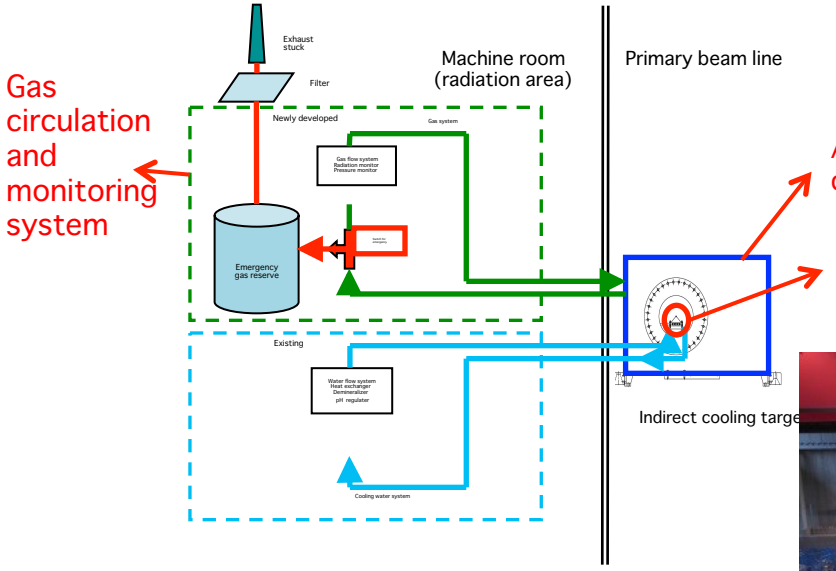
Hadron Hall Incident

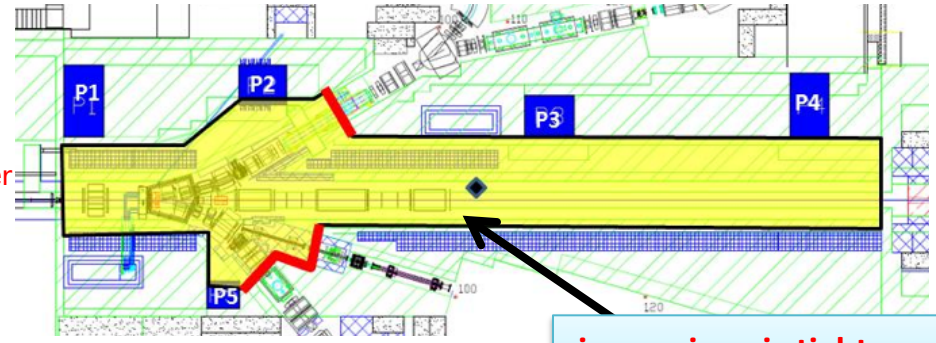
- **The radioactive material leaked into the beam line tunnel** which housed the primary proton beam line, because the target container was not very tightly hermetically-sealed.
- **The radioactive material leaked into the Hd-hall** since the airtightness of the beam line tunnel was not perfect. At this point workers in the Hd-hall were exposed to radiation.
- Due to operation of exhaust ventilation fans in the Hd-hall, **the radioactive material was released to the environment** outside of the radiation controlled area of the Hd-hall and J-PARC.

- **34 out of 102 radiation workers** staying in the Hd-hall during the incident was internally exposed to radiation. The maximum amount of their radiation doses was found to be **1.7 mSv** through a whole-body counter measurement. Fortunately medical examination confirmed the absence of any adverse effects due to the radiation exposure.
- The total amount of radioactive material released into the Hd-hall was estimated to be approximately **20 billion ($2x10^{10}$) Bq**. The radiation dose on the site boundary at the location closest to the Hd-hall was estimated to be below **0.29 μSv**.

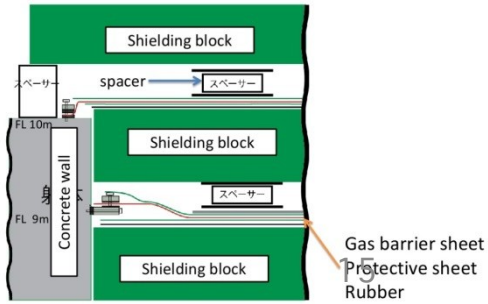
Countermeasures

- **Hardware: against the insufficient airtightness!**
  - Strengthen interlocks including the accelerator side
  - **Airtight target chamber** and gas circulation system
  - Reinforced **airtightness of the primary beam line**
  - Air exhaust system and monitors at the Hadron Hall
- **Software:** organization, manuals, training, education, etc.



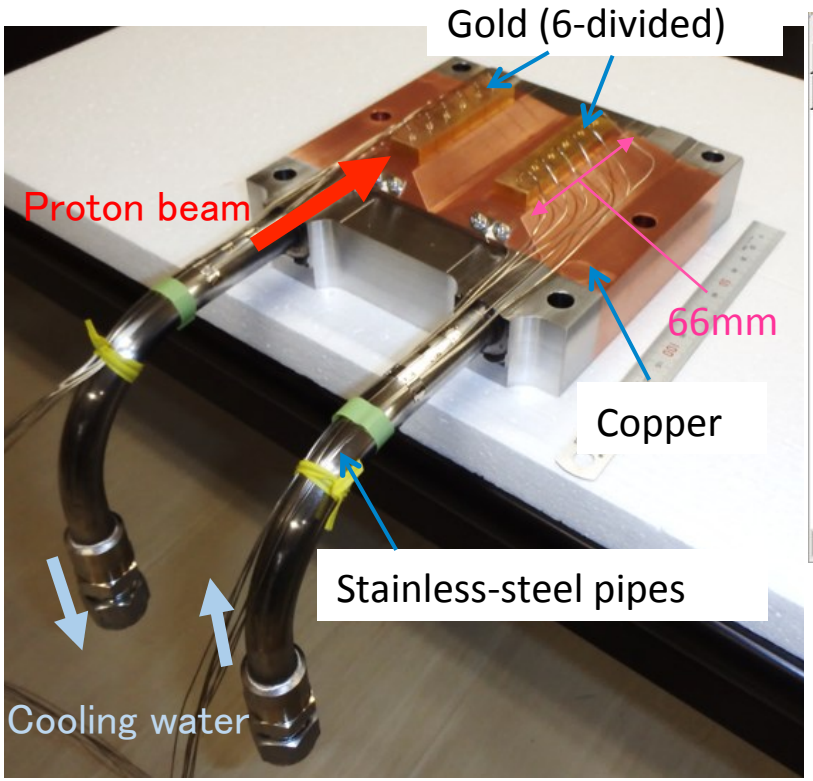


improving air-tightness of Primary Beam Line

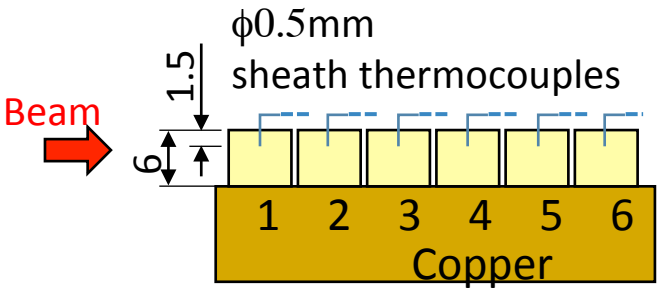


Airtightness of Target Chamber

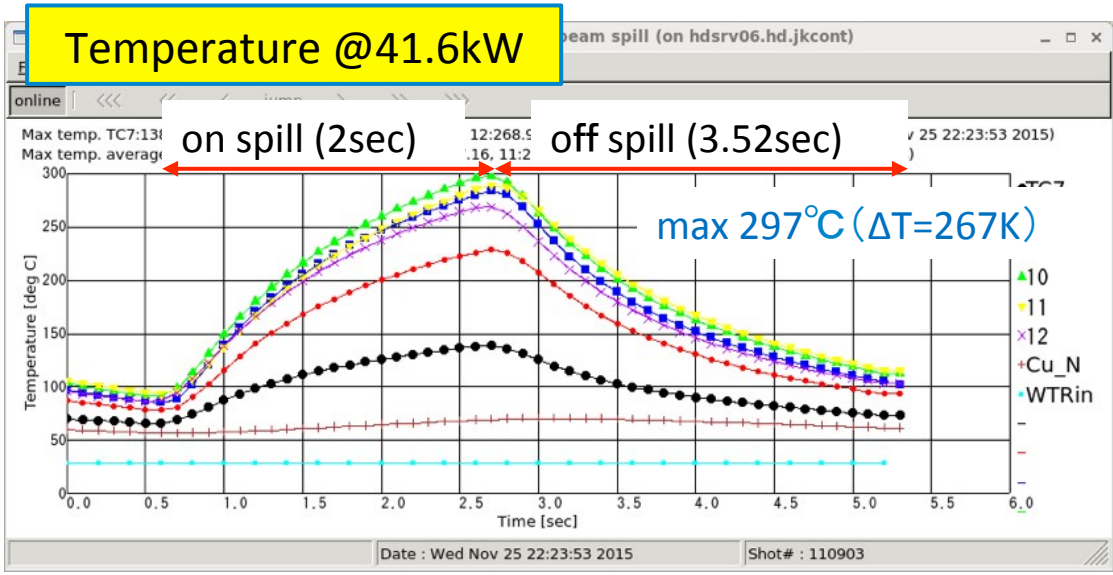
Current Production Target



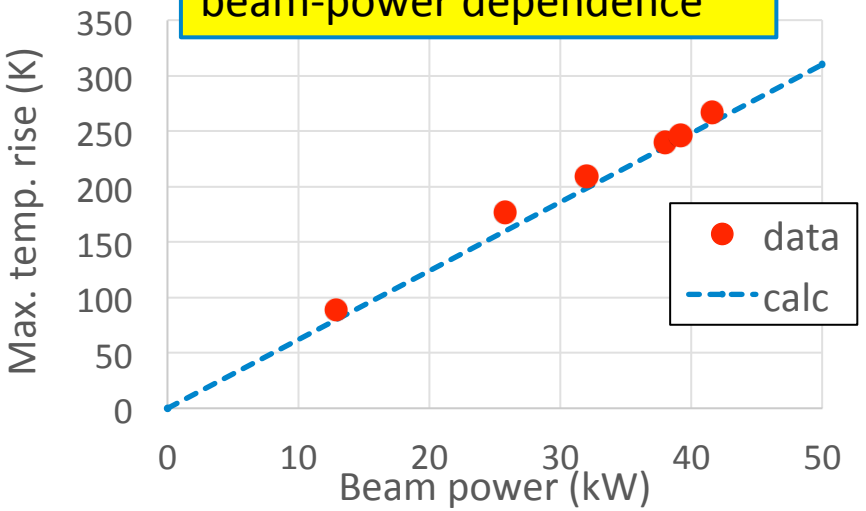
Temperature of each gold piece was measured with thermocouples every 100ms



Temperature @41.6kW



beam-power dependence



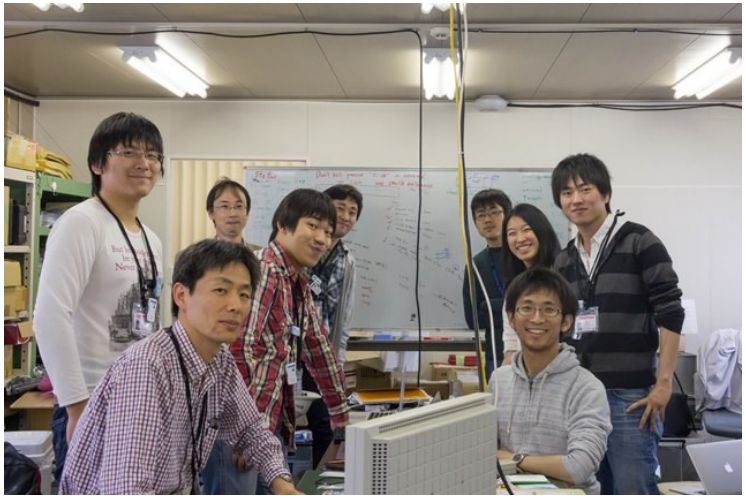
Measured temperature was in good agreement with calculation

Restart of Hadron Beam Operation

April 24, 2015

(Almost 2 years after the incident)

User operation restarted with beam power of **24kW**



朝日新聞　２０１５年４月２５日　朝刊　２８ページ　茨城全県

J-PARC

実験施設が再開
放射能漏れから2年

東海村にある加速器実験施設「J-PARC」で24日、放射性物質の漏出事故＝を起こしたハドロン実験施設の運転が約2年ぶりに再開された。

「標的の温度、異常なし」

午前11時すぎ、陽子ビームを標的に当てる作業を開始。運転管理室では職員が標的の温度や放射能濃度のモニター画面を確認した。

この日から、国内外の大学や研究機関の三つの実験が始まった。他に約10の実験が控えているという。

運転管理室で標的の温度などを確認する職員ら＝東海村のJ-PARC

放射性物質の漏出事故

2013年5月、陽子ビームを標的の金に当てて粒子を発生させる実験中に起きた。機器劣化による誤作動で設定値を大きく超えるビームが当たり、金の中の放射性物質が蒸発。研究者ら34人が被曝（ひばく）し、排気ファンを回したことで放射性物質が屋外に漏れた。警報が出た後も4時間以上実験を続け、自治体への報告が1日半遅れたことが批判を浴びた。

事故は国際原子力事象評価尺度で、1995年の高速増殖炉もんじゅ（福井県）のナトリウム漏れ事故と同じ「レベル1」とされた。

J-PARCは、日本原子力研究開発機構と高エネルギー加速器研究機構が共同で運営。ハドロン実験施設は2009年に完成した。陽子ビームの出力が高く、世界最高性能の施設とされる。標的となる金などの原子核と衝突させて粒子を作り出し、物質の起源や宇宙の成り立ちを探究している。事故前の12年度は利用期間中、常時約100人が利用した。

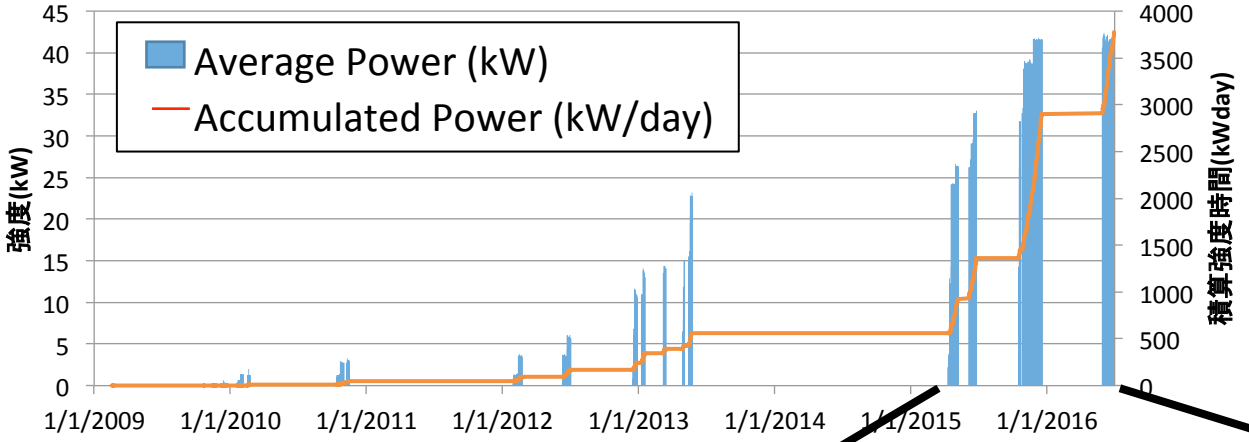
事故で八つの実験が中断や延期を余儀なくされた。事故当時、チームの責任者として実験に取り組んでいた大阪大の山中卓教授（高エネルギー物理学）は「2年は長かったが、安全対策や住民への説明を一つ一つ丁寧にした結果。ようやく研究を進められるのでホッとしている」と話す。

J-PARC側は、約19億円をかけて安全対策を講じた。異常な量のビームが出る原因となった電源基板に劣化対策を施し、放射性物質が外に漏れないよう排気ファンを撤去。異常時の行動基準もマニュアルに盛り込んだ。こうした再発防止策を踏まえ、県や村は先月、運転再開を了承した。

事故以降、一市民の立場でJ-PARCの動向をブログで発信してきた常総市の行政書士吉性隆さん（50）は、ウェブサイトでの会議資料の掲載など情報公開が進んだことに一定の評価をしつつ、釘を刺す。「研究者と住民との安全認識の差はだいぶ縮まった。ただ、施設全体の災害対策でまだ不安な点がある。今後も住民目線で監視したい」

J-PARCの斉藤直人センター長は「安全確保を最優先に施設を運営する。最先端の研究成果を生み出し、社会に貢献していきたい」と話している。（酒本友紀子）

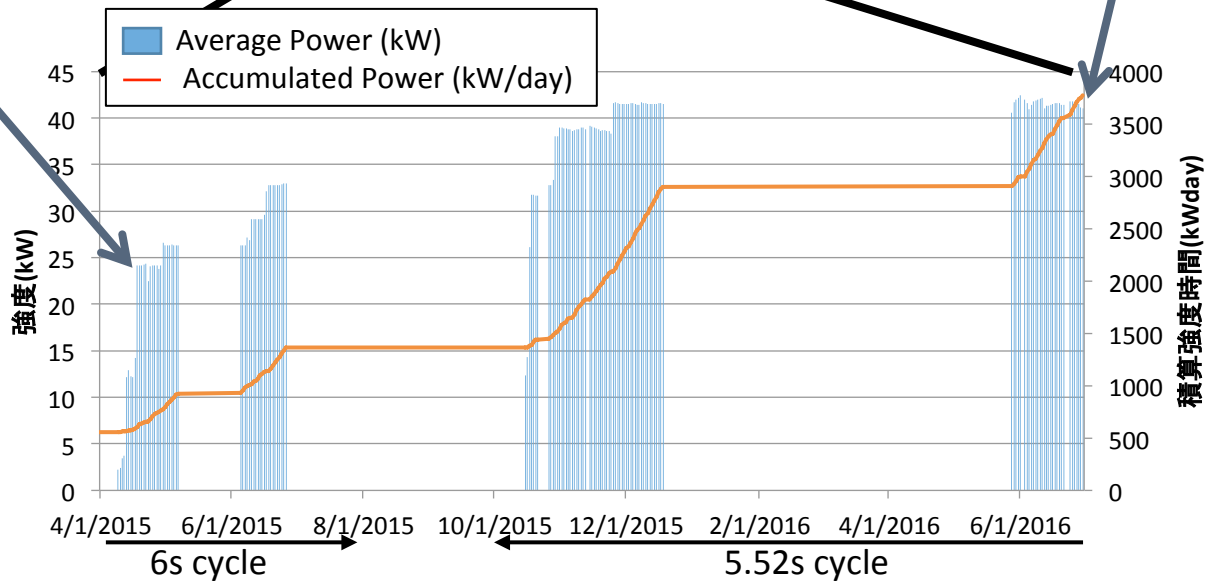
Development of Beam Intensity



Test beam extraction (one pulse) intensity reached 54kW in late June 2016.

41.6 kW

24 kW @resumption



Accumulated beam time and intensity for HD

Feb, 2009 - May, 2013: 1.26x10^6 spills, **560 kW*days** ←Before Hadron Incident

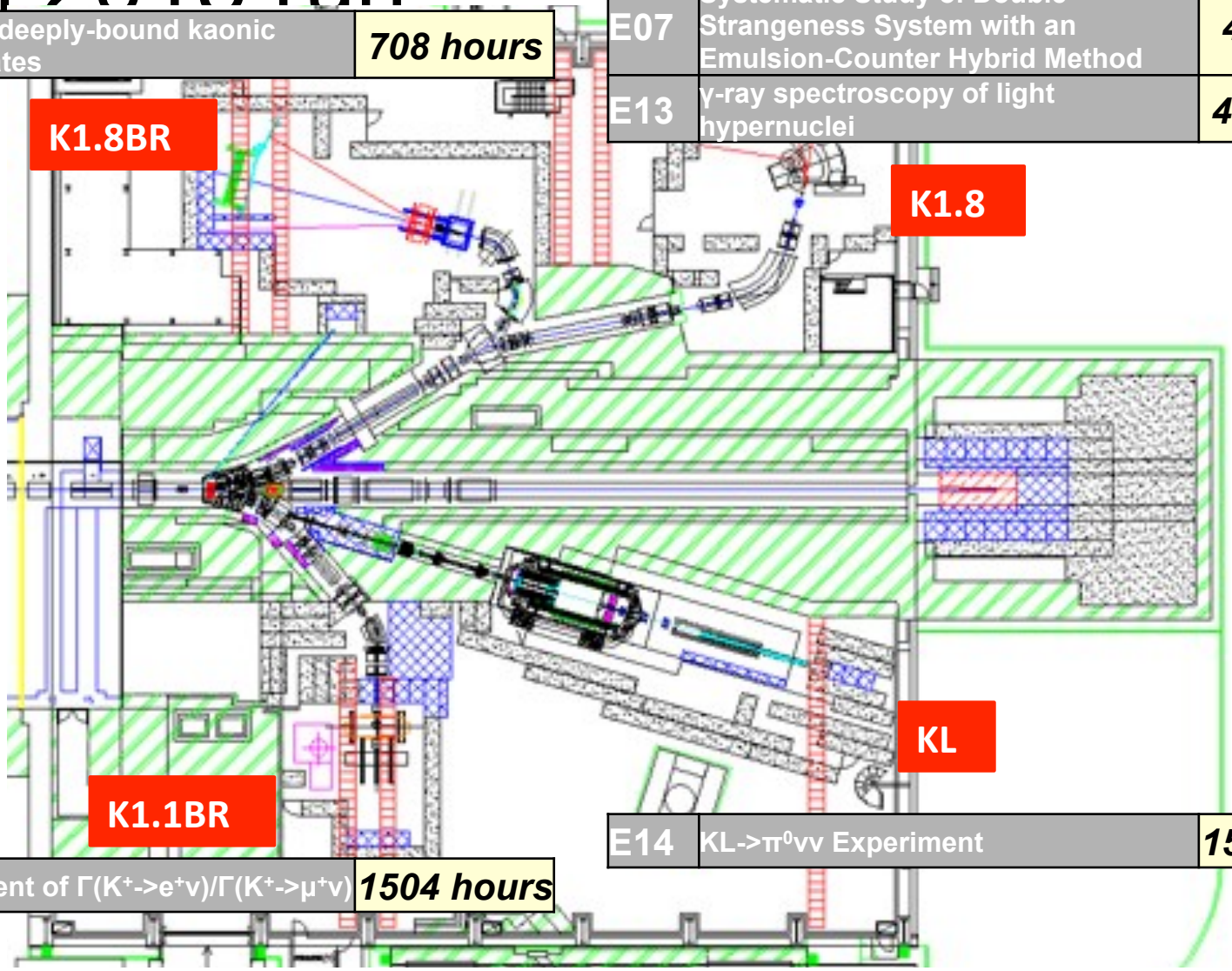
Apr, 2015 - Dec, 2015: 1.05x10^6 spills, **2338 kW*days** ←in JFY2015

May, 2016 - Jun, 2016: 0.33x10^6 spills, **875 kW*days** ←in June 2016 Run

Beam time used for experiments in 2015 run

E05	Spectroscopic Study of Ξ- Hypernucleus	*319 hours*
E07	Systematic Study of Double Strangeness System with an Emulsion-Counter Hybrid Method	*42 hours*
E13	γ-ray spectroscopy of light hypernuclei	*435 hours*

E15	search for deeply-bound kaonic nuclear states	*708 hours*



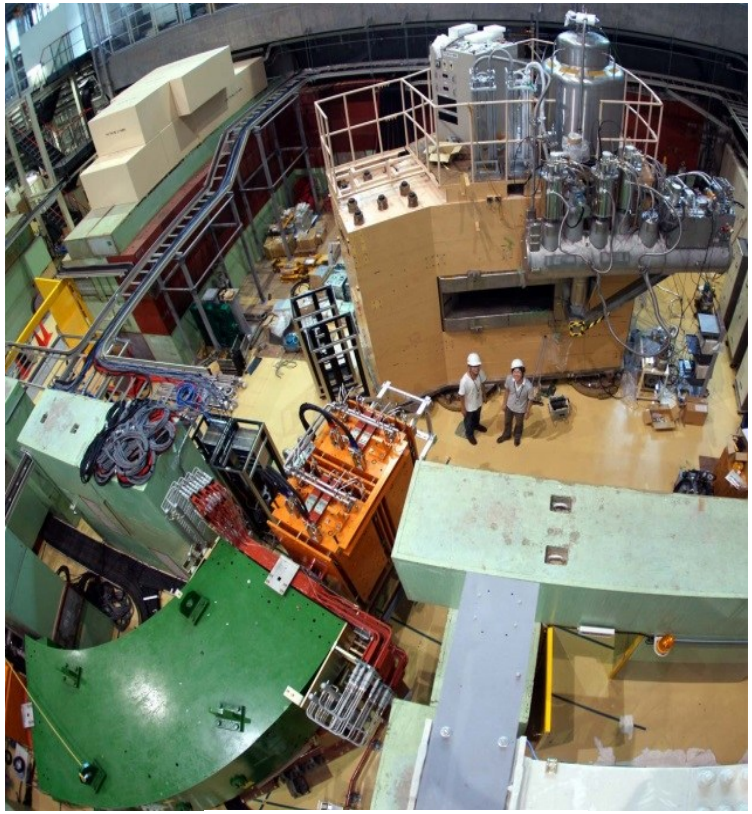
E14	KL->π⁰νν Experiment	*1509 hours*
E36	Measurement of Γ(K⁺->e⁺ν)/Γ(K⁺->μ⁺ν)	*1504 hours*

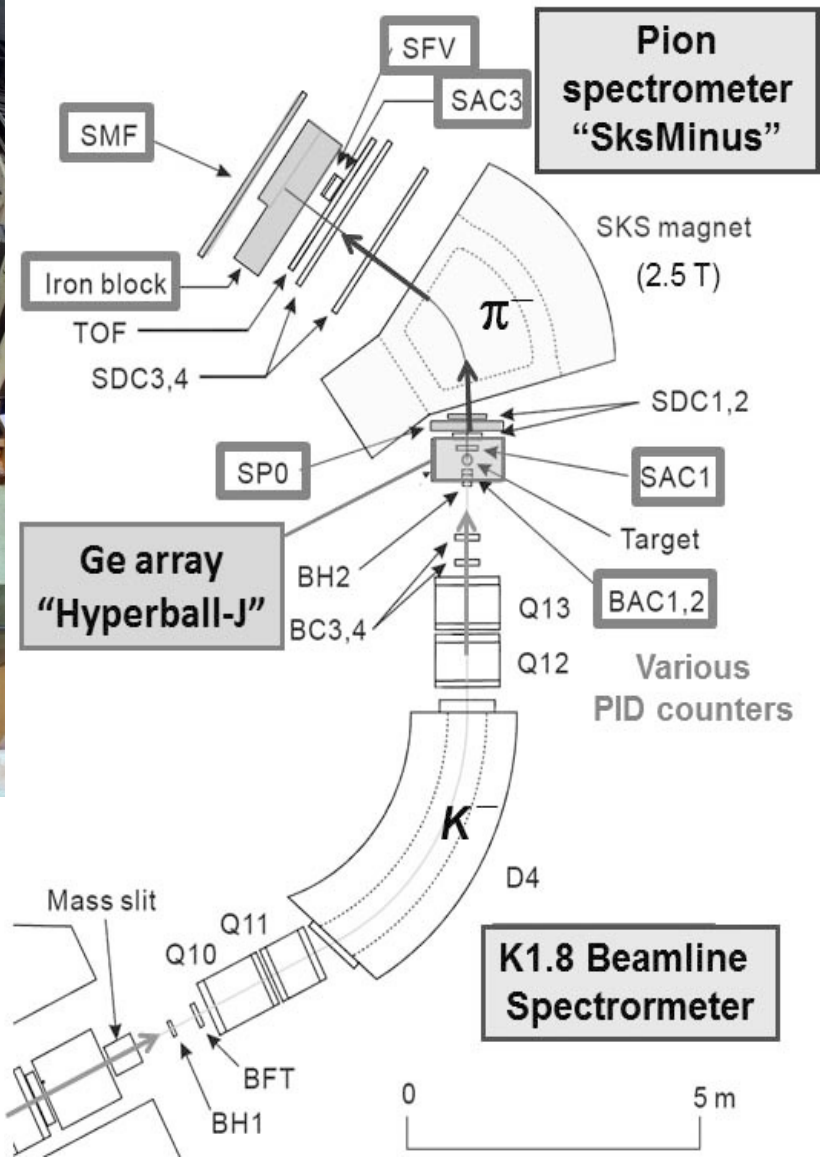
A highlight of recent results

-- Charge Symmetry Breaking in ΛN interaction from hypernuclear γ-ray spectroscopy (E13) --

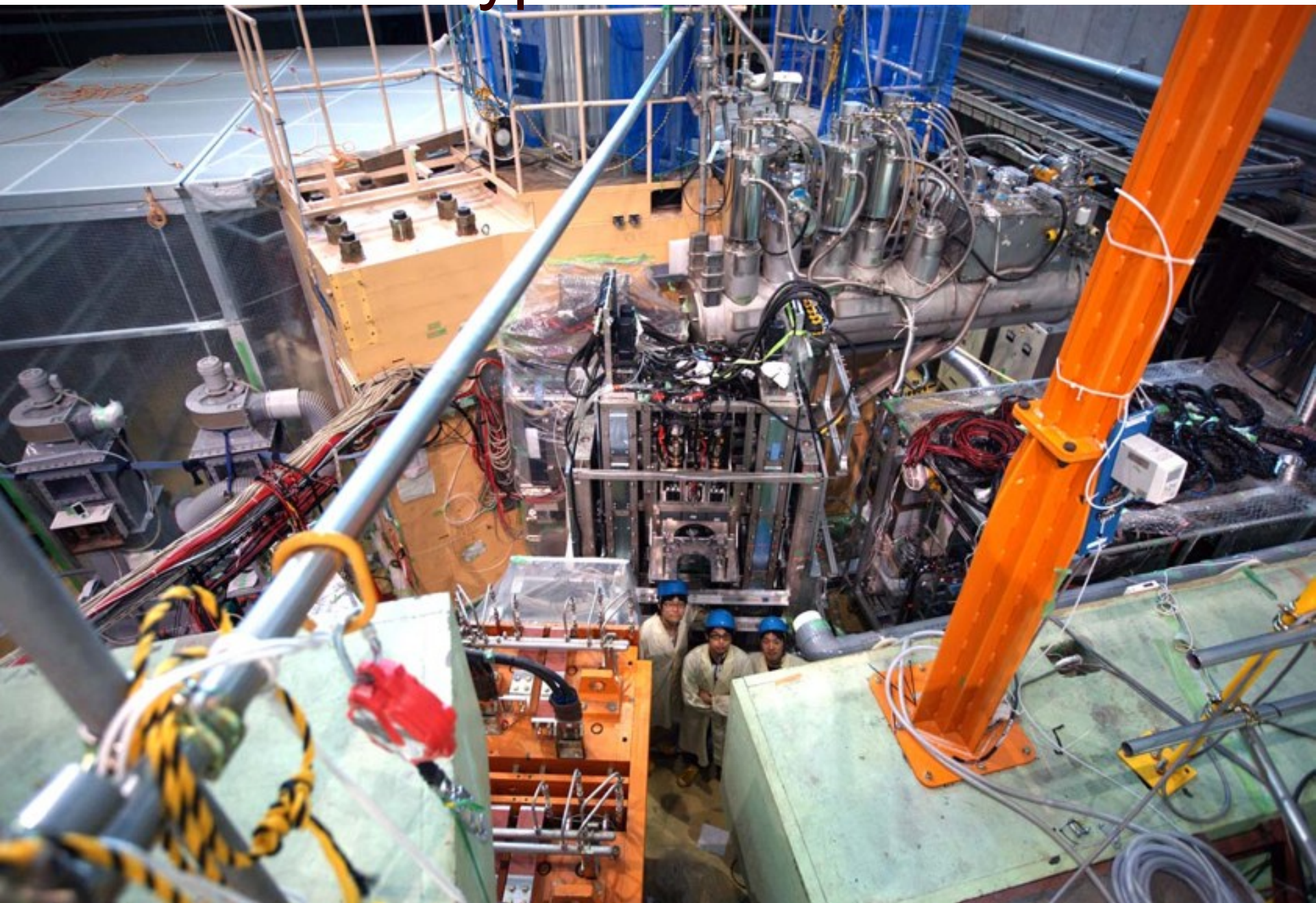
Setup at K1.8 for E13-1

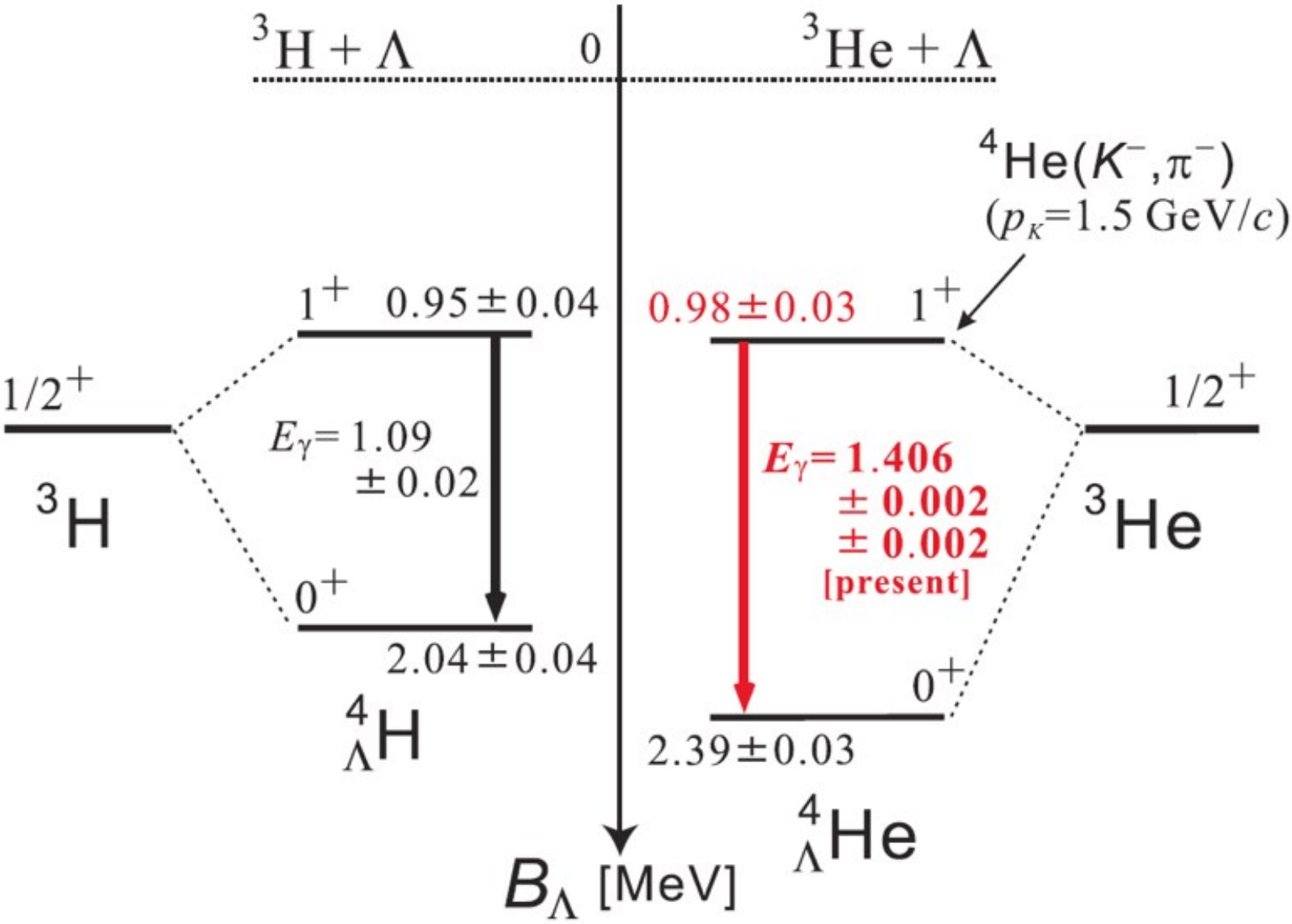
- Detect gamma-rays from hypernuclei





Hyperball-J & SKS





Plenary Talk by Prof. Hiro Tamura on Wednesday

Talk by Dr. M. Ukai on Friday Morning Hall L

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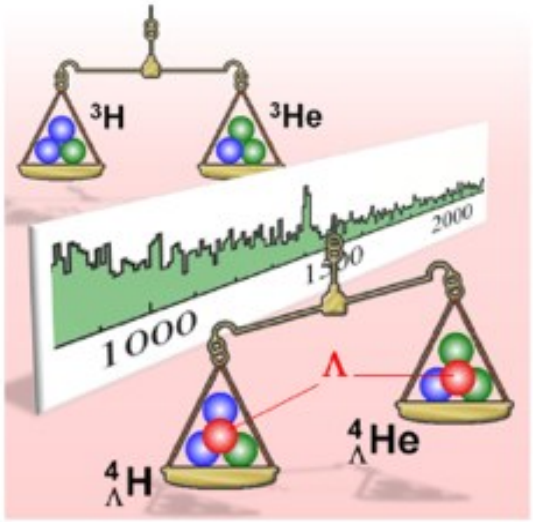


EDITORS' SUGGESTION

Observation of Spin-Dependent Charge Symmetry Breaking in ΛN Interaction: Gamma-Ray Spectroscopy of $^4_\Lambda$He

The energy spacing of the spin-doublet states in the $^4_\Lambda$He hypernucleus indicate a large spin dependent charge symmetry breaking in the ΛN interaction.

T. O. Yamamoto *et al.* (J-PARC E13 Collaboration)

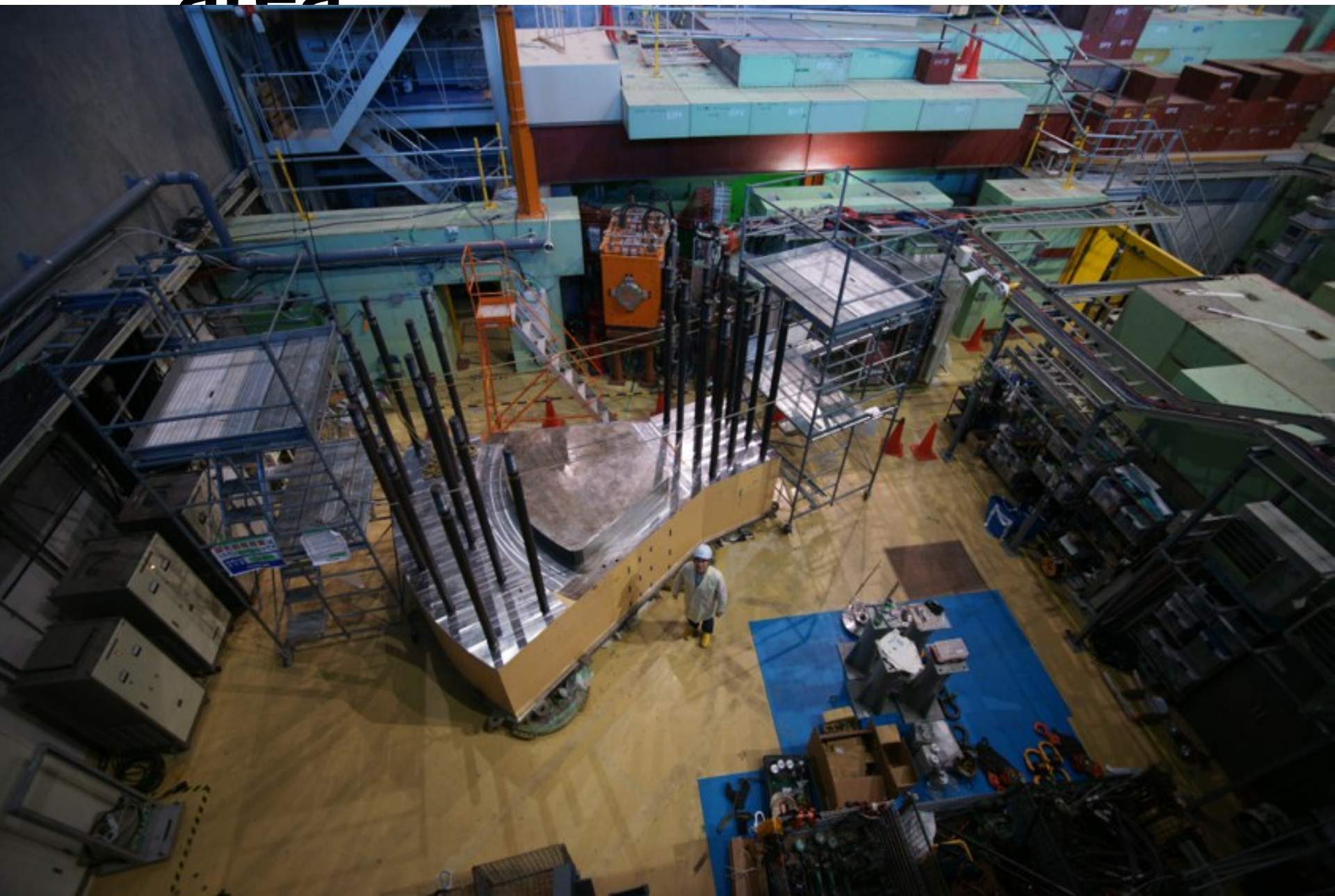
Phys. Rev. Lett. **115**, 222501 (2015)

Press-released from Tohoku U., KEK, JAEA, J-PARC

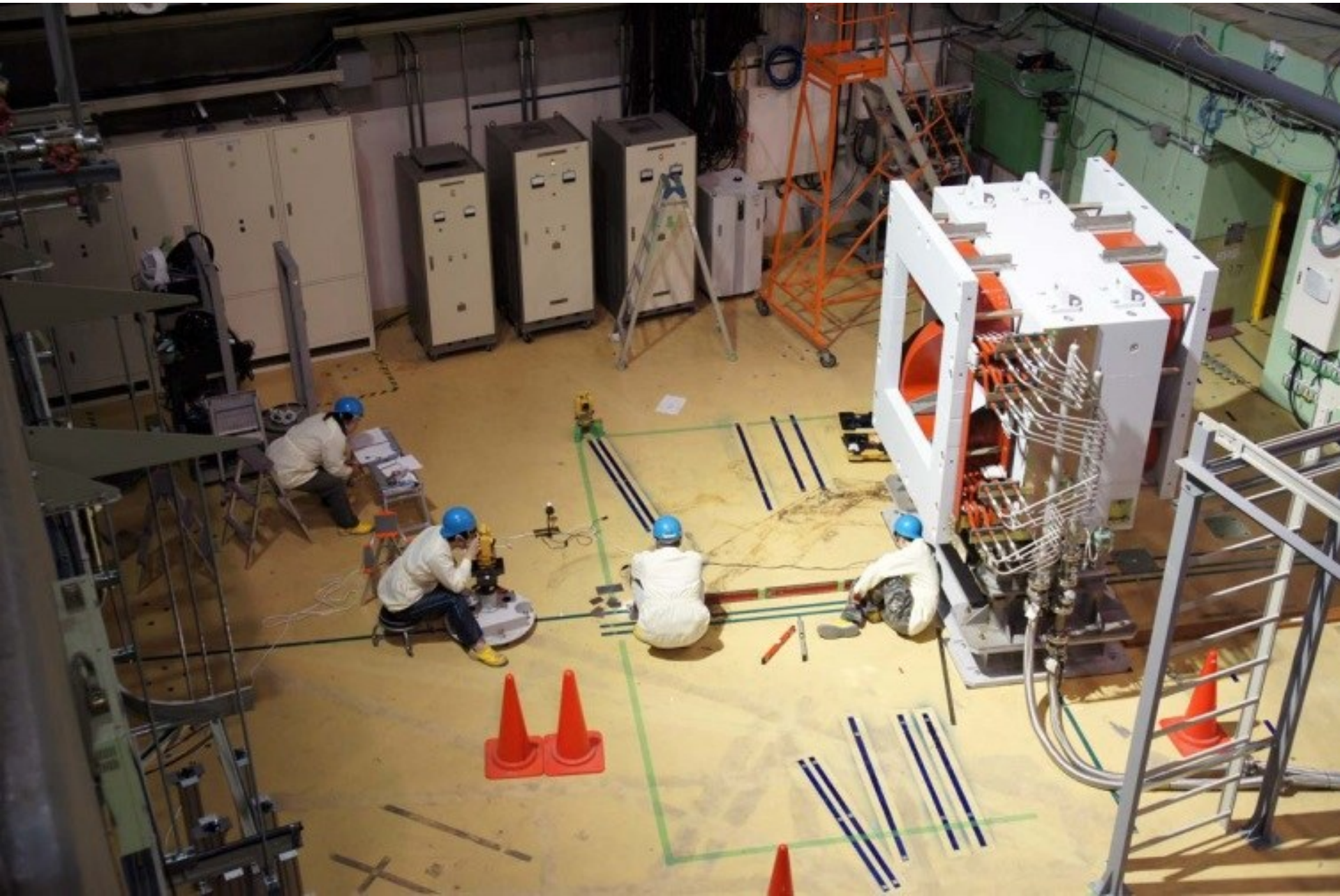
Toward double strangeness systems (E07 and E05)

Talk by Prof. K. Nakazawa, Thusday afternoon at QCD session, Hall R6
Talk by Prof. T. Nagae, Friday morning at NSA session, Hall L

SKS removal from K1.8 area



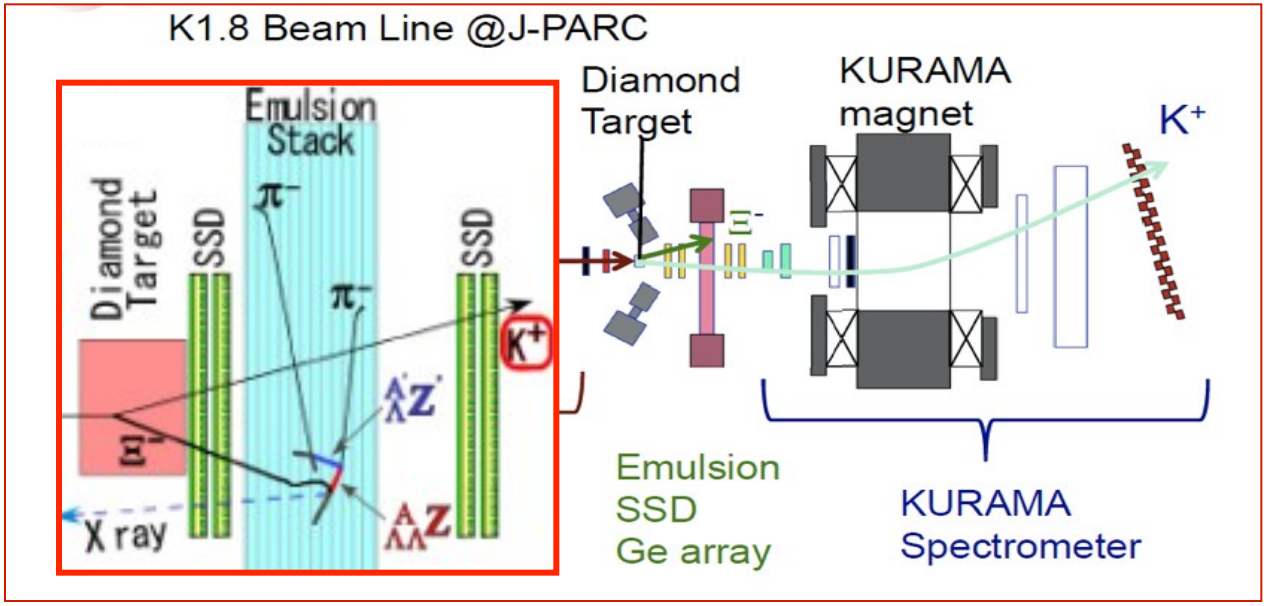
KURAMA set up at K1.8 Area

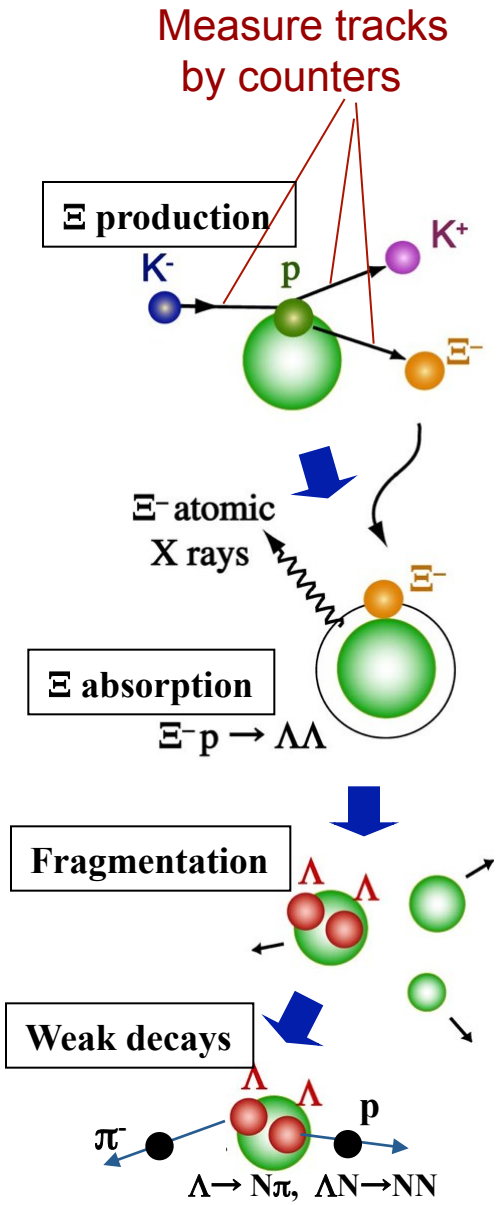


J-PARC E07: S=-2 Systems by emulsion

- Collect ~10^2 ΛΛ hypernuclear events from ~10^4 Ξ^-_{stop}
  - ΛΛ interaction strength without nuclear effects
- Measure Ξ^- -atomic X-rays with Ge detectors
  - Shift and width of X-rays -> Ξ-nuclear potential
  - Stopped Ξ^- events identified from emulsion image

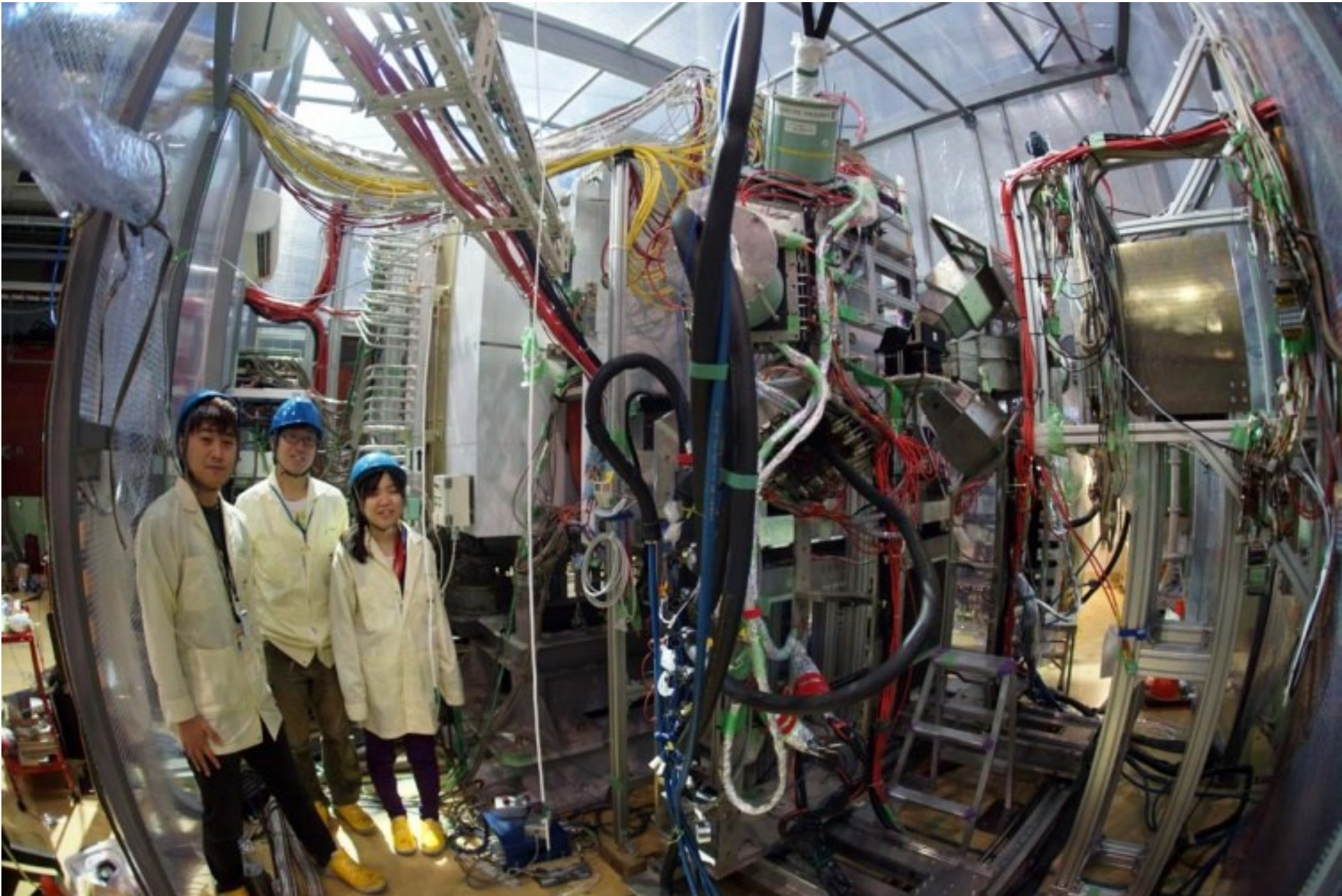
–> no background



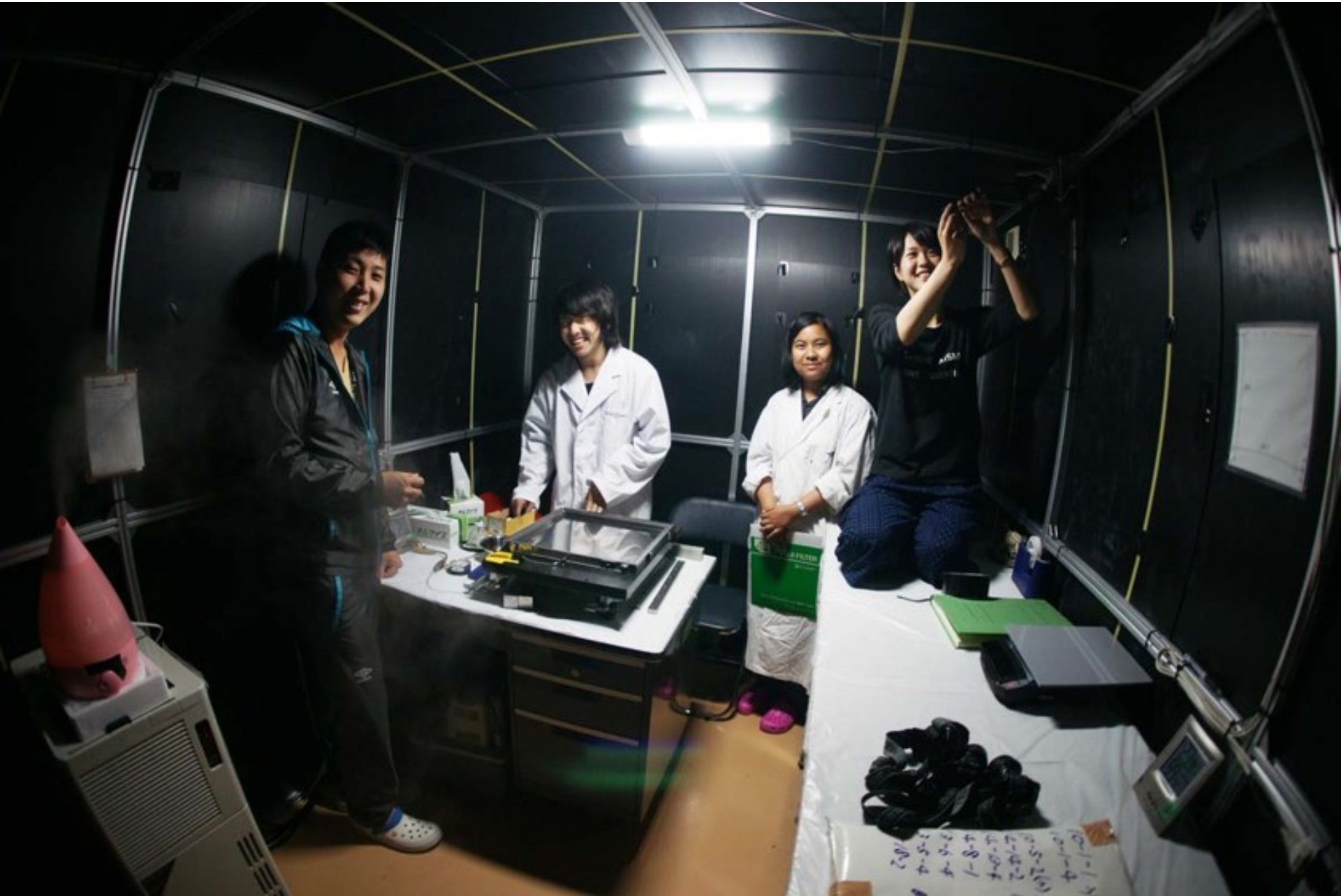


Emulsion and all the counters are beam-tested and ready.
Under switchover from SKS to KURAMA now

KURAMA for Hybrid Emulsion Exp.



Dark Room for hybrid emulsion exp.



Prof. Nakazawa preparing his hybrid emulsion experiment

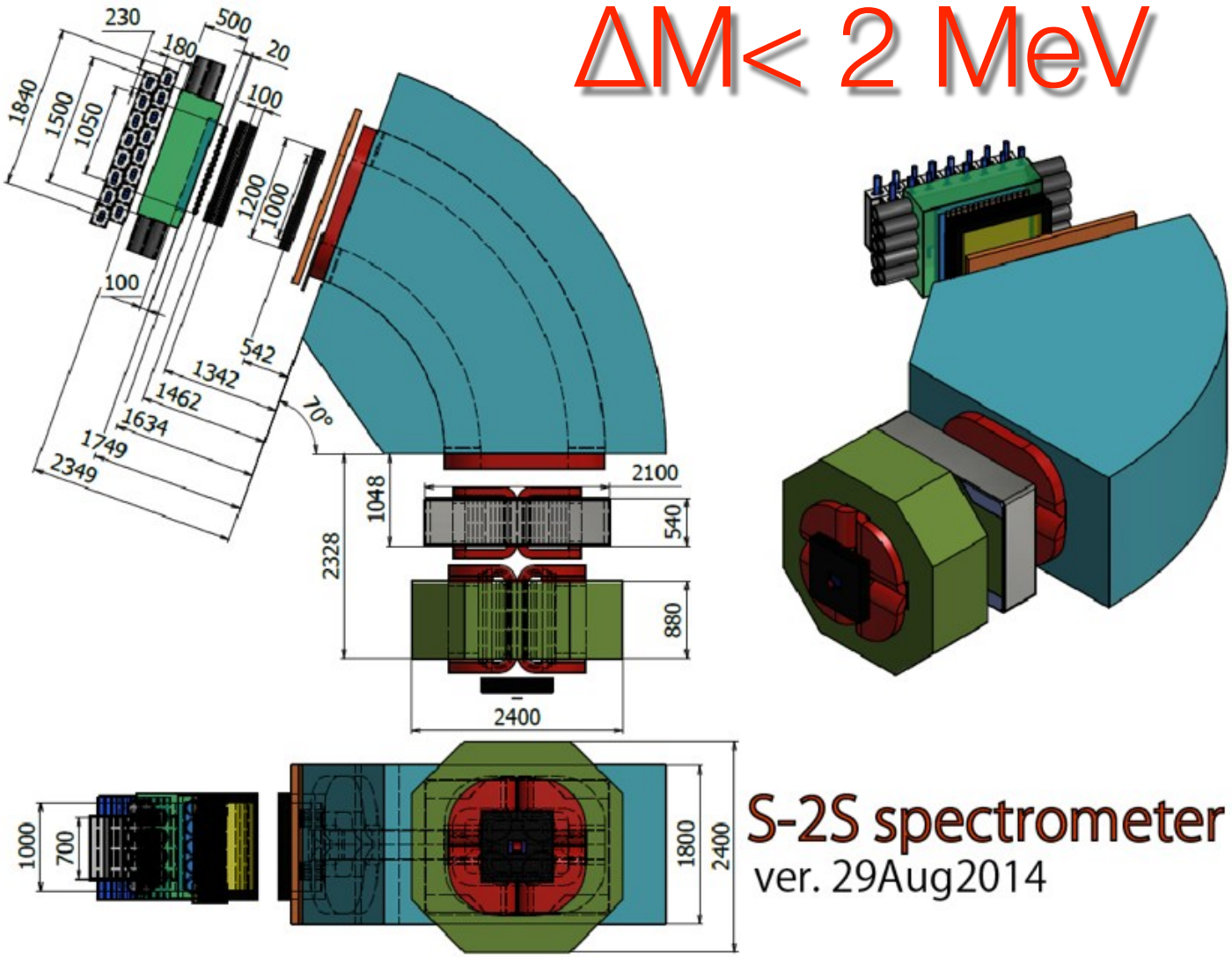
Talk by Prof. K. Nakazawa,
Thusday afternoon at QCD session, Hall R6

S-2S spectrometer for E05

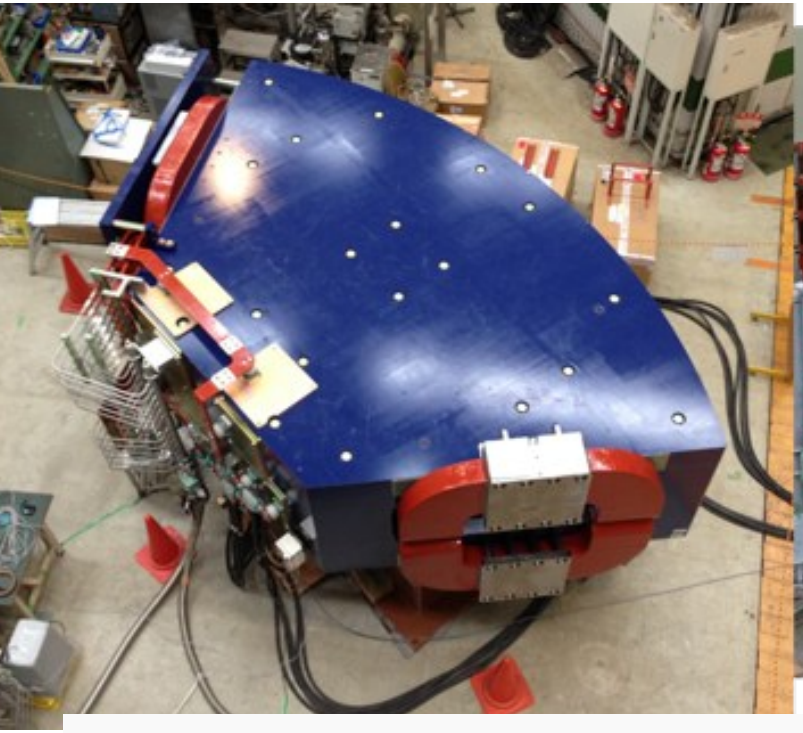
2.9×10^{10} K^-/day

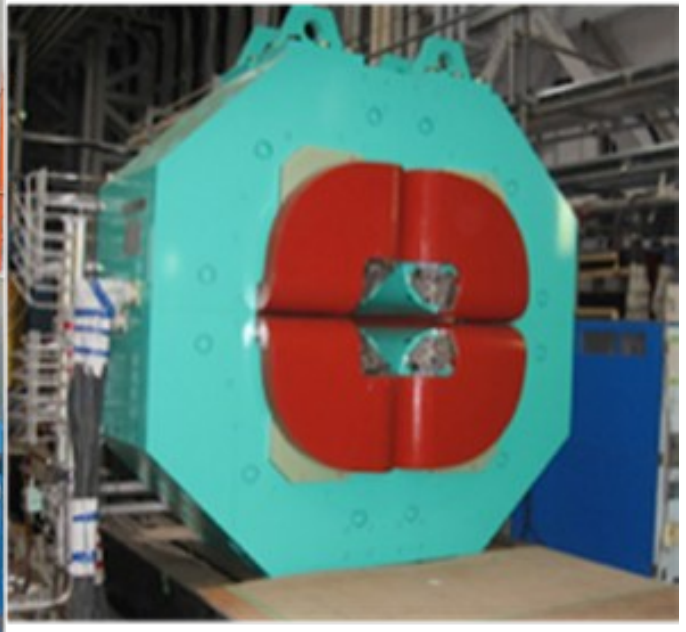
$\Delta M < 2$ MeV

- Grant-In-Aid for Specially promoted research 2011 – 2015, Total ~$3M
- 60 msr, $\Delta p/p = 0.05\% \rightarrow \Delta M = 1.5$ MeV
- Construction of S-2S(QQD): ~3 years
  - ★ Installation in 2016
  - ★ Data taking in 2017 with > 50 kW !!



S-2S spectrometer for E05





All Three Big Magnets are ready to be installed!

Talk by S. Kanatsuki, Monday afternoon

Talk by Prof. T. Nagae, Friday morning at NSA session, Hall L

Summary 0

- The beam operation at the Hadron Facility restarted from April, 2015.
- The beam power at the restart was 24kW, and then improved gradually to 42kW in December.
- Whole system, including the newly installed equipment, worked properly during 2015 and 2016 run.

April 28, 2015

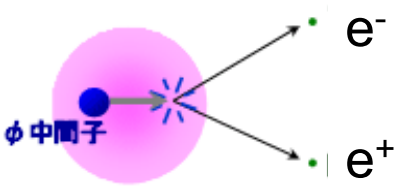
Summary 1

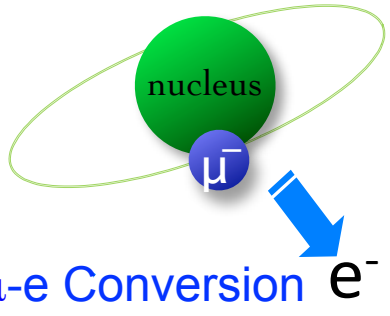
- Physics experiments re-started at the Hadron Experimental Facility (HEF) of J-PARC after the recovery works from the radiation leak incident.
- The first physics papers have been published from the several experiments using new data as well as previously accumulated data.
- Main nuclear physics experiments at HEF are now going to S=-2 hypernuclei! via (K-,K+) reactions.
- **Thank you very much again for your continuous support during our hardest days of Hadron Hall Incident.**

NEXT STEP

- The construction the high-momentum beam line, **high-p**, with **COMET branch** will be completed soon. Mass shift of phi meson would be the first experiment, and other experiments are being discussed.
- **Hadron Hall Extension** was proposed to Government and was selected one of 27 major big projects in Science Council of Japan. Now discussion on the extension is becoming active.
- An International workshop on HH Extension was held on 5-6 March in 2016 by HUA and IPNS.

Experiments at High-p/COMET

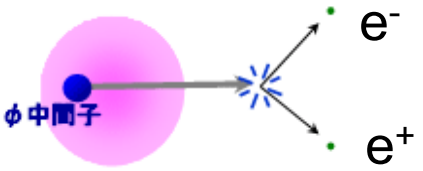


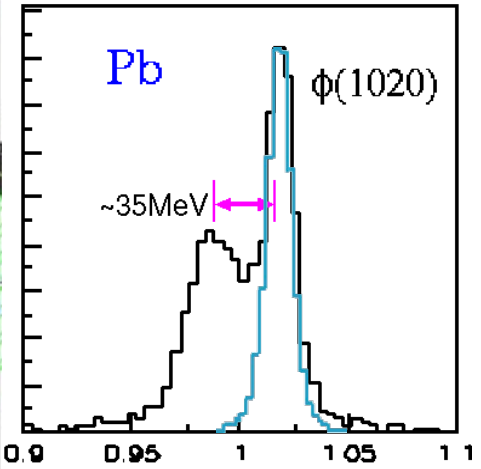


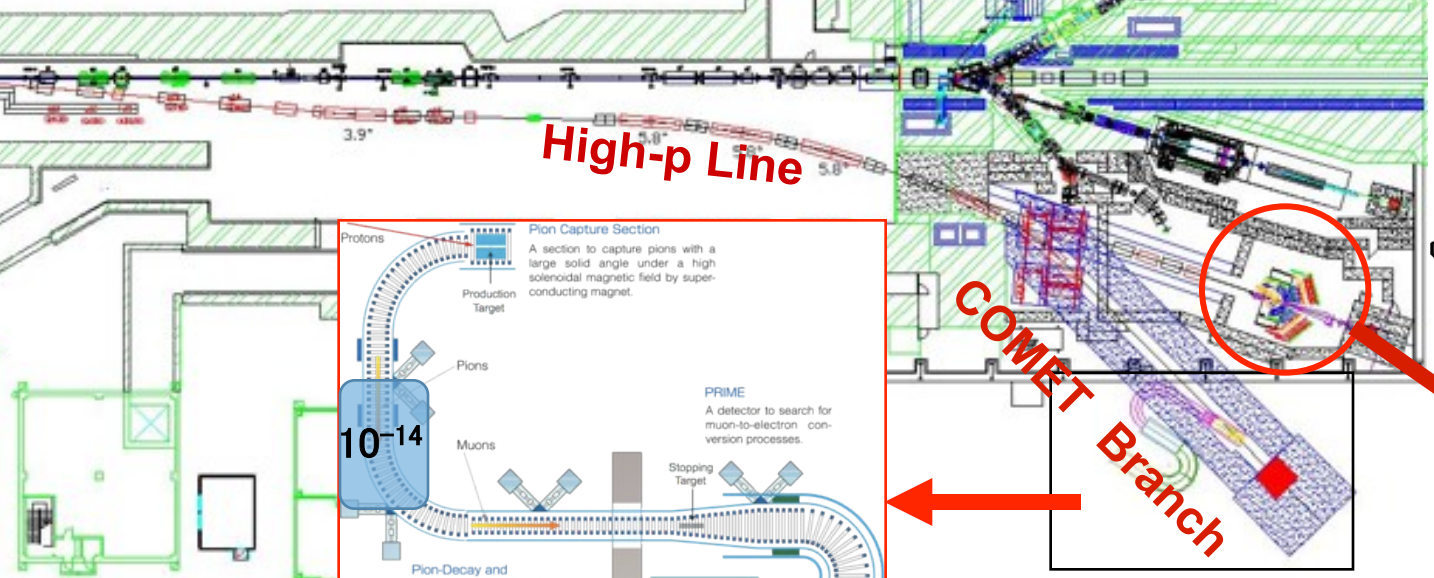
Neutrino-less muon nuclear capture (=μ-e conversion)

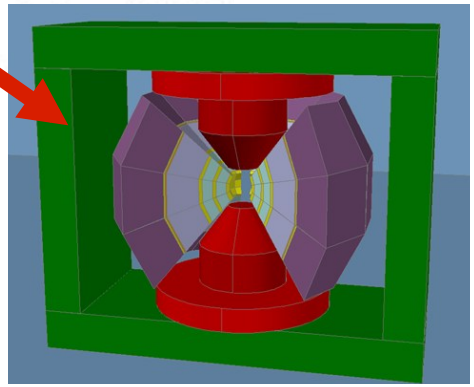
$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

lepton flavours changes by one unit

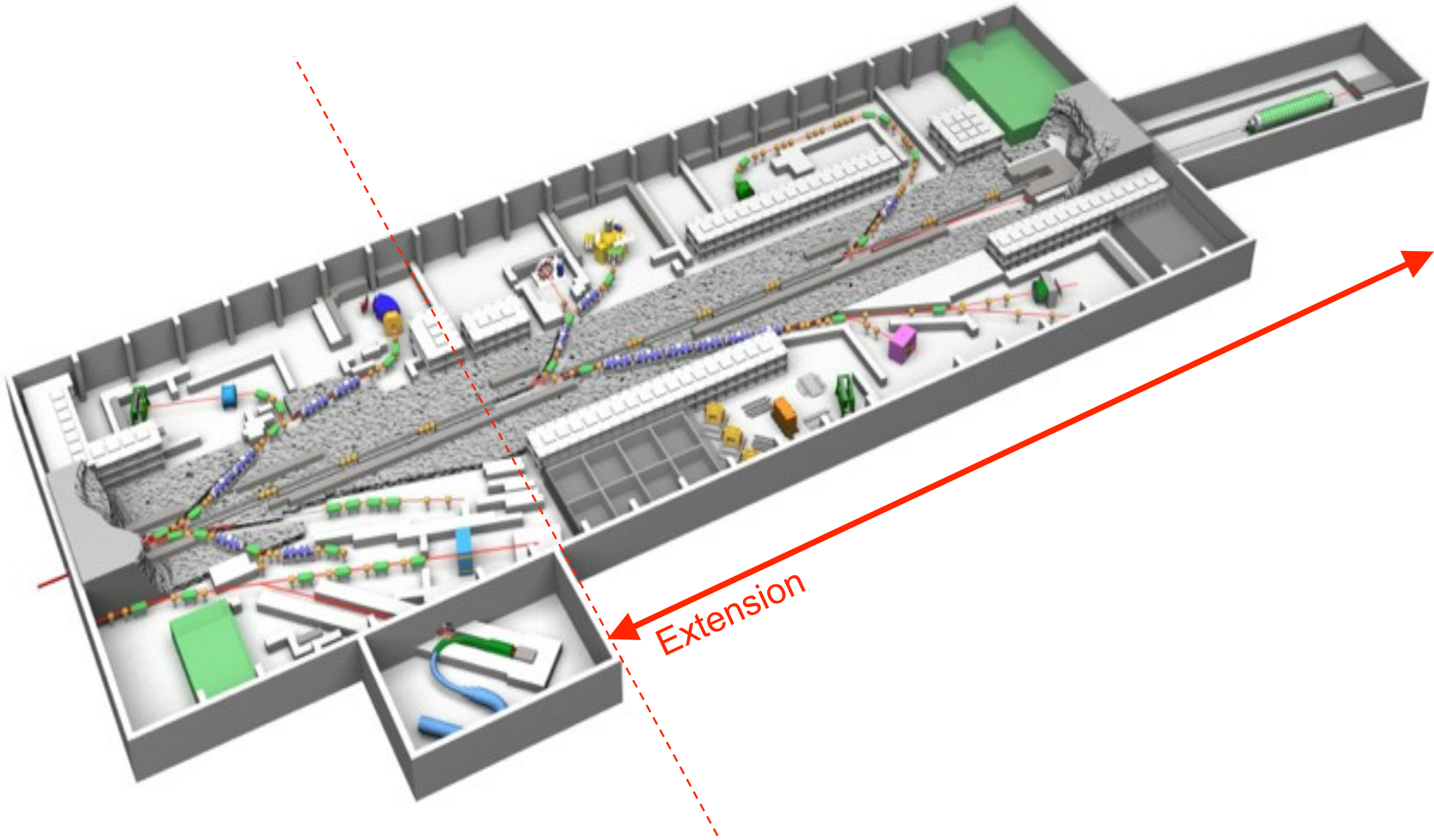








Next Step: Hadron Hall Extension



Next Step: Hadron Hall Extension

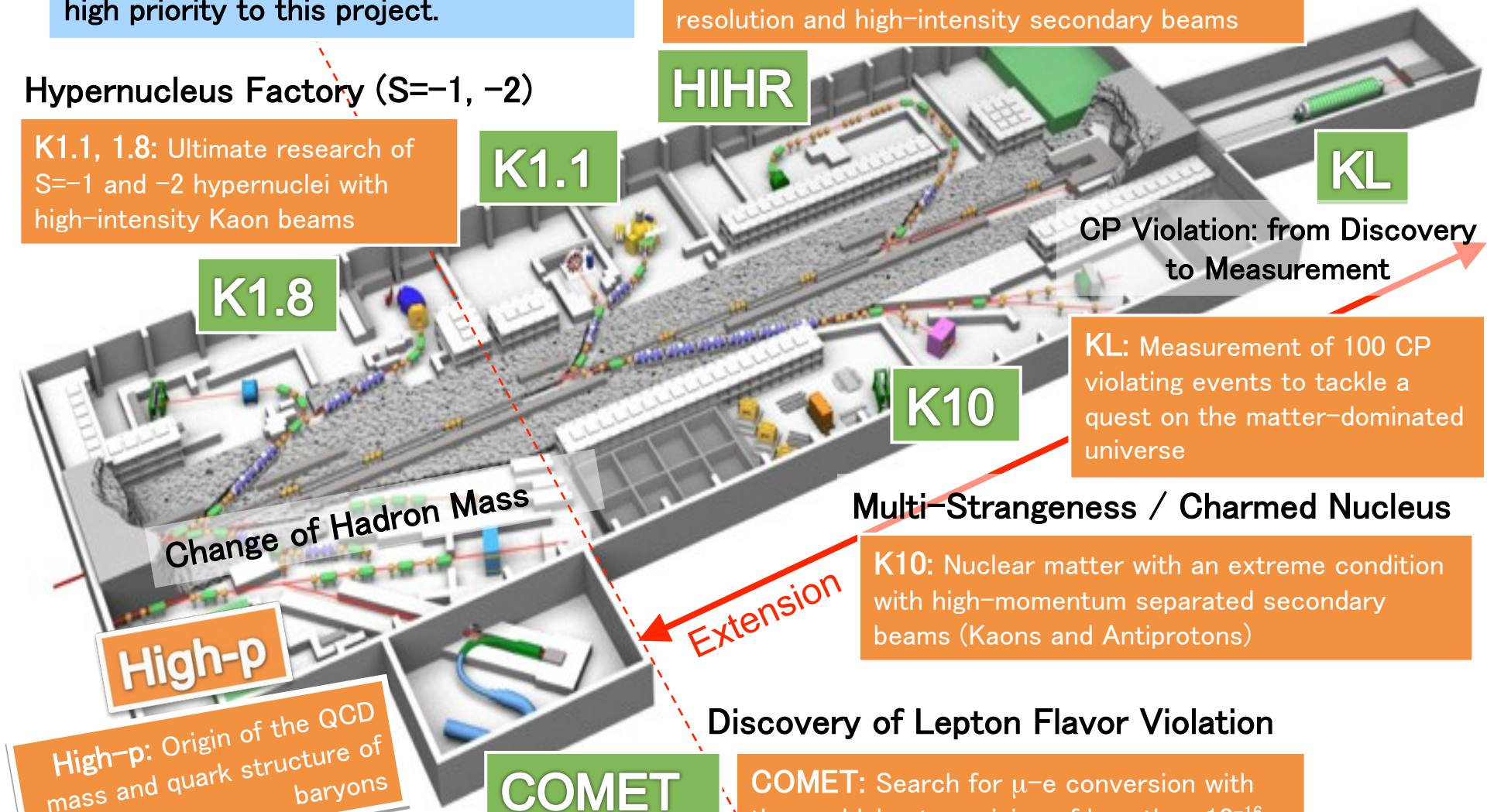
Both Nuclear Physics community and High Energy Physics community gave high priority to this project.

Hypernucleus Microscope

HIHR: Very Precise spectroscopy with high-resolution and high-intensity secondary beams

Hypernucleus Factory (S=−1, −2)

K1.1, 1.8: Ultimate research of S=−1 and −2 hypernuclei with high-intensity Kaon beams



CP Violation: from Discovery to Measurement

KL: Measurement of 100 CP violating events to tackle a quest on the matter-dominated universe

Multi-Strangeness / Charmed Nucleus

Extension

K10: Nuclear matter with an extreme condition with high-momentum separated secondary beams (Kaons and Antiprotons)

High-p: Origin of the QCD mass and quark structure of baryons

Discovery of Lepton Flavor Violation

COMET: Search for μ−e conversion with the world-best precision of less than 10^{-16}

International Workshop on

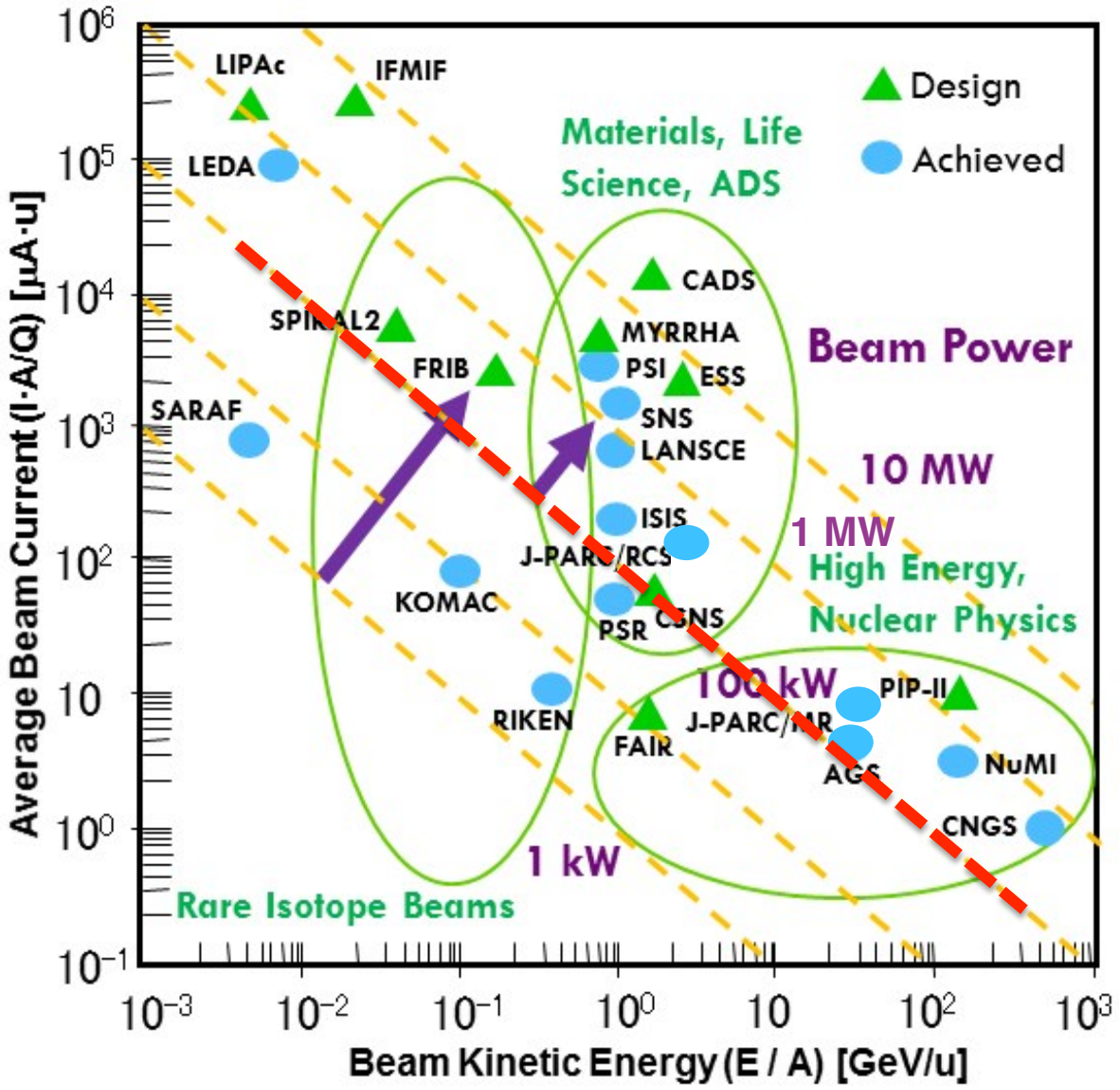
Physics at the Extended Hadron Experimental Facility of J-PARC

March 5-6 2016 Tokai

61 participants including 13 from abroad

Backup

A Quest for High Intensity



High Intensity

High Statistics

- More Precision
- More Rare Searches
- Picture ➡ Movie

Discovery!?

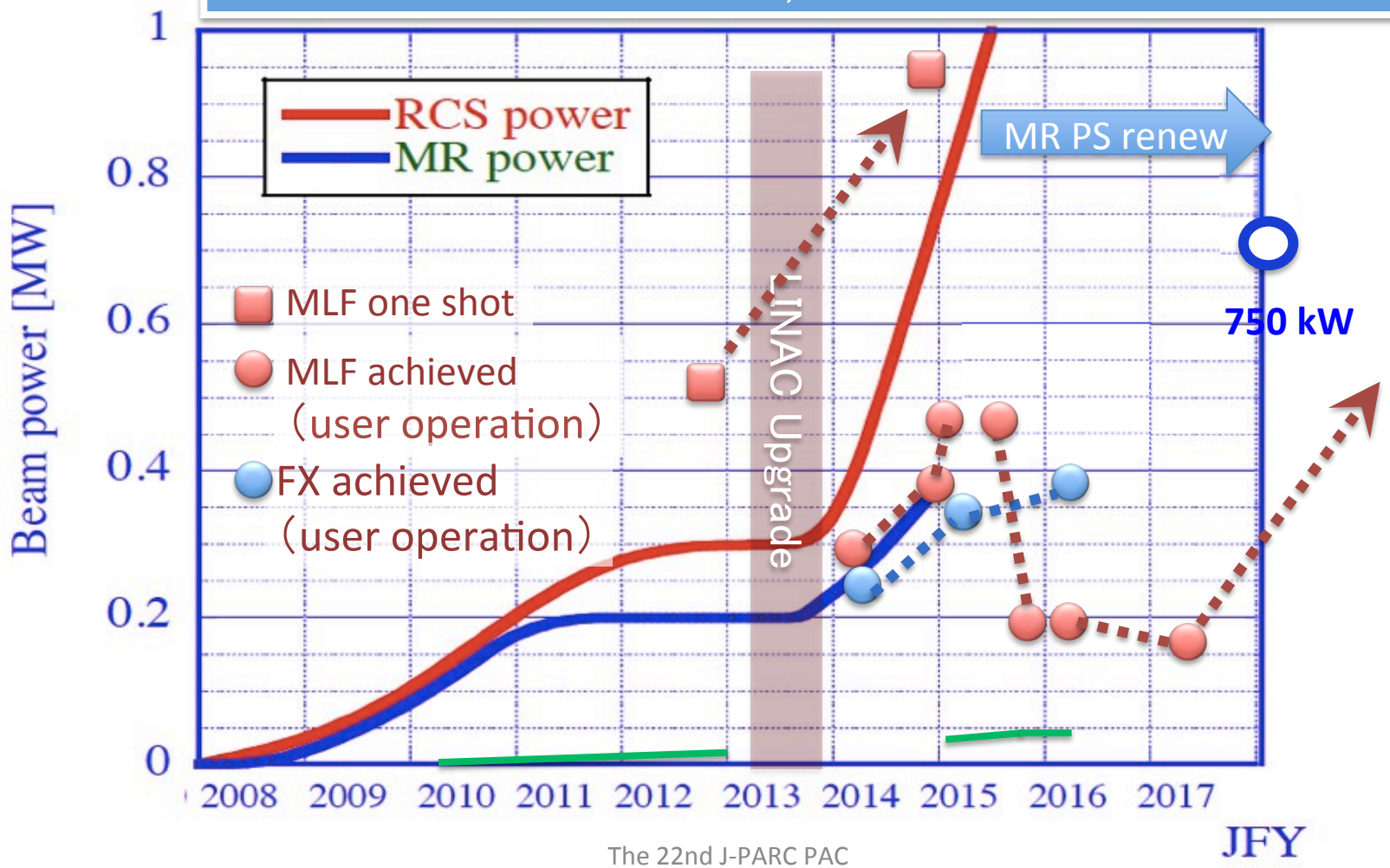
Jie Wei / Y. Yamazaki

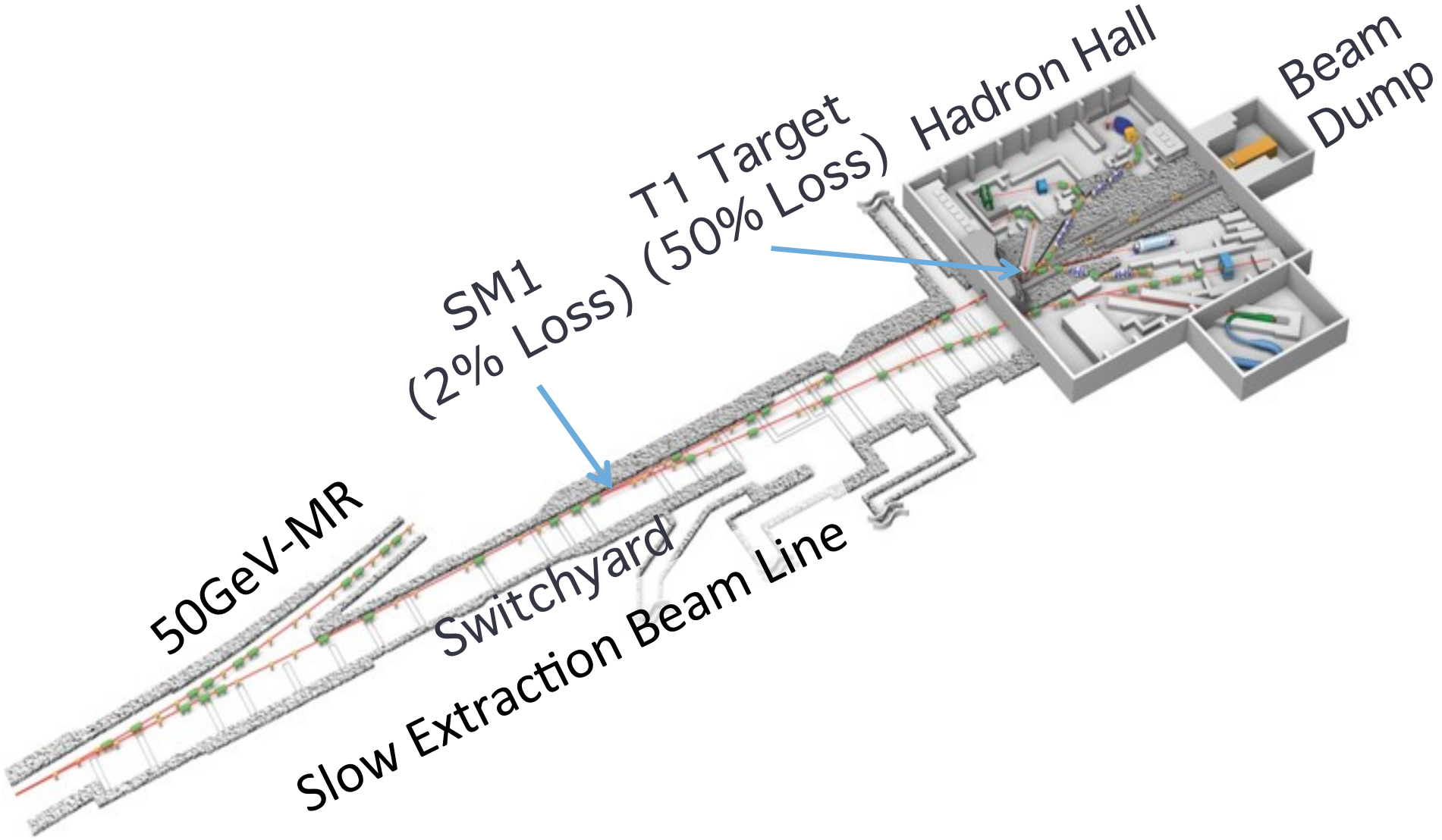
Beam Power : Plan vs Reality

RCS ::1 MW achieved in Jan, 2015

Thanks to new working point!

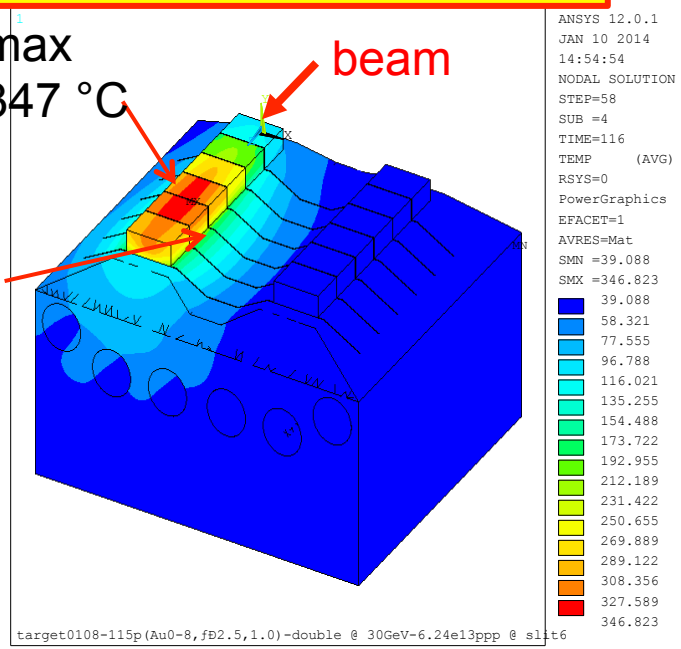
MR::so far 0.38 MW for FX ; 1.3 MW reachable with new PS++

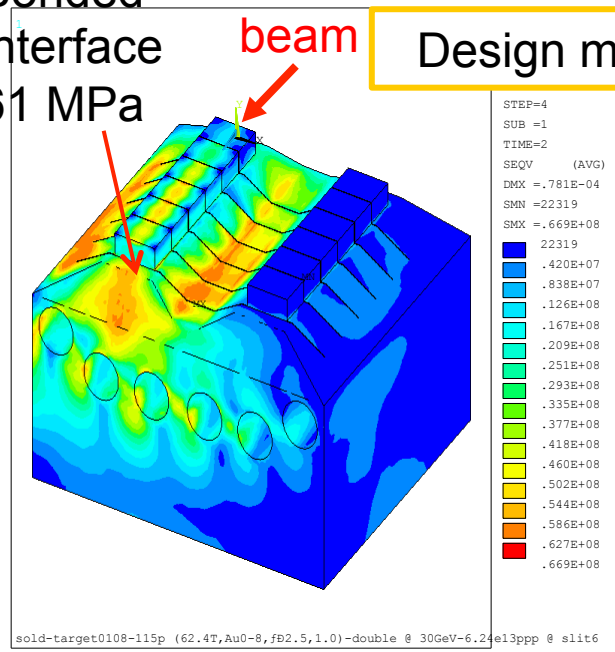



50GeV-MR
Switchyard
Slow Extraction Beam Line
SM1
(2% Loss)
T1 Target
(50% Loss)
Hadron Hall
Beam
Dump

Result of Thermal Analysis of Target (50kW)

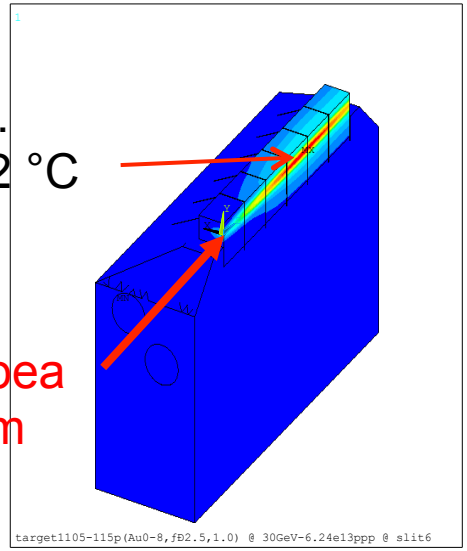
In normal operation (2-sec extraction)





Design margin: 2.1

In accident (5-msec extraction)



*Latent heat and radiation cooling are not included.

Bonding strength:
171MPa(@25°C)
137MPa(@200°C)
76MPa(@400°C)
linear interpolation:
129MPa(@225°C)

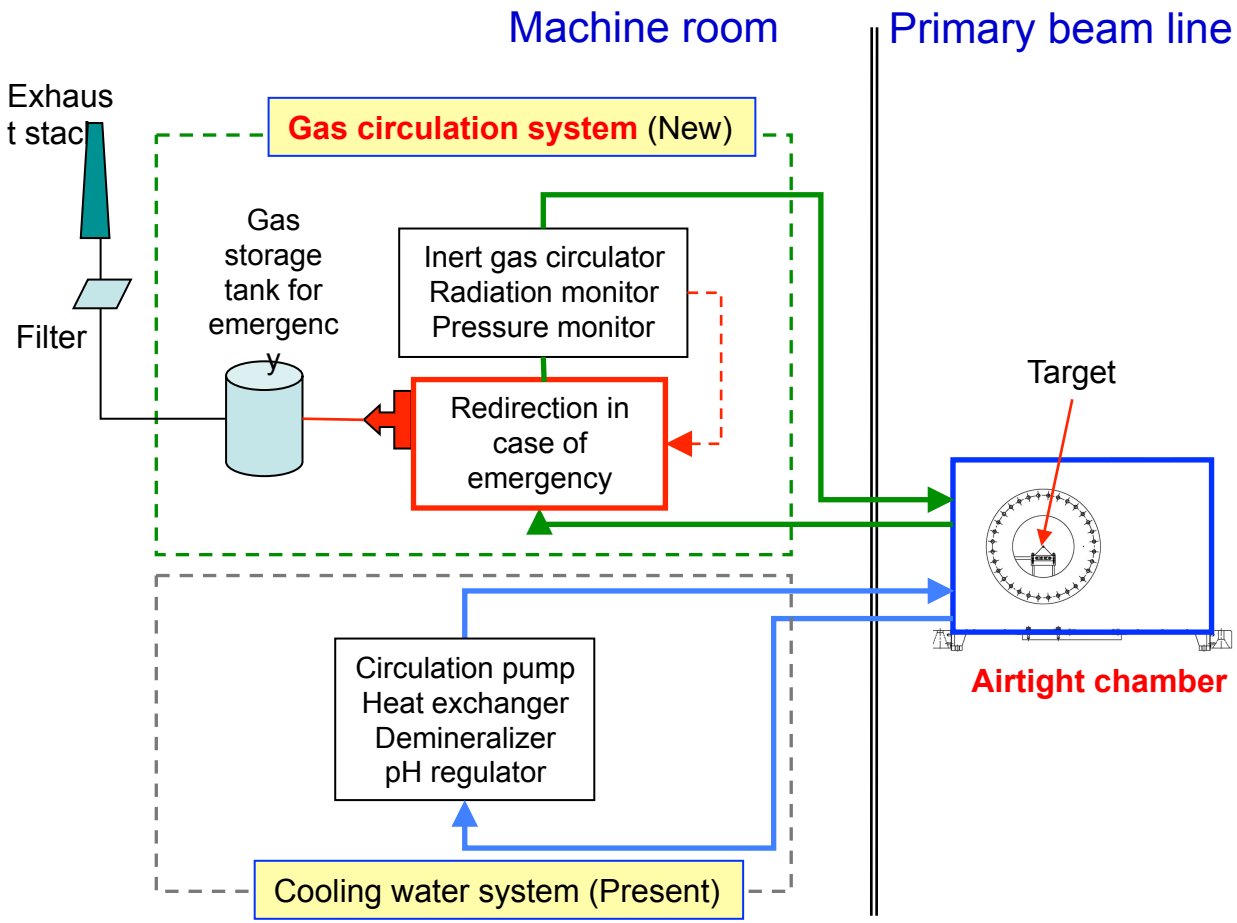
Countermeasures on target against recurrence of the accident

Large mass-number, high density, small beam spot

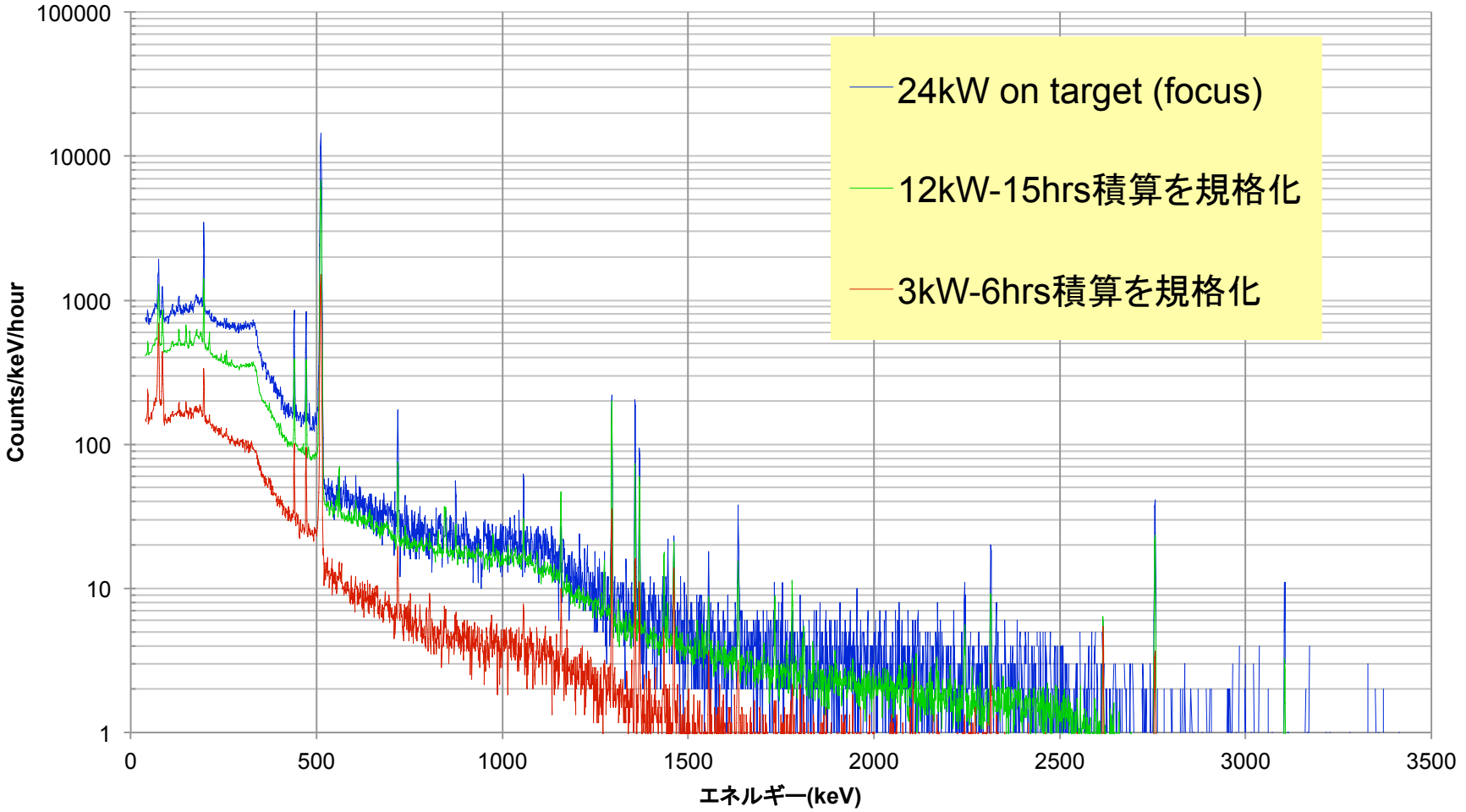
⇨ Difficult to make a target which can withstand against any short-pulse beams

Countermeasures

- Prevention of radioactive materials leak even in case of target failure
  - Airtightness of target chamber
- Quick detection of target failure
  - Improvement of monitoring system



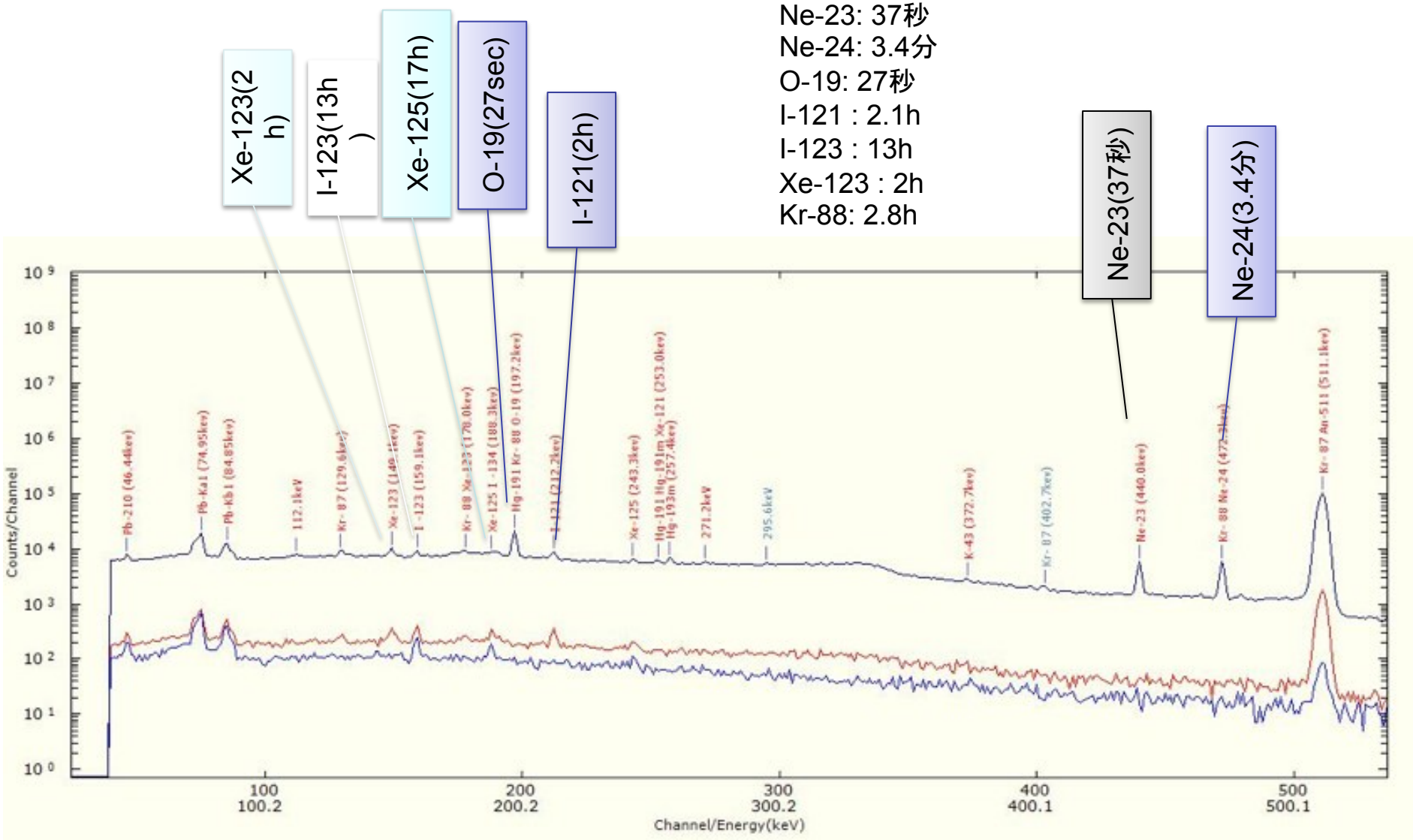
標的HeガスGe 測定器のスペクトル
beam power 24kW vs 12kW vs 3kW



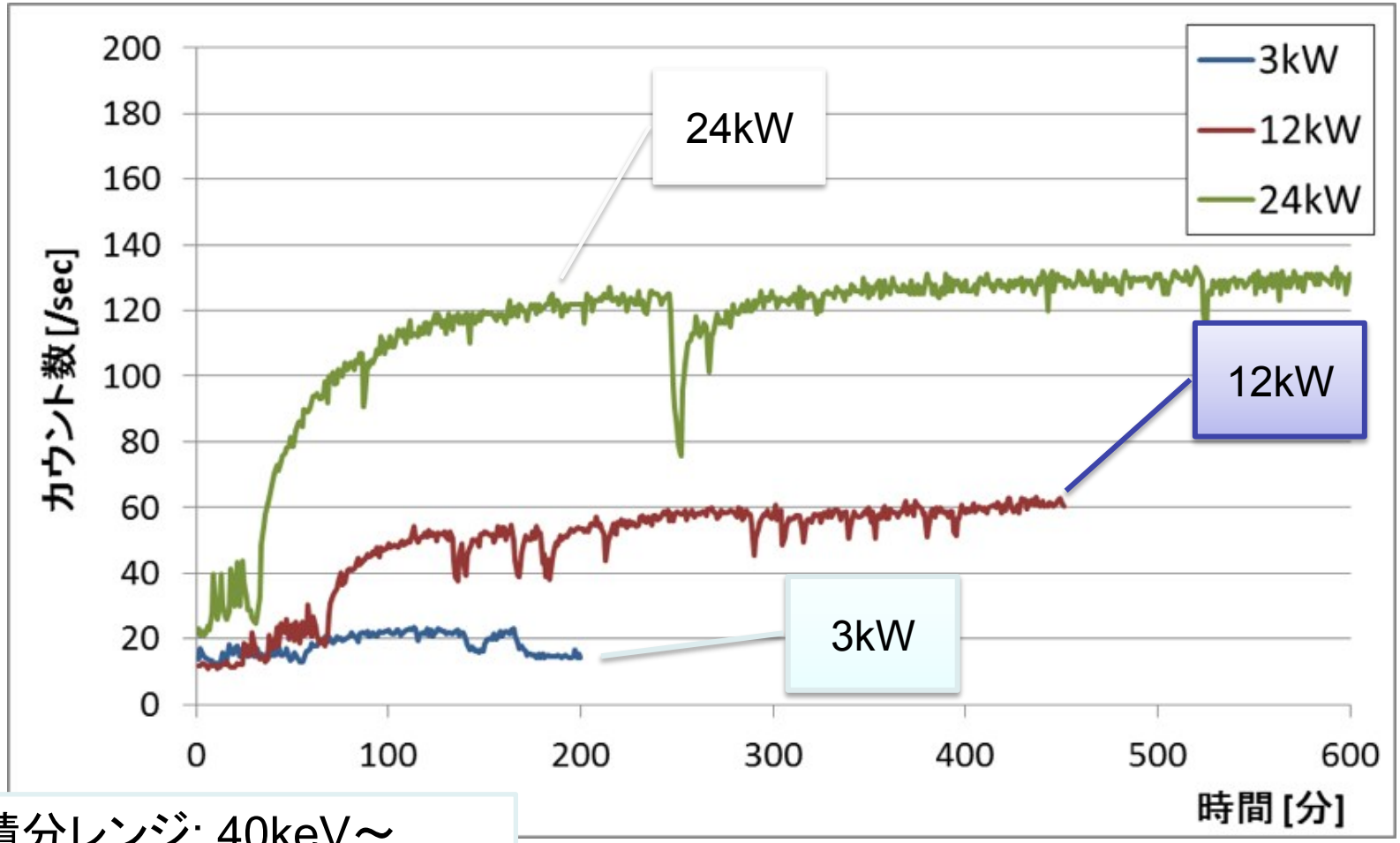
核種の同定を進めている

ー 12kW-15時間積算
ービーム停止7分後から1時間積算
ービーム停止10時間後から1時間積算

Ne-23: 37秒
Ne-24: 3.4分
O-19: 27秒
I-121 : 2.1h
I-123 : 13h
Xe-123 : 2h
Kr-88: 2.8h



標的Heガス Geレート

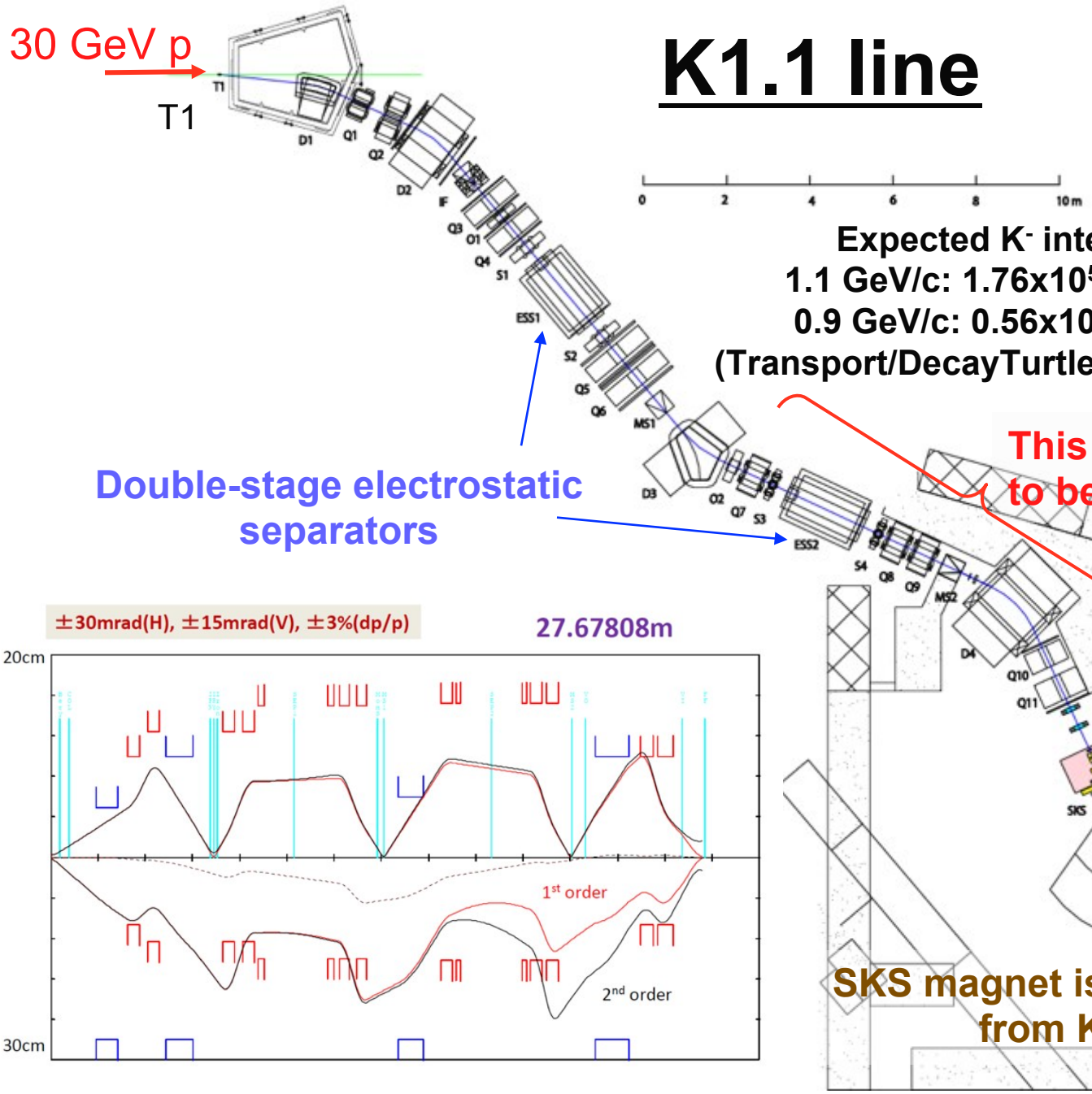


積分レンジ: 40keV～4MeV

変動は加速器の停止によるものであり、安定して動作している

24kWの実測値: 120cps (～430Bq/cc)
警報閾値: 1000cps (～3.6kBq/cc)
事故想定: 57kBq/cc

K1.1 line



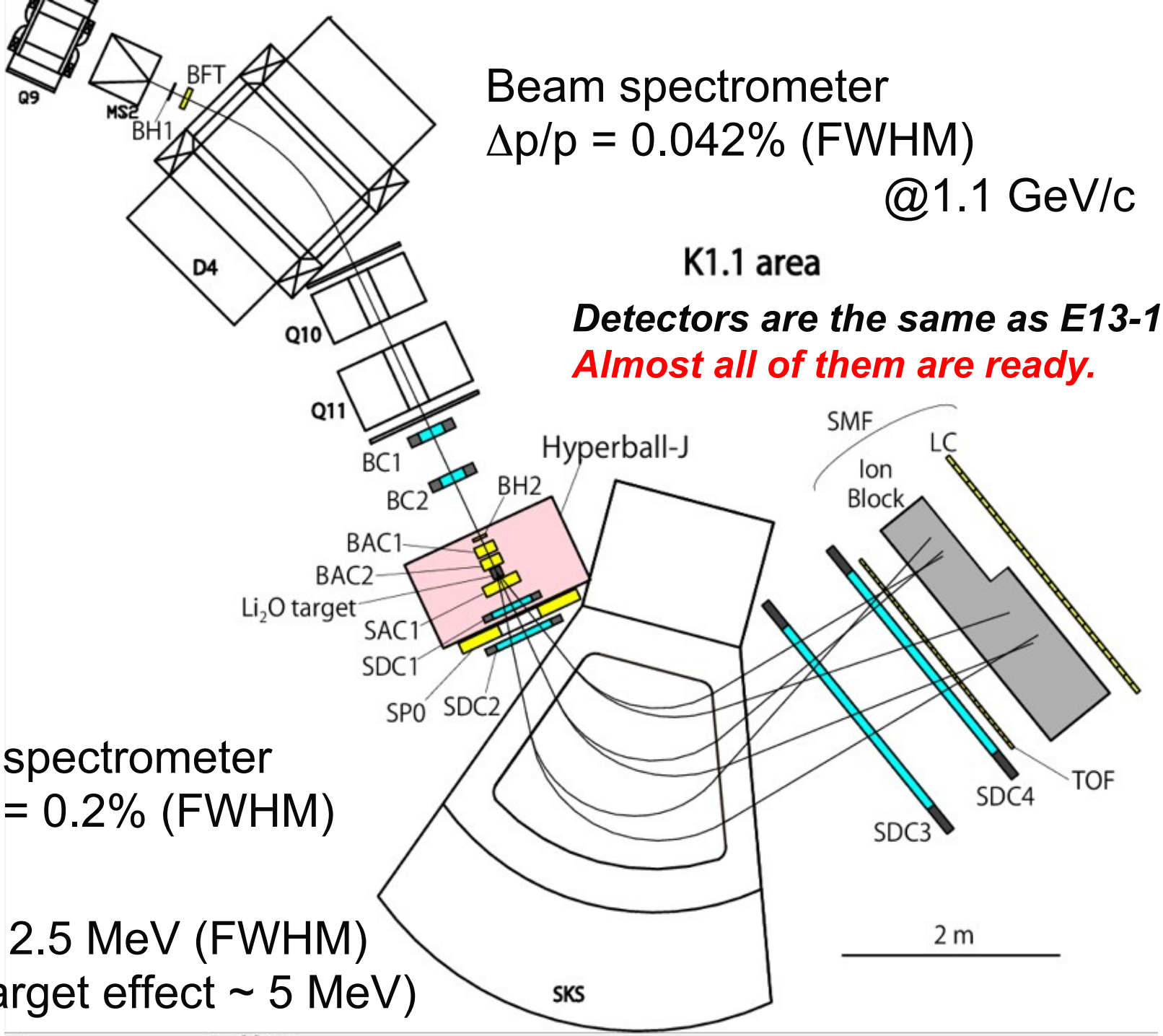
Expected K^- intensity @ 50 kW
1.1 GeV/c: 1.76×10^5 /spill (K^-/all=0.58)
0.9 GeV/c: 0.56×10^5 /spill .
(Transport/DecayTurtle: not final parameters)

Double-stage electrostatic separators

This part needs to be constructed.

SKS magnet is now being moved from K1.8 to K1.1

Beam spectrometer
$\Delta p/p$ = 0.042% (FWHM)
@1.1 GeV/c



Detectors are the same as E13-1
Almost all of them are ready.

SKS spectrometer
$\Delta p/p$ = 0.2% (FWHM)

Δm < 2.5 MeV (FWHM)
(<< target effect ~ 5 MeV)

Two YOKOZUNAs in South

Restart of Hadron Facility

User Run, 2015 April 24.

COMET Construction Status

SC magnets production

Hall construction


40t
KAMEI