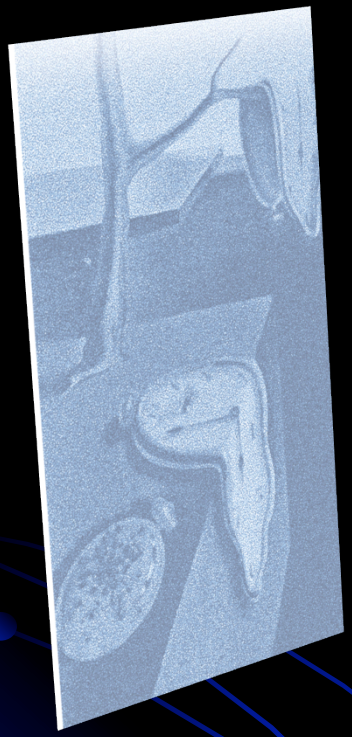
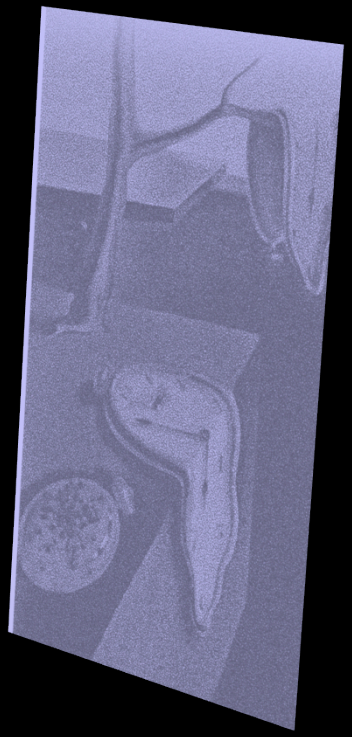
THE MTV EXPERIMENT
FROM T-VIOLATION TO LORENTZ-VIOLATION





Jiro Murata

Rikkyo University

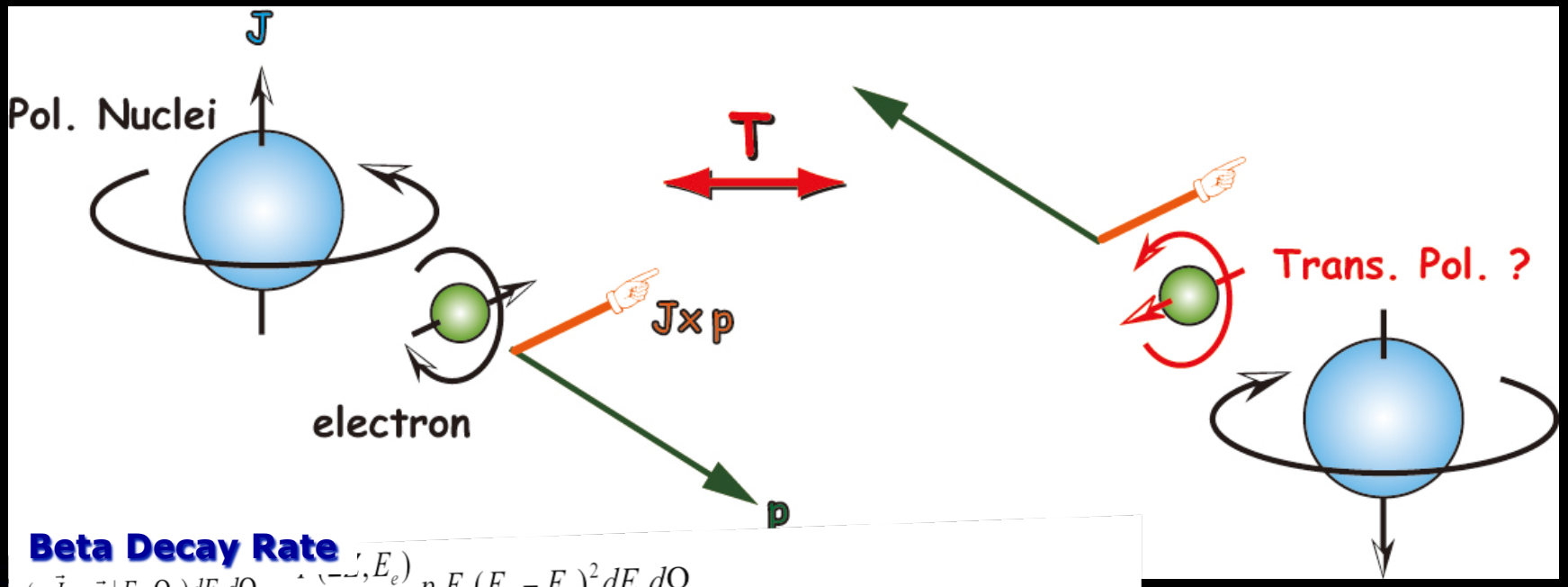
for the MTV collaboration

INPC2016, Sydney, Sep 11-16, 2016

International Nuclear Physics Conference
Adelaide Convention Centre, Australia
11-16 September 2016

Rikkyo J. Murata, Y. Nakaya, Y. Totsuka, S. Tanaka, R. Tanuma, T. Iguri
E. Seitaibashi, J. Onishi, T. Toyoda, M. Ikeda,
R. Kishi, K. Ninomiya, S. Saiba, Y. Sakamoto, Y. Shimizu
Tohoku-CYRIC H. Kawamura / RIKEN H. Baba
Nagoya M. Yokohashi, F. Goto, M. Kitaguchi, H. Shimizu
TRIUMF J. Behr, M. Pearson, P. Levy, R. Openshaw

Measurement = *R*-Correlation
Searching P-odd & T-odd New Interaction

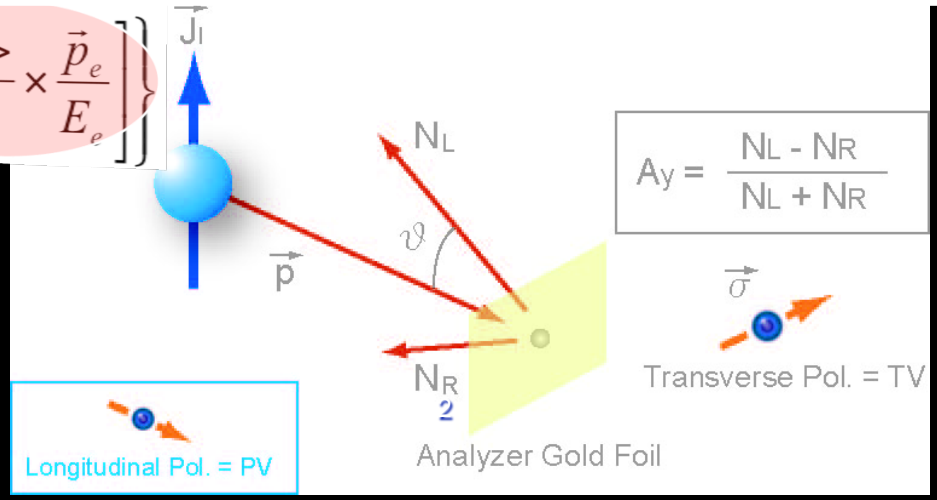


Beta Decay Rate

$$\omega(<\vec{J}>,\vec{\sigma}\,|\,E_e,\Omega_e)dE_e d\Omega_e = \frac{F(\pm Z,E_e)}{(2\pi)^4} p_e E_e (E_0 - E_e)^2 dE_e d\Omega_e$$

$$\times\xi\left\{1 + b\frac{m}{E_e} + \frac{\vec{p}_e}{E_e}\cdot\left(A\frac{<\vec{J}>}{J} + G\vec{\sigma}\right) + \vec{\sigma}\cdot\left[N\frac{<\vec{J}>}{J} + Q\frac{\vec{p}_e}{E_e+m}\left(\frac{<\vec{J}>}{J}\frac{\vec{p}_e}{E_e}\right) + R\frac{<\vec{J}>}{J}\times\frac{\vec{p}_e}{E_e}\right]\right\}$$

Utilizing Analyzing Power of Mott Scattering



Required Components

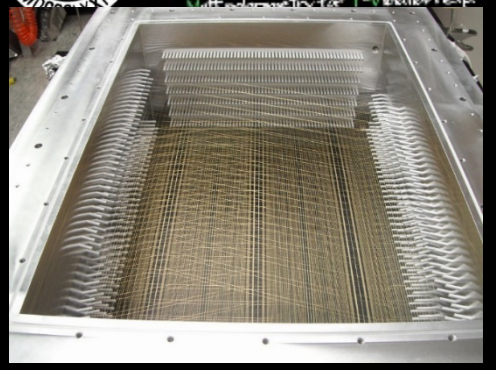
Production	Pol. Nuclei
Measurement	Electron Momentum
Measurement	Electron Trans. Pol.

MTV Run-II Precision

2010 MTV experiment using MWDC at TRIUMF-ISAC

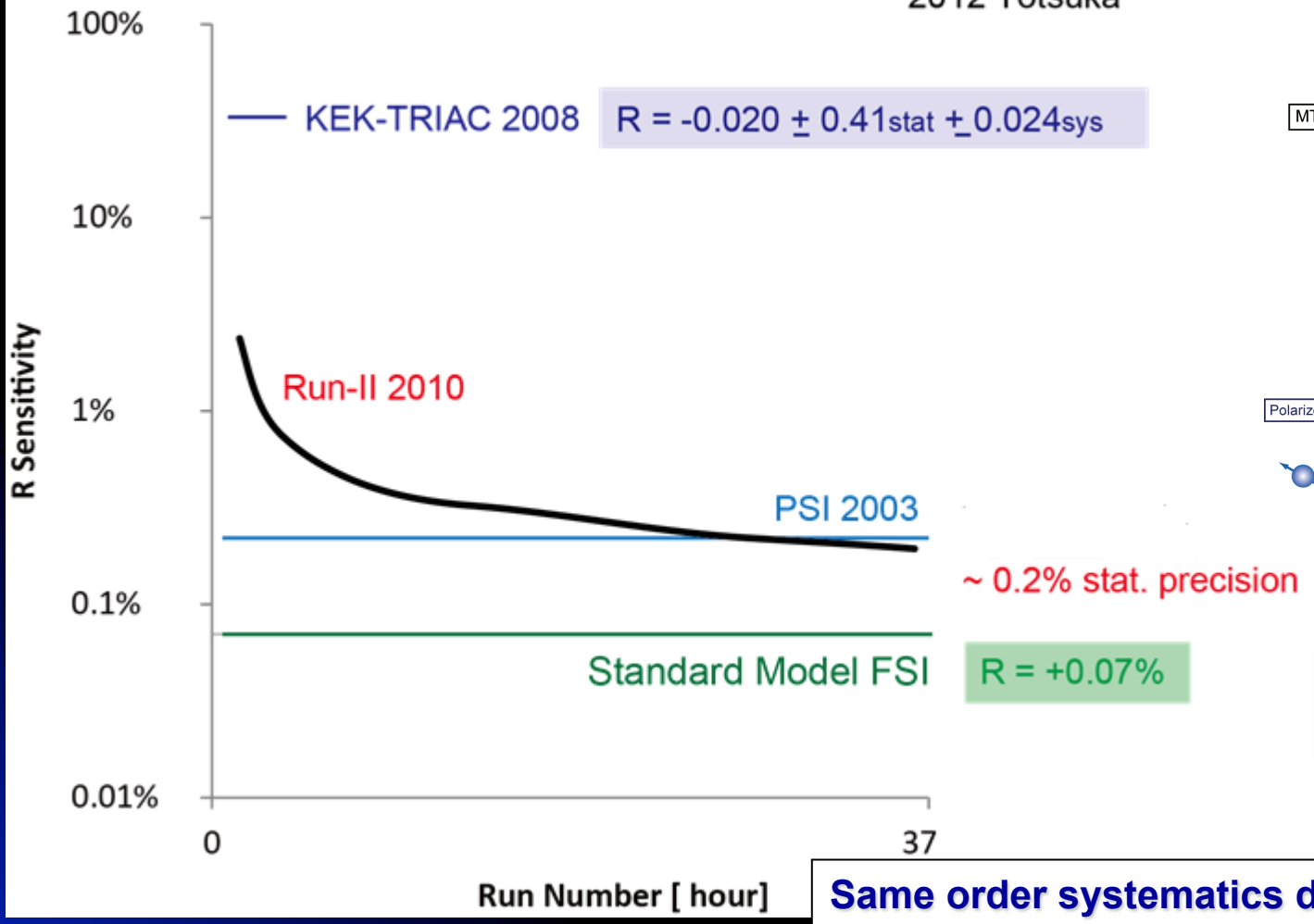
1 x10^{7}pps @80% (250M V-tracks)

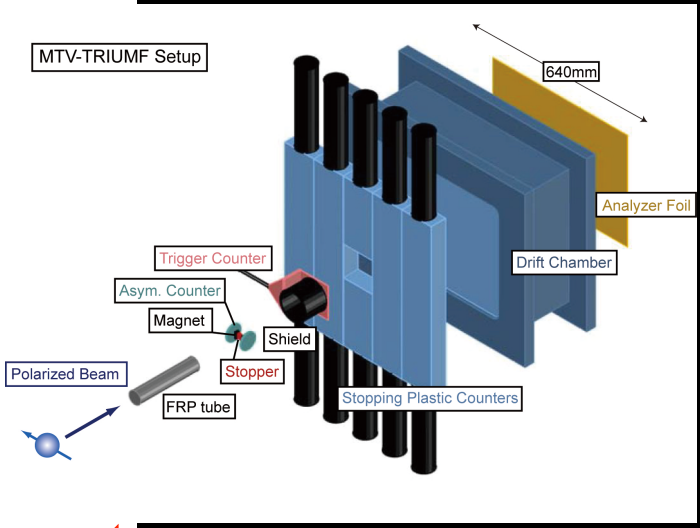
$$A_R = \left(7.5 \pm 1.2_{\text{stat.}} \pm 6.5_{\text{sys}}\right) \times 10^{-4}$$



MTV Run-II Acheived Sensitivity

2012 Totsuka

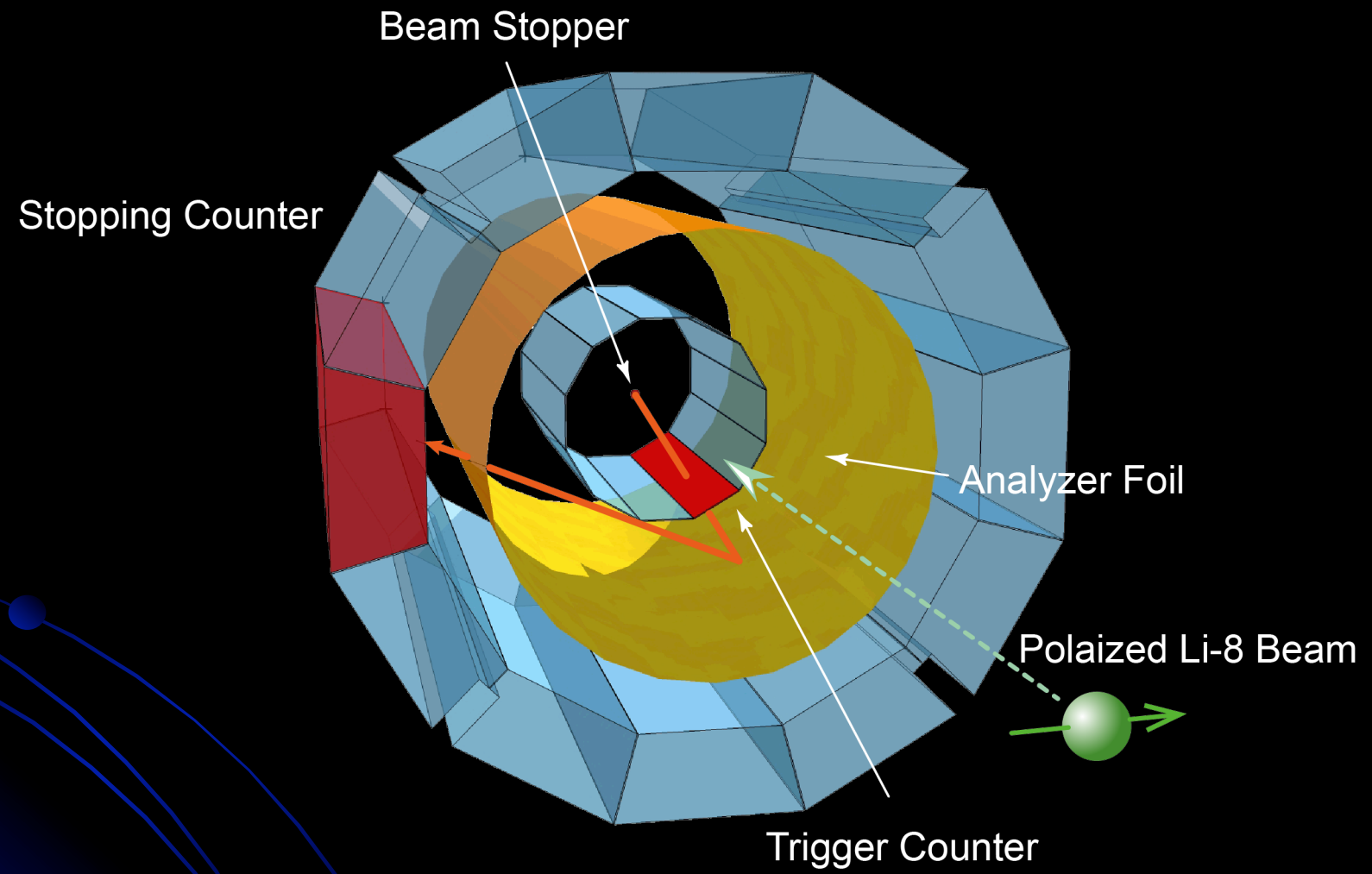




Reaching the highest level stat. precision !

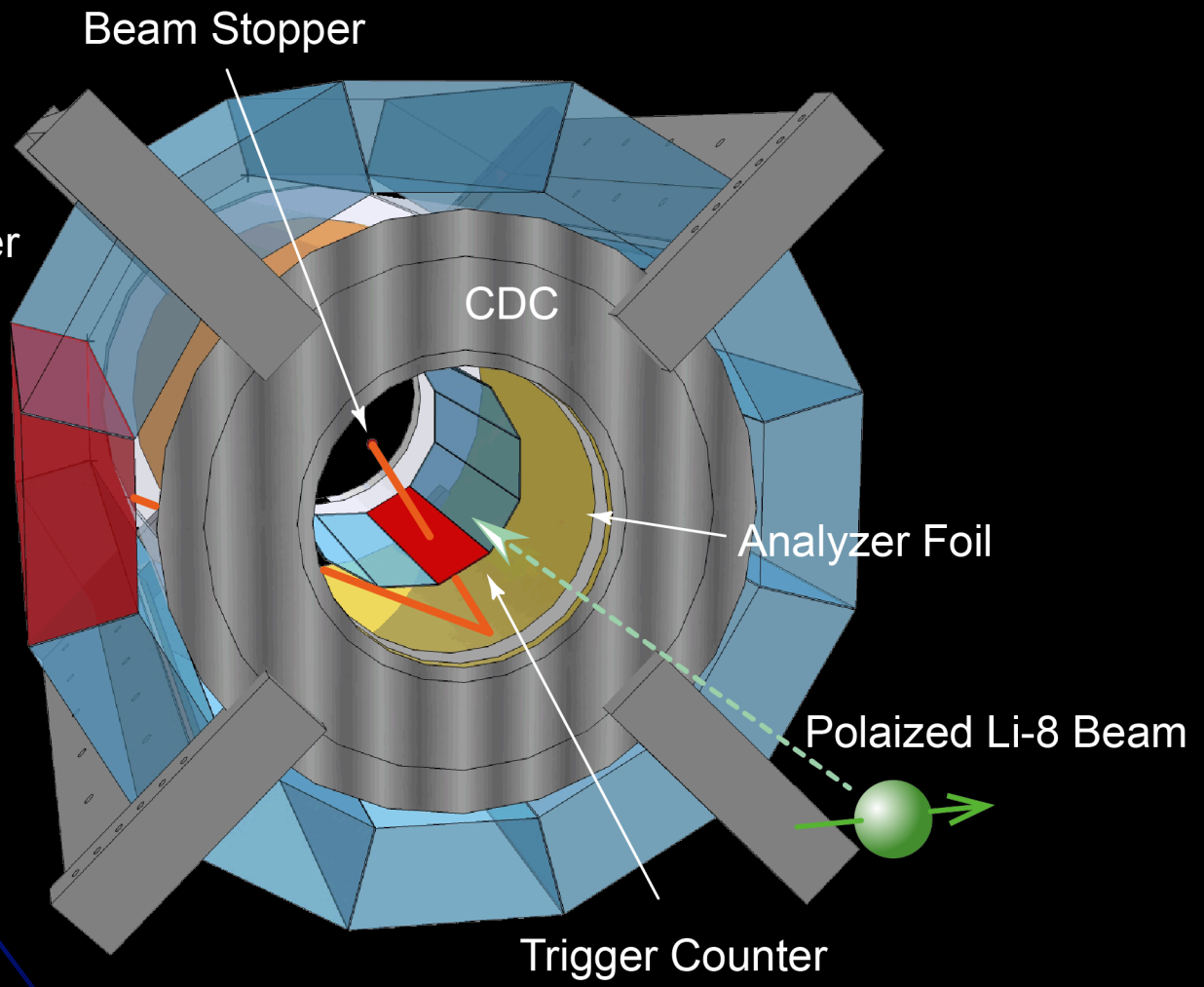
Same order systematics due to detector asymmetry etc.

Next generation detector : CDC



To Remove Systematics : N-correlation, Asymmetric Acceptance (Fake Tracking)

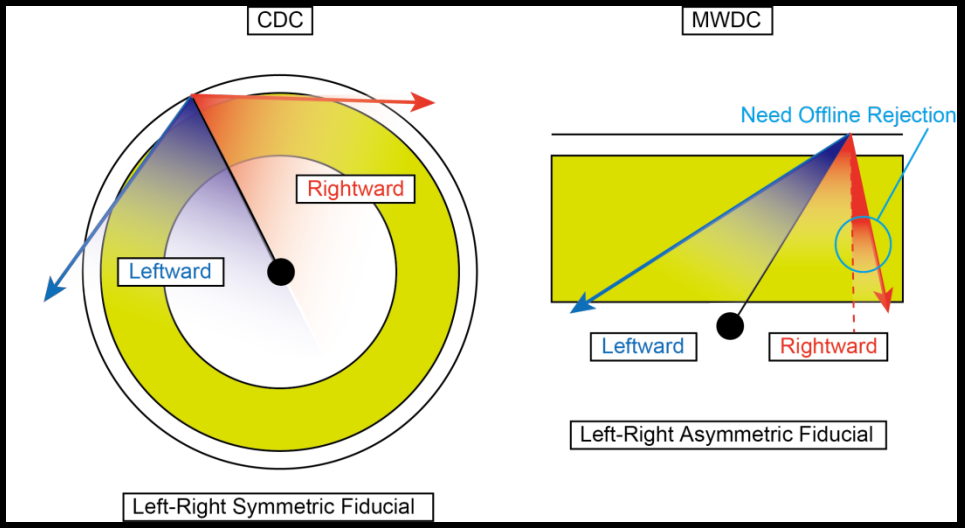
Next generation detector : CDC



To Remove Systematics : N-correlation, Asymmetric Acceptance (Fake Tracking)

Geometrical Systematics Reduction

Asymmetric Acceptance

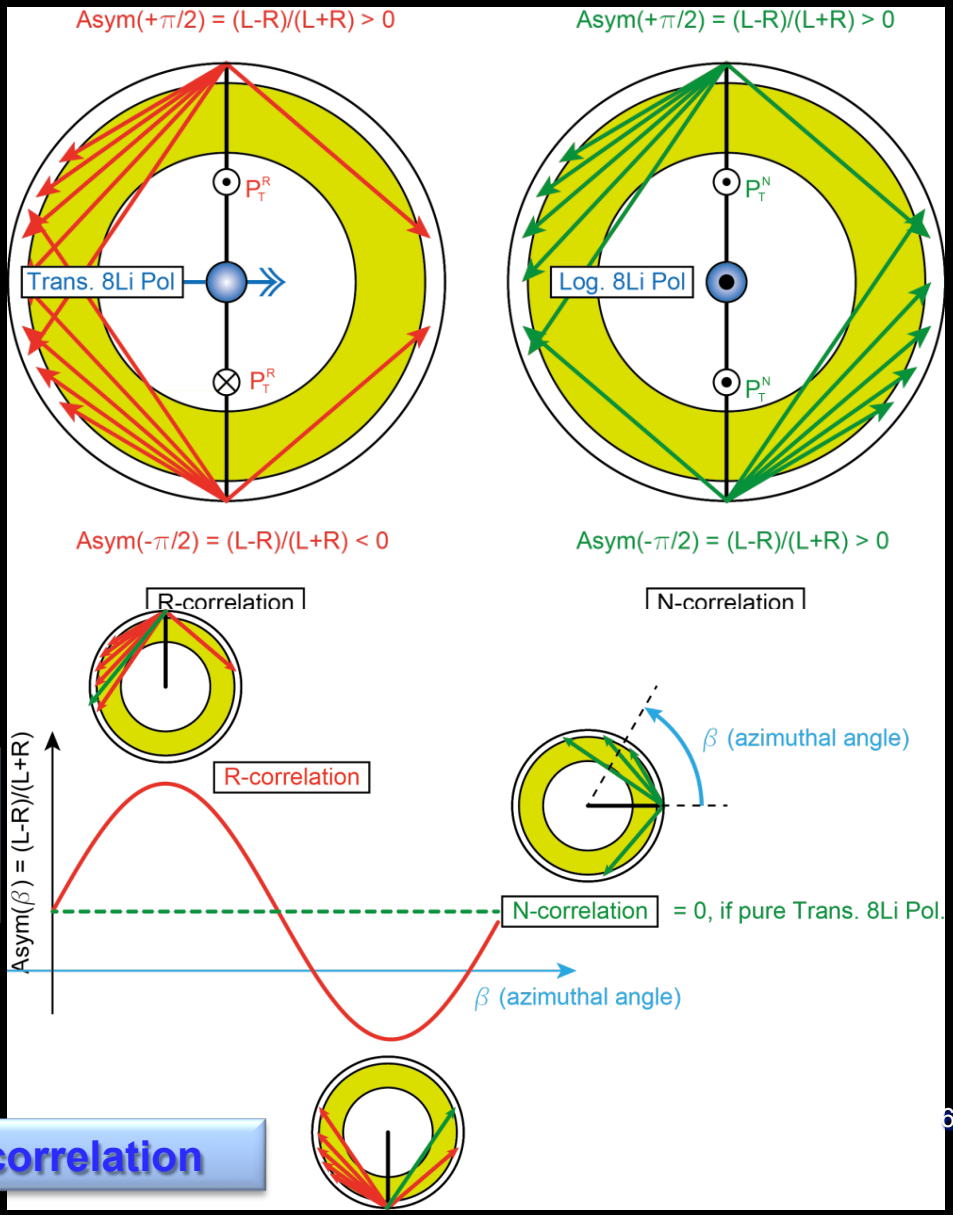


~~Asymmetric Geometry~~
+ Parity Violation
= no fake signal

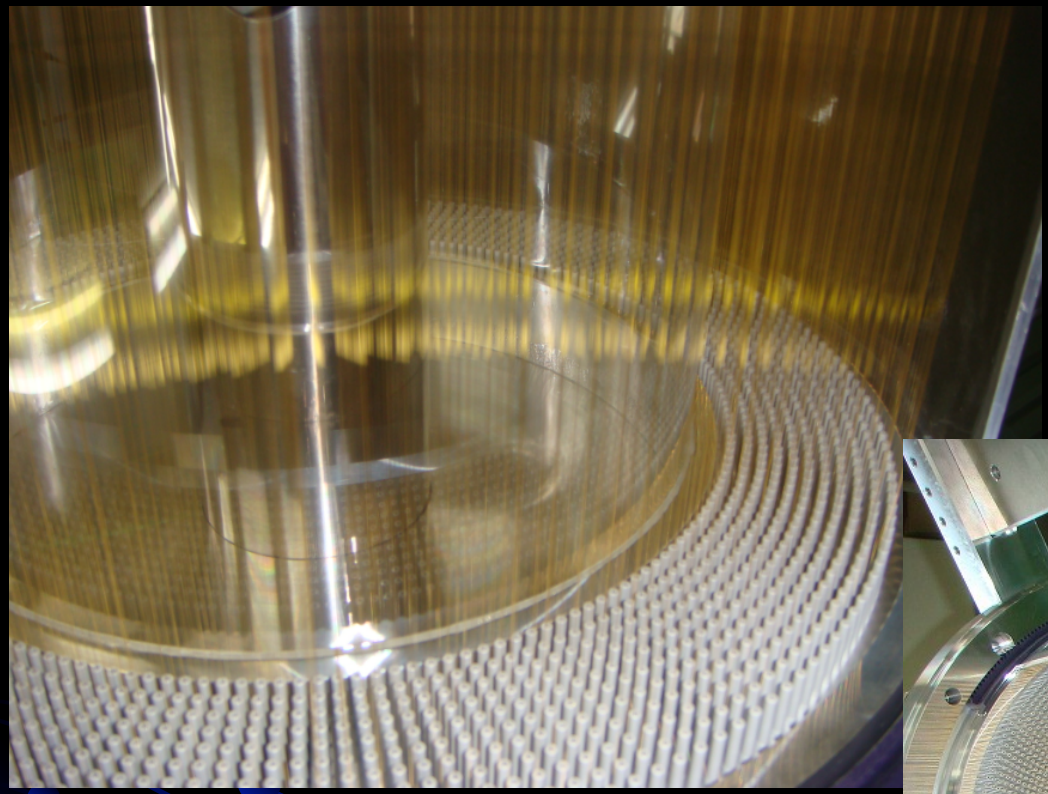
Asymmetric Geometry
+ Parity Violation
= non-zero signal

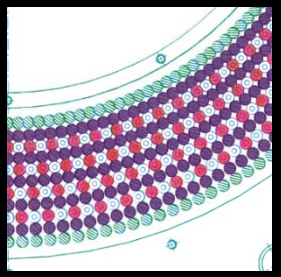
Different Pattern for R/N correlation

N-correlation

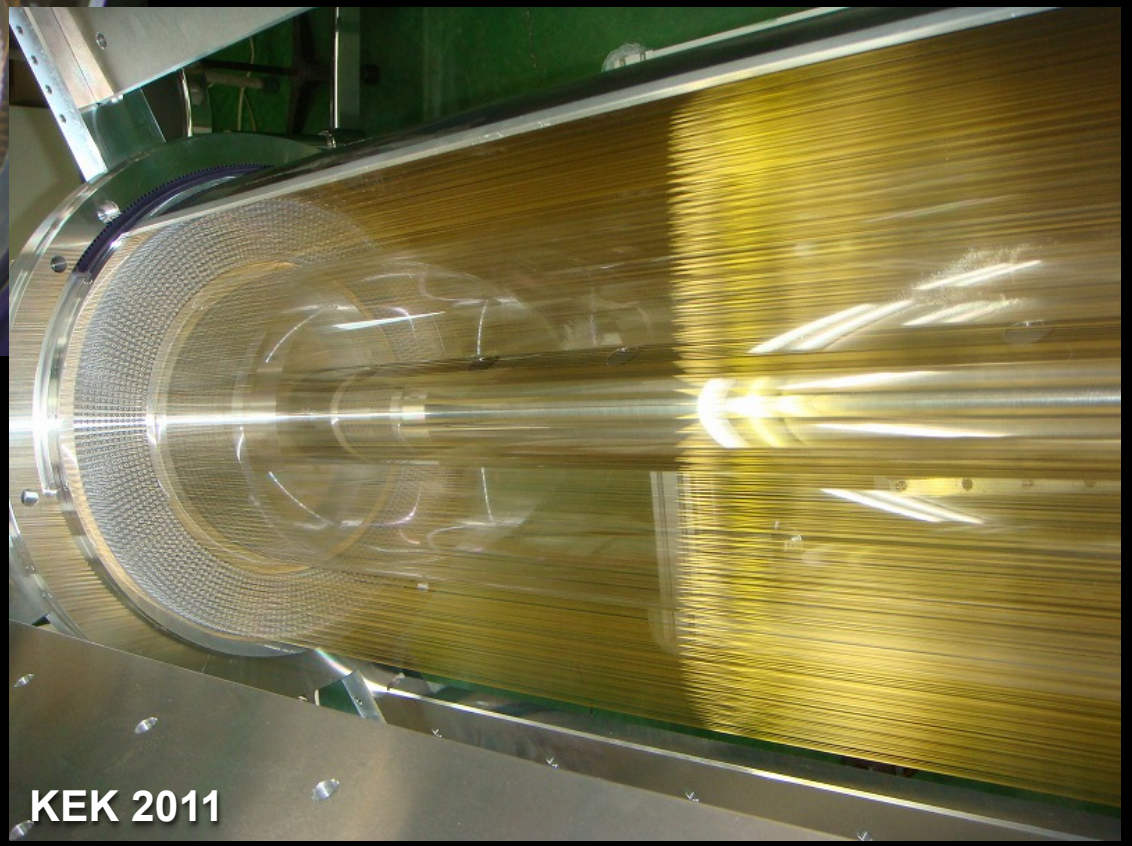


MTV-CDC





- **Anode** (20μm Au-W) ×400
  >> signal readout
- **Cathode** (100μm Au-Al) ×1000
  >> applied voltage
- **Shield** (100μm Au-Al) ×400
  >> shut down noise
- **Field** (100μm Au-Al) ×400
  >> applied voltage

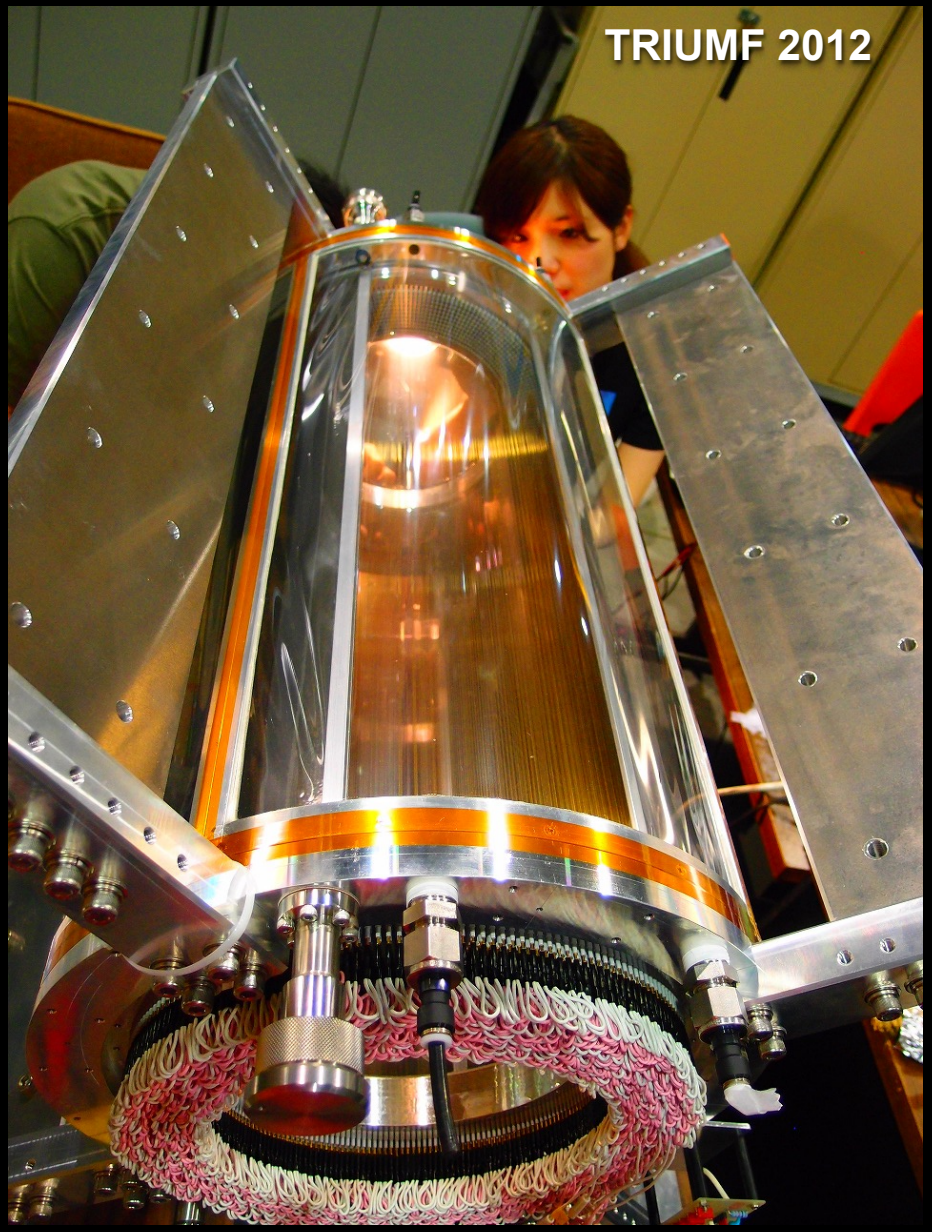


Designed in 2009 – 2010,
Fabricated in 2011

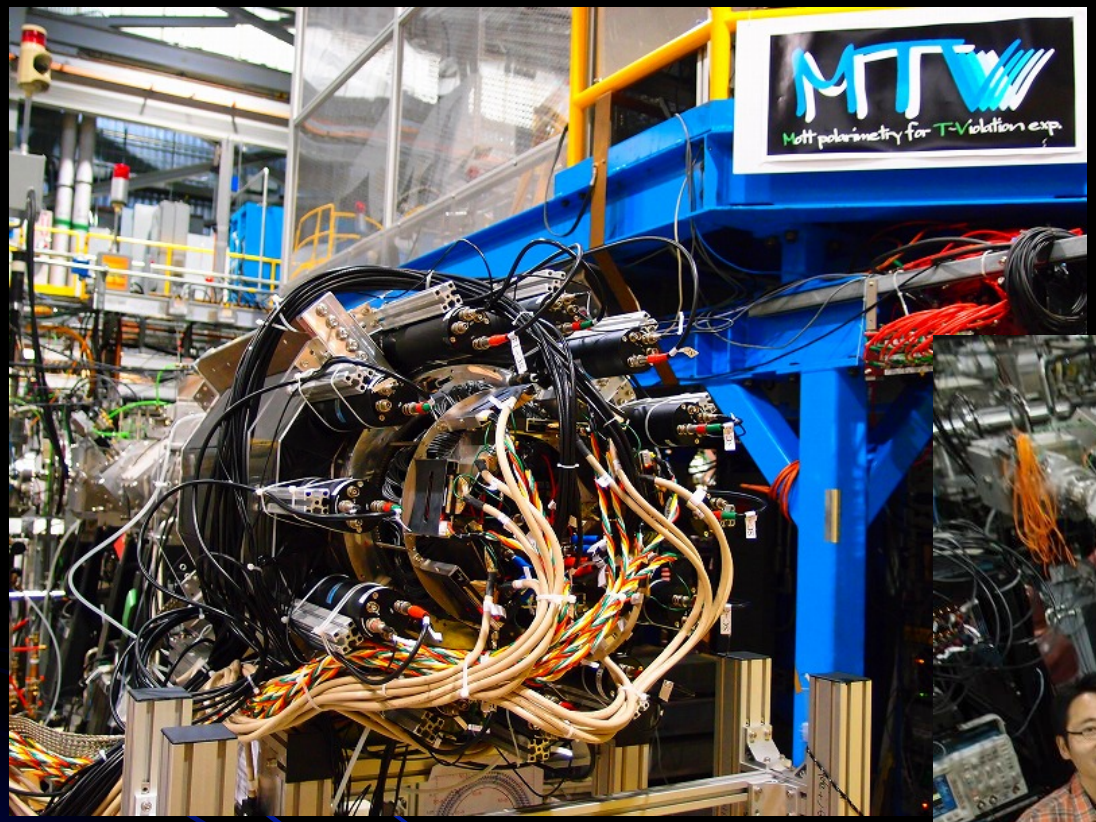
Cell size **4mm x 400 anode**
10 mm x 104 anode (MWDC)

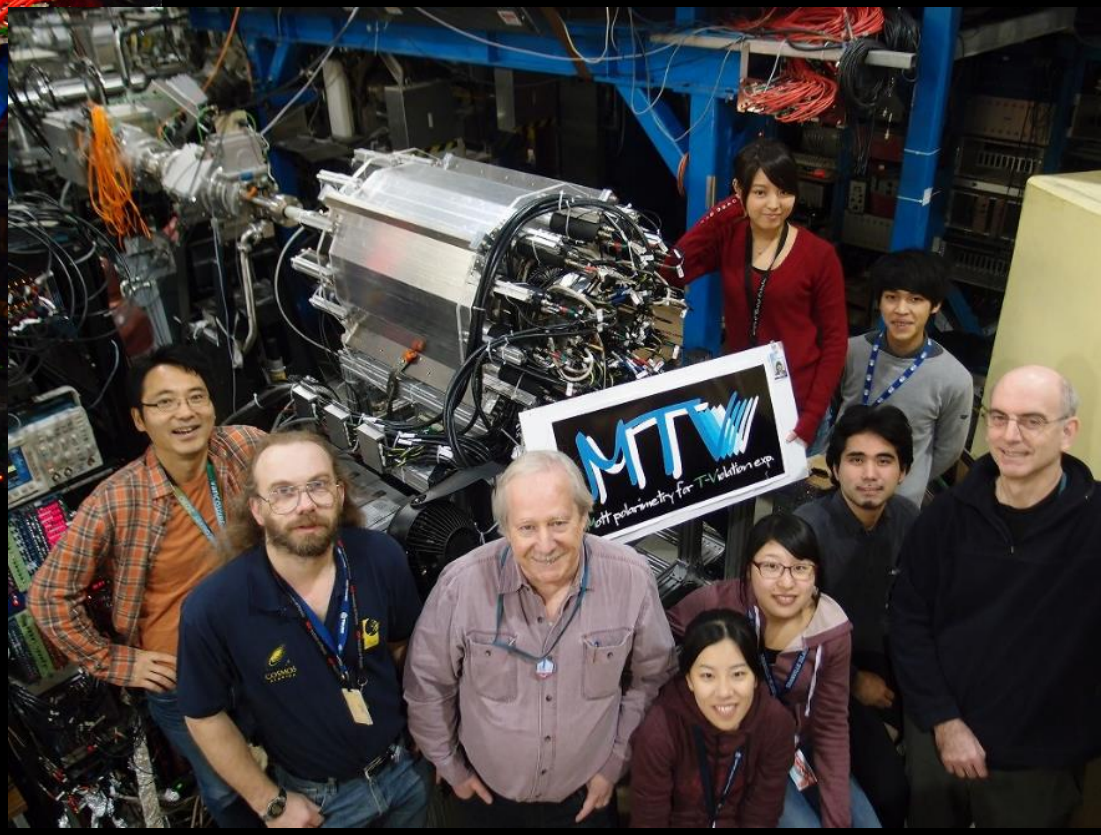
High rate capability,
Large and symmetric acceptance

MTV-CDC



MTV-CDC commissioning





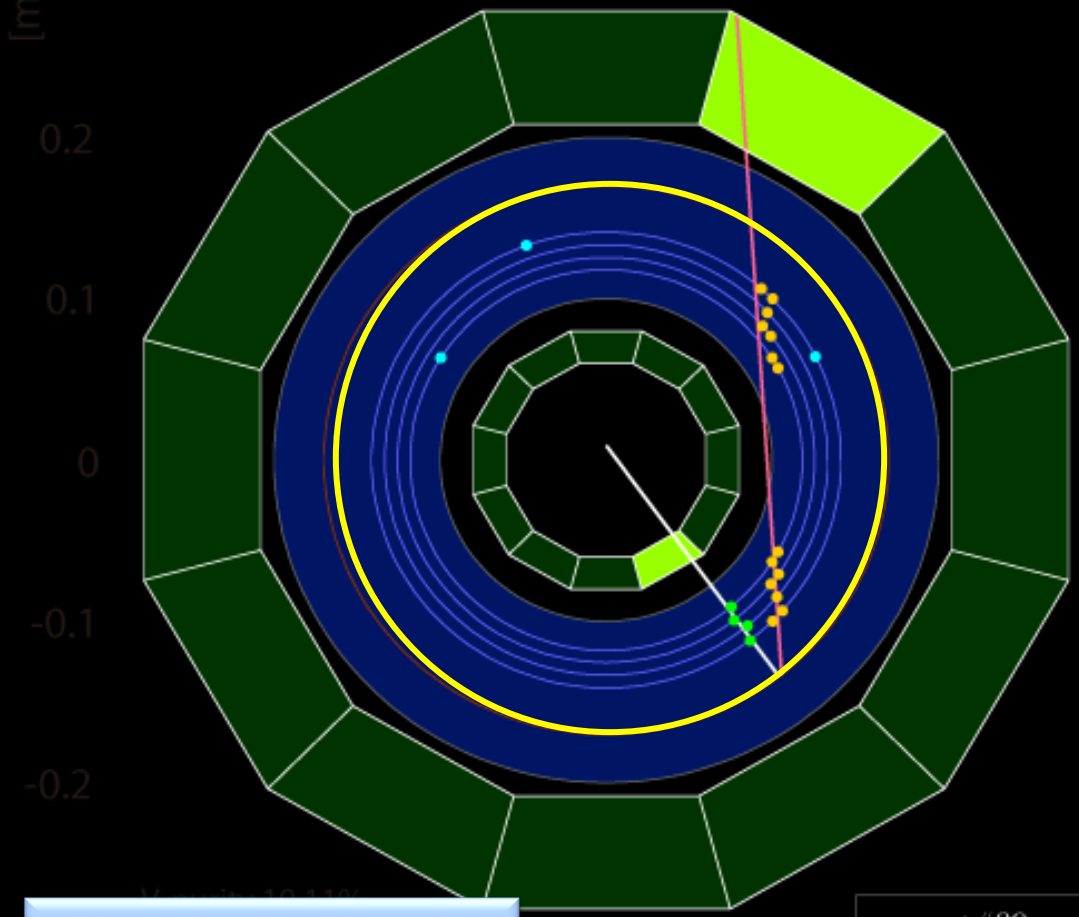
2011 : CDC installation
2012 : Full setup commissioning
2013 - 14 : Systematics test
2015 : Final test (with systematic control)

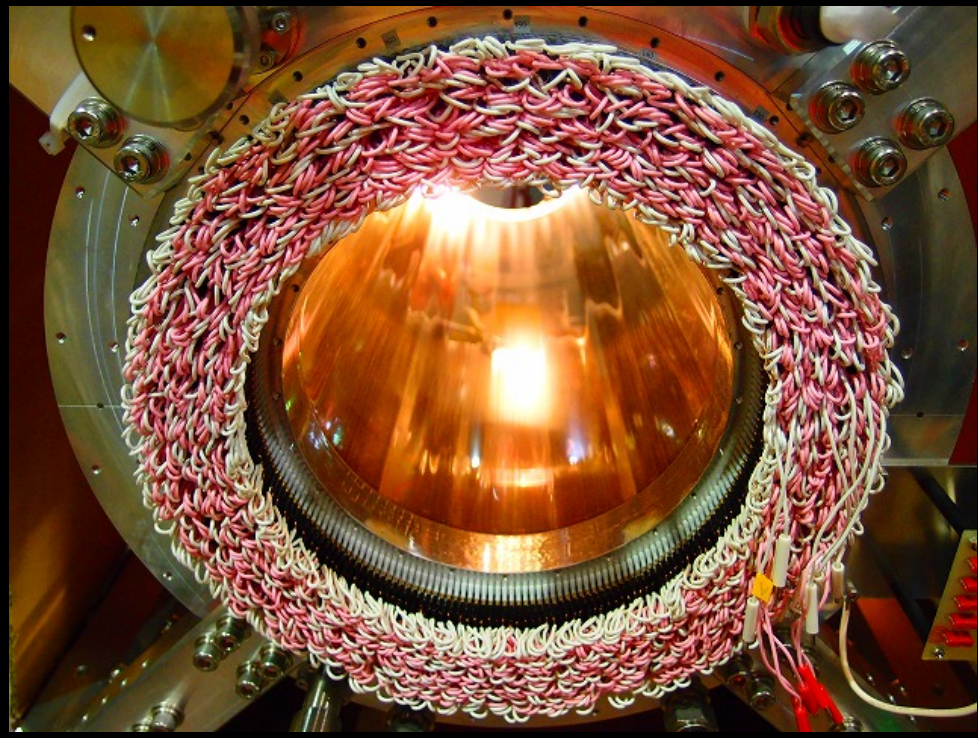
Tanaka, NIM A752 (2014) 47-53

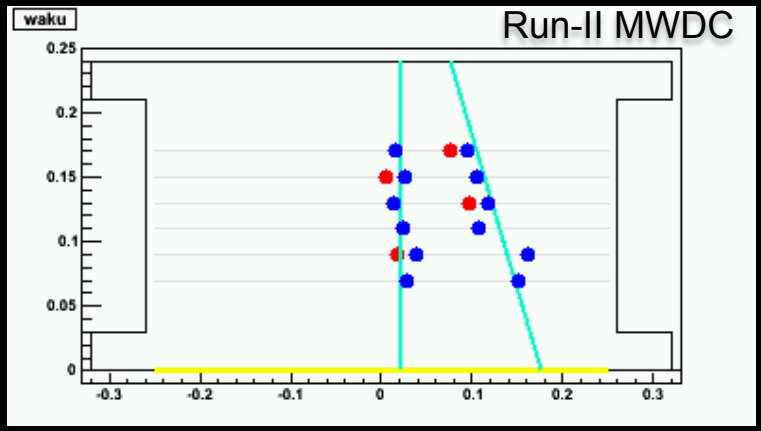
CDC-Tracking

MTV
Mott polarimetry for T-Violation exp.

Run-IV 2012



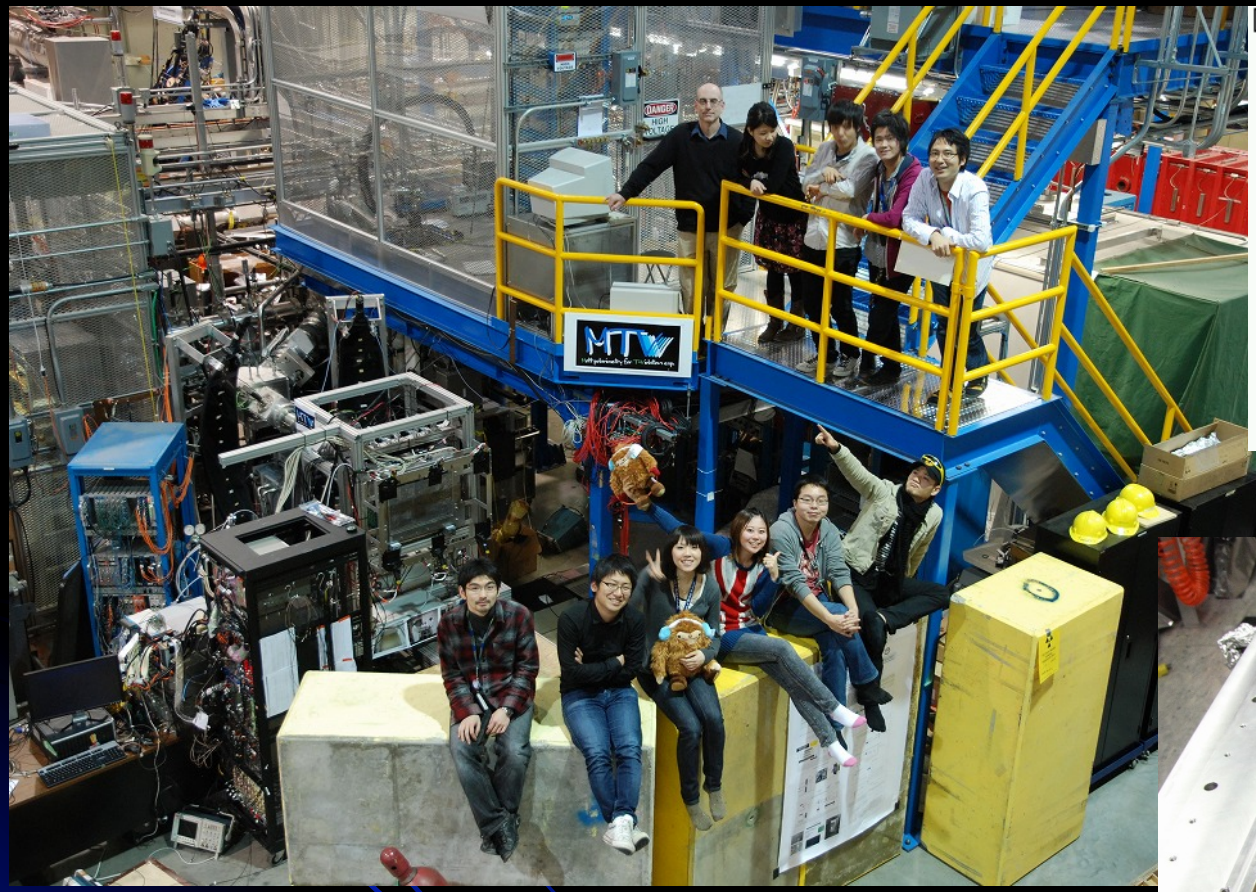


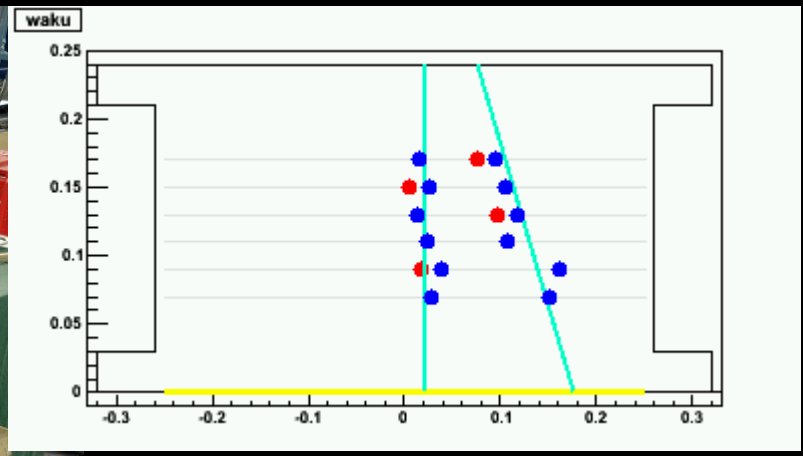


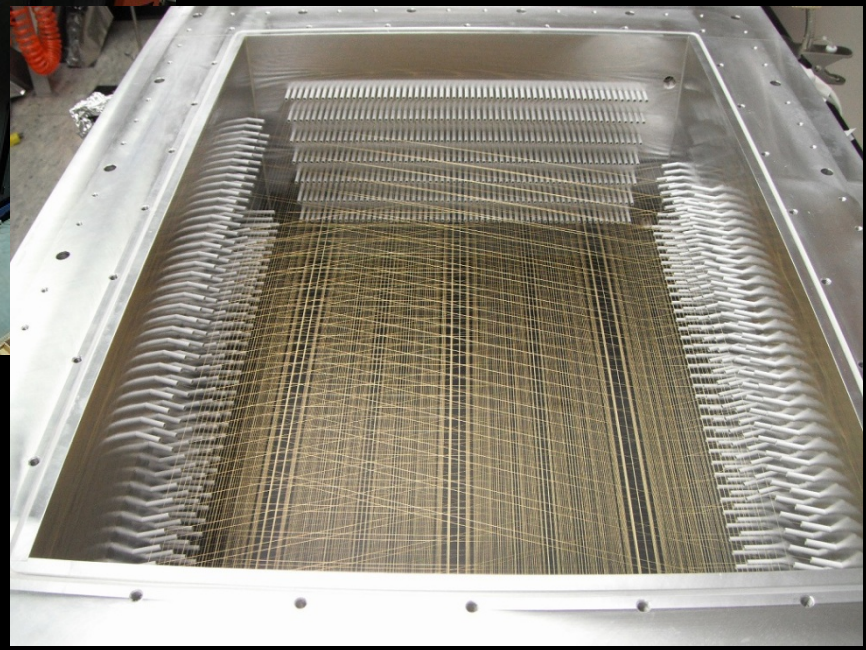
Excellent V-tracking

significant improvement of event reliability !

MTV Run-II : First Physics Run 2010

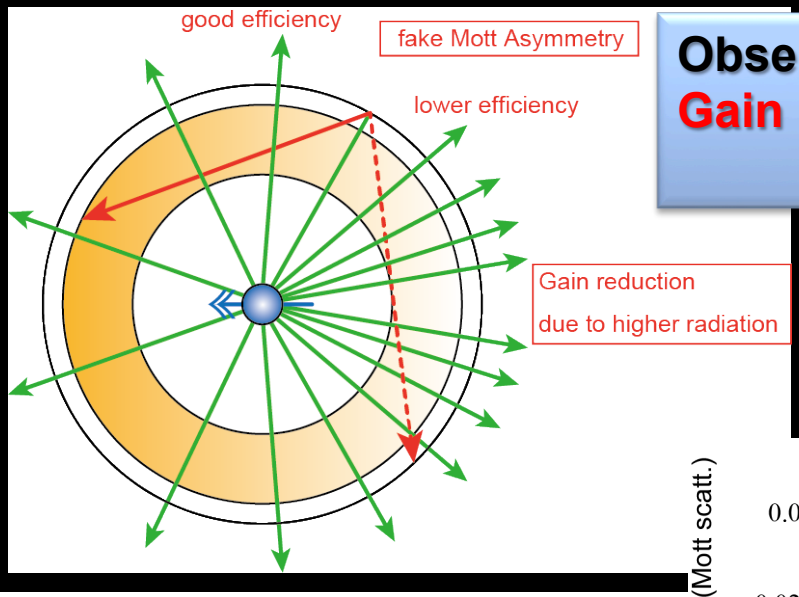






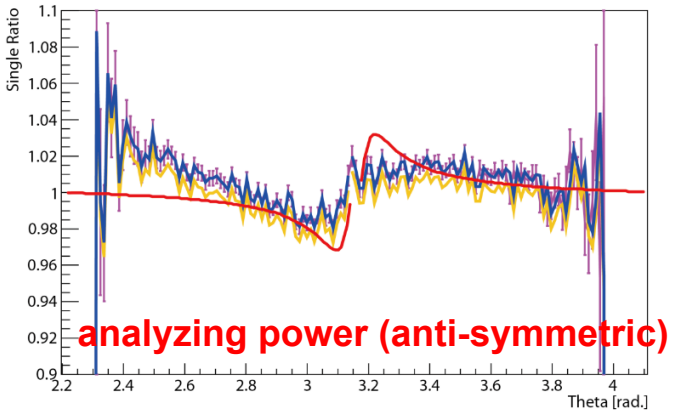
1 week data production in Nov. 2010
First Physics Run
28G Lvl-1 / 3G Lvl-2 Trigger
2.5G events recorded
~ 250M V-tracks (sigma(R)~ 10^{-3})

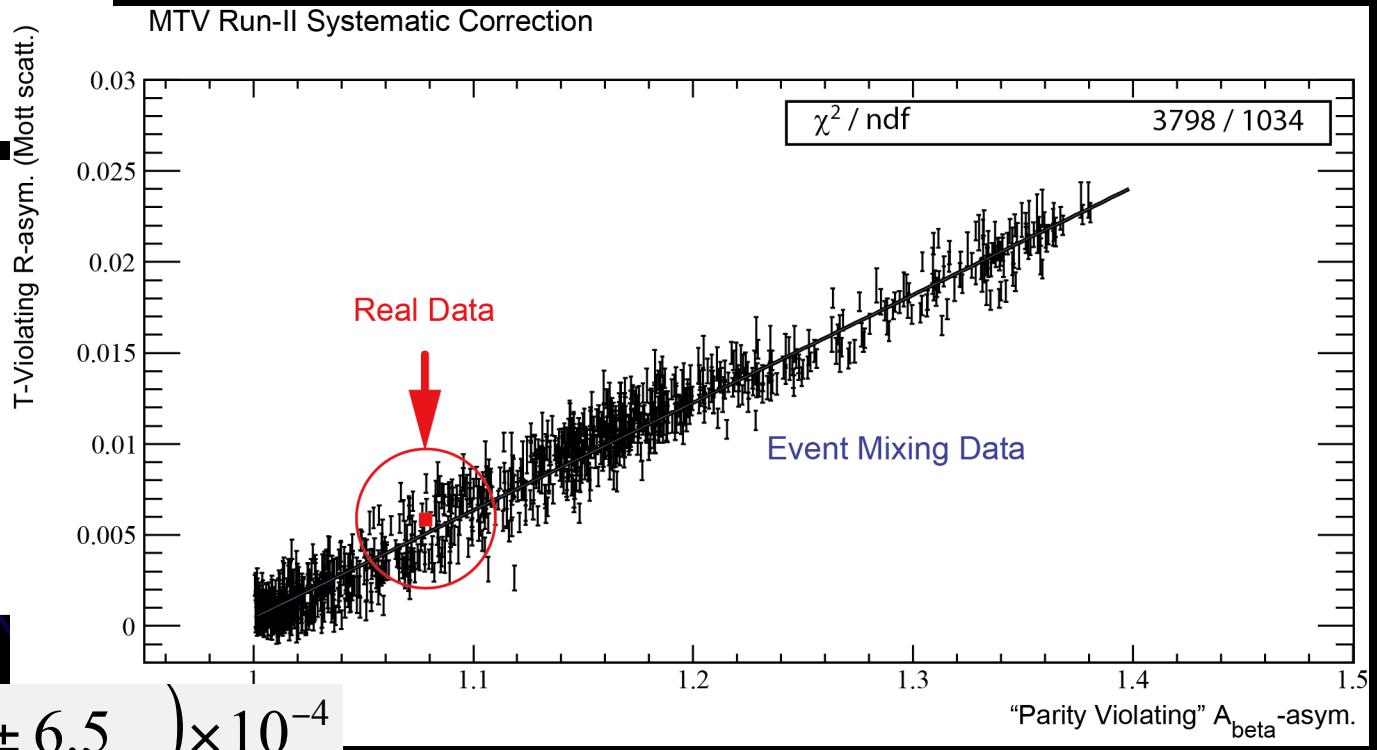
MTV systematics on Run-II



Observed Strange Asymmetry : Understood as
Gain reduction due to space charge effect
& Parity Violating beta asymmetry

Evaluation and Correction using
mixing real data making artificial beta asymmetry
(dominant systematic error)

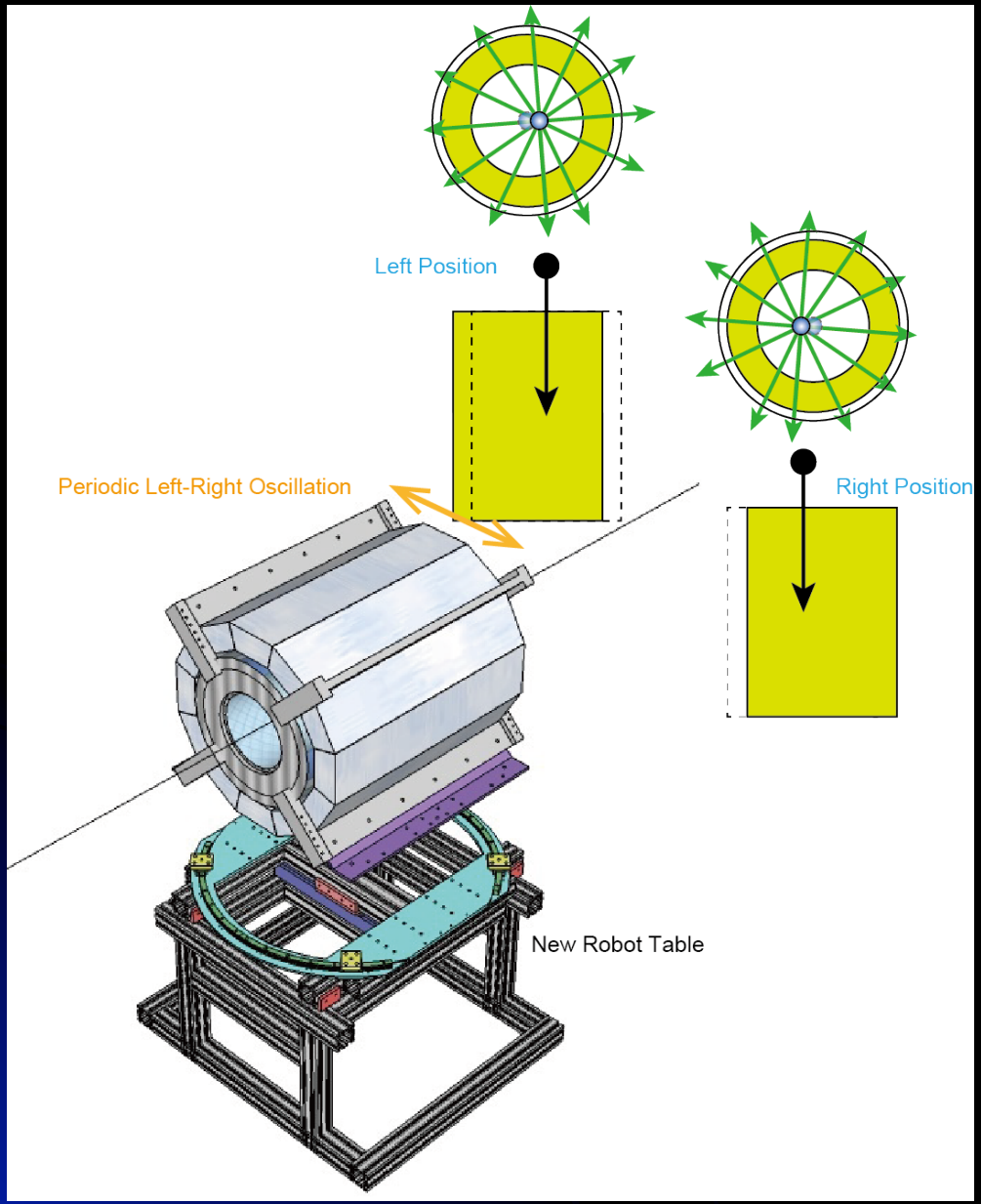




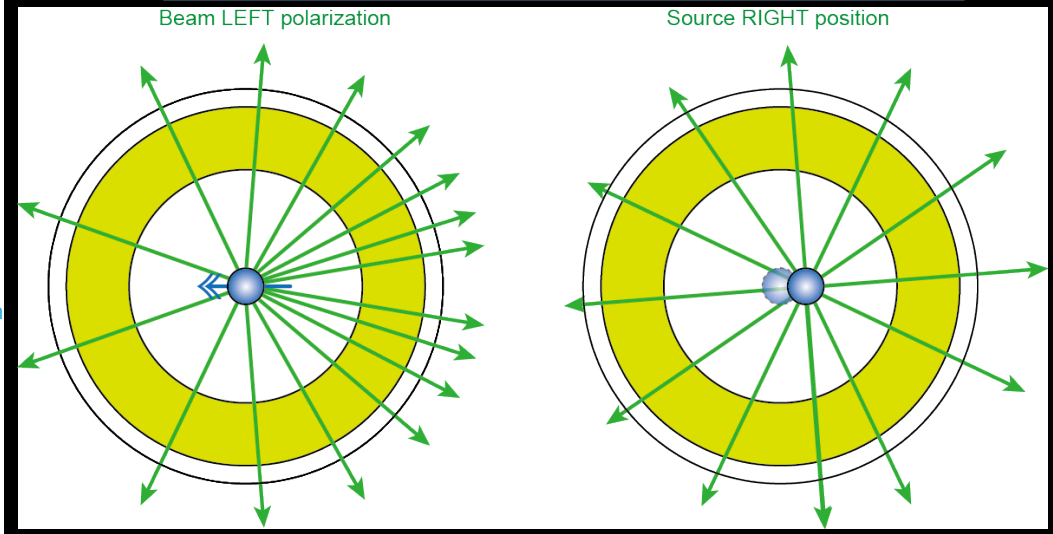
$$A_R^{\exp} - A_R^{fake} = \left(7.5 \pm 1.2_{\text{stat.}} \pm 6.5_{\text{sys}}\right) \times 10^{-4}$$

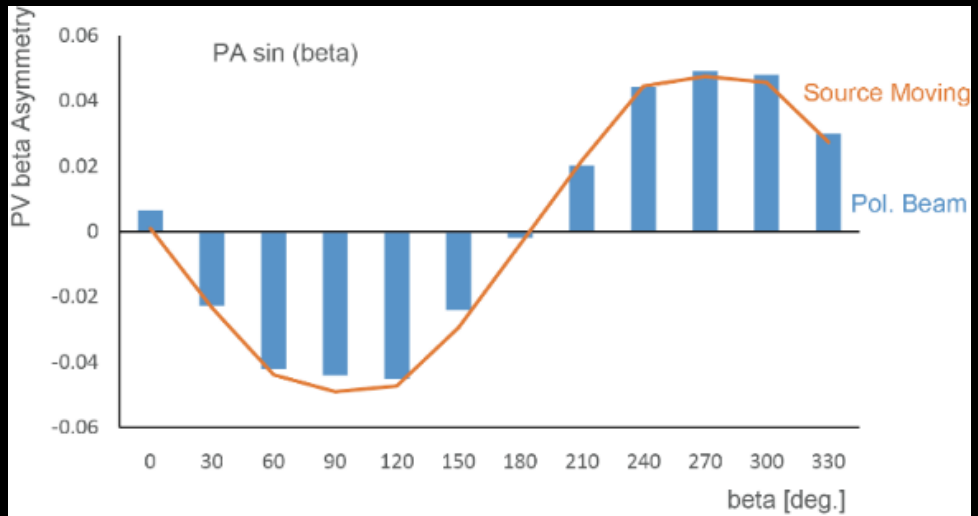
MTV Run-II FINAL !

Systematics Calibration Robot



Artificial Parity Violation Signal :
Left – Right oscillation robot
Moving at different frequency





Systematics Correction

MTV2015

unpol Li-8 at 10^6pps

Calibration Signal Observed !

2M events/1 hour

Robot Frequency

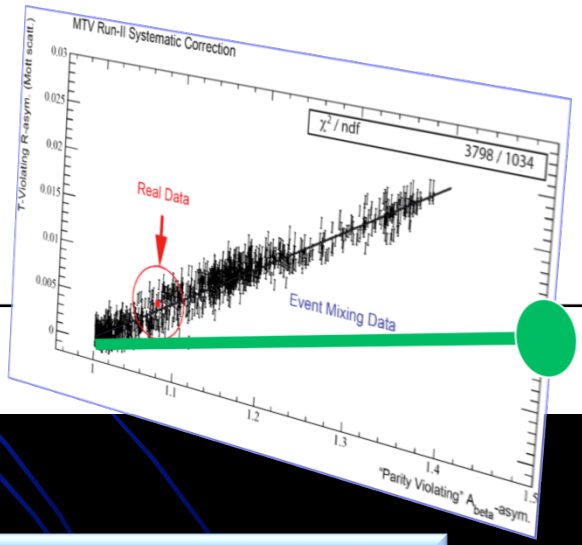
Expected PV fake peak x 6

FFT Amplitude of Asymmetry

Frequency [Hz]

Precision ~ 10^{-4} @ 1hour

$$\sigma_{Asym} \sim 1/\sqrt{N_{event}} \sim 7\times10^{-4}$$



Systematics are under control now !

Asym. 10^{-5} (R 0.1%) precision is expected

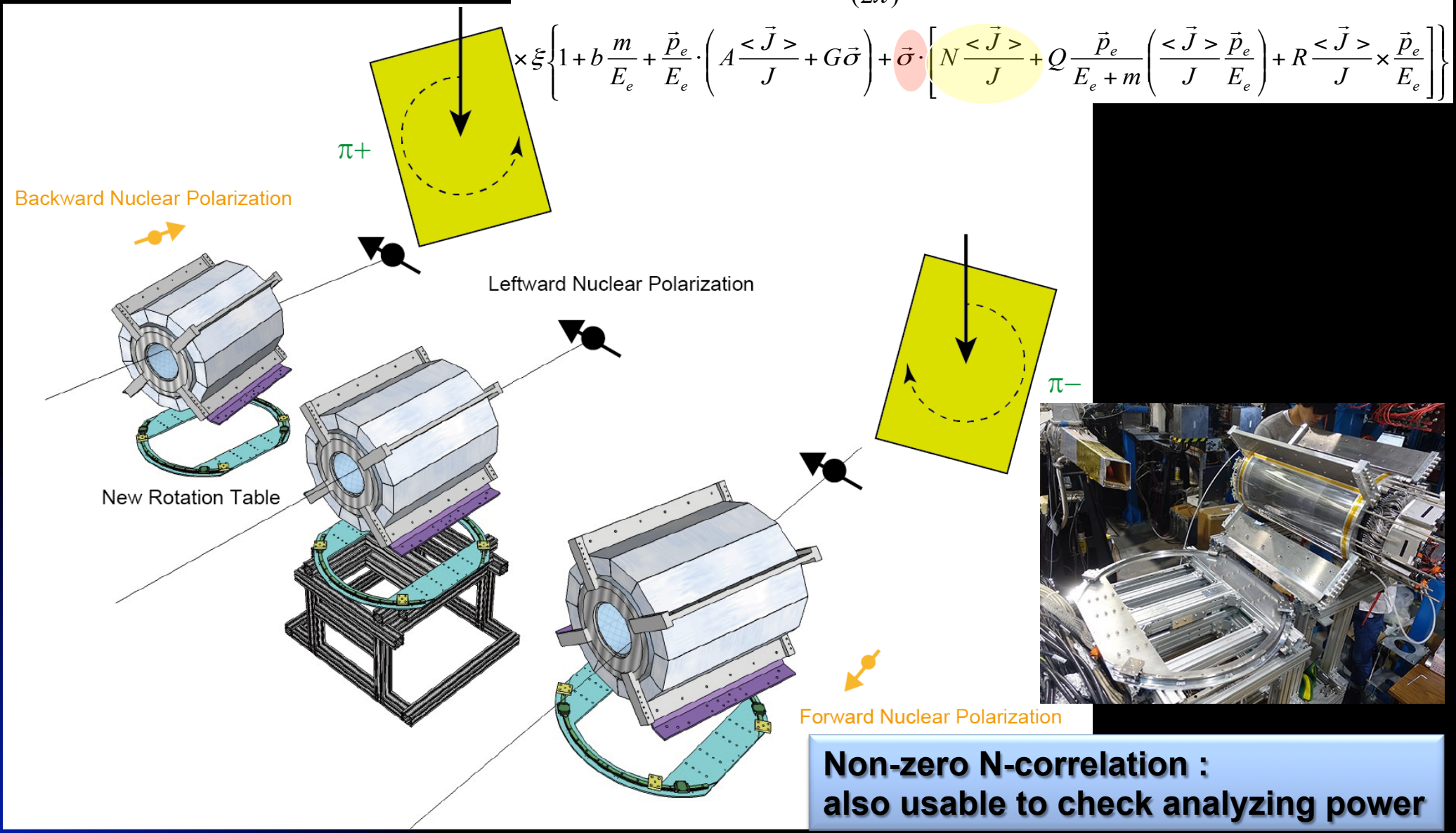
Asym = 4x10^{-5} expected in 24 shifts

Asym = 3.5x10^{-5} FSI prediction

N-Correlation

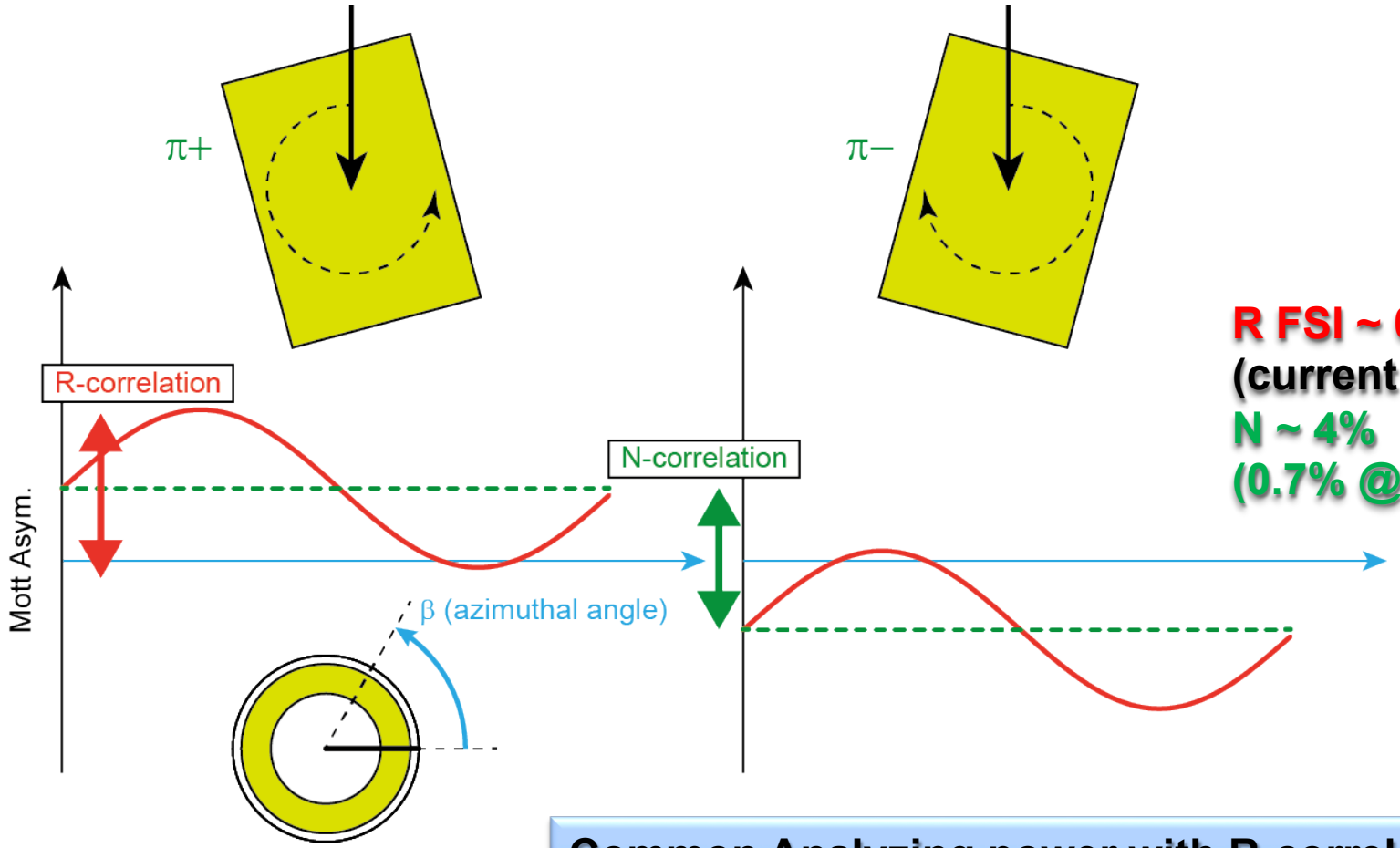
$$\omega(<\vec{J}>,\vec{\sigma}\,|\,E_e,\Omega_e)dE_e d\Omega_e = \frac{F(\pm Z,E_e)}{(2\pi)^4}\, p_e E_e (E_0 - E_e)^2 dE_e d\Omega_e$$

$$\times \xi\left\{1 + b\frac{m}{E_e} + \frac{\vec{p}_e}{E_e}\cdot\left(A\frac{<\vec{J}>}{J} + G\vec{\sigma}\right) + \vec{\sigma}\cdot\left[N\frac{<\vec{J}>}{J} + Q\frac{\vec{p}_e}{E_e+m}\left(\frac{<\vec{J}>}{J}\frac{\vec{p}_e}{E_e}\right) + R\frac{<\vec{J}>}{J}\times\frac{\vec{p}_e}{E_e}\right]\right\}$$



Non-zero N-correlation :
also usable to check analyzing power

N-Correlation



R FSI ~ 0.07%
(current precision)
N ~ 4%
(0.7% @ 10deg.)

Common Analyzing power with R-correlation : can be checked by N-correlation

Lorentz Violation

Theories of Quantum Gravity : Difficult to be directly tested

Requesting violation of Lorentz symmetry : Test of LV ~ QG

Lorentz symmetry is not well tested in weak interaction

LV like P, C, T, CP ??

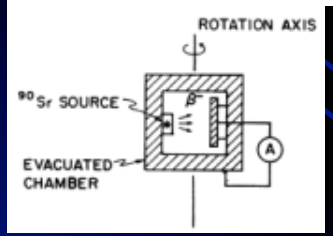
$$\langle W^{\mu+}(p)W^{\nu-}(-p)\rangle = \frac{-i(g^{\mu\nu}+\chi^{\mu\nu})}{M_W^2}$$

Weak LV propagator

PHYSICAL REVIEW D VOLUME 14, NUMBER 1 1 JULY 1976

Test of the rotational invariance of the weak interaction*

Riley Newman† and Stephen Wiesner‡
Columbia University, New York, New York 10027



High Precision tests in 1970's (no spin correlation)

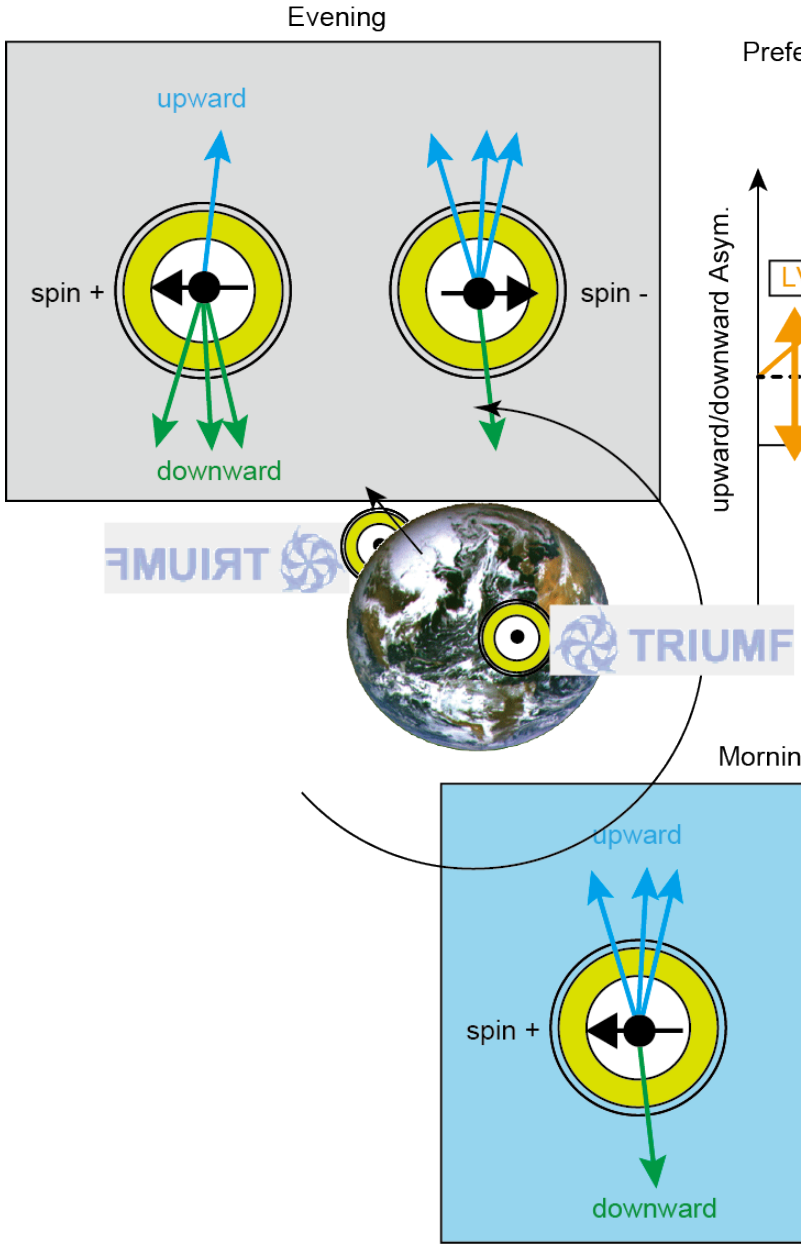
Preferred Direction in Universe ??

LV Data Table : 2016 Kostelecky-0801.0287v9

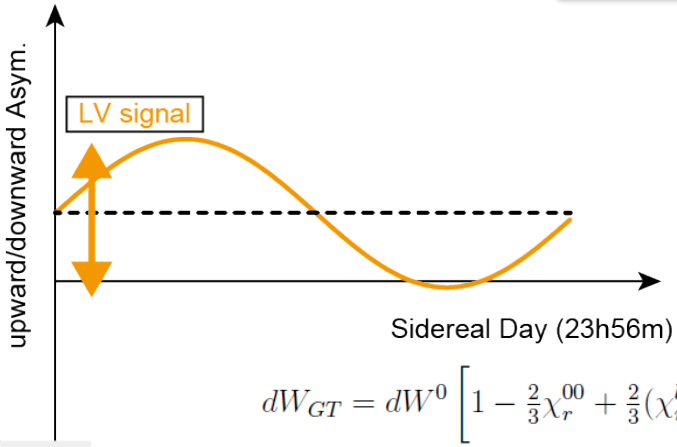
Table D33. Electroweak sector, $d = 3, 4$

Combination	Result	System	Ref.
$\lvert(k_\phi)_X\rvert, \lvert(k_\phi)_Y\rvert$	$< 10^{-31}$ GeV	Xe-He maser	[200]*
$\lvert(k_\phi)_Z\rvert, \lvert(k_\phi)_T\rvert$	$< 2.8 \times 10^{-27}$ GeV	"	[200]*
$\lvert(k_{\phi\phi})_S^{XT}\rvert$	$< 3.3 \times 10^{-3}$	Kaon decay	[201]*
$\lvert(k_{\phi\phi})_S^{YT}\rvert$	$< 6.3 \times 10^{-3}$	"	[201]*
$\lvert(k_{\phi\phi})_S^{ZT}\rvert$	$< 6.0 \times 10^{-3}$	"	[201]*
$2(k_{\phi\phi}^A)^{32} + \frac{1}{9}(k_{\phi W})^{32}$	$(-9 \text{ to } 2) \times 10^{-3}$	Nuclear beta decay	[202]
$2(k_{\phi\phi}^A)^{13} + \frac{1}{9}(k_{\phi W})^{13}$	$(-6 \text{ to } 4) \times 10^{-3}$	"	[202]
$(k_{\phi\phi}^S)^{ZT}$, $(k_{\phi\phi}^A)^{YX}$, $(k_{\phi W})^{YX}$	$(-0.5 \text{ to } 1) \times 10^{-8}$	"	[203]*
$(k_{\phi\phi}^S)^{ZZ}$	$(-1 \text{ to } 0.4) \times 10^{-6}$	"	[203]*
$(k_{\phi\phi}^S)^{TT}$	$(-1 \text{ to } 3) \times 10^{-6}$	"	[203]*
$\lvert(k_{\phi\phi}^S)^{XX}\rvert, \lvert(k_{\phi\phi}^S)^{YY}\rvert$	$< 1 \times 10^{-6}$	"	[203]*
$\lvert(k_{\phi\phi}^S)^{XT}\rvert, \lvert(k_{\phi\phi}^S)^{YT}\rvert, \lvert(k_{\phi\phi}^A)^{XZ}\rvert, \lvert(k_{\phi\phi}^A)^{YZ}\rvert, \lvert(k_{\phi W})^{XZ}\rvert, \lvert(k_{\phi W})^{YZ}\rvert$	$< 2 \times 10^{-8}$	"	[203]*
$\lvert(k_{\phi\phi}^S)^{XY}\rvert, \lvert(k_{\phi\phi}^S)^{XZ}\rvert, \lvert(k_{\phi\phi}^S)^{YZ}\rvert$	$< 5 \times 10^{-7}$	"	[203]*
$\lvert(k_{\phi\phi}^A)_{\mu\nu}\rvert$	$< 3 \times 10^{-16}$	Cosmological birefringence	[200]*
$\lvert(k_{\phi B})_{\mu\nu}\rvert$	$< 0.9 \times 10^{-16}$	"	[200]*
$\lvert(k_{\phi W})_{\mu\nu}\rvert$	$< 1.7 \times 10^{-16}$	"	[200]*
$\lvert(k_{\phi\phi}^S)_{XX}\rvert, \lvert(k_{\phi\phi}^S)_{YY}\rvert, \lvert(k_{\phi\phi}^S)_{ZZ}\rvert$	$< 10^{-27}$	Clock comparisons	[200]*
$\lvert(k_{\phi\phi}^S)_{XY}\rvert$	$< 10^{-27}$	"	[200]*
$\lvert(k_{\phi\phi}^S)_{XZ}\rvert, \lvert(k_{\phi\phi}^S)_{YZ}\rvert$	$< 10^{-25}$	"	[200]*
$\lvert(k_{\phi\phi}^S)_{TT}\rvert$	$< 4 \times 10^{-13}$	H^- ion, $\bar{p}$ comparison	[200]*
$\lvert(k_W)^\alpha{}_{\mu\alpha\nu}\rvert$	$< 10^{-5}$	Astrophysics	[60]*

Lorentz Violation I



Preferred Direction of nuclear polarization



Sidereal variation of upward/ downward anisotropy

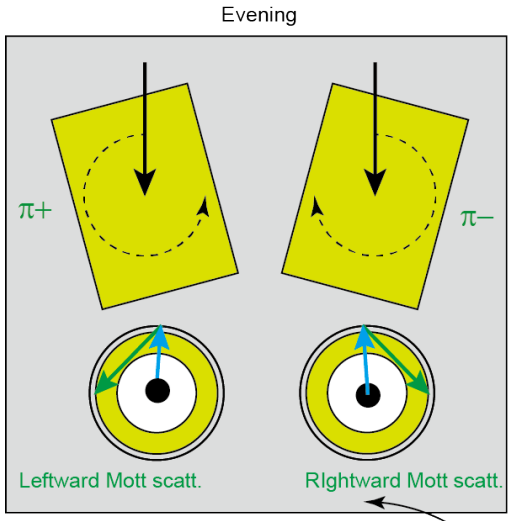
pol Li-8 beam
duration ~ week

KVI Na-22 exp.

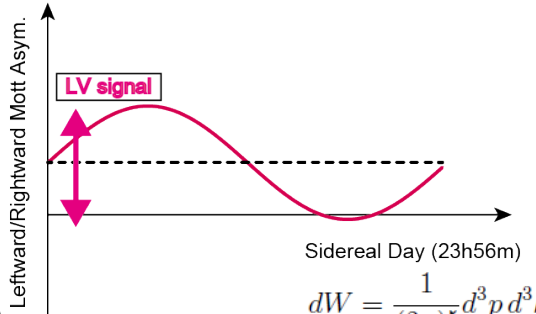
$$dW_{GT} = dW^0 \left[1 - \tfrac{2}{3}\chi_r^{00} + \tfrac{2}{3}(\chi_r^{l0} + \tilde{\chi}_i^l)\frac{p^l}{E_e}\right]$$
$$\mp\Lambda^{(1)}\left[(1-\chi_r^{00})\frac{\mathbf{p}\cdot\hat{\mathbf{I}}}{E_e} + \tilde{\chi}_i^l\hat{I}^l + \frac{\chi_r^{lk}p^l\hat{I}^k}{E_e} - \frac{\chi_r^{l0}(\mathbf{p}\times\hat{\mathbf{I}})^l}{E_e}\right]$$
$$+\Lambda^{(2)}\left[-\chi_r^{00} + (\chi_r^{l0} + \tilde{\chi}_i^l)\frac{p^l}{E_e} + 3\chi_r^{kl}\hat{I}^k\hat{I}^l - 3\chi_r^{l0}\hat{I}^l\frac{\mathbf{p}\cdot\hat{\mathbf{I}}}{E_e} - 3\chi_i^{ml}\hat{I}^m\frac{(\mathbf{p}\times\hat{\mathbf{I}})^l}{E_e}\right]$$

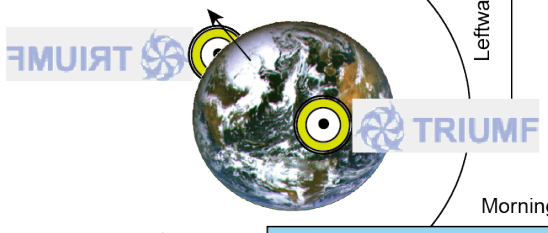
2013 Noordmans-1302.2730

No Mott analyzing …

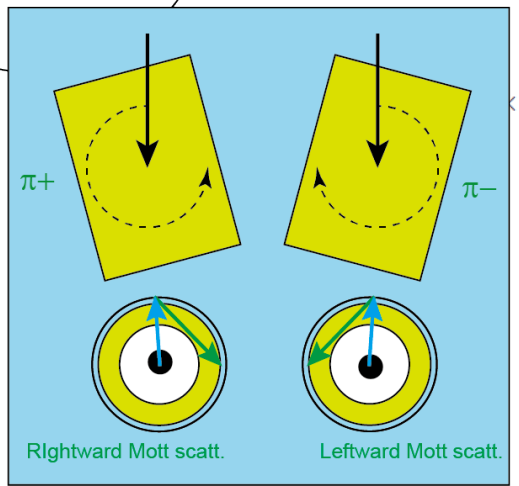


Preferred Direction of electron polarization





Morning



Sidereal variation of leftward/ rightward Mott asymmetry

unpol Sr-Y 90 source duration ~ months

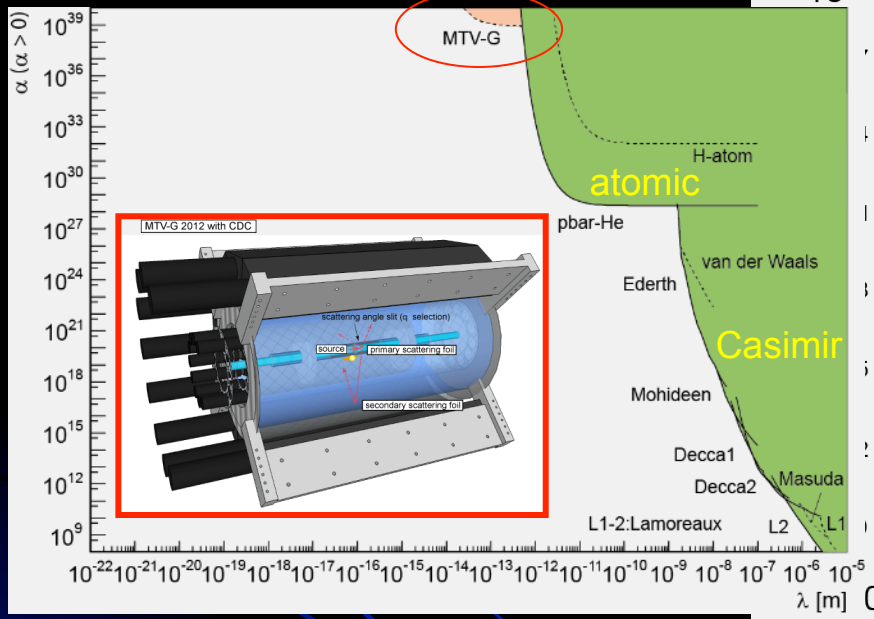
$$dW = \frac{1}{(2\pi)^5} d^3p\, d^3k\, \delta(E_e + E_\nu - E_0) F(E_e, \pm Z)\xi$$
$$\times \left\{ \left(1 \mp \frac{\mathbf{p}\cdot\hat{\mathbf{s}}_e}{E_e}\right) \left[\frac{1}{2}\left(1 + B\frac{\mathbf{k}\cdot\hat{\mathbf{I}}}{E_\nu}\right) + t + \frac{\boldsymbol{w}_1\cdot\mathbf{k}}{E_\nu} + \boldsymbol{w}_2\cdot\hat{\mathbf{I}} + T_1^{km}\hat{I}^k\hat{I}^m + \frac{T_2^{kj}\hat{I}^k k^j}{E_\nu} + \frac{S_1^{kmj}\hat{I}^k\hat{I}^m k^j}{E_\nu} \right] \right.$$
$$+ \left(\left(1 \mp \frac{(E_e - \gamma m_e)(\mathbf{p}\cdot\hat{\mathbf{s}}_e)}{E_e^2 - m_e^2}\right) \frac{p^l}{E_e} \mp \frac{\gamma m_e}{E_e} s_e^l \mp \frac{m_e}{E_e}\sqrt{1-\gamma^2}(\hat{\mathbf{p}}\times\hat{\mathbf{s}}_e)^l \right)$$
$$\left. \times \left[\frac{1}{2}\left(A - 3c\frac{\mathbf{k}\cdot\hat{\mathbf{I}}}{E_\nu}\right)\hat{I}^l + \frac{1}{2}(a+c)\frac{k^l}{E_\nu} + w_3^l + \frac{T_3^{lj}k^j}{E_\nu} + T_4^{lk}\hat{I}^k + S_2^{lmk}\hat{I}^m\hat{I}^k + \frac{S_3^{lmj}\hat{I}^m k^j}{E_\nu} + \frac{R^{lmkj}\hat{I}^m\hat{I}^k k^j}{E_\nu} \right] \right\}$$

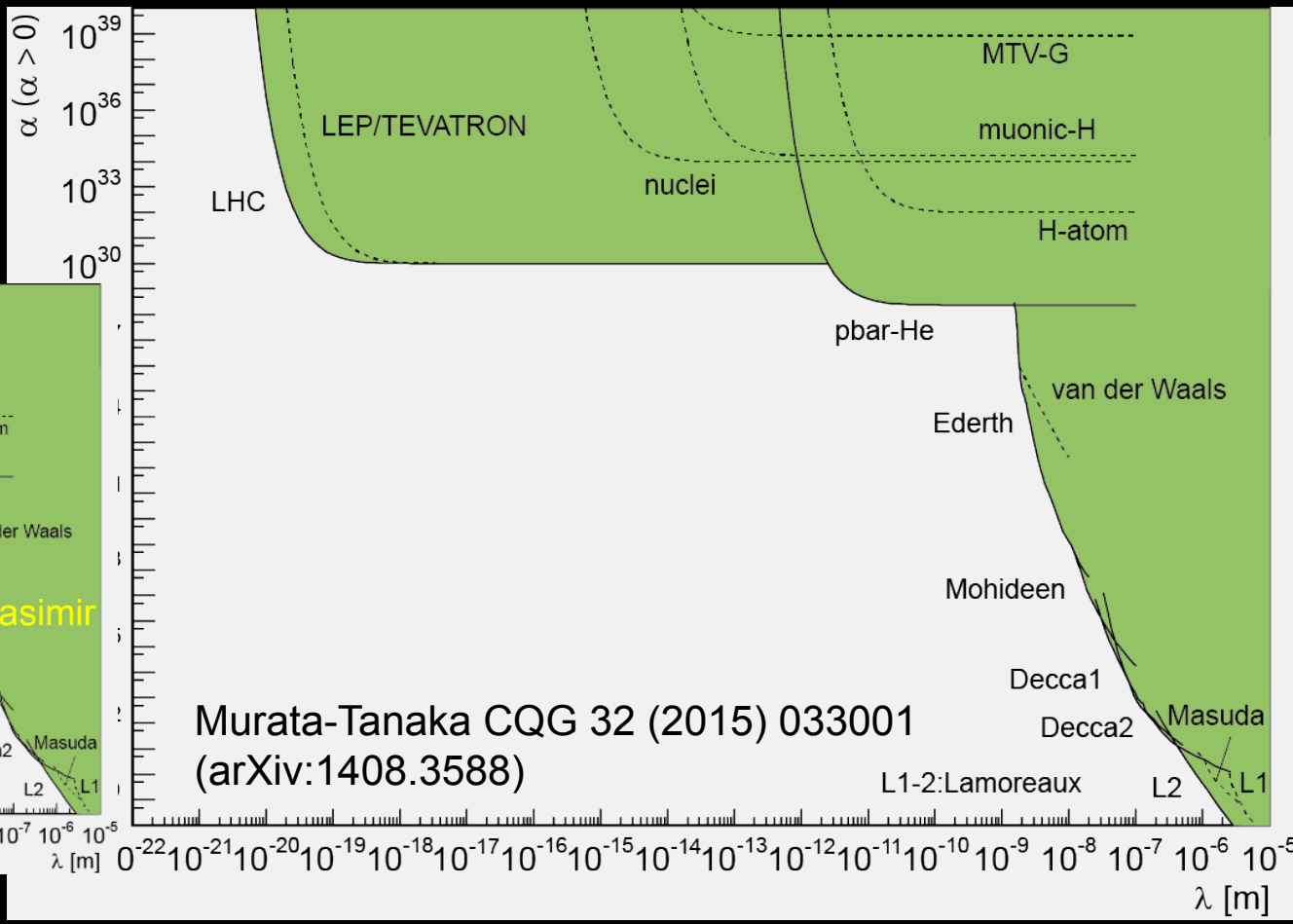
2013 Noordmans-1302.2730

Same as electron momentum measurements ?

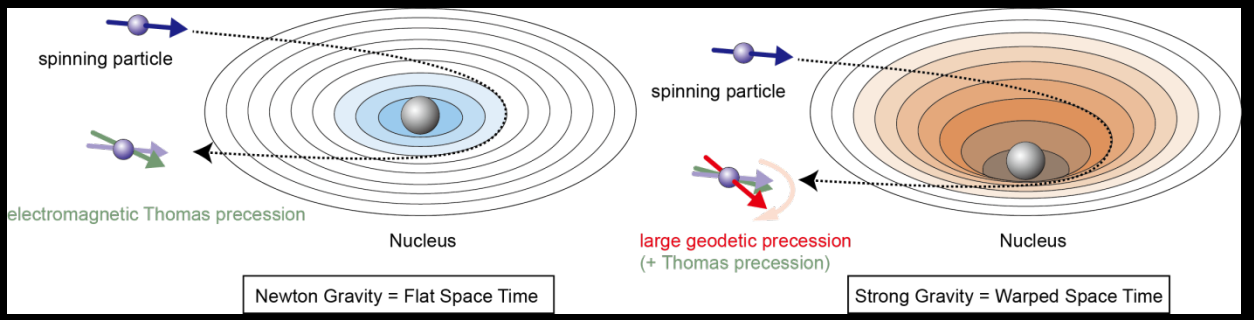
Strong Gravity at Nuclear Scale

$$V'_{Yukawa} = -G\frac{Mm}{r}\left[1+\alpha\cdot e^{-r/\lambda}\right]$$





< 10 um
Gravity cannot observed
Setting Upper Limits



Summary:
Expected Physics from MTV 2016-17

Tools

A. Polarized Li-8 production run ~ 2 weeks (R,N,LV)
B. Unpol Sr/Y-90 production run ~ 6 months (LV)
C. Left-Right oscillation robot to control PV-like systematics
D. Rotational table to flip detector directions

Physics

1. T-Violating R-correlation : reaching non-zero FSI precision
2. nonzero Transverse pol. from N-correlation :
3. Tests of Lorentz Invariance in weak interaction & polarization correlations

FSI physics

1. Check sign & Electron Momentum Dependence (Test of SM)
2. Systematic Study over various Nuclei (R_{FSI}, N)

$$R_{8Li} \approx \frac{1}{3}\mathrm{Im}\left[\frac{C_T + C_T'}{C_A}\right] + \frac{1}{3}\frac{\alpha Z_F m_e}{p_e}$$

MTV 2016


POLARIMETER
OSAKA
studies the structures of exotic nuclei
MTV
using isotope decay to test physics beyond the Standard Model

backup

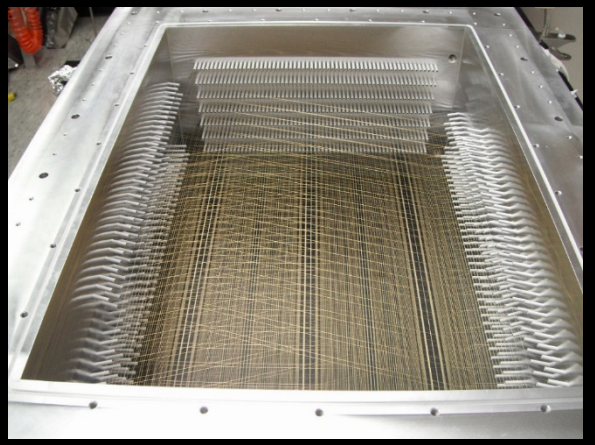
S1183-MTV
Activity Summary

2008 Test Experiment at KEK-TRIAC

2008 First Proposal to EEC
2009 – 2010 MTV experiment using MWDC
(2010 EEC Progress Report)

1 x10^7pps x 11shifts (250M V-tracks)

Same order systematics due to detector asymmetry



2011-12 CDC Commissioning
(2012 EEC Progress Report)

2013-14 CDC Systematics Study

Systematics due to PV understood !

Final Result : $A_R < 6 \times 10^{-4}$

only 6 shifts used !

2015 CDC Systematics Calibration System Completed

Systematics are now well understood and under controlled

Test Result in 1hour : A_R <~ 1 x 10^{-3}

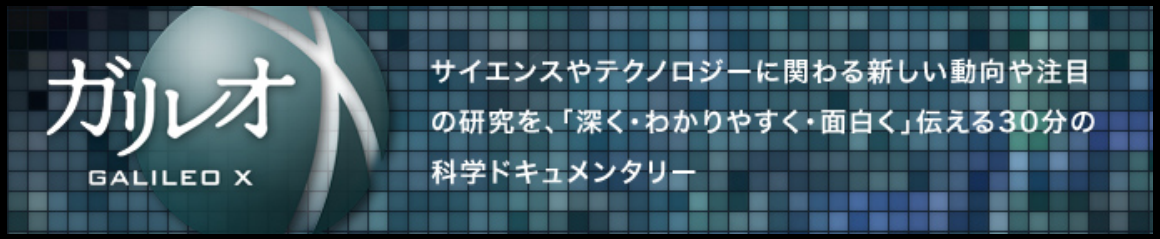
2016 EEC Progress Report

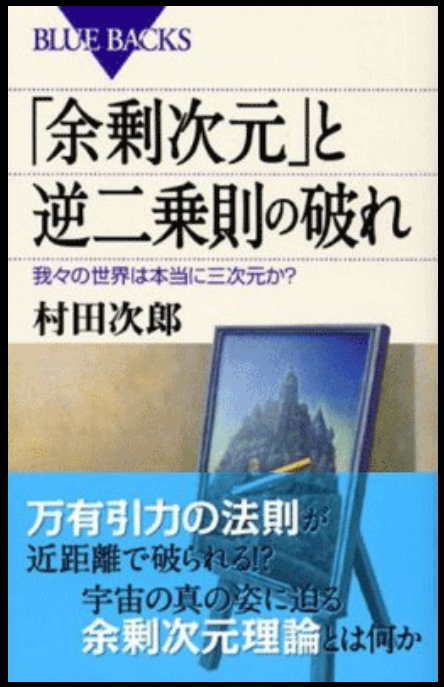
A_R ~ 10^{-5} precision (< FSI level), 10^6pps x 12+12 shifts

2016 – 17 Physics Production

MTV on TV program !

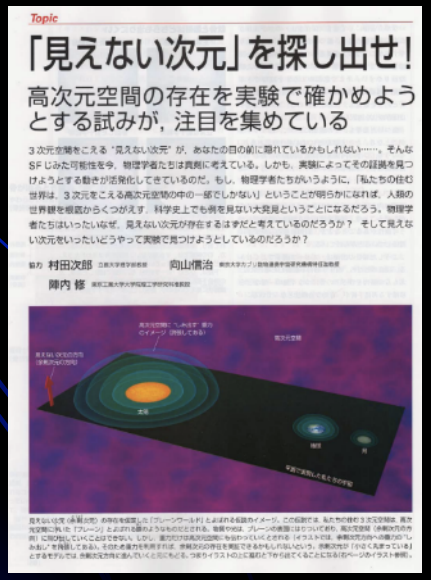
BS Fuji Galileo-X, Nov 2013



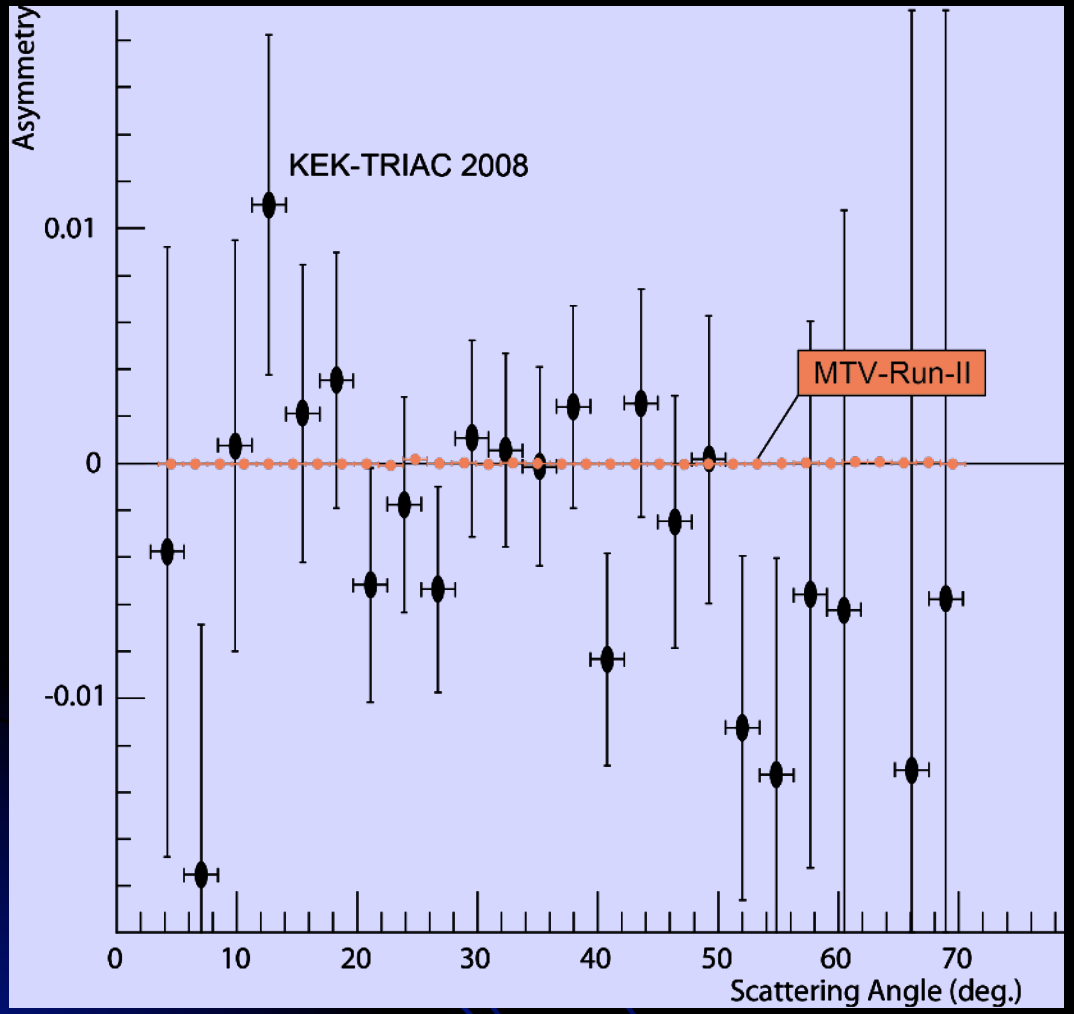


Scientific American JAPANESE edition. 2013

Book for young readers (blue backs) 2011



Run-II result



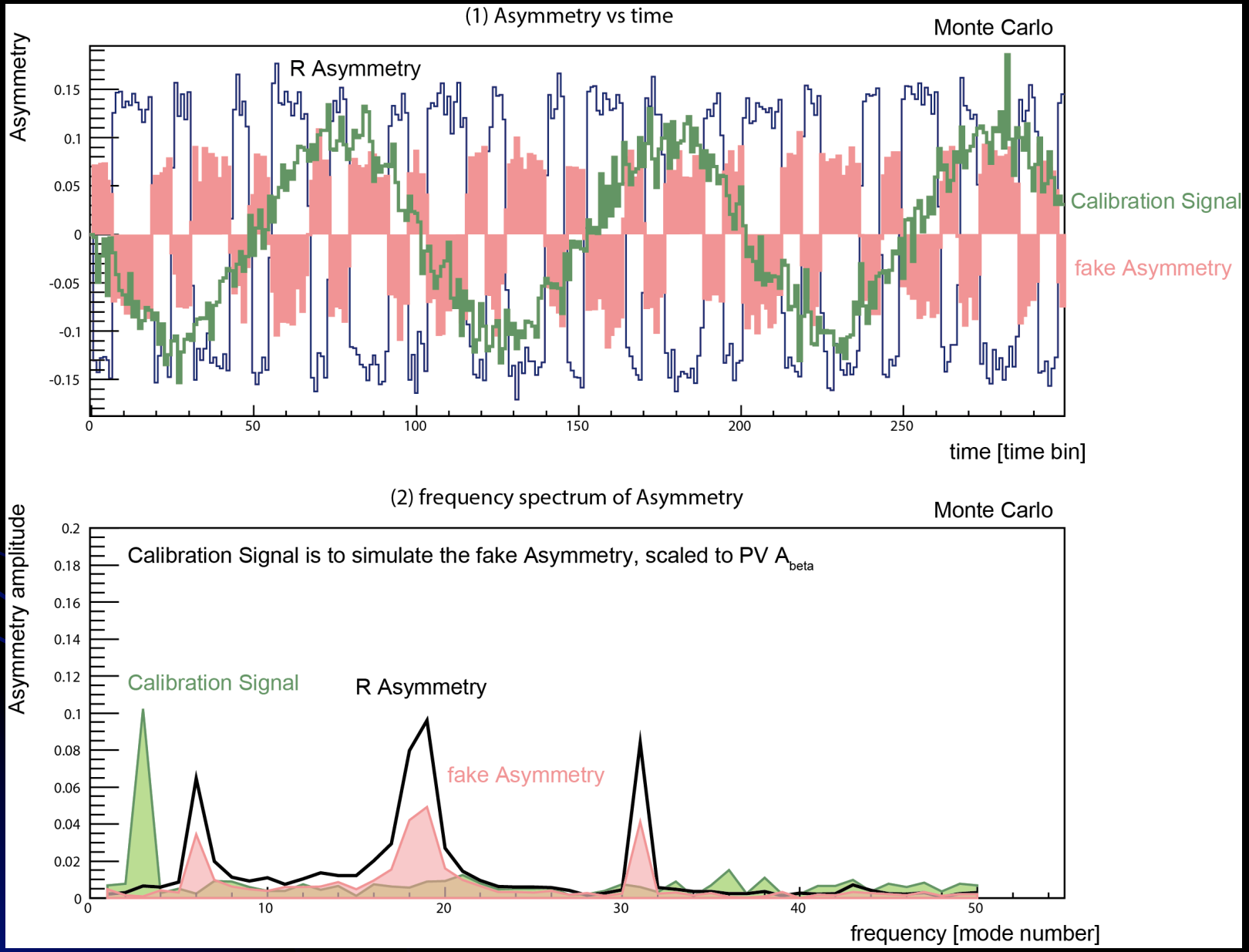
Systematics :

1. **Beam pol. Tilting (N-correlation)**
2. **Detector asymmetry & PV beta asym.**
3. **Gain Reduction & PV beta asym.**

Evaluate & Correct

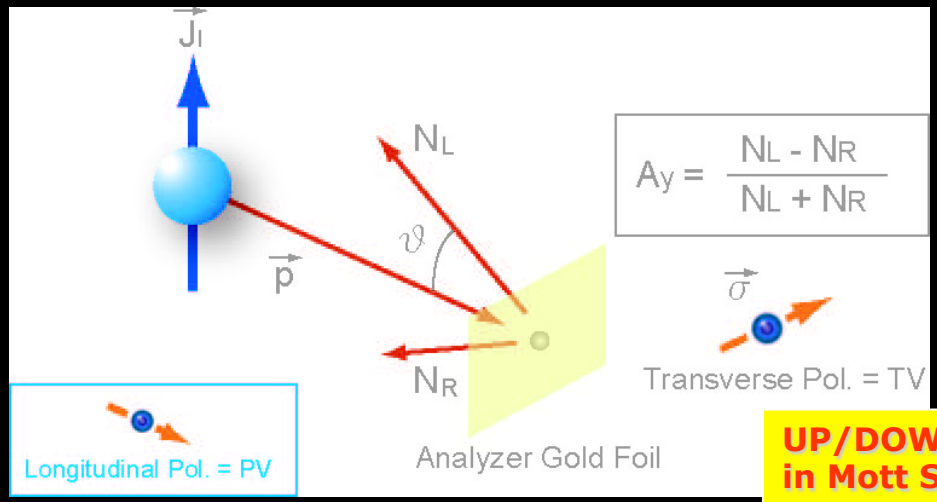
$$A_R = \left(7.5 \pm 1.2_{\text{stat.}} \pm 6.5_{\text{sys}}\right) \times 10^{-4}$$

Systematics Calibration : expected signal

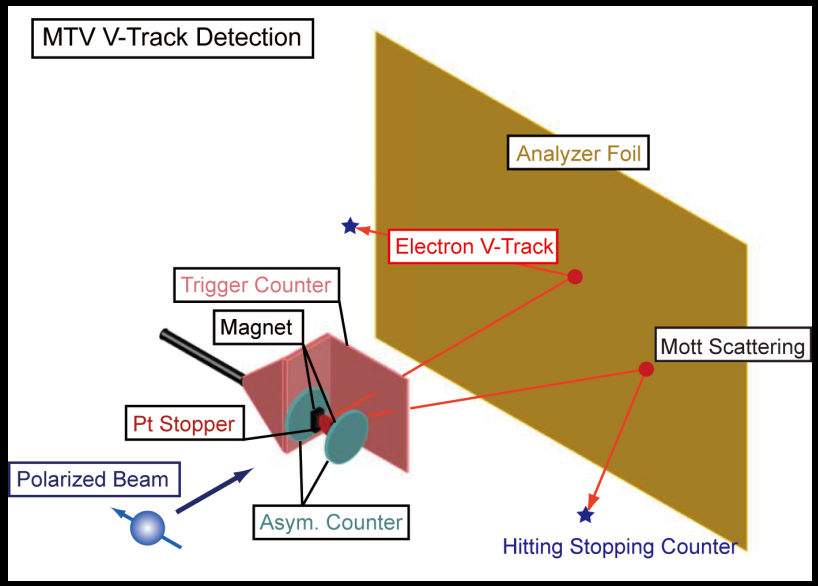


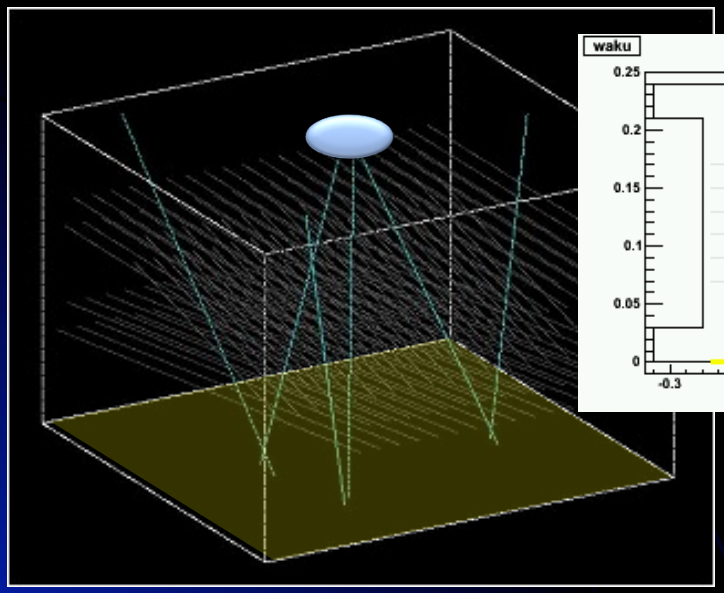
Transverse Polarization Measurement

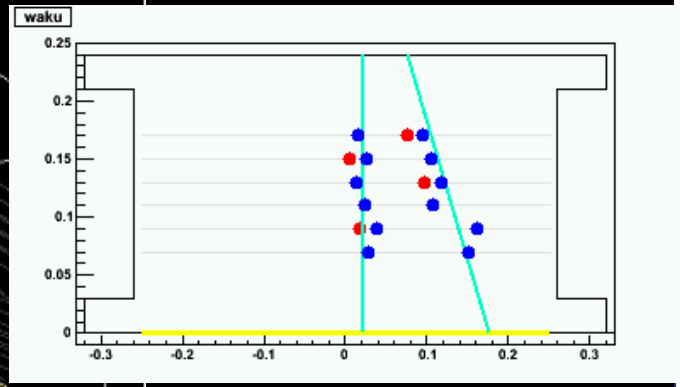
Utilizing Analyzing Power of Mott Scattering



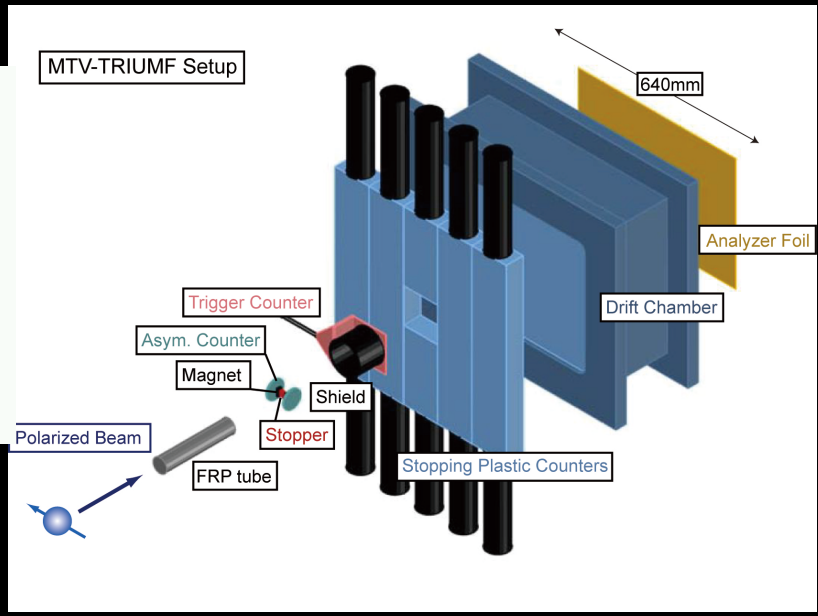
UP/DOWN Asymmetry in Mott Scattering



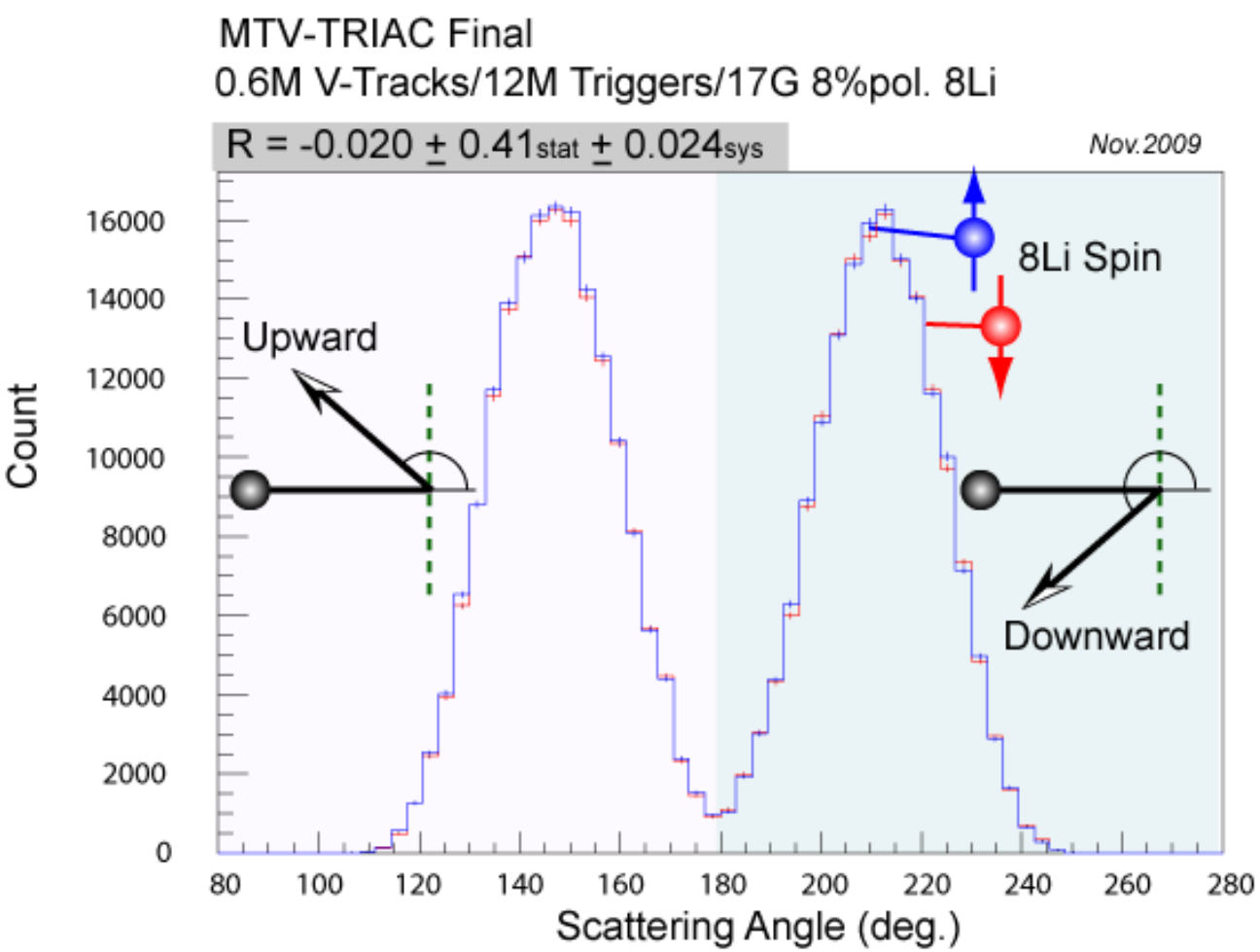




V-Track events



Results of KEK-TRIAC Experiment



$$R \sim \frac{Asym}{<\varepsilon><J>}$$

$$\sigma_R \sim \frac{\sigma_{Asym}}{<\varepsilon><J>}$$

$$\sigma_{Asym} \sim 1/\sqrt{N_{event}} = 1/\sqrt{1M} \sim 0.2\%$$

effective analyzing power

$<\varepsilon> \sim 0.065$

polarization $<J> \sim 0.08$

$$\sigma_R \sim \frac{0.2\%}{0.065 \times 0.08} = 40\%$$

40% precision for (8% pol.), 1.3x10^{5}pps x 2days (37hours)

First Results from Reliable Tracking Measurement !

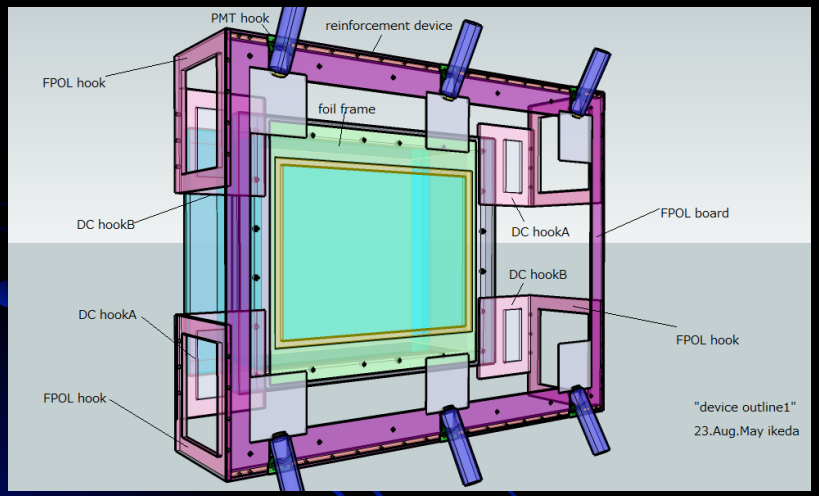
H. Kawamura, PhD Thesis, (2010) Rikkyo-U

Systematics –I : N-correlation

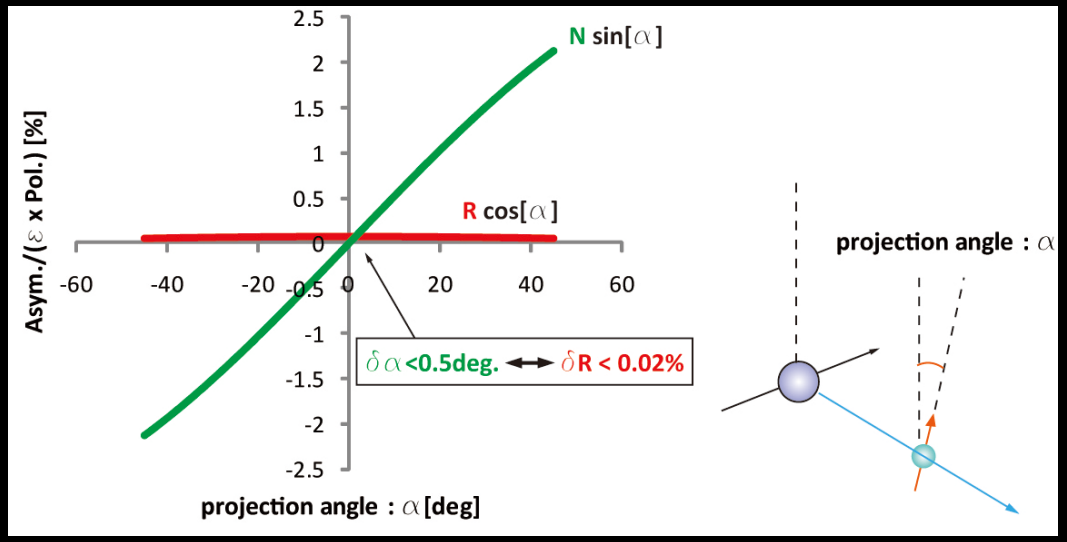
Source = Tilting of beam polarization angle

$$\omega(\langle \vec{J} \rangle, \vec{\sigma} | E_e, \Omega_e) dE_e d\Omega_e = \frac{F(\pm Z, E_e)}{(2\pi)^4} p_e E_e (E_0 - E_e)^2 dE_e d\Omega_e \times \xi \left\{ 1 + b\frac{m}{E_e} + \frac{\vec{p}_e}{E_e} \cdot \left(A\frac{\langle \vec{J} \rangle}{J} + G\vec{\sigma} \right) + \vec{\sigma} \cdot \left[N\frac{\langle \vec{J} \rangle}{J} + Q\frac{\vec{p}_e}{E_e + m}\left(\frac{\langle \vec{J} \rangle}{J} \frac{\vec{p}_e}{E_e} \right) + R\frac{\langle \vec{J} \rangle}{J} \times \frac{\vec{p}_e}{E_e} \right] \right\}$$

N-correlation



FPOL (Forward Polarimeter)



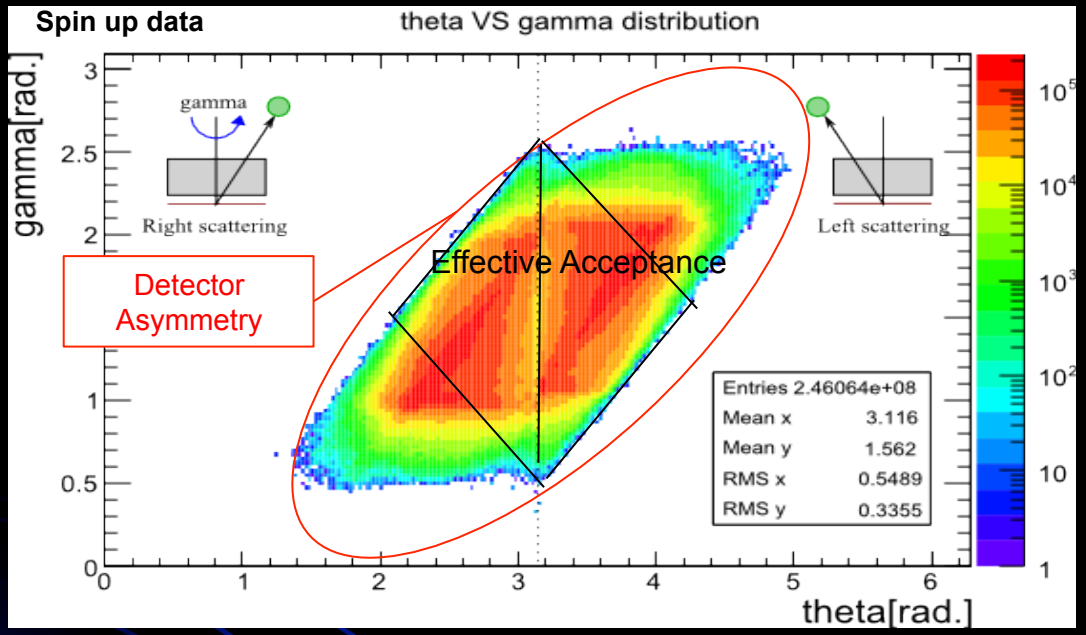
Delta_α = 6.1 +- 0.29 [mrad.]

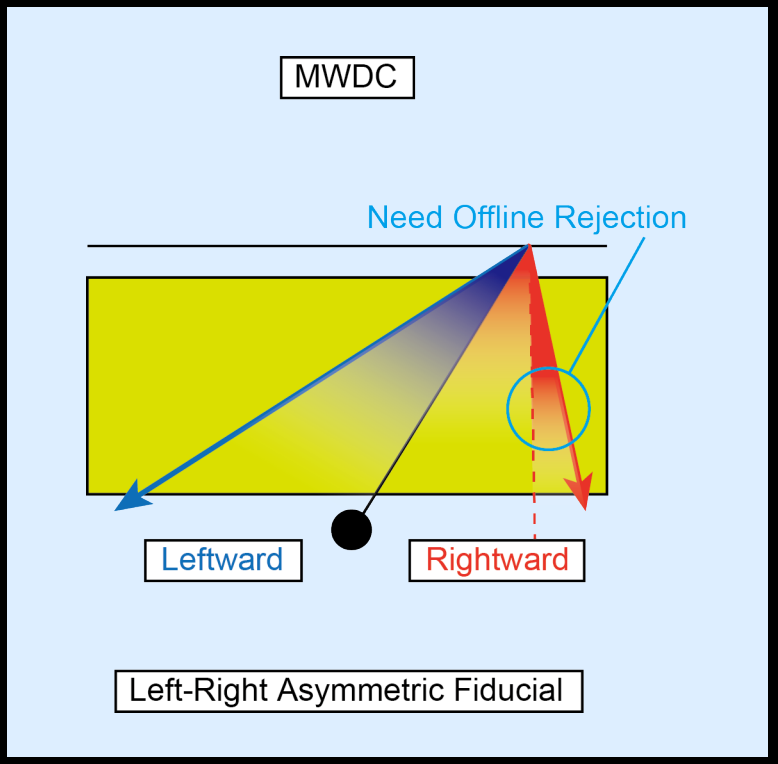
$$R_{N-correlation} = 0.024 \pm 0.029\%$$

Axial-Symmetric detector is desired

Systematics –II : Detector Asymmetry

Source = Detector Asymmetry + Parity Violation





Asymmetric Acceptance

$$D_{1D}(|\theta|) = \left(\frac{1+Asym(|\theta|)}{1-Asym(|\theta|)}\right)^2 \frac{\int \varepsilon(-|\theta|,\gamma)\eta_{PV}^{U}(\gamma)d\gamma}{\int \varepsilon(-|\theta|,\gamma)\eta_{PV}^{D}(\gamma)d\gamma} \frac{\int \varepsilon(+|\theta|,\gamma)\eta_{PV}^{D}(\gamma)d\gamma}{\int \varepsilon(+|\theta|,\gamma)\eta_{PV}^{U}(\gamma)d\gamma}$$

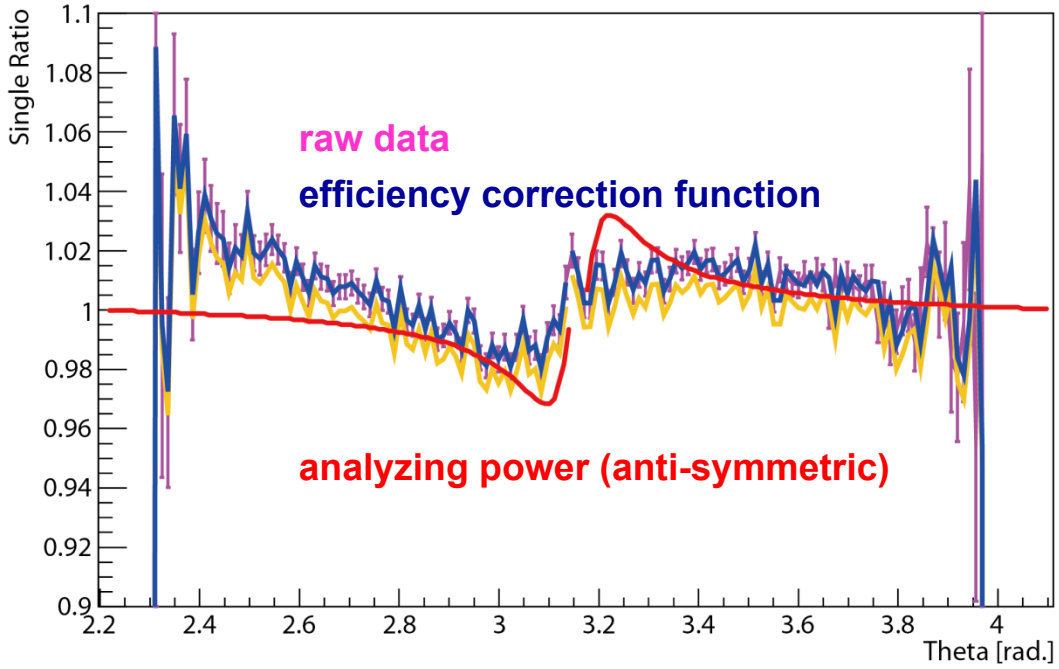
$$D(|\theta|,\gamma) = \frac{R^{UD}(-|\theta|,\gamma)}{R^{UD}(+|\theta|,\gamma)} = \left[\frac{1+Asym(|\theta|)}{1-Asym(|\theta|)}\right]^2$$

Resolved in two dimensional offline analysis

Symmetric detector is desired

Systematics-III : Accidental (fake V-track)

Mysterious asymmetry contradict with analyzing power



Understood in the CDC systematics study

Trial of analytical cancelation (not successful)

$$\varepsilon^U(\theta,\gamma) = \varepsilon^0(\theta,\gamma)(1+\alpha(\theta,\gamma))$$
$$\varepsilon^D(\theta,\gamma) = \varepsilon^0(\theta,\gamma)(1-\alpha(\theta,\gamma))$$

$$R^{UD}(-|\theta|,\gamma) = \frac{N^U(-|\theta|,\gamma)}{N^D(-|\theta|,\gamma)} = \frac{n_0(|\theta|)t^U[1+Asym(|\theta|)]\varepsilon^0(-|\theta|,\gamma)(1+\alpha(-|\theta|,\gamma))\eta^U_{PV}(\gamma)}{n_0(|\theta|)t^D[1-Asym(|\theta|)]\varepsilon^0(-|\theta|,\gamma)(1-\alpha(-|\theta|,\gamma))\eta^D_{PV}(\gamma)} = \frac{t^U[1+Asym(|\theta|)](1+\alpha(-|\theta|,\gamma))\eta^U_{PV}(\gamma)}{t^D[1-Asym(|\theta|)](1-\alpha(-|\theta|,\gamma))\eta^D_{PV}(\gamma)}$$

$$R^{UD}(+|\theta|,\gamma) = \frac{N^U(+|\theta|,\gamma)}{N^D(+|\theta|,\gamma)} = \frac{n_0(|\theta|)t^U[1-Asym(|\theta|)]\varepsilon^0(+|\theta|,\gamma)(1+\alpha(+|\theta|,\gamma))\eta^U_{PV}(\gamma)}{n_0(|\theta|)t^D[1+Asym(|\theta|)]\varepsilon^0(+|\theta|,\gamma)(1-\alpha(+|\theta|,\gamma))\eta^D_{PV}(\gamma)} = \frac{t^U[1-Asym(|\theta|)](1+\alpha(+|\theta|,\gamma))\eta^U_{PV}(\gamma)}{t^D[1+Asym(|\theta|)](1-\alpha(+|\theta|,\gamma))\eta^D_{PV}(\gamma)}$$