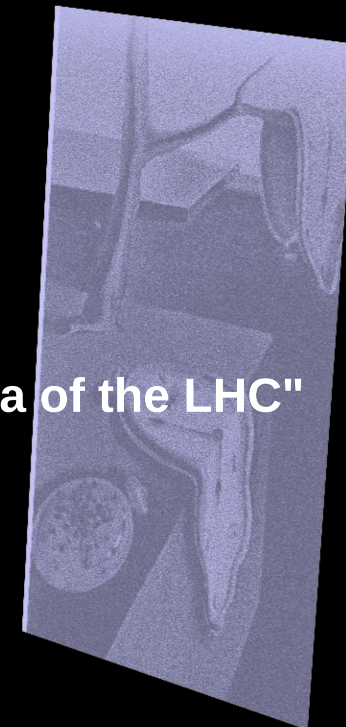
The MTV T-Violation Experiment with 8Li

Jiro Murata

Rikkyo University

for the MTV collaboration



Solvay Workshop on "Beta-Decay Weak Interaction Studies in the Era of the LHC"
Brussels, 3 - 5 September 2014

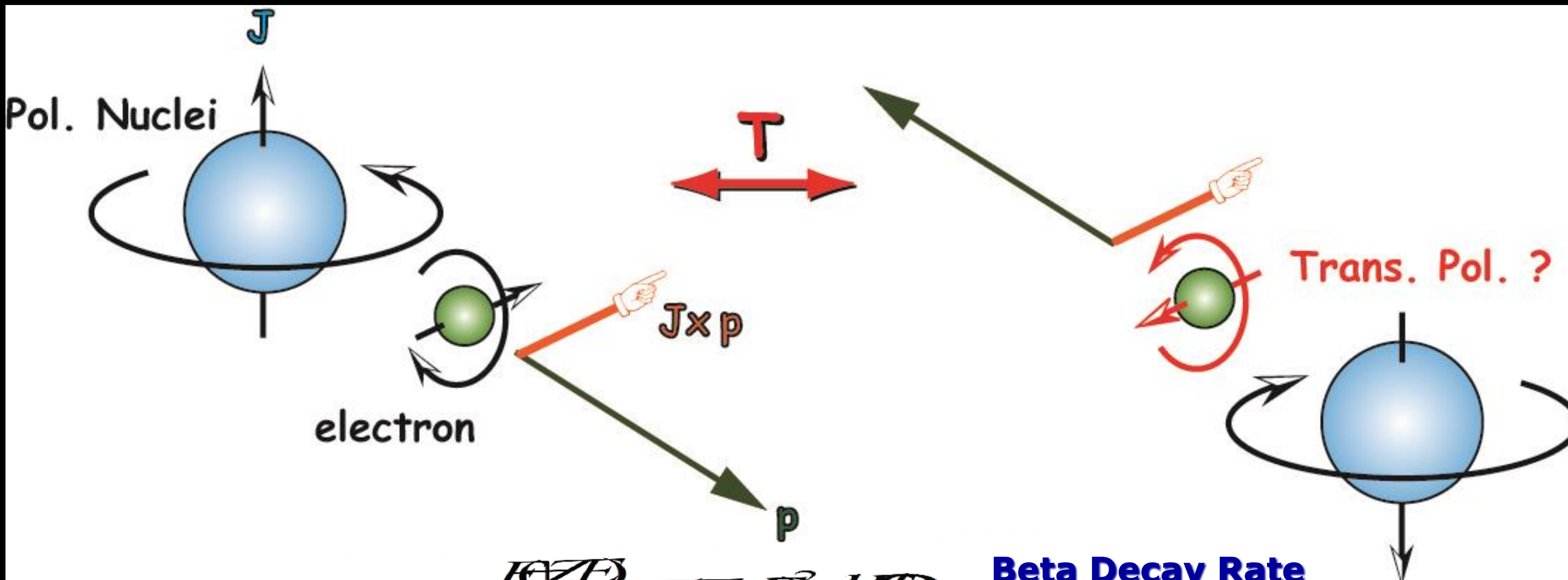
INTERNATIONAL SOLVAY INSTITUTES
BRUSSELS

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, T. Yoshida, Y. Sakamoto
Tohoku-CYRIC H. Kawamura / RIKEN H. Baba
TRIUMF J. Behr, M. Pearson, P. Levy, R. Openshaw

TRIUMF

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

MTV Mott polarimetry for T-Violation exp.



Beta Decay Rate

$$\omega(\langle \vec{J}\rangle \mid E_e,\Omega_e)\,dE_e\,d\Omega_e = \frac{F(Z,E_e)}{(2\pi)^4}\,p_e E_e (E_0-E_e)^2\,dE_e\,d\Omega_e$$

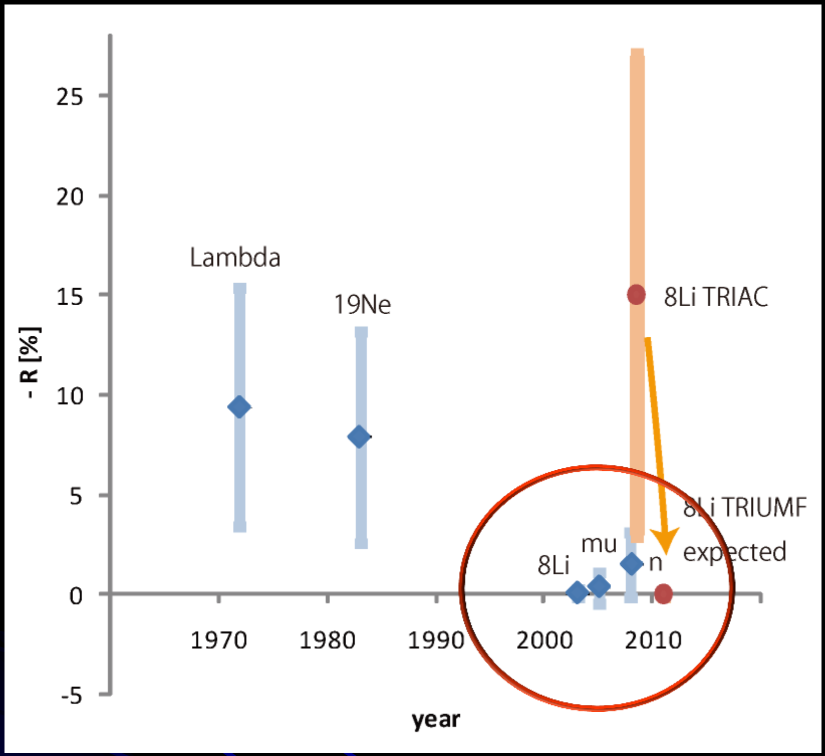
$$\times\,\xi\left\{1 + b\frac{m}{E_e} + \frac{\vec{p}_e}{E_e}\cdot\left(A\frac{\langle\vec{J}\rangle}{J} + G\vec{\sigma}\right) + \vec{\sigma}\cdot\left[N\frac{\langle\vec{J}\rangle}{J} + Q\frac{\vec{p}_e}{E_e+m}\left(\frac{\langle\vec{J}\rangle}{J}\cdot\frac{\vec{p}_e}{E_e}\right) + R\frac{\langle\vec{J}\rangle}{J}\times\frac{\vec{p}_e}{E_e}\right]\right\}$$

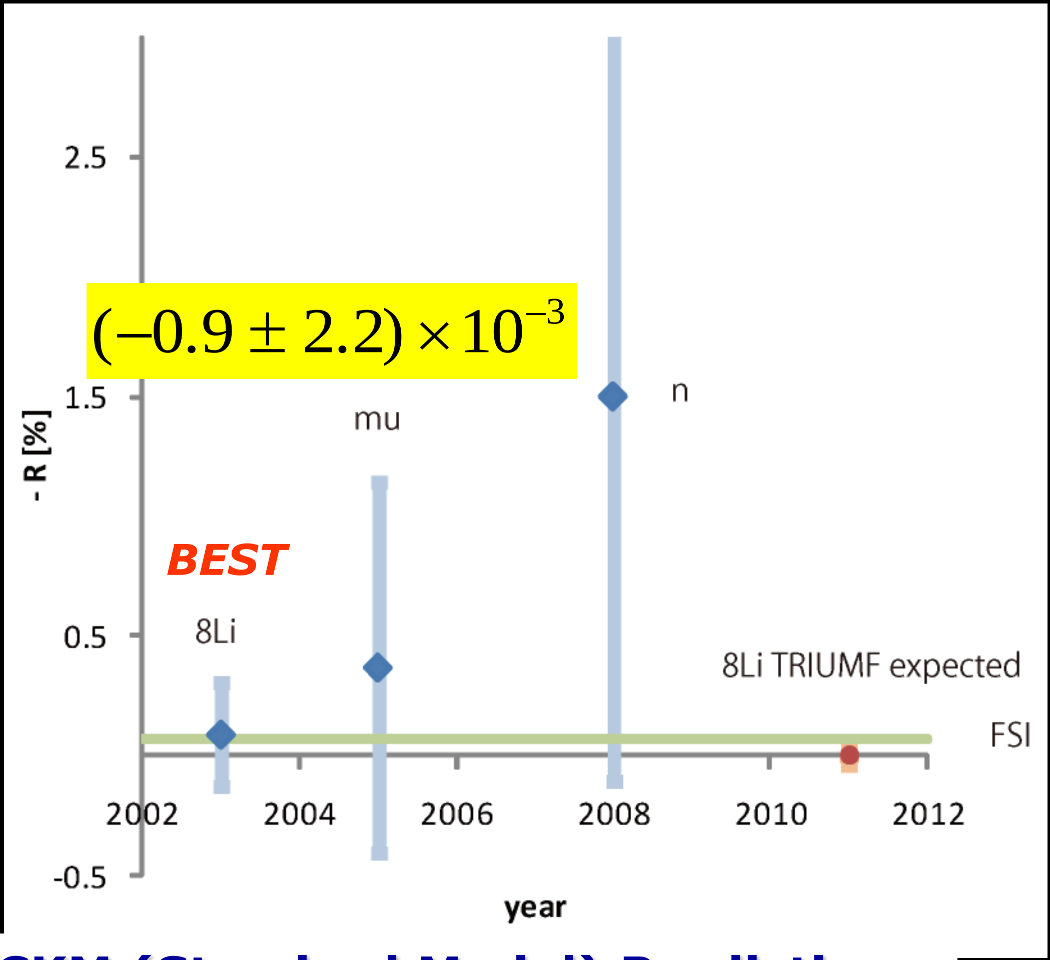
Required Components

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

Zero or Non-Zero ?

Past Studies





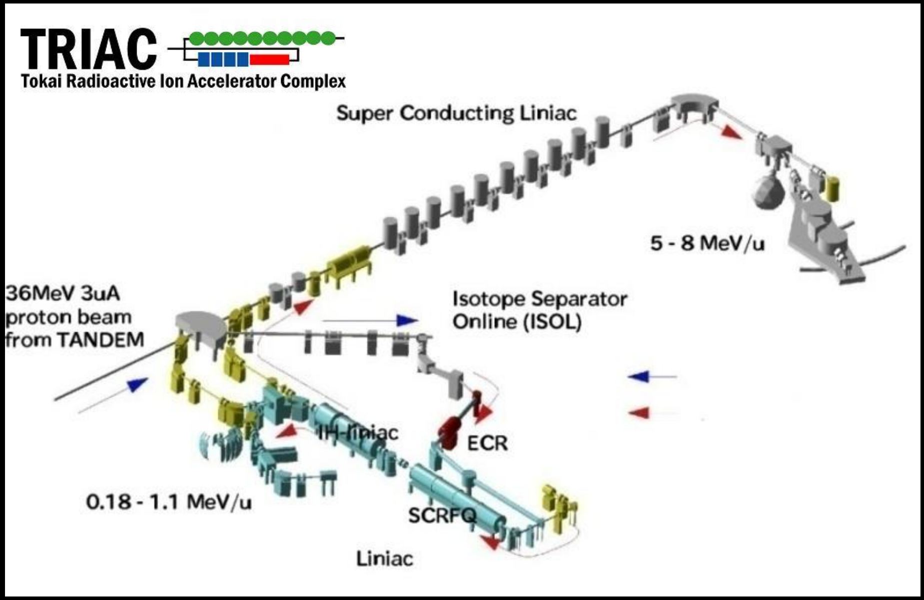
Experimental Sensitivity >> CKM (Standard Model) Predictions

→ **Search of New Physics beyond the Standard Model**

Suppression of CKM effect is desired

u, d system = Normal Nuclear is rather better system

Polarized 8Li Beam Facilities



178keV/u @ 10^5pps

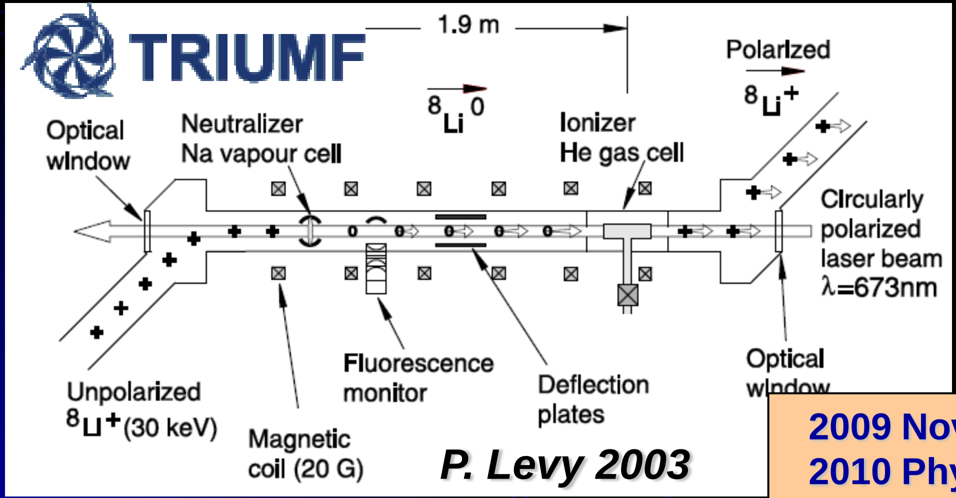
8% polarization

Ann. Pt 20um @500Gauss

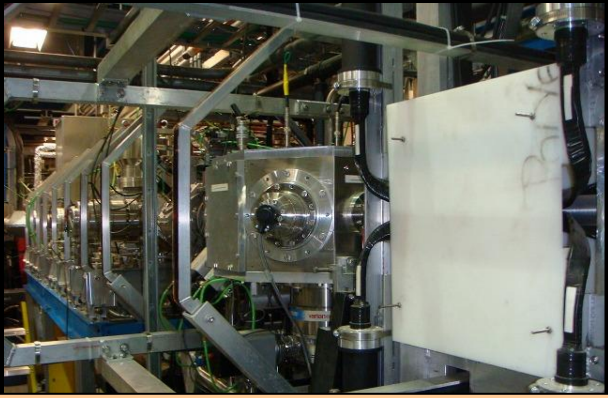
Tilted Foil : 3ug/cm² Polystyrene x 20 @ 70deg.

2008 Apr: Unpol. Test Exp.
2008 Sep. Physics Run : 40% precision

Y. Hirayama 2007



P. Levy 2003



28keV @ 10^7pps

80% polarization

500MeV 100uA p + Nb/Ta

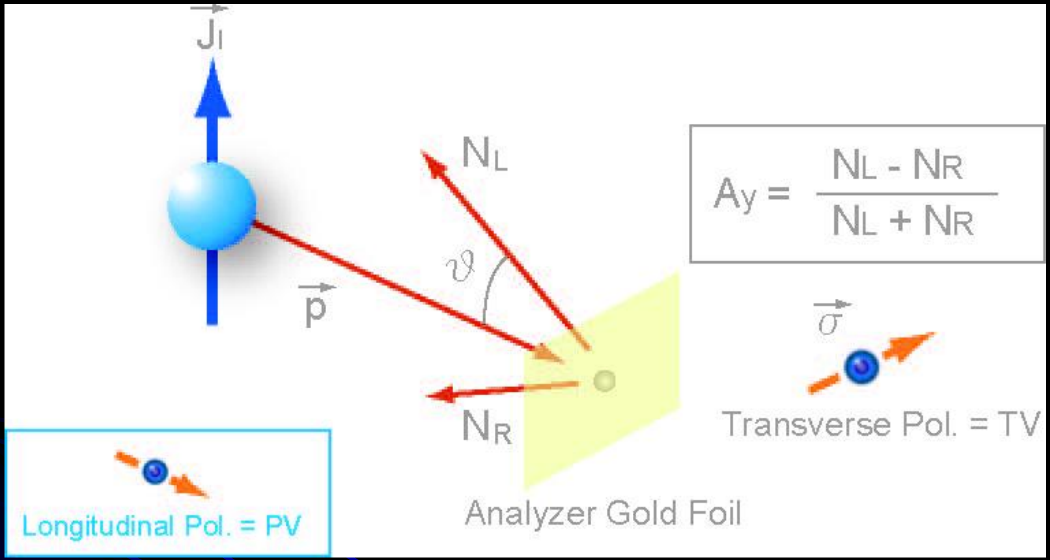
Al 10um @500Gauss

Collinear Laser Optical Pumping

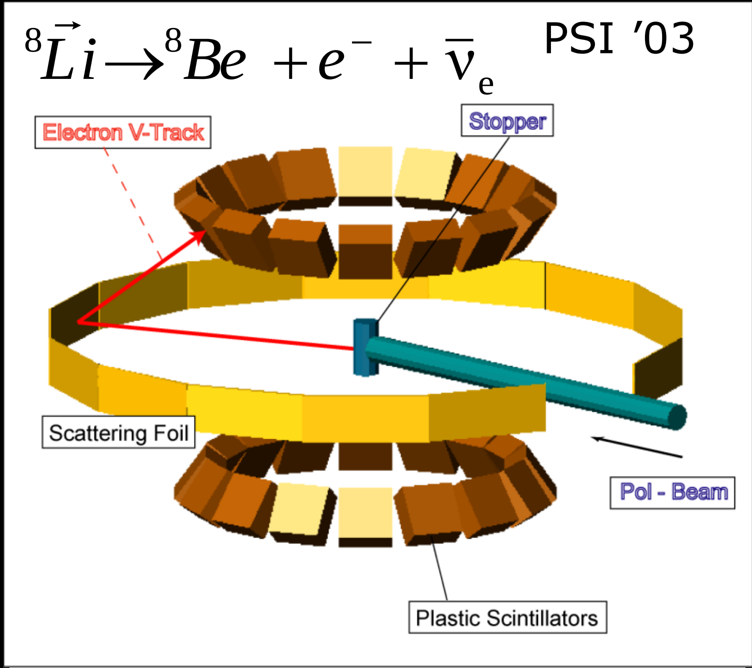
2009 Nov. Test Exp. : 1% precision Run-I
2010 Physics Run : 0.1% precision achieved Run-II
2011 CDC commissioning Run-III
2012-13 CDC full setup test Run-IV & V

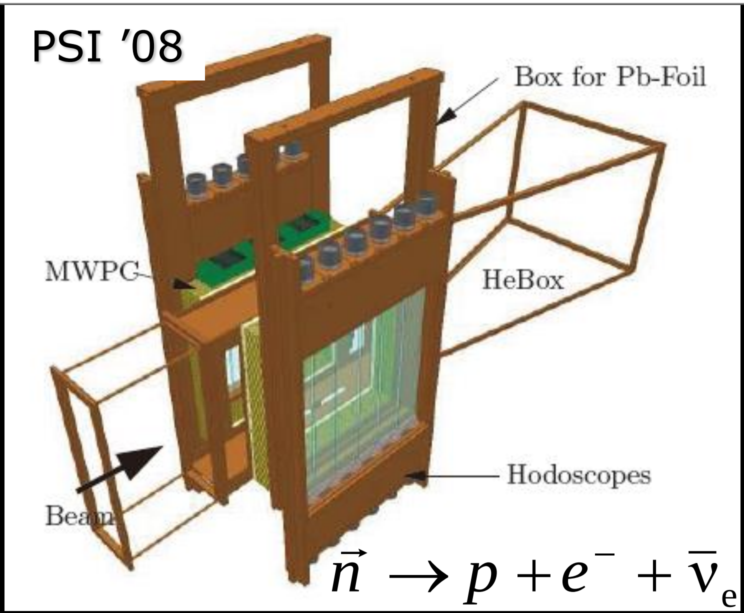
Transverse Polarization Measurement

Utilizing Analyzing Power of Mott Scattering



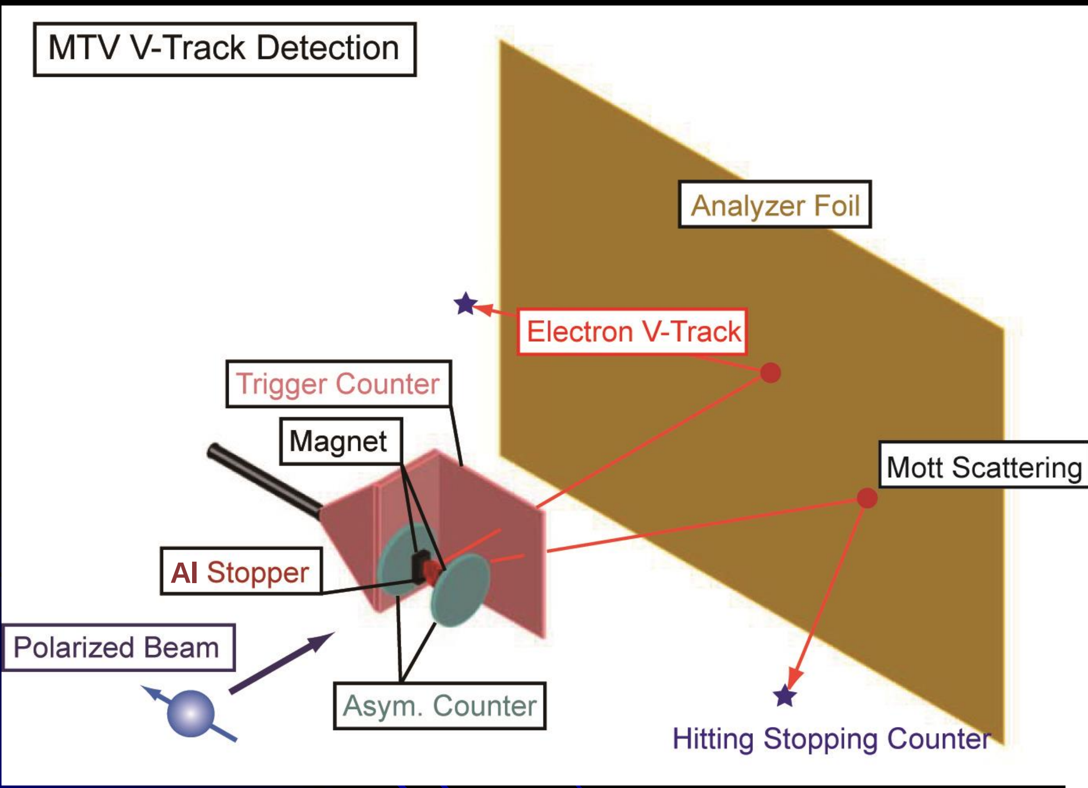
UP/DOWN Asymmetry in Mott Scattering

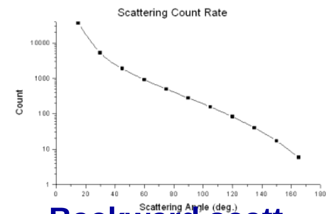




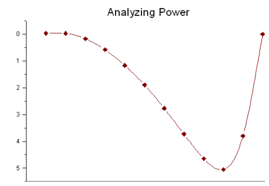
Principle and Experimental Setup

Measuring Mott Scattering using Drift Chamber





Backward scatt.
~ 10^- 4



Analyzing Power
~ 50% max.

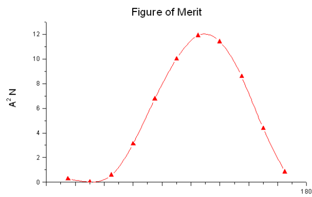
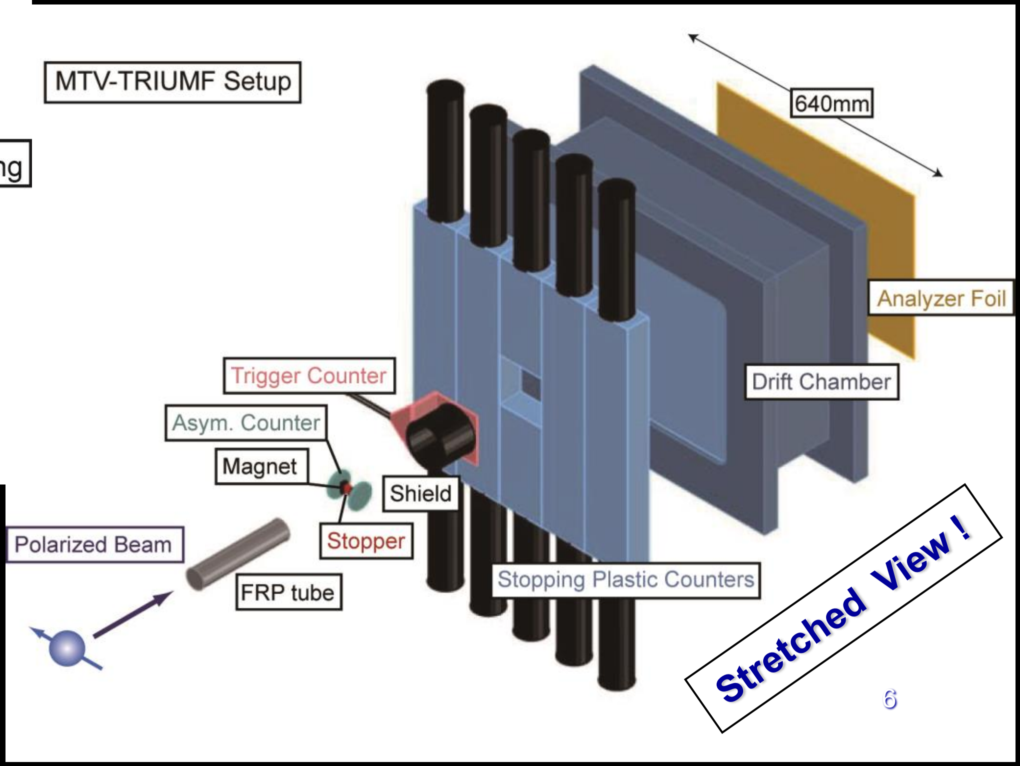


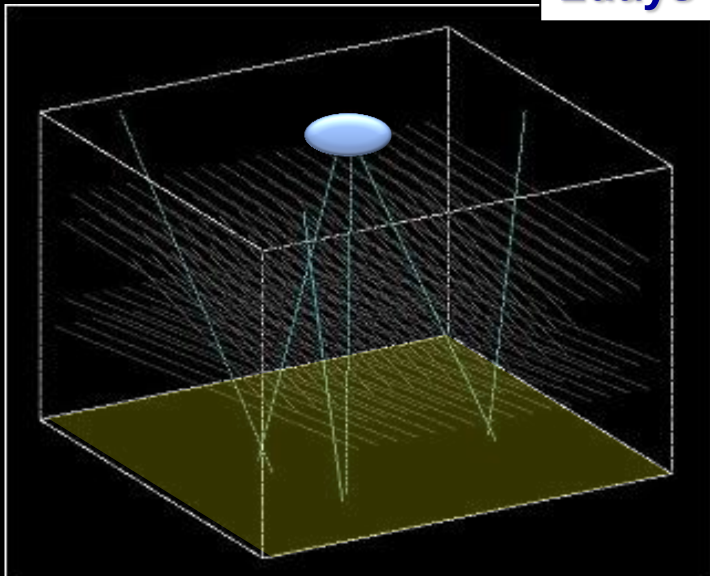
Figure of Merit
max. at 110deg.



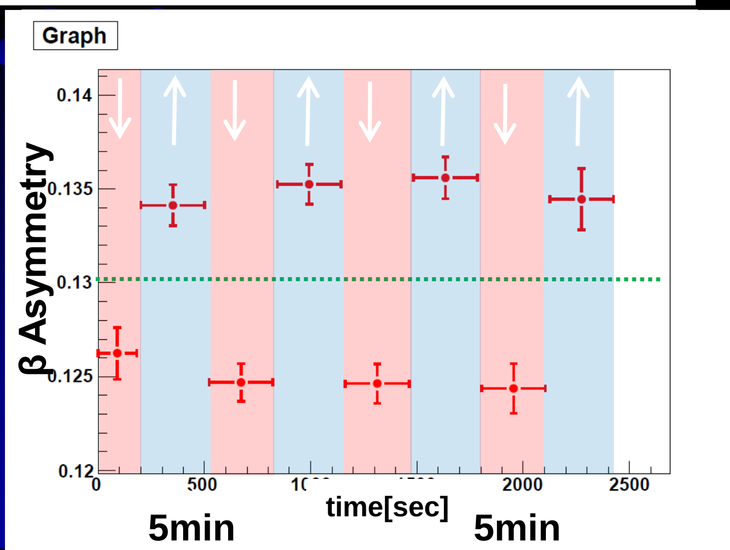
Transverse Polarized 8Li ~10^7 pps – 80% pol. @ 30keV
Stopper: Aluminium at room temperature, B0=500G

KEK-TRIAC Experiment

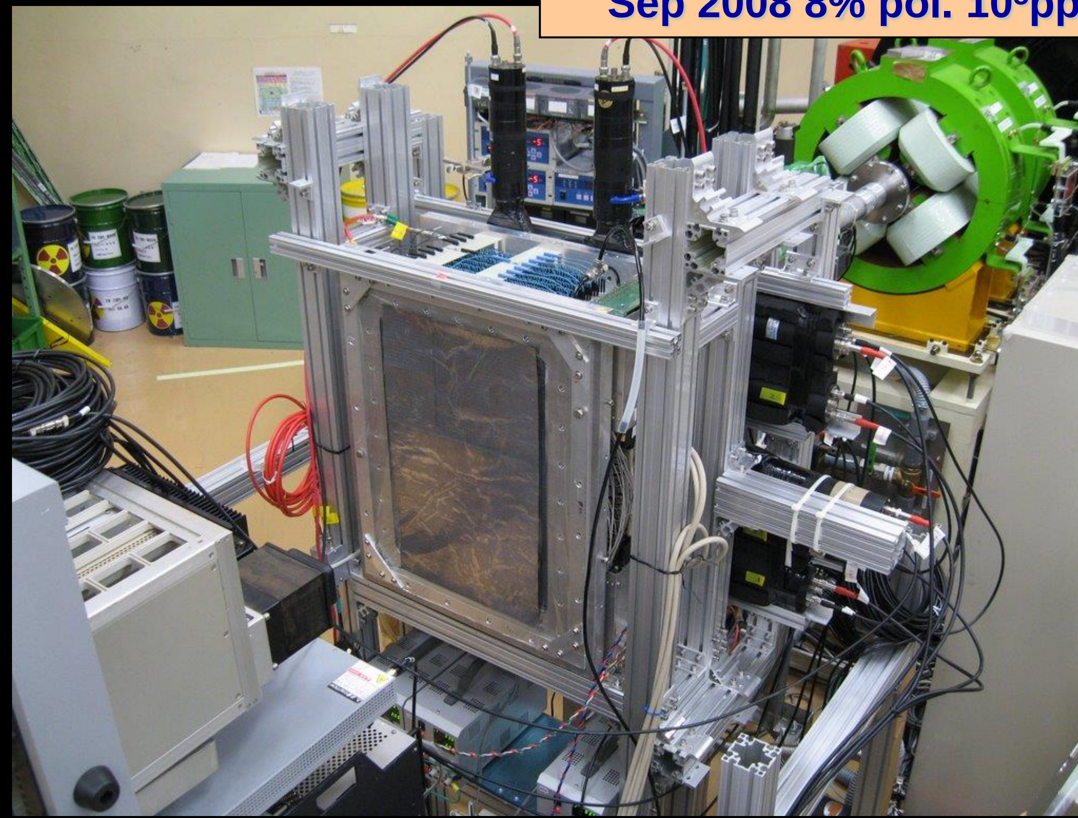
2days Physics Run performed Sep. 2008



Confirm V-Track reconstruction !

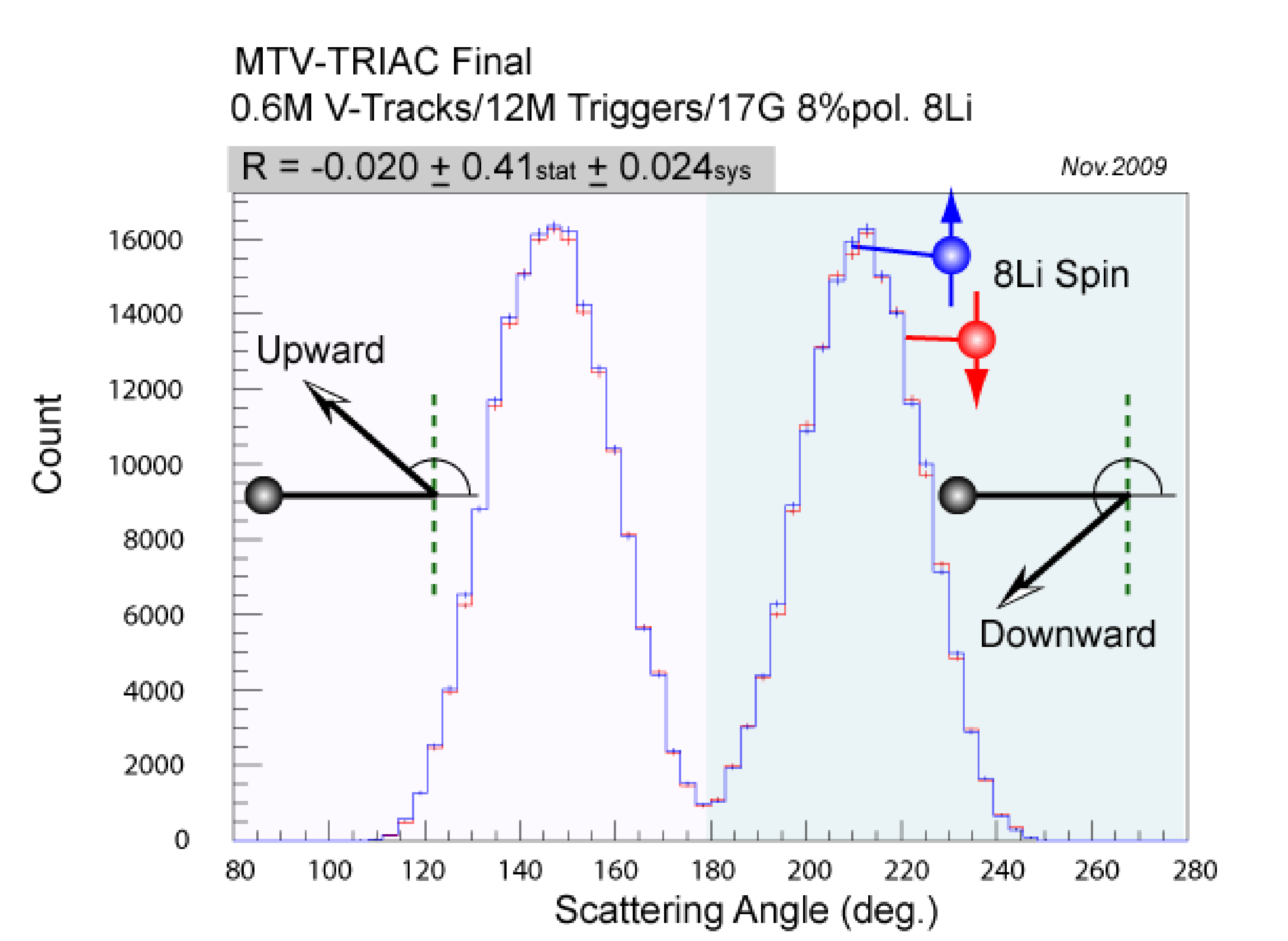


Apr 2008 Unpol. 10^4pps
Sep 2008 8% pol. 10^5pps



0.6M V-Track events obtained with 8% pol. 10^5pps 8Li beam

Results of KEK-TRIAC Experiment



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

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

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

effective analyzing power

$$<\varepsilon> \sim 0.065$$

polarization $<J> \sim 0.08$

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

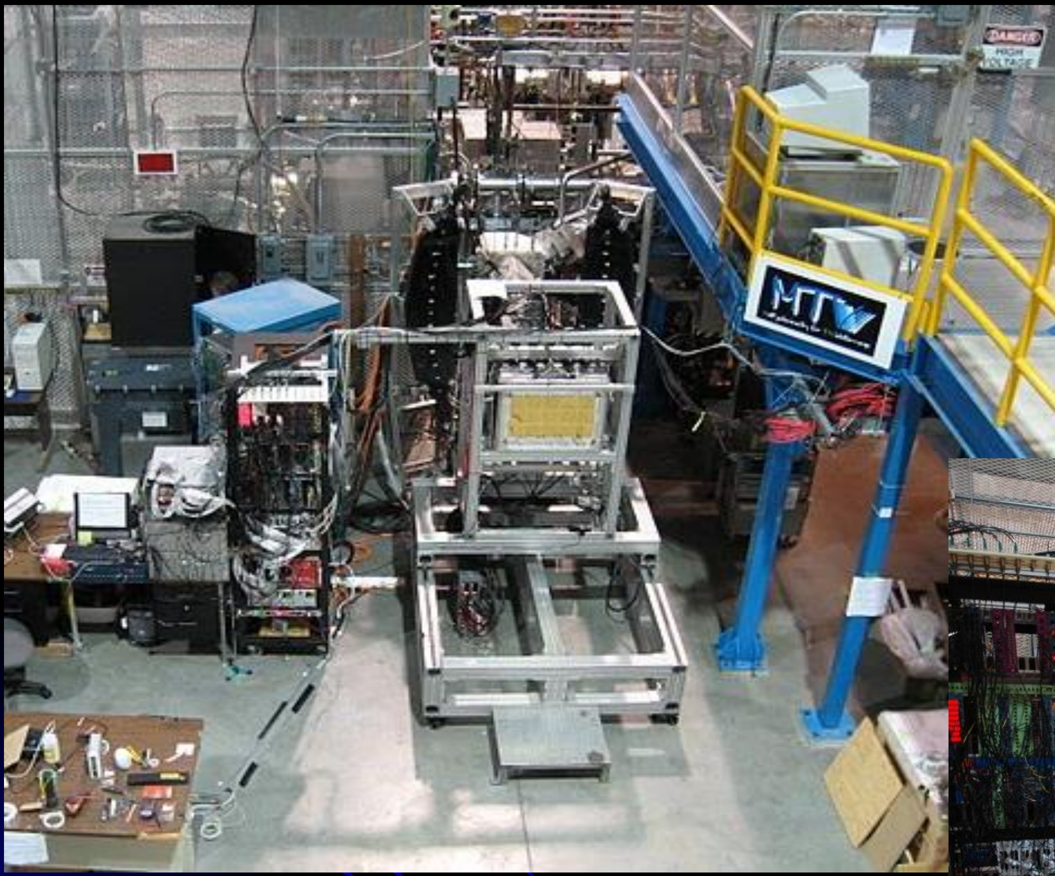
40% precision for (8% pol.), 1.3x10^{5}pps x 2days (37hours)

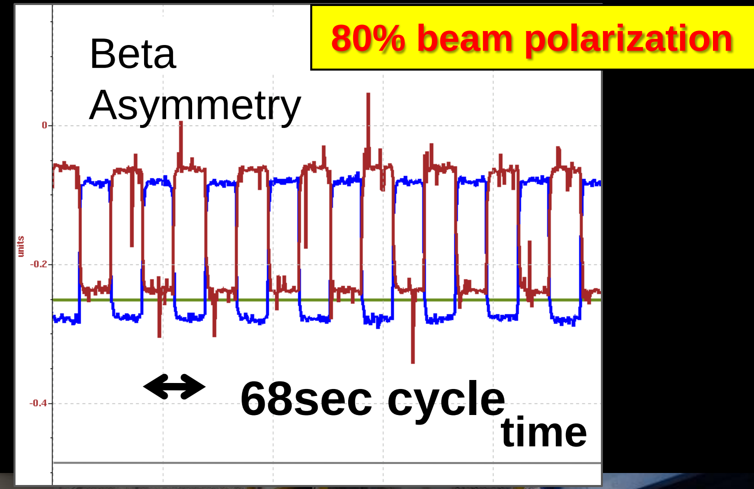
First Results from Reliable Tracking Measurement !

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

TRIUMF

MTV Run-I Commissioning at TRIUMF-ISAC



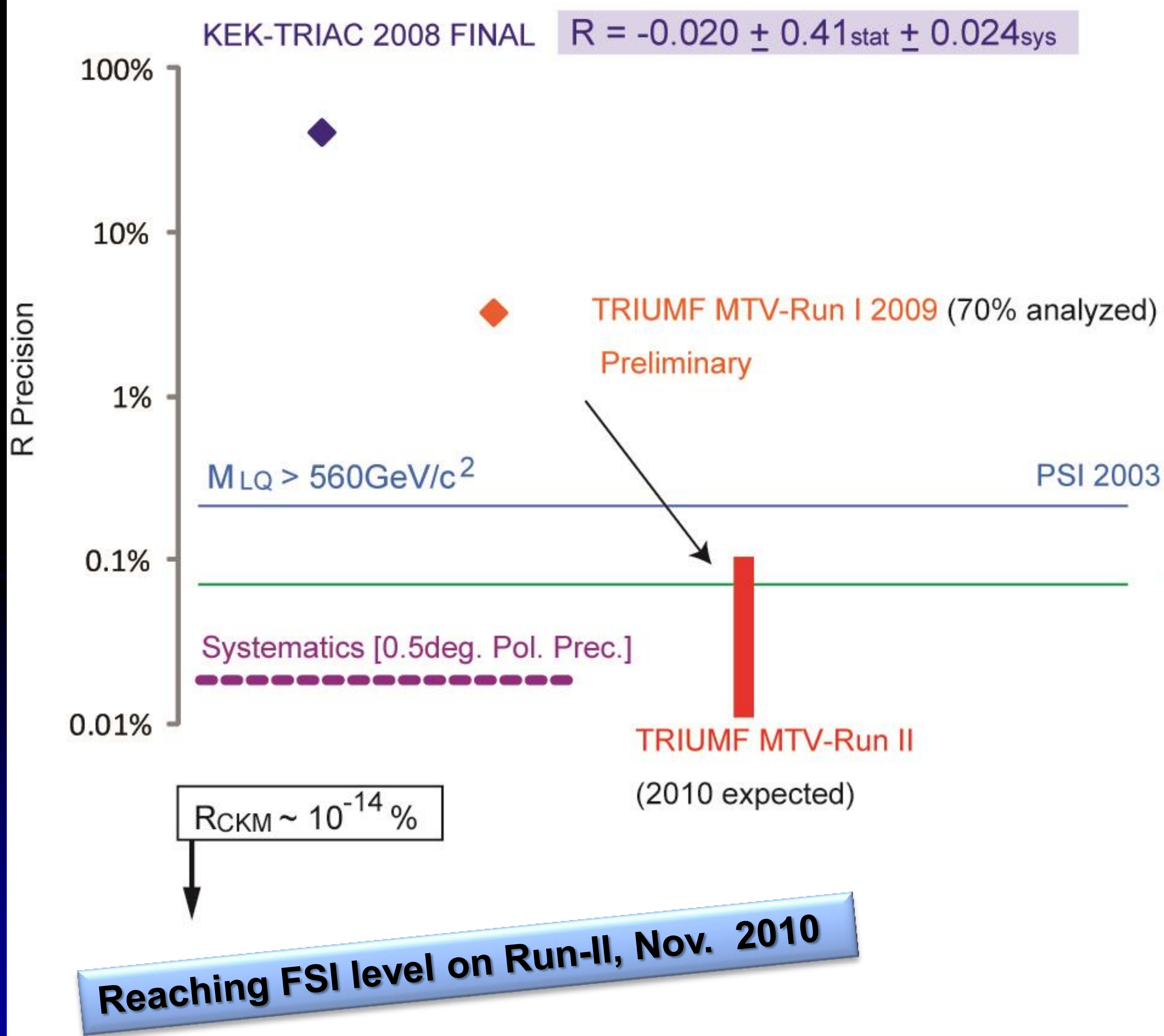


Shipping from Japan in July 2009
100MBq 90Sr Commissioning in August
First Test Beam in Nov. 2009
Physics Run : 2010

Expected Sensitivity at MTV Run-II in 2010

Improvement [stat. FOM]

100um Foil > 10um Foil		x 1/10
Efficiency 100% > 10%		x1/10
Pol 8% > 80%	(x10)	x100
Beam 10^5 > 10^7		x100
Total		x100



$R = 0.065 \pm 0.036_{stat}$

$R = (0.09 \pm 0.22_{stat+sys})\%$

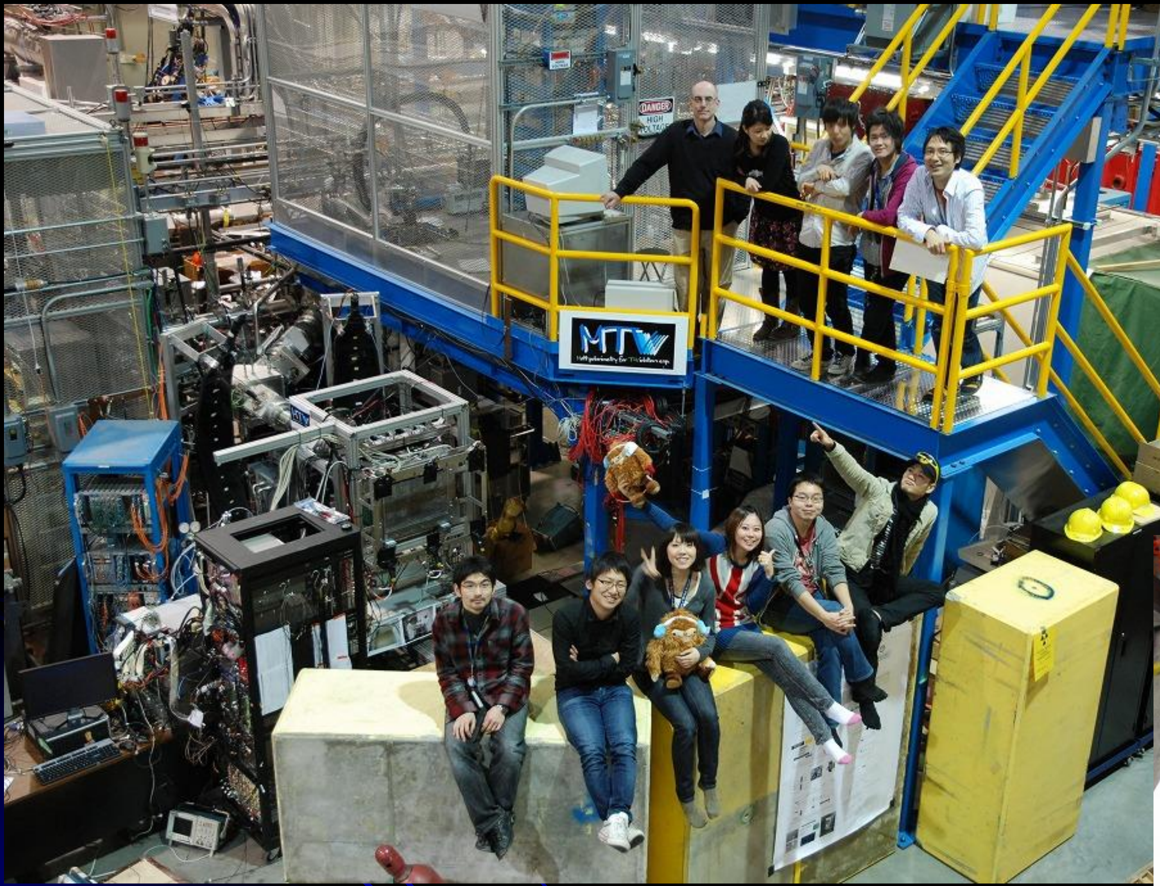
$0.09\% = (0.16 - 0.07)\%$

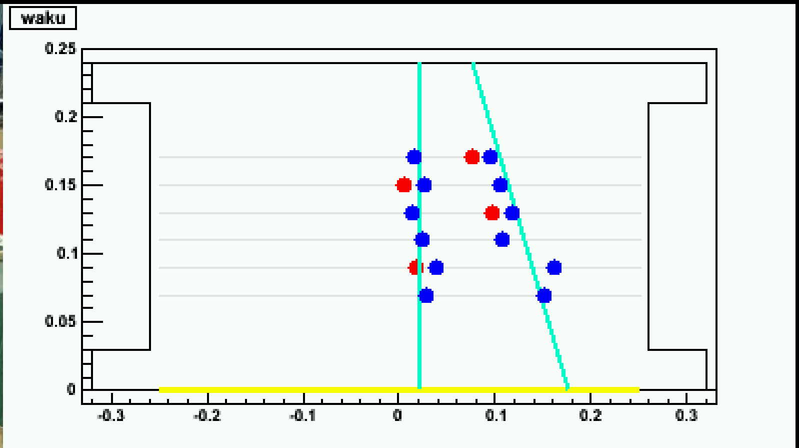
Standard Model FSI $R = +0.07\%$

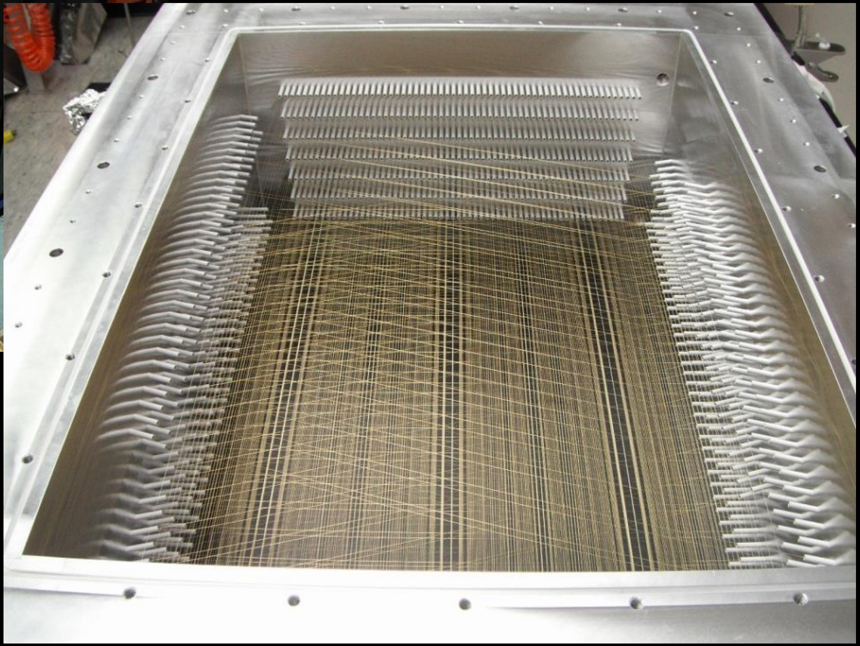
Improvement [stat. FOM]

DAQ 1kHz > 100kHz	x10
10um Foil > 100um Foil	x10
2days > 14days	x10
Efficiency 10% > 100%	x10
Trigger Acceptance	x 2
Ana. power 6.5% > 11%	x 2
Total	$x10^4$

MTV Run-II : First Physics Run 2010

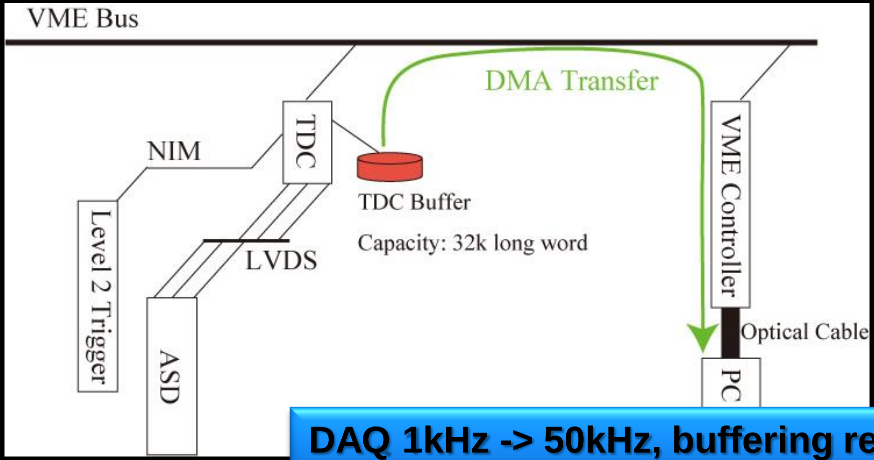




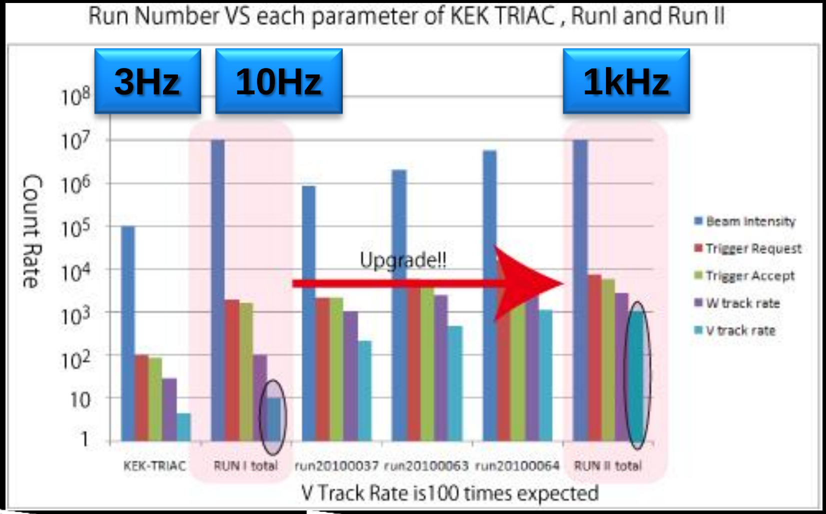


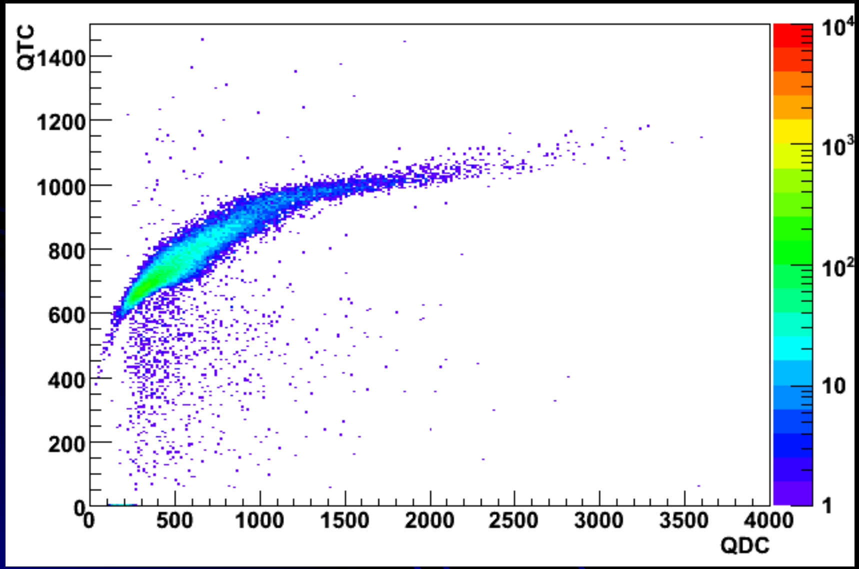
1 week data production in Nov. 2010
First Physics Run
28G Lvl-1 / 3G Lvl-2 Trigger
2.5G events recorded
~ 250M V-tracks

Run-II achievement

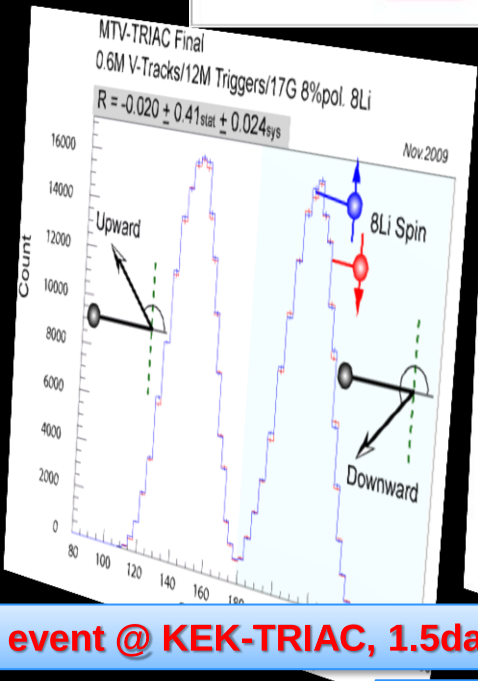


DAQ 1kHz -> 50kHz, buffering readout

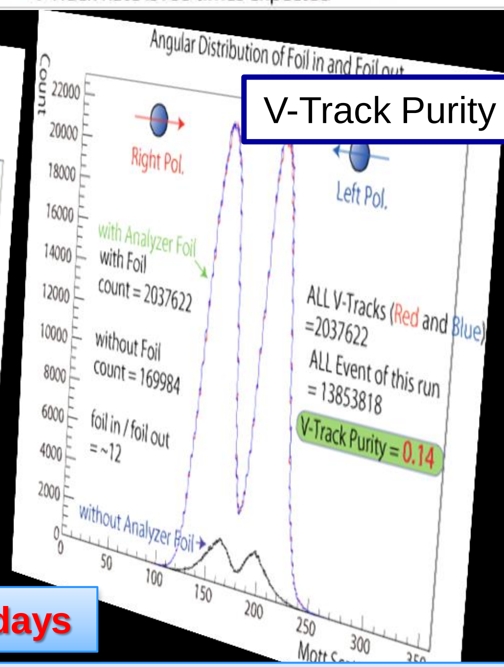




pQTC Charge readout using TDC



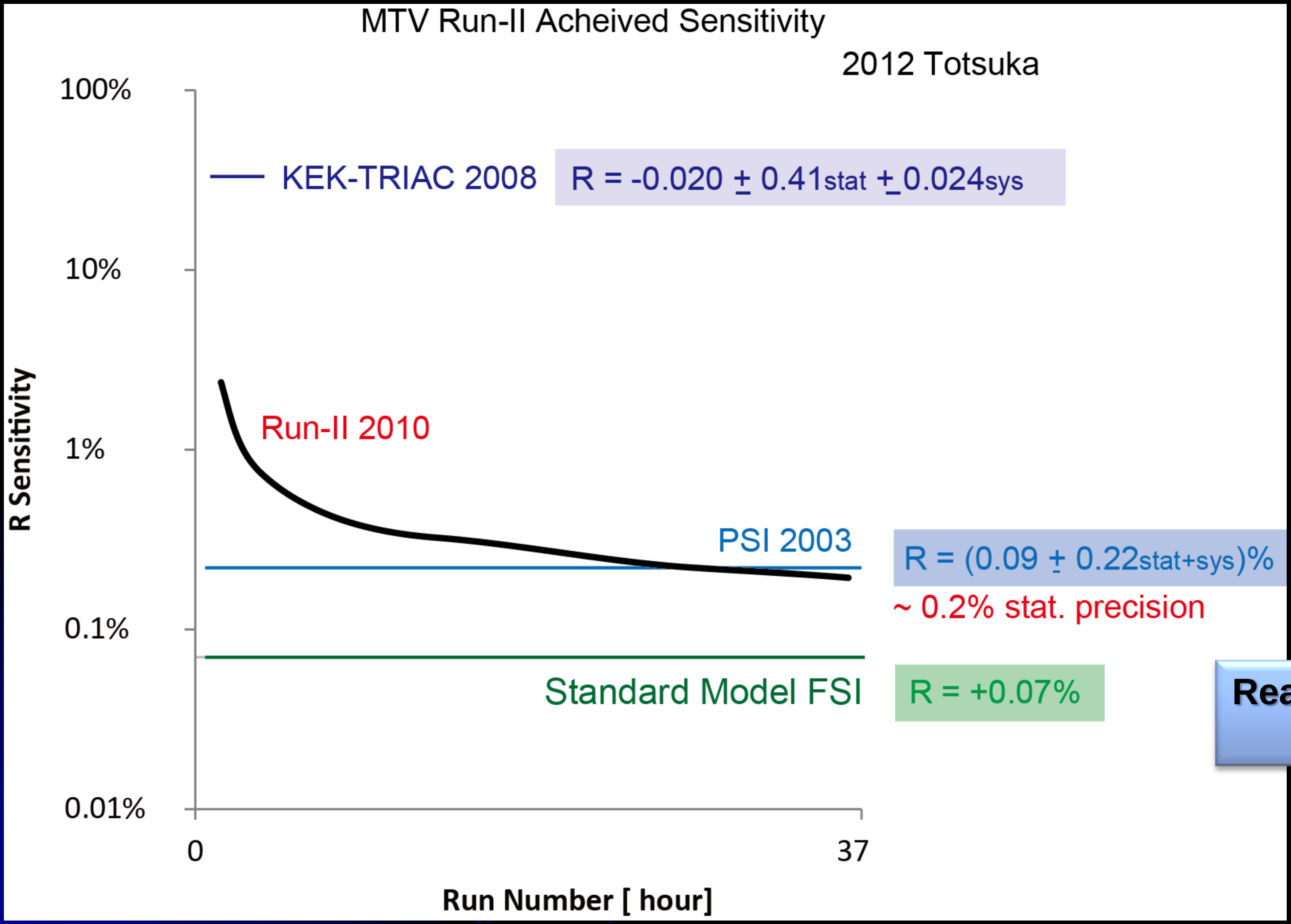
670k event @ KEK-TRIAC, 1.5days



V-Track Purity = **0.14**

250M event @ TRIUMF Run II, 37 hours of 5.5days

Achieved Statistical Precision



0.6M events @ 8% pol

250M events @ 80% pol

Reaching the highest stat. precision !

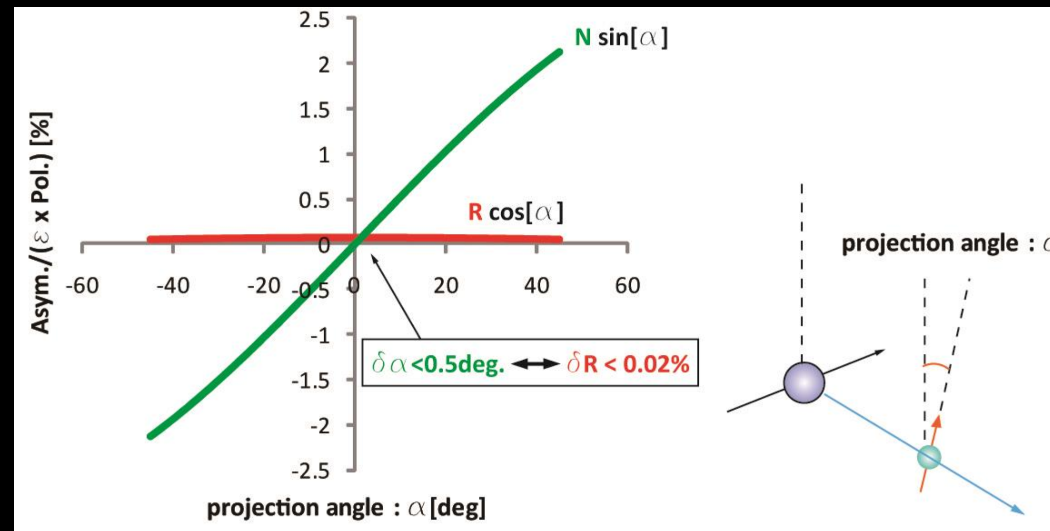
(only 37 hours from 5.5days data taking was effective due to beam spot problem ..)

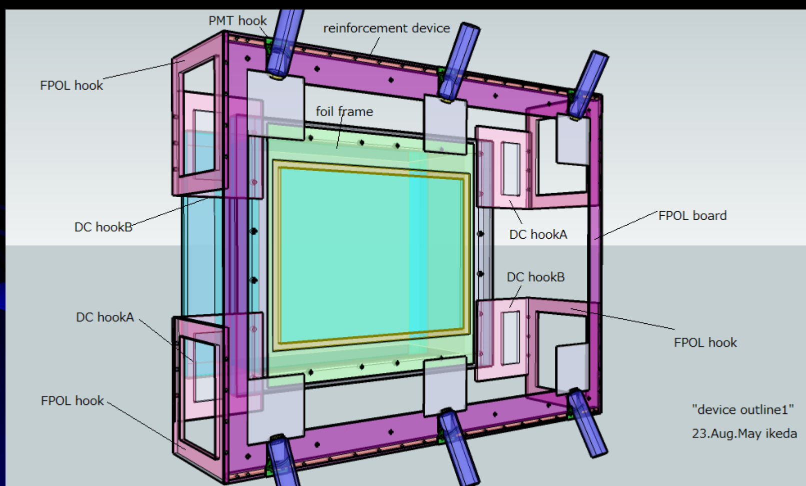
Systematics –I : N-correlation

Source = Tilting of beam polarization angle

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

N-correlation





FPOL (Forward Polarimeter)

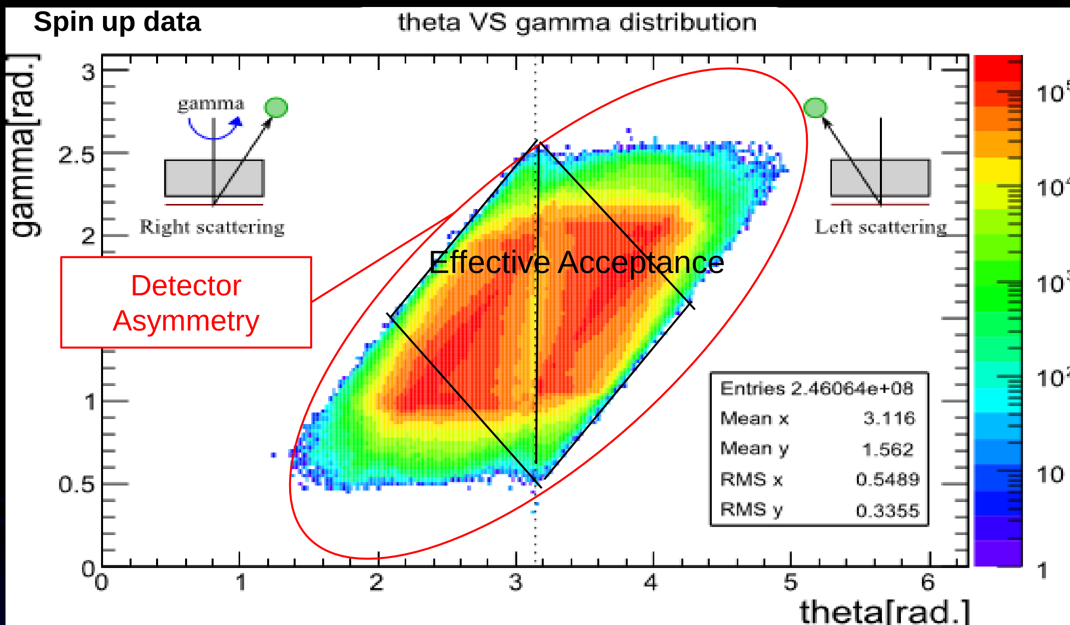
Delta_α = 6.1 +- 0.29 [mrad.]

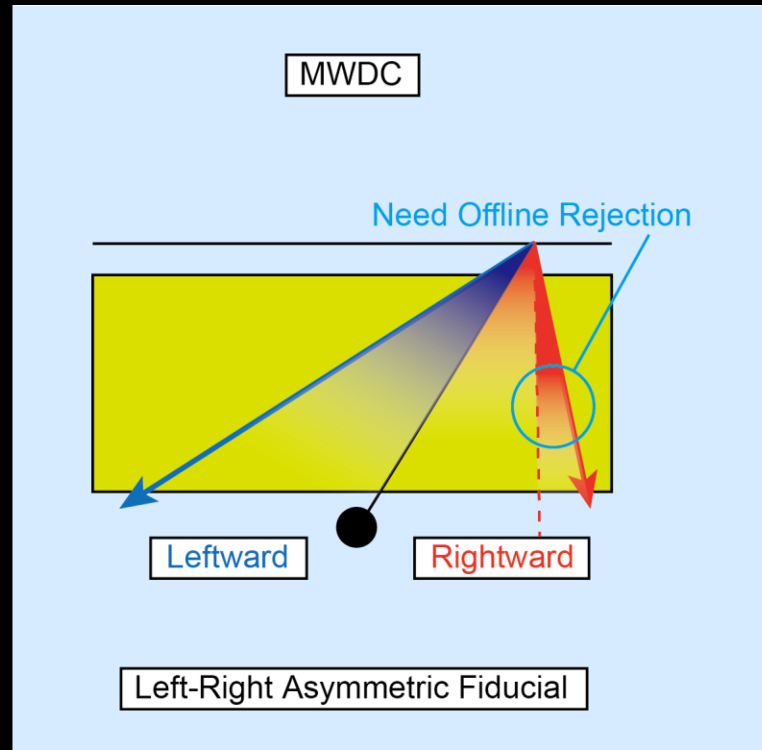
$$R_{N-correlation} = 0.024 \pm 0.029\%$$

Axial-Symmetric detector is desired

Systematics –II : Detector Asymmetry

Source = Detector Asymmetry + Parity Violation





Asymmetric Acceptance

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

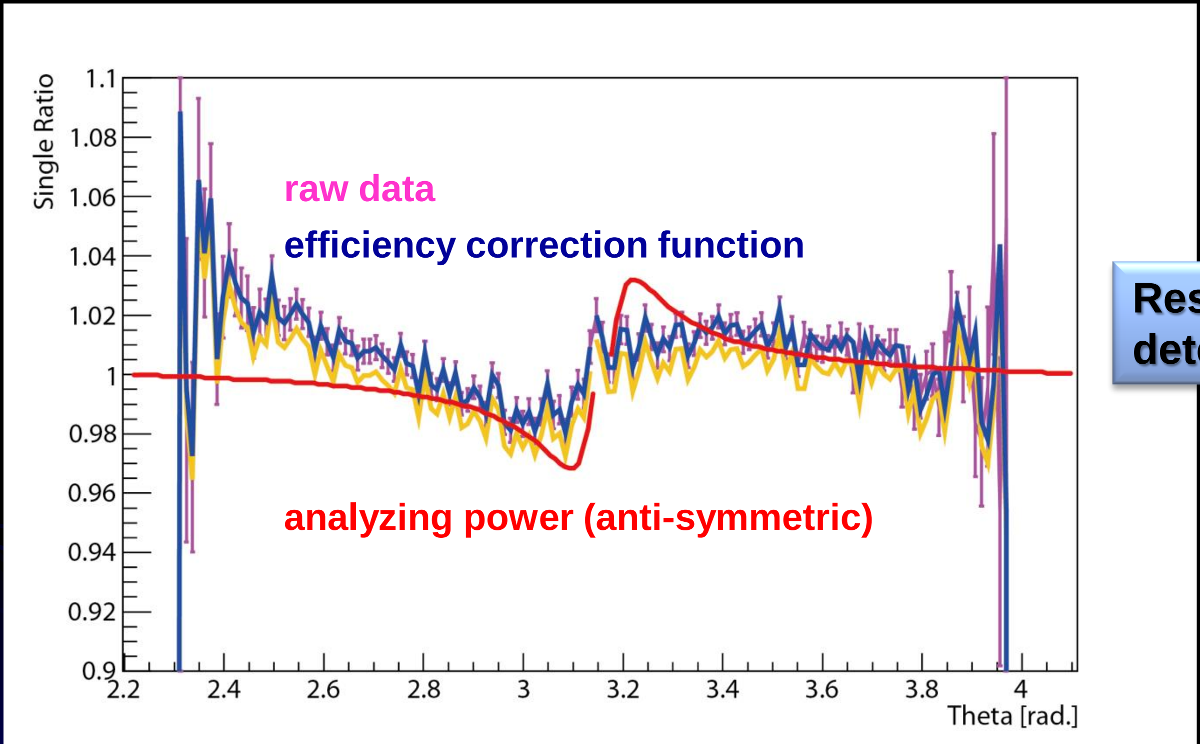
$$D(|\theta|,\gamma) = \frac{R^{UD}(-|\theta|,\gamma)}{R^{UD}(+|\theta|,\gamma)} = \left[\frac{1+Asym(|\theta|)}{1-Asym(|\theta|)}\right]^2$$

Resolved in two dimensional analysis

Symmetric detector is desired

Systematics-III : Efficiency

Source = Non-Isotropic Efficiency Non-conservation during beam spin-flip



Power un-stability on Vth / LV / HV under
high counting rate environment

Resolved in efficiency determination analysis using unpol. data

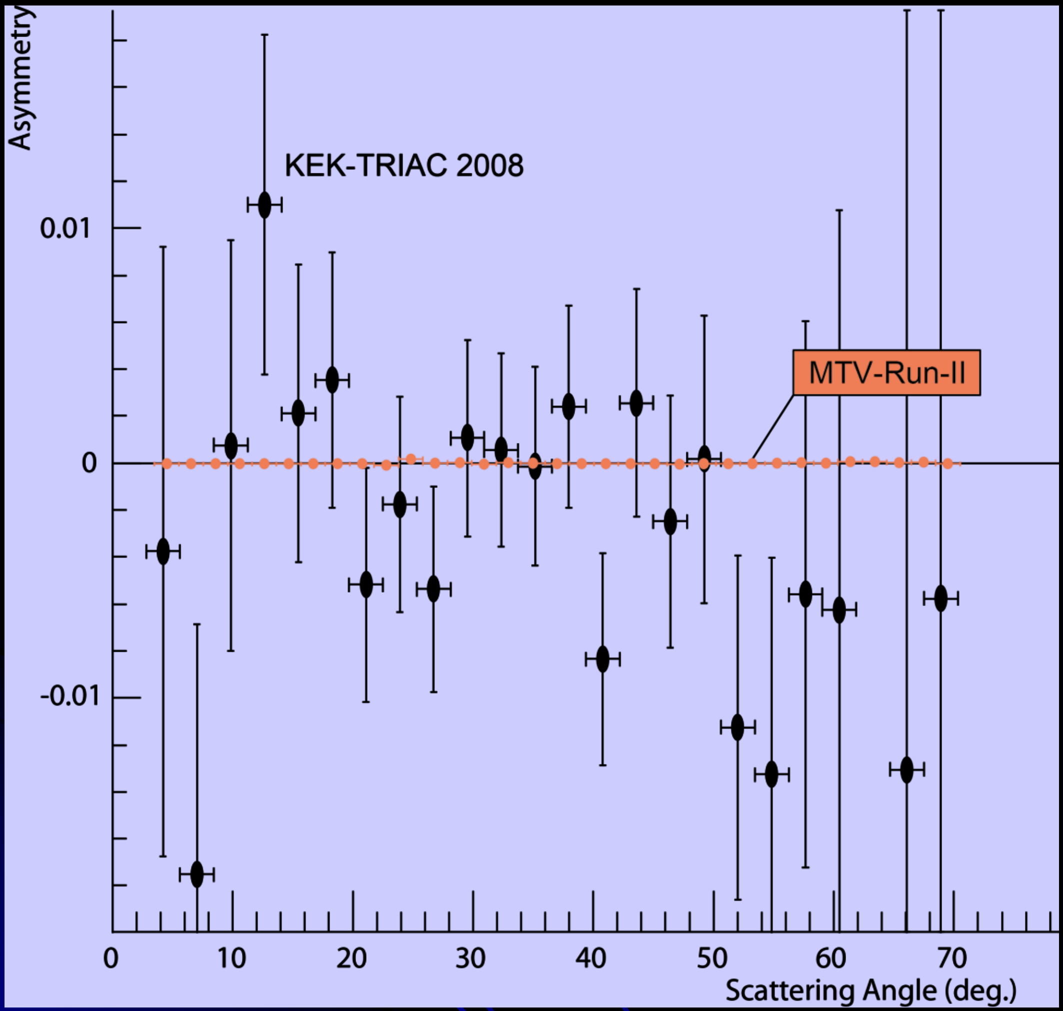
$$\varepsilon^U(\theta,\gamma)=\varepsilon^0(\theta,\gamma)(1+\alpha(\theta,\gamma))$$
$$\varepsilon^D(\theta,\gamma)=\varepsilon^0(\theta,\gamma)(1-\alpha(\theta,\gamma))$$

Low intensity data taking is desired

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

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

Run-II result

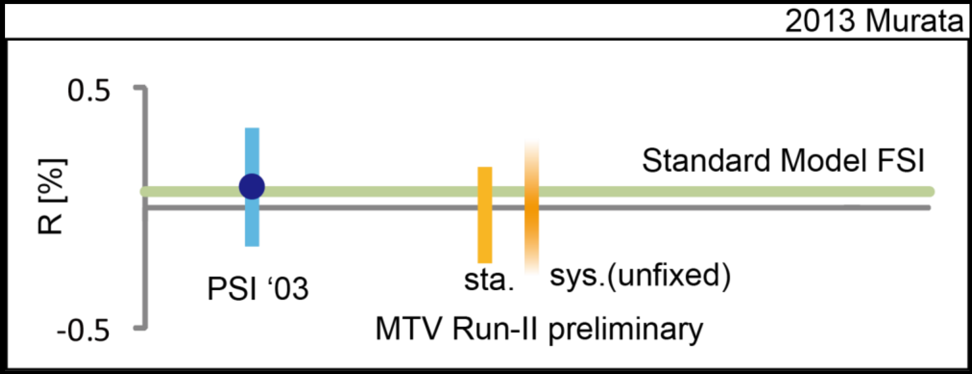


Systematics :

1. **Beam pol. tilting**
2. **Detector asymmetry**
3. **Efficiency un-stability**

Almost Corrected …

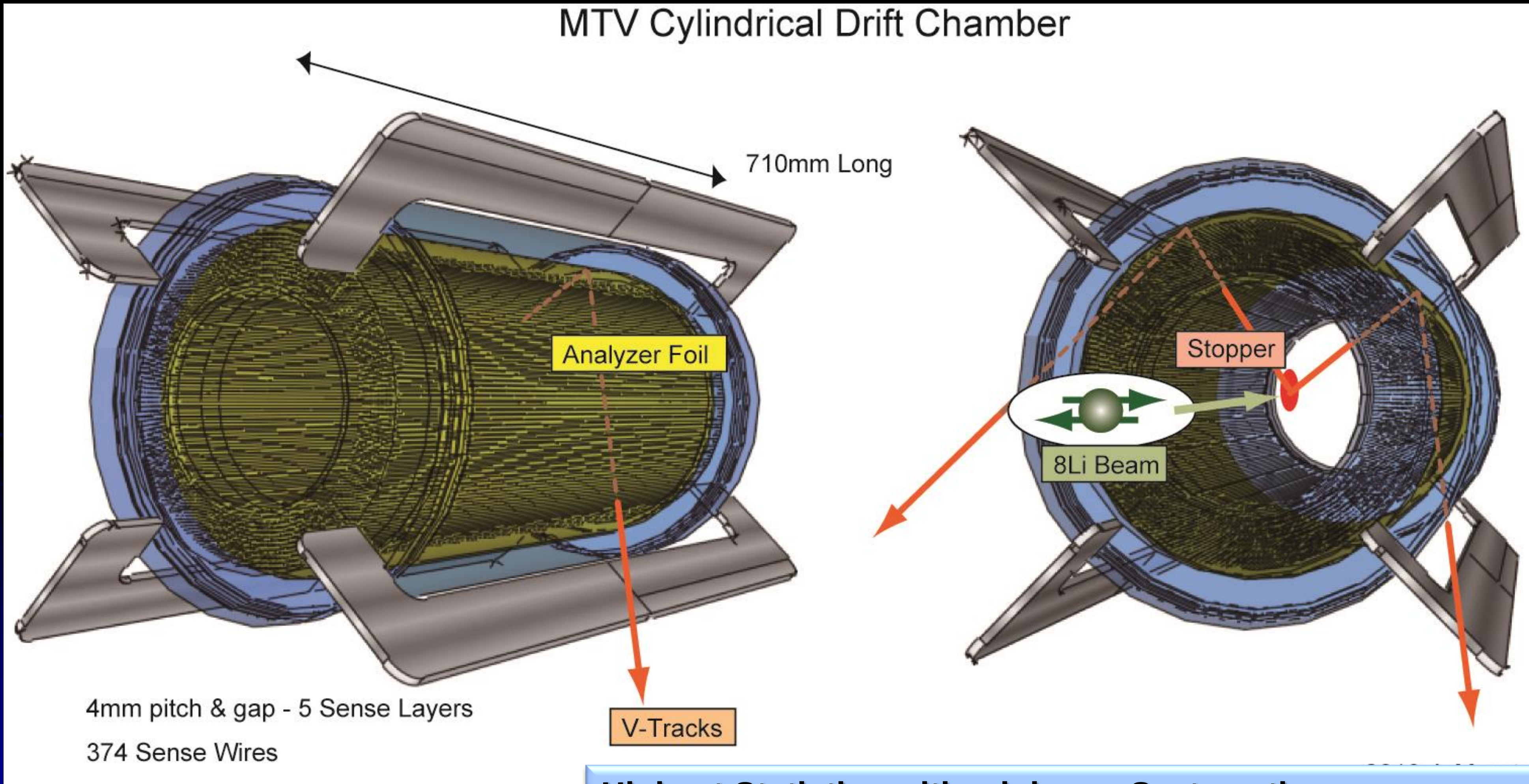
$$Asym \sim (0.2 \pm 2.1) \times 10^{-4}$$



Still has difficulty in unpol. data

Next Generation Detector: MTV-CDC

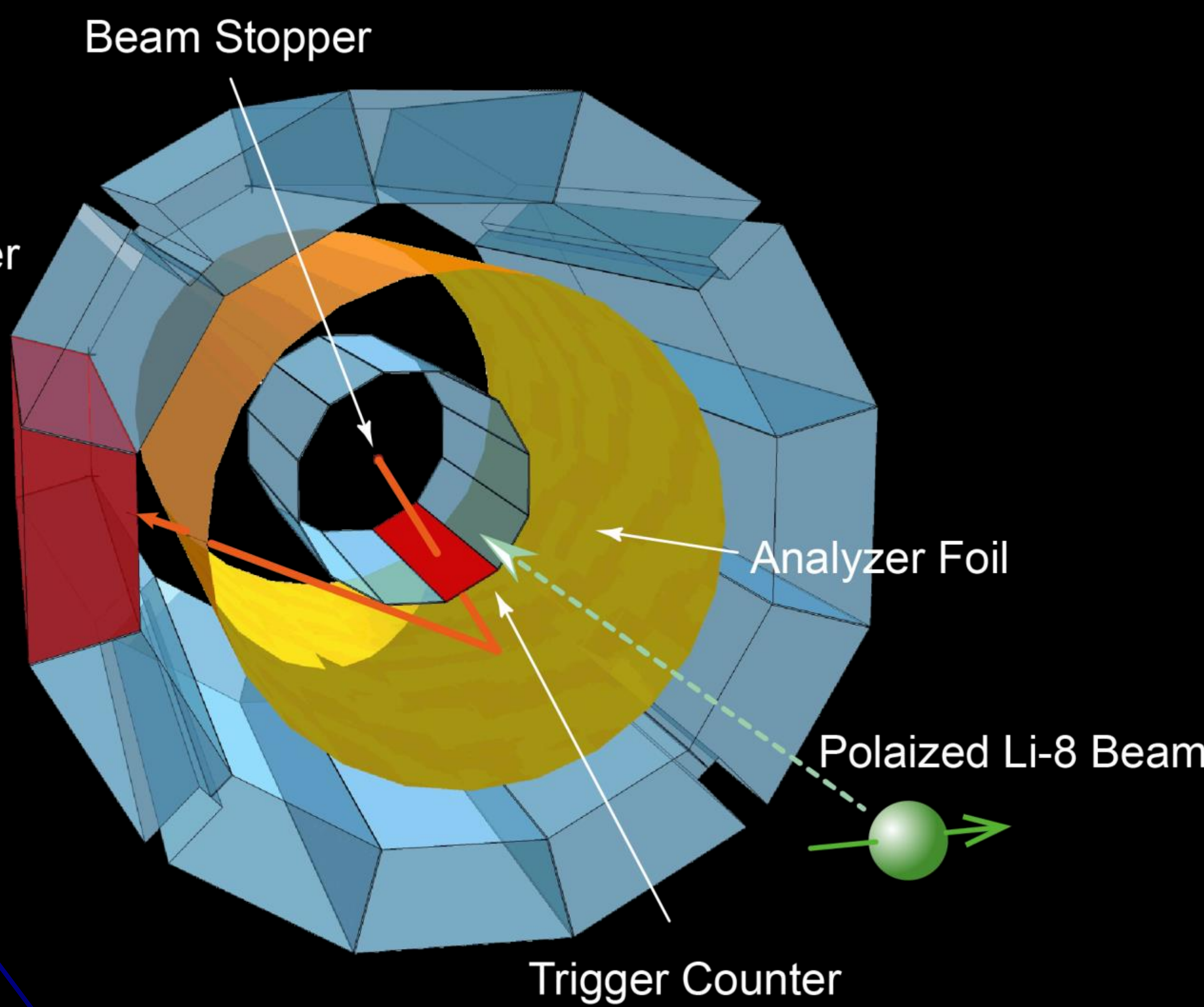
Remaining Systematics : Asymmetric Acceptance + Beta Asymmetric Emission
>> Offline restoration analysis using Tracking Information



Highest Statistics with minimum Systematics
Designed 2009, Fabrication 2010, Commissioned 2011

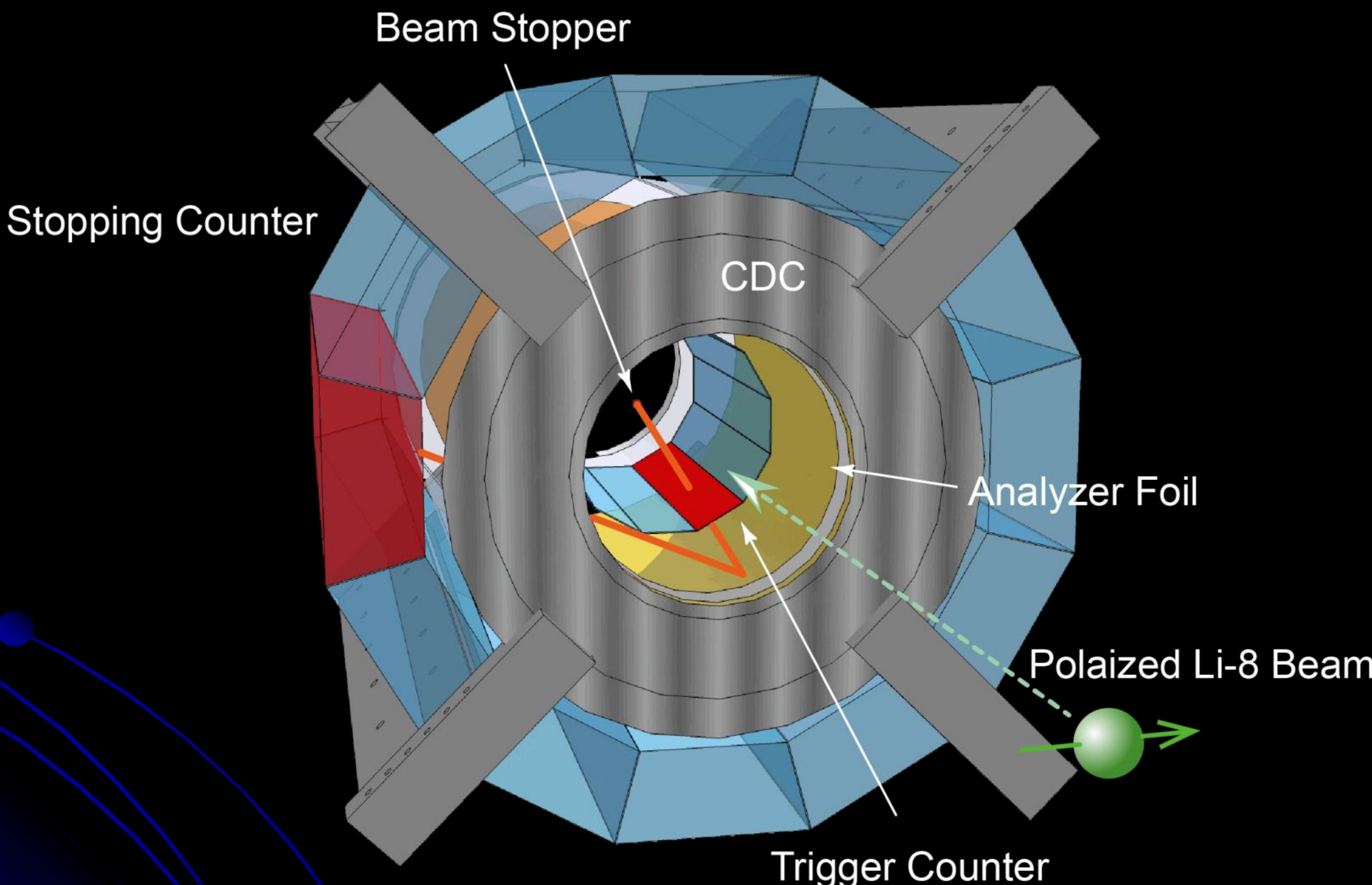
MTV-CDC

Next generation detector : CDC



To Remove Systematics : N-correlation, Asymmetric Acceptance

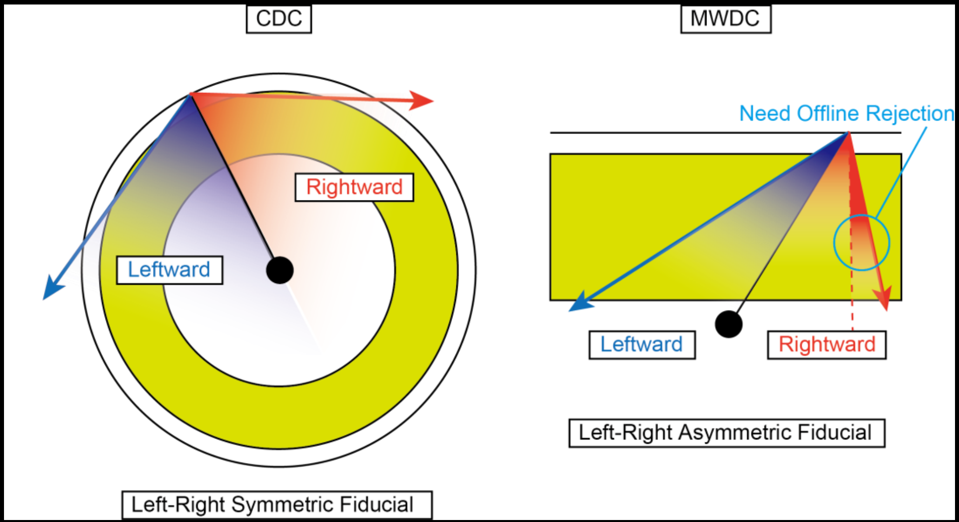
Next generation detector : CDC



To Remove Systematics : N-correlation, Asymmetric Acceptance

Geometrical Systematics Reduction

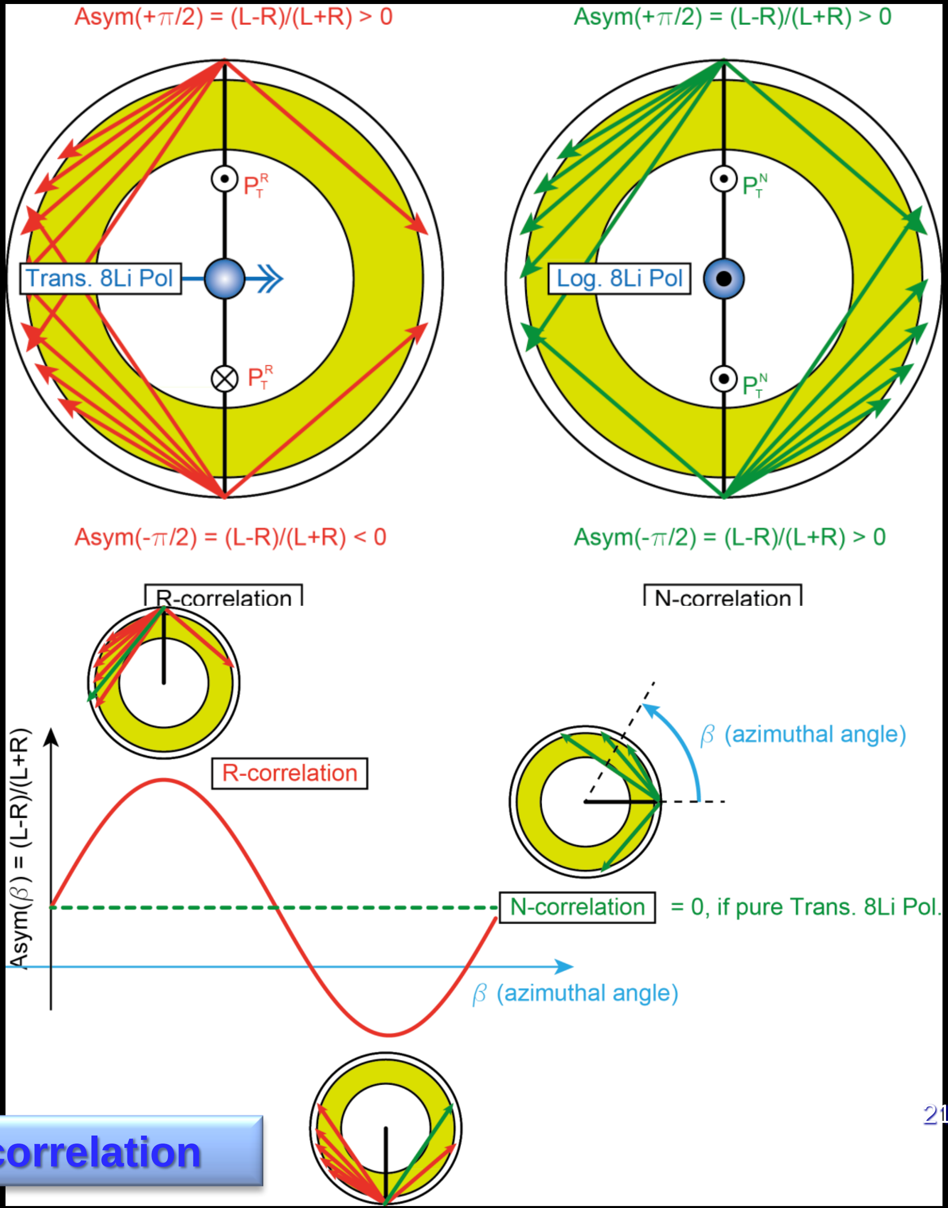
Symmetric Acceptance



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

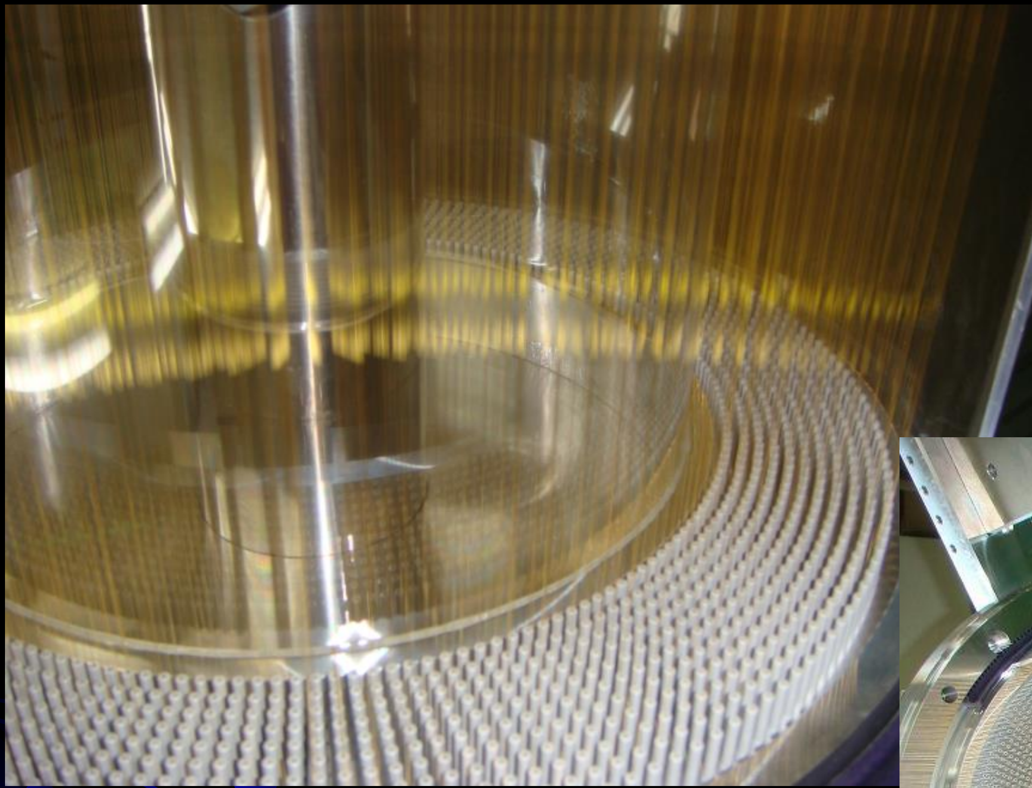
Asymmetric Geometry
+ Parity Violation
= non-zero signal

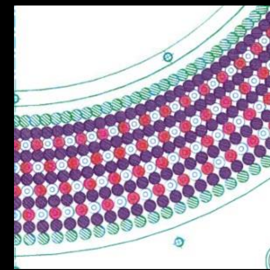
Indep. on beam pol. direction



Different Pattern for R/N correlation

MTV-CDC





Anode (20μm Au-W) ×400
>> signal readout

Cathode (100μm Au-Al) ×1000
>> applied voltage

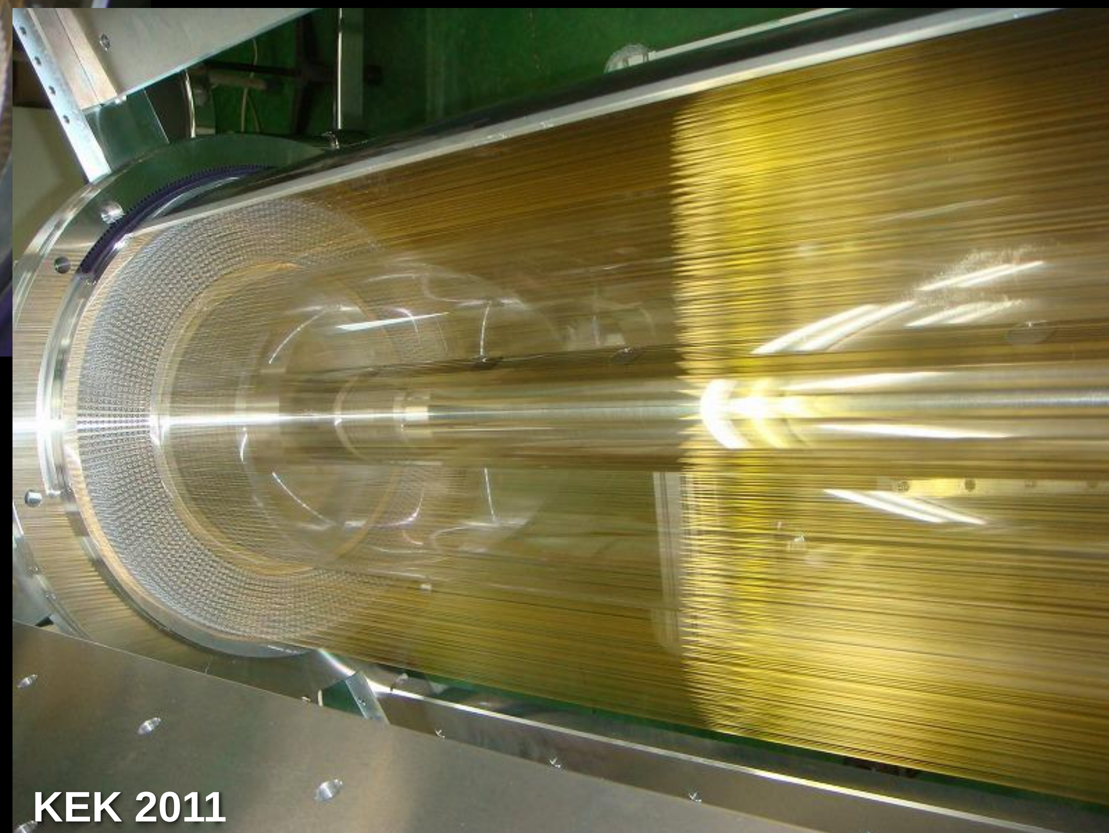
Shield (100μm Au-Al) ×400
>> shut down noise

Field (100μm Au-Al) ×400
>> applied voltage

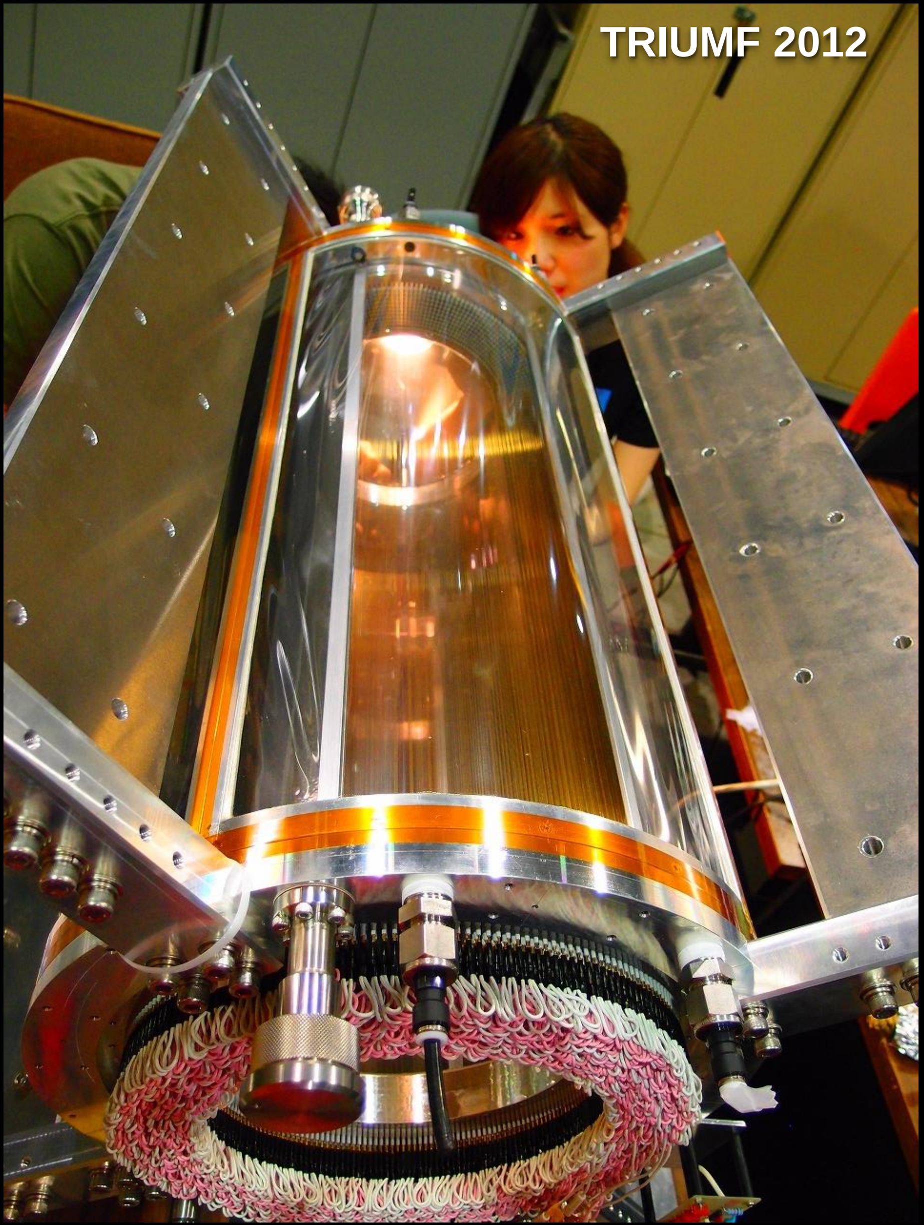
Designed in 2009 – 2010,
Fabricated in 2011

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

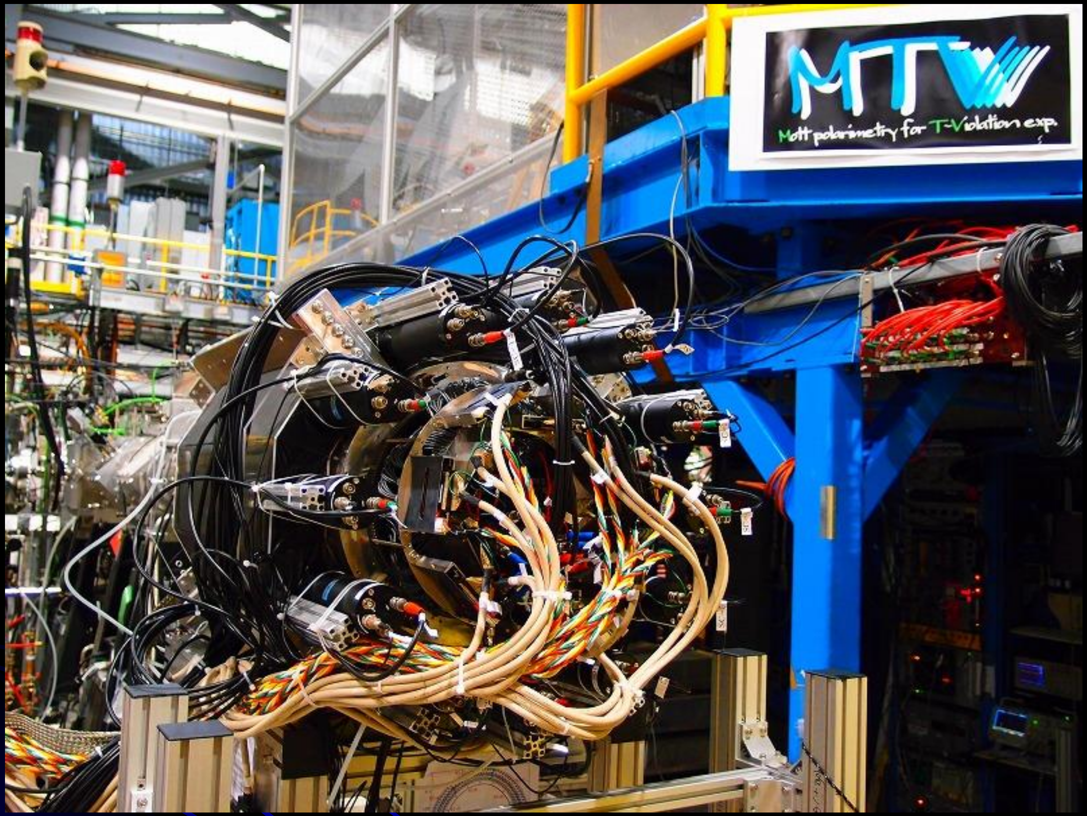
High rate capability,
Large and symmetric acceptance



MTV-CDC



MTV-CDC Performance Test
Run-IV 2012

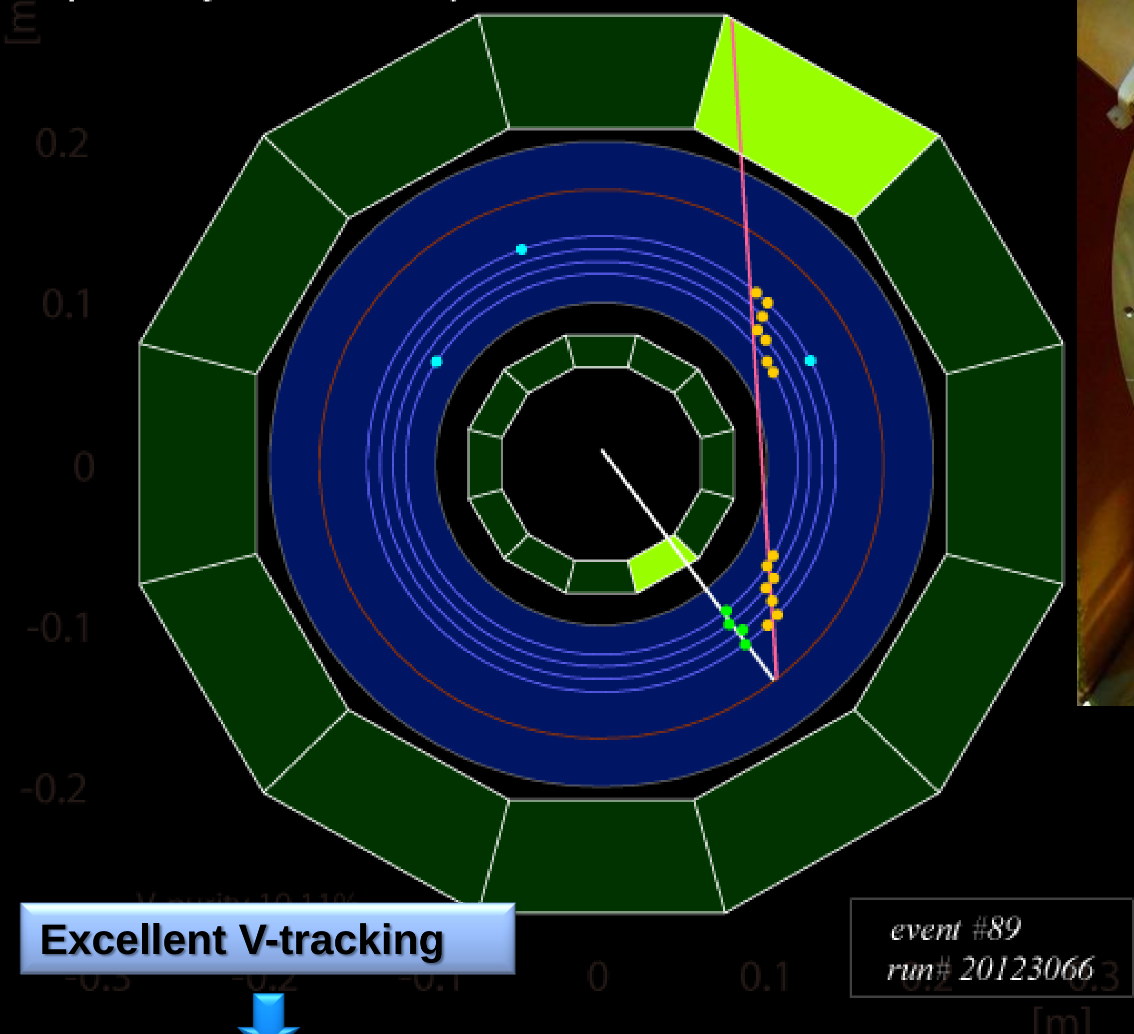


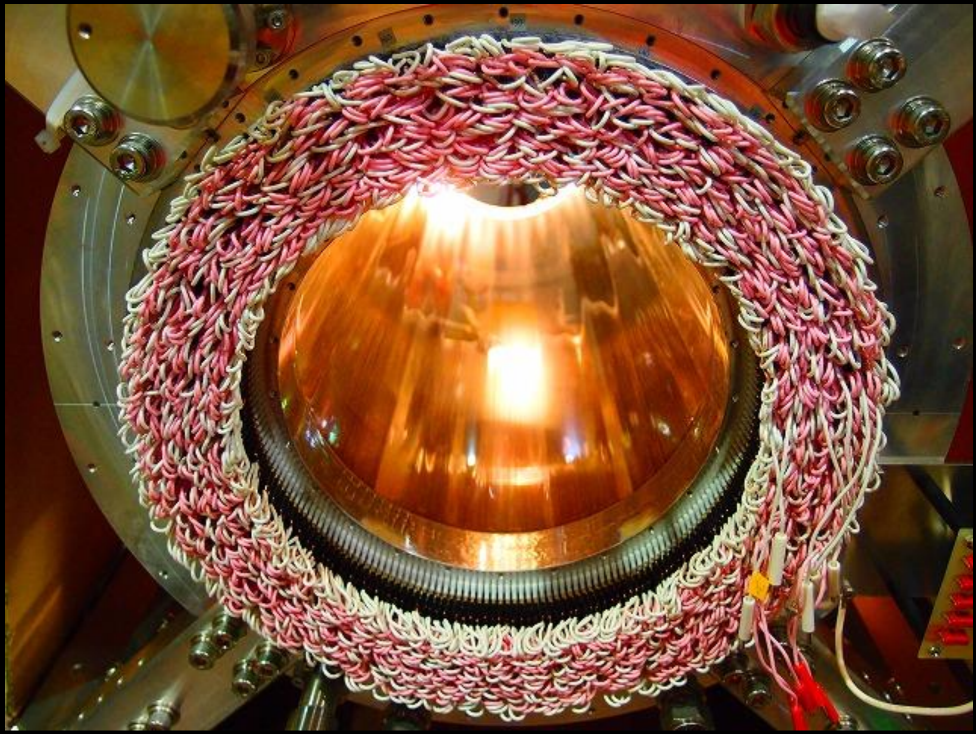
Beam test Run-III : CDC commissioning 2011
Run-IV : Full setup test 2012

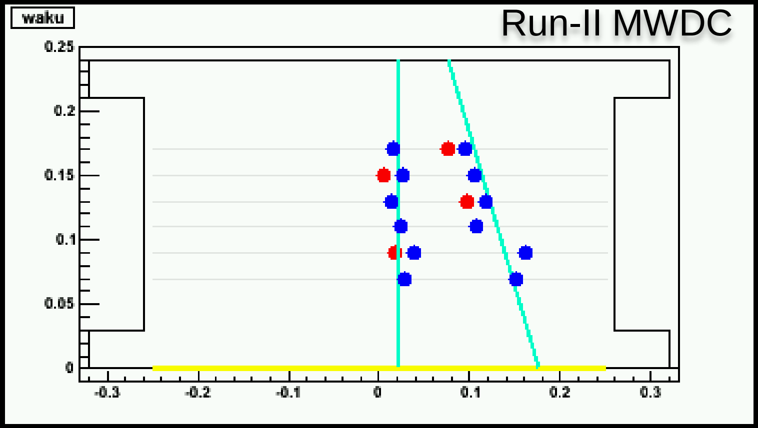
MTV-Tracking

Mott polarimetry for T-Violation exp.

Run-IV 2012





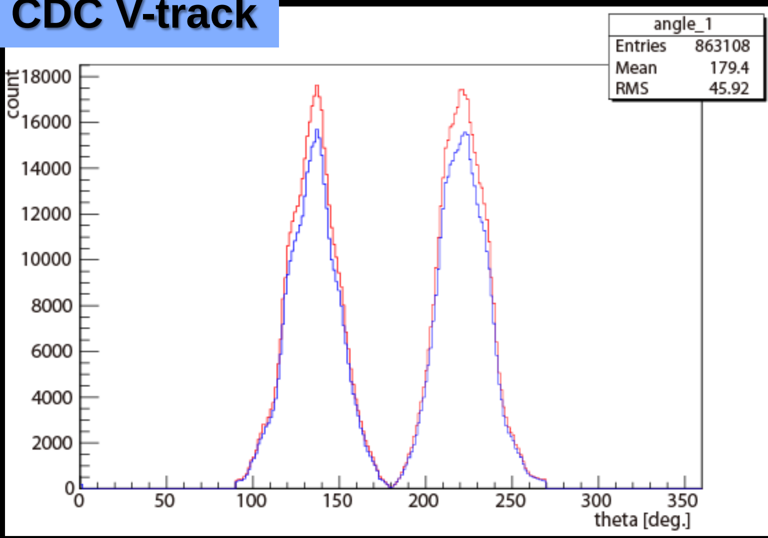


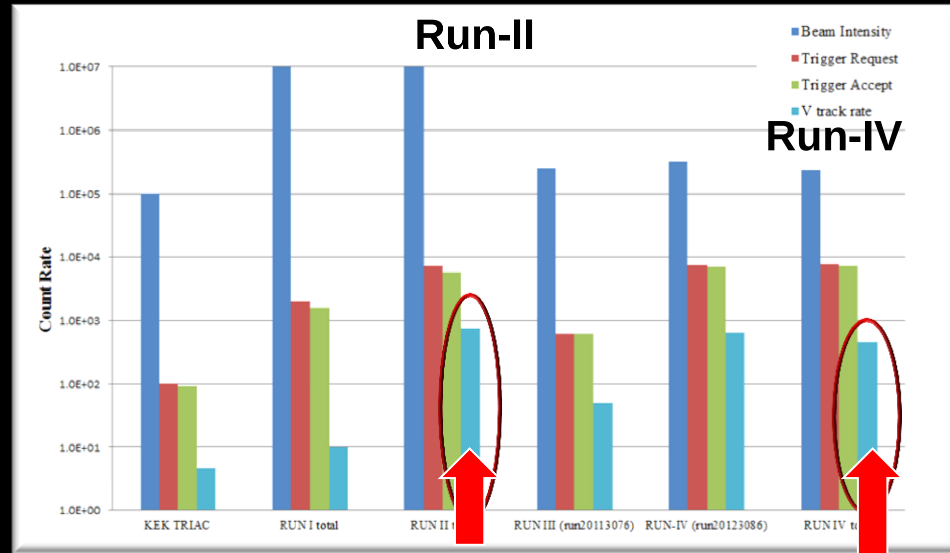
Excellent V-tracking

Significant Improvement of event Reliability !

CDC performance

CDC V-track





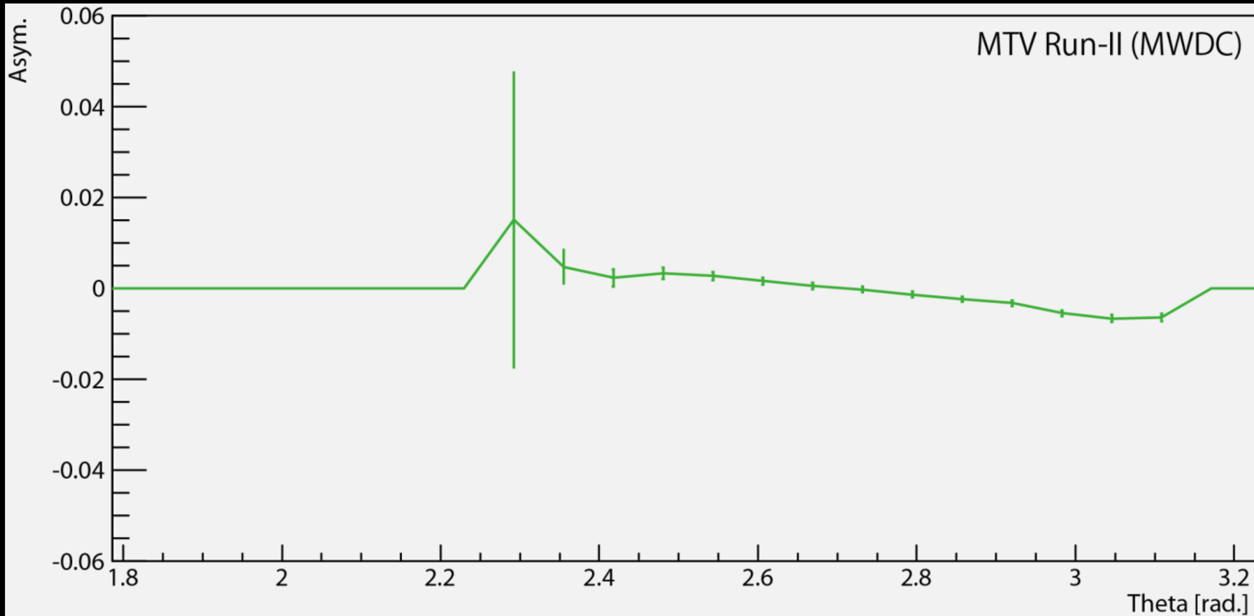
0.8kHz @ 10Mpps

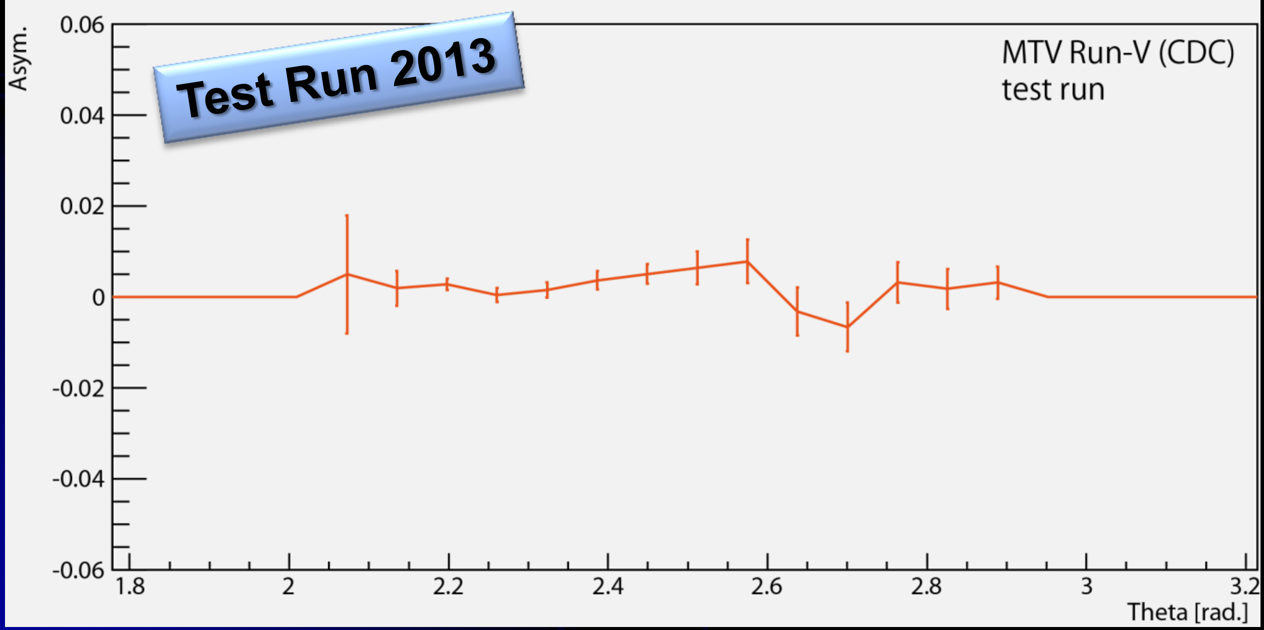
0.8kHz @ 100kpps

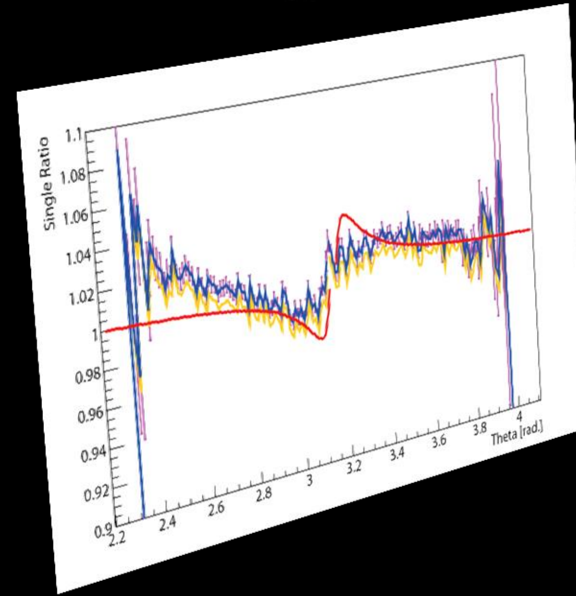
Same event rate achieved (thanks to fast full FPGA-DAQ)

Should be robust to the efficiency un-stability systematics (by reducing 1-st level counting rates)

CDC systematics







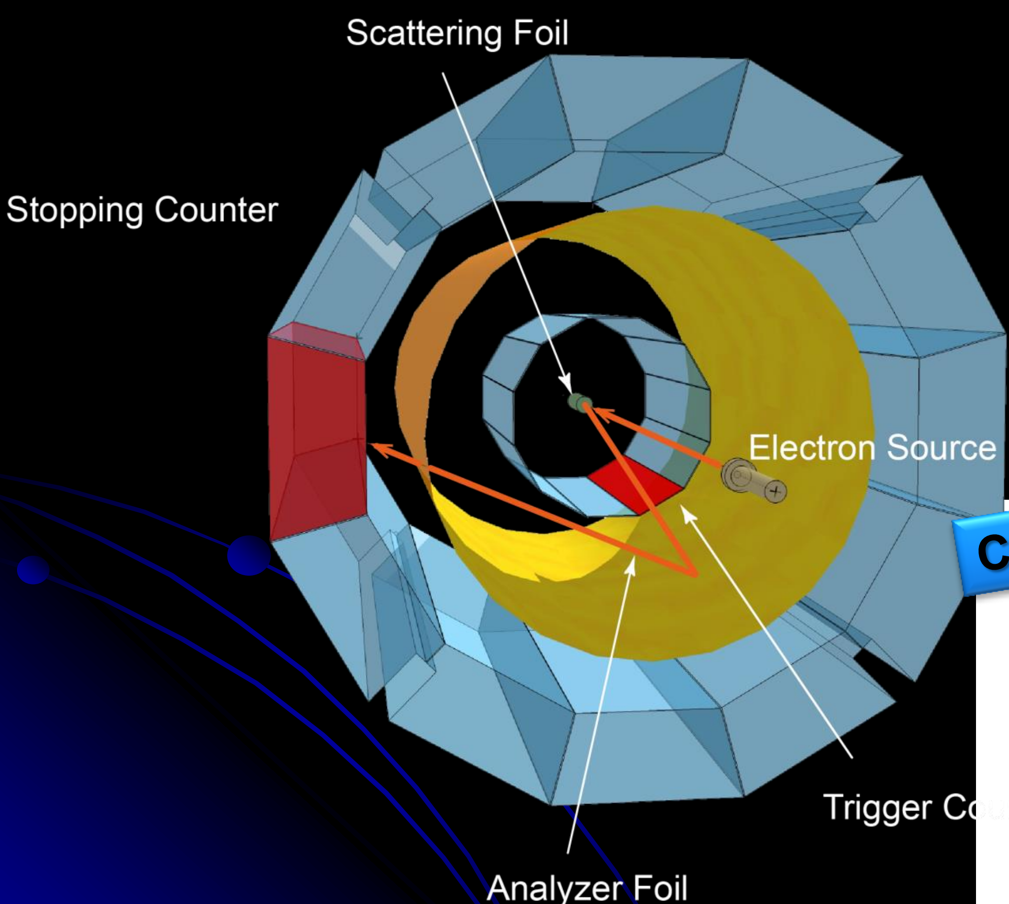
Systematic behavior is not clear within statistics …

Final source test in 2014 before physics production (8 days)

MTV Run-V 2013 23hours

Calibration & Systematics Check

MTV-G CDC

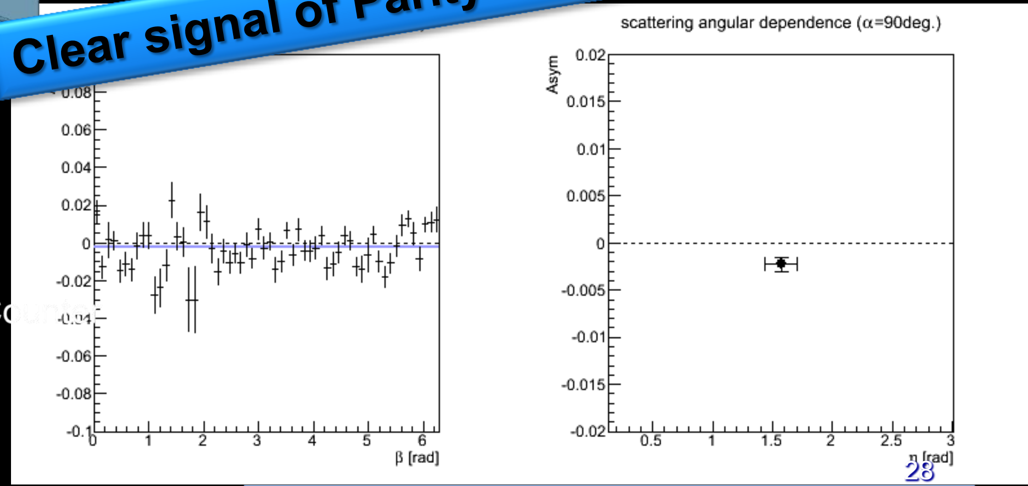


Longitudinal pol. electron

Coulomb Scatt.

Transverse pol. electron

Clear signal of Parity Violating Polarization !



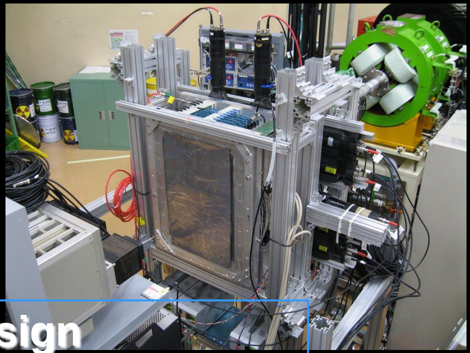
Analyzing power confirmation

TRIUMF

The MTV experiment
Activity Summary

2008 Test Experiment at KEK-TRIAC

R~40% precision for (8% pol.), 1.3x10^5pps x 37hours (0.6M V-tracks)



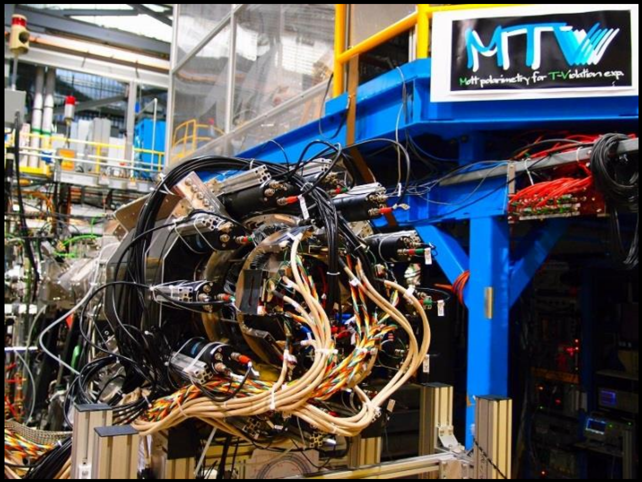
2009 – 2010 MTV exp. at TRIUMFTRIAC using MWDC

2010 CDC design
2011 CDC construction

R ~ 0.2% precision for (80% pol.), 1 x10^7pps x 11shifts (250M V-tracks)

Achieved the Highest Statistics

2011 CDC Commissioning
2012 MTV-CDC Full Setup Test
2013 CDC Systematics Test (physics)
2014 CDC Systematics Test (source)
2015 -16 Physics Production



0.01% precision, 10^7pps x 16 shifts remaining

Systematics Reduction
using Symmetric Detector

1. N-correlation (symmetric)
2. asymmetric acceptance (symmetric)
3. Efficiency non-stability (wide acceptance)

We are almost ready to the next run !

Formalism

$$D\xi = \delta_{J'J} M_F M_{GT} \sqrt{\frac{J}{J+1}} \Big[2\,\mathrm{Im}(C_S C_T^* - C_V C_A^* + C_S' C_T'^* - C_V' C_A'^*) \mp 2\frac{\alpha Z m}{p_e} \mathrm{Re}(C_S C_A^* - C_V C_T^* + C_S' C_A'^* - C_V' C_T'^*) \Big], \quad \text{(B7)}$$

$$R\xi = |M_{GT}|^2 \lambda_{J'J} \Big[\pm 2\,\mathrm{Im}(C_T C_A'^* + C_T' C_A^*) - 2\frac{\alpha Z m}{p_e} \mathrm{Re}(C_T C_T'^* - C_A C_A'^*) \Big] + \delta_{J'J} M_F M_{GT} \sqrt{\frac{J}{J+1}} \Big[2\,\mathrm{Im}(C_S C_A'^* + C_S' C_A^* - C_V C_T'^* - C_V' C_T^*) \mp 2\frac{\alpha Z m}{p_e} \mathrm{Re}(C_S C_T'^* + C_S' C_T^* - C_V C_A'^* - C_V' C_A^*) \Big]. \quad \text{(B10)}$$

$$N\xi = 2\,\mathrm{Re}\Big\{ |M_{GT}|^2 \lambda_{J'J} \Big[\frac{1}{2}\frac{\gamma m}{E_e} (|C_T|^2 + |C_A|^2 + |C_T'|^2 + |C_A'|^2) \pm (C_T C_A'^* + C_T' C_A^*) \Big] + \delta_{J'J} M_F M_{GT} \sqrt{\frac{J}{J+1}} \Big[(C_S C_A^* + C_V C_T^* + C_S' C_A'^* + C_V' C_T'^*) \pm \frac{\gamma m}{E_e} (C_S C_T^* + C_V C_A^* + C_S' C_T'^* + C_V' C_A'^*) \Big] \Big\}, \quad \text{(B9)}$$

$$N_{8Li} \approx \frac{1}{3} \frac{m_e}{E_e}$$

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

FSI ~ 0.07 %

N ~ 3%

Theoretical Calculation of Final State Interaction

$$R\xi = |M_{\mathrm{GT}}|^2 \lambda_{J'J}\Big[\pm 2\,\mathrm{Im}(C_T C_A'^* + C_T' C_A^*) - 2\frac{\alpha Z m}{p_e}\,\mathrm{Re}(C_T C_T'^* - C_A C_A'^*)\Big] + \delta_{J'J} M_F M_{\mathrm{GT}} \sqrt{\frac{J}{J+1}}\Big[2\,\mathrm{Im}(C_S C_A'^* + C_S' C_A^* - C_V C_T'^* - C_V' C_T^*) \mp 2\frac{\alpha Z m}{p_e}\,\mathrm{Re}(C_S C_T'^* + C_S' C_T^* - C_V C_A'^* - C_V' C_A^*)\Big]. \qquad \text{(B10)}$$

J. D. Jackson, et. al., NP4 (1957) 206

P. Vogel, B. Werner / Final-state interactions

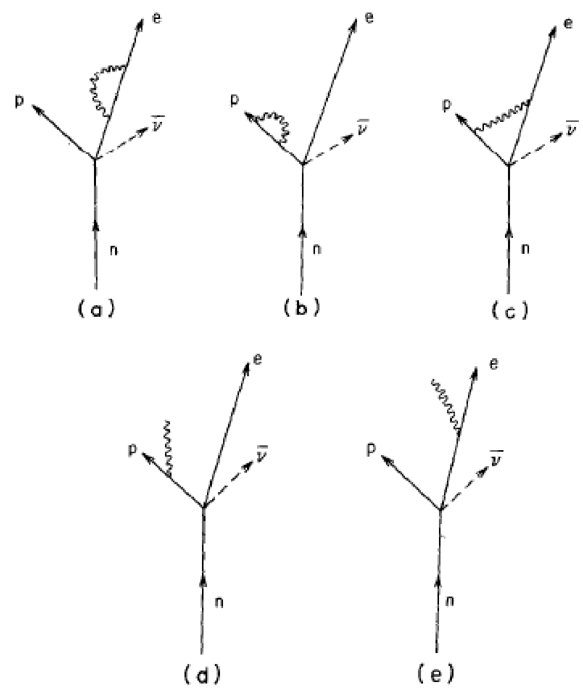


Fig. 1. Feynman graphs describing radiative corrections.

Radiative Correction

NLO ~ alpha/pi = 0.2%

Realistic Electron Wave Function

Finite Size Effect ~ 10%

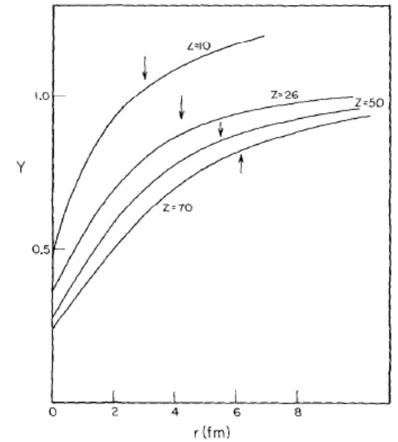


Fig. 4. The expression (26), divided by its point Coulomb limit, for $p_e = 0.6 m_e c$ and the indicated Z-values. The position of the nuclear radius is indicated by an arrow.

$$\xi R^{(\mathrm{rad})} = \frac{Z\alpha^2 m_e}{\pi p_e}\langle M\rangle\Big[\langle\sigma\rangle^2 \frac{C_A^2}{M_S}\Big(\frac{3+3/\lambda}{2}\ln\frac{\Lambda}{M_N} + \frac{1+5/\lambda}{8} + g(\beta)\Big) \pm \delta_{II'}\langle 1\rangle\langle\sigma\rangle \frac{2C_V C_A}{\sqrt{I(I+1)}}\Big(\frac{6+3\lambda+3/\lambda}{4}\ln\frac{\Lambda}{M_N} + \frac{-2+9\lambda+5/\lambda}{16} + g(\beta)\Big)\Big].$$

P. Vogel and B. Werner, NPA404 (1983) 345

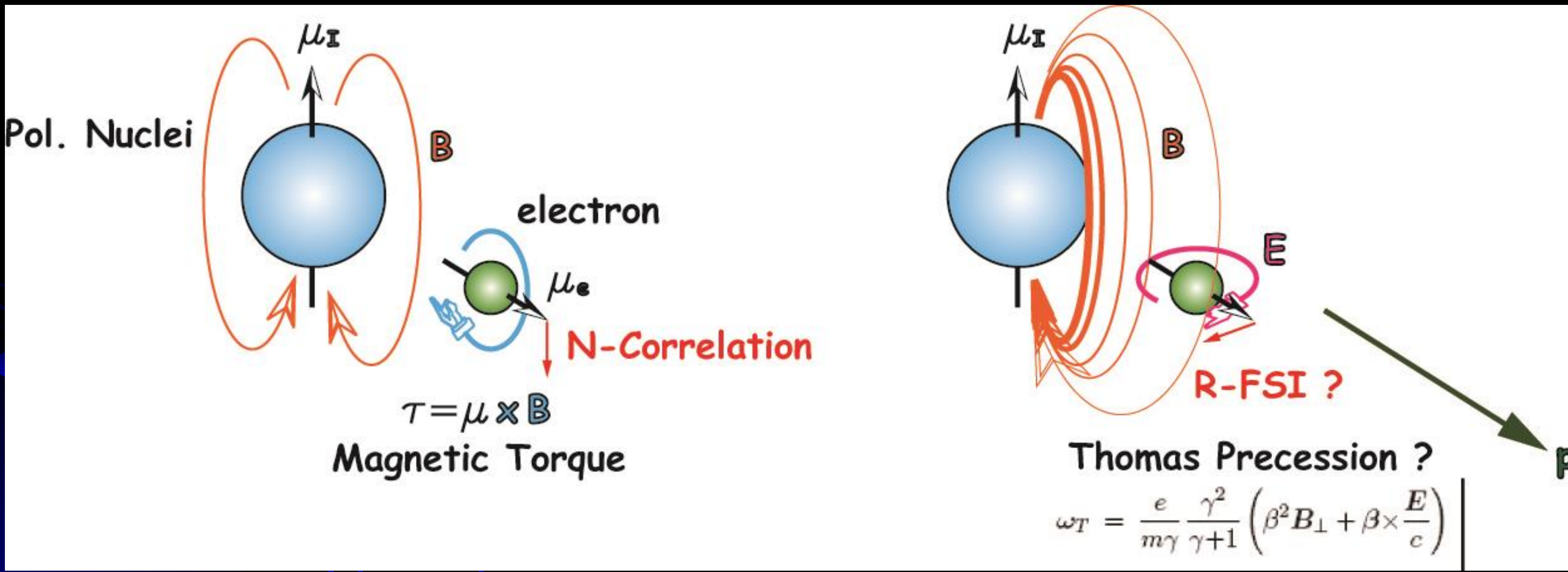
Final State Interaction is really comes from Charge ?

Point Charge = Electric Monopole Moment = No Axis

Impossible to produce TRANSVERSE POLARIZATION ?

$$R_{FSI} \approx A \frac{\alpha Z_F m_e}{p_e}$$

Source of Electromagnetic FSI = Magnetic Dipole Moment ?



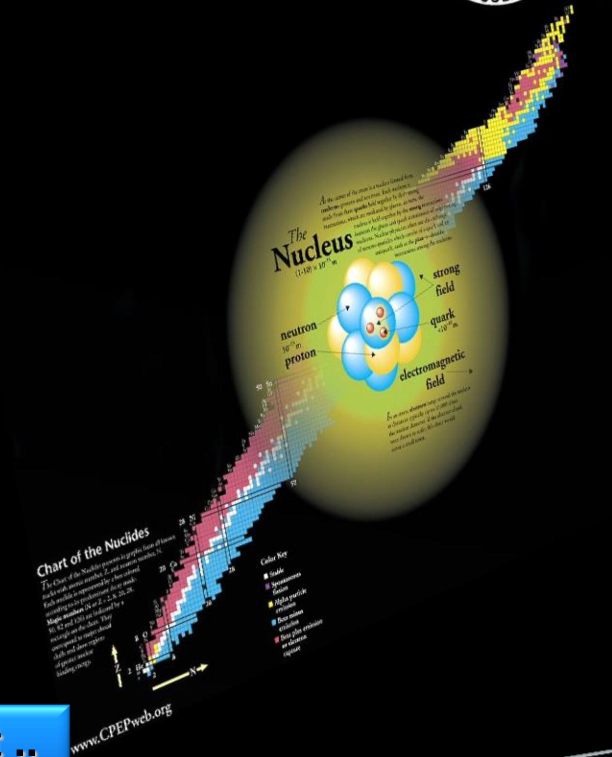
Future

Non-zero signal ~ 0.01% ?

FSI or New Physics ?

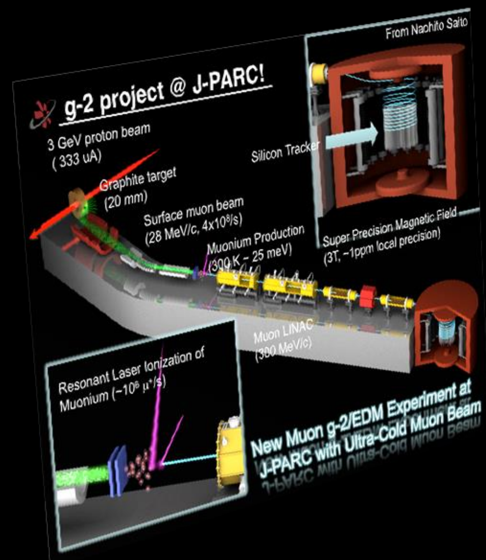
1. **Check Electron Momentum Dependence**
2. **Systematic Study over various Nuclei**

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



Systematic study of FSI itself is an interesting subject ..

Application of MTV to mu-TRV at J-PARC ?

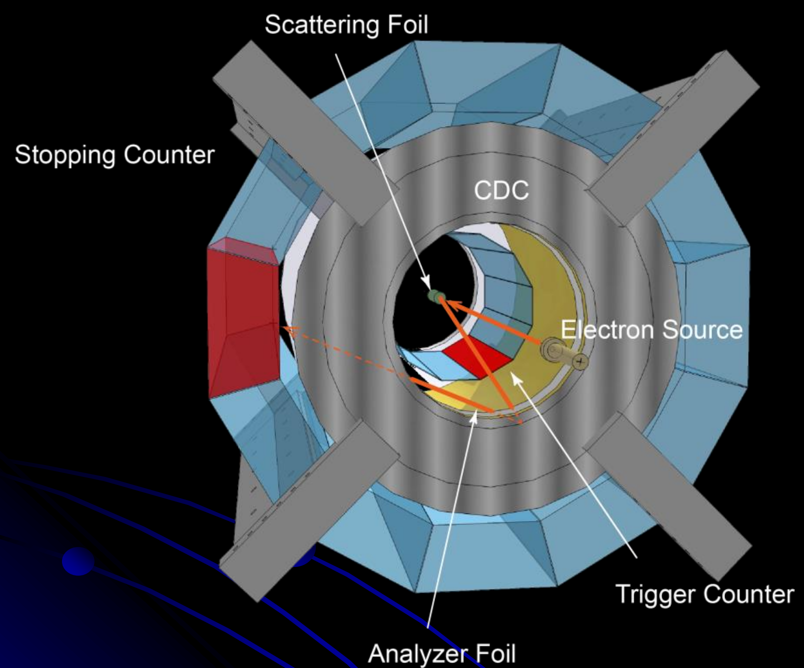


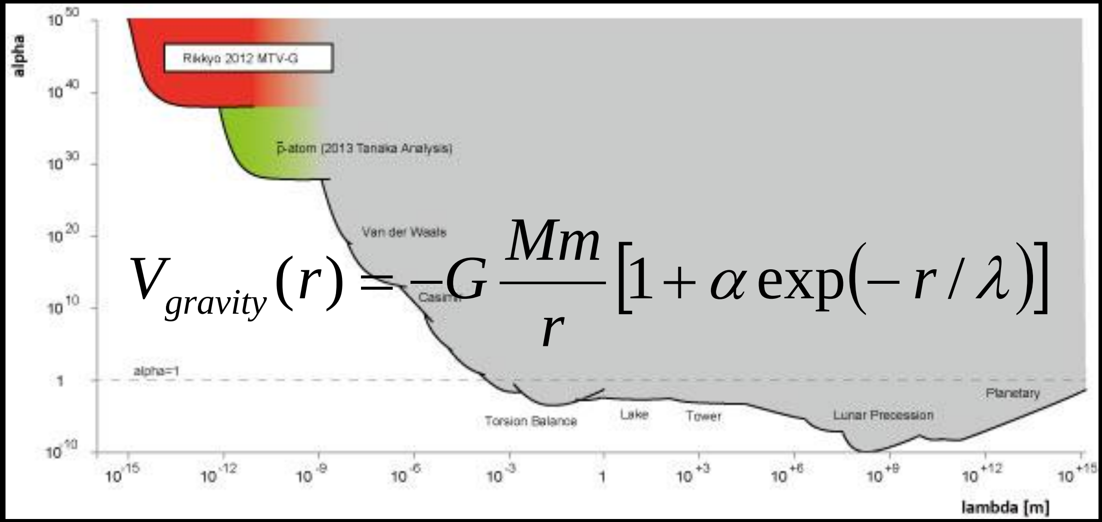
Need different polarimer for high energy electron (Mott analyzing power is small)

MTV-G : Gravity Experiment

Test of Gravitational inverse square law at nuclear scale, to search large extra-dimension

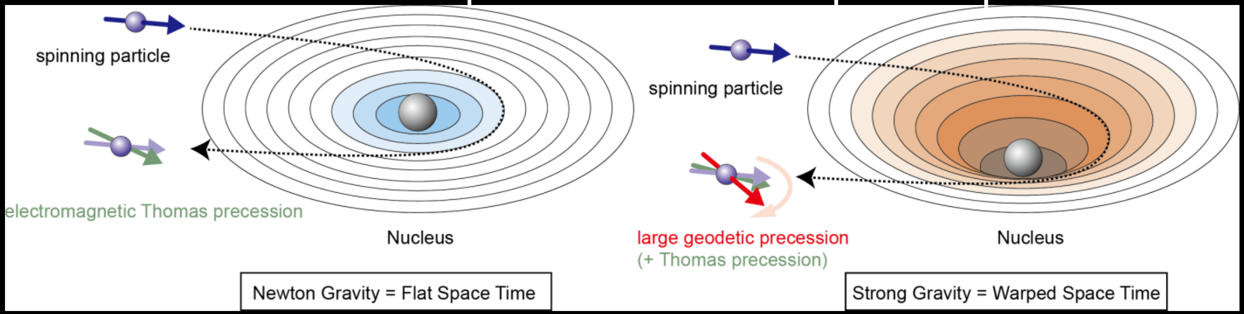
MTV-G CDC



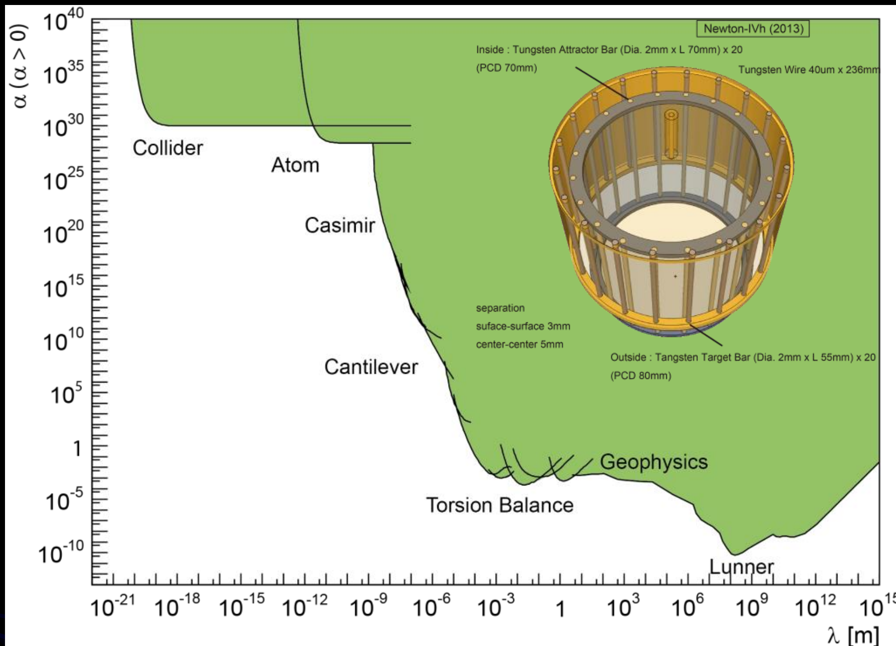


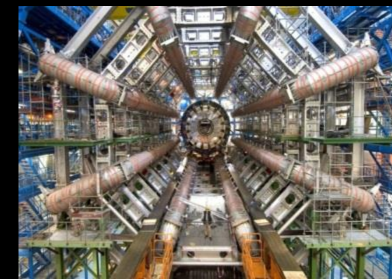
$$V_{gravity}(r) = -G\frac{Mm}{r}\left[1+\alpha\exp(-r/\lambda)\right]$$

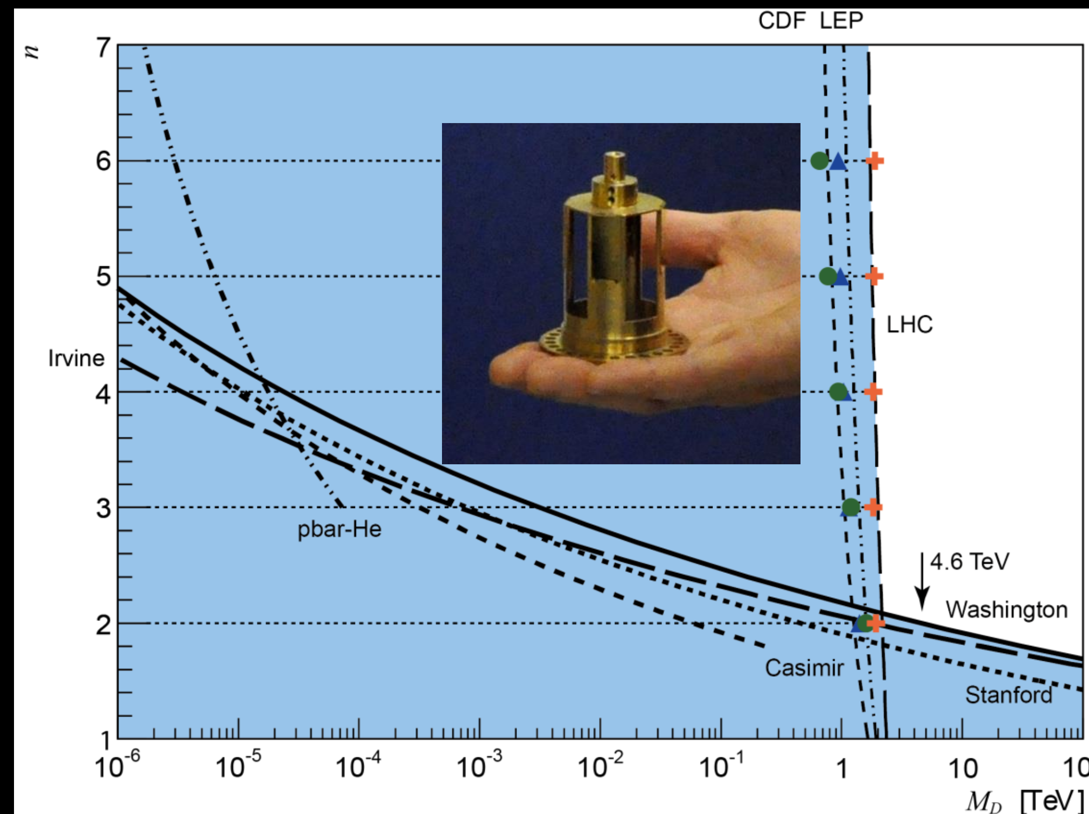
Geodetic precession in a warped scape-time



Low energy tests vs the LHC







To compete with the LHC like micro gravity experiments !

J. Murata arXiv:1408.3588

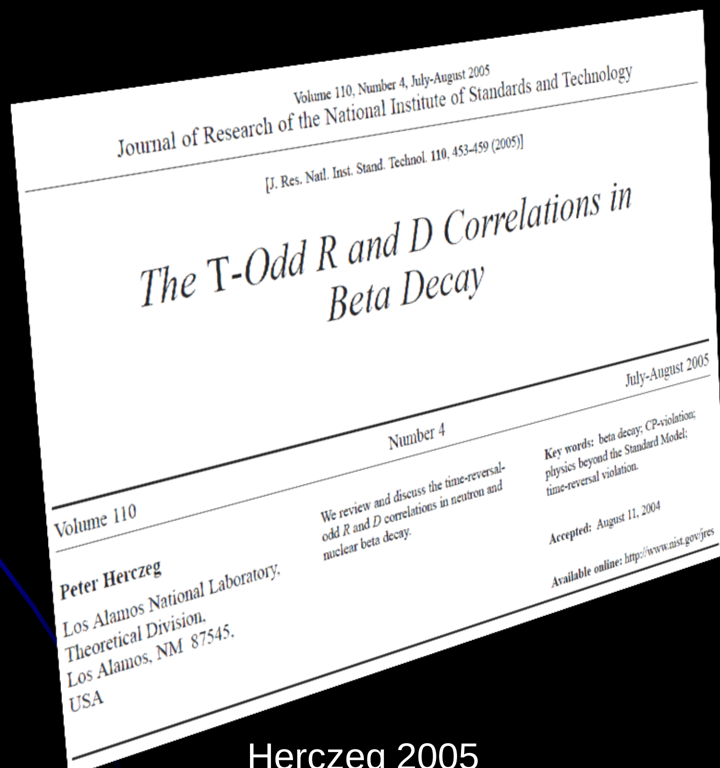
Review of short-range gravity experiments in the LHC era (Topical Review in Classical and Quantum Gravity)

Summary

The finest precision test of T-Violation at 10^{-4} level will be performed very soon.

We will see something non-zero effect, for the first time.

We hope that theoretical model calculations are triggered !



Volume 110, Number 4, July-August 2005
Journal of Research of the National Institute of Standards and Technology

[J. Res. Natl. Inst. Stand. Technol. 110, 453-459 (2005)]

The T-Odd R and D Correlations in Beta Decay

Volume 110 Number 4 July-August 2005

Peter Herczeg

Los Alamos National Laboratory,
Theoretical Division,
Los Alamos, NM 87545,
USA

We review and discuss the time-reversal-odd *R* and *D* correlations in neutron and nuclear beta decay.

Key words: beta decay; CP-violation; physics beyond the Standard Model; time-reversal violation.

Accepted: August 11, 2004

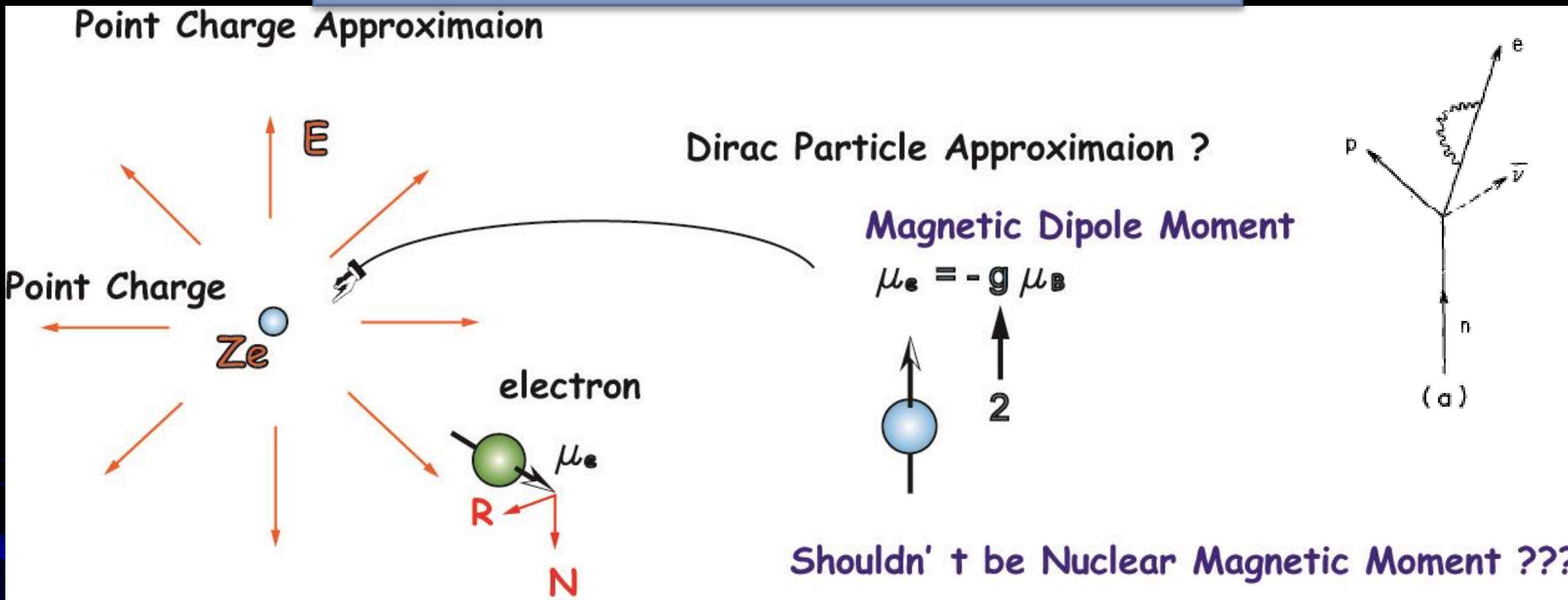
Available online: http://www.nist.gov/jres

Herczeg 2005

Dirac Particle Approximation ?

Point Charge = Electric Monopole Moment = No Quantum Axis

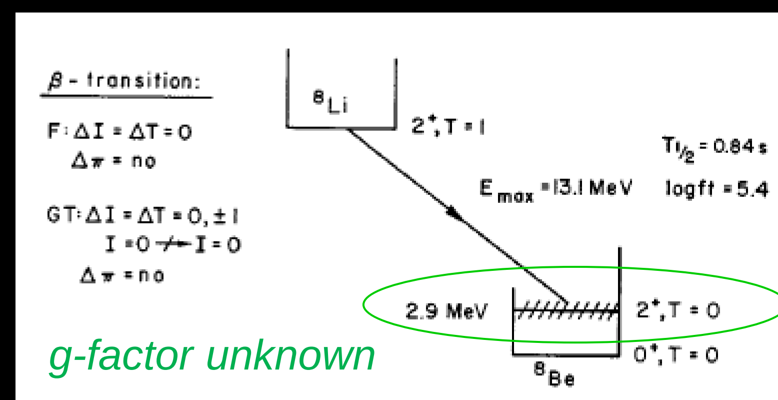
Dirac Particle Assumption : $\mu = -g \cdot \mu_B$ **?**



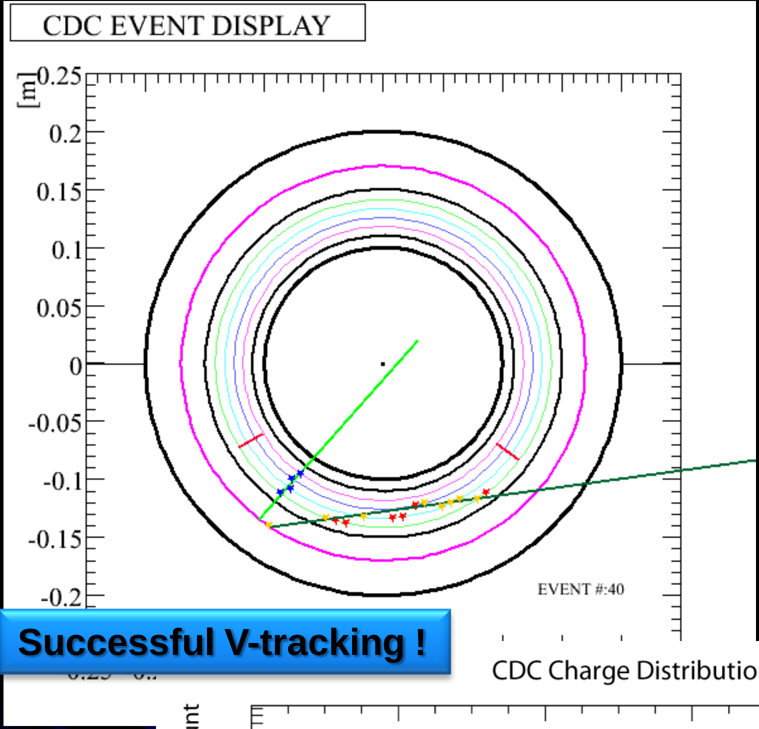
Nuclear / Bohr magneton

$$\mu_N / \mu_B$$

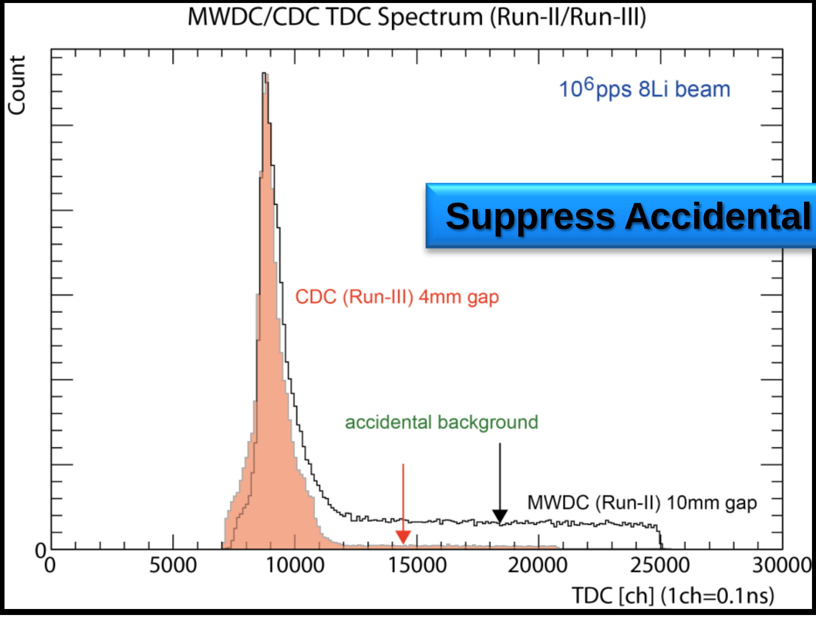
g-factor for 2+ excited state required ??



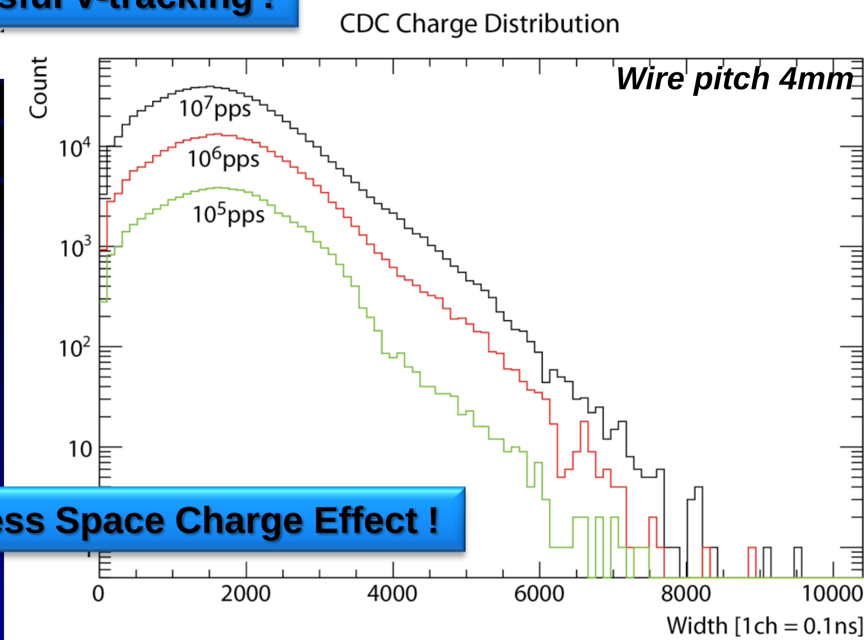
CDC Performance

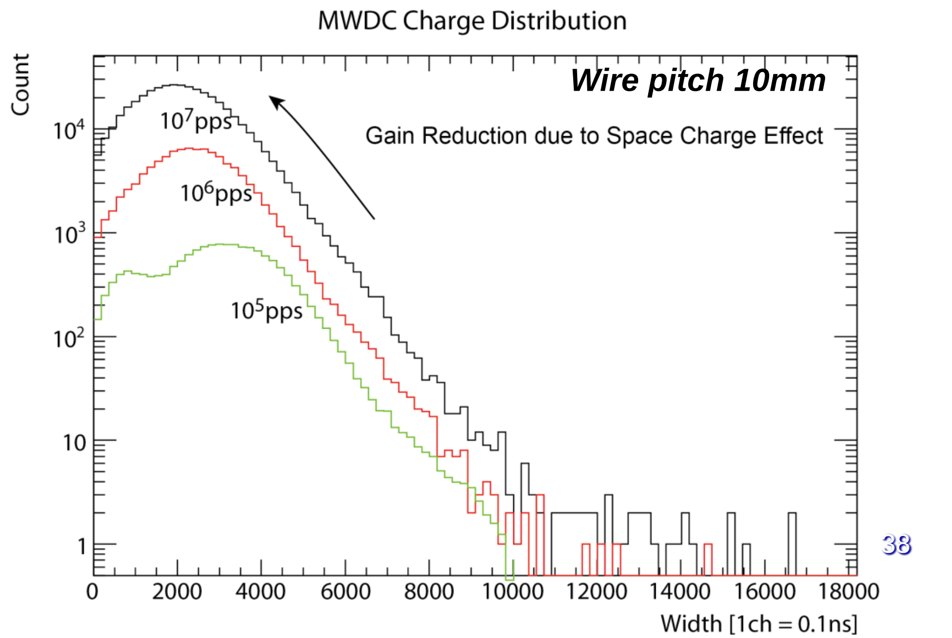


Successful V-tracking !



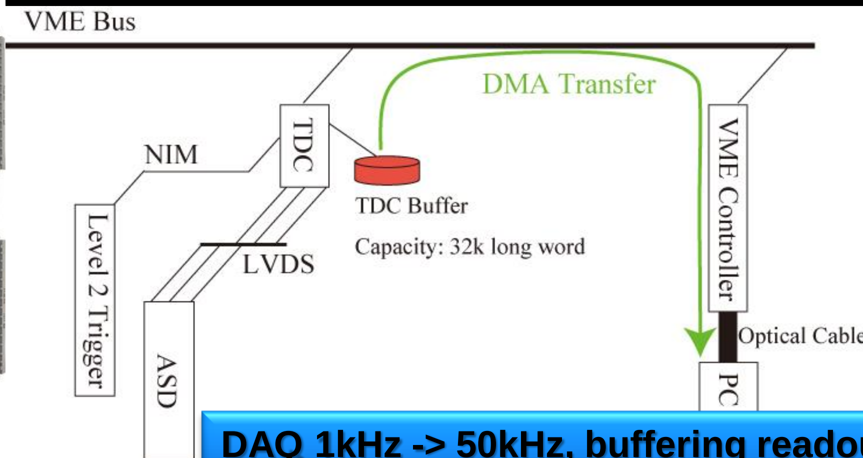
Suppress Accidental Hits !



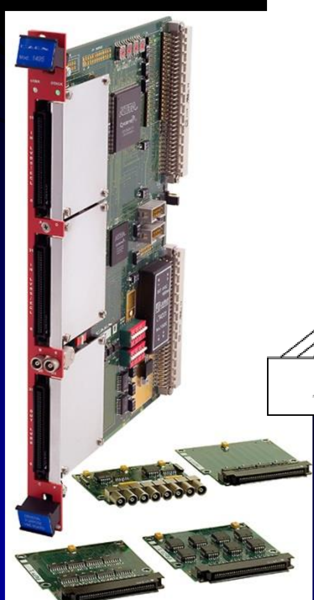


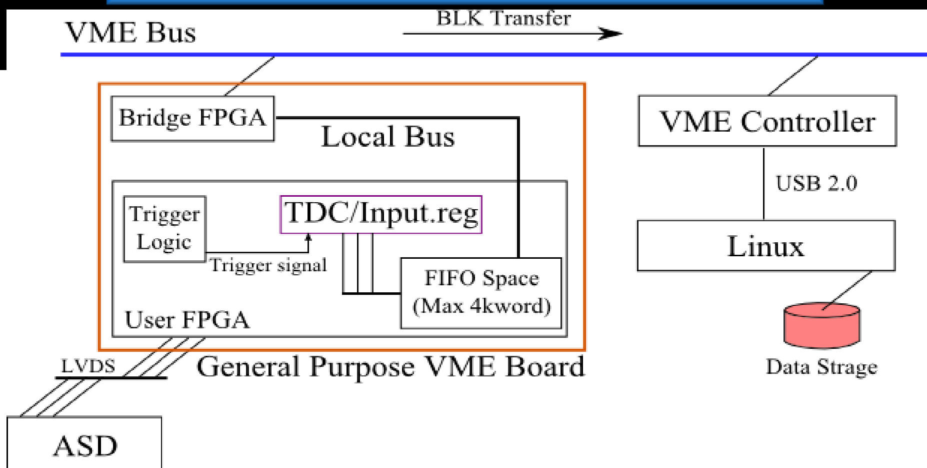
Suppress Space Charge Effect !

MTV-DAQ/Trigger History



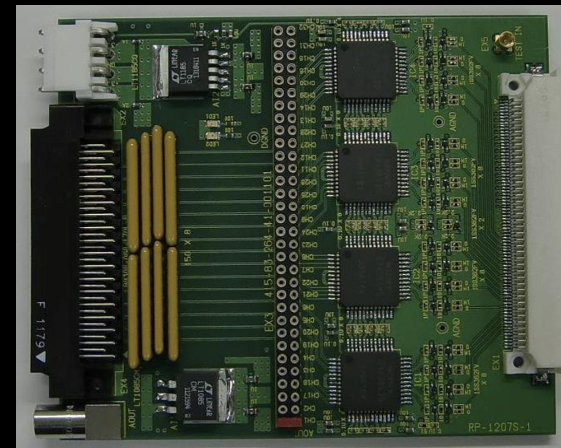
DAQ 1kHz -> 50kHz, buffering readout



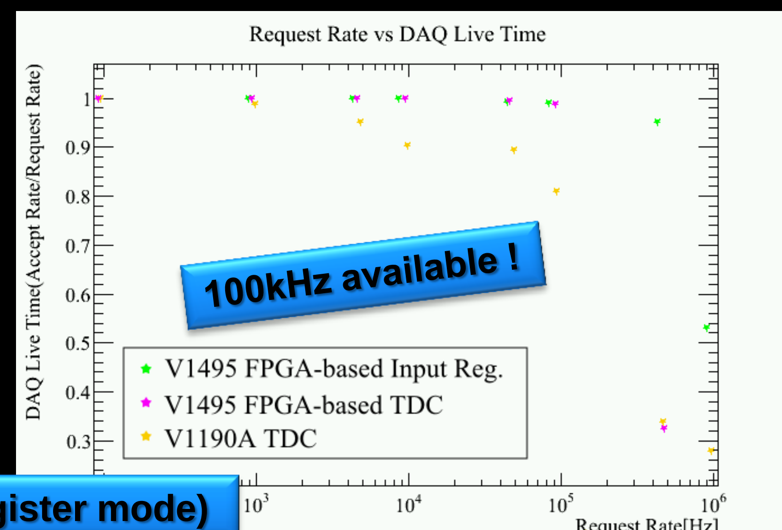


64bit/hit -> 32bit/hit (TDC mode), 1bit/hit (I/O register mode)

Custom FPGA system : Trigger & DAQ (TDC/IO reg.)



New FEE Board for MTV-CDC



100kHz available !

Ready to use !