SPIN-Praha-2008

ASI on Symmetries and Spin
2008/Jul/24

The First T-Violation Experiment at KEK-TRIAC

Rikkyo Univ./RIKEN
Hirokazu Kawamura

Time reversal symmetry ← Transverse polarization of Beta-ray

Physics motivation

Experimental setup

- Early studies and technical issues
- New tracking detector based polarimeter

First experiment at KEK-TRIAC RNB07K04

- Results and predictions

Future plan at TRIUMF S1183

Summary

Collaboration

Rikkyo	J. Murata, H. Kawamura, T. Toyoda, E. Seitaibashi, M. Nitta, M. Hata, T. Akiyama, Y. Ikeda, K. Ninomiya
RIKEN	D. Kameda
JAEA	D. Nagae
KEK	Y. Hirayama and TRIAC-group

RIKEN NiSHiNA CENTER

TRIAC Tokai Radioactive Ion Accelerator Complex

Physics Goal = Search for P-odd & T-odd interaction

SAINT PAUL'S UNIVERSITY · TOKYO · MDCCCLXXIV

T-Conserving & P-Violating correlation

V-A without CKM (Real Coupling)

$\vec{J}_I \cdot \vec{p}_e$ Angular asymmetry of beta-ray
Wu (60Co)

$\vec{\sigma}_e \cdot \vec{p}_e$ Longitudinal polarization of electron in beta-decay

T-Violating & P-Conserving correlation

Im(V), Im(A),Im(T), Im(S) Coupling

$\vec{J}_I \cdot (\vec{p}_e \times \vec{p}_\nu)$ Beta-Neutrino correlation In polarized nuclei
19Ne – Calaprice

$\vec{\sigma}_\mu \cdot (\vec{p}_\pi \times \vec{p}_\mu)$ Transverse polarization of muon in K meson decay
KEK-PS, J-PARC

$K^+ \rightarrow \pi^0 \mu^+ \nu$

T-Violating & P-Violating correlation

Im(Tensor), Im(Scalor)

$\vec{J}_I \cdot (\vec{p}_e \times \vec{\sigma}_e)$ Transverse polarization of electron from polarized nuclei
8Li – Sromicki @ PSI

$\vec{\sigma}_\mu \cdot (\vec{p}_e \times \vec{\sigma}_e)$ Transverse polarization of electron from polarized muon

$M_{LQ} > 560 GeV / c^2$

Model
Leptoquarks, θ-term, m-Higgs, W_R ,(CKM)

Measurement = *R*-correlation

Beta decay

$$\frac{d\omega}{dE_\beta d\Omega_\beta d\Omega_\nu} = \frac{1}{(2\pi)^5} p_\beta E_\beta (E_0 - E_\beta)^2 \cdot \left(1 + a\frac{\vec{p}_\beta \cdot \vec{p}_\nu}{E_\beta E_\nu} + b\frac{m}{E_\beta} + \vec{J}_I \cdot \left(A\frac{\vec{p}_\beta}{E_\beta} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_\beta \times \vec{p}_\nu}{E_\beta E_\nu} \right) + \vec{\sigma}_\beta \cdot \left(G\frac{\vec{p}_\beta}{E_\beta} + H\frac{\vec{p}_\nu}{E_\nu} + K\frac{\vec{p}_\beta}{E_\beta + m}\left[\frac{\vec{p}_\beta \cdot \vec{p}_\nu}{E_\beta E_\nu}\right] + L\frac{\vec{p}_\beta \times \vec{p}_\nu}{E_\beta E_\nu} + N\vec{J}_I + Q\frac{\vec{p}_\beta}{E_\beta + m}\left[\vec{J}_I \cdot \frac{\vec{p}_\nu}{E_\nu}\right] + R\vec{J}_I \times \frac{\vec{p}_\beta}{E_\beta} \right) \right)$$

$$R\vec{J} \cdot \frac{\vec{p}_\beta \times \vec{\sigma}_\beta}{JE_\beta}$$

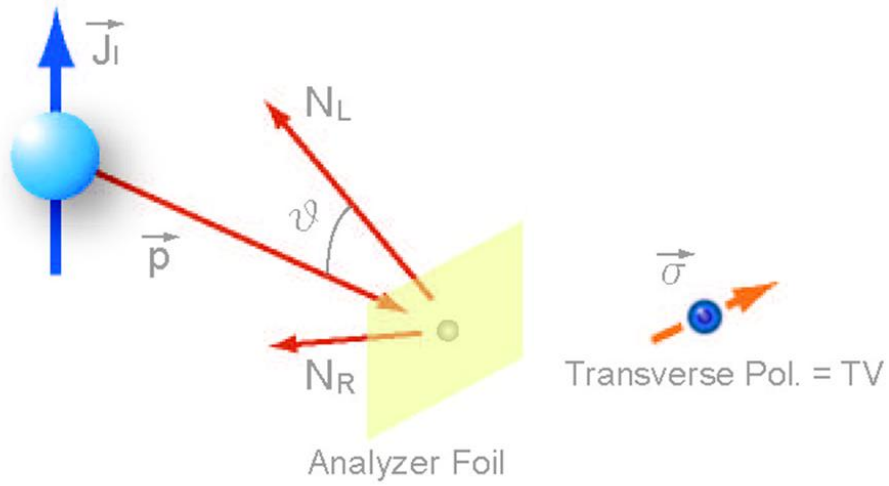
Required components

Production	Polarized Nuclei
Measurement	Electron Momentum
Measurement	Electron Transverse Polarization

Zero or Non-Zero ?

T-violation !

Utilize Analyzing Power of Mott scattering



Asymmetry ← Spin-Orbit Interaction

Previous Measurements (P-violating & T-violating)

$^{19}\vec{\mathrm{Ne}} \rightarrow {}^{19}\mathrm{Fe} + e^+ + \nu_e$	$(-79 \pm 53) \times 10^{-3}$	Princeton '83
$^{8}\vec{\mathrm{Li}} \rightarrow {}^{8}\mathrm{Be} + e^- + \bar{\nu}_e$	$(-0.9 \pm 2.2) \times 10^{-3}$ **BEST**	PSI '03
$\vec{\mu}^+ \rightarrow e^- + \bar{\nu}_\mu + \nu_e$	$(-3.7 \pm 7.7) \times 10^{-3}$	PSI '05
$\vec{\Lambda}^0 \rightarrow \pi^- + \vec{p}$	$(-94 \pm 60) \times 10^{-3}$	CERN '72
$\vec{n} \rightarrow p + e^- + \bar{\nu}_e$	$(-15 \pm 16) \times 10^{-3}$ Preliminary	PSI nTRV exp.

Experimental Sensitivity >> CKM (Standard Model) Predictions

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

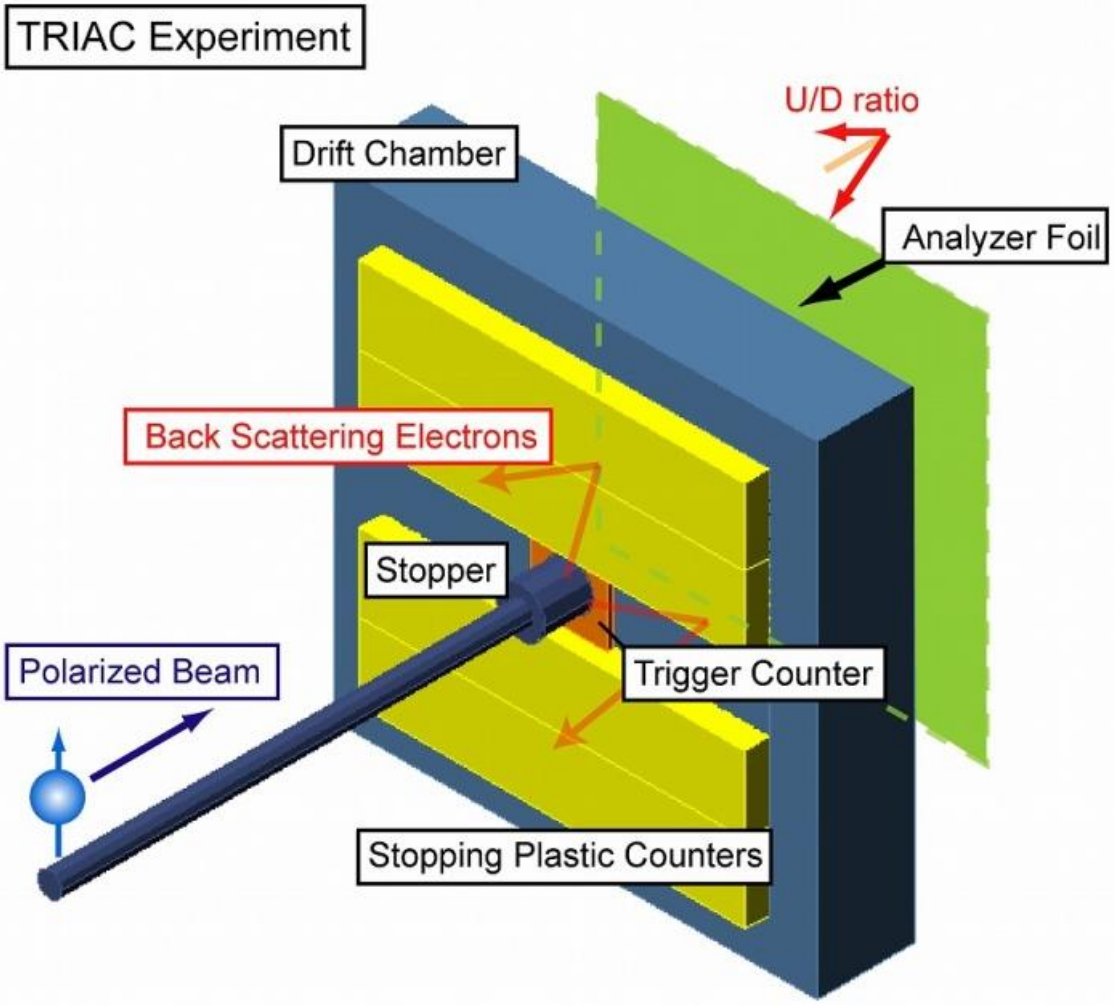
Suppression of CKM effect is desired

⇒ **u, d system = Normal Nuclear is rather better system**

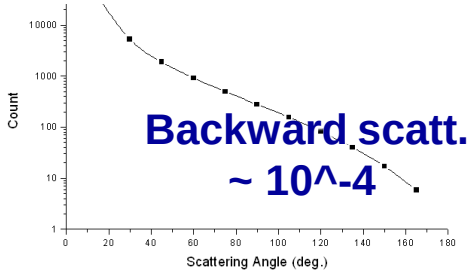
Null-Experiment: Independent of Nuclear Structure Ambiguity

Experimental Setup

Measuring Mott scattering using Drift chamber



Scattering Count Rate



Analyzing Power

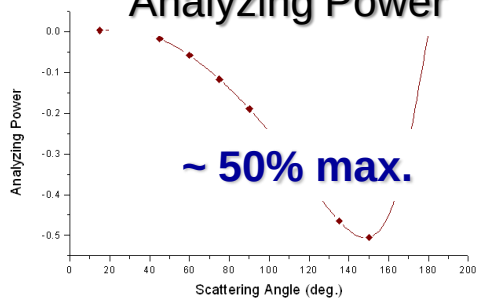
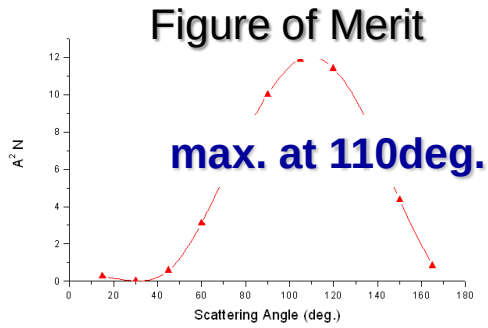
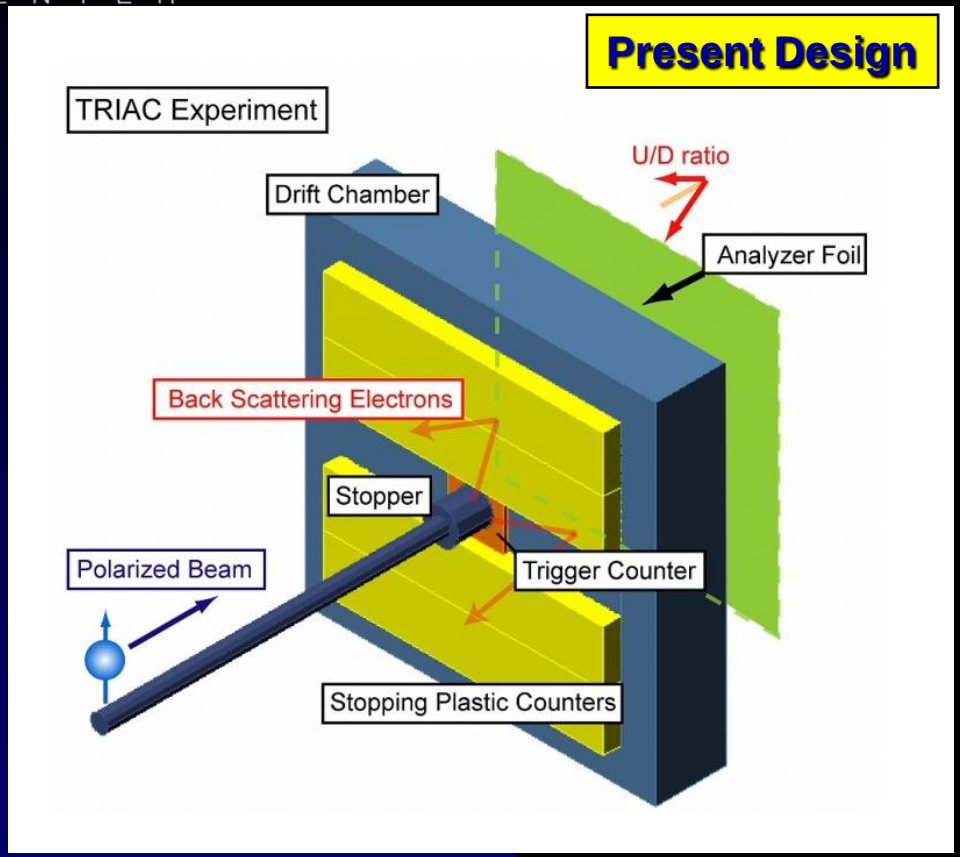


Figure of Merit

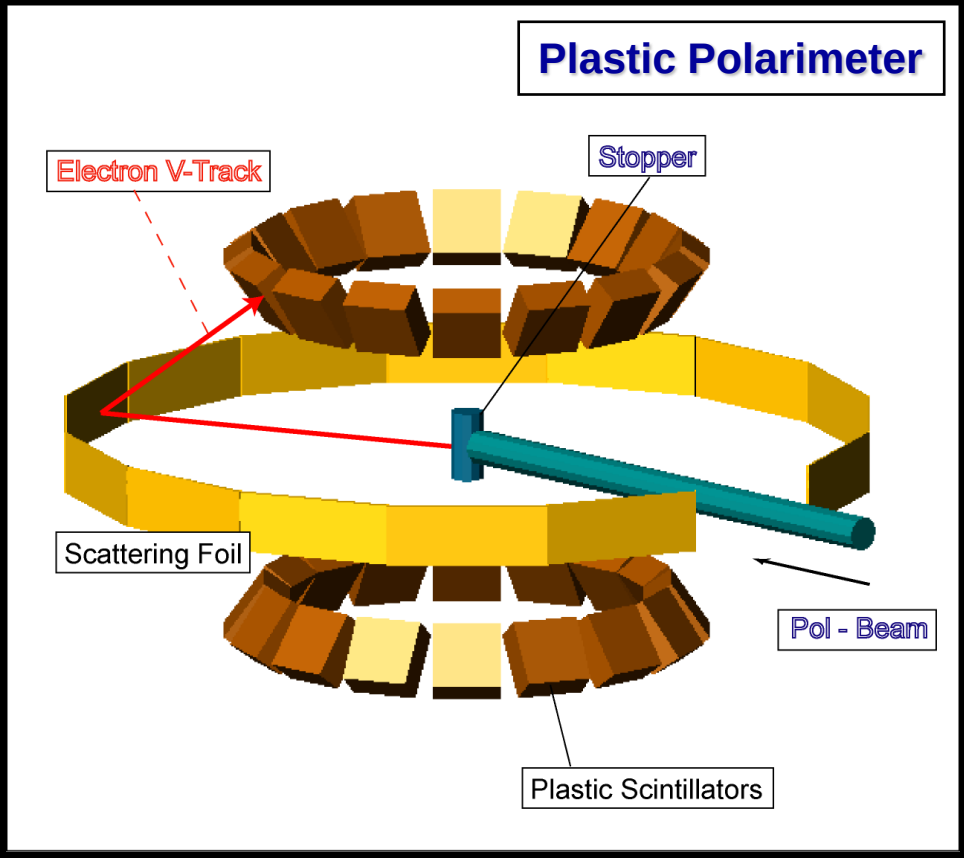


Compare the Configuration

Present Design



Plastic Polarimeter



Tracking Detector →

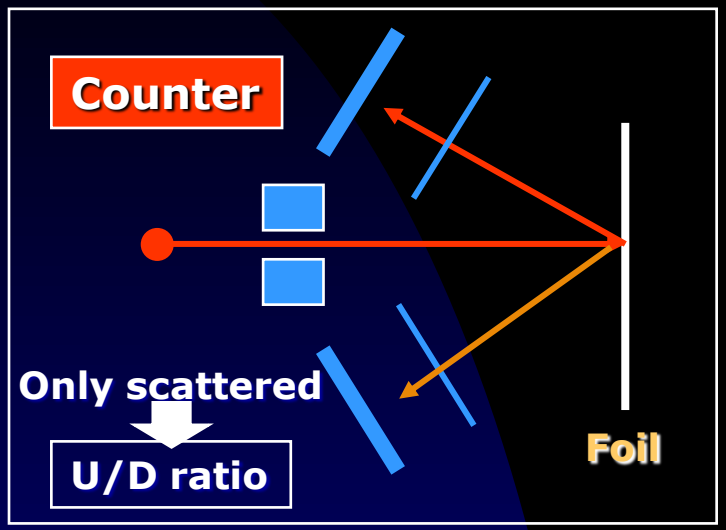
Enlarge solid angle & Improve sensitivity

PSI 8Li Exp.

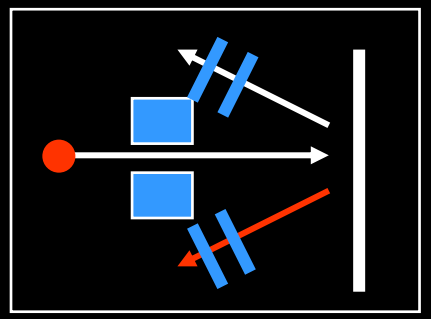
10MeV 0.9uA 7Li(d,p)8Li
99.9% 7Li target, 700MBq
B = 7mT, Pol = 20% @LHe
Relaxation time > 20sec
Lead foil analyzer 100micron

Merit of New Tracking Measurement

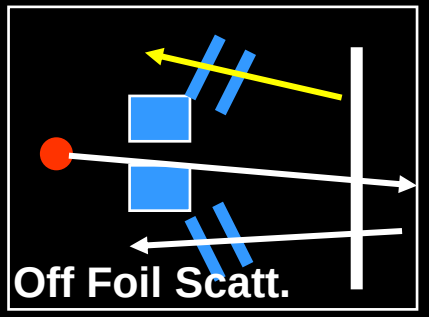
PSI exp. = Plastic Up/Down Counter



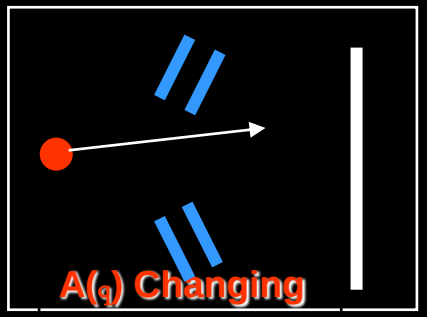
Foil Activation



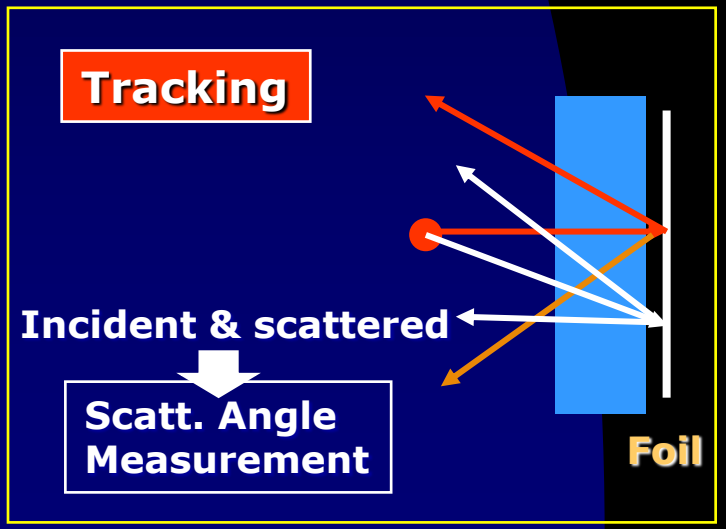
Slits



Fake Events



U/D Acceptance Changing

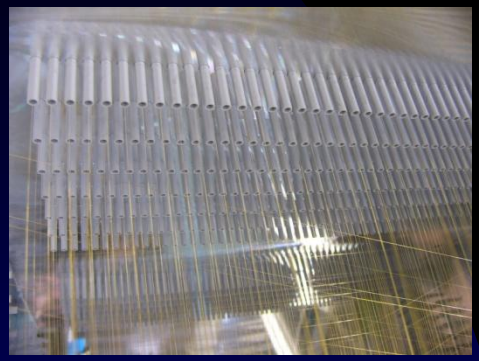


Large Acceptance

Background Rejection

DC Polarimeter

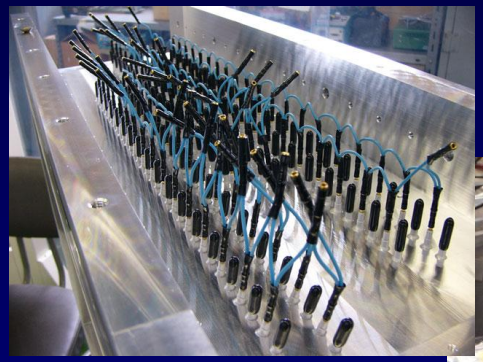
XX' UU' VV' Planer DC
104 Anode

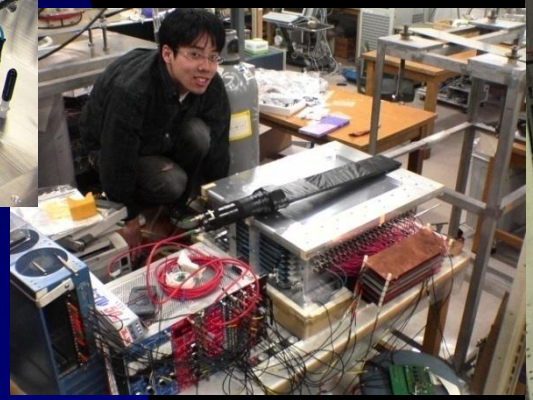


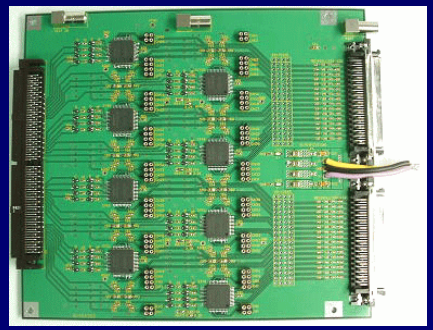
Sense 20um Au-W @ 50g x 104
Field 100um Au-BeCu @ 150g x 110
Cathode 100um Au-BeCu @ 150g x 413
Total 627 Wires

Sense - Field Pitch = 10mm
Sense - Cathode Gap = 10mm
XX'(1/2cell off) x 40
UU'(15.9deg.) x 32
VV'(-15.9deg.) x 32
Cathode(90deg.)

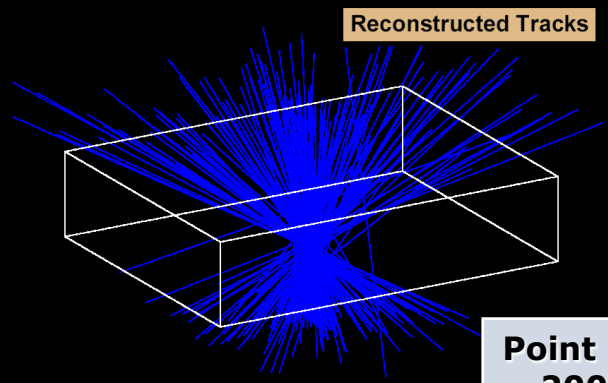
P10 Gas @ 1atm





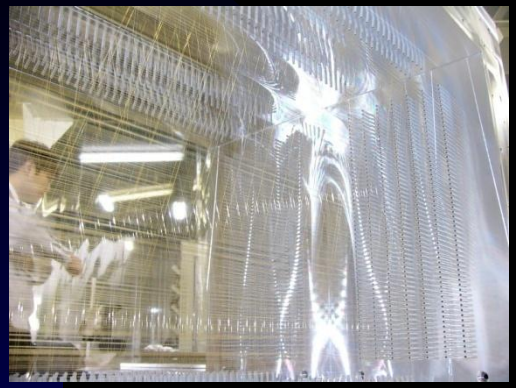


64ch ASD preamp x 2
+ VME AMU-TDC x 2

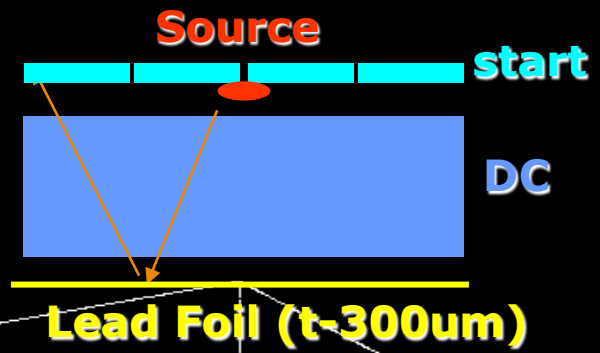


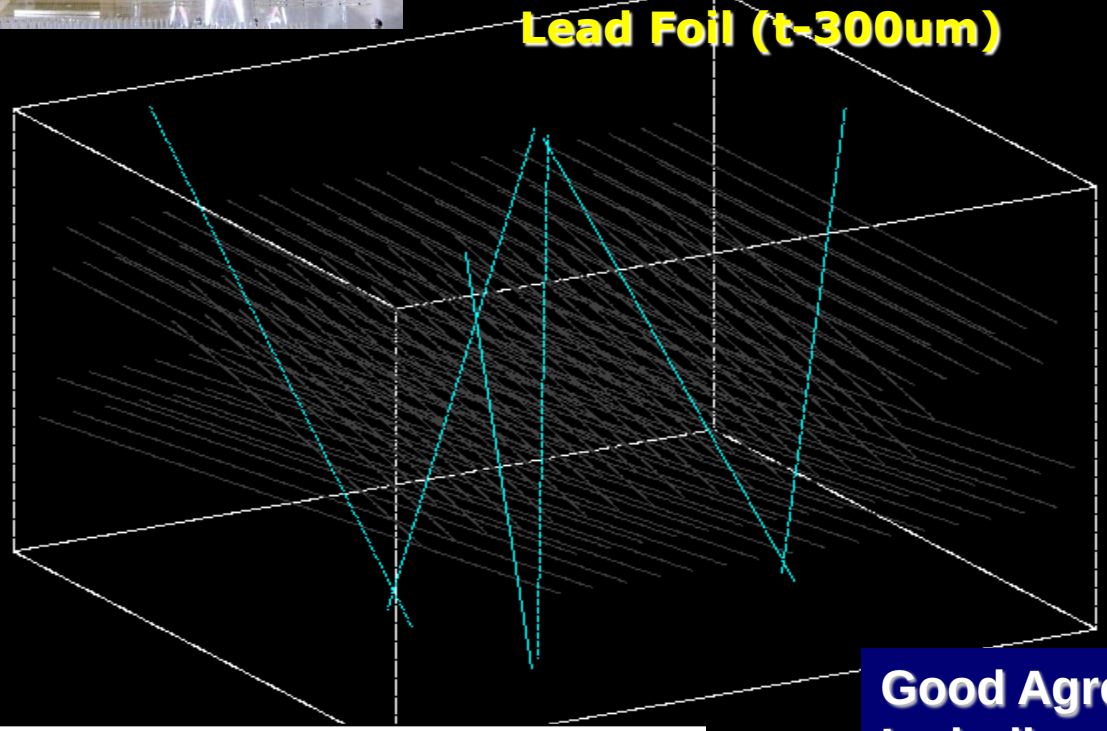
Point Source Tracks
~ 200 um res.

V-Track Reconstruction



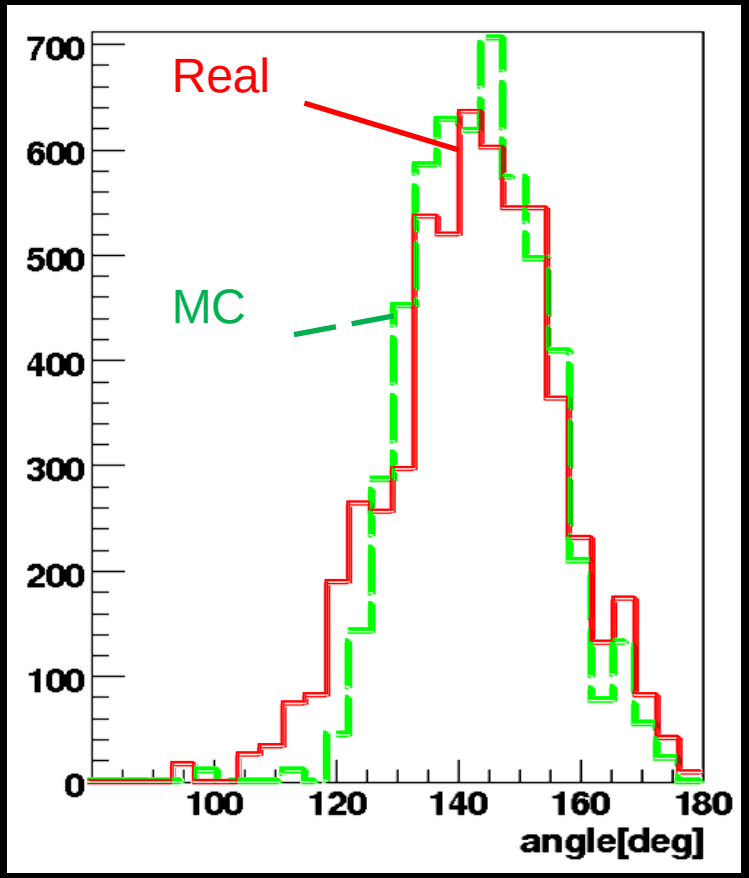
90Sr/Y beta source (Qb=2.283MeV)





Reconstructed V-Tracks (real data)

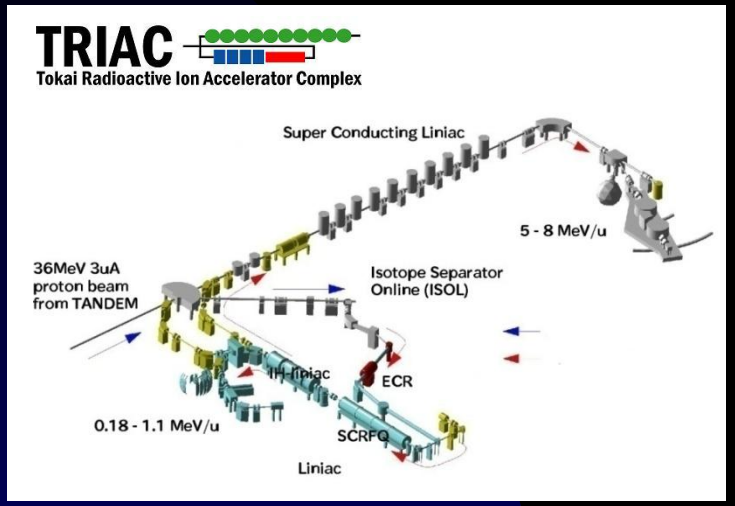
Scattering Angular Distribution

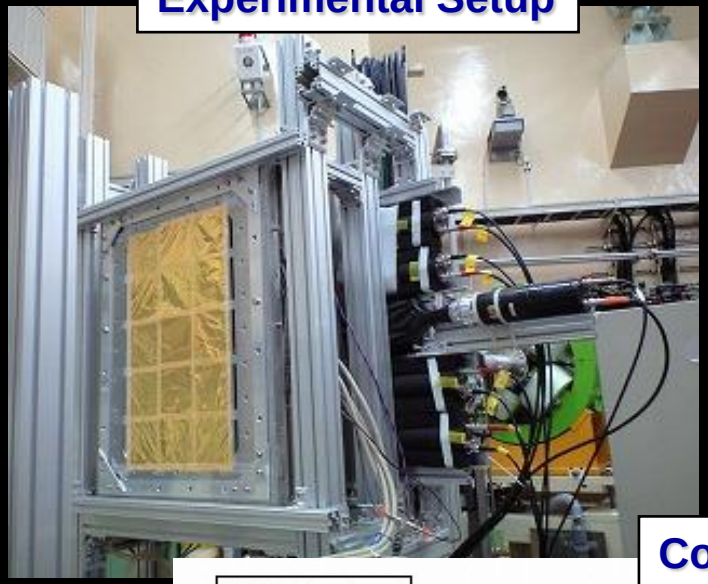


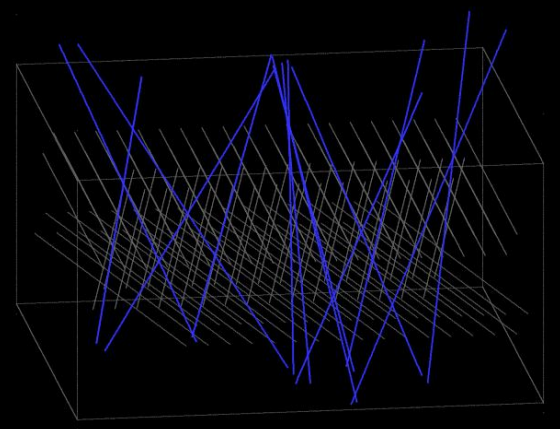
Good Agreement with Full Detector Simulation
Including Multiple Scattering

KEK-TRIAC Experiment

Experimental Setup



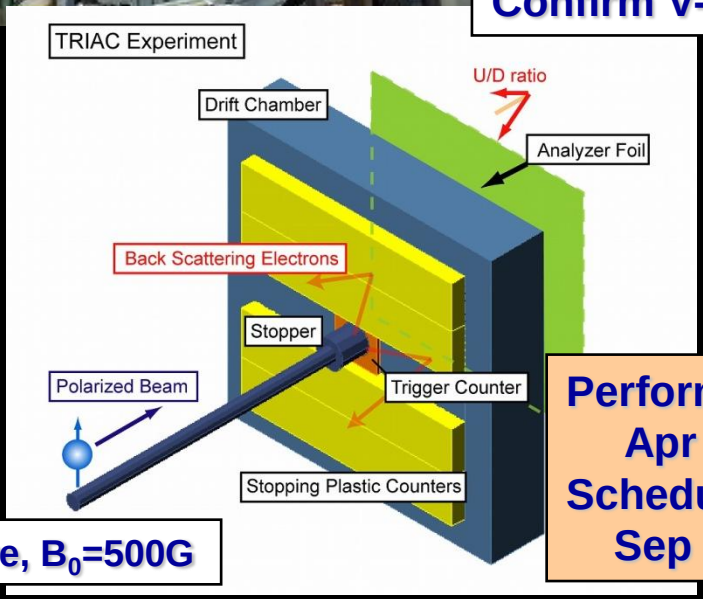




Confirm V-Track reconstruction !

8Li Beam : 178keV/u @ 10^5pps

~ % polarization

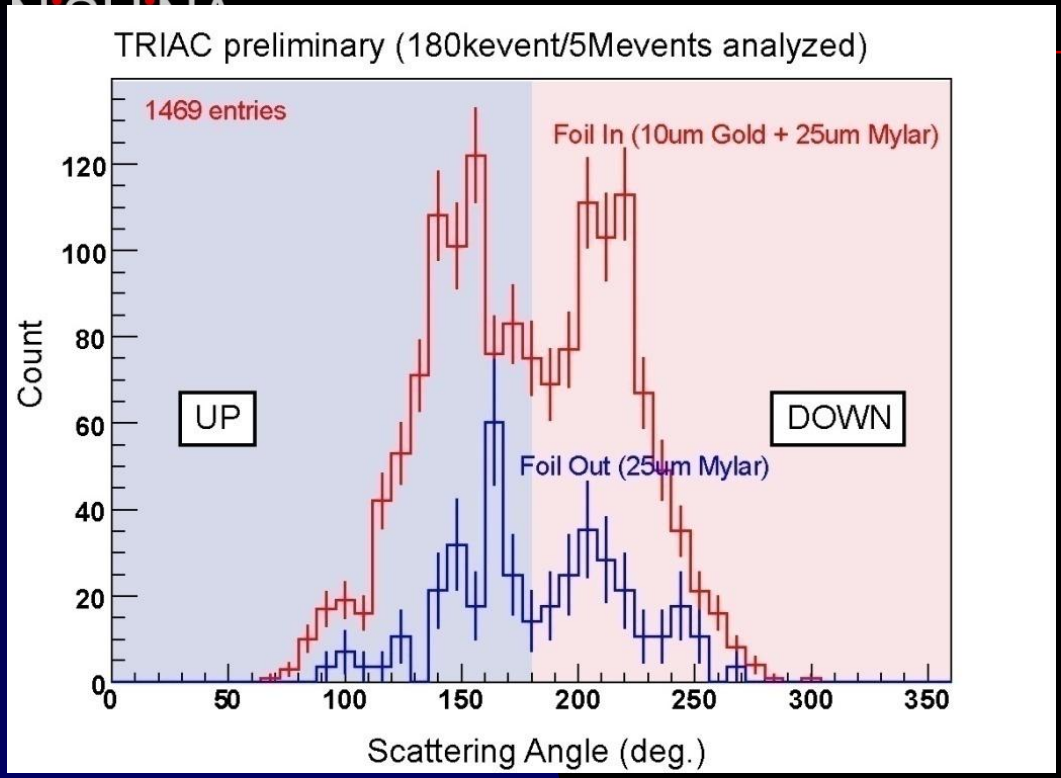


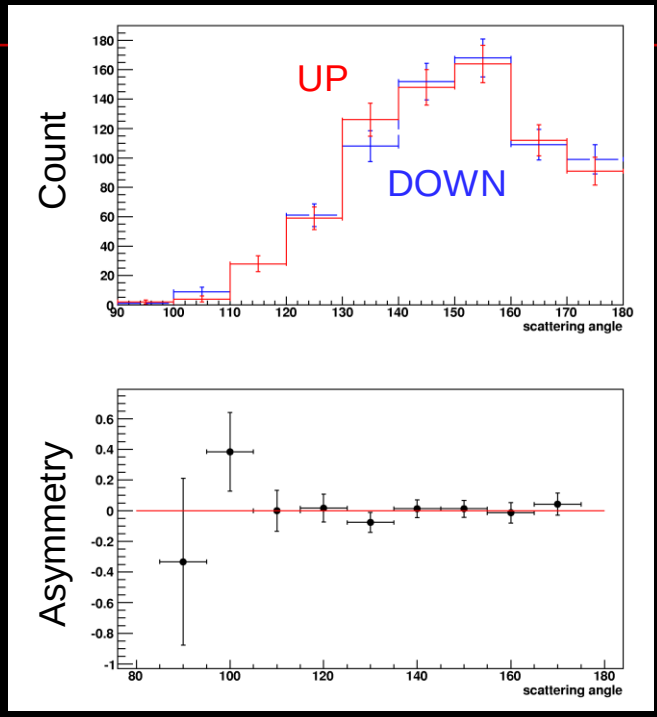
Tilted Foil : 10ug/cm^2 Carbon x 10 @ 70deg.

Performed:
Apr 2008 Unpol. 10^4pps
Scheduled:
Sep 2008 10% pol. 10^5pps

Stopper : Annealed Platinum at room temperature, B_0=500G

Results from KEK-TRIAC Experiment





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

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

effective analyzing power $<\varepsilon> \sim 0.1$

polarization $<J> \sim 0.1$

$$\sigma_{Asym} \sim 1/\sqrt{N_{event}} = 1/\sqrt{1.5k} \sim 0.02$$

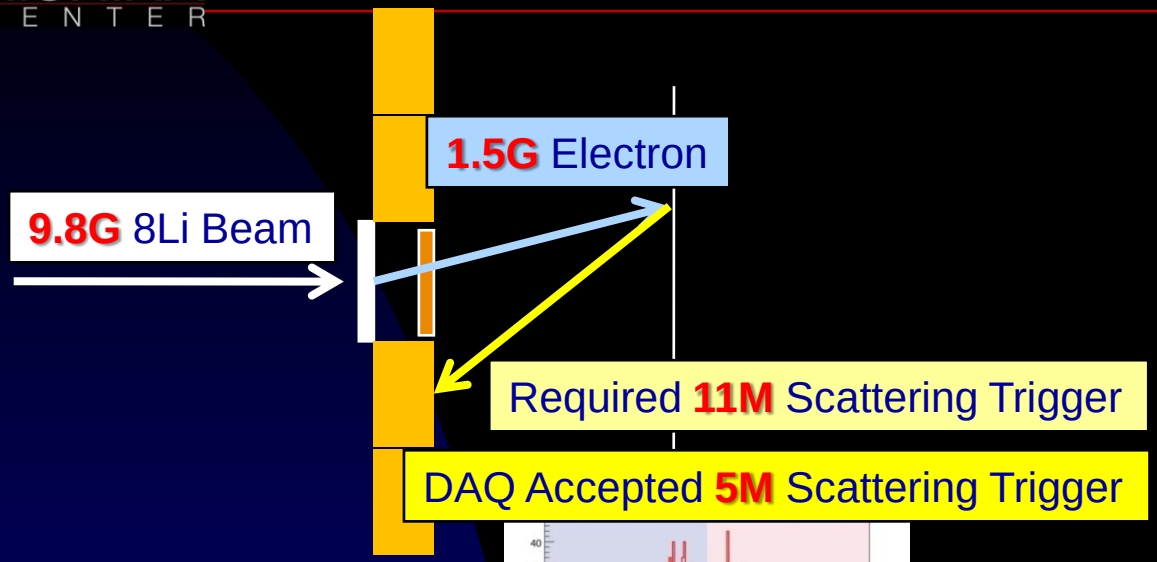
$$\sigma_R \sim \frac{0.02}{0.1 \times 0.1} = 2$$

180k events analyzed (3.6% of 5M events)

~40% precision expected for (10% pol.), 10^4pps x 3days

TRIAC Apr-08 40% precision

Statistics Summary of KEK-TRIAC Experiment



Reconstructed **1.5k** V-Track Events from **3.6%** (0.18M)data

Reconstructed **42k** V-Track Events expected

$$\sigma_{Asym} \sim 1/\sqrt{N_{event}} \sim 0.004$$

$$\sigma_R \sim \frac{\sigma_{Asym}}{<\varepsilon><J>} = \frac{0.004}{0.1\times 0.1} = 40\%$$

TRIAC Apr-08 40% precision

TRIAC Sep 2008 Expected 2days

DC Trigger & 10micron → 100micron foil

500M Trigger expected

4.2M V-Track expected

$\sigma_R \sim 4\%$ expected

TRIAC Sep-08 4% expected

TRIUMF Expected 12days

10^5 pps → 10^7pps, 10% → 70% pol.

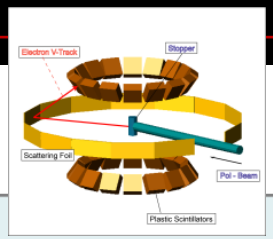
300G Trigger expected

2.4G V-Track expected

$\sigma_R \sim 0.02\%$ expected

TRIUMF 0.02% expected

Expected Physics Sensitivity



PSI '03: 700Mpps 20% pol
TRIAC: 100kpps 10% pol
TRIUMF ISAC: 10Mpps 70% pol

Error Budget in PSI exp.
Total Error 0.29%
Statistics 0.26%
Systematic 0.13%

Systematic Source
Background, Accidental,,,

Assumption:
Twice Acceptance, Effective Analyzing Power ~ 0.3

Final State Interaction

$$R\xi = |M_{GT}|^2 \lambda_{J'J}\left[\pm 2\,\mathrm{Im}\left(C_T C_A'^{*} + C_T' C_A^{*}\right) - \frac{\alpha Zm}{p_e} 2\,\mathrm{Re}\left(C_T C_T'^{*} - C_A' C_A^{*}\right)\right]$$
$$+ \delta_{J'J} M_F M_{GT} \sqrt{\frac{J}{J+1}}\left[\begin{array}{l} 2\,\mathrm{Im}\left(C_S C_A'^{*} + C_S' C_A^{*} - C_V C_T'^{*} - C_V' C_T^{*}\right) \\ \mp \frac{\alpha Zm}{p_e} 2\,\mathrm{Re}\left(C_S C_T'^{*} + C_S' C_T^{*} - C_V C_A'^{*} - C_V' C_A^{*}\right)\end{array}\right]$$

$$R_{Measured} = (1.6 \pm 2.2) \times 10^{-3}$$

$$R_{\mathrm{FSI}} = 0.7 \times 10^{-3}$$

$$R = R_M - R_{\mathrm{FSI}} = (0.9 \pm 2.2) \times 10^{-3}$$

PSI Precision ~ FSI × 3

Still there is room for discovery, however, no one is trying to do it now.

Possible Strategies

1. Precision Evaluation of FSI

$$R_{FSI} \approx A \frac{\alpha Zm}{p}$$

Systematic Study for various nuclei

Precise Subtraction of FSI

True T-Violation

2. Study of FSI itself

Large FSI at Heavy Nuclei

Nuclear Size, Structure Dependence,,,

Summary

DC based Mott Polarimeter has been developed.

First experiment at KEK-TRIAC has been performed.

Confirm V-track reconstruction.

R precision ~ 40% in April 2008 exp.

RNB07K04

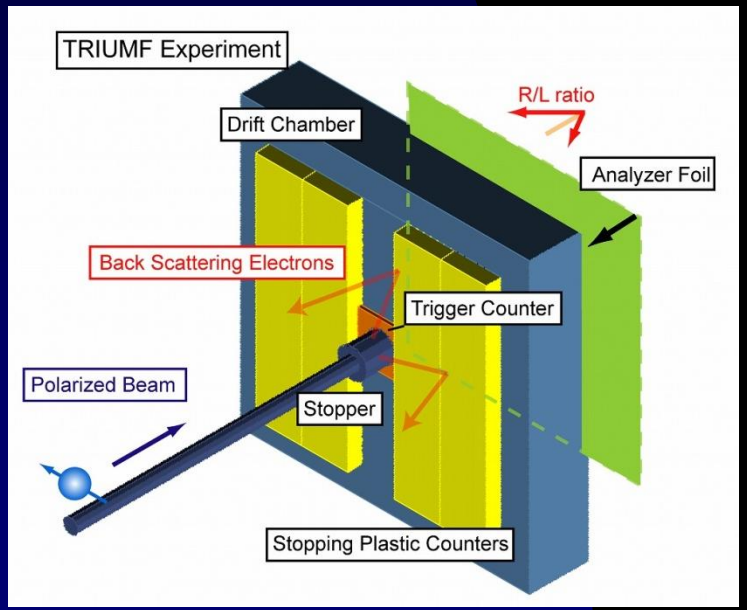
In the future, 4% in September 2008 exp.

RNB08K04

0.02% in TRIUMF 2009 exp.

S1183

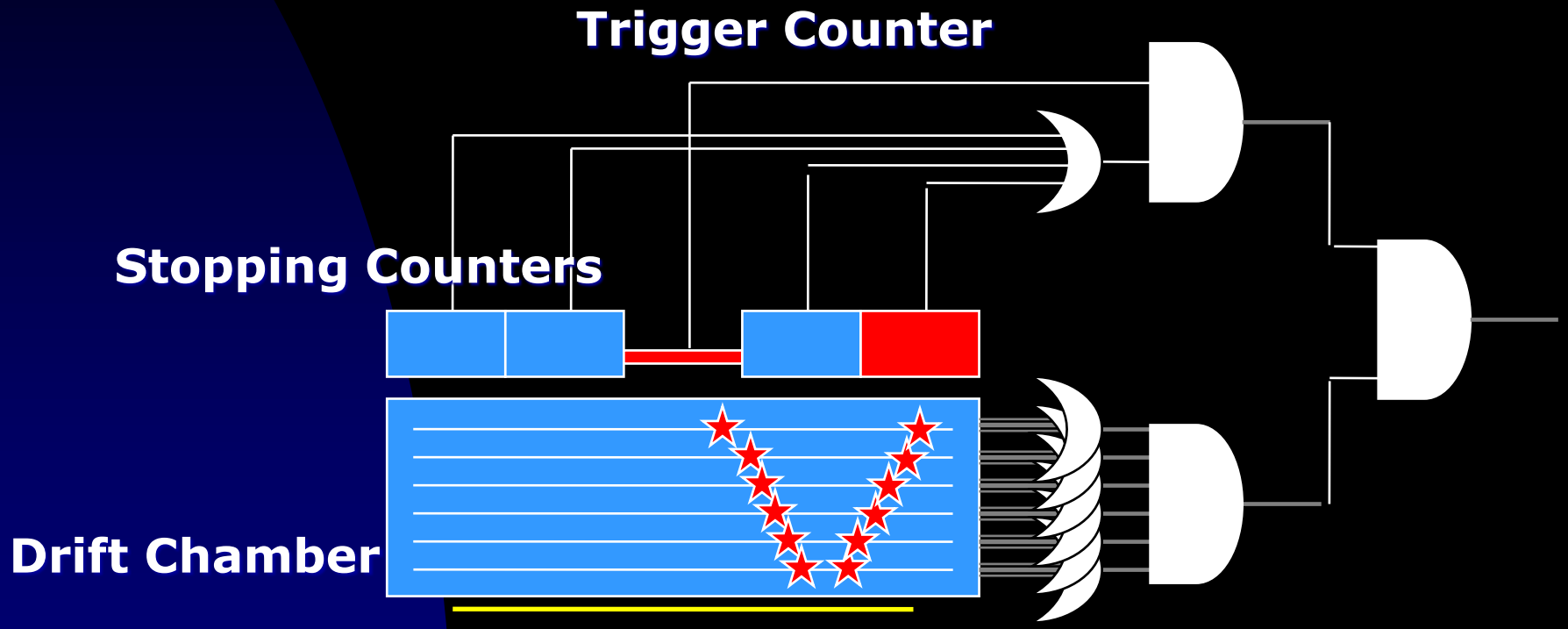
~ FSI effect



At SPIN 2008, I want to report the actual result of September experiment.

Trigger Logic

Schematic View of V-track Event

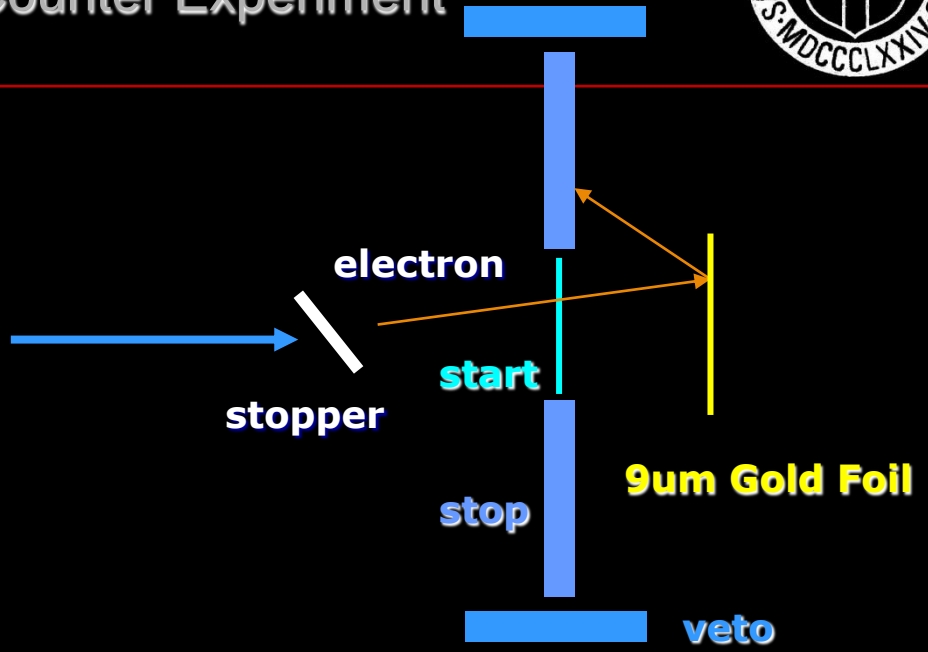


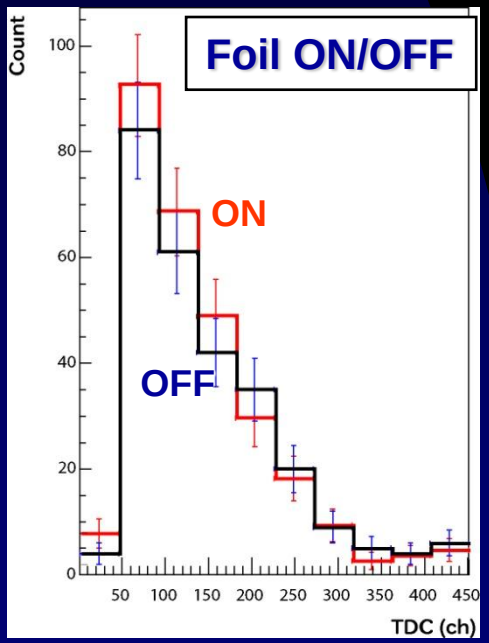
Background Rate in Counter Experiment

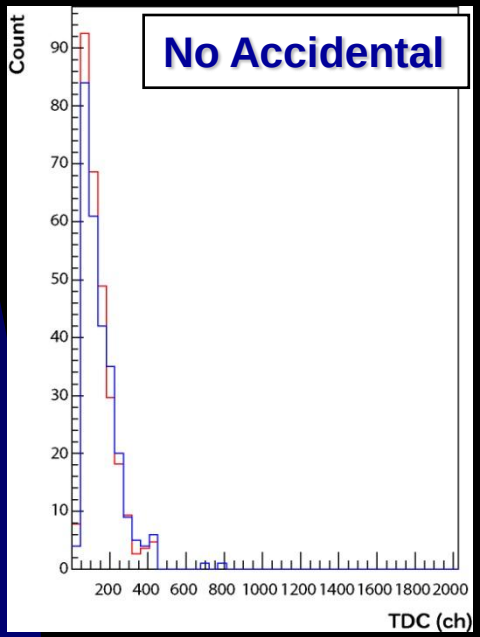
Test Experiment @ RIKEN-RIPS Beam Line

Polarized Secondary Beam : 31Al 95MeV/u

Qbeta- = 8.0MeV







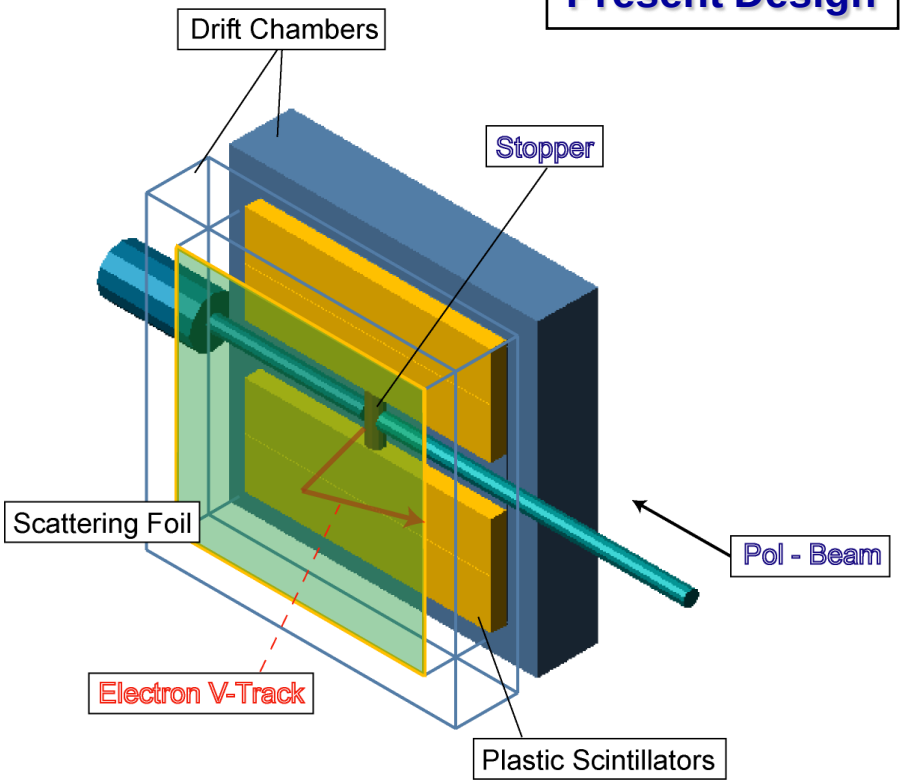
TDC (start – stop)

Signal / Background ~ 10%

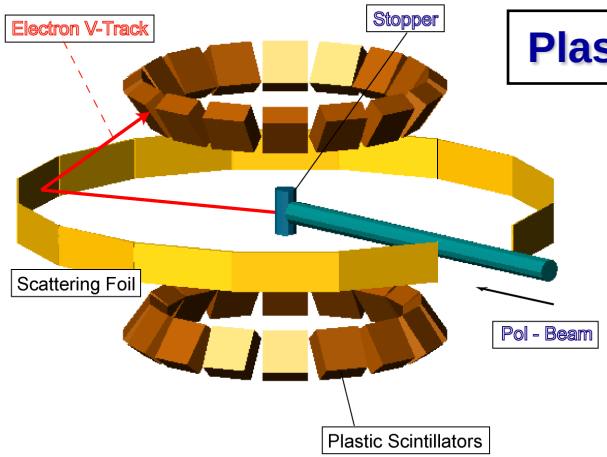
Tracking Device -> Reject Ghost Events

Configuration Dependence on Acceptance

Present Design

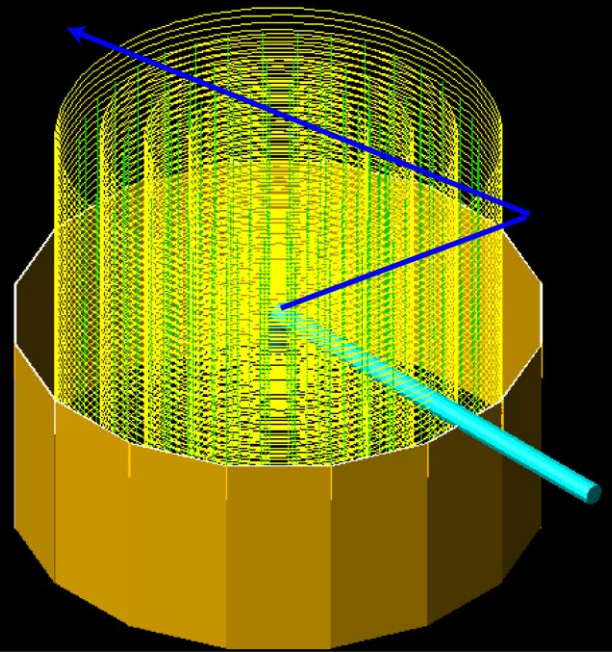


Plastic Polarimeter



PSI 8Li Exp. type

10MeV 0.9uA 7Li(d,p)8Li
99.9% 7Li target, GBq
B = 7mT, Pol = 20% @LHe
Relaxation time > 20sec
Lead foil analyzer 35mg/cm2



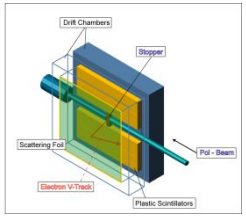
Drift Chamber Polarimeter
: Limited Solid Angle, not suitable for High Rate

GOAL : Cylindrical MWPC Polarimeter
: Large Solid Angle, good for High Rate

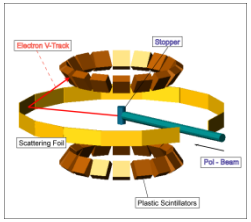
Monte-Carlo Estimation of the Acceptance

Drift Chamber Polarimeter

Over 90deg ~ 1/1270 @ 10micron Gold Foil



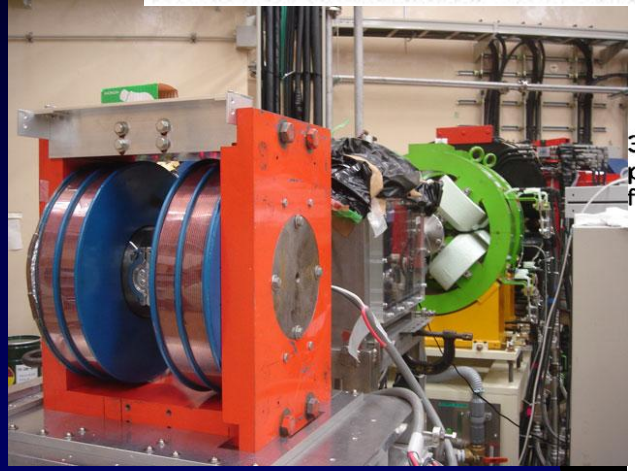
Plastic Polarimeter

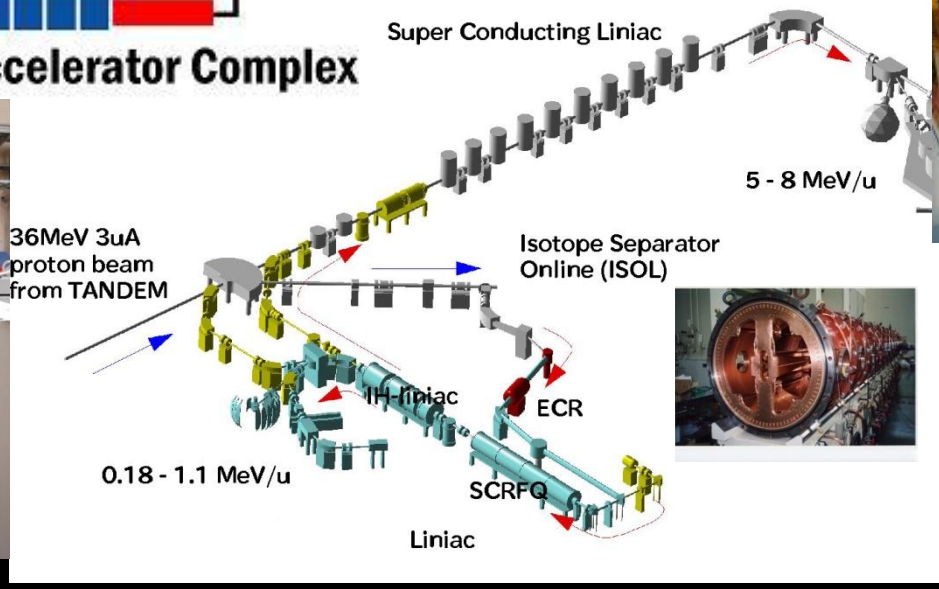


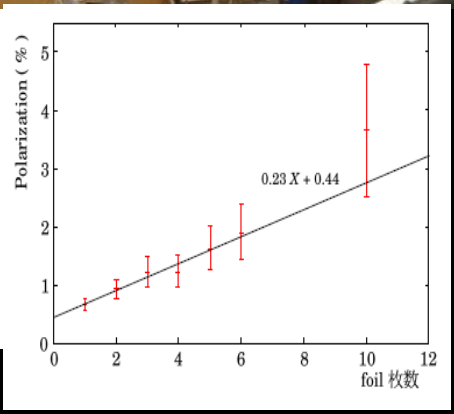
Around peak FOM

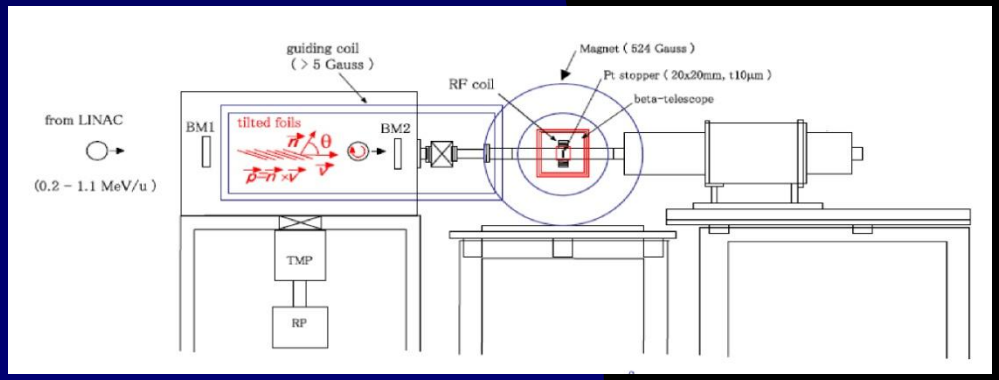
Stopped RI Facility at KEK-TRIAC

TRIAC
Tokai Radioactive Ion Accelerator Complex









2005 Hirayama et. al. (KEK)

Unpol 8Li Beam (178keV/u)

~ % polarization

up to 10% ?

Tilted Foil : 10ug/cm^2 Carbon x 10 @ 70deg.

Polarized Low Energy 8Li beam is available !

Previous Measurements (P-violating & T-violating)

$^{19}\vec{\mathrm{Ne}} \rightarrow {}^{19}\mathrm{Fe} + e^+ + \nu_e$	$(-79 \pm 53) \times 10^{-3}$	Princeton '83
$^{8}\vec{\mathrm{Li}} \rightarrow {}^{8}\mathrm{Be} + e^- + \bar{\nu}_e$	$(-0.9 \pm 2.2) \times 10^{-3}$ **BEST**	PSI '03
$\vec{\mu}^+ \rightarrow e^- + \bar{\nu}_\mu + \nu_e$	$(-3.7 \pm 7.7) \times 10^{-3}$	PSI '05
$\vec{\Lambda}^0 \rightarrow \pi^- + \vec{p}$	$(-94 \pm 60) \times 10^{-3}$	CERN '72
$\vec{n} \rightarrow p + e^- + \bar{\nu}_e$	$(-15 \pm 16) \times 10^{-3}$ Preliminary	PSI nTRV exp.

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**

Null-Experiment: Independent of Nuclear Structure Ambiguity

偏極保持装置の開発

検出器立体角の確保・・・ストッパーとDCの距離

β - NMR

外部偏極保持磁場の一様性

RF磁場によるスピン反転

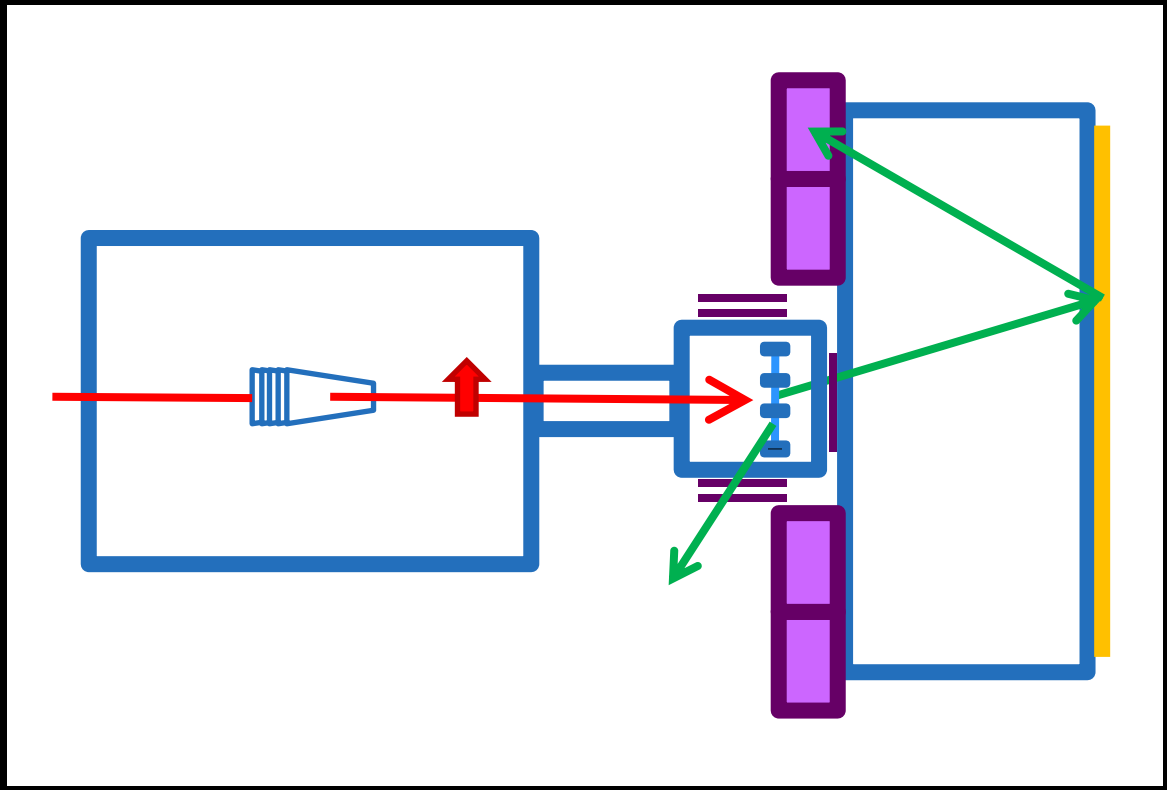
必要なし

コンパクトなストッパー

冷凍機を用いない
永久磁石を用い小型化

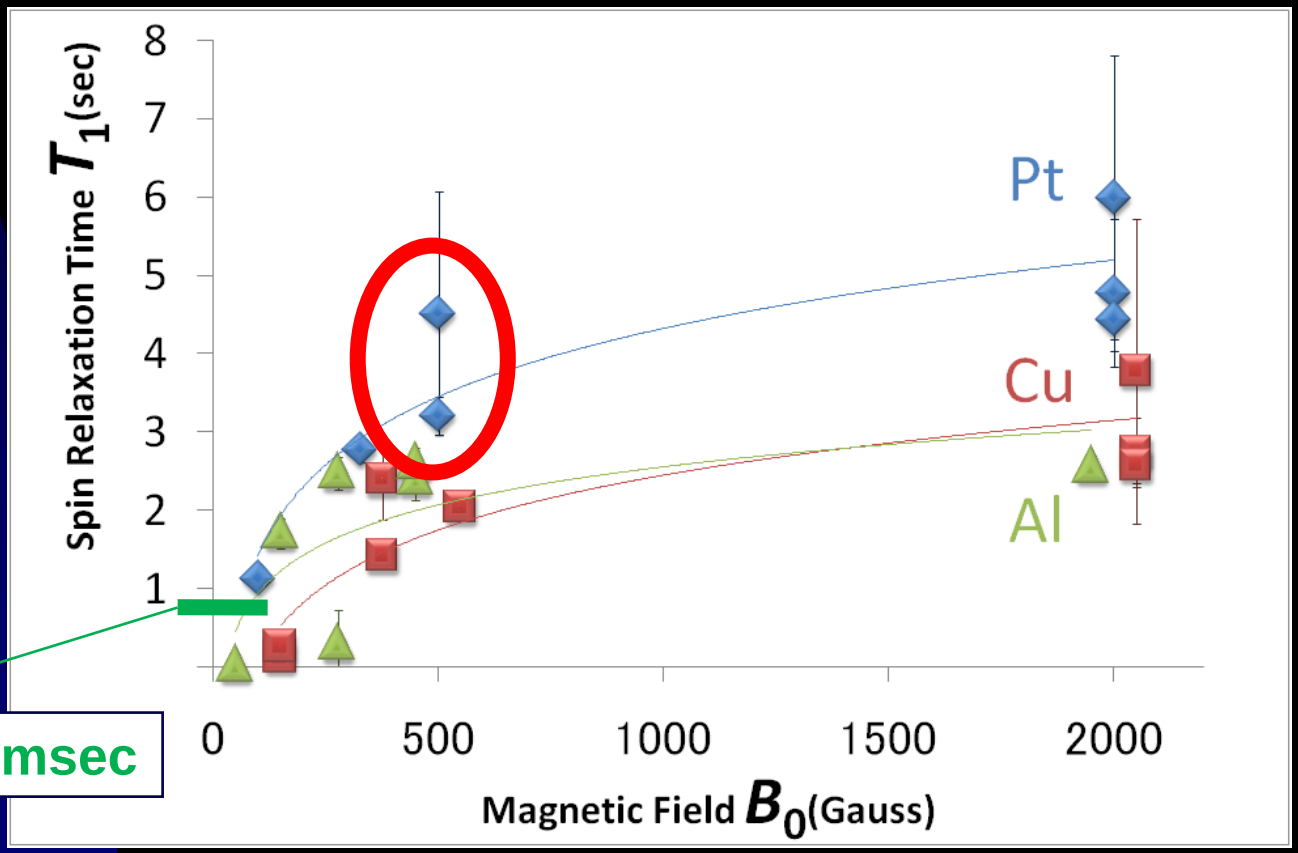
- 漏れ磁場
- 電子線偏向

最適な磁場強度
偏極緩和の調査



偏極保持装置の開発

^{8}Li偏極緩和時間の磁場強度依存性
＠阪大バンデ/松多グループ



Life time(^{8}Li) = 838msec

U/D ratio

$$W(\theta) = 1 + \frac{v}{c} AP\cos(\theta)$$

A;Asymmetry Parameter

=-1/3 （^{8}Li）

P;Polarization

v/c≒1

$$\left(\frac{U}{D}\right)_{off} = G\frac{1+AP}{1-AP}$$

AFP法　$P \rightarrow -P$

$$\left(\frac{U}{D}\right)_{on} = G\frac{1-AP}{1+AP}$$

G:検出効率の比