July 1, 2006
PAC meeting

J-PARC 50-GeV PS Proposal

Measurement of T-violating Transverse Muon Polarization in $K^+ \rightarrow \pi^0 \mu^+ \nu$ Decays

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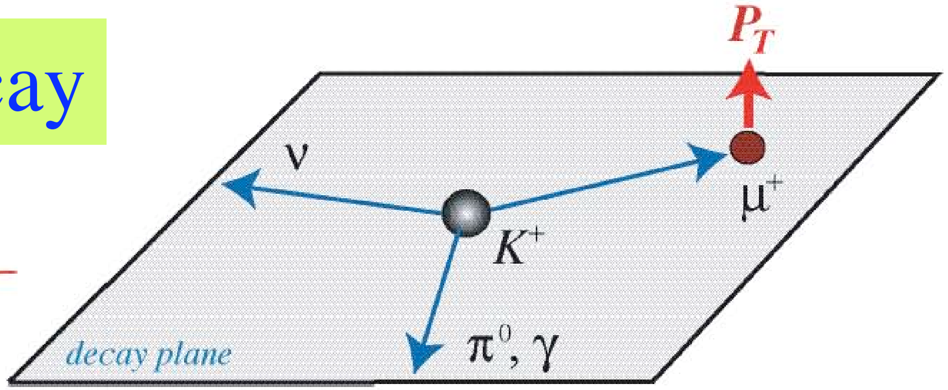
Transverse muon polarization

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

$$P_T = \frac{\sigma_\mu \cdot (\boldsymbol{p}_{\pi^0, \gamma} \times \boldsymbol{p}_{\mu^+})}{|(\boldsymbol{p}_{\pi^0, \gamma} \times \boldsymbol{p}_{\mu^+})|}$$

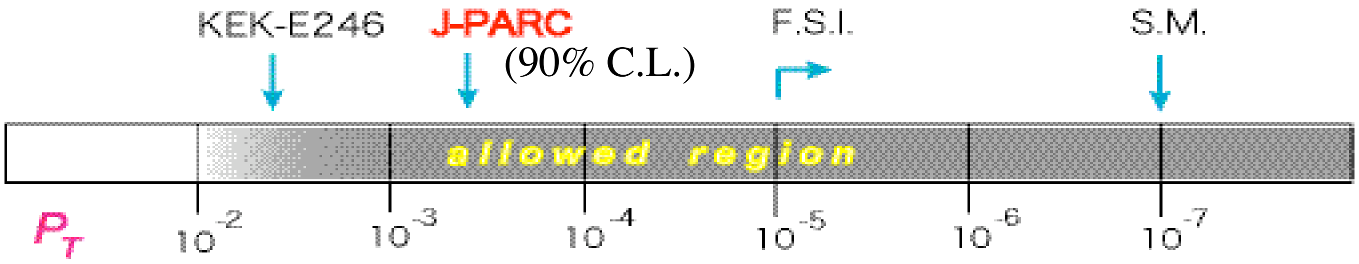


- P_T is T-odd and spurious effects from final state interaction are small. Non-zero P_T is a signature of T violation.
- Very clear channel to search for T violation. Long history of theoretical and experimental studies. (J.J. Sakurai, 1957)
- Powerful tool to study CP violation due to CTP theorem.
- One of the typical experiments of high-precision frontier.

  cf. neutron EDM, g_μ-2

Theoretical aspects

- Standard Model contribution to P_T :
  - Only from vertex radiative corrections and $P_T(\mathrm{SM}) < 10^{-7}$
- Spurious effects from final state interactions (FSI)
  - Recent elaborate calculation : $P_T(\mathrm{FSI}) < 10^{-5}$



- There is a large window for new physics in the region of

$$P_T = 10^{-3} \sim 10^{-5}$$

- There are theoretical models which allow sizeable P_T without conflicting with other experimental constraints.

Features of P_T in looking for new physics

- Interference phenomena with the SM *W*-exchange
  - $P_T \sim 1/\Lambda^2$ (Λ is the mass scale of new interactions in the effective Lagrangian)
- Sensitive to CP violation in the Higgs sector
  - After the Higgs boson will be discovered, it becomes more important to look for associated CP violating couplings
- Stringent constraint to exotic scalar interactions
  - $P_T \sim 0.38\ \mathrm{Im}C_S\ (\mathrm{TeV}/\Lambda)^2$ (C_S is the scalar coefficient)
- P_T can be studied also in other channels
  - $K^+ \to \mu^+ \nu \gamma$, $K^+ \to \pi^+ \mu^+ \mu^-$,
  - Possibility to distinguish models

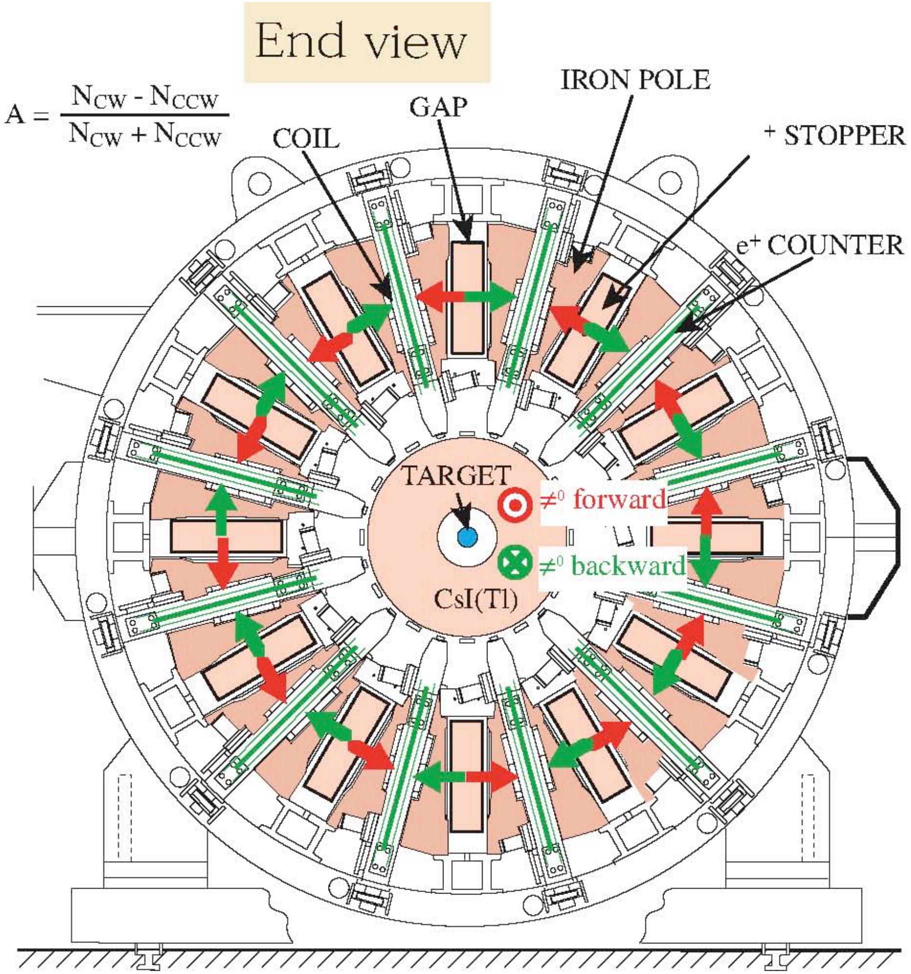
Model descriptions of P_T

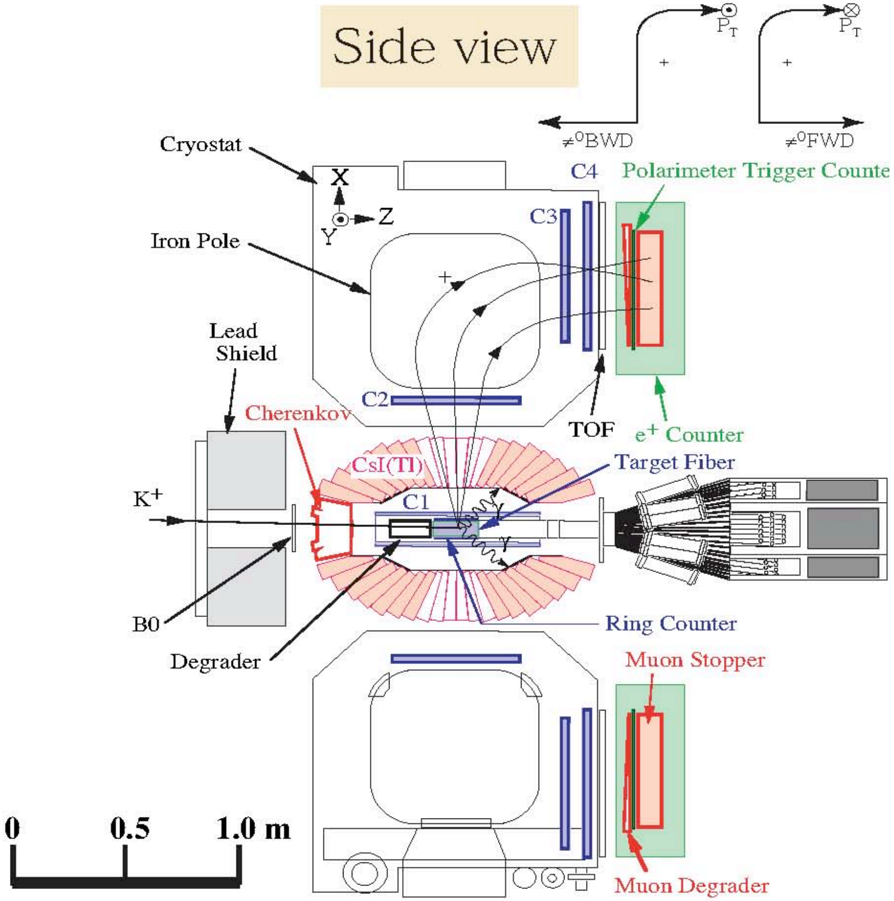
$$P_T = \mathrm{Im}\xi \cdot \frac{m_\mu}{m_K} \frac{|\vec{p}_\mu|}{[E_\mu + |\vec{p}_\mu| \vec{n}_\mu \cdot \vec{n}_\nu - m_\mu^2/m_K]} \qquad \mathrm{Im}\xi = \frac{(m_K^2 - m_\pi^2)\mathrm{Im}G_S^*}{\sqrt{2}(m_s - m_u) m_\mu G_F \sin\theta_C}$$

P_T is sensitive to scalar interactions

- Multi-Higgs doublet (3 Higgs doublet) model
  - $\mathrm{Im}\xi = (m_K^2/m_H^2)\,\mathrm{Im}(\gamma_1\alpha_1^*)$
  - $|\mathrm{Im}(\gamma_1\alpha_1^*)| < 544\,(m_H/\mathrm{GeV})^2$ from the E246 limit
  - $B\rightarrow\tau\nu X$ constraints also $\mathrm{Im}(\gamma_1\alpha_1^*)$ but weaker ($<1900\,(m_H/\mathrm{GeV})^2$)
  - N-EDM and $b\rightarrow s\gamma$ constraint differently $\mathrm{Im}(\alpha_1\beta_1^*)$
- SUSY with squark mixing
  - $\mathrm{Im}\xi \propto \mathrm{Im}[V_{33}^{H+} V_{32}^{DL*} V_{31}^{UR*}]/ m_H^2$
  - $m_H \geq 140$ GeV from the E246 limit and no stringent limit from other modes
- SUSY with R-parity violation
  - $\mathrm{Im}\xi^l \sim \mathrm{Im}\,[\lambda_{2i2}(\lambda_{i12})^*]$, $\qquad \mathrm{Im}\xi^d \sim \mathrm{Im}\,[\lambda'_{21k}(\lambda'_{22k})^*]$
  - No stringent limits from other modes

KEK-PS E246 experiment





- Stopped K^+ decay at K5
- SC Toroidal spectrometer

- Measurement of e^+ emission *cw/ccw* asymmetry when π^0 in *fwd/bwd* directions

Final result : Phys. Rev. D73, 072005 (2006)

E246 result

$$A_T = (A^{fwd} - A^{bwd}) / 2$$

$$A^{fwd(bwd)} = \frac{N_{cw} - N_{ccw}}{N_{cw} - N_{ccw}}$$

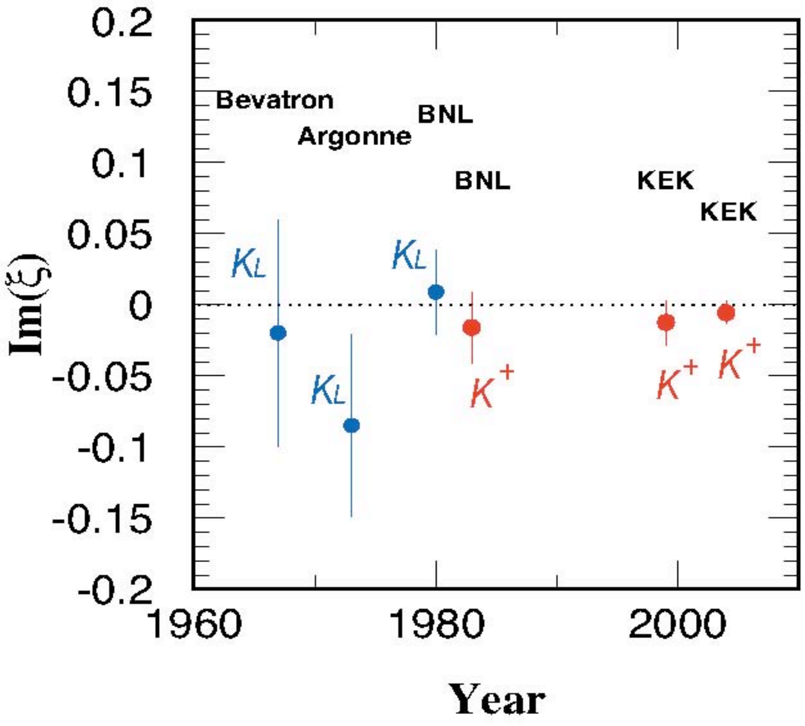
$$P_T = A_T / \{\alpha <\cos\theta_T>\}$$

α : analyzing power

$<\cos\theta_T>$: attenuation factor

$$\mathrm{Im}\xi = P_T / KF$$

KF : kinematic factor



$$P_T = -0.0017 \pm 0.0023(stat) \pm 0.0011(syst)$$

($|P_T| < 0.0050$: 90% C.L.)

$$\mathrm{Im}\xi = -0.0053 \pm 0.0071(stat) \pm 0.0036(syst)$$

($|\mathrm{Im}\xi| < 0.016$: 90% C.L.)

Statistical error dominant

J-PARC experiment

- We aim at a sensitivity of $\delta P_T \sim 10^{-4}$

$\delta P_T^{stat} \leq 0.1\ \delta P_T^{stat}(E246) \sim 10^{-4}$ with

1) $\times$ 30 of beam intensity,
2) $\times$ 10 of detector acceptance, and
3) higher analyzing power

$\delta P_T^{syst} \sim 0.1\ \delta P_T^{syst}(E246) \sim 10^{-4}$ by

1) precise calibration of misalignments using data
2) correction of systematic effects

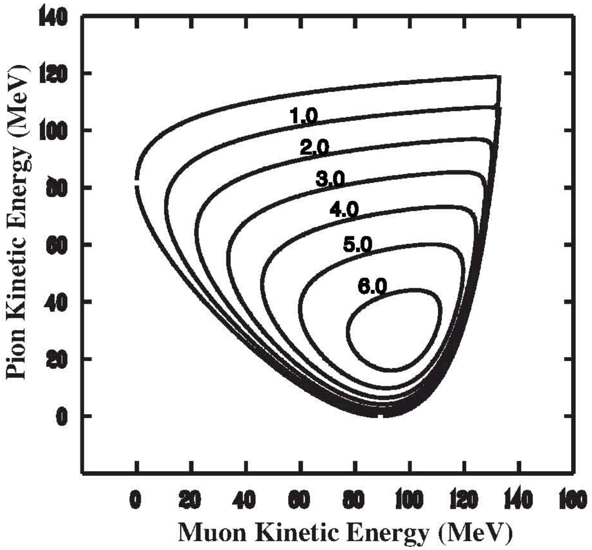
Source	δP_T in E246	J-PARC
μ^+ multiple scattering	7.1×10^{-4}	not existing
Decay plane angle (θ_r)	1.2×10^{-4}	corrected
Decay plane angle (θ_z)	0.7×10^{-4}	correcetd
B offset (ε)	3.0×10^{-4}	not existing
B field rotation (δ_r)	0.4×10^{-4}	measured by data and corrected
B field rotation (δ_z)	5.3×10^{-4}	measured by data and corrected
e^+ counter shits and rotations	2.9×10^{-4}	not existing
Shifts of other elements	3.2×10^{-4}	measured by data and corrected

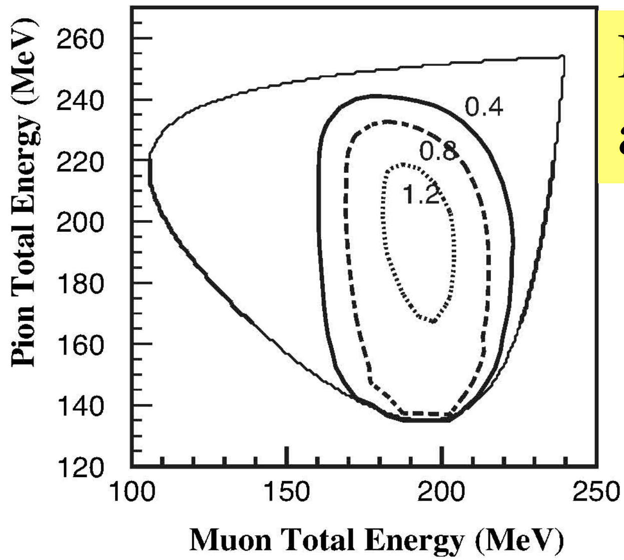
Method of experiment

- Stopped K^+ decay
  - Superior to in-flight decay
- Toroidal spectrometer

- E246 detector upgrade
  - –Well known performance
  - –Well studied systematics
  - –Good alignment in magnet and CsI(Tl)
  - –Lower cost

FoM ($A\sqrt{N}$) distribution





Detector acceptance

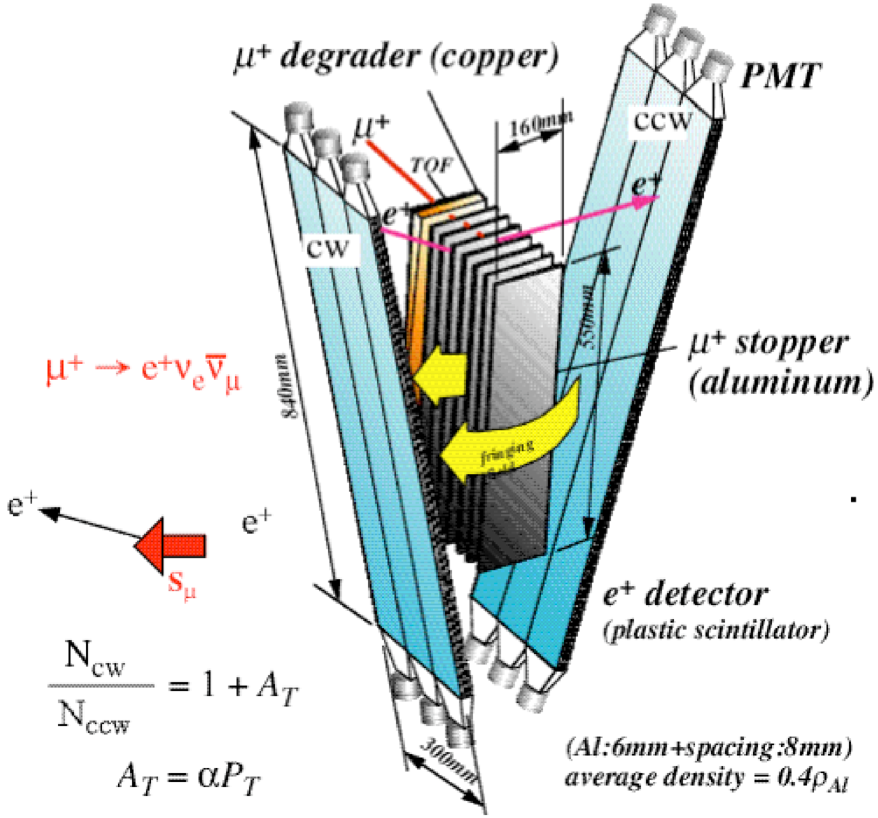
Upgrade of the detector

- Muon polarimeter : passive → active
- Muon magnetic field : toroid → muon field magnet
- Target : smaller and finer segmentation
- Charged particle tracking : addition of two chambers
- CsI(Tl) readout : PIN diode → APD
- Electronics and data taking : TKO → KEK-VME & COPPER

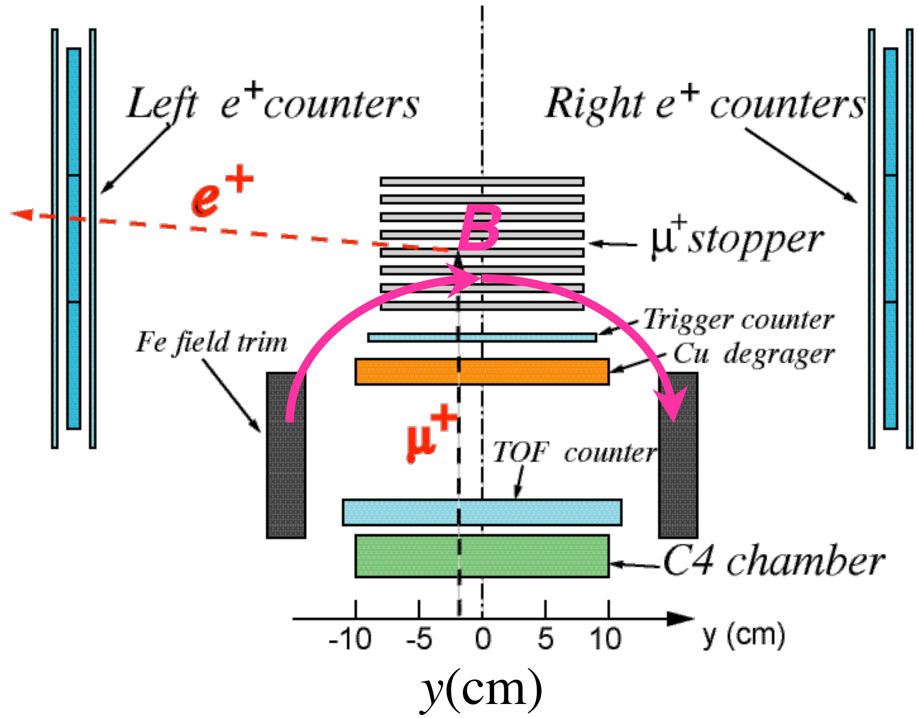
- New analysis scheme

E246 muon polarimeter

One-sector view



Cross section



- Passive polarimeter with
  - *Al* muon stopper
  - *Left/Right* positron counters

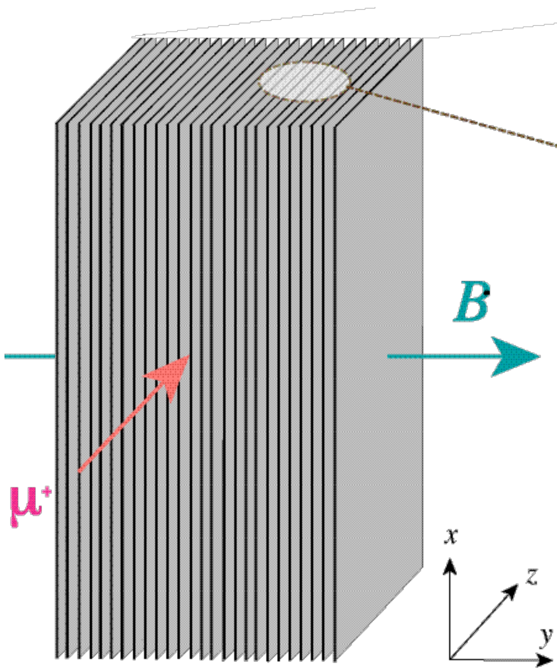
  simple analysis and systematics

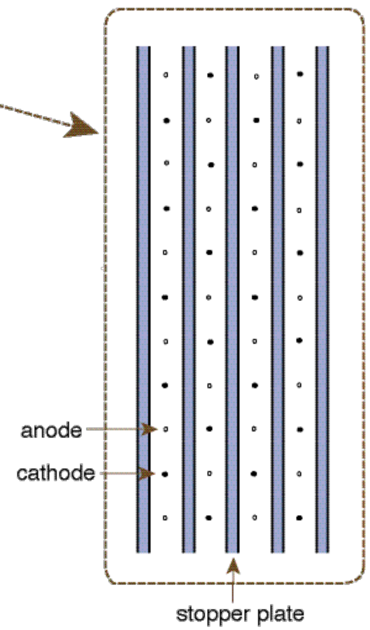
$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$

$$W(e+) \propto 1 + A\cos\theta$$

Active polarimeter

- Identification of muon stopping point/ decay vertex
- Measurement of positron energy E_{e^+} and angle θ_{e^+}
- Large positron acceptance of nearly 4π
- Larger analyzing power
- Higher sensitivity
- Lower BG in positron spectra





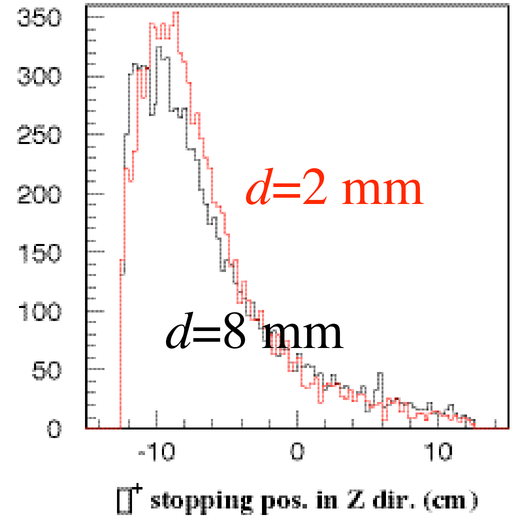
Parallel plate stopper with
Gap drift chambers

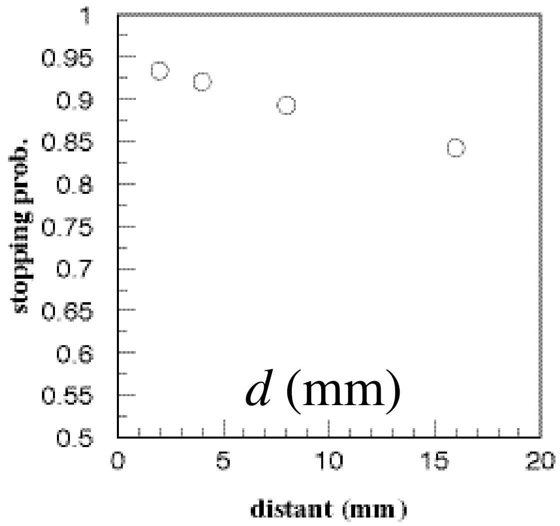
Number of plates	33
Plate material	Al, Mg or alloy
Plate thickness	~ 2 mm
Plate gap	~ 8 mm
Ave. density	$0.24\ \rho_{Al}$
μ^+ stop efficiency	~ 85%

- Small systematics for *L*/*R* positron
- asymmetry measurement
- Fit for π^0 *fwd*/*bwd* measurement
- Simple structure

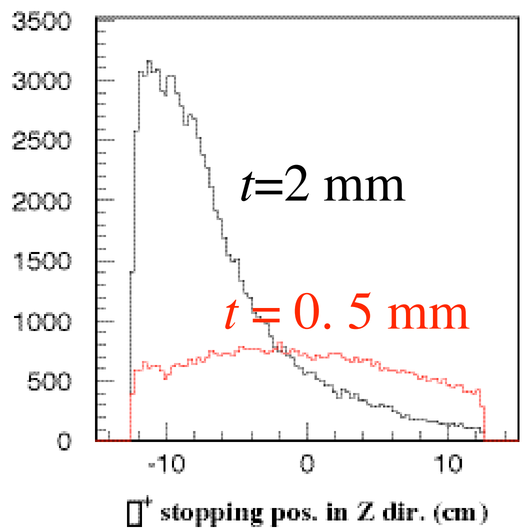
Muon stopping distribution
in the stopper

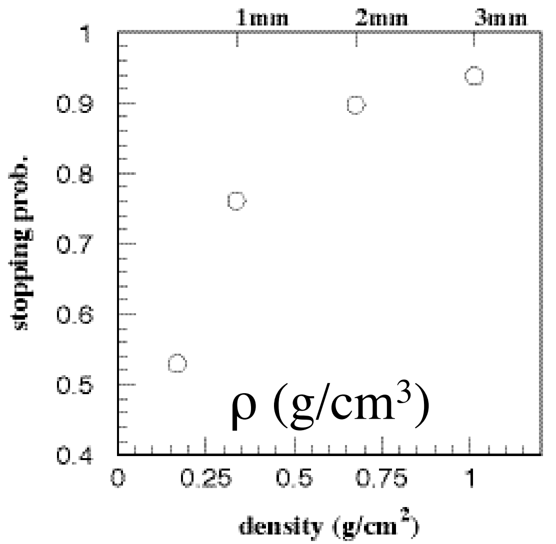
t = 2 mm





d = 8 mm



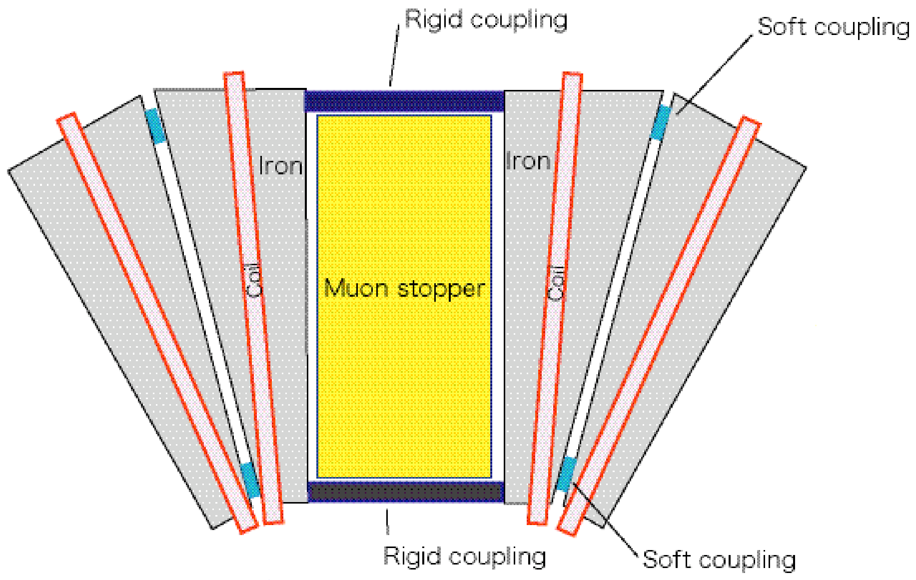


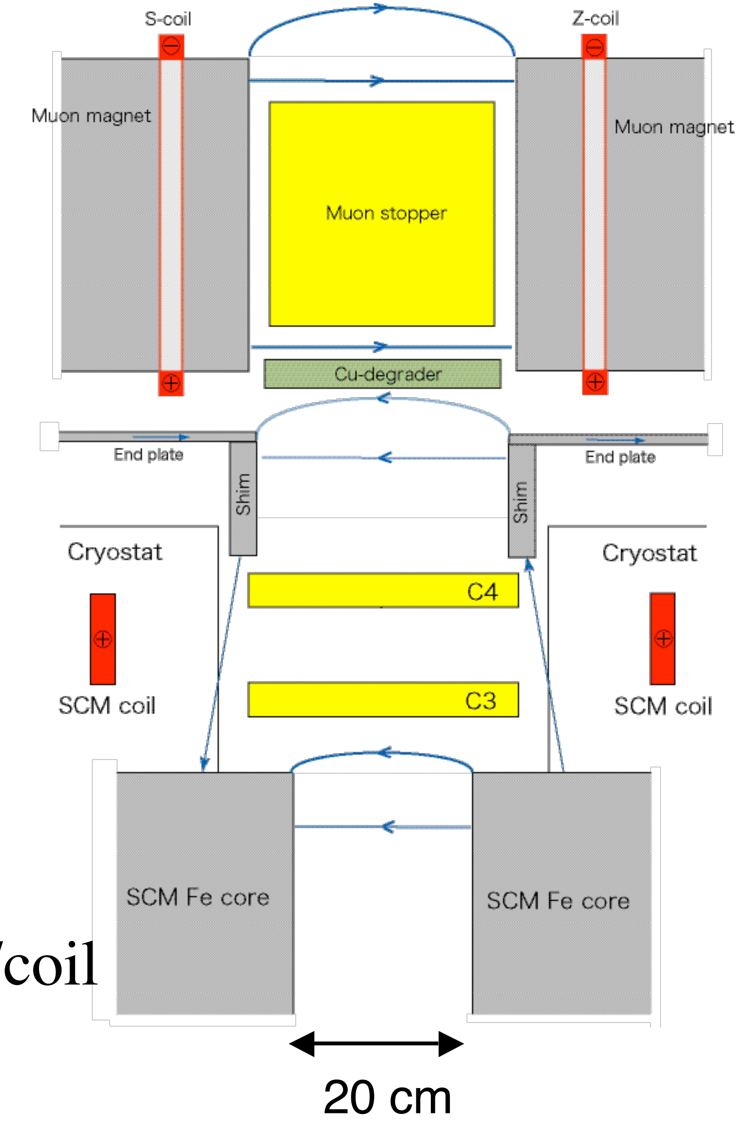
$\rho = 0.2\rho_{Al}$
$= 0.54\ \mathrm{g/cm^3}$

$\varepsilon_{stop} > 85\%$

for
t = 2 mm
d = 8 mm

Muon field magnet





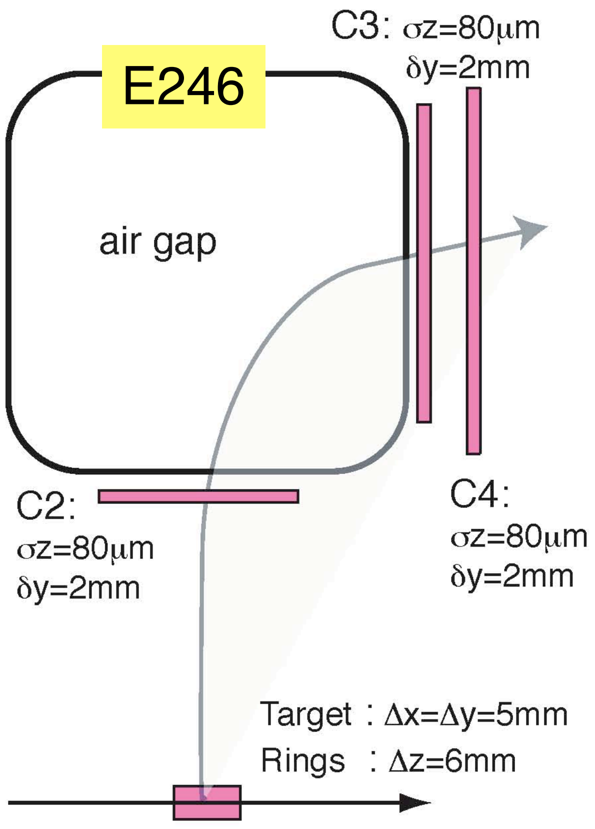
- Uniform field of 0.03 T
- Precise field alignment of 10^{-3}

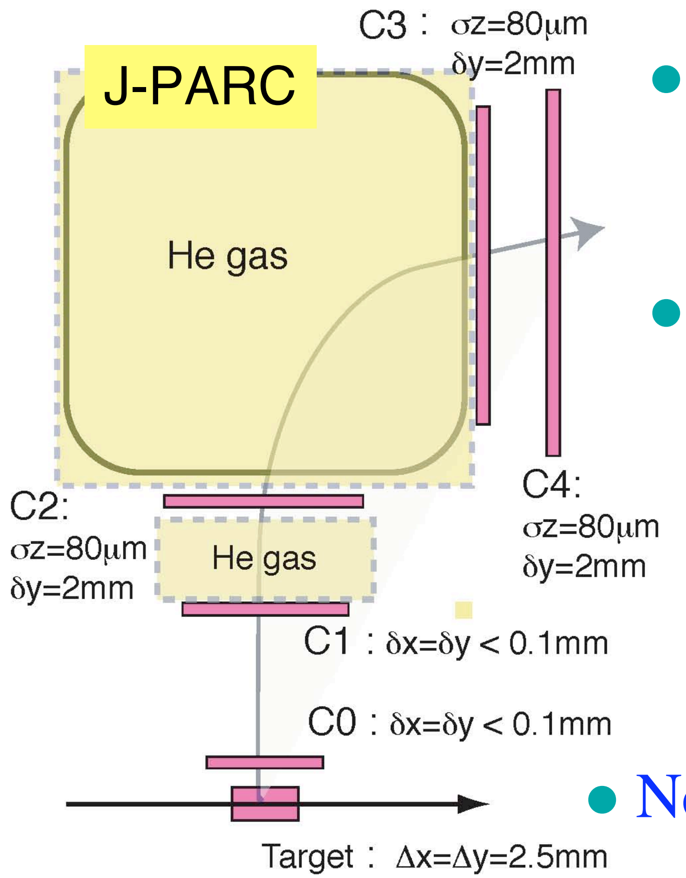
- Gap : 30 cm
- Pole face : 60 cm ×40 cm
- No. of coils : 24
- Mag. motive force : 3.6×10^{3} A Turn/coil
- Total power : 6 kW
- Total weigt : ~ 5 t

Target and tracking

- Better kinematical resolution
- Stronger $K_{\pi 2}$ *dif* μ^+ BG suppression

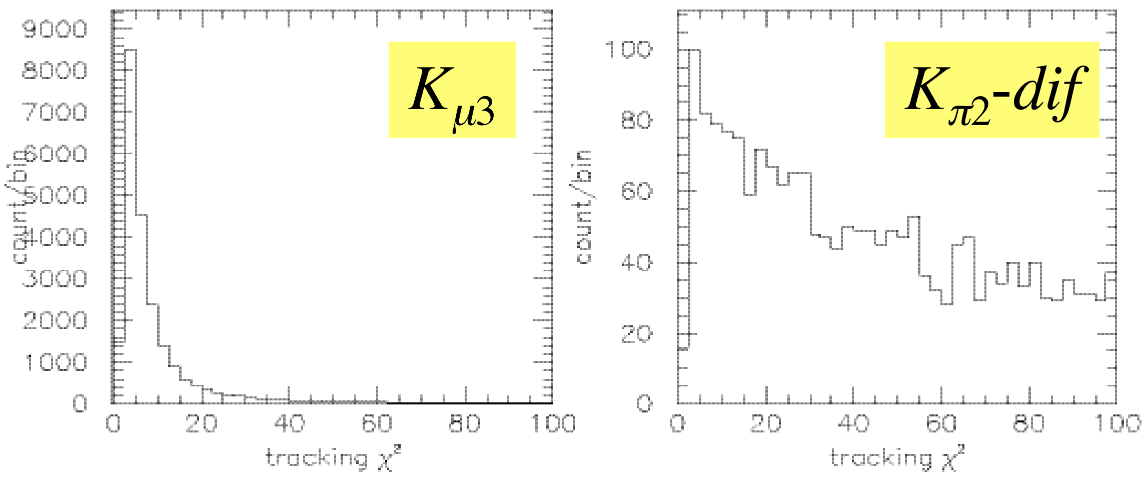
- Addition of C0 and C1 GEM chambers with
  - high position resolution
  - higher rate performance





- Larger C3-C4 distance
- Use of He bags
- New target

MC studies of tracking

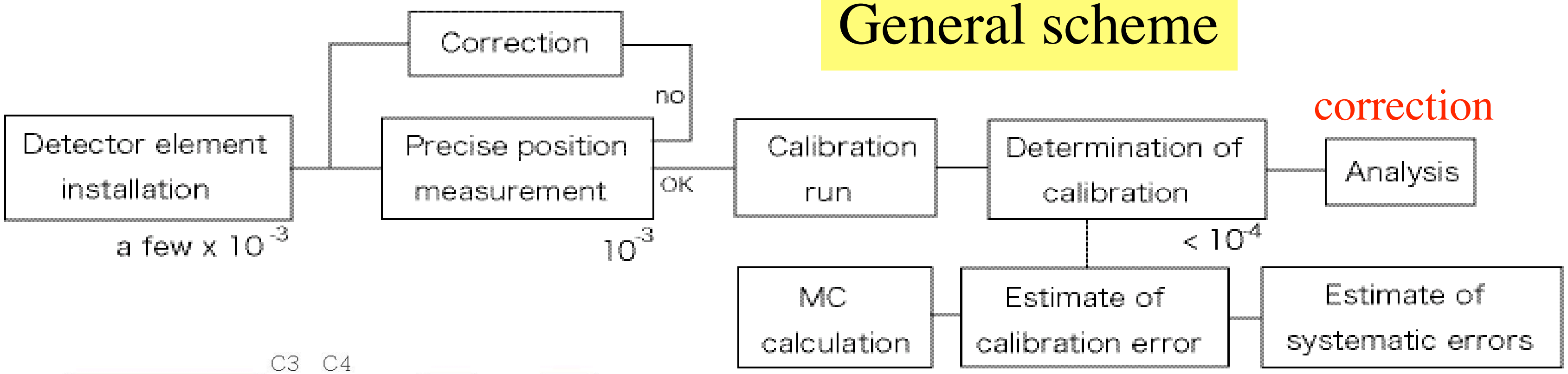


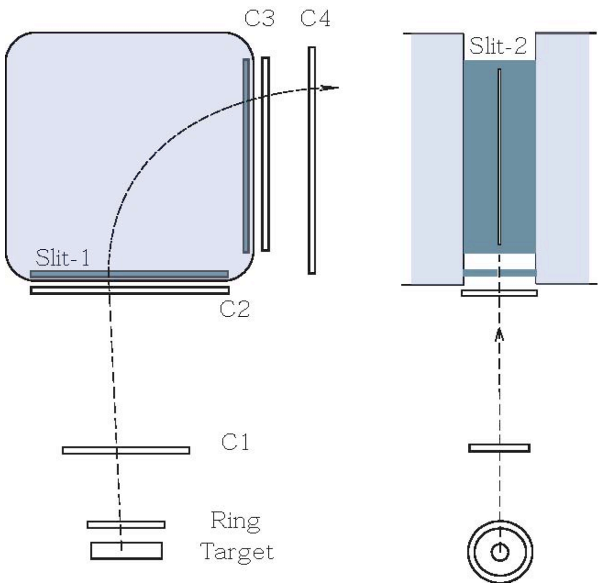
- Four chamber tracking including C0 with 0.1mm resolution ==> Suppression of $K_{\pi2}$-*dif* down to ~1.0%
- Remaining BG is from the π^+ decay between the target and C0.
- Further suppression down to 0.1% level with the fit trajectory consistency with target fibers, and target fiber analysis.
- Up/down cancellation of $P_T(\pi_{\mu2})$ in each gap with a cancellation power of at least 10.

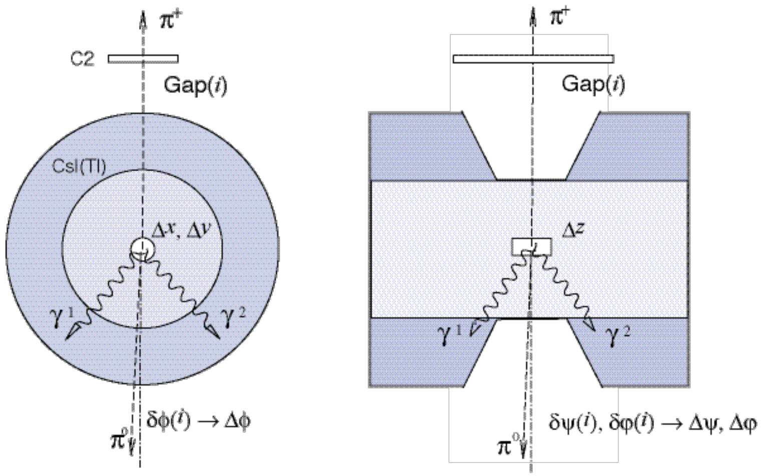
$$\delta P_T(\pi_{\mu2}\ \mathrm{BG}) < 10^{-4}$$

Alignment calibration

General scheme







(1) Reference frame = magnet gap

(2) Tracking system (using slits)

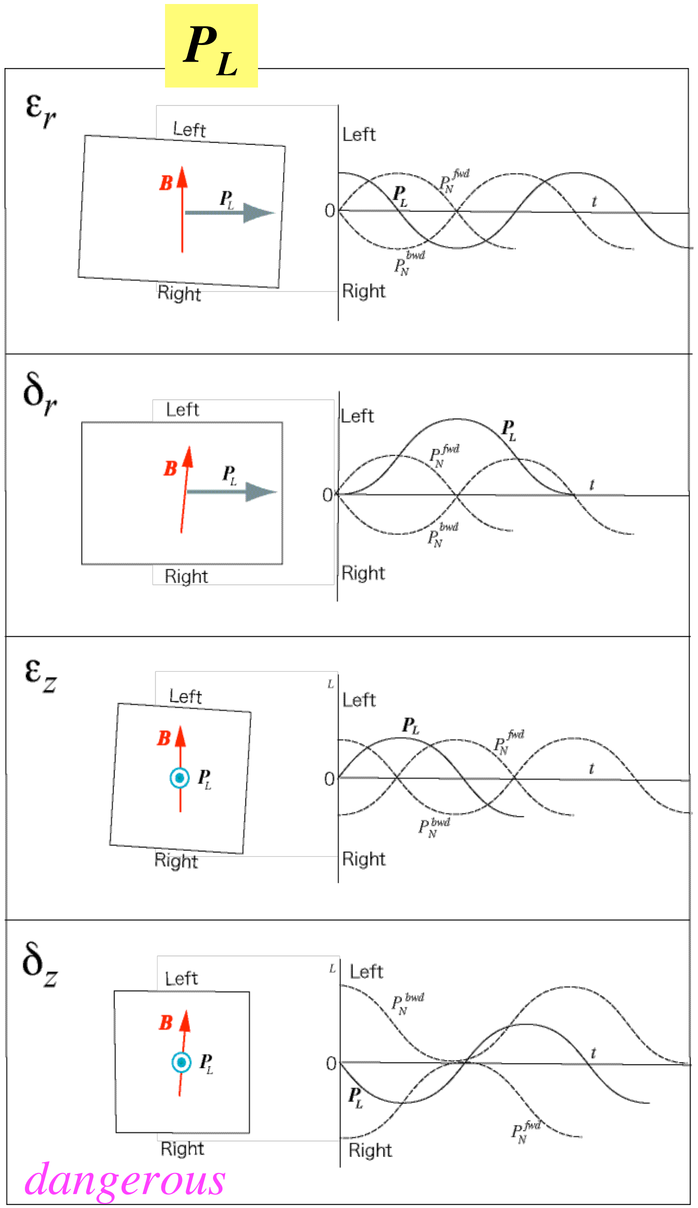
(3) CsI(Tl) π^0 detector (using $K_{\pi 2}$)

$\Delta\phi, \Delta\psi, \Delta\varphi$

(4) Polarimeter & Muon field

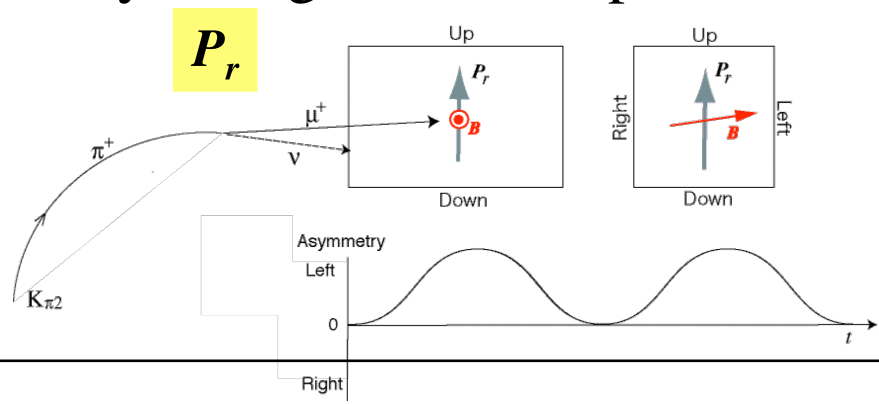
$\varepsilon_r, \varepsilon_z, \delta_r, \delta_z$

Calibration of four misalignments



Polarimeter *left/right* asymmetry measurement using

- longitudinal pol. P_L from $K_{\mu 3}$ or $K_{\mu 2}$
- radial polarization P_r from $K_{\pi 2}$ -π^+ decay in flight or r component of P_L



$$A(P_L) = \varepsilon_r \cos\omega t + \delta_r (1-\cos\omega t) + (\varepsilon_z - \delta_z) \sin\omega t$$

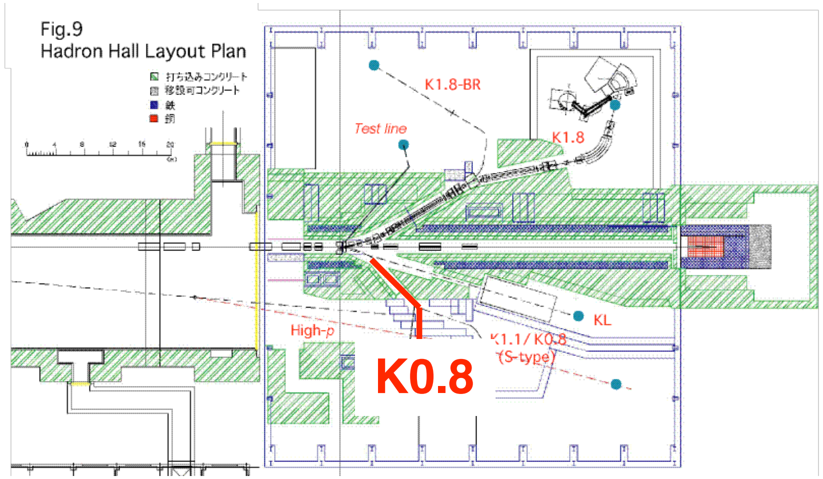
$$A(Pr) = (\varepsilon_r - \delta_r) \sin\omega t + \delta_z - (\varepsilon_z - \delta_z) \cos\omega t$$

Unique determination of ε_r ε_z δ_r δ_z

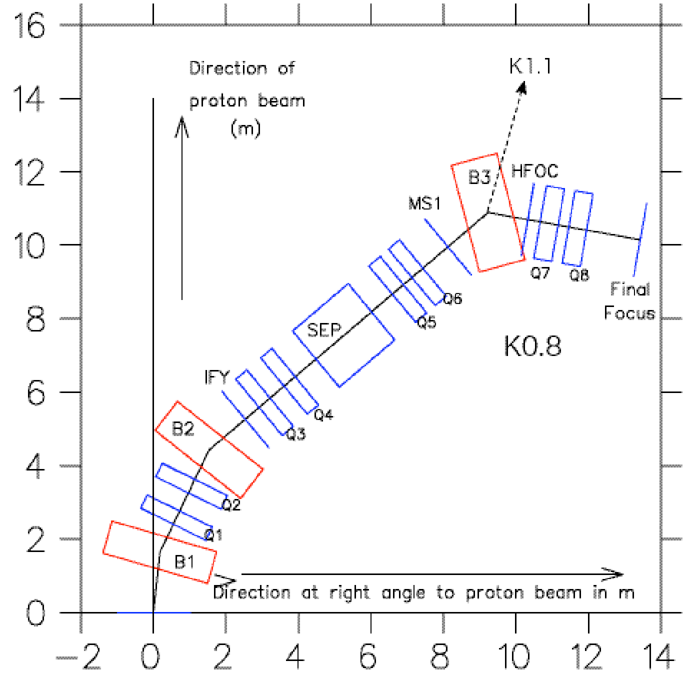
Now a MC study is going on.

Beamline

K0.8 (K1.1-BR)



Momentum	800 MeV/c
Momentum bite	±2.5%
Acceptance	6.5 msr % $\Delta p/p$
K^+ intensity	3 ×10^6 /s
K/π ratio	> 2
Beam spot	1.04 ×0.78 cm (FWQM)
Final focus	achromatic



- Good K/π ratio due to two vertical focuses, FY and MS1, and a horizontal focus HFOC
- Better performance than K5
- Alternate use with K1.1 by replacing B3

Sensitivity estimate

Statistical sensitivity

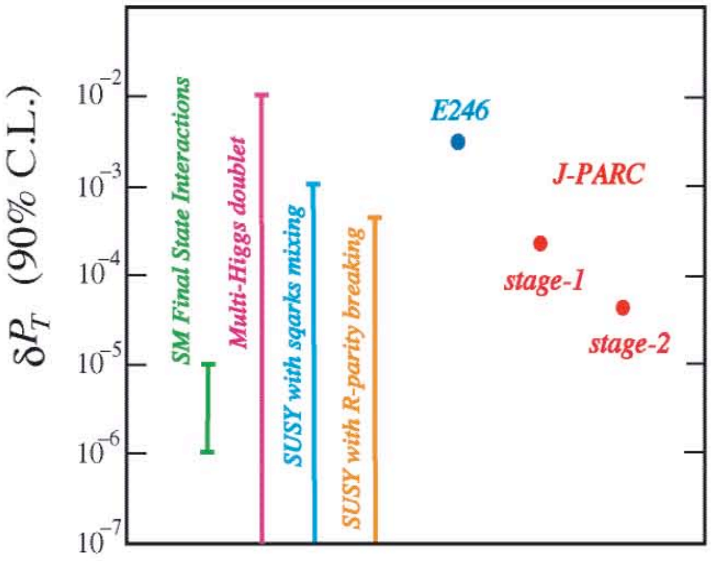
Standard analysis

- Net run time — 1.0×10^{7} s
- Proton beam intensity — 9μA on T1
- K^{+} beam intensity — 3×10^{6} /s
- Total number of good $K_{\mu 3}$ — 2.4×10^{9}
- Total number of *fwd/bwd* (N) — 7.2×10^{8}
- Sensitivity coefficient — $3.73\sqrt{N}$
- δP_T — 1.35×10^{-4}

including left/right regions

- δP_T — 0.8×10^{-4}

(A careful systematic error study is necessary)



Systematic errors

Source	δP_T
δ_z	$< 10^{-4}$
θ_z	$< 10^{-4}$
θ_{e^+}, E_{e^+}	$< 10^{-4}$
Total	$\sim 10^{-4}$

Cost estimate and funding

(very rough estimate in k¥)

SC magnet and cryogenic system	182,000
Muon field magnet system	42,000
Detector upgrade	131,000
Electronics and DAQ	60,000
Measurements and others	40,000
Total	455,000

- Funding for detector upgrade : We intend to apply for a Grant-in-Aid after obtaining stage-1 approval.
- The J-PARC experimental money will be also helpful.
- R&D of detector components : Small budget request in each country.
- Transfer of the cryogenic system : We ask KEK to finish it.

Time schedule

- Time schedule is dependent on funding, but
- We aim at the following.

Year (JFY)	Construction	Experiment	Other conditions
2006	1) Detector design 2) Start of budget application 3) Formation of collaboration		PAC decision
2007	1) Detector element R&D 2) Muon field magnet and mapping 3) Construction of C0 prototype 4) Modification of CsI(Tl) readout		Completion of the hall
2008	1) Transfer of the Toroid and He refrigerator 2) Installation of K1.1 and K0.8 branch 3) Production of C0 and C1 4) Production of Target and Polarimeter		Start of J-PARC exp. budget
2009	1) Setup of the spectrometer 2) Field mapping 3) Detector setup	4) Beam tuning	
2010		1) Engineering run 2) Data taking	Full intensity from Acc.?
2011		1) Data taking	
2012		1) Analysis	

Collaboration

(present group)

Country	Institutions	Responsibilities
Canada	U.Saskatchewan TRIUMF UBC U. Montreal	• Beamline • Target
USA	MIT U. South Carolina Iowa State U.	• GEM chambers • Tracking upgrade
Japan	KEK Tohoku U. Osaka U. NDA	• Muon field magnet • Active polarimeter • CsI(Tl) readout • DAQ

We will organize more people after obtaining an approval.

Summary

- P_T in $K_{\mu 3}$ is a very sensitive probe of new physics
- We propose a J-PARC experiment in the early stage of Phase 1 to pursue a limit of $\delta P_T \sim 10^{-4}$.

- K0.8 beamline as a branch of K1.1
- Upgraded E246 detector

- Beam time request = 1.3×10^7 s (net) at $I_p = 9\mu A$ on T1

- We would like to take the first step this year toward
  - Collaboration forming
  - Fund application
  - Detector R&D

  after obtaining some status.