Progress Report to PAC6
J-PARC E06 Experiment (TREK)

Measurement of T-violating Transverse Muon Polarization (P_T) in $K^+ \to \pi^0 \mu^+ \nu$ Decays

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Outline

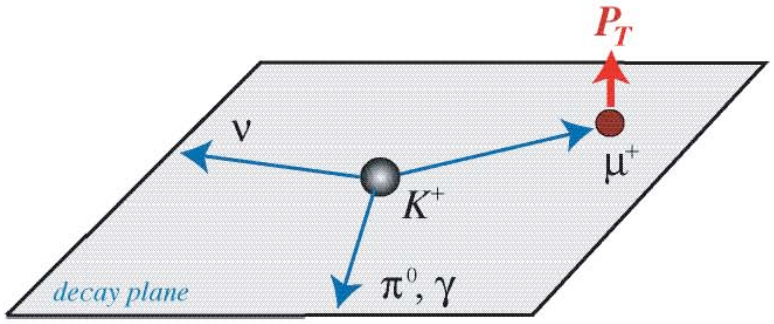
1. Introduction
2. Funding efforts
3. Status of detector R&D and design
4. Muon polarimeter
5. Systematic error study on local misalignments
6. Summary

Presentation is parallel to the "Progress Report"

Transverse μ^+ polarization in $K_{\mu 3}$

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

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



- P_T is T-odd, and spurious effects from final state interaction are small: $P_T(\mathrm{FSI}) < 10^{-5}$

  Non-zero P_T is a signature of T violation.

- Standard Model (SM) contribution to P_T : $P_T(\mathrm{SM}) < 10^{-7}$

  P_T in the region 10^{-3}~10^{-4} is a sensitive probe of CP violation beyond the SM.

- There are theoretical models of new physics which allow a sizable P_T without conflicting with other experimental constraints.

TREK experiment aims for a sensitivity of 10^{-4}

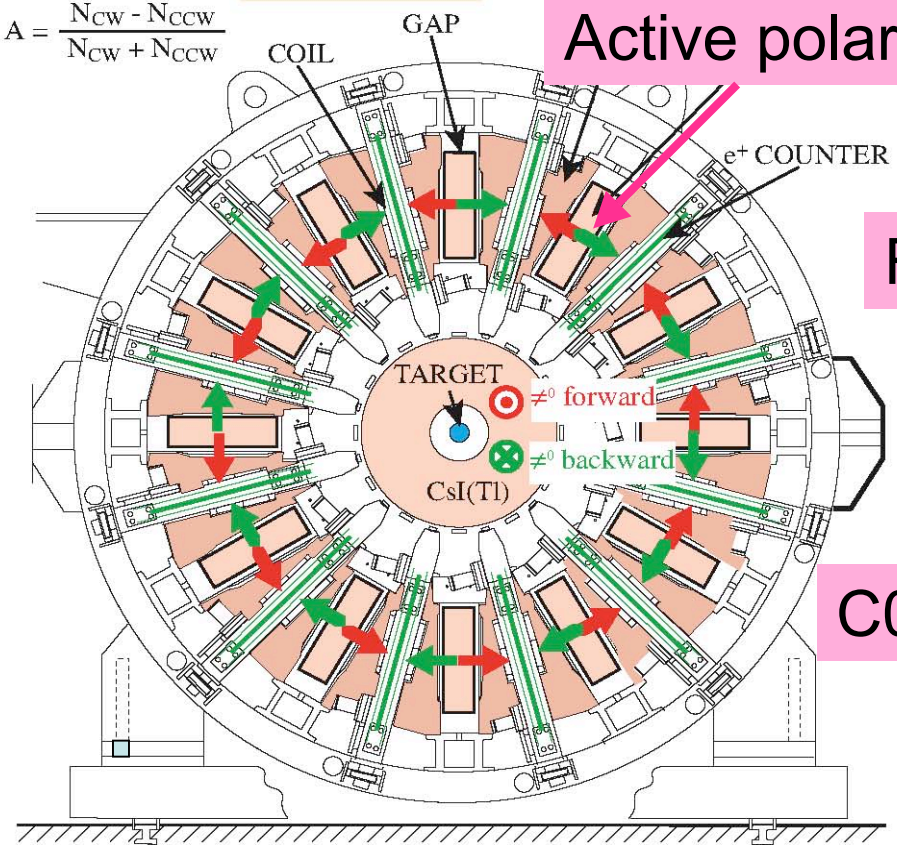
P_T measurement

Use of upgraded E246 detector

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

End view

$$A = \frac{N_{CW} - N_{CCW}}{N_{CW} + N_{CCW}}$$

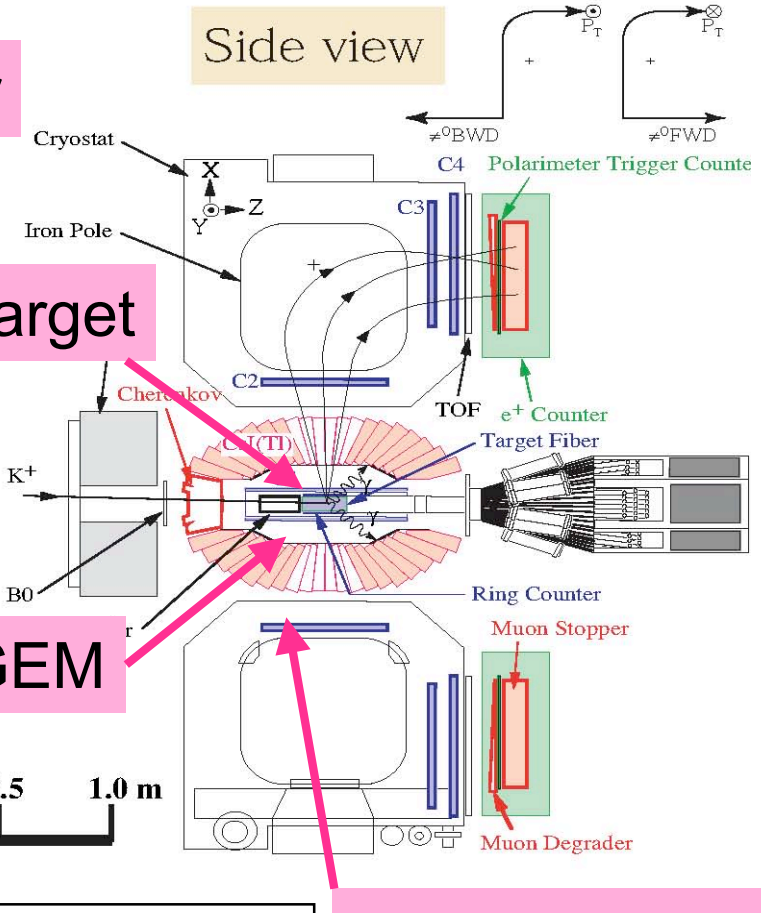


Active polarimeter

Fiber target

C0,C1 GEM

Side view



CsI(Tl) readout

P_T measured as the azimuthal asymmetry A_{e^+} of the μ^+ decay e^+

Suppression of systematic errors is essential

PAC5 meeting in June

- Outline of the TREK experiment
- Theoretical model descriptions of P_T
- Funding and collaboration
- Progress in detector R&D
  - Systematic error analysis of the polarimeter global misalignment

We requested a recommendation for Stage-2 approval

High evaluation of physics and detector R&D
However, the PAC conclusion was the

Necessity of total funding of the experiment to go to Stage 2

Funding efforts

- Japan
  - Aug. 2008:

    Grant-in-Aid (Kaken-hi) “New science field” : failed
  - Oct. 2008 :

    Grant-in-Aid (Kaken-hi) “Specially promoted research”

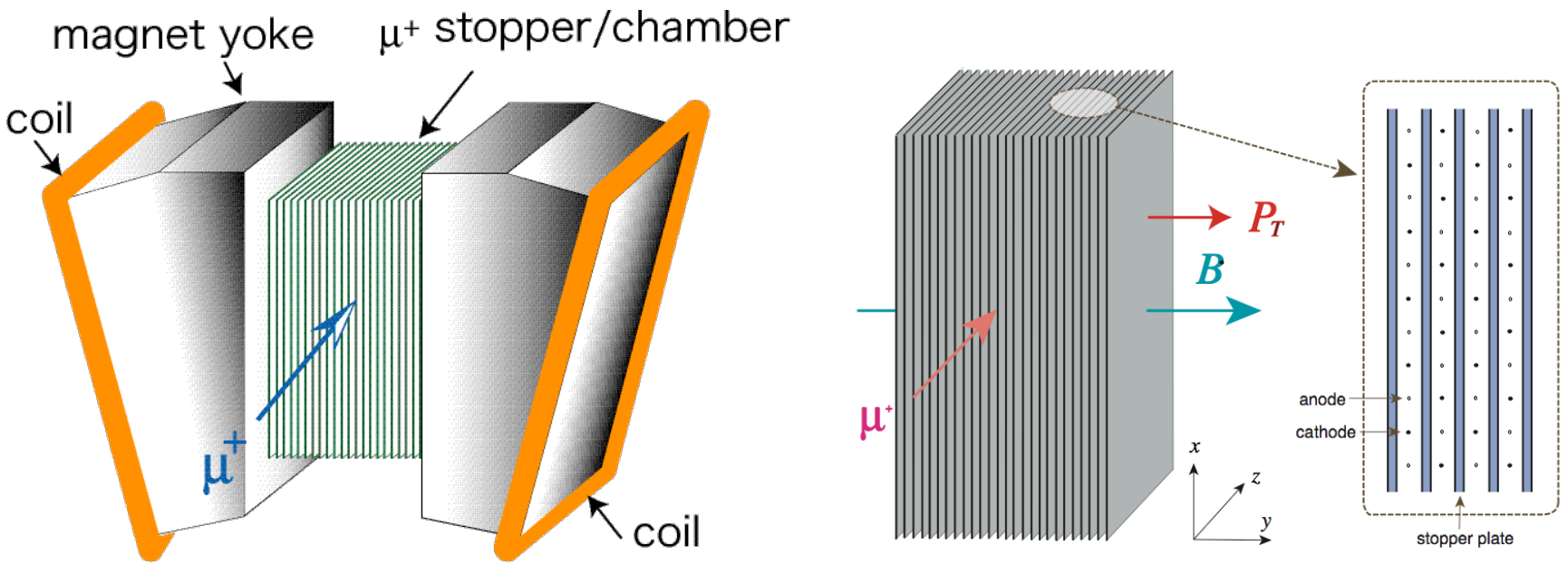
    Application of 3.5 Oku Yen for the total detector and operation of TREK
- Canada (UBC)
  - Oct.2008 : Request to NSERC for additional target money
  - Continuing efforts for K1.1-BR beamline elements
- USA (Hampton University)
  - Sept. 2008 : Request to NSF for GEM projects

  - Necessity for full approval to get grant in USA and other countries

Detector R&D and design

- Polarimeter (Japan) : Grant is funded for chambers
  - GARFIELD calculation : done in Japan and Canada
  - 1/5 prototype model : completed and will be tested at FTBL in Nov.
  - Full size model designing : will be made soon after the test of the 1/5 model.
  - Muon magnet and one gap test arrangement : designed and will be ordered
  - Systematic error analysis : done and will be reported now
- Target (Canada) : Grant is partially funded
  - MPPC radiation hardness test with π^+ beam : October 18-24 @TRIUMF
  - Fiber readout test with a WLS fiber : within this year @ TRIUMF
- CsI(Tl) (Russia) : Internal effort
  - New current amplifier for APD readout test : being made @ INR
- GEM chamber (USA) : Internal effort
  - Simulation calculation with GEANT4 : being made

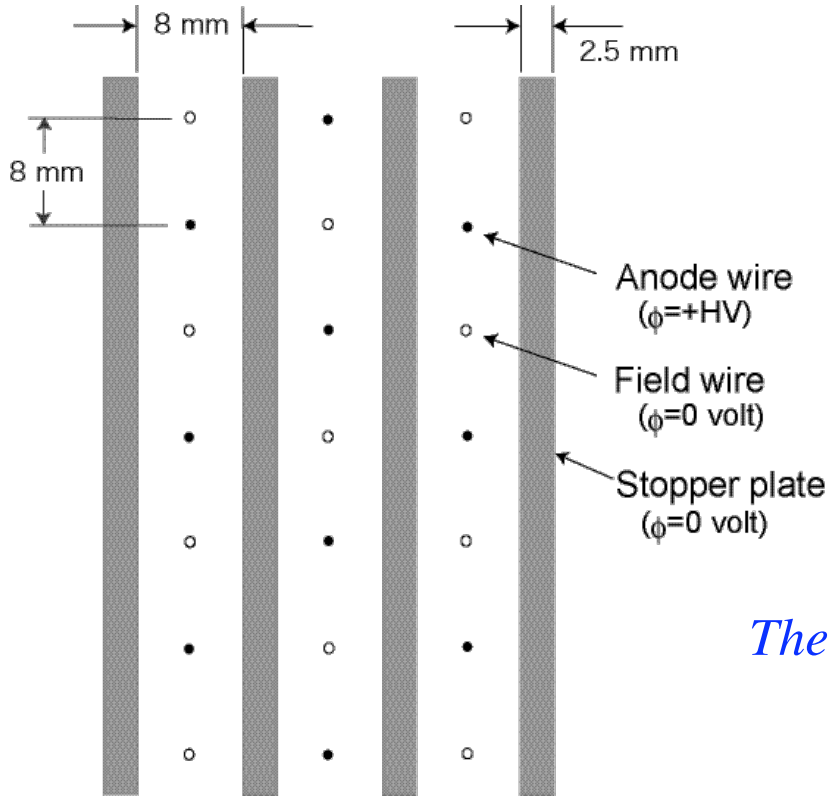
Muon polarimeter



Polarimeter = Drift chamber with stoppers
+ Muon field magnet

- Most essential part of the TREK experiment
- Good alignment is needed for the chamber and magnetic filed
- Optimization for π^0-*fwd/bwd* events (namely e^+-*L/R* asymmetry)

Drift chamber

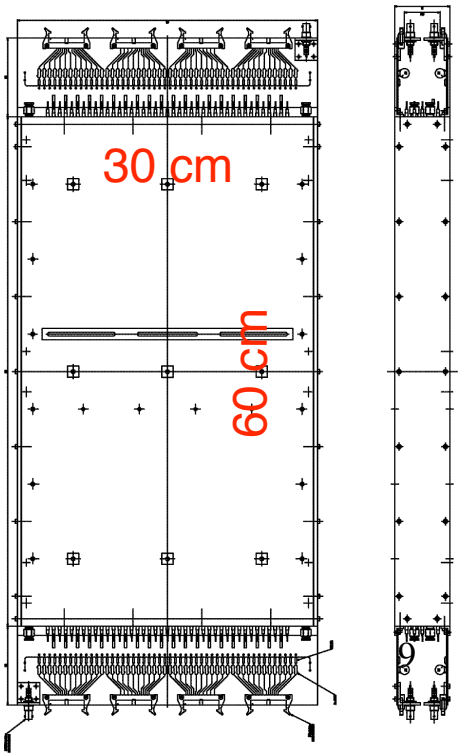


- Stopper plates as electrodes
- Long cell with A.R.=2.0
- Small number of wires
- Wire coordinate readout
  - Charge division or
  - Cathode strips (split stopper)

5 layers

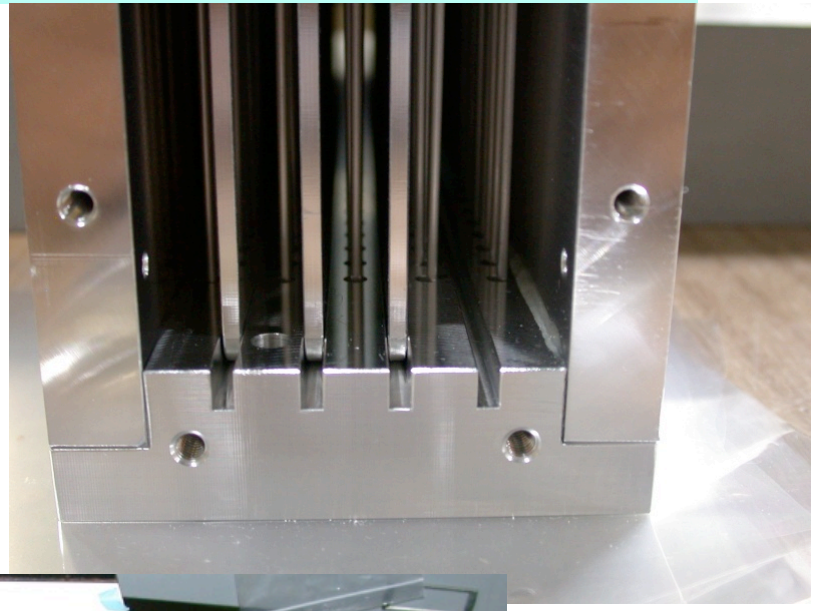
The 1/5 model is made
will be tested with

- Beta ray
- FTBL

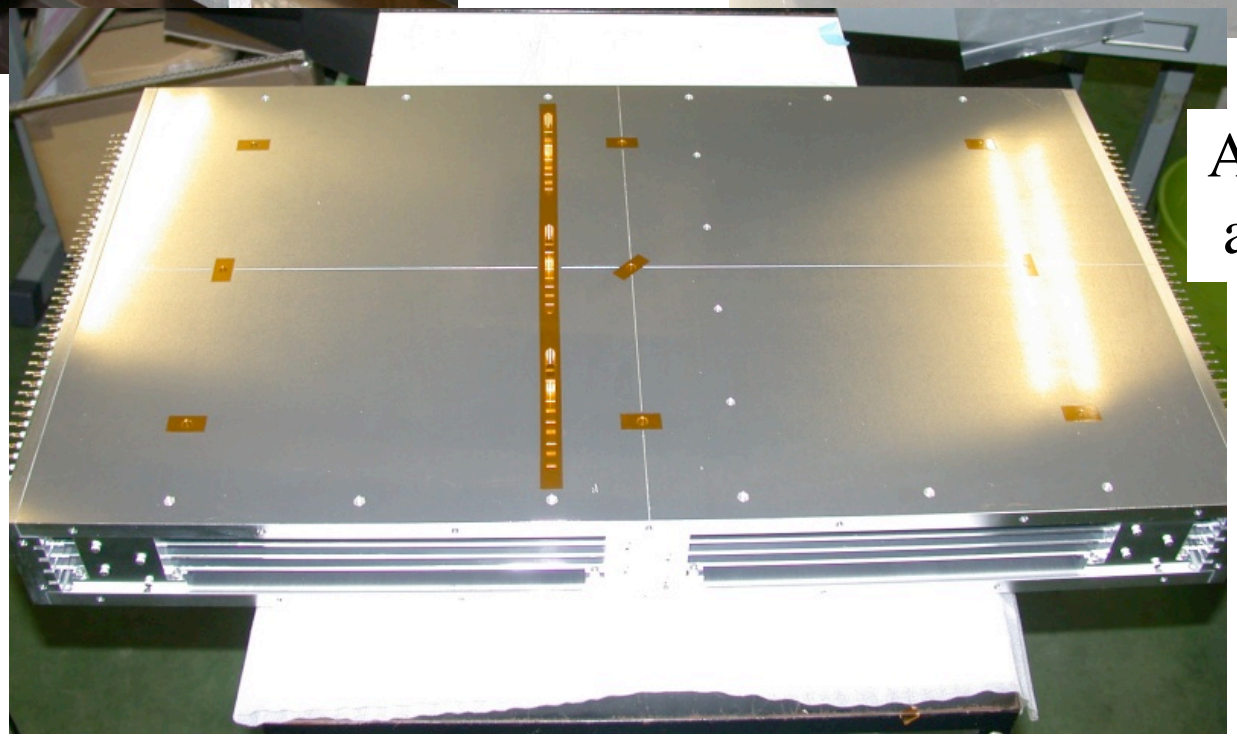


GARFIELD calculation → 1/5 size prototype → Full size prototype

1/5 prototype model

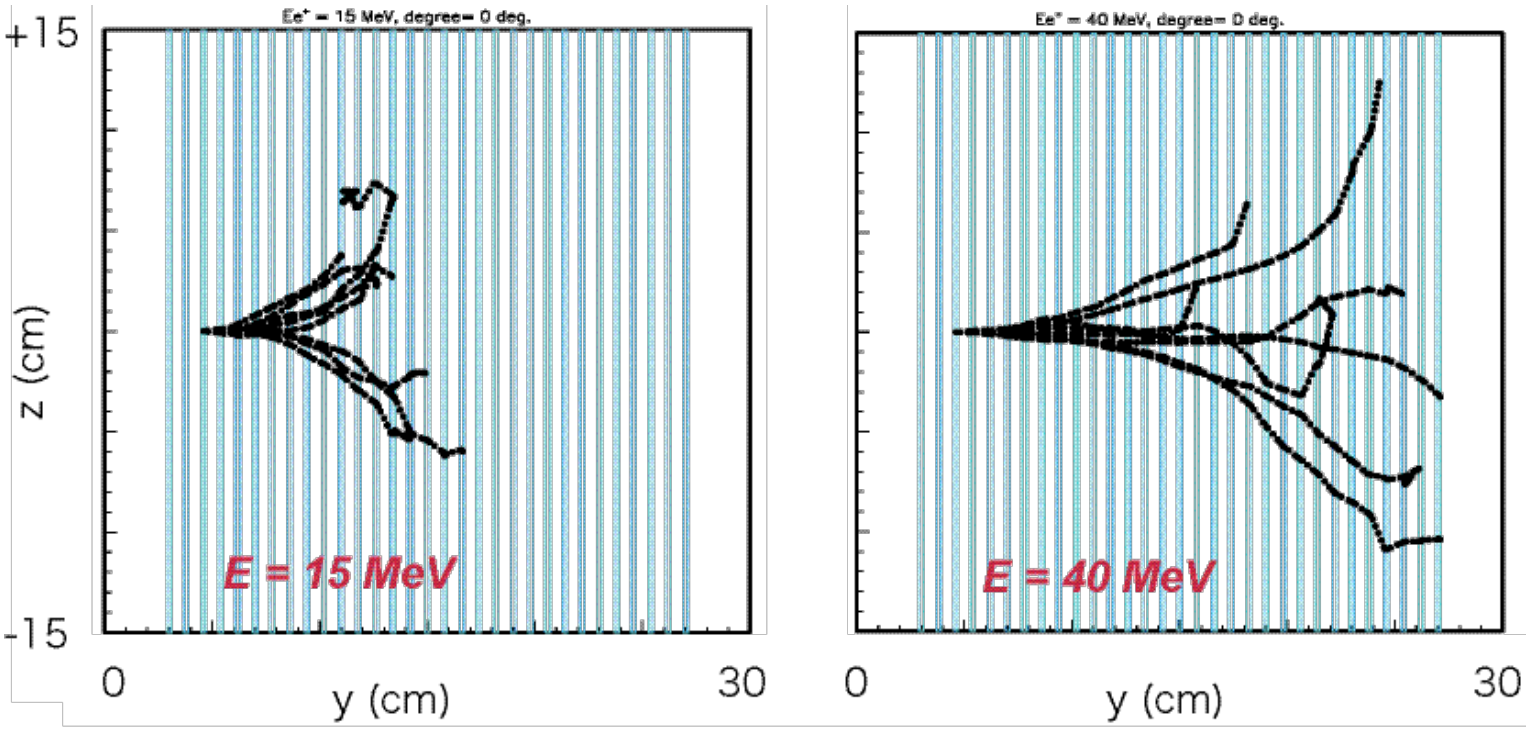


Positioning of plates



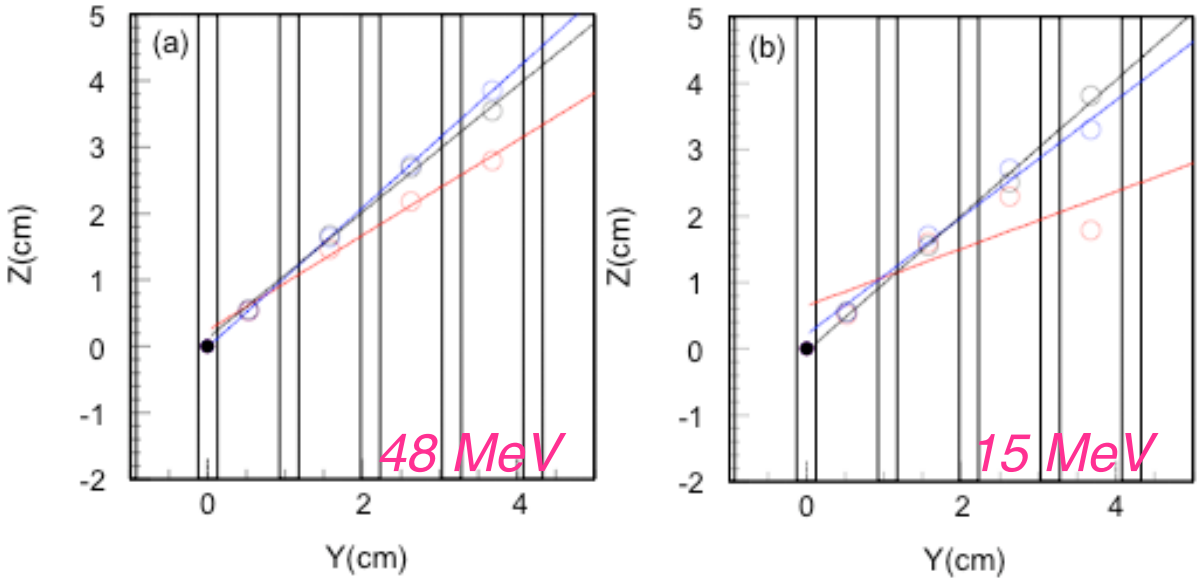
After assembling

Scattering characteristics



- Large scattering effects
- Limitation to tracking performance

Tracking performance



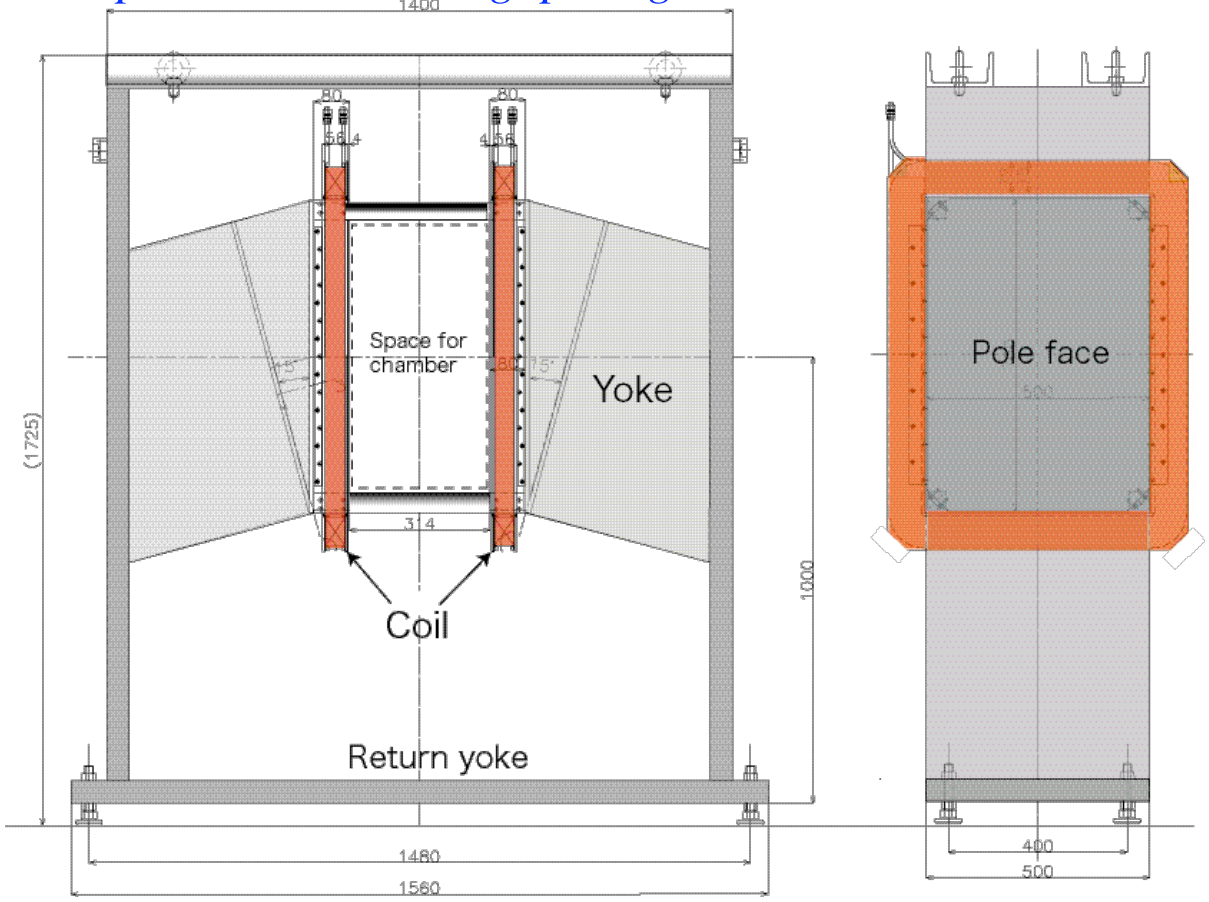
- Optimum number of layers for tracking = 4 - 5
- Tracking resolution in the (y, z) plane for 30 MeV :

Emission angle (degree)	Devay vertex resolution (σ in mm)	Emission angle resolution (σ in degrees)
0	0.5	4
30	0.5	5
60	1	6

- A similar moderate resolution for x if we adopt the charge division readout.

Muon field magnet

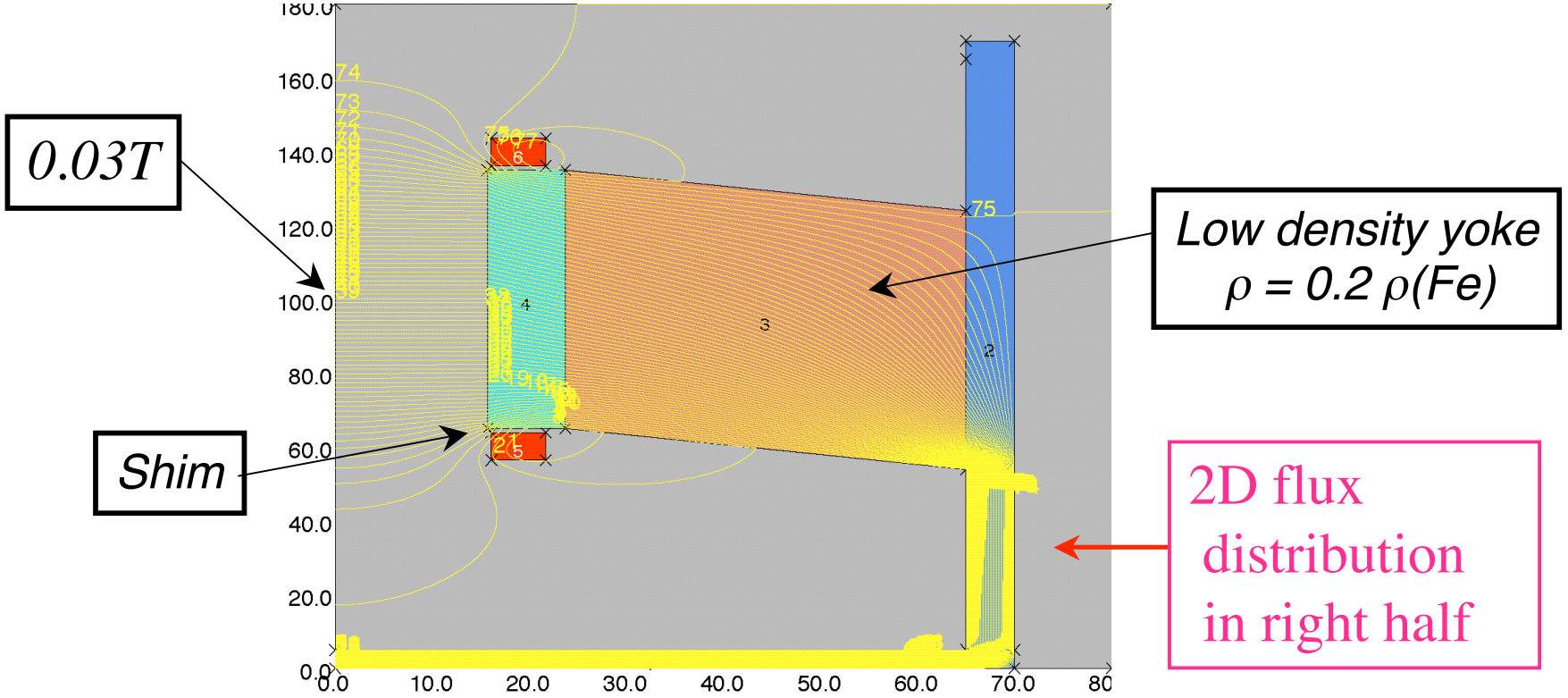
Design is completed and a one-gap magnet will be made within this FY.



- One gap test arrangement (B_0 = 0.03 T) with return yoke
- To be tested for :
  - ① Field distribution precision
  - ② muon polarization measurement performance next year

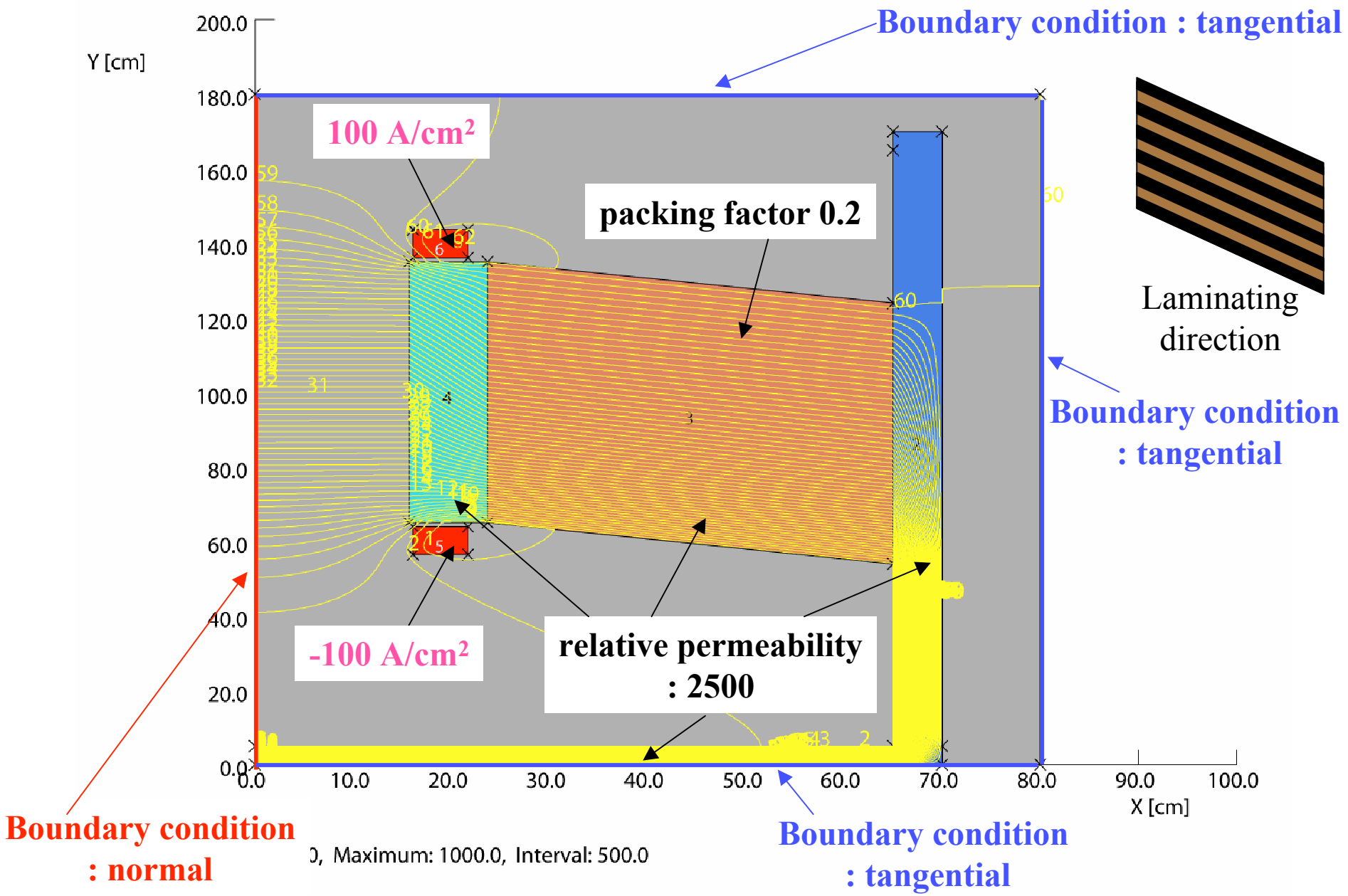
Magnetic field calculation

2D and 3D calculations with TOSCA



- Optimization of shim structure to make a flat field distribution on the polarimeter chamber volume
- Reduction of weight of the yoke (brown part)

Packing factor : 0.2



Local misalignment

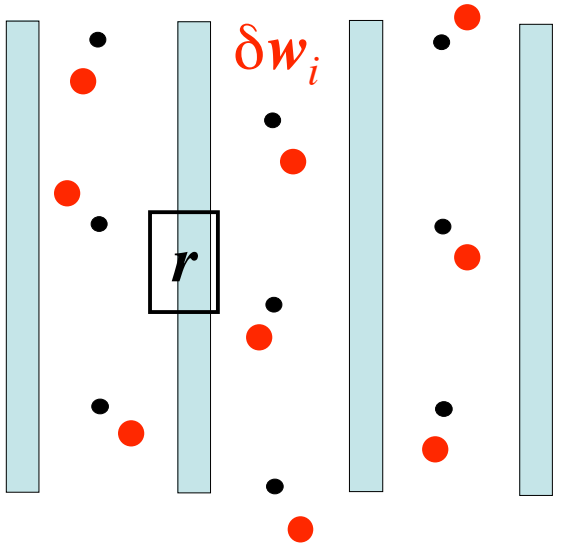
Polarimeter global misalignment is controllable

- Most serious effect = wire displacement

==> Shift of measured emission angle

==> Bias to emission angle analysis

  - Ambiguity in cone angle to define left-right emitted events
  - In accurate weight in weighted analysis



- Wire misalignments δw_i ==> Local spurious asymmetry : $\delta A^{sp}(\boldsymbol{r})$

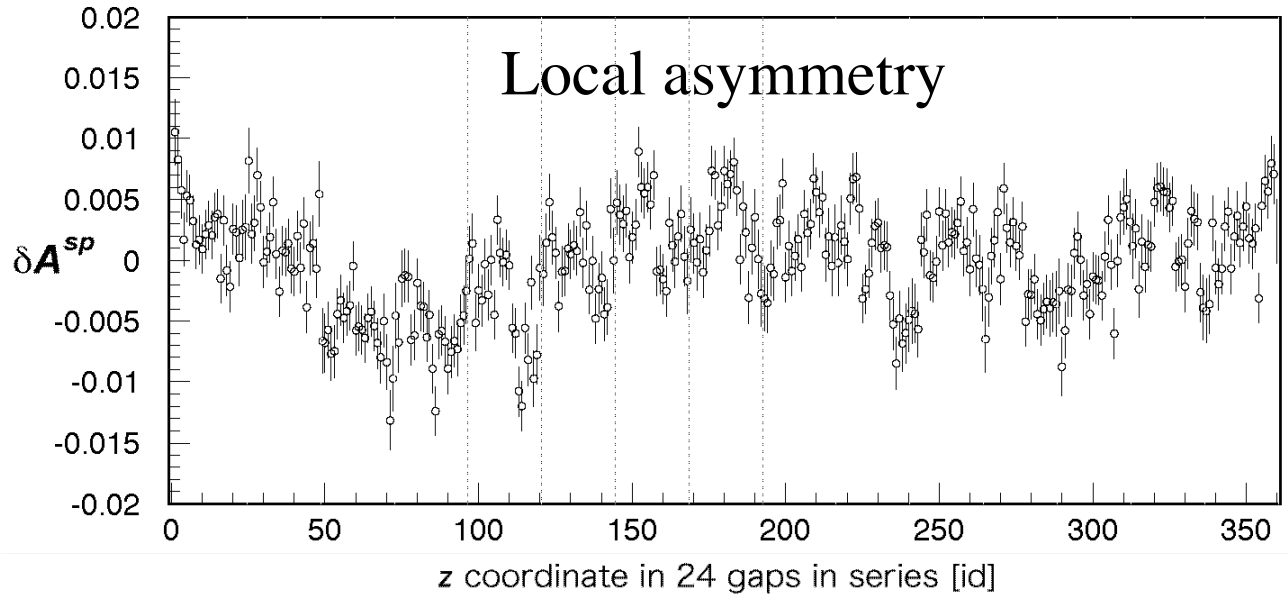
$$\delta P^{sp}{}_T = \int \delta\rho(\boldsymbol{r})\, \delta A^{sp}(\boldsymbol{r}) / \alpha(\boldsymbol{r})\, d\boldsymbol{r}$$

$$\delta\rho(\boldsymbol{r}) = \rho_{fwd}(\boldsymbol{r}) - \rho_{bwd}(\boldsymbol{r})$$

$\alpha(\boldsymbol{r})$ = analyzing power

Tolerance to $\delta A^{sp}(\boldsymbol{r})$ or δw_i → Constraint on $\delta\rho(\boldsymbol{r})$

MC simulation

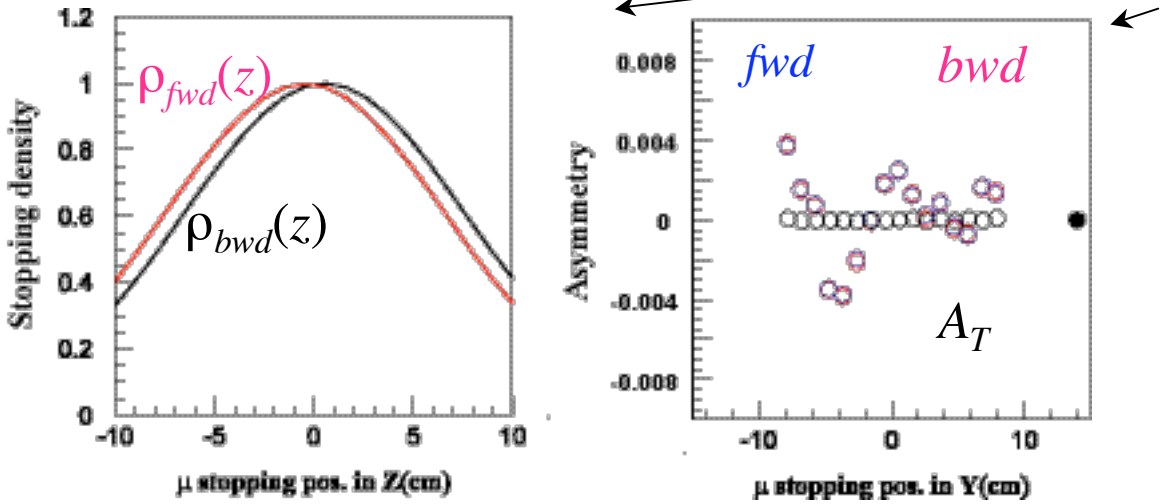


Assumption of MC :

- Random shift of $w(r, y, z)$
- $\sigma(w)$ = 1.0 mm

as exaggerated

$A^{sp}(z)$ in series



left : stopping distribution

right : A^{sp} integrated over z

A_{fwd} (blue)

A_{bwd} (red)

A_T (black) $=(A_{fwd}-A_{bwd})/2$

fwd-bwd ρ(z) shifts of ±5 mm

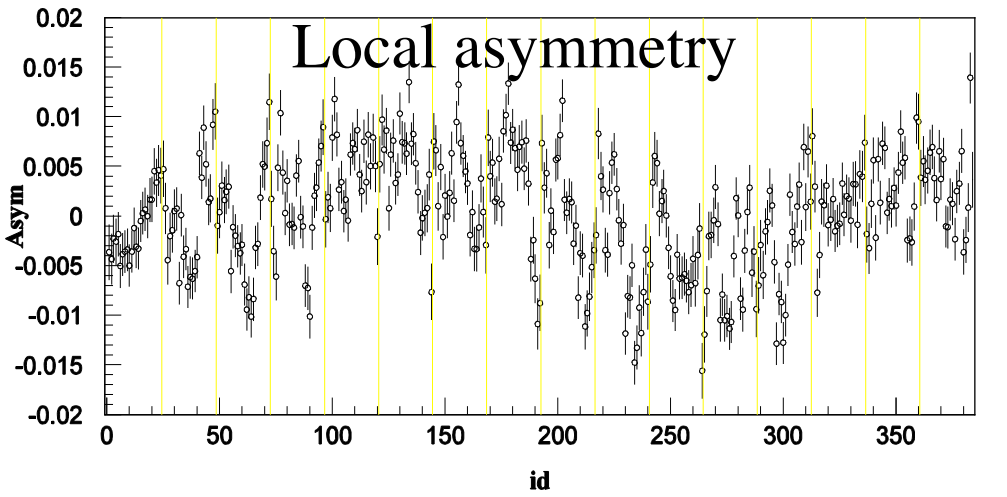
as exaggerated

$\langle A^{sp} \rangle = (-0.18 \pm 0.78) \times 10^{-4}$

$\delta P_T = (-0.5 \pm 2.4) \times 10^{-4}$

Chamber inefficiency

MC simulation of local asymmetry distribution



Assumption of MC :

- Random efficiency
- $<\varepsilon_{wire}> = 99.5\%$
- $\sigma_{eff} = 0.5\%$

← $A^{sp}(z)$ in series

left : ε distribution

right : A^{sp} integrated over z

A^{sp}_{fwd} (blue)

A^{sp}_{bwd} (red)

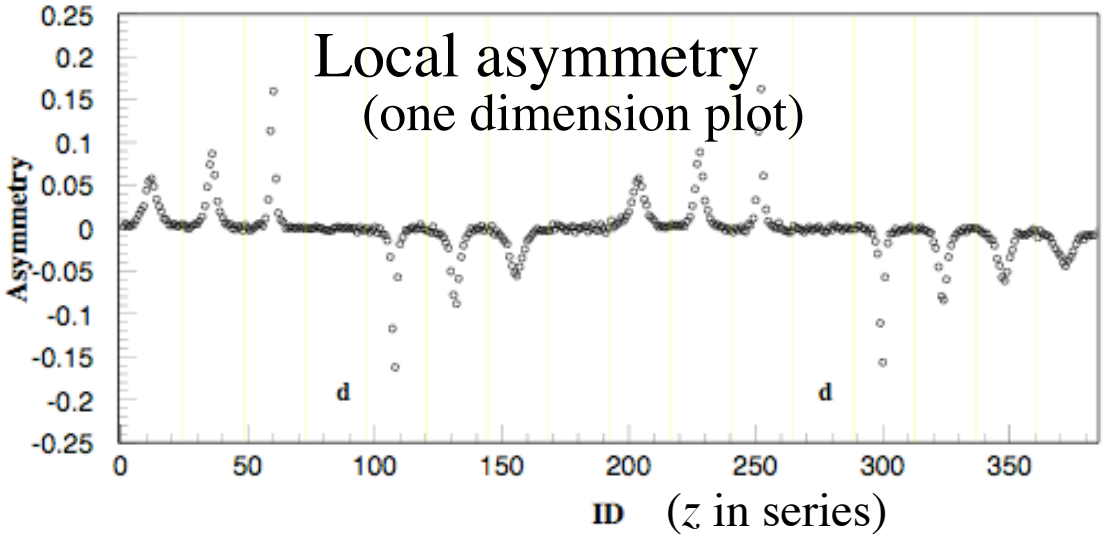
A^{sp}_{T} (black)

with *fwd-bwd* ρ(z) shifts of ±5 mm as exaggerated

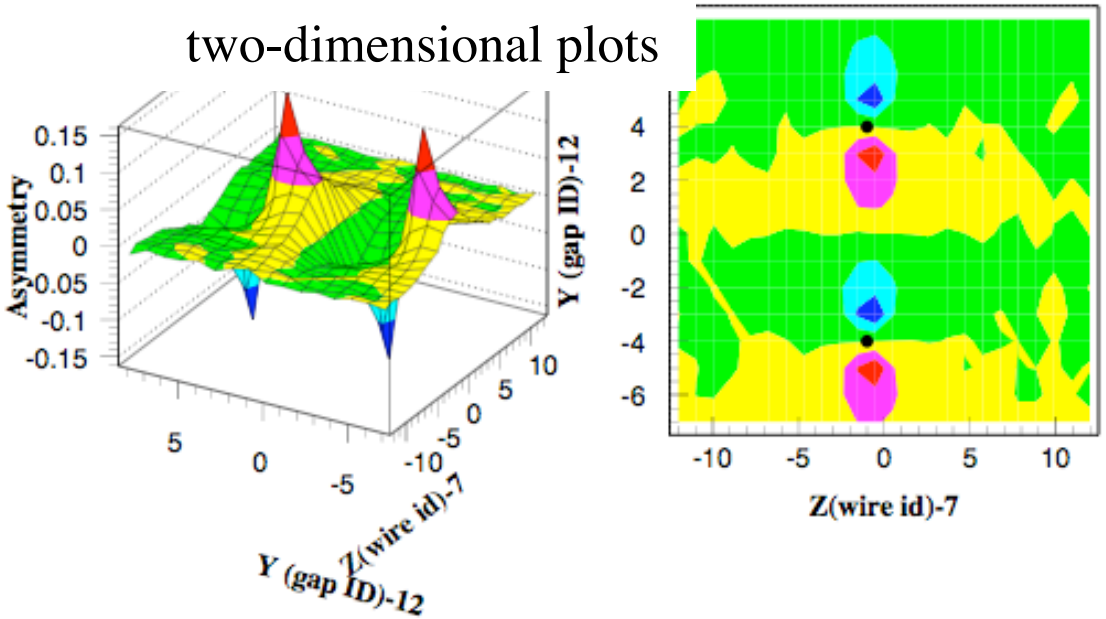
$<A^{sp}> = (-0.24 \pm 0.82) \times 10^{-4}$

$\delta P_T = (-0.8 \pm 2.7) \times 10^{-4}$

Effect of very bad wires



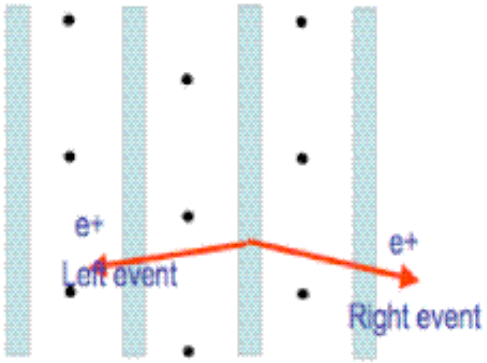
two-dimensional plots



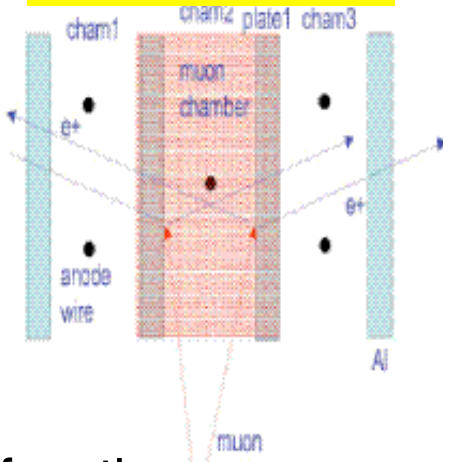
- Assumption
  - Bad 2 wires with ε=0.5
  - 4 layer tracking
- Result
  - Local singularity in A^{sp}
  - Pos. A^{sp} and neg. A^{sp} symmetric structure
  - Cancelled in the integration $\int \delta\rho(z)\, A^{sp}(z)\, dz$
- Better to avoid such a condition
- Necessity to monitor the wire efficiency during the measurement.

Asymmetry due to staggered wires

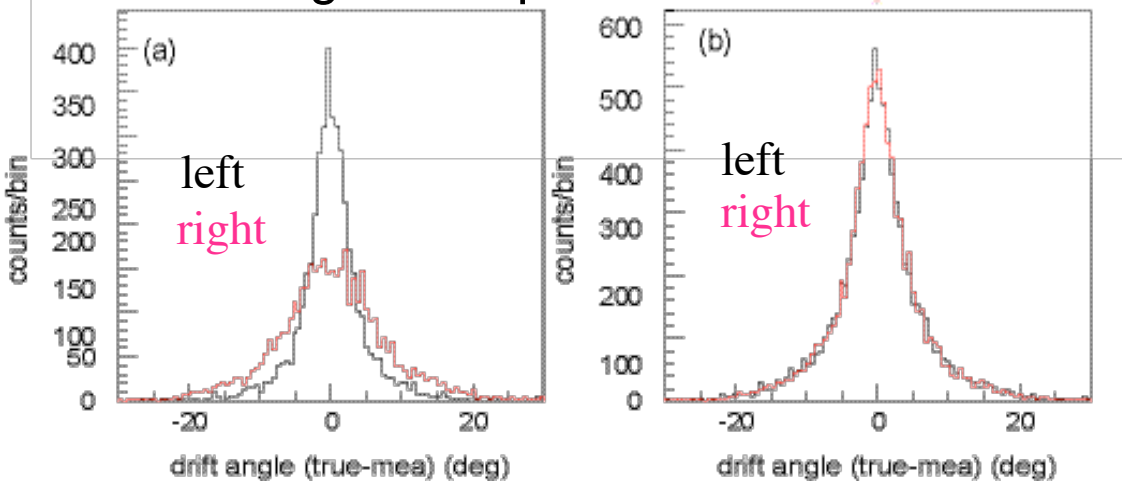
Stopper analysis



Gap analysis



Angular response functions



Stopper analysis

- LHS/RHS structural difference
- Different angular response
- Spurious local asymmetry
- After-effect of a muon track

Gap analysis

- No LHS/RHS asymmetry
- No influence of a muon track
- Slight degradation of angular resolution

We will adopt the "Gap analysis"

Systematics due to other effects

- Non-uniform efficiency distribution in the tracking system
- Dead channels in the CsI(Tl) calorimeter

(1) Distortion of kinematical phase space

Admixture of P_L, P_N to P_T

Correction with Decay Plane Rotation θ_z, θ_r

(2) Influence on $\delta\rho(\boldsymbol{r}) = \rho_{fwd}(\boldsymbol{r}) - \rho_{bwd}(\boldsymbol{r})$

Different δP^{sp}_T (it can be larger)

Artificial symmetrization of $\rho_{fwd}(\boldsymbol{r}) : \rho_{bwd}(\boldsymbol{r})$ to $\delta\rho(\boldsymbol{r}) = 0$

Summary

- We are still making efforts to obtain a grant for the total setup.
- We have started the polarimeter construction in Japan.
- Other R&D for the detector are under way in several places.
- No serious sources of systematic errors have been found in the polarimeter local misalignment, as we did not find any in the global misalignment of the chambers and the magnetic fields.
- Validity of the TREK experiment in terms systematic error is being confirmed. We will be able to suppress the error to less than 10^{-4}.