The Reconstruction and Calibration of the BESIII Main Drift Chamber

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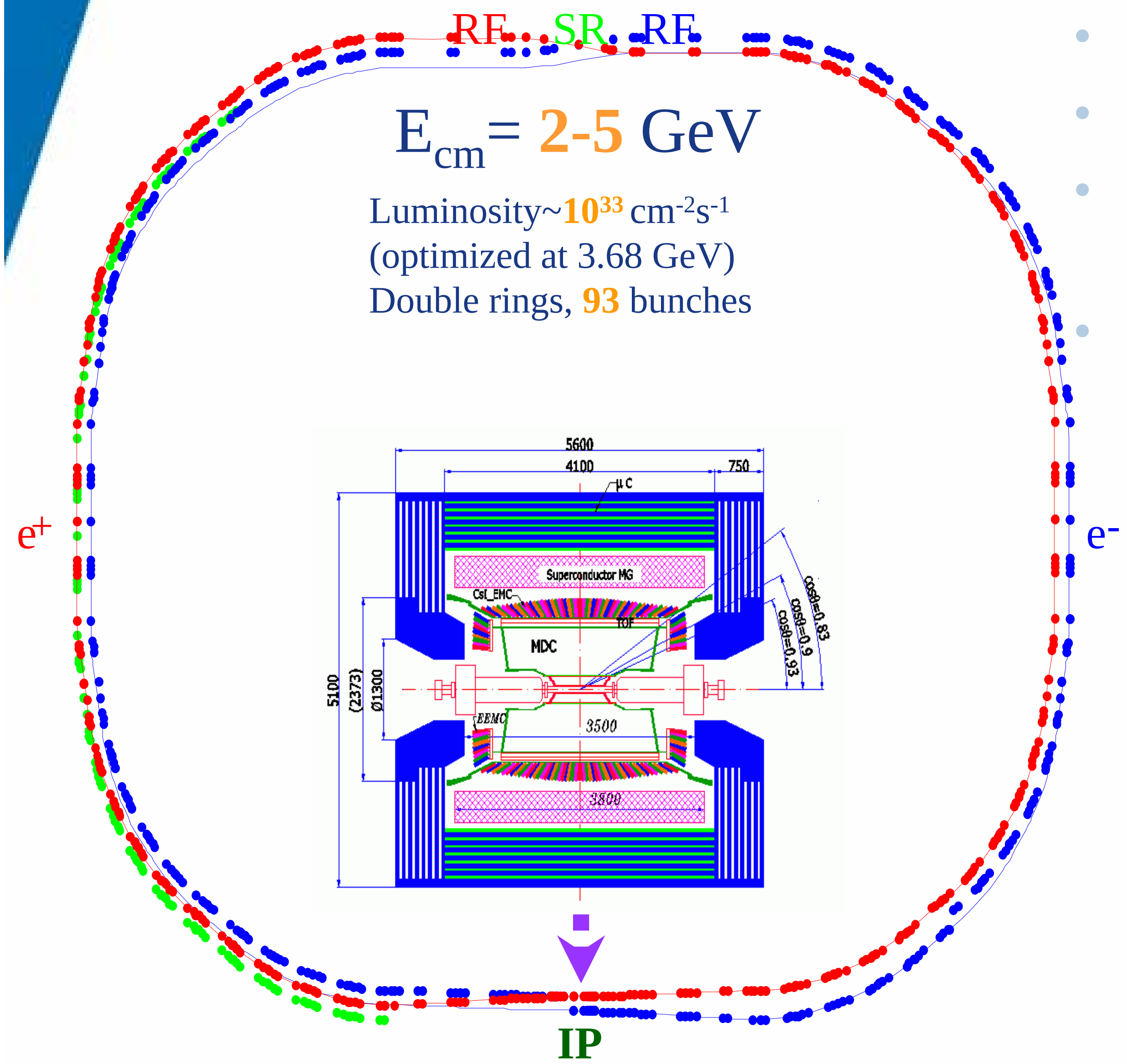
Outline

- Introduction to BEPCII/BESIII
- BESIII Main Drift Chamber (MDC)
- BESIII MDC Tracking
  - MdcPatRec algorithm(based on BaBar)
  - TrkReco algorithm(based on Belle)
  - Tracking performance with Monte Carlo Data
- BESIII MDC Fitting
  - Fitting with Kalman filter ---KalFitAlg algorithm
- BESIII MDC Calibration and Alignment
  - MDC Calibration and Alignment
  - Preliminary results with data of cosmic ray test

The Beijing Electron Positron Collider II (BEPCII)

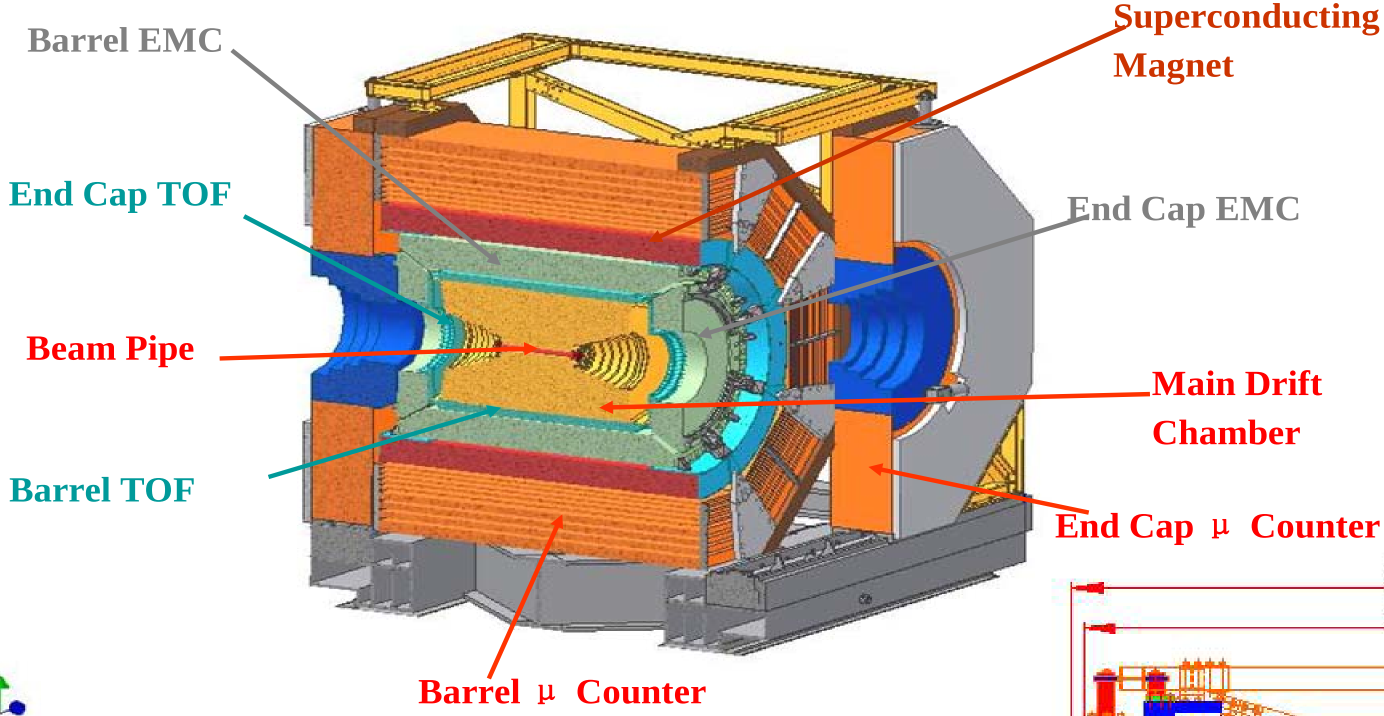
E_{cm}= 2-5 GeV

Luminosity~10^{33} $cm^{-2}s^{-1}$
(optimized at 3.68 GeV)
Double rings, 93 bunches

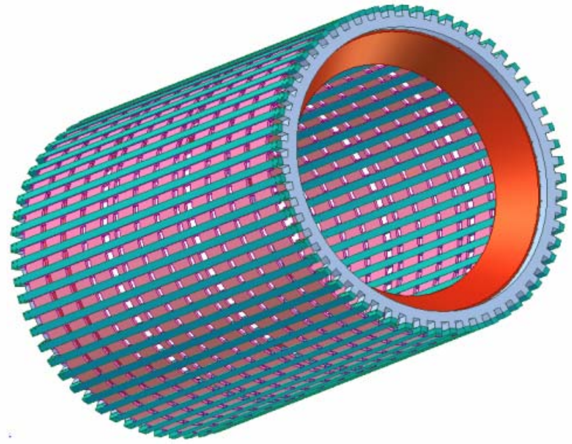


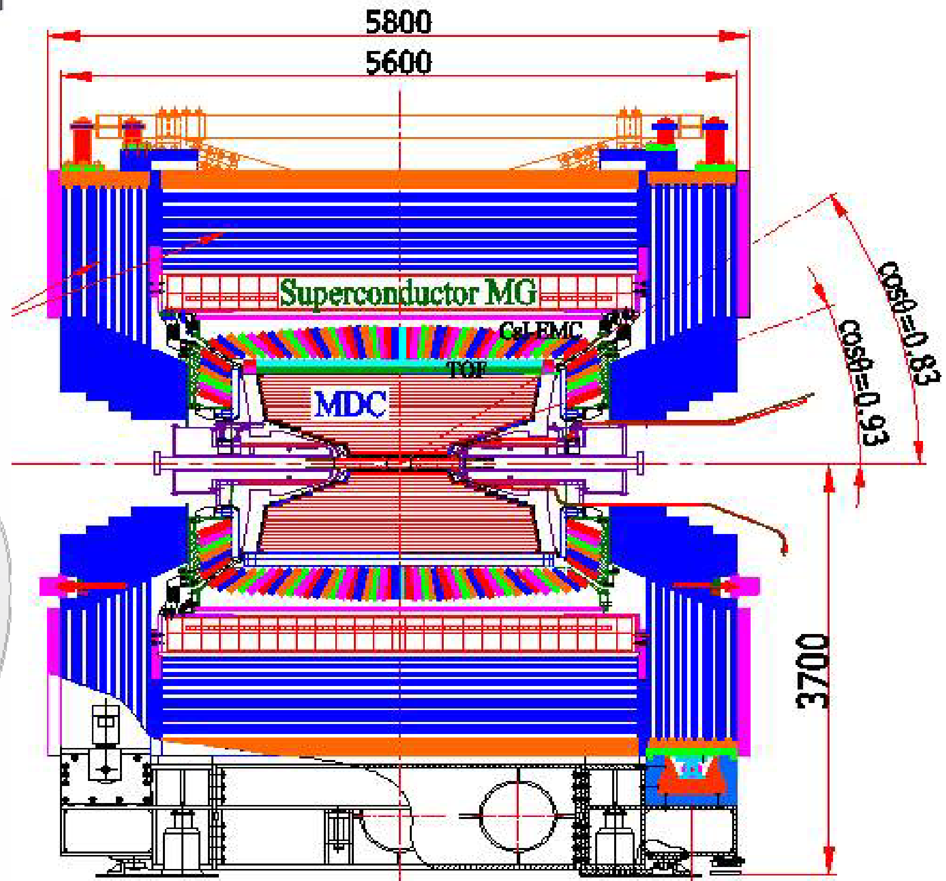
- Upgrade of BEPC
- e^+e^- multi-bunch collider
- Scheduled to provide collisions in summer , 2008.
- Physics:
  - **Precision measurement of CKM matrix**
  - **Precision test of Standard Model**
  - **QCD and hadron production**
  - **Light hadron spectroscopy**
  - **Charmonium physics**
  - **Search for new physics**

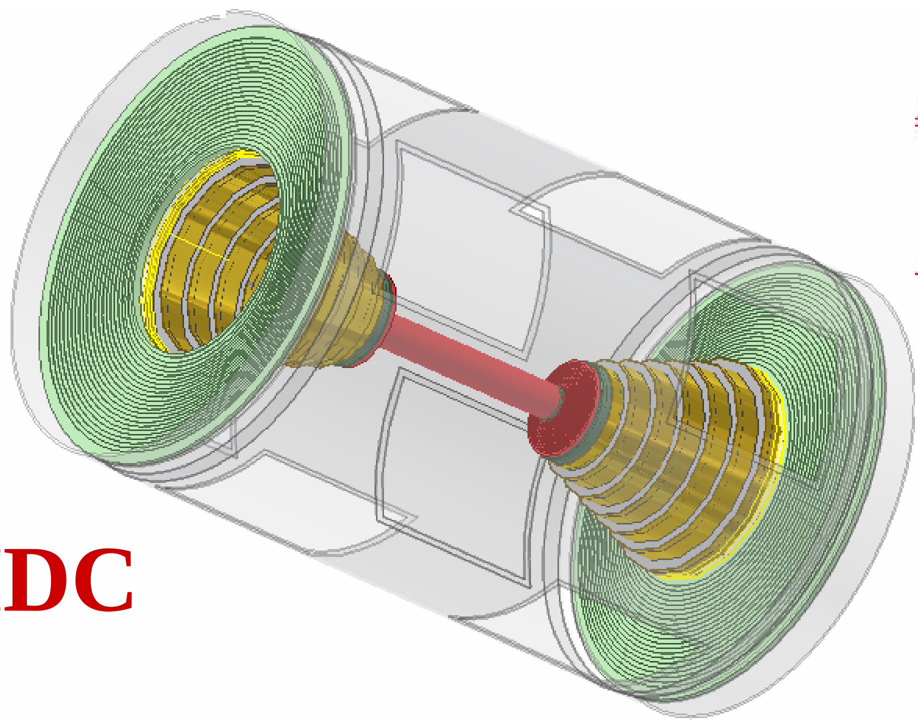
BESIII Detector



EMC







MDC

BESIII Main Drift Chamber (MDC)

MDC Parameters

R inner: 63mm

R outer: 810mm

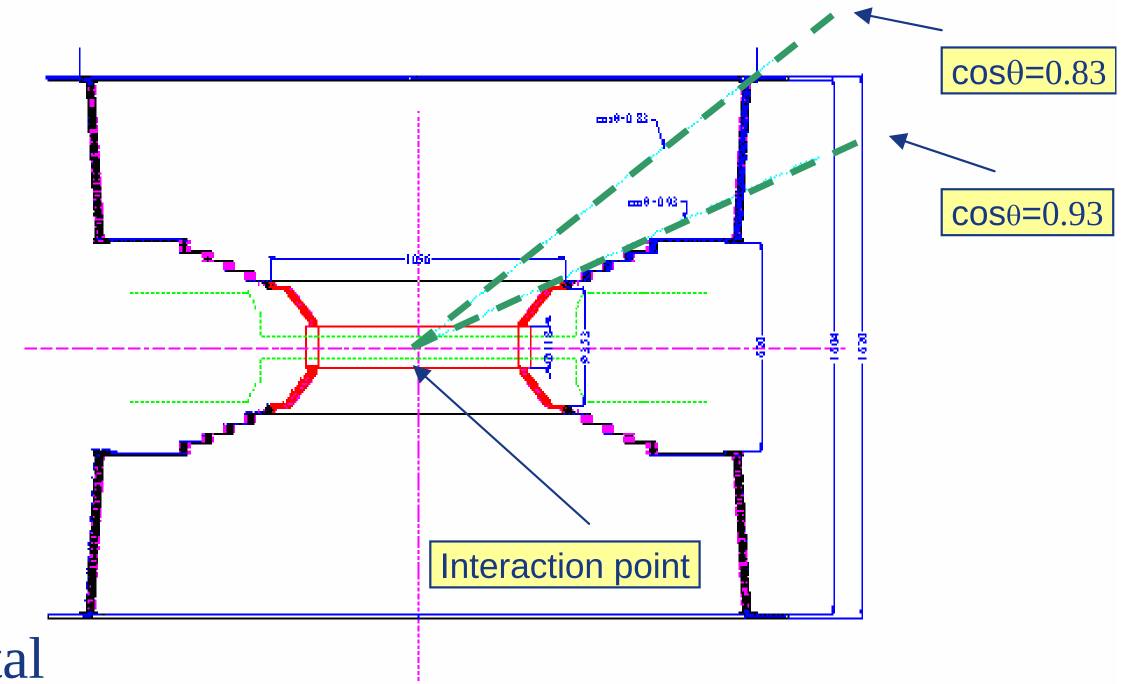
cosθ: from -0.93 to 0.93

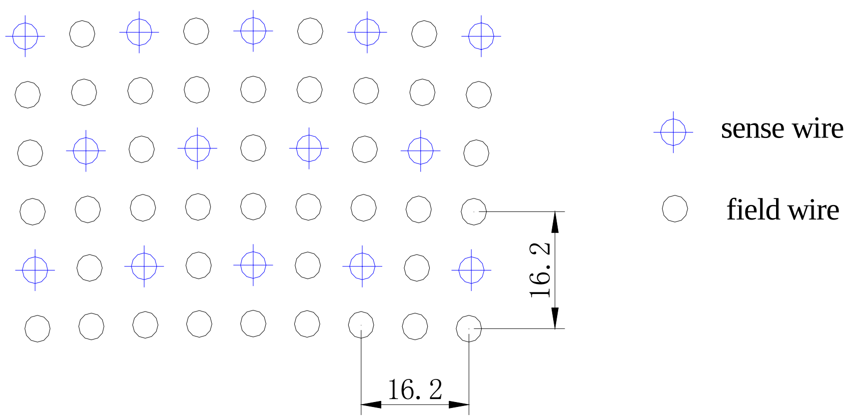
Layers: 43 layers , 11 super-layers

End-plates: ladder shape

Gas: He + C_3H_8 (60:40)

Cell: small cell geometry,6796 in total





Expected performance

Position resolution:

130μm

Mom. resolution (σp/p):

0.5%@1GeV/c

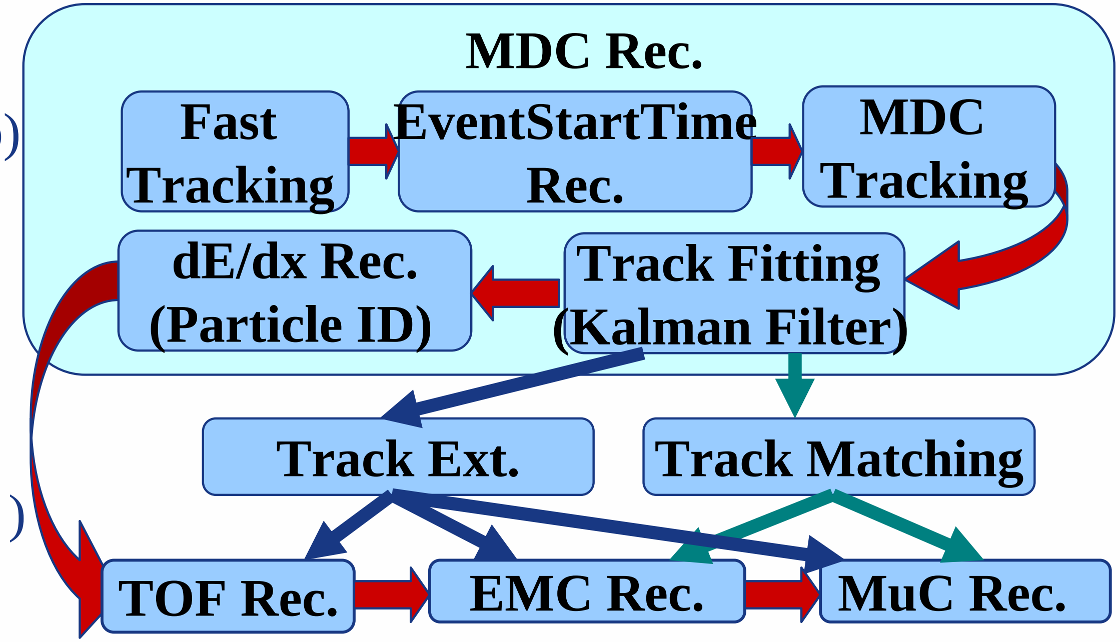
dE/dx resolution:

6-7%

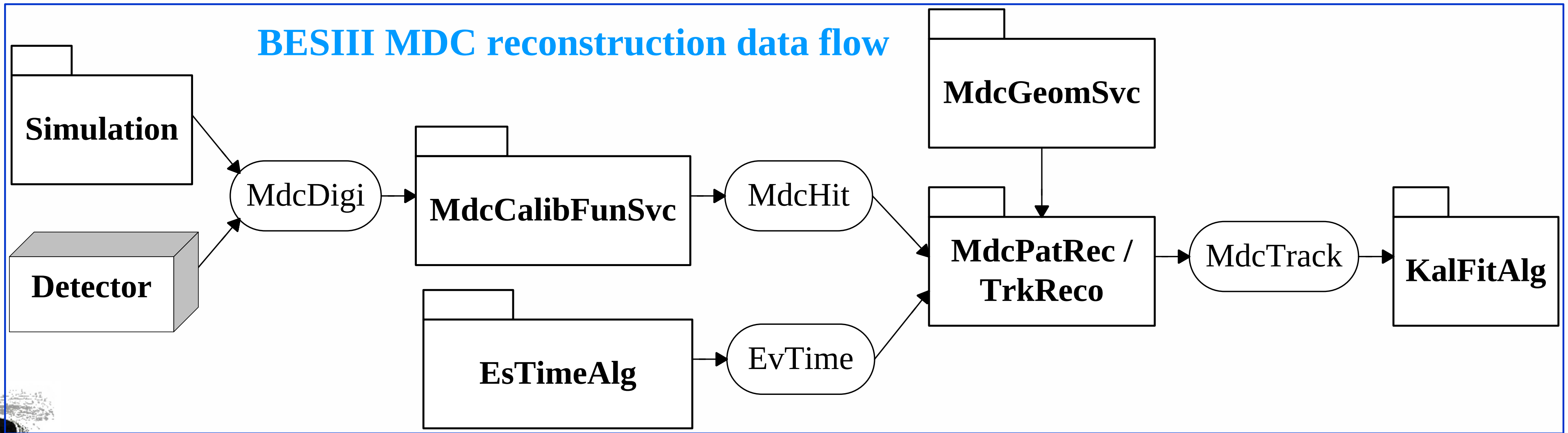
Main Drift Chamber Offline Software

Software Environment:

- Underlying framework
  GAUDI (originally developed by LHCb)
- Simulation: **GEANT4**
- Database: **MySQL/Oracle**
- Software configuration management:
  CMT and CVS
- Computer language:
  C++ (BESII legacy code written in **Fortran**)
- Operation system:
  SLC3/ gcc3.2.3
- Reused code from
  Belle, BaBar, ATLAS,GLAST …



BESIII event recon. modules and general flow



BESIII MDC reconstruction data flow

MDC Tracking Module (TrkReco & MdcPatRec)

TrkReco (Based on Belle)

- **Init:** Geometry-Surv., Cal.-Constant, Adjust-constant Get Hit Information
- **R-ϕ Tracking:** Segment finding by conformal transformation and TSF method
- **Z Finding**
- **3D Helix Fit**

Circle & Line Fit

MdcPatRec (Based on BaBar)

- **Init:** Geometry-Sur., Cal.-Constant, Adjust-constant Get Hit Information ....
- **Segment finding:** Search segments in each super-layer by " template matching" metheod
- **Tracking:** Link segments to 2-D tracks, Add stereo segments

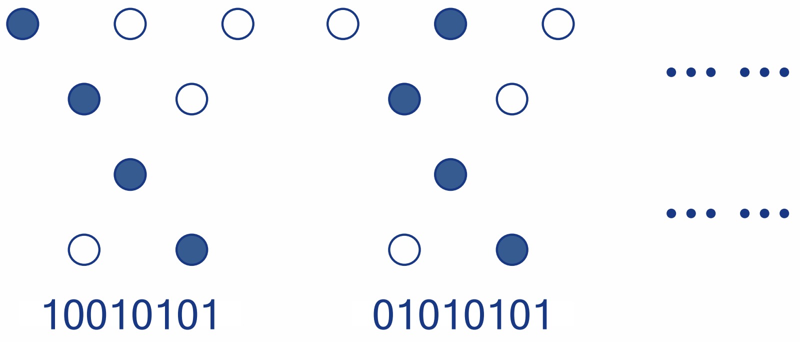
3D Helix Fit

Line & Circle Fit

MdcPatRec: Segment finding by template matching method

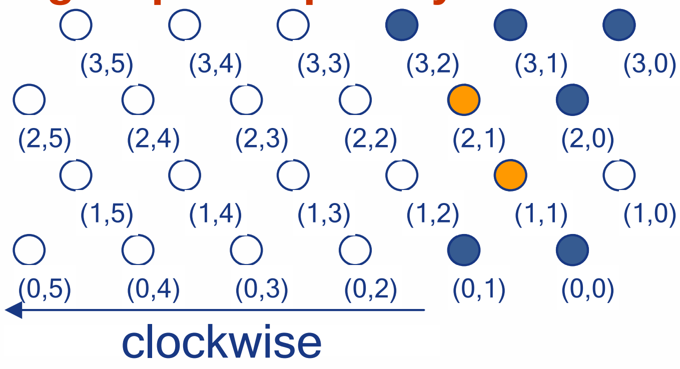
- 4-hits and 3-hits patterns are predefined in **template dictionary**. Hit group in super-layers which matches template called segment.

Template dictionary



○wire in template ● wire has hit

Hit group in super-layer



● wire in group ● reference wire

To solve the problem of geometry asymmetry :

- Take 2 reference wires
- Calculate angle to get "neighbor" hits in group

Find neighbors by angle

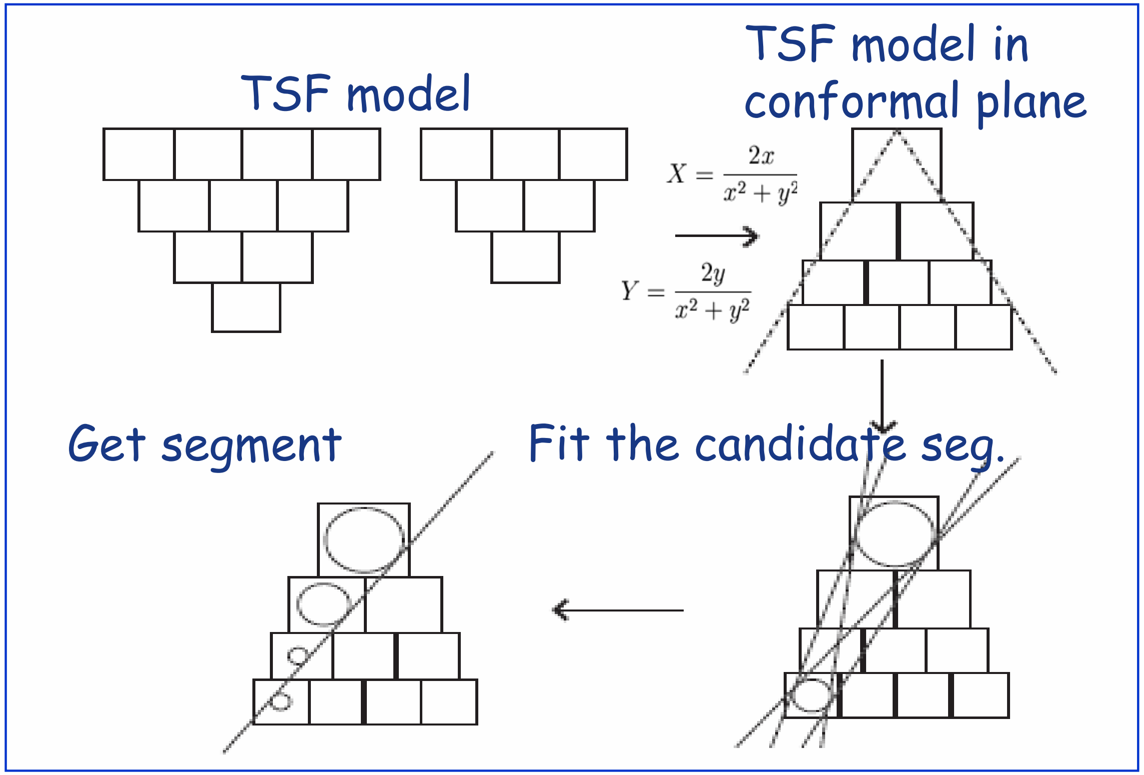
$$n = \frac{\varphi_{reference} - \varphi_{offset}}{\varphi_{cell\,width}}$$

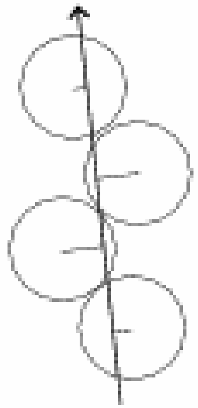
$\lfloor n \rfloor$ cell # of $-\varphi$ neighbor wire

$\lceil n \rceil$ cell # of φ neighbor wire

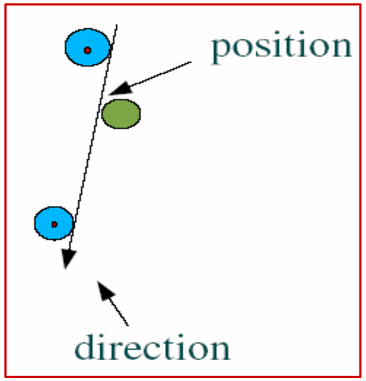
TrkReco: TSF Segment Finding

The TSF segment finding is based on conformal transformation. Both position and drift distance of fired wires are considered in TSF.



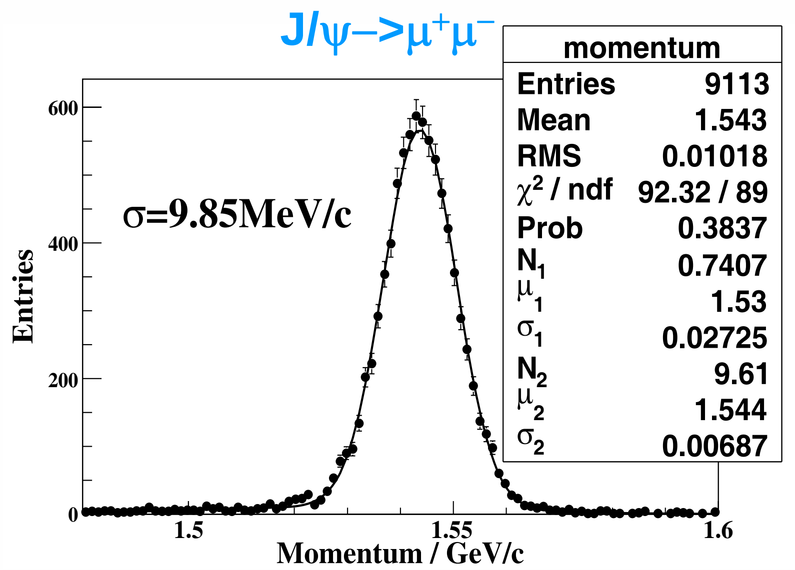


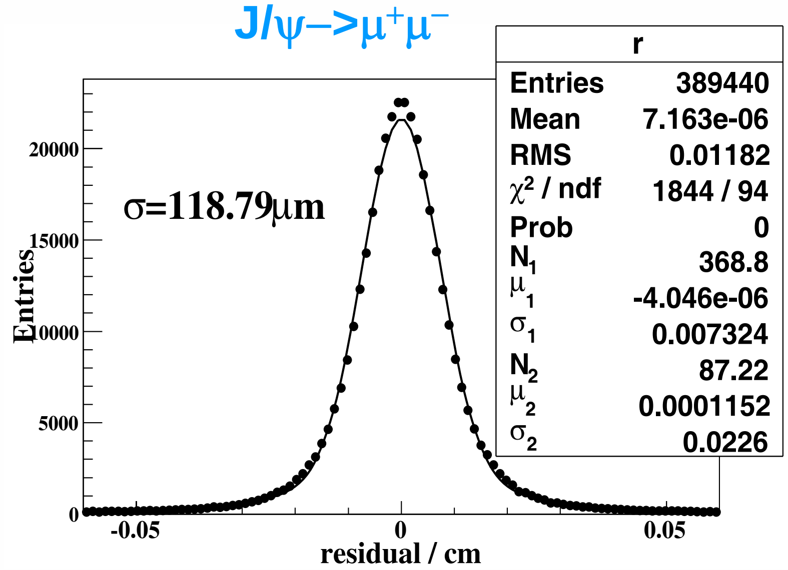
Relation of track to space and time of hit wire got more accurate info in conformal plane.



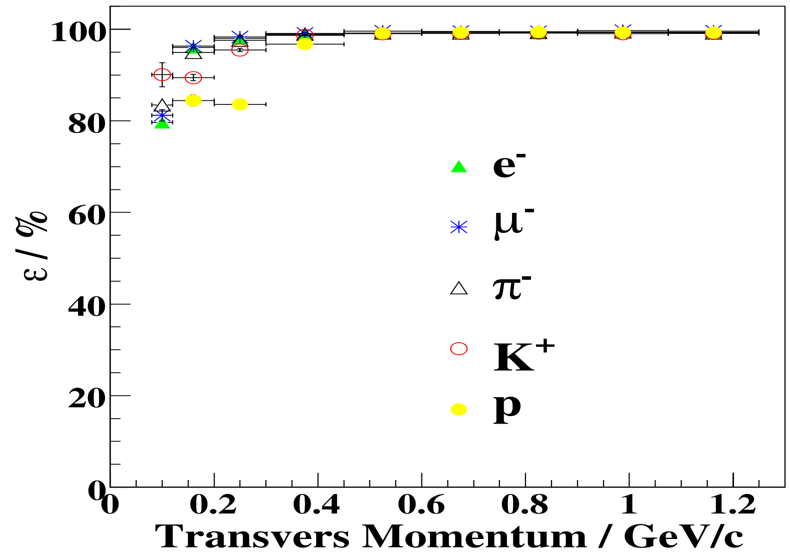
Direction and position are saved for each segment. They are used in segment linking.

MDC Tracking Performance (Monte Carlo Data)

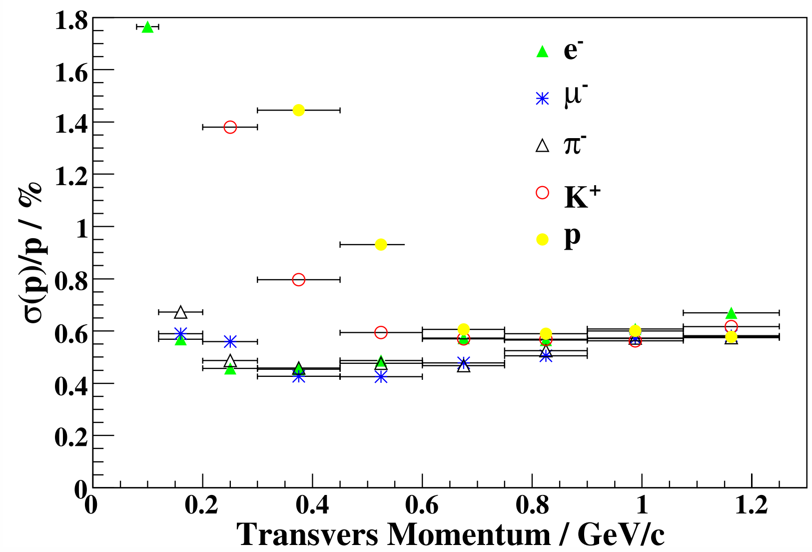




Tracking efficiency Vs Pt



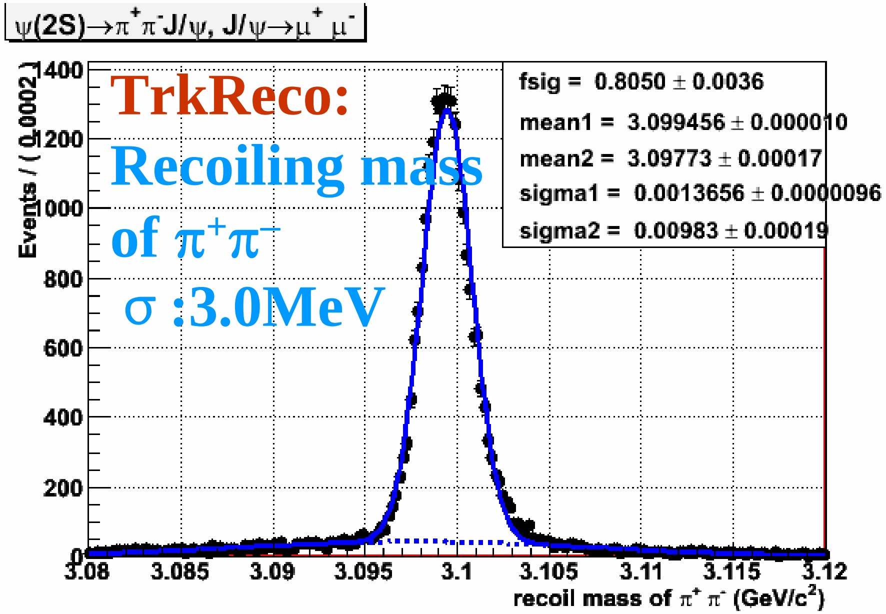
Momentum Resolution Vs Pt

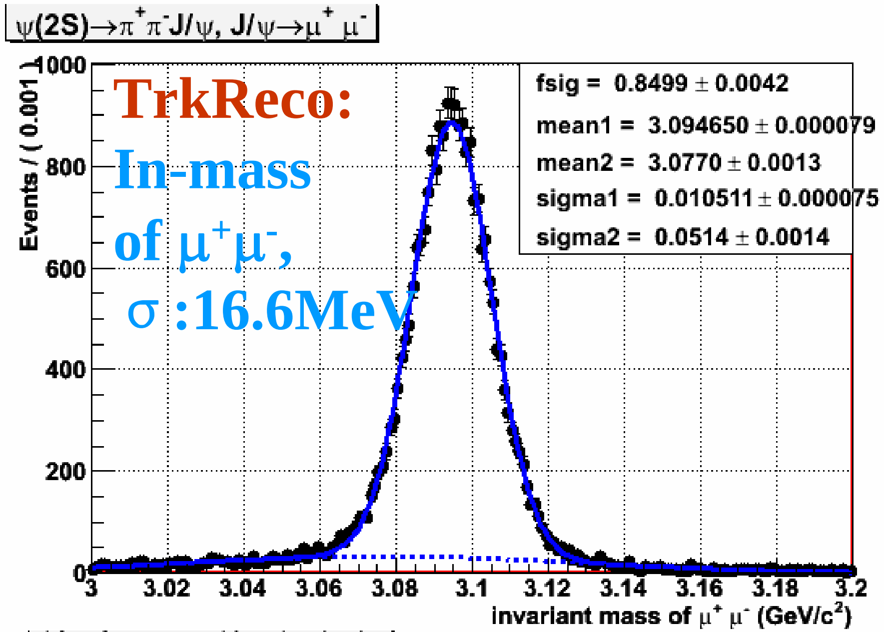


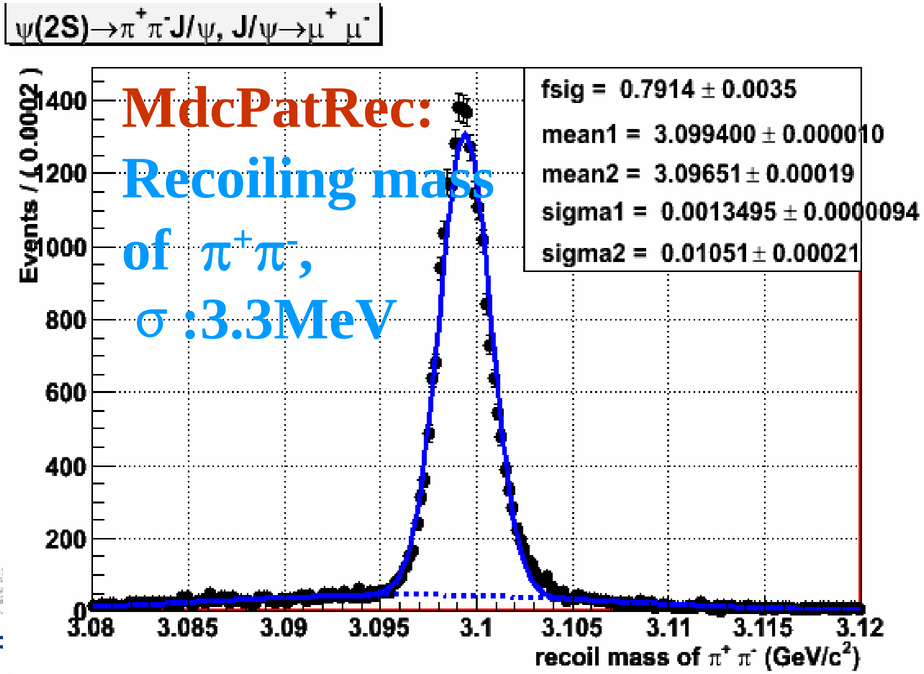
$\sigma(p)/p = 0.48\%$@ $1\text{GeV}/c$

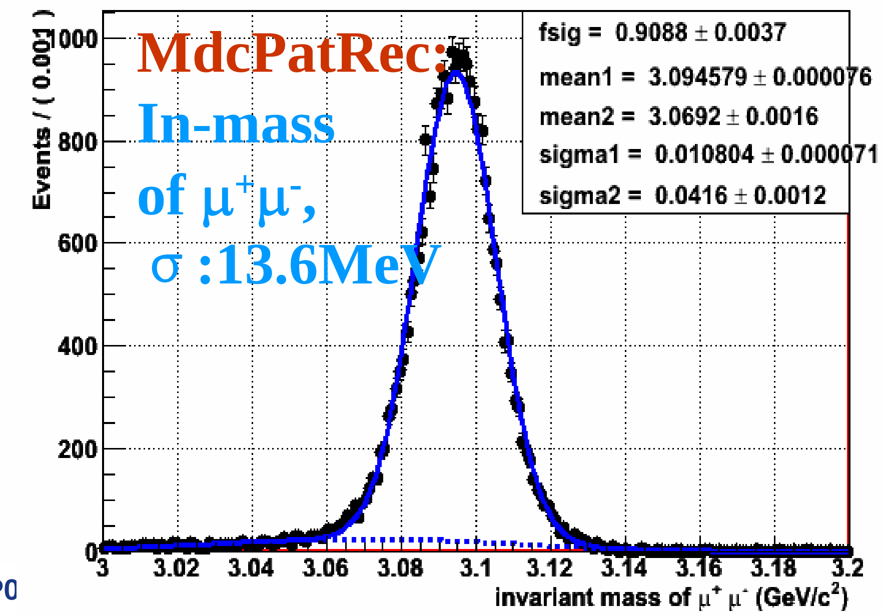
Physics Performance (Monte Carlo Data)

- $\psi(2S) \to \pi^+\pi^- J/\psi \to \pi^+\pi^-\mu^+\mu^-$ event





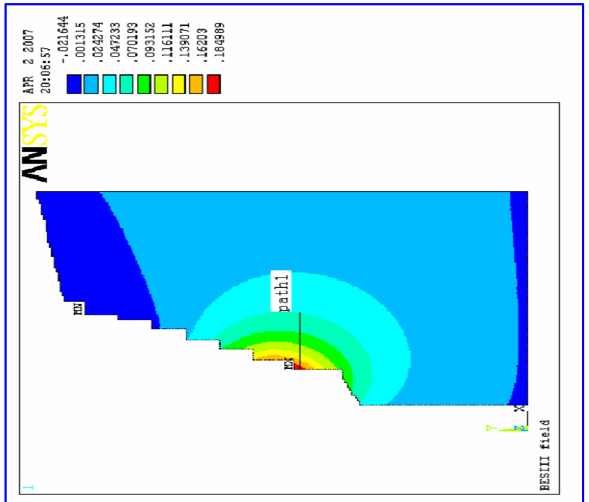


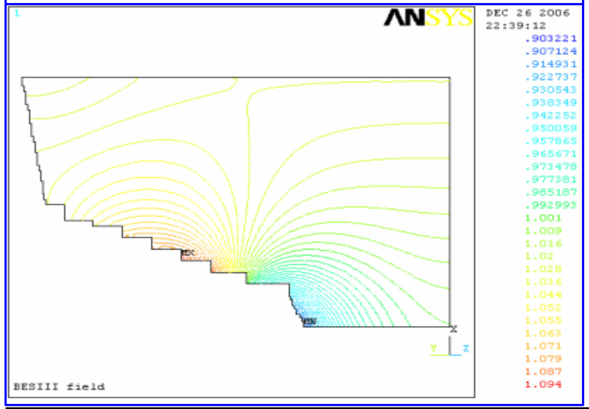


MDC Track Fitting with Kalman Filtering: KalFitAlg algorithm

•KalFitAlg solve the multiple scattering, energy loss effect, non-uniform magnetic field effect and others precise correction with **Kalman filtering** method.

Magnetic field map (Br & Bz)





non-uniformity : 5%~10%

- **Non-uniform magnetic field:**

$$\Delta\phi_0 = |k|(\Delta P_y \cos\phi_0 - \Delta P_x \sin\phi_0)$$
$$\Delta k = |k|k(\Delta P_x \cos\phi_0 + \Delta P_y \sin\phi_0)$$
$$\Delta \tan\lambda = \Delta P_z |k| + \frac{\tan\lambda \Delta k}{k}$$

- **Multiple scattering**:

$$\sigma_\theta = \frac{0.0141}{p\beta}\sqrt{\frac{L}{X_R}} \equiv \sqrt{HL} \quad \sigma_x = \frac{0.0141}{p\beta}L\sqrt{\frac{L}{3X_R}} \equiv L\sqrt{\frac{HL}{3}}$$

$$\mathbf{V}_{\alpha\,\mathrm{MS}} \equiv \langle\delta\alpha\delta\alpha^T\rangle = (HL)\mathbf{M}\begin{pmatrix} 1 & 0 & 1/2 & 0 \\ 0 & 1 & 0 & 1/2 \\ 1/2 & 0 & 1/3 & 0 \\ 0 & 1/2 & 0 & 1/3 \end{pmatrix}\mathbf{M}^T.$$

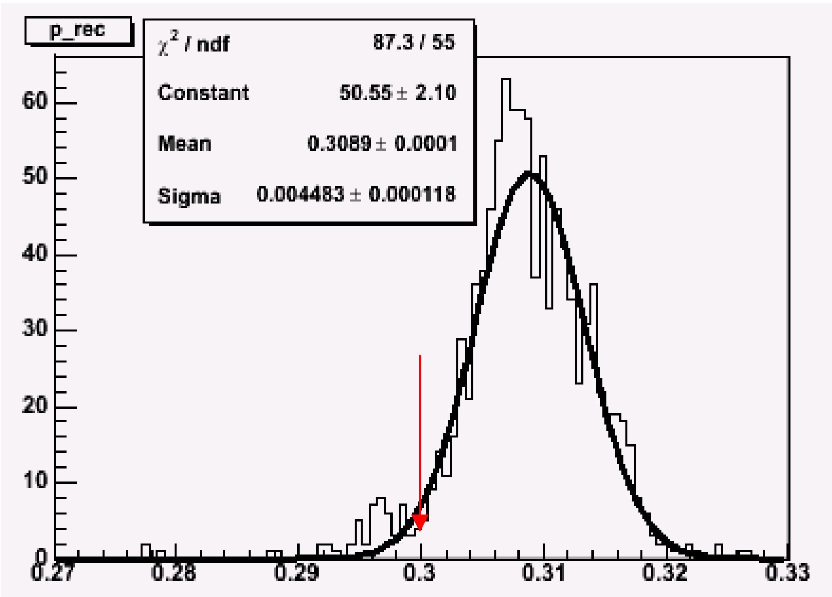
- **Energy loss:**

$$\Delta p = \int_0^t \frac{dp}{dx}dx = \int_0^t \frac{1}{\beta}\frac{dE}{dx}dx = \int_0^t \frac{A}{\beta^3}\left[\ln\left(\frac{2m_e c^2\beta^2\gamma^2}{I_0}\right) - \beta^2\right]dx$$

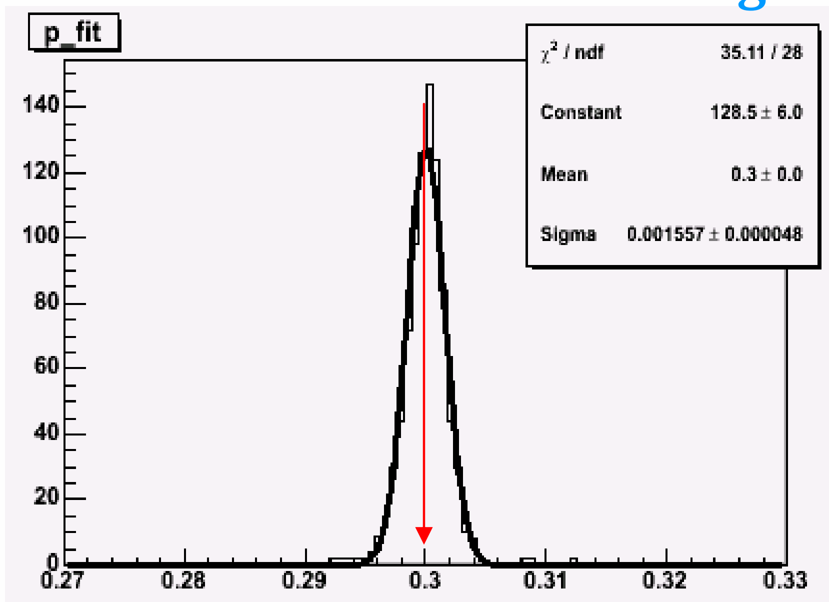
KalFitAlg Performance

By μ p=0.3GeV/c cosθ=0.83

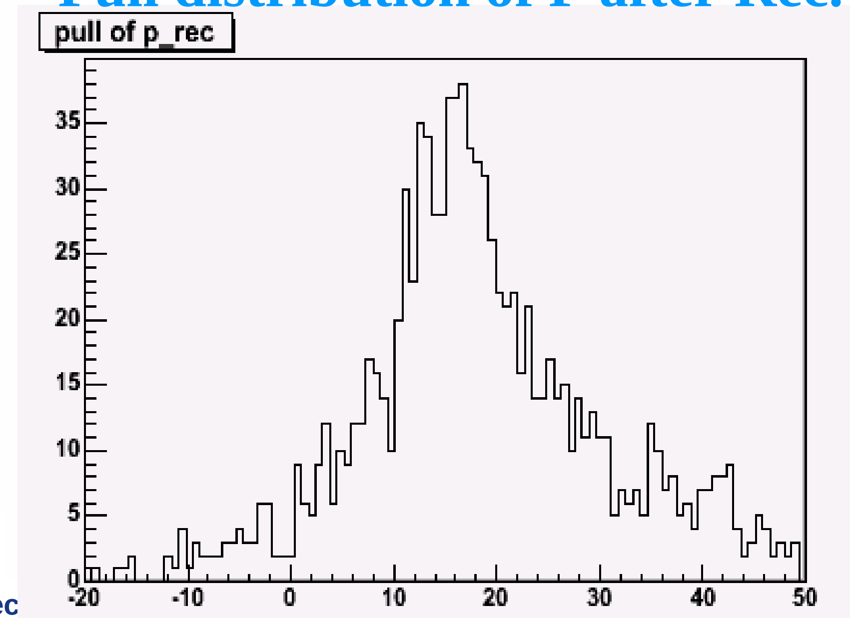
Momentum of Rec. Track



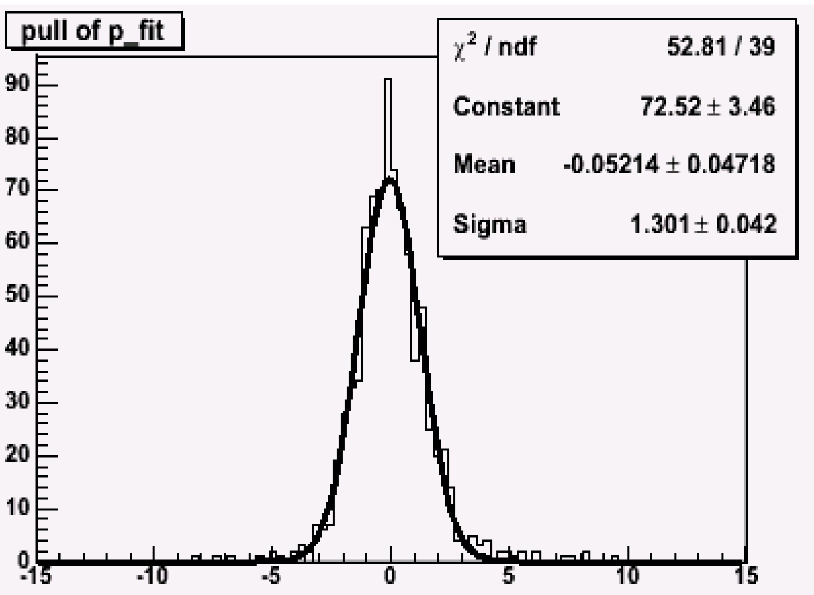
Momentum after KalFitAlg



Pull distribution of P after Rec.



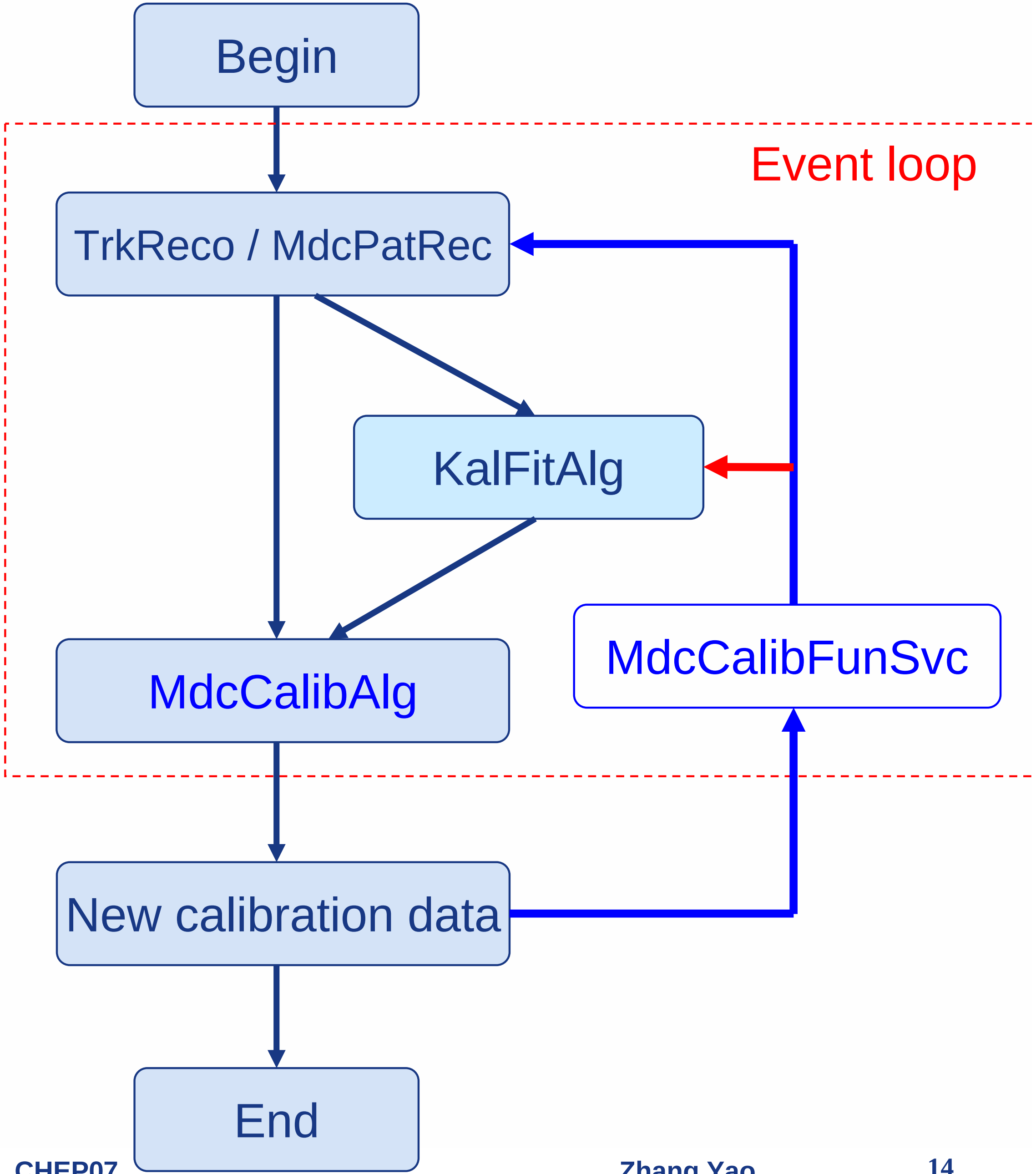
Pull distribution of P after KalFitAlg



MDC Calibration

- The calibration software for the drift chamber has been developed in the framework of the BESIII Offline Software System (BOSS).
- A preliminary test with Monte Carlo simulation has been finished:
  - **X-T relation (drift dist-drift time):** fitted to a 5th order polynomial (in the linear region) plus 1st order polynomial (near the edge regions)
  - **T0 calibration**

MDC Calibration Flow Chart

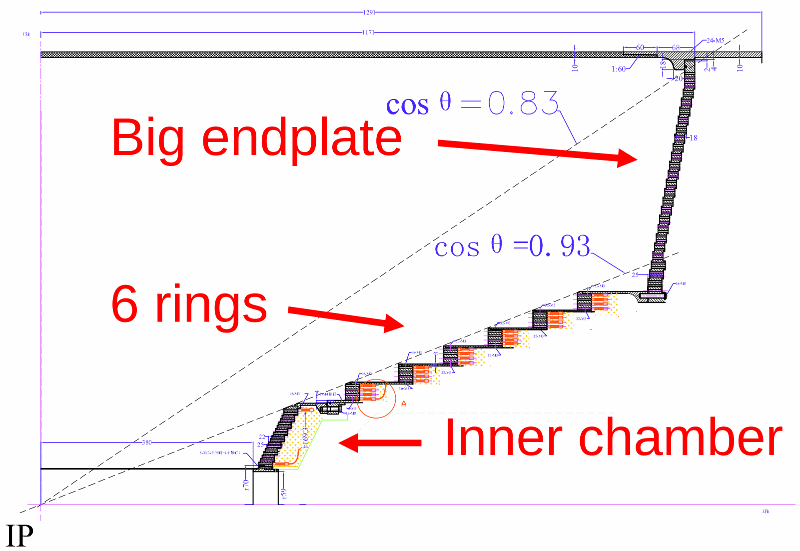


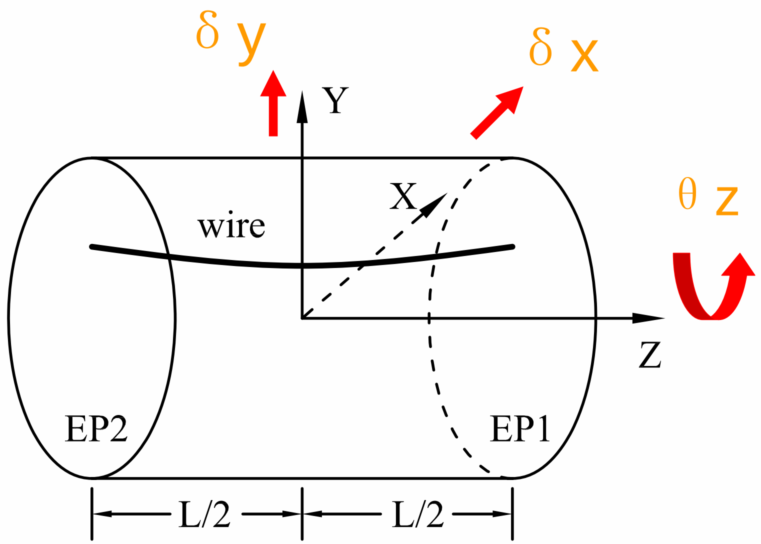
MDC Alignment

- Alignment with tracks is the only possible strategy to estimate positions and orientations of components of a track detector with sufficiently high precision.

- 16 independent elements in total.
  - Inner chamber (× 2)
  - Ring × 6 (× 2)
  - big endplate (× 2)
- For each element , 3 alignment parameters (δx, δy, θz) are considered
- 48 alignment parameters in total.

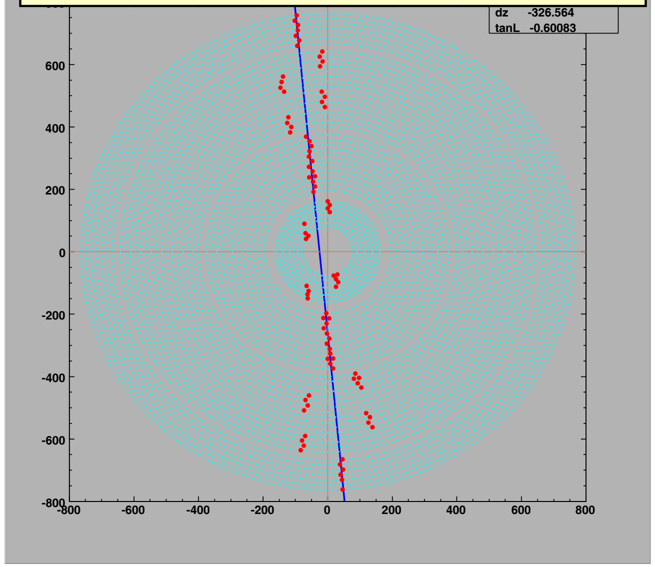
- Methods of alignment in study:
  - **Millepede Matrix method**
  - **Kalman filter method**
  - **Residual distribution method**

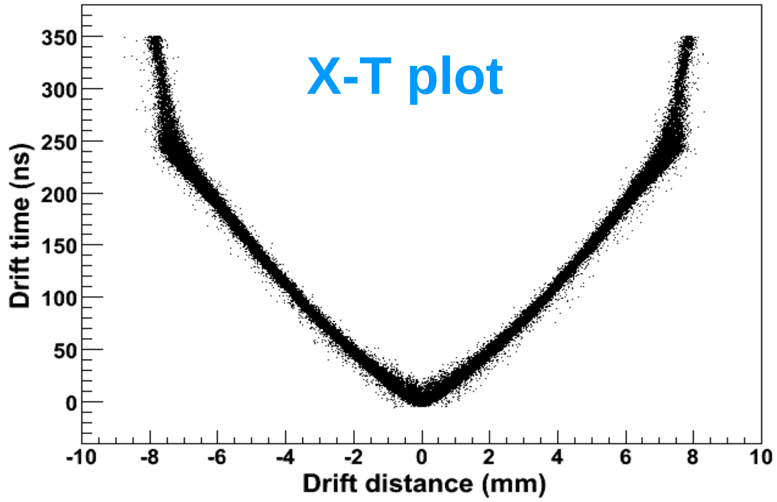




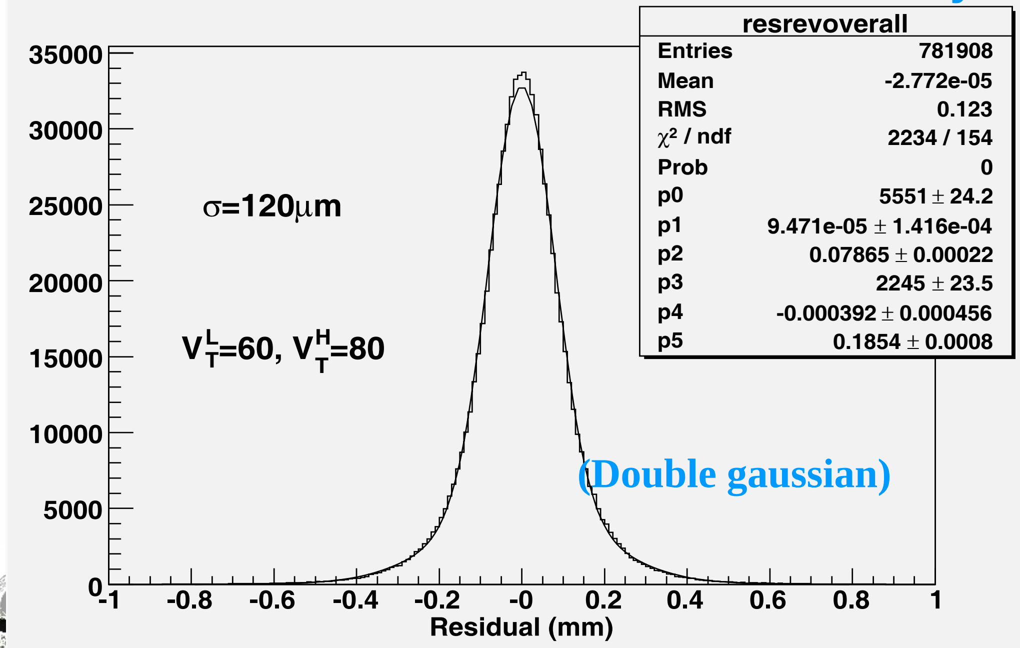
Preliminary results from cosmic ray test

Event display from x-y plane

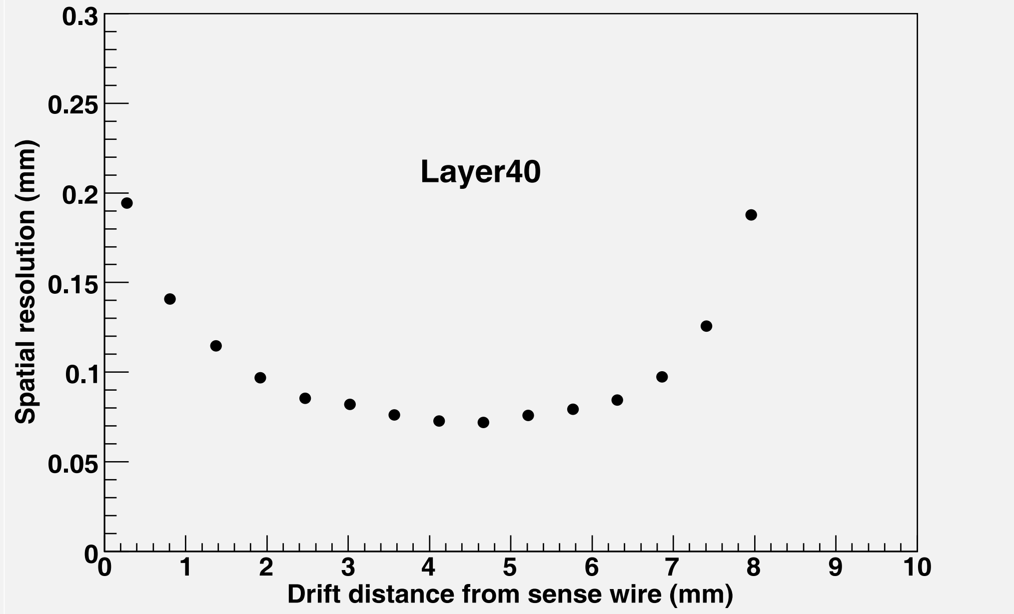




Residual distribution of the outer axial layers



Spatial resolution vs. drift distance



Summary

- **Both TrkReco and MdcPatRec algorithm get reasonable performance under BOSS**
- **Performance of MdcPatRec and TrkReco with Monte Carlo $J/\psi \to \mu^+\mu^-$ event:**
  - Tracking efficiency: **>99%**
  - Momentum resolution (σp) : ~ **10.** MeV/c
  - Spatial resolution(σ xy): **~120** μm
  - Vertex resolution (σ d0) : ~**0.2** mm σ z0: ~ **1.**mm
  - CPU time: **10**ms/track, Memory leak: **0**MB

- **Track fitting algorithm --- KalFitAlg**
  - Significantly improve the momentum resolution and the mean value.
  - Works well both under B uniform and B Non-uniform case.
  - Track parameters are improved especially for low Pt particles.

- **Calibration and alignment**
  - Results of the Monte Carlo show that the calibration software runs well
  - Several alignment methods are investigated. They are effective in the estimation of alignment parameters with Monte Carlo data
  - Test of calibration and alignment software with data of cosmic ray test is in progress

Thank you!

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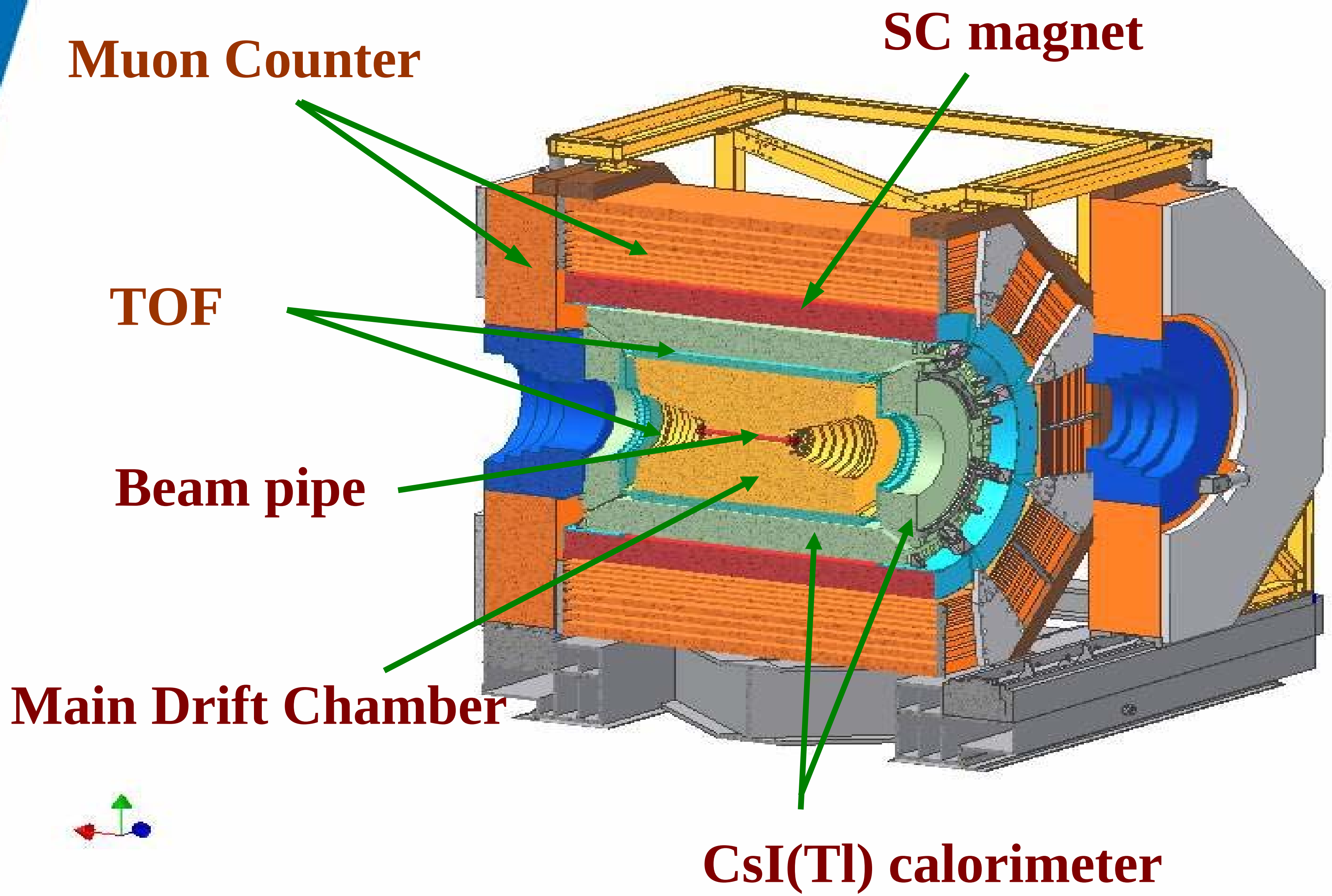
BESIII Detector



The detector is hermetic for neutral and charged particle with excellent resolution , PID adequate, and large coverage.

BESIII Main Sub-systems

- **CsI EM Calorimeter: ΔE/E ~3.5%@1GeV (inc. dead material)**
- **MDC: small cell, Al field wire and He-based gas**

  △P/P (1GeV) = 1.4 %@0.4T, 0.6 %@1T, $\sigma_{dE/dx}$ = 6-7 %
- **Time of Flight: ΔT: barrel 90 ps; endcap 110 ps**
- **μ counter(RPC): readout strip width: ~4 cm**
- **Luminosity Monitor(LM) △L/ L = 3-5%**
- **SC Solenoid: 1 Tesla, I.R. 1.32 m, Length 3.8 m**
- **New Trigger and Online system for multi-bunch and high lum. Operation, 4000Hz, 3000Hz to mass storage**
- **New Electronics: pipeline operation**
- **Offline computing: PC farm, mass storage**

BES III Expected Event Rates

At ψ'' 10^{33}, at J/ψ and 4.14 GeV, ~0.6×10^{33}

Particle	Energy	Single Ring ($1.2f_b^{-1}$)	Double Ring ($4f_b^{-1}$)
D^0	ψ''	7.0×10^6	2.3×10^7
D^+	ψ''	5.0×10^6	1.7×10^7
Ds	4.14GeV	2.0×10^6	4×10^6
$\tau^+\tau^-$	3.57GeV 3.67GeV	0.6×10^6 2.9×10^6	0.2×10^7 0.96×10^7
J/ψ		$3\text{-}4\times10^9$	$6\text{-}10\times10^9$
ψ'		0.6×10^9	2×10^9

Event statistics at BESIII

Physics Channel	Energy (GeV)	Luminosity (10^{33} $cm^{-2}s^{-1}$)	Events/year
J/ψ	3.097	0.6	1.0×10^{10}
τ	3.67	1.0	1.2×10^7
ψ'	3.686	1.0	3.0×10^9
D	3.77	1.0	2.5×10^7
Ds	4.03	0.6	1.0×10^6
Ds	4.14	0.6	2.0×10^6

BEPCII **Design Goals**

Beam energy	1 – 2 GeV
Optimal energy	1.89 GeV
Luminosity	$1 \times 10^{33}\ cm^{-2}s^{-1}$ @ 1.89 GeV
Linac requirements	Full energy injection: 1.55 – 1.89 GeV Positron injection rate > 50 mA/min
Dedicated SR	250 mA @ 2.5 GeV

Increase beam current， reduce beam size

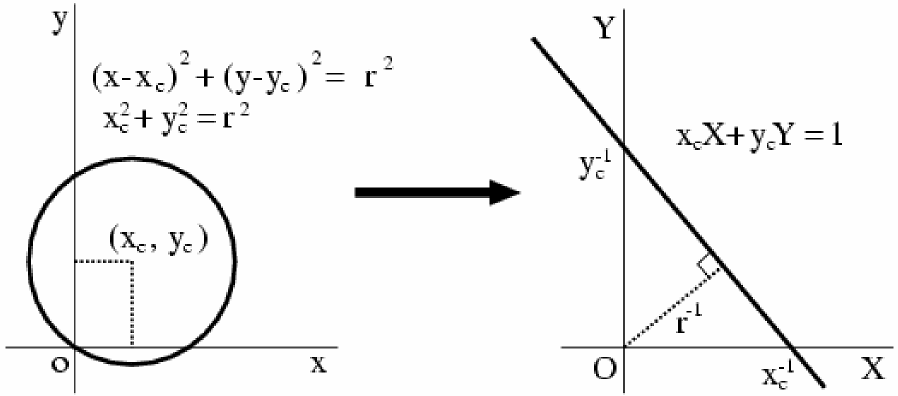
Physics to be studied in τ-charm region

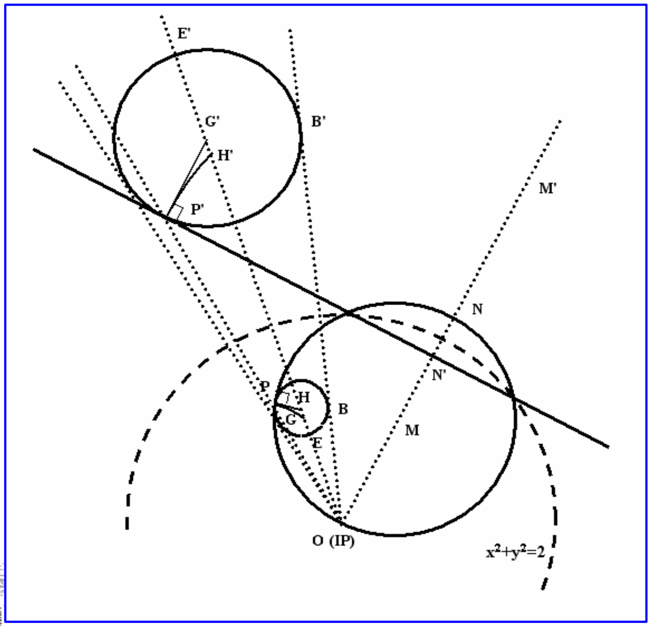
- **Search for glueballs, quark-gluon hybrids and exotic states**
- **Charmonium Spectroscopy and decay properties**
- **Precision measurement of R**
- **Tau physics: tau mass, tau-neutrino mass, decay properties, Lorenz structure of charged current, CP violation in tau decays …**
- **Charm physics: including decay properties of D and D_s, f_D and f_{Ds}; charmed baryons.**
- **Light quark spectroscopy, m_c**
- **Testing QCD, QCD technologies, CKM parameters**
- **New Physics: rare decays, oscillations, CP violations in c- hadrons**
- **…..**

TrkReco : Conformal Transformation

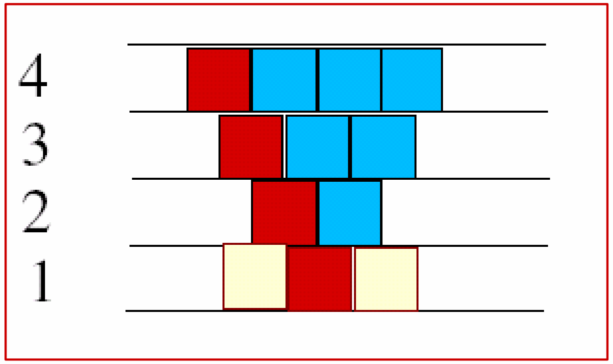
- Conformal transformation :
  - A circle or line which passes through the origin is transformed into a line.
  - A circle or line which doesn't pass through the origin is transformed into a new circle.

$$X = \frac{2x}{x^2 + y^2}, \qquad Y = \frac{2y}{x^2 + y^2}.$$





•Circle M is a track in r-phi, and circle H is a drift circle.
They are transformed into line N'P' and circle G'.



To avoid missing adjacent hits, we append the neighbor hits of seed, if it is reasonable.

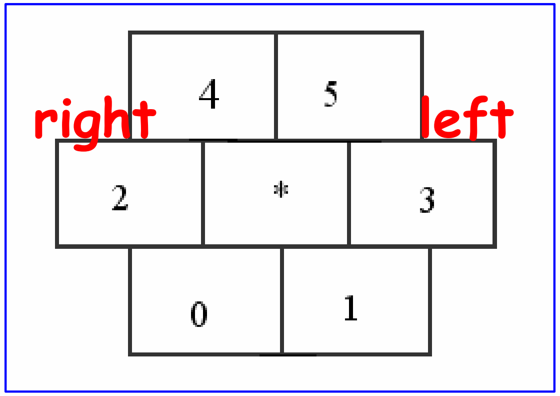
The principle of TSF and design

Solve L/R ambiguity

Solve L/R by neighbor (old method):

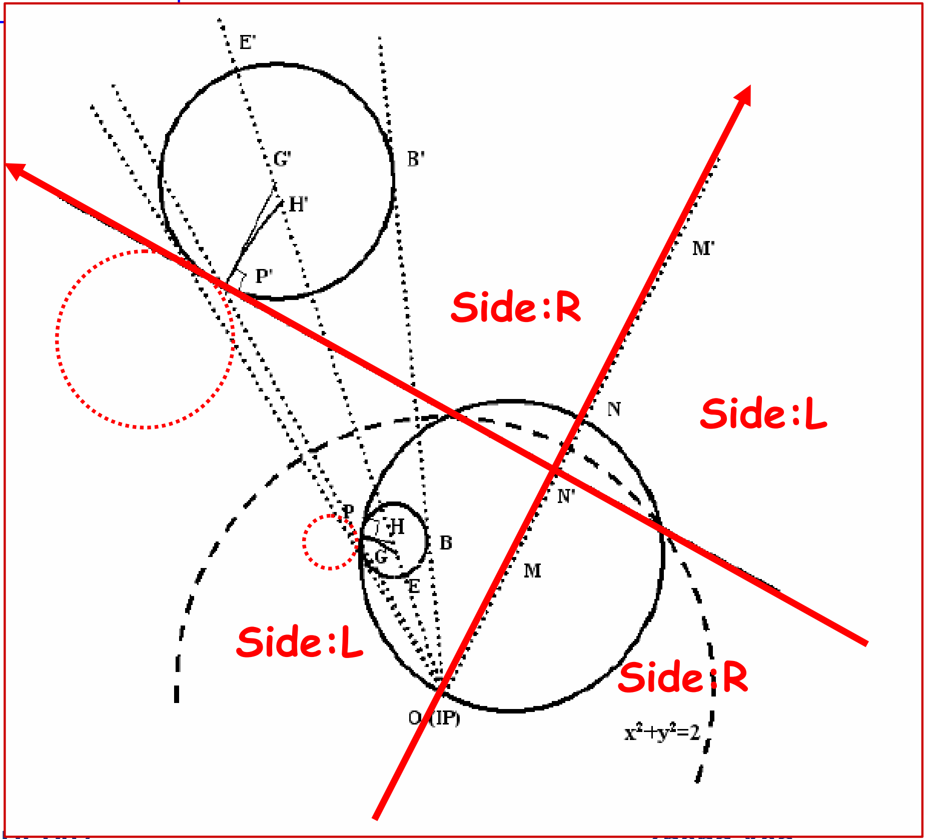
Depend on distribution of the hit wires in the six neighbor sense wires.

Will be confused as the noise rises.



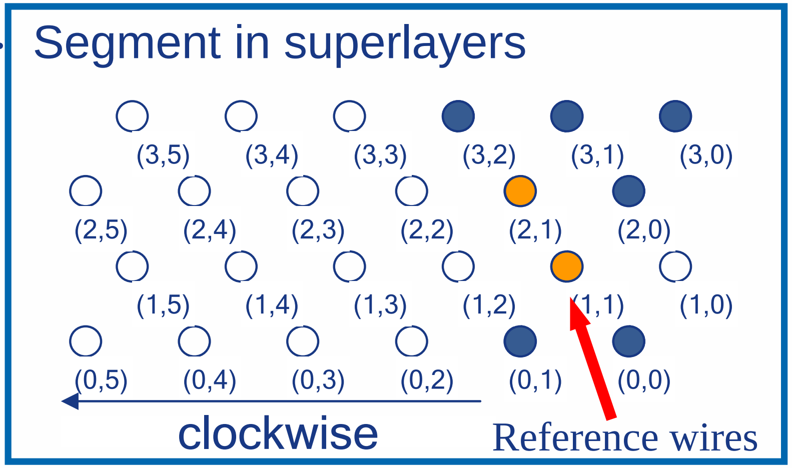
Solve L/R by TSF:

Corresponding to the hits in natural plane, we have their L/R in conformal plane as shown in the right figure.

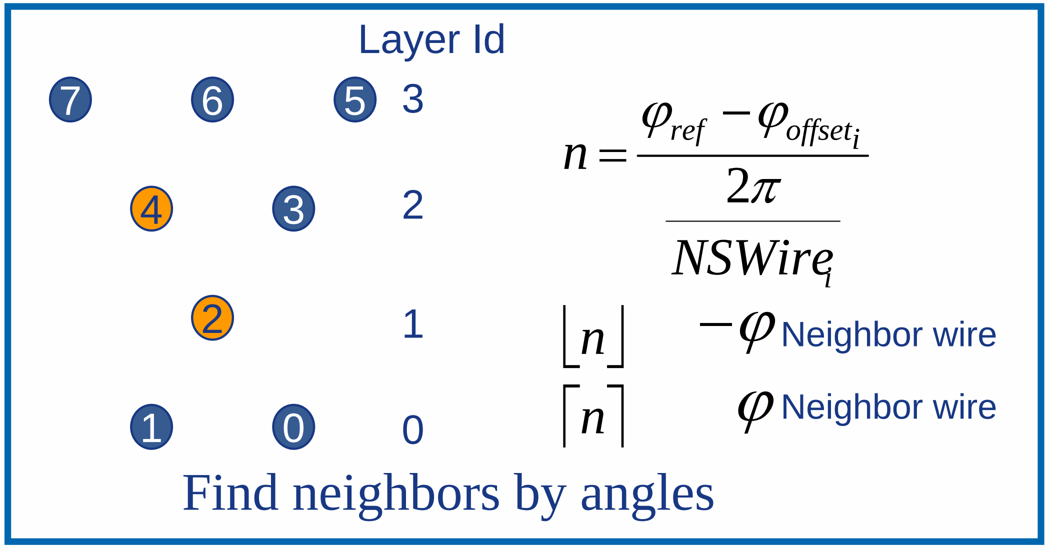


MdcPatRec: Segment finding by template matching method

- Predefined 4-hits and 3-hits pattern in ***template dictionary***.
- Find hit group which matches template in super-layers.
- Take 2 reference wires and use angle
- of reference wires to get "neighbors"

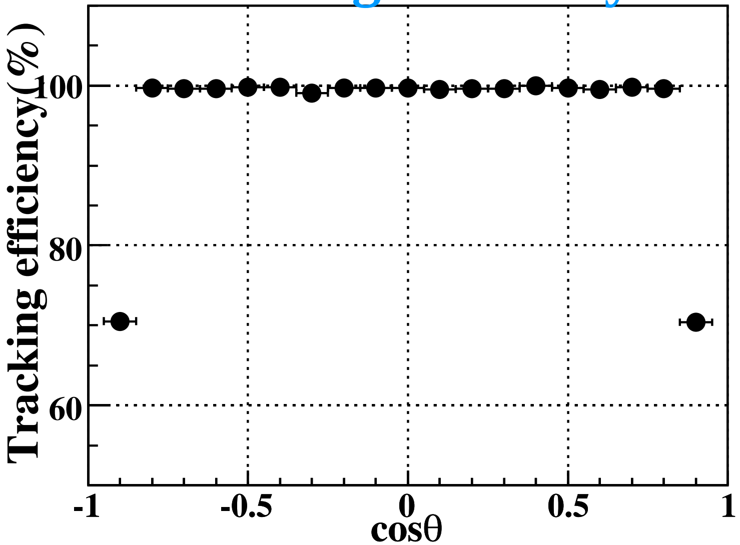


Parts of Chamber	SL type	No. of layers	No. of wires per layer
Inner	Stereo−	4	40,44,48,56
	Stereo+	4	64,72,80,80
	Axial	4	76,76,88,88
	Axial	4	100,100,112,112
	Axial	4	128,128,140,140
	Stereo−	4	160 × 4
Outer	Stereo+	4	192 × 4

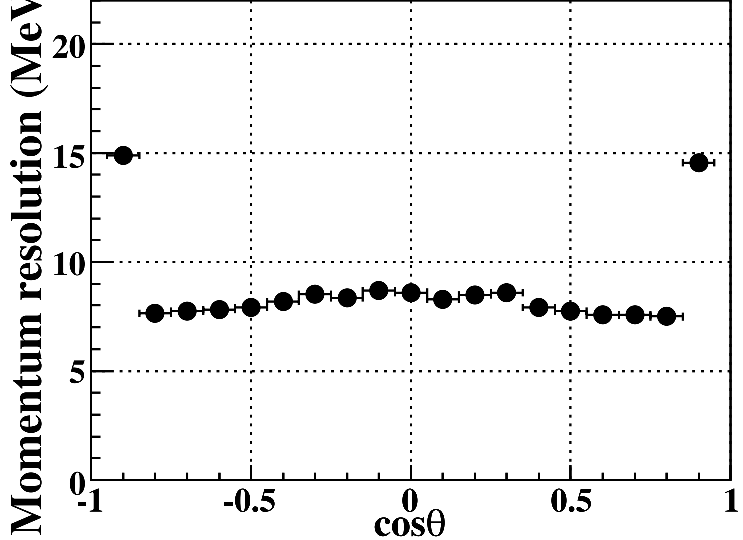


Performance Vs. cosθ

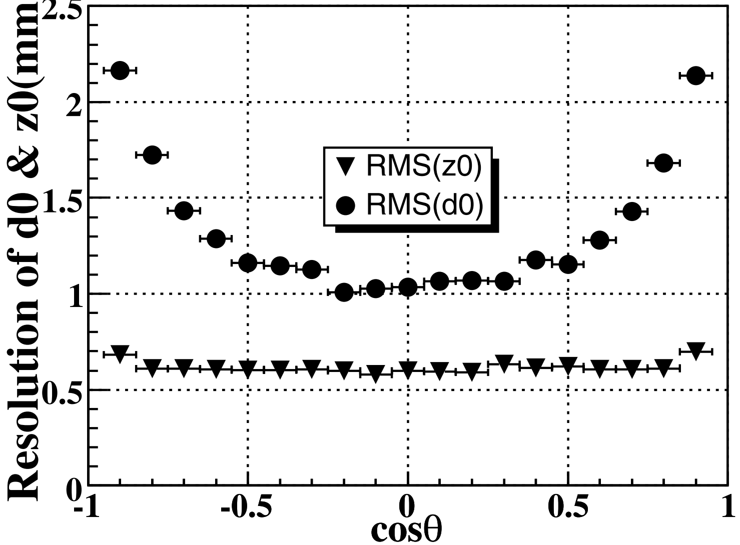
Tracking efficiency



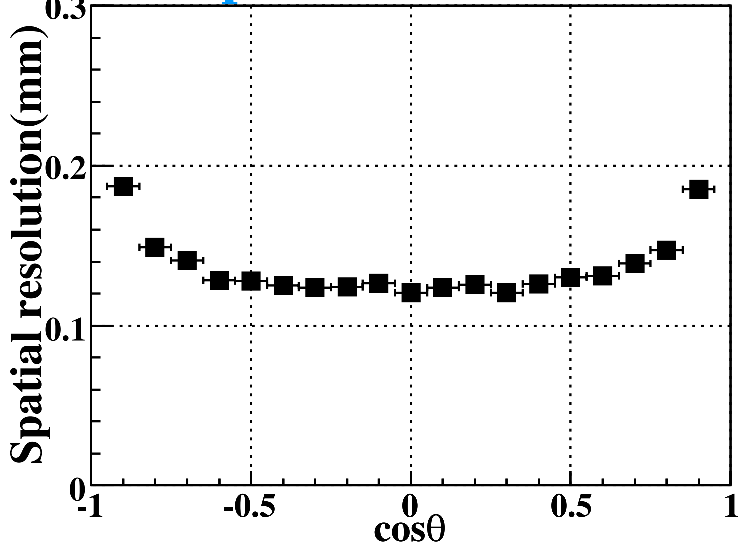
Momentum resolution



Vertex resolution



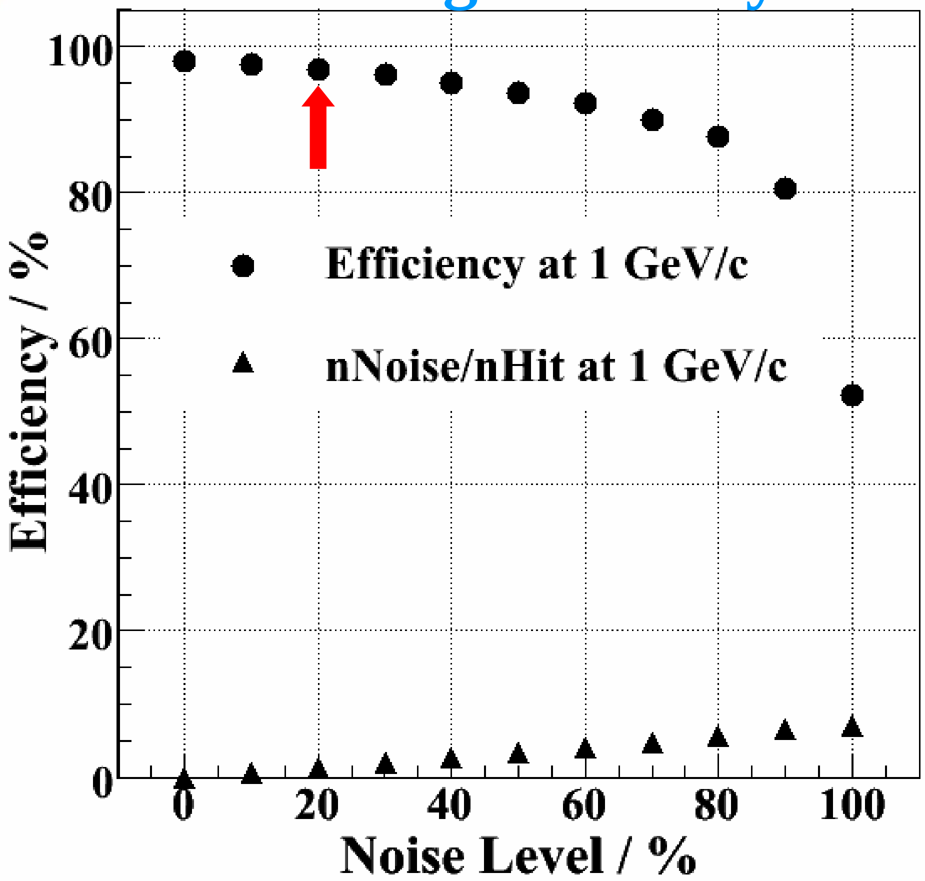
Spatial resolution



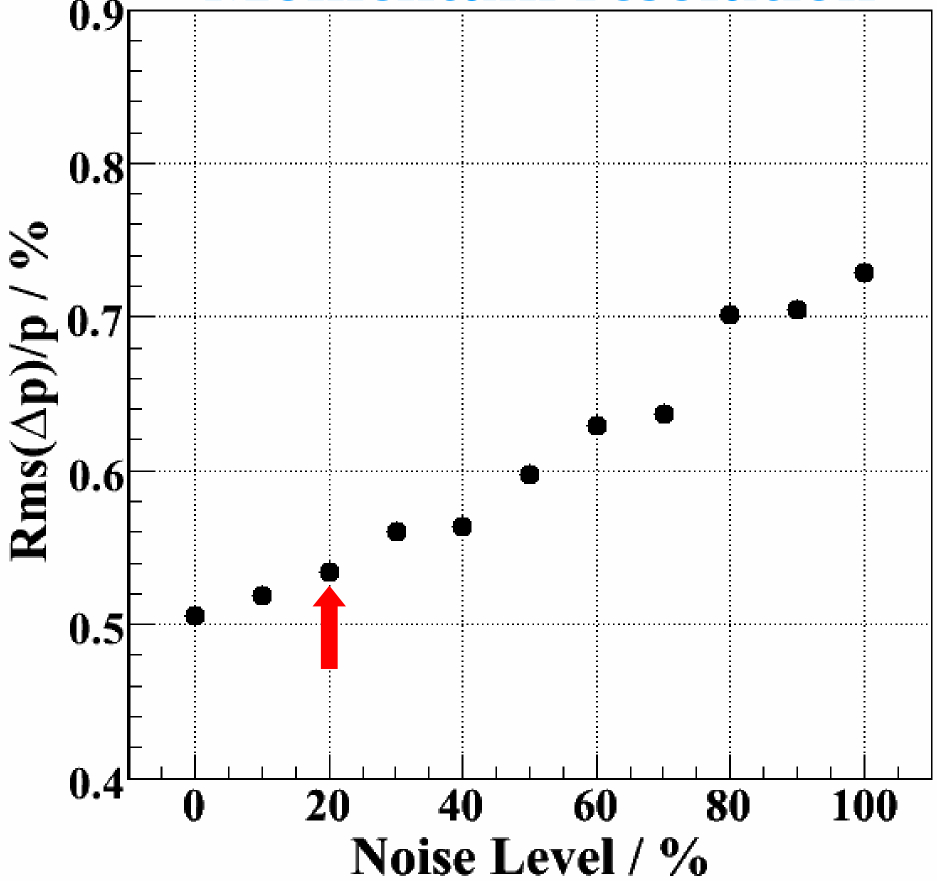
- $J/\psi \to \mu^+\mu^-$

Performance Vs. noise

Tracking efficiency



Momentum resolution



- μ^- @1GeV/c, Noise level: 0%~100% (@first layer of MDC)

MDC Track Fitting: KalFitAlg algorithm

KalFitAlg is used to solve the multiple scattering, energy loss effect, non-uniform magnetic field effect and others precise correction.

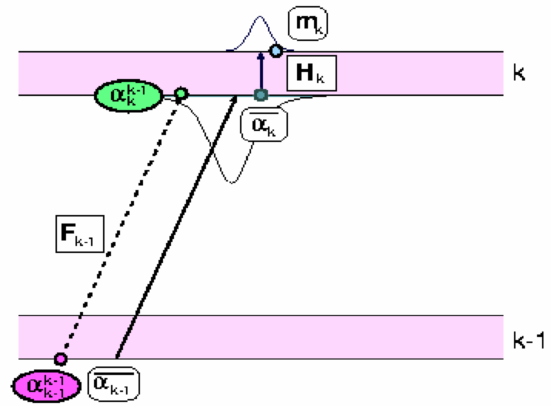
System equation: $\bar{\alpha}_k = F_{k-1}\bar{\alpha}_{k-1} + w_{k-1}$

Measurement equation: $m_k = H_k\bar{\alpha}_k + \varepsilon_k$

Prediction:

$$\alpha_k^{k-1} = F_{k-1}\alpha_{k-1}^{k-1}$$

$$C_k^{k-1} = F_{k-1}C_{k-1}^{k-1}F_{k-1}^T + Q_{k-1}$$

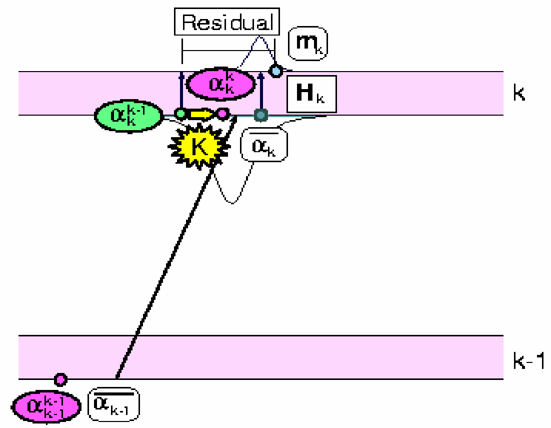


Filtering:

$$\alpha_k^k = \alpha_k^{k-1} + K_k(m_k - H_k\alpha_k^{k-1})$$

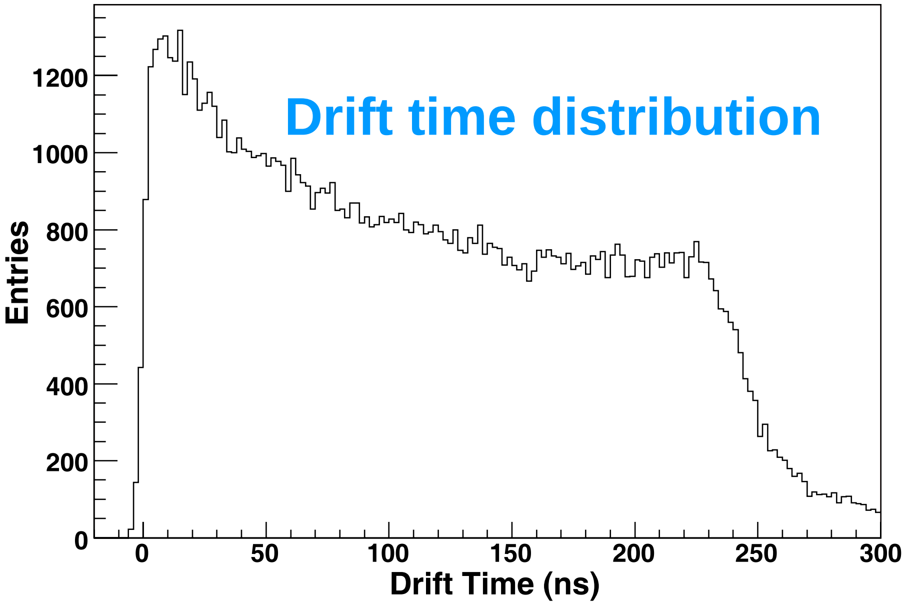
$$K_k = C_k^{k-1}H_k^T(V_k + H_kC_k^{k-1}H_k^T)^{-1}$$

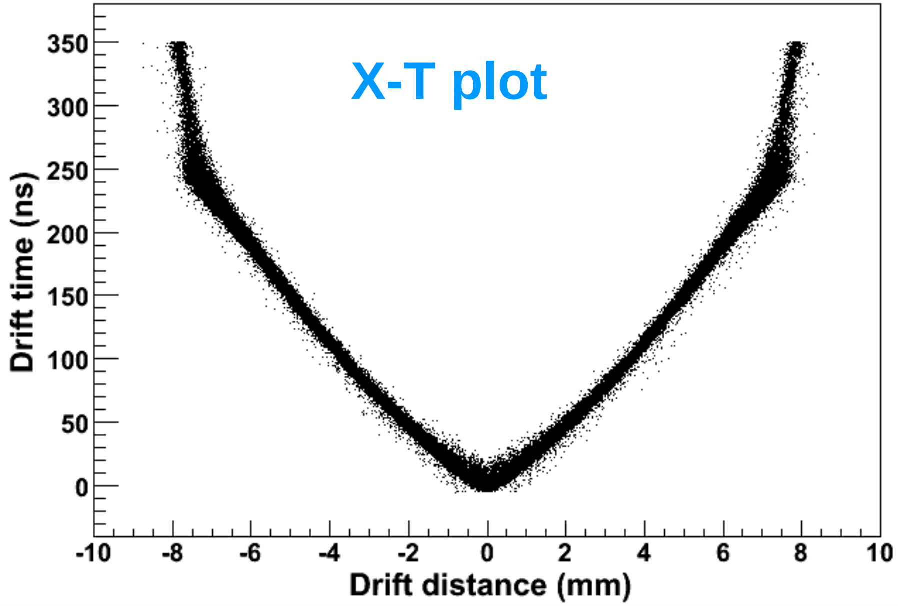
$$C_k^k = (1 - K_kH_k)C_k^{k-1}$$

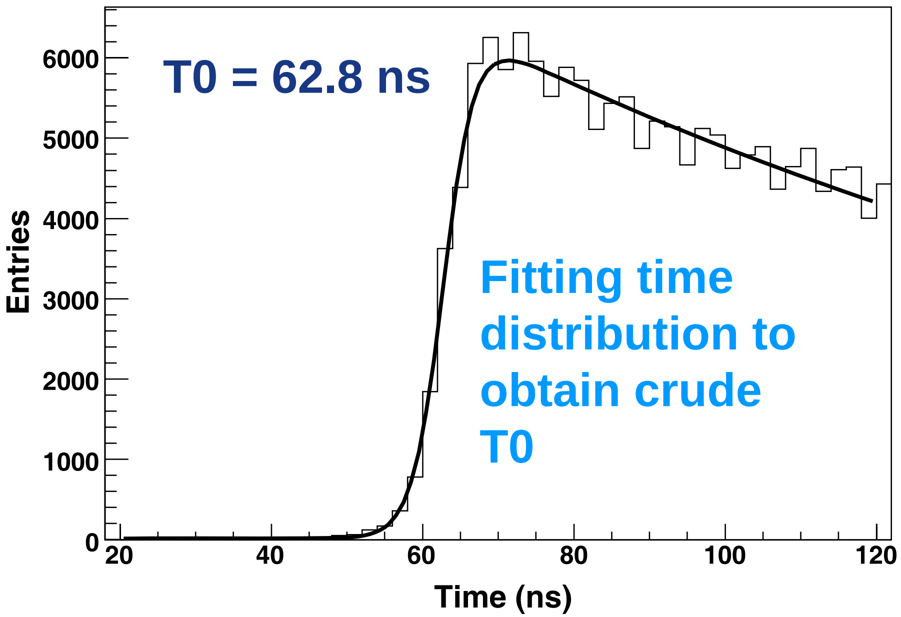


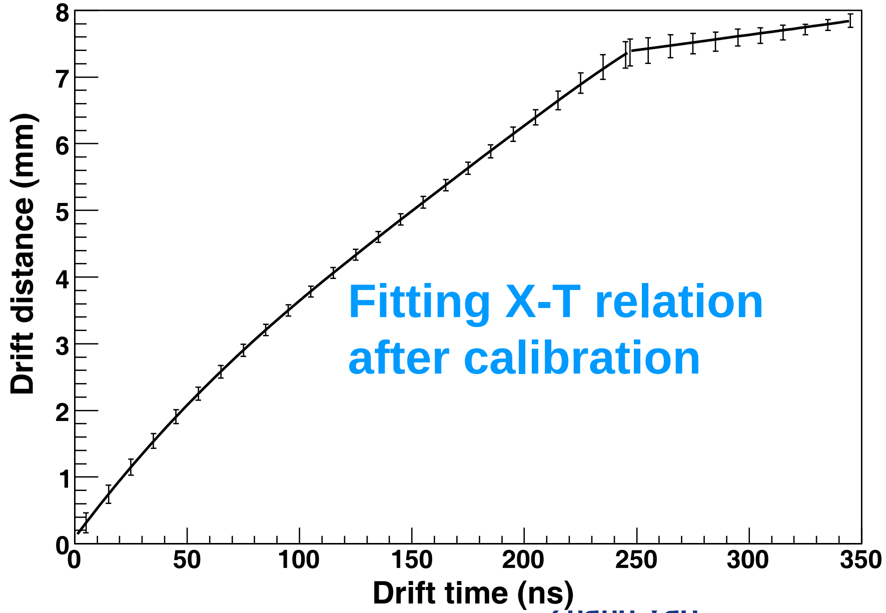
Smoothing: estimate of "past" state vector based on all measurement up to "present"

Preliminary results with data of cosmic ray test



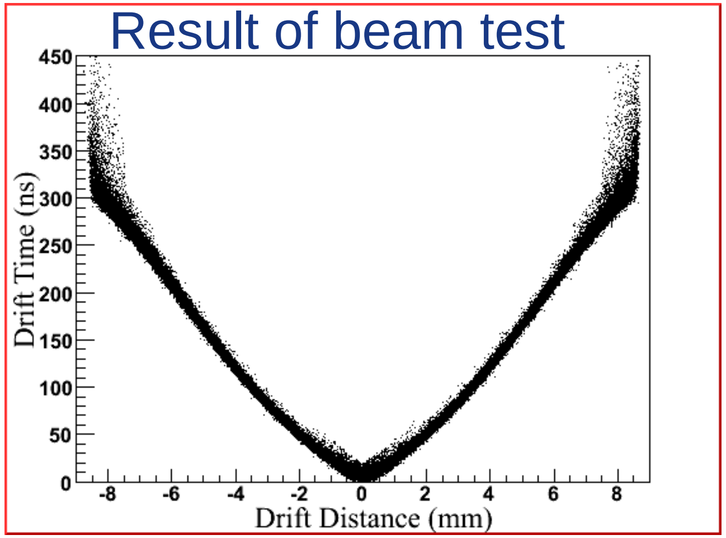






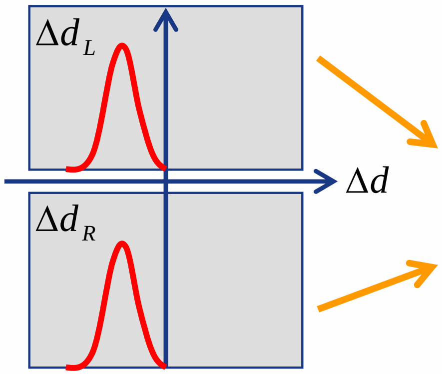
X-T and T0 calibration

- **X-T relation**: The relation between the drift time and the distance from the sense wire to the track



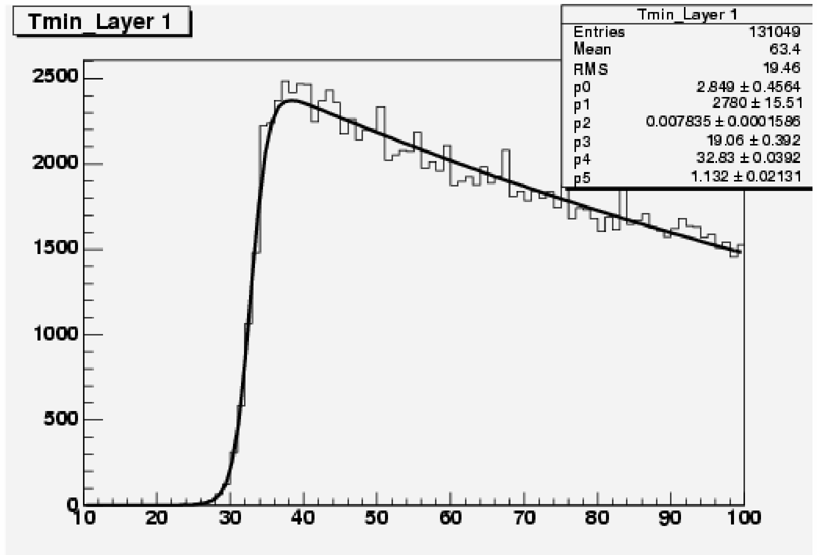
- fitted to a 5th order polynomial (in the linear region) plus 1st order polynomial (near the edge regions)
- determined layer by layer
- as a function of track incident angle in rΦ plane, for every 10 degrees

- Crude T0 is from leading edge of the time distribution
- Wire by wire T0 calibration



residual

$$T0^{new} = T0^{old} + \frac{\Delta d_R + \Delta d_L}{2v}$$



Drift Time (ns)