MEG実験アップグレードに向けた Radial TPCの研究

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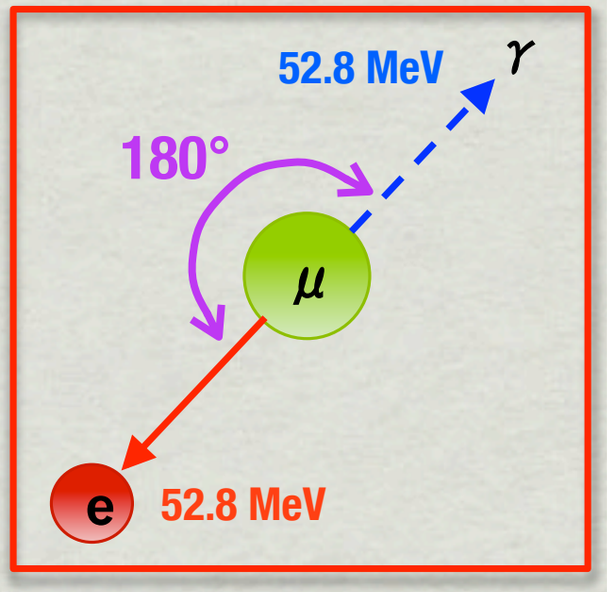
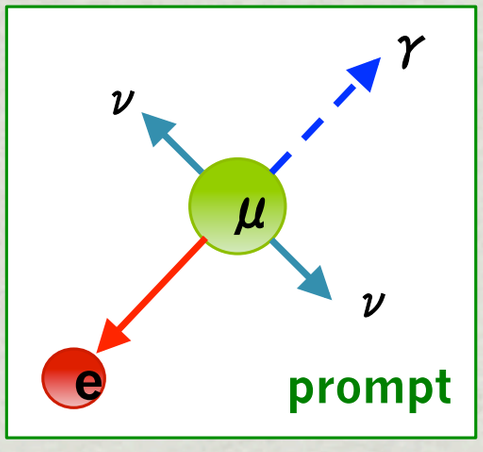
Outline

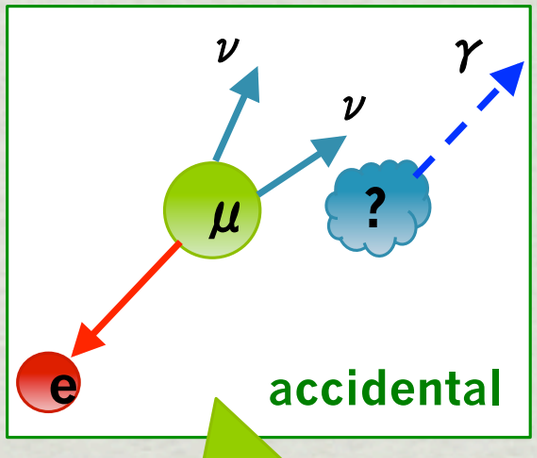
- MEG experiment
- Upgrade plan
- TPC concept
- Simulation study
- Event reconstruction
- Performance evaluation
- Expected sensitivity
- Prototype construction
- Summary

MEG experiment

- Lepton flavor violating decay, μ→eγ is forbidden in the SM
  - But some of models beyond the SM predict visible μ→eγ in the range of 10^{-12}-10^{-15} branching ratio
  - Current upper limit : $\mathcal{B}(\mu \to e\gamma) < 2.4\times10^{-12}$ (PRL **107**,171801(2011))
    - **Already in new physics region !**
  - μ→eγ is a good probe to search for new physics
- Background
  - Radiative muon decay (prompt)
  - Michel decay + overlapped γ (accidental)
- Experimental requirements
  - High resolution to suppress accidental background
  - High rate μ beam to get large statistics → DC muon beam @ PSI

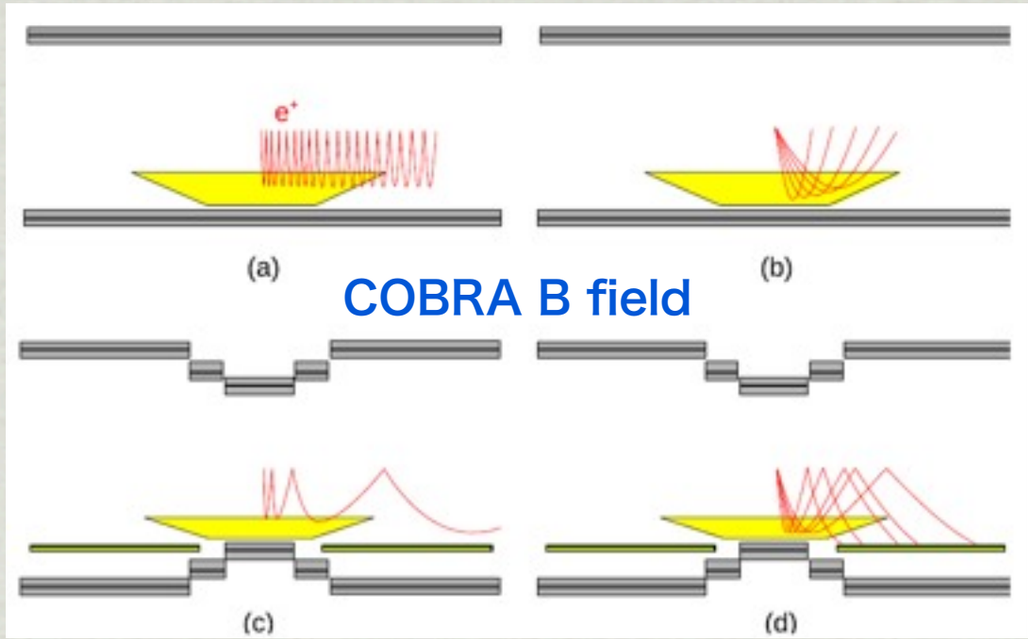


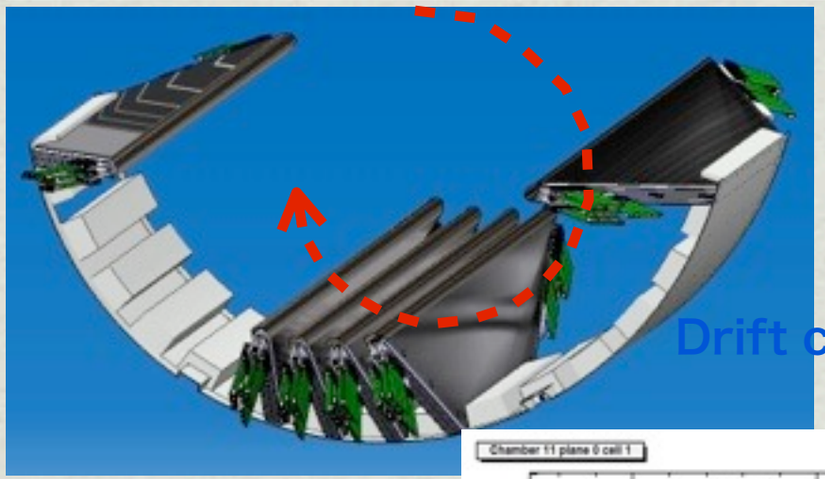


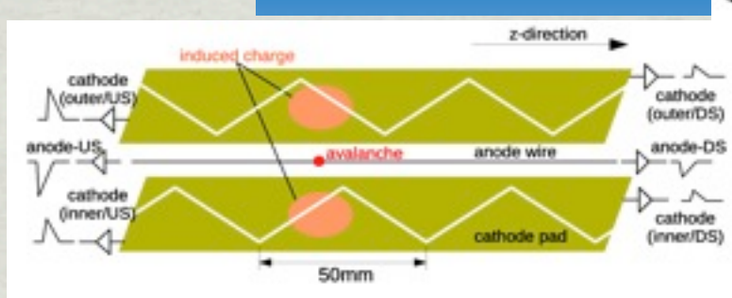


MEG experiment

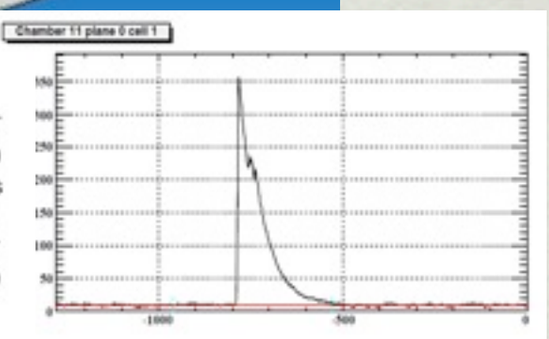
- Xenon calorimeter (D. Kaneko : 12pSH-8)
- Positron spectrometer
  - COBRA (COnstant Bending RAdius) magnet
    - high graded magnetic field optimized for signal e+
  - Drift chamber
    - high resolution tracker with low mass materials
  - Timing counter
    - precise timing measurement for e+







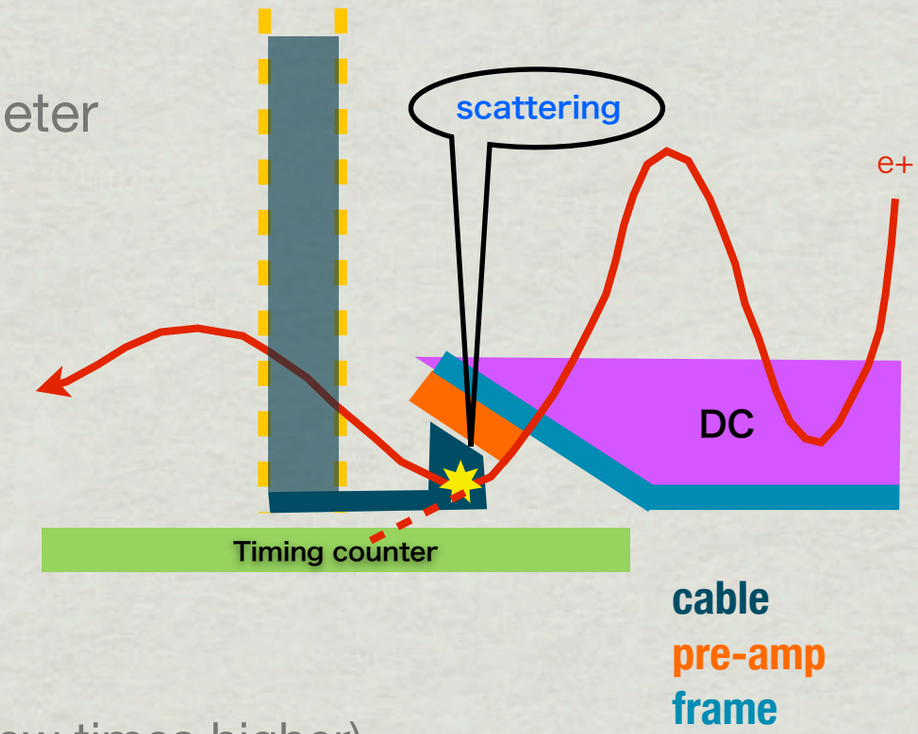
Vernier cathode



Waveform

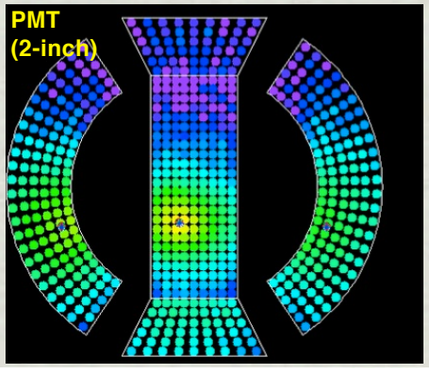
Upgrade plan

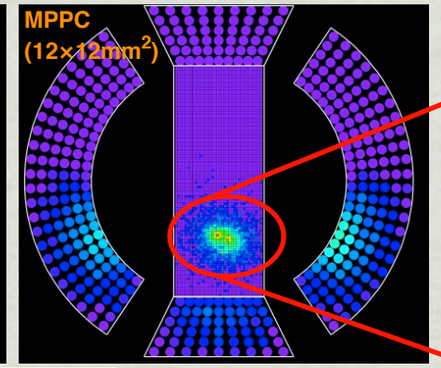
- Physics analysis of 2011 + improved 2009&2010 data is ongoing (Y. Uchiyama : 13aSH-9)
- The data taking of MEG phase-I will finish in 2013
  - Expected final sensitivity : 6×10^{-13}
- Several R&Ds for MEG upgrade plan is ongoing to get better sensitivity
  - Goal sensitivity for the upgrade plan → **~5×10^{-14}**
    - More statistic : Efficiency improvement & Higher rate capability
    - Background reduction : Resolution improvement
- Goal performance for the upgrade of positron spectrometer
  - Efficiency : 40 → **>80** % (twice better)
  - Momentum resolution : 330 → **<165** keV (twice better)
  - Angular resolution : ~10 → **5** mrad (twice better)
  - Vertex resolution : 2(Z)/1(Y) → **<1** mm (twice better)
  - Rate capability : 3×10^{7} → **$(5\text{-}10)\times10^{7}$** (stopping μ)/sec (a few times higher)

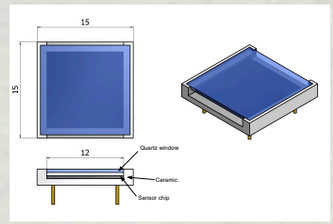


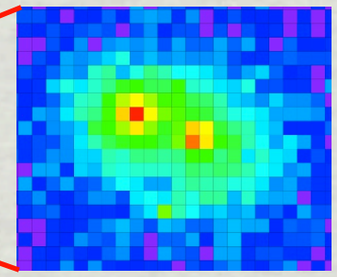
Upgrade plan

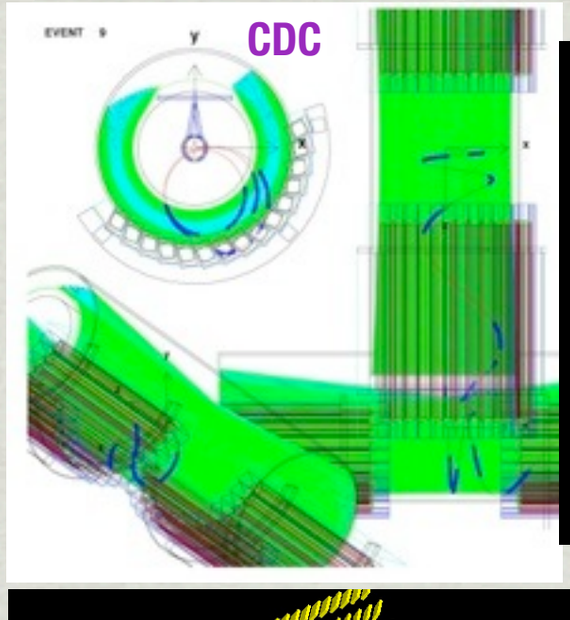
- **Detector upgrade studies**
- Xenon Calorimeter
  - Replace inner face photo sensors to smaller one (R. Sawada : 12pSH-7)
- Positron Spectrometer
  - Keep the COBRA magnet
  - Higher Efficiency, better resolution tracker
    - Stereo wire cylindrical drift chamber (CDC)
    - **Radial projection TPC (RTPC)**
  - New Timing Counter
    - Pixelated Timing Counter w/ MPPC (M. Nishimura : 14pSK-4)
- Overview (T. Iwamoto : 14aSK-6)

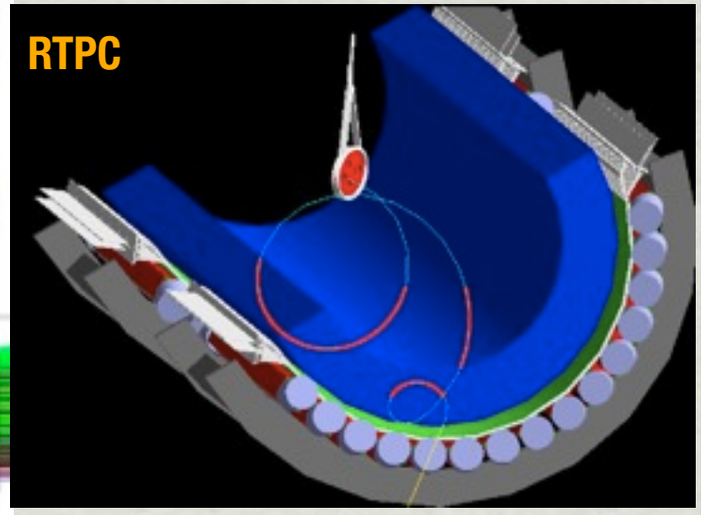


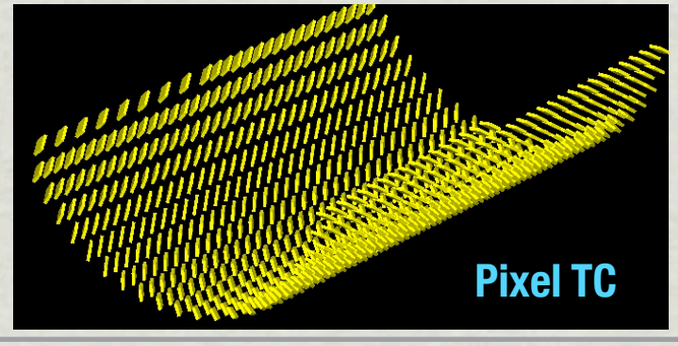


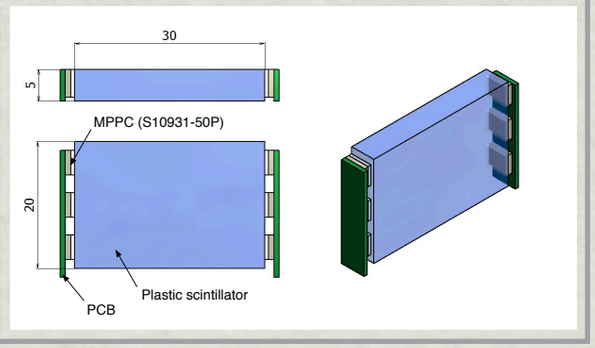












Upgrade plan

- **Detector upgrade studies**
- Xenon Calorimeter
  - Replace inner face photo sensors to smaller
  - 2inch(Hamamatsu R12699-01)
- Positron Spectrometer
  - Keep the COBRA magnet
  - Higher Efficiency, better resolution tracker
    - Stereo wire cylindrical drift chamber (CDC)
    - **Radial projection TPC (RTPC)**
  - New Timing Counter
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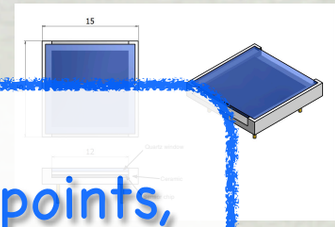
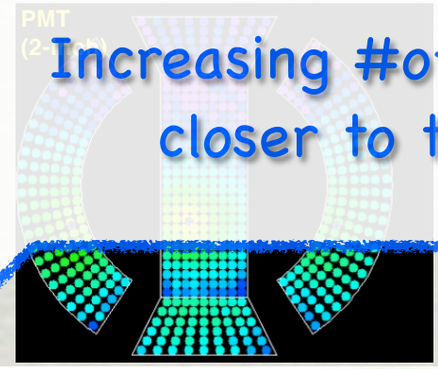
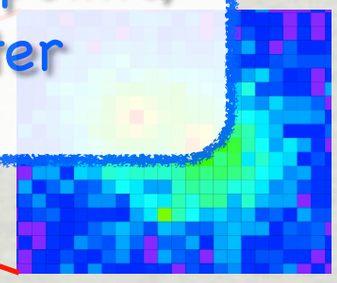
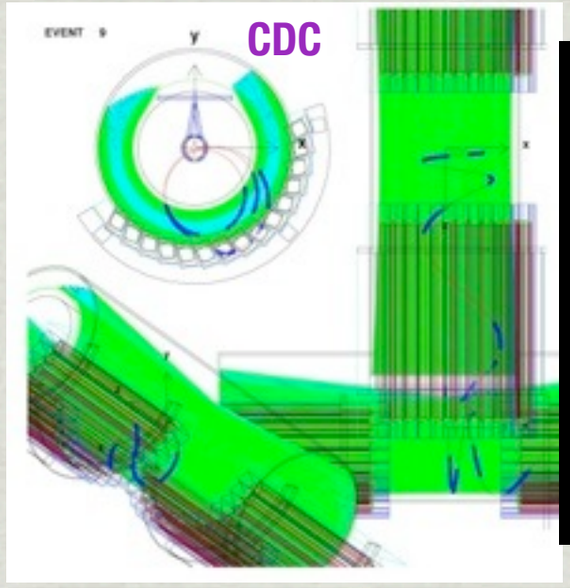
Large coverage & Less materials between Tracker and Timing counter

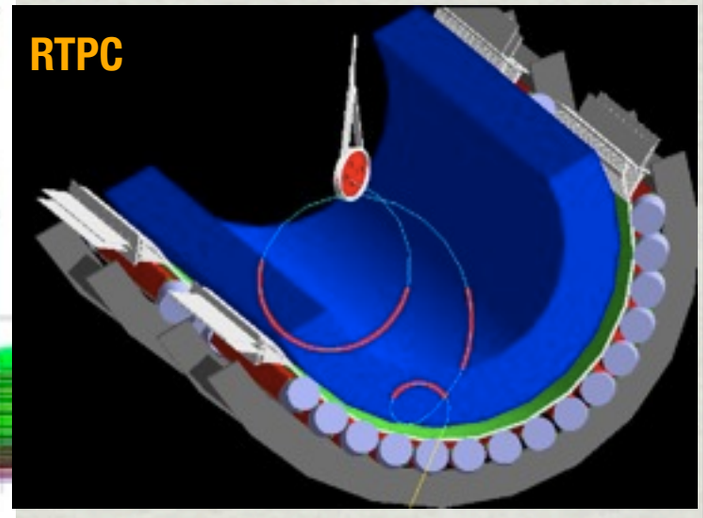
Increasing #of measurement points, closer to the Timing counter

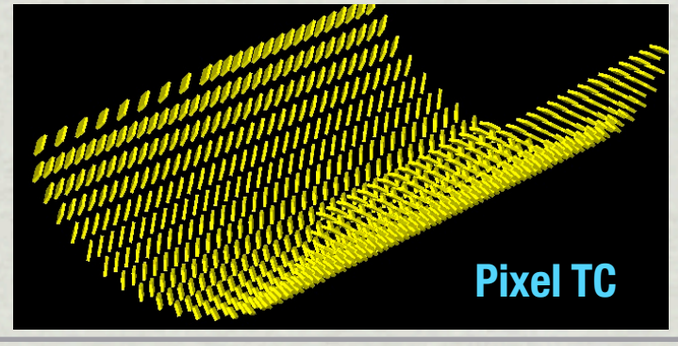


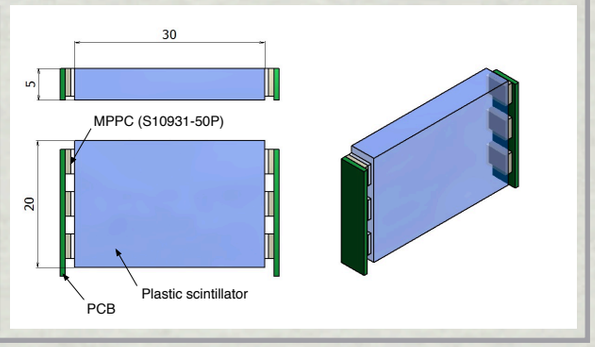












Upgrade plan

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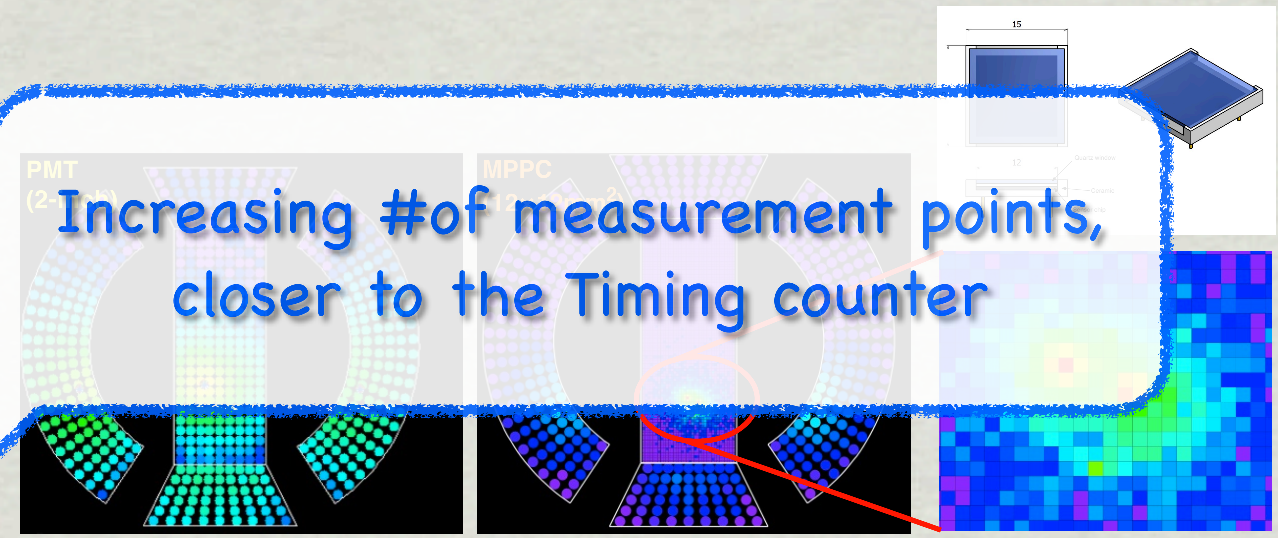
- Xenon Calorimeter
  - Replace inner face photo sensors to smaller ones (K. Sawada PI2pSH-7)
- Positron Spectrometer
  - Keep the COBRA magnet
  - Higher Efficiency, better resolution tracker
    - Stereo wire cylindrical drift chamber (CDC)
    - Radial ... TPC (RTPC)
  - New Timing Counter
    - Pixelated Timing Counter w/ MPPC (M. Nishimura P4pSK-4)

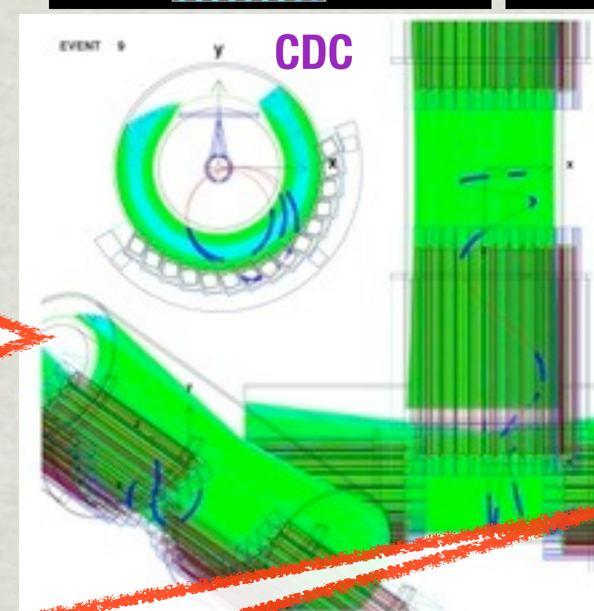
Large coverage & Less materials between Tracker and Timing counter

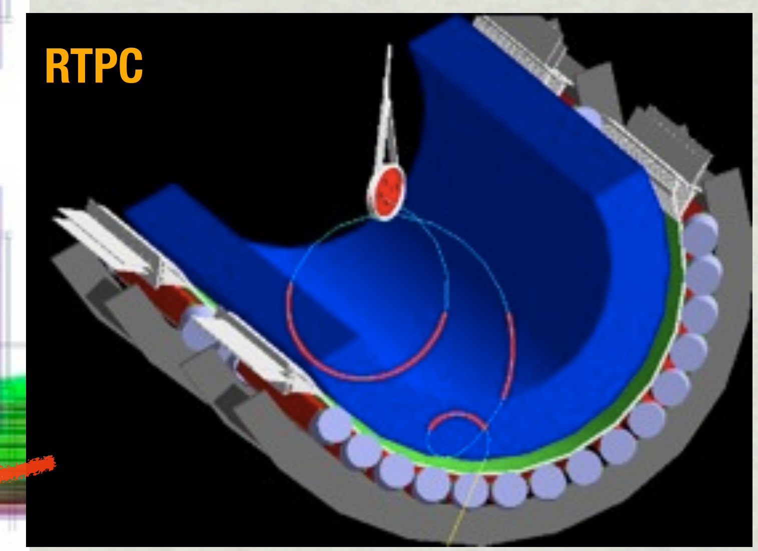
Increasing #of measurement points, closer to the Timing counter

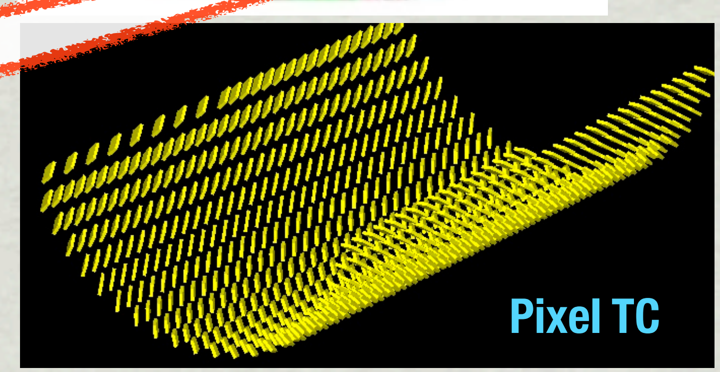
1. Well known technology
2. Less #of channels than the TPC
3. Rate capability (<7x10[7])

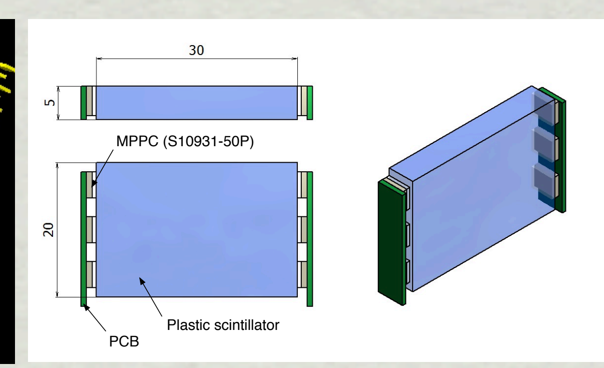
1. More challenging (interesting)
2. High Rate may not be issue
3. No wires in the tracking region





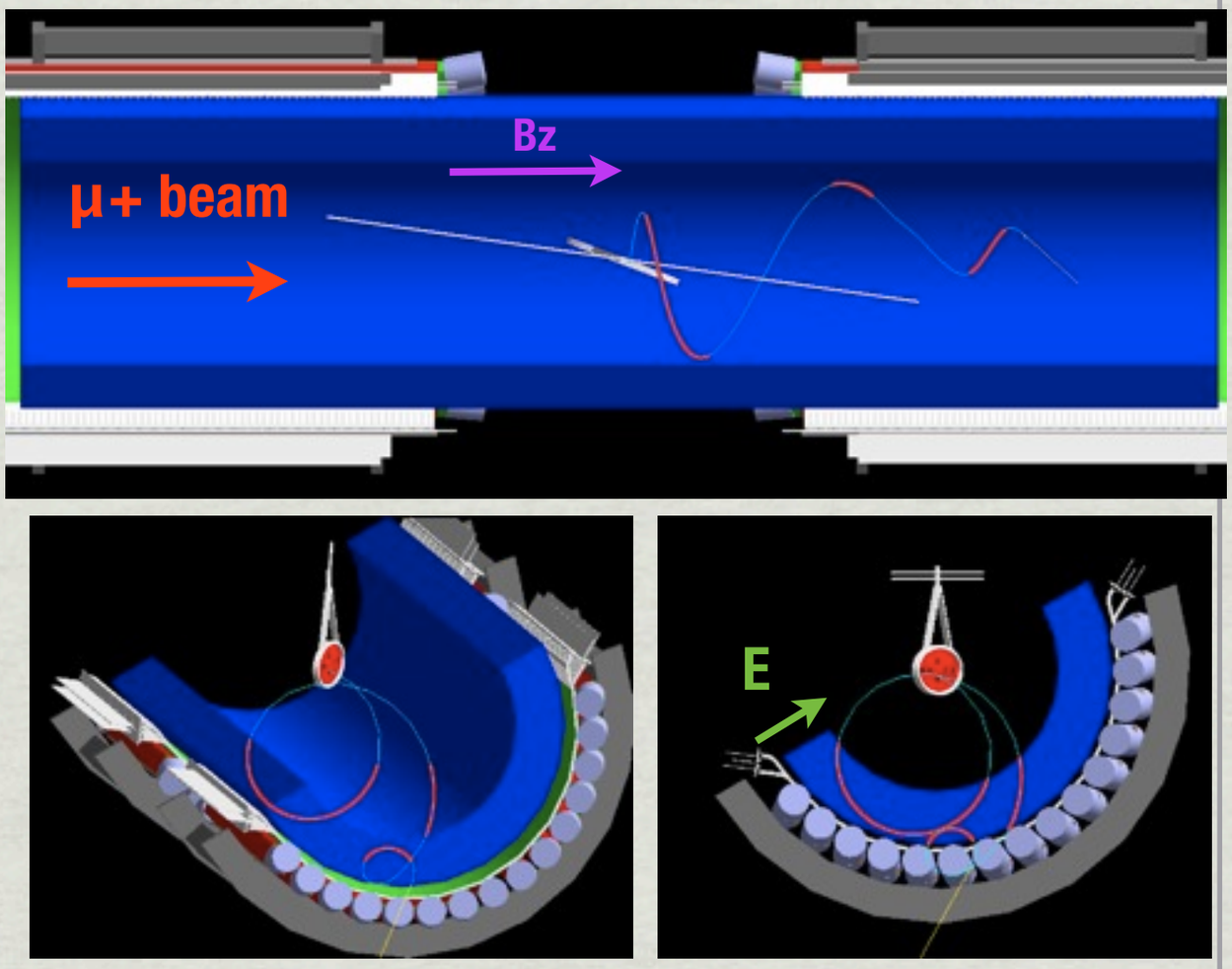




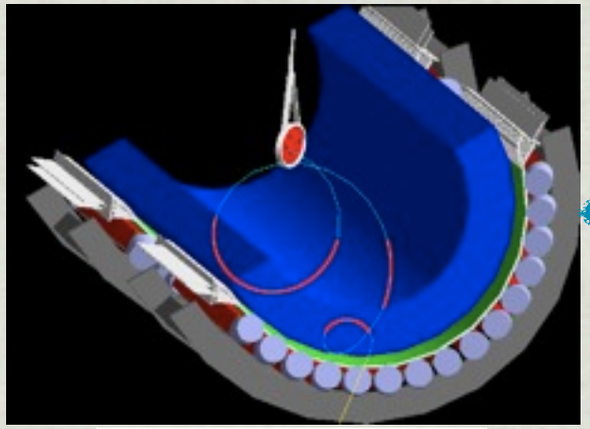


TPC concept

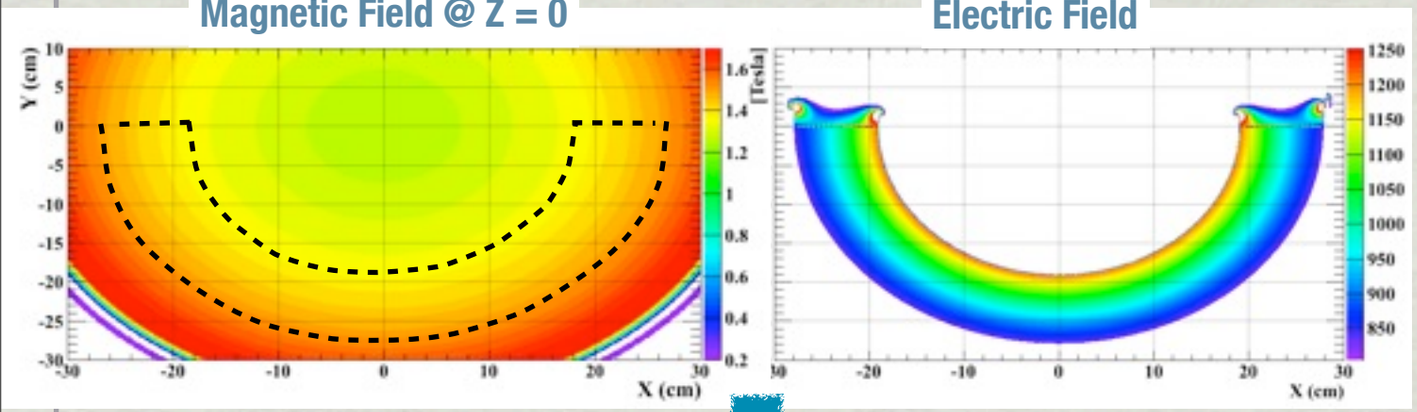
- Unique gas volume / Wider coverage
  - Reduce the resolution degradation from Multiple Scattering and AIF background as well
  - Larger sensitive region
  - Improve the efficiency
  - Increase #of measurement points
- High granularity
  - Increase #of measurement points
  - Good separation power for pileup e+
- Radial E field
  - Shorter drift distance than in longitudinal E field
    - Smaller diffusion effect and shorter drift time
  - Electron will be amplified by multi-layered GEMs @ R_{Max}
    - Wide and curved GEMs are required ← 1 of the most challenging part !

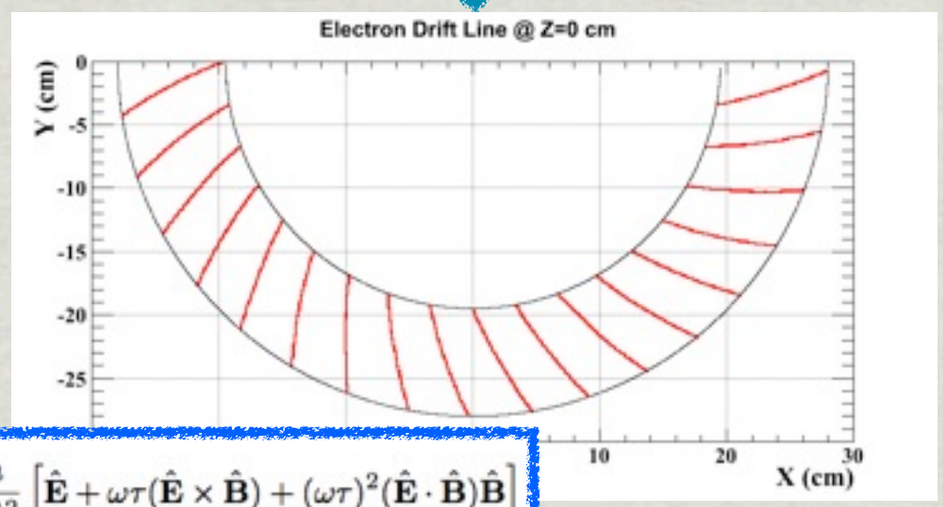


Simulation study



Geant4 simulation of signal e+ w/ TPC





$$\mathbf{u} = \frac{eE\tau/m}{1+(\omega\tau)^2}\left[\hat{\mathbf{E}} + \omega\tau(\hat{\mathbf{E}}\times\hat{\mathbf{B}}) + (\omega\tau)^2(\hat{\mathbf{E}}\cdot\hat{\mathbf{B}})\hat{\mathbf{B}}\right]$$

- There are 2 main simulation part
  - Event generation, Detector simulation and physics processes
    - Done by Geant4
  - Gas simulation
    - Drift part of ionized electron
      - E field is calculated by ANSYS (FEA)
      - Drift line of ionized electron is bent by magnetic field
        - 3D TXY table can be generated w/ Garfield++
    - Gas amplification
      - To be calculated w/ Garfield++

Simulation study

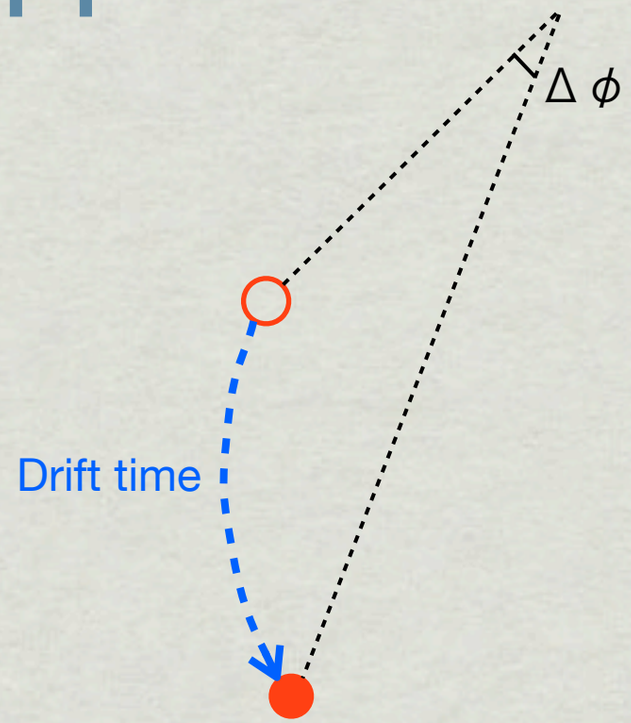
- Purpose of the simulation study
  - To optimize base of TPC design and determine candidates of gas mixture
  - To generate simulation event and evaluate the performance of TPC
- Current settings
  - Muon target : 205 → **140** μm (to reduce the scattering effect in the target)
  - Gas mixture
    - He:CO2:C2H6 = 70:10:20
  - Strength of E field
    - 800-1300 V/cm
  - TPC design detail

@ 1kV	Radiation Length	D_T/D_L um/√cm	v_D cm/us	Np /cm
He:CO2=70:30	0.09% X0	120/130	1.9	15
He:C2H6=70:30	0.07% X0	215/146	3.0	22
He:C2H6=50:50	0.10% X0	195/133	3.5	45

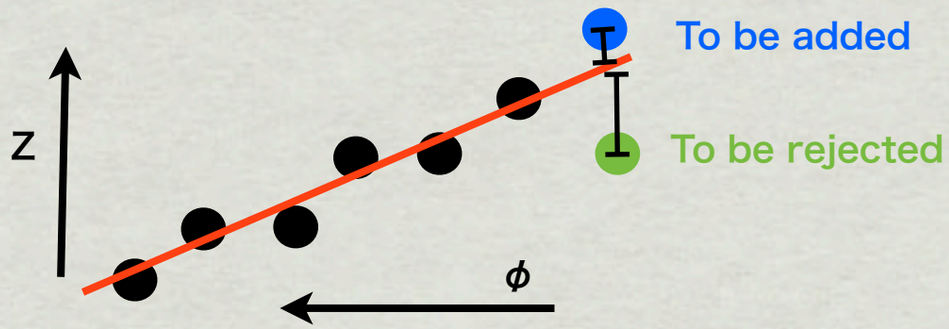
Rmin	Rmax	Z coverage	φ coverage	wall thickness	anode	cathode	Gas amplification
195 mm	280 mm	[-1000, 1000] mm	[-150, 30] °	40 μm Mylar	1 μm Copper	5 μm Copper	50 μm GEM ×3

Event reconstruction

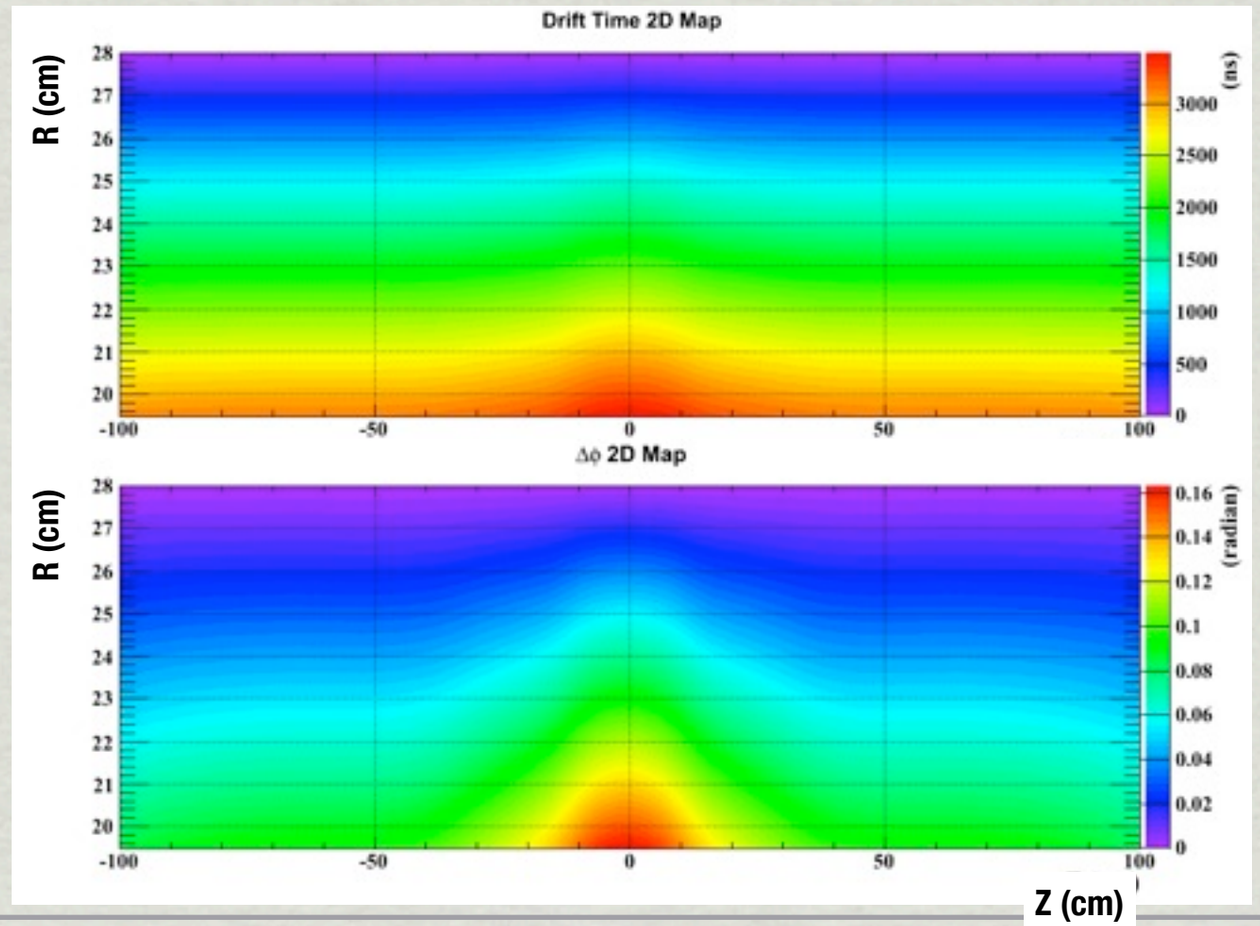
- Hit reconstruction
  - 3D TXY table is generated by Garfield++ simulation for the 1st study
  - Necessary items
    - Drift Time, Δϕ, Δz, Diffusion parameters
  - Hit position can be reconstructed from these parameters



- Track finding
  - Local pattern recognition

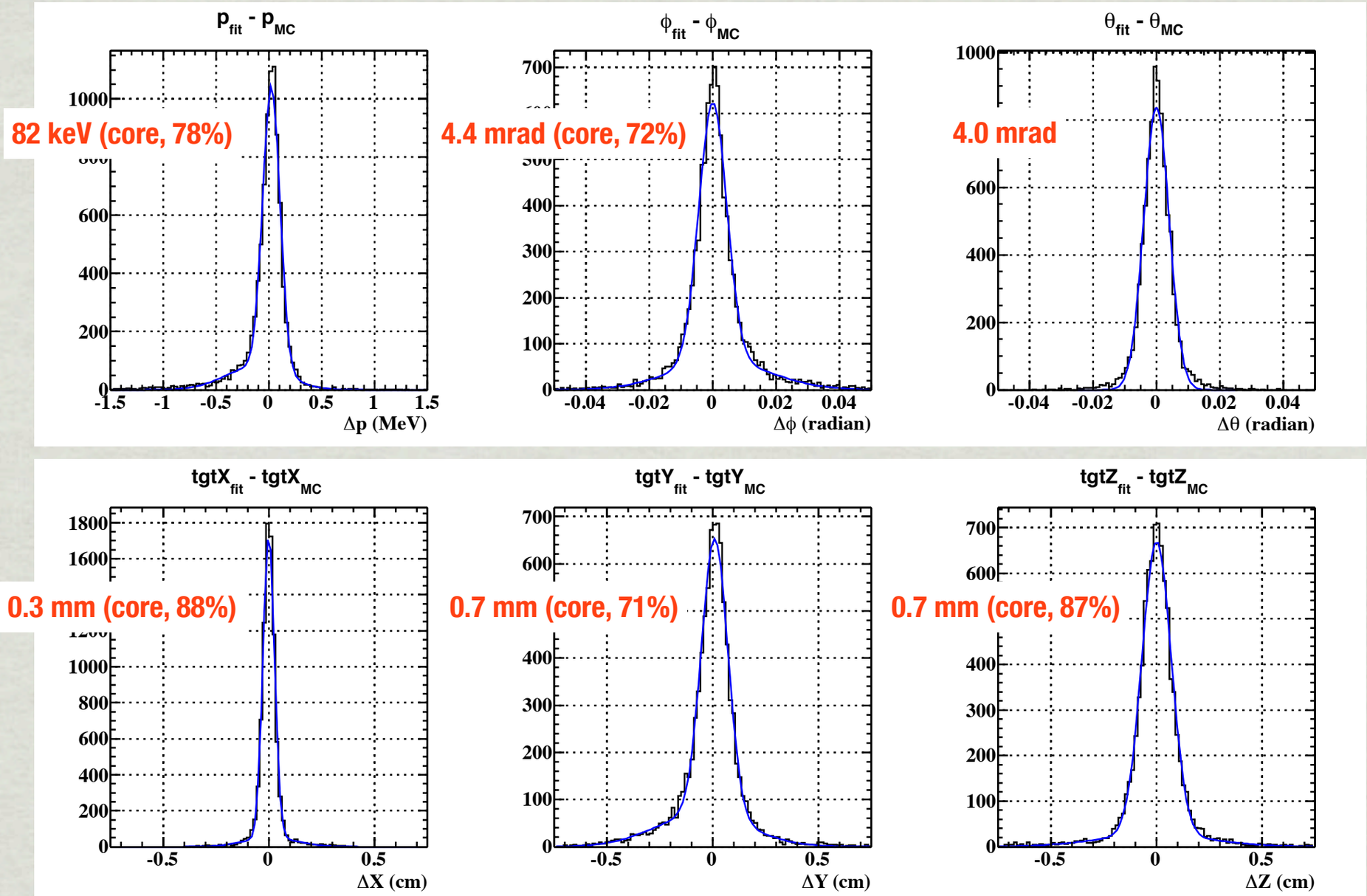


- Track fitting
  - Kalman filter



Performance evaluation

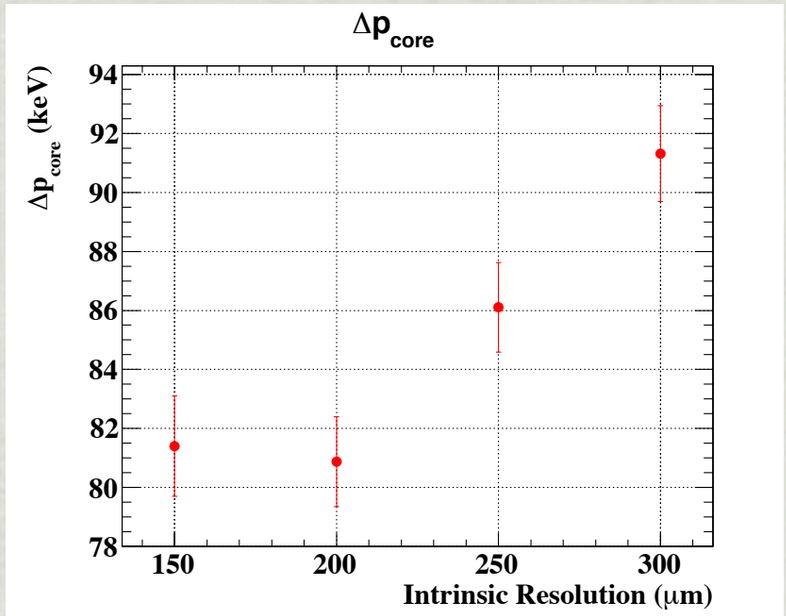
- Hit reconstruction is not implemented yet → MC true hits smeared by Garfield calculation
- Momentum & Angular resolutions (e.g. intrinsic position resolution ~ 150μm for Z & R)

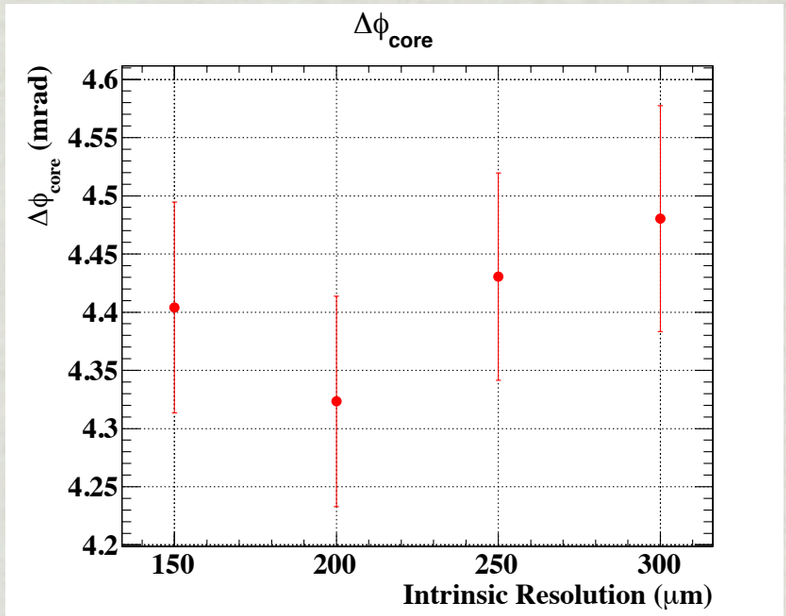


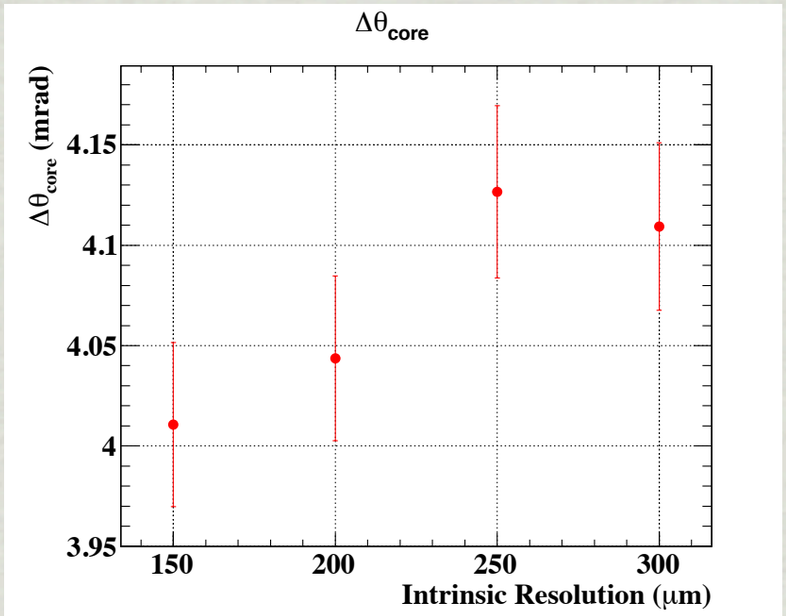
- Vertex
- Very good resolutions !

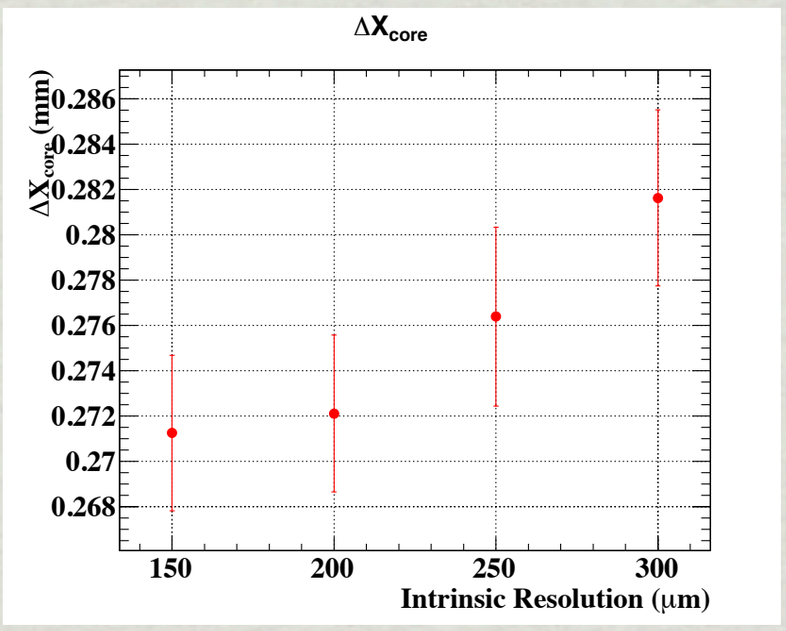
Performance evaluation

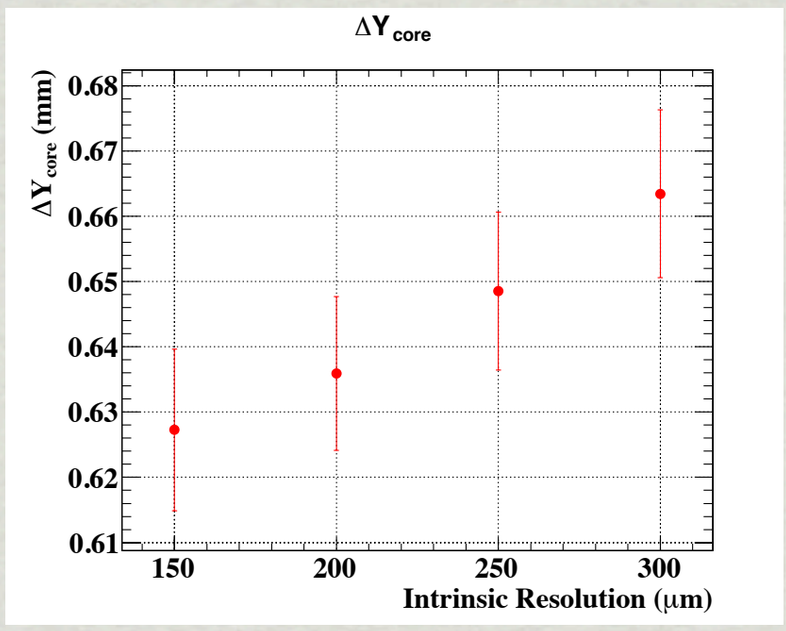
- Resolutions are depend on intrinsic resolution, and enough good even @ $\sigma_{int}^{R,Z}$ = 300μm

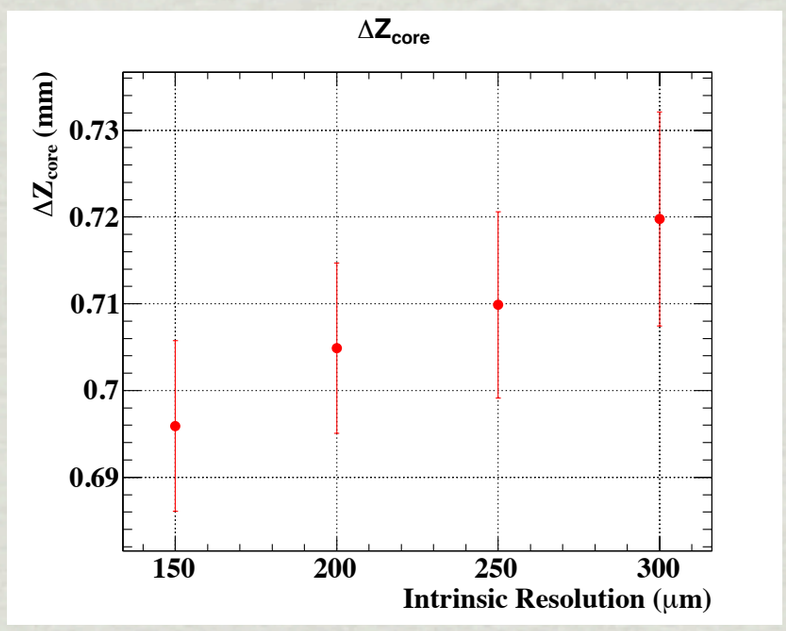










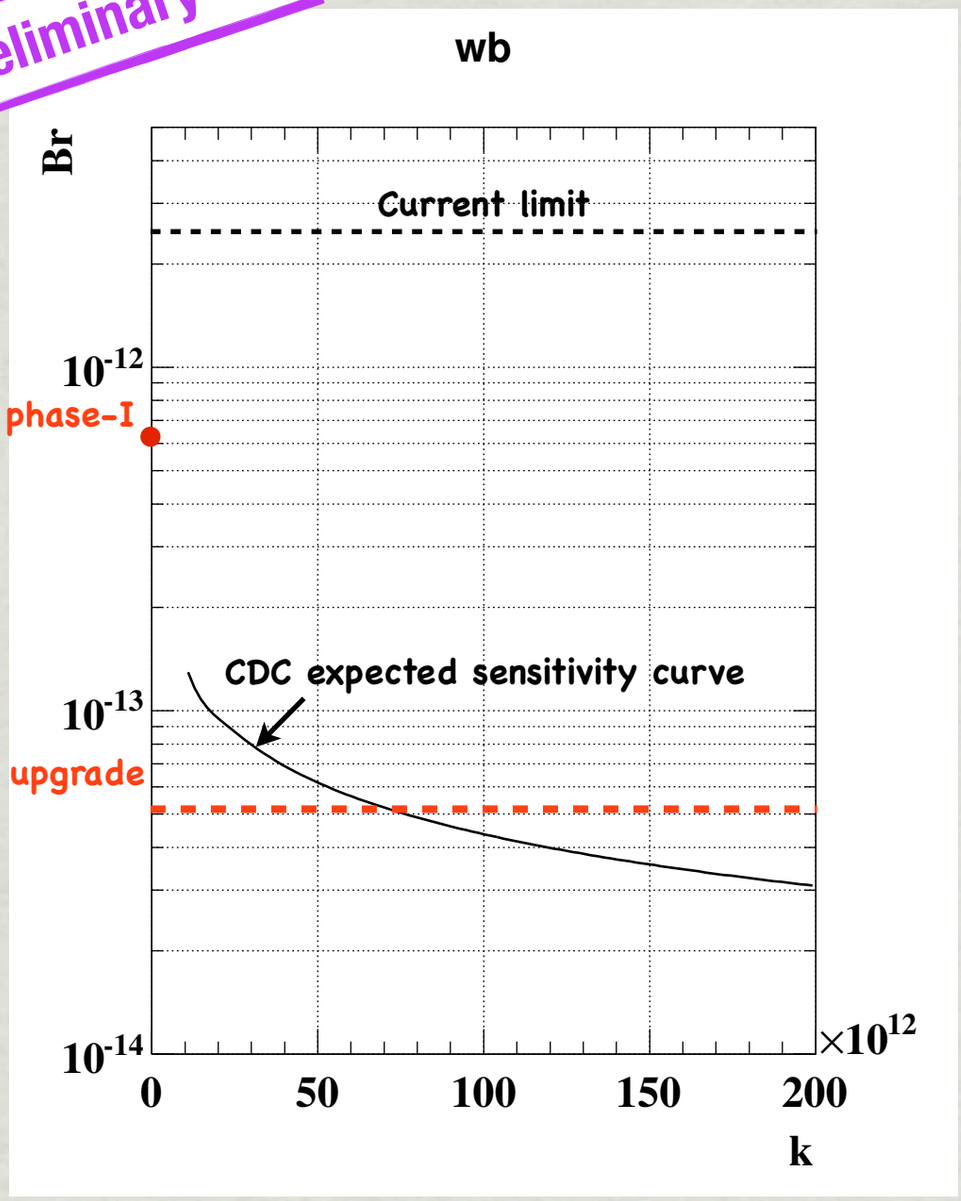


- $\varepsilon_{(good\ track\ +\ analysis\ cut)}$ ~ 90% (not including $\varepsilon_{TPC\text{-}TC}$, not optimized perfectly)

Expected sensitivity

- Current goal sensitivity, ~5×10^{-14} is based on...
  - 5.5×10^{7} μ/sec, 3 years data taking → $k=7.7\times10^{13}$
  - CDC + 140μm thickness target
    - Δpe+ : 330 → **110** keV
    - Δϕ/θ : 10 → **5/5** mrad
    - Vertex : 1-2 → **1** mm
    - εe+ : 40 → **85** %
    - per event error
  - XEC + MPPC, New Timing Counter
- The RTPC can realize better performance than the CDC
  - Δpe+ : 330 → **85** keV
  - Δϕ/θ : 10 → **4.5/4** mrad
  - Vertex : 1-2 → **0.7** mm
  - εe+ : 40 → **~80** % (assumption)
  - how about the sensitivity ? → better sensitivity was expected, but...

Preliminary



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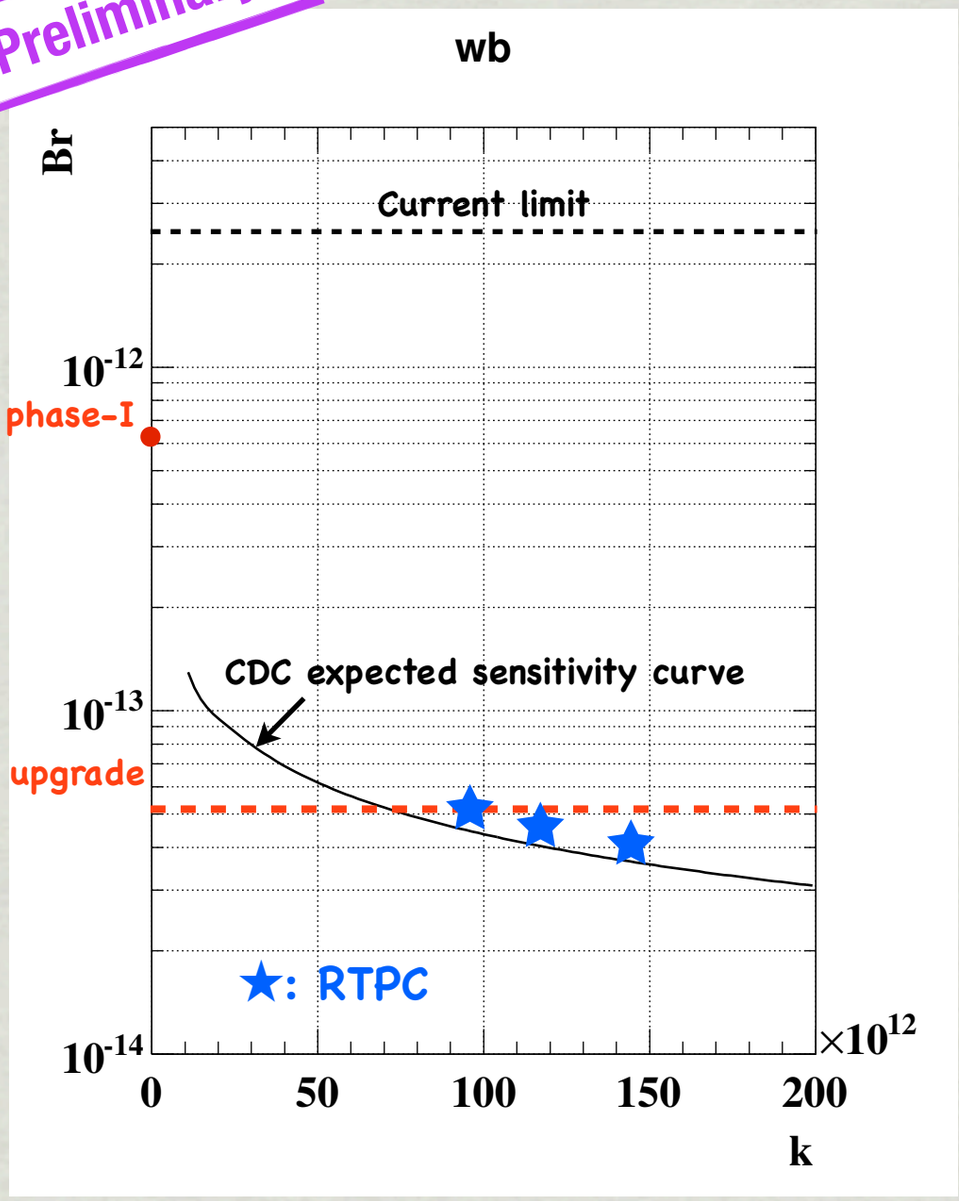
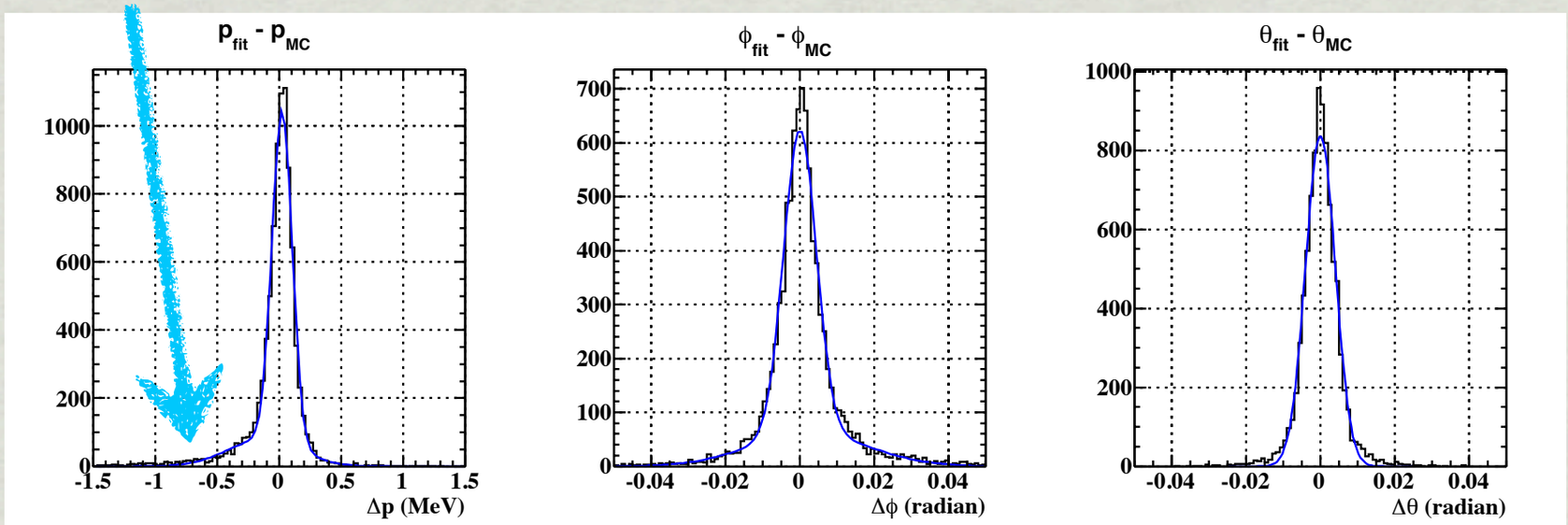
  - εe+ : 40 → **~80** % (assumption)
  - Goal sensitivity can be achievable, not so different from the CDC case → why ?

Very Preliminary

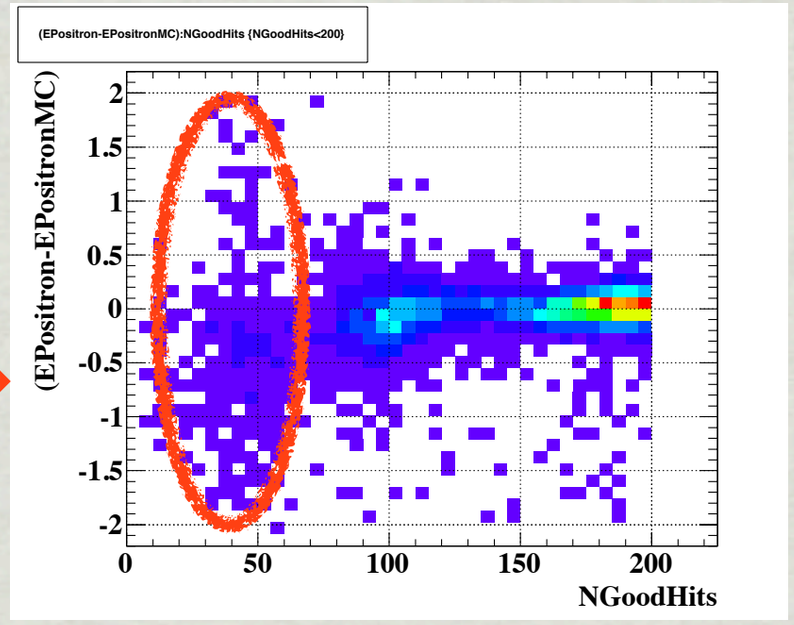


Whats worsen sensitivity ?

- In the RTPC case, overall resolution shape is used for the sensitivity calculation
  - “Per event error” is used for the CDC case → probably more sensitive way
- Here is an asymmetric large tail → it should worsen the sensitivity



Less #of hits region ! →



#of hits should be used for the event selection !

Whats worsen sensitivity ?

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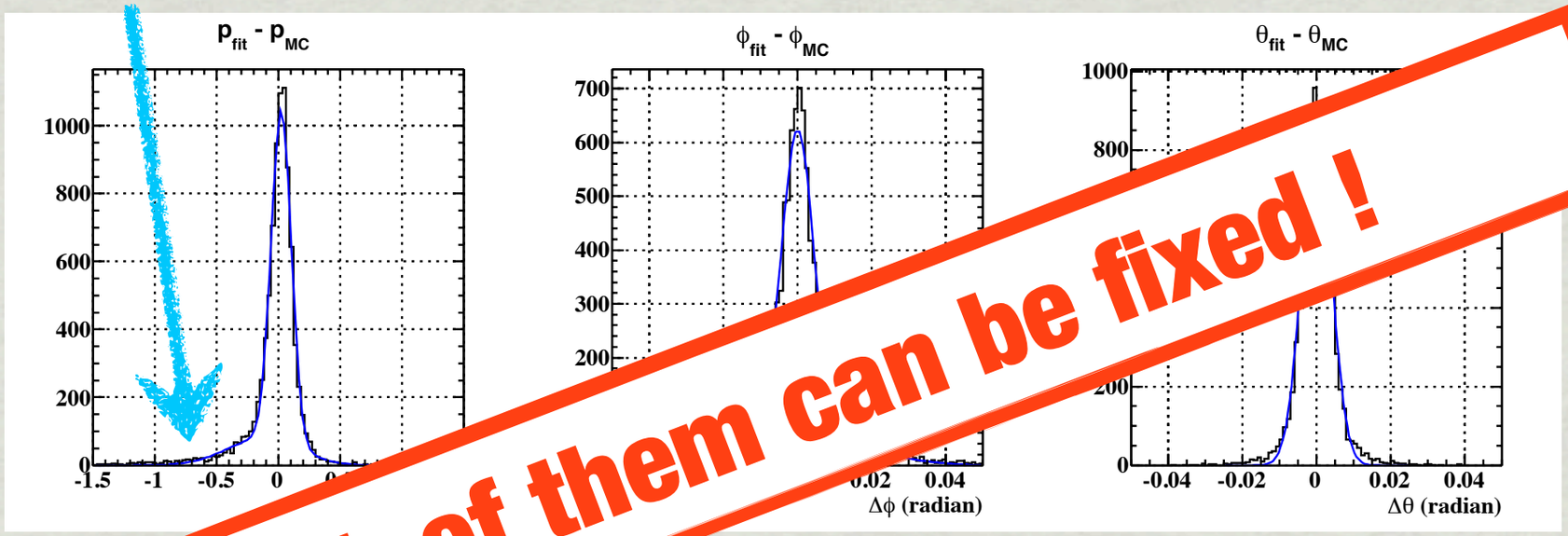
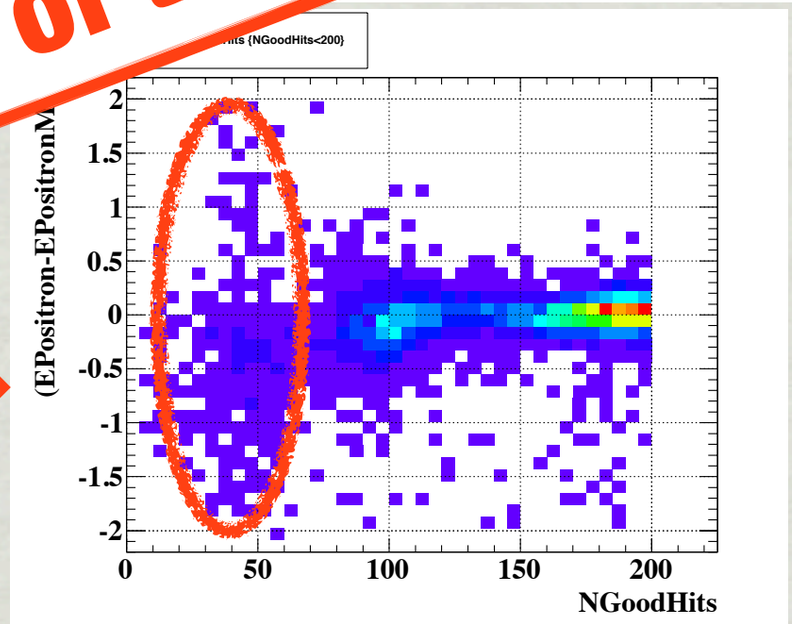


Both of them can be fixed !



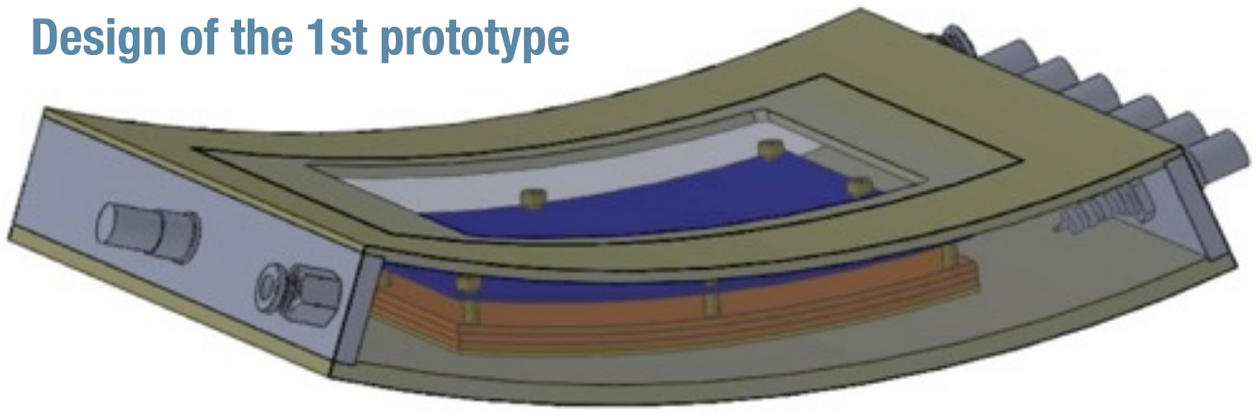
Less #of hits region ! →

#of hits should be used for the event selection !

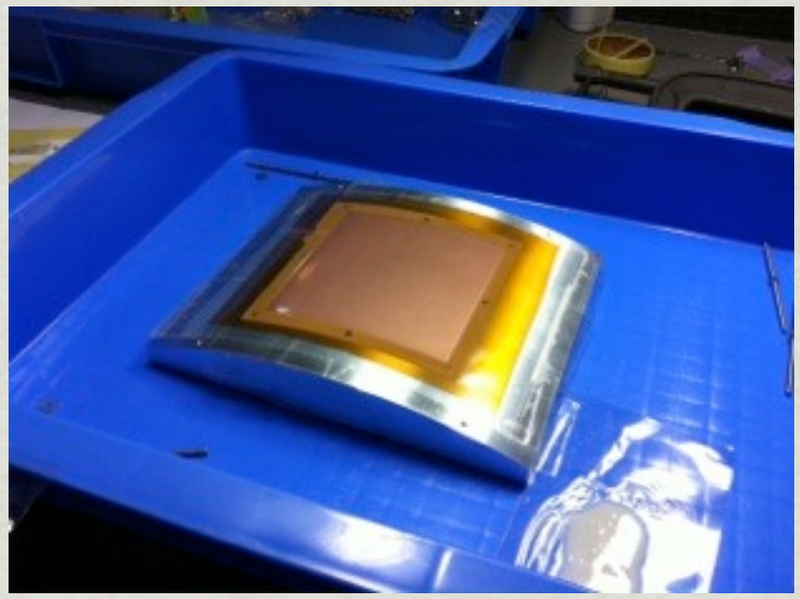
Prototype construction

- The prototype study is one of the most important things for development
  - 1st prototype construction is already started
  - Aims for 1st prototype
    - To establish the technique to construct such a curved GEM foil in high position accuracy
    - To study how to operate 3-layered curved GEMs
    - To study several gas properties in “Helium based gas mixture”
  - Assembly will be finished in this year
  - Test study to be done after the assembly

Design of the 1st prototype



Bending test for GEM



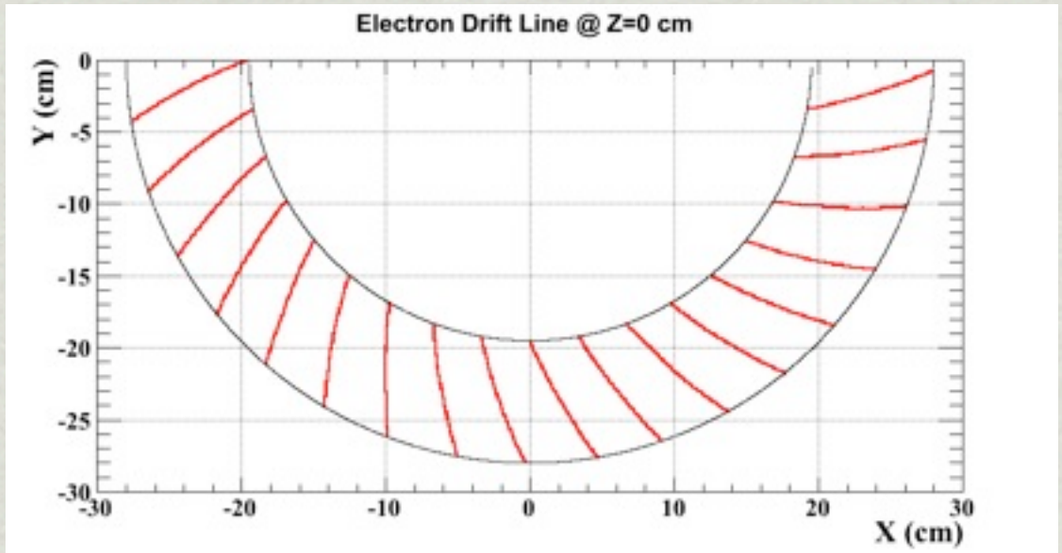
Summary

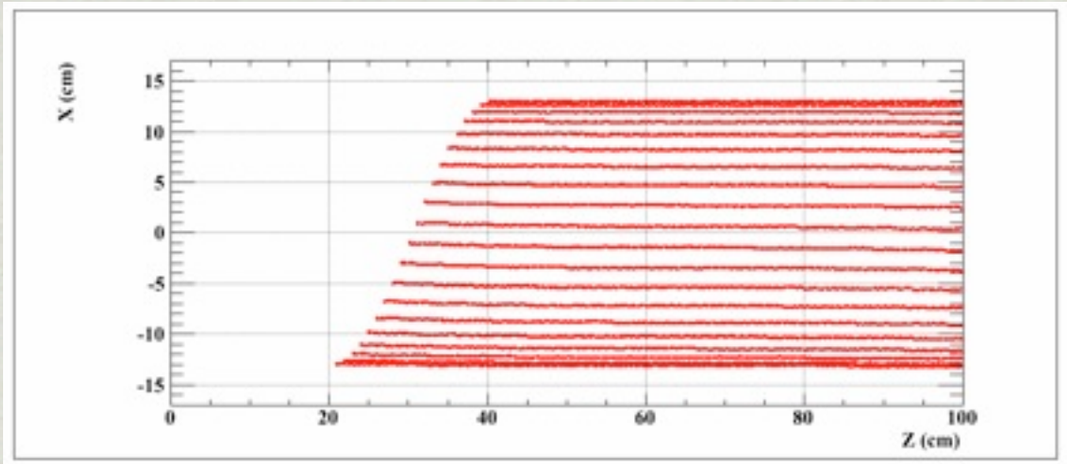
- MEG upgrade studies are started to improve the sensitivity by one order magnitude, ~5×10^{-14}
- RTPC is one of the good alternative option for upgrade MEG tracker
- MC simulation study is progressing to evaluate the realistic performance of RTPC
- Rough performance evaluation was done
  - Slightly better than the CDC and comparable sensitivity for the same stopping μ rate is expected
  - More reasonable event selection and per event error will be applied for the RTPC case
- More realistic simulation and reconstruction algorithm will be implemented
  - e.g. Use TXY table also for the reconstruction, Electronics simulation
- Construction of 1st prototype has been started
  - Assembly will be finished until the end of this year
- Some of test data will be taken with 1st prototype by next March
- Front end electronics and readout scheme should be discussed

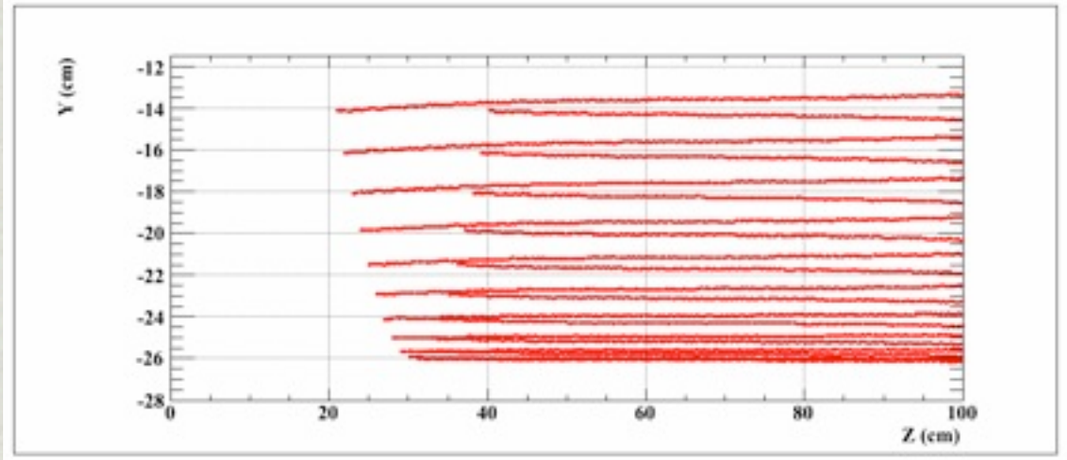
Backup

Why radial ?

- If we choose the RTPC, not only diffusion effect, but also effect from field uncertainty is much smaller than in the longitudinal case
- Uncertainty of B field should be smaller than 0.2%



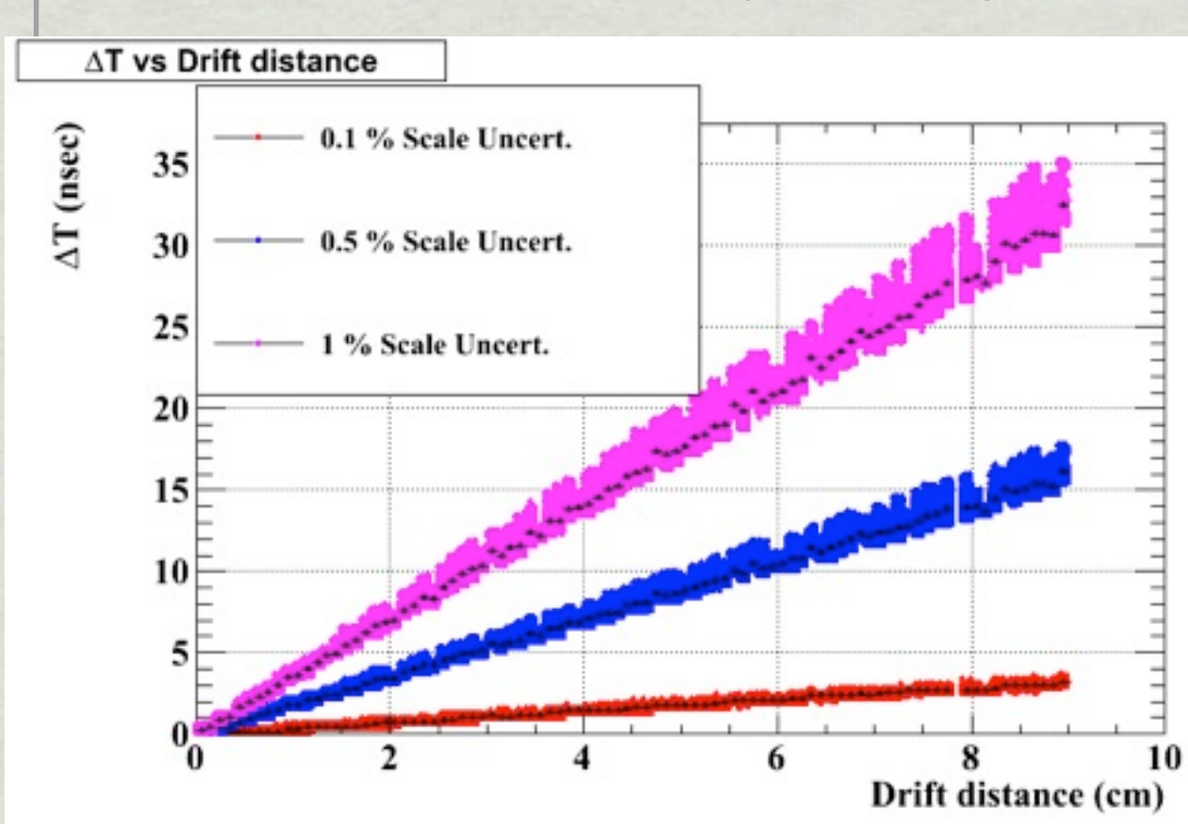


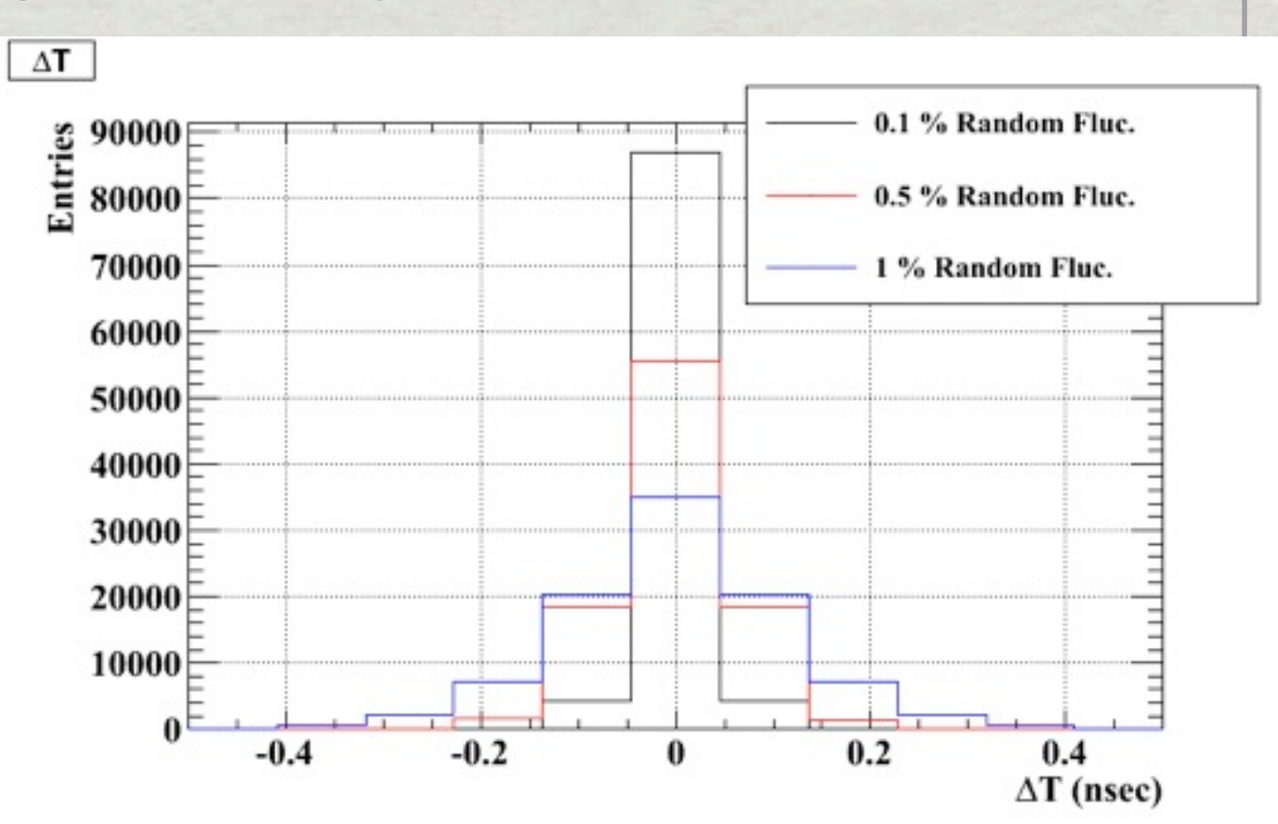


	Radial/Long. shift in X	Radial/Long. shift in Y	Radial/Long. shift in Z	Radial/Long. scale 0.2%
RMS x (um)	4.1 / 19	1.7 / 17	2.7 / 15	5.3 / 5.6
RMS y (um)	3.2 / 18	2.1 / 15	1.7 / 13	3.8 / 21
RMS z (um)	12 / 13	5.4 / 26	7.0 / 33	13 / 29
RMS t (ns)	0.2 / 2.7	<0.1 / 1.9	0.2 / 2.1	0.3 / 3.8

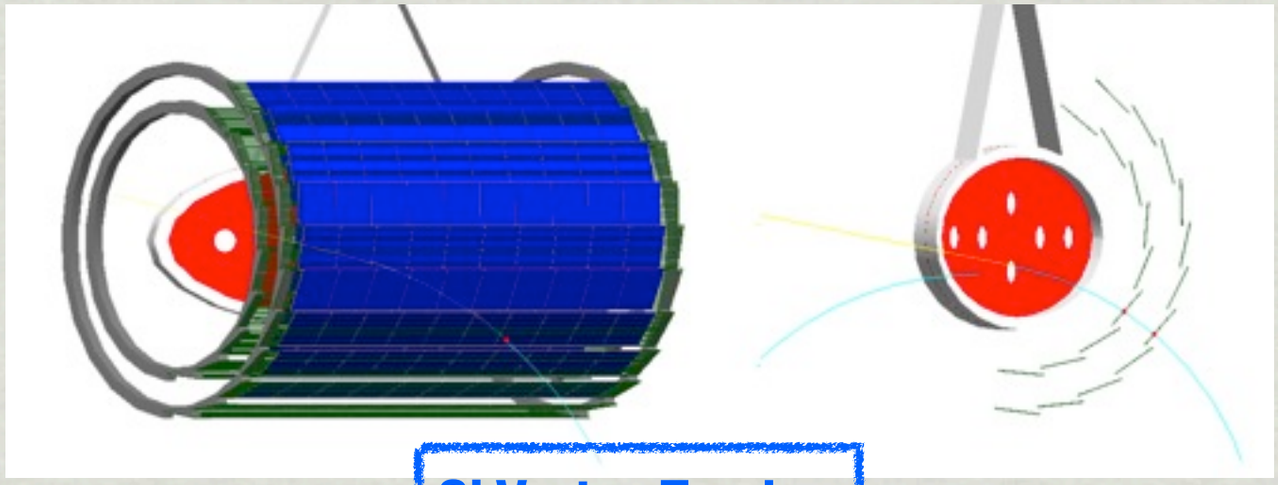
Field accuracy

- Field accuracy requirement for E field is also estimated
  - Random fluctuation may not be the issue
  - On the other hand, we have to handle or calibrate scale uncertainty or position dependent uncertainty better than 0.2% → might be one of the challenging parts
    - → Better accuracy positioning for the detector
    - → Calibration tool (The laser system can be good candidate ?)

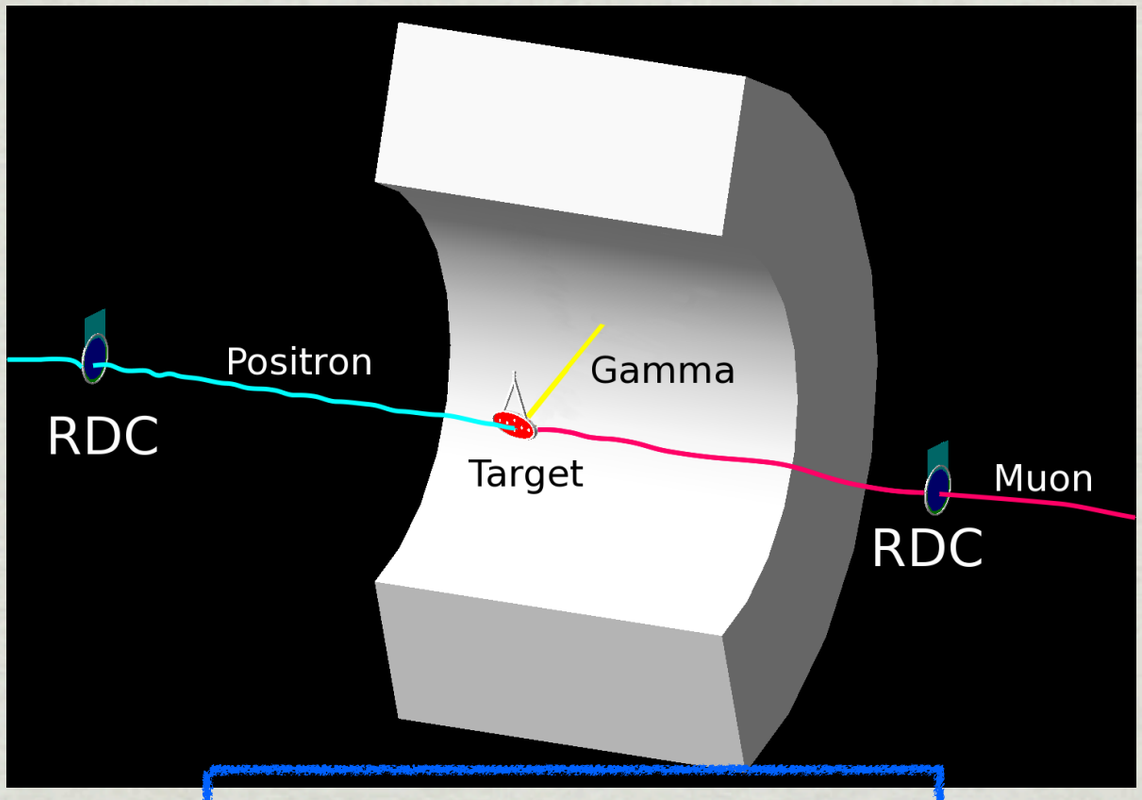




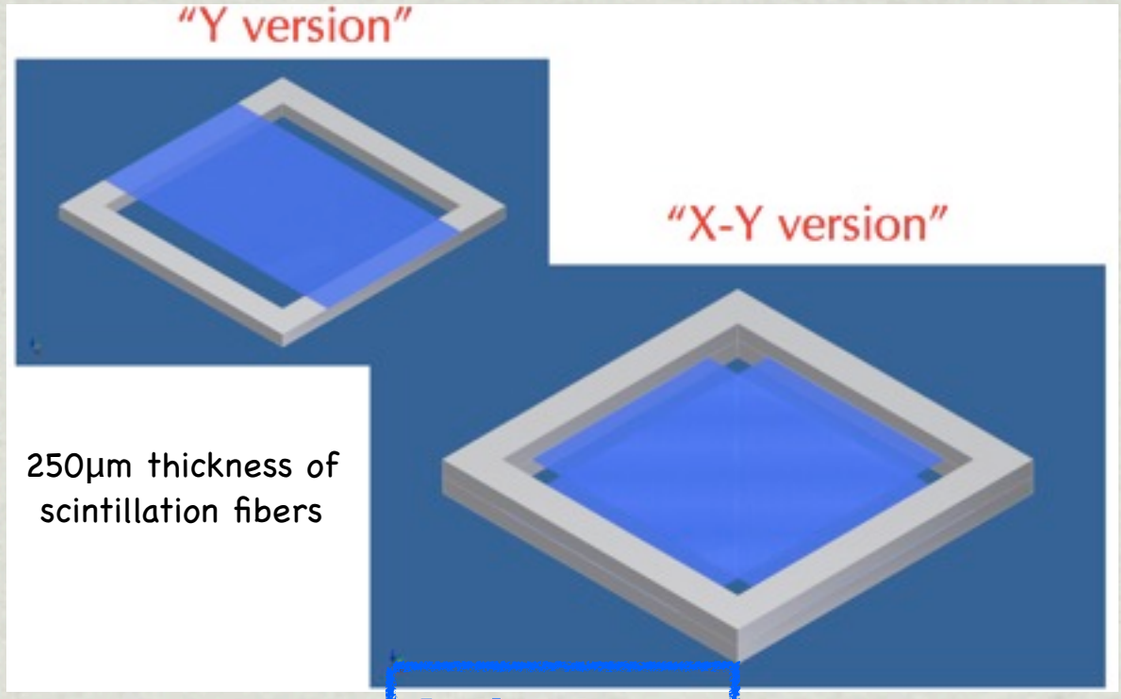
Other upgrade options



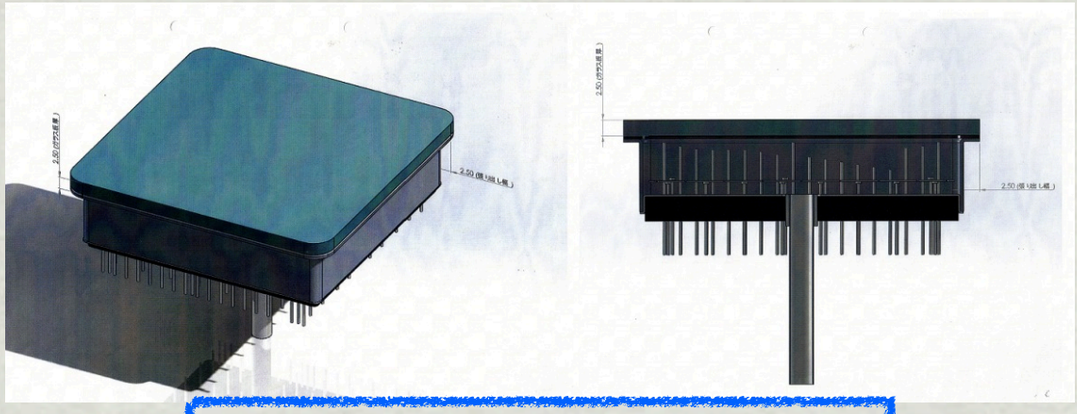
Si Vertex Tracker



Radiative decay veto counter



Active target



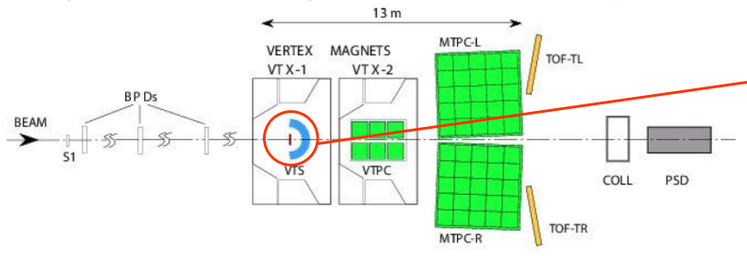
1 inch flat panel PMT for Xe

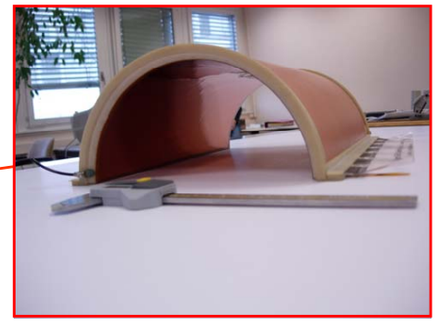
RTPC w/ curved GEM

- There are only a few experiments they are using (or going to use) RTPC w/ curved GEM

Cylindrical GEM for NA49-Future

A possible ''critical'' experiment at the CERN SPS



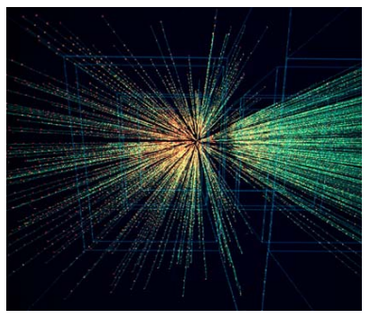


-a precise determination of an event centrality (PSD)

-full acceptance for charged hadrons (VTS)
and limited for identified hadrons (TPCs)

-a high event rate (DAQ)

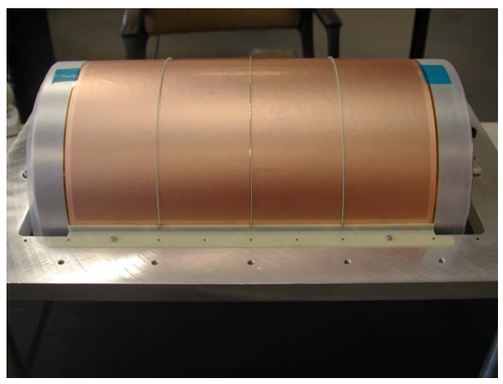
-high precision measurements of inclusive spectra
of identified hadrons (TPCs+TOF)

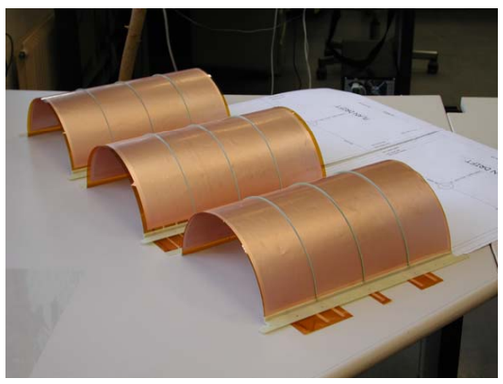


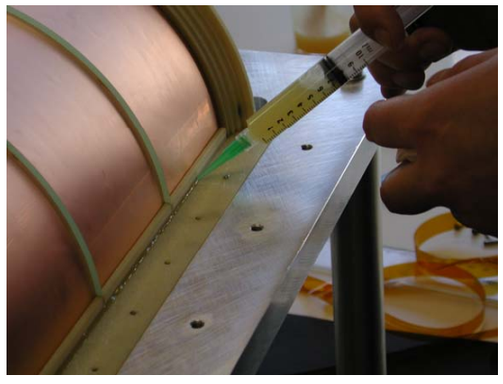
GEM at CERN
Leszek Ropelewski CERN PH-DT2-ST & TOTEM

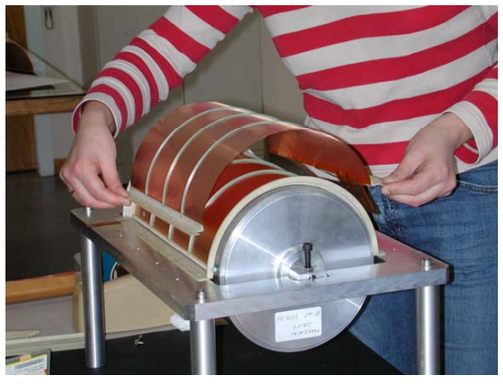
Cylindrical GEM Assembly 2

GEM foils







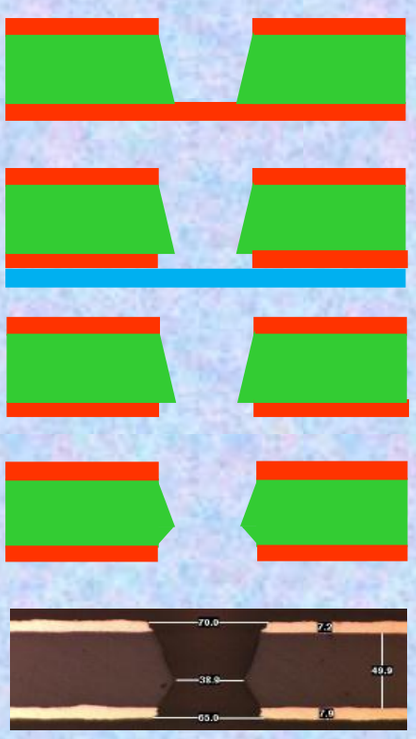


RTPC w/ curved GEM

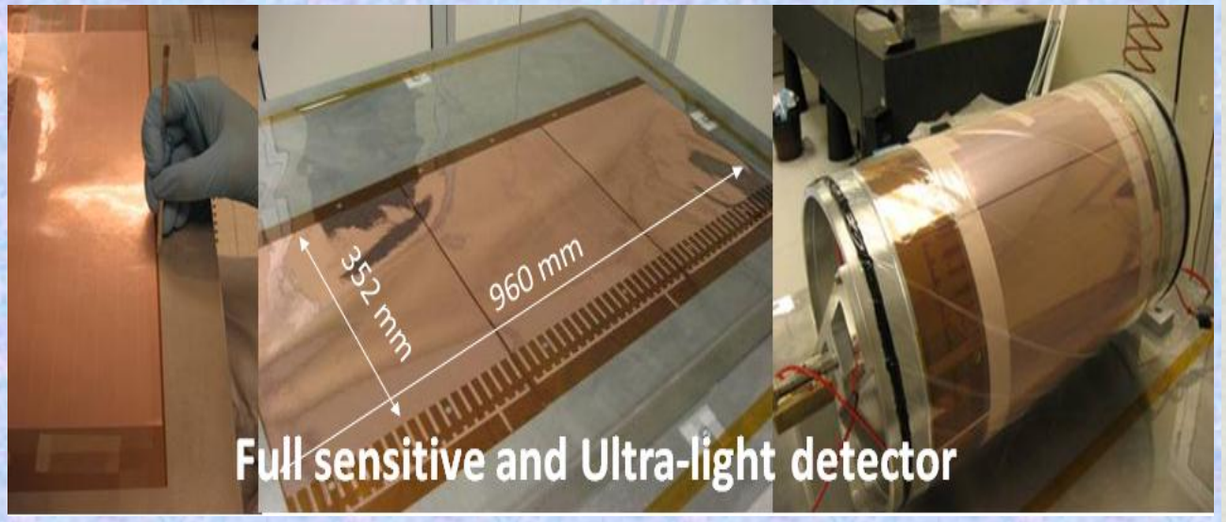
- Another experiment, KLOE2 is planning to use large area curved GEM for their inner tracker

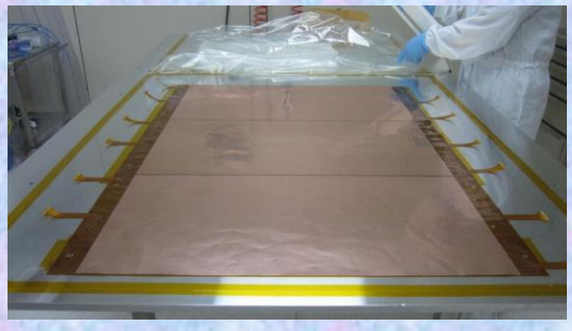
"Development of Micro-Pattern Gas Detector Technologies"
RD51 Collaboration, 110th LHCC Meeting, CERN, 13-14 June 2012

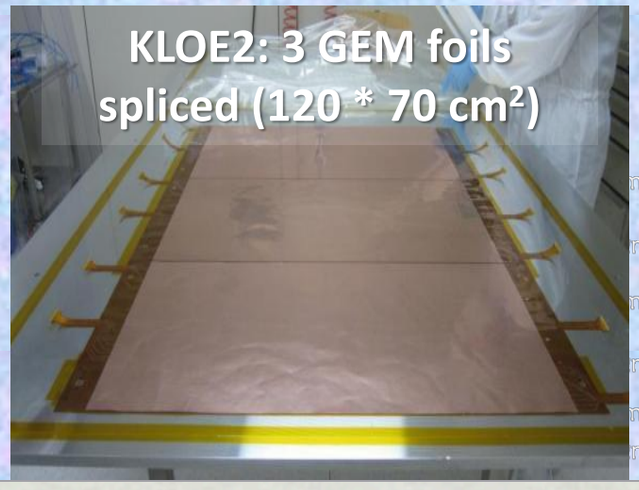
Since 2009: Single Mask GEM:

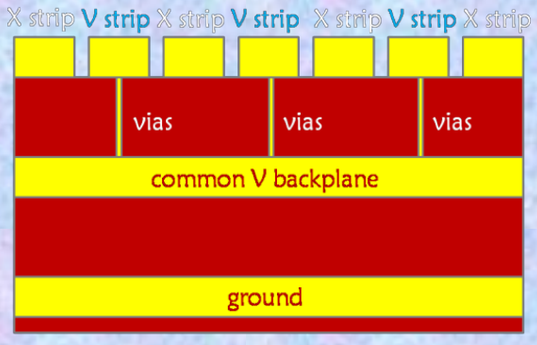


Large Area Cylindrical GEM Detectors for KLOE2 Tracker:





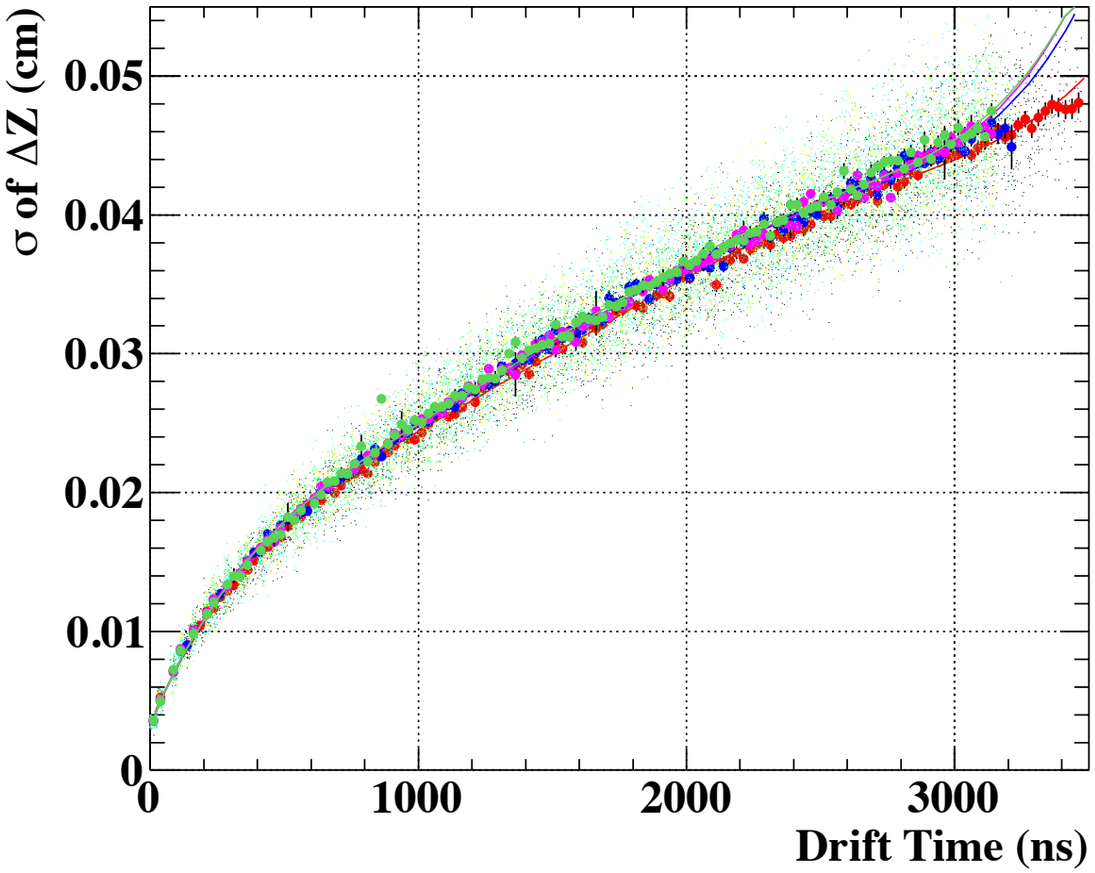


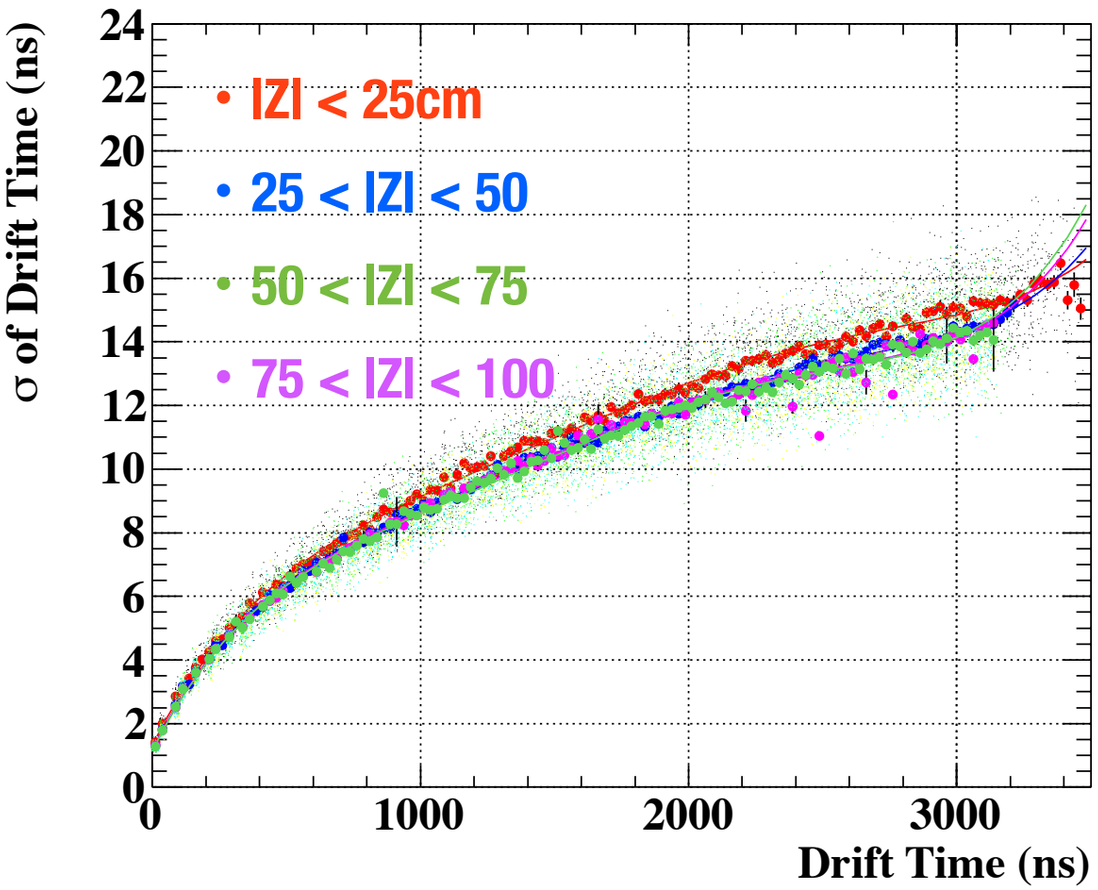


The readout is a multilayer flexible circuit on a polyimide substrate providing a 2-dim point with XV strips at 650 µm pitch

Diffusion effect

- Diffusion effect is calculated by Garfield++





Schedule ?

- We are planning 2 years R&D and 3 years physics data taking