Stony Brook University | The State University of New York

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DIS 2012

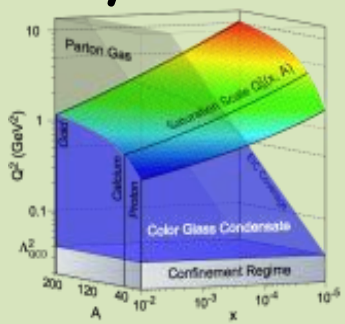
March 28, 2012

AN eRHIC DETECTOR: DESIGN CONSIDERATION AND ITS REALIZATION BY MEANS OF DETECTOR R&D

QCD: Charges to Physics Questions

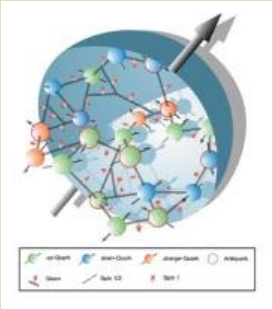
Physics of strong color fields

Quantitatively probe the universality of strong color fields in AA, pA, and eA



- Establish the existence of saturation regime
- Explore non-linear QCD
- Measure momentum and space-time of glue

Spin physics with polarized e+p



- Precisely image sea-quarks and gluons for determining spin, flavor, and spatial structure of the nucleon

Determine quark and gluon contributions to the proton spin at last

Dedicated EIC Detector @ eRHIC

- Detector must be multi-purpose
  - One detector for inclusive (ep -> e'X), semi-inclusive (ep->e'hadron(s)X), exclusive (ep -> e'πp) reactions in ep/eA interactions
  - run at very different beam energies (and ep/A kinematics)

  $E_{p/A}/E_e \sim 1 - 65$ → HERA: 17 – 34; lepton beam energy always 27GeV
- Inclusive DIS:
  - with increasing center-of-mass energy lepton goes more and more in original beam direction
  - high Q^2 events go into central detector
  - low Q^2 events have small scattering angle and close to original beam energy

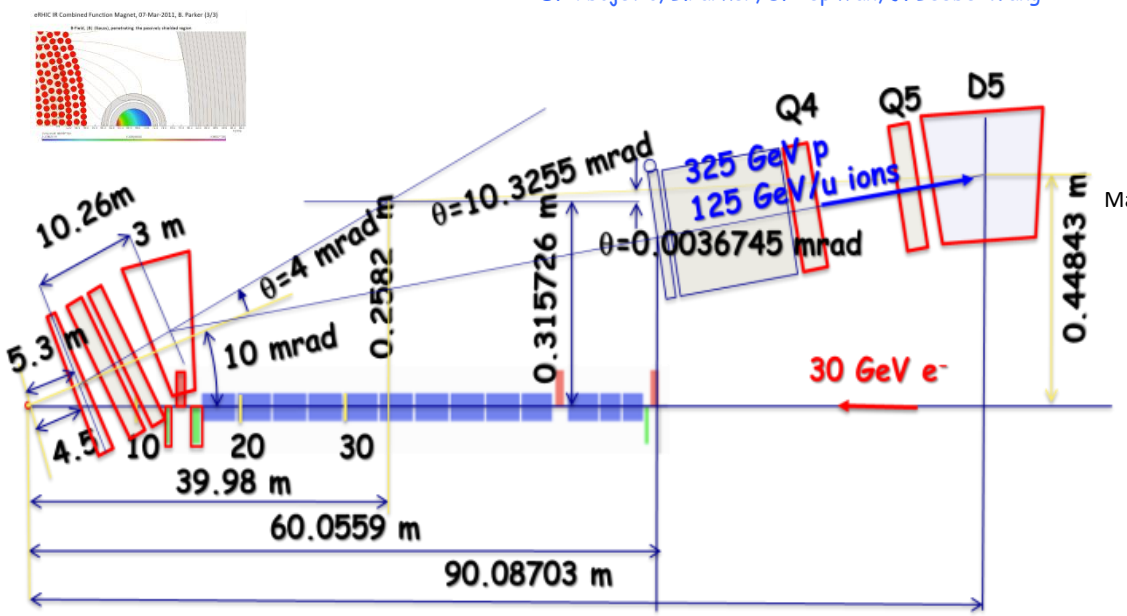
  need low forward electron tagger for low Q^2 events

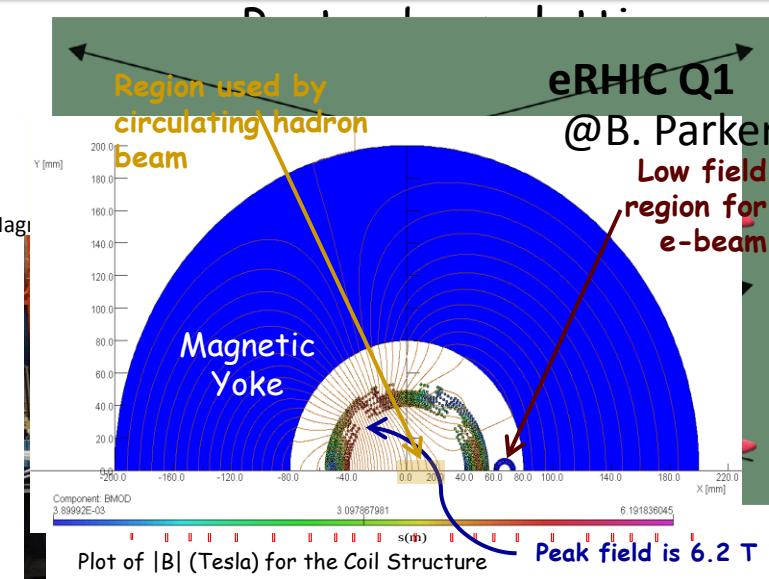
  low-mass high resolution trackers over wide angular acceptance
- Semi-Inclusive DIS
  - hadrons go from very forward to central to even backward with lepton beam energy increasing

  good particle-ID over the entire detector
- Exclusive Reactions:
  - decay products from excl. ρ / ϕ / J/ψ go from very forward to central to even backward with lepton beam energy increasing

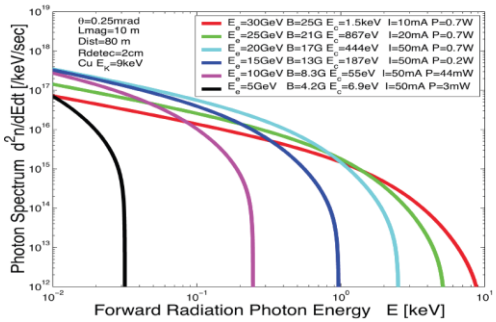
Design Interaction Region

© D.Trbojevic, B.Parker, S. Tepikian, J. Beebe-Wang





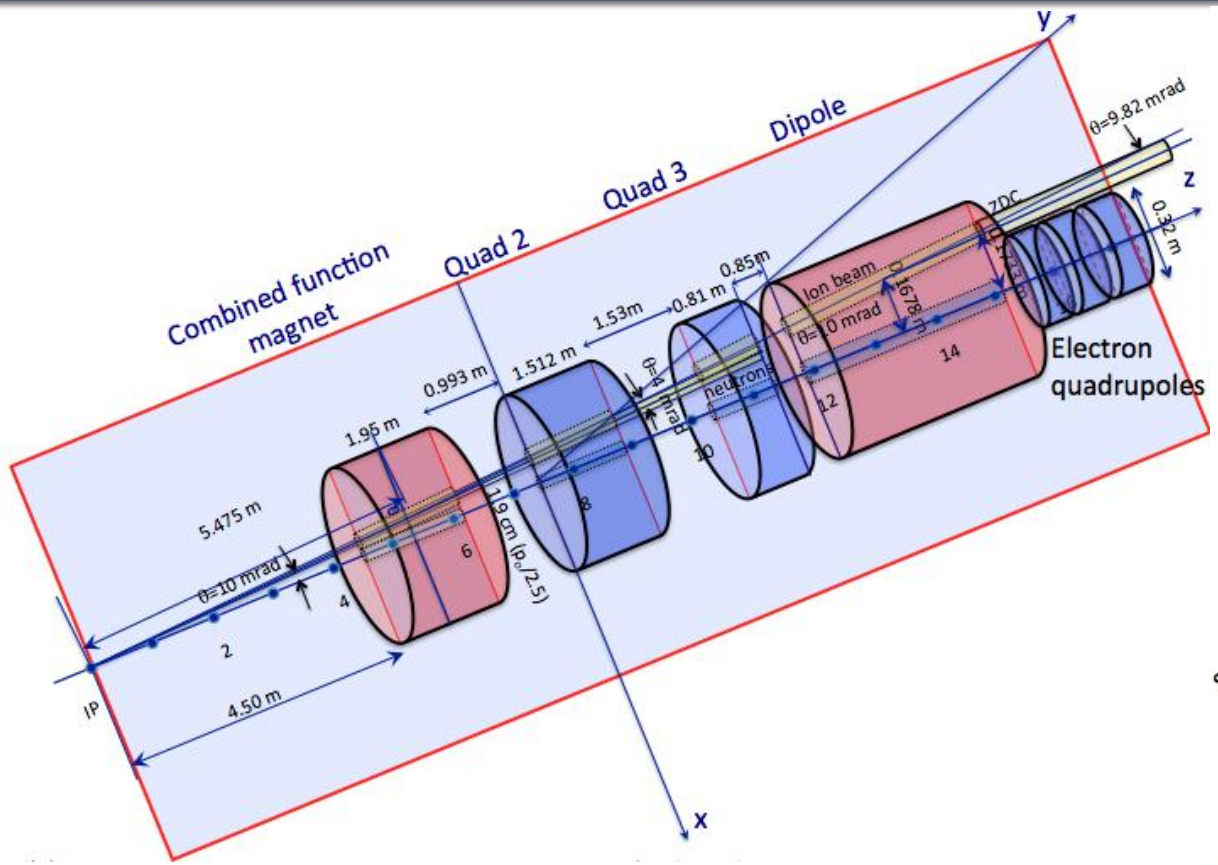
Plot of |B| (Tesla) for the Coil Structure

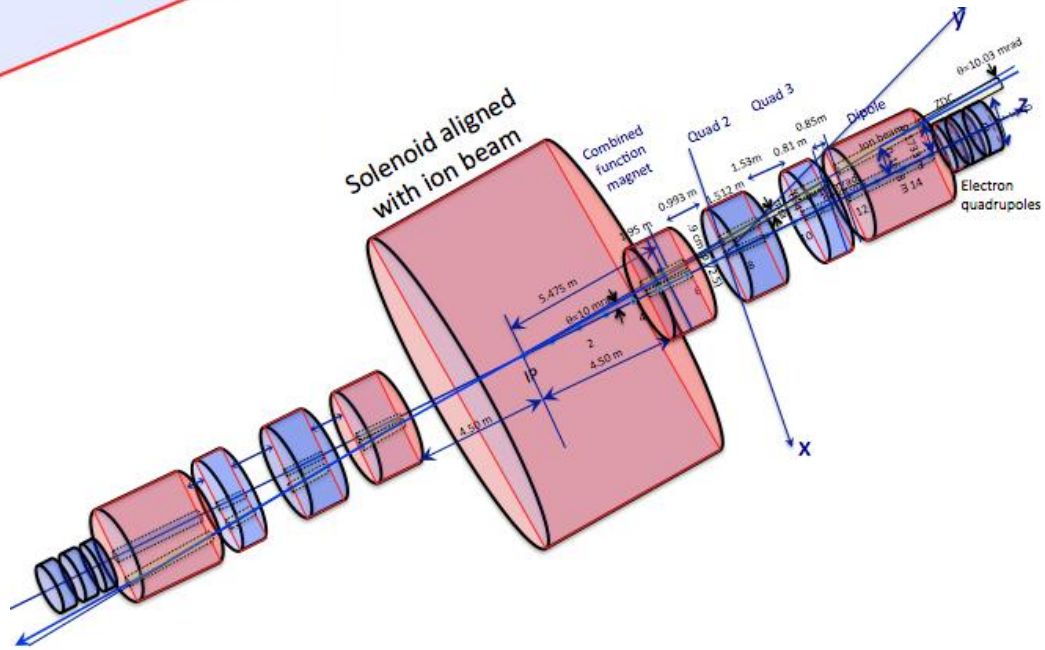


eRHIC - Geometry high-lumi IR with β*=5 cm, l*=4.5 m and 10 mrad crossing angle → this is required for 10^{34} cm^{-2} s^{-1}

- 10 mrad crossing angle and crab-crossing
- High gradient (200 T/m) large aperture Nb_3Sn focusing magnets
- Arranged field-free region where electron pass through the hadron triplet magnets
- Integration with the detector: efficient separation and registration of low angle collision products
- Gentle bending of the electrons to avoid SR impact in the detector

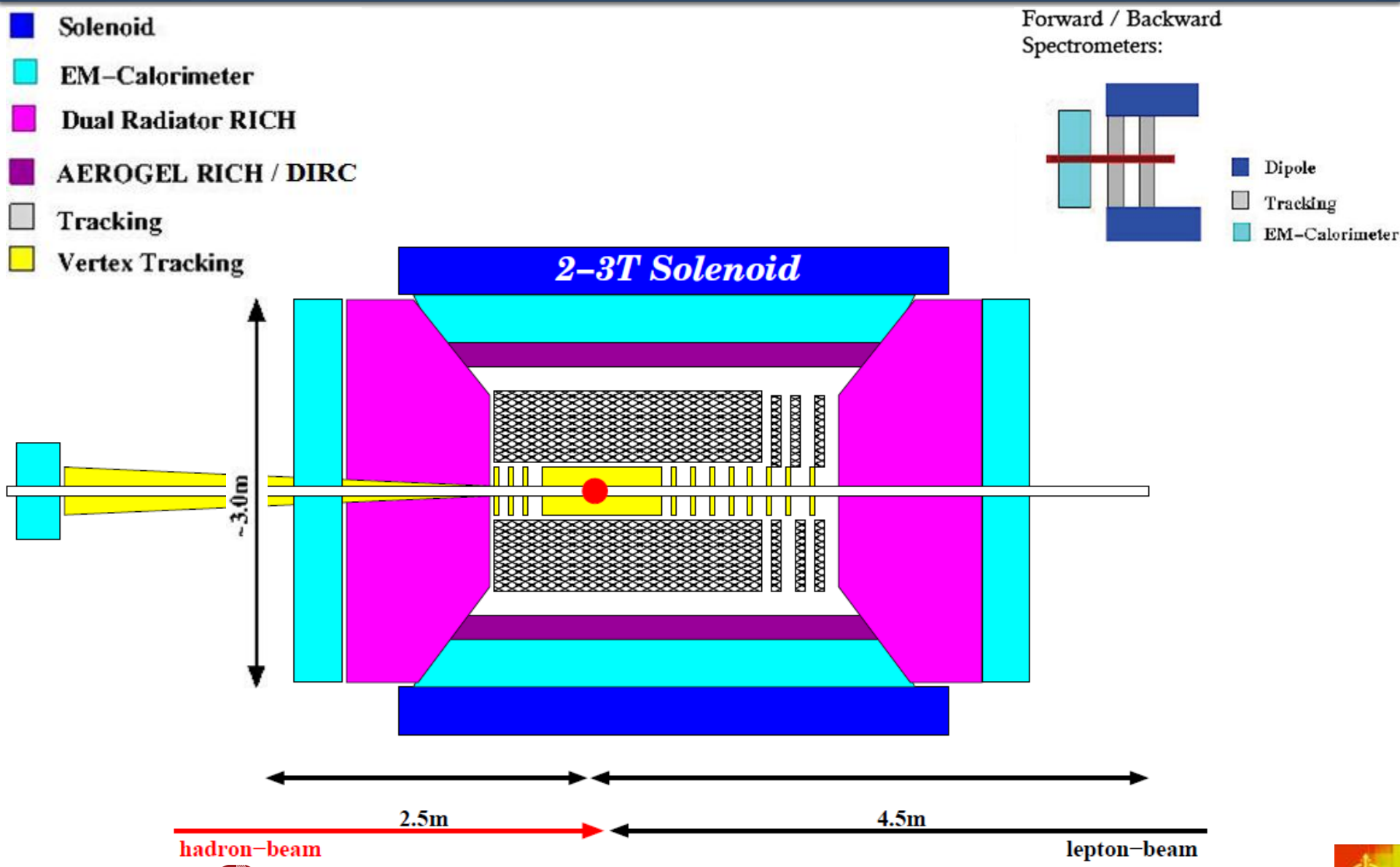
Design Interaction Region



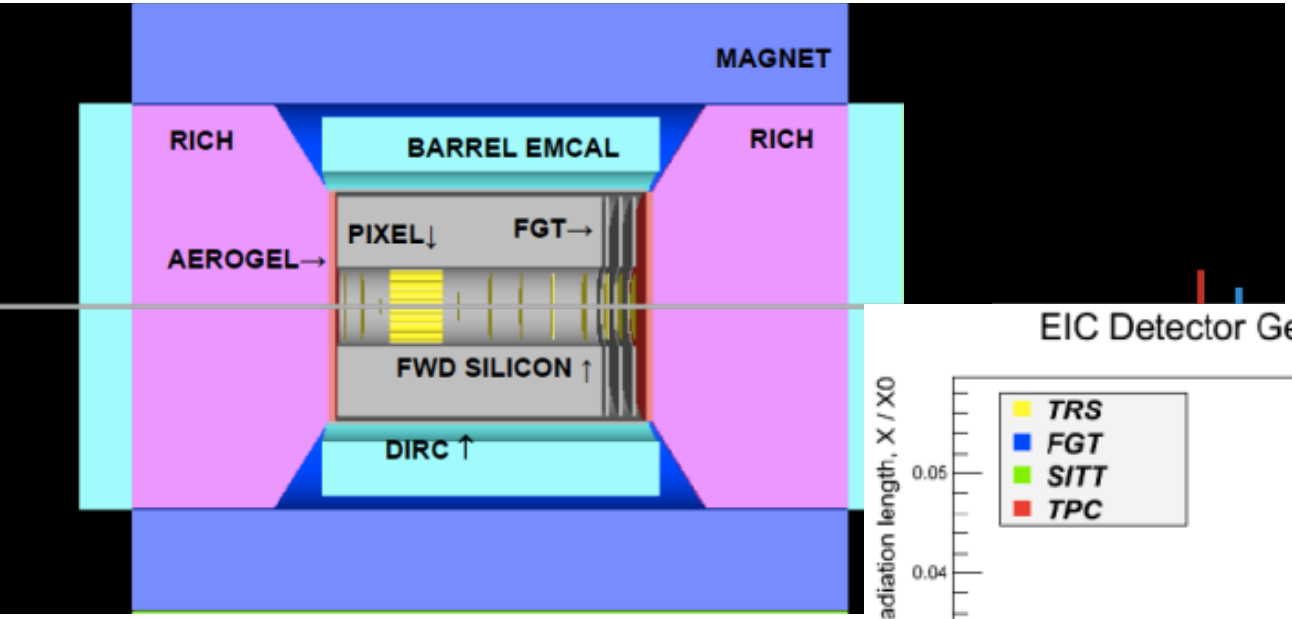


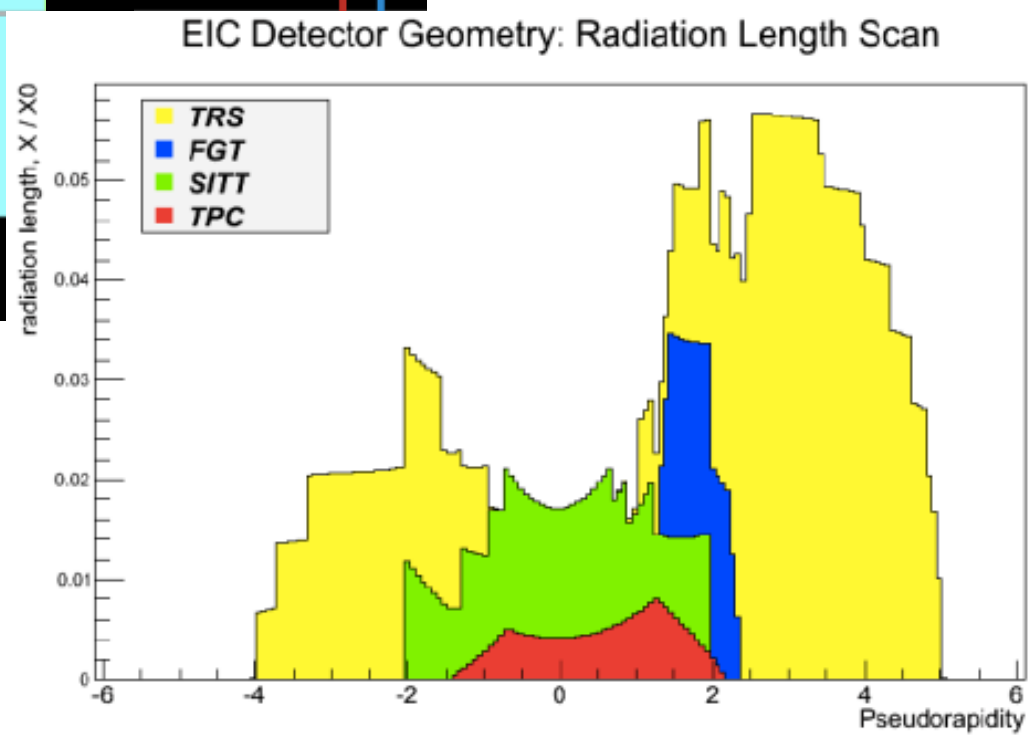
All optimized for dedicated detector
Have $\pm$4.5m for main-detector
→ roman pots / ZDC
→ low Q^2-tagger
need to be integrated in the IR design

Detector Concept



Detector Concept





Tracking - Vertex

- Si-Vertex Detector
  - MAPS technology from IPHC concept as STAR-HFT, CBM, Alice, …
    - Barrel:

    4 double sided layers @ 2.5 / 5.0 / 7.5 / 15.0 cm, 10 sectors in Φ

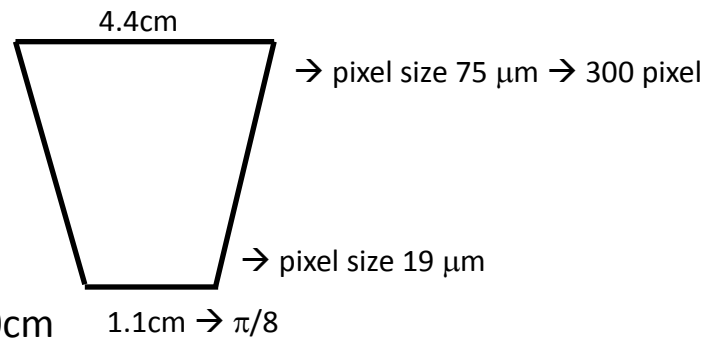
    Rapidity coverage: at least $|\eta| = 1$

    Chip 20mm x 30mm → 1cm 300 pixel pitch 33 μm

    Dual sided readout, one column 60 μs readout time

    Radiation length 5 ‰ / layer (50μm Si)

    < 5μm Vertex resolution



    - Forward Disks:

    At least 4 single sided disks spaced in z starting from 20cm

    Radial extension 3 (19 μm pixel) to 12 cm (75 μm pixel),

    Dual sided readout → 300x200ns = readout time 60μs

    Need a 0.3xm region at each side of the wedge for readout

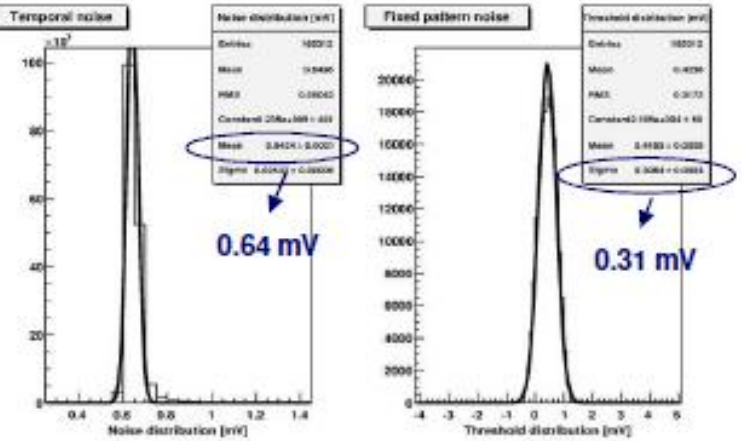
    Radiation length 3 ‰ / layer

    Stitching technology

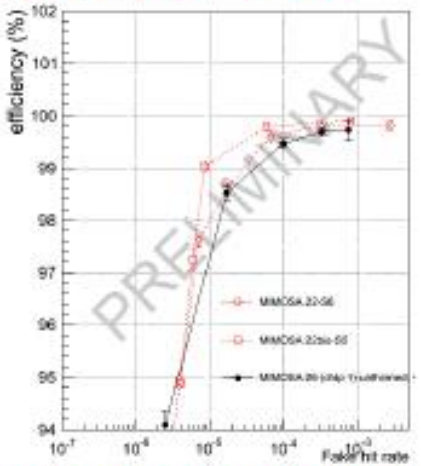
Tracking - Vertex

- *MIMOSA26 is a reticule size MAPS with binary output, 10 k images / s*
  - *Pixel array: 1152 x 576, 18.4 µm pitch*
  - *Architecture:*
    - *Pixel (Amp+CDS) array organised in // columns r.o. in the rolling shutter mode*
    - *1152 ADC, a 1-bit ADC (discriminator) / column*
    - *Integrated zero suppression logic*
    - *Remote and programmable*

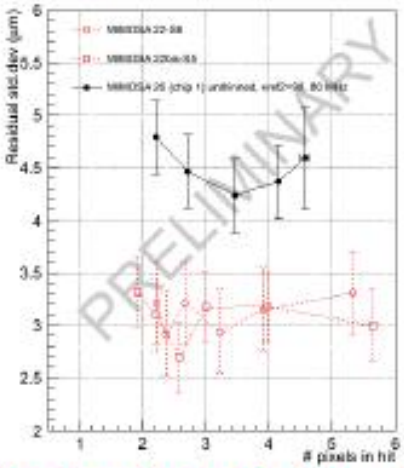
- *Lab. and beam tests*



ENC ~ 13-14 e⁻

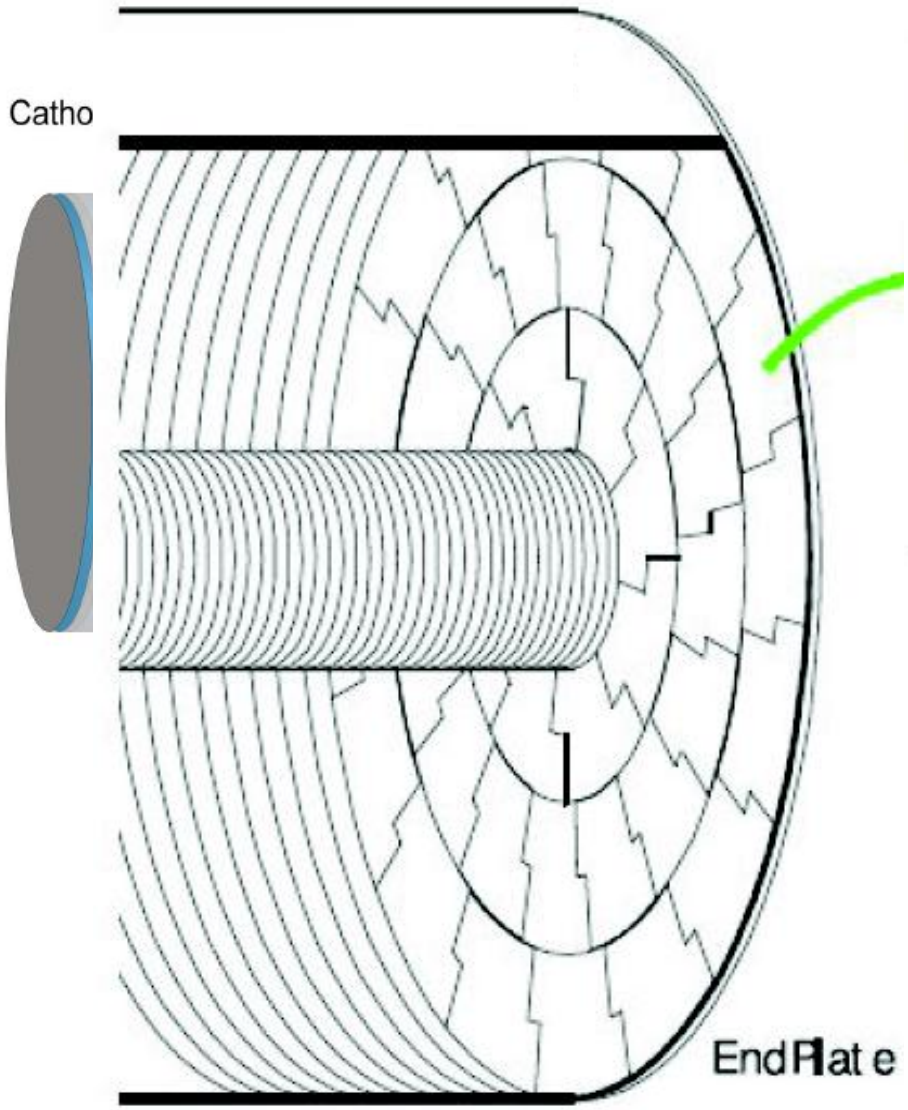


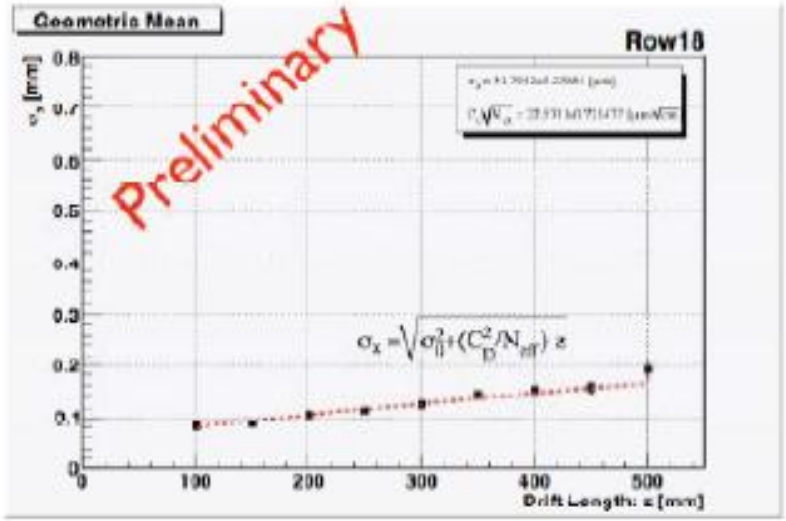
Efficiency 99.5% for fake rate 10^{-4}



Single point resolution ~4 µm

Tracking - Barrel





S

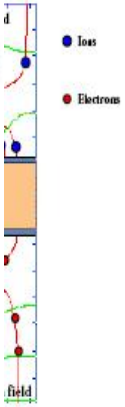
B=IT

fitting result

$$\frac{C_D}{\sqrt{N_{eff}}} = 22.6 \pm 0.7 [\mu m/\sqrt{cm}]$$

$$\begin{cases} C_D = 101.6 \pm 0.4 [\mu/\sqrt{cm}] \\ \frac{C_D}{\sqrt{N_{eff}}} = 22.6 \pm 0.7 [\mu m/\sqrt{cm}] \end{cases}$$

$$\longrightarrow N_{eff} \sim 20 \pm 1$$

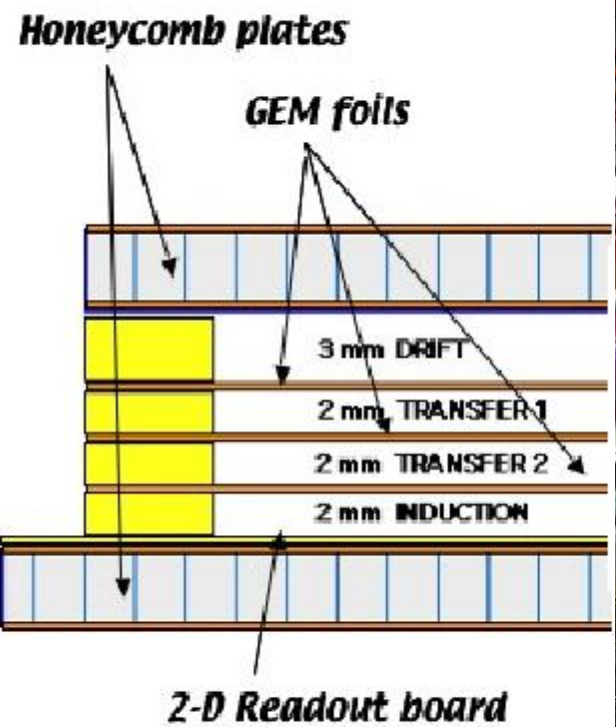


Tracking - Barrel

- TPC readout with Micro Pattern Gas Detector (GEM, MicroMegas)
- Readout based on
  - Pads and analogue FE (ALTRO)
  - Pixel readout -> TimePix: can provide digital dE/dx measurement
  - Combination of both
- Counting gas studies
  - Resolution (longitudinal/transverse diffusion)
  - Drift velocity
  - Ion back drift
  - Field distortions
- Low mass TPC
- Best track finding (> 25 space points) with $\sigma_r < 150\ \mu m$, $\sigma_z \sim 300\ \mu m$

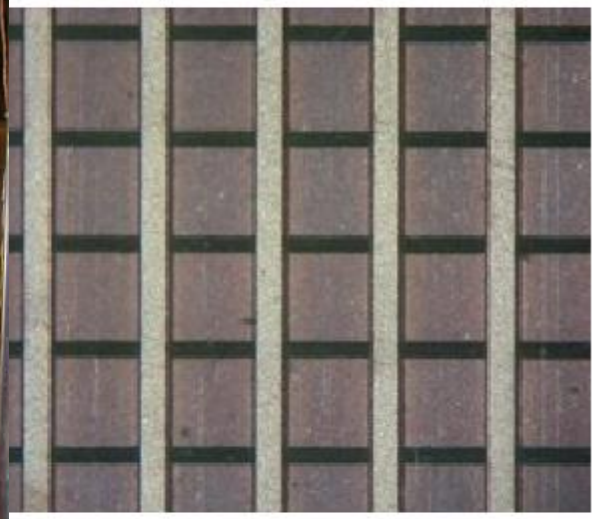
Tracking - Forward

COMPASS GEM Tracker → GEM Forward Tracker in eRHIC



GDD, CERN

0 μm

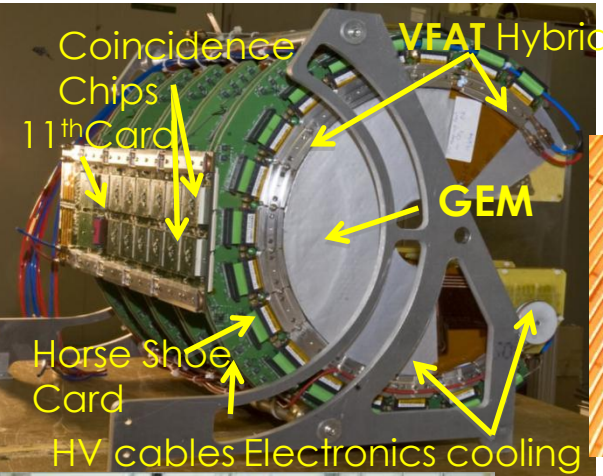


Pitch for each layer: 400 μm

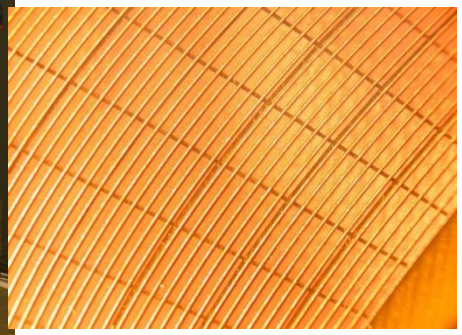
Tracking - Forward

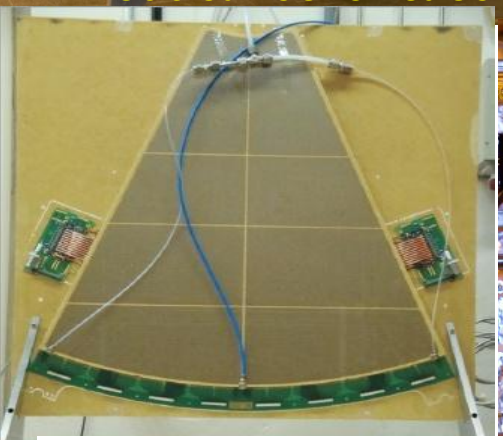
GEMs are used in the TOTEM (tracking and triggering) and LHCb Muon (triggering)

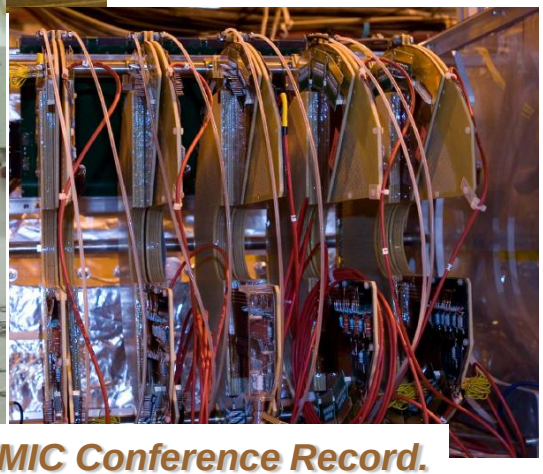
TOTEM GEMs:



2D readout (strips & pads)



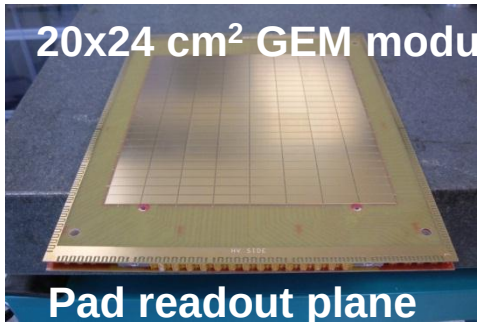


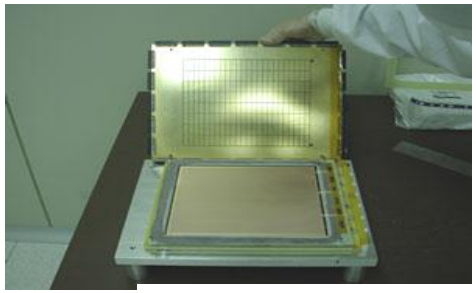


S. Lami, 2009 IEEE NSS/MIC Conference Record.

LHCb Muon Trigger:

(12 double TGEM detectors)
Rate - 5 kHz mm-2
Time resolution 4.5 ns rms
Radiation hard up to integrated charge of 20 mC mm-2 (15 LHCb years)





M. Alfonsi et al, NIM A535(2004)319

Particle Identification

Barrel

- TPC with dE/dx combined with Cherenkov detector (CD) with gaseous radiator (CF_4; n_r= 1.0005)
- DIRC
- ToF: “next generation” with ~10ps time resolution -> t_0 problem
- Aerogel as proximity focused CD plus ToF
- Proximity focused CD with liquid radiator (C_6F_{14}, n_r=1.27)
- EmCal

Forward

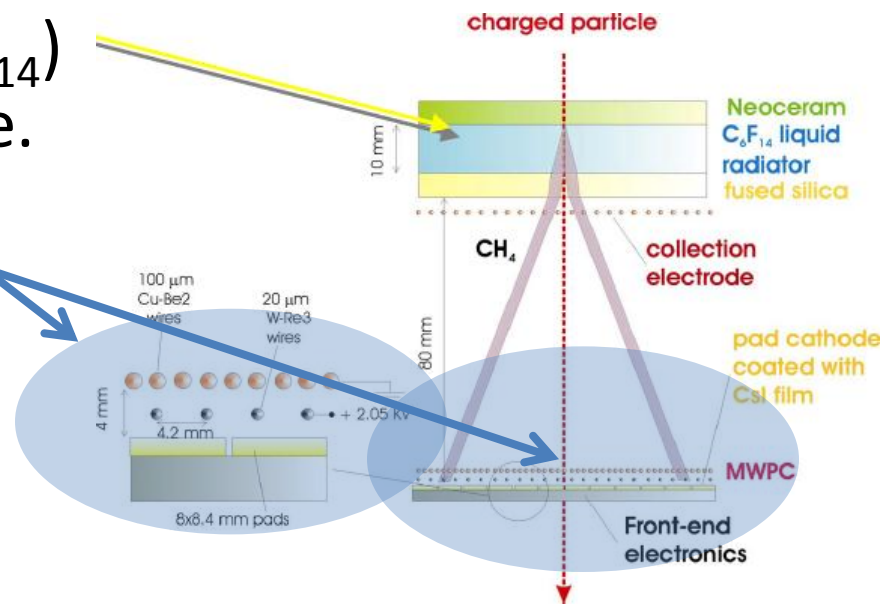
- CD with gaseous radiator (C_4F_{10} or C_4F_8O; n_r=1.0014, CF_4) and CsI-GEM photo-detectors, plus tracking
- ToF
- EmCal

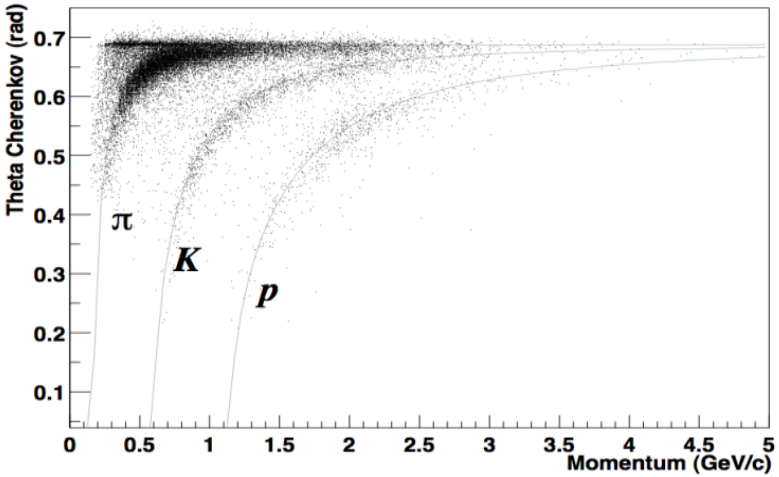
Very forward

- EmCal

Barrel Particle Identification

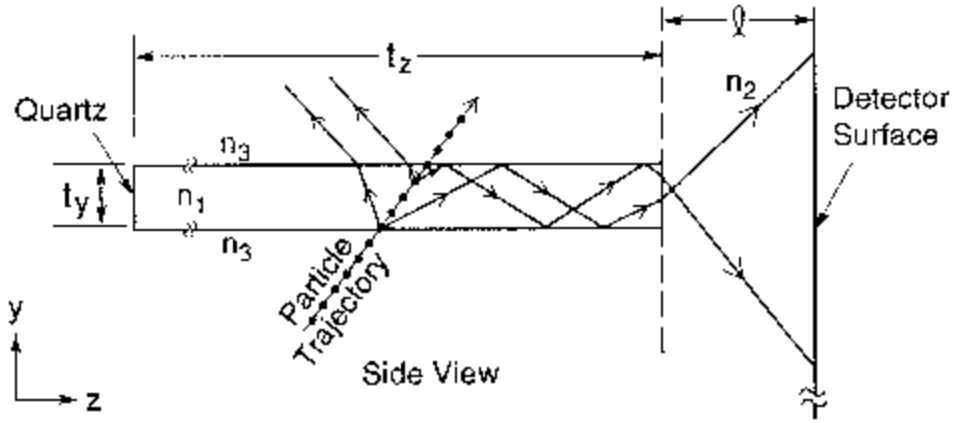
- Liquid radiator (e.g. liquid C_6F_{14}) followed by expansion volume.
- HBD like readout (GEMs with CsI) -> smaller readout area
- π/K separation depends on:
  - Index of refraction
  - Expansion distance
- Other radiators required to fulfill the need of production / transparency to VUV photons (~100-200 nm for CsI readout)





Barrel Particle Identification

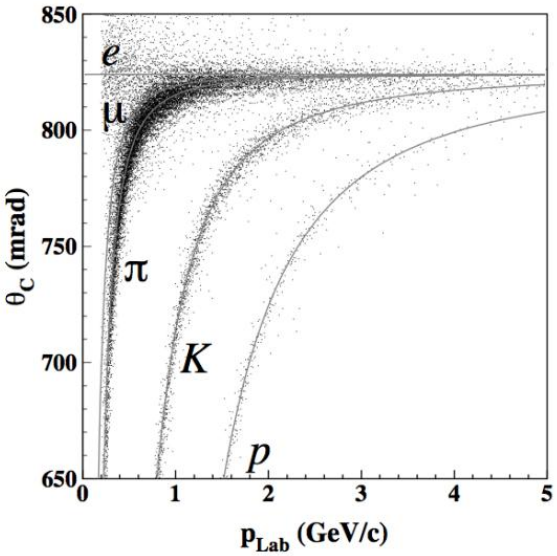
DIRC: Detection of Internally Reflected Cherenkov light



- DIRC intrinsically 3-dim detector
- Radiator and light guide: Synthetic Fused Silica
- Internal reflections are responsible for conservation of Cherenkov angle
- Readout in “expansion region” -> compact device
- Cherenkov photons are measured
  - x, y, t “coordinates”
  - Define θ_c, ϕ_c, t_{prop}

Barrel Particle Identification

DIRC @ BABAR



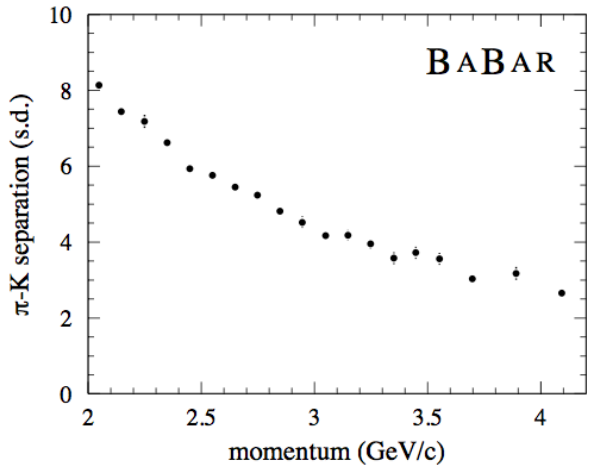
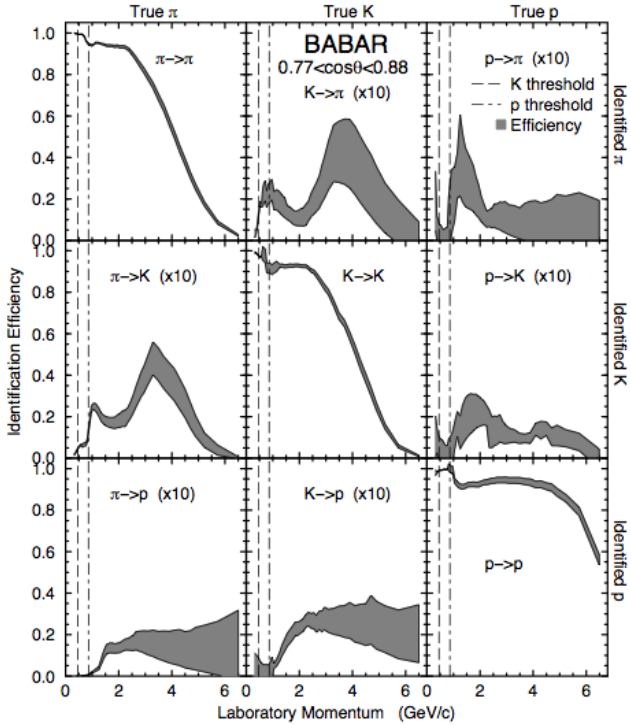


Figure 54. DIRC π-K separation versus track momentum measured in $D^0 \to K^-\pi^+$ decays selected kinematically from inclusive D^* production.



- BABAR PID in 1-5 GeV range
- Efficiency drop about 2.5 GeV
- Getting worse for p > 3.5 GeV
  - Extend with higher granularity readout?

Forward Particle Identification

Cherenkov UV radiators

Material	n	π_{thr} (GeV/c)	K_{thr} (GeV/c)	P_{thr} (GeV/c)	Θ_{max} (β=1) deg
Fused silica	1.474	0.13	0.45	0.85	47.
C6F14	1.29	0.17	0.60	1.13	39.
AeroGel	1.05 – 1.01	0.4 – 1.	1.5 – 3.5	3. – 7.	18 - 8
C4F10	1.0014	2.6	9.	17.	3.
Isobutane	1.00127	3.	10.	18.	2.9
Argon	1.00059	4.	14.	27.	2.
CF4	1.00050	5.	16.	30.	1.8
Methane	1.00051	5.	16.	30.	1.8

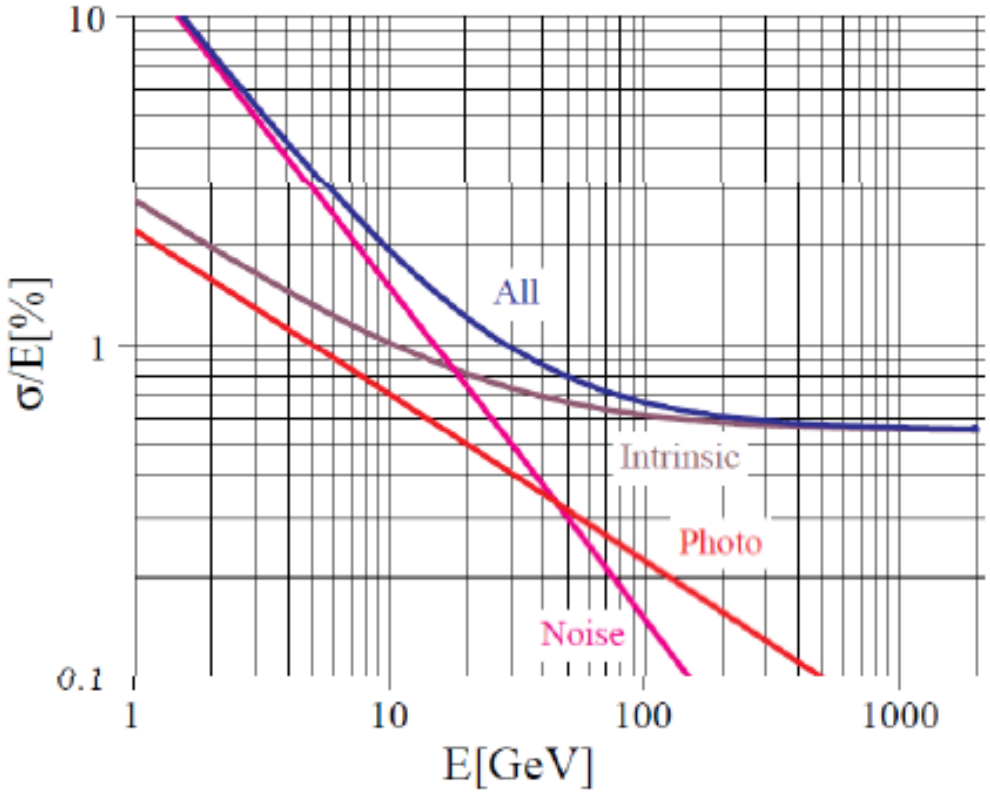
EM Calorimetry

- EMCal:
  - Backward/Barrel:
    - PWO ($PbWO_4$) - crystal calorimeter -> good resolution, small Molière radius -> electron-ID: e/π
    - measure lepton via EMCal (important for DVCS)
  - Forward:
    - Less demanding: sampling calorimeter (scintillating fibers and tungsten powder)
- Preshower
  - Si-W technology as proposed for PHENIX MPC-EX

EM Calorimetry

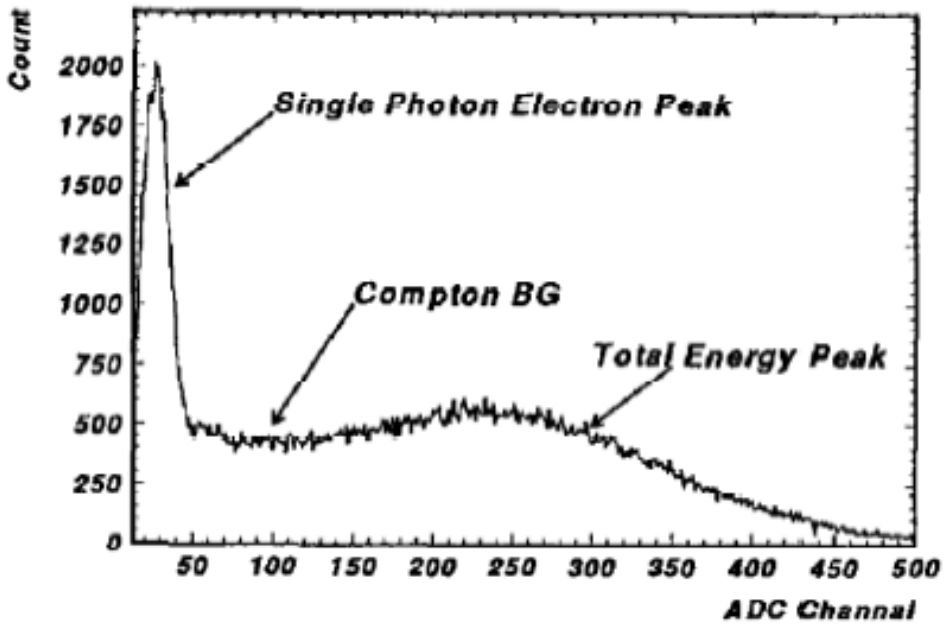
PWO

- Pros: Inexpensive and easy production
- Cons: Low light yield output, resolution affected by electronic noise



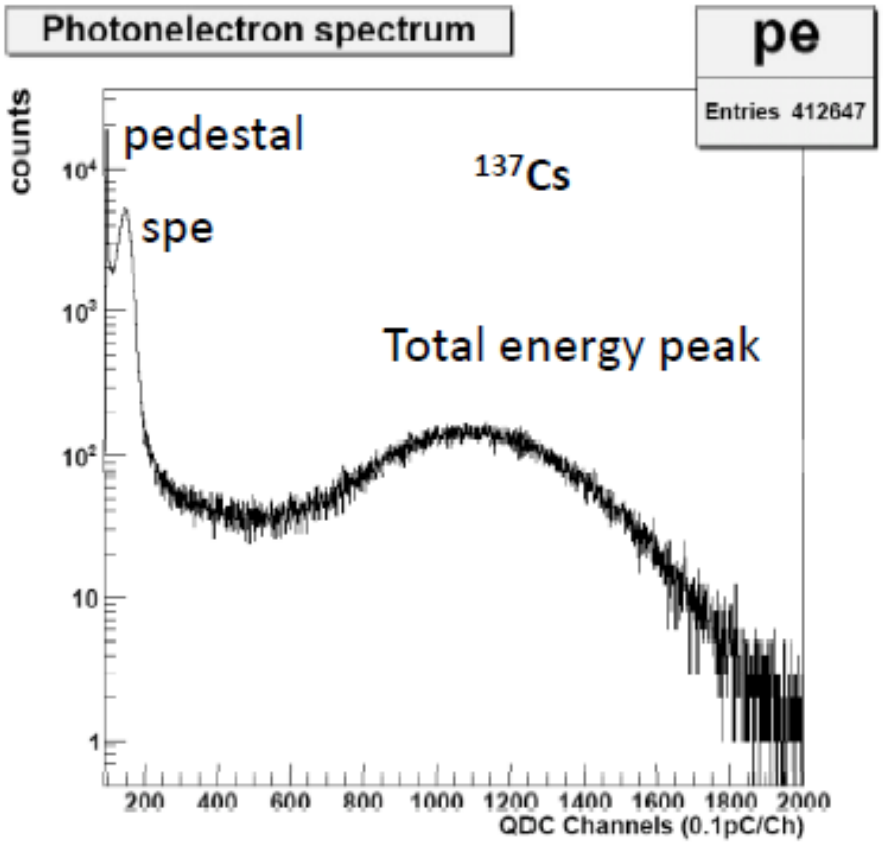
Good resolution for high energy electrons, worse for low energy
Study needed for doped PWO to improve light yield output and electronic noise reduction.

EM Calorimetry



Jian Wu et al, NIMA 404 (1998) 311

CMS PWO: ~18 phe/MeV for ^{137}Cs



About a factor of 2 achieved with new doped technique.

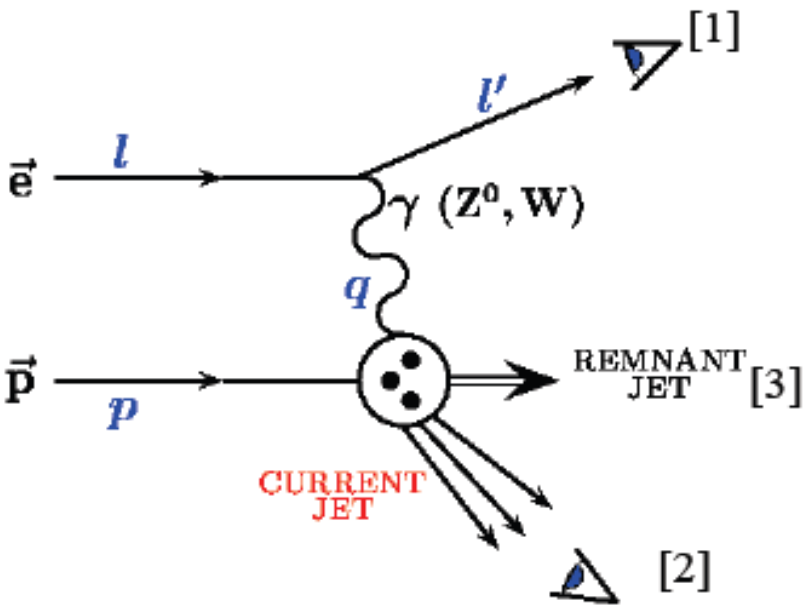
Doped PWO from SICCAS:
^{60}Co: 29.8 phe/MeV
^{137}Cs: 30.4 phe/MeV

Summary

- ✓ The Electron Ion Collider EIC will answer compelling questions for QCD
- ✓ eRHIC is one EIC option
  - eRHIC will be considering eSTAR, ePHENIX, and a dedicated eRHIC-detector
  - Dedicated eRHIC detector capable to cover EIC physics
- ✓ Ongoing studies for eRHIC sub detectors
- ✓ Detector R&D for
  - ✓ Tracking -> VTX, Forward, Barrel
  - ✓ PID
  - ✓ Calorimetry
- ✓ BNL announced Generic Detector R&D for an Electron Ion Collider: https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

The Instrument: EIC

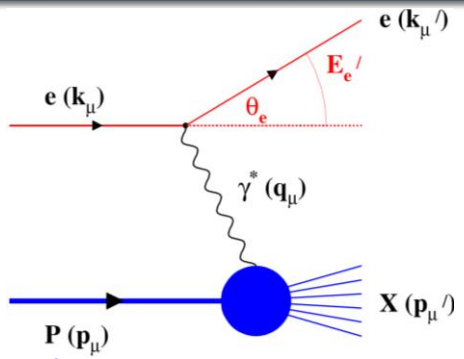
Future DIS experiment at an Electron Ion Collider: A high energy, high luminosity (polarized) *ep* and eA collider and a suitably designed detector

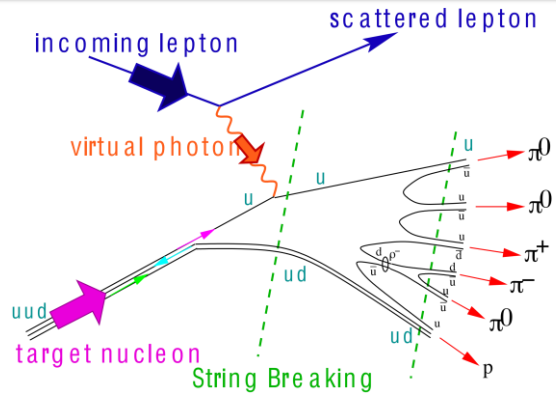


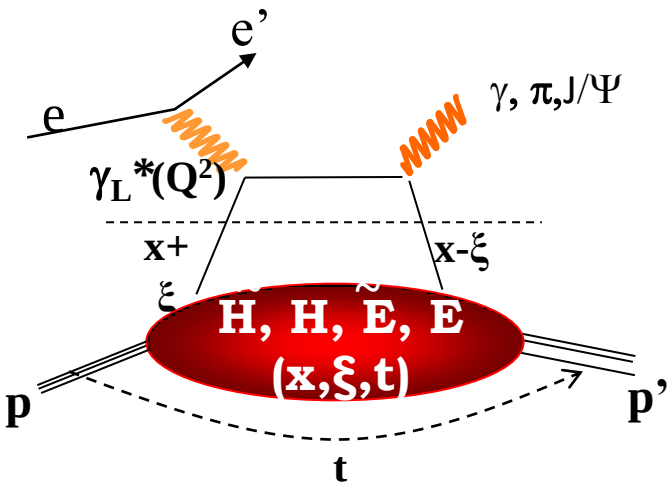
Measurements:
[1] → Inclusive
[1] and [2] **or** [3] →Semi-Inclusiv
[1] and [2] **and** [3] →Exclusive

Inclusive → Exclusive
Low → High Luminosity
Demanding Detector capabilities

Physics Requirements







Inclusive Reactions:

- Momentum/energy and angular resolution of e' critical
- Very good electron id
- Moderate luminosity >10^{32} cm^{-1} s^{-1}
- Need low x ~10^{-4} → high √s (Saturation and spin physics)

Semi-inclusive Reactions:

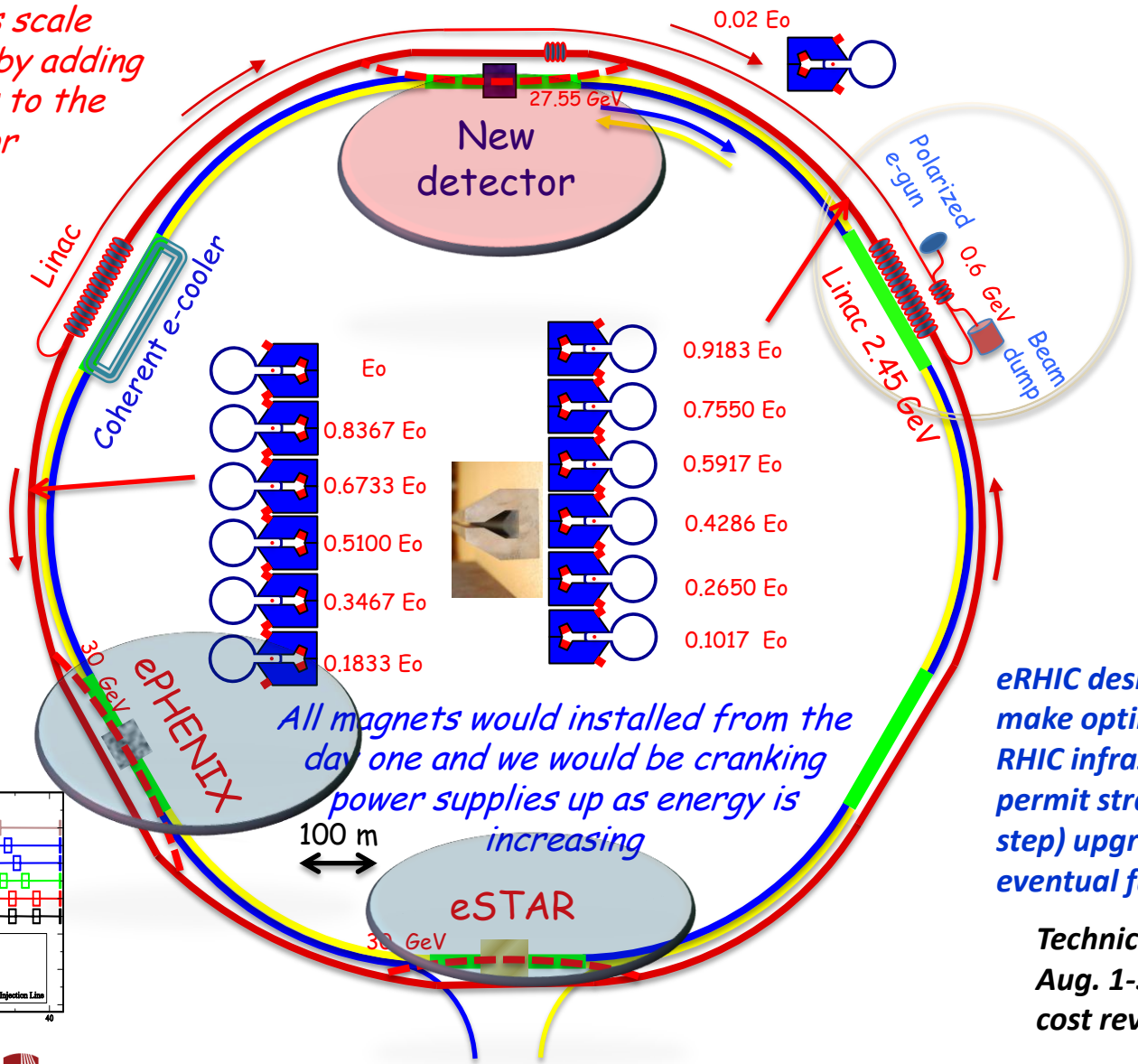
- Good particle ID: π,K,p separation over a wide range in η
- Full Φ-coverage around γ*
- Good vertex resolution → Charm, bottom identification
- High luminosity >10^{33} cm^{-1} s^{-1} (5d binning (x,Q^2,z,p_t,Φ))
- Need low x ~10^{-4} → high √s

Exclusive Reactions:

- Exclusivity → high rapidity coverage → rapidity gap events
- high resolution in t → Roman pots
- high luminosity >10^{33} cm^{-1} s^{-1} (4d binning (x,Q^2,t,Φ))

EIC: eRHIC

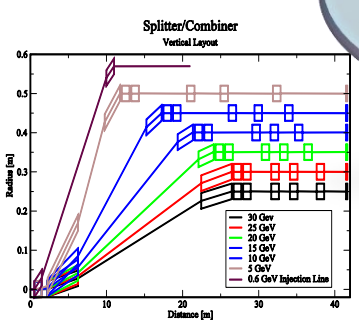
All energies scale proportionally by adding SRF cavities to the injector



E/Eo
0.0200
0.1017
0.1833
0.2650
0.3467
0.4283
0.5100
0.5917
0.6733
0.7550
0.8367
0.9183
1.0000

V. Litvinenko

All magnets would installed from the day one and we would be cranking power supplies up as energy is increasing



eRHIC design has evolved to make optimal use of existing RHIC infrastructure, and to permit straightforward (multi-step) upgrades from Phase 1 to eventual full electron energy.

Technical design review Aug. 1-3, 2011; aim for cost review Spring 2012

Detector Requirements

- Wide acceptance $-5 < \eta < 5$ for both the scattered lepton and the produced hadron.
- The same coverage in electromagnetic calorimetry and tracking.
- High electron track finding / reconstruction efficiency, high precision for momentum (energy) reconstruction.
- Particle identification to separate electrons and hadrons as well as pions, kaons and protons over a momentum range of 0.5 GeV to 10 GeV for rapidities between $|\eta| < 2$ and 0.5 GeV to 80 GeV for

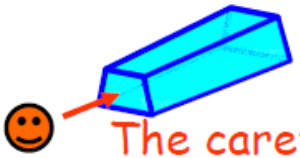
  $2 < |\eta| < 5$.
- Good vertex resolution.
- High acceptance for forward going protons and neutrons from exclusive reactions as well from the breakup of heavy ions.

EM Calorimetry

Small d, small sampling fraction (A)	*Small d, large sampling fraction (B)*	*Large d, large sampling fraction (C)*
SciFi calorimeters.	"Shashlik" type.	Tile/Fiber type.
Pros: Good energy , position resolution. Fast, compact, hermetic. Cons: Projectivity, high cost (1/10th of crystals). Example (H1)	Pros: Excellent energy resolution Reasonably fast Small dead areas Cons: Low density, projectivity. Moderate cost Example (KOPIO/PANDA)	Pros: Energy resolution OK Reasonably fast Very cost effective Cons: Moderate density, large dead areas. Example (STAR BEMC)
$R_{Moliere}$ 1.8 cm	6 cm	3 cm
X_0 0.7 cm	3.4 cm	1.2 cm
Energy resol. ~10% /√(E)	4%/√(E)	15%/√(E)
Density ~10 g/cm^3	2.5 g.cm^3	6 g/cm^3
Number of fiber/tower~ 600 (0.3 mm diameter, 0.8mm spacing)	0.3 mm Pb/1.5 mm Sc 400 layers	5mm Pb/ 5mm Sc 20 layers

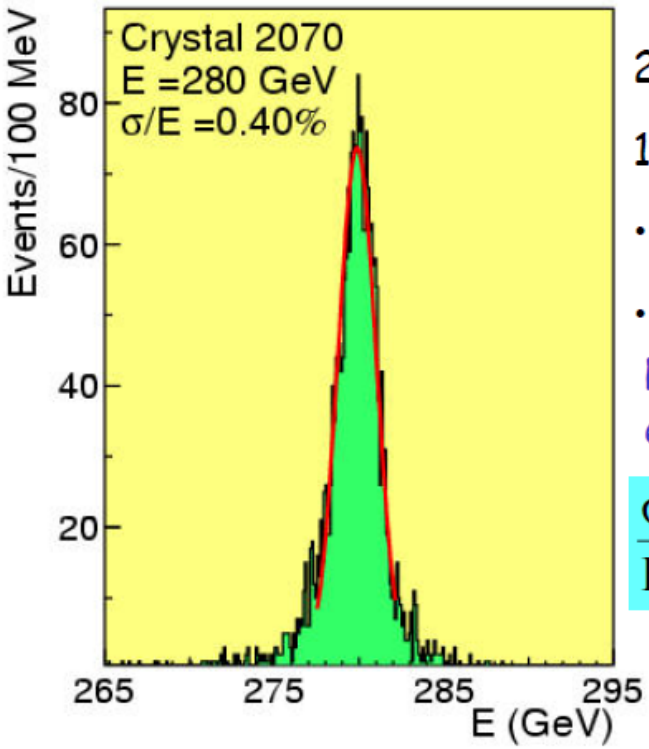
EM Calorimetry

PWO @ CMS



Test-beam performance

The careful control of crystal properties shows that a very good resolution can be obtained



280 GeV electrons

1999 prototype

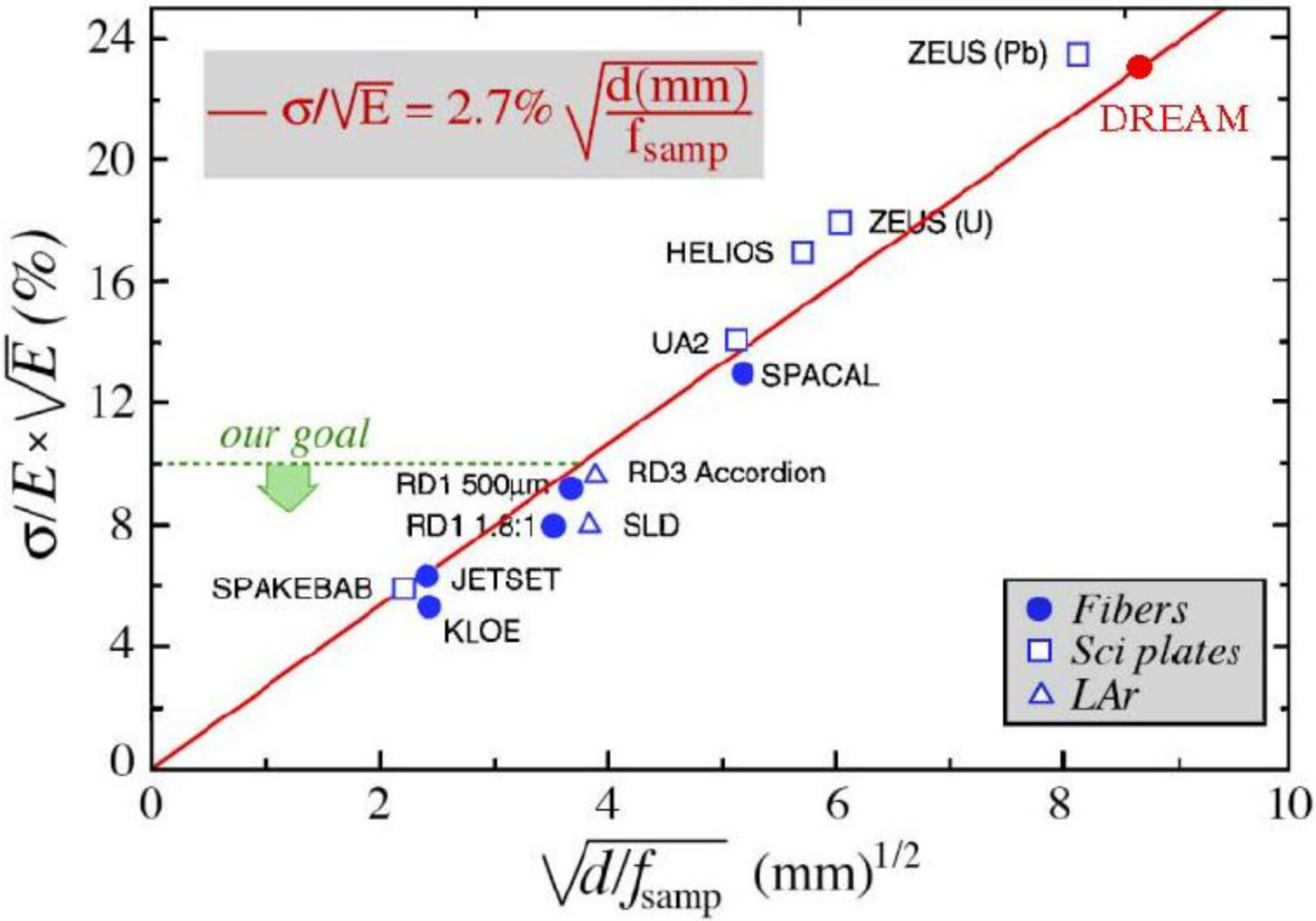
- 30 preprod. crystals
- Charge ADC

Resolution as a function of energy

$$\frac{\sigma}{E} = \frac{2.74\%}{\sqrt{E}} \oplus 0.40\% \oplus \frac{142\text{MeV}}{E}$$

EM Calorimetry

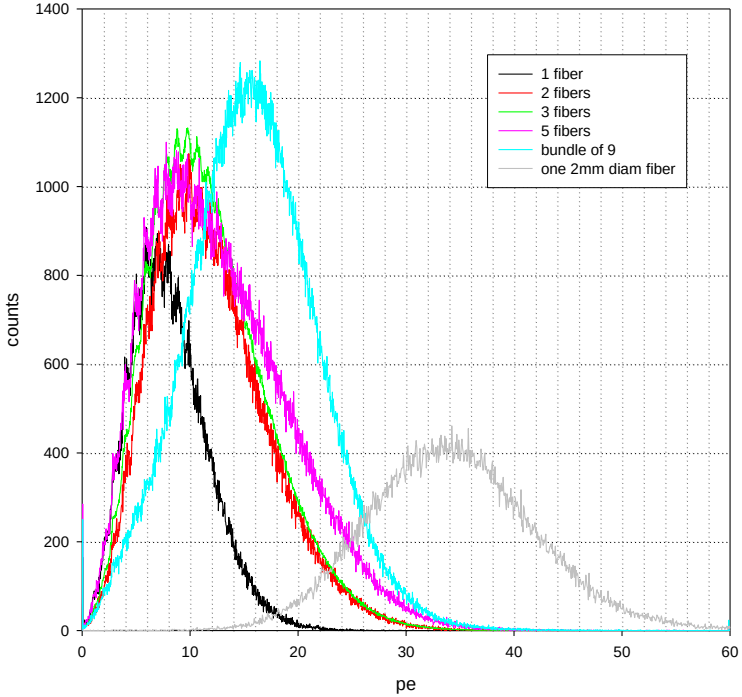
Electromagnetic fiber calorimeter



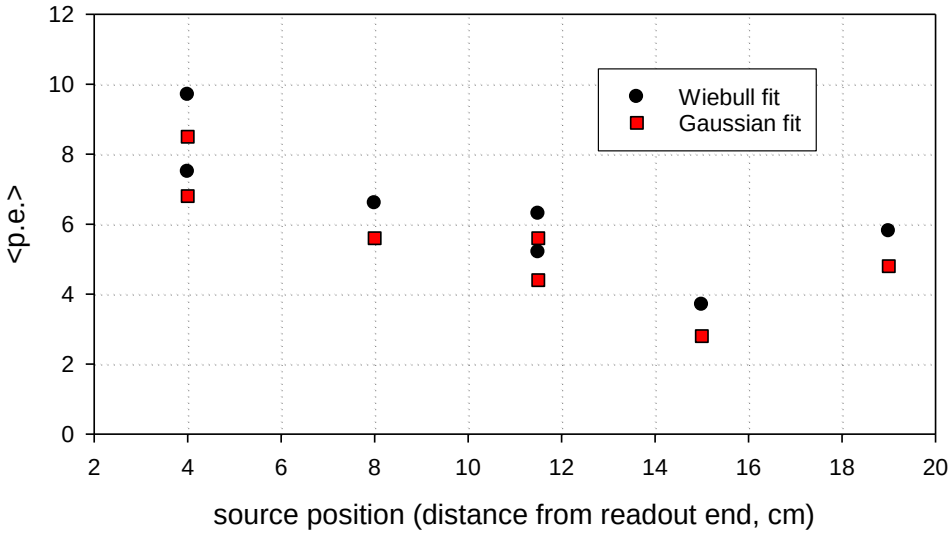
EM Calorimetry

Electromagnetic fiber calorimeter

uncollimated Cs-137 source exciting scintillating fibers, read out with a 3mmx3mm Hamamatsu MPPC



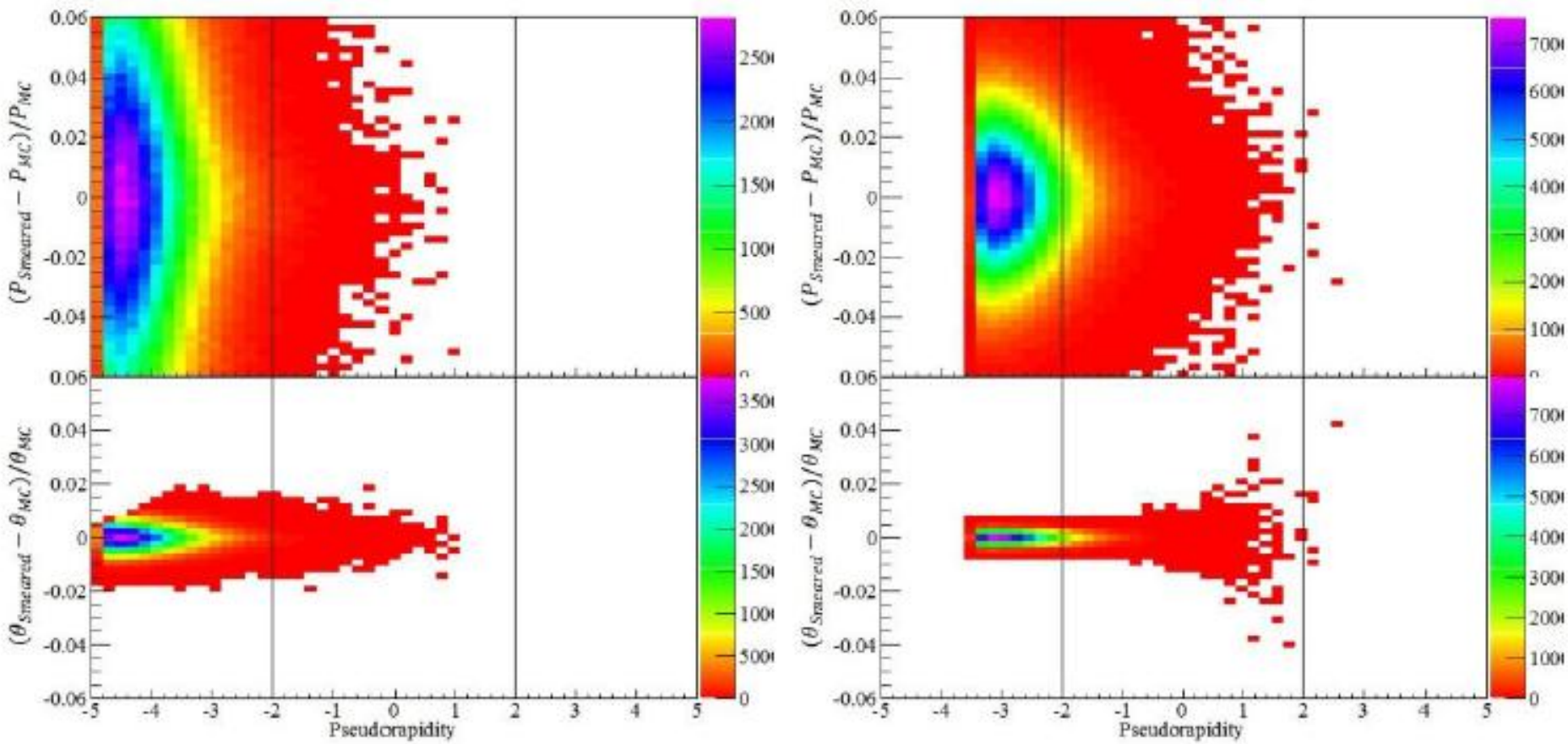
Measured scintillation light from a 23cm long bundle of nine 1mm diam BCF10 scintillating fibers.Read out with a 3x3mm MPPC. Uncollimated Cs-137 source moved along length.



Challenge is to collect all this light onto a relatively small area (SiPM or APD)

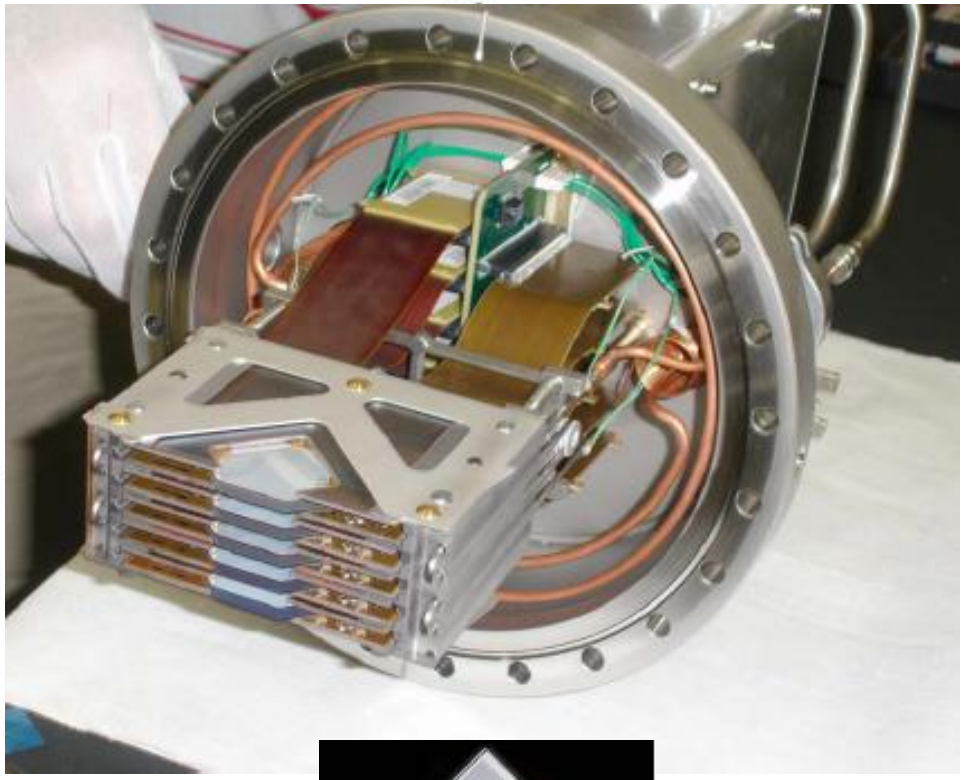
Momentum/Theta Resolution

Momentum/Theta resolution using parameterization inspired by ZEUS 20 GeV x 100 GeV and 5 GeV x 100 GeV



Roman Pots

Example: Roman Pot system @ TOTEM



- Vertical and horizontal pots
- Vacuum compensation system interconnected to machine vacuum
- Individual stepper motors
- Adjustable jacks for alignment

Si sensor

Closest approac m center (f=0):

$h(t) = \delta + c + t + f + s(t) + 10\sigma = 10\sigma + \leq 450\ \mu m$

δ = 47 μm insensitive area

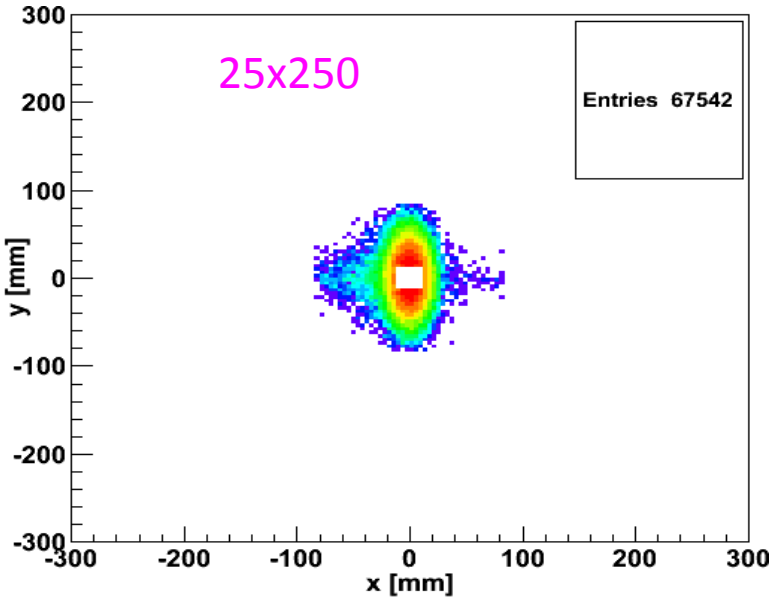
c = 200 μm distance to window

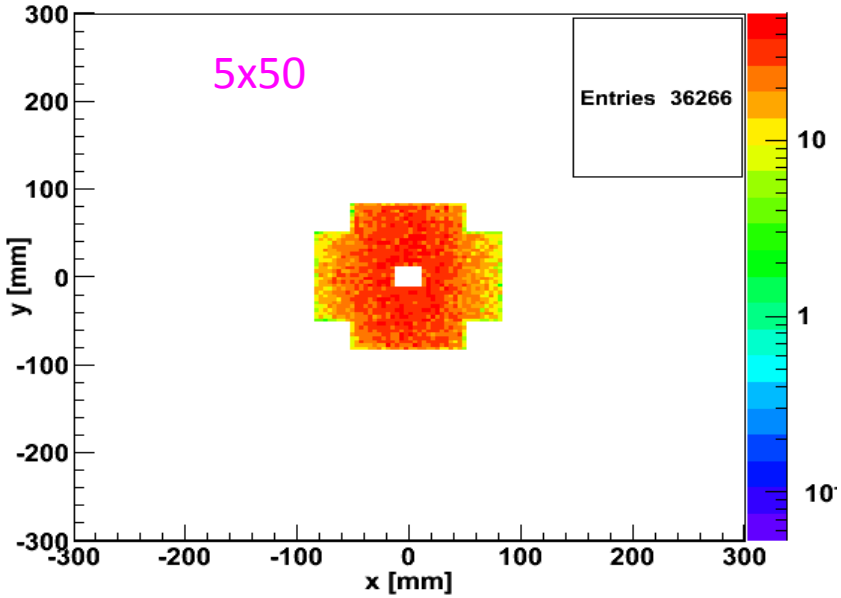
t = 150 μm window thickness

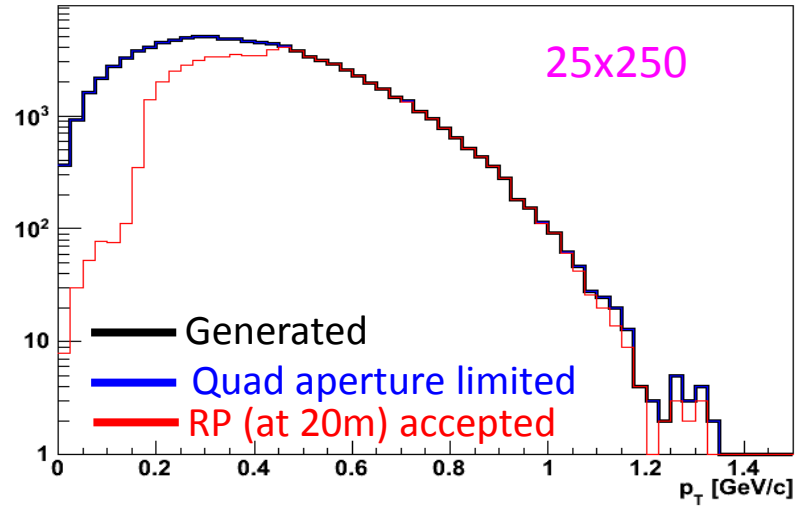
s(t) = < 50 μm flatness

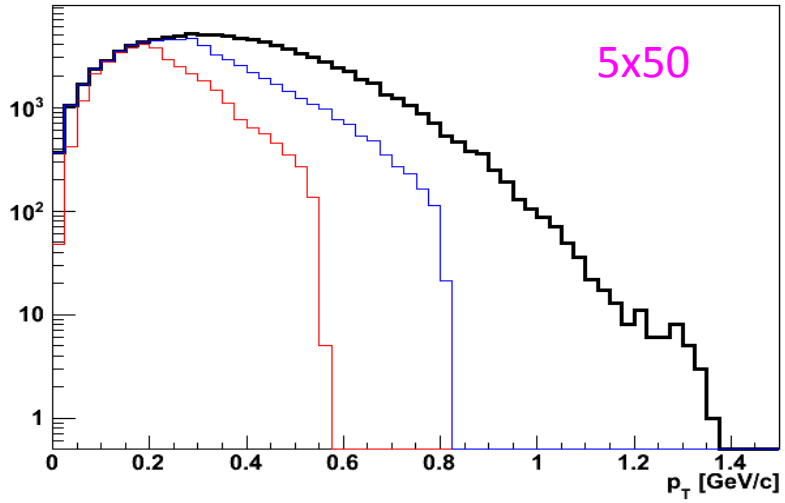
f = window displacement in case of vacuum loss (= 50 μm at 100 mbar).

Roman Pots

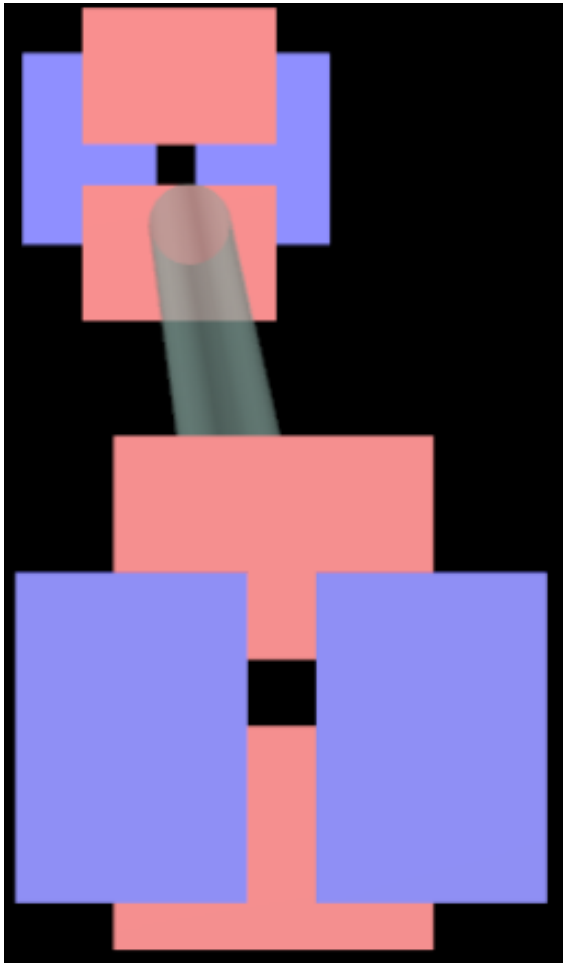

25x250
Entries 67542
y [mm]
x [mm]


5x50
Entries 36266
y [mm]
x [mm]


25x250
Generated
Quad aperture limited
RP (at 20m) accepted
p_T [GeV/c]


5x50
p_T [GeV/c]

Roman Pots



- Two horizontal RP stations at z=20m
  - Active area 10 cm x 7 cm each
- Two vertical RP stations at z=22m
- Each station implemented as
  - Four layers Si
  - One layer scintillator