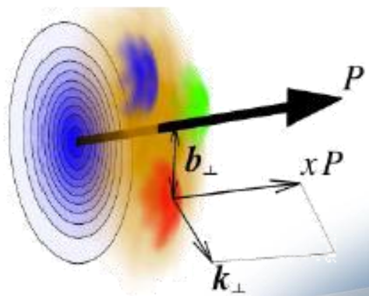
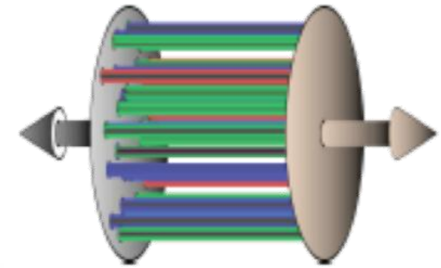
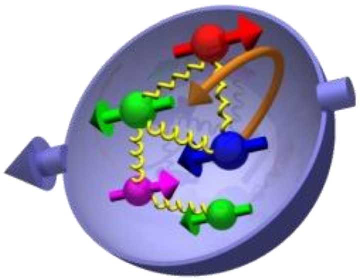
ePHENIX: Magnet and Tracking

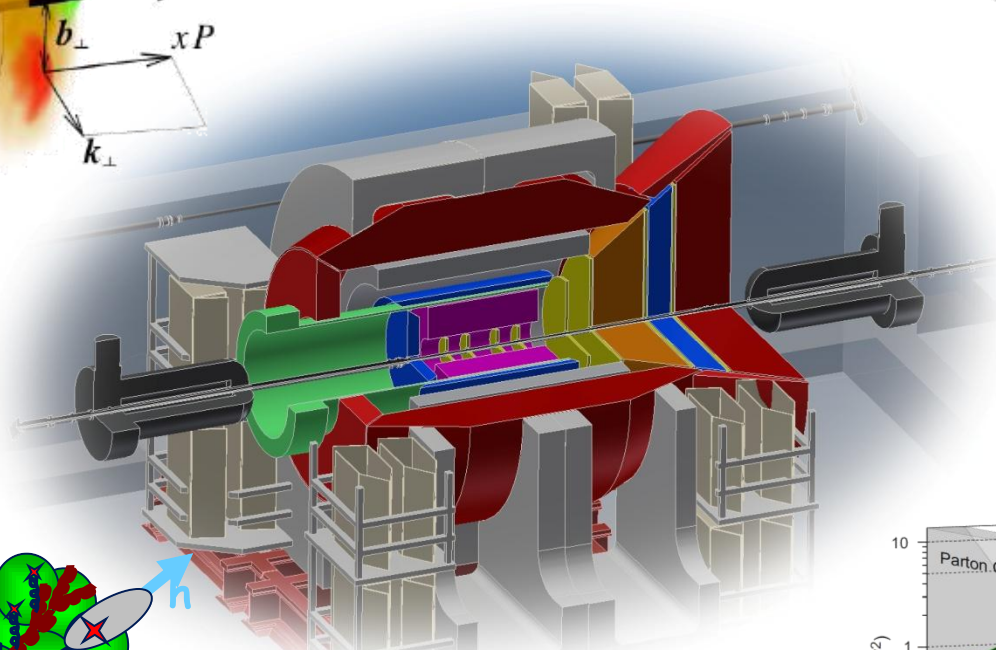
Jin Huang (LANL)

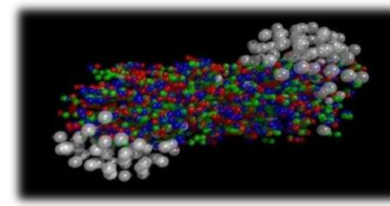
PHENIX

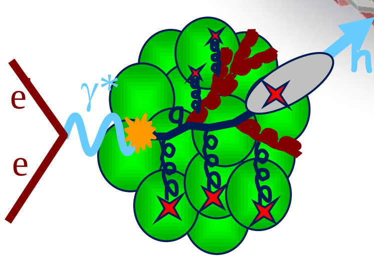


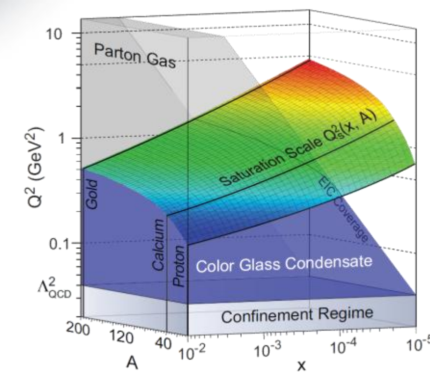












- ePHENIX is designed to be a comprehensive EIC detector at a moderate cost (connect to Kieran's talk).
- Magnetic field design and tracking define the topology of the experiment
- A upgrade path that supports pp, pA before EIC era (Joe's talk)

Brainstorming for fs/ePHENIX manget

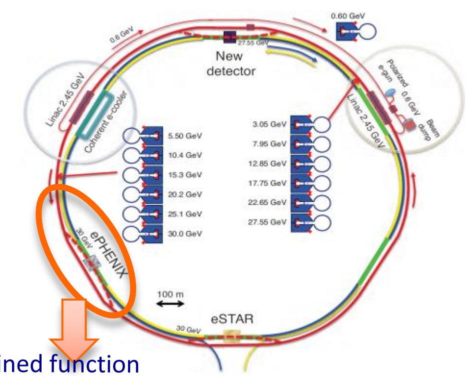
- PHENIX has been planning upgrade programs aimed at both central and forward region
  - Central MIE sent to DOE by BNL Apr 2013
- Productive series of workfests hosted to brainstorm/develop forward detector designs
  - Last workshop: May 2013 @ Santa Fe and July 2013 @ Japan/RIKEN
- Current progress
  - Converged on detector concept designs
  - We got the BaBar magnet! (See John. H.'s talk)
  - Performance quantified in first order
  - Developing GEANT simulation models
- ePHENIX LOI writing committee formed, planned collaboration release at end of August

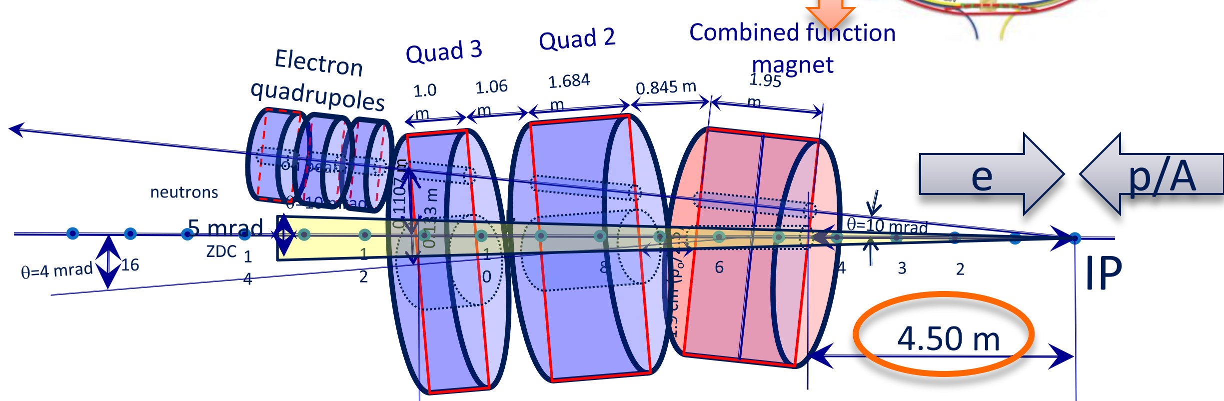
e/sPHENIX forward workfest, Santa Fe, May 21-25

PHENIX

Forward detector design
Goals and constraints

- Compatible with central arm upgrade
- Fit in the default IR for s/ePHENIX
  - IR limit in Z = 4.5m
  - Height limit of beam-rail of 4.5 m
  - No bending magnetic field on beam
- An upgrade path that supports pp/pA/AA

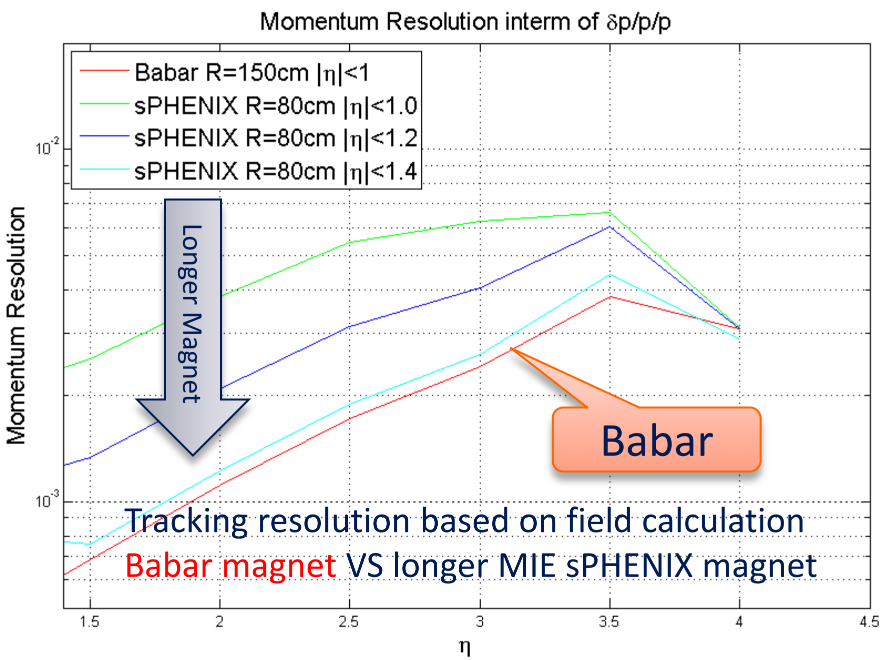




From D. Trbojevic

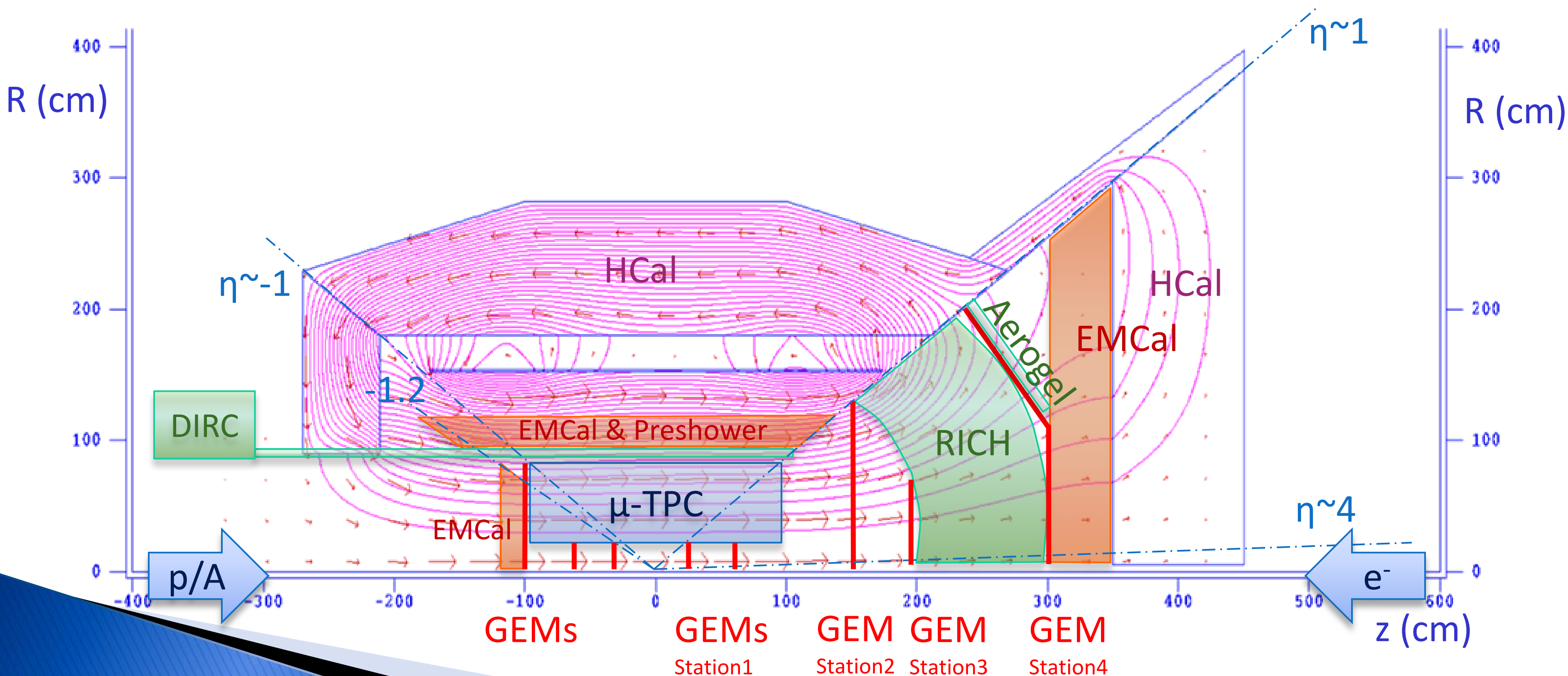
Recent development: Babar Magnet

- Cancelation of SuperB has made BaBar solenoid potentially available
- It is awesome news that PHENIX is getting it (See John. H.'s talk)
- Favor for ePHENIX tracking
  - Designed for homogenious field in central tracking
  - Longer field volume for forward tracking
  - Higher current density at end of the magnet -> better forward bending
  - Work with RICH

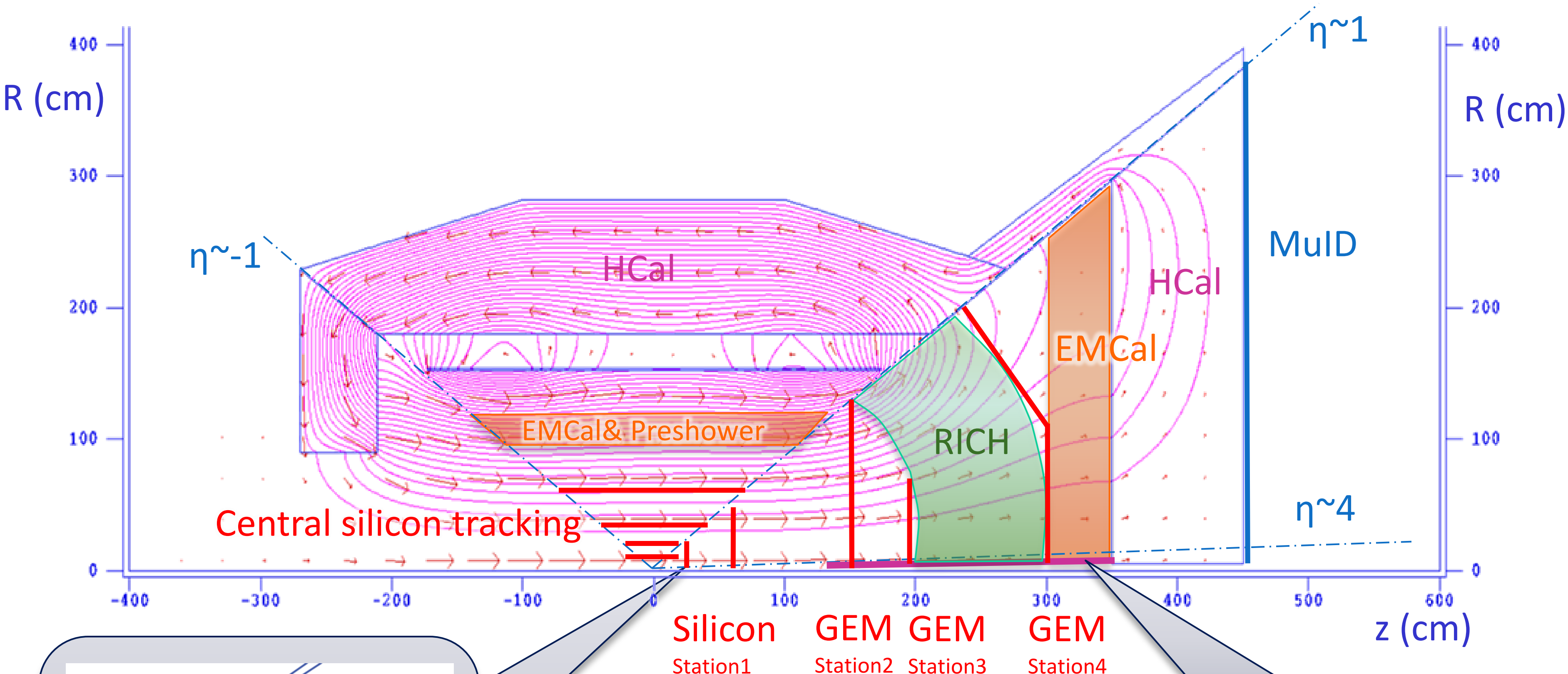


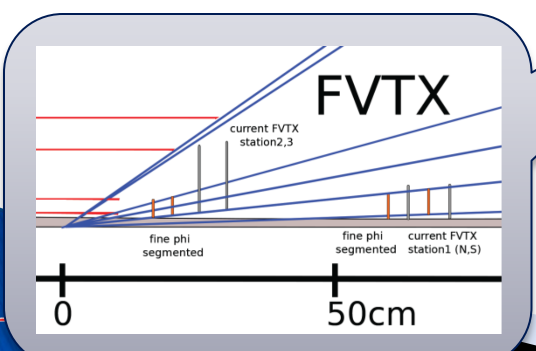
ePHENIX tracking/field overview

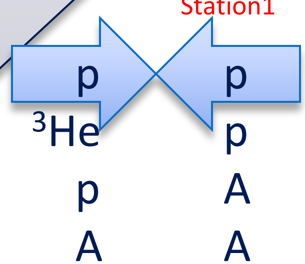
- Hadron-going direction: GEM tracker in fringe field
- Central rapidity: TPC tracker @ 1.5T longitudinal field
- Electron-going direction: GEM tracker @ 1.5T longitudinal field



Allow hadron collisions







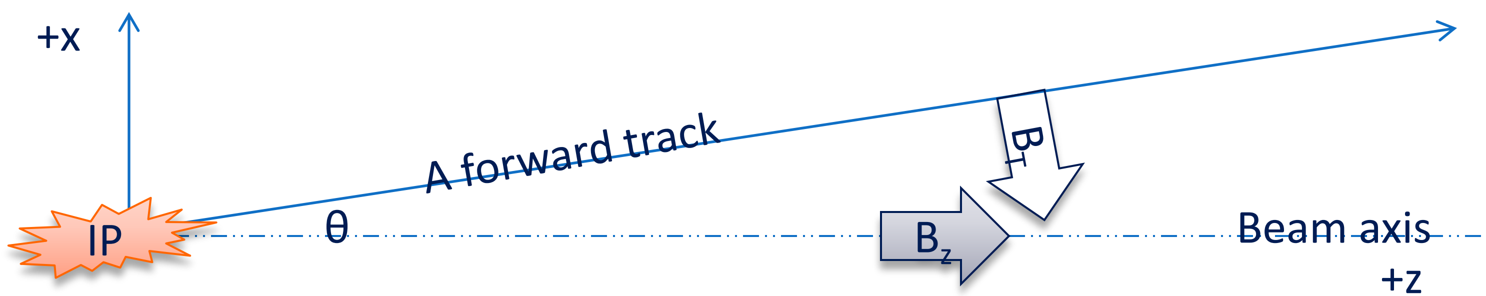
Forward field shaper (Cesar's studies)

Numerical field calculation from POISSION shown
Crosschecked with Opera/FEM and used in analysis of later slides

Hadron going direction

Tracking overview for forward directions

- Field transverse to the track → bending of the track → sagitta → measurement of (1/p)
- Besides brutal force increase of tracking resolution/field strength, geometry and field direction play an important role
- For a cylindrical symmetric field:



Transverse field is directly related to shape of central longitudinal field:

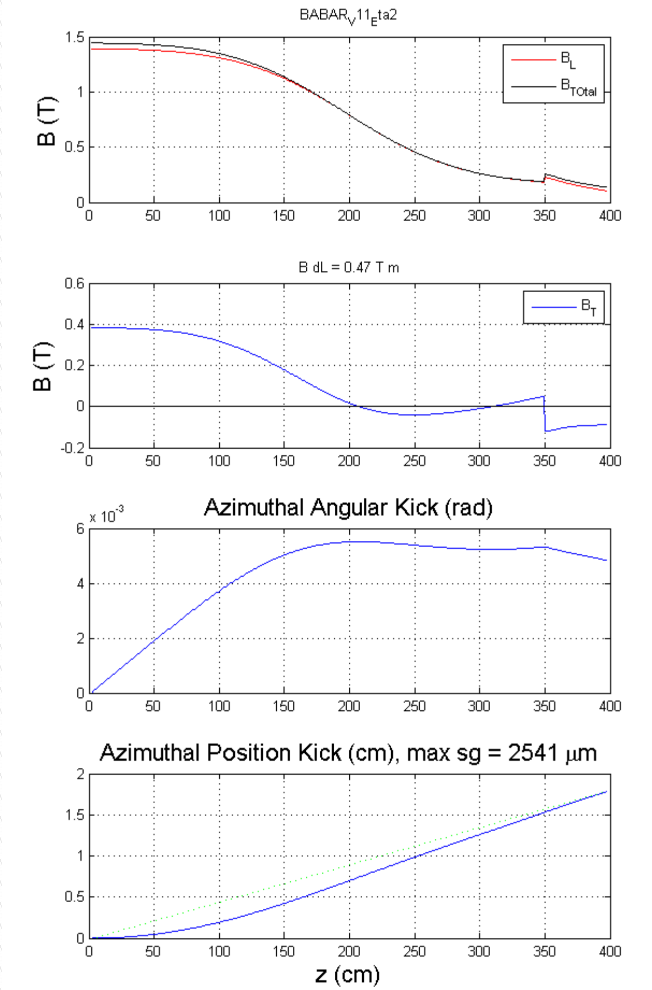
$$B_T = B_z \tan\theta + \frac{\tan\theta}{2} z \frac{\partial B_z}{\partial z} + O\left(\theta^2\right)$$

Geometry Term

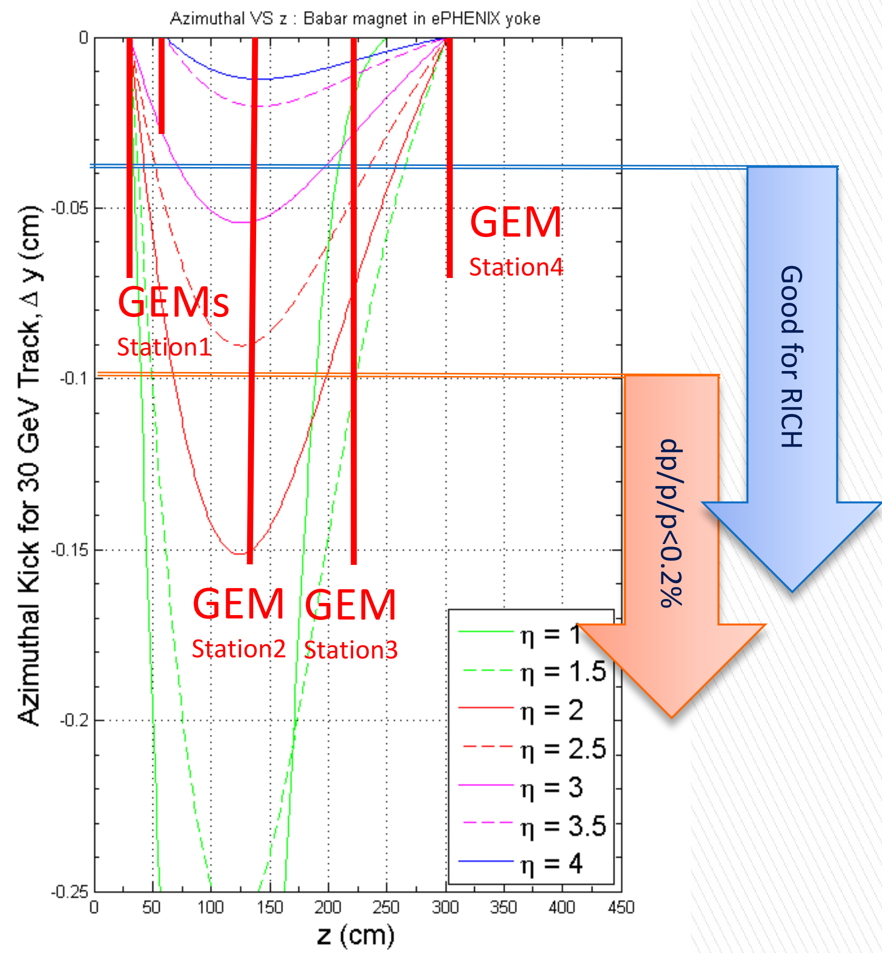
Flux Term

BaBar's graded current density help both

Tracking optimization with numerical field simulation



Using ϕ segmented GEM with resolution of R Δϕ = 50μm

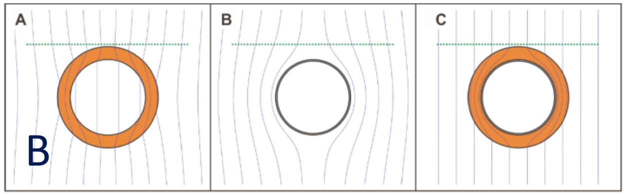


Magnetic bending
Track of η=2.0, p=30 GeV

Summary for sagitta
Track of p=30 GeV

Very forward tracking:
If we need improved forward field

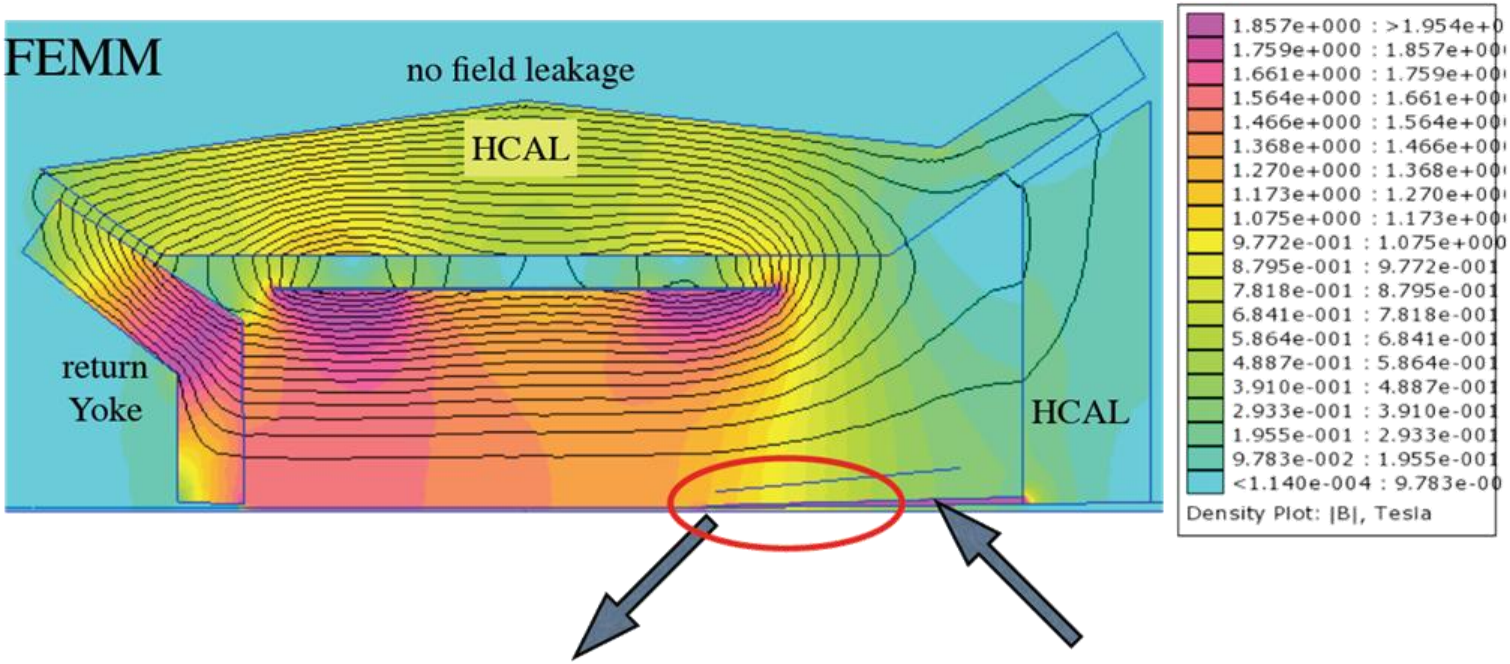
Design Family	Example
Piston	• Passive piston (C. L. da Silva) • Super conducting piston (Y. Goto)
Dipole	• Forward dipole (Y. Goto, A. Deshpande, et. al.) • Redirect magnetic flux of solenoid (T. Hemmick) • Use less-magnetic material for a azimuthal portion of central H-Cal (E. Kistenev)
Toroid	• Air core toroid (E. Kistenev) • Six fold toroid (J. Huang)
Other axial symmetric Field shaper	• Large field solenoidal extension (C. L. da Silva) • Pancake field pusher (T. Hemmick)

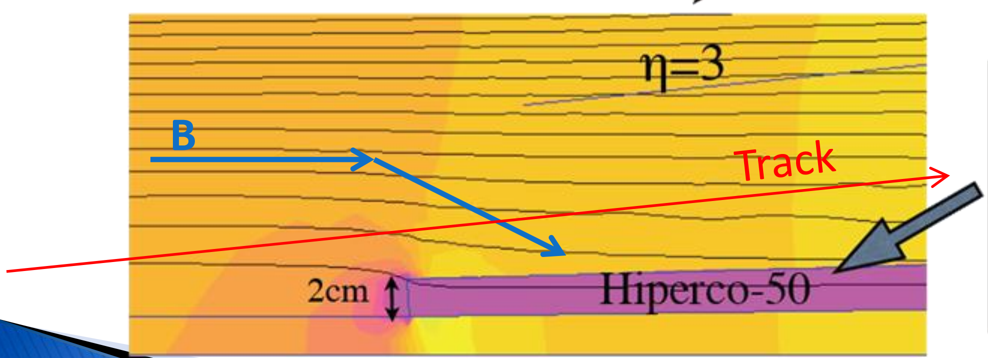


Beam line magnetic field shielding, based on superconducting pipe.
Test device planned (Stony Brook Group)

Very forward tracking: Passive piston field shaper

by C. L. da Silva





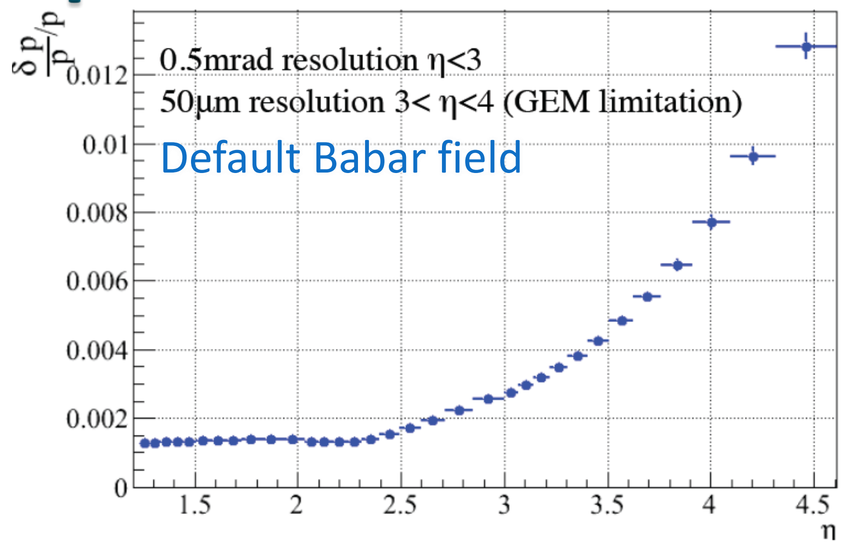
Passive Piston helping flux return at small angle

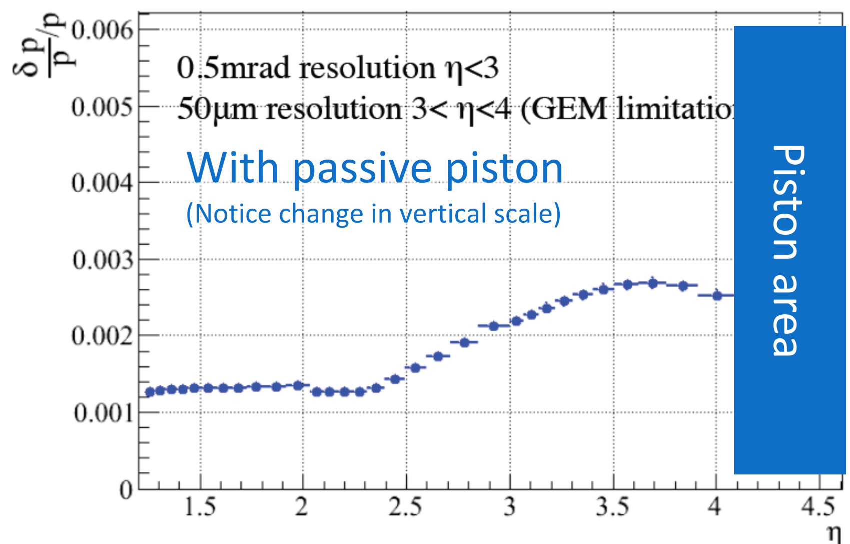
Hiperco-50: 49%Co+49%Fe alloy provide high field saturation (<2.25T)

Very forward tracking: Passive piston field shaper Performance

by C. L. da Silva

- Advantage :
  - Significantly improved very forward field where Babar field is least effective
  - Simple implementation
  - Minimal interaction with Babar field and beam
- Challenges that under study
  - Blocking Hcal acceptance of 4<η<5 for diffractive studies
  - Background shower from piston
  - Further improvement limited by total piston flux (may use silicon detector)
- Good ideas for improving momentum resolution is there. Not have to use for stage-I EIC, Not in LOI base design.



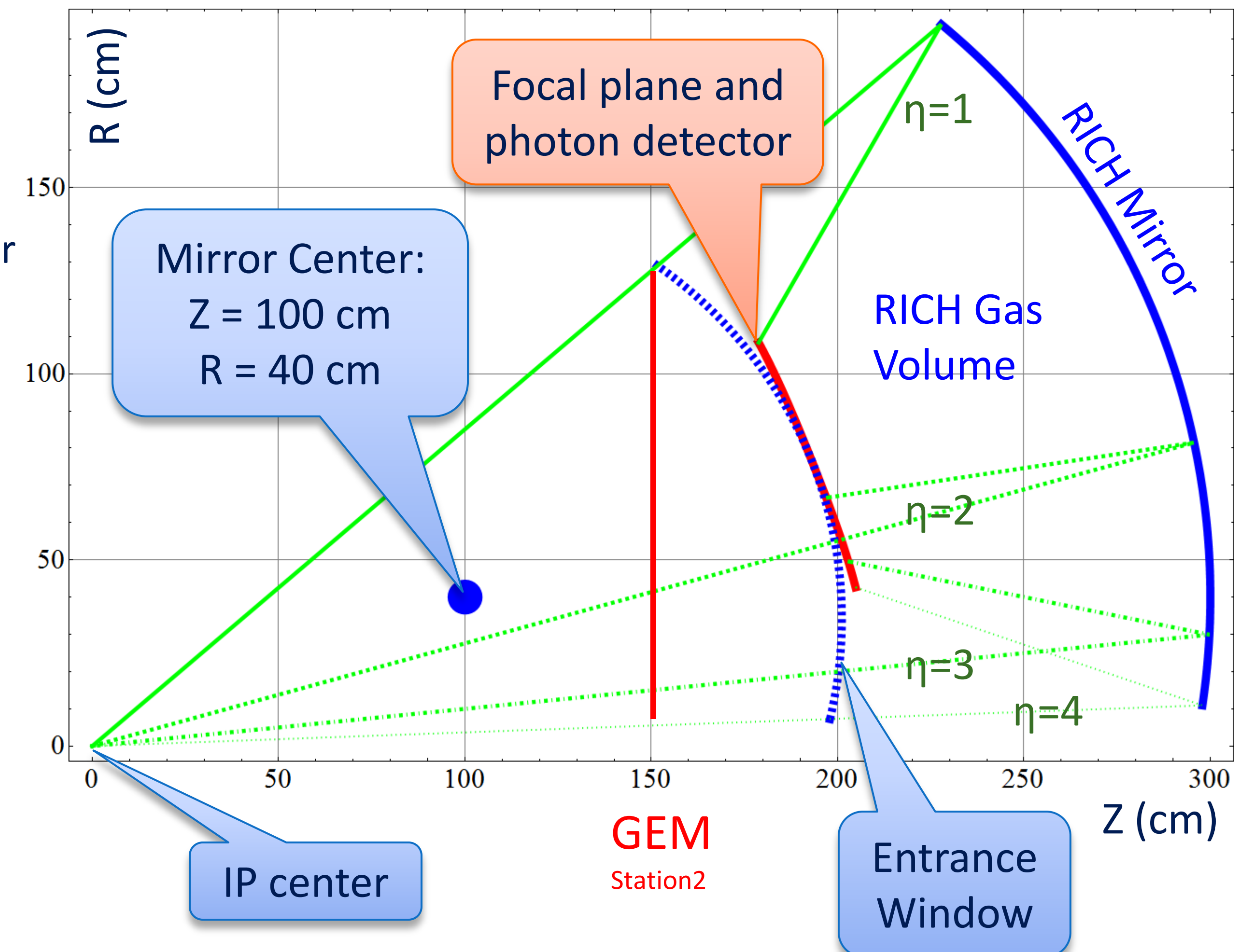


RICH with ePHENIX tracking and field: Generic feature of current design

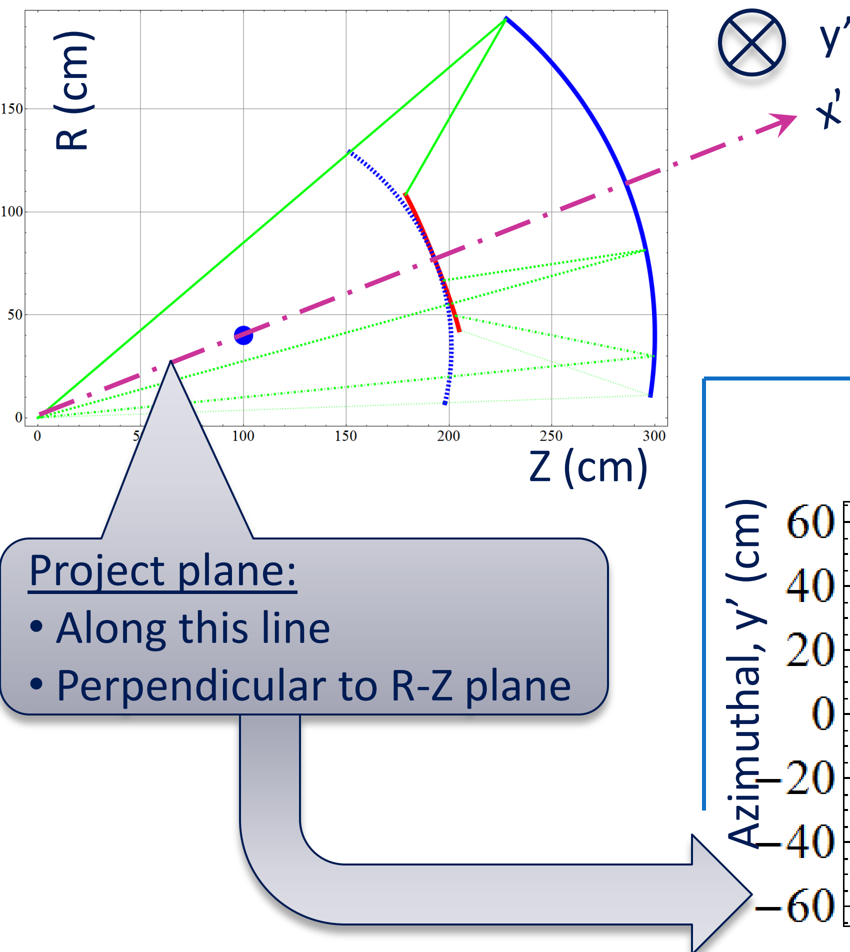
- Good optical focusing – spherical mirror
- Generic geometry – Mirror R = 2m
  - spherical mirrors focus light to a inner sphere of half radius at leading order (from Tom)
  - Therefore, for 1m RICH volume -> ~1m focusing distance -> ~ 2m RICH mirror radius
- Mirror segment – six (or eight) azimuthal segments
  - Following study shows that it is best to make mirror center away from beam line -> need azimuthal segmented mirror and photon detectors
  - Minimize number of azimuthal segments -> minimal rings crossing the edges
- Focal plane – Six flat readout planes (~triangle shape, 70x70 cm)
  - Analytically calculated for RICH light at the vicinity of the primary tracks
  - Almost flat surface for optimized design
- RICH Entrance window – match well with GEM and
  - Analytically fix to 1m RICH gas volume for tracks originated from IP center

RICH with ePHENIX tracking and field: Proposed Design: R-Z projection

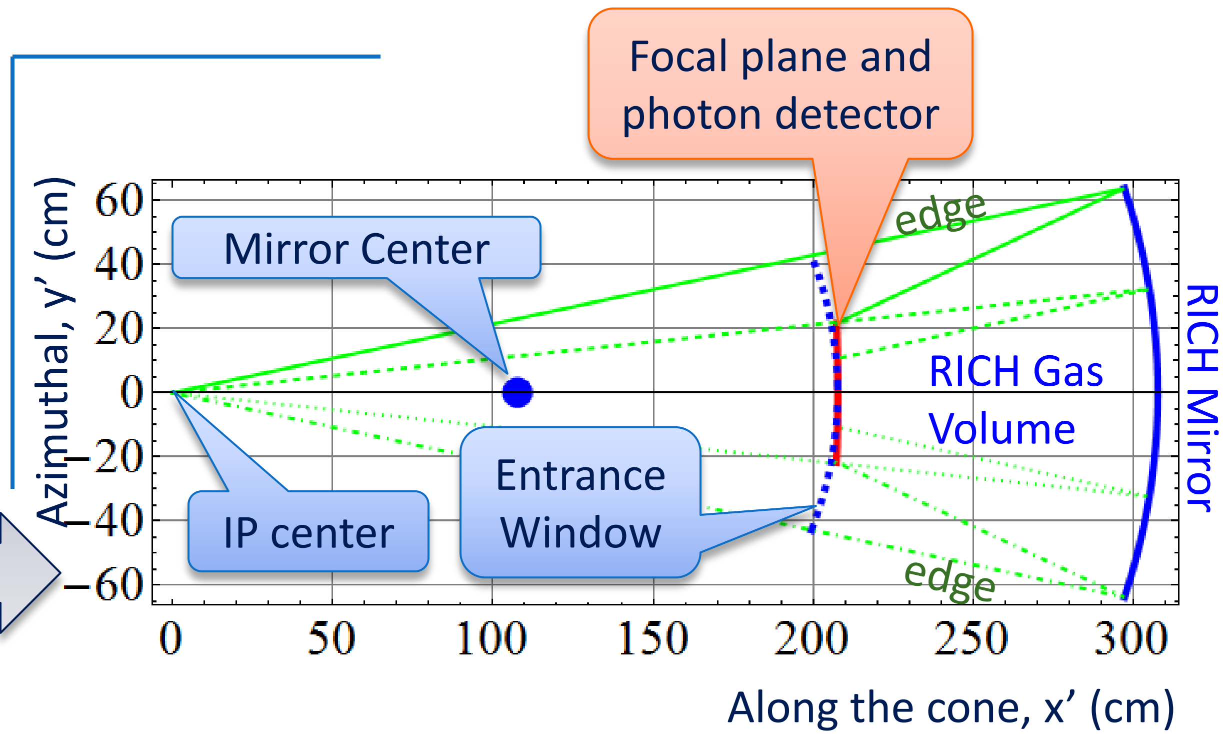
- "Beautiful" optics and assuming spherical mirrors
- 1 meter RICH gas volume along track
- Photon sensor is flat (easier for GEM construction)
- Small area for photon readout
- Avoid invading tracking space (Z > 1.5m, away from the optimal sagitta plane)
- Z < 3.0m from EMCal limit and allow a volume for aerogel at lower eta
- Defocusing due to extended vertex is small for most (Z-η). Defocusing <5% θMAX for worse case(Z-η) = (50 cm, 1.0)



Proposed Design: azimuthal projection

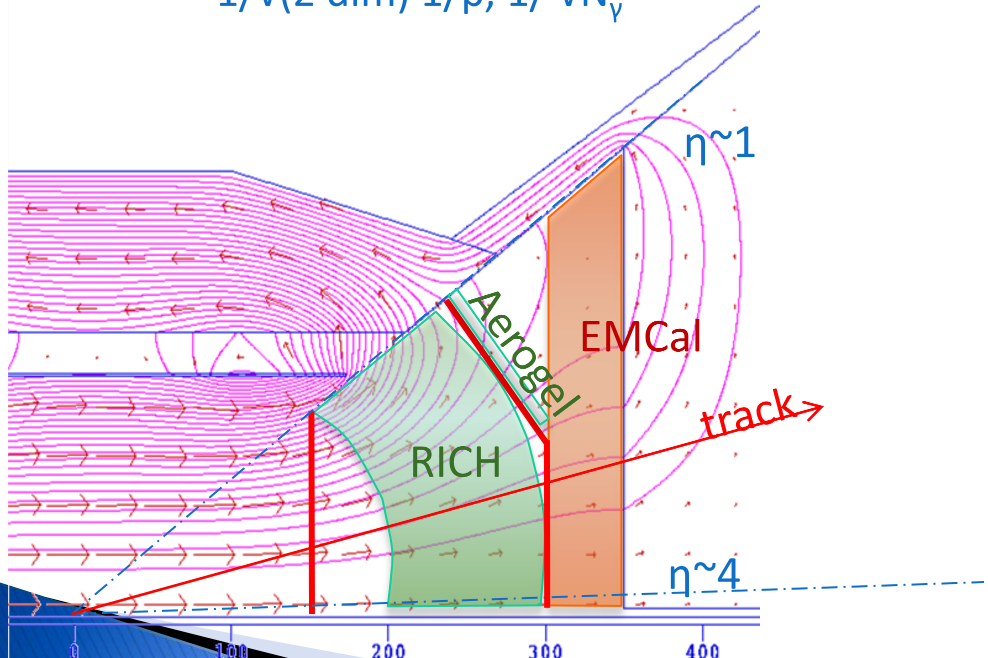


- One of 6 sextants shown
- Size x~2 along the eta=1 cut



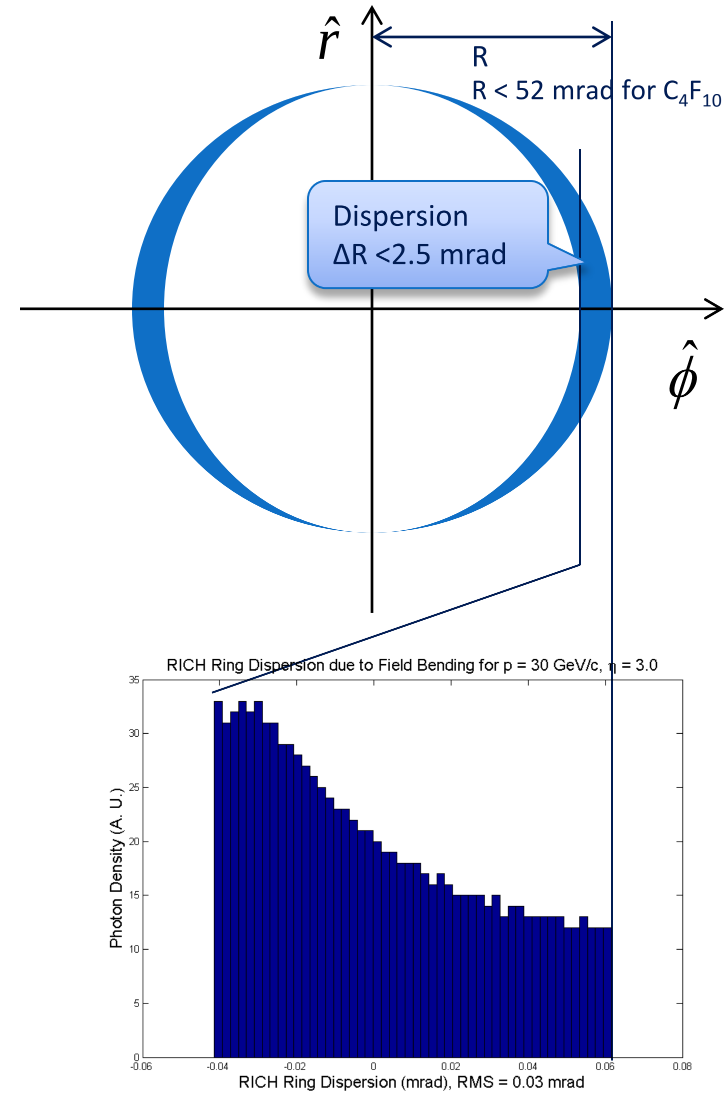
Estimating field distortion for RICH

- Field calculated numerically with field return
- Field lines mostly parallel to tracks in the RICH volume
- Field distortion of RICH ring only contribute to a minor uncertainty
  - Uncertainty on R suppressed by $1/\sqrt{(2\ \text{dim})}$ $1/p$, $1/\sqrt{N_\gamma}$



A RICH Ring:

Photon distribution due to tracking bending only

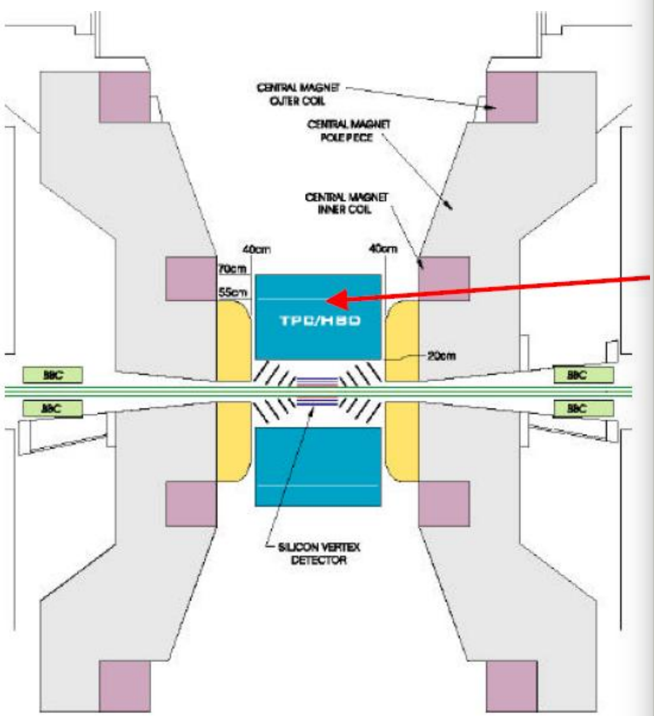


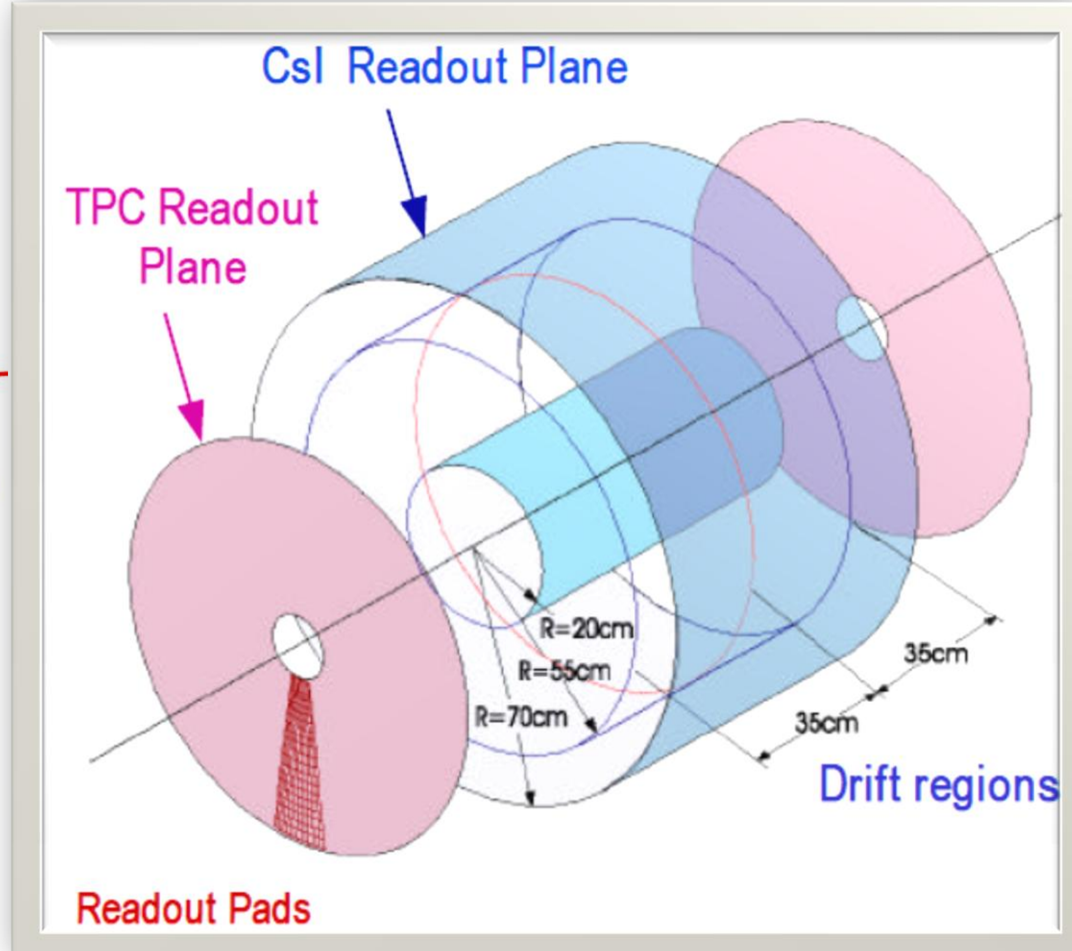
Central barrel tracking

Designs considered

- Under assumption that VTX can not be used for ePHENIX
  - Assuming cumulated radiation dose is high due to sPHENIX operation
  - Need tracker with low radiation length
- Compact GEM based TPC
  - Thin in material and easy for readout
  - Limited hadron PID for p<1GeV
  - d(1/p) ~ 0.4%/GeV for a micro-TPC design as next few slides
  - Default design and used for costing
- Cylindrical GEM tracker
  - Good resolution per plane
  - Need to concern about field effect : drifting direction perpendicular to magnetic field. Back-to-back GEM per layer considered
  - d(1/p) ~ 0.4%/GeV for 4 layer GEM tracking

Once upon a time there was a TPC proposed for PHENIX

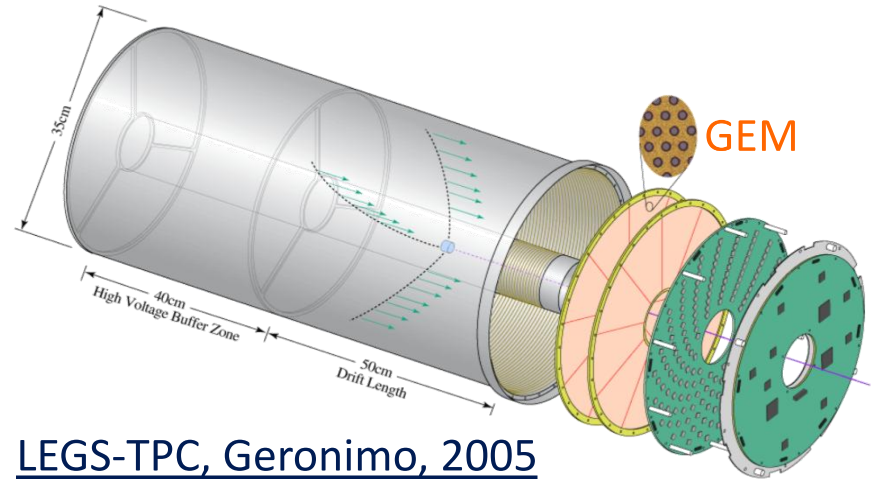




Craig Woody, Linear Collider Workshop, 2003

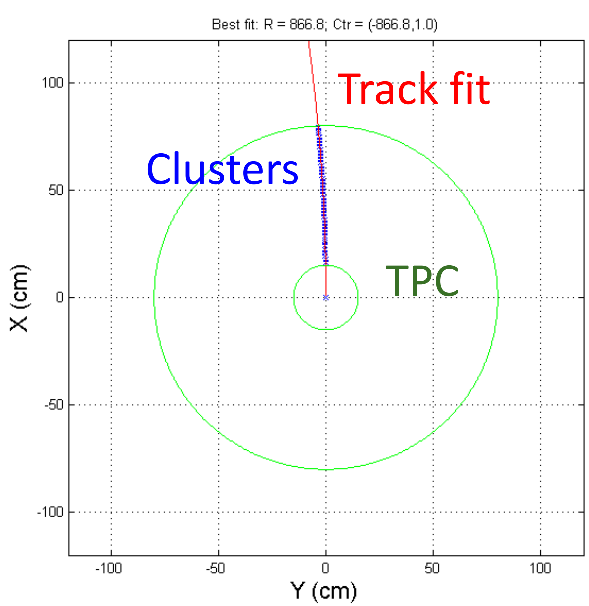
TPC

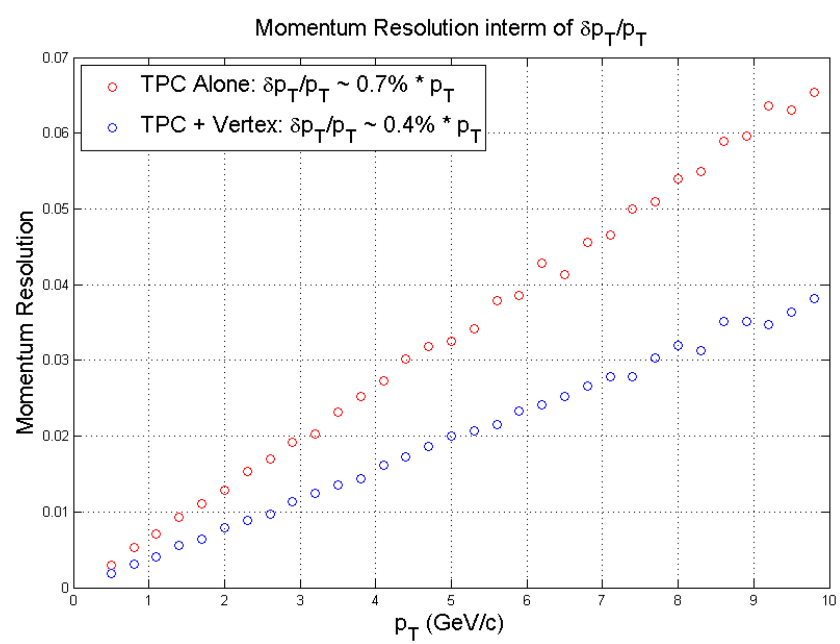
- Based on LEGS-TPC design
  - 80% argon, 10% CF_4 and 10% CO_2
  - Max 10μs drift time
  - GEM for amplification
- Tracking studies
  - 1.5 Tesla field
  - Radius = 15 – 80 cm (~1/3 STAR TPC), Length = ± 90 cm
  - RΔϕ resolution = 300 μm
  - 40 R segments, 2 mm RΔϕ readout pad segmentation



LEGS-TPC, Geronimo, 2005

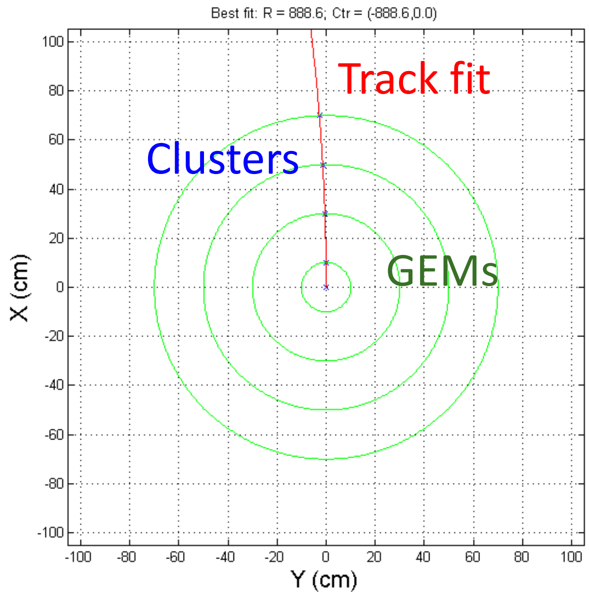
LEGS: Laser Electron Gamma Source @ BNL

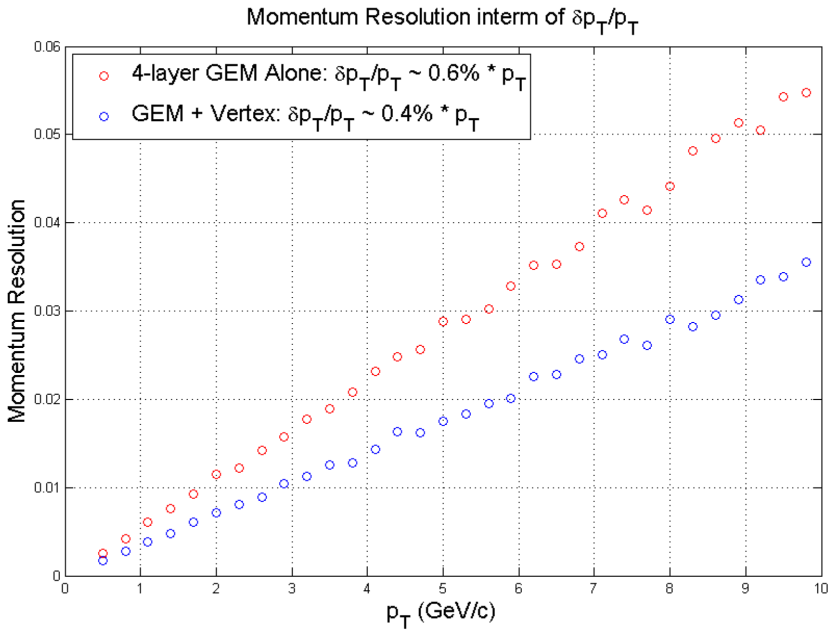




Cylindrical GEMs

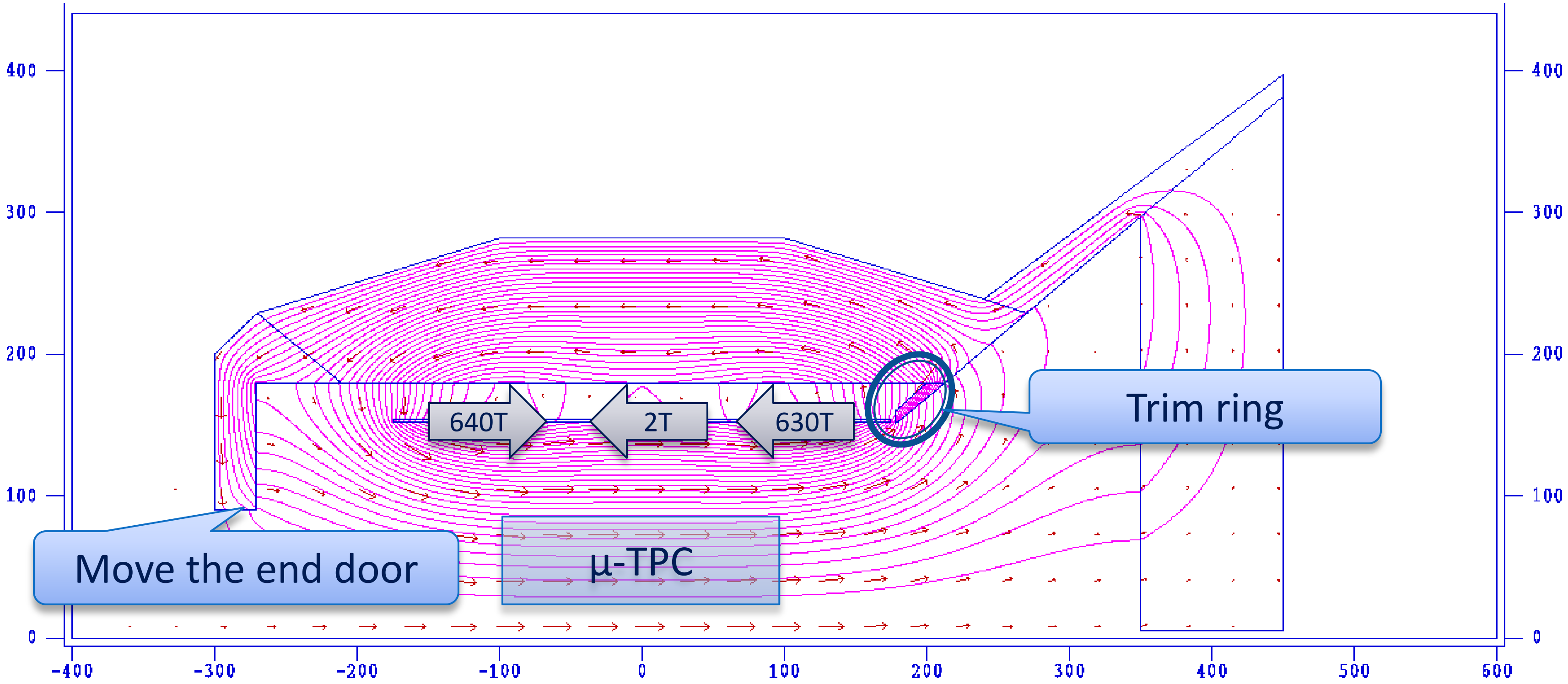
- GEM considerations
  - Fine segmented in the ϕ direction for momentum measurement
  - Back-to-back two GEMs per layer to cancel magnetic drifting effect in leading order
- Tracking study:
  - Uniform 1.5 Tesla field
  - 4 GEM layers at R = 15, 30, 50, 70 cm
  - ϕ resolution , $\delta(\phi * R) = 100\ \mu m$





Further tweaking the yoke

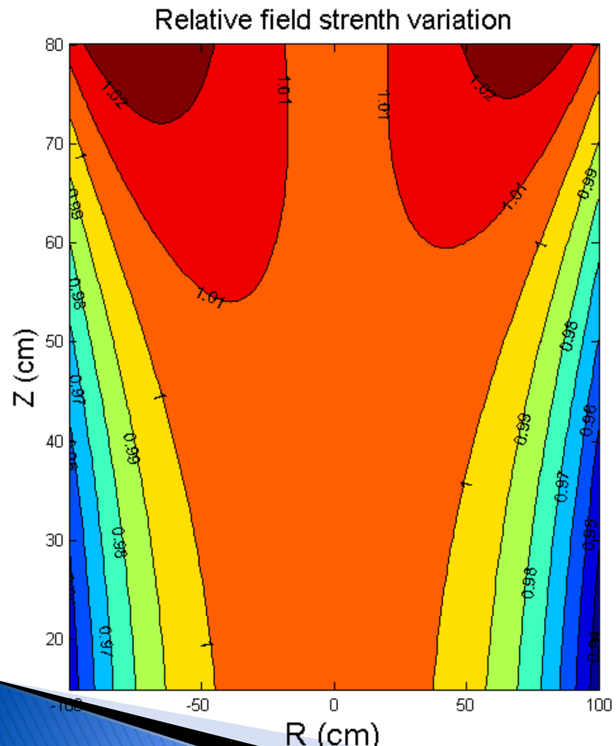
Significantly improved field uniformity and balance



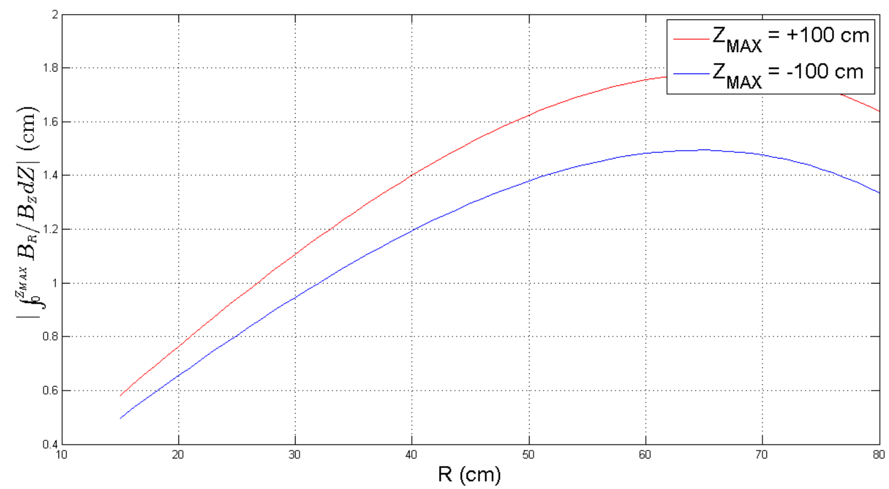
Net force on coil reduced from ~300T to few T

Further study needed

- Reached quoted uniformity for Babar (±3% for central tracking volume)
- But is it enough for TPC? – Further optimization needed



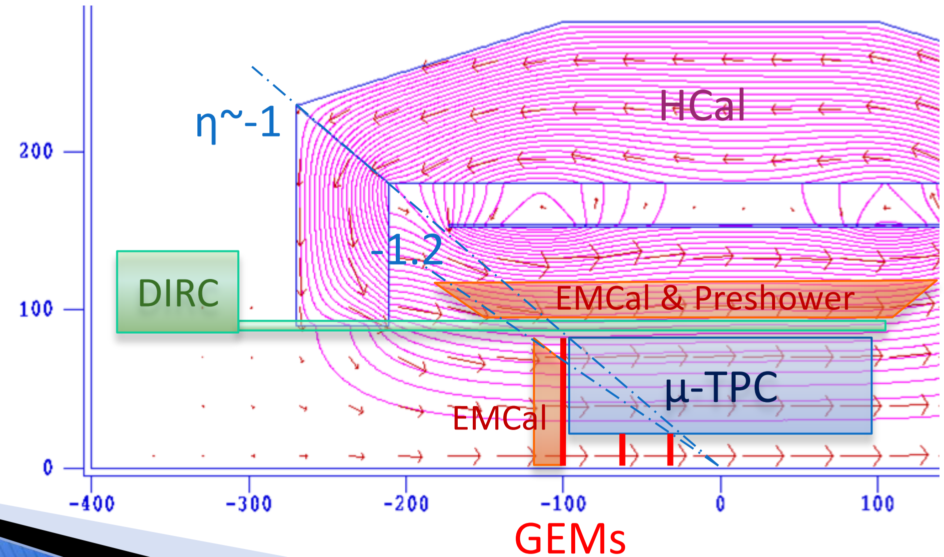
Field correction ~ few mm in Rϕ



Electron going direction tracking

Considerations

- Tracking space for electron-going direction is very compact; Z>-100 cm
- However, a few percent momentum resolution is only needed for E/p matching at p<a few GeV (See Kieran's talk)
- Use a combination of phi segmented tracking detectors
  - $-1.0>\eta>-1.5$: TPC track segment
  - $-1.5>\eta>-2.0$: Vertex + GEM + TPC
  - $-2.0>\eta>-3.0$: Vertex + GEM
  - dp/p<5% for p<4GeV: good enough for E-P matching and electron ID

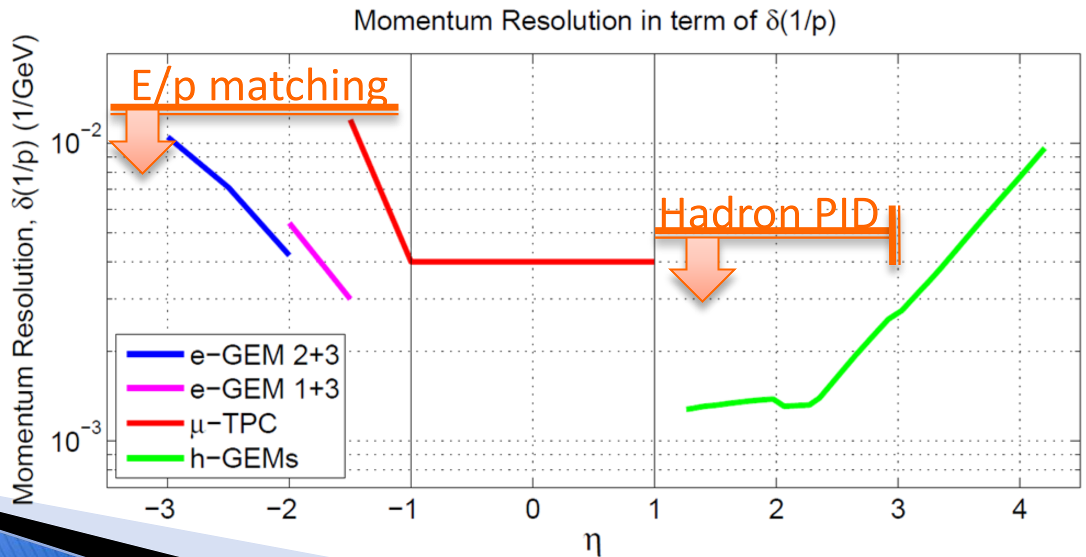


Vertex for electron direction tracking

- Vertex used in electron side track fitting for hard scattering events
  - For exclusive events, electron ID can use event topology
- Use timing system for vertex measurement
  - Electron beam bunch ~ mm width, its location VS time marked by RF time
  - High precision timing detector serve as BBC for hadron going side
    - Cover $4<\eta<5$ @ in front of EMCal,
      $\Delta T<30$ ps → $\Delta z_{VERTEX} < 5mm$ → $dp/p \lesssim 2\%$
    - Possible by MRPC / MCP-PMT technologies
    - For high multiplicity events, can be further refined by tracking

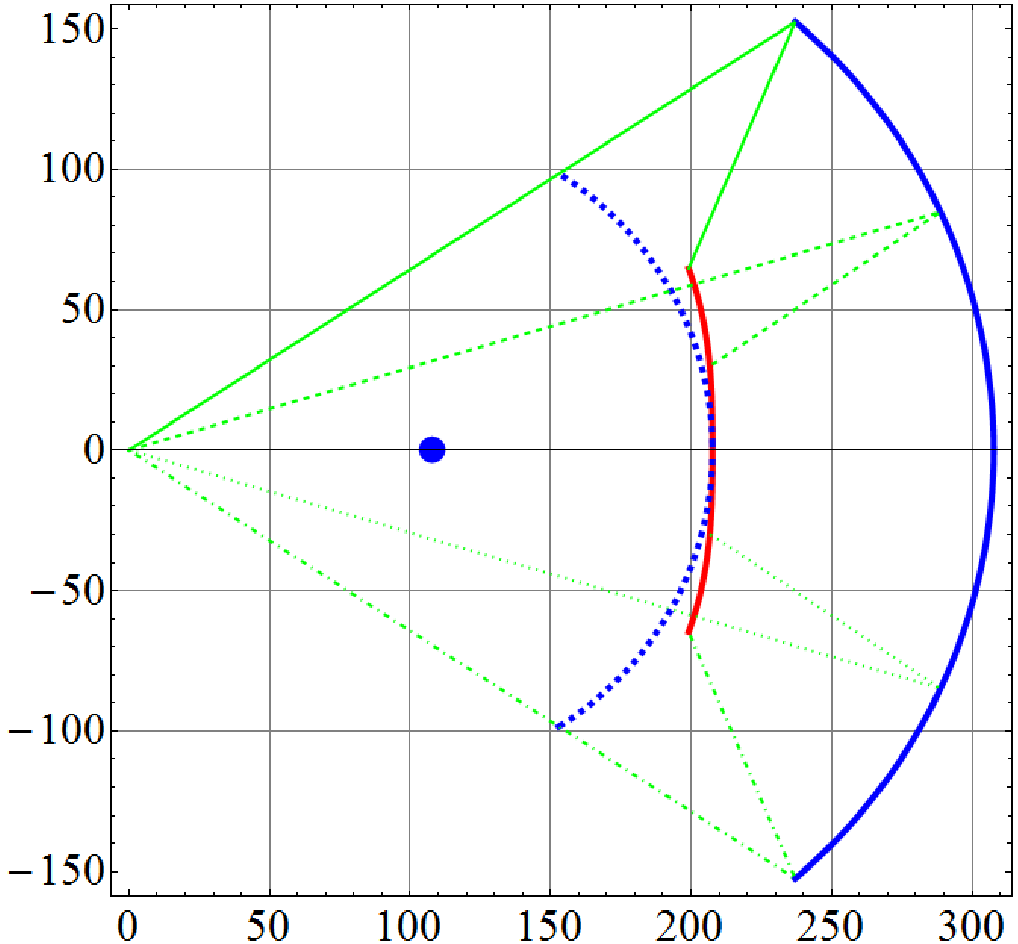
Conclusion

- BaBar magnet is very efficient for ePHENIX
  - 1.5 T nominal central field
  - Large field volumne and graded coil -> better tracking @ forward
  - Good field homogeneity in central region
- A set of yoke and tracking design proposed
  - Initial design indicates good enough for ePHENIX main purpose at 1st stage
  - More detailed work are needed and on the way
  - Improvement ideas always welcomed



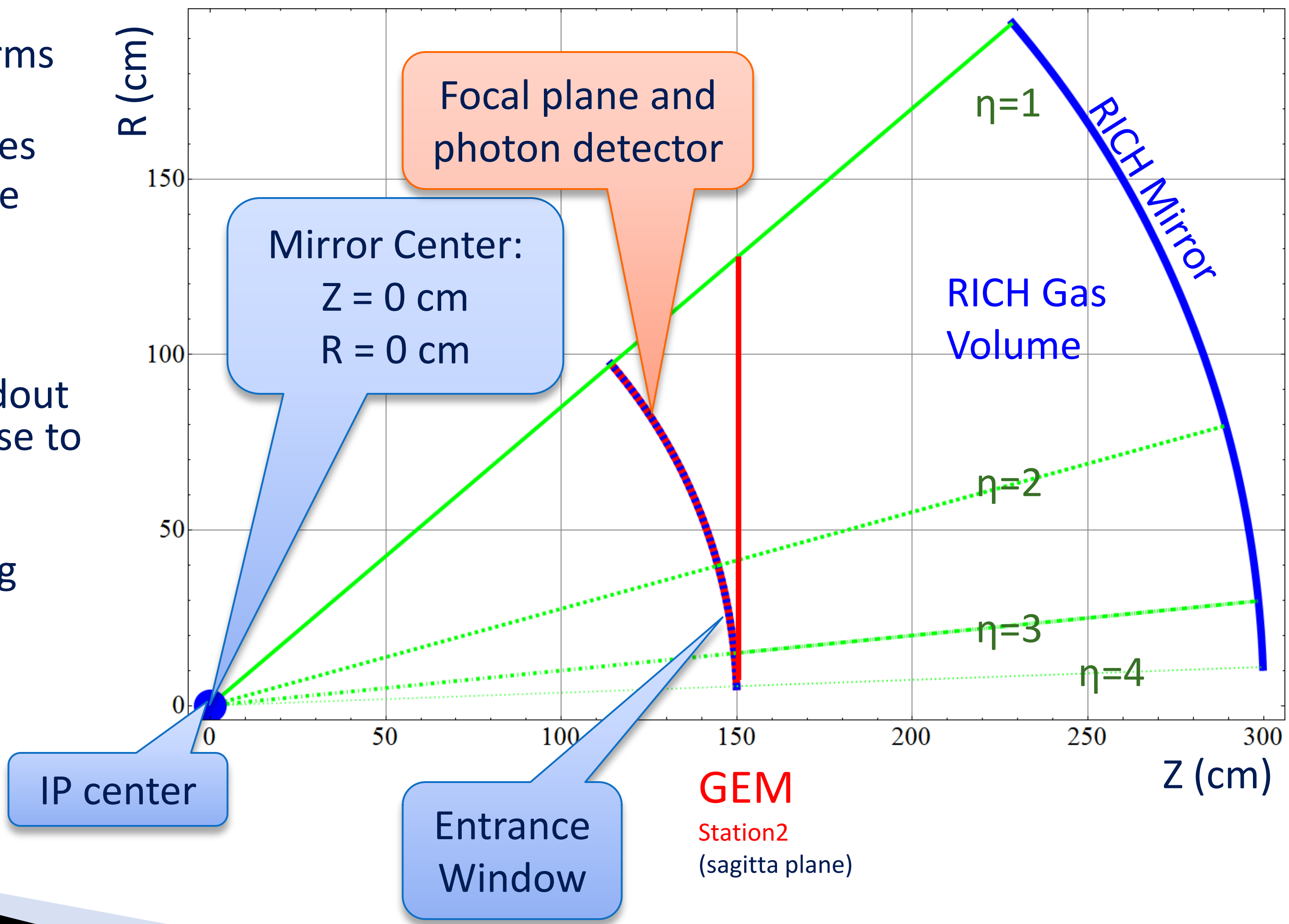
Backup Slides

Extended Shape of the focal Plane



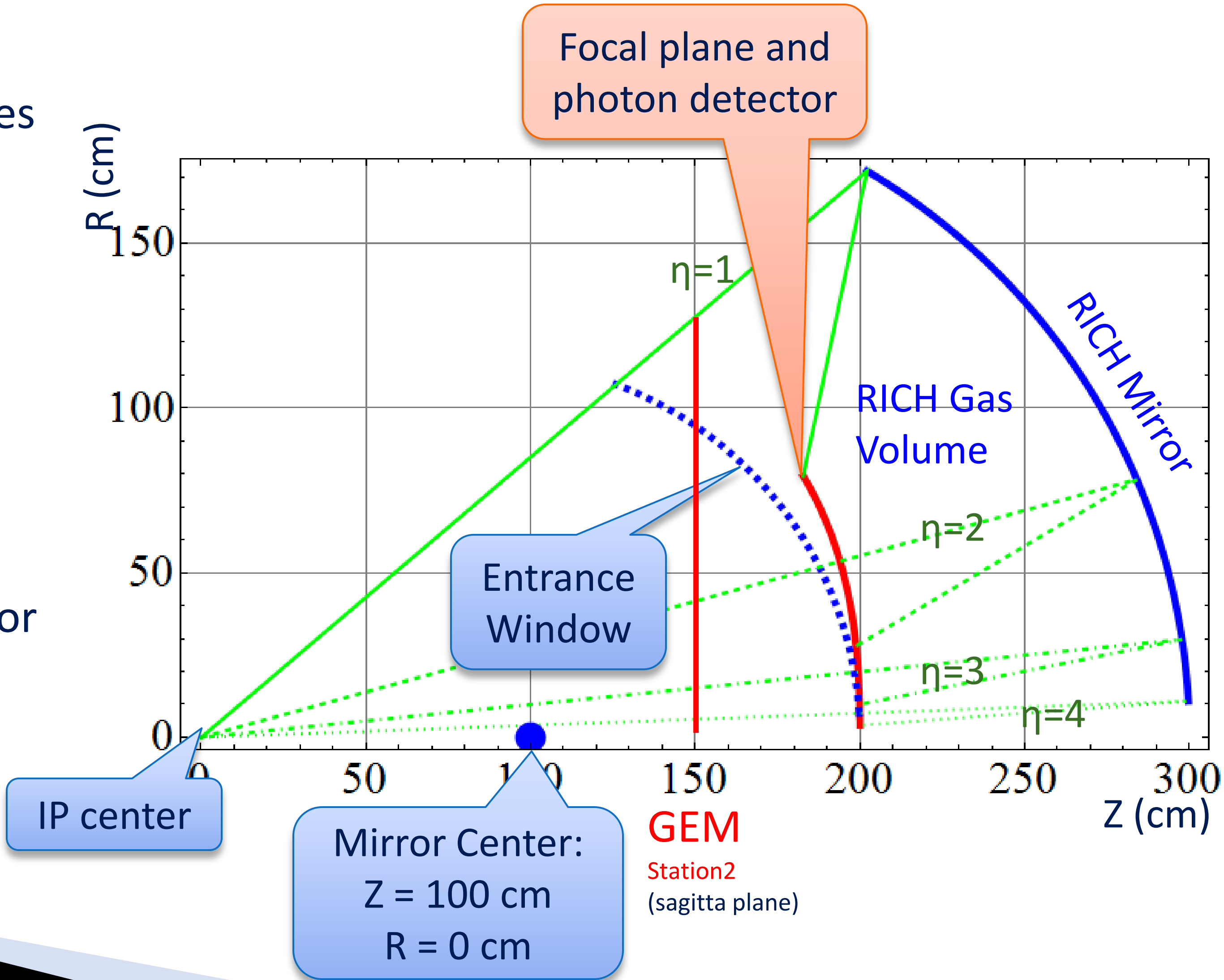
Considered Design: Ideal optics

- Advantage
  - Perfect optics (forms circle rings)
  - No azimuthal edges
  - Large RICH volume
- Disadvantage
  - Cut into sagitta tracking plane
  - Large area to readout RICH photons/close to beam line
  - Limiting space for additional tracking plane for pattern recognition



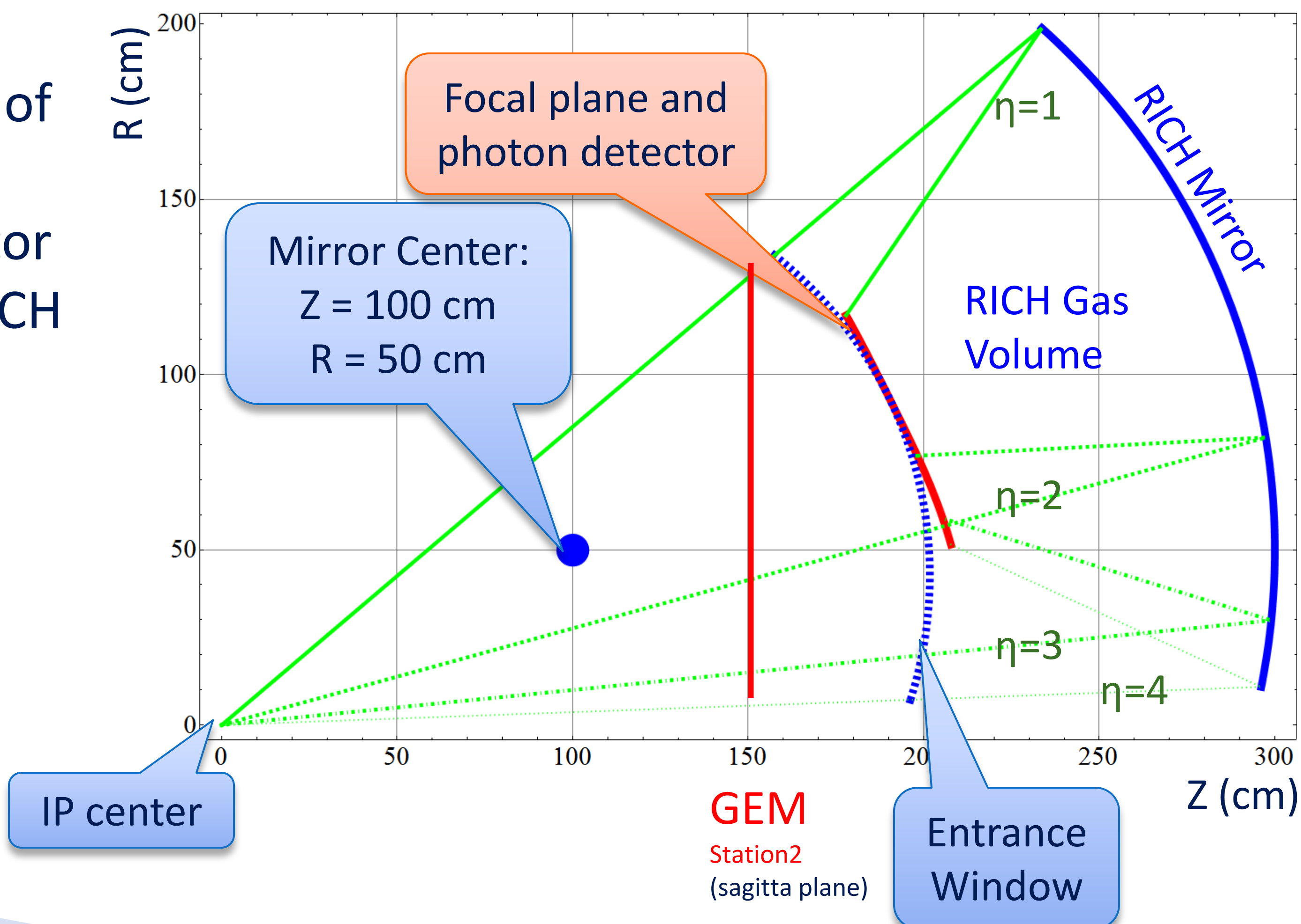
Considered Design: Single sphere mirror

- Advantage
  - No azimuthal edges
- Disadvantage
  - Cut into sagitta tracking plane
  - Focal plane is too close to beam
  - Focal plane is not flat
  - Steep angle of impact on the photon detector for low eta RICH photons



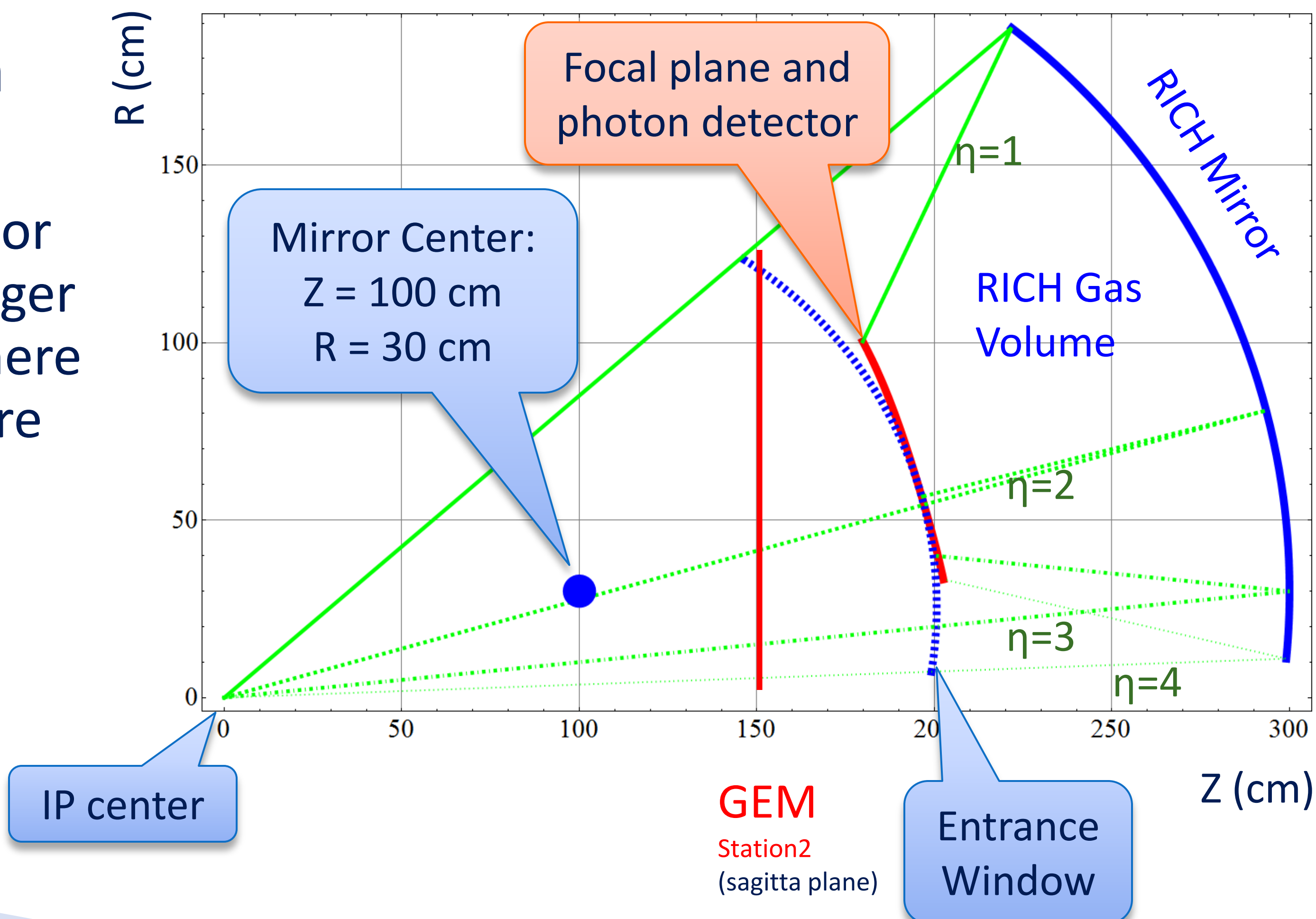
Considered Design: More off-beam

- Disadvantage
  - Steeper angle of impact on the photon detector for high eta RICH photons



Considered Design: More focus-to-beam

- Similar to the default design
- Disadvantage
  - Photon detector moves into larger eta region, where tracking is more vulnerable to multiple scattering



Considered Design: Less azimuthal segmented - Quadrant

- Advantage
  - Less edges (four azimuthal edges)
- Disadvantage
  - Steeper angle of impact at focal plane -> more stretched elliptic ring
  - This problem is double worse along the cone of eta=1