Detector: magnetic field concept studies

Rolf Ent, EICC meeting at LBNL, Dec. 11 2008

General idea: use parametric MC studies to guide magnetic field choice for detector/accelerator lattice, and guide space requirement for general purpose detector
(as opposed to a "Caldwell-type" detector).

90+% of the work was done by Tanja Horn, with some input from Richard Milner and me.

We had quite some progress during a week at MIT, as part of an ongoing NSF/REU program at Hampton with some 8-10 students annually involved in a Hampton/MIT Summer program for undergraduate research with an Electron Ion Collider, started in 2007.

Emerging detector concept

(from ep summary@EIC08 meeting)

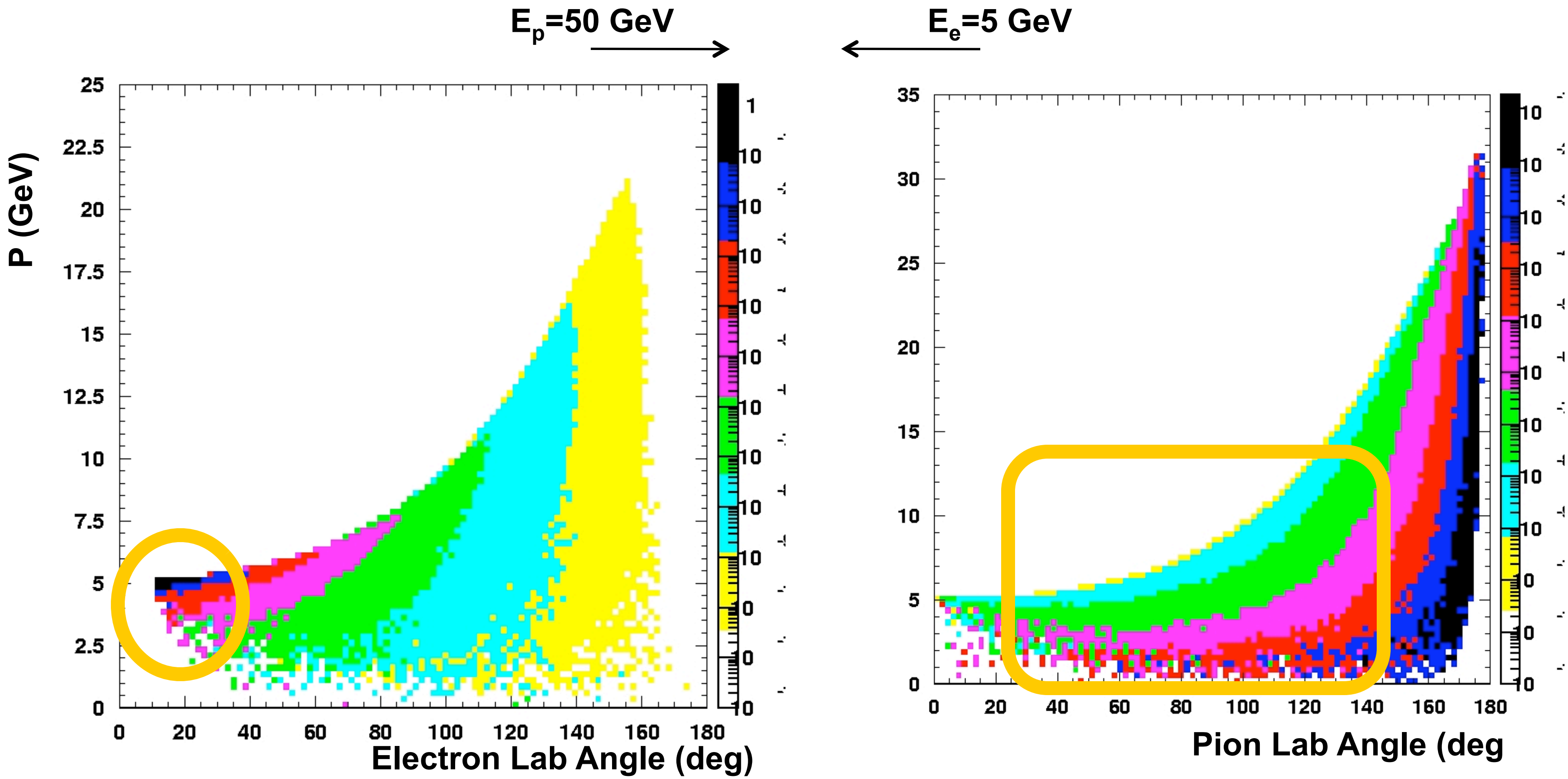
- 2 "main" components
  - electron detection in forward direction ($\theta<40^0$)
  - final state detection and hadron identification in proton direction (θ > 140^0 ?)
- some low resolution energy measurement for central angles
- vertex detection (resolution better than 100 μm)
- plus:
  - electron detection at very low angles (how?)
  - detection of "recoiling" neutron and proton (maximum acceptance)
- plus:
  - luminosity measurement with accuracy of ~ 1%
  - polarization measurements with accuracy of ~ 1% (both electron

Emerging detector concept

(from ep summary@EIC08 meeting)

- Open questions (certainly not complete):
  - what is the optimal magnetic field configurations for such a detector ?
    - simple solenoid most likely NOT sufficient
    - solenoid plus toroid or solenoid plus dipole ?
  - what angular/momentum resolution do we need for the electron?
  - what angular resolution do we need in the hadron detection?
- what about jet physics ???
- what about e-A ?
- any other processes not yet considered ?
- how do we get a real handle on backgrounds from beam gas events ?

$^1H(e,e'\pi^+)n$ – Electron and Pion Kinematics



- Most electrons scatter at angles <25°
- More forward angles correspond to (very) low Q^2 → not likely that good resolution is needed → solenoid may be "o.k." for electron side, or "small" dipole field addition.
- BUT access to the high Q^2 region of interest for GPD studies requires larger electron angles → reasonable resolutions needed for ~5-10 GeV particles.

General Considerations for Magnetic Fields

- Solenoid is "easy" field, but not much field at small scattering angles

- Toroid would give better field at small (~5 degrees) angles with an asymmetric acceptance
  - Improves acceptance for positive hadrons (outbending)
  - Improves detection of high Q^2 electrons (inbending)
  - Limits acceptance at very small angles (~3^o?) due to coils
  - May limit acceptance for π+π- detection

- Vary Solenoid field to see how far one can push and compare with toroidal field
  - But … may not want too large a central solenoid field to access low-momentum reaction products from e.g. open charm production (~0.5 GeV/c)

- Could also add central toroidal or dipole field(s) to solenoid
  - Small dipole component may be useful for lattice design (~0.3-0.5 Tm?)
  - goal of dipole field on electron side to optimize resolutions
  - goal of dipole field on hadron side to "peel" charged particles away from beam

Detector Considerations @EIC

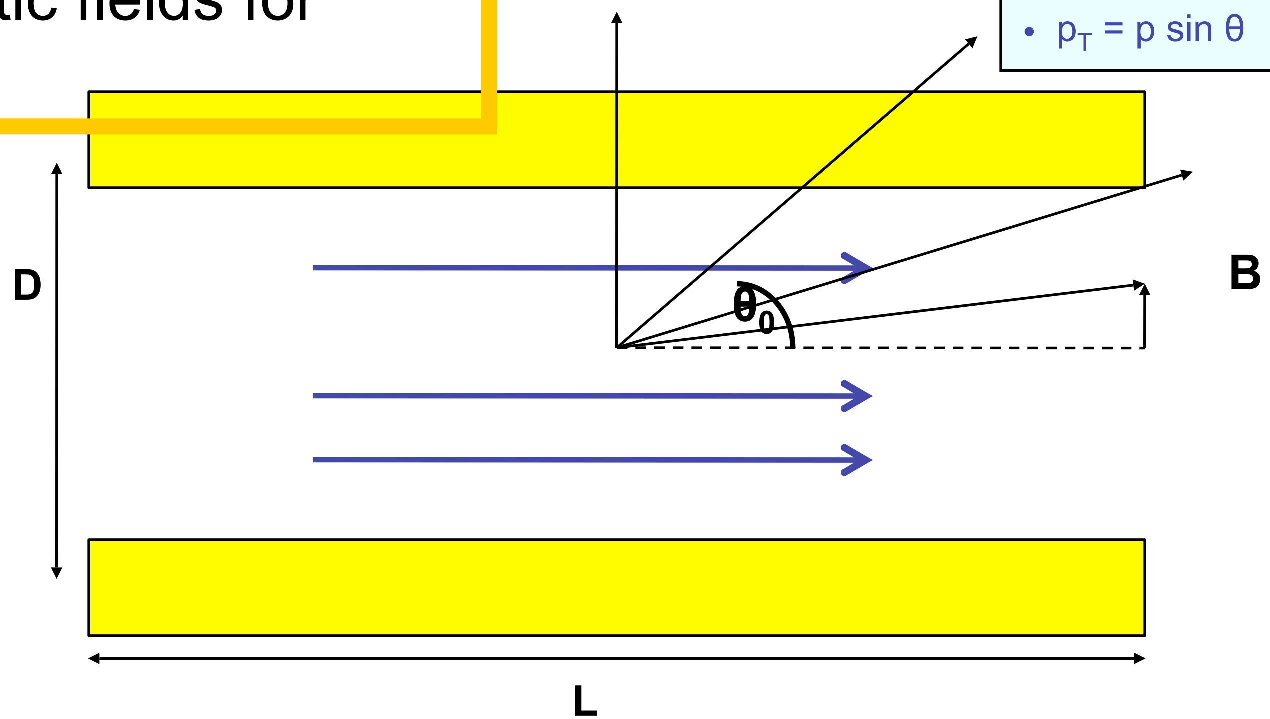
(status@EIC06 meeting)

Open Charm Production **(Glue, Glue, Glue!)**:

1) Dominant reaction mechanism through glue at small x → e/ion momentum mismatch not so relevant and created nearly at rest → Decay products at large angles.
2) Background reduction critical issue → requires **<100 μ vertex resolution** → drives vertex detector
3) Decay products have typical momenta between 0-2 GeV → Need good particle id in this region and good track capability in large rate region → for the former, use dE/dx plus TOF of hodoscope? (with 100 ps timing resolution, 3.2 meters gives 3σ π/K separation)
4) HERA typical momentum cutoff of 5 GeV, studies show can push down to ~Field (in Tesla) of Solenoid. STAR has only 0.5 T field and lower cut-off of 0.4 GeV → Need low T (about 0.5) magnetic field in central region.

General Solenoid Field

Note: in all cases used idealistic fields for now!



- $B_T = B \sin\theta$ (from **v** x **B**)
- $p_T = p \sin\theta$

Initial solenoid:
B=4T, L=5m, D=2.5m

- $\theta_0 = \tan^{-1}(x/L)$
- $L' = (L/2)/\cos\theta, \quad \theta<\theta_0$
  $L' = (x/2)/\sin\theta, \quad \theta>\theta_0$

Solenoid Fields - Overview

Experiment	Central Field	Length	Inner Diameter
ZEUS	1.8 T	2.8 m	0.86 m
H1	1.2T	5.0 m	5.8 m
BABAR	1.5T	3.46 m	2.8 m
BELLE	1.5T	3.0 m	1.7 m
GlueX	2.0T	3.5 m	1.85 m
ATLAS	2.0T	5.3 m	2.44 m
CMS	4.0T	13.0 m	5.9 m
PANDA(*design)	2.0T	2.75m	1.62 m
CLAS12(*design)	5.0T	1.19 m	0.96 m

Conclusion: ~4-5 Tesla fields, with length scale ~ inner diameter scale o.k.

Formulas – used in parametric MC

Multiple scattering contribution:

$$\left(\frac{\delta p}{p}\right)_{msc} = \frac{1}{0.3B_T}\frac{0.0136z}{L\beta\cos^2\gamma}\sqrt{n_{r.l.}}$$

Intrinsic contribution (first term):

$$\left(\frac{\delta p}{p}\right)_{intr} = \frac{p}{0.3B_T}\frac{\sigma_{r\phi}}{L'^2}\sqrt{\frac{720}{n+4}}$$

- z = charge of particle
- L = total track length through detector (m)
- γ= angle of incidence w.r.t. normal of detector plane
- $n_{r.l.}$ = number of radiation lengths in detector

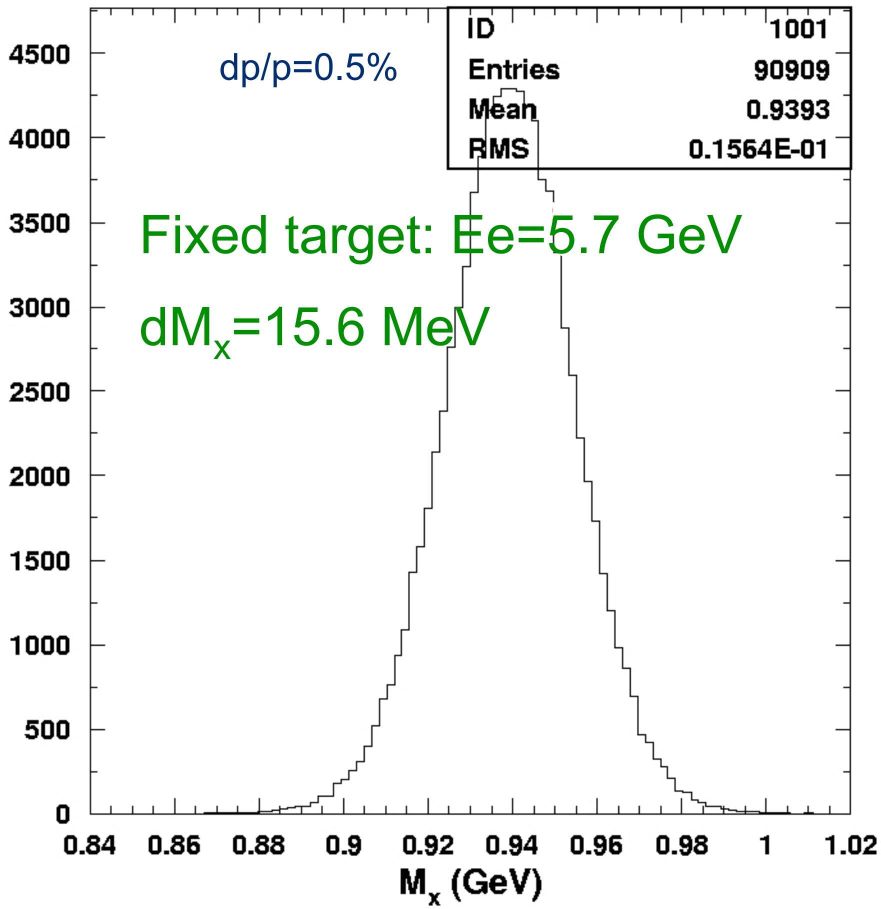
- B=central field (T)
- $\sigma_{r\varphi}$=position resolution (m)
- L'=length of transverse path through field (m)
- N=number of measurements

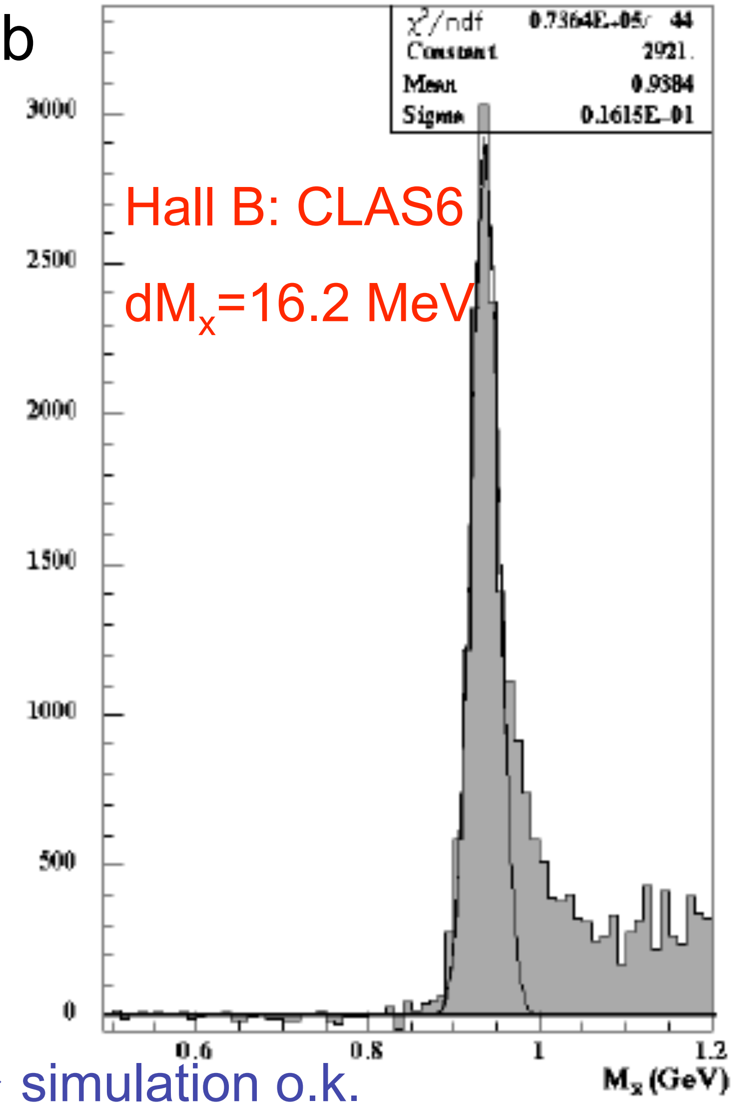
Assumptions:

- **circular detectors around interaction point**
- **$n_{r.l.}$ = 0.03 (from Hall D CDC)**

M_x Resolution – fixed target

Cross-check simulation w. 6 GeV JLab

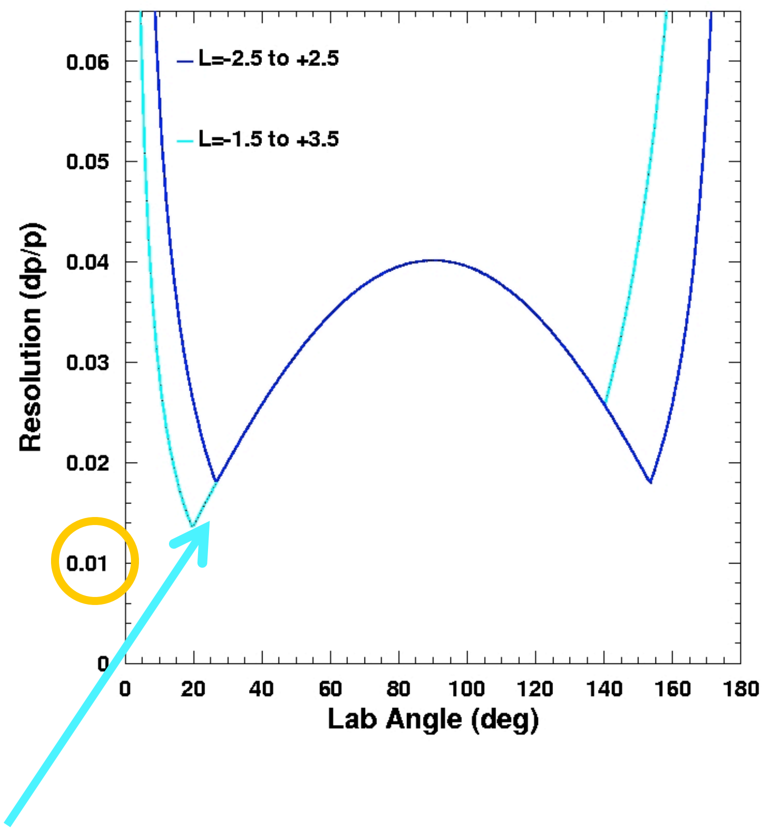




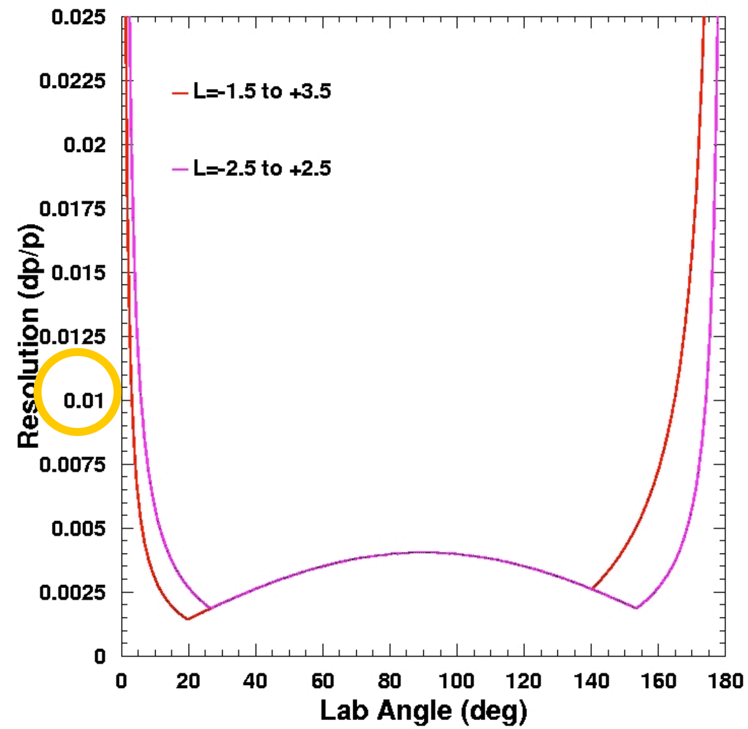
Conclusion: in good agreement with data → simulation o.k.

dp/p angular dependence

p = 50 GeV

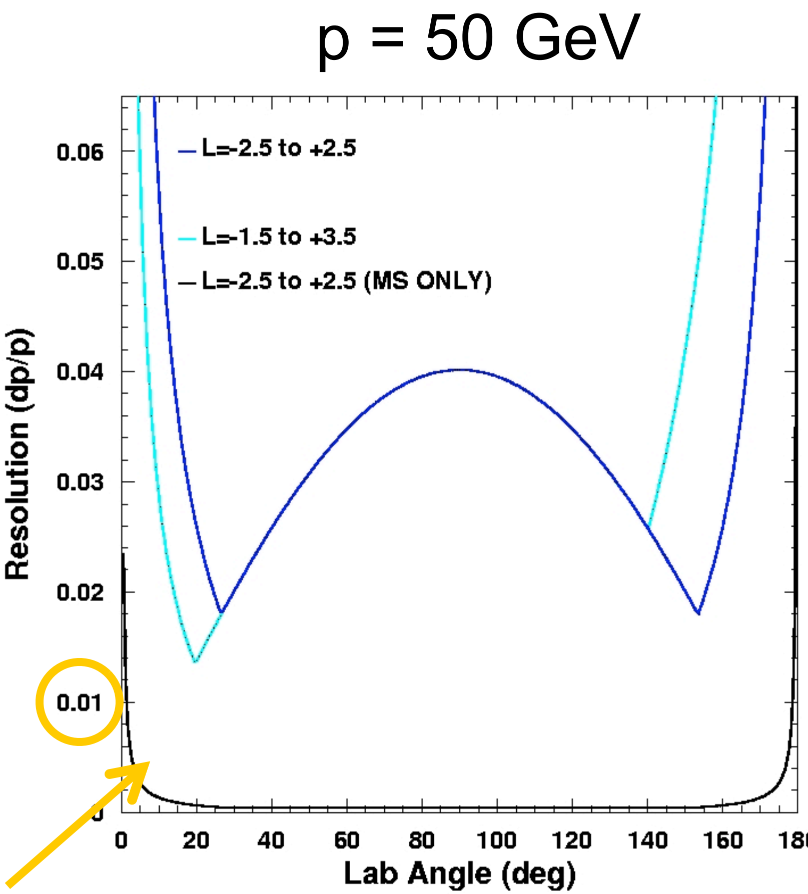


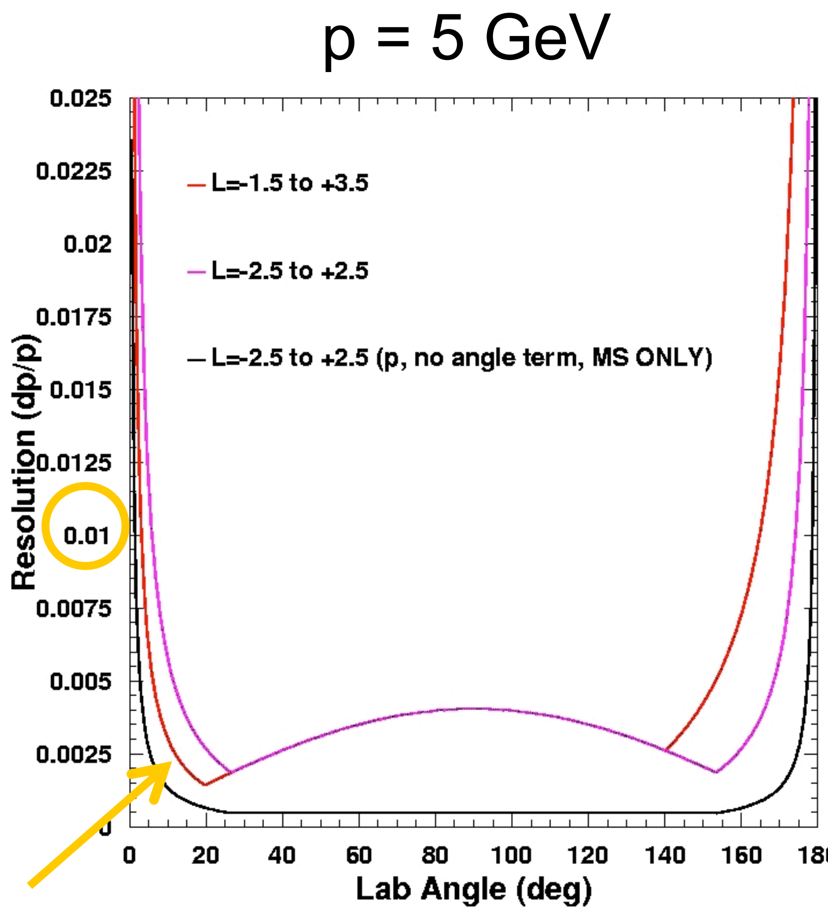
p = 5 GeV



Can improve resolution at forward angles by offsetting IP

Multiple scattering contribution

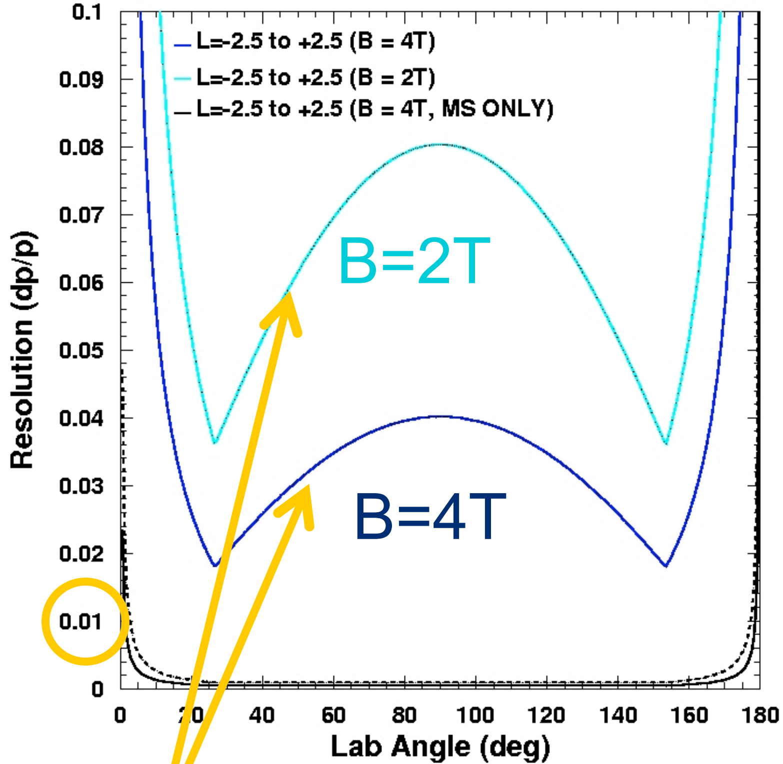




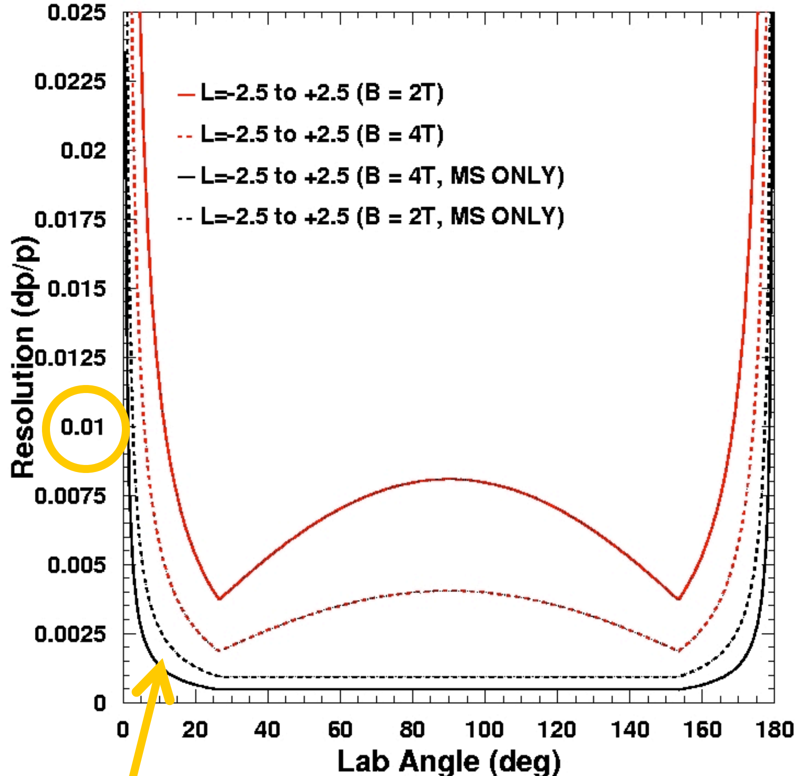
Multiple scattering contribution dominant at small angles (due to B_T term in denominator) and small momenta

"Easier" Solenoid Field – 2T vs. 4T?

p = 50 GeV



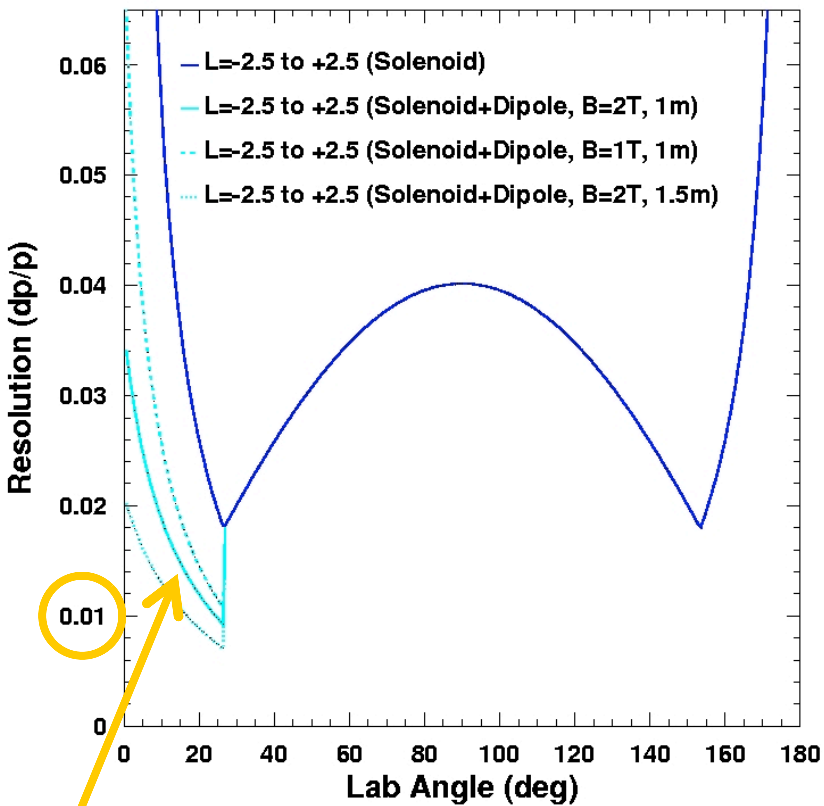
p = 5 GeV



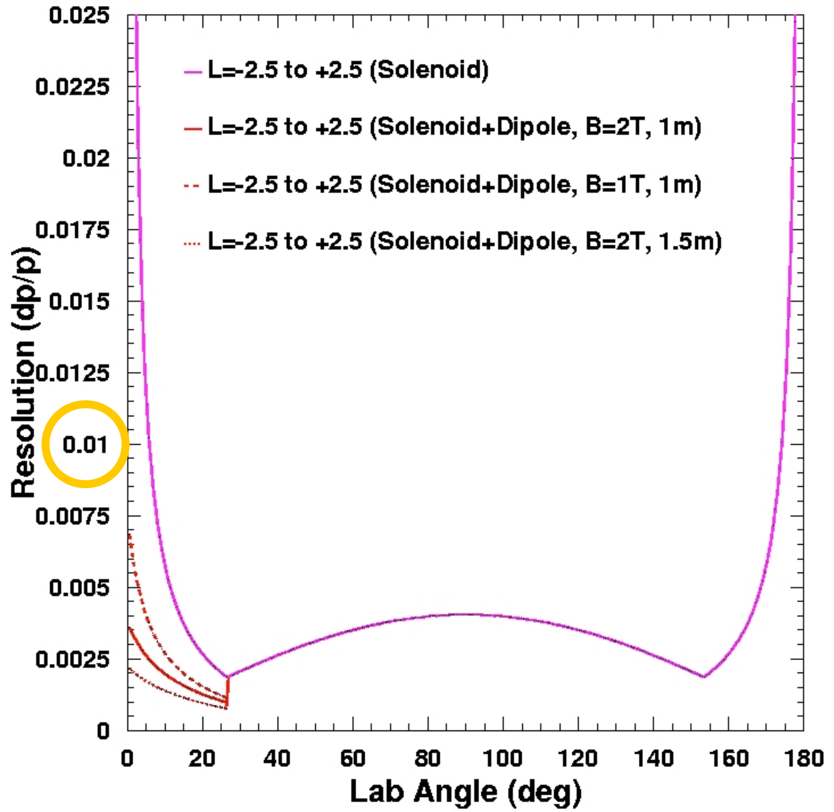
- Intrinsic contribution ~ 1/B
- Multiple scattering contribution ~ 1/B

Include dipole field

p = 50 GeV



p = 5 GeV

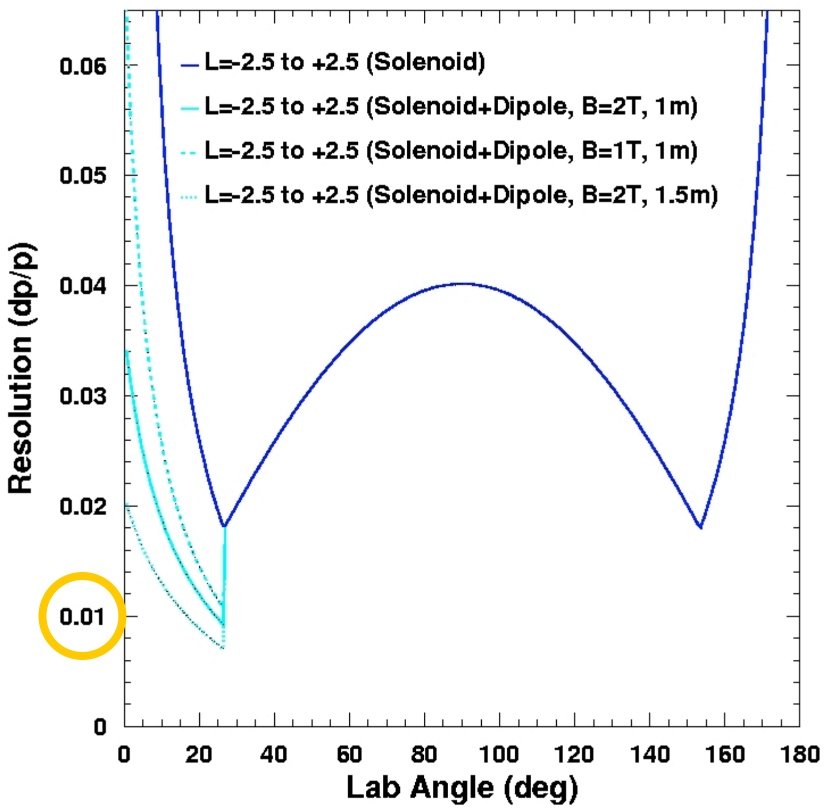


As expected, substantially improves resolutions at small angles

Or include CLAS12 toroidal field

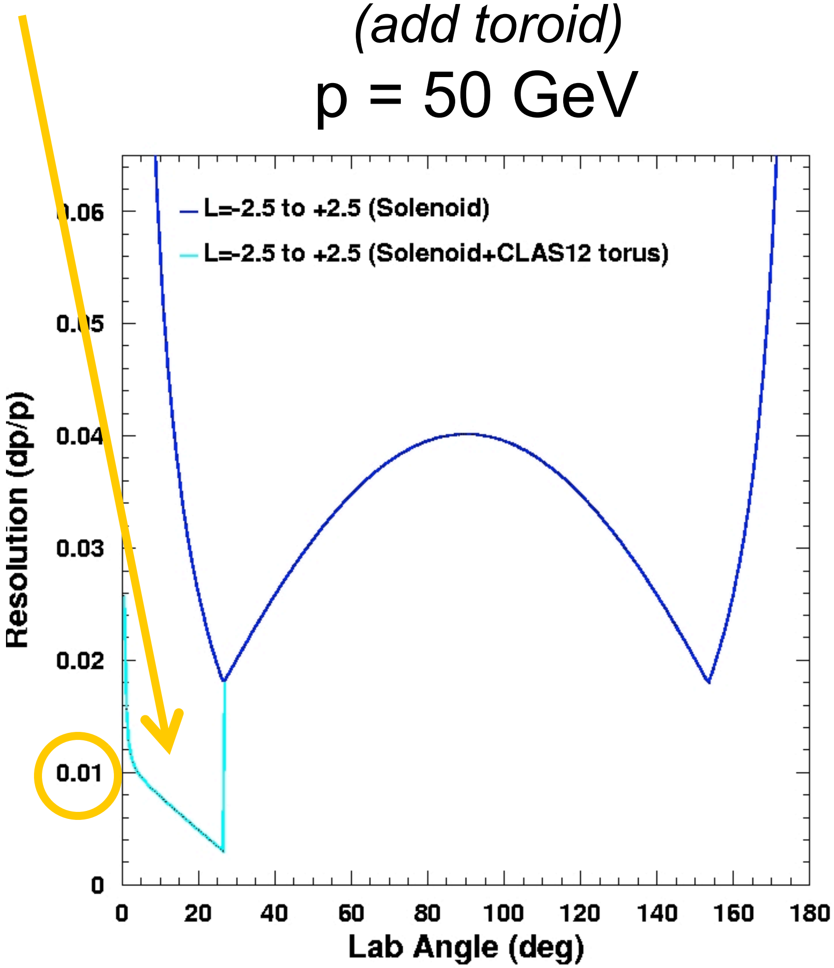
(add dipole)

p = 50 GeV



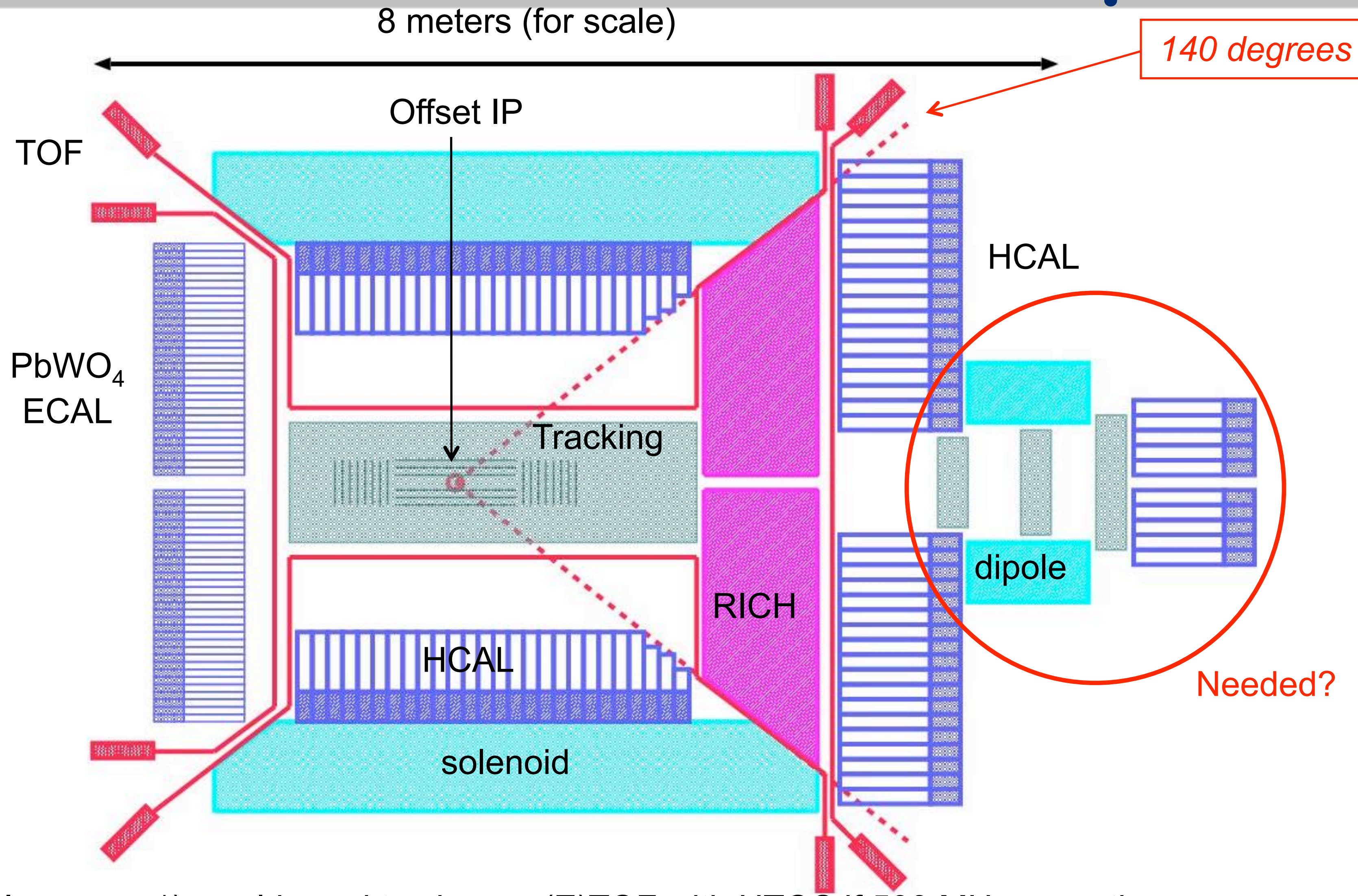
(add toroid)

p = 50 GeV



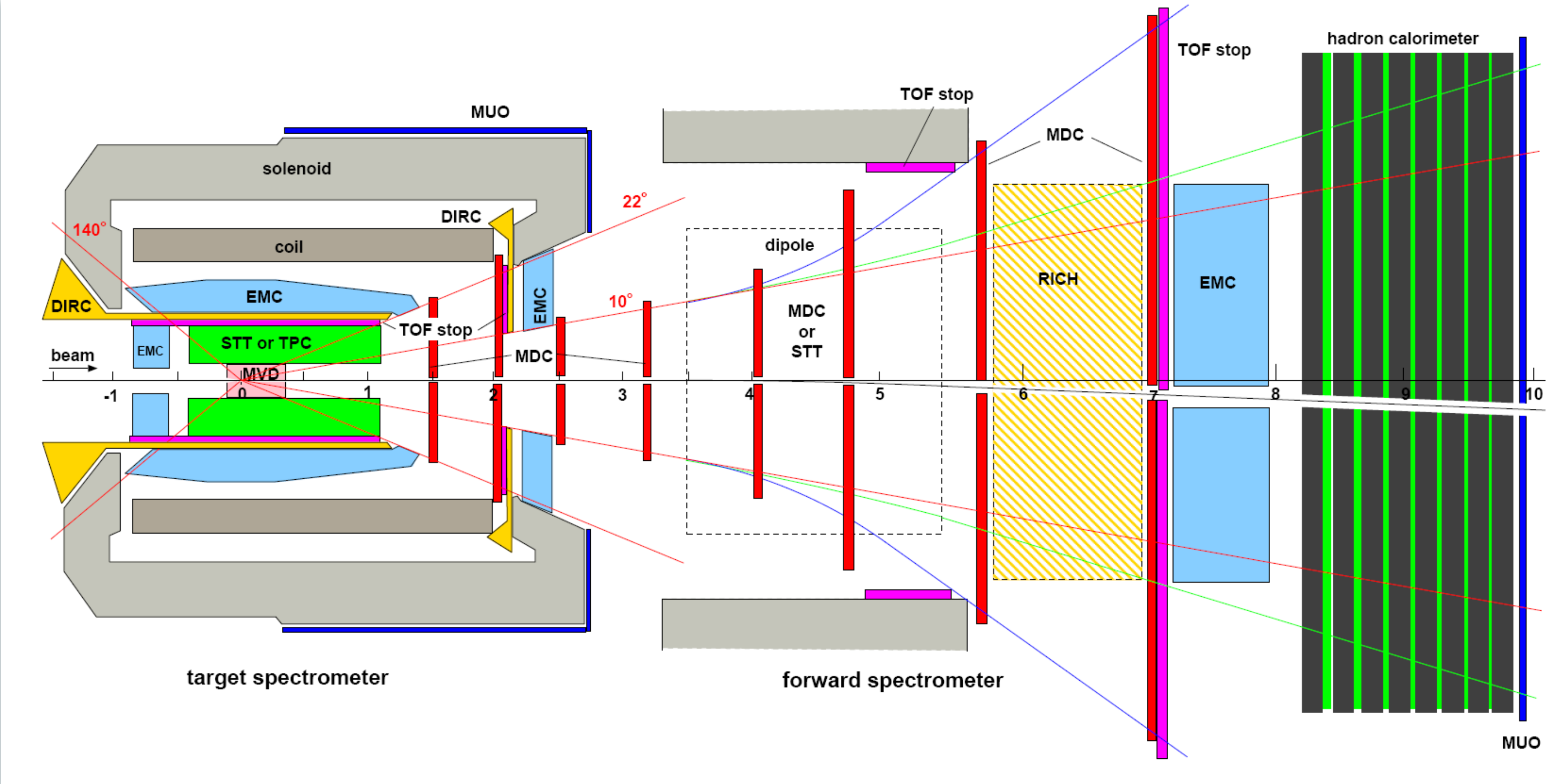
Does the same trick, but would get acceptance loss at small angles (~3^o?)

detector cartoon - ~Sep. 08



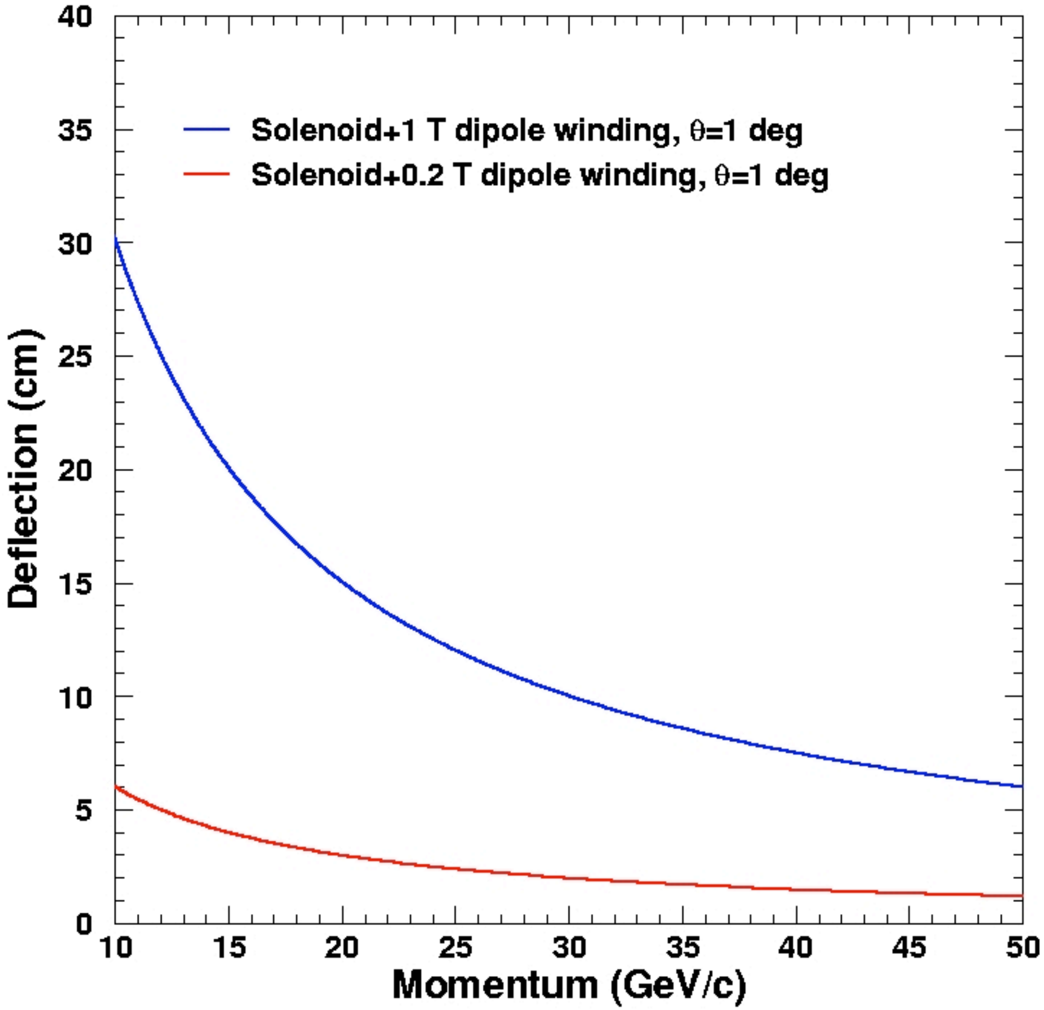
Issues:
1) would need to change (E)TOF with HTCC if 500 MHz operation
2) need add'l Particle Id. (RICH/DIRC) for large angle π/K/p?
3) conflict with charm measurements that require low central field?

Similar to PANDA Detector Concept



See PANDA Technical Progress Report: also here discussions of solenoid vs. solenoid + dipole vs. solenoid + toroid.

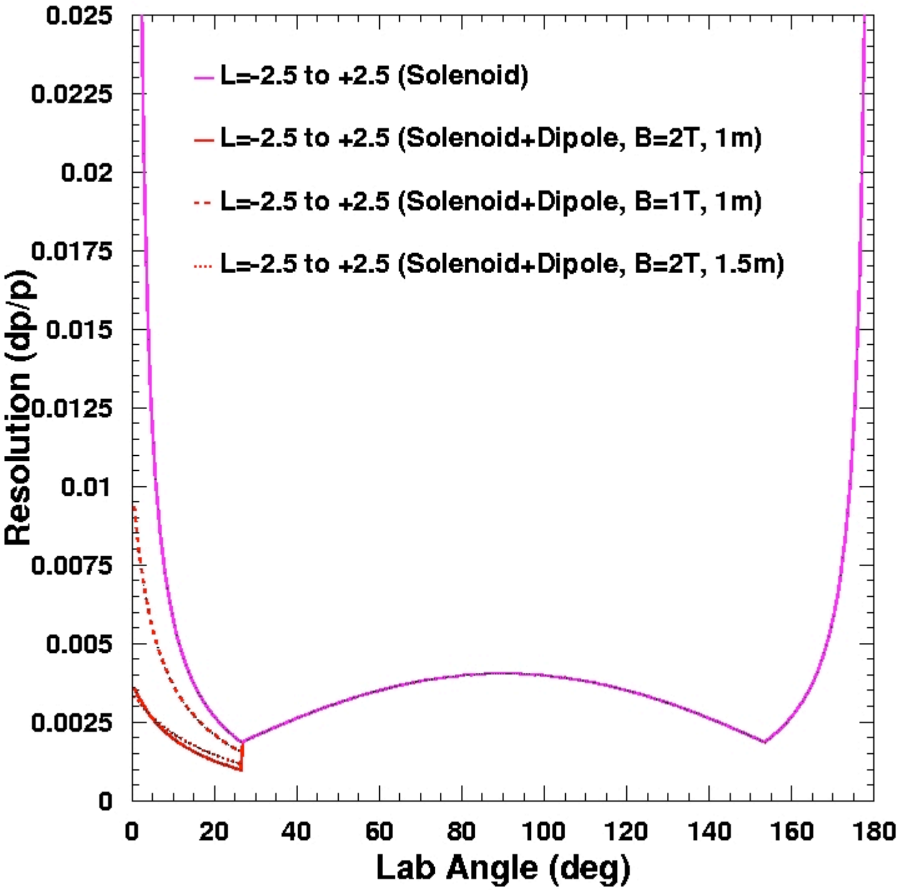
Dipole field requirement on hadron side

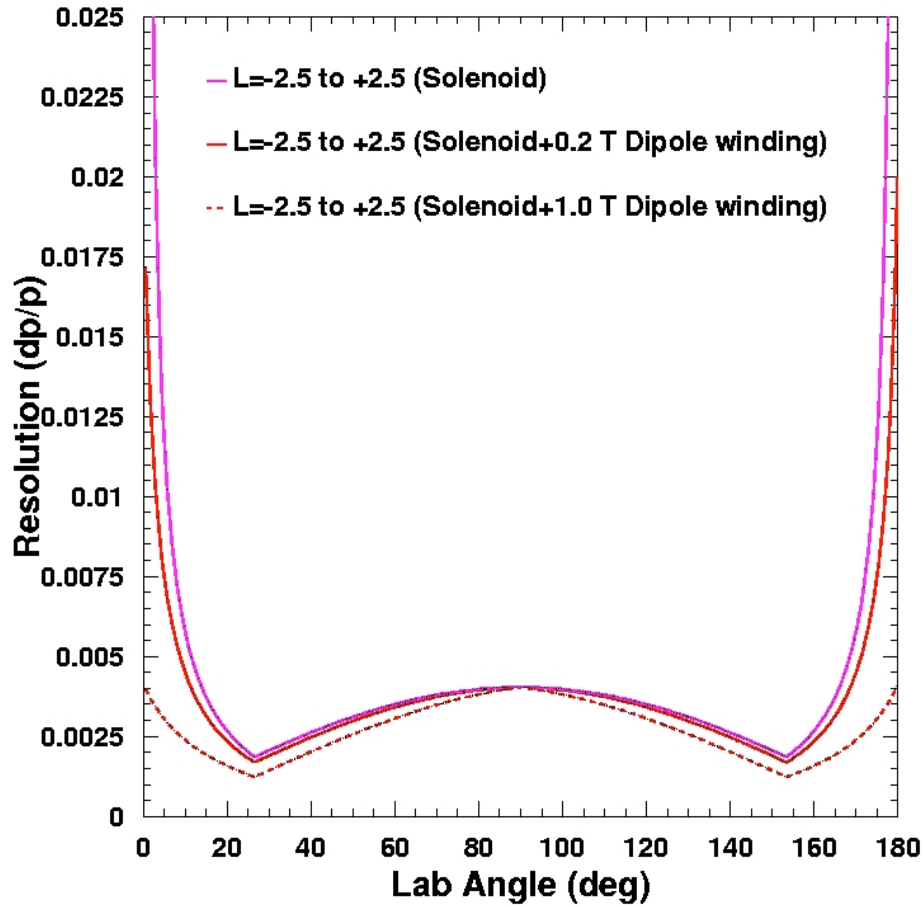


- Of order 0.5-1 Tm dipole component sufficient on hadron side to peel the charged particles away from beam line and allow for tagging/vetoing?
- Need a map of angle vs. momentum of particles of interest to better constrain.
- Of course, such options also need to be checked for resolutions required for SIDIS and DES reactions.

Dipole field vs. dipole component in solenoid

5 GeV momentum particles





- Need some 1T dipole component in solenoid windings to make this useful
- Would give small improvement also at central angles, but worth the effort?

Revisions to detector cartoon?

- smaller central solenoid, with smaller magnetic field, to lower threshold for charged particle detection?
    - if threshold momentum ~ field value, can likely only have ~0.5-1 T field → affects resolutions.
    - or need low solenoid field and large solenoid field runs.
- dipoles on either side
    - on electron side to provide good resolutions for inclusive scattering kinematics

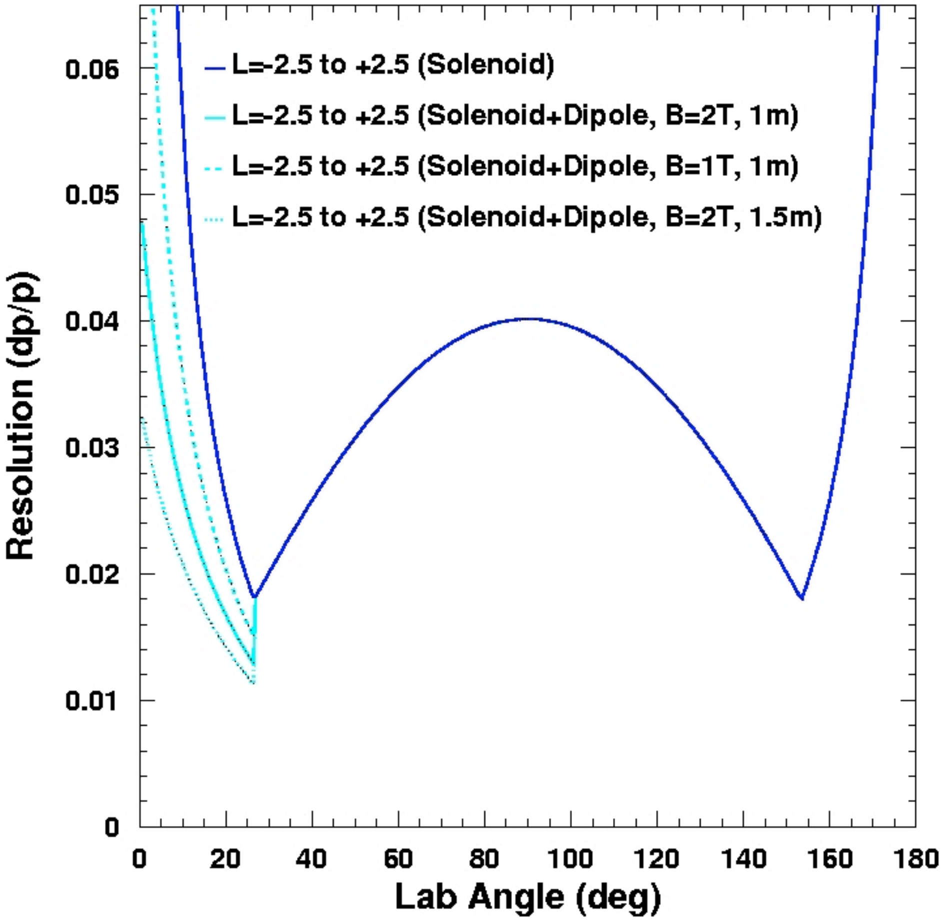
      (need input in form of dp/p vs. angle/momentum!)
    - on hadron side to peel charged particles/fragments away from beam line

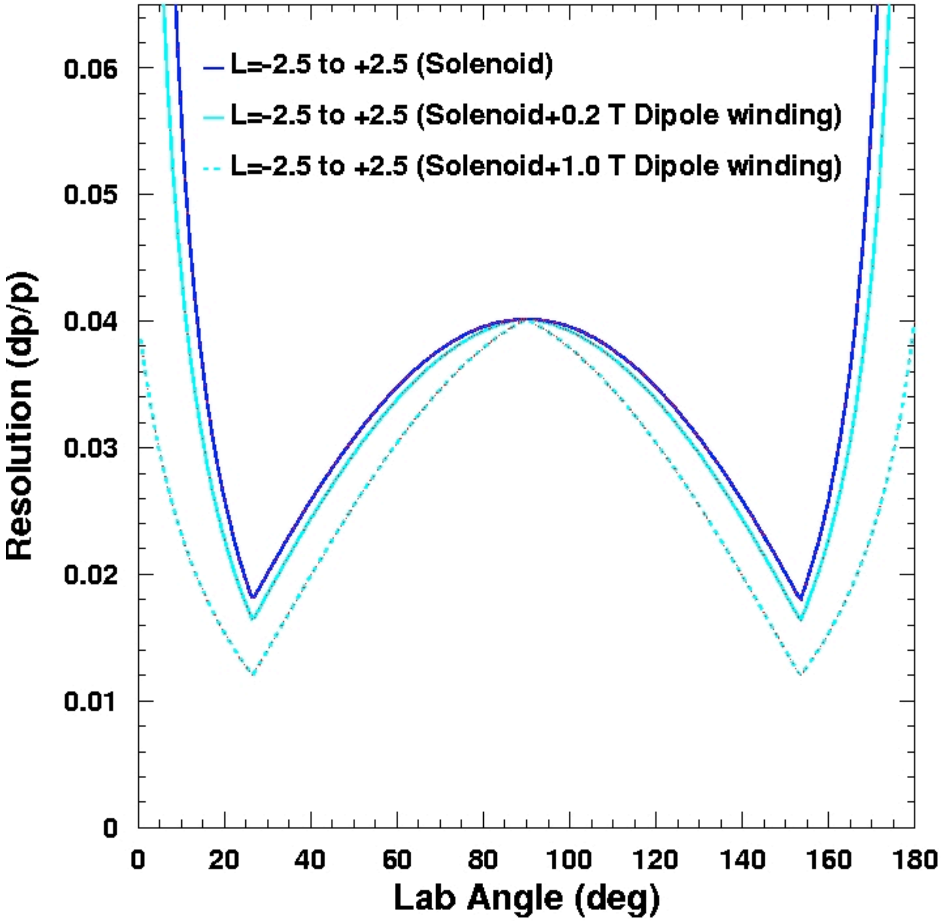
      (need quantitative input on angles/momenta)
- such a concept needs likely more space than 8 meters.
- make the first beam quadrupole focusing elements as large as possible, with large inner aperture, to allow for tagging.

Backup

Dipole field vs. dipole component in solenoid

50 GeV momentum particles





Remaining puzzle

Formalism often given in terms of p_T resolution …

Transverse Momentum Formulas

Multiple scattering contribution:

$$\left(\frac{\delta p_T}{p_T}\right)_{msc} = \frac{p_T}{0.3B}\frac{0.016z}{Lp\beta\cos^2\gamma}\sqrt{n_{r.l.}}$$

Intrinsic contribution (first term):

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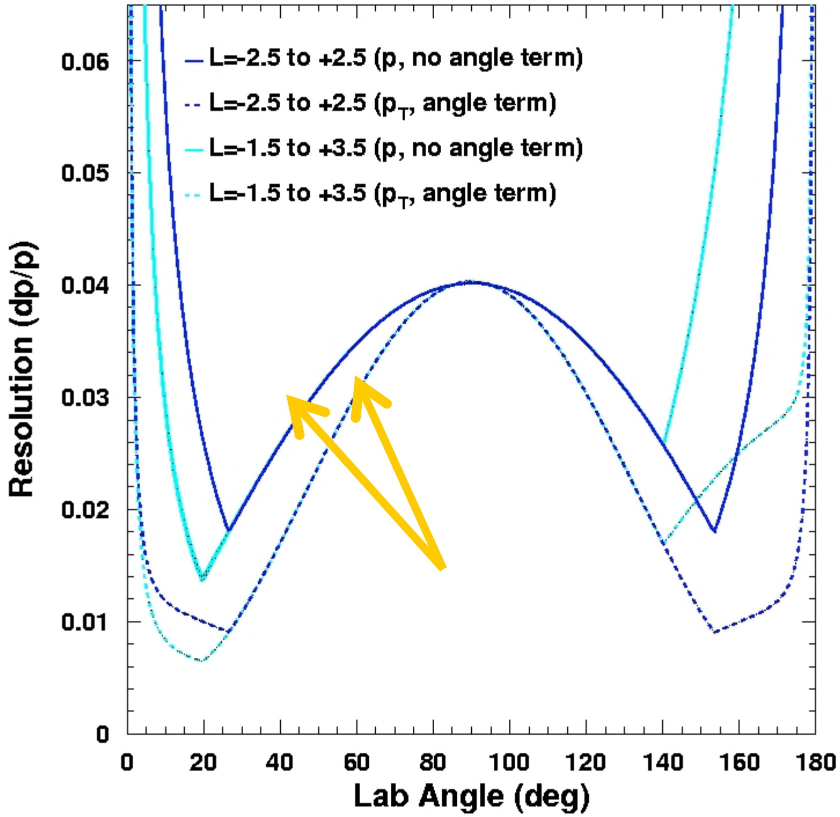
Compare both formalisms

Must include angular dependence term ($p_T = p\sin\Theta$)



Puzzling why results are not identical, something missing?