Building the Detector – Accelerator Interface

presented by,

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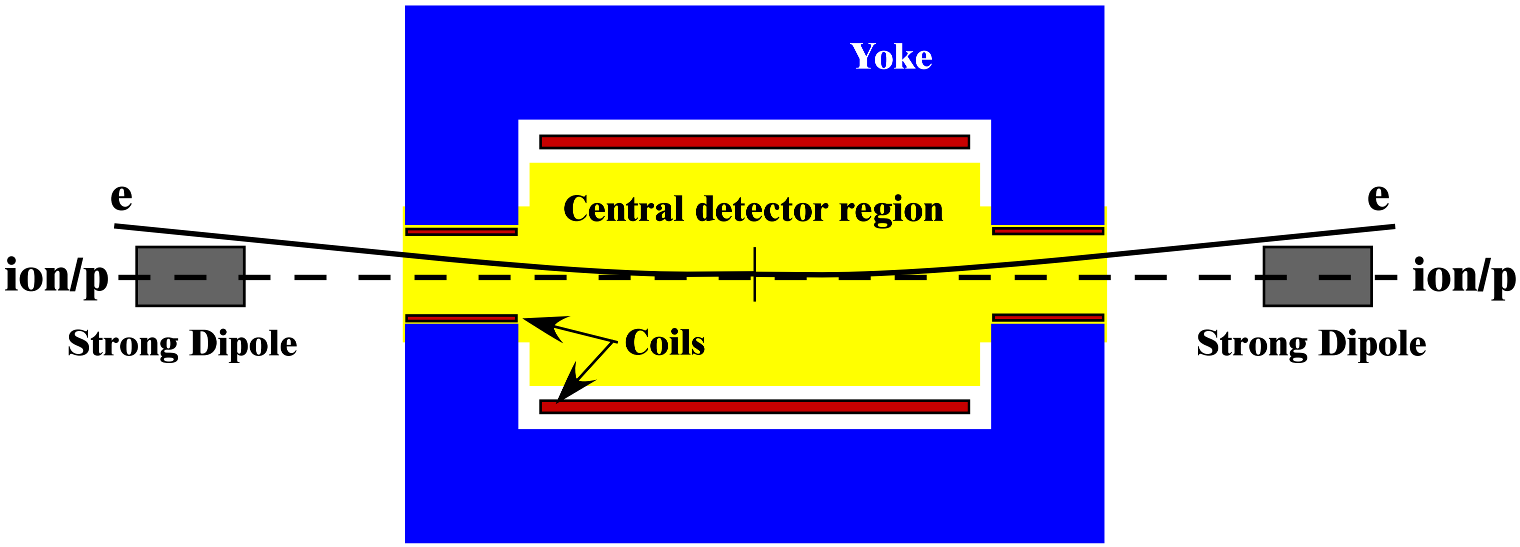
Interaction Region Subgroup

My charge from IR group leader:

A) Integration of accelerator and detector components, dual role magnets.

B) Beam separation scheme(s), discussed in the context of the IP design flexibility to accommodate variable beam momenta, variable beam momentum ratio and variable collision schemes: ep, eA, pp and pA.

Design Principles, Tips and Tricks: Short list of EIC IR design suggestions.



- Weak dipole bend in the central region (e-beam synrad).
- Strong bend outside for protons/ions (e-beam shielded).
- Put quadrupole focusing in outer flux return yoke (β^*).
- Try to incorporate an antisolenoid close in (polarization).

Design Principles, Tips and Tricks: How to get the most from an EIC.

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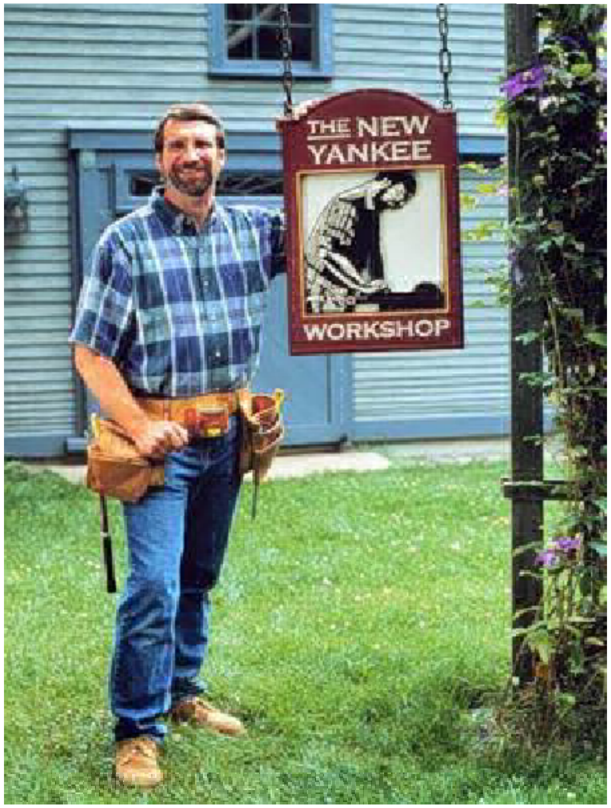
On television Norm Abram always has the correct tool to ensure that parts from his projects fit together smoothly. He makes home construction and renovation look simple.

Today I do not claim to have an IR design worked out which is ready to be built; however, I do plan to:

- Identify some of the tools which are needed.
- Give examples to illustrate a few useful tricks.
- And outline principles which should lead to a satisfactory IR design.

Main Theme:

IR space is precious and this fact forces experimentalists and accelerator designers to cooperate closely if they hope to achieve their goals. A powerful way to do this is to make the IR magnets serve dual purposes.



Norm Abram from the PBS series, "The New Yankee Workshop"

IR Leader: Please compare/contrast IR layouts with large & small momentum ratios.

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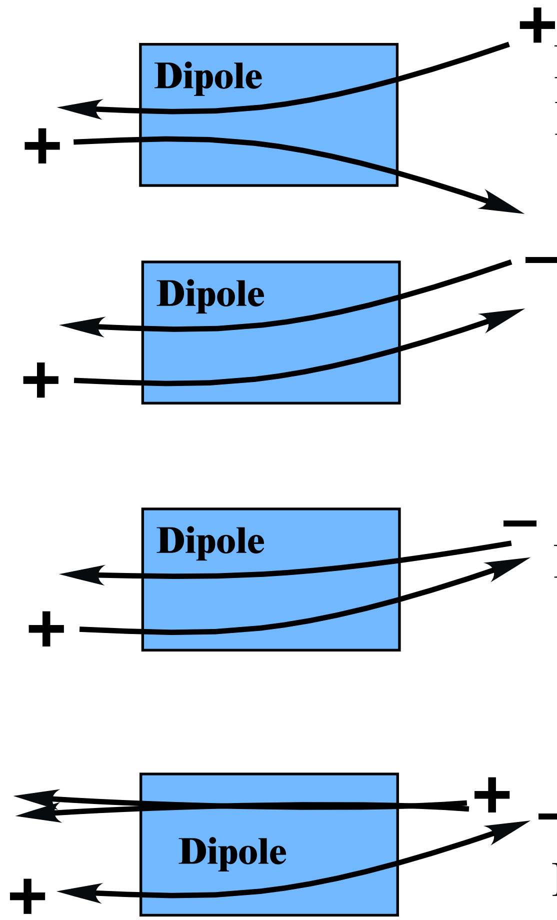
Ah… but what are the relative charges?

Dipole field separates like sign charges going in opposite directions. To separate opposite sign particles requires a momentum difference.

However for large momentum ratio a dipole field separates both polarities.

HERA: Protons @ 920 GeV and Electrons/Positrons @ 27.5 GeV for 33½:1 momentum ratio, so proton orbit is hardly changed by flipping dipole polarity.



Examples: RHIC DX Magnet, 180° System at Bates

Examples: Tevatron, CESR, BEPC-II

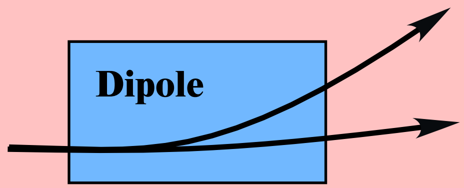
Example: PEP-II

Example: HERA

The dipole field appropriate to bend HERA electrons hardly effects the proton beam.

Synrad backgrounds and heating implicitly limit dipole fields used for beam separation.

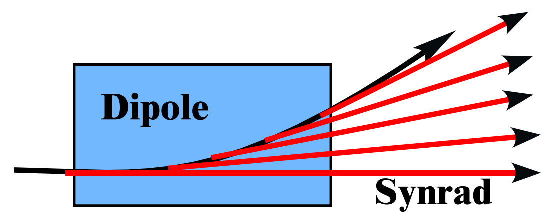
For EIC we are (probably) stuck with oppositely charged beams and have to use either a momentum ratio or a non-zero crossing angle to separate the beams.



All things being equal, one would like to use strong dipole fields to separate beams (spectrometer principle).

Note: Such a dipole may also be desired by experiments to momentum analyze secondary particles and separate out neutral particles.

- For HERA upgrade synrad backscatter background was major concern for experiments.
- Synrad heating of beampipe absorbers significant eRHIC design constraint at 2000 Yale workshop (e.g. use PEP-II heating limit). But using only soft bending gives up spectrometer functionality.*



*See eRHIC note, Sebastion White, December 5, 1999.

A non-zero crossing angle permits even equal rigidity beams to be separated.

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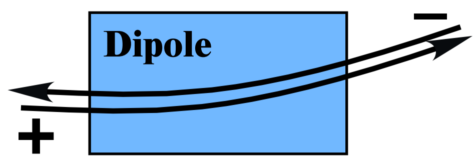
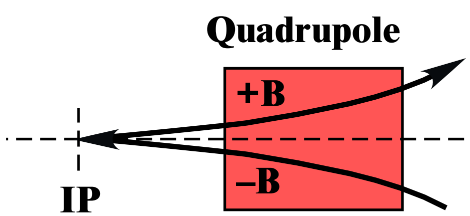
Examples: Tevatron, CESR, or BEPC-II beams in a dipole.





B-field reverses sign across a quadrupole centerline. So with a small seed displacement quadrupole defocusing can help to separate BEPC-II e^+ and e^- beams.

A similar trick **could be used for EIC even without a crossing angle,** if we start beam separation early enough. Then the first quadrupole could be used to help. **We would have to adjust the quadrupole magnetic center so that the e-beam only sees small B-fields** (large B-field is ok for p/ion beam).

Accelerator Beam Line Layout and Experimental Physics Facts of Life.

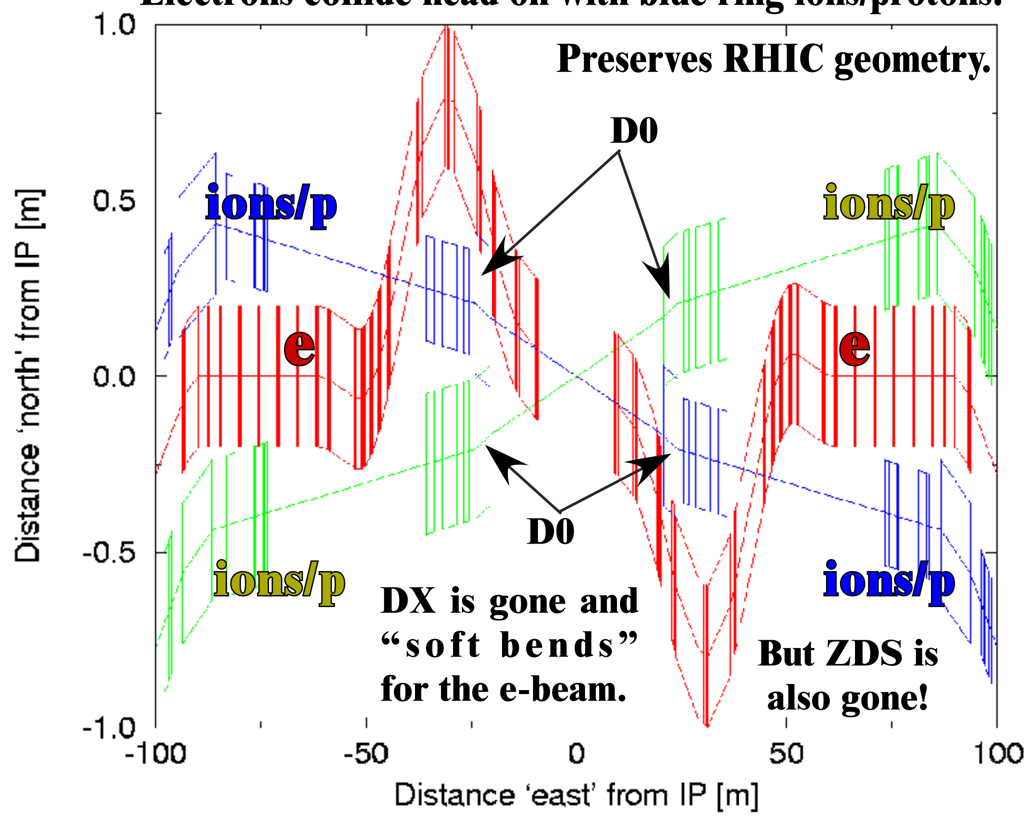
Interaction Region Subgroup

The eRHIC layout presented by J. Kewish at the Yale 2000 Workshop, preserves RHIC geometry by crossing the ion/p beams from one D0 to diagonally opposite D0. Instead of 4.3 T DX dipole, electrons are deflected by 0.134 T BS1 dipole magnet for tolerable synchrotron radiation (synrad) production.

Experimental Concern:

S. White and others pointed out that this arrangement does not separate small angle particles and neutrals sufficiently from the circulating beams to do physics.

Electrons collide head on with blue ring ions/protons.



How can we recapture the "spectrometer functionality" provided by RHIC DX magnet?

Experimental Physics Layout and Some Magnet Design Facts of Life.

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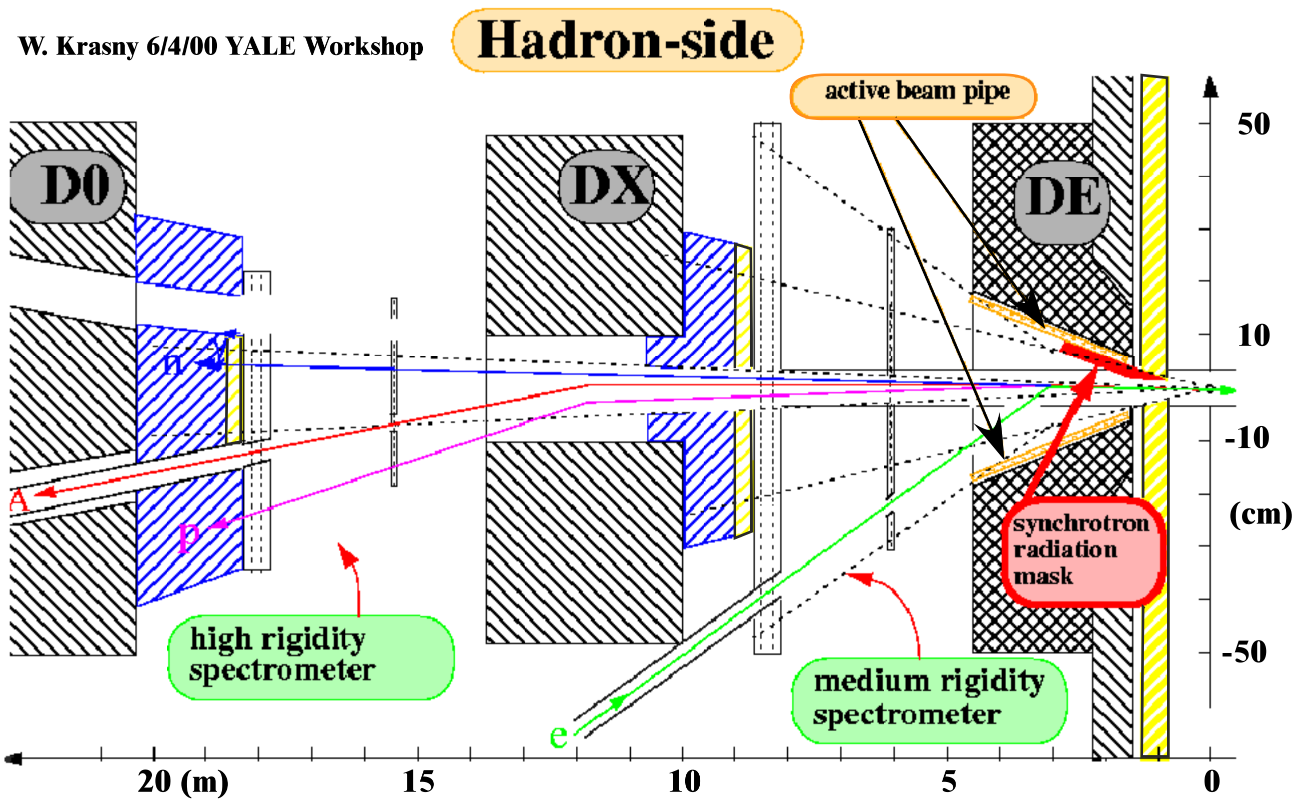

DE dipole, integrated with experimental detector, gives weak bend to get past superconducting DX magnet. DX then provides strong bend for high rigidity spectrometer.

Design Dilemma:

DE dipole field needed to clear DX is too high (synrad). Smaller field sends e-beam through DX yoke (leakage fields there are also too high).

How can we improve upon this layout while keeping the advantages of a weak – strong bend geometry?

HERA Example: Trading space between experimental detector and accelerator.

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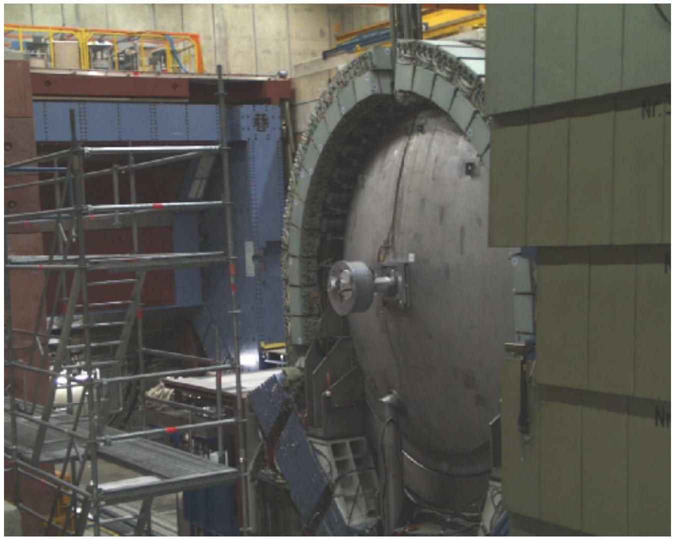
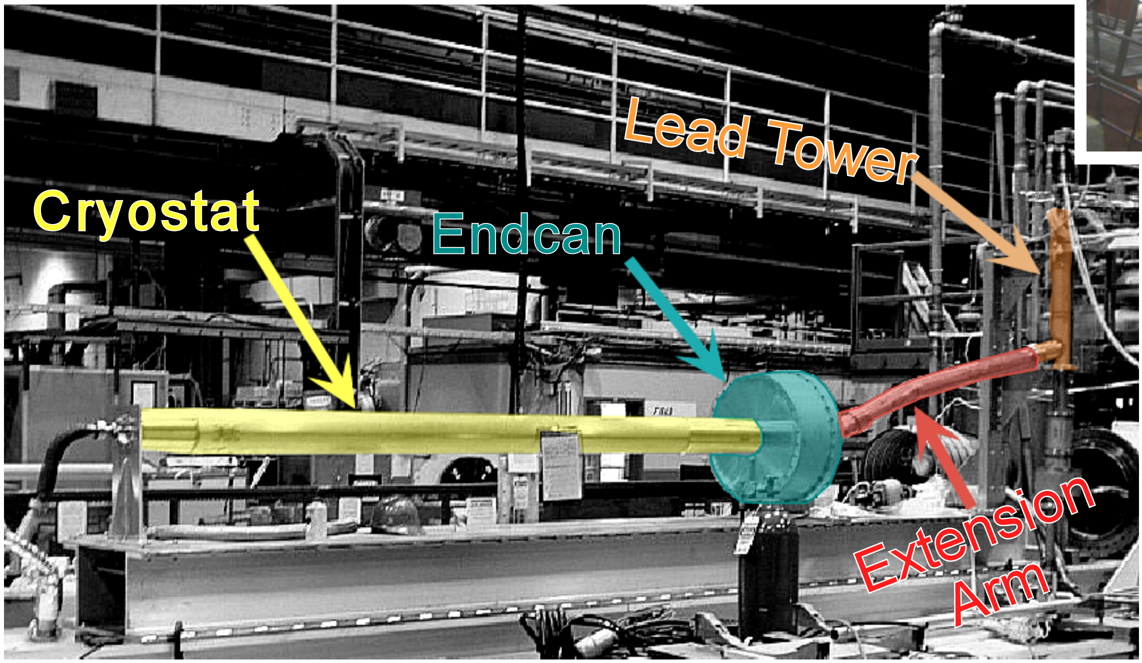
- Temptation for accelerator physicist is to put small diameter coils close to IP to start beam focusing and separation as early as possible.
- Then forced to choose between losing inner or outer aperture (some dead space is unavoidable).





Superconducting G0 magnet shown at left on test stand at BNL and installed into experiment H1 at DESY (above). G0 has a mini-cryostat to provide sufficient inner space for synrad and beams but not to take up too much radial space in detector.

Observation: A cylindrical yoke is compatible with many different coil types.

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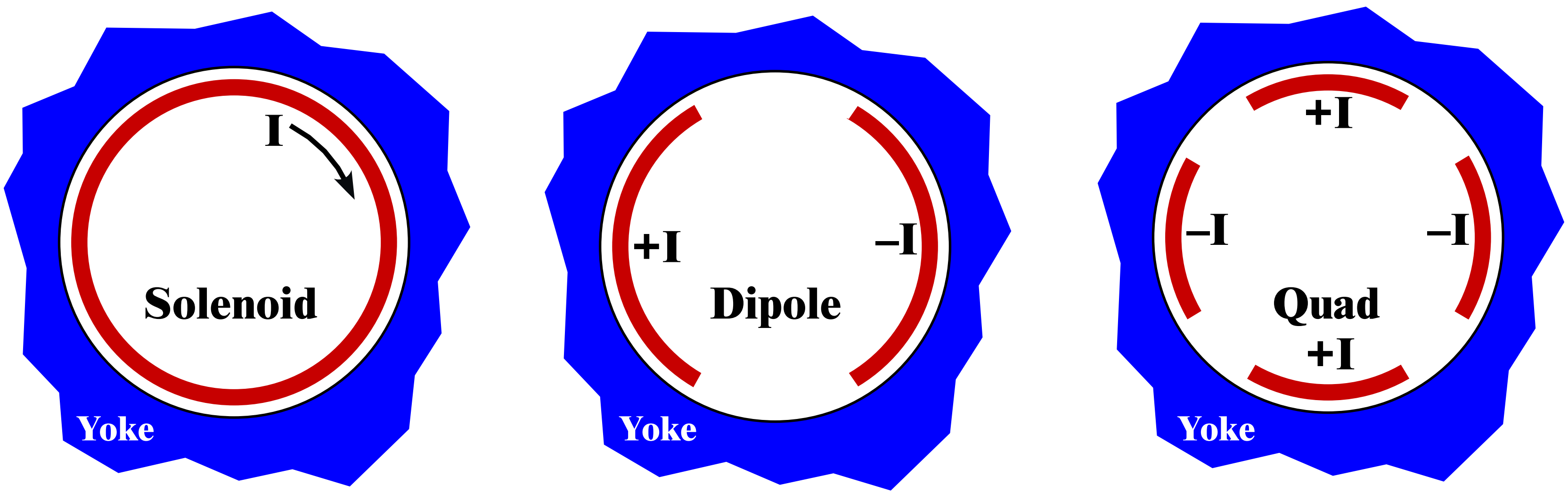

- Solenoidal and dipole coils both fill space with flux efficiently (uniform field).
- For quadrupole, peak field goes $\propto$ Gradient $\times R_{coil}$ so a quadrupole coil is only practical for small coil radius (e.g. return yoke but not main body).

A cylindrical yoke is compatible with a low field strength dipole plus regular solenoid.

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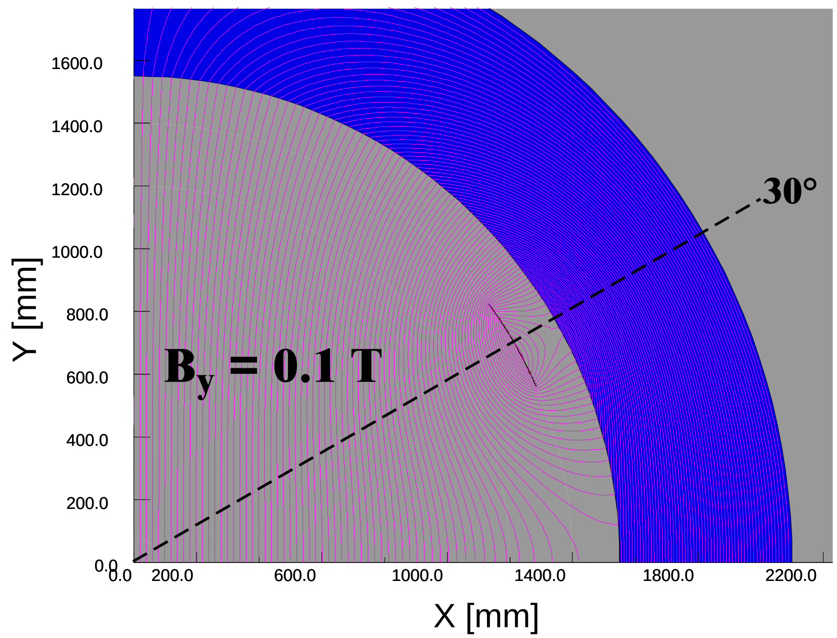
Dipole (¼ Model + Boundary Conditions)



- ♦ Dipole with 0.1 T does not require excessive superconductor (even with R_{coil} = 1.4 m).
- ♦ Wind on top detector solenoid coil.
  - Avoid radiation length at small R.
  - Avoid issues with coil torques.
  - Even the partial coil shown at left, gives good field quality for beams.

Design shown has 10^{-5} field uniformity at R = 80 mm.

Tips and Tricks: Add a small transverse component to field in detector solenoid.

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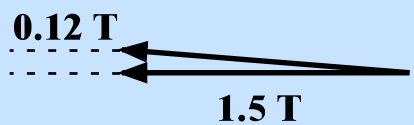
Consider the following: Add 0.12 T $\perp$ inside a 1.5 T detector solenoid.

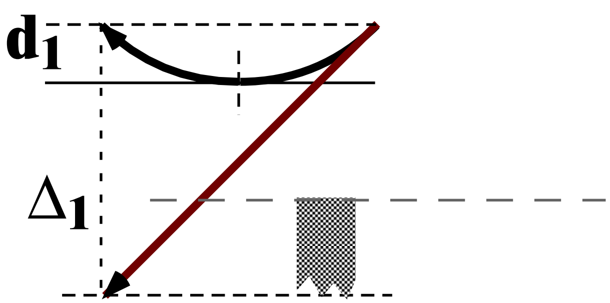


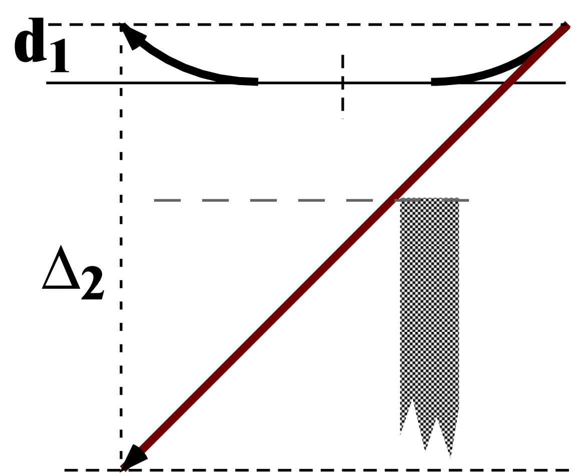
Magnitude changes $\approx \frac{1}{2}(0.12/1.5)^2 \times 100 = 0.3\%$

Direction changes by $\approx (0.12/1.5) \times 1000 = 80$ mr

Effect is similar to tipping solenoid with respect to beam.

By keeping the bend center close to IP it is possible to pass synrad cleanly through both the experiment and the accelerator magnets.





- Keep central beam pipe diameter small.
- Avoid sensitivity to collimator position.

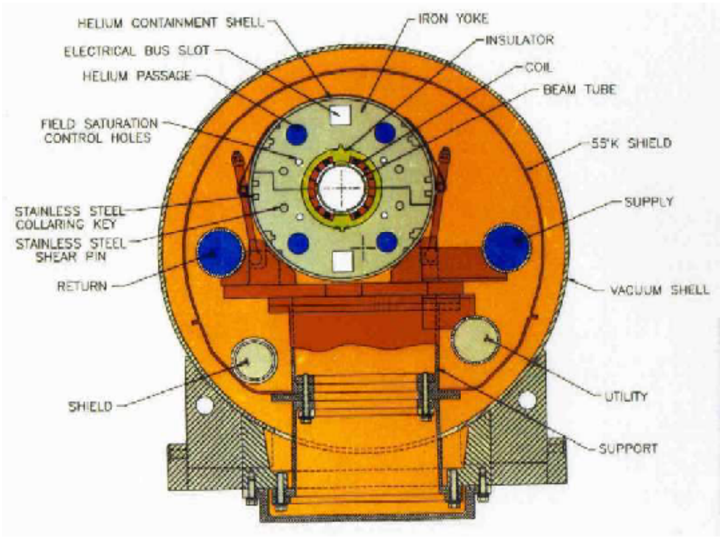
Beamline Layout and Magnet Design Facts of Life.

Interaction Region Subgroup

It is hard to get past a superconducting magnet while using only soft bends.*

* If your IR section length is too limited.

- Complicated to make through hole in cold mass and cryostat.
- And even then have to watch out for large fringe or leakage fields.



Yale 2000 eRHIC design avoids trouble by making D0 first superconducting magnet. But then there is no Zero Degree Spectrometer.

For $B_{pole} \approx 1$ T soft iron useful for field shaping and copper coils work fine for apertures that are not too large.

Some of the special magnets created for the HERA Luminosity Upgrade.

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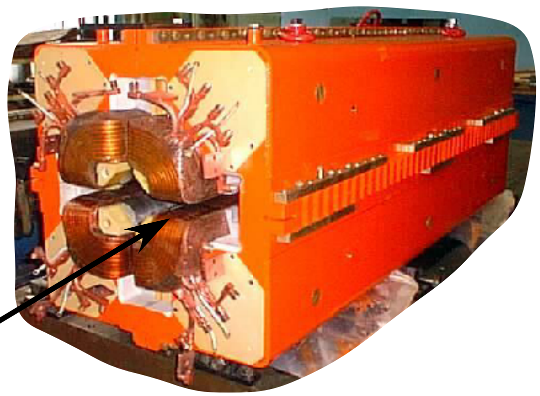
GI & GJ, Normal Quads

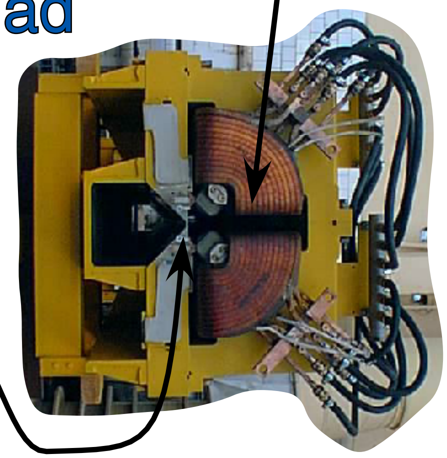


Coil gap
for synrad

GM, Magnetic Septum Quad

Coil gap
for synrad

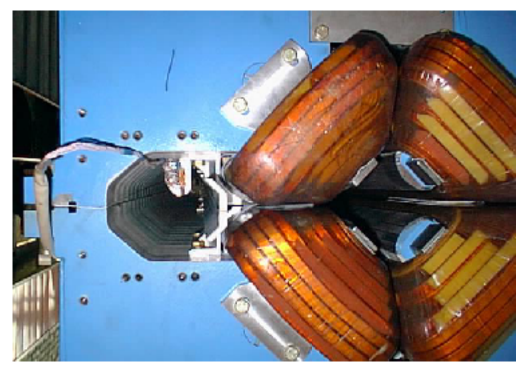
Septum
between e
& p beams



Gap for
synrad

Septum
between e
& p beams

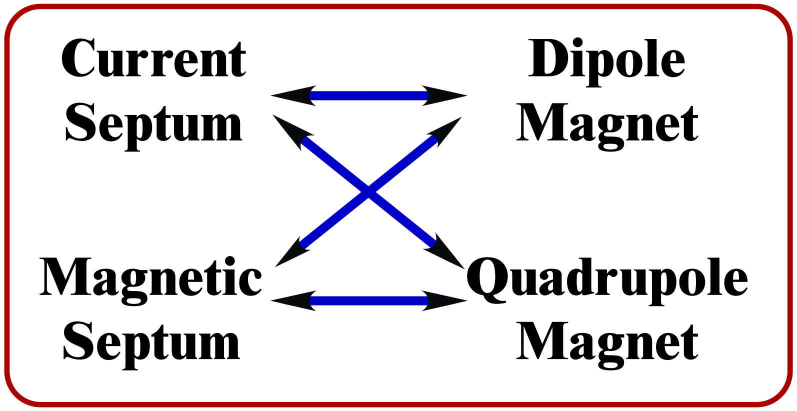
GN, Current Septum Quad



GA & GB, Normal Quads

Design Principles: Septum magnets provide a variety of fields for beams.

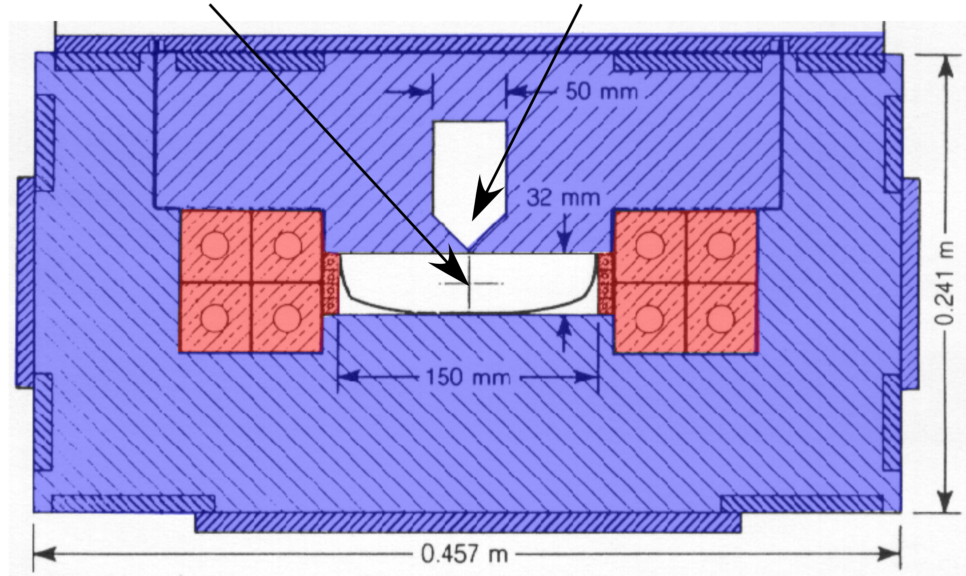
Interaction Region Subgroup



Proposal: Investigate using a septum dipole outside EIC detector to provide spectrometer functionality.

- Provide apertures for many beams.
- Instrument to integrate with detector.
- Easier to get close to a warm magnet.
  - ▲ Maintaining lever arm offsets lower field.
  - ▲ Get magnet close in for large solid angle.

- Many septum magnet configurations are commonly used.
- Lambertson dipole, shown below, is typical for separating injected or extracted beams.

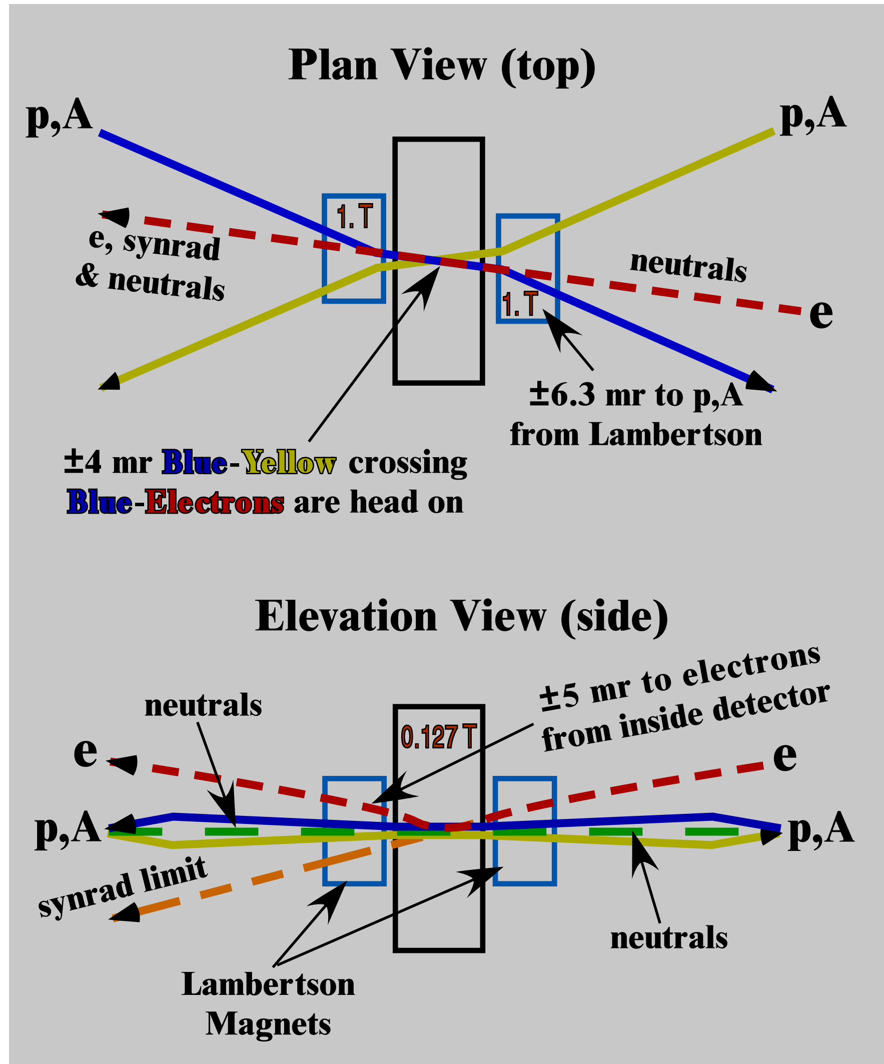


SSC Collider Ring Abort Lambertson Magnet

Proposal for hybrid eRHIC layout that is compatible with weak – strong bends.

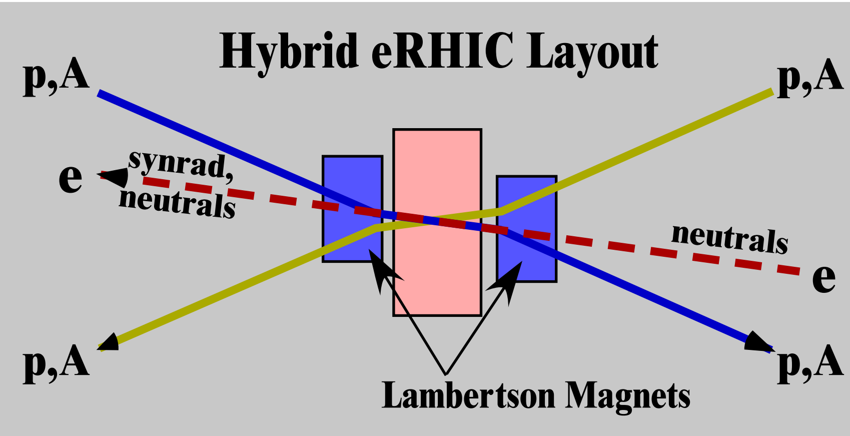
Interaction Region Subgroup

- E-beam strikes head on with Blue at IP.
- A small vertical deflection inside detector separates electrons from circulating beams.
- Ions/p bent by 1 T field inside a Lambertson dipole (electrons in reduced B-field region).
- Long drift downstream of Lambertson gives spectrometer lever arm.
- Keep Lambertson short to pass synrad etc. via small Blue/Yellow crossing angle (but with reduced neutral separation).
- Small vertical kicks to Blue/Yellow beams compensated before triplets – proton spin should be ok.



Optimization and some features of the proposed hybrid eRHIC layout.

Interaction Region Subgroup

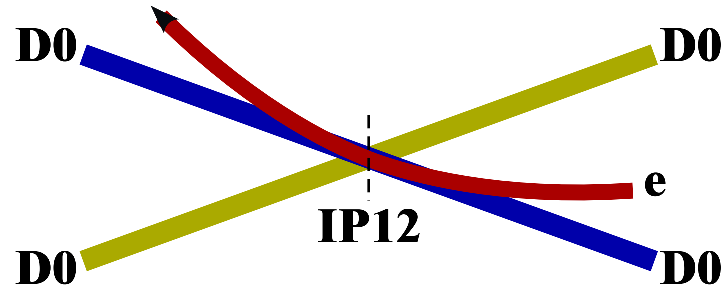


- For hybrid scheme to work well, will have to integrate Lambertson magnets with detector (instrument warm magnet).
- Ion/p crossing angle is critical parameter for optimization. Zero crossing angle possible, but then downstream gets filled in with magnets.

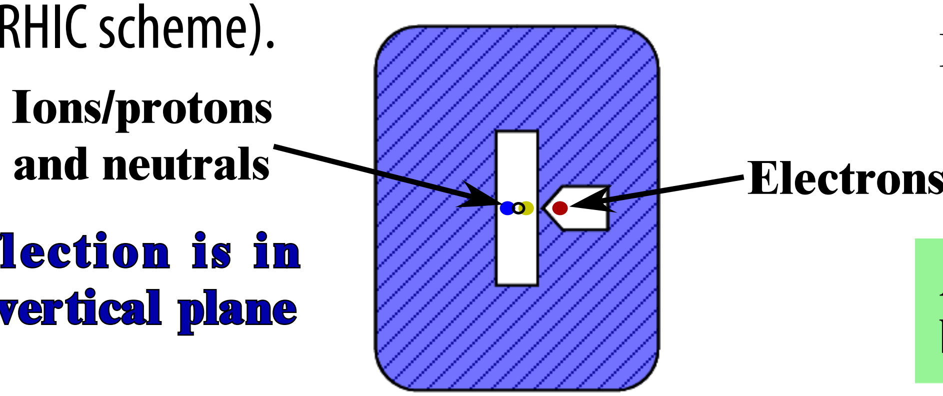
- If it really is deemed desirable to also have option for (p,A) and (A,A) then need to determine largest allowable crossing angle.
- Having a symmetric vertical bend for e-beam does not preclude using antisymmetric horizontal bends further from the detector.
- Moving Lambertson close to detector increases acceptance for all beams but also increases solid angle covered by septum.
- Separating beams via Lambertson magnets not limited to eRHIC.

Design Options: Two weak – strong bend layouts (not recommended for eRHIC).

- Make the weak electron bend in the horizontal plane.
- Then with Lambertson magnet can have strong bends in the vertical plane (compatible with 8.3 mr crossing angle eRHIC scheme).

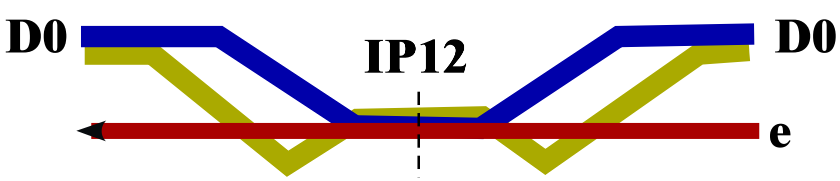


eRHIC Plan View

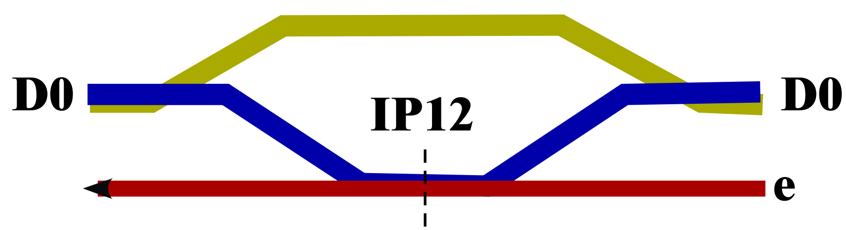


Deflection is in the vertical plane

Adjust until the yellow and blue path lengths are same.



Option A: Elevation View



Option B: Elevation View

Both options put strong vertical bends in RHIC yellow and blue rings. But this is not really advisable (likely impact to RHIC proton spin program).

Design Principles, Tips and Tricks: Use of symmetric and antisymmetric bends.

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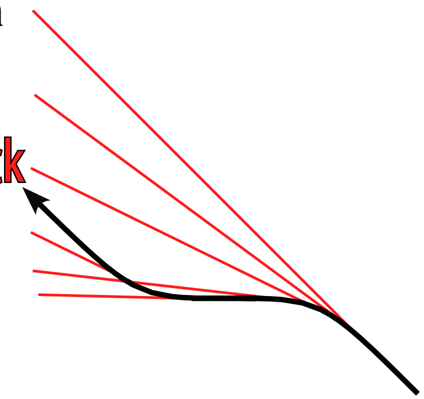
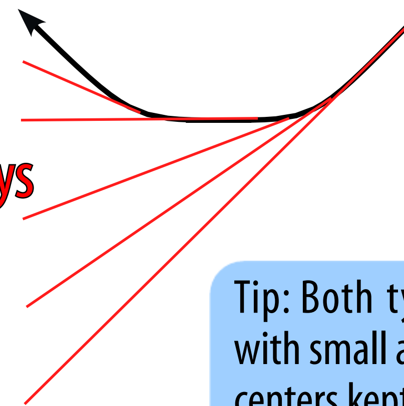
Antisymmetric Bend Geometry Synrad Fan

Fan folds back on itself



Symmetric Bend Geometry Synrad Fan

Fan always stays on same side



Tip: Both types work best with small angles and bend centers kept close together.

- Antisymmetric helps to keep far downstream apertures smaller.
- Antisymmetric provides opportunity for some optics cancellations.

Trick: Keep weak – strong bend scheme by using Lambertson septum to leverage effect of a small vertical kick close to IP.

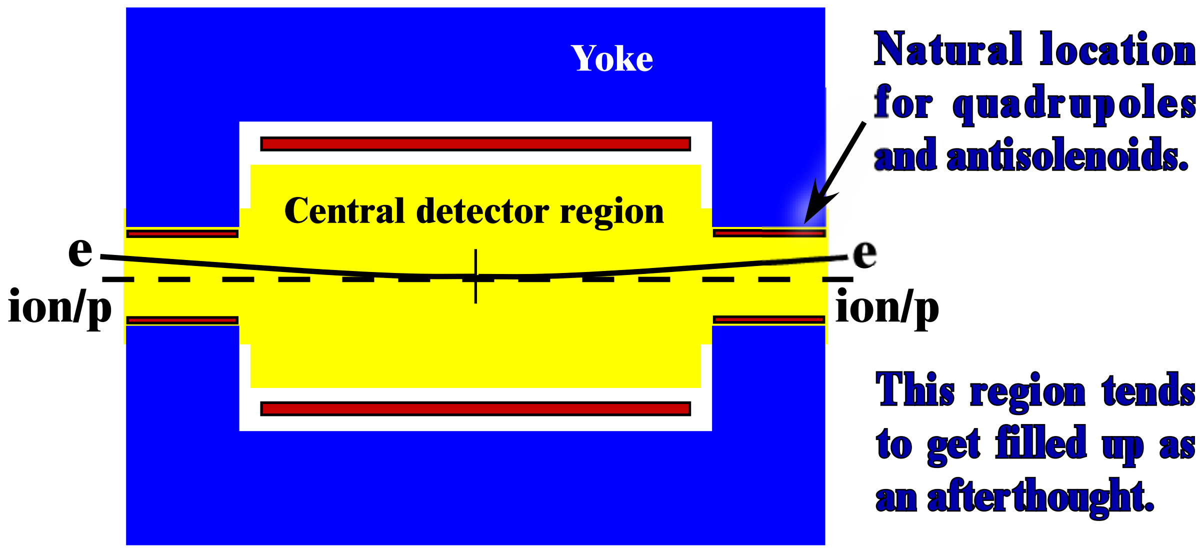
Note that we can mix the two geometries shown above. Overall geometry with hard bends from spin rotator can be antisymmetric but with small symmetric bump near IP to use Lambertson magnet.

Design Principle: For $\beta^* \approx 0.1 - 0.4$ m, try to put first quadrupole about 1 m from IP.

Ring – Ring
Hybrid Linac Ring – Ring
Linac – Ring

〉 **Round Beams** ⇒ **Triplet Optics**

- Consider from the beginning integrating large aperture quadrupoles in return yoke.
- Offset magnet center and/or add dipole field so e-beam sees reduced B-field.



Also skew quadrupole pairs may be needed in region outside detector.

Provocative Question: Can we combine solenoid and antisolenoid in one magnet?

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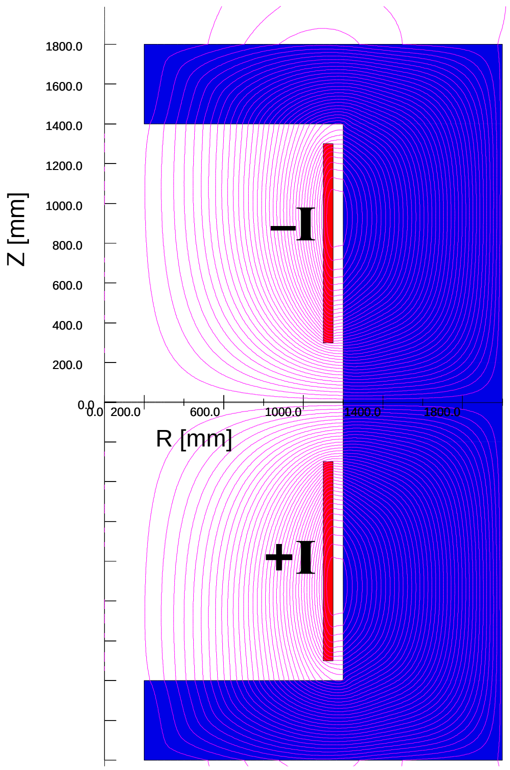
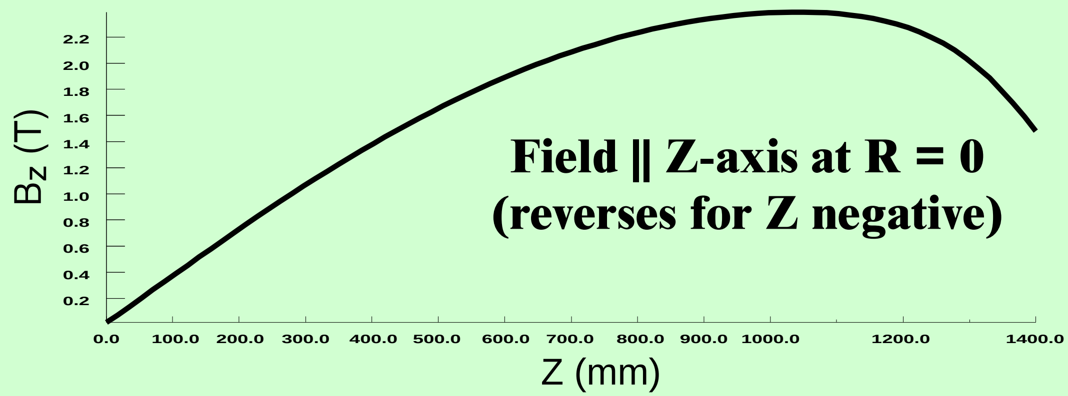
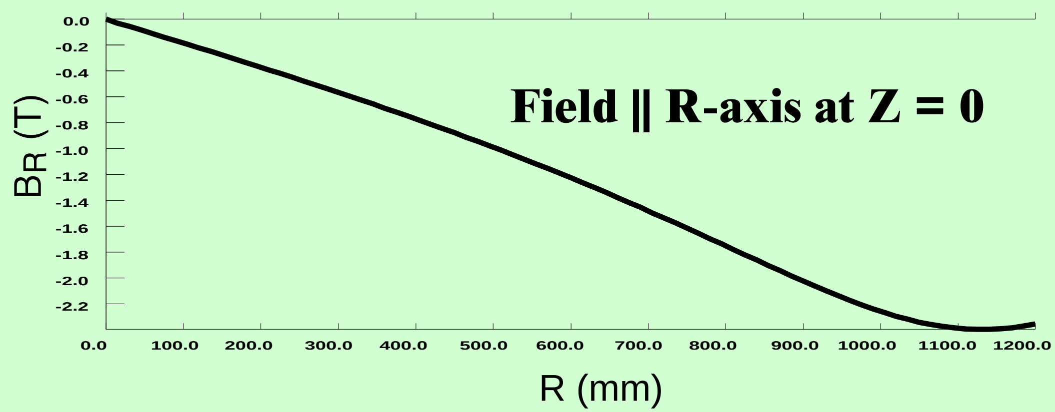


Double Solenoid Model





So far the best that has been proposed is to put small diameter, high field superconducting antisolenoid coils inside the detector. But such magnets limit experimental acceptance, perturb the detector field and are hard to support. Is a double solenoid configuration, as outlined above, useful for doing physics?

The detector – accelerator interface and getting the most from EIC (summary).

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- For basic design can build upon existing experience (HERA, B-factories).
- Some technological choices are more accommodating of experimental requirements (e.g. linac – ring: energy variability, no spin rotators) but cost considerations will force groups to set priorities.
- Investigate new ideas:
  - **Integrate weak dipole field into the detector solenoid.**
  - **Integrate detector components into accelerator magnets.**
  - **Try using Lambertson style magnets for beam separation.**
  - **Integrate large aperture quadrupoles in solenoid return yoke.**
  - **Investigate utility of double solenoid scheme for detector.**
- None of the above are magic fixes; however, in order to really push the limits on luminosity, particle acceptance, kinematic range etc. many elements will have to serve dual purposes.

The traditional split (fight) for accelerator/experimental real estate might not yield the best result. Figure out how to cooperate from the beginning.