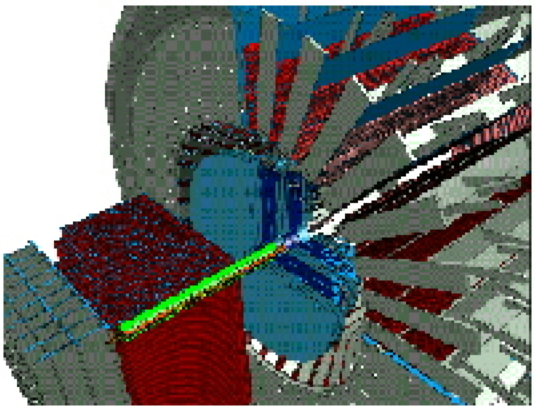
Investigating the Experimental Detector Accelerator Interface: eRHIC

Just the physics please!

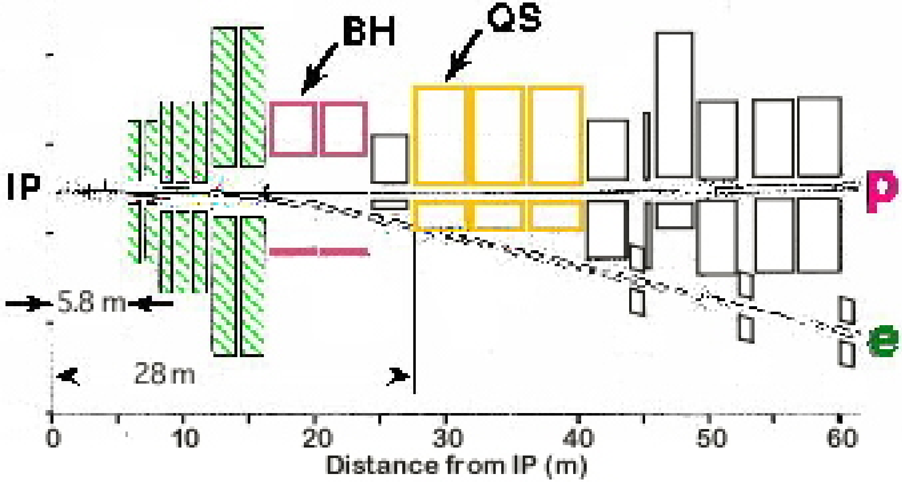


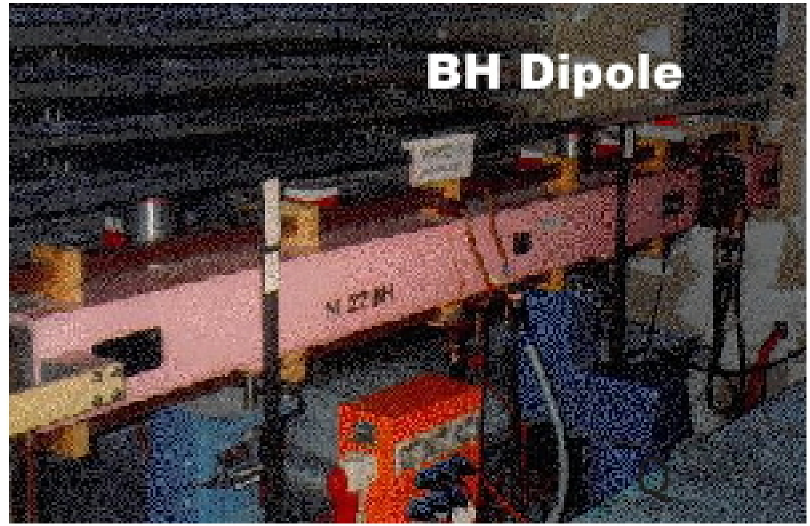
BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnets Group

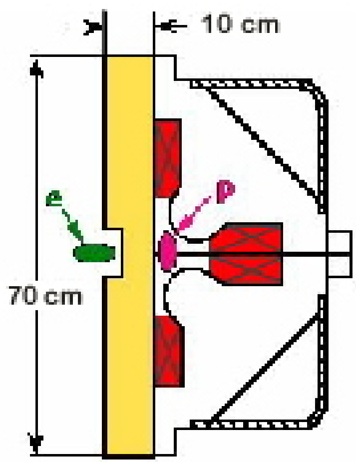
Can you provide background on what has been done in the past?

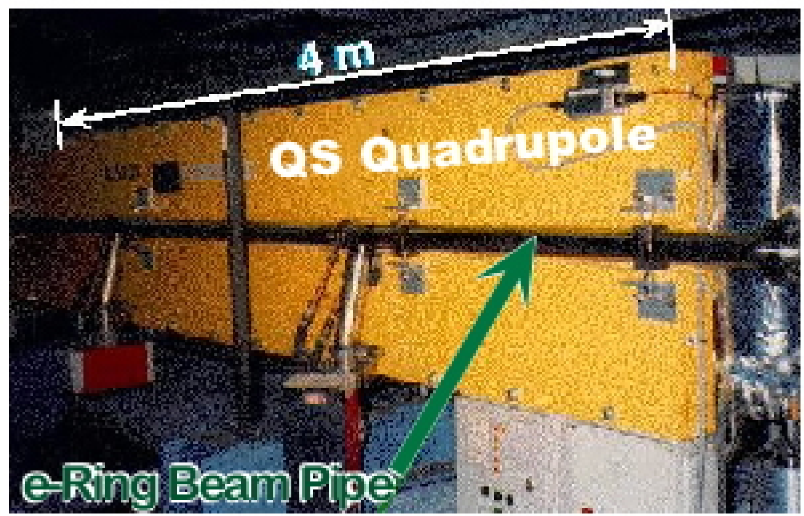
HERA Layout Before Luminosity Upgrade





- Beams "gently" separated.
- Separation < 10 cm at 28 m.
- The first superconducting quadrupole is at 115 m.
- p-ring has vertical bend just beyond region shown.

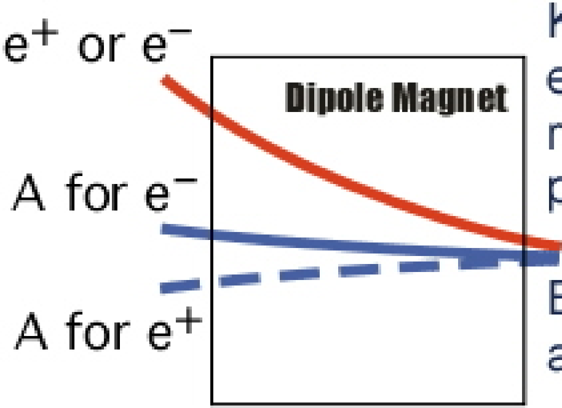




Are you positive that you know all the particles that are involved?

Historically HERAe has switched from electrons to positrons and back a few times.

- Experimenter Requests
- Accelerator Physics Issues



Keeping the same e-orbit means reversing all dipole polarities.

But ion deflection also gets reversed!

Be careful setting apertures!

Permanent magnets in arcs?

Ok, so how low in energy do we have to go ?

Historically HERAp has been asked to provide beam time at reduced proton energy.

- Are there experiments which require different kinematics?
- If so can everything be done with the ion (proton) beam?
- How are radiative corrections handled for high-z "targets?"

Permanent magnets in arcs?

What is the spin tune?

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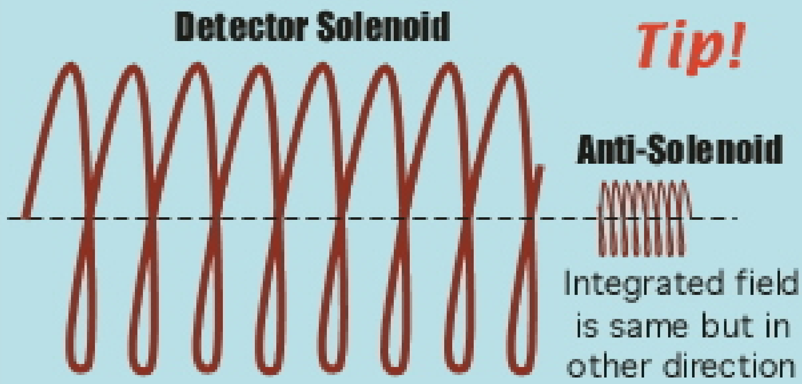
Do the particles have any special features or unique characteristics?

Yes, the electrons should be polarized. We need spin rotators for controlling spin orientation and the electrons have to come from a polarized source.

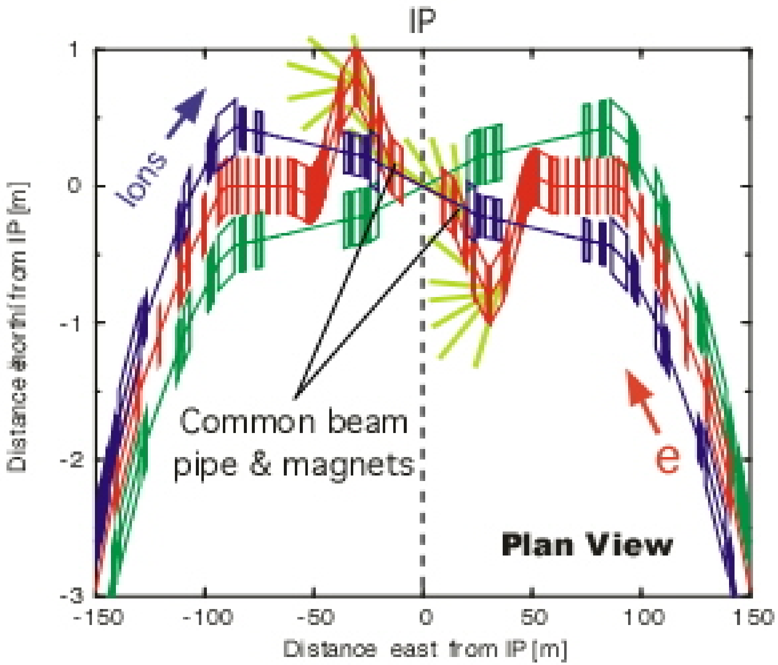
- Spin rotators have interleaved horizontal and vertical bends.
- Spin matching gives strong optics constraints (watch dispersion!).
- Spin rotator bends will produce a lot of synchrotron radiation.
- HERA Upgrade studies found: synrad + dispersion = poor e-beam emittance (for reduced luminosity).

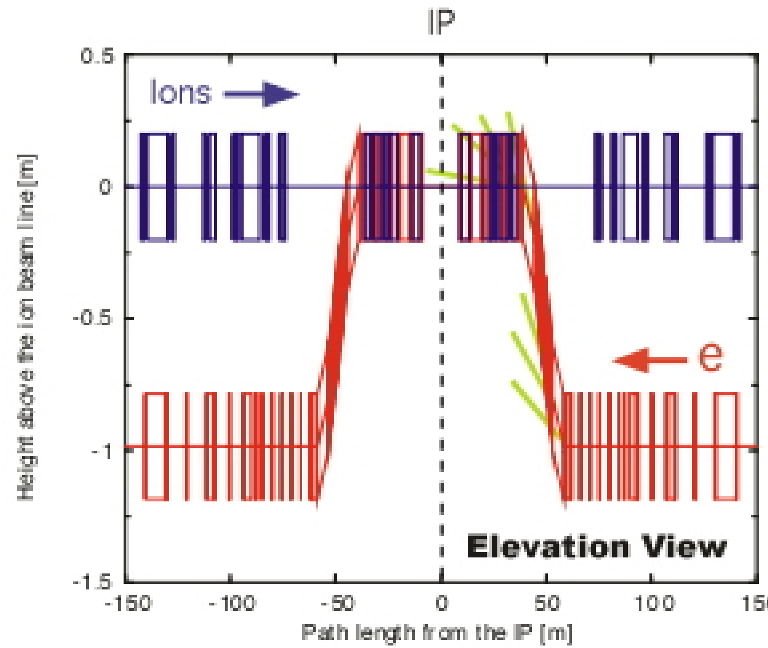


If experiments use solenoids and the e-beam circulates, then an anti-solenoid is very useful (avoids complicated skew-quadrupole arrangements for which there is no obvious space).

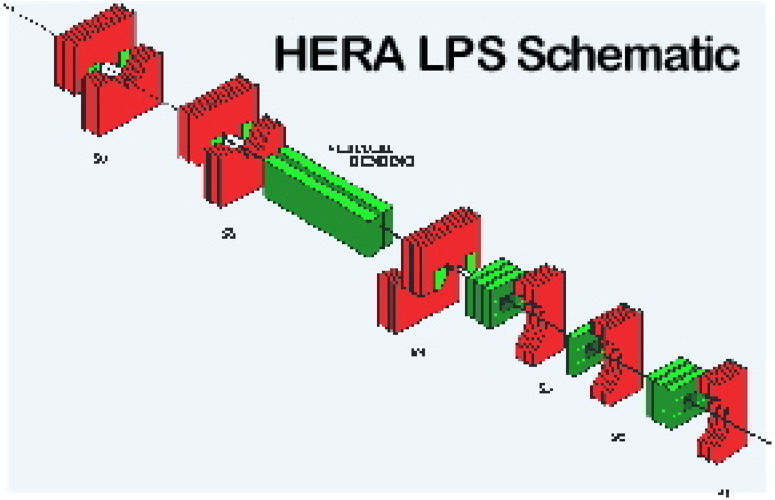
"Spin rotators," they sound interesting. What are they really like?

They are integrated with the beam separation scheme and make use of the vertical bends needed to put the e-ring at the tunnel floor. Bends are ~70 mrad with fields close to 0.44 T at 10 GeV. The strongest synrad found in eRHIC will be generated here.





Is there a need for something similar to the HERA LPS & Lumi-Monitor systems?



- HERAp is essentially flat for ± 65 m from the IP (BU, first vertical bend).
- Before and after this bend there are detectors for charged and neutral particles which are interlaced with the accelerator components (e.g. LPS, Luminosity Monitor etc.).

- Does the eRHIC IR straw design have enough bend to separate out neutrals?
- Does the eRHIC IR straw design have enough bend for charged fragments?
- Simply compromising on luminosity does not help if geometry is not right!

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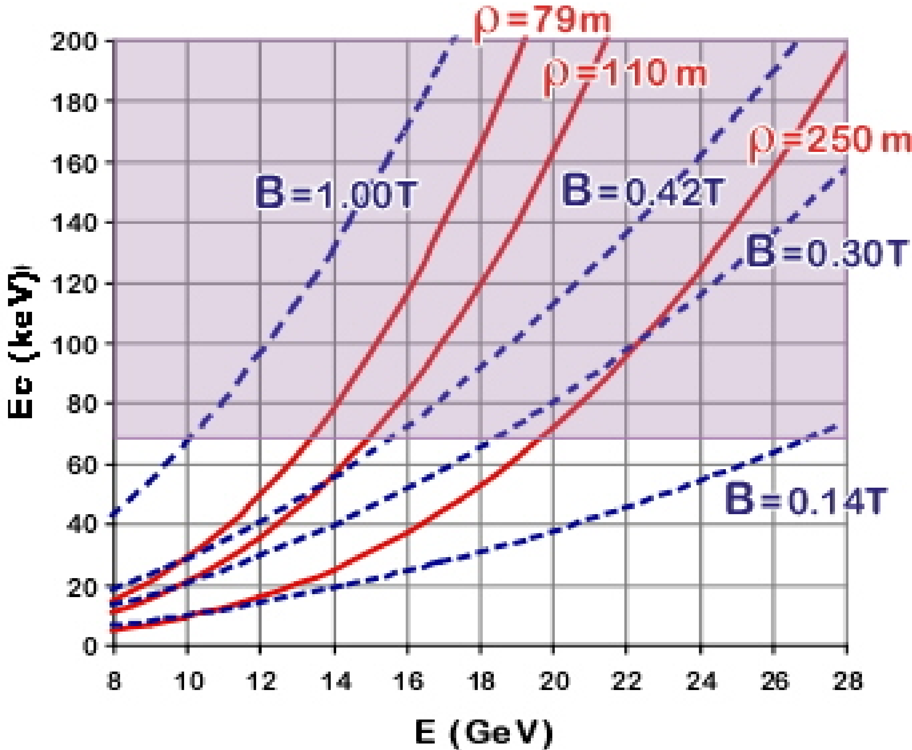
What is wrong with generating synrad? How critical is it anyway?

Some synrad is inevitable. In the eRHIC arcs the bend radius is large, 242.5 m, and field low, 0.136 T, so at 10 GeV/c the heating, 2.4 kW/m/A, of the beam pipe can be handled. But synrad near the experiments is a potential source of background.

$$E_c\,(\mathrm{keV}) = \frac{2.22\,E^3\,(\mathrm{GeV})}{\rho\,(\mathrm{m})}$$

$$\rho\,(\mathrm{m}) = \frac{3.336\,P\,(\mathrm{GeV/c})}{B\,(\mathrm{T})}$$



For Ec > 70 keV even tungsten losses much of its effectiveness in controlling synrad.

What does it mean to let all the synrad pass through the experiment?

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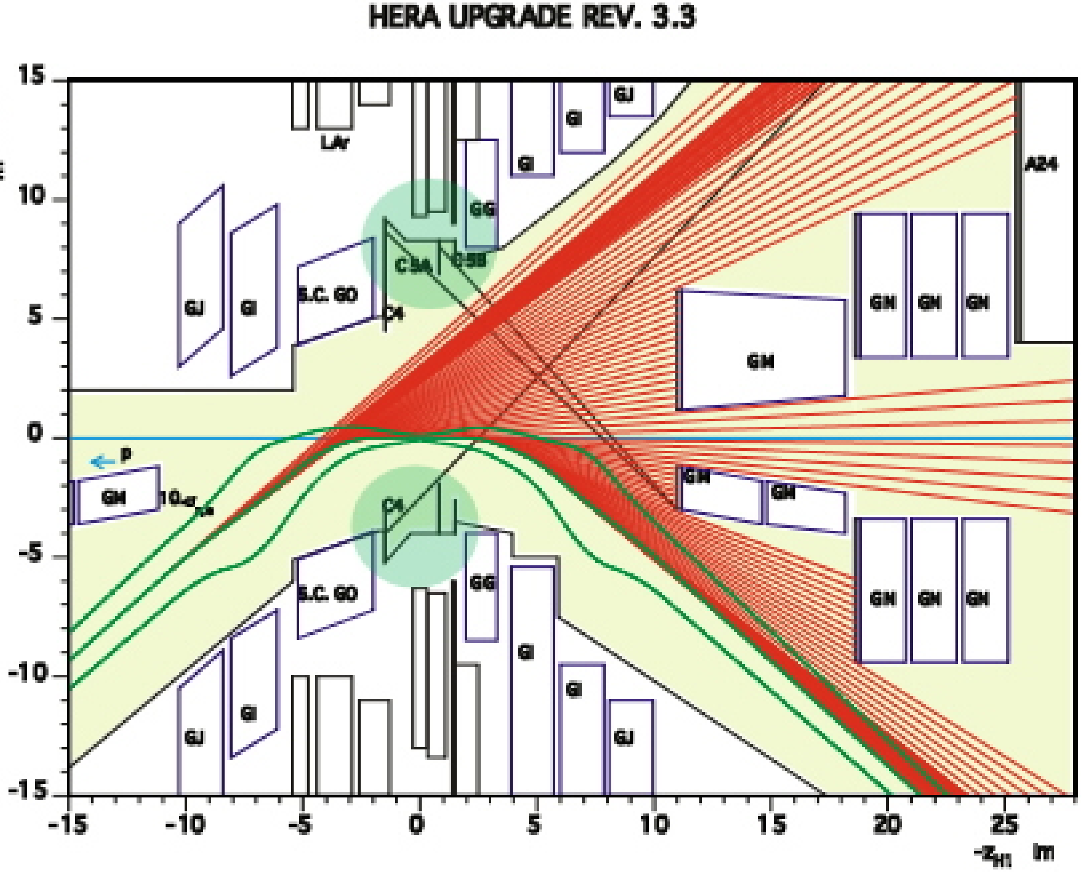
The layout of the H1 vacuum beam pipe is shown at the right. ZEUS has a similar arrangement. The intent is to have the primary synrad pass cleanly through to absorbers at 11, 19 and 24 m. The central detector region is protected from back scattered radiation by collimators.

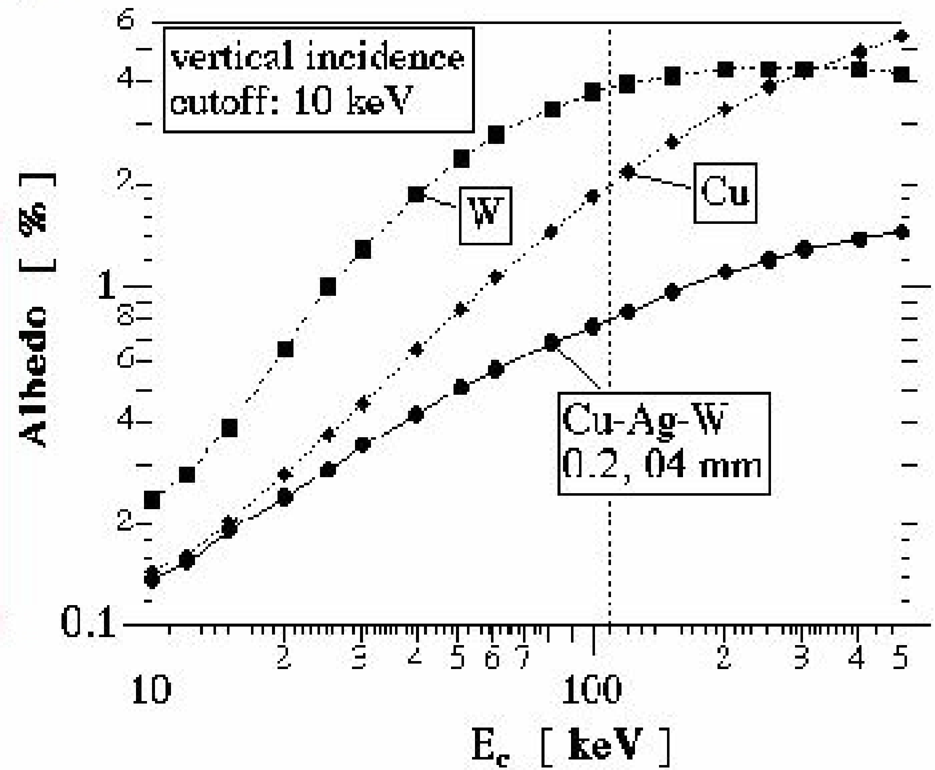


Synchrotron Radiation Albedo

Must absorb > 10^{18} γ/sec ($E_c \approx 110$ keV).

Small backscatter fraction significant!

- **Primary absorbers at 11, 19(?) and 26m.**
- **Use secondary backscatter collimators (keep radiation from central detector).**
- **Minimize albedo via multiple coatings (note factor 5 reduction compared to uncoated absorber as shown at right).**



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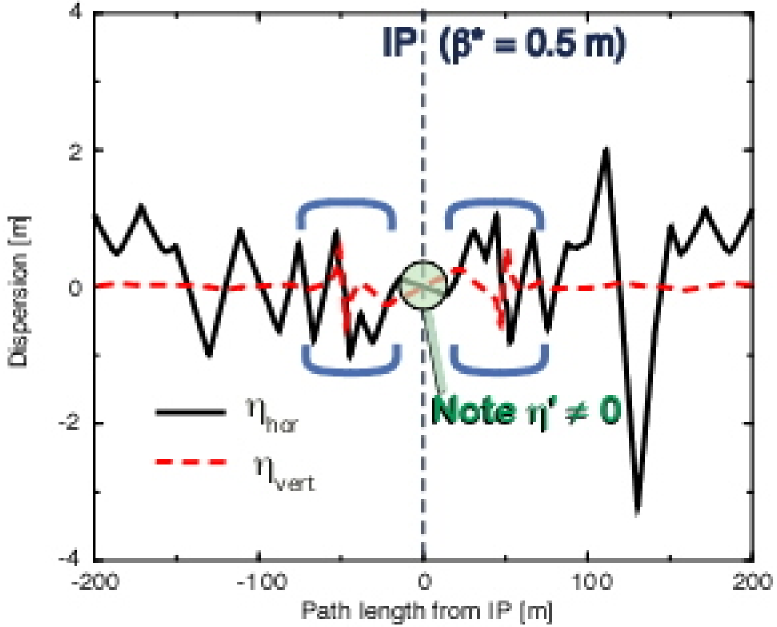
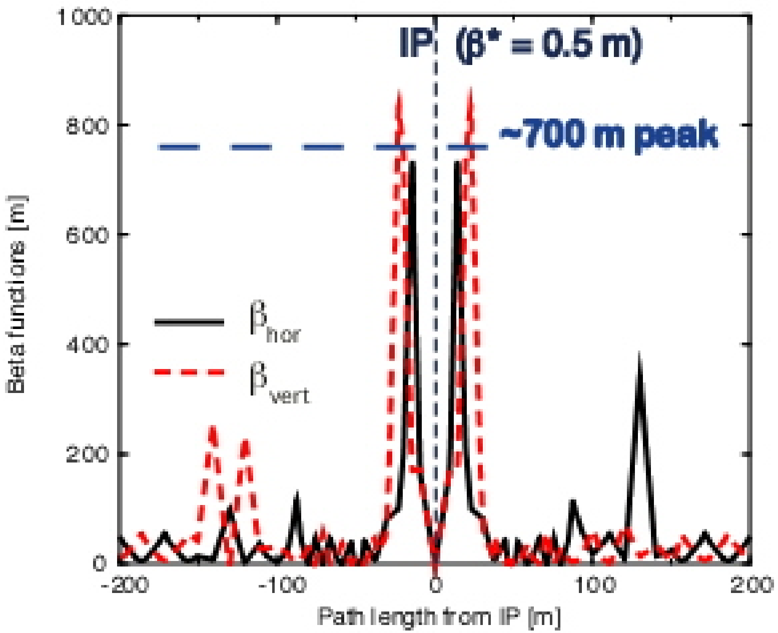
What about the eRHIC optics.... What does it look like near the IP?

- Large β-functions imply large beam sizes and possibility of large chromatic effects.
- Measure by summing $k \beta L$ (note $kL = 1/f$).
- Can correct for this with sextupoles but too much non-linearity can spoil the dynamic aperture (beam loss).

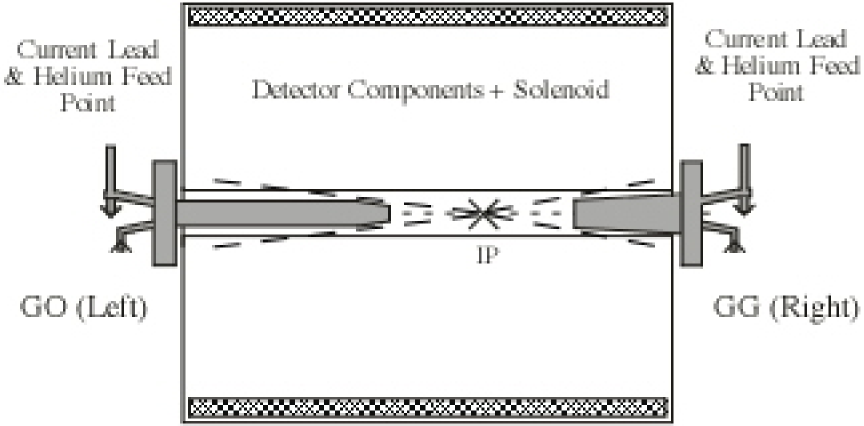




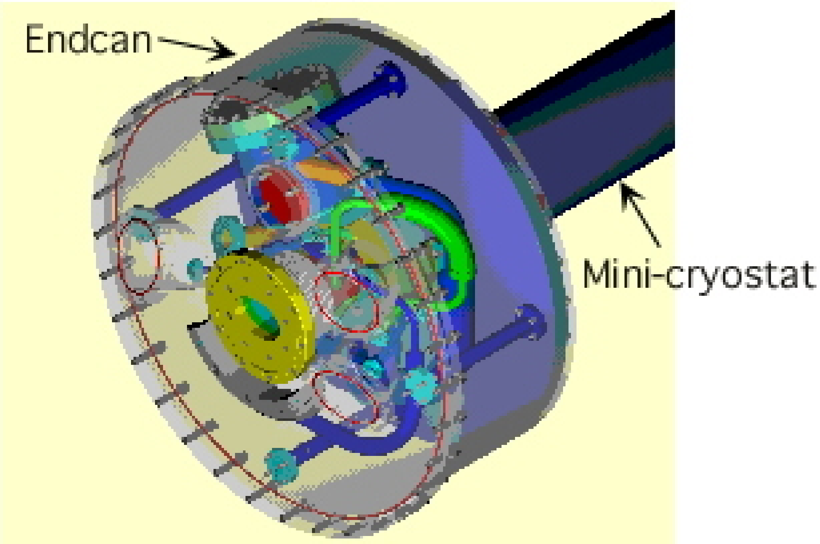
- Spin matching brings additional optics constraints (e.g. relations between β & η).

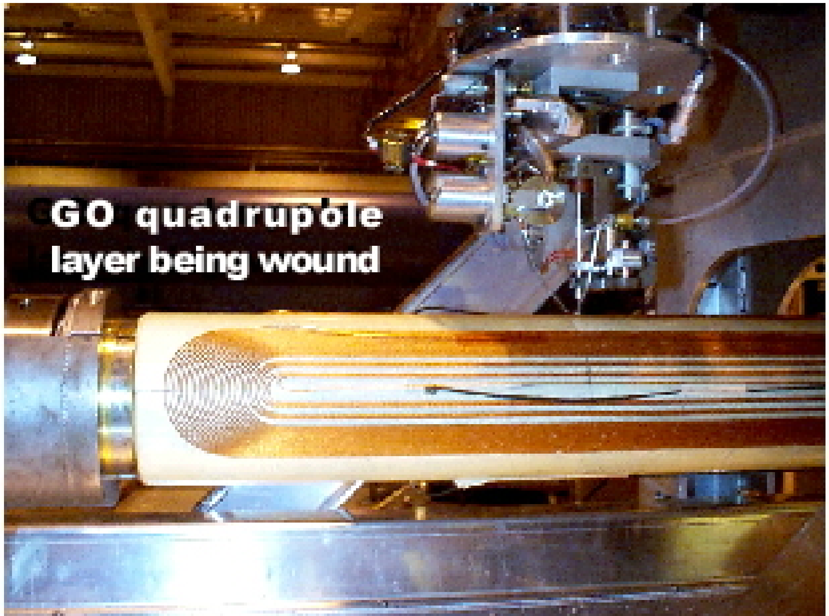
- Check that dispersion from spin rotators does not increase equilibrium emittance.
- Reduce chromatic effects by starting e-ring focusing closer to IP.

How is the HERA layout changed for the luminosity upgrade?

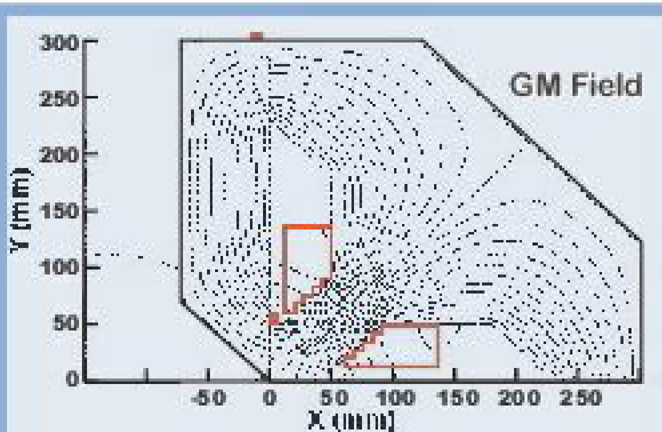


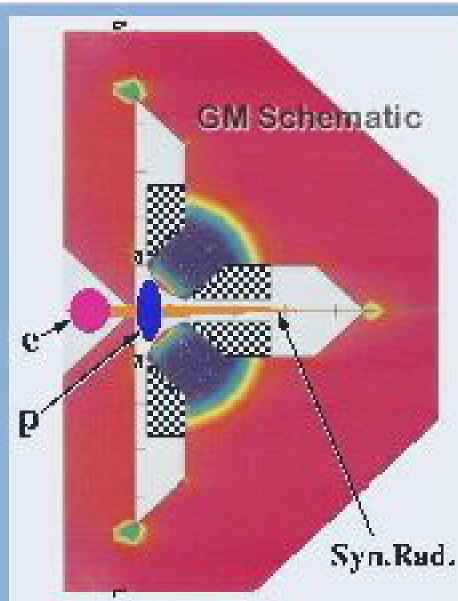
- Magnets go inside HERA experimental detectors.
- Multilayer coils with dipole, quadrupole, skew quadrupole, skew dipole and sextupole windings.
- For GG, a short tapered magnet, we achieved better than 10^{-4} field uniformity at 75% coil radius!





What else is DESY doing for the HERA luminosity upgrade?





GM, HERA's Magnetic Septum Quadrupole

- For luminosity upgrade GM starts proton focusing at 11 m (previously 28 m).
- Inherently a combined function magnet, so is suitable for heavy ions but not e (synrad).

If 700 m beta-maxima seem too big, how can we get them down?

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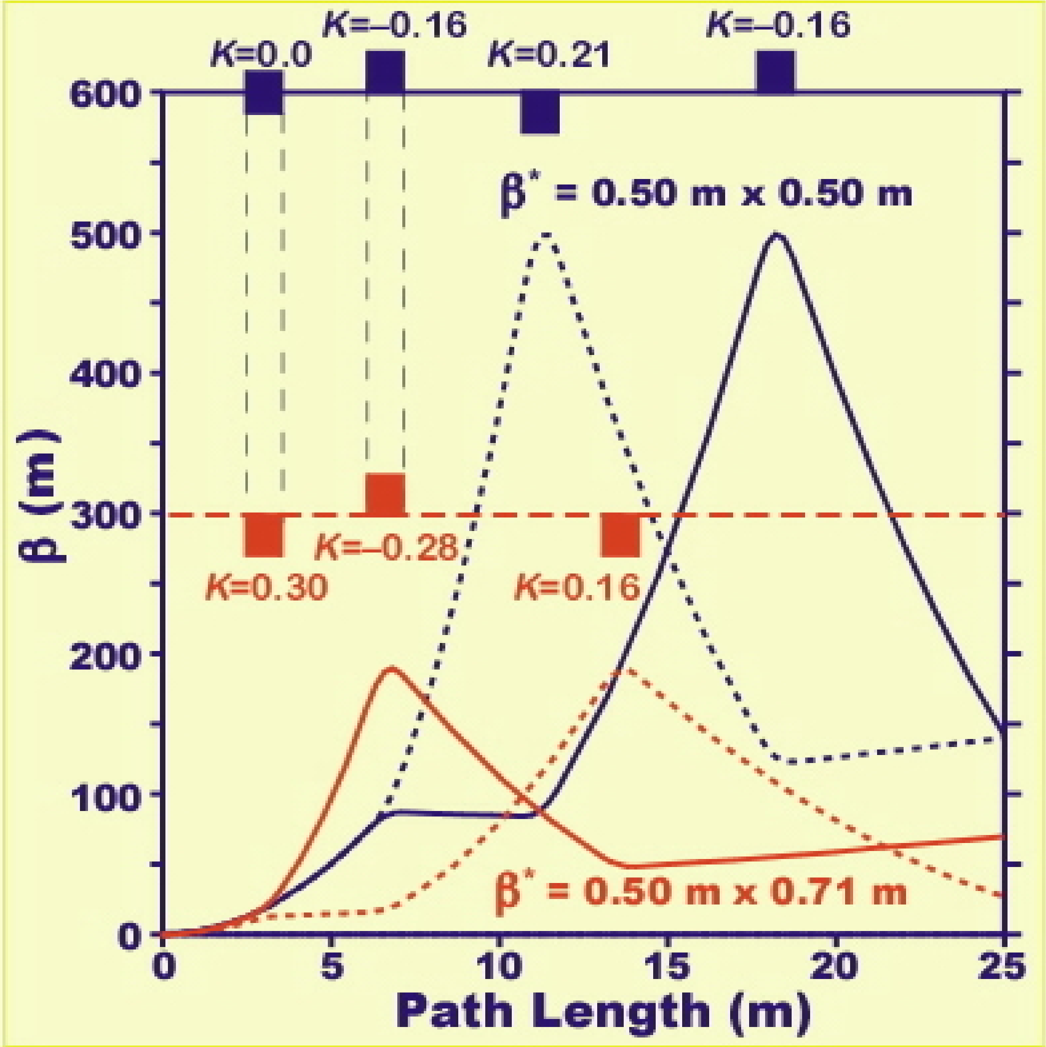


Start focusing sooner!

Solution 1: sum $K\beta_x L = -73$

sum $K\beta_y L = 67$

Solution 2: sum $K\beta_x L = -37$

sum $K\beta_y L = 28$

For the above example chromaticity is cut in half

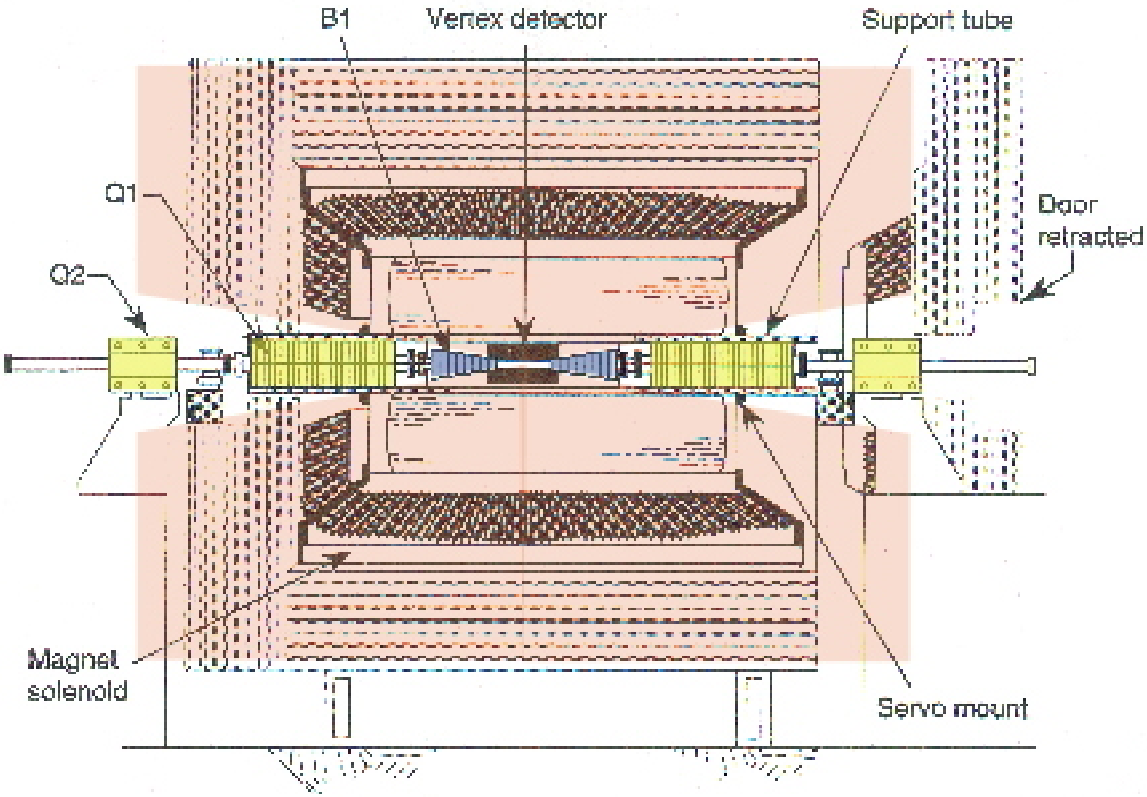
For 10 GeV, $K = 0.3$ => 10 T/m

Permanent magnet quadrupoles?

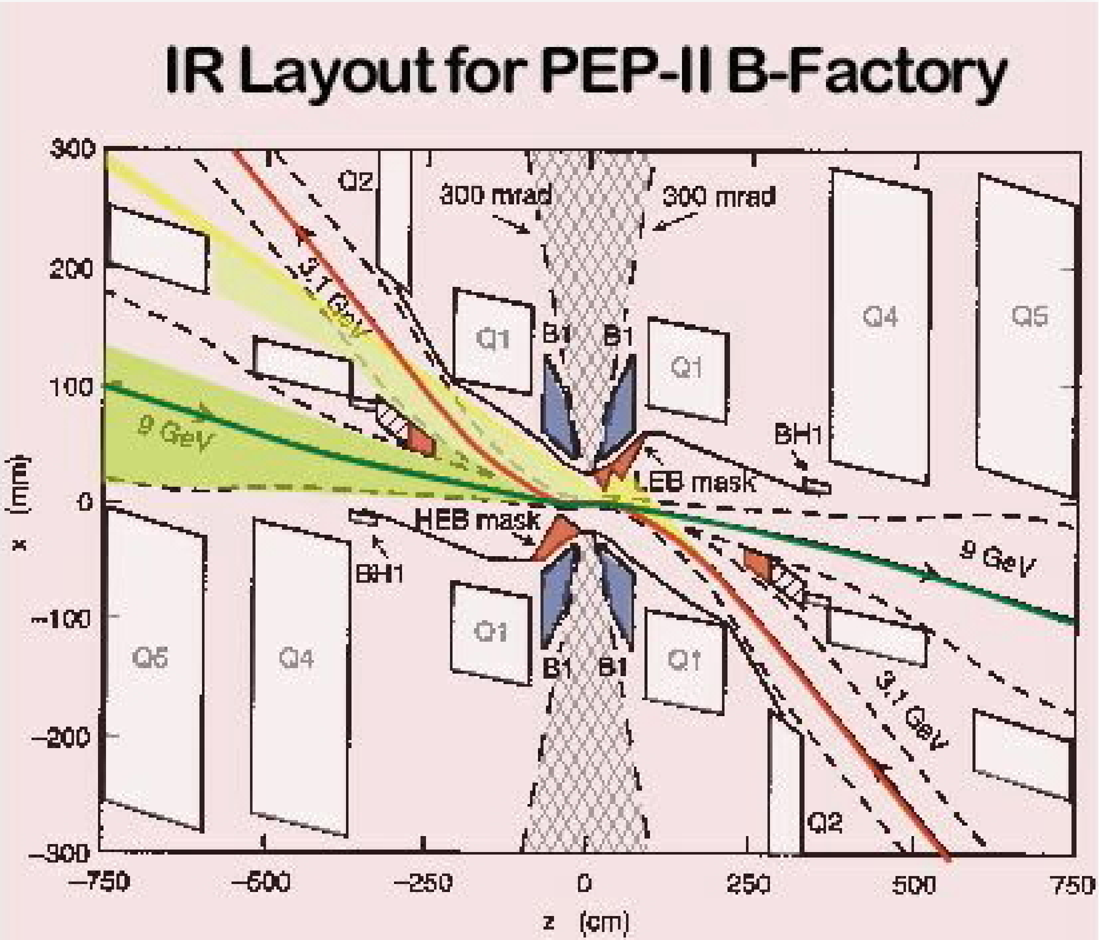
Can quadrupoles be integrated into the experimental detectors?

Are other experiments at other accelerators faced with these problems?

PEP-II B-Factory IR Magnets & Supports

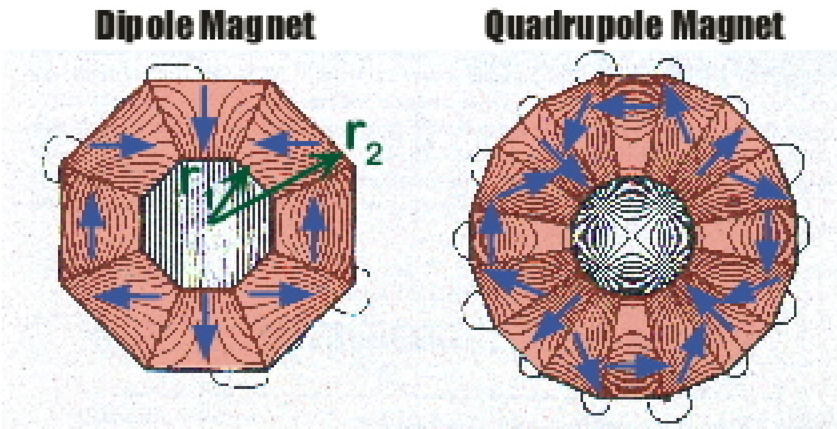


What about the PEP-II B-Factory IR design at SLAC?

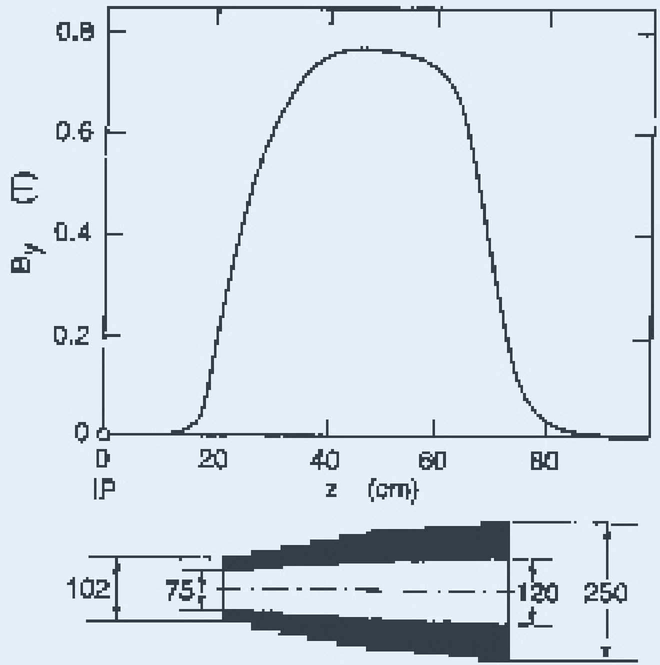


- Dipoles inside experiment.
- Quad's inside experiment.
- Septum Quadrupoles used.
- Synrad masks close in.
- ±300 mrad clear reagon.

How does one get tapered permanent magnet dipoles & quadrupoles?



- Magnetization rotates by $2\pi[N+1]/M$ per block (multipole = N, number of segments = M).
- Field strength goes ~ $\ln[\,f(r_1,r_2)\,]$.
- Vary r_1 and r_2 vs. length for tapered magnet.
- PEP-II: for B1 dipole => 0.80 T
  Q2 quadrupole => 10.64 T/m



Transverse field on axis for PEP–II tapered B1 dipole magnet. Dimensions are in mm.

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So what do the PEP-II B-Factory lattice functions look like?

For PEP-II LER:

$\beta^*_{hor,ver} = 0.375, 0.015$ m

and PEP-II HER:

$\beta^*_{hor,ver} = 0.500, 0.020$ m

Even with quadrupoles and dipoles inside the detector the HER lattice has > 400 m β-peaks. For LER β < 120 m. These β-peaks would be much higher without such special measures.

PEP-II HER IR Lattice Functions*

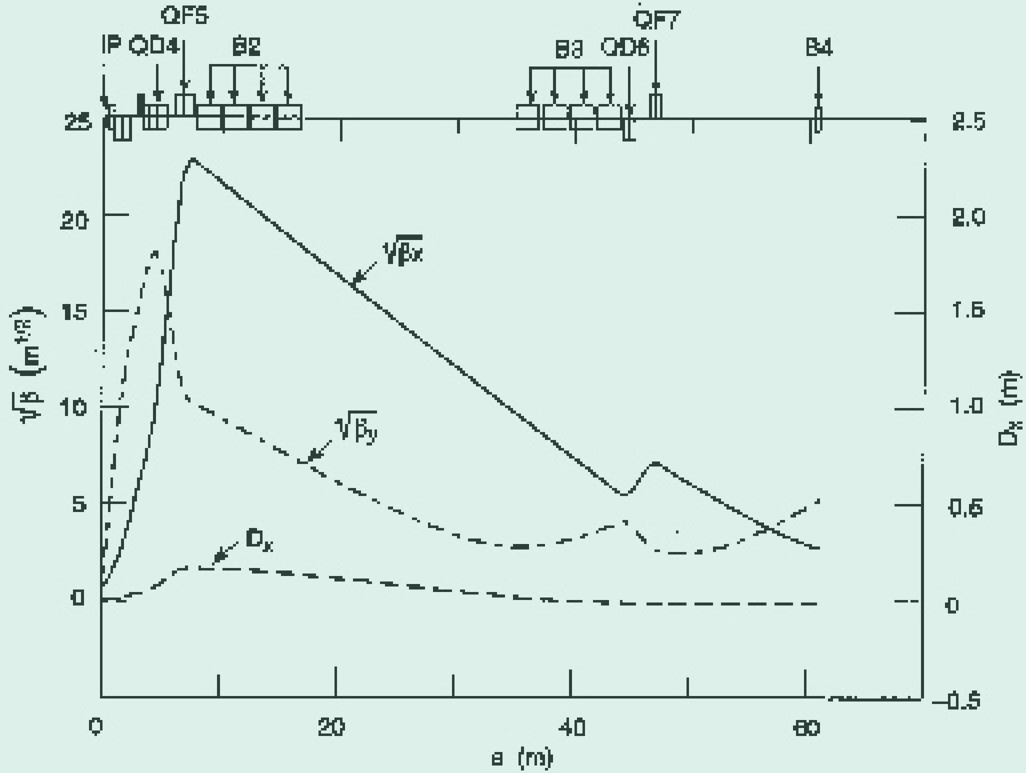

Fig. 4-12. Lattice functions for the first 60 m of the IR straight section of the HER. The weak dipoles B2 and B3 match the dispersion function to zero.

*PEP-II Conceptual Design Report, June 1993.

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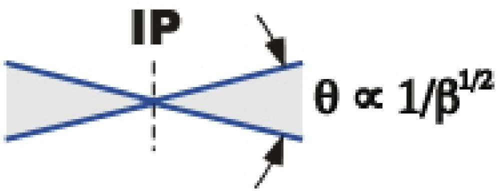
Other than putting magnets inside the experiments, what can be done to reduce β-maxima?

β-maxima are reduced by increasing β*. While this *normally* leads to larger IP spot size (lower luminosity) there are positive benefits from larger β*.

- **Raising β* reduces the beam divergence at IP (neutrals as well as for beam particles).**
- **Smaller apertures imply that detectors can be placed closer to circulating beam.**

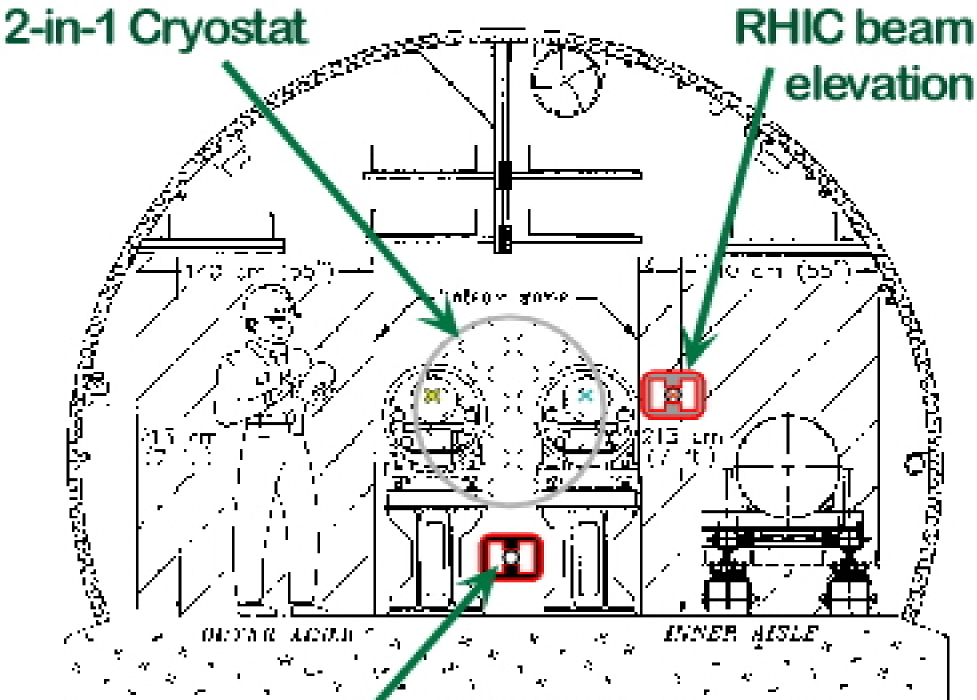


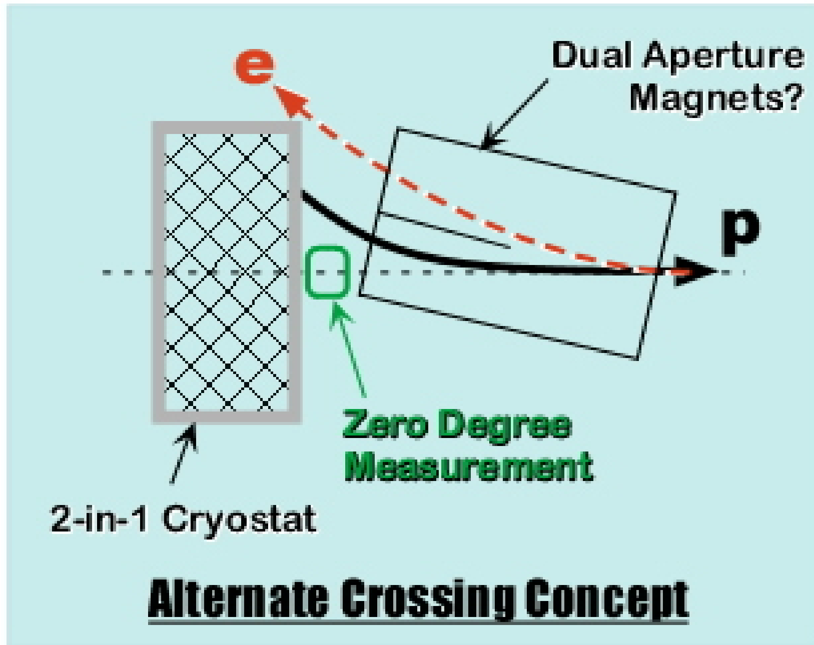
Caveat: Too high β* can lead to excessive beam-beam tune shift.

Optimizing IP Spot Size *Tip!*

Sometimes it is possible to reduce peak β-functions by raising β* without taking too much of a luminosity penalty. Reducing dispersive, chromatic (non-linear) and coupling contributions can help to reduce the equilibrium emittance and thereby keep spot size small even with larger β*. Also not all experiments need the highest possible luminosity.

Which way did they go? What did the getaway magnet look like?





Hard to see how to avoid giving the electrons too strong a bend or the ions too little... may have to design dedicated eA IR(s).

By the way, how is eRHIC able to get across the other experiments?

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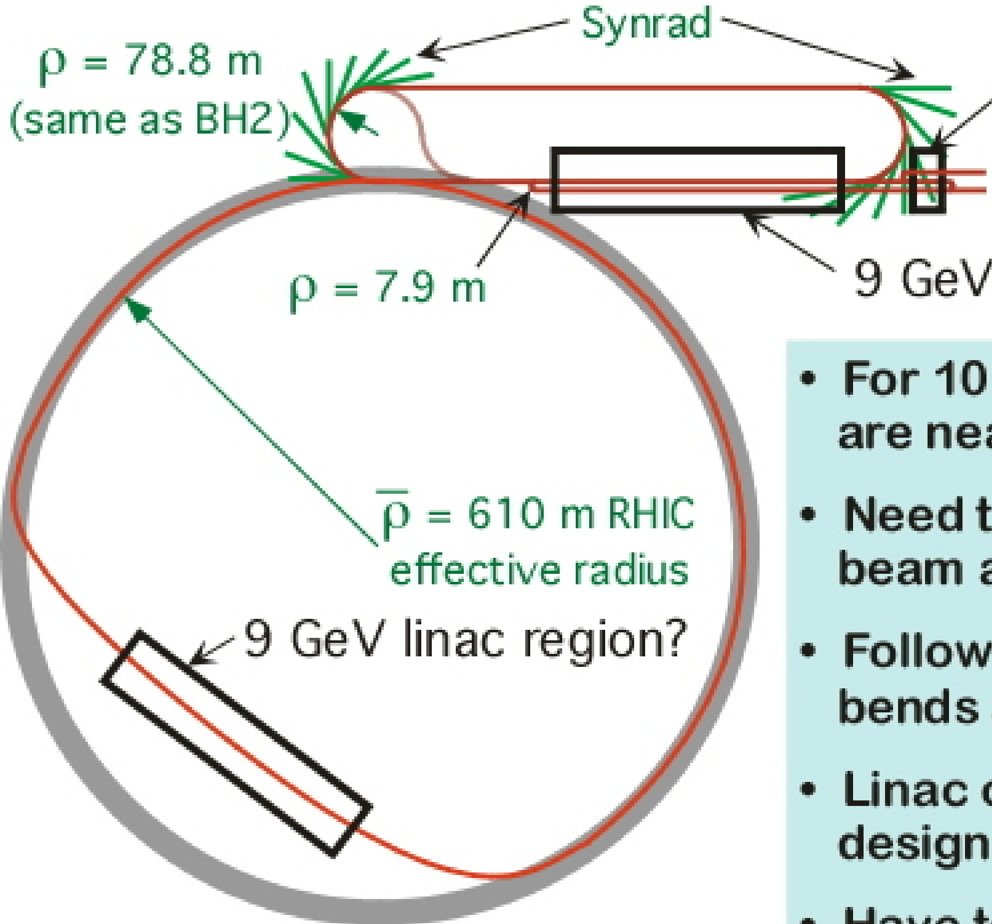
… and about the linac option, where does it fit in?



Note: For this schematic bend radii are drawn to scale but lengths are not.

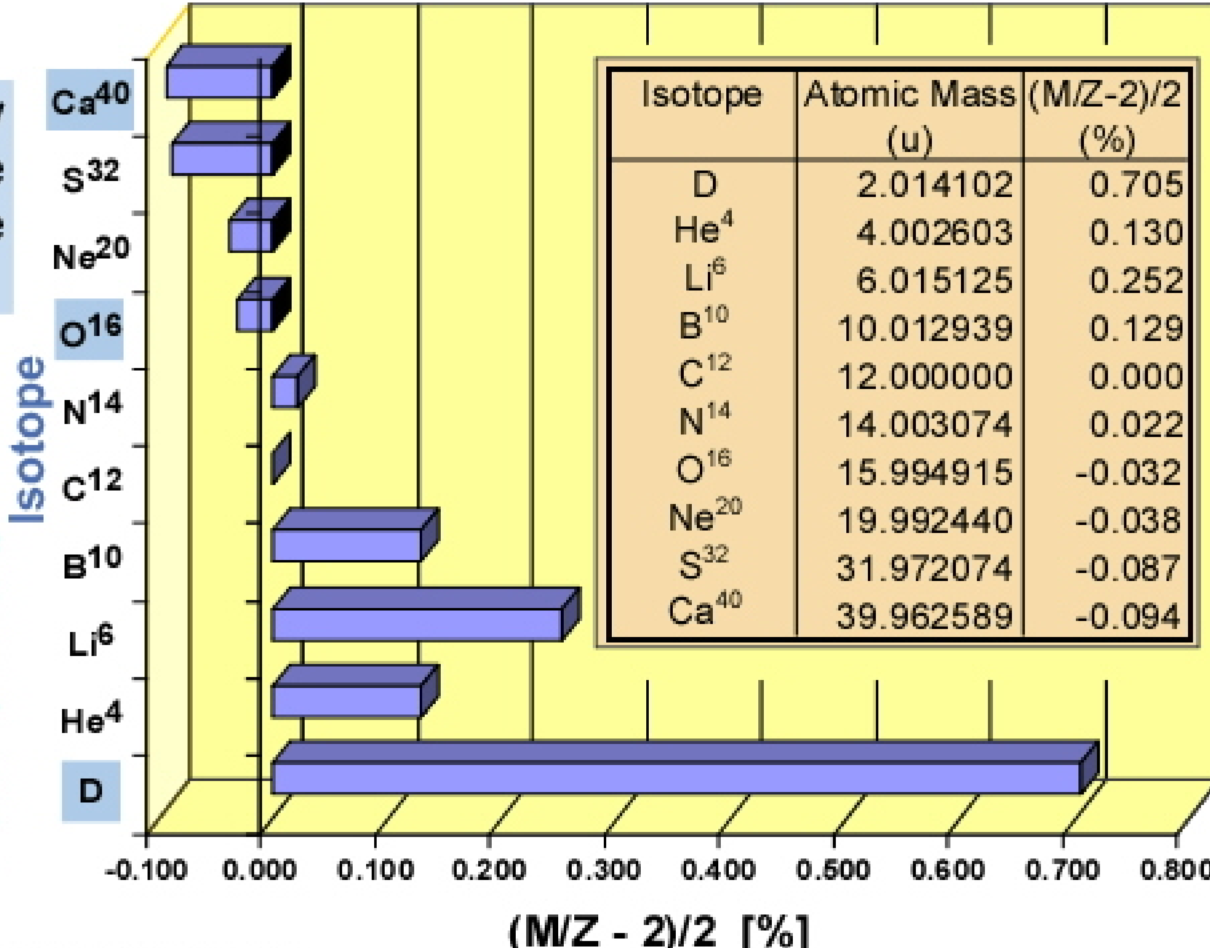
- **For 10 GeV proposed spin rotator dipoles are near synrad heating limit (minimum ρ).**
- **Need twice as many dipoles to return the beam along the same path.**
- **Following RHIC tunnel can reduce strong bends at the cost of more arc length.**
- **Linac option, along with giving machine design flexibility can easily avoid other IPs.**
- **Have to keep synrad from arcs from hitting linac superconducting cavities!**

Just one more thing... are you sure you can identify the particles which go together?

To improve systematics it may be desirable to have multiple particle types in the machine <u>at the same time</u>.

Look for constant M/Z ratio.

Have to generate a bit more negative-dispersion? Do RHIC quadrupoles have enough focusing strength and flexibility to, for example, create an imaginary-γ_T lattice? Better to just minimize peak dispersion?

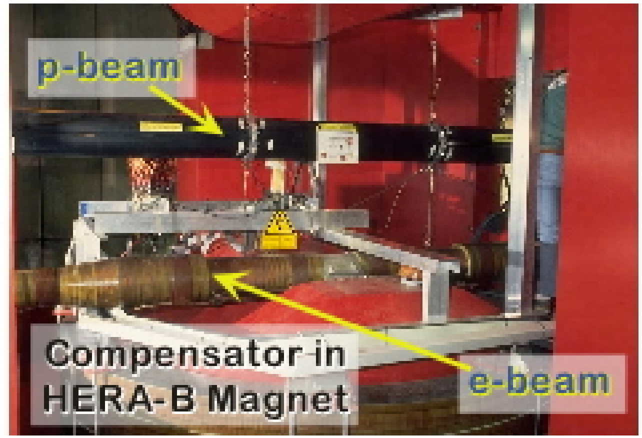


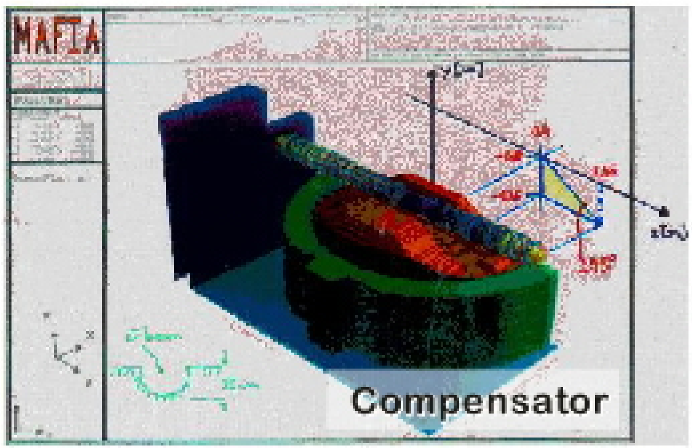
Isotope	Atomic Mass (u)	(M/Z-2)/2 (%)
D	2.014102	0.705
He^4	4.002603	0.130
Li^6	6.015125	0.252
B^{10}	10.012939	0.129
C^{12}	12.000000	0.000
N^{14}	14.003074	0.022
O^{16}	15.994915	-0.032
Ne^{20}	19.992440	-0.038
S^{32}	31.972074	-0.087
Ca^{40}	39.962589	-0.094

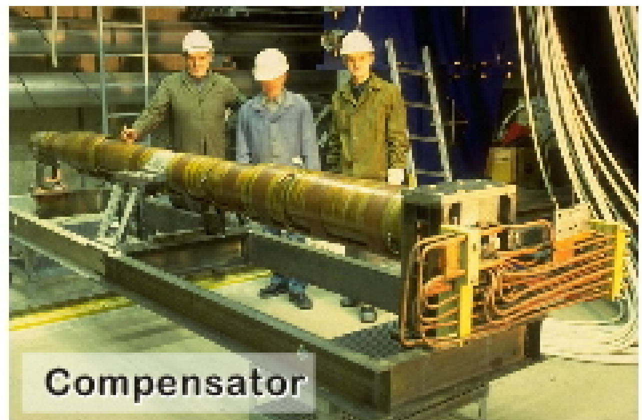
First RHIC is filled with ions. Then they are ramped up to top energy.

... just one last question. What path does eRHIC take?

Getting an electron beam to pass through an experimental detector without either spoiling beam polarization or the experimental detector itself can sometimes be very challenging (e.g. HERA-B).







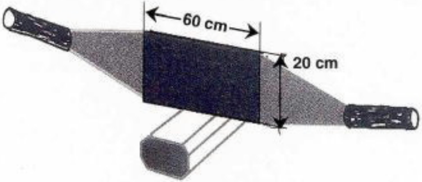
Satellite Bunches in Nearby HERAp 208 MHz Buckets

- At highest beam currents, bunch rotation in PETRA incomplete for particles in "tails"
- With both 52 & 208 MHz RF on in HERA, some protons can get trapped in wrong (nearby) buckets.
- These protons reduce live time & are source of HEP background
- FToF counter used for satellite signal

Forward Time of Flight (FToF)

P.Biddulph

Installed Feb/March 1994



- 7 m from IP & 5 cm from proton beam
- Active Area 20 x 60 cm^2
- Pulse height threshold set high
- Only 35% efficient!
- Used as veto

Figure 1: FToF Counter Schematic

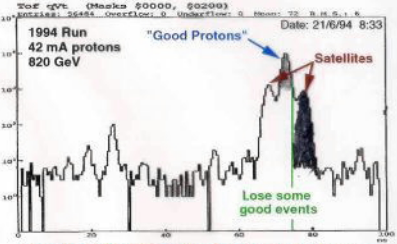


Figure 2: FToF Spectrum for "Bad" Conditions

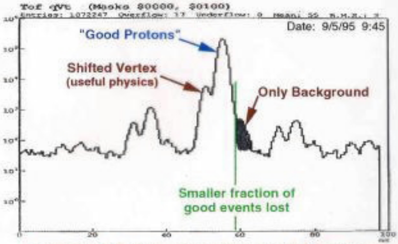


Figure 3: FToF Spectrum for "Good" Conditions