Joint AP & Detector WG

- V.Ptitsyn, BNL, eRHIC and MEeIC parameters and layouts
- Y.Hao, BNL, Beam-beam interactions in MEeIC
- J.Beebe-Wang,BNL, Beam Induced Detector Background
- C.Montag, BNL, Synchrotron Radiation Fans
- Y.Zhang, ELIC designs (including staging) and its merging with the detector

- M. Savastio, Polarized PDFs at EIC
- R.Ent, Magnetic Field Configurations

Legend:

Talks to be covered by me

Talks to be covered by Elke

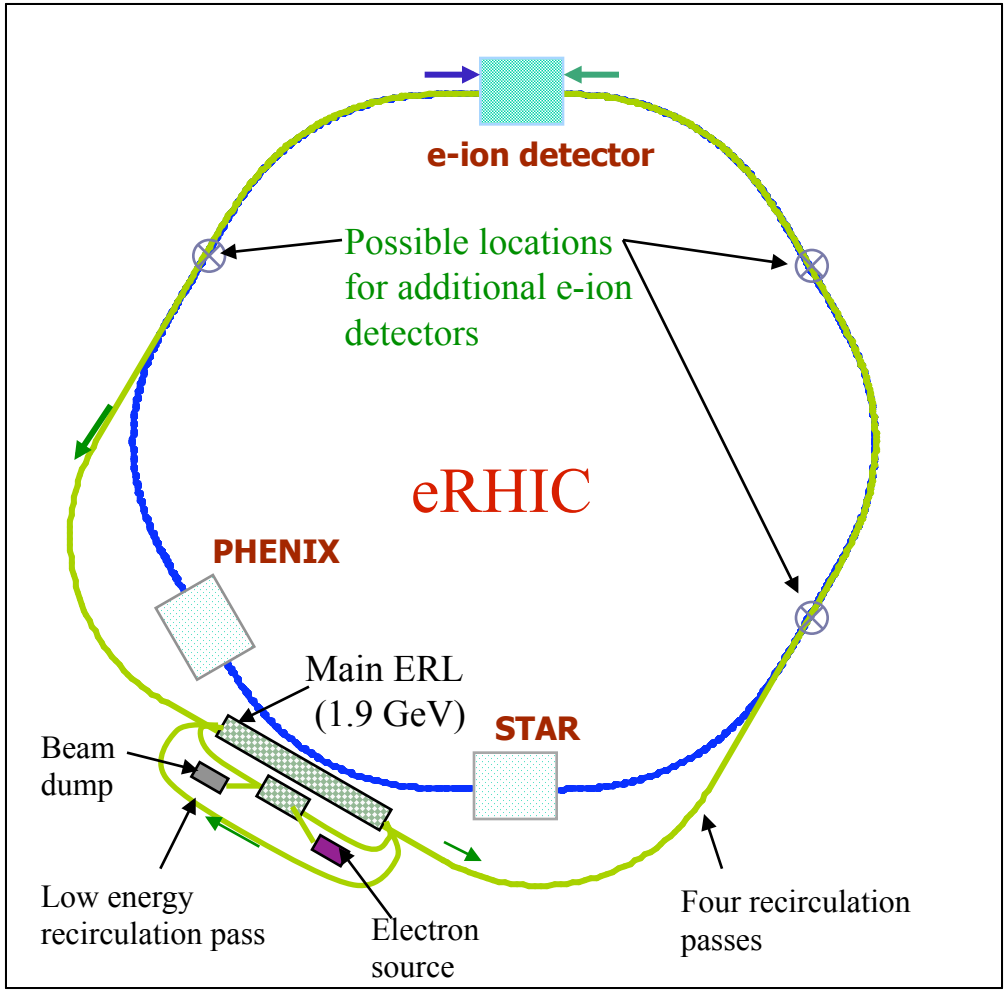
V.Ptitsyn, BNL

eRHIC and MEeIC

- In both designs the ions (or protons) circulate in the existing RHIC ring.
  - eRHIC: 3-20 (30) GeV electron energy.
  - MEeIC, Medium Energy eIC: 2-4 GeV electron energy
- In both designs the ions (or protons) circulate in the existing RHIC ring.
  - eRHIC : completely new IR design (and magnets) even for ions
  - MEeIC: should be based on the present IR scheme (and magnets) for ions.
- MEeIC is considered as first stage for eRHIC. Major components have to be the same.

ERL-based eRHIC Design

V.Ptitsyn



- 10 GeV electron design energy. Possible upgrade to 20 GeV by doubling main linac length.
- 5 recirculation passes (4 of them in the RHIC tunnel)
- Multiple electron-hadron interaction points (IPs) and detectors;
- Full polarization transparency at all energies for the electron beam;
- Ability to take full advantage of transverse cooling of the hadron beams;
- Possible options to include polarized positrons: compact storage ring; compton backscattered; undulator-based. Though at lower luminosity.

Details were presented yesterday by T.Roser

Other design options

V.Ptitsyn

Under consideration also:

➢*Medium Energy EIC at RHIC (MEeIC)*

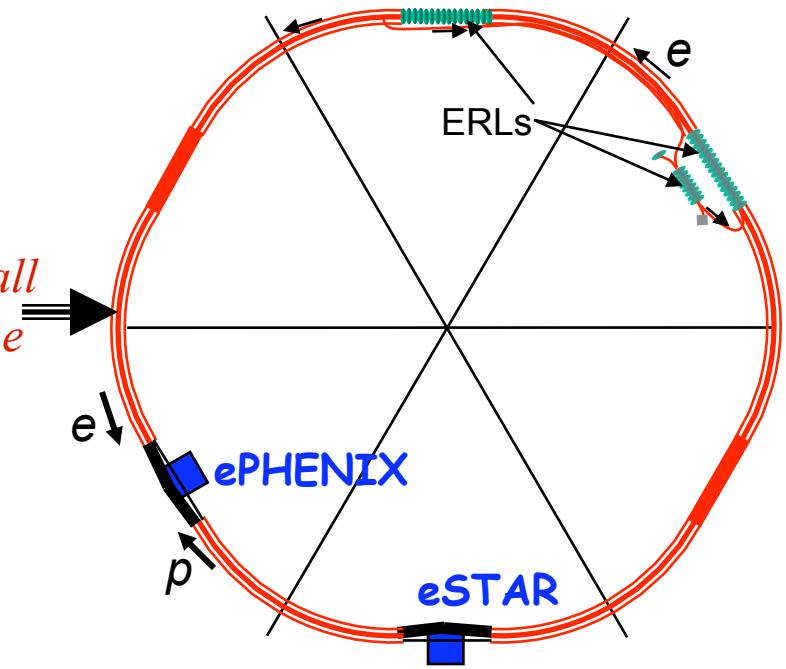
Electron energy up to 2-4 GeV. Acceleration done by an ERL linac placed in the RHIC tunnel. It can serve as first stage for following higher electron energy machine.
Luminosity ~ 10^{32} $cm^{-2}s^{-1}$ (without cooling)

➢*High energy (up to 20-30 GeV) ERL-based design with all accelerating linacs and recirculation passes placed in the RHIC tunnel.*

Considerable cost saving design solution.
Luminosity exceeds 10^{33} $cm^{-2}s^{-1}$

➢*Ring-ring design option.*

Backup design solution which uses electron storage ring.
See eRHIC ZDR for more details.
The average luminosity is at 10^{32} $cm^{-2}s^{-1}$ level limited by beam-beam effects.

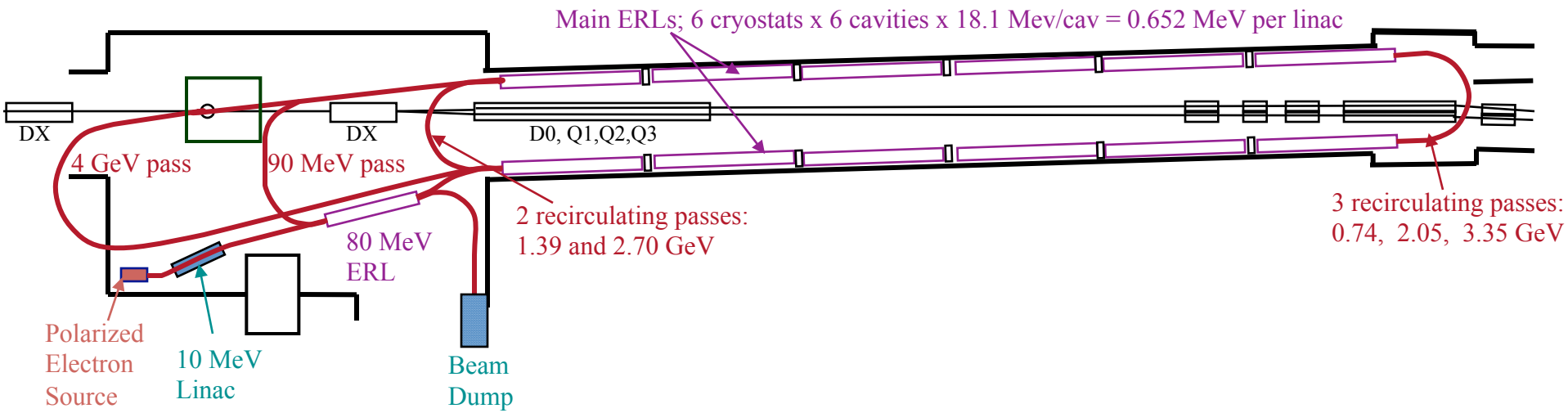


Details, today in afternoon – V. Litvinenko, Staging of eRHIC

V.Ptitsyn

MEeIC Layout

Recirculating pass energies are shown for 4 GeV top energy



Details, today in afternoon – V. Litvinenko, Staging of eRHIC

MEEIC parameters for e-p collisions

	not cooled		pre-cooled		high energy cooling	
	p	e	p	e	p	e
Energy, GeV	**250**	**4**	**250**	**4**	**250**	**4**
Number of bunches	**111**		**111**		**111**	
Bunch intensity, 10^{11}	**2.0**	**0.31**	**2.0**	**0.31**	**2.0**	**0.31**
Bunch charge, nC	**32**	**5**	**32**	**5**	**32**	**5**
Normalized emittance, 1e-6 m, 95% for p / rms for e	**15**	**73**	**6**	**29**	**1.5**	**7.3**
rms emittance, nm	**9.4**	**9.4**	**3.8**	**3.8**	**0.94**	**0.94**
beta*, cm	**50**	**50**	**50**	**50**	**50**	**50**
rms bunch length, cm	**20**	**0.2**	**20**	**0.2**	**5**	**0.2**
beam-beam for p /disruption for e	**1.5e-3**	**3.1**	**3.8e-3**	**7.7**	**0.015**	**7.7**
Peak Luminosity, 1e32, $cm^{-2}s^{-1}$	**0.93**		**2.3**		**9.3**	

Details, today in afternoon – V. Litvinenko, Staging of eRHIC

Conclusion

Y. Hao

- Beam-beam study provide hints to optimize the luminosity and reduce the power loss in ERL
- Due to the focusing effect, the actual luminosity can be 20% larger (NotCooled) or 40% larger (PreCooled) than design values.
- The aperture required is easy to achieve for both cases.
- The kink instability can be suppressed by proper energy spread.

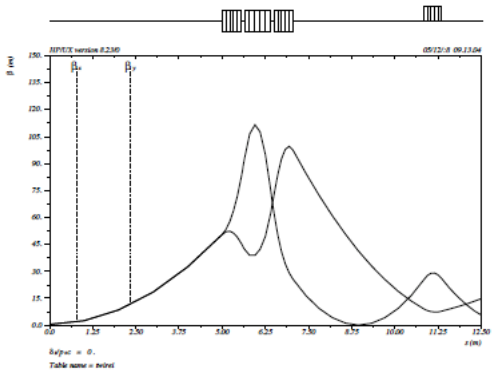
Details, today in afternoon – V. Litvinenko, Staging of eRHIC

J.Beebe-Wang gave very detailed talk on vacuum and synchrotron radiation effects in the IP
- will be covered later by Elke

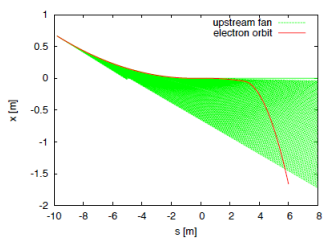
C. Montag

Electron Beam Focussing

Incoming beam:

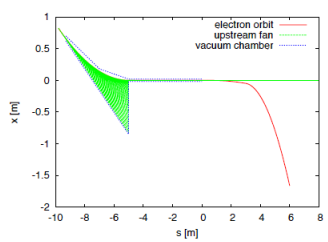


Fan geometry with soft, long bend on incoming side:



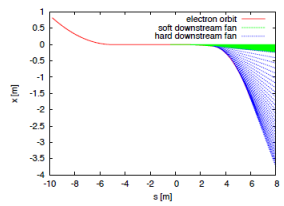
0.4 kW at 2.2 keV critical photon energy
Are these soft X-ray photons allowed to hit the detector beampipe?

Fan geometry with hard, short bend near DX on incoming side:



4 kW at 10.1 keV critical photon energy
Largely absorbed upstream of detector
(Permanent magnet) quad triplet inside detector?

Fan geometry on outgoing side:



soft initial bend from detector-integrated dipole
hard 180° bend
SR background needs to be studied
Detector "blind-spot" in horizontal plane helps, but can we build a wide, thin detector pipe that doesn't collapse?

SR Fan Accomodation

Upstream of detector:

- Required large separation produces a very wide synchrotron radiation fan
- Choice between soft, wide fan or hard, narrow fan

Summary

- Electron beam focussing to $\beta^* = 0.5$ m is rather straightforward.
- Accomodation and absorption of synchrotron radiation fan from upstream separation seems feasible.
- Hard x-rays from 180° downstream dipole are a huge concern. Need detailed studies to minimize background from back-scattered photons.

Science Driven Accelerator Design

- High Energy EIC (CM energy: 20 ~ 100 GeV)
  - First in discussion, endorsed by NSAC LRP
  - Colliding beam energies: 30 to 250 GeV/u ions x 3 to 10 GeV electrons
  - Explore the new QCD frontier: strong color fields in nuclei
  - Precisely image the sea-quarks and gluons in the nucleon
- Ultra High Energy EIC (CM energy: 115 ~ 160 GeV)
  - Colliding beam energies: 325 GeV/u ions x 10 to 20 GeV electrons
  - There are science cases calling even high energy
- Low to Medium Energy EIC (CM Energy: 8 ~ 20 GeV)
  - Colliding beam energies: up to 15 GeV/u ions x up to 10 GeV electrons
  - Gluons via J/ψ production
  - Higher CM in valence region
  - Study the asymmetric sea for $x \approx m_\pi/M_N$

With expansion of ELIC storage rings from to 1.5 km to ~2.5 km, we are able to extend beam energies up to 250 GeV for protons, 100 GeV/u for ions respectively (superconducting magnet capability) and up to 10 GeV for electrons (within synchrotron radiation power limit)

Yuhong Zhang Details, today in afternoon – G.Kraft, Staging of ELIC

ELIC New Nominal Parameters

Beam energy	**GeV**	**250/10**	**150/7**	**100/5**
Figure-8 ring	**km**	**2.5**		
Collision frequency	**MHz**	**499**		
Beam current	**A**	**0.22/0.55**	**0.15/0.33**	**0.19 /0.38**
Particles/bunch	**10^9**	**2.7/6.9**	**1.9/4.1**	**2.4/4.8**
Energy spread	**10^{-4}**	**3/3**		
Bunch length, rms	**mm**	**5/5**		
Horizontal emit., norm.	**μm**	**0.7/51**	**0.42/35.6**	**0.28/25.5**
Vertical emit., norm.	**μm**	**0.03/2.0**	**0.017/1.42**	**0.028/2.6**
Beta*	**mm**	**5/5**		
Vert. b-b tune-shift		**0.01/0.1**		
Peak lumi. per IP	**10^{34} $cm^{-2}s^{-1}$**	**2.9**	**1.2**	**1.1**
Luminosity lifetime	**hours**	**24**		

- These parameters are derived assuming a 6 m detector space, 27 mrad crab crossing angle, 10 to 14 sigma radius for aperture, 10 kW/m synchrotron radiation power density limit

- Collision frequency has been reduced to 499 MHz as suggested by EICC Steering Committee

Yuhong Zhang

Details, today in afternoon – G.Kraft, Staging of ELIC

ELIC at Ultra High Energy

- As a potential future upgrade option, ELIC rings can accommodate proton beam with energy up to 325 GeV, electron beam with energy up to 20 GeV.
- Electron current is severely limited by synchrotron radiation power, it must be reduced to 0.1 A at 20 GeV, however, luminosity is still at a level above 10^{34} $cm^{-2}s^{-1}$

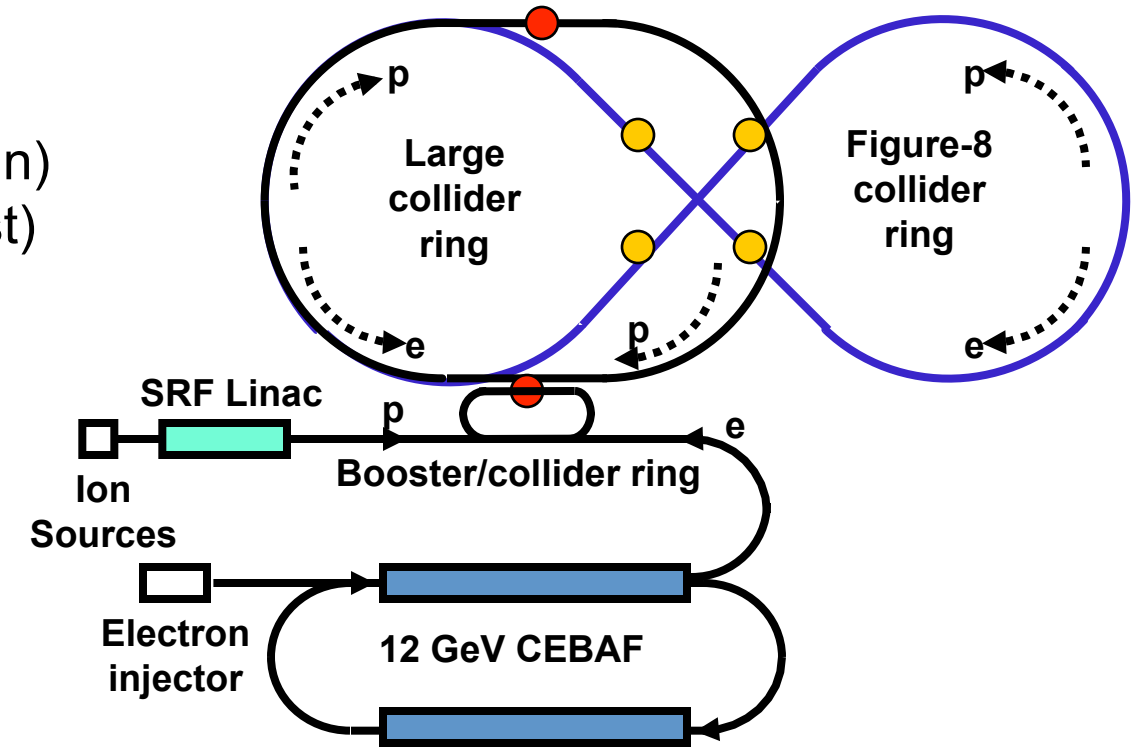
Beam energy	GeV	325/10	325/20
Figure-8 ring	km	2.5	
Collision freq	MHz	499	
Beam current	A	0.22/0.71	0.44/0.1
Particles/bunch	10^9	2.8/8.9	5.4/1.3
Energy spread	10^{-4}	3/3	
Bunch length, rms	mm	5/5	
Horizontal emit., norm.	μm	0.9/50.9	0.9/102
Vertical emit., norm.	μm	0.036/2.0	0.036/4.1
Beta*	mm	5/5	
Vert. beam-beam tune-shift		0.01/0.1	0.0014/0.1
Peak lumi. per IP	10^{34} $cm^{-2}s^{-1}$	3.7	1.0

Details, today in afternoon – G.Kraft, Staging of ELIC

MEIC and Staging of ELIC

Coherent picture

- Energy range (physics domain)
- Project Staging (energy boost)
- simultaneous operation
- Technology staging
- Product/cost optimization



(see G. Krafft's talk)

- Low Energy Collider (stage 1)
  - Both *e* and *p* in a compact ring (320 m)
- Medium Collider (stage 2)
  - Large warm ion ring (1400 m)/Compact superconducting ion ring (320 m)
  - Large electron ring (1400 m)
- High Energy Collider (stage 3) (Full ELIC)

Conclusions

- We continue to push design optimization and studies of a polarized electron-ion collider based on CEBAF. The CM energy range of this collider has been expanded greatly to support wide science programs
- The present ELIC nominal design covers CM energy from 20 to 100 GeV, i.e., 30 on 3 GeV up to 250 GeV on 10 GeV, consistent with the NSAC LRP, and reaches a luminosity above 10^{34} $cm^{-2}s^{-1}$.
- ELIC can also accommodate colliding beam energies up to 325 GeVs for protons and 20 GeV for electrons with a similar high luminosity.
- Recently, a feasibility study and initial design of a low to medium energy electron collider based on CEBAF has been carried out for new science programs, and also as a staging option for the high energy ELIC.
- We continue to actively pursue R&D programs and have made significant progress for several key technologies required by ELIC/MEIC. We have initiated collaborations with various national labs and universities.

Yuhong Zhang

Discussions lasted till 6:15 pm…

- There was a suggestion that there should be cost estimates attached to various options

- Attention was brought that with realistic cost estimates, the luminosity can be limited by power of synchrotron radiation, which would require additional RF system capacity with installation cost of hundred(s) of millions of dollars and running cost of ten(s) of millions of dollars ,,,,,

Summary from Accelerator and Detector Working group

EIC meeting, Berkley, December 2008

E.C. Aschenauer

E. Kinney

B. Surrow

Beam Induced Detector Background

- Talk by Joanne Beebe-Wang

1) **Beam particles-residual gas interaction**
   a) Coulomb scattering
   b) Bermsstrahlung
2) **Synchrotron radiation**
   a) direct radiation generated in upstream magnets
   b) backward scattering from down stream components
   c) forward from mask tip and upstream vacuum chamber
3) **Touschek Scattering**
   only important for low energy colliders
4) **Thermal Photon Compton Scattering**
   only important for very high energy colliders
5) **Beam-beam interaction**
   (Yue Hao's simulation)

Questions get first answers

- Impacts on backgrounds in detector
  - Synchrotron radiation
    - power and critical energy?
    - impact on vacuum
    - beam pipe material and shape
    - detector acceptance
    - how fast can e and p/A be separated
  - Higher order modes
    - do we have HOMs
    - beam pipe heating → vacuum and beam pipe material

Two directions of synchrotron radiation in the eRHIC IR:
Forward (direction of the electrons) generated by 10GeV electrons bent through a 0.2 Tesla detector integrated dipole magnet located 1m (from the magnet center to IP) upstream.
backward (opposite direction of the electrons) caused by the secondary radiation of the absorber located 7.2m downstream,

In the current design, the fraction of the forward radiation fan hitting the absorber is 20% and 27%, generated in the magnets located 1m (from the magnet center to IP) upstream and downstream of the detector,

Number of Dipole Magnets at IP	2
Magnetic Field	0.2 Tesla
Magnet Effective Length L	1.0 m
Electron Beam Current	0.5 A
Electron Relativistic Factor γ	1.96E+04
Synchrotron Radiation Power P_0	5.08 kW
Critical Photon Energy E_0	13.3 keV

Spectrum Upstream of Magnets

The photon spectrum of forward synchrotron radiation:

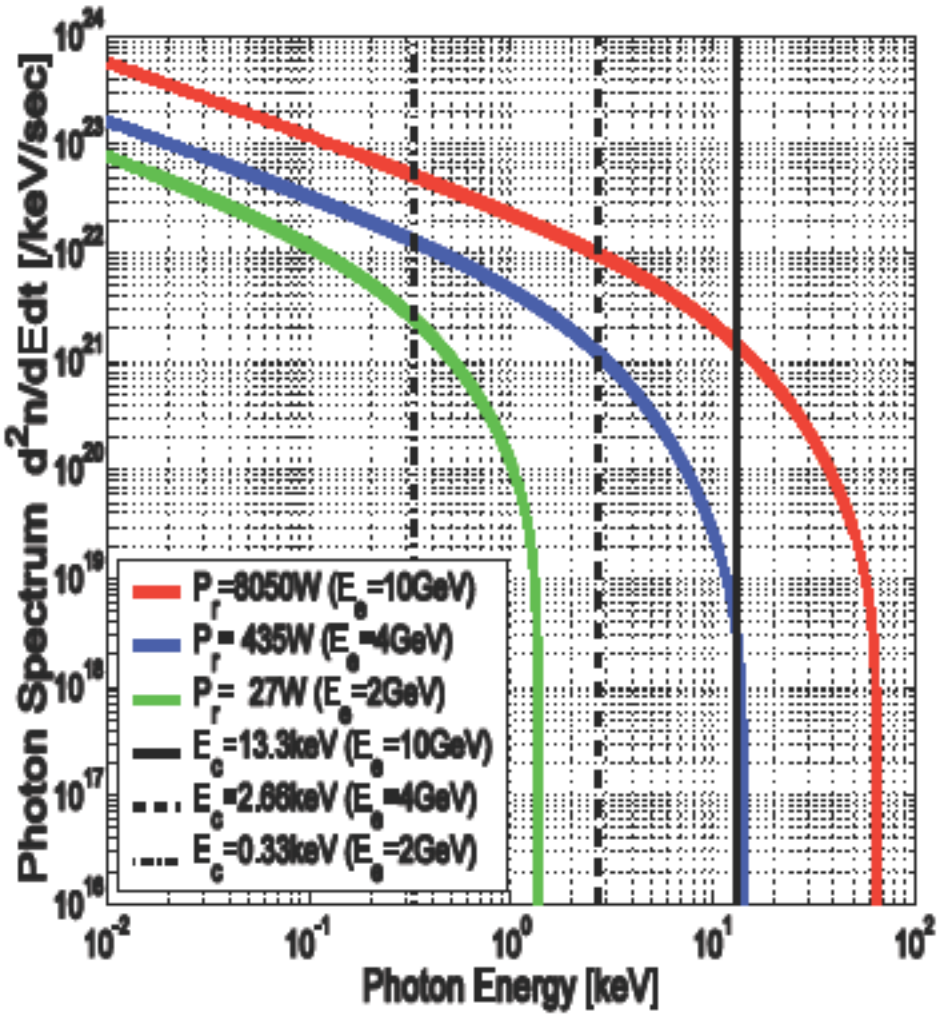
$$\frac{d^2n}{dtdE} = \frac{P_0\gamma}{E_C^{\,2}}\frac{S(\omega/\omega_C)}{(\omega/\omega_C)}$$

P_0 = synchrotron radiation power

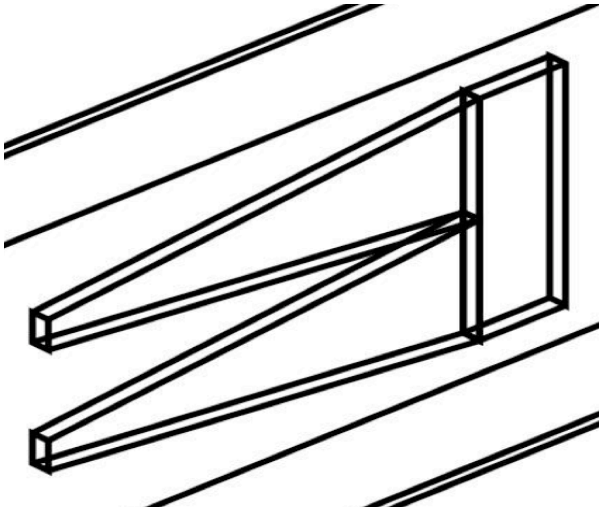
γ = electron relativistic factor (E^e_{total}/E^e_{rest})

E_C = the critical photon energy

S function defined as: $S\left(\frac{\omega}{\omega_C}\right) = \frac{9\sqrt{3}\,\omega}{8\pi\,\omega_C}\int_{\omega/\omega_C}^{\infty} K_{5/3}(z)\,dz$



The Absorber design is based on the high power synchrotron radiation absorber of HERA.



Material of V-shaped Absorber	Copper
Absorber V-opening Width	1 cm
Absorber V-opening Height	3 cm
Absorber V-opening Depth	25 cm
Surface tilt angle of the V-opening	60 mrad
Interaction Point from Absorber	7.2 m
Upstream Magnet from Absorber	8.2 m
Downstream Magnet from Absorber	6.2 m
Material of Vacuum Chamber	Stainless Steel
Diameter of Vacuum Chamber	15 cm
Material of the Detector Surface	???
Diameter of Detector Opening	15 cm

Backward Radiation into IR

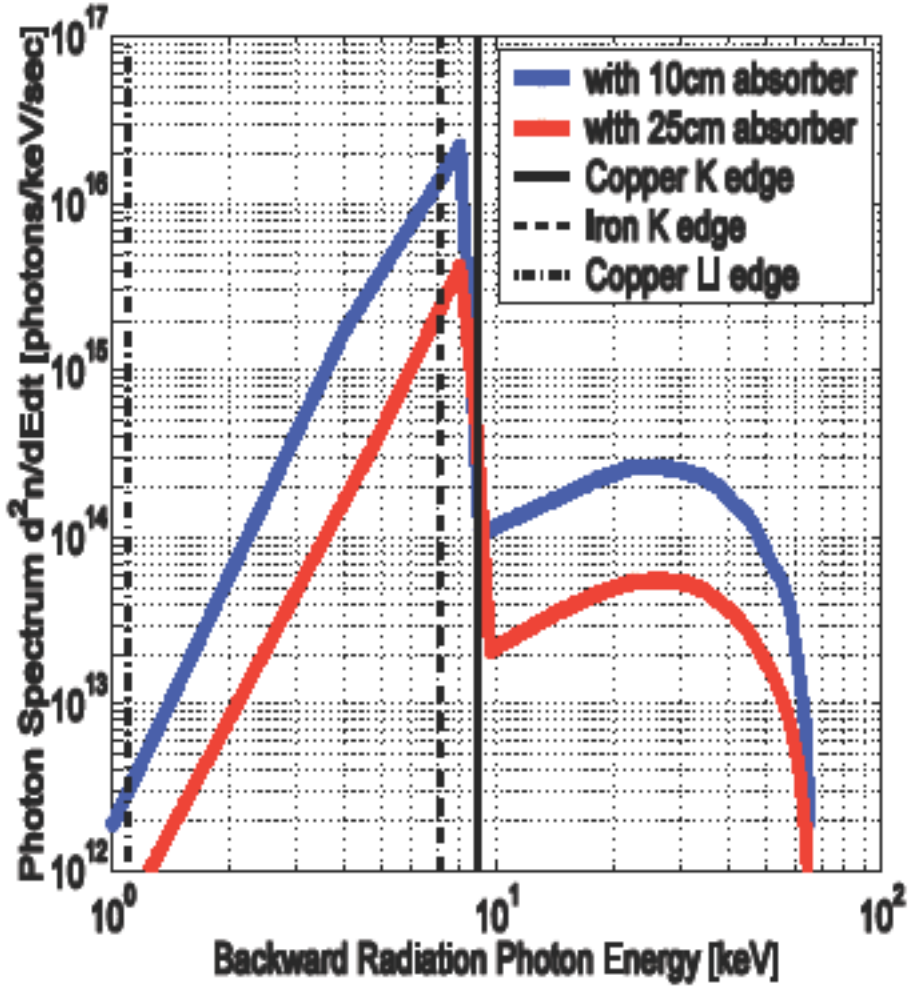
Total Backward Radiation Level:

[photons/sec]

P_{25cm} = 1.2e16

P_{10cm} = 7.0e16

P_{10cm} / P_{25cm} = 6



- Need to think about absorber material and coating
- Diffuse radition from beam-pipe
  - material and roughness

Questions get first answers

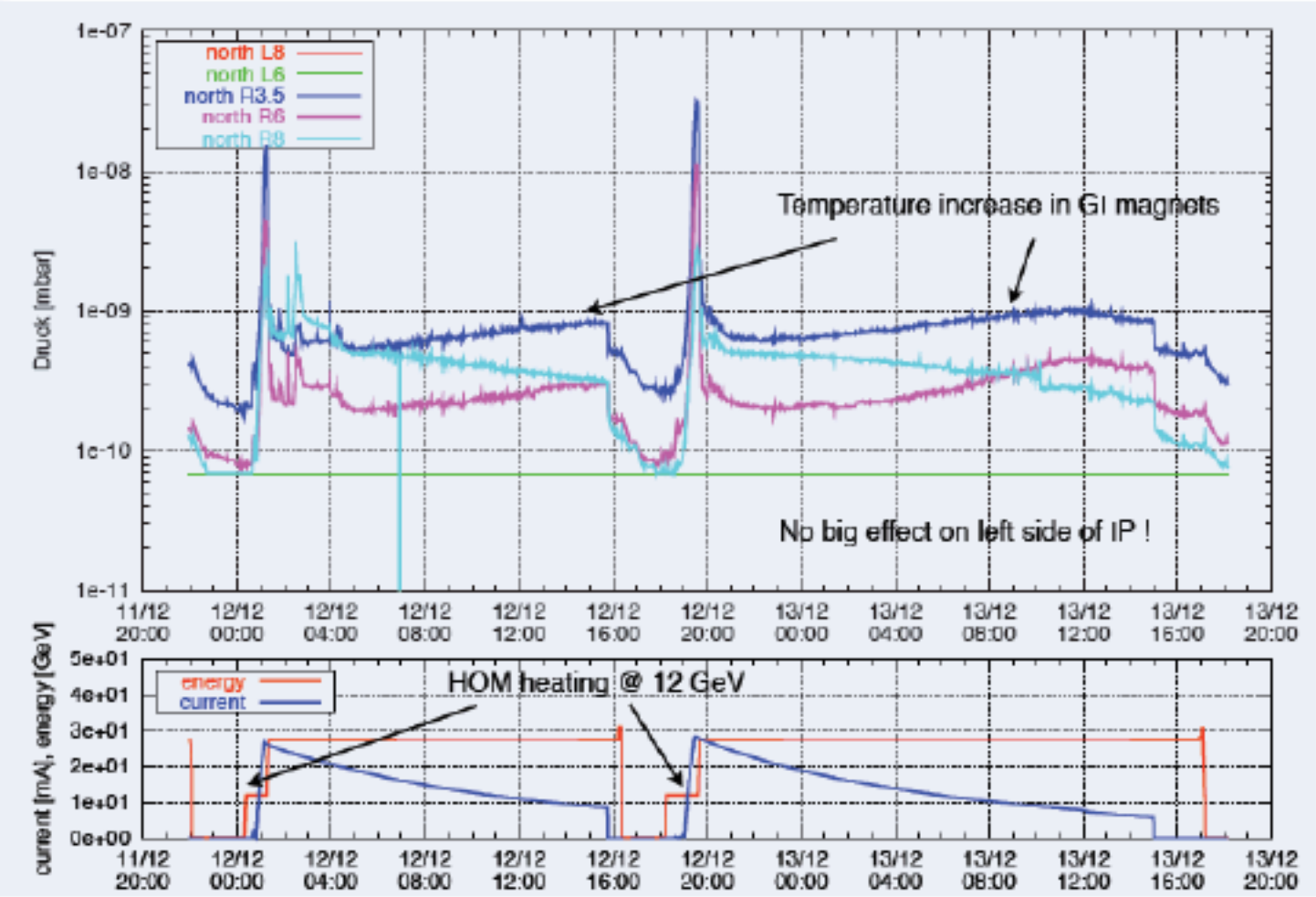
- VACUUM
  - What is the estimated vacuum in the IP?
    - How was it estimated?
  - Where are pumping stations foreseen?
    - How much pumping will be at those stations?
    - What kind of pumps?
  - What is the estimated vacuum in the beam line sections approaching the IP with small or zero relative angle?
    - How long are these "approaching" sections?
  - What is the profile/size of the beam pipes in the IP and approaching sections?
    - What is the expected variation of vacuum along the approaching sections?

Questions get first answers

- VACUUM
  - What is the conductance from the IP to the closest pumping stations?
  - In the IP and approaching beam pipe, which pieces will bear the synch light load?
    - What material/surface processing will they have?
    - What will be the conductance away from these pieces to the closest pumps?
  - What are the chief residual gas components which are expected?
    - high occupancy due to beam gas events
      - fine segmentation → detector cost
      - pumps in IR → acceptance
  - What kind of bake-out procedures are planned?
- Are any collimators foreseen in the IP or approaching sections?
  - Where will the beam aperture limits closest to the IP be?

What was seen at HERA

- Pressure during Lumi Fill

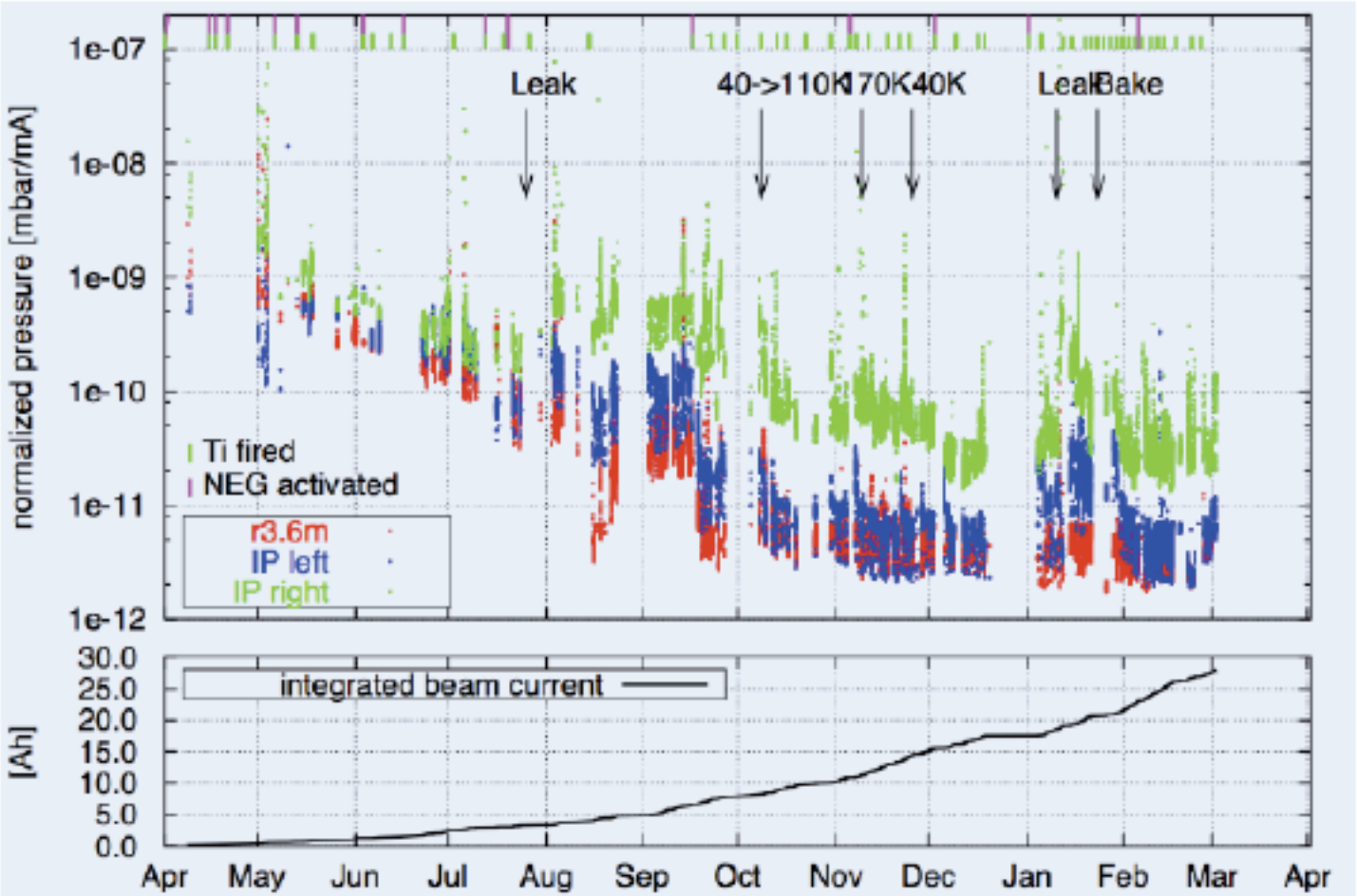


Dynamic pressure increase due to thermal and photo desorption

What was seen at HERA

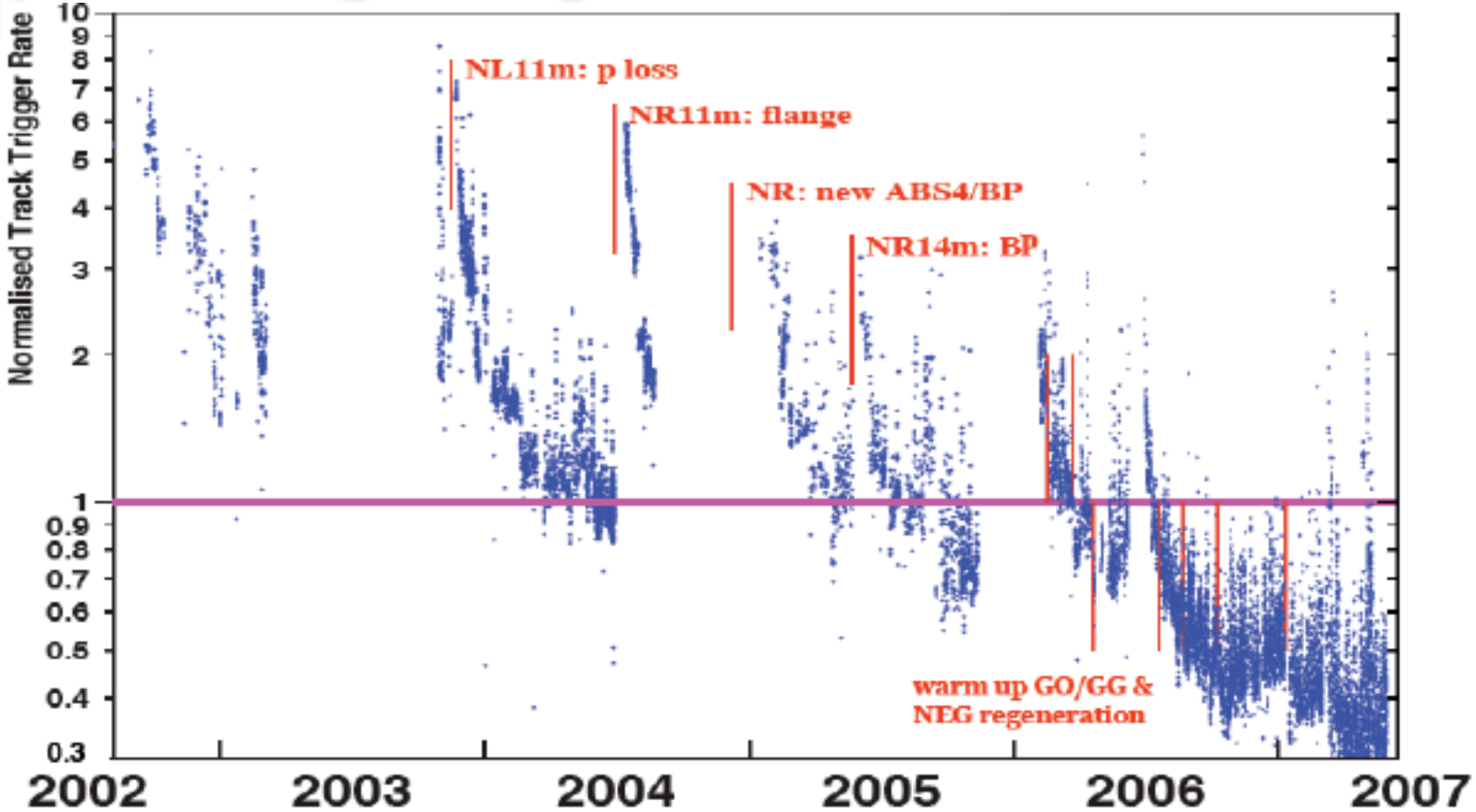
- Pressure development

Pressure vs. integrated electron current 2002 - 03



What was seen at HERA

- proton beam gas background



Two time constants for vacuum conditioning

- Short term after leaks 20 – 30 days
- Long term 600 days

Good vacuum needs patience and takes time. Continuous operation

(Input from vacuum expert Dick Hseuh, BNL)

1) Pressure=1×10^{-9} mbar (electron lifetime > 30 hours)
(with special effort, it may reach 1×10^{-10} mbar, but one can't count on it.)

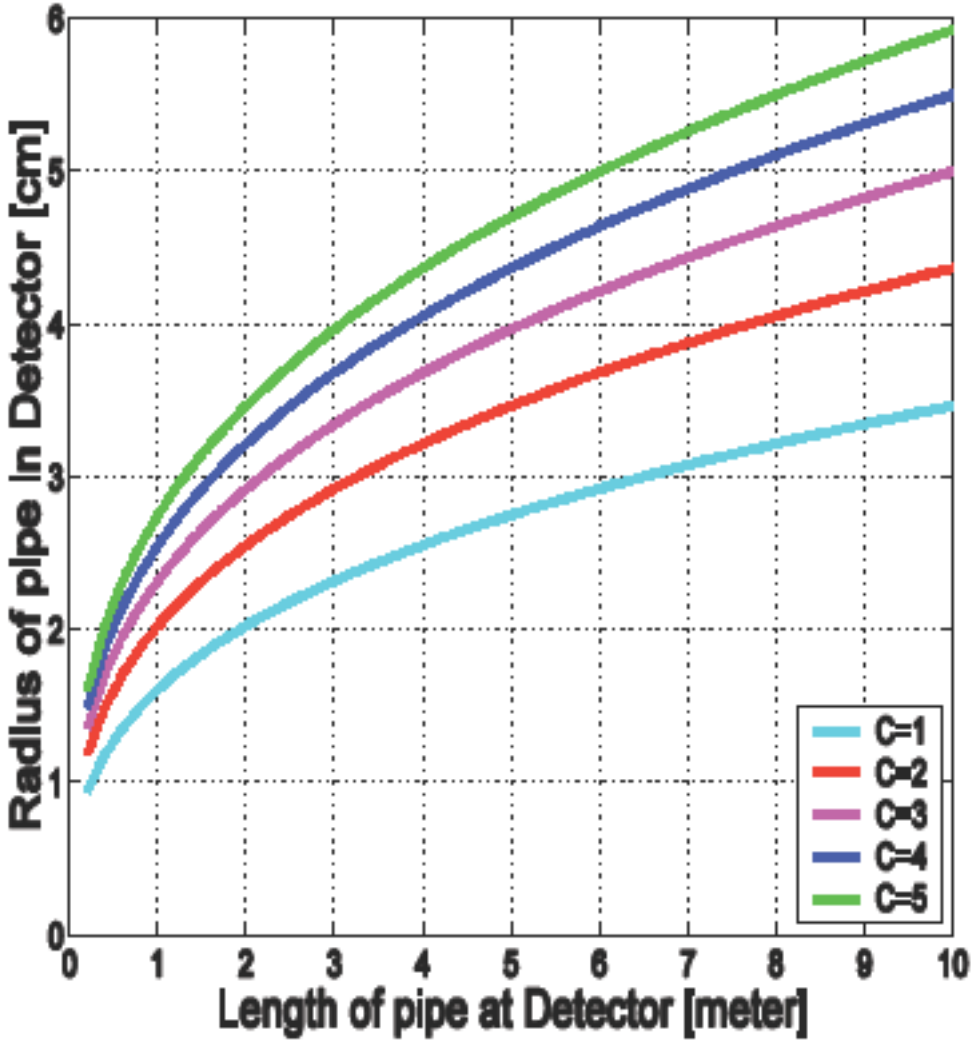
2) Inside of the detector 50% H_2 , 50% CO (including H_2O etc.)

(Could reach 80% H_2, 20% CO in the vacuum chamber away from detector. But it is hard to reduce CO in detector due to particle hitting the surface)

3) Photon desorption rate (C+O=CO per photon hit):
10^{-3} to 10^{-2} for a virgin material, surface dominated
10^{-5} after surface becomes clean, reaches equilibrium

4) The pumping speed of the lumped pumps (>>10^2 L/s)

Pipe Length vs Radius



Conductance of pipe for CO:

$C=12r^3/L$ [Litters/sec]

STAR:

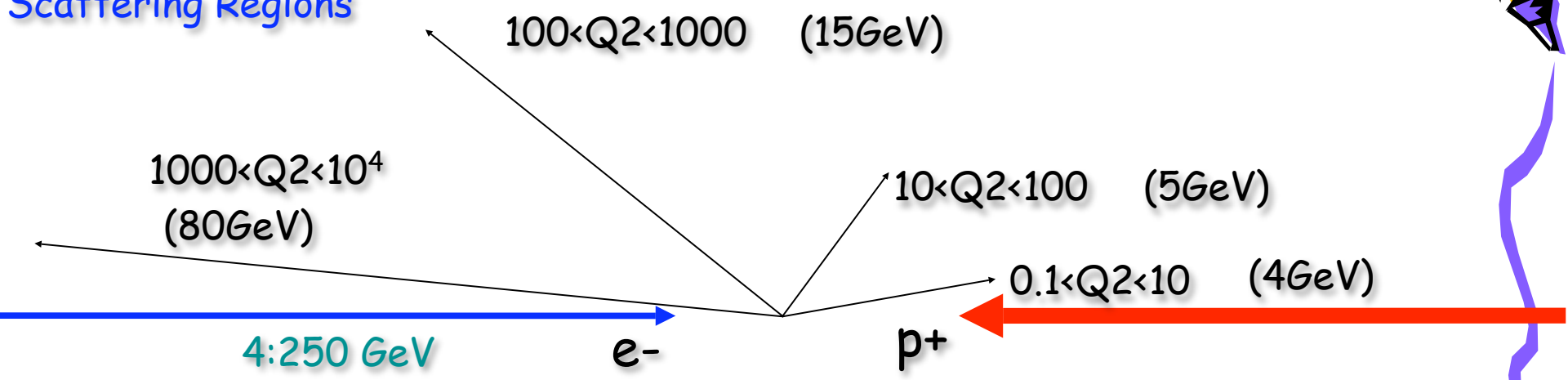
L=4m, r=3.5cm

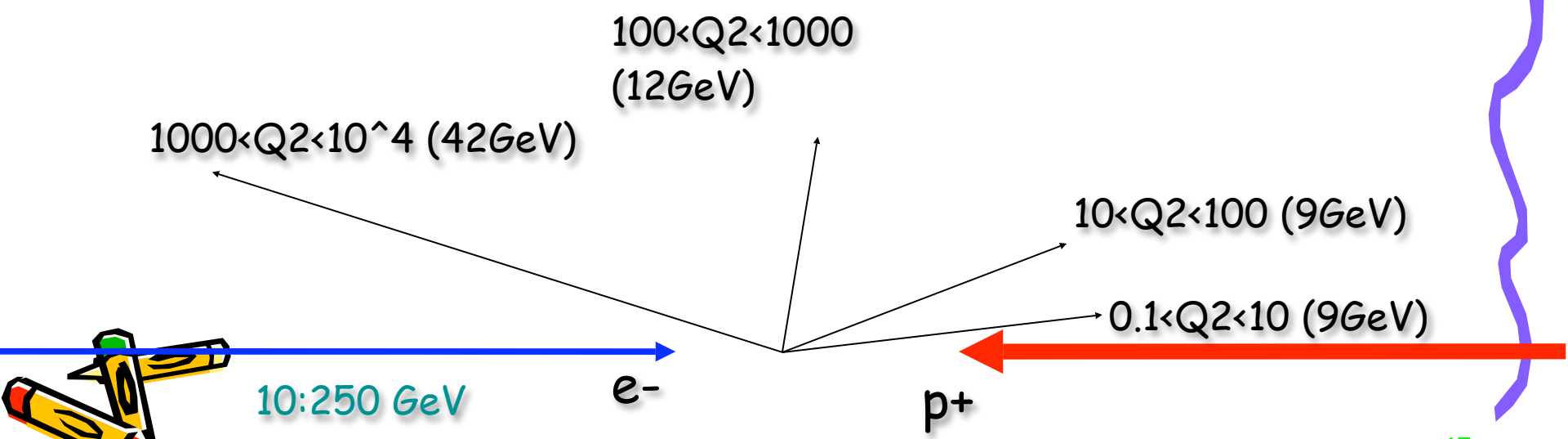
C=1.3 [Litters/sec]

PHENIX:
L=3m, r=3.5cm
C=1.7 [Litters/sec]

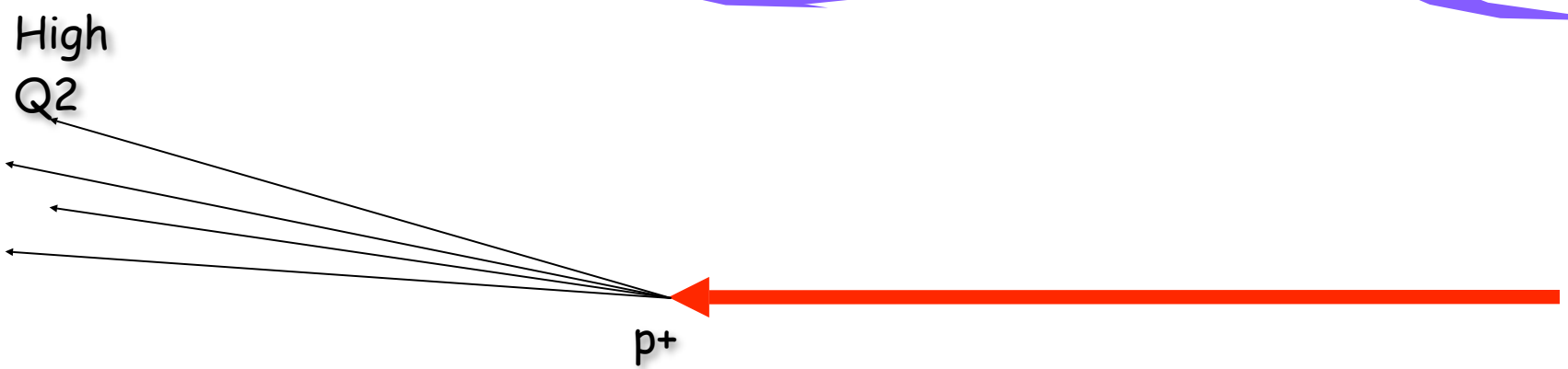
Michael Savastio: DIS Kinematics

e- Average
Scattering Regions

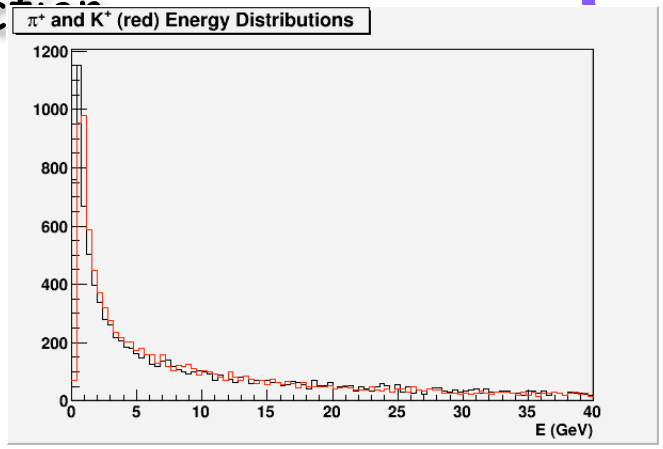




Hadron Kinematics



- Pions scatter to greater theta at s=10000
- Mean pion scattering angle of about 40^0 for 1000<Q2<10000
- Scattered pion energy similar at s=4000 and s=10000
- K+ scattering angles indistinguishable from Pi+ angles
- Kaon E only slightly greater than for pions (~1GeV)
- Will need pion/kaon particle ID in proton direction
- Pions/Kaons mostly covered in 0<theta<50^0



First Attempt of a Detector Design

- by Tanja Horn, Rolf Ent and Richard Milner
  - Magnetic Field configration
- 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)

Simulation of Resolutions

Multiple scattering contribution:

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

- 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

Intrinsic contribution (first term):

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

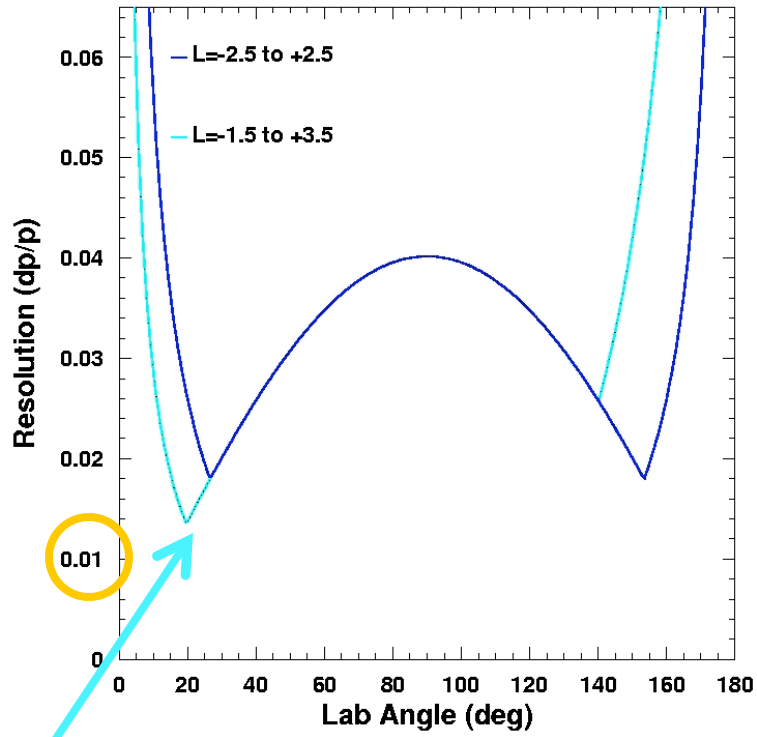
- B=central field (T)
- $\sigma_{r\varphi}$=position resolution (m)
- L'=length of transverse path through field (m)
- N=number of measurements

Assumptions:

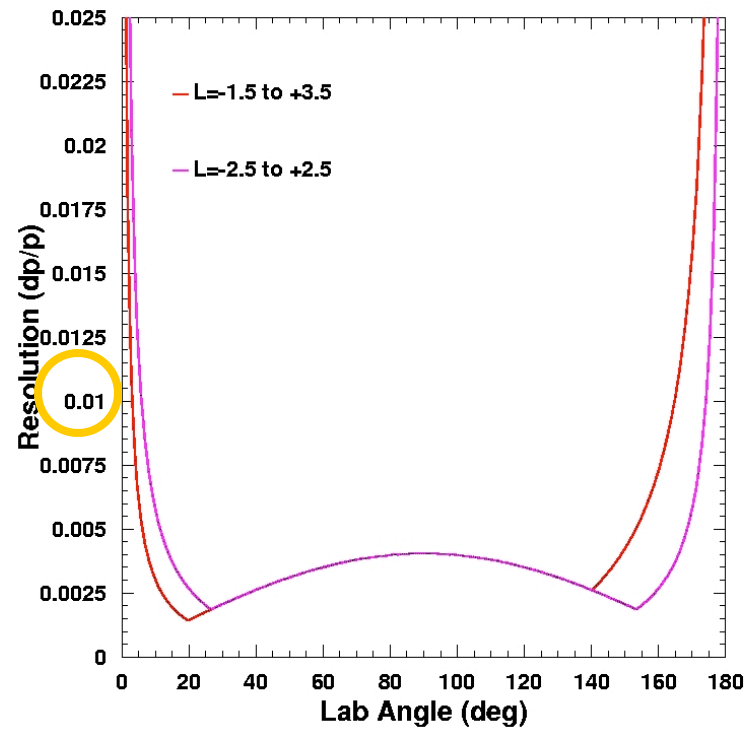
- **circular detectors around interaction point**
- **$n_{r.l.}$ = 0.03 (from Hall D CDC)**
- all simulations done for pions !!!

dp/p angular dependence

p = 50 GeV



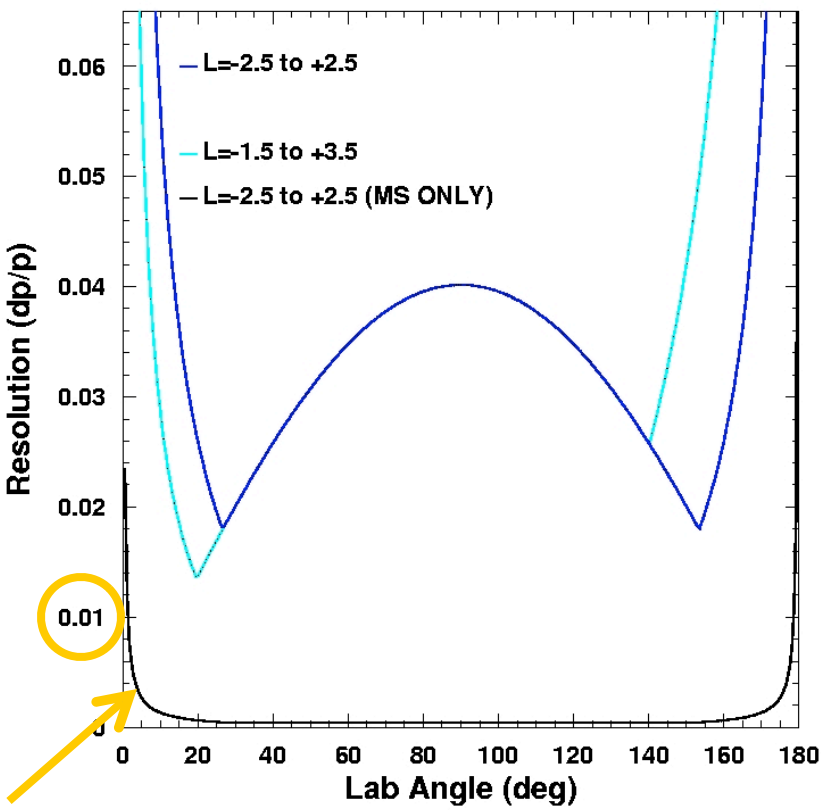
p = 5 GeV



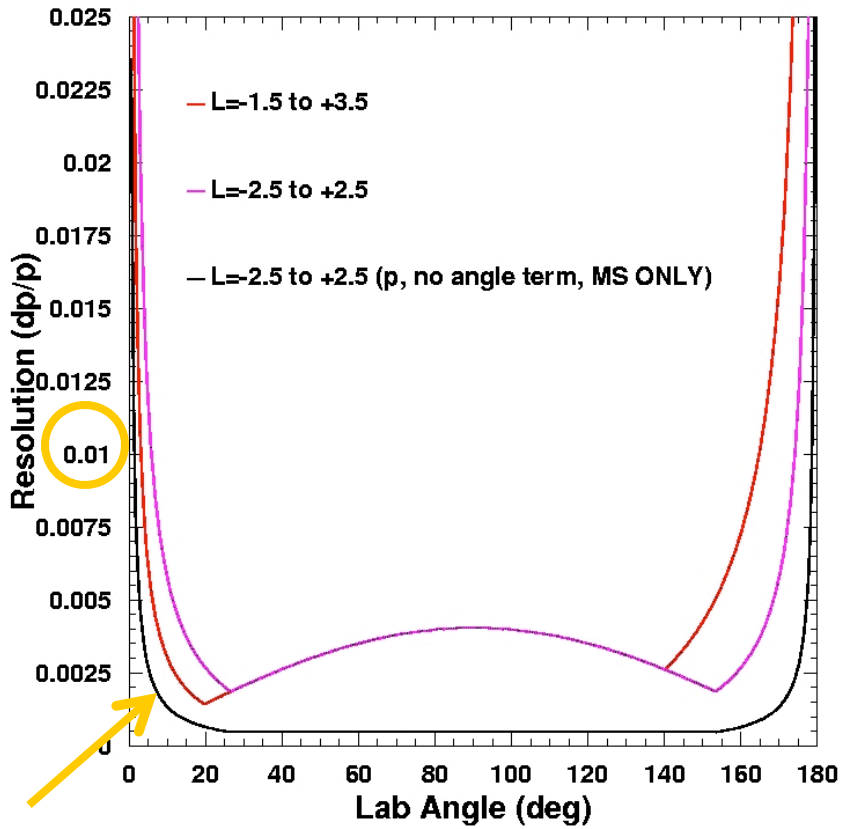
Can improve resolution at forward angles by offsetting IP

Multiple scattering contribution

p = 50 GeV



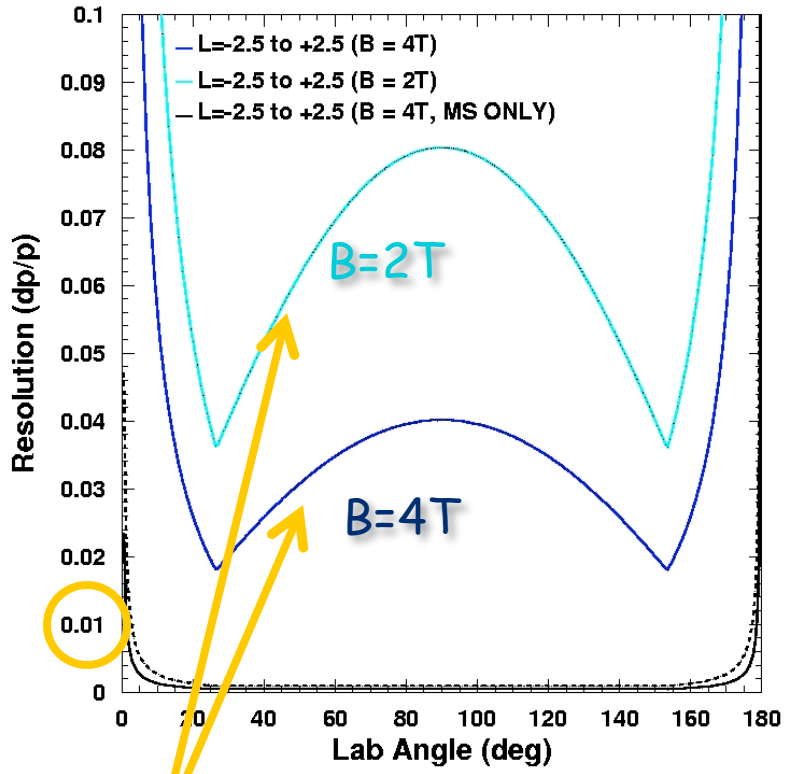
p = 5 GeV



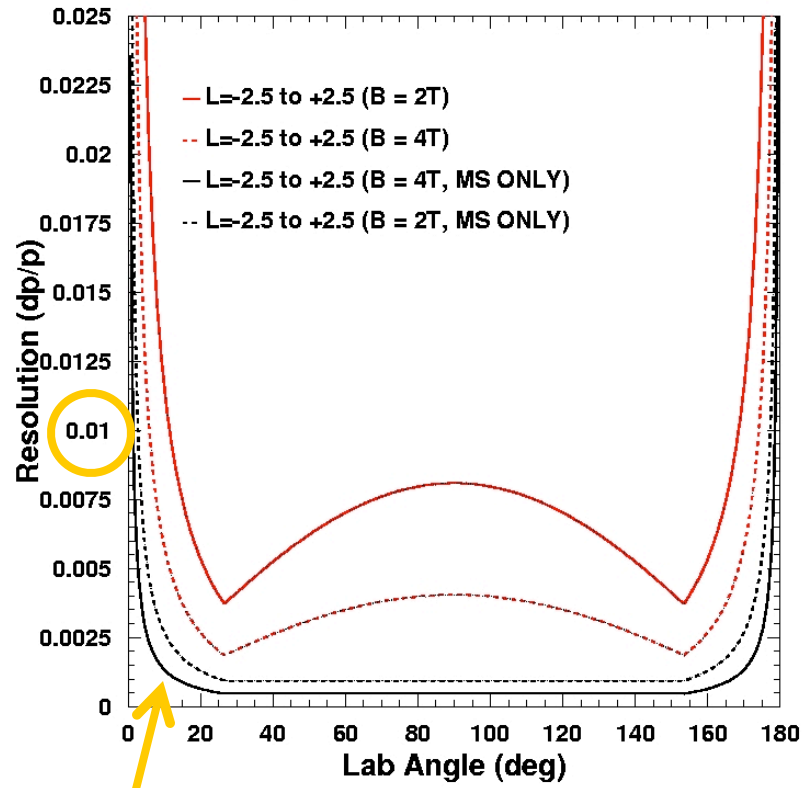
Multiple scattering contribution dominant at small angles (due to B_T term in denominator) and small momenta

"Easier" Solenoid Field - 2T vs. 4T?

p = 50 GeV

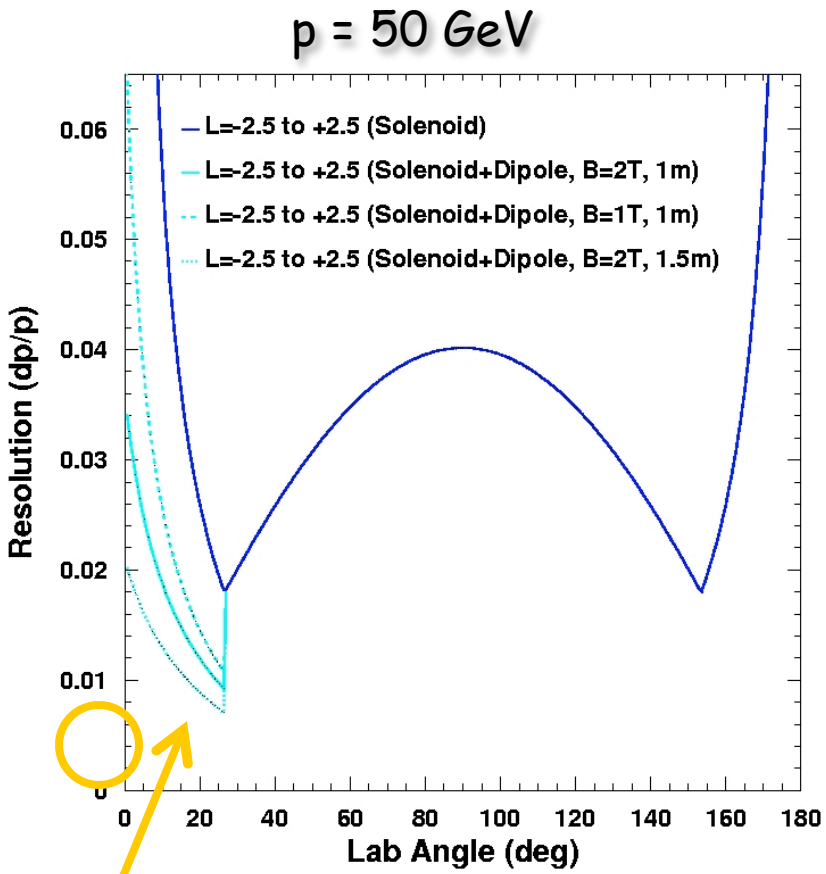


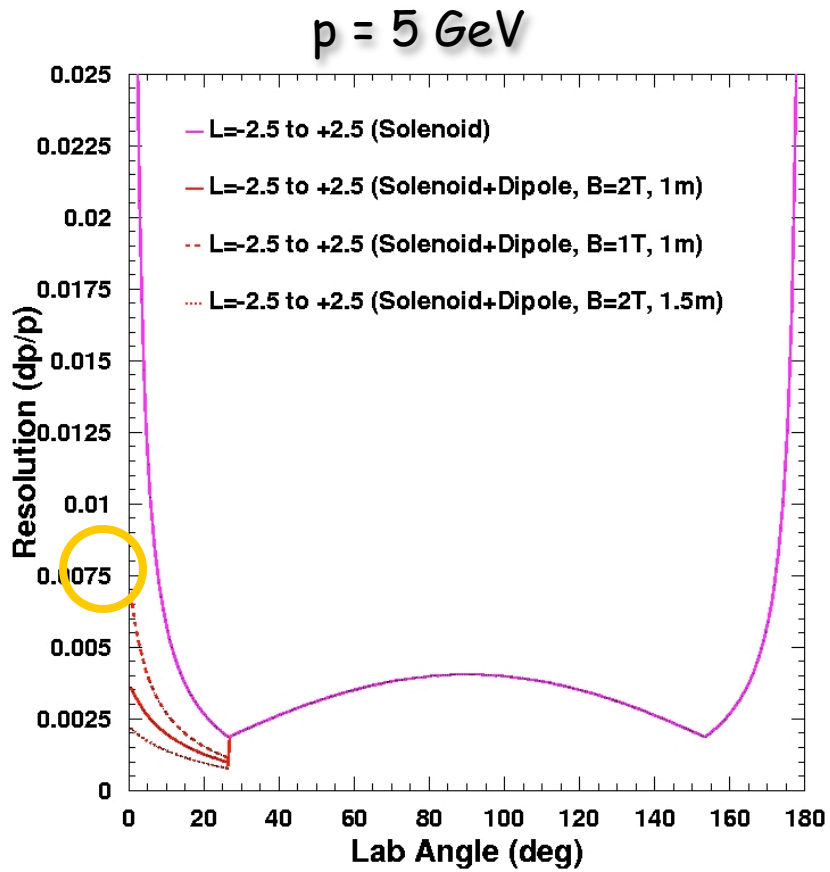
p = 5 GeV



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

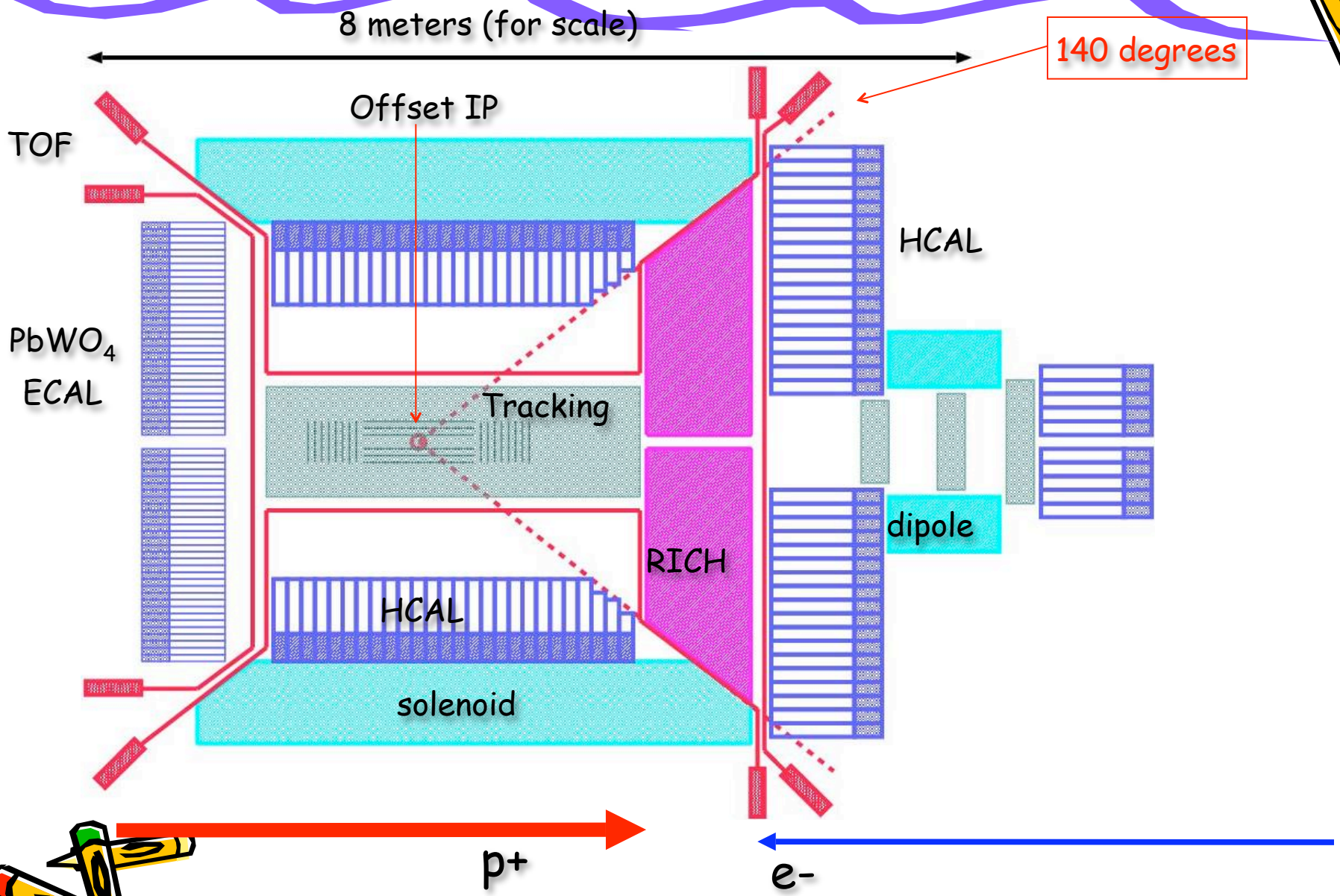
Include dipole field



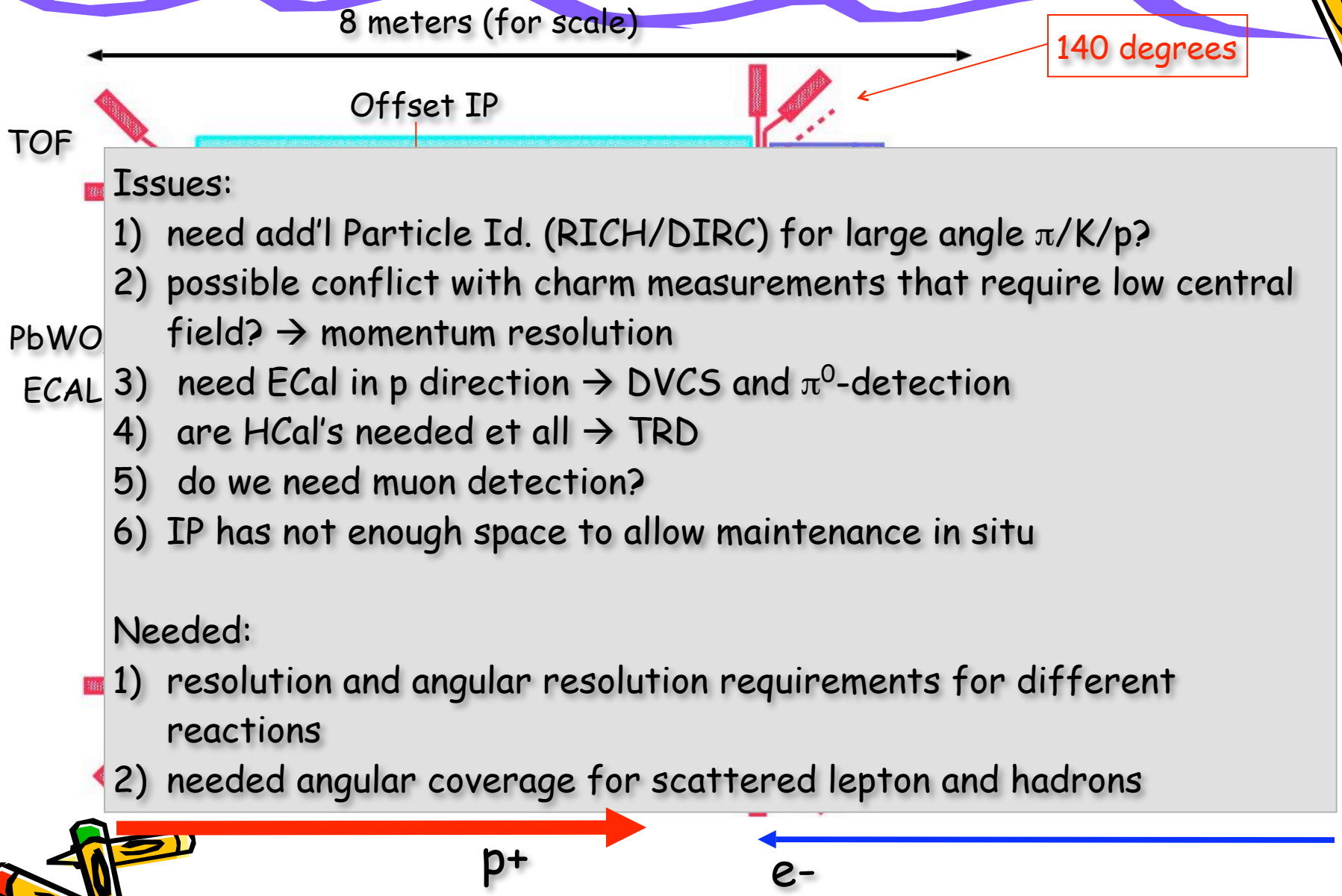


As expected, substantially improves resolutions at small angles

Emerging Detector Cartoon



Emerging Detector Cartoon



Issues:

1) need add'l Particle Id. (RICH/DIRC) for large angle π/K/p?
2) possible conflict with charm measurements that require low central field? → momentum resolution
3) need ECal in p direction → DVCS and π^0-detection
4) are HCal's needed et all → TRD
5) do we need muon detection?
6) IP has not enough space to allow maintenance in situ

Needed:

1) resolution and angular resolution requirements for different reactions
2) needed angular coverage for scattered lepton and hadrons

Additional Slides

Questions which need answers

- General Questions:
  - Luminosity:
    - HERA ep: 2-5 10^{31} cm^{-1} s^{-1}
    - Hermes:
      - polarised: 3.5 – 5 10^{31} cm^2/s
      - unpolarised: 3 10^{32} - 3 10^{33} cm^2/s
    - COMPASS:
      - polarised: 4 10^{32} cm^2/s
  - For a stage option how much of the detector can be reused for final stage

Questions which need answers

- General questions solutions dependent on EIC machine option
  - very small angle lepton detectors
    - integration in machine lattice; technology?
  - very small angle proton / nucleus detectors for diffractive / exclusive physics
    - integration in machine lattice; technology
  - luminosity measurement

    ep: 1% systematic eA: ???
    - integrate in beam lattice → background, acceptance
  - lepton and proton polarisation measurements

    ep: 1% systematic

    lepton: integration in machine lattice → background

    proton: impact on proton beam → emittance

    technology ?????

How should the detector look like

- Especially for ELIC design
  - design of L1-trigger for 1.5GHz repetition rate
  - all detectors have to be extremely fast
  - conventional wire chambers excluded
  - Cerenkov to trigger on scattered electron – maybe
  - proton & lepton forward detectors can they work???
- lepton and hadron polarimeters
  - how can we measure bunch polarizations @ 1.5GHz
  - need to sort out polarization bunch pattern

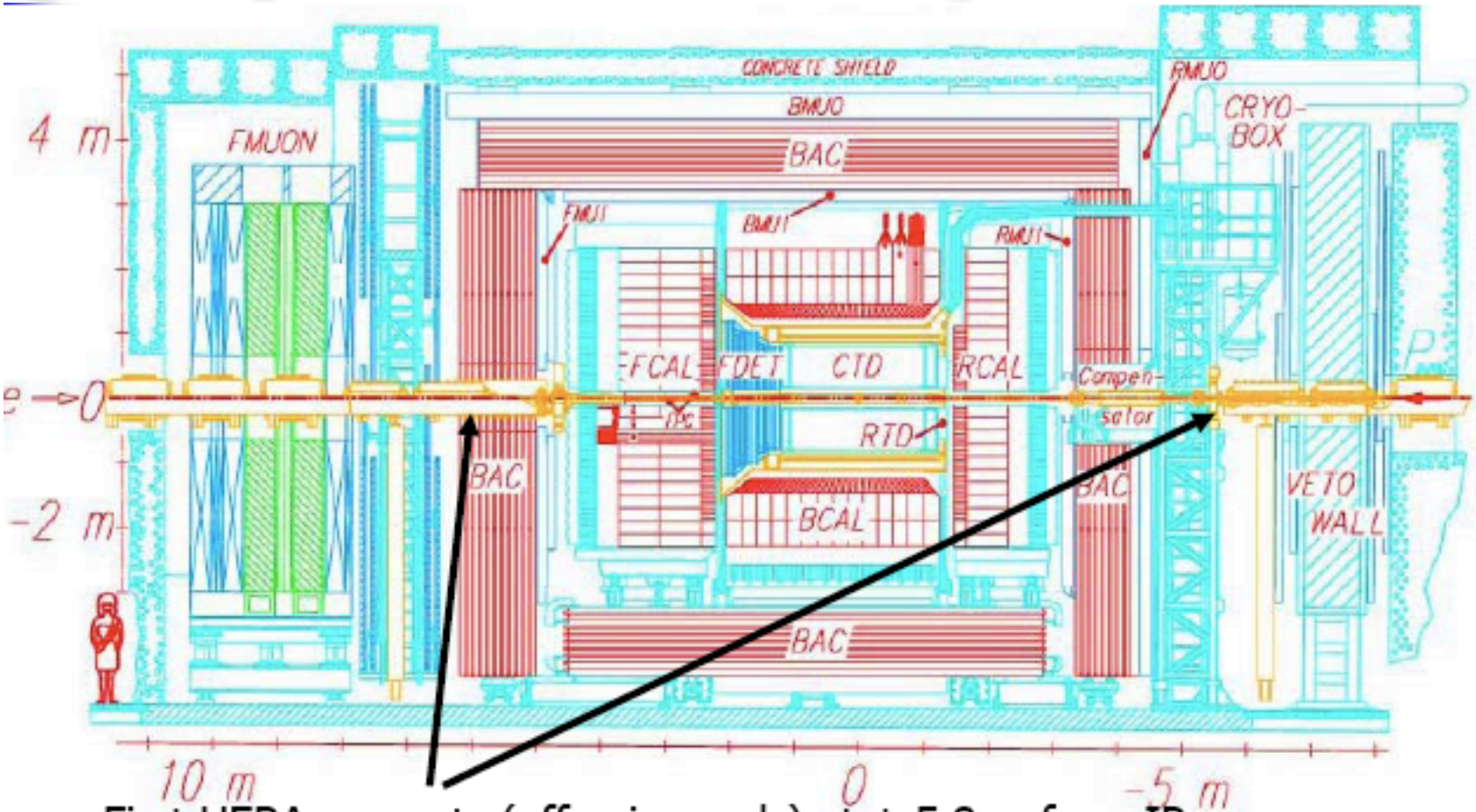
What can we learn from HERA

- IR design considerations
  - Very asymmetric beam energies
  - High luminosity -> low beta quadrupole magnets close to IP, high gradients (different focusing magnets for p and e beam)
  - Early beam separation, use off-axis quad magnets (combined focusing and beam separation)
  - Sufficient beam aperture

  - Acceptable background conditions:
    - synchrotron radiation and
    - particle background
  - Good detector acceptance
  - Detector coverage down to small angles
  - Little "dead" material (machine elements) in front detector components

What can we learn from HERA

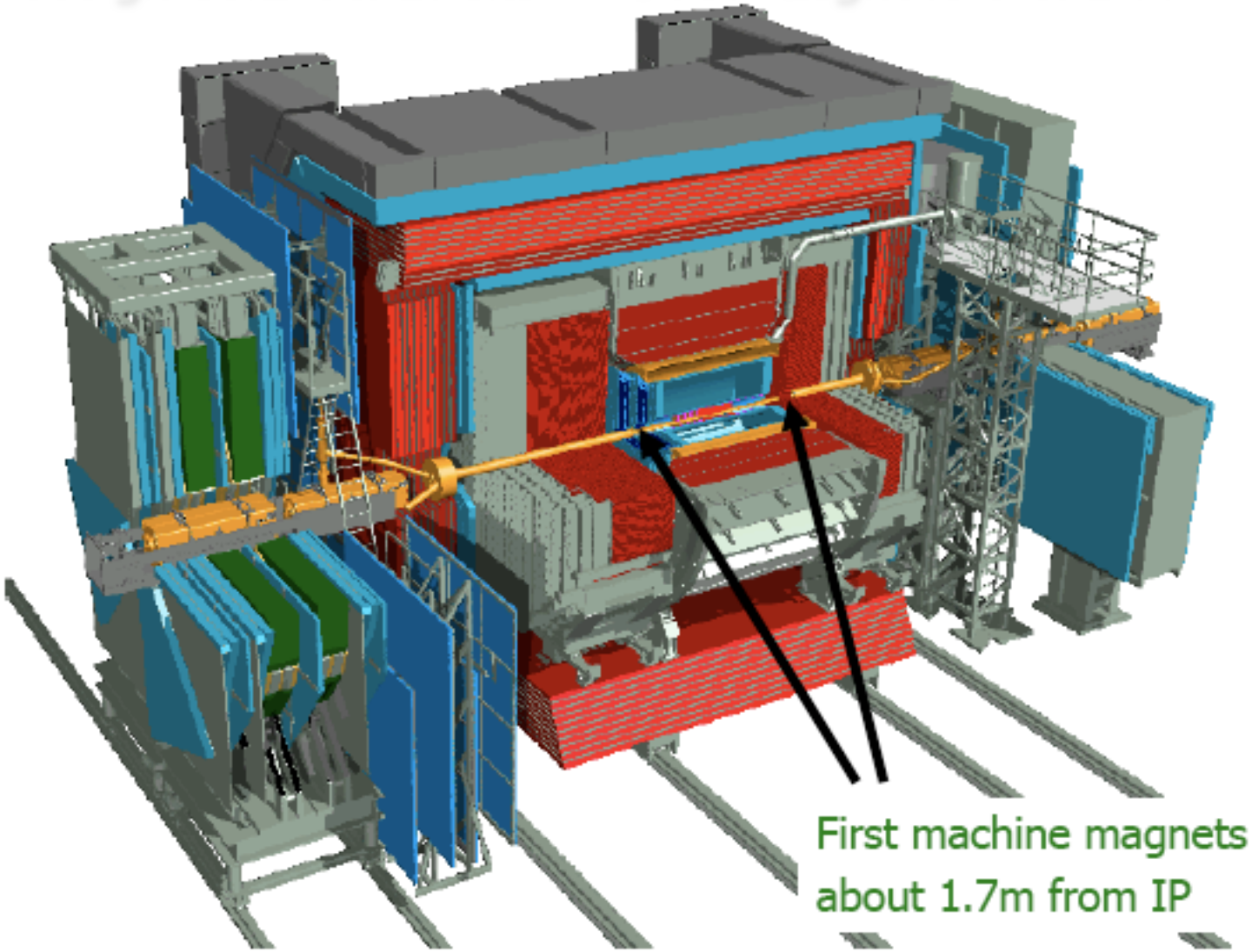
- IR design considerations → first magnets Hera I



First HERA magnets (off-axis quads) at ± 5.8 m from IP
Calorimeter covers >99.8% of full solid angle
Very small hole in FCAL (6.3 cm diameter), small vertical opening of RCAL

What can we learn from HERA

- IR design considerations → first magnets Hera II



What can we learn from HERA

Background Sources

Electron/positron beam

- Synchrotron radiation
  - Backscattering
  - Photo desorption

  -> degradation of vacuum
- Beam gas interactions
  - Off momentum electrons
- Higher order mode losses
  - Local heating at injection and ramp (short bunches)

  -> degradation of vacuum

Proton beam

- Low beam lifetime during injection and ramping
- Beam gas interactions, large hadronic cross section
  - Secondary interactions with aperture limitations, i.e. with magnets, beam pipe, masks

Need

- Careful design of interaction region and masks
- Excellent vacuum system

What can we learn from HERA

Background HERA II

After recommissioning of HERA very severe background conditions. H1 and ZEUS could only turn on chamber HV at low currents. HERA beam currents limited in order to avoid radiation damage. Extensive background studies to understand and improve background conditions. Several month shutdown to implement improvements.

- Proton beam-gas interactions most severe background
  - Installed larger pumps at some critical locations, where possible
  - Increased conductance of pumping ports
  - Reduced HOM losses by improving shape of masks
  - Added integrated ion getter pump close to IP (H1)
  - Beam conditioning, slow vacuum improvement
- Synchrotron radiation background
  - Added far upstream synchrotron radiation collimator
  - Masks in IR improved (3D design problem) (ZEUS)
  - Improved alignment of HERA magnets
  - Better beam steering and control
- Electron beam-gas (off-momentum positron)
  - Additional pumps 30m upstream
  - Reduced thickness of synchrotron radiation mask

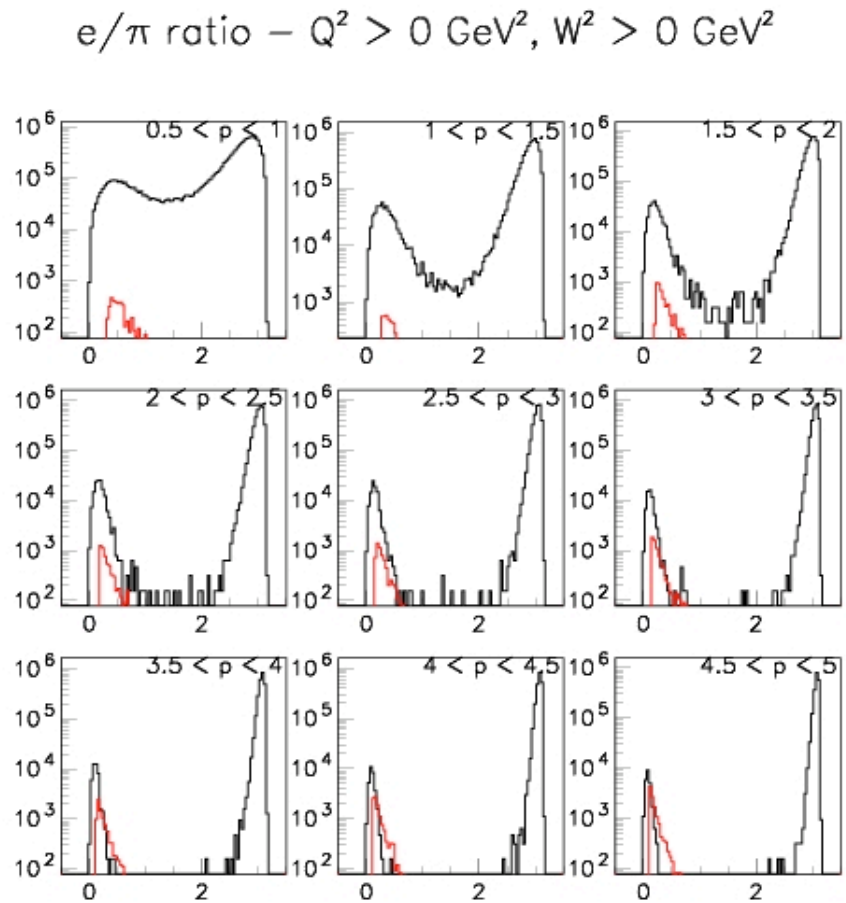
What can we learn from HERA

Vacuum system

- Separate vacuum chambers (e, p and S.R.) starting at 11m from IP (location of synchrotron radiation absorber)
- As much pumping as possible:
  - All vacuum chambers equipped with integrated pumps if possible
  - Stainless steel chambers with NEG pumps above and below
  - Ion getter (60l/s) and Ti sublimation pumps between magnets
  - Integrated ion getter pump 1.3m from IP inside detector
- Stainless steel chambers protected by emergency absorbers
- Some special flanges due to lack of space
- In-situ bake-out not possible
- Super conducting magnet beam pipes at 40-80K
  - Have to be warmed up for regeneration of NEG pumps
  - Unfortunately, no valves between superconducting and warm magnets (NEG pumps) due to space contraints.

How should the detector look like

- General requirements independent of EIC machine option
  - cover a wide range in Q^2 → detect scattered lepton
    - ep and eA need good lepton-hadron separation
      - needed over a wide momentum range



Important Items not yet covered

- Magnetic field configuration
  - momentum / angular resolution:
    - ep: 1% $\Delta p/p$ / ?? eA: ?? / ??
  - could a dipol – solenoid option be used to do
    - separate e & p(A) beams
    - could it be used as a analyzer for exclusive/diffractive recoil particles
    - impact on ELIC design
      - crab crossing angle
- Vertex tracker
  - resolution:
    - ep: 25μm (?) eA: ?