Preliminary Detector Design for the EIC at JLab

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Outline

1. Introduction

2. Interaction Region

3. Detector Requirements and Challenges

4. Brief Overview of Current Detector Ideas

Why a collider?

Easier to reach high CM energies ($E_{cm}^2 = s$)

- $s = 4E_eE_p$ for colliders (*e.g.*, 4 x **9** x **60** = 2160 GeV^2)
- $s = 2E_eM_p$ for fixed target experiments (*e.g.*, 2 x **11** x 0.938 = 20 GeV^2)

Spin physics with high figure of merit

- Unpolarized FOM = ***Rate = Luminosity*** · ***Cross Section*** · ***Acceptance***
- Polarized FOM = ***Rate*** · **(*Target Polarization*)^2** · **(*Target Dilution*)^2**
- No *dilution* and high ion polarization (also *transverse*)
- No current (*luminosity*) limitations, no holding fields (*acceptance*)
- No *backgrounds* from target (Møller electrons)

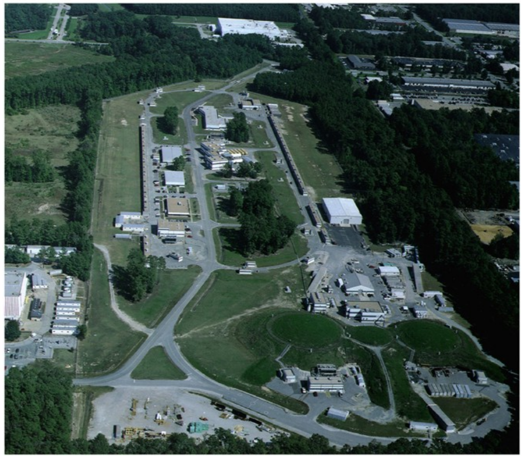
Easier detection of reaction products

- Can optimize kinematics by adjusting beam energies
  - Laws of physics do not depend on reference frame, but measured uncertainties do!
- More symmetric kinematics improve acceptance, resolution, particle identification, etc
- Access to neutron structure with deuteron beams through spectator tagging ($p_p \neq 0$)

Past and future e-p and e-A colliders

HERA, Hamburg, 1992-2007
27 GeV e on 920 GeV p, L = 5 x 10^{31}

LHeC, CERN, Geneva



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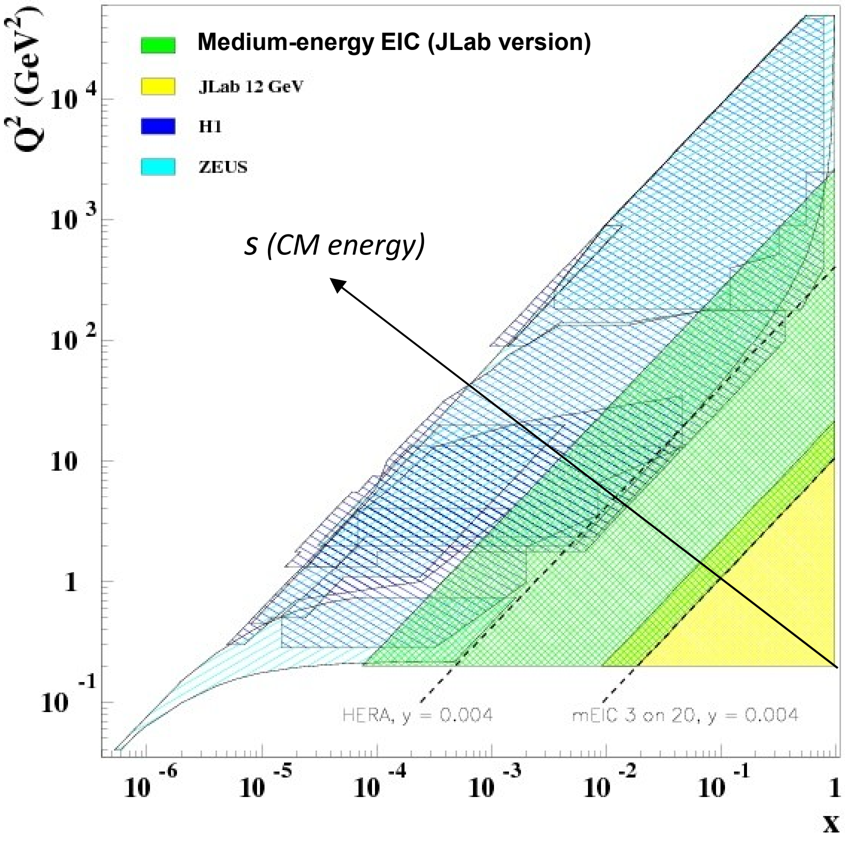
EIC

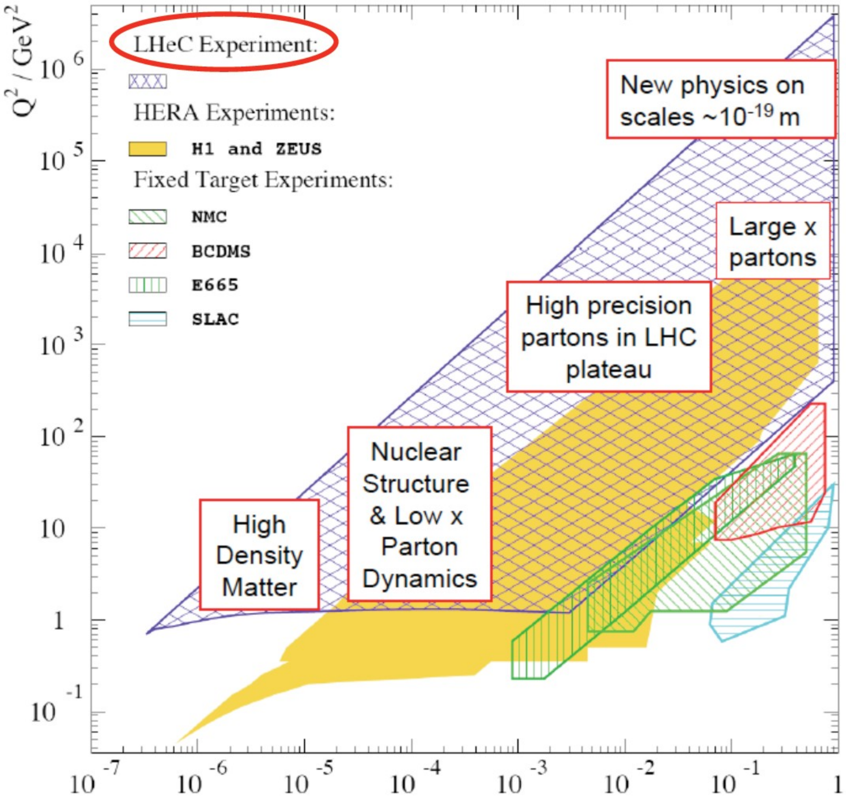
↔

Brookhaven, Upton, NY

Kinematic coverage

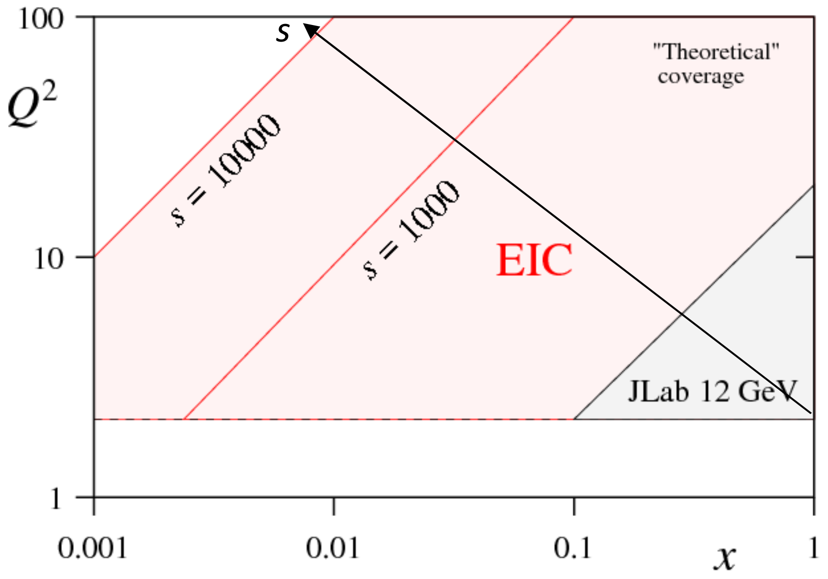
$Q^2 \sim xys$





- Medium-energy EIC
  - Overlaps with and is complementary to the LHeC (both JLab and BNL versions)
  - Overlaps with JLab 12 GeV (JLab version with moderate ring size)
  - Provides high luminosity and excellent polarization for the range in between
    - Currently only low-statistics fixed-target data available in this region

Physics and luminosity



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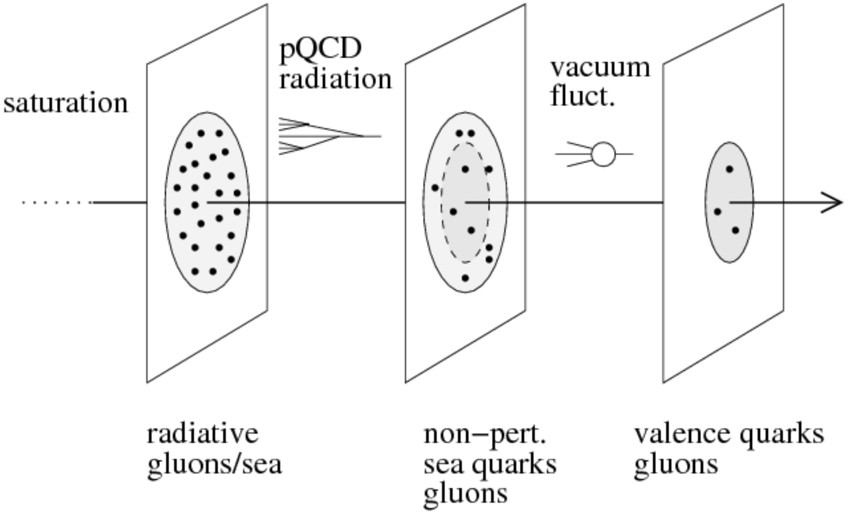
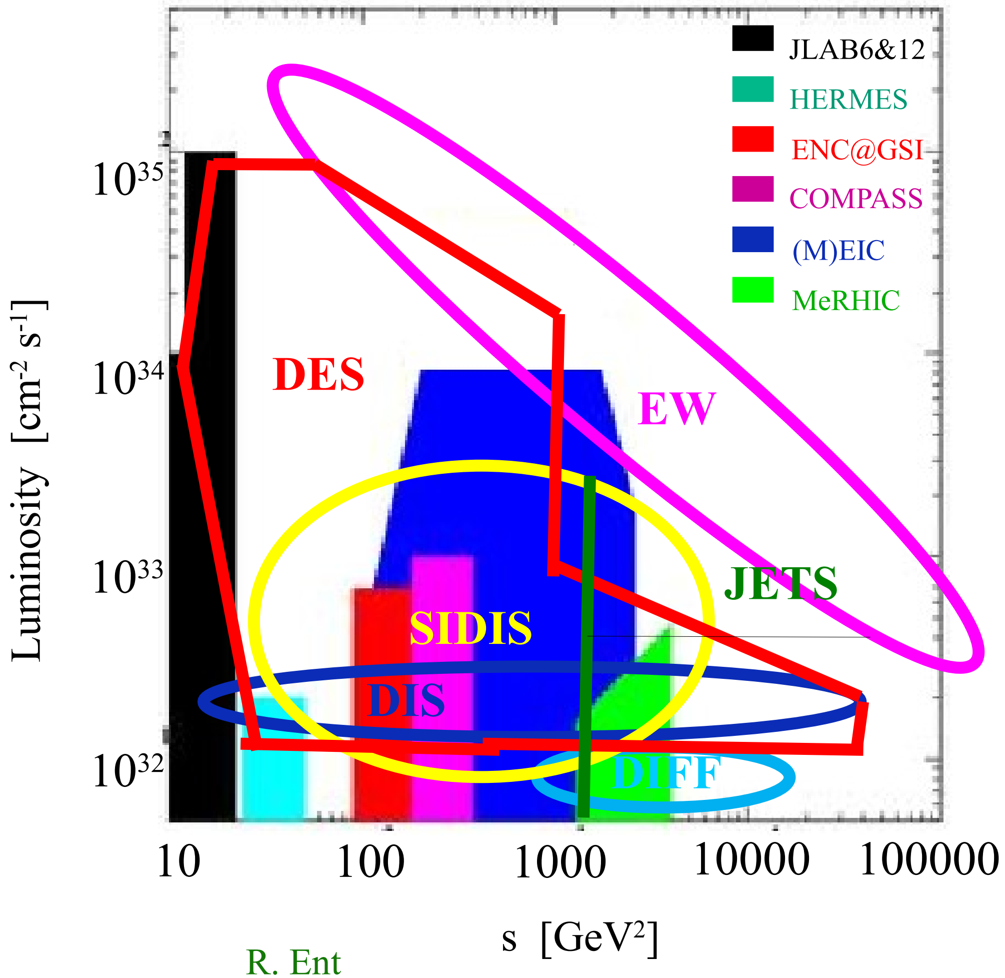
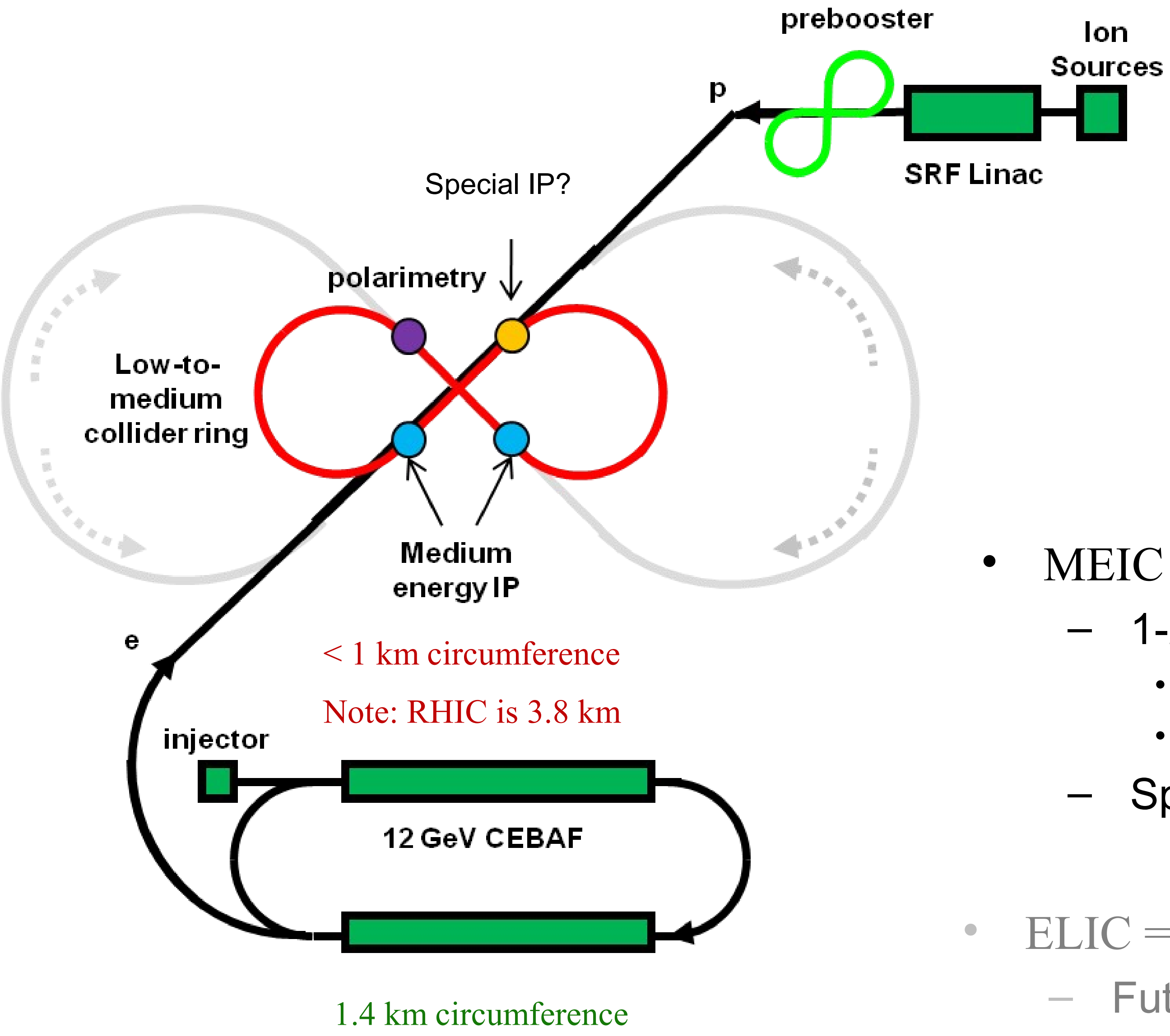




R. Ent

- Right plot (L vs. s) is a projection on the diagonal of the left one (Q^2 vs. x)

MEIC@JLab – Detector Layout



< 1 km circumference

Note: RHIC is 3.8 km

1.4 km circumference

Electron energy: 3-11 GeV

Proton energy: 20-60 GeV

$s = 250 - 2650\ \mathrm{GeV}^2$

Can operate in parallel with fixed-target program

- MEIC = EIC@JLAB
  - 1-2 high-luminosity detectors
    - Luminosity ~ $10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
    - Low backgrounds
  - Special detector?
- ELIC = high-energy EIC@JLab
  - Future upgrade?

Hadronic background – a comparison with HERA

Random background

- Dominated by interaction of beam ions with residual gas
- Worst case at maximum energy

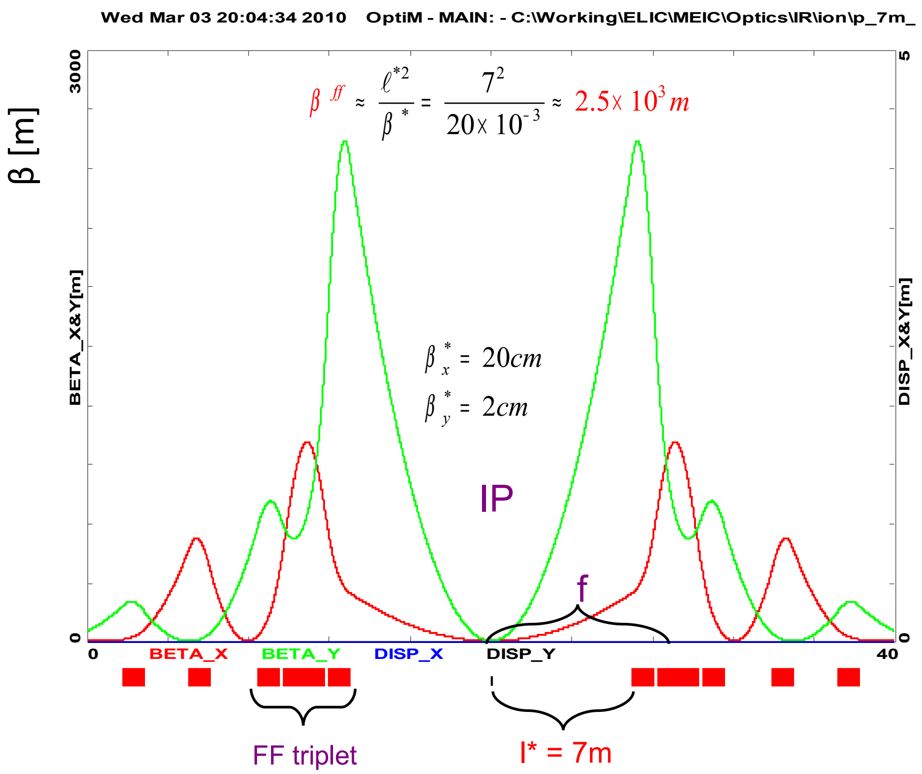
Comparison of MEIC (11 on 60 GeV) and HERA (27 on 920 GeV)

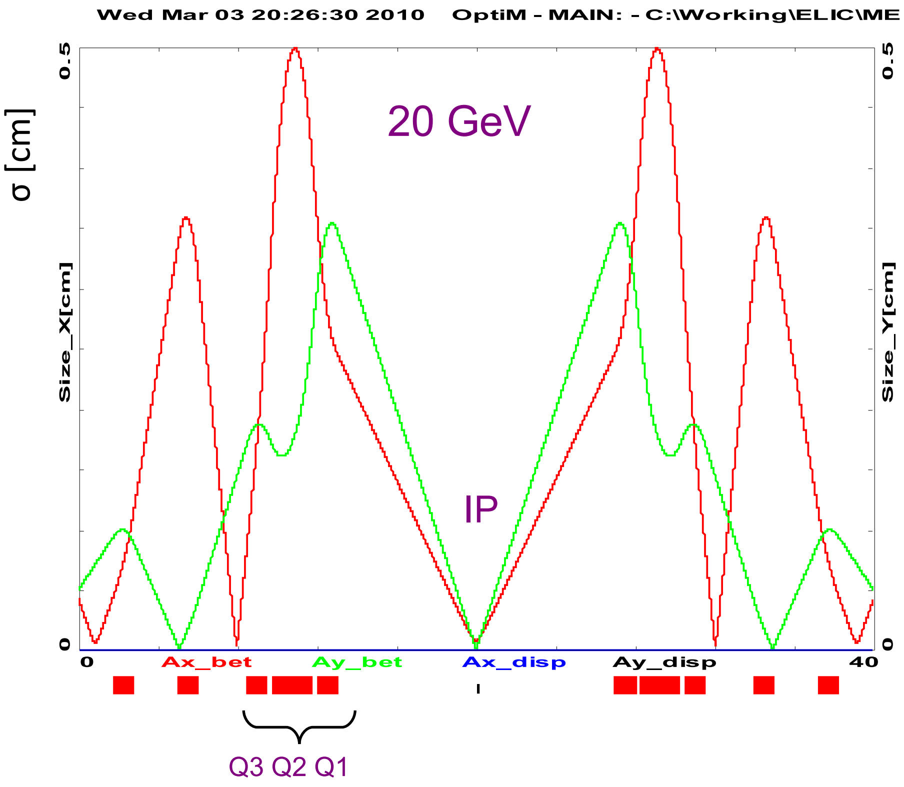
- Distance from arc to IP: 40 m / 120 m = 0.33
- Average hadron multiplicity: $(2640 / 100000)^{1/4} = 0.4$
- p-p cross section (fixed target): $\sigma(60\text{ GeV}) / \sigma(920\text{ GeV}) = 0.7$
- At the same current and vacuum, MEIC background is 10% of HERA

Hadronic background not a major problem for the MEIC

- With HERA vacuum, the MEIC would at 60 GeV and 1 A have backgrounds like HERA at 0.1 A
  - But good vacuum is much easier to maintain in a short section of a small ring!
- MEIC luminosity is also about 100 times higher (depending on kinematics)
- Signal-to-background will be considerably better at the MEIC

Ion quadrupole apertures and the minimum energy





- Beam size: $\sigma = \sqrt{(\varepsilon\, \beta\, m / p)}$
- Focal length: $f = \sqrt{(\beta^* \beta^{max})}$
- Quad gradient: $G \sim p / f$
- Peak field: rG
  - Max aperture size ~ $1 / G \sim 1 / E_{max}$
  - Max beam size ~ $1 / \sqrt{(\beta^* E_{min})}$
  - $E_{min} \sim \sqrt{(E_{max})} / \beta^*$

Gradients: 20 - 60 GeV

Q1 G[T/m] = -32 to -97
Q2 G[T/m] = 22 to 67
Q3 G[T/m] = -21 to -63

Beam size (σ): up to 5 mm
Aperture (r): 10-15 σ
Peak field (rG): up to 5-7T

Trigger, accelerator RF, and luminosity

1. Luminosity at high energy

- Naïve scaling:

  Luminosity ~ $I_e I_p / \beta^*$
- E_p scaling due to Lorentz boost is often shown, but is not always a good approximation

2. Luminosity at low energy

- "Hourglass effect" requires that the bunch length $L = \beta^*$
- Due to "space charge", in rings with large circumference C one has:
  - $I_p \sim f_{RF} L / C = f_{RF} \beta^* / C$, and I_e = constant
- **Luminosity ~ f_{RF} / C**

3. Effective low-energy operation requires f_{RF} ~ 1 GHz

- Cannot trigger on each bunch crossing as in hadron machines!
- The solution is an asynchronous electron trigger

Detector requirements

1. Mainly driven by exclusive physics

- Hermeticity (also for hadronic reconstruction methods in DIS)
- Particle identification (also SIDIS)
- Momentum resolution (kinematic fitting to ensure exclusivity)
- Forward detection of recoil baryons (also baryons from nuclei)
- Muon detection (J/Ψ)
- Photon detection (DVCS)

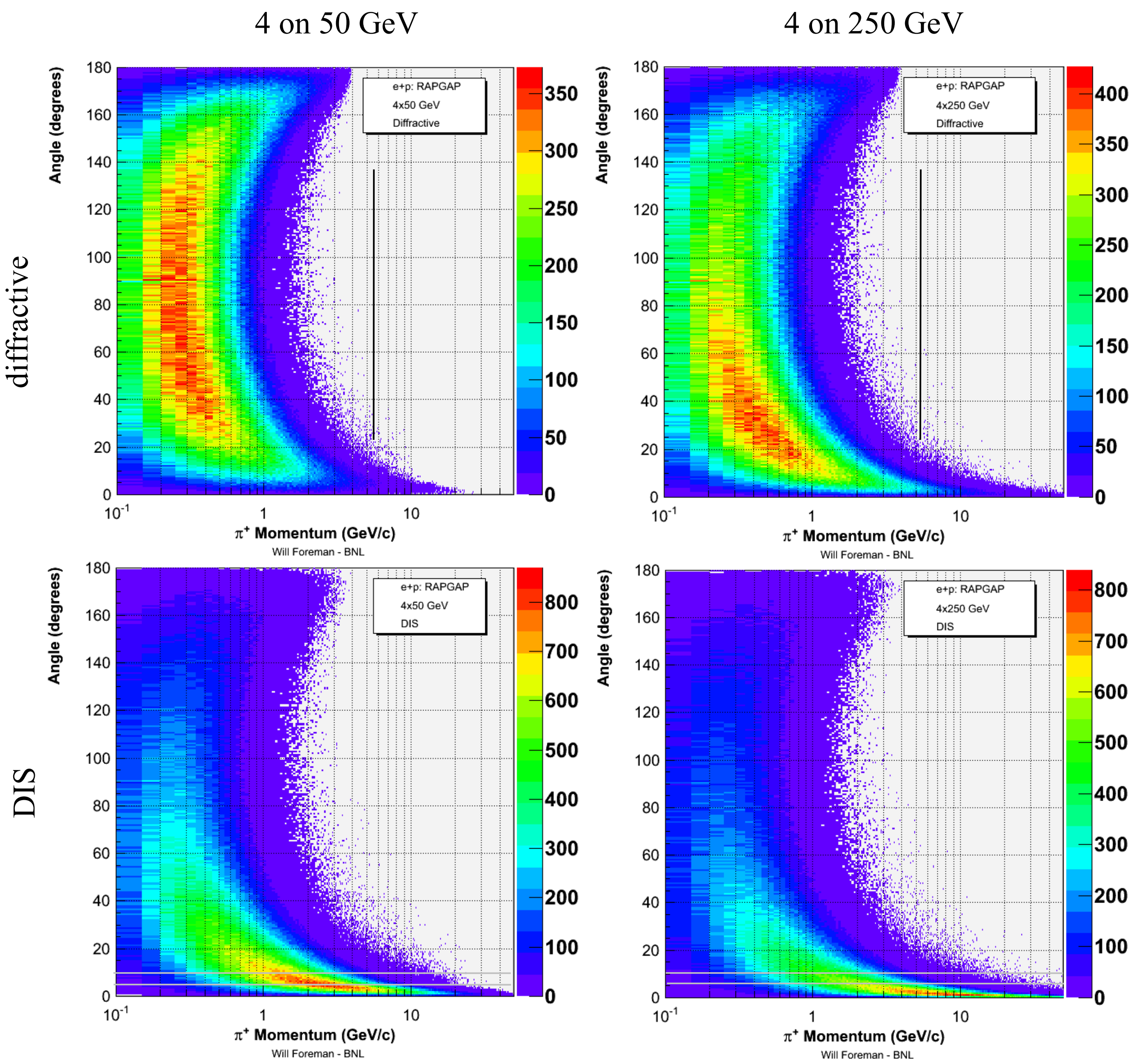
2. But not only …

- Very forward detection (spectator tagging, diffractive, coherent nuclear, etc)
- Vertex resolution (charm, strangeness)
- Hadronic calorimetry (jet reconstruction)

3. More details in workshop reports tomorrow!

Diffractive and (SI)DIS mesons

(no cuts)



- Both reactions produce high-momentum mesons at small angles
- This constitutes the background for exclusive reactions!

Low Q^2 (J/Ψ) vs high Q^2 (light mesons) – 4 on 30 GeV

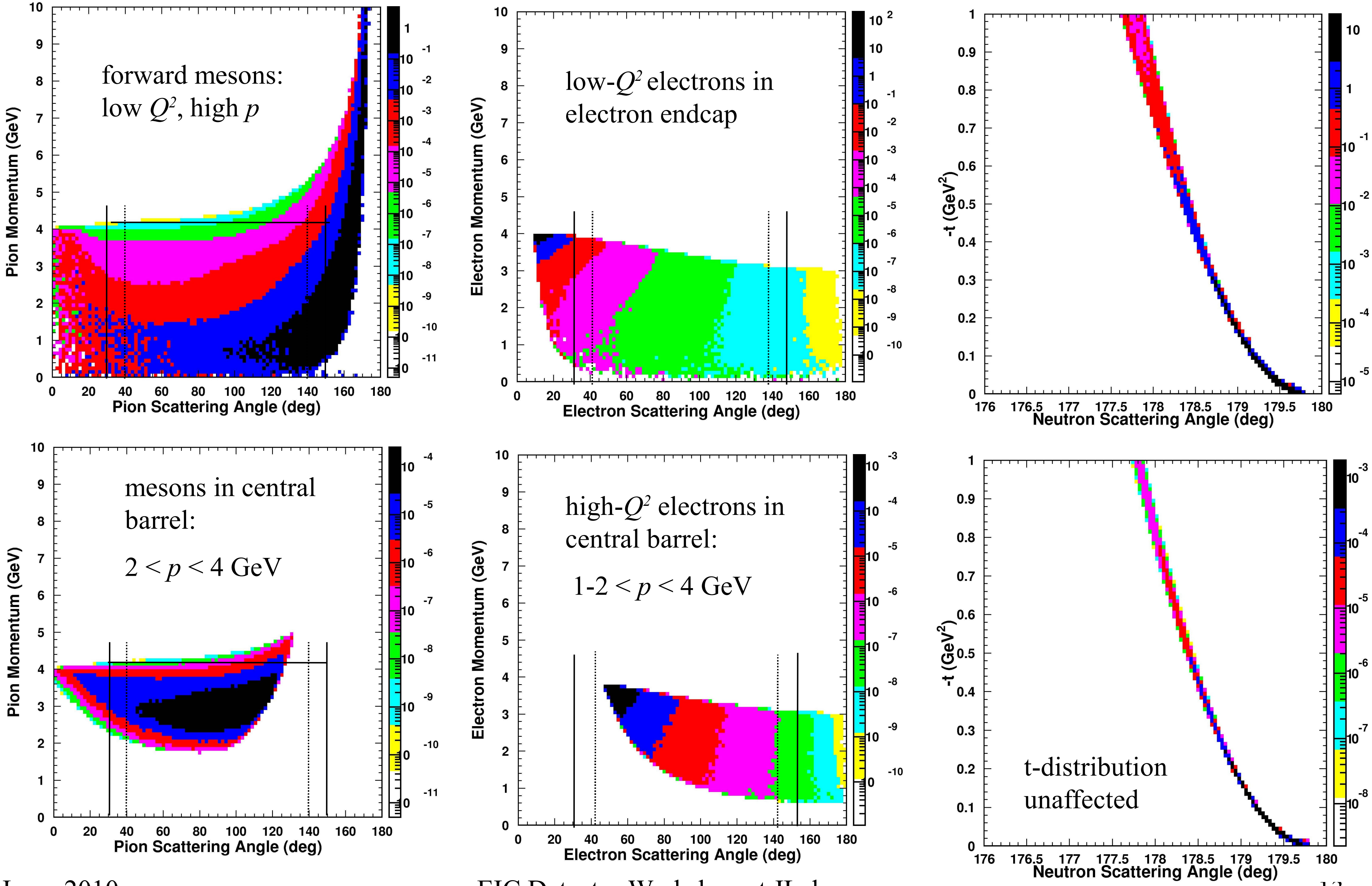
mesons

scattered electrons

recoil baryons

no Q^2 cut

$Q^2 > 10$ GeV^2


forward mesons: low Q^2, high p

low-Q^2 electrons in electron endcap

mesons in central barrel:

$2 < p < 4$ GeV

high-Q^2 electrons in central barrel:

$1\text{-}2 < p < 4$ GeV

t-distribution unaffected

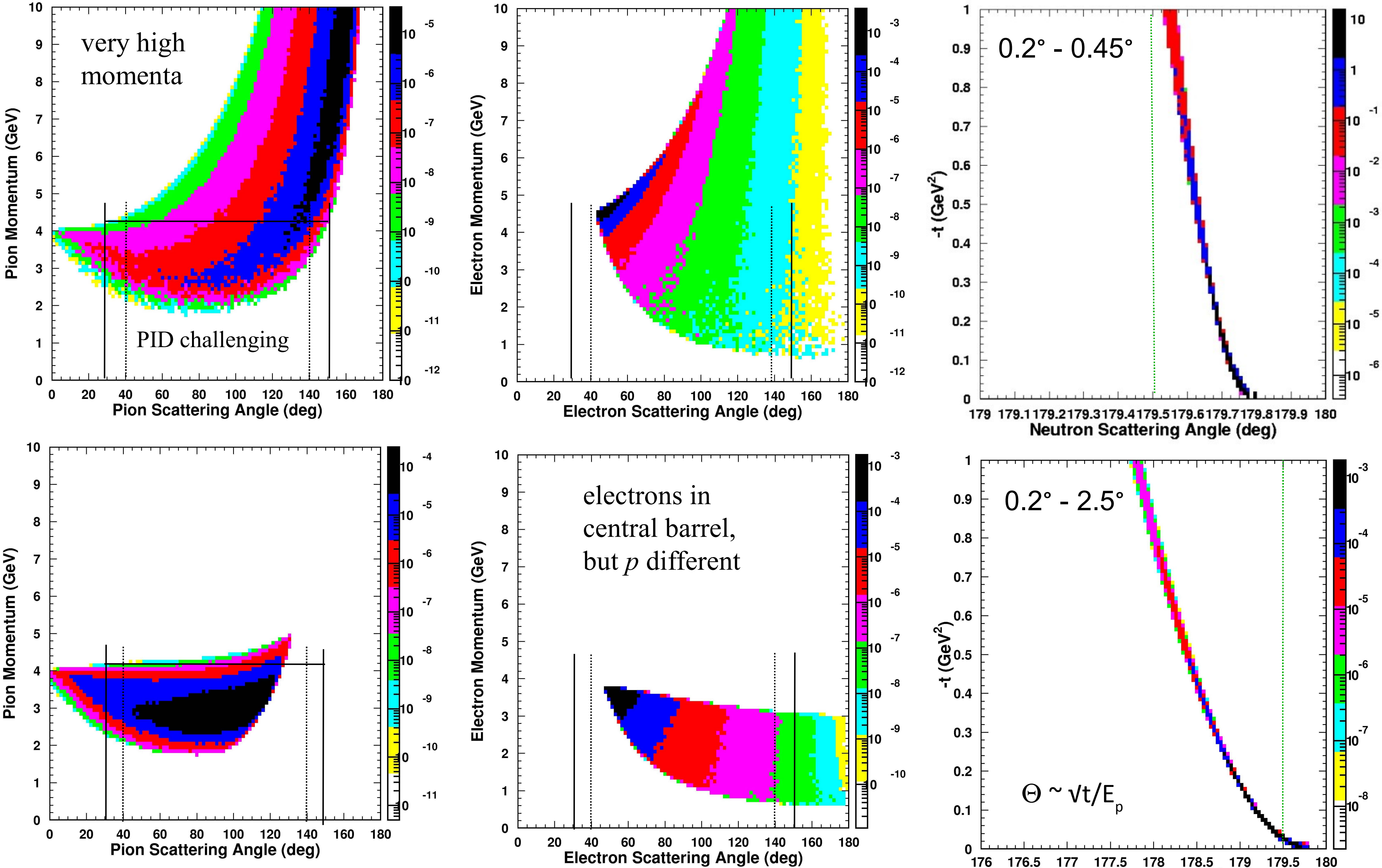
Exclusive light meson kinematics ($Q^2 > 10$ GeV^2)

$ep \rightarrow e'\pi^+ n$

mesons | scattered electrons | recoil baryons

4 on 250 GeV

4 on 30 GeV



Tanja Horn

Main detector challenges

1. Central Detector

- Particle ID (e/π/K/p)
- Momentum resolution (tracker radius / layout)

2. Forward hadron detection

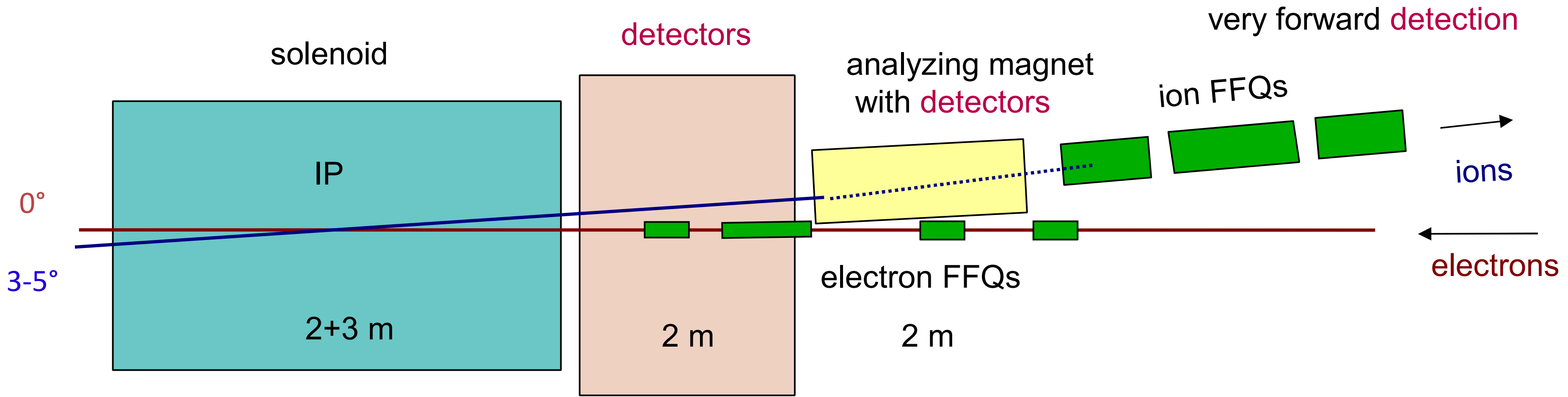
- Acceptance (3 stages needed)
- Momentum resolution at intermediate angles (0.5-5°)

3. Low-Q^2 electron tagging

- Endcap design (DIRC readout?)
- Common dipole for both beams?

4. Integration with accelerator

Three stage forward detection strategy



solenoid

detectors

analyzing magnet
with detectors

very forward detection

ion FFQs

IP

0°

3-5°

ions

electrons

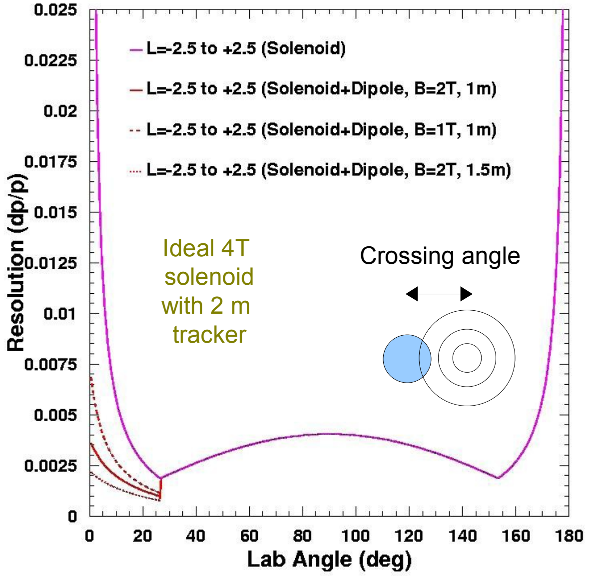
electron FFQs

2+3 m

2 m

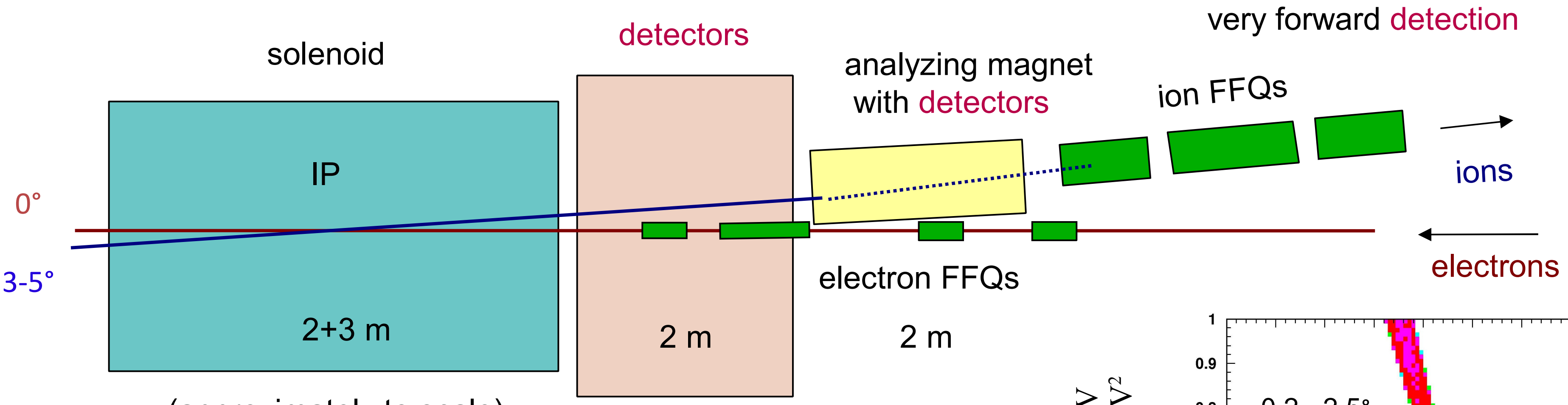
2 m

(approximately to scale)



- Charged particle tracking resolution in a solenoidal field becomes very poor at small angles (up to 5-10°)
  - F = v x B
- A crossing angle of 3-5° between the ion beam and solenoid axis moves this spot to a peripheral point in φ
  - Good place for (very small) electron quads
- A crossing angle also allows a downstream analyzing magnet with comparable aperture (3-5°)
- High-momentum particles scattered at angles < 0.5° can be detected after passing through the ion quads

Analyzing magnet - dipole



very forward detection

detectors

solenoid

analyzing magnet
with detectors

ion FFQs

ions

IP

0°

3-5°

electrons

electron FFQs

2+3 m

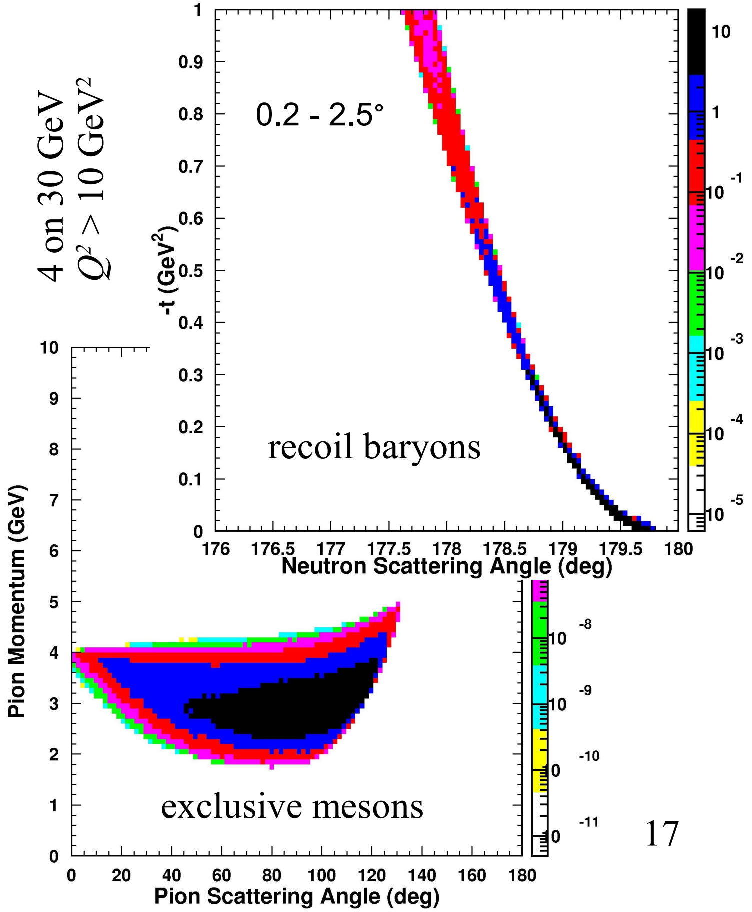
2 m

2 m

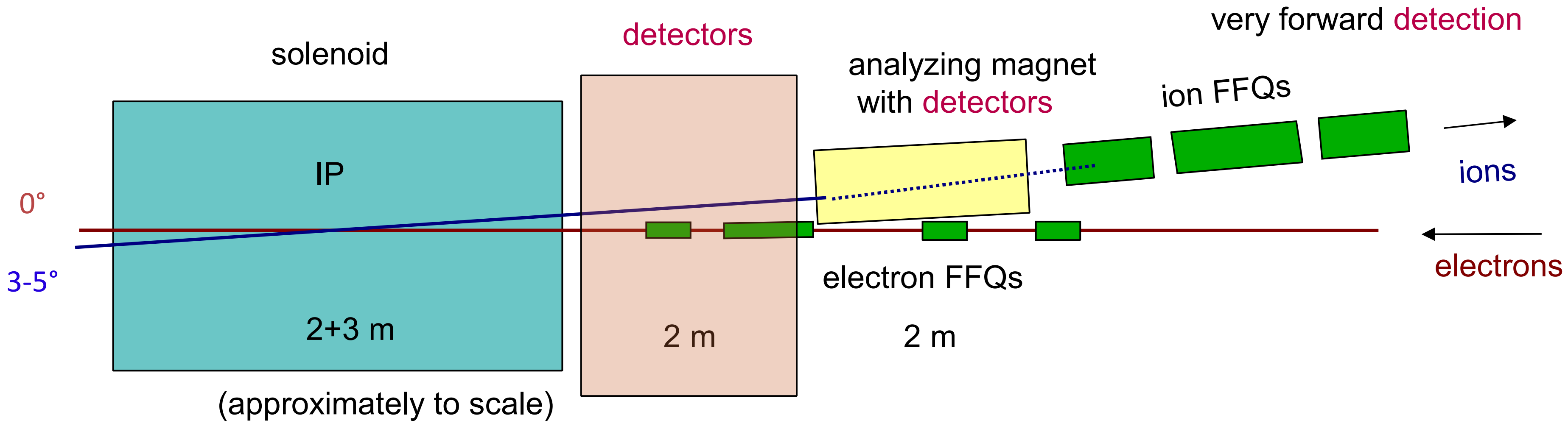
(approximately to scale)

- Analyzing magnet for high-momentum mesons and recoil baryons
  - Critical to ensure exclusivity and give access to full range in *-t*

- A 1-2 Tm dipole bypassed by the electron beam is very advantagous
  - No synchrotron radiation
  - Electron quads can be placed close to IP
  - Dipole field is not determined by electron energy
  - Positive particles are bent *away* from the electron beam
  - Dipole does not interfere with RICH and forward calorimeters
    - Excellent hermeticity

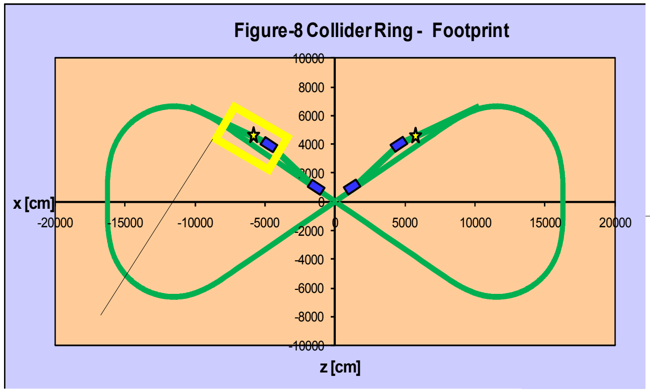


Analyzing magnets - quadrupoles?



- By bending all charged particles, a dipole on the ion beam line
  - provides excellent resolution at small angles and does not interfere with optics
  - will bent away low-momentum particles scattered at small angles prior to quads
  - may limit very forward acceptance for neutrals within the quad aperture if field is too strong
- Weak, large-aperture quads would not bend the ion beam and may impact forward detection less, but
  - a single quad, even if weak, will defocus the beam, reducing luminosity
  - a doublet will not affect the optics adversely, but makes tracking more complicated
  - a quad solution will provide less resolution, in particular at small angles
  - Would needs to be explored.

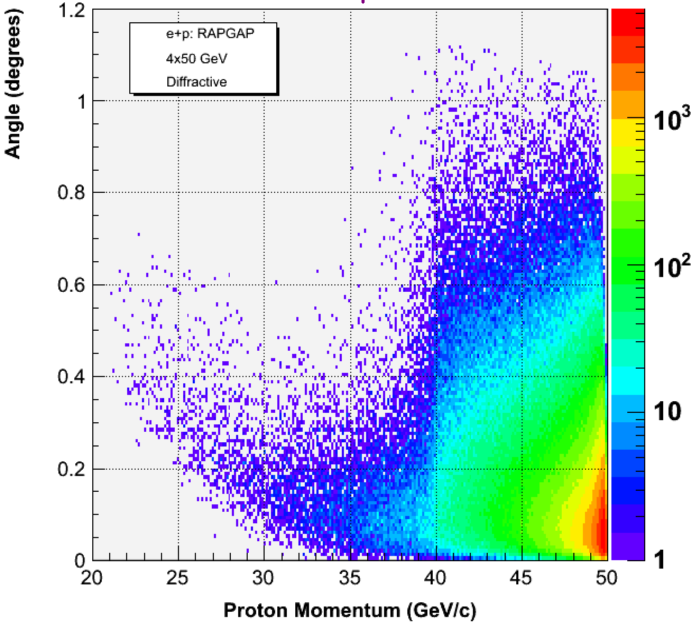
Very forward detection (< 0.5°)



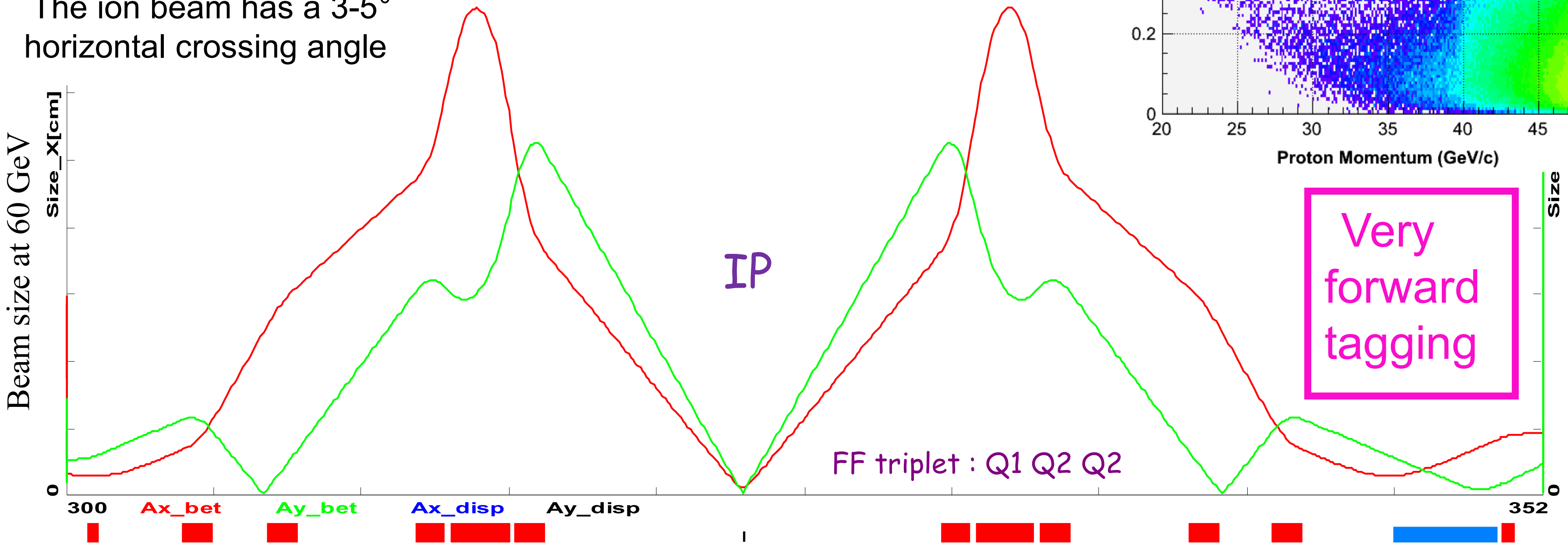
The ion beam has a 3-5° horizontal crossing angle

- Diffractive processes
- Spectator tagging
- Coherent processes

Diffractive recoil protons for 4 on 50



Beam size at 60 GeV



IP

FF triplet : Q1 Q2 Q2

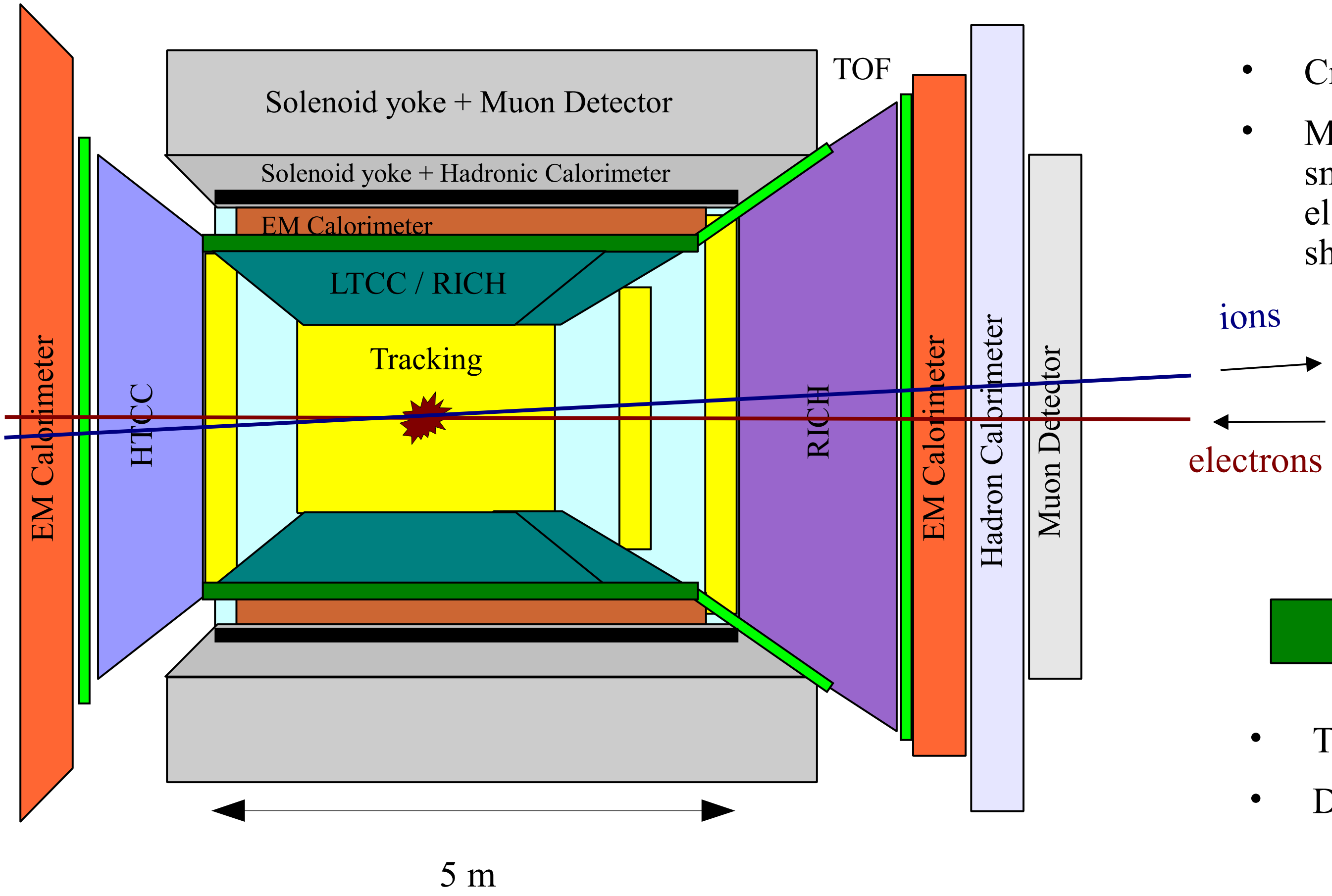
Very forward tagging

20-40 Tm dipole

~ 20 meters

- Quad gradient and aperture scale with distance
- Aperture angle depends only on E_{max} and quad length

Central detector



- Crossing angle: 3-5°
- Magnet apertures for small-angle ion and electron detection not shown

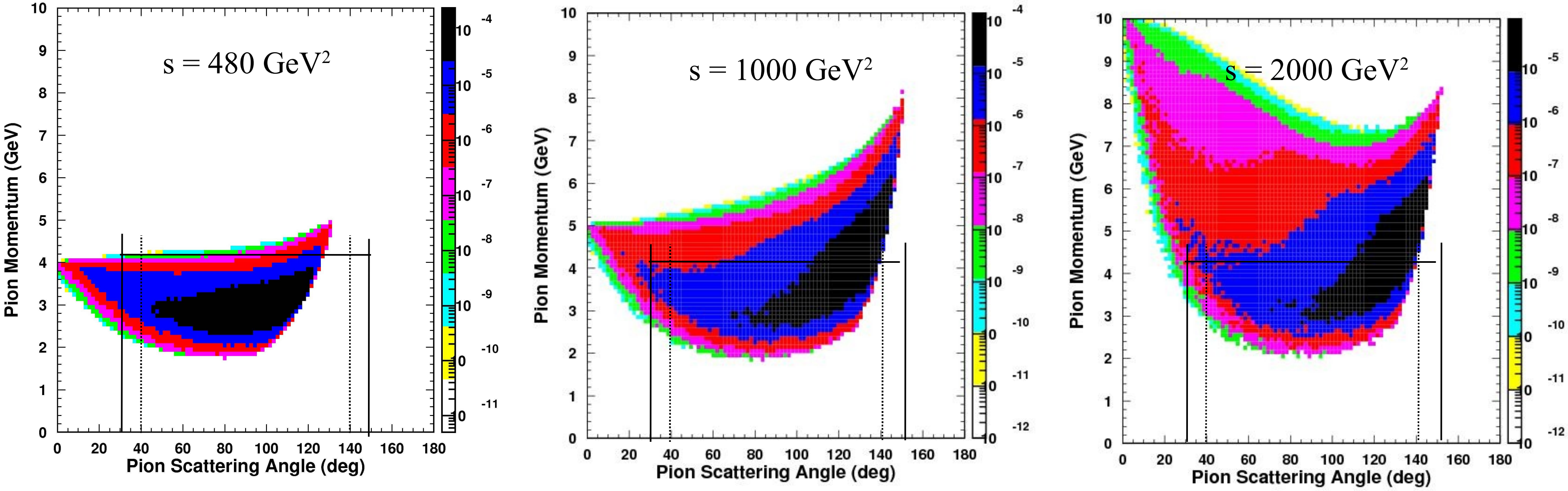
🟩

- TOF (5-10 cm)
- DIRC (10 cm)

- The IP the IP is offset within the solenoid towars the electron endcap to provide more tracking space
- Only active elements are shown. Detector can be “closed” magnetically

Identification of exclusive mesons at higher energies

$Q^2 > 10$ GeV^2



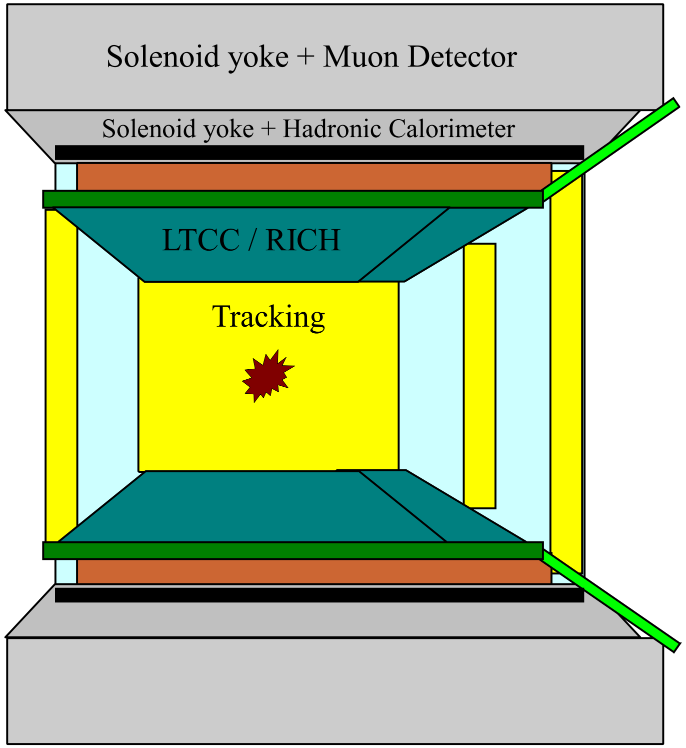
4 on 30 GeV

5 on 50 GeV

10 on 50 GeV

- At higher ion energies a DIRC alone is no longer sufficient for π/K separation
- Need to cover meson momenta up to 7-9 GeV/c for operations at 60 GeV
- Two options
  - Supplement the DIRC with a gas Cerenkov (threshold or RICH)
  - Replace it with a dual radiator (aerogel / gas) RICH

Central Detector



Tracking

- Vertex tracker (silicon pixel?)
- Central tracker (DC, micropattern?)
- Tracking planes (DC)
  - Configuration to be optimized

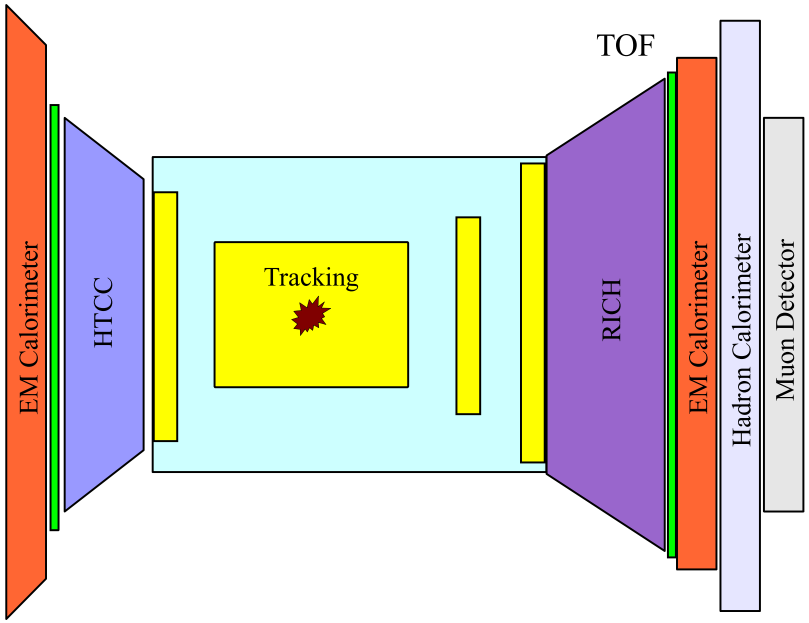
Solenoid Yoke, Hadron Calorimeter, Muons

- 3-4 T solenoid with about 4 m diameter
- Hadronic calorimeter and muon detector integrated with the return yoke (*c.f.* CMS)

Particle Identification

- TOF for low momenta
  - Precise timing also important for trigger
- p/K separation
  - DIRC or dual radiator (aerogel) RICH
- π/K separation options
  - DIRC + LTCC up to 9 GeV (higher if RICH)
  - dual radiator RICH up to ~8 GeV (?)
- e/π separation
  - C_4F_8O LTCC / RICH up to 3 / 5 GeV
  - EC: Tungsten powder / scintillating fiber?

Detector Endcaps



Electron side (left)

- Bore angle: ~45° (line-of-sight from IP)
- High-Threshold Cerenkov
- Time-of-Flight Detectors
- Electromagnetic Calorimeter

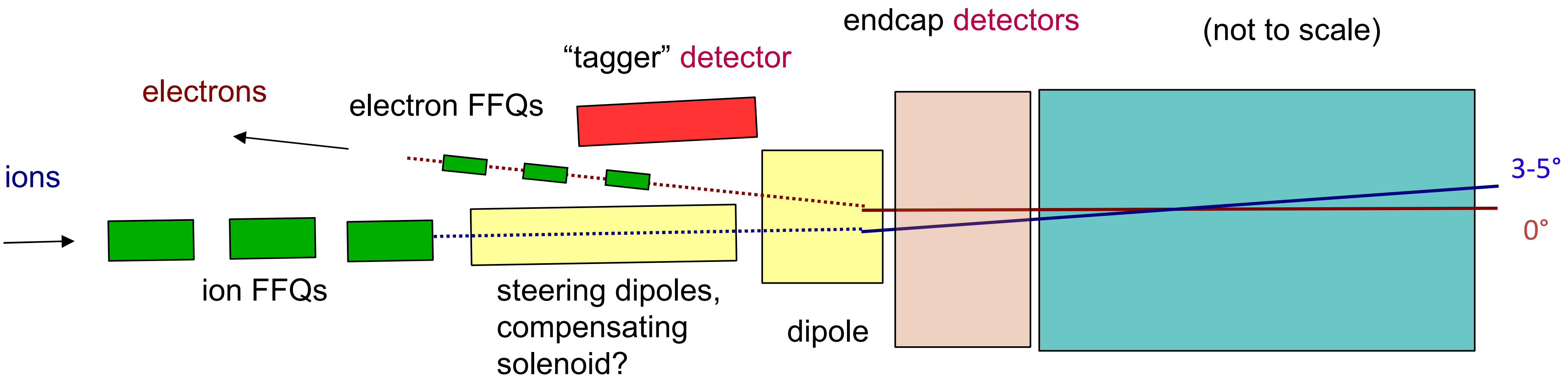
Ion side (right)

- Bore angle: 30-40° (line-of-sight from IP)
- Dual-radiator RICH (HERMES / LHCb ?)
- Time-of-Flight Detectors
- Electromagnetic Calorimeter
- Hadronic Calorimeter
- Muon detector (at least at small angles)
  - Important for J/Ψ photoproduction (at low Q^2)

Tracking

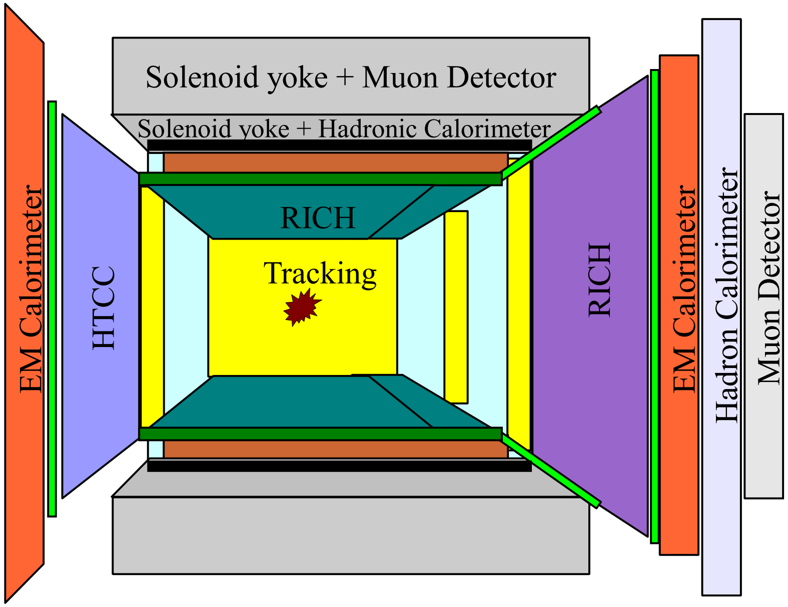
- Forward / Backward
  - IP shifted to electron side (2+3 m)
  - Vertical planes in central tracker
  - Drift chambers on either side

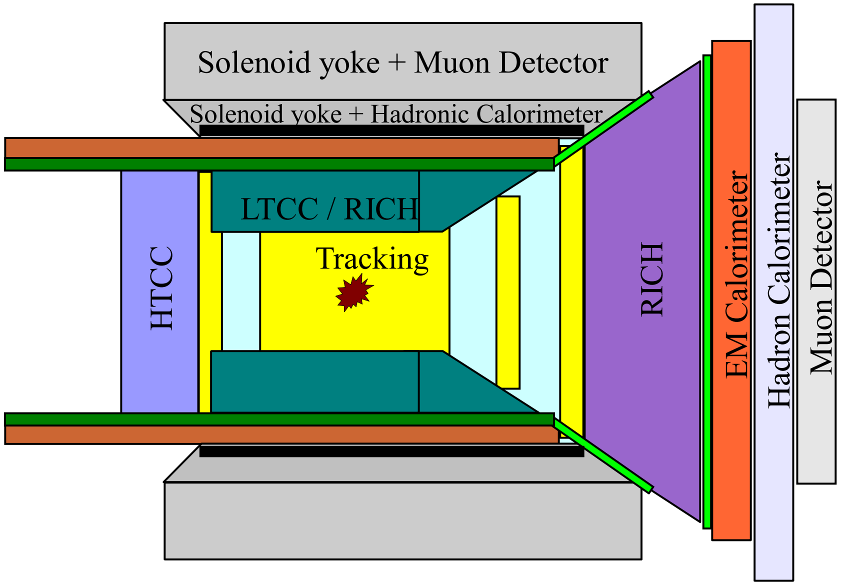
Low-Q^2 tagging – very conceptual!



- Synchrotron radiation is not an issue for outgoing electrons
  - Can use dipole covering small scattering angles
  - Effect on electron emittance of strong dipole in high-β region?
- Common dipole requires additional steering to allow independently adjustable beam energies
- Endcap layout required for detailed design!

Electron endcap options





- The exact endcap configuration will to a large extent depend on the readout for the DIRC
- The alternative configuration on the right provides easier access to the DIRC

Summary - main detector challenges

1. Central Detector

- Particle ID (e/π/K/p)
- Momentum resolution (tracker radius / layout)

2. Forward hadron detection

- Acceptance (3 stages needed)
- Momentum resolution at intermediate angles (0.5-5°)

3. Low-Q^2 electron tagging

- Endcap design (DIRC readout?)
- Common dipole for both beams?

4. Integration with accelerator