Detector options for a low energy electron-ion collider at BNL - MeRHIC

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BNL

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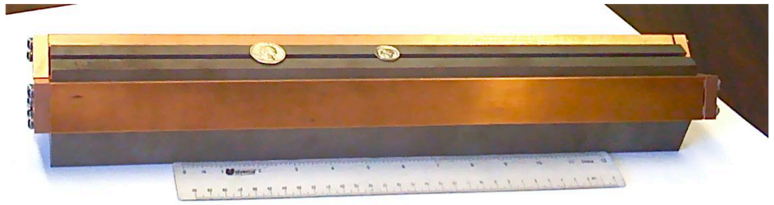
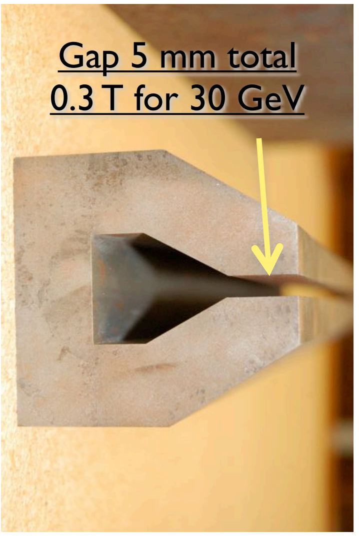
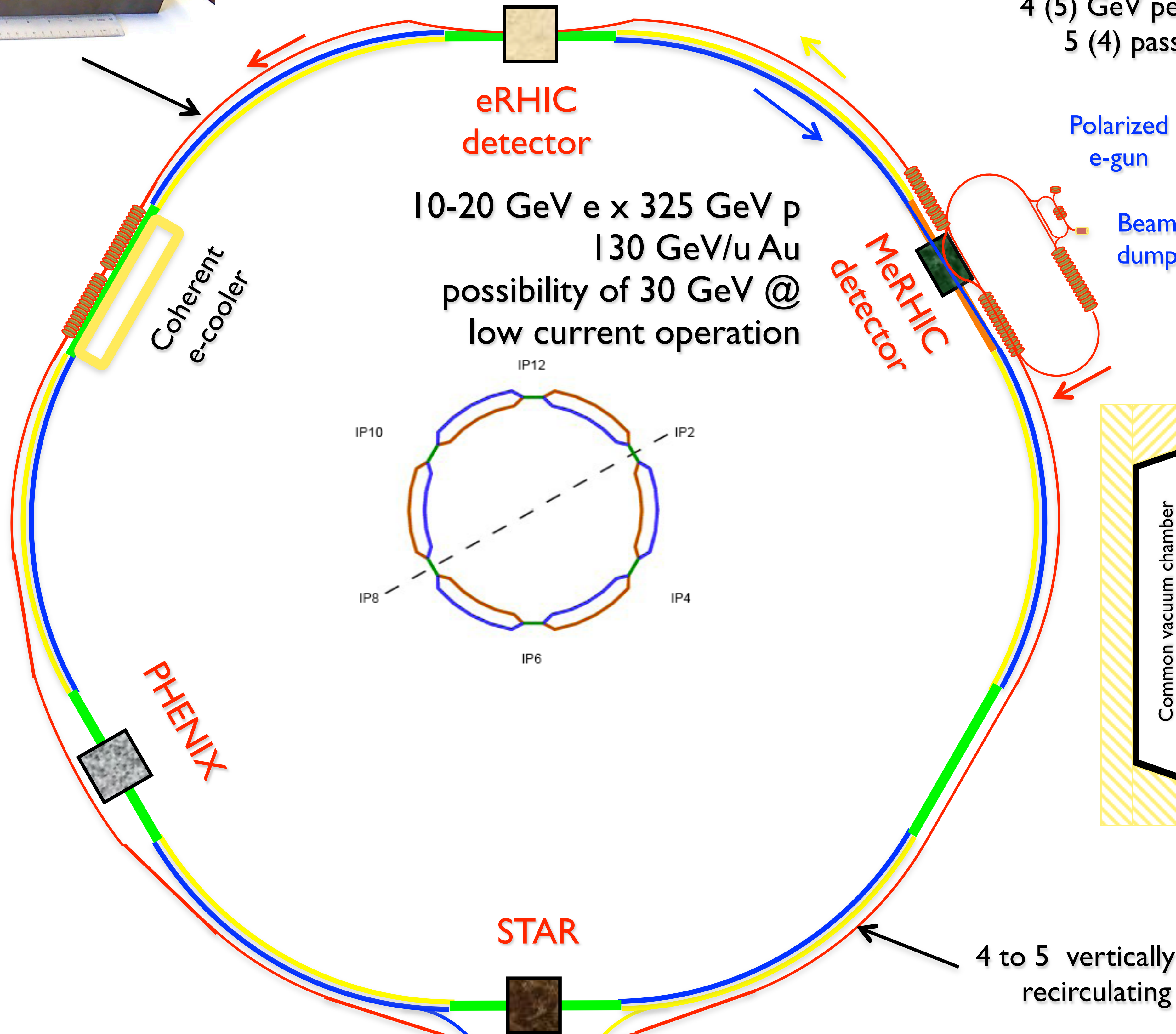
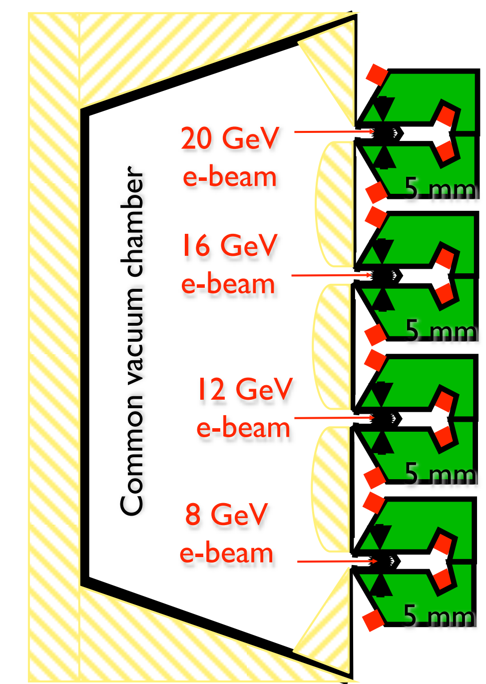
MeRHIC @ BNL





2 x 200 m SRF linac
4 (5) GeV per pass
5 (4) passes





4 to 5 vertically separated
recirculating passes

macl@bnl.gov

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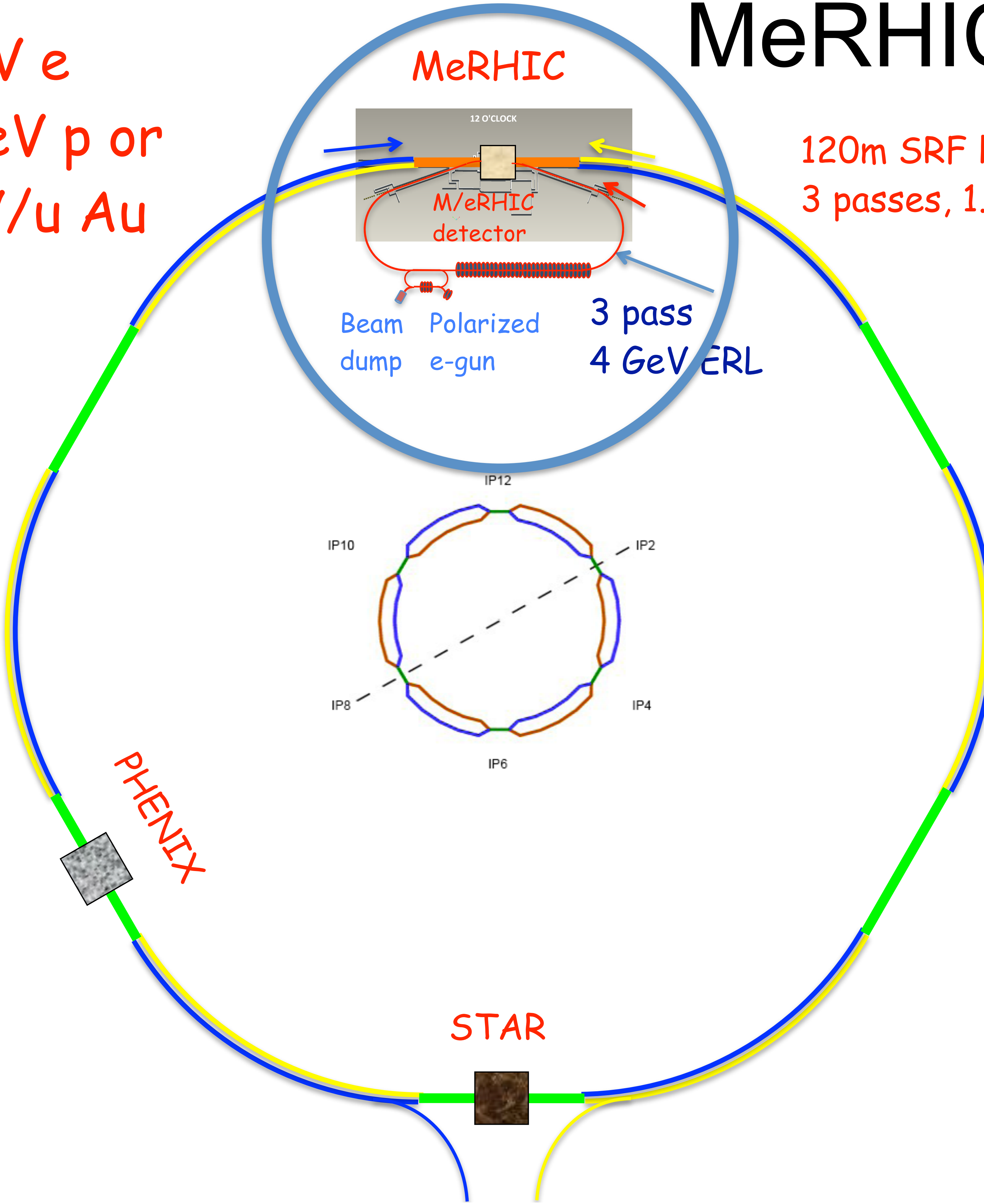
Designs evolve with time .....

MeRHIC at BNL

4 GeV e
x 250 GeV p or
100 GeV/u Au

120m SRF linac
3 passes, 1.3 GeV/pass



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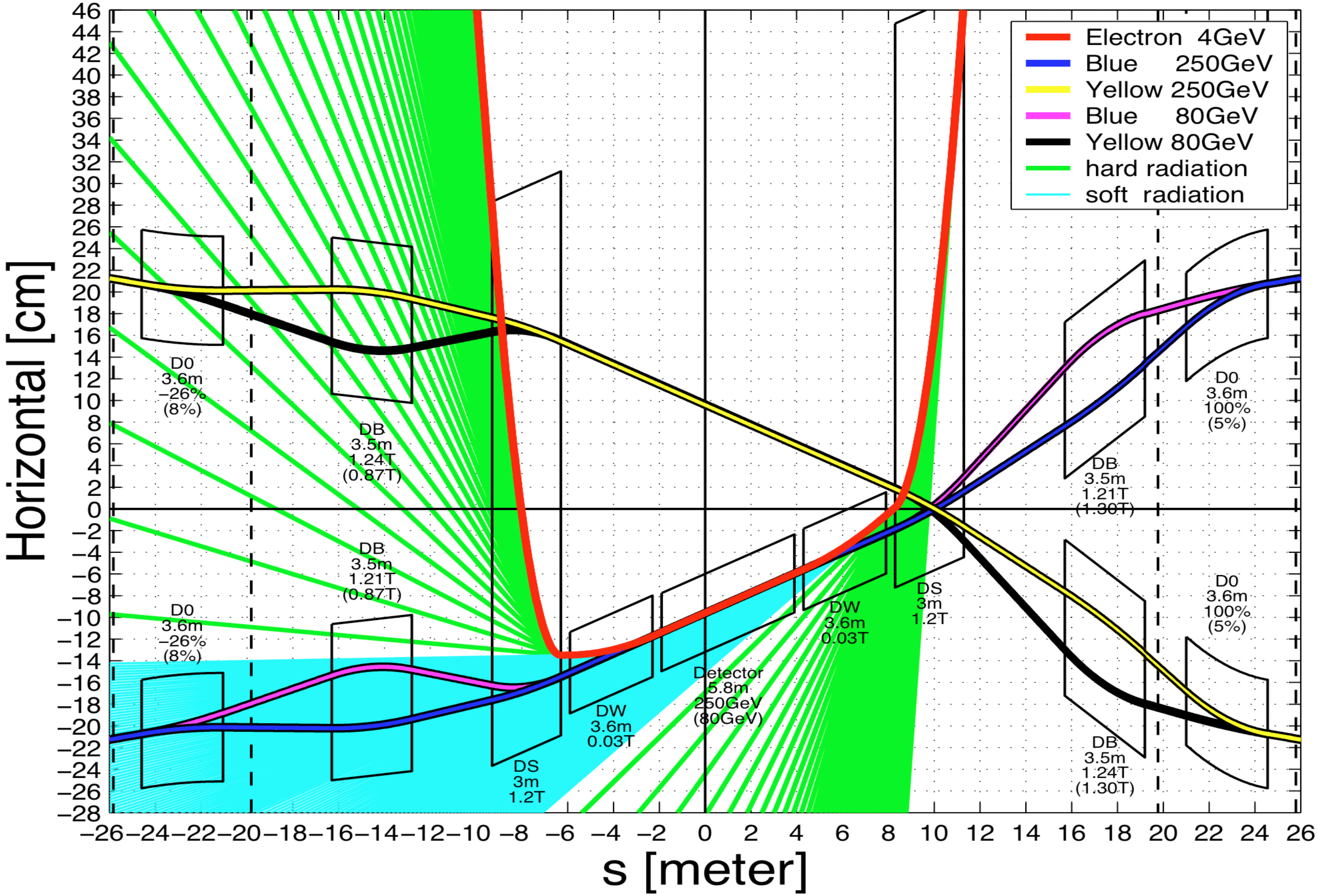
Office of Nuclear Physics
Exploring Nuclear Matter - Quarks to Stars

Latest IR Design for MeRHIC

- No synchrotron shielding included



Detector requirements from physics

- e+p physics
  - Need the same detector for inclusive (ep → e'X), semi-inclusive (ep → e'X + hadrons) and exclusive (ep → e'p+π) reactions
    - Need to have a large acceptance (*both* mid- and forward-rapidity)
    - Crucial to have particle identification
      - e, π, K, p, n over wide momentum range and scattering angles
      - excellent secondary vertex resolution (charm)
    - small systematic uncertainty for e/p polarisation measurements
    - small systematic uncertainty for luminosity measurements
- e+A physics
  - most requirements similar to e+p guidelines
  - additional complication arises from the need to tag the struck nucleus in exclusive and diffractive reactions
- Also, important to have the same detector for all energies

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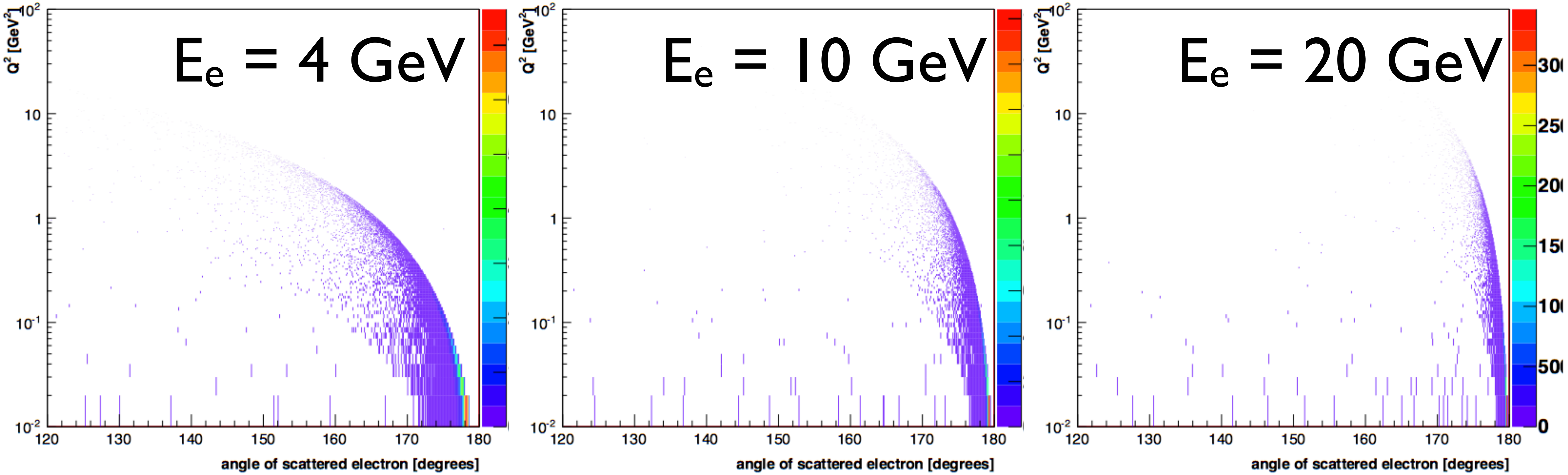
PYTHIA MC Generator - diagnostic plots



- Analysis of electron scattering angle in PYTHIA
  - higher energy electrons go at smaller angles wrt beam axis
    - harder to detect!!
    - independent of hadron energy

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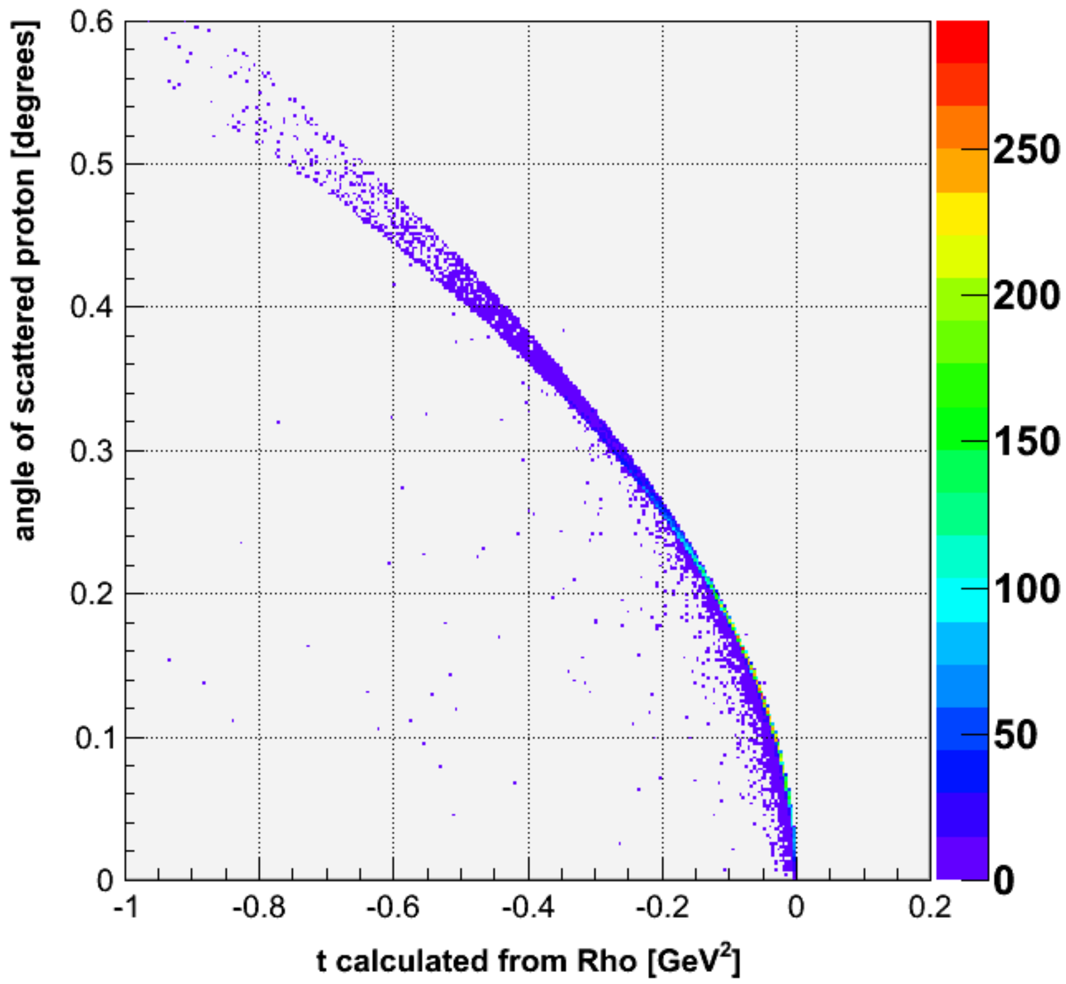
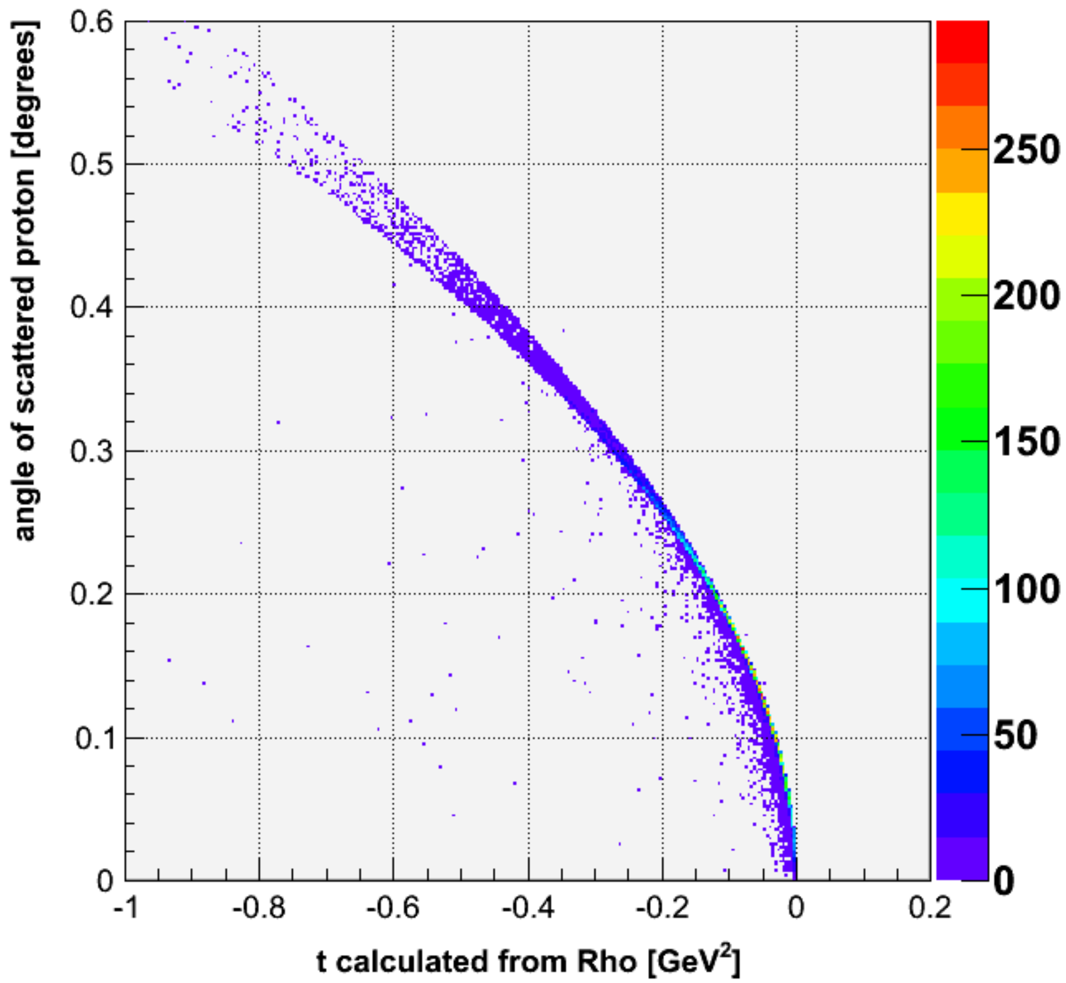
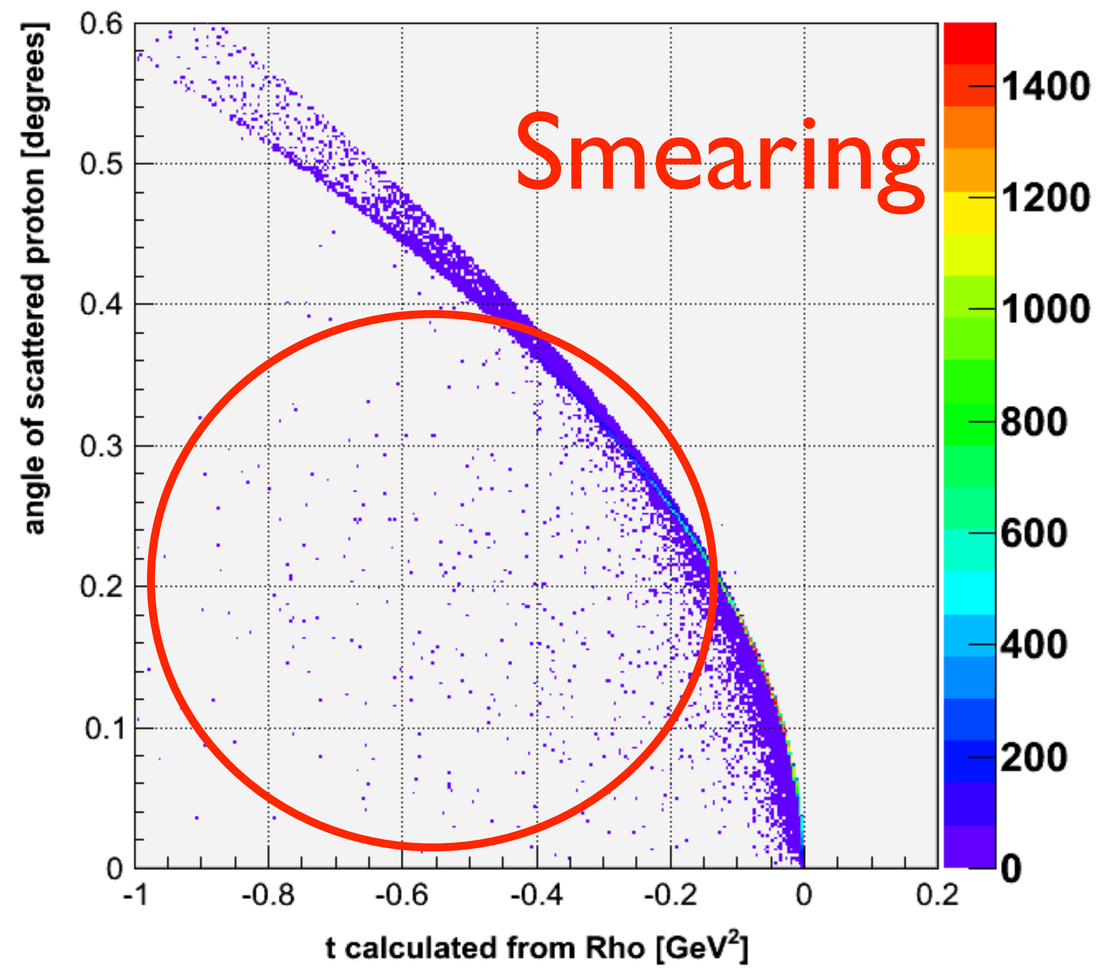
PYTHIA MC Generator - radiative corrections



PYTHIA MC Generator - radiative corrections



with radiative corrections



- Radiative corrections (via RADGEN)
  - Smear the t calculation at the ρ vertex
  - t calculated from the proton vertex is unaffected but harder to measure experimentally
    - need a proton spectrometer

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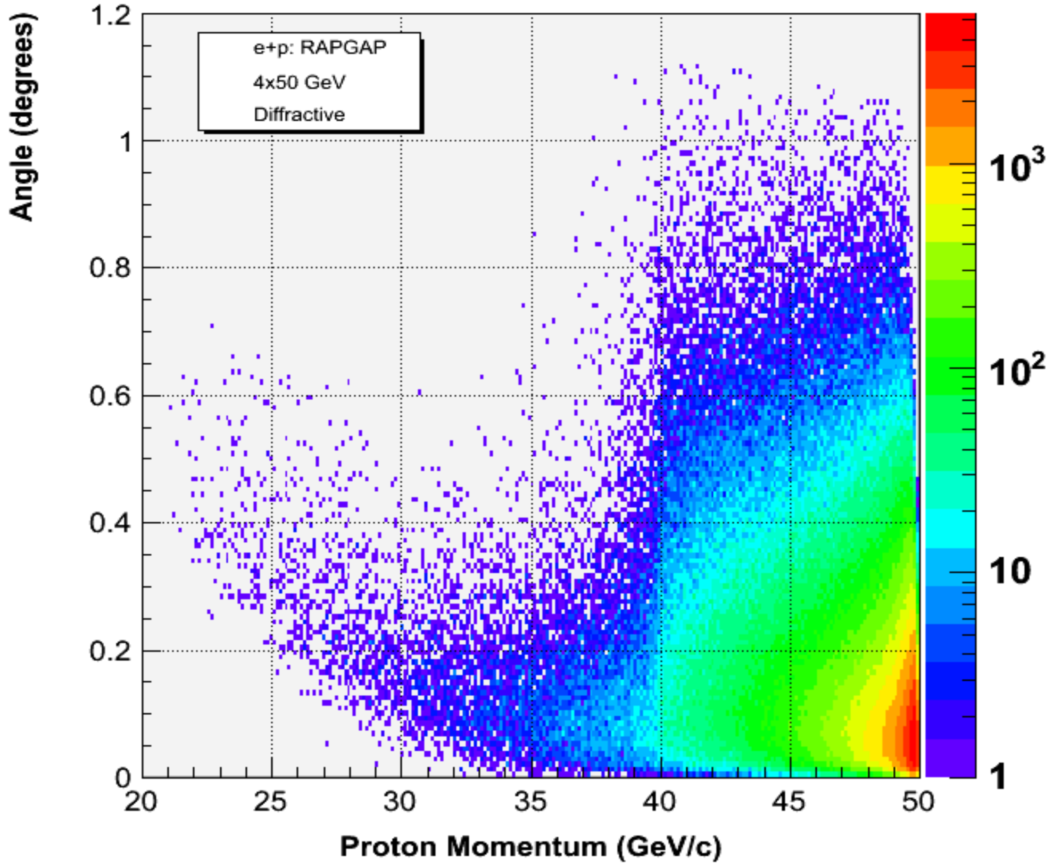
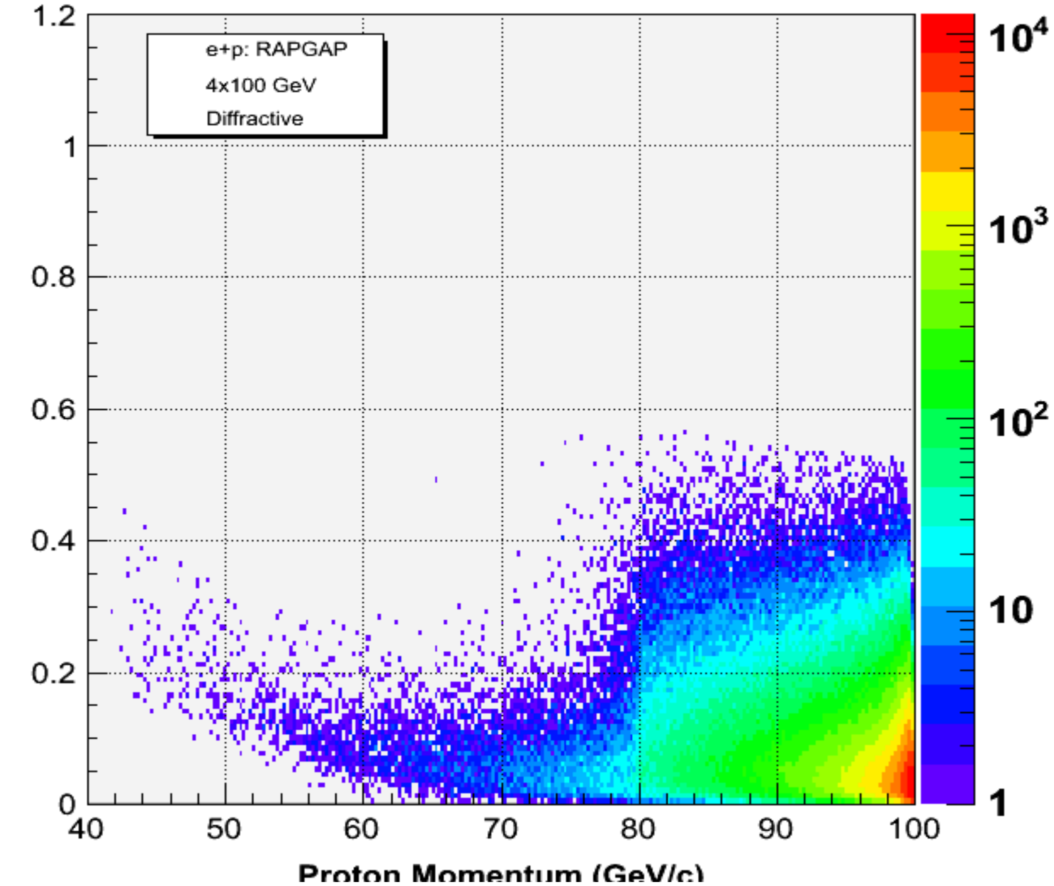
RAPGAP kinematics: scattered proton (diffractive)

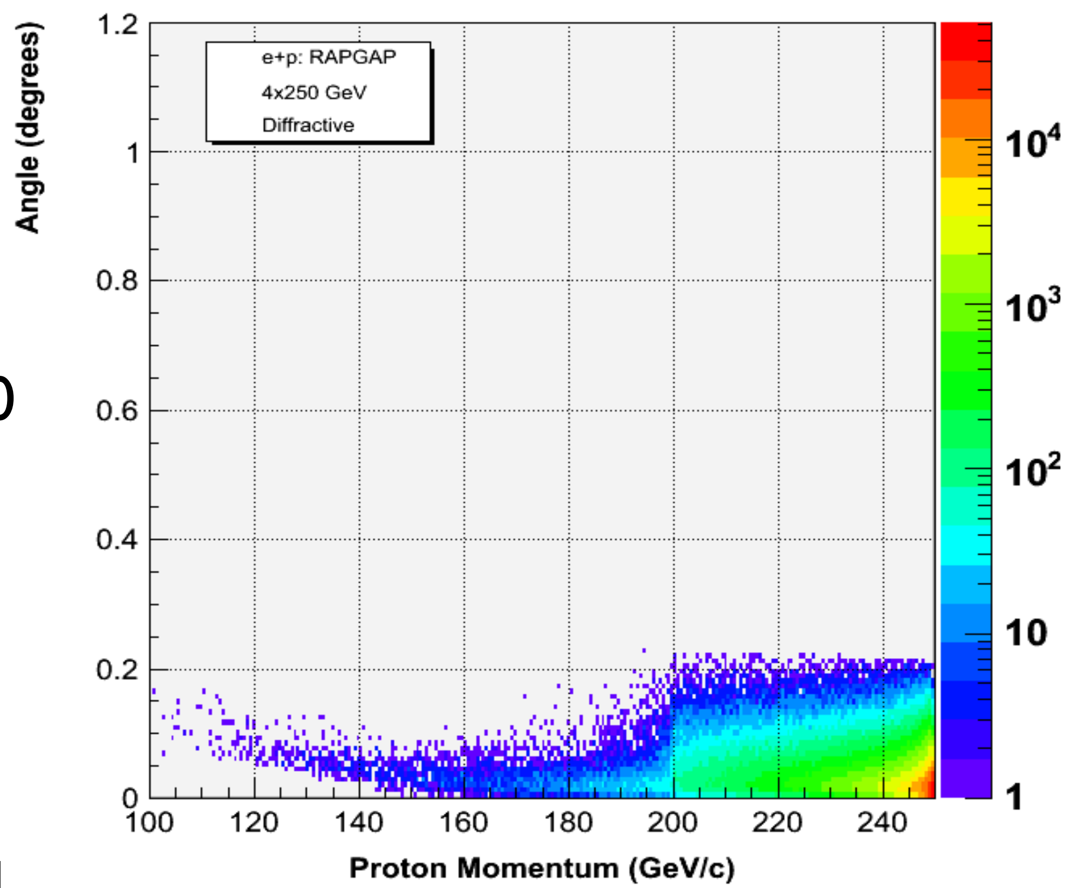
4x50



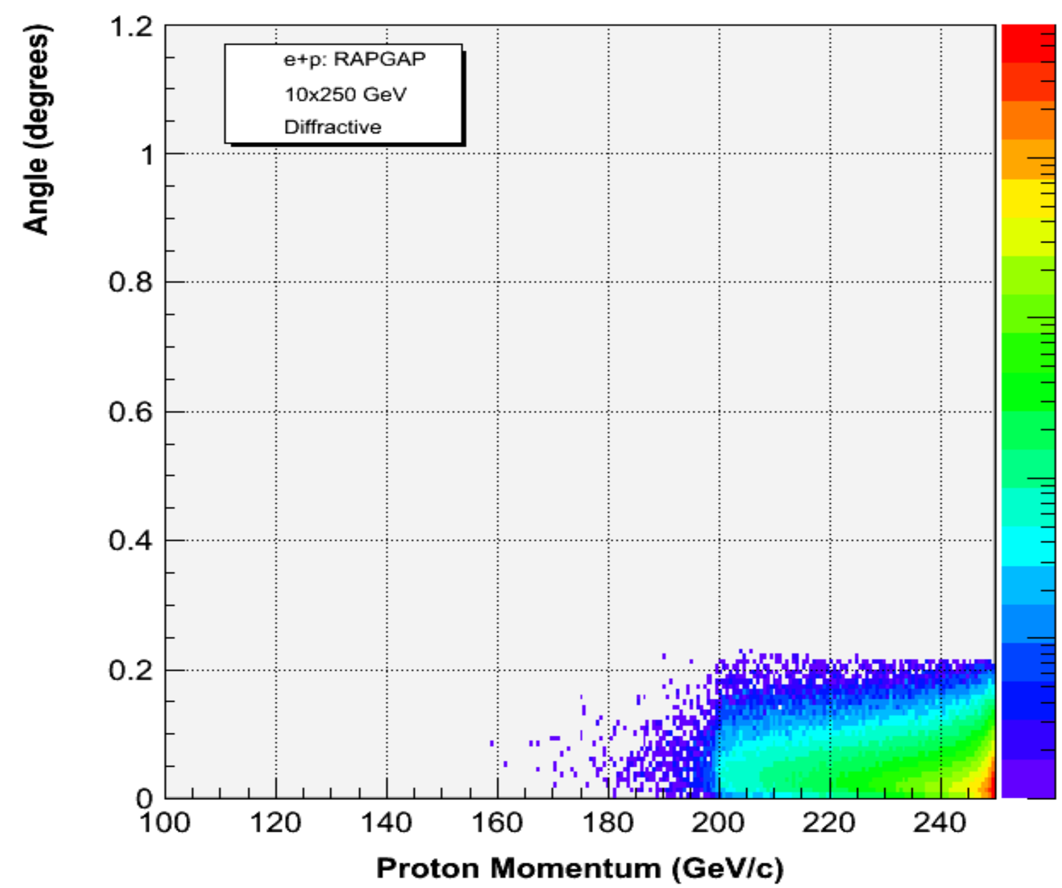
4x100



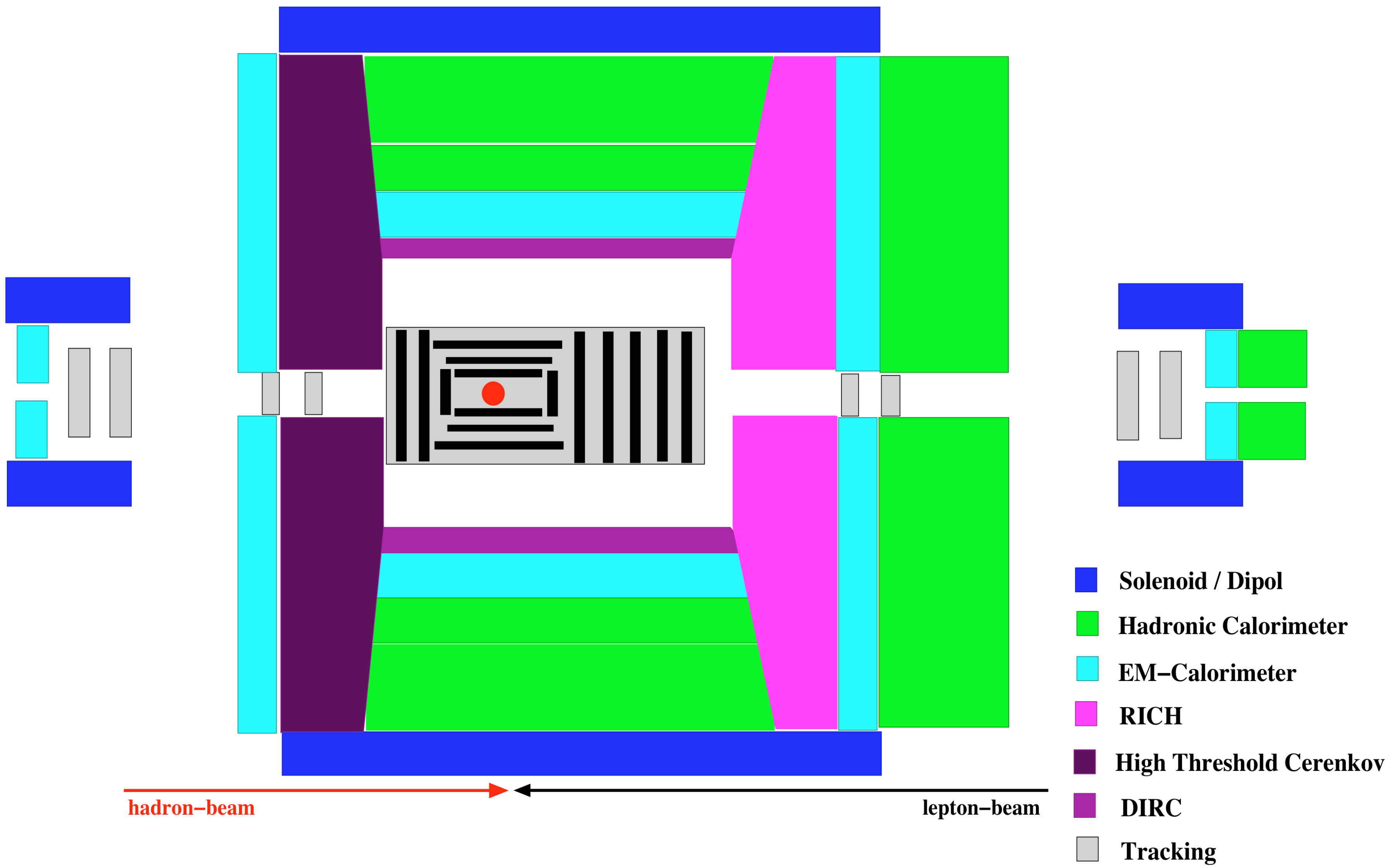
4x250



10x250



First attempt at detector design



- Dipoles need to have good forward momentum resolution
  - Solenoid has no magnetic field for r ➞ 0
- RICH, DIRC for hadron pid
- High threshold Cherenkov ➞ fast trigger for scattered lepton
- Radiation length very critical ➞ low lepton energies

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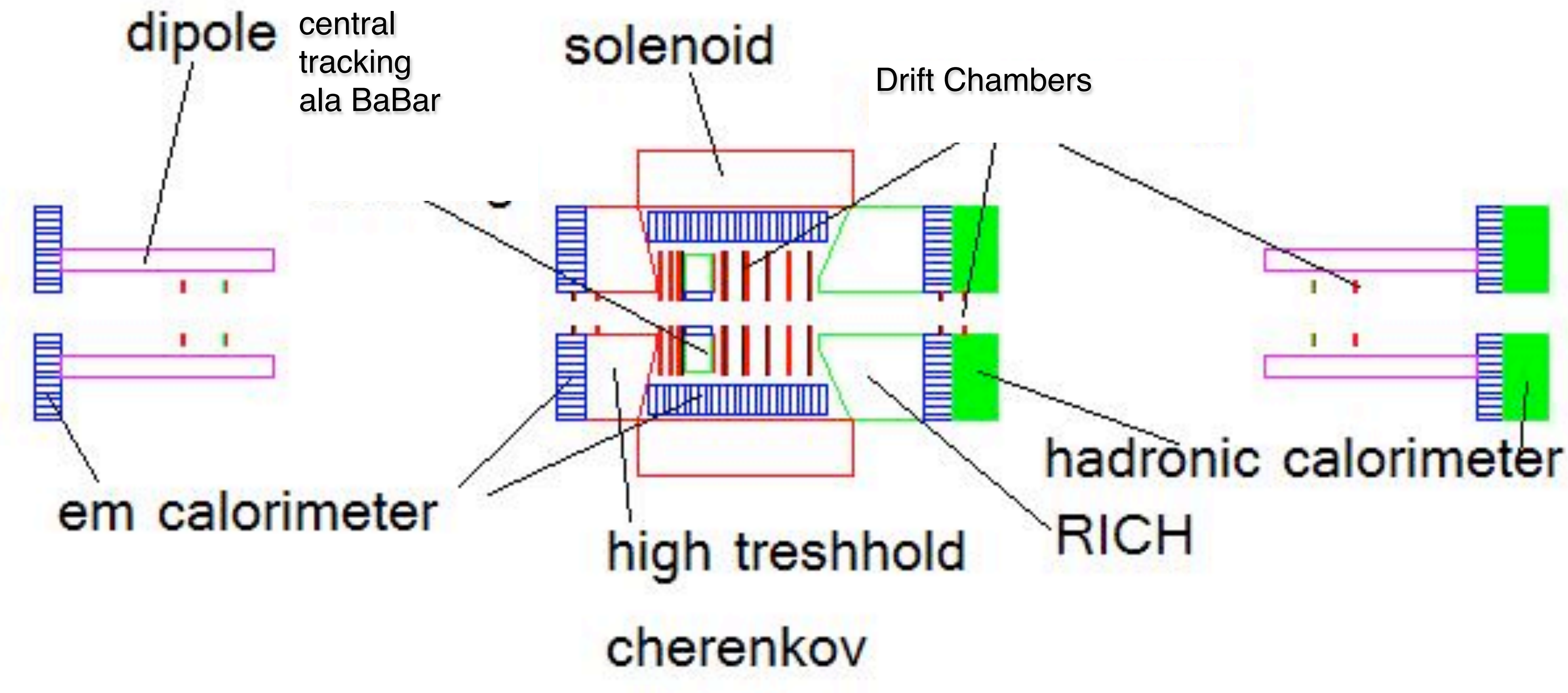
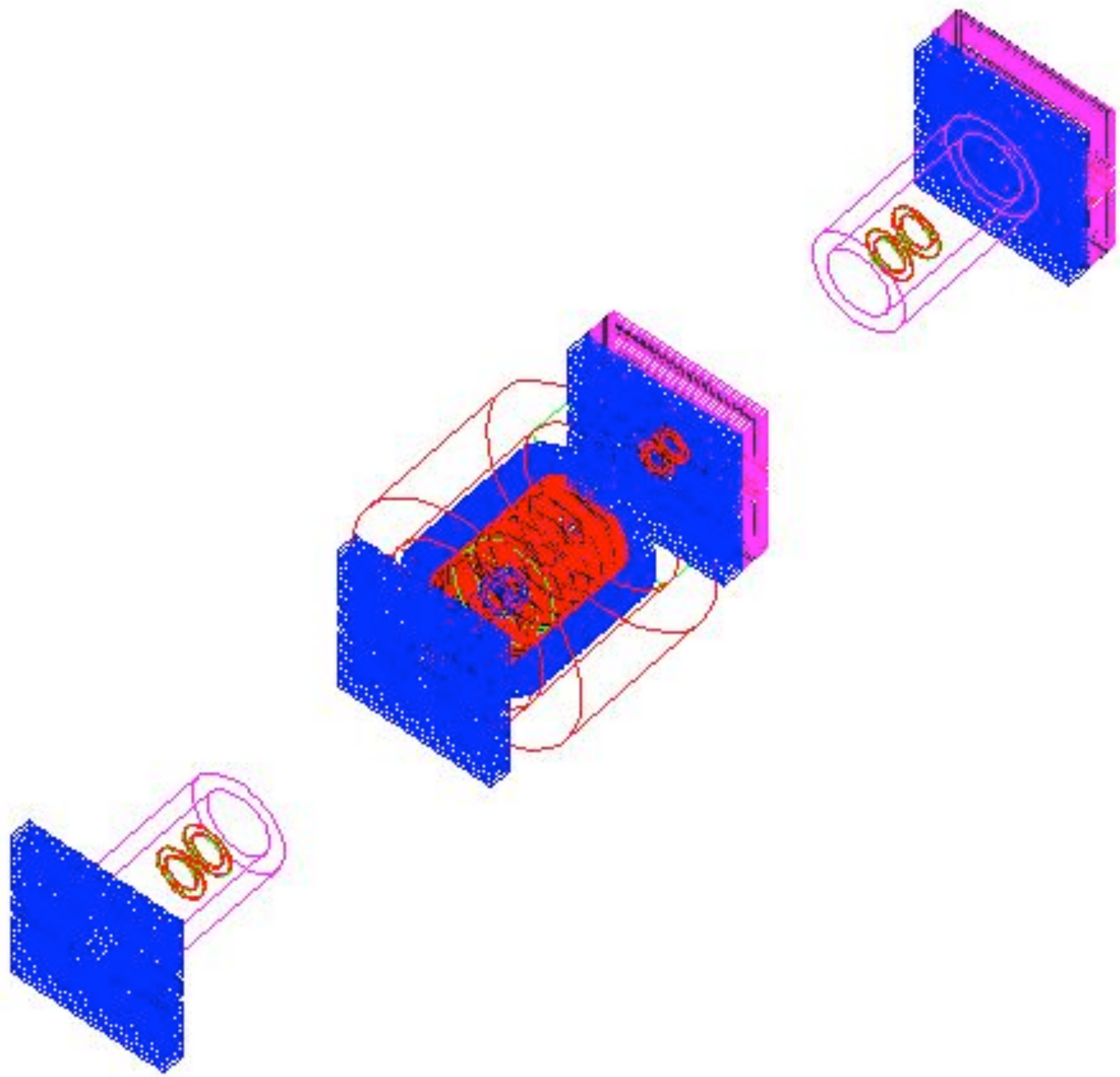
MeRHIC Detector in Geant 3



DIRC is present but not seen

due to position of cut

MeRHIC detector in Geant 3



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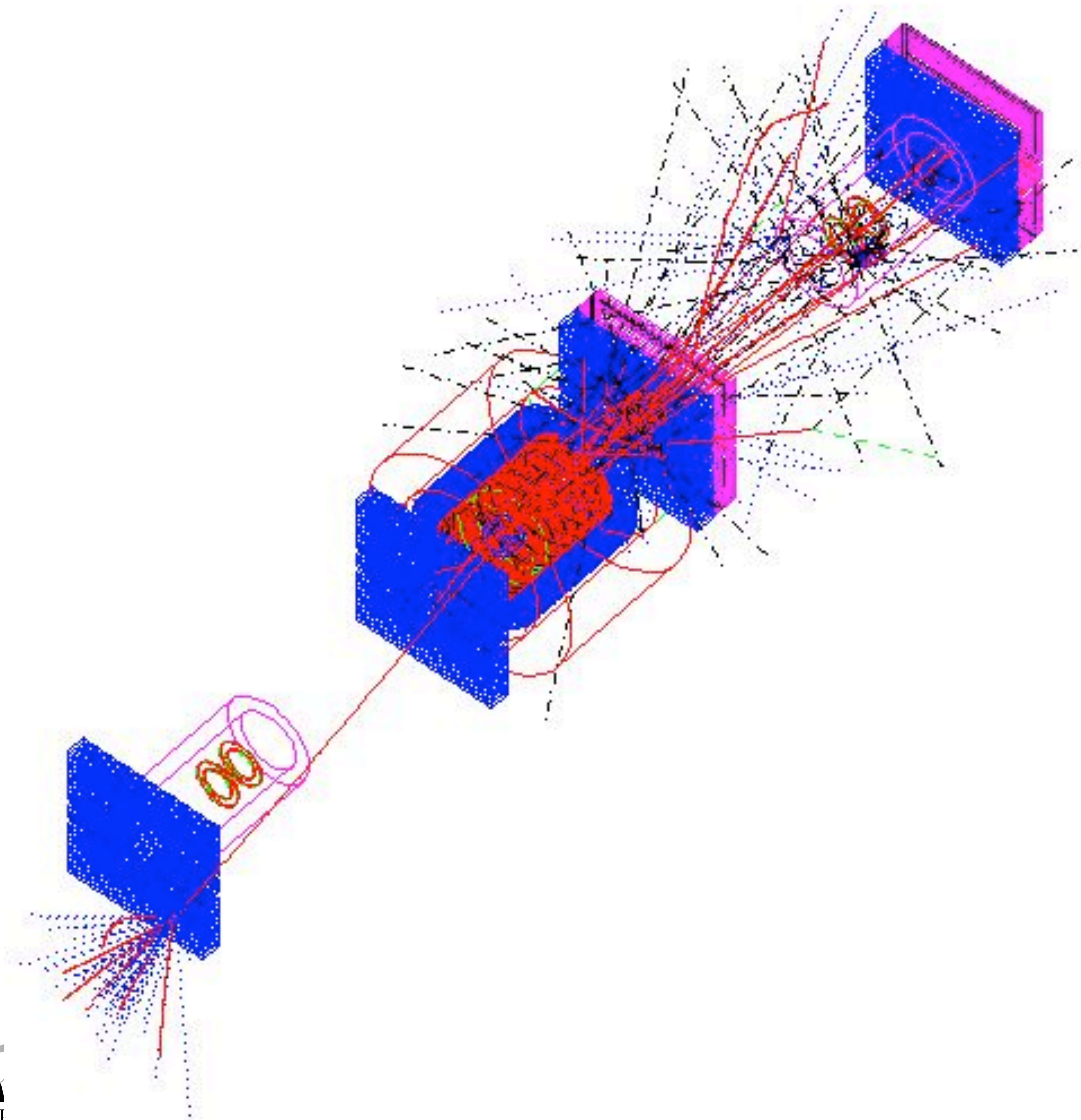
MeRHIC detector in Geant 3



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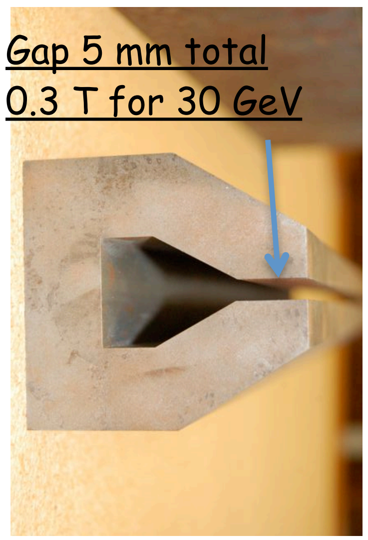
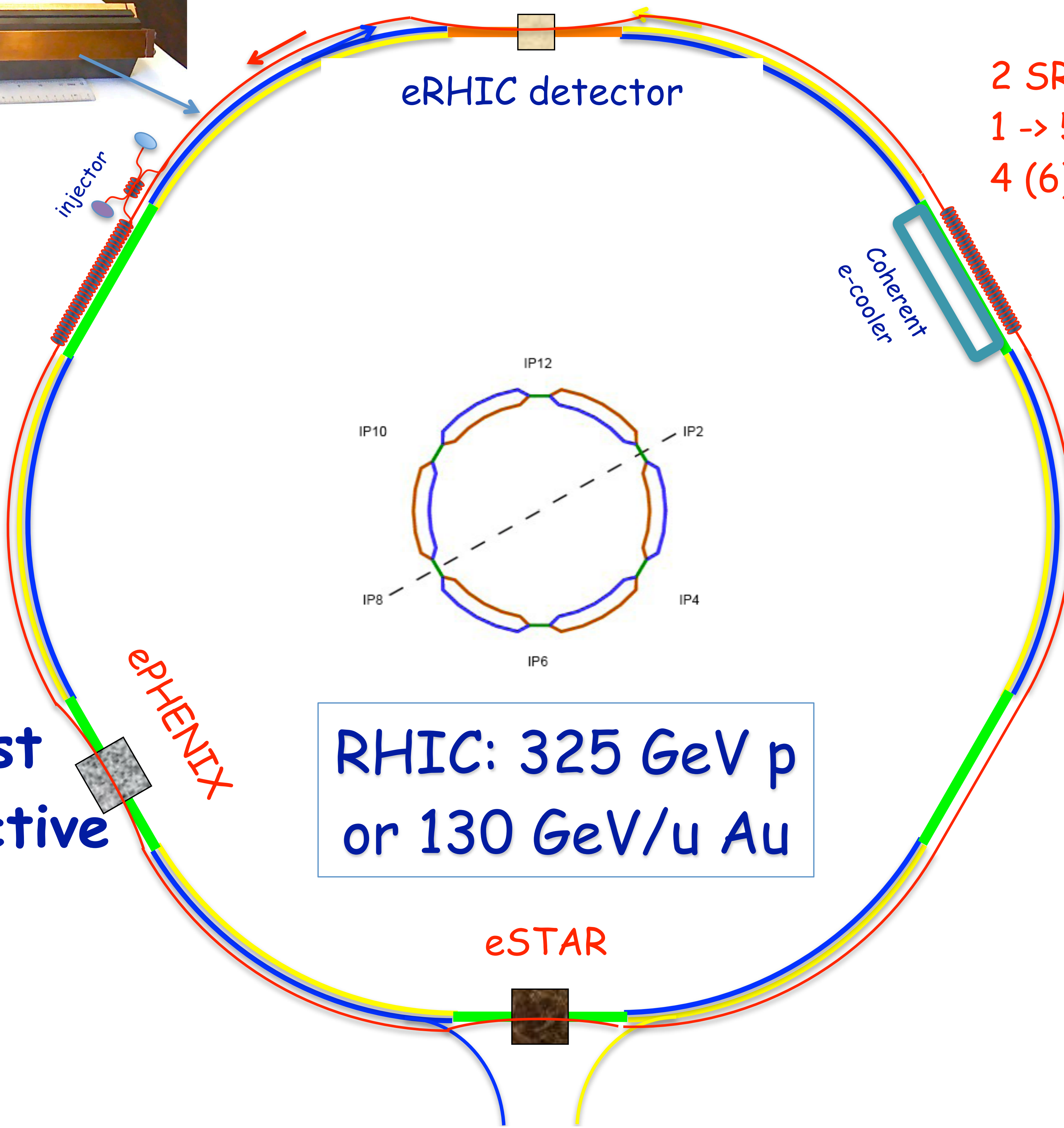
Designs evolve with time (part 2).....

Staging all-in tunnel eRHIC:

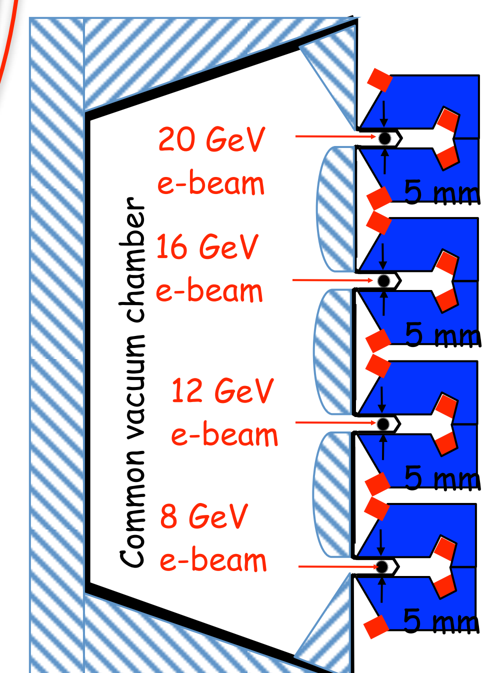
energy of electron beam is increasing from 5 GeV to 30 GeV by building-up the linacs





2 SRF linac
1 -> 5 GeV per pass
4 (6) passes

4 to 6 vertically separated recirculating passes.
# of passes will be chosen
to optimize eRHIC cost



RHIC: 325 GeV p or 130 GeV/u Au

The most cost effective design

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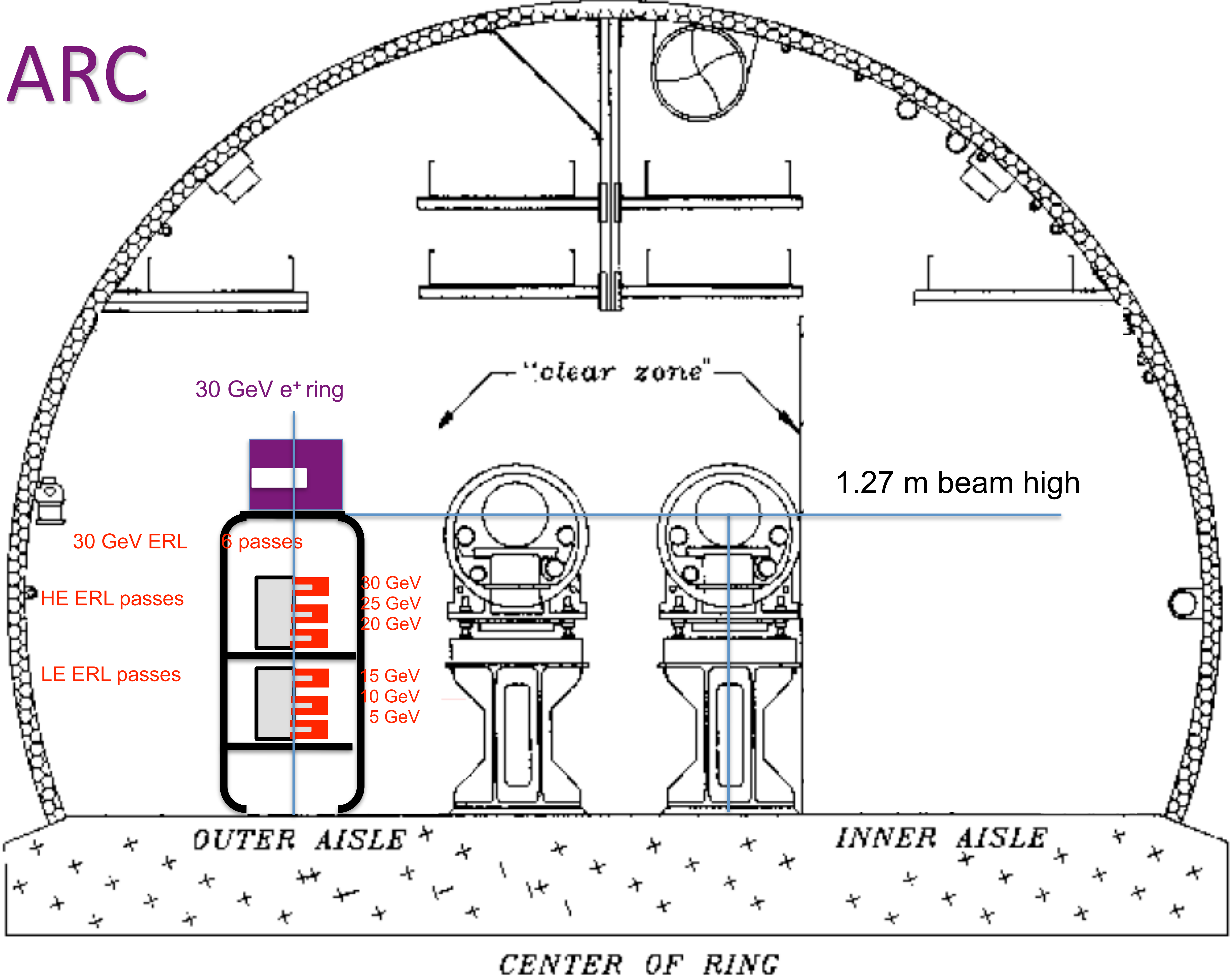
ARC


"clear zone"
30 GeV e+ ring
1.27 m beam high
30 GeV ERL
6 passes
HE ERL passes
30 GeV
25 GeV
20 GeV
LE ERL passes
15 GeV
10 GeV
5 GeV
OUTER AISLE
INNER AISLE
CENTER OF RING

Incorporating eSTAR and ePHENIX

- Without changing the DX-D0 focusing magnets, the luminosity in e+h collisions will be lower (x10)
- Parallel operations of both h+h and e+h collisions does now allow cooling of the beam and hence the luminosity will be lower (x10)
  - Running in sequential mode (alternate years) allows running at full luminosity, including coherent electron-cooling (CeC)
- CeC would provide for an increase in luminosity of x10 for e+h collisions and x6 for polarised p+p collisions
  - Two designs of the IR exist for both low luminosity (~ $3x10^{33}$) and high luminosity (~ $2x10^{34}$)
- By using a crossing angle (and crab cavities), one can have energy-independent geometries for the IRs and no synchrotron radiation in the detectors

STAR: A Correlation Machine

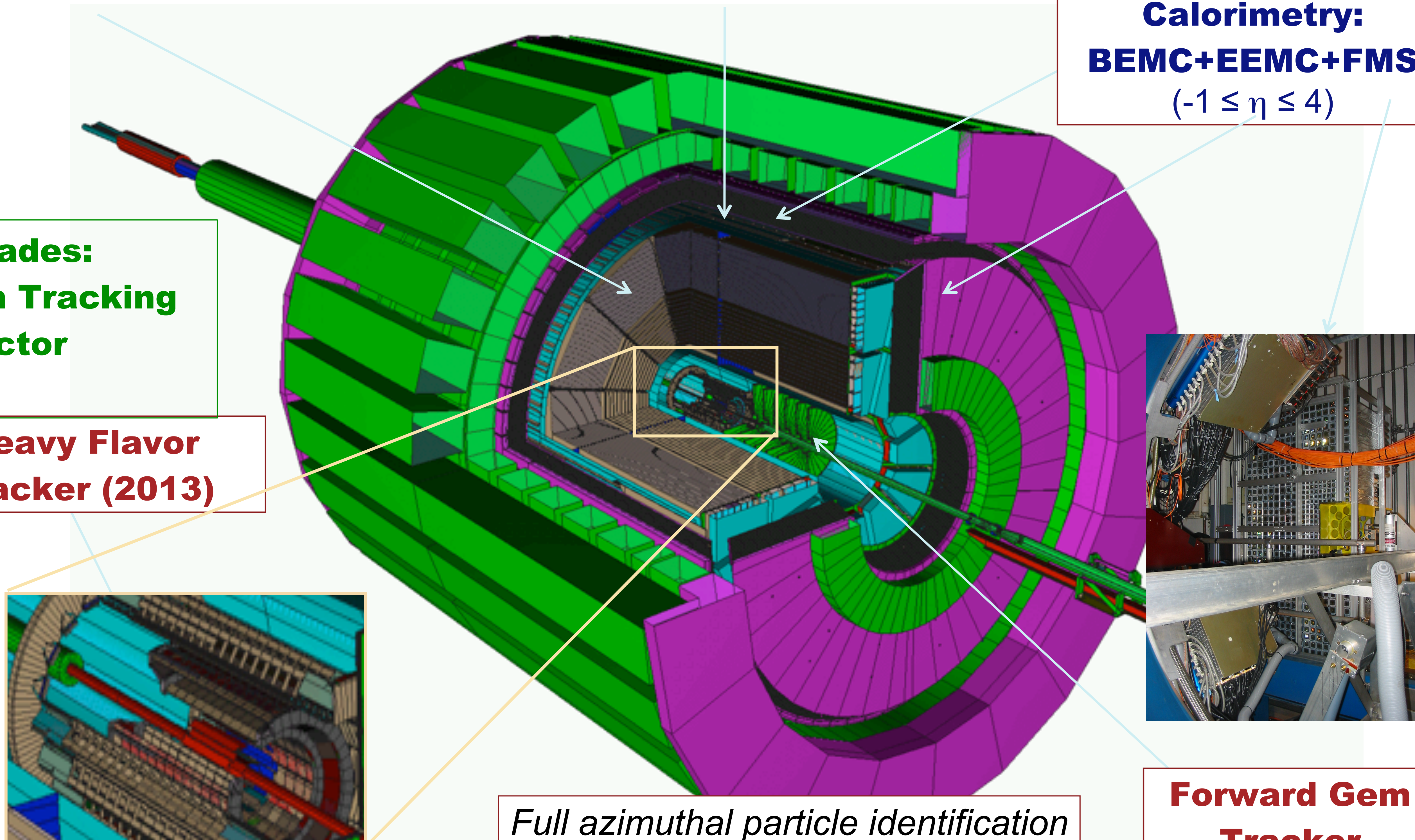
Tracking: TPC

Particle ID: TOF

Electromagnetic Calorimetry: BEMC+EEMC+FMS
($-1 \leq \eta \leq 4$)

Upgrades:
Muon Tracking Detector
HLT

Heavy Flavor Tracker (2013)

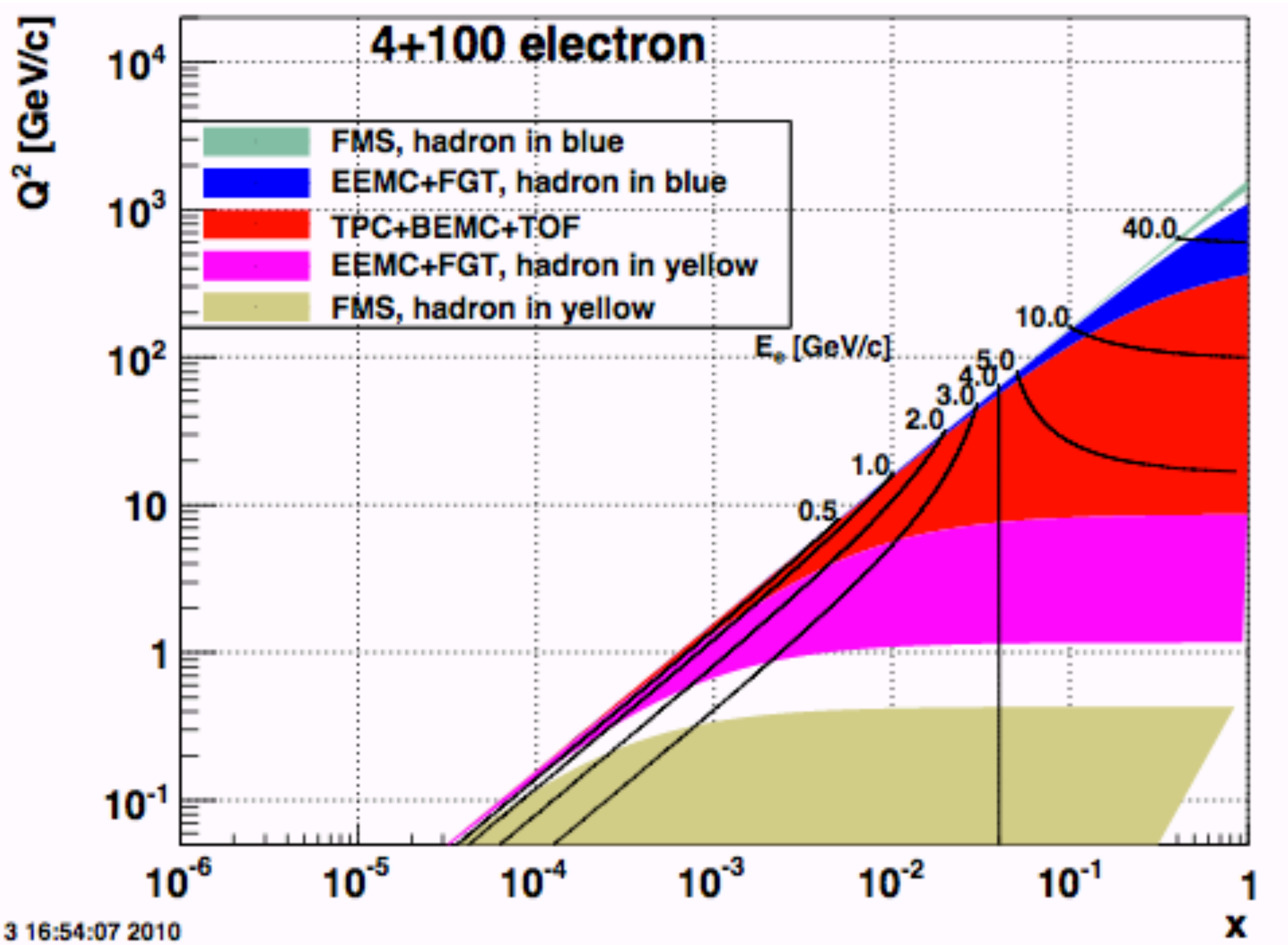


Forward Gem Tracker (2011)

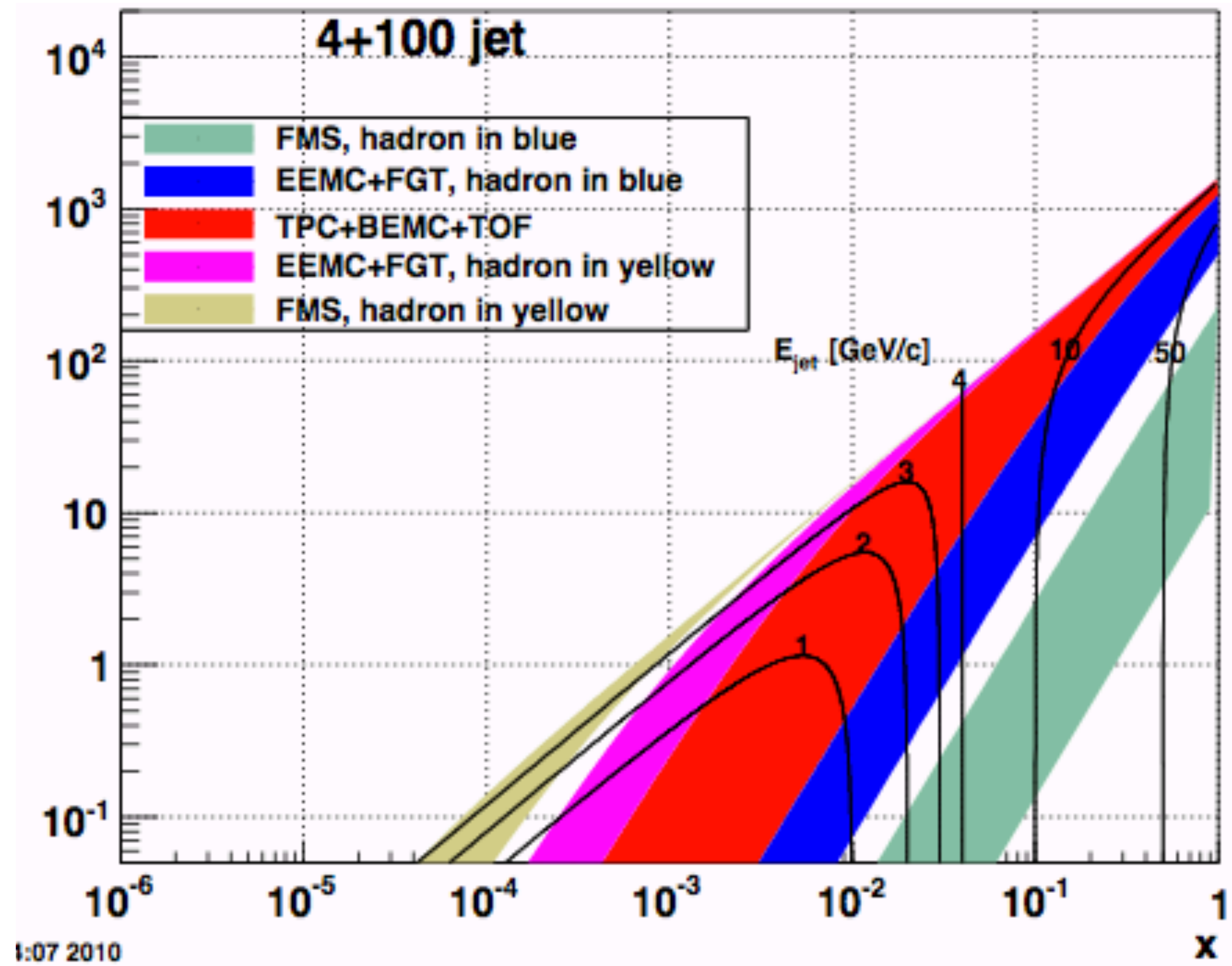
Full azimuthal particle identification over a broad range in pseudorapidity

Kinematics at 4+100

Scattered electron



Scattered jet



4+100 open kinematics: scatters the electron and jet to mid-rapidity
Forward region (FMS): Electron either Q^2 < 1 GeV, or very high x and Q^2
Jet either very soft or very hard
Note: current thinking has hadron in the blue beam: optimized for high x and Q^2

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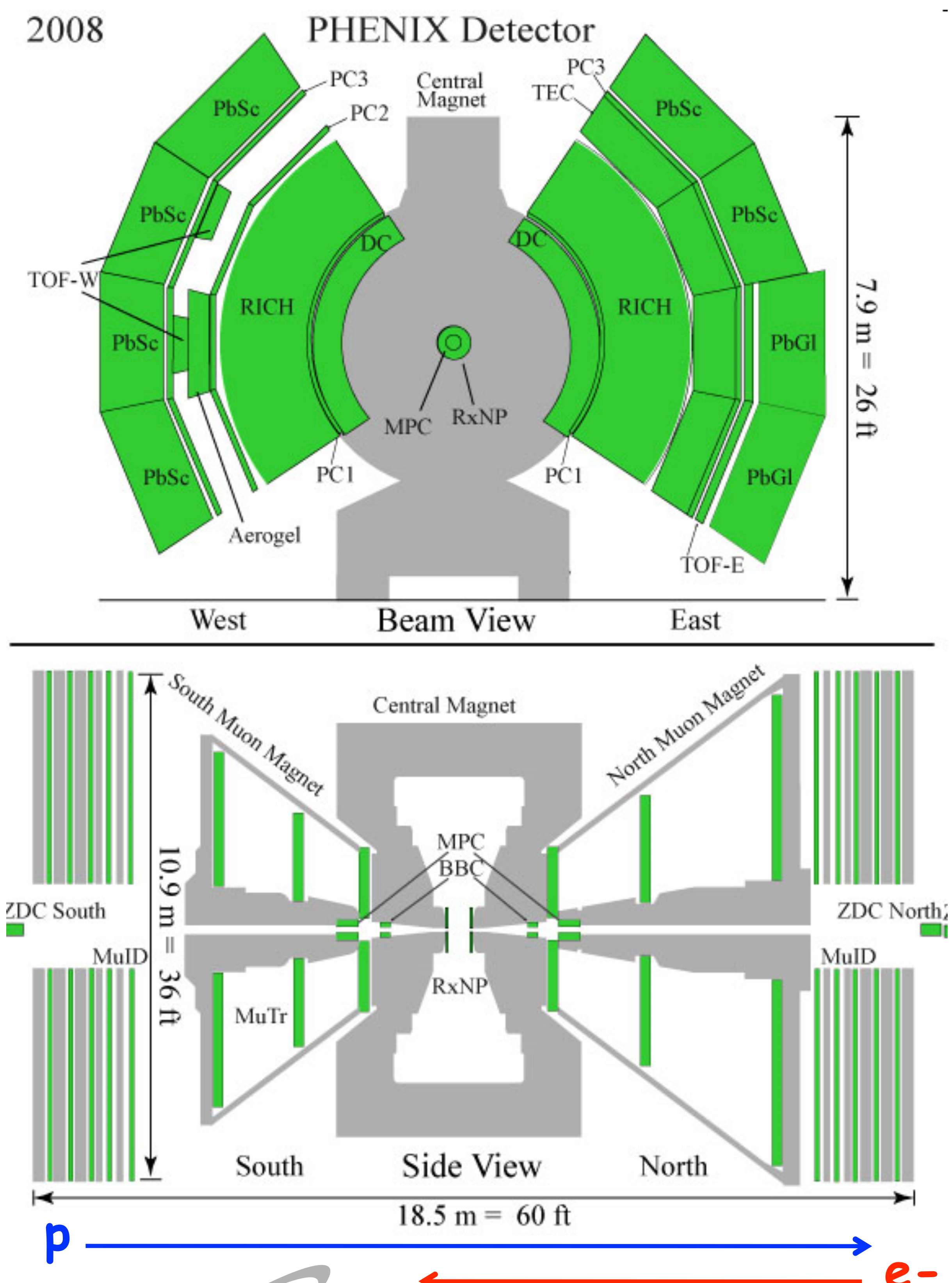
Current PHENIX setup



MPC	$3.1 < \|\eta\| < 3.9$
	$2.5^o < \Theta < 5.2^o$
Muon Arms	$1.2 < \|\eta\| < 2.4$
South:	$12^o < \Theta < 37^o$
North:	$10^o < \Theta < 37^o$
Central Arms	$\|\eta\| < 0.35$
	$60^o < \Theta < 110^o$

electrons will not make it
to the south muon arm
→ to much material

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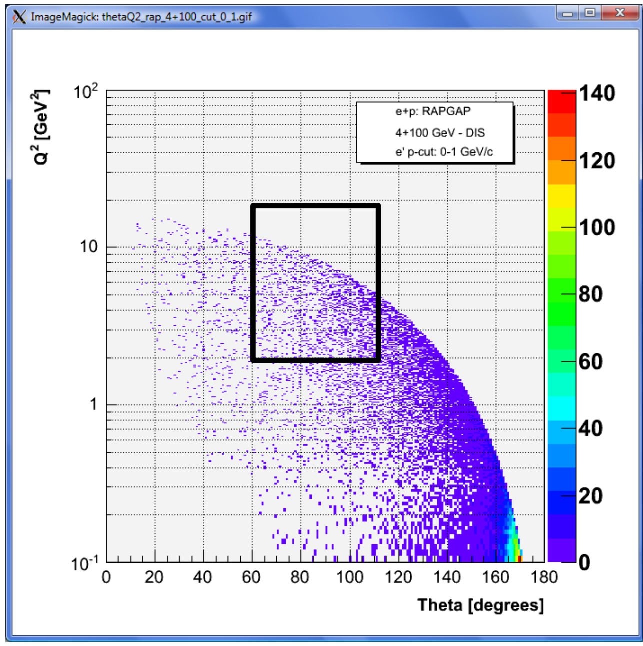
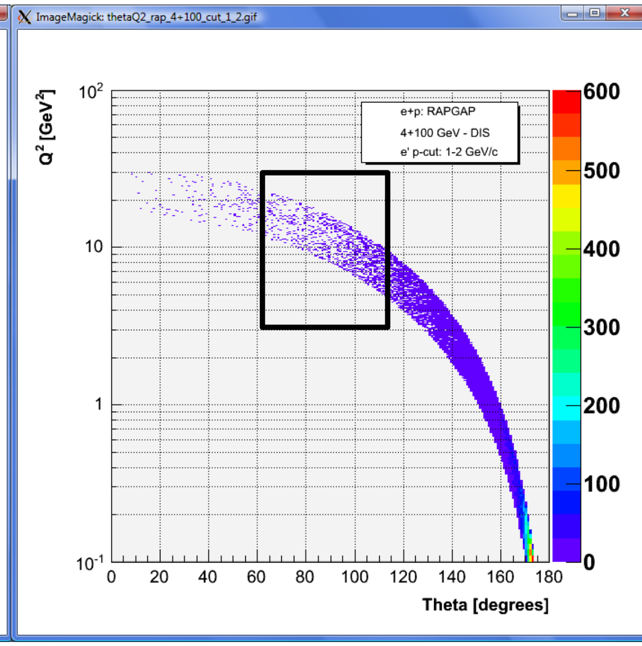
What will the current PHENIX see?

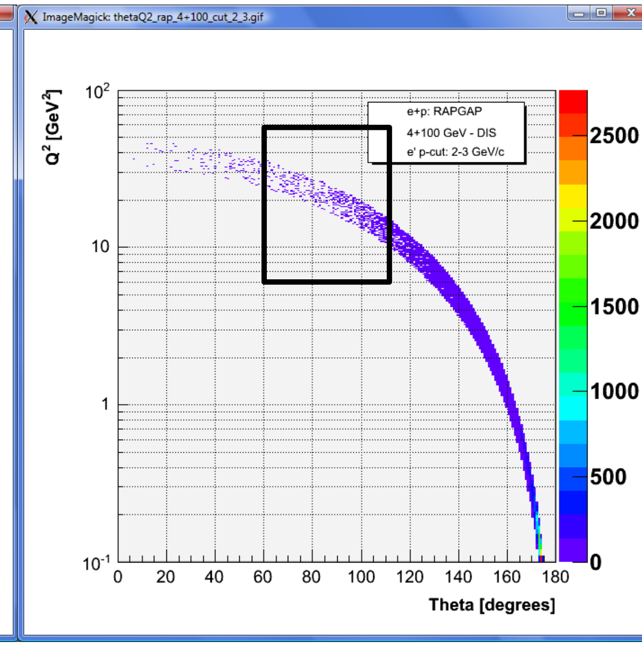
p_e: 0-1 GeV



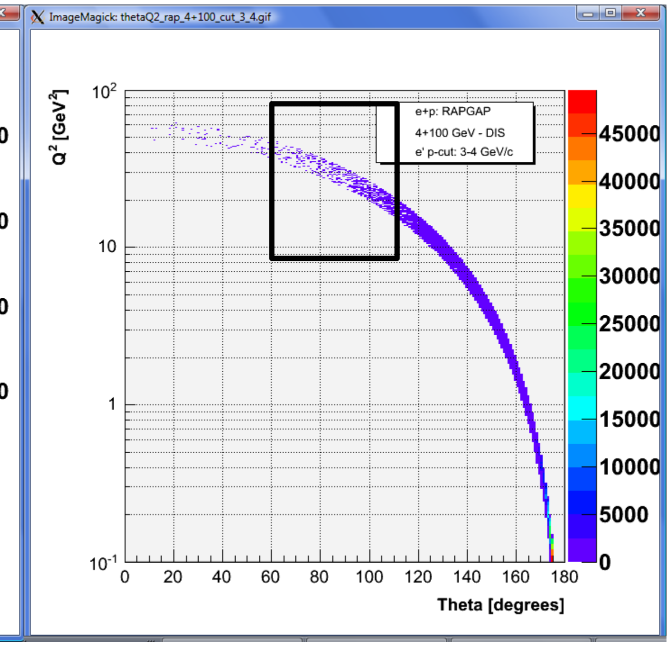
p_e: 1-2 GeV

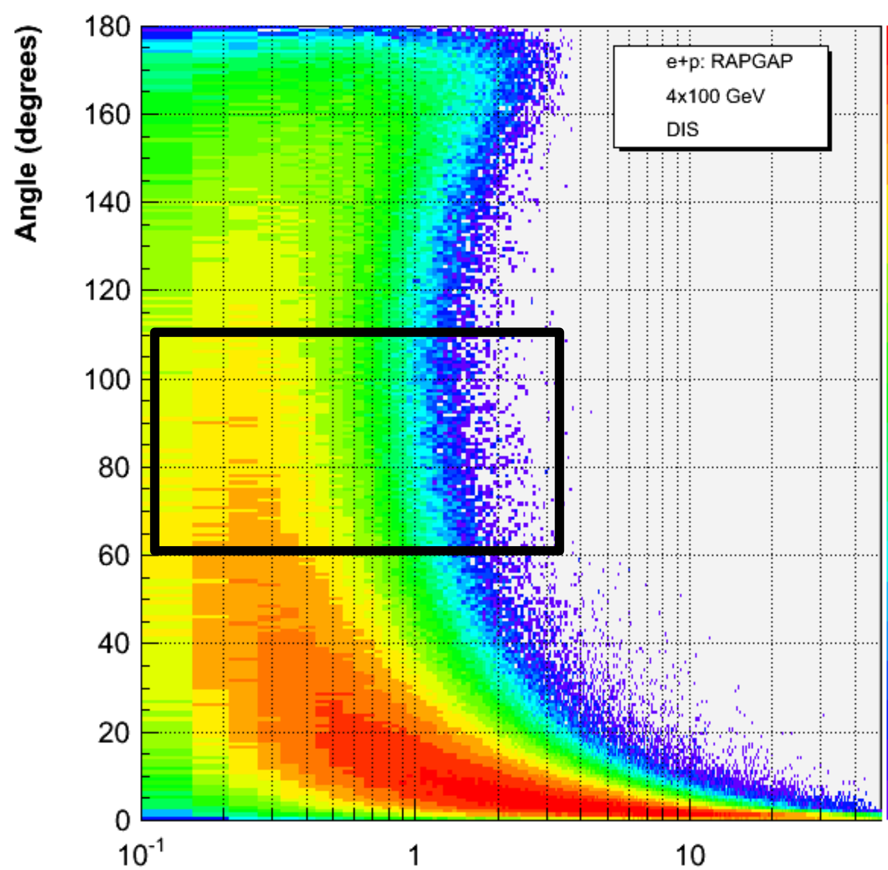


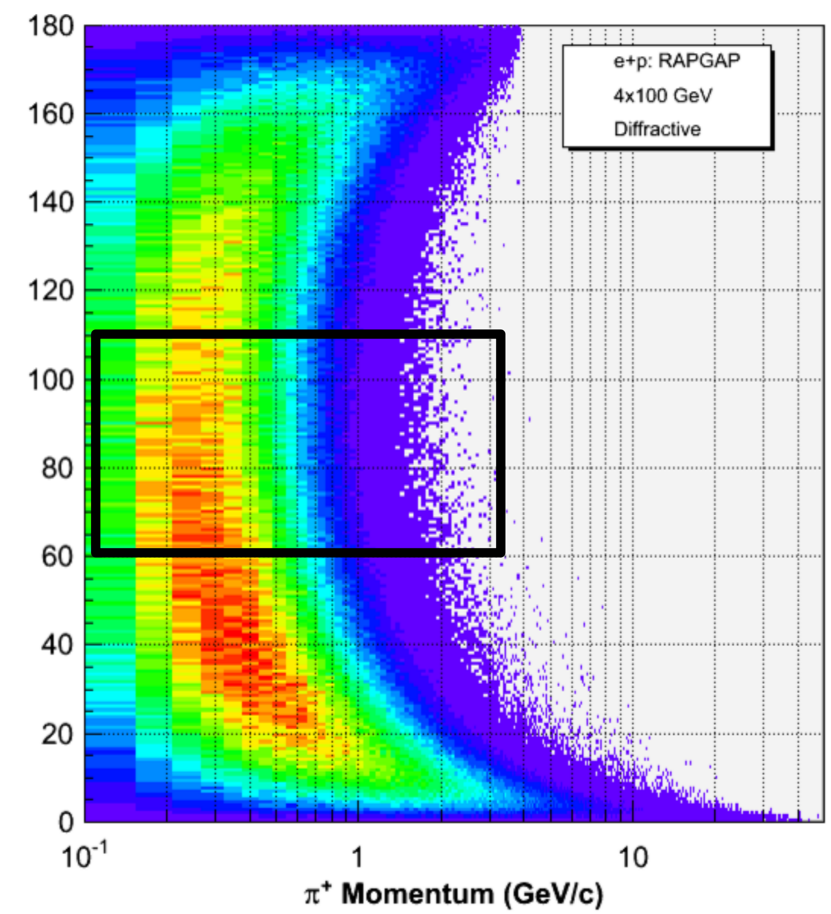
p_e: 2-3 GeV



p_e: 3-4 GeV







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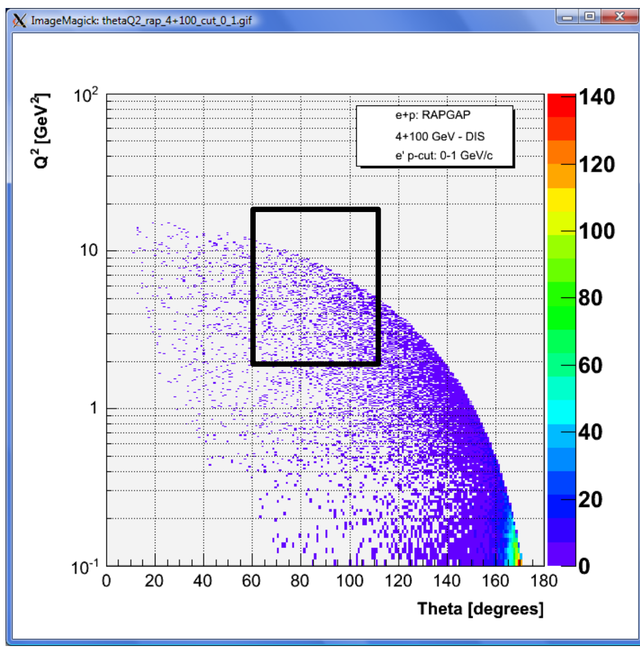
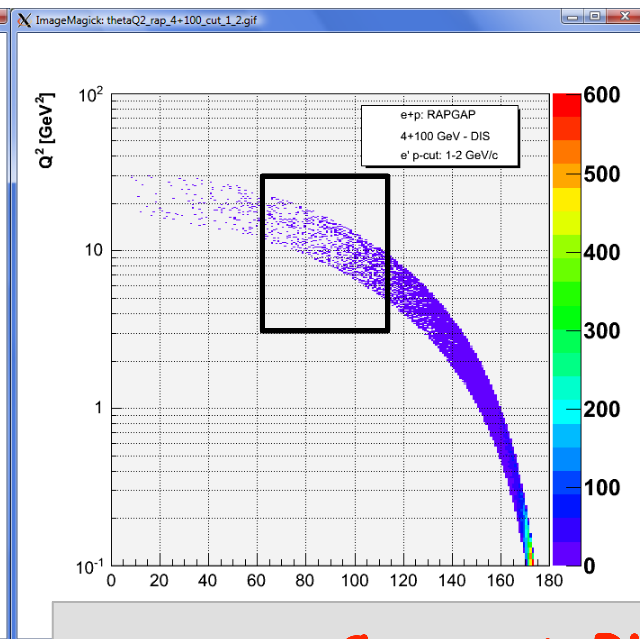
What will the current PHENIX see?

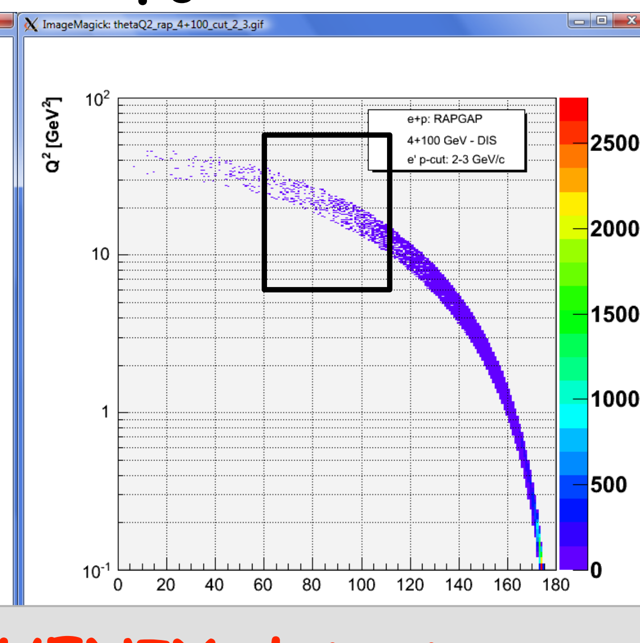
p_e: 0-1 GeV



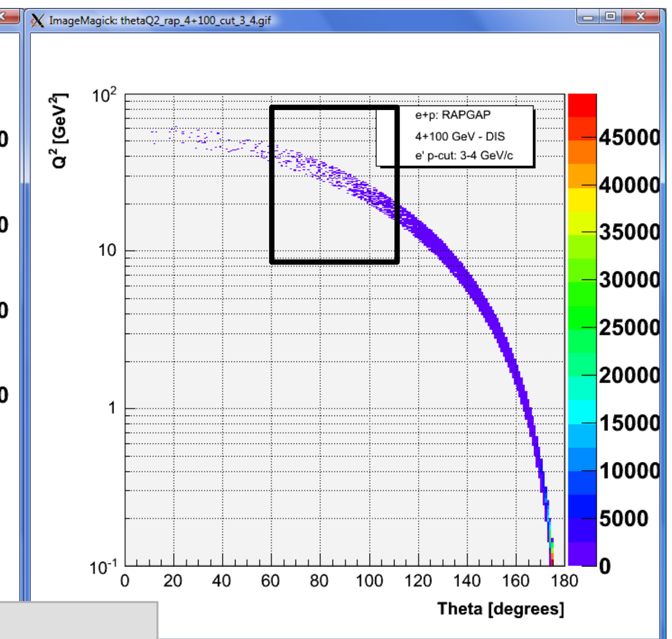
p_e: 1-2 GeV



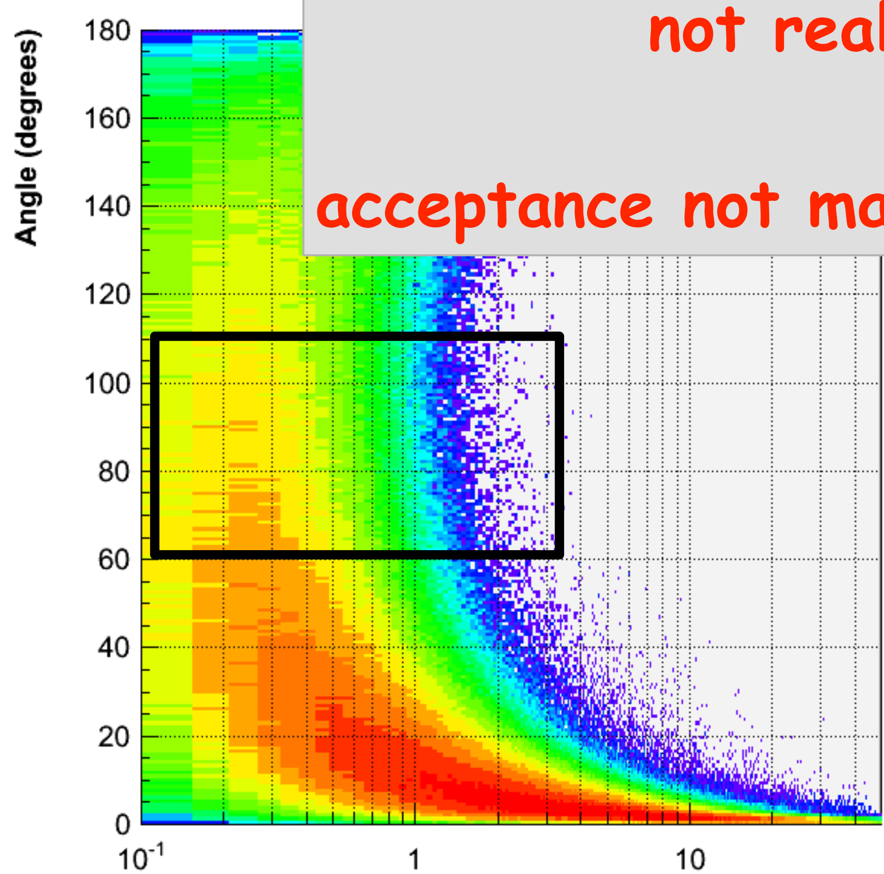
p_e: 2-3 GeV

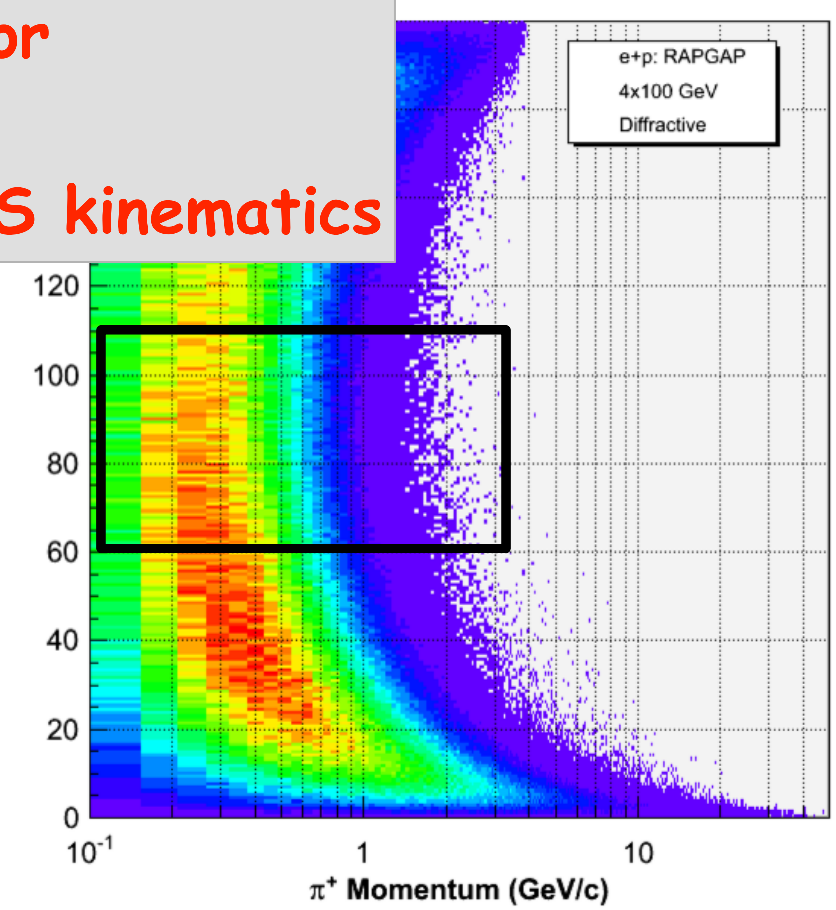


p_e: 3-4 GeV



Current PHENIX detector
not really useable for
DIS
acceptance not matched to DIS kinematics





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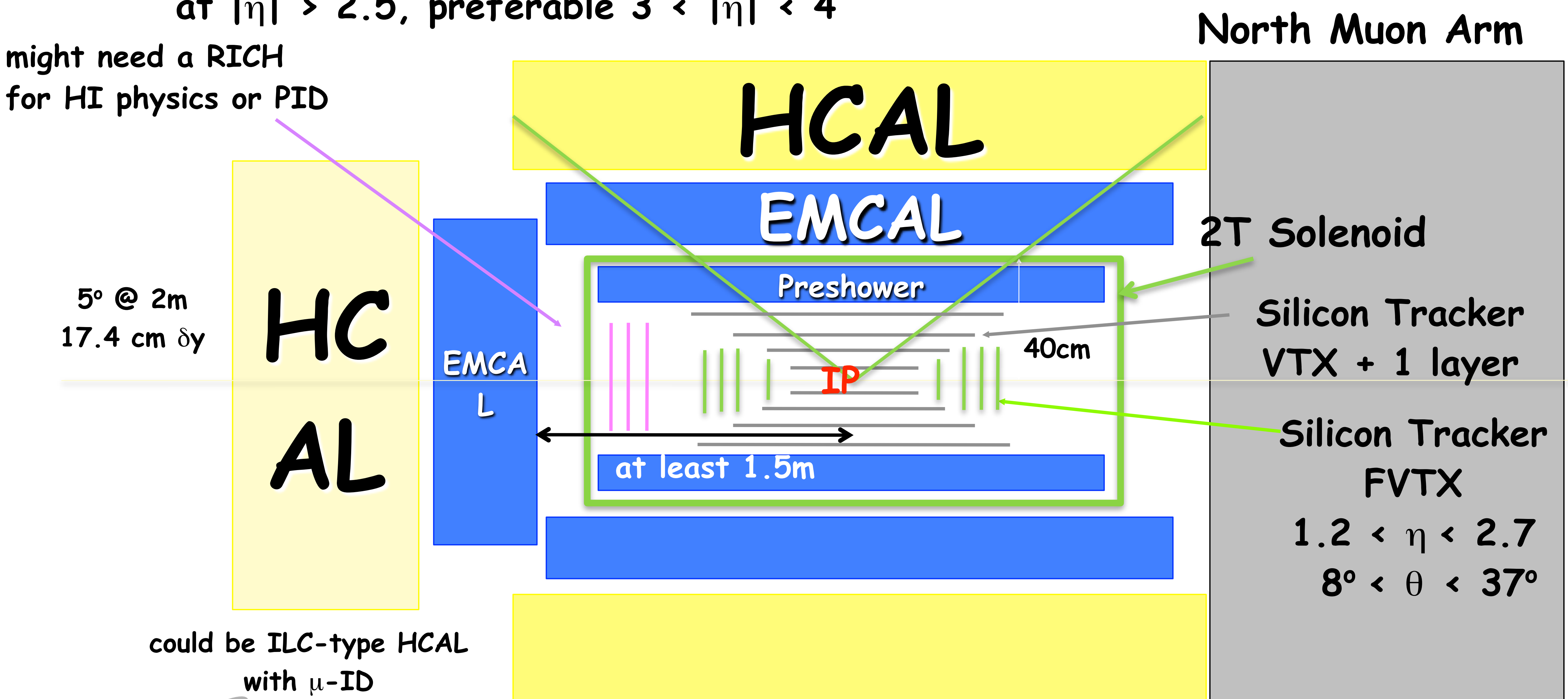
What could an ePHENIX look like?

- Coverage in $|\eta| =< 3 \rightarrow 0.1 < Q^2 < 100$ ($5^o - 175^o$)
  - need an open geometry detector
  - planes for next decadal plan
    - replace current central detector with a new one covering $|\eta| =< 1$
    - replace South muon arm by a endcap spectrometer able to do DY at $|\eta| > 2.5$, preferable $3 < |\eta| < 4$



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What could an ePHENIX look like?

- Coverage in $|\eta| =< 3 \rightarrow 0.1 < Q^2 < 100$ (5^o - 175^o)

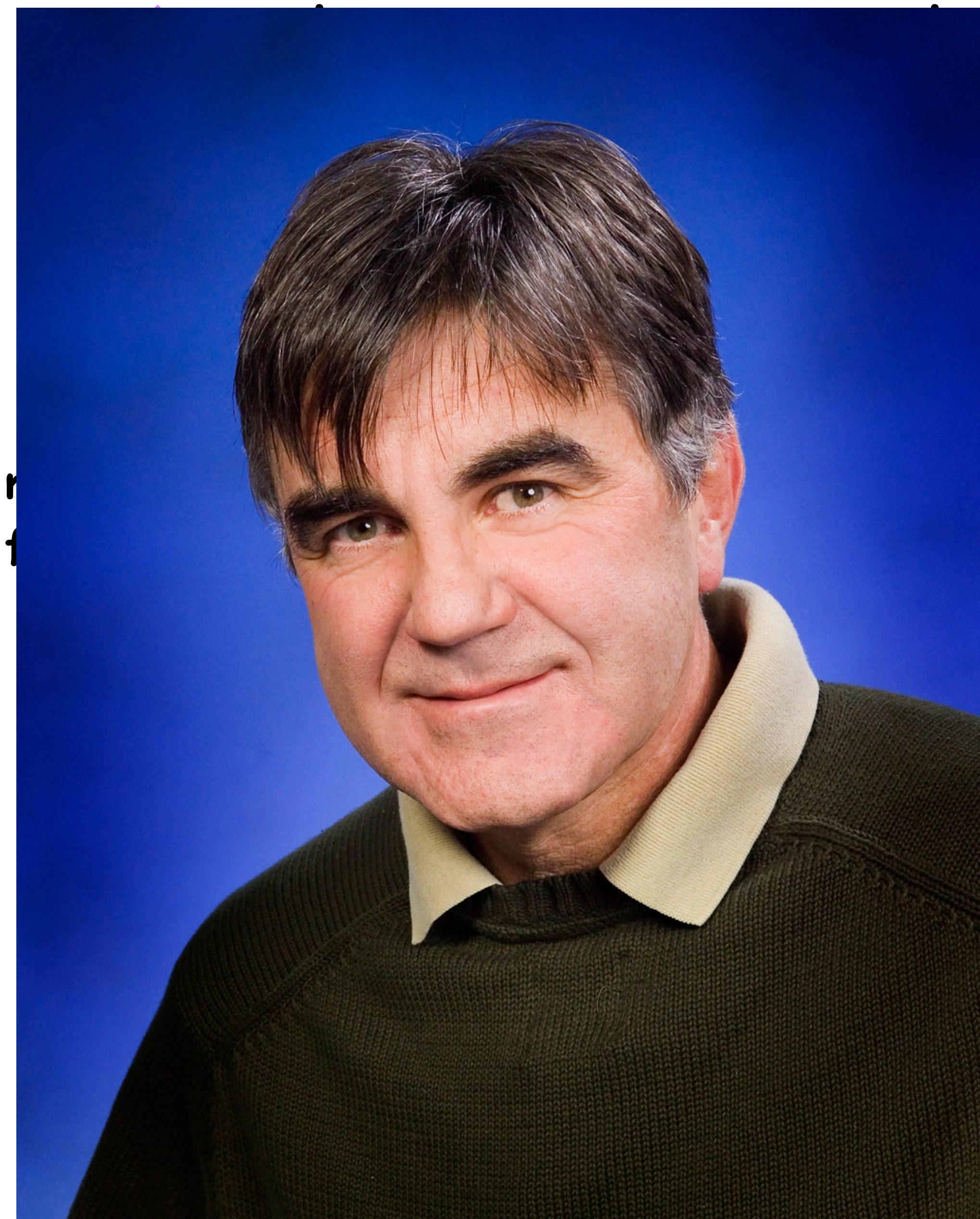
tector

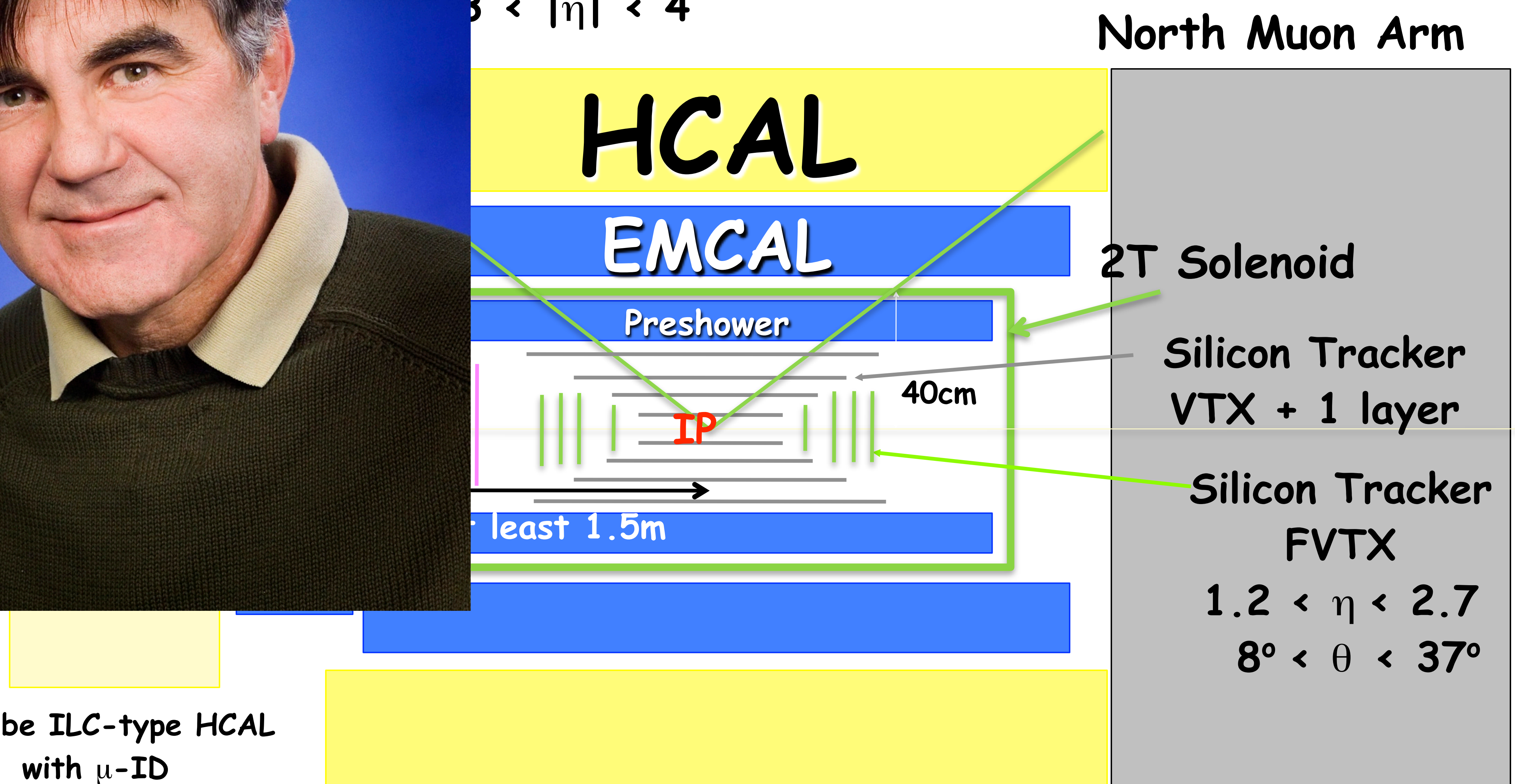
an

tector with a new one covering $|\eta| =< 1$

a endcap spectrometer able to do DY

3 < $|\eta|$ < 4





could be ILC-type HCAL with μ-ID

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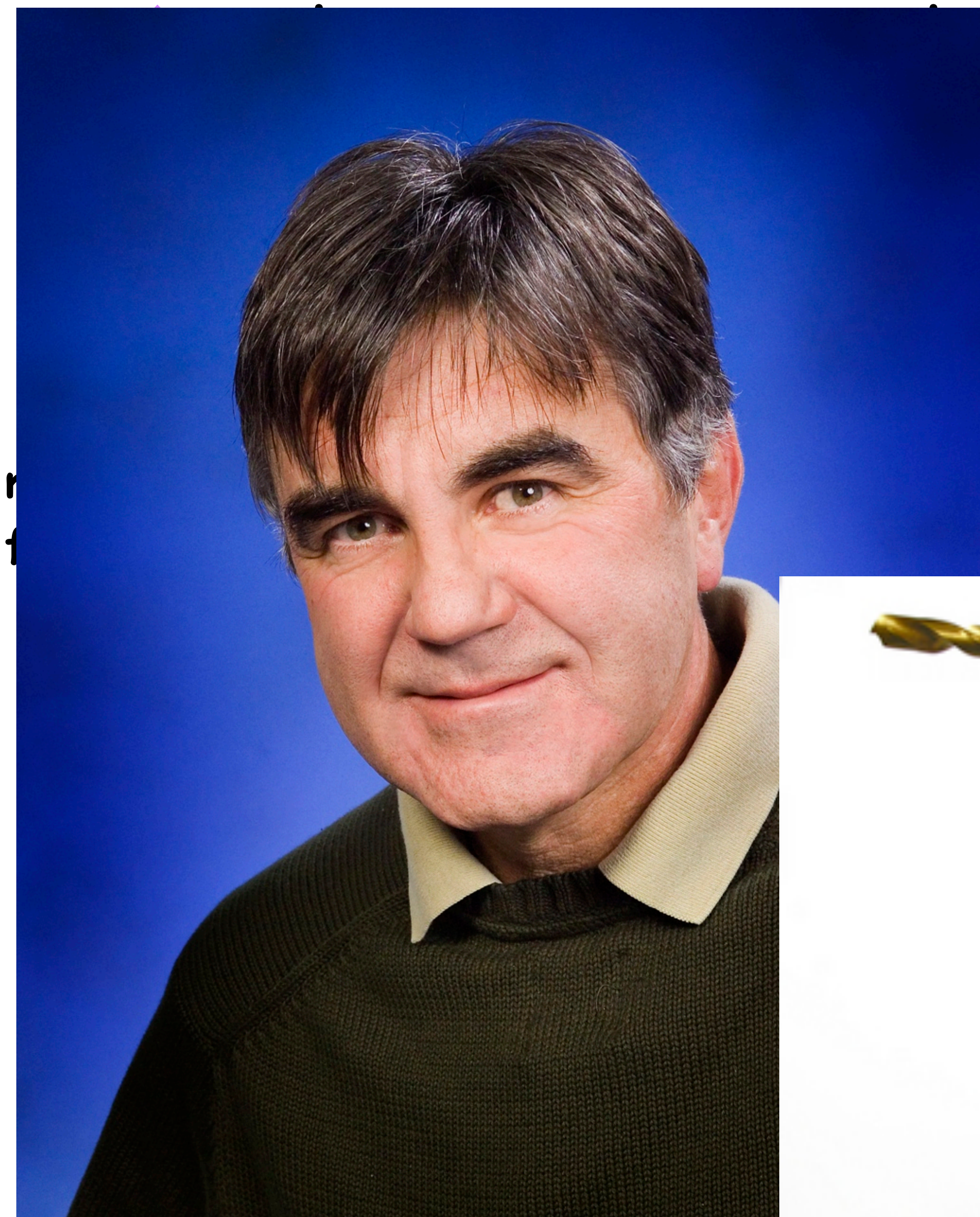
What could an ePHENIX look like?

- Coverage in $|\eta|$ =< 3 → $0.1 < Q^2 < 100$ ($5^o - 175^o$)
  - …tector
  - …an
  - …ector with a new one covering $|\eta|$ =< 1
  - … a endcap spectrometer able to do DY
  - …3 < $|\eta|$ < 4



North Muon Arm

HCAL

2T Solenoid

Silicon Tracker
VTX + 1 layer

Silicon Tracker
FVTX
$1.2 < \eta < 2.7$
$8^o < \theta < 37^o$

could be ILC-type HCAL
with μ-ID

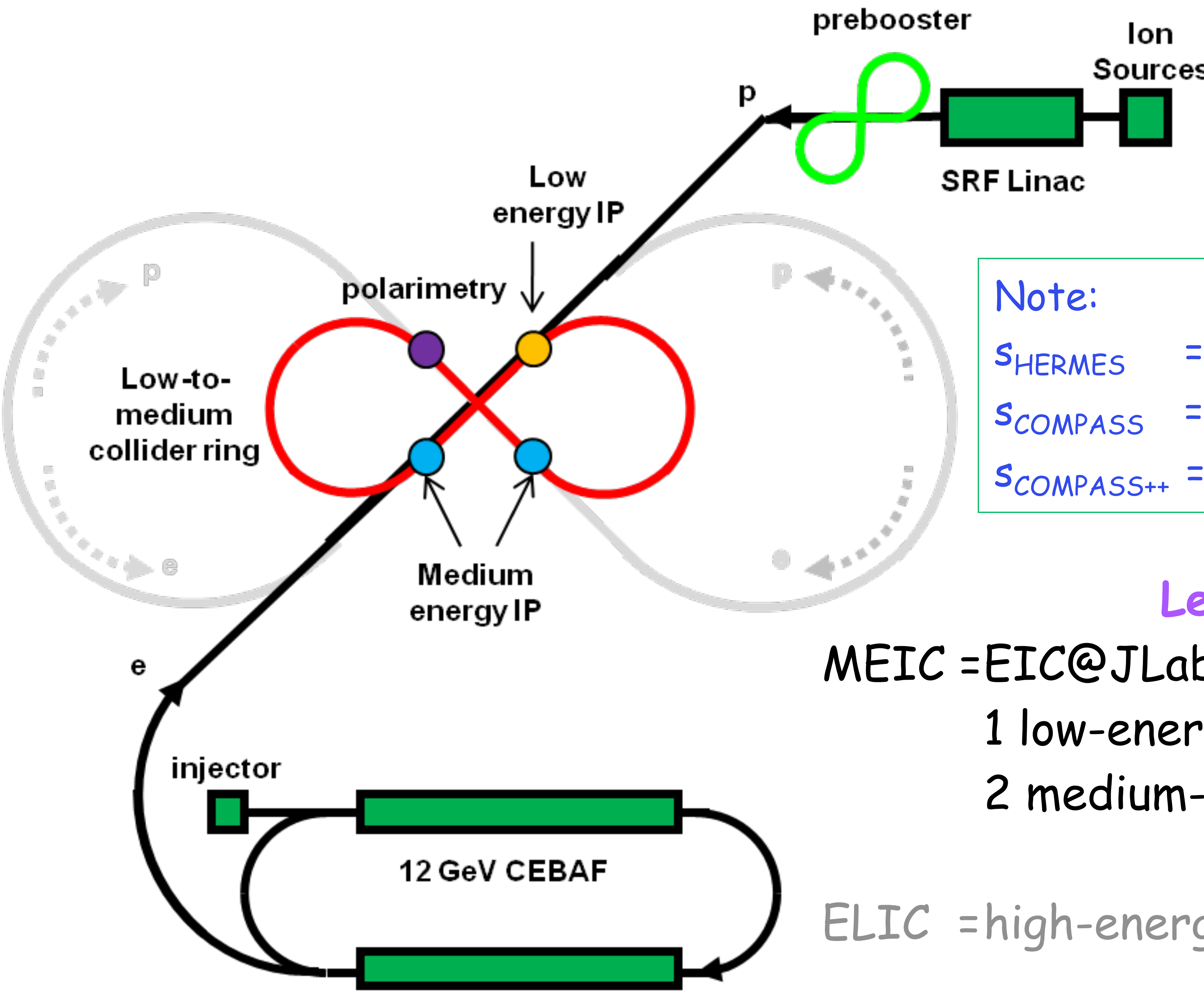
Summary and Outlook

- Lots of MC generators at BNL (anyone can use) for study of detector geometries
  - spin: gmc_trans, PEPSI; low-x: PYTHIA, RAPGAP; e+p, e+A: xDVMP
- Work underway in implementing detector designs in GEANT to study with the generated events
  - Need to implement the Roman-Pot design into the geometry
- Working closely with the C-AD department for the design of the interaction regions
- Looking at the possible use of eSTAR and ePHENIX concepts
  - eSTAR looks promising and the STAR geometry is in the same format as what we are using for our other studies
  - a possible ePHENIX is not really viable with the current setup
    - thoughts of a future, upgraded PHENIX are being put forward to deal with jet physics in heavy-ion collisions
      - would be much better in the era of ePHENIX but still some problems persist

BACKUP SLIDES

MEIC

A High-Luminosity EIC at JLab - Concept



Note:

s_{HERMES} = 51 unpol. L = 10^{32+}

$s_{COMPASS}$ = 340 unpol. L = 10^{32}

$s_{COMPASS++}$ = 340 L = 10^{32+}

Legend:

MEIC =EIC@JLab

1 low-energy IR (s ~ 200)

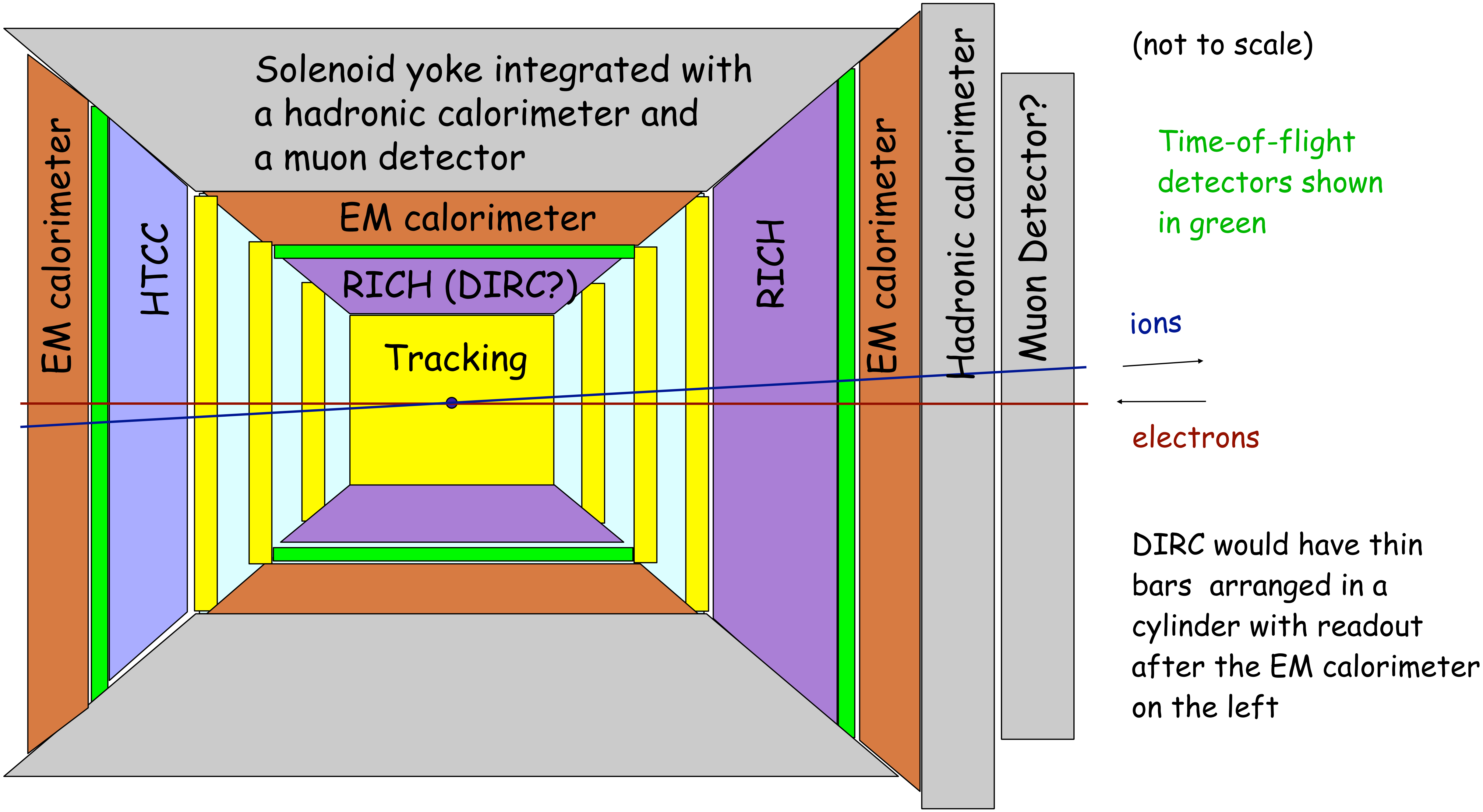
2 medium-energy IRs (s < 2600)

ELIC =high-energy EIC@JLab (s = 11000)

(E_p ~ 250 limited by JLab site)

Use CEBAF "as-is" after 12-GeV Upgrade

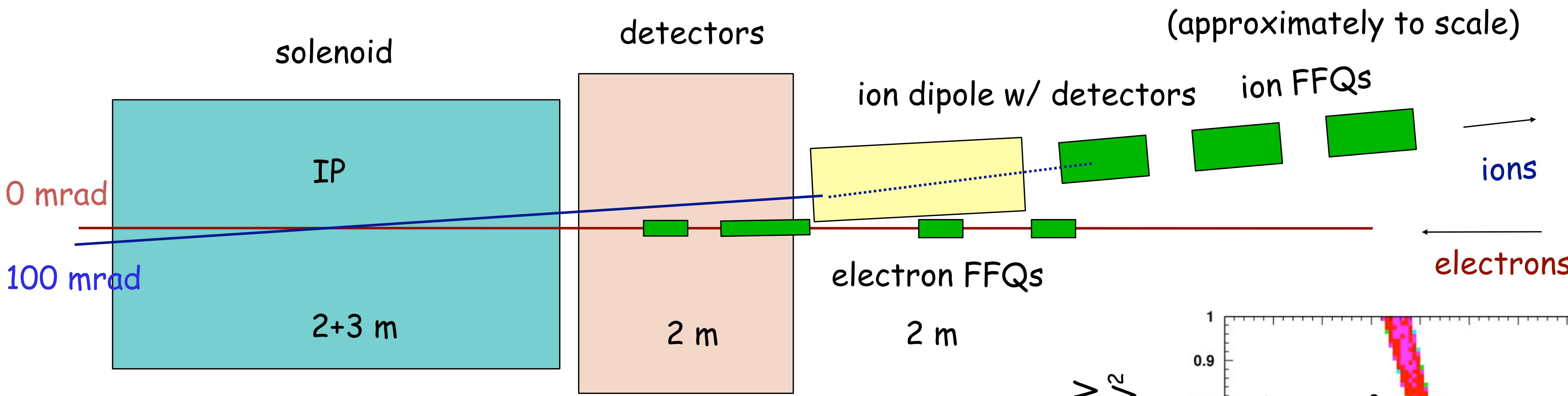
Overview of central detector layout



- IP is shown at the center, but can be shifted left
  - Determined by desired bore angle and forward tracking resolution
  - Flexibility of shifting IP also helps accelerator design at lower energies (gap/path length difference induced by change in crossing angle)

Detector/IR cartoon

Make use of a 100 mr crossing angle for ions!



- Downstream dipole on ion beam line has several advantages
  - No synchrotron radiation
  - Electron quads can be placed close to IP
  - Dipole field not determined by electron energy
  - Positive particles are bent away from the electron beam
  - Long recoil baryon flight path gives access to low -t
  - Dipole does not interfere with RICH and forward calorimeters
    - Excellent acceptance (hermeticity)