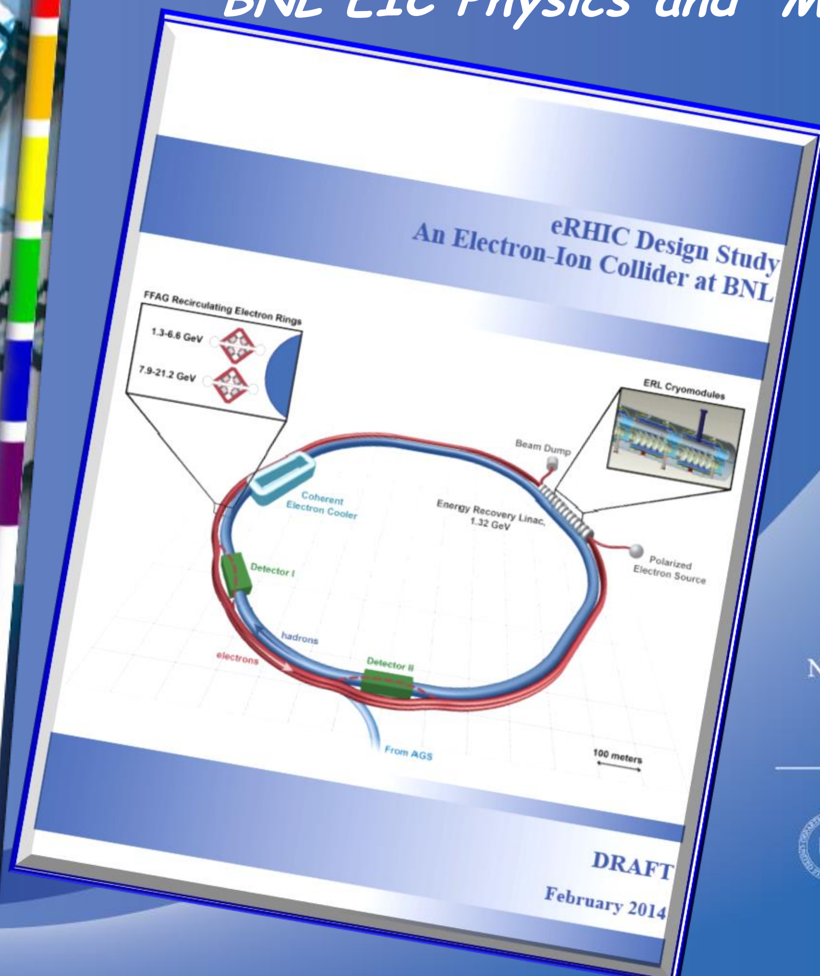
The eRHIC Detectors, IR, Polarimetry- and Luminosity Measurements

E.C. Aschenauer
for the
BNL EIC Physics and Machine Taskforces

arXiv: 1212.1701 & 1108.1713



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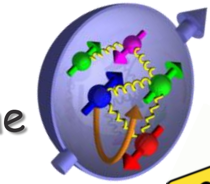
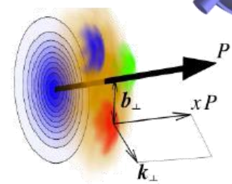
MOST COMPELLING SCIENCE QUESTIONS

How are sea quarks and gluons and their spin distributed in space and momentum inside the nucleon?

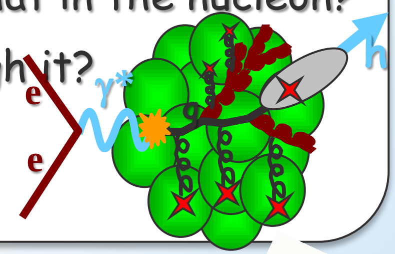


- How are these quark and gluon distributions correlated with the over all nucleon properties, such as spin direction?
- What is the role of the motion of sea quarks and gluons in building the nucleon spin?

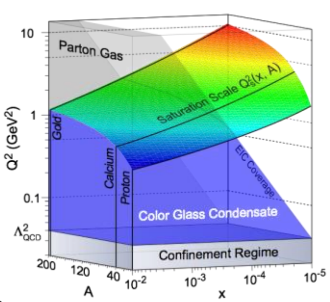


How does the nuclear environment affect the distribution of quarks and gluons and their interaction in nuclei?

- How does the transverse spatial distribution of gluons compare to that in the nucleon?
- How does matter respond to fast moving color charge passing through it? Is this response different for light and heavy quarks?



Where does the saturation of gluon densities set in?



- Is there a simple boundary that separates the region from more dilute quark gluon matter? If so how do the distributions of quarks and gluons change as one crosses the boundary?
- Does this saturation produce matter of universal properties in the nucleon and all nuclei viewed at nearly the speed of light?

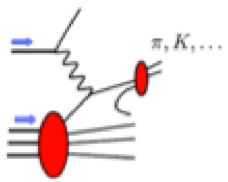
REQUIREMENTS TO REALIZE THE PROGRAM

Requirements from Physics:

- High Luminosity ~ 10^{33} $cm^{-2}s^{-1}$ and higher
- Flexible center of mass energy
- Electrons and protons/light nuclei (p, He^3 or D) highly polarised
- Wide range of nuclear beams (D to U)
- a wide acceptance detector with good PID (e/h and π, K, p)
- wide acceptance for protons from elastic reactions and neutrons from nuclear breakup

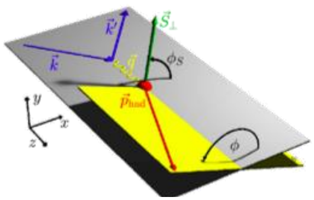
WHAT IS NEEDED TO REALIZE EIC PROGRAM

experimental program to address these questions:



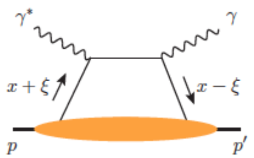
inclusive and semi-inclusive DIS

longitudinal motion of spinning quarks and gluons



azimuthal asymmetries in DIS

adds their transverse momentum dependence



exclusive processes

adds their transverse position

machine & detector requirements

prerequisites

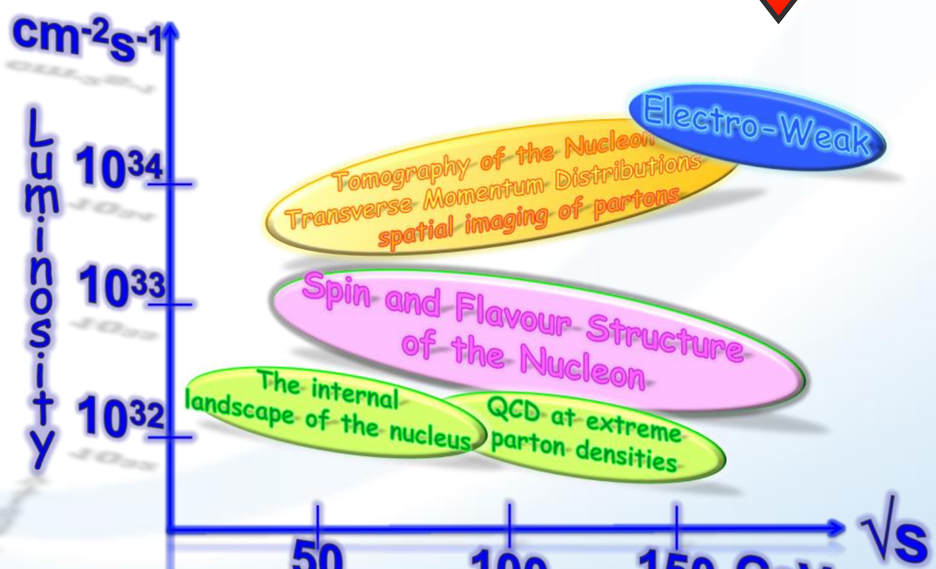
all need $\sqrt{s_{ep}} > 50$ GeV

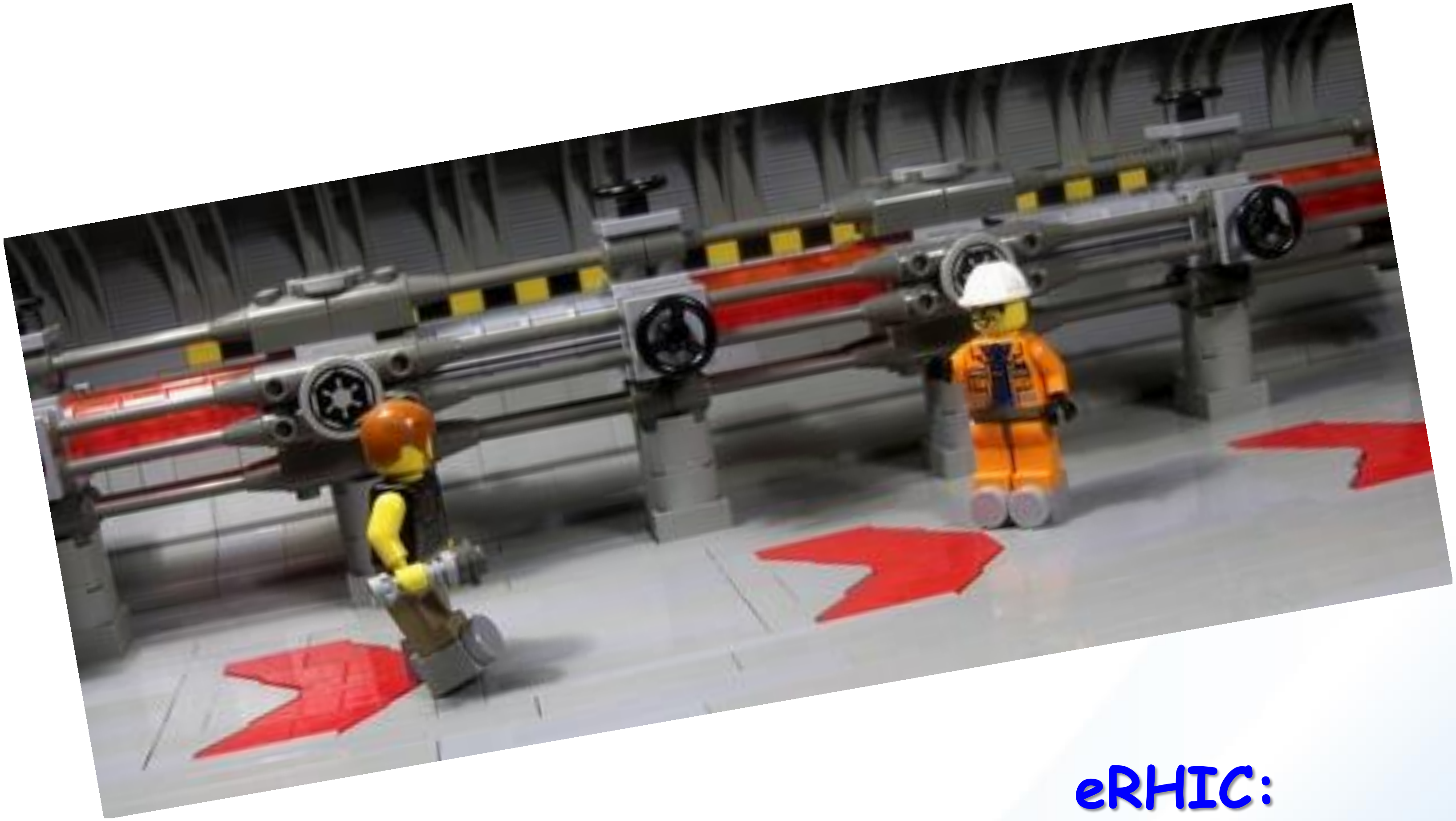
to access $x < 10^{-3}$ where sea quarks and gluons dominate

$\mathcal{L} \simeq 10\,\mathrm{fb}^{-1}$

$\mathcal{L} = 10 \div 100\,\mathrm{fb}^{-1}$

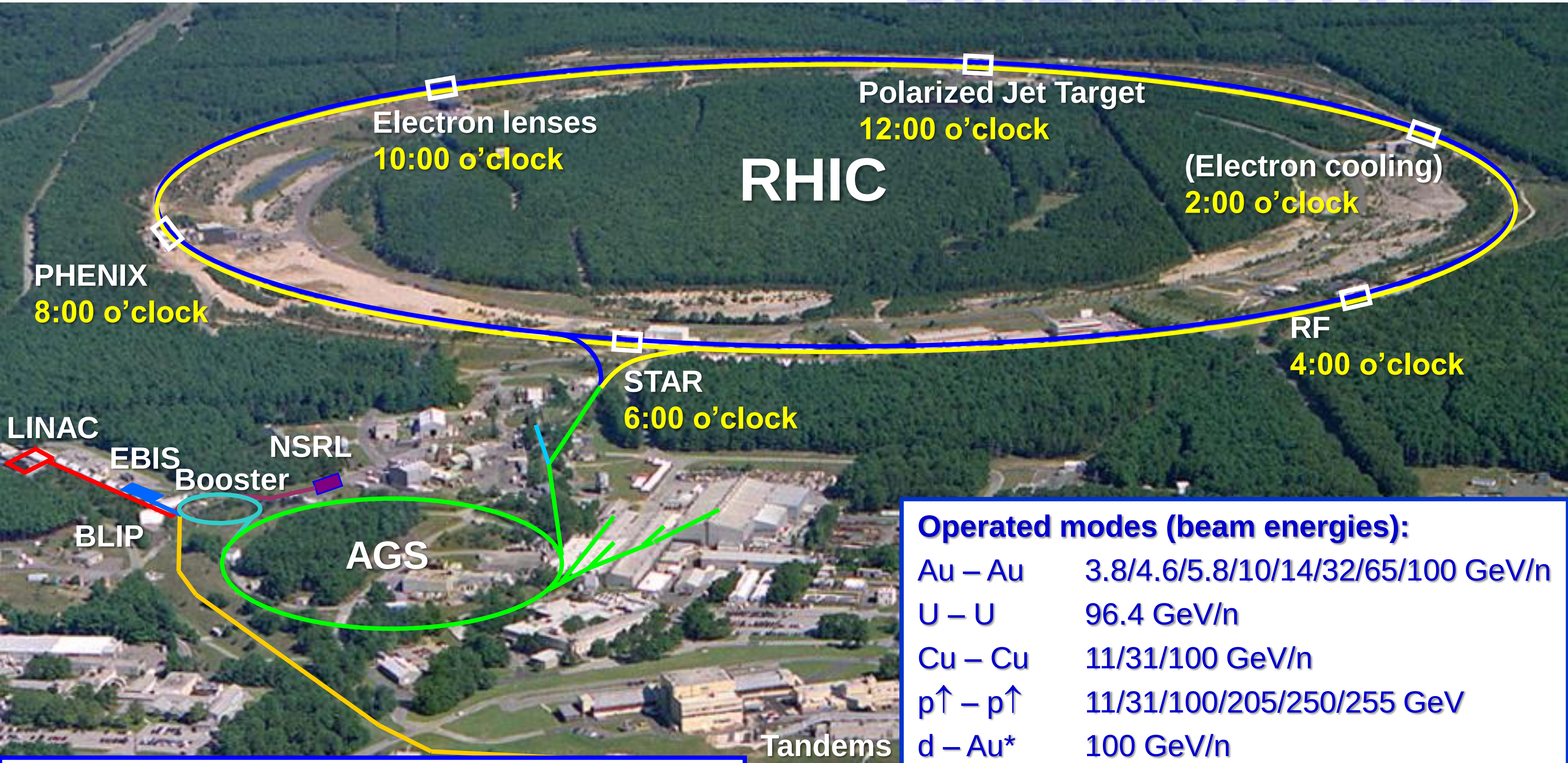
- multi-dimensional binning
- to reach $k_T > 1$ GeV
- to reach $|t| > 1$ GeV^2





eRHIC:
A very novel machine design

RHIC – A HIGH LUMINOSITY (POLARIZED) HADRON COLLIDER



Achieved peak luminosities:

Au – Au (100 GeV/n)	195×10^{30} cm^{-2} s^{-1}
p↑ – p↑ (255 GeV)	245×10^{30} cm^{-2} s^{-1}

Other large hadron colliders (scaled to 255 GeV):

Tevatron (p – pbar)	110×10^{30} cm^{-2} s^{-1}
LHC (p – p)	493×10^{30} cm^{-2} s^{-1}

Operated modes (beam energies):

Au – Au	3.8/4.6/5.8/10/14/32/65/100 GeV/n
U – U	96.4 GeV/n
Cu – Cu	11/31/100 GeV/n
p↑ – p↑	11/31/100/205/250/255 GeV
d – Au*	100 GeV/n
Cu – Au*	100 GeV/n

Planned or possible future modes:

Au – Au	2.5 GeV/n
p↑ – A*	100 GeV/n (A = Au, Cu, Al)
^{3}He – A*	100 GeV/n (A = Au, Cu, Al)
p↑ – ^{3}He↑*	166 GeV/n

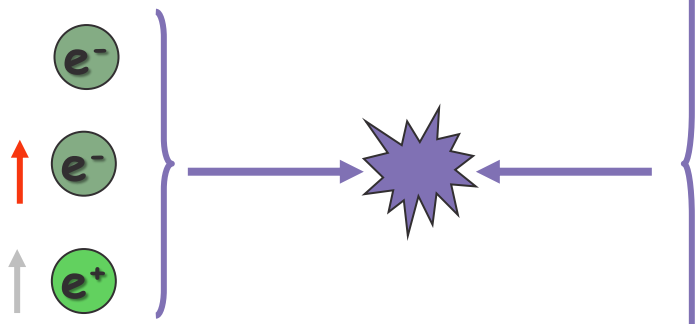
(*asymmetric rigidity)

WHAT IS eRHIC

Add an electron accelerator to the existing \$2.5B RHIC including existing RHIC tunnel and cryo facility

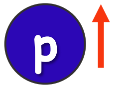
Electron accelerator

Unpolarized and polarized leptons 5-20 (30) GeV

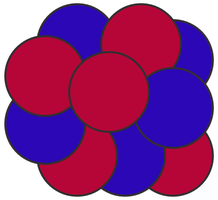


70% e^- beam polarization goal
polarized positrons?

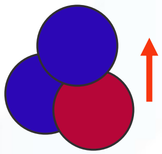
RHIC



70% Polarized protons
50-250 GeV

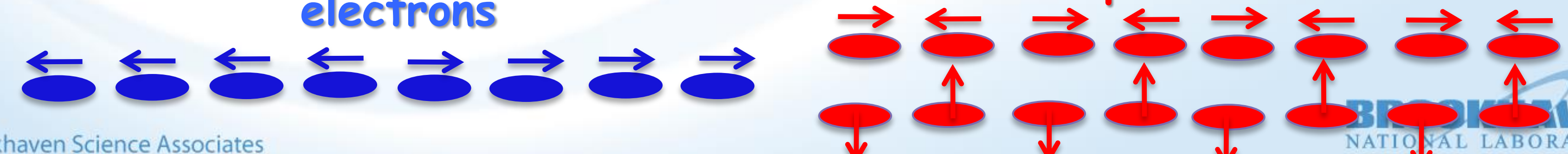


Light ions (d,Si,Cu)
Heavy ions (Au,U)
50-100 GeV/u



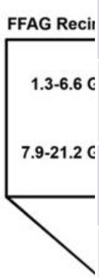
Polarized light ions
He^3 166 GeV/u

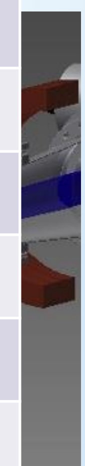
Center mass energy range: $\sqrt{s}$=30-200 GeV; L~100-1000xHera
any polarization direction in electron-hadron collisions

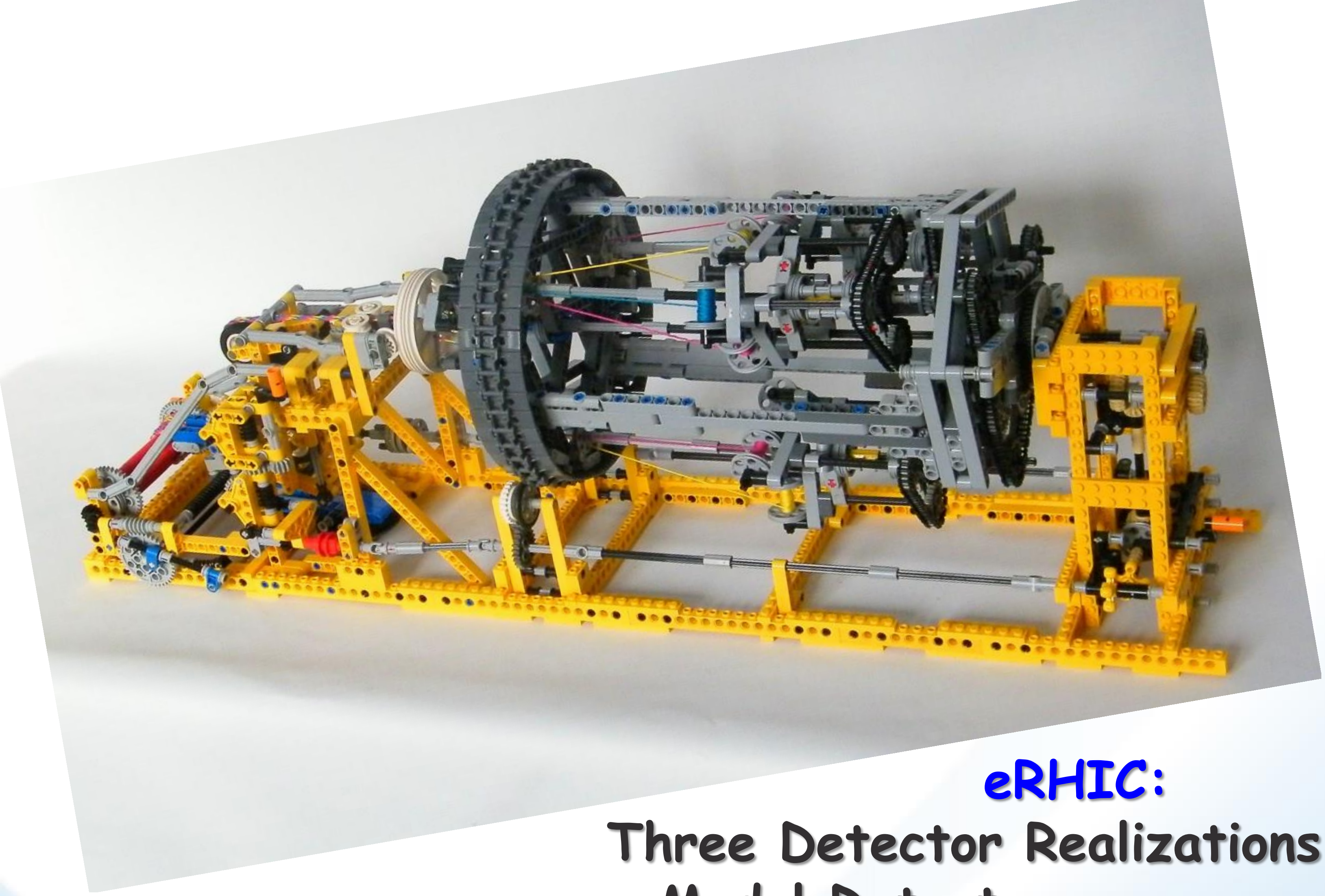


eRHIC DESIGN

	e	p	$^{3}He^{2+}$	$^{197}Au^{79+}$
Energy, GeV	15.9	250	167	100
CM energy, GeV		122.5	81.7	63.2
Bunch frequency, MHz	9.4	9.4	9.4	9.4
Bunch intensity (nucleons), 10^{11}	0.33	0.3	0.6	0.6
Bunch charge, nC	5.3	4.8	6.4	3.9
Beam current, mA	50	42	55	33
Hadron rms norm. emittance, μm		0.27	0.20	0.20
Electron rms norm. emittance, μm		31.6	34.7	57.9
Beta*, cm (both planes)	5	5	5	5
Hadron beam-beam parameter		0.015	0.014	0.008
Electron beam disruption		2.8	5.2	1.9
Space charge parameter		0.006	0.016	0.016
rms bunch length, cm	0.4	5	5	5
Polarization, %	80	70	70	none
Peak luminosity, 10^{33} $cm^{-2}s^{-1}$		1.5	2.8	1.7



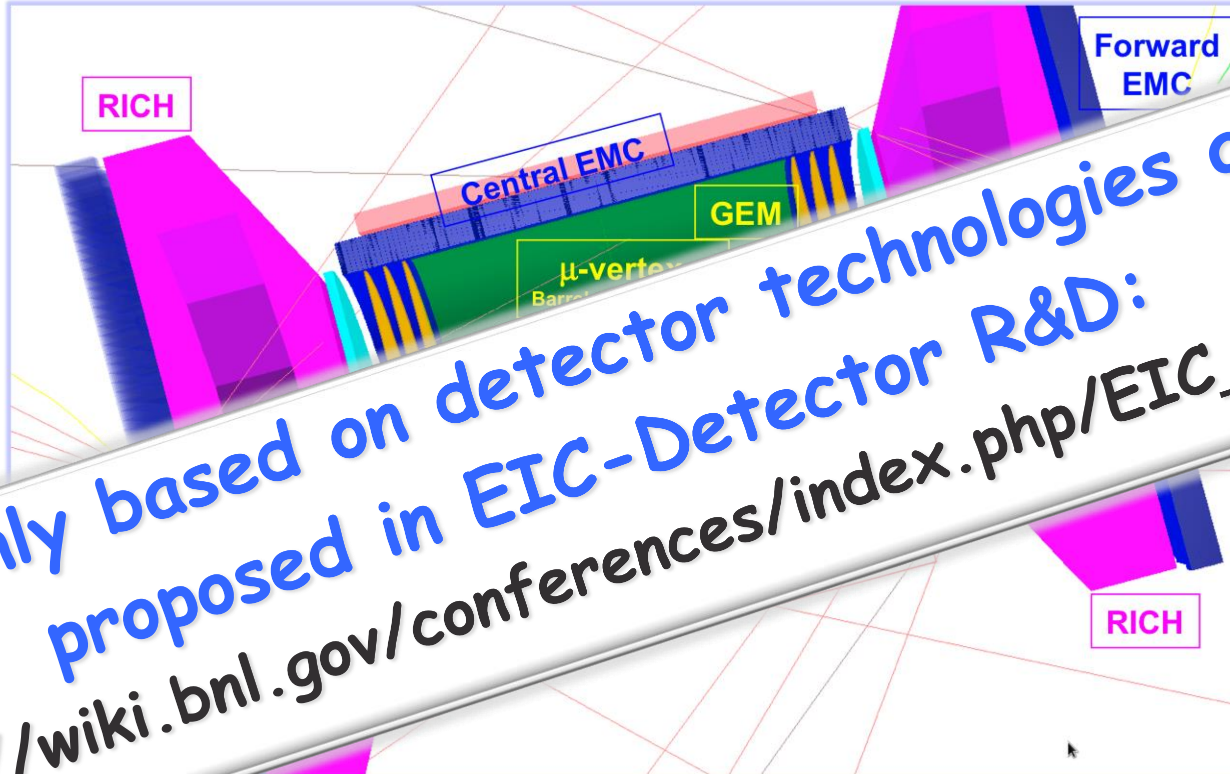




eRHIC:

Three Detector Realizations Studied
a Model Detector
ePHENIX
eSTAR

THE MODEL DETECTOR



Upstream low Q^2 tagger and

Mainly based on detector technologies as proposed in EIC-Detector R&D:
https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

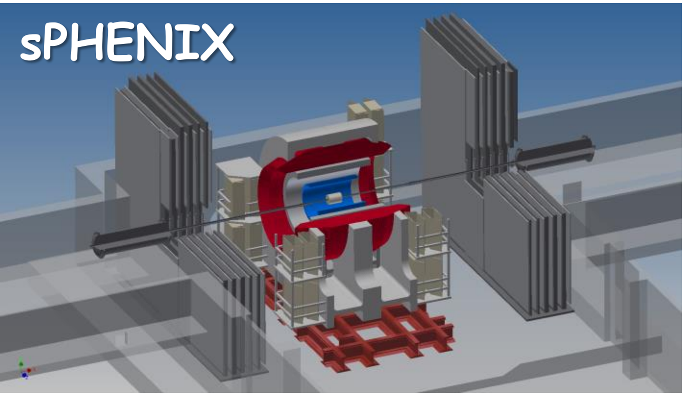
PI

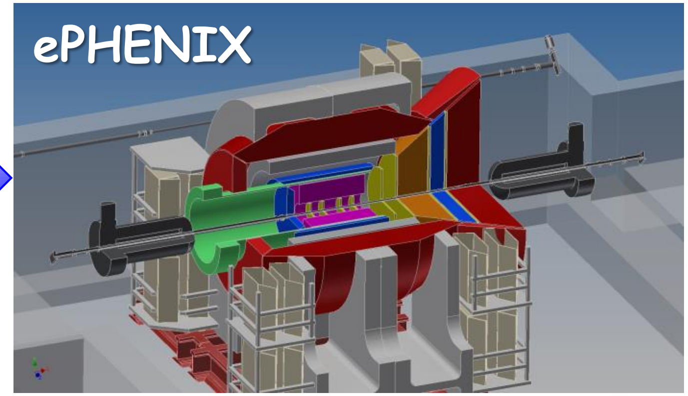
-1<|η|<1: DIRC or proximity focusing Aerogel-RICH + TPC: dE/dx
1<|η|<3: RICH

Lepton-ID:

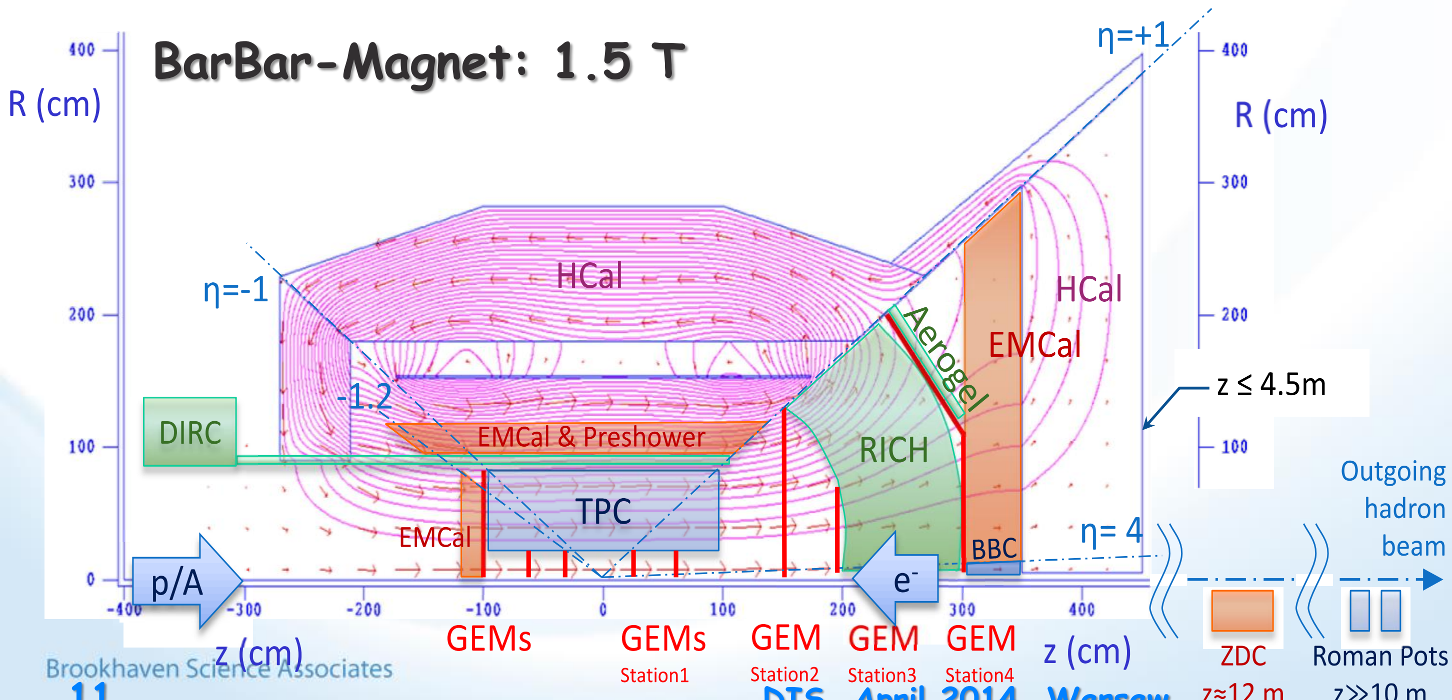
-3 <η< 3: e/p
1<|η|<3: in addition Hcal response & γ suppression via tracking
|η|>3: ECal+Hcal response & γ suppression via tracking
-5<η<5: Tracking (TPC+GEM+MAPS)

sPHENIX TO ePHENIX





Concept for an EIC detector build around the BarBar solenoid
arXiv:1402.1209

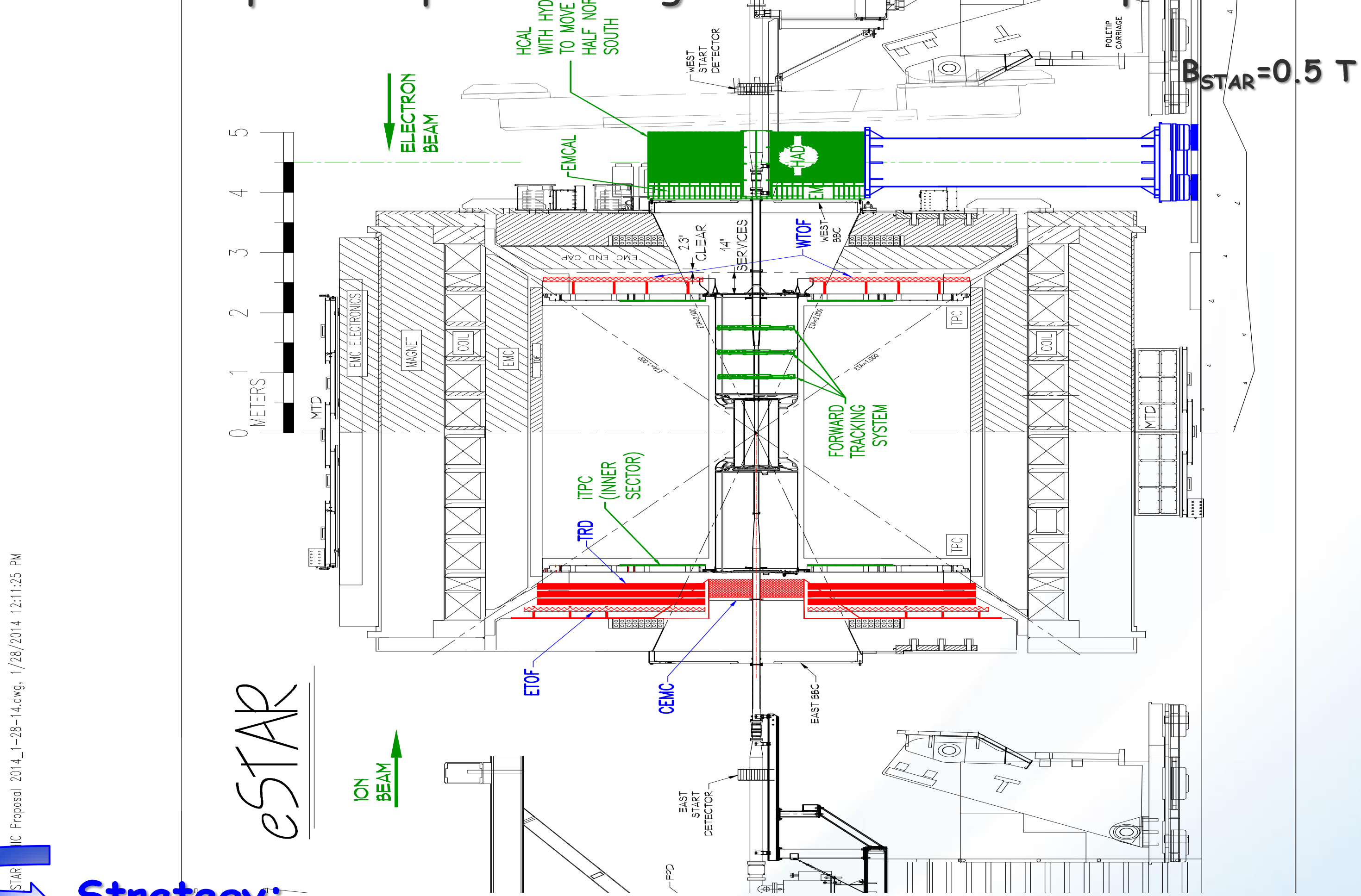


Barrel + Forward
Lead – Scint Ecal:
12%/√E

Back Ecal: Crystal
1.5%/√E

STAR TO eSTAR

eSTAR LoI: https://drupal.star.bnl.gov/STAR/starnotes/public/sn0592



Strategy:

add lepton ID for η > -1 (indicated in red)

add tracking Ecal and Hcal for η > -2 (indicated in green)

move RP to correct locations

eRHIC:

Interaction Region
Polarimetry
and
Luminosity

REQUIREMENTS FROM PHYSICS ON IR

Summarized at:
https://wiki.bnl.gov/eic/index.php/IR_Design_Requirements

Hadron Beam:

1. the detection of neutrons of nuclear break up in the outgoing ... beam direction → location/acceptance of ZDC
2. the detection of the scattered ... reaction in the outgoing ...
   the ...

→ lo...

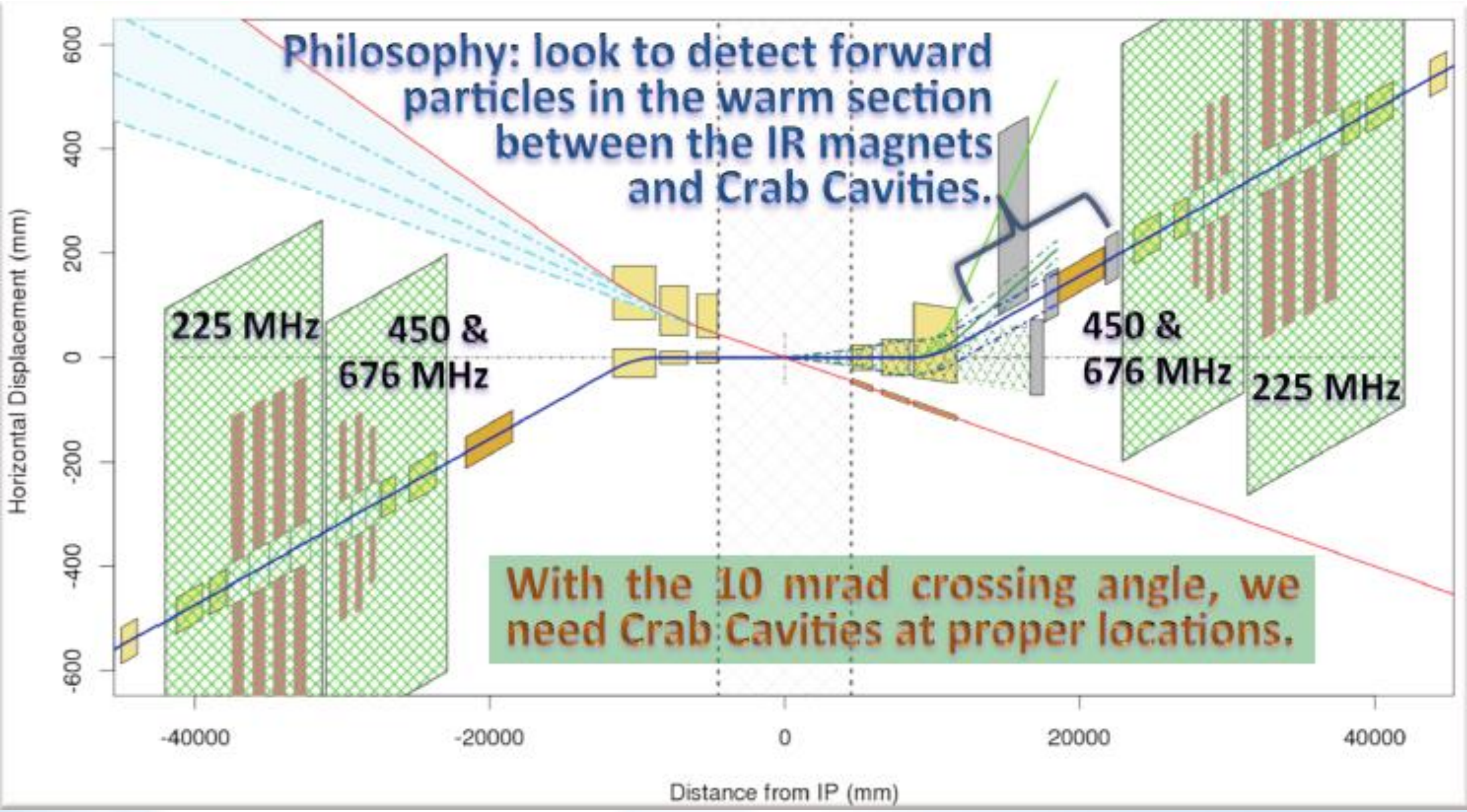
→ im...

Lepto...

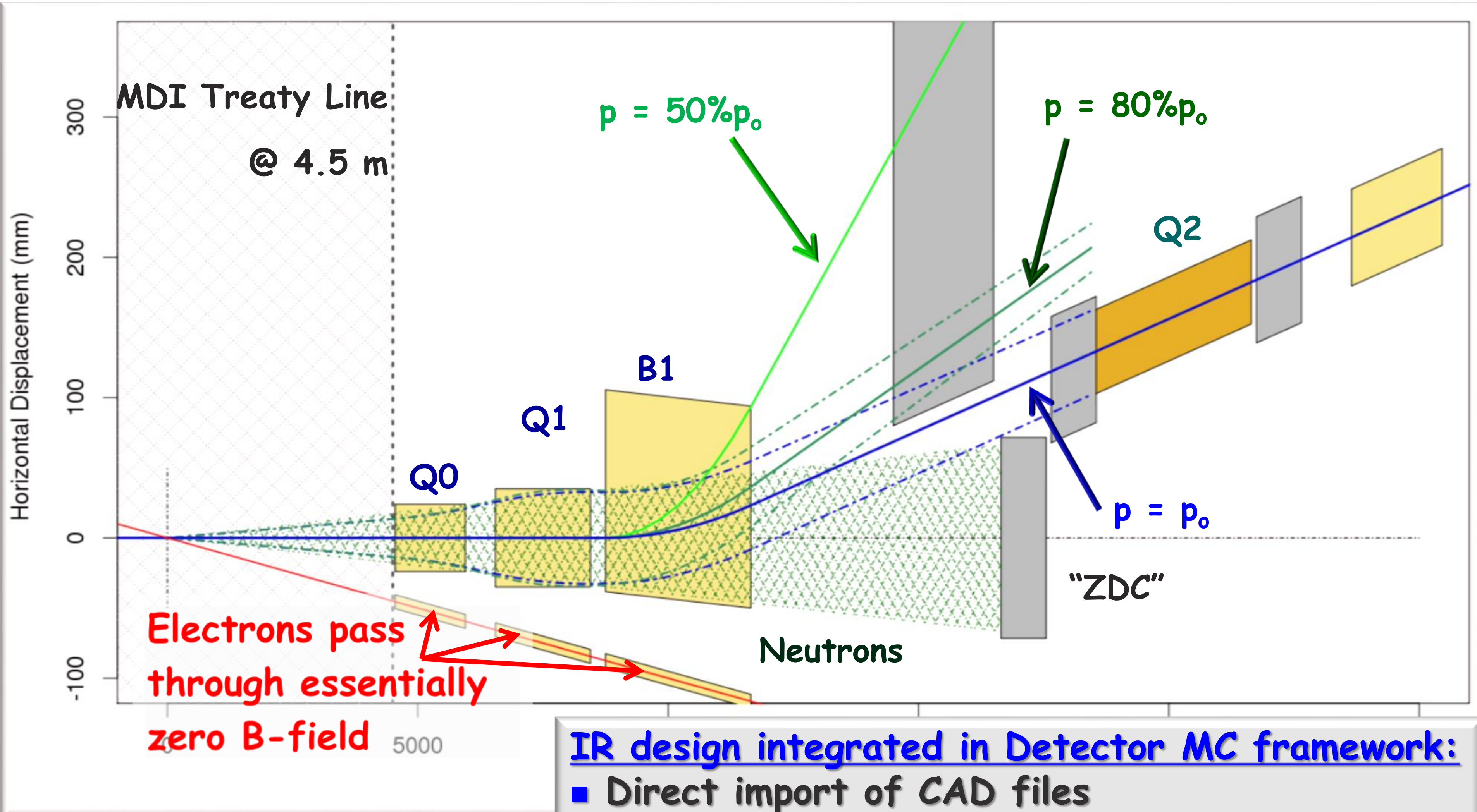
3. the ... free region around the IR
4. mini... impact of detector magnetic field on lepton beam
   → synchrotron radiation
3. space for low Q^2 scattered lepton detection
4. space for the luminosity monitor in the outgoing lepton beam direction
5. space for lepton polarimetry

Important

EIC is a high luminosity machine 10^{33} $cm^{-2}s^{-1}$
such controlling systematics becomes crucial
→ luminosity measurement
→ lepton and hadron polarization measurement



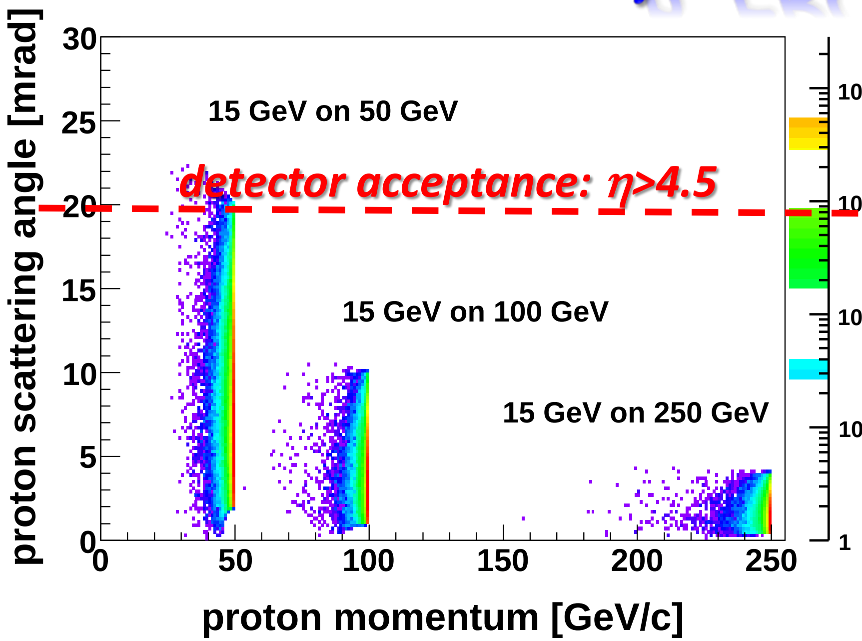
Design: compromises detector and machine requirements

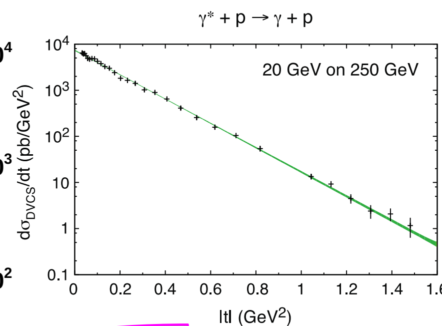


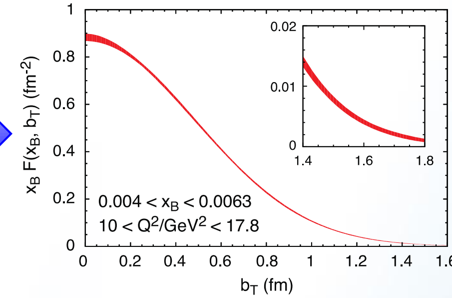
IR design integrated in Detector MC framework:

- Direct import of CAD files
  - Geometry
  - Material tags
- Direct import of .madx field info files
- Detectors: Roman pots, ZDC, Lumi monitor, e-Polarimeter

p' FROM EXCLUSIVE REACTIONS

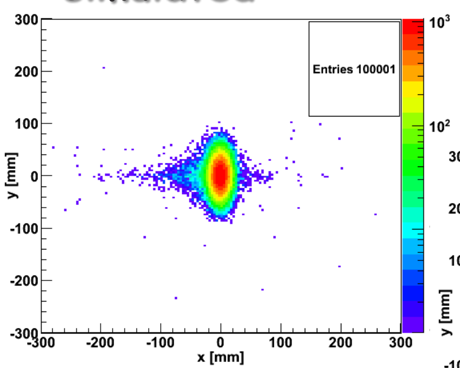




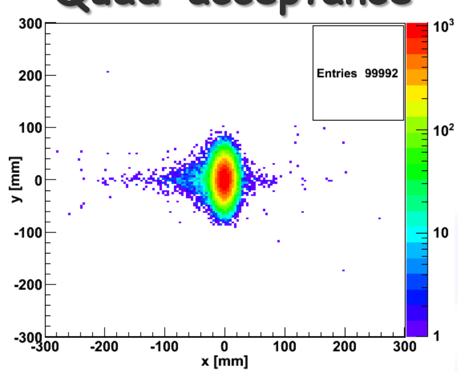


- t ($\sim p_t^2$) reach influences b_T uncertainty t_{min}~ 0.175 GeV² → 300 GeV² $\delta f/f$ > 50%
- beam cooling critical to achieve high low t (p_t) acceptance

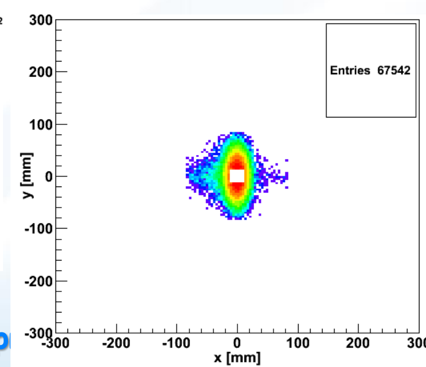
simulated

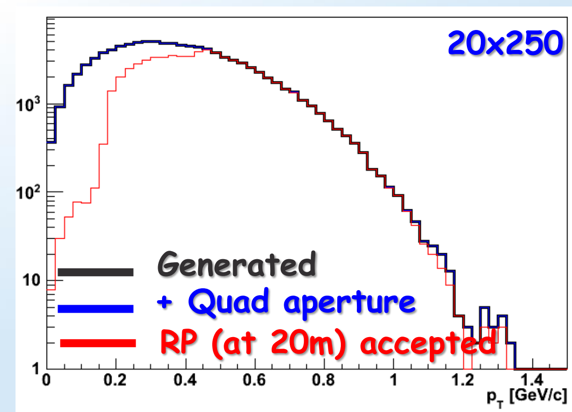


simulated + Quad-acceptance

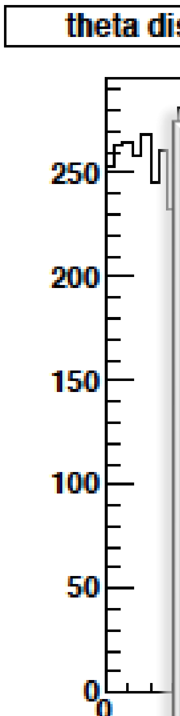


simulated + Quad-acceptance + 10 σ BC clearance





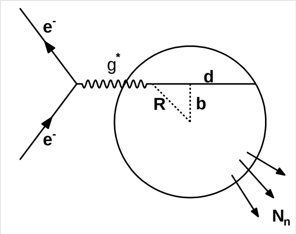
Results from GEMINI++ for 50 GeV Au

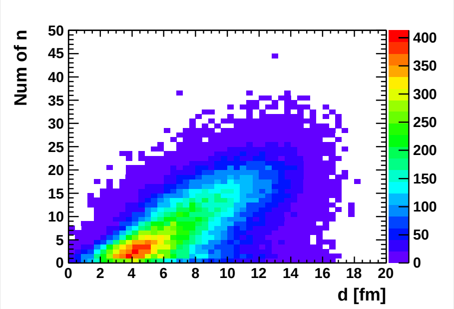


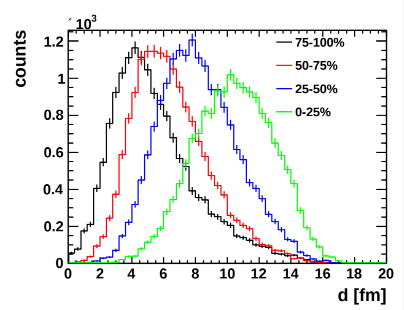
Important:

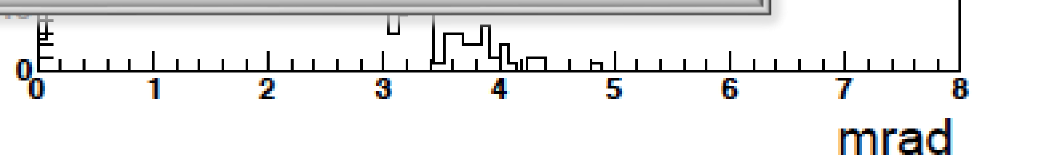
- For coherent VM-production rejection power of incoherent needed up to 10^4
  → ZDC detection efficiency is critical

Can we reconstruct the eA collision geometry:









+/-5mrad acceptance seems sufficient

POLARIZATION AND LUMINOSITY COUPLING

- **Concept:**

  Use Bremsstrahlung ep …

  - diff…

Goals for Luminosity Measurement:

- Integrated luminosity with precision δL< 1%
- Measurement of relative luminosity: physics-asymmetry/10
- Fast beam monitoring for optimization of ep-collisions and control of mid-term variations of instantaneous luminosity

Important

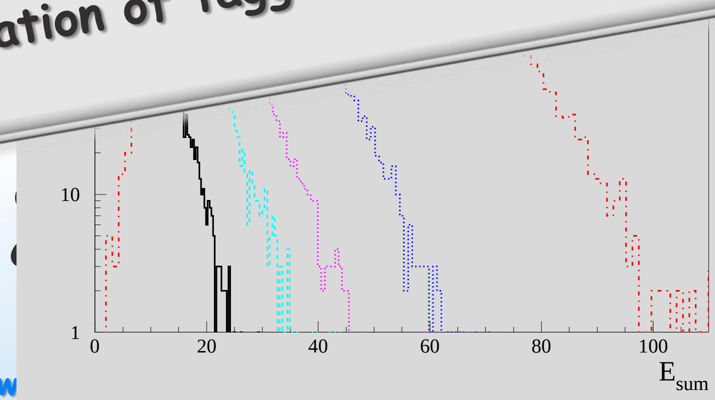
need to monitor not only polarisation level but also polarisation bunch current correlation

Low-Q^2 tagger

- detect low Q^2 scattered electrons
  → quasi-real photoproduction physics
- possibly also detect lepton from lepton polarimeter compton scattering
- design could be inspired by the Hall-D tagger design
  - pileup can be avoided by fine segmentation of tagger detector

… a with the help … (…insk), the CERN CLIC-QED …

- hopefully a is small



- eRHIC design is using the idea of a “Gatling” electron gun with a combiner?
  → 20 cathodes
  → one proton bunch collides always with electrons from one specific cathode

Important questions:

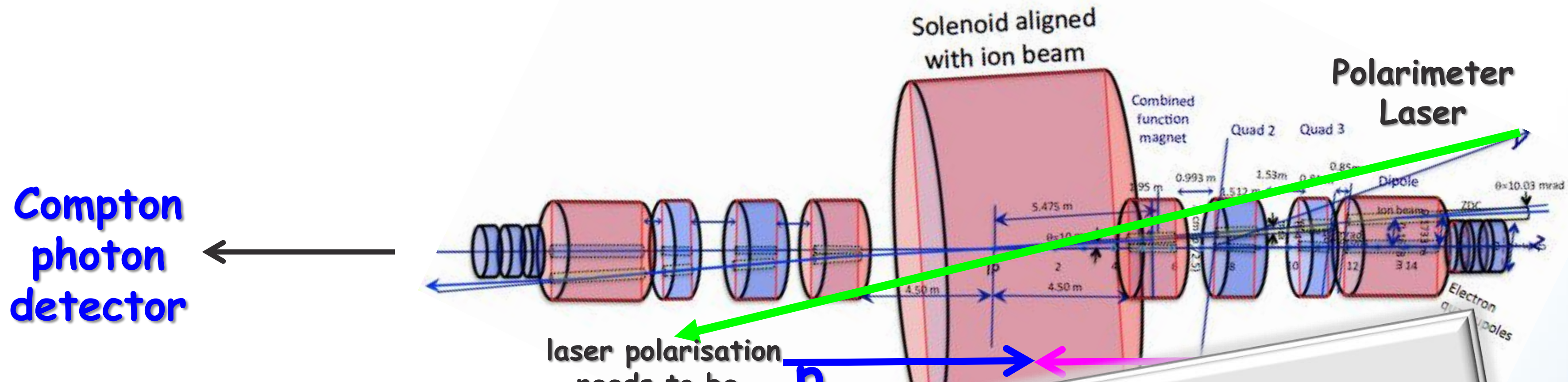
- What is th...
- ... polarization.
- ...easure polarization in the ring
- ...ow much polarization loss do we expect from the source to flat top in the ERL.
  → Losses in the arcs have been significant at SLC

- Is there the possibility for a polarization profile for the lepton bunches
  → if then in the longitudinal direction can be circumvented with 352 MHz RF

Challenge:
Integrate Compton polarimeter into IR and Detector design together with Luminosity monitor and low Q^2-tagger
→ longitudinal polarization → Energy asymmetry
→ segmented Calorimeter → to measure possible transverse polarization component → position asymmetry

Details talk by V. Ptitsyn

THE LEPTON POLARIMETER: LOCATION?



- Measure Polarization at IP
  - overlap of bremsstrahlun…
  - only possibl… …hods
- … …easure at location spin is fully
  - …ce
  - …ar… should rotate spin by integer number of π
- After IP:
  - does collision reduce polarization?
  - need to measure at location, where bremsstrahlung contribution is small
- Before IP:
  - need to find room for photon calorimeter

Summary:
- all of this needs to be carefully modeled
- work to integrate eRHIC IR into EICroot has started

RHIC HADRON POLARIMETRY

Polarized hydrogen Jet Polarimeter (HJet)

- Source of absolute polarization (normalization of other polarimeters)
- Slow (low rates ⇒ needs looong time to get precise measurements)

Proton-Carbon Polarimeter (pC) @ RHIC and AGS

- Very fast ⇒ main polarization monitoring tool
- Measures polarization profile (polarization is higher in beam center) and lifetime
- Needs to be normalized to HJet

Local Polarimeters (in PHENIX and STAR experiments)

- Defines spin direction in experimental area
- Needs to be normalized to HJet

All of these systems are necessary for the proton beam polarization measurements and monitoring

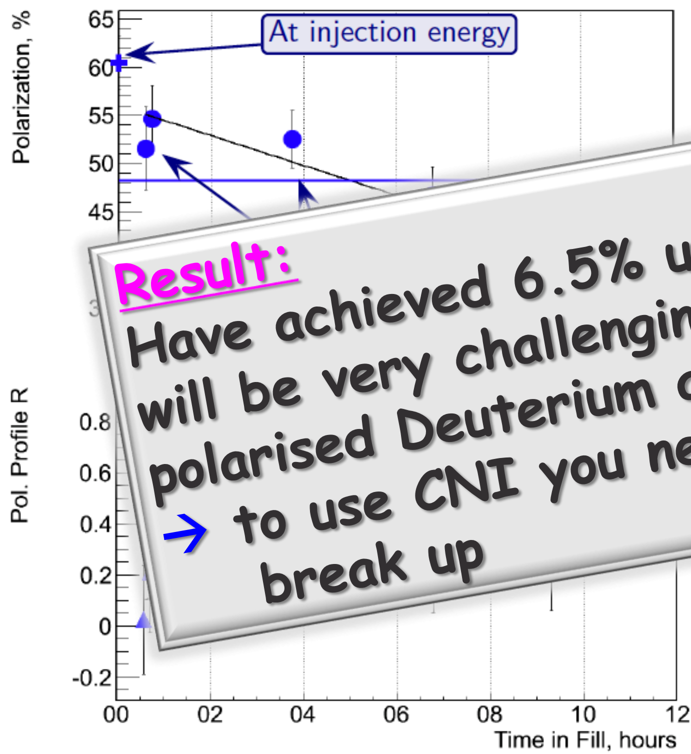
Account for
beam polarization decay through fill → $P(t)=P_0 exp(-t/\tau_p)$
growth of beam polarization profile **R** through fill

pCarbon polarimeter

Collider

$\otimes I_1(x_0, y)$

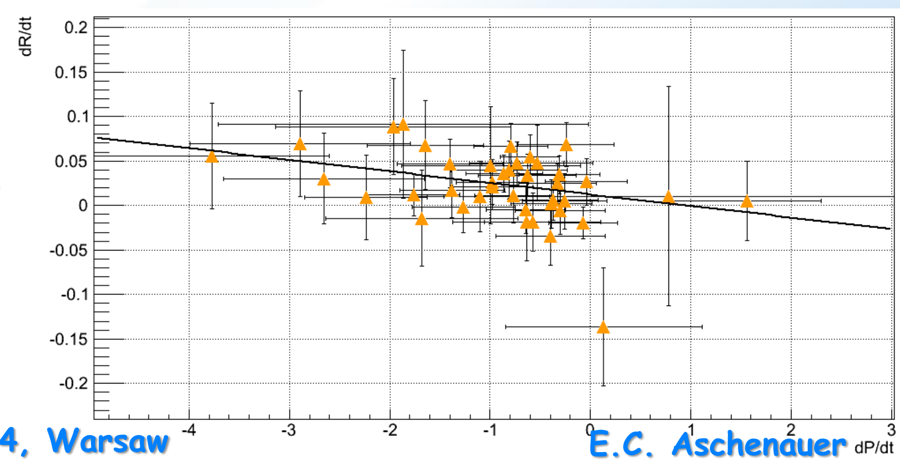
$=x_0$



Result:
Have achieved 6.5% uncertainty for DSA and 3.4 for SSA will be very challenging to reduce to 1-2%
polarised Deuterium and He-3 polarimetry will be challenging
→ to use CNI you need to make sure D and He-3 did not break up

Fills at 250 GeV

$$R = \frac{\sigma_I^2}{\sigma_P^2}$$



Polarization lifetime has consequences for physics analysis
→ different physics triggers mix over fill
→ different <P>

SUMMARY

- Established and documented requirements from physics on the detector and IR design
  - https://wiki.bnl.gov/eic/index.php/Detector_Design_Requirements
  - https://wiki.bnl.gov/eic/index.php/IR_Design_Requirements
- Performed three different design studies on eRHIC detector realizations
  - a model detector
  - ePHENIX
  - eSTAR
- Working hand-in-hand with CAD to integrate into the IR-design
  - Roman Pots and a low Q^2 tagger
  - the luminosity detector
  - electron and hadron polarimeter

Continue to optimize and finalize current detectors and IR design

THANKS TO MY EIC-BNL-TF COLLEAGUES AND CAD

FURTHER TALKS ON eRHIC AND DOCUMENTS/PAPERS

- Wednesday WG-7
  - A. Kiselev: Baseline Design of an eRHIC Detector and Interaction region
  - E. Sichtermann: eSTAS-a detector for eRHIC
  - A. Bazilevsky: ePHENIX: An EIC detector built around the BaBar magnet
  - J.H. Lee: Probing Gluon saturation through Dihadron Correlations at an EIC
- Thursday WG-6+7
  - T. Burton: Charged current DIS on longitudinally polarised nucleons at an EIC
- **Documents**
  - INT-Report: Gluons and the quark sea at high energies: distributions, polarization, tomography arXiv:1108.1713
  - EIC-WP: arXiv:1212.1701
- **Physics Papers:**

- Probing gluon saturation through dihadron correlations at an Electron-Ion Collider; L. Zheng, E. C. Aschenauer, J. H. Lee, Bo-wen Xiao arXiv:1403.2413 PRD 89 (2014) 074037
- Prospects for Charged Current Deep-Inelastic Scattering off Polarized Nucleons at a Future Electron-Ion Collider; Elke C. Aschenauer, Thomas Burton, Till Martini, Hubert Spiesberger, Marco Stratmann arXiv:1309.5327 PRD 88 (2013) 114025
- Deeply Virtual Compton Scattering at a Proposed High-Luminosity Electron-Ion Collider; Aschenauer, E.C., Fazio, S., Kumericki, K. and Mueller, D. arXiv:1304.0077, JHEP09(2013)093
- Helicity Parton Distributions at a Future Electron-Ion Collider: A Quantitative Appraisal; Aschenauer, E.C., Sassot, R. and Stratmann, M. arXiv:1206.6014 Phys.Rev. D86 (2012) 054020
- The dipole model Monte Carlo generator Sartre 1; Toll, T. and Ullrich, T.; arXiv:1307.8059
- Exclusive diffractive processes in electron-ion collisions; Toll, T. and Ullrich, T.;

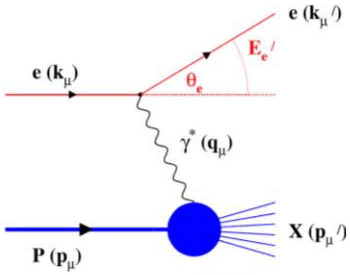
  arXiv:1211.3048 Phys.Rev. C87 (2013) 024913

BACKUP

WHAT IS NEEDED TO REALIZE THIS PROGRAM

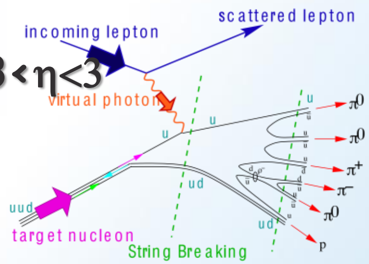
Inclusive Reactions in ep/eA:

- Physics: Structure Fcts.: g_1, F_2, F_L
- Very good electron id → identify scattered lepton
- Momentum/energy and angular resolution of e' critical
- scattered lepton → kinematics of event (x,Q^2)\



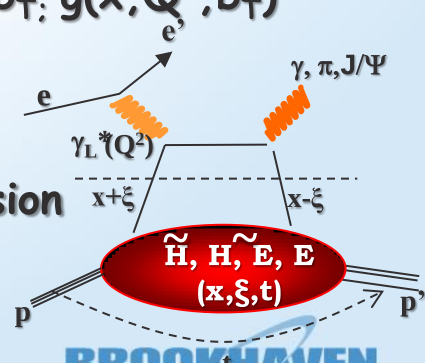
Semi-inclusive Reactions in ep/eA:

- Physics: TMDs, Helicity PDFs, FF → flavor separation, dihadron-corr.,…
  → Kaon asymmetries, cross sections
- Excellent particle ID: $\pi^\pm$,$K^\pm$,$p^\pm$ separation over a wide range in $-3<\eta<3$
  → excellent p resolution at forward rapidities
- TMDs: full Φ-coverage around γ^*, wide p_t coverage
- Excellent vertex resolution → Charm, Bottom separation

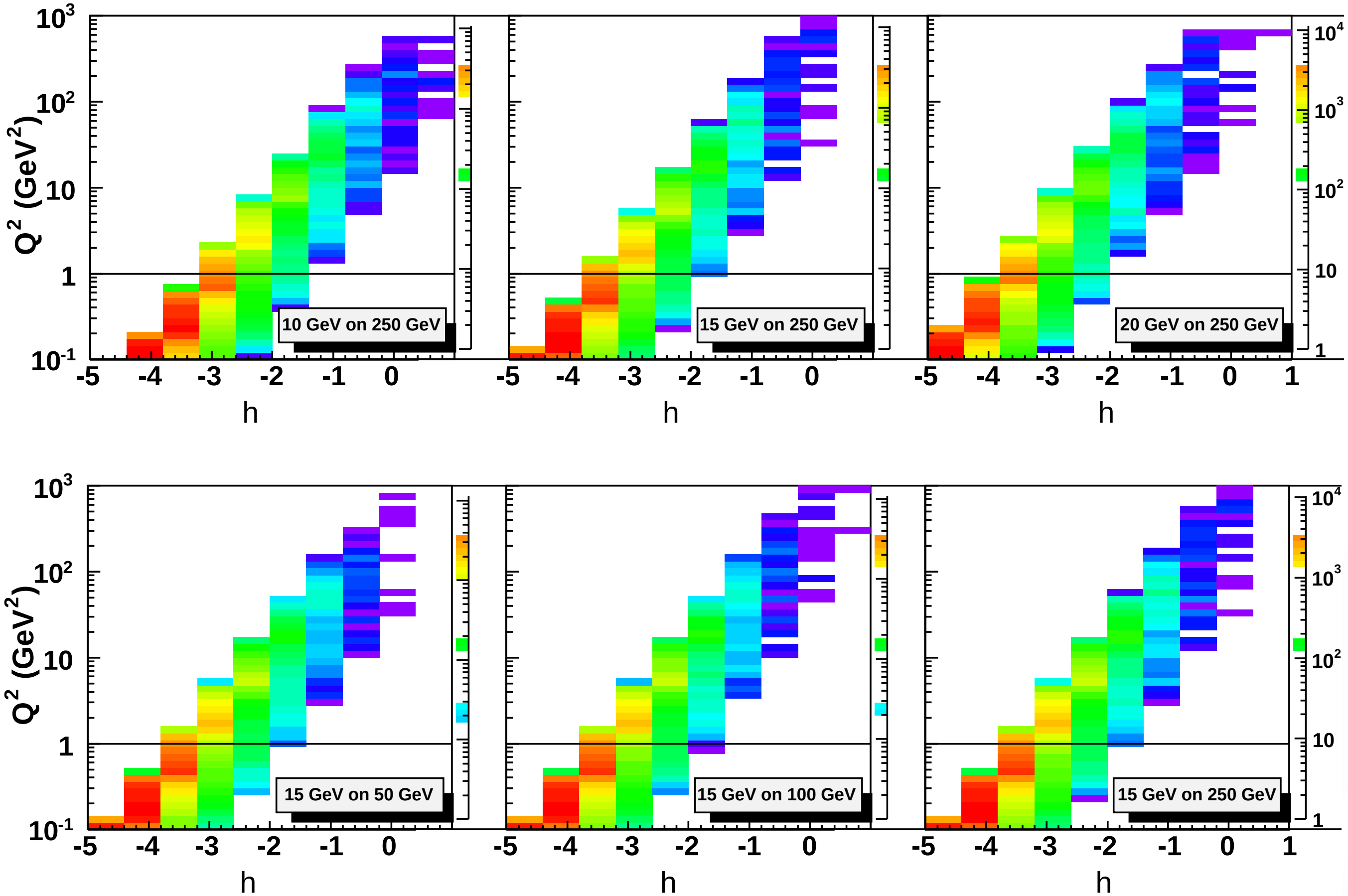


Exclusive Reactions in ep/eA:

- Physics: DVCS, excl. VM/PS prod. → GPDs, parton imaging in b_T: $g(x,Q^2,b_T)$
- Exclusivity → large rapidity coverage → rapidity gap events
  ↘ reconstruction of all particles in event
- high resolution, wide coverage in t → b_t → Roman pots
- eA: veto nucleus breakup, determine impact parameter of collision
  → acceptance for neutrons in ZDCs



LEPTON KINEMATICS



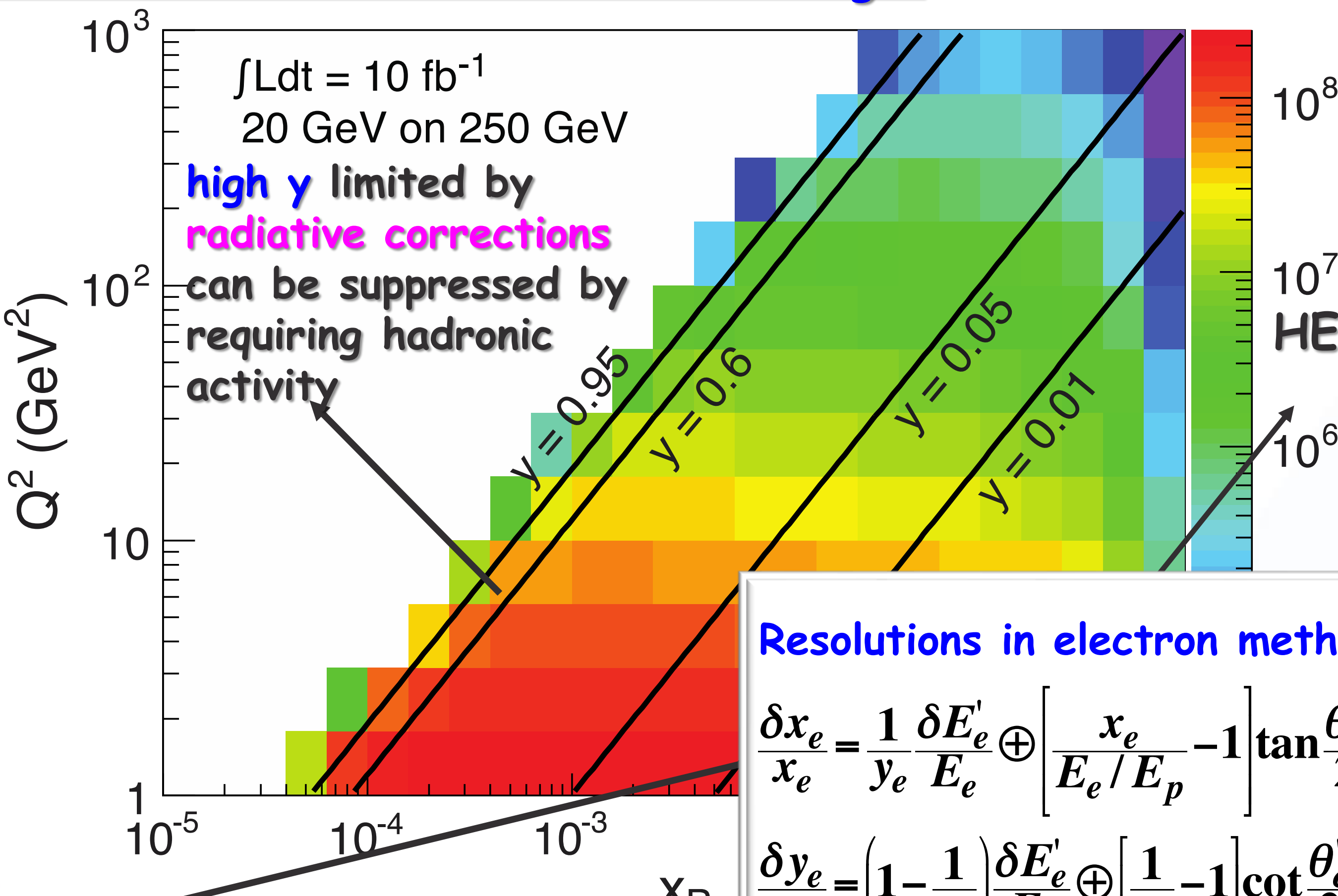
Increasing lepton beam energy: scattered lepton boosted to negative η

Increasing hadron beam energy: no influence on scattered lepton kinematics

→ Q^2 < 0.1 GeV: scattered lepton needs to be detected in dedicated low-Q^2 tagger

→ kinematic coverage in Q^2-x-η critical for physics, which requires Rosenbluth separation high to low y reach

Possible limitations in kinematic coverage:



high y limited by radiative corrections can be suppressed by requiring hadronic activity

HERA achieved $y>0.005$

low y-coverage: limited by E'_e res

→ y-coverage can be extended b

→ or use hadron or double angle

→ CC events require the hadron r

Resolutions in electron method:

$$\frac{\delta x_e}{x_e} = \frac{1}{y_e}\frac{\delta E'_e}{E_e} \oplus \left[\frac{x_e}{E_e/E_p} - 1\right]\tan\frac{\theta'_e}{2}\delta\theta'_e$$

$$\frac{\delta y_e}{y_e} = \left(1 - \frac{1}{y_e}\right)\frac{\delta E'_e}{E_e} \oplus \left[\frac{1}{y_e} - 1\right]\cot\frac{\theta'_e}{2}\delta\theta'_e$$

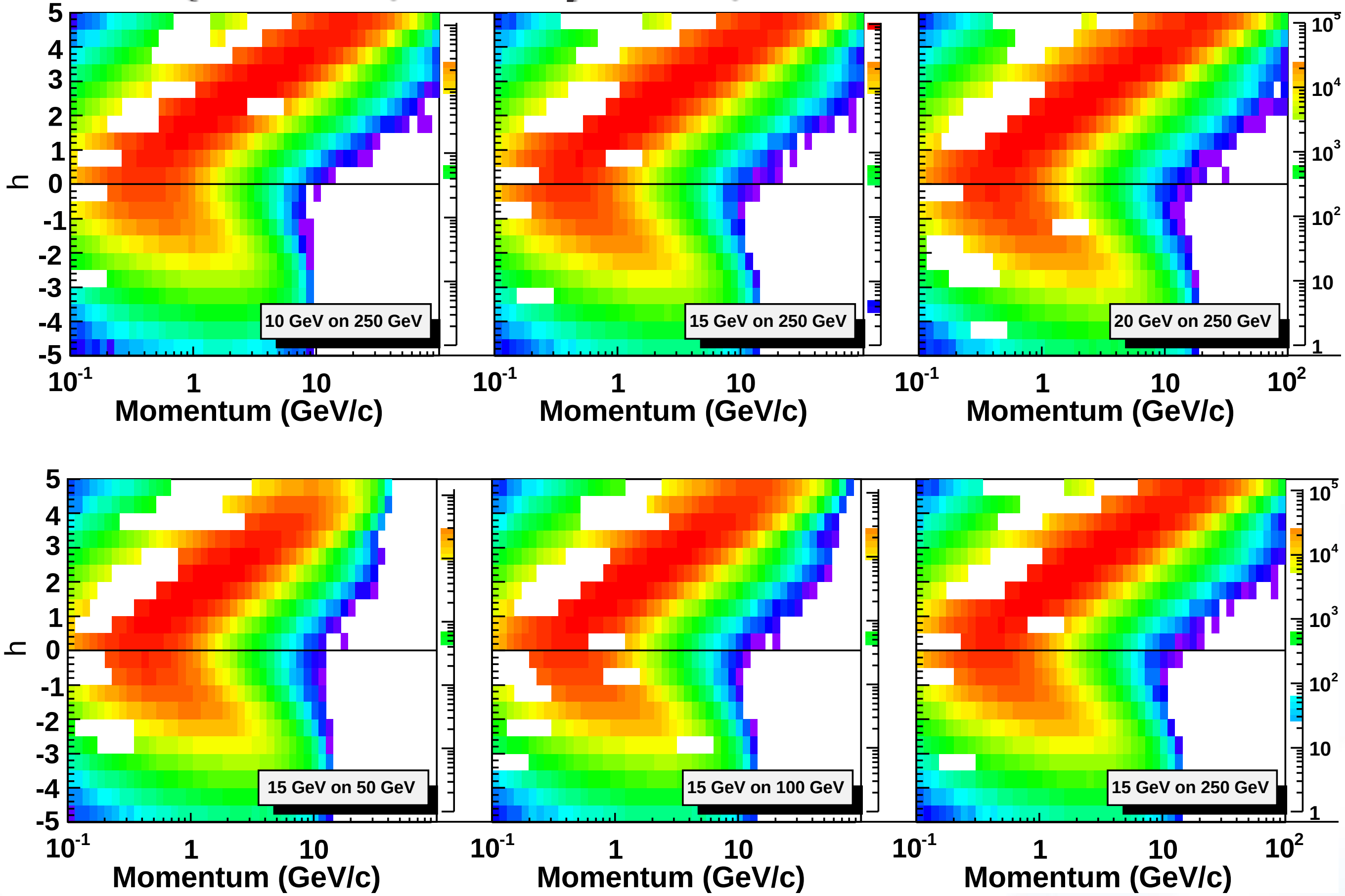
diverges for $y_e \to 0$ depends on E'_e

$$\frac{\delta Q_e^2}{Q_e^2} = \frac{\delta E'_e}{E_e} \oplus \tan\frac{\theta'_e}{2}\delta\theta'_e$$

diverges for $\theta'_e \to 180°$ depends on E'_e and θ'_{ezz}

SIDIS: PION KINEMATICS

Cuts: $Q^2>1$ GeV, $0.01<y<0.95$, $z>0.1$



Increasing lepton beam energy boosts hadrons more to negative rapidity

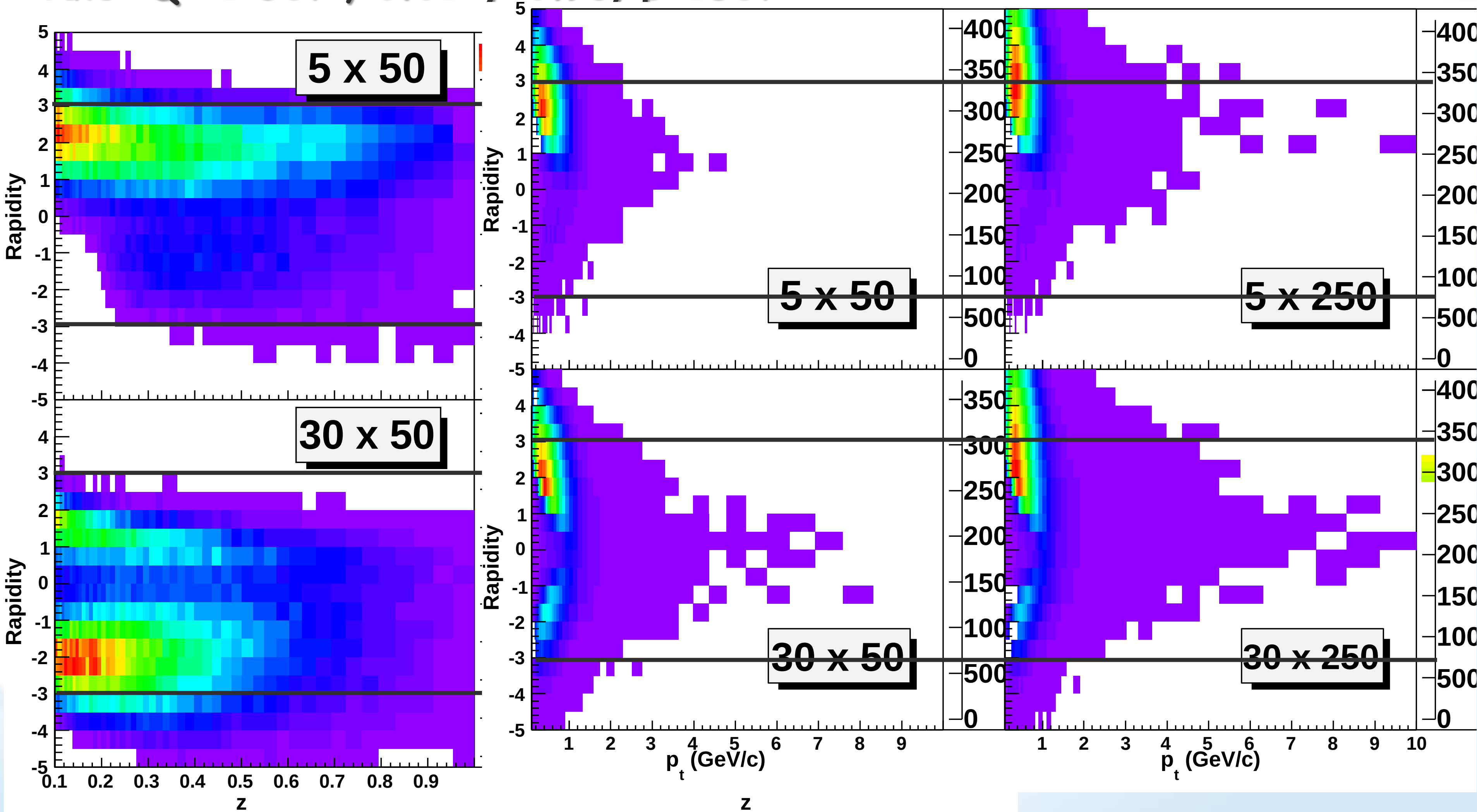
Increasing hadron beam energy influences max. hadron energy at fixed η

→ no difference between $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$

→ Impact on hadron and lepton PID

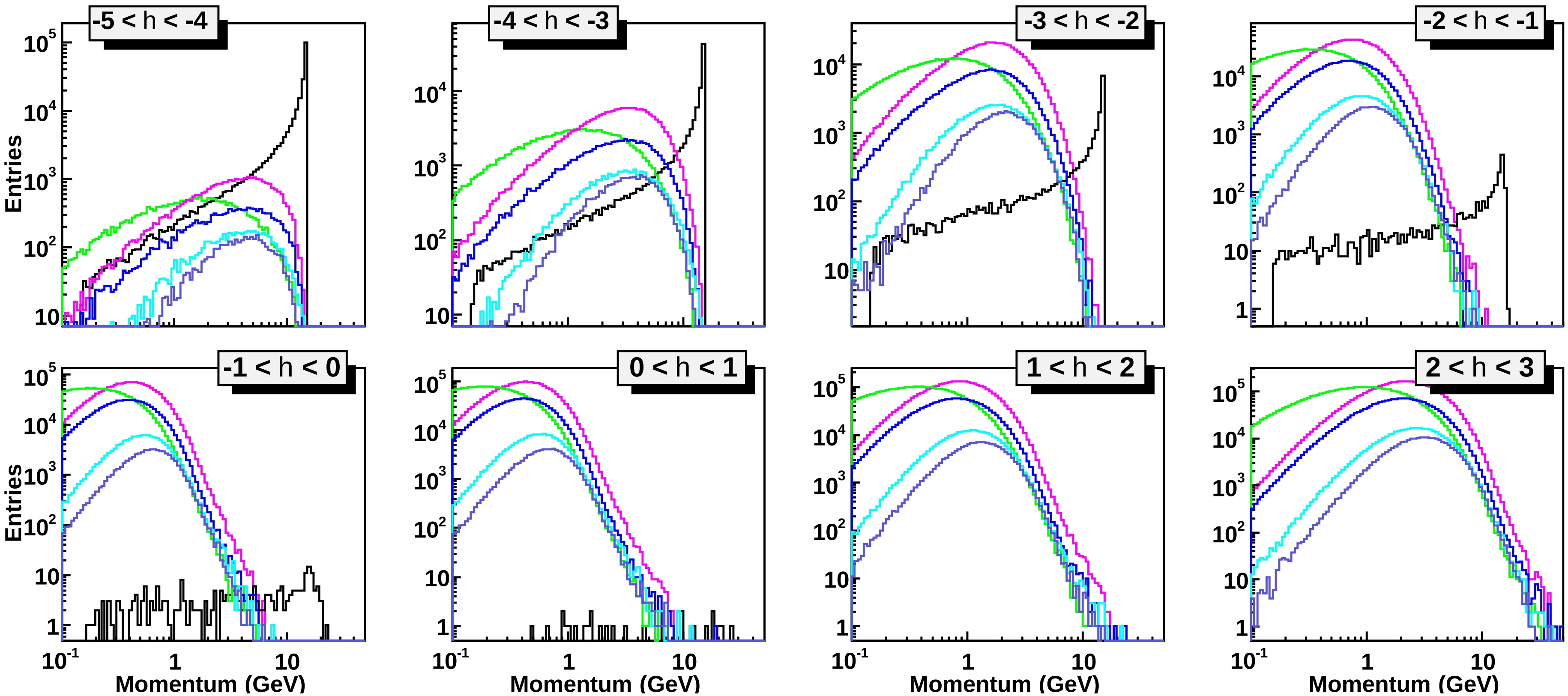
HADRON COVERAGE

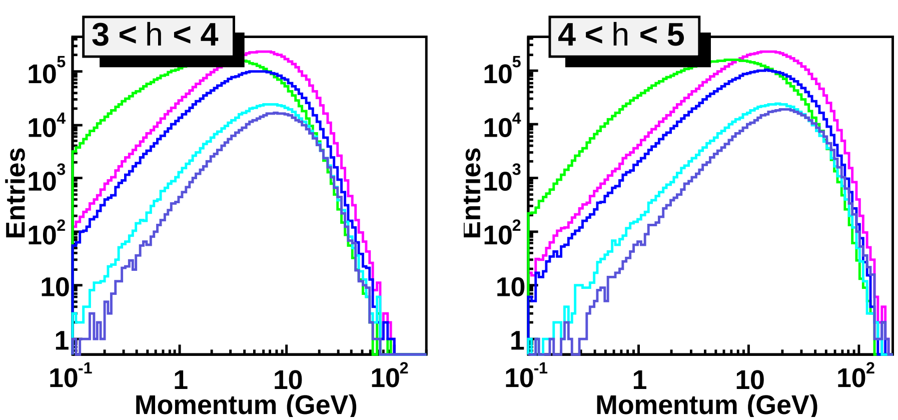
Cuts: $Q^2>1$ GeV^2, $0.01<y<0.95$, p>1GeV



$-3<\eta<3$ covers entire p_t & z-region important for physics

PID REQUIREMENTS





Lepton-PID:

$h^{+/-}$, γ suppression: 1:1 η <4 to 10^4:1 η >-1

Hadron-PID:

π/K ratio 3-4 K/p ~ 1 independent of η and ($\sqrt{s}$)

η <-3: 1 GeV< p < 10 GeV

-3<η <-1: 0.1 GeV < p < 4 GeV

-1<η < 1: 0.1 GeV< p < 4 GeV

1<η < 3: 0.1 GeV< p < 30 GeV

3<η : 1 GeV< p < 100 GeV

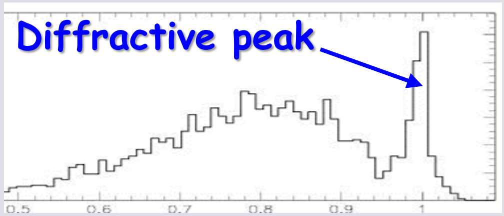
→ impact on PID technology

EXCLUSIVE REACTIONS: EVENT SELECTION

How can we select events: two methods

proton/neutron tag method

- Measurement of *t*
- Free of p-diss background
- Higher M_X range
- to have high acceptance for Roman Pots / ZDC challenging → IR design

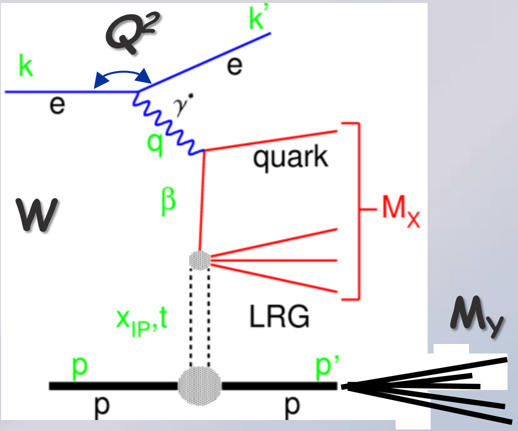


$$x_L = \frac{p'_z}{p_z} \approx 1 - x_{IP}$$

Need for roman pot spectrometer AND ZDC

Large Rapidiy Gap method

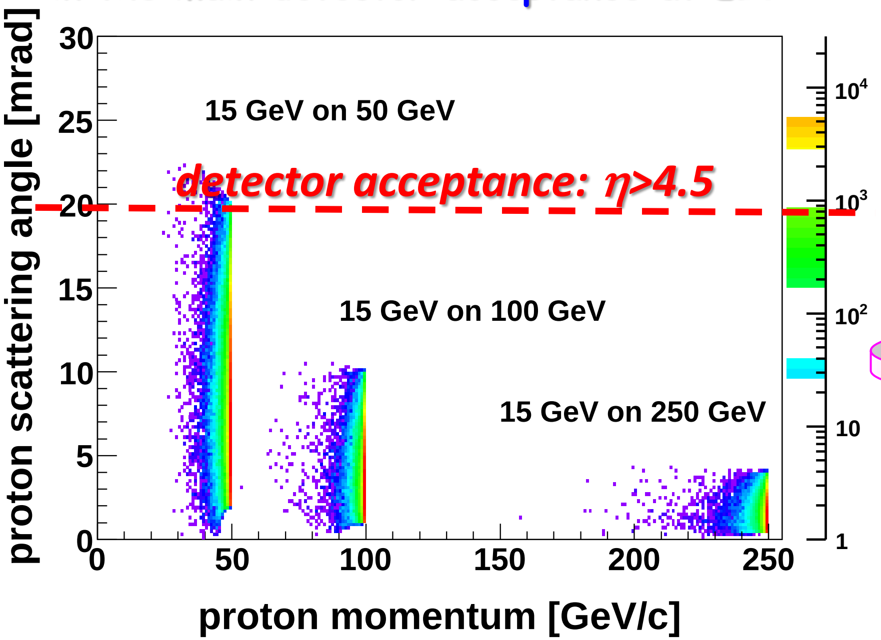
- *X* system and e' measured
- Proton dissociation background
- High acceptance in η for detector → crucial for eA

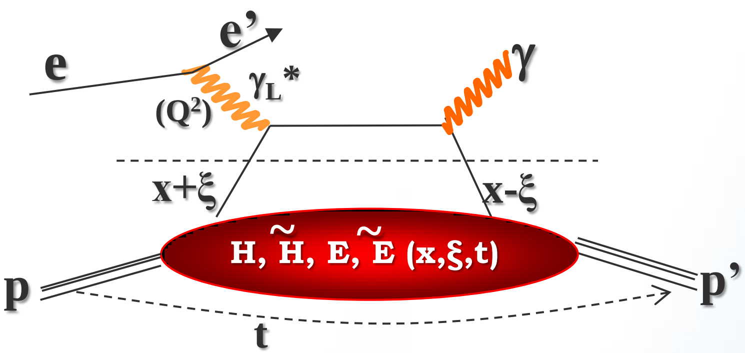


Need for HCal in the forward region

DVCS KINEMATICS

leading protons are hardly
in the main detector acceptance at EIC



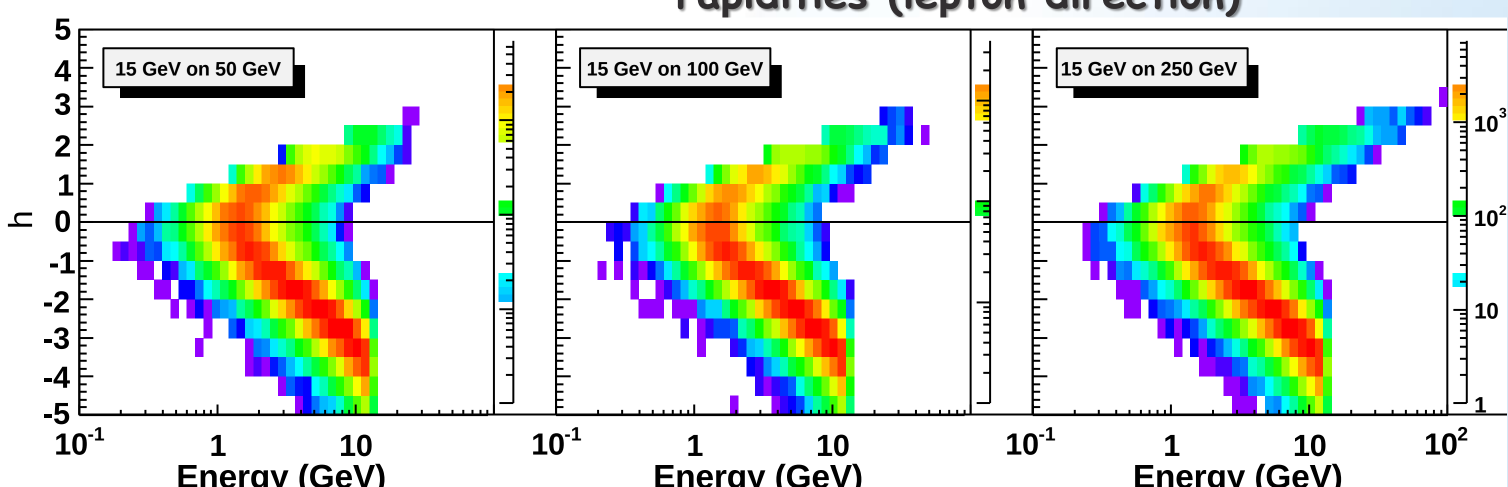


to detect proton
machine, IR and RP design
need to go hand in hand

Increasing Hadron Beam Energy:
influences max. photon energy at fixed η
→ photons are boosted to negative
rapidities (lepton direction)

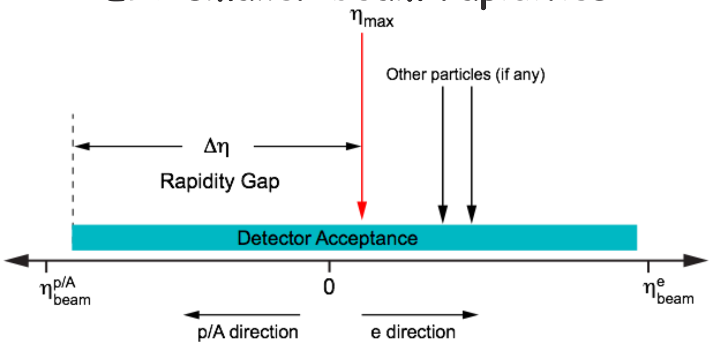
DVCS – photon:

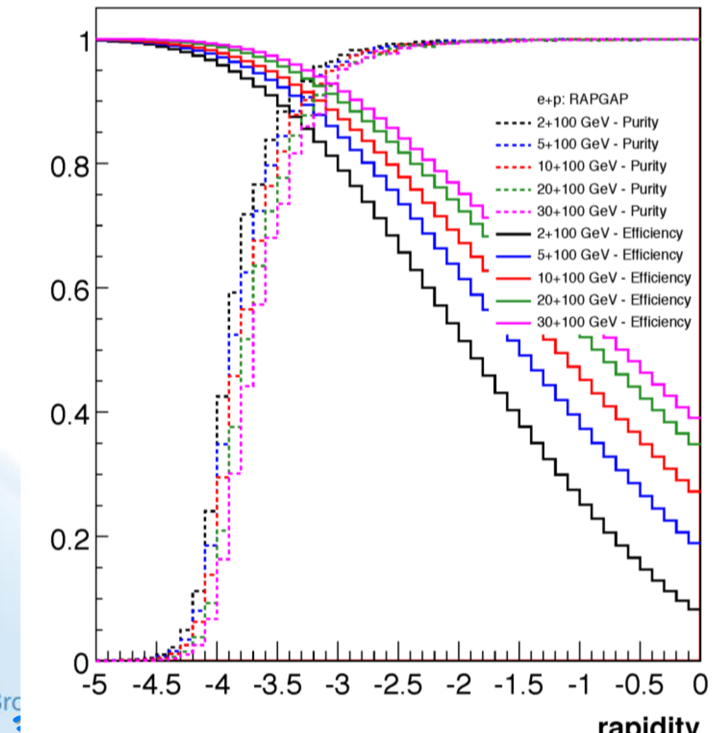
Cuts: $Q^2>1$ GeV,
$0.01<y<0.85$,



LARGE RAPIDITY GAP METHOD

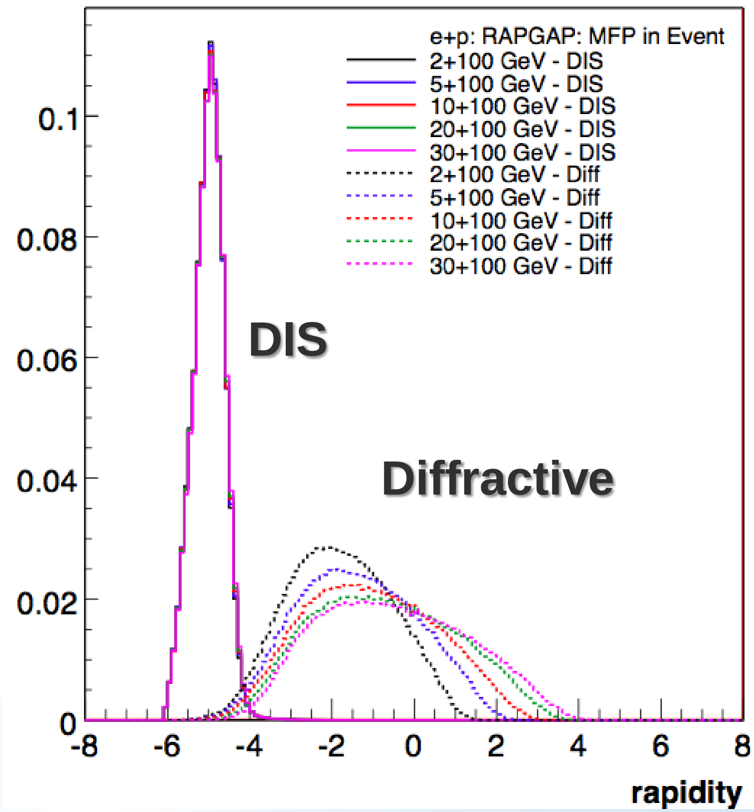
- Identify **Most Forward Going Particle (MFP)**
  - Works at HERA but at higher $\sqrt{s}$
  - EIC smaller beam rapidities





Diffractive ρ^0 production at EIC:
η of MFP

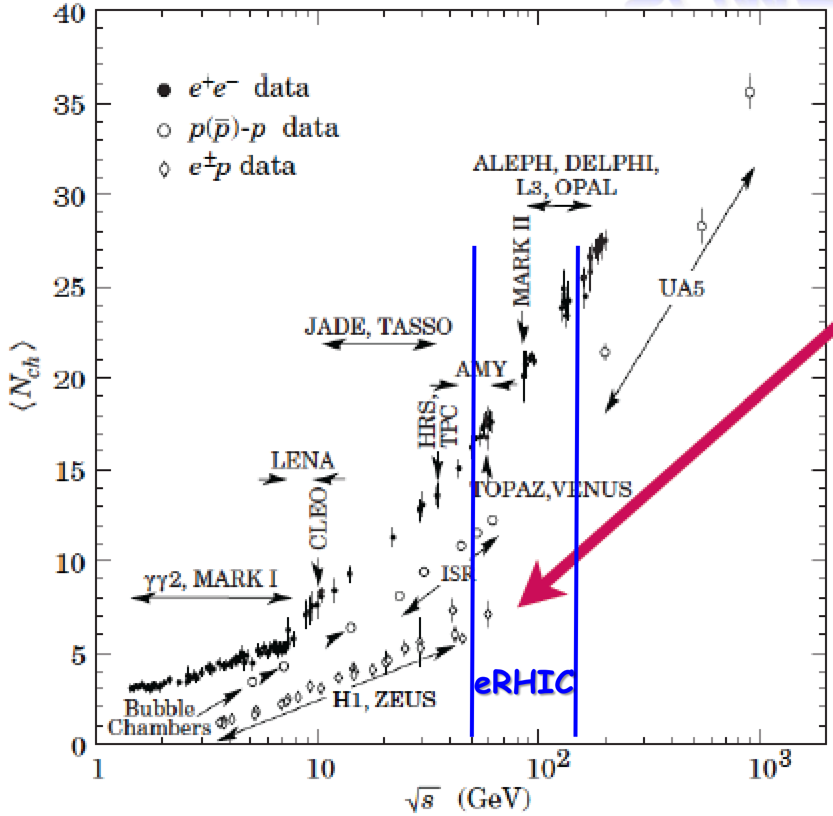
M. Lamont



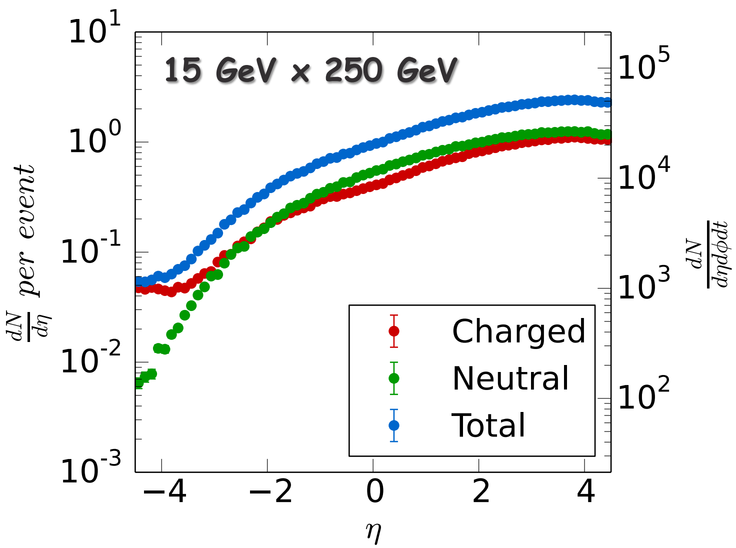
Hermeticity requirement:

- needs just to detector presence
- does not need momentum or PID
- simulations: $\sqrt{s}$ not a show stopper for EIC
  (can achieve 1% contamination, 80% efficiency)

SOME THOUGHTS ABOUT RATES



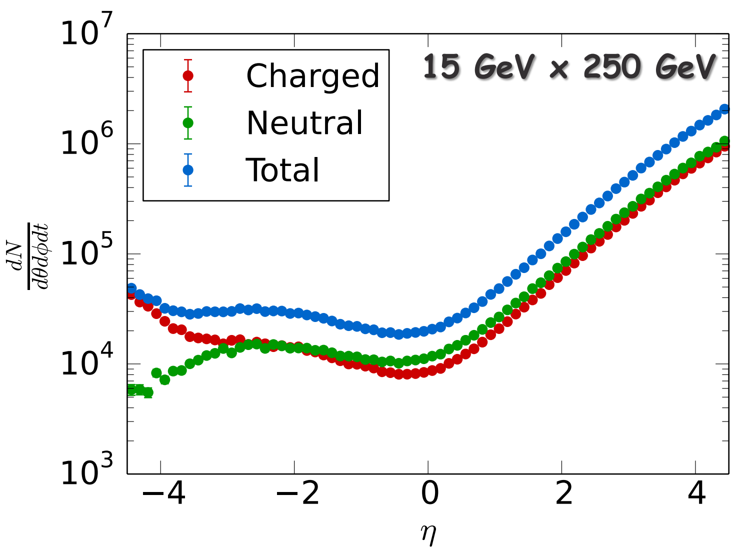
low ∫multiplicity: 4-
$\sqrt{s}$ = 55-145 GeV
$N_{ch}(ep) \sim N_{ch}(eA) < N$



Cross section: $\sigma_{ep} < \sigma_{\gamma^* p} < \sigma_{\gamma p}$

Pythia σ_{ep}: 0.030 – 0.060 mb
Luminosity: 10^{33} cm^{-1} s^{-1} = 10^{6} mb^{-1} s^{-1}

Interaction rate:
30 - 60 kHz



Barrel silicon tracker:

- 6 layers at [30..160] mm radius
- 0.37% X_0 in acceptance per layer simulated precisely
- digitization: single discrete pixels, one-to-one from MC points

forward/backward silicon trackers:

- 2x7 disks with up to 180 mm radius
- N sectors per disk; 200 μm silicon-equivalent thickness
- digitization: discrete ~20x20 μm^2 pixels

TPC:

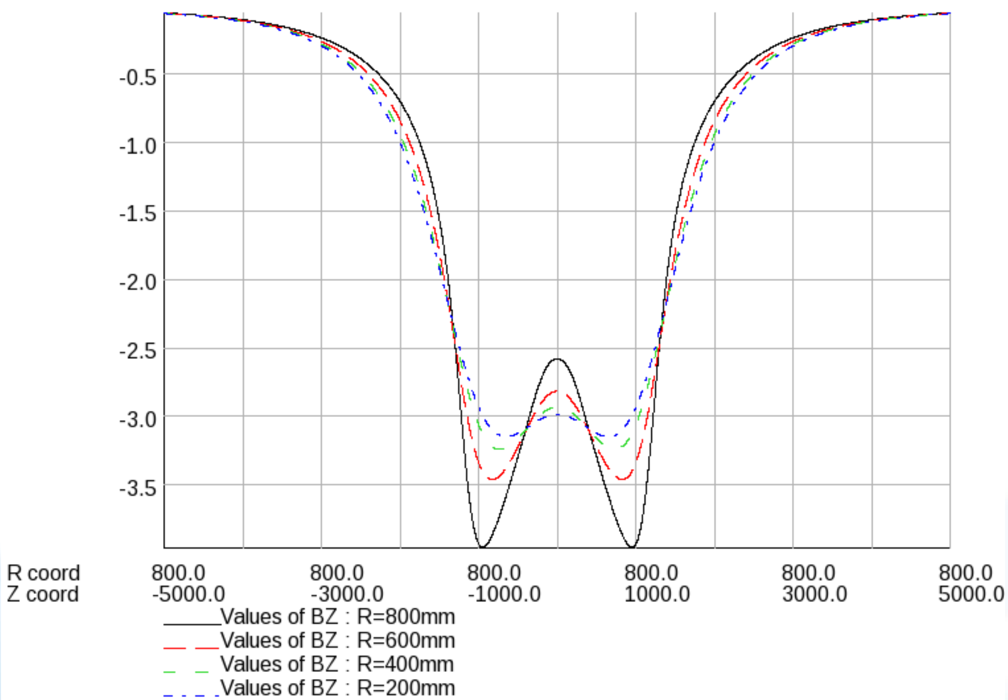
- ~2m long; gas volume radius [200..800] mm
- 1.2% X_0 IFC, 4.0% X_0 OFC; 15.0% X_0 aluminum end-caps
- digitization: 1) idealized, assume 1x5 mm GEM pads; 2) complete (FopiRoot source codes adapted, GEM pad shape tuning in progress)

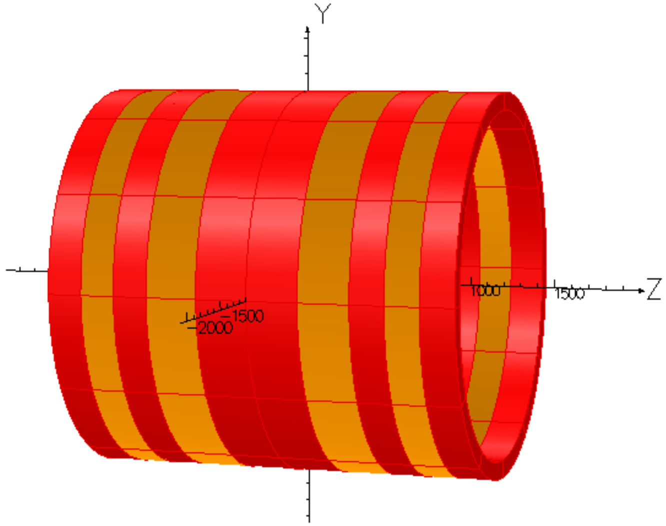
GEM trackers:

- 3 disks behind the TPC end-caps
- STAR FGT design
- digitization: 100 μm resolution in X&Y; gaussian smearing

EIC SOLENOID MODELING

- Constant field option available (of course
- OPERA 2D/3D output adapted



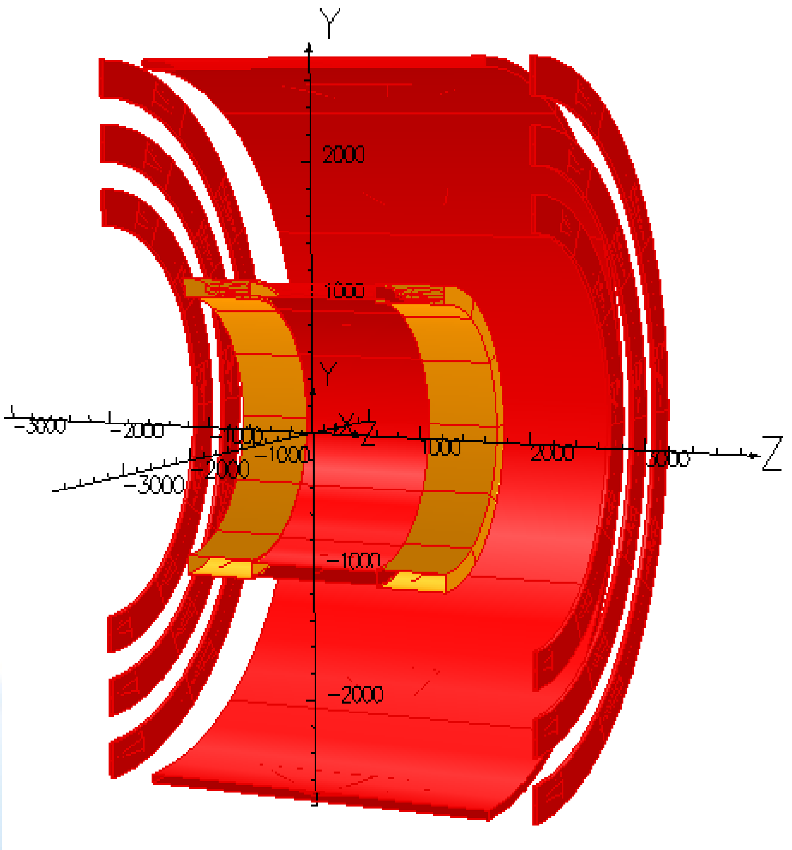


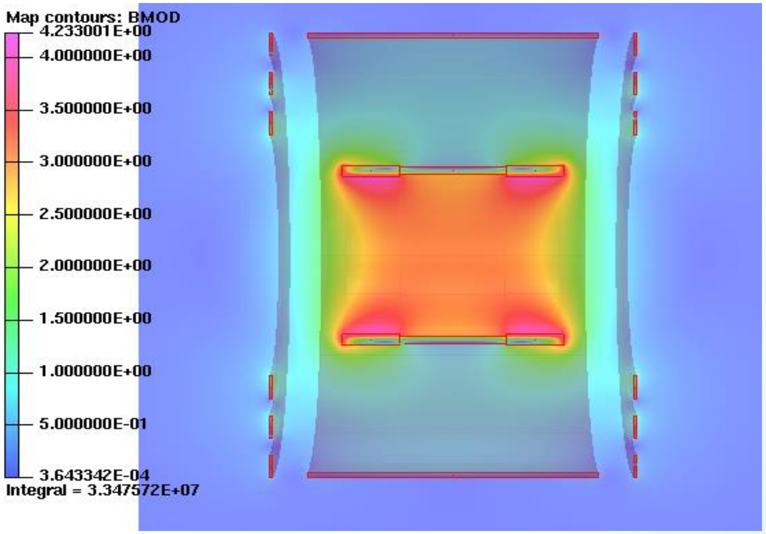
Presently used design: MRS-B1

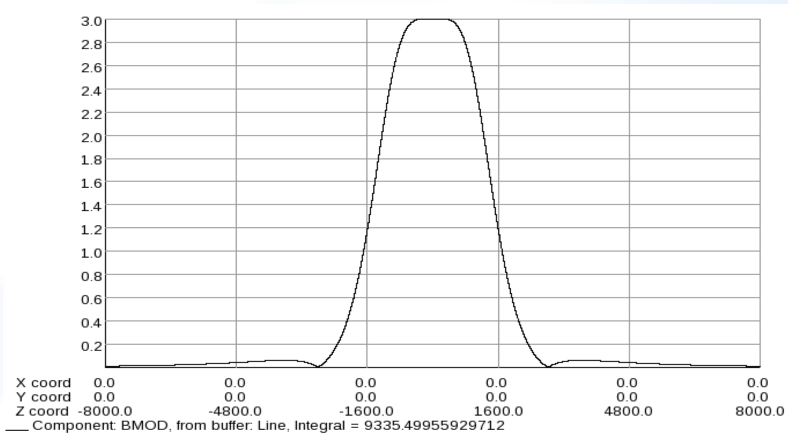
Total Length	: 2.4 m
Inner Radius	: 1.0 m
Outer Radius	: 1.1 m
Central B field:	3.0 T

EIC SOLENOID MODELING

Other options investigated, like 4-th concept solenoid design



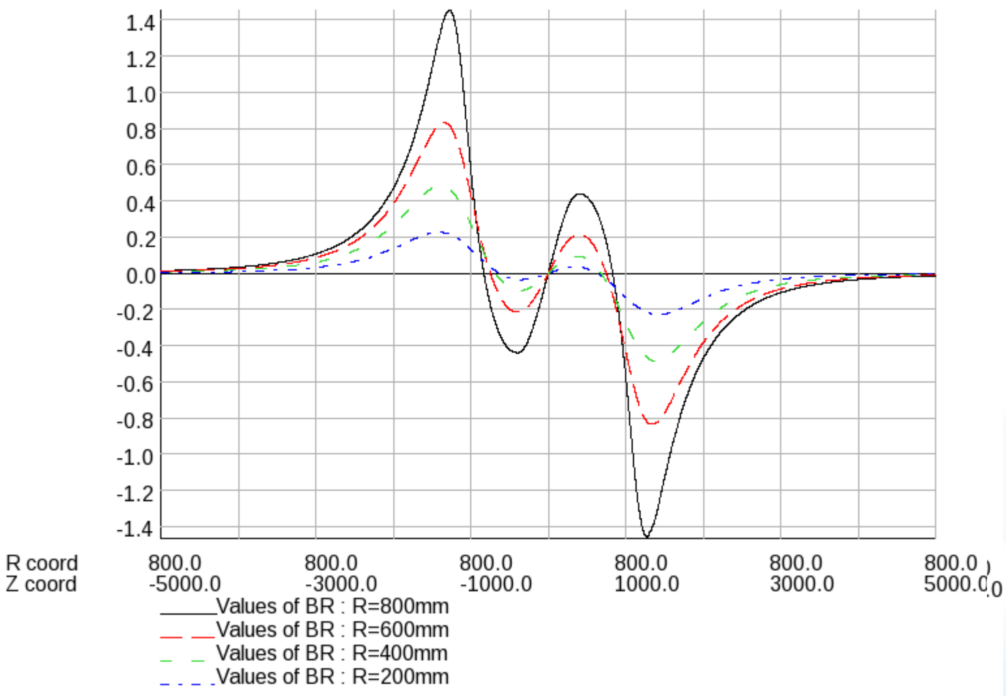




EIC SOLENOID MODELING

main requirements:

- Yield large enough bending for charged tracks at large η
- Keep field inside TPC volume as homogeneous as possible
- Keep magnetic field inside RICH volume(s) small



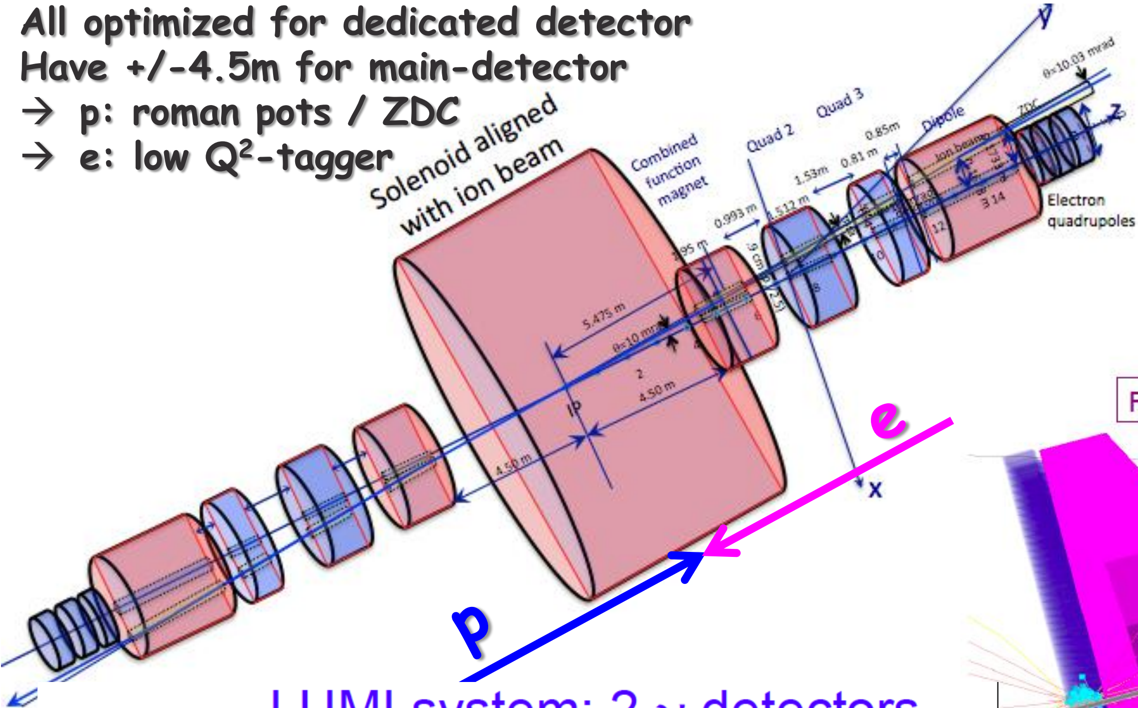
-> use OPERA-3D/2D software

Presently used design: MRS-B1

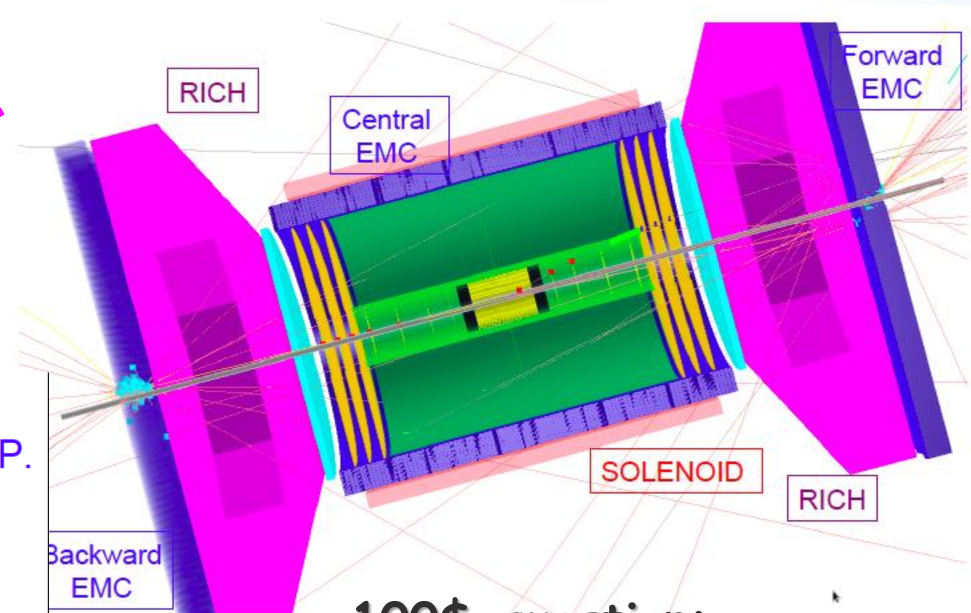
Total Length	:	2.4 m
Inner Radius	:	1.0 m
Outer Radius	:	1.1 m
Central B field	:	3.0 T

DETECTOR AND IR-DESIGN

All optimized for dedicated detector
Have +/-4.5m for main-detector
→ p: roman pots / ZDC
→ e: low Q²-tagger

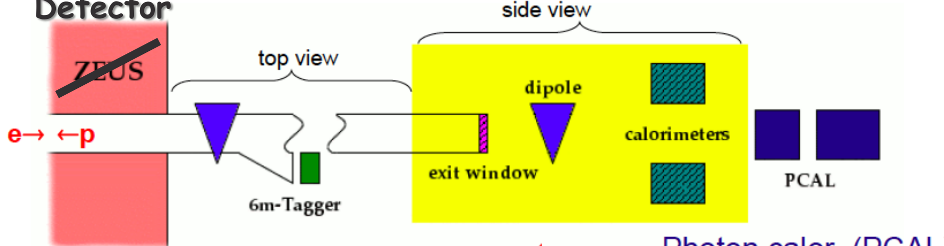


eRHIC-Detector:
collider detector with
-4<η<4 rapidity coverage
and excellent PID



LUMI system: 2 γ detectors

~100 m from I.P.



<u>e tagger @ 6m from I.P.</u>
- Measure scattered *e*
- W-scint. spaghetti calor.
- Check photon accept. (work in progress...)
- Also for physics: tag high W photoprod.
- Not discussed more here...

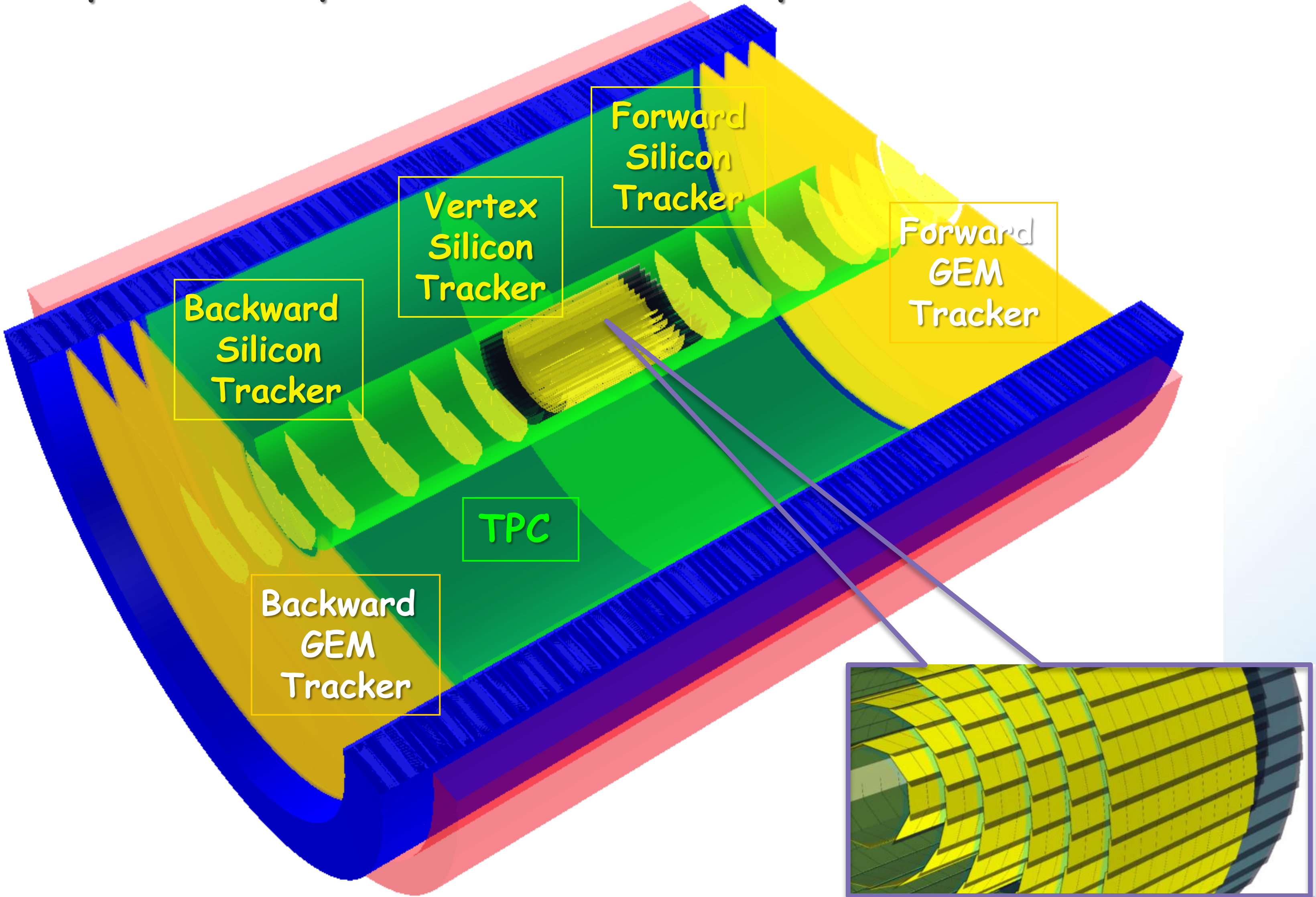
<u>Pair spectrometer</u>
- Measure pairs from $\gamma \rightarrow e^+e^-$ in exit window

<u>Photon calor. (PCAL)</u>
- Direct measure γ

100$-question:
Can we combine
low Q²-tagger
lumi-monitor
and compton polarimeter
in one detector system?

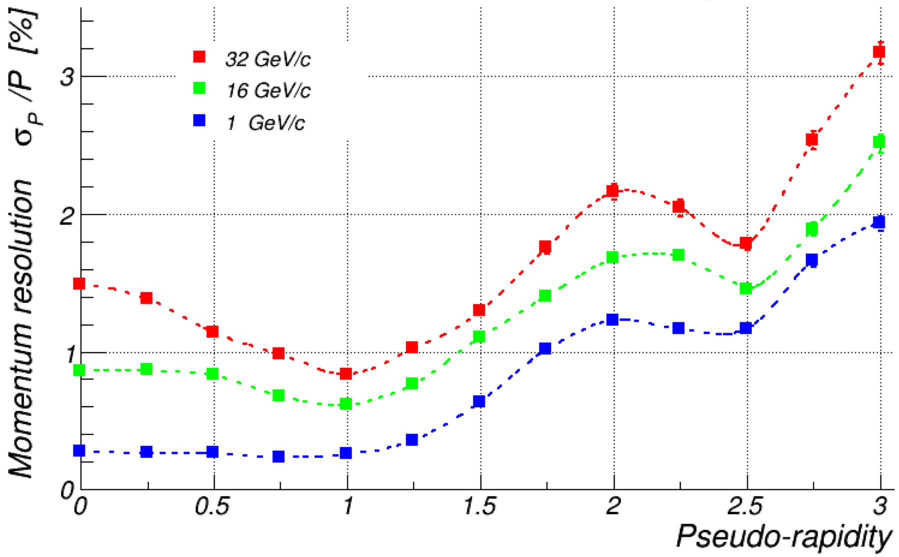
THE eRHIC MODEL DETECTOR CONCEPT

- Implemented in quite some detail whenever possible



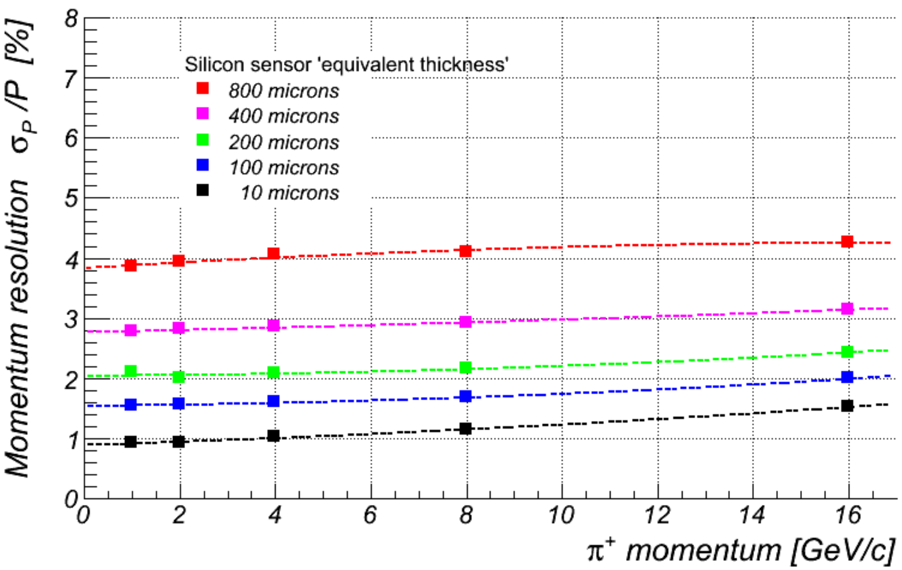
TRACKING PERFORMANCE

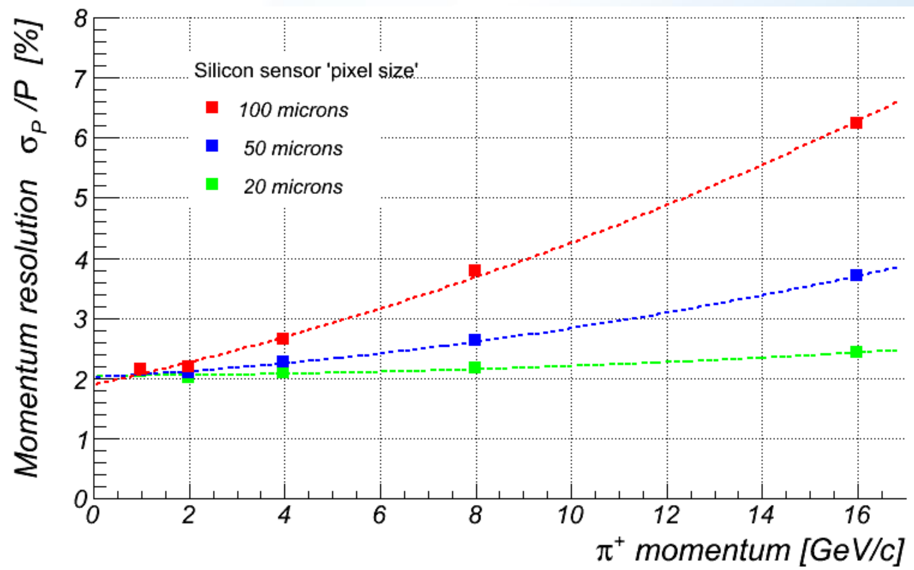
π^+ track momentum resolution vs. pseudo-rapidity



- ❑ Excellent tracking resolution over a wide range in η
- ❑ optimize tracking in combination with magnetic field (see backup)
- ❑ studied alternative tracking setting

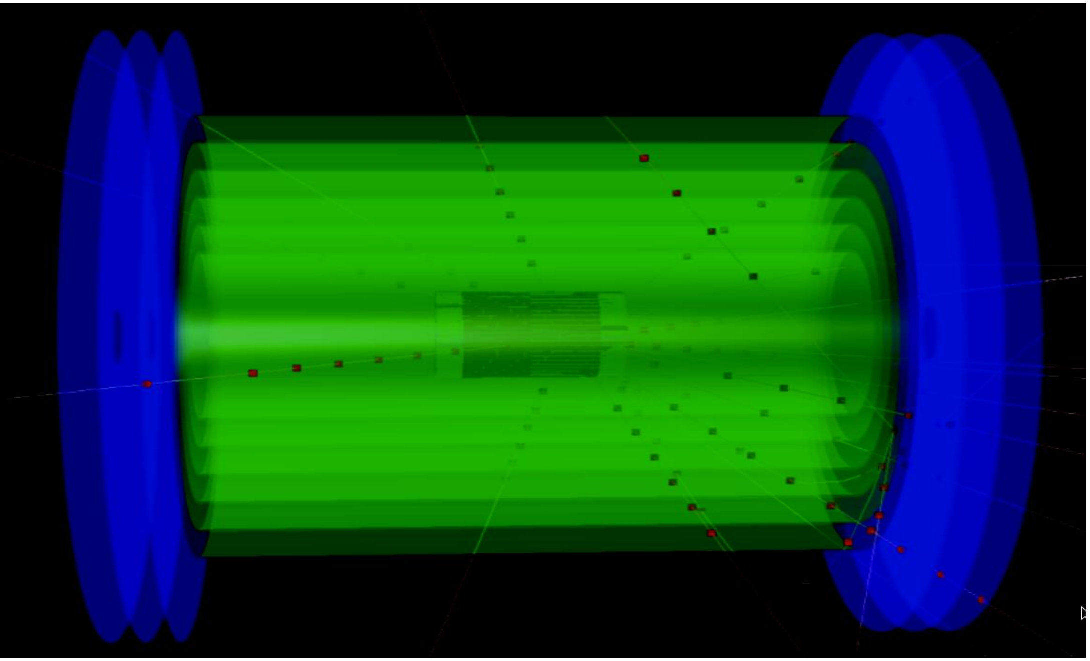
π^+ track momentum resolution at $\eta = 3.0$ vs. Silicon thickness



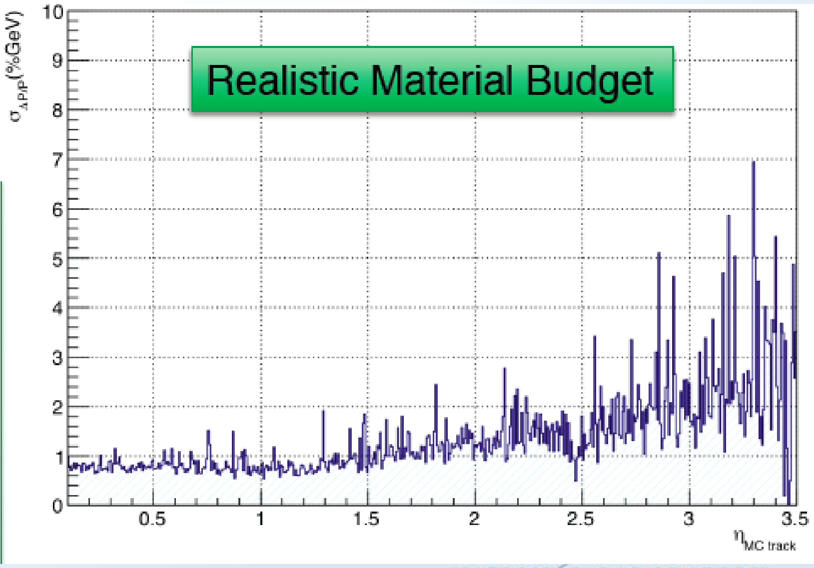


Maxence Vandenbroucke

AN ALTERNATIVE TRACKING SETUP

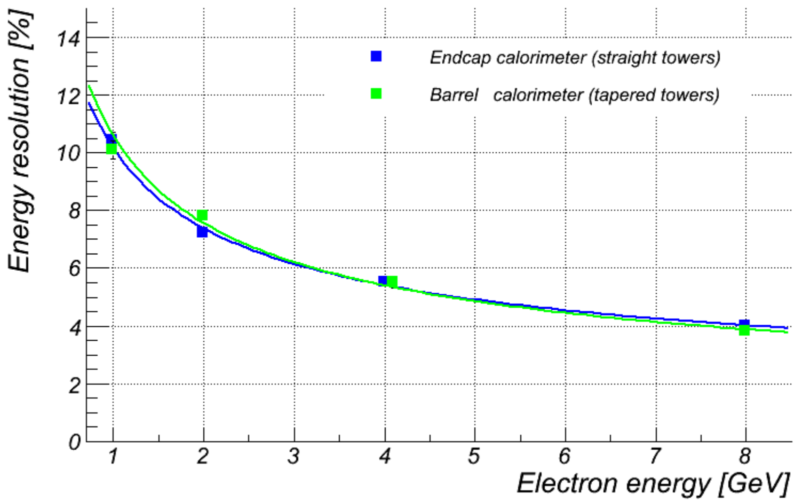


- use 6 cylindrical layers of micromegas instead of TPC (200 μm resolution)
- use forward GEM disks at high rapidity



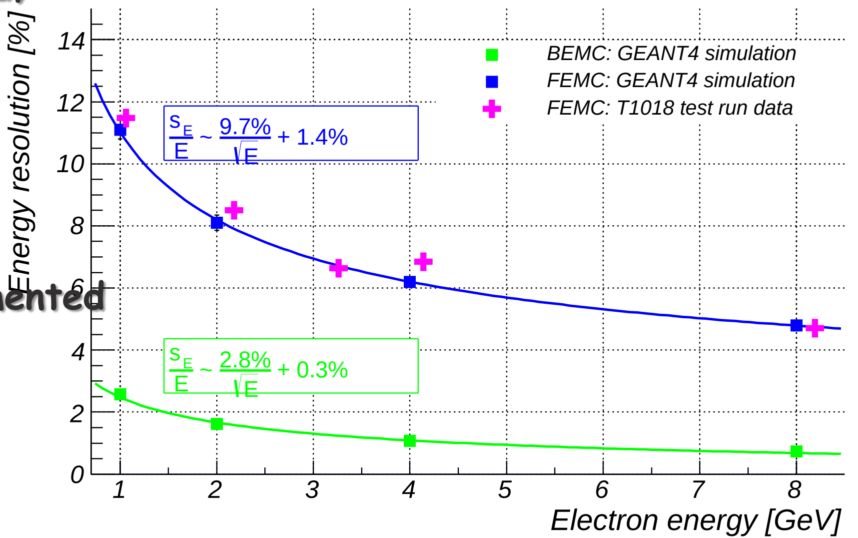
THE MODEL DETECTOR CALORIMETER SYSTEM

C(entral)EMC:
- same tungsten powder + fibers technology as FEMC, …
- … but towers are tapered
- non-projective; radial distance from beam line [815-980] mm
- barrel calorimeter collects less light, but response (at a fixed 3° angle) is perfectly linear

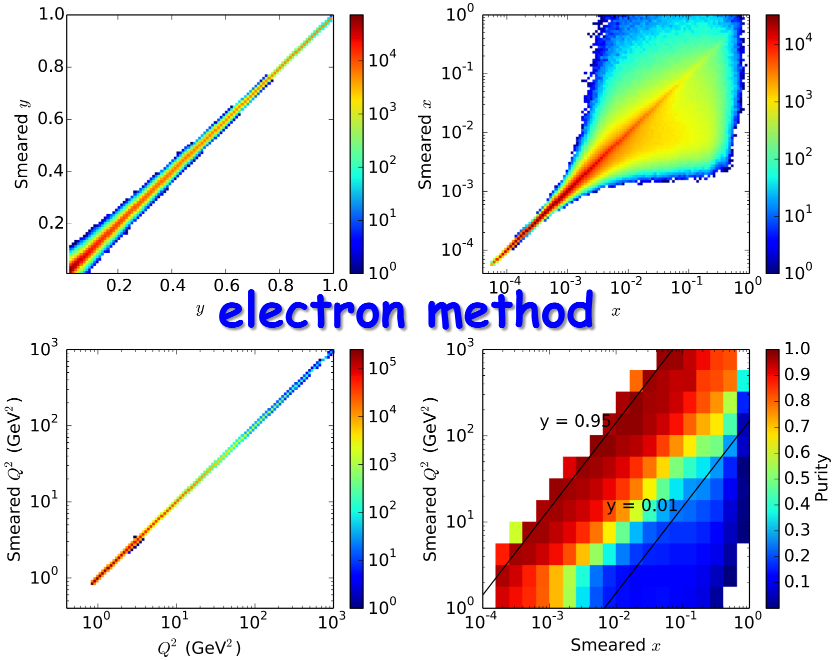


F(orward)EMC:
- tungsten powder scintillating fiber sampling calorimeter technology
- +2500 mm from the IP; non-projective geometry
- sampling fraction for e/m showers ~2.6%
- "medium speed" simulation (up to energy deposit in fiber cores)
- "Realistic" digitization: 40 MHz SiPM noise in 50 ns gate; 4m attenuation length; 5 pixel single tower threshold; 70% light reflection on upstream fiber end;

B(ack)EMC:
- PWO-II, layout a la CMS & PANDA
- -2500 mm from the IP
- both projective and non-projective geometry implemented
- digitization based on PANDA R&D



RESOLUTION IN KINEMATICS VARIABLES

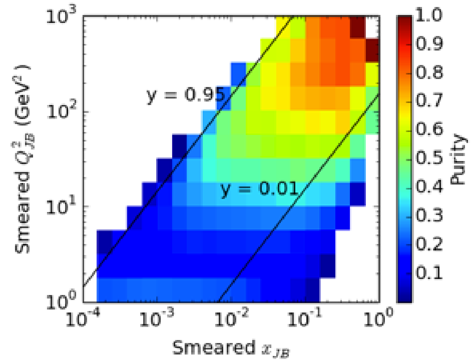


electron method

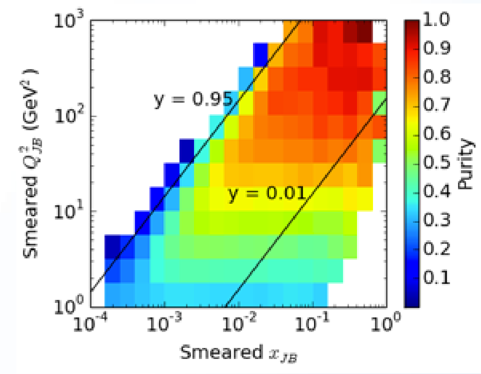
all plots for 15 GeV on 250 GeV

high $Purity = \frac{N_{gen} - N_{out}}{N_{gen} - N_{out} + N_{in}}$ important to unfold measured quantities to Born level

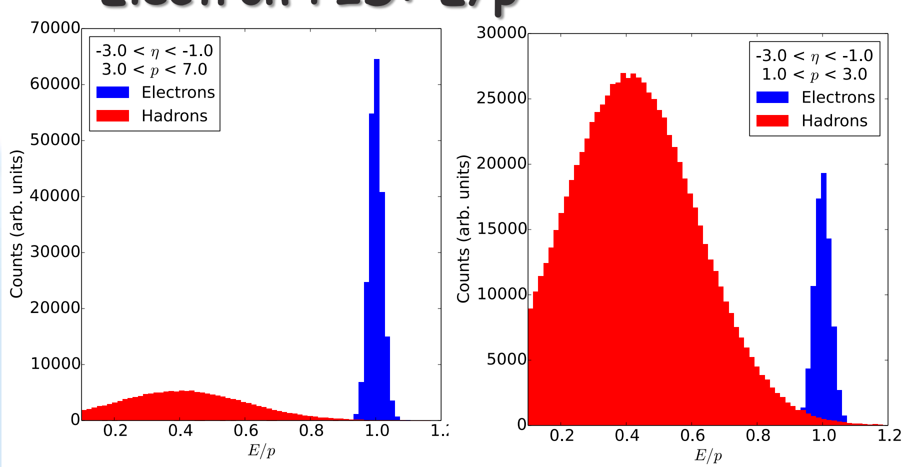
hadron method:



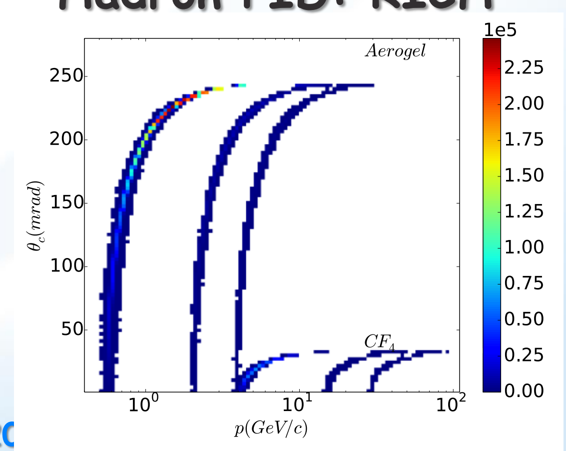
DA method:



Electron PID: E/p



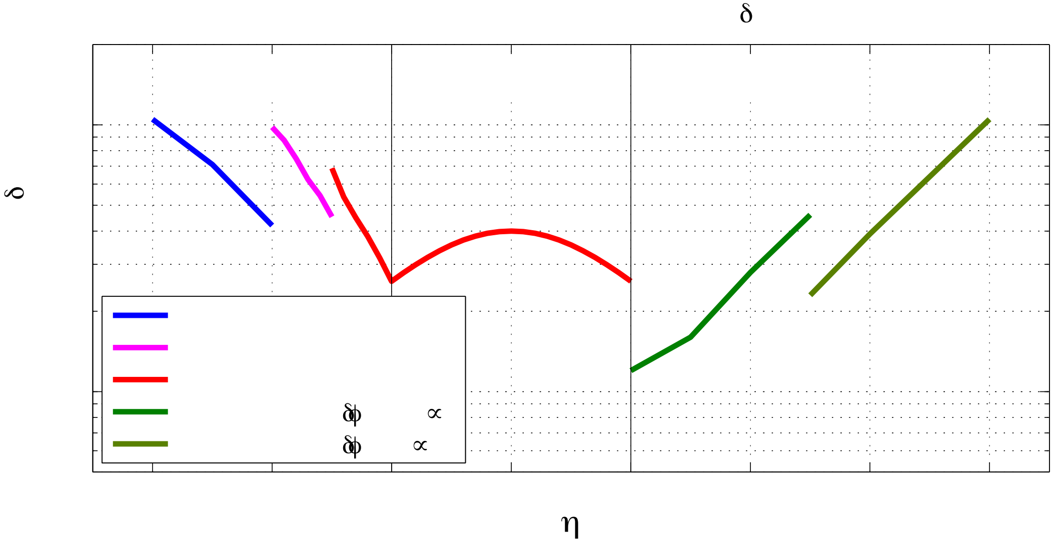
Hadron PID: RICH



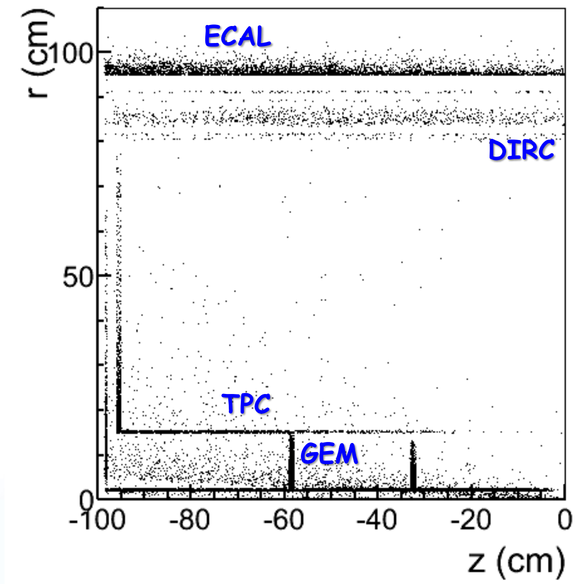
p-resolution critical for RICH performance
→ no photon detector resolution

BROOKHAVEN NATIONAL LABORATORY
E.C. Aschenauer

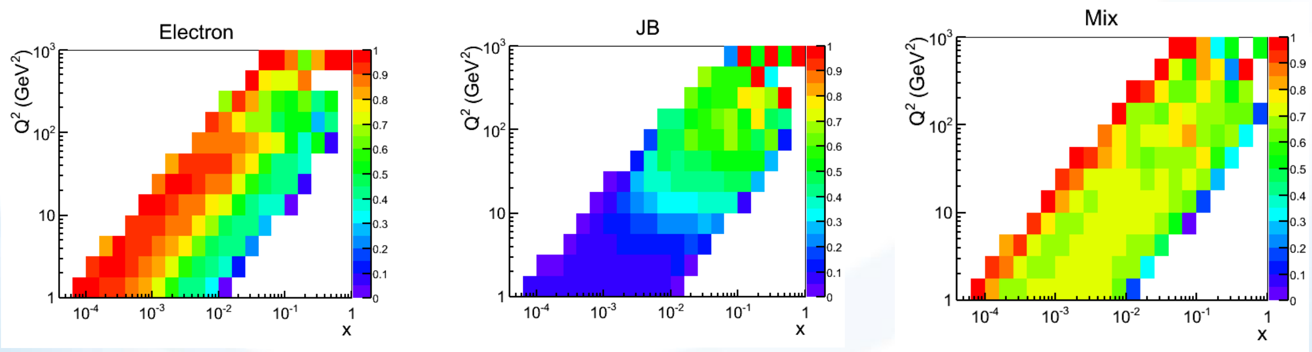
Momentum Resolution:



Bremsstrahlung Sources



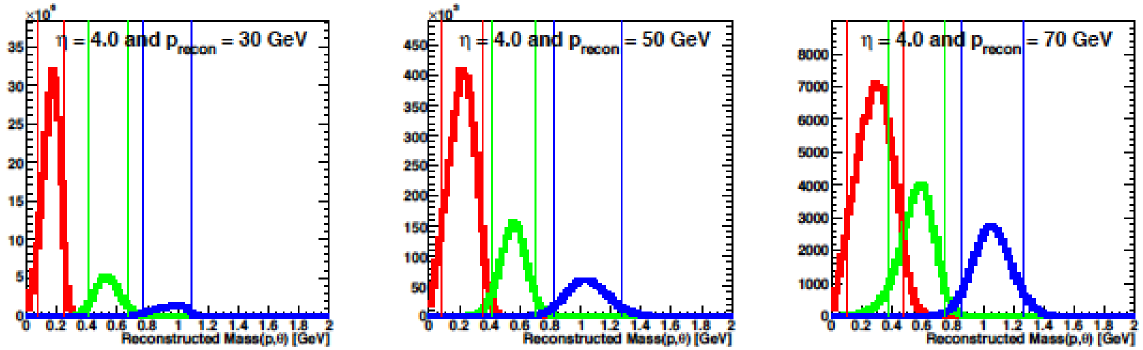
$$Purity = \frac{N_{gen} - N_{out}}{N_{gen} - N_{out} + N_{in}}$$ for electron, JB and DA method



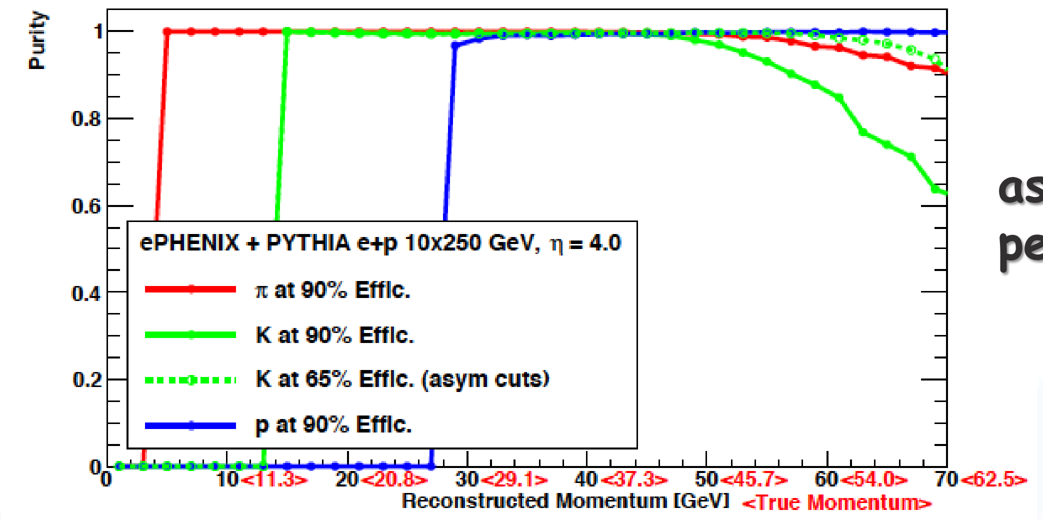
plots for 15 GeV on 250 GeV

ePHENIX DETECTOR PERFORMANCE

Hadron PID at η=4 for a CF_4 gas based RICH detector:



lines: 90% efficiency



assumed radius resolution 2.5% per photon

Momentum reconstructed through tracking and HCal

eSTAR DETECTOR PERFORMANCE

Coverage	Orientation	Tracking	EMC	HCAL	Resolution (momentum or energy)
$-4<\eta<-2$	Electron Beam direction; EAST		BSO		$\sigma_E/E=2\%/\sqrt{E}\oplus0.75\%$
$-2<\eta<-1$		iTPC+GTRD+ETOF			$\sigma_p/p=1/(p_T/p_Z-1/6)\times(0.45\%p_T\oplus0.3\%)\oplus(p_Z/p_T)\times0.2\%/p/\beta$
$-1<\eta<1$	Mid-Rapidity	TPC+TOF	SMD+EMC		$\sigma_E/E=14\%/\sqrt{E}\oplus2\%$ $\sigma_p/p=0.45\%p_T\oplus0.3\%\oplus0.2\%/p/\beta$
$1<\eta<1.7$	Hadron Beam direction; WEST	iTPC+TOF			$\sigma_p/p=1/(p_T/p_Z-1/4)\times(0.45\%p_T\oplus0.3\%)\oplus(p_Z/p_T)\times0.2\%/p/\beta$
$1<\eta<2$		iTPC+FTS	SMD+EMC		$\sigma_E/E=16\%/\sqrt{E}\oplus2\%$
$2.5<\eta<5$		FTS	W-fiber EMC	HCAL	$\sigma_E/E=12\%/\sqrt{E}\oplus1.4\%$ $\sigma_E/E=38\%/\sqrt{E}\oplus3\%$

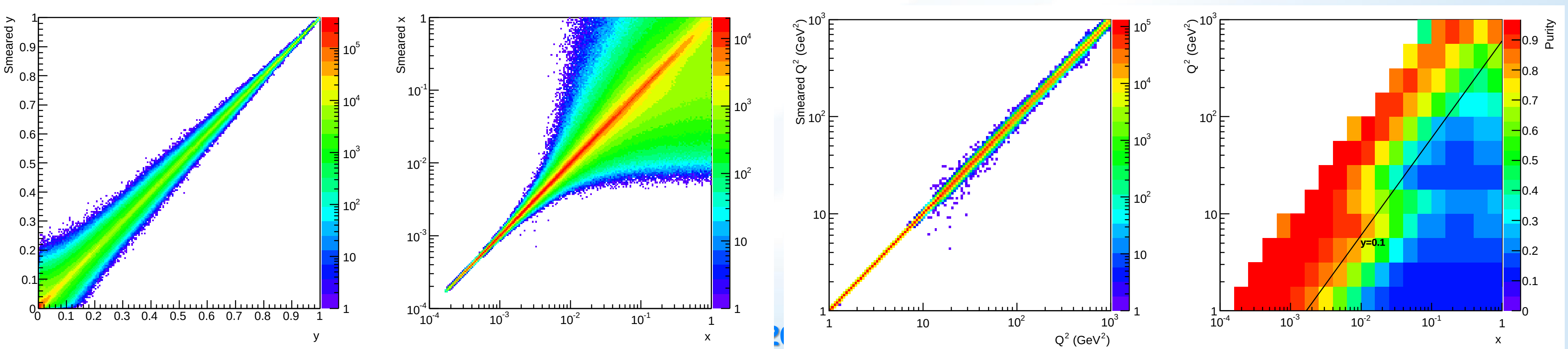
p and E Resolutions

PID Performance:

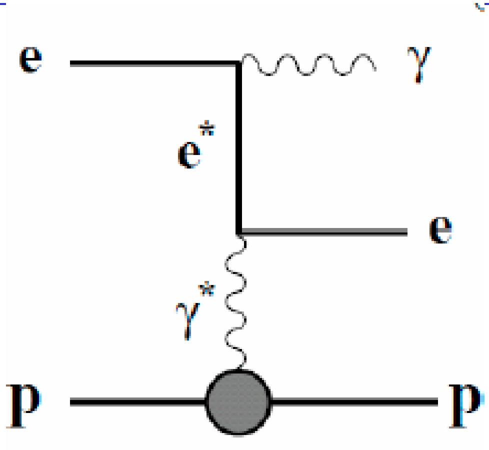
	$e^\pm$	γ/π^0	$\pi^\pm$	$K^\pm$	p
$-4<\eta<-2$	Y	Y	N	N	N
$-2<\eta<-1$	Y	N	$0.1<p<15$ GeV	$0.1<p<3$ GeV	$0.1<p<5$ GeV
$-1<\eta<1$	Y	Y			
$1<\eta<1.7$	Y	Y			
$1.7<\eta<2$	Y	Y	N	N	N
$2<\eta<2.5$	Tracking without PID (charged hadrons)				
$2.5<\eta<5$	Y	Y	Tracking and Energy without PID		

resolutions in kinematic variables from the lepton method combining new and very well understood STAR detectors.

$$Purity=\frac{N_{gen}-N_{out}}{N_{gen}-N_{out}+N_{in}}$$



LUMINOSITY MEASUREMENT: PHYSICS PROCESSES

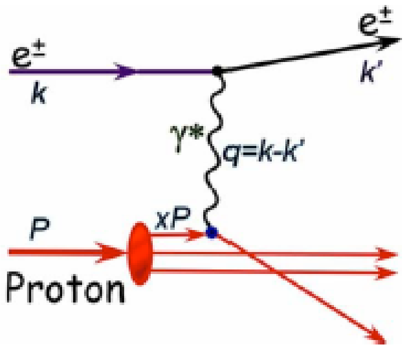


Bremsstrahlung ep→ eγp

Bethe-Heitler (collinear emission):
- very high rate of 'zero angle' photons and electrons, but
- sensitive to the details of beam optics at IP
- requires precise knowledge of geometrical acceptance
- suffers from synchrotron radiation
- aperture limitation
- pile-up

QED Compton (wide angle bremsstrahlung):
- lower rate, but
- stable and well known acceptance of central detector

→ **Methods are complementary, different systematics**



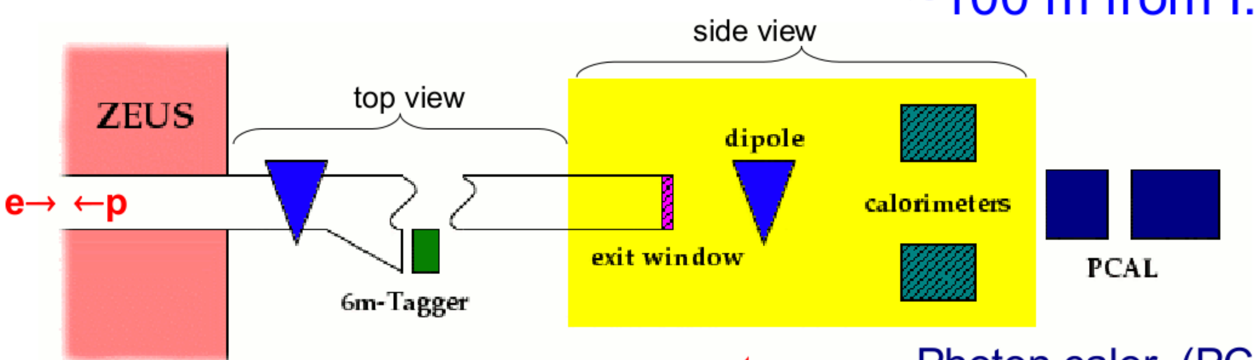
NC DIS in (x,Q^2) range where F_2 is known to $O(1\%)$ for relative normalisation and mid-term yield control

- Concept:

  Use Bremsstrahlung ep → epγ as reference cross section
  - normally only γ is measured
  - Hera: reached 1-2% systematic uncertainty

ZEUS LUMI system: 2 γ detectors

~100 m from I.P.



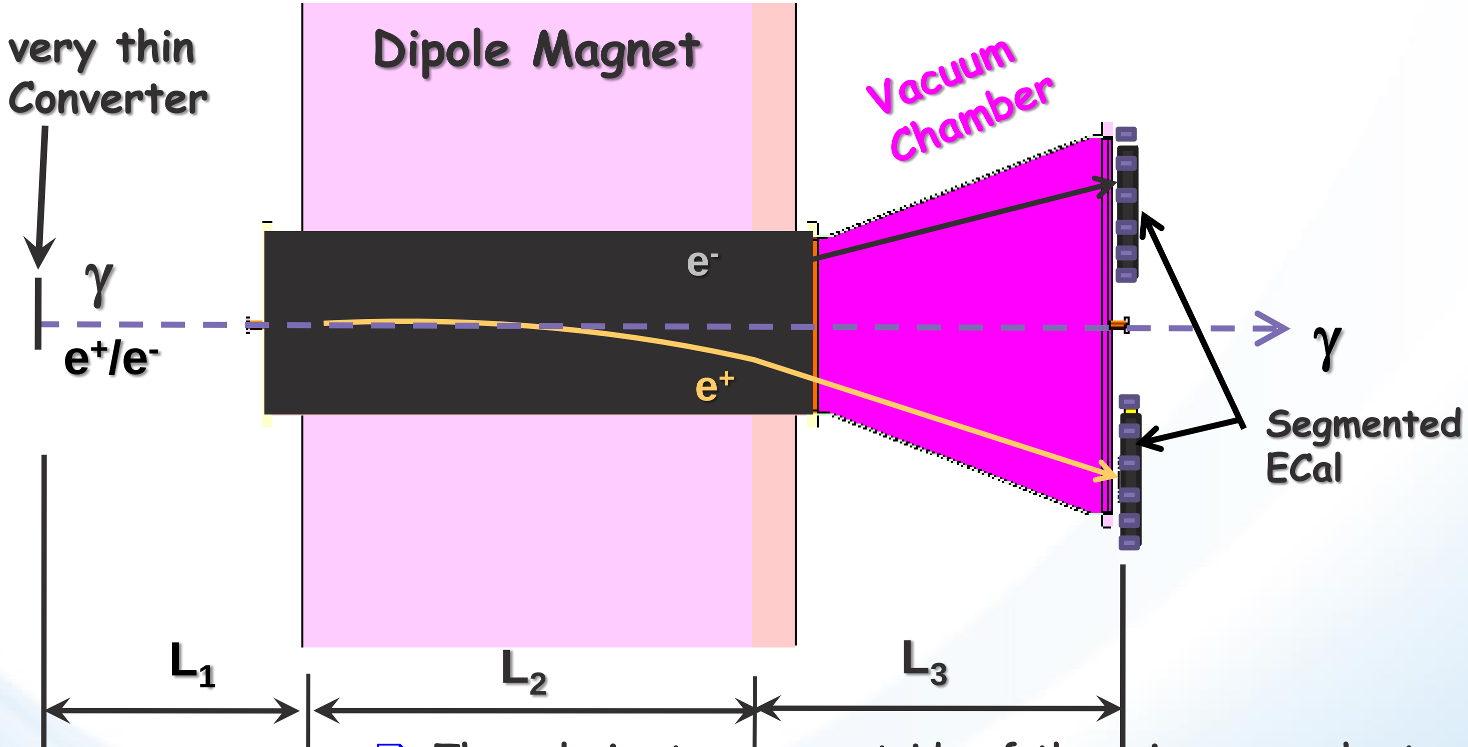
Photon calor. (PCAL)
- Direct measure γ

e tagger @ 6m from I.P.
- Measure scattered *e*
- W-scint. spaghetti calor.
- Check photon accept. (work in progress...)
- Also for physics: tag high W photoprod.
- Not discussed more here...

Pair spectrometer
- Measure pairs from $\gamma \to e^+e^-$ in exit window

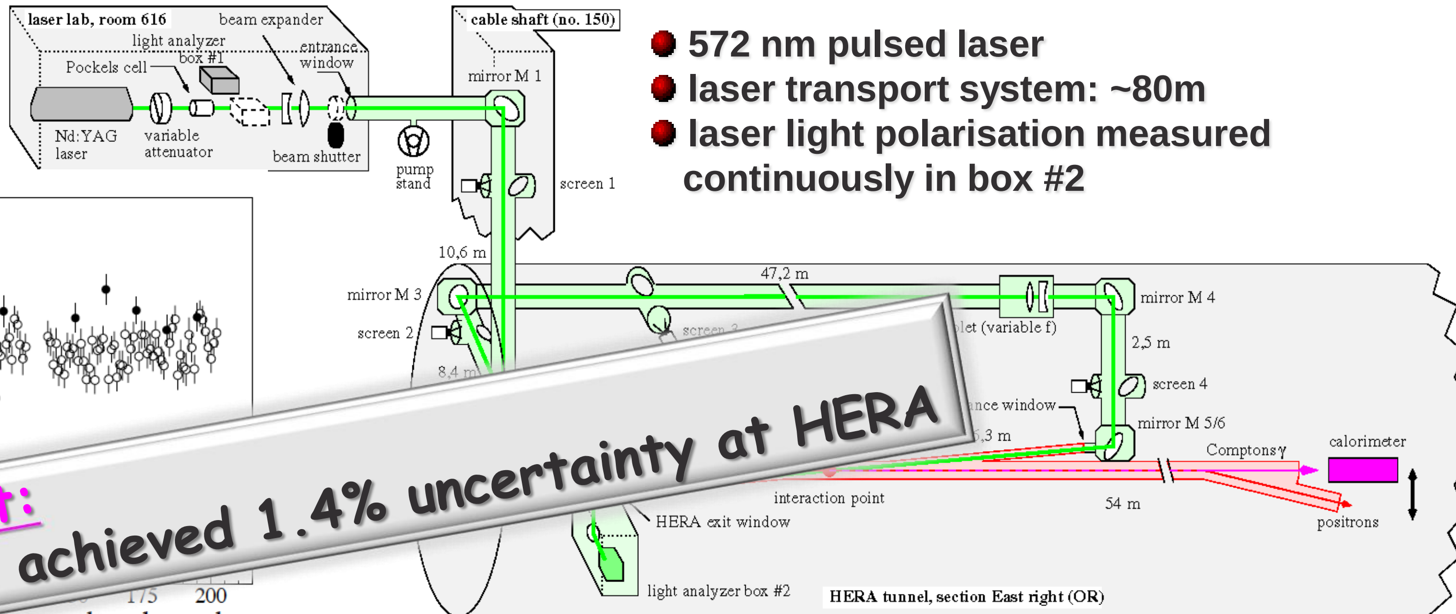
3

- zero degree calorimeter
  - high rate → measured energy proportional to # photons
  - subject to synchrotron radiation
- alternative pair spectrometer

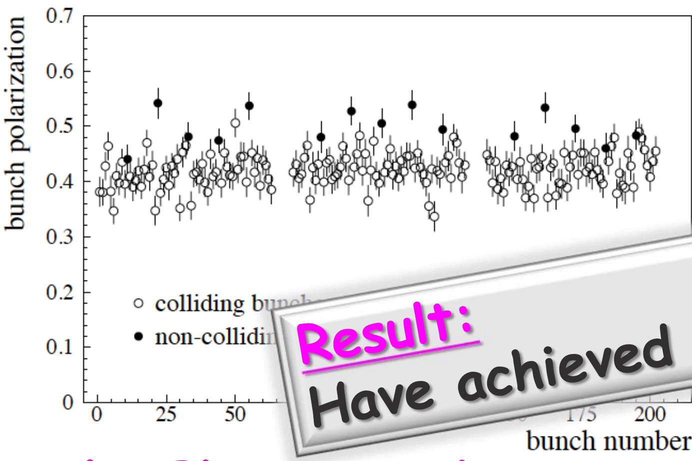


- The calorimeters are outside of the primary synchrotron radiation fan
- The exit window conversion fraction reduces the overall rate
- The spectrometer geometry imposes a low energy cutoff in the photon spectrum, which depends on the magnitude of the dipole field and the transverse location of the calorimeters

❑ Method: Compton backscattering



- 572 nm pulsed laser
- laser transport system: ~80m
- laser light polarisation measured continuously in box #2



Result:
Have achieved 1.4% uncertainty at HERA

Multi-Photon Mode:

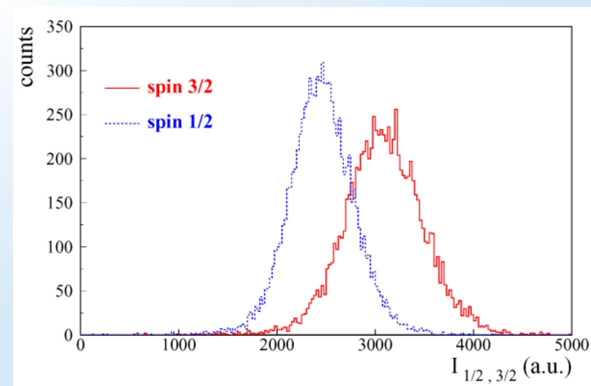
Advantages:

- eff. independent of brems. bkg and photon energy cutoff
- $dP/P = 0.01$ in 1 min

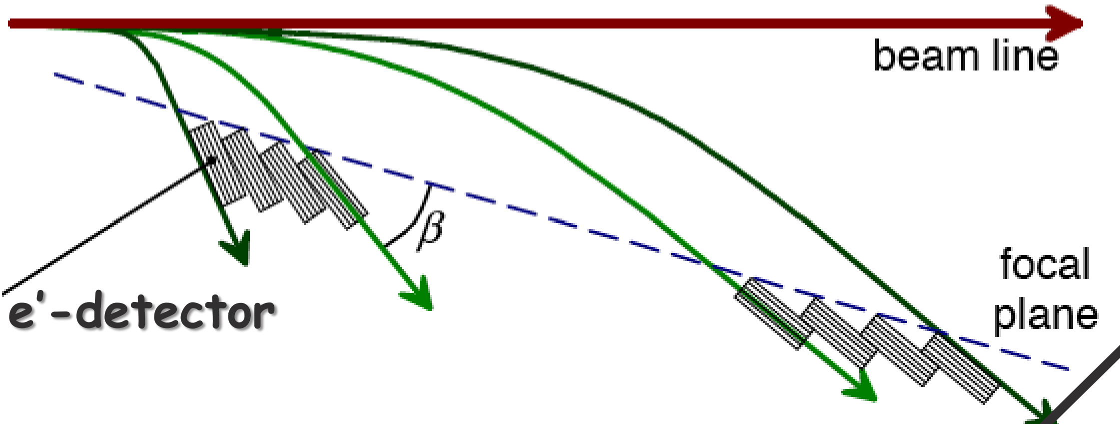
Disadvantage:

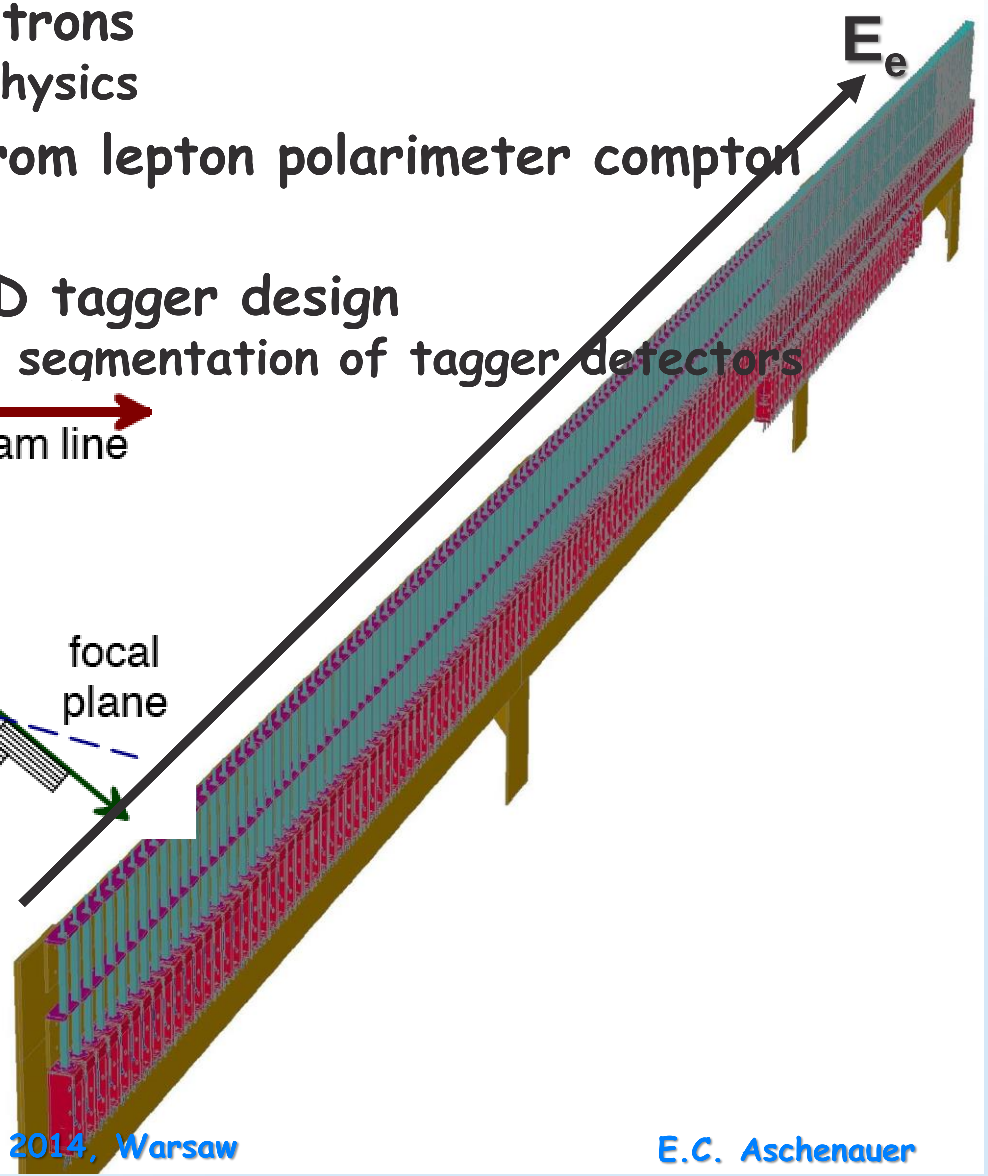
- no easy monitoring of calorimeter performance

$$A_m = (I_{3/2} - I_{1/2}) / (I_{3/2} + I_{1/2})$$
$$= P_e \, P_\lambda \, A_{p;} \qquad A_p = 0.184$$



- e'-tagger:
  - detect low Q^2 scattered electrons → quasi-real photoproduction physics
  - possibly also detect lepton from lepton polarimeter compton scattering
  - design could follow the Hall-D tagger design
    - pileup can be avoided by fine segmentation of tagger detectors

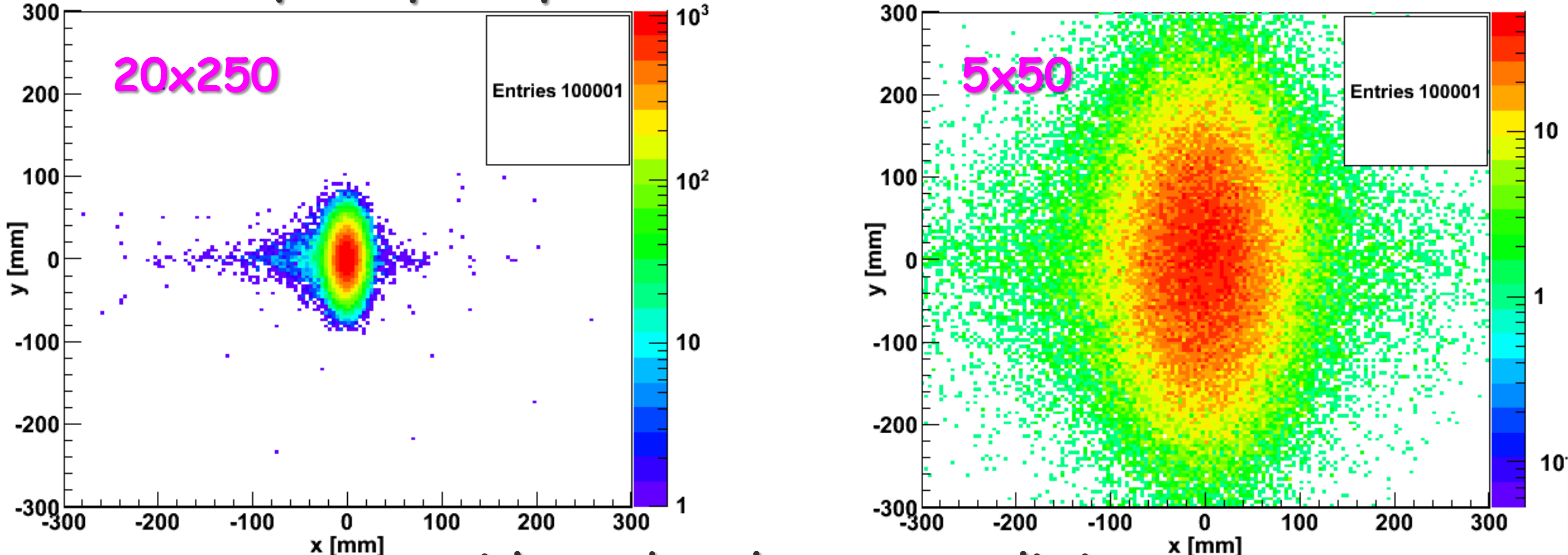




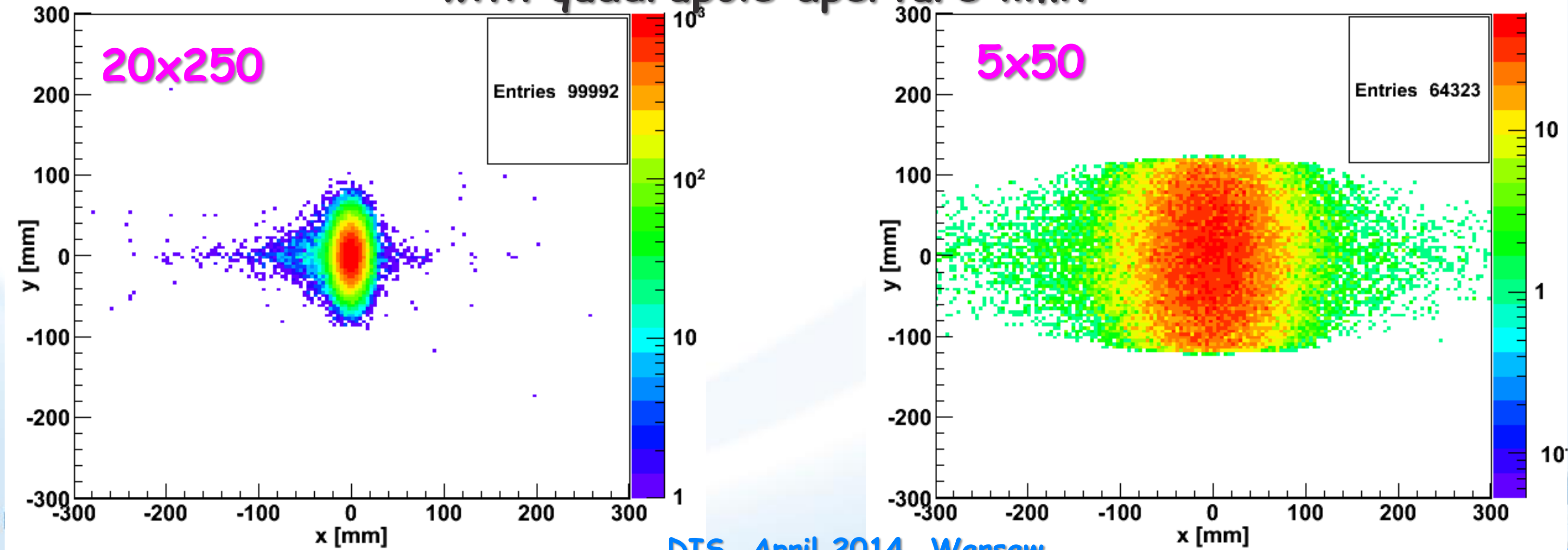
Array of Scintillators very finely spaced
might need less segmentation
Scintillator → Calorimeter

PROTON DISTRIBUTION IN Y VS X AT S=20 M

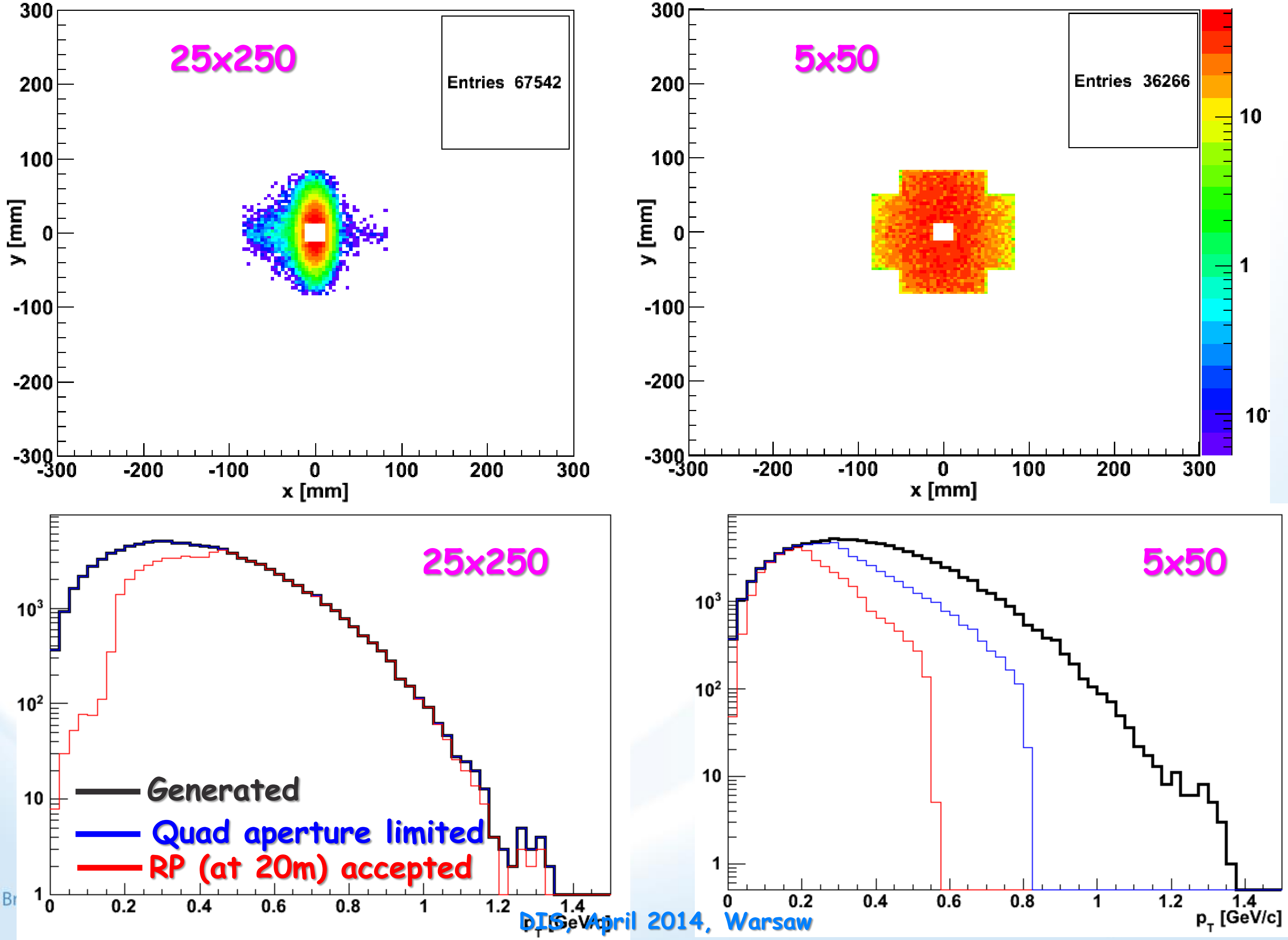
without quadrupole aperture limit



with quadrupole aperture limit

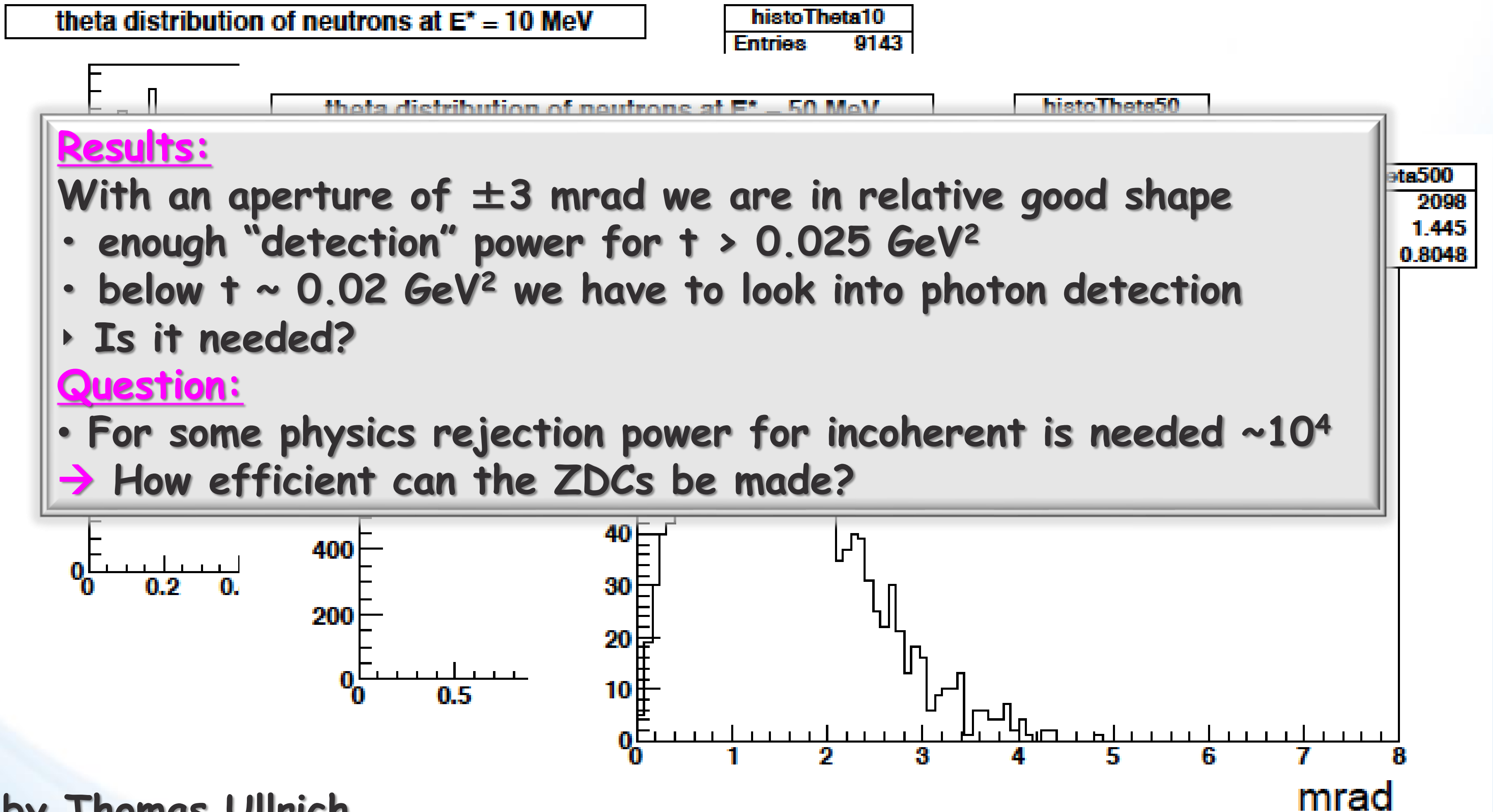


ACCEPTED IN "ROMAN POT" (EXAMPLE) AT S=20M



KINEMATICS OF BREAKUP NEUTRONS

Results from GEMINI++ for 50 GeV Au



Results:

With an aperture of ±3 mrad we are in relative good shape

- enough "detection" power for t > 0.025 GeV^2
- below t ~ 0.02 GeV^2 we have to look into photon detection
  - Is it needed?

Question:

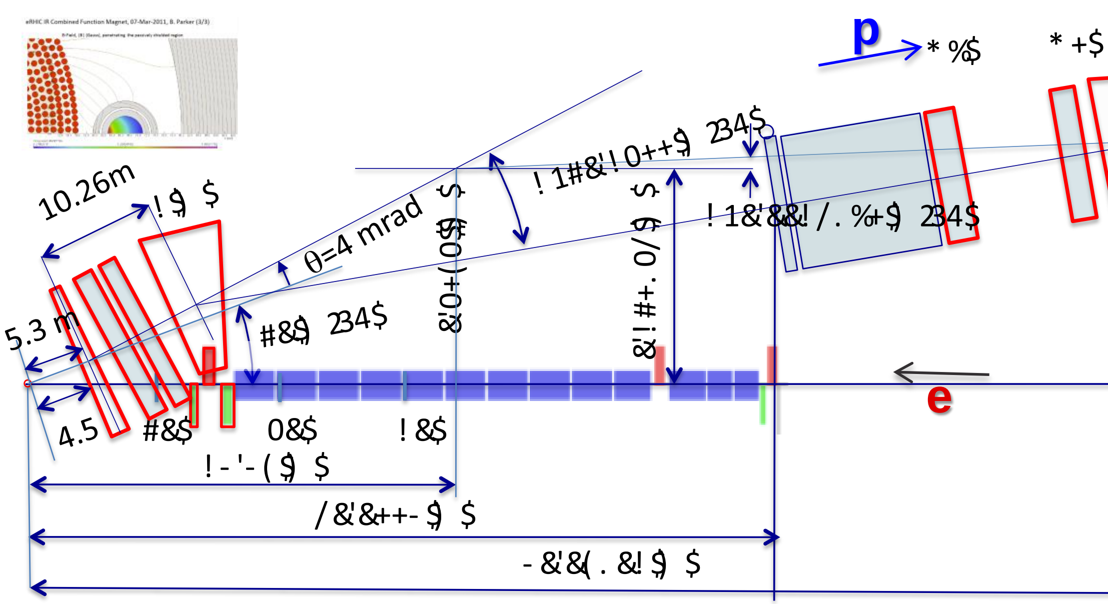
- For some physics rejection power for incoherent is needed ~10^4

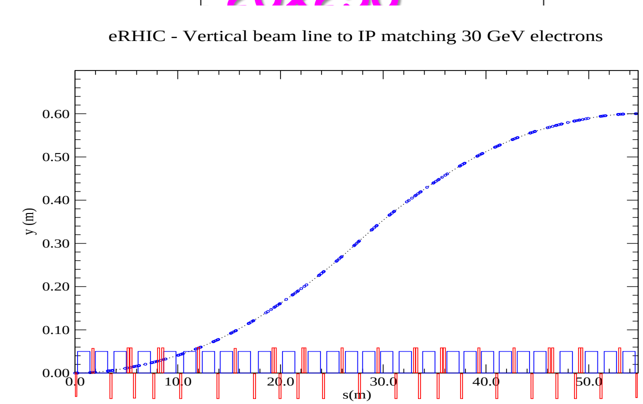
→ How efficient can the ZDCs be made?

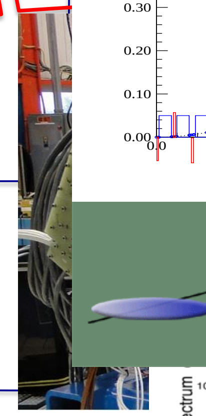
by Thomas Ullrich

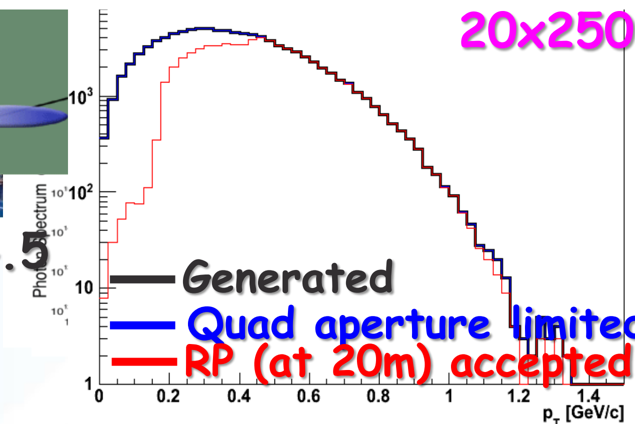
+/-5mrad acceptance seems sufficient

eRHIC: HIGH-LUMINOSITY IR









eRHIC - Geometry high-lumi IR with β*=5 cm, l*=4.5 and 10 mrad crossing angle → 10^{34} cm^{-2} s^{-1}

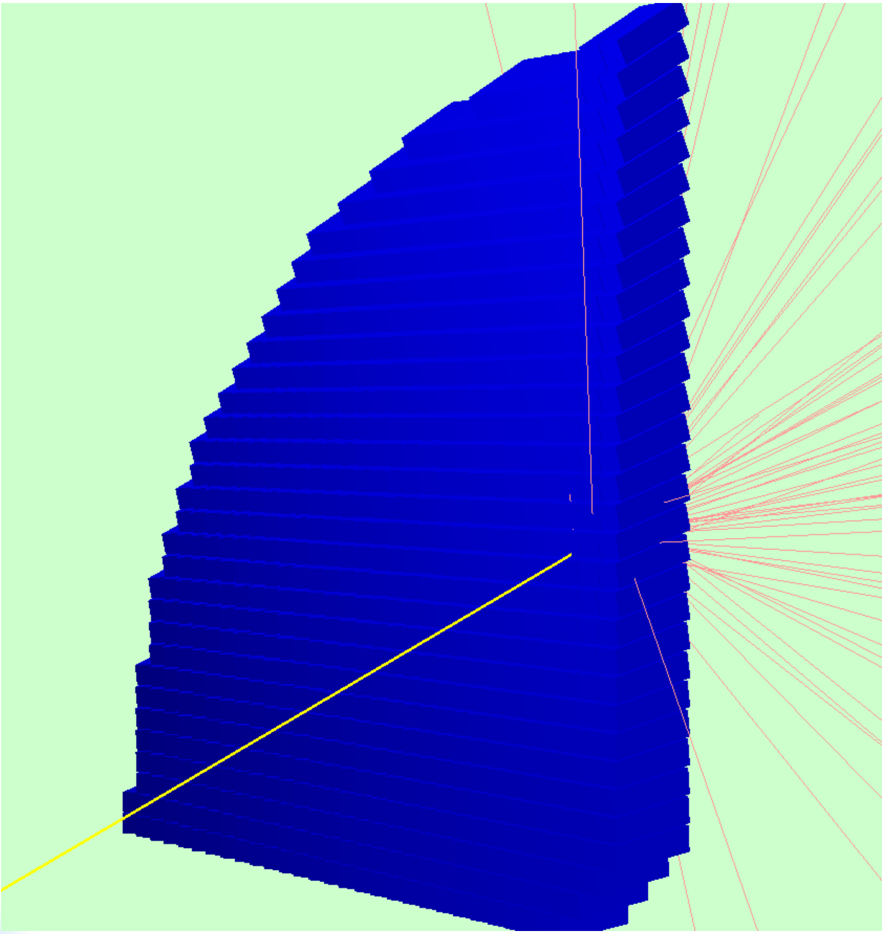
- 10 mrad crossing angle and crab-crossing
- High gradient (200 T/m) large aperture Nb_3Sn focusing magnets
- Arranged free-field electron pass through the hadron triplet magnets
- Integration with the detector: efficient separation and registration of low angle collision products
- Gentle bending of the electrons to avoid SR impact in the detector

Electron-"Ion" colliders in the past and future:

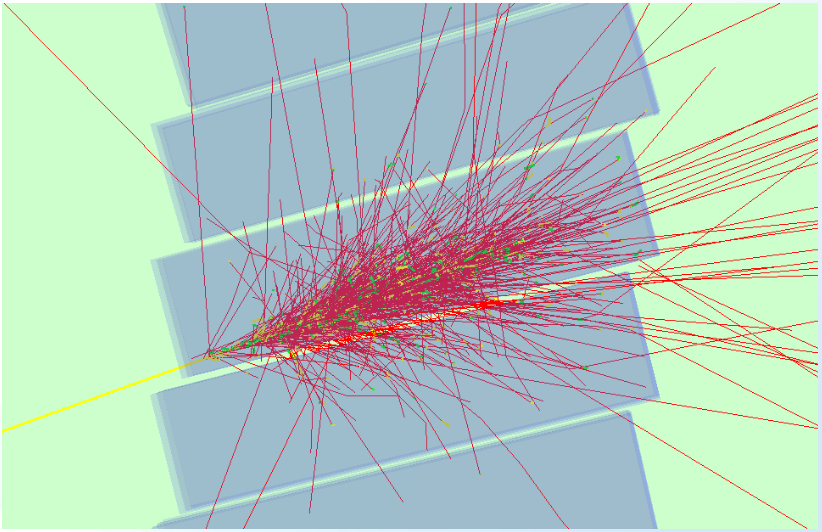
	HERA@DESY	LHeC@CERN	eRHIC@BNL	MEIC@JLab	HIAF@CAS	ENC@GSI
E_{CM} (GeV)	320	800-1300	45-175	12-140	12 → 65	14
proton x_{min}	1×10^{-5}	5×10^{-7}	3×10^{-5}	5×10^{-5}	7×10^{-3} $\rightarrow 3 \times 10^{-4}$	5×10^{-3}
ion	p	p to Pb	p to U	p to Pb	p to U	p to ~ ^{40}Ca
polarization	-	-	p, ^{3}He	p, d, ^{3}He (^{6}Li)	p, d, ^{3}He	p,d
L [cm^{-2} s^{-1}]	2×10^{31}	10^{33}	10^{33-34}	10^{33-34}	$10^{32-33} \rightarrow 10^{35}$	10^{32}
IP	2	1	2+	2+	1	1
Year	1992-2007	2022 (?)	2022	Post-12 GeV	2019 → 2030	upgrade to FAIR

BACKWARD EM CALORIMETER (BEMC)

- PWO-II, layout a la CMS & PANDA
- -2500mm from the IP
- both projective and non-projective geometry implemented
- digitization based on PANDA R&D

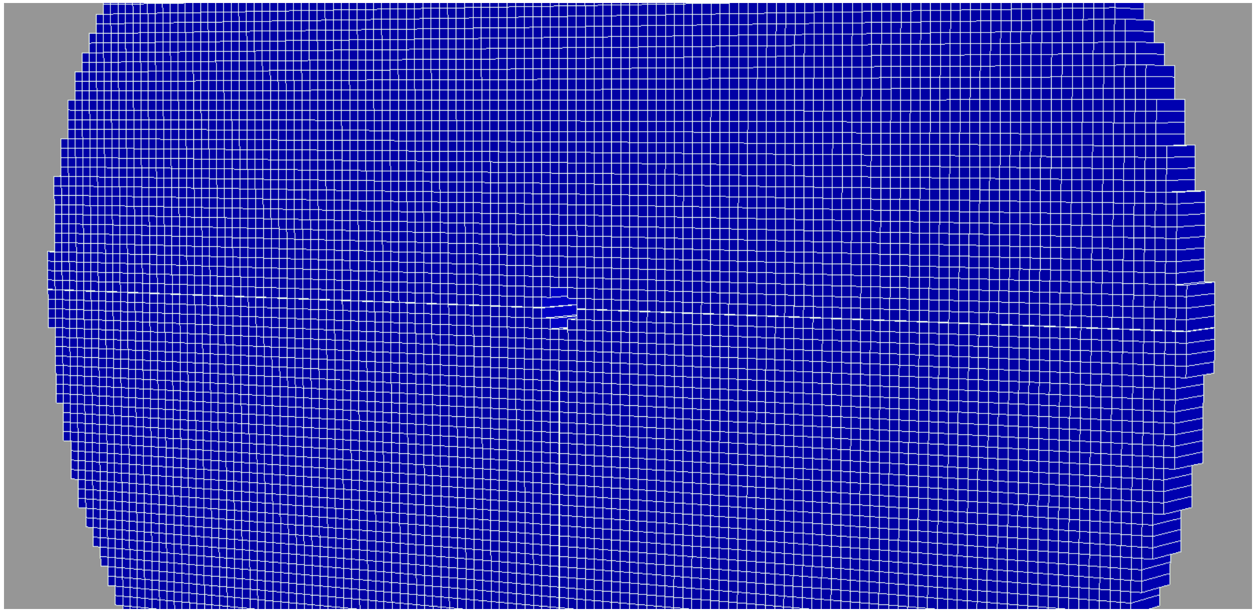


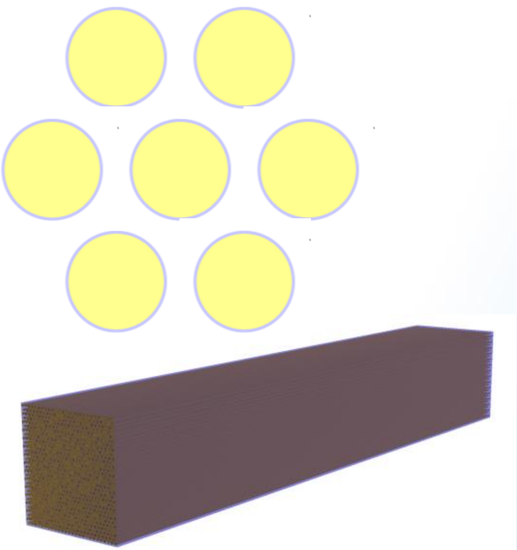
10 GeV/c electron hitting one of the four BEMC quadrants



Same event (details of shower development)

FORWARD EM CALORIMETER (FEMC)



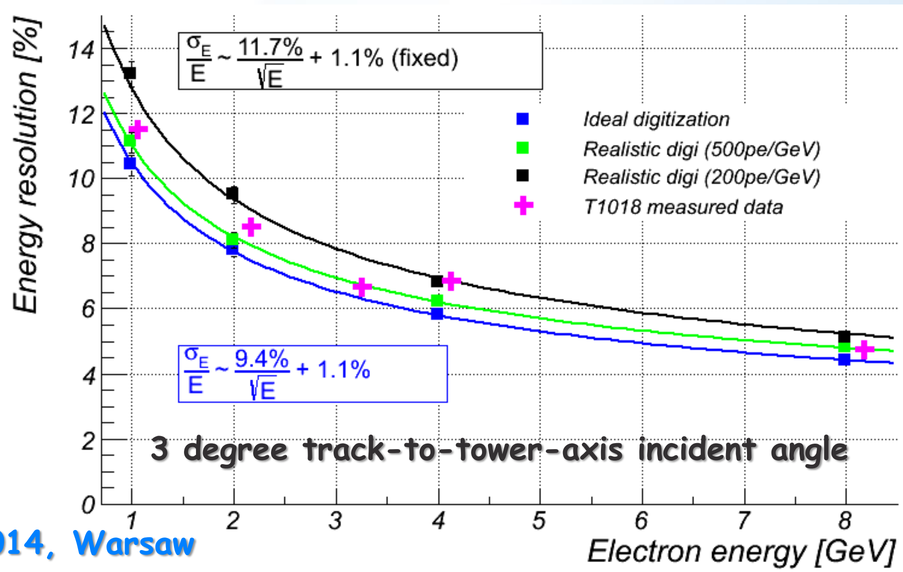


tower (and fiber) geometry described precisely

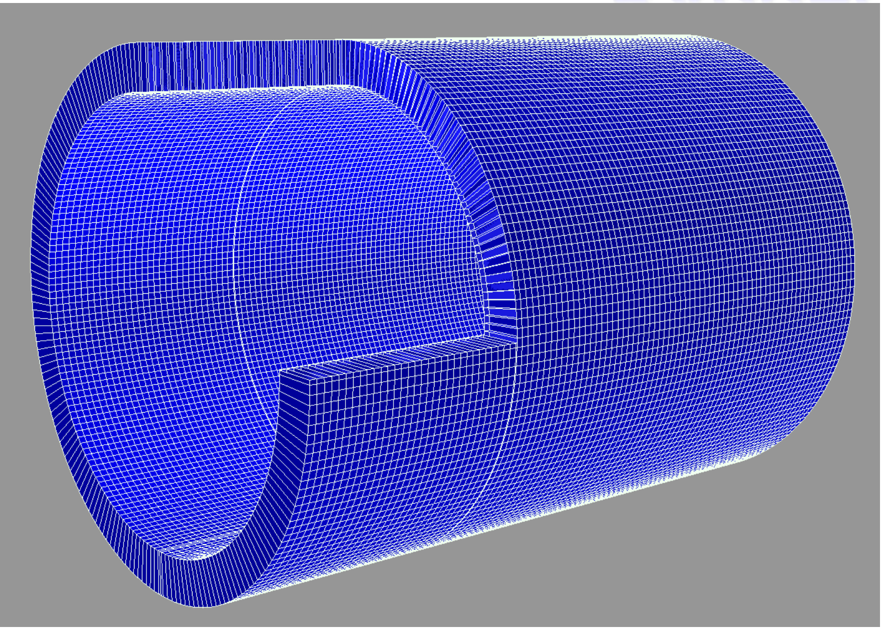
- tungsten powder scintillating fiber sampling calorimeter technology
- +2500mm from the IP; non-projective geometry
- sampling fraction for e/m showers ~2.6%
- "medium speed" simulation (up to energy deposit in fiber cores)
- reasonably detailed digitization; "ideal" clustering code

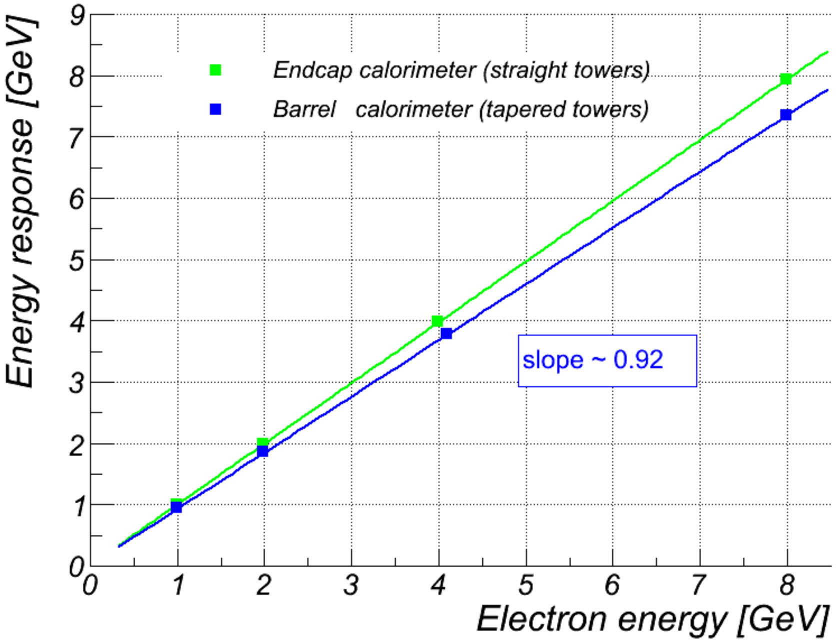
- "Realistic" digitization: 40MHz SiPM noise in 50ns gate;
- 4m attenuation length; 5 pixel single tower threshold;
- 70% light reflection on upstream fiber end;

-> good agreement with original MC studies and measured data



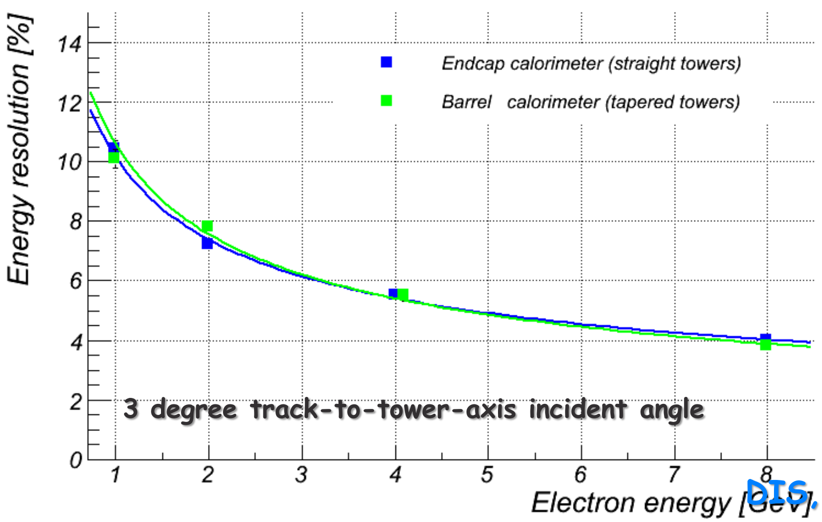
BARREL EM CALORIMETER (CEMC)





- same tungsten powder + fibers technology as FEMC, …
- … but towers are tapered
- non-projective

-> barrel calorimeter collects less light, but response (at a fixed 3^o angle) is perfectly linear



-> simulation does not show any noticeable difference in energy resolution between straight and tapered tower calorimeters