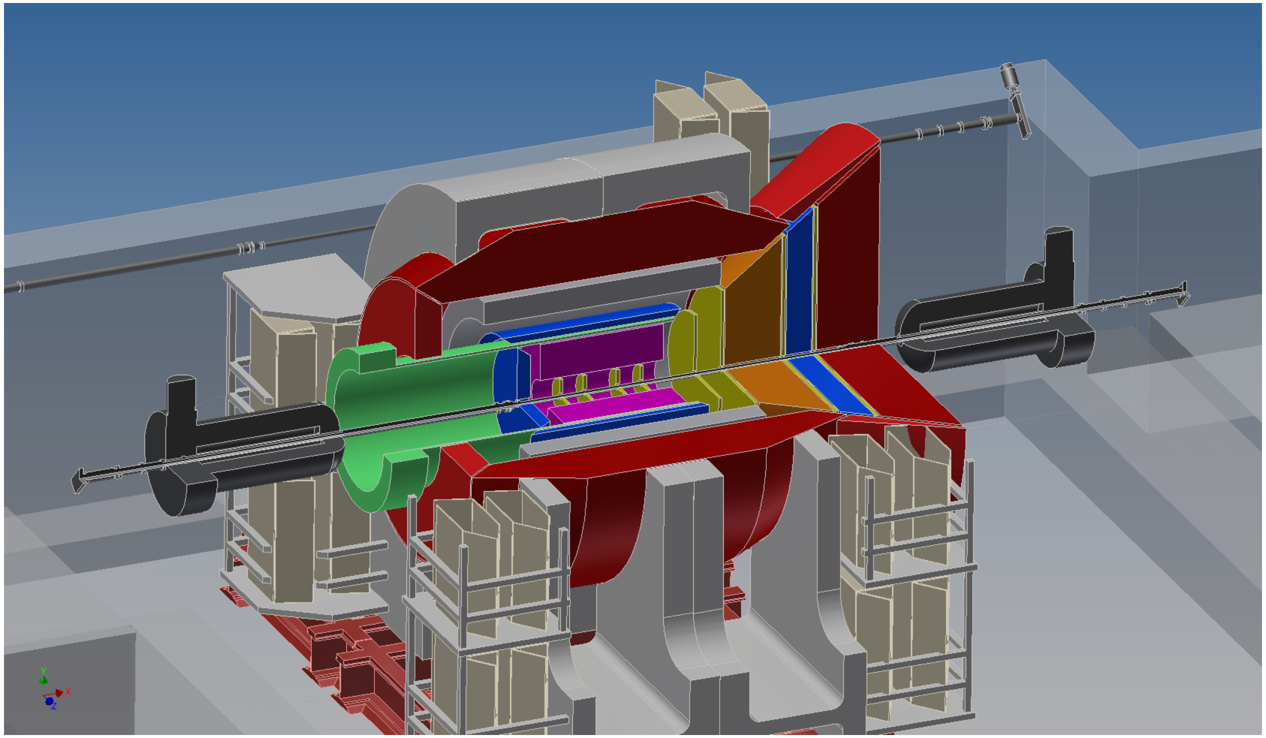
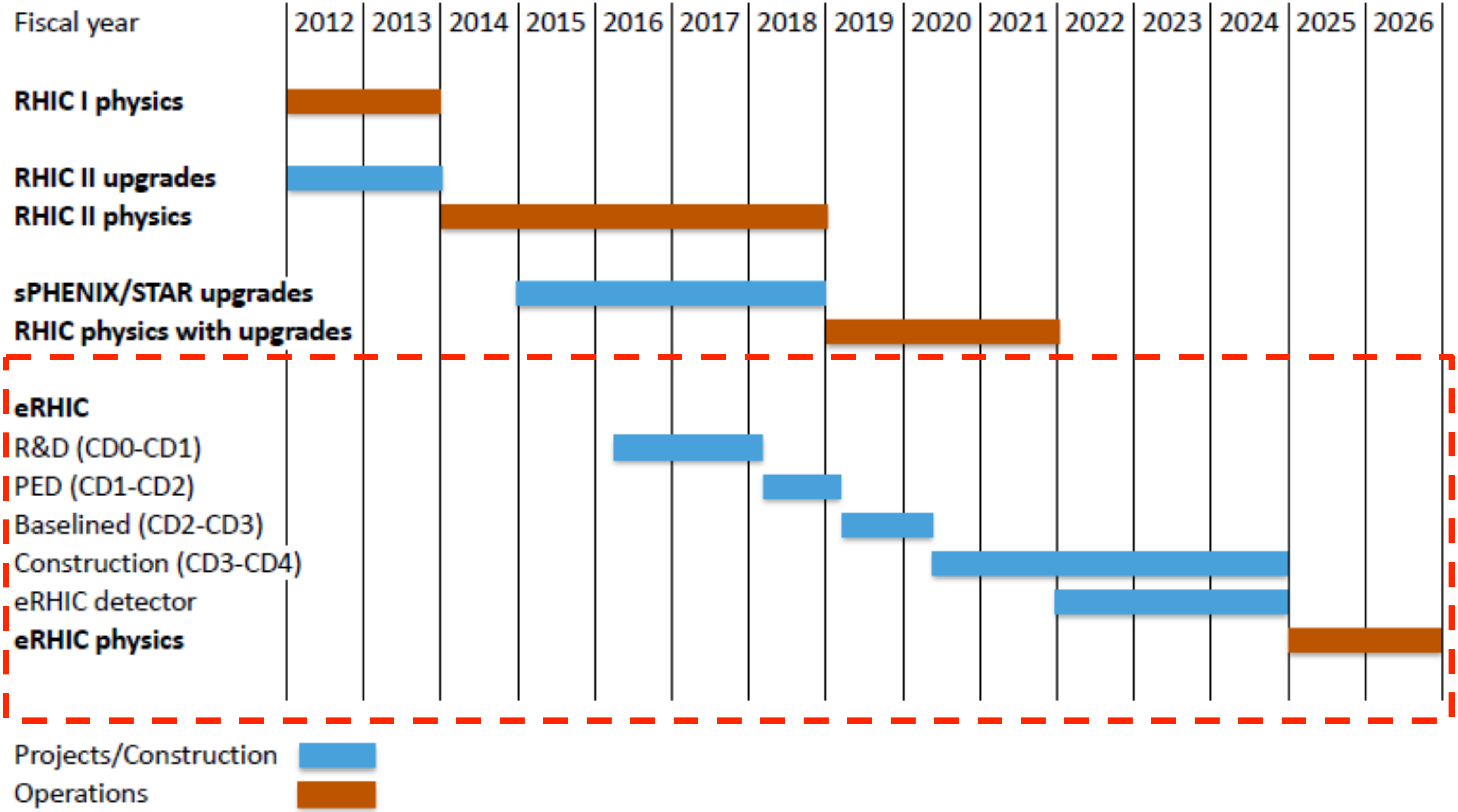
ePHENIX

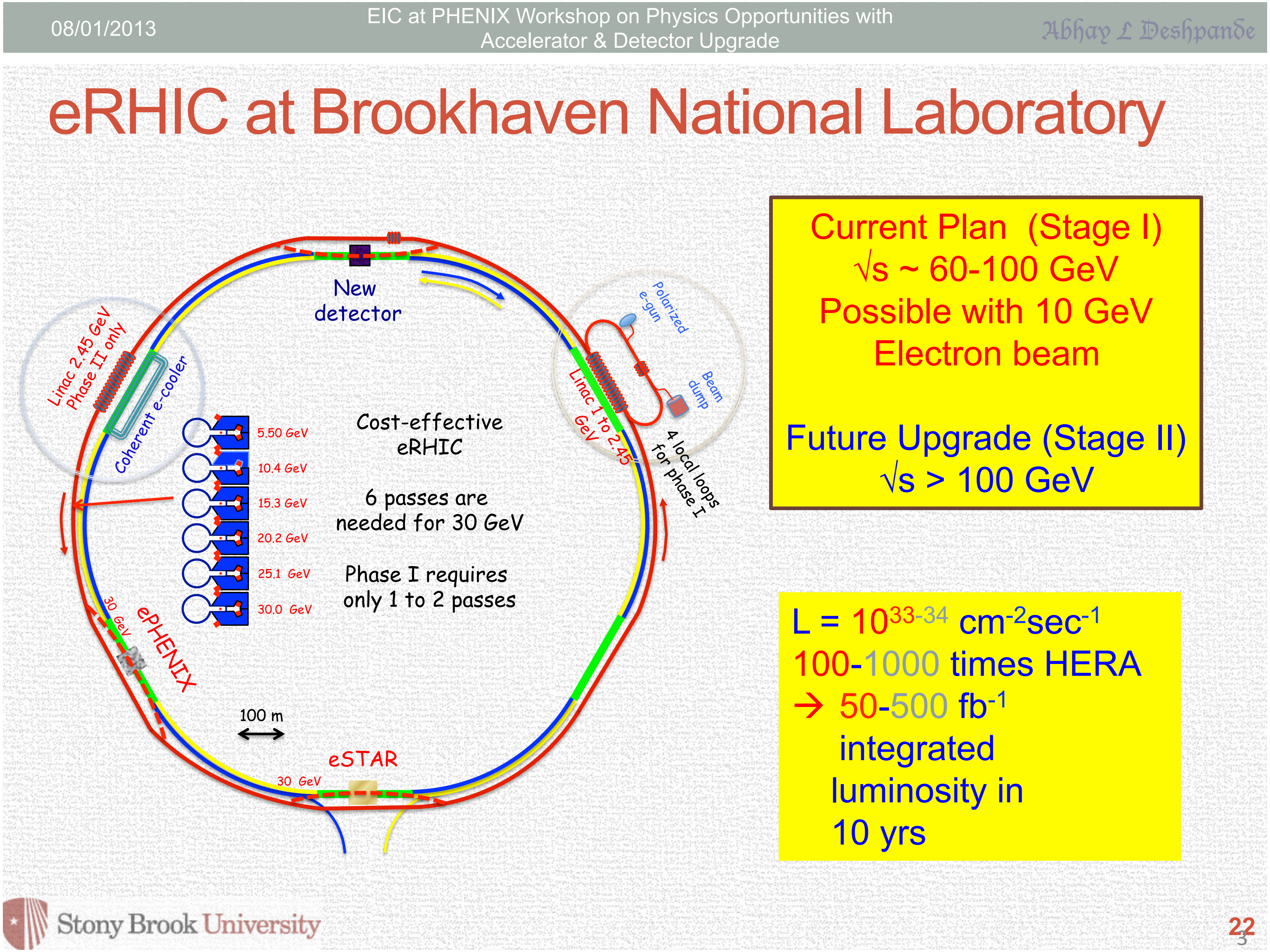


Itaru Nakagawa

RIKEN/RBRC

Schedule


Fiscal year
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
RHIC I physics
RHIC II upgrades
RHIC II physics
sPHENIX/STAR upgrades
RHIC physics with upgrades
eRHIC
R&D (CD0-CD1)
PED (CD1-CD2)
Baselined (CD2-CD3)
Construction (CD3-CD4)
eRHIC detector
eRHIC physics
Projects/Construction
Operations



eRHIC at Brookhaven National Laboratory

Cost-effective eRHIC

6 passes are needed for 30 GeV

Phase I requires only 1 to 2 passes

Current Plan (Stage I)
$\sqrt{s}$ ~ 60-100 GeV
Possible with 10 GeV
Electron beam

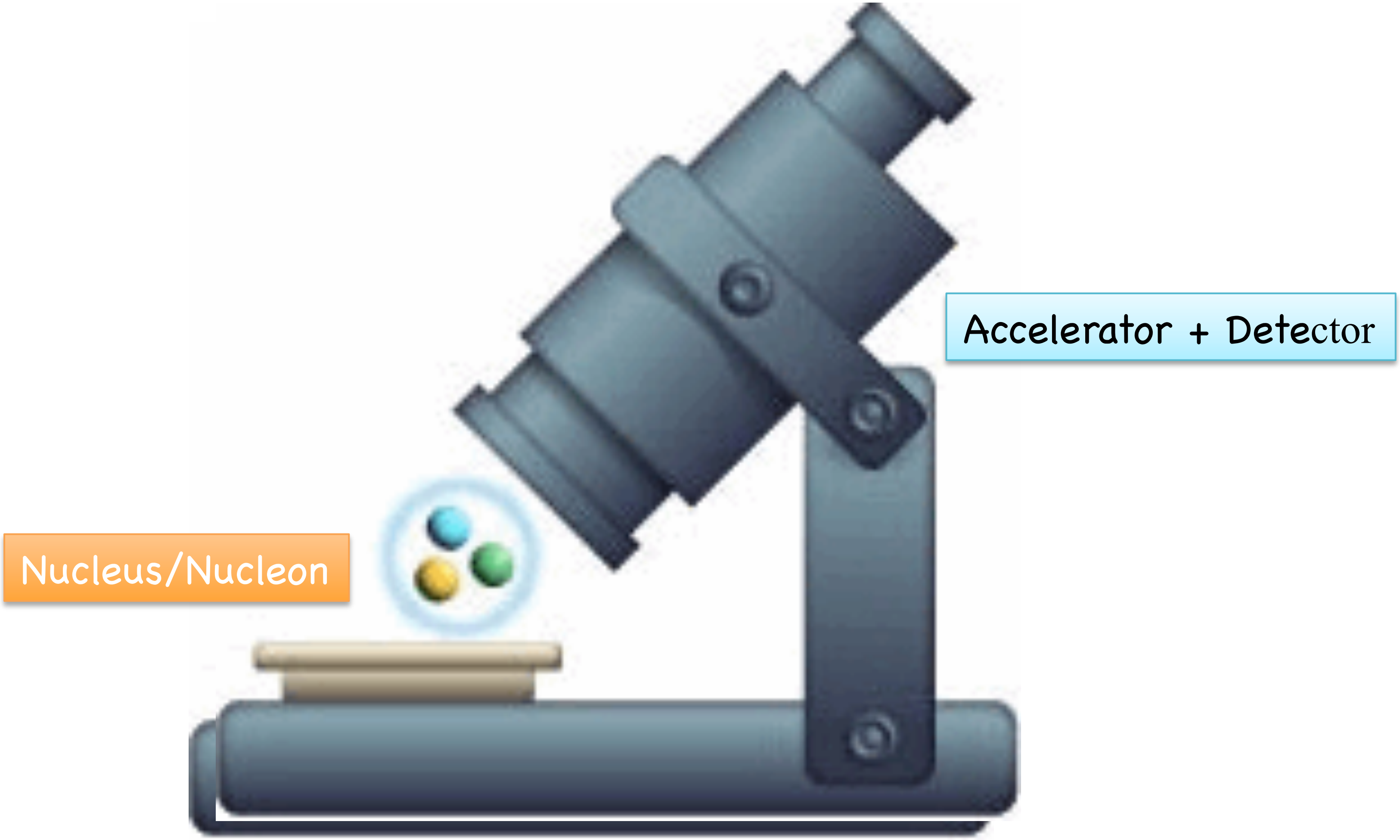
Future Upgrade (Stage II)
$\sqrt{s}$ > 100 GeV

L = $10^{33\text{-}34}$ cm^{-2}sec^{-1}
100-1000 times HERA
→ 50-500 fb^{-1} integrated luminosity in 10 yrs

Stony Brook University

From Abhay’s presentation slide at the PHENIX future workshop in Aug. 2013

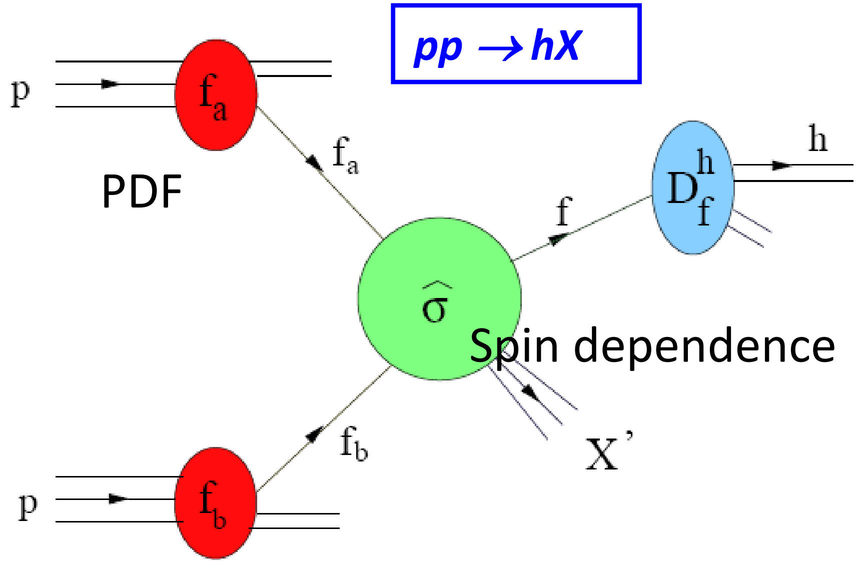
What's new eA after pA/pp?



Accelerator + Detector

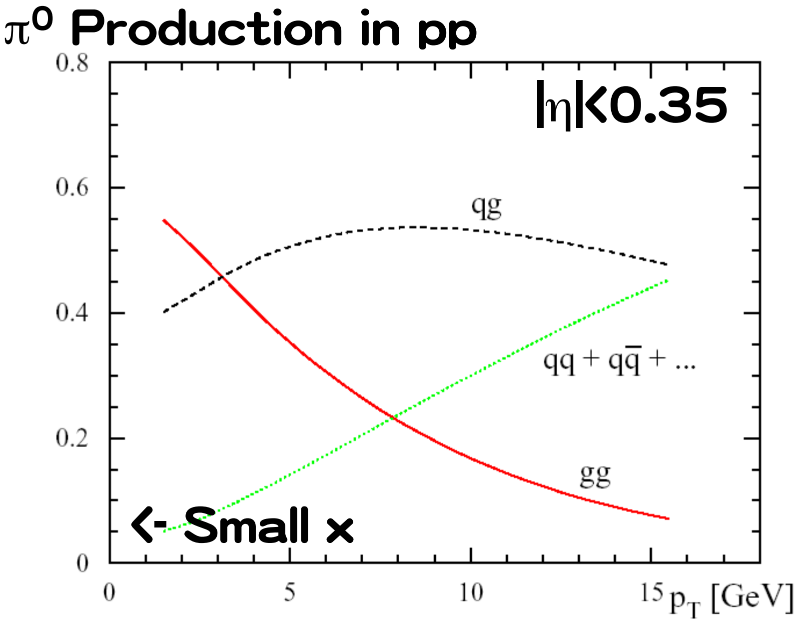
Nucleus/Nucleon

What’s new eA after pA/pp?


$pp \rightarrow hX$

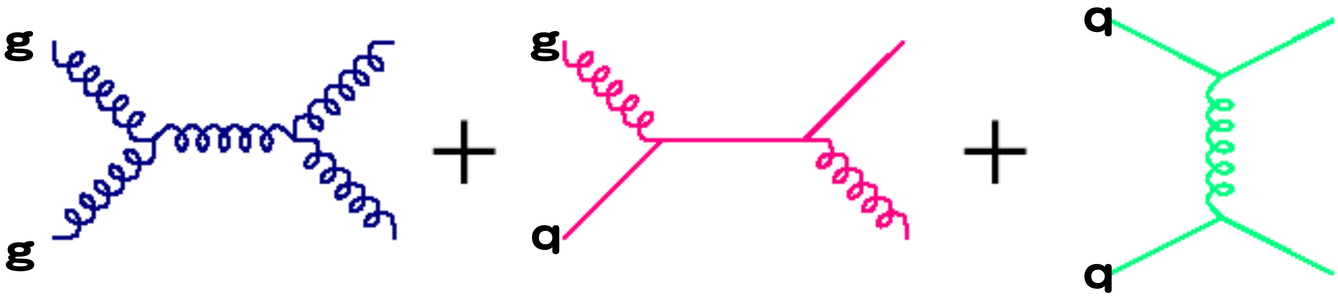
PDF

Spin dependence


π^0 Production in pp

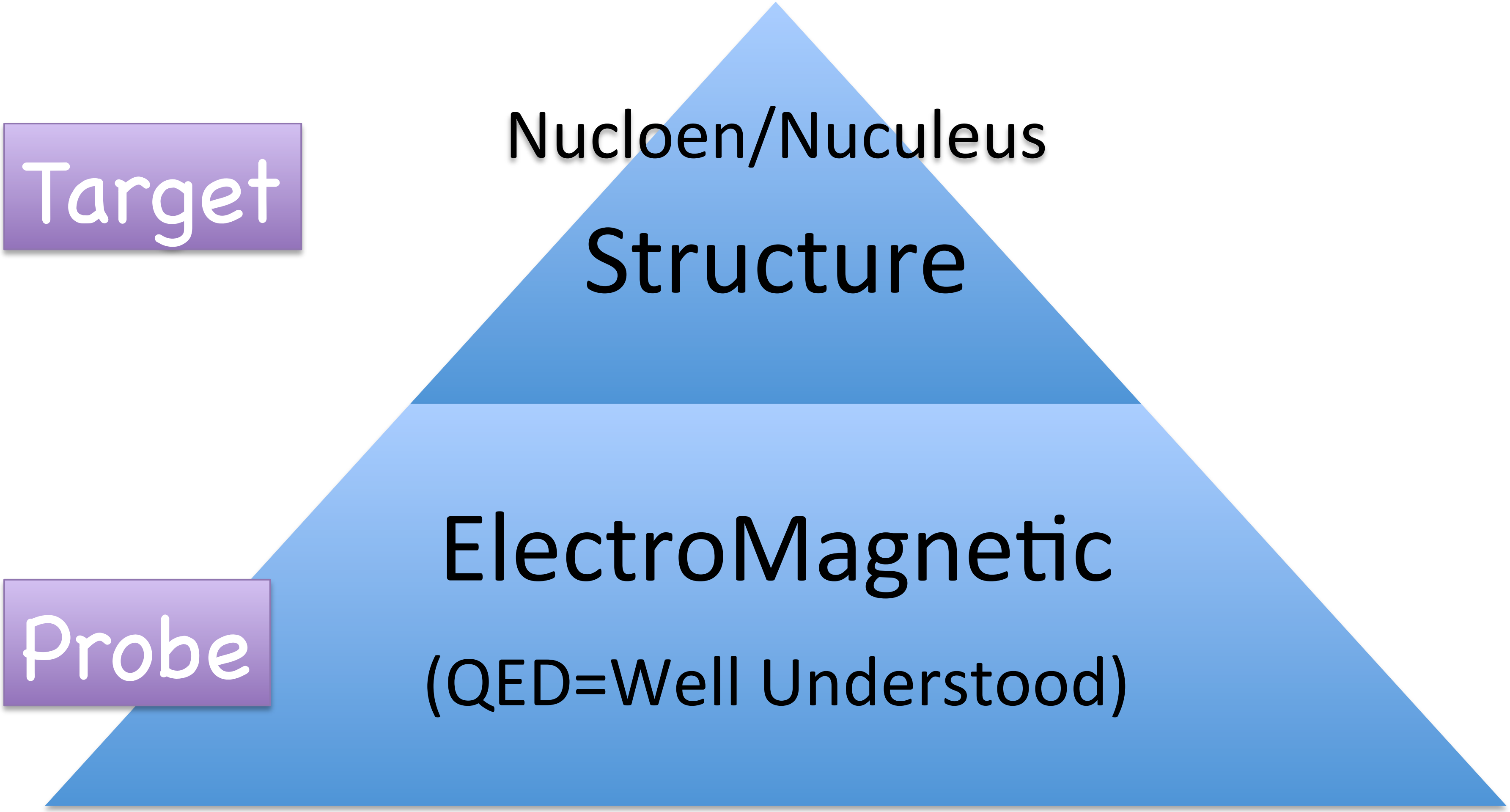
$|\eta|<0.35$

<- Small x



Reaction is the mixture of gluon-gluon, gluon-quark, quark-quark

What's new eA after pA/pp?



Target

Nucloen/Nuculeus

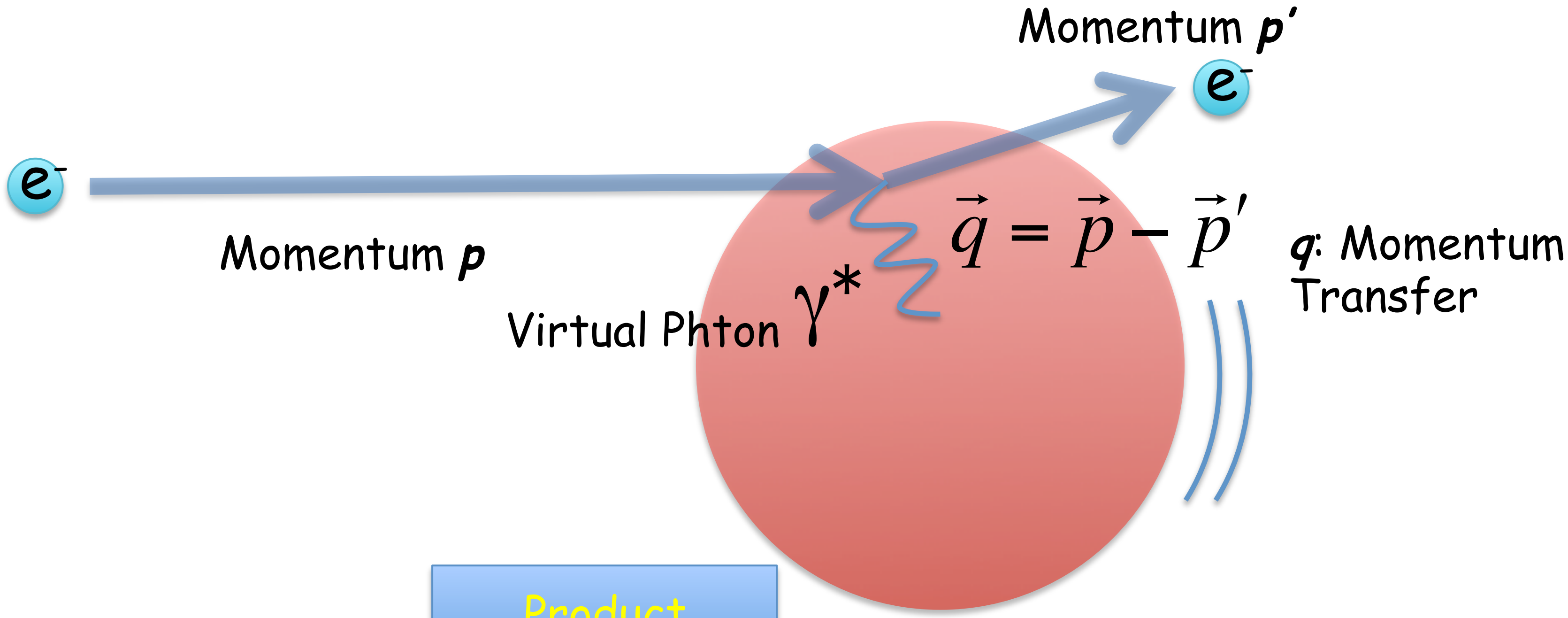
Structure

Probe

ElectroMagnetic

(QED=Well Understood)

Form Factor of Nucleus



Momentum ***p'***

e⁻

e⁻

Momentum ***p***

Virtual Phton γ^*

$\vec{q} = \vec{p} - \vec{p}'$

q: Momentum Transfer

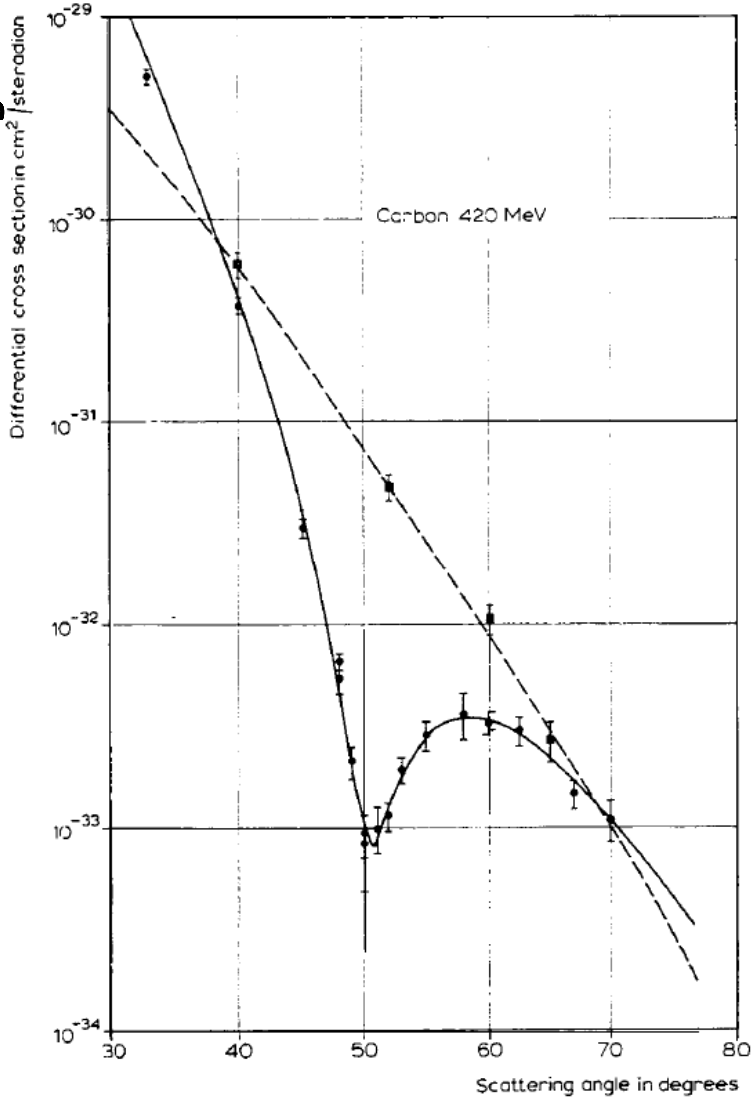
Product

$$\left(\frac{d\sigma}{d\Omega}\right)_{\exp} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \bullet \left|F(q^2)\right|^2$$

Point like Scattering (QED!)

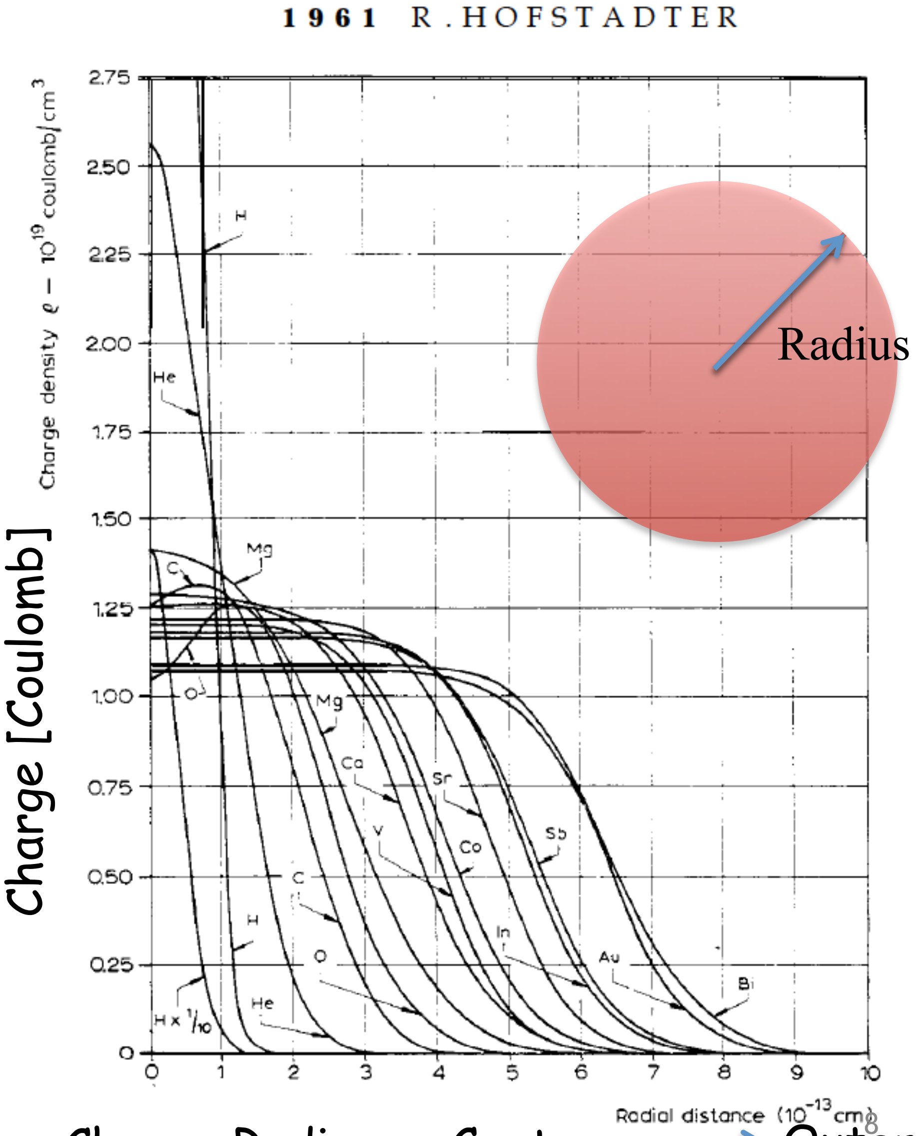
Charge Form Factor (Target information)

Nuclear Charge Form Factor



Cross Section Small → Large

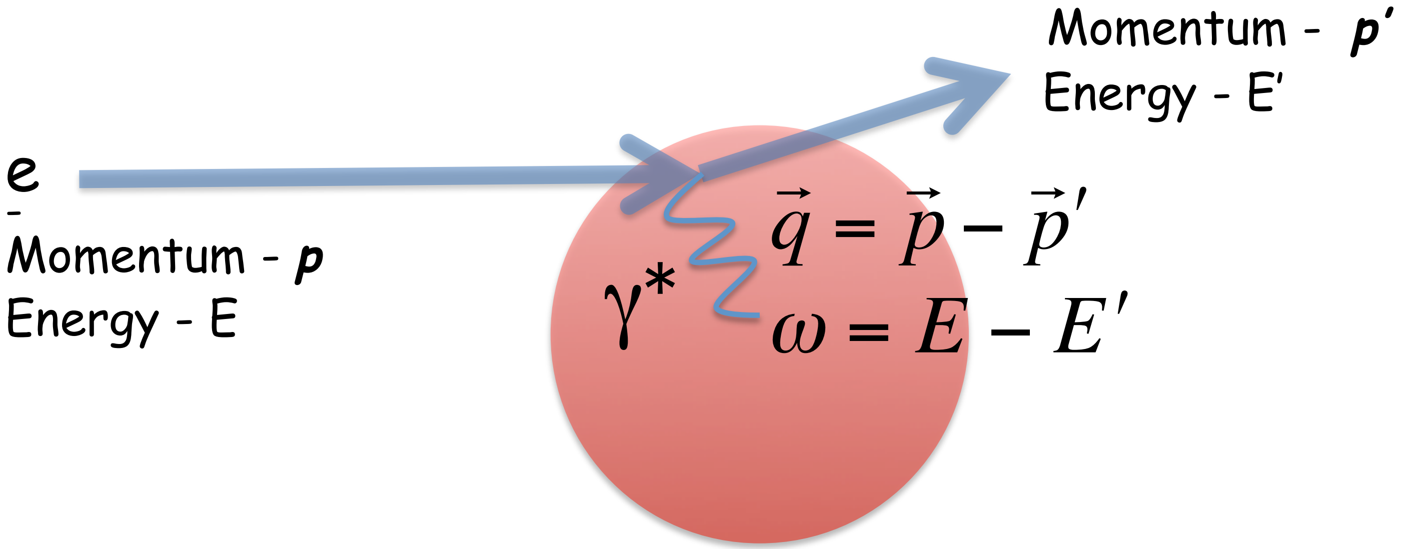
Scattering Angle Small → Large



Charge [Coulomb]

Charge Radius Center → Outer

High Momentum Scattering



e^-

Momentum - ***p***

Energy - E

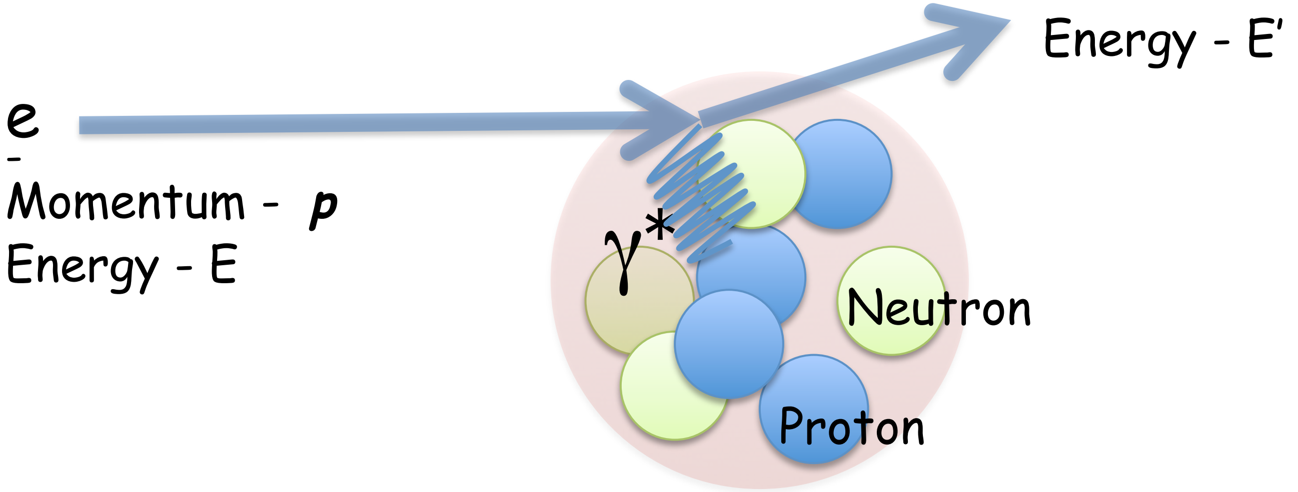
Momentum - ***p'***

Energy - E'

γ^*

$$\vec{q} = \vec{p} - \vec{p}'$$

$$\omega = E - E'$$



e^-

Momentum - ***p***

Energy - E

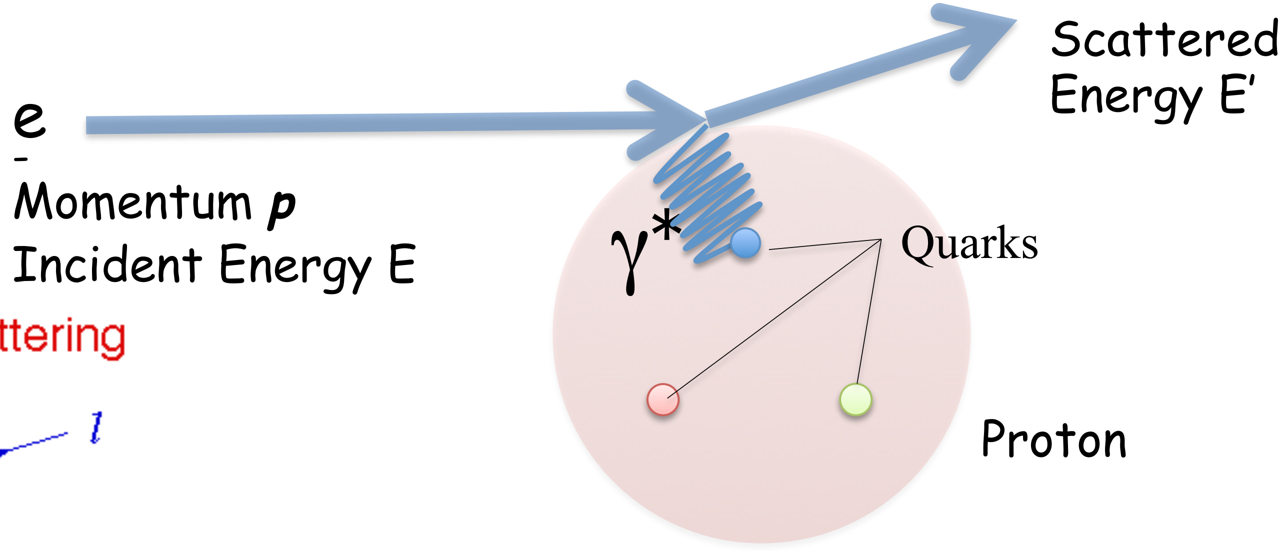
Energy - E'

γ^*

Neutron

Proton

Even Higher Energy

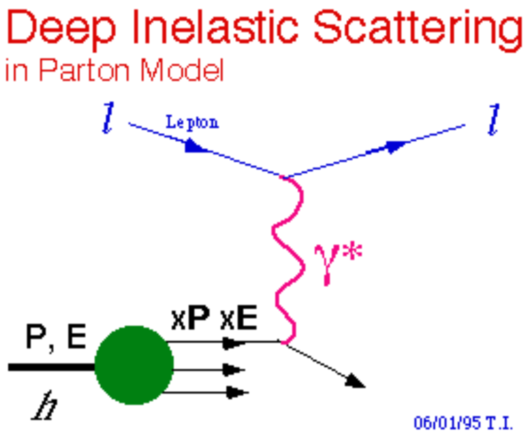


e^-

Momentum *p*

Incident Energy E

Scattered Energy E'



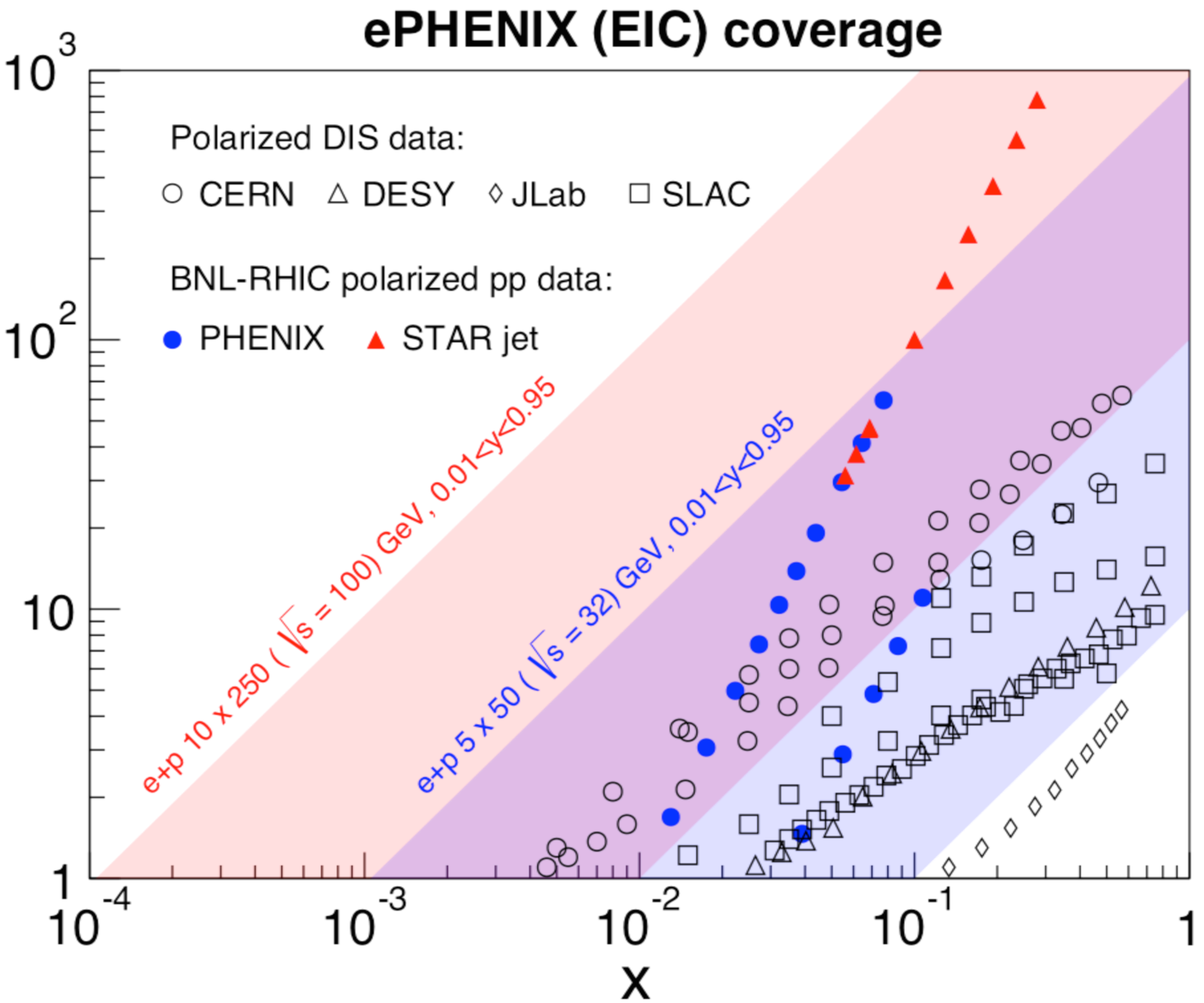
ep→eX

$$\frac{d^2\sigma}{dQ^2 d\nu} = \sigma_{\mathrm{Mott}} \left[W_2(Q^2,\nu) + 2W_1(Q^2,\nu)\tan^2\frac{\theta}{2} \right]$$

Point Like Scattering

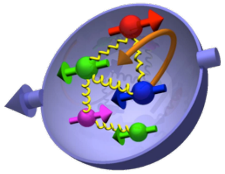
Structure Functions

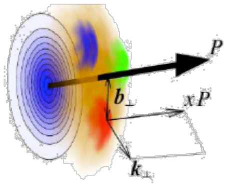
Access to Unexplored Kinematic Region



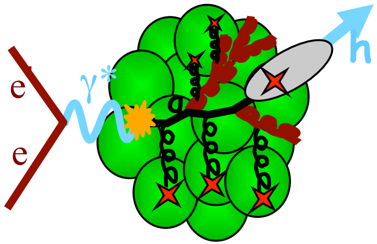
EIC Physics

1. Distribution of quarks and gluons and their spins in space and momentum inside the nucleon
   Nucleon helicity **structure**
   Parton transverse motion **structure** in the nucleon
   Spacial **structure** of partons and parton orbital angular momentum

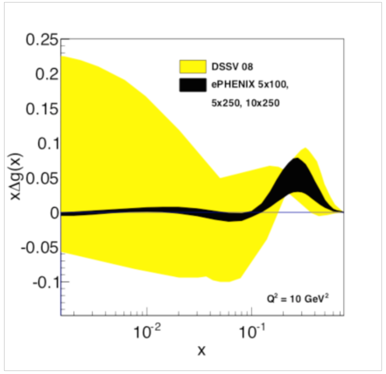




2. QCD in nuclei
   Nuclear modification of parton distributions
   Gluon saturation
   Propagation/Hadronization in nuclear matter



3. ~~Weak interactions & beyond standard model~~
   Require highest energy and lum. -> not for stage-1

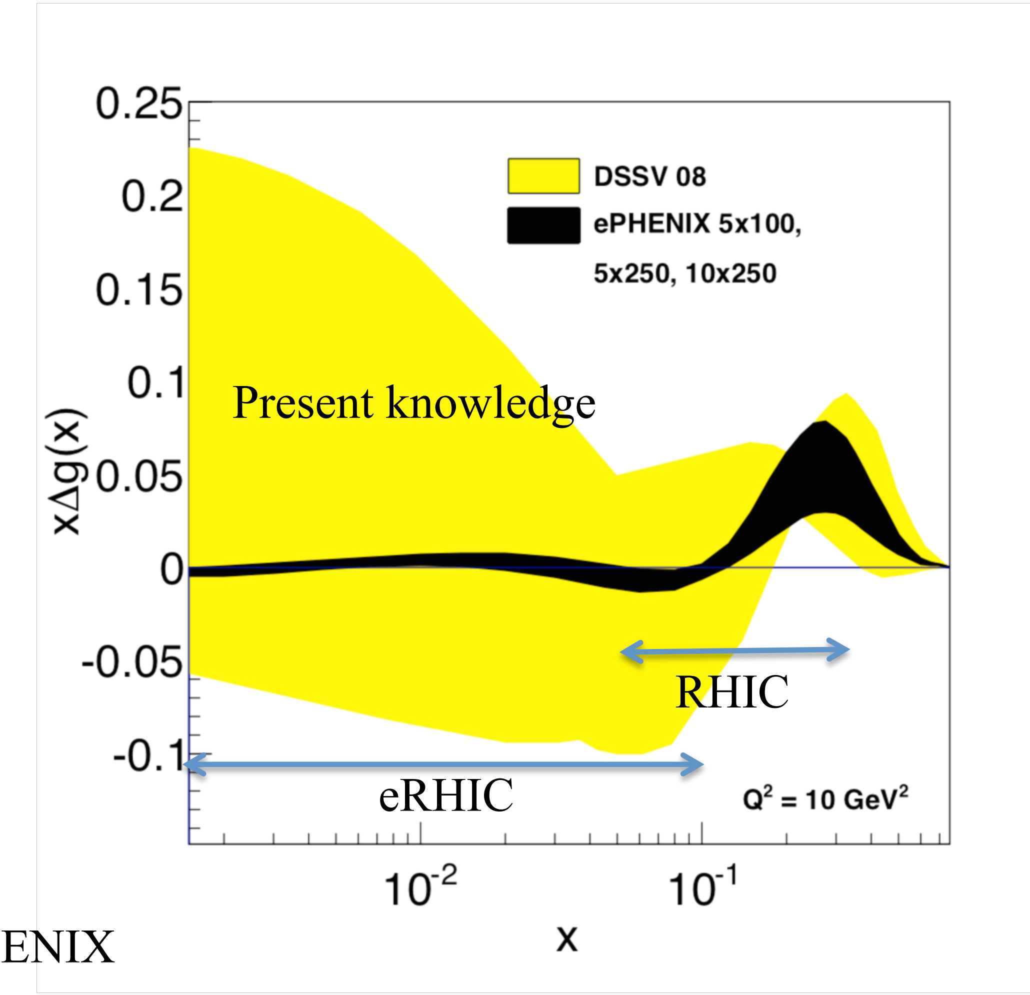


Proton structure: longitudinal spin

Inclusive and semi-inclusive DIS

Unique capability to reach much lower x and span a wider range in Q^2

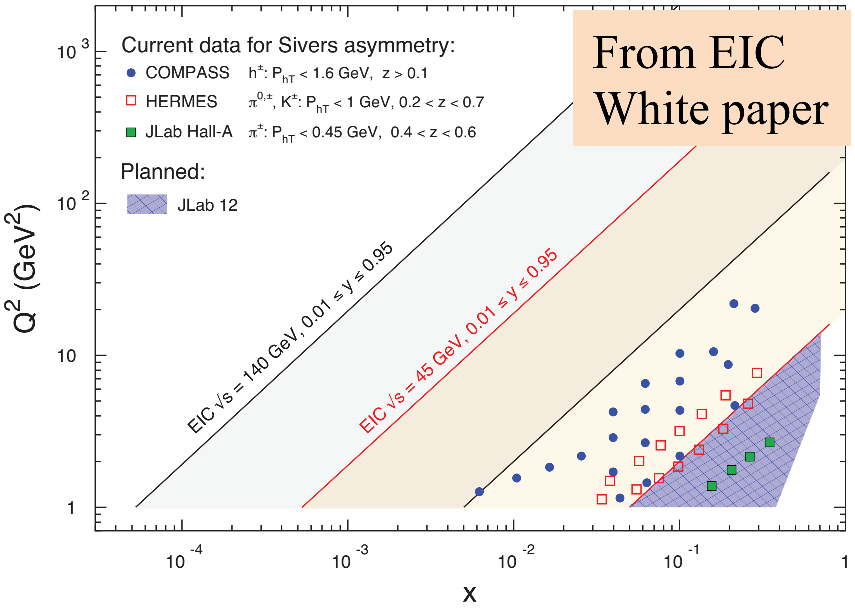
=> Precise evaluation of the long. spin component of the gluons and flavor separated (sea)quarks to the nucleon spin



PHYTHIA generator and ePHENIX acceptance/efficiencies

10 fb^{-1} in each energy configuration: 5×100, 5×250, 10×250

Motion of confined gluons and quarks



From EIC White paper

For the first time, determination of Sivers distributions over wide range in x will be possible

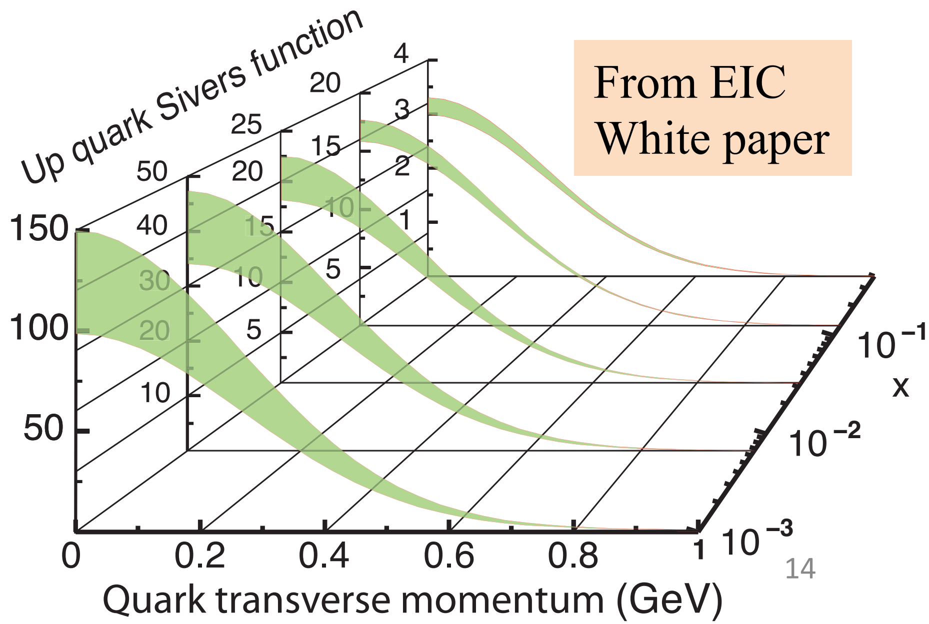
We're working on evaluation of expected Sivers constraint with ePHENIX data

Semi-inclusive DIS

Transverse Momentum Distributions (Sivers)

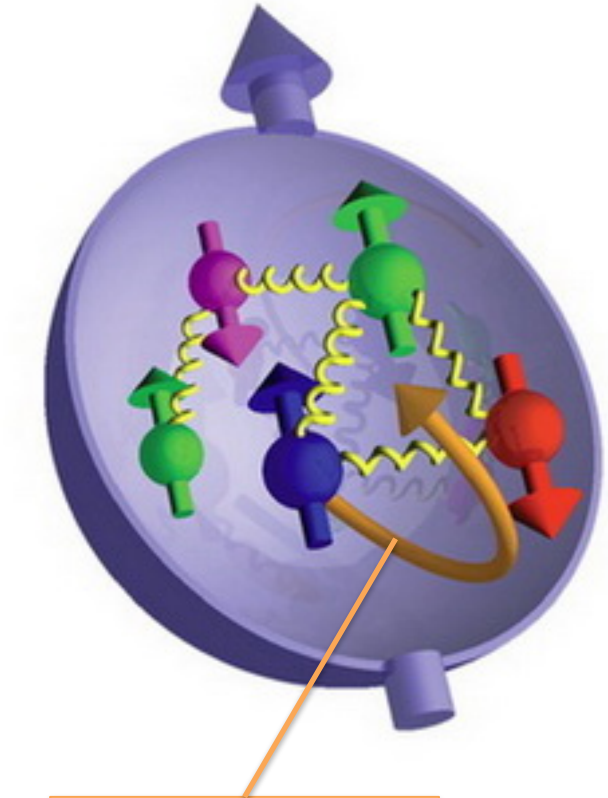
Greatly expand x&Q^2 coverage

High luminosity => fully differential analysis over x, Q^2, z and P_{hT}



From EIC White paper

Proton Tomography

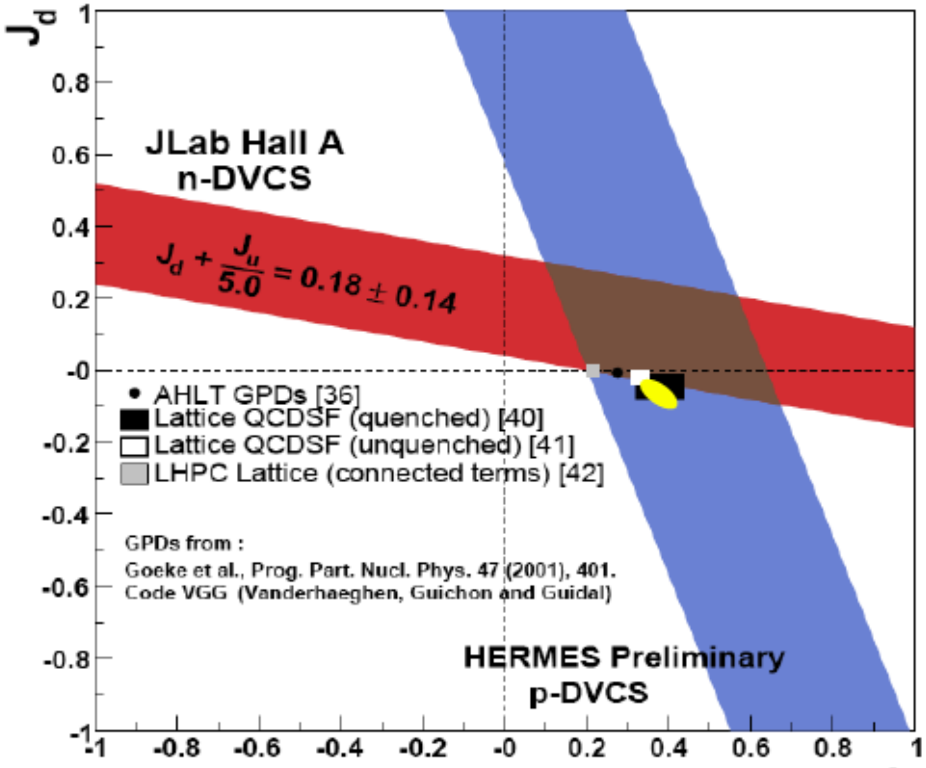


Orbital Motion of Quark and Gluon

Exclusive DIS

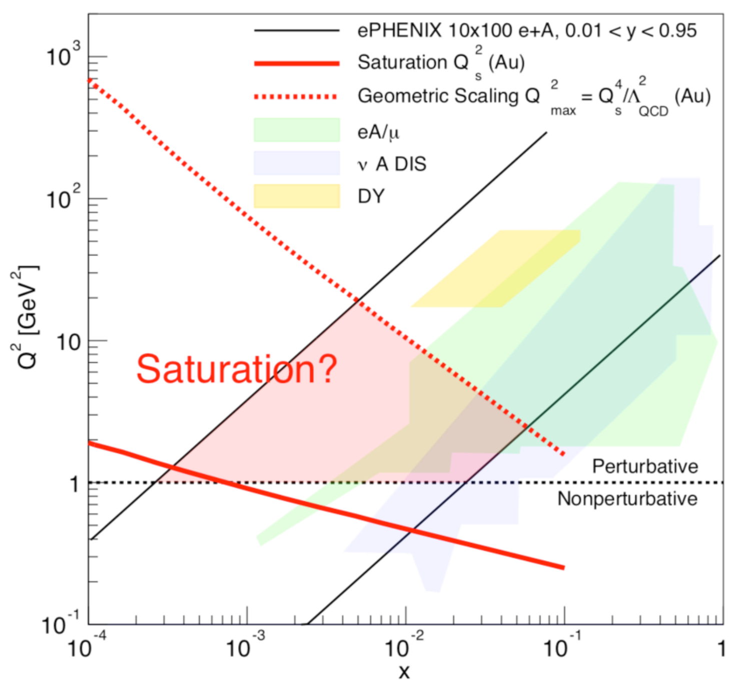
Generalized Parton Distributions

Hints on parton orbital angular momentum



Mazouz et al. (JLab), PRL 99, 242501 (2007)

Gluon Saturation



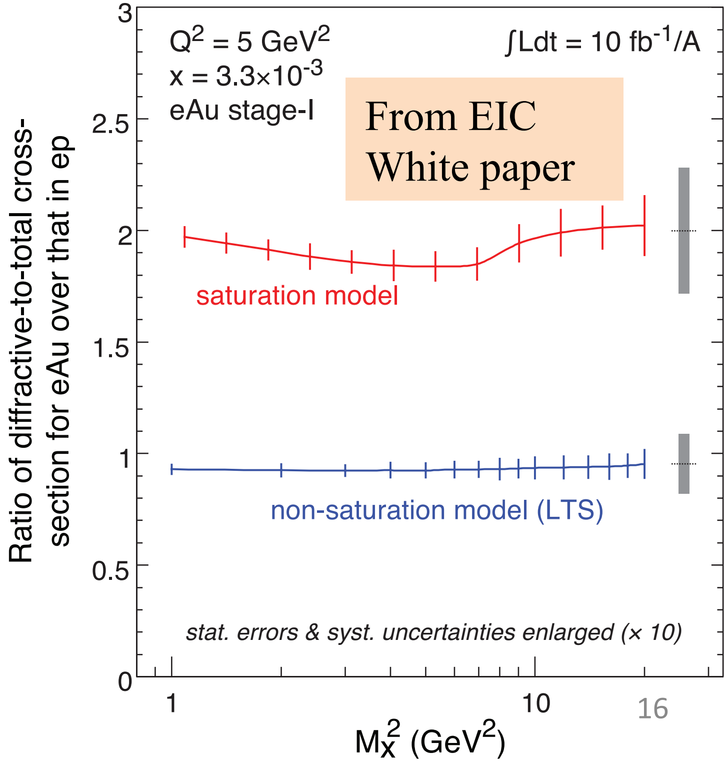
$$Q_s^2(x) \propto \left(\frac{A}{x}\right)^{1/3}$$

Saturation effects are greatly enhanced in eA collisions:

Collider energy -> low x

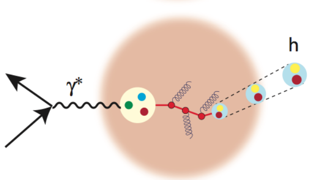
Heavy Ions -> high A

ePHENIX with its HCal and EMCal coverage is expected to do similar job (with diffractive measurements)



From EIC White paper

Hadronization



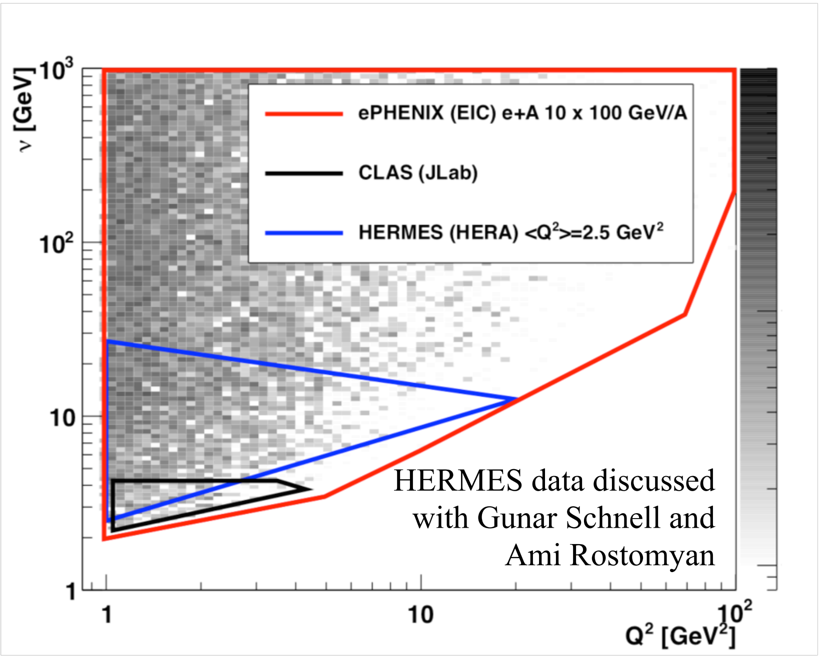
Semi-inclusive eA

Probe color neutralization and hadronization

Previous experiments are limited by low ν, Q^2

eRHIC:

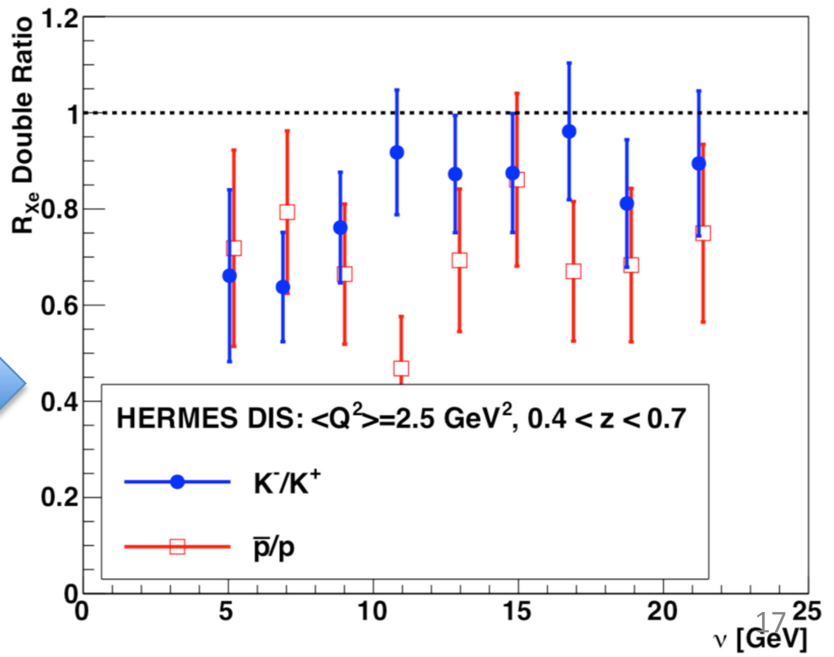
- Much larger range of ν, Q^2
- Wide range of nuclear size
- Excellent ePHENIX hadron PID up to 60 GeV



HERMES data discussed with Gunar Schnell and Ami Rostomyan

ePHENIX with its excellent hadron PID at eRHIC with its high luminosity and wide kinematic reach, is expected to provide much smaller uncertainties in wider range of ν, Q^2 and nucleus size

Evaluation is ongoing



General Detector Concept

Inclusive DIS and scattered electron measurements

With focus in e-going direction and barrel

High resolution EMCal and tracking; minimal material budget

Semi-inclusive DIS and hadron ID

With focus in h-going direction and barrel

Barrel: DIRC for p_h<4 GeV/c

h-going direction: aerogel for lower p_h and gas RICH for higher p_h

Exclusive DIS (DVCS etc.)

EMCal and tracking coverage in $-4<\eta<4$

High granularity EMCal in e-going direction

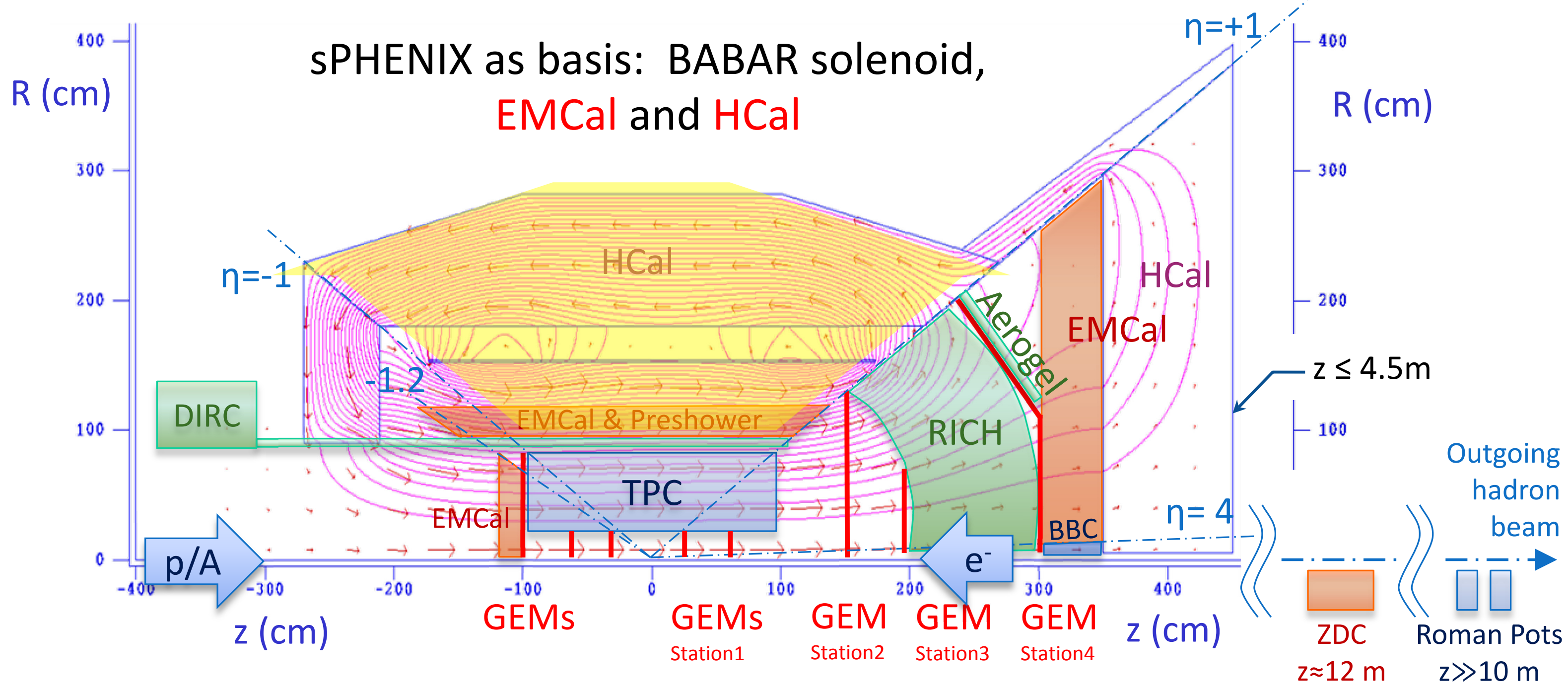
Roman Pots in h-going direction

Diffractive

Rapidity gap measurements: HCal in $-1<\eta<5$; EMCal in $-4<\eta<4$

ZDC in h-going direction

ePHENIX Detector Concept



- -4<η<-1 (e-going):
  - Crystal calorimeter with high energy and position resolution
  - GEM Trackers
- -1<η<1 (barrel):
  - Add Compact-TPC and DIRC
- 1<η<4 (h-going):
  - HCal & EMCal (1<η<5)
  - GEM Trackers
  - Aerogel RICH (1<η<2)
  - Gas RICH
- Far Forward (h-going)
  - ZDC and Roman Pots

BaBar Magnet

BaBar solenoid in its transfer frame, May 17 2013

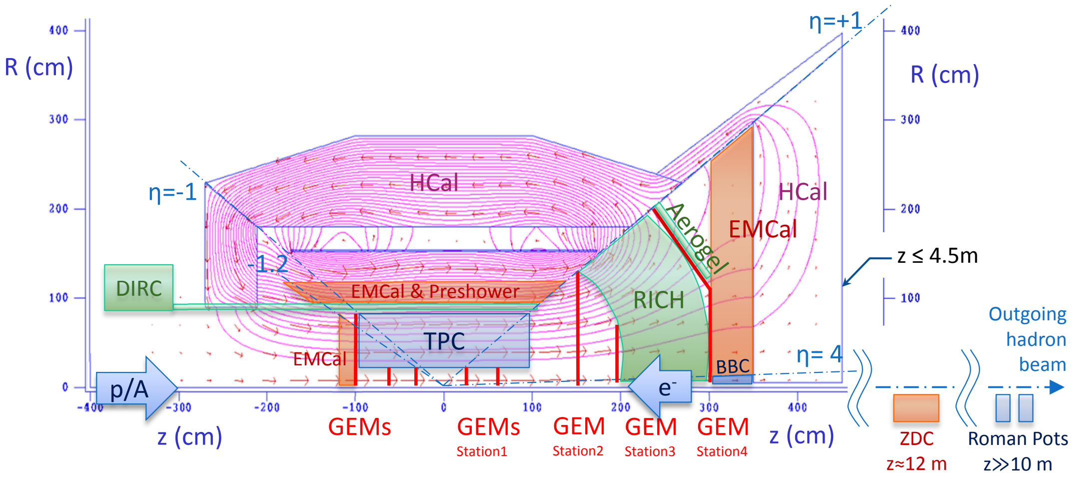
Major Parameters:

- ✓ Superconducting Solenoid
- ✓ Field: 1.5T
- ✓ Inner radius: 140 cm
- ✓ Outer radius: 173 cm
- ✓ Length: 385 cm

Higher current density at magnet ends and field shaping in forward angles provide high analyzing power for momentum determination in e-going and h-going directions

Flux return and field shaping:

Forward HCal
Steel lapmshade
Barrel HCal
Steel endcup

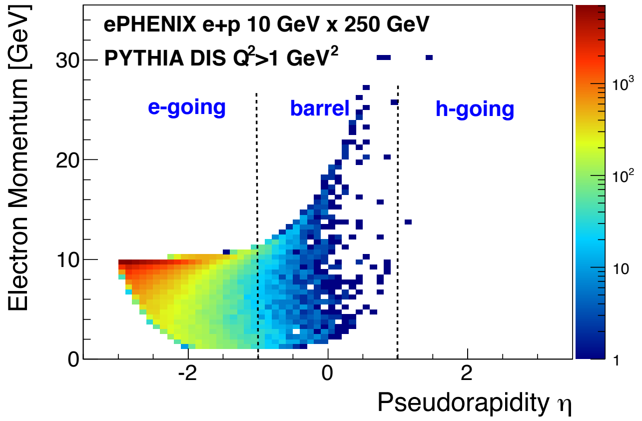


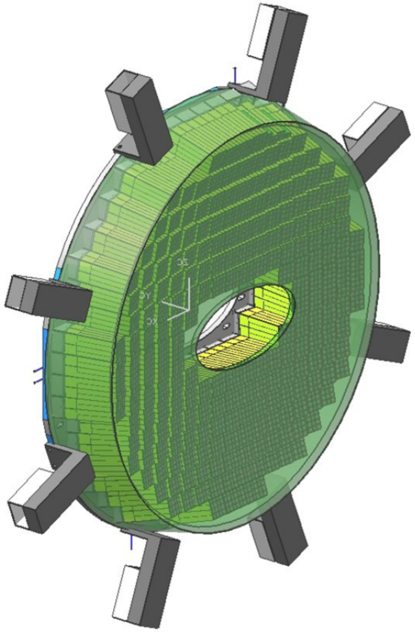
Main space limitation observed: |z|<4.5m
(due to focusing magnet location)

DIS kinematics

Measure scattered electron energy and angle:

$$Q^2 = 4EE'\sin^2\left(\frac{\theta}{2}\right) \qquad y = 1 - \frac{E'}{E}\cos^2\left(\frac{\theta}{2}\right) \qquad x = \frac{Q^2}{sy}$$

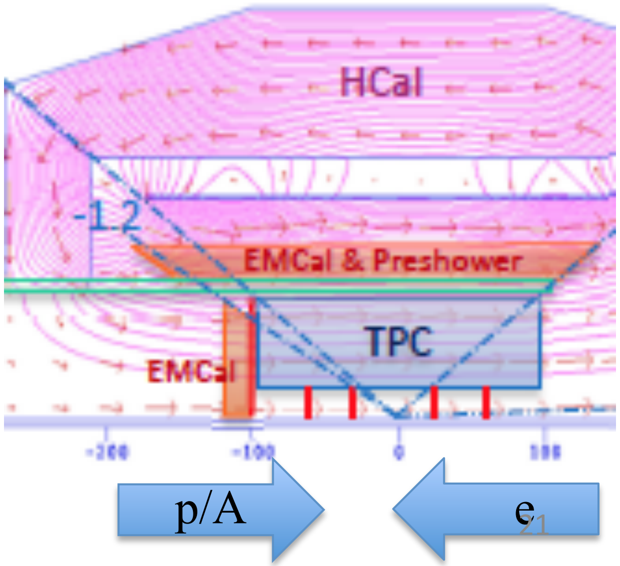




TDR for PANDA
arXiv:0810.1216

- Endcap Calorimeter:
  - $PbWO_4$ crystal
  - Similar to PANDA endcap design
  - $\sigma_E/E \sim 1.5\%/\sqrt{E}$
  - $\sigma_X < 3\text{mm}/\sqrt{E}$
- Barrel Calorimeter:
  - sPHENIX EMCal
  - Tungsten based
  - $\sigma_E/E \sim 12\%/\sqrt{E}$

Scattering mainly in e-going direction and barrel



Inclusive DIS and Kinematics

eID and background rejection

Hadron rejection:

EMCal energy response and E/p

×20-30 at 1 GeV/c

×100 at 3 GeV/c

EMCal shower profile

Expect ×3-10

Not yet included in plots

EMCal long. segmentation and/or preshower

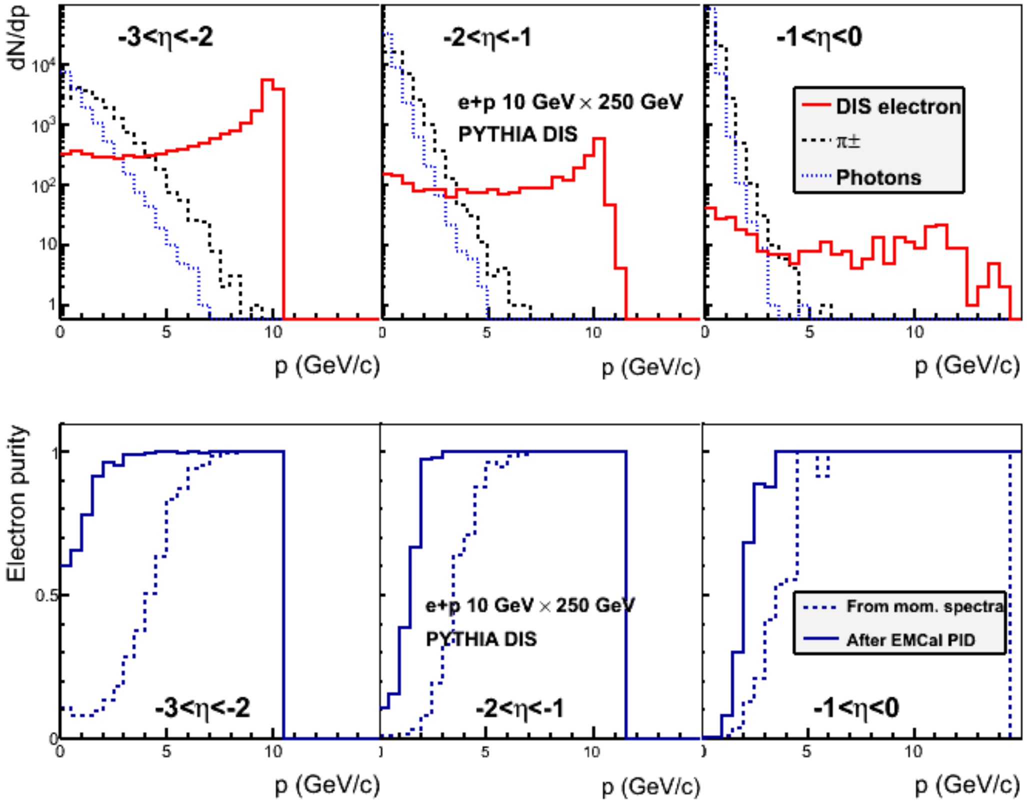
For future considerations

Photon rejection (γ –> e^+e^-)

Minimal material

Rejection with tracking and E/p

GEANT study is ongoing

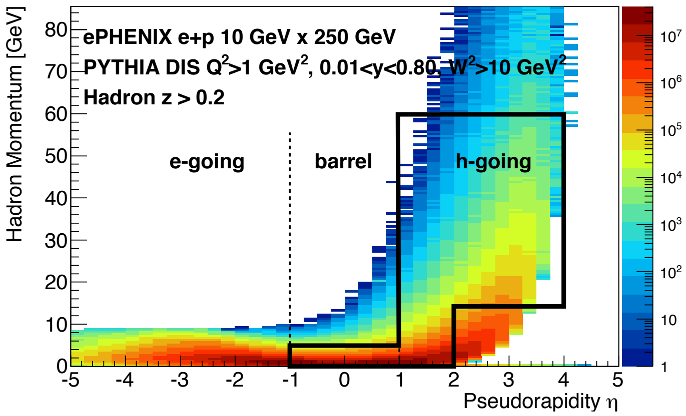


Reliable eID down to

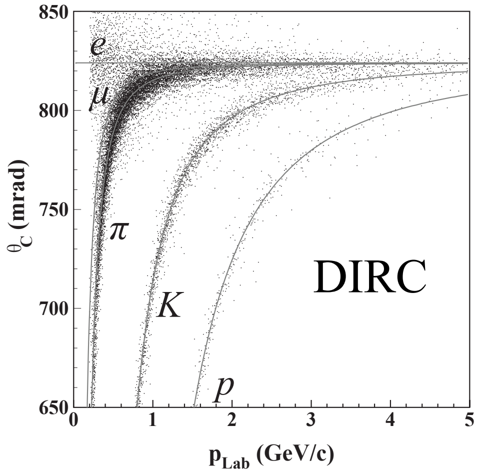
p=2 GeV/c for 10 GeV e-beam

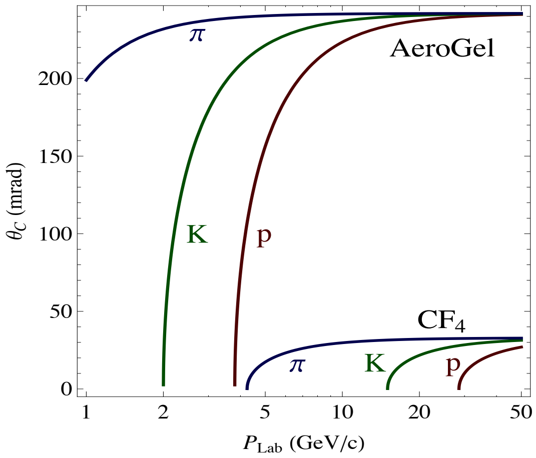
p=1 GeV/c for 5 GeV e-beam

Semi-inclusive DIS and hadron ID



Focus on h-going direction and barrel





DIRC:

-1<η<1

PID at <4 GeV/c

Aerogel:

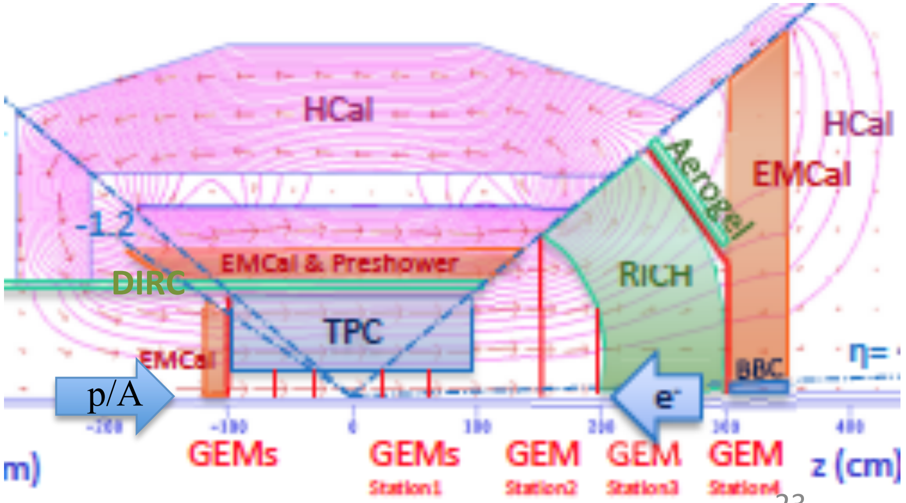
1<η<2

PID at <15 GeV/c

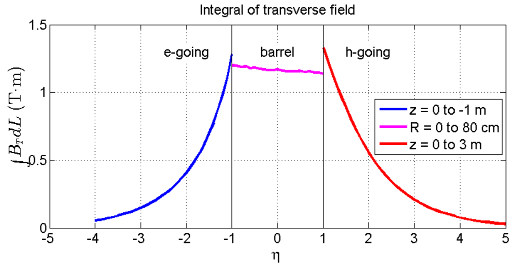
Gas RICH (CF4):

1<η<4

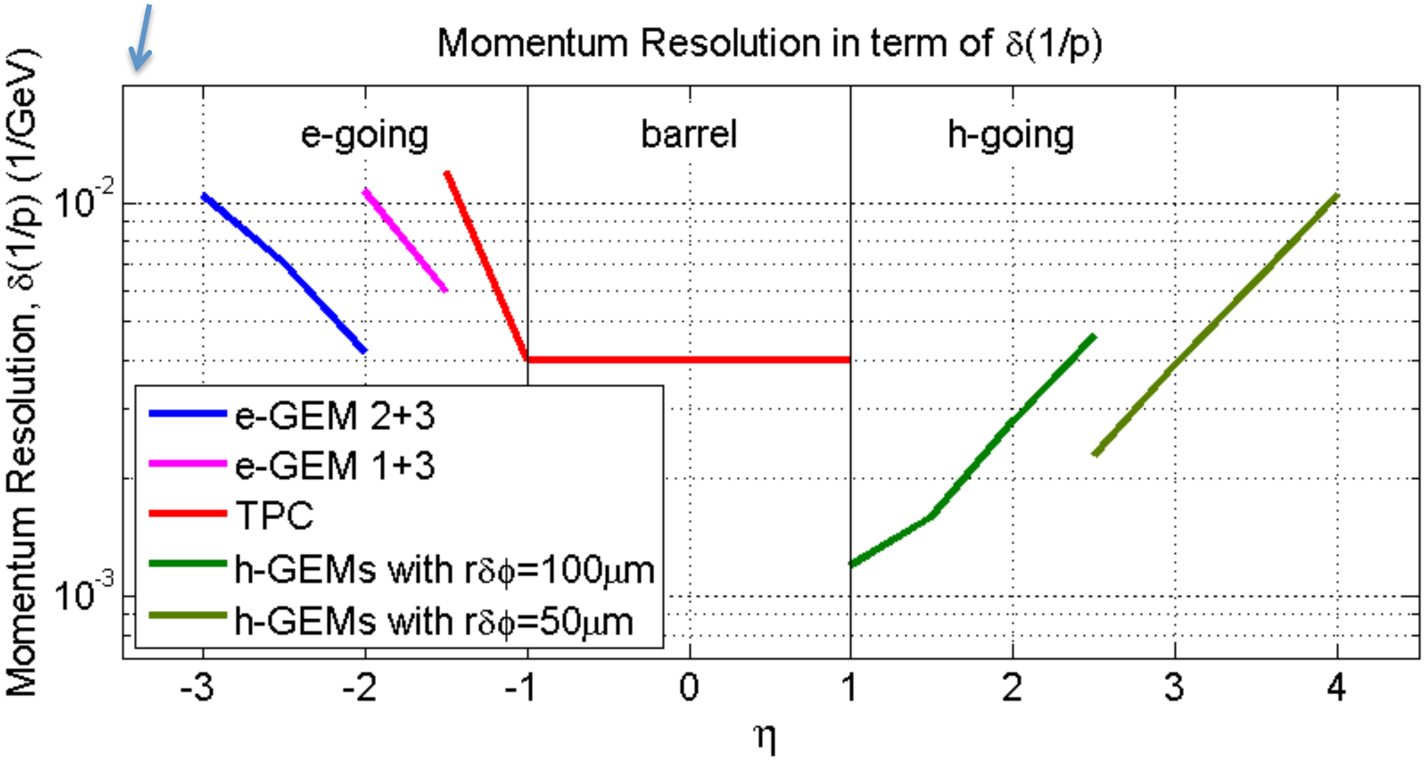
PID at <60 GeV/c



Momentum Resolution



$\delta p/p \sim a \times p$



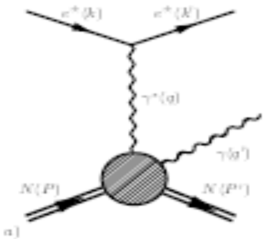
Good resolution over full tracking acceptance (-3<η<4)

e-going, $\sigma_p/p \sim (0.4\text{-}1.0\%) \times p$: primarily needed for electron ID (E/p)

barrel, $\sigma_p/p \sim 0.4\% \times p$: hadron momentum, electron momentum at p<10 GeV/c

h-going, $\sigma_p/p \sim (0.1\text{-}1.0\%) \times p$: crucial for PID

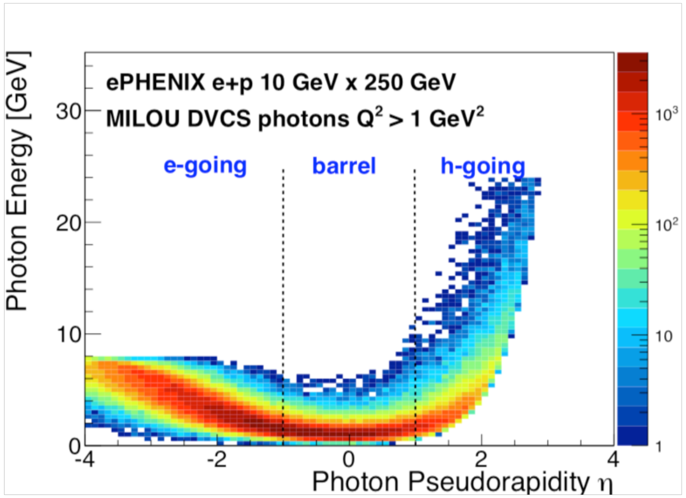
Backup



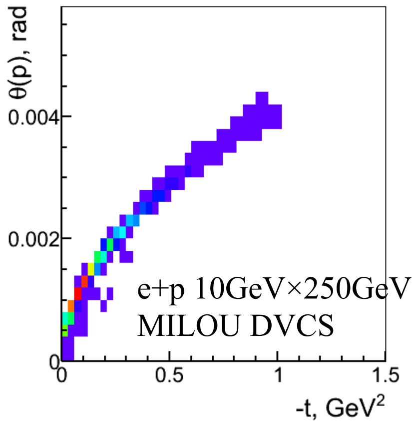
Exclusive Measurements

DVCS:

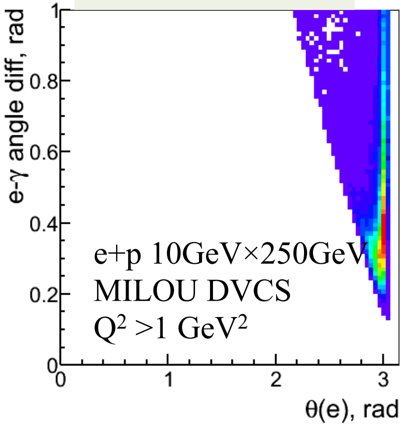
- Wide coverage for photon measurements
  - EMCal and tracking in |η|<4
- Separation of e-γ in EMCal
  - 0.02×0.02 EMCal granularity is enough
- Intact proton detection is highly desirable
  - Roman Pots



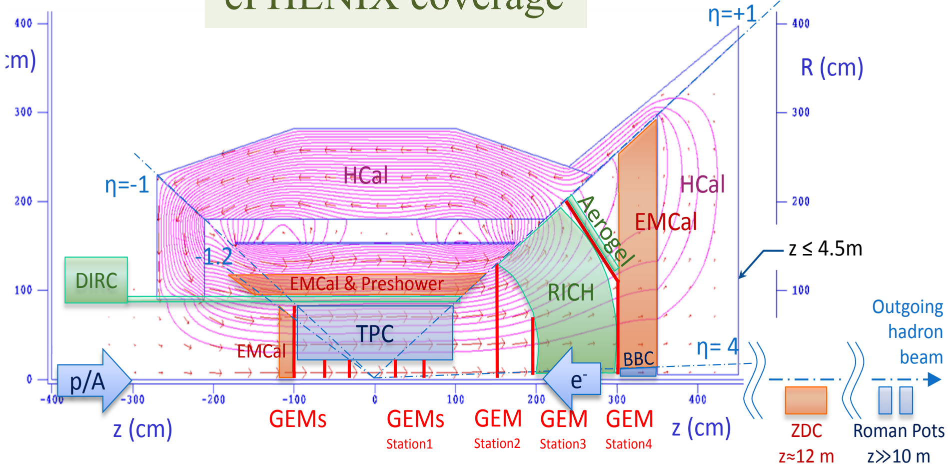
Proton scattering angle



e-γ angle

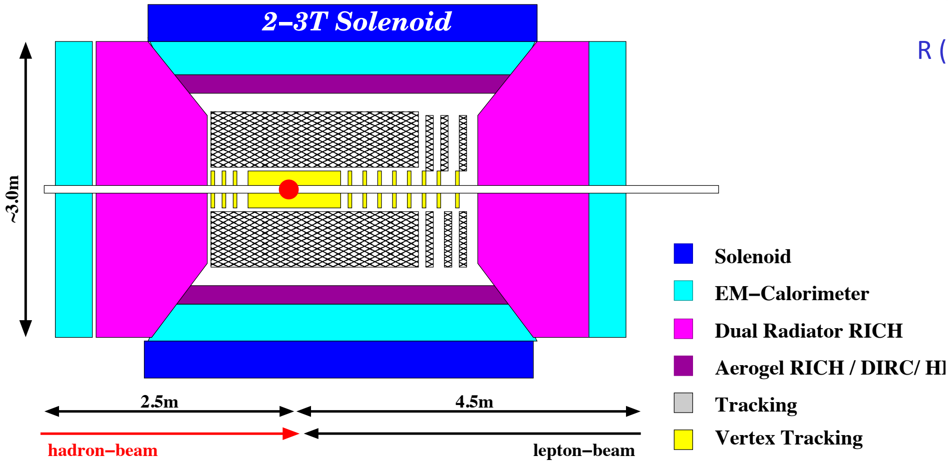


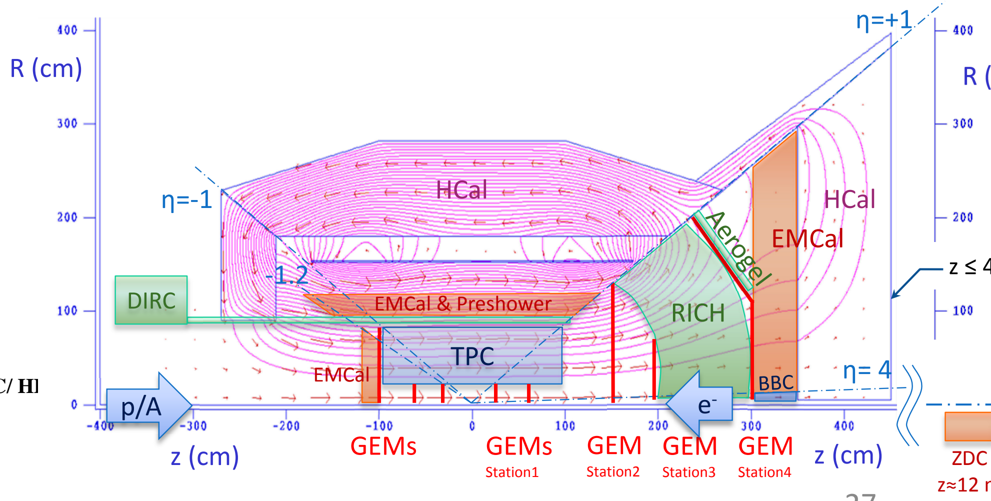
ePHENIX coverage



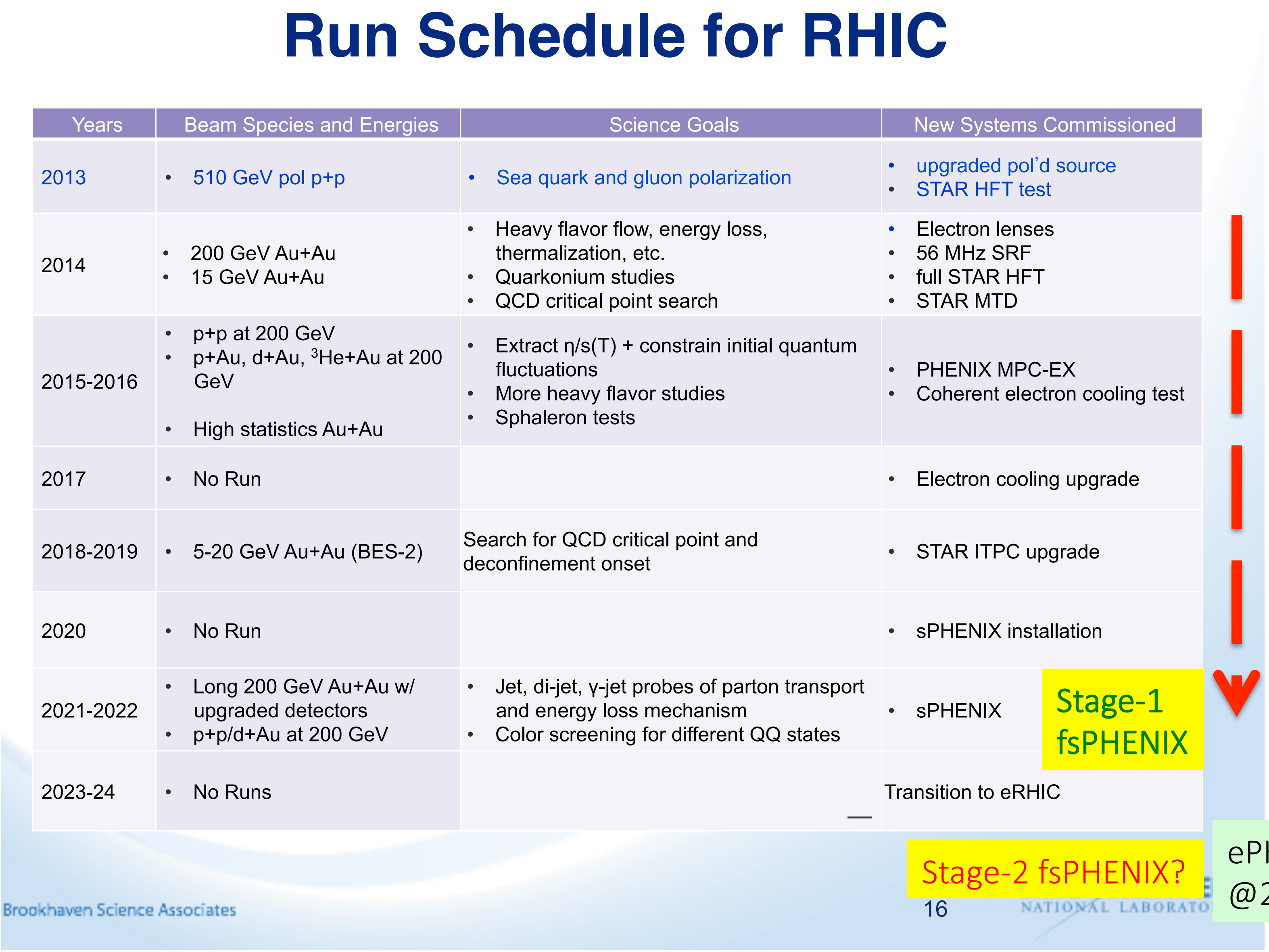
Feasibility of ePHENIX vs. EIC detector

	EIC	ePHENIX
Magnet	New(?) Solenoid	Re-use BarBar Magnet
central	VTX+TPC+PID+EMCal	VTX+TPC+PID+EMCal+HCal
h-going	GEM+RICH+EMCal	GEM+RICH+Aerogel+EMCAL+HCal
e-going	GEM+EMCal+RICH	GEM+EMCal
Cost	~$200M?	$80M(Equipment)+$30M(Labor) on top of sPHENIX





Where could fsPHENIX fit?



Run Schedule for RHIC

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 510 GeV pol p+p	• Sea quark and gluon polarization	• upgraded pol'd source • STAR HFT test
2014	• 200 GeV Au+Au • 15 GeV Au+Au	• Heavy flavor flow, energy loss, thermalization, etc. • Quarkonium studies • QCD critical point search	• Electron lenses • 56 MHz SRF • full STAR HFT • STAR MTD
2015-2016	• p+p at 200 GeV • p+Au, d+Au, ^{3}He+Au at 200 GeV • High statistics Au+Au	• Extract η/s(T) + constrain initial quantum fluctuations • More heavy flavor studies • Sphaleron tests	• PHENIX MPC-EX • Coherent electron cooling test
2017	• No Run		• Electron cooling upgrade
2018-2019	• 5-20 GeV Au+Au (BES-2)	Search for QCD critical point and deconfinement onset	• STAR ITPC upgrade
2020	• No Run		• sPHENIX installation
2021-2022	• Long 200 GeV Au+Au w/ upgraded detectors • p+p/d+Au at 200 GeV	• Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism • Color screening for different QQ states	• sPHENIX
2023-24	• No Runs	—	Transition to eRHIC

Stage-1 fsPHENIX

Stage-2 fsPHENIX?

Brookhaven Science Associates

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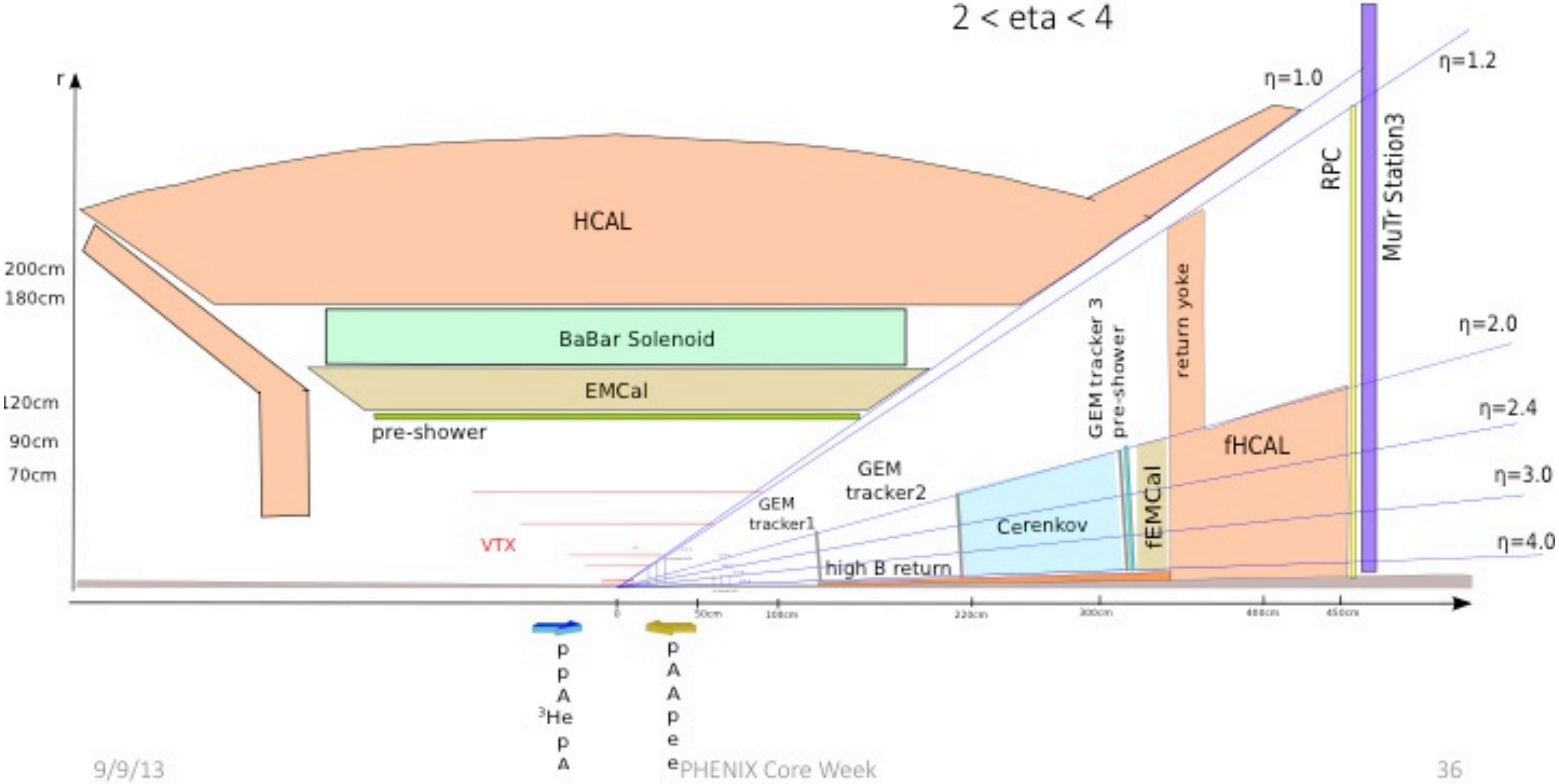
NATIONAL LABORATO

fsPHENIX: $$, Construction, Installation, Physics

ePHENIX @2025

fsPHENIX Stage-1c

Smaller Scale "Full fsPHENIX Detector" "Prototype ePHENIX" @1/3 of total cost?



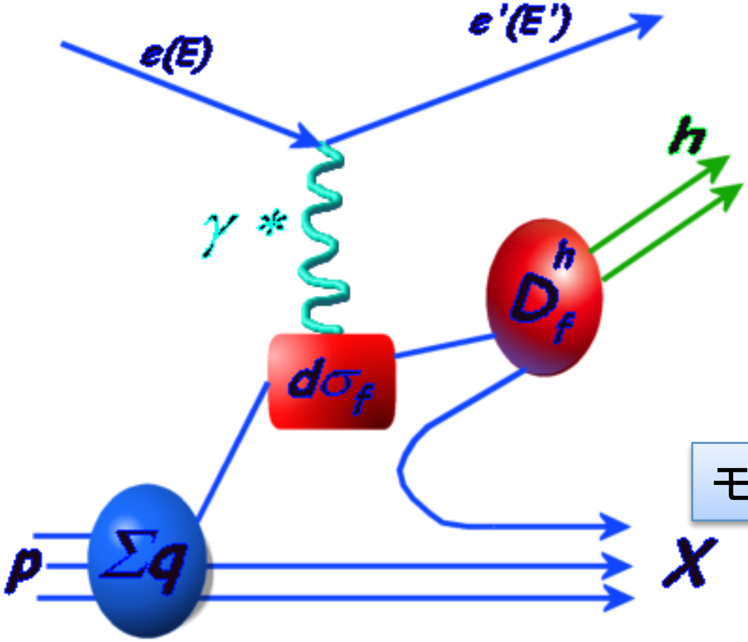
fsPHENIX

Detector		Funding Request	Cost $M (2<eta<5)	Advantage
GEM Tracker		LANL	1.3	Tech. R&D
EMCal	Detector	Reuse	10 (2.5)	
	Readout	?	5.7 (1.5)	
HCal		JSPS	7 (2)	Can do jet physics w/ tracker
RICH		SUNY	10 (2.5?)	R&D Already started

() is rapidity range 2 to 5.

Polarized Semi-DIS

Flavor Tagging



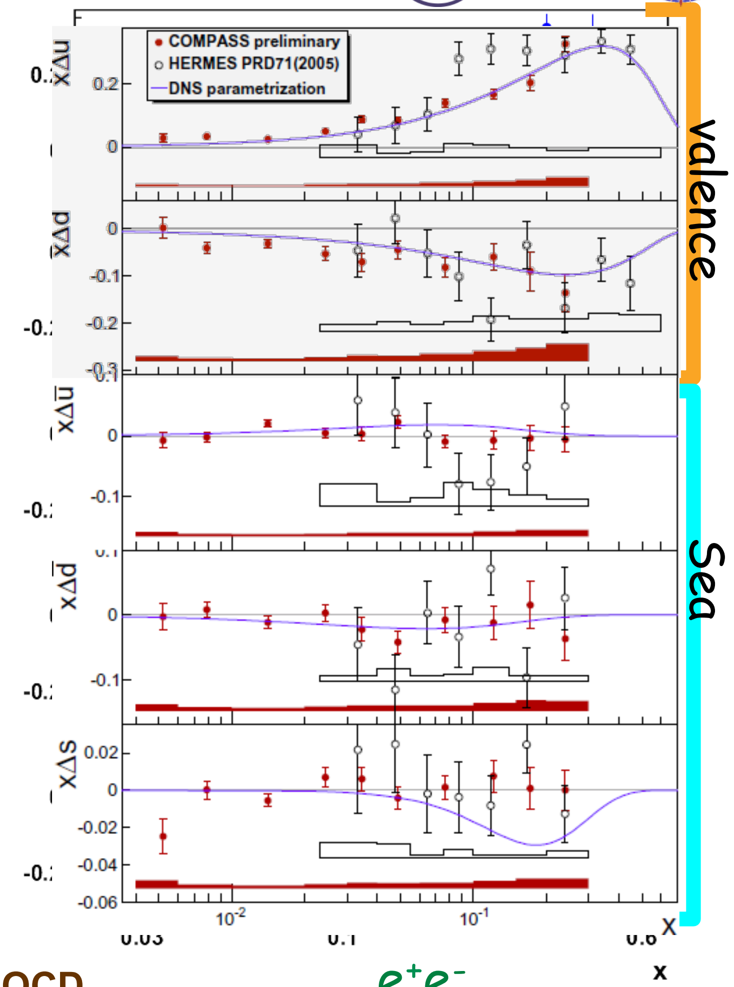
$$u\bar{d} \to \pi^+$$

$$\bar{u}d \to \pi^-$$

$$u\bar{s} \to K^+$$

$$\bar{u}s \to K^-$$

モデル依存！



Proton Structure

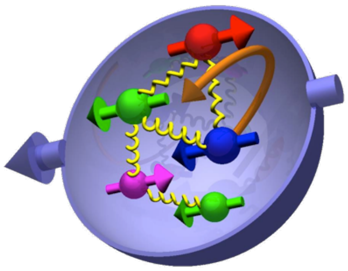
pQCD

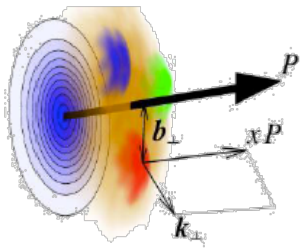
e^+e^-

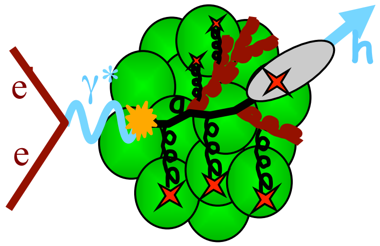
$z=E_h/\nu$

$$\frac{d^3\sigma^{\uparrow\downarrow}\left(pp^{\uparrow} \to \pi^+ X\right)}{dx_1 dx_2 dz} \propto \boxed{q_i^{\uparrow}(x_1)\cdot q_j^{\downarrow}(x_2)} \times \boxed{\frac{d^3\hat{\sigma}^{\uparrow\downarrow}(q_i q_j \to q_k q_l)}{dx_1 dx_2}} \times FF_{q_{k.l}}(z, k_T)$$

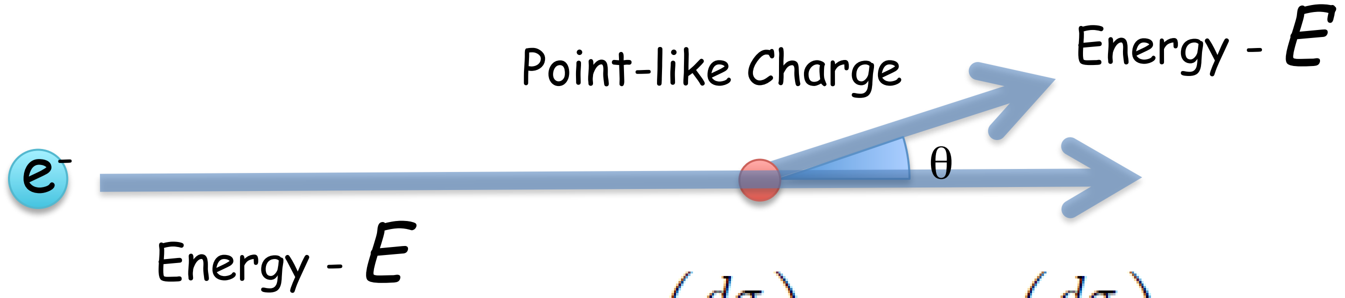
Physics Expectations



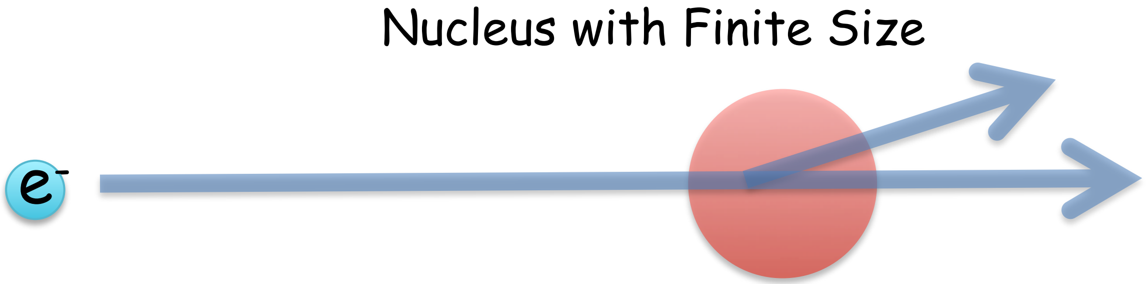




Electron Scattering



$$\left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{Mott}} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{Rutherford}} \cdot \cos^2\frac{\theta}{2} \cdot \frac{E'}{E}$$



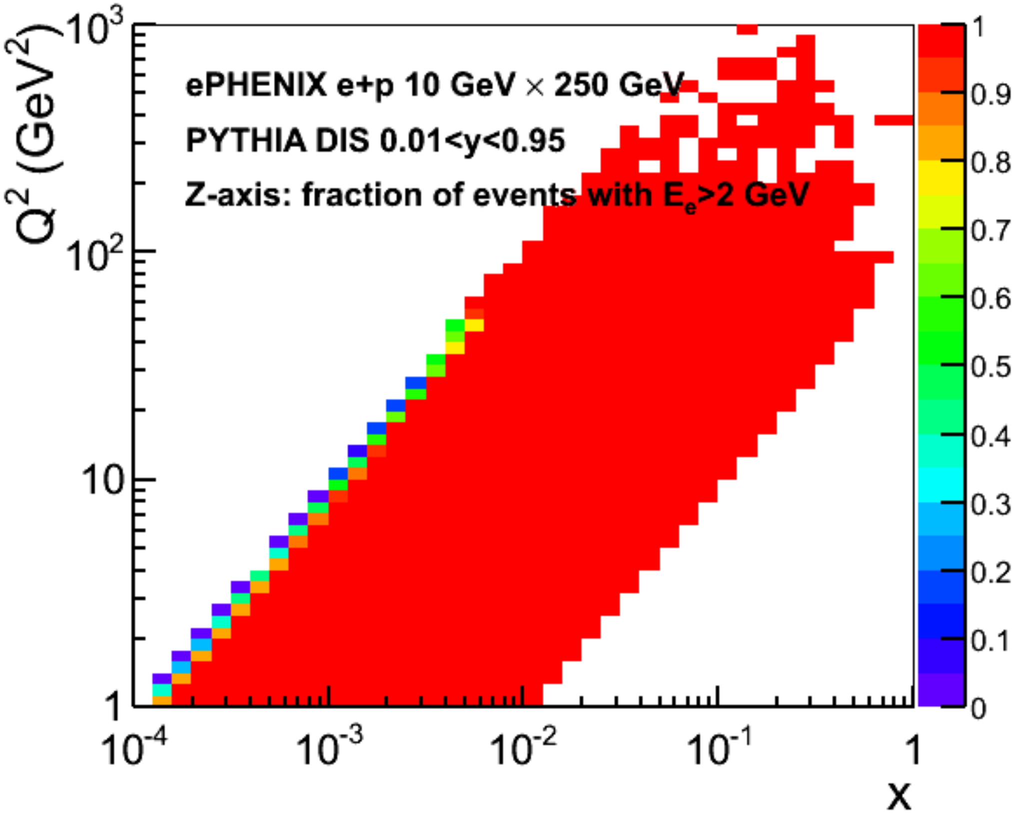
$$\left(\frac{d\sigma}{d\Omega}\right)_{\exp} \neq \left(\frac{d\sigma}{d\Omega}\right)_{Mott}$$

Summary

Inclusive DIS and Kinematics

What if poor eID at <2 GeV/c

Don’t lose much of the (x,Q^2) space



Inclusive DIS and Kinematics

Resolutions for (x,Q^2)

For perfect angle measurements:

$$\frac{\sigma_{Q^2}}{Q^2} = \frac{\sigma_{E'}}{E'} \qquad \frac{\sigma_x}{x} = \frac{1}{y}\frac{\sigma_{E'}}{E'}$$

Defines the precision of unfolding technique to correct for smearing due to detector effects

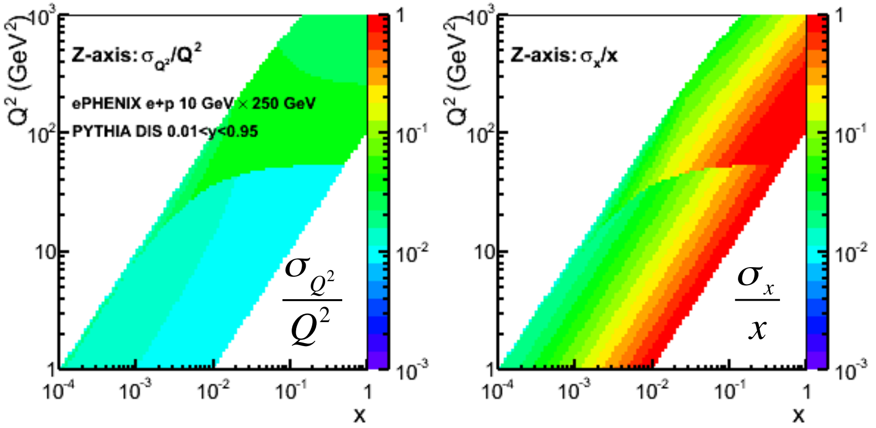
Results in statistics migration from bin to bin –> bin survival probability

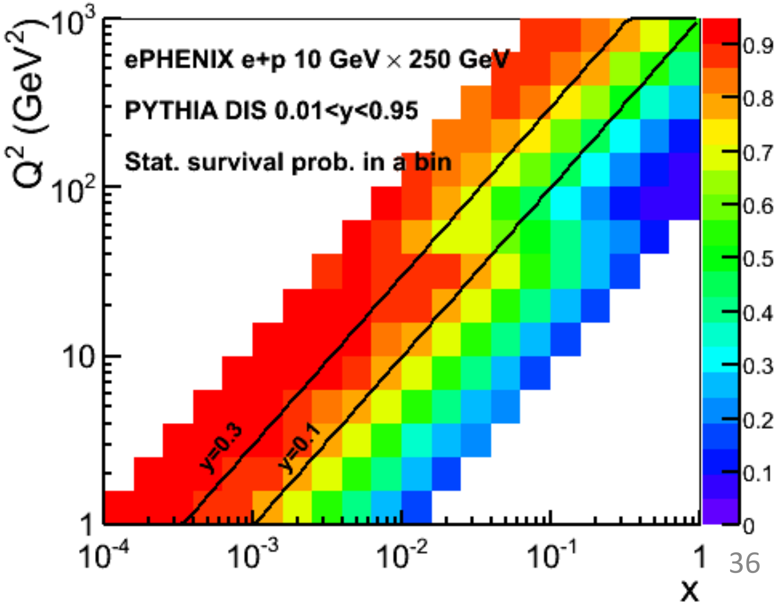
From HERMES experience: ~80% needed

Enough precision for scattered angle from EMCal position resolution –> no effect on bin survivability

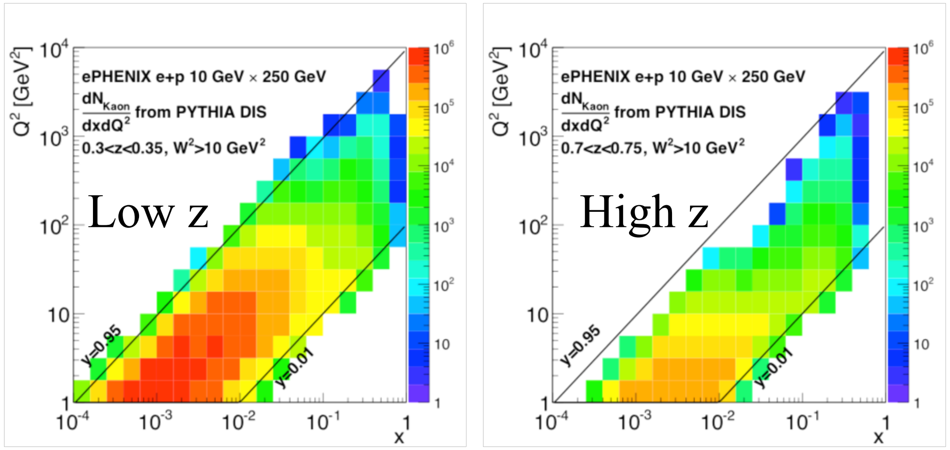
Jacqet-Blondel method (with hadronic final state) will help at lower y and higher Q^2

Plan to exercise with full unfolding to quantify the detector and radiation effects



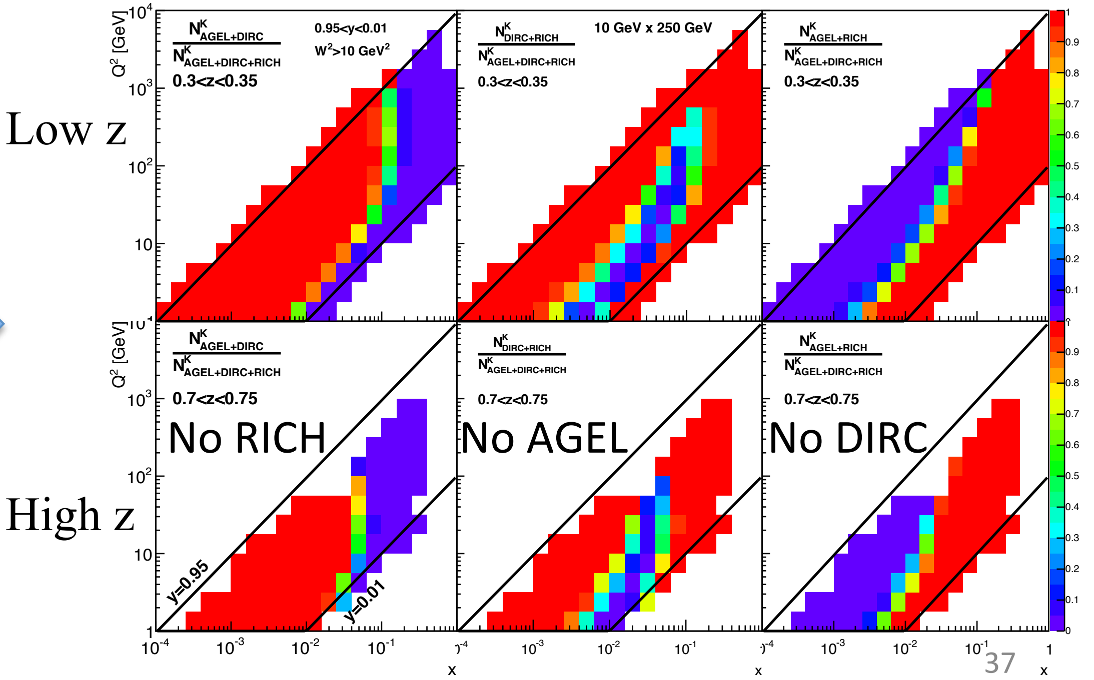


Semi-inclusive DIS and hadron ID



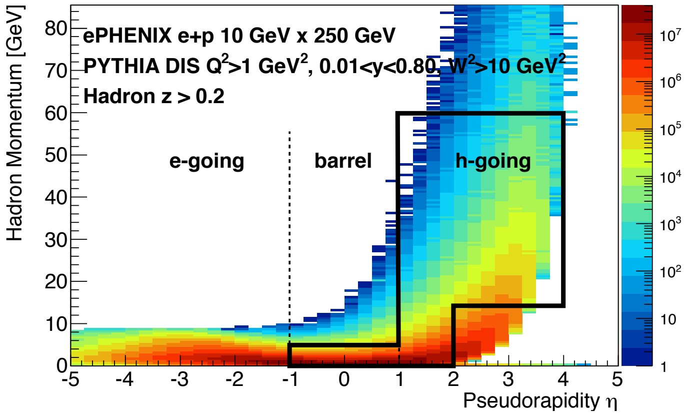
(x,Q²) coverage with K

(x,Q²) loss if not have given detector



All three detectors are important

Hadron ID with gas RICH

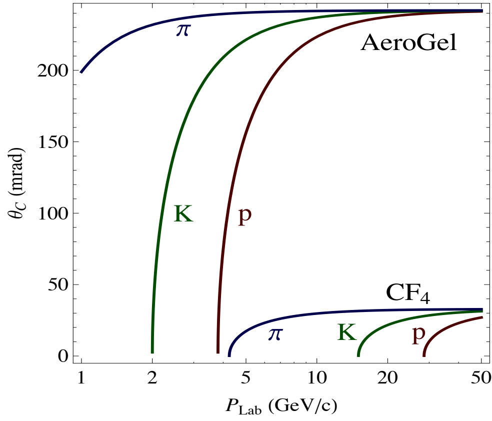


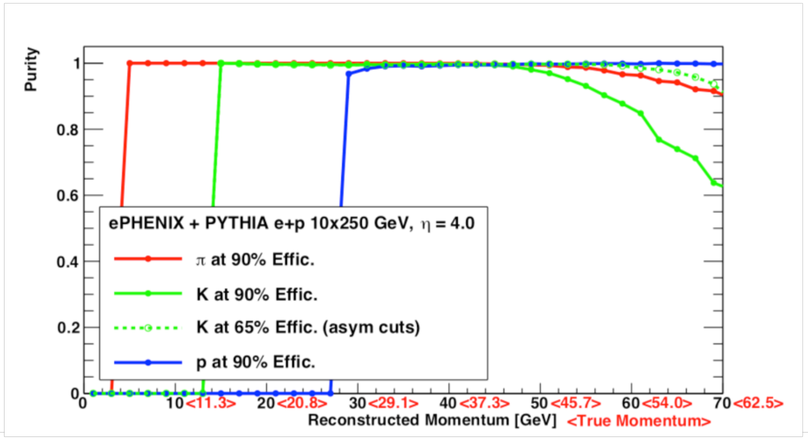
Gas RICH (CF4): 1<η<4

Highest momentum measurements require:

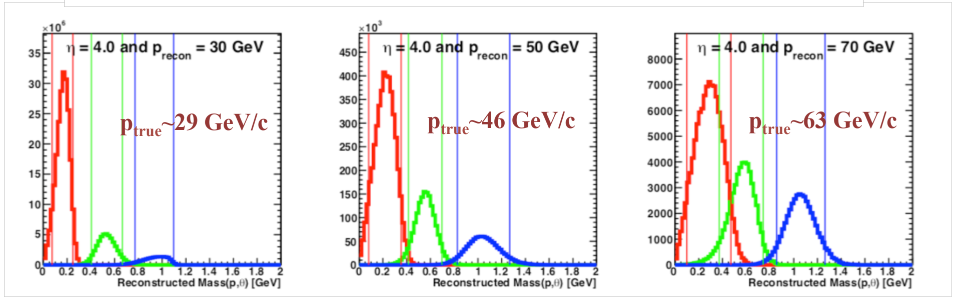
- Good momentum resolution (combination of tracking and HCal)
- Good ring resolution

Need to balance efficiency and purity to get best measurement





- ➢ PID up to ~60 GeV/c
- ➢ Currently limited by ring resolution (2.5% per photon - the current feedback from EIC R&D)
- ➢ Much smaller smearing due to magnetic field and off-center-vertex tracks

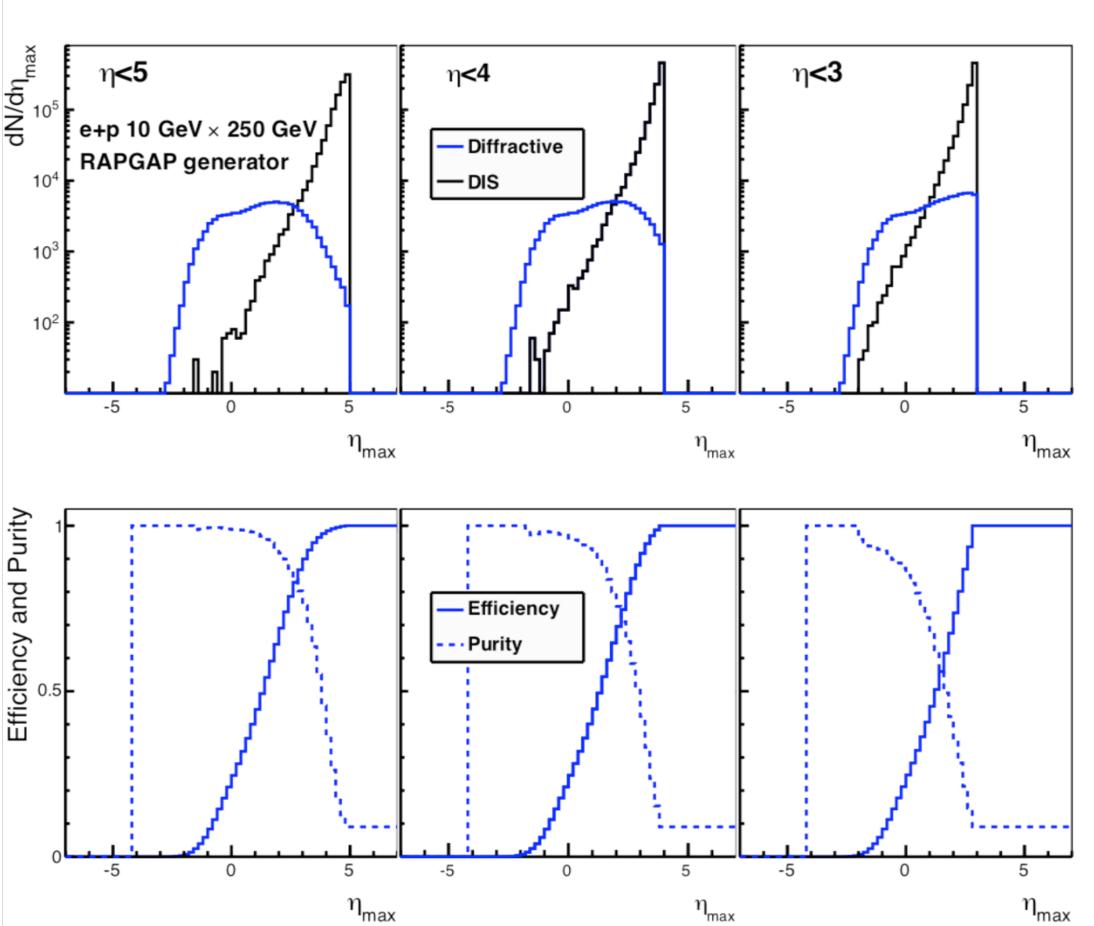


Diffractive Measurements

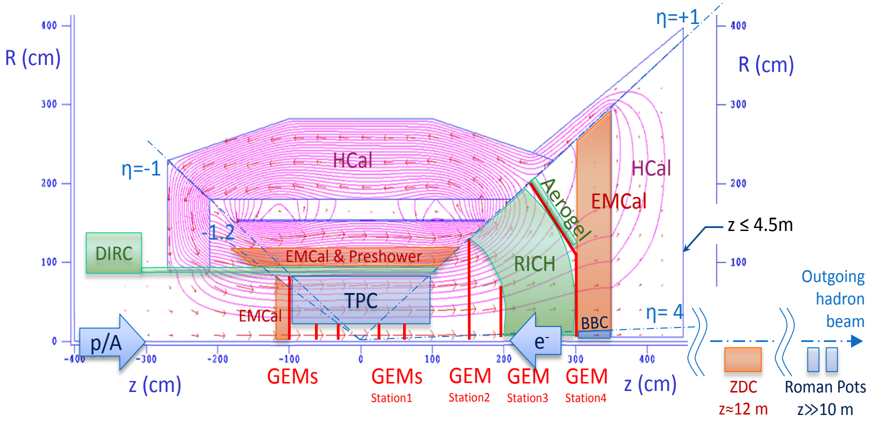
- Measure most forward going particle, to determine rapidity gap

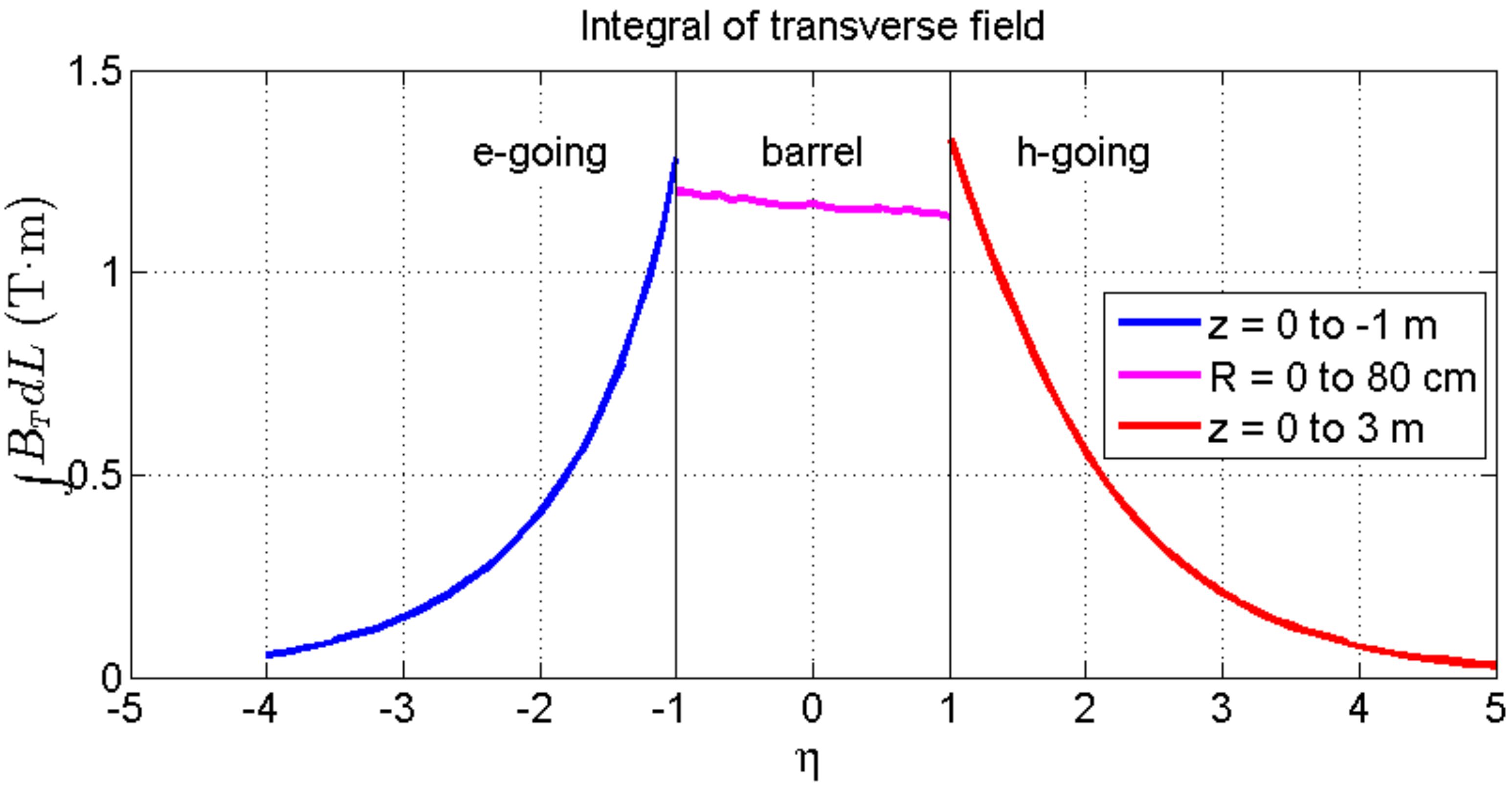
  HCal with -1<η<5 and EMCal with -4<η<4 are excellent in separation of DIS and diffractive

- ZDC to measure nucleus breakup



$B_T dL$


R (cm)
400
300
200
100
0
η=+1
R (cm)
400
300
200
100
η=-1
HCal
HCal
EMCal
Aerogel
z ≤ 4.5m
-1.2
DIRC
EMCal & Preshower
RICH
TPC
EMCal
BBC
η= 4
Outgoing
hadron
beam
p/A
e⁻
-400
-300
-200
-100
0
100
200
300
400
z (cm)
GEMs
GEMs
Station1
GEM
Station2
GEM
Station3
GEM
Station4
z (cm)
ZDC
z≈12 m
Roman Pots
z≫10 m


Integral of transverse field
$\int B_T dL$ (T·m)
1.5
1
0.5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
η
e-going
barrel
h-going
z = 0 to -1 m
R = 0 to 80 cm
z = 0 to 3 m

TPC

LEGS TPC

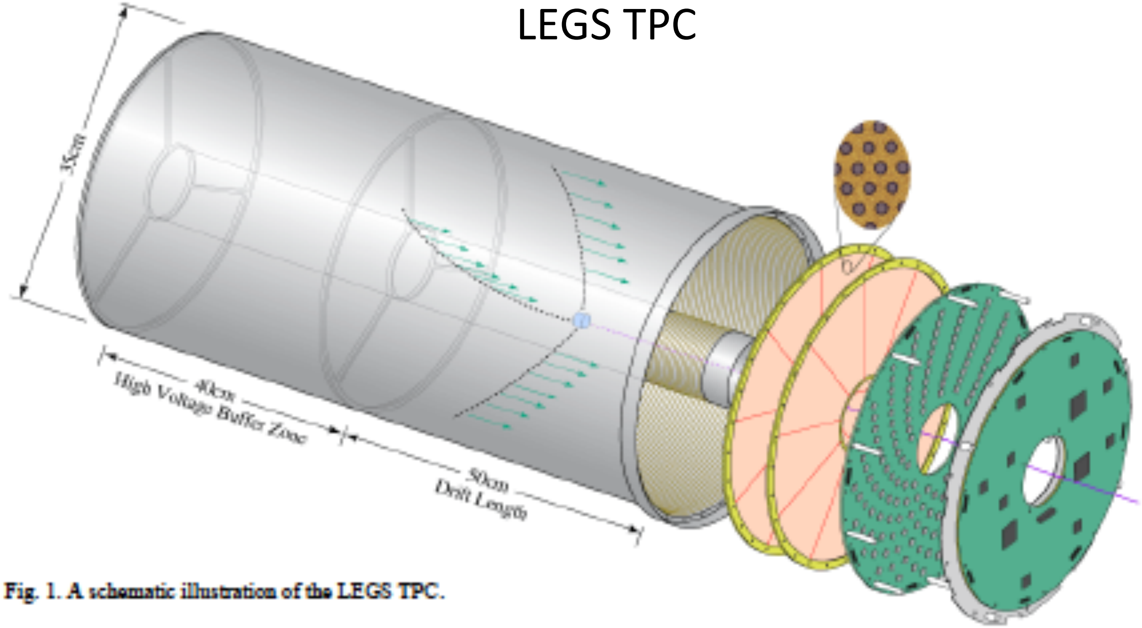
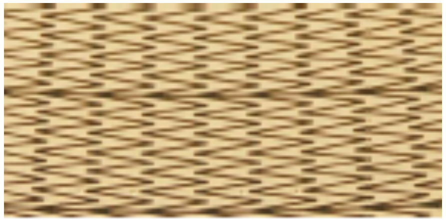


Fig. 1. A schematic illustration of the LEGS TPC.

Chevron-type readout pattern with a pad size 2mm × 5mm

Achieved pos. res. 200 μm



ePHENIX TPC:

R=15-80cm, |z|<95cm

Gas mixture with fast drift time: 80% Ar, 10% CF4, 10% CO2

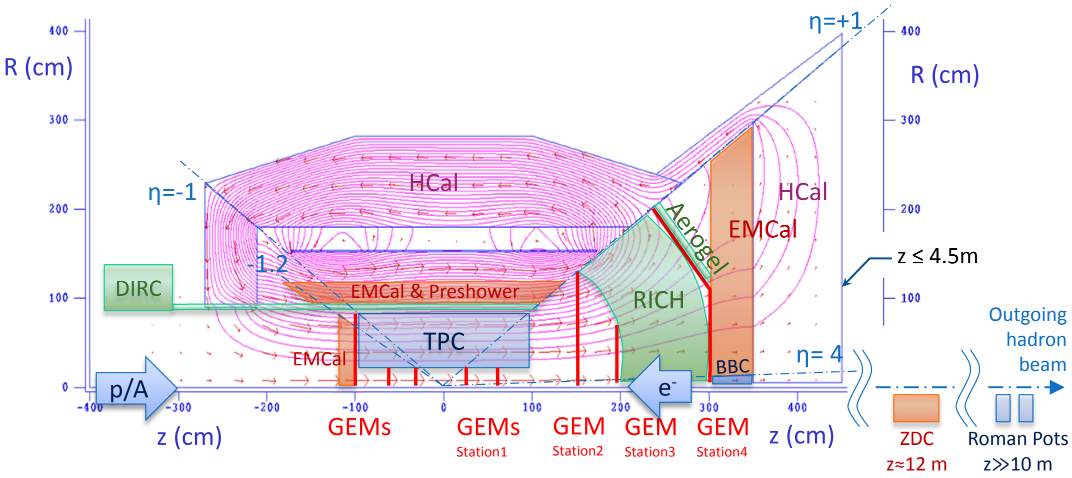
For 650 V/m -> 10cm/μs -> Drift time 10 μs

2×10mm pads –> 180k pads (both ends readout)

Pos. resolution 300 μm (twice longer drift distance tha LEGS) and 40 readout rows => $\sigma_p/p \sim 0.4\%\times p$

Tracking with GEM

Improved pos. res.
with mini-drift GEM



e-going direction

Station 1-2: z=30, 55cm r=2-15cm

Station 3: z=98 cm

-3<η<-2: 50µm with 1mm pad

-2<η<-1: 100µm with 2mm pad

Δr=1cm for St1-2 and Δr=10cm for St3

h-going direction

Station 1: z=17 and 60cm with r=2-15cm

Station 2-4: z=150, 200, 300 cm, 1<η<4

2.5<η<4: 50µm with 1mm pad

1<η<2.5: 100µm with 2mm pad

Δr=1-10cm

Collision vertex is necessary in e-going direction:

BBC: η=4-5, z=3m, σ_t=30ps (with MRPC or MCP) -> σ_z=5mm -> const term in σ_p/p~2%

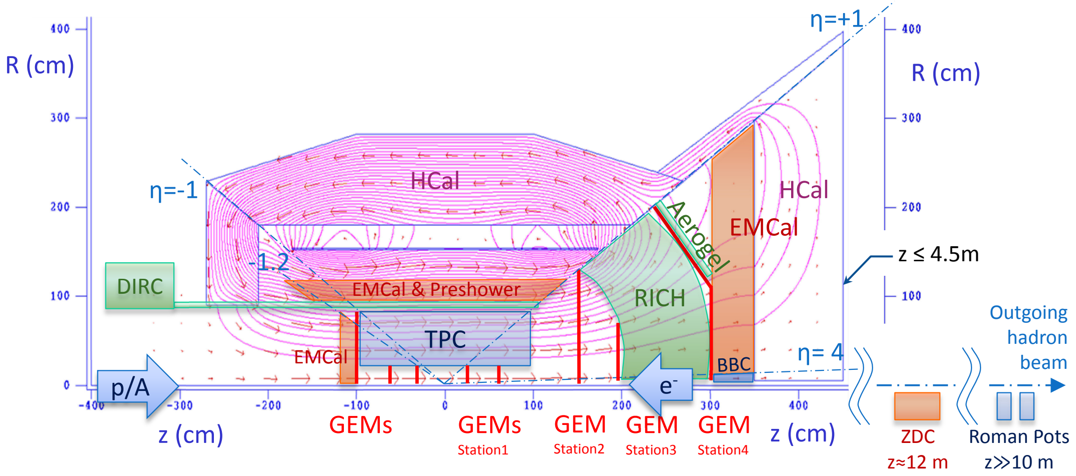
Total channel count: 217k

Large area GEMs are being developed in CERN for CMS (needed for our St 2-4)

Calorimetry

EMCal coverage $-4<\eta<4$
HCal coverage $-1<\eta<5$

Readout: SiPM



e-going direction

Crystall EMCal:

2cm×2cm
5k towers
$\sigma_E/E \sim 1.5\%/\sqrt{E}$
$\sigma_x \sim 3\text{mm}/\sqrt{E}$

Barrel (sPHENIX)

Tungsten-fiber EMCal:

2cm×2cm
25k towers
$\sigma_E/E \sim 12\%/\sqrt{E}$

Steel-Sc HCal:

10cm×10cm
3k towers
$\sigma_E/E \sim 100\%/\sqrt{E}$

h-going direction

Pb-fiber EMCal:

3cm×3cm
26k towers
$\sigma_E/E \sim 12\%/\sqrt{E}$

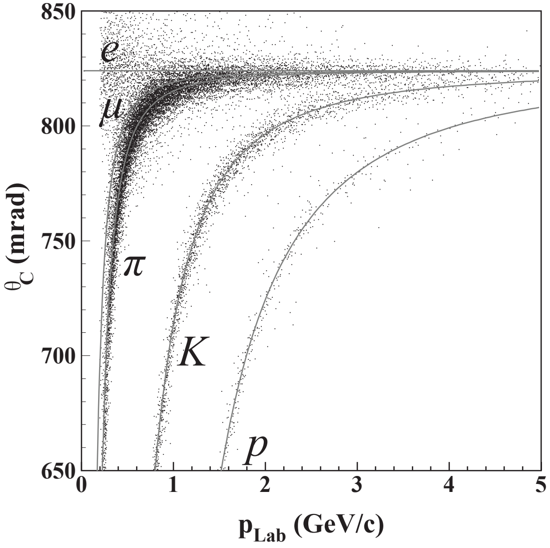
Steel-Sc HCal:

10cm×10cm
3k towers
$\sigma_E/E \sim 100\%/\sqrt{E}$

Hadron PID

DIRC

$-1<\eta<1$
Mirror focusing ?
Threshold for π/K/p:
0.2/0.7/1.5 GeV

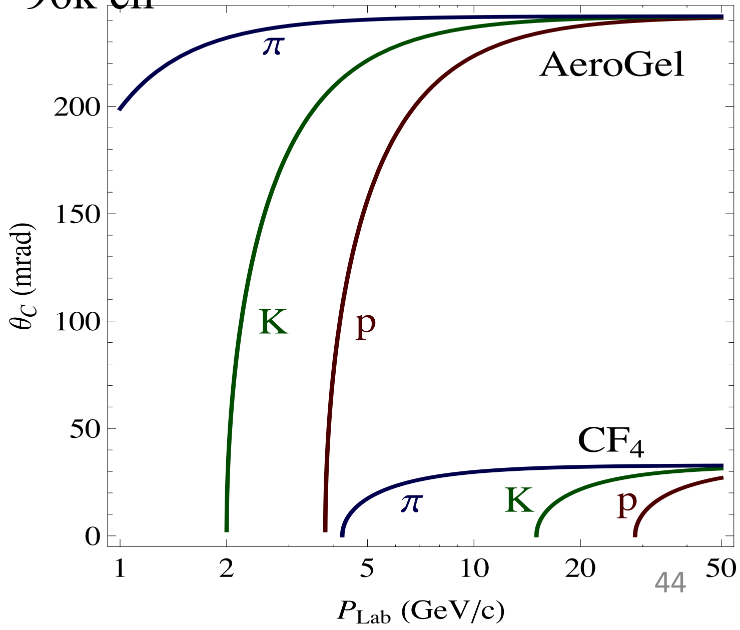


Gas RICH (CF4)

$1<\eta<4$
Mirror focusing
Threshold for π/K/p:
4/15/29 GeV
6 azimuthal segments
Photodetection: GEM with CsI
Area 6×0.3m^2 –> 96k ch
In gas volume!

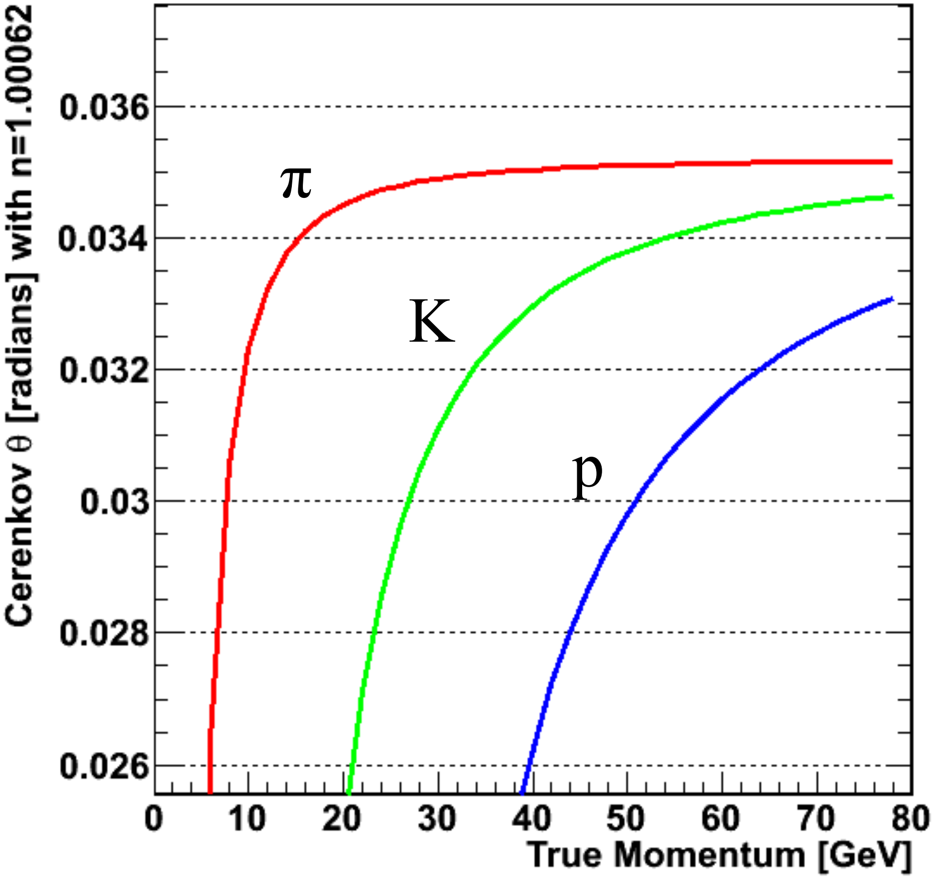
Aerogel

$1<\eta<2$
Proximity focused
Threshold for π/K/p:
0.6/2/4 GeV



Cerenkov Angle in CF4

n=1.0006



Hadron PID: gas RICH

Goals and assumptions/restrictions

1m gas volume along the track => F=1m => R=2m

Z>1.5m (optimal sagitta plane)

Z<3.0m (EMCal)

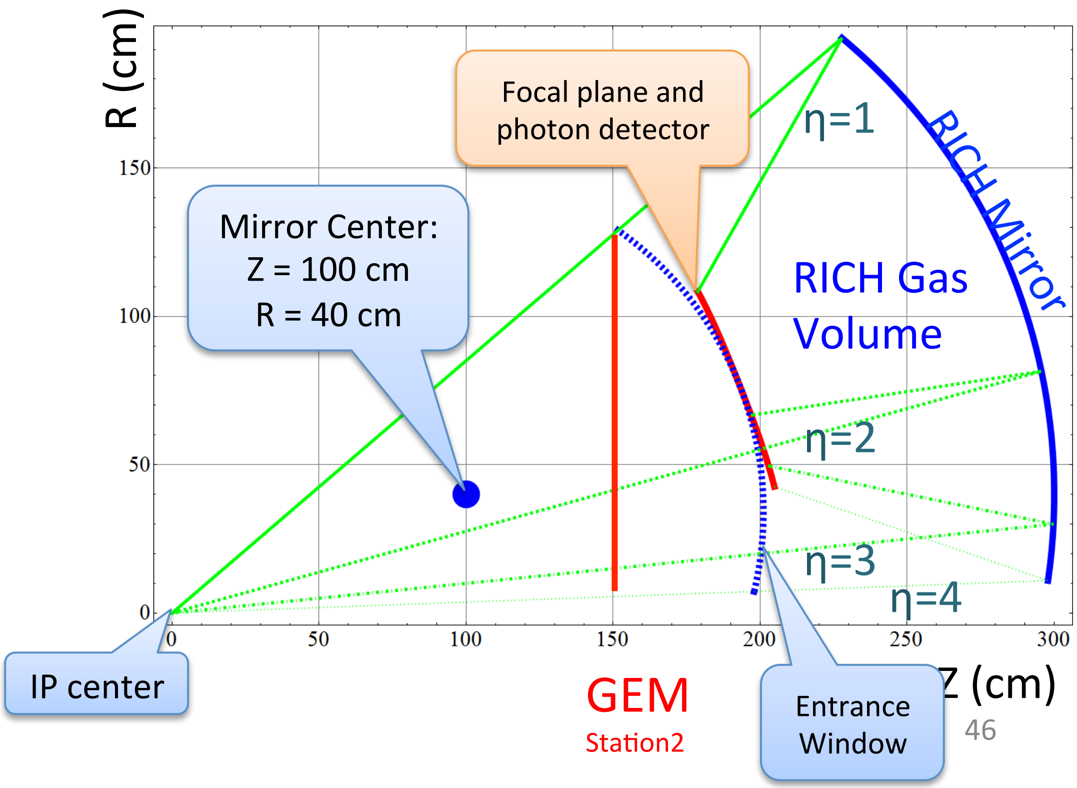
Photon detector inside tracking volume –> GEM as thin –> flat

Low number of edges between mirrors

Small area for photon readout

Moving mirror center to beam line:

- Focal plane not flat
- Steeper impact angle on the photon detector
- Photon detector closer to beam line
- RICH volume moves to z<1.5m



Hadron PID: gas RICH

CF4 (n=1.00062)

Ring resolution

Ring radius resolution: 2.5%/$\sqrt{N_\gamma}$

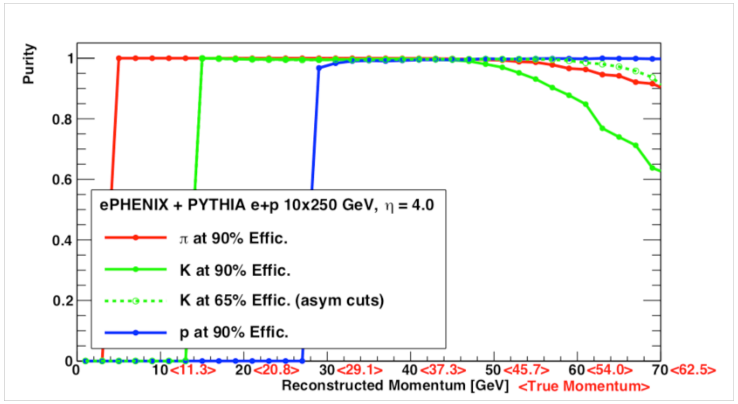
- From current EIC R&D studies
- LHCb and COMPASS claimed 1% per photon

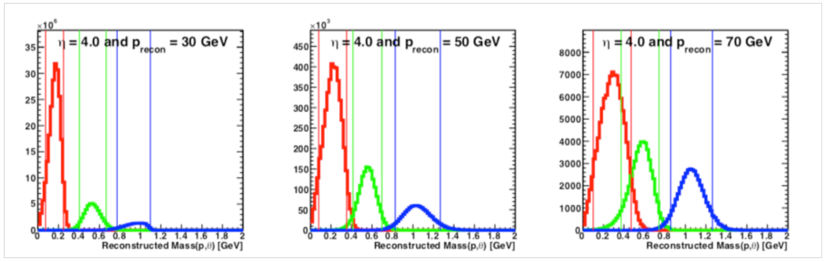
Residual magnetic field (~0.5 T) bends tracks radiating photons => ring smearing

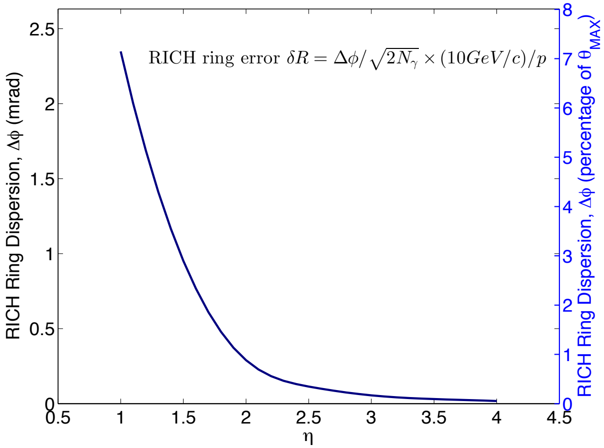
- Since field is near parallel to tracks the effect is minimal

Off-center vertex tracks have shifted focal plane => ring smearing

- For $\eta=1$ and z=40cm => ring dispersion 5%/$\sqrt{N_\gamma}\times$(10 GeV/c) / p
- For larger η effect is smaller





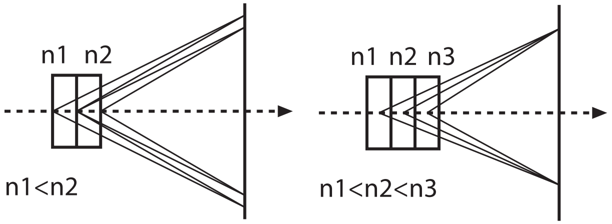


Ring resolution limits PID at higher p

Hadron PID: Aerogel

Allows to identify K for 3<p<10 GeV

Focusing



Challenges:

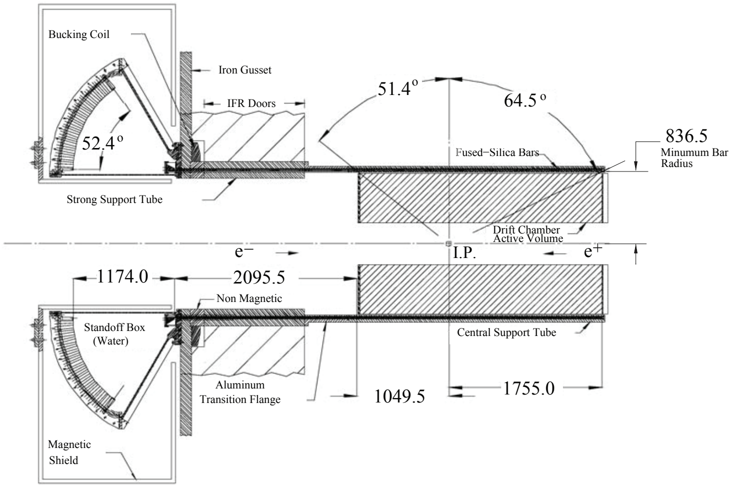
- Fringe field
- Low light output
- Visible wavelength range
- Limited space for light focusing

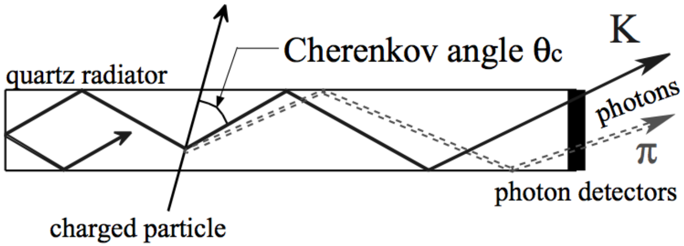
Photon detection:

Microchannel Plate Detector

- Multi-alkali photocathode
- Also ToF with σ=20-30ps
- Being developed by LAPPD Collaboration

Hadron PID: DIRC





BaBar DIRC

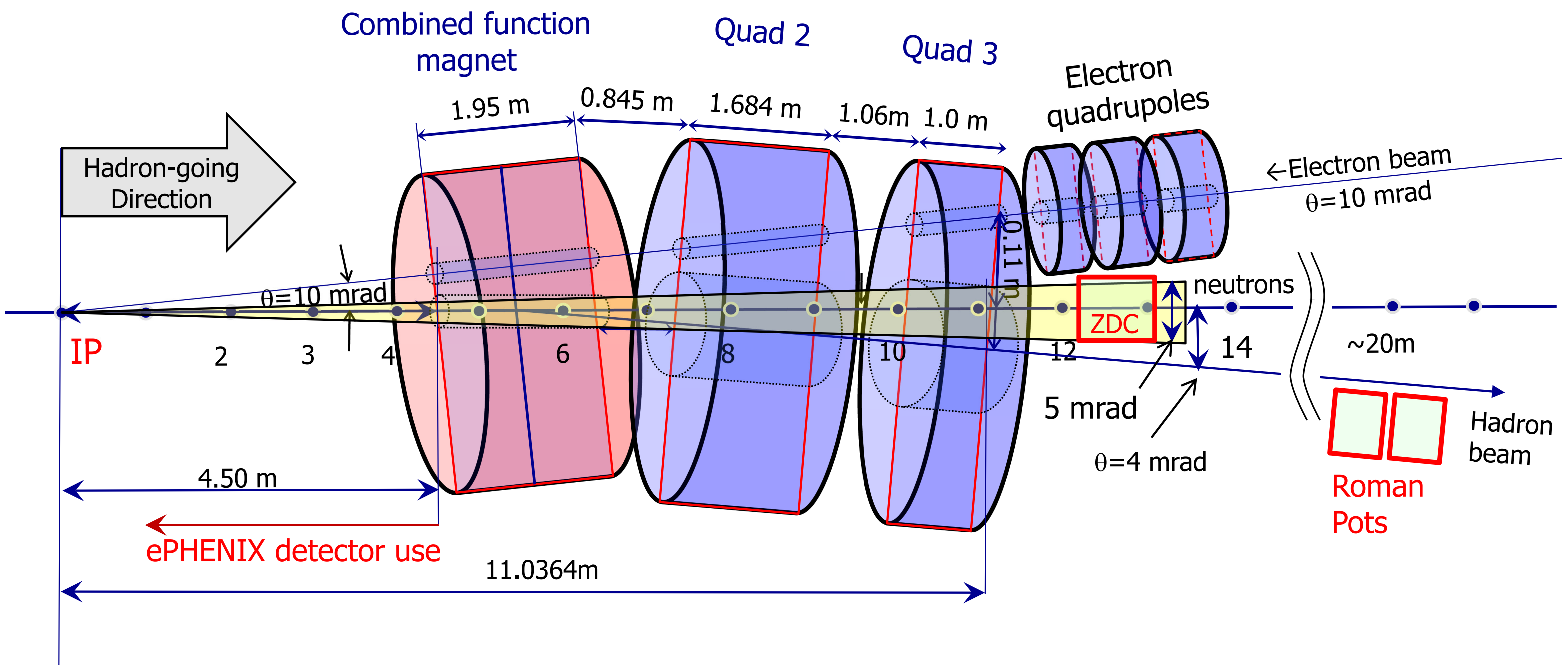
- Quartz radiator bars, Cerenkov light internally reflected
- No focusing => Large water filled expansion volume
- PMT for readout

ePHENIX DIRC

- Mirror Focusing to avoid large expansion region
- Pixelated multi-anode PMT for readout

Ring resolution limits PID at higher p

Beamline Detectors



ZDC

12 m downstream

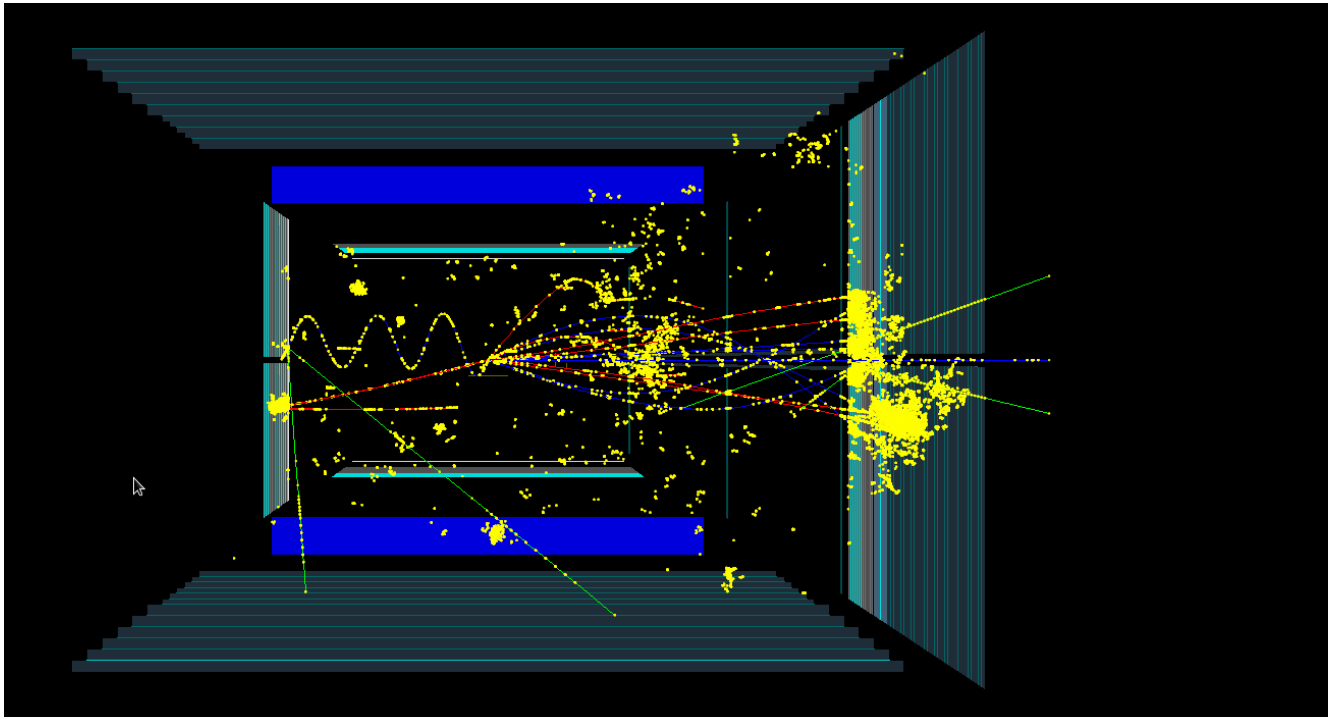
5 mrad cone opening of the IP is available from ePHENIX and IP design

Roman Pots

>20 m downstream

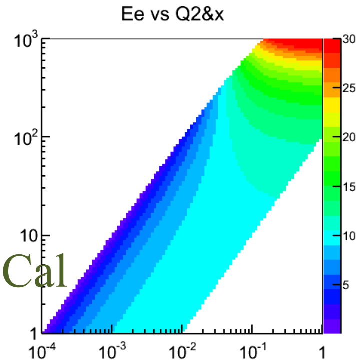
Similar to STAR design

GEANT simulation

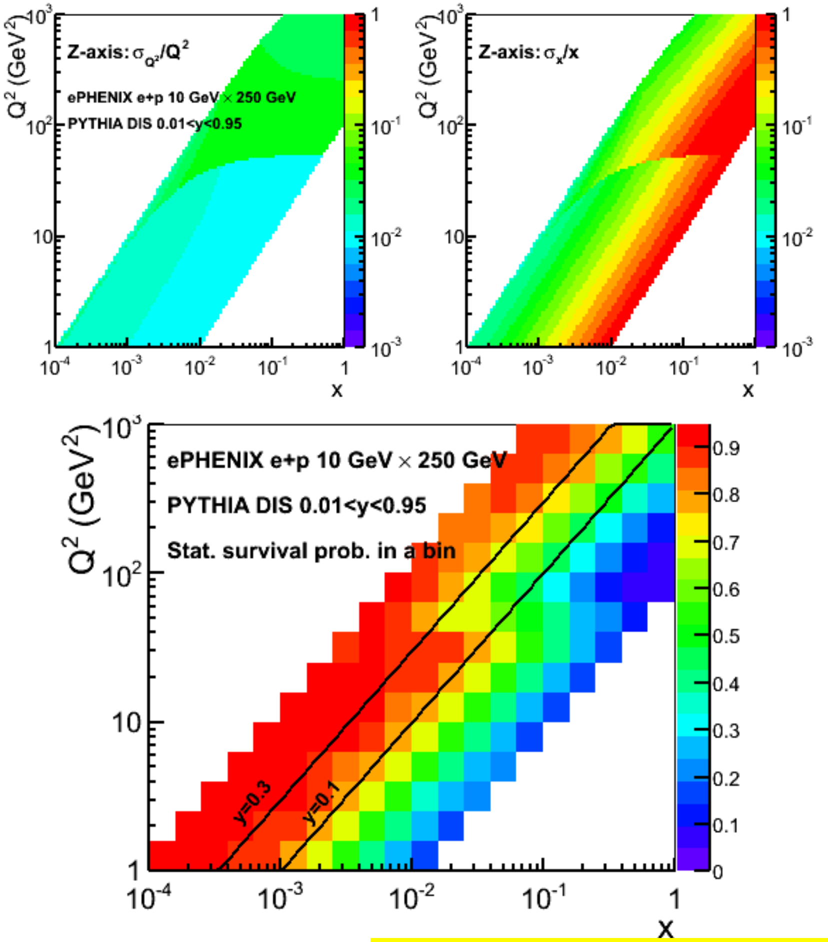


GEANT4 description of ePHENIX exists
Simulation and analysis software common with sPHENIX and PHJENIX

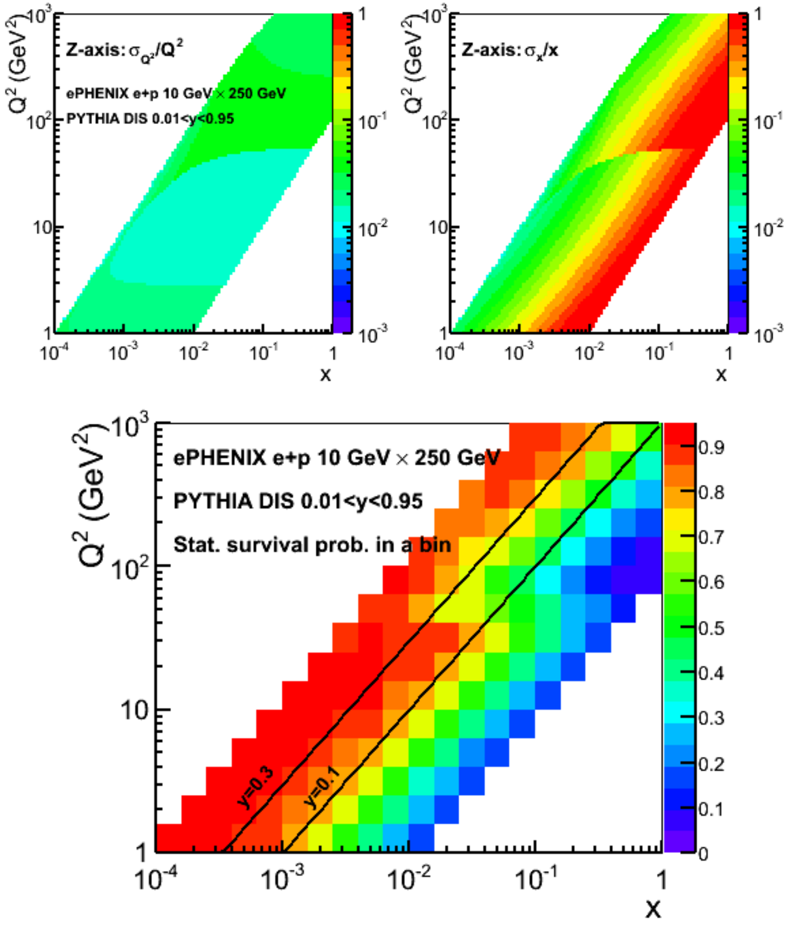
DIS kinematics: angle from EMCal



With perfect angle measurements



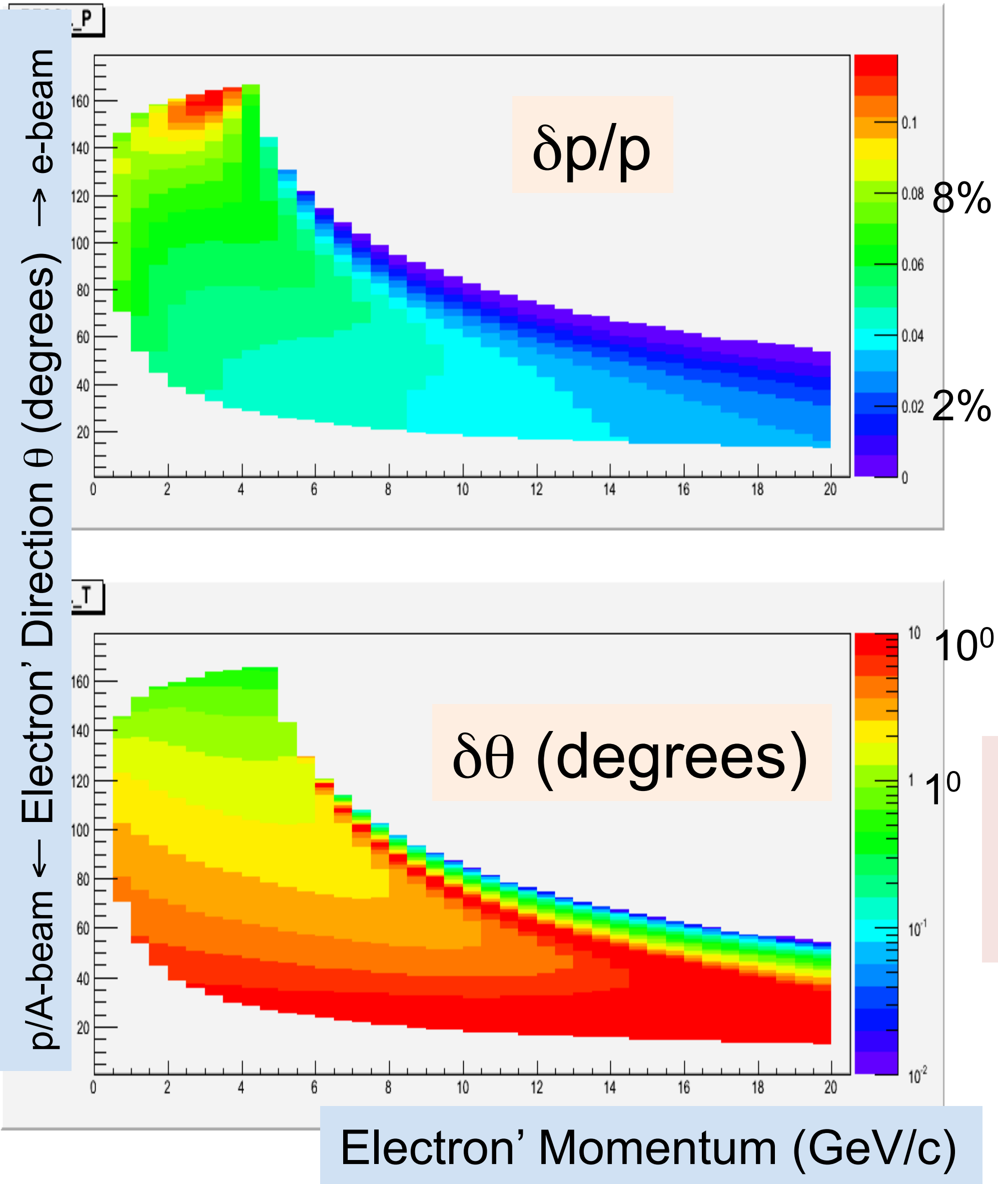
With angle smearing due to EMCal pos. resolution



Only minor effect from angle measurements with EMCal

Tom H: Momentum and angle resolution

5 GeV (e) × 100 GeV (p)



Inclusive measurements:

$$\sigma_{red} = F_2\left(x,Q^2\right) - \frac{y^2}{Y_+} F_L\left(x,Q^2\right)$$

$$(x,Q^2) \rightarrow (p,\theta)_{e'}$$

Resolution → Systematics → Unfolding

Assume: σ_{syst}~1/5 of systematics

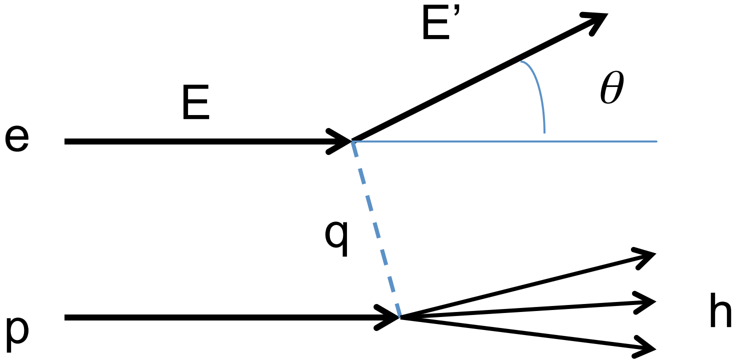
0.1×0.1 binning in $\log_{10}(x) \times \log_{10}(Q^2)$

Require: 1% uncertainty in each bin

"Reasonable" resolutions may be enough:

$\delta p/p \sim$ 2-8%

$\delta\theta \sim$ 1 degree



Electron vs Jacquet-Blondel

Electron

$$Q^2 = 4EE'\sin^2\left(\frac{\theta}{2}\right)$$

$$y = 1 - \frac{E'}{E}\cos^2\left(\frac{\theta}{2}\right)$$

$$x = \frac{Q^2}{sy}$$

y→0: $\sigma_y/y \sim 1/y$

JB

$$Q^2_{JB} = \frac{p^2_{T,h}}{1-y_{JB}} \qquad p^2_{T,h} = \left(\sum_h p_{x,h}\right)^2 + \left(\sum_h p_{y,h}\right)^2$$

$$y_{JB} = \frac{(E-p_z)_h}{2E_e} \qquad (E-p_z)_h = \sum_h (E_h - p_{z,h})$$

$$x_{JB} = \frac{Q^2_{JB}}{sy_{JB}}$$

y→0: $\sigma_y/y \sim \text{const}$

JB

JB and DA methods give better resolution at lower y and higher Q^2

Our studies:

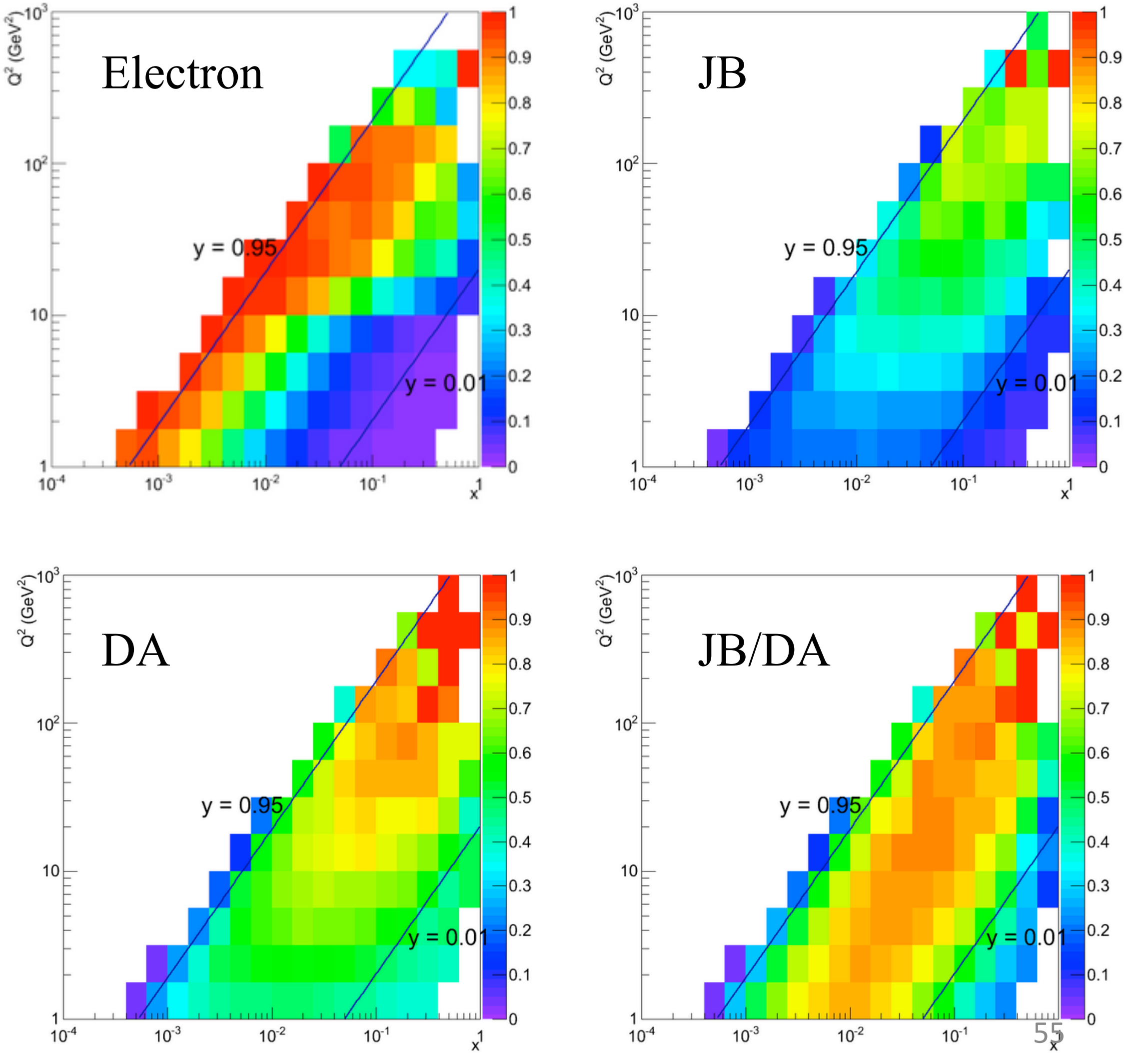
- Enough to measure hadrons in $|\eta|<4$
- Hadron PID is important

  Particularly for lower Q^2
- For $y<0.2$ – enough to measure in $-1<\eta<4$

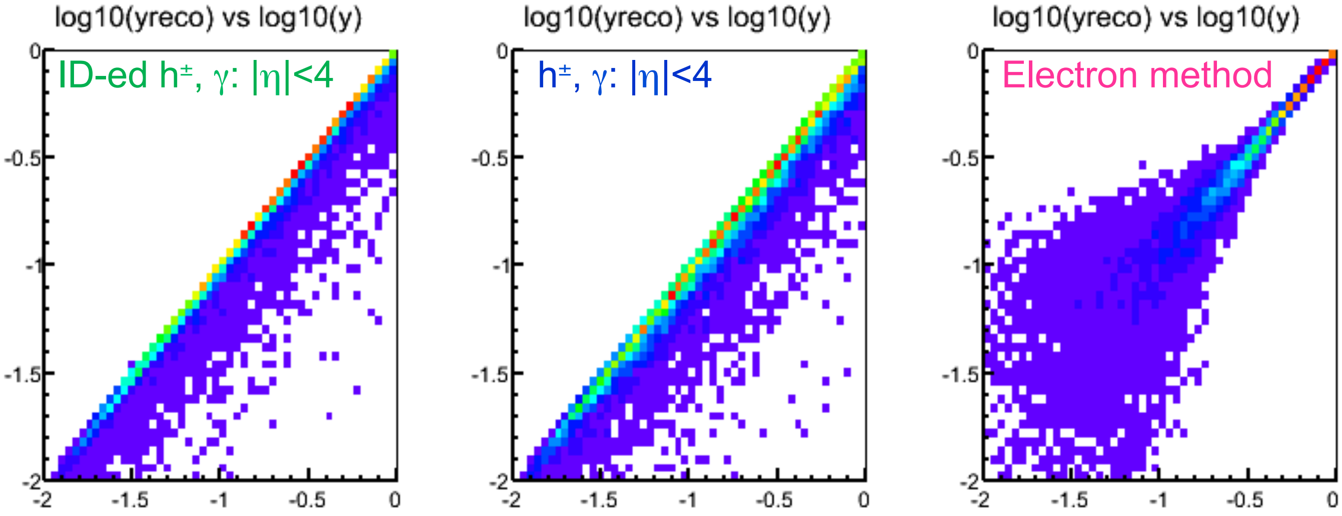
  The acceptance we'll equip with hadron ID

EIC group studies:

https://wiki.bnl.gov/eic/index.php/Q2-x_bin_migration



JB: 5x100 Q2>10



- Enough to measure hadrons in |η|<4
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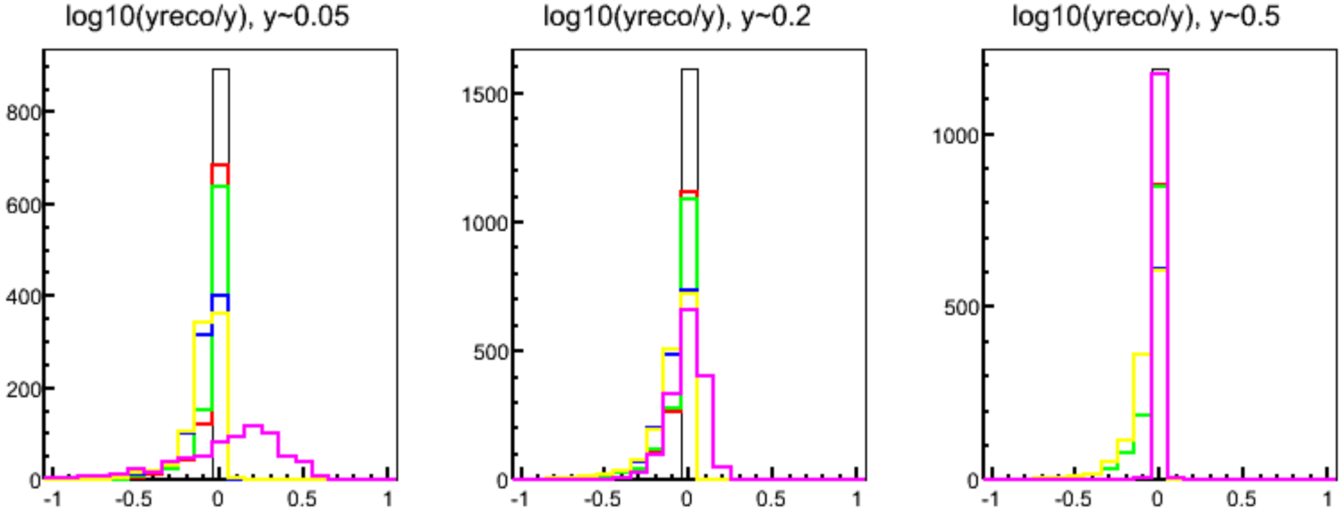
  Particularly for lower Q^2
- For y<0.2 – enough to measure in -1<η<4

  The acceptance we'll equip with hadron ID

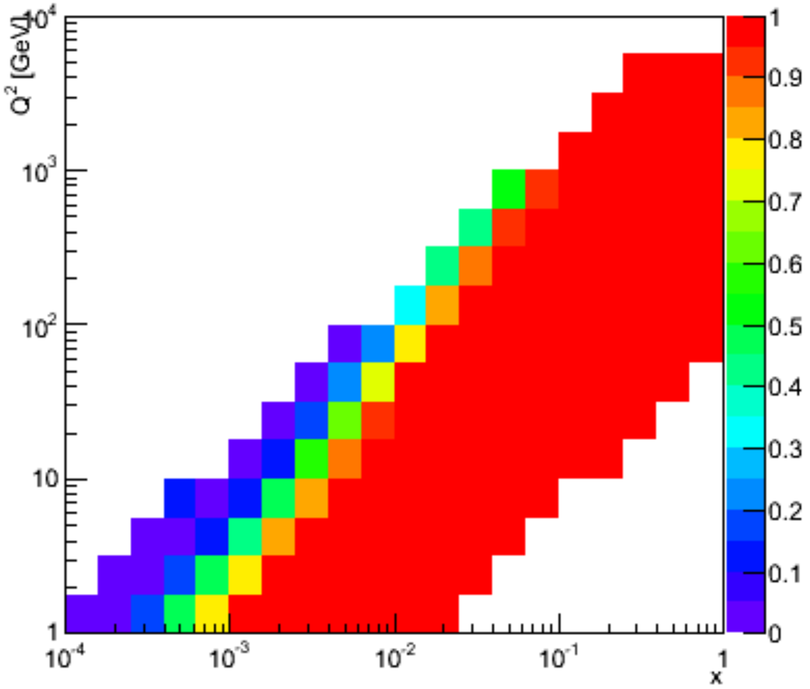


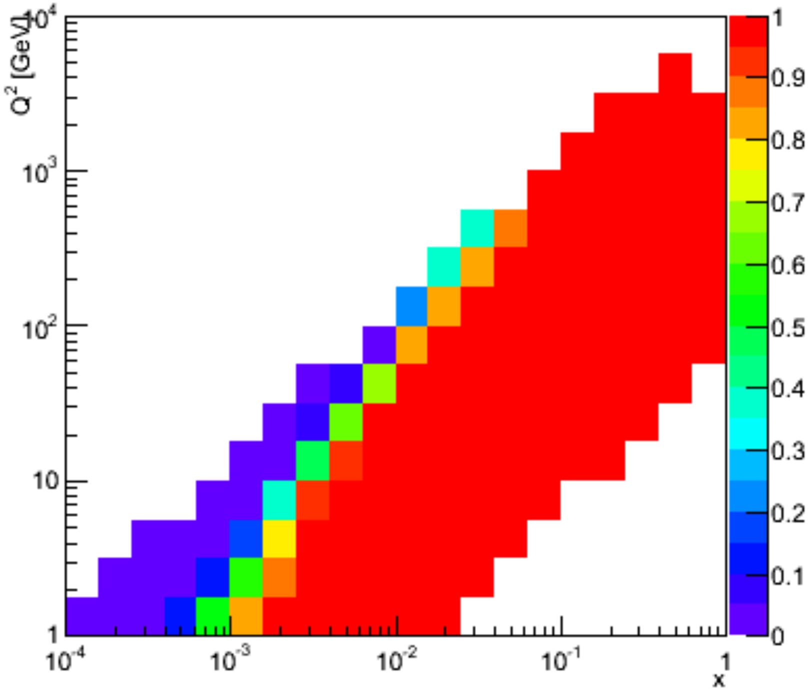
All
ID-ed h±, γ
ID-ed h±, γ: |η|<4
h±, γ: |η|<4
h±, γ: |η|<4, p-smeared
Electron method

Green ~ Red
Blue ~ Yellow

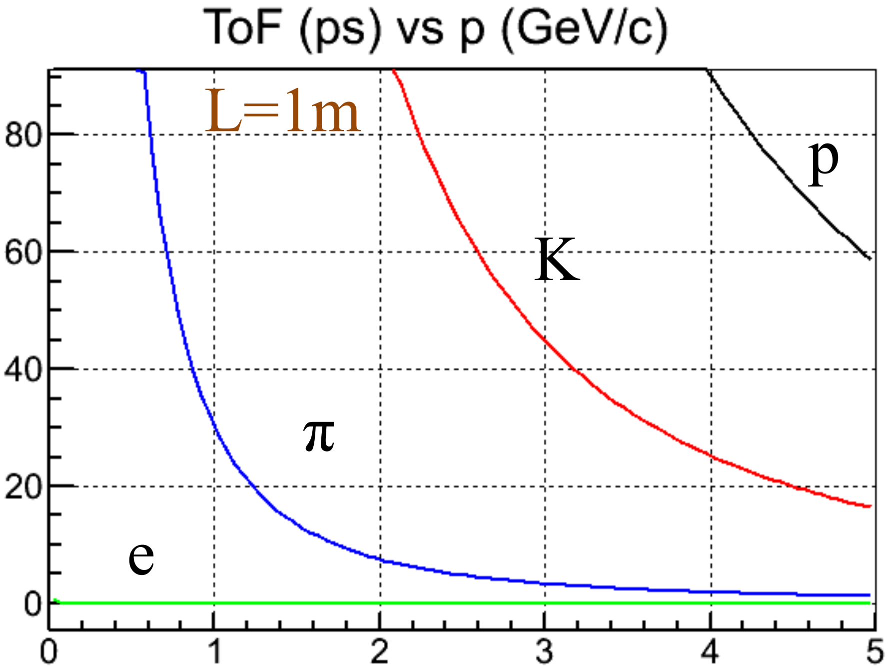
(x,Q2) loss due to no ePID in e-going direction

e+p 10 GeV × 250 GeV
PYTHIA DIS $0.01<y<0.95$ $W^2>10$ GeV^2


0.30<z<0.35


0.70<z<0.75

ToF for PID?



With 10 ps resolution including t_0:

e/π separation at <1 GeV/c

K/π separation at <4 GeV/c

Need t_0 ($\sigma<10$ps) and vertex ($\sigma\sim1$mm)

Cost and schedule

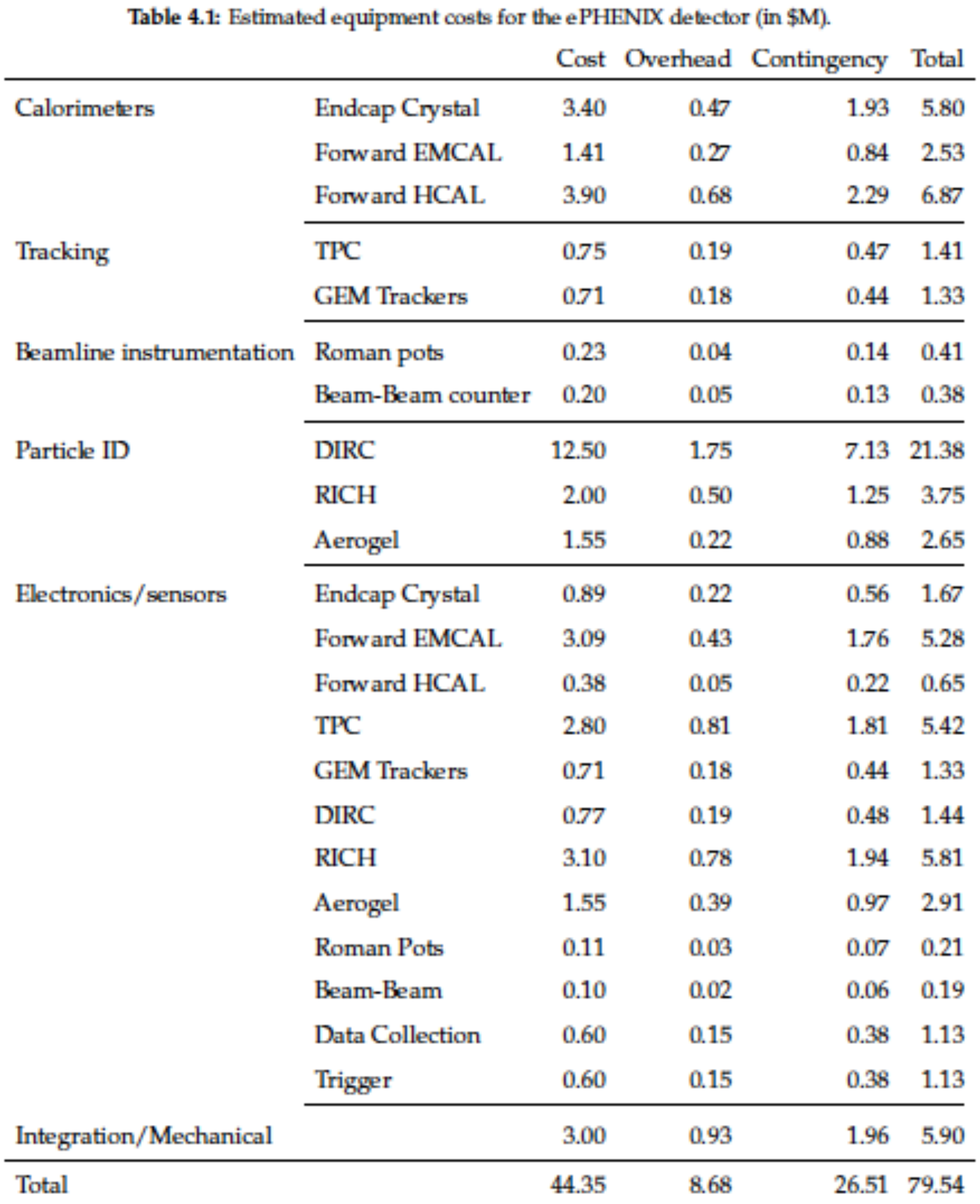


Table 4.1: Estimated equipment costs for the ePHENIX detector (in $M).

		Cost	Overhead	Contingency	Total
Calorimeters	Endcap Crystal	3.40	0.47	1.93	5.80
	Forward EMCAL	1.41	0.27	0.84	2.53
	Forward HCAL	3.90	0.68	2.29	6.87
Tracking	TPC	0.75	0.19	0.47	1.41
	GEM Trackers	0.71	0.18	0.44	1.33
Beamline instrumentation	Roman pots	0.23	0.04	0.14	0.41
	Beam-Beam counter	0.20	0.05	0.13	0.38
Particle ID	DIRC	12.50	1.75	7.13	21.38
	RICH	2.00	0.50	1.25	3.75
	Aerogel	1.55	0.22	0.88	2.65
Electronics/sensors	Endcap Crystal	0.89	0.22	0.56	1.67
	Forward EMCAL	3.09	0.43	1.76	5.28
	Forward HCAL	0.38	0.05	0.22	0.65
	TPC	2.80	0.81	1.81	5.42
	GEM Trackers	0.71	0.18	0.44	1.33
	DIRC	0.77	0.19	0.48	1.44
	RICH	3.10	0.78	1.94	5.81
	Aerogel	1.55	0.39	0.97	2.91
	Roman Pots	0.11	0.03	0.07	0.21
	Beam-Beam	0.10	0.02	0.06	0.19
	Data Collection	0.60	0.15	0.38	1.13
	Trigger	0.60	0.15	0.38	1.13
Integration/Mechanical		3.00	0.93	1.96	5.90
Total		44.35	8.68	26.51	79.54

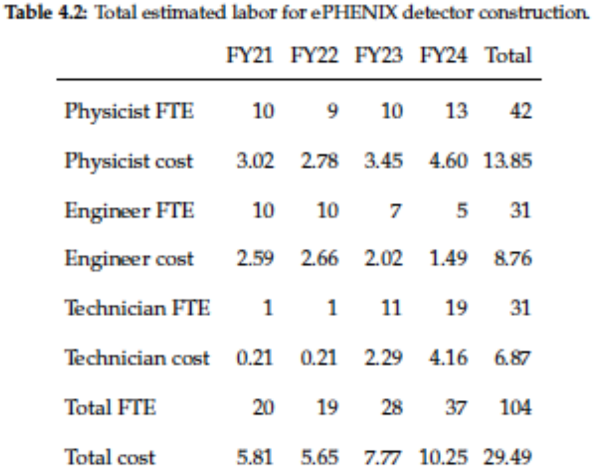
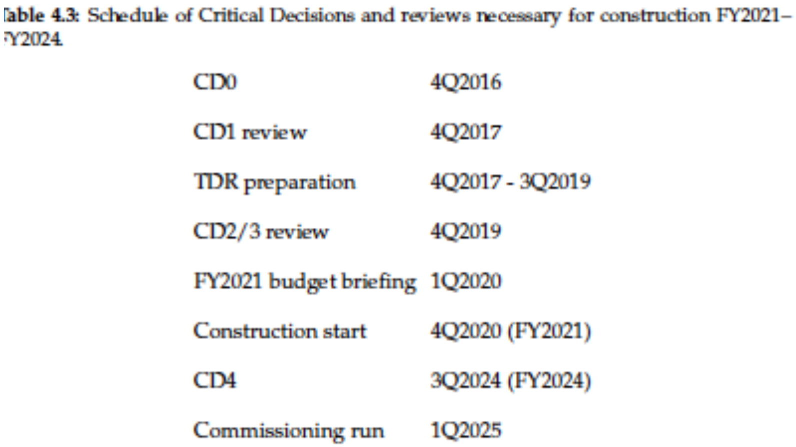


Table 4.2: Total estimated labor for ePHENIX detector construction.

	FY21	FY22	FY23	FY24	Total
Physicist FTE	10	9	10	13	42
Physicist cost	3.02	2.78	3.45	4.60	13.85
Engineer FTE	10	10	7	5	31
Engineer cost	2.59	2.66	2.02	1.49	8.76
Technician FTE	1	1	11	19	31
Technician cost	0.21	0.21	2.29	4.16	6.87
Total FTE	20	19	28	37	104
Total cost	5.81	5.65	7.77	10.25	29.49



able 4.3: Schedule of Critical Decisions and reviews necessary for construction FY2021–Y2024.

CD0	4Q2016
CD1 review	4Q2017
TDR preparation	4Q2017 - 3Q2019
CD2/3 review	4Q2019
FY2021 budget briefing	1Q2020
Construction start	4Q2020 (FY2021)
CD4	3Q2024 (FY2024)
Commissioning run	1Q2025