EIC detector, software, experimental possibilities

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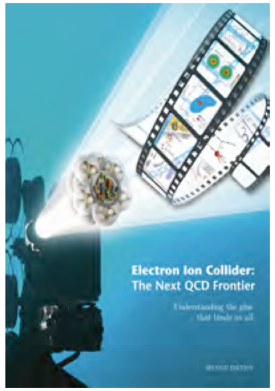
Outline

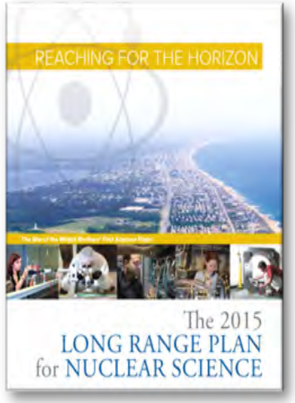
- Current status of the EIC project
- Yellow book activity and a "Handbook detector"
- Status of the simulation
- Conclusion

Most of the slides are from the 2nd EIC Yellow Book meeting.
Thanks to everyone who contributed!

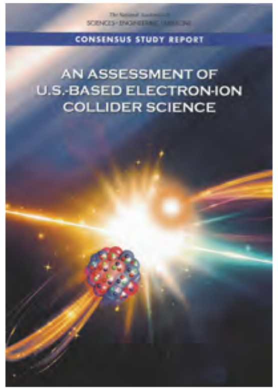
The EIC

2015 2016 2018 2019

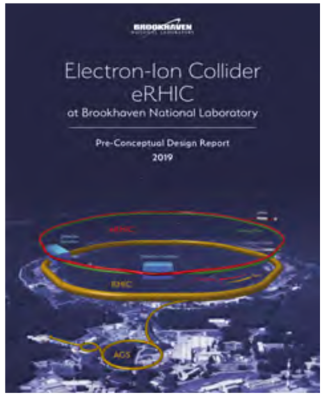




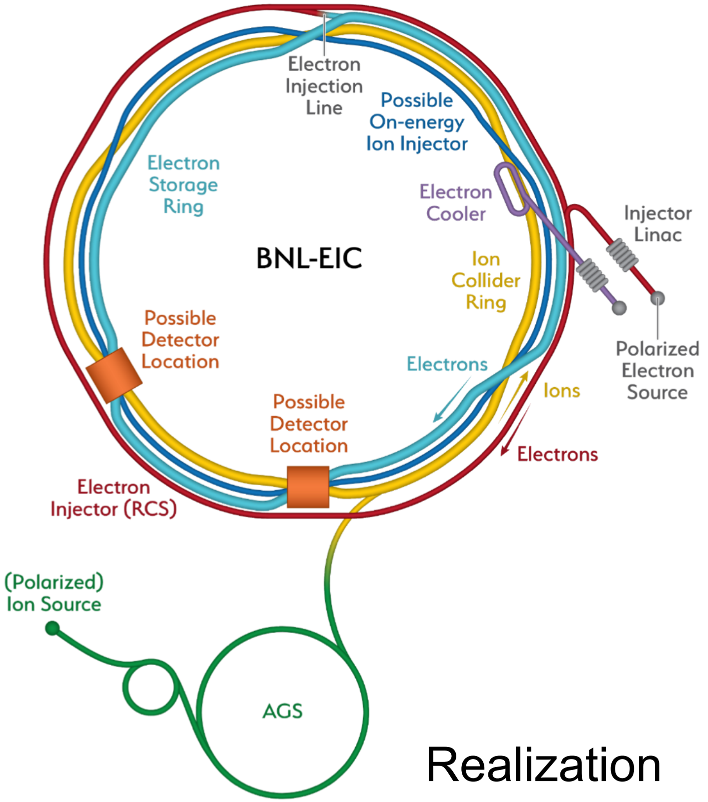
Physics motivations



Evaluation



Proposals

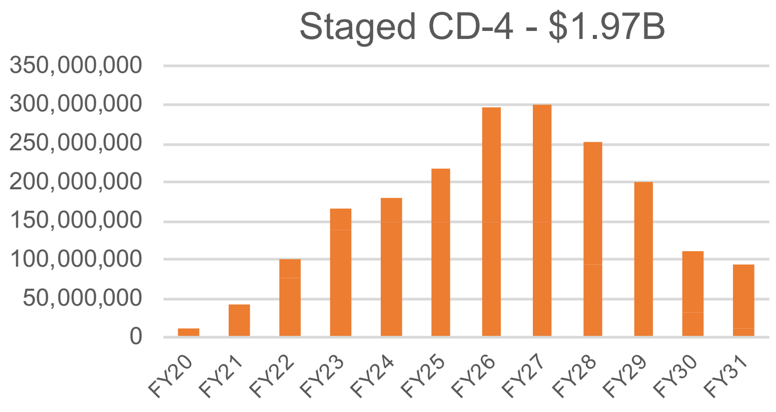


Realization

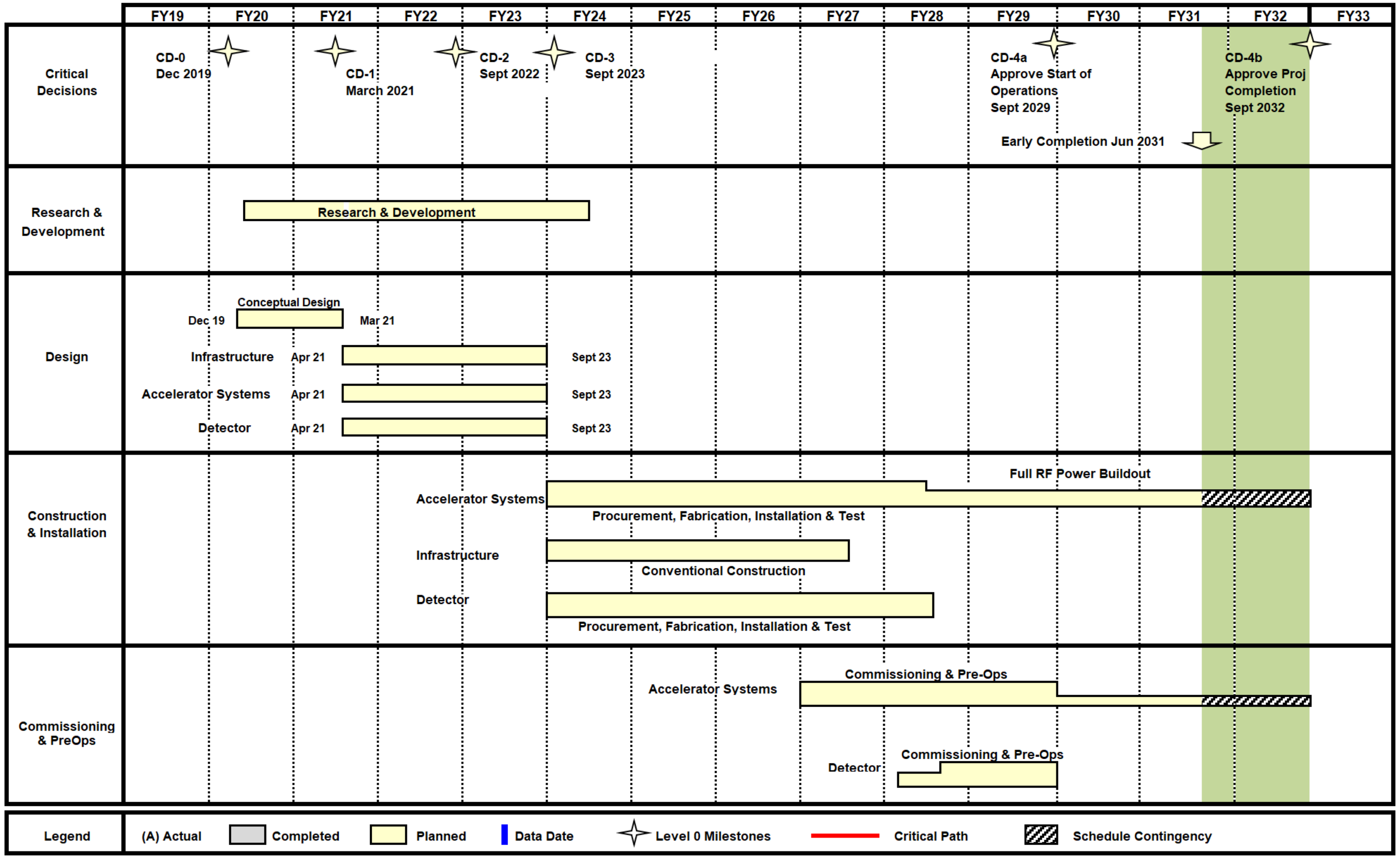
Center of Mass Energies	20 GeV – 141 GeV
Maximum Luminosity	10^{34} cm^{-2}s^{-1}
Hadron Beam Polarization	80%
Electron Beam Polarization	80%
Ion Species Range	p to Uranium
Number of interaction regions	up to two

EIC project

Jim Yeck, EIC Project Director
at the 2nd “Yellow Book” meeting

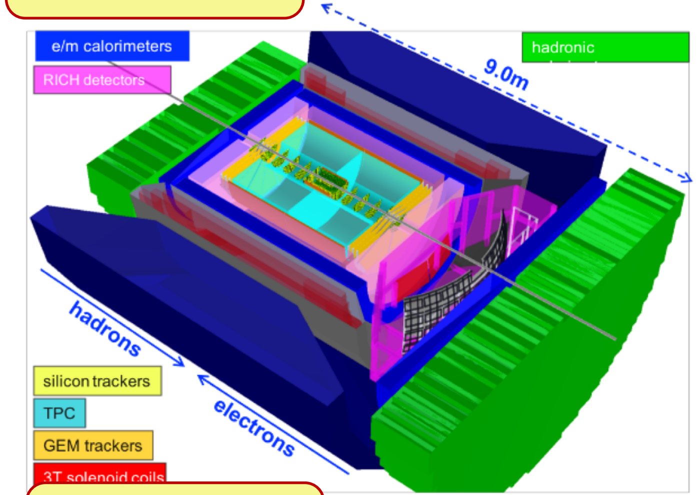


- CD-1: March 2021
- CD-2: September 2022
- CD-3: September 2023
- CD-4a: September 2029
- CD-4b: September 2031

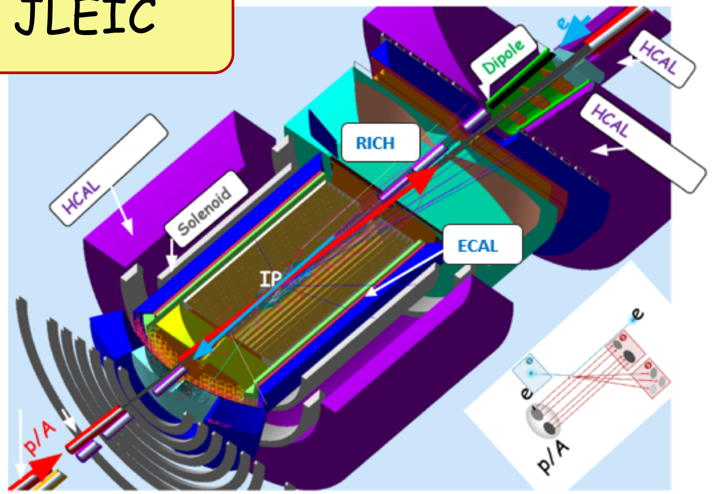


The EIC detector

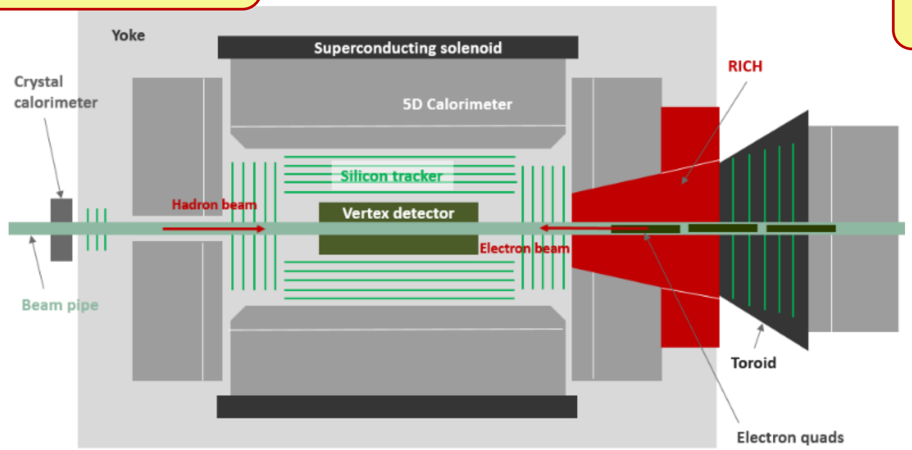
BEAST



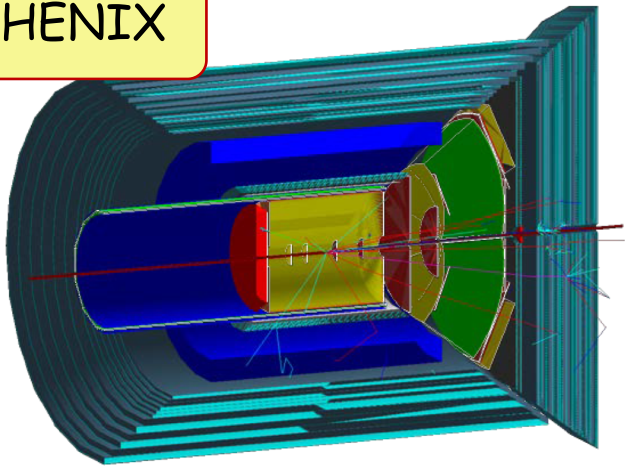
JLEIC



TOPSIDE



ePHENIX



Yellow Book activity
to set requirements
for a community
reference detector

("HandBook detector")

http://www.eicug.org/web/

The EICUG Yellow Book

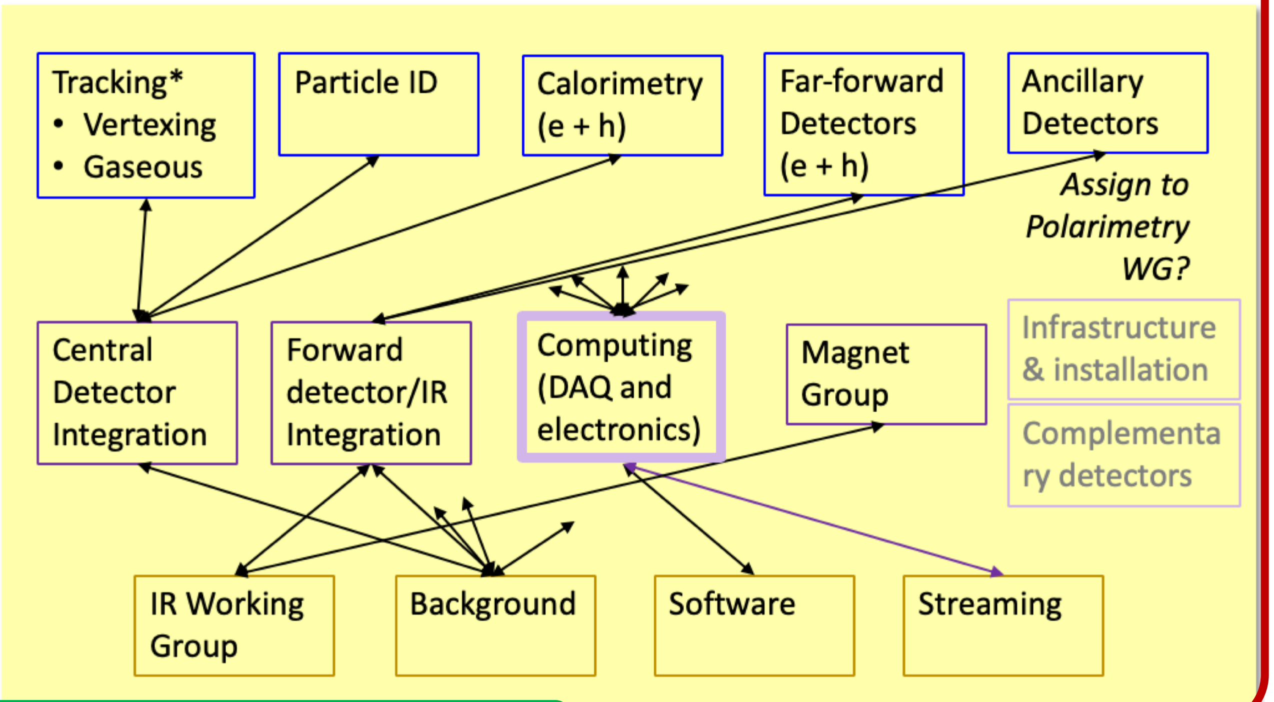
Dec 2019 kickoff meeting at MIT
March 2020 1st meeting Temple (remote)
May 2020 2nd meeting Pavia (remote)
September 17-19, 2020, CUA, Washington D.C.
November 19-21, 2020, UCB – Berkeley, CA

Meson structure WG

Physics WGs

Processes→ / ↓ Topics	Inclusive	Semi-Inclusive	Jets, Heavy Flavor	Exclusive, Diffractive, Forward Tagging
Global properties and parton structure	Incl. SF	h, hh	j, Q	Incl. diffr., excl. J/Ψ, Υ, tagged DIS on pol. D/He
Imaging		h	j, jj, j+h, Q+Qbar, [QQbar]	Excl-DIS: DVCS, DVMP (J/Ψ, Υ, ρ^0, ϕ, π+, K, ρ+, K*…), Elastic scattering
Nucleus	Incl. SF	h, hh	j, jj, Q, [QQbar]	Diffr. SF, coh. & incoh. VM, jj, h, hh D/He FF, nucl. fragments
Hadronization		h, hh, j+h	j, Q	
Other fields		CC DIS, γ-A total X-sec		γ-A diffr. X-sec γ-A elast. X-sec 8

Detector WGs

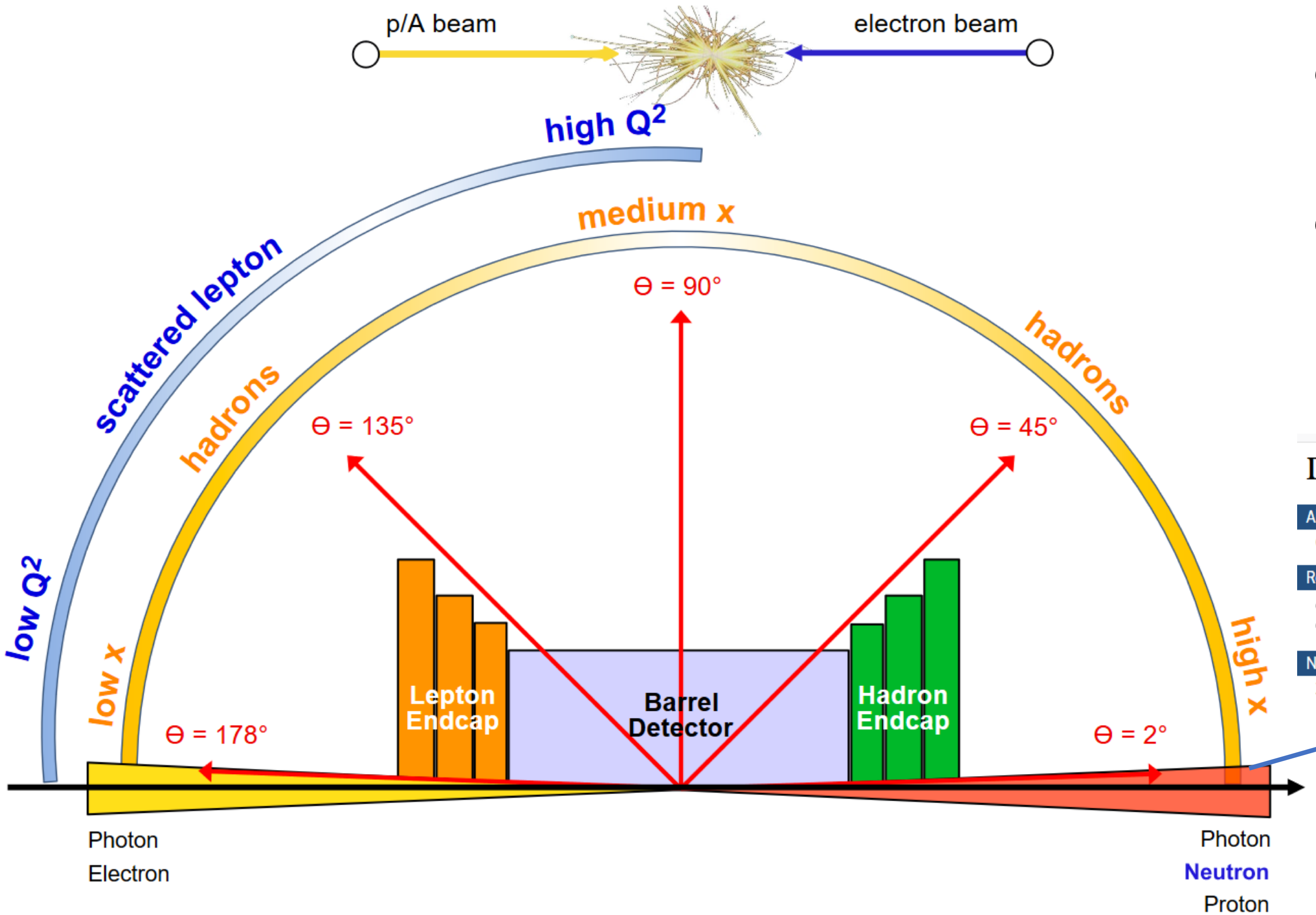


Software WGs

MC generators, Smearing
Geant4, Reconstruction

The Interactive Detector Matrix

https://physdiv.jlab.org/DetectorMatrix/



Collects physics requirements, lists all technologies for a given region, and links to studies that established the numbers

Example:

Details for Zero-Degree Neutron Detection

Abstract:

Geometry needs for zero-degree calorimeter used to detect neutrons from incoherent nuclear breakup reactions.

Referenced Files:

- ZDC neutron angle as function of energy.
- Zero-Degree High Precision Hadronic Calorimetry.

Notes:

ZDC: size 60x60x200cm

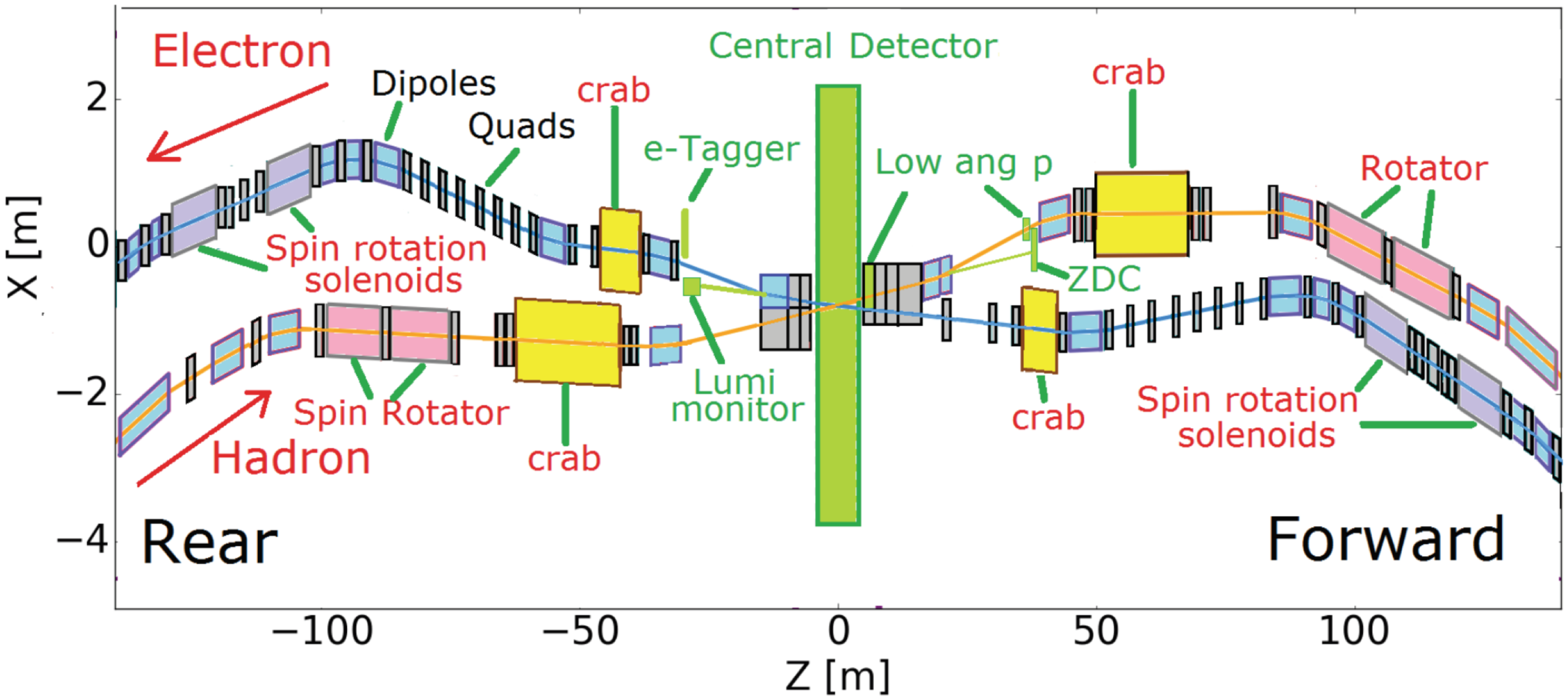
The Interactive Detector Matrix

Is the official EIC set of physics requirements and technology parameters

View Matrix | View Model | View Help | Login to Edit

η	Nomenclature			Tracking			Electrons		π/K/p		HCAL	Muons
				Resolution	Allowed X/X_0	Si-Vertex	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Resolution σ_E/E	
-6.9 to -5.8	↓ p/A	Auxiliary Detectors	low-Q2 tagger	$\sigma_\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV2								
...												
-4.5 to -4.0			Instrumentation to separate charged particles from photons				2%/√E					
-4.0 to -3.5												
-3.5 to -3.0		Central Detector	Backward Detector	σ_p/p ~ 0.1%⊕0.5%	~5% or less X	TBD		π suppression up to $1{:}10^4$	≤ 7 GeV/c	≥ 3 σ	~50%/√E	
-3.0 to -2.5												
-2.5 to -2.0				σ_p/p 0.1%⊕0.5%			2%/√E					
-2.0 to -1.5				σ_p/p 0.05%⊕0.5%			7%/√E					
-1.5 to -1.0							7%/√E					
-1.0 to -0.5			Barrel	σ_p/p ~0.05%×p+0.5%		σ_{xyz} ~ 20 μm, $d_0(z)$ ~$d_0(r\Phi)$ ~ $20/p_T$ GeV μm + 5 μm	(10-12)%/√E		≤ 5 GeV/c			TBD
-0.5 to 0.0												
0.0 to 0.5												
0.5 to 1.0												
1.0 to 1.5			Forward Detectors	σ_p/p ~0.05%×p+1.0%		TBD					~50%/√E	
1.5 to 2.0									≤ 8 GeV/c			
2.0 to 2.5									≤ 20 GeV/c			
2.5 to 3.0				σ_p/p ~ 0.1%×p+2.0%								
3.0 to 3.5									≤ 45 GeV/c			
3.5 to 4.0	↑ e	Auxiliary Detectors	Instrumentation to separate charged particles from photons									
4.0 to 4.5												
...			Neutron Detection									
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\|t\|)/\|t\| < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c								

The interaction region



IP is at the center of Solenoid
Available space for central detector: -4.5m/+4.5m along Z

Solenoid:
~ 4m long, ~1.4 m radius
1.5-3 T field

25mrad beam crossing angle

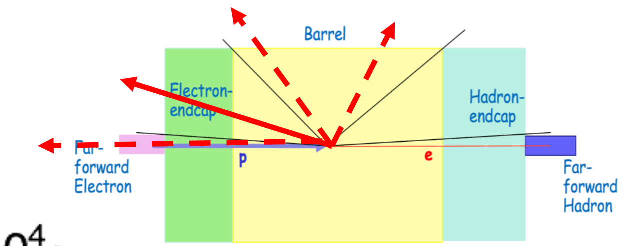
Solenoid is centered along the electron beam line to minimize synchrotron radiation impact.

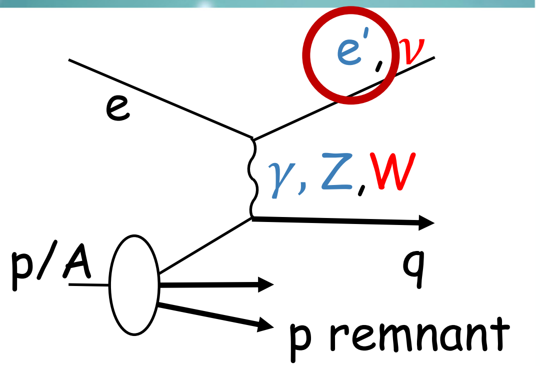
Proton (Ion) beam 41-275 GeV
Electron beam 5-18 GeV

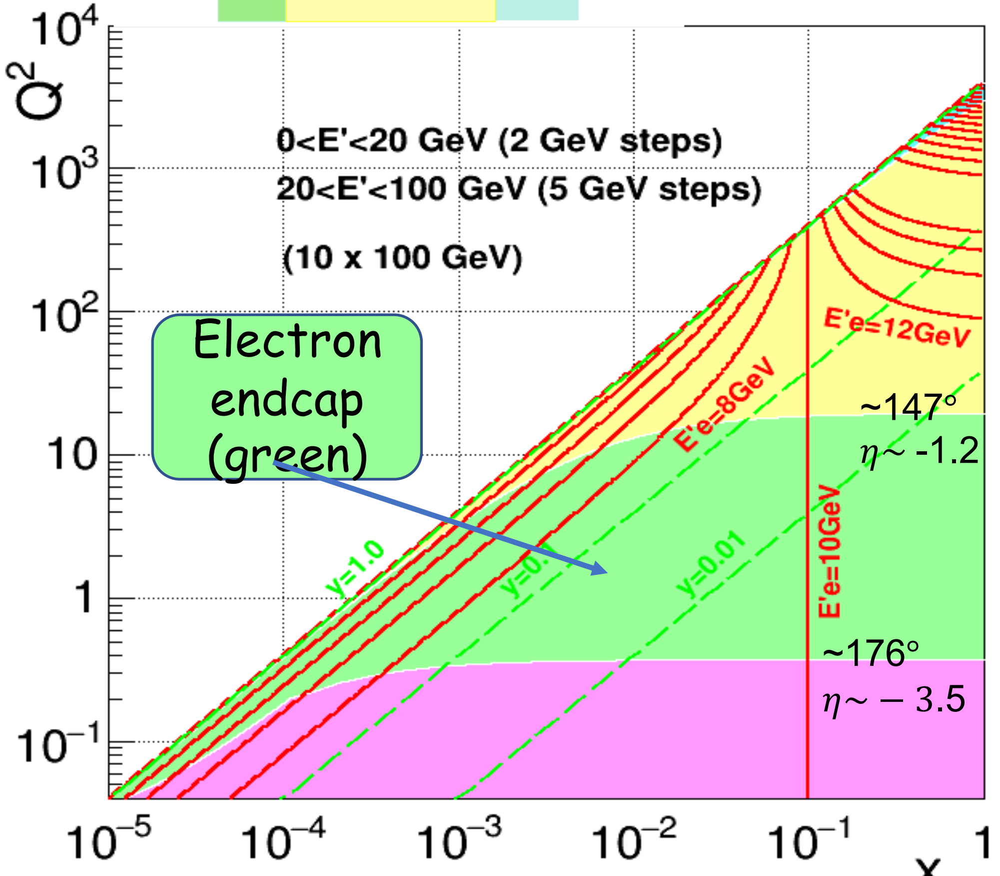
Detector should be :

- capable of performing EIC physics described in the White Paper, Long range plan and recommendations from the National Academy of Science.
- be able to operate under different beam configurations (beam energy)
- and different beam operation conditions (injections) , high Luminosity environment (high occupancy, high radiation (neutrons, synchrotron rad))
- IR space constrains.

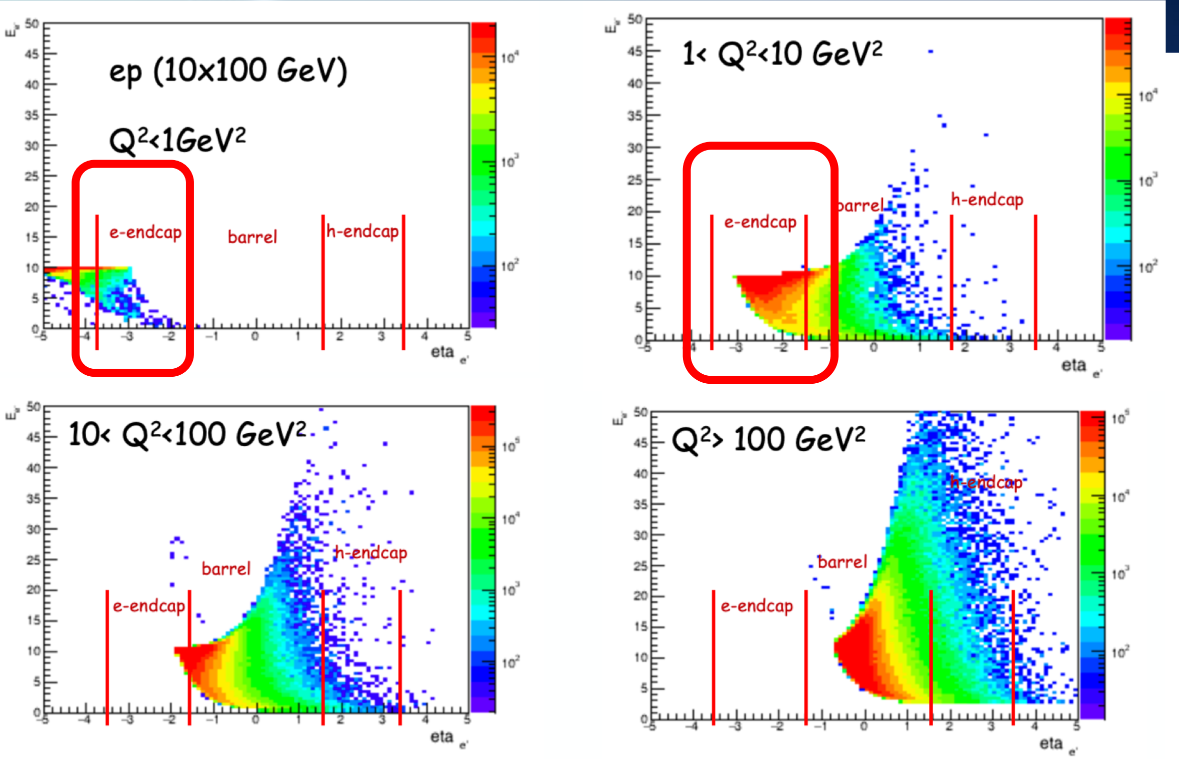
Electron Endcap







Scattered angle => Q^2



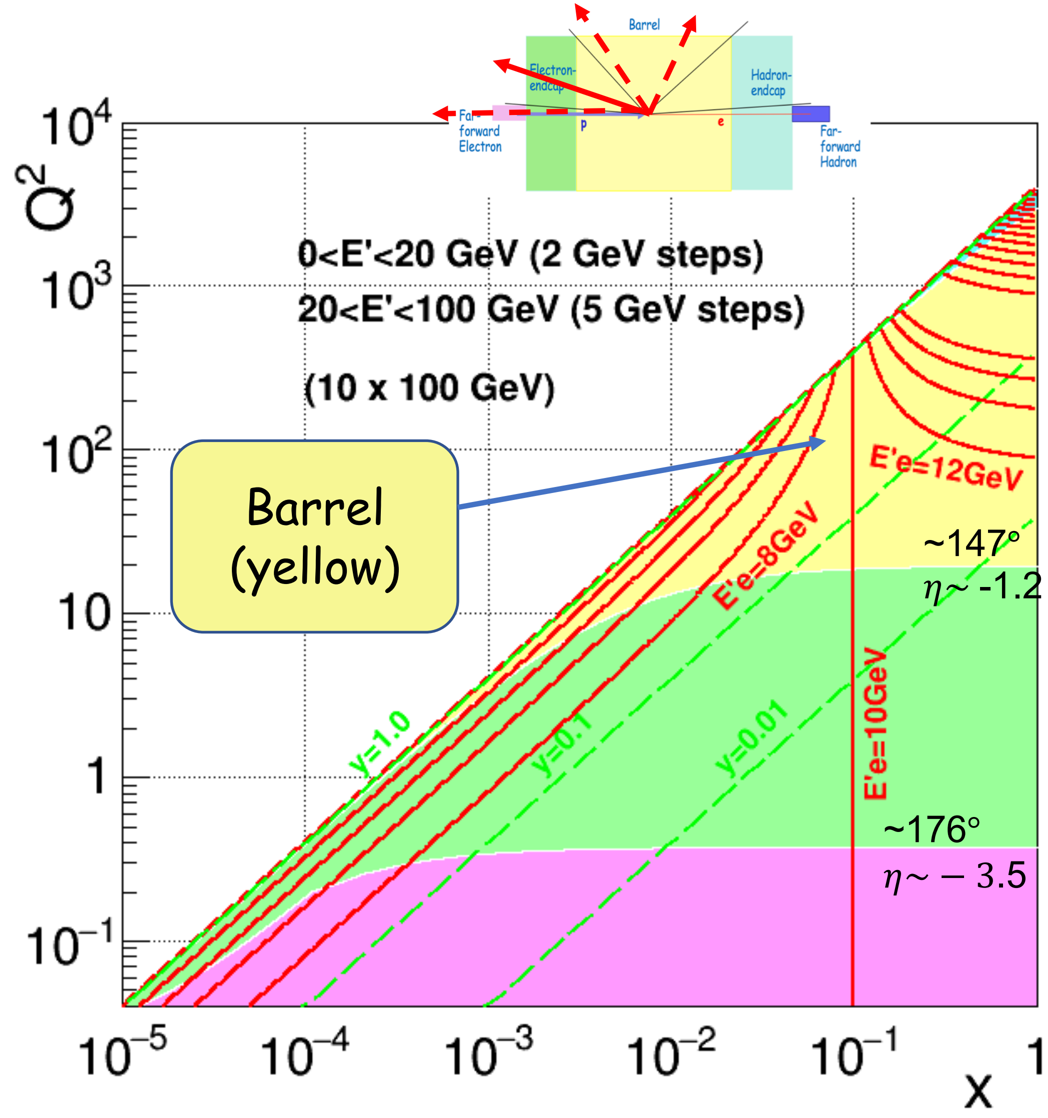
- Electrons mostly scatters to electron-endcap (green),
- Their energy/momentum are low (below initial e-beam energy) in the electron endcap
- And higher in the barrel or hadron-endcap
- Precision measurements of the electron scattered angle and Energy => defines precision measurements of Q^2 and x

$$Q^2_{\mathrm{EM}} = 2E_eE_{e'}(1+\cos\theta_{e'}),$$

$$y_{\mathrm{EM}} = 1 - \frac{E_{e'}}{2E_e}(1-\cos\theta_{e'}),$$

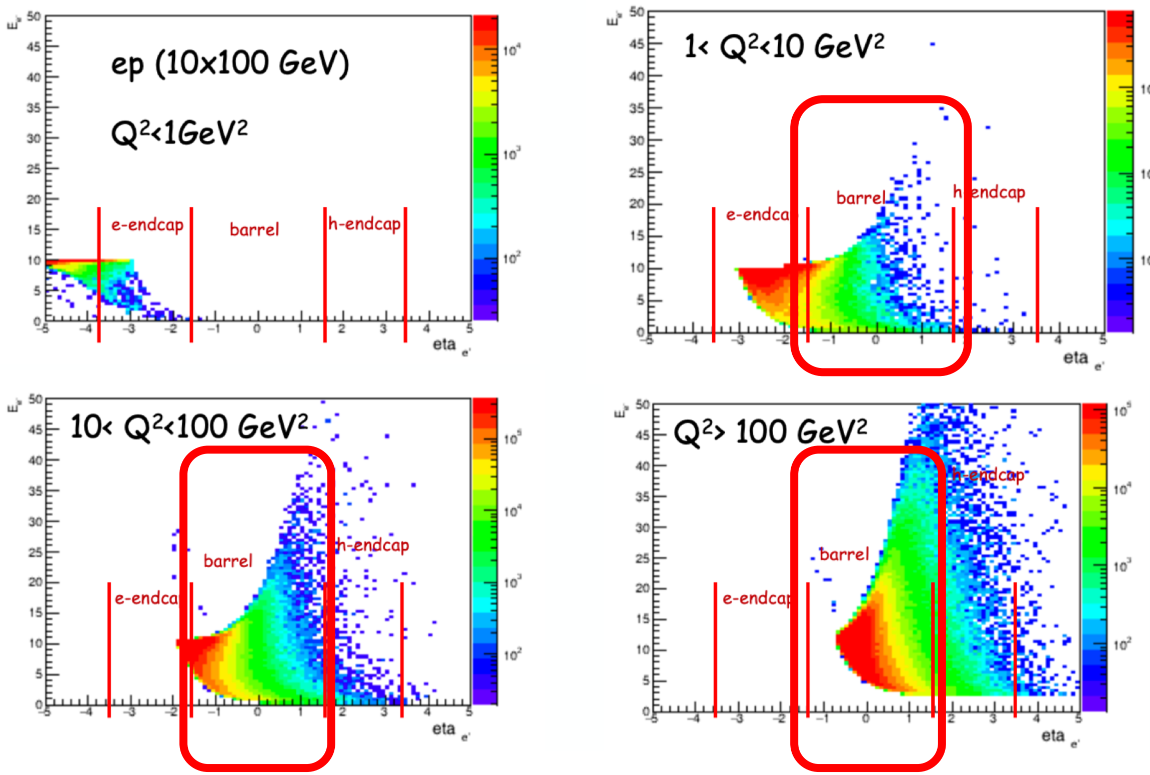
$$x = \frac{Q^2}{4E_eE_{\mathrm{ion}}}\frac{1}{y}$$

Barrel



Scattered angle -> Q^2

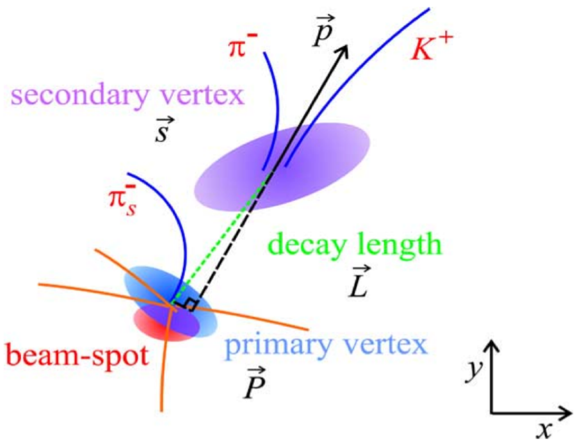
- Scattered electrons: from very low to very high (above initial beam energy) - depending on Q^2

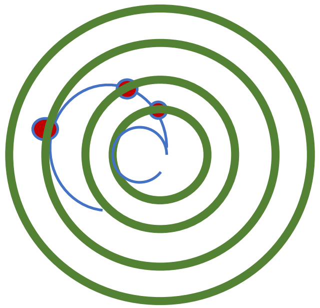


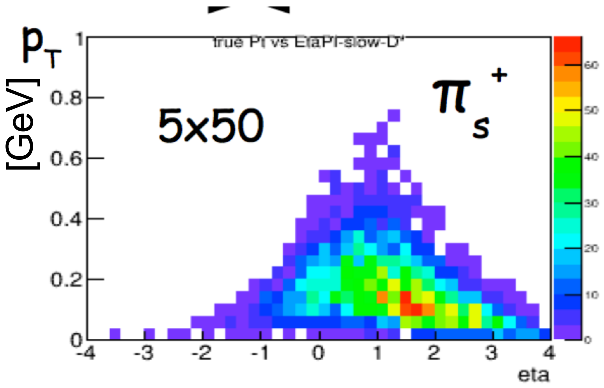
Decay particles: Heavy Flavor
JETS
Need good PID for hadrons and Calorimeter for JETs

Barrel

$$D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^- \pi^+) \pi_s^+$$







- Decay particles
- Low-pt particles (Solenoid filed!)

- minimize material of the beampipe

- First few layers of Vertex detector
  - as close as possible to IP for better vertex resolution
  - with minimum material (including sensitive area, support structure, cooling, cabling, readout, etc. for low –Pt particles

  => "Vertex detector are going towards 0.1-0.2% X_0 per layer"

  (EIC detector HANBOOK)

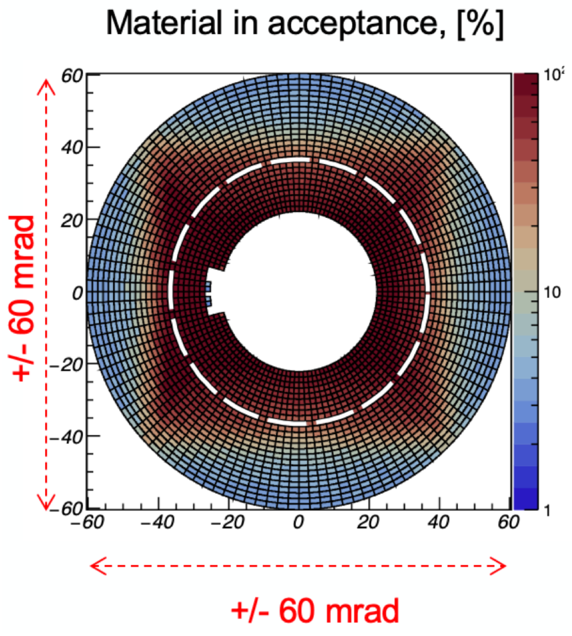
Need minimum material in the barrel, to minimize multiple scattering for low-pt particles

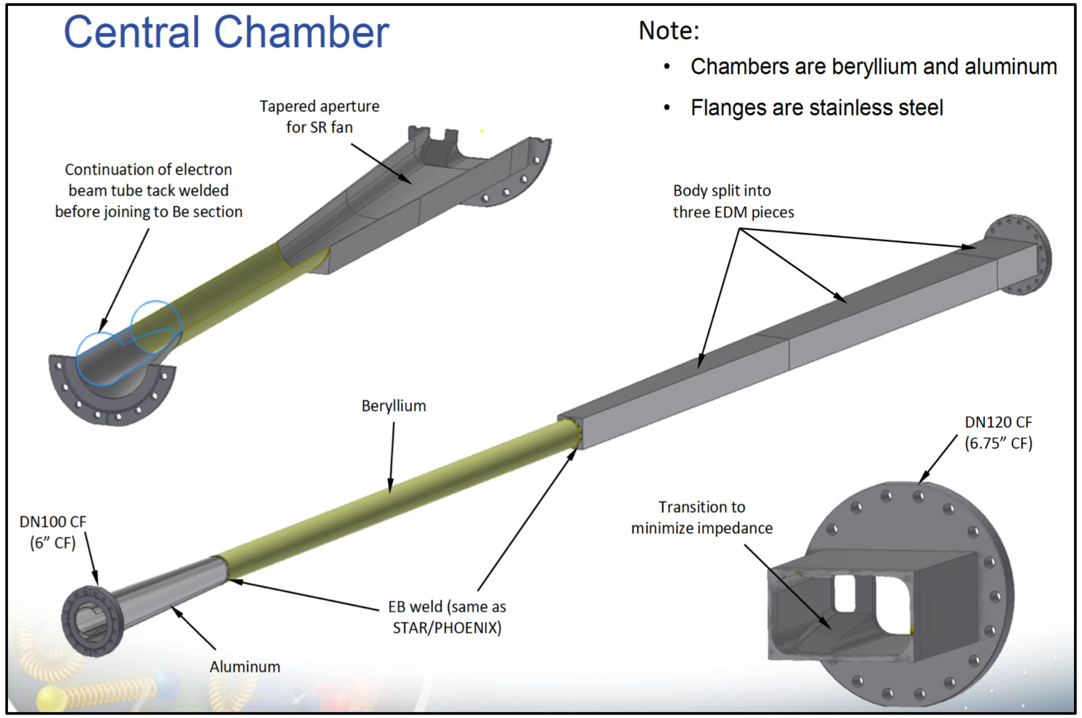
Beampipe

A. Kiselev

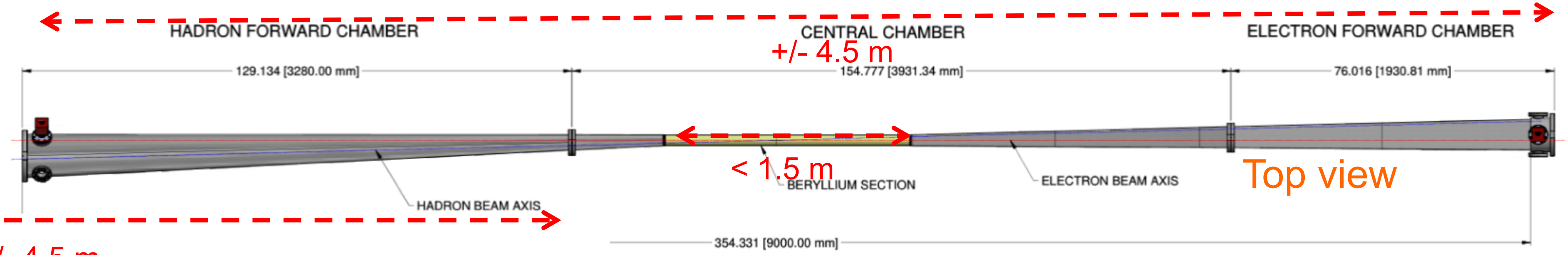
Limitations:
- Beam halo
- Synchrotron rad
- crossing angle
- heat

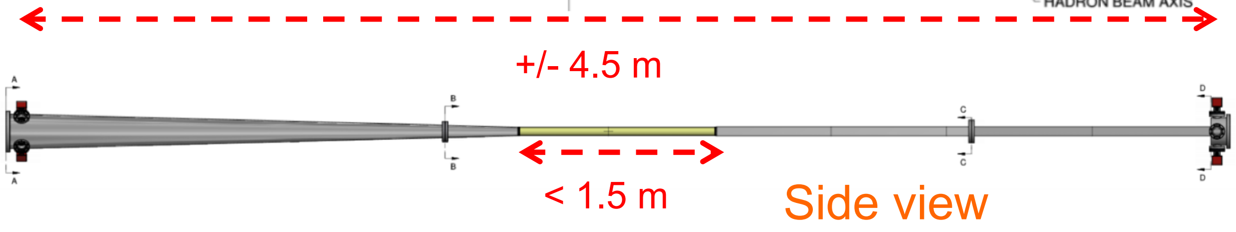
Central beampipe:
Beryllium beampipe
62mm inner diameter ,
63.5 mm outer diameter,
1.485 m long





Cones & rectangles:
still under developme
(needs improvement)





Tracking WG

Ongoing performance studies

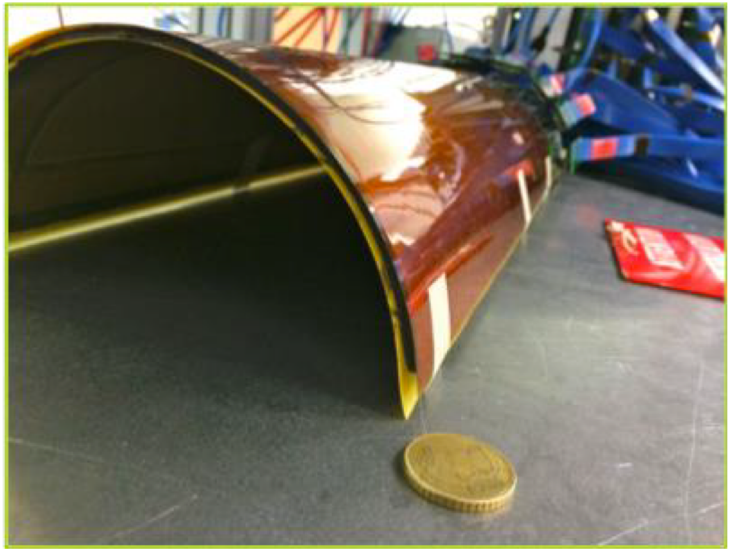
- central region Si-vertex + TPC + Fast MPGD Layers
- endcap region GEM (MPGD) trackers
- all-silicon (barrel) tracker + forward/backward silicon disks
- comparisons all-silicon vs BeAST (Si-vertex + TPC + MPGDs) concepts

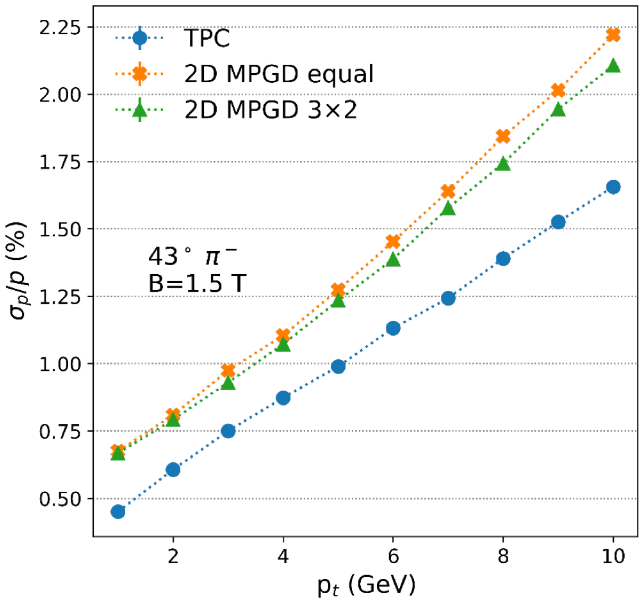
	TPC + Fast MPGD Layer	Cylindrical MPGD (Micromegas, μRWELL)	Drift Chambers / Straw Tubes	Planar MPGDs (GEM, Micromegas, μRWELL)	Small TGCs	MPGD-TRDs
Barrel region	Pros: - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel** Cons: - **End cap material** - calibration space charge distortion	Pros: - Space point & angular res. - Time resolution (< 10 ns) - **Low material in End cap** - **Cost & robustness** Cons: - Momentum res. - Fabrication challenges - **Material budget in barrel**	Pros: - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel** Cons: - **End cap material** - calibration - Stability issues	Pros: - Alternative to cylindrical MPGDs arrangement in polygons - **Easier fabrication** Cons: - Momentum res. - Detector space barrel - **Material budget in barrel**	N/A	N/A Radiator size
Hadron End Cap	N/A Only planar option		Pros: - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel** Cons: - **Material budget** - calibration - Stability issues	Pros: - Momentum & angular res. - Low material (<0.4%) - **Cost & robustness** Cons: - **?**	Pros: - Momentum & angular res. - **Cost & robustness** Cons: - **Material budget**	Pros: - Additional tracking - Angular res. for RICH - **Additional e/π PID** Cons: - Radiator size
Electron End Cap	N/A Only planar option		N/A	Pros: - Momentum & angular res. - Low material (<0.4%) - **Cost & robustness** Cons: - **?**	N/A Mainly because of material budget	Pros: - Additional tracking - **Complement main e PID in electron end cap** Cons: - Radiator size?

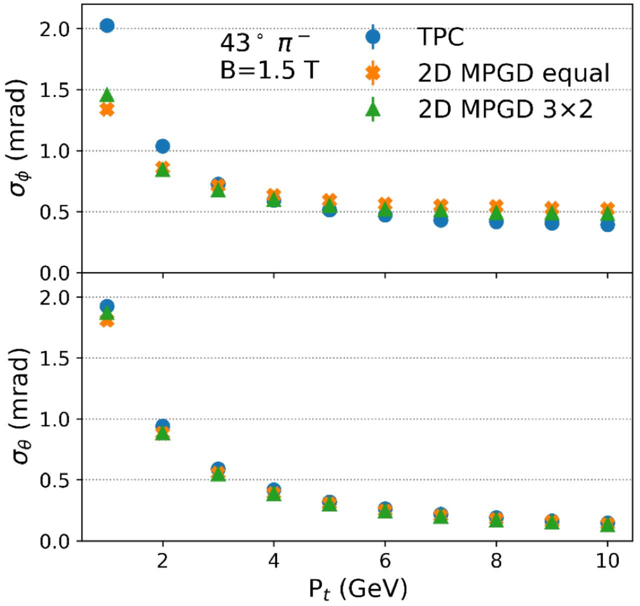
Cylindrical Micromegas

Qinhua Huang, CEA Saclay

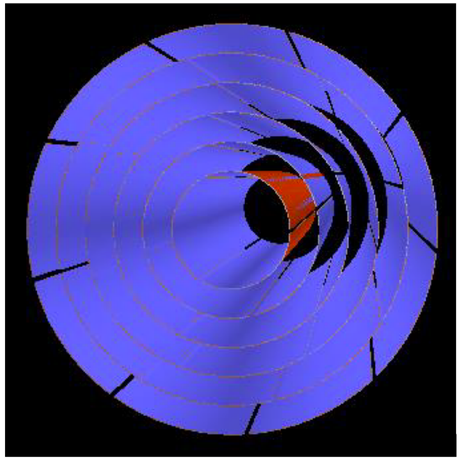
Barrel MPGD tracker as TPC alternative:
- Curved MPGD tiles with low material budget
- Micromegastechnology is being used in CLAS12
- Possibly readout 2D coordinates on a single layer
- Simulation and performance study are under the ePhenixcontext
- ePhenixTPC is replaced with the tracker
- R is from 20 to 80cm, 2 tracker configsare studied

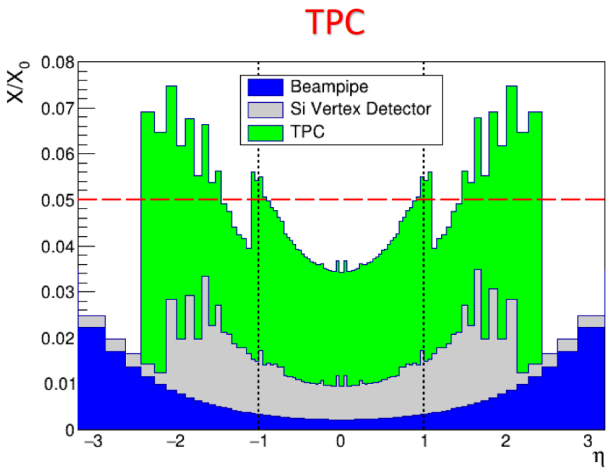


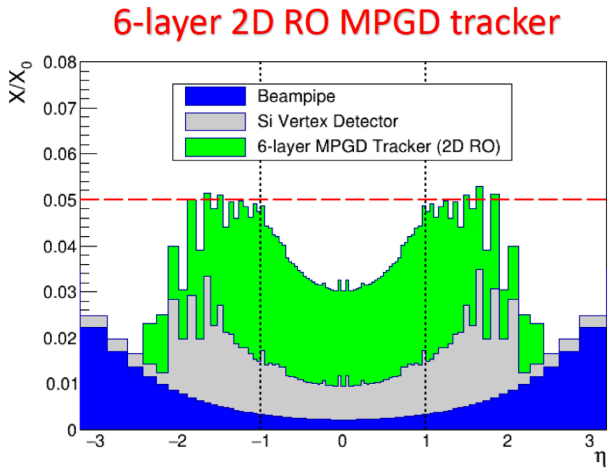




X/X0 ~ 0.3% per layer







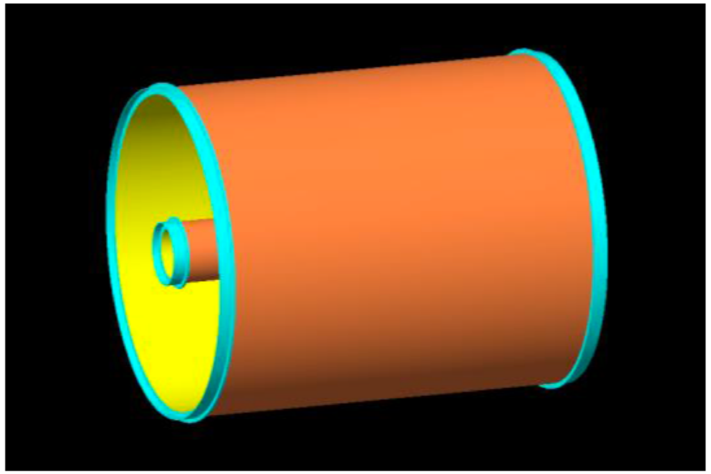
Si-vertex + TPC + MPDGs

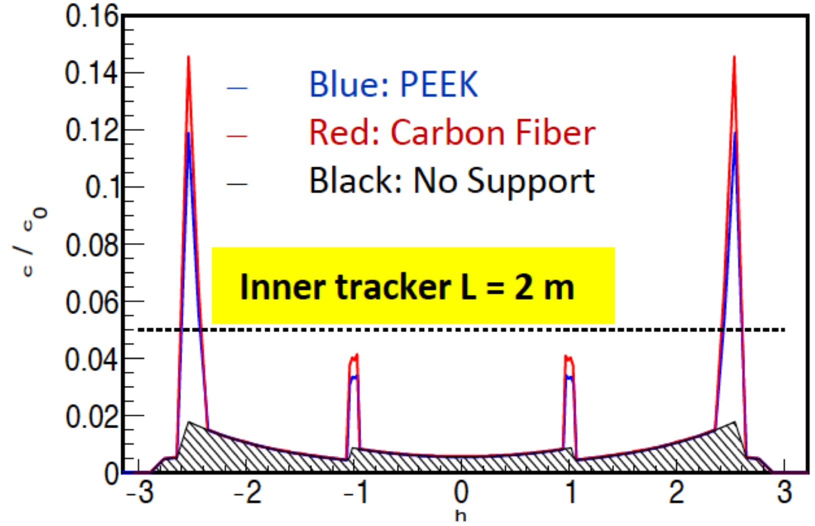
Matt Posik, for eRD6

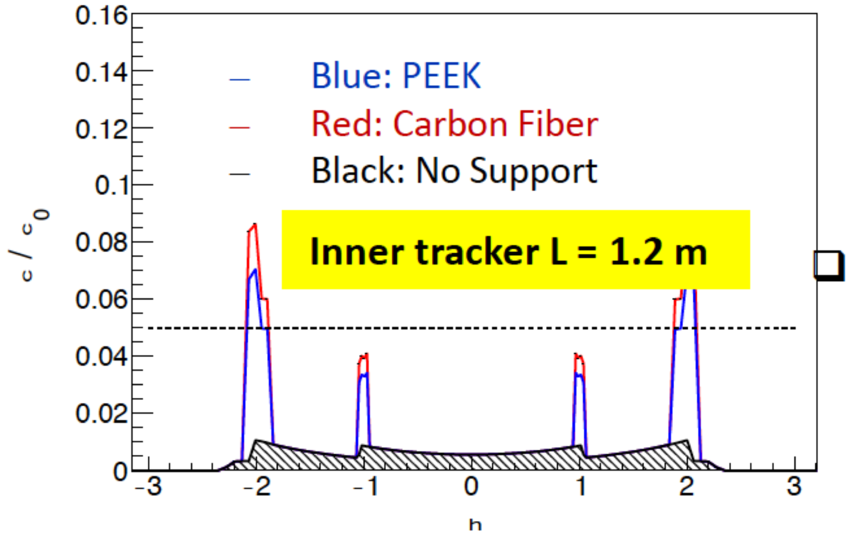
Material budget

- Detector configuration; Fast layers in barrel region
  - Outer µRWell layer: L =2 m; radius = 80.0 cm
  - Inner µRWell layer: L = 1.2 m; radius = 12.5 cm
- Support Ring Structure Geometry
  - Tube: thickness = 0.5 cm, length = 7.2 cm
  - Ring (inner): thickness = 1.6 cm, length = 1.2 cm
  - Ring (outer): thickness = 0.5 cm, length = 1.2 cm

Mock prototype (support ring)



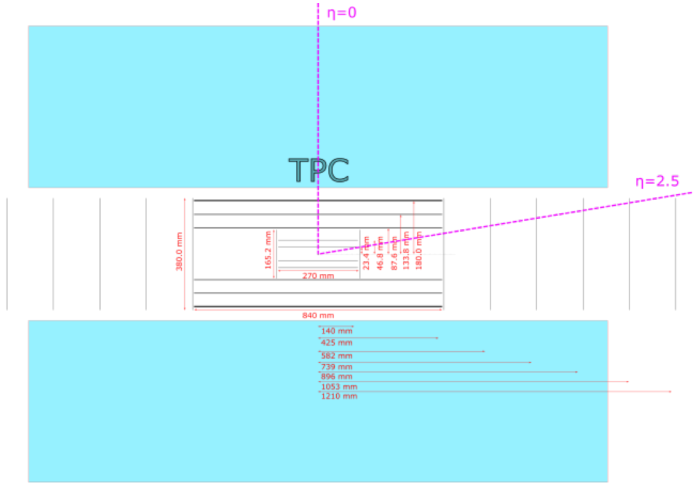


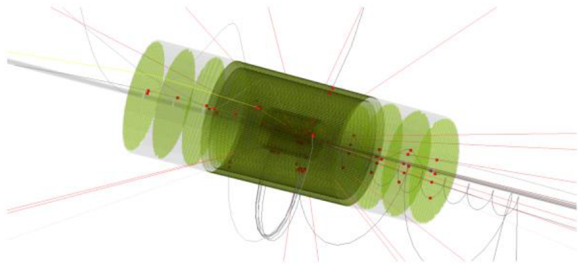


- Next Steps Implement
  - **supports every ~ 50 cm**
  - **Readout card material & endcap**

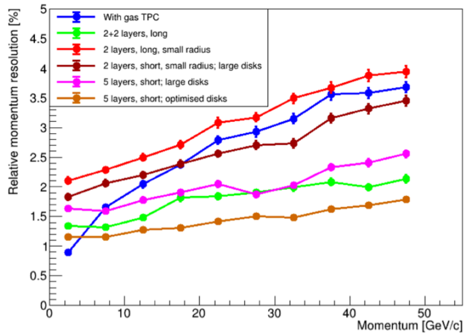
All-silicon and Si+TPC studies

Håkan Wennlöfet al (UoB), Rey Cruz-Torres (UCB), Winston DeGraw (UCB),Ernst Sichtermannet al (eRD16)

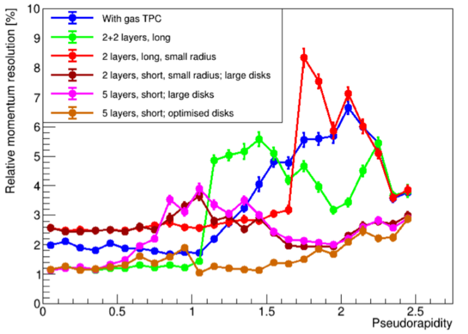


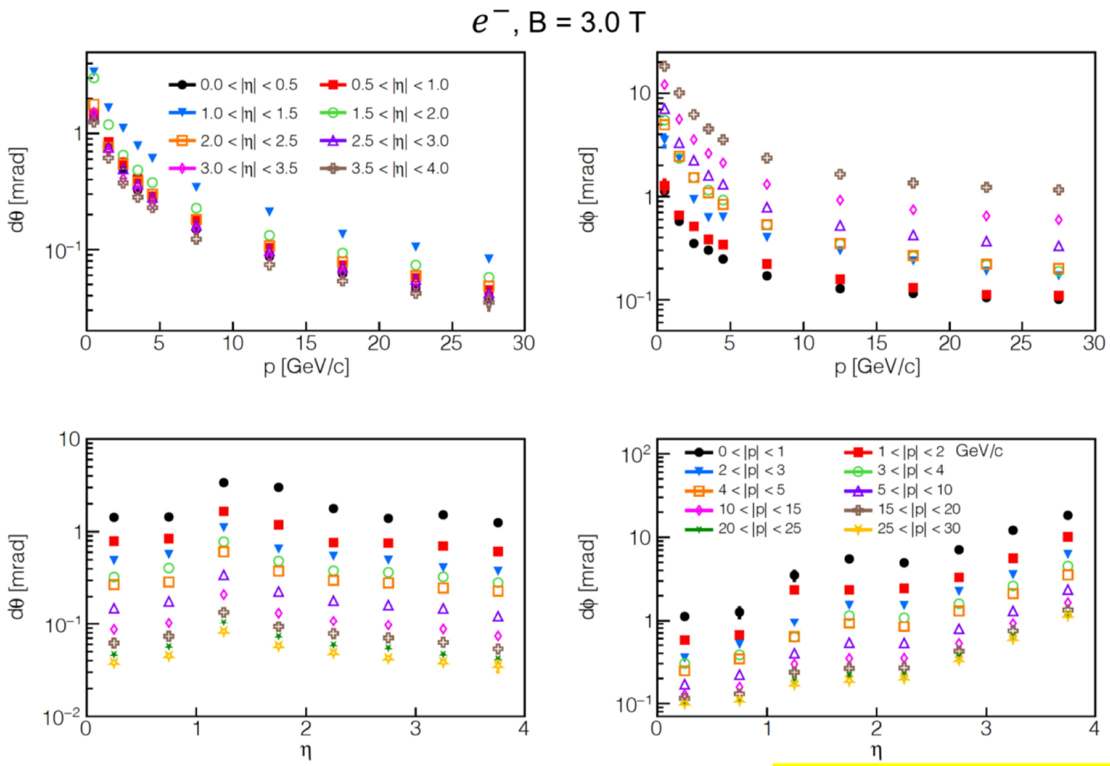


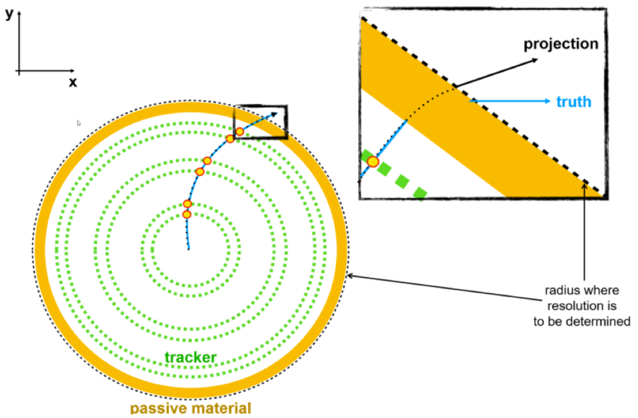
Relative momentum resolution vs p



Relative momentum resolution vs η



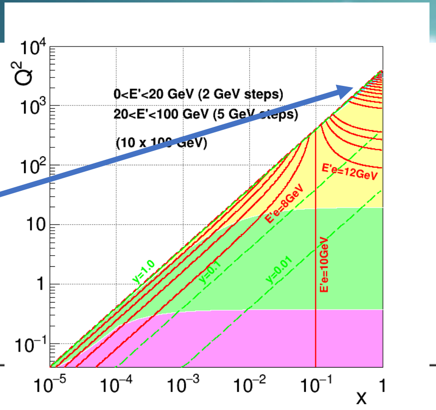


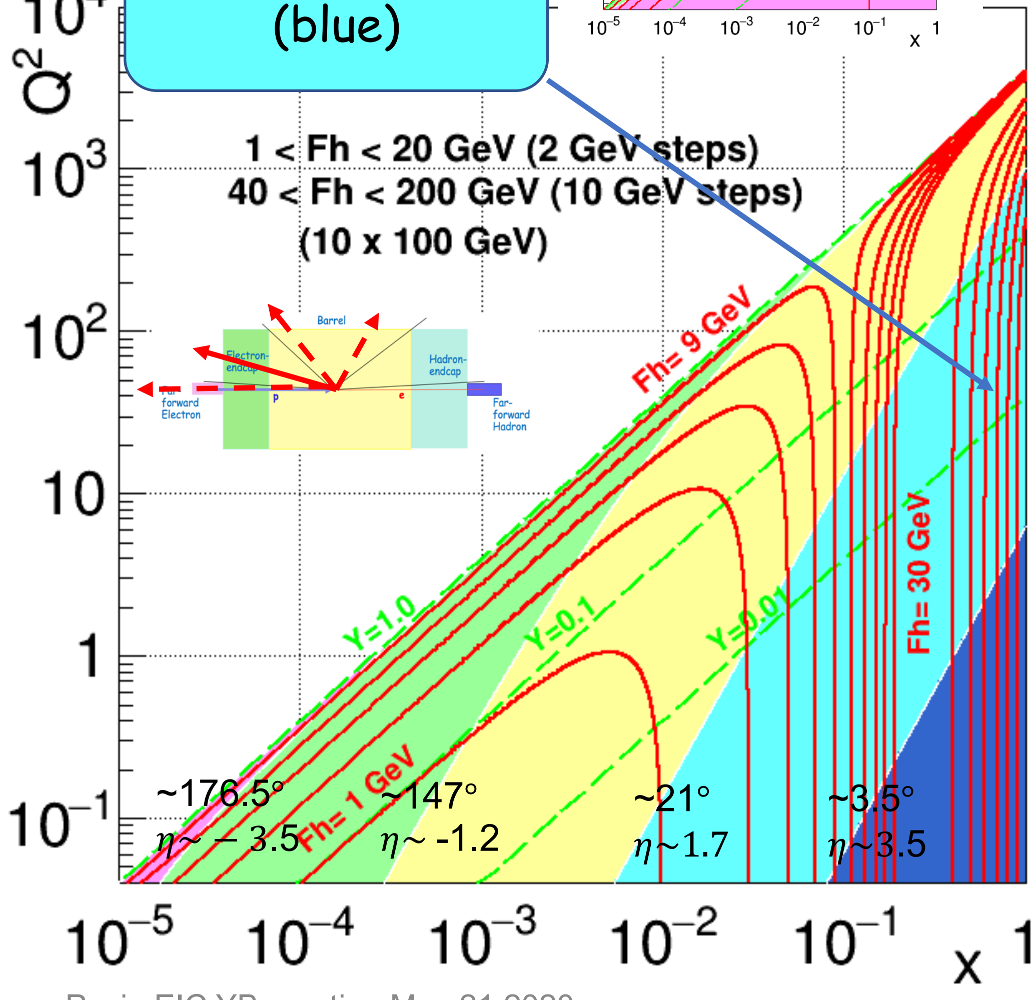


- Large disk coverage is important to keep resolution at higher η
- All-silicon layout can outperform Si+TPCat p≥5 GeV/c

Hadron-endcap

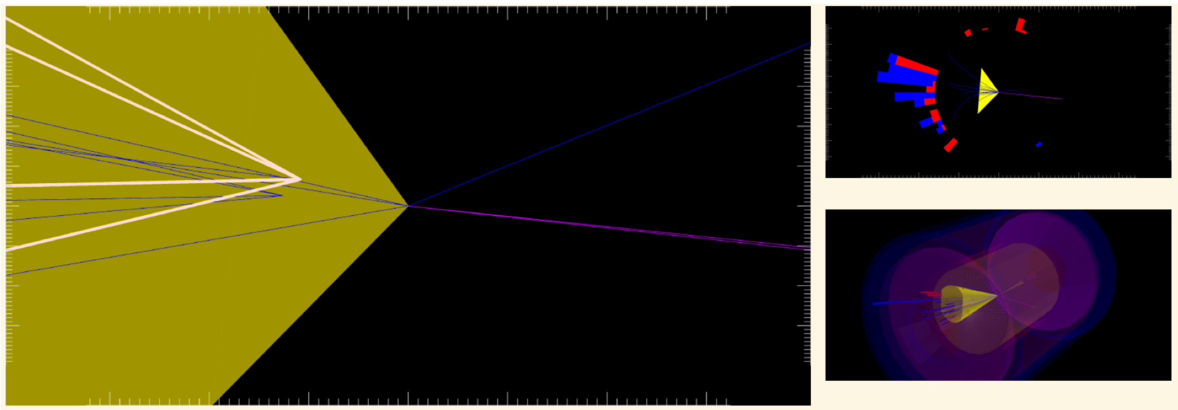
Hadron endcap (blue)





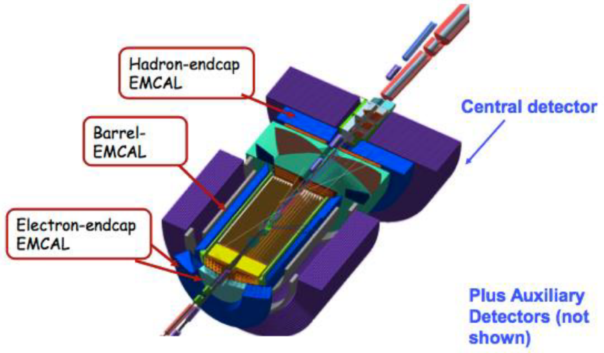
- Scattered electron's energy/momentum is very high… hadrons/jets energies are high …
- due to the kinematic boost, most of the decay particles also goes into the hadron-endcap (decay products of J/PSI, Charm, etc…) !
- High-x JETs
- Need good measurements of jet/struck-quark to improve measurements of x (x ~ Ejet)

Charm jet



Calorimeter

Hermetic coverage
Good EMCAL resolution
PFA for JETS

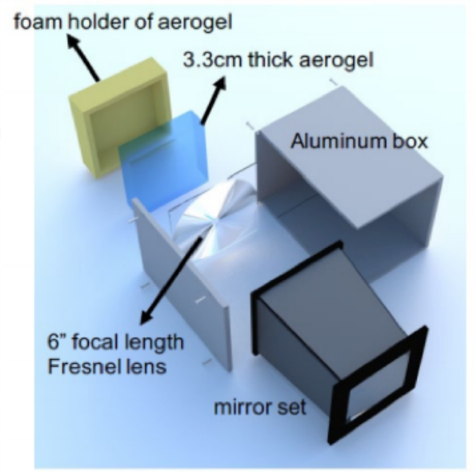


Detector Matrix for the calorimeters

η	Nomenclature	EmCal						HCal			
		Energy resolution %	Spatial resolution mm	Granularity cm^2	Min photon energy MeV	PID e/π πsuppression	Technology examples*	Energy resolution %	Spatial resolution mm	Granularity cm^2	Technology solution
-3.5 : -2	backward	2/√E ⊕ 1	3/√E ⊕ 1	2x2	50	100	$PbWO_4$	50/√E⊕10	50/√E ⊕ 30	10x10	Fe/Sc
-2 : -1	backward	7/√E ⊕ 1.5	3(6)/√E ⊕ 1	2.5x2.5 (4x4)	100	100	DSB:Ce glass; Shashlik; Lead glass	50/√E⊕10	50/√E ⊕ 30	10x10	Fe/Sc
-1 : 1	barrel	(10-12) /√E ⊕ 2	3/√E ⊕ 1	2.5x2.5	100	100	W/ScFi	100/√E⊕ 10	50/√E ⊕ 30	10x10	Fe/Sc
1 : 3.5	forward	(10-12) /√E ⊕ 2	3/√E ⊕ 1	2.5x2.5 (4x4)	100	100	W/ScFi Shashlyk, glass	50/√E⊕ 10	50/√E ⊕ 30	10x10	Fe/Sc

mRICH (Electron endcap)

X. He
M. Sarsour

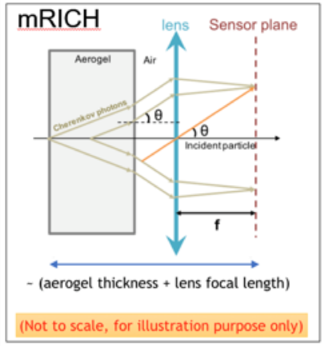


Cherenkov radiator
- Aerogel, n = 1.03
- Radiator length, L = 3cm
- Lens with focal length, f = 6"

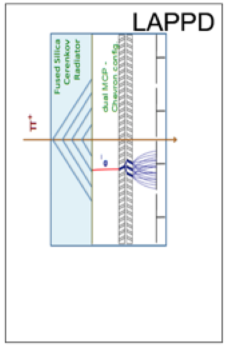
Photon Detector
- 3 mm pixel size

Pros	Cons
Sweet momentum coverage for K/pi separation from 3 GeV to close to 10 GeV. It also provides the capability of e/pi separation around 2 GeV.	Photon sensors and readout electronics see direct hits of particles. Radiation hardness concerns.
Modular design for array installation. Each module is independent with other modules and can be calibrated separately. Projective capability.	Acquire aerogel tiles and maintain their long-term stability (optical)
Performed two beam tests. The working principles have been validated in the first beam test in 2016 and the results have been published in NIM A. Further beam tests with tracking capabilities are expected and under planning.	Need high density photon sensors working in magnetic field.
Full GEANT4 simulation has been developed and verified using the beam test data.	Could create extra dead areas between modules. [Could be minimized by projective and creative integration schemes]
An array of mRICH modules have been implemented in the sPHENIX for EIC simulations.	

Provide a time meas. with proper sensor? Utility of the device is expanded if it provides picosec TOF & Cherenkov



+



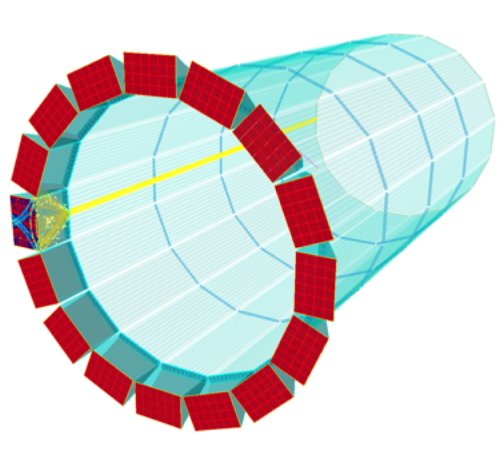
- More quantitative estimate of dead area (foam holder/box/Fresnel corners)
- Sensor issue is general, independent of radiator and optics.

π/K separation up to 10GeV (3σ)

DIRC (Barrel)

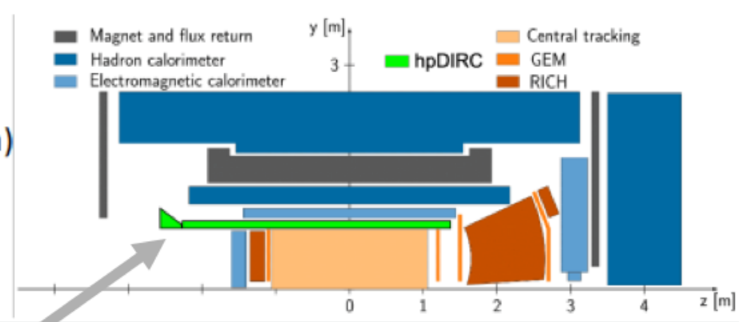
G. Kalicy
J. Schwiening

Generic reference design: 1m barrel radius, 16 sectors
176 bars: synthetic fused silica,17mm (T) ´ 32mm (W) ´ 4200mm (L)
Photo sensors: MCP-PMTs -3x3mm2 pixels



- Pros:
  - **Radially compact** (impact on cost of post-DIRC systems)
  - **Flexible design** (to deal with sensor in B-field and detector integration)
  - **Low demand on detector infrastructure** (no cryogenic cooling, no flammable gases)
  - **Excellent performance over wide angular range** (≥ 3 s.d. π/K up to 6 GeV/c, low momentum e/π (3 s.d. at 1GeV/c)
  - **Supplemental time-of-flight measurement**
  - **R&D at advanced stage** (PID performance estimate based on test beam results, excellent agreement between simulation and prototype data)

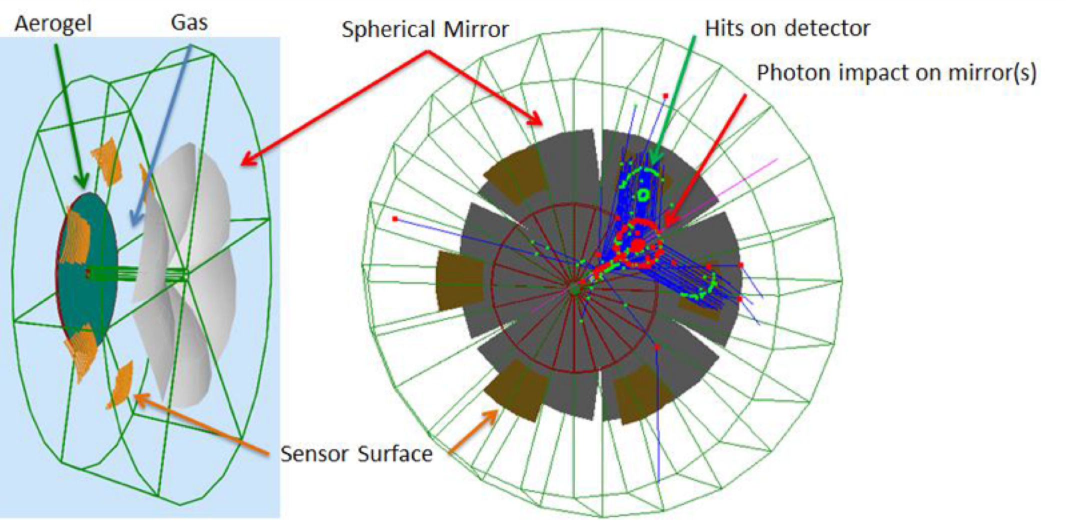
- Cons:
  - Potential challenge of integrating expansion volume, in particular for BaBar DIRC design (focusing block and sensors outside flux return?)
  - No currently proven sensor solution for 3 T magnetic field option



More then 3σ separation
π/K up to 6GeV
e/π up to 1 GeV

dRICH (Hadron endcap)

E. Cisbani
M. Contalbrigo



- Cherenkov radiator
  - Refractive Index
  n = 1.02 (aerogel) 1.0008 (C_2F_6)
  - length of the radiator
  L = 4 cm (aerogel) , 160 cm (C_2F_6)
- Mirrors
- Photon Detector
  3 mm pixel size; 200-500 nm MAPMT
- Particle Generation
  Originate from the vertex

More then 3σ separation
π/K separation 3-50GeV

- **Pro**

1. **>3σ π-K separation in 3 – 50 GeV** whole range in RICH mode (Montecarlo simulation) – as well as large coverage for K-p (and electron) PID
2. **Photon detector out of acceptance** and far from the beam pipe in moderate magnetic field (≤ 1/2 of central zone): less constraints on material budget (e.g. mechanical supports, shielding, cooling); neutron flux is also reduced
3. Expected to be **cheaper and more compact** (also in terms of services) than 2 (or more) detectors solution (sparing on photon detector and related electronics)
4. **Material budget** likely smaller than 2 detector solutions: from CLAS12/RICH-LTCC: X_0≈1% vessel (no pressurization) + 1% mirror + aerogel, acrylic filter and gas
5. Two dual radiator RICHes already operated (**lesson learned**)
6. Rather **advanced software available**: detailed Montecarlo, parameterization, full PID reconstruction, automated optimization procedure

- **Con**

1. **More demanding PID** respect to single radiator RICH
2. **LHCb dual radiator RICH1 issues**: underestimation of aerogel stability in contact with freon gas? large multiplicity and relative large background ?
3. **Aerogel chromatic** performances are critical and need to be well investigated in terms of stability and interference with other gases
4. **R&D on photo sensors** needed (common to other detectors)
5. **Gas Procurement** potential issue due to possible ecological restrictions and costs (common to other detectors)

Time of Flight

- Multiple technologies (two examples):
  - LAPPD:
    best σ_t B-field ~⊥, moderate pixel size
  - LGAD:
    excellent σ_t field tolerant, tiny pixels

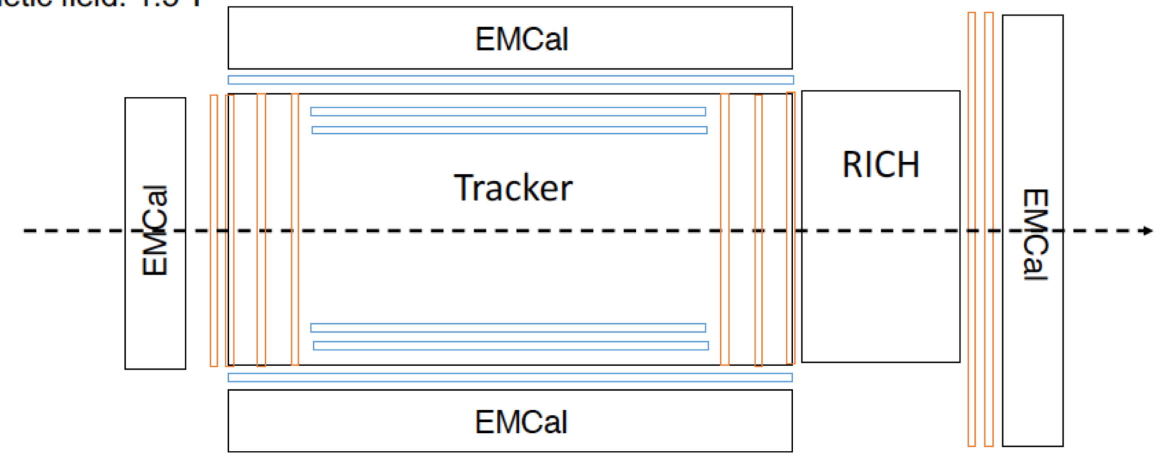
  - <20ps resolution

Endcap ToF

Barrel ToF

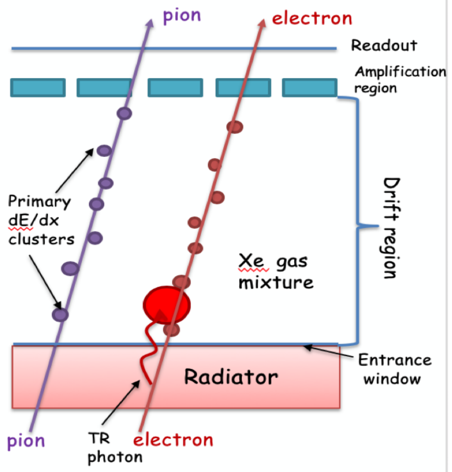
Timing Layers for outer tracker with LGADs?

- Tracker geometry: L=2.5m, r=1.2m
- RICH length: 1.5 m
- Magnetic field: 1.5 T



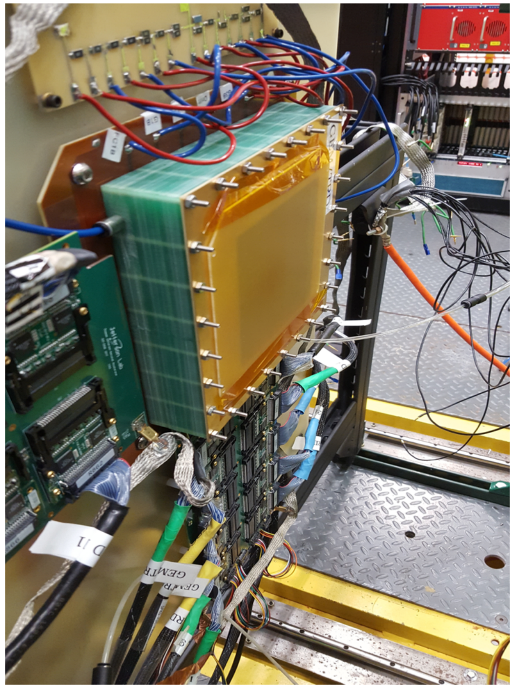
Add timing layers as outer tracker
- at L=+/-1.5, 2.0, 2.5m
- at r=+/-0.8,1.0m

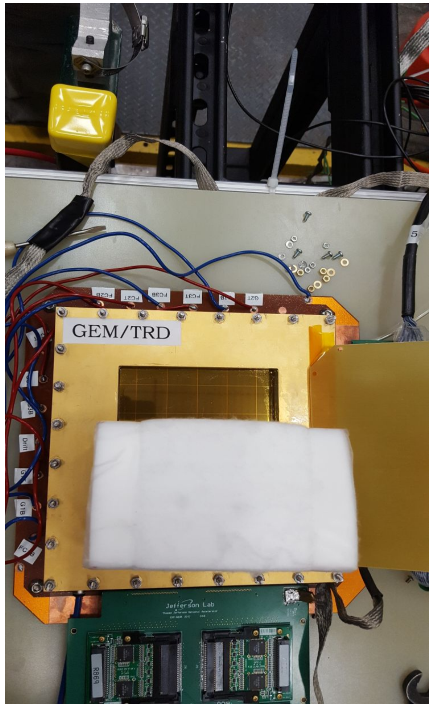
Transition Radiation Detector (for e/π separation)



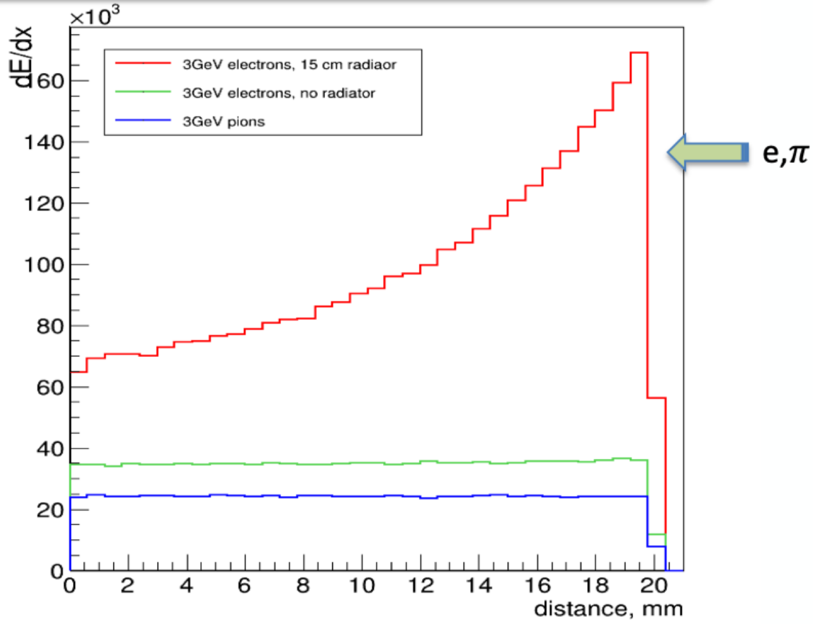
- Electron identification is very important for EIC physics. Due to a large hadron background expected in the forward (Hadron-endcap) region, a high granularity tracker combined with TRD functionality could provide additional electron identification - GEM-TRD/T

eRD22 R&D project

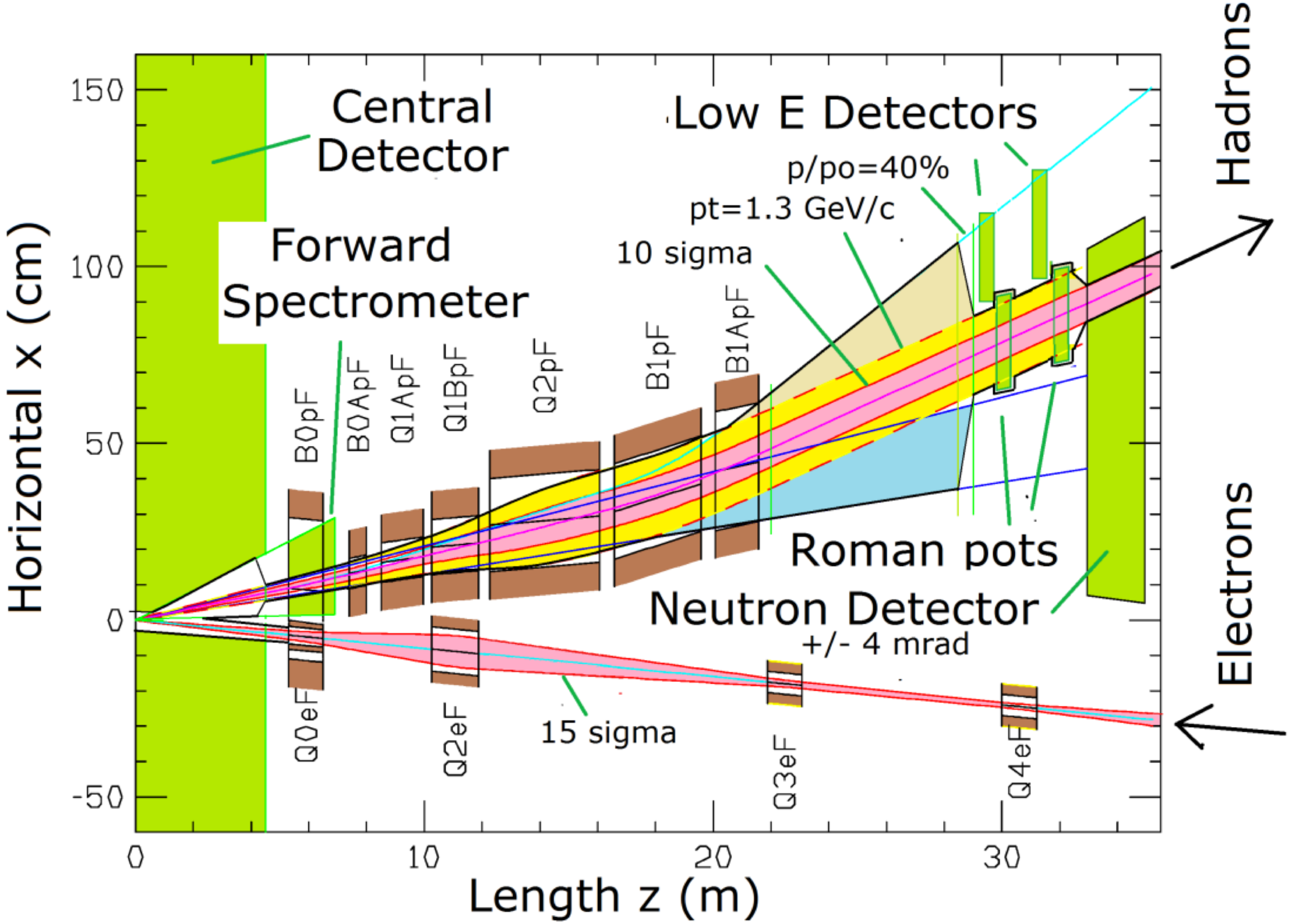




Energy deposition (dE/dx + TR) vs distance



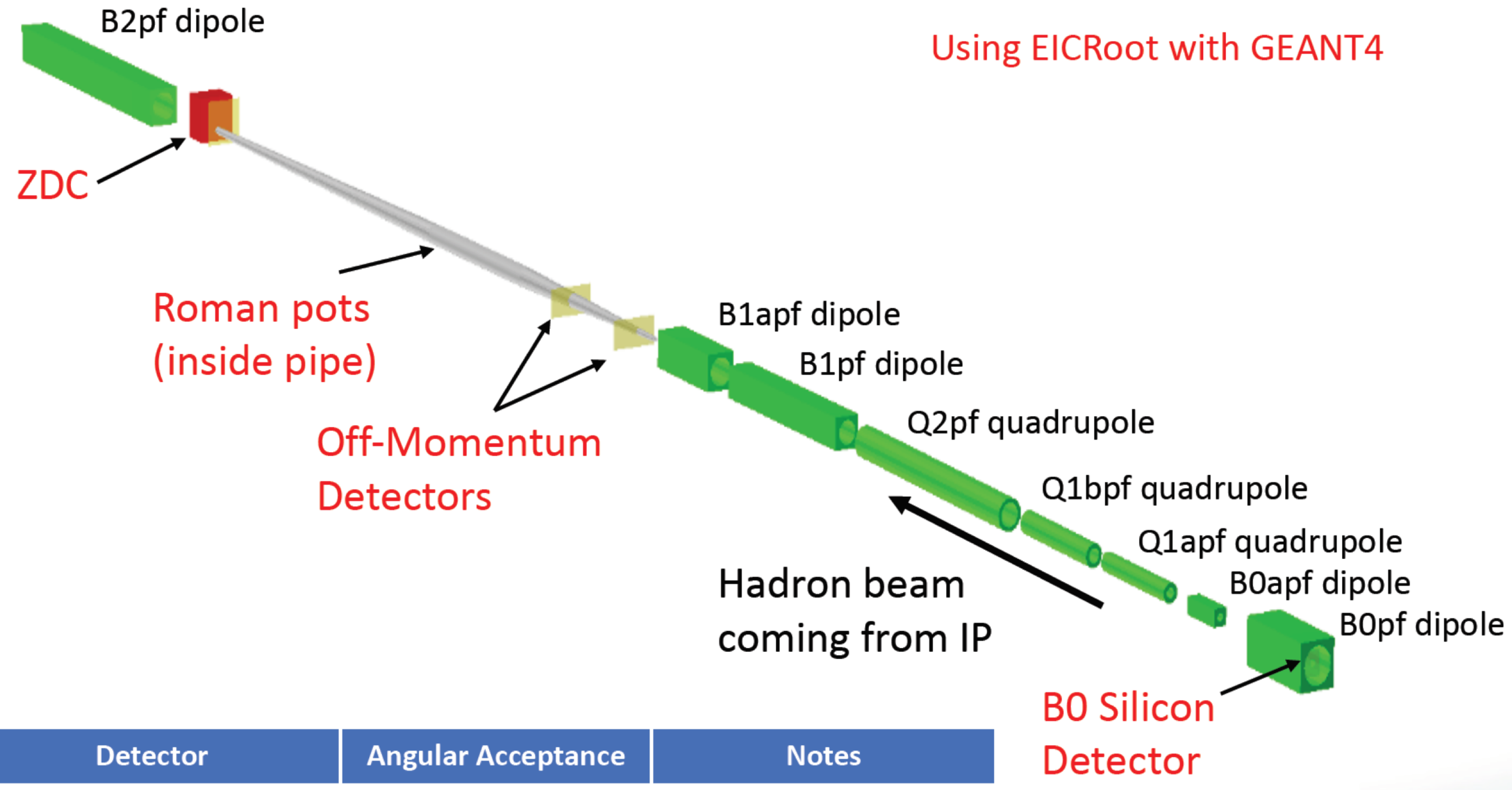
Far-Forward direction



- B0pF: Forward Spectrometer (6 -20 mrad)
- Neutron Detector (+/-4 mrad)
- Roman pots (sensitive 1 to 5 mrad)

Name	R1	length	B	grad	B pole
	[m]	[m]	[T]	[T/m]	[T]
B0ApF	0.043	0.6	-3.3	0	-3.3
Q1ApF	0.056	1.46	0	-72.608	-4.066
Q1BpF	0.078	1.61	0	-66.18	-5.162
Q2pF	0.131	3.8	0	40.737	5.357
B1pF	0.135	3	-3.4	0	-3.4

Far-Forward Region Layout

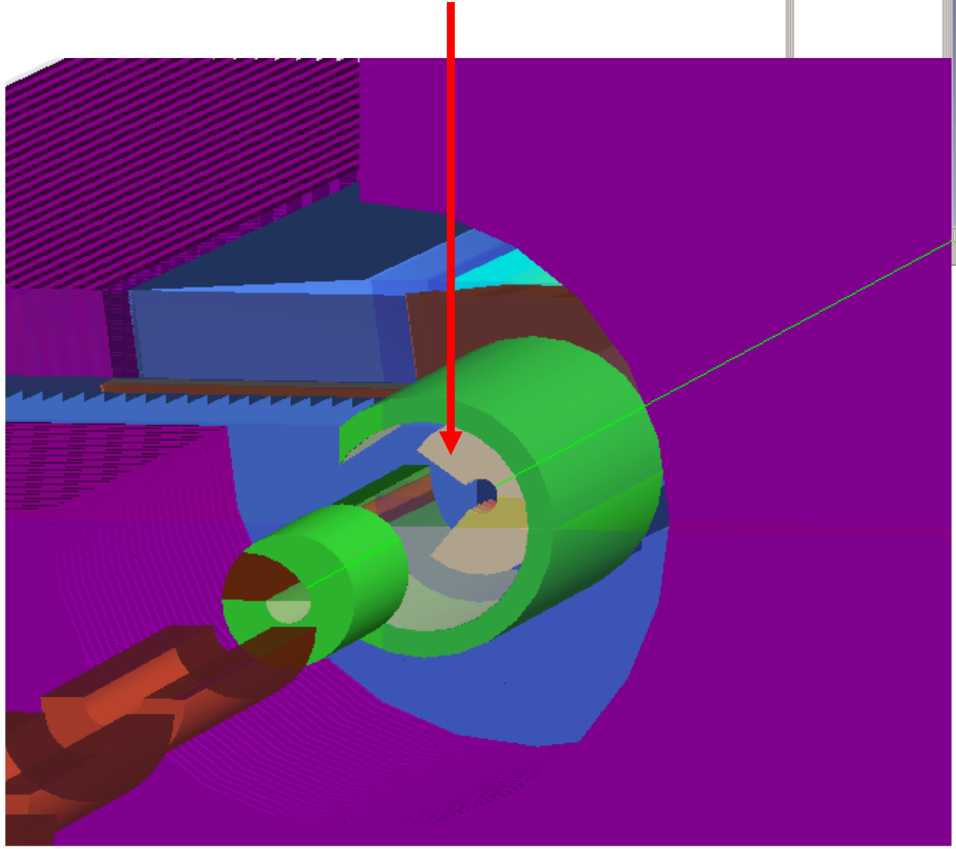


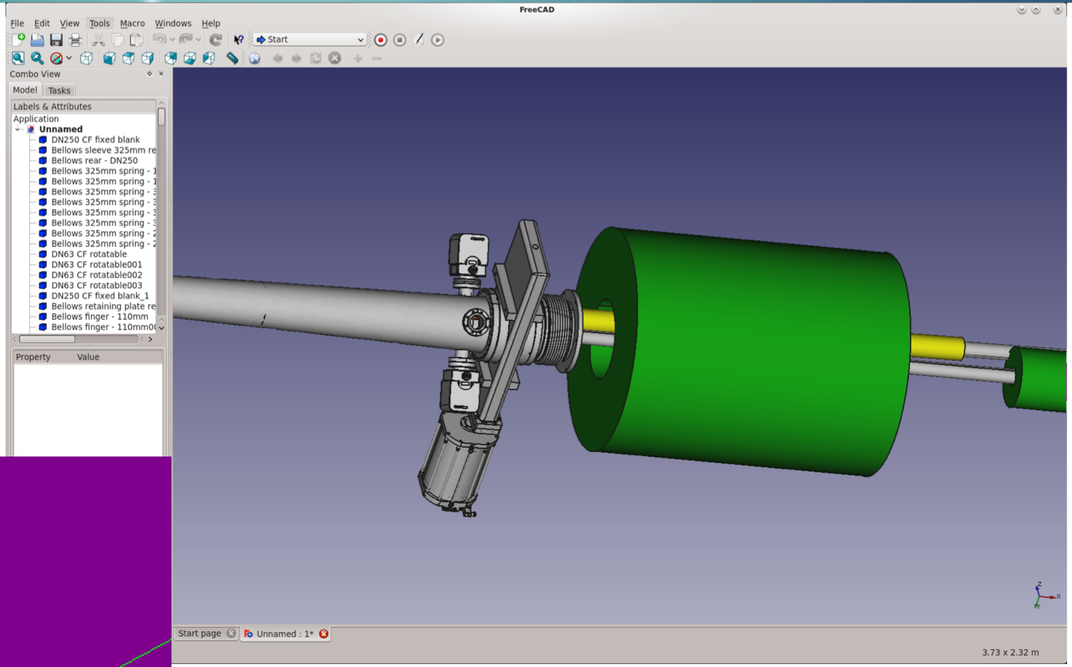
Detector	Angular Acceptance	Notes
ZDC	$\theta < 5.5$ mrad	About 4.0 mrad at $\varphi \sim \pi$
Roman Pots	$0.0 < \theta < 5.0$ mrad	Need 10σ cut.
Off-Momentum Detectors	$0.0 < \theta < 5.0$ mrad	Roughly $.4 < x_L < .6$
B0 Sensors	$5.5 < \theta < 20.0$ mrad	Still need to optimize.

$$x_L = \frac{p_{z,nucleon}}{p_{z,beam}}$$

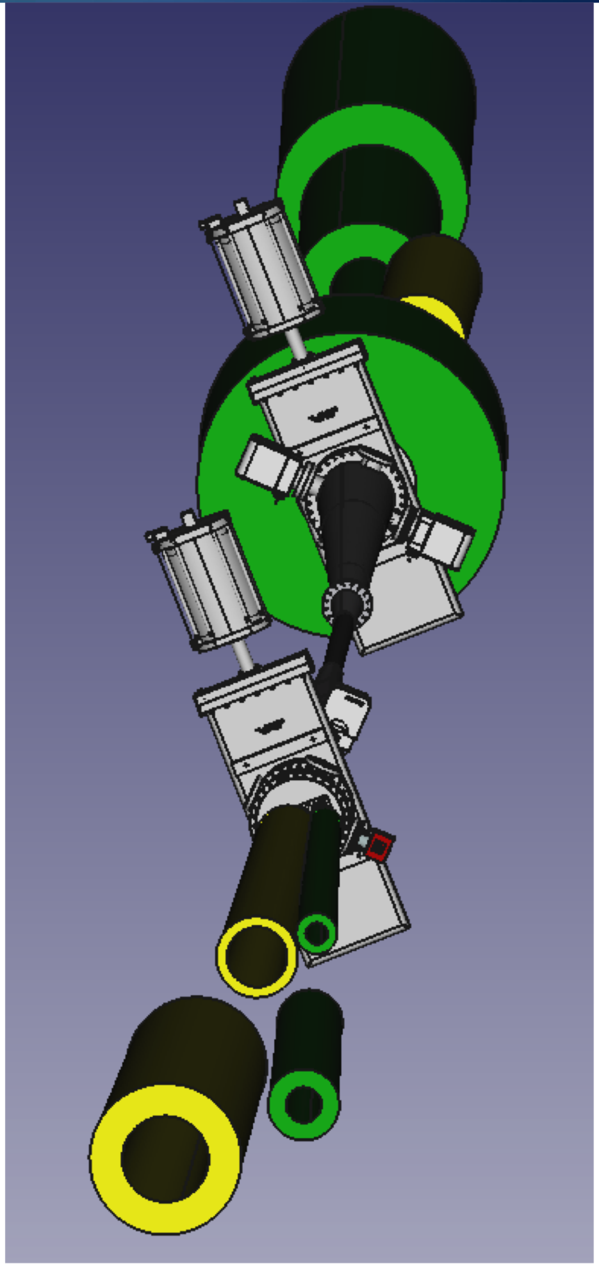
B0-dipole sensors

B0 sensors:
- Rin ~ 3.4 cm , Rout ~ 20 cm
- 50x50 μm^2 pixels
- Zpos= 5.9m, Xpos =15 cm ;

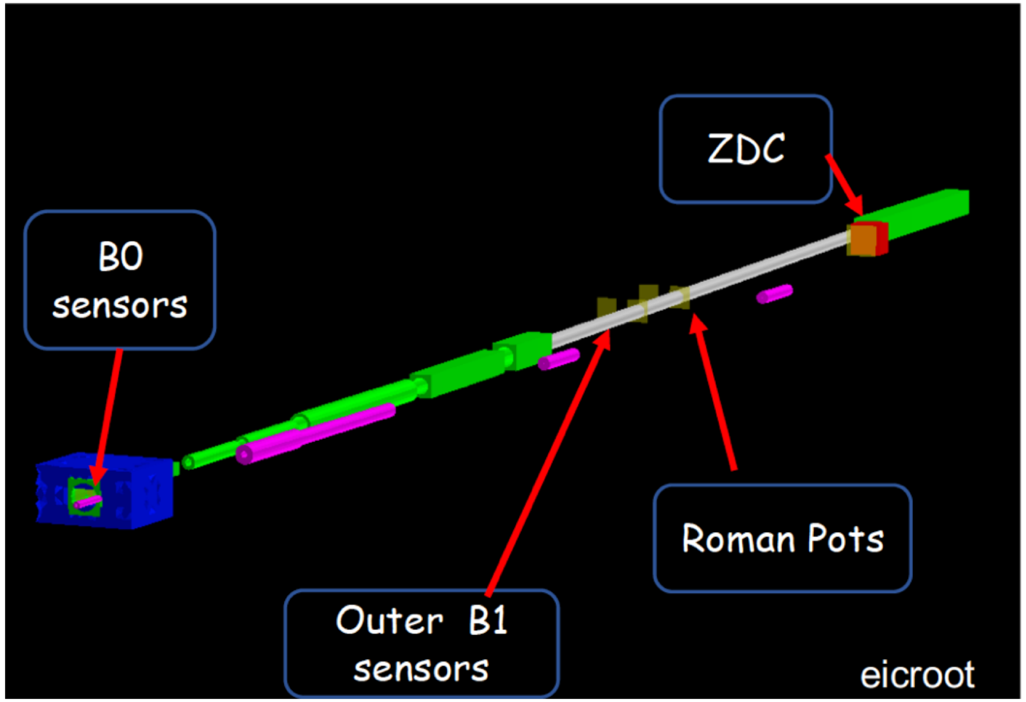




-Vacuum pumps in front of B0 tracker (high background area)
-shape of B0 tracker : asymmetric in φ due to the crossing angle)
-placement, cryo
-Pre-shower or EMCAL after B0 tracker?



Roman Pots and Off momentum sensors



B1 off-momentum sensors:

- Rin ~ 10 *cm (to be confirmed by beampipe design)
- 10x30cm
- 500x 500 μm^2 pixels
- Zpos = 22.5 *m , Xpos = 75 *cm

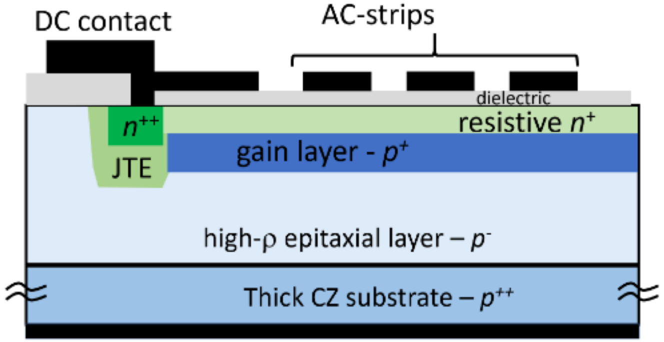
Roman Pots :

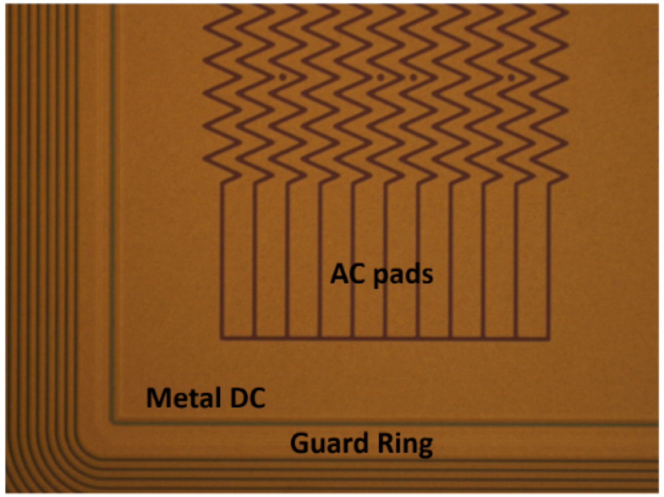
- Rin ~ 10σ away from the beam
- 20x10cm
- 500x 500 μm^2 pixels

2 stations:

- Zpos = 26.2 *m, Xpos = 82 *cm
- Zpos = 28.2 *m, Xpos = 91 *cm

AC-LGAD (fast timing detectors developed for HL-LHC)

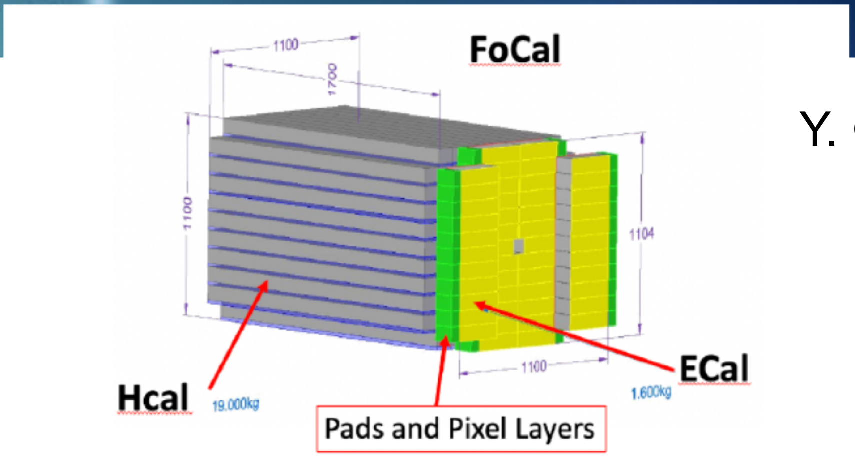




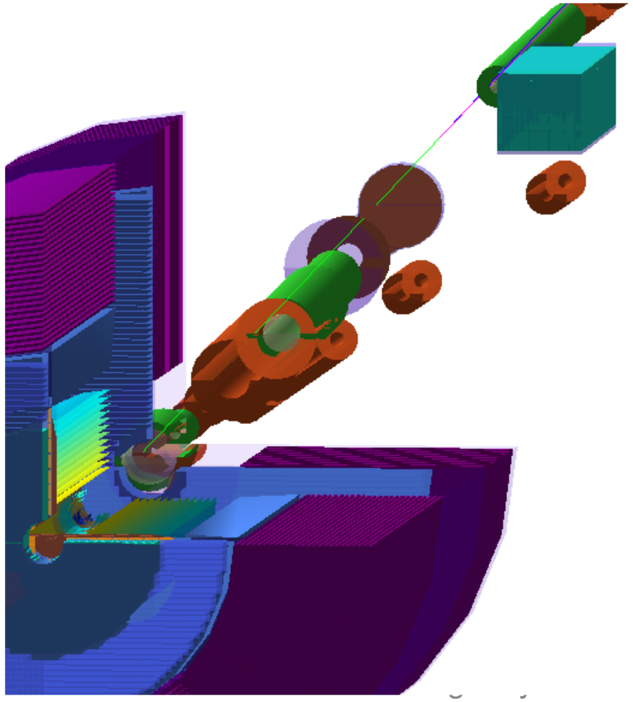
Zero Degree Calorimeter (ZDC)

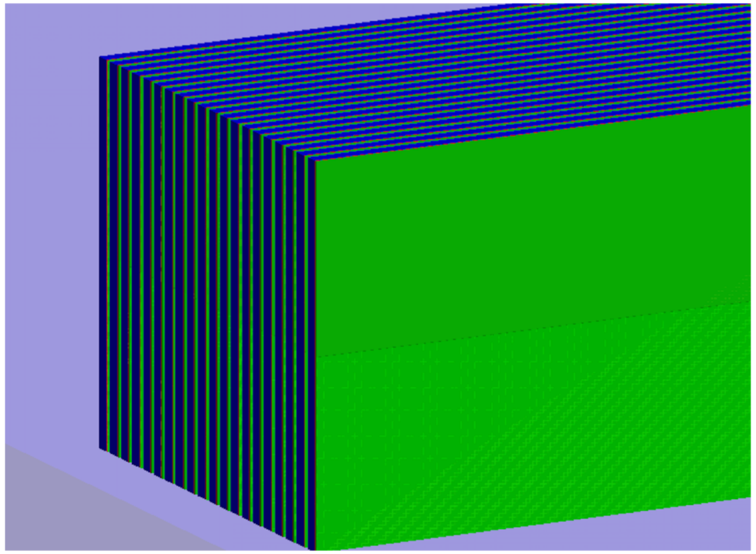
Y. Goto

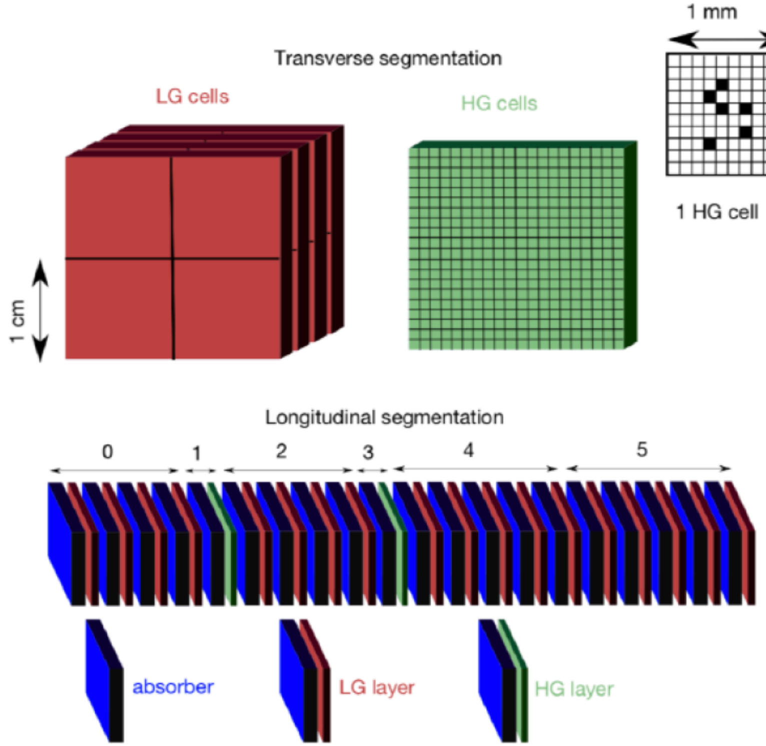
60x60 x 200 cm
EMCAL
  LG: 1x1cm^2
  HG: 100x100um^2
HCAL: 10x10 cm
Zpos = 38*m
Xpos = 90*cm



HCal: ~2K channels





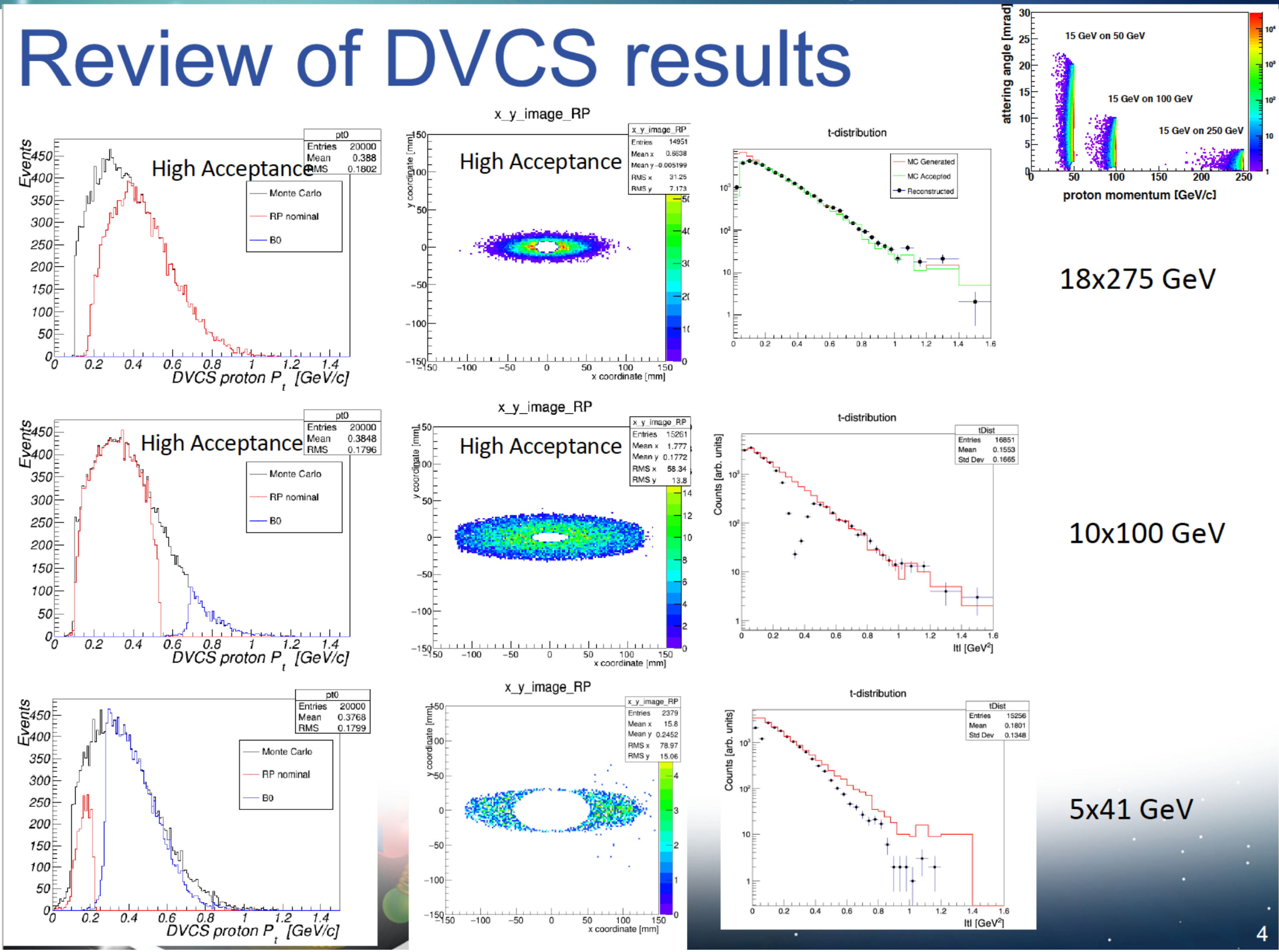


ZDC: $\sigma_E \sim \frac{50\%}{\sqrt{E}} + 5\%, \sigma_\theta \sim \frac{3\ mrad}{\sqrt{E}}$

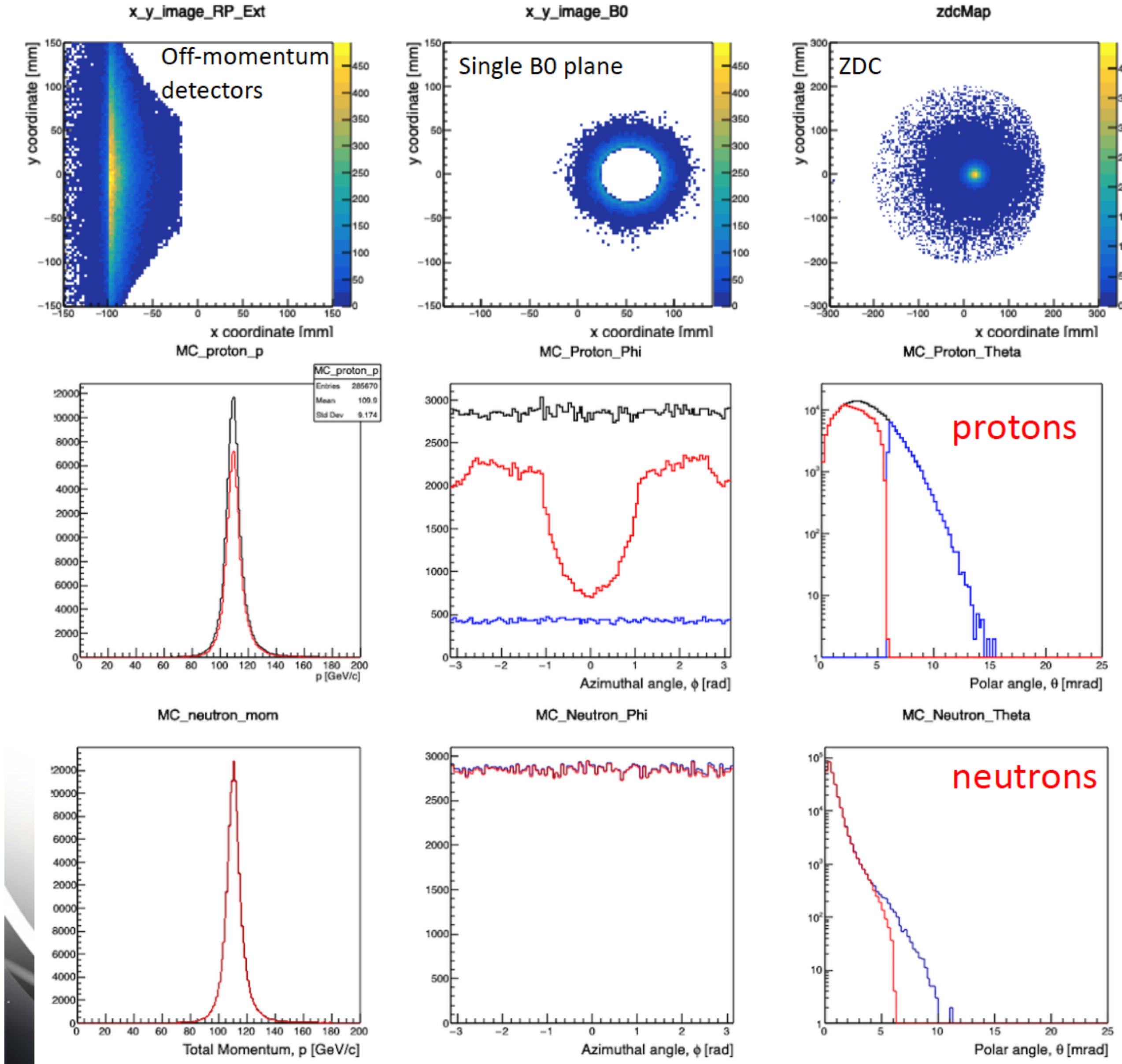
Alex Jentsch,

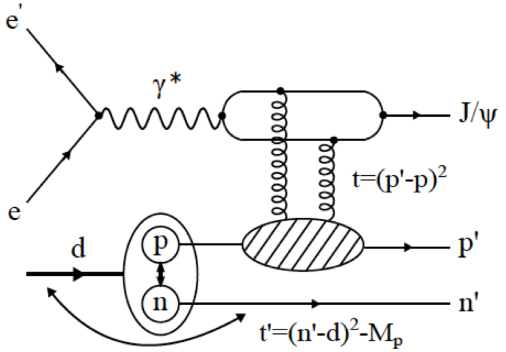
Status of the Far-Forward WG

- Understand detailed geometric acceptance with baseline IR design.
- Propose baseline detector concepts for FF hadron & photon detection and study resolutions.
- Iterate on the above points with possible, achievable improvements (e.g. ZDC energy resolution, pixel sizes, etc.)
- Use studies to help inform second IR design to potentially cover gaps in the baseline IR.



Results from e+D nuclear breakup





Particular process in BeAGLE: incoherent diffractive J/psi production off bounded nucleons.

Neutron spectator case.

https://arxiv.org/abs/2005.14706

5

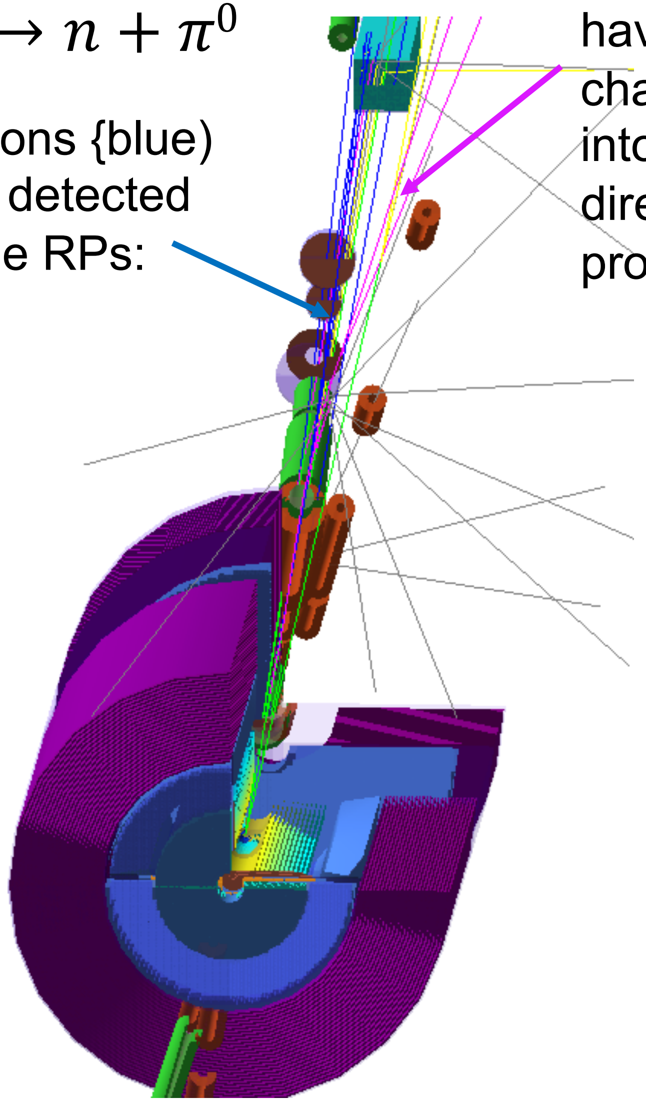
Lambda decays (275 GeV) see next talk by Richard Trotta

$\Lambda \to p + \pi^-$

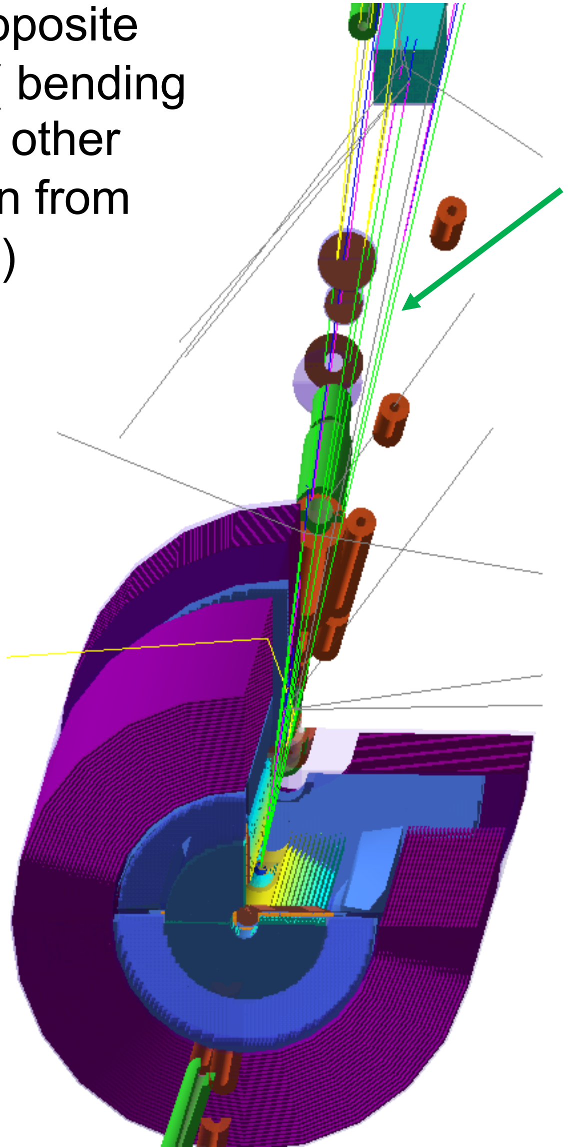
$\Lambda \to n + \pi^0$

Protons {blue} are detected in the RPs:

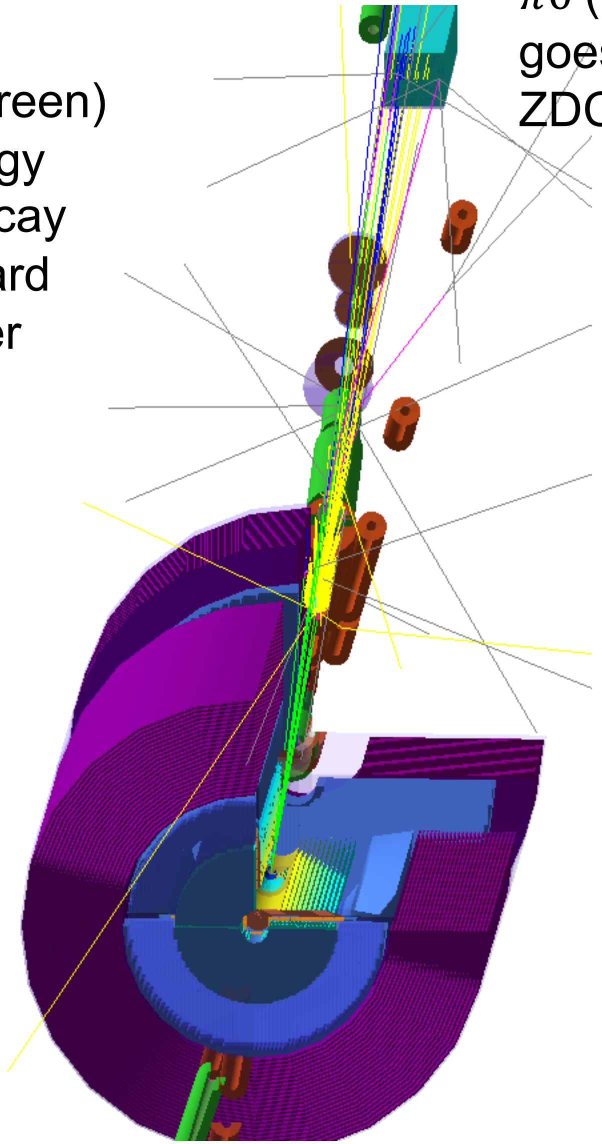
π^- {magenta} have opposite charge(bending into an other direction from protons)



Ca 30% of Lambdas (green) at high energy does not decay before forward spectrometer

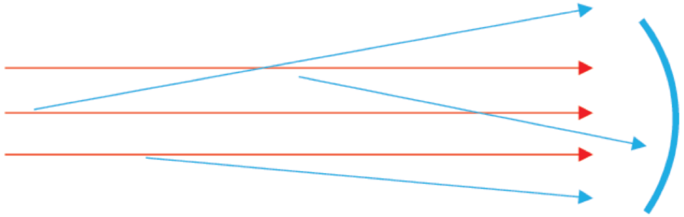


Neutrons {gray) and fraction of $\pi0$ (yellow) goes into ZDC

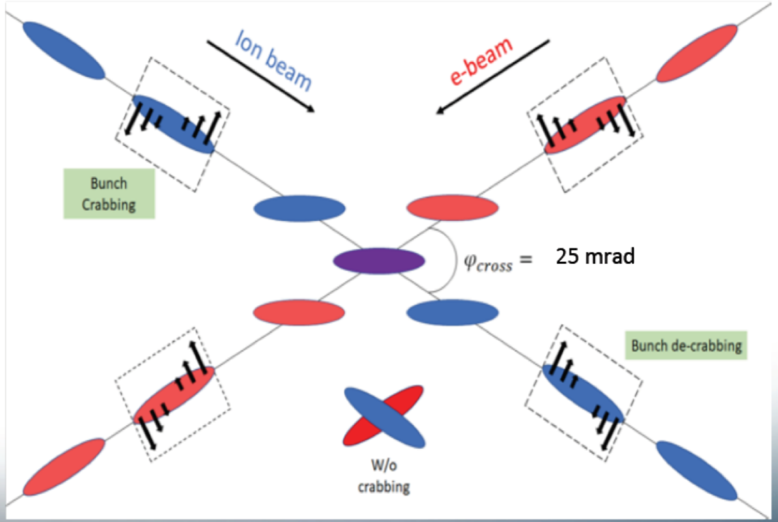


Digression: particle beams

- Angular divergence
  - Angular “spread” of the beam away from the central trajectory.
  - Gives some small initial transverse momentum to the beam particles.



- Crab cavity rotation
  - Can perform rotations of the beam bunches in 2D.
  - Used to account for the luminosity drop due to the crossing angle – allows for head-on collisions to still take place.



These effects introduce smearing in our momentum reconstruction.

Resolutions

p_T Resolution	Proton		Neutron	
	%	MeV/c	%	MeV/c
$p_T < 140$ MeV/c	15	22	29	37
$140 < p_T < 350$ MeV/c	8	25	14	43
$350 < p_T < 630$ MeV/c	6	30	10	52
$p_T > 630$ MeV/c	4	26	9	70

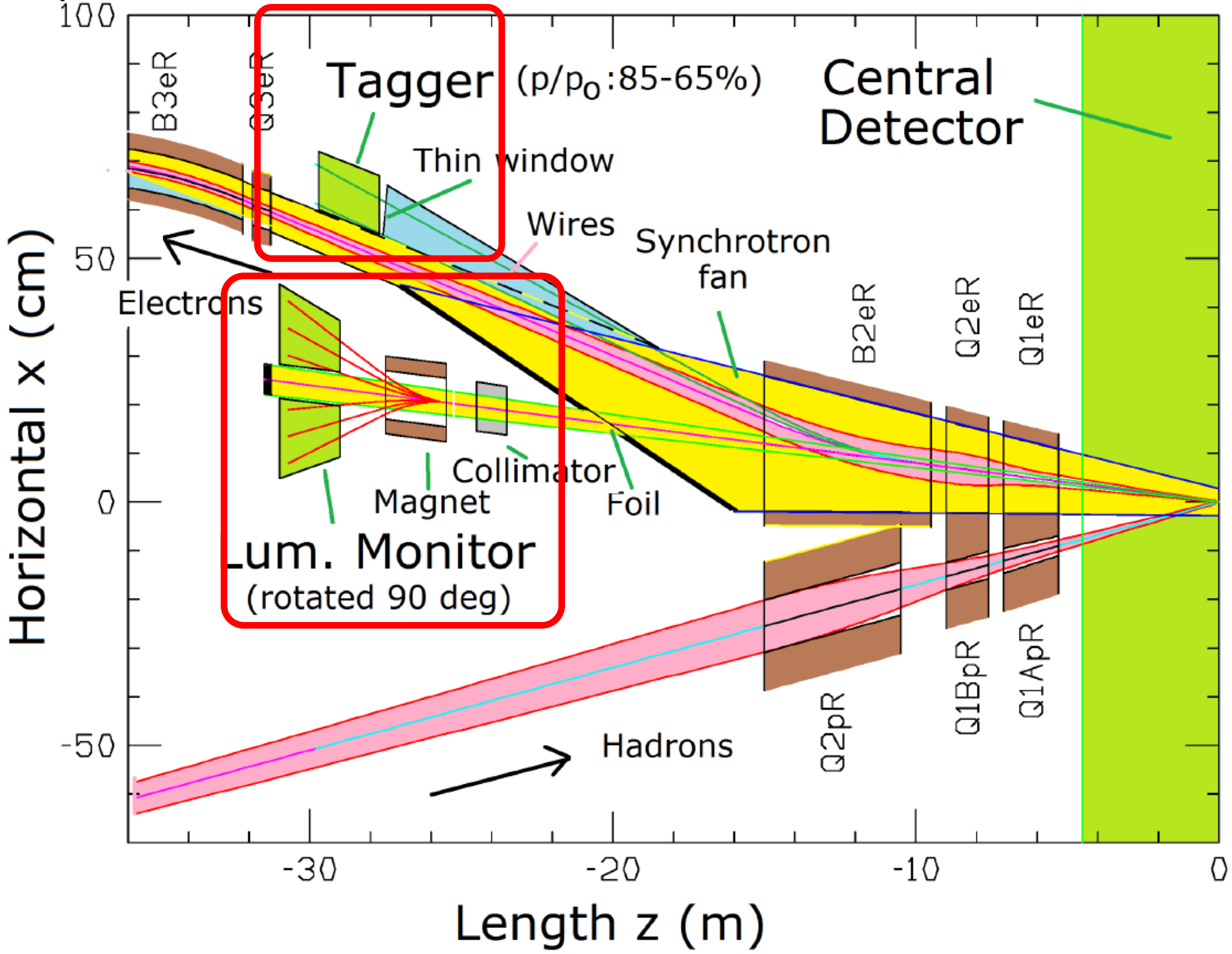
E Resolution	Neutron	
	%	GeV/c
$50 < p < 80$ GeV/c	7.5	5.5
$80 < p < 110$ GeV/c	7	7
$110 < p < 130$ GeV/c	6.7	8.5
$p > 130$ GeV/c	6.2	11

Assumptions:

1) ZDC
   - energy resolution $\frac{\sigma_E}{E} = \frac{50\%}{\sqrt{E}} \oplus 5\%$
   - Angular resolution $\frac{3\text{ mrad}}{\sqrt{E}}$
2) Off-Momentum Detectors
   - 500 um x 500 um pixels
3) B0 Sensors
   - 50 um x 50 um pixels
4) Using angular divergence numbers from pCDR 18x100 GeV e+p with strong cooling.

Methods	Momentum transfer t (GeV^2)							
	0–0.05	0.05–0.11	0.11–0.17	0.17–0.25	0.25–0.35	0.35–0.49	0.49–0.69	0.69–1.20
1. $\delta t/t$ (%) with $t = (p' - p)^2$	-	-	-	-	-	-	-	-
2. $\delta t/t$ (%) with $t = (e - e' - V)^2$	> 100	> 100	> 100	> 100	> 100	> 100	> 100	> 100
3. $\delta t/t$ (%) with $t \approx (p_{T,V} + p_{T,e'})^2$	20.3	7.8	5.8	4.8	3.9	3.4	3.0	2.5
4. $\delta t/t$ (%) with $t = (p' - (-n))^2$	49.6	41.6	36.2	31.6	28.2	24.4	17.9	16.0

Low-Q^2 / Backwards direction



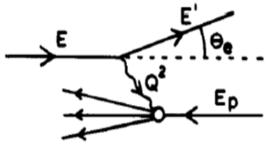
- Luminosity Monitor
- Low-Q^2 tagger

- Synchrotron radiation shielding
- Thin window
- Beampipe –design
- Coincidence with Lumi detector

Low-Q^2 / Backwards direction

Jaroslav Adam

Mechanism for Q^2 measurement in the tagger



$$Q^2 = 2EE'(1 - \cos(\theta_e))$$

- Hit position in x and y and electron energy E' is used to get the original angle θ_e
- Reconstruction matrix R_{ijk} is used to find θ_e for a given set of x, y and E'

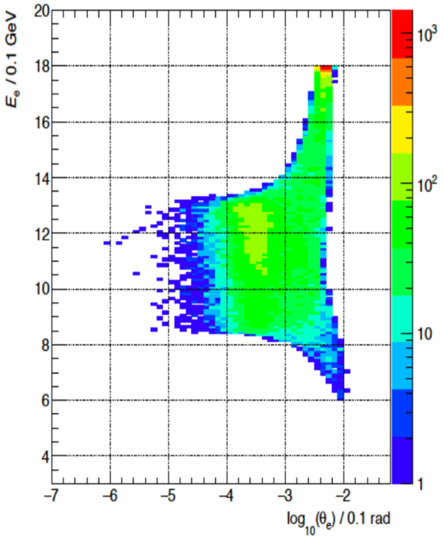


Figure: Energy and polar angle

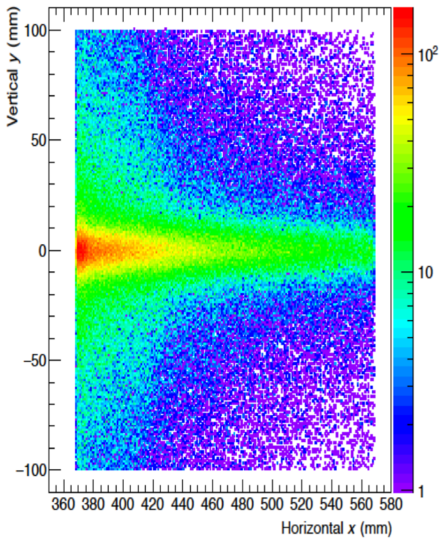


Figure: Hit position on the tagger

- Both plots show the same Pythia6 events which hit the tagger, beam effects are applied
- Energy-angle plot shows acceptance in θ_e from 0.01 mrad to 10 mrad and energy from 6 to 18 GeV

- Interval of accepted events in x and Q^2 is a narrow correlated band
- Angular tagger acceptance ranges from 0.01 mrad to 10 mrad and energy acceptance from 6 to 18 GeV
- Q^2 reconstruction still looks feasible down to 10^{-5} GeV^2 with beam effects included
- Achieved with pads segmented by 0.5×0.5 mm^2, also will depend on energy resolution
- Upper limit at 10^{-2} GeV^2 is given by the acceptance

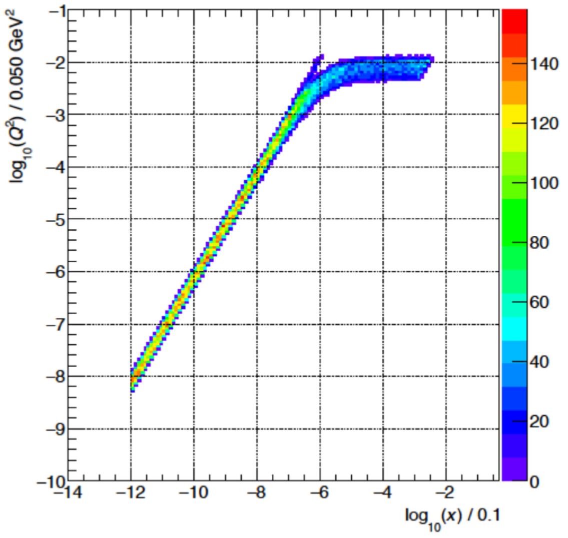


Figure: Quasi-real events in tagger

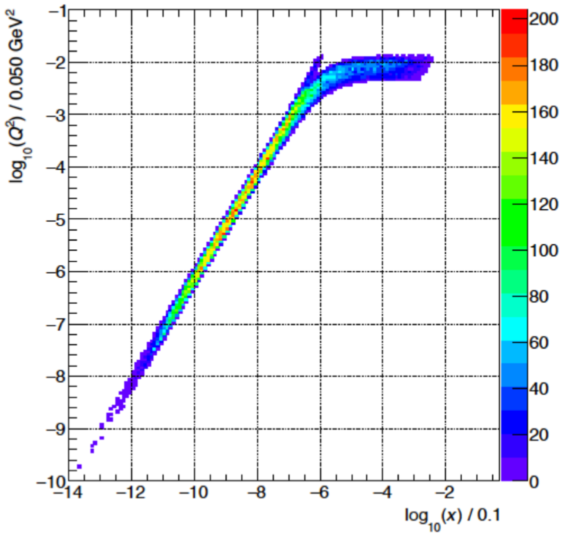


Figure: Pythia6 events in tagger

Software

Electron-Ion Collider User Group

The world's most powerful microscope for studying the "glue" that binds the building blocks of visible matter.

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EIC Software

Software Working Group

The EICUG has formed a Software Working Group that collaborates with EIC Software initiatives and other experts in NP and HEP on detector and physics simulations for the EIC. The short-term goal of the working group is to meet in FY20 the requirements for common tools and documentation in the EICUG.

JupyterLab

The Software Working Group has adapted **JupyterLab** as a collaborative workspace to further develop EIC Science, to examine detector requirements, and to work on detector designs and concepts. JupyterLab is a web-based interactive analysis environment to create and share documents that contain the analysis code, the narrative of the analysis including graphics and equations, and visualizations of the analysis results. This will allow the EICUG not only to pursue simulations in a manner that is accessible, consistent, and reproducible to the EICUG as a whole, but also to build a collection of analyses and analysis tools in the fully extensible and modular JupyterLab environment. A quick start tutorial for fast simulations is available on the website for EIC Software.

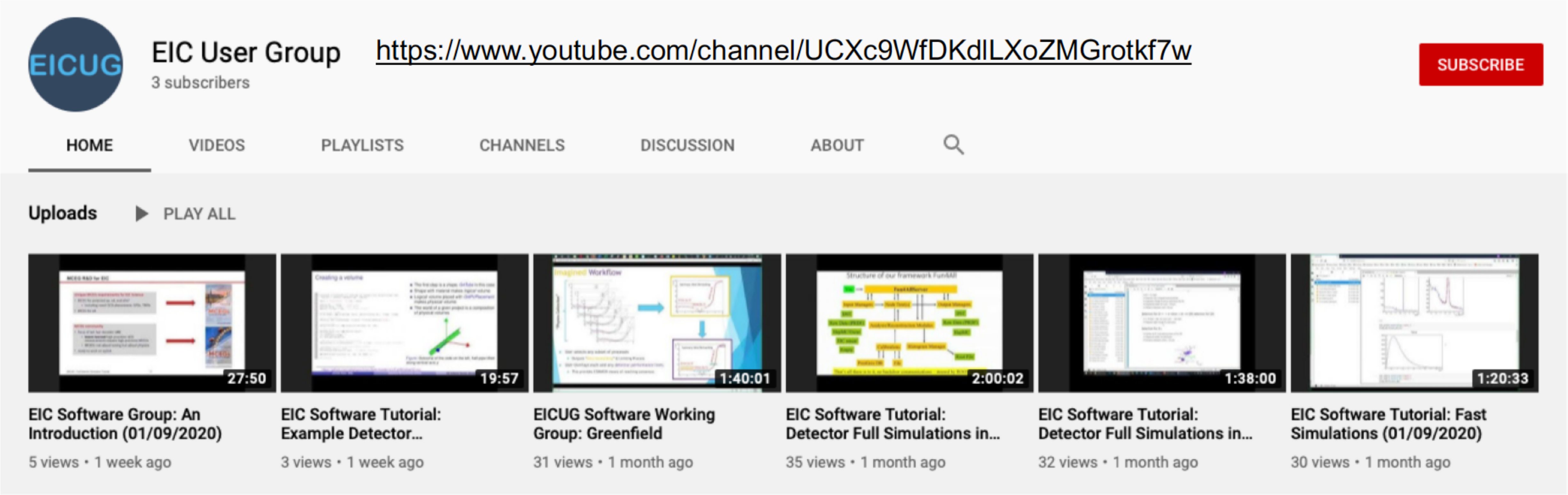
Important links

Mailing list	eicug-software@eicug.org (subscribe via Google Group)
Repository	https://github.com/eic and https://gitlab.com/eic (will be merged with https://github.com/eic)
Website	https://eic.github.io

Docker and Singularity containers to distribute software

- Fun4All centered around the use of ROOT macros
- ESCalate integrated into a JupyterLab/JupyterHub environment
- EICroot (Geant3/4)

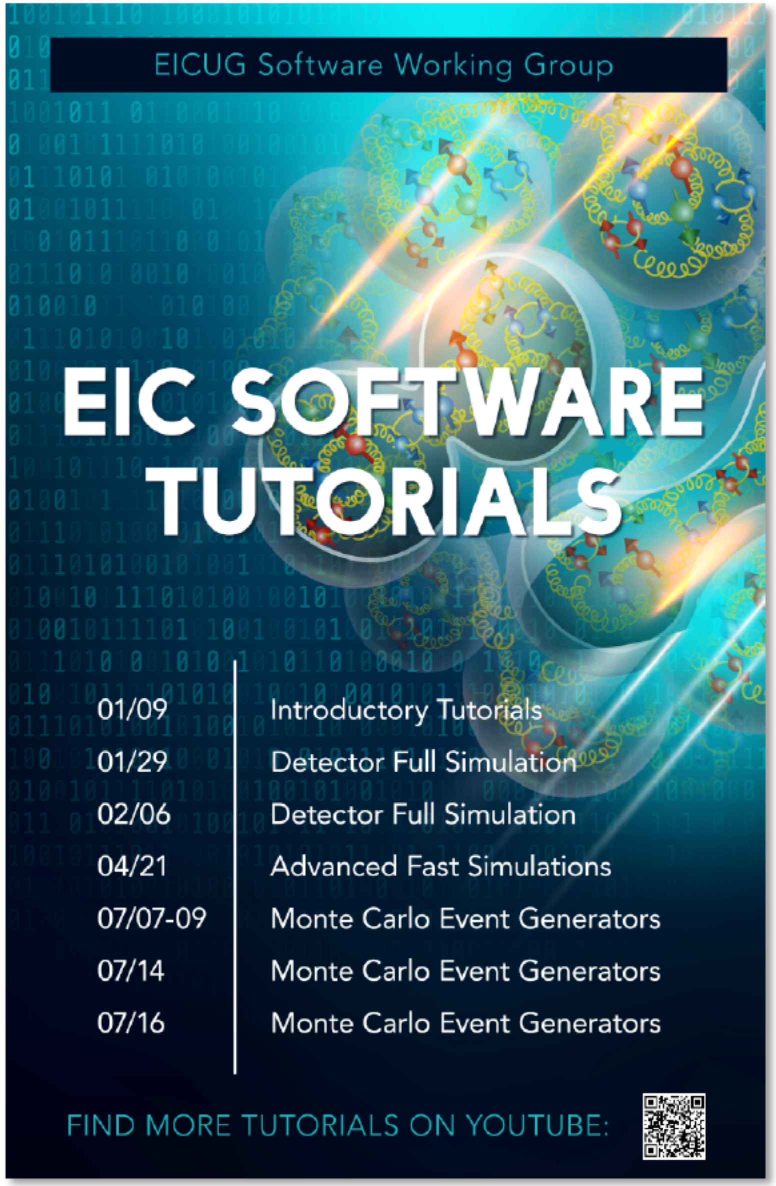
Online tutorials



Recordings from tutorials

- **Fast Simulation Tutorial** Introduction to JupyterLab workspace, using fast simulations as example
- **Detector Full Simulation Tutorials** Geant4 for EIC, how to modify existing detector concepts, and how to integrate a new detector into one of the existing detector concepts.
- **(new) Jim Pivarski Tutorial: uproot and Awkward Array** process and analyze Root files with pure Python libraries
- **(new) Advanced Fast Simulation Tutorial** Fast simulations on the command line and in JupyterLab, singularity

Upcoming meetings and tutorials



May 27 RICH simulations

Topic description of the RICH detectors in Geant4

By M. Asai (Geant4), S. Easo (CERN)

June 10 ACTS

Topic track and vertexing reconstruction software

By X. Ai (Berkeley)

July 7-9, 14, 16 Monte Carlo Event Generators

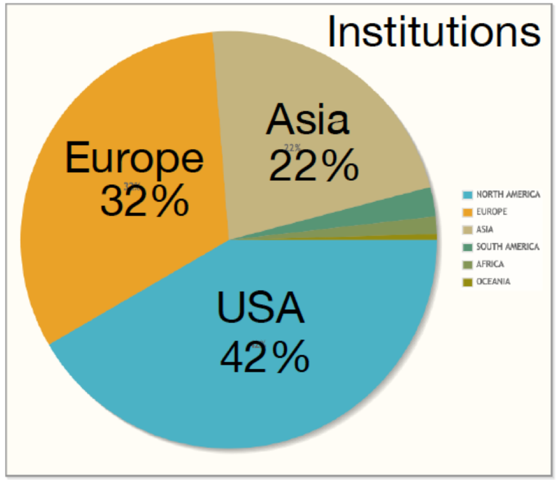
Topic Pythia8+DIRE, Herwig 7, Sherpa 2, Rivet, discussion

By C. Bierlich (Copenhagen, LUND), S. Hoeche (FNAL), S. Plätzer (Vienna), and S. Prestel (LUND)

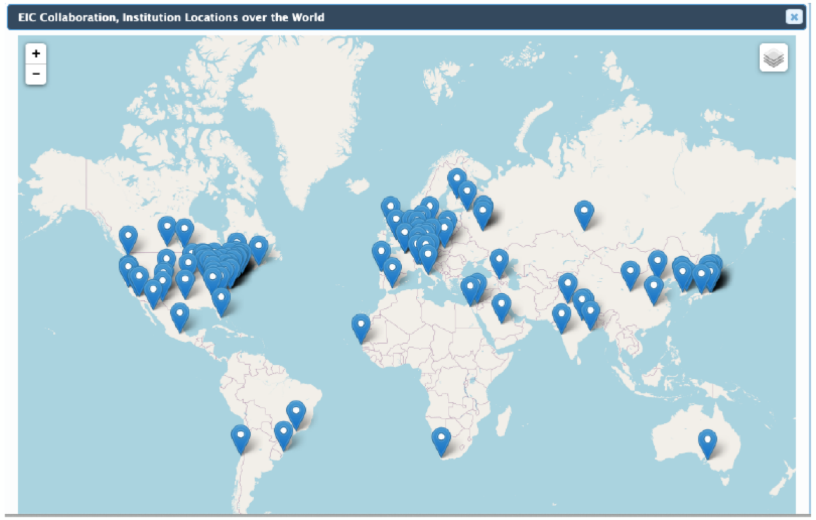
EICUG status

www.eicug.org

- EICUG organization established in 2016
- EICUG **now**: **1073** members
  - **645** Exp. scientists
  - **273** Th. scientists
  - **147** Accel. scientists
  - **3** Support
  - **5** Other
- EICUG **now**: **221** institutions from **31** countries in **6** world regions



- EICUG now: world map



It is a right time to join the EIC User Group!

2

Thank you!

Backup