General requirements for exclusive VMP and JLEIC detector

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and Brent Lawson (student, working on HERA-II analysis)

VM-GPD, Stony Brook, June 3-6,2018

U.S. DEPARTMENT OF ENERGY JSA Jefferson Lab

Detector for VM

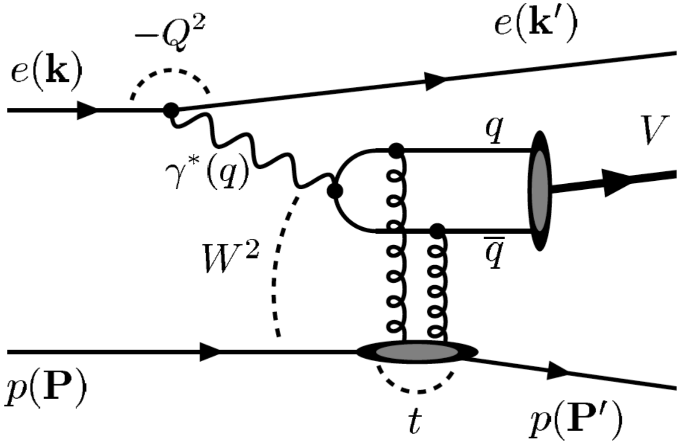


Figure 2. Exclusive vector meson production described by perturbative quantum chromodynamics.

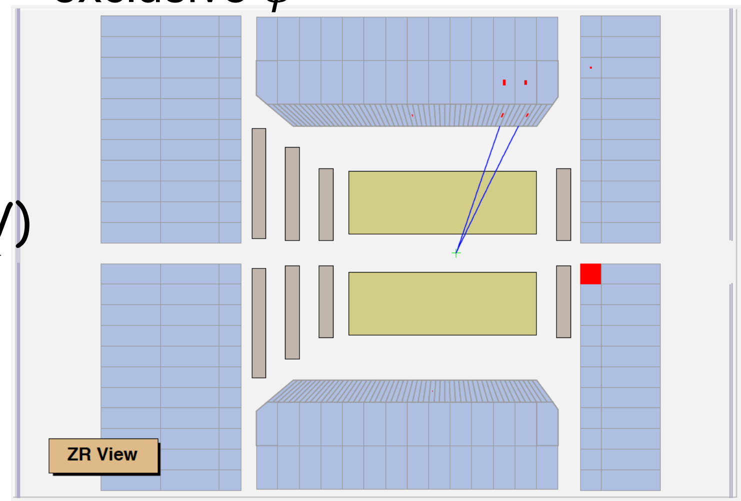
-Scattered electron
-decay products of VM
-recoil proton

Need to understand how the design of past detectors (ZEUS,H1,etc) impacted the observation of VM production to guide optimal designs for the EIC detector.
Need to know background

VM at ZEUS

exclusive ϕ

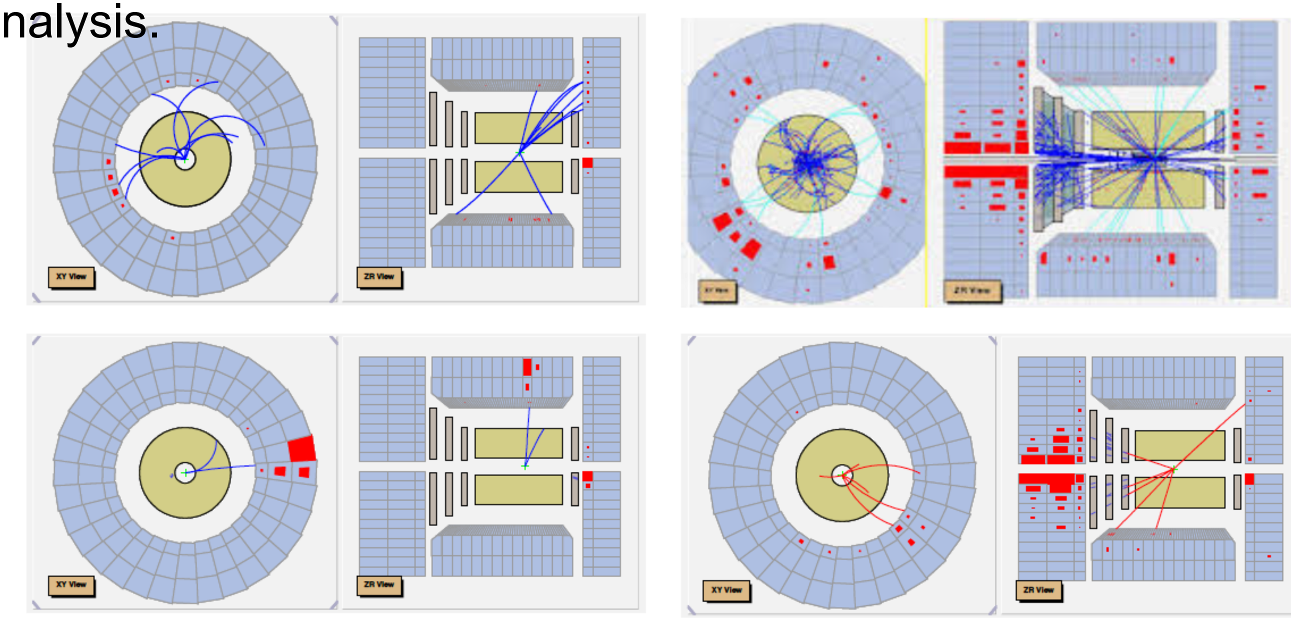
e (27.5 GeV)



p (920 GeV)

Figure 3. Example of the tracks and energy deposits for exclusive ϕ production.

Background: Examples of events that are not exclusive ϕ production, that needs to be removed during the analysis.



VM ($\phi \to K^+ K^-$) at ZEUS

Cuts used for data selection

1. $2 <$ # of tracks in CTD < 5
2. Tracks must have opposite charges and be associated with primary vertex
3. $E_e' > 10\ GeV$ in a reliable region of detector
4. Tracks must pass through > 3 superlayers in the CTD
5. Tracks must have trans. momentum > 0.15 GeV
6. Tracks must be within $|\eta| < 1.7$ (angle)
7. $|Vtx_z| < 50$ cm and $Vtx_r < 0.8$ cm
8. Energy in inner ring of forward calorimeter $<$ 1 GeV
9. No extraneous tracks with $E > 0.3$ GeV
10. $2 < Q^2 < 70\ GeV^2$
11. $45 < E\text{-}p_z < 65$ GeV
12. $35 < W < 200$ GeV
13. $|t| < 0.6$
14. $1.01 < M_{KK} < 1.10$ GeV

No PID

at HERA- initial e: 27.5GeV

For track reconstruction (no vertex for HERA-1)

Only CTD area

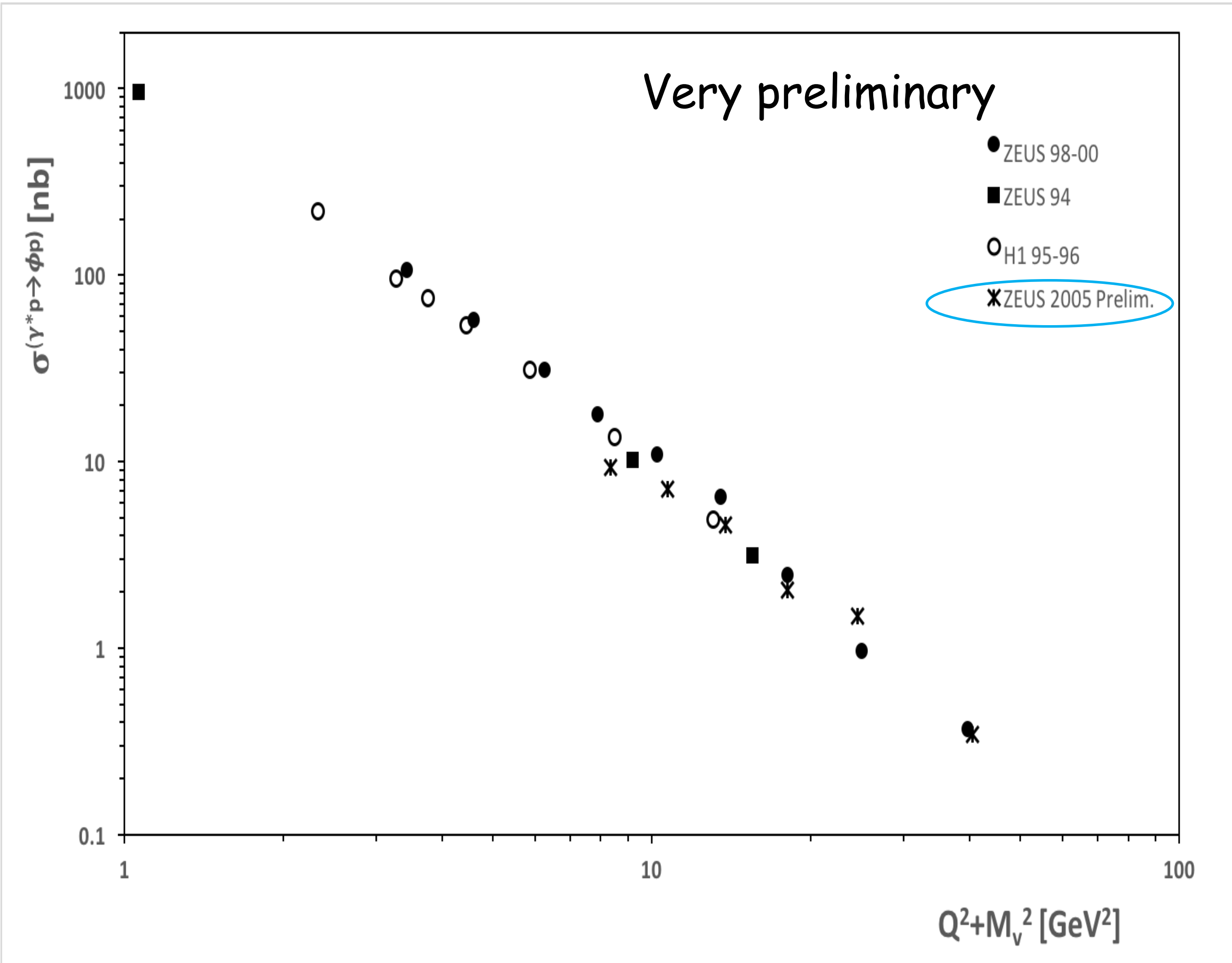
Beam background rejection

"Exclusivity" cut, no forward detection at HERA.

NC DIS: E-pz ~ 2Ee ~ 55 GeV

VM ($\phi \to K^+ K^-$) at ZEUS

Brent Lawson



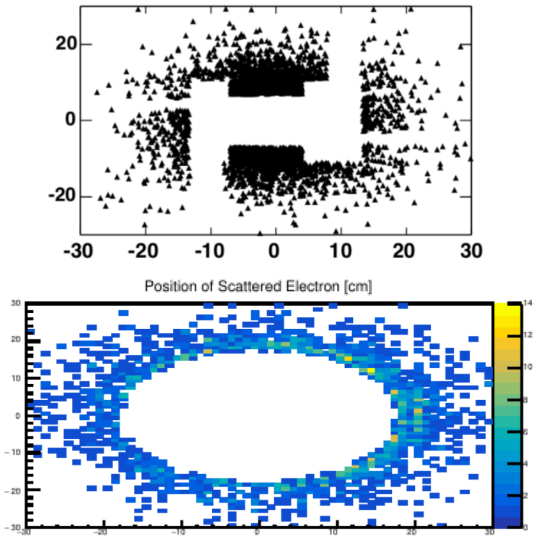
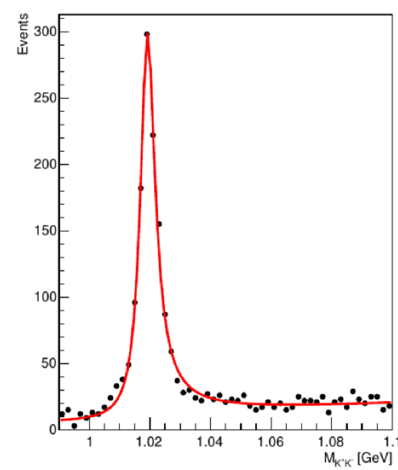


Figure 9. Electron position cuts from ZEUS detector during HERA-I[4] and HERA-II

Invariant mass peak for ϕ vector meson fit with a Relativistic Breit-Wigner distribution and a second order polynomial to describe the background



VM ($\phi \to K^+ K^-$)

At HERA :

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14. $1.01 < M_{KK} < 1.10$ GeV

At EIC :

PID detectors for π/K separation

Ee' > 1 GeV
Need high resolution of EMCAL !!

Could go down to few tens of GeV (due to vertex detector)

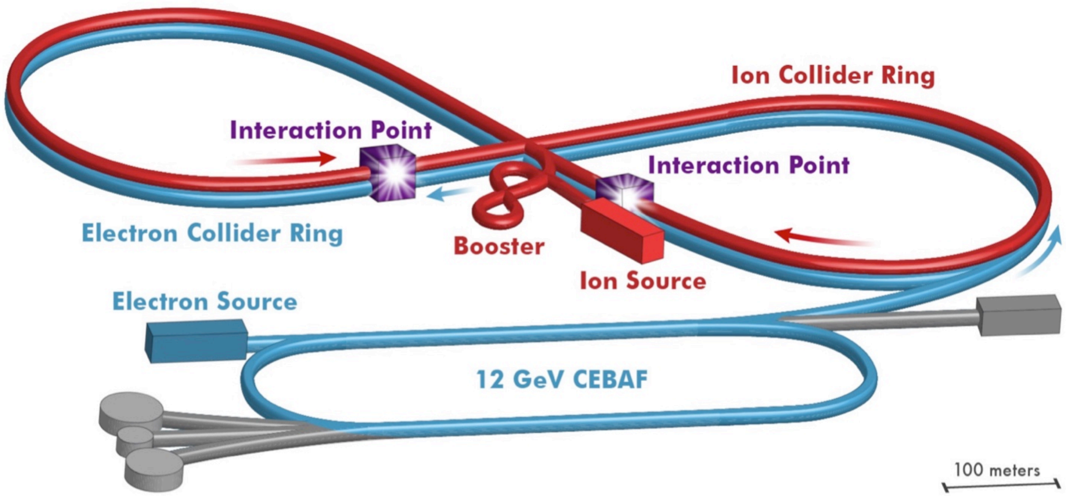
Need to provide good tracking resolution in endcaps!

Forward detection!

NC DIS: E-pz ~ 2Ee ~ 20 (…) GeV

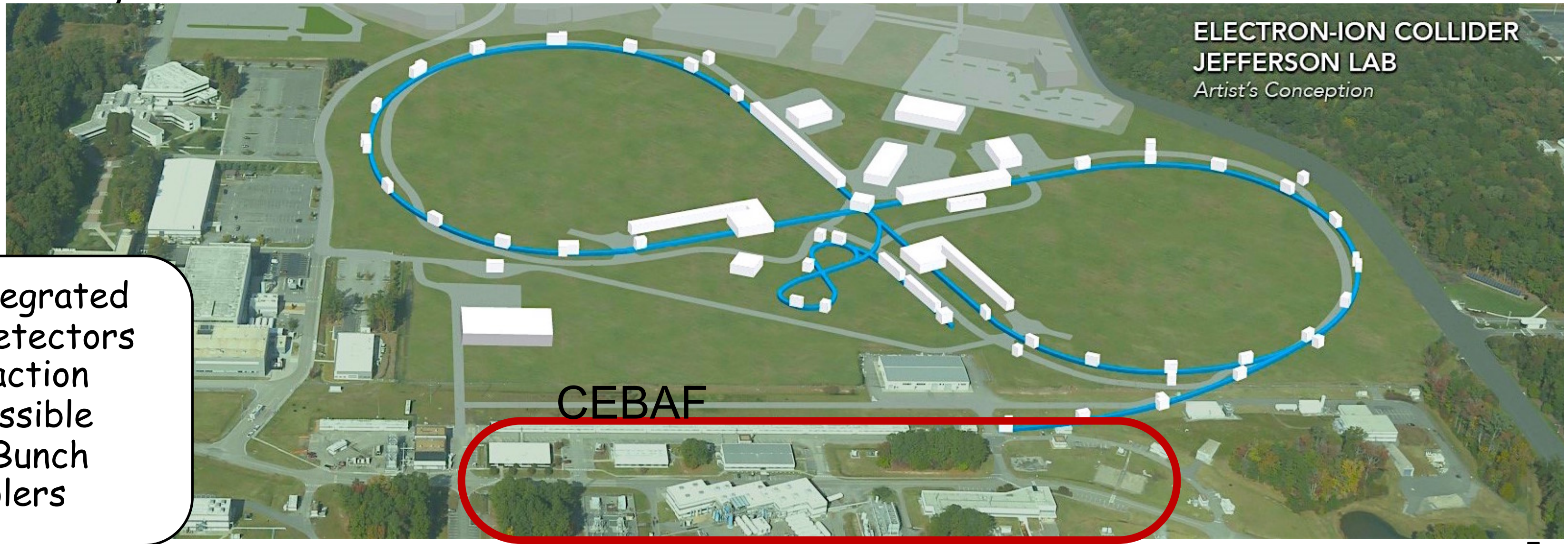
JLEIC design (JLab)

e-: 3 to 10 -12 GeV
p : 20 to 100 (400) GeV
$\sqrt{s}$: 20 to **65 (140) GeV**
(Magnet Technology Choice)
Luminosity: $\sim 10^{34}\ cm^{-2}s^{-1}$



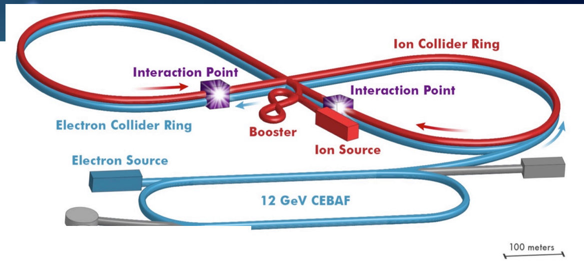
Exploring existing Electron complex
CEBAF (adding Electron collider ring)
Adding Ion complex
Ion source, SRT linac, Booster, Ion collider ring

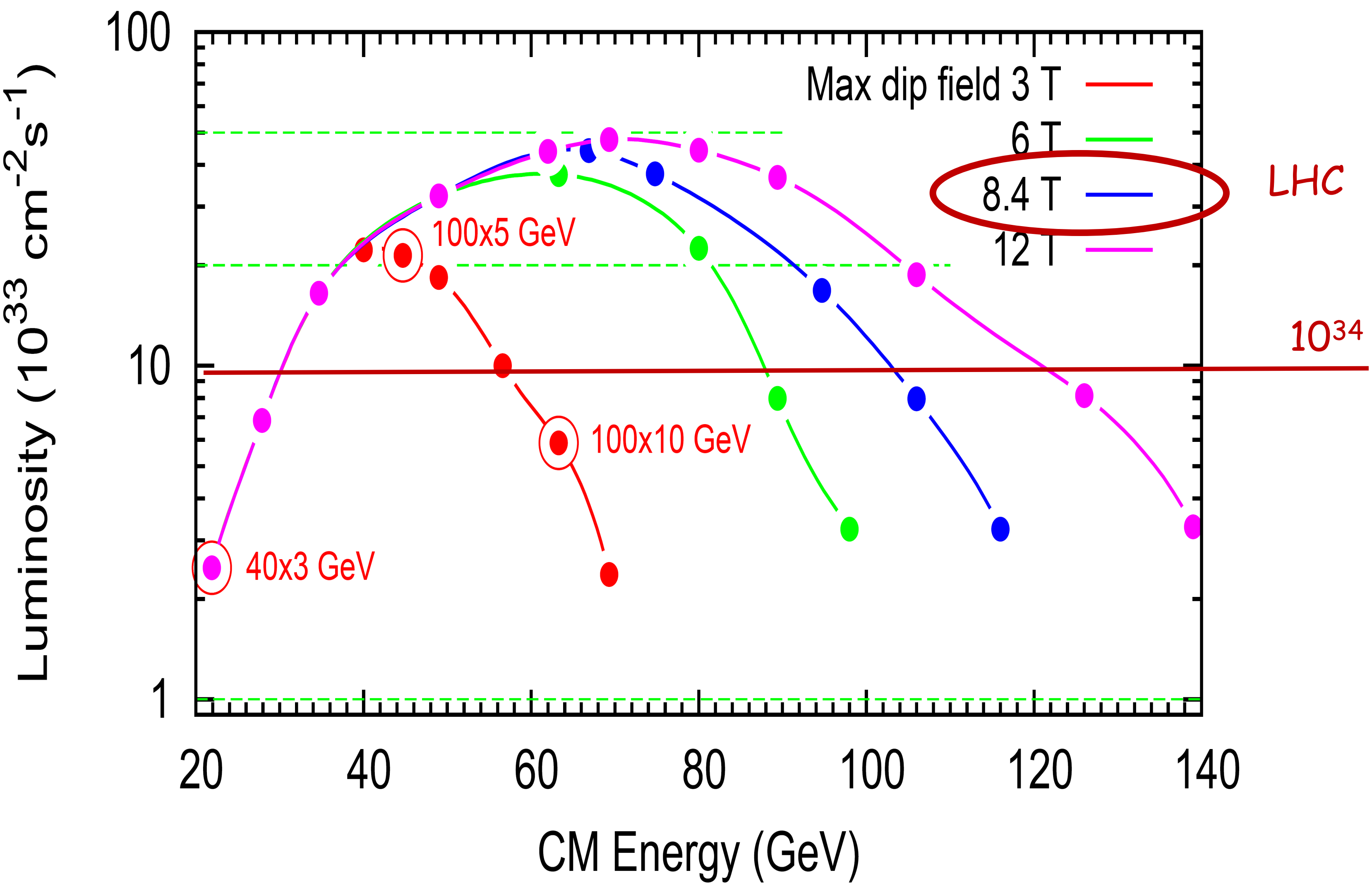
Figure 8: High polarization (~80%)



-Fully integrated IR and detectors
-2 Interaction Points possible
-DC and Bunch beam coolers

JLEIC design (JLab)

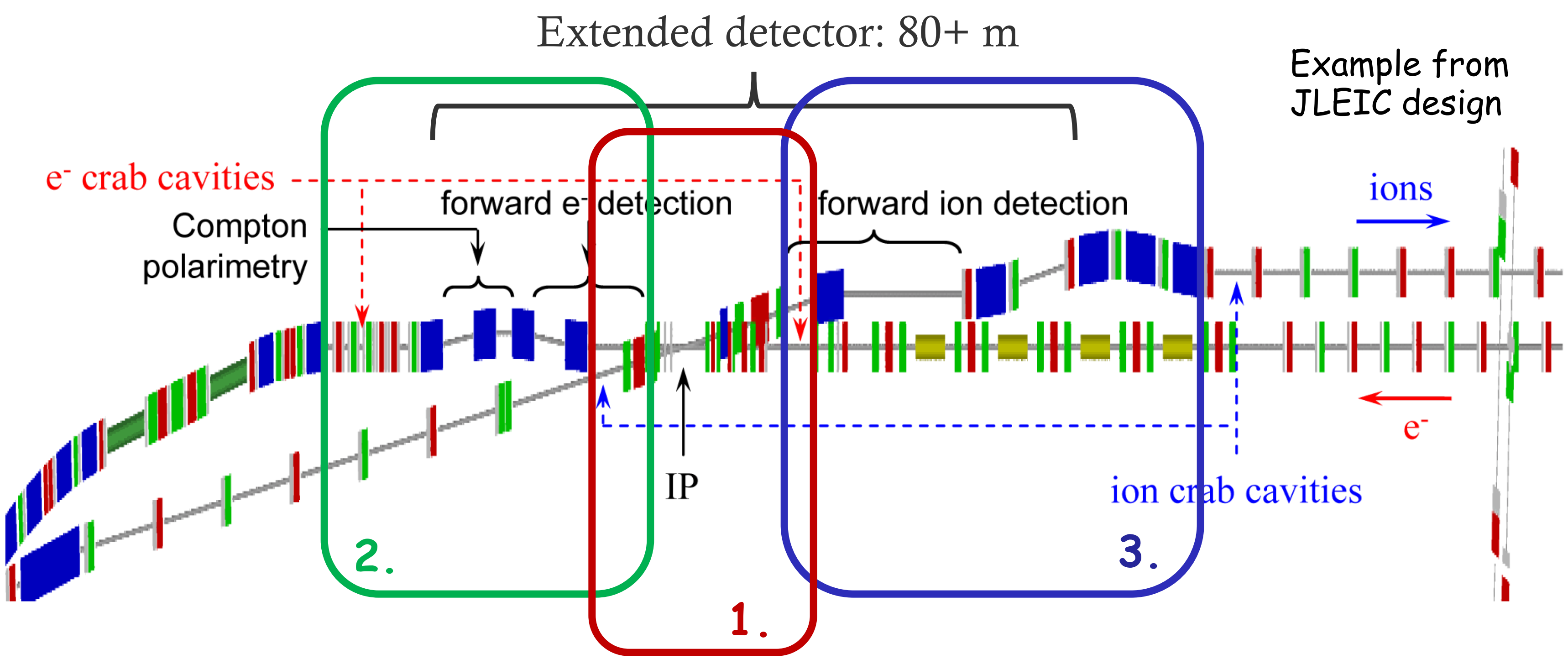




The integration with accelerator

- Total size ~80m
1. **Central detector** ~10m
2. **Far-forward electron detection** ~30m
3. **Forward hadron spectrometer** ~40m

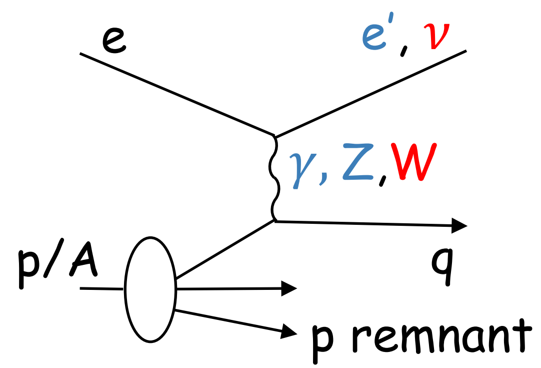
- IP placement (to reduce a background)
 -Far from electron bending magnets (**synchrotron**)
 -close to proton/ion bending (**hadron background**)



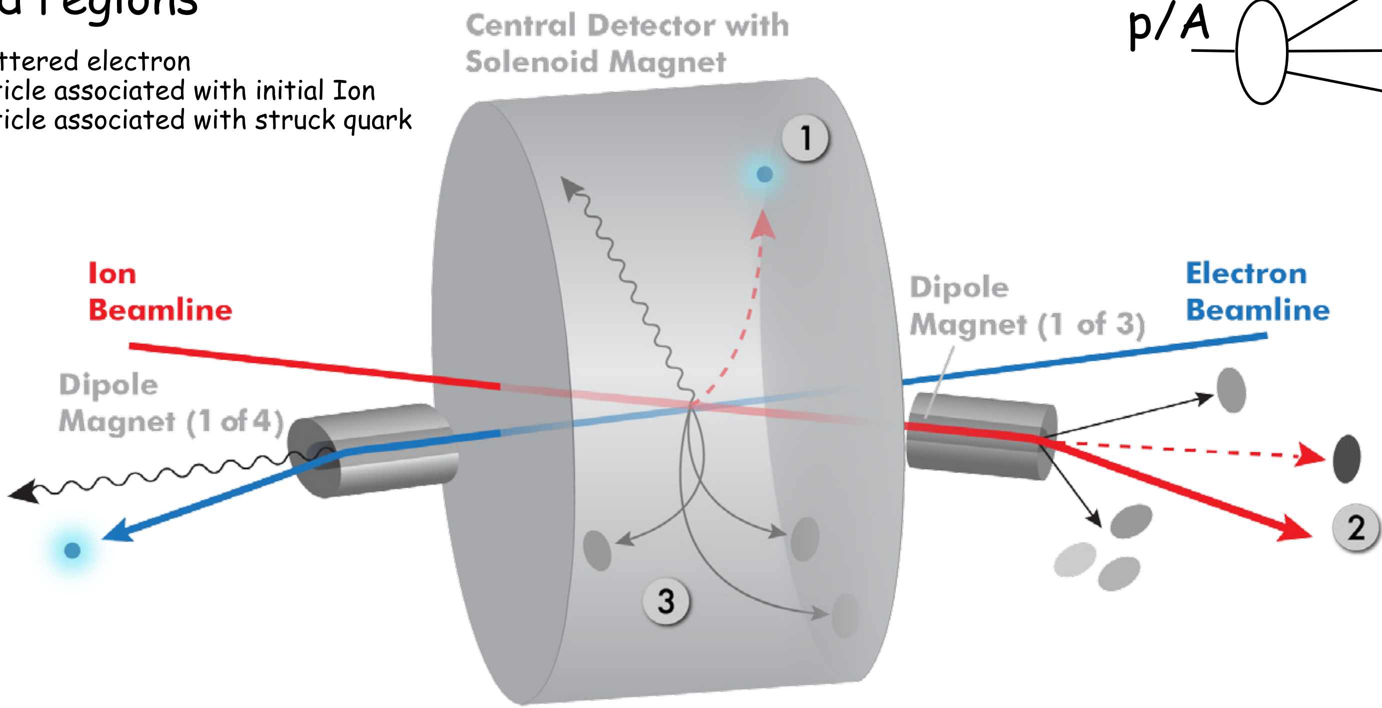
Example from JLEIC design

Total acceptance detector

Beam elements limit forward acceptance
Beam crossing angle creates room for forward dipoles (50mrad) and gives a space for detectors in the forward regions



1. Scattered electron
2. Particle associated with initial Ion
3. Particle associated with struck quark



- Central detector - limitation in size:
  -in R – size of solenoid magnet
  -in L - a distance between ion quadrupoles which inverse proportional to luminosity

Need a Total acceptance detector (and IR) also for variable beam energies.

Detector for VM

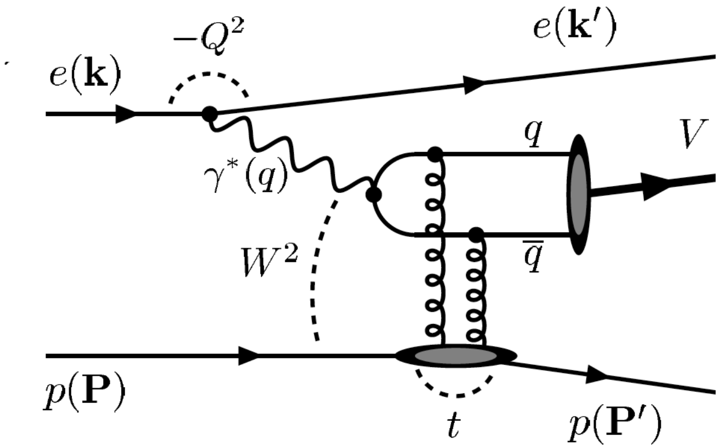
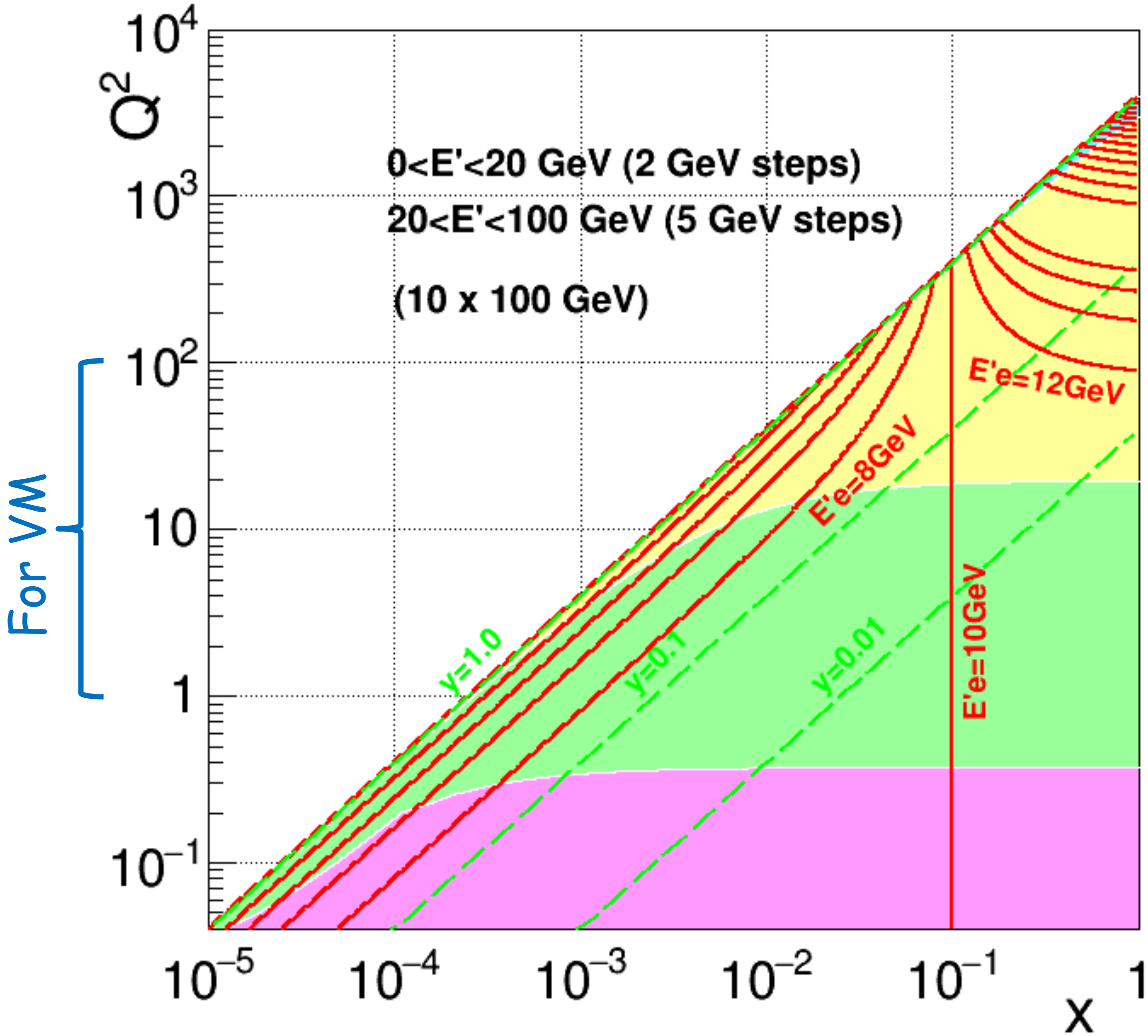


Figure 2. Exclusive vector meson production described by perturbative quantum chromodynamics.

- Scattered electron
- decay products of VM
- recoil proton

Detector for VM: scattered electron

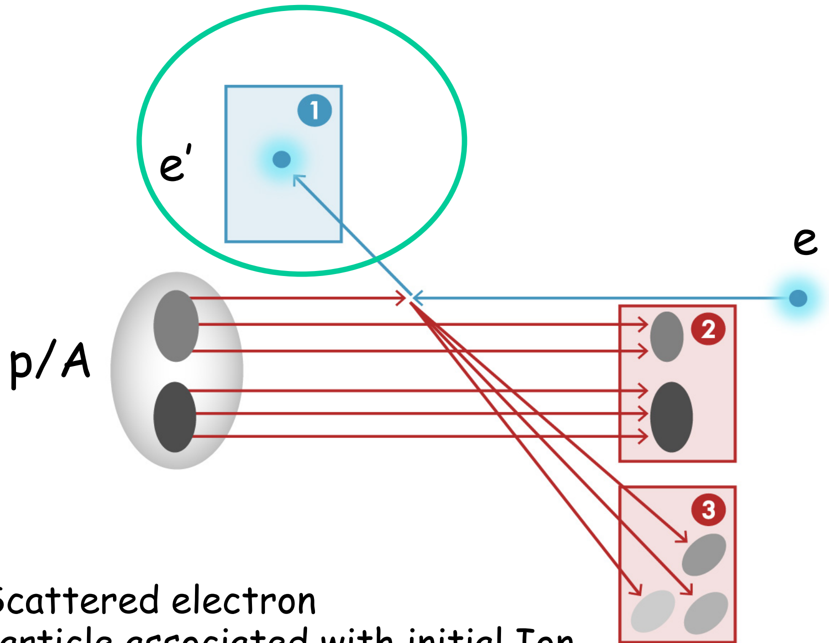


Scattered angle and energy of scattered electron define kinematic (x,Q^2)

in electron endcap/barrel (depending on Q^2),

$E_{e'}$< 12 GeV, need to measure very precise in EMCAL

DIS kinematic -Part 1
Scattered electron



1. Scattered electron
2. Particle associated with initial Ion
3. Particle associated with struck quark

Kinematic reconstruction
a) *Electron method* uses **information from scattered electron ONLY:**

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

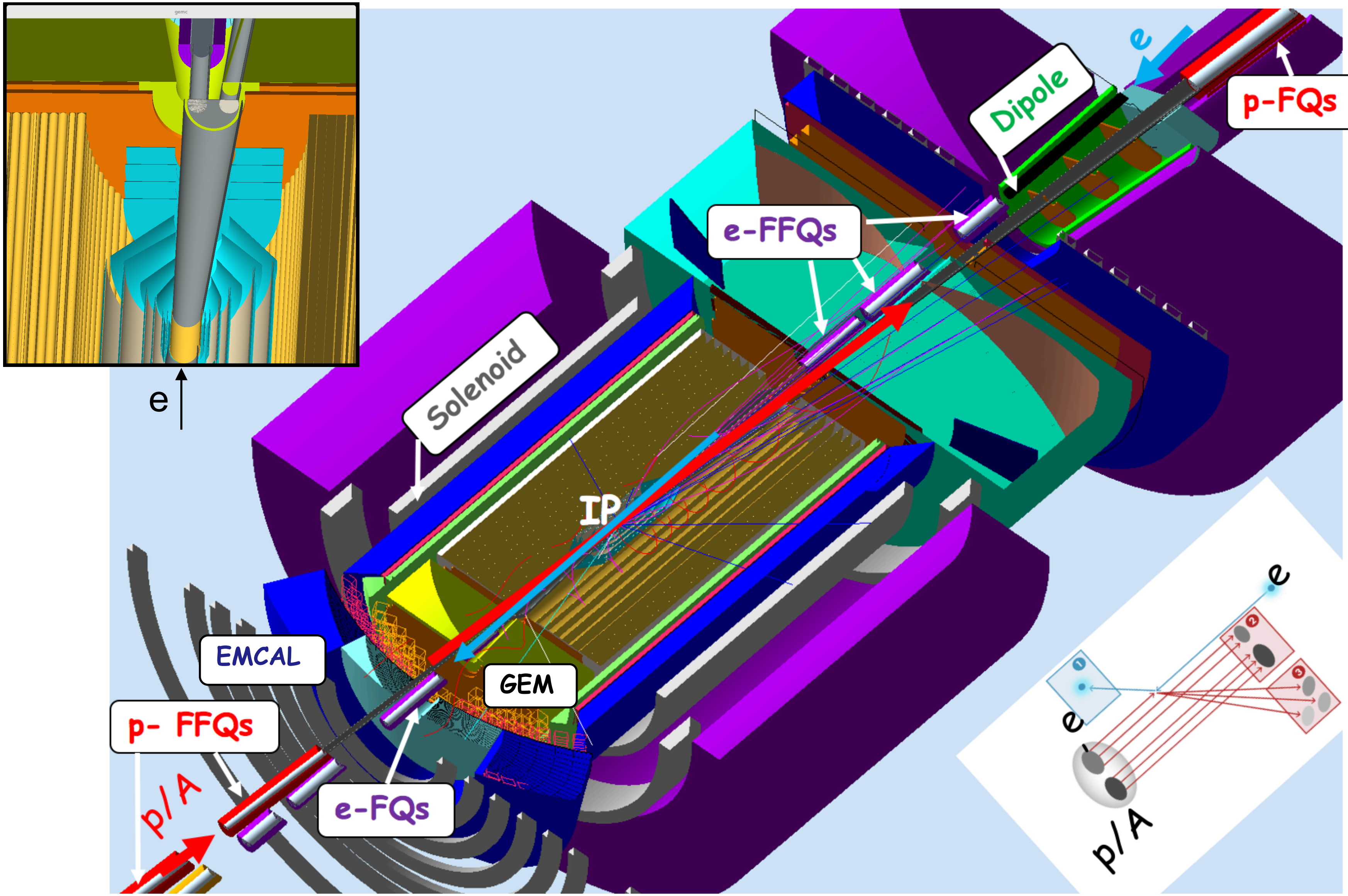
$$y_{\mathrm{EM}} = 1 - \frac{E_{e'}}{2E_e}(1-\cos\theta_{e'})\,,$$

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

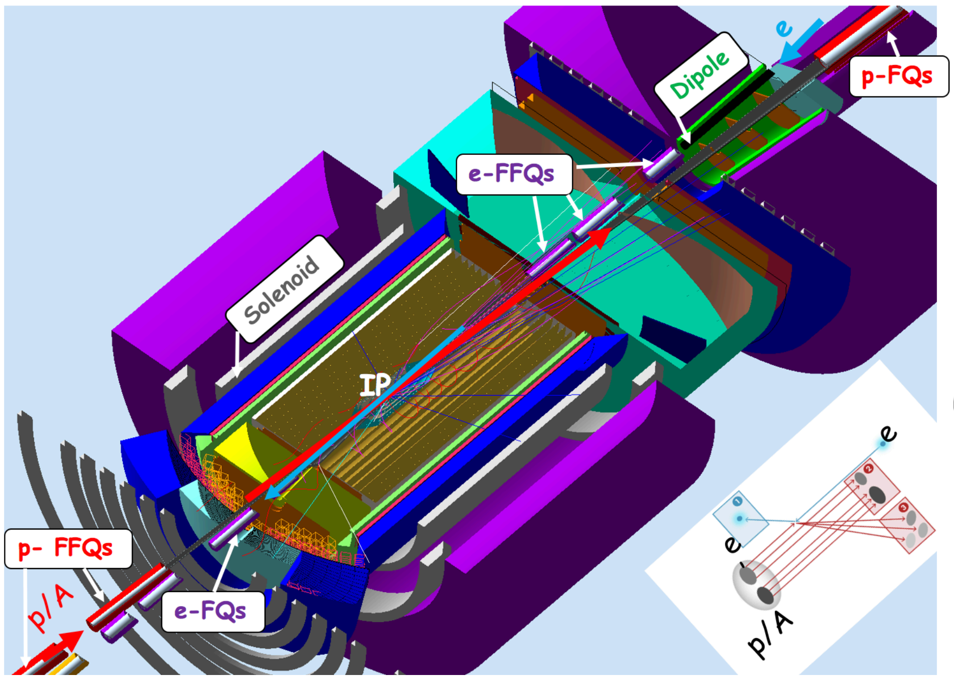
Notes:
- Linear dependence on $E_{e'}$ of the Q^2
- This method could NOT be used for $y < 0.1$

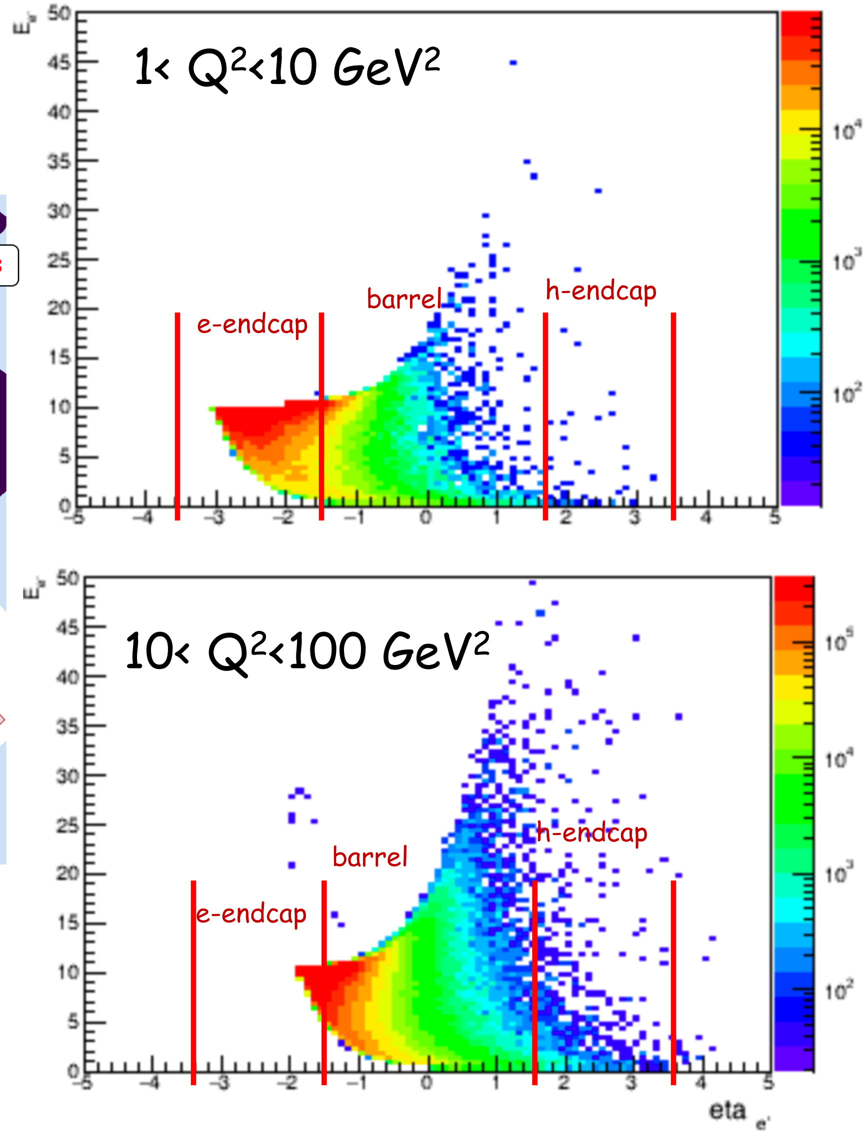
High performance EM calorimeter is need in the electron endcap where scattered electron **has low energy**.

JLEIC Central detector - TOP view



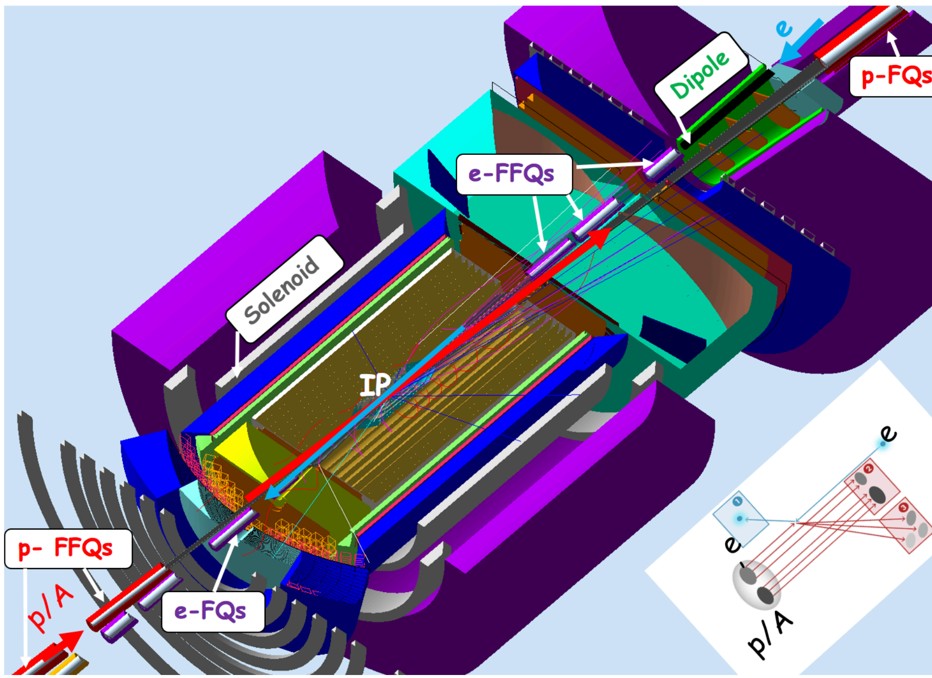
DIS kinematic -Part 1 Scattered electron





EM Calorimeter

Electromagnetic Calorimeters measure EM showers and early hadron showers:
Energy, position, time



$PbWO_4$ Crystal EM Calorimeter (at small angles, electron endcap)

-Tungsten glass, similar to CMS or PANDA
- Time resolution: <2 ns
- Energy resolution: $<2\%/\sqrt{E(GeV)} + 1\%$
- Cluster threshold: 10 MeV

Sampling EM Calorimeter

- **Shashlyk** (scintillators +absorber)

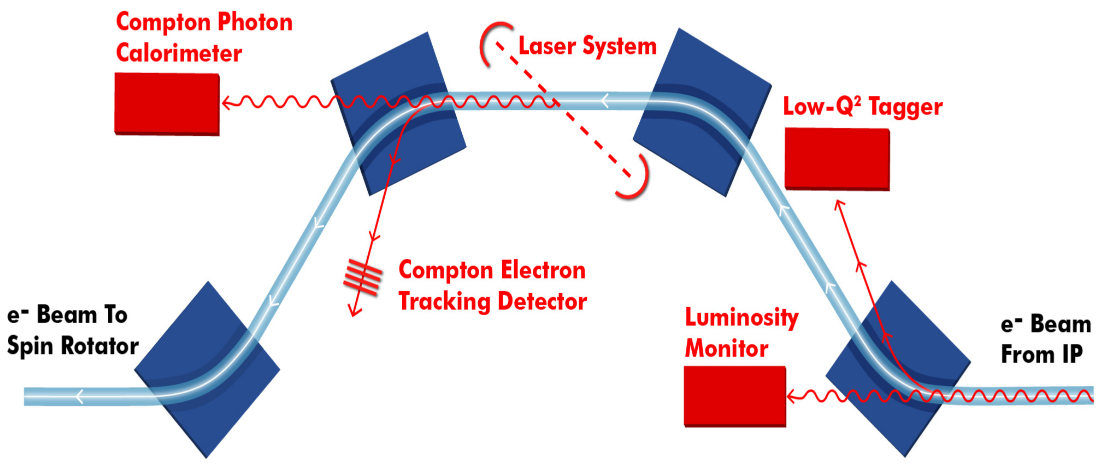
-WLS fibers for readout

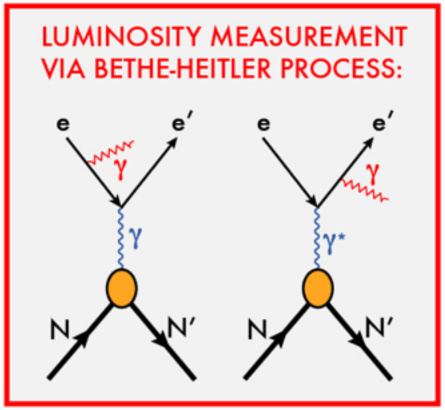
-**Sci-fiber EM(SPACAL):**

- Compact W-scifi calorimeter, developed at UCLA
- Spacing 1 mm center-to-center
- Resolution $\sim 12\%/\sqrt{E}$
- On-going EIC R&D

Chicane for Electron Far-Forward Area

Example from
JLEIC design





- **Low Q2 tagger**

✓ For low Q^2 electrons

- **Luminosity monitor:**

✓ Luminosity measurements via Bethe-Heitler process
✓ First dipole bends electrons
✓ Photons from IP collinear to e-beam

- **Polarization measurements**

✓ First two Dipoles compensate each other
✓ The same polarization as at IP
✓ Minimum background and a lot of space.
✓ Measurements of both Compton photons and electrons

Detector for VM

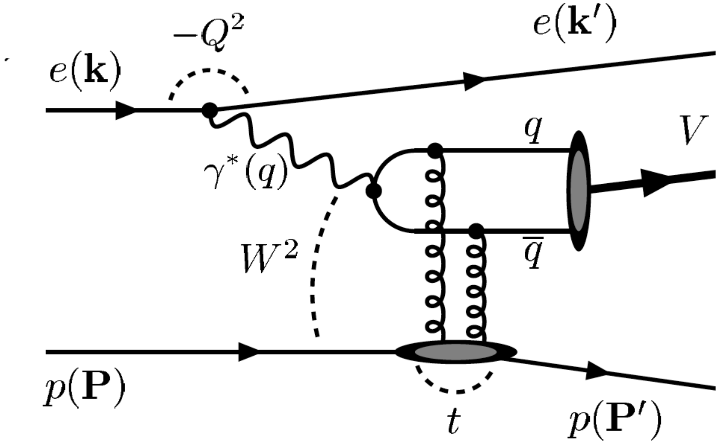


Figure 2. Exclusive vector meson production described by perturbative quantum chromodynamics.

- Scattered electron
- decay products of VM
- recoil proton

Decay products of VMs: momentum reconstruction

ϕ-mesons

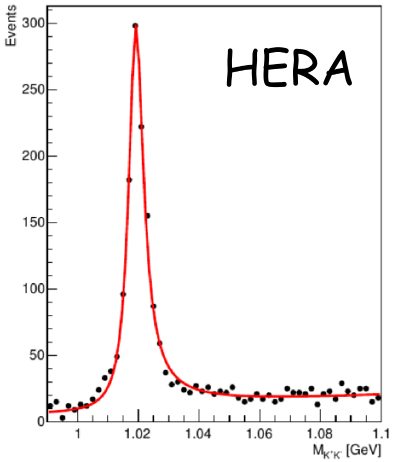
Br (ϕ->K+K-) ~49%

ρ-mesons

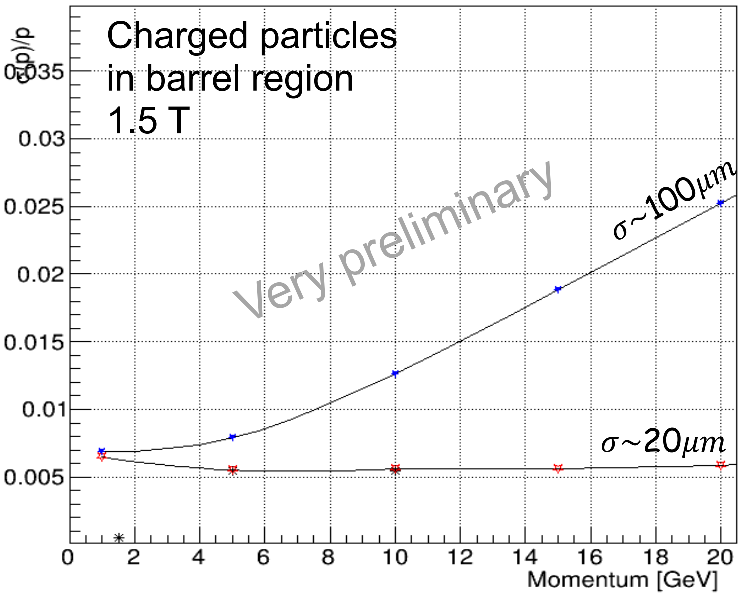
Br (ρ->π+π-) ~ 100%

- Momentum resolution affects invariant mass spectrum width
- At EIC, momentum resolution below few % is required

Invariant mass peak for ϕ vector meson fit with a Relativistic Breit-Wigner distribution and a second order polynomial to describe the background



Momentum resolution



Decay products of VMs

ϕ-mesons

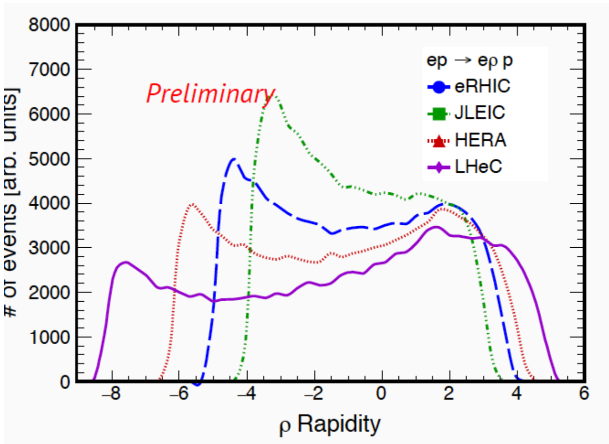
Br (ϕ->K+K-) ~49%

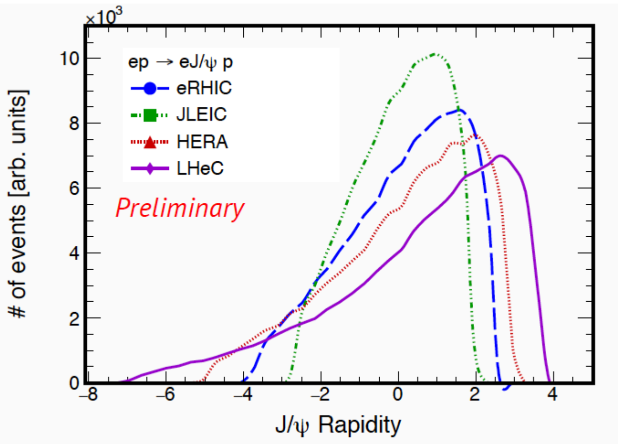
ρ-mesons

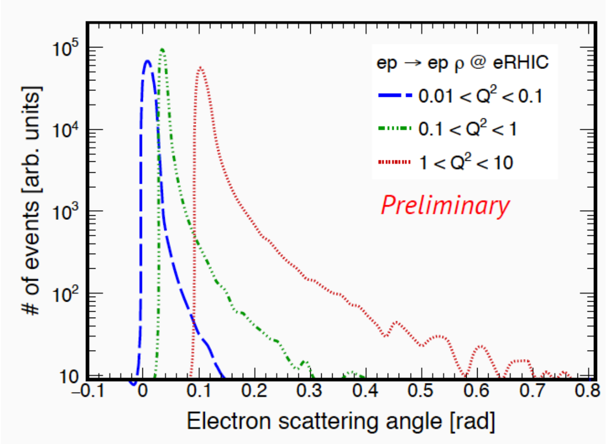
Br (ρ->π+π-) ~ 100%

Need π, K identification

Michael Lomnitz - DIS 2018



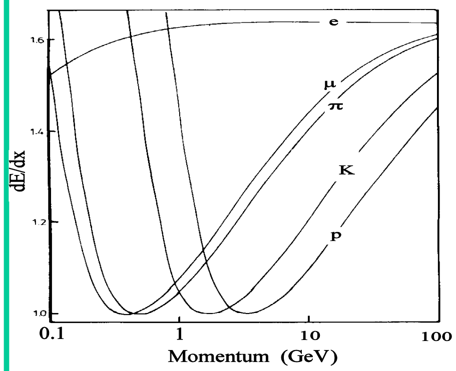


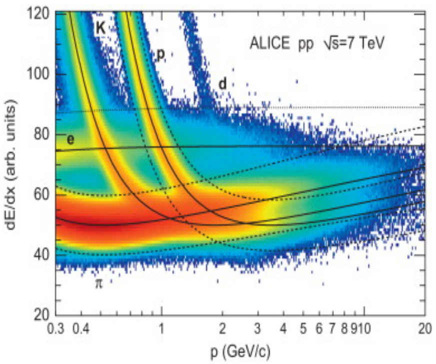


Individual hadrons (π, K, p)

Energy Loss Measurements dE/dx

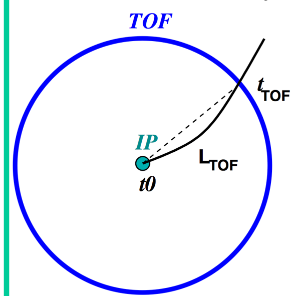
No extra detector required:
use information from tracking/vertex detectors





- Limitation : p<1GeV
- Could be used for higher momentum due to he relativistic rise of the Bethe-Bloch curves
- Depending on available electronics a **cluster counting** method could be used to improve momentum coverage

Time-of-flight (psTOF)

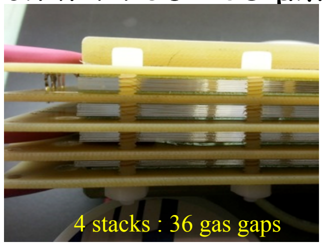


- **Limit in space** (barrel) => PID momentum limitation => could be improved by high precision timing measurements <10psec
- Radial space needed: ~10cm.

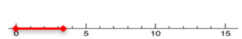
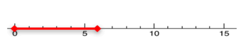
- **t0: self-determined =>** need to know a **vertex origination** to **measure L_TOF** precise (total particle length/curvature)

Multi-gap Resistive Plate Chamber (MRPC) R&D: achieved ~18 ps resolution with 36-105 μm gap glass MRPC

Barrel (1m) for 20ps (10ps):
π/K < 2.5 (3.5) GeV,
K/p < 4.2 (6) GeV
End-caps (4m):
π/K < 5 (7.3) GeV,
K/p < 8.5 (12.5) GeV

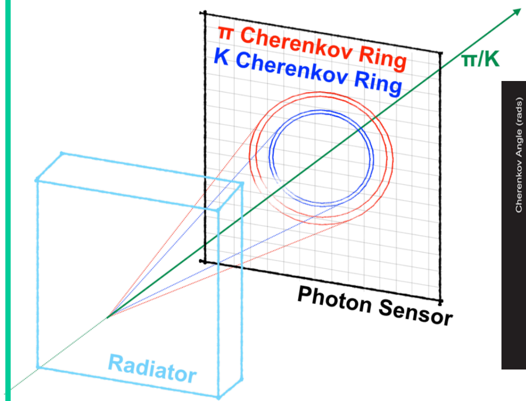


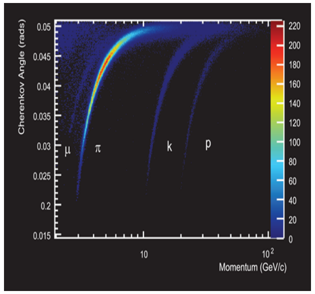
Mickey Chiu

σ_{tot}=10 ps	1m (Barrel)		
σ_{tot}=10 ps	4m (Hadron)		

Individual hadrons (π, K, p)

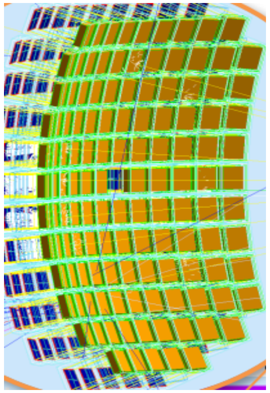
Cherenkov radiation





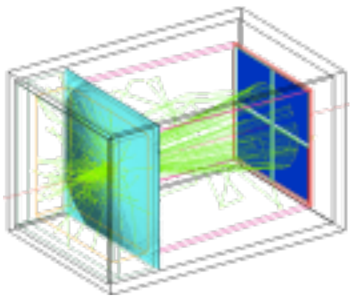
- In the limited momentum range (threshold, space): $P_{min} < p < P_{max}$
- Require precise knowledge of particle momentum
- Require precise knowledge of particle track (angle, entrance and/or exit point)
- A magnetic field and high multiplicity tracks could disturb operation of a gas RICH.

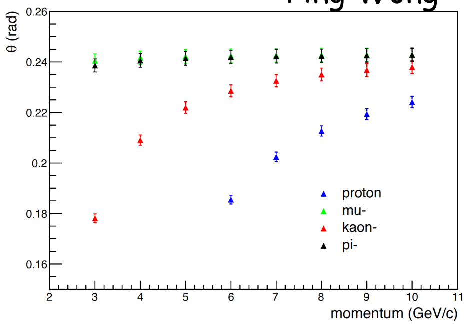
Electron end-cap: Modular RICH



- Modular aerogel RICH: compact, using lens-based design to **reduce ring size and sensor plane area**
- Separation (3σ):
  0.56 GeV < e/π < 2 GeV ,
  0.56 (2.0) GeV < π/K < 8 (10) GeV,
  2.0 (3.8) GeV < K/p < 12 GeV

Ping Wong





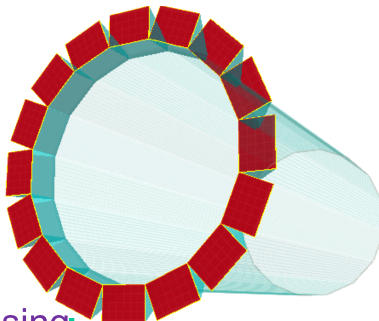
Hadron blind detector (HBD)

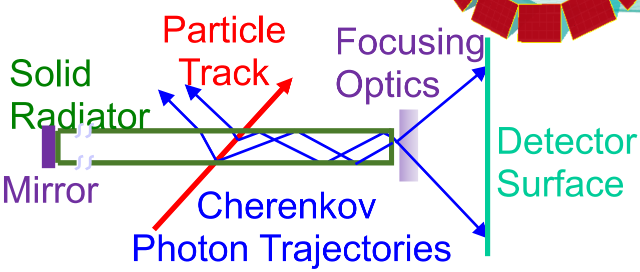
- Threshold cherenkov detector for e/π separation
- Limited momentum coverage

Individual hadrons (π, K, p)

Barrel: DIRC

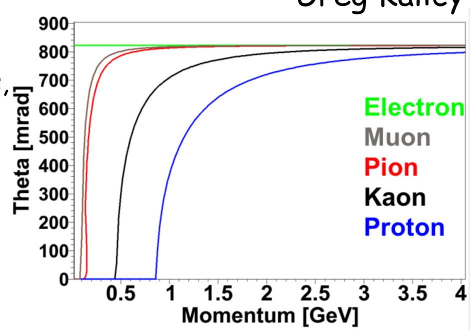
- radially compact (5 cm)





Greg Kalicy

Current design based on narrow synthetic fused silica bars arranged in 16 barboxes, coupled to solid prisms with custom made 3-layer lens, read out by arrays of MCP-PMTs.



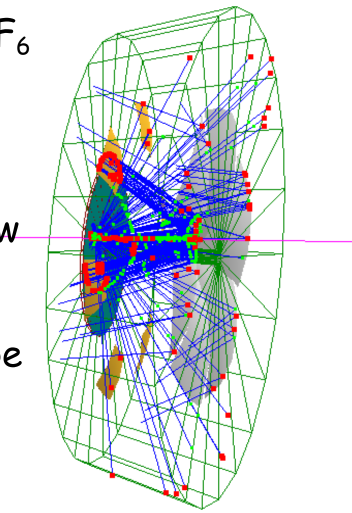
- Simulation for particle identification (3σ):

0.15 < e/π < 1.8 GeV
0.15 (0.45) < π/K < 6 GeV,
0.45 (0.8) < p/K < 10 GeV,

Hadron end-cap: dual-radiator RICH

Alessio Del Dotto

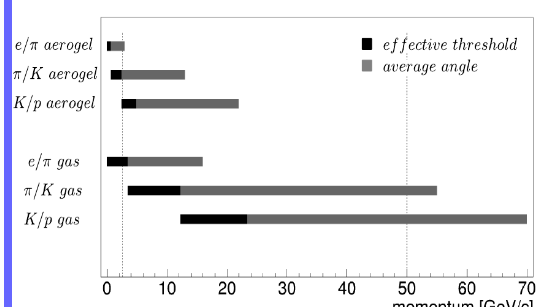
- JLEIC design geometry constraint: ~160 cm length
- Aerogel in front, followed by C_2F_6
- Outward reflecting mirror
- Focal plane away from the beam, reduced background

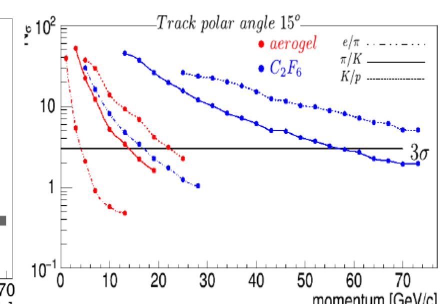


- Sensitive to magnetic field=> New 3T solenoid minimized a field in RICH region
- Aerogel drives the detector to be solid state (e.g. SiPMs, LAPPDs)

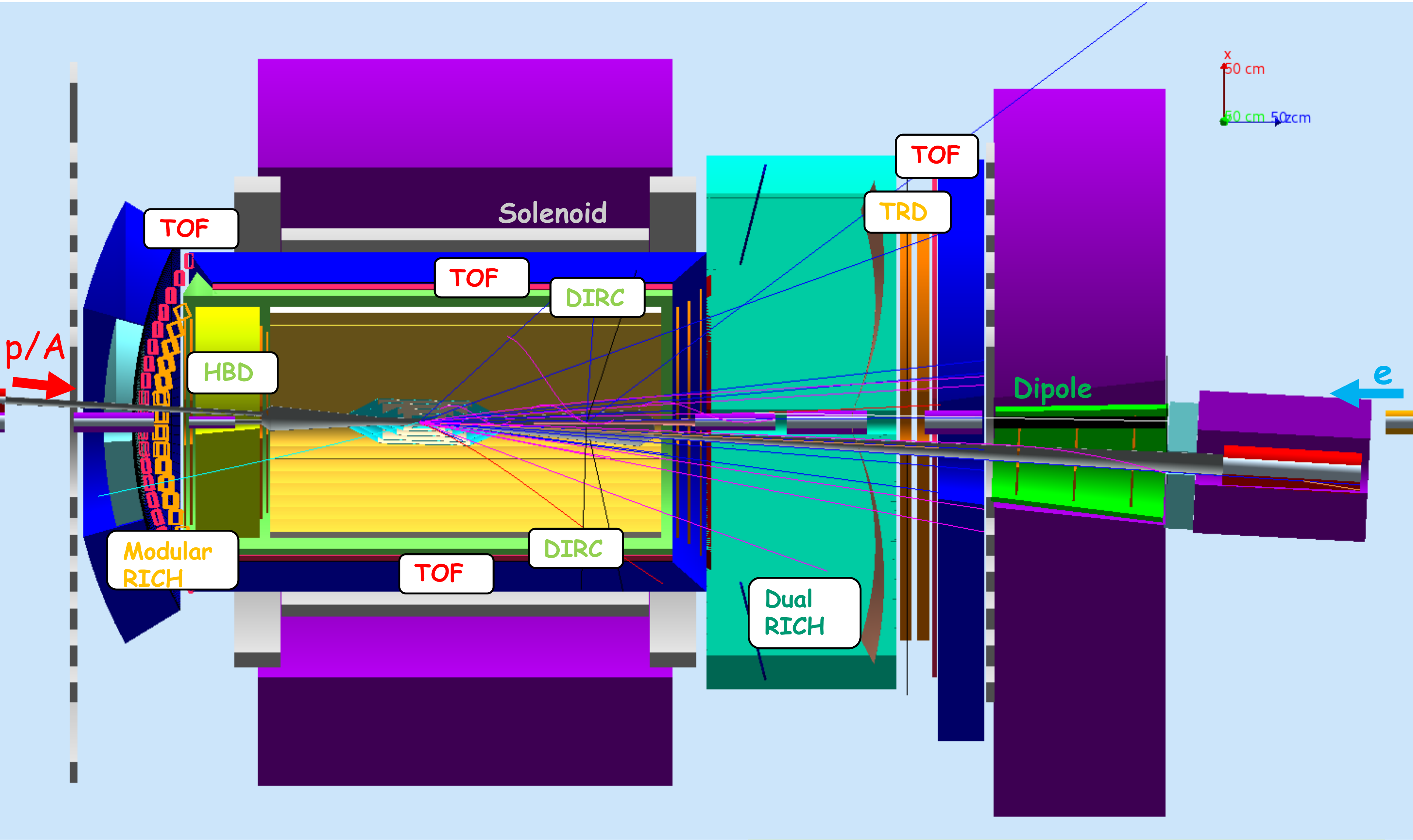
- Particle identification:

0.003(0.8) < e/π < 4 GeV	0.01 (3.48) < e/π < 18 GeV
0.8 (2.84) < π/K < 14 GeV	3.48(12.3) < π/K < 55 GeV
2.84(5.4) < p/K < 22 GeV	12.3 (23.4) < p/K < 70 GeV



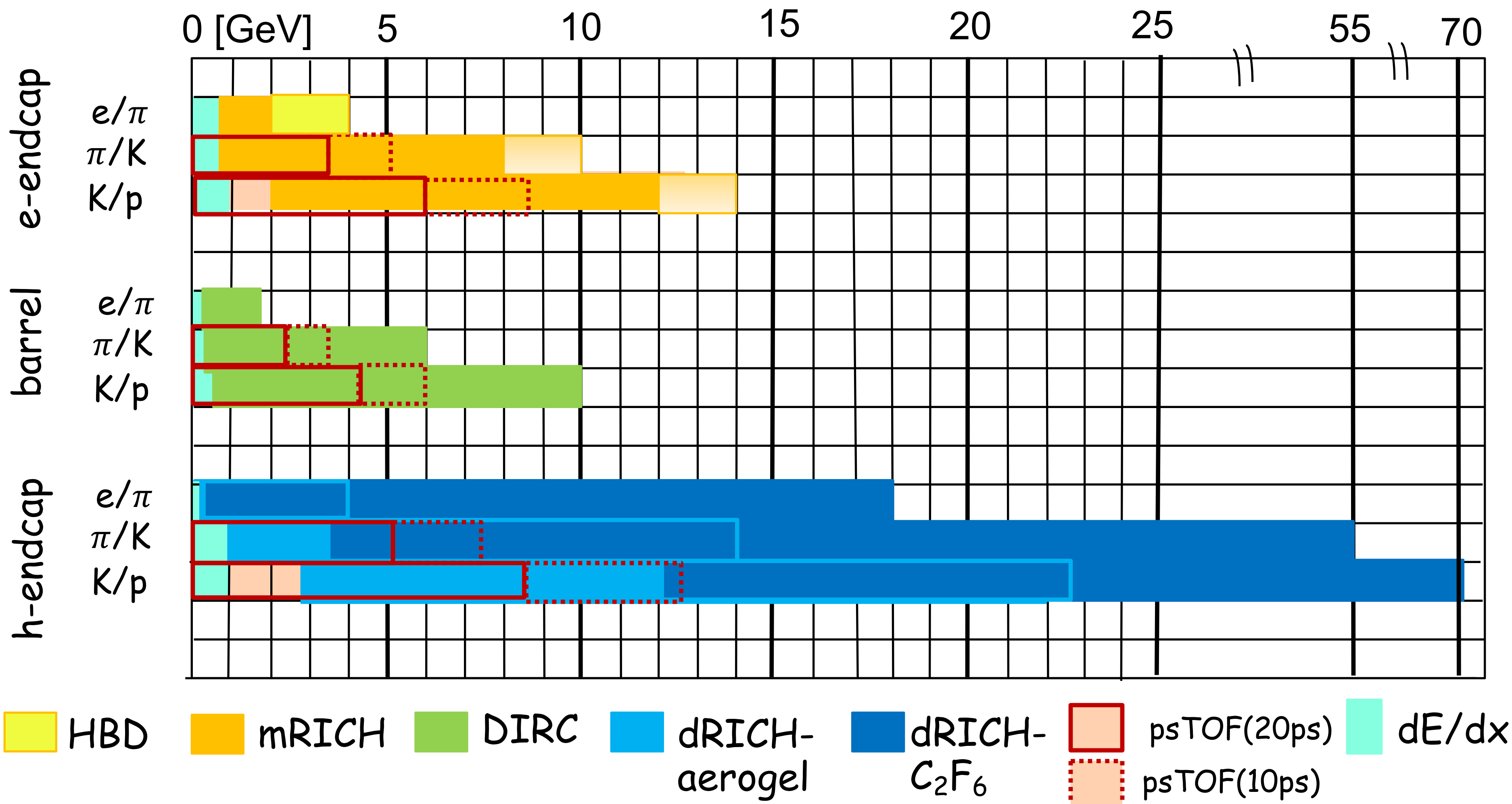


EIC Central detector overview /PID



Modular design of the central detector

Individual hadrons (π, K, p): Cherenkov, TOF



** Here, electron/hadron separation only from Cherenkov detectors is shown. Main e/h rejection is done by calorimeters.

J/ψ identification

- ✓ Kinematics: boosted towards hadron-endcap

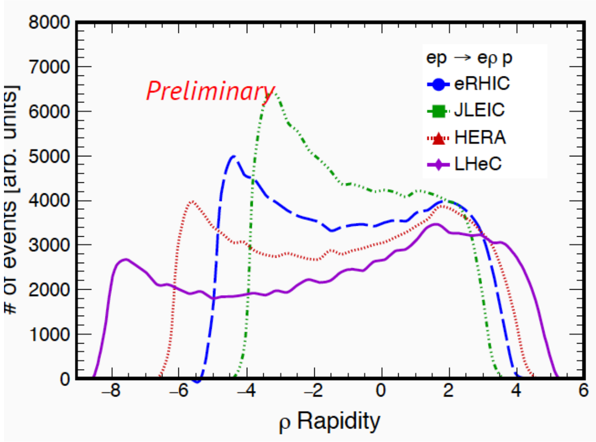
J/ψ

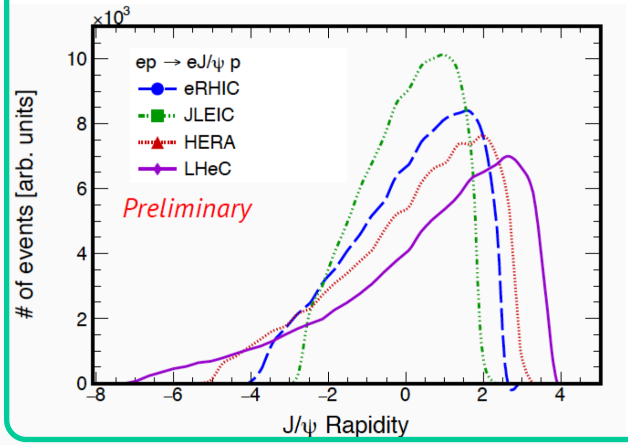
Br (J/ψ->e+e-) ~6%

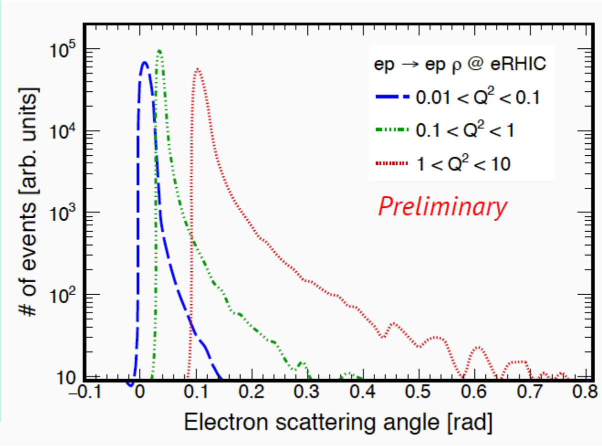
Br (J/ψ->μ+μ-) ~6%

Need lepton identification

Michael Lomnitz - DIS 2018







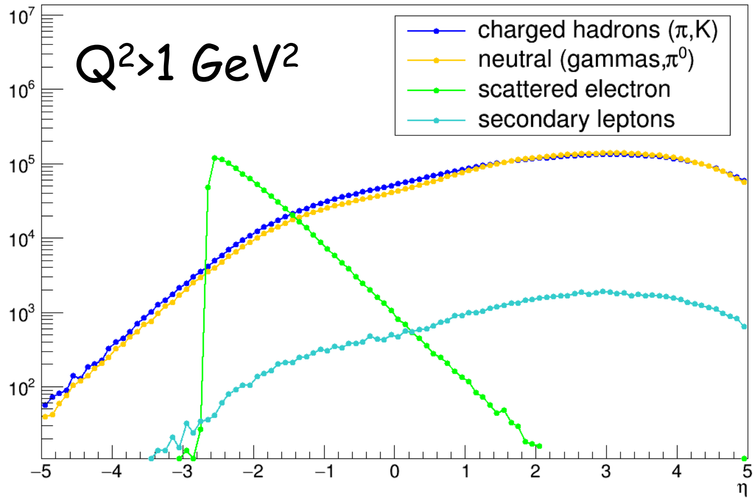
Electron identification (e/hadron separation)

Br (J/ψ->e+e-) ~6%

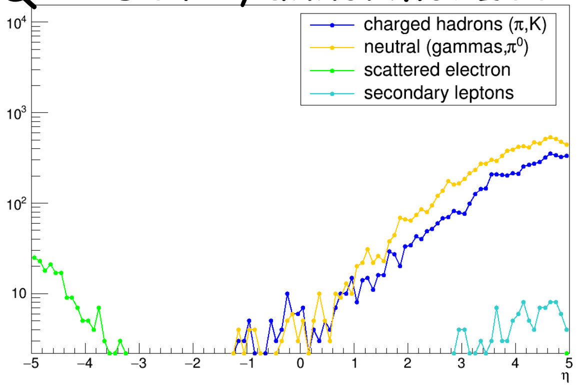
- ✓ For electron identification we use mainly calorimeter
- ✓ e/π rejection for EMCAL is 50 (100)
- ✓ HCAL e/π rejection ~ 5.

- ✓ Kinematics: boosted towards hadron- endcap
- ✓ Very high hadron background
- ✓ Need hadron suppression by 10^4
- ✓ Need additional tools for electron identification

Minbias events at EIC



Example, background, PHP , Q^2<1 GeV^2 , unnormolized

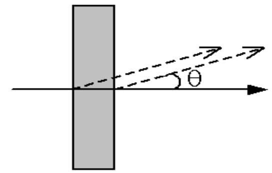


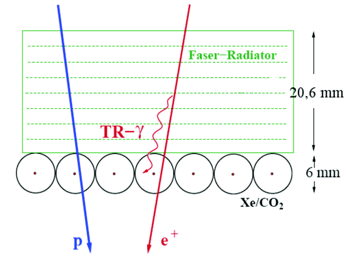
Electron identification (e/hadron separation)

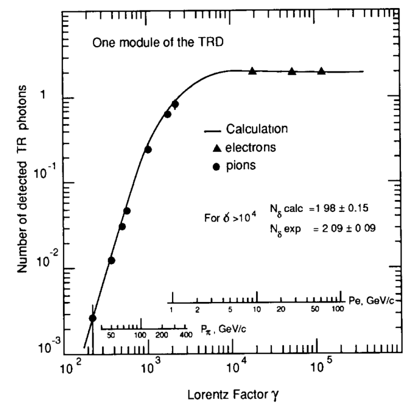
In the Hadron-endcap:
(In addition to EMCAL)

- HCAL
- Dual radiator RICH
- Transition radiation detector

Transition radiation

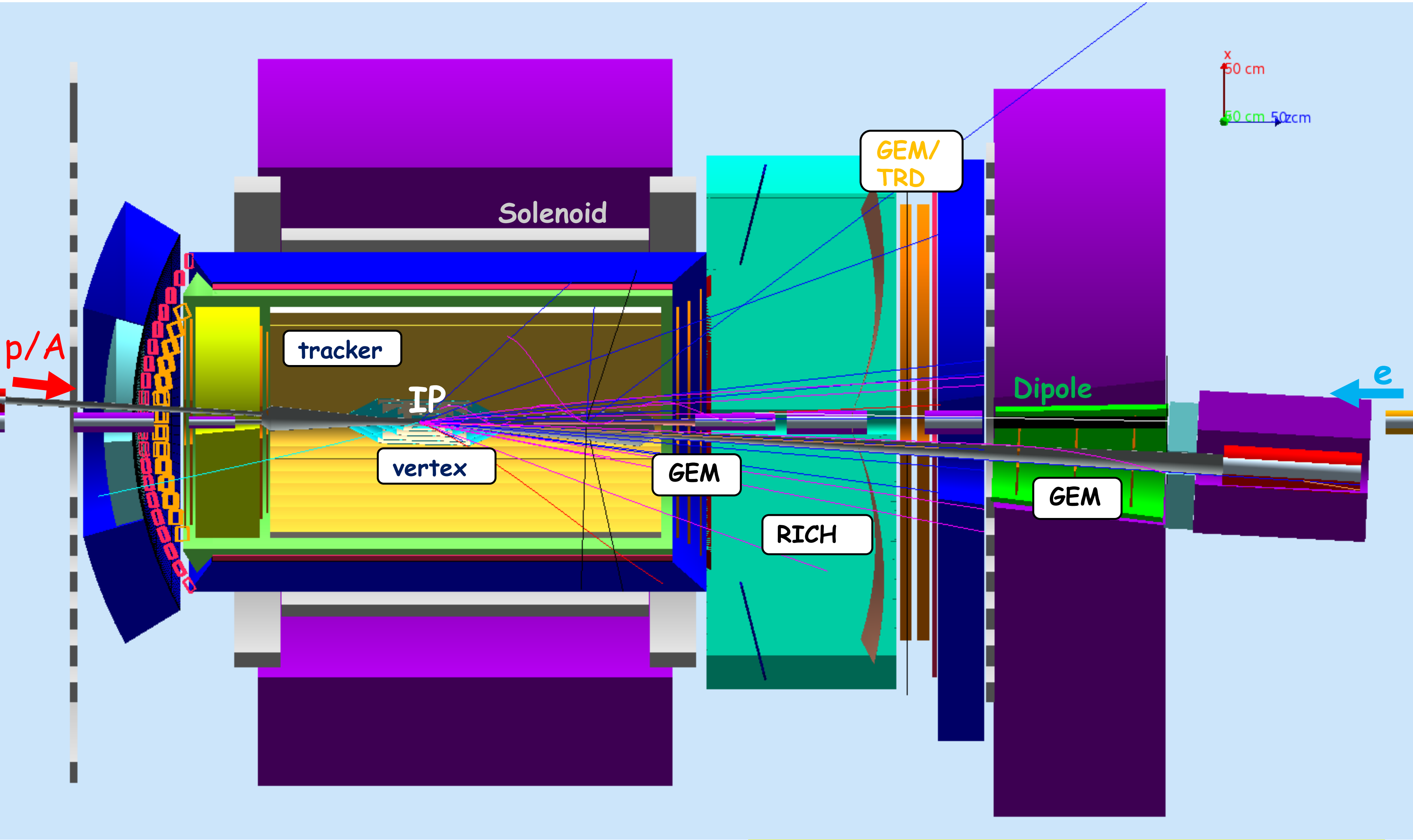






- Provides e/π separation 1-100GeV
- It is a tracking device (could be combined with tracker)
- Provides also dE/dx high precision (heavy gas), could also work in a cluster counting mode.
- Depending on configuration provides additional e/π rejection 10-100

JLEIC detector overview

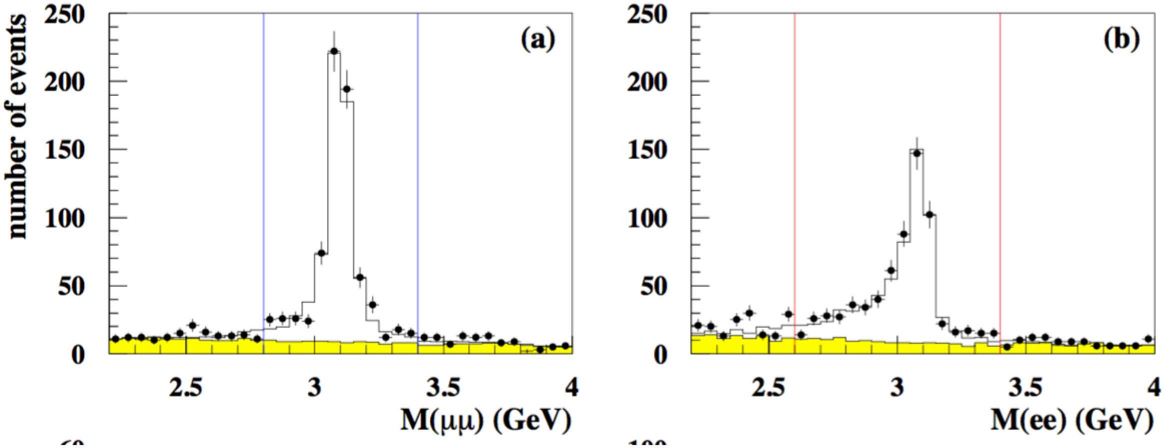


Modular design of the central detector

Muon identification

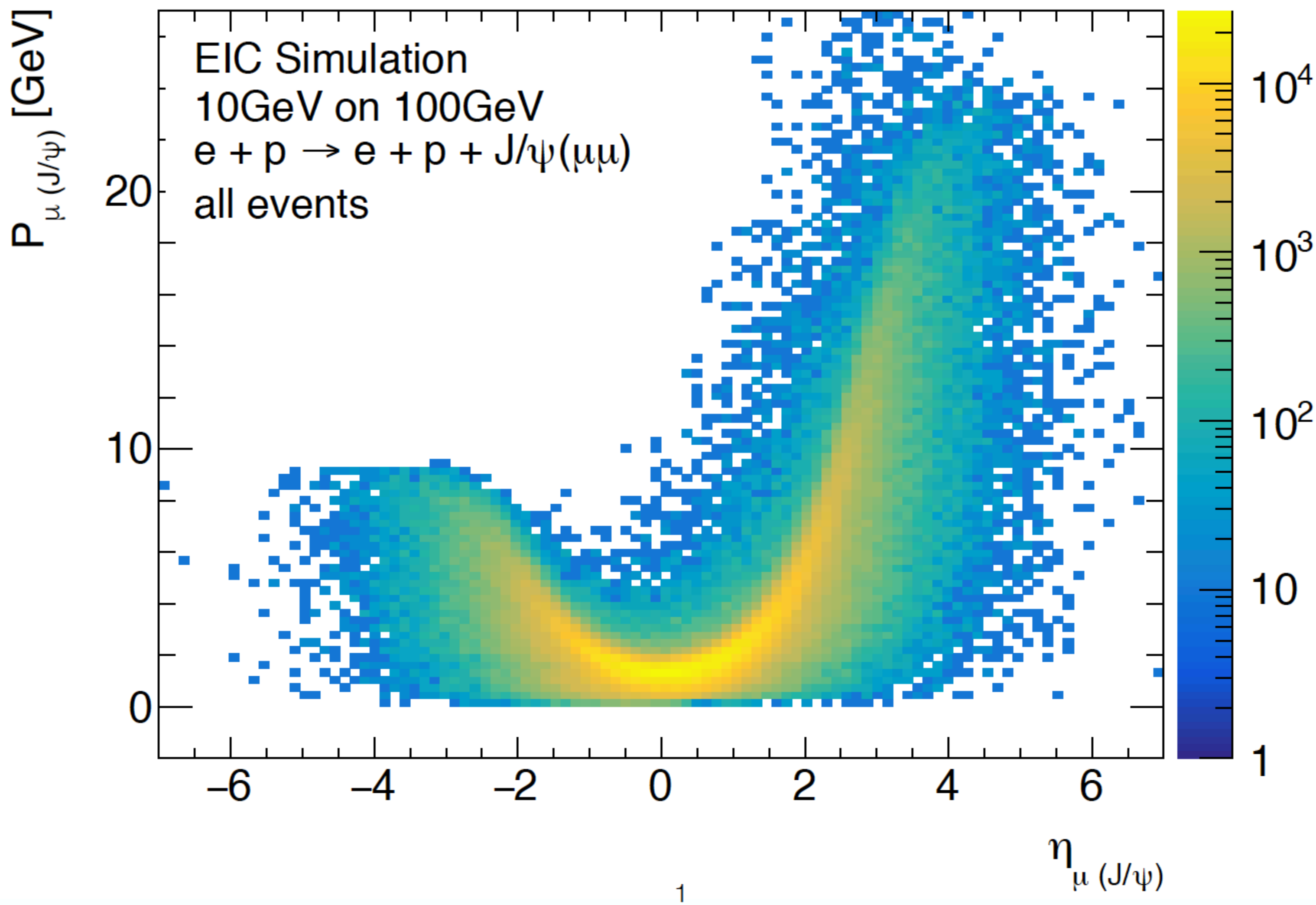
ZEUS/HERA data
(Robert Ciesielsky)

$Br\ (J/\psi \to \mu^+\mu^-) \sim 6\%$

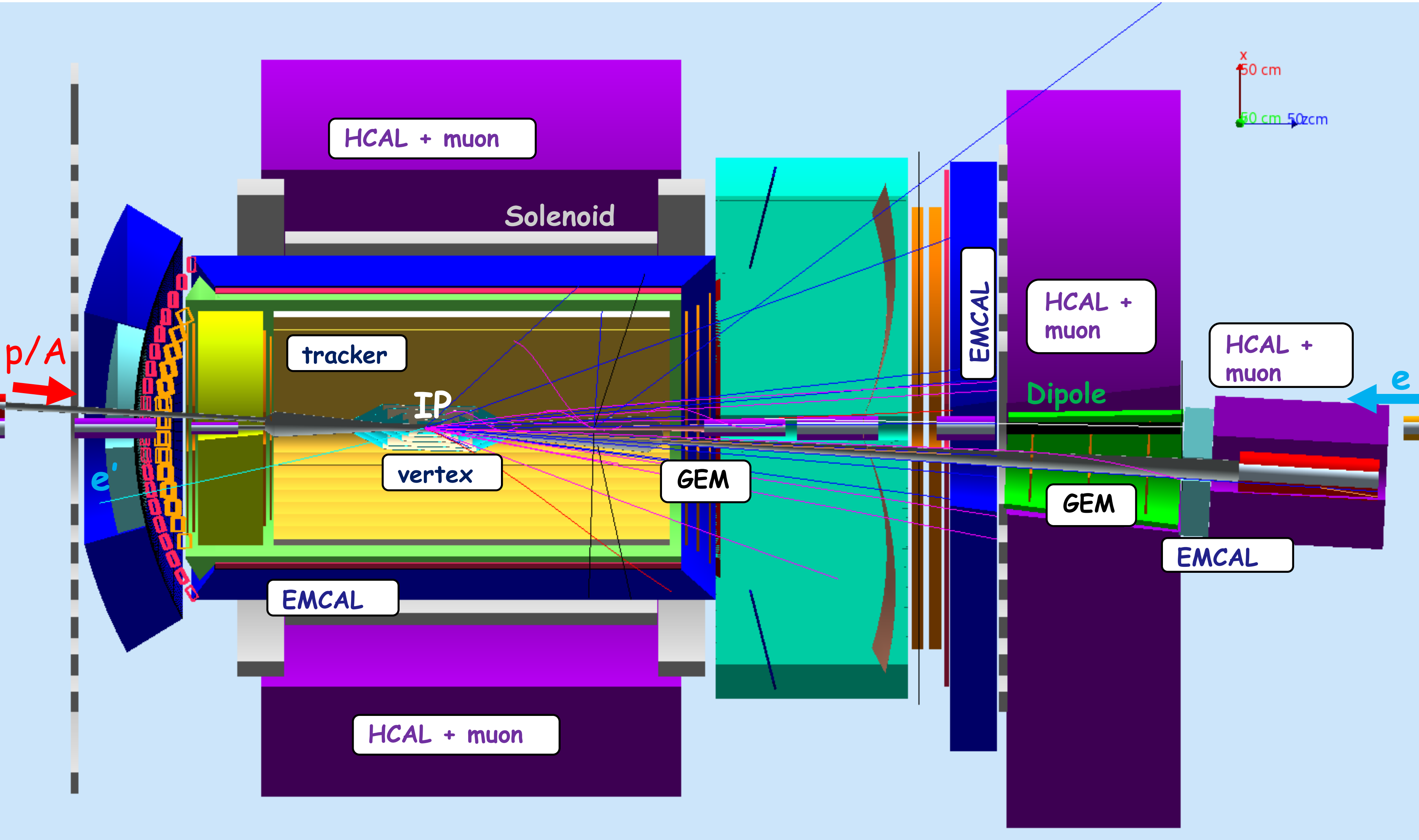


- Much cleaner sample from muon decay channel
- E_{emcal}/E_{tot} , for muons Min energy in EMCAL and HCAL
- In addition (R&D needed) :
  - Need instrumentation: muon chambers.
  - dE/dx, cluster counting

Muons from J/ψ



EIC Central detector overview



Modular design of the central detector

Detector for VM

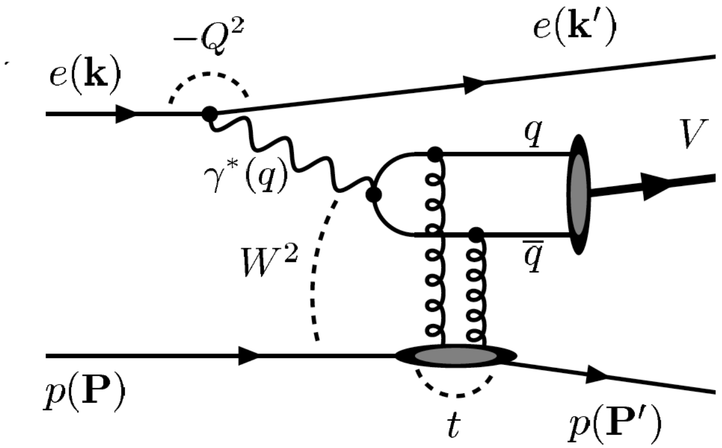


Figure 2. Exclusive vector meson production described by perturbative quantum chromodynamics.

- Scattered electron
- decay products of VM
- recoil proton

Detector for VM

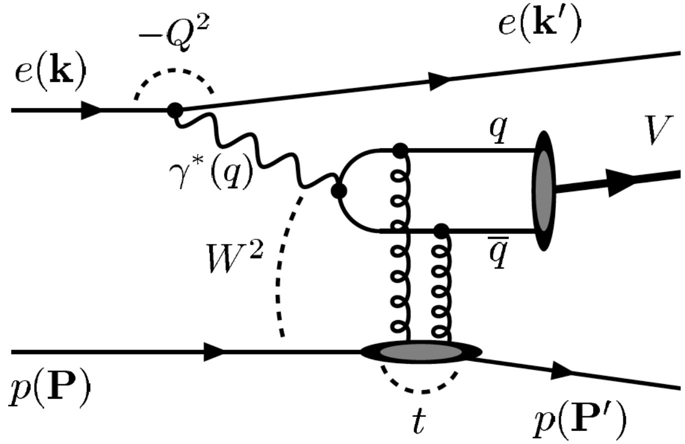


Figure 2. Exclusive vector meson production described by perturbative quantum chromodynamics.

$t=(P_p - P_{p'})^2=-P^2{}_{T\ J/\psi}$ (for $Q^2>0$)

At HERA (no detection for p') :

$$|t| \approx (p_x^e + p_x^{l+} + p_x^{l-})^2 + ((p_y^e + p_y^{l+} + p_y^{l-})^2,$$

For EIC : far-forward proton detection!

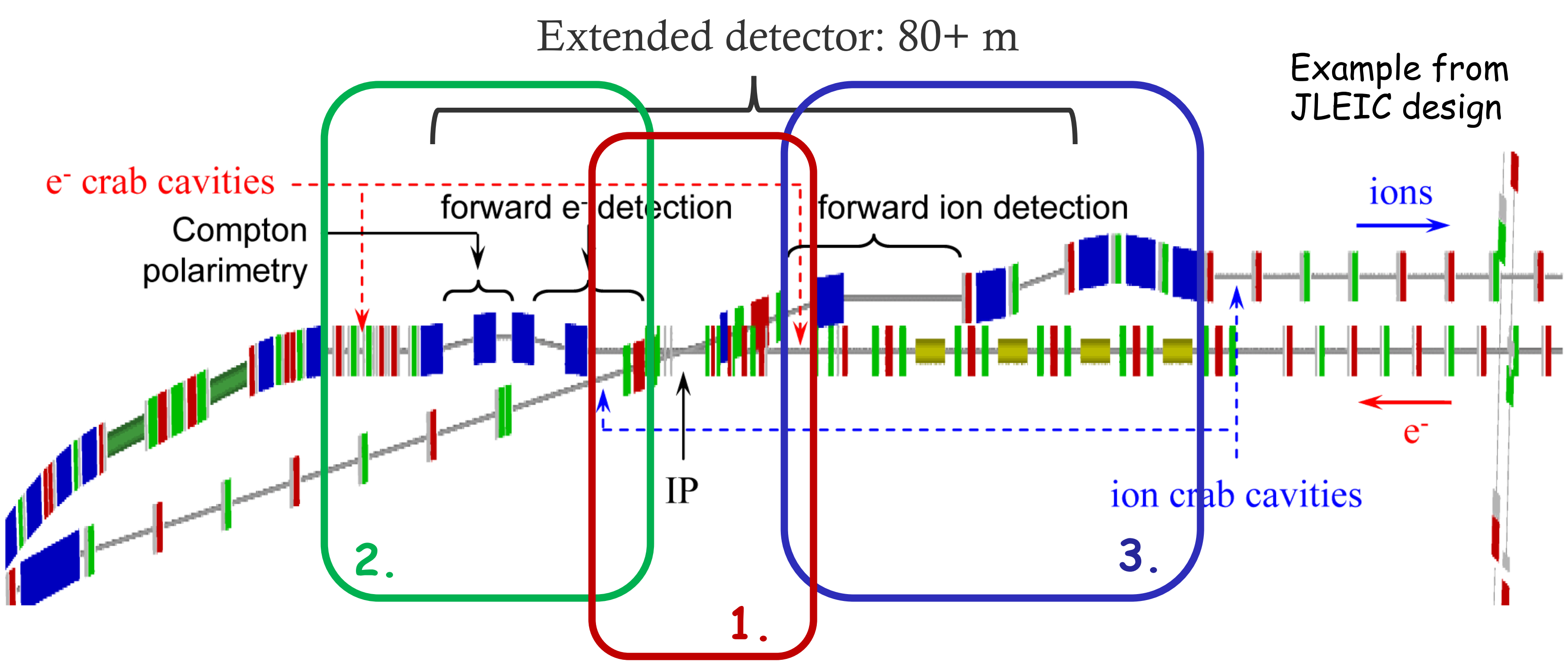
Integration with accelerator

- Total size ~80m
1. **Central detector** ~10m
2. **Far-forward electron detection** ~30m
3. **Forward hadron spectrometer** ~40m

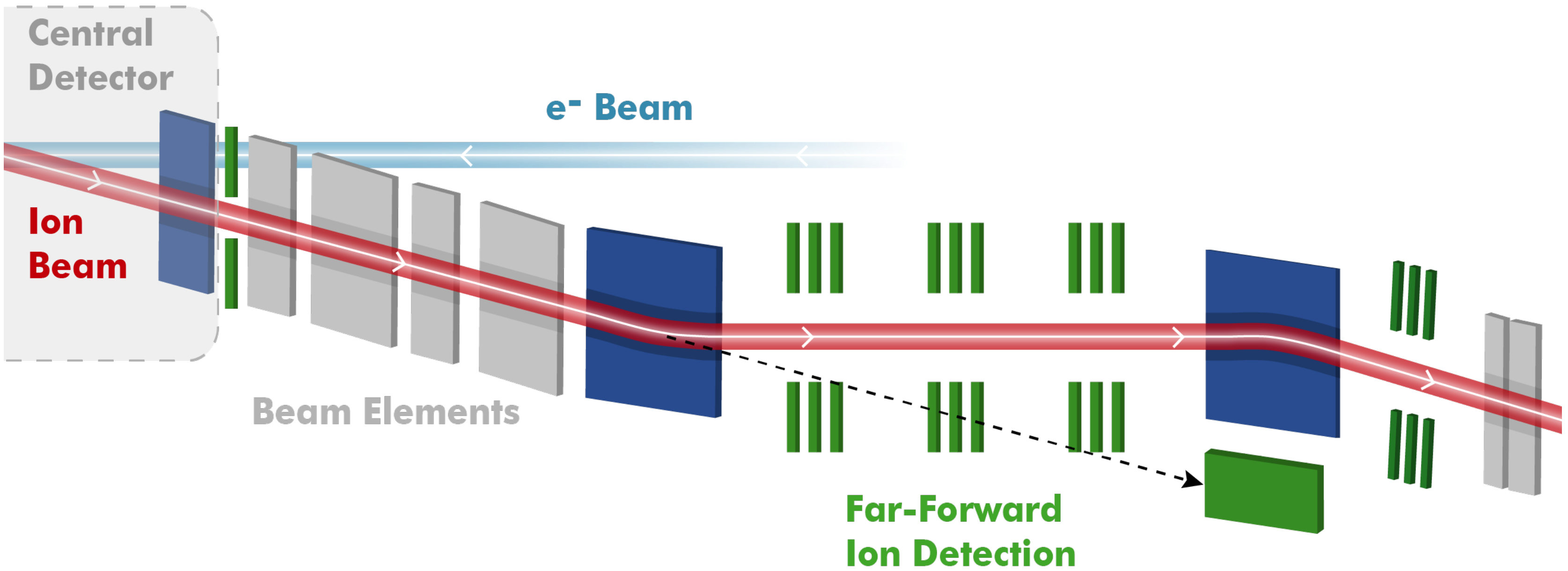
- IP placement (to reduce a background)

-Far from electron bending magnets (**synchrotron**)

-close to proton/ion bending (**hadron background**)



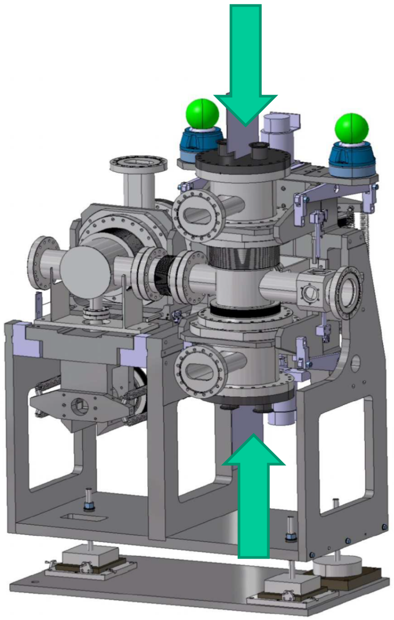
Far-forward ion direction area

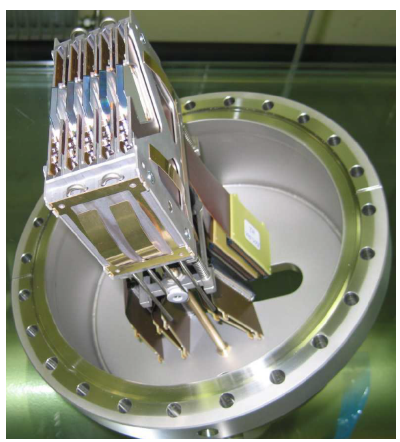


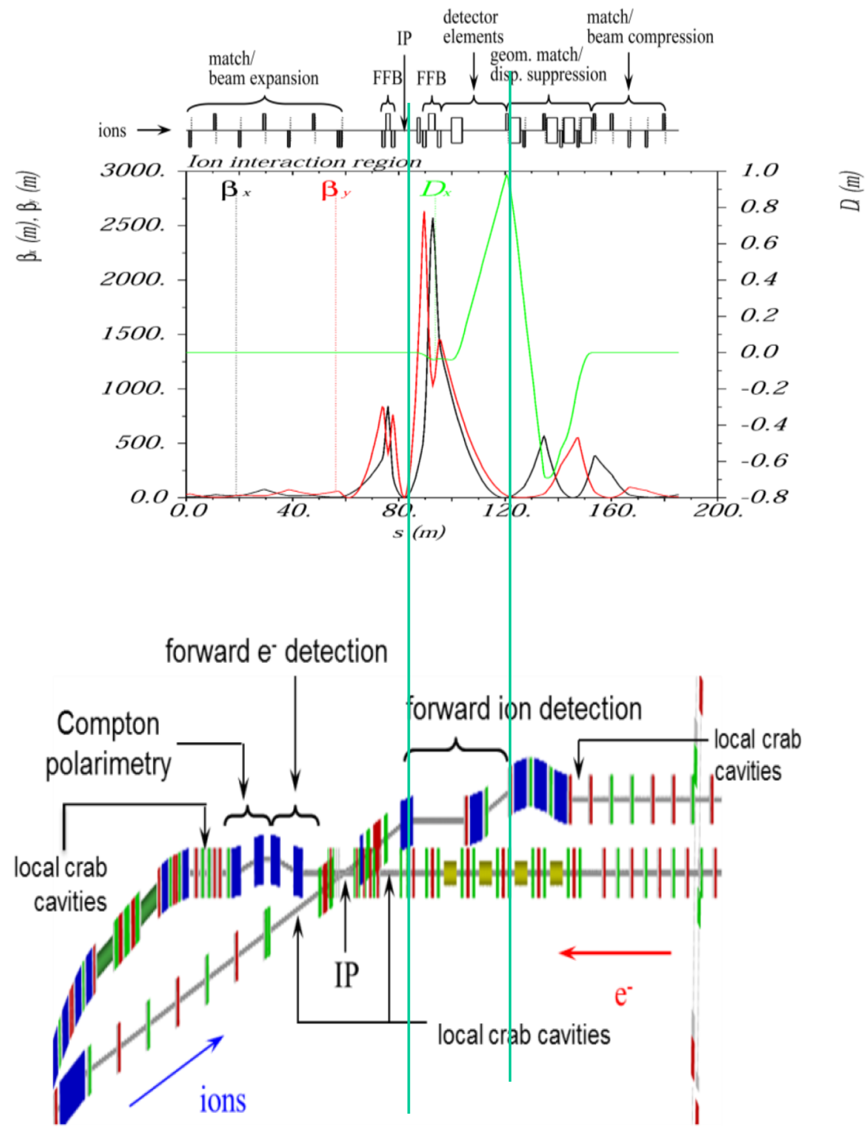
- **GEM detectors** (decay products of Λ', Σ (π,K))
- **Roman-pots** for (p)-tagging
- **Zero degree calorimeter** for (n)-tagging

Roman pots

- Ion ring forward detection
- Maximum focusing to allow to place detector as close as possible to the beam (up to 1mm at LHC)
- Dispersion maximum for best moment resolution
- several planes of solid state detector (silicon, diamond, LGAD)

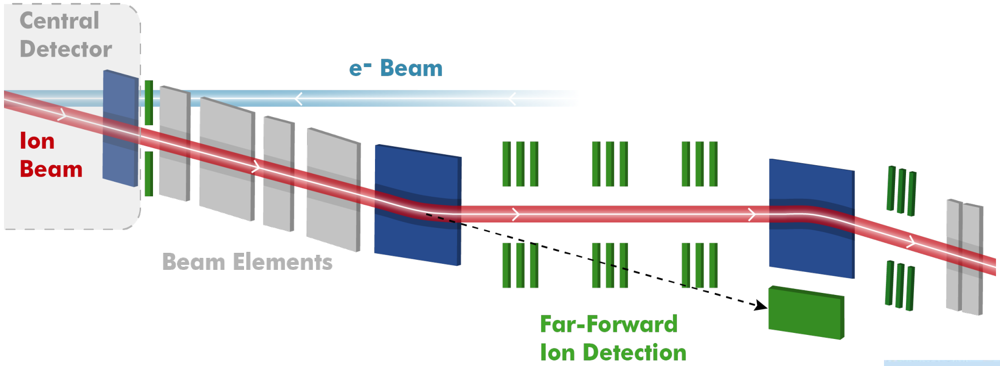






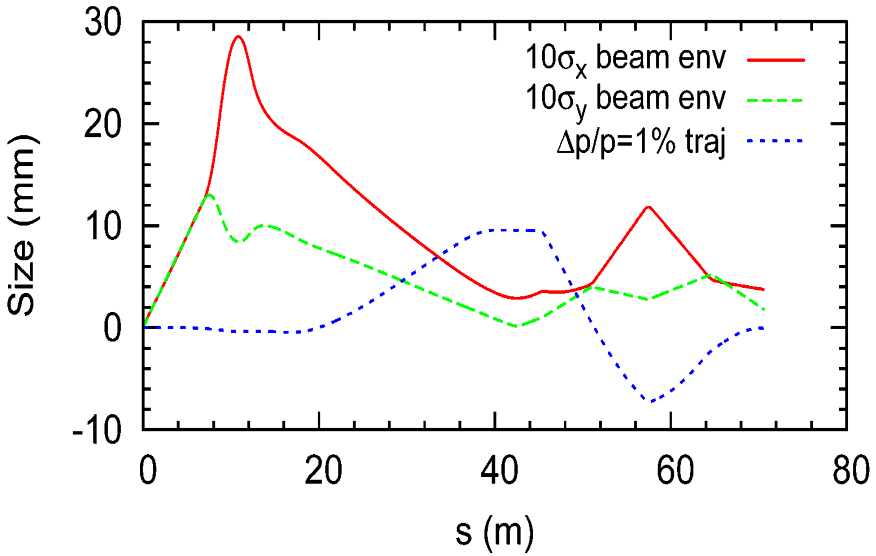
Alexandre Camsonne
Yulia Furletova

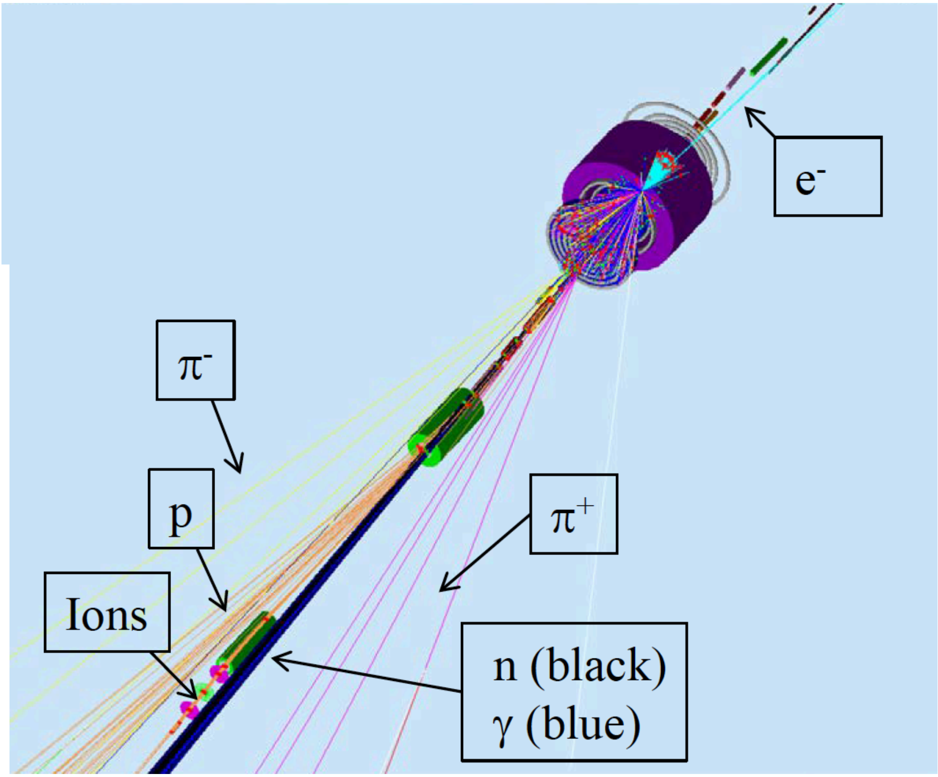
Far-forward ion direction area



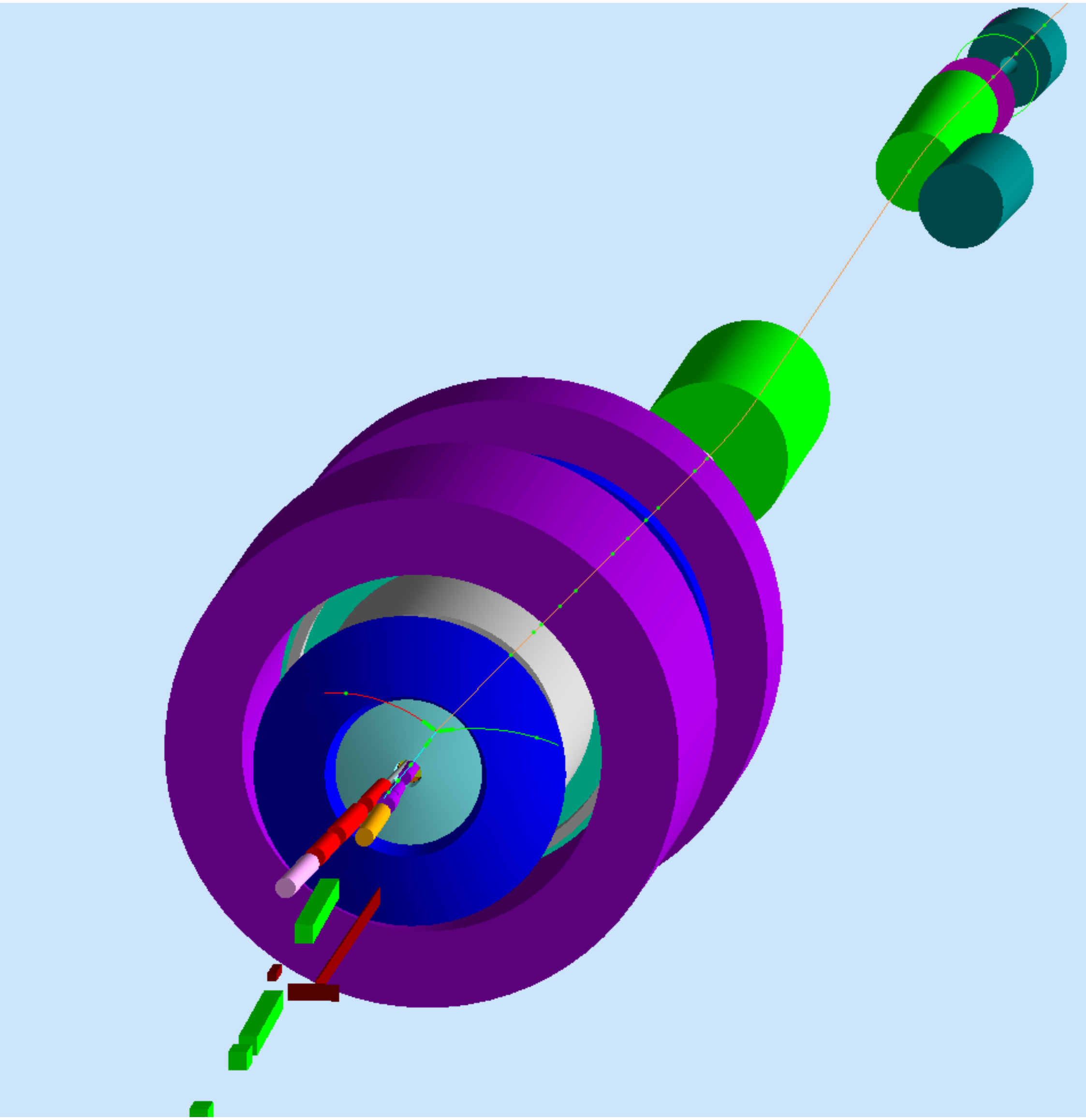
ep-> e + VM + p
ed -> e +VM + n + p_{spec}

- Main beam is focused
- High dispersion for off momentum particles



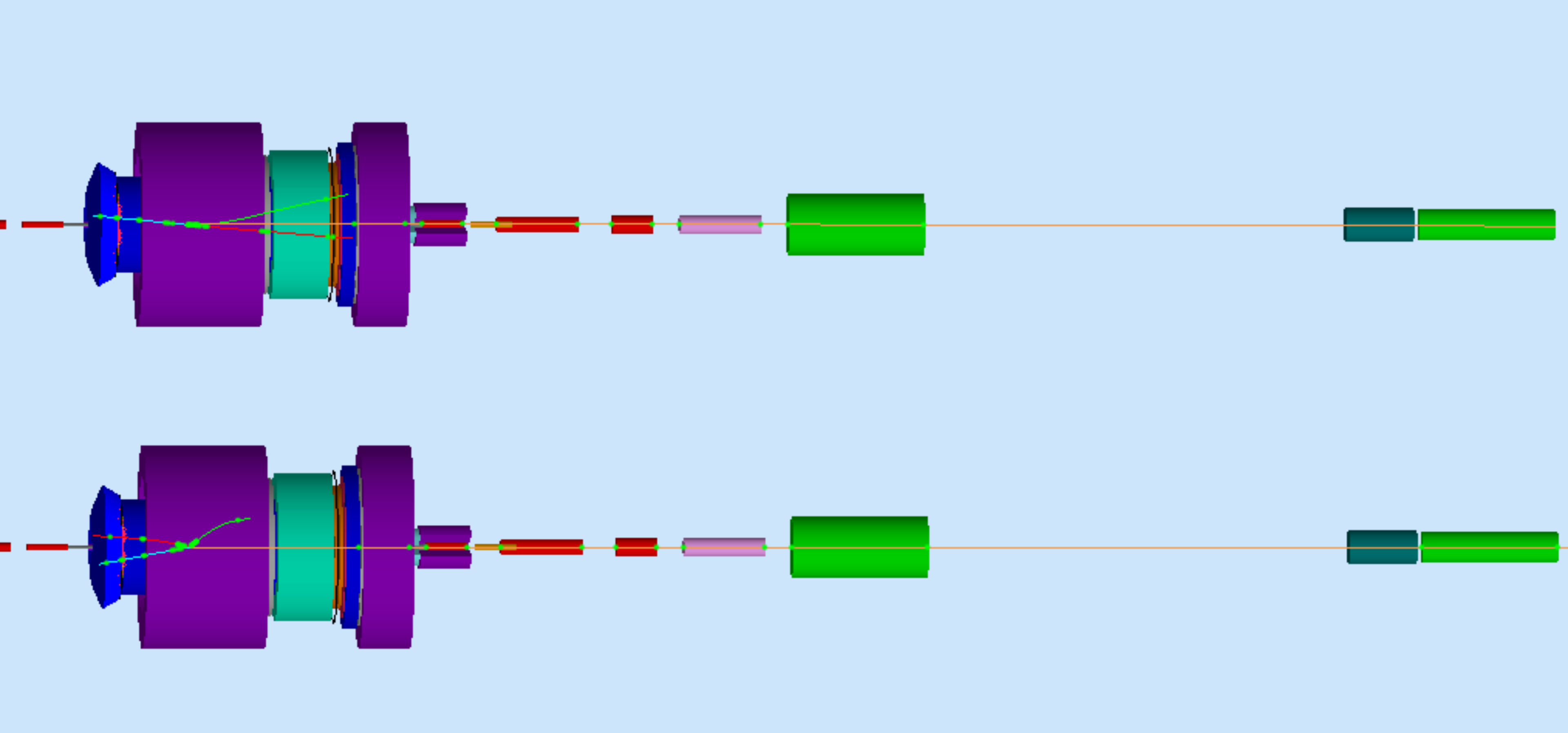


Exclusive J/ψ with JLEIC detector



Using events, generated by Sylvester J. Joosten

Exclusive J/ψ with JLEIC detector



Systematics

For EIC have to improve systematic err!

At HERA:

- Electron "box" cut ~ 6%
- Exclusivity cut ~ 5%
- Background fit
- Electron reconstruction method (EM vs constrained)

Summary

- Physics must drive the detector design.

- JLEIC detector design is based on a *total* acceptance detector and particle identification concept. This means excellent forward/rear coverage in addition to the central coverage, as well as on identification of individual particle species.

- **Machine parameters**, **interaction region** and **detector design** must go hand in hand, paying close attention to the emerging **physics program** of the EIC (a good collaboration among Accelerator Physicists, Experimentalists, and Theoreticians)

- Backup