DIRC-based PID for the EIC Central Detector

T. Horn[1], C. Hyde[2], P. Nadel-Turonski[3,*], K. Peters[4], C. Schwarz[4], J. Schwiening[4].

1) The Catholic University of America, Washington, DC 20064

2) Old Dominion University, Norfolk, VA 23529

3) Jefferson Lab, Newport News, VA 23606

4) GSI, 63291 Darmstadt, Germany

BNL, May 9, 2011

Outline

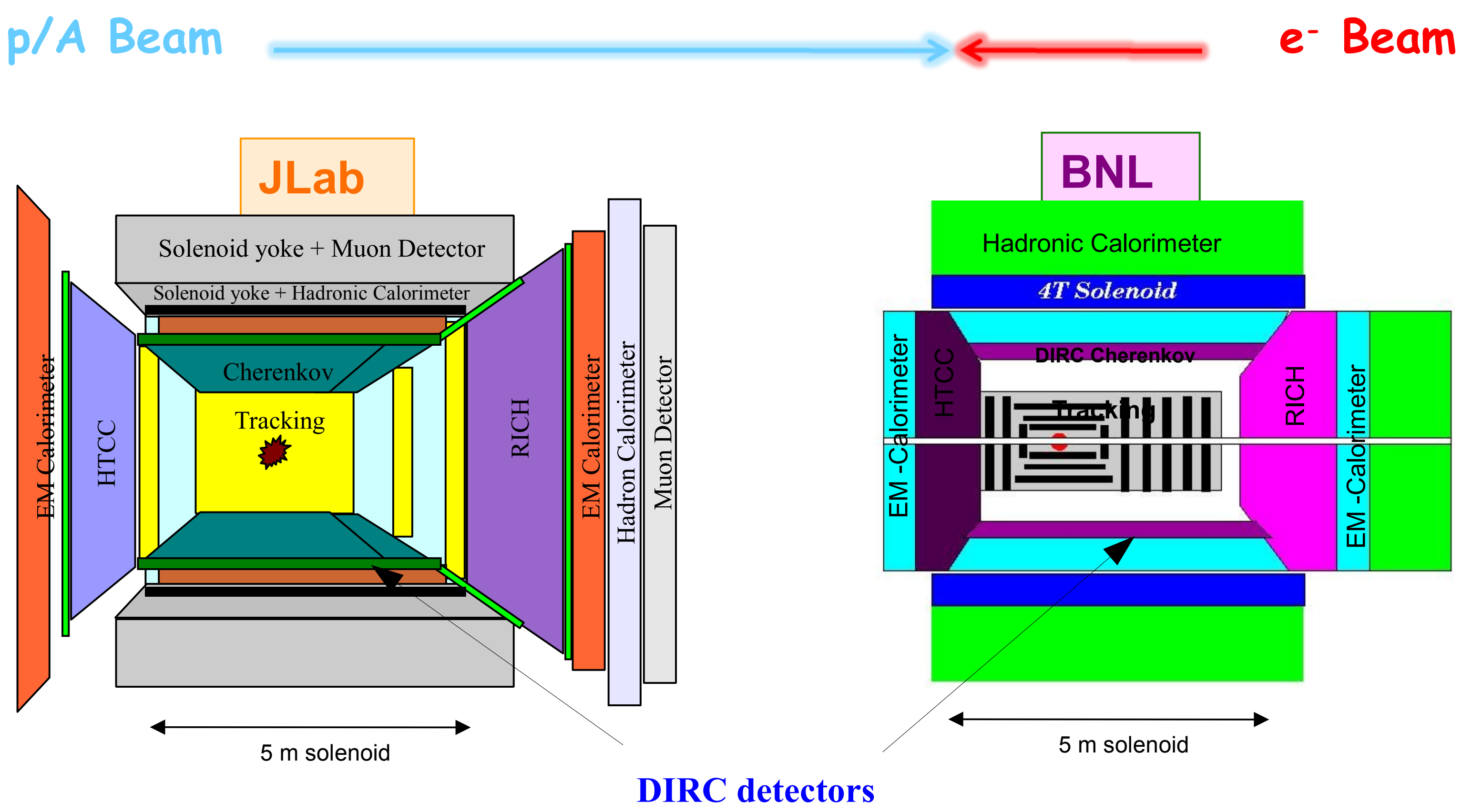
1. PID requirements

2. DIRC detectors

3. Integration with EIC detector

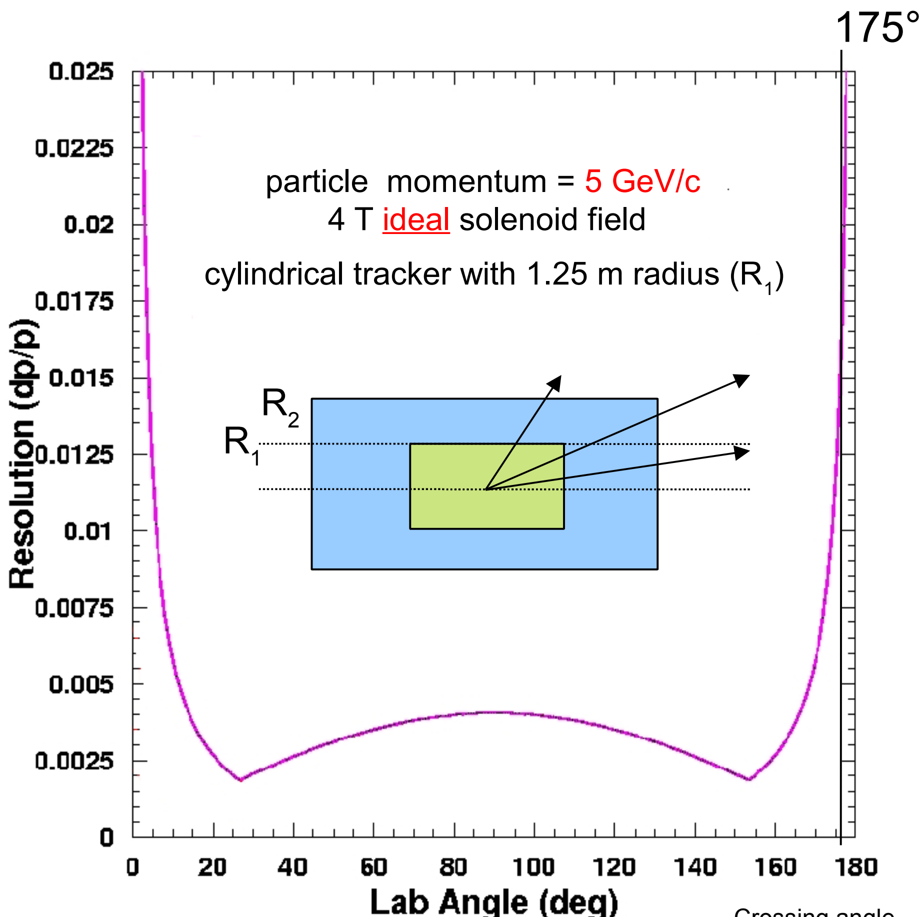
4. Funding request

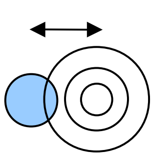
EIC detector cartoons shown at the INT



- Both the JLab and BNL versions of the detector shown at the INT included a DIRC
  - DIRC requires about 8 cm radial space (2 cm active)
- JLab cartoon also shows a supplementary Cherenkov in addition to the basic DIRC

Tracking momentum resolution in a solenoid field





$\Delta p/p \sim \sigma p / BR^2$

- Tracker (not magnet!) radius R is important at central rapidities
- Only solenoid field B matters at very forward rapidities

Radial space is at a premium if one wants to reach a good momentum resolution over a wide angular range

- A 2 Tm dipole covering 3-5° can eliminate divergence at small angles
- A beam crossing angle moves the region of poor resolution away from the ion beam center line.
  - 2D problem!

R&D goals

1. Demonstrate feasibility of using a DIRC in hermetic EIC detector

- Compact readout "camera" (expansion volume + sensors)
- Operation in magnetic field up to 2-4 T

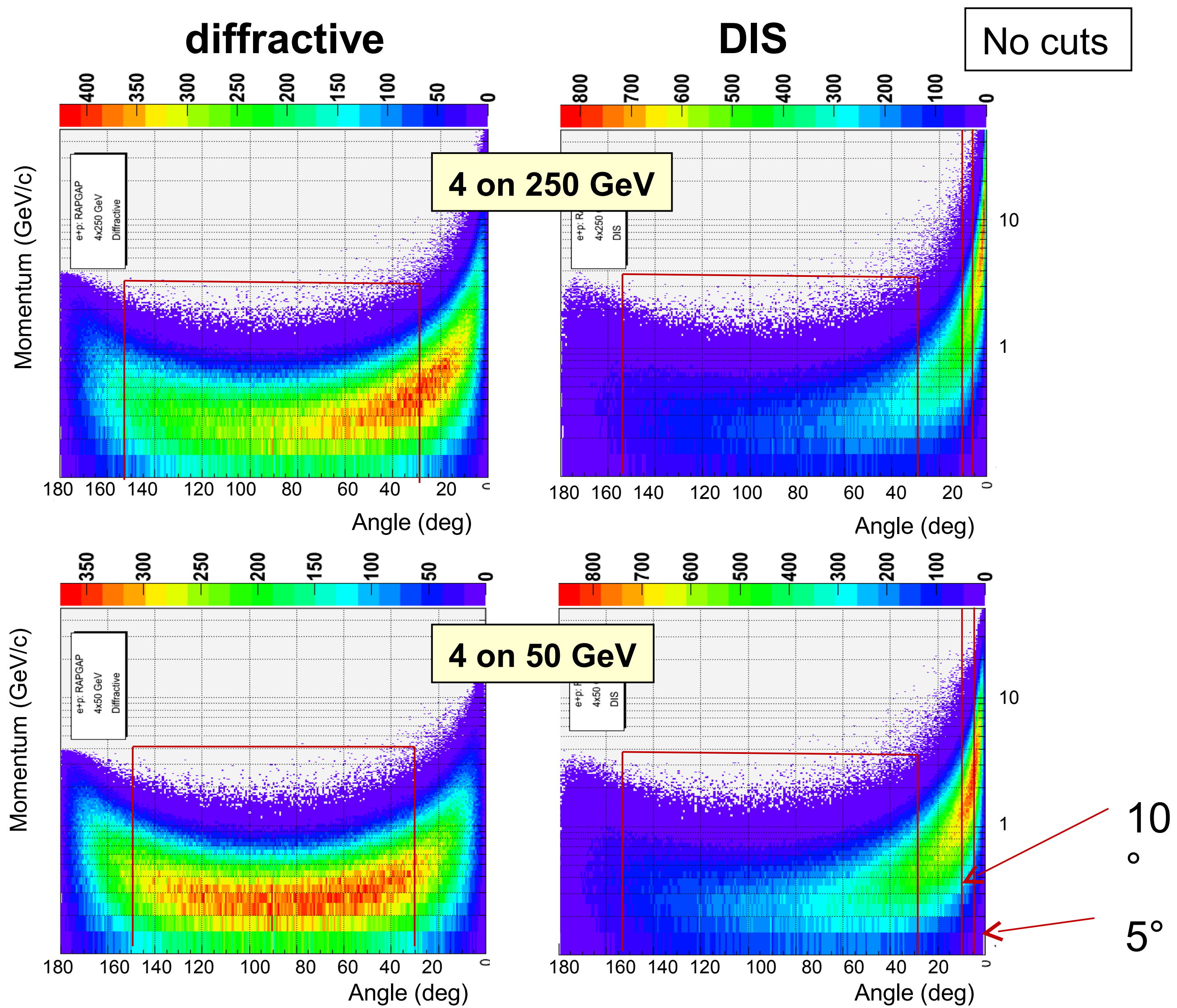
2. Investigate possibility of pushing state-of-the-art performance

- Extend 3σ π/K separation beyond 4 GeV/c, maybe as high as 6 GeV/c
- Also improve e/π, π/K, and K/p separation

3. Study integration of the DIRC with other detector systems

- Supplementary gas Cherenkov?
- Backgrounds
- Integration with solenoid, tracking, calorimeter, etc

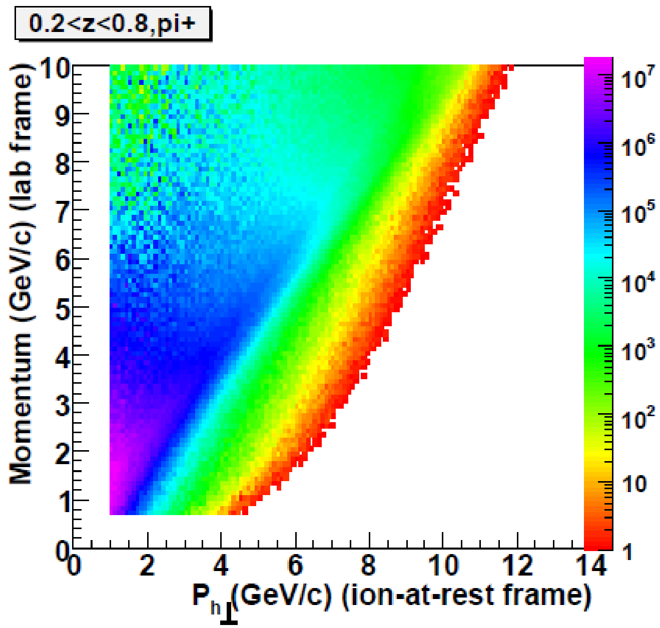
DIS and diffractive mesons

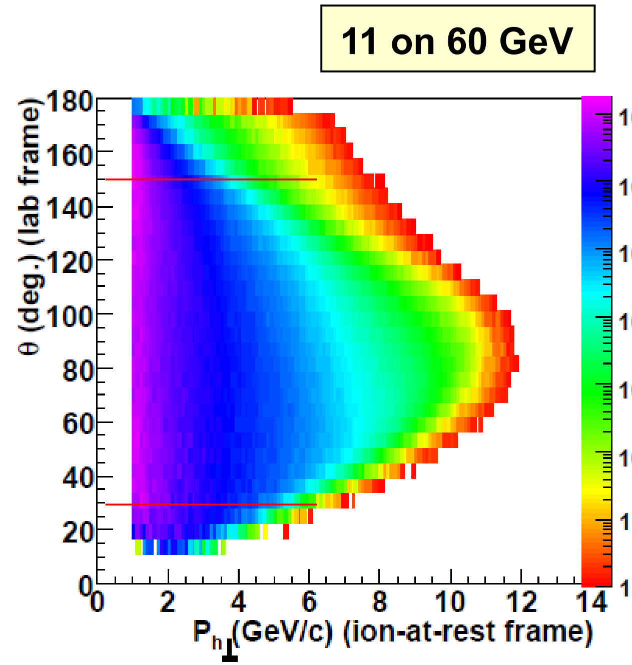


π/K identification up to 4 GeV/c in the central detector seems sufficient for most DIS and diffractive kinematics, but...

Semi-Inclusive DIS, leading mesons

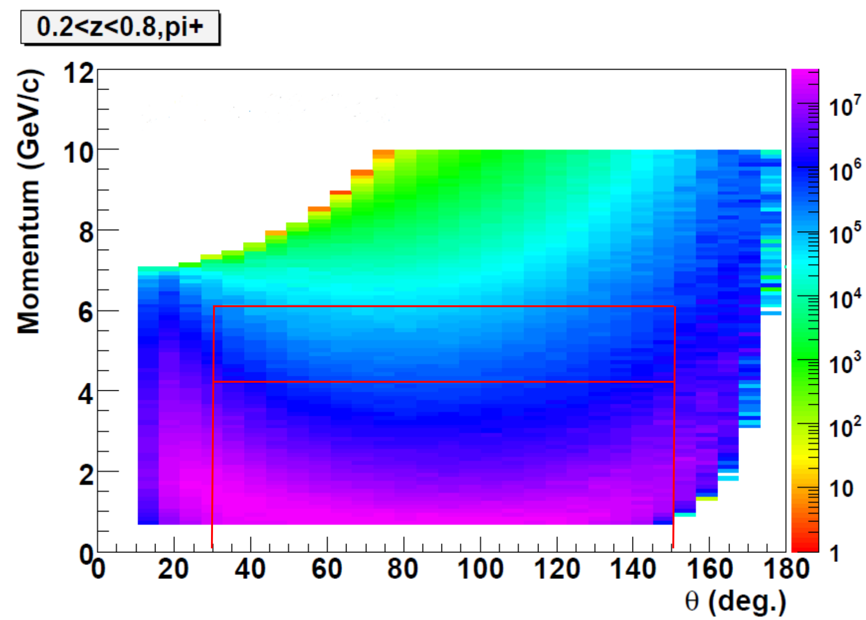
- p_T defined with respect to photon, not electron
- Component along beam direction boosted in lab frame
- Generally $p^{lab} > p_T^{rest}$





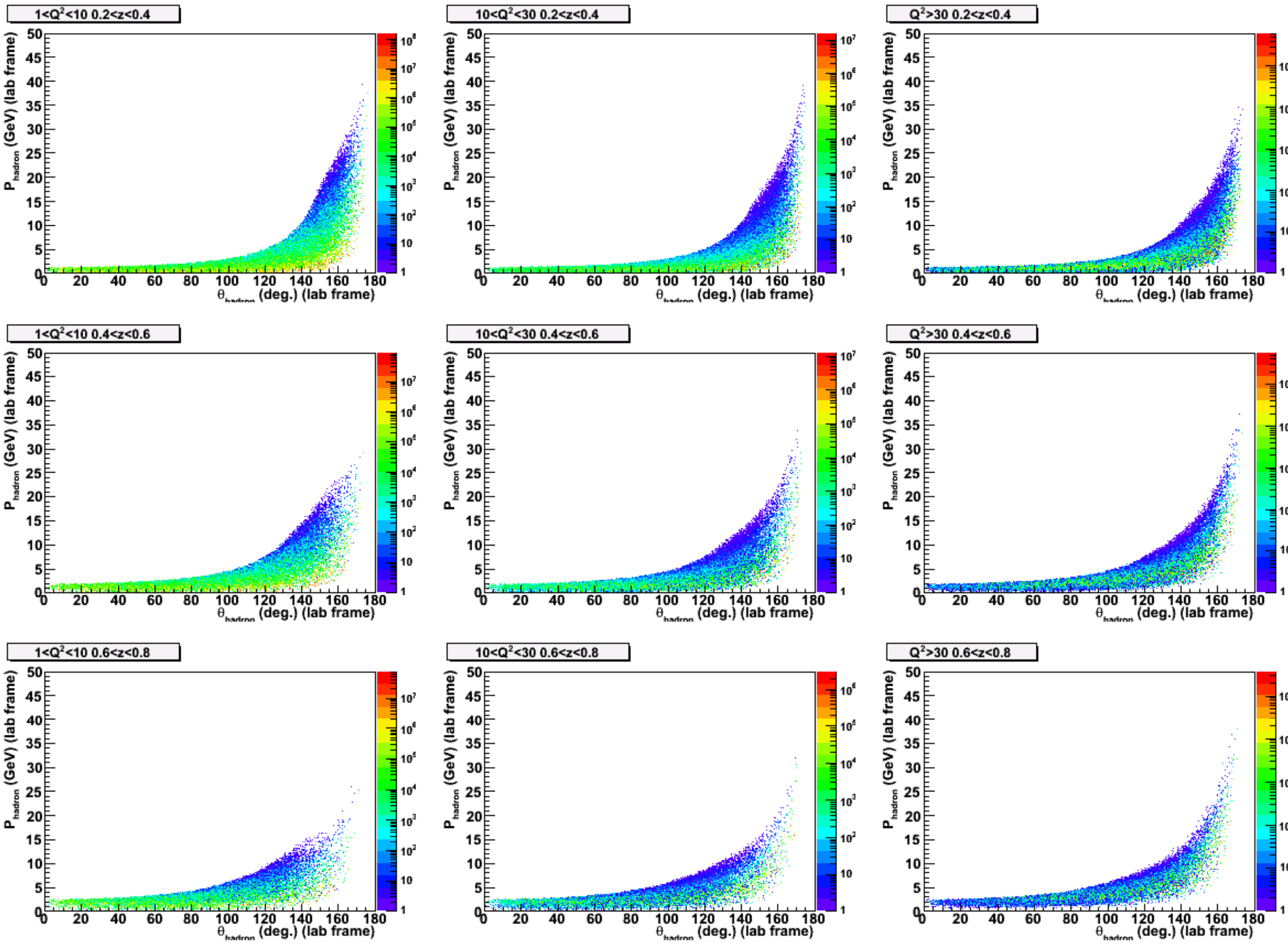
- π/K separation up to 4-6 GeV/c would provide decent p_T coverage, in particular for a medium-energy machine (stage-I)

- Providing PID over the full p_T range for the highest beam energies would require a combination of detectors and lots of radial space (tradeoff with momentum resolution)



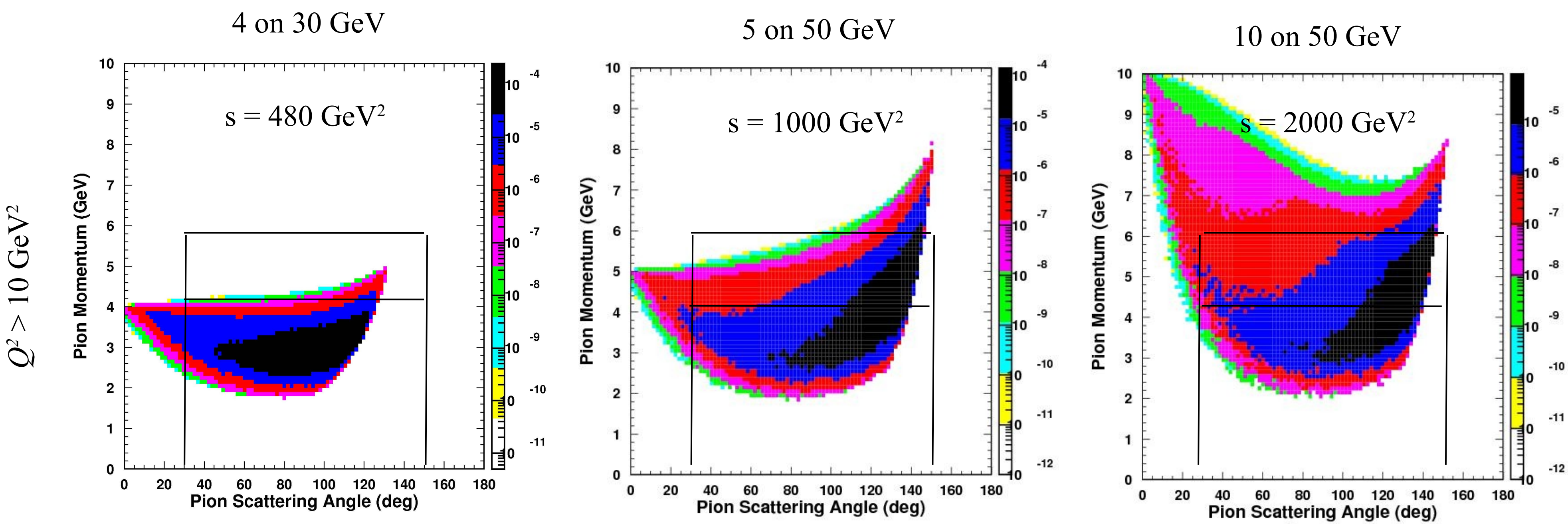
SIDIS, leading mesons

4 on 50 GeV



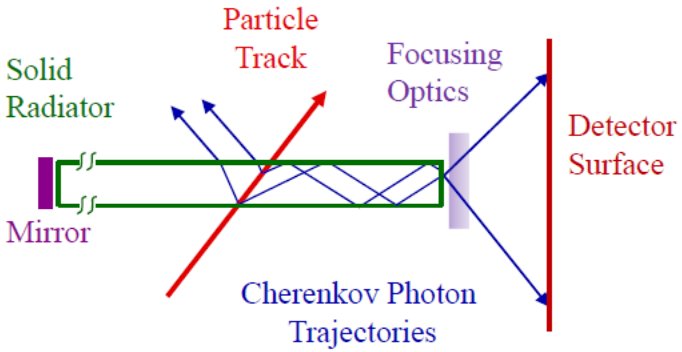
- Lab momenta do not strongly depend on *z* and Q^2 (coverage ok even with cut on p).
- Meson momenta at extreme angles depend on the respective beam energies

Exclusive mesons (Q^2 > 10 GeV^2)



- π/K separation beyond 4 GeV/c is required already at relatively modest energies.
- Pushing the π/K separation to 6 GeV/c would provide almost full coverage for ion energies of 50 GeV, and partial coverage thereafter.

DIRC principle



- Charged particle traversing radiator with refractive index n with $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos\theta_c = 1/\beta n(\lambda)$.

- For $n>\sqrt{2}$ some photons are always totally internally reflected for $\beta\approx 1$ tracks.

- Radiator and light guide: bar made from Synthetic Fused Silica

- Magnitude of Cherenkov angle conserved during internal reflections (provided optical surfaces are square, parallel, highly polished)

- Photons exit radiator into expansion region, detected on photon detector array. (pinhole imaging/camera obscura or focusing optics)

- DIRC is intrinsically a 3-D device, measuring: x, y, and time of Cherenkov photons, defining θ_c, ϕ_c, $t_{propagation}$ of each photon.

DIRC event reconstruction

Calculate unbiased likelihood for signals to originate from e/μ/π/K/p track or from background:

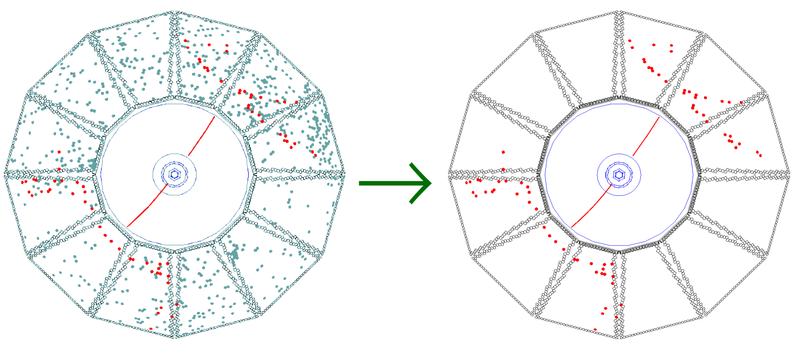
Likelihood: **Pdf(θ_c) ⊗ Pdf(Δt) ⊗ Pdf(N_γ)**

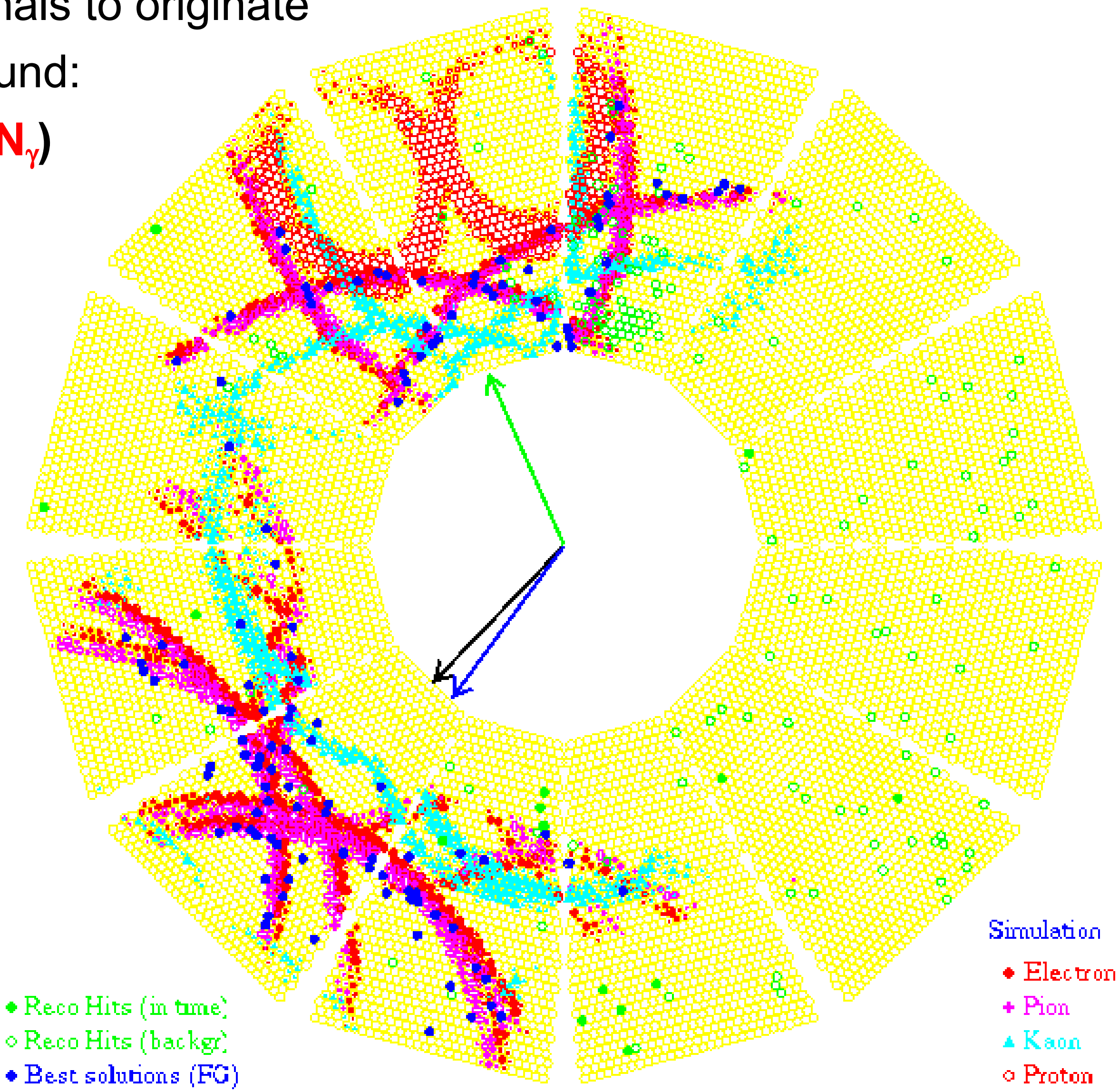
Example: comparison of real event to simulated response of BABAR DIRC to e/π/K/p.

Time resolution important for background suppression

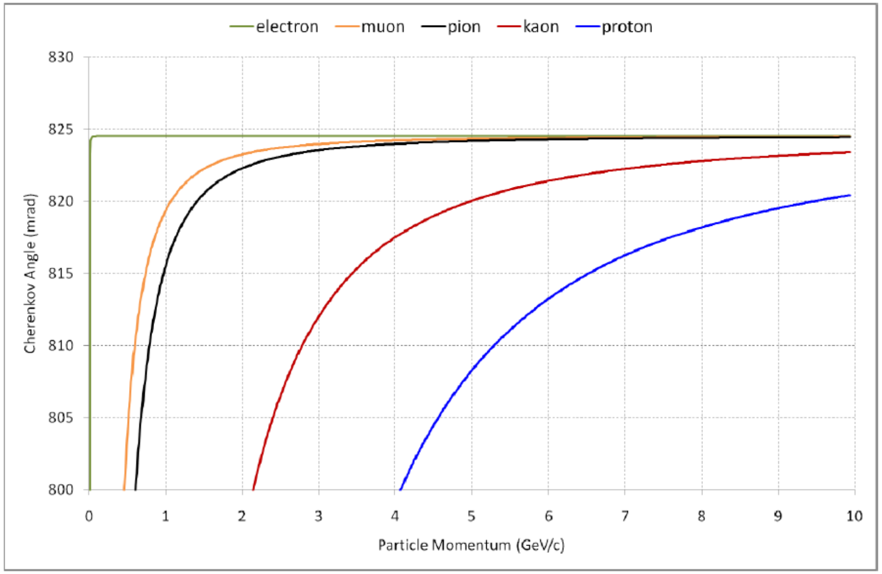
± 300 nsec trigger window (~500-1300 background hits/event)

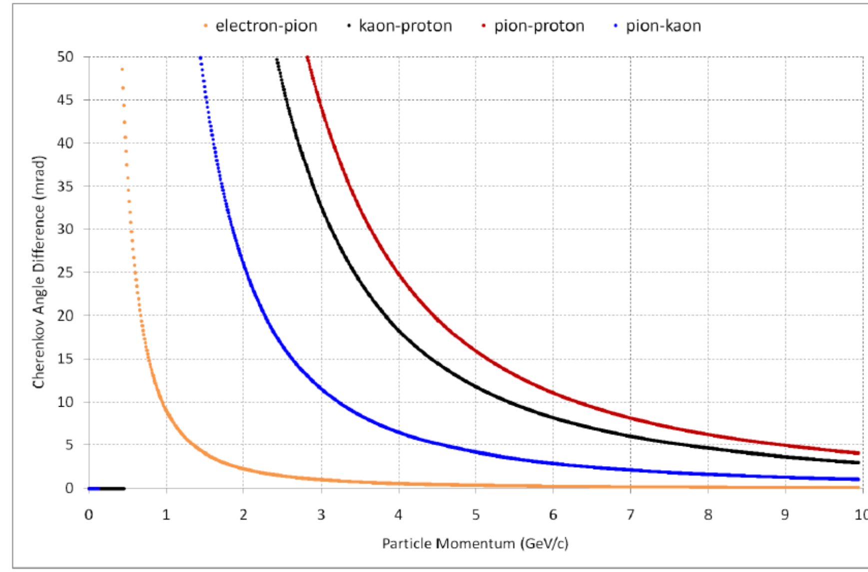
± 8 nsec Δt window (1-2 background hits/sector/event)

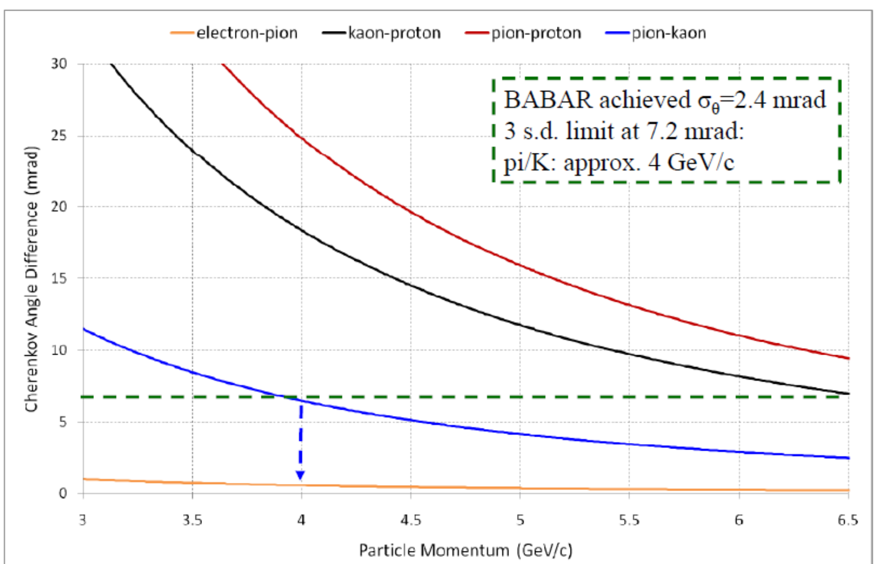


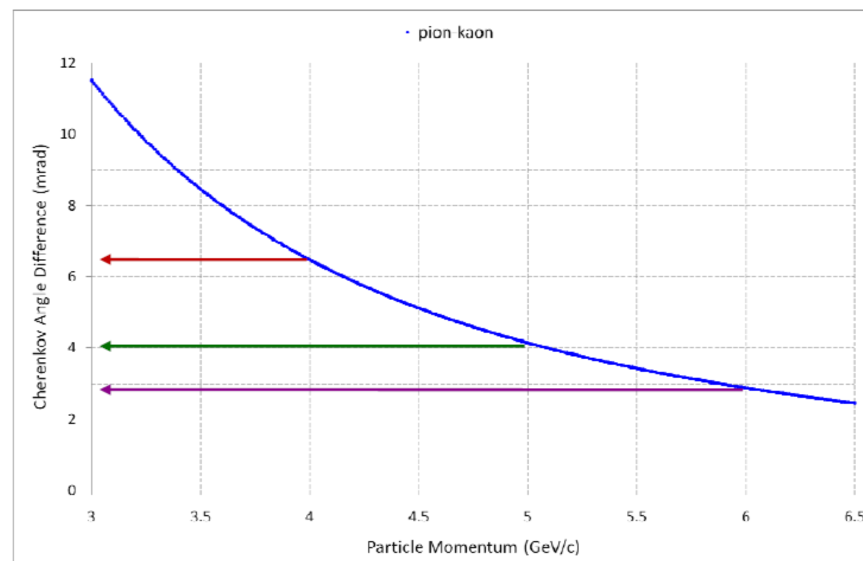


Momentum coverage and Θ_c resolution









- Extending π/K separation from 4 to 6 GeV/c requires $\sigma_\theta \sim 1$ mrad (vs 2.4 in BaBar – a 58% reduction).

Improving the Θ_c resolution

$$\sigma_{\theta_c}^{track} = \frac{\sigma_{\theta_c}^{photon}}{\sqrt{N_{p.e.}}} \otimes \sigma^{correlated}$$

Correlated term:
tracking detectors, multiple scattering, etc

$$\sigma_{\theta_c}^{photon} = \sqrt{\sigma_{bar-size}^2 + \sigma_{pixel-size}^2 + \sigma_{chromatic}^2 + \sigma_{bar-imperfection}^2}$$

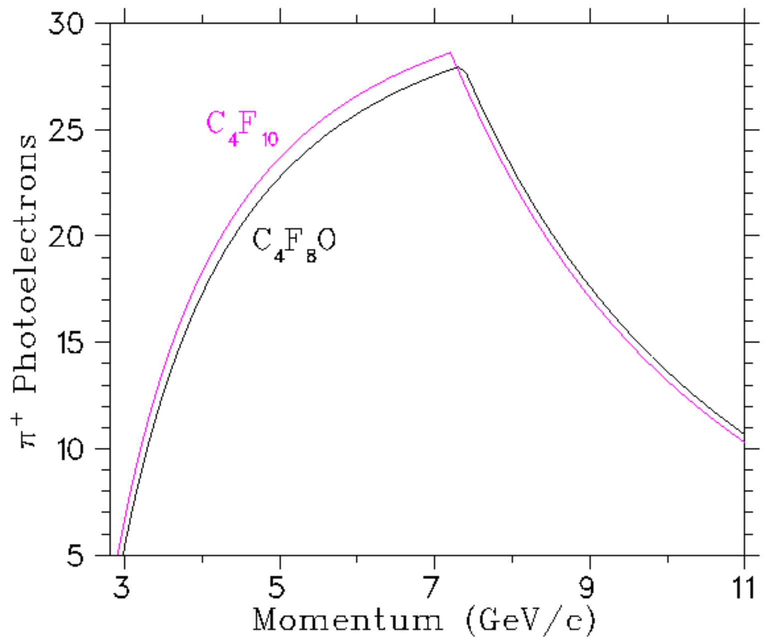
BABAR-DIRC Cherenkov angle resolution: 9.6 mrad per photon → 2.4 mrad per track

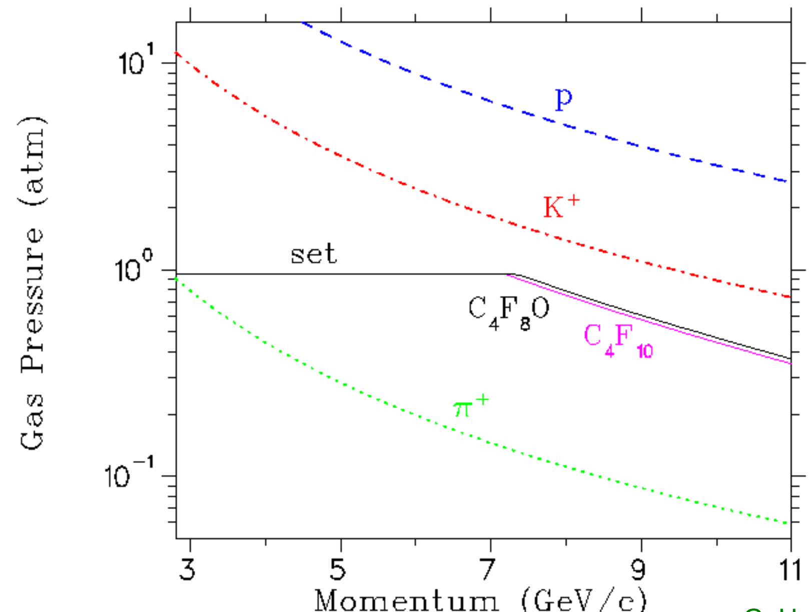
Limited in BABAR by:			Could be improved via:
· size of bar image	~4.1 mrad	→	· focusing optics
· size of PMT pixel	~5.5 mrad	→	· smaller pixel size
· chromaticity ($n=n(\lambda)$)	~5.4 mrad	→	· better time resolution
	9.6 mrad	→	4-5 mrad (?) per photon
· number of photons	15-50	→	· photocathode/SiPM

topics for R&D proposal (focusing optics, smaller pixel size, better time resolution, and the resulting 4-5 mrad per photon)

- DIRC bar thickness can in principle also be increased beyond the 17 mm (19% r.l.) used in Babar
- Excellent 3D imaging (2 spatial + time) essential for pushing performance beyond state-of-the-art

Supplementary threshold Cherenkov detector



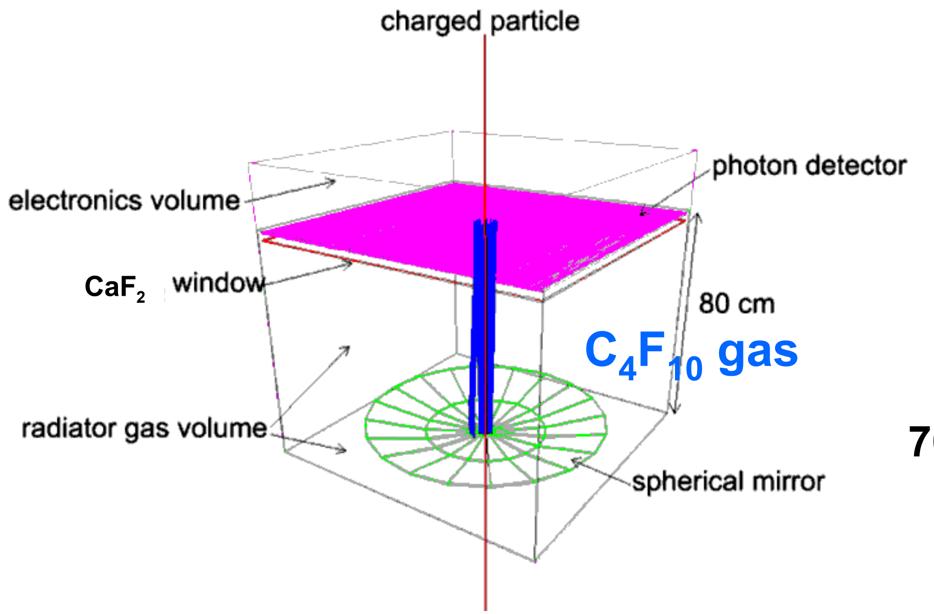


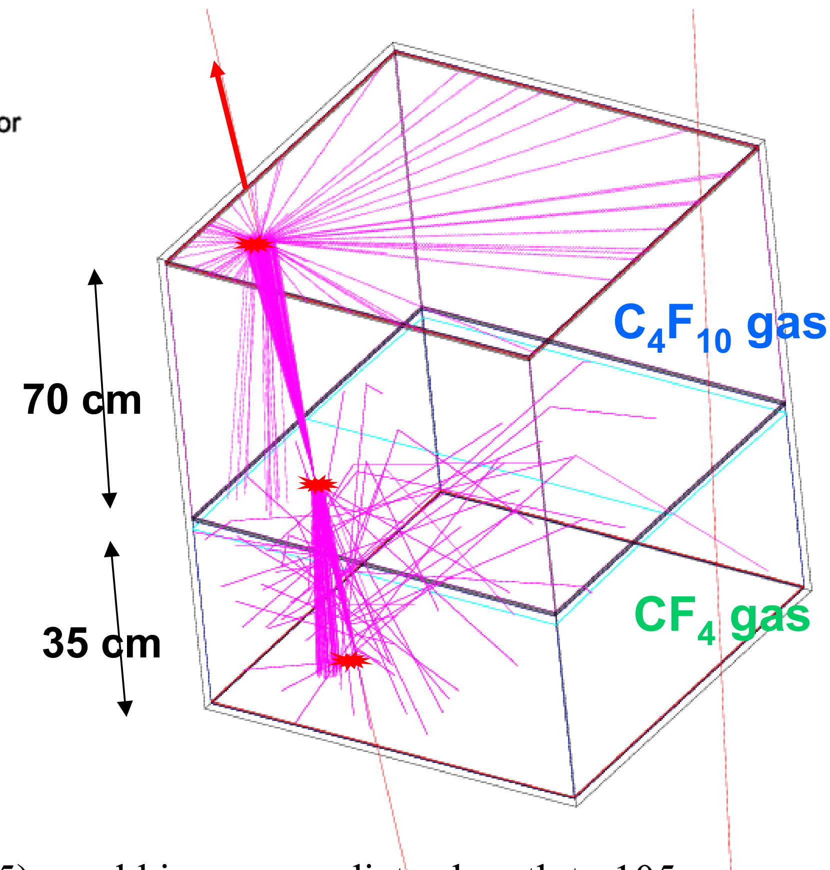
Number of p.e. in 60 cm of gas (left), and threshold as function of gas pressure (right)

- If needed, a supplementary threshold Cherenkov can provide
  - e/π separation for 1-3 GeV/c
  - π/K separatation for 4-9 GeV/c (higher with some underpressure)
- A radiator thickness of 60 cm (+ 10 cm for readout ?) is clearly adequate, 40 cm may be sufficient
- C_4F_{10} gas can be replaced by the more eco friendly C_4F_8O

Barrel RICH ideas for ALICE

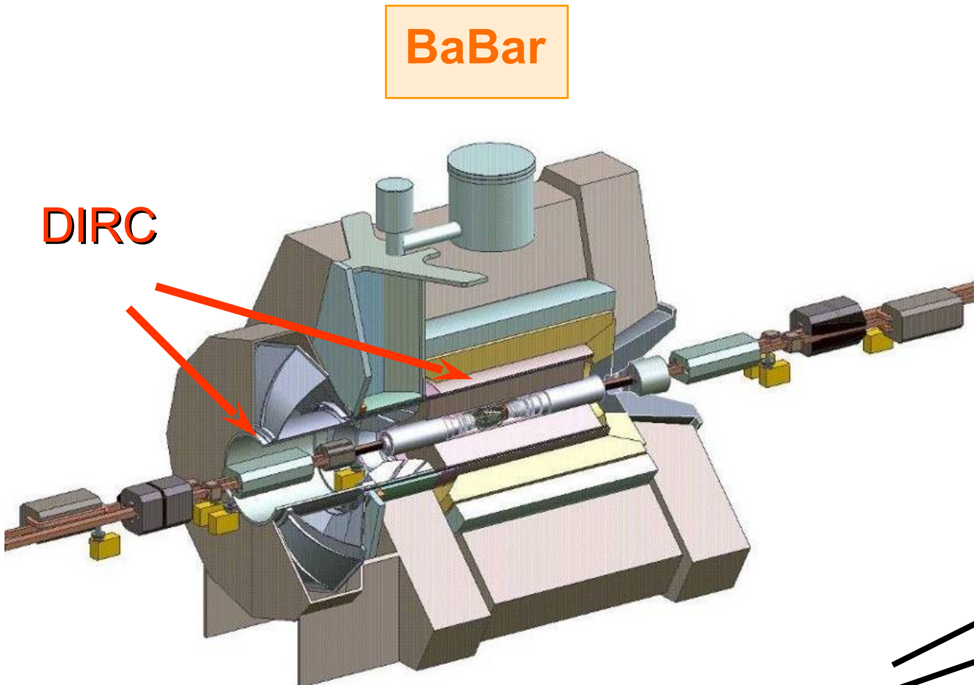
NIM A617, 424 (2010), talk by N. Smirnov at
JLab EIC detector workshop, June 5-6, 2010

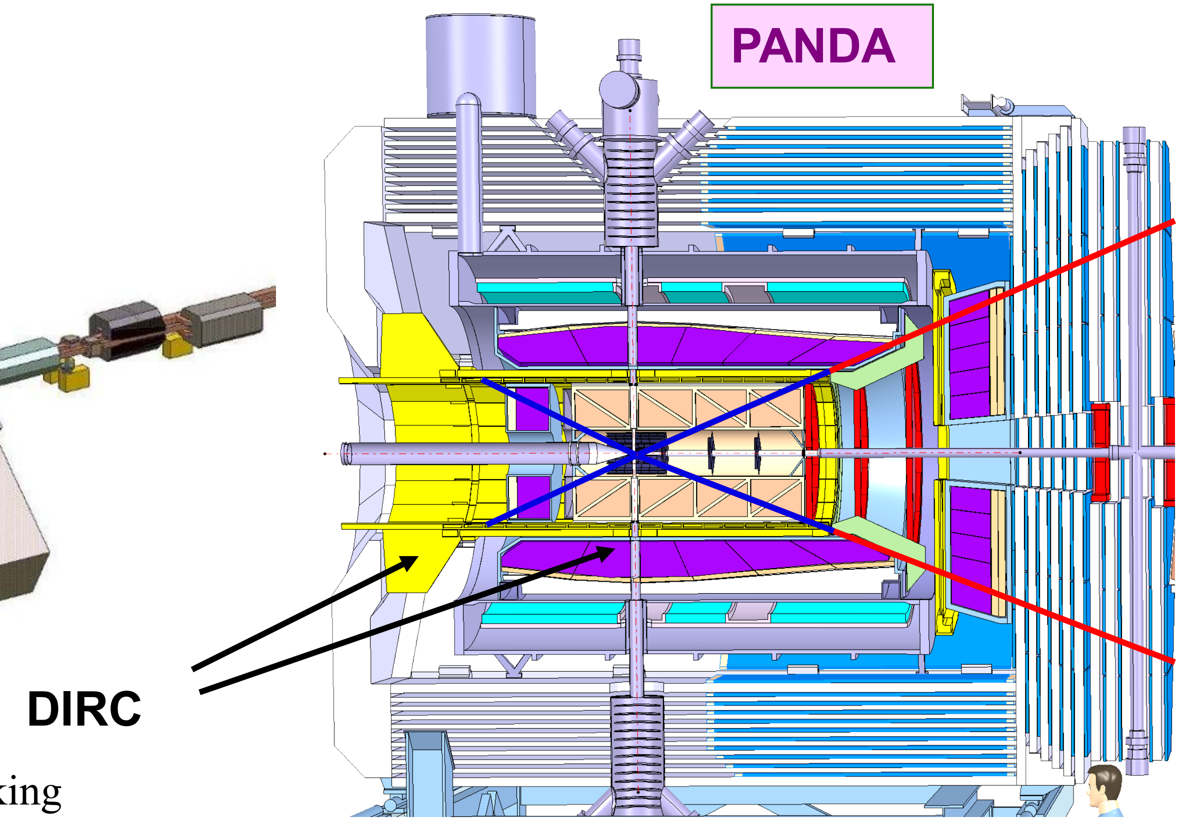




- ALICE barrel RICH with C_4F_{10} gas would extend the maximum momentum coverage from 9 to 14 GeV compared with a threshold Cherenkov, but requires 80 cm for radiator alone.
- Adding a second radiator with CF_4 gas (n = 1.0005) would increase radiator length to 105 cm
- Kaon momenta up to 4+ GeV/c would still need to be covered by aerogel or a DIRC
- ALICE ideas suggest that it may be possible to cover a wide range of momenta in the central detector, but it would require a detector with a very large radius (and hence weak solenoid field)

DIRC "camera" (expansion volume + sensors)

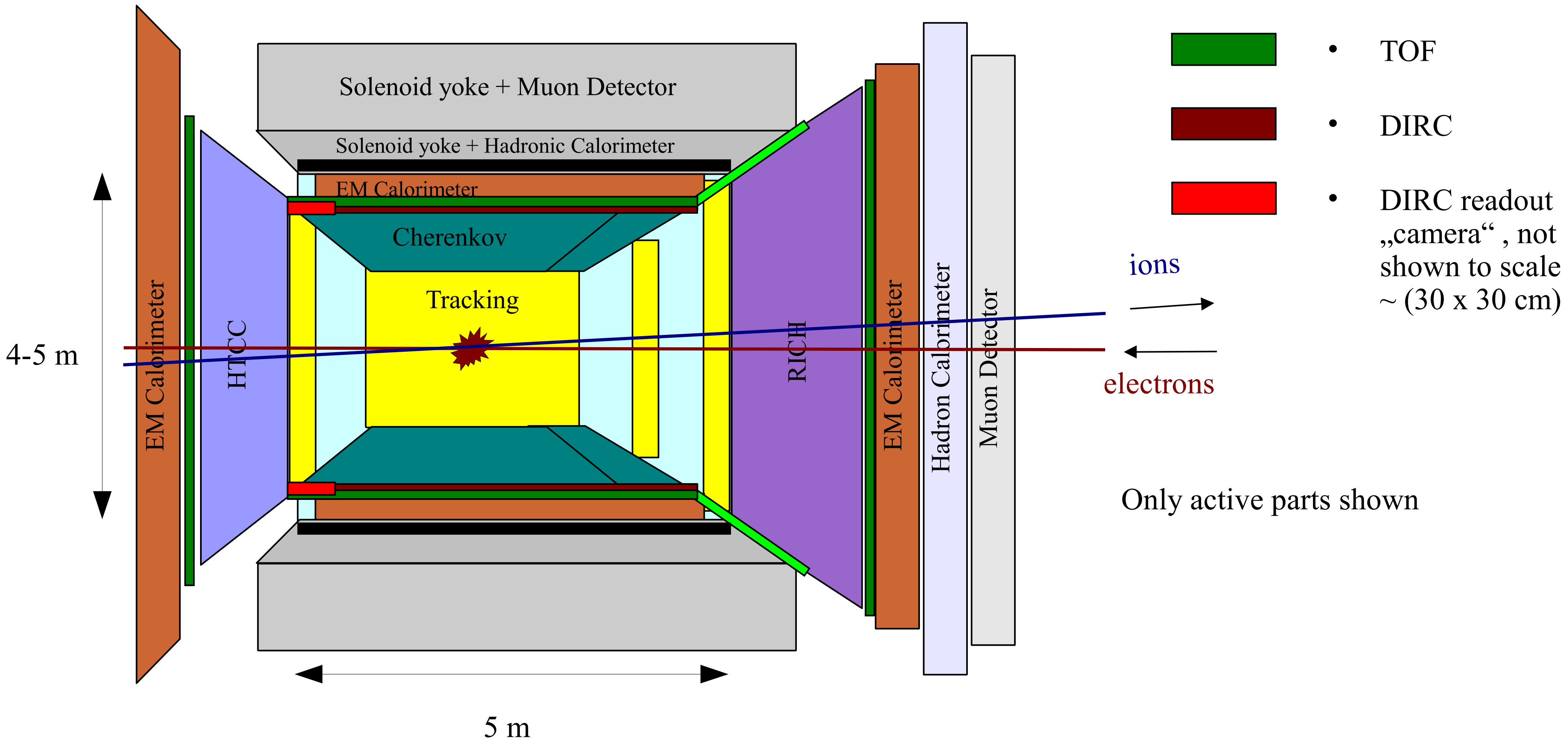




- Expansion volumes (EV) are shrinking
  - BaBar: 1.2 m long tank with 6000 liters of water
  - PANDA: 30 cm long, 30 cm high EV with mineral oil
  - SuperB: 22 cm long, 56 cm high EV of fused silica

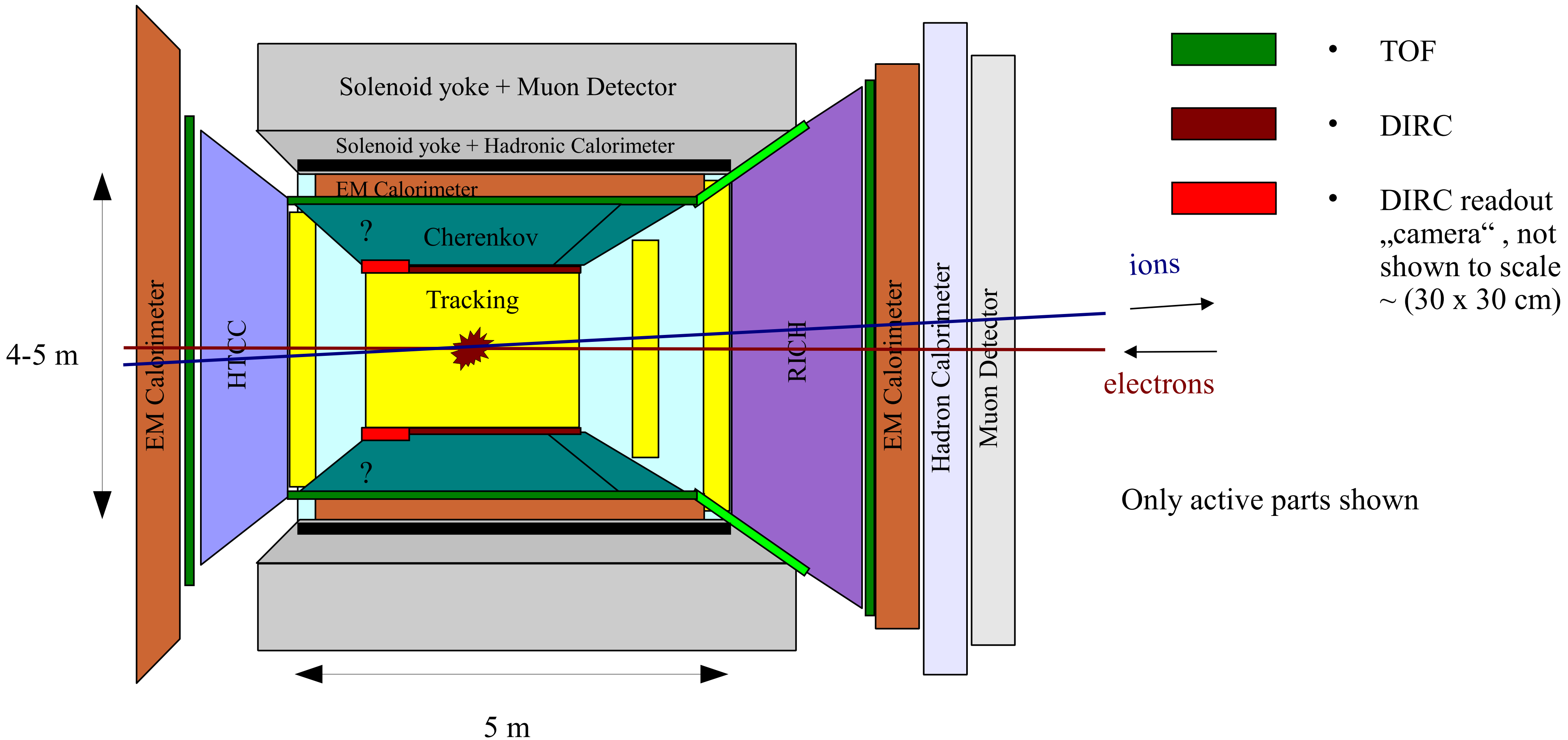
- Due to space constraints, the Belle II Time Of Propagation (TOP) DIRC sacrifices spatial resolution (originally also only in one dimension) for compactness of the expansion volume (10 x 10 cm^2).
  - Difficult to push performance using time only, in particular for long DIRC bars

EIC: DIRC outside of gas Cherenkov



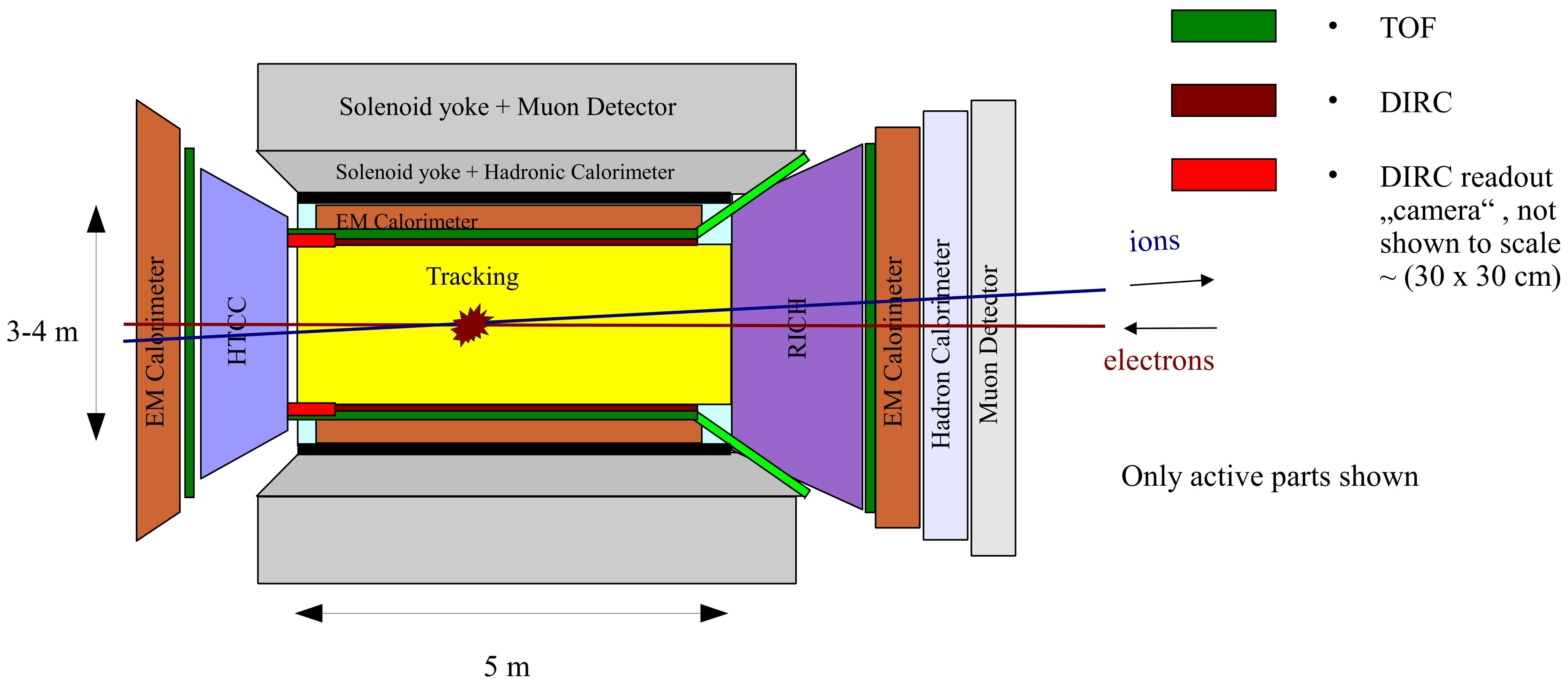
- *Pros:* low mass in front of gas Cherenkov, short distance to TOF
- *Cons:* large DIRC radius (expensive), larger distance to tracker (angular resolution?)
- Can readout replace part of the DIRC bar without shadowing the endcap?
  - Slightly reduced backward angular coverage probably ok

DIRC inside of gas Cherenkov



- *Pros:* lower DIRC cost and better timing
- *Cons:* more mass in front of Cherenkov, larger distance to TOF
- Part shadowed by DIRC readout can be optimized

DIRC only



- *Pros:* reduced cost of detectors in endcaps and barrel, DIRC close to TOF and tracking
- *Cons:* smaller pi/K separation range, sufficient low-energy electron PID?
- *Magnet:* optimum may be a compromise between field and radius (important for resolution at large angles)

Funding Request and Responsibilities

Budget	Year 1	Year 2	Year 3	Total
Postdoc (50%)	$45k	$46k	$47k	$138k
Undergrad	$8.3k	$8.3k	$8.3k	$24.9k
Hardware	$47k	$37k	$30k	$114k
Travel	$14.7k	$17.7k	$19.7k	$52.1k
Total	*$115k*	*$109k*	*$105k*	*$329k*

The salaries for the postdoc and undergraduate students include university overhead.
Matching funds are available for the postdoc. The travel and hardware include JLab overhead.

Responsibilities

- The main responsibility of the US part of the collaboration (JLab, CUA, ODU) will be simulations, design, and integration of the DIRC into the EIC detector. To carry out these tasks, a postdoc will be hired at ODU and undergraduate students at CUA, the latter focusing on the overall detector optimization and performance.
- The primary responsibility of the German part of the collaboration (GSI) will be to guide the design of the hardware, prototype construction, and carrying out a range of tests.
- An important part of the proposal is also to provide travel support, creating opportunities for the US partners (including the postdoc) to take part in the hardware development at GSI, and for the German partners to present their results to, and participate in the activities of the EIC collaboration.

Deliverables

Year 1 – requirements, simulations, simple EV prototype

1. Initial e/π identification requirements for the central EIC detector.
2. Simulation and reconstruction framework for DIRC prototype.
3. DIRC resolution studies and design of prototype.
4. Compact expansion volume prototype with multi-pixel readout.
5. DAQ system tested using laser pulser.

Year 2 – integration with EIC and design of final prototype

1. Integration of a DIRC into the EIC detector.
2. Performance plots for EIC DIRC.
3. Design for final prototype EV.
4. Test of sensor response at 2-4 T magnetic field.
5. Cherenkov ring resolution in test beam (if available).

Year 3 – tests with final "camera" prototype

1. Performance parameters of DIRC in the EIC detector.
2. In-beam test of compact EV (if available)
3. Comparison of photon yield for different multi-pixel sensors
4. Determination of Cherenkov angle resolution of final prototype EV

Summary

1. A DIRC offers interesting capabilities for the EIC detector

- Standalone: better tracking, cost reduction (magnet, endcaps, calorimeter)
- With supplementary gas Cherenkov: high p_T-coverage

2. We propose a 3-year R&D effort

- Feasibility studies (simulations, component tests)
- Integration with EIC detector (simulations)
- Extending performance beyond state-of-the-art (simulations, prototyping)

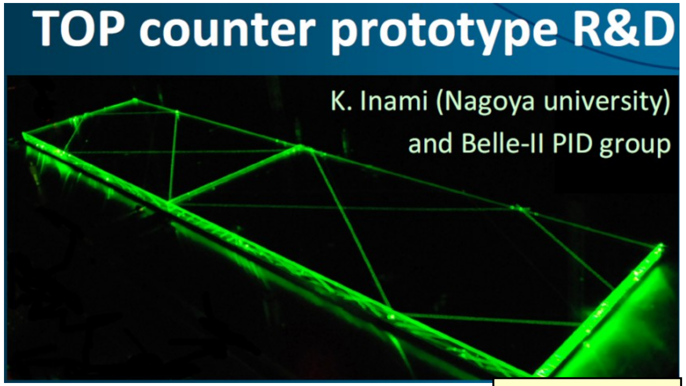
Thank you!

Backup

For upgrade of Belle detector for Japanese Super B project;

replace Aerogel Cherenkov Counter in barrel with time-of-propagation (TOP) DIRC;

design goal 4σ π/K separation up to 4 GeV/c;
use plates (~40 cm x 250 cm), synthetic fused silica.



K. Inami RICH2010

Initial design was pure 2D TOP detector
high precision timing + one space coordinate
(linear array or PMT pixels – HPK SL10).

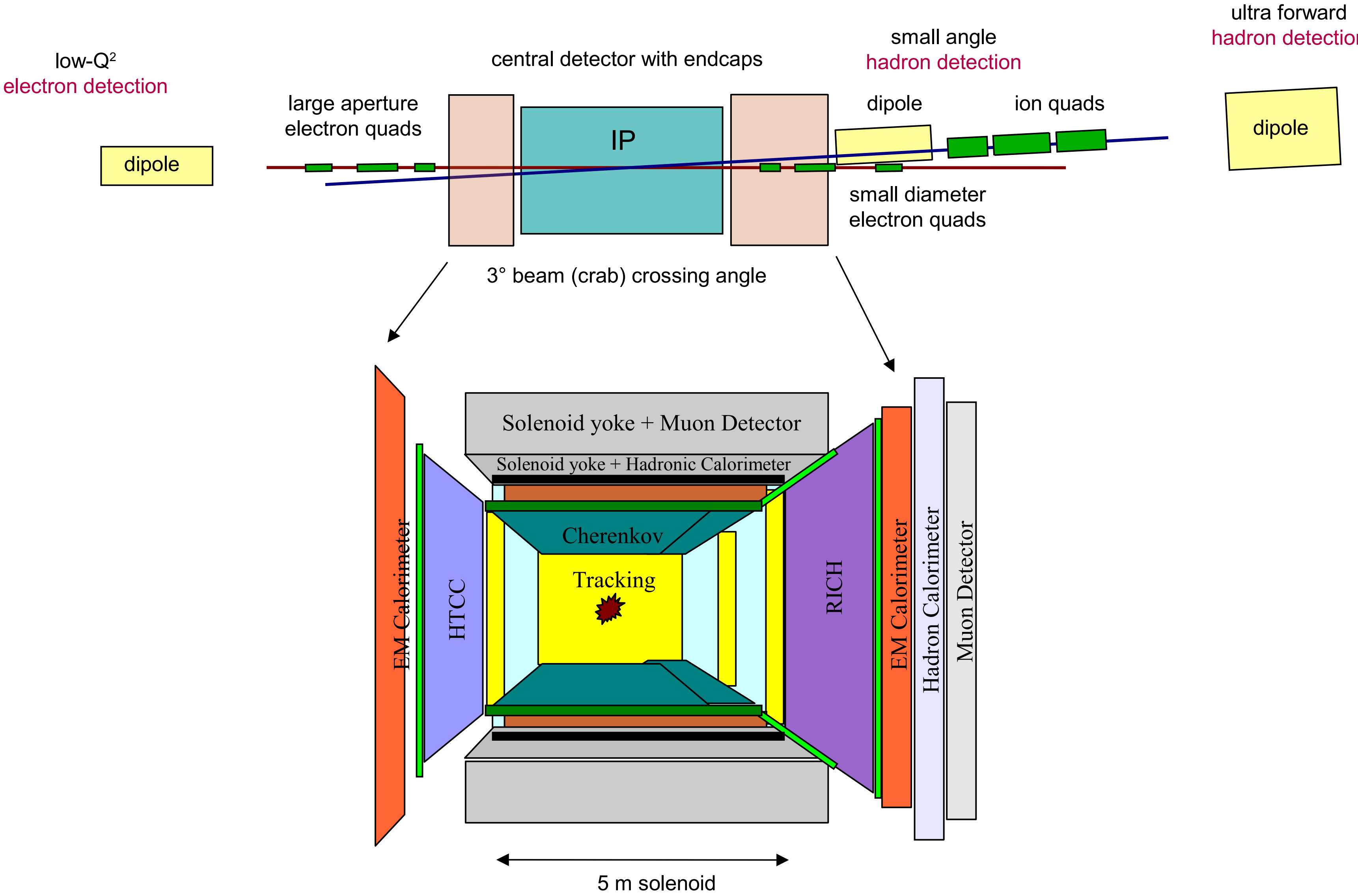
Recent addition of alternative 3D designs:

segmentation of barrel into a “TOF zone” and “TOP zone”
with focusing optics and second space coordinate (X, Y of hit, 4x4 version of SL10);

small fused silica expansion volume with 4x4 version of SL10.

3D has many advantages, redundancy and robustness among them.

Interaction Region – overview



Interaction Region – accelerator view