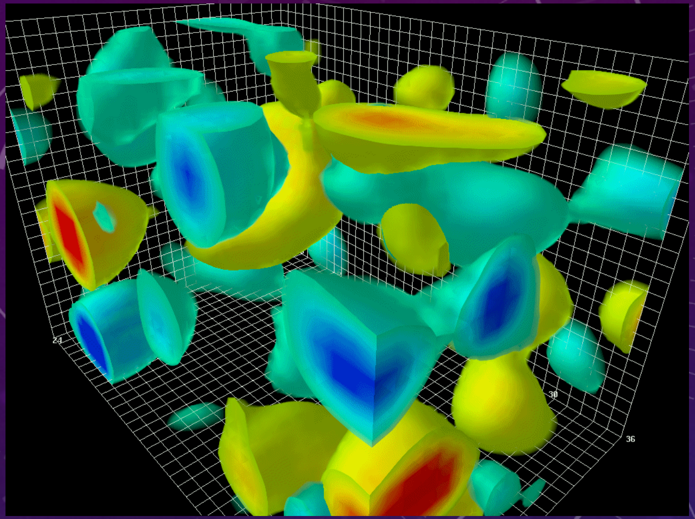
The QCD vacuum $(2\ \mathrm{fm})^3$



www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/Nobel/index.html

A COMPACT DETECTOR FOR ELECTRON-ION COLLIDER SCIENCE

Charles Hyde

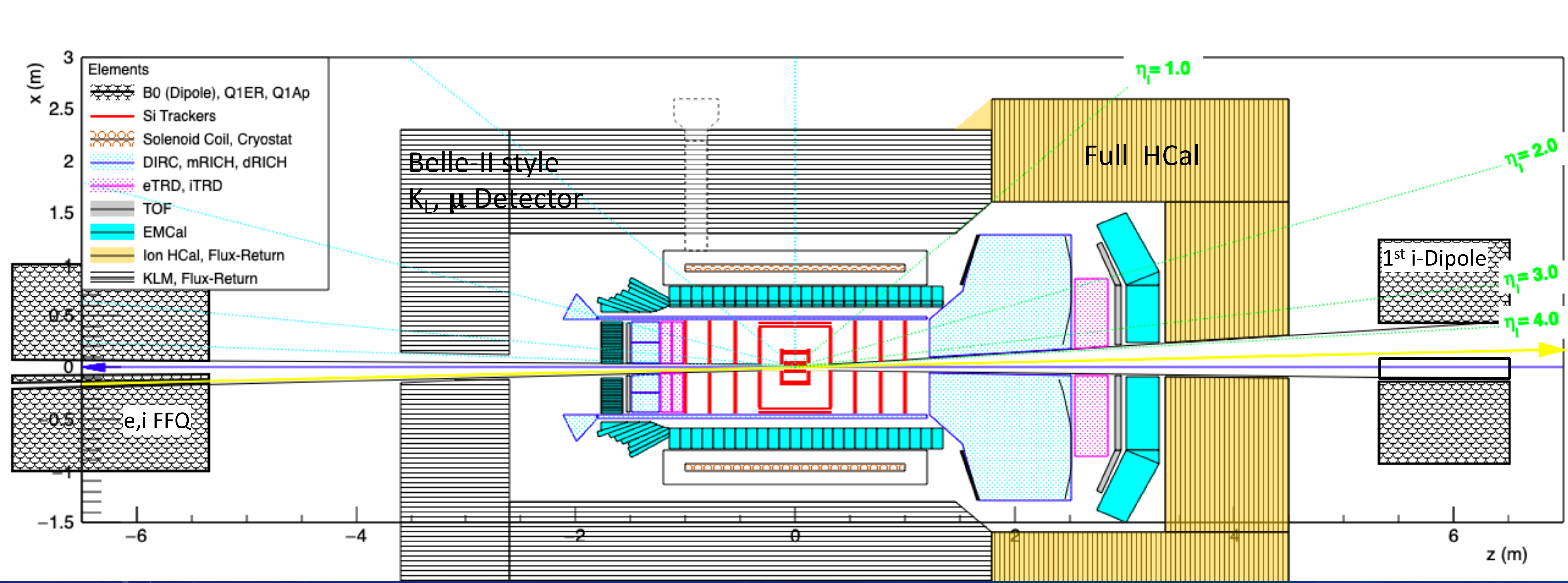
Old Dominion University

Pawel Nadel-Turonski

Stony Brook University

- Capitalize on Detector R&D to optimize performance
  eRD16/ 2@: All Si Tracker
  eRD14: PID: DIRC, modular RICH, Dual RICH
  Shorter (3m) Smaller Bore magnet (2m i.d.)

- IR magnet clear zone: IP±4.5 m



IMPLEMENTATION SUMMARY

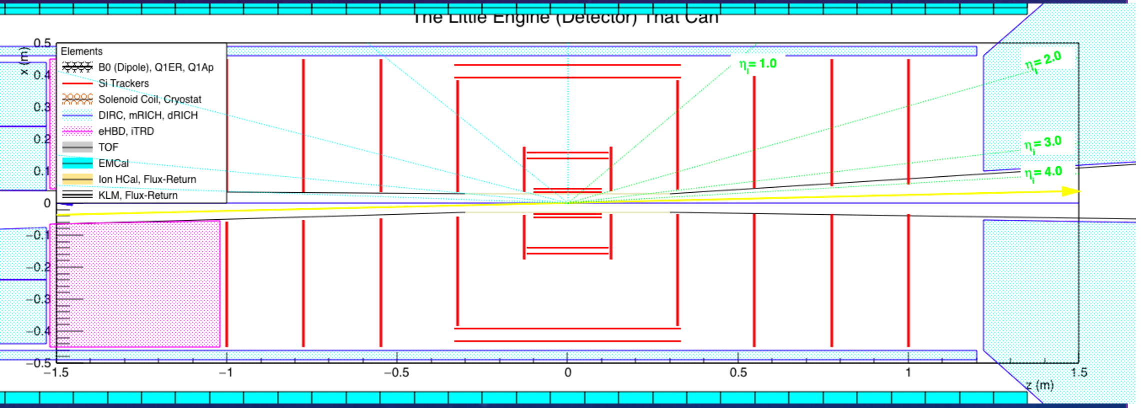
1) To reduce risk, the design is based on existing technologies and results from EIC R&D
   - All Si-tracker from eRD25/eRD16 ➔ compact implementation of all PID systems from eRD14
2) Additional electron ID: TRD in both endcaps
3) Hadronic Calorimetry matched to EIC kinematics/multiplicity
   - HCal on the hadron side covering eta > 1.
   - At central and backward rapidity, lower cost K_{Long} - Muon (KLM) detector,
4) The Hcal and KLM: flux return for a new, small solenoid with a field of 1.5 - 3 T.
5) The compact size: Ample space for supports and services.
   8 m length allows for up to 1 m adjustment in placement of beamline elements.
6) 3D Implementation in GEANT4 started (Vitaly Baturin, ODU)

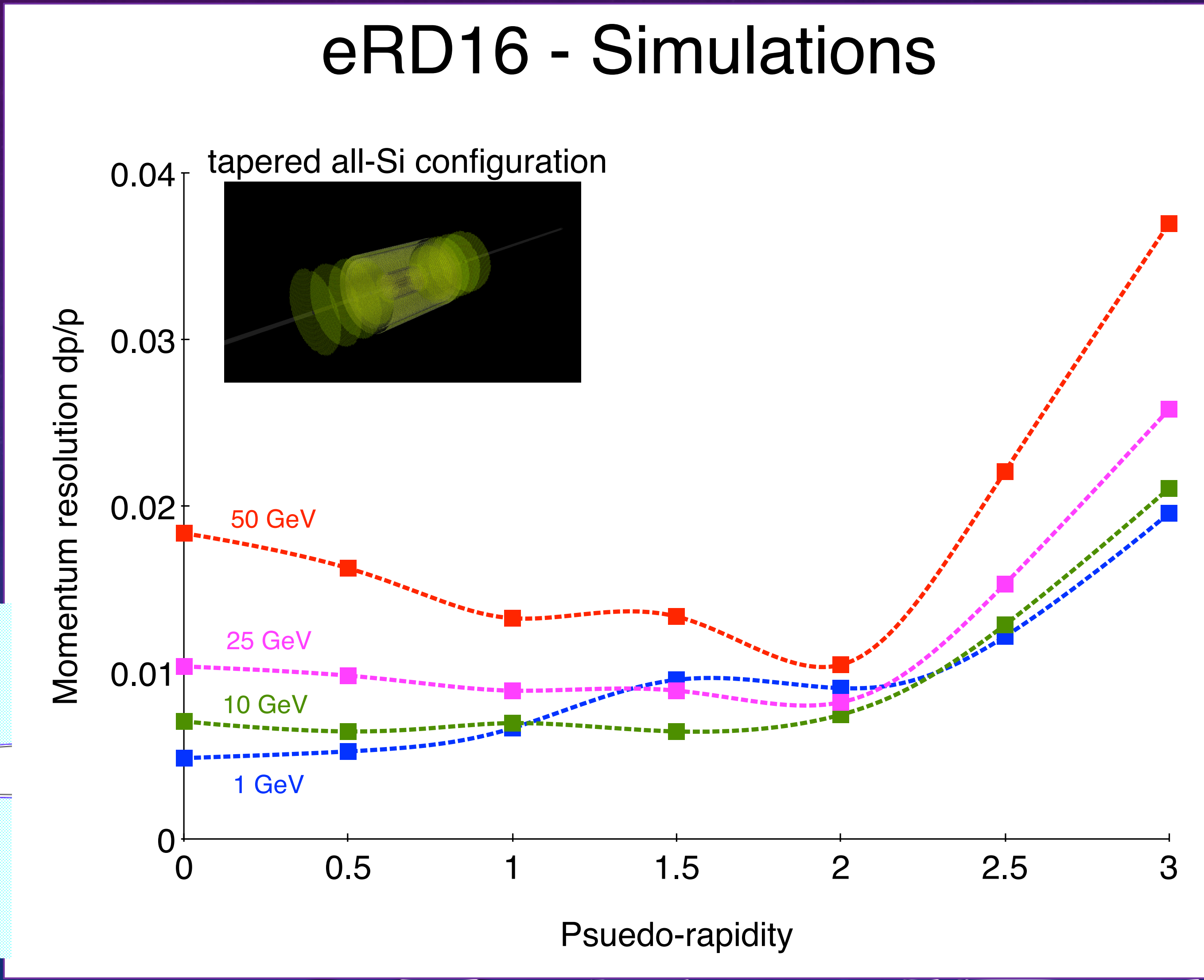
Additional Information
(14 slides of details)

Si Tracking Performance

https://wiki.bnl.gov/conferences/images/2/23/20190711-eRD16.v1.pdf

- Si Vertex Tracker:
  - Two MAPS layers, 20x20 μm^2 pixels
- Magnet Bore 160 cm diam.
  - 4 Si-strip Barrel Layers
  - Maximum radius 45 cm
  - 5 Si-strip Disk Layers, each endcap
- Performance @3T ≥ Si+TPC



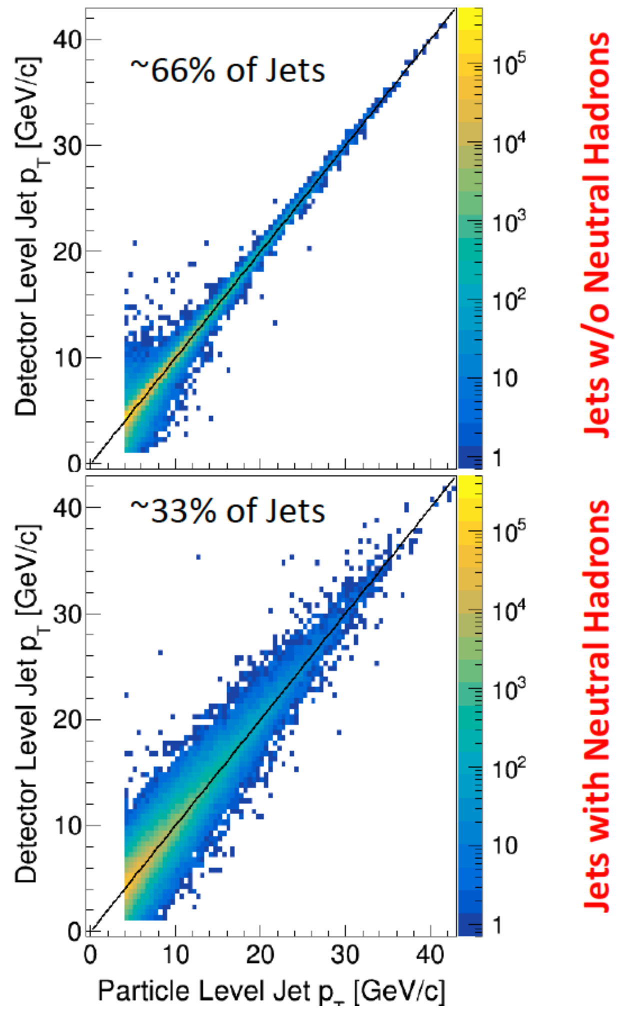


Jet Reconstruction, |η| <1.0

- EIC events have modest multiplicity.
- Charged particles via tracking, PID
  - $\delta p/p$ ~ 1% to 3%
- Photons in EM Calorimeters
  - 12%/sqrt(E) for $-1.5 < \eta < 2.0$
  - 2%/sqrt(E) for $-4 < \eta < -1.5$
  - 10%/sqrt(E) for $\eta > 2.0$
- Muons, K_L^0, neutrons tagged in BELLE-II $K_{Long}\mu$ (KLM) instrumented flux return
  - Muons: PID in KLM, tracking in central Si
  - K_L^0: Veto events with large shower in KLM, correct with K_S^0 sample
  - Neutrons, (rare) vetoed by KLM

Brian Page
EICUG "Pavia Meeting"
Calorimeter WG Parallel Session
19 March 2020

Neutral Hadron Veto



arXiv:1911.00657

- A low energy resolution HCal may not improve jet energy resolution much, but may be useful as a neutral hadron veto
- Identify jets which contain neutral hadrons by finding energy clusters which do not have tracks pointing to them
- The roughly 66% of jets which do not contain neutral hadrons will have energy resolutions defined by the tracker and can have a very small correction
- Only apply a large correction to the 33% of jets which have neutrals

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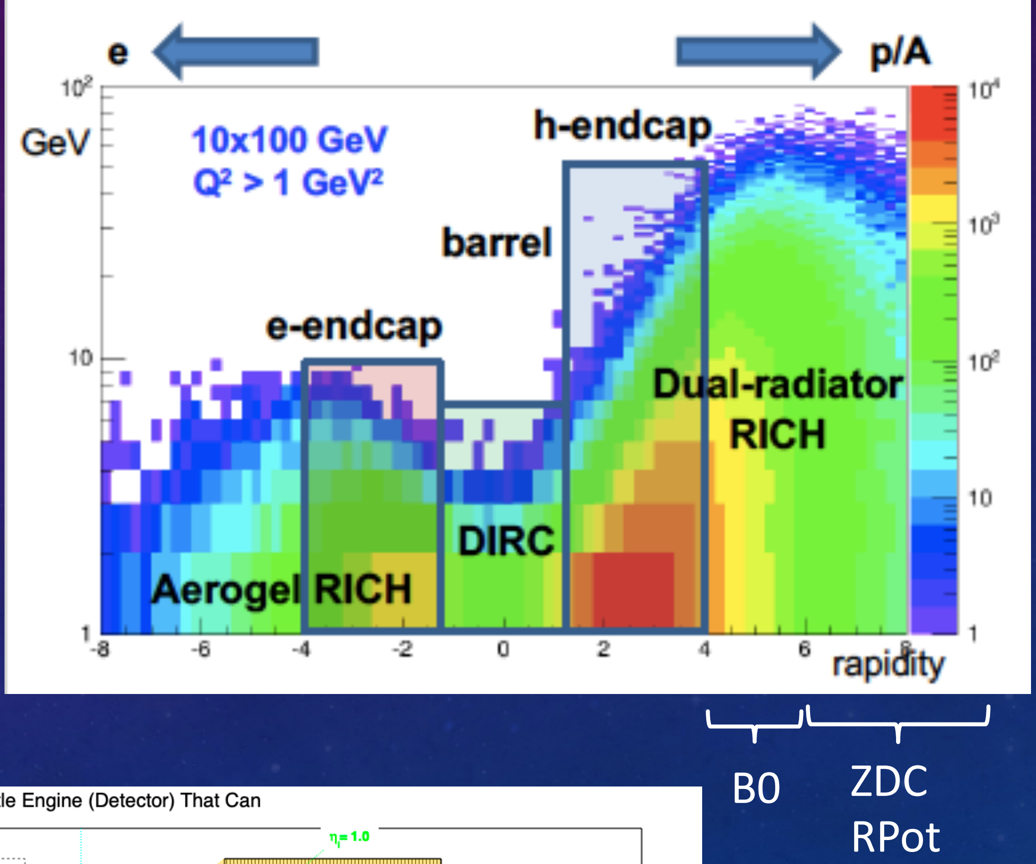
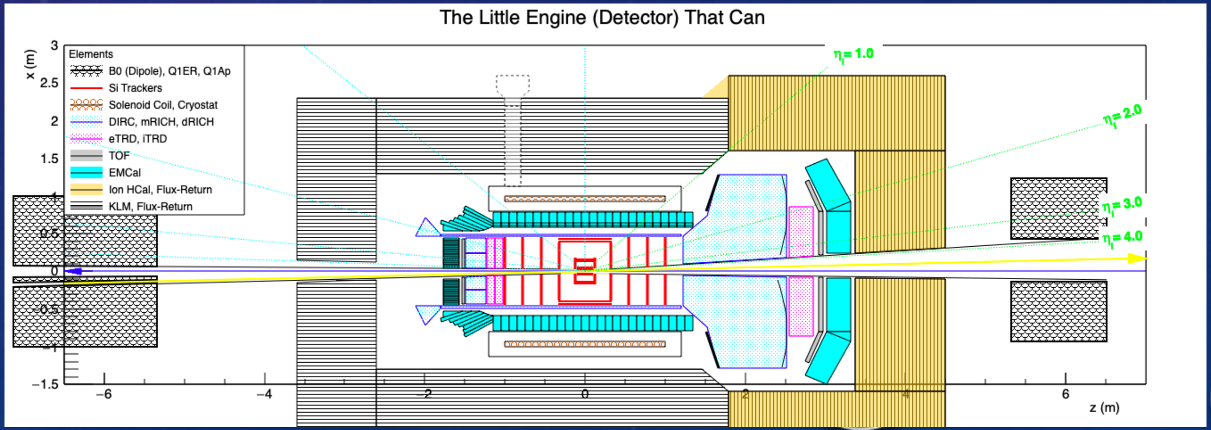
Hadron PID: eRD14 Concepts

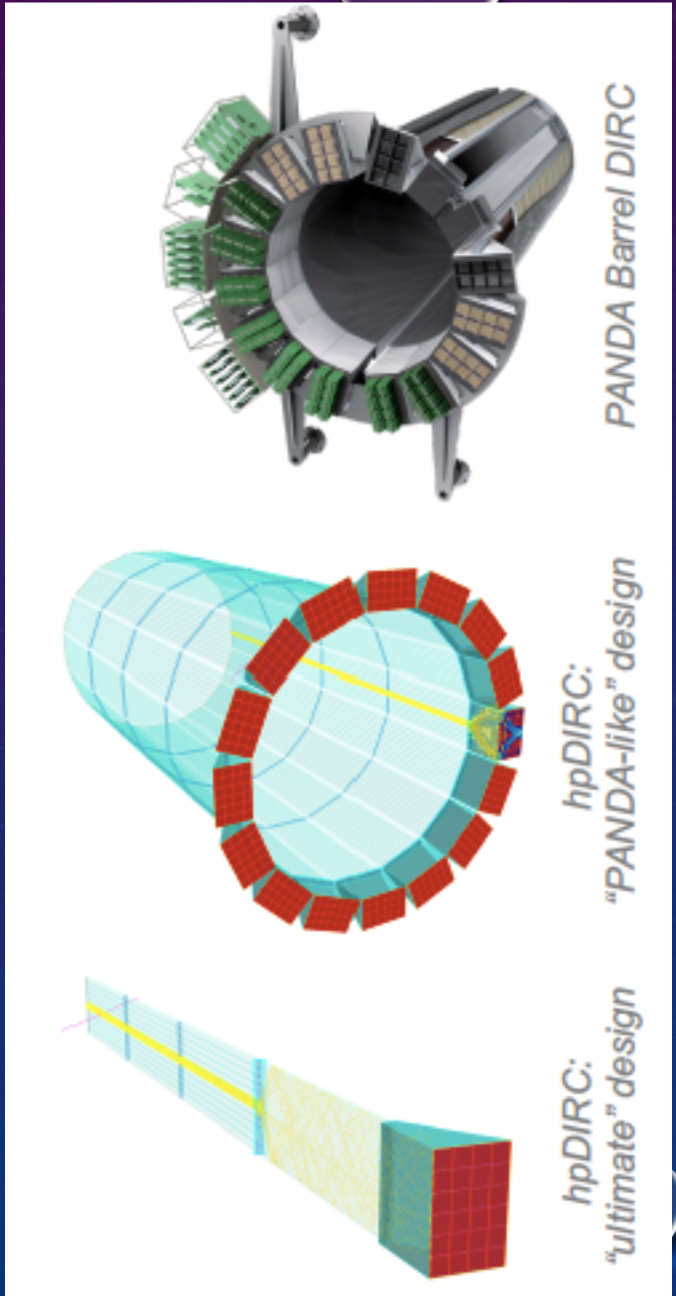
- Hadron endcap Dual Cherenkov (1.6< η < 4.0)
  - dRICH: Aerogel plus heavy gas
  - Common photo-sensors reduces cost
  - B-field must be shaped approximately projective to minimize “lighthouse” effect
- Barrel DIRC high performance PID goal (|η|<1.8): ≥3σ π/K for p < 6 GeV/c
- Electron Endcap Modular RICH (mRICH), Aerogel radiator (n= 1.02) and Fresnel lens (20 cm)[3]
  - $K^{\pm}/\pi^{\pm}$ separation ≥ 3σ for p≤ 8 GeV
  - -4.0 < η < -1.5





High Performance DIRC
$-2.1 \leq \eta \leq 1.6$

- 3σ pi/K separation up to 6 GeV/c
  - Focusing lens
  - $(3\ \text{mm})^2$ pixelated photo-sensors
  - Simulation validated by PANDA beam tests with lens and $(6\ \text{mm})^2$ pixels
  - Requires tracking precision 0.5 mr from central tracker
  - Details in eRD14 reports to R&D Committee
- New element for vetoing/correcting multiple scattering:
  - High spatial precision pre-shower in Barrel EMCal
  - 100 µm precision after 10 cm drift ≈ 1 mrad precision on m.s.



$e^{\pm}/\pi^{\pm}$ and γ/π^0 SEPARATION

- Forward Electron Endcap:
  - High-granularity, high resolution PbWO4 calorimeter
  - Two-layer (20 cm) TRD with GEM photo-cathode
- Barrel region
  - EMCal, with high spatial resolution pre-shower layer (Si+W)
    - ALICE FOCAL pre-shower with Si pixel layers at $2X_0$ and $5X_0$
    - 1 mm spatial resolution of shower → > 6σ 2cluster separation for $E(\pi^0) \leq 14$ GeV
    - Total absorption, any suitable technology with $X_0 \leq 1$cm
- Forward Ion Endcap
  - EMCal Shashlyk ~ 10%/sqrt(E)
  - Transition Radiation Detector (3 layer, 30 cm)

NEW CUSTOM SOLENOID

- Primary magnetic volume is π 2m^3. Compare with BaBar: π 7.8m^3
- Possibilities of shaping field
  - Projective field in track volume of dRICH
  - Field orthogonal to dRICH PhotoSensor plane
  - Field orthogonal to DIRC PhotoSensor plane
- Nominal field is 1.5 T
  - Could be increased to 3T if field shaping is sufficiently successful

HCAL IN FORWARD ION ENDCAP

- Design includes coverage $1<\eta<4$
- What range is needed?
- Jet cluster: $|\Delta\eta| <\pm 0.5$
- *E_{Jet} < 50 GeV* for $\eta<2$

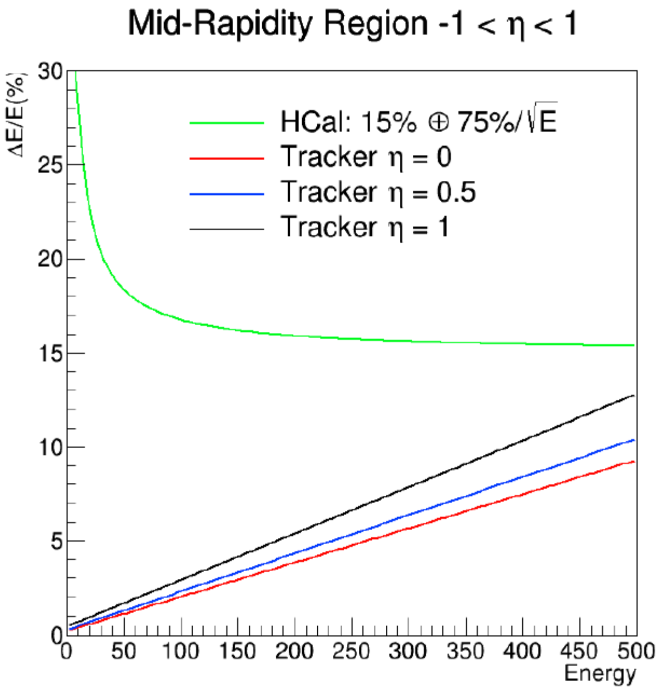
Jets and Calorimetry: First Look

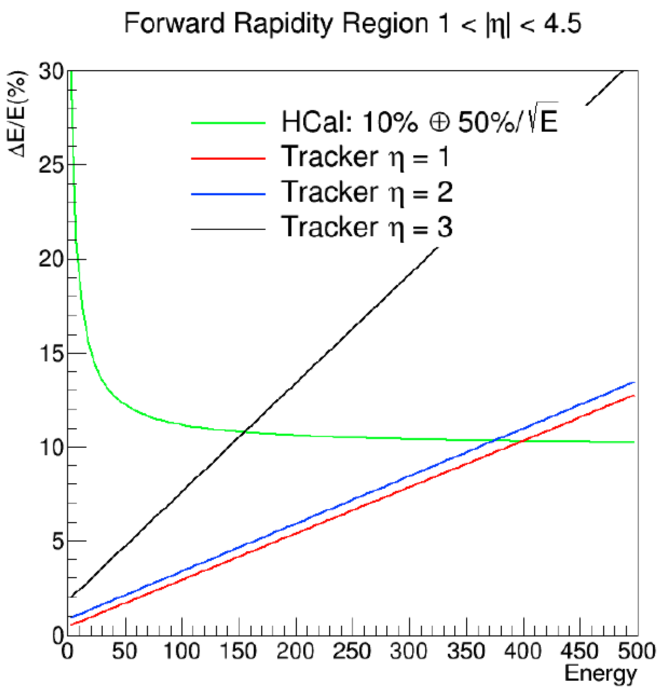
Brian Page
Calorimeter WG Parallel Session
3/19/2020

Hcal in barrel and e-endcap serves only as a K^0_L veto
- nn-bar pairs are very rare

Not clear if *any* measurement would specifically require independent determination of K^0_L and K^0_S rather than just inferring total K^0 from K^0_S
- K^0_s can be measured w/o Hcal

Tracker Vs HCal Resolution





- Tracker provides better resolutions for nearly all energies and pseudorapidities
- Assumption: use tracker for all hadrons except long lived neutrals such as neutrons and K^0_Ls

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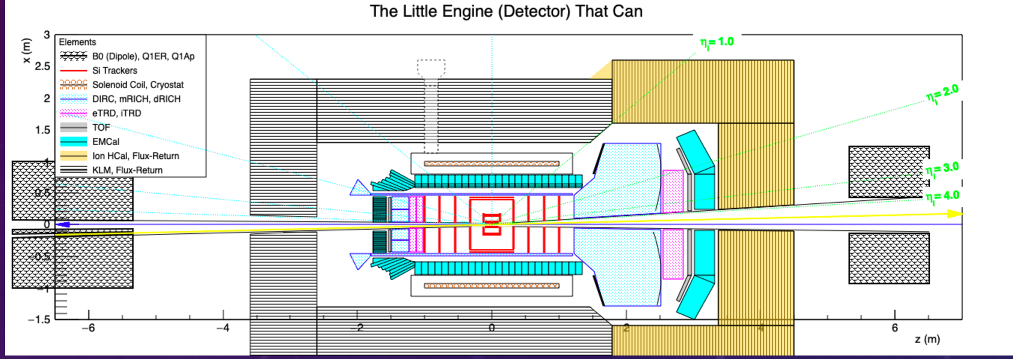
A SCINTILLATOR BASED ENDCAP K_L AND MUON DETECTOR FOR THE BELLE II EXPERIMENT

HTTPS://ARXIV.ORG/PDF/1406.3267.PDF



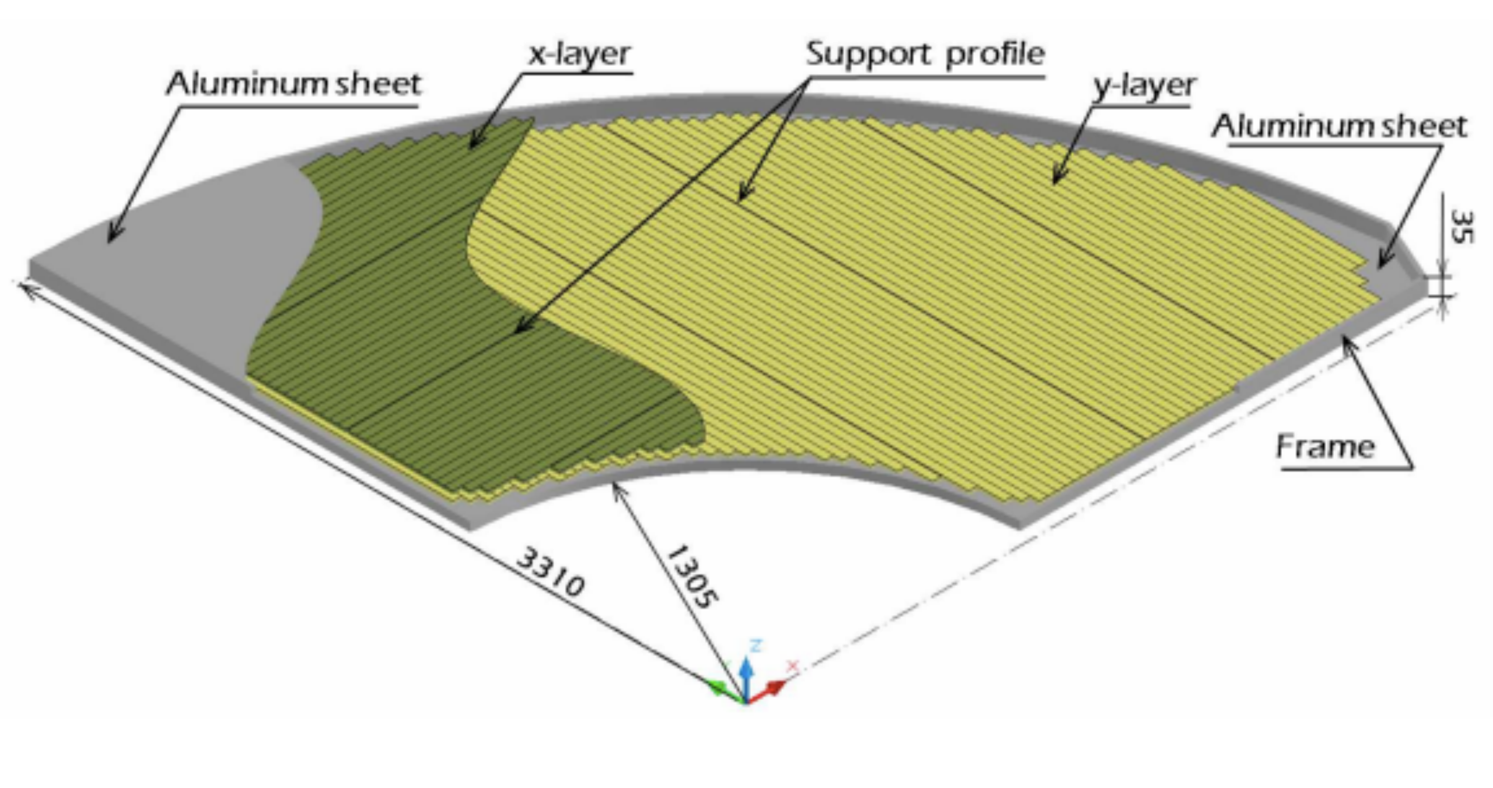


Figure 2: Schematic view of one superlayer formed by scintillator strips. Sizes are given in mm.

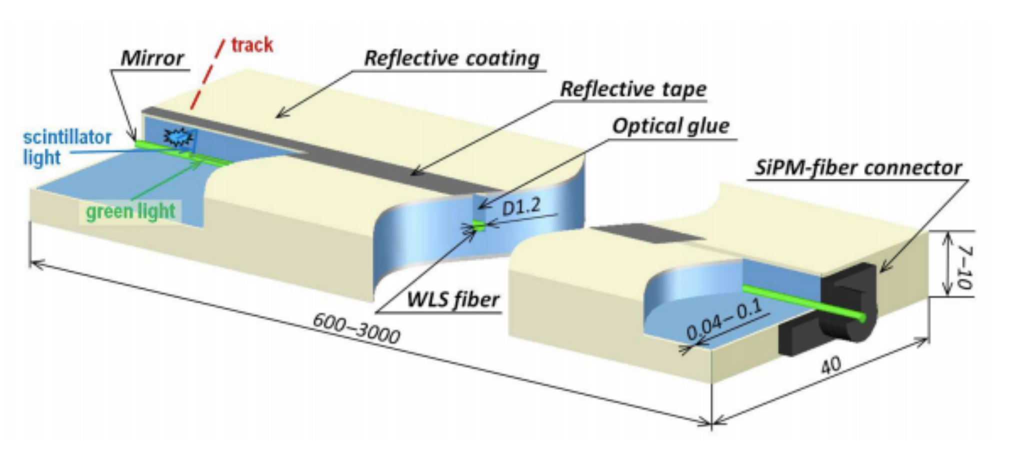


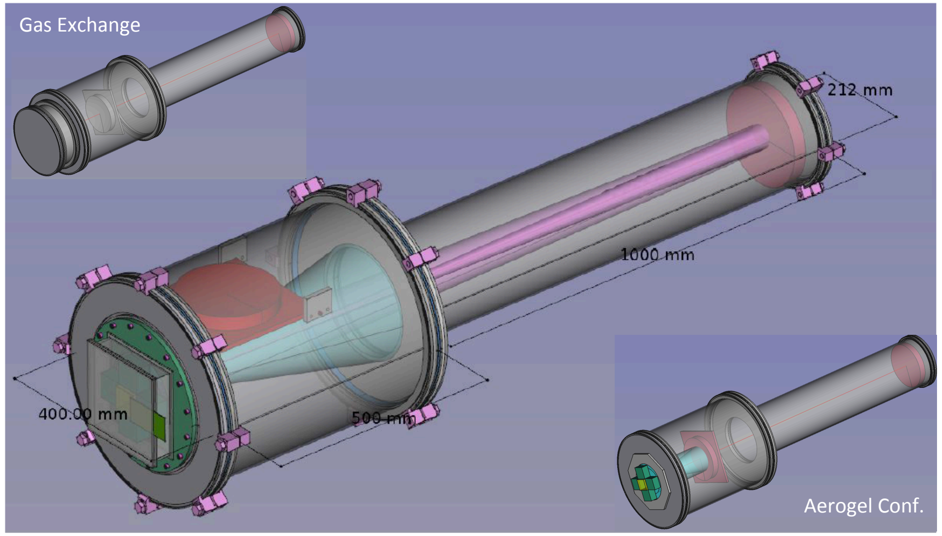
Figure 1: Schematic view of the scintillator strip. Dimensions are in mm.

- Individual single channel SiPM readout

Dual RICH: Simulations and Prototyping

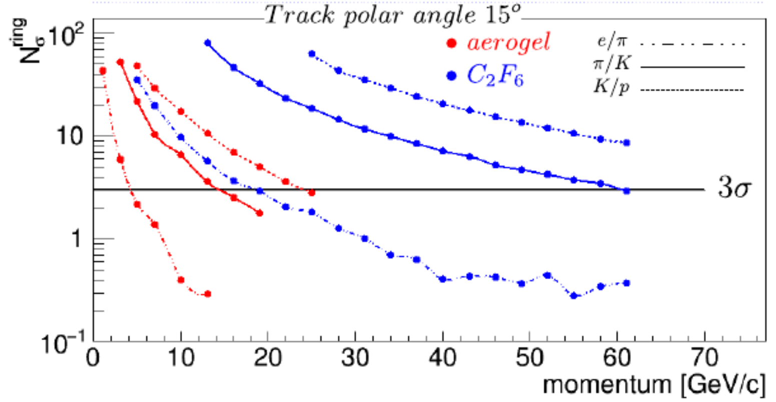
- eRD14 report, Sept 2019
- Evaristo Cisbani → https://indico.bnl.gov/event/6819/

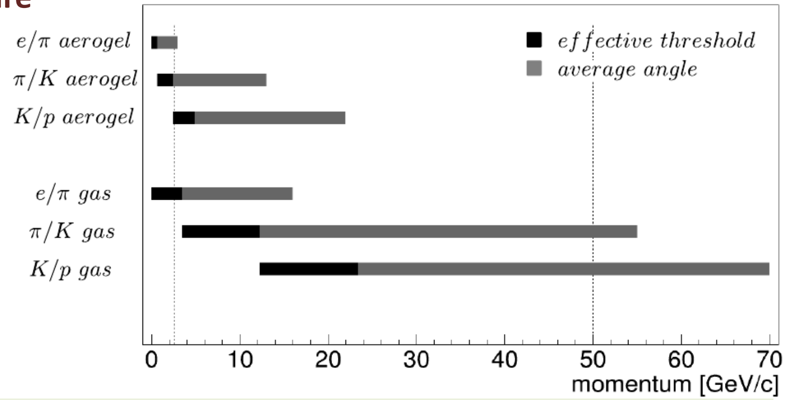
dRICH Prototype Design



dRICH baseline MC performance

- Montecarlo: GEMC (Geant4)
- Aerogel Optical properties from CLAS12 RICH data, scaled to 1.02
- Acrylic Filter (<300nm) after the aerogel to minimize Rayleigh
- Gas number of photons normalized by 0.7 factor from «poor» literature
- Include 3T central magnetic field
- Mirror quality from CLAS12
- QE from realistic CLAS12/PMT measurements (200-500 nm)
- Cherenkov Angle reconstruction based on Inverse Ray Tracing

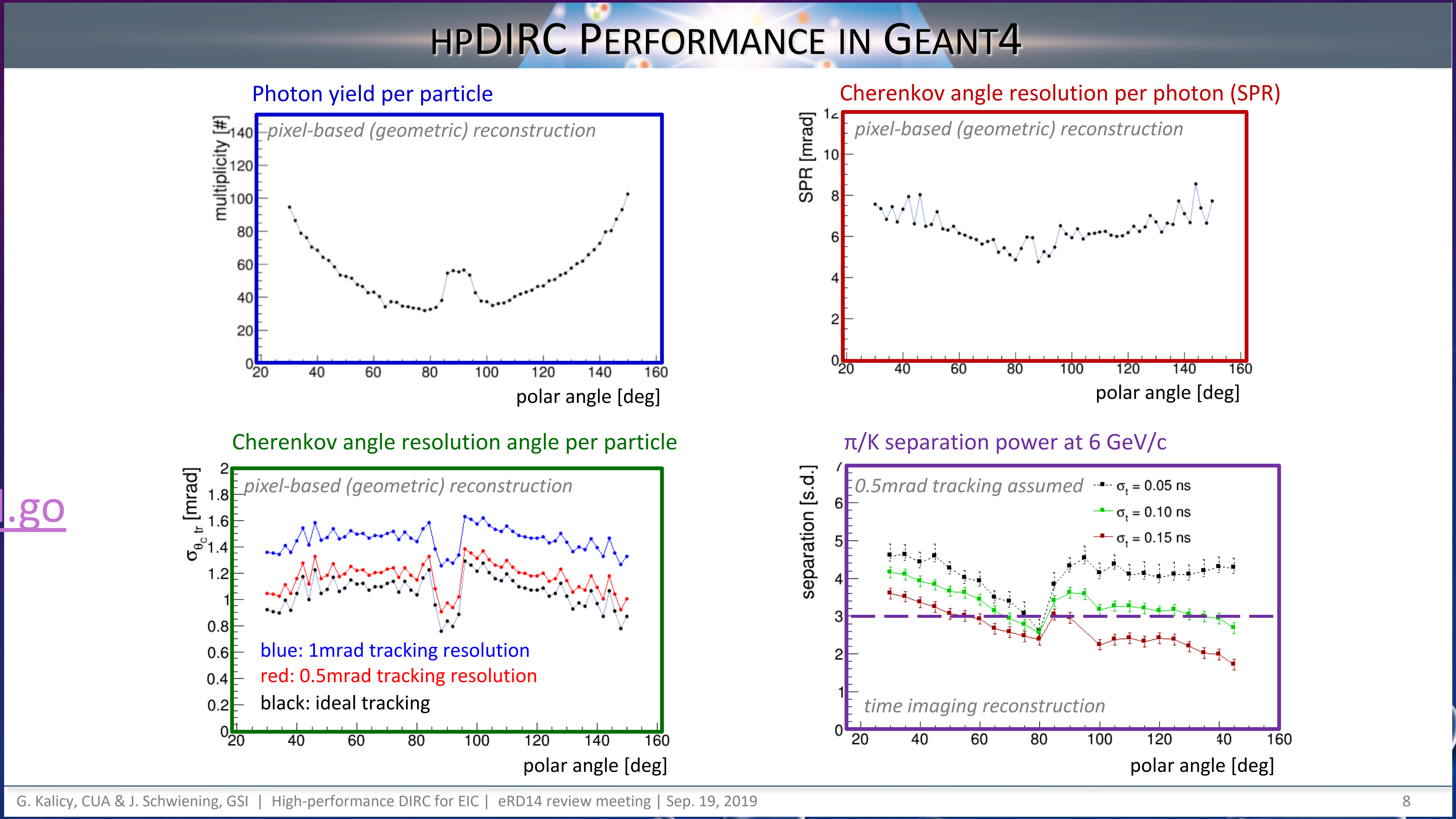




Hadron identification (π/K/p, better than 3 sigma apart); continuous coverage from ~3 up to ~50 GeV/c for π/K and up to ~15 GeV/c for e/π

19/Sep/2019 E.Cisbani - dRICH development (part 1) 9

DIRC SIMULATION STATUS

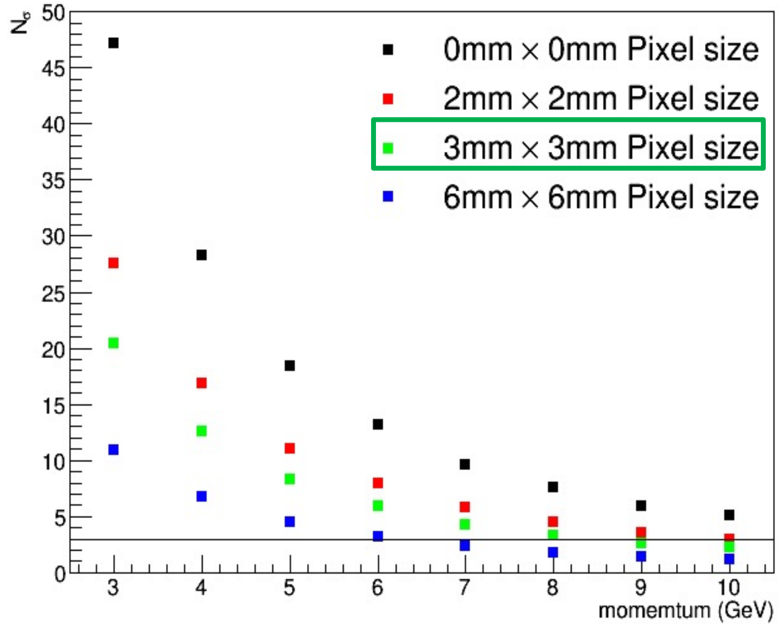


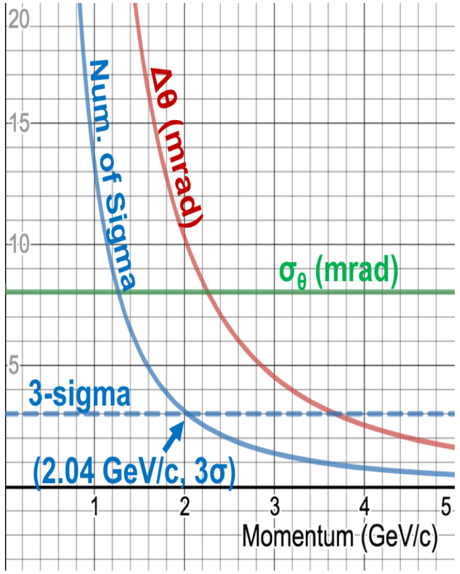
- eRD14 report
  Sept 2019
- https://indico.bnl.gov/event/6819/

MRICH PID (ELECTRON ENDCAP)

- $K^\pm/\pi^\pm$ separation ≥ 3σ for p≤ 8 GeV/c
- –4< η < –1.5
  - Switch mRICH and eTRD from cartoon

Projected mRICH Performance





- Projected K/pi separation of mRICH 2nd prototype detector (**Green dots**)
- 2nd prototype detector can achieve 3-sigma K/pi separation up to 8 GeV/c

- Projected e/pi separation of mRICH 2nd prototype detector (**blue solid line**)
- 2nd prototype detector can achieve 3-sigma e/pi separation up to 2 GeV/c

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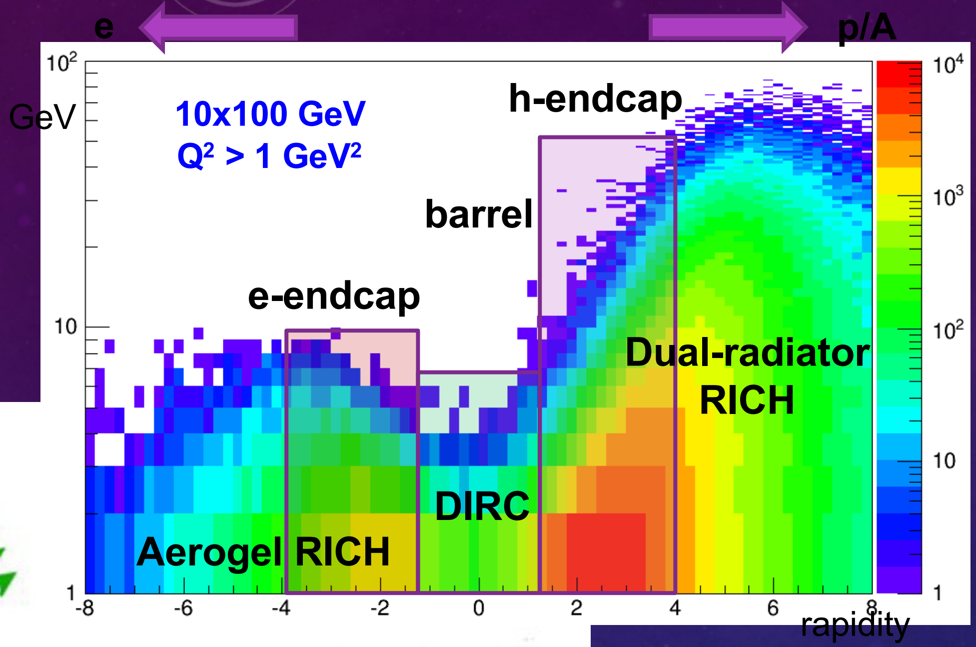
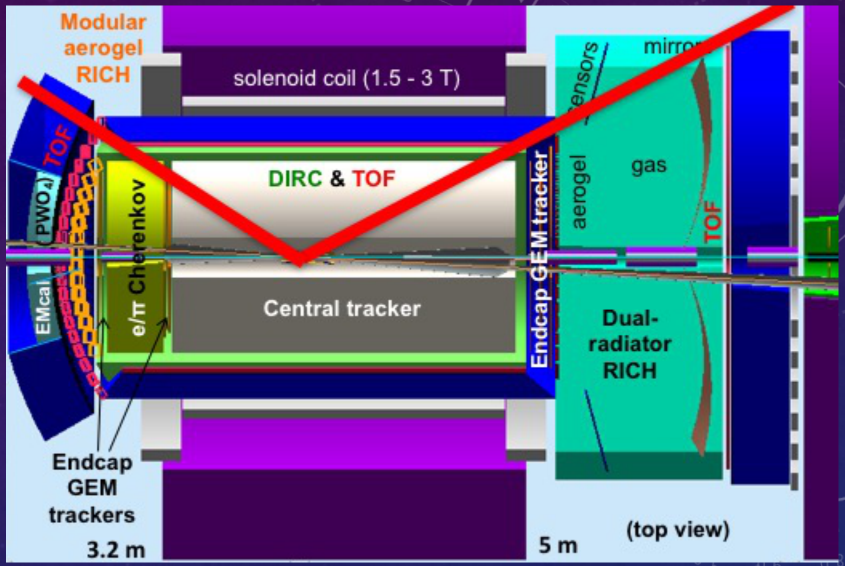
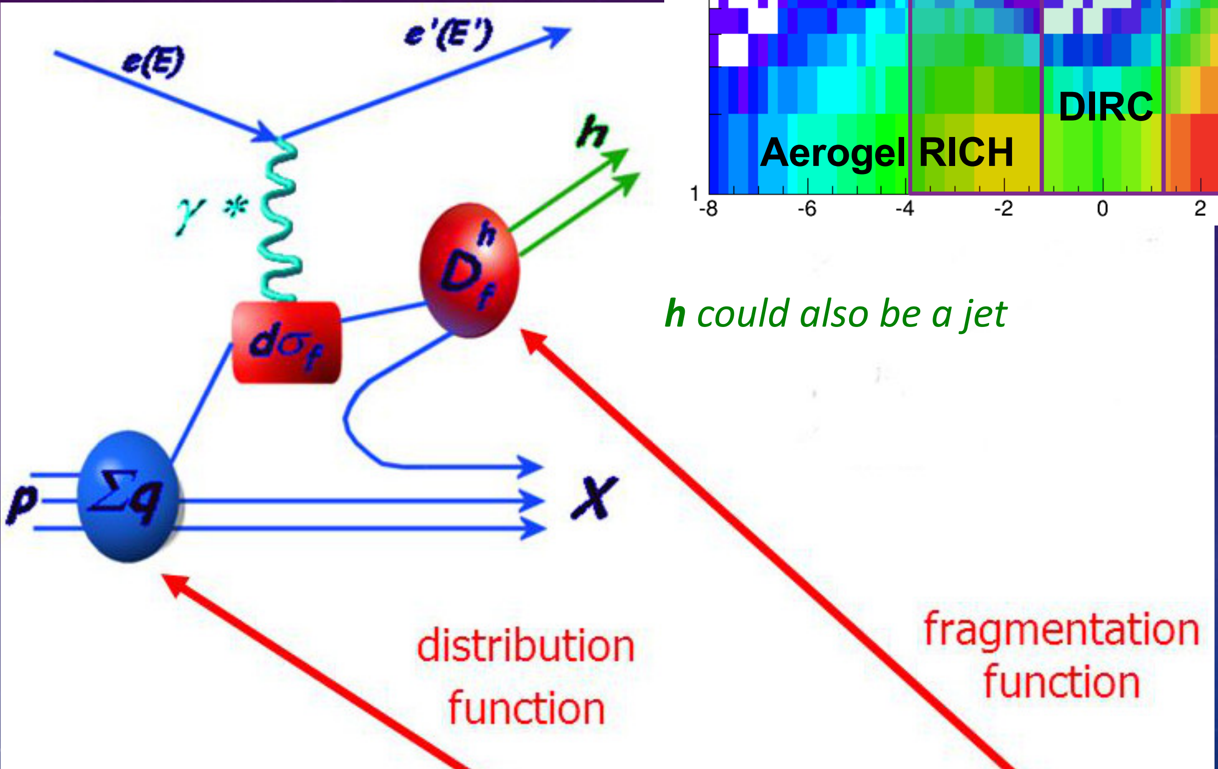
PID for the EIC





Semi-Inclusive DIS (SIDIS)



h could also be a jet

$$d\sigma^h(z) \propto \sum_f q_f(x) \otimes d\sigma_f \otimes D_f^{q\to h}(z)$$

- Particle ID is an essential capability required for the EIC physics program
  - SIDIS, open charm, etc
- Imaging Cherenkov detectors are the primary technology
  - Photosensors and electronics are also key R&D areas for the consortium

ALICE INNER TRACKING SYSTEM (ITS) AND UPGRADE

- ALICE ITS: http://alice.web.cern.ch/detectors/more-details-alice-its#
- ITS upgrade: https://ep-news.web.cern.ch/content/alice-its-upgrade-pixels-quarks
- The MAPS-based ITS Upgrade for ALICE: https://arxiv.org/pdf/2001.03042.pdf
- 2018 ITS EOI and cost estimate of 5.3 MCHF: https://cds.cern.ch/record/2644611/files/ITS3%20EoI.1.pdf

ALICE ITS UPGRADE

- All MAPS (ALPIDE chip)
  - Si layer thicknesses from 50 to 100 µm
  - 40 mW/cm^2
  - Low mass carbon fiber support/cooling staves
- 7 cylindrical layers at radii from 2.3 cm to 39.3 cm
- 10 m^2, 12.5 Gpixels
- Data rate: 50 KHz Pb-Pb collisions