Hadron Identification for Flavor Separation at EIC

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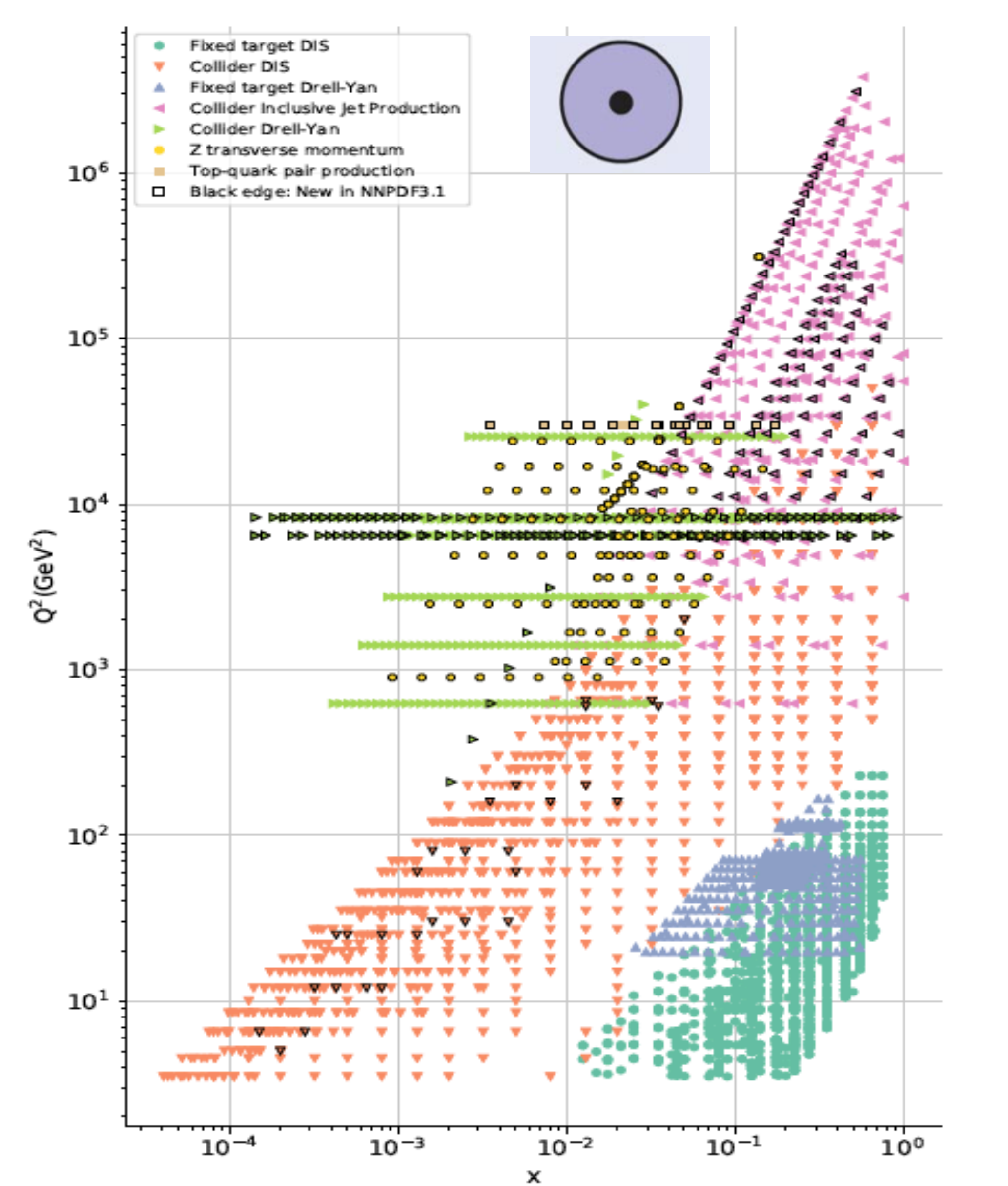
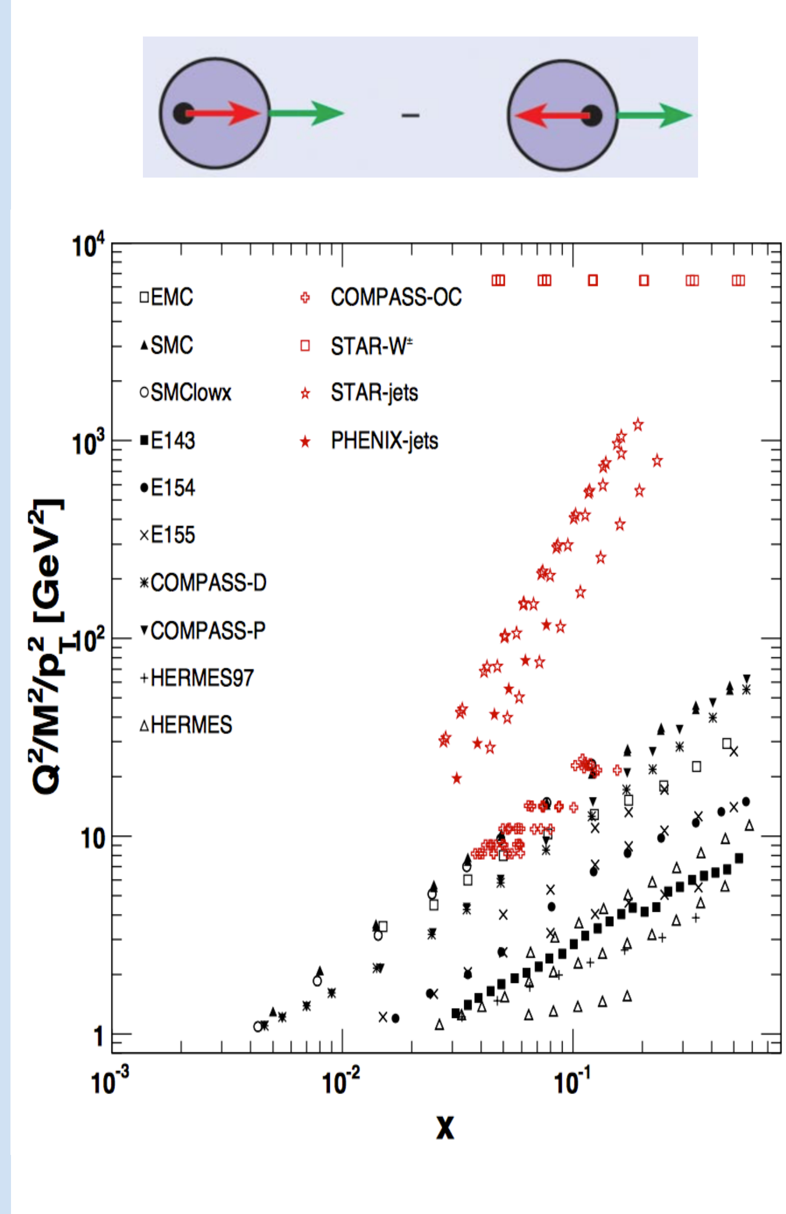
INFN Ferrara

QCD with Electron-ion Collider (QEIC)
January 6, 2020 IIT Bombay, India

Kinematic Coverage

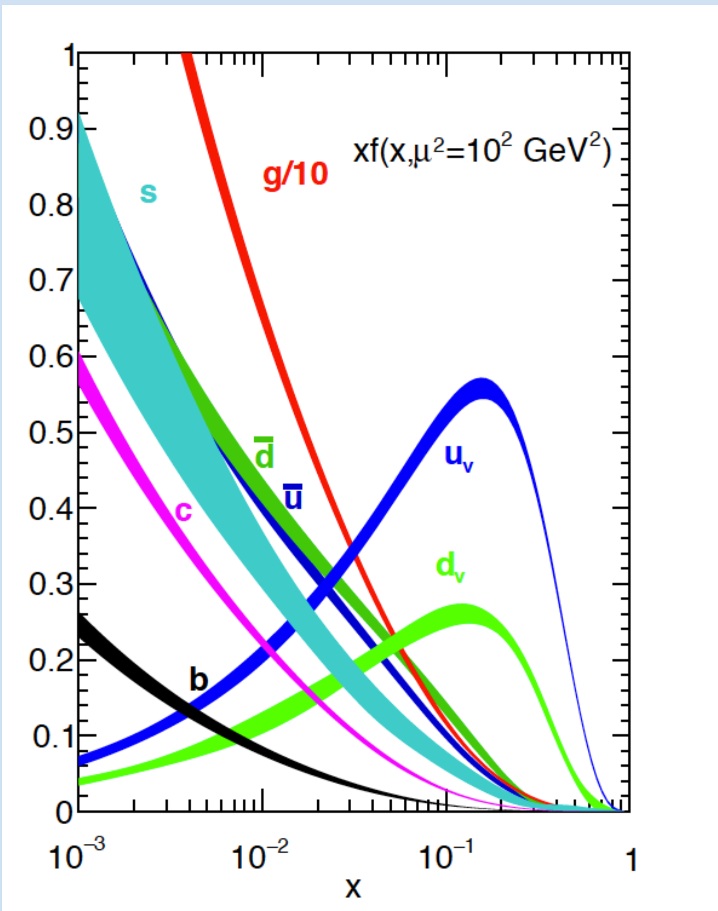


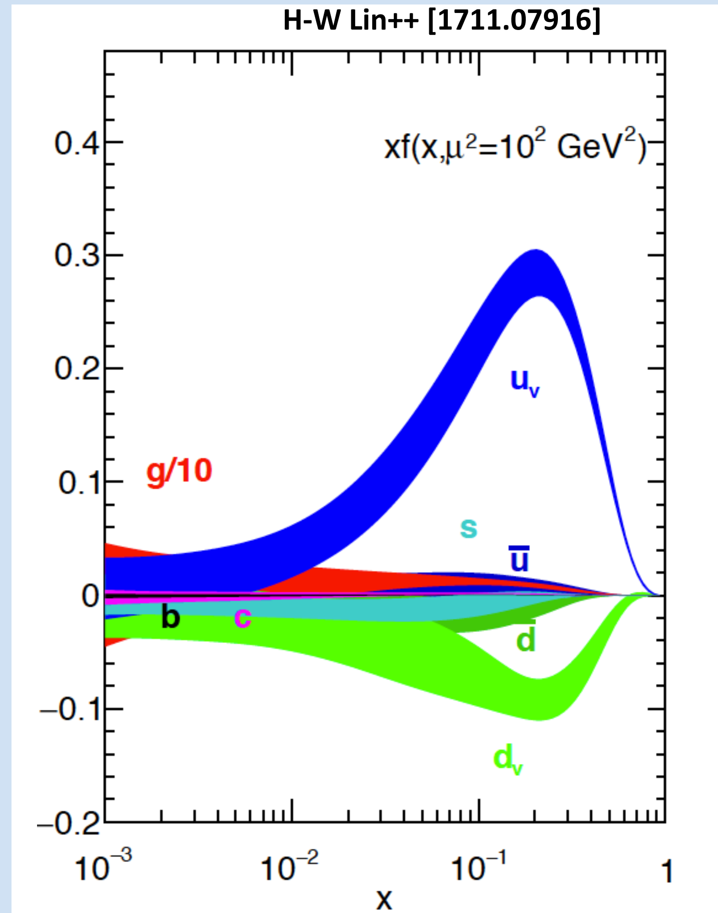


Parton Content

MMHT [arXiv 1412.3989]
HERAPDF2.0 [arXiv 1506.06042]
CT14 [arXiv 1506.07443]
CJ15 [arXiv 1602.03154]
ABMP16 [arXiv 1701.05838]
NNPDF3.1 [arXiv 1706.00428]

BB [arXiv 1005.3113]
LSS [arXiv 1010.0574]
DSSV [arXiv 1404.4293]
BS [arXiv 1408.7057]
NNPDF [arXiv 1406.5539]
JLAM [arXiv 1601.07782]

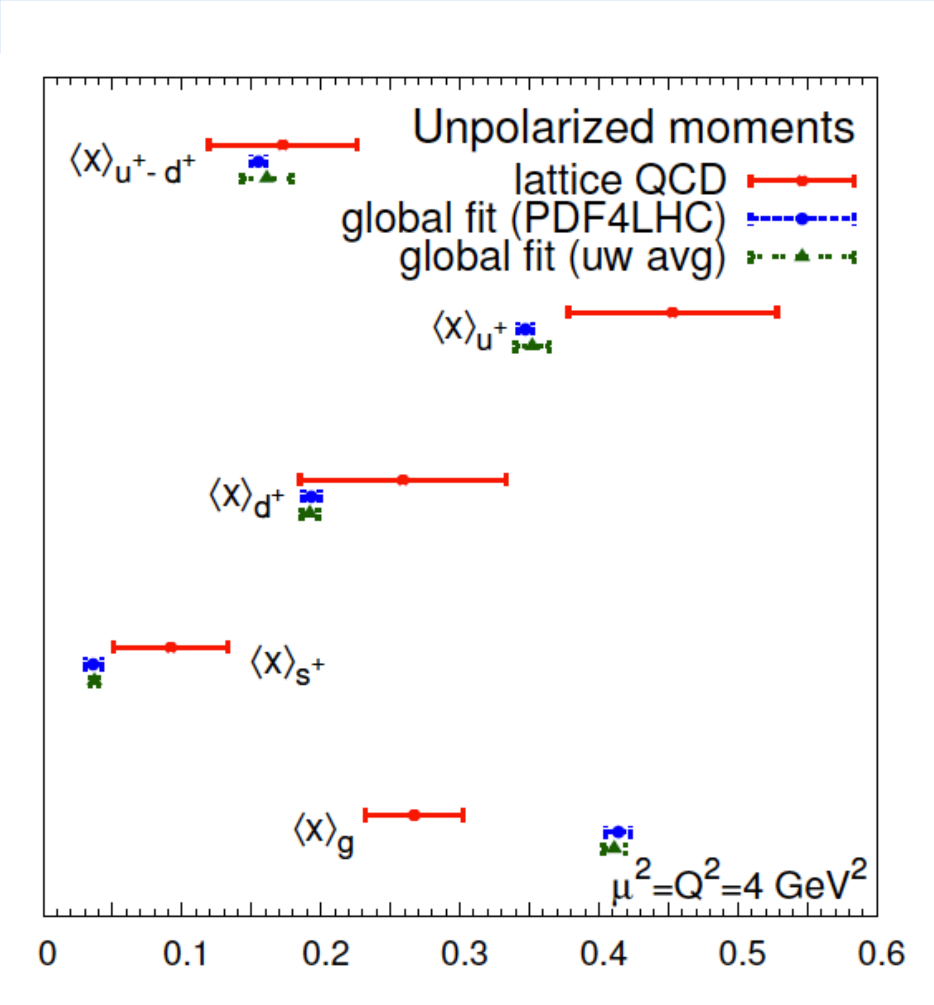




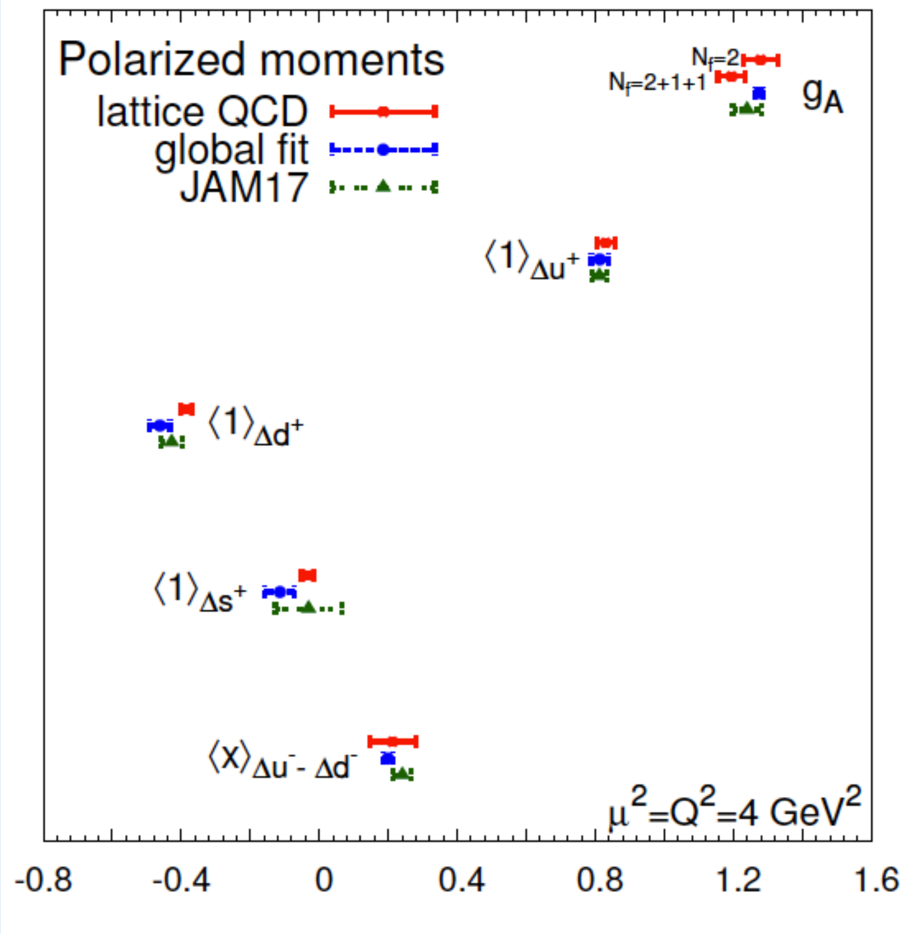
Parton Content

Unpolarized moments

Polarized (helicity) moments



H-W Lin++ [1711.07916]



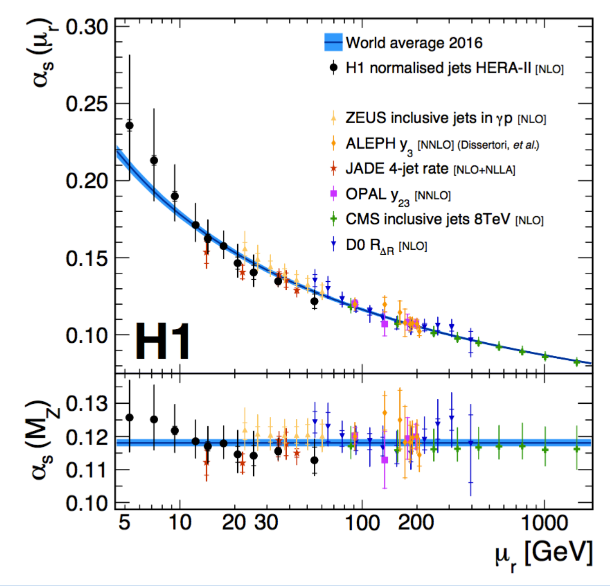
Inclusive Jets @ HERA

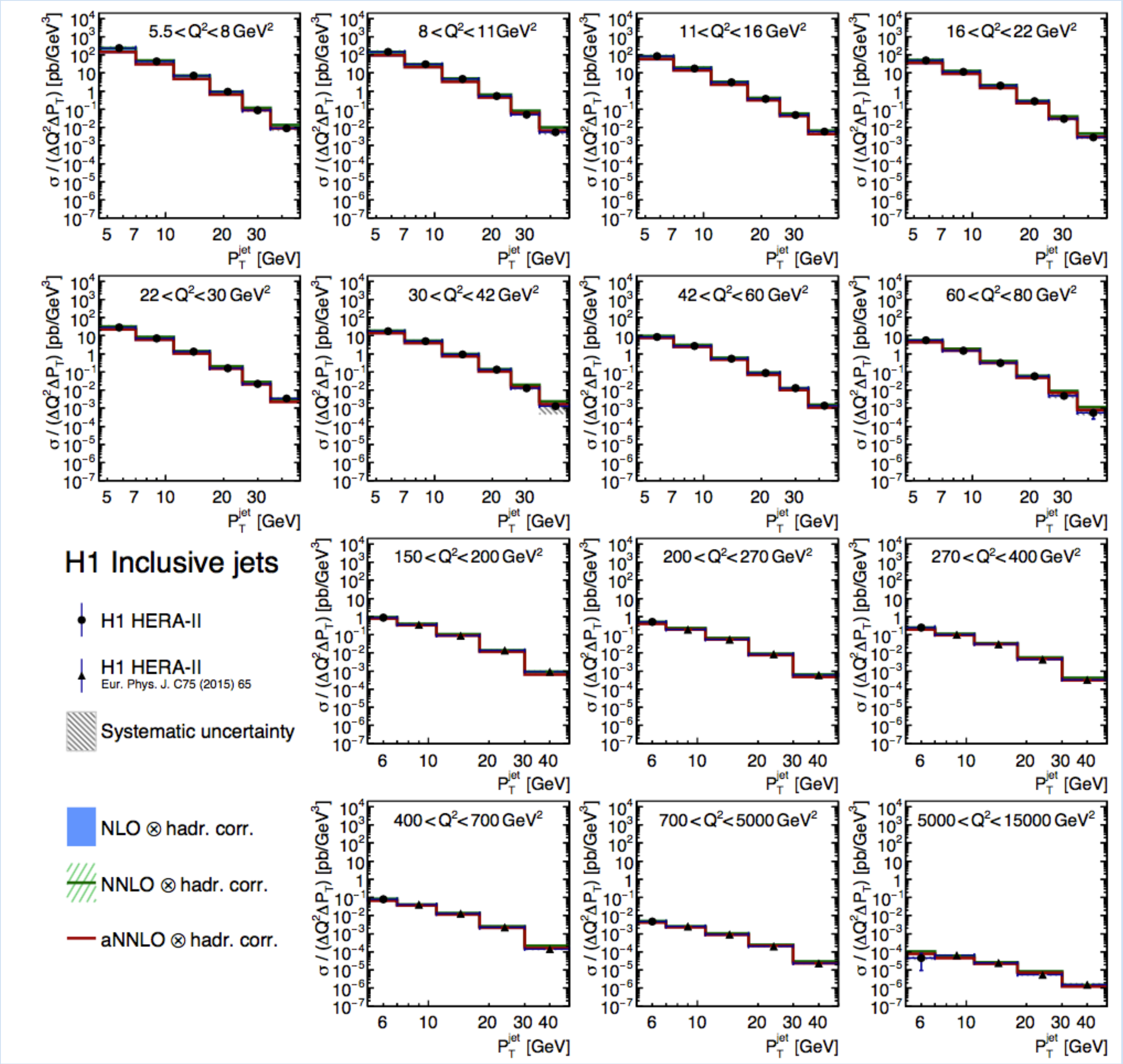
Good perturbative description
(hard gluon emission)

p_T>5 GeV Q^2>5 GeV^2

Part in a p_T<<Q TMD regime

H1 [arXiv: 1611.03421]

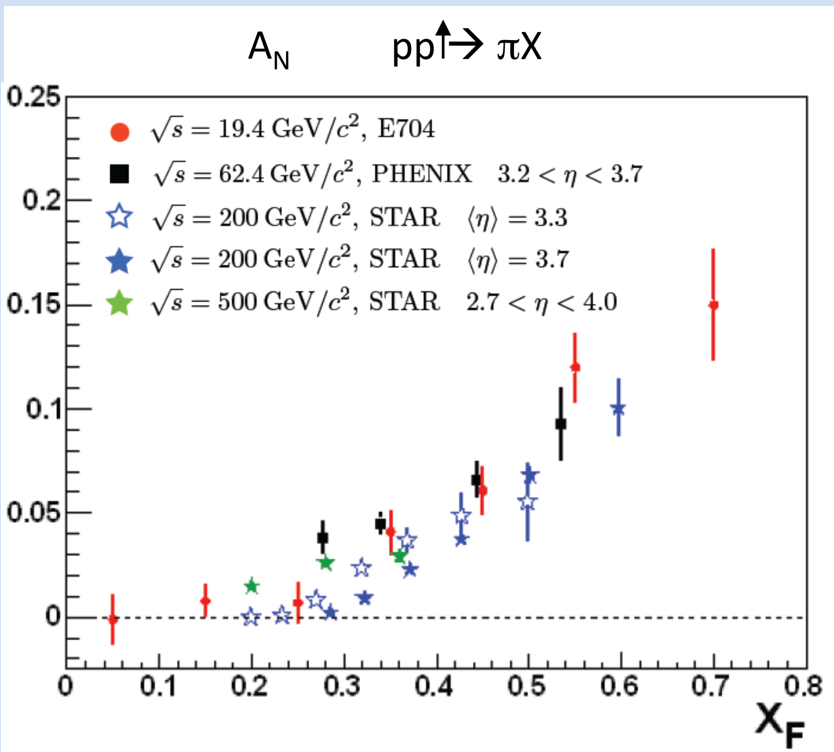




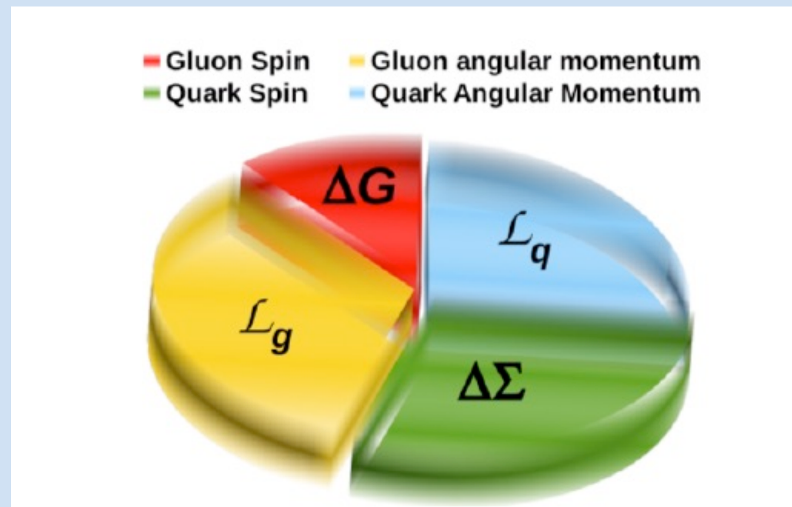
Can QCD be a precision science ?

Should not be confused with pQCD, which already can,
but is not touching the intimate nature of the strong interaction

Single Spin Asymmetries



Proton Spin Budget

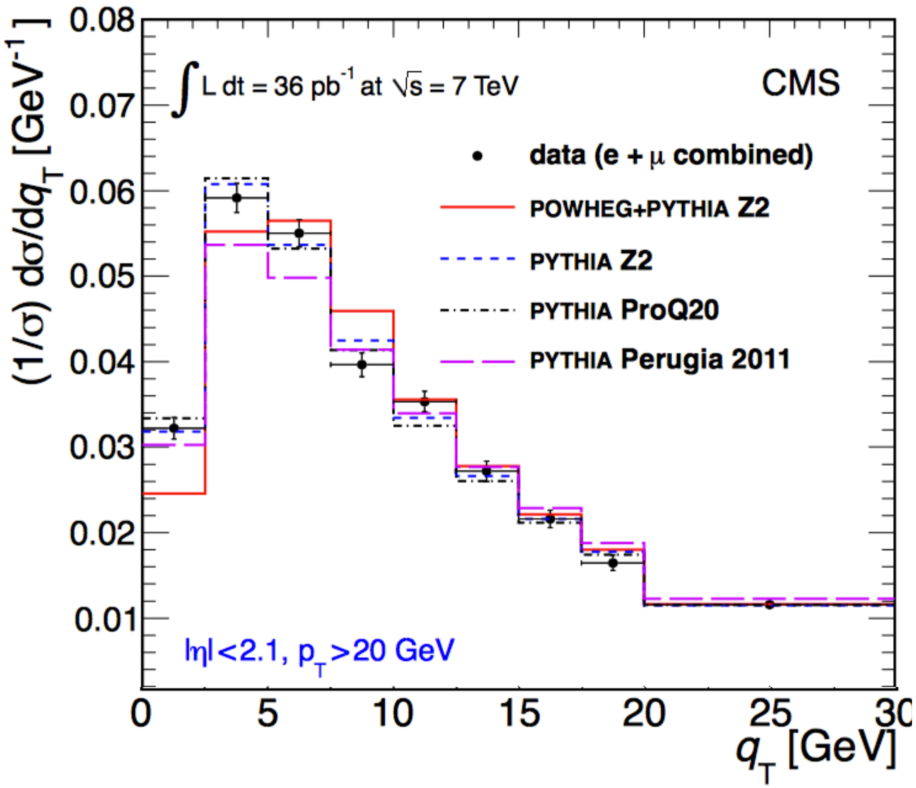


$$\frac{1}{2} = \frac{1}{2}\sum_f (q_f^+ - q_f^-) + L_q + \Delta G + L_g$$

Non Perturbative QCD Signals

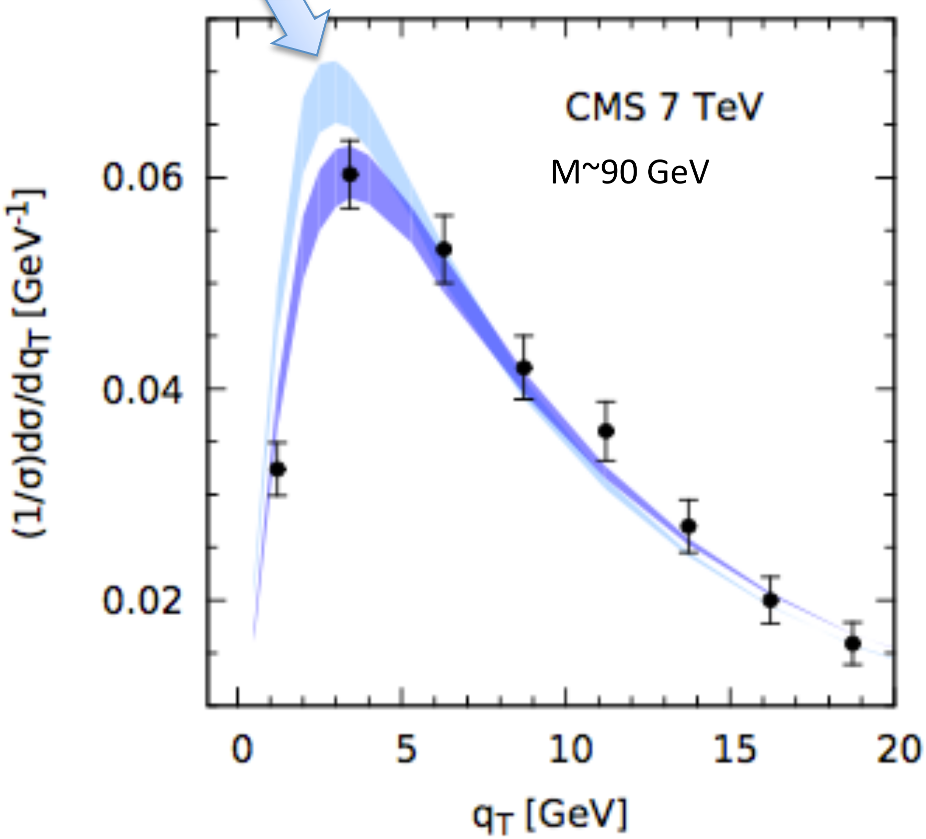
Non perturbative PDF component shows effects up to vector boson production at LHC

CMS [arXiv: 1110.4973]



$f_p^q(x, k_\perp^2)$

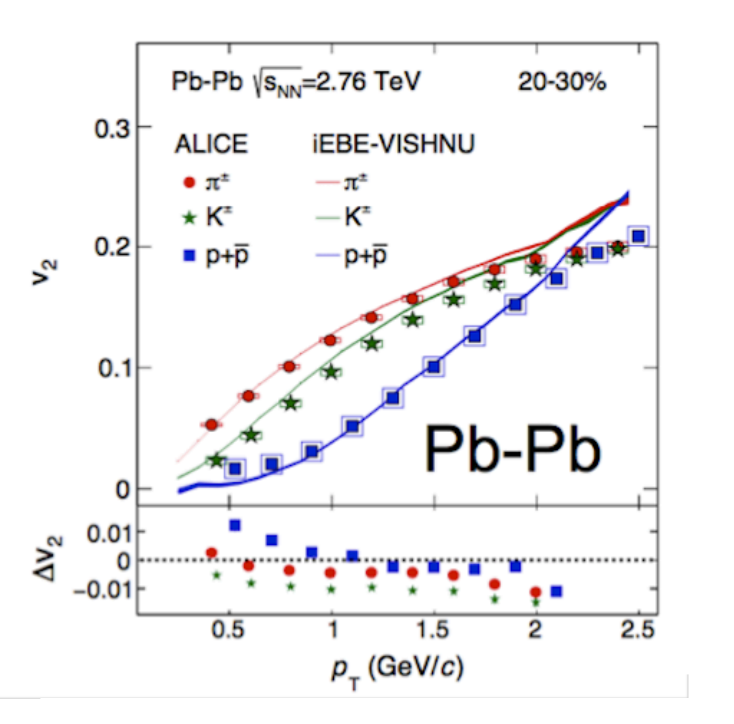
D'Alesio++ [arXiv: 1407.3311]



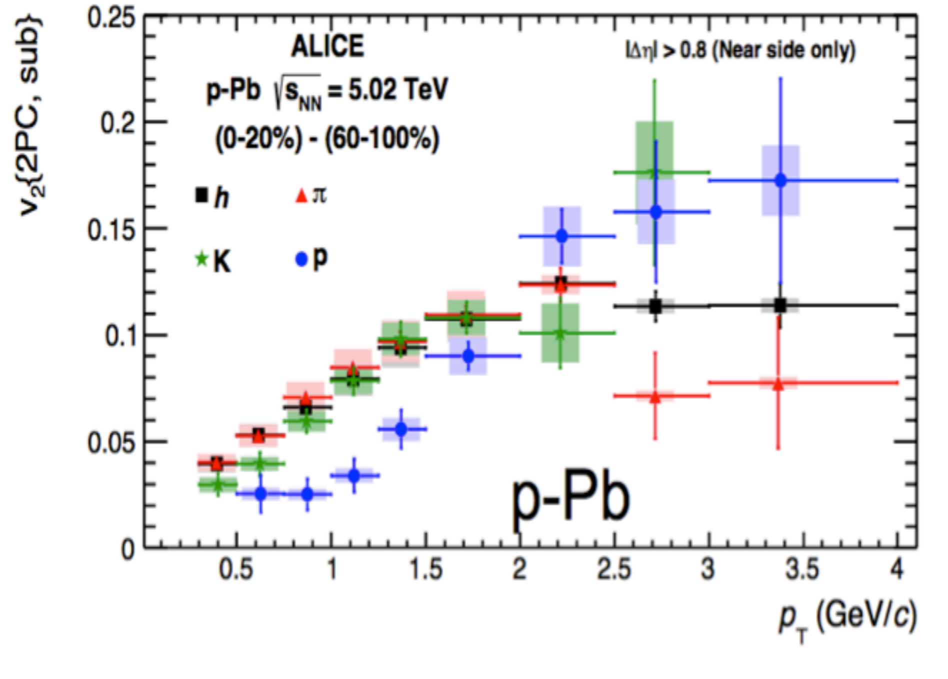
Still Surprising Proton

Is there a collective motion in small systems ?

$$\frac{dN}{d\varphi} = \frac{N_0}{2\pi}\left(1 + 2v_1\cos(\varphi - \Psi_1) + 2v_2\cos[2(\varphi - \Psi_2)] + \dots\right)$$



ALICE [PLB 726 (2013) 164]

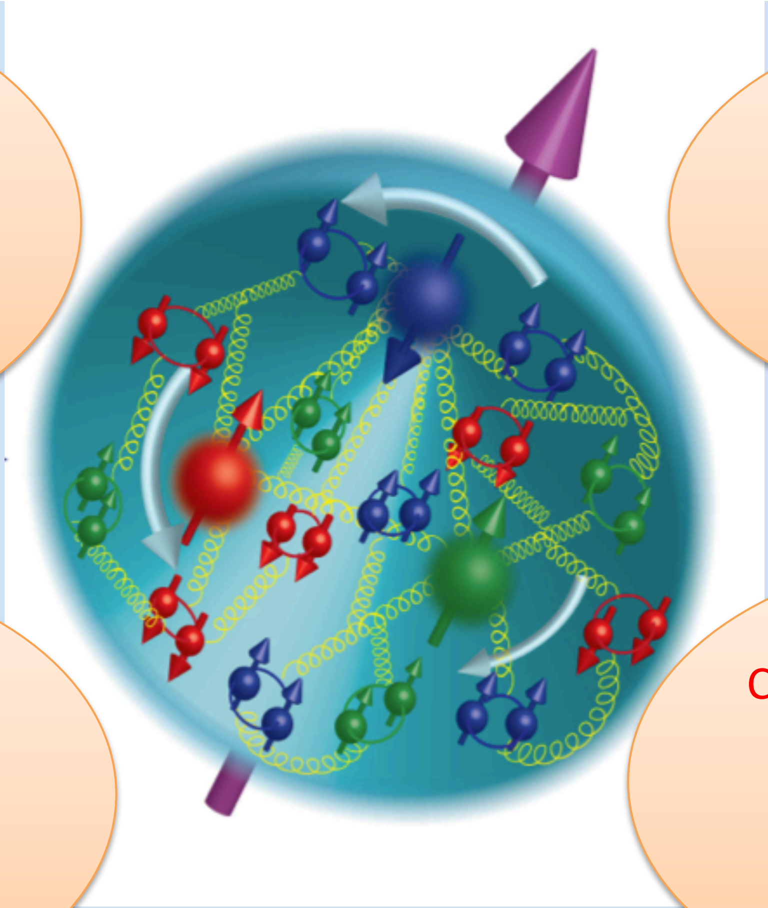


The Strong Force Confined Universe

$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \sum_{q=u,d,s,c,b,t} \bar{q}\left[i\gamma^{\mu}(\partial_{\mu} - igA_{\mu}) - m_q\right]q$$

Dynamic Spin
- Parton polarization
- Orbital motion
- Form Factors
- Magnetic Moment

Parton Correlations
- dPDFs
- Short range
- MPI



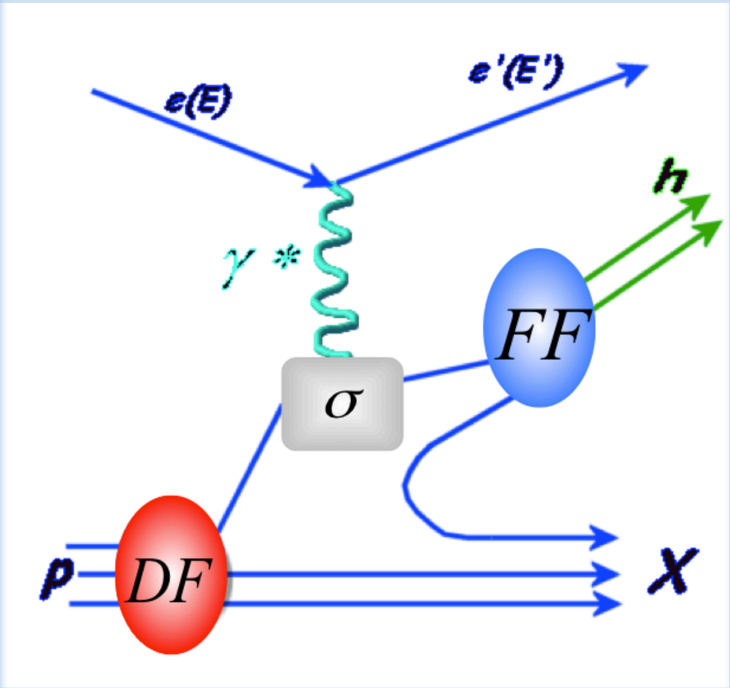
Hadronization
- Spin-orbit effects
- Parton energy loss
- Jet quenching

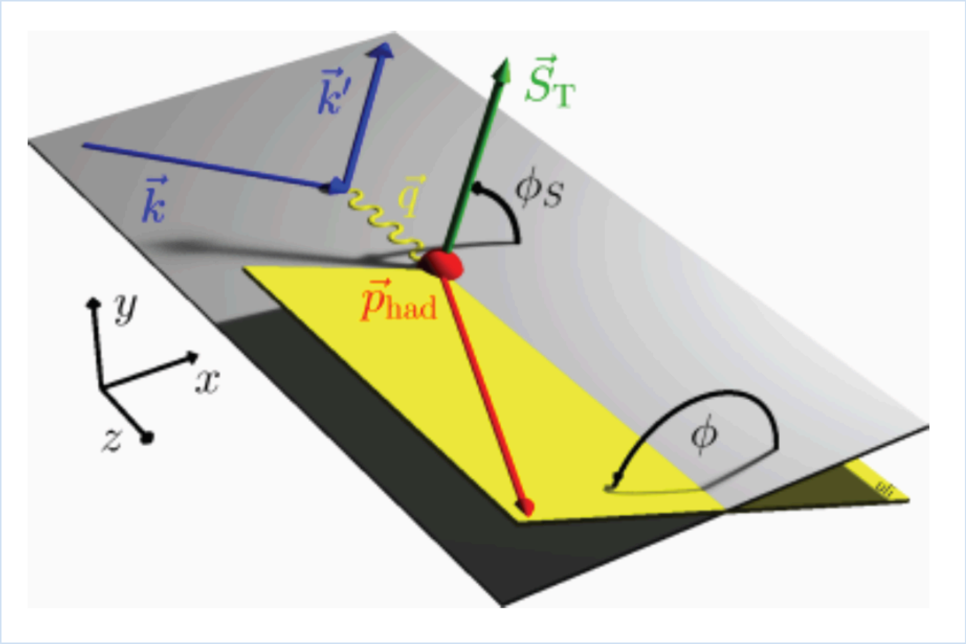
Color charge density
- Nucleon tomography
- Diffractive physics
- Gluon saturation
- Color force

3D momentum and spin-orbit effect:
Parton kinematics and flavor from observed hadron kinematics and type

Distribution and fragmentation convoluted:

$$d^6\sigma^h \propto \sum_q e_q^2 q(x,k_T) \otimes D_q^h(z,p_T)$$

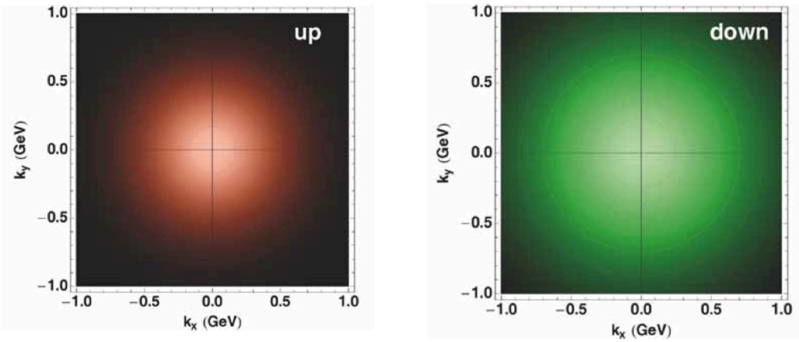




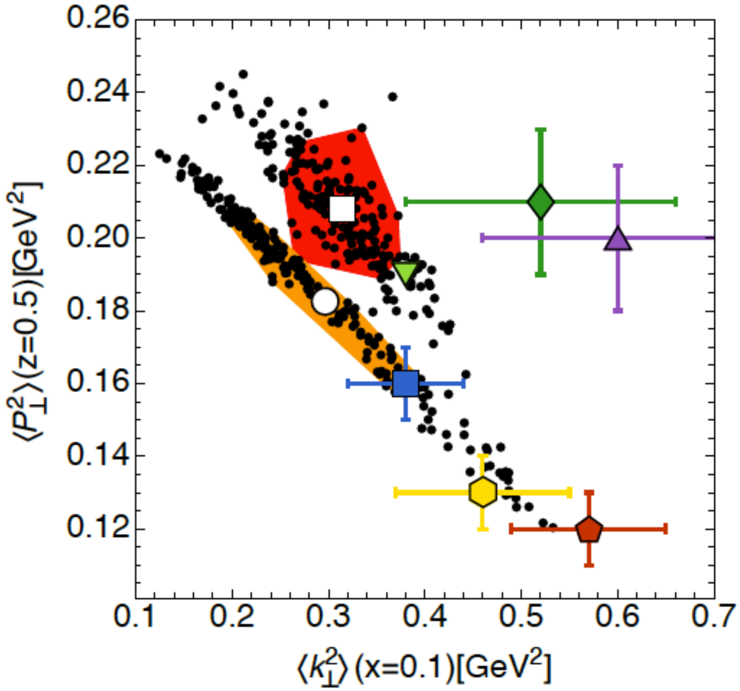
Hadron PID is needed to access flavor separation

Unpolarised TMDs

$$\left\langle P_{h\perp}^2 \right\rangle = z^2 \left\langle k_T^2 \right\rangle + \left\langle p_T^2 \right\rangle$$



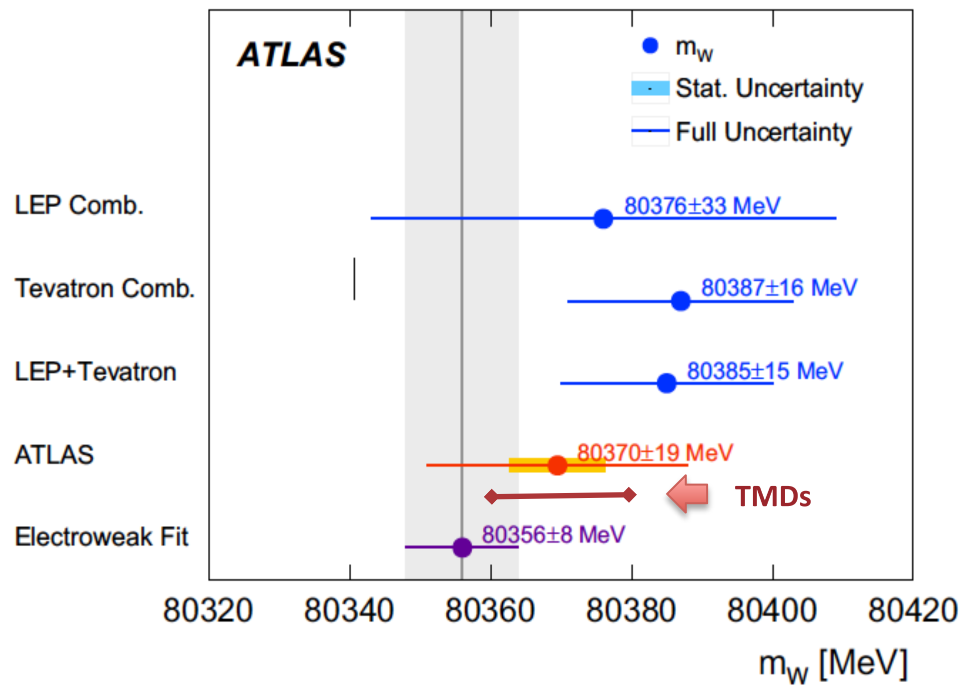
A. Bacchetta++ [arXiv:1703.10157]



$$m_W = 80370 \pm 7\,(\text{stat.}) \pm 11\,(\text{exp. syst.}) \pm 14\,(\text{mod. syst.})\ \text{MeV}$$

+9 / -6 (TMDs)

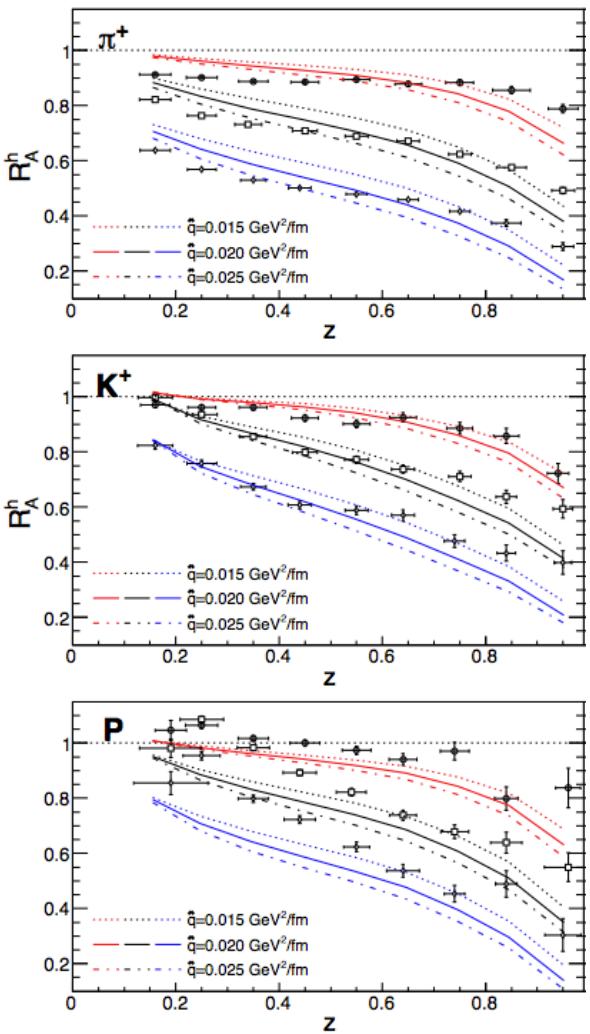
ATLAS++ [arXiv:1701.07240]



DIS

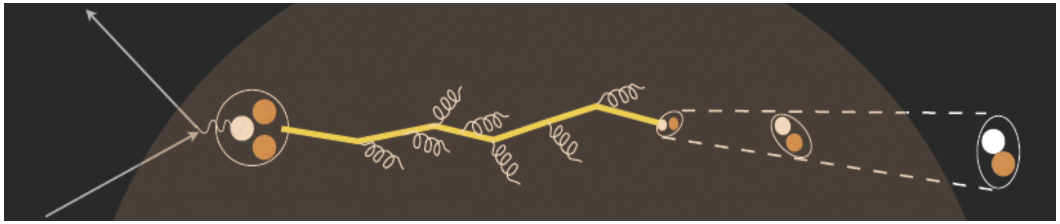
$$\hat{q}_0 \approx 0.020 \pm 0.005 \text{ GeV}^2/\text{fm}$$

N-B Chang ++ [arXiv:1401.5109]



Parton propagation in nuclear matter

In DIS: kinematic control via scattered electron and target nuclei



RHIC

$$\hat{q} \approx 1.2 \pm 0.3 \text{ GeV}^2/\text{fm}$$

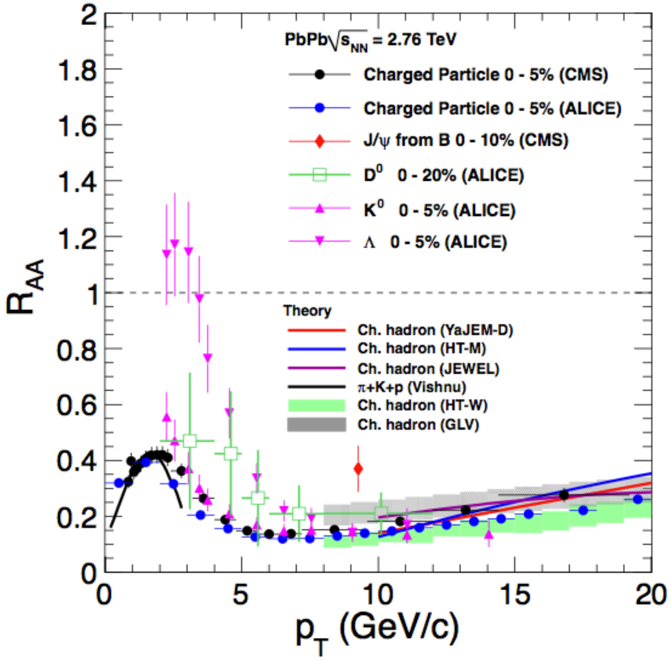
Au+Au $\sqrt{s} = 200 \text{ GeV/n}$

JET Coll. [arXiv:1312.5003]

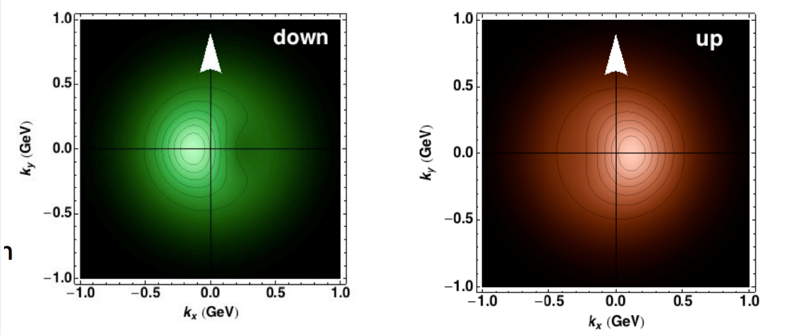
LHC

$$\hat{q} \approx 1.9 \pm 0.7 \text{ GeV}^2/\text{fm}$$

Pb+Pb $\sqrt{s} = 2.76 \text{ TeV/n}$



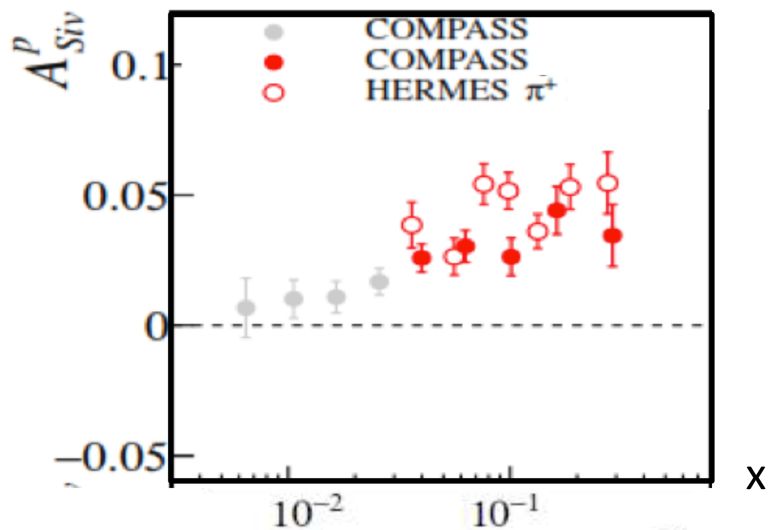
$$\sigma_{UT}^{\sin(\phi+\phi_S)} \propto f_{1T}^{\perp} \otimes D_1$$

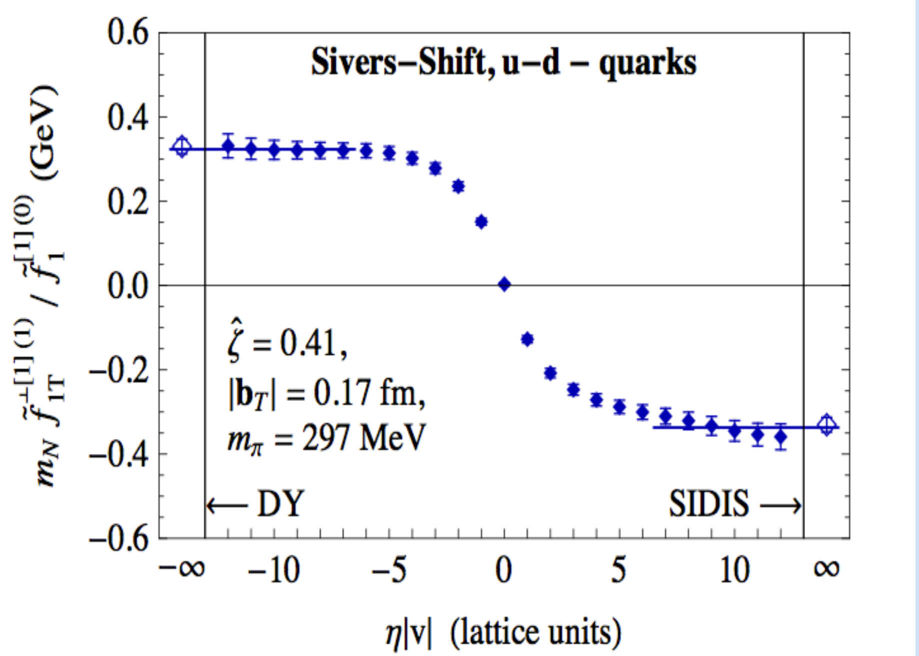


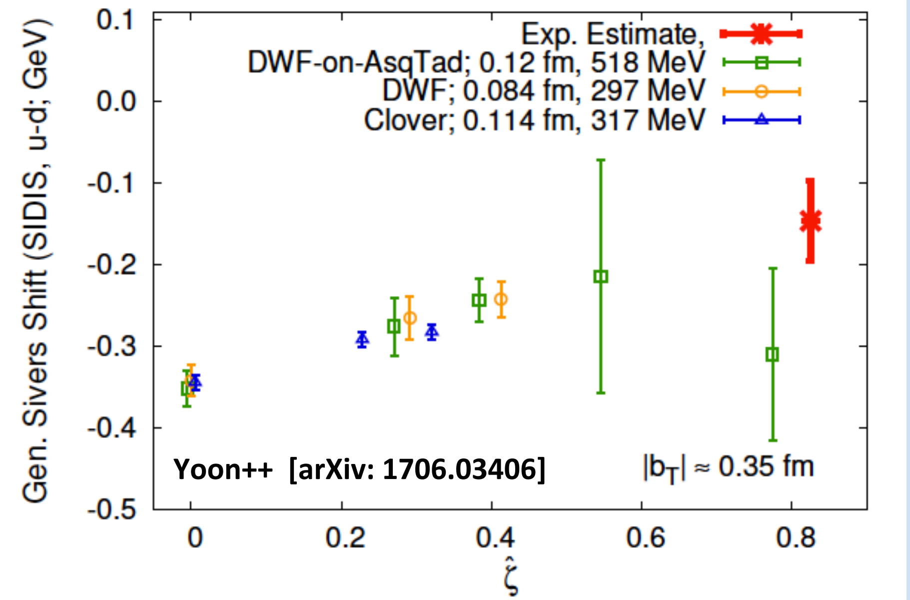
Sivers from polarized SIDIS

HERMES [arXiv:0906.3918]

COMPASS [arXiv:1205.5122]

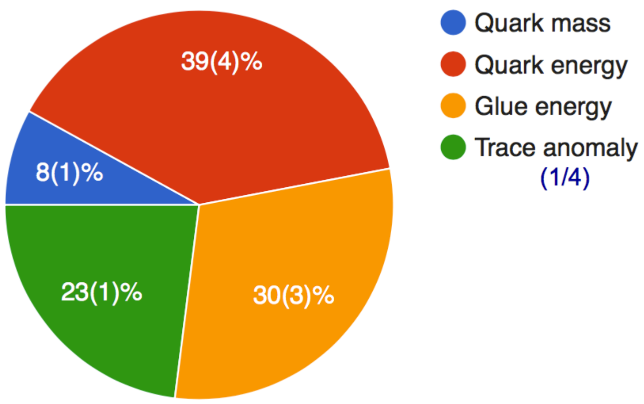






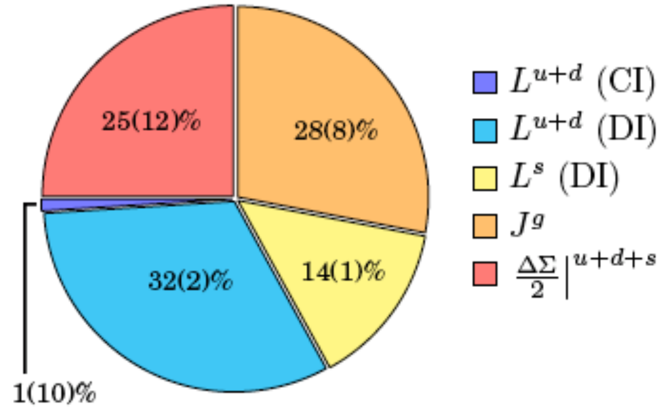
Nucleon mass components

K-F Liu @ this Conf.

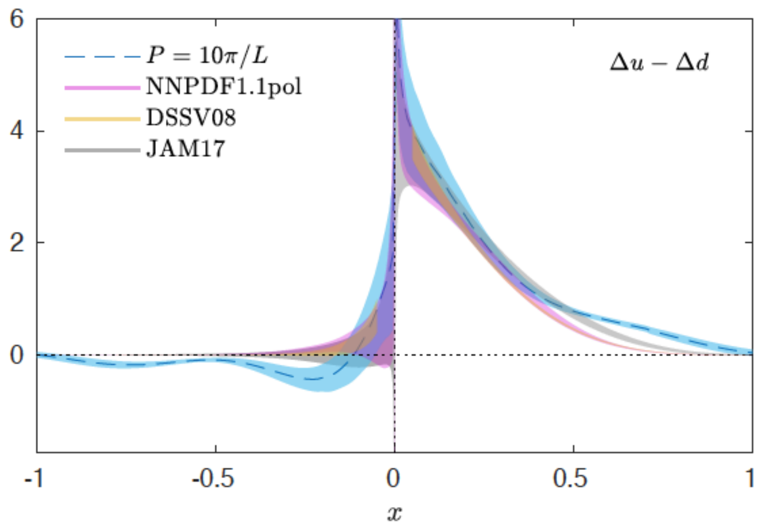


Spin decomposition

K-F Liu++ [arXiv 1203.6388]

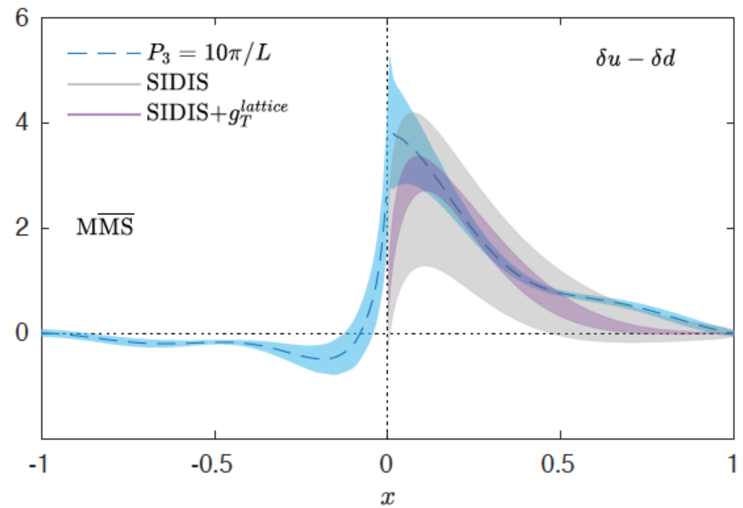


Helicity distribution



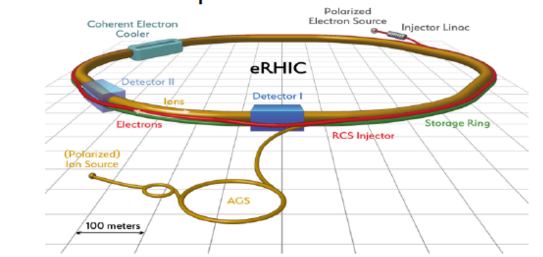
Transversity distribution

C. Alezandrous++ [arXiv 1902.00587]

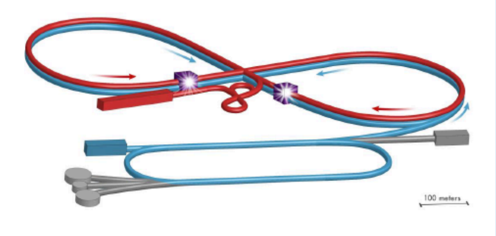


Electron-Ion Collider

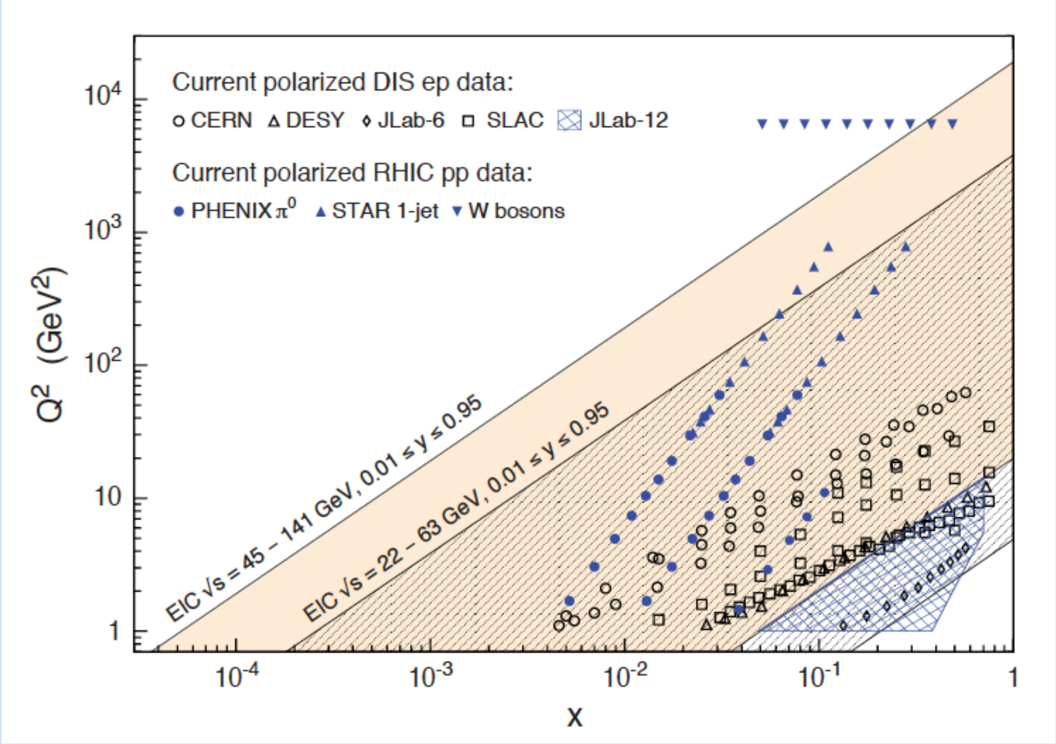
BNL concept

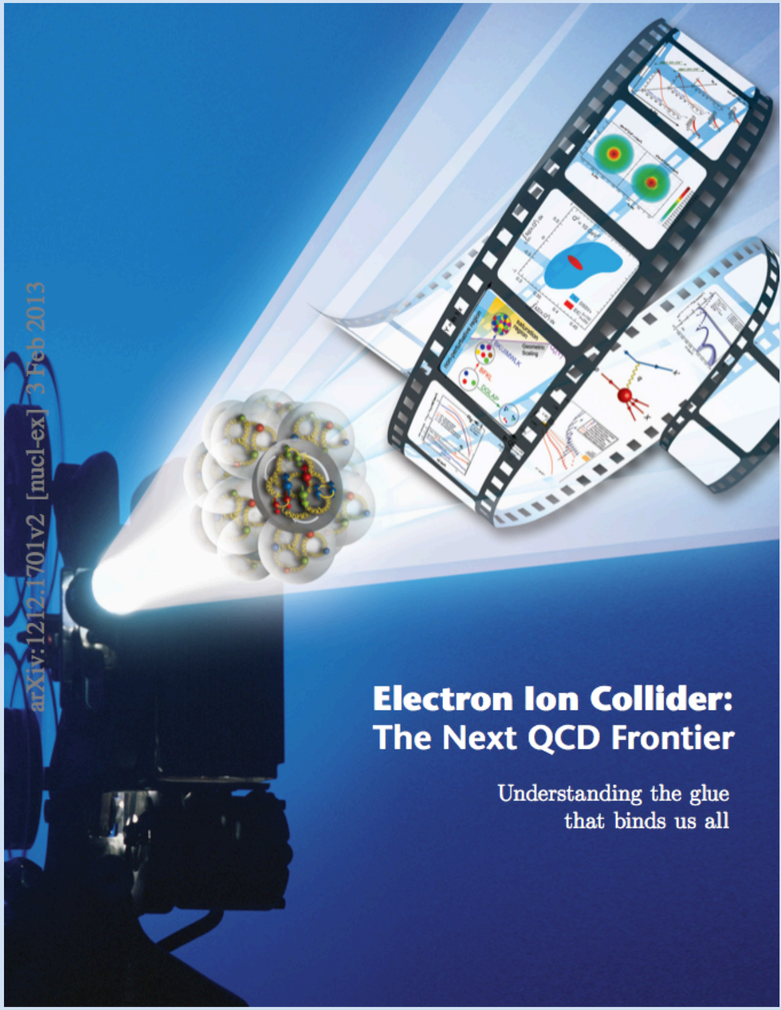


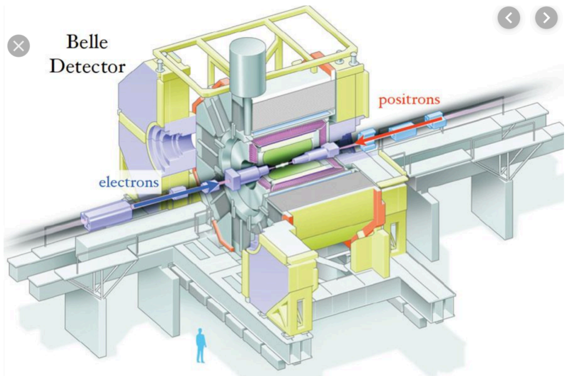
JLab concept



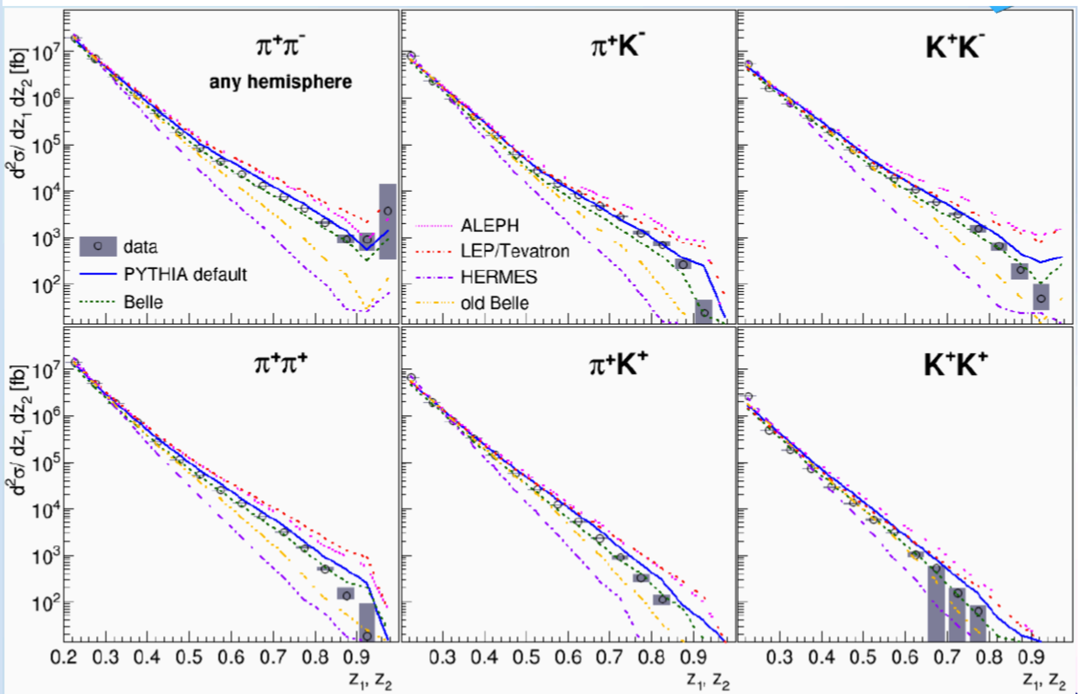
Data in the much needed "intermediate" energy region matching "pure" pQCD with "pure" TMD regime.

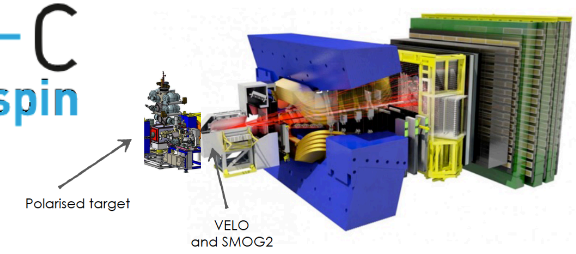




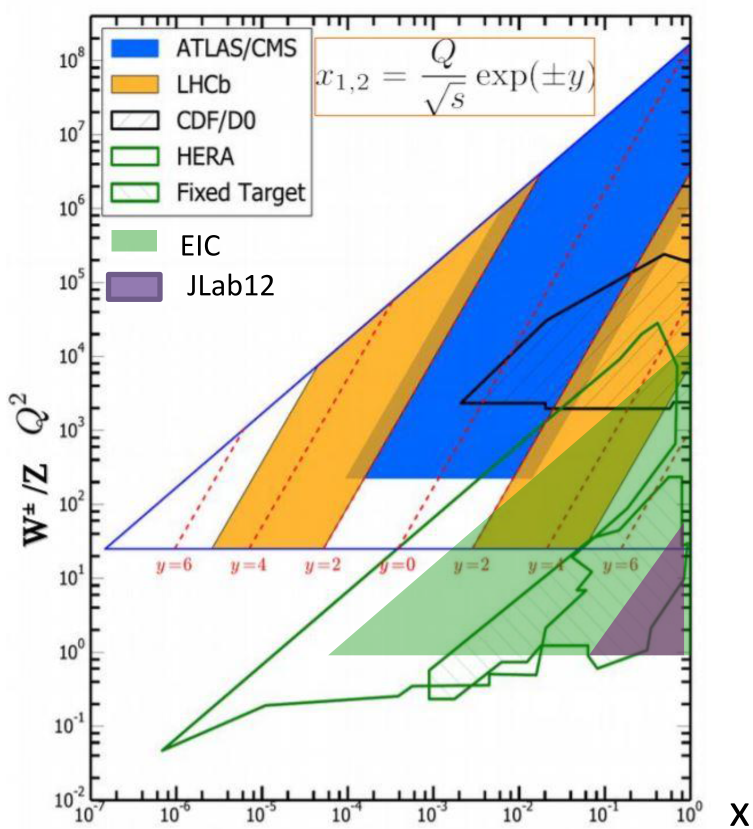


More and more precise Fragmentation Function information is becoming available





Bridge to hadron probes and HEP



EIC Detector Challenges

Specific requirements to move beyond the longitudinal description

- Resolve partons in nucleons

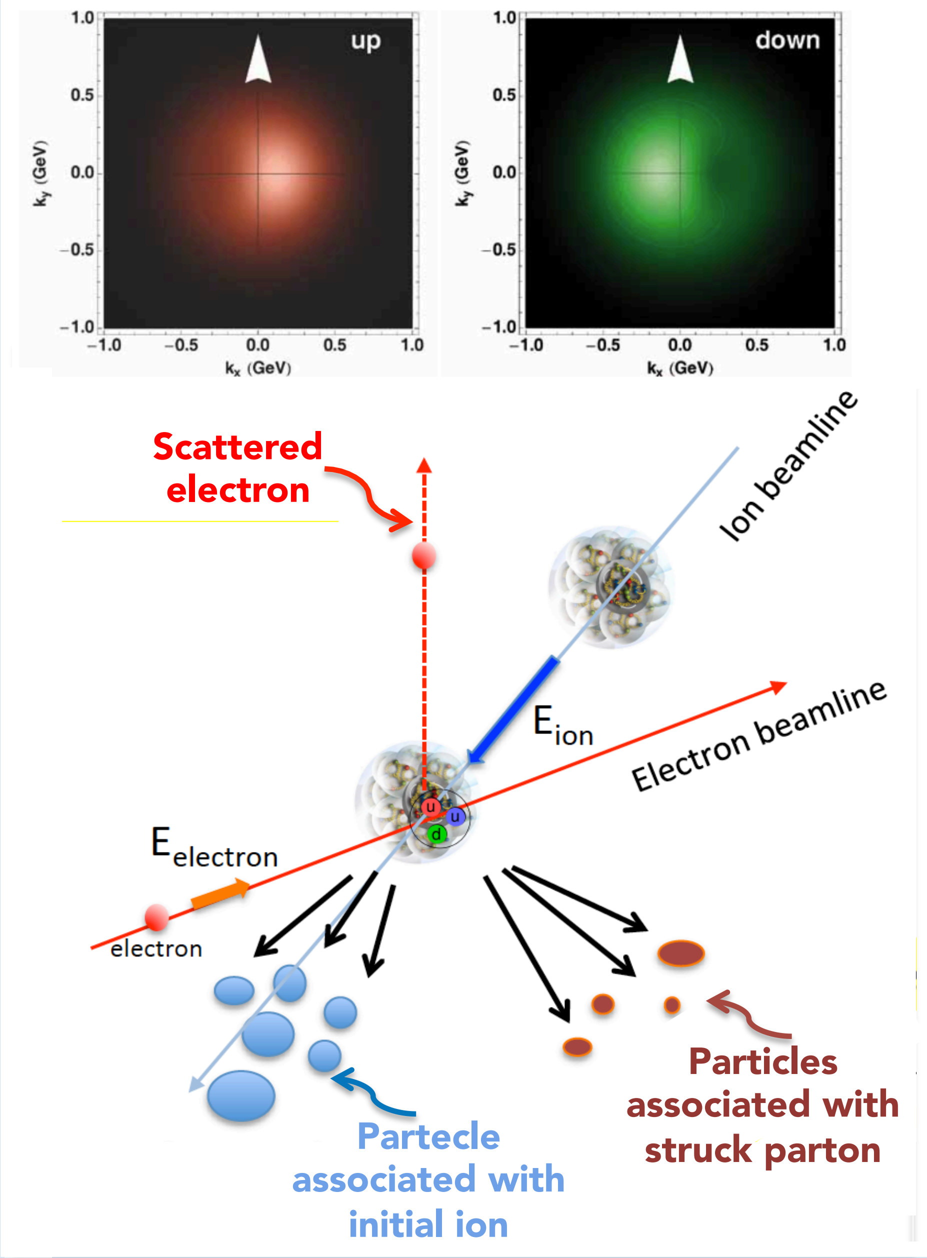
➔ high beam energies and luminosities Q^2 up to **~1000 GeV²**

- Need to resolve quantities (k_t, b_t) of the order **a few hundred MeV** in the proton Correlated quantitites, multi-D analyses

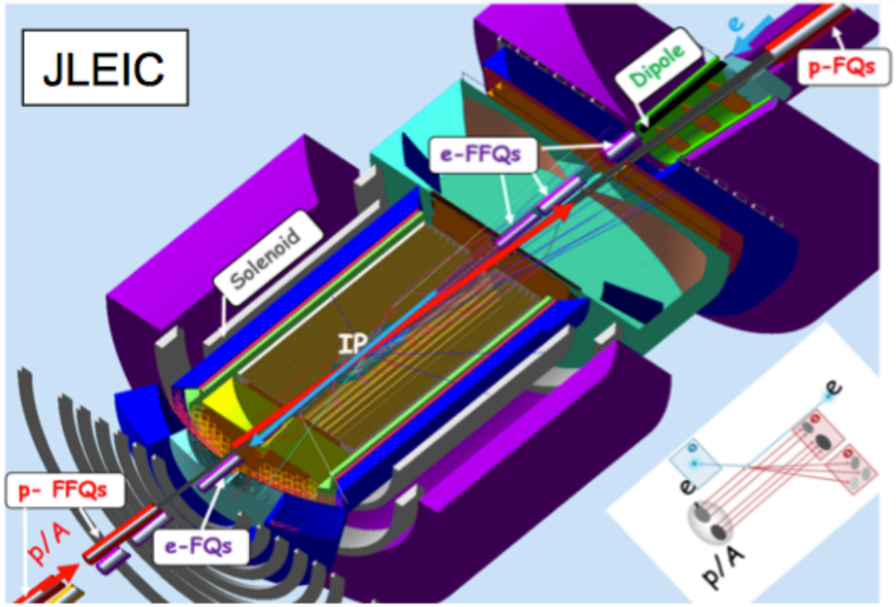
➔ High Granularity, wide dynamic range

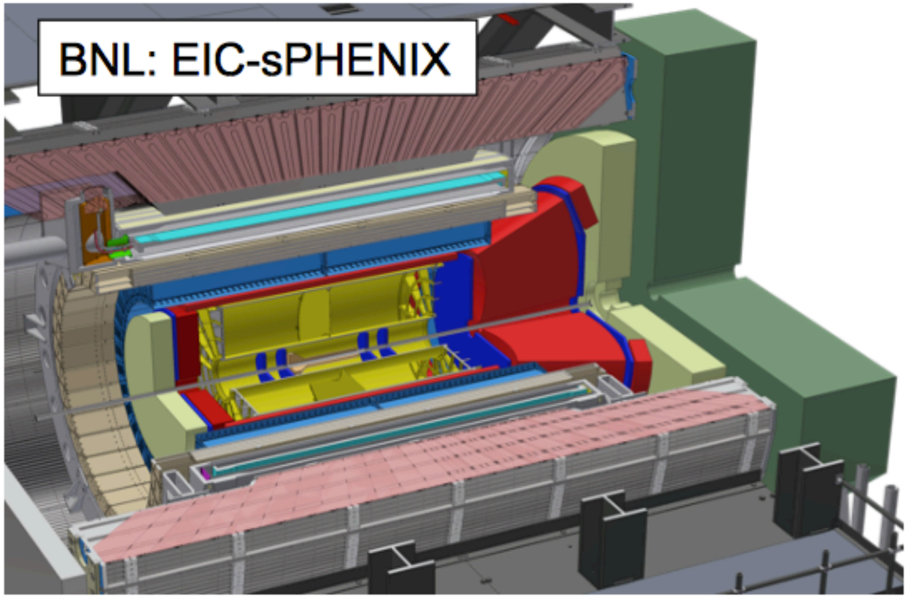
- Need to detect **all types of remnants** to seek for correlations:
  - scattered electron
  - particles associated with initial ion
  - particles associated with struck parton

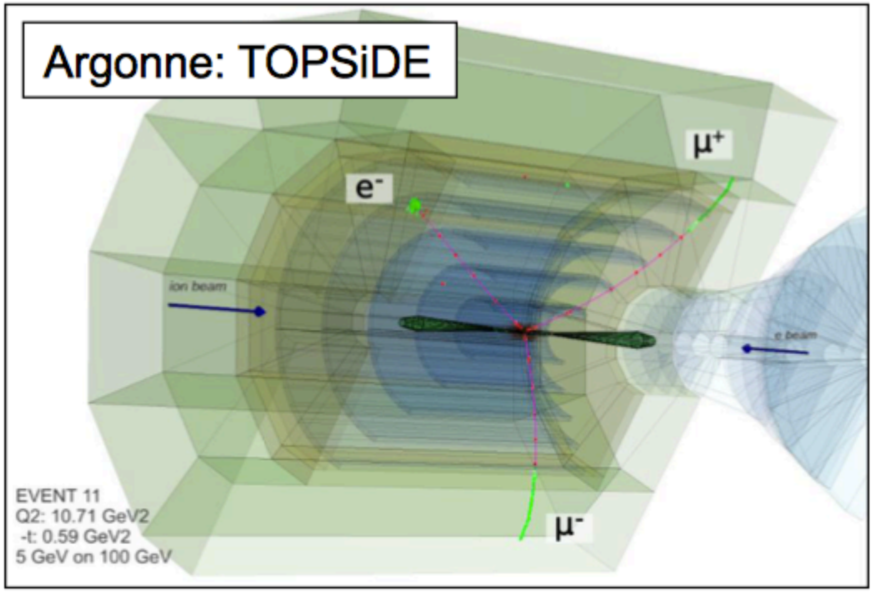
➔ Large acceptance, Forward particle detection, Excellent PID

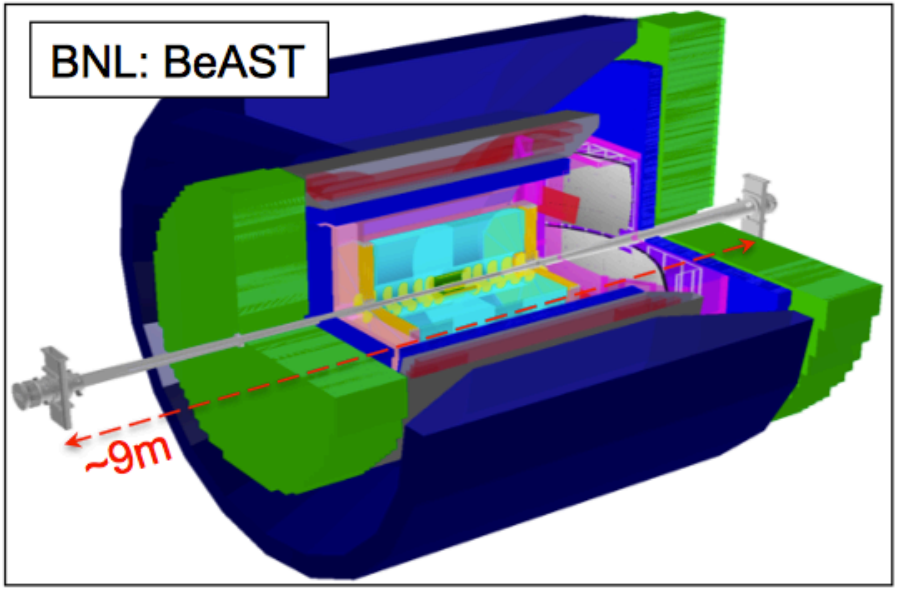


Detector Concepts @ EIC



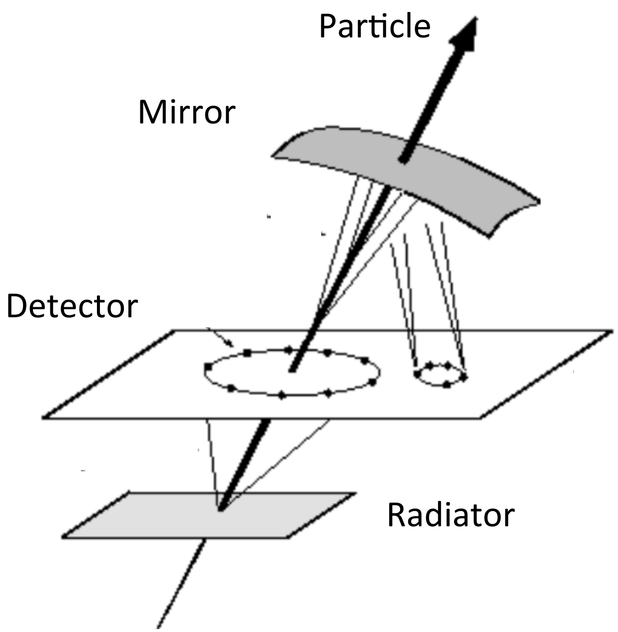




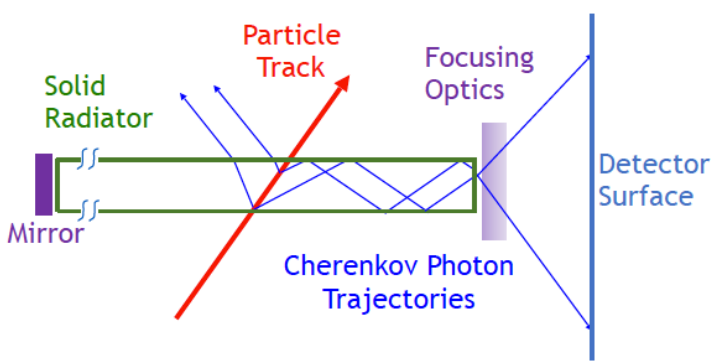


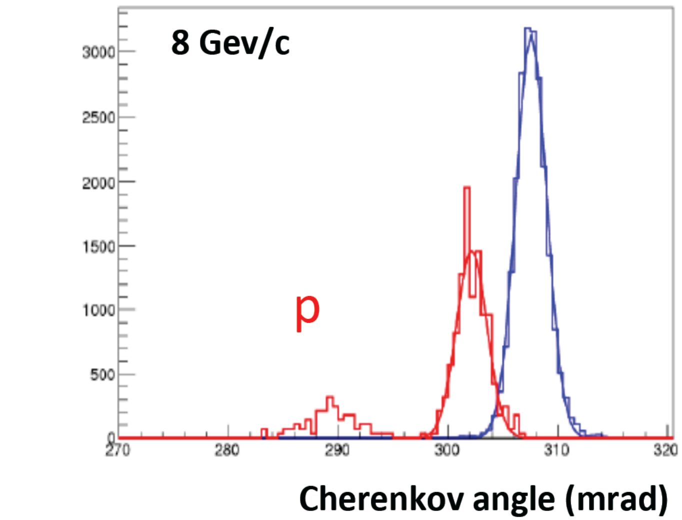
Cherenkov Detectors for PID

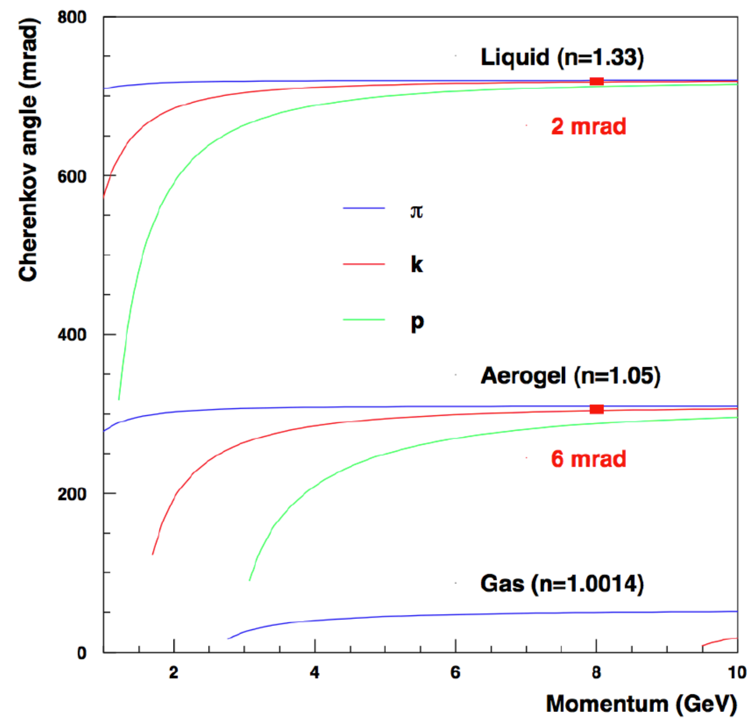
Ring-imaging (RICH):



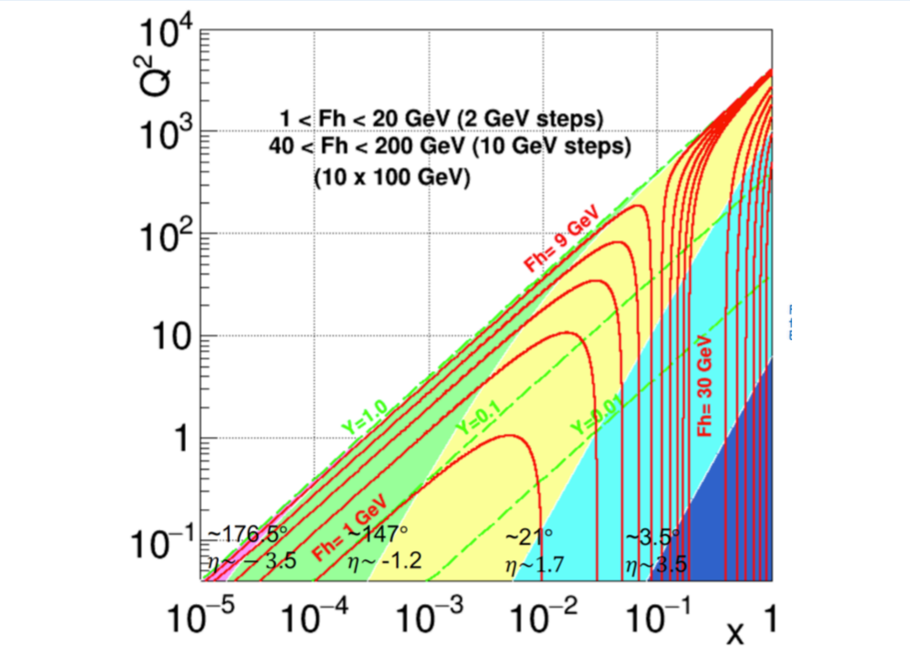
Internal-reflection (DIRC):

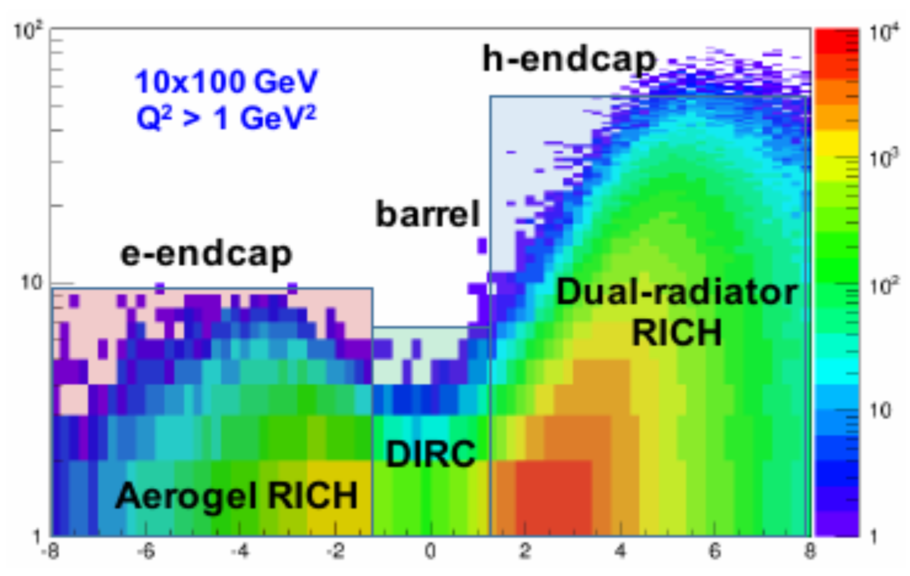






Hadron Identification @ EIC





eRD14 Consortium: An integrated program for particle identification at a future EIC detector

barrel: A high-performance DIRC

p/k separation up to ~ 6-7 GeV/c **DIRC**

h-endcap: A RICH with two radiators (gas+aerogel)

p/k separation up to ~ 50 GeV/c **dRICH**

e-endcap: A compact and projective aerogel RICH

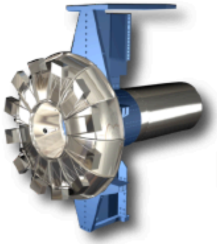
p/k separation up to ~ 10 GeV/c **mRICH**

TOF: possible to cover lower momenta

Photosensors & electronics: parallel development to match the needs of the next generation devices

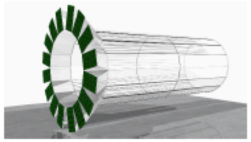
DIRC Evolution

- First DIRC detector
- Successfully operated (1998-2008)
- Used for 98% of publications
- Discovered many mesons



BABAR DIRC

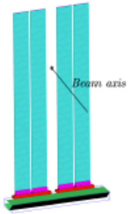
- Lens based Focusing DIRC detector
- Compact design
- Advanced R&D program



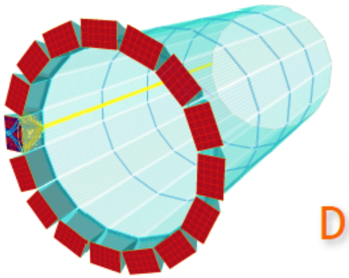
PANDA BARREL DIRC

- Mirror based Focusing DIRC detector
- Reusing BaBar DIRC radiators

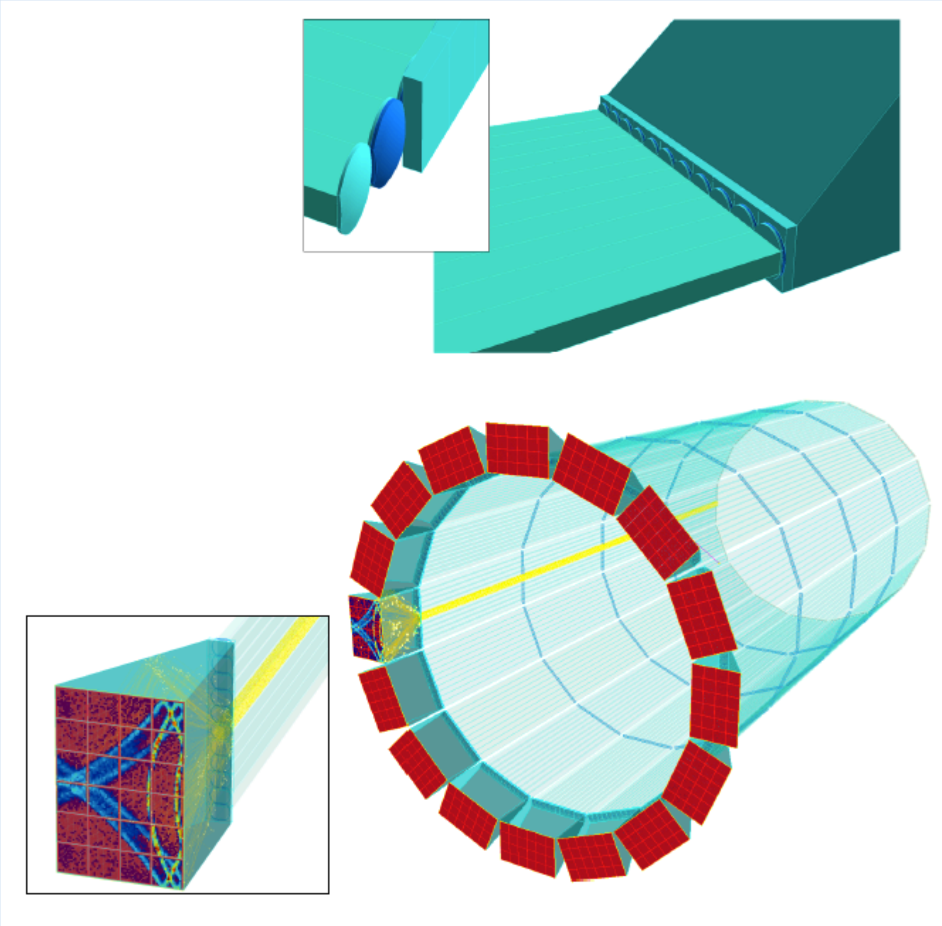
GlueX DIRC



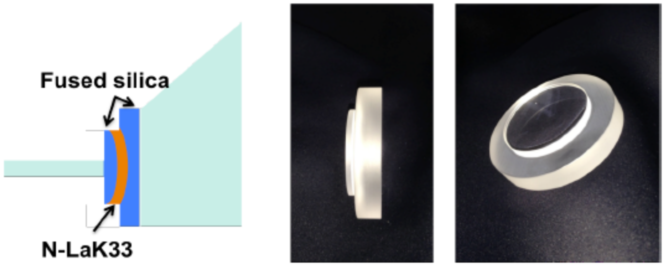
- High Performance DIRC detector
- New innovative components
- First DIRC aiming to utilize high-resolution 3D (x,y,t) reconstruction



EIC DIRC

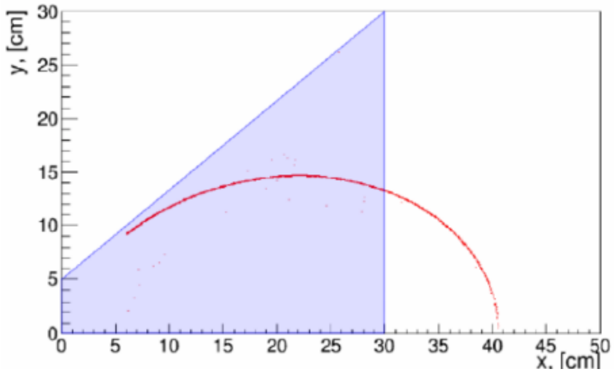


Spherical 3-layer lens prototype

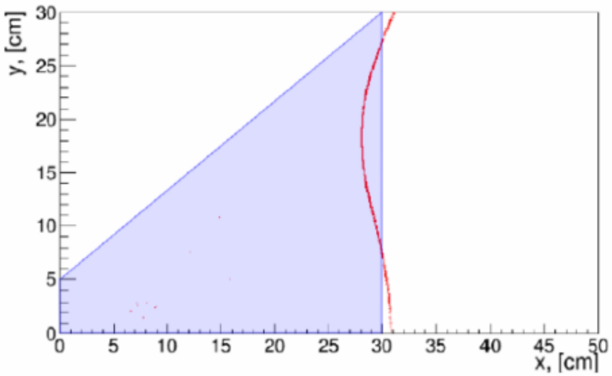


GEANT4 Simulations of the focal plane:

Standard lens



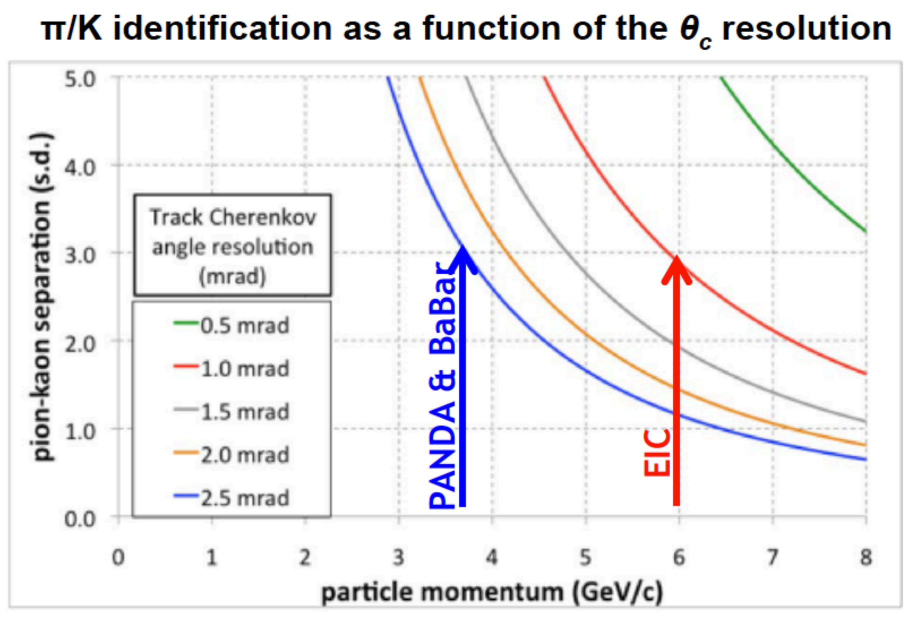
3 component lens

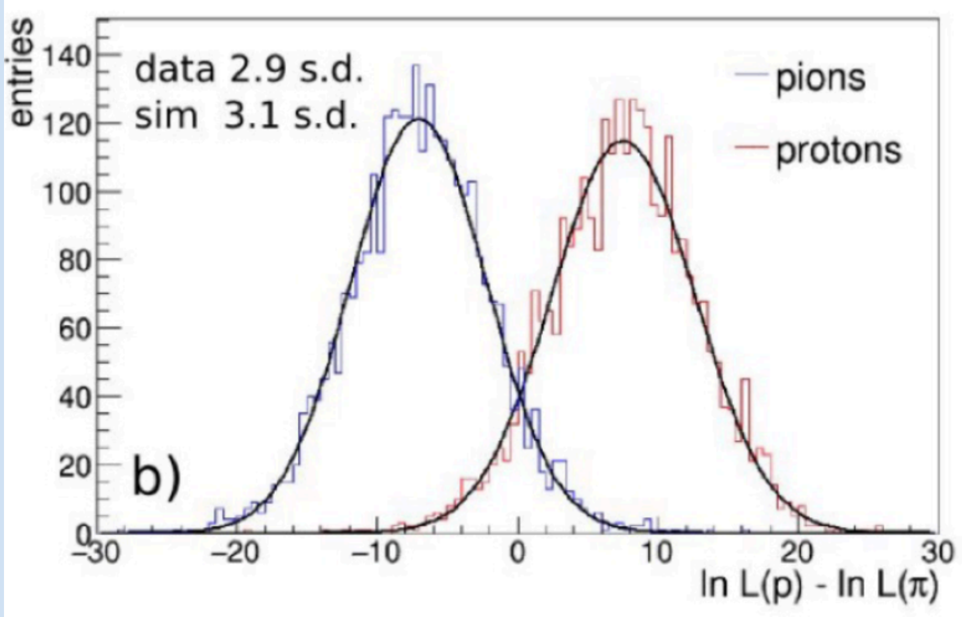


DIRC @ EIC

EIC DIRC should push forward the DIRC status-of-the-art

Performance of cost-saving wide plate with 3-layer lens promising

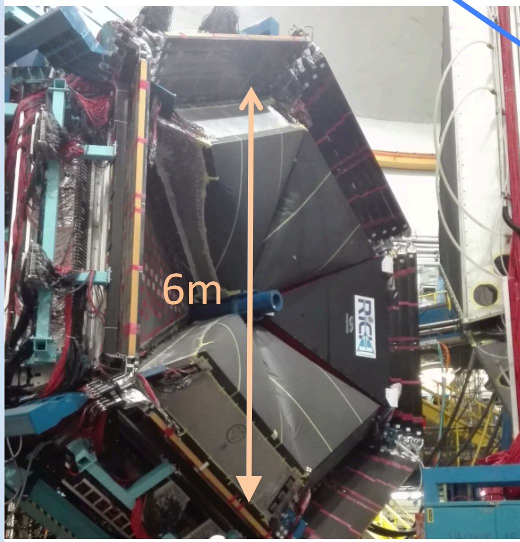


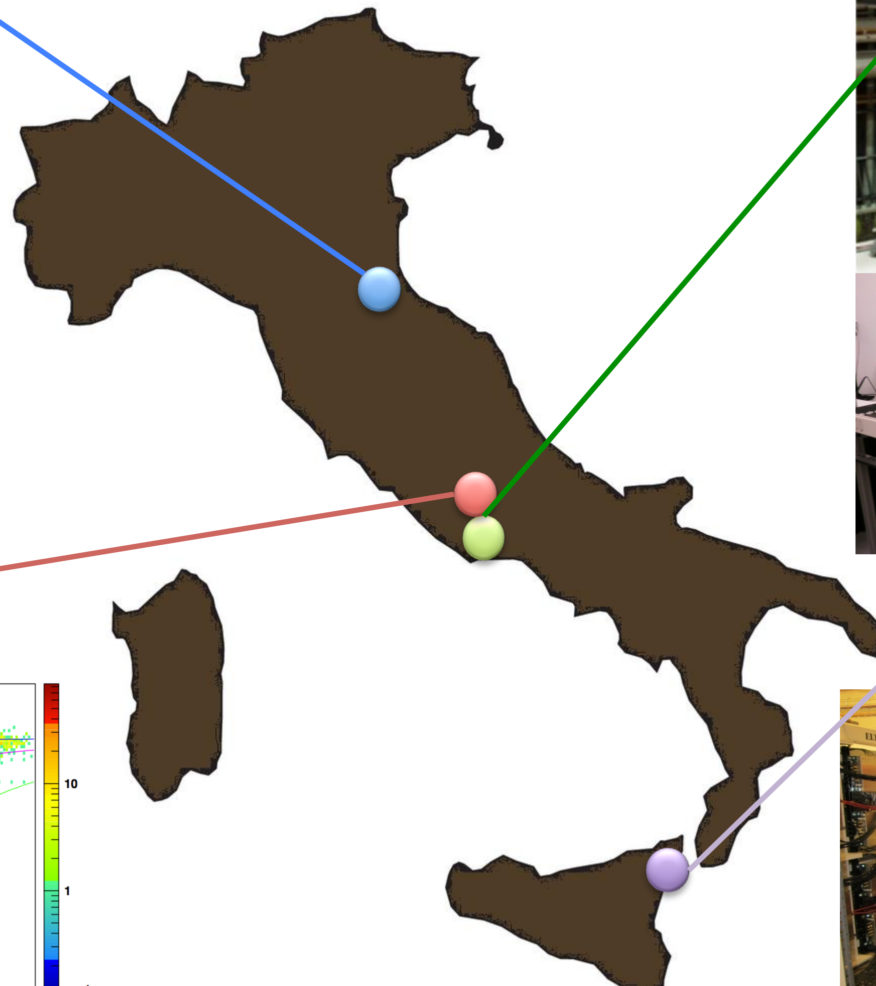


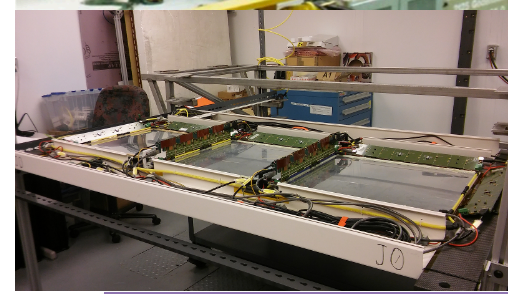
INFN-FE
CLAS12 RICH

INFN within eRD14 Consortium

INFN-RM1
HERMES RICH
Hall-A Tracking

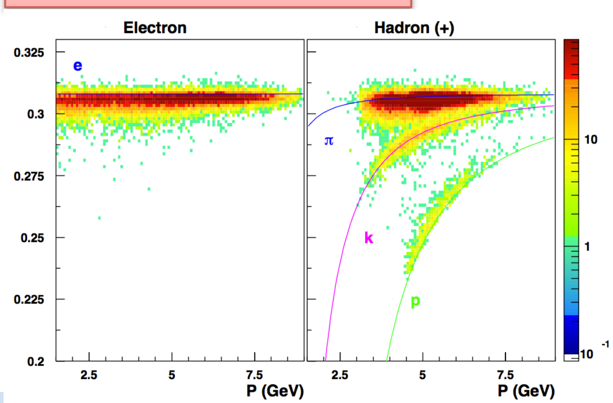


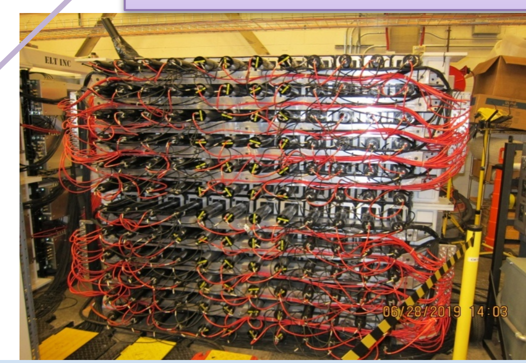




INFN-LNF
CLAS12 RICH

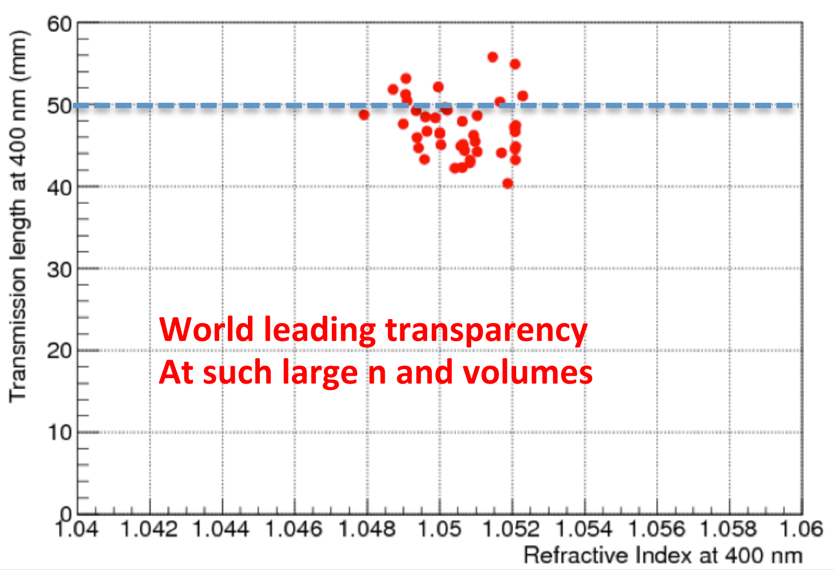
INFN-CT
Hall-A HCAL

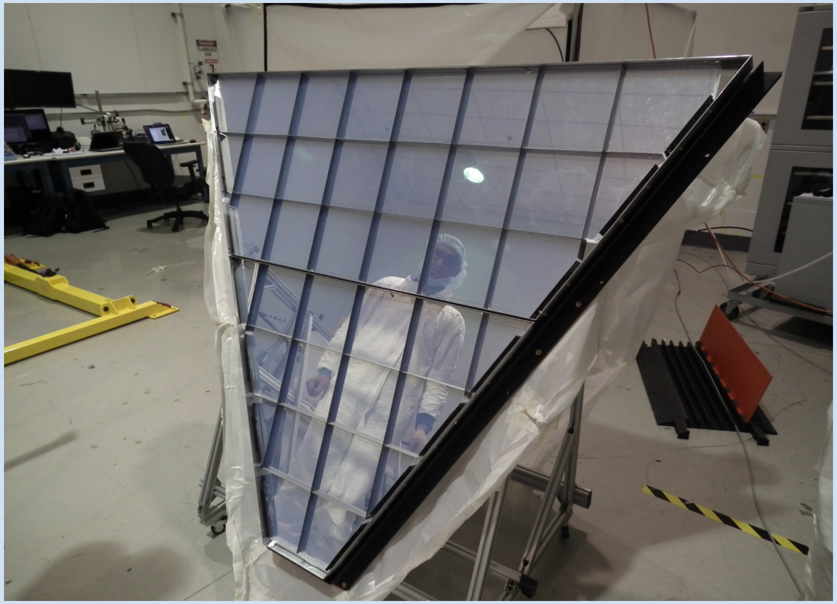




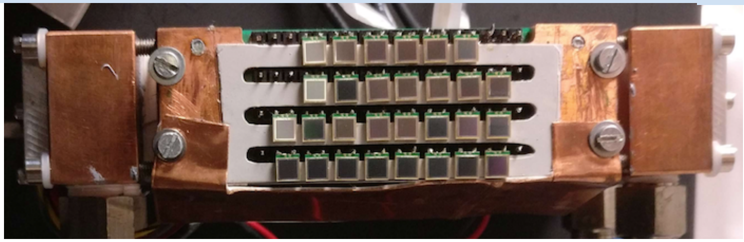
CLAS12 RICH Advances

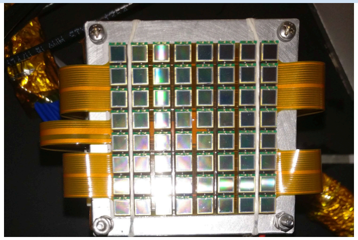
M. Contalbrigo et al., NIMA876 (2017) 168-172

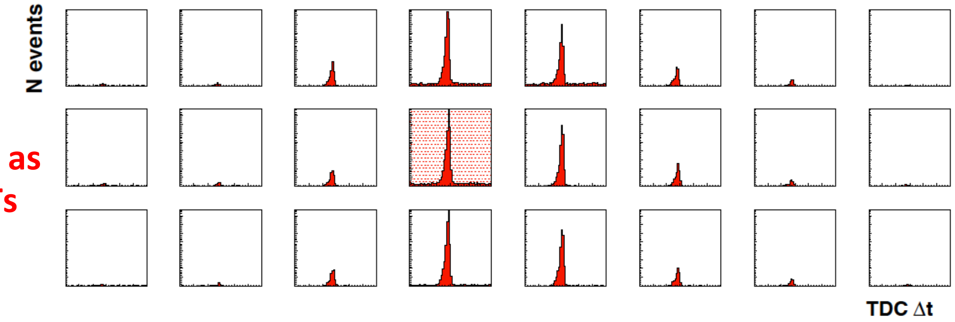




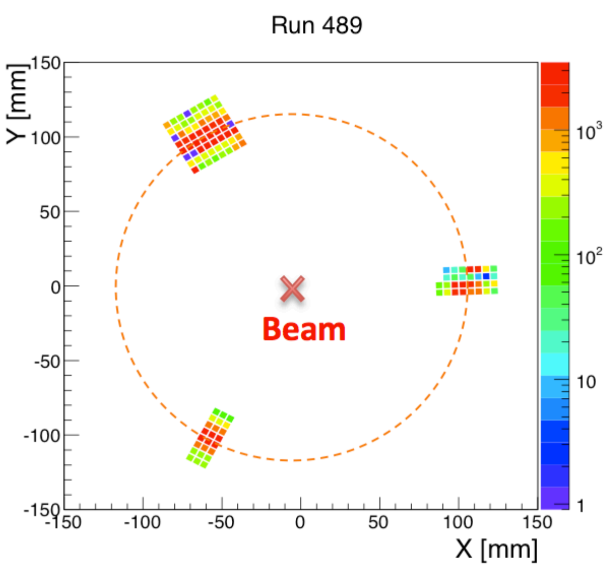
M. Contalbrigo et al., NIMA766 (2014) 22





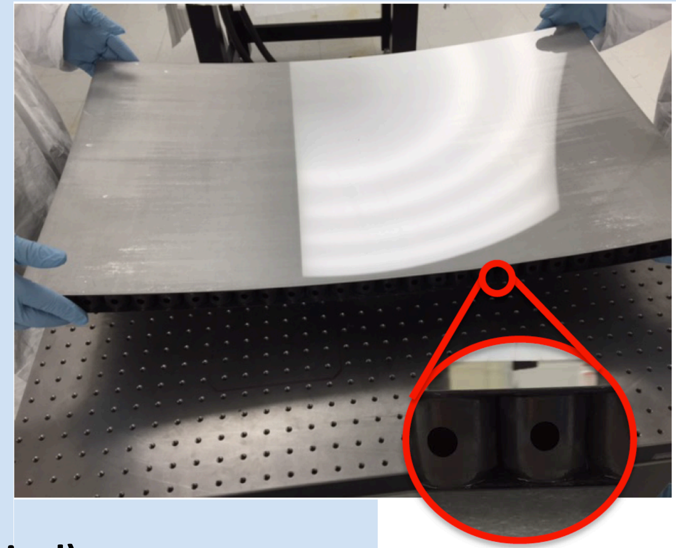


Cooled SiPM as good as PMTs

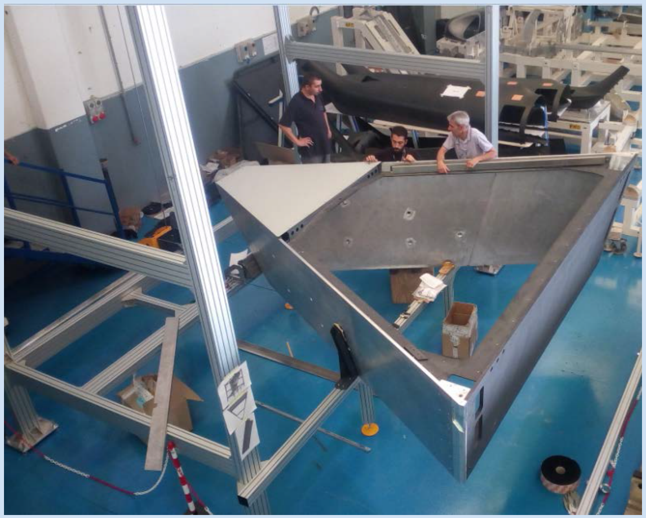


CLAS12 RICH Advances

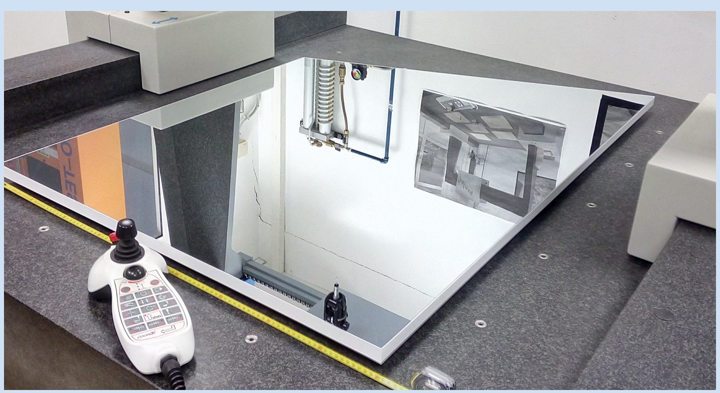
M.Mirazita et al., NIMA876 (2017) 54-58



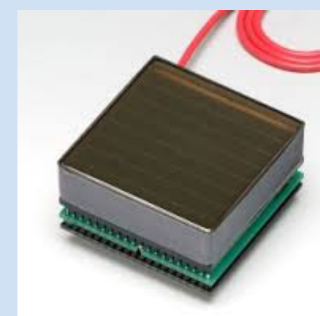
Aeronautic technology for structure
to maximize lightness and stiffness. Trapezoid of composite materials: CFRP inside acceptance, Al outside



Carbon Fiber Mirrors (spherical)
to maximize lightness and stiffness. Consolidate technology (HERMES, AMS, LHCb) but ~ 30 % material budget reduction



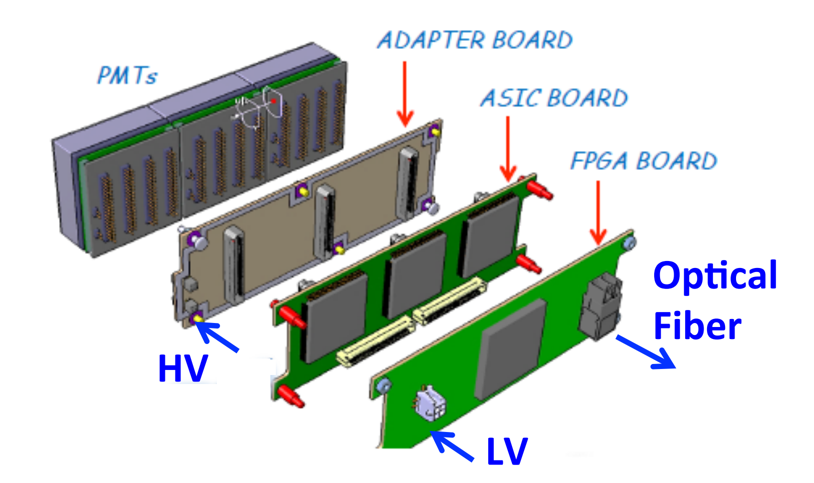
Photon Detector
First use of H8500/H12700 flat panel multi-anode PMTs
64 pixels on a 5x5 cm^2 area

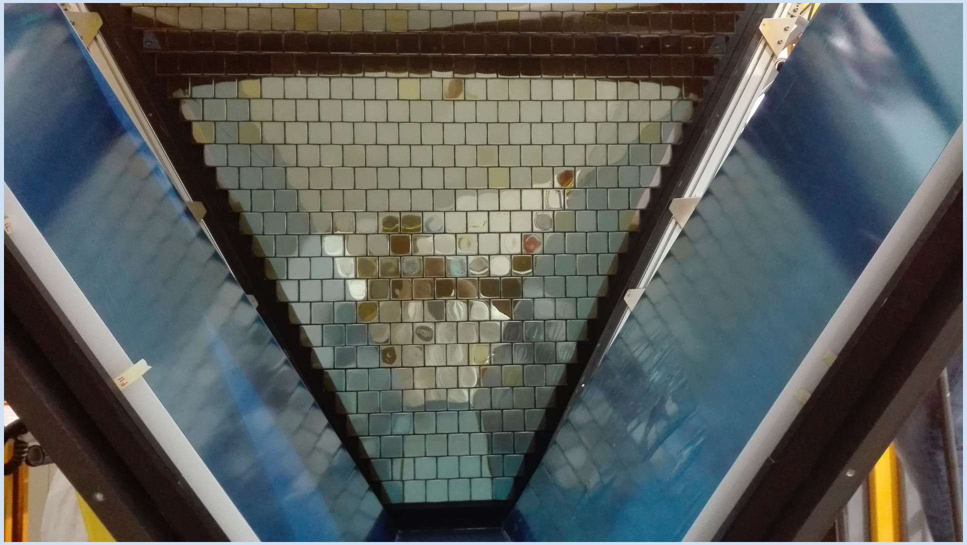


Glass-Skin Mirrors (planar)
Innovative technology never used in nuclear exps.
~ 1/5 cost for squared meter vs CFRP

Modular Readout Electronics

Compact (matches sensor area)
Modular Front-End (Mechanical adapter, ASIC, FPGA)
Scalable fiber optic DAQ (TCP/IP or SSP)
Tessellated (common HV, LV and optical fiber)

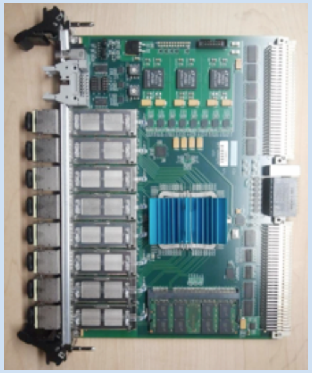


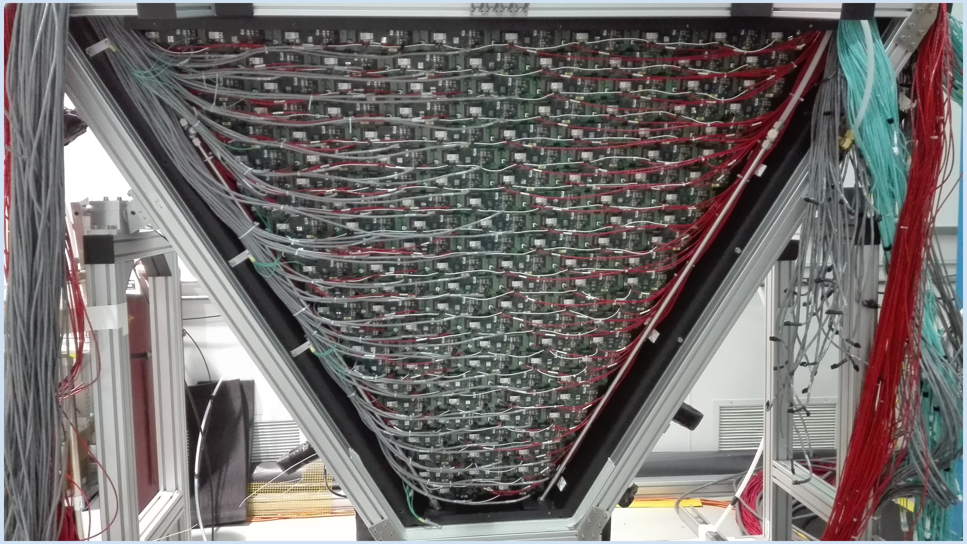


Constant threshold discrimination
1 ns FPGA timestamp (clock distribution driven)

Applications:

- CLAS12 RICH
- **EIC R&D**
- Gluex DIRC
- SOLID
- Medical Imaging
- Homeland Security



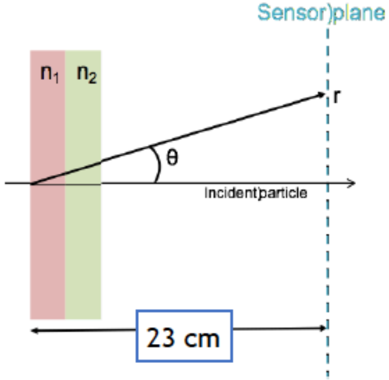


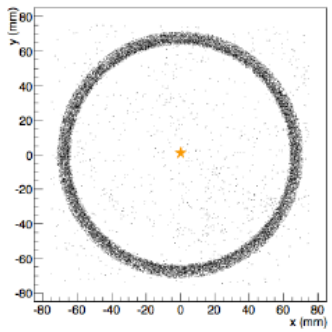
SSP Back-end

Fresnel lens focusing aerogel detector concept

9 GeV/c pion beam launched at the center of xy plane in simulation

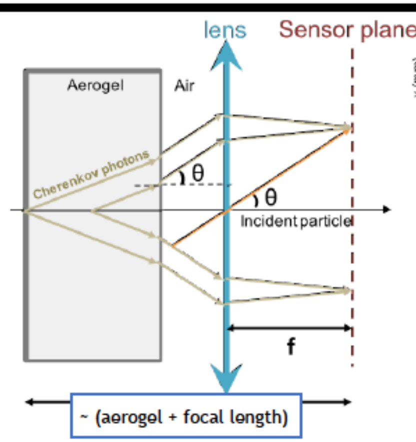
Two-Layer Proximity Focusing Design (BELLE-2 ARICH)

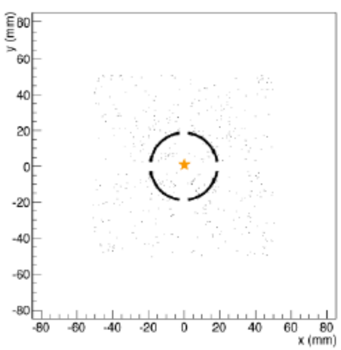




- EIC mRICH designed for K/pi ID up to 9 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

Lens-Based mRICH Design





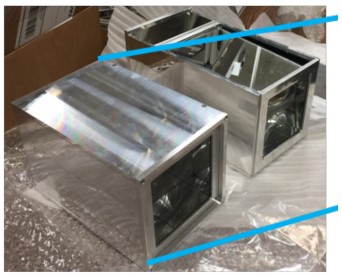
- 9 GeV/c pion beam launched at the center of xy plane in simulation
- **Smaller and thinner ring image**

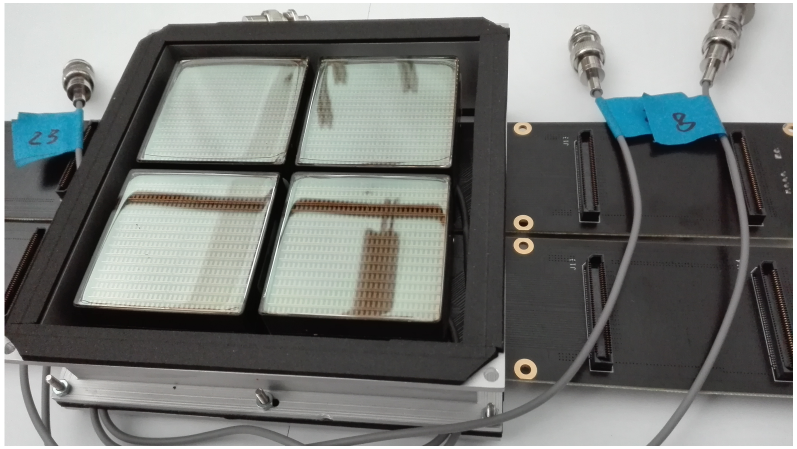
mRICH @ EIC

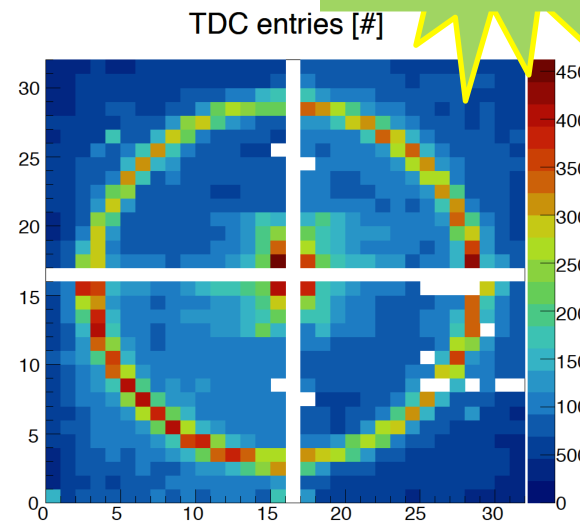
≥3σ π/k separation
~ 2 ÷ 10 GeV/c

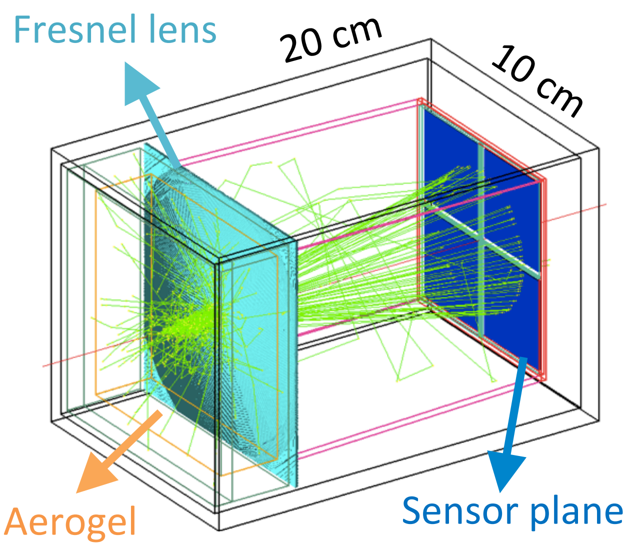
Compact and modular RICH independent elements

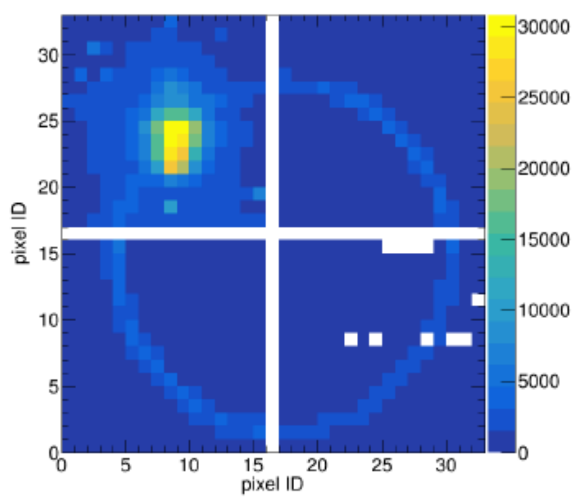
Two completed mRICH prototypes

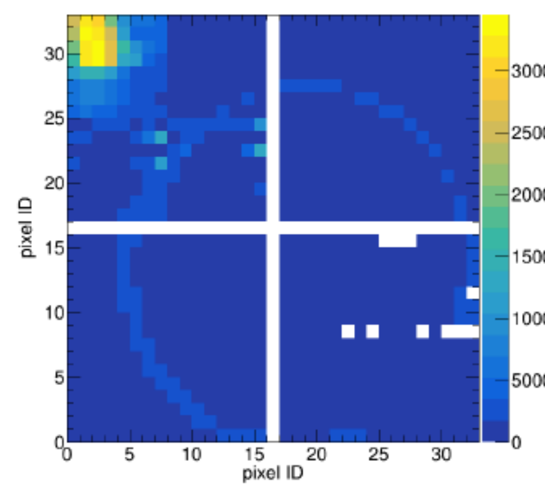








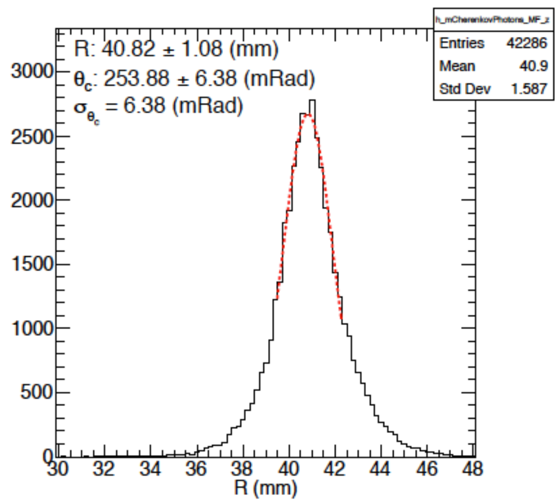


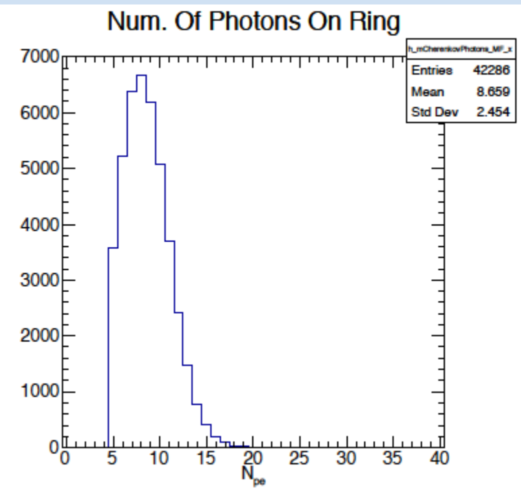


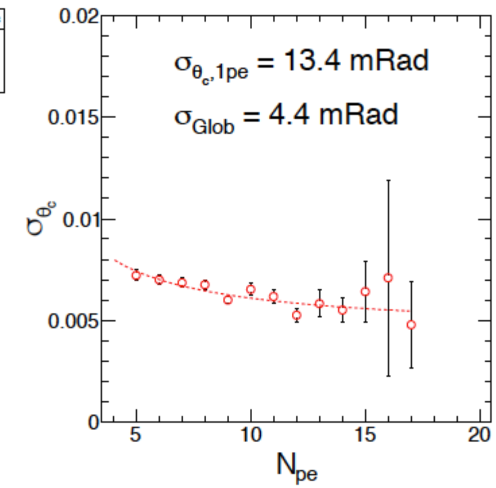
Preliminary results of the mRICH prototype test beam

Data

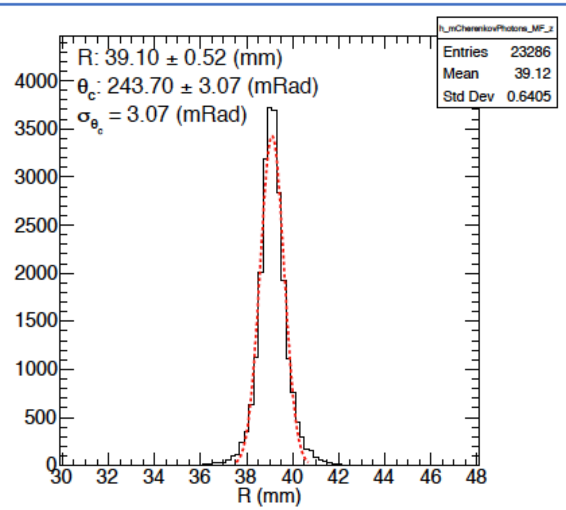
No precision tracking was available. Beam size is ~6mm in radius.

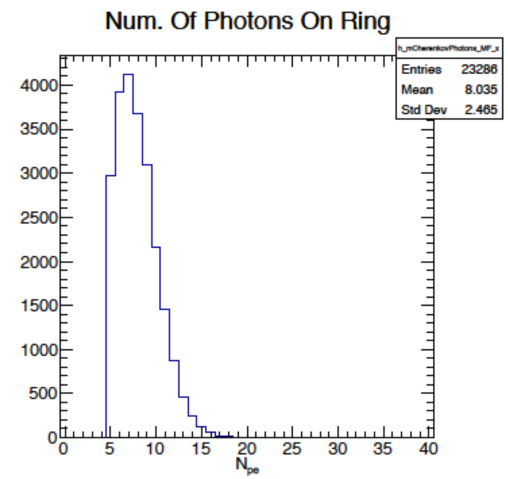


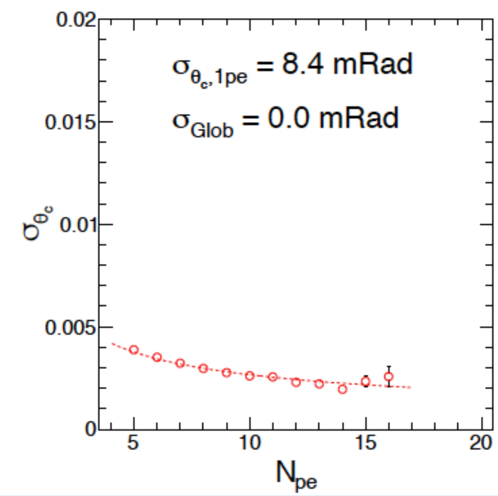




Simulation







Dual RICH @ EIC

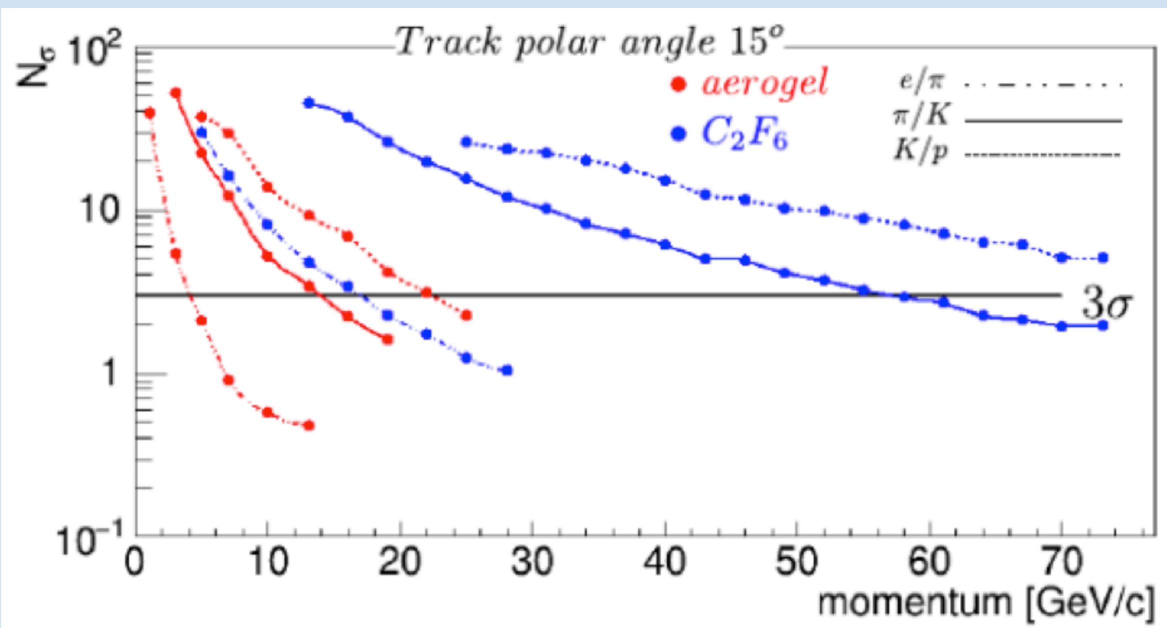
Dual-Radiator RICH within eRD14 - PID

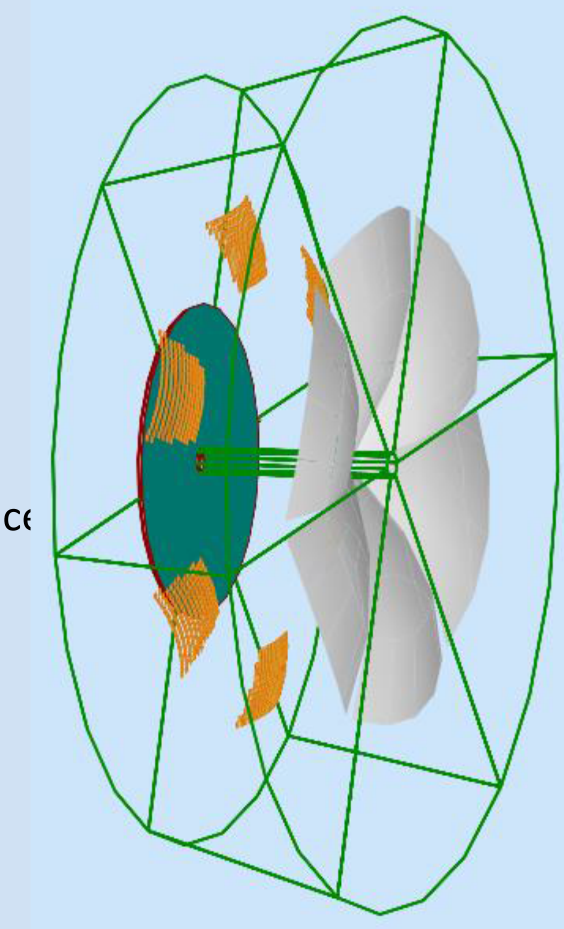
- GOAL: Discriminate Hadrons in 3 to 50 GeV/c
  - need to operate in magnetic field

- Proposed configuration fitting the spectrometer constraints (evaluated by detailed GEANT4 simulations)

-- dual radiator RICH: aerogel and C_xF_y gas -- focusing mirror

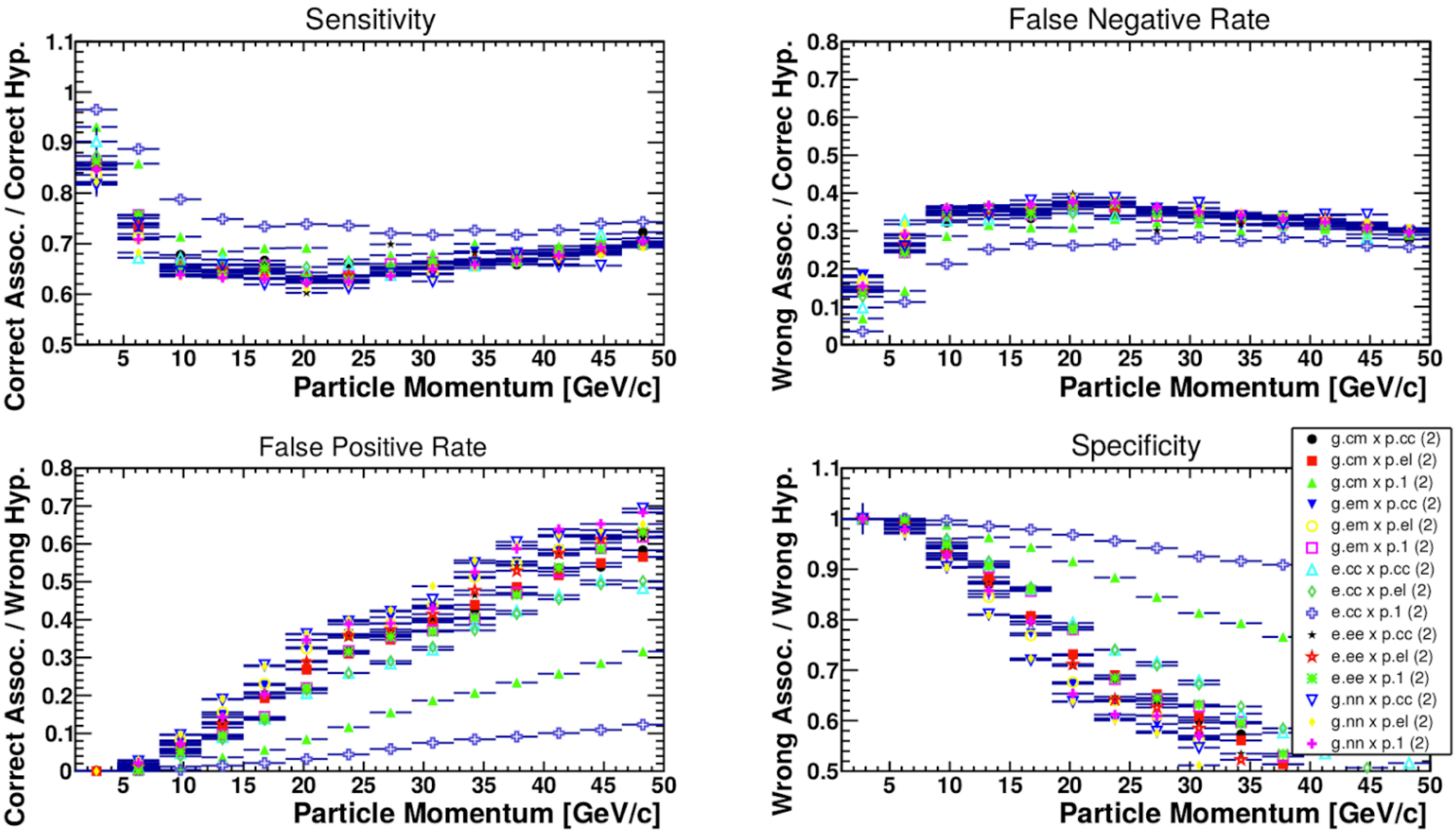
-- 6 open sectors -- curved detector surface



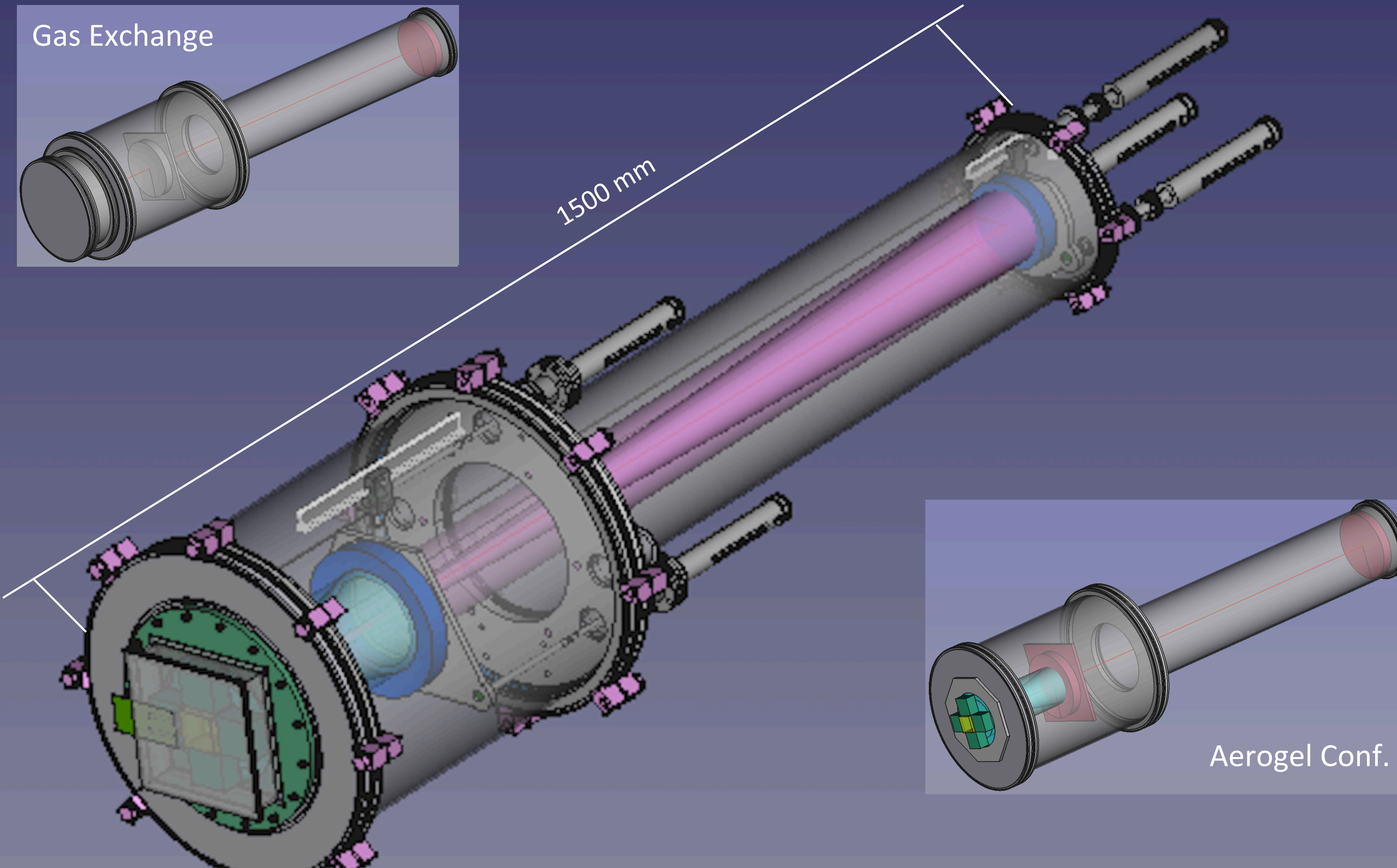


≥3σ π/k separation
~ 2 ÷ 50 GeV/c

dRICH Simulated Performance



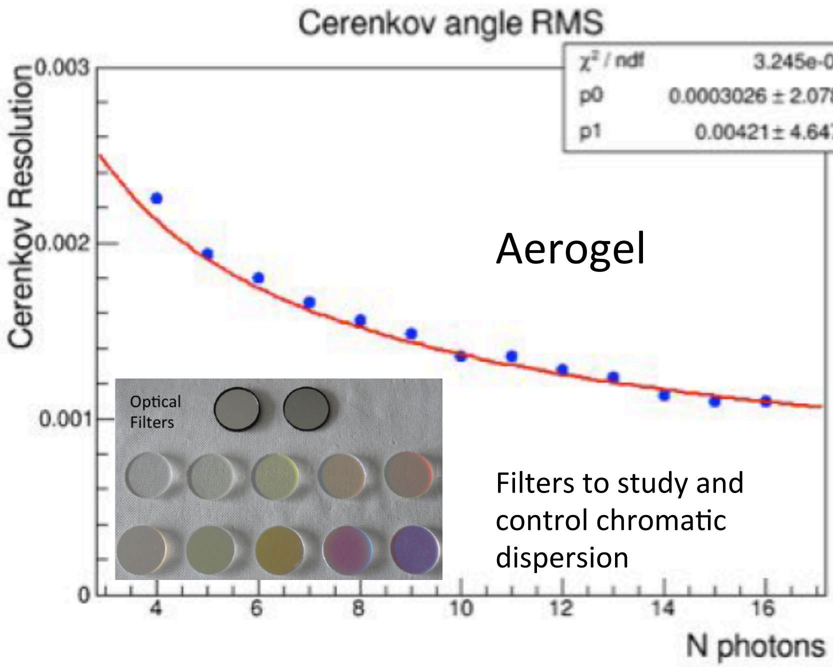
dRICH Prototype Design

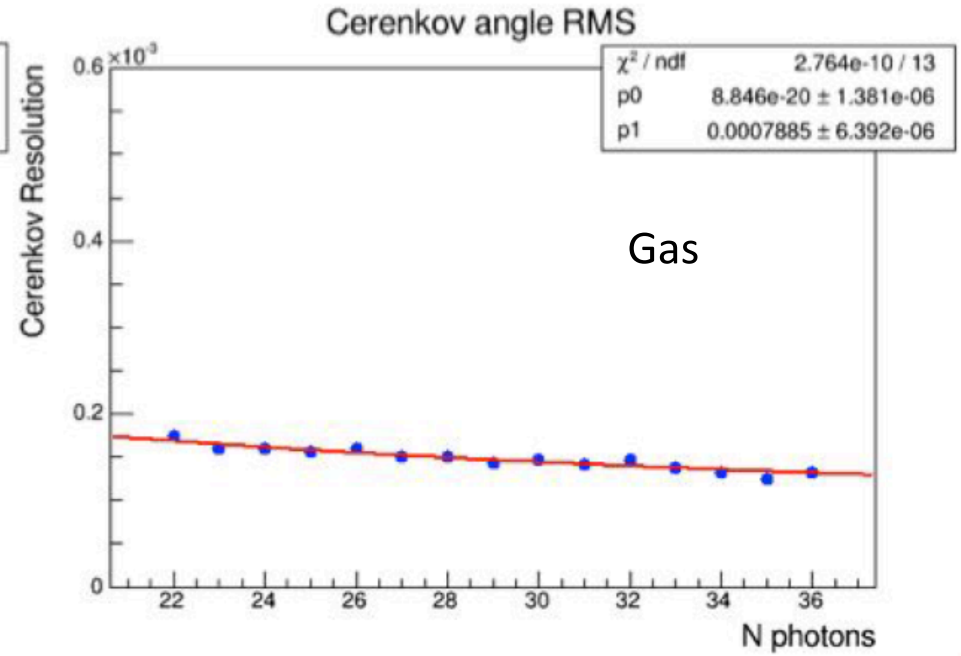


Commercial vacuum technology for safety and cost effectiveness
Overlapping rings for parallel beam particles

dRICH Prototype Performance

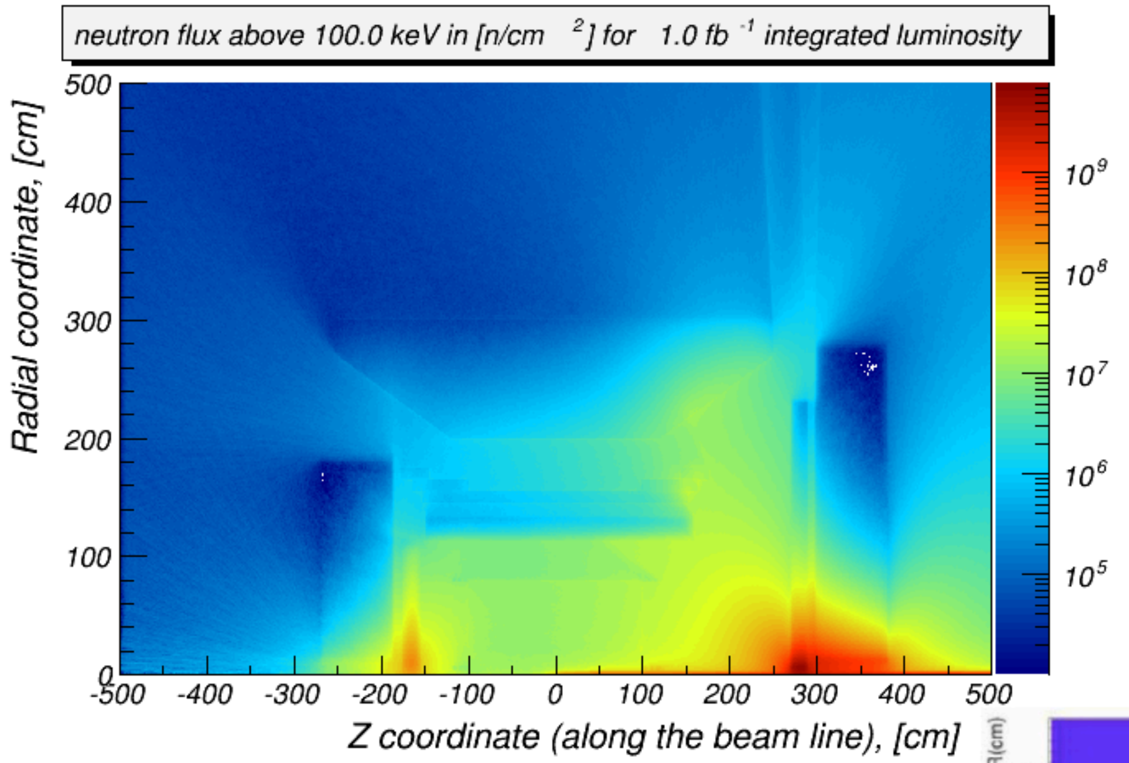
Montecarlo simulation





1 p.e. Error (mrad)	Aerogel	@EIC	C_2F_6 Gas	@EIC
Chromatic error	3.2	(2.9)	0.51	(0.8)
Emission	0.5	(0.5)	0.5	(1.2)
Pixel	2.5	(0.5)	0.42	(0.5)

EIC Detector Environment



Neutron Fluence
(courtesy of A. Kiselev)

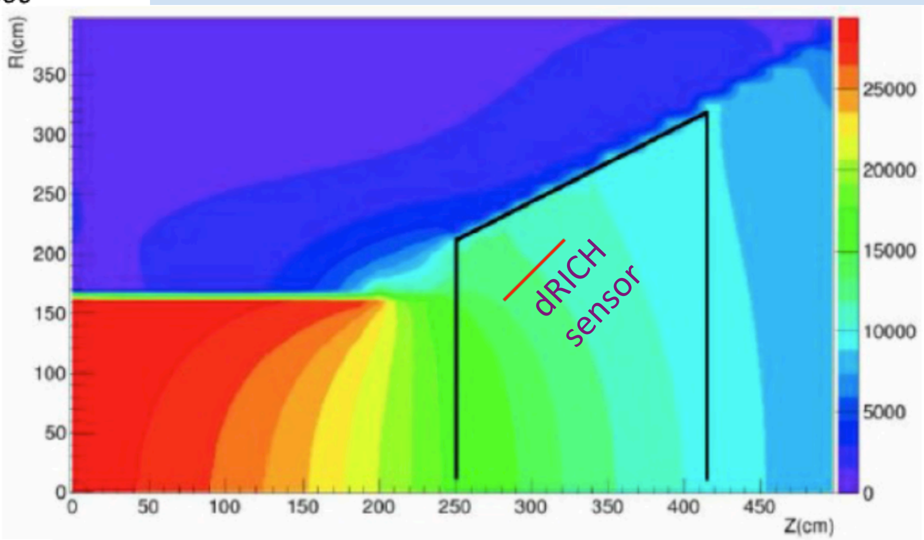
Moderate except for
very forward regions

Reference value ~ 10^{11} n_{eq}/cm^2
for several years at max lumi (10^{34})

Magnetic Field

~ 1 T order of magnitude
Detector orientation to be tuned

SiPM: PET study up to 7 T
10.1109/NSSMIC.2008.4774097

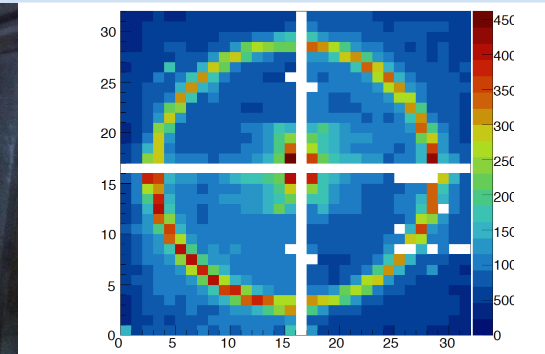


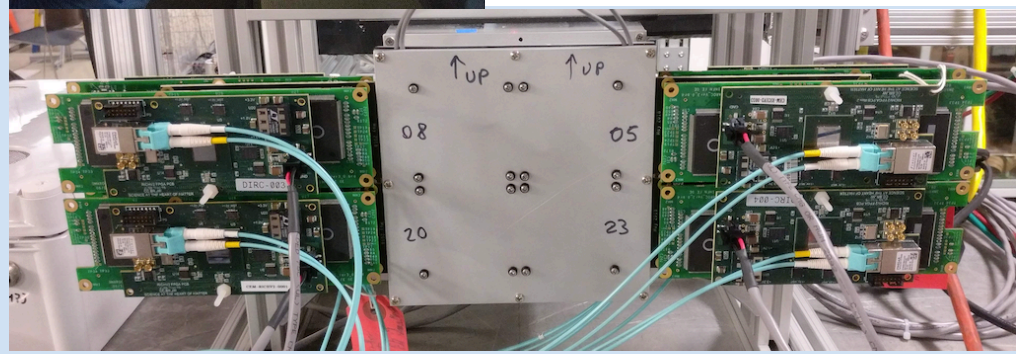
Sensor and Readout

Readout Independent element for flexibility: supports various detectors with integrated cooling

Reference:
MAROC (Discriminator) + SSP/VSX (VME)

Dedicated:
SiREAD (Sampling) + SSP/Ethernet

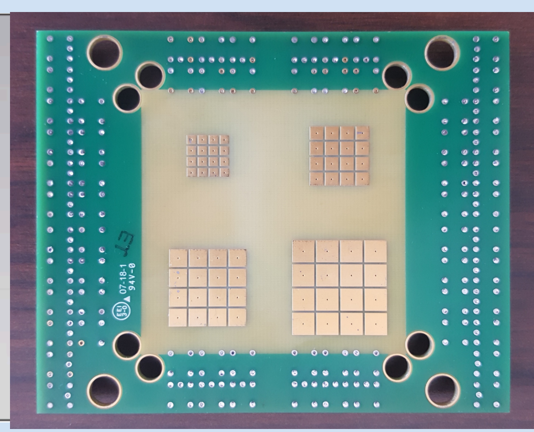




Sensors Reference MA-PMTs

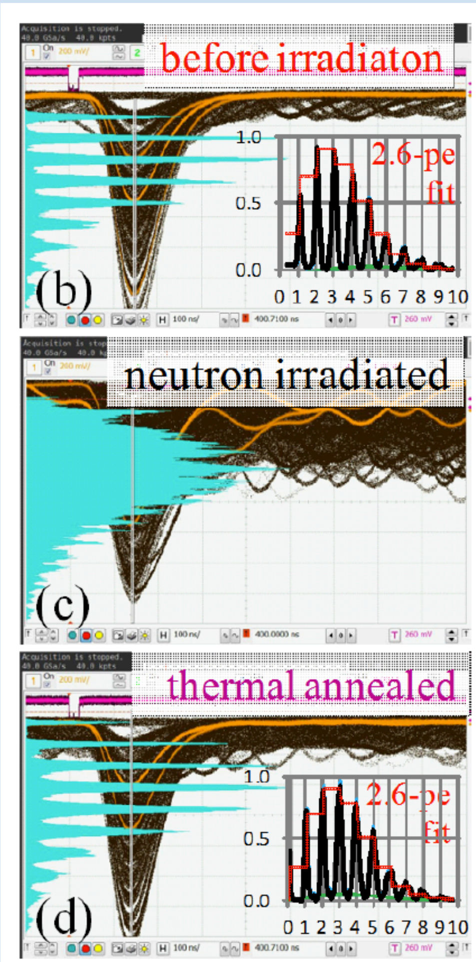
B-field tolerant MCP-PMTs (LAPPDs)

+ Robust/Compact/Cost-effective: SiPMs



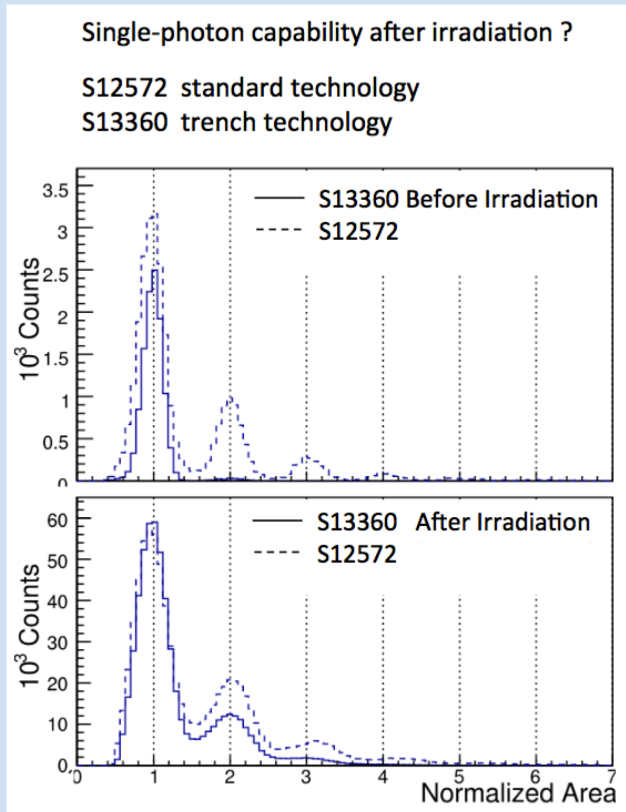
SiPM Radiation Tolerance

T. Tsang et al.
JINST 11 (2016) P12002



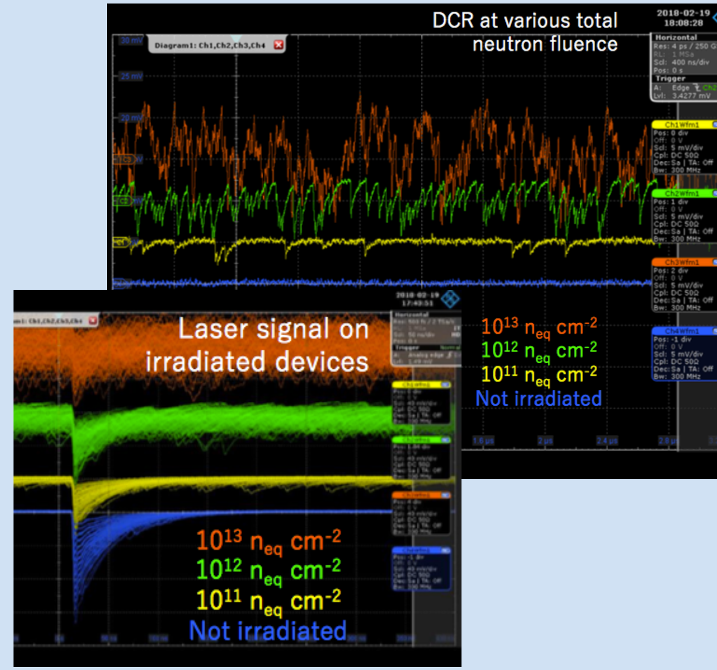
T= 25 C
10^9 n_{eq} cm^2
Annealing at 250 °C

I. Balossino et al.
NIMA 876 (2017) 89



T= 0 C
few 10^9 n_{eq} cm^2

M. Calvi et al.
NIMA 922 (2019) 243



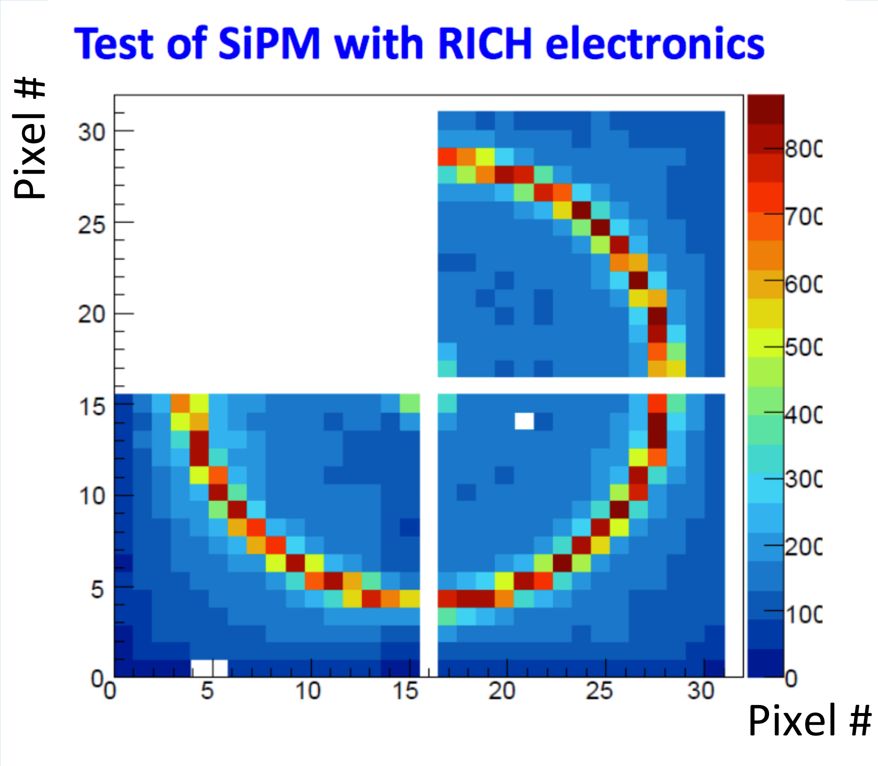
SiPM: Hamamatsu S13360-1350CS (50 μm cells)

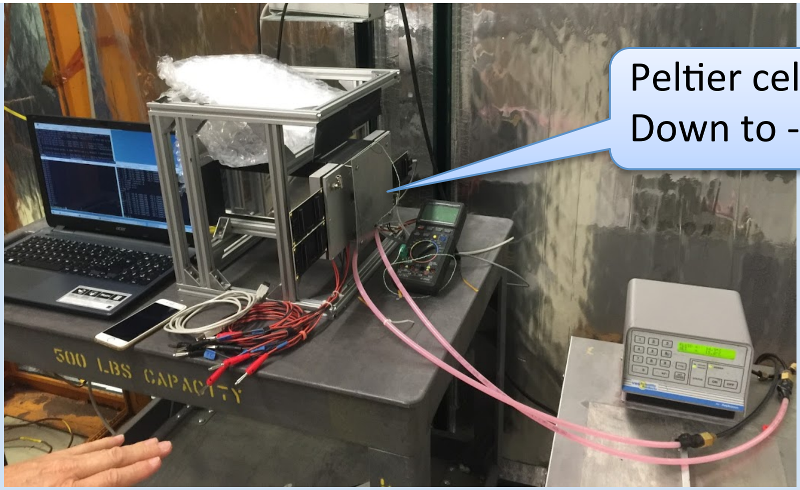
Temperature: –30 °C

≥ 10^{11} n_{eq} cm^2

SiPM Option

Viable solution with cooling





Peltier cell cooling
Down to -30° in N_2

Conclusions

The last decade provided many evidences that correlation of partonic transverse degrees of freedom in the nucleon do exist and manifest in hadronic interactions

Next step: Moving from phenomenology to rigorous treatment (predictive power)

Hadron identification provides access to the peculiar flavor dynamics within the QCD complex and rich confined world

New data coming from SIDIS, DY, e+e- and pp reactions should allow to:

- Constrain models in the valence region
- Test factorization, universality and evolution
- Study higher twist effects
- Investigate non-perturbative to perturbative transition (along P_T)
- Flavor separation via proton and deuteron targets and hadron ID
- Test of Lattice QCD calculations