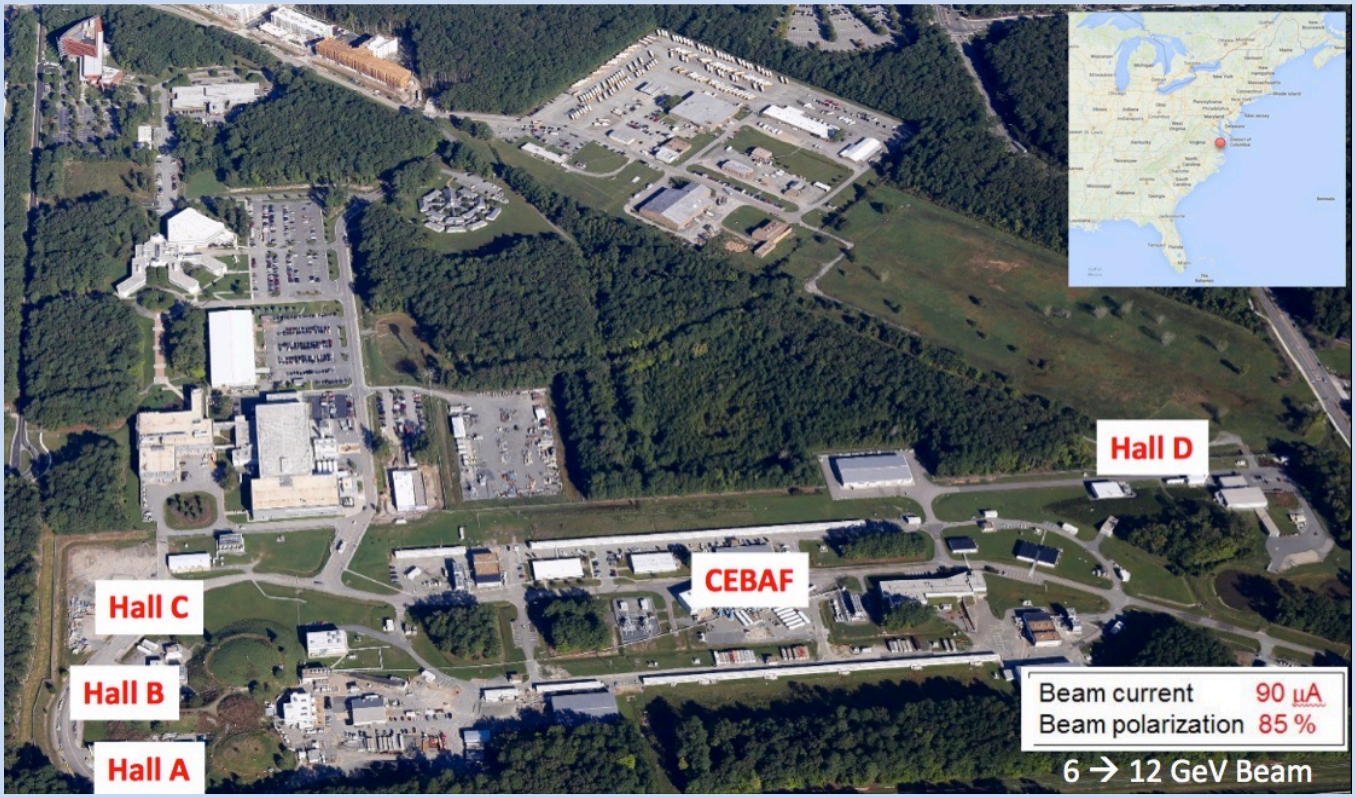
Nuove sfide di Fisica Adronica a JLab ed EIC

Marco Contalbrigo – INFN Ferrara

Congresso Nazionale SIF 2023 - 11-15 Settembre 2023

INFN@ JLab

INFN presence from the beginning (1991). **Italian spokespersonship**: > 20% of approved experiments



Deputy AD
Patrizia Rossi

JLUO Chair
Marco Contalbrigo

Hall-B Leader
Marco Battaglieri

[till 12/21]

Alessandra Filippi: Chair of HPS Editorial Board
HPS Executive Committee member

Lucilla Lanza: CLAS Speaker Committee member

Evaristo Cisbani: SBS Corrdinating Committee member

Marco Mirazita: CLAS Service Work member

Andrea Celentano: HPS Publication Committee member

Raffaella De Vita: Hall-B Software Coordinator and CCC member [till 07/23]

Contalbrigo Marco: CLAS DPWG Chair and CCC member [till 09/22]

Marzio de Napoli: HPS Executive Committee member [till 05/23]

INFN 12 GeV Projects

Nucleon 3D

RM1, CT, BA

E07-109 Proton form factor ‘22
E17-004 Neutron form factor ‘22
E09-018 SIDIS off neutron (^{3}He) ’23

FE, LNF,GE

E06-112 Quark dynamics ‘18
E12-008 TMDs ‘18
C11-111 TMDs ‘21
C12-009 Dihadron probes ’21

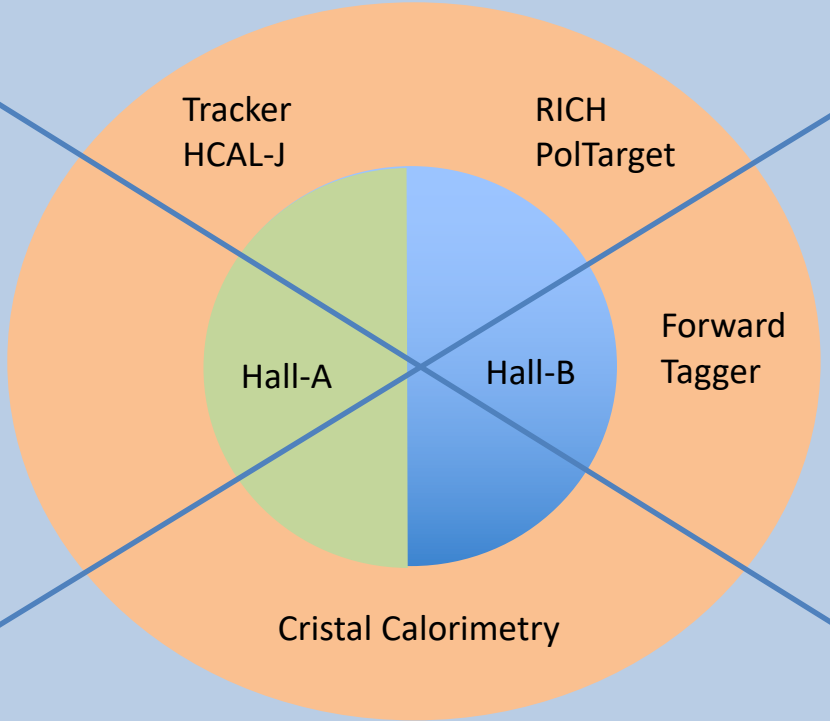
Nuclear Potentials

RM1

E17-003 ‘18
Lambda-nn off trithium (^{3}H)

E11-101 ‘19
PREX-II: neutron skin

E15-008 ‘24
Lambda hypernuclei



Spectroscopy

GE, RM2, TO, PV

E11-005 ‘18
MESONX

E12-001A ‘18
J/psi and penta-quark

E16-010 ‘18
Hybrid Baryons

Dark Sector

GE, CT, PV, LNS, RM2, TO, PD

E11-006 HPS ‘17

E16-001 BDX ‘24

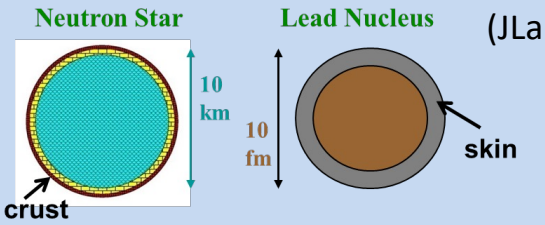
Neutron rich matter study at accelerators:
Parity violating asymmetry in electron scattering
to probe neutrons and measure the neutron skin

^{208}Pb well described by density functional theory

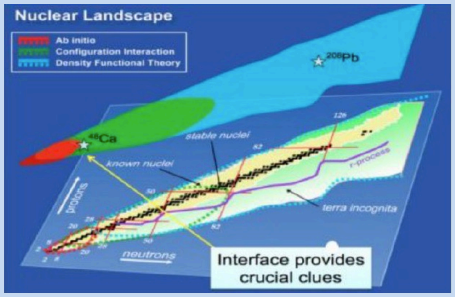
Ab initio calculations describe light to medium nuclei

^{48}Ca could provide a bridge and differentiate among models

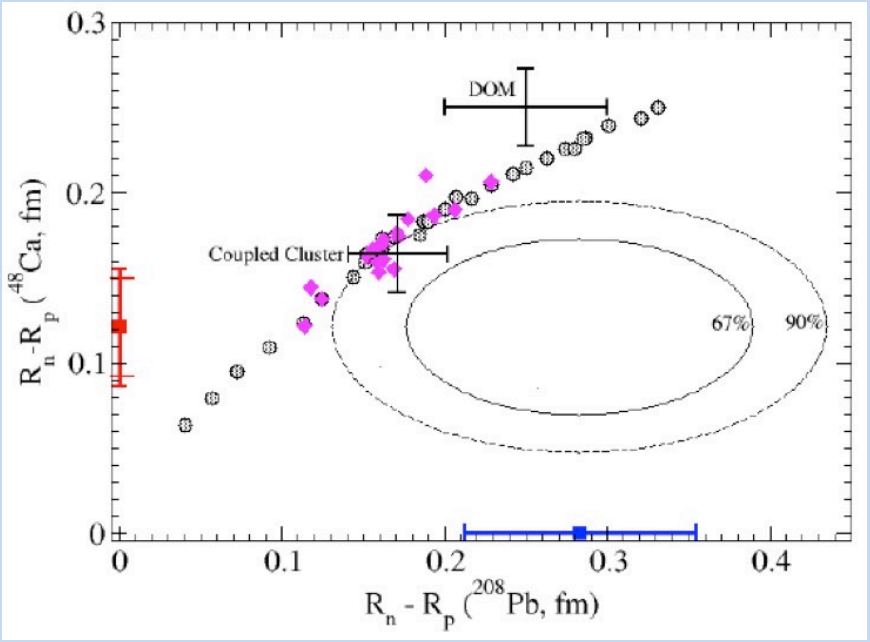
(LIGO)

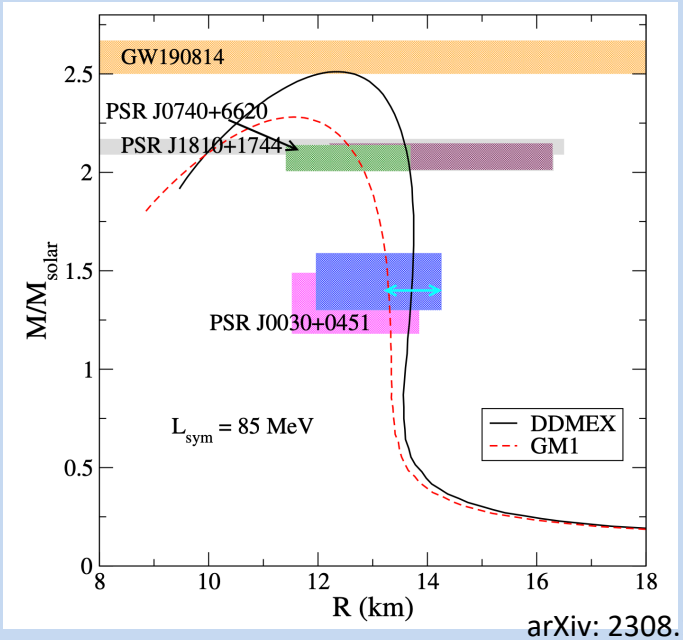


(JLab)



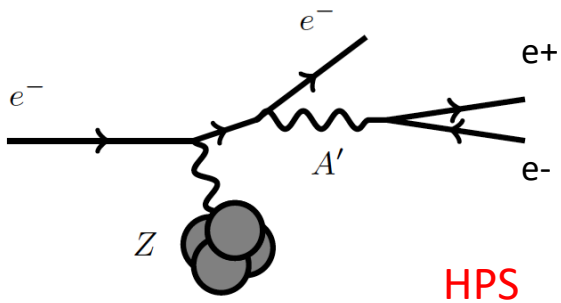
$$A_{PV} = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}}\left[1 - \underbrace{4\sin^2\theta_W} - \frac{F_N(Q^2)}{F_P(Q^2)}\right]$$



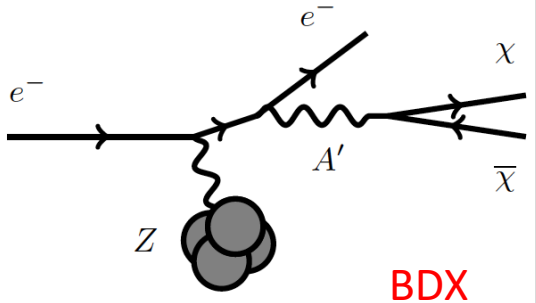


arXiv: 2308.16449

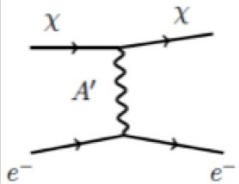
CEBAF intense high-energy electron beam allows to cover unexplored regions

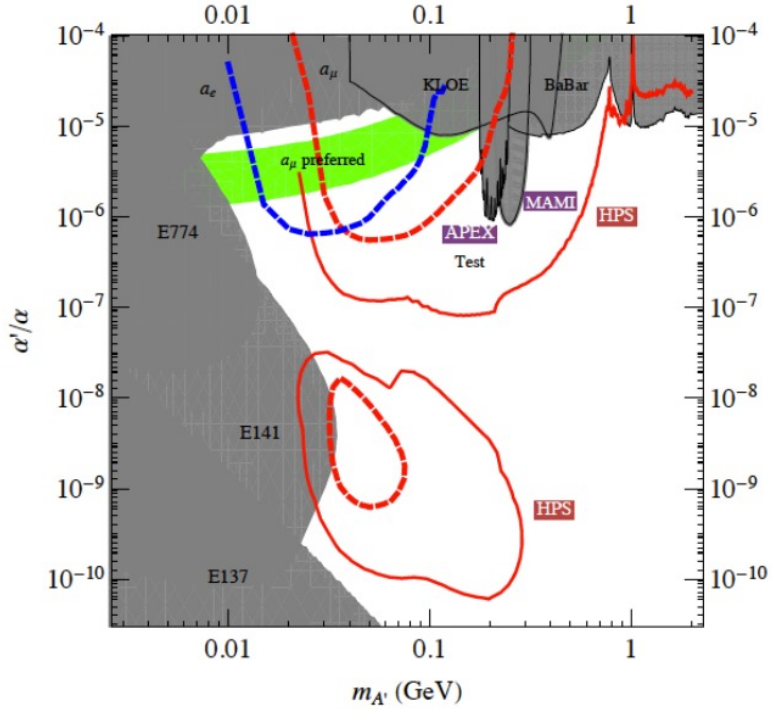


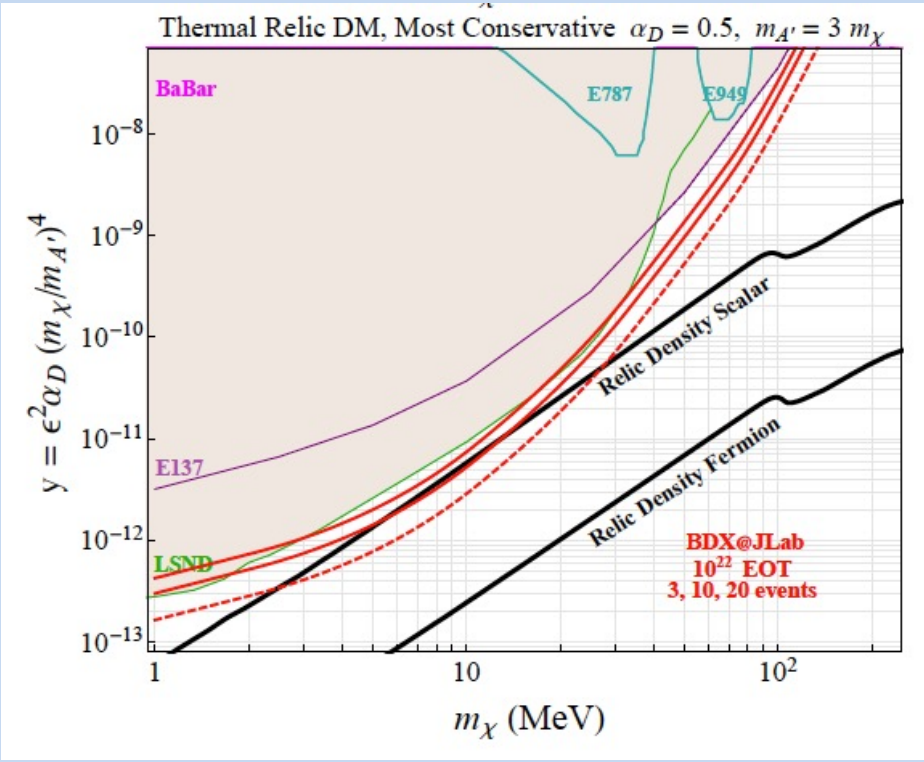
HPS



BDX

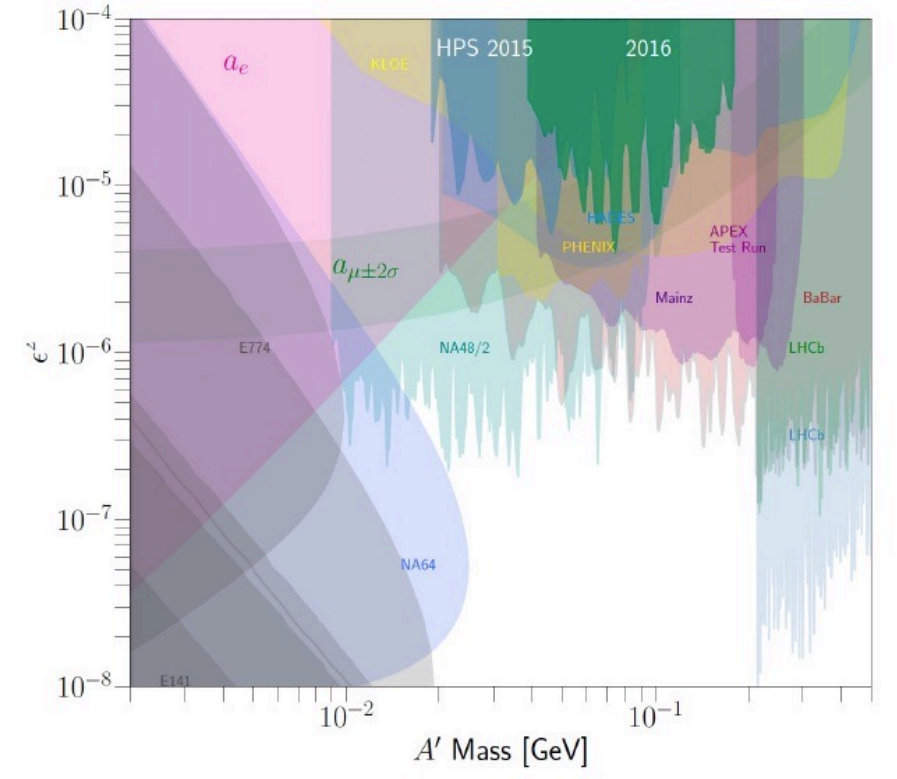




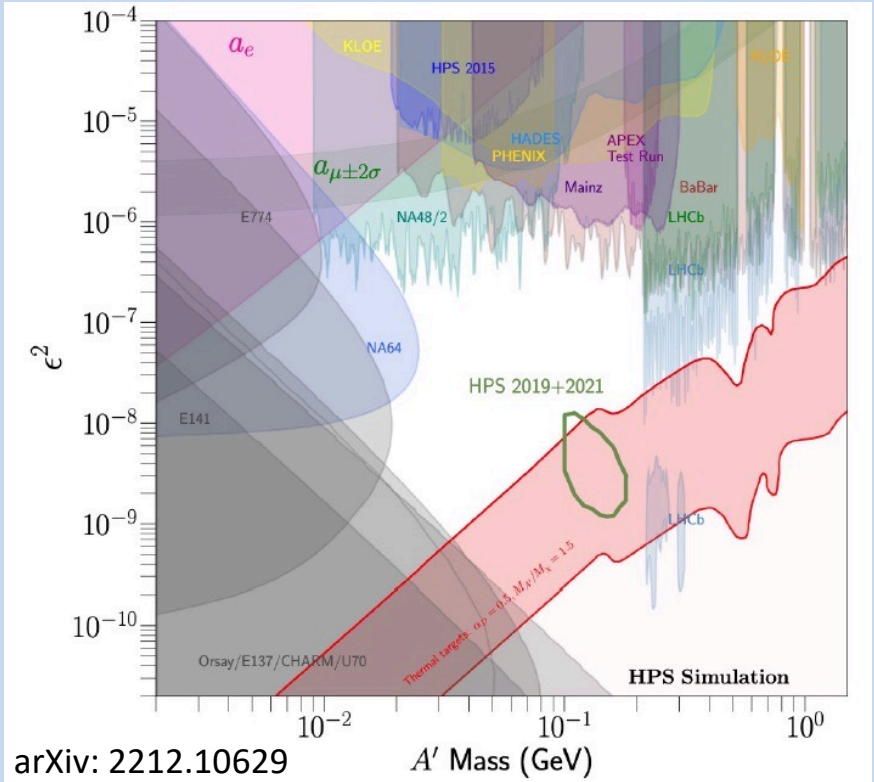


Heavy Photon Search

2016 Run: Analysis completed, drafting paper



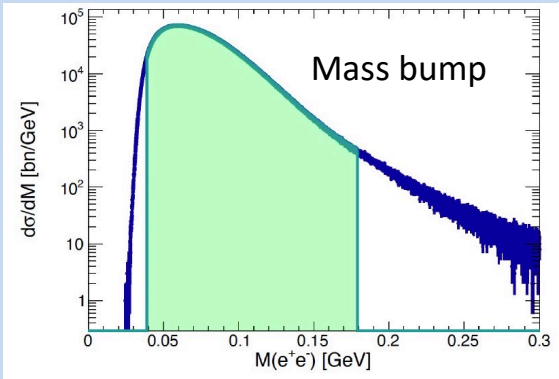
2019 Run: Upgraded detector & data-taking completed

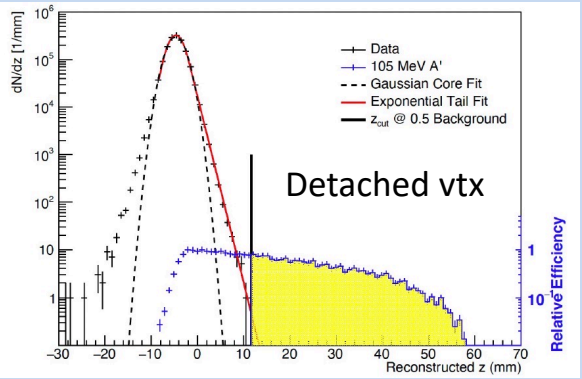


arXiv: 2212.10629

Moving towards unexplored regions with discovery potential

Still 107 PAC-approved data-taking days left

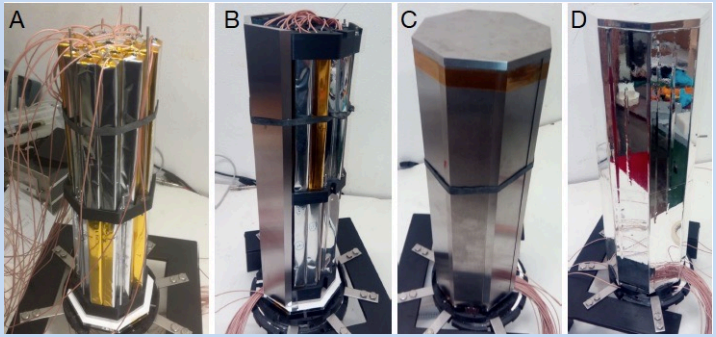




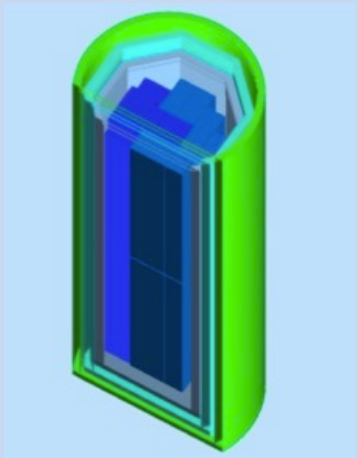
December ‘19 – fall ’20

E_e = 2.2 GeV **2.5×10^{21} EOT**

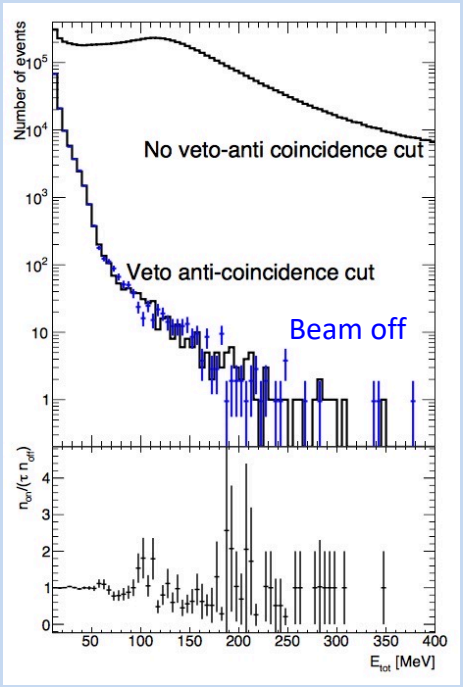
After unblinding no excess found



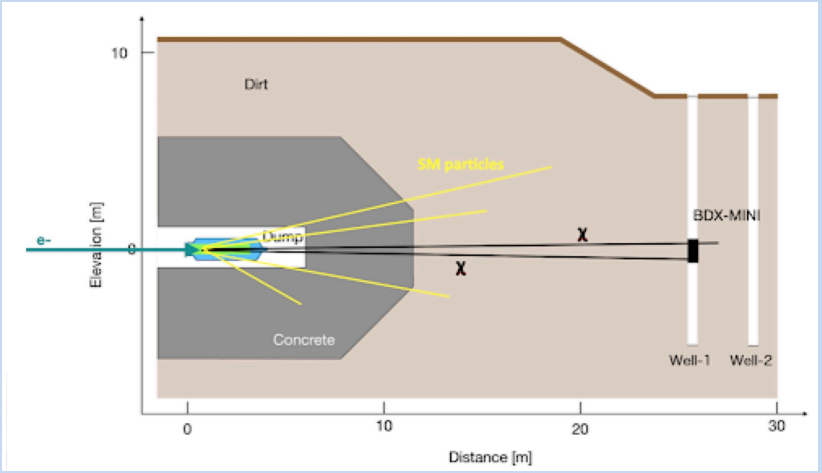
ECAL + veto attivo

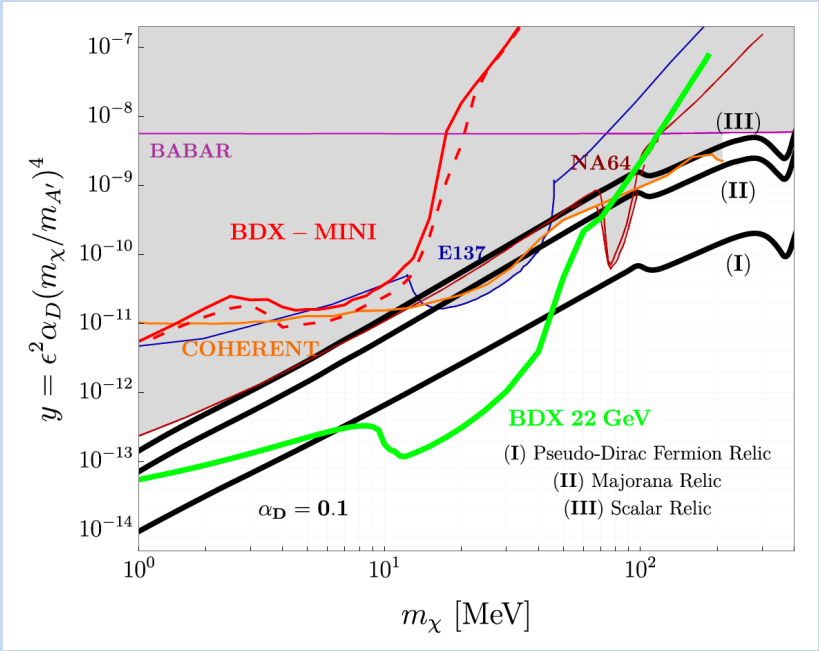


arXiv: 2208.01387



Despite the small scale, BDX-mini is competitive with LDM experiments (NA64, E137,..)





$$W_p^q(x,\vec{k}_T,\vec{b}_T)$$

d^2b_T d^2k_T

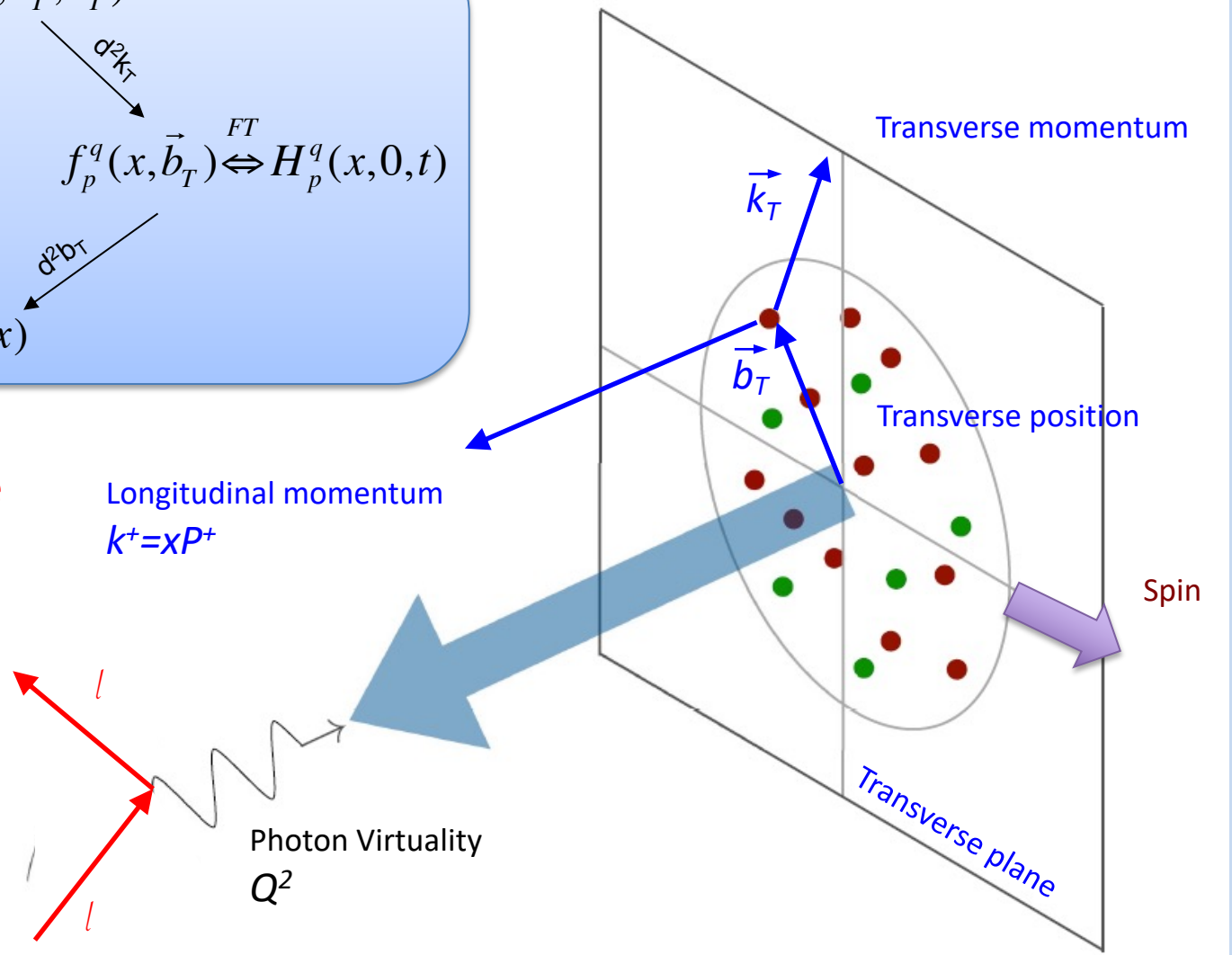
$$f_p^q(x,\vec{k}_T) \qquad f_p^q(x,\vec{b}_T) \overset{FT}{\Leftrightarrow} H_p^q(x,0,t)$$

d^2k_T d^2b_T

$$f_p^q(x)$$

Confinement Scale

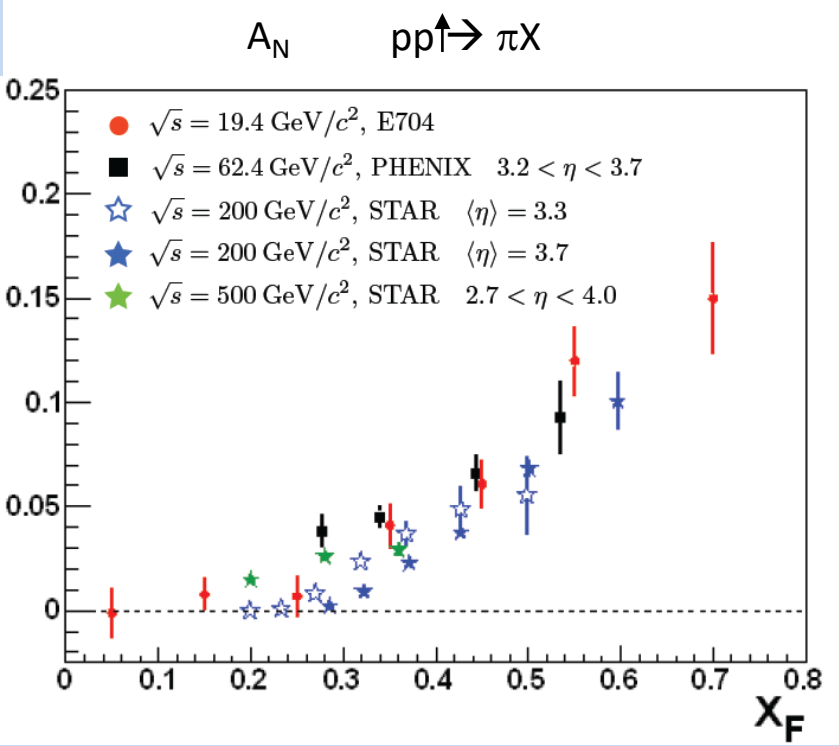
High Energy Probe
Hard Scale



Can QCD be a precision science ?

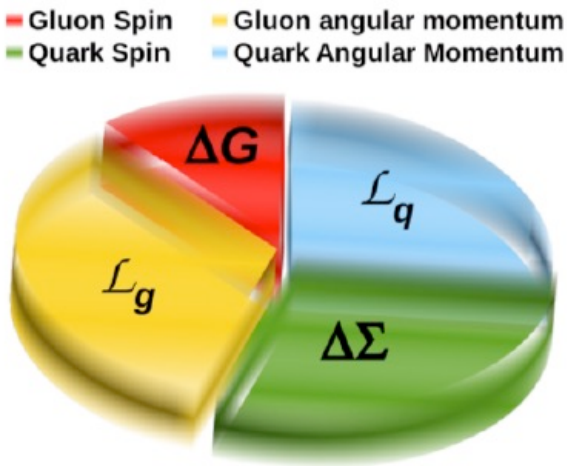
Should not be confused with pQCD, which already can,
but is not touching the intimate nature of the strong interaction

Single Spin Asymmetries



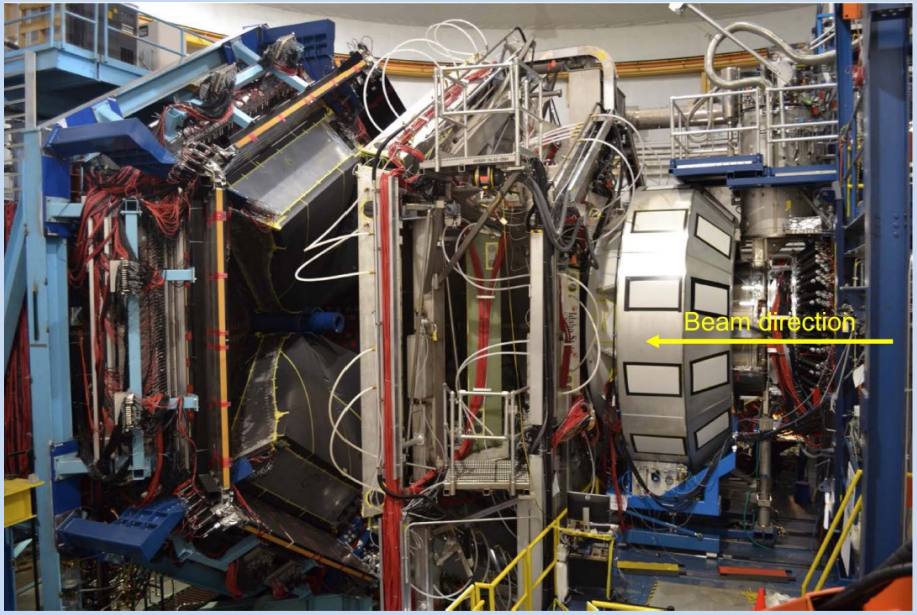
?

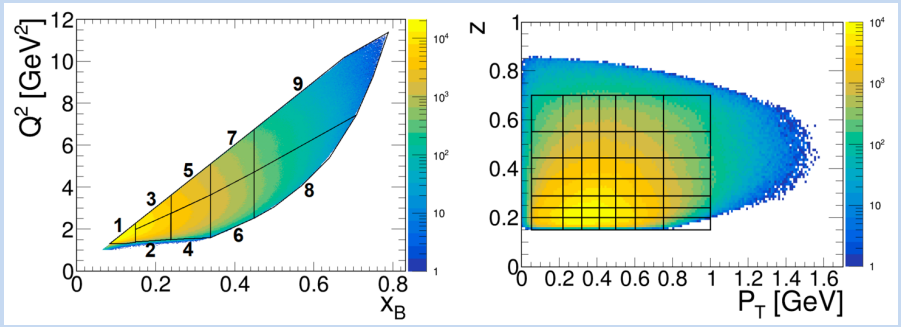
Proton Spin Budget

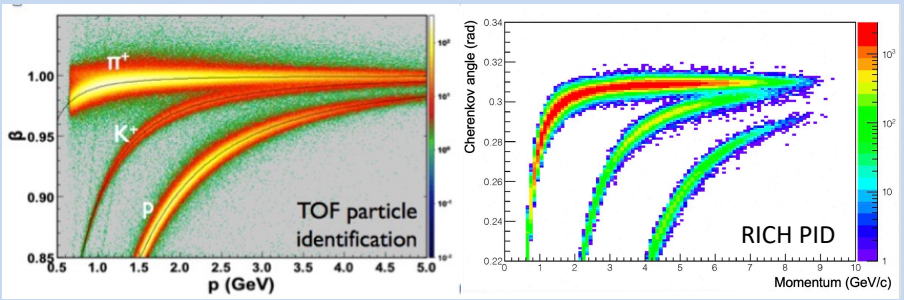


$$\frac{1}{2} = \frac{1}{2}\sum_f (q_f^+ - q_f^-) + L_q + \Delta G + L_g$$

CLAS12 wide coverage, excellent PID, various polarized targets, high luminosity



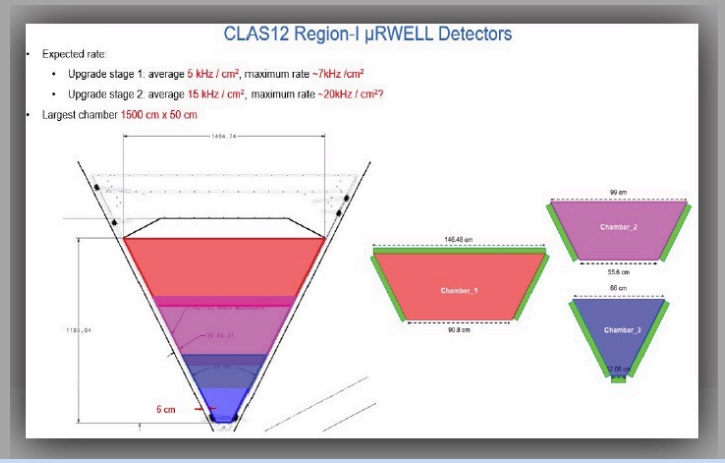




Year	Period	Run	Target	Polarization	Beam
2018	Spring-Fall	RGA	Proton	-	10.6 GeV
	Fall	RGK	Proton	-	6.5-7.5 GeV
2019	Spring	RGA	Proton	-	10.6 GeV
2019	Spring-Fall	RGB	Deuteron	-	10.6 GeV
2020	Spring-Fall	RGF	Deuteron	-	10.6 GeV
2021	Fall	RGM	Nuclear	-	Several GeV
2022	Spring-Fall	RGC	NH_3-ND_3	Longitudinal	10.6 GeV
> 2022		RGH	NH_3-ND_3	Transverse	10.6 GeV
> 2022			^{3}He	Longitudinal	10.6 GeV
> 2022		RGG	^{7}LiD, ^{6}LiH	Longiudinal	10.6 GeV

Luminosity upgrade Stage-1: 2×10^{35} cm^{-2}s^{-1} 3 years

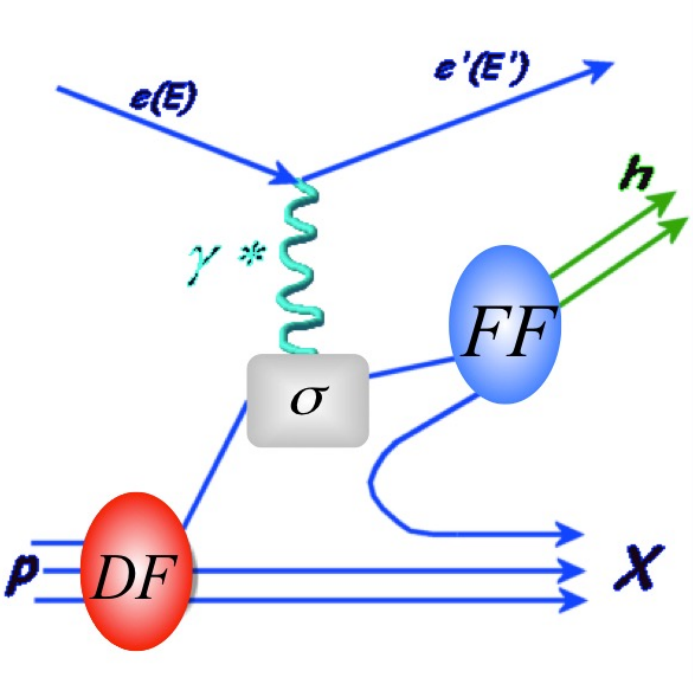
Stage-2: > 10^{37} cm^{-2}s^{-1} 7-10 years

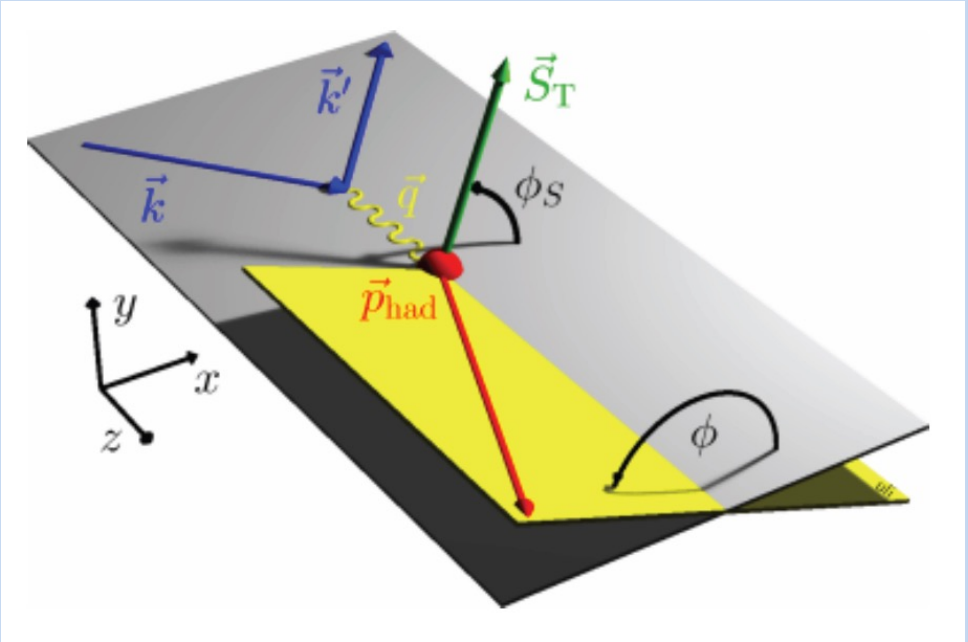


3D momentum and spin-orbit effect:
Parton kinematics and flavor from observed hadron kinematics and type

Distribution and fragmentation convoluted:

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



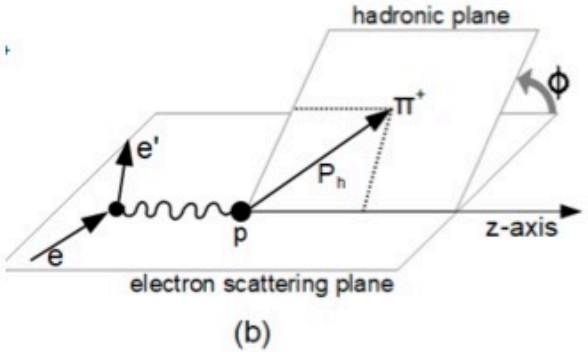


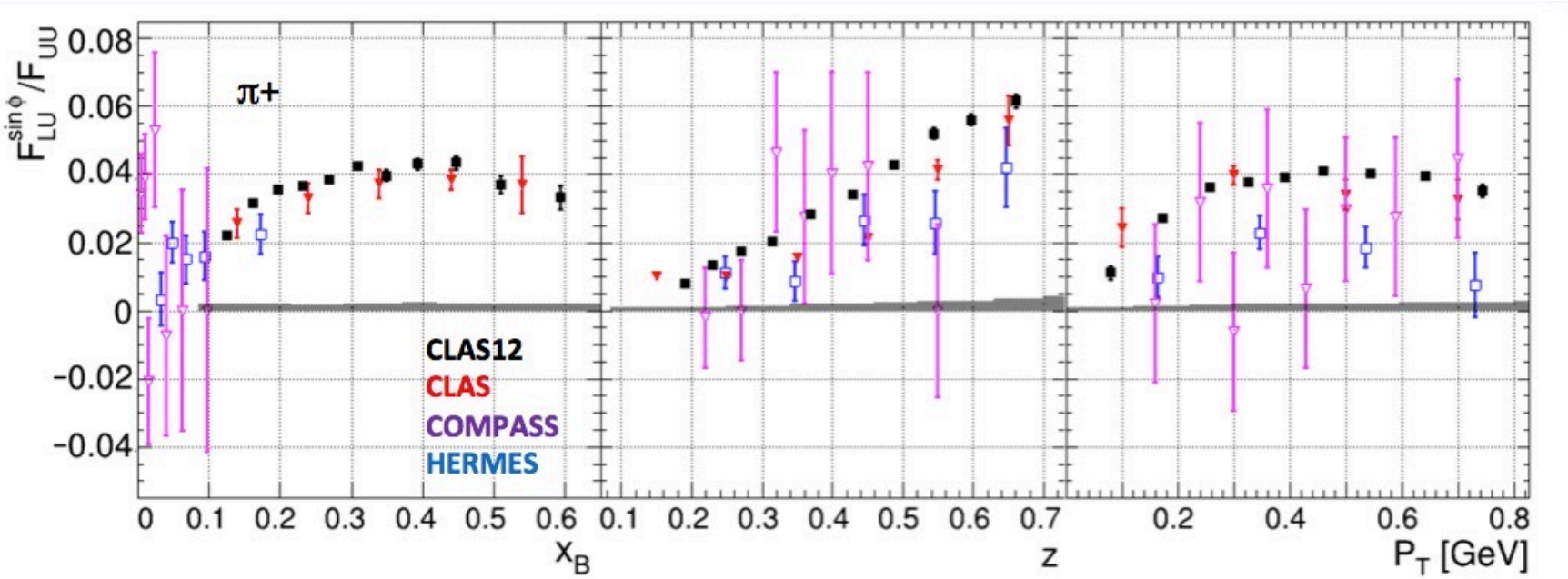
CLAS12 proton data (RGA)

S. Diehl et al., e-Print: 2101.03544

$$F_{LU}^{\sin\phi} = \frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{h}\cdot k_T}{M_h}\left(x_B e H_1^{\perp} + \frac{M_h}{M} f_1 \frac{\tilde{G}^{\perp}}{z}\right) + \frac{\hat{h}\cdot P_T}{M}\left(x_B g^{\perp} D_1 + \frac{M_h}{M} h_1^{\perp}\frac{\tilde{E}}{z}\right)\right]$$

86.9±2.6 %

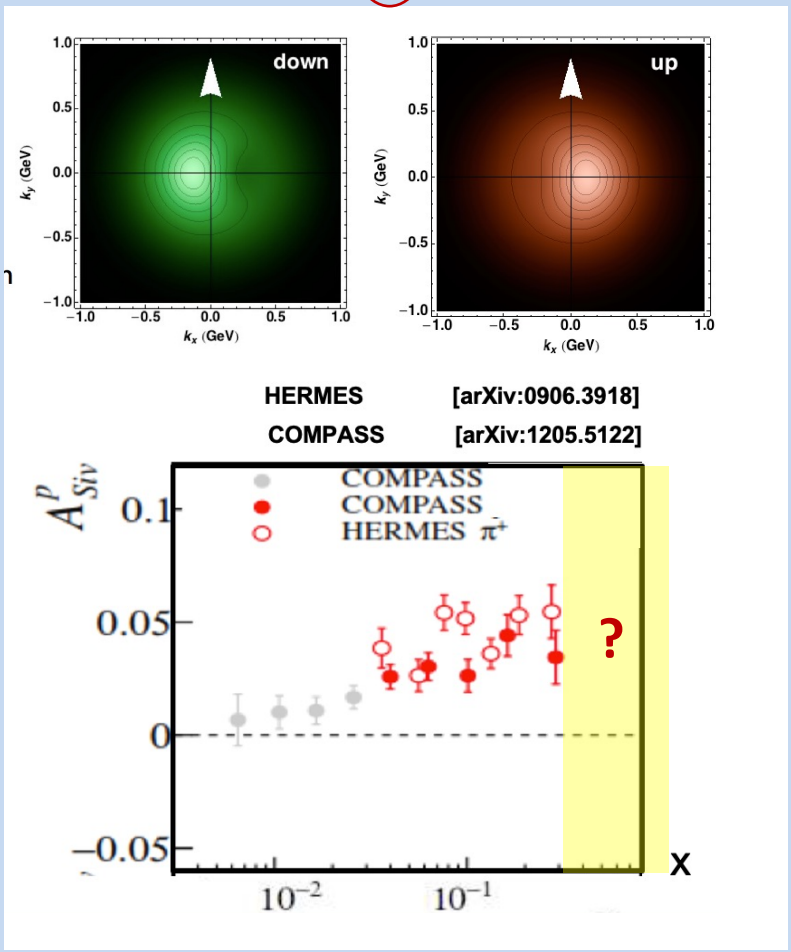




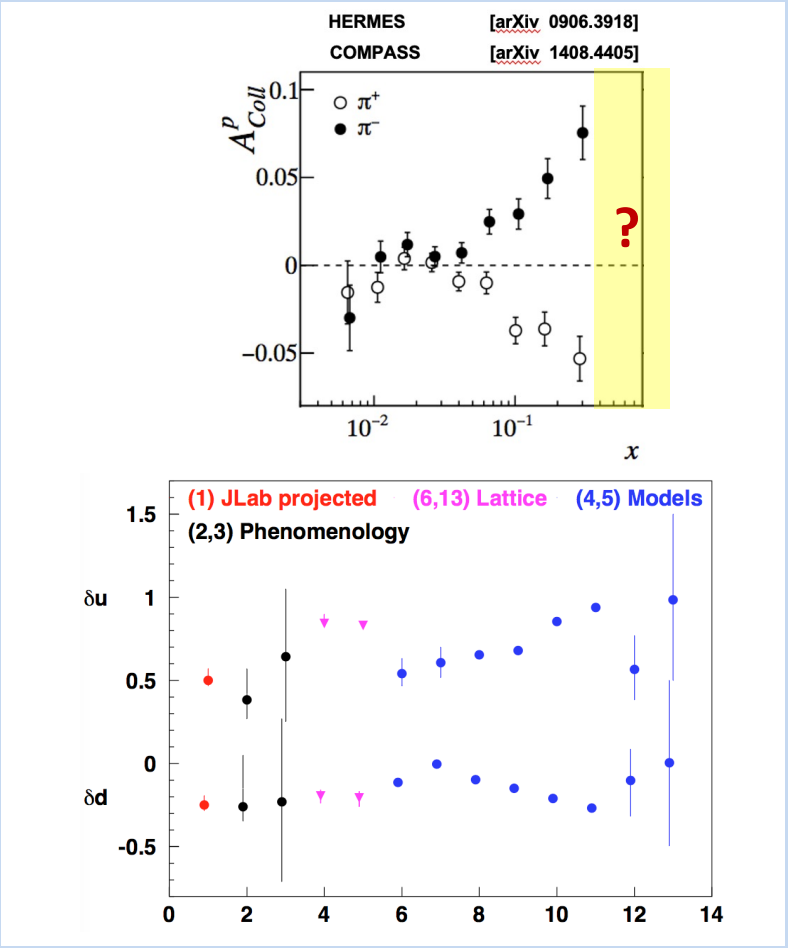
$$\sigma_{UT}^{\sin(\phi+\phi_S)} \propto f_{1T}^{\perp} \otimes D_1$$

Spin-orbit in QCD

$$\sigma_{UT}^{\sin(\phi+\phi_S)} \propto h_1 \otimes H_1^{\perp}$$



Sivers effect:
Correlation between nucleon spin and collective motion of the partons

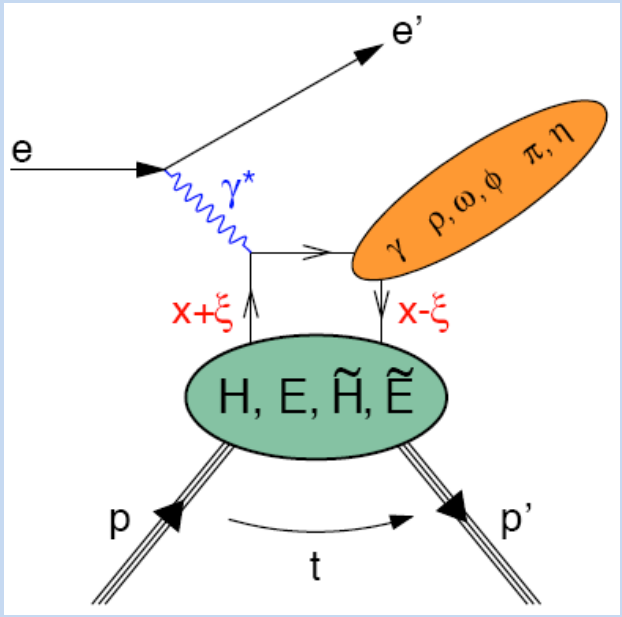


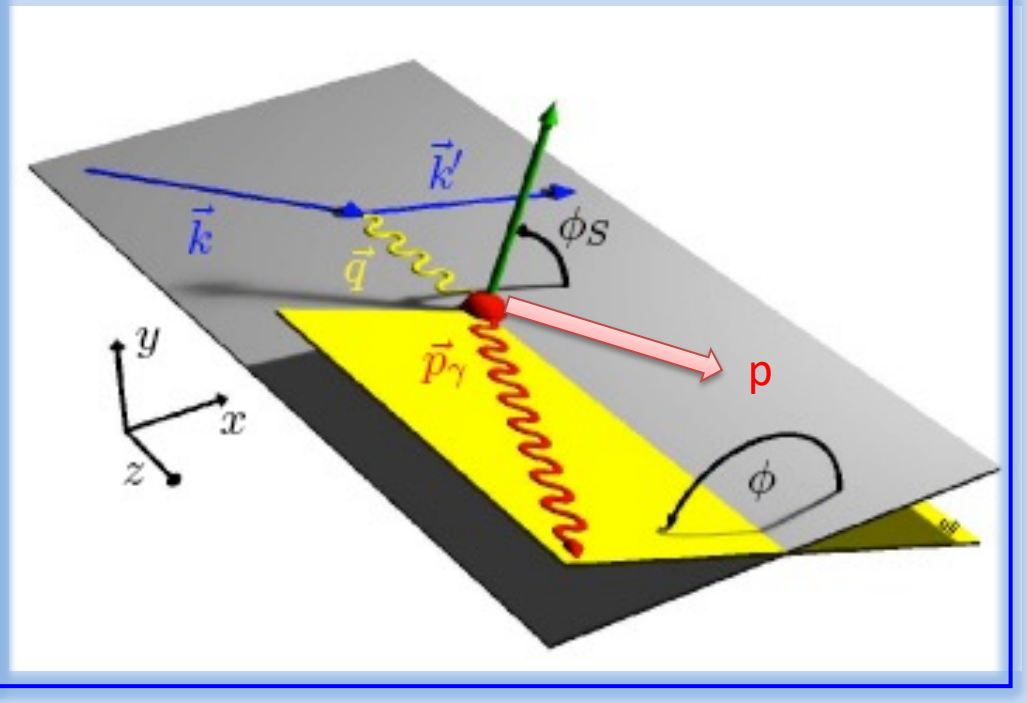
Tranversity & Tensor Charge
Fundamental quantity related to BSM searches (tensor coupling, particle EDM)

Transverse size & nucleon tomography:
Impact parameter derived from the transverse momentum transferred to nucleon

Various final states to prove GPDs and flavors

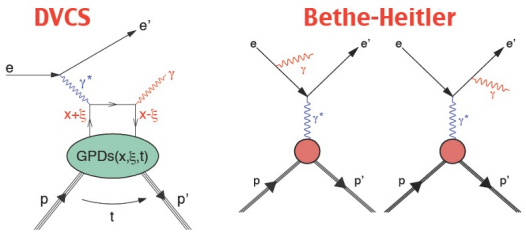
$$f_p^q(x,\vec{b}_T) \overset{FT}{\Leftrightarrow} H_p^q(x,0,t)$$





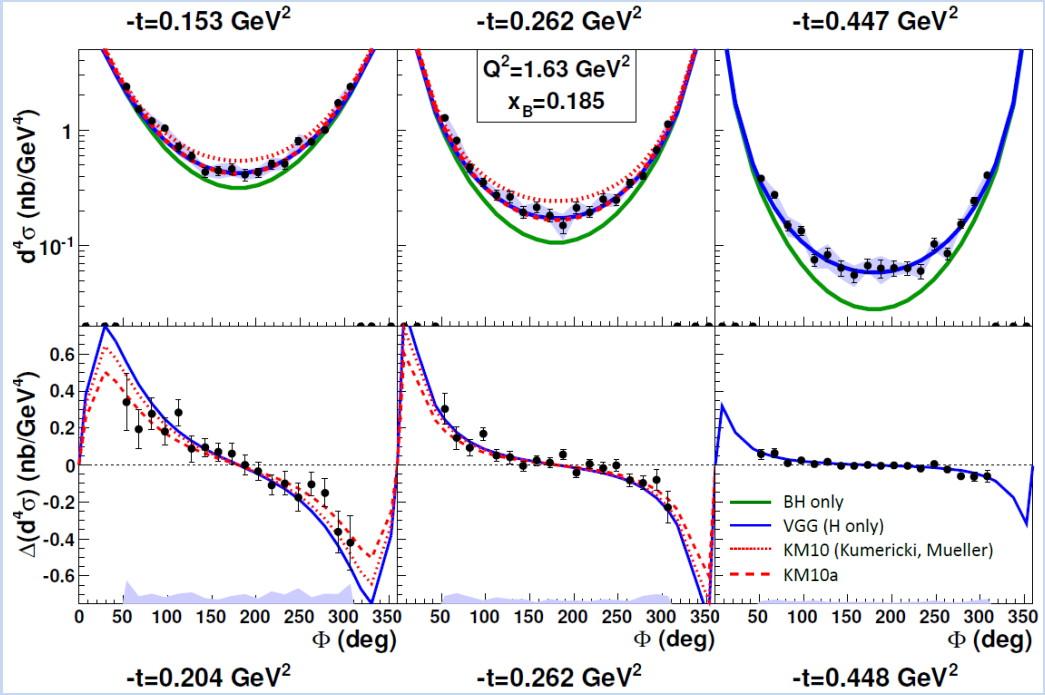
Informations on the real and imaginary part of the QCD scattering amplitude

$$\frac{d^4\sigma}{dQ^2\, dx_B\, dt\, d\phi} \propto \left(|\mathcal{T}_{DVCS}|^2 + |\mathcal{T}_{BH}|^2 + \mathcal{I}\right)$$



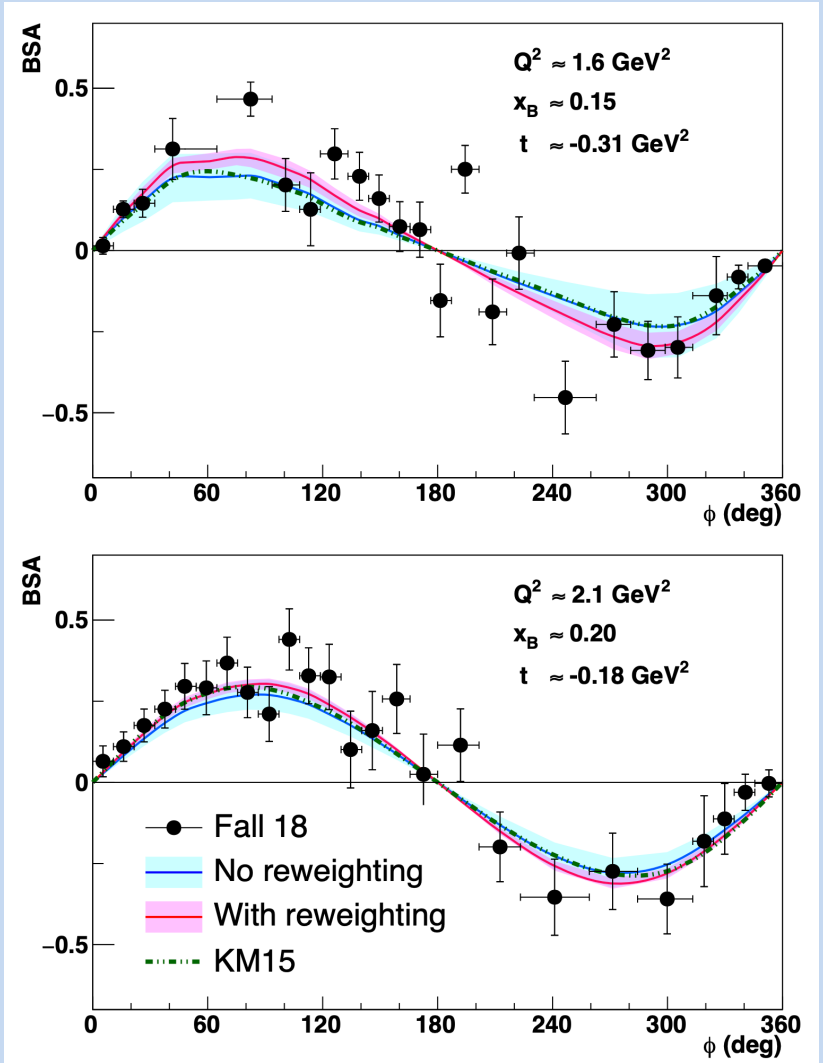
CLAS

H.-S. Jo et. al. [arXiv: 1504.02009]



CLAS12

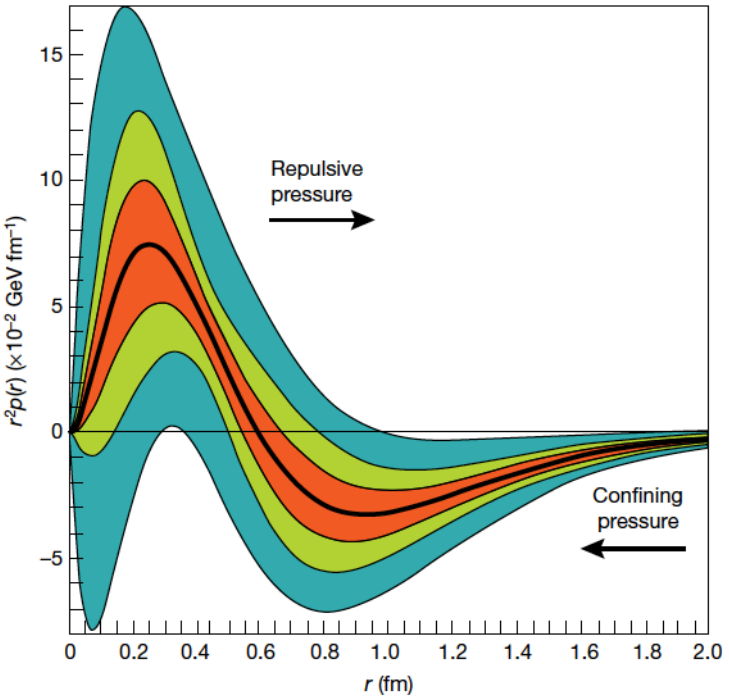
G. Christiaens et. al. [arXiv: 2211.11274]



GPDs moments are related to the proton momentum-energy tensor,
e.g. how pressure and momentum are distributed within the nucleon

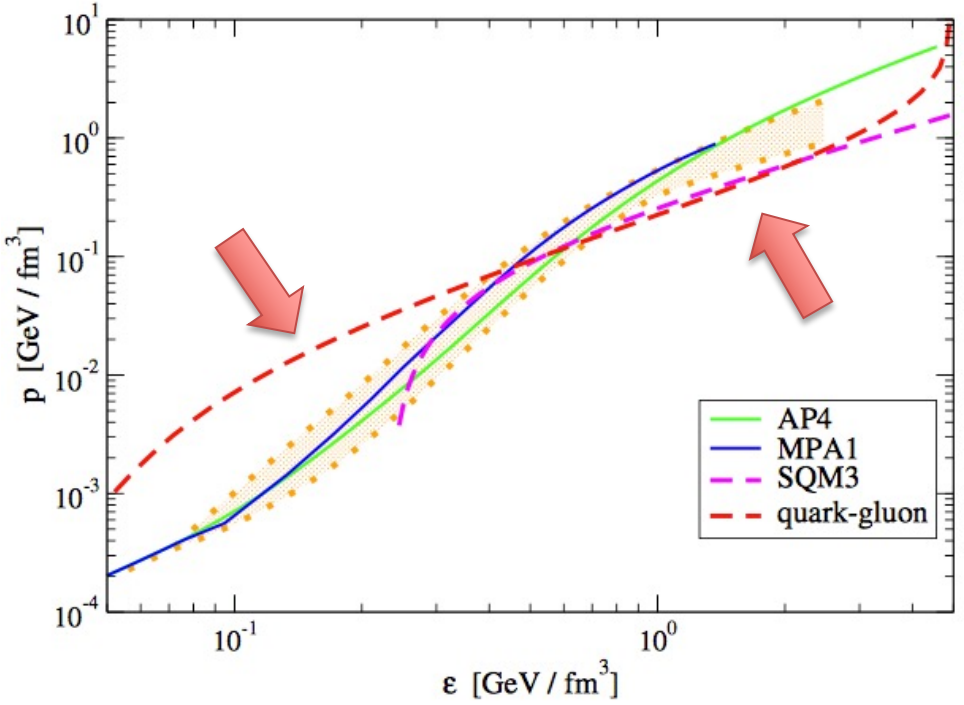
Pressure inside the nucleon

V.Burkert++ [Nature 577 (2018)]

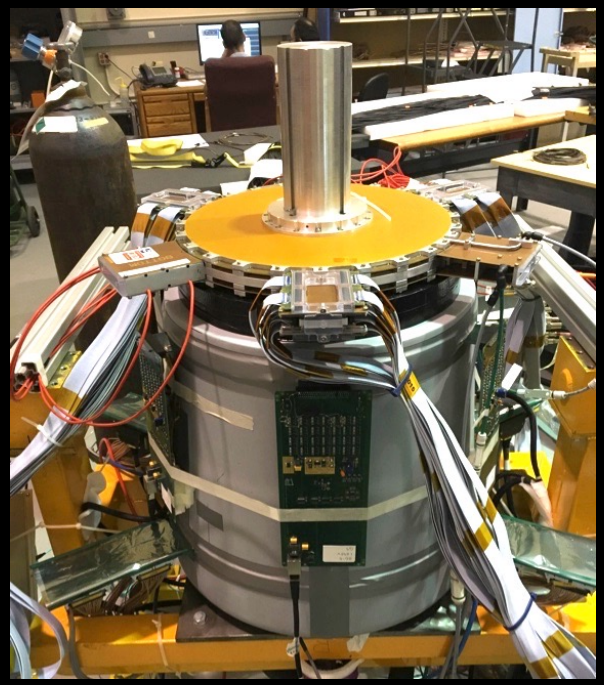


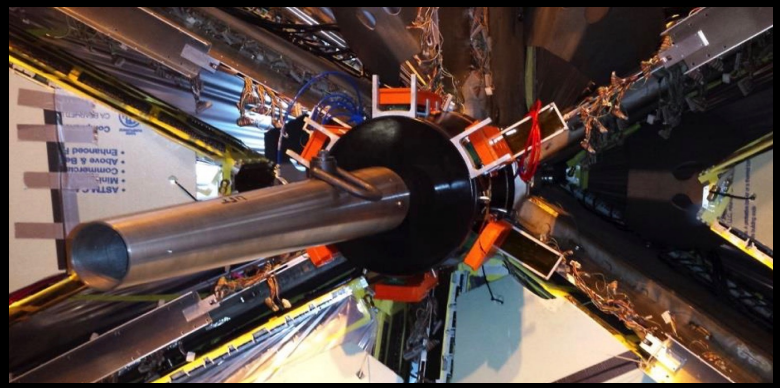
Neutron star equation of state

S.Liuti++ [arXiv 1812.01479]

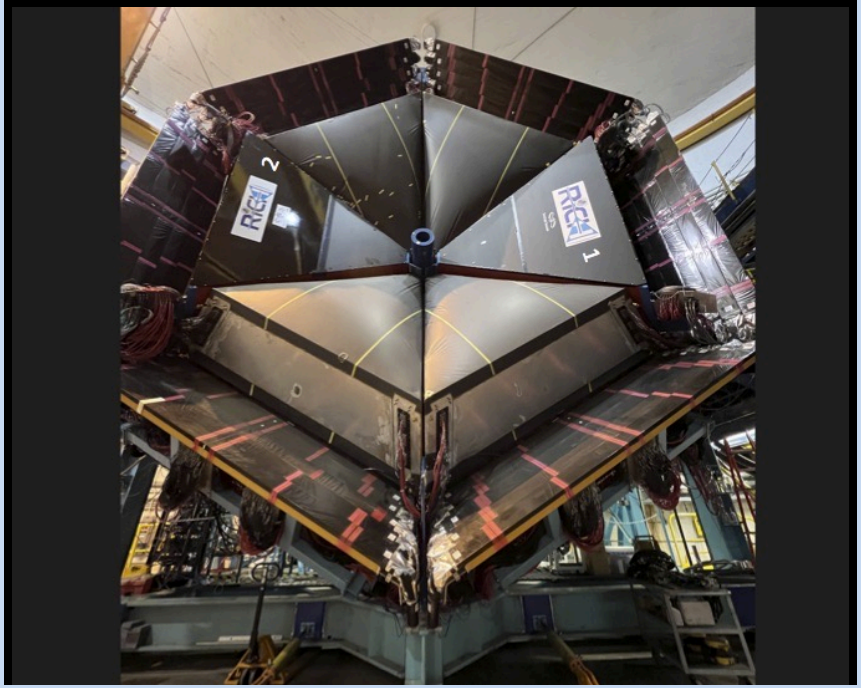


Forward Tagger completed in 2018
Small-angle calorimeter (nucleon 3D)
Quasi-real photoproduction regime (spectroscopy)

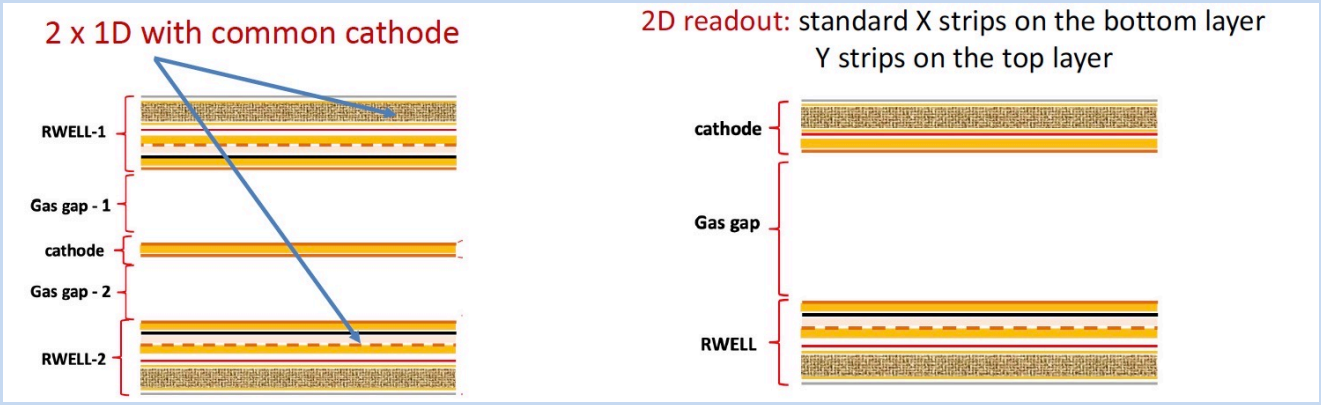


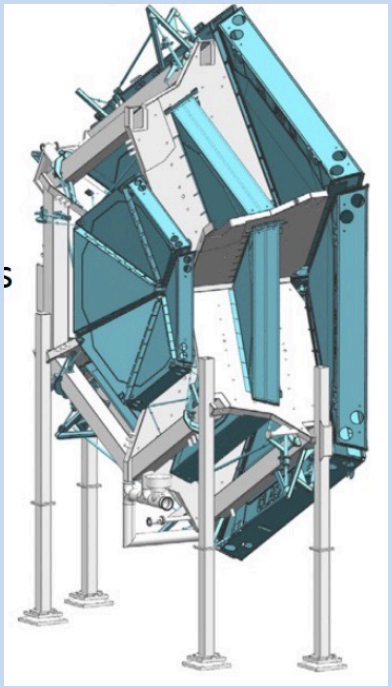


RICH completed in 2022
Hadron ID in the 3-8 GeV/c momentum range
MIUR priority project (“premiale”)



Under study @ INFN: Alternative 2D-readout schemes and light assembling





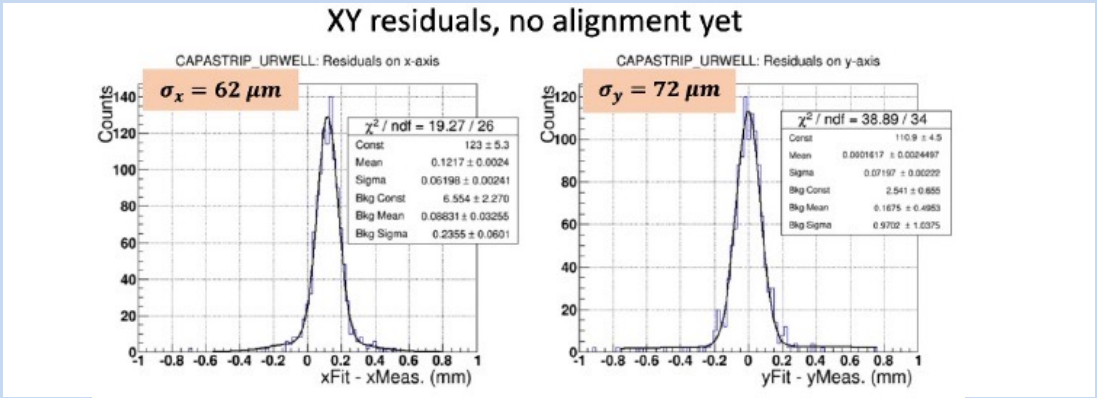
Towards: 50x50 cm^2 prototype

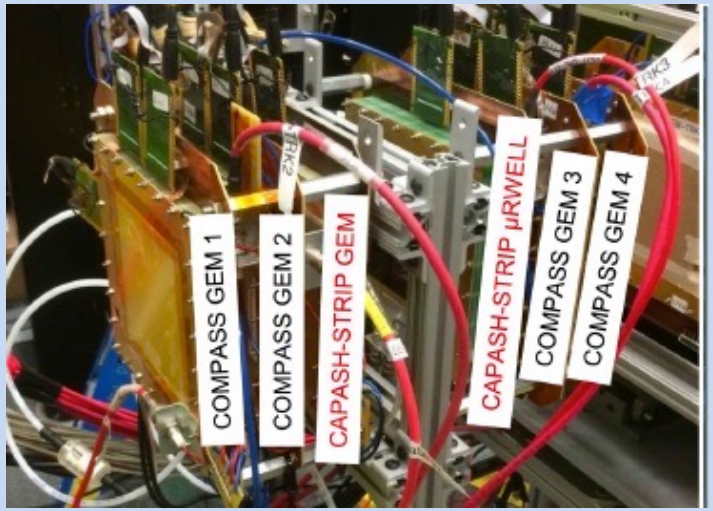
Study charge collection, time and spatial resolution

Requirements: σ_s ~ 100 mm

Δt ~ 10 ns

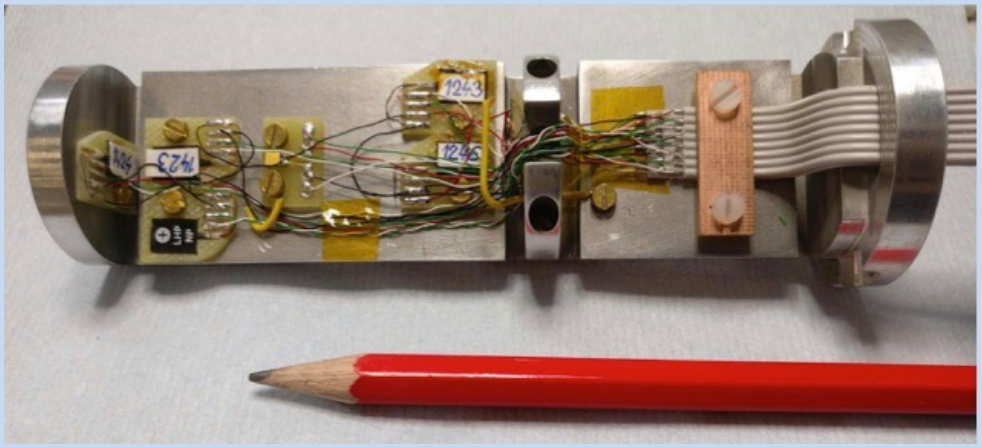
Eff > 95%

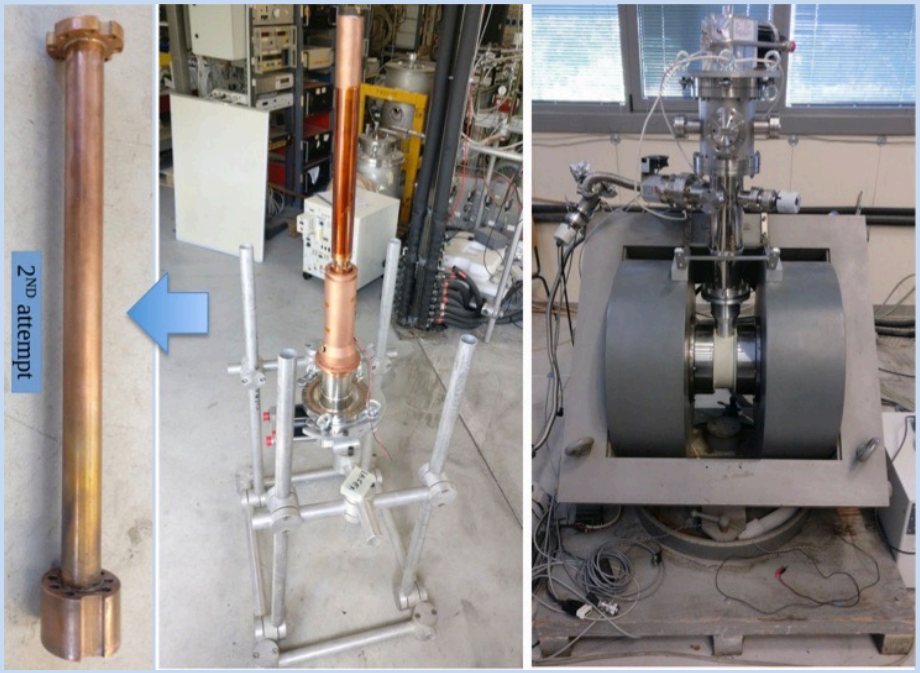


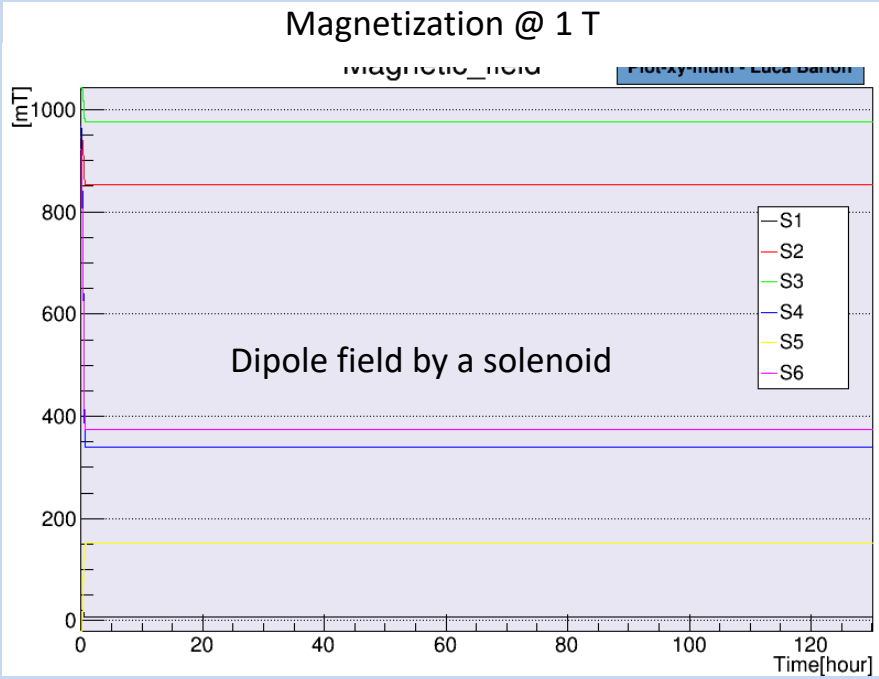


INFN: Target Holding Magnet

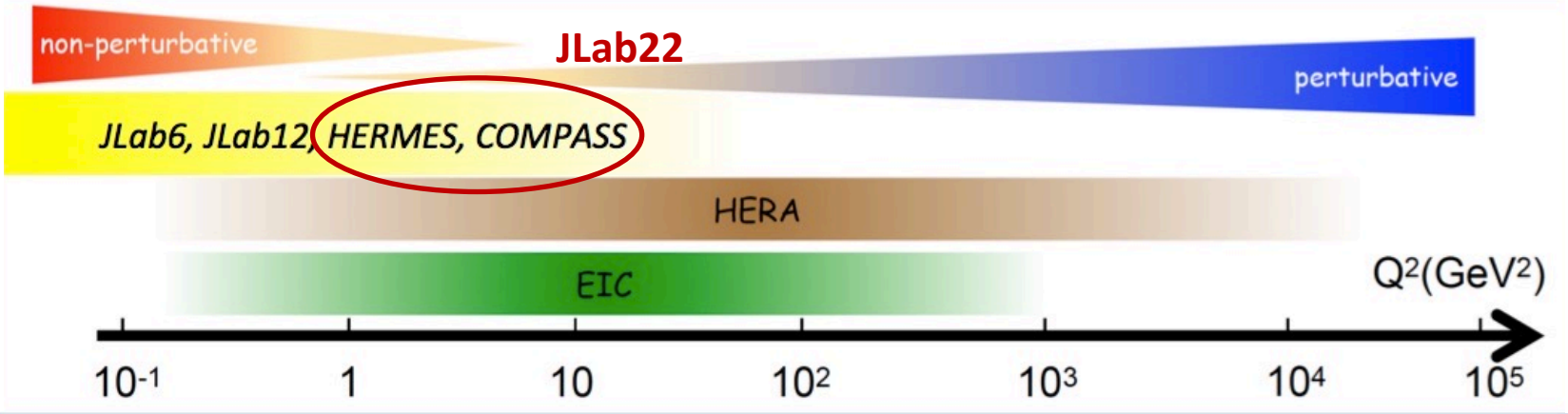
Under study: New concept
pre-conditioned MgB_2 bulk superconductor
- No coil shaping within experiment
- No current leads, just low T
- Minimum material, large acceptance



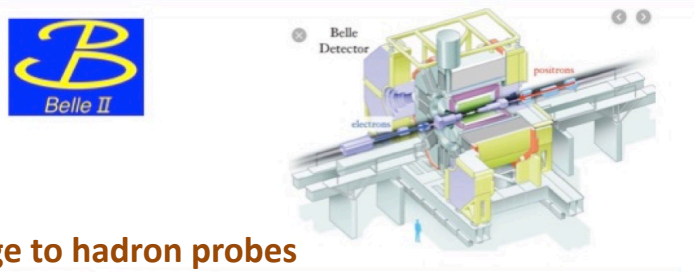




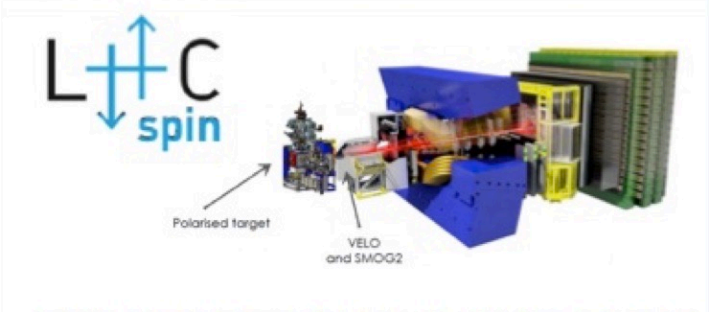
Energy range matching perturbative and non-perturbative regimes



Unprecedented fragmentation information

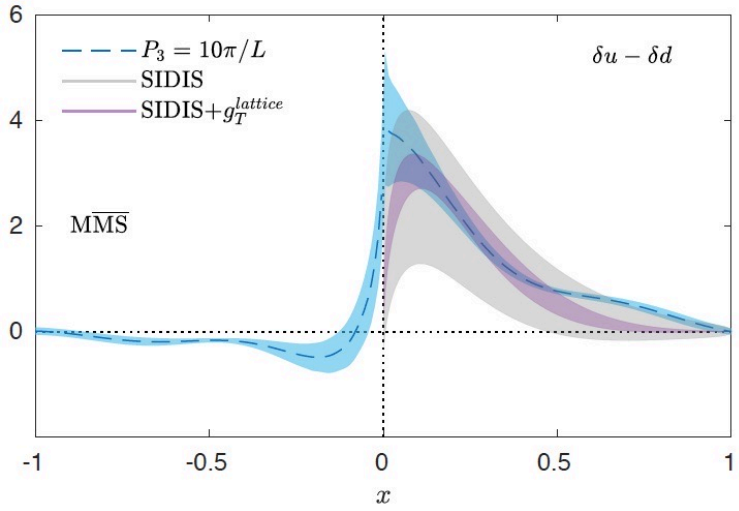


Bridge to hadron probes

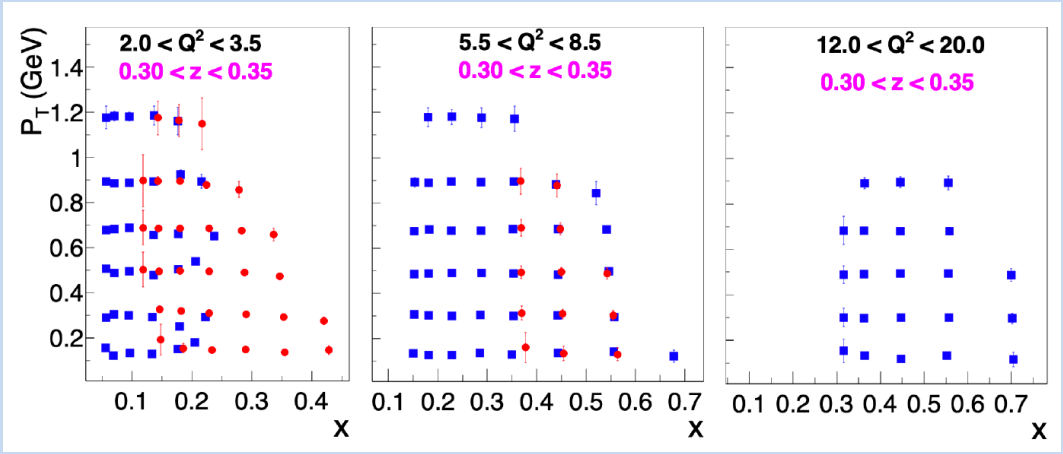


New lattice achievements

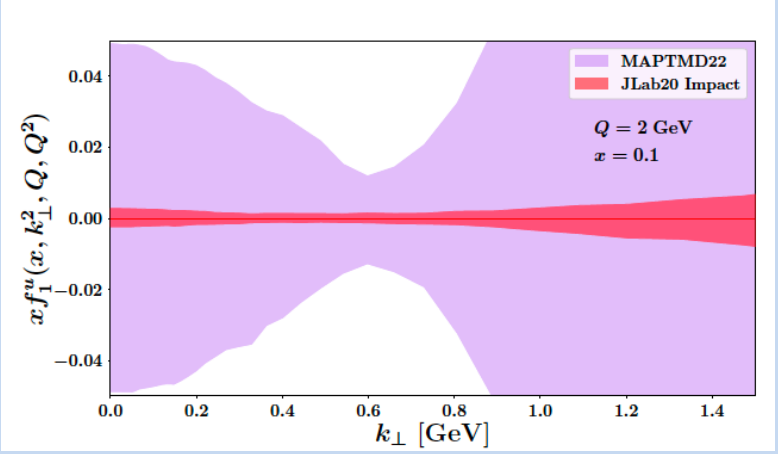
C. **Alexandrou++ [arXiv: 1902.00857]**



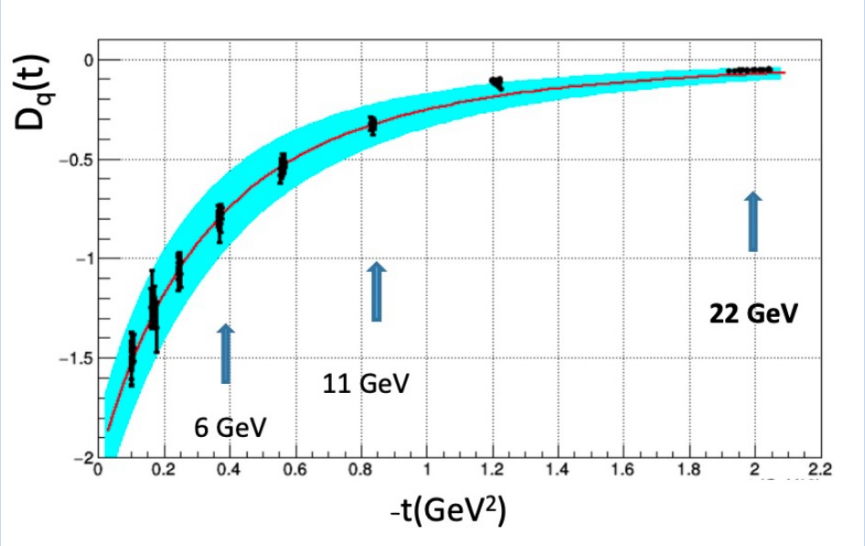
Luminosity frontier at 22 GeV [arXiv: 2306.09360]



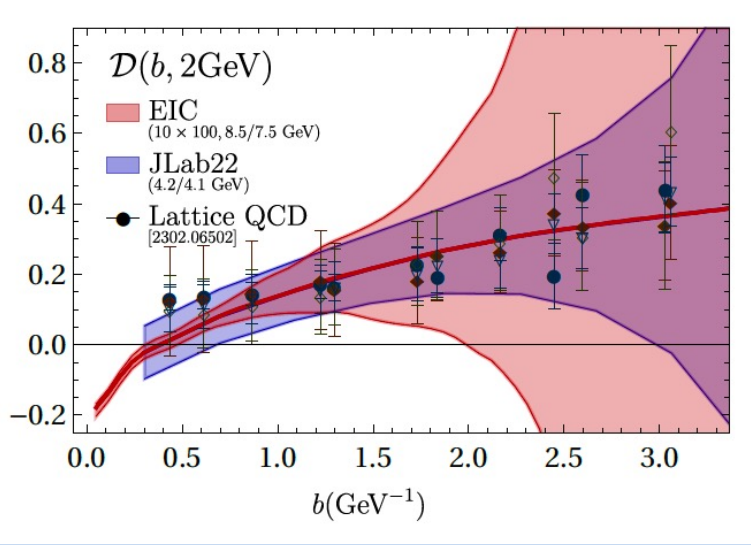
Broader reach, unprecedent precision



Mechanical properties of the nucleon (energy-momentum tensor)

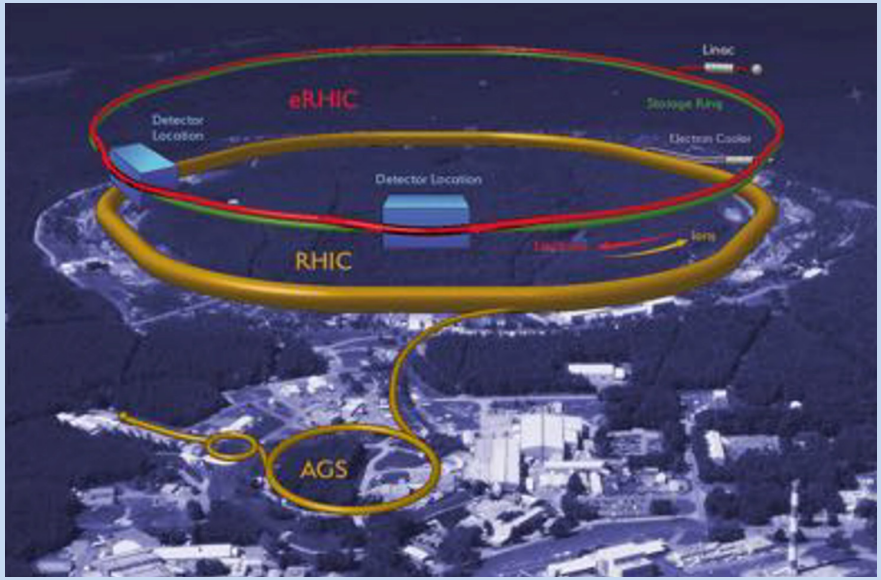


New evolution kernels (theory fundation)

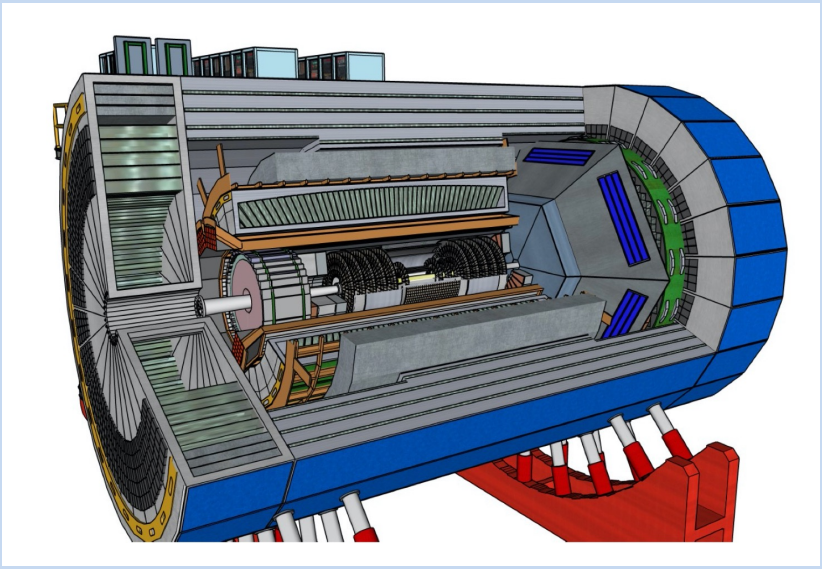


The EIC Project

BNL Accelerator Complex



ePIC Detector



p: 41 GeV, 100 to 275 GeV → p/A beam ← e beam e: 5 GeV to 18 GeV

EIC User Group

Marco Radici Chair of EICUG Steering Committee

Marta Ruspa EICUG Steering Committee member

Cristina Tuve' Chair of EICUG Election and Nominating Committee

ePIC Collider Experiment

Silvia dalla Torre ePIC Deputy Spokesperson
Pietro Antonioli Deputy Chair del Membership Committee
Salvatore Fazio ePIC Analysis co-Coordinator
Marco Battaglieri Streaming Computing Model Leader
Marco Contalbrigo Forward RICH Leader 1

INFN @ ePIC

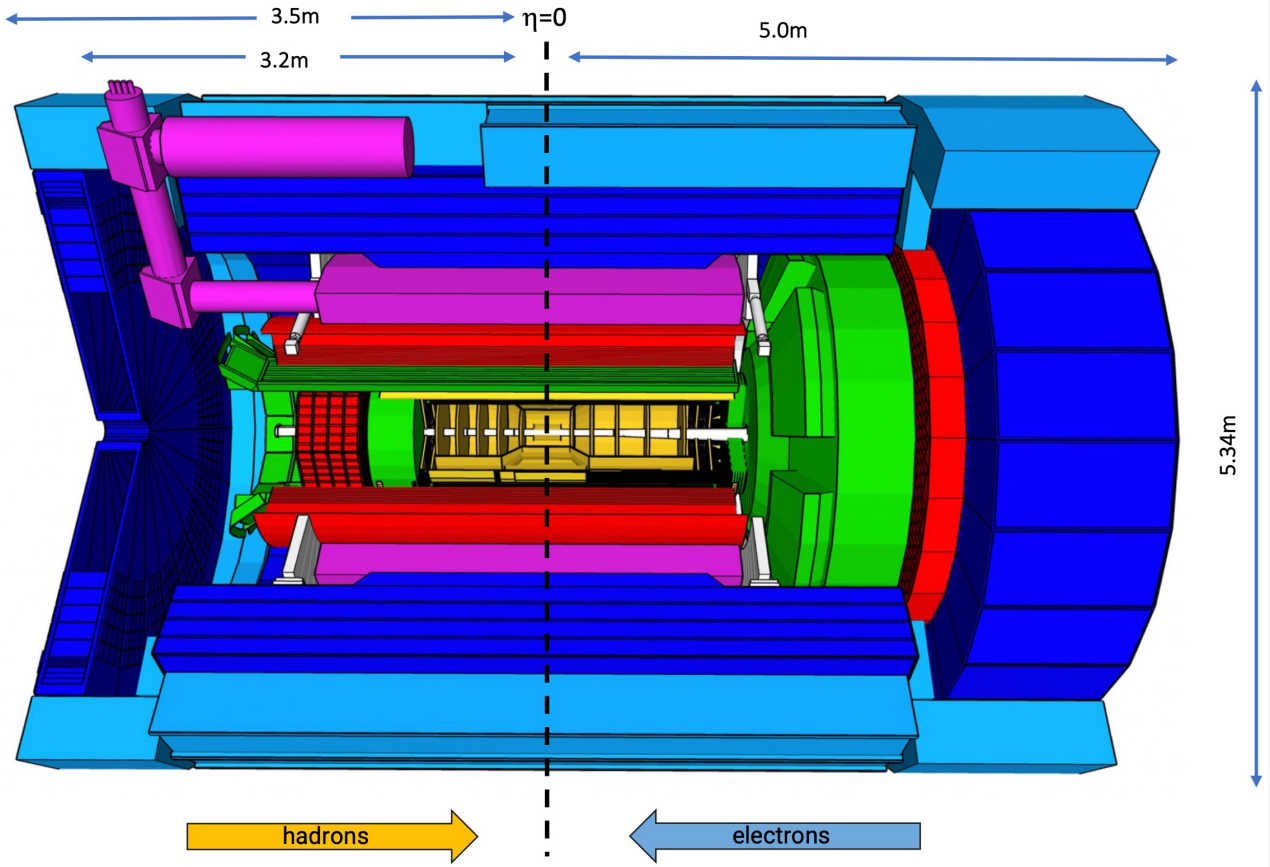
Magnet
- New 1.7 T SC solenoid, 2.8 m bore diameter

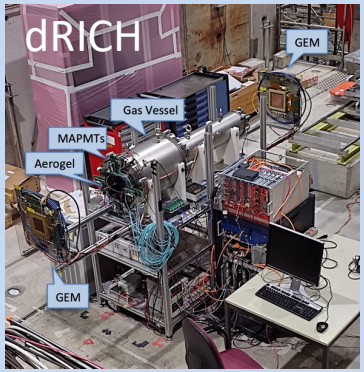
Tracking
- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous tracker: MPGDs (μRWELL, MMG) cylindrical and planar

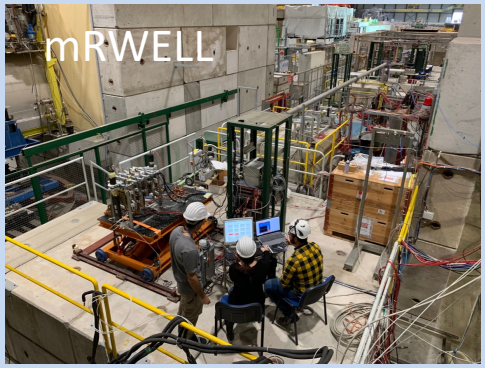
PID
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

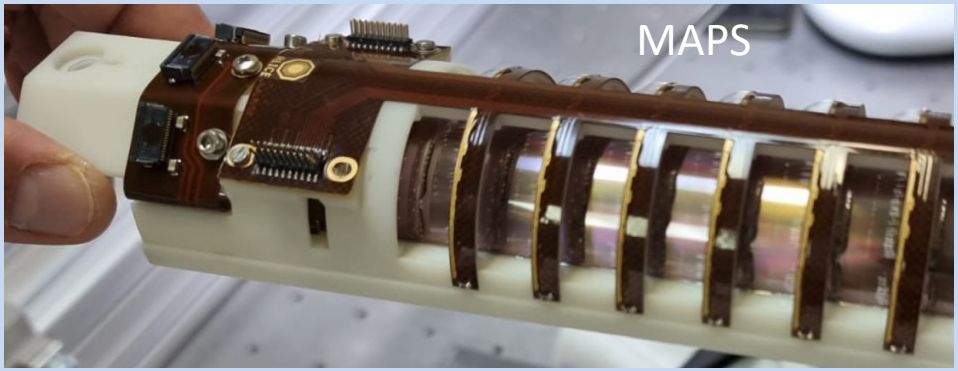
EM Calorimetry
- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

Hadron calorimetry
- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)









Conclusions

New challenges in hadronic physics and non-perturbative QCD could be addressed by

JLab at 12 and 22 GeV Facility aiming at the intensity frontier
EIC Facility aiming at the energy frontier

New data coming from JLab at high-luminosity and EIC at high-energy should allow to access:

- 3D structure of ordinary matter
- Mechanical properties of the nucleon
- Precise Standar Model tests and BSM Physics
- Dark matter signals
- Nuclear potentials and neutron stars equation of state
- …..

A comprehensive study provides access to the peculiar dynamics of the QCD world