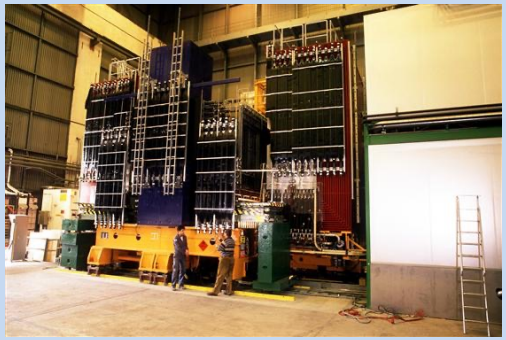
M. Contalbrigo

MC contriuted to the BSM studies in the electro-weak sector (ν oscillations, K_L rare decays) and in estalishing a new investigation paradigm in the strong sector (nucleon 3D):

Strong force dynamics in the confined state probed by parton transverse degreees of freedom

MC is CERN SPSC member

NOMAD
Neutrino oscillaitons

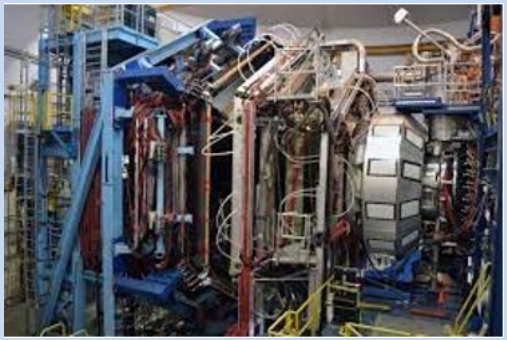


NA48
CP-violation in kaon sector

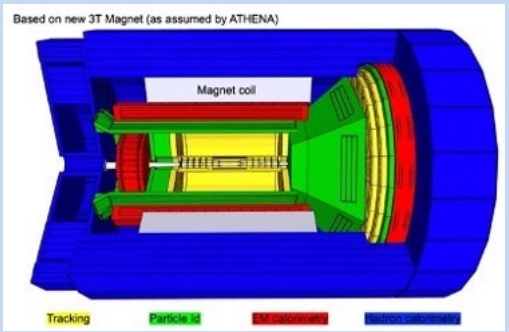
COSY
Spin in accelerators for BSM physics

HERMES
Spin physics

CLAS/CLAS12
Strong force dynamics (intensity)



EIC
Strong force dynamics (energy)



Nucleon 3D

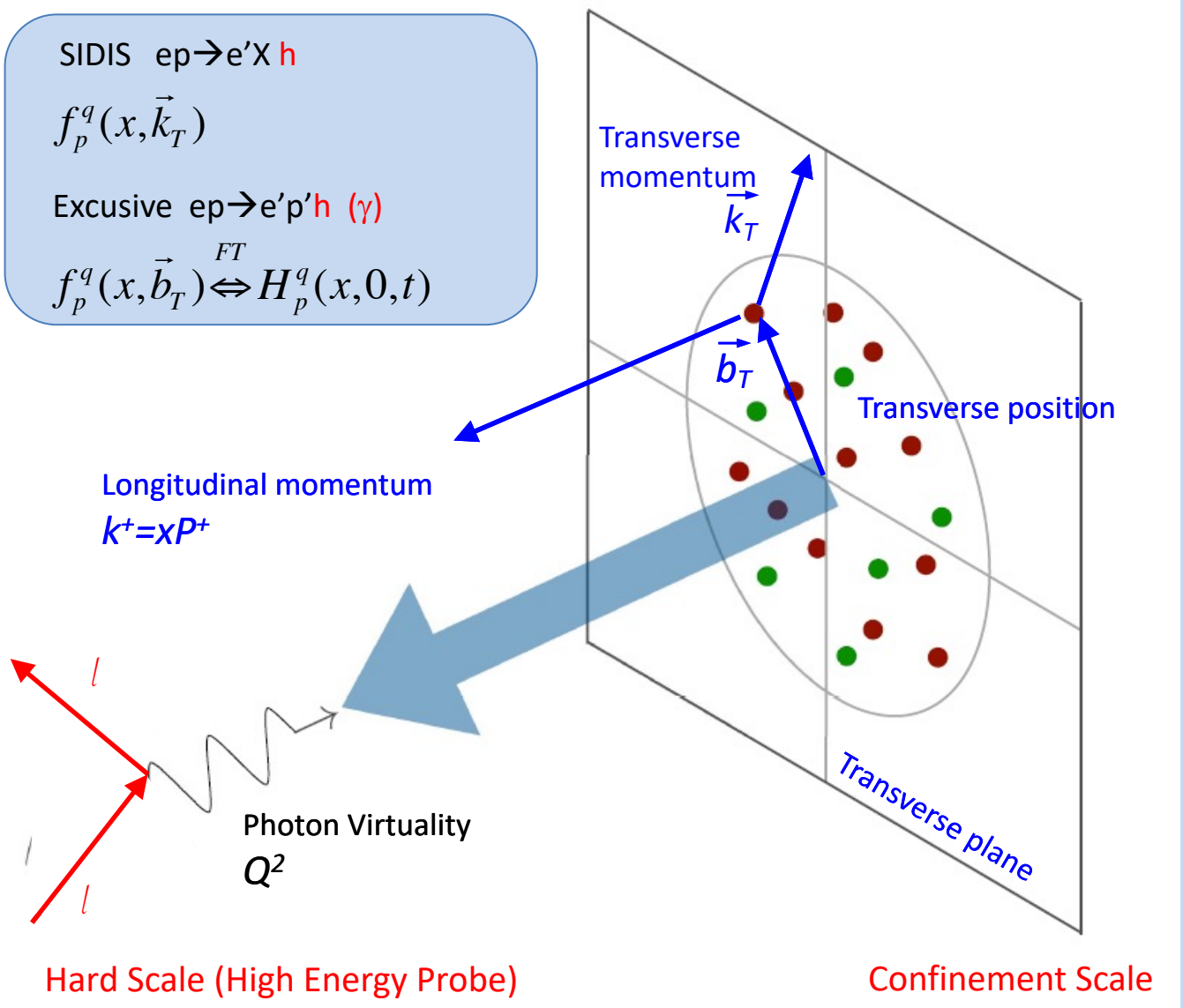
Parton tranverse degrees of freedom carry unprecedented information on peculiar strong force dynamics

SIDIS ep→e'X h

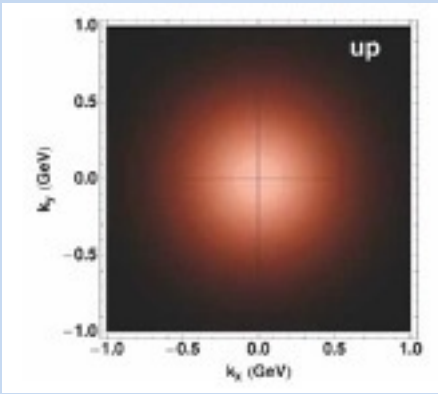
$f_p^q(x,\vec{k}_T)$

Excusive ep→e'p'h (γ)

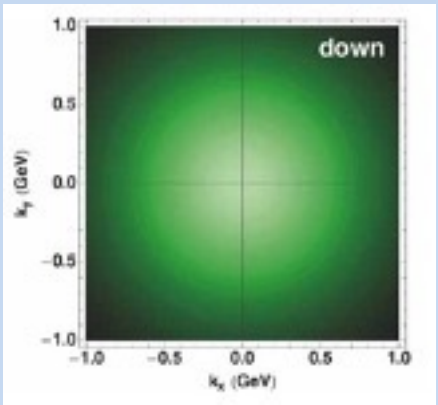
$f_p^q(x,\vec{b}_T) \overset{FT}{\Leftrightarrow} H_p^q(x,0,t)$



Quark up



Quark down



Impact on precise physics up to LHC (W mass, low pT)

Nucleon 3D

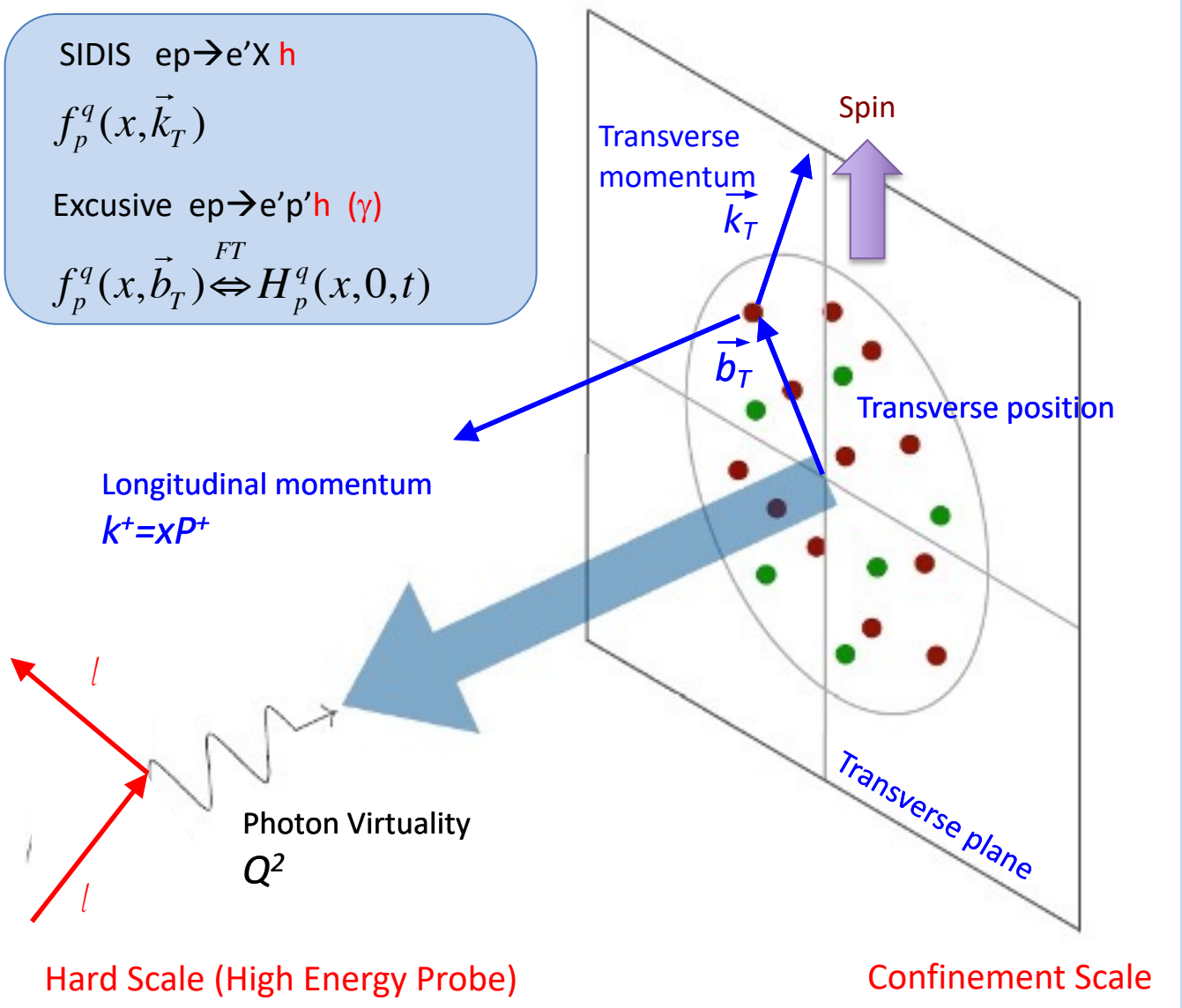
Parton tranverse degrees of freedom carry unprecedented information on peculiar strong force dynamics

SIDIS ep→e'X h

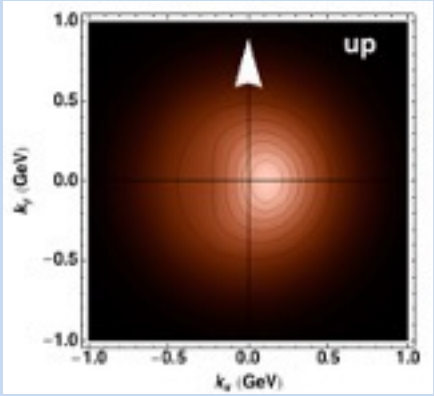
$f_p^q(x,\vec{k}_T)$

Excusive ep→e'p'h (γ)

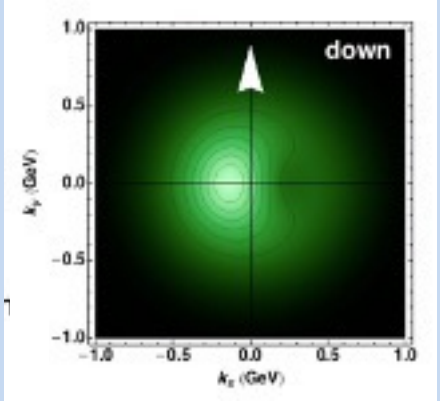
$f_p^q(x,\vec{b}_T) \overset{FT}{\Leftrightarrow} H_p^q(x,0,t)$



Quark up

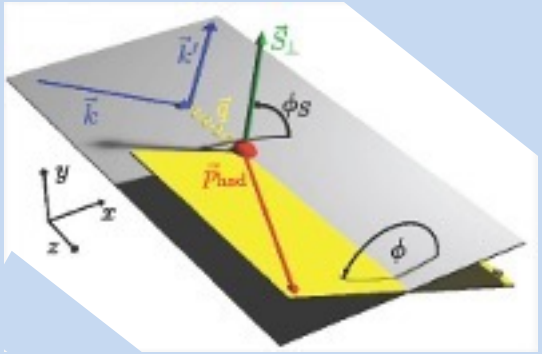


Quark down



QCD spin-orbit effects
Natural asymmetries
(SSA, DY Lam-tung, e+e-)

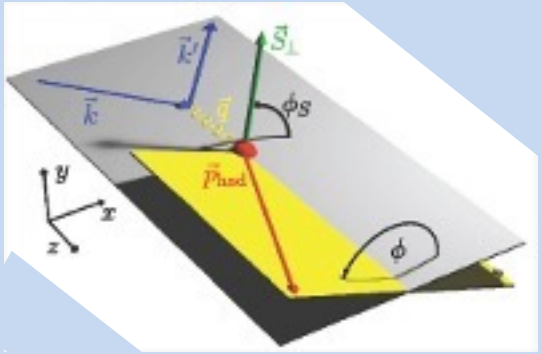
$$\frac{d^6\sigma}{dxdQ^2dzdP_h d\phi d\phi_S} \overset{LT}{\propto} \left[F_{UU} + \varepsilon \cos(2\phi) F_{UU}^{\cos(2\phi)} \right]$$



$$\frac{d^6\sigma}{dxdQ^2dzdP_h d\phi d\phi_S} \overset{LT}{\propto} \left[F_{UU} + \varepsilon\cos(2\phi)F_{UU}^{\cos(2\phi)}\right] + S_L\left[\varepsilon\sin(2\phi)F_{UL}^{\sin(2\phi)}\right]$$

$$+ S_T\left[\sin(\phi-\phi_S)F_{UT}^{\sin(\phi-\phi_S)} + \varepsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \varepsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)}\right]$$

$$+ S_L\lambda_e\left[\sqrt{1-\varepsilon^2}F_{LL}\right] + S_T\lambda_e\left[\sqrt{1-\varepsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)}\right] + O\left(\frac{1}{Q}\right)$$



$$\frac{d^6\sigma}{dxdQ^2dzdP_h d\phi d\phi_S} \overset{LT}{\propto} \left[F_{UU} + \varepsilon\cos(2\phi)F_{UU}^{\cos(2\phi)}\right] + S_L\left[\varepsilon\sin(2\phi)F_{UL}^{\sin(2\phi)}\right]$$

$$+ S_T\left[\sin(\phi-\phi_S)F_{UT}^{\sin(\phi-\phi_S)} + \varepsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \varepsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)}\right]$$

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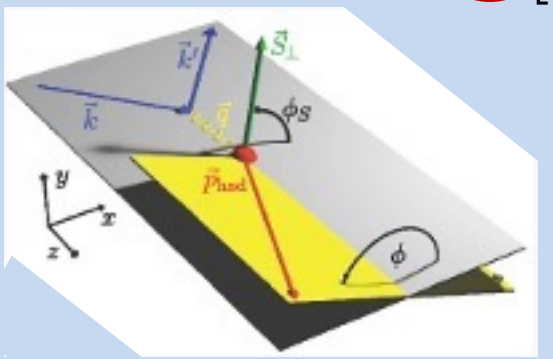

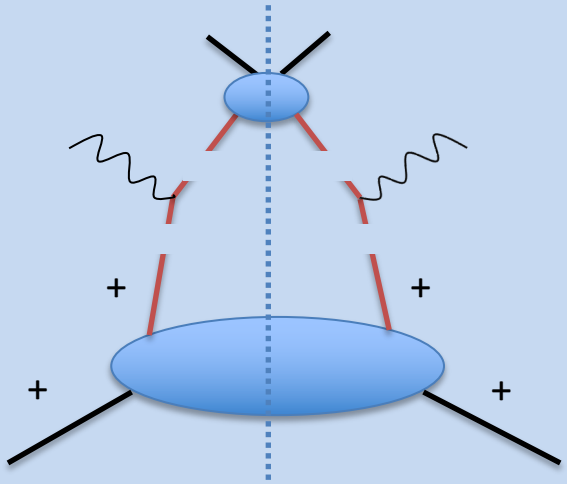

Parton fragmentation function

Hard scattering

Parton distribution function

TMD Factorization holds for $p_T \ll Q$

Wide kinematic coverage is needed to resolve the convolution

$$F_{UU} = f \otimes D = x\sum_q e_q^2 \int d^2p_T d^2k_T \;\; \delta^{(2)}(\mathbf{P}_{h\perp} - z\mathbf{k}_T - \mathbf{p}_T) \;\; w(\mathbf{k}_T, \mathbf{p}_T) \;\; f^q(x, k_T^2) \;\; D^q(z, p_T^2)$$

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HERMES @ DESY (precursors)
First obsrvations 2001-2012

Deputy spokesperson
Analysis Corrdinator
Physics WG convener
Editorial Borad member
Run coordinator

Polarized target
Target coordinator

MC as Target Coordinator maintenance and analysis

Unique target internal to a high-energy acelerator ring
Unpolarized gas, polarized hydrogen and deuterium

No dilution of not polarized nuclear elements (vs NH_3)

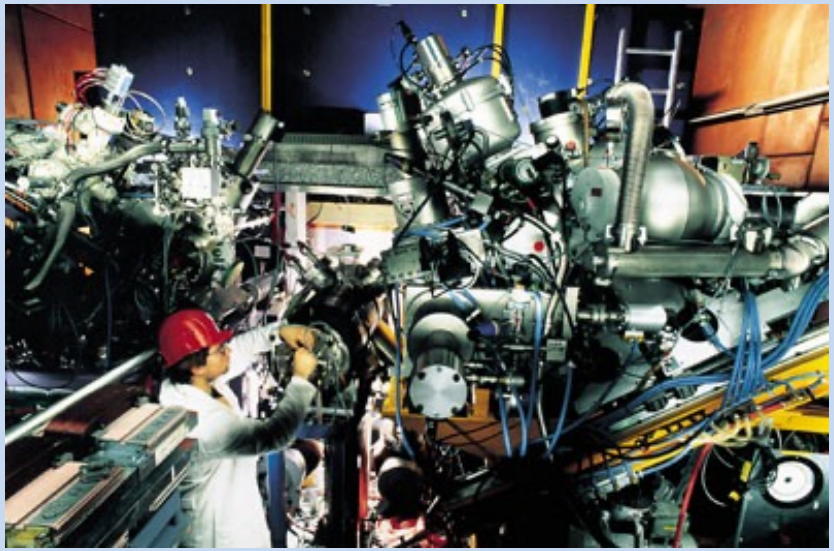
Target cell to increase x 100 density

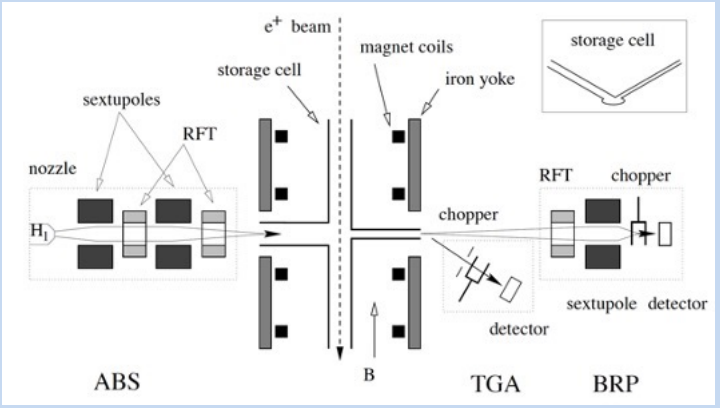
Temperature 60-100 K

Areal density 1-2 10^{14} nucleons/cm^2

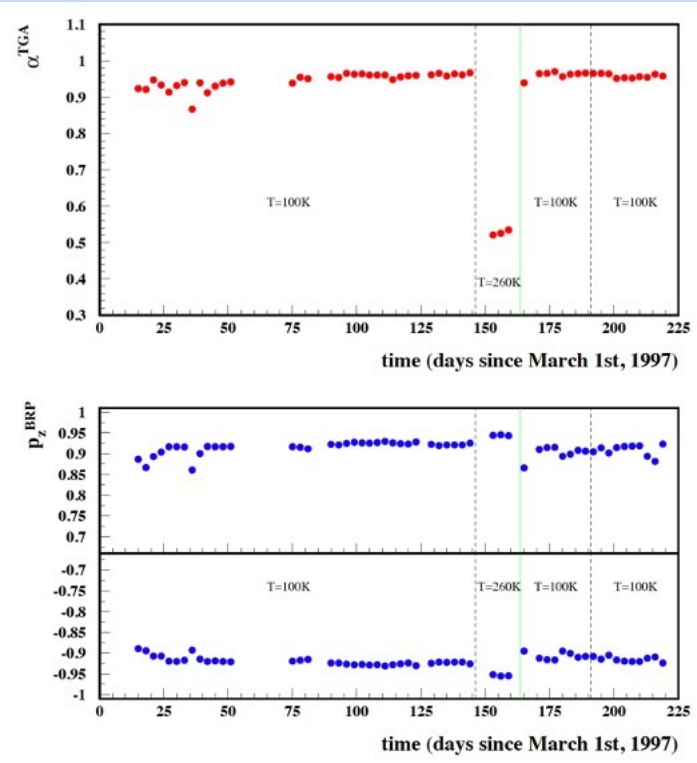
Spin flip every 1 -3 minutes

P ~ 85 % longitudinal, ~ 73 % transverse





1997 Hydrogen run: atomic fraction and polarization

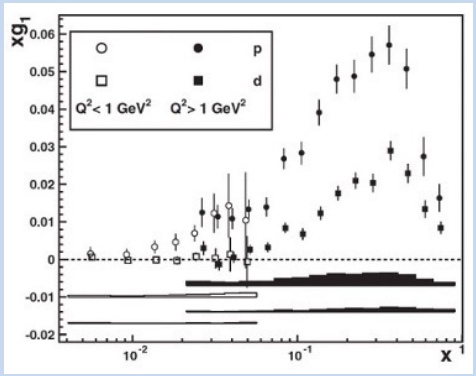


MC as Deputy Spokesperson, Analysis Coordinator, EB member

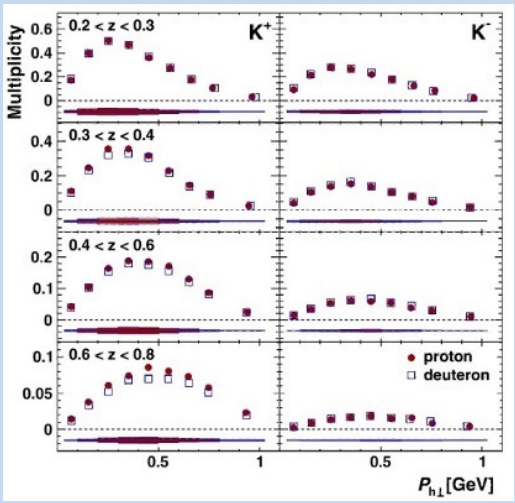
Several first observations, limited in statistics
but all configurations available ad pure target

Axial charge

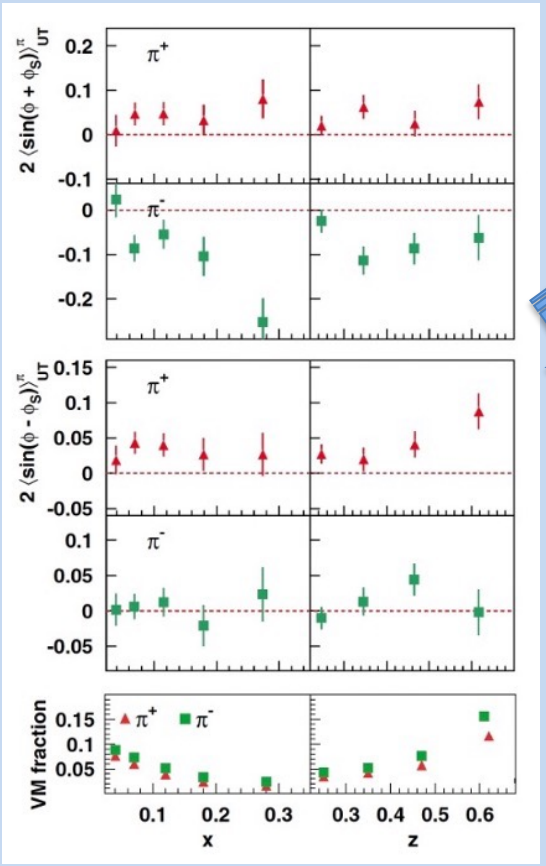
Most precise $\Delta\Sigma = 0.330 +/- 0.039$



Most precise flavor
separated multiplicity

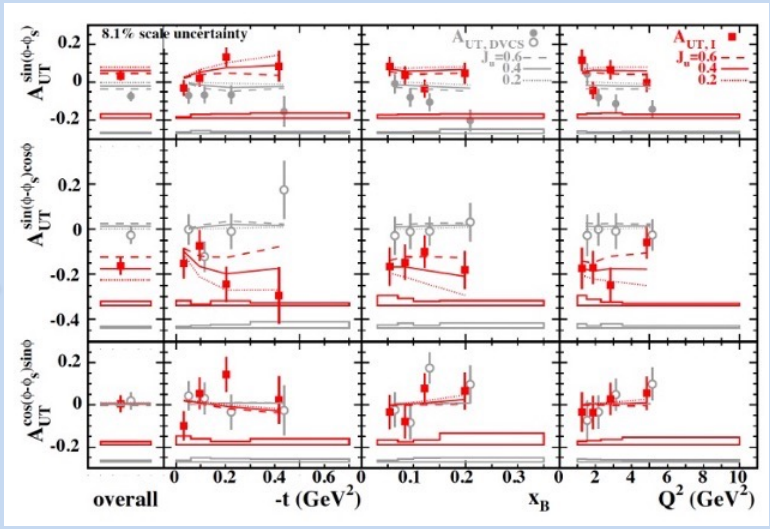


First Sivers and Transversity evidence



Tensor charge

First Compton scattering with trasnversely polarized target



Angular momentum

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Editorial Borad member
Run coordinator

CLAS/CLAS12 @ JLab (luminosity)
Valence region 2010-

Experiment spokesperson
CLAS Coord. Committee member
Physics WG convener
Run coordinator
Chair of Jlab User Organization

RICH Project Leader
PI CLASMED project
Compact SC magnets

MC is NFN National Responsible
MC as INFN Gr3 Coordinator

FE group: 8 researchers
JLab Collaboration ~ 50 researchers

Responsible of laboratories:
- Cherenkov detectors
- Photosensors
- Superconducting magnets

Activity Leader
- Hadron Physics 3
- Strong 2020

Training Degree, PhD, Postdoc

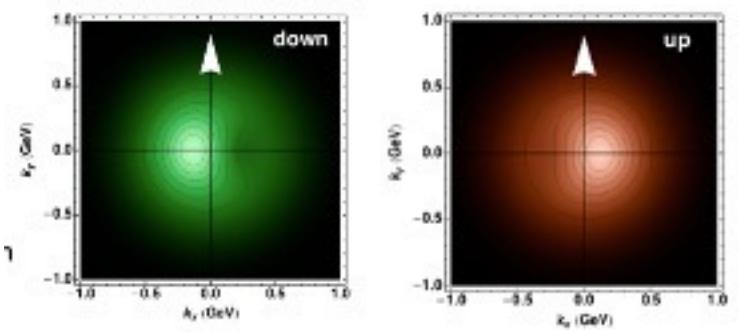
Polarized target
Target coordinator

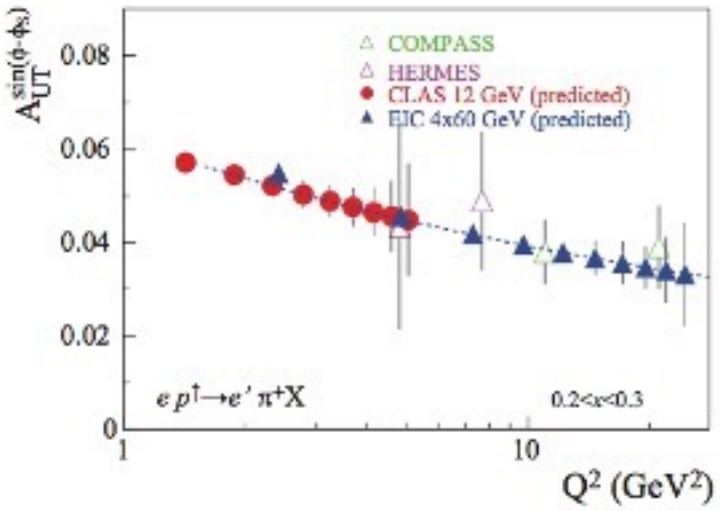
Spokesperson transverse target RG
Polarized target

MC is spokesperson of transverse target experiments

Most sensitive configuration for
- QCD spin-orbit effects
- Tensor charge of the nucleon

SIDIS spin-orbit and and tensor charge



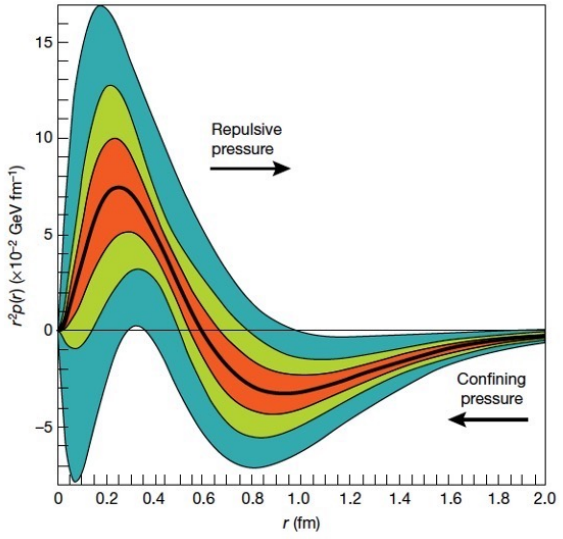


Exclusive physics and mechanical properties

$$\begin{pmatrix} A_{LU,I}^{\sin(1\phi)} \\ A_{UL,+}^{\sin(1\phi)} \\ A_{UT,I}^{\sin(\varphi)\cos(1\phi)} \\ A_{UT,I}^{\cos(\varphi)\sin(1\phi)} \end{pmatrix} \Rightarrow \Im\mathrm{m} \begin{pmatrix} \mathcal{H} \\ \widetilde{\mathcal{H}} \\ \mathcal{E} \\ \widetilde{\mathcal{E}} \end{pmatrix}$$

$$\int x \left[H(x,\xi,t) + E(x,\xi,t) \right] dx = 2J(t)$$

$$\int x\, H(x,\xi,t)\, dx = M_2(t) + \frac{4}{5}\xi^2 d_1(t)$$



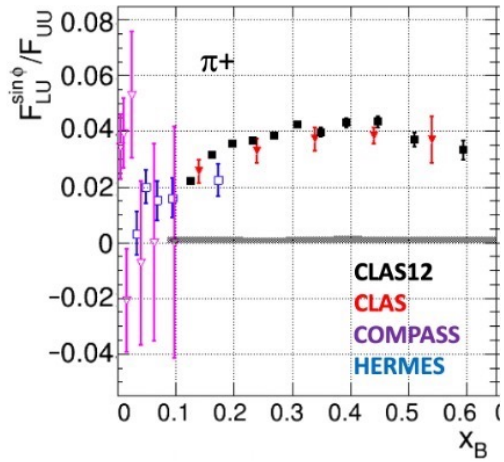
MC is chair of Deep-Process Working Group since 2016. First CLAS12 publications came from DPWG.

Unprecedented precision, valence region coverage, discovery potential.

SIDIS physics and tensor charge

ep → e'hX

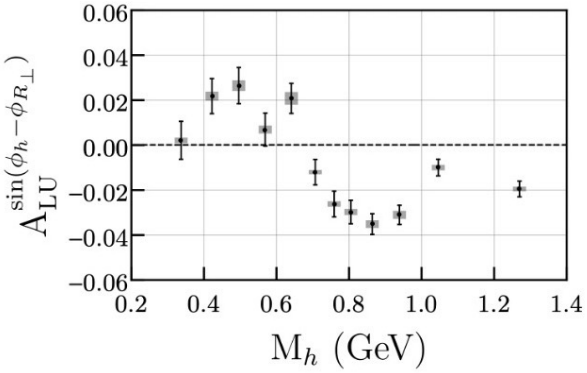
S. Diehl et al., e-Print: 2101.03544



Superior Precision (valence)

ep → e'hhX

T.B. Hayward et al., PRL 126 (2021) 152501

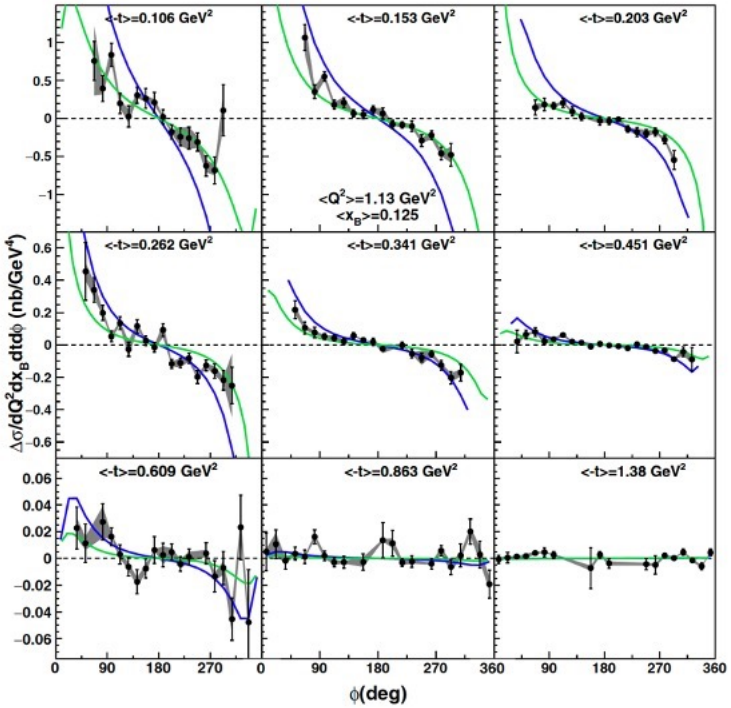


New evidence of spin-orbit effect

Exclusive physics and mechanical properties

ep → e'p'γ

N.Hirlinger et. al. PRC 98 4 (2016) 045203



Cross section

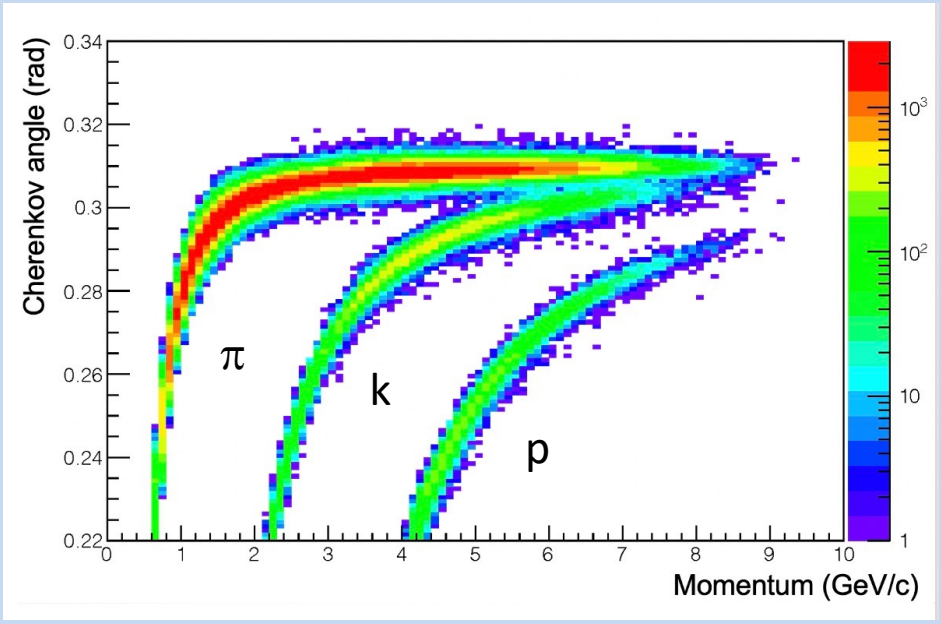
RICH detector to access the strange (kaon) sector

MC is RICH Project Leader and PI of CLASMED

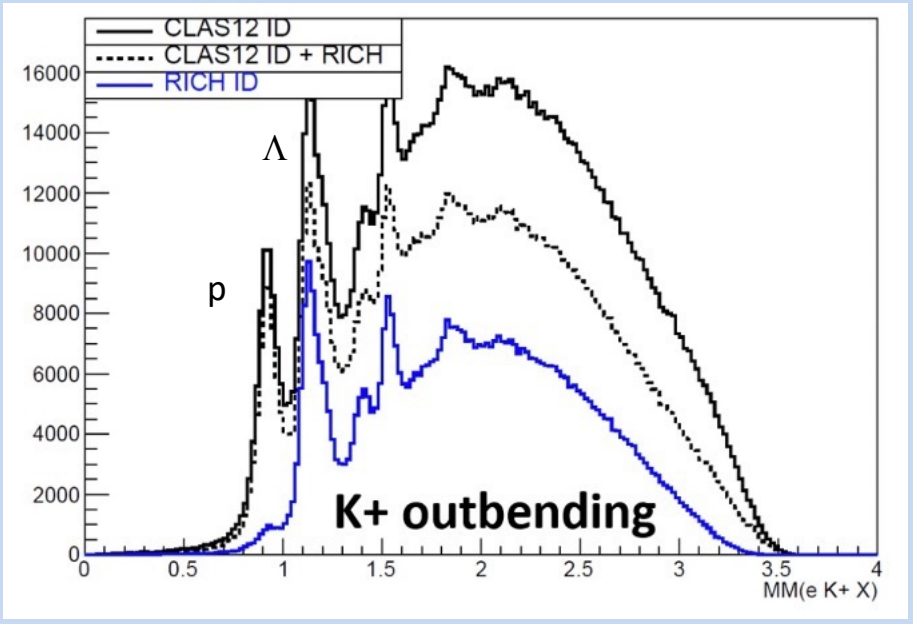
- Coordination
- Design
- Front-end electronics
- Optical component R&D and characterization

First module installed in 2018 before data-taking
Second symmetric module expected in 2022, before polarized runs

Good hadron separation (direct light)

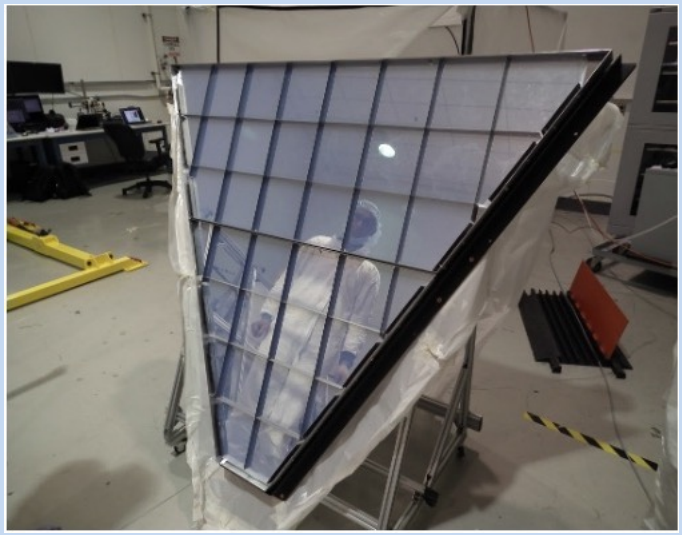


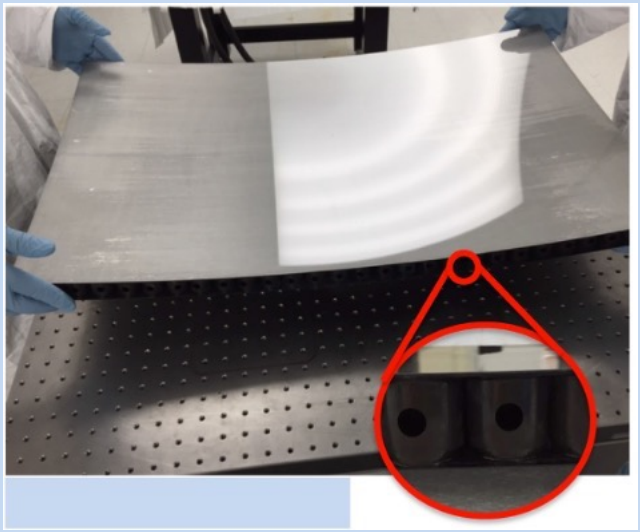
Effective suppression of mis-identifications (direct light)



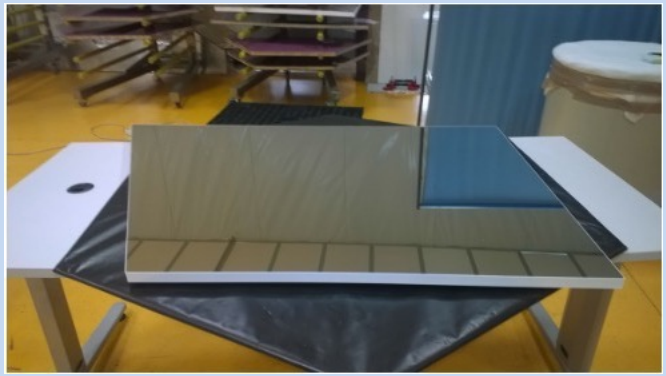
RICH Achievements

Aerogel
World leading transparency
at such large refractive indexes and volumes

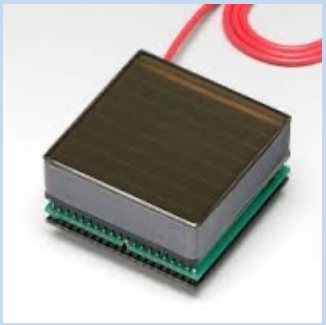




Carbon Fiber Mirrors (spherical)
to maximize lightness and stiffness. Consolidate technology (HERMES, AMS, LHCb) but ~ 30 % material budget reduction



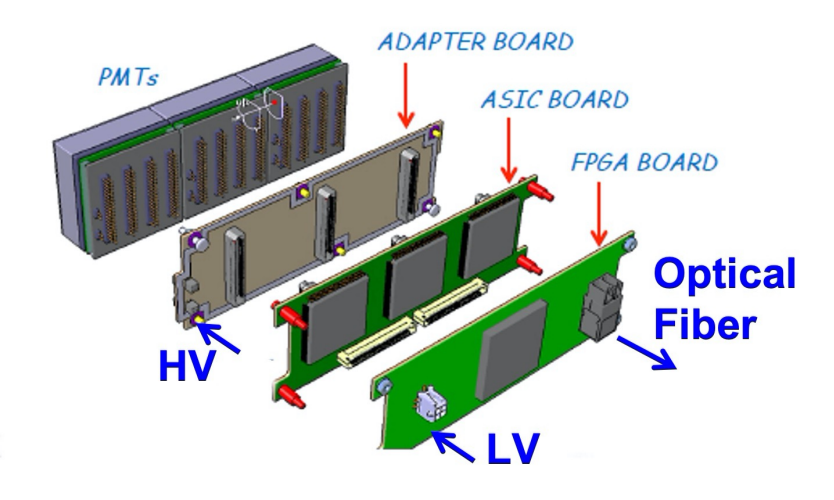
Photon Detector
First use of H8500/H12700
flat panel multi-anode PMTs
64 pixels on a 5x5 cm^2 area



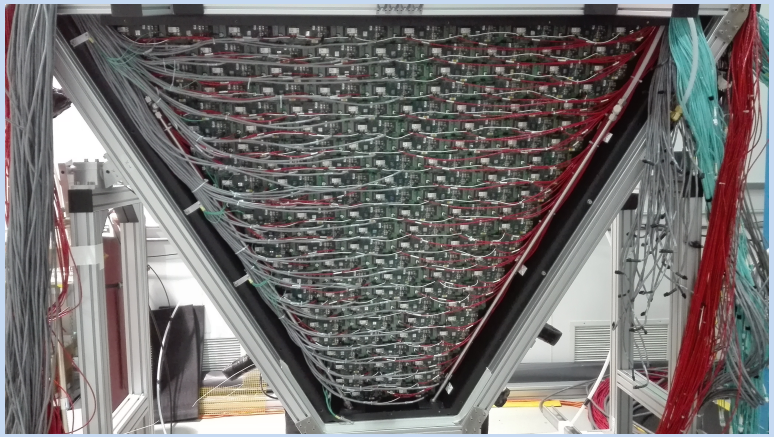
Glass-Skin Mirrors (planar)
Innovative technology never used in nuclear exps.
~ 1/5 cost for squared meter vs CFRP

Readout Electronics

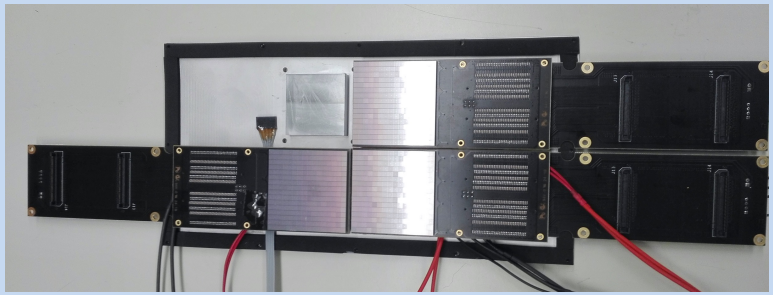
Compact (matches sensor area)
Modular Front-End (Mechanical adapter, ASIC, FPGA)
Scalable fiber optic DAQ (TCP/IP or SSP)
Tessellated (common HV, LV and optical fiber)



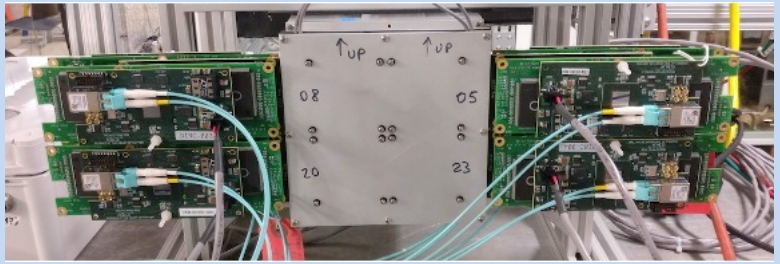
Developed for CLAS12 RICH



Coupled to cool SiPM matrices for EIC

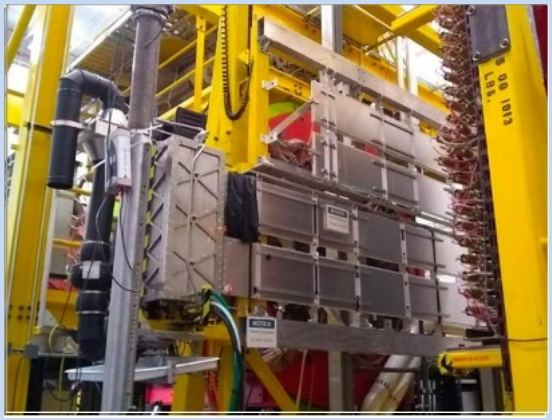


Coupled to H13700 for EIC mRICH / dRICH

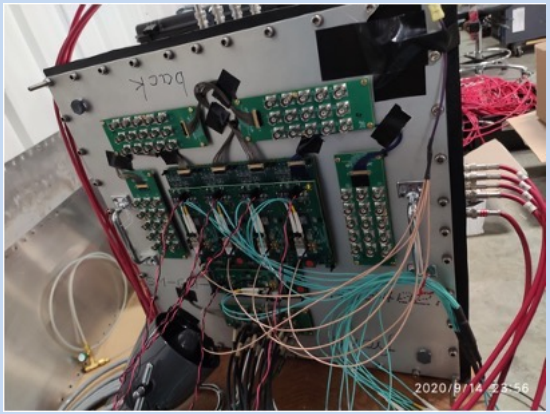


Proposed for INFN TechTranfer

Adopted by Gluex DIRC



Upgraded for SOLID R&D

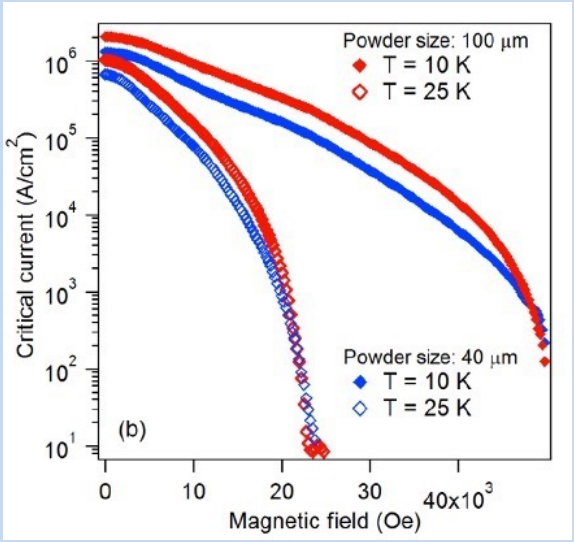


MC is activity leader

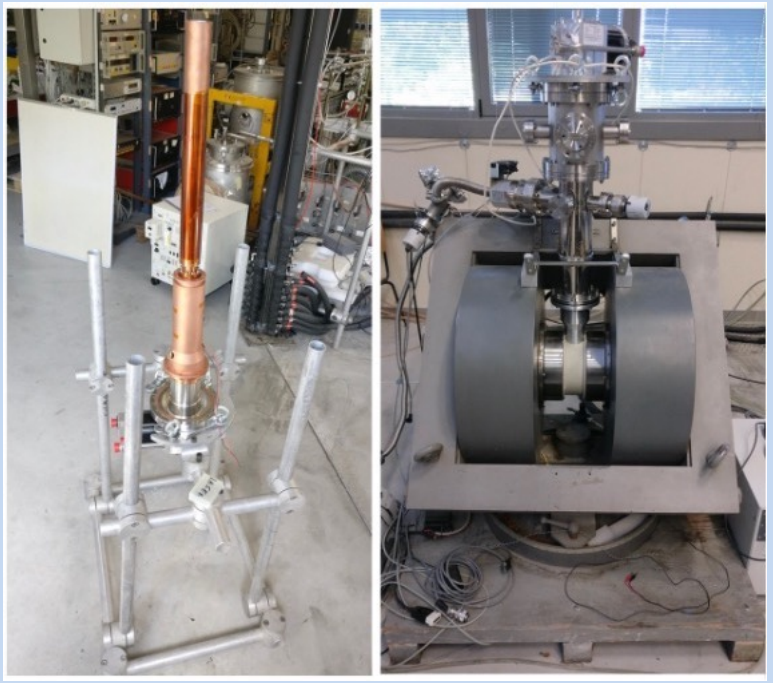
Bulk MgB_2 magnet (cylinder)
Freezes the field at transition (~40 K)

Minimum material budget (no copper safe ring)
While cool, does not require current leads
No destructive quenches
Decouple mechanics from field shape

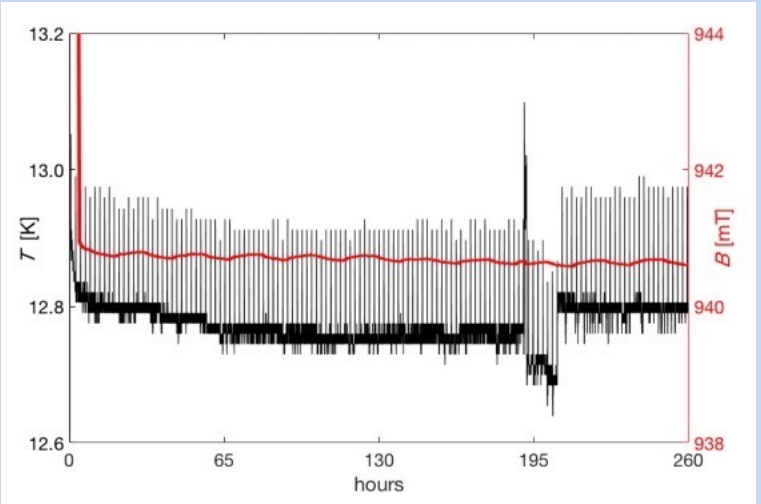
Optimization of the composite powders



Test-stand with normal conductor dipole



Long stability test (up to one month)



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PI CLASMED project
Compact SC magnets

Super-Hermes.

Polarized target
Target coordinator

Spokesperson transverse target RG
Polarized target

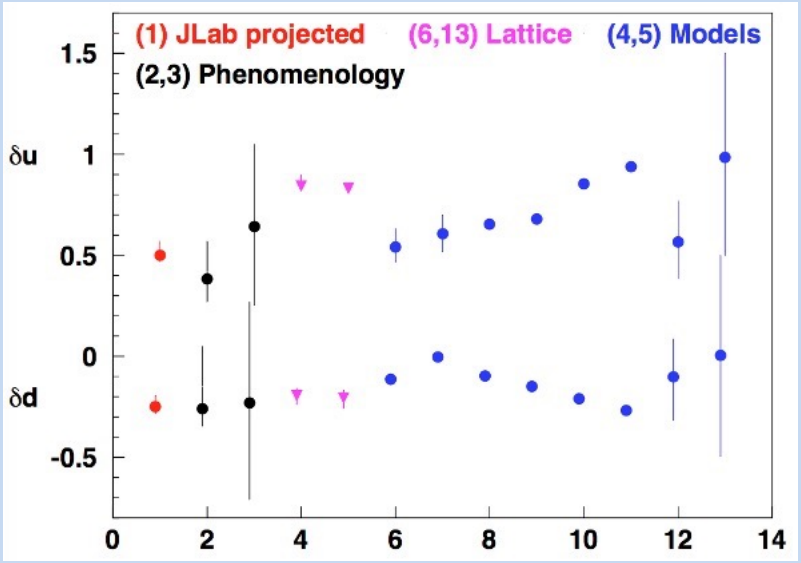
PAX / EDM search

Transverse Polarization Spin-off

Tensor Charge measures transverse quark polarization in a transversely polarized nucleon

Universality: Polarized target @ LHCb
Polarized antiproton beams

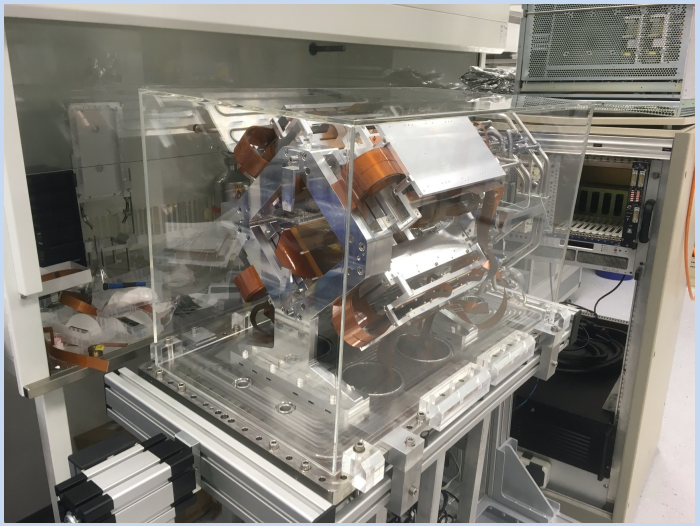
BSM Physics: Tensor coupling & EDM search



PREFER: polarized fusion

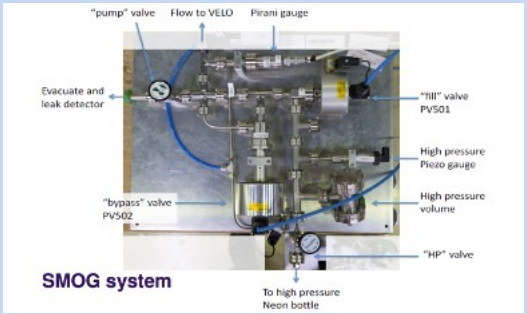
COLUMBUS: test-bench fot superconducotr at working temperature

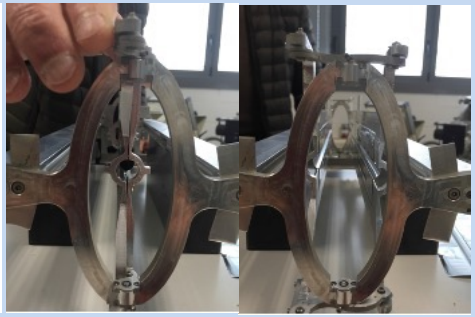
Spin manipulation program at FZJ
PAX, Fundamental symmetries, EDM



Fixed target program at LHCb. (LCH bridge to EIC)

Phase I: unpoalrized SMOG2
Phase II: plarized LHCspin





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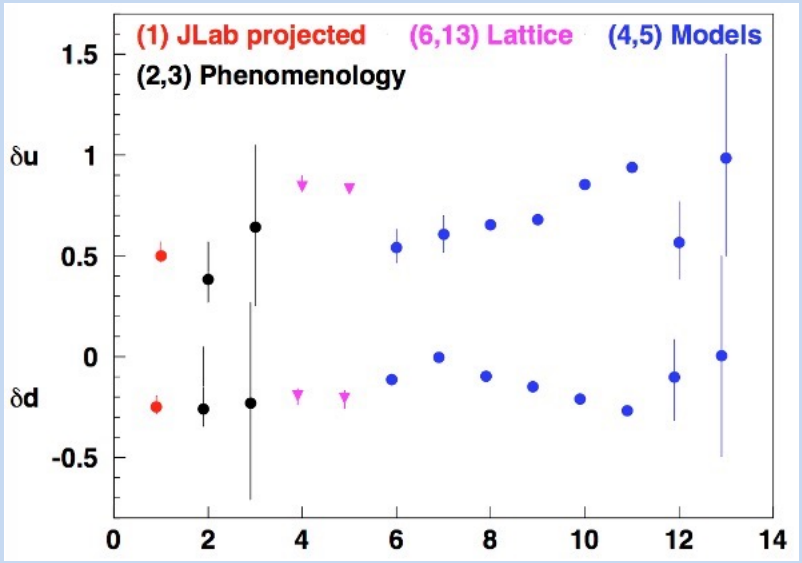

Spin manipulation program at FZJ
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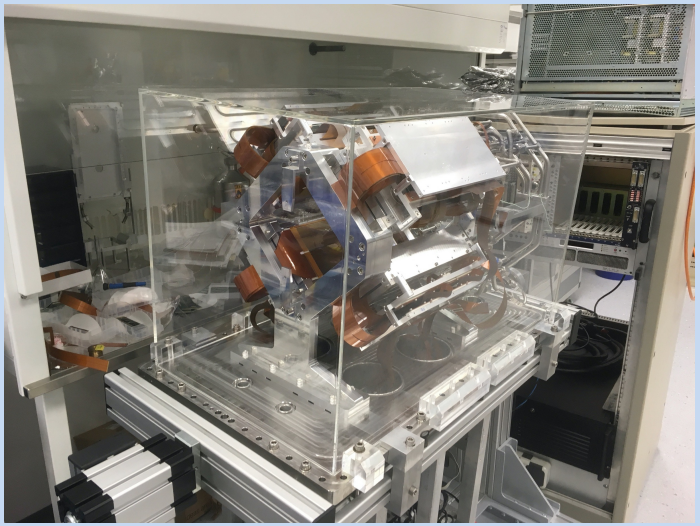

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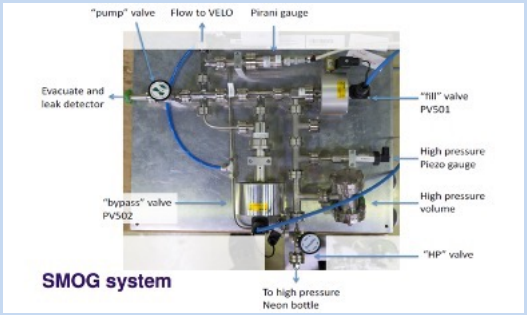
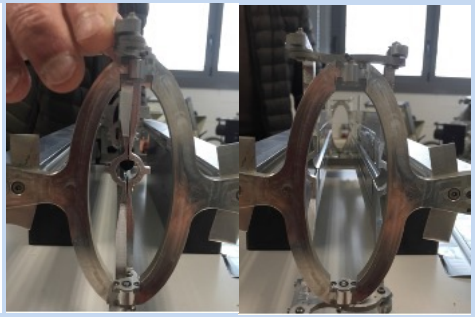
Proton EDM: $d_p = d_u \, \delta_T u + d_d \, \delta_T d$

Neutron EDM: $d_n = d_u \, \delta_T d + d_d \, \delta_T u$

Propaedeutic studies ongoing at COSY, Juelich FZ





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Strong force dynamics in the confined state probed by parton transverse degreees of freedom

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HERMES @ DESY (precursors)
First obsrvations 2001-2012

Deputy spokesperson
Analysis Corrdinator
Physics WG convener
Editorial Borad member
Run coordinator

CLAS/CLAS12 @ JLab (luminosity)
Valence region 2010-

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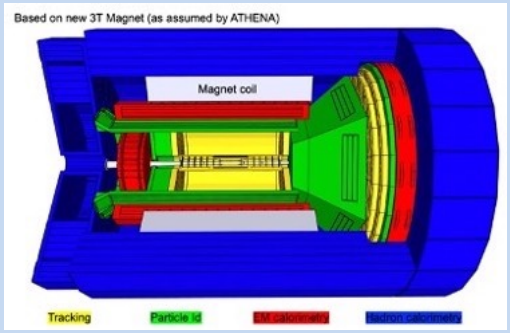
Extended coverage 2031-



POETIC IAC member
PSQ@EIC OC member
Yellow-report author

RICH for particle ID
Photo-detection in high-B

Super-Hermes.

L⃗C spin

PAX / EDM search

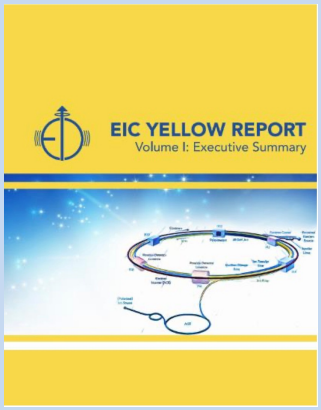
Polarized target
Target coordinator

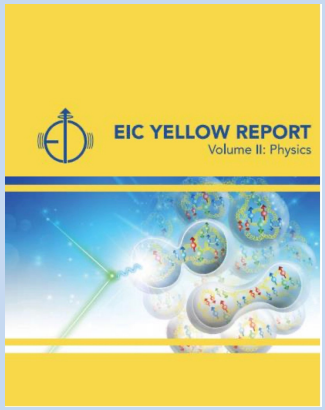
Spokesperson transverse target RG
Polarized target

Dual Radiator RICH for EIC

MC is IAC member and YR author

SIDIS physics
Complementarity of 2 IPs





MC is PID R&D activity leader

dRICH (mRICH)
SiPM and readout electronics

dRICH: effective solution, part of EIC reference detector

Lead by INFN, being selected for targeted R&D

Challenge 1: wide coverage (3-60 GeV/c, 5-25 deg)

Two radiators Aerogel (n_{AERO}~1.02) + Gas (n_{C2F6} ~ 1.0008)

Challenge 2: Single-photon detection in ~1T magnetic field

Silcon Photomultipliers

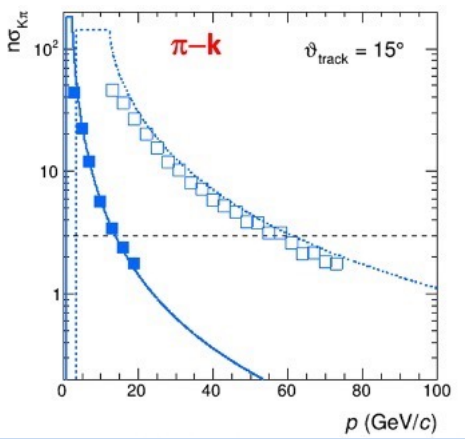
FE, BO, CT, LNF, LS, RM1, TO, TS

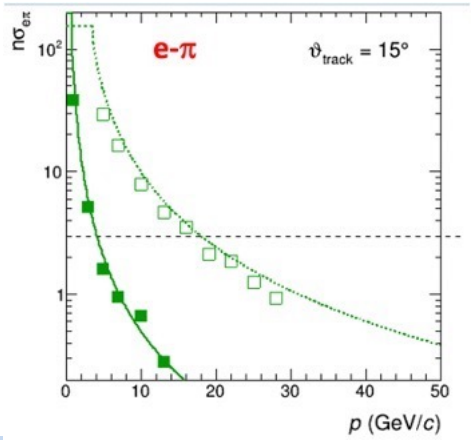
INFN

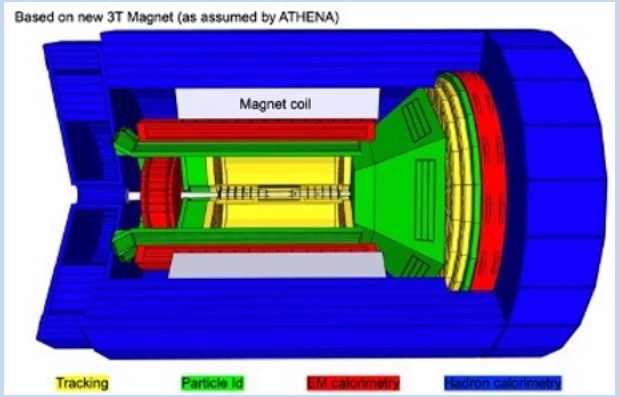
Georgia State University

Duke University

Stony Brook University







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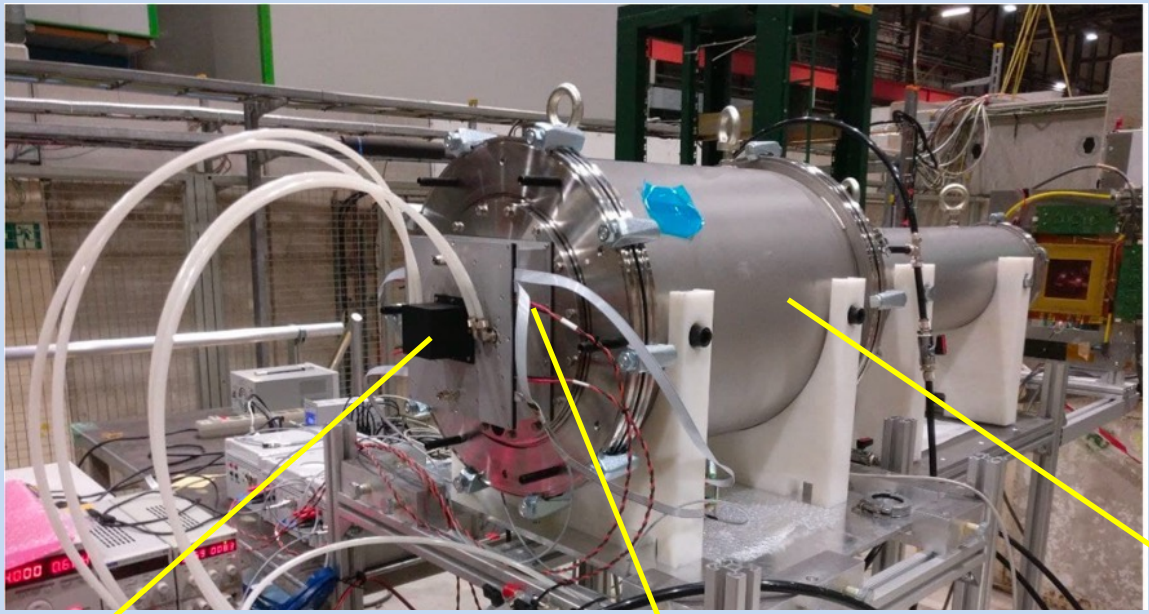
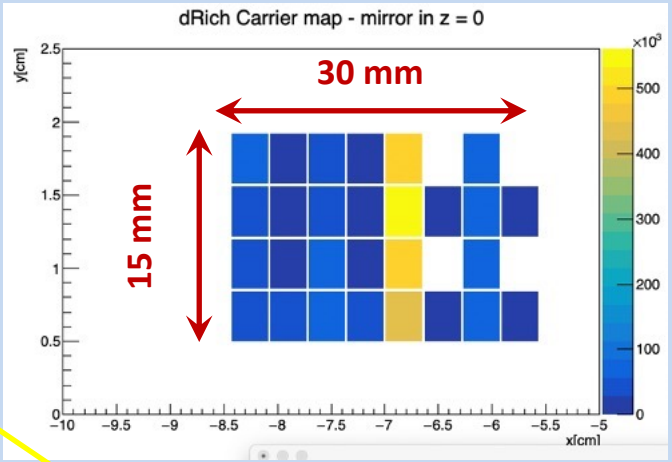
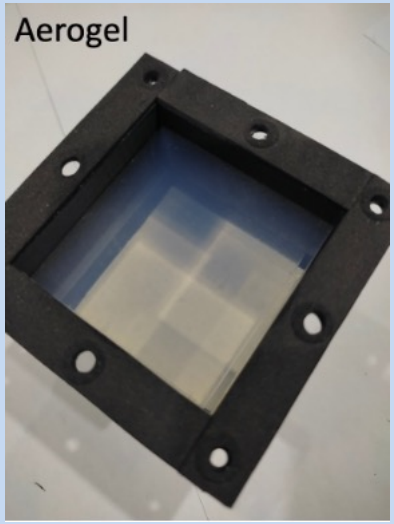
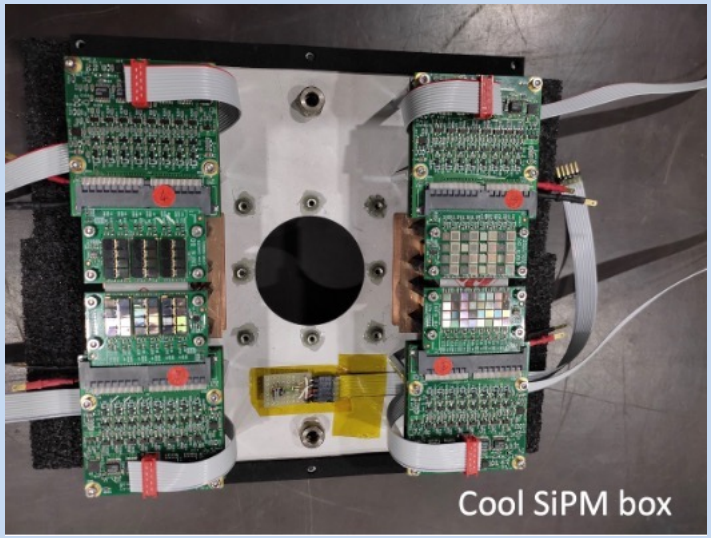
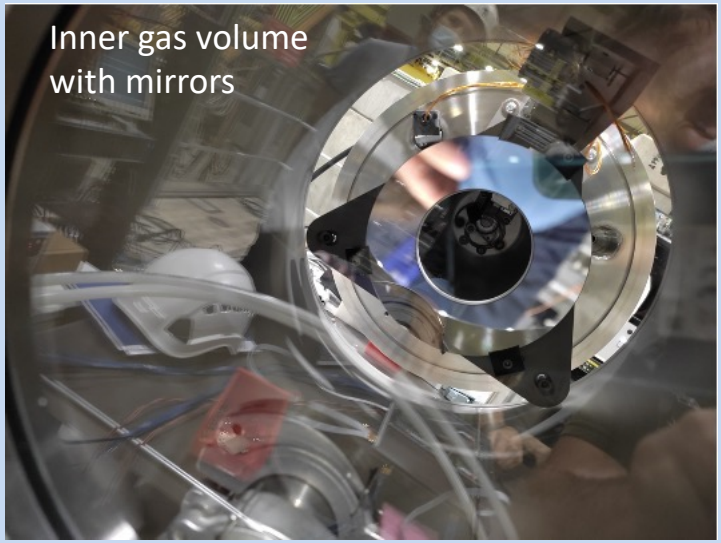


Cherenkov signal by cool SiPM (-30°) readout by ALCOR chip









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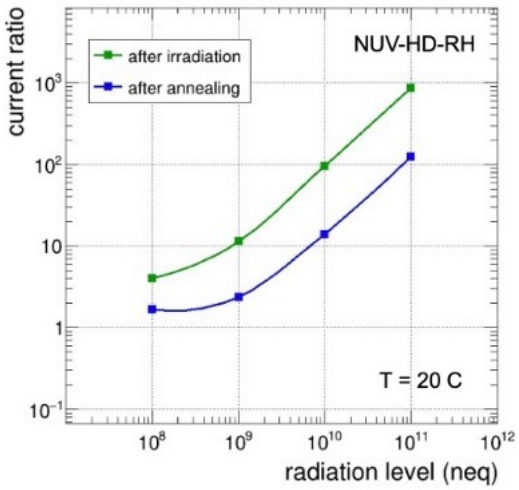
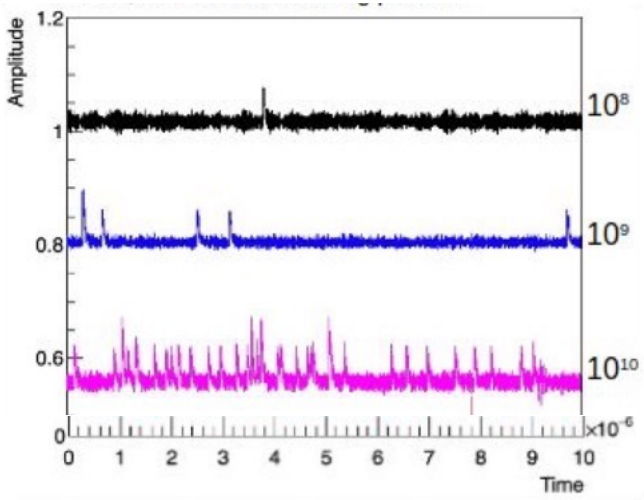
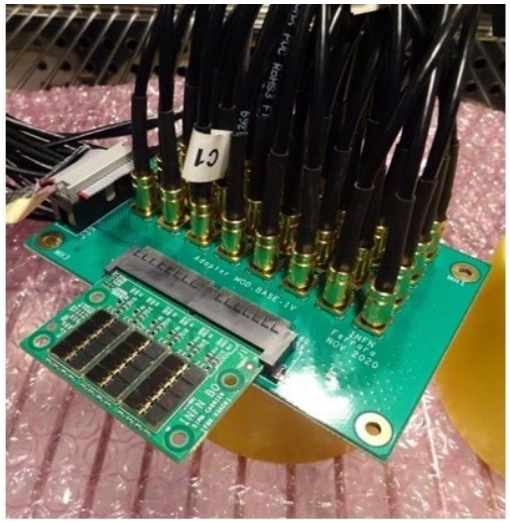
Custom laboratory characterization: annealing and low-T working point

Current vs overvoltage

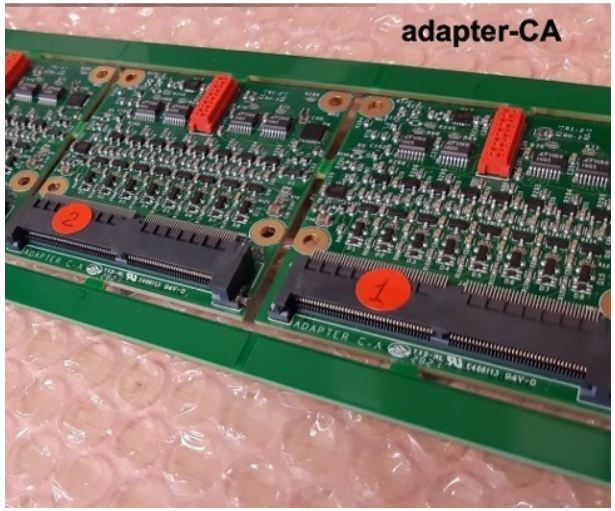


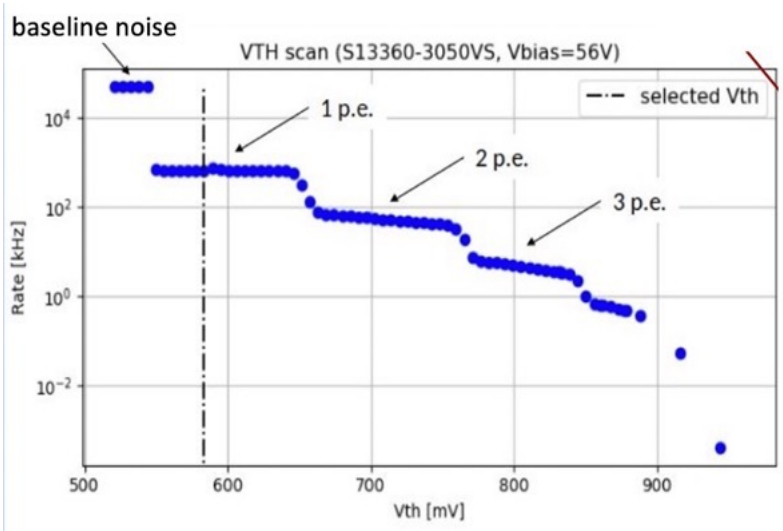
Dark count from high-frequency sampling





ToT readout (ALCOR) to study readout specs





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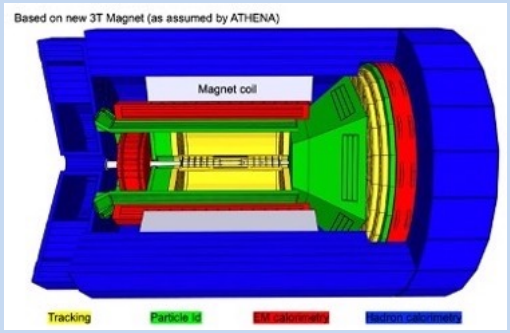

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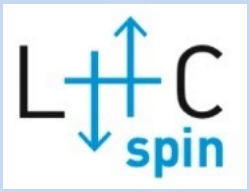
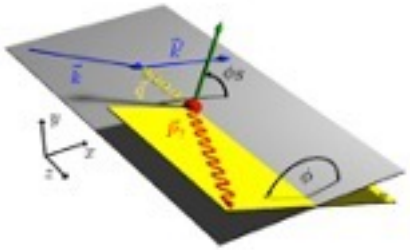


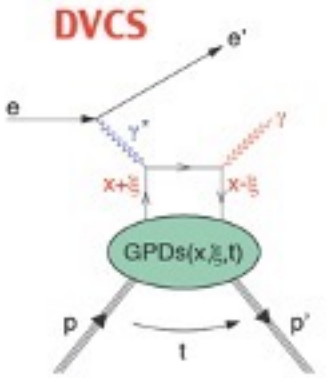
Polarized target
Target coordinator

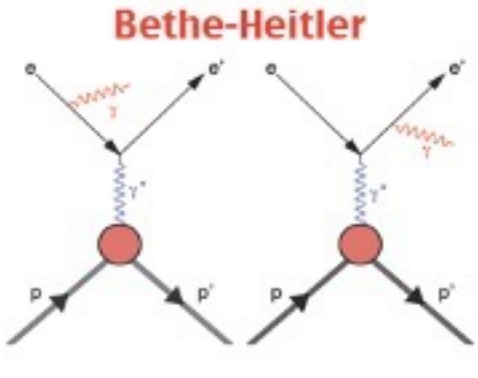
Spokesperson transverse target RG
Polarized target

Interference magnifies the rare DVCS signal and provide access to the QCD scattering amplitude

$$\frac{d^4\sigma}{dQ^2\, dx_B\, dt\, d\phi} \propto \sigma_{unp} \propto |\mathcal{M}_{BH}|^2 + \mathrm{Re}(\mathcal{M}_{int}) + |\mathcal{M}_{DVCS}|^2,$$
$$\Delta\sigma_{pol} \propto 2\,\mathrm{Im}(\mathcal{M}_{int})$$







Cross-section measurements are challenging but provide the most complete information to theory

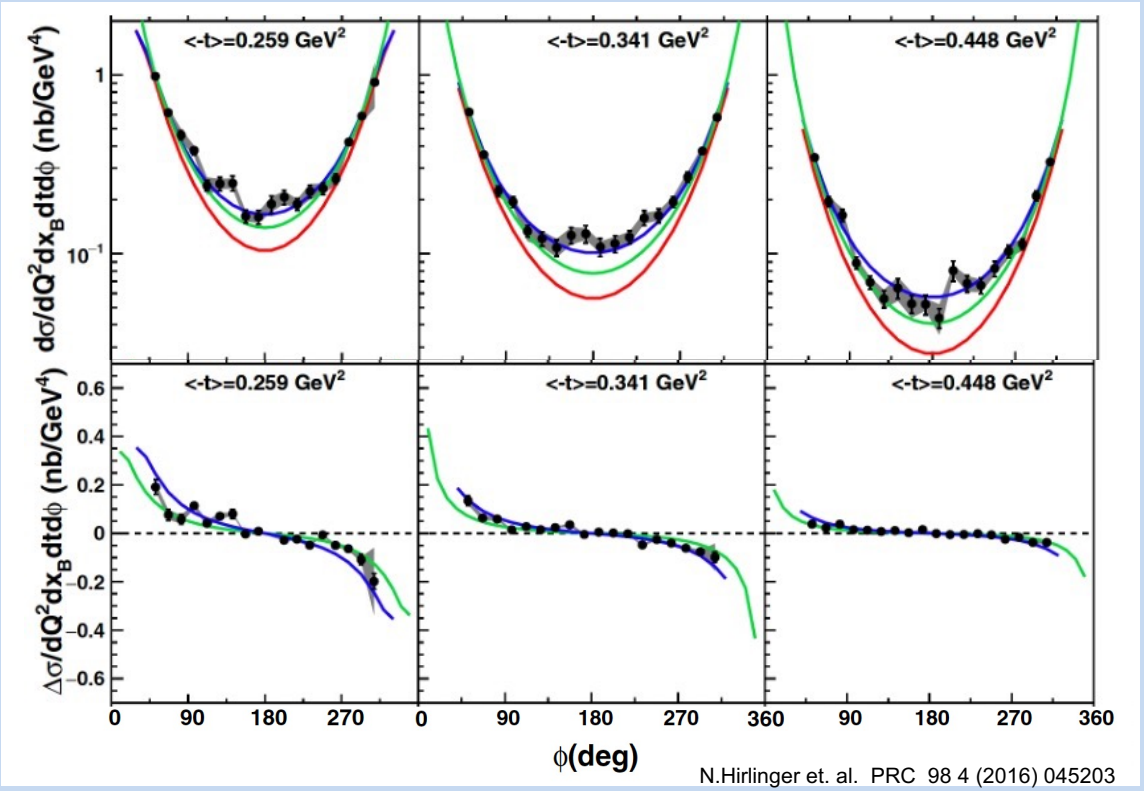
Analysis coordination
Result review coordination
Complementary channel
Transverse target experiments

Systematics on:

Radiative corrections

π0 background

Acceptance



N.Hirlinger et. al. PRC 98 4 (2016) 045203

TMD Review

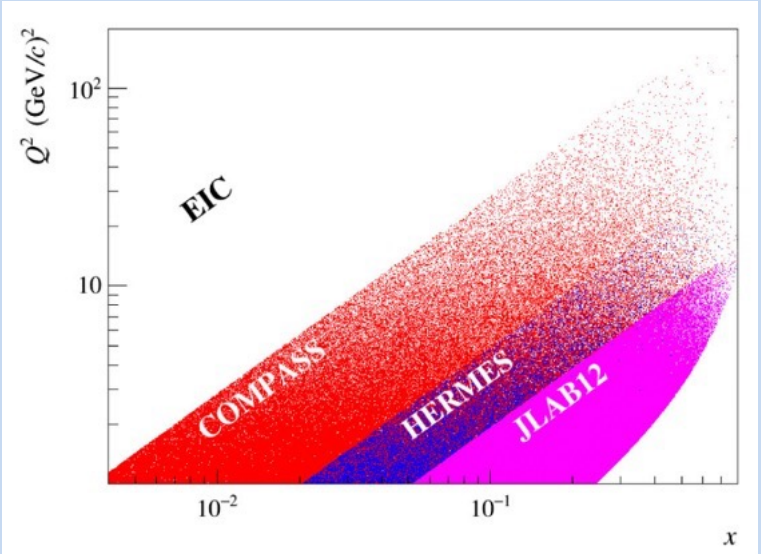
Compendium of first 10 years of observations
Critical discussion of present understanding
Most urgent theoretical and experimental validations
Future perspectives for precision

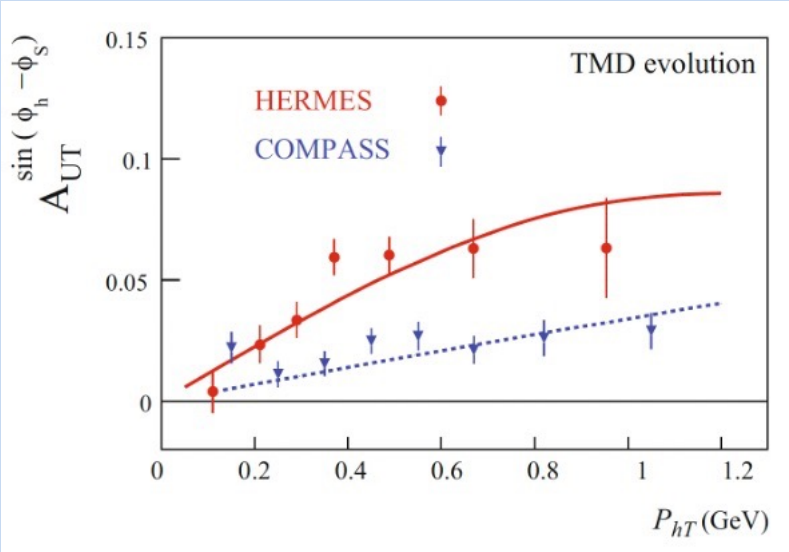
Several results (HERMES, JLab)
Projections of future proposals (Jlab, EIC)

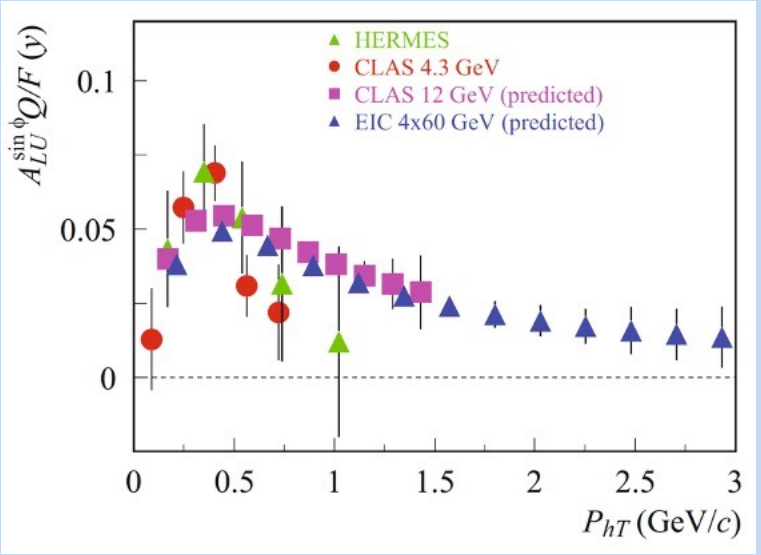
Connections (low-x, QGP, BSM)

Coparison among experiements

Extraction methods and systematics





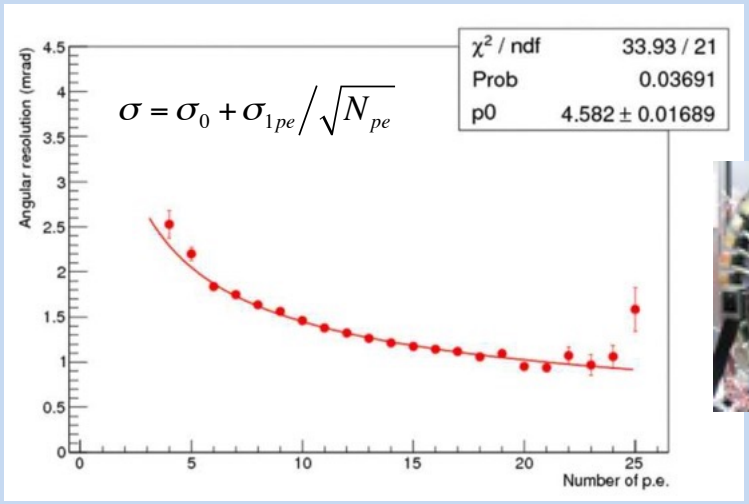


CLAS12 RICH

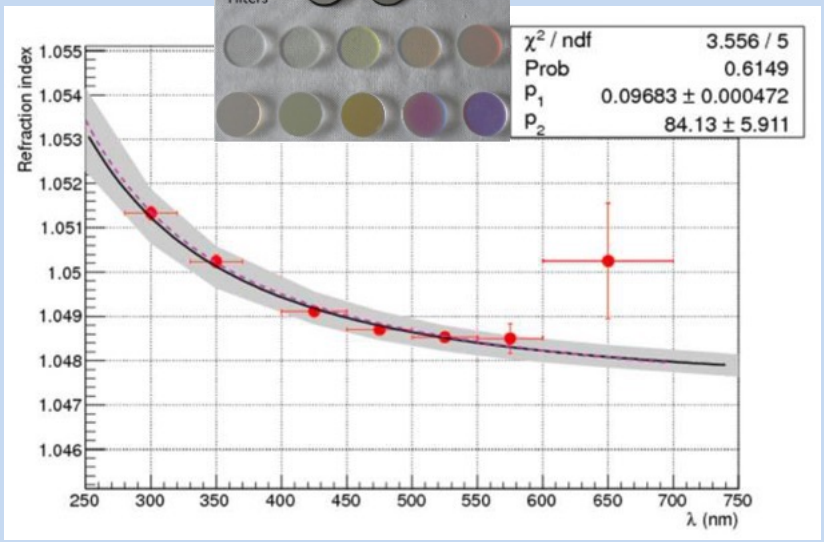
Design & simulations
Aergoel R&D, handling and characterization
Mirrors for hybrid optics validation
SiPM sensors and electronics
Data analysis

In 6 months: TDR
DOE review & approval
MIUR priority project

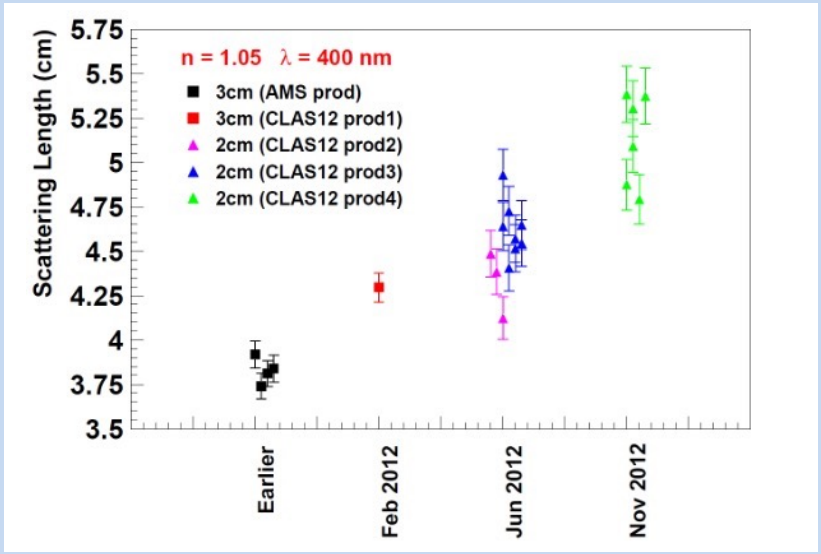
1.5 mrad resolution provides 4σ separation at 8 GeV/c



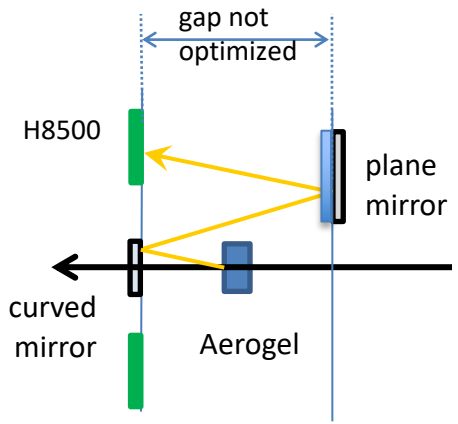
New method to measure dominant chromatic effect

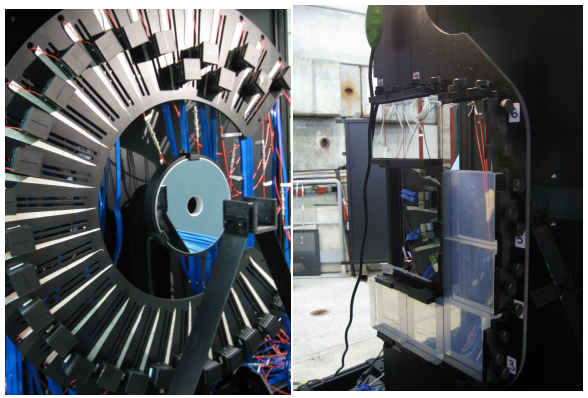


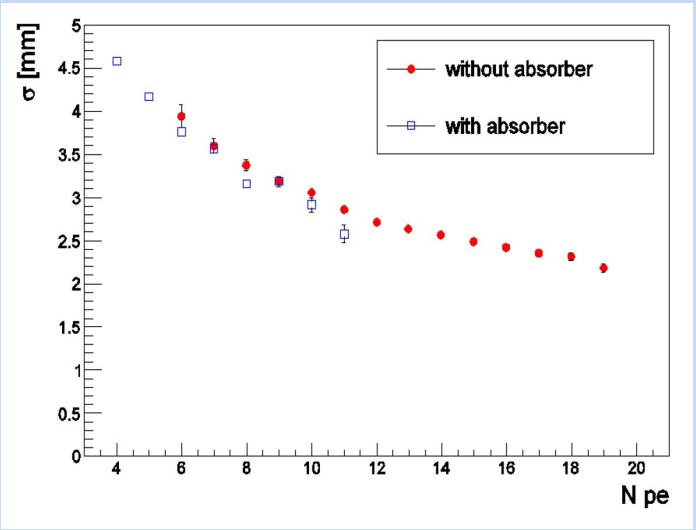
Achieved ~ 0.0050 μm^4 cm^{-1} aerogel clarity



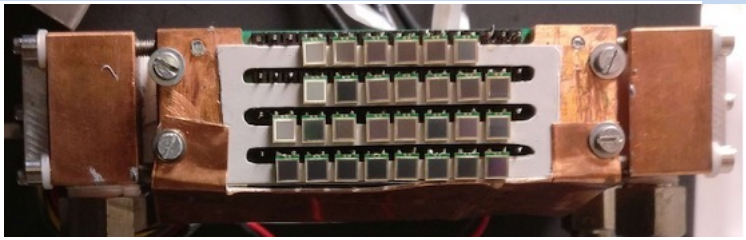
Resolution is not degraded by designed hybrid optics

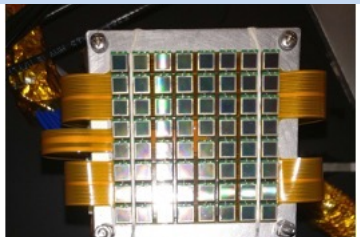


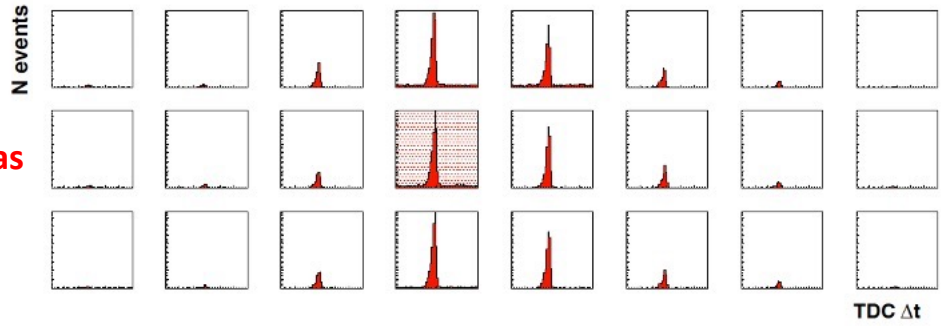




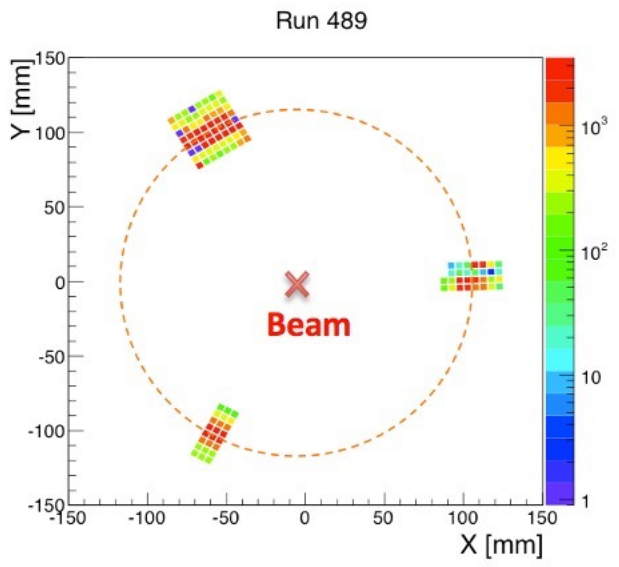
Proof-of-principle of SiPM use with respect H8500 multi-anode reference







Cooled SiPM as good as PMTs

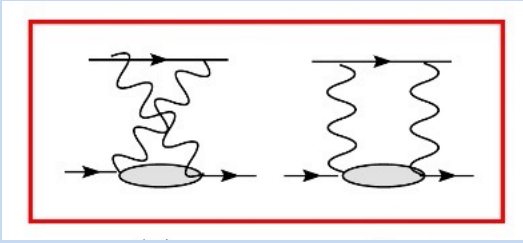


CLAS12 TPE

Coordination analysis
Review analysis
Review paper
Study of radiative corrections for hadronic tensor

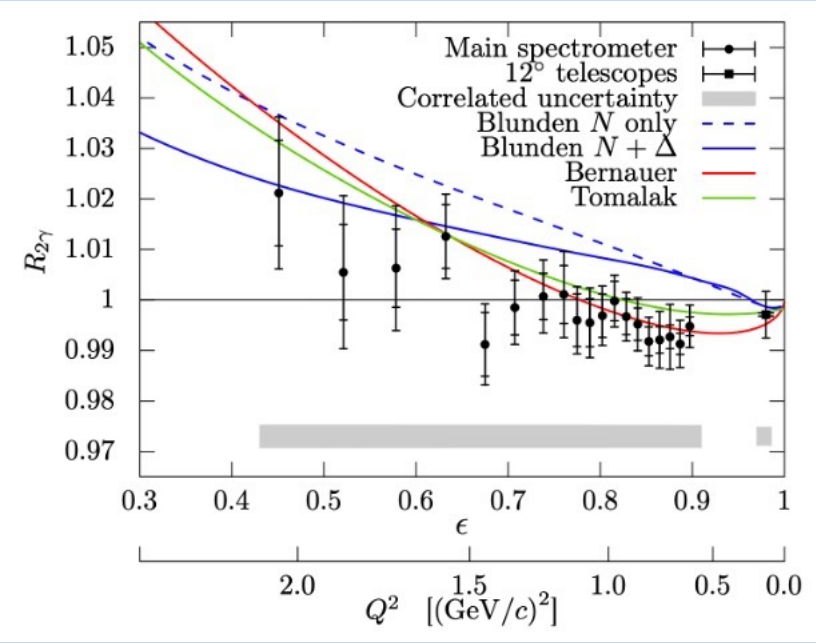
Complementary measurement:
OLYMPUS With independent beams
HERMES. Tw-photon exchnge in DIS

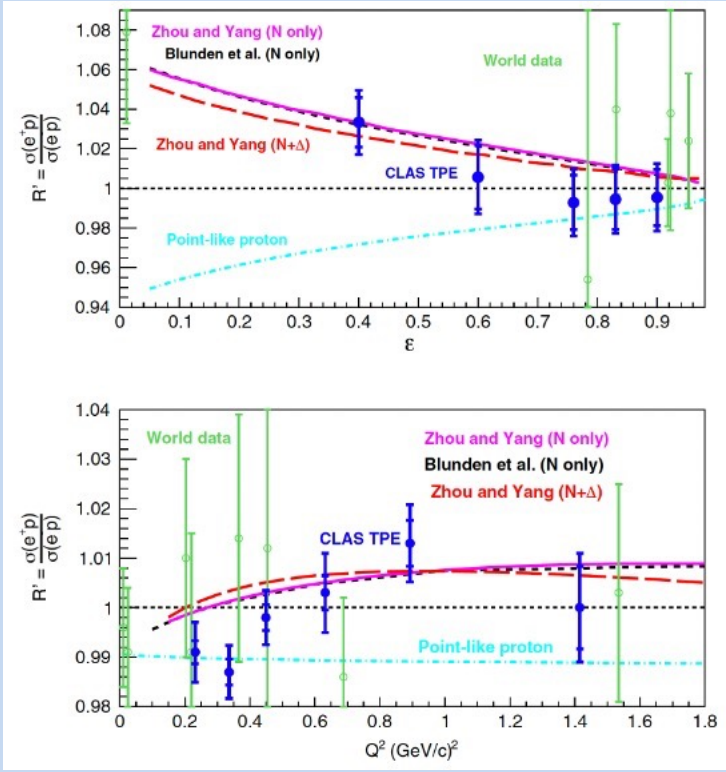
Wide range of intermediate hadronc states
1γ 2γ interference sensitive to the beam charge



CLAS: Unique terziary beam for simultaneous Measurement, wide acceptnace decouple ε and Q^2

OLYMPUS PRL118 (2017) 9, 092501



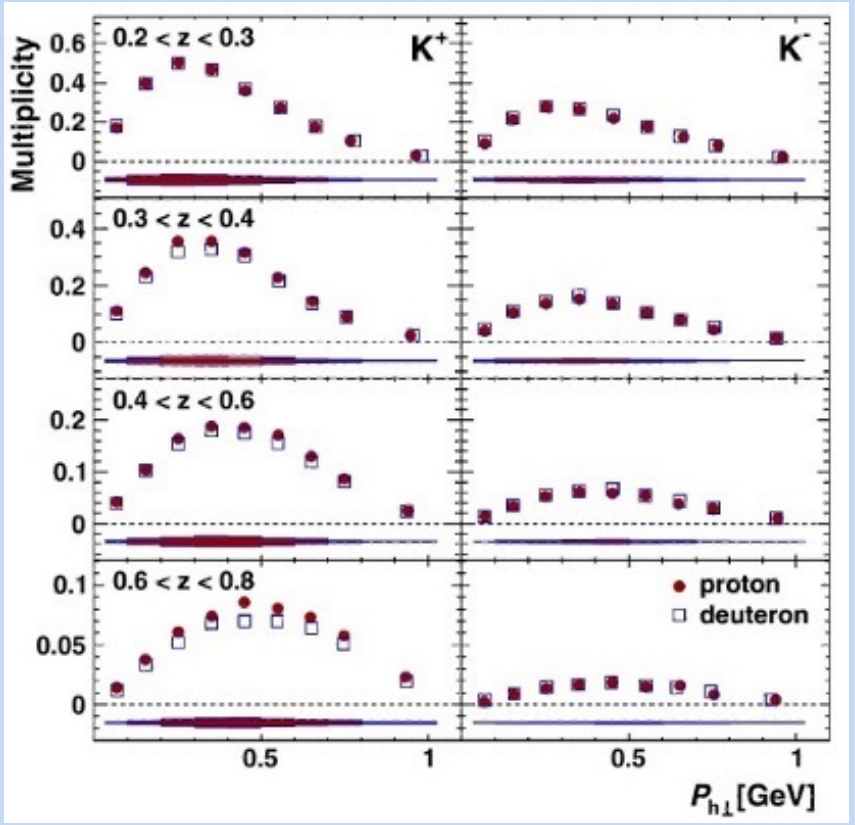


Analysis coordination
- Multi-D unfolding of experimental effect
- Systematic evaluation method

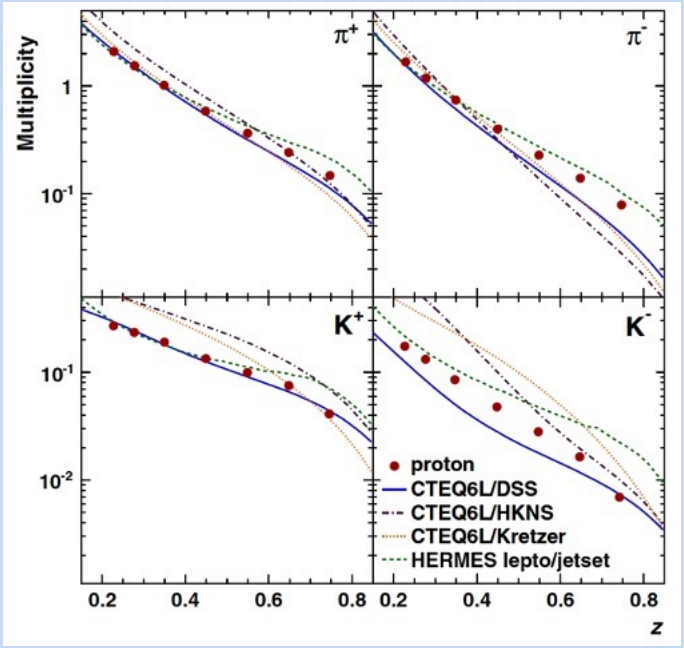
Editorial review of the article

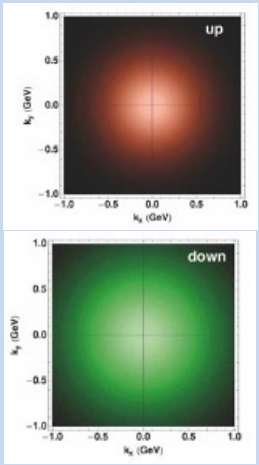
Target
- Coordination and maintenance
- Calibration and analysis

Most precise favor separated multiplicities



Comparison with phenomenological fits





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

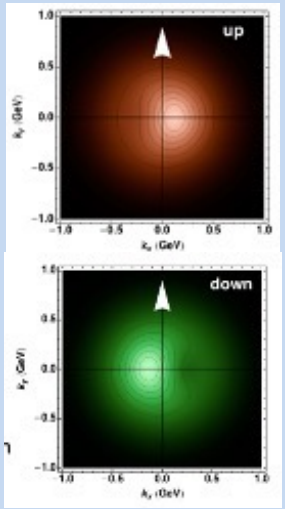
Related to
- TMD evolution
- Precision physics (W mass)
- Hadronizaion in cold nuclear media

HERMES SIVERS

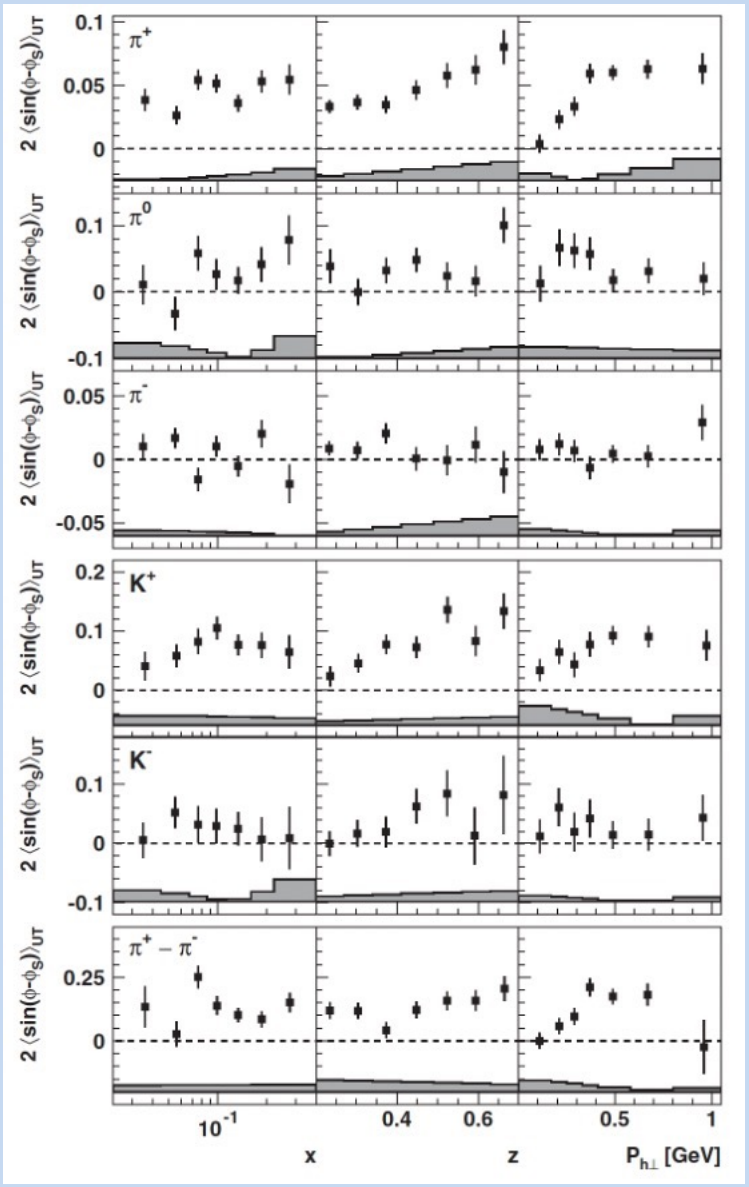
Analysis coordination
- Un-binned maximum likelihood
- Systematic evaluation method

Editorial review of the article

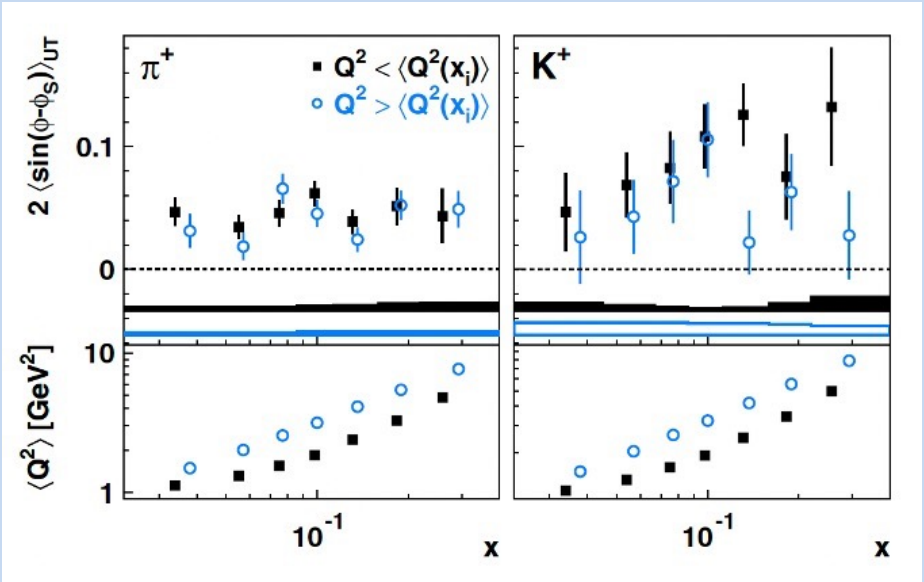
Target
- Coordination and maintenance
- Calibration and analysis



Flavor separation



No evidence of higher-twist or exclusive decay contamination



HERMES G_1

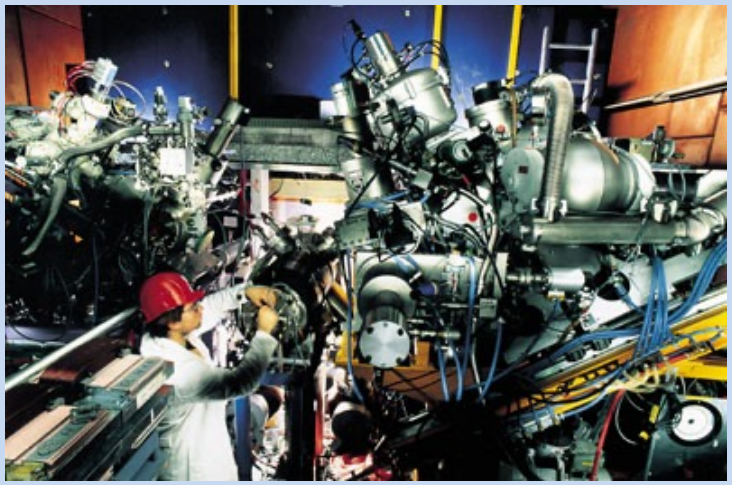
Target
- Coordination and maintenance
- Calibration and analysis
- Tensor polarization

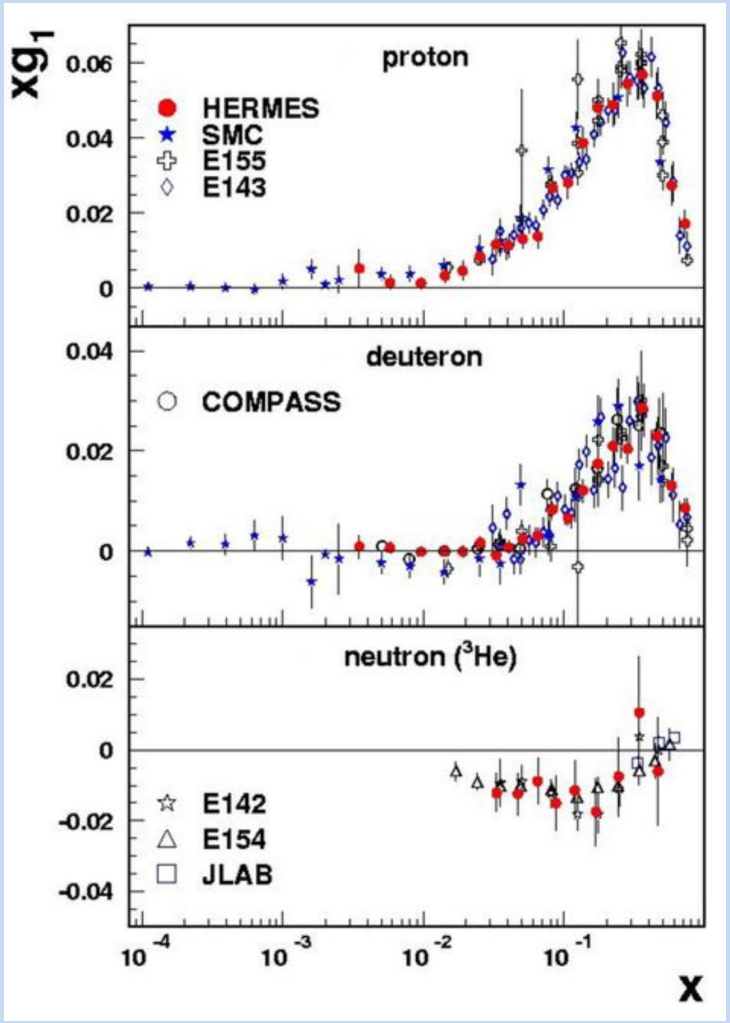
Analysis coordination

Extraction method validation
Systematic evaluation

Most precise deuteron measurement
determination of $\Delta\Sigma$ (axial charge)

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L^q + L^g$$





HERMES A_{UT}

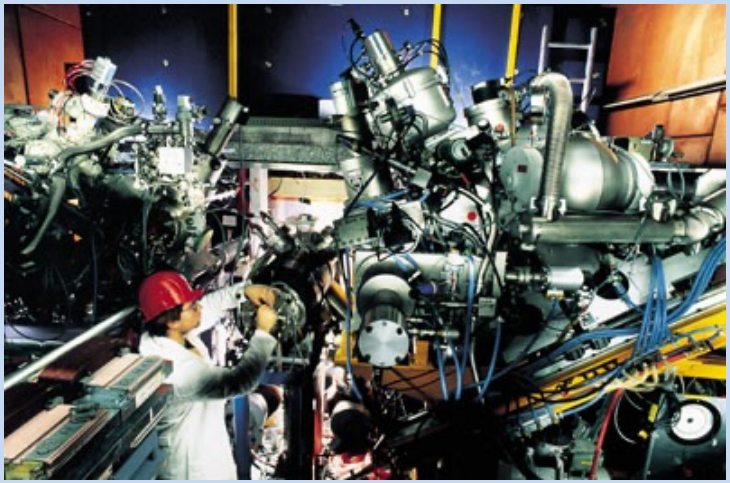
Target
coordination and maintenance
calibration and analysis

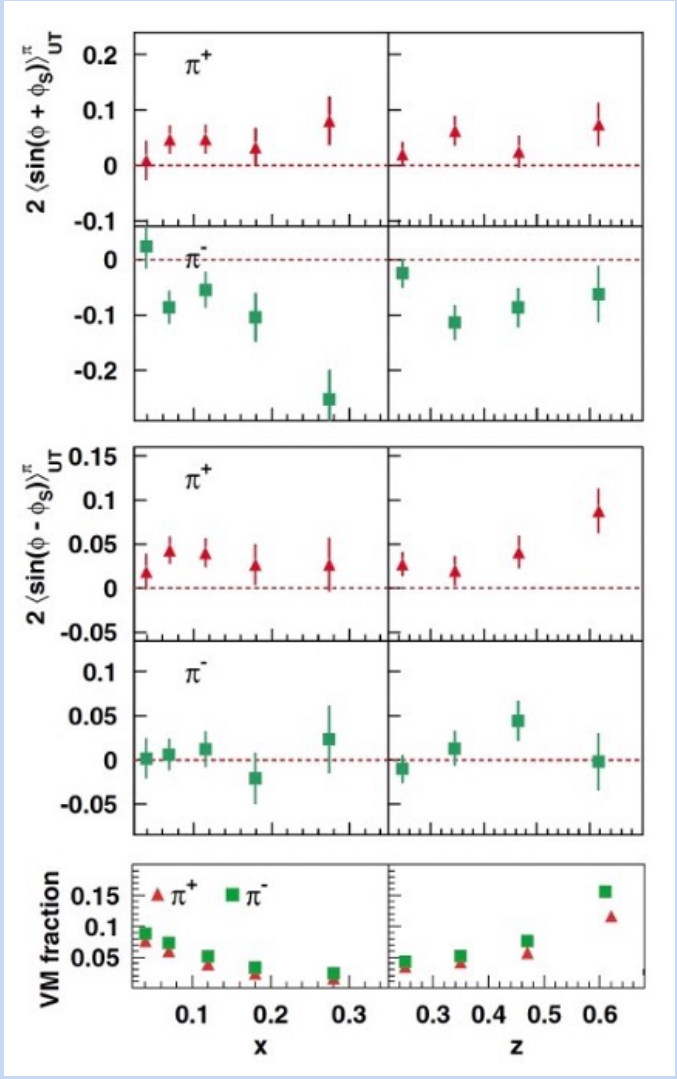
Analysis coordination

Extraction method validation
Systematic evaluation

First evidence for

Transversity: quark polarization
related to Tensor charge & BSM
Collins function: spin-orbit in fragmentation
Sivers function: spin-orbit in the nucleon





NOMAD $\nu\mu \rightarrow \nu e$

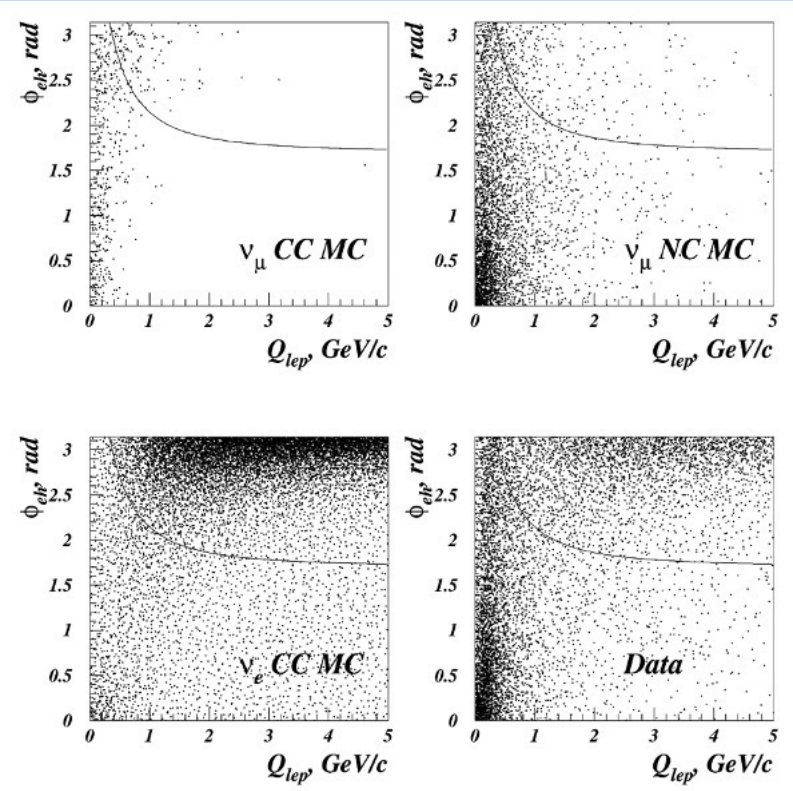
Electron energy reconstruction
- ECAL calibration with π^0
- Off-time muon background in ECAL
- Sum-up bremsstrahlung photons
- Account for DC material (early shower development)

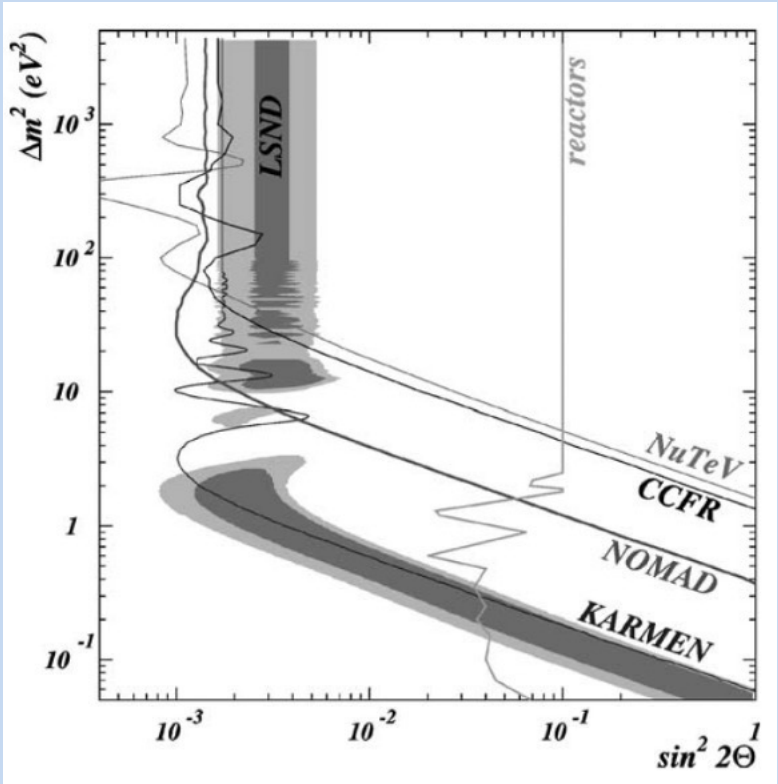
Preliminary $\nu_\mu \rightarrow \nu_\tau$ oscillation analysis

Electron preliinary selection

- $(E_{\rm brem} - p_\pi)/(E_{\rm brem} + p_\pi) > -0.3$
- $(E_{\rm brem} - p_e)/(E_{\rm brem} + p_e) < 0.4$

To be compared with 2.1% E_{brem} resolution

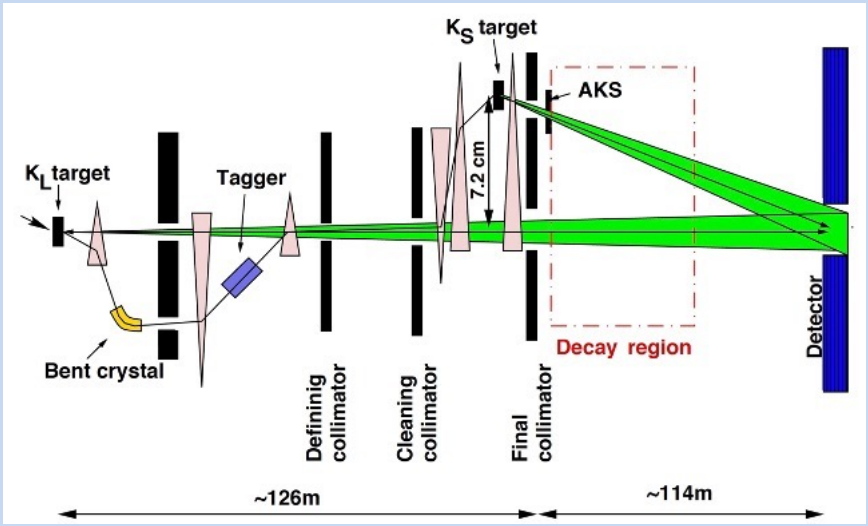




NA48 Direct CP

Beam intensity monitor
- Equalization
- Random triggers for accidentals
- Systematics due to accidentals

Neutral decays
- Neutral trigger and identification
- Rare neutral decays ($3\pi^0$, $\pi^0\gamma\gamma$, $\gamma\gamma$,)



$$R = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \Big/ \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)} \approx 1 - 6 \times \mathrm{Re}(\varepsilon'/\varepsilon)$$

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (15.3 \pm 2.6) \times 10^{-4}$$