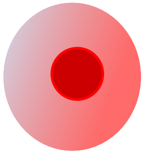
Hard Exclusive Measurements using the CERN polarized muon beam and the transversely Polarized target

to get information on the GPD E

Nicole d'Hose, CEA-Saclay, mini-workshop at CERN, 20 June 2018

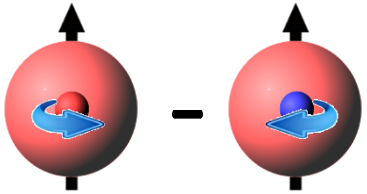
The GPD E is the grail for OAM quest

$\mathbf{H}(x, \xi, t) \xrightarrow{t\to 0} q(x)$ or $f_1(x)$

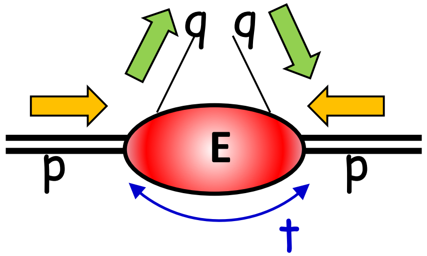


"Elusive"

$\mathbf{E}(x, \xi, t) \longleftrightarrow f_{1T}^{\perp}(x, k_T)$



Sivers: quark k_T &
nucleon transv. Spin



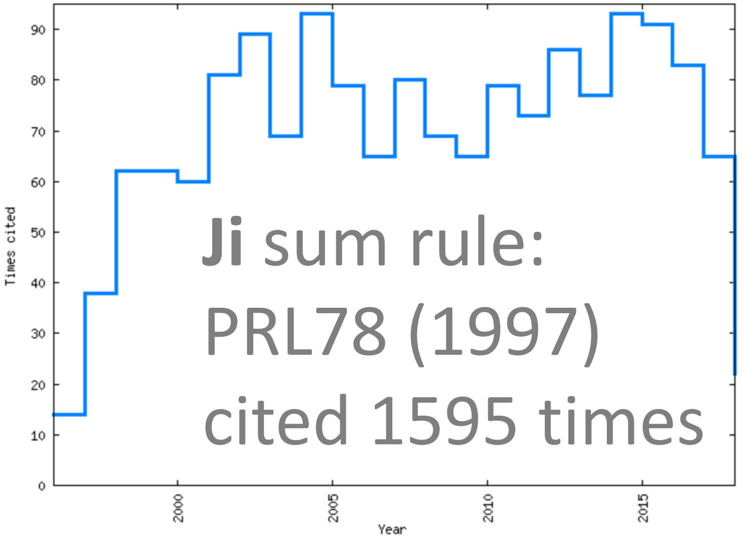
Relation to OAM

$$\boxed{J^q = \frac{1}{2} \lim_{t \to 0} \int \left(\mathbf{H}^q(x, \xi, t) + \mathbf{E}^q(x, \xi, t)\right) x\, dx}$$

$\frac{1}{2} = J^q + J^g = \frac{1}{2}\Delta\Sigma + L^q + J^g$ Ji PRL78 (1997)

$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \mathfrak{L}^q + \Delta G + \mathfrak{L}^g$ Jaffe and Manohar NPB337 (1990)

$\frac{1}{2}\Delta\Sigma \sim 0.15$ well know from DIS/SIDIS
$\Delta G \sim 0.2$ known from SIDIS/pp
L and $\mathfrak{L}$ unknown



Ji sum rule:
PRL78 (1997)
cited 1595 times

What has been done so far: Jlab 6 GeV and HERMES

$\vec{\ell}\, d \rightarrow \ell\, n\, \gamma\, (p)$

$$\Delta\sigma_{LU}^{\sin\phi} = Im\,(F_{1n}\mathcal{H} + \xi(F_{1n}+F_{2n})\widetilde{\mathcal{H}} + t/4m^2\, F_{2n}\mathcal{E})$$

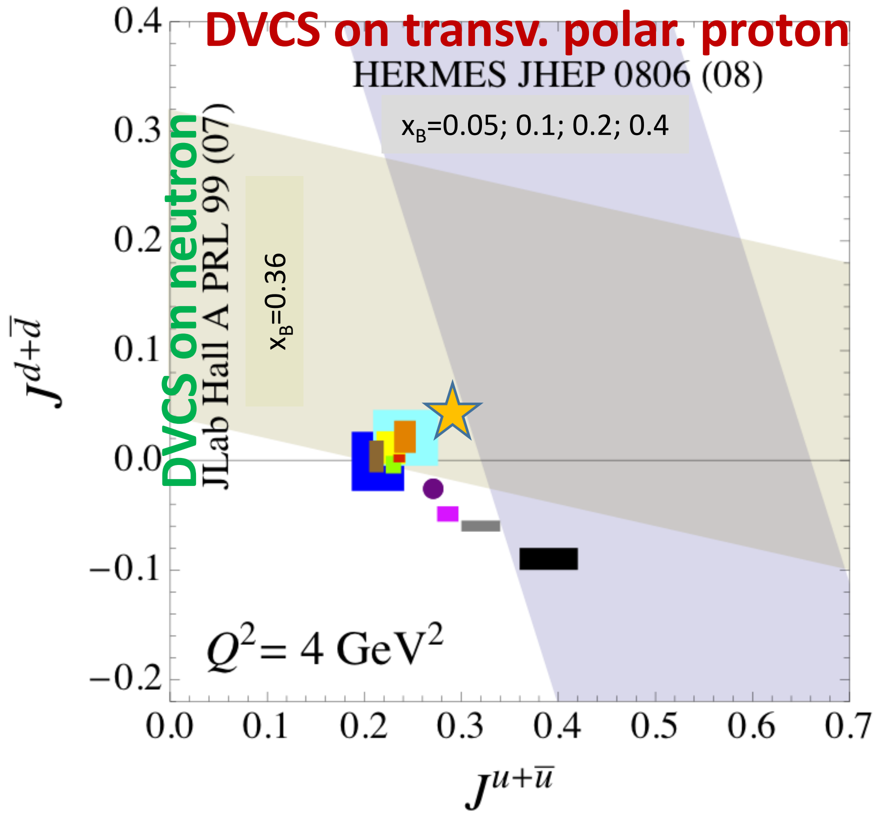
beam target
polarisation

another experiment was done in 2010

$\vec{\ell}\, p^{\uparrow} \rightarrow \ell\, p\, \gamma$

$$\Delta\sigma_{UT}^{\sin(\phi-\phi_s)\cos\phi} = -\, t/4m^2\ Im\,(F_{2p}\mathcal{H} - F_{1p}\mathcal{E})$$
$$\Delta\sigma_{LT}^{\sin(\phi-\phi_s)\cos\phi} = -\, t/4m^2\ Re\,(F_{2p}\mathcal{H} - F_{1p}\mathcal{E})$$

Model dependent extraction of J^u and J^d

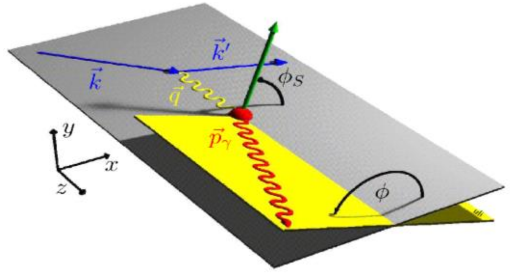


From Dudek et al., EPJA48 (2012)

- 🟦 Goloskokov & Kroll, EPJ C59 (09) 809
- 🟫 Diehl et al., EPJ C39 (05) 1
- 🟪 Guidal et al., PR D72 (05) 054013
- 🟪 Liuti et al., PRD 84 (11) 034007
- 🟧 Bacchetta & Radici, PRL 107 (11) 212001
- 🟦 LHPC−1, PR D77 (08) 094502
- 🟥 LHPC−2, PR D82 (10) 094502
- 🟩 QCDSF, arXiv:0710.1534
- 🟨 Wakamatsu, EPJ A44 (10) 297
- ⬛ Thomas, PRL 101 (08) 102003
- ⬜ Thomas, INT 2012 workshop

$\Big\}$ **Old Lattice QCD**

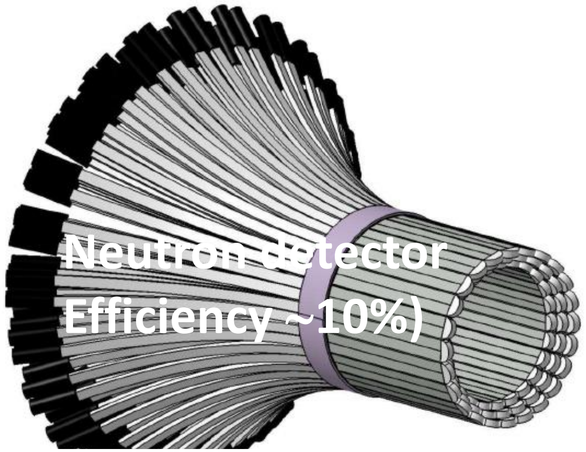
★ Alexandrou et al., PRL119(2017)142002 **New Lattice QCD**
with disconnect diagrams J^u=0.31 J^d=0.05 J^s=0.05



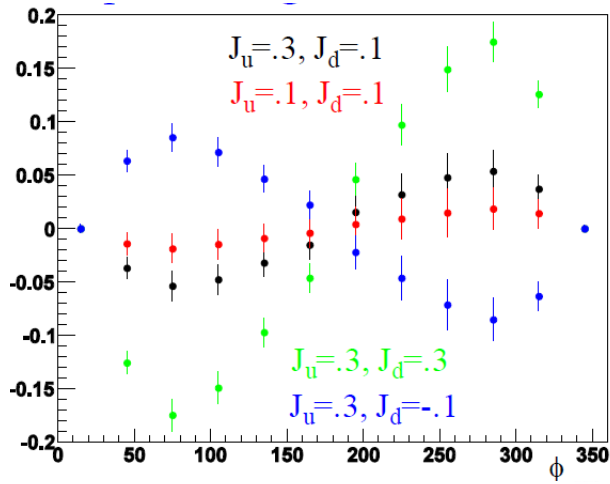
What will be done in ~2020: Jlab 11 GeV with CLAS12

Exp E12-11-003: DVCS on the neutron

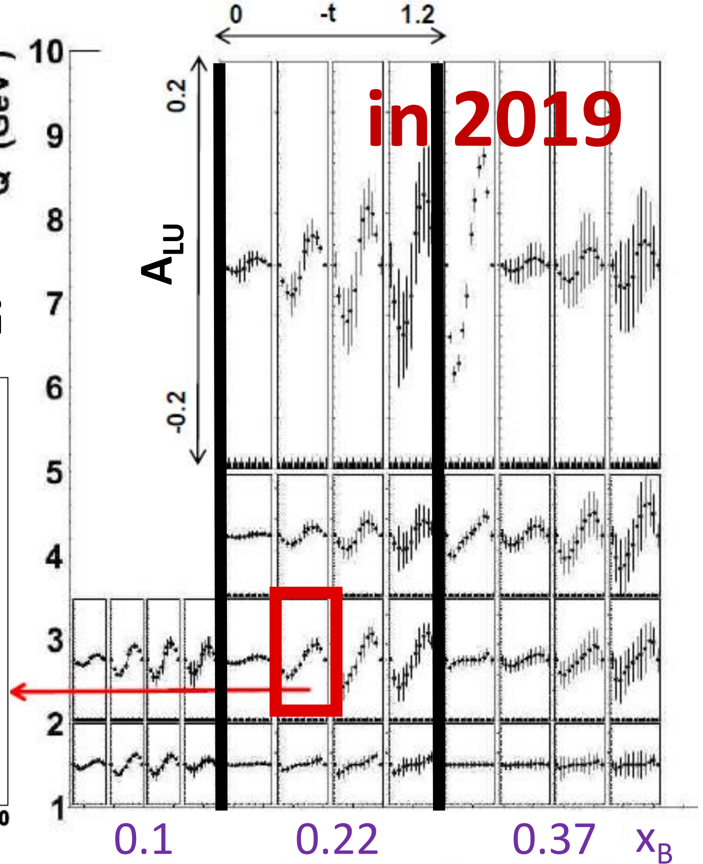
$$\Delta\sigma_{LU}^{\sin\phi} = Im\,(F_{1n}\mathcal{H} + \xi(F_{1n}+F_{2n})\widetilde{\mathcal{H}} + t/4m^2\,F_{2n}\mathcal{E})$$



Model prediction using VGG



90 days on LD2 target
Lumi= 10^{35} cm^{-2} s^{-1}/nucleon



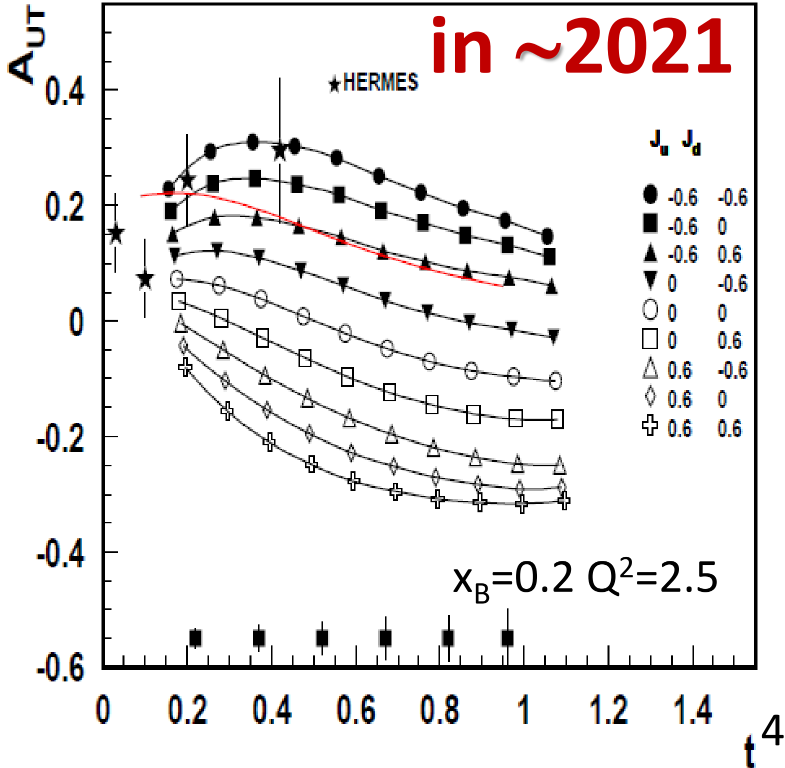
in 2019

Exp E12-12-010: DVCS on a transversely polarized HD-Ice target Pol H = 60% Pol D = 35%

$$\Delta\sigma_{UT}^{\sin(\phi-\phi s)\cos\phi} = -\,t/4m^2\;Im\,(F_{2p}\,\mathcal{H} - F_{1p}\,\mathcal{E})$$

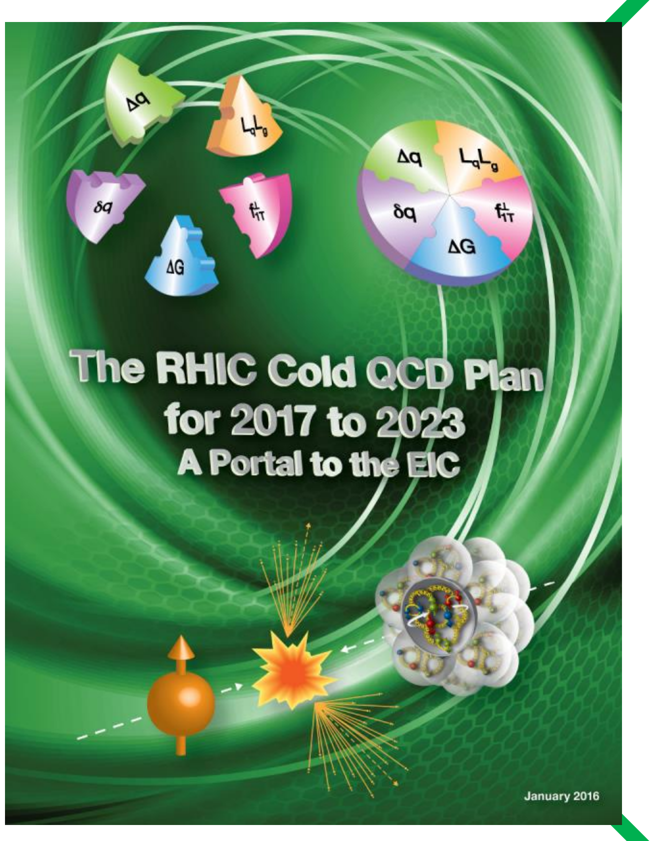
$$\Delta\sigma_{LT}^{\sin(\phi-\phi s)\cos\phi} = -\,t/4m^2\;Re\,(F_{2p}\,\mathcal{H} - F_{1p}\,\mathcal{E})$$

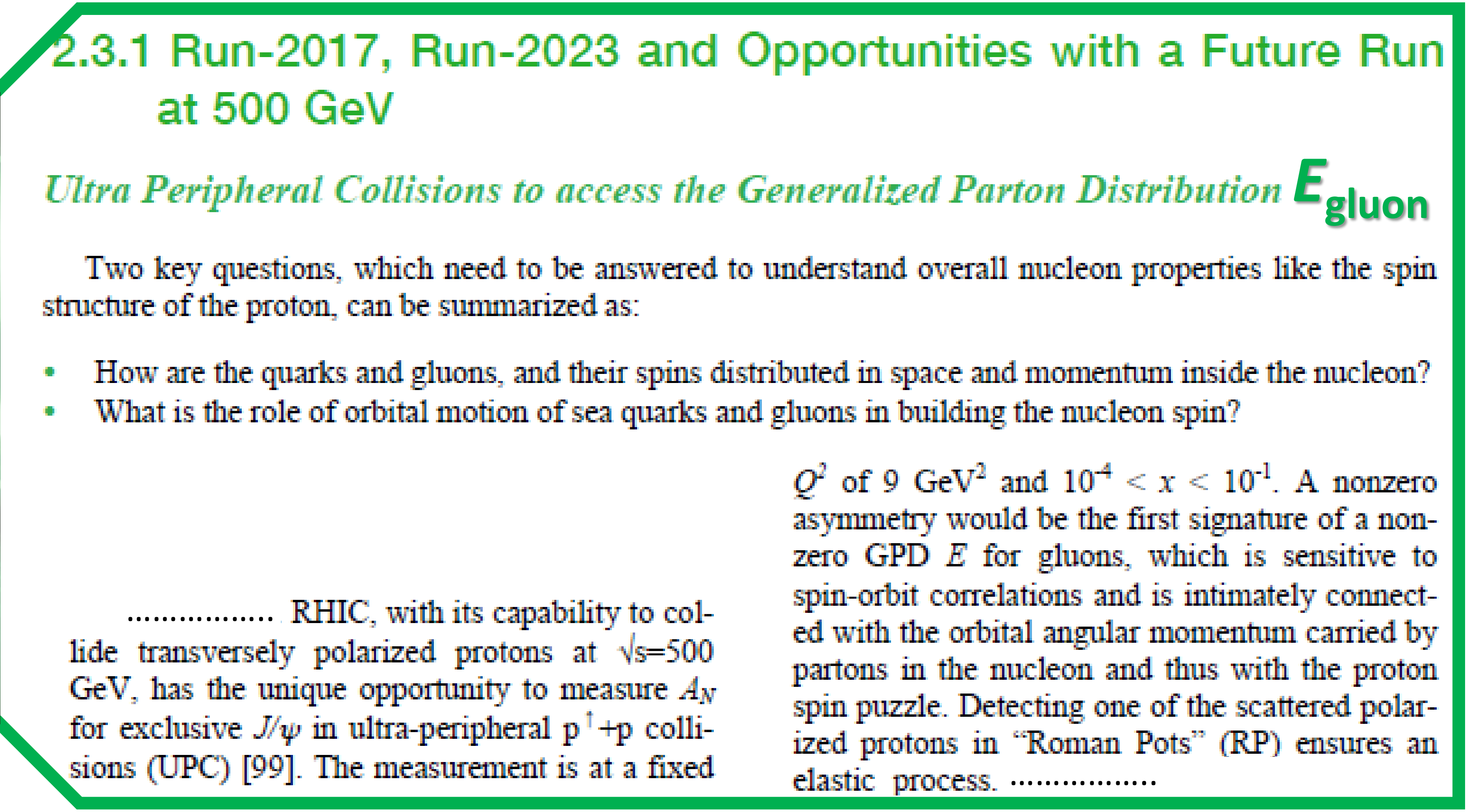
110 days on HD-Ice target
Lumi= 5 x 10^{33} cm^{-2} s^{-1}/nucleon



in ~2021

Competition at RHIC in 2017 and 2023


The RHIC Cold QCD Plan for 2017 to 2023
A Portal to the EIC
January 2016


2.3.1 Run-2017, Run-2023 and Opportunities with a Future Run at 500 GeV

Ultra Peripheral Collisions to access the Generalized Parton Distribution E_{gluon}

Two key questions, which need to be answered to understand overall nucleon properties like the spin structure of the proton, can be summarized as:

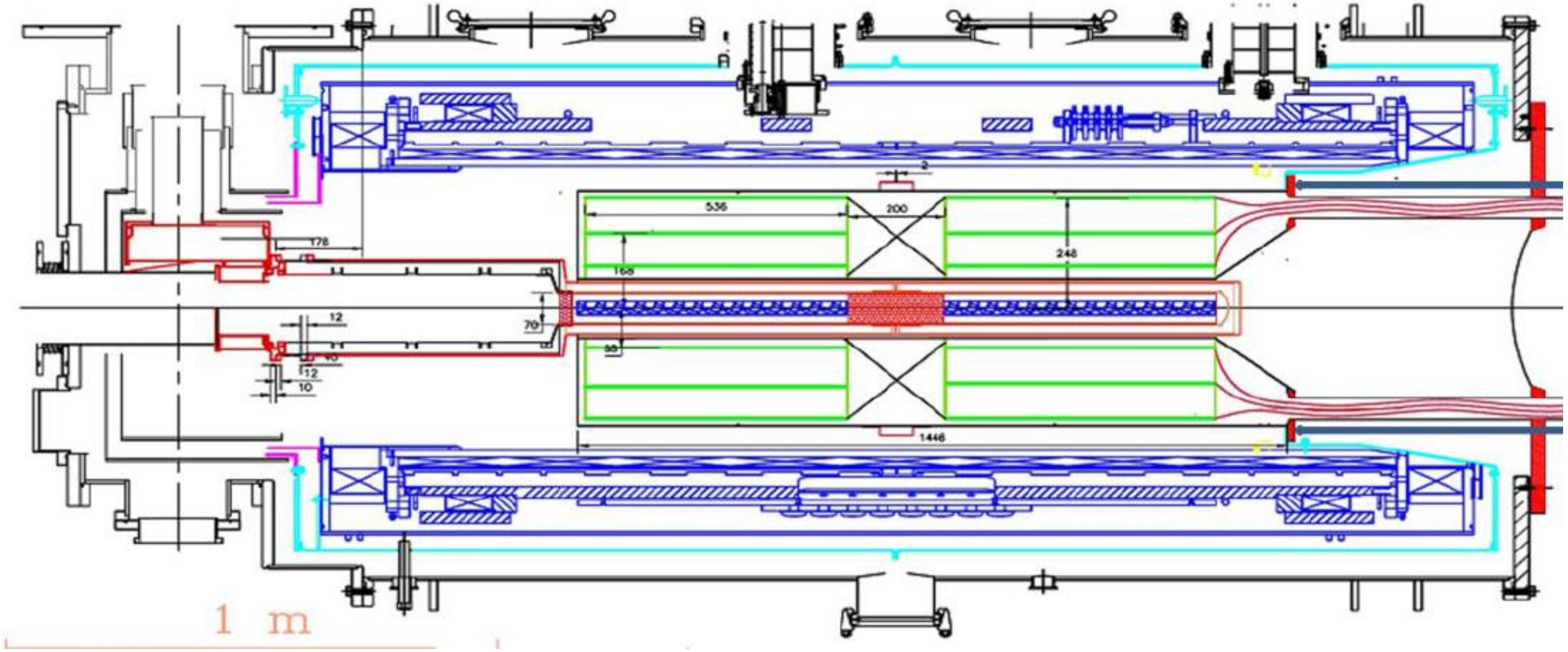
- How are the quarks and gluons, and their spins distributed in space and momentum inside the nucleon?
- What is the role of orbital motion of sea quarks and gluons in building the nucleon spin?

.... RHIC, with its capability to collide transversely polarized protons at $\sqrt{s}$=500 GeV, has the unique opportunity to measure A_N for exclusive J/ψ in ultra-peripheral $p^{\uparrow}$+p collisions (UPC) [99]. The measurement is at a fixed Q^2 of 9 GeV^2 and $10^{-4} < x < 10^{-1}$. A nonzero asymmetry would be the first signature of a nonzero GPD E for gluons, which is sensitive to spin-orbit correlations and is intimately connected with the orbital angular momentum carried by partons in the nucleon and thus with the proton spin puzzle. Detecting one of the scattered polarized protons in "Roman Pots" (RP) ensures an elastic process. ....

11k J/ψ in 2017 ($p^{\uparrow}$ p @ 510 GeV) and 13k in 2023 ($p^{\uparrow}$ Au @ 200 GeV)
Important input for the photoproduction of J/ψ at EIC

Possible recoil detection with the COMPASS polarized target

A recoil proton detector is mandatory to ensure the exclusivity. A Silicon detector is included *between* the target surrounded by the modified MW cavity   *and* the polarizing magnet



3 cylindrical layers of Silicon det. are included in ~18cm

No possibility for ToF
➔PID of p/π with dE/dx
momentum (as low as possible)
and trajectory measurments

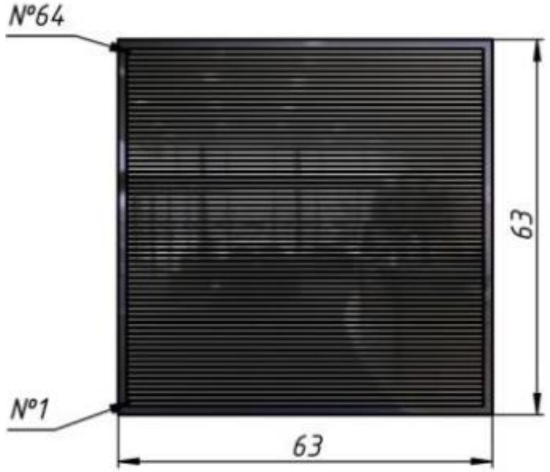
Environment:

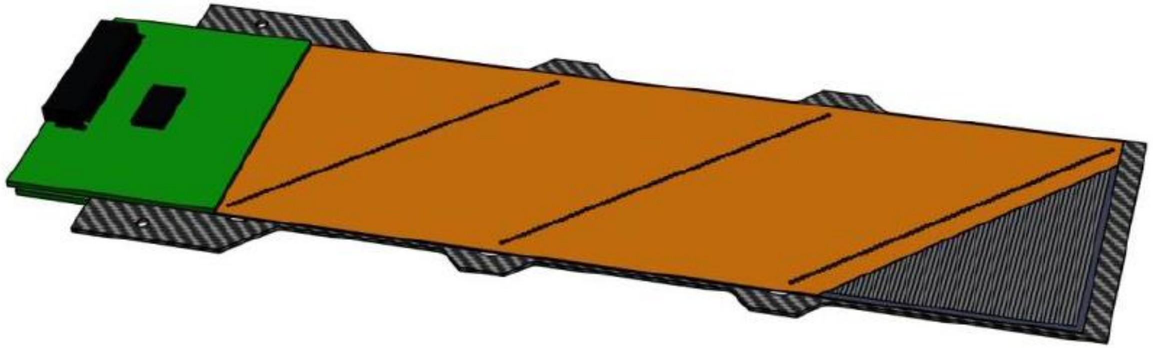
- Magnetic field (long and transv) 0.5-2T
- Presence of MW field temporary
- A low temperature 5-10K
- A vacuum of about 10^{-6} mm Hg

Modified MW as thin as possible 0.2-0.6mm thick copper foil

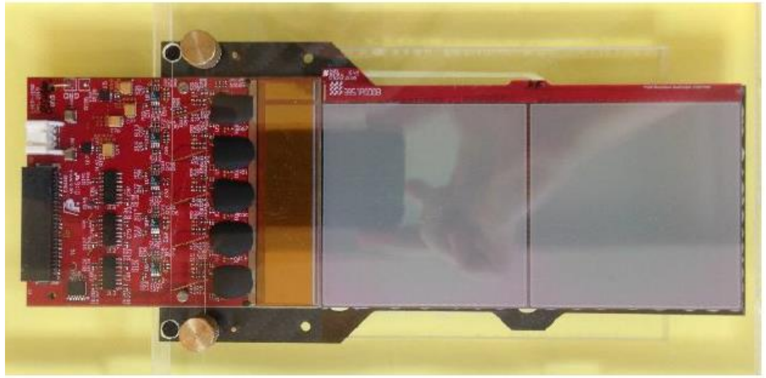
Operation of SI and evacuation of the heat of the read out electronics:
SI detectors in a separate block warmed at ~70K and ‘’warm’’ chips fixed on the flange at the room temp
(use of 1.25m long flat aluminium-polyimide multilayer flexible buses)

A technology developed at LHEP at JINR for NICA

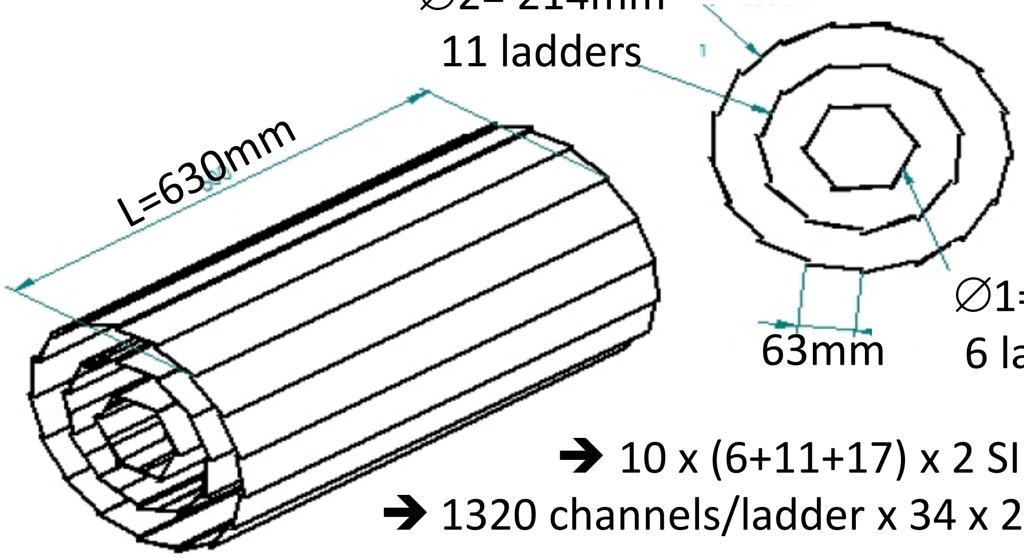




The ladder supporting the double-sided SI strip detector, 63x63 mm each, with a strip pitch of **500 µm**



Silicon detector unit with electronics developed for BM@N experiment.



∅3= 336mm
17 ladders

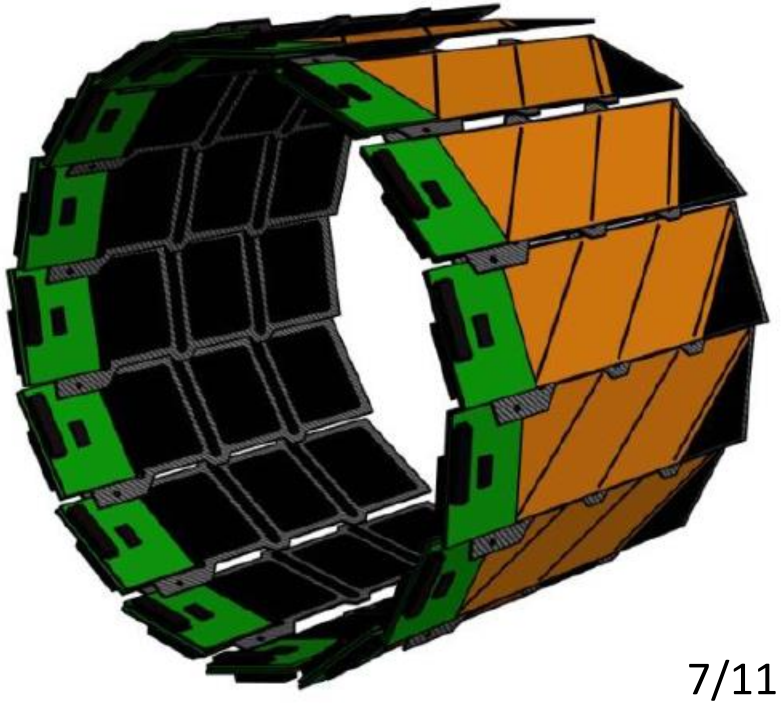
Thickness det1,2,3
=100, 100, 300µm

∅2= 214mm
11 ladders

∅1= 110mm
6 ladders

➔ 10 x (6+11+17) x 2 SI detectors = 680 detectors

➔ 1320 channels/ladder x 34 x 2 ladders= 90 000 channels



Performances studied in MC

New Silicon detector with NH3 target

tmin

NH3 target	radius 20mm	
MW Cavity	thickness	0.6 mm
1^{st} SI det	thickness	300 μm
2^{nd} SI det	thickness	1000μm

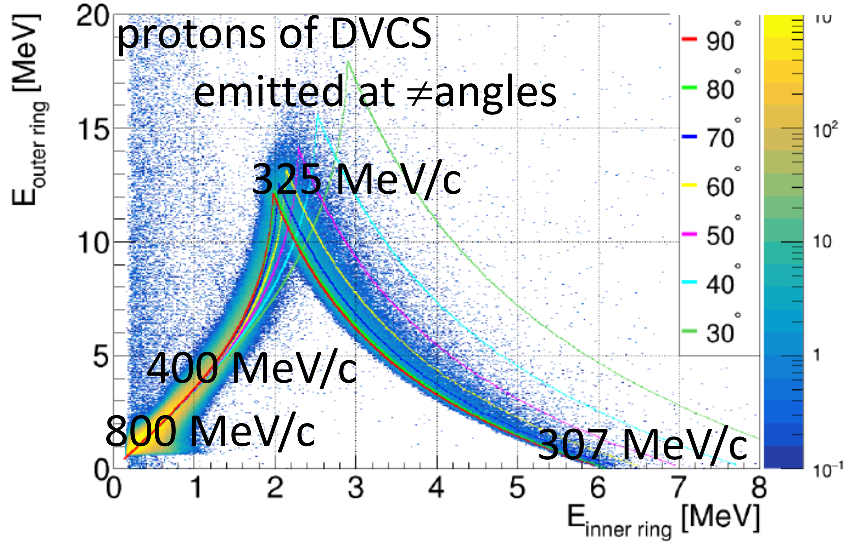
-tmin= 0.092 GeV^2 Pp=306.7 MeV/c Combined eff ($\mu p \gamma$) = 40%

CAMERA with LH2 target

-tmin= 0.066 GeV^2 Pp=258.5 MeV/c Combined eff ($\mu p \gamma$) = 56%

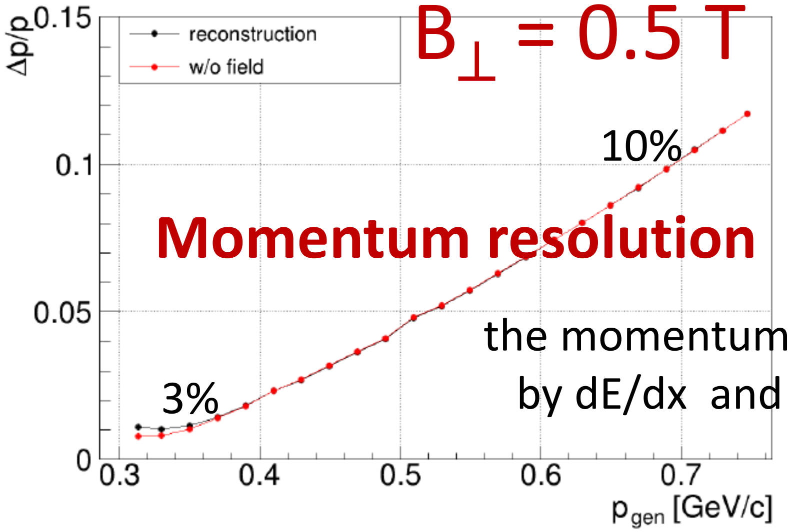
Particle Identification

TGEANT



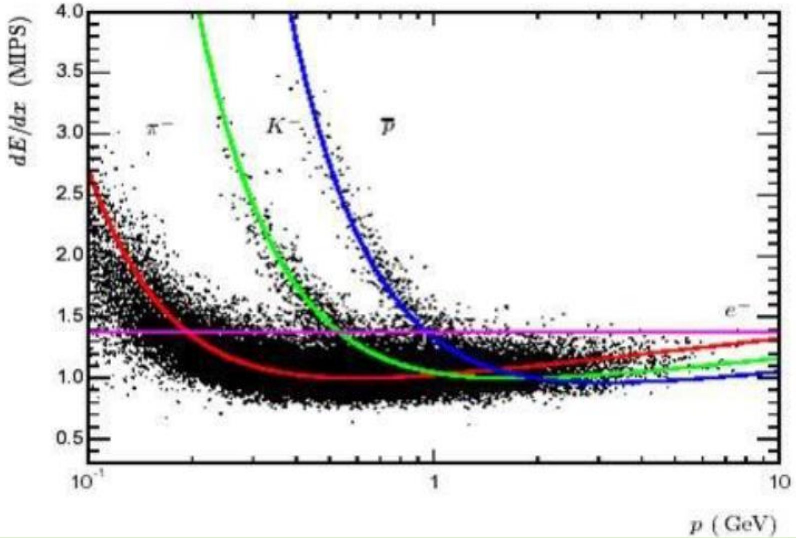
protons of DVCS emitted at ≠angles

$B_\perp$ = 0.5 T



Momentum resolution

the momentum determined by dE/dx and θ angle



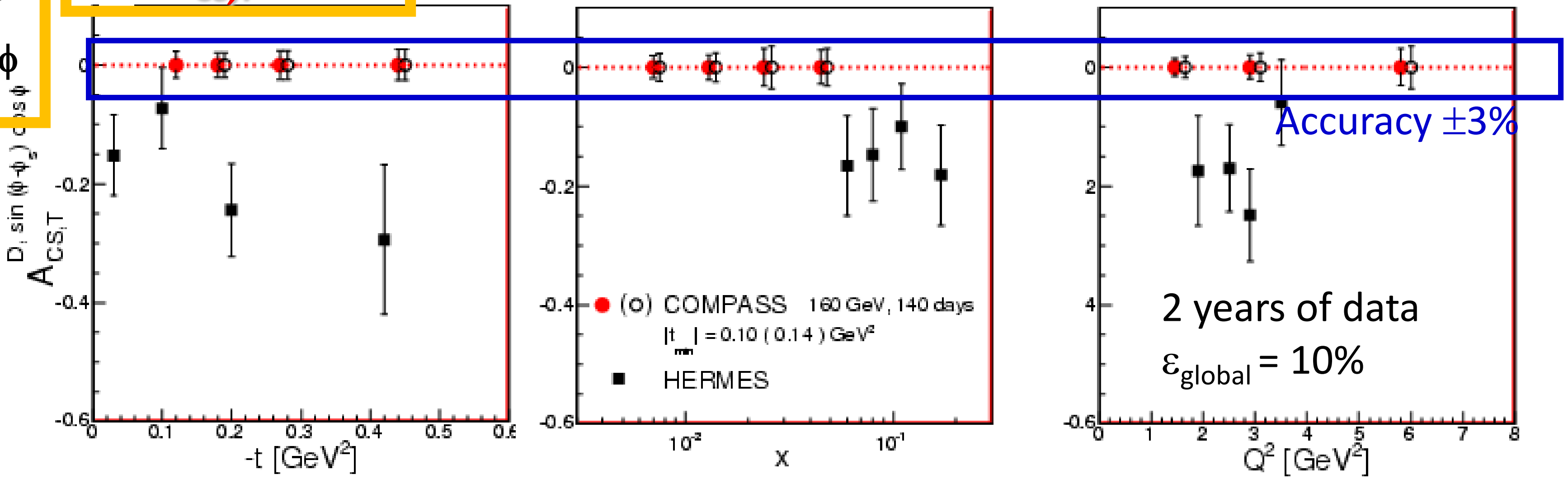
DVCS with 160 GeV pol. μ^+ & μ^- beams and Transv Pol target

$$\mathcal{D}_{CS,T} \equiv \Delta\sigma_T(\mu^{+\downarrow}) - \Delta\sigma_T(\mu^{-\uparrow})$$

$$\rightarrow Im(F_2\mathcal{H} - F_1\mathcal{E}) \sin(\phi - \phi s) \cos\phi$$

$$\mathcal{A}^{\sin(\phi-\phi s)\cos\phi}_{\mathcal{D}_{CS,T}}$$

1.2m long transv. polarized NH_3 target



Accuracy ±3%

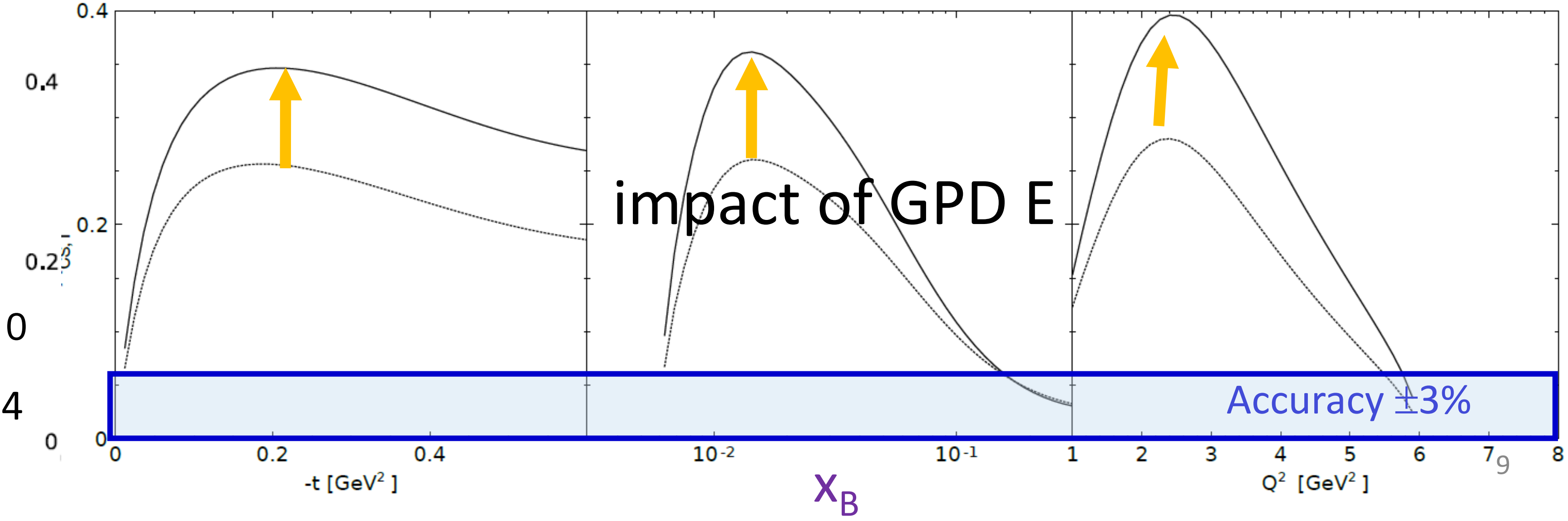
2 years of data

ε_{global} = 10%

From Pawel Sznajder
Using the PARTONS code
Formalism at LO

———	GK and CFFs@LO
- - - - -	Idem with GPDs E = 0

$J^u \sim 0.23$; $|J^d| < 0.05$; $|J^s| < 0.04$



impact of GPD E

Accuracy ±3%

Mesons with 160 GeV pol. μ^+ & μ^- beams and Transv Pol target

Exclusive meson production allows to separate favors of quarks

In 2 years the statistics will not exceed all the statistics already cumulated without recoil detector

However the promising term is

$$\boxed{Im\ \sigma_{00}^{+-} \propto Im\,(\mathcal{E}^* \mathcal{H})}$$

$$\gamma^*_L \to \rho^0_L$$

Experimentaly we measure

$$\boxed{A_T^{\sin(\phi-\phi_s)} \propto Im\,(\sigma_{++}^{+-} + \epsilon\ \sigma_{00}^{+-})}$$

.

A Rosenbluth separation is not feasible with high energy muon beams but the recoil detection allows the study of the ρ decay angular distribution to separate transverse/longitudinal ρ.

If we assume (and check) the SCHC we separate transverse/longitudinal γ^* and extract the GPD E contribution.

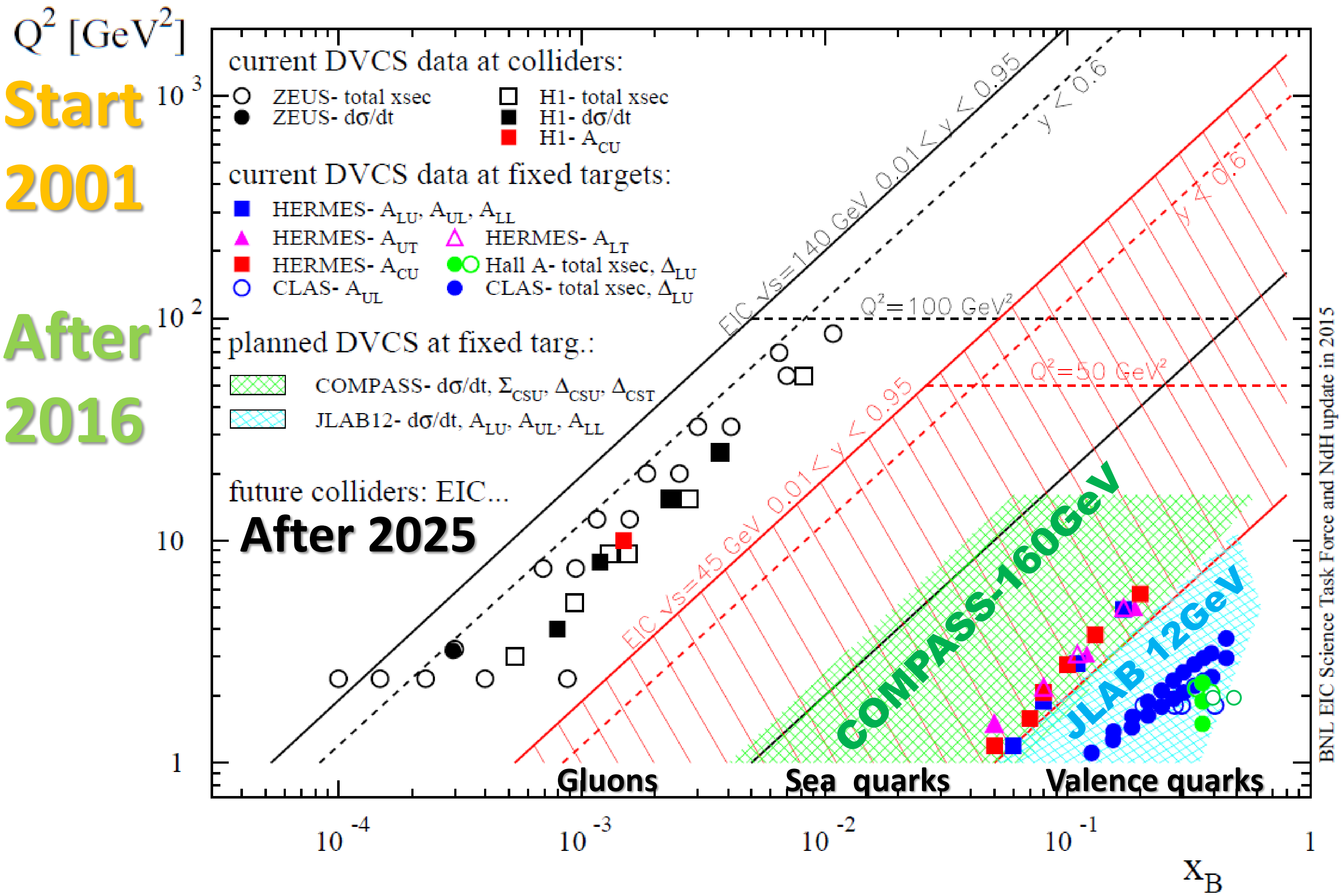
Concluding remarks

Is today the "GPD E" & “OAM”physics case a sufficiently "hot" topic
to build a recoil detector compatible with the polarized target?
This is a very challenging project but a major hardware task.

The luminosity of the CERN muon beam with NH3 target
is about 1/10 of the JLab e- beam with the HD ice target.
Statistics at CERN in 300 days will be ~1/3 of those at Jlab in 100 days.
Moreover the $0.01<x_B<0.1$ domain of the CERN high energy muon beam
is unique before any collider is built, and so this experiment
should be done exactly in parallel of the Jlab experiments at $x_B>0.1$,
before 2024, to provide immediately its impact.

SPARES

The past and future DVCS experiments



Start 2001

After 2016

After 2025

Last Predictions in Lattice

Alexandrou et al., PRL119(2017)142002

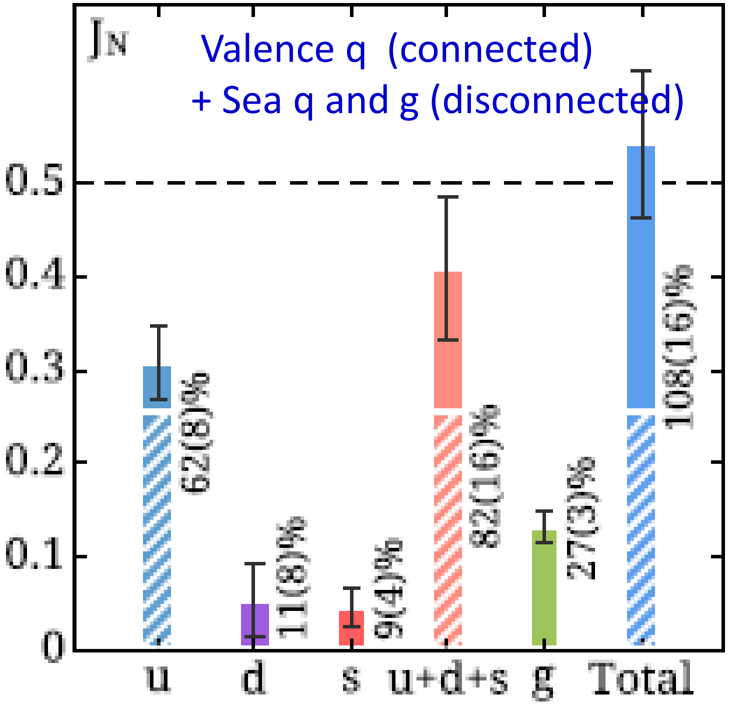


TABLE II: Our results for the intrinsic spin ($\frac{1}{2}\Delta\Sigma$), angular (L) and total (J) momentum contributions to the nucleon spin and to the nucleon momentum $\langle x \rangle$, in the $\overline{\text{MS}}$-scheme at 2 GeV, from up (u), down (d) and strange (s) quarks and from gluons (g), as well as the sum of all contributions (tot.), where the first error is statistical and the second a systematic due to excited states.

	$\frac{1}{2}\Delta\Sigma$	J	L	$\langle x \rangle$
u	0.415(13)(2)	0.308(30)(24)	-0.107(32)(24)	0.453(57)(48)
d	-0.193(8)(3)	0.054(29)(24)	0.247(30)(24)	0.259(57)(47)
s	-0.021(5)(1)	0.046(21)(0)	0.067(21)(1)	0.092(41)(0)
g	-	0.133(11)(14)	-	0.267(22)(27)
tot.	0.201(17)(5)	0.541(62)(49)	0.207(64)(45)	1.07(12)(10)

LATTICE 2017

$\frac{1}{2}\Delta\Sigma = 0.20$

$L^q = 0.21$

$J^g = 0.13$

$J^u = 0.31$ $J^d = 0.05$ $J^s = 0.05$

DVCS with 160 GeV pol. μ^+ & μ^- beams and Transv Pol target

DVCS ⊕ BH

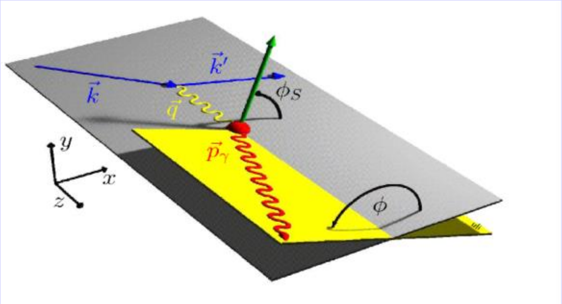
$$\begin{aligned} d\sigma \sim\, & d\sigma^{\mathrm{BH}}_{UU} + e_\ell d\sigma^{\mathrm{I}}_{UU} + d\sigma^{\mathrm{DVCS}}_{UU} \\ & + e_\ell P_\ell d\sigma^{\mathrm{I}}_{LU} + P_\ell d\sigma^{\mathrm{DVCS}}_{LU} \\ & + e_\ell S_L d\sigma^{\mathrm{I}}_{UL} + S_L d\sigma^{\mathrm{DVCS}}_{UL} \\ & + e_\ell \underline{S_\perp d\sigma^{\mathrm{I}}_{UT}} + \underline{S_\perp d\sigma^{\mathrm{DVCS}}_{UT}} \\ + P_\ell S_L d\sigma^{\mathrm{BH}}_{LL} & + e_\ell P_\ell S_L d\sigma^{\mathrm{I}}_{LL} + P_\ell S_L d\sigma^{\mathrm{DVCS}}_{LL} \\ + P_\ell \underline{S_\perp d\sigma^{\mathrm{BH}}_{LT}} & + e_\ell P_\ell \underline{S_\perp d\sigma^{\mathrm{I}}_{LT}} + P_\ell \underline{S_\perp d\sigma^{\mathrm{DVCS}}_{LT}} \end{aligned}$$

Using configurations of the transv. polar. target ↑↓ and positive muon +↓ and negative muon −↑

$$\mathfrak{D}_{CS,T} = (d\sigma_{\uparrow}^{+\downarrow} - d\sigma_{\downarrow}^{+\downarrow}) - (d\sigma_{\uparrow}^{-\uparrow} - d\sigma_{\downarrow}^{-\uparrow}) = \boxed{d\sigma^{I}_{UT}} - d\sigma^{DVCS}_{LT} - d\sigma^{BH}_{LT}$$

$$\mathfrak{S}_{CS,T} = (d\sigma_{\uparrow}^{+\downarrow} - d\sigma_{\downarrow}^{+\downarrow}) + (d\sigma_{\uparrow}^{-\uparrow} - d\sigma_{\downarrow}^{-\uparrow}) = -d\sigma^{I}_{LT} + d\sigma^{DVCS}_{UT}$$

$$\mathfrak{D}_{CS,T} \rightarrow \boxed{d\sigma^{I}_{UT}} \propto -\, t/4m^2\; Im(F_2\mathcal{H} - F_1\mathcal{E})\, \sin(\phi - \phi_S)\cos\phi$$



DVCS with 160 GeV pol. μ^+ & μ^- beams and Transv Pol target

$$\mathcal{S}_{CS,T} \equiv \Delta\sigma_T(\mu^{+\downarrow}) + \Delta\sigma_T(\mu^{-\uparrow})$$

$$\rightarrow (-\,\mathrm{Re}\mathcal{E}\;\mathrm{Im}\mathcal{H} + \mathrm{Im}\mathcal{E}\;\mathrm{Re}\mathcal{H}\,)\sin(\phi-\phi_s)$$

$$\mathcal{A}_{\mathcal{S}}^{\sin(\phi-\phi_s)}$$

From Pawel Sznajder
Using the PARTONS code
Formalism at LO

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╍╍╍╍╍╍ Idem with GPDs E = 0

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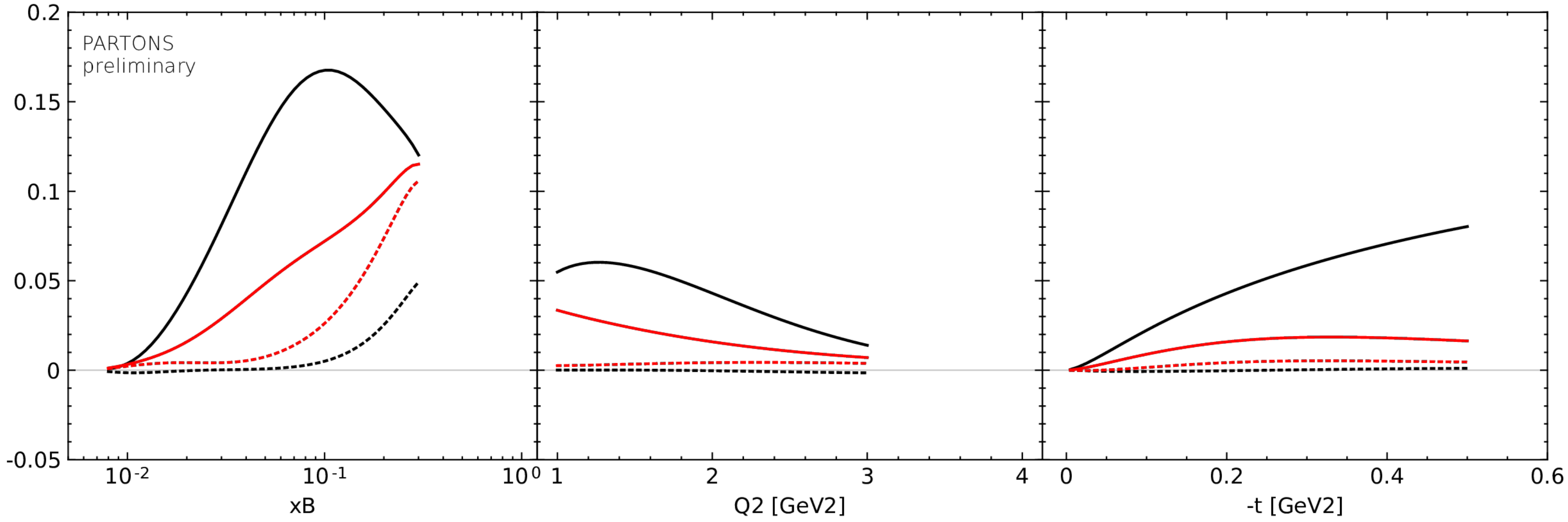
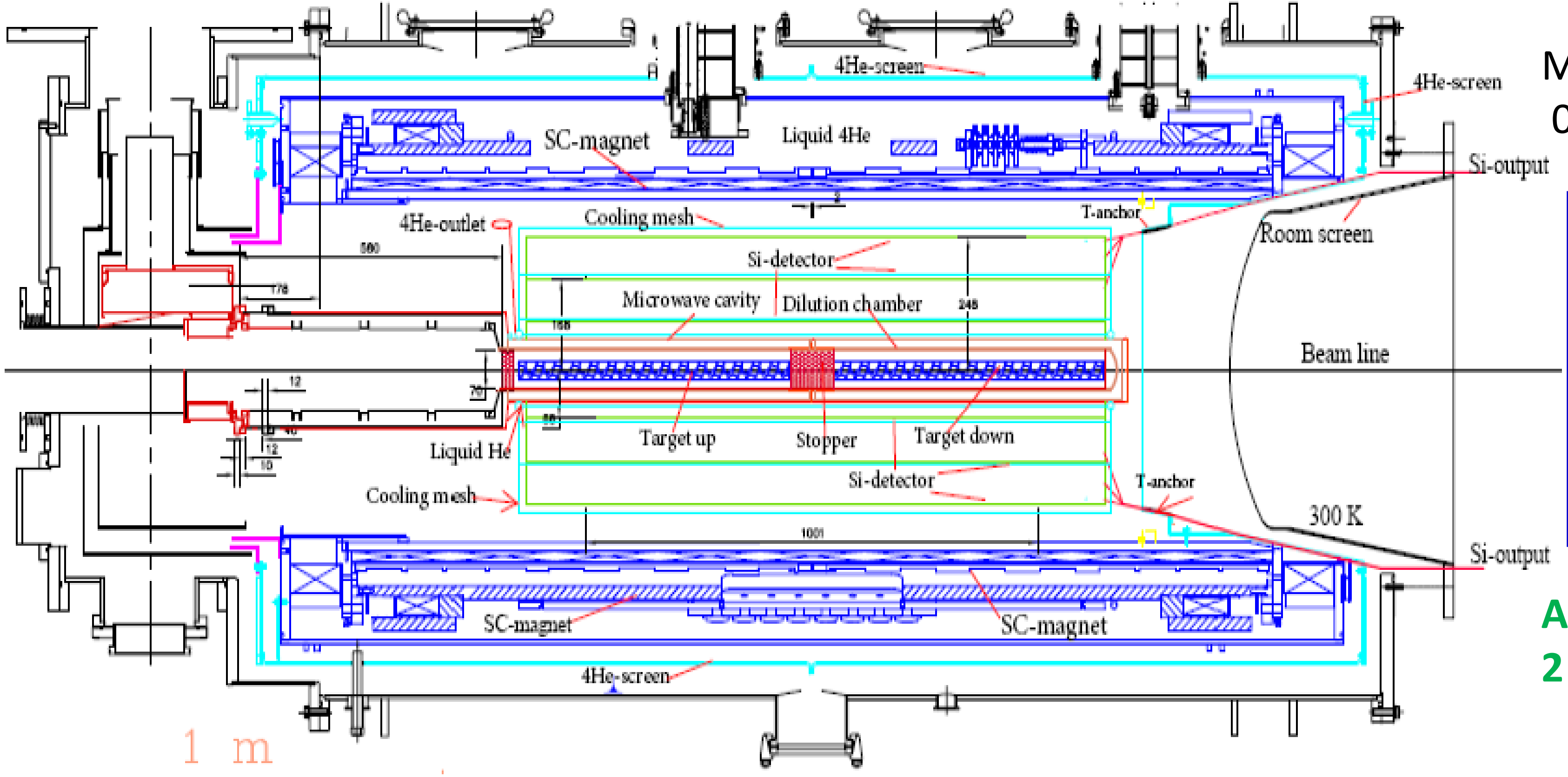


A proposed solution

The target can be adapted to include a recoil proton detector *between* the target surrounded by the modified MW cavity *and* the polarizing magnet



Modified MW as thin as possible
0.2 – 0.6mm thick copper foil

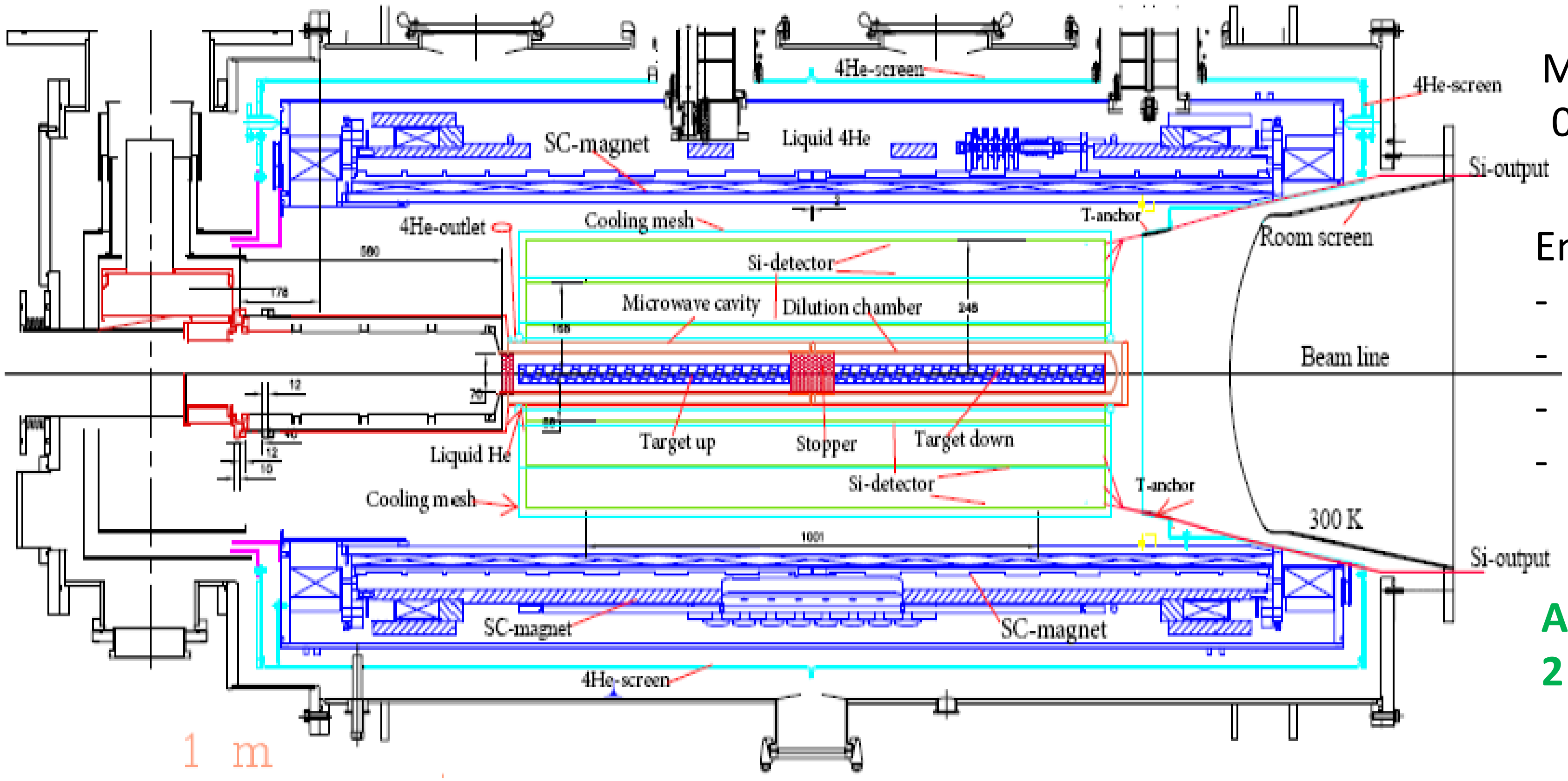
NH3 target	r = 20mm
Dilution Chamber	r = 35mm
MW cavity	r = 50mm
1st cylindrical SI det	r = 85 mm
2nd cylindrical SI det	r = 165 mm
3rd cylindrical SI det	r = 245 mm

About 180mm are left to include 2 or 3 cylindrical layers of Silicon detectors

No possibility for ToF ➔ PID of protons/pions with dE/dx
momentum (as low as possible) and coordinates (as for HERMES)

A proposed solution

The target can be adapted to include a recoil proton detector *between* the target surrounded by the modified MW cavity *and* the polarizing magnet



Modified MW as thin as possible
0.2 – 0.6mm thick copper foil

Environment:

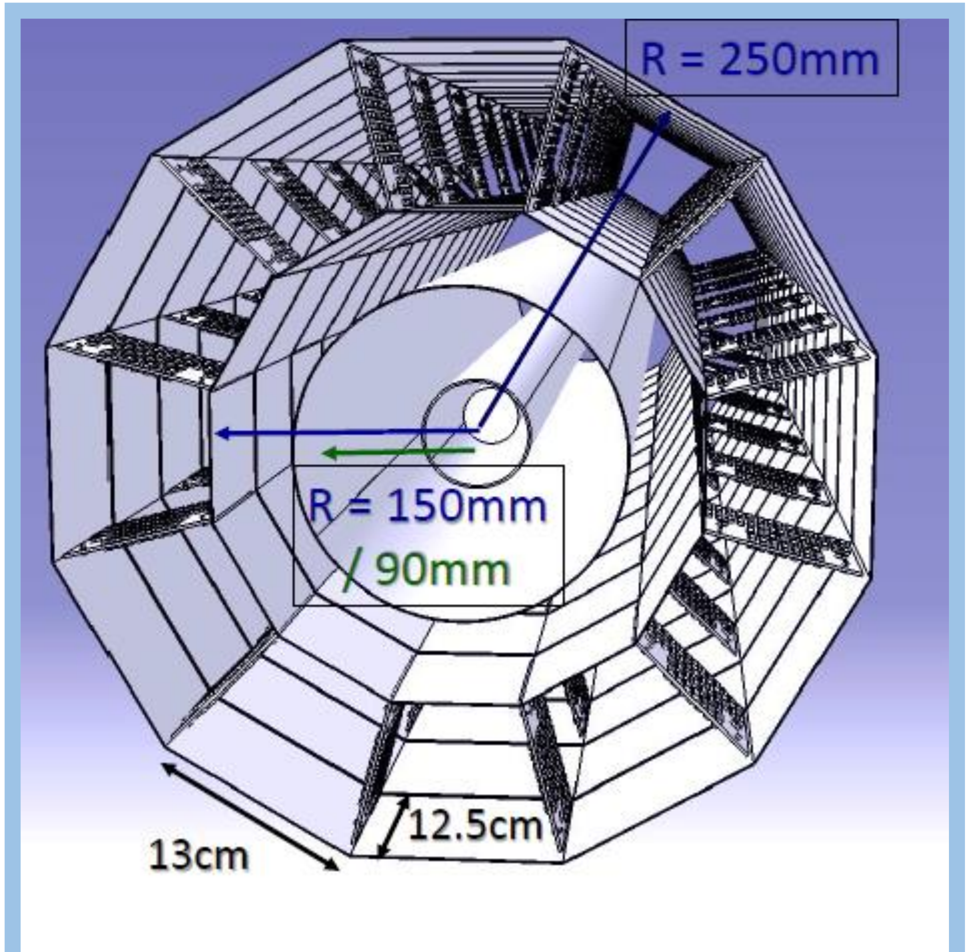
- Magnetic field (long and transv) 0.5-2T
- Presence of MW field temporary
- A low temperature 5-10K
- A vacuum of about 10^{-6} mm Hg

About 180mm are left to include 2 or 3 cylindrical layers of Silicon detectors

An important Issue: operation of SI and evacuation of the heat of the read out electronics

Here the circulating flow of He4 cooling the MW cavity cools also a mesh surrounding the SI detectors

A Very First Sketch (studied in MC1)



About 300 modules read by APV25 chips

MW cavity	r = 90mm	
1st inner SI det	r = 150 mm	(thickness=300µm)
2nd outer SI det	r = 250 mm	(thickness=1000µm)

About 300 modules read by APV25 chips

Si strip pitch size for optimum position resolution about 1.3cm (inner) and 2.2cm (outer) (for $\Delta\phi=5°$)
× 1 cm (for $\Delta z=3mm$)

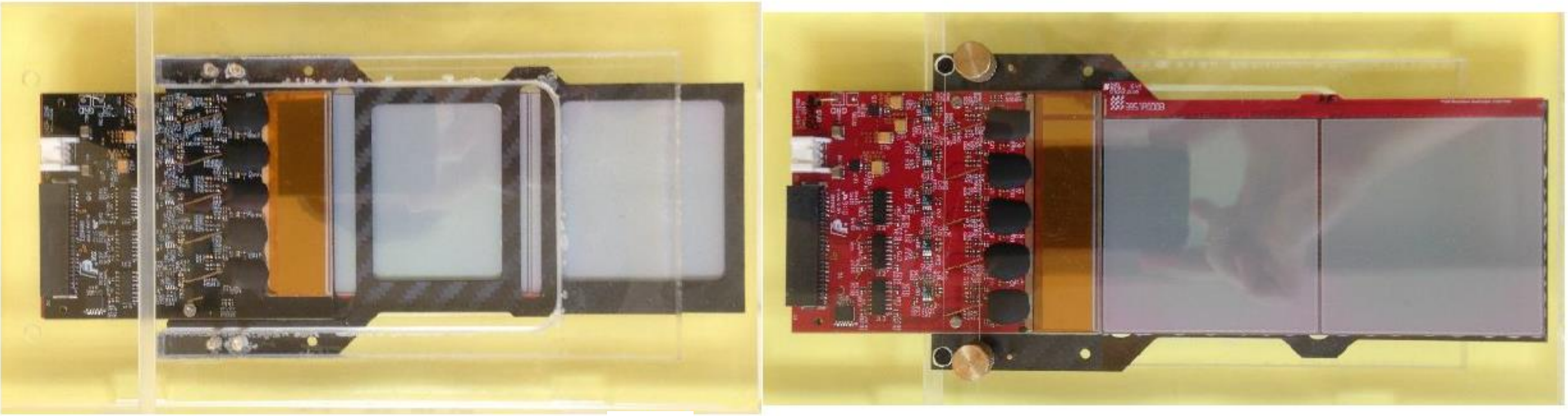
resolution improved by about a factor 3 compared to the present CAMERA

➔ less than 10 000 channels

Thermal load

very first estimate ~ 10 Watts

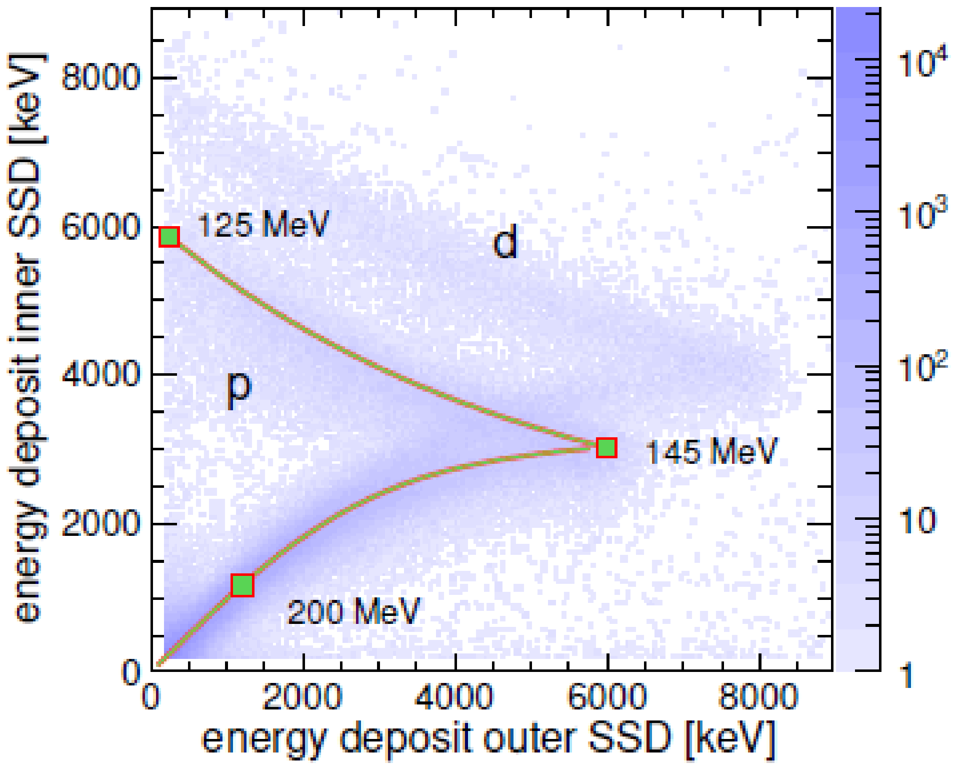
A technology developed at JINR for NICA



The Silicon detector unit developed for BM@N (*Baryonic Matter at Nuclotron)* experiment at NICA. The unit contains electronics for 640 strips. The front-end electronics is based on a charge sensitive preamplifier chip VATAGP7 (IDEAS)

Long flat aluminium-polyimide multilayer flexible buses (thickness < 50 µm)
Technology in Ukraine (microcable production and micro electronics assembly) used in numerous experiments

Particle Identification

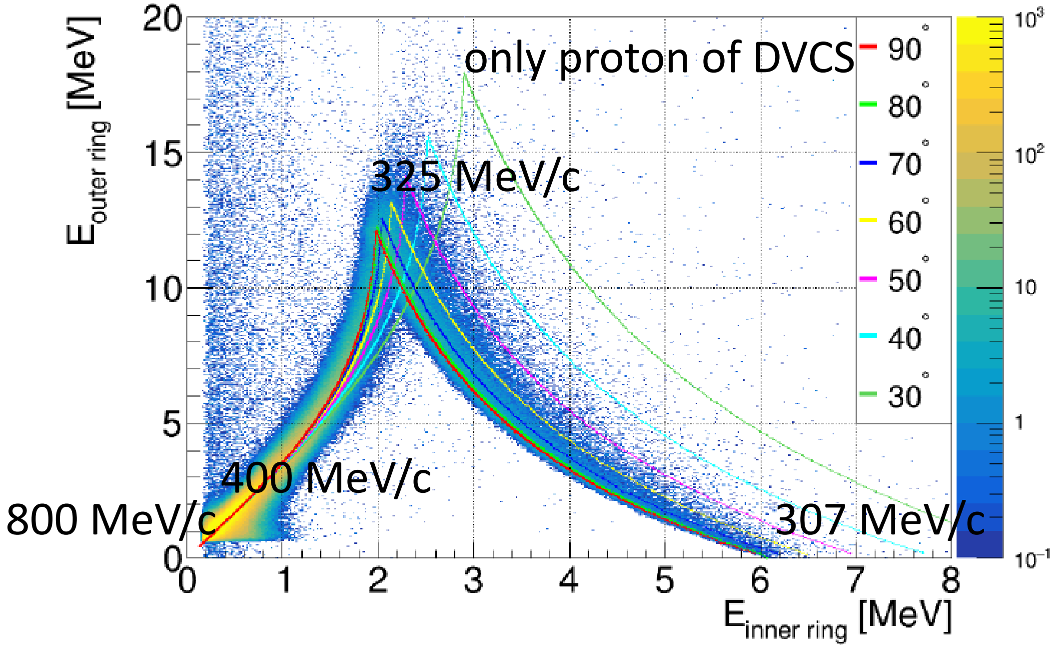


HERMES Recoil Detector
arXiv:1302.6092
JINST (2013)

Momentum Reconstruction Method

TGEANT

Colored lines: Mean energy loss calculations for different θ angles

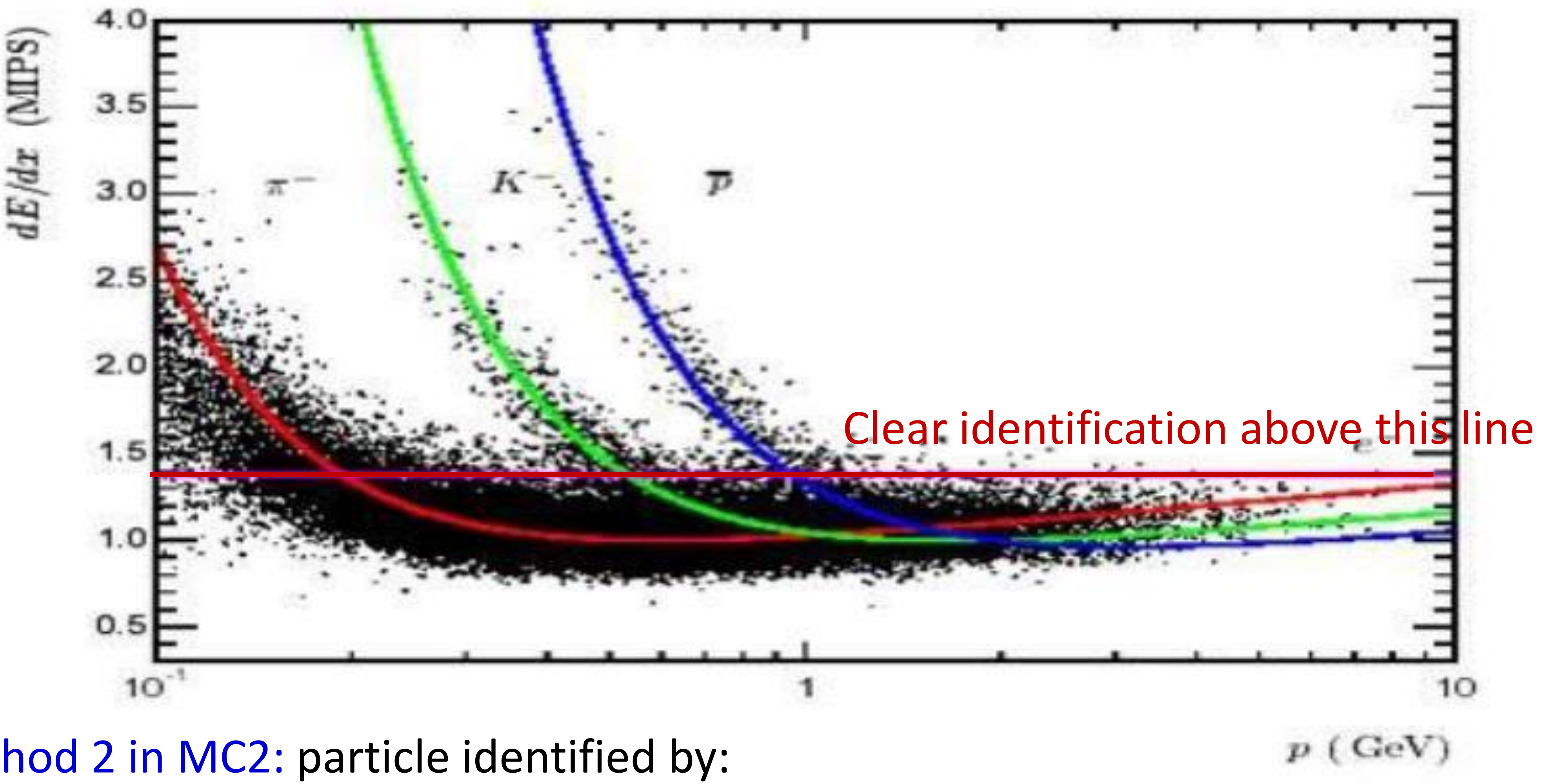


Method 1 in MC1 :

the momentum is determined by the

- dE/dx in the inner and outer rings
- and θ angle

Particle Identification



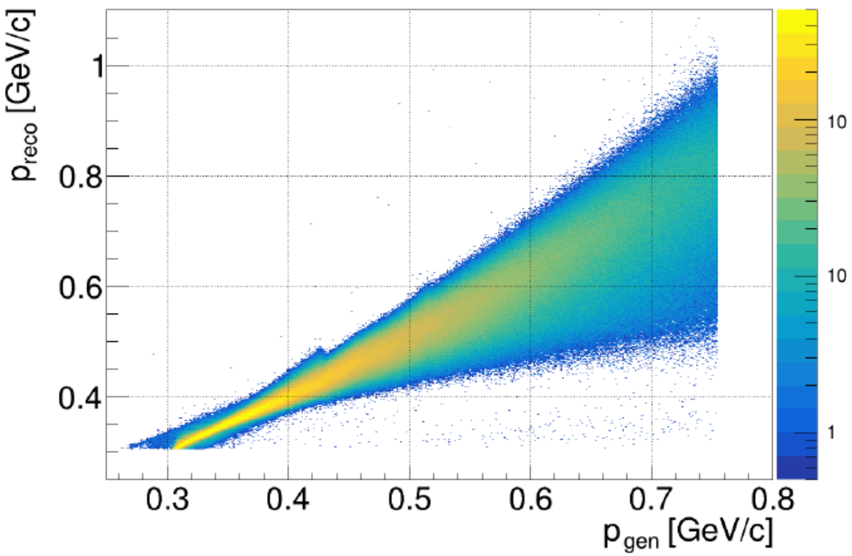
Clear identification above this line

Method 2 in MC2: particle identified by:

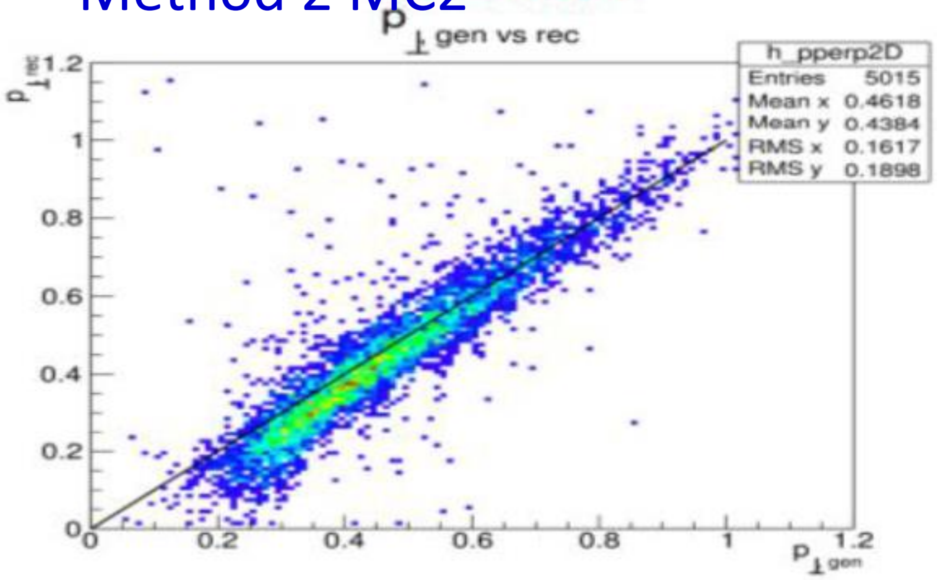
- the momentum measured in the magnetic field (with 3 geometrical points in the 3 SI layers)
- and dE/dx in one layer

Proton Momentum resolution

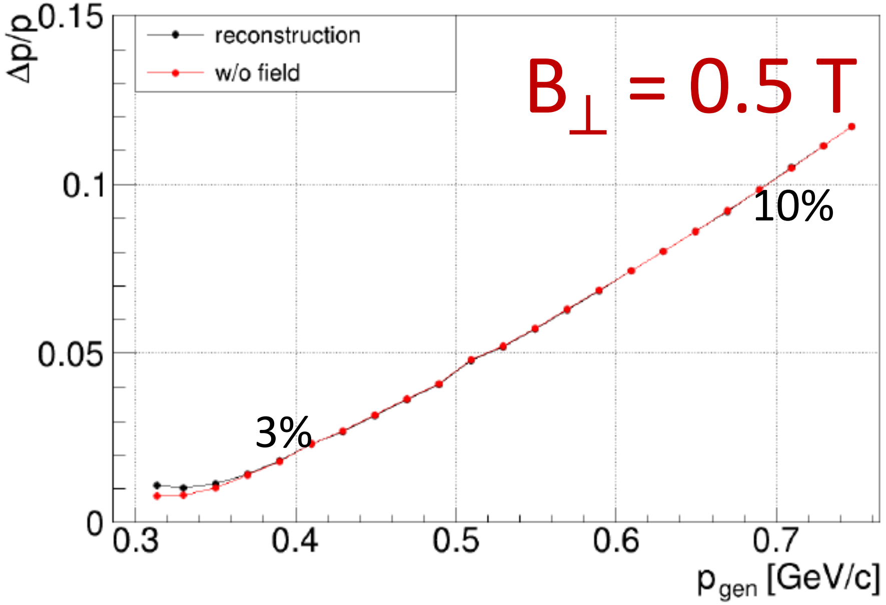
Method 1 MC1



Method 2 MC2



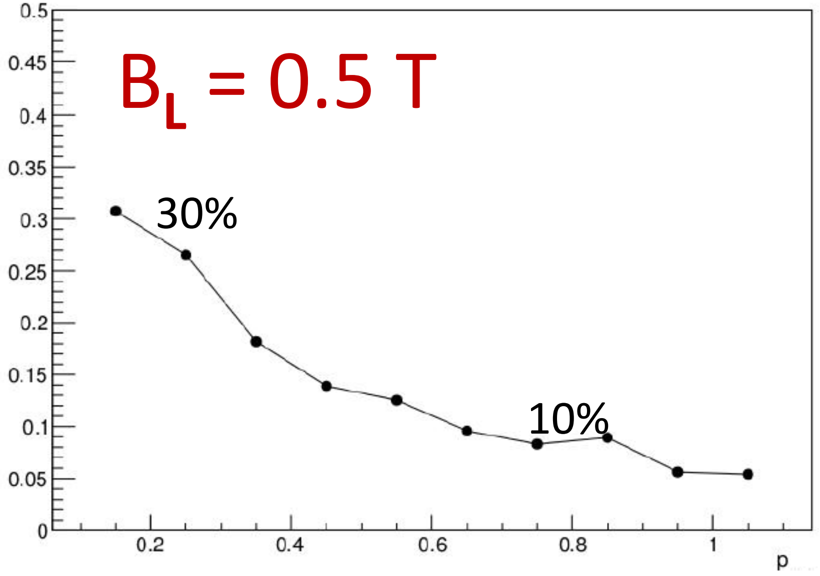
HERMES Recoil Detector
arXiv:1302.6092
JINST (2013)



$B_{\perp} = 0.5$ T

10%

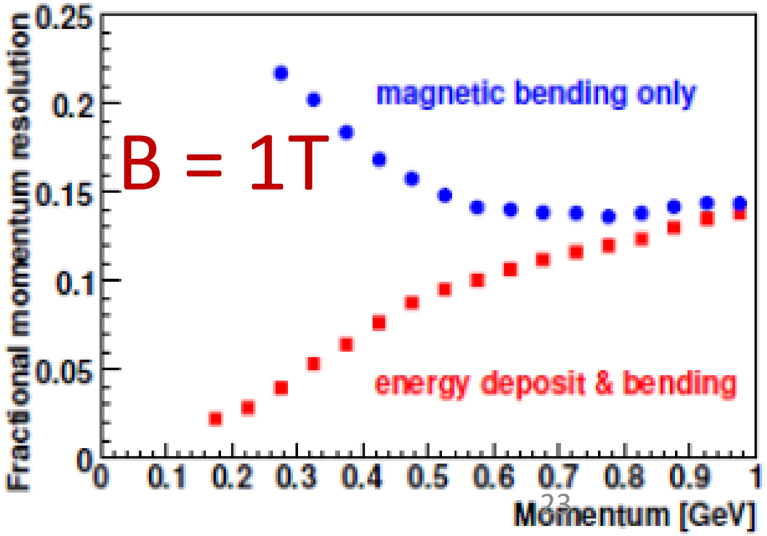
3%



$B_L = 0.5$ T

30%

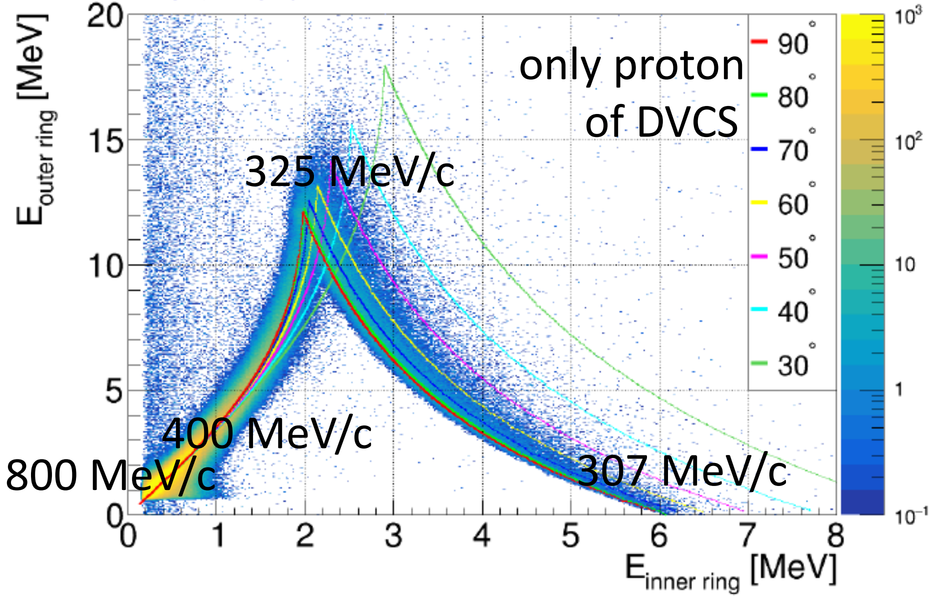
10%



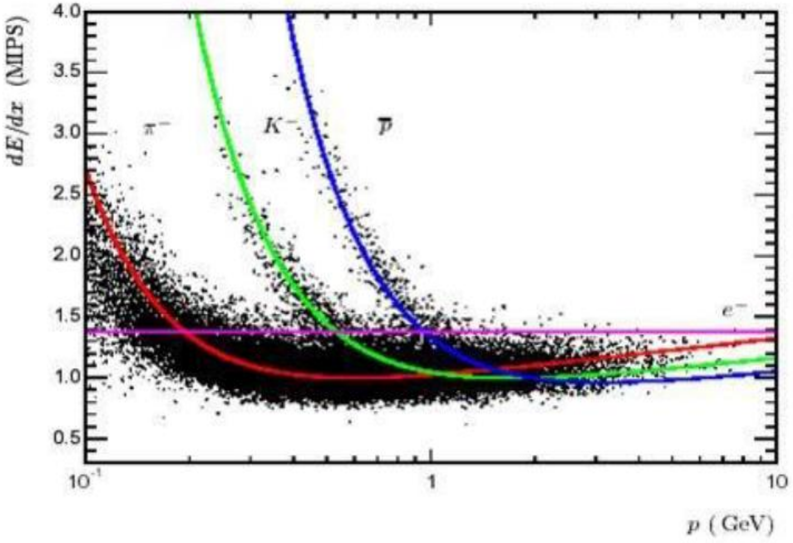
B = 1T

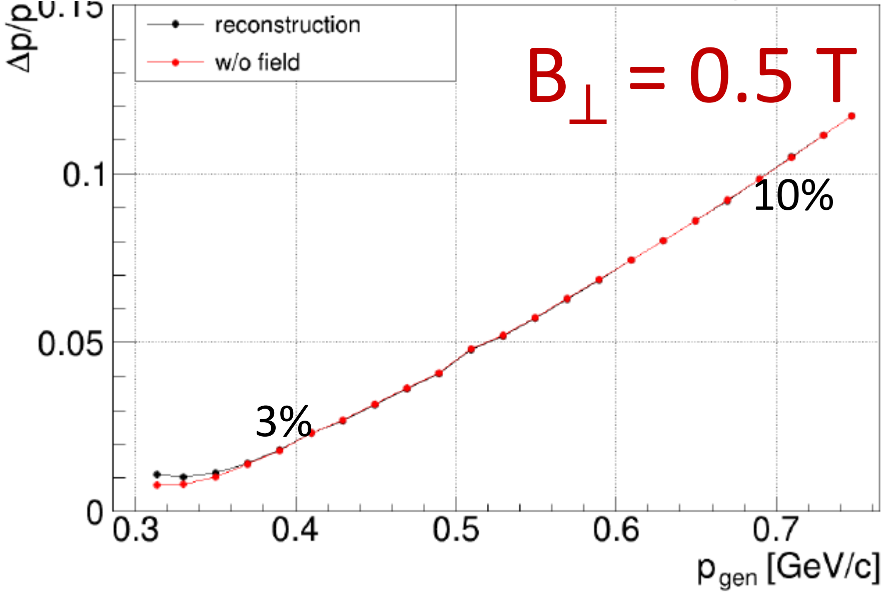
Proton Momentum resolution

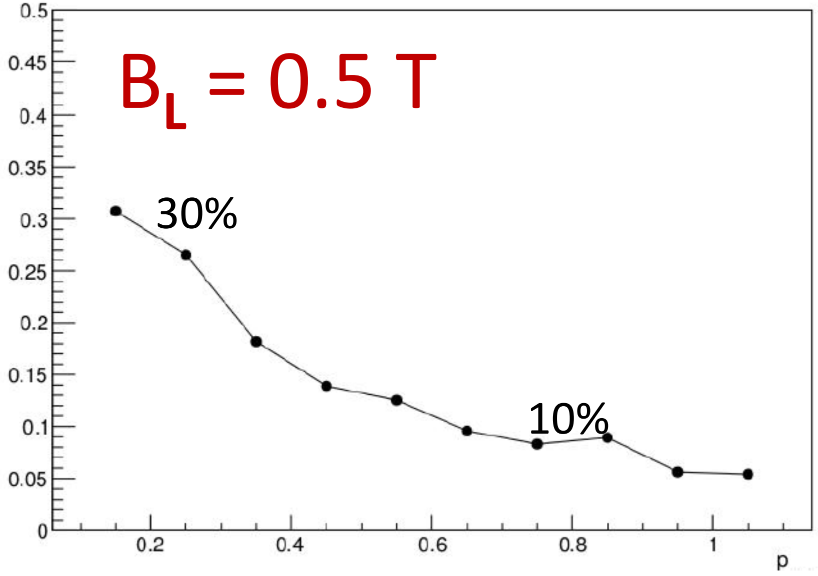
Method 1 MC1



Method 2 MC2







Method 1:

- supposes only proton
- good for low momentum
- good for small magnetic field

Method 2:

- can separate proton from kaon and pion
- can measure higher momentum

➔ combined method