DVCS AT COMPASS
SHORT FUTURE WITH TRANSV. POLAR. TARGET

Nicole d'Hose – CEA Saclay
on behalf of the COMPASS Collaboration

Goal of a GPD E measurement

- GPD E and AOM
- Competition in the world: JLab12 (neutron and transv. polar. targets), RHIC, EIC
- Predictions using a transversely polarized target at COMPASS

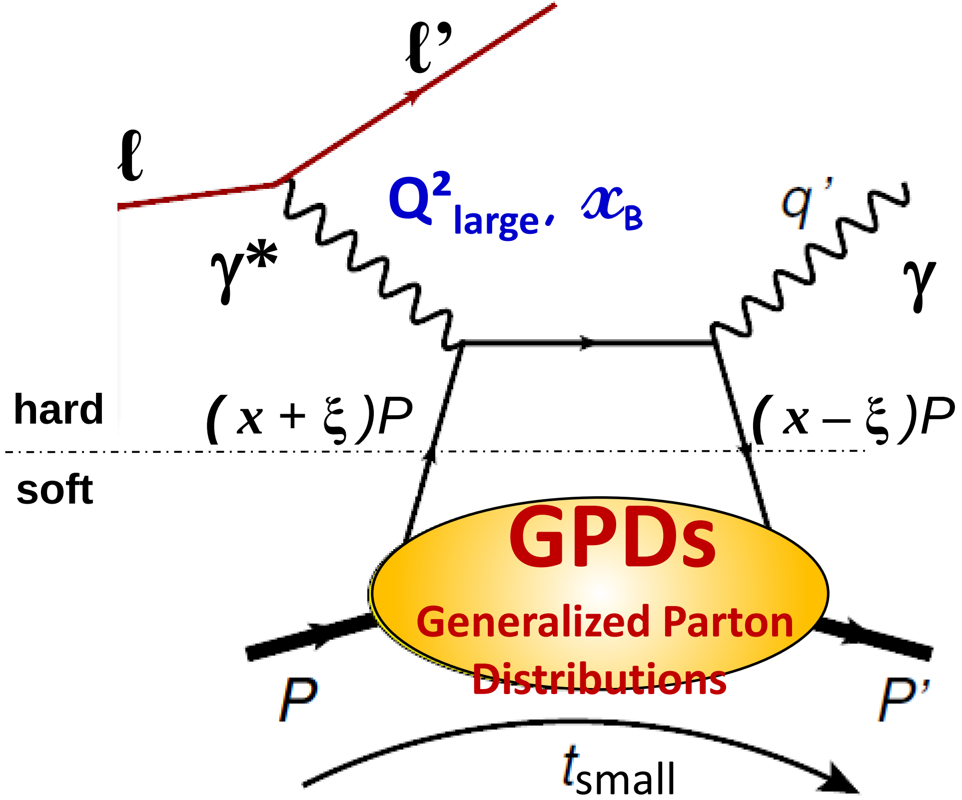
Possible realisation at COMPASS

Work in progress - Tentative summary of all the studies done so far

- Solution with Silicon recoil detector and Transv. Polar. Target
- MC studies with TGeant

Deeply virtual Compton scattering (DVCS)

D. Mueller *et al*, Fortsch. Phys. 42 (1994)
X.D. Ji, PRL 78 (1997), PRD 55 (1997)
A. V. Radyushkin, PLB 385 (1996), PRD 56 (1997)



DVCS: **ℓp→ ℓ' p' γ**
the golden channel
because it interferes with
the Bethe-Heitler process

also meson production
ℓp→ ℓ' p' π, ρ or **ϕ** or **J/ψ...**

The GPDs depend on the following variables:

x: average long. momentum

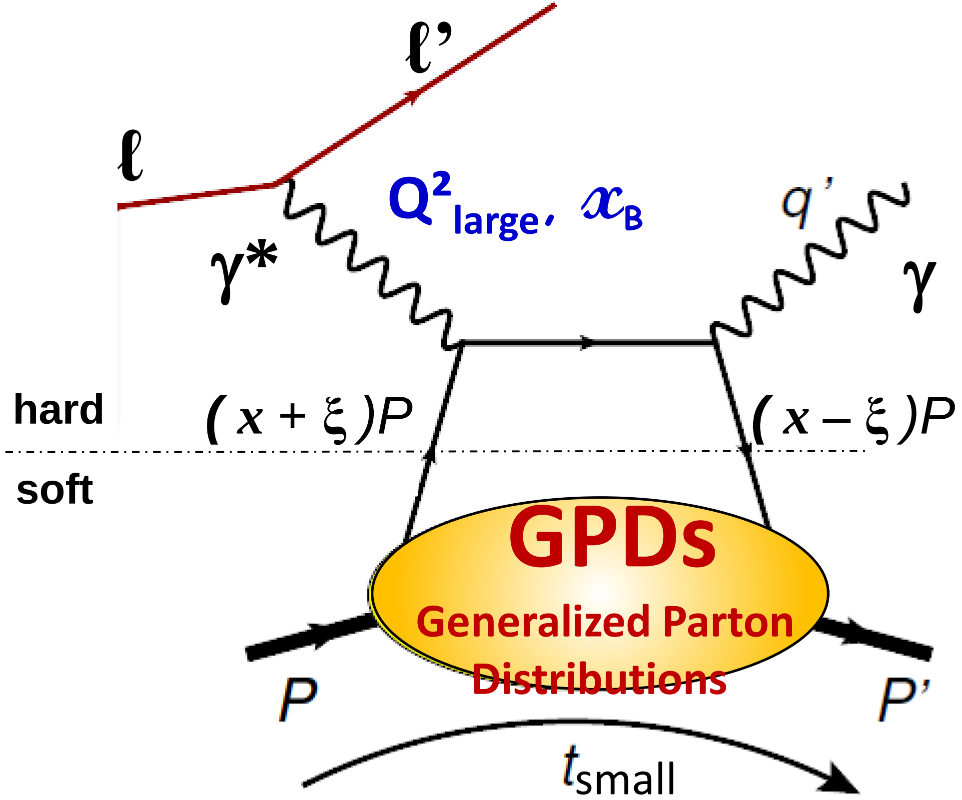
ξ: long. mom. difference $\simeq x_B/(2 - x_B)$

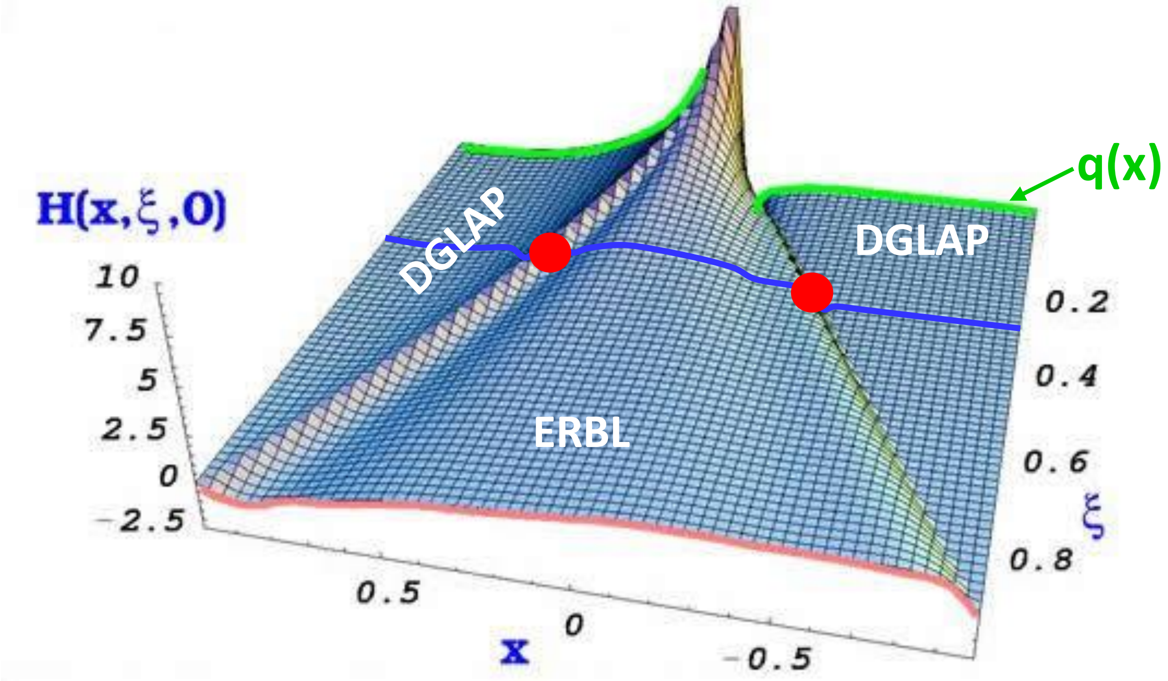
t: four-momentum transfer
related to $b_\perp$ via Fourier transform

The variables measured in the experiment:

E_ℓ, Q^2, $x_B \sim 2\xi/(1+\xi)$,
t (or $\theta_{\gamma^*\gamma}$) and ϕ

Deeply virtual Compton scattering (DVCS)





From Goeke, Polyakov, Vanderhaeghen, PPNP47 (2001)

The amplitude DVCS at LT & LO in α_s:

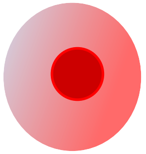
Real part Imaginary part

$$\mathcal{H} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\pi H(x=\pm\xi,\xi,t)$$

t, ξ fixed

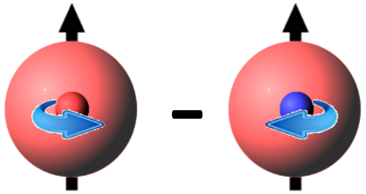
The GPD E is the grail for OAM quest

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



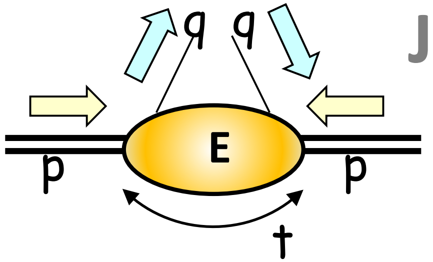
"Elusive"

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



Sivers: quark k_T & nucleon transv. Spin

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

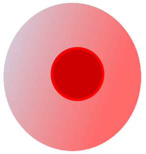


Ji sum rule: PRL78 (1997) cited 1504 times

Relation to OAM

The GPD E is the grail for OAM quest

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



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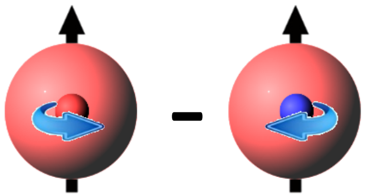


Sivers: quark k_T & nucleon transv. Spin

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

$$\tfrac{1}{2} = J^q + J^g = \tfrac{1}{2}\Delta\Sigma + L^q + J^g$$

Ji PRL78 (1997)

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

Jaffe and Manohar NPB337 (1990)

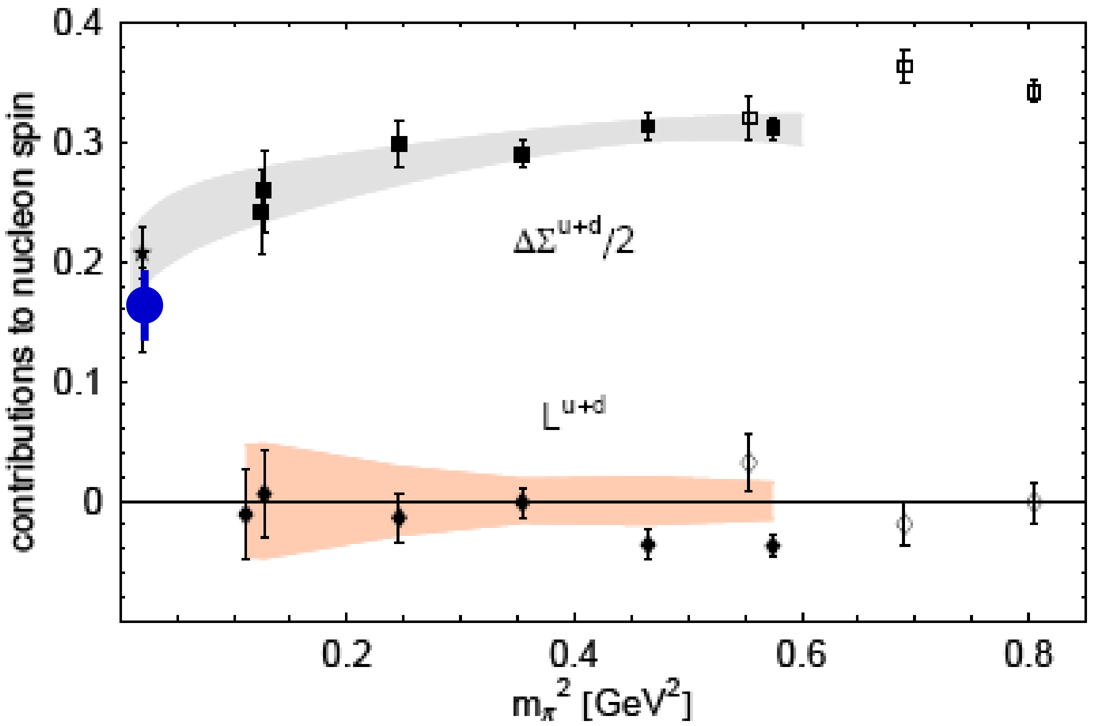
$\tfrac{1}{2}\Delta\Sigma \sim 0.15$ well know from DIS/SIDIS

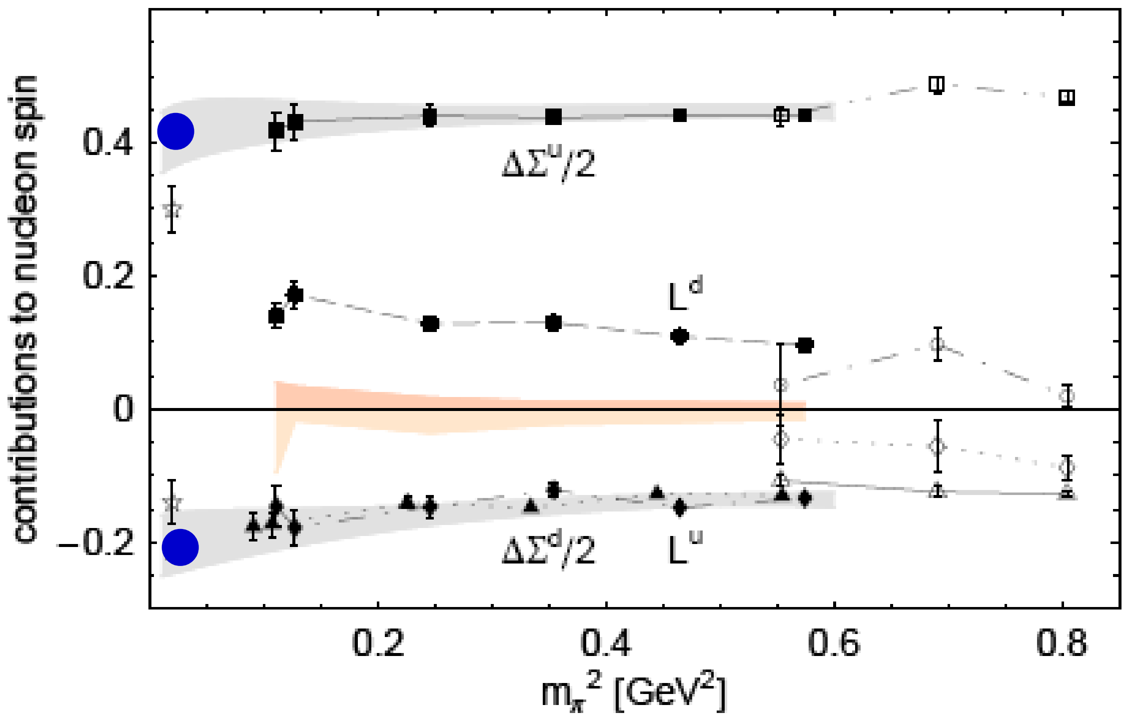
$\Delta G \sim 0.2$ known from SIDIS/pp

L and $\mathcal{L}$ unknown

Predictions in Lattice

Hägler et al., hep-lat 0705.4295, Phys.Rev.D77:094502,2008 (disconnected contributions not included)





COMPASS results:

$\Delta\Sigma$: 0.26 to 0.36

Δu: 0.82 to 0.85

Δd: -0.45 to -0.42

Δs: -0.11 to -0.08

$J^u = \Delta\Sigma^u/2 + \mathbf{L}^u \sim 0.2$

$J^d = \Delta\Sigma^d/2 + \mathbf{L}^d \sim 0$

What has been done so far ?

2007: $\vec{\ell}\, d \rightarrow \ell\, n\, \gamma\, (p)$ Jlab 6 GeV

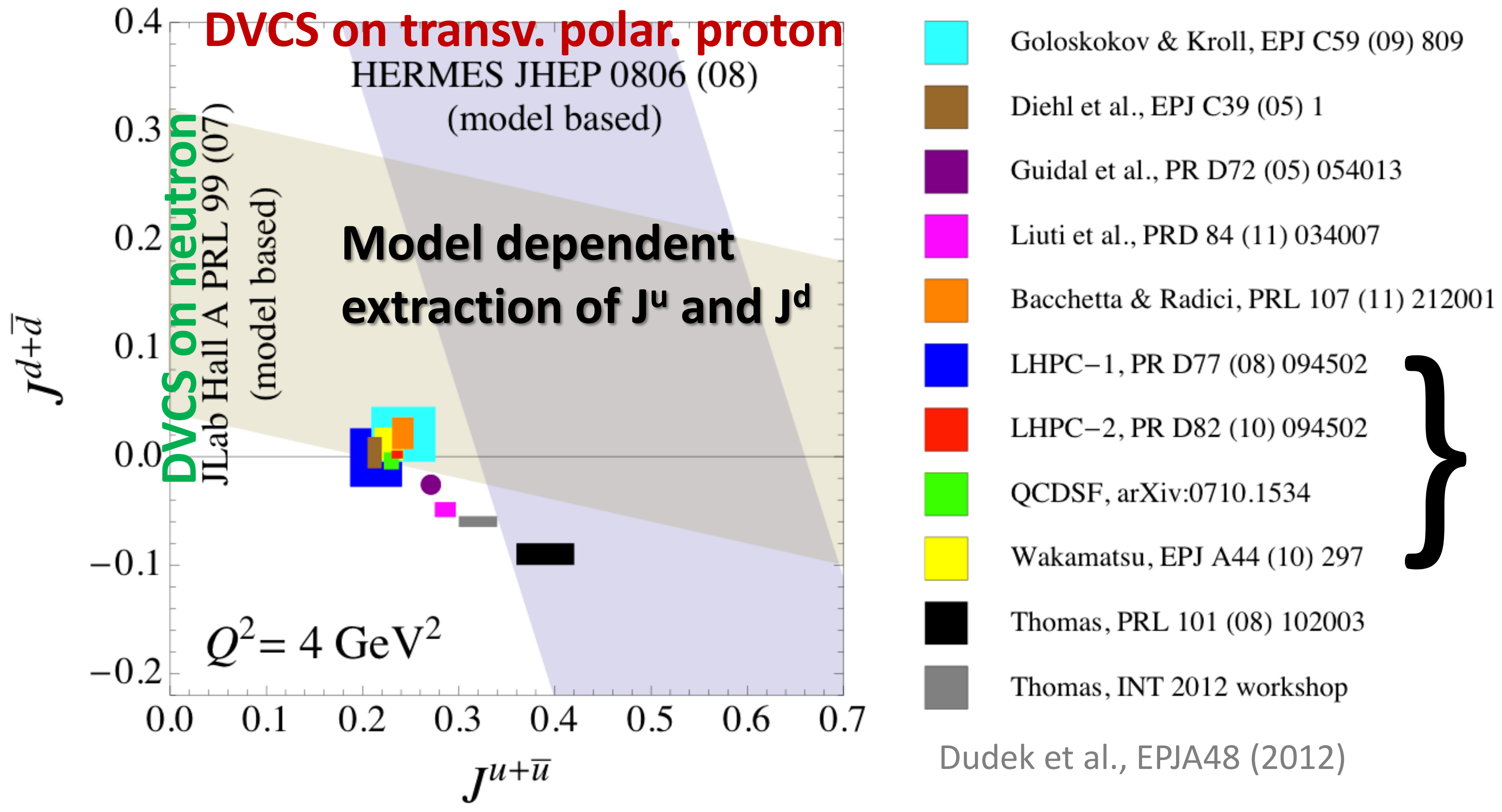
$$\Delta\sigma_{LU}^{\sin\phi} = Im\,(F_{1n}\mathcal{H} + \xi(F_{1n}+F_{2n})\widetilde{\mathcal{H}} + t/4m^2\, F_{2n}\mathcal{E})$$

analysis still on going for another experiment done in 2010

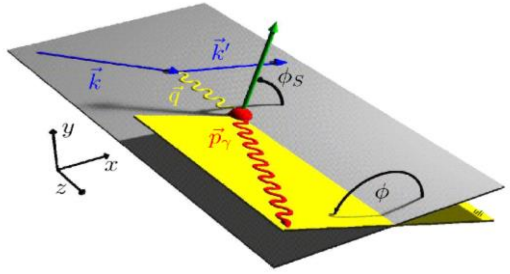
2008: $\vec{\ell}\, p^{\uparrow} \rightarrow \ell\, p\, \gamma$ HERMES

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

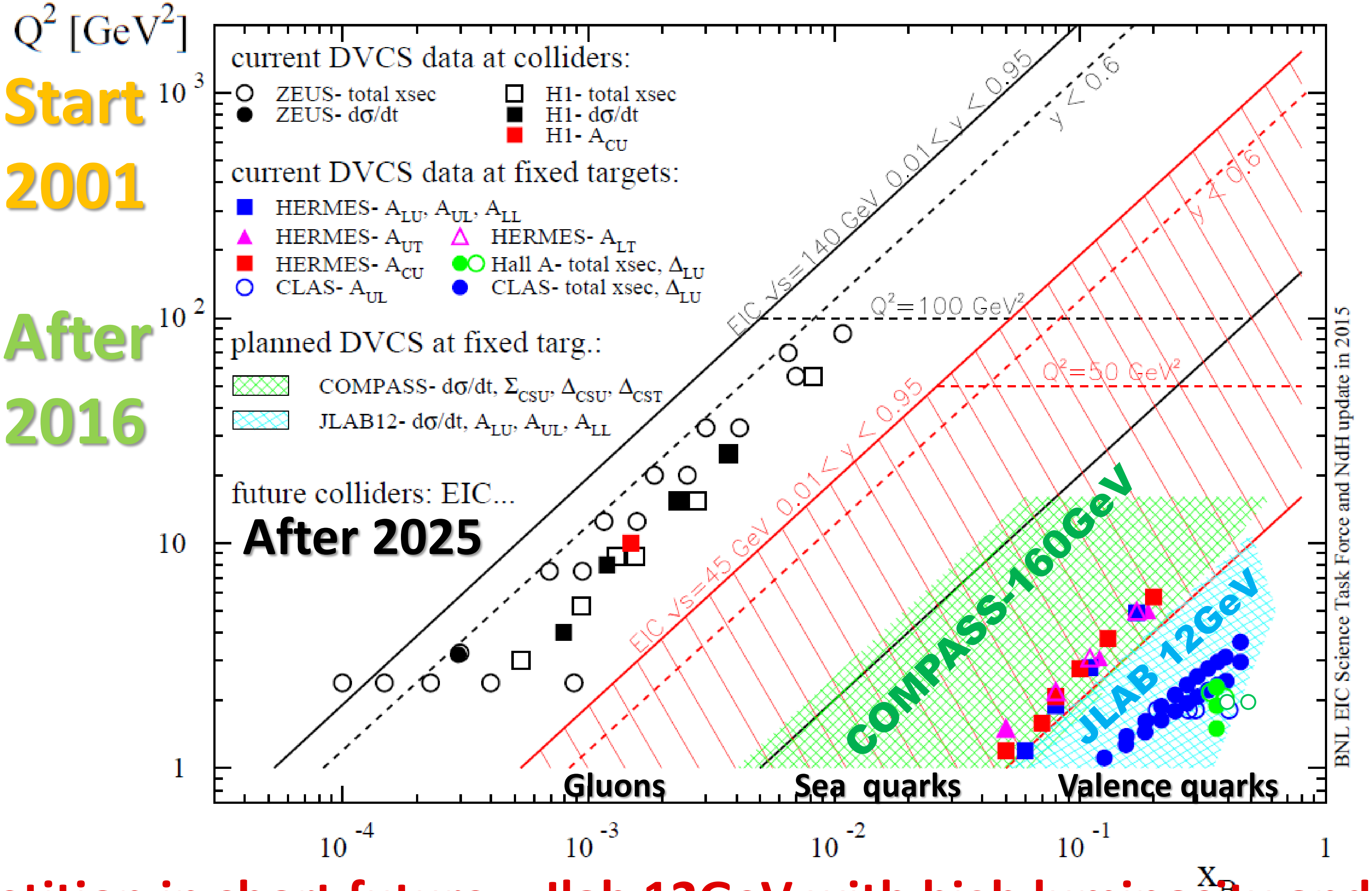
$$\Delta\sigma_{LT}^{\sin(\phi-\phi s)\cos\phi} = -\,t/4m^2\; Re\,(F_{2p}\mathcal{H} - F_{1p}\mathcal{E})$$



Dudek et al., EPJA48 (2012)

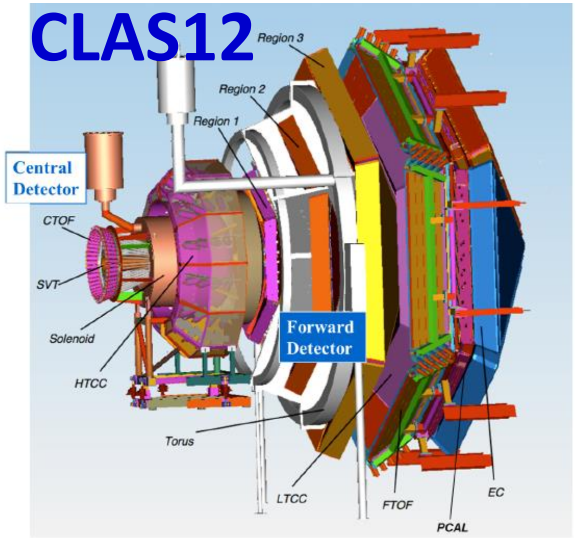


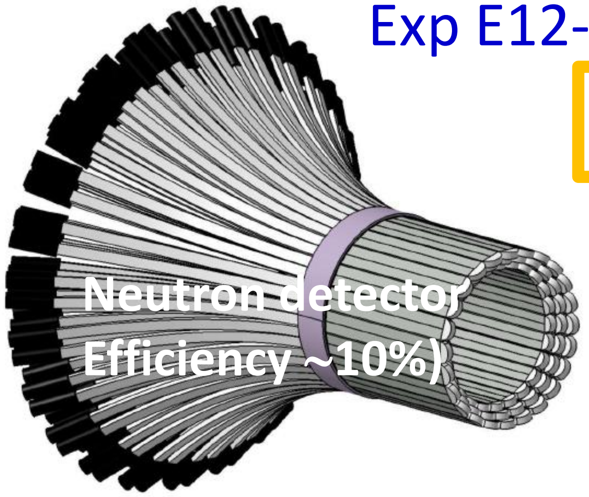
The past and future DVCS experiments



Competition in short future: Jlab 12GeV with high luminosity and RHIC

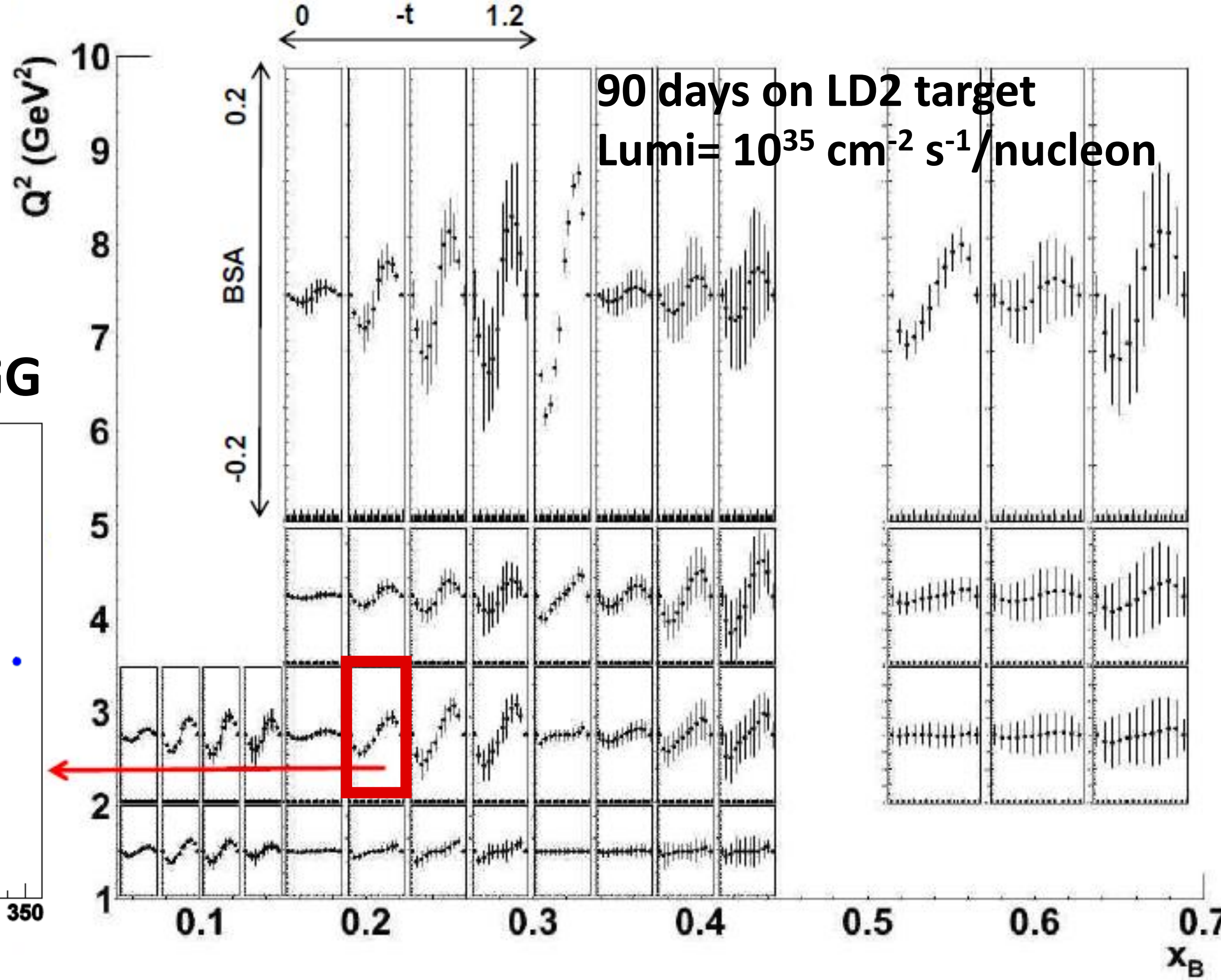
Competition at Jlab 11 GeV





Exp E12-11-003: DVCS on the neutron with CLAS12 at 11 GeV

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



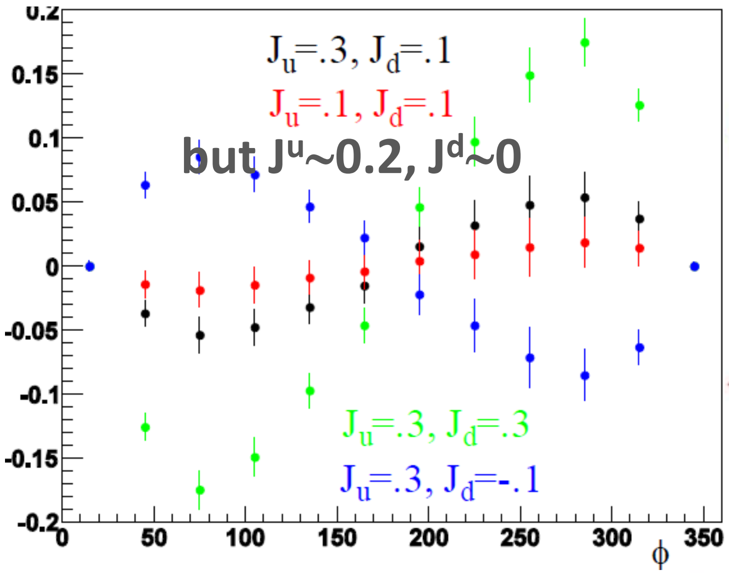
Flavor separation with proton and neutron

$Hu=9/15(4Hp-Hn)$

$Hd=9/15(4Hn-Hp)$

This experiment should be done in 2019

Model prediction using VGG



Competition at Jlab 11 GeV

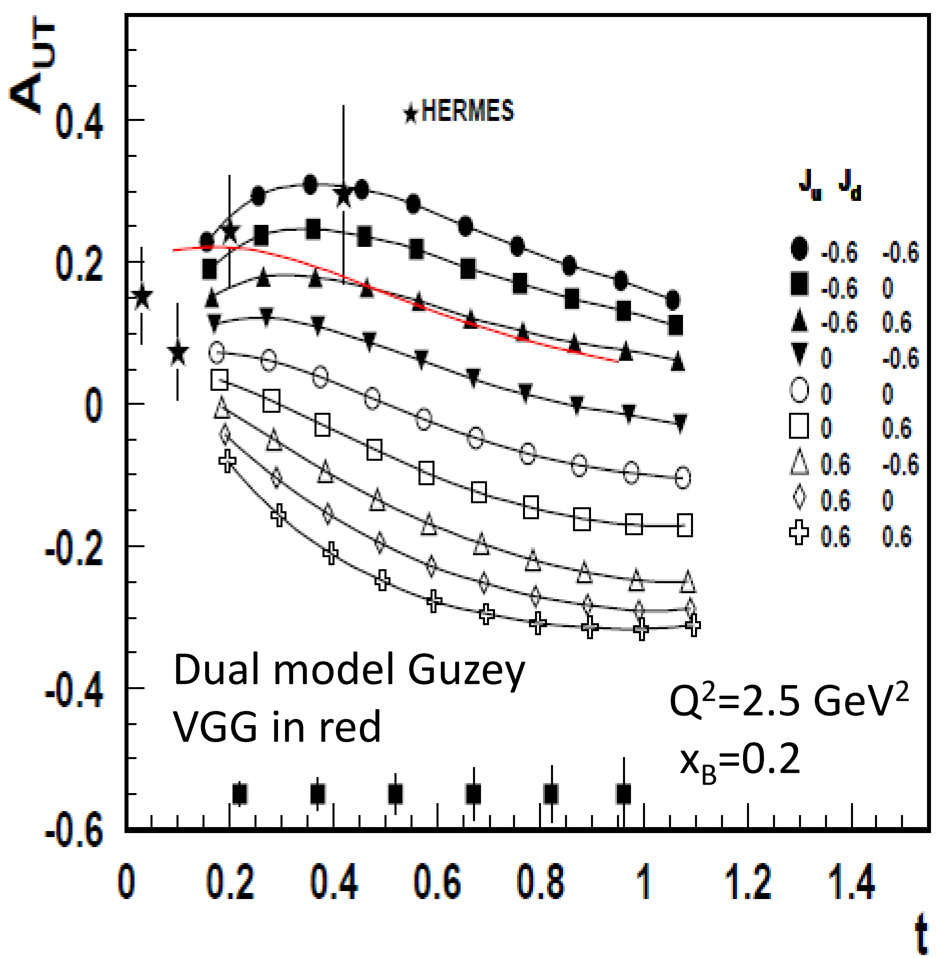
Exp E12-12-010: DVCS on a transversely polarized HD-Ice target

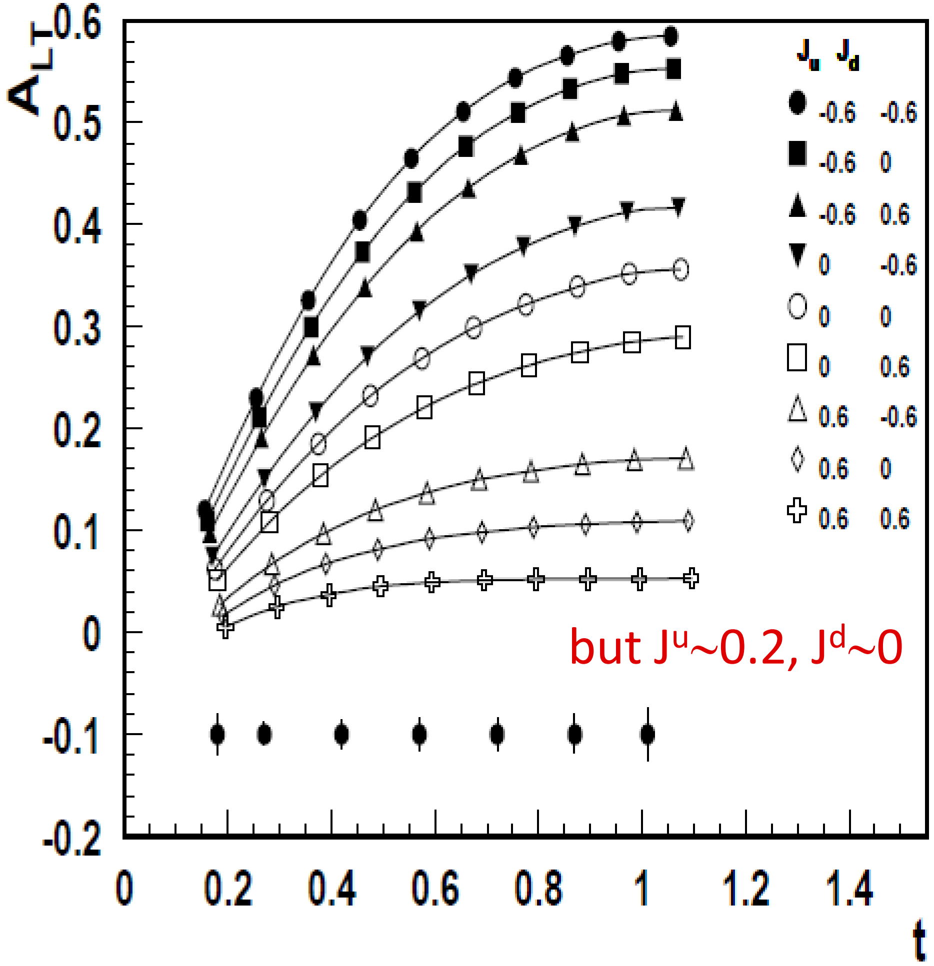
$$\Delta\sigma_{UT}^{\sin(\phi-\phi_s)\cos\phi} = -\,t/4m^2\ \mathbf{Im}\,(F_{2p}\,\mathcal{H} - F_{1p}\,\mathcal{E})$$
$$\Delta\sigma_{LT}^{\sin(\phi-\phi_s)\cos\phi} = -\,t/4m^2\ \mathbf{Re}\,(F_{2p}\,\mathcal{H} - F_{1p}\,\mathcal{E})$$

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

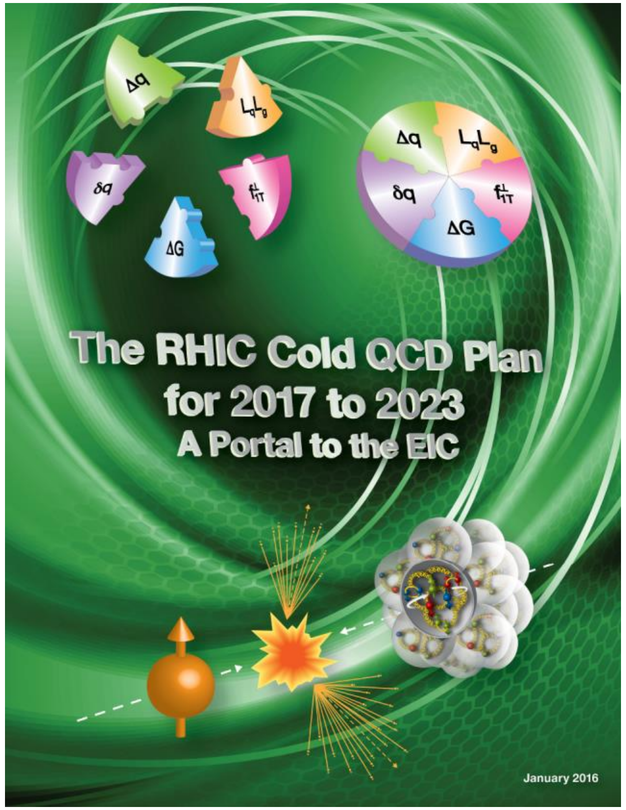
Pol H = 60%
Pol D = 35%

This experiment should start end of 2019





Competition at RHIC in 2017 and 2023



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

COMPASS with Transv. Pol. Target to constrain the GPD E

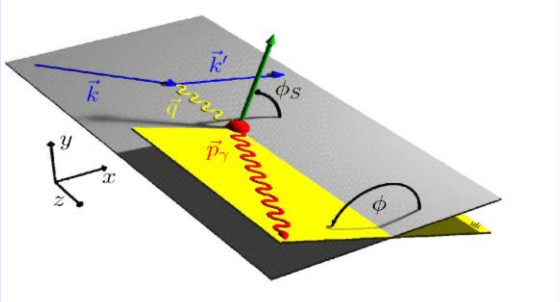
$$\begin{aligned} d\sigma \sim\; & d\sigma^{\mathrm{BH}}_{UU} + e_\ell d\sigma^{\mathrm{I}}_{UU} + d\sigma^{\mathrm{DVCS}}_{UU} \\ & + e_\ell P_\ell d\sigma^{\mathrm{I}}_{LU} + P_\ell d\sigma^{\mathrm{DVCS}}_{LU} \\ & + e_\ell S_L d\sigma^{\mathrm{I}}_{UL} + S_L d\sigma^{\mathrm{DVCS}}_{UL} \\ & + e_\ell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

Using configurations of the transv. polar. target $\uparrow\downarrow$ and positive muon $+\downarrow$ and negative muon $-\uparrow$

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

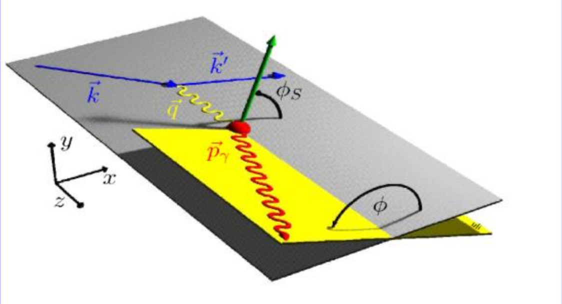
$$\mathcal{S}_{CS,T} = (d\sigma_{\uparrow}^{+\downarrow} - d\sigma_{\downarrow}^{+\downarrow}) + (d\sigma_{\uparrow}^{-\uparrow} - d\sigma_{\downarrow}^{-\uparrow}) = -d\sigma^{I}_{LT} + d\sigma^{DVCS}_{UT}$$

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

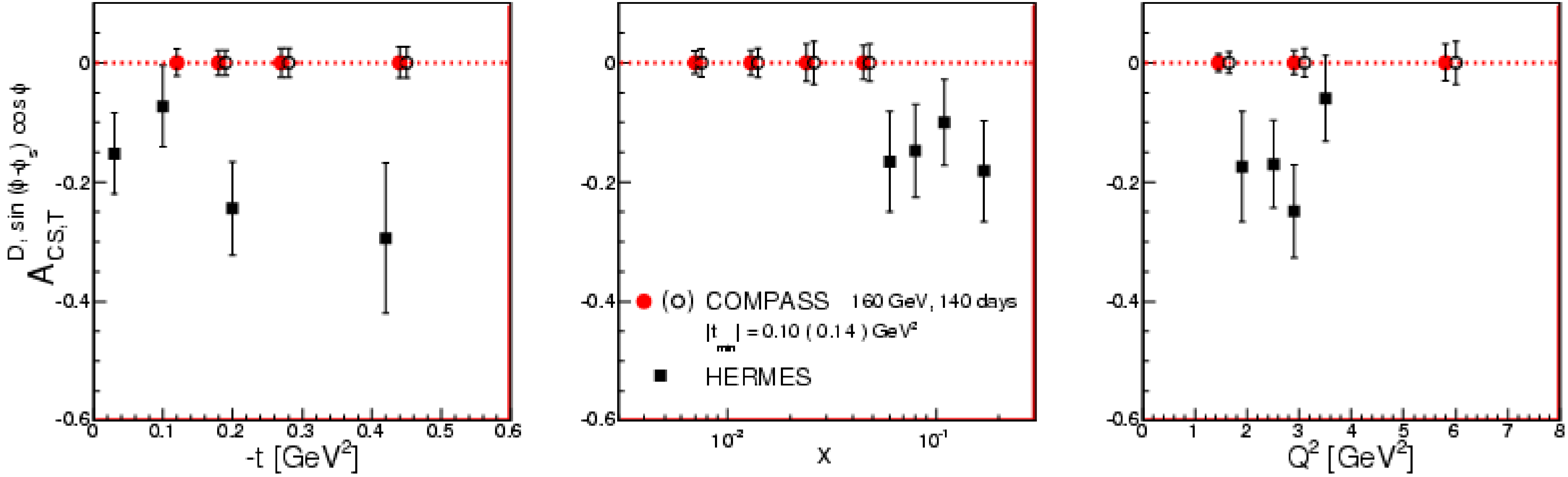


COMPASS with Transv. Pol. Target to constrain the GPD E

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



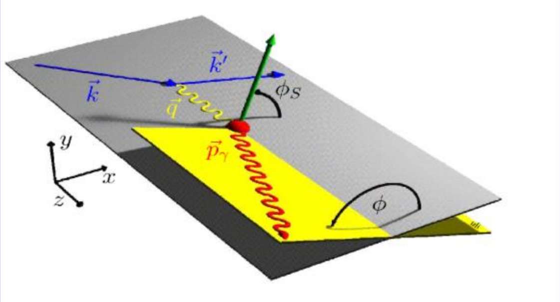
2 years of data 160 GeV muon beam + 1.2 m polarised NH_3 target + ε_{global} = 10% **Lumi= 5 x 10^{32} cm^{-2} s^{-1}**



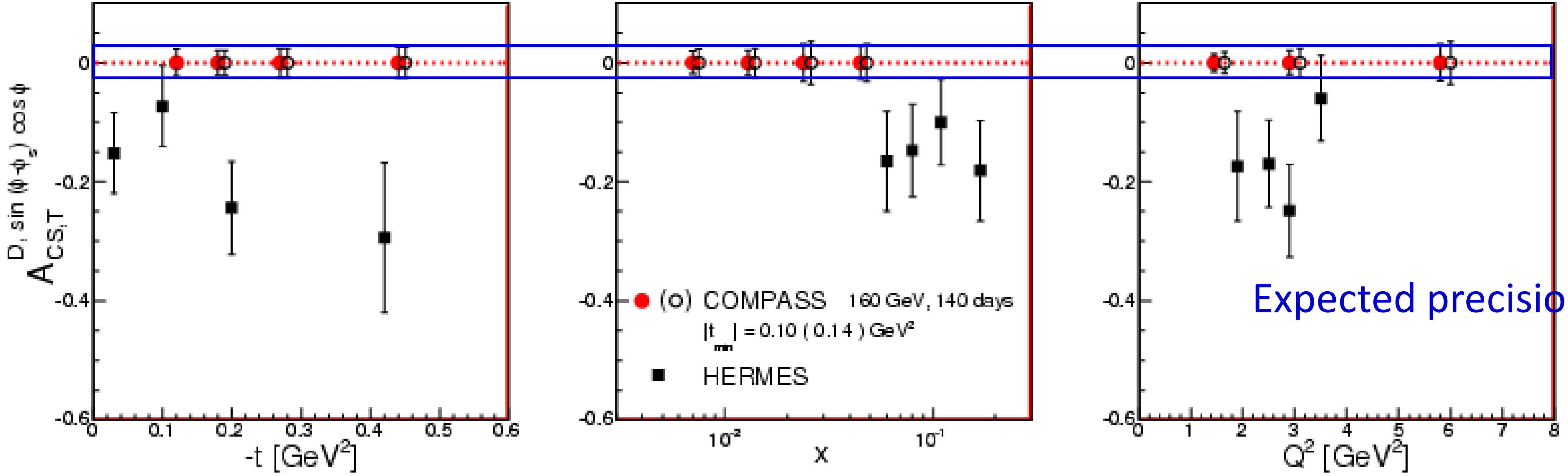
COMPASS-II Proposal, CERN-SPSC-2010-014/SPSC-P-340

COMPASS with Transv. Pol. Target to constrain the GPD E

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



2 years of data 160 GeV muon beam + 1.2 m polarised NH_3 target + ε_{global} = 10% **Lumi= 5 x 10^{32} cm^{-2} s^{-1}**



Expected precision ±2.5%

COMPASS-II Proposal, CERN-SPSC-2010-014/SPSC-P-340

COMPASS with Transv. Pol. Target to constrain the GPD E

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

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

★ **$\mathfrak{D}_{CS,T}^{\sin(\phi-\phi_S)}$**	$\propto$	**0.65 Im$\mathcal{E}$ - Im$\mathcal{H}$**
★ **$\mathfrak{D}_{CS,T}^{\sin(\phi-\phi_S)\cos\phi}$**	$\propto$	**- 0.65 Im$\mathcal{E}$ + Im$\mathcal{H}$**
$\mathfrak{D}_{CS,T}^{\sin(\phi-\phi_S)\cos 2\phi}$	$\propto$	- Im$\mathcal{E}$ + 0.54 Im$\mathcal{H}$ +0.34 Im$\widetilde{\mathcal{H}}$
$\mathfrak{D}_{CS,T}^{\sin(\phi-\phi_S)\cos 3\phi}$	$\propto$	0.19 Im$\mathcal{E}$ + Im$\mathcal{H}$
$\mathfrak{D}_{CS,T}^{\sin(\phi-\phi_S)\sin\phi}$	$\propto$	-1
$\mathfrak{D}_{CS,T}^{\sin(\phi-\phi_S)\sin 2\phi}$	$\propto$	0
$\mathfrak{D}_{CS,T}^{\sin(\phi-\phi_S)\sin 3\phi}$	$\propto$	0
$\mathfrak{D}_{CS,T}^{\cos(\phi-\phi_S)}$	$\propto$	**-1 (+ ε $d\sigma_{LT}^{DVCS}$)**
$\mathfrak{D}_{CS,T}^{\cos(\phi-\phi_S)\cos\phi}$	$\propto$	+1
$\mathfrak{D}_{CS,T}^{\cos(\phi-\phi_S)\cos 2\phi}$	$\propto$	0
$\mathfrak{D}_{CS,T}^{\cos(\phi-\phi_S)\cos 3\phi}$	$\propto$	0
★ **$\mathfrak{D}_{CS,T}^{\cos(\phi-\phi_S)\sin\phi}$**	$\propto$	**-Im$\widetilde{\mathcal{H}}$**
$\mathfrak{D}_{CS,T}^{\cos(\phi-\phi_S)\sin 2\phi}$	$\propto$	-Im$\mathcal{E}$ + 0.18 Im$\mathcal{H}$ +0.28Im$\widetilde{\mathcal{H}}$
$\mathfrak{D}_{CS,T}^{\cos(\phi-\phi_S)\sin 3\phi}$	$\propto$	-0.09 Im$\mathcal{E}$ +Im$\widetilde{\mathcal{H}}$

$\mathfrak{S}_{CS,T}^{\sin(\phi-\phi_S)}$	$\propto$	**- Re$\mathcal{E}$ Im$\mathcal{H}$ + Im$\mathcal{E}$ Re$\mathcal{H}$**
$\mathfrak{S}_{CS,T}^{\sin(\phi-\phi_S)\cos\phi}$	$\propto$	+ Re$\mathcal{E}$ Im$\mathcal{H}$ - Im$\mathcal{E}$ Re$\mathcal{H}$
$\mathfrak{S}_{CS,T}^{\sin(\phi-\phi_S)\cos 2\phi}$	$\propto$	- Re$\mathcal{E}$ Im$\mathcal{H}$ + Im$\mathcal{E}$ Re$\mathcal{H}$
$\mathfrak{S}_{CS,T}^{\sin(\phi-\phi_S)\cos 3\phi}$	$\propto$	0
$\mathfrak{S}_{CS,T}^{\sin(\phi-\phi_S)\sin\phi}$	$\propto$	**0.65 Re$\mathcal{E}$ + Re$\mathcal{H}$**
$\mathfrak{S}_{CS,T}^{\sin(\phi-\phi_S)\sin 2\phi}$	$\propto$	0.87 Re$\mathcal{E}$ - Re$\mathcal{H}$ -0.34 Re$\widetilde{\mathcal{H}}$
$\mathfrak{S}_{CS,T}^{\sin(\phi-\phi_S)\sin 3\phi}$	$\propto$	0
$\mathfrak{S}_{CS,T}^{\cos(\phi-\phi_S)}$	$\propto$	**-0.03 Re$\mathcal{E}$ - Re$\widetilde{\mathcal{H}}$**
$\mathfrak{S}_{CS,T}^{\cos(\phi-\phi_S)\cos\phi}$	$\propto$	**0.02 Re$\mathcal{E}$ + Re$\widetilde{\mathcal{H}}$**
$\mathfrak{S}_{CS,T}^{\cos(\phi-\phi_S)\cos 2\phi}$	$\propto$	- Re$\mathcal{E}$ + 0.18 Re$\mathcal{H}$ +0.53 Re$\widetilde{\mathcal{H}}$
$\mathfrak{S}_{CS,T}^{\cos(\phi-\phi_S)\cos 3\phi}$	$\propto$	0
$\mathfrak{S}_{CS,T}^{\cos(\phi-\phi_S)\sin\phi}$	$\propto$	0
$\mathfrak{S}_{CS,T}^{\cos(\phi-\phi_S)\sin 2\phi}$	$\propto$	0
$\mathfrak{S}_{CS,T}^{\cos(\phi-\phi_S)\sin 3\phi}$	$\propto$	0

From Pawel Sznajder   Kinematic factors for $x=0.02$ $Q^2=2$ $t=-0.2$ Coeff in front of CFF normalized to the largest one (Coeff > 0.02)

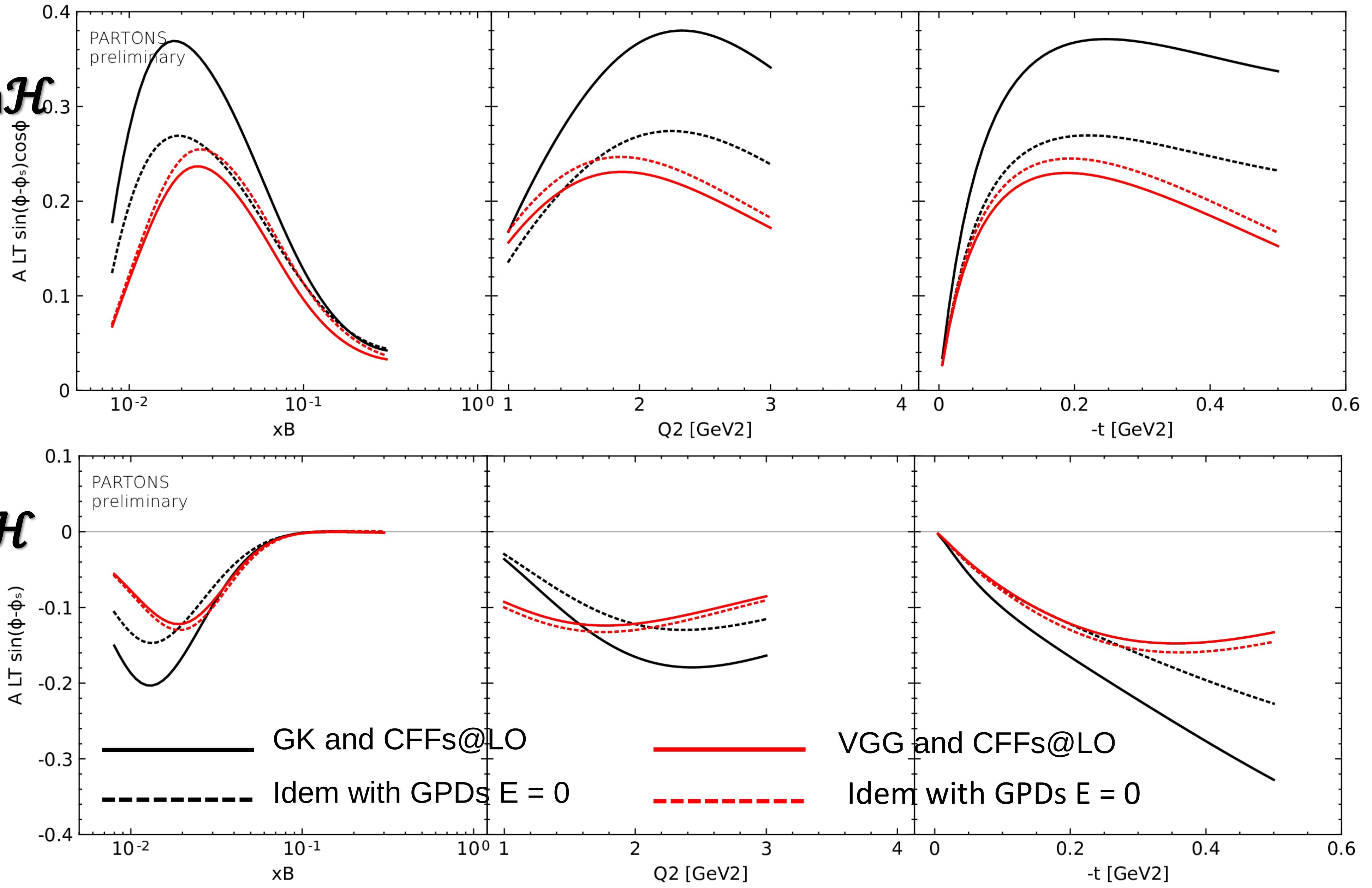
COMPASS with Transv. Pol. Target to constrain the GPD E

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

  $\propto$ -0.65 Im$\mathcal{E}$ + Im$\mathcal{H}$

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

  $\propto$ 0.65 Im$\mathcal{E}$ - Im$\mathcal{H}$

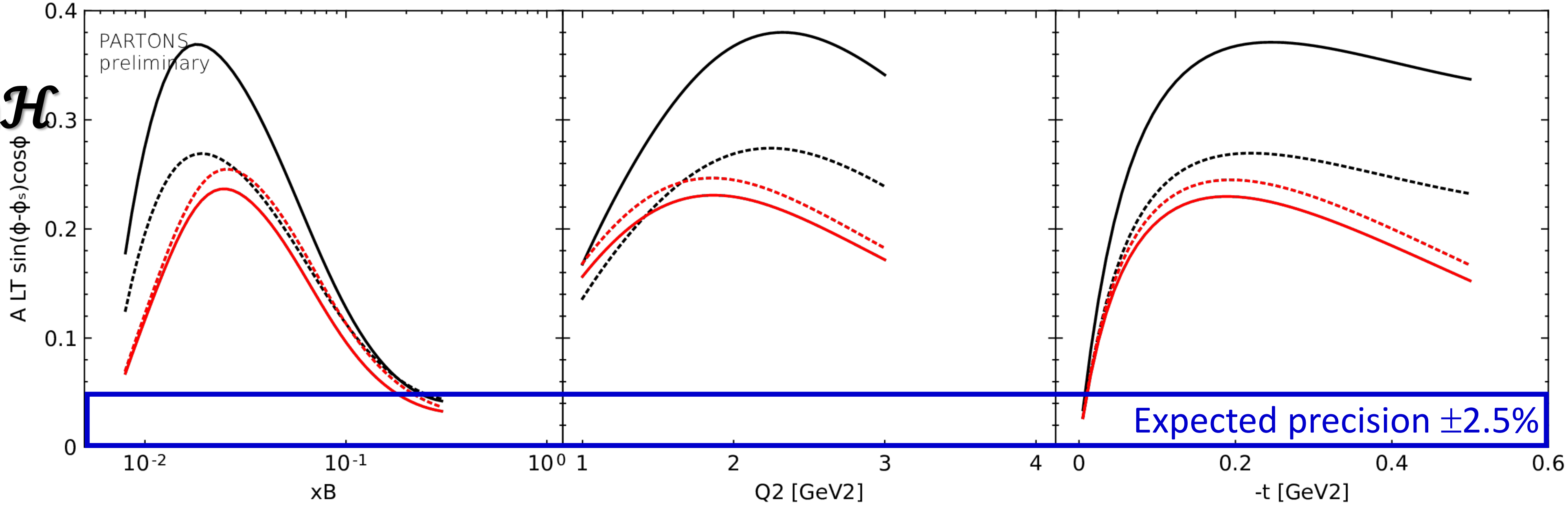


From Pawel Sznajder
Using the PARTONS code
Formalism at LO

COMPASS with Transv. Pol. Target to constrain the GPD E

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

  $\propto$ -0.65 Im$\mathcal{E}$ + Im$\mathcal{H}$



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

  $\propto$ 0.65 Im$\mathcal{E}$ - Im$\mathcal{H}$

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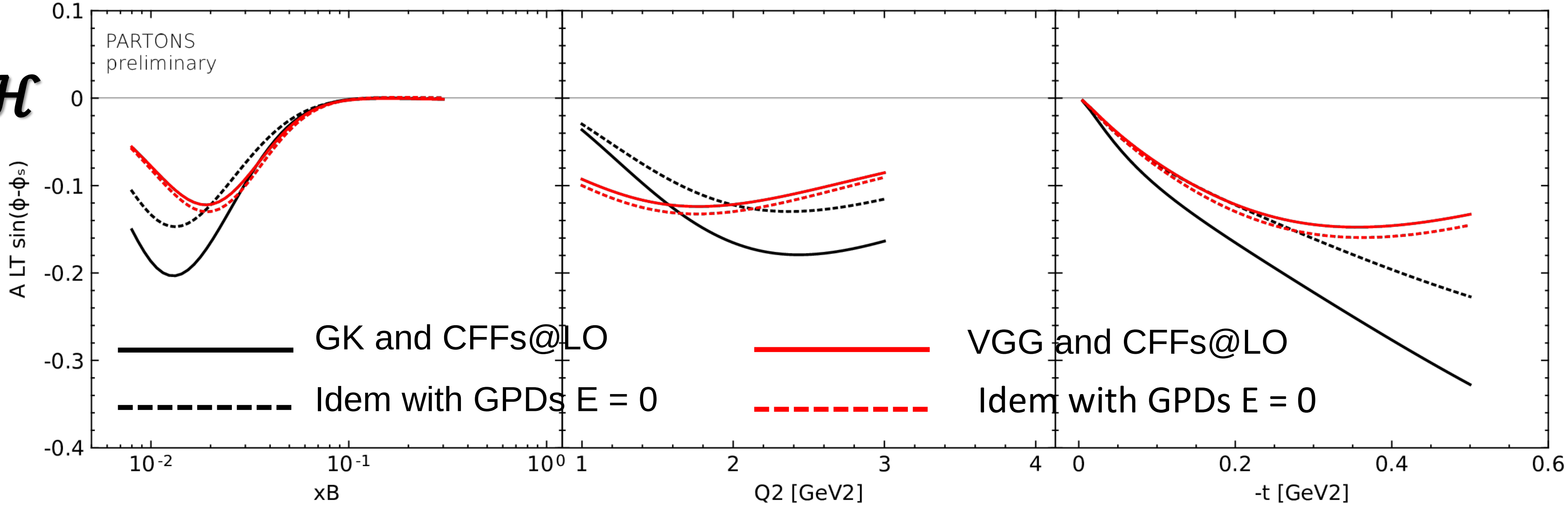
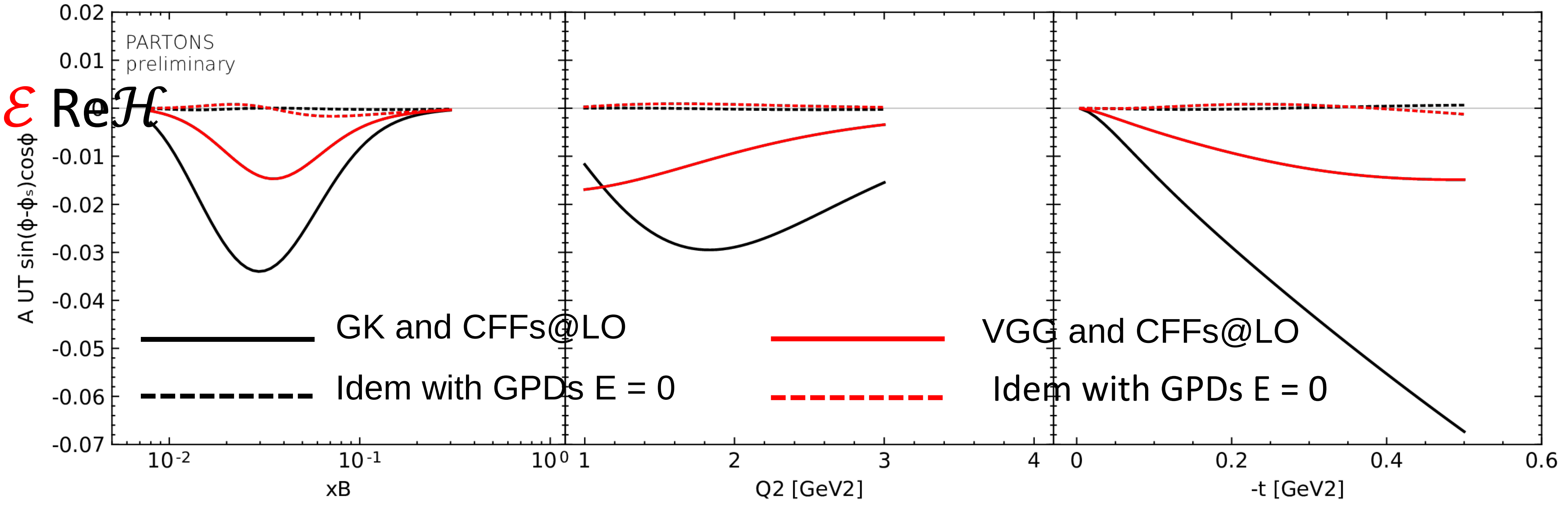


COMPASS with Transv. Pol. Target to constrain the GPD E

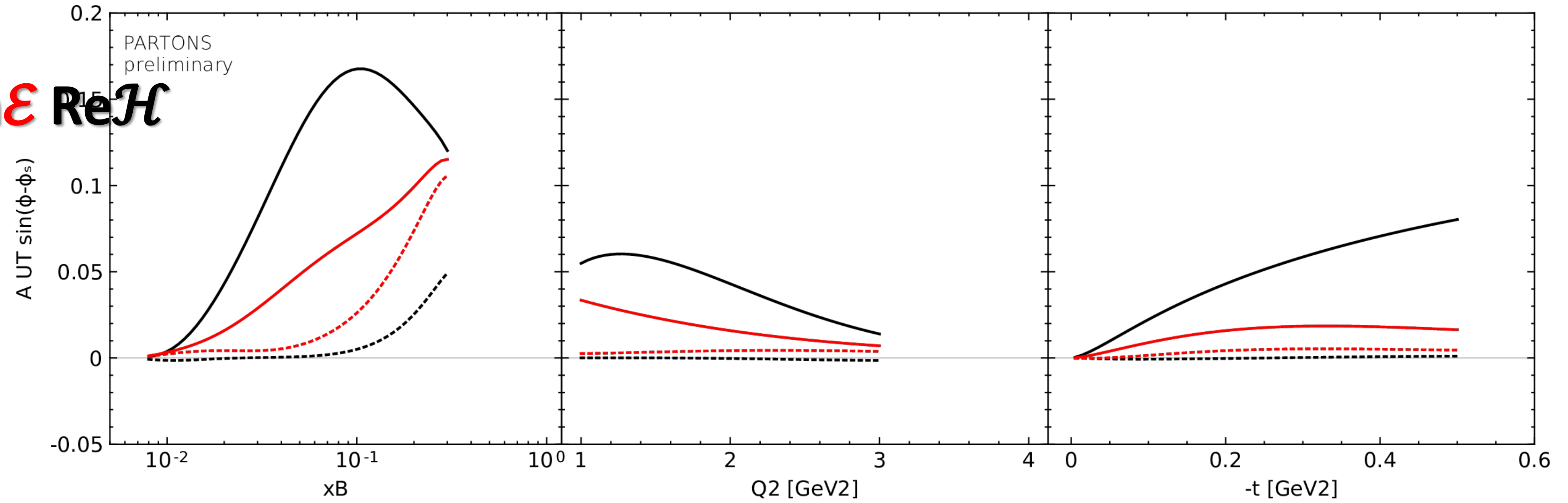
$\mathfrak{S}_{CS,T}^{\sin(\phi-\phi S)\cos\phi}$

$\propto + \mathrm{Re}\mathcal{E}\,\mathrm{Im}\mathcal{H} - \mathrm{Im}\mathcal{E}\,\mathrm{Re}\mathcal{H}$



$\mathfrak{S}_{CS,T}^{\sin(\phi-\phi S)}$

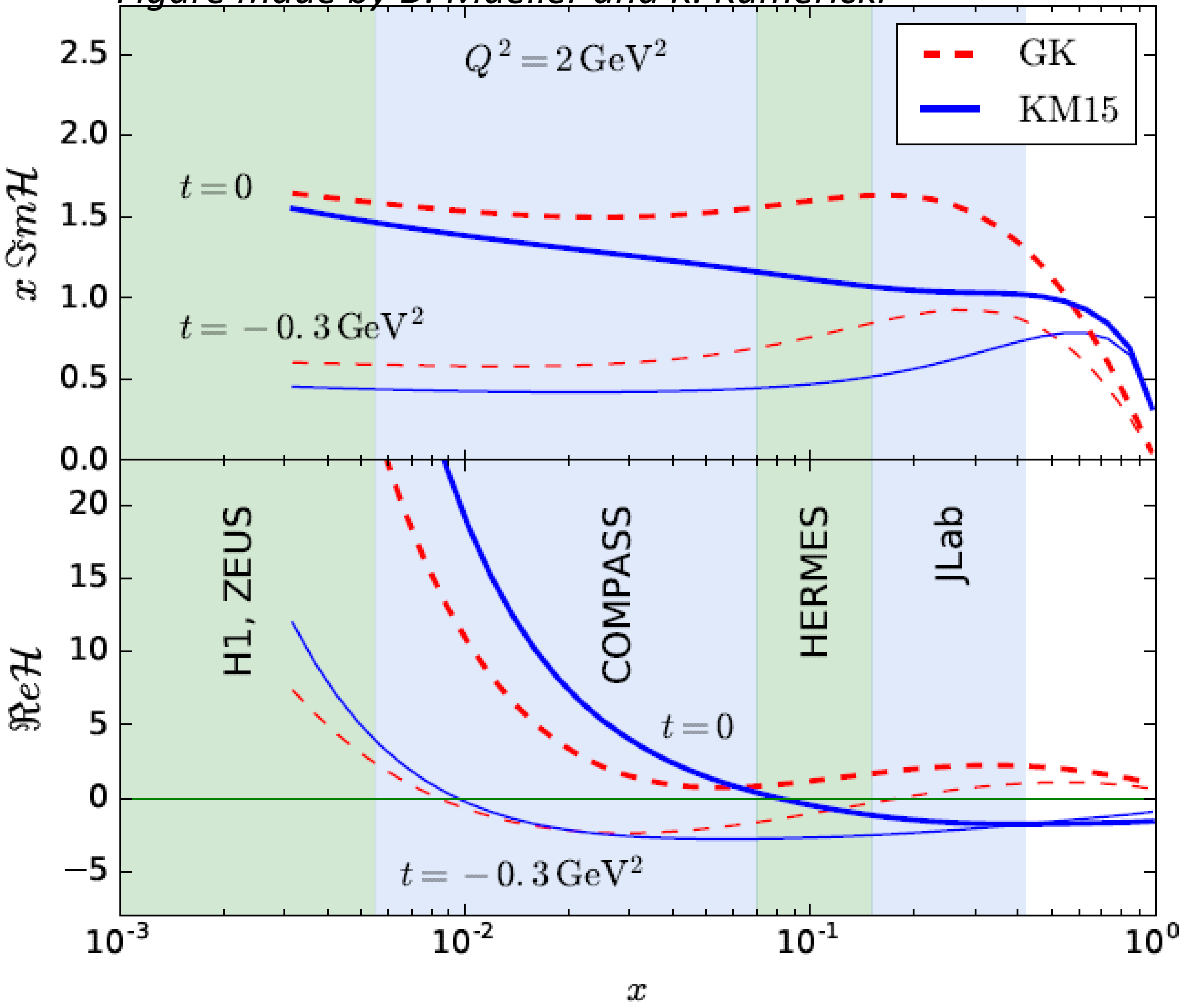
$\propto - \mathrm{Re}\mathcal{E}\,\mathrm{Im}\mathcal{H} + \mathrm{Im}\mathcal{E}\,\mathrm{Re}\mathcal{H}$



From Pawel Sznajder
Using the PARTONS code
Formalism at LO

Impact of DVCS @ COMPASS in global analysis ?

Figure made by D. Mueller and K. Kumericki



Im $\mathcal{H}$ is rather well known?

COMPASS 2012 + 16-17 $d\sigma^{DVCS}/dt$

Re $\mathcal{H}$ linked to the *D term* is still poorly constrained

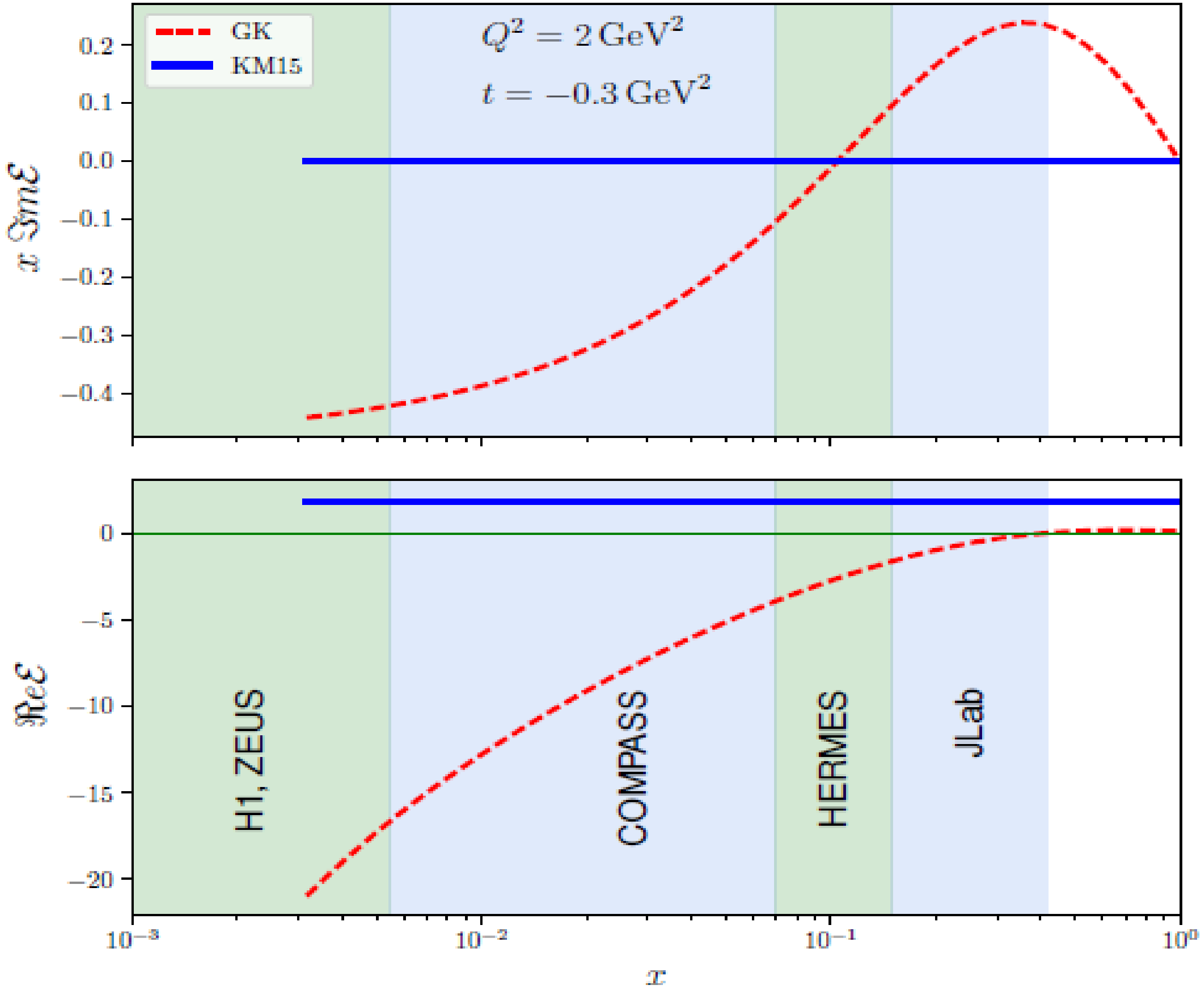
COMPASS 2016-17

KM15 K Kumericki and D Mueller arXiv:1512.09014v1

GK S.V. Goloskokov, P. Kroll, EPJC53 (2008), EPJA47 (2011)

Impact of DVCS @ COMPASS in global analysis ?

Figure made by D. Mueller and K. Kumericki



Im E is rather unknown

Re E is rather unknown

KM15 K Kumericki and D Mueller arXiv:1512.09014v1

GK S.V. Goloskokov, P. Kroll, EPJC53 (2008), EPJA47 (2011)

what is the impact of the CFF E measurement

on AOM

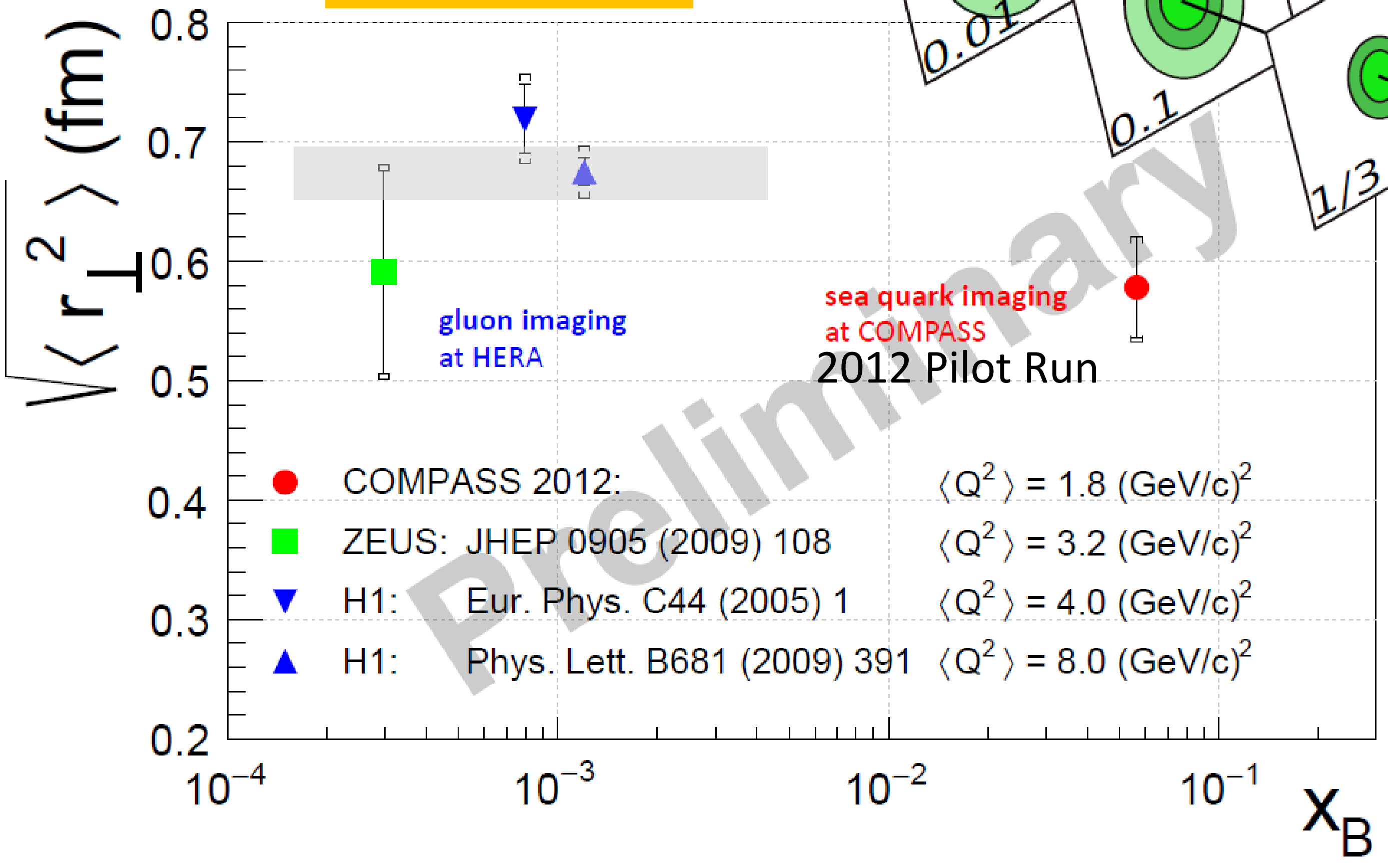
of valence quarks?   or sea quarks? or gluons?

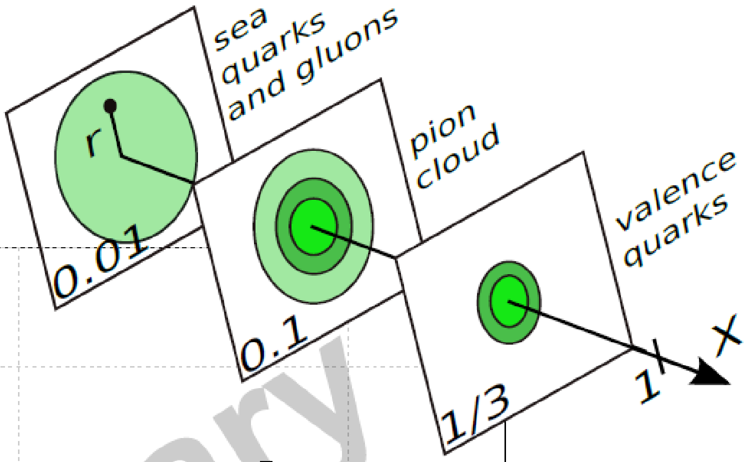
Proton « radius » measured at COMPASS

Comparison with HERA results

$d\sigma^{DVCS}/dt = A\ \exp\text{-}B|t|$

$< r_\perp^2 > \approx 2B(x_{Bj})$





Results presented by Matthias Gorzellik

$\sqrt{< r_\perp^2 >}$ to be compared to $\sqrt{4 \frac{d}{dt} F_1^p}\Big|_{t=0} = 0.66 \pm 0.01$ fm $\neq \sqrt{4 \frac{d}{dt} G_E^p}\Big|_{t=0} = 0.72 \pm 0.01$ fm

$+ \sqrt{\kappa / m_p^2}$

$r_p = 0.88$ fm

Proton « radius » measured at JLab

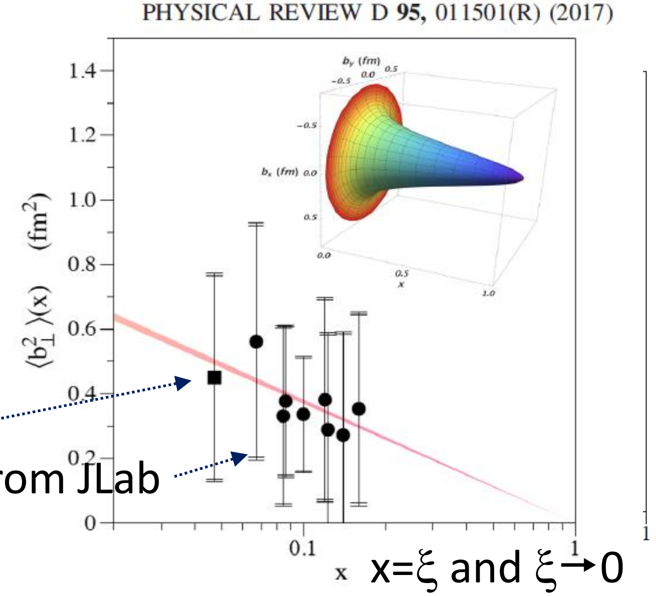
Fit of 8 CFFs at L.O and L.T.

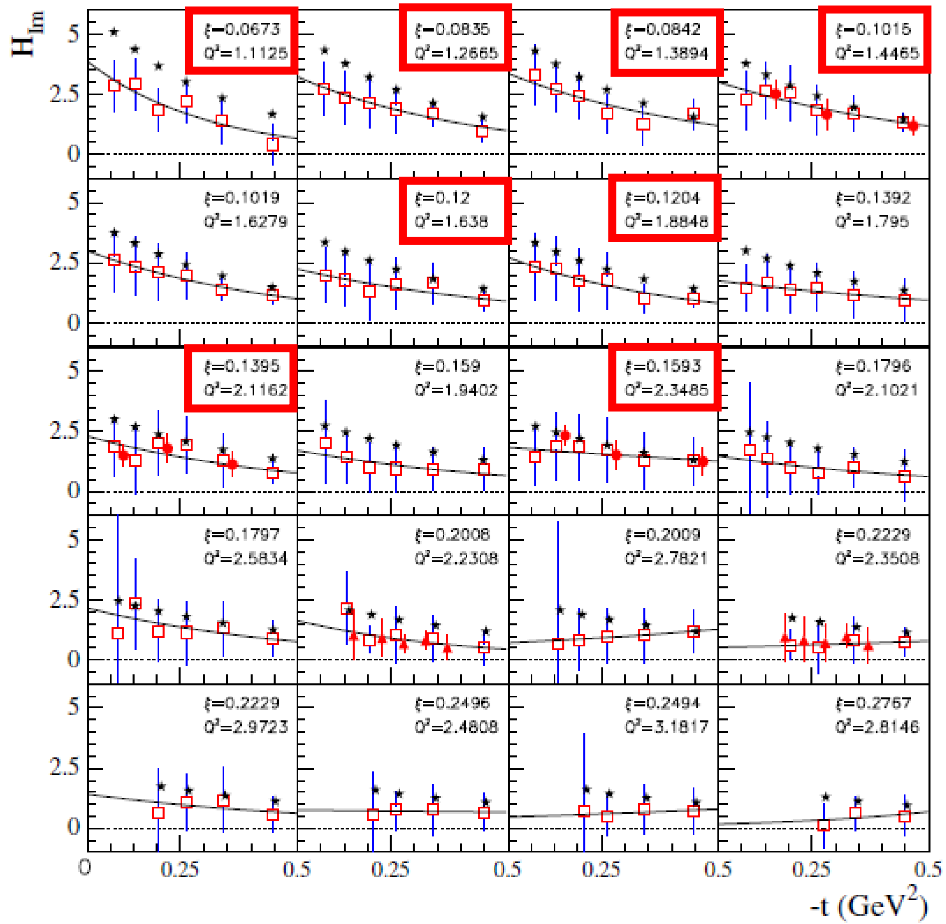
Dupré, Guidal, Vanderhaeghen, PRD95, 011501(R)(2017)

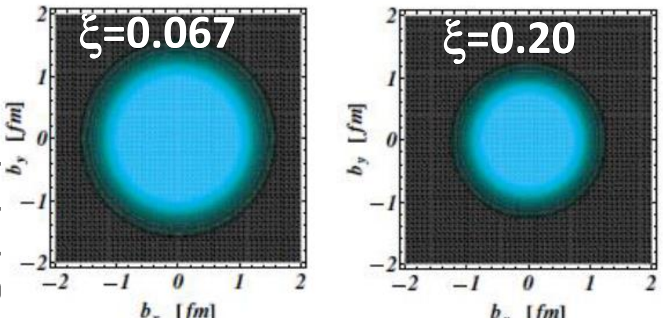
$Im\ F_1\mathcal{H} = A'\ \exp{-B'|t|}$

- □ CLAS σ and Δσ
- ▲ HallA σ and Δσ
- ● CLAS A_{UL} and A_{LL}
- ★ VGG model
- — Fit $A\ e^{-B'|t|}$

$< b_\perp^2 > \approx 4B'$

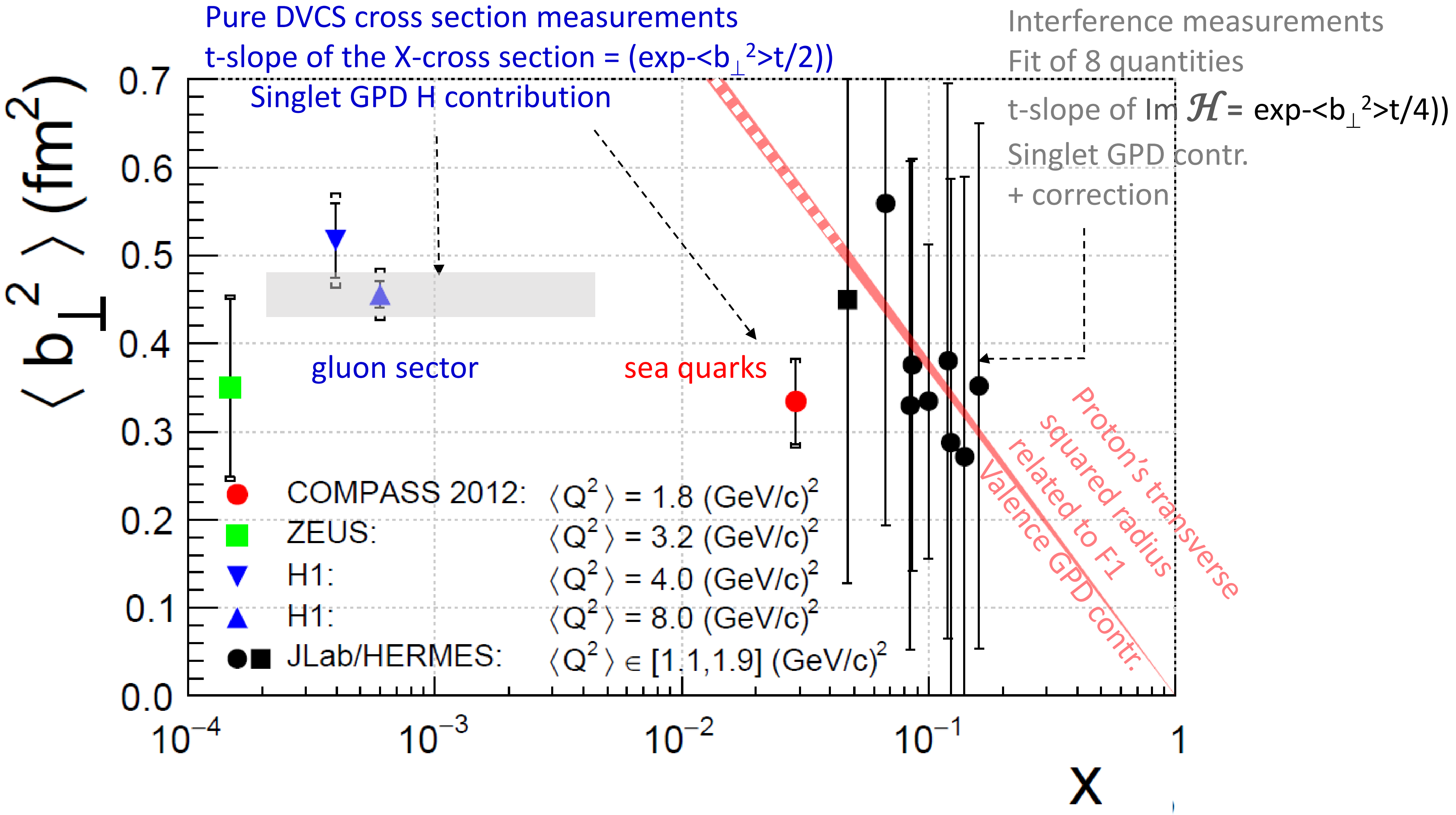






Guidal, Moutarde, Vanderhaeghen, Rept. Prog. Phys. 76 (2013)

Can we compare all the Proton « radii »?



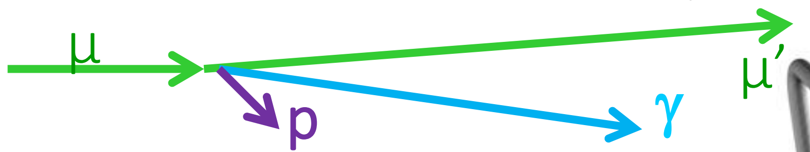
POSSIBLE REALISATION AT COMPASS

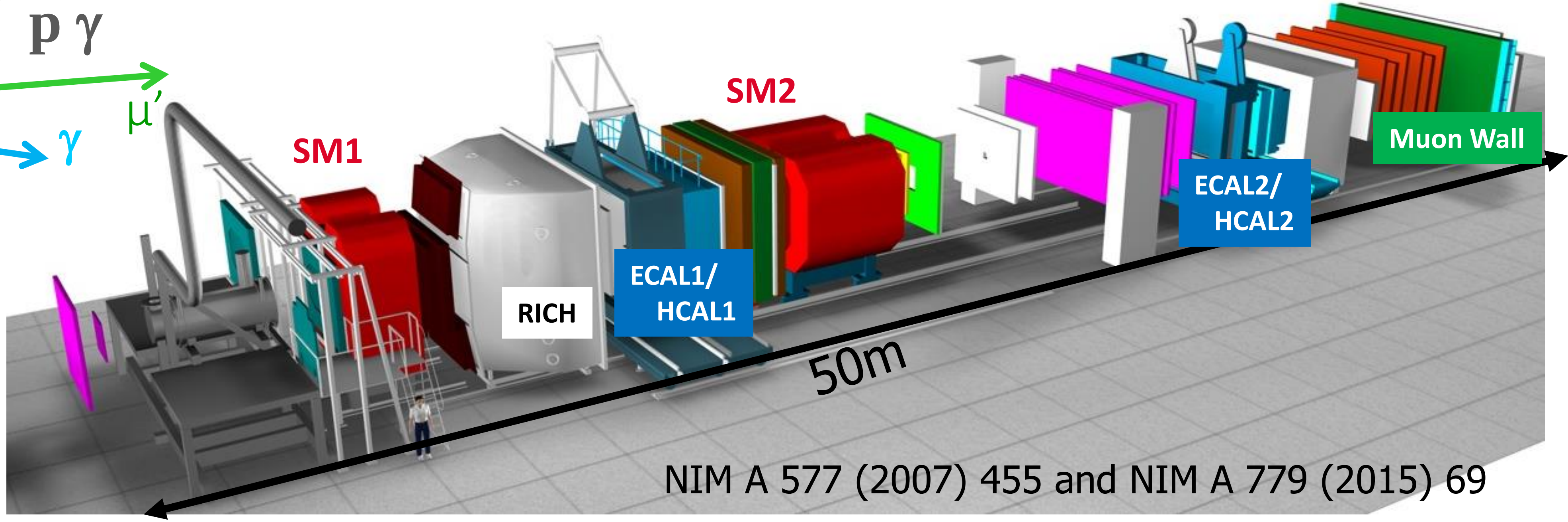
Summary of the ongoing studies

Work in progress

How to combine a recoil detector and a polarized target?

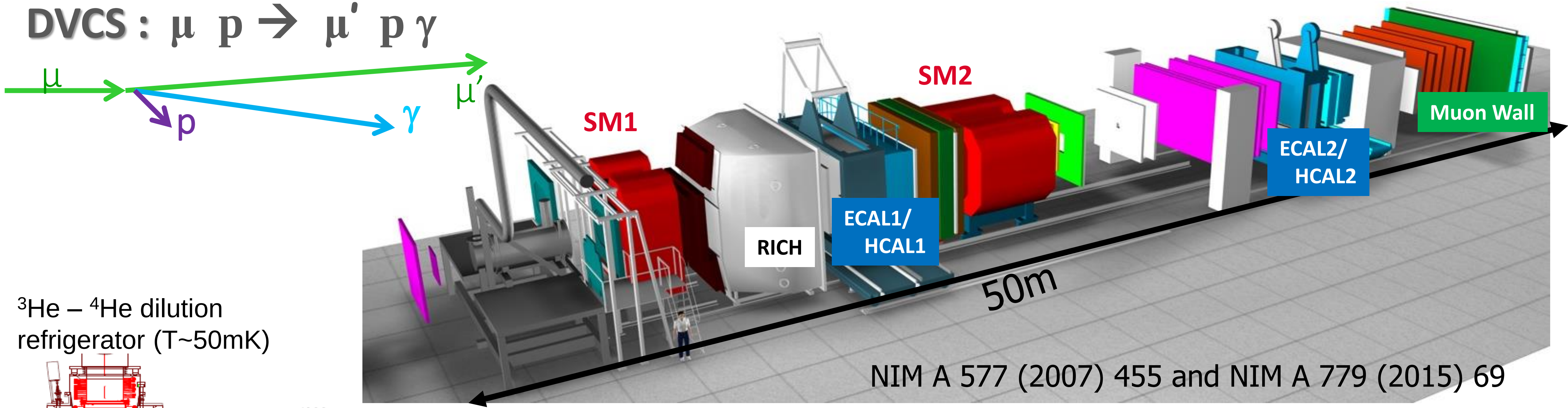
DVCS : μ p → μ' p γ

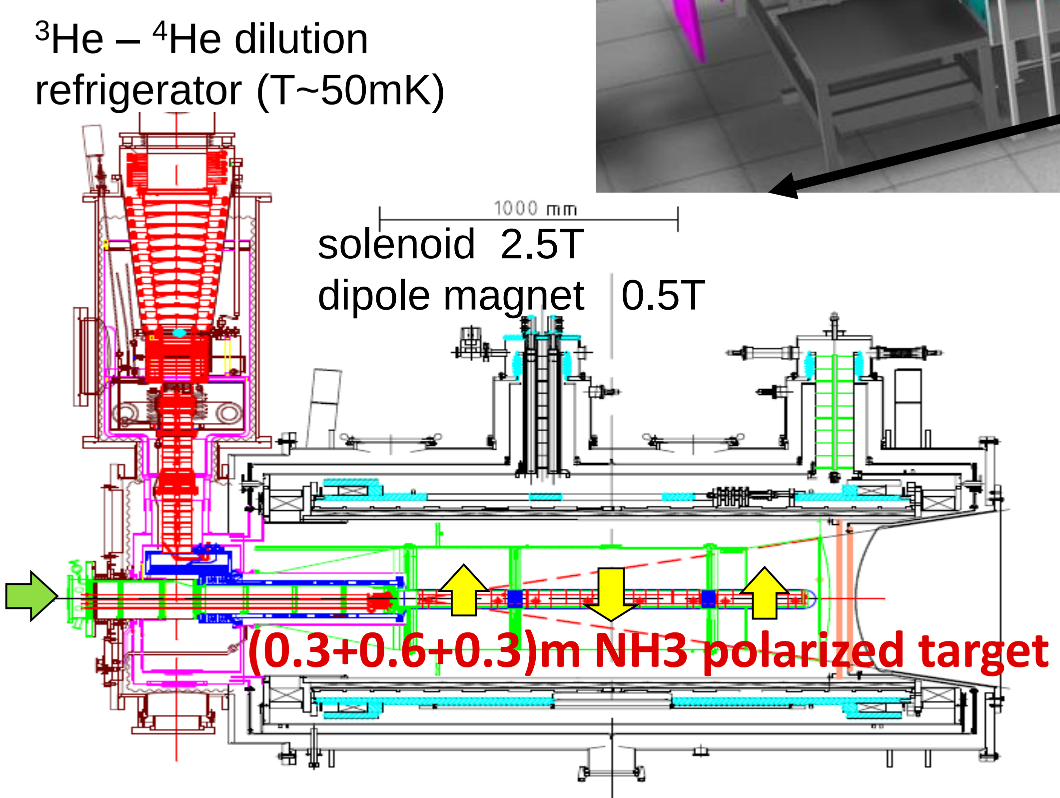




How to combine a recoil detector and a polarized target?

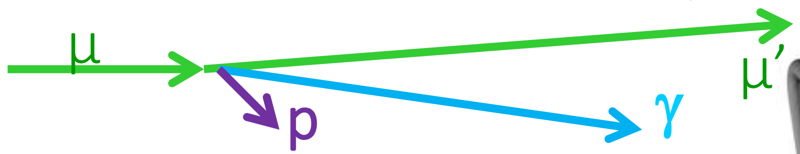
DVCS : μ p → μ' p γ

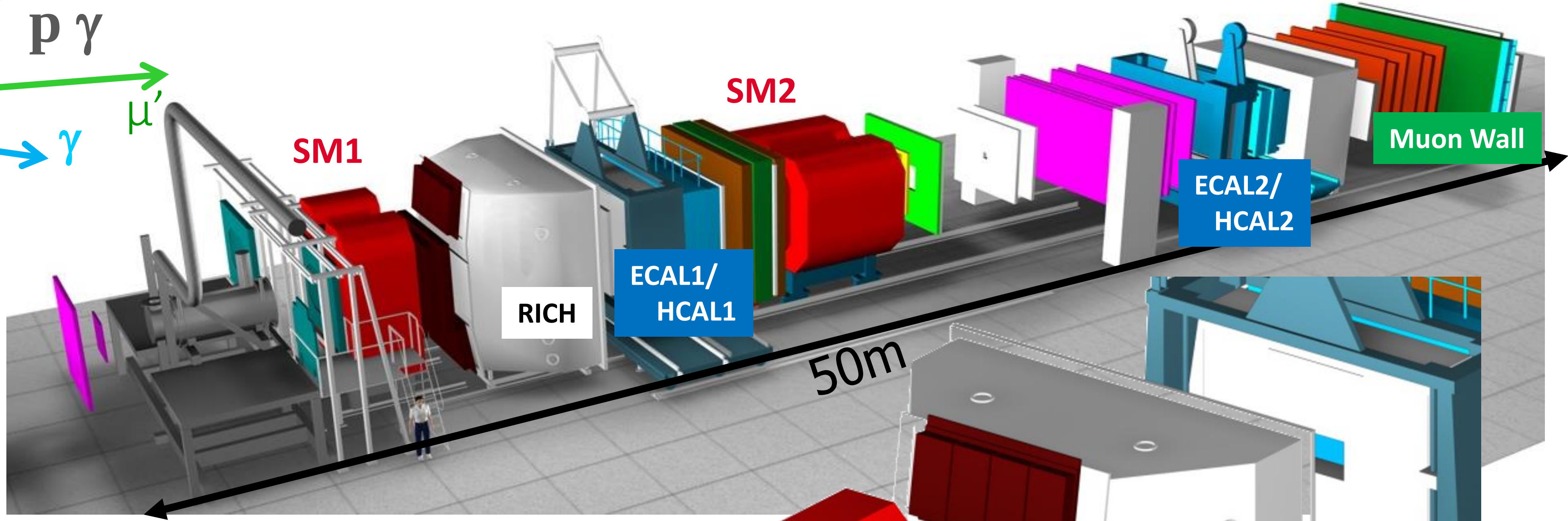




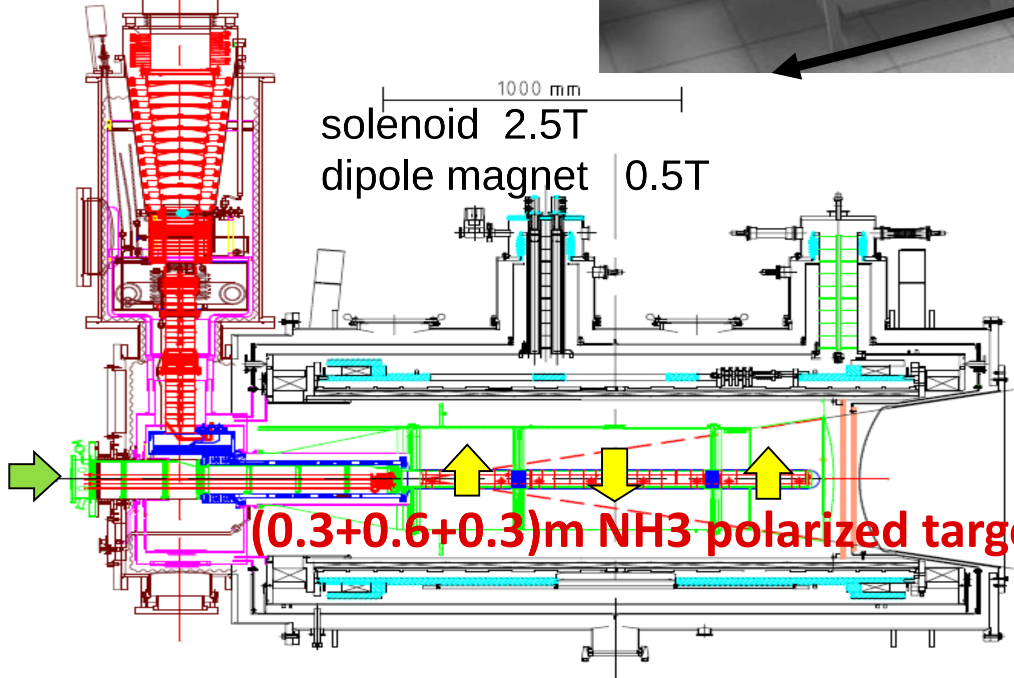
How to combine a recoil detector and a polarized target?

DVCS : $\mu\ p \rightarrow \mu'\ p\ \gamma$

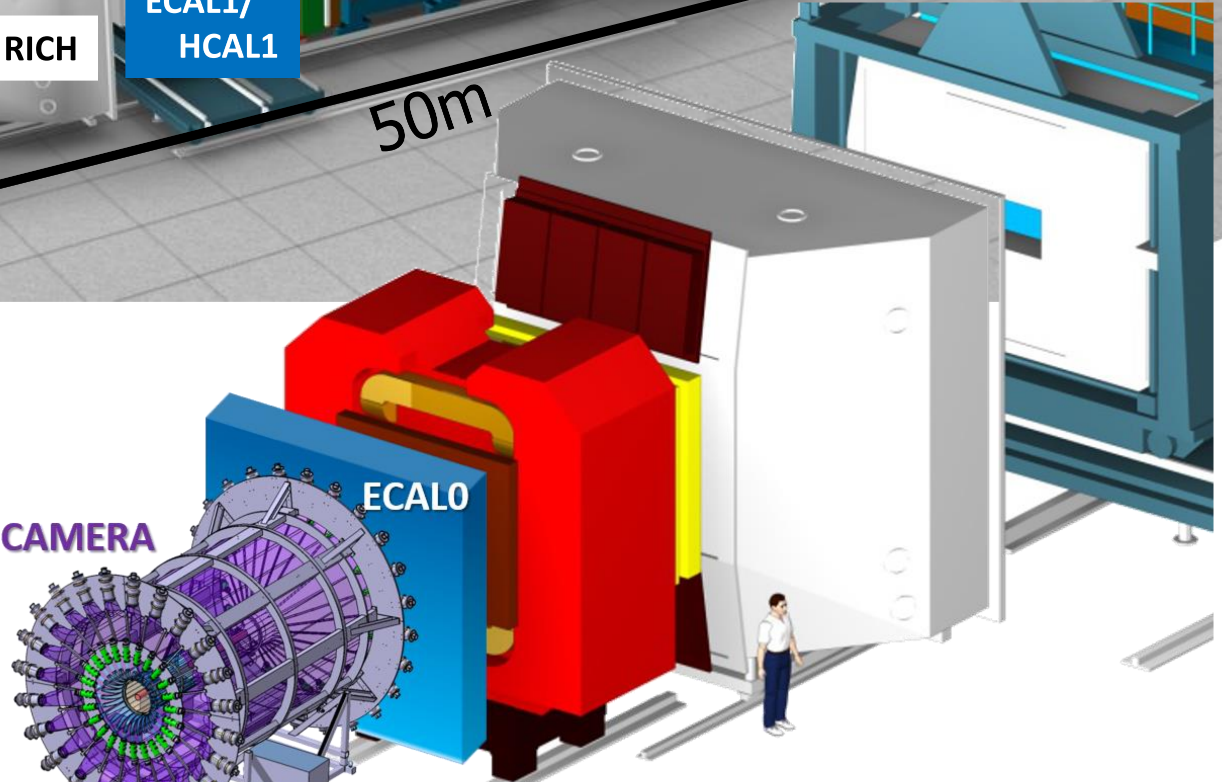




^{3}He – ^{4}He dilution refrigerator (T~50mK)



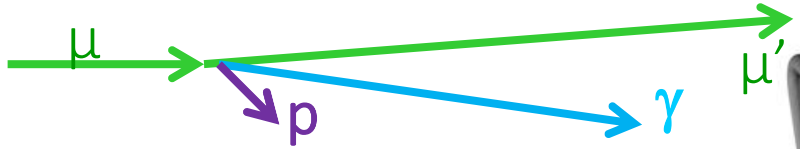
(0.3+0.6+0.3)m NH3 polarized target

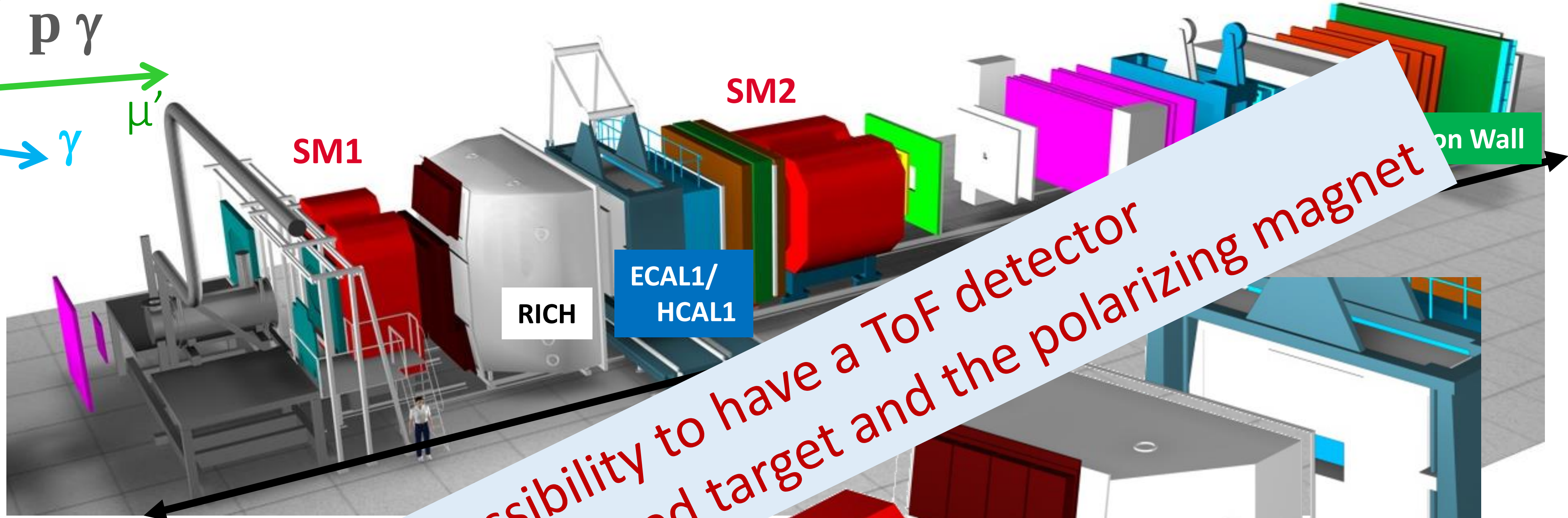


4m long Recoil proton detector TOF between 2 barrels surrounding a 2.5m long LH2 target

How to combine a recoil detector and a polarized target?

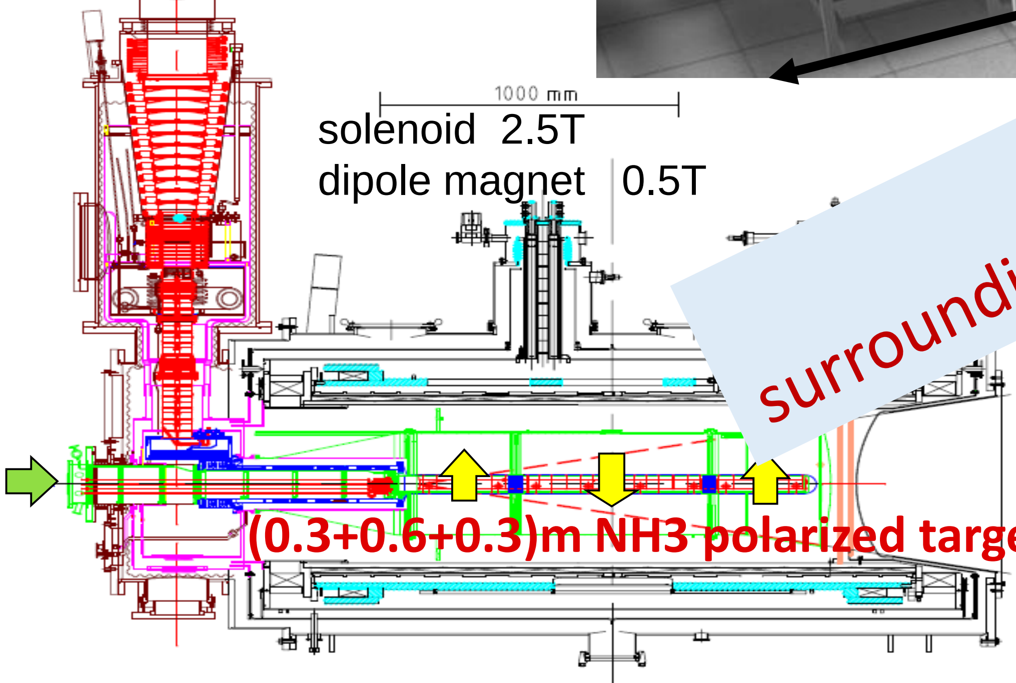
DVCS : $\mu\ p \rightarrow \mu'\ p\ \gamma$



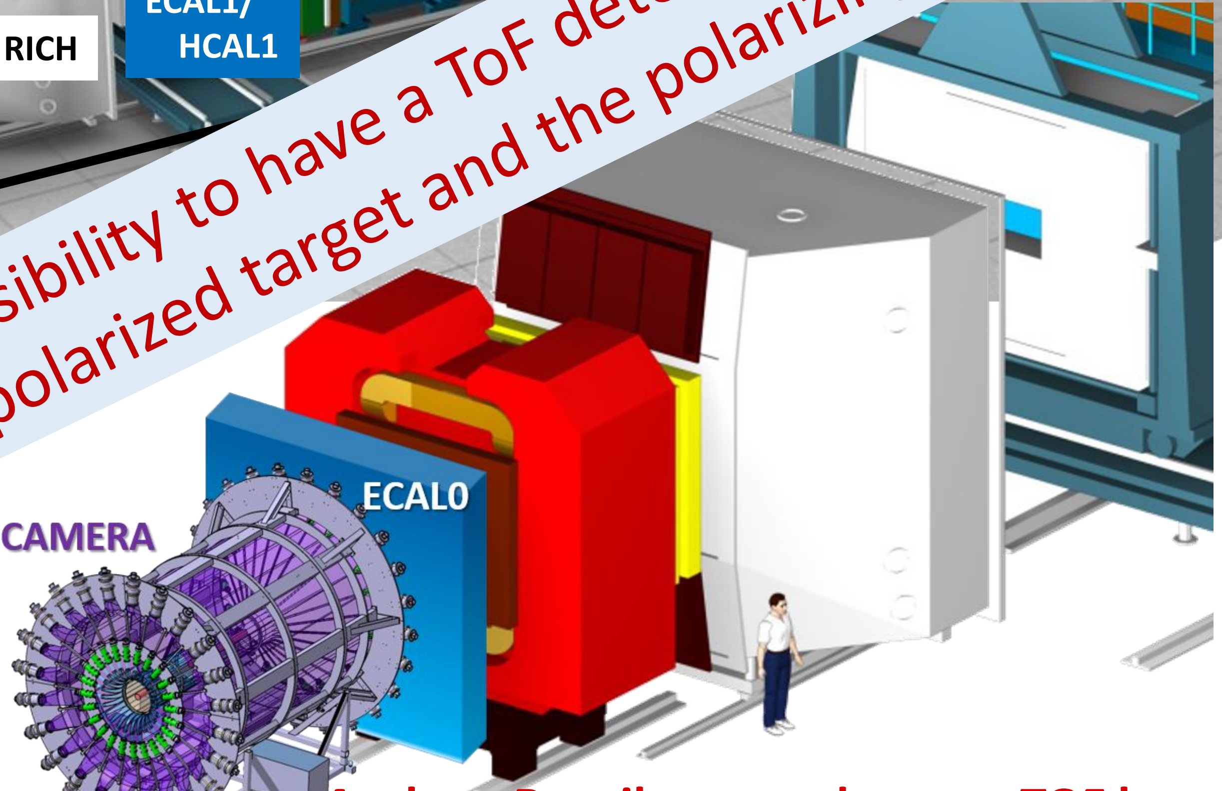


No possibility to have a ToF detector surrounding the polarized target and the polarizing magnet

^3He – ^4He dilution refrigerator (T~50mK)



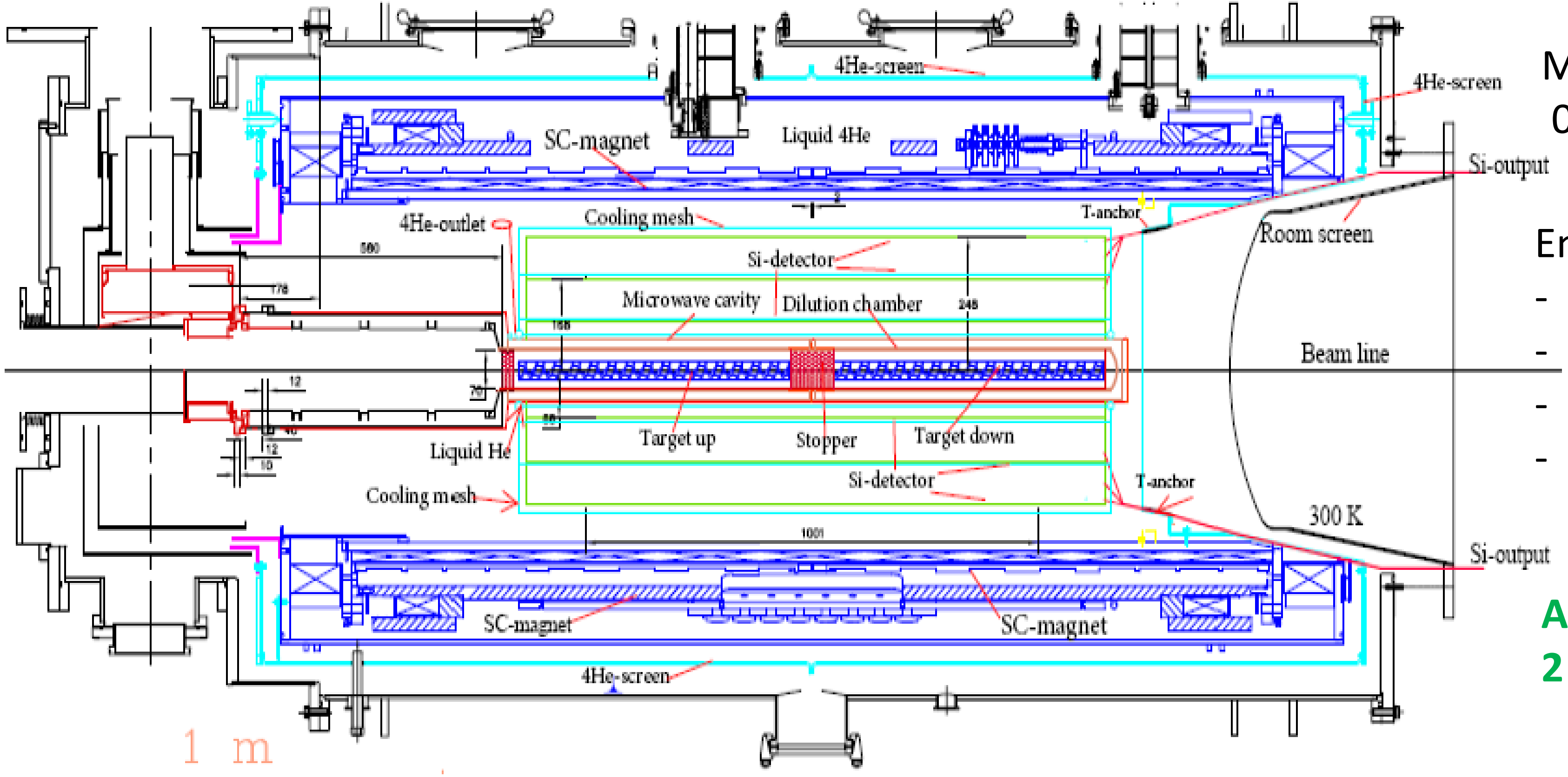
(0.3+0.6+0.3)m NH3 polarized target



4m long Recoil proton detector TOF between 2 barrels surrounding a 2.5m long LH2 target

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

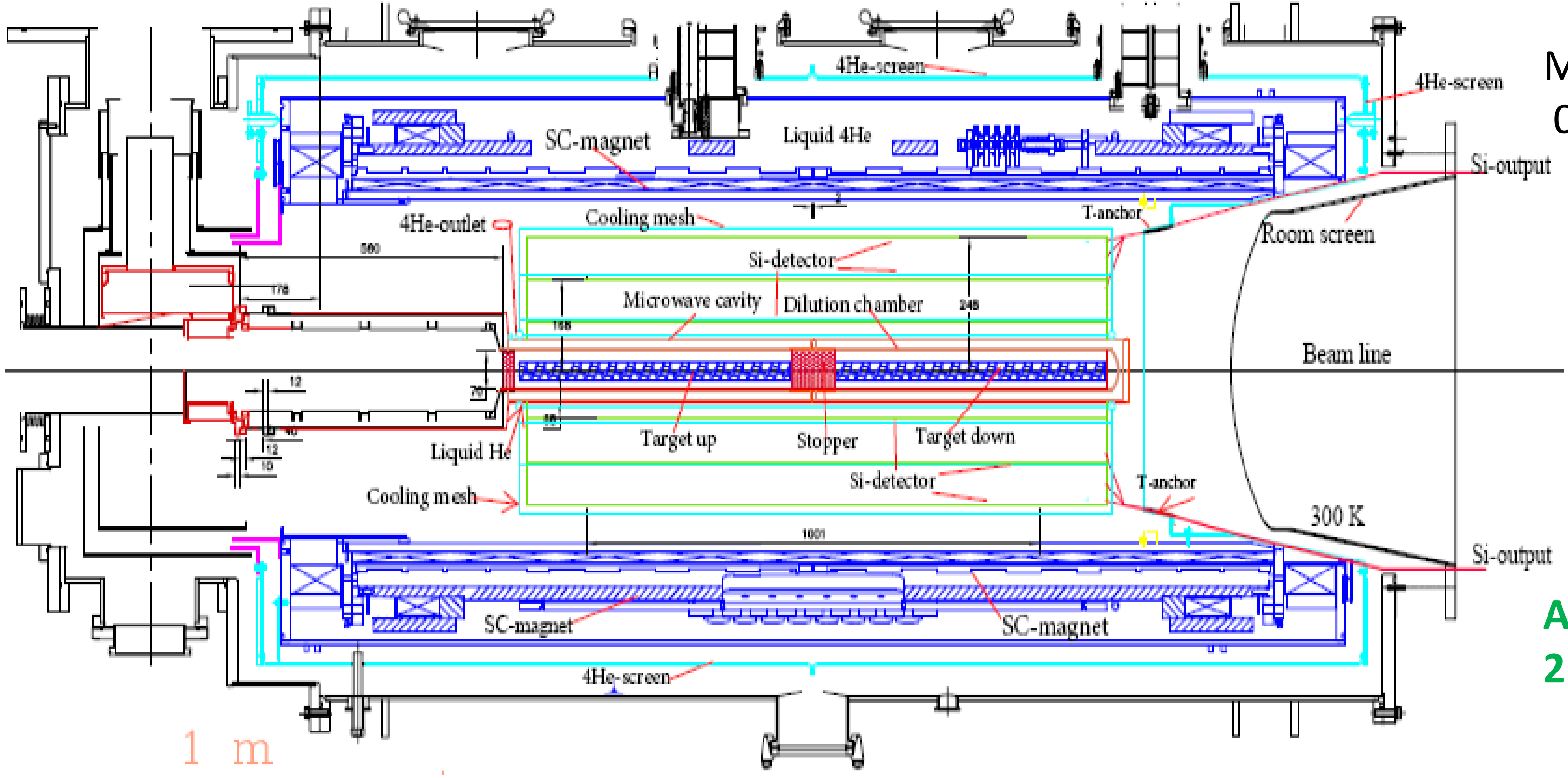
Environment:

- 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

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

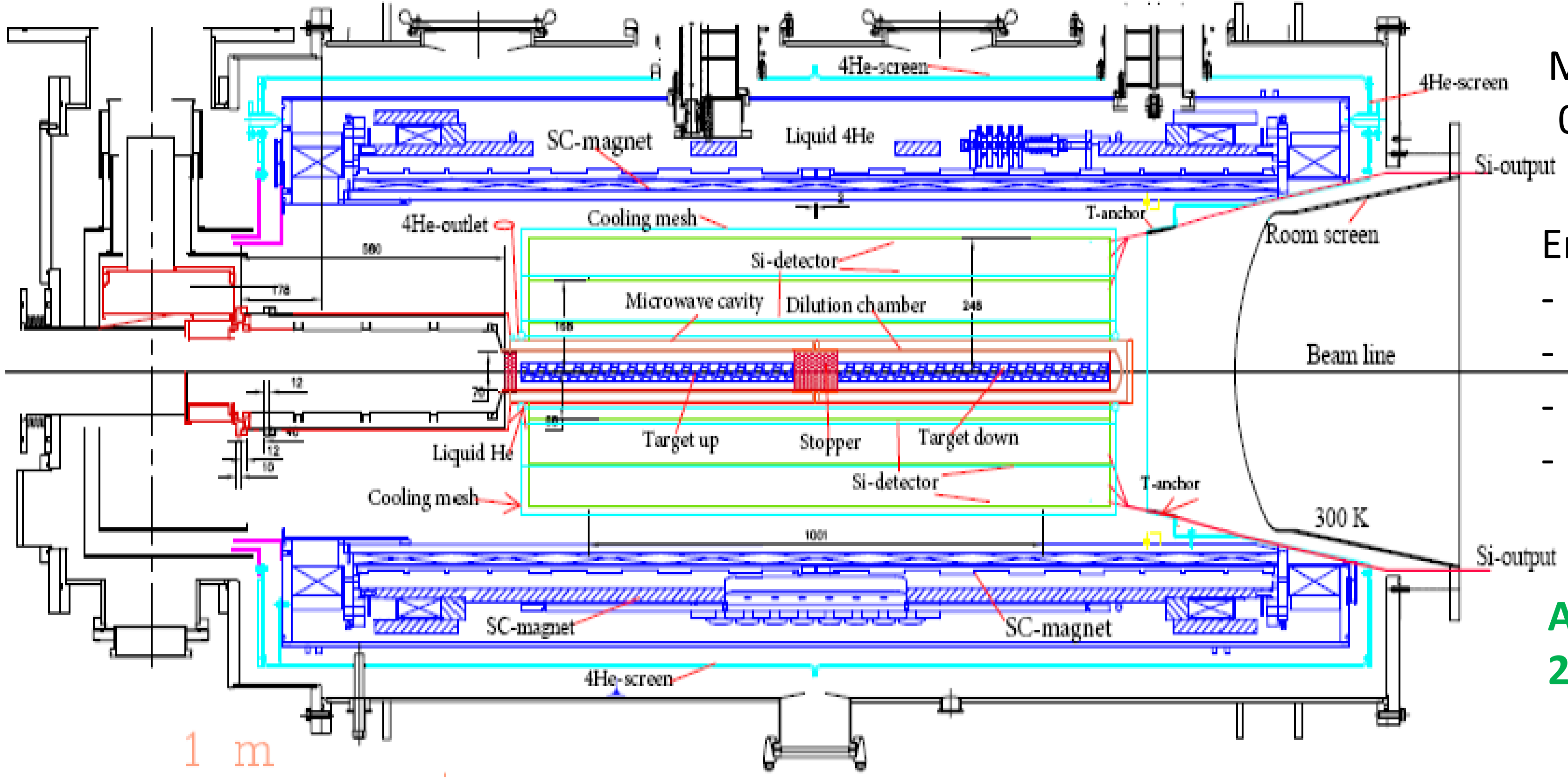
NH3 target	r = 20mm
Dilution Chamber	r = 35mm
MW cavity	r = 50mm
1st cylindrical SI det	r = 85 mm
2nd cylindrical SI det	r = 165 mm
3rd cylindrical SI det	r = 245 mm

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
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- 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

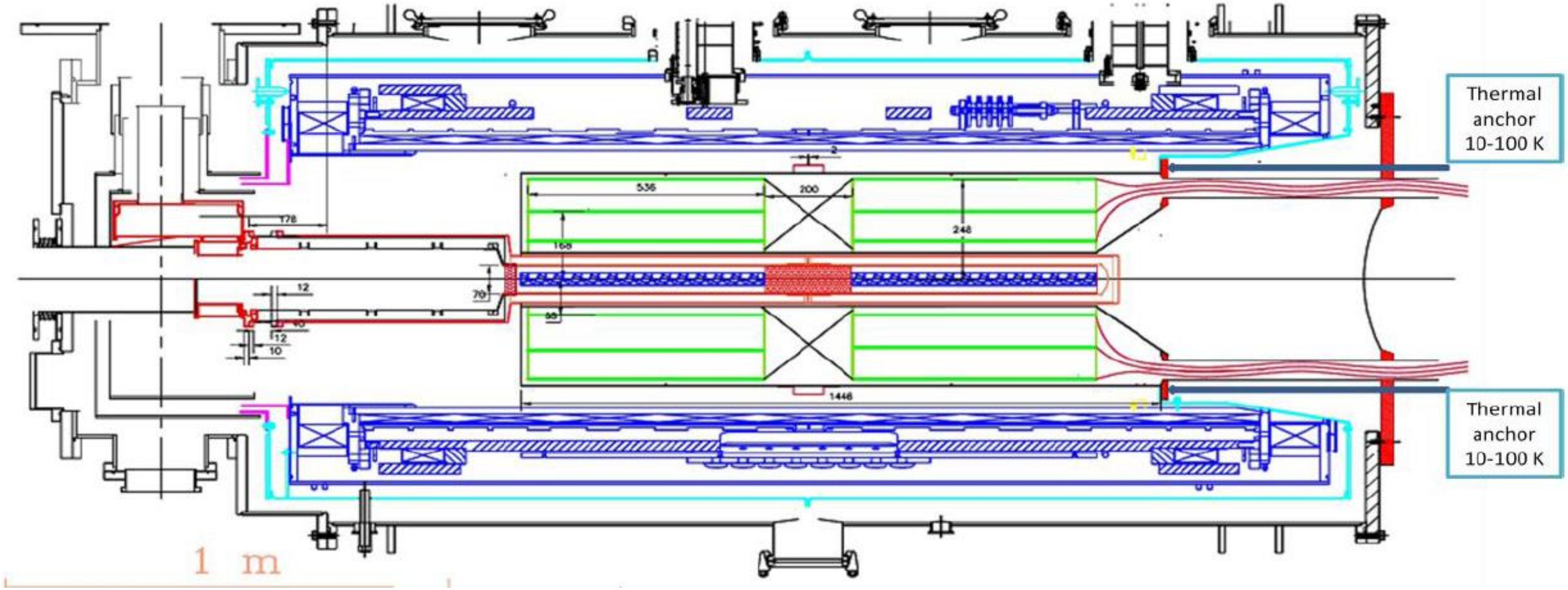
About 180mm are left to include 2 or 3 cylindrical layers of Silicon detectors

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 proposed solution

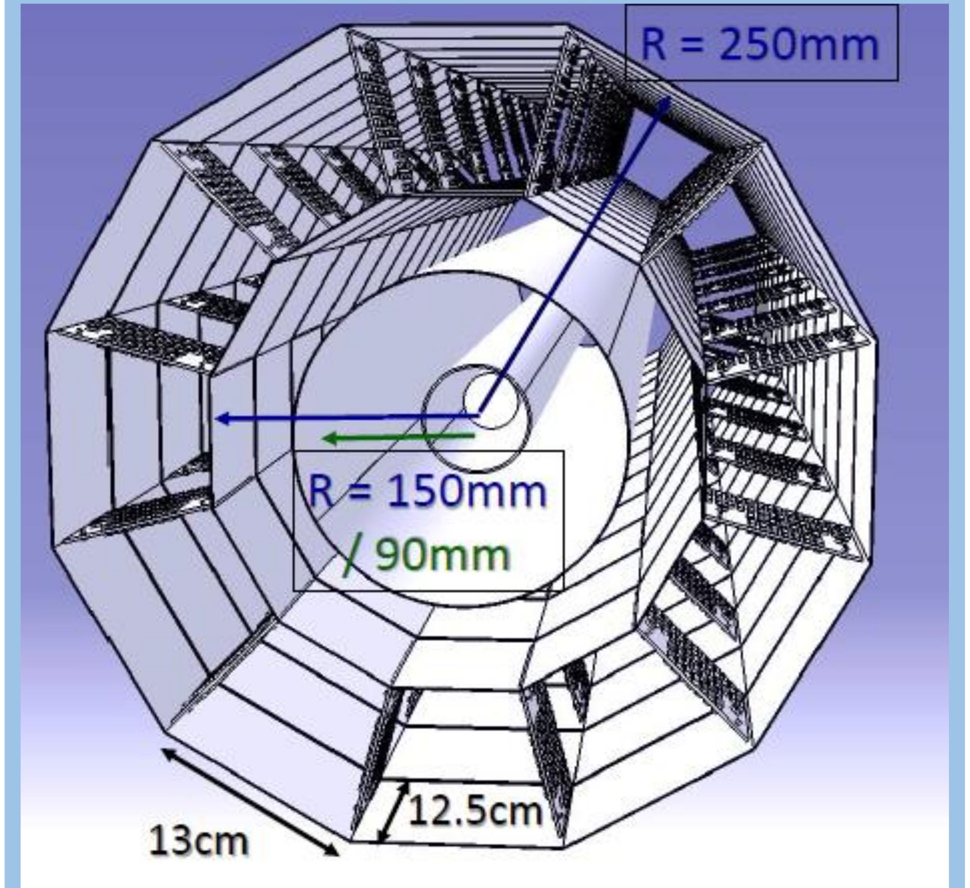
The target can be adapted to include a recoil proton detector
between the target surrounded by the modified MW cavity *and* the polarizing magnet



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

A second design: 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 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 Δz=3mm)

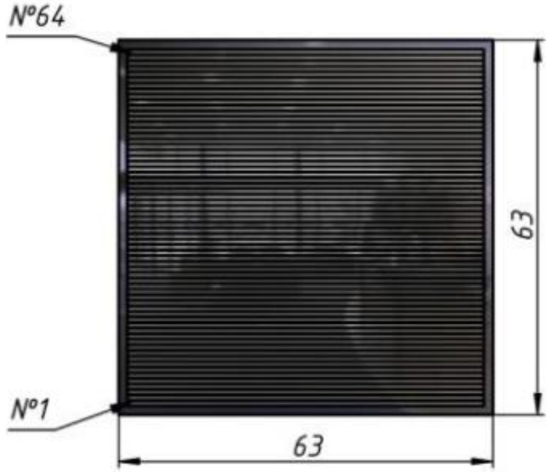
resolution improved by about a factor 3 compared to the present CAMERA

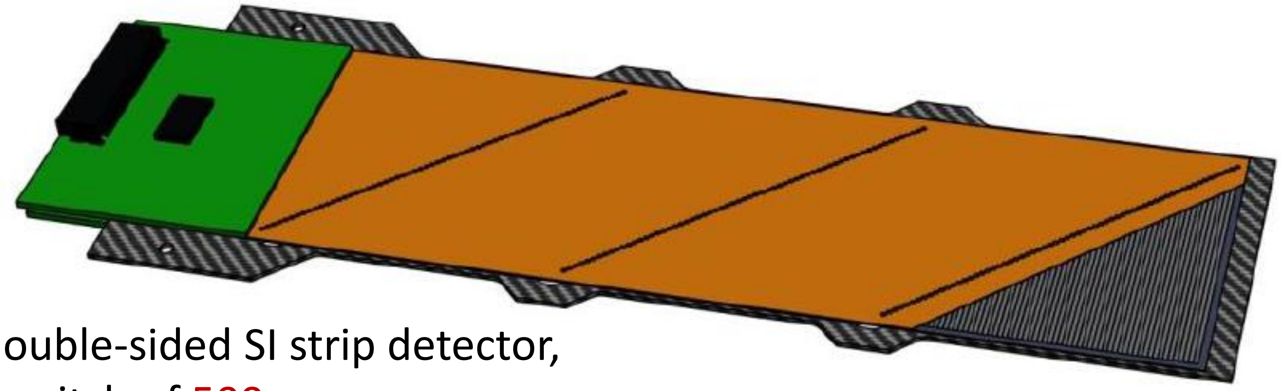
➔ less than 10 000 channels

Thermal load

very first estimate ~ 10 Watts

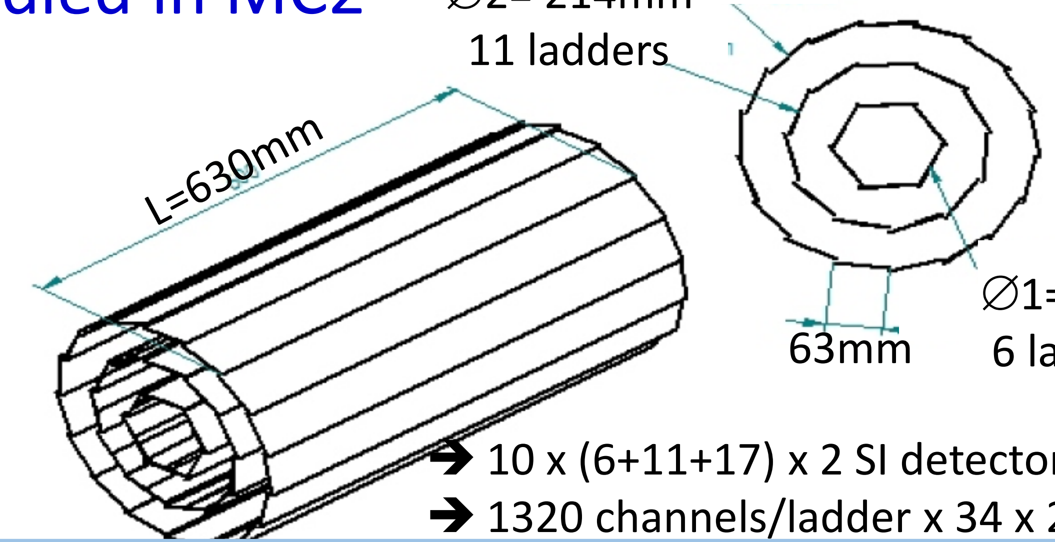
A technology developed at JINR for NICA



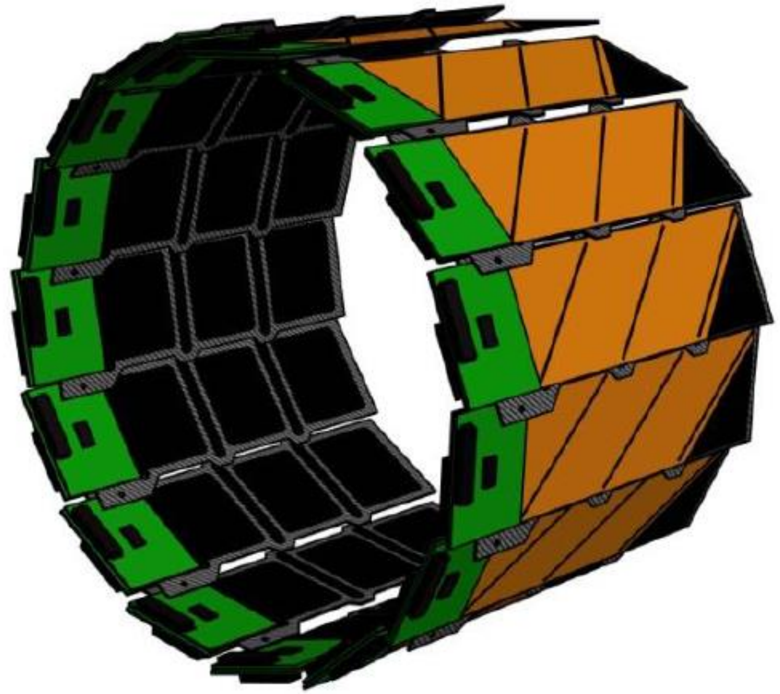


The ladder supporting the double-sided SI strip detector,
63x63 mm each, with a strip pitch of 500 µm

2nd skech studied in MC2



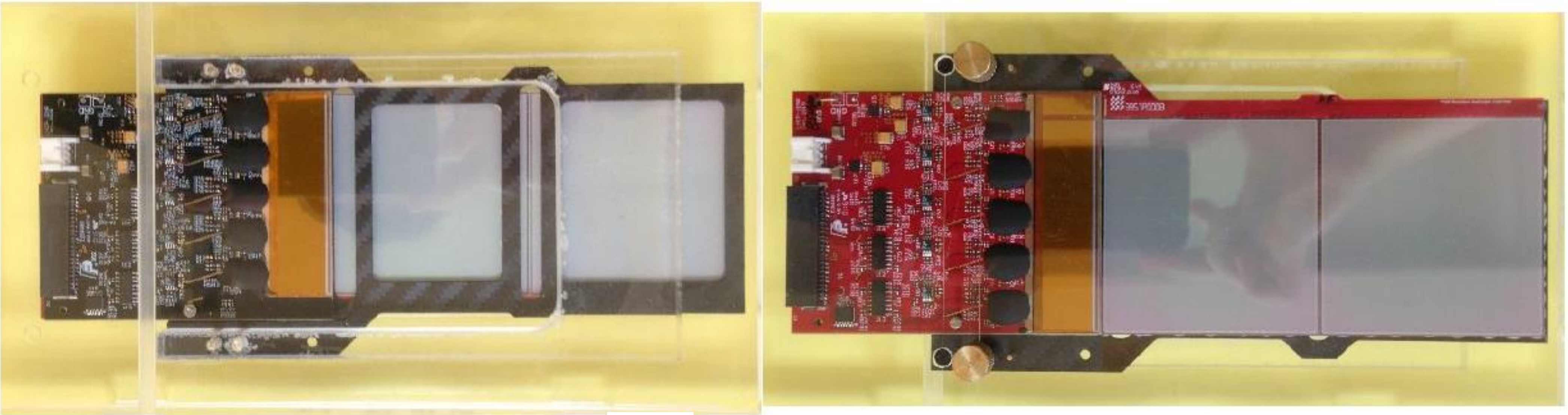
Thickness det1,2,3 =100, 100, 300µm



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

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

A technology developed at JINR for NICA



The Silicon detector unit developed for BM@N 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

To be studied

List of Tests of the Silicon detectors and associated electronics in the environment close to the present polarized target.

- responses and resolutions of commercially available Silicon detectors,
- operation of the FE-electronics (preamplifiers) and cables in the environments of the PT,
- tests of materials which will be used in mechanical supports of Silicon detectors,
- tests of the flat aluminium-polyimide multilayer flexible buses of different length at different temperatures.

Commercially available cryocooler equipped with temperature regulation and measurmeent devices

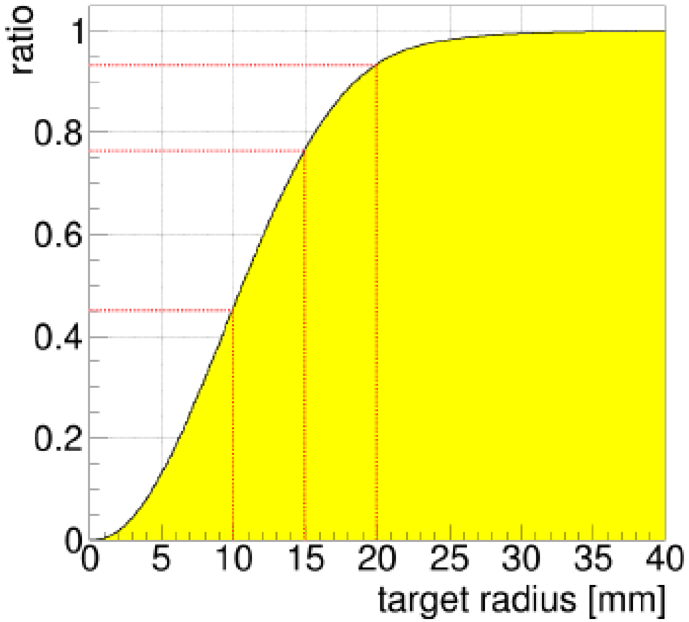
Value of a reasonable small t

Reference: Ring A: 300 μm, Ring B: 1000 μm, (in the very first sketch MC1 but quite general)
Target radius: 20 mm, Cavity thickness: 0.6 mm, Cavity radius: 100 mm

Setup changes w.r.t reference		$-t_{min}/(\mathrm{GeV}/c)^2$	Combined efficiency	Detection of $p + \gamma + \mu$
Reference	Pp=306.7 MeV/c	0.0917	38.1%	
NH3 target radius 15 mm	Pp=289.1 MeV/c	0.0817	34.4%	
NH3 target radius 10 mm		0.0758	21.2%	
Cu Cavity Thickness 0.5 mm		0.0907	38.6%	
Cu Cavity Thickness 0.4 mm		0.0895	39.3%	
Cu Cavity Thickness 0.3 mm		0.0876	39.7%	
Cu Cavity Thickness 0.2 mm		0.0866	40.3%	
Cu Cavity Radius 90 mm		0.0917	37.8%	
Cu Cavity Radius 80 mm		0.0917	37.3%	
Cu Cavity Radius 70 mm		0.0917	36.8%	
Ring A Thickness 200 μm		0.0913	38.3%	
Ring A Thickness 250 μm		0.0915	38.2%	
Ring A Thickness 350 μm		0.0919	38.1%	
CAMERA	Pp=258.5 MeV/c	0.0656	56.6%	

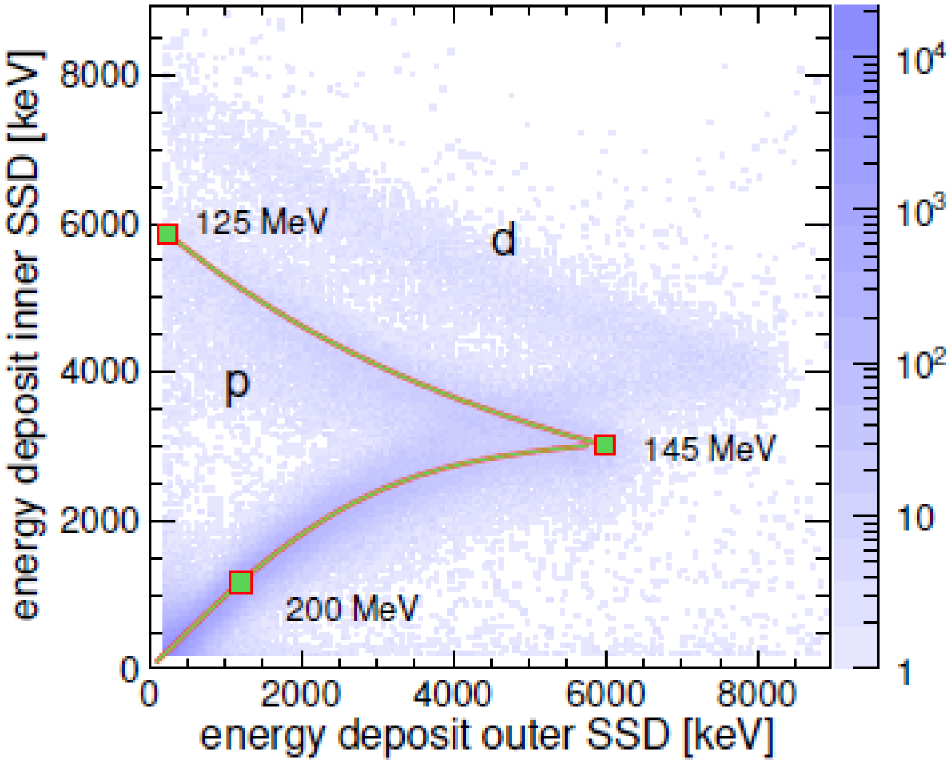
GEANT

Intercept of the beam with the target area

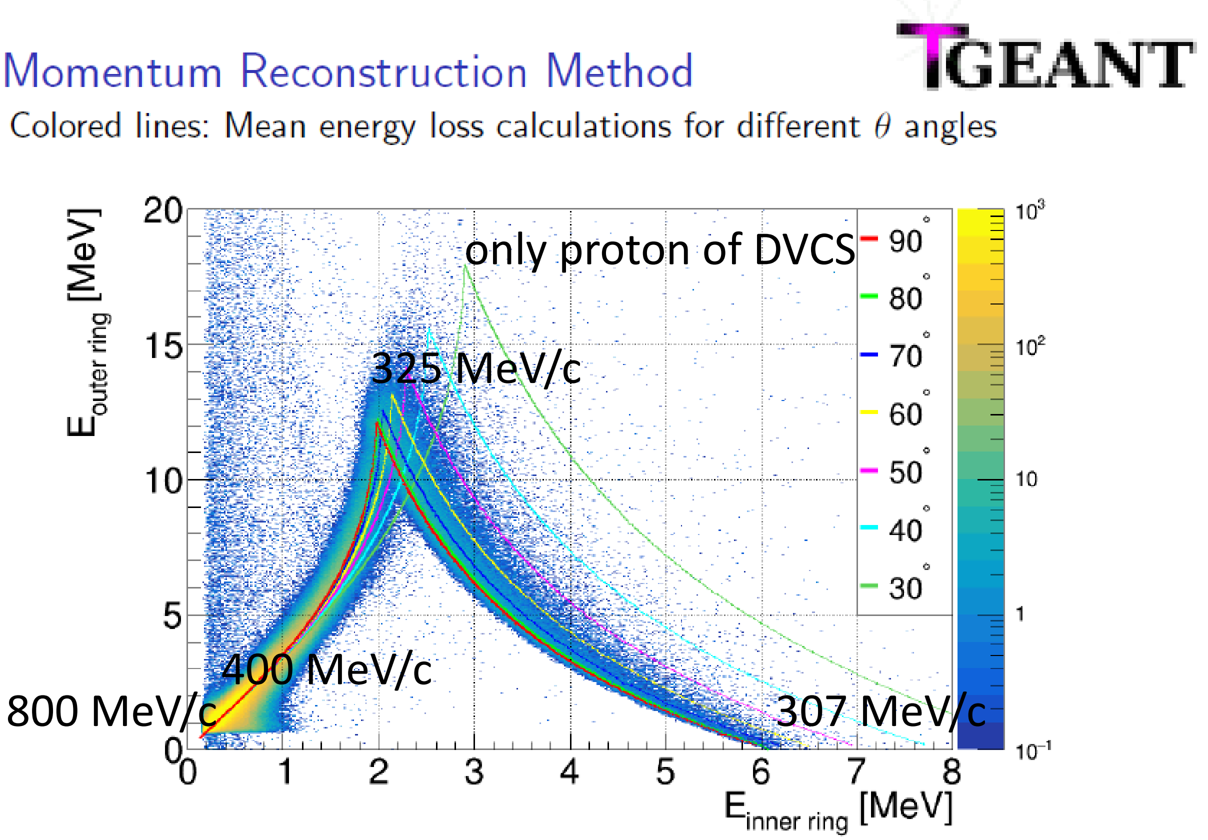


It could be worth to reduce the beam intercept with a target radius of 15mm to reach smaller t_{min}

Particle Identification



HERMES Recoil Detector
arXiv:1302.6092
JINST (2013)

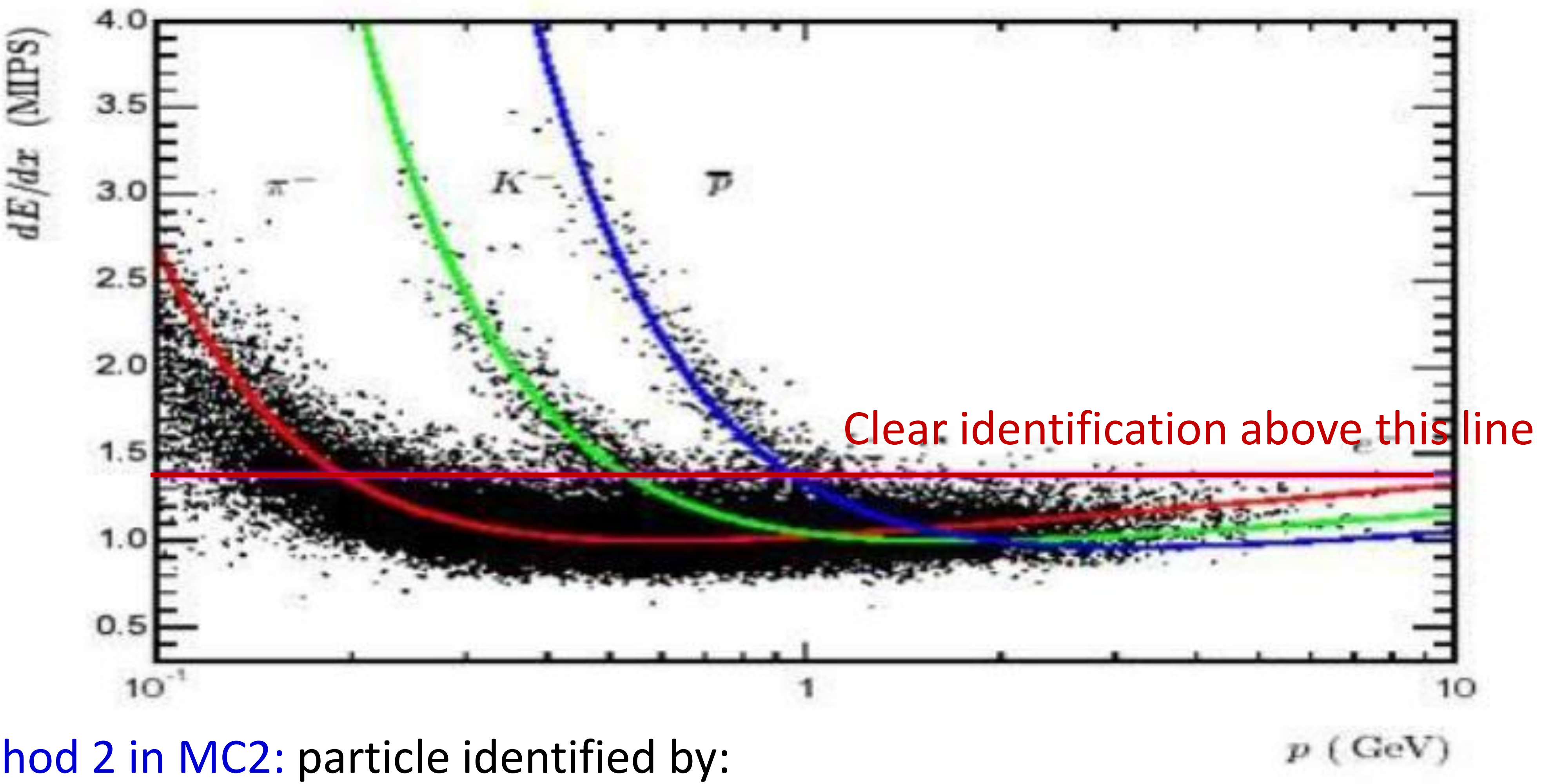


Method 1 in MC1 :

the momentum is determined by the

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

Particle Identification

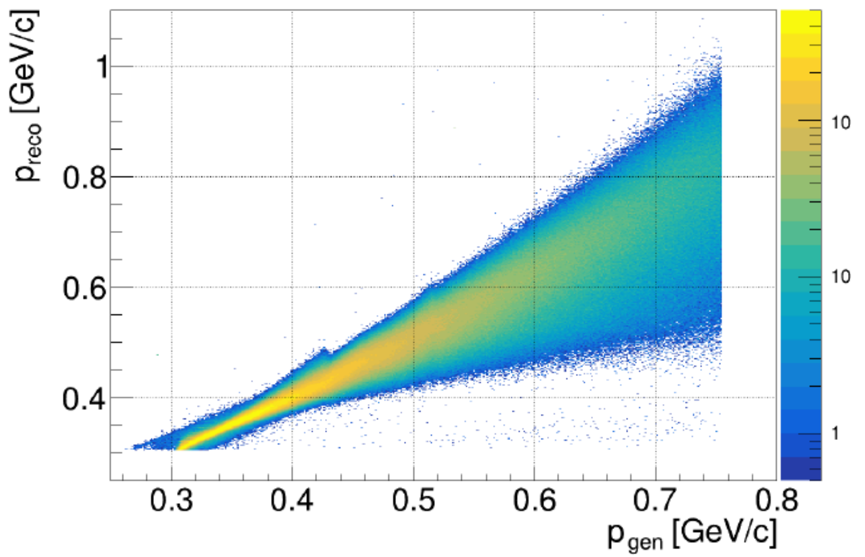


Method 2 in MC2: particle identified by:

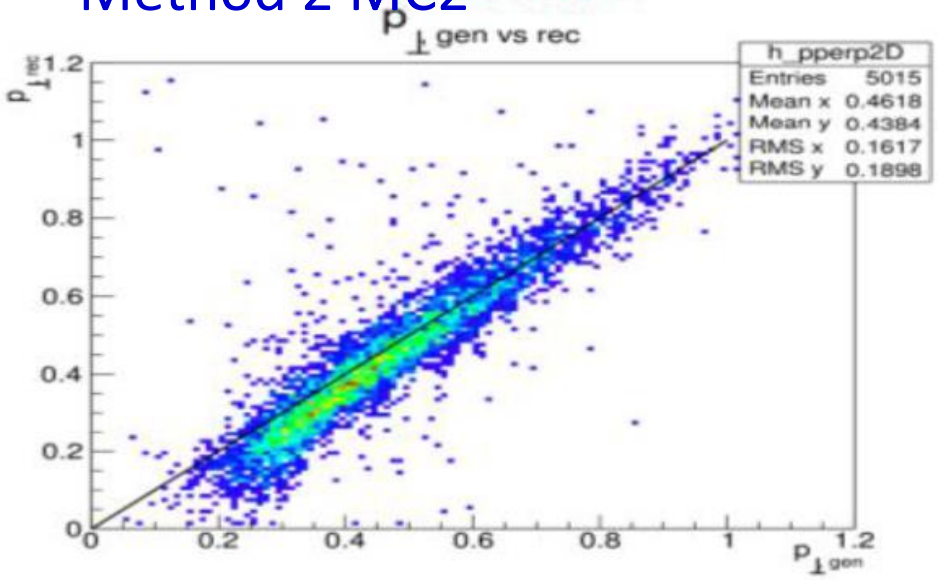
- the momentum measured in the magnetic field (with 3 geometrical points in the 3 SI layers)
- and dE/dx in one layer

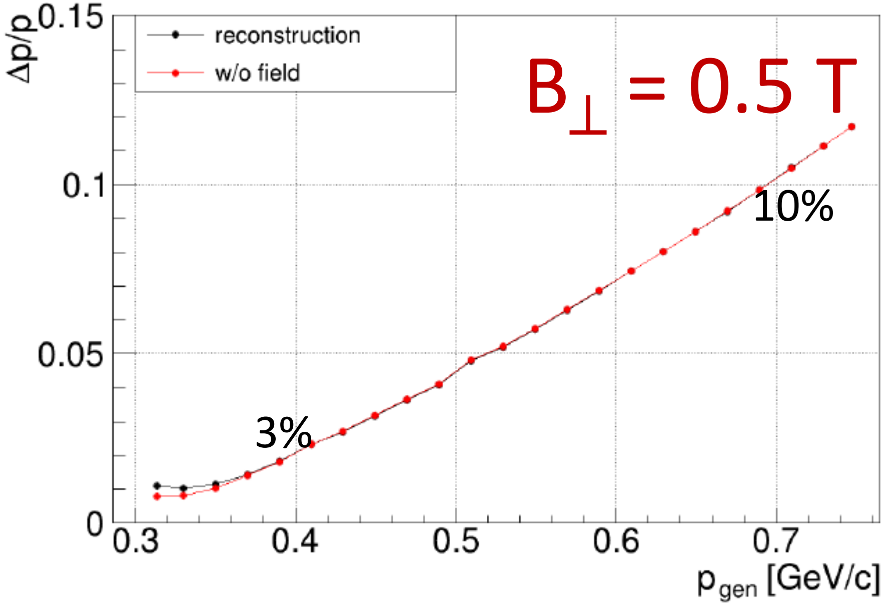
Proton Momentum resolution

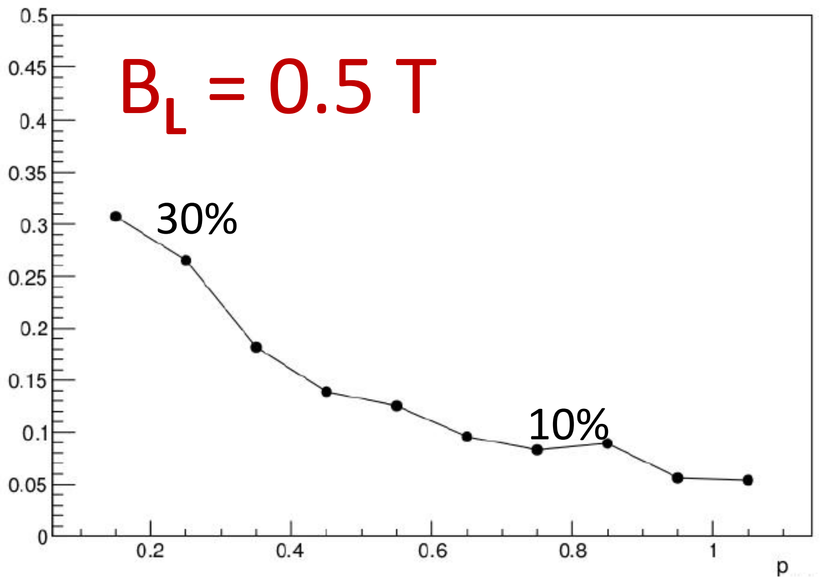
Method 1 MC1



Method 2 MC2

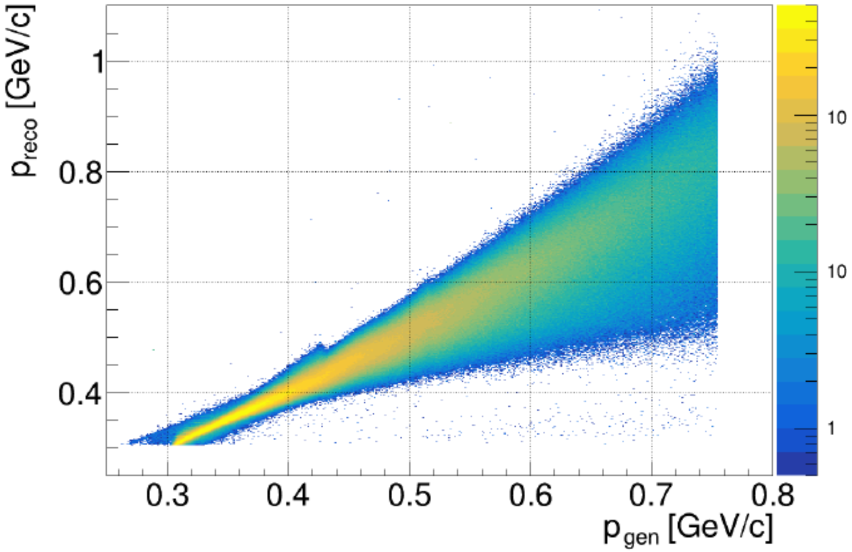




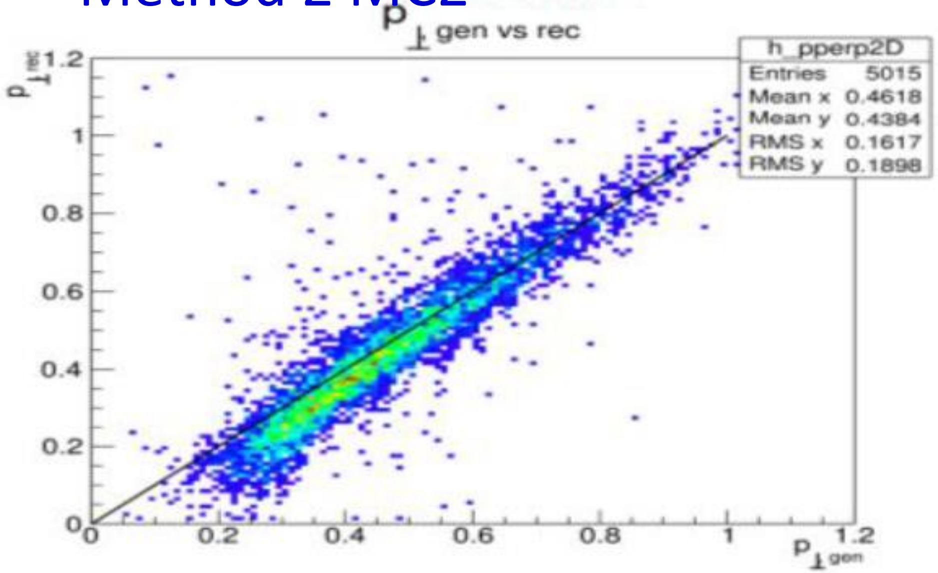


Proton Momentum resolution

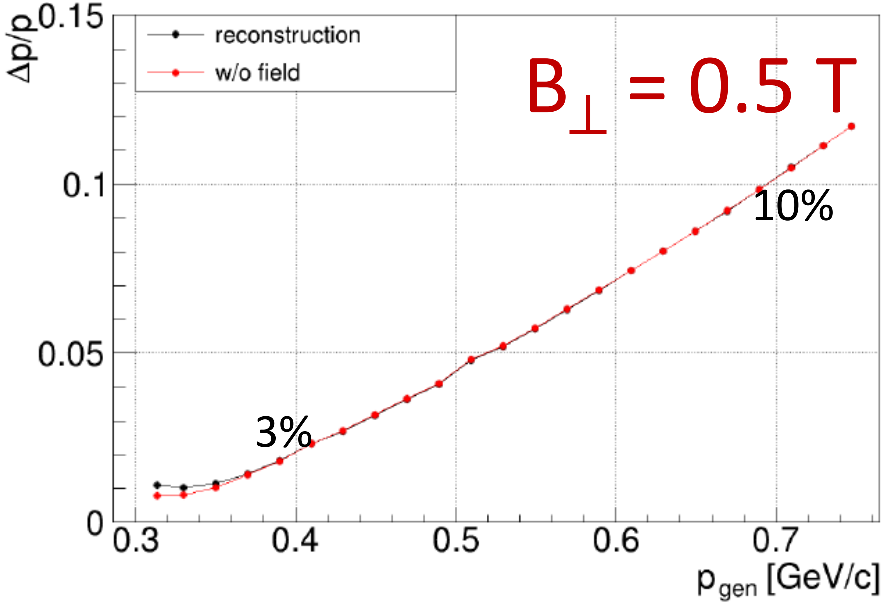
Method 1 MC1

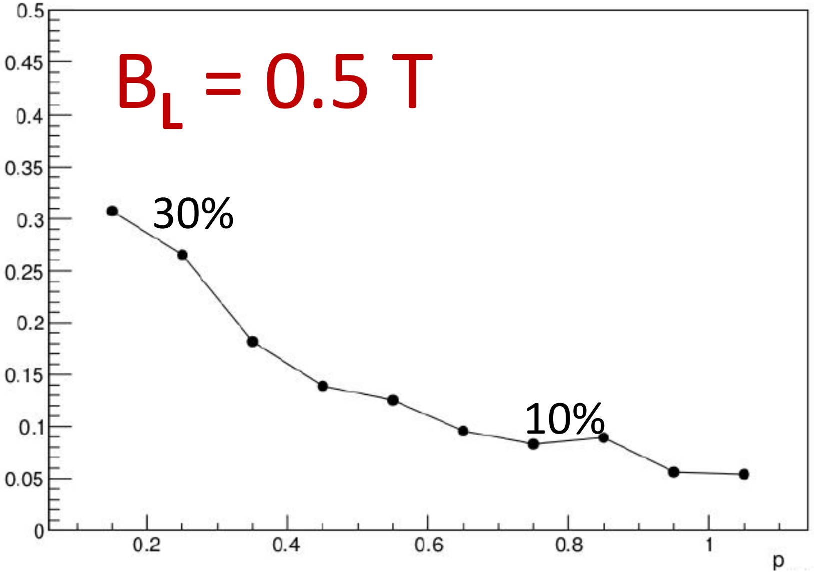


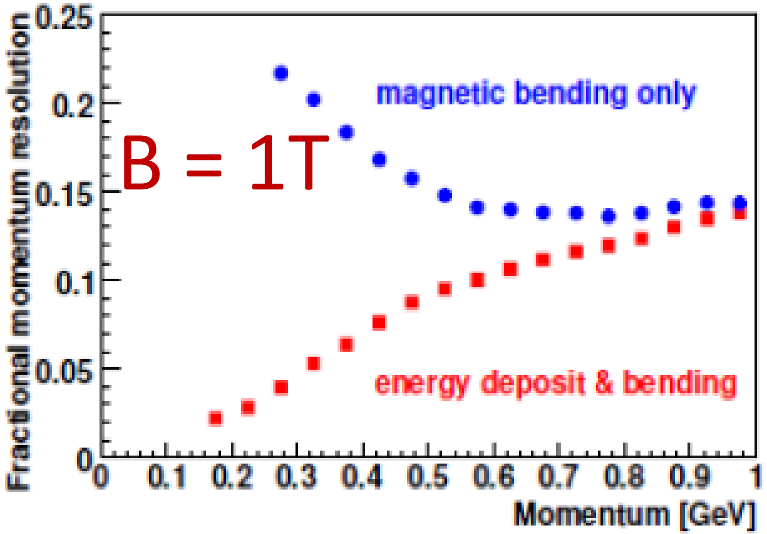
Method 2 MC2



HERMES Recoil Detector
arXiv:1302.6092
JINST (2013)

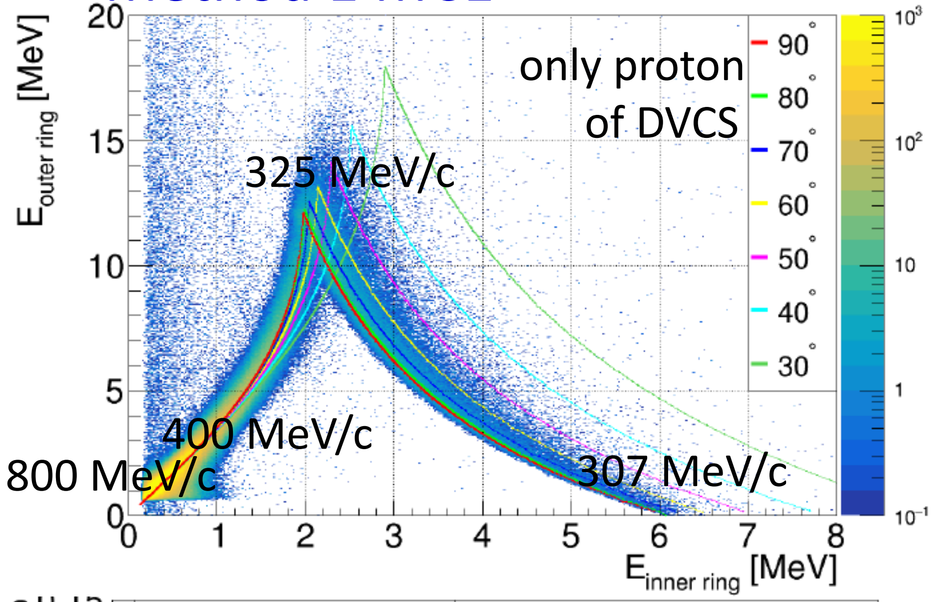




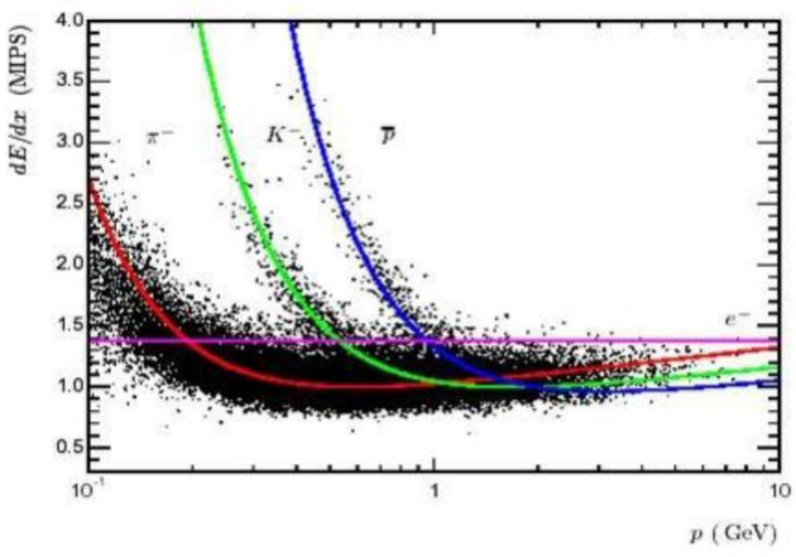


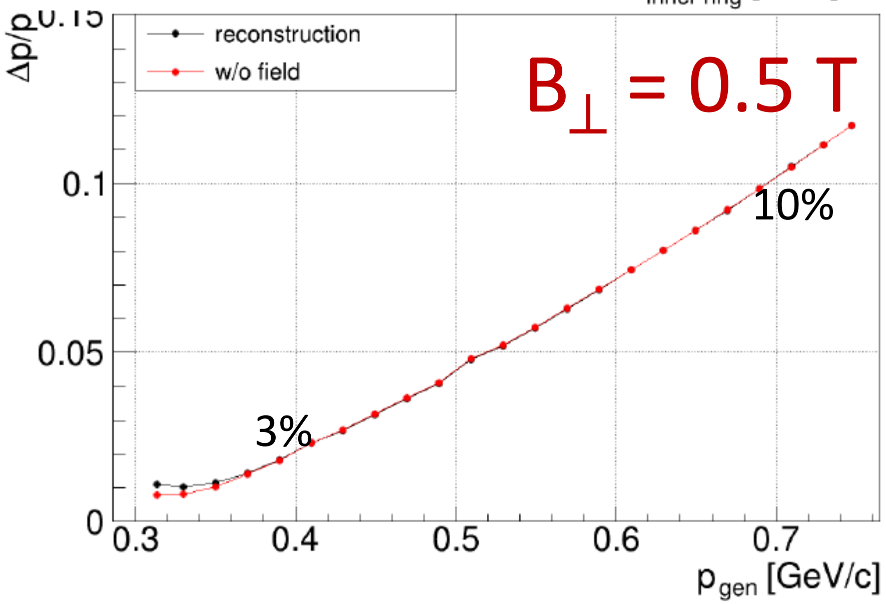
Proton Momentum resolution

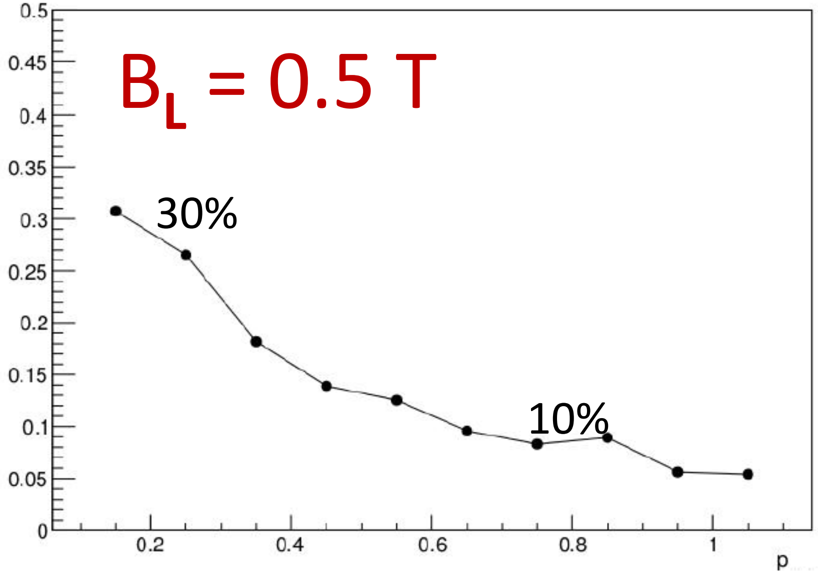
Method 1 MC1



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

Very Challenging project

Designs and MC simulations in progress

Many issues (operation of SI, cooling,
stability in Temperature for good resolution, …)

Is the "COMPASS GPD E" physics case sufficiently "hot"
to build a recoil detector compatible with the
polarized target, a major hardware task?

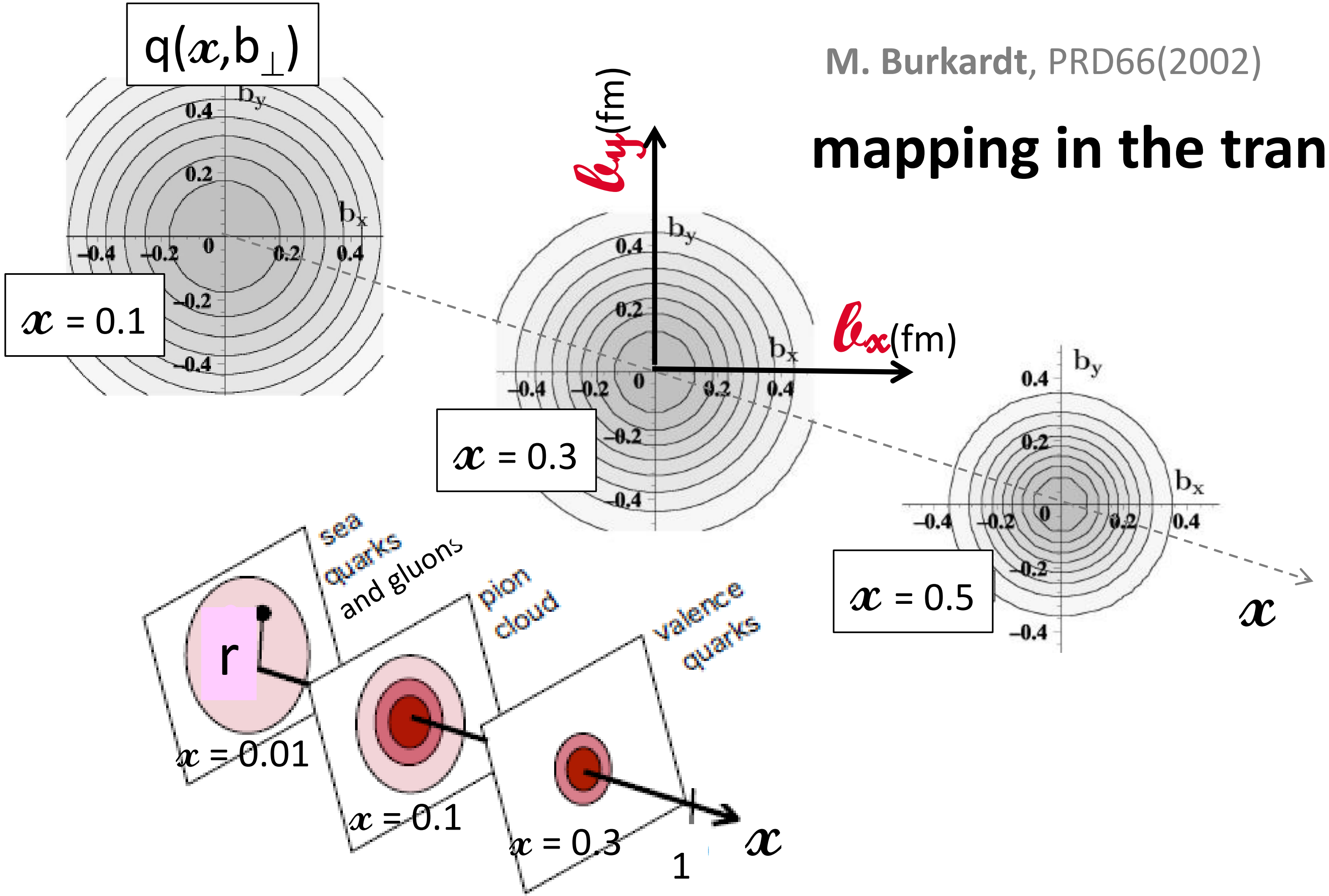
COMPASS has a limited luminosity comparatively to Jlab 12GeV
However it provides a unique high energy muon beam
to access the small x domain before any collider is built

Im $\mathcal{H}$ is used to study the 3D imaging

Proton
moving
towards us

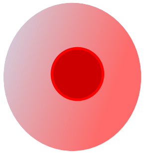
M. Burkardt, PRD66(2002)

mapping in the transverse plane

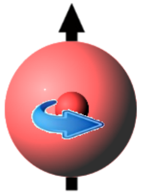
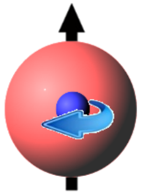


Correlation between the spatial distribution of partons
and the longitudinal momentum fraction

The GPD E is the grail for OAM quest

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

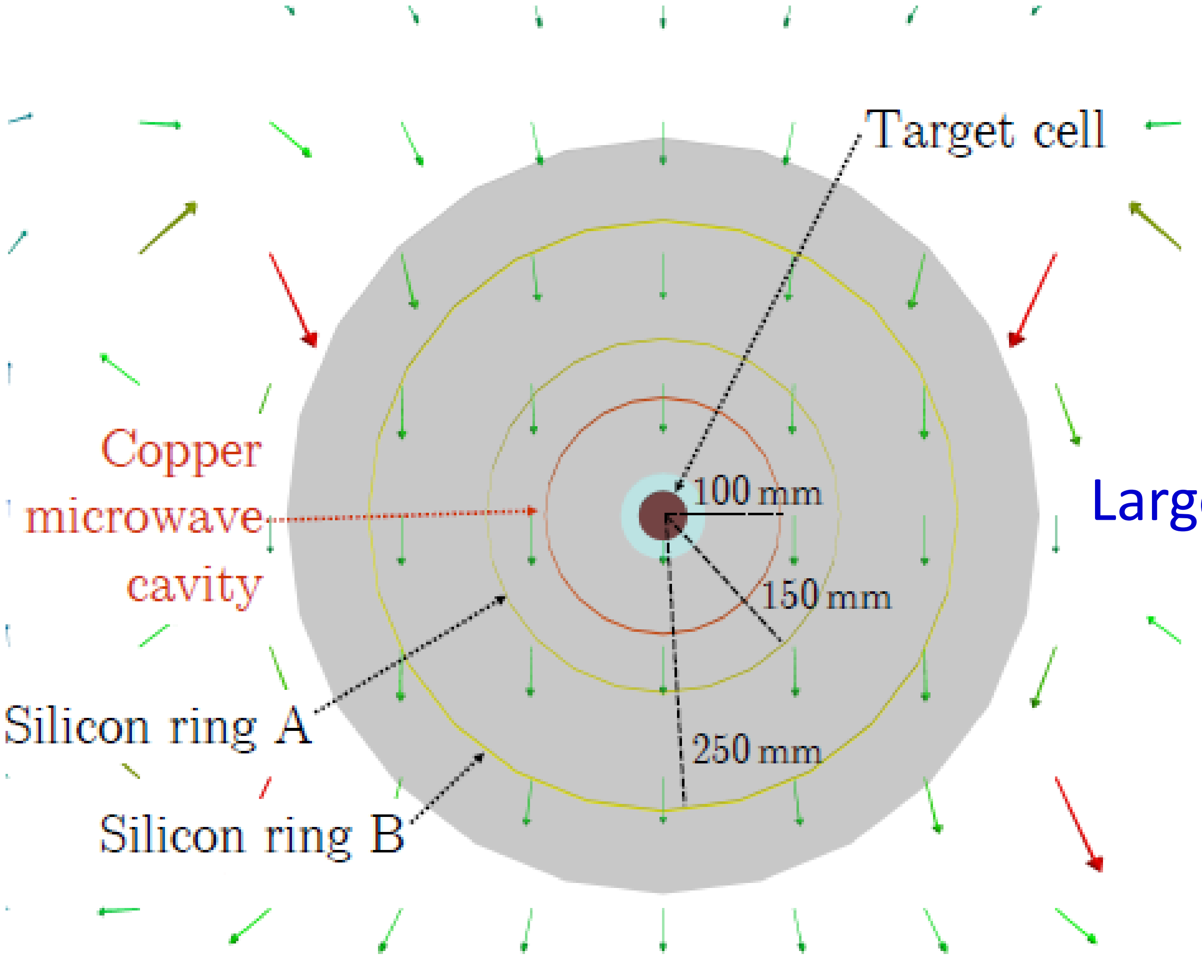
"Elusive"

$\mathbf{E}(x, \xi, t) \longleftrightarrow f_{1T}^{\perp}(x, k_T)$  -  **Sivers:** quark k_T & nucleon transv. Spin

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

Ex: Jlab	$x_B = 0.1, 0.2, 0.36$	$\lvert t \rvert_{min} \sim 0.01, 0.044, 0.16$ GeV^2	$\lvert t \rvert_{min\ exp} \sim 0.1$ GeV^2
COMPASS	$x_B = 0.01$	$\lvert t \rvert_{min} \sim 10^{-4}$ GeV^2	$\lvert t \rvert_{min\ exp} \sim 0.06$ GeV^2
EIC	$x_B = 0.0001$	$\lvert t \rvert_{min} \sim 10^{-8}$ GeV^2	goal of very small $\lvert t \rvert$ measurement

Influence of the transverse magnetic field



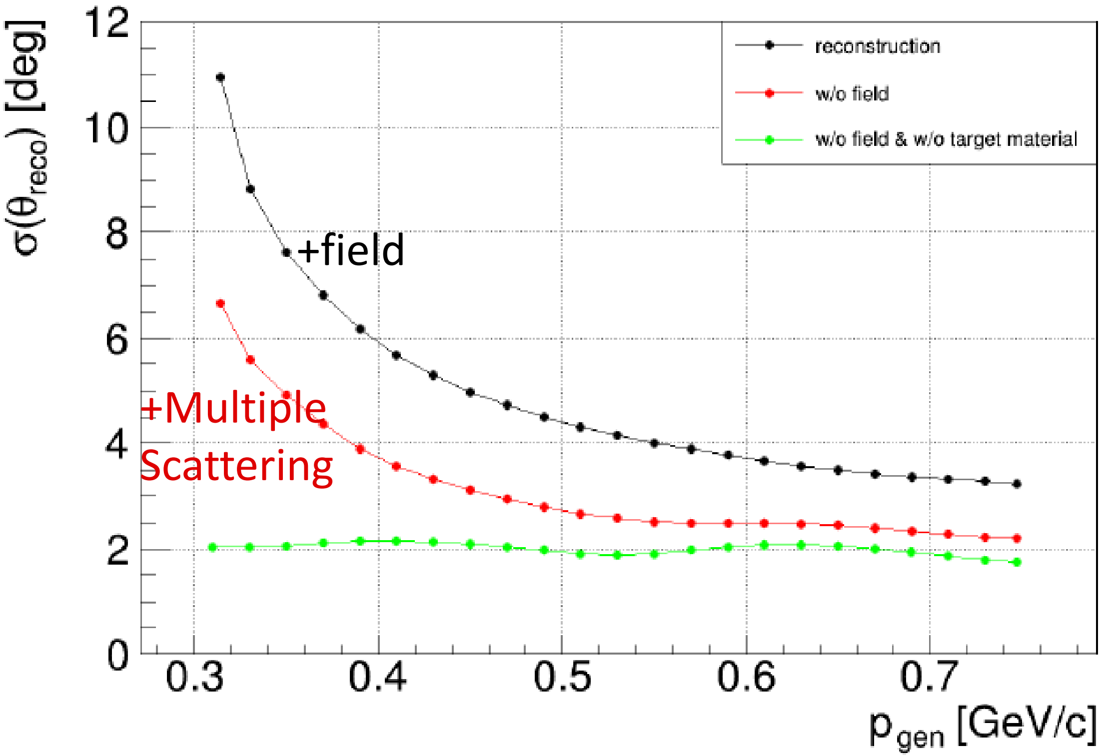
Largest variation in z (or θ)

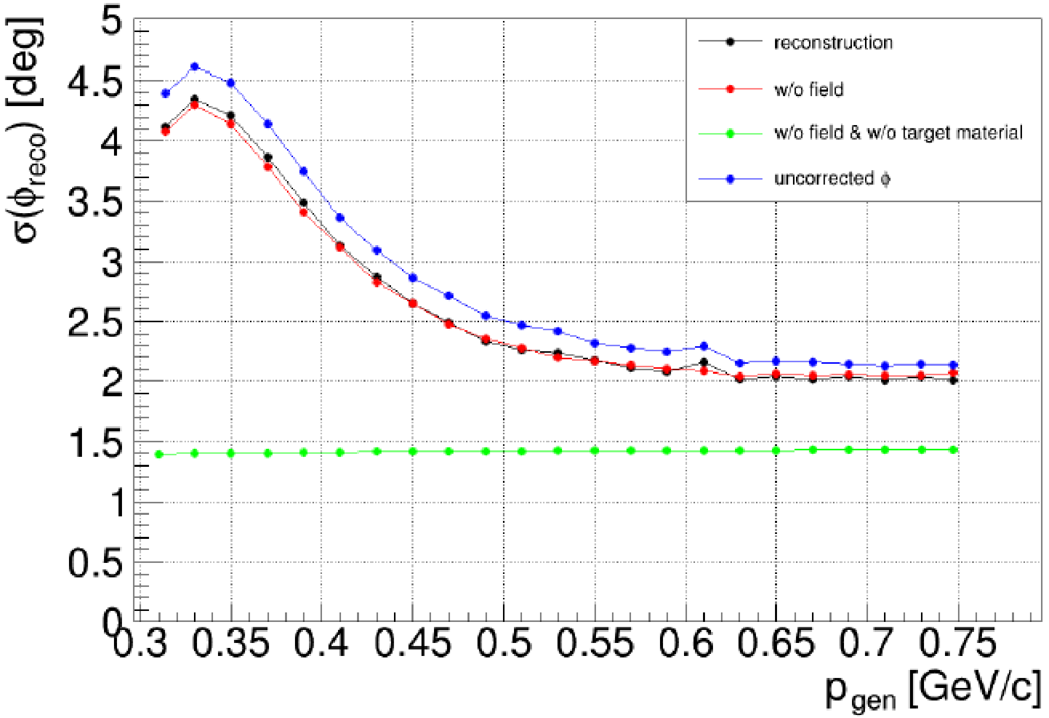
Effect decreases when proton momentum increases

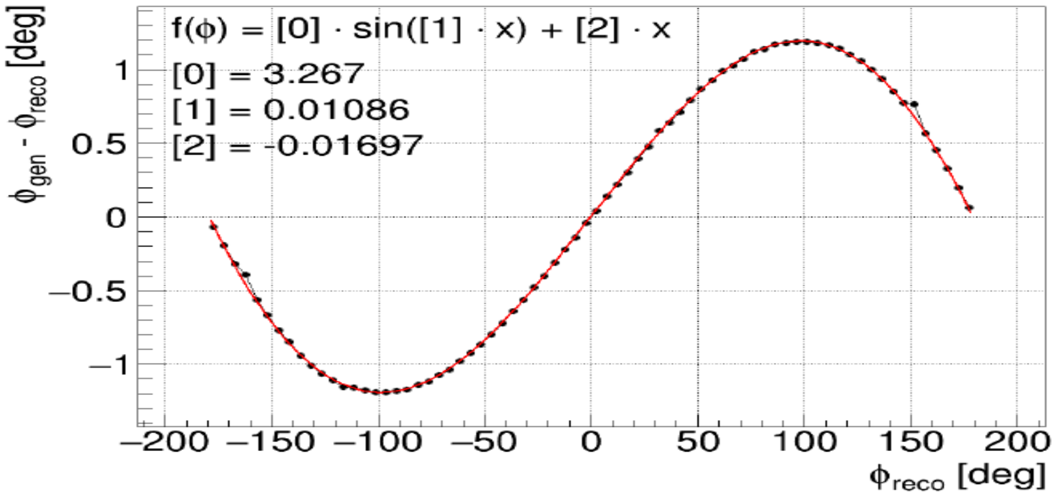
Largest variation in ϕ

TGEANT

Angular resolutions







Method 1 MC1

Pixel Size Effects

Method 1 MC1

Reference: 20 mm NH3, 0.6 mm Cu,
300 µm Ring A, 1000 µm Ring B