LOI12-18-002 submitted to Jefferson Lab PAC46

nDVCS with proton spectator tagging with SBS in Hall A

https://userweb.jlab.org/~efuchey/LOI-Props/nDVCS-TDIS_LOI.pdf

Eric Fuchey
University of Connecticut

Also on behalf of
***Alexandre Camsonne*, *Marco Carmignotto*, *Rachel Montgomery*, *Zhihong Ye*, *Andrew Puckett*, *Zhenyu Ye*, cospokespersons.**

Spin 2018

University of Ferrara, September 10th-14th, 2018

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Overview

Physics case:

- Nucleon spin puzzle and GPDs;
- Experimental access to GPDs;
- DVCS on neutron: - constraint on quark AM;
  - potential other physics on deuterium;

Experimental setup:

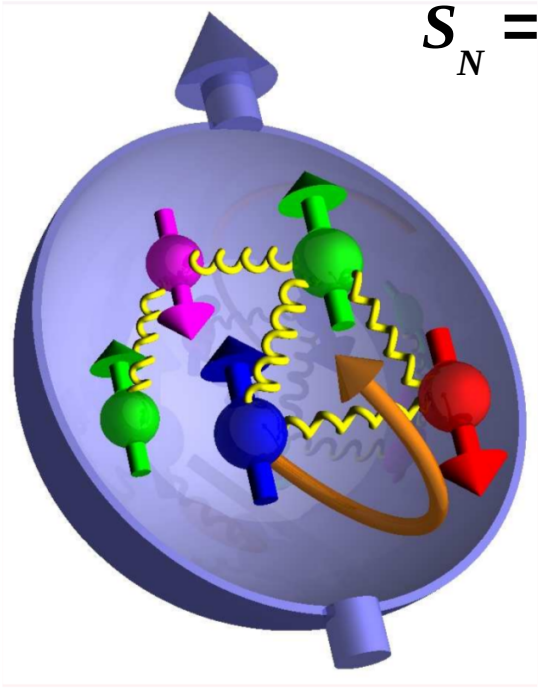
- nDVCS experiment and setup:
  - * SBS
  - * mTPC
  - * DVCS EM Calorimeter;
- Advantages of spectator proton tagging technique;

Expected results:

- Experimental effects;
- Kinematic coverage;
- Projections / Comparisons with ALERT;

Summary and next steps

Physics case:
Nucleon Spin Puzzle and GPDs



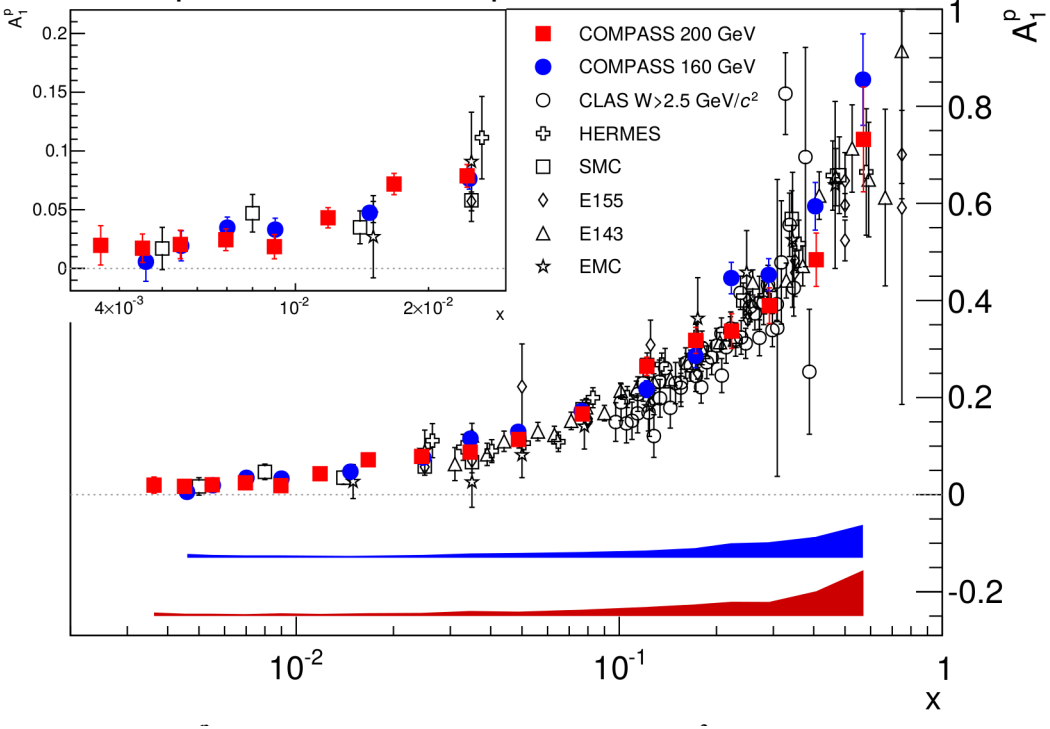
$$S_N = \tfrac{1}{2} = \tfrac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

Well known | known | unknown

Static quark model:
$\Delta\Sigma = 1$...

Experiments:
=> $\Delta\Sigma \sim 0.3$

Compass coll.: arXiv:hep-ex/1503.08935



ΔG ? (phenix, compass)

$\Delta g/g = 0.113 \pm 0.038(stat.) \pm 0.036(syst.)$
[Compass coll.: arXiv:hep-ex/1512.05053]

$L_{q,g}$? => needs "3D" parameterization

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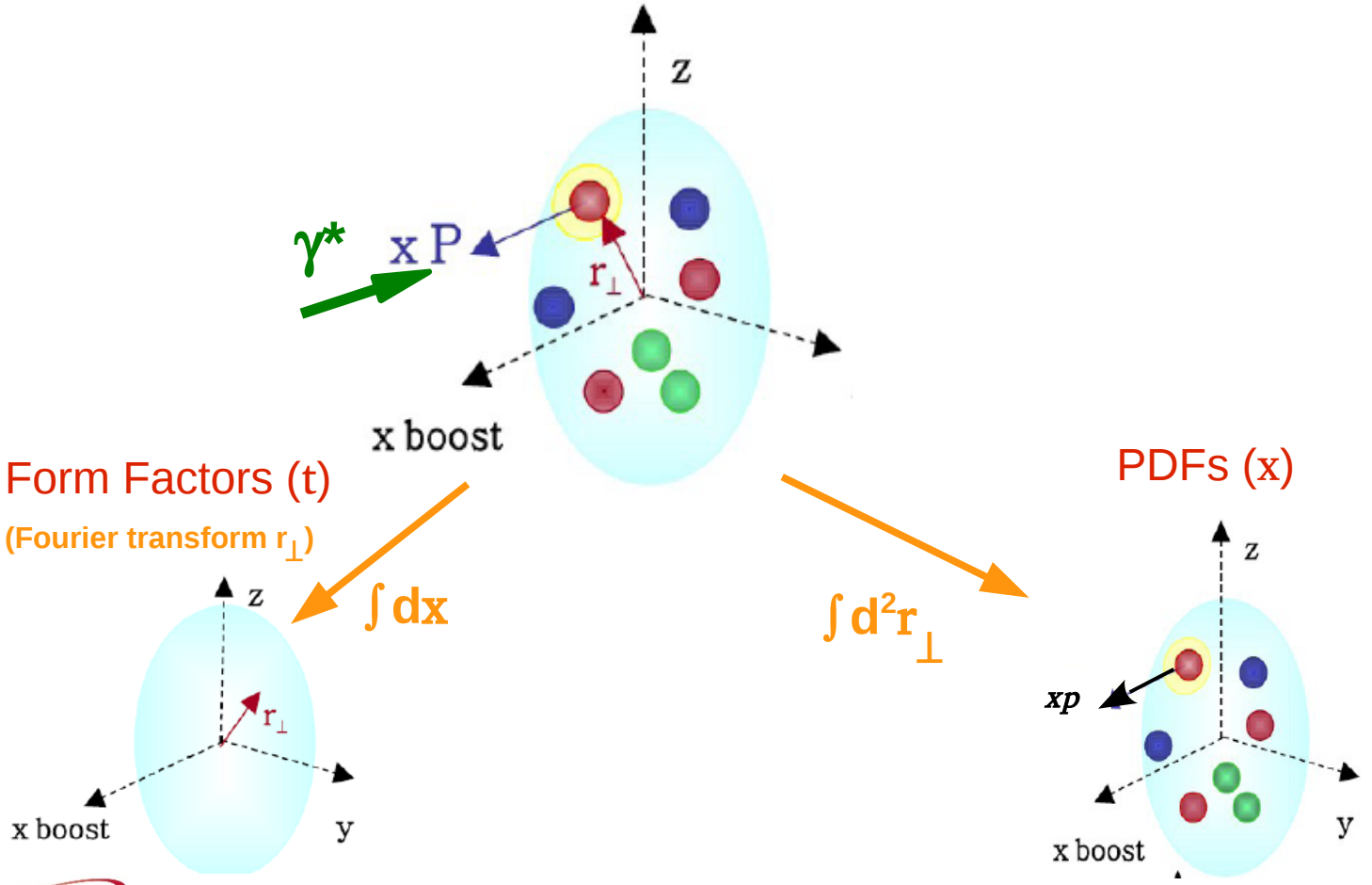
Physics case:
Nucleon Spin Puzzle and GPDs

'3D' Structure of nucleon :

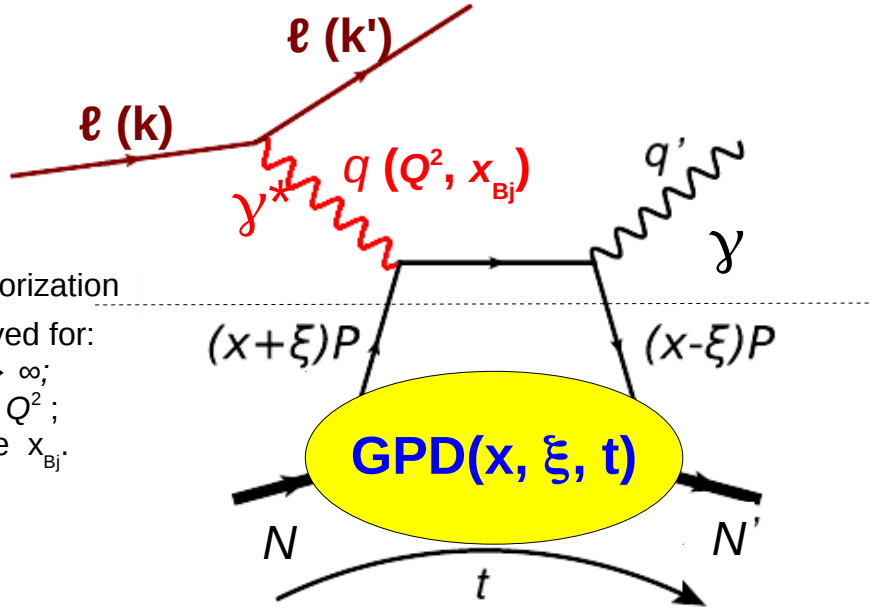
=> *Correlation* $r_\perp \leftrightarrow xP$

=> **Orbital Angular momentum**

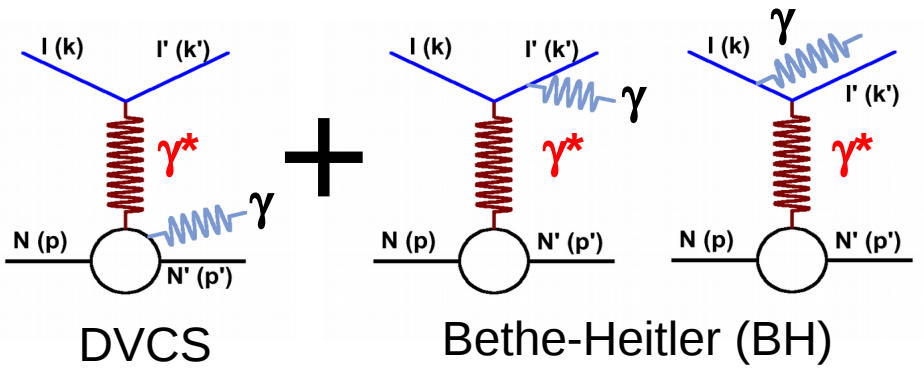


Physics case:
Experimental access to GPDs: DVCS

Exclusive reactions:
(DVCS: $\ell N \to \ell N \gamma$, HEMP: $\ell N \to \ell N h$)

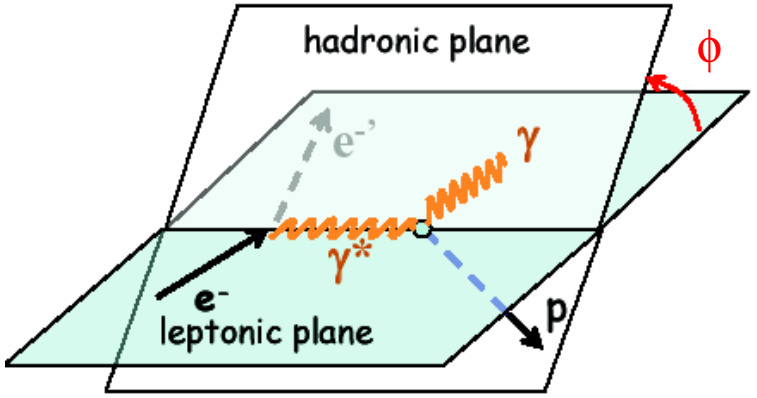


DVCS interferes with Bethe-Heitler:



$$\sigma^{lp \to lp\gamma} \propto \left[|BH|^2 + |DVCS|^2 + 2|DVCS||BH| \right]$$

ϕ modulation in beam spin asymmetry A_{LU}.



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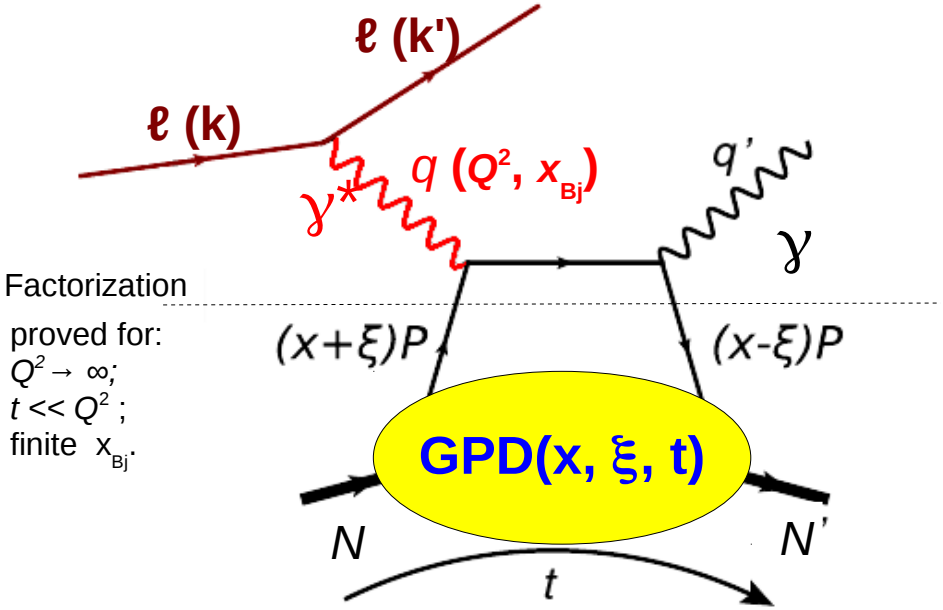

4 "chiral-even" GPD: $H, E, \widetilde{H}, \widetilde{E}$
+ 4 "chiral-odd" GPD$_T$: $H_T, E_T, \widetilde{H}_T, \widetilde{E}_T$

Ji sum rule: $\int dx\, x\, [H+E](t=0) = 2J$

At Leading Order:
Proton (unpolarized) : H
Neutron (unpolarized): E
Longitudinally polarized proton: $\widetilde{H}$
Transversely polarized proton: E

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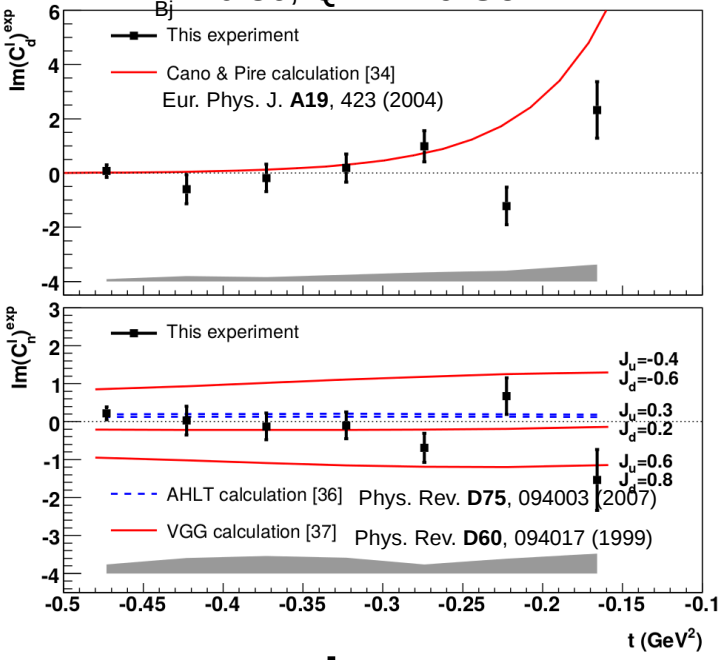
Physics case:
DVCS on neutron : constraint on quark AM

DVCS on neutron: => GPD E => quark AM J

Reminder:Ji sum rule: $\int dx\, x\, [H+E](t=0) = 2J$

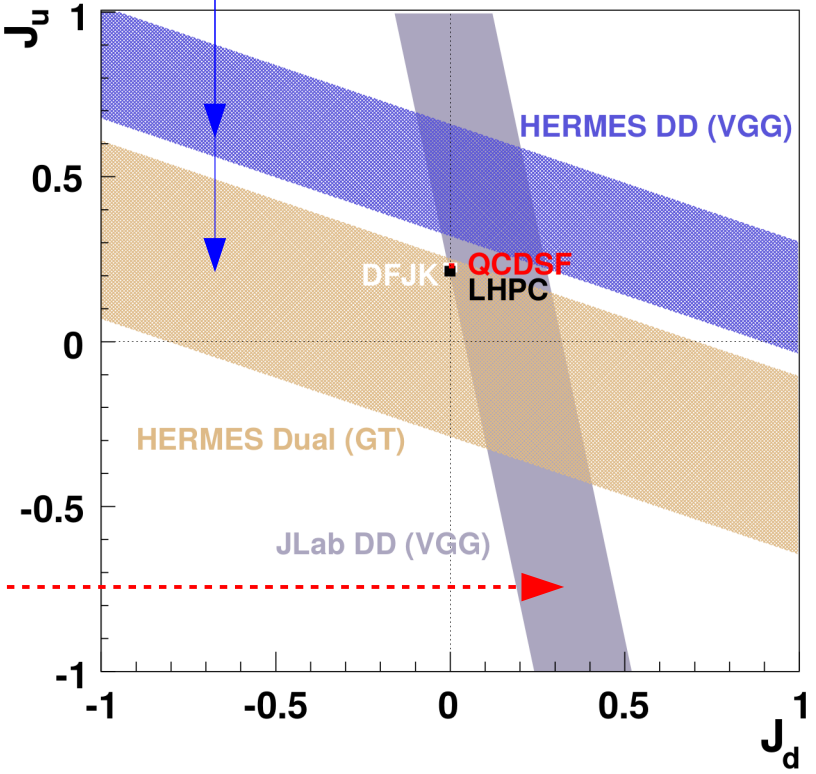
Compton Form Factors extracted from cross sections
[Mazouz and Hall A coll. : Phys. Rev. Lett. **99**, (2007) 242501]

x_{Bj} = 0.36, Q^2 = 1.9 GeV^2



constraint $J_{d,u}$

+HERMES TTSA on proton: ($J_{u,d}$)
[HERMES coll.: J. High Energy Phys. **0806** (2008) 066]



VGG: Vanderhaeghen, Guichon, Guidal, Phys. Rev. **D60**, 094017 (1999)
GT: Guzey, Teckentrup, Phys. Rev. **D74** (2006) 054027.
QCDSF/UKQCD Coll.: Eur. Phys. J. **A32** (2007) 445.
LHPC Coll.: Phys. Rev. **D77** (2008) 094502.
Diehl, Feldmann, Jakob, Kroll, Eur. Phys. J. **C39** (2005) 1.
} L-QCD

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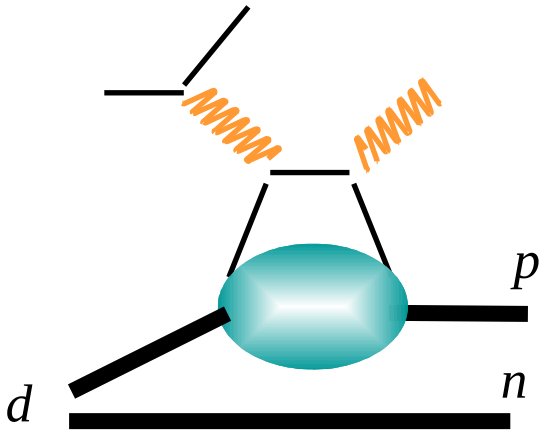
Physics case:
DVCS on neutron: potential other physics on deuterium

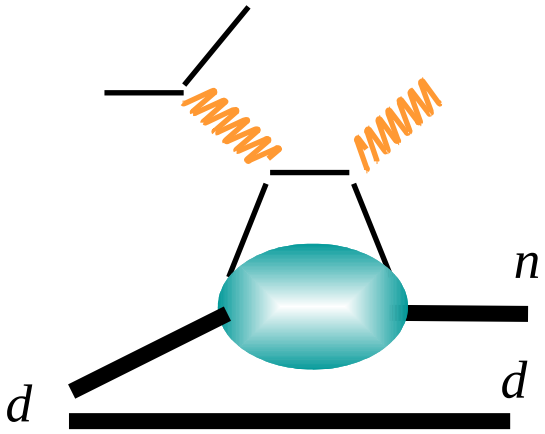
With a Deuterium target one can have 3 different DVCS processes

$$D(e,e'\gamma)\,X = d(e,e'\gamma)\,d + n(e,e'\gamma)\,n + p(e,e'\gamma)\,p + \mathrm{K}$$



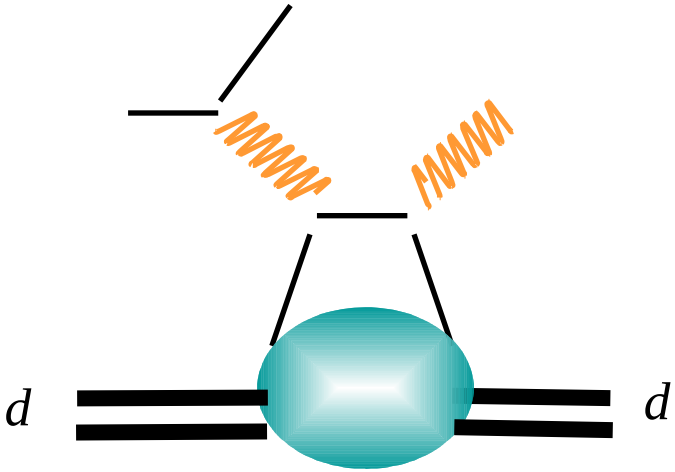
p-DVCS

(incoherent)



n-DVCS

(incoherent)



d-DVCS

(coherent)

II

V

Access deuteron GPDs

+ exclusive π^0 electroproduction on neutron, deuterium:
$en \rightarrow en\pi^0$, $ed \rightarrow ed\pi^0$

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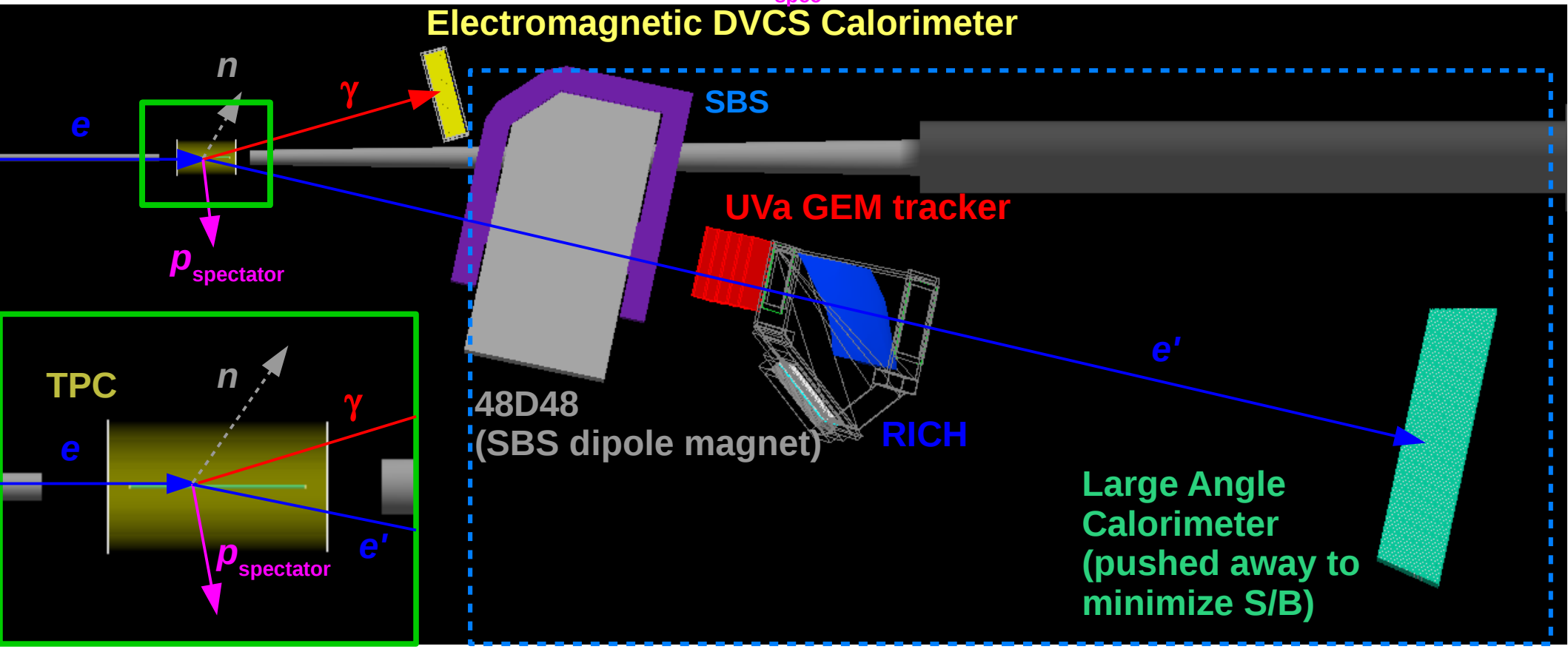
Summary and next steps

Experimental setup:
nDVCS experiment and setup

Most equipment common with Tagged DIS experiment (H/D(e, e' p_{spec})X) in Hall A (except EM calorimeter)

nDVCS: D(*e*,*e'*γp_{spec})*n*



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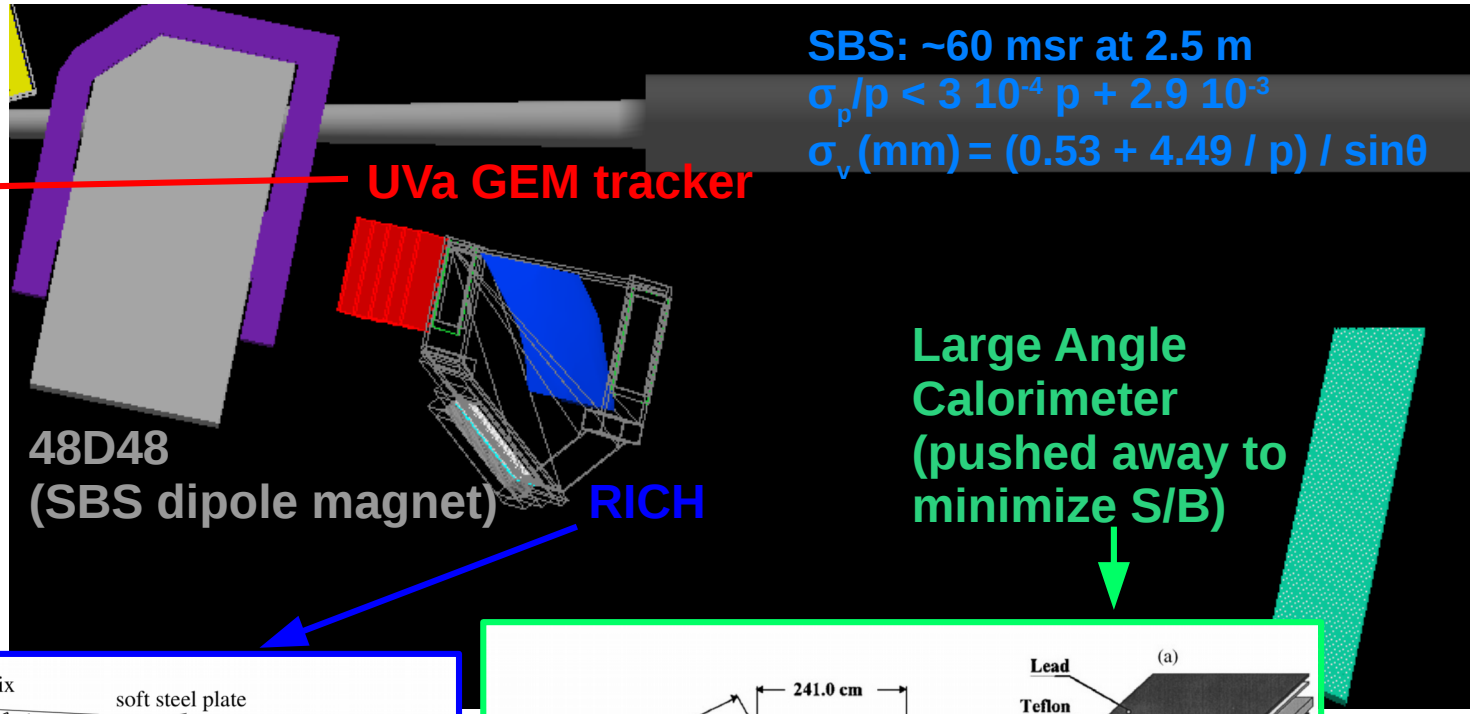
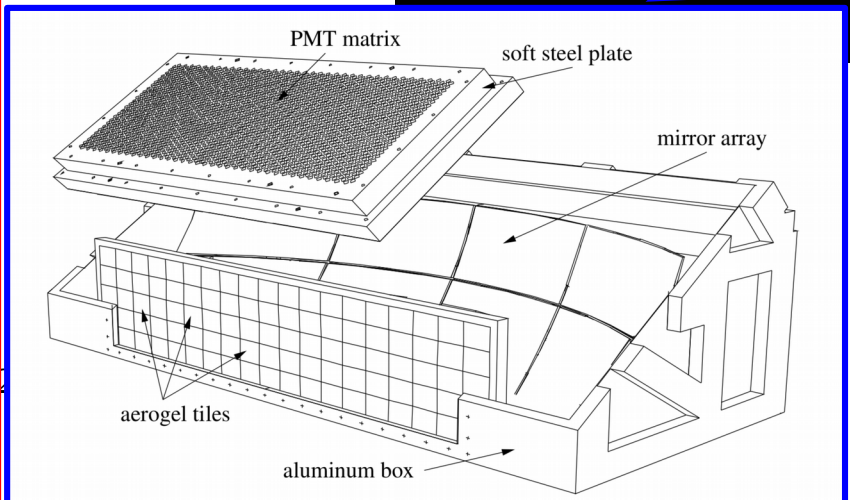
Experimental setup:
nDVCS experiment and setup: SBS

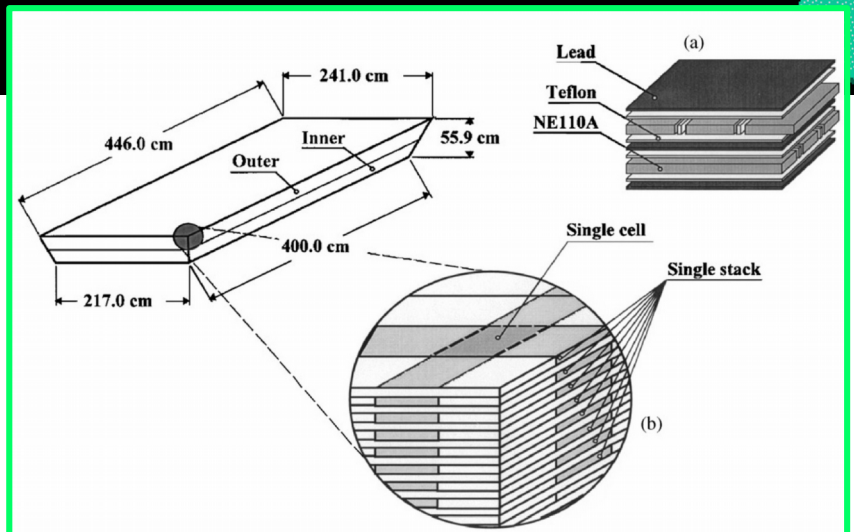
Super BigBite Spectrometer: medium solid angle dipole with modular detector package.

***Purpose:* measure scattered electrons:** (D(e,$e'\gamma p_{spec}$)n)

Detector package (for this expt): UVA GEMs, SBS (*HERMES*) RICH, Large Angle Calorimeter (Hall B CLAS6)







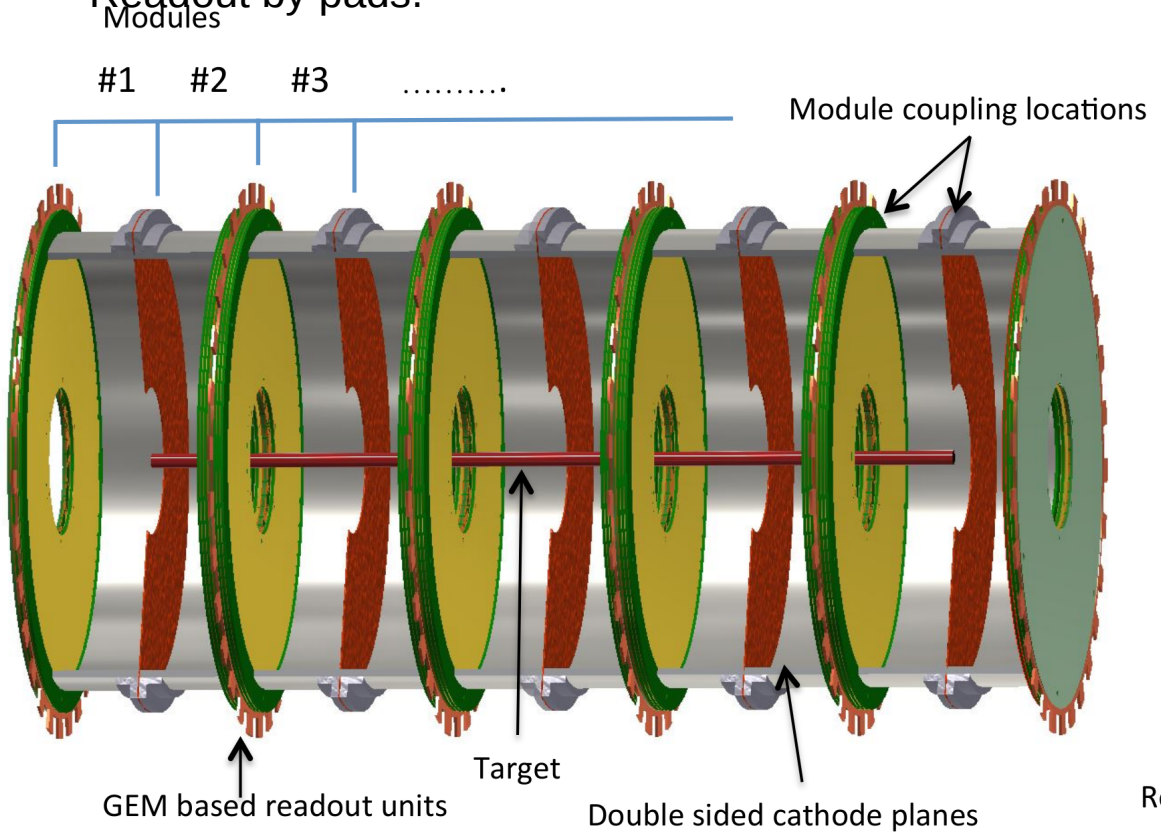
Experimental setup:
nDVCS experiment and setup: TDIS mTPC

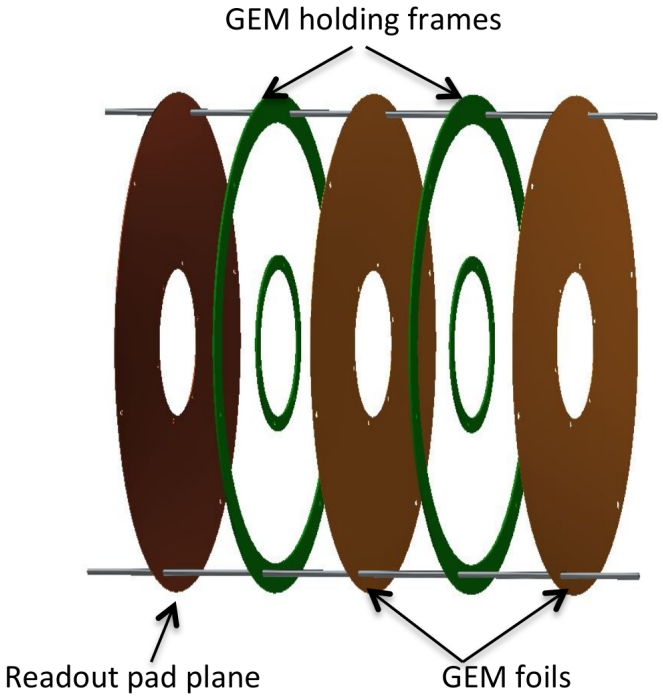
mTPC (m for “multiple Time Projection Chamber”):

Purpose: **detect low momentum spectator proton** (D(e,$e'\gamma p_{spec}$)n)

Actively developed for Tagged DIS experiment (H/D(e, e' p_{spec})X) by UVA.

* Split into 10 modules => drift time ~ 1-2 μs => “high” luminosity ~ 3.0 10^{36} cm^{-2} s^{-1} N^{-1}.
* Electric field // magnetic field;
* Drift electron amplified by GEM foils
* Readout by pads.





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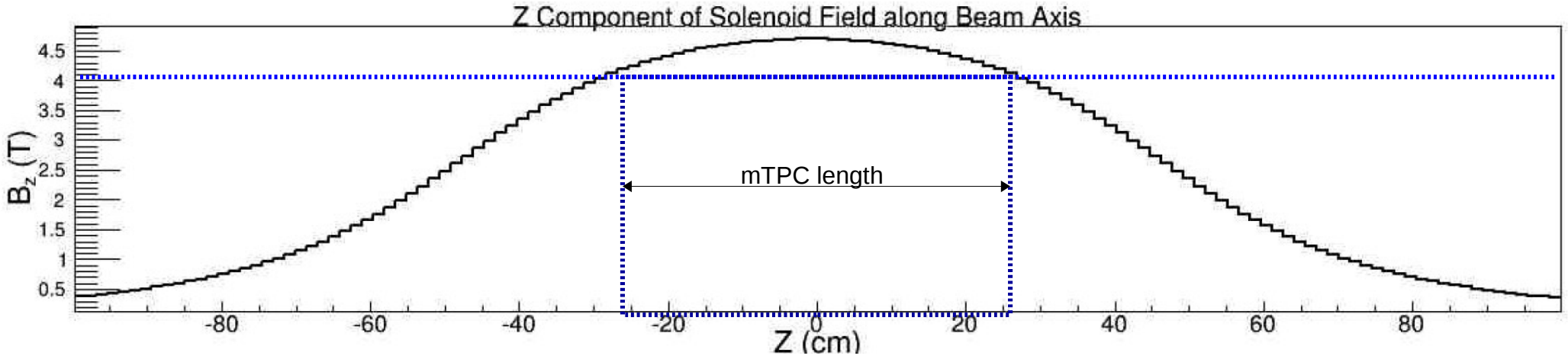
Experimental setup:
nDVCS experiment and setup: TDIS mTPC

TOSCA magnetic field profile for the mTPC
=> above 4T along the mTPC length



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Experimental setup:
nDVCS experiment and setup: EM Calorimeter

DVCS Calorimeter:

Purpose: **detect the high energy photon** (D(e,e'γp_{spec})n)

First option

NPS/PRIMEX $PbWO_4$ calorimeter:

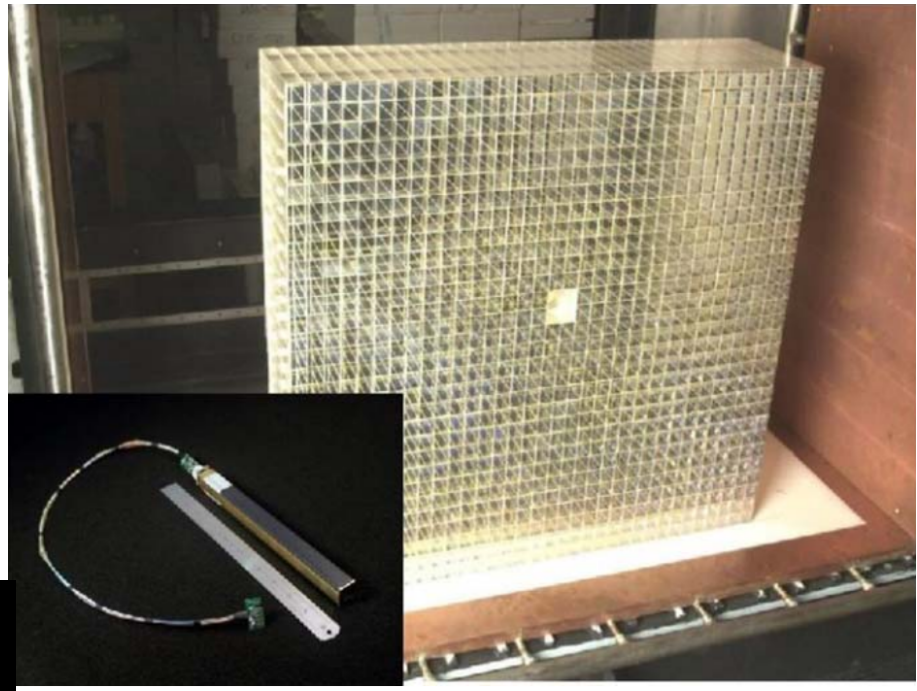
1116 (36x31) $PbWO_4$ blocks, 2.05x2.05*18 cm^3.

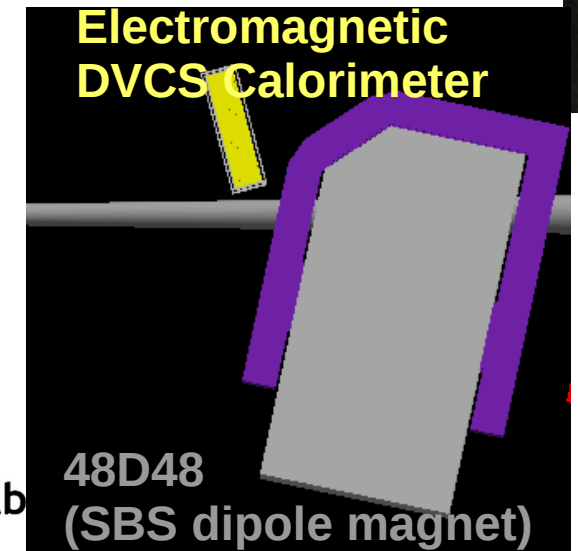
Assets:

- Energy and position resolution;
- Size/coverage: 63.6 x 73.8 cm^2

(~120 msr at ~15 deg, 2 m from target)

Because of SBS magnet fringe field proximity, a careful study to shield this fringe field will be required (as well as mechanical compatibilty...)





Experimental setup:
nDVCS experiment and setup: EM Calorimeter

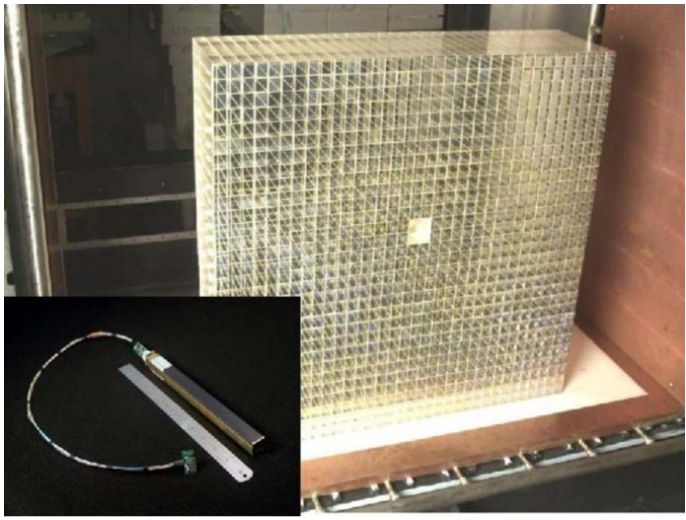
If NPS/PRIMEX blocks not available

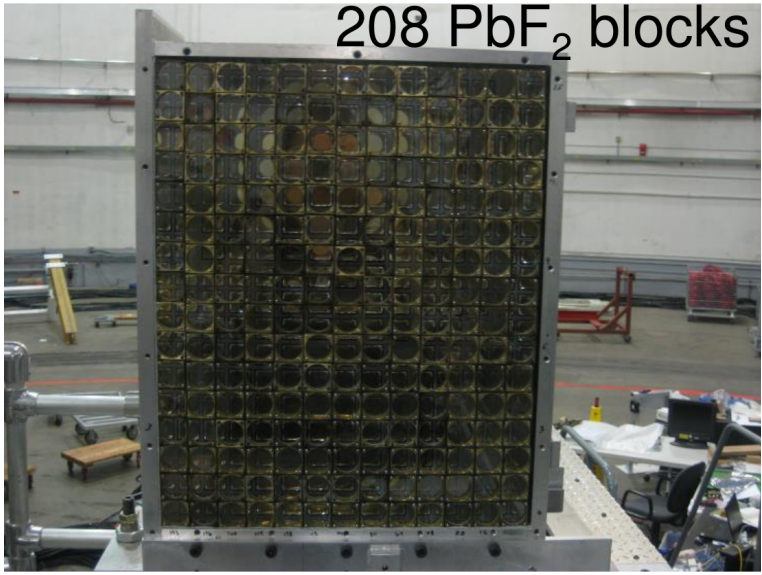
Possible backup: DVCS Hall A PbF_2 calorimeter:

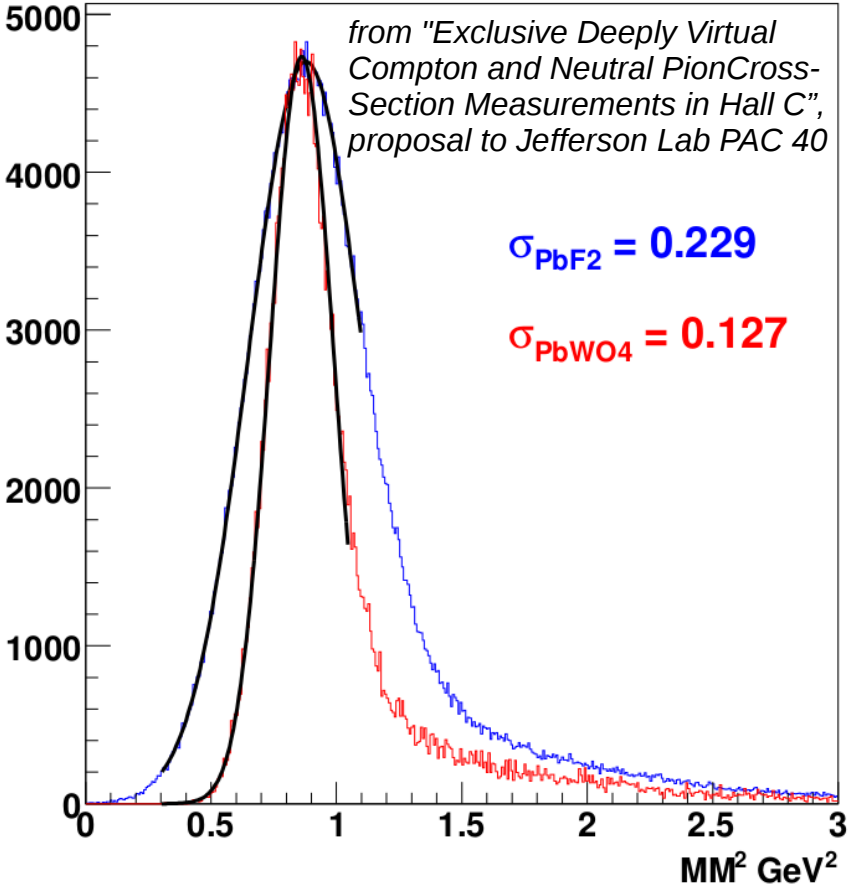
208 (13*16) PbF_2 blocks, 3.0*3.0*18.5 cm^3.

Too small as is, but can be extended
(e.g. with lead glass away from the beam)

Main drawback: worse energy and position resolution;
(~x2 wider exclusive peak in MM distribution)







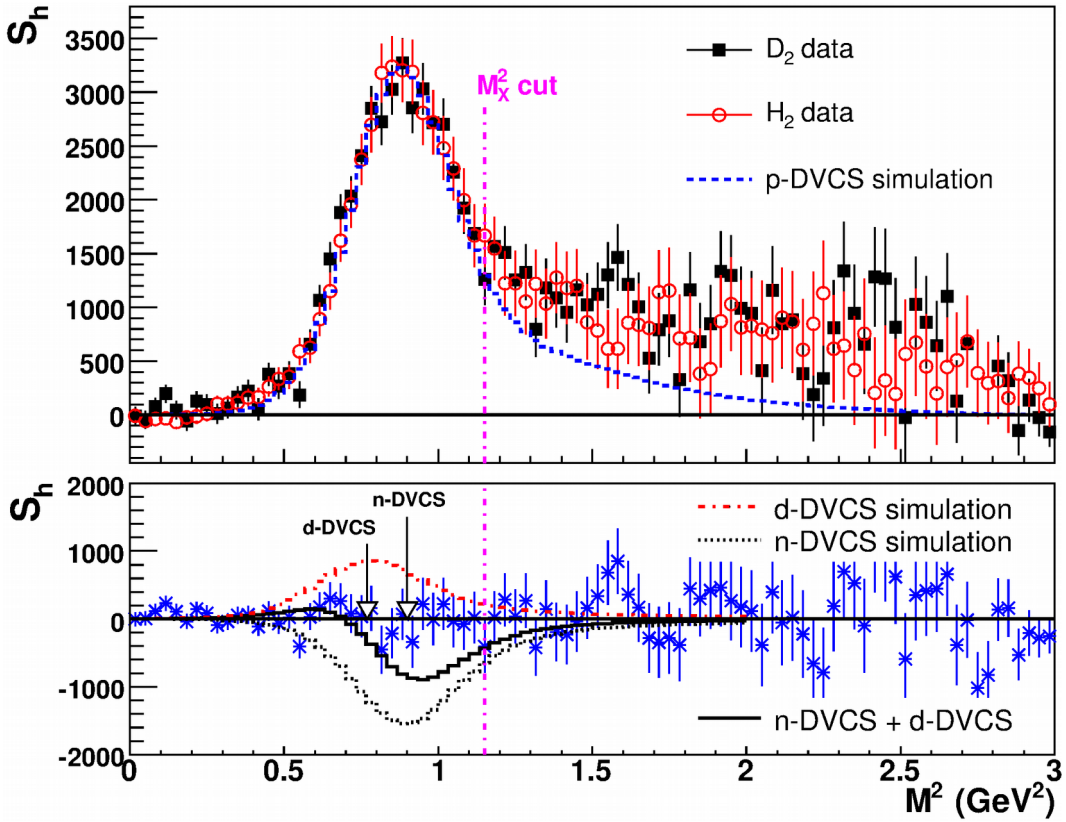
$$MM^2 = M_X^2 = (k + N + k' - q')$$

Experimental setup:
Advantages of proton spectator tagging technique

* **Unambiguous identification of *en*→*enγ* among *D(e, e'γ)X***
(highly desirable: without it, systematic uncertainty on n/p separation can be huge.)

* detection of spectator proton in mTPC may provide better vertex and momentum resolution than detection of a neutron

=> spectator proton information *may* improve the resolution on the reconstructed missing mass of the system D(e, e'γ p_{spec})n



Example of D(e, e'γ)X data with no p/n disambiguation: data from Hall A 6 GeV
M. Mazouz *et al.,* Phys. Rev.Lett. 99 (2007) 242501

$$M_X^2 = (k + N(\vec{p} = \vec{0}) + k' - q')$$

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  - potential other physics on deuterium;

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- nDVCS experiment and setup:
  * SBS
  * mTPC
  * DVCS EM Calorimeter;
- Advantages of spectator proton tagging technique;

Expected results:

- Experimental effects;
- Kinematic coverage;
- Projections / Comparisons with ALERT;

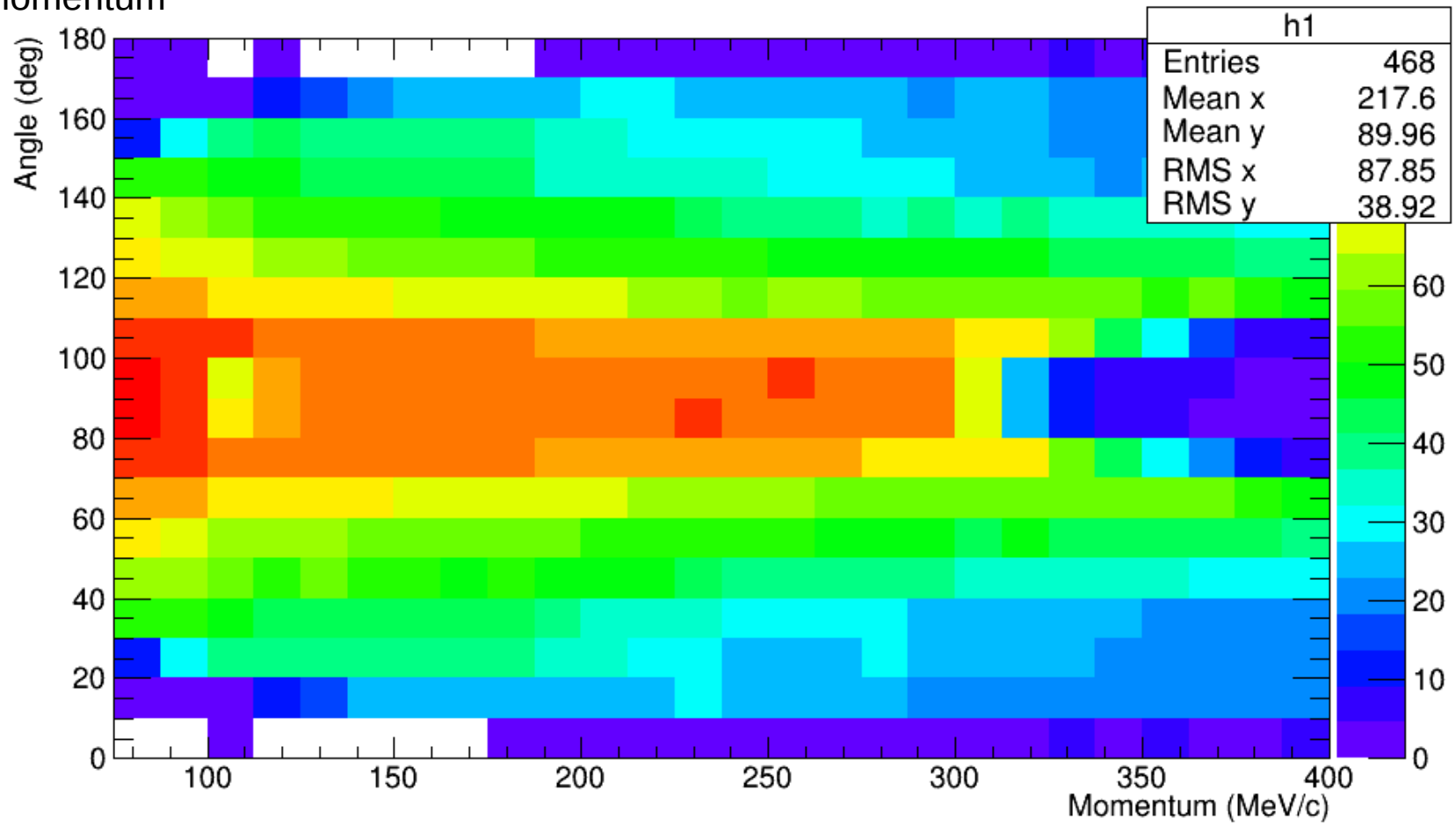
Summary and next steps

Expected results :
Experimental effects : mTPC efficiency

mTPC efficiency: (Courtesy from Marco Carmignotto, JLab)

Semi-empirical efficiency:

proportion of protons reaching active gas volume and reconstructed within 10 % of generated momentum



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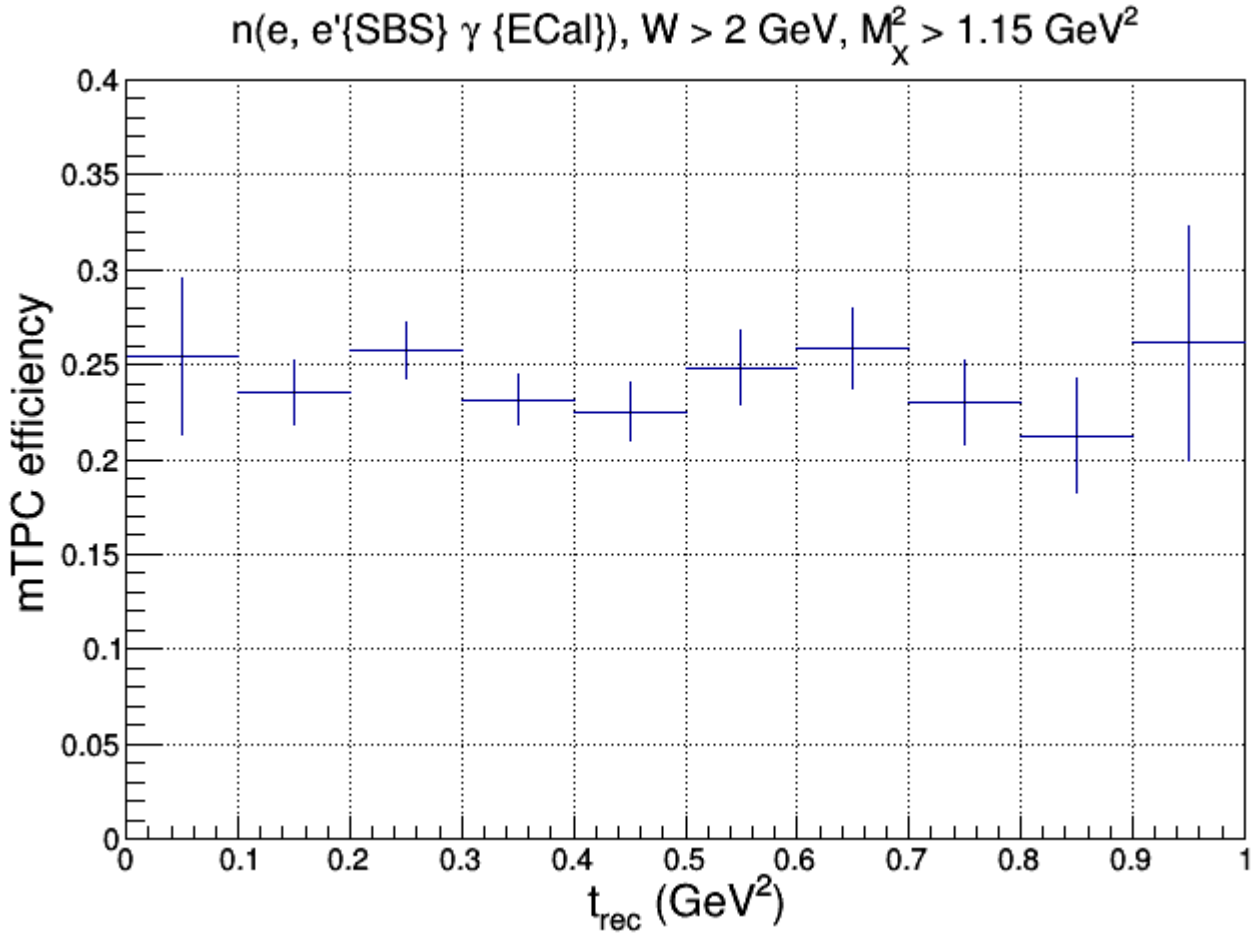
Expected results :
Experimental effects : mTPC efficiency

mTPC efficiency:

~25 % n(e, e' γ)X events correctly tagged with spectator proton with such efficiencies (*no dependence in t*)



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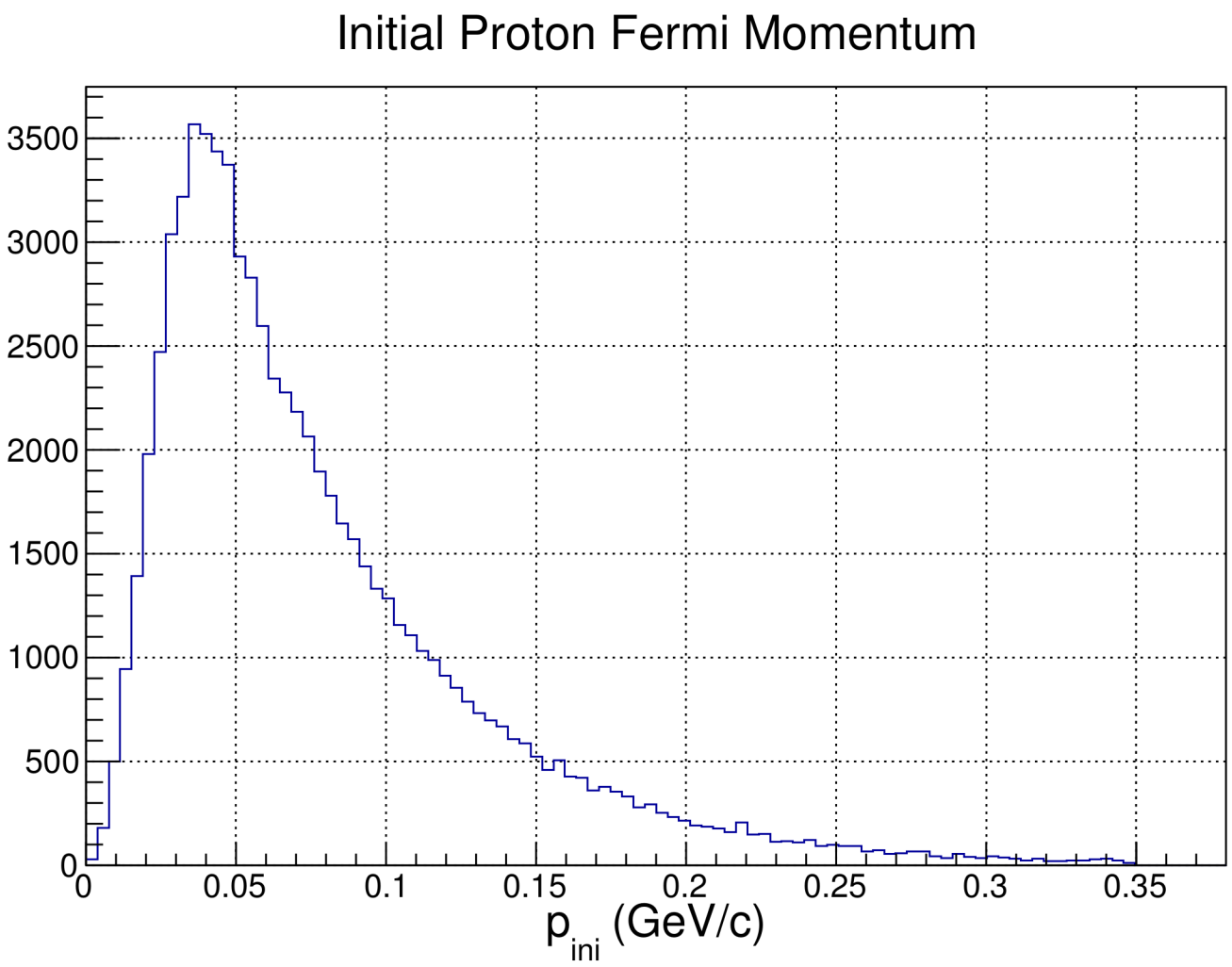
Expected results:
Experimental effects: Fermi Momentum/ radiative corrections

Fermi momentum (fit to Bernheim eD data)



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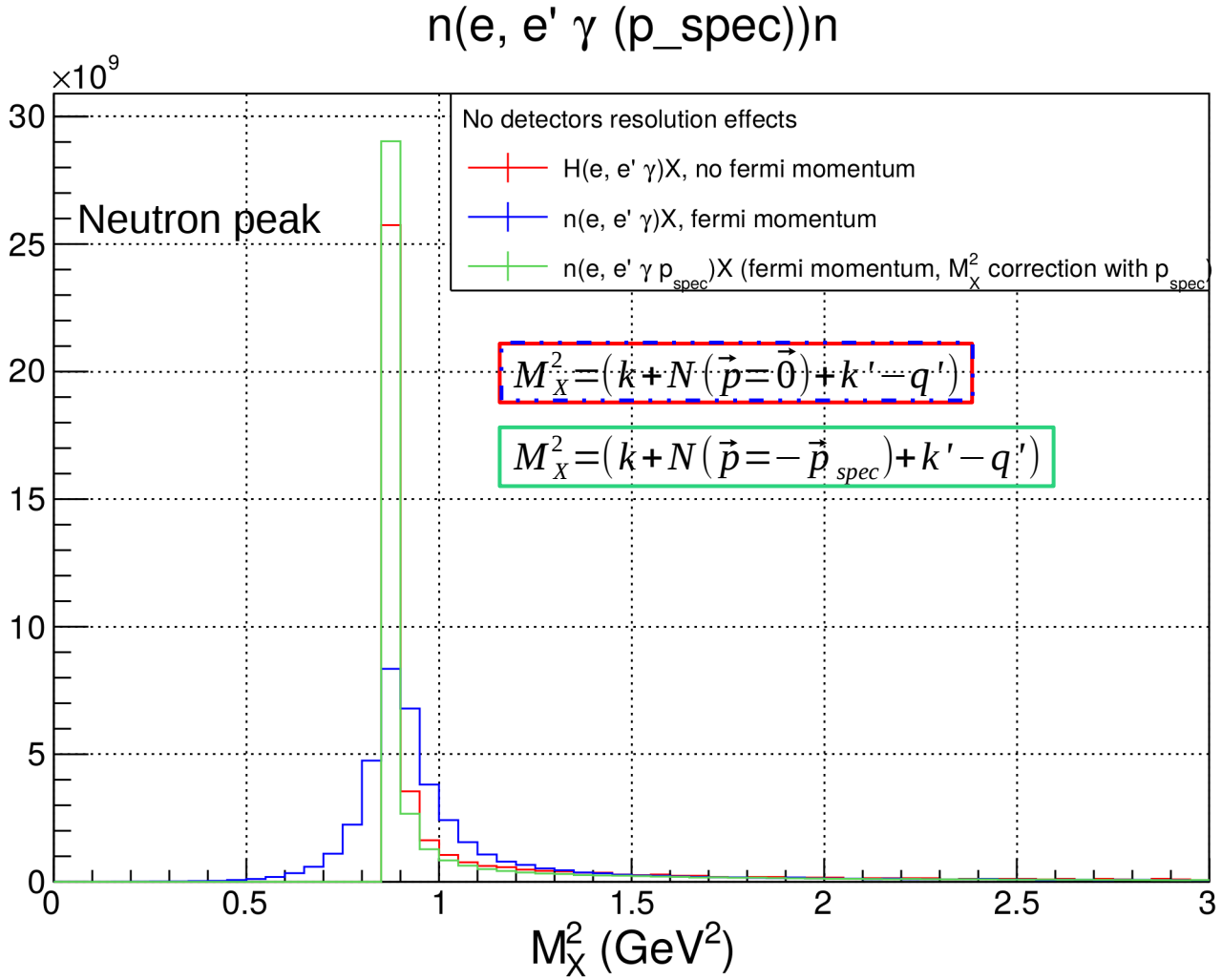
Expected results:
Experimental effects: Fermi Momentum/ radiative corrections

Missing mass squared, radiative effects (Mo/Tsai)
+ Fermi momentum only

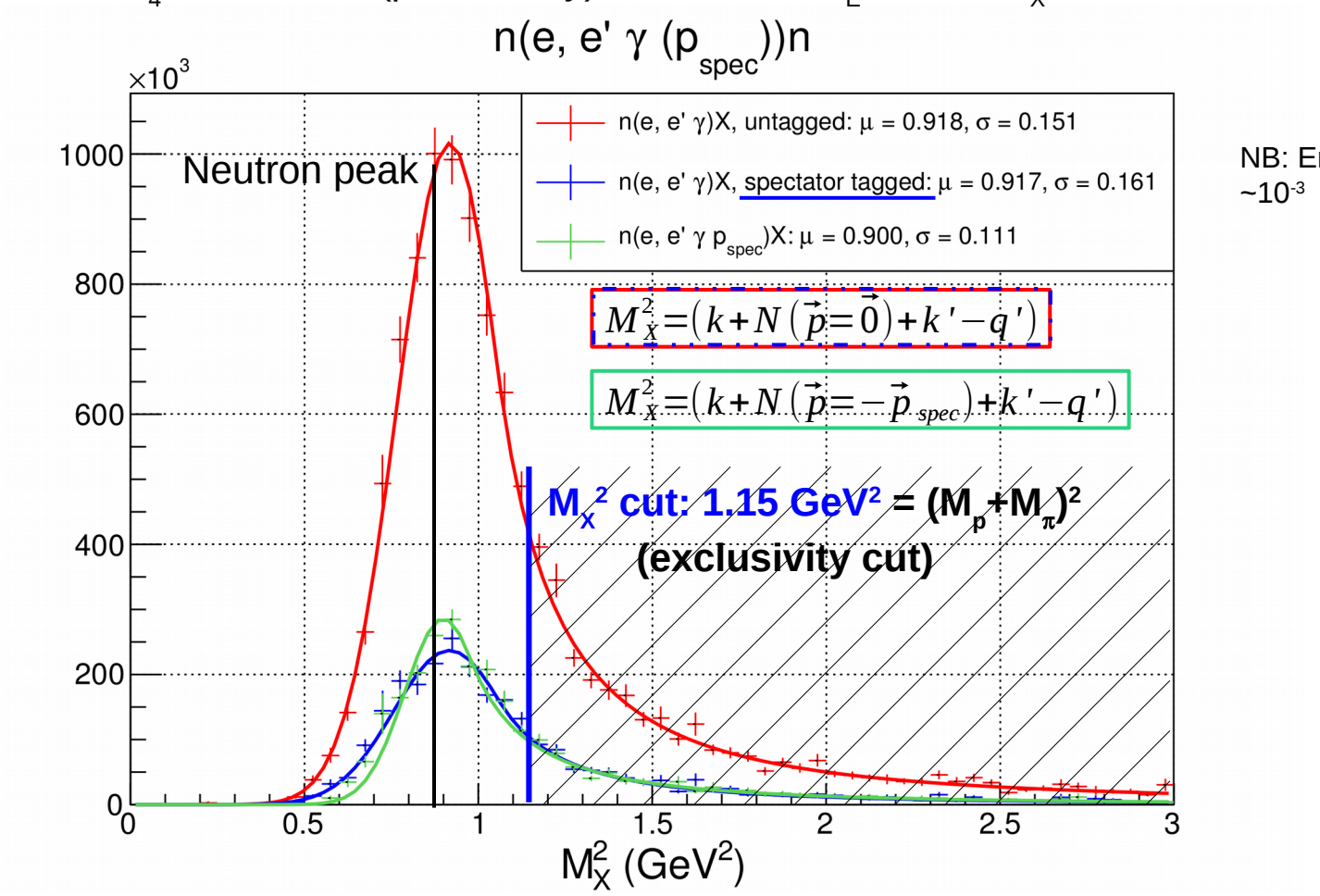


Radiative tail past neutron peak not negligible wrt Fermi Momentum smearing

Expected results:
Experimental effects: radiative corrections

Reconstructed missing mass squared:

After inclusion of SBS (preliminary) resolutions: σ_p~0.5 %, σ_v~6.6 mm and $PbWO_4$ calorimeter (preliminary) resolutions: σ_E~2.5 %, σ_X~5.0 mm

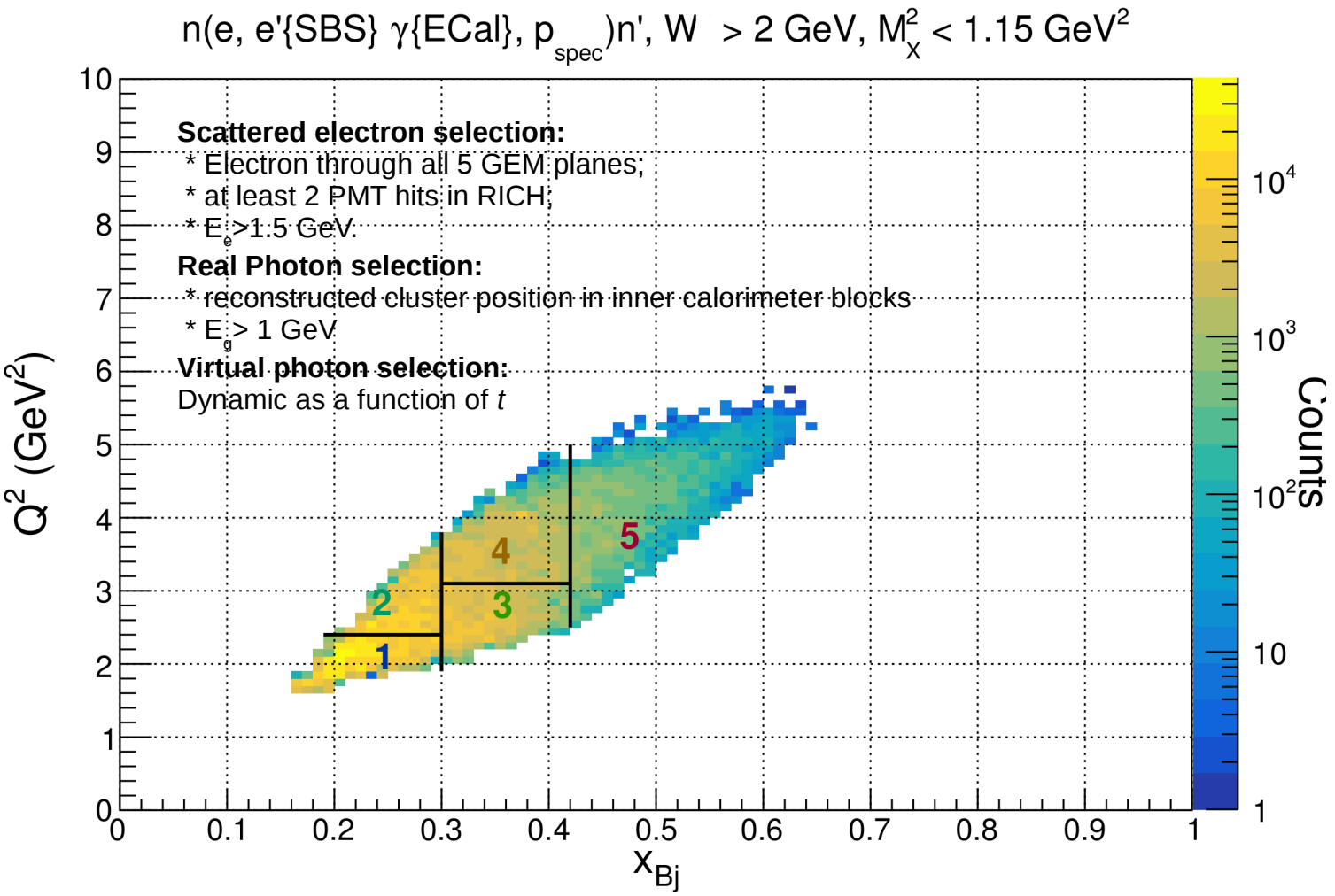


NB: Errors on μ, σ from fit: ~10^{-3}

Inclusion of spectator proton in final state gives modest improvement on missing mass squared (wrt e.g. BoNuS at 4 GeV) due to magnitude of radiative corrections in our simulations

Expected results:
Kinematic coverage

Q^2, x_{Bj} coverage after selection on SBS and calorimeter, spectator proton association, exclusivity cut



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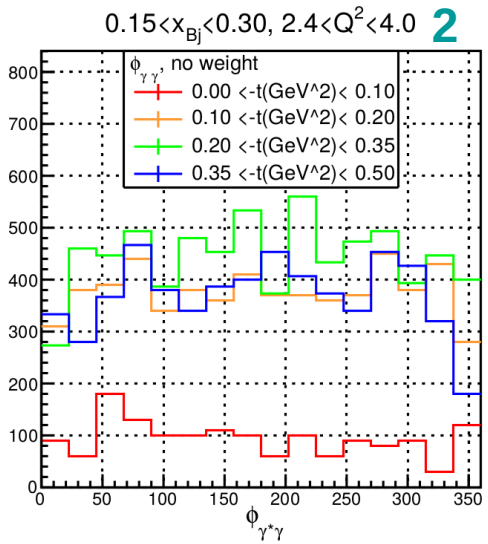
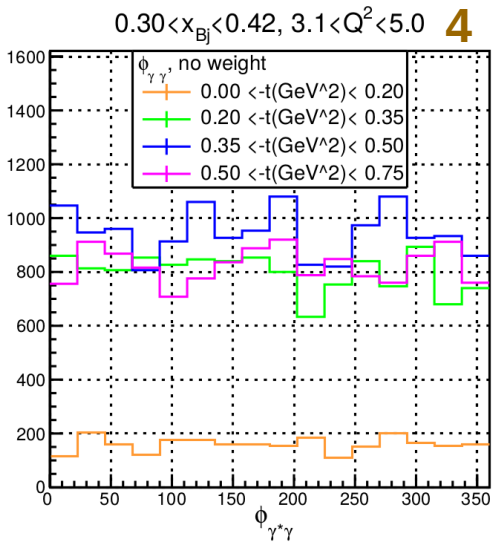
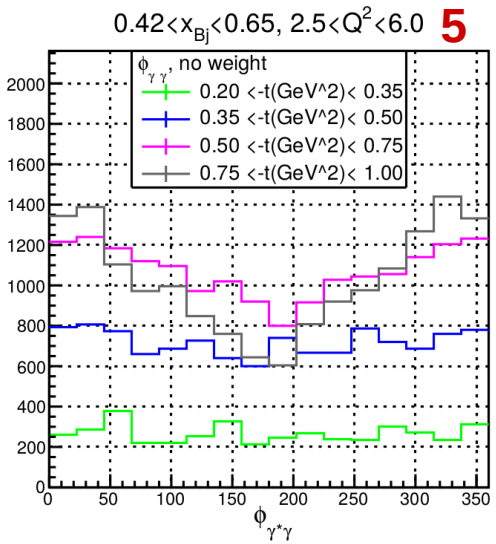
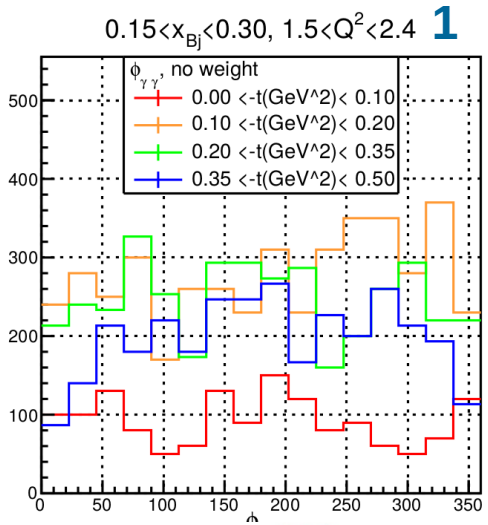
Expected results:
Kinematic coverage

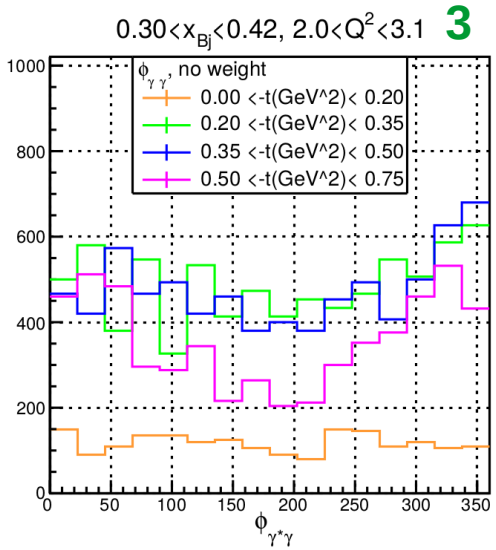
***t*, ϕ coverage** (no XS weight) after selection on SBS and calorimeter, spectator proton association, exclusivity cut for each x_{Bj}, Q^2 bin











Real Photon selection:
* reconstructed cluster position in inner calorimeter blocks
* $E_g > 1$ GeV

Virtual photon selection:
Dynamic as a function of *t*

Phi distribution ~uniform in *t*

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Expected results:
Projections

Beam time, luminosity:

We wish to run at the same time as Tagged DIS experiment in Hall A

=> 5 days beam on deuterium target at 3.0 10^{36} cm^{-2} s^{-1} N^{-1} = **1.5 10^{36} cm^{-2} s^{-1} n^{-1}.**

TDIS existing beam time request				
Target	Current (μA)	Beam Energy (GeV)	Beam Time (hrs)	Notes
Hydrogen	50	11	264	includes 1 day for commissioning
Deuterium	25	11	144	includes 1 day for commissioning
Hydrogen Deuterium	5 5	11 4.4	120 16 8	 mTPC calibration with HCAL Beam Energy Changes
Total (TDIS)			552	23 days
Preliminary additional beam time request for n-DVCS				
Hydrogen Total (n-DVCS only)	6	4.4	24 24 12 60	SBS move DVCS calorimeter calibration Møller measurements 2.5 days
Total (TDIS + nDVCS)			612	25.5 days

NB: additional time requested for:

- DVCS calorimeter calibration (implies SBS movement...)
- Beam Polarimetry (2-3 Møller runs, 4 hours each)

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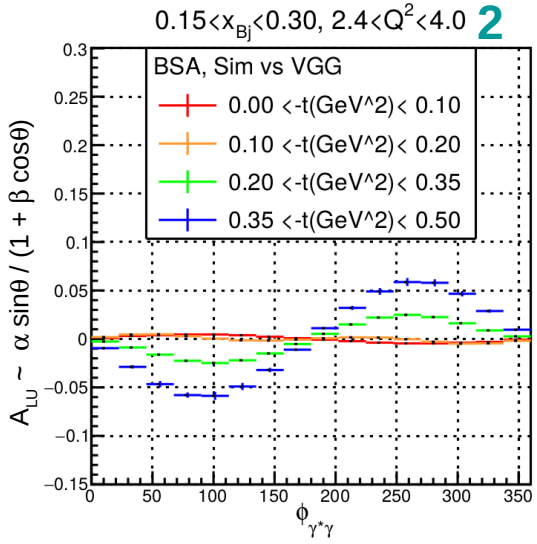
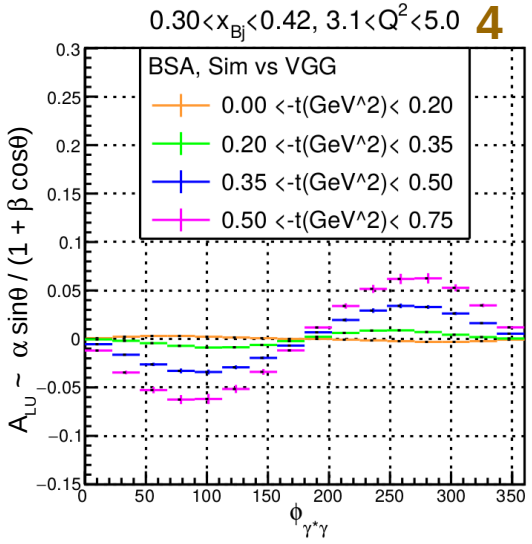
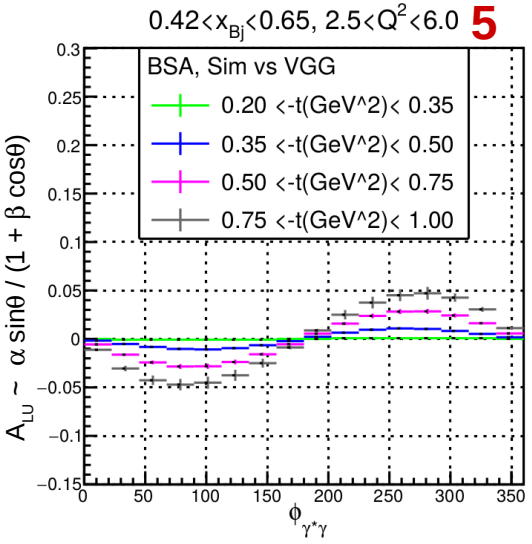
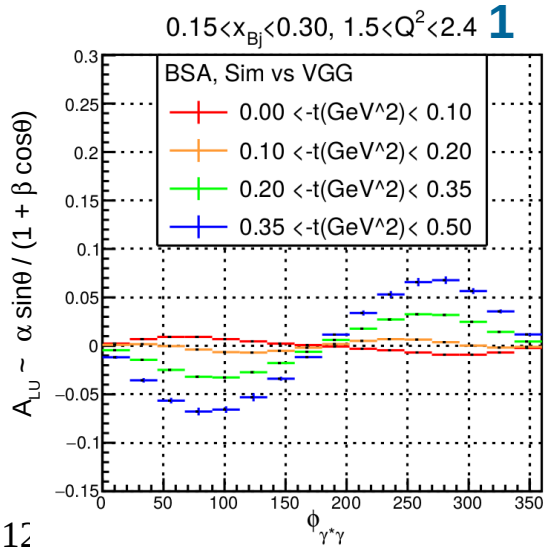
Beam time, luminosity:

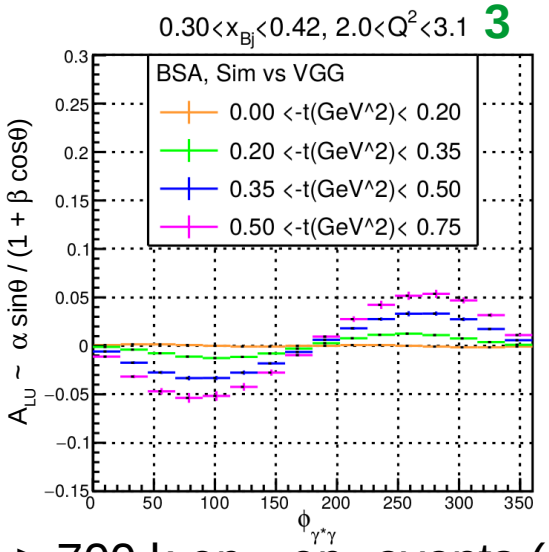
5 days beam on deuterium target at 3.0 10^{36} cm^{-2} s^{-1} N^{-1} = **1.5 10^{36} cm^{-2} s^{-1} n^{-1}.**

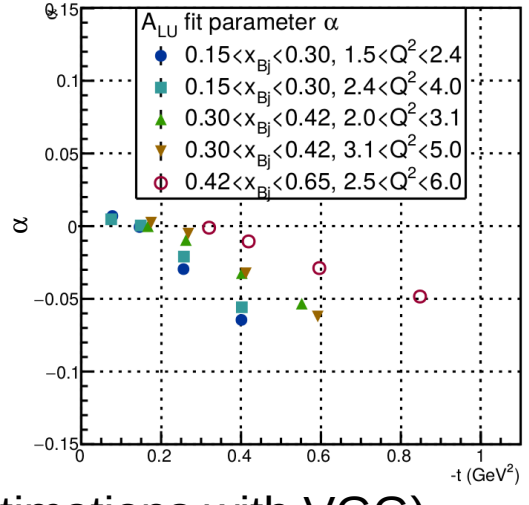












> 700 k $en \rightarrow en\gamma$ events (estimations with VGG)

Beam spin asymmetries sizable over our kinematic range

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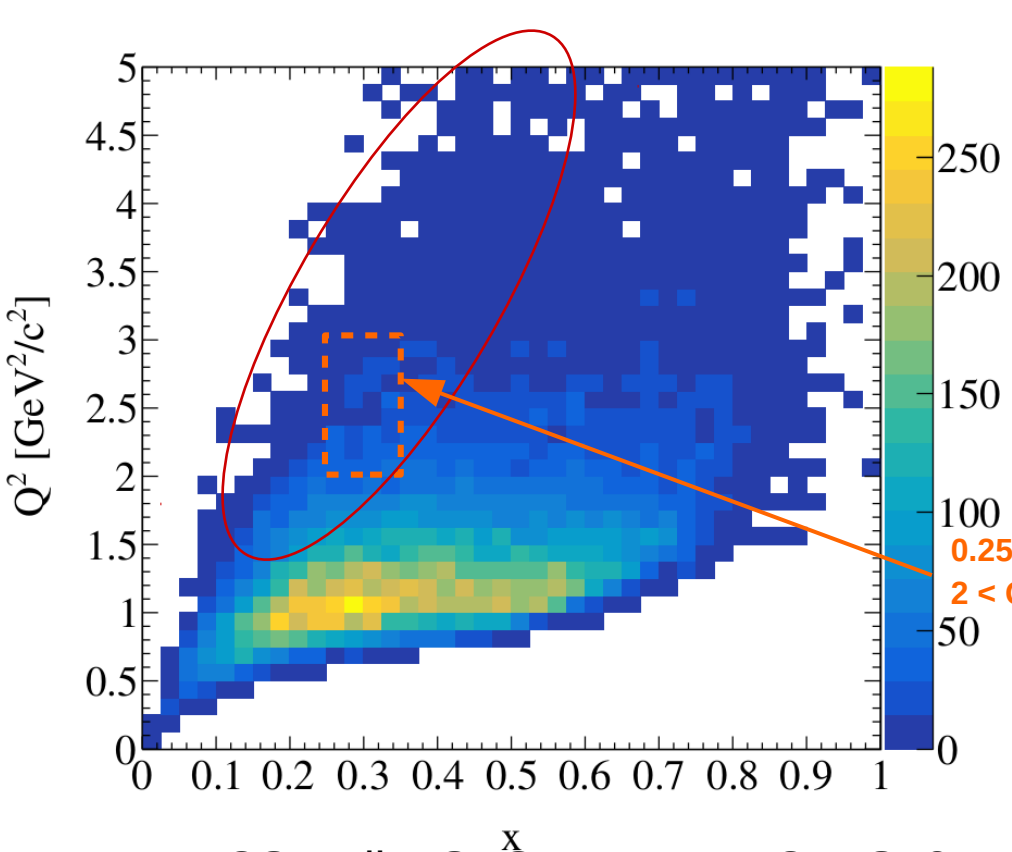
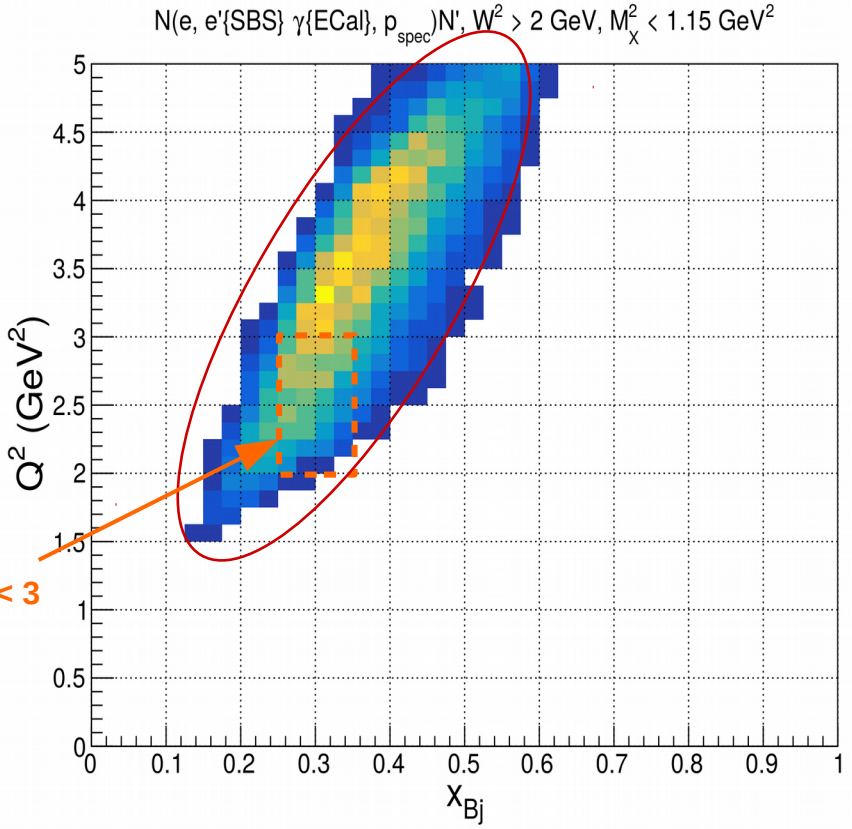
Expected results:
(preliminary) comparison with ALERT (CLAS12)





nDVCS Hall A SBS vs ALERT CLAS12: **reduced kinematic coverage**

nDVCS with SBS in Hall A: Luminosity **3×10^{36} cm^{-2} s^{-1} N^{-1}** for **5 days**
ALERT with CLAS12 in Hall B: Luminosity **6×10^{34} cm^{-2} s^{-1} N^{-1}** per nucleon for **20 days**
=> **10x more statistics on the region of overlap (higher Q^2 at x~0.3).**

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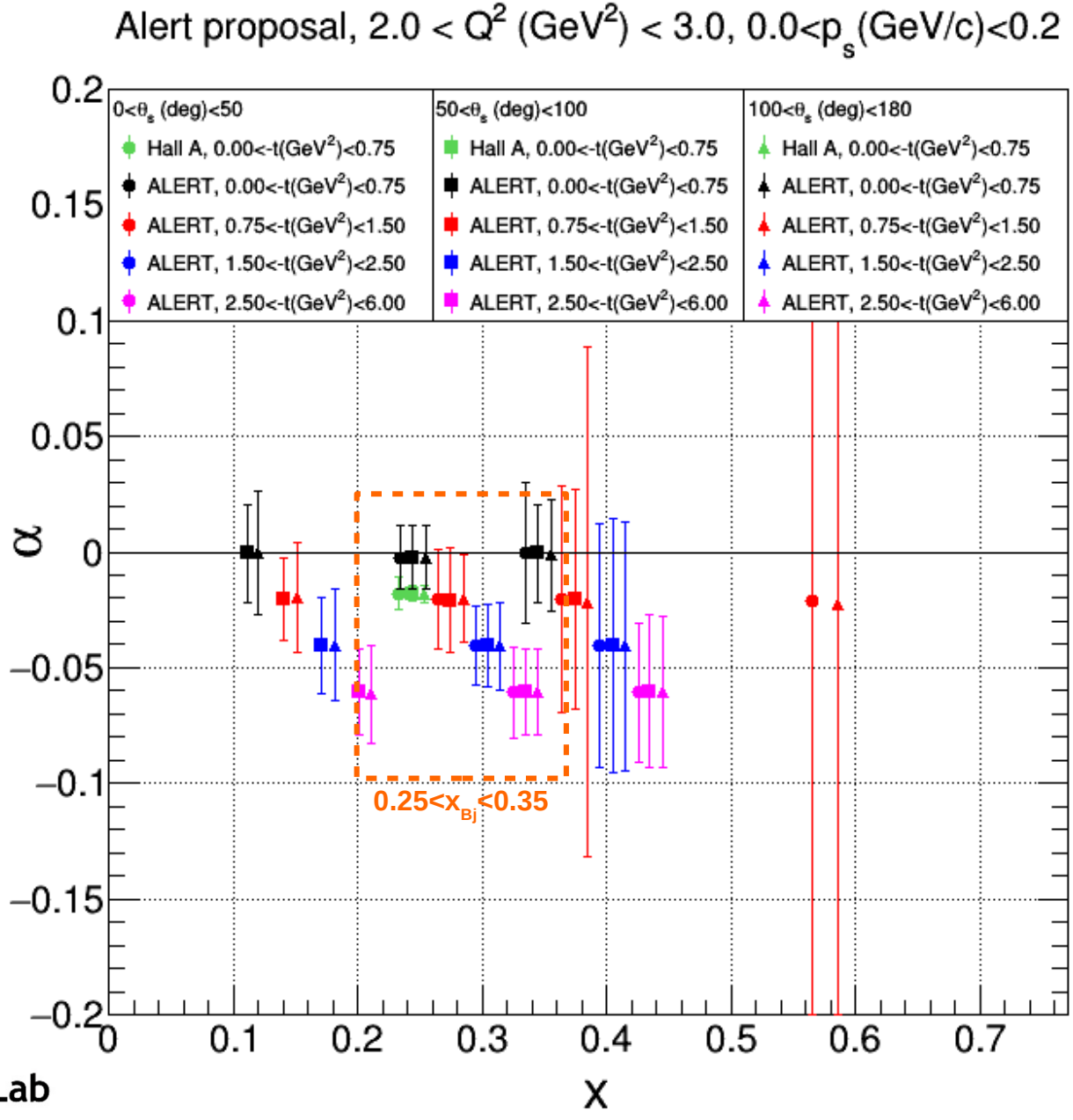
Expected results:
(preliminary) comparison with ALERT (CLAS12)

(0.25 < x_{Bj} < 0.35,
0.0 < P_s (GeV/c) < 0.2)

Bin	x	Q^2	t	θ_s	P_s
units		GeV^2	GeV^2	°	GeV/c
	0.05	1	0	0.0	0.0
	0.25	1.5	0.75	50	0.2
	0.35	2.0	1.5	100	0.35
	0.5	3.0	2.5	180	0.5
	0.8	10	6.0		



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Summary and next steps

Summary:

* nDVCS with spectator proton tagging constitutes a great improvement over the previous nDVCS experiments:

- *unambiguous* nDVCS / pDVCS / dDVCS separation;

- spectator proton information may improve missing mass squared resolution, hence *exclusivity selection*

* Proposed experiment would run jointly with TDIS on deuterium for 5 days:

- ~700 k estimated $en \rightarrow en\gamma$ counts total;
- possibility to scan nDVCS observables along x_{Bj}, Q^2 in valence region

* additional time requested for:

- DVCS calorimeter calibration (implies SBS movement...)
- Beam Polarimetry (2-3 Møller runs, 4 hours each)

Overall **positive feedback from PAC!**
PAC values the scientific case and recommands preparation of a full proposal
Main concerns: availability of $PbWO_4$ blocks (and subsequent effect on missing mass), final state interactions, radiative corrections

Summary and next steps

Needs for a full proposal:

* Evaluate π^0 contamination (started), and evaluate nDVπ^0P expected counts;

* Compare our expected statistics with other nDVCS experiments:
  - Hall B with recoil neutron detection;
  - ALERT (in progress), which will perform a similar measurement.

* enlarge proposal to coherent dDVCS:
  - dDVCS cross section model for $de \rightarrow de\gamma$ yield estimation (should hopefully get soon);
  - mTPC deuteron detection/reconstruction efficiency.

* study magnetic shielding of calorimeter + mechanical compatibility of calorimeter with setup.

* Want: study other options for electron detection than SBS;

Thank you for your attention !

PAC summary for LOI12-18-002

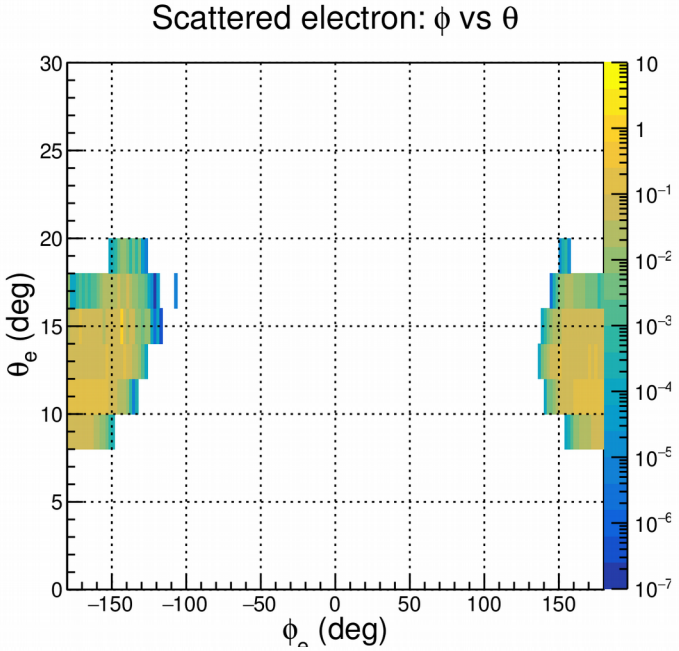
Motivation: The LOI proposes to perform DVCS measurements off deuterons in Hall A. The focus is on measurements off the neutron, which provide different flavor sensitivity as compared to proton targets. It is planned to measure both the unpolarized cross section and the longitudinal beam-spin asymmetry. The former involves integrals over GPDs (hence probing the region $x \neq \xi$), while the latter provides information on the imaginary part of the DVCS amplitude at the point $x = \xi$ and especially on the GPD E which is of great interest in nucleon spin structure. In addition to investigating DVCS off the neutron there are also ideas to study coherent DVCS off the deuteron, which so far has not been explored. The PAC finds the physics case interesting and the proposed measurements to be well motivated.

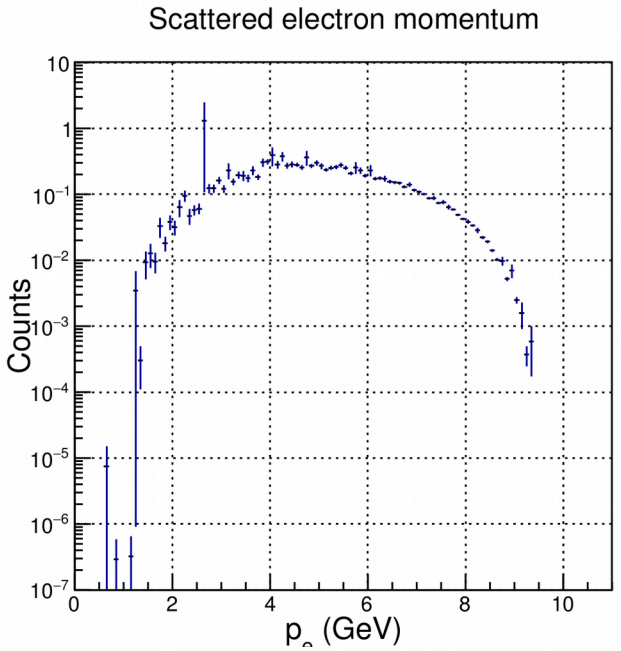
Measurement and Feasibility: Neutron DVCS measurements in Hall A have in the past been carried out by subtracting results from scattering off deuterons and protons, a technique that is prone to large systematics. The idea in the present experiment is to employ TDIS methods to observe the spectator proton in the TPC and measure its momentum, so that scattering off a quasi-free neutron can be established. Measuring the momentum of the produced photon and using missing-mass techniques, the exclusivity of the event may then be validated. It is noted that the ALERT run group plans to use a similar technique; the proponents of the present LOI expect that they will achieve significantly higher statistics in the region of kinematic overlap. While the proposed experiment would use components of the approved TDIS experiment, it does require a new DVCS calorimeter for photon detection, for which the proponents envisage to use $PbWO_4$ crystals from NPS. Initial studies based on the assumption of availability of these components are encouraging overall.

Issues: This LOI is put forward as a potential run group addition to TDIS. The PAC rejects this notion. Given that new equipment (and hence funding) is needed, as well as a modest amount of additional beam time over that allocated for TDIS, this LOI cannot be considered as seed for a run group addition. Run groups are fixed entities with common apparatus and beam time, and any additions that might impact the program need to be blessed by the full collaboration. The proponents would thus have to come up with their own full proposal that is based on use of TDIS equipment and on a robust plan for the additional DVCS calorimetry, along with its own request for beam time. If the proponents prepare such a proposal they should do so in close discussion with TDIS and Lab management. The proposal should address radiative corrections and their role for missing-mass reconstruction, final-state interactions, and $\varphi\gamma\gamma$ acceptance. The PAC is concerned about the potential unavailability of the NPS crystals. Using instead PbF_2 crystals will significantly impact resolution and coverage and might require upgrades. If such a backup solution is seriously considered careful simulation studies will be necessary.

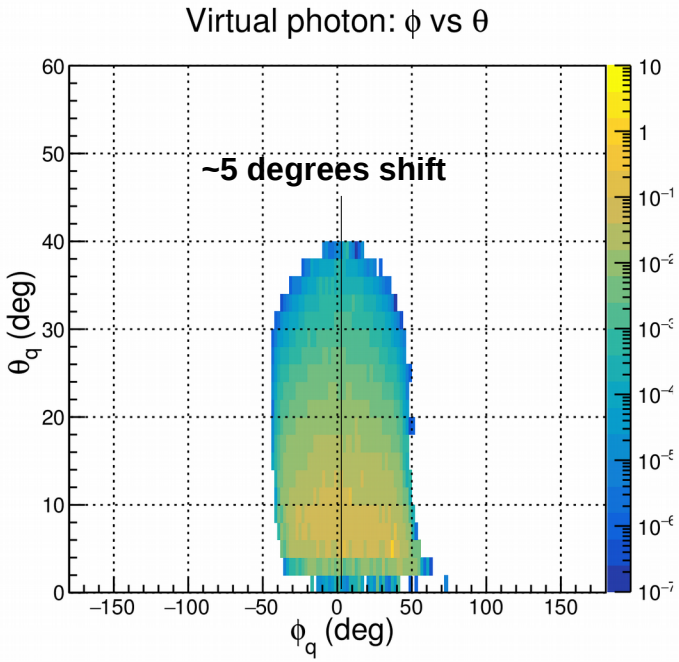
Summary: The PAC values the scientific case. It cannot consider this as an LOI for a run group addition to TIDS but instead recommends preparation of a separate proposal.

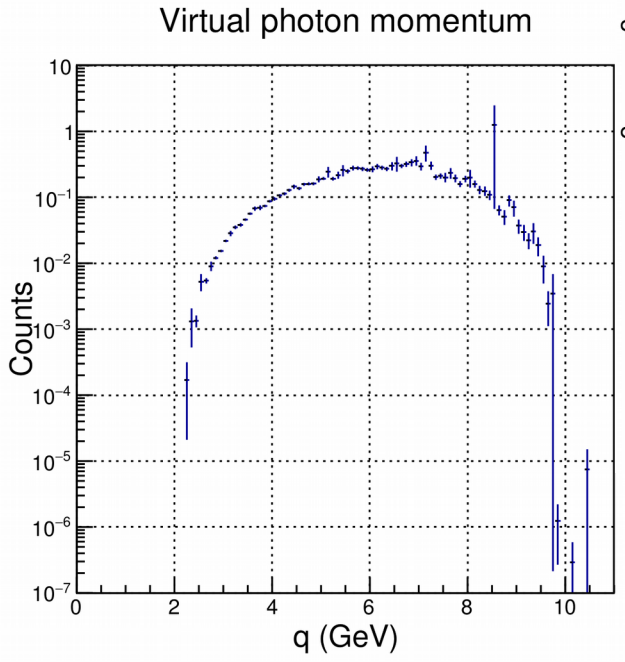
Expected results:
Statistics selection, kinematic coverage

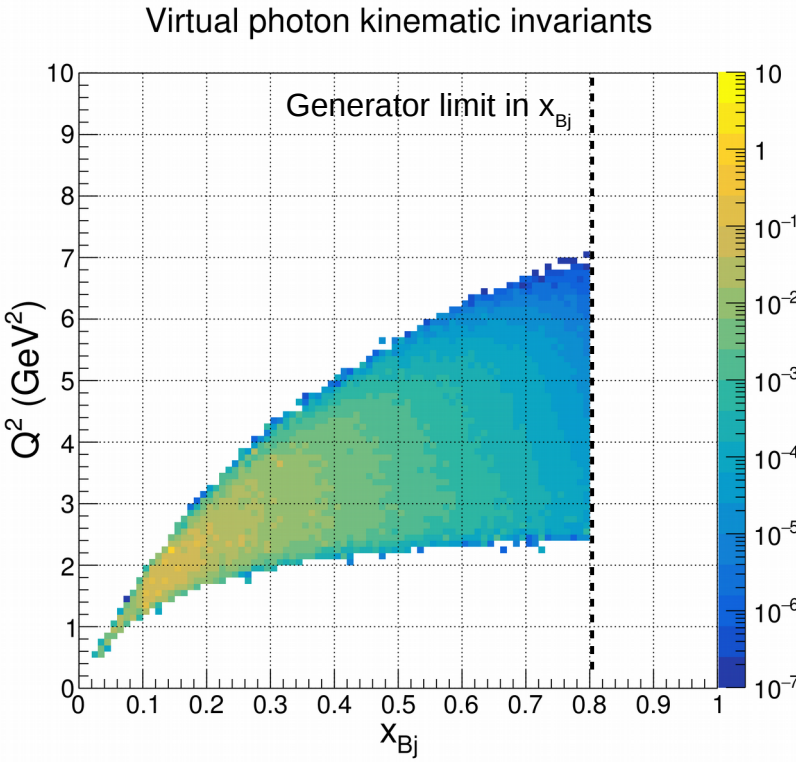




Scattered electron selection:
* Electron through all 5 GEM planes;
* at least 2 PMT hits in RICH;
* E_e>1.5 GeV.

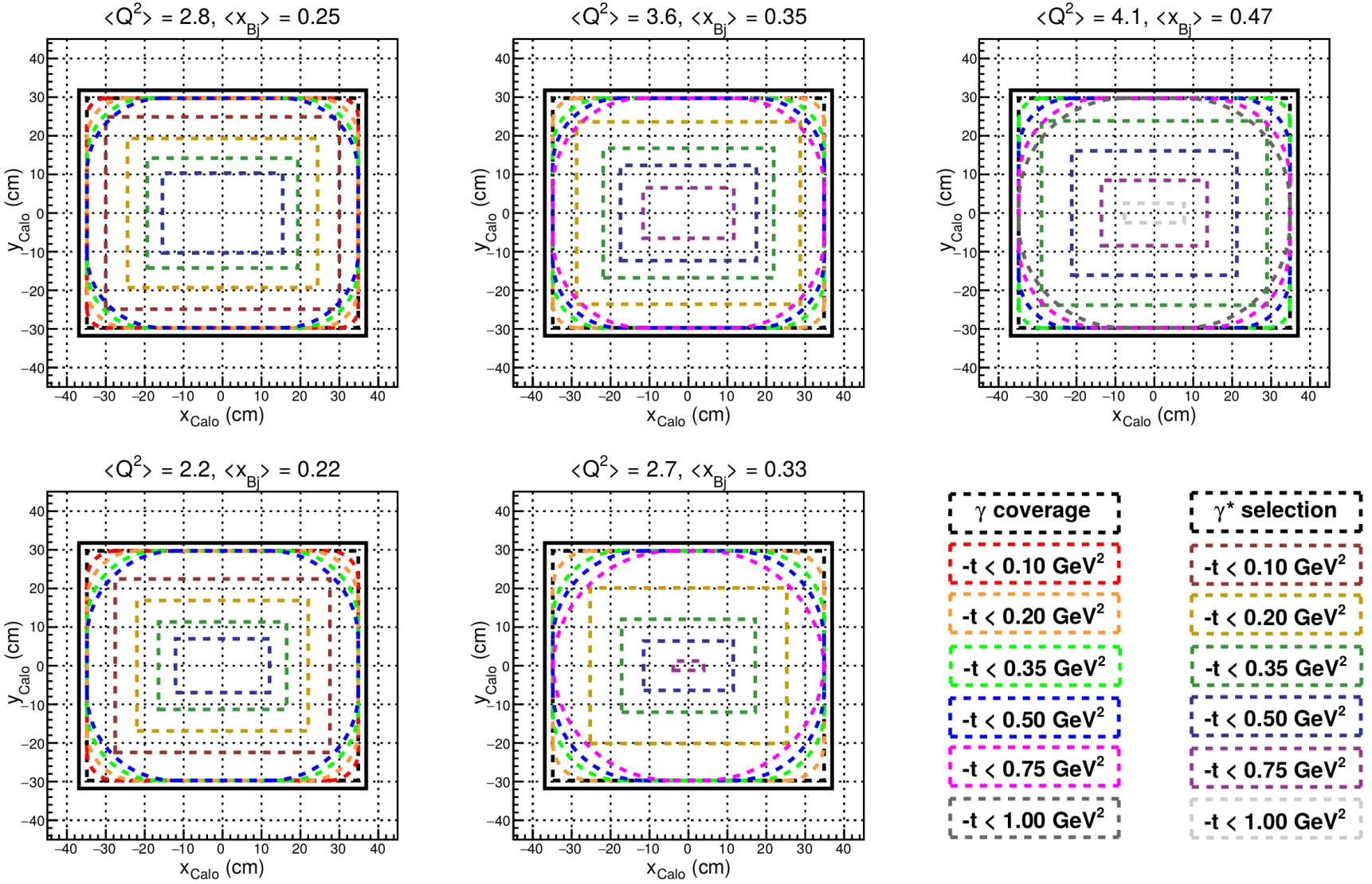






Solenoid field does not have significant incidence on acceptance

Expected results:
Statistics selection, kinematic coverage

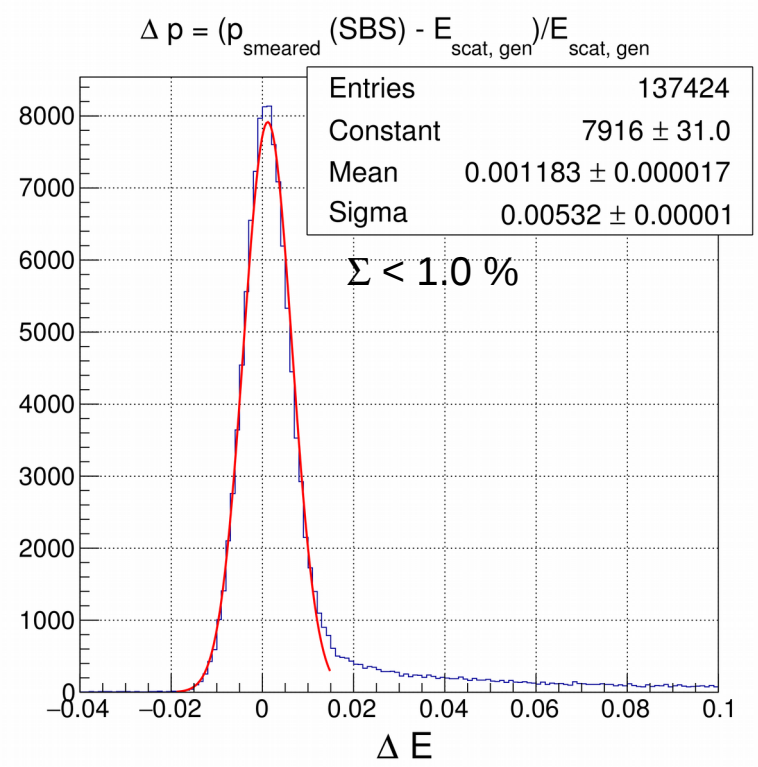


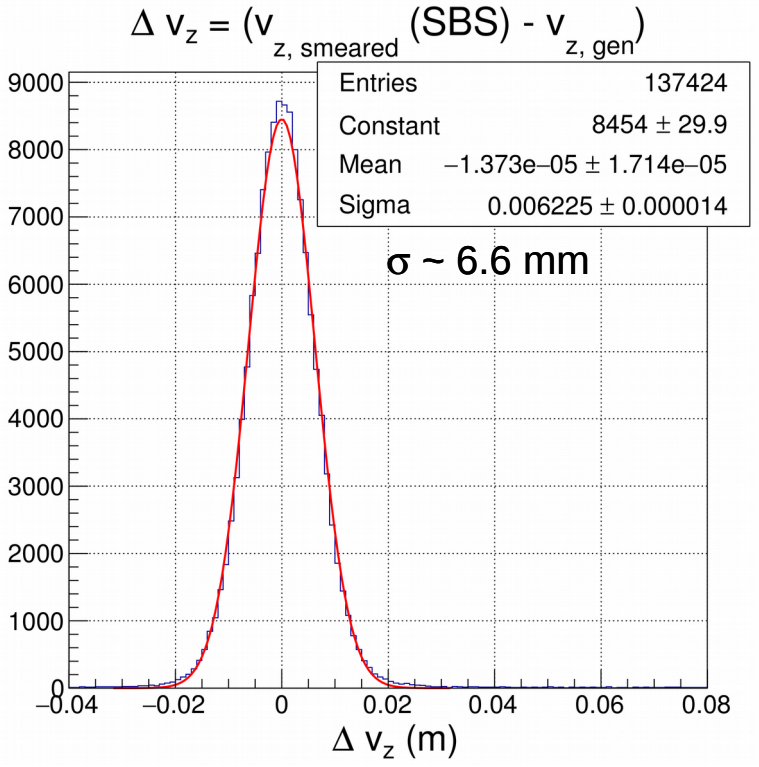
Expected results:
Experimental effects: SBS resolution

Electron reconstruction:

Smearing "by-hand" with SBS claimed resolutions:
- does not include reconstruction/optics model ;
- includes electron energy loss between vertex and GEMs

(uses the GEM hit mometum info for the scattered electron)





"by-hand smearing" might be a tad too clean, but an independent study showed that it was not completely unreasonable.

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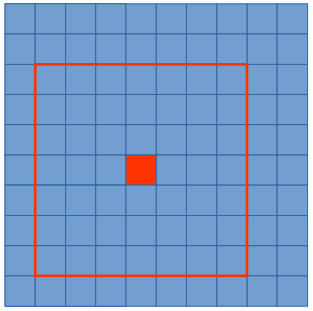
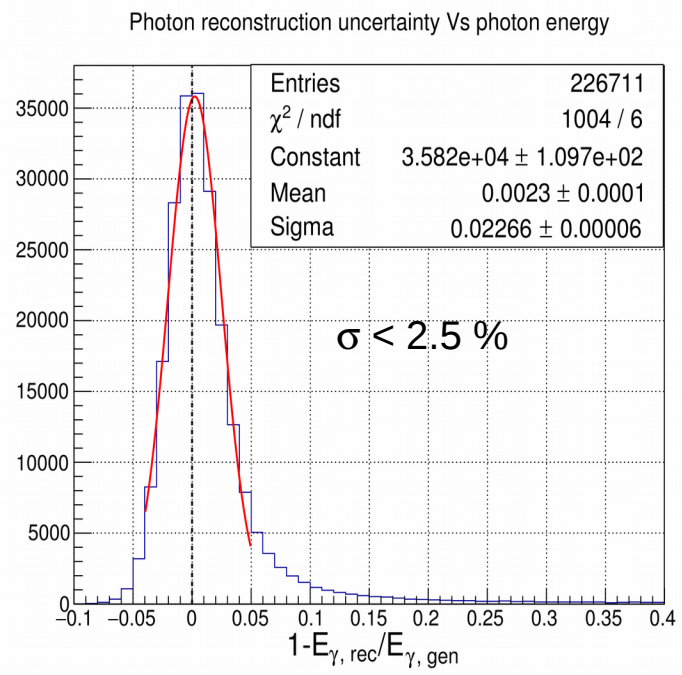
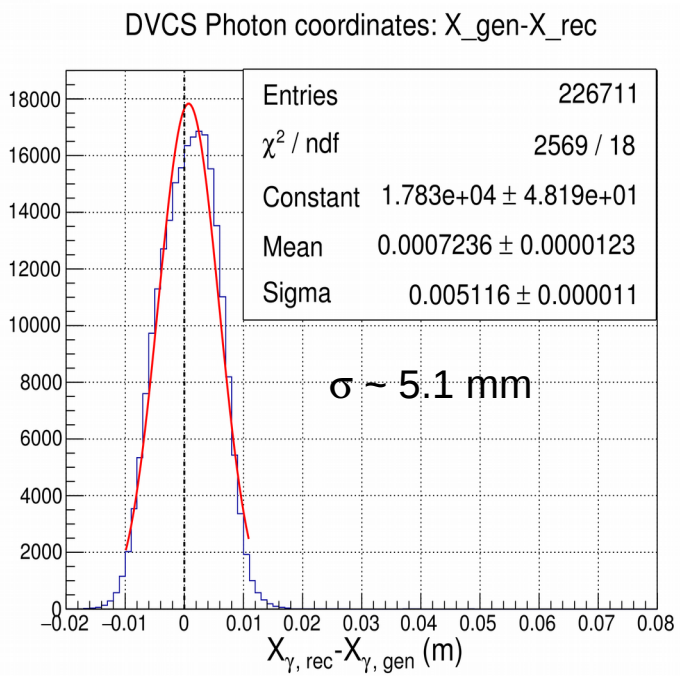
Expected results:
Experimental effects: Calorimeter resolution

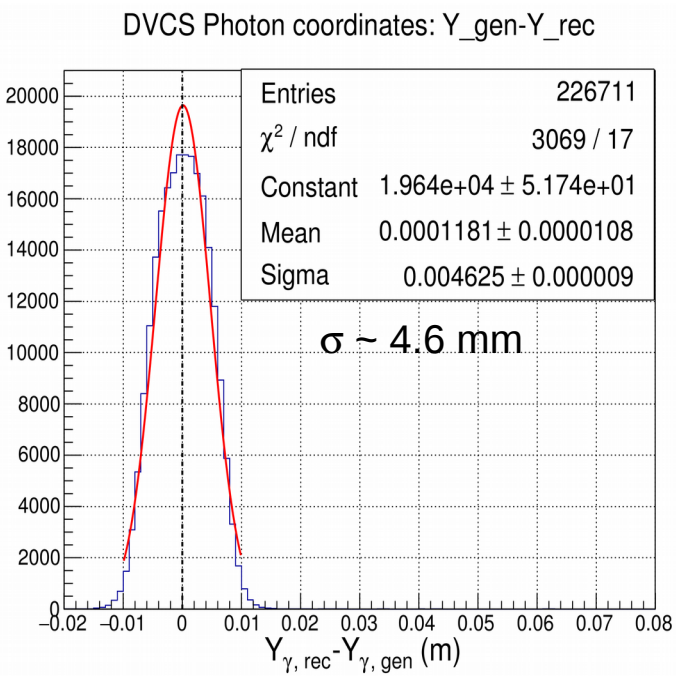
Photon reconstruction:

DVCS ECal Clustering:
7*7 blocks around the maximal energy deposit
Reminder : "NPS" Ecal : 31x36 2.05cm $PbWO_4$ blocks.









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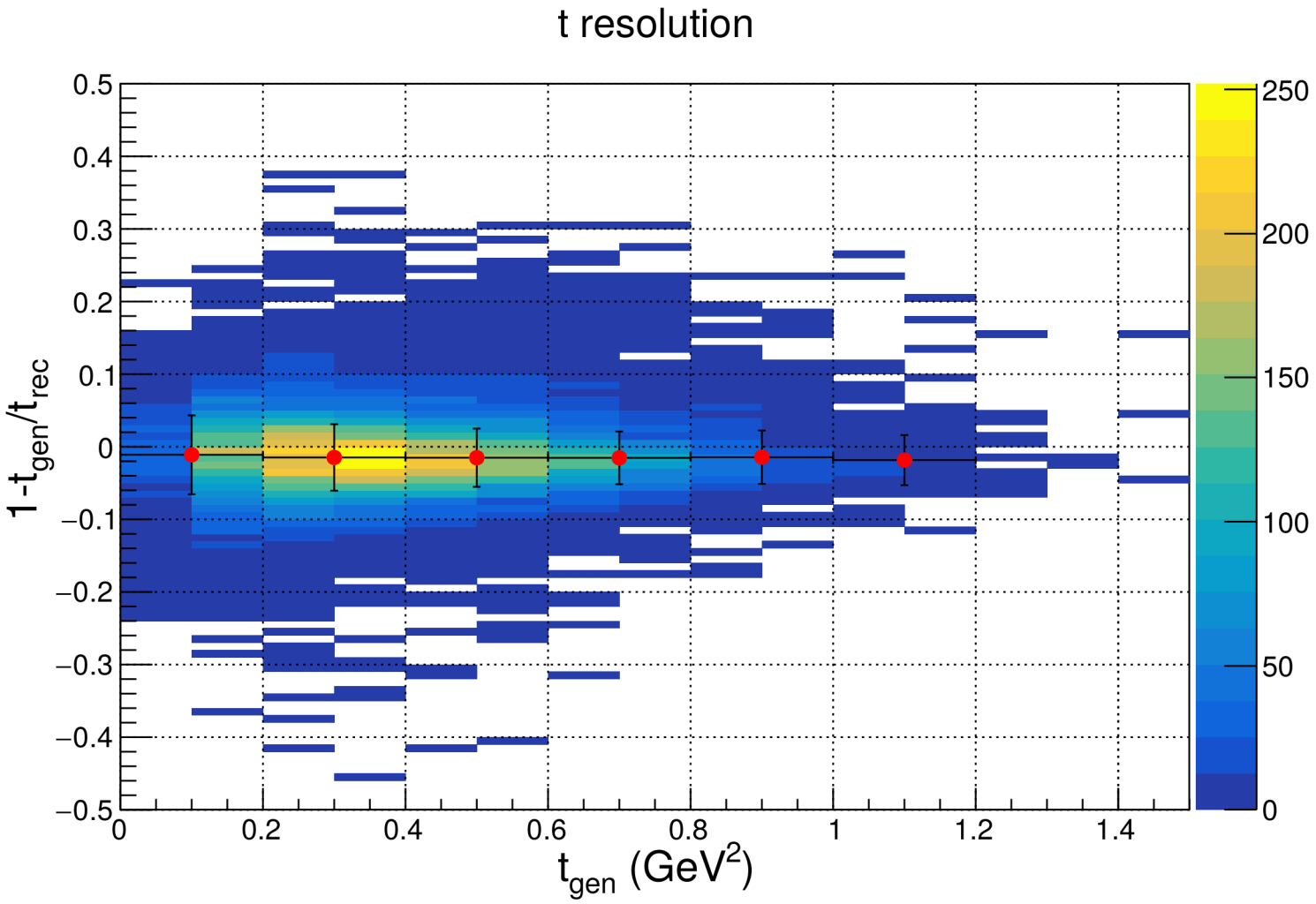
Expected results:
Experimental effects: resolution in *t*



Resolution better than 5% in *t*

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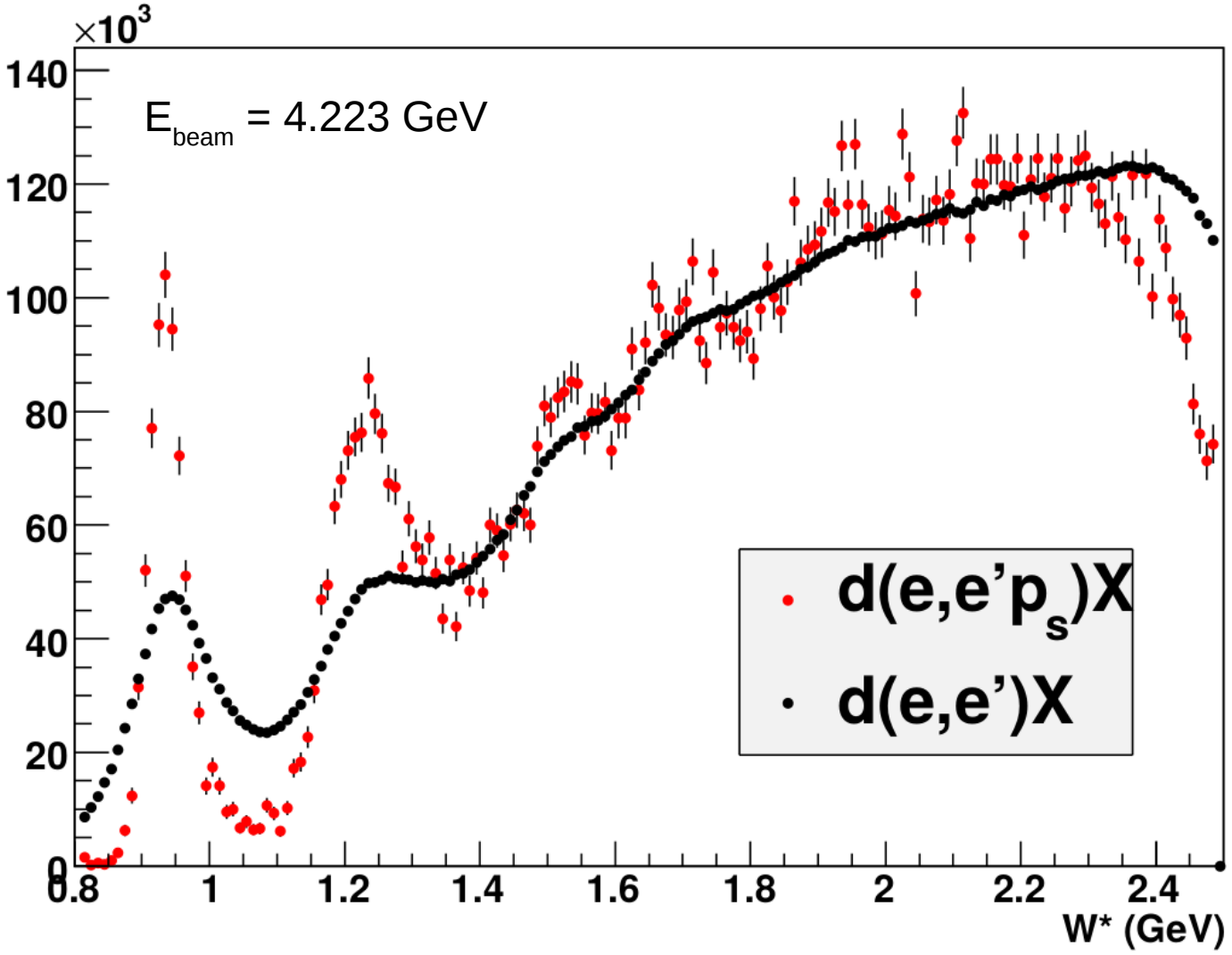
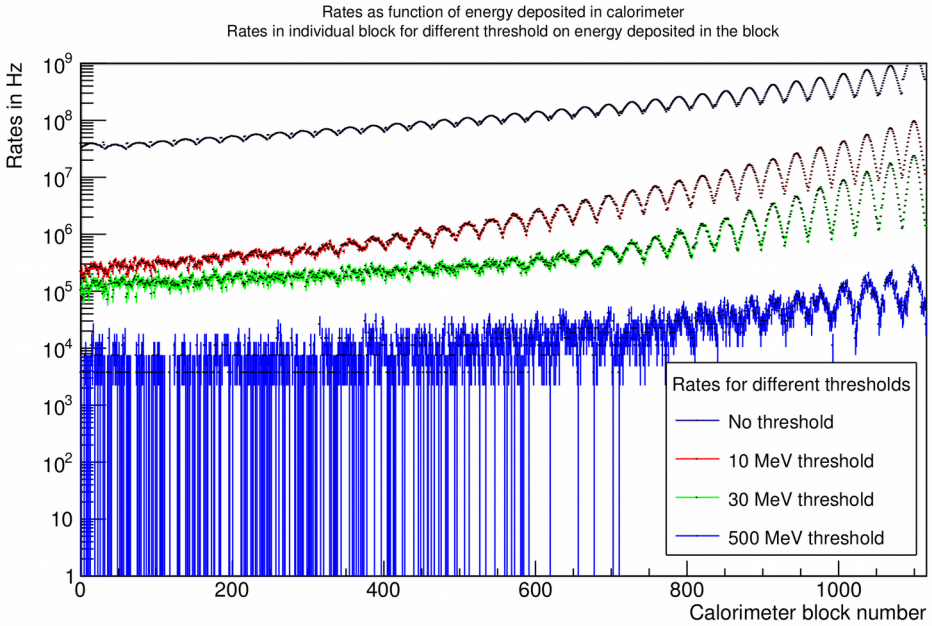
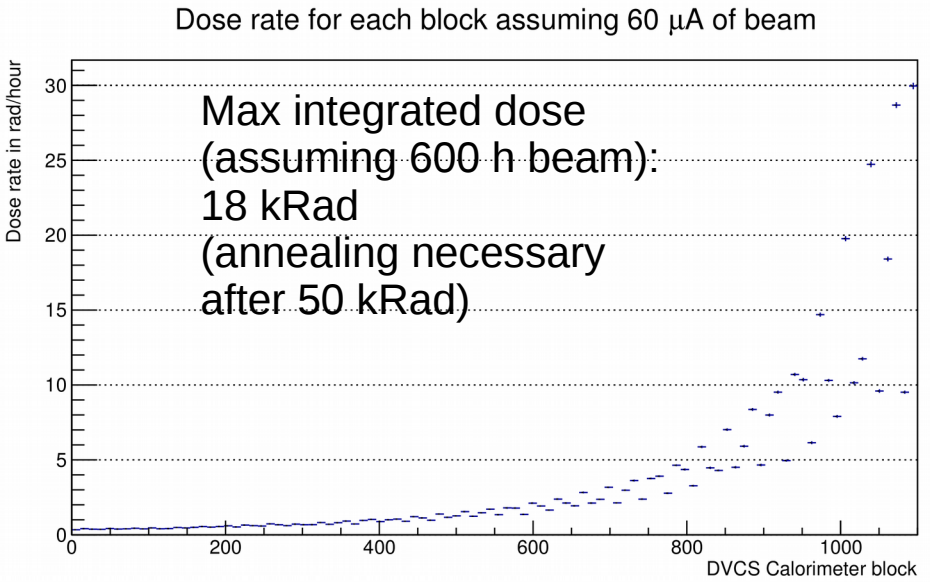
Expected results:
Fermi momentum correction for BoNuS



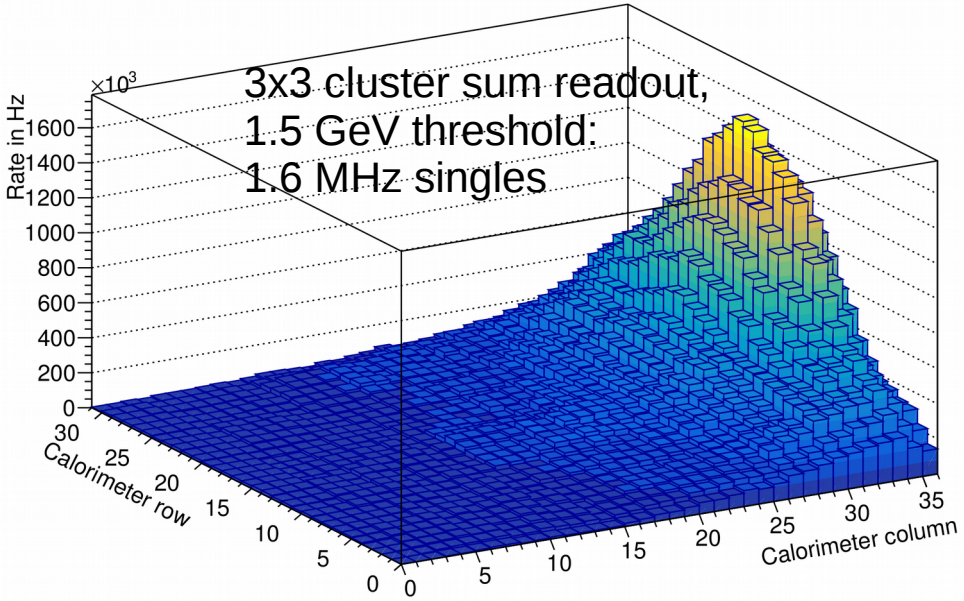
Expected results:
Backgrounds: DVCS ECal

Background in DVCS calorimeter





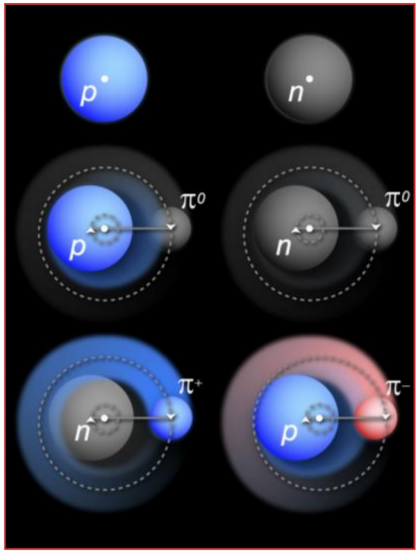
Block readout rate using 3x3 cluster sum readout scheme



Experimental setup:
TDIS experiment and setup

TDIS: Tagged Deep Inelastic Scattering *eN → eNX*

TDIS AT JLAB



J. Arrington, AIP Conf.Proc. 1560 (2013) 525-532

TDIS:

- Allow us to access the meson component of the nucleon
- Independent way to measure meson DIS
- Potential meson target (through Sullivan process)

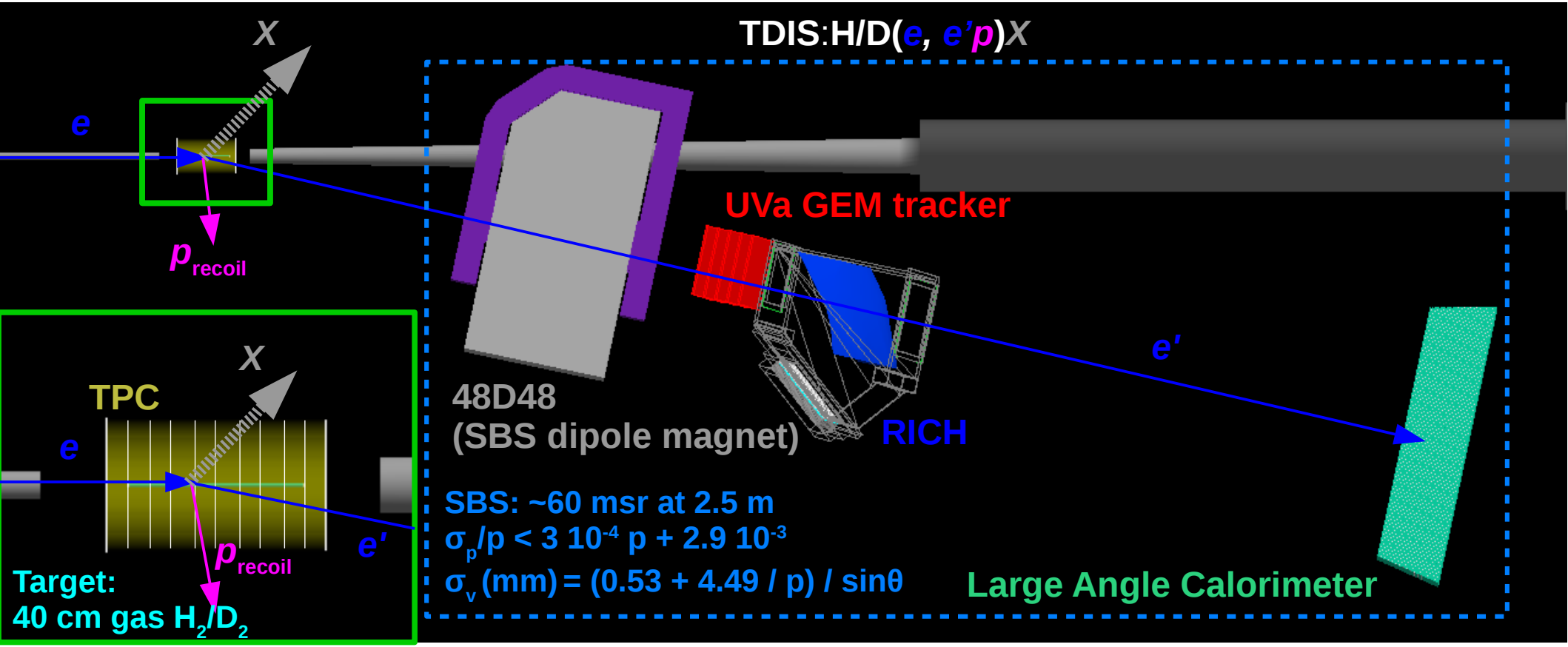
TDIS at JLab:

- High-x for mesons ($x_B{}^{nucleon} \sim 0.05 - 0.15$)
- High luminosity ($\mathcal{L} \sim 3$ x 10^{36} cm^{-2}/s)

[by Bogdan Wojtsekhowski]

Experimental setup:
TDIS experiment and setup

***Two* conditionally approved experiments**: **23 days**
C12-15-006 - *Measurement of Tagged Deep Inelastic Scattering*
Spokespeople: C. Keppel, B. Wojtsekhowski, P. King, D. Dutta, J. Annand, J. Zhang
C12-15-006A - *Measurement of Kaon Structure Function through Tagged Deep Inelastic Scattering (TDIS)*
Spokespeople: K. Park, T. Horn, R. Montgomery

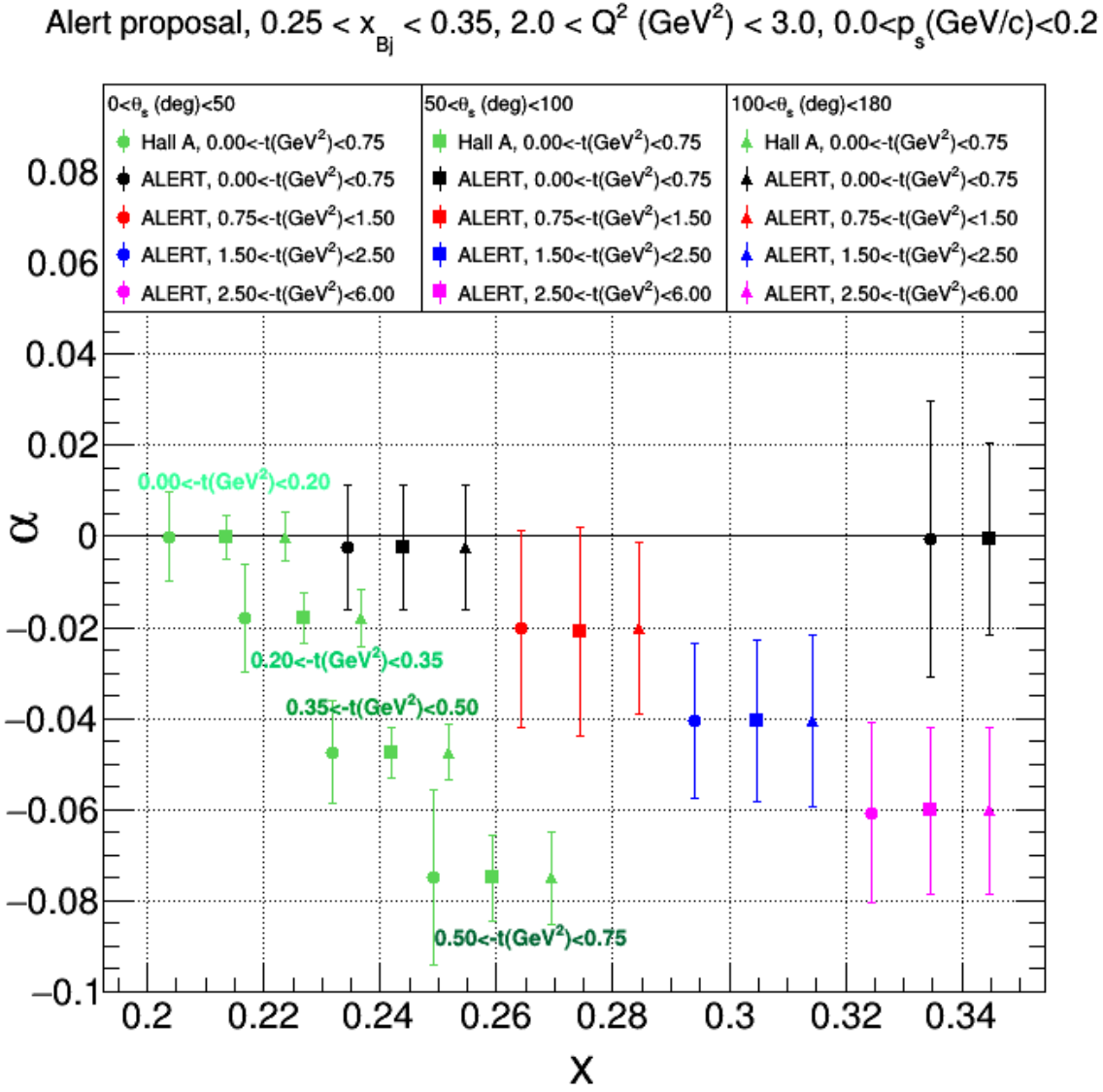


Expected results:
(preliminary) comparison with ALERT (CLAS12)

(0.25 < x_{Bj} < 0.35,
0.0 < P_s (GeV/c) < 0.2)

Bin units	x	Q^2 GeV^2	t GeV^2	θ_s °	P_s GeV/c
	0.05	1	0	0.0	0.0
	0.25	1.5	0.75	50	0.2
	0.35	2.0	1.5	100	0.35
	0.5	3.0	2.5	180	0.5
	0.8	10	6.0		

Our projections are in green



nDVCS Hall A SBS vs ALERT CLAS12:
Lower kinematic coverage but higher statistics