CLAS12 Run Group B

Electroproduction on deuterium with CLAS12

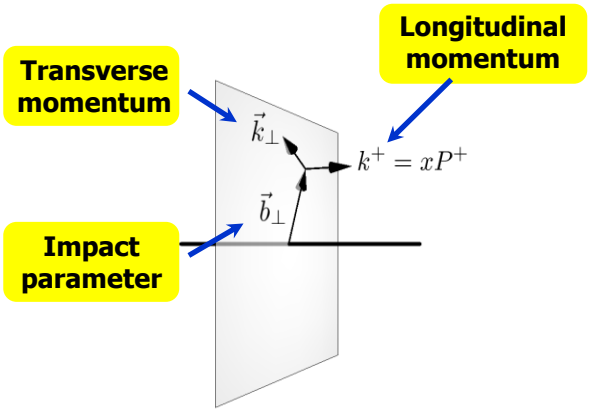
- Physics goals
- Presentation of the RG-B experiments
- Experimental setup
- Running conditions
- Run plan and task sharing

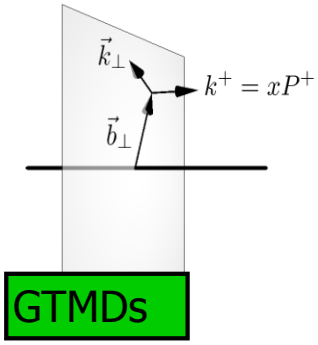
Silvia Niccolai, IPN Orsay, on behalf of RG-B

CLAS Collaboration meeting, JLab, 11/14/2018

Multi-dimensional mapping of the nucleon

A complete picture of nucleon structure requires the **measurement of all these distributions**.





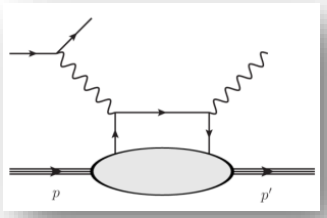
GTMDs

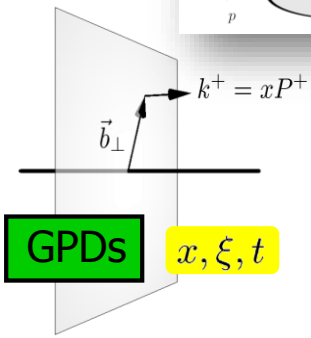
$x, \xi, k_\perp^2, \vec{k}_\perp \cdot \vec{\Delta}_\perp, t$

$\int \mathrm{d}^2\vec{k}_\perp$

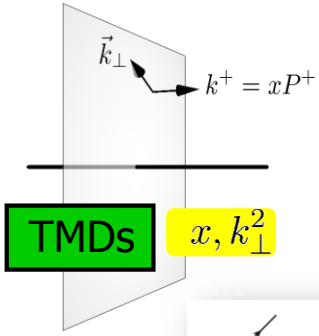
$\int \mathrm{d}^2\vec{b}_\perp$

DVCS



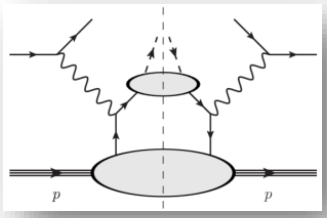


GPDs x, ξ, t



TMDs $x, k_\perp^2$

SIDIS

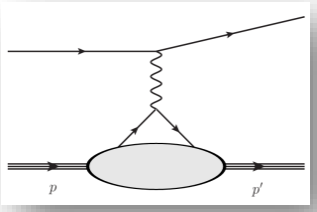


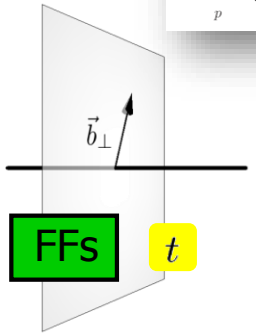
$\int \mathrm{d}x$

$\int \mathrm{d}^2\vec{b}_\perp$

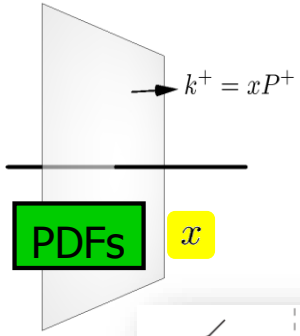
$\int \mathrm{d}^2\vec{k}_\perp$

Elastic Scattering



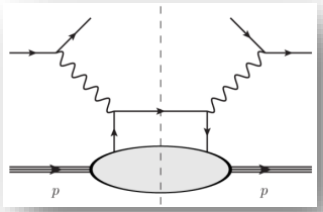


FFs t



PDFs x

DIS



Run-Group B aims to measure all these distributions, using **deuteron** as a **neutron target** → **Quark-flavor separation, combining with proton results**

+ EMC effect, SRC
+ J/ψ photoproduction on deuteron

CLAS12 Run-Group B

- Common features to all experiments of RG-B:
  - ✓ **Liquid deuterium target**
  - ✓ **Beam energy: 11 GeV**
  - ✓ **Luminosity = 10^{35} cm^2/s**
- Maximum approved PAC days: **90**
- 4 PAC-approved experiments, 1 High-Impact experiment, 3 Run-Group experiments
- First experiment approved in 2007, last one in 2018

E12-07-104	Neutron magnetic form factor	G. Gilfoyle	A-	30
E12-09-007(a)	Study of parton distributions in K SIDIS	K. Hafidi→W. Armstrong	A-	56
E12-09-008	Boer-Mulders asymmetry in K SIDIS	M. Contalbrigo	A-	56
E12-11-003	Deeply virtual Compton scattering on the neutron	S. Niccolai	A **(HI)**	90
E12-09-008b	Collinear nucleon structure at twist-3 in dihadron SIDIS	S. Pisano→M. Mirazita	--	
E12-11-003a	In medium structure functions, SRC, and the EMC effect	O. Hen	--	
E12-11-003b	Study of J/ψ photoproduction off the deuteron	Y. Ilieva	--	

2019 schedule: first part of RG B in January 30th - March 10th 2019, second part in November 1st – December 19th

→ 44.5 PAC days (1/2 of approved run time for nDVCS)

E12-11-003: DVCS on the neutron

ed→ e(p)nγ Fully exclusive final state: CLAS12+FT+CND

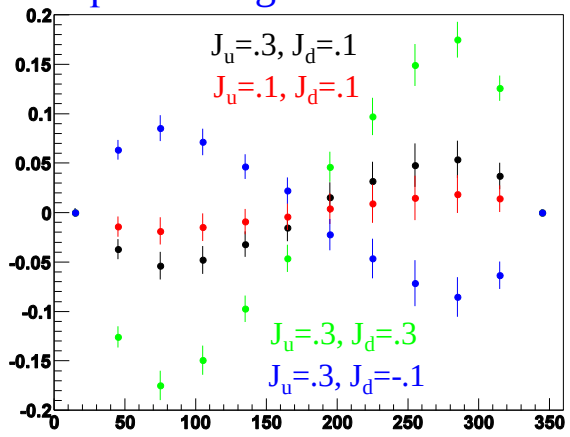
Spokespersons: A. El Alaoui,V. Kubarovsky, S. Niccolai, S. Pisano, D. Sokhan

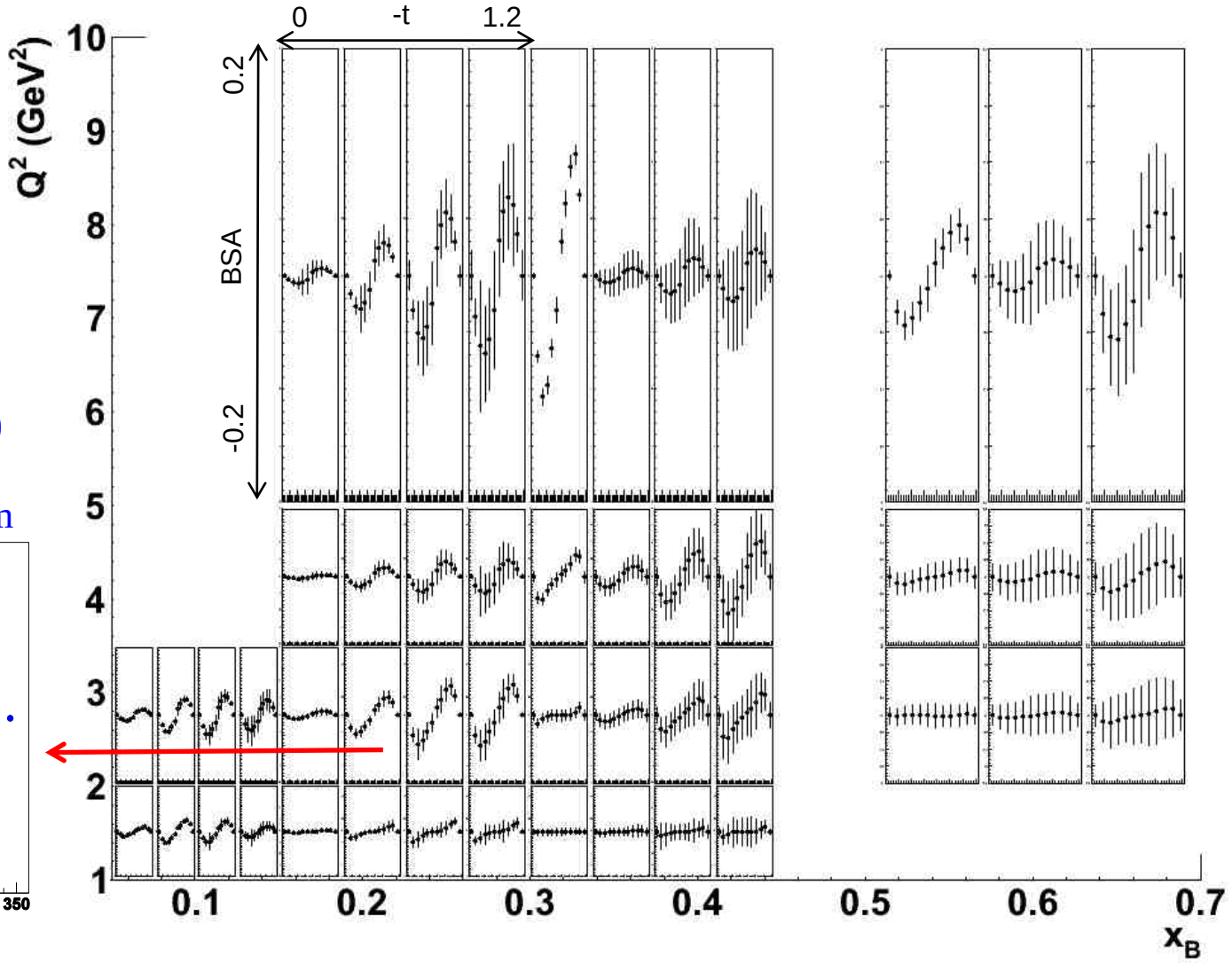
Goal: nDVCS beam-spin asymmetry, the most sensitive observable to the **GPD E**

- Liquid deuterium target
- L = 10^{35} /nucleon
- Full field, inbending
- 90 days

JLab PAC: **high-impact experiment**

Model predictions (VGG) for different values of quarks' angular momentum





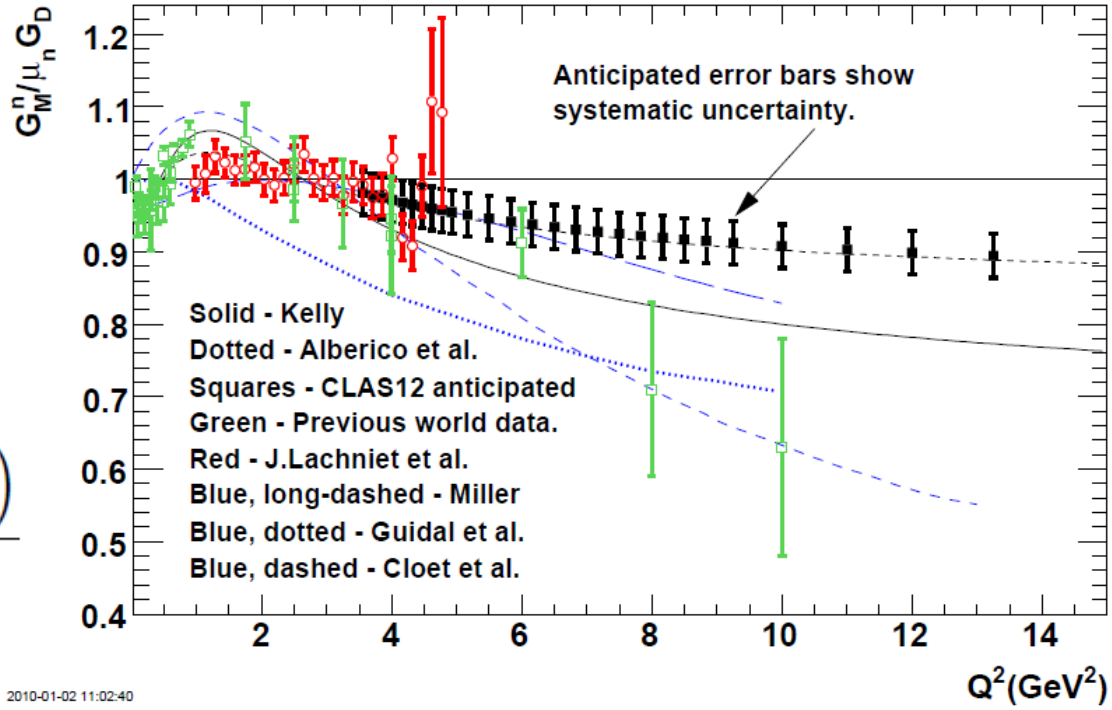
E12-07-104: Measurement of the neutron magnetic form factor at high Q^2 using the ratio method on deuterium

Spokespersons: W. Brooks, G. Gilfoyle, K. Hafidi

Goal: extract G_M^n for $3<Q^2<14$ GeV^2 via the ratio of **quasi-elastic e-n** and **quasi-elastic e-p** on deuteron

$$R = \frac{\frac{d\sigma}{d\Omega}(^2\mathrm{H}(e,e'n)_{QE})}{\frac{d\sigma}{d\Omega}(^2\mathrm{H}(e,e'p)_{QE})} =$$

$$= a(Q^2)\frac{\sigma^n_{mott}(G_E^{n\,2} + \frac{\tau_n}{\varepsilon_n}G_M^{n\,2})\left(\frac{1}{1+\tau_n}\right)}{\frac{d\sigma}{d\Omega}(^1\mathrm{H}(e,e')p)}$$



- Both particles of the two quasi-elastic final states will be detected in CLAS12
- Neutrons will be detected in the FEC, PCAL and FTOF
- Neutron efficiency must be frequently monitored to minimize systematics
- Full torus field, inbending
- Approved for 30 days of running

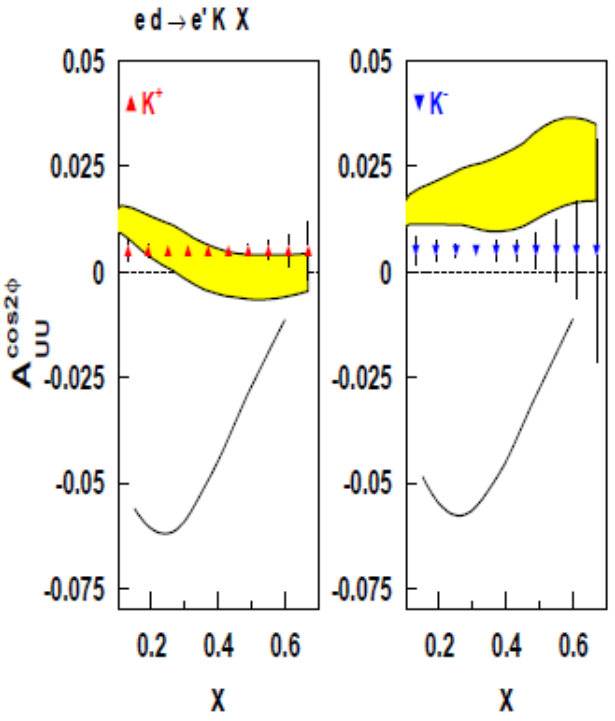
E12-09-008: Boers-Mulders asymmetry in K SIDIS

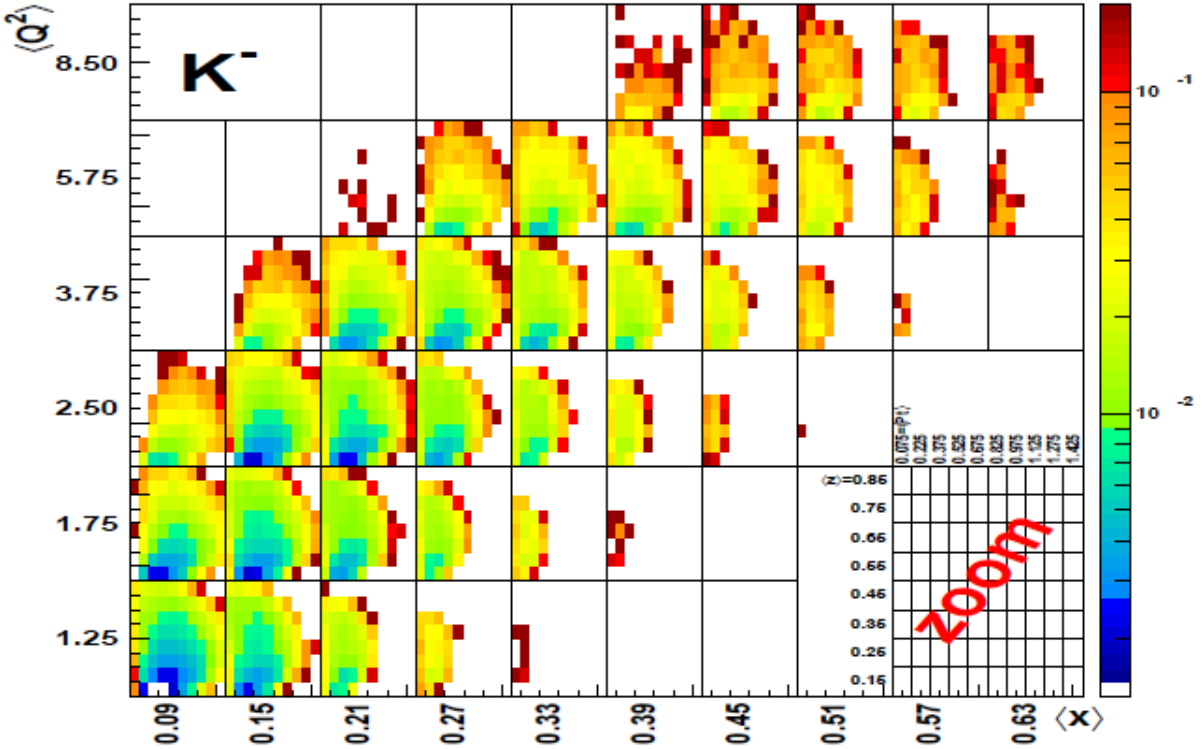
Spokespersons: H. Avakian, M. Contalbrigo, K. Joo, Z. Meziani

Goal: measurement of **spin azimuthal asymmetries** in **K-SIDIS**
→ transverse momentum dependence of **valence quark transverse spin distributions**
→ **spin-orbit correlations**

Azimuthal Modulations of F_{UU}

$$\frac{d^5\sigma^{ep\to e'hX}}{dx\,dy\,dz\,df\,dP_{h\perp}^2} \propto \{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos(f)F_{UU}^{\cos(f)} + \varepsilon\cos(2f)F_{UU}^{\cos(2f)}\}$$



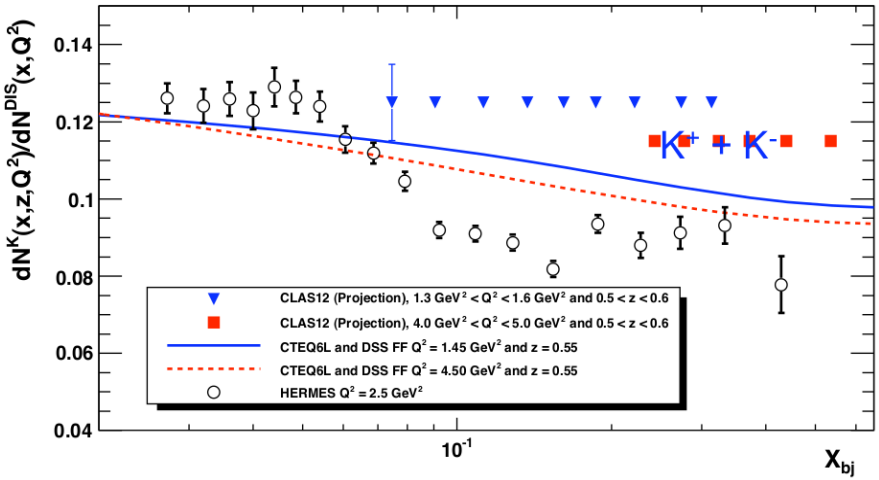


- **RICH** is required for kaon ID
- 56 approved days, 50% (27 days) outbending (opposite field polarity for systematic checks)
- Proton- and deuteron-target data will be combined for flavor separation

E12-09-007a: Study of partonic distributions in SIDIS K production

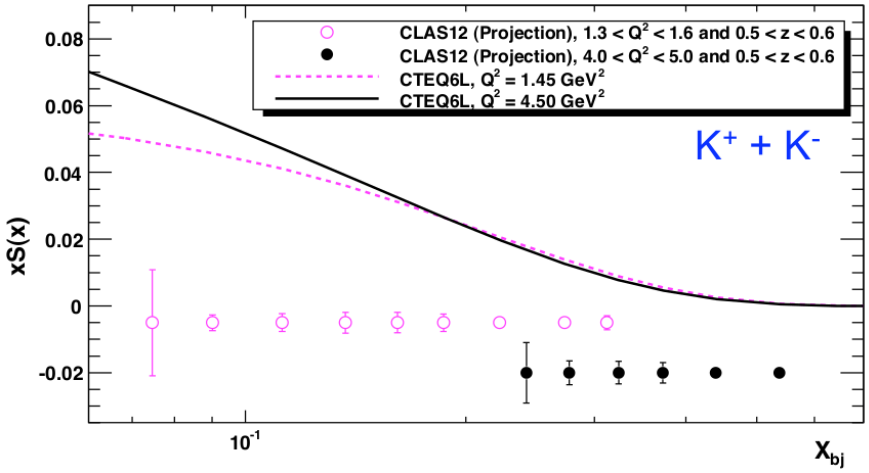
Spokespersons: H. Avakian, F. Benmoktar, A. El Alaoui, K. Hafidi, M. Mirazita
Contact person: W. Armstrong

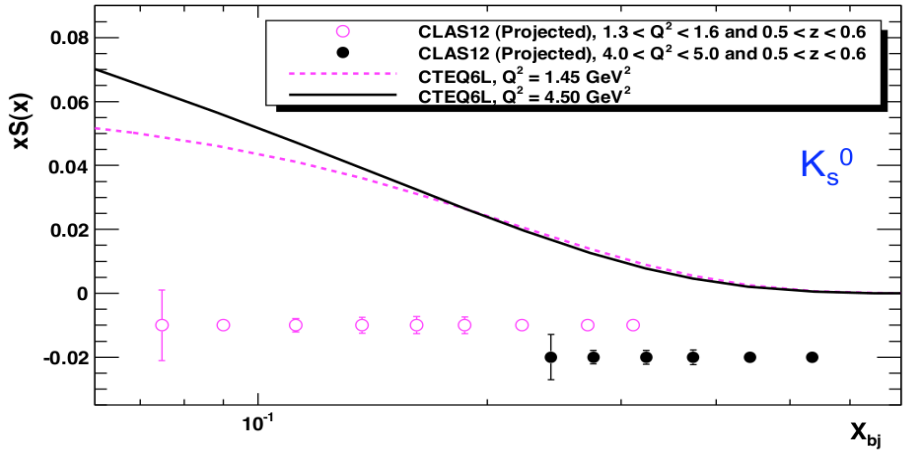
Goal: measure **multiplicities** for various hadrons (π^+, π^-, π^0, K^+, K^-, K^0_s) on deuterium, for $0.05 < x < 0.7$
→ Measure **fragmentation functions** and their Q^2 dependence
→ **Extract strange quark parton distribution functions**



- 56 PAC days (including 2 days of diagnostics)
- H- and D-target data will be combined
- **RICH** necessary for kaon ID
- 50 % of beam time with reverse magnetic field

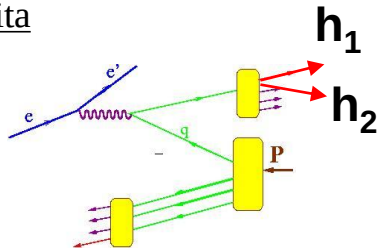
Need **both torus field settings** to eliminate systematic associated with different-charge acceptances.





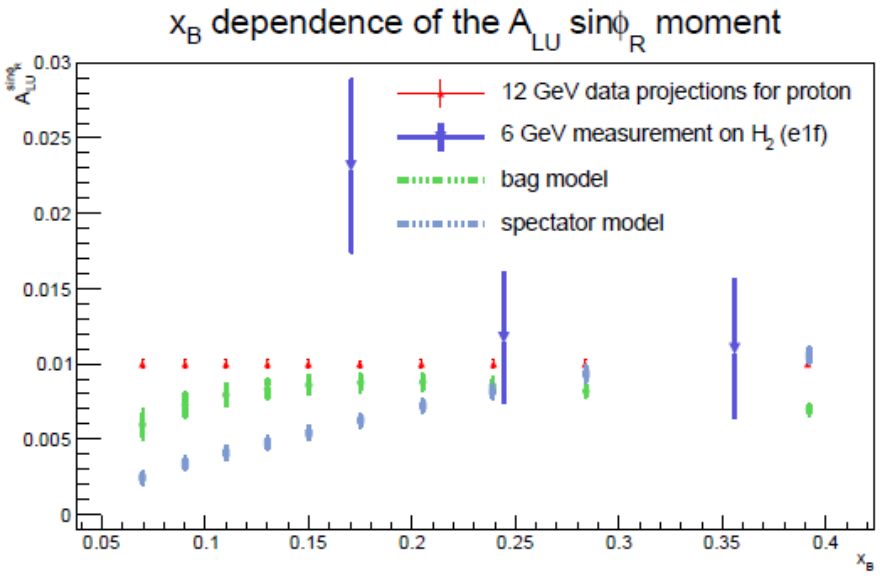
E12-09-008b: Higher-twist collinear structure of the nucleon through di-hadron SIDIS on unpolarized hydrogen and deuterium

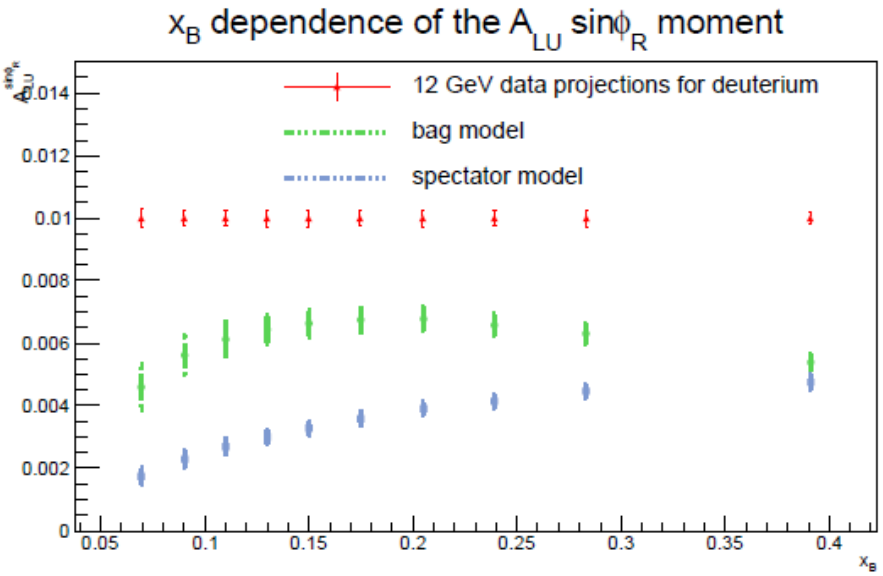
Spokespersons: S. Pisano, A. Courtoy
Contact person: M. Mirazita



Goals:

- Measure **multiplicities** and **beam spin asymmetry**
- Extract the unpolarized di-hadron Fragmentation Function and the collinear PDF e(x)



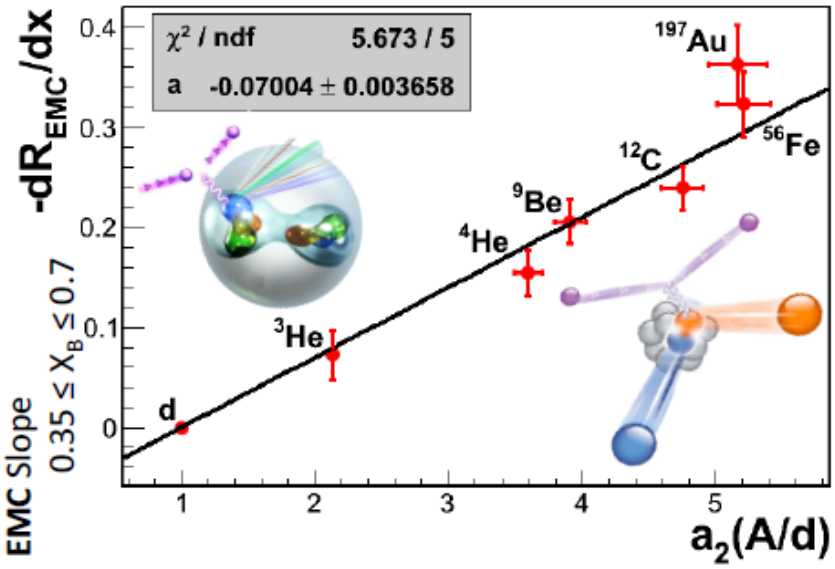


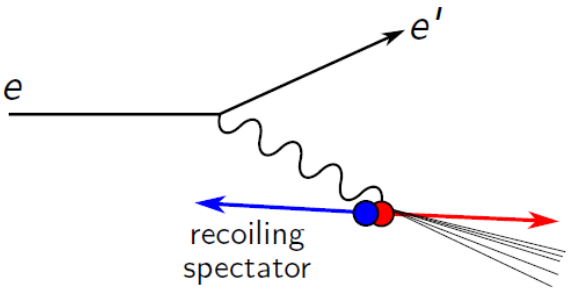
Also: 3D extraction of the BSA in (x_B, z, m_{pp}) bins on proton (RG-A) and deuteron (RG-B)

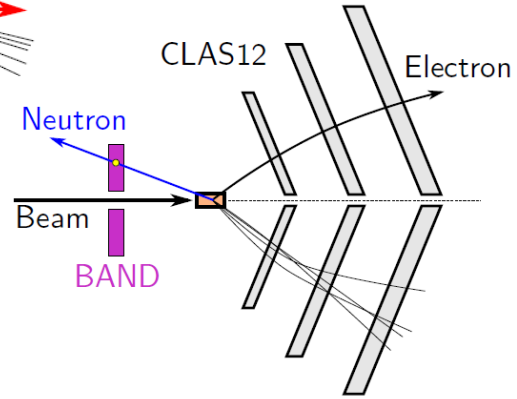
Measuring on both proton and deuteron will allow flavor decomposition

E12-11-003a: In medium proton structure functions, SRC and the EMC effect measured with CLAS12 and the Back Angle Neutron Detector

Spokespeople: O. Hen, L. Weinstein, H. Hakobyan and E. Piasetzky







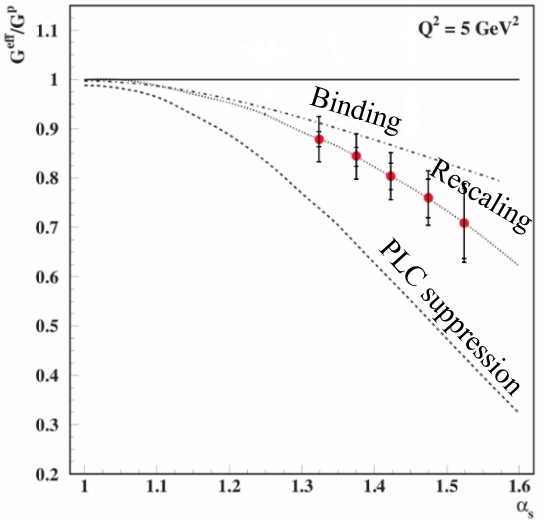
BAND will measure DIS on deuterium tagging a backward high-momentum neutron.

Is the nucleon modification of the EMC Effect due to Mean-Field nucleons or to correlated pairs?

- Measure the **bound proton structure function** as a function of neutron momentum or virtuality in deuterium
- SRC hypothesis predicts modification increasing with virtuality
- A way to select DIS on high-momentum nucleons is needed

Expected results for:

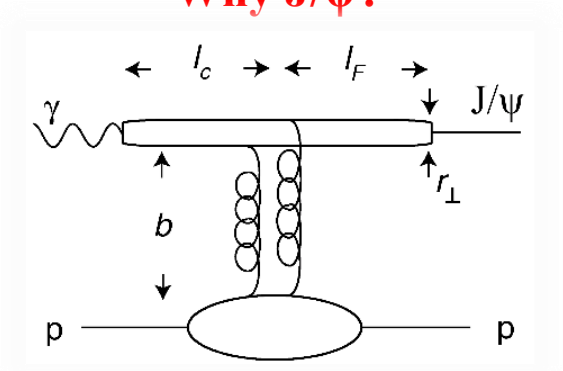
- **75 beam days**
- **Single-cell LD_2**
- **Full field inbending**



Study of J/ψ photoproduction off deuteron

Spokespeople:
Y. Ilieva, B. McKinnon, P. Nadel-Turonski, V. Kubarovsky, S. Stepanyan, Zh.W. Zhao

Why J/ψ?



- Small transverse size: $r_\perp \sim 1/m_c = 0.13$ fm
- Large t at threshold, $|t_{min}| = 1.7$ (GeV/c)^2
- $b \sim 1/|t|^{1/2} = 0.2$ fm
- The $c\bar{c}$ couples to gluon field in the target
- → Process dominated by **multi-gluon exchange**
- Probes the **short-range structure** of the target

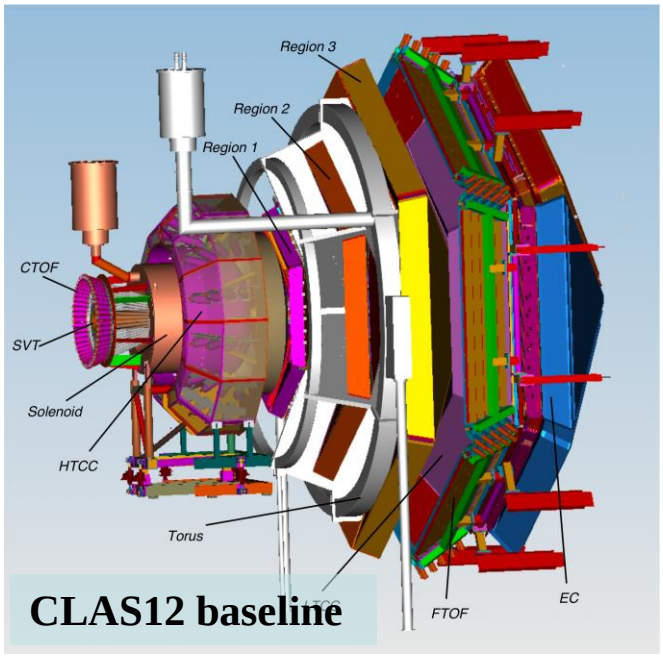
Goals: determine the cross sections of:

- Quasi-free photoproduction off **neutron**: γ(n)→J/ψ n
  - Search for isospin partners of **LHCb pentaquarks**
  - Test **bound-nucleon gluonic form factors**
- Final-State Interactions (J/ψN rescattering)
  - Estimate $\sigma_{J/\psi N}$
- **Coherent** photoproduction: γd→J/ψd
  - Study gluonic form-factor of deuteron

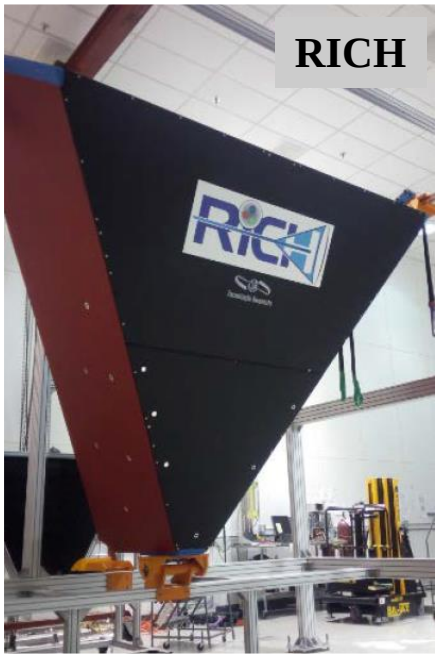
Experimental configuration

- Unpolarized LD2 target and 11-GeV electron beam, L=10^{35} $s^{-1}cm^{-2}$.
- Standard CLAS electron trigger and a Muon trigger (established during RGA).
- Charged-hadron detection in the Forward and Central Detectors.
- Neutron detection in the Forward Detector (will look for CND capabilities as well).
- Full torus field, electrons in-bending.

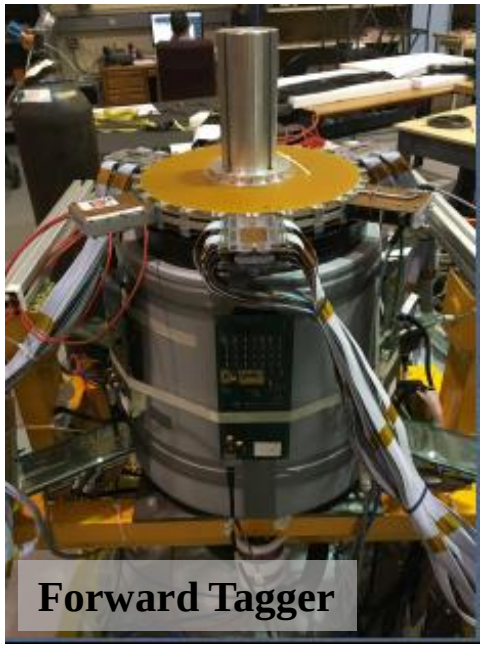
Run group B: experimental setup for the spring run

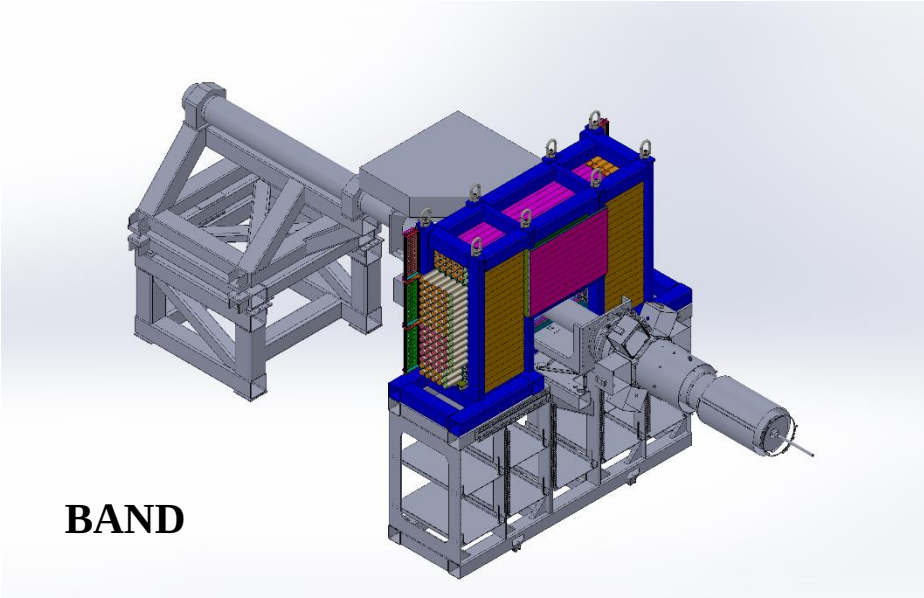


CLAS12 baseline



RICH


Forward Tagger

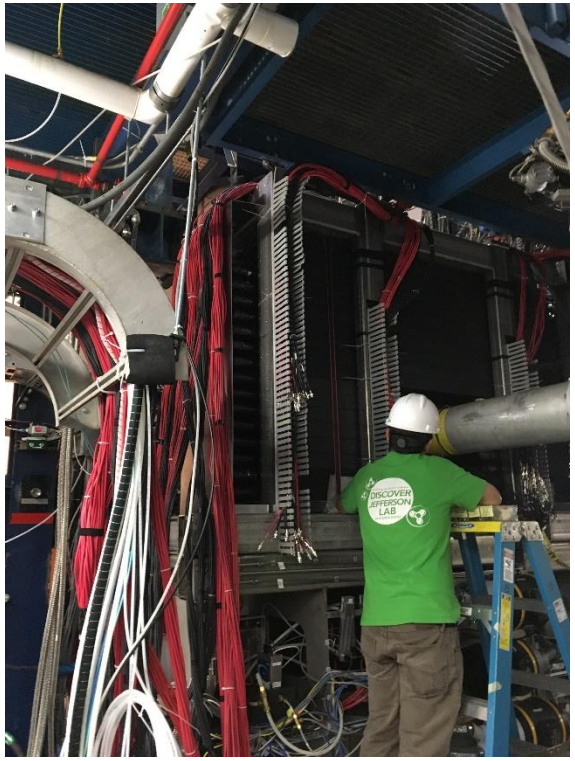

BAND

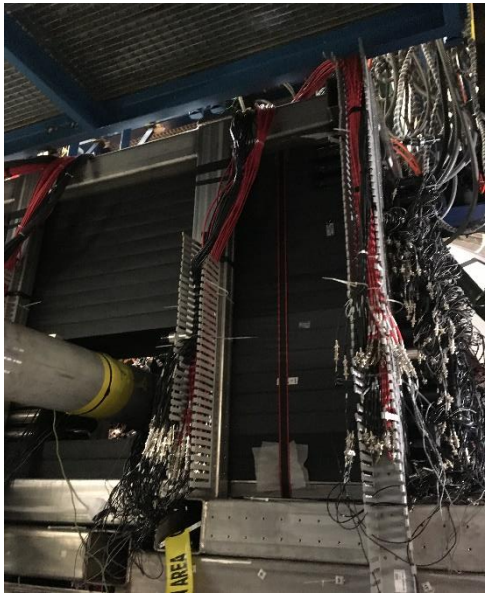
BAND: description and installation

Back Angle Neutron Detector

- 160 – 170^{o}
- ~ 40% neutron efficiency
- Plastic scintillator

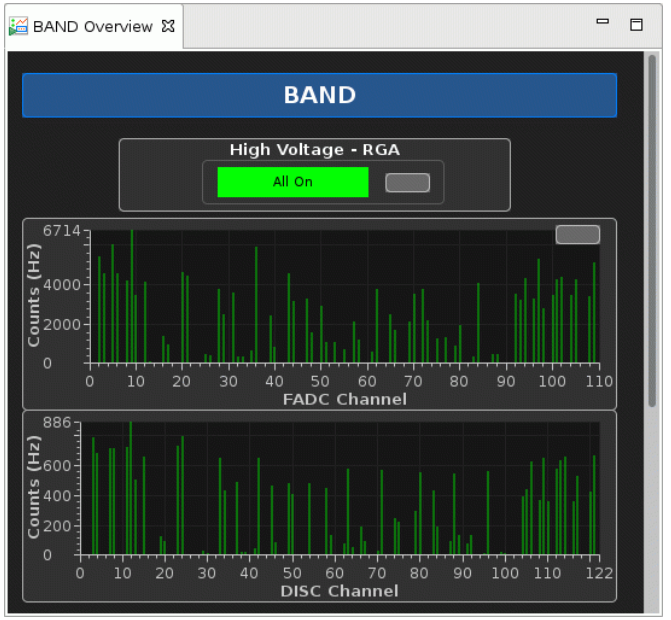
- 116 7.2 x 7.2 cm^2 bars read out on both ends
- Veto Layer
  - 24 2 x 7.2 cm^2 bars
  - one 2” PMT per bar
- Installed in the hall on top of SVT cart in August





BAND status update

- BAND - fall RG-A run:
  - Only ~44% of PMTs equipped with FADCs and TDCs
  - Dedicated trigger board for cosmics
  - First gain matching calibrations
  - Development of DAQ settings
- In progress
  - Calibration software
  - Implementation in CLAS software
- BAND monitoring done (thanks Cole)
- HV control and scalers done (thanks Nathan)

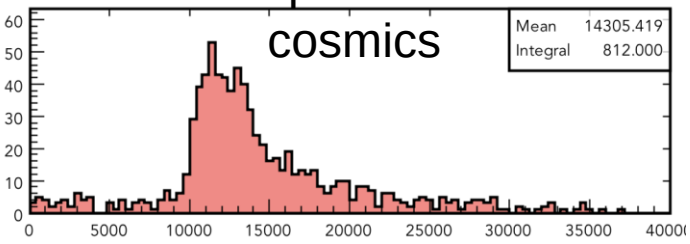


Rates with beam at 45nA

- To be done:
  - Install remaining readout hardware and cables
  - Install laser calibration system

  → This work will happen during the January downtime

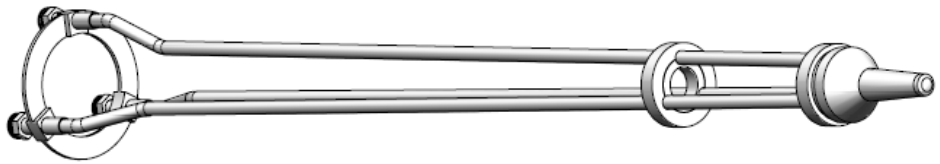
ADC spectrum with cosmics



Run group B: running conditions and run plan

All RG experiments agreed on the same set of running conditions ***(ERR, February 2018)***

- Common goal: **maximize statistics on deuterium**
  - Single cell target: liquid deuterium – preferred over dual target
- **RG-A data** will be used to **subtract proton contribution and/or evaluate neutron efficiencies**:
  - Same target cell as RG-A (5 cm long, single cell)
- Magnetic field settings: **same as RG-A**, for consistency
  - 75% full torus field inbending, 25% full torus field outbending – solenoid full field
- Ancillary runs: **periodic liquid hydrogen target** runs (~8%), plus empty target and Moeller runs
- Luminosity: as close as possible to **10^{35} cm^2/s**
- Beam energy: as close as possible to **11 GeV**



Time it takes to change target material: one shift?
Bob Miller will do tests in late December and January

RSAD, COO, ESAD, and Operation Manuals are done
RG-B Web page and wiki page have been created
Shifts are assigned

Run group B: draft of trigger configuration

Same as RG-A, without the FT trigger

- ***Inclusive electron scattering trigger***

Scattered electron detected in the **Forward Detectors**: High Threshold Cherenkov Counter (HTCC), Drift Chambers (DC), Preshower Calorimeter (PCAL) and Electromagnetic Calorimeter (EC).

- ***"Muon" trigger***

Select events with two muons detected in the Forward Detectors only.
This trigger does not require to detect the scattered electron at all.

- ***Technical triggers (prescaled)***
  - Electron trigger without DC segments
  - PCALxECAL trigger with low threshold
  - Forward tagger trigger with low threshold
  - Random triggers (generator + Faraday cap)

Trigger performances for fall RG-A run: production rates at 45nA beam (with FT):

- Inbending: 12kHz event rate (Electron trigger: ~30%; Muon trigger: ~21%), data rate: ~300MB/sec, LT=96%.
- Outbending: 14kHz event rate (Electron trigger: ~50%; Muon trigger: ~20%), data rate: ~330MB/sec, LT=95%

Projected raw-data size for 45 PAC days of RG-B: ~500 TB

Responsibilities and manpower

Run coordinators for the spring run of RG-B: S. Niccolai, Y. Ilieva, J. Gilfoyle, M. Contalbrigo, M. Mirazita, L. Weinstein, (S. Stepanyan, P. Turonski, V. Kubarovsky)

Monitoring coordinator: Y. Ilieva
Chef: Z. Zhao
Monitoring and reconstruction « workers »: K. Price, R. Wang, L. Baashen, M. Armstrong, A. Movsisyan, O. Soto
Analysis coordinator: S. Niccolai

Calibrations: task sharing (according to the CLAS12 Task List)

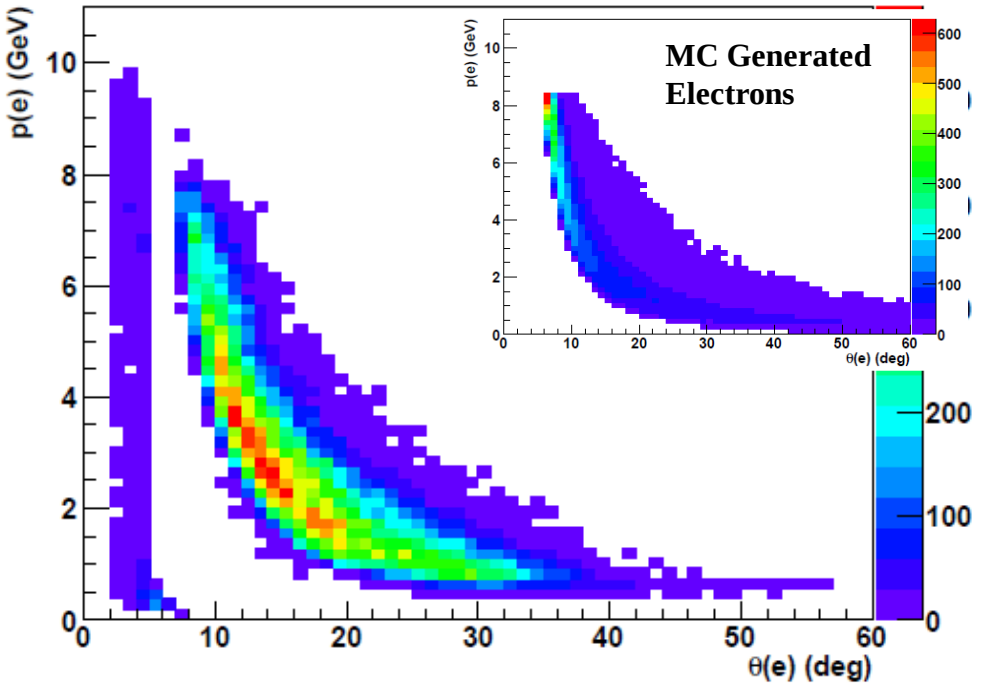
- HTCC: GWU
- LTCC: Temple
- DC: UMISS
- FTOF: ANL
- CTOF: FIU
- RICH: Duquesne
- FTCAL: INFNGE
- FTHODO: York
- CND: Glasgow
- ECAL, PCAL: To be assigned (Jlab?)
- CVT (alignment): Richmond
- BAND: MIT/ODU

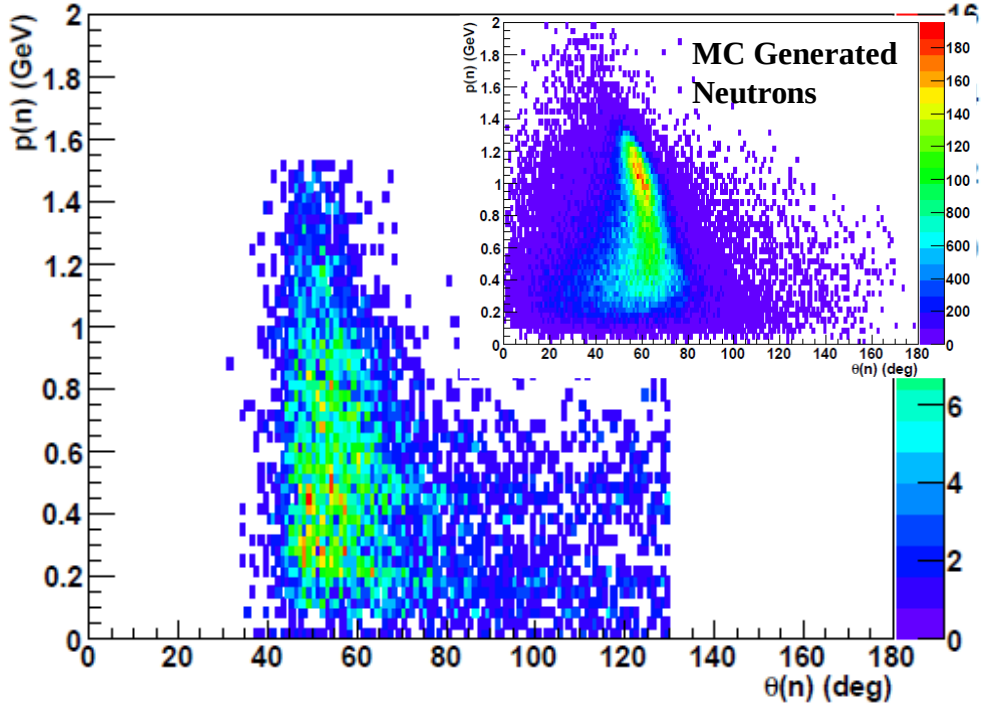
- Calibration procedures are being tested for RG-A
- Data reconstruction (COATJAVA) is in use for RG-A

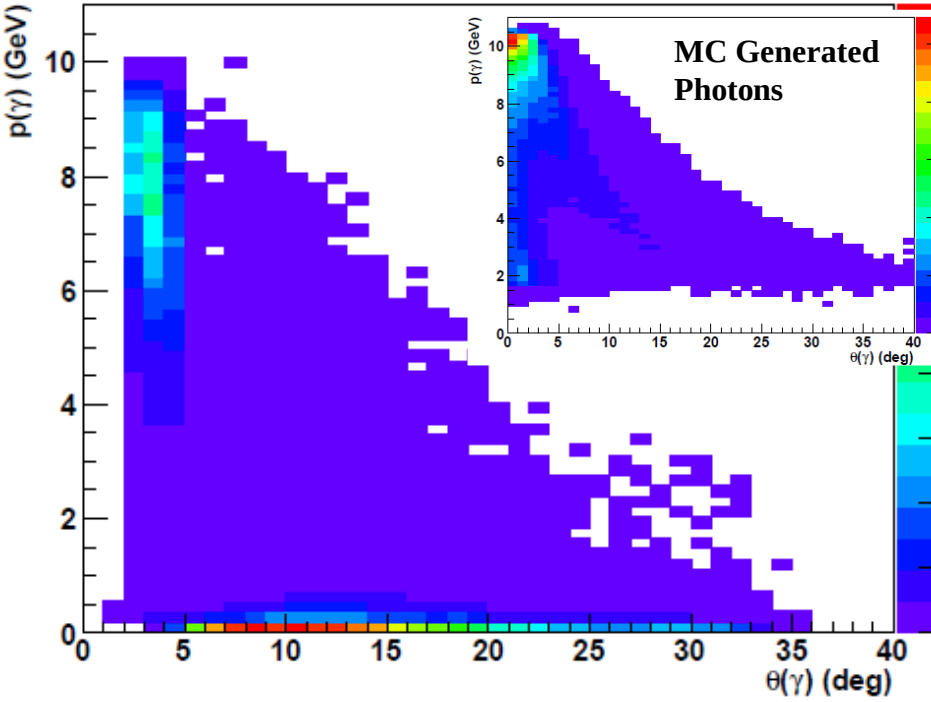
Readyness for physics results: the example of nDVCS

Event generator: pDVCS/nDVCS on deuterium
→ GEMC 2a.4.2, RG-A gcard + deuterium target
→ COATJAVA 5b.5.0
→ ROOT-based data analysis (code on github)
→ PID from EB

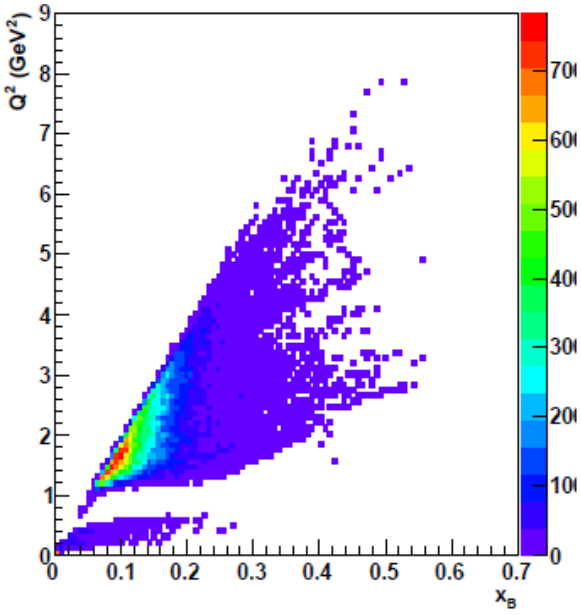
- Electrons detected in **FD**
- Photons detected in **EC** and **FT**
- Neutrons detected in **CND** only (so far)

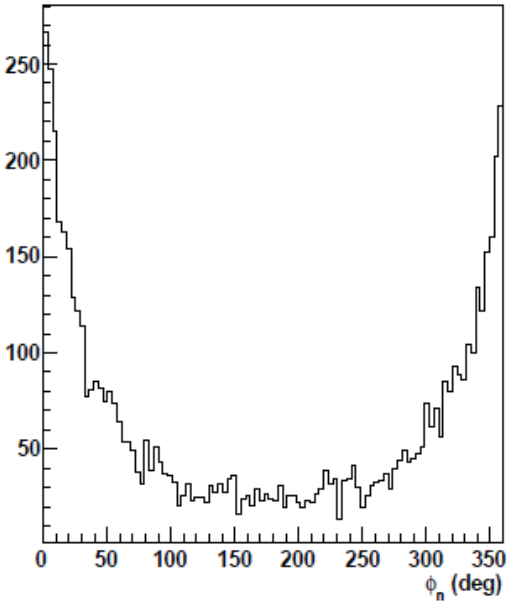


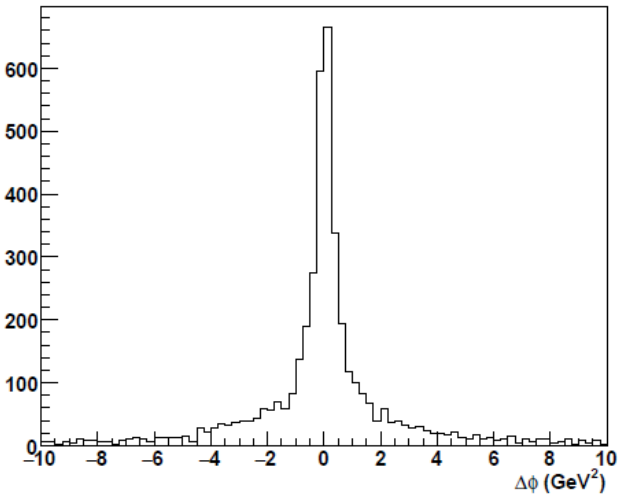


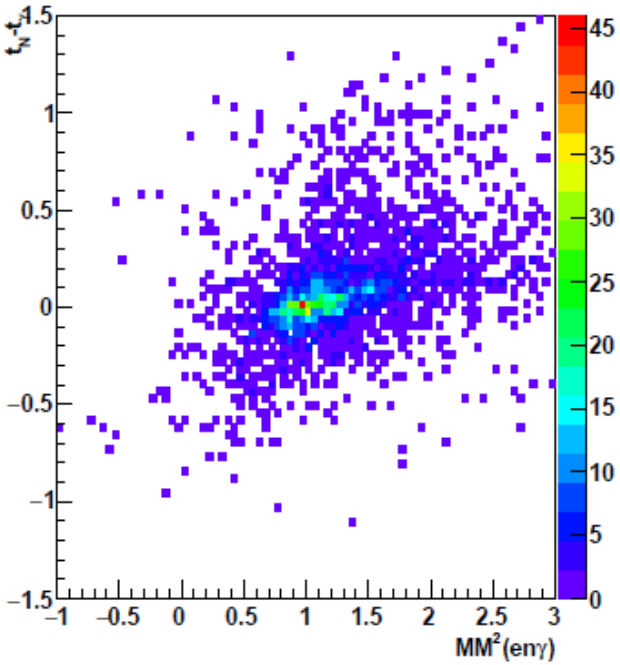


nDVCS: kinematic variables and exclusivity cuts

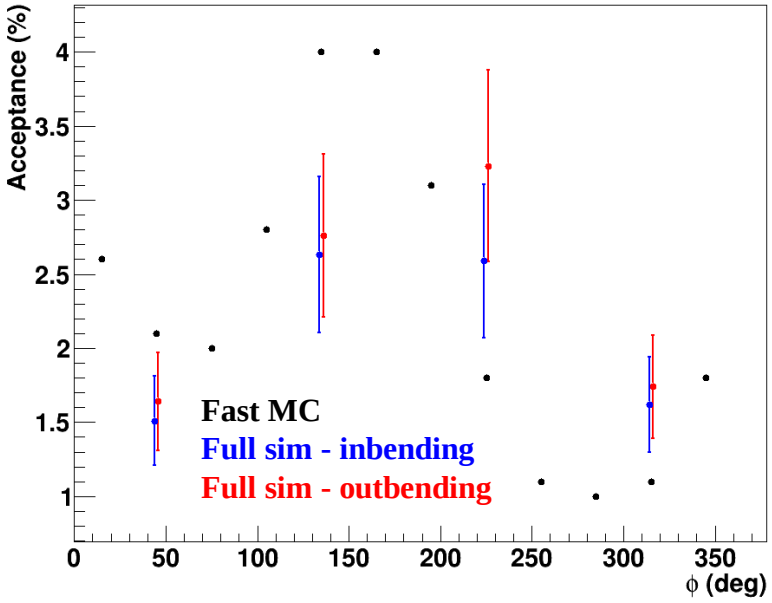








Q^2=2.75 GeV^2 x_B=0.275 t=-0.35 GeV^2



- ✓ PID
- ✓ Channel selection
- • Background studies ongoing

Acceptances are compatible with proposal estimates (done with Fast MC)

Summary

- RG-B has 7 experiments, sharing the common goal to advance in the multi-dimensional imagining of the nucleon, disentangling the quark flavor dependence
- Strictly linked to RG-A → same running conditions (beam energy, target cell, magnetic fields)
- Detector configuration: same as RG-A (+LD2) + BAND
- Task sharing for data taking, calibrations, and reconstruction is established
- The experiment groups have manpower to accomplish these tasks and their own analyses
- The tools for the data analysis are available and are being tuned on simulation and RG-A data

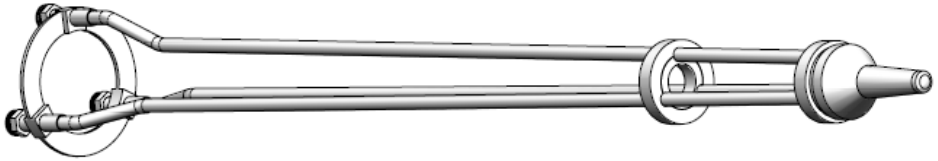
→ Looking forward to take data in the spring!

Back-up slides

Run group B: running conditions

All RG experiments agreed on the same set of running conditions ***(ERR, February 2018)***

- Common goal: **maximize statistics on deuterium**
  - Single cell target: liquid deuterium – preferred over dual target
- **RG-A data** will be used to **subtract proton contribution and/or evaluate neutron efficiencies**:
  - Same target cell as RG-A (5 cm long, single cell)

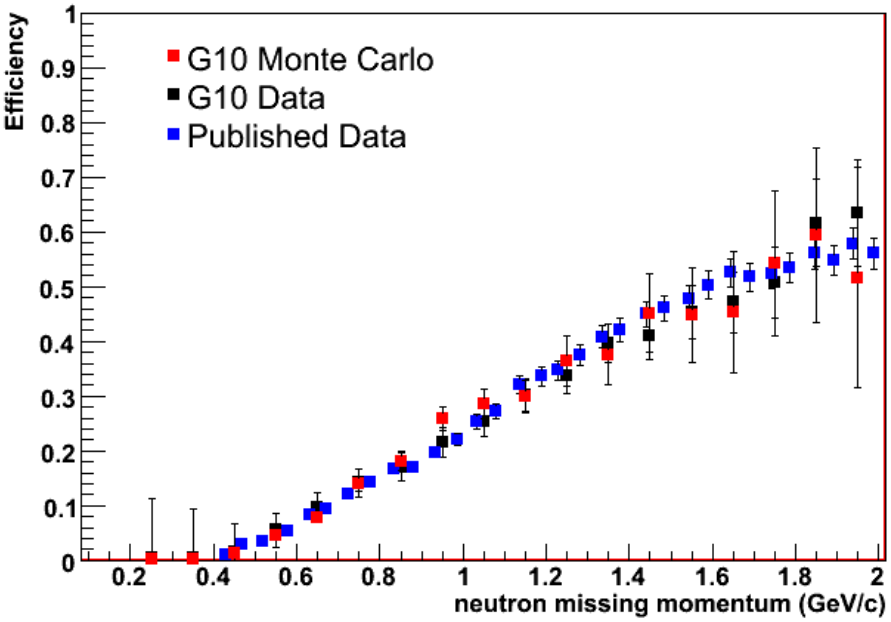


Time it takes to change target material: one shift at most (Bob Miller)

RG-B will have **periodic hydrogen-target runs (~8%)** to monitor neutron-detection efficiency

→ ~60% of the hydrogen running than what would be obtained with the dual target for 30 days

NDE will also be monitored from **kinematically complete reactions on deuterium**



Example of NDE extracted from deuterium data:

- Work by S. A. Pereira on CLAS-g10 data set
- Chosen reaction **$\gamma d \rightarrow p n \pi^+ \pi^-$**
- Exclusivity cuts to select the final state precisely
- Efficiency obtained comparing detected and expected neutrons

Possible channels to measure NDE in RG-B:

- **$ed \rightarrow e' p n \pi^+ \pi^-$**
- **$ed \rightarrow e' p n$**

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- Magnetic field settings: **same as RG-A**, for consistency
  - 75% full torus field inbending, 25% full torus field outbending – solenoid full field

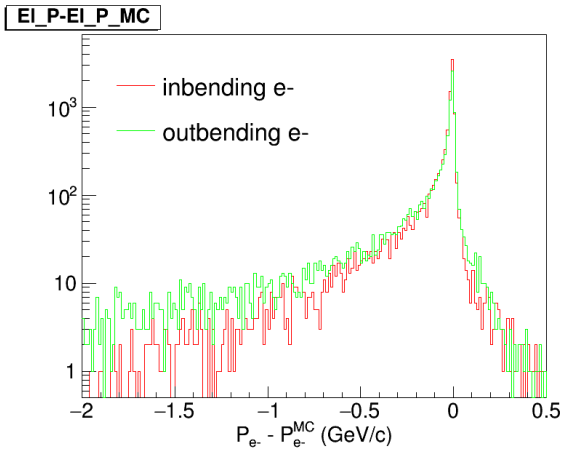
For 90 days of running: 67 days inbending, 23 days outbending

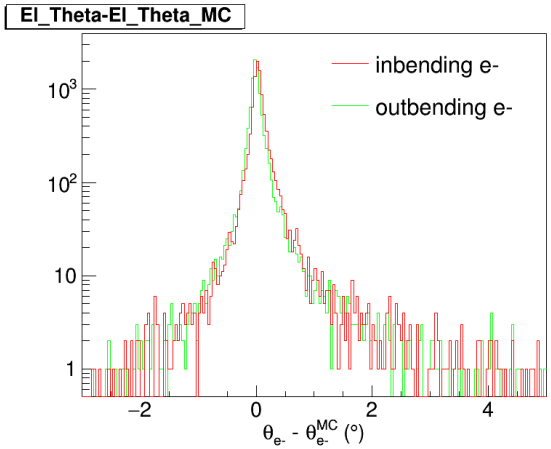
✓ SIDIS proposals originally asked for 27 days outbending → **OK**

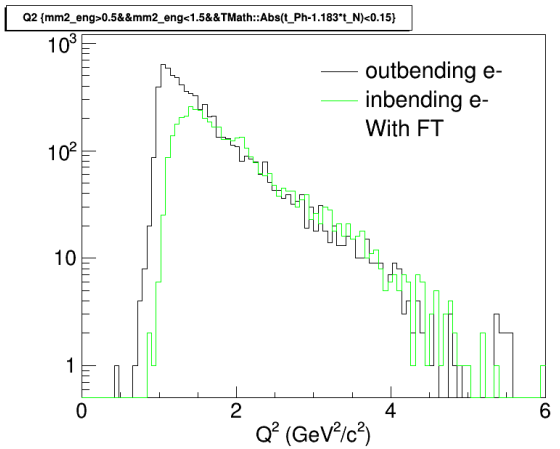
✓ GMn proposal asked for 30 days inbending → **OK**

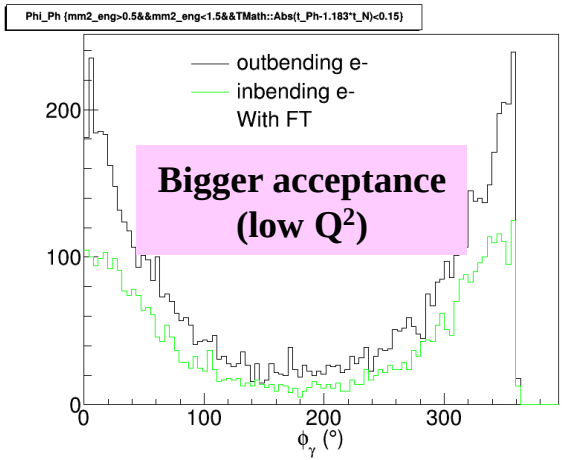
✓ nDVCS originally asked for 90 days inbending → **OK**

Small difference on resolutions









Full simulations+reconstruction for nDVCS

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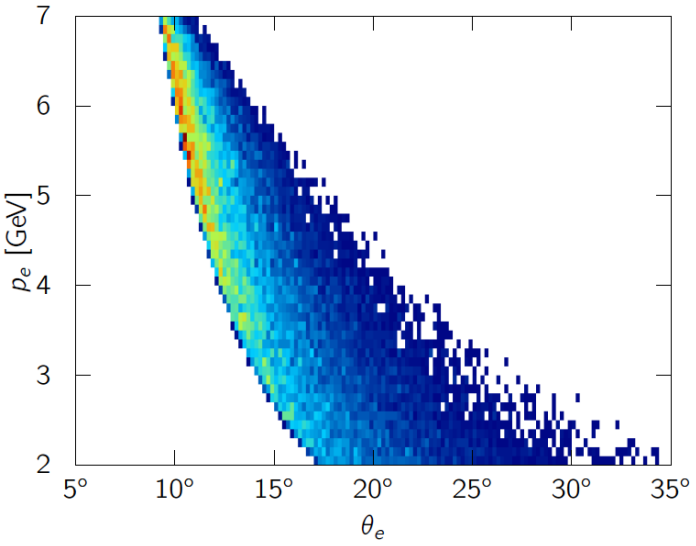
- ✓ nDVCS originally asked for 90 days inbending → **OK**
- ✓ SRC/EMC experiment asked for 90 days inbending → **OK**



The relevant electrons of the SRC/EMC experiment will be in the middle of the CLAS12 acceptance