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

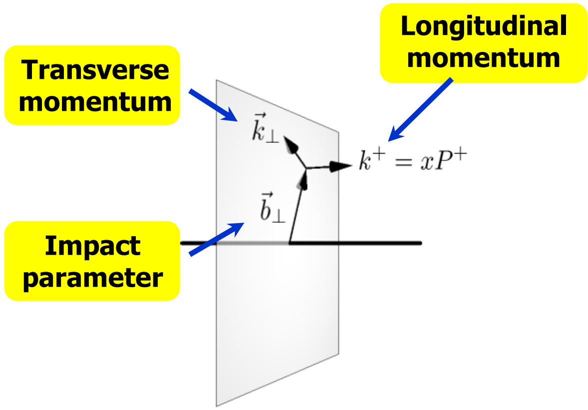
Silvia Niccolai, IPN Orsay, on behalf of RG-B

CLAS Collaboration meeting, JLab, 7/13/2018

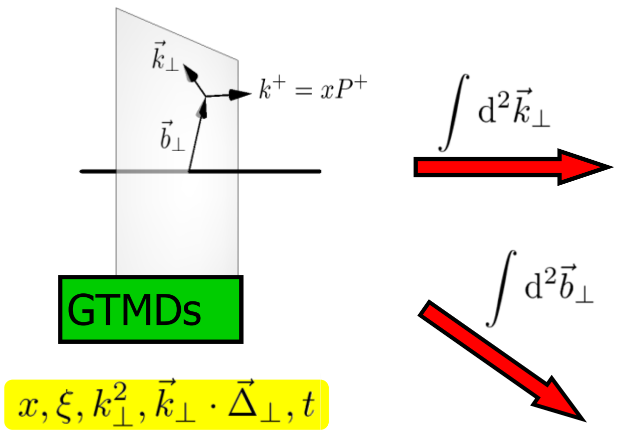
CEBAF Large Acceptance Spectrometer

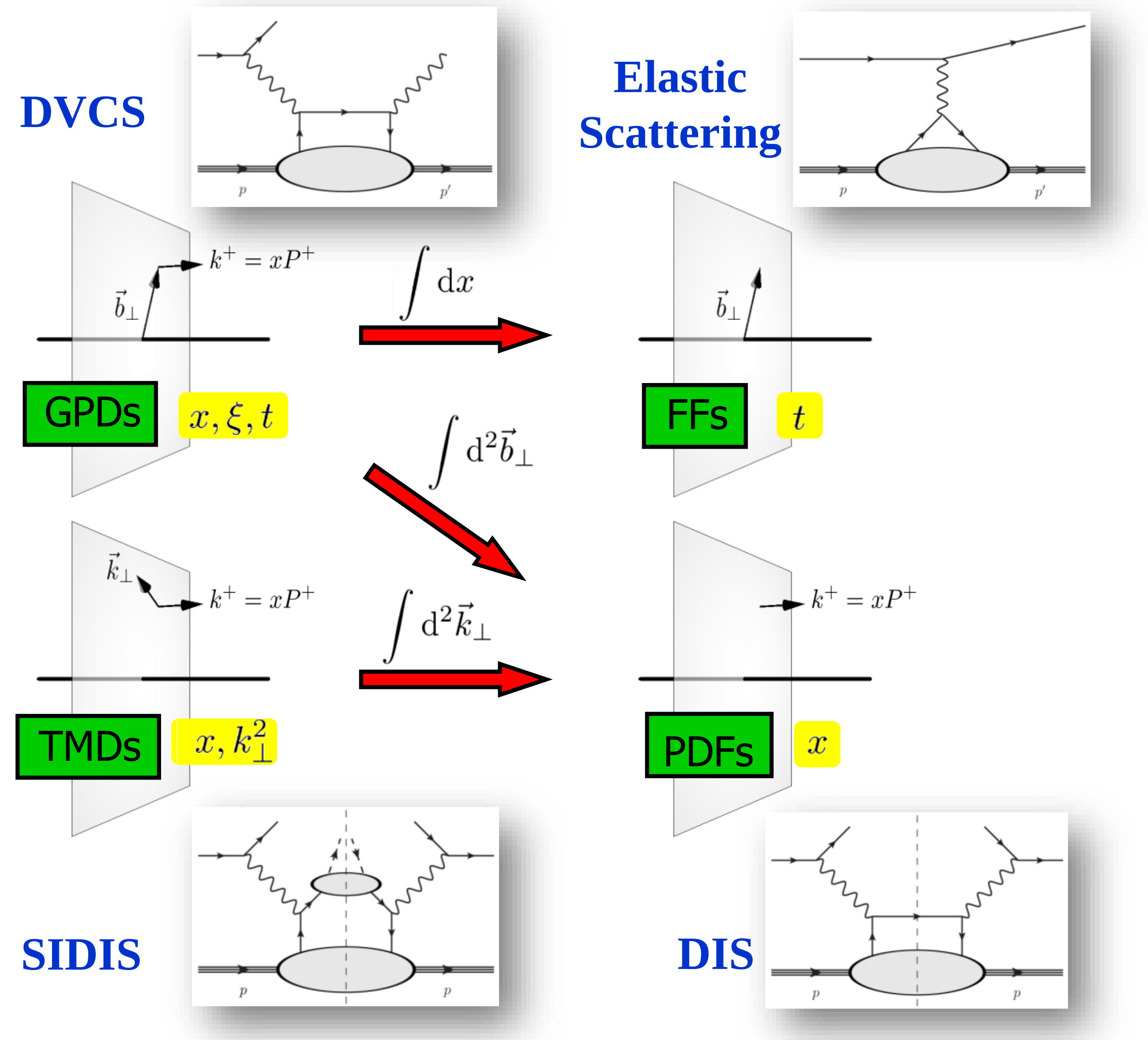
INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

Multi-dimensional mapping of the nucleon



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





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

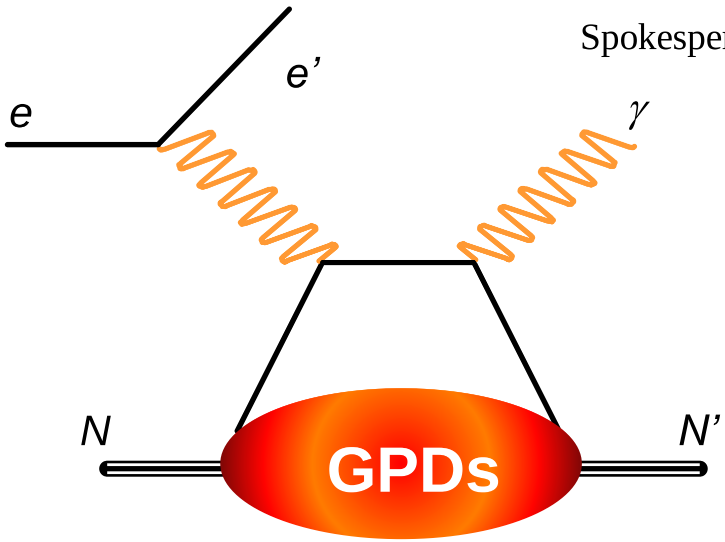
CLAS12 Run-Group B

- Common features to all experiments of RG-B:
  - ✓ **Liquid deuterium target**
  - ✓ **Beam energy: 11 GeV**
  - ✓ **Luminosity = 10^{35} cm^2/s**
- 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	--	

Schedule: first half of RG B running in January 30th - March 10th 2018, second half in October 1st – November 24th

E12-11-003: DVCS on the neutron



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

A combined analysis of DVCS observables for proton and neutron targets is necessary for flavor separation of GPDs

$$(H,E)_u(\xi,\xi,t) = \tfrac{9}{15}\left[4(H,E)_p(\xi,\xi,t) - (H,E)_n(\xi,\xi,t)\right]$$

$$(H,E)_d(\xi,\xi,t) = \tfrac{9}{15}\left[4(H,E)_n(\xi,\xi,t) - (H,E)_p(\xi,\xi,t)\right]$$

The beam-spin asymmetry of nDVCS is the observable the most sensitive to the least constrained GPD, E ($\rightarrow J_q$)

Polarized beam, unpolarized target:

$$\Delta\sigma_{LU} \sim \sin\phi \, \mathrm{Im}\left\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} + kF_2\mathcal{E}\right\}d\phi$$

Proton $\Rightarrow$ $\mathrm{Im}\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$

Neutron $\Rightarrow$ $\mathrm{Im}\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \mathcal{E}_n\}$

The BSA for nDVCS:

- is complementary to the TSA for pDVCS on transverse target, aiming at E
- depends strongly on the kinematics $\rightarrow$ wide coverage needed

E12-11-003: DVCS on the neutron

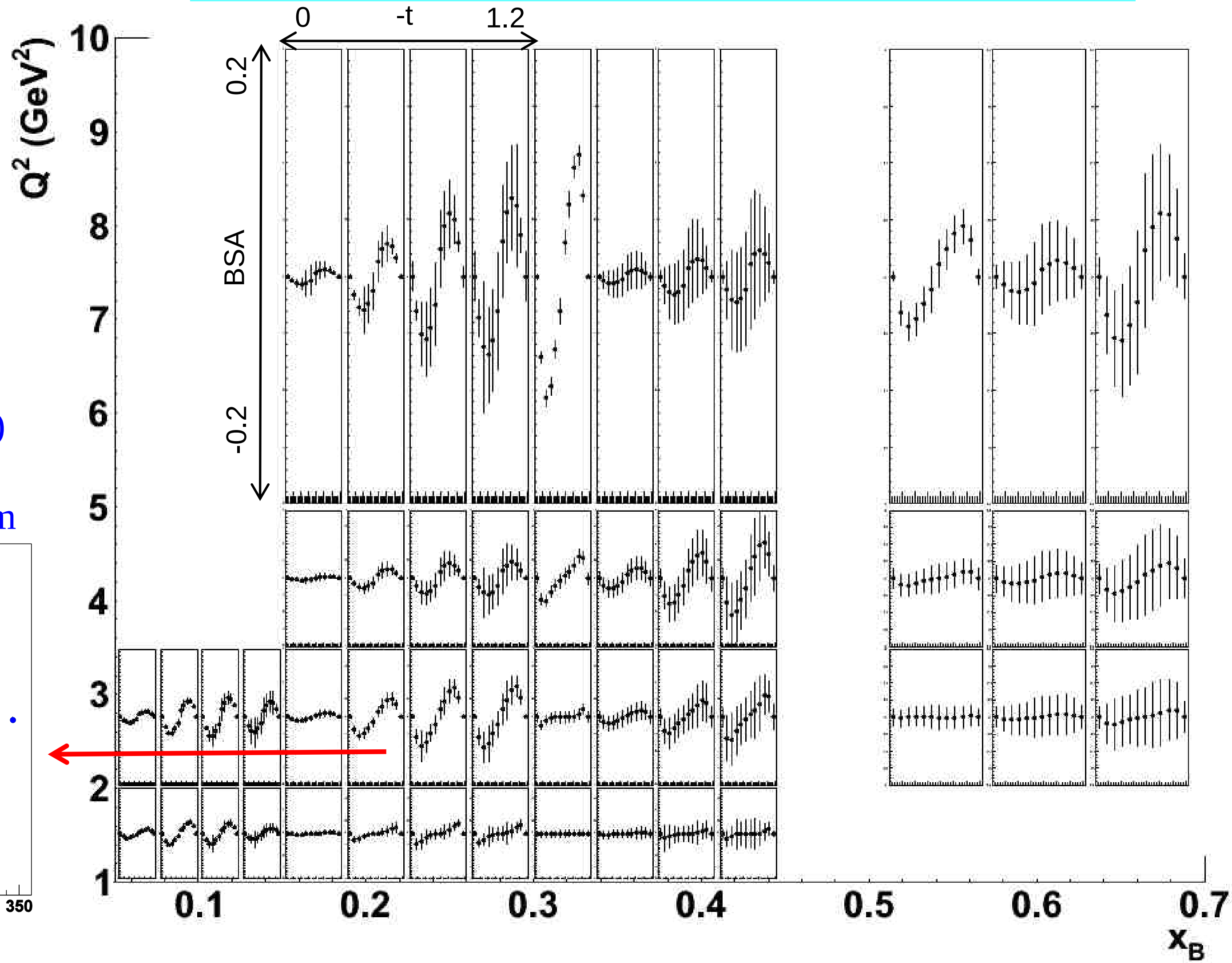
ed→ e(p)nγ Fully exclusive final state:
CLAS12+FT+CND

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

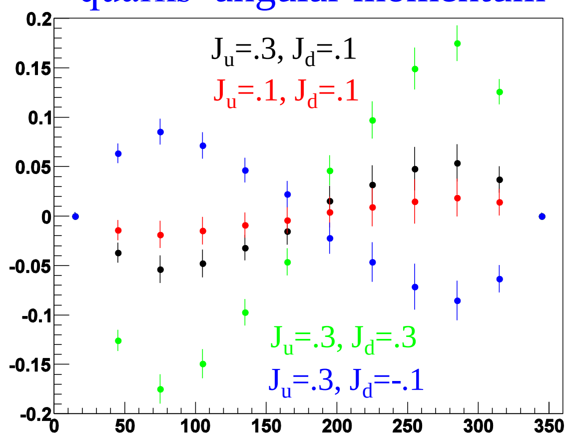
- Liquid deuterium target
- L = 10^{35} /nucleon
- Full field, inbending
- 90 days

JLab PAC:
high-impact experiment

Projections for the nDVCS beam-spin asymmetry



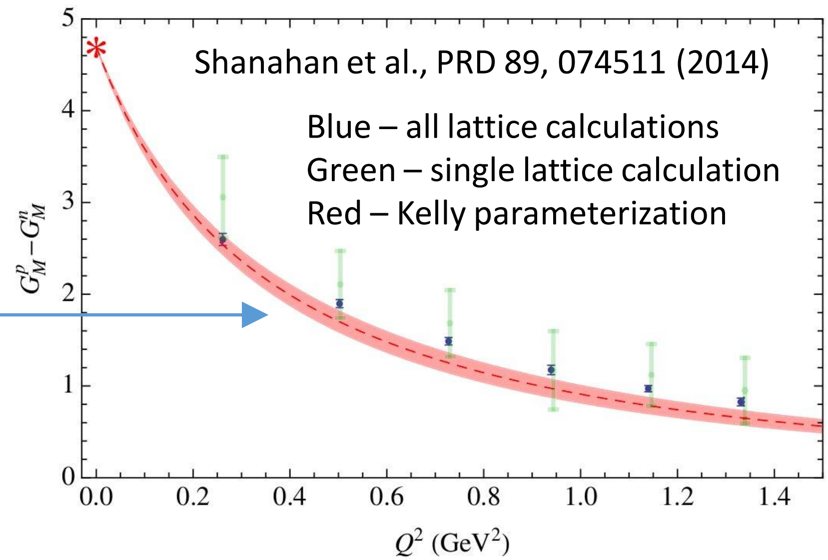
Model predictions (VGG) for different values of quarks' angular momentum

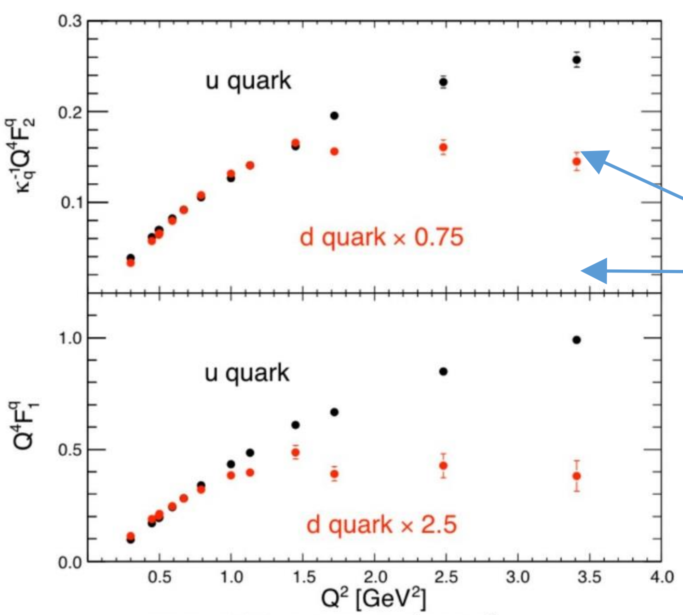


E12-07-104: Measurement of the neutron magnetic form factor at high Q^2 using the ratio method on deuterium

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

- **Elastic electromagnetic form factors** (EEFFs) are fundamental observables that describe the **distribution of charge and magnetization**
- JLab program has **seven approved experiments** to measure **all four EEFFs**
- Early test of lattice QCD, because the isovector form factor is less computationally intensive





PRL **106**, 252003 (2011).

- All four EEFFs are needed to do **flavor decomposition** which shows surprising **differences between *u* and *d* quarks**
- The form factors are the **first moments of the GPDs** and provide a important constraint on their value

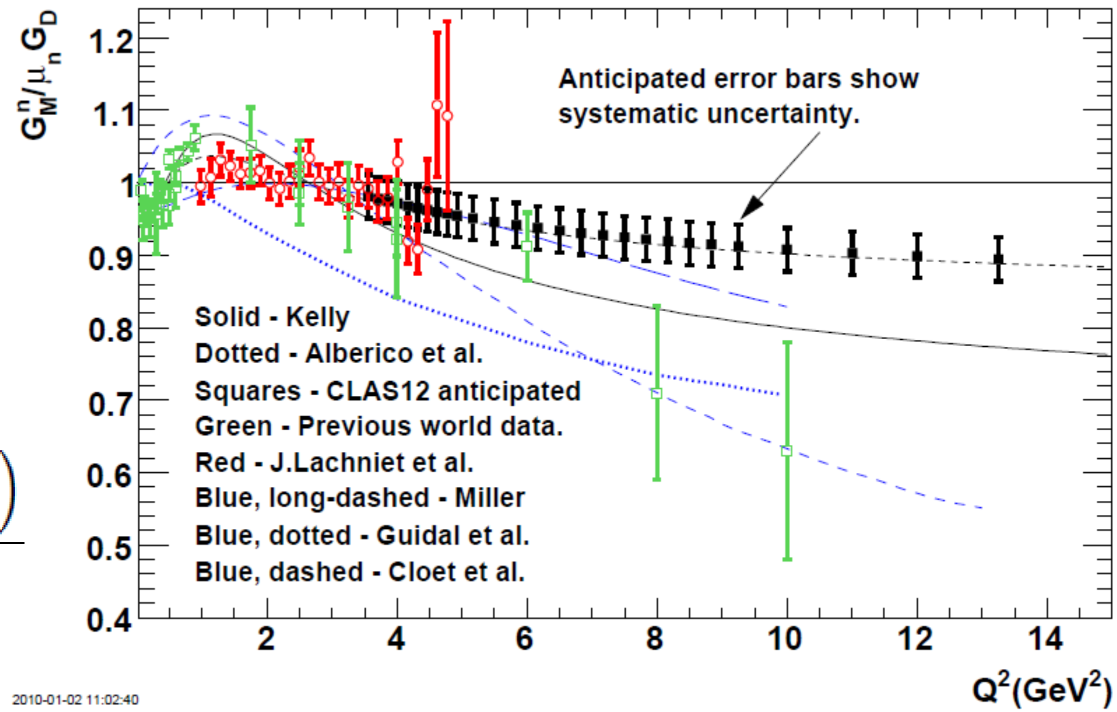
E12-07-104: Measurement of the neutron magnetic form factor at high Q^2 using the ratio method on deuterium

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

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

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



- Both particles of the two quasi-elastic final states will be detected in CLAS12
- Neutrons will be detected in the FEC, PCAL and FTOF
- A dual target (H/D) was approved by the PAC to monitor neutron efficiency and 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

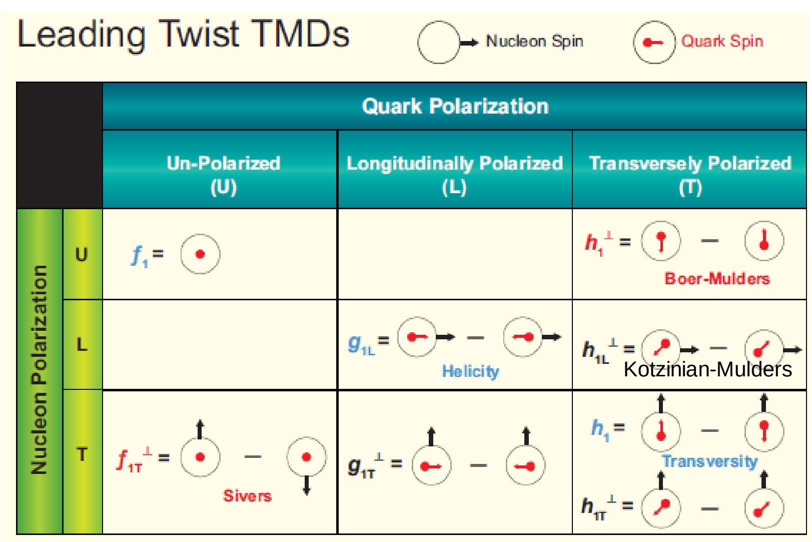
Goal: measurement of **spin azimuthal asymmetries** in **K-SIDIS**
→ transverse momentum dependence of **valence quark transverse spin distributions**
→ **spin-orbit correlations**

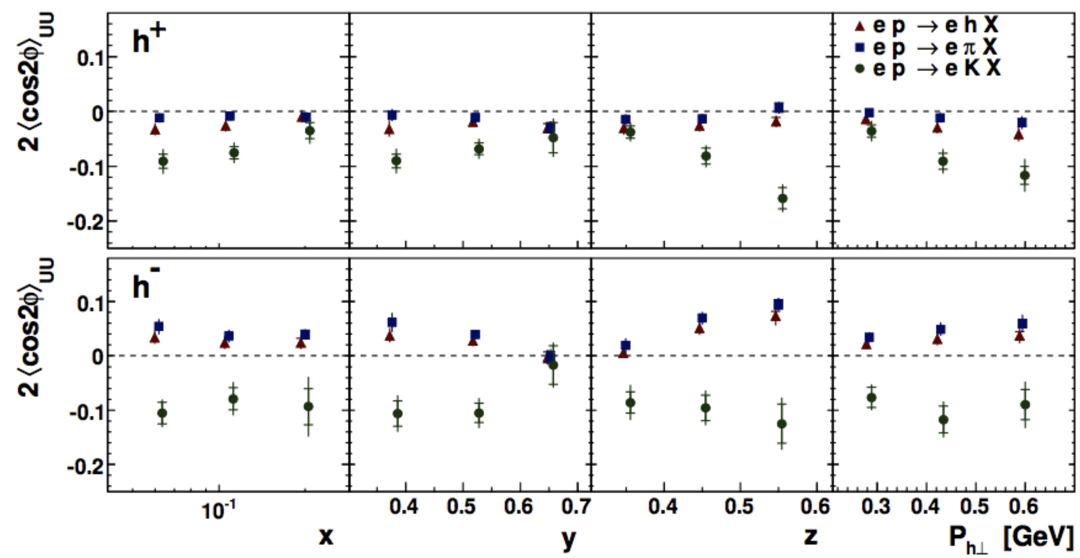
Azimuthal Modulations of F_{UU}

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

$$F_{UU}^{\cos 2\phi} \propto [h_1^\perp H_1^\perp + \ldots]$$

QCD dynamic Boer-Mulders effect
Surprising flavor dependence!





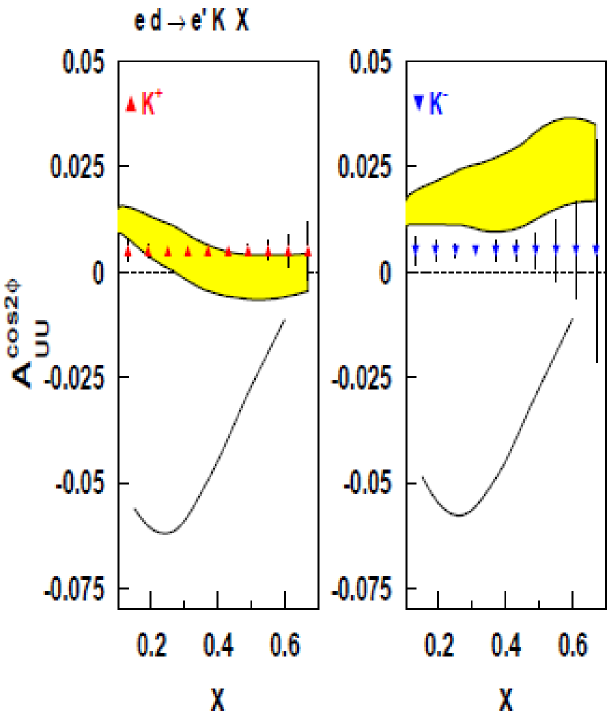
HERMES DATA

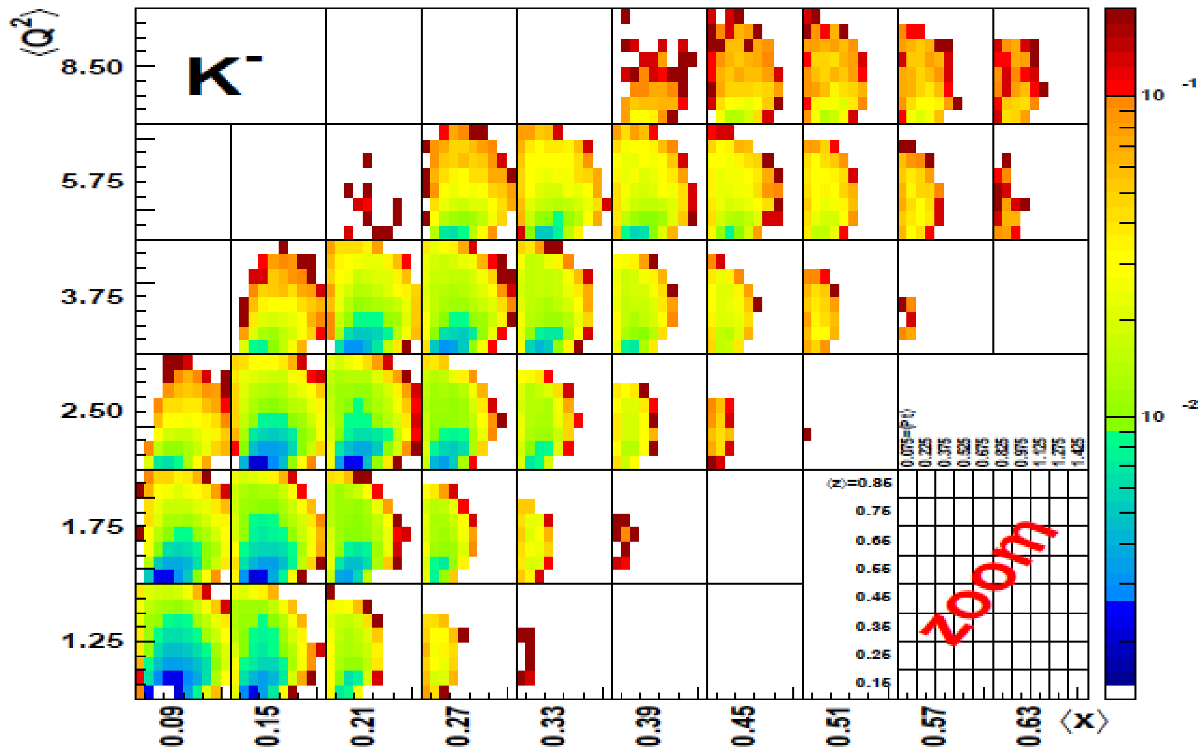
Phys. Rev. D87 (2013), no.1, 02010

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

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

Projections for CLAS12 experiment: error bars and kinematic coverage





- **RICH** is required for kaon ID
- 56 approved days, 50% (27 days) outbending
- Dual target (H/D), opposite field polarity for systematic checks

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

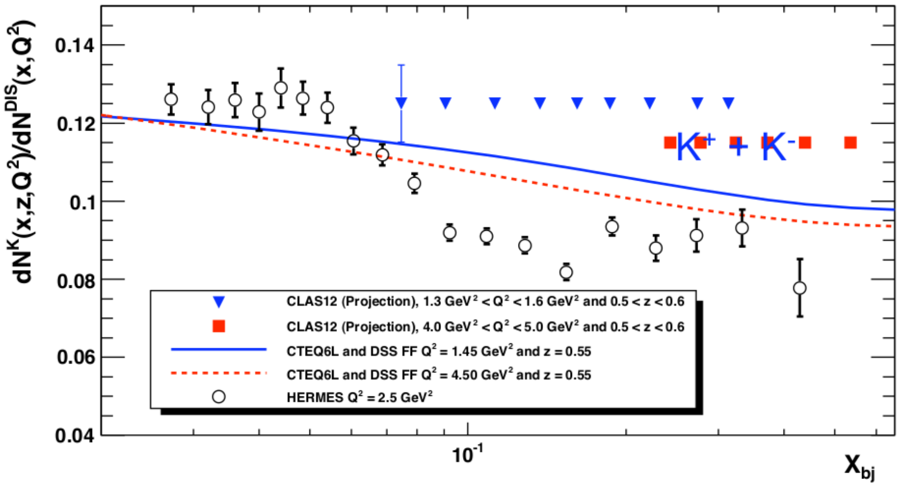
Spokespersons: H. Avakian, F. Benmoktar, A. El Alaoui, K. Hafidi, M. Mirazita
Contact person: W. Armstrong

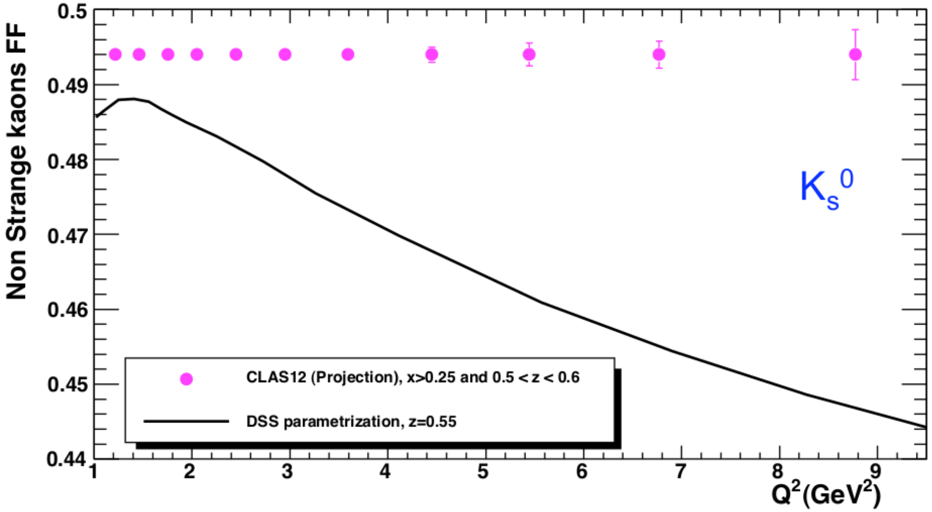
Goal: measure **multiplicities** for various hadrons (π^+, π^-, π^0, K^+, K^-, K^0_s) on deuterium, for $0.05 < x < 0.7$
→ Measure **fragmentation functions** and their Q^2 dependence
→ **Extract strange quark parton distribution functions**

- Part of an extensive program on unpolarized and polarized **proton and deuterium** targets (**RG-A**, **RG-B**, and **RG-C**)

HERMES: $0.2 < z < 0.8$ & integrated over Q^2

CLAS12: $1.3 < Q^2 < 1.6$ GeV^2 & $0.5 < z < 0.6$
$4.0 < Q^2 < 5.0$ GeV^2 & $0.5 < z < 0.6$

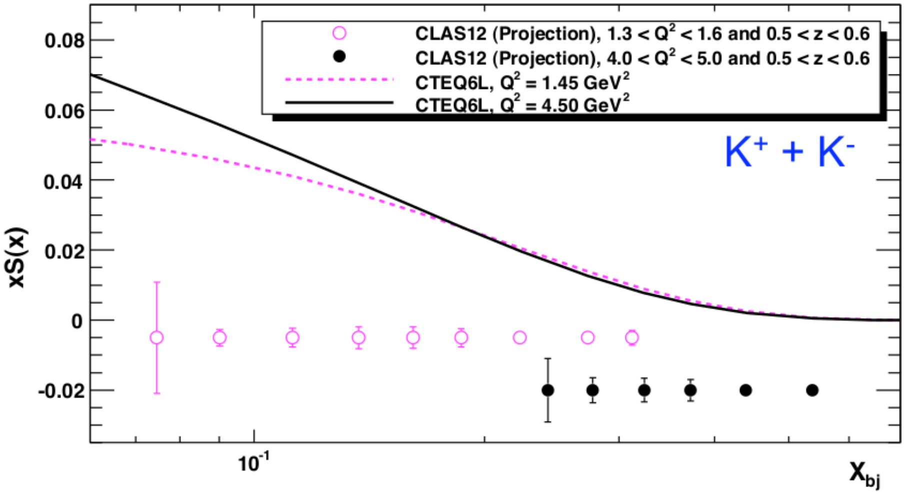




E12-09-007a: Study of partonic distributions in SIDIS K production

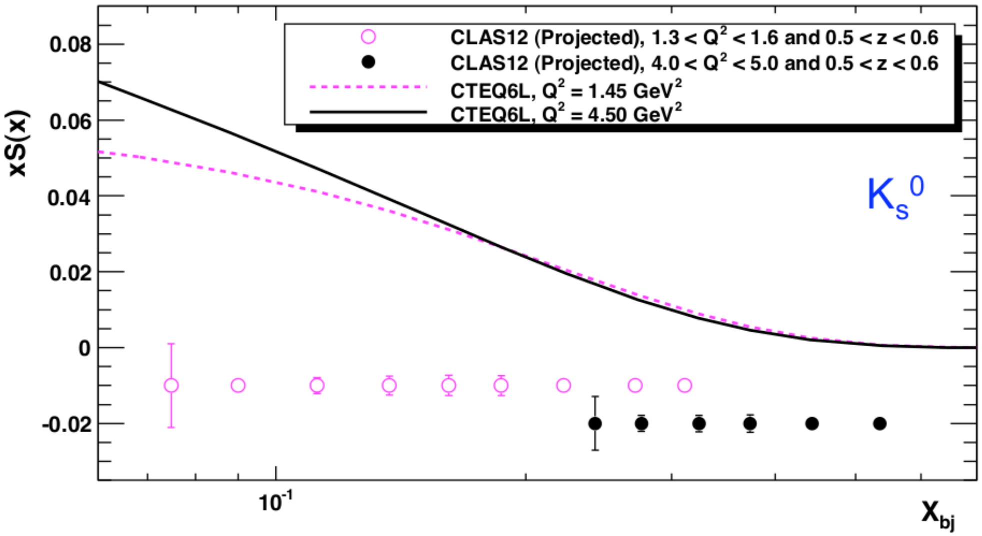
Spokespersons: H. Avakian, F. Benmoktar, A. El Alaoui, K. Hafidi, M. Mirazita
Contact person: W. Armstrong

- 56 PAC days (including 2 days of diagnostics)
- Dual (H/D) target
- **RICH** necessary for kaon ID
- 50 % of beam time with reverse magnetic field (27 days)



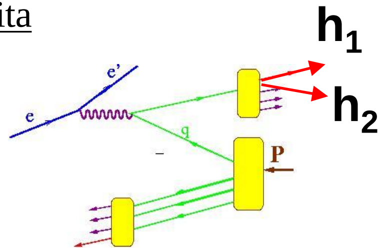
Need **both torus field settings** to eliminate systematic associated with different-charge acceptances.

Two field settings are also needed for pair-symmetric background corrections



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

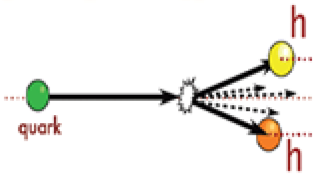
Spokespersons: S. Pisano, A. Courtoy
Contact person: M. Mirazita



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

unpolarized di-hadron FF

Hadron pair multiplicity



$$M^h(z, m_{\pi\pi}, x; Q^2) \quad = \quad \frac{\sum_q e_q^2 \, f_1^q(x;Q^2) \, D_1^q(z, m_{\pi\pi}; Q^2)}{\sum_q e_q^2 \, f_1^q(x;Q^2)}$$

measured by Belle

Beam spin asymmetry

$$A_{LU,p}^{\sin\phi_R \sin\theta}(z, m_{\pi\pi}, x; Q, y) = -\frac{W(y)}{A(y)} \frac{M}{Q} \frac{|\boldsymbol{R}|}{m_{\pi\pi}} \frac{\left(4\, x e^{u_V}(x) - x e^{d_V}(x)\right) H_{1,sp}^{\sphericalangle,u}(z, m_{\pi\pi})}{\left(4\; f_1^{u_V}(x) + f_1^{d_V}(x)\right) D_1^u(z, m_{\pi\pi})}$$

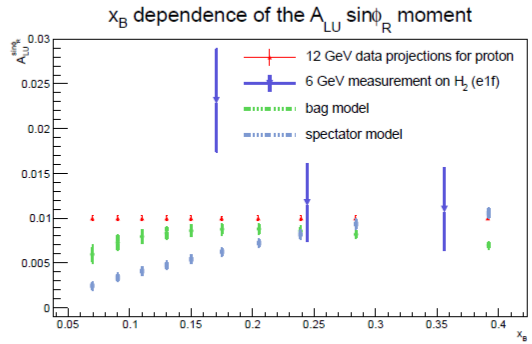
$$A_{LU,d}^{\sin\phi_R \sin\theta}(z, m_{\pi\pi}, x; Q, y) = -\frac{W(y)}{A(y)} \frac{M}{Q} \frac{|\boldsymbol{R}|}{m_{\pi\pi}} \frac{3\; \left(x e^{u_V}(x) + x e^{d_V}(x)\right)\; H_{1,sp}^{\sphericalangle,u}(z, m_{\pi\pi})}{5\; \left(f_1^{u_V}(x) + f_1^{d_V}(x)\right) D_1^u(z, m_{\pi\pi})}$$

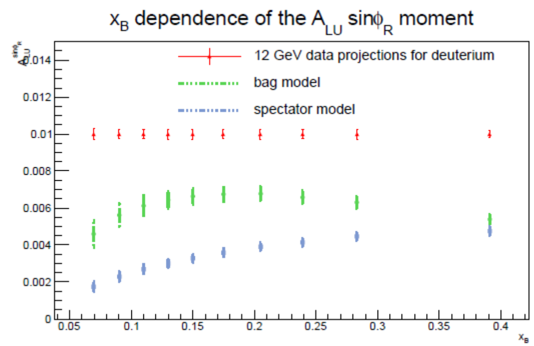
Measuring on both proton and deuteron will allow flavor decomposition

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

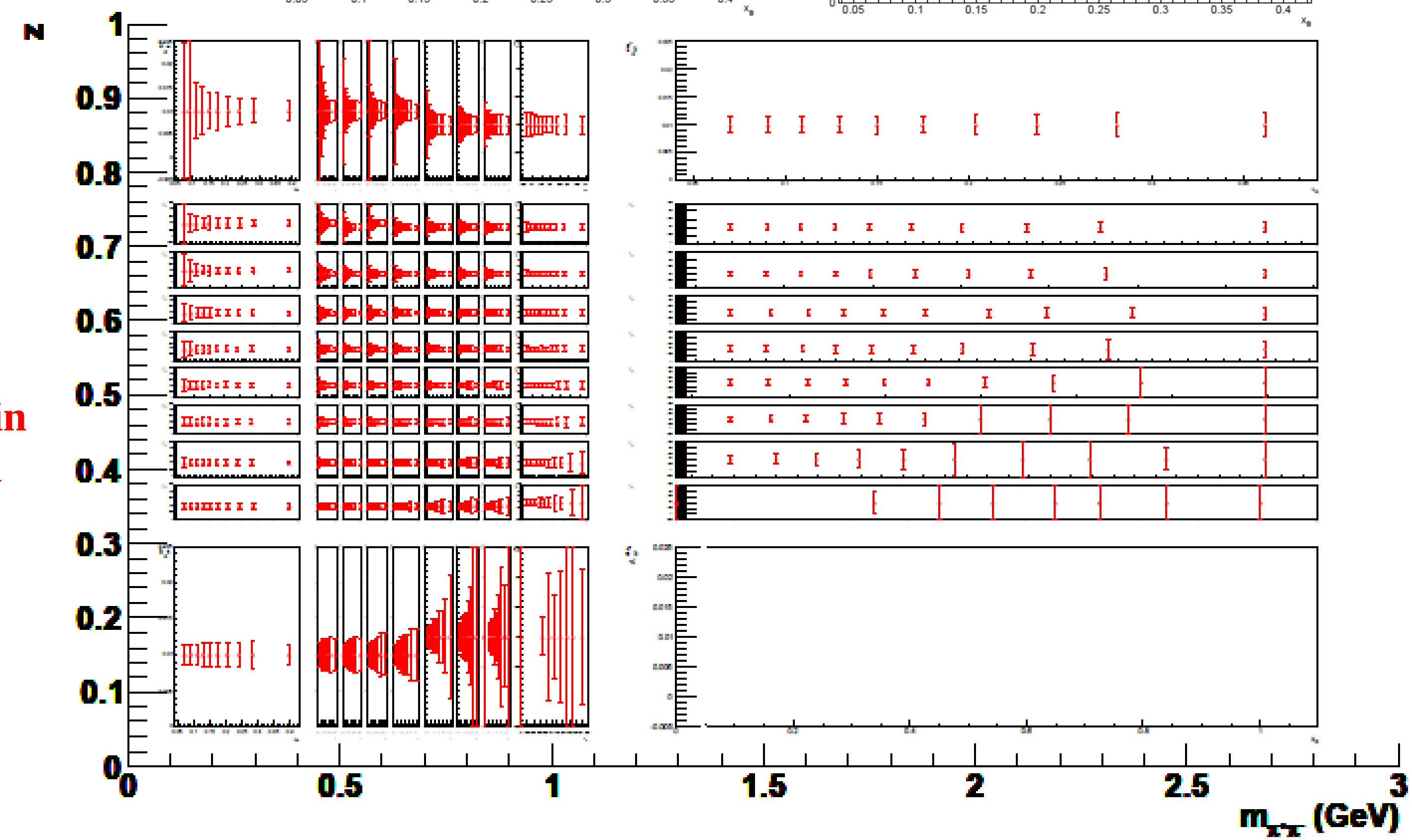
x_B dependence of the BSA on proton and deuteron





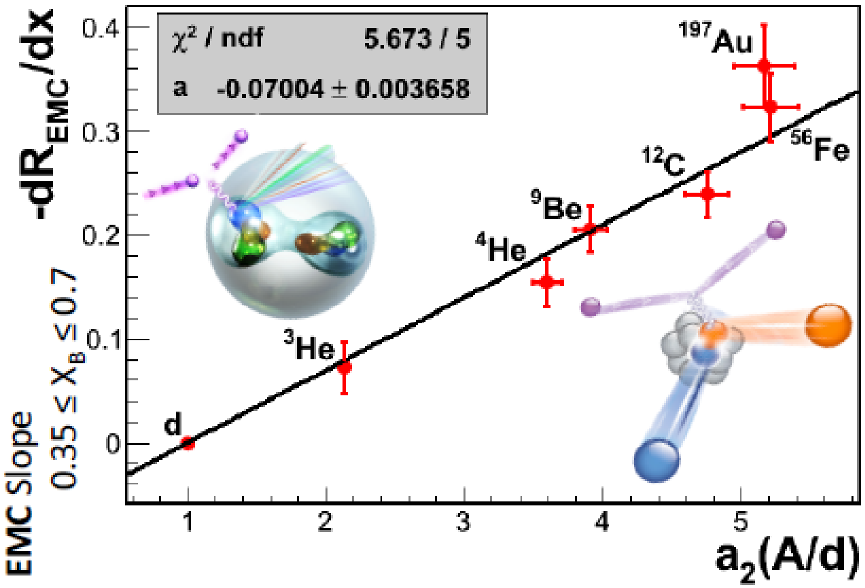
Results for 56 days at 10^{35} luminosity Proton data from projections of Run Group A

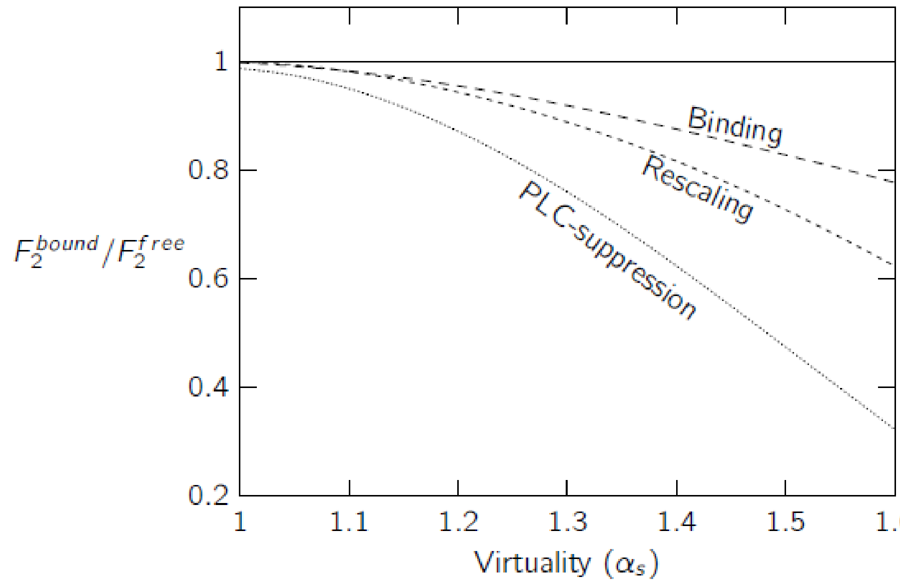
3D extraction of the BSA in (x_B, z, m_{pp}) bins on proton



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





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

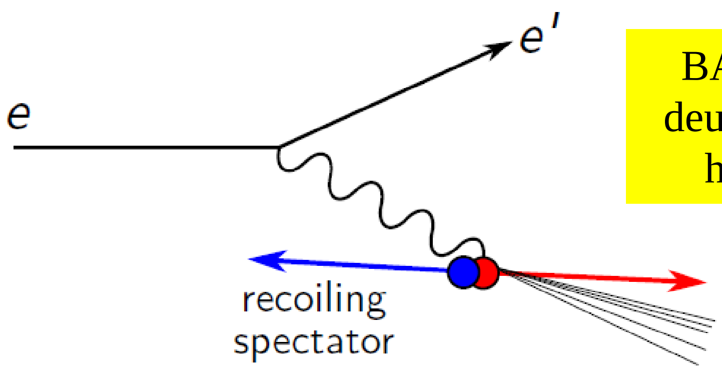
- Measure the **bound proton structure function** as a function of neutron momentum or virtuality in deuterium

SRC hypothesis predicts modification increasing with virtuality

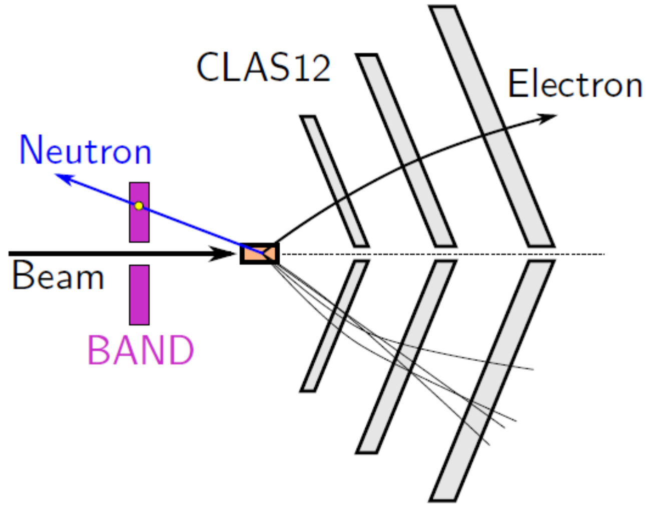
A way to select DIS on high-momentum nucleons is needed

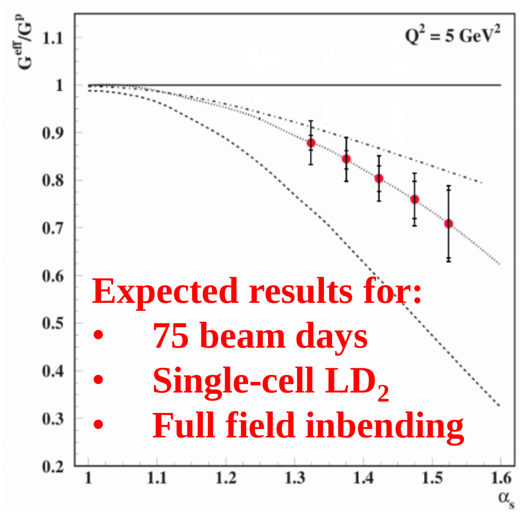
E12-11-003a: In medium proton structure functions, SRC and the EMC effect measured with CLAS12 and the Back Angle Neutron Detector

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



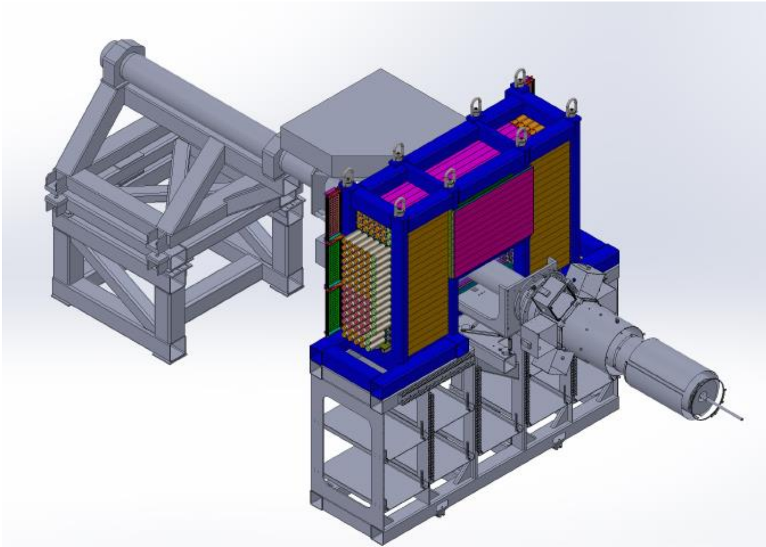
BAND will measure DIS on deuterium tagging a backward high-momentum neutron.





Expected results for:
- **75 beam days**
- **Single-cell LD_2**
- **Full field inbending**

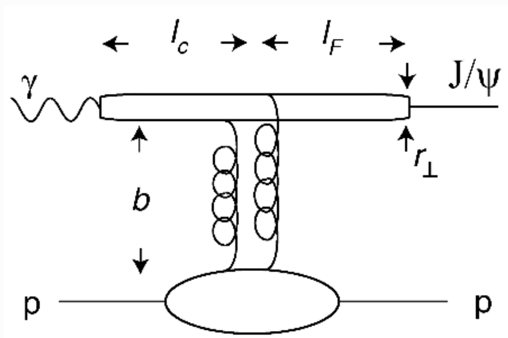
Build new scintillator-based **Back Angle Neutron Detector**
- 160-170°
- ~ 40% neutron detection efficiency
- ~ 7x7 cm^2 scintillators
- $\Delta p/p > 1.5\%$
- funded and constructed by Tel Aviv, MIT, ODU, UTSM, and FSU



Study of J/ψ photoproduction off deuteron

Spokespeople: M.D. Baker, A. Freese, L. Guo, Ch. Hyde, Y. Ilieva, B. McKinnon, P. Nadel-Turonski, M. Sargsian, V. Kubarovsky, S. Stepanyan, N. Zachariou, Zh.W. Zhao

Why J/ψ?



- Small transverse size: $r_\perp \sim 1/m_c = 0.13$ fm
- Large t at threshold, $|t_{min}| = 1.7\ (\mathrm{GeV}/c)^2$
- $b \sim 1/|t|^{1/2} = 0.2$ 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.

Objectives

To determine the cross section of:

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

Study of J/ψ photoproduction off deuteron

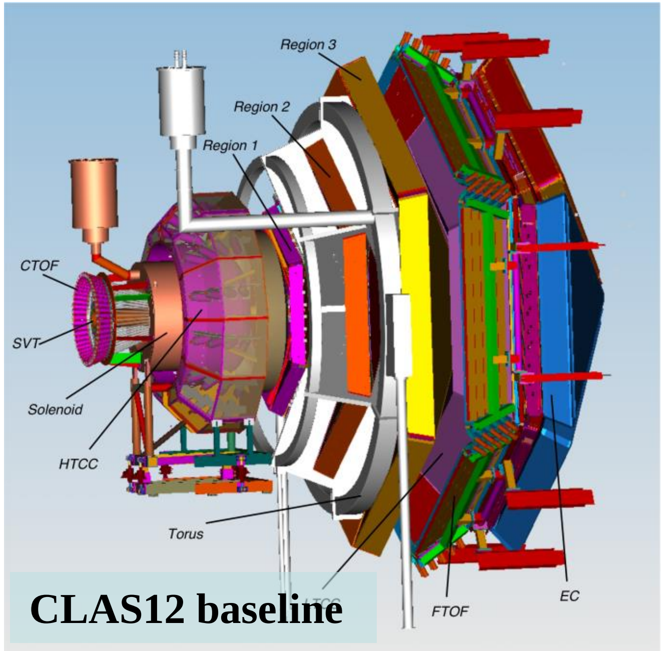
Experimental Configuration

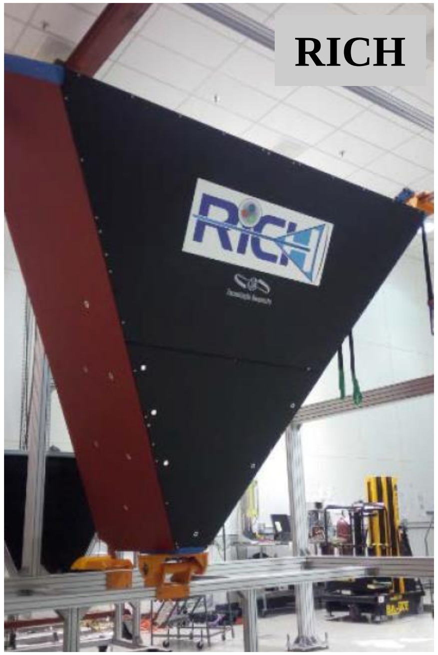
- Unpolarized LD2 target and 11-GeV electron beam, $L=10^{35}\ s^{-1}cm^{-2}$.
- Standard CLAS electron trigger and a Muon trigger (established during RGA).
- Charged-hadron detection in the Forward and Central Detectors.
- Neutron detection in the Forward Detector (will look for CND capabilities as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

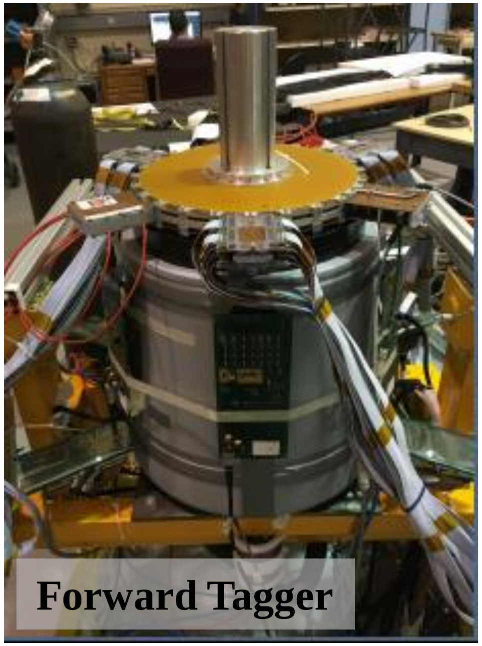
Expected yields

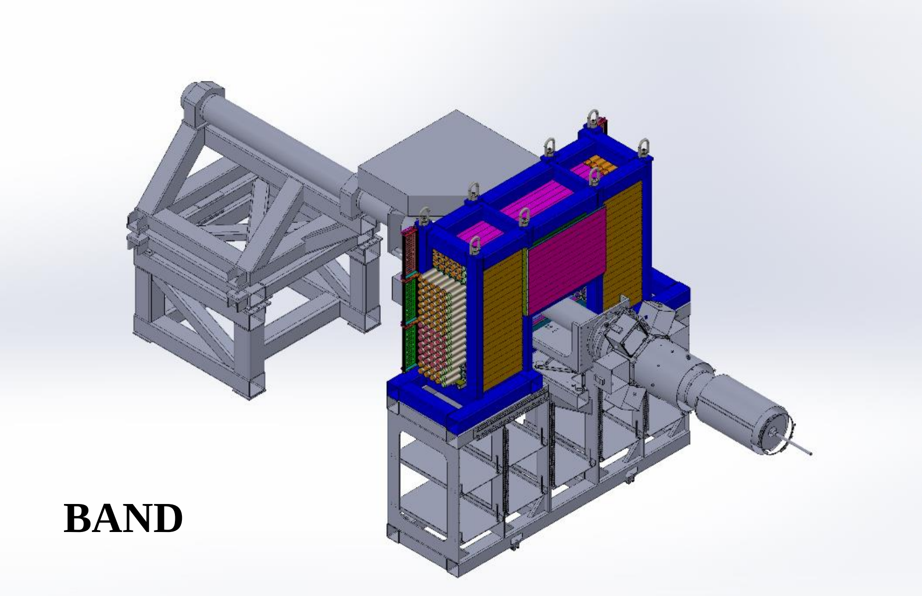
- Quasi-free production off neutron: ~30 J/ψ per day (including both, e^+e^- and $\mu^+\mu^-$ decays).
- Incoherent production: < 3 J/ψ per day (including both, e^+e^- and $\mu^+\mu^-$ decays).
- Coherent production: ~ 0.3 – 1 J/ψ per day (including both, e^+e^- and $\mu^+\mu^-$ decays).

Run group B: experimental setup



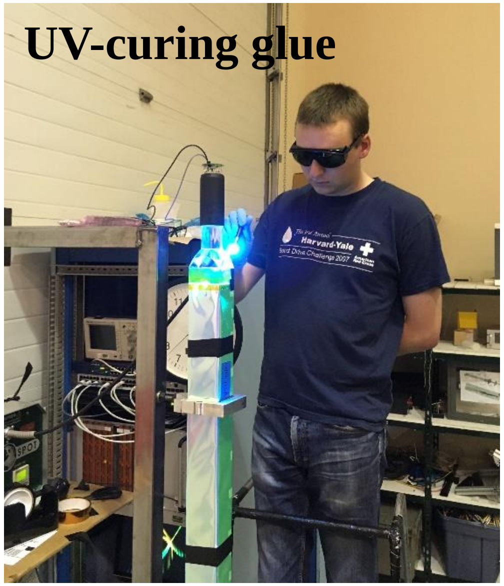


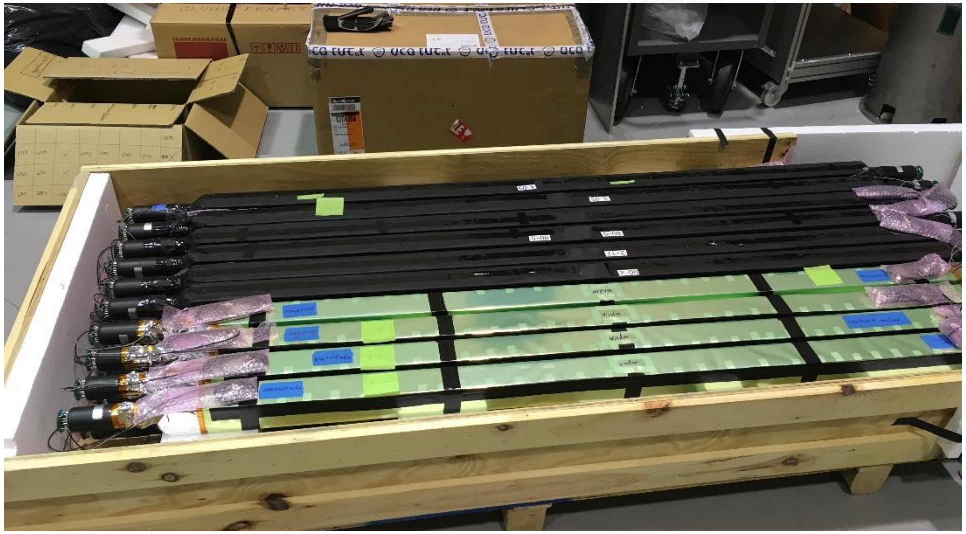




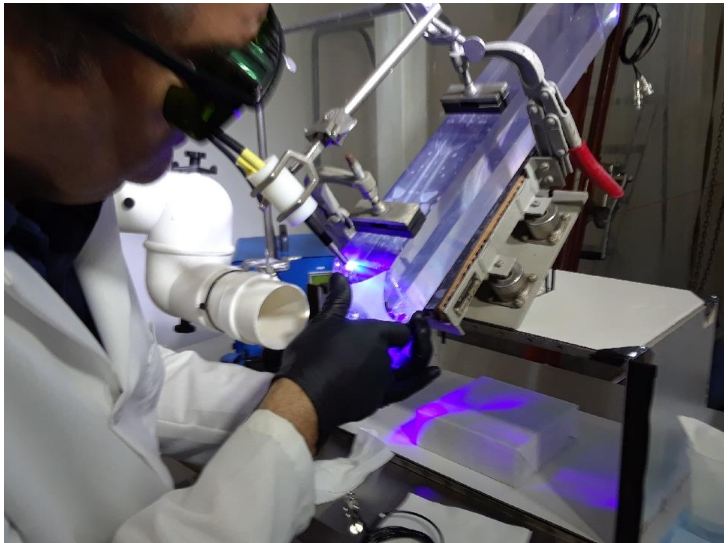
BAND: Scintillator Assembly

Goal: install an almost-complete detector this summer for testing and commissioning with beam during Run Group A





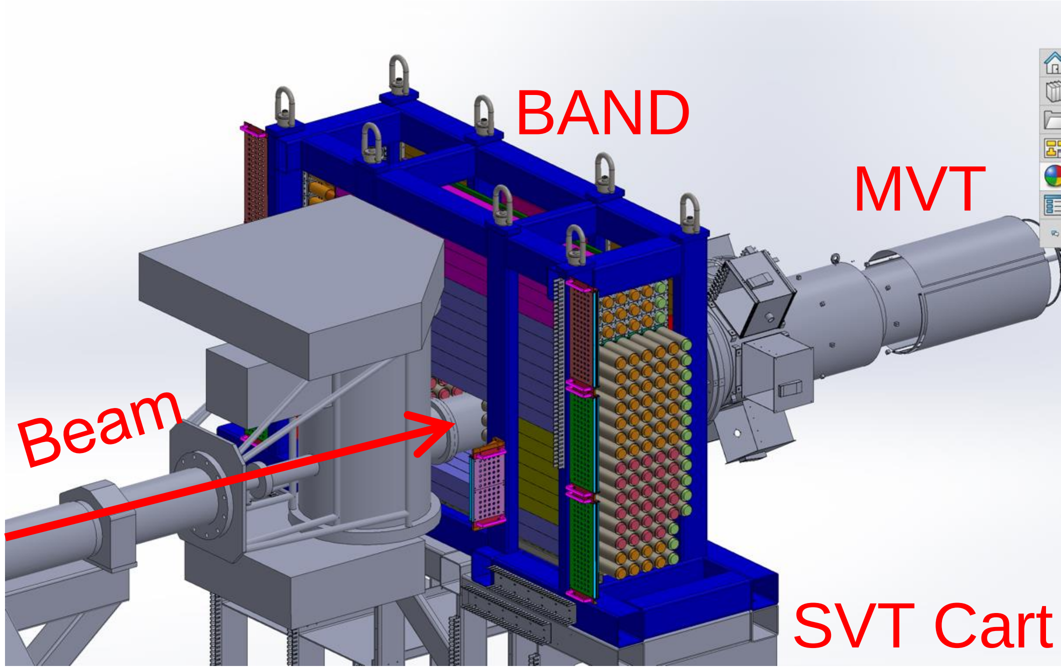
Glued bars, before and after light-tight wrapping.



116 7.2x7.2 cm^2 scintillators
24 2x7.2 cm^2 veto scintillators
Lead shielding
Laser calibration system

BAND status

- **Frame:**
  - ✓ Design complete (UTFSM)
  - ✓ Under construction (MIT), expected 7/27
- **Scintillators:**
  - ✓ Light guides done (FSU)
    - ✓ veto light guides expected 7/16
  - ✓ All bars and PMTs tested (ODU/MIT/JLab)
  - ✓ Assembly underway (ODU/MIT/JLab), exp. 7/20
- **Laser and distribution box on hand (MIT)**
  - ✓ Optical fiber delivery delayed
- **Inner magnetic shields (MIT) expected 7/27**
  - ✓ Remainder expected by 10/1
- **Most electronics and cables on hand, some ordered**
  - ✓ Will read out ~50% of detector during RGA



Installation in CLAS12 starting about 7/30

Run group B: running conditions

<u>**All RG experiments agreed on the same set of running conditions**</u> ***(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**:
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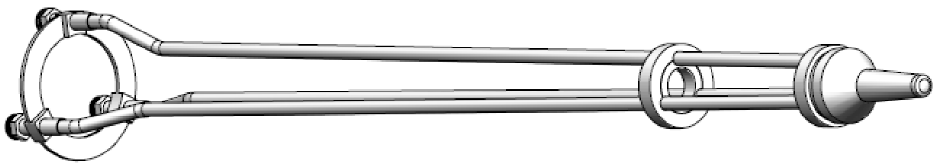
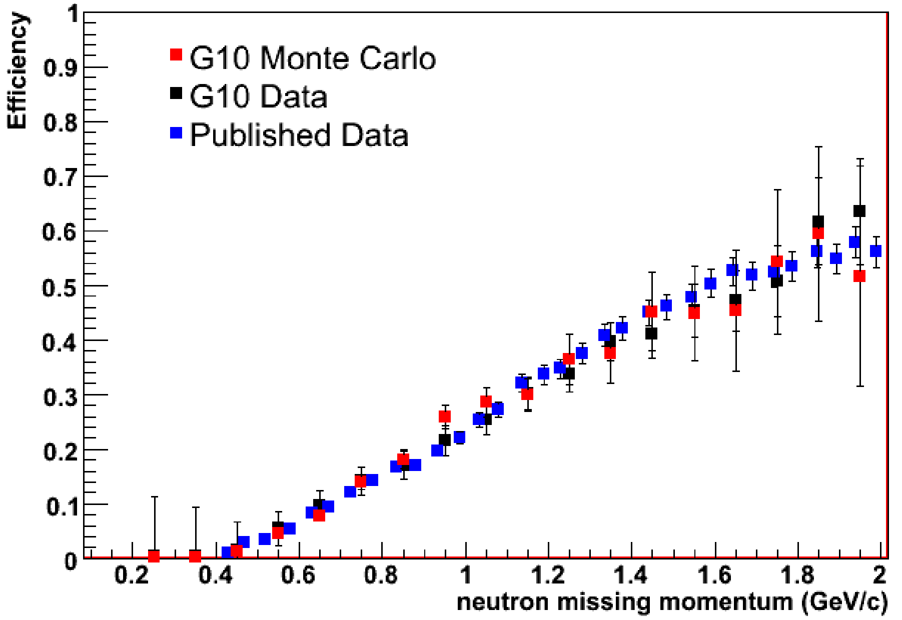


Time it takes to change target material: one shift at most (Bob Miller)

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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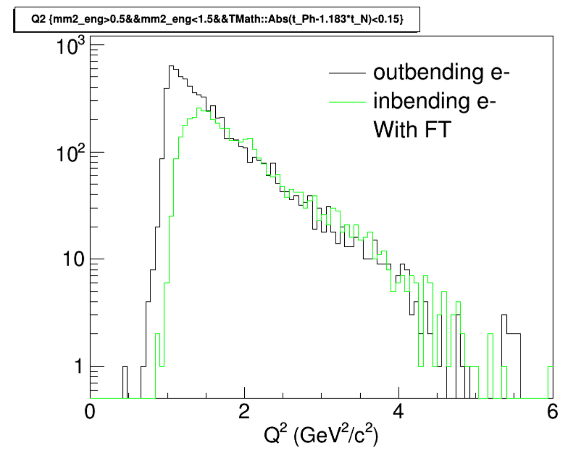
  - 75% full torus field inbending, 25% full torus field outbending – solenoid full field

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

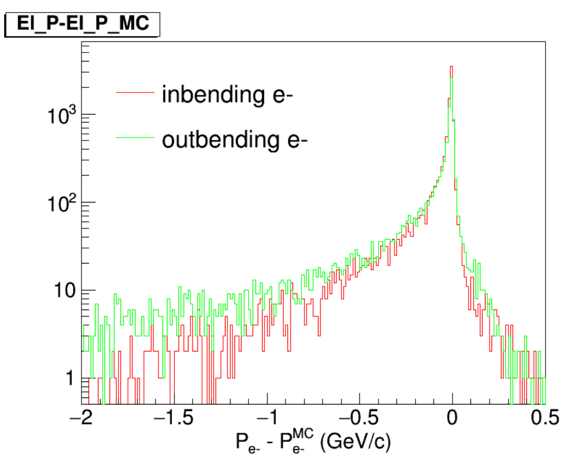
✓ SIDIS proposals originally asked for 27 days outbending → **OK**

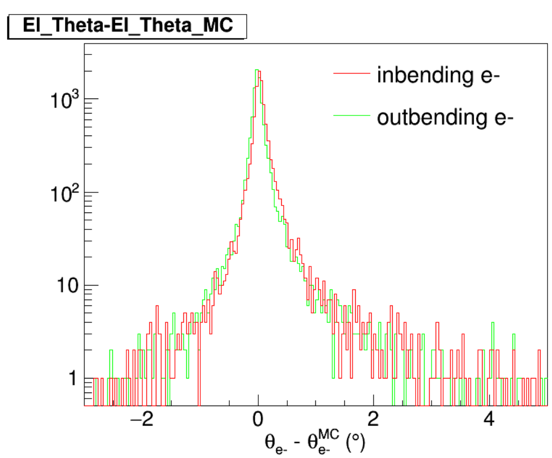
✓ GMn proposal asked for 30 days inbending → **OK**

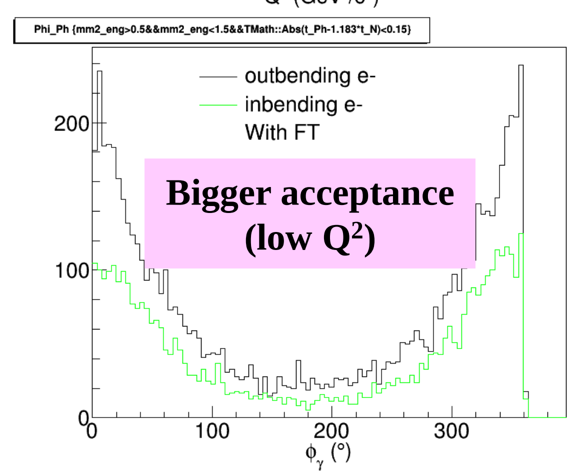
✓ nDVCS originally asked for 90 days inbending → **OK**



Small difference on resolutions







Bigger acceptance (low Q^2)

Full simulations+reconstruction for nDVCS

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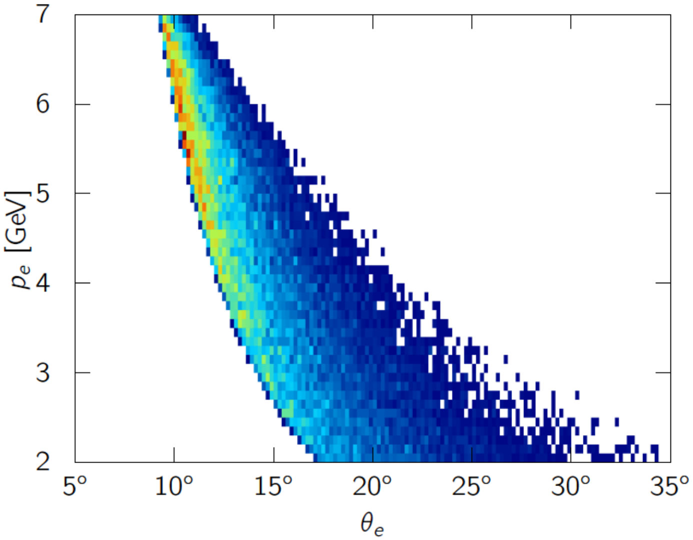
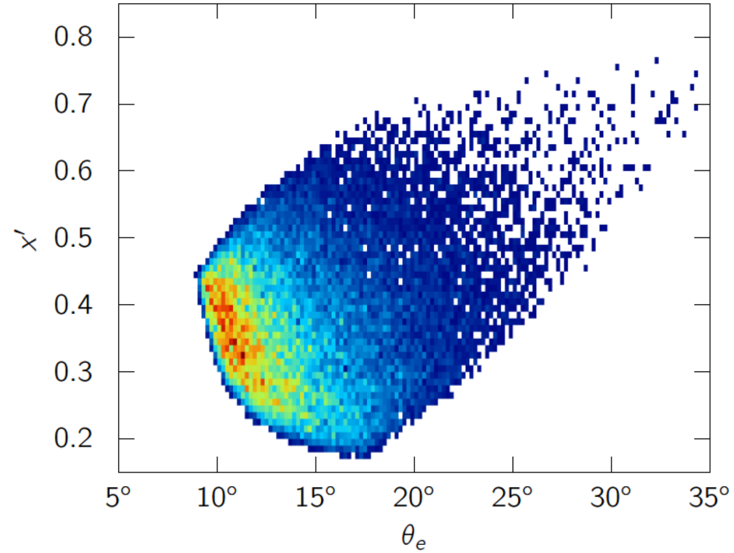
✓ SRC/EMC experiment asked for 90 days inbending → **OK**



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



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- Ancillary runs: **8% of liquid hydrogen target** runs, plus empty target and Moeller runs
- Luminosity: **10^{35} cm^2/s**
  - ➢ Beam current ~ **62 nA**
- Beam energy = 11 GeV

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

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).

Rates for RG-A at ~50 nA: 5.2 kHz for inbending torus, 9.4 kHz for outbending

- ***"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.

Rates for RG-A at ~50 nA: 2.8 kHz for inbending torus, 2.1 kHz for outbending

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

Responsibilities and manpower

Run coordinators for RG-B: S. Niccolai, J. Gilfoyle, M. Contalbrigo, M. Mirazita, O. Hen, W. Armstrong, D. Sokhan, V. Kubarovsky (~1.5 weeks each, for the first 3-months run)

Calibrations: task sharing

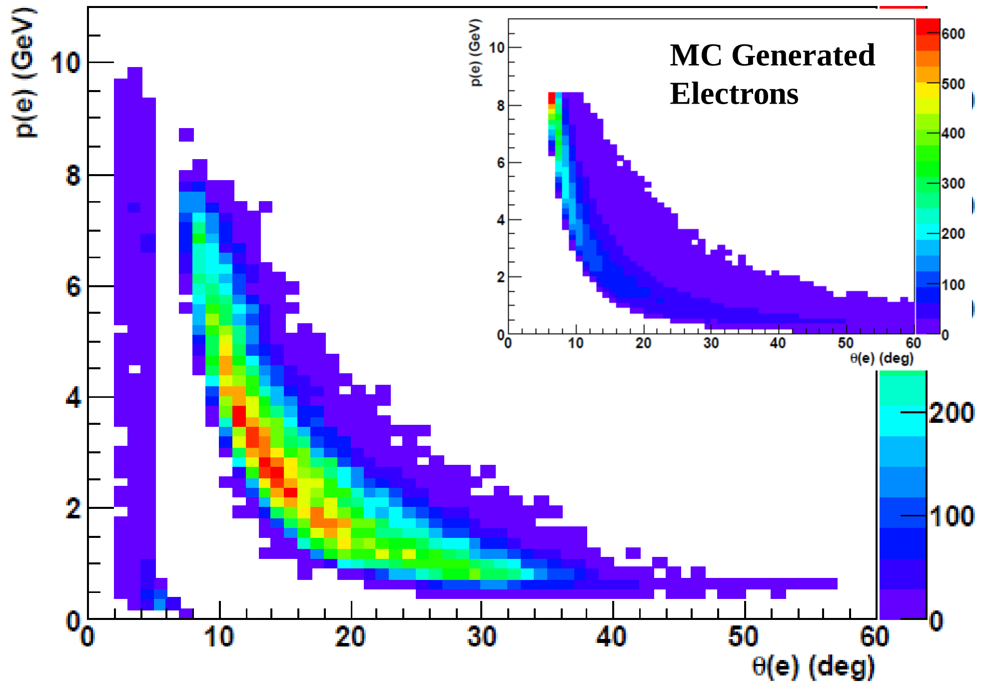
- HTCC, LTCC: JLab
- DC: ANL/JLab
- FTOF: Richmond/ANL
- CTOF: Orsay
- RICH: Frascati/Ferrara
- FT: Orsay/Glasgow
- CND: Orsay
- ECAL, PCAL: Richmond
- CVT: JLab/Saclay
- BAND: MIT/ODU

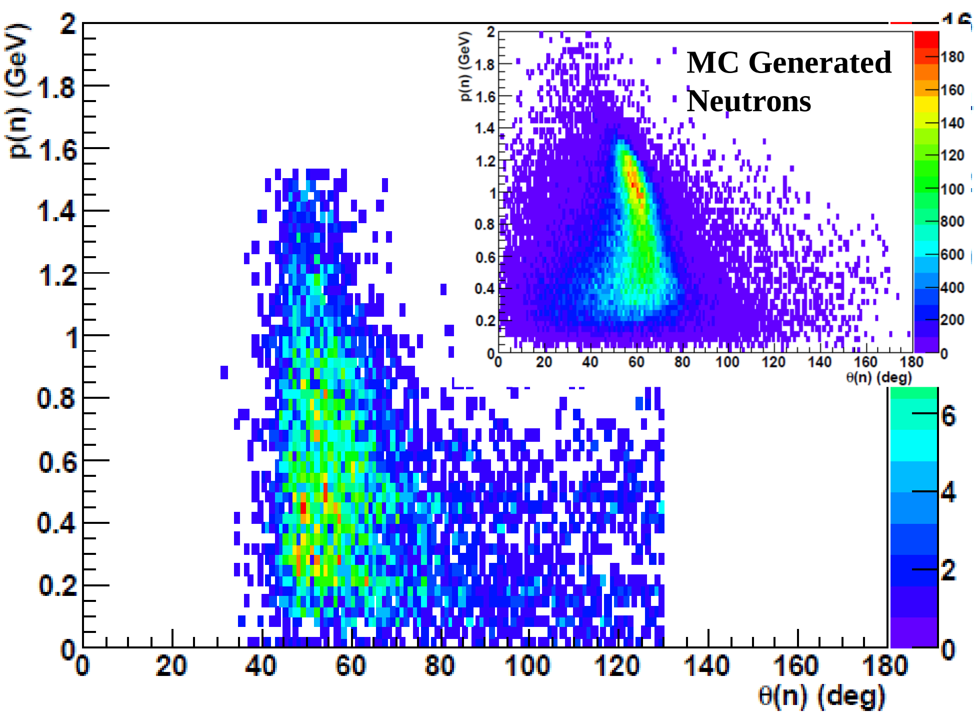
> ➢ Calibration procedures are being finalized and tested during RG-A
> ➢ Data reconstruction (COATJAVA) is already in use for RG-A

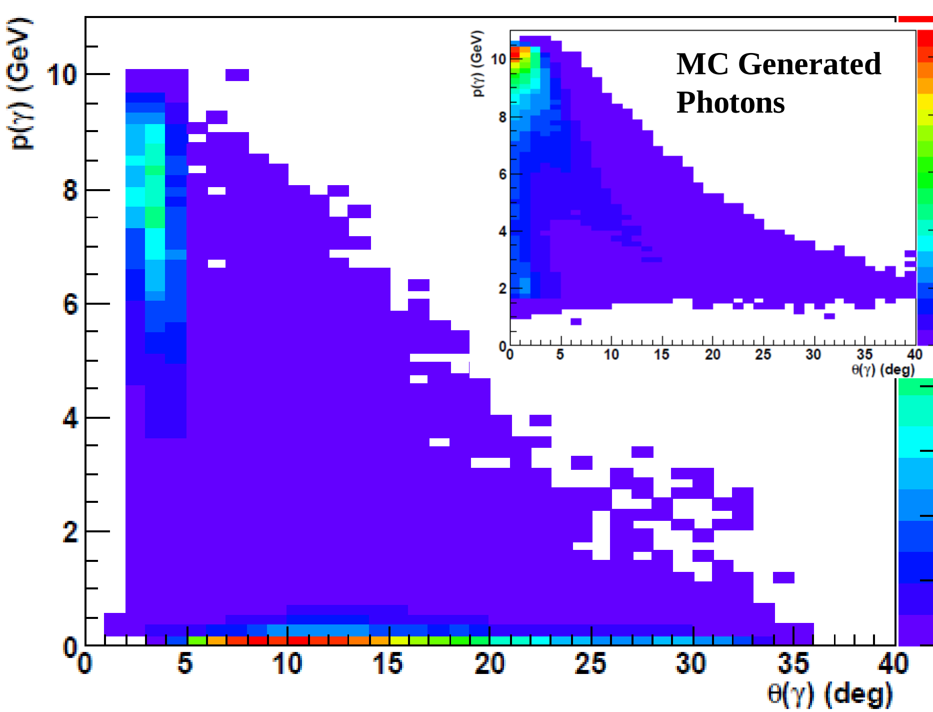
Readyness for physics results: the example of nDVCS

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

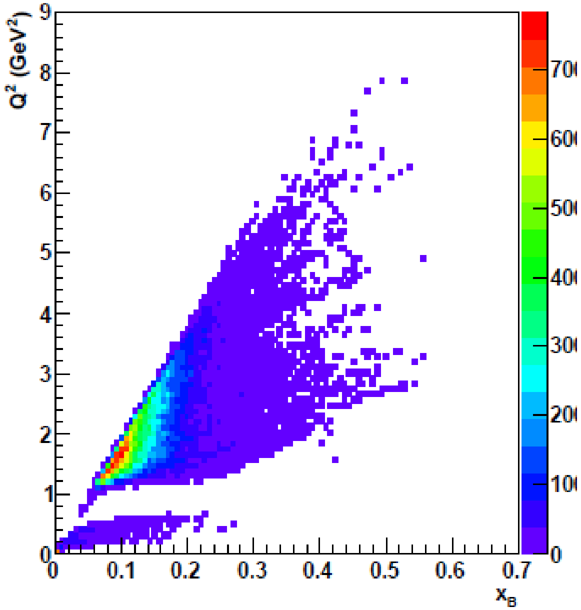
- Electrons detected in **FD**
- Photons detected in **EC** and **FT**
- Neutrons detected in **CND** only (so far)

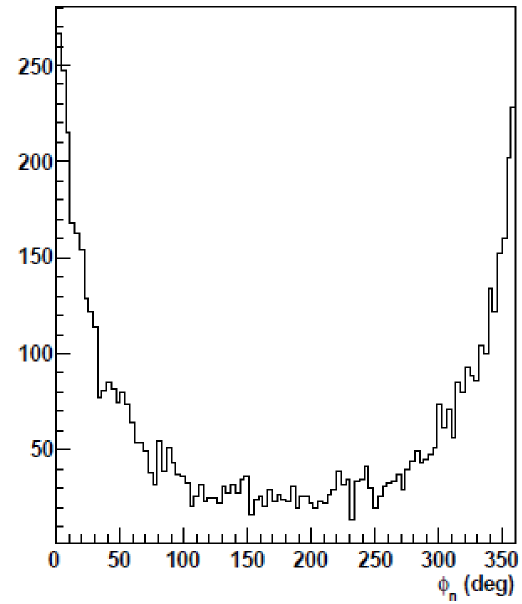


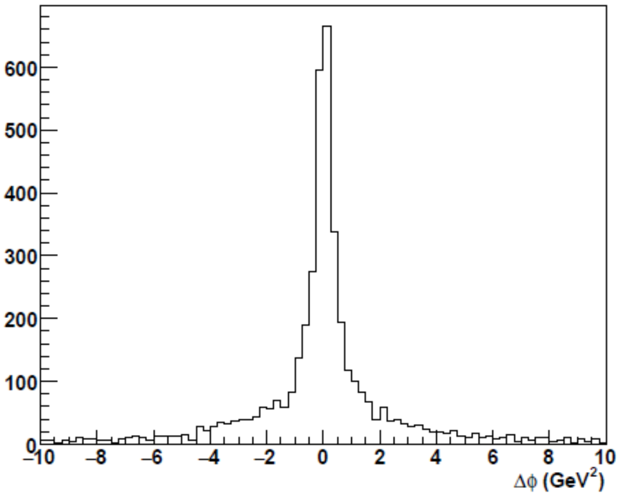


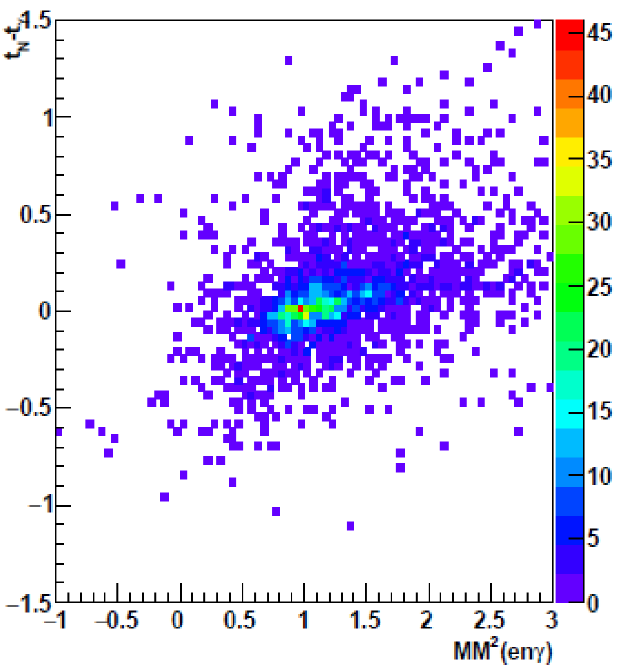


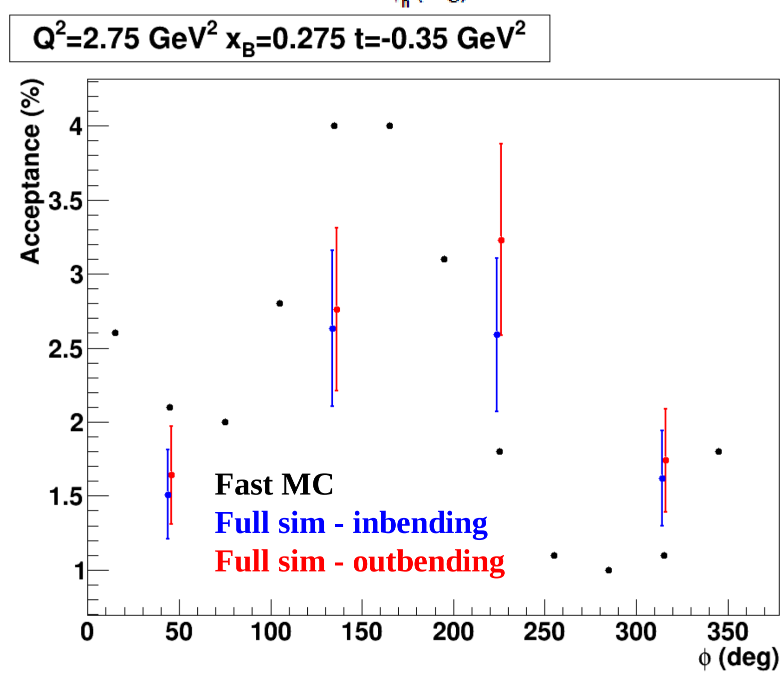
DVCS: kinematic variables and exclusivity cuts











- ✓ 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 (installation in July)
- 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 2019!**

Back-up slides

Di-hadron: Kinematic distributions