ALERT Run Group

Tagged EMC
Nuclear GPDs
Tagged DVCS
& more

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On behalf of the CLAS Collaboration

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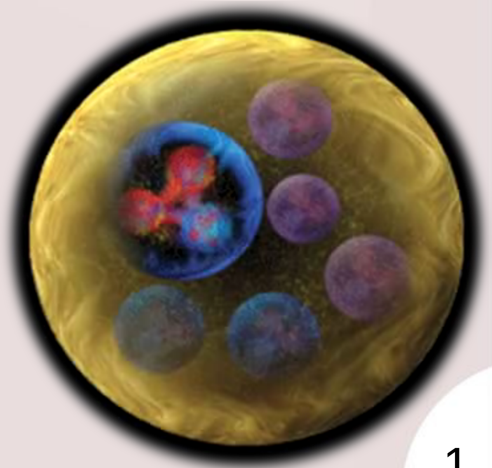
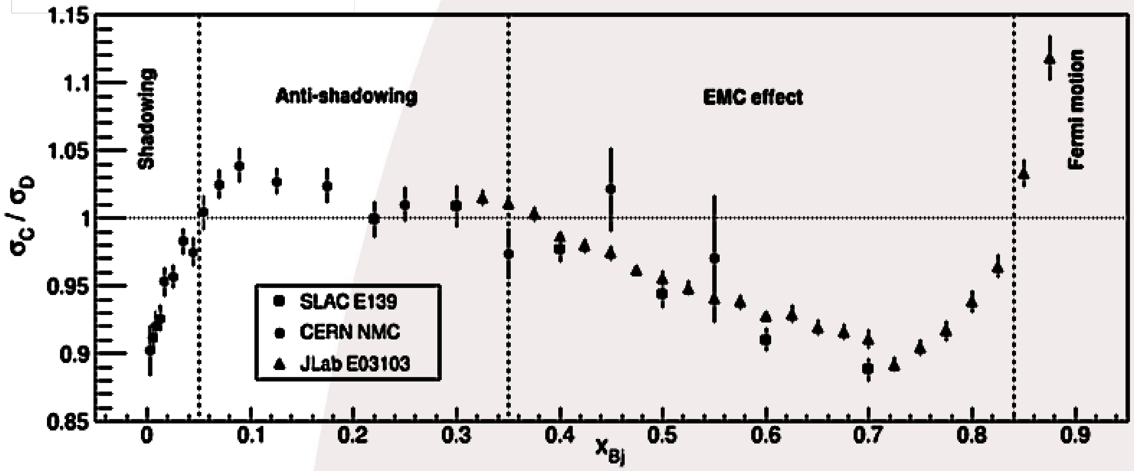


INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

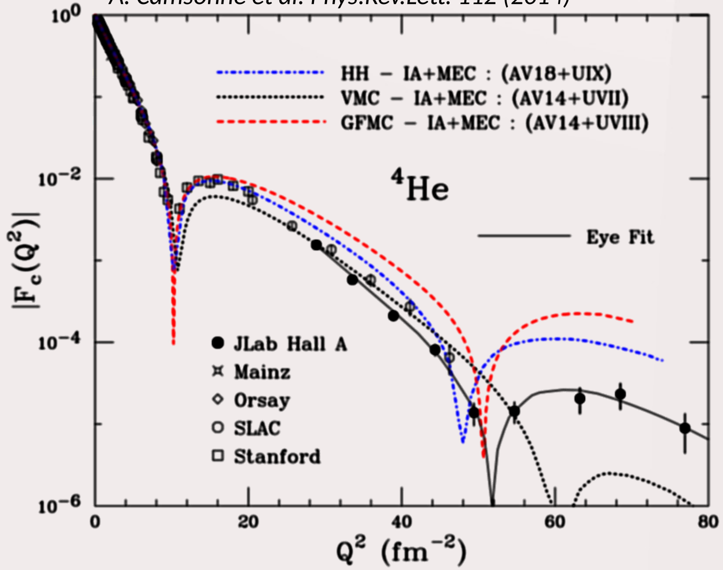
Outline

- **Physics Motivation**
- ALERT Detector
- Coherent Measurements
- Tagged Measurements
- Summary & Beam Time Request

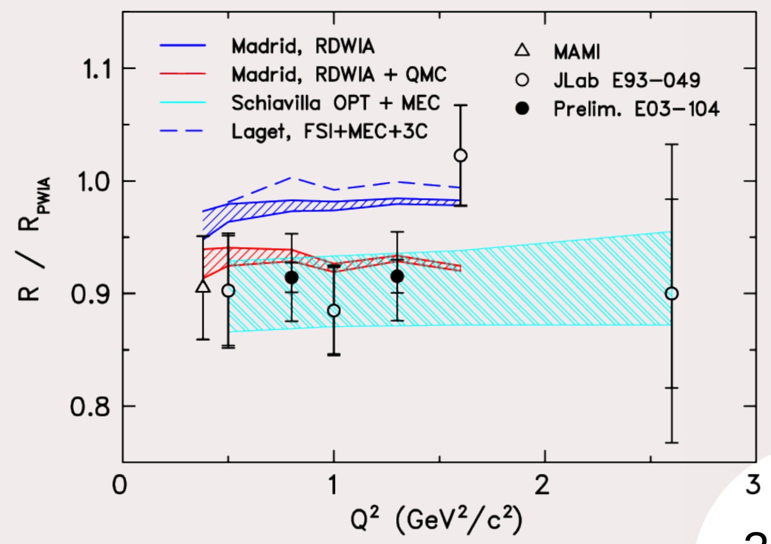
Lessons from the Past



A. Camsonne et al. Phys.Rev.Lett. 112 (2014)



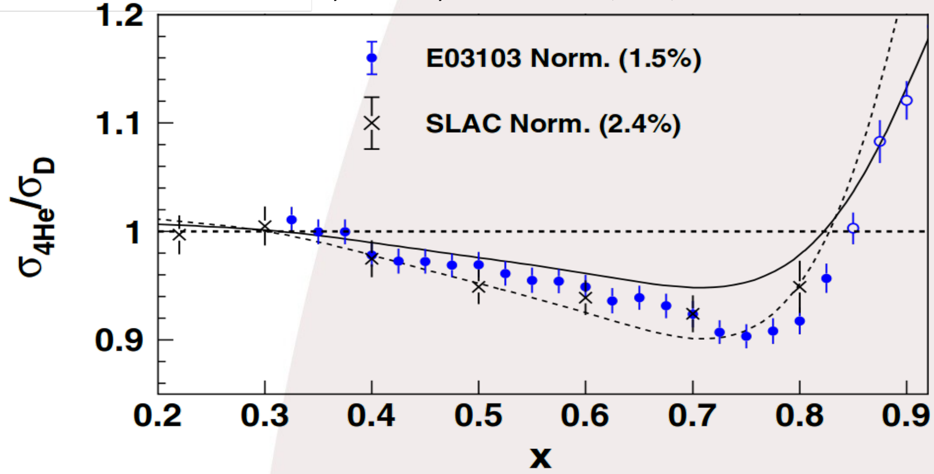
S. Strauch et al. Phys.Rev.Lett. 91 (2003) 052301



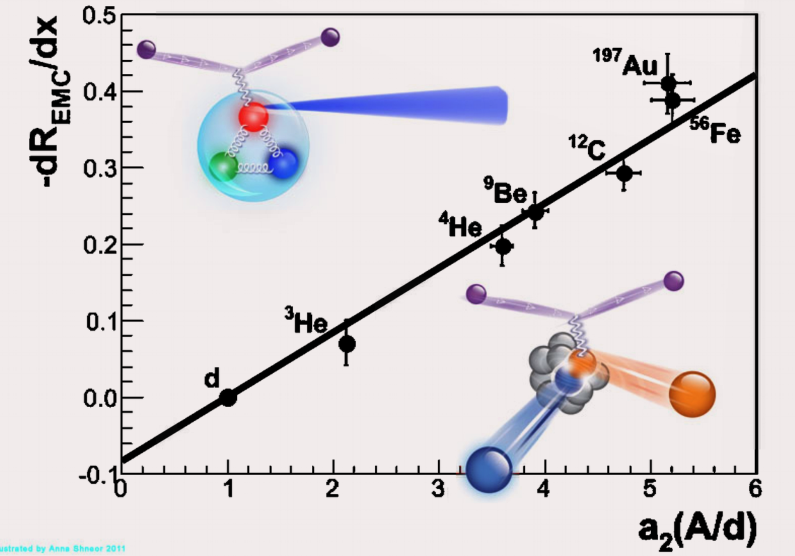
- **Nuclear Parton Distribution Functions (PDFs)**
  – We did not expect a significant effect
    - Binding is only at the level of MeVs
    - Several effects were discovered: shadowing, EMC…
- **Nuclear Form Factors (FFs)**
  – Reveal the transverse structure of nuclei
  – Mostly interpreted in term of nucleons
- **Bound nucleon FFs**
  – Quasi-elastic scattering on a bound nucleon
  – Attempt to reveal the modification of nucleon structure in the nuclear medium
  – Final State Interactions (FSI) could play a significant role

EMC: The Most Prominent Nuclear Effect

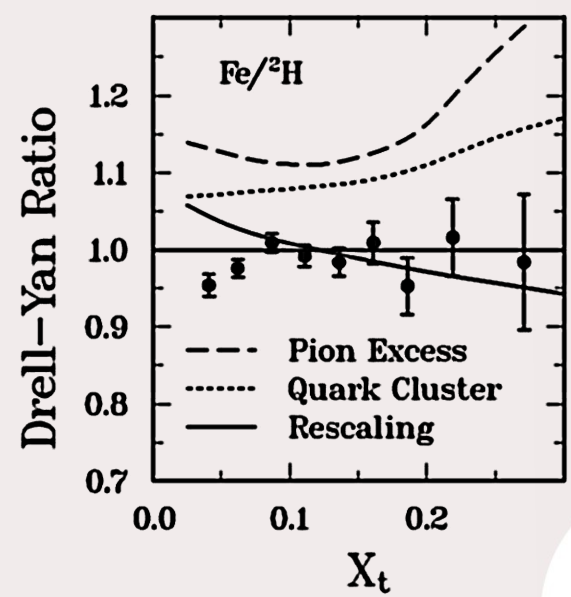
J. Seely et al. Phys.Rev.Lett. 103 (2009) 202301



L.B. Weinstein et al., Phys.Rev.Lett. 106, 52301 (2011)



D.M. Alde et al. Phys. Rev. Lett. 64, 2479 (1990)



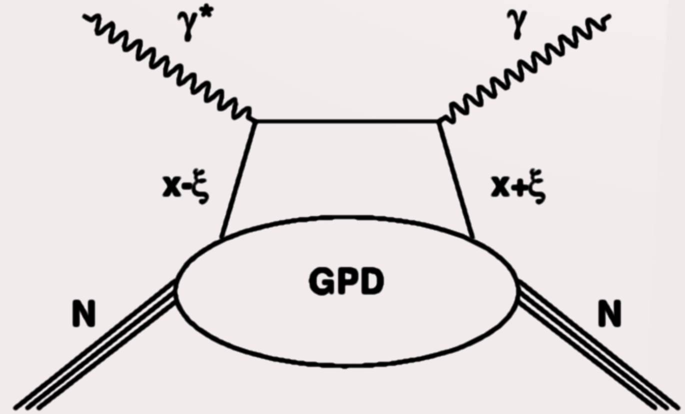
- **Do nuclear pions play a role?**
  - Drell-Yan experiment showed otherwise…
- **Is it x or Q^2-rescaling?**
  - Q^2-rescaling by modifying QCD in medium
  - x-rescaling due to the binding
- **Is there a dependence on nucleon virtuality?**
  - Hint from nucleon-nucleon Short Range Correlations (SRC)
  - Tagging the spectator of the reaction might help with the answer

Generalized Parton Distributions

- **Generalizing the parton distributions**
  - Three dimensions: *x*, *ξ* and *t*
  - Accessible through exclusive processes
  - Spin-0 → 1 GPD / Spin-½ → 4 GPDs

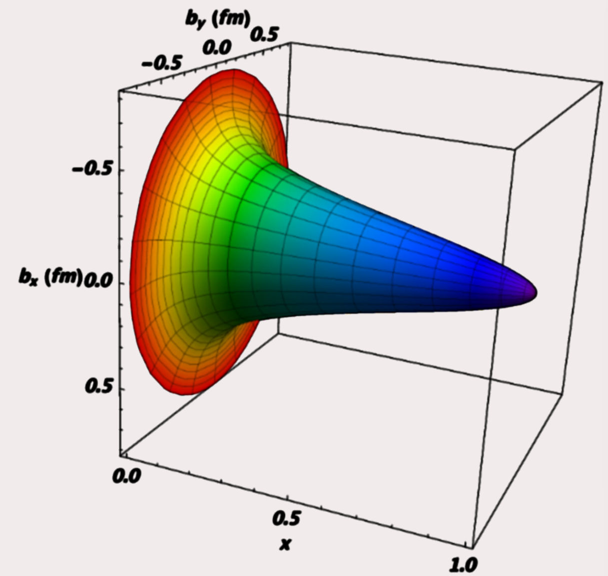
    Spin-1 → 9 GPDs
- **Deep virtual Compton scattering (DVCS)**
  - Using factorization gives access to GPDs
  - *x* is not experimentally accessible → Compton Form Factors (CFF)
- **GPDs can be interpreted as 3D maps**
  - Fourier transform at ξ=0
  - Fits to the data gives access to 3D image
    - For the nucleon, 8 CFFs are free parameters

      → Need assumptions to constrain them



$$F_{Re}(\xi,t) = \mathcal{P}\int_{-1}^{1} dx \left[\frac{1}{x-\xi} \mp \frac{1}{x+\xi}\right] F(x,\xi,t),$$

$$F_{Im}(\xi,t) = F(\xi,\xi,t) \mp F(-\xi,\xi,t).$$



RD, M. Guidal, M. Vanderhaeghen arXiv:1606.07821

The ALERT Run Group Program

- **We propose a comprehensive program to study nuclear effects:**
  - We will address key questions about the EMC effect (PR12-16-011) using tagged deep inelastic scattering (DIS)
    - Is EMC due to x or Q^2 rescaling?
    - Is the transition from mean field to SRC regime smooth?
  - We will access Tagged DVCS in the same fashion (PR12-16-011B)
    - Is there an off-forward EMC effect ?
    - How is the nucleon profile modified in nuclei ?
- **We will access the nuclear structure in term of partons**
  - We will measure together the quark and gluon GPDs (PR12-16-011A)
    - GPDs will be obtained through the coherent nuclear DVCS and ϕ production
  - We will obtain a full picture of ^{4}He in term of quarks and gluons
    - Is the gluon radius the same as the charge radius ?
- **We show in PR12-16-011C that this data will be used to study many other interesting physics (π^0, deuterium GPDs, ...)**

Detector Needs

- **The use of a recoil detector is necessary**
  - Helium recoils produced in DVCS and Deep Virtual Meson Production (DVMP) have a low energy (from 250 MeV/c and up)
  - Tagged reactions produce fragments with recoil momenta of around 60 MeV/c and up depending on the nuclei
- **Important requirements**
  - Optimize detection threshold by minimizing the absorption in the target material
  - Fast detector response for high luminosity running
  - Ability to differentiate among isotopes for tagged measurements
- **We had success measuring tagged DIS on deuterium and coherent DVCS on ^{4}He with CLAS**
  - Confirmed that identification of these processes is possible
  - Also showed its limitations

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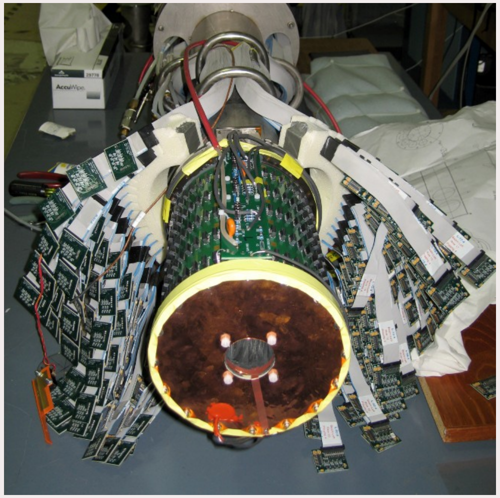
Available Detector Options

- **CLAS12 Central Detector**
  - It will not be able to detect the recoil spectators at low enough energy

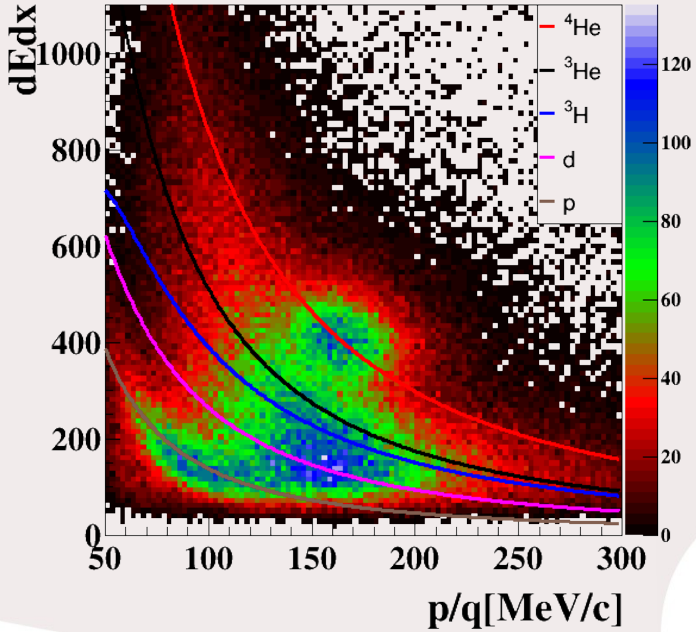
- **Radial Time Projection Chamber (RTPC)**
  - RTPC has great capabilities for slow recoil detection
    → we built it and used it for ^{4}He coherent DVCS in CLAS
  - However particle identification is limited
    - Even with improvements it cannot differentiate between ^{3}He and ^{3}H
  - The data acquisition rate was the limiting factor for the luminosity of this experiment
  - Because of pile-up, the time resolution (few hundreds ns) and long drift time (few µs) severely limit its performance at high luminosity

→ We need another detector

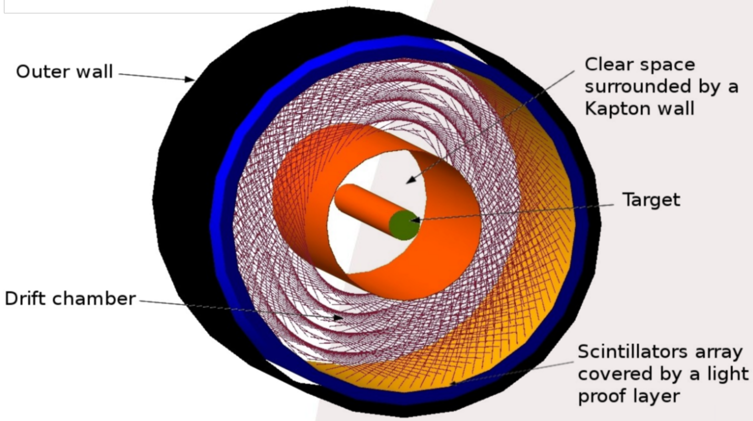
Nuclear DVCS RTPC

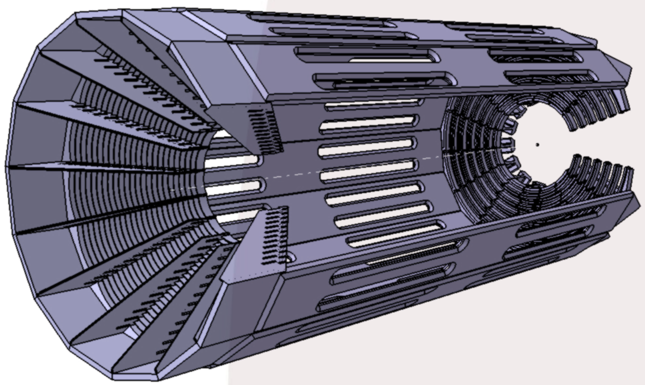


RTPC PID performance

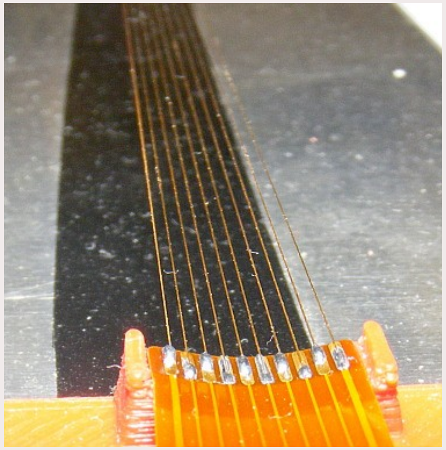


The ALERT Detector



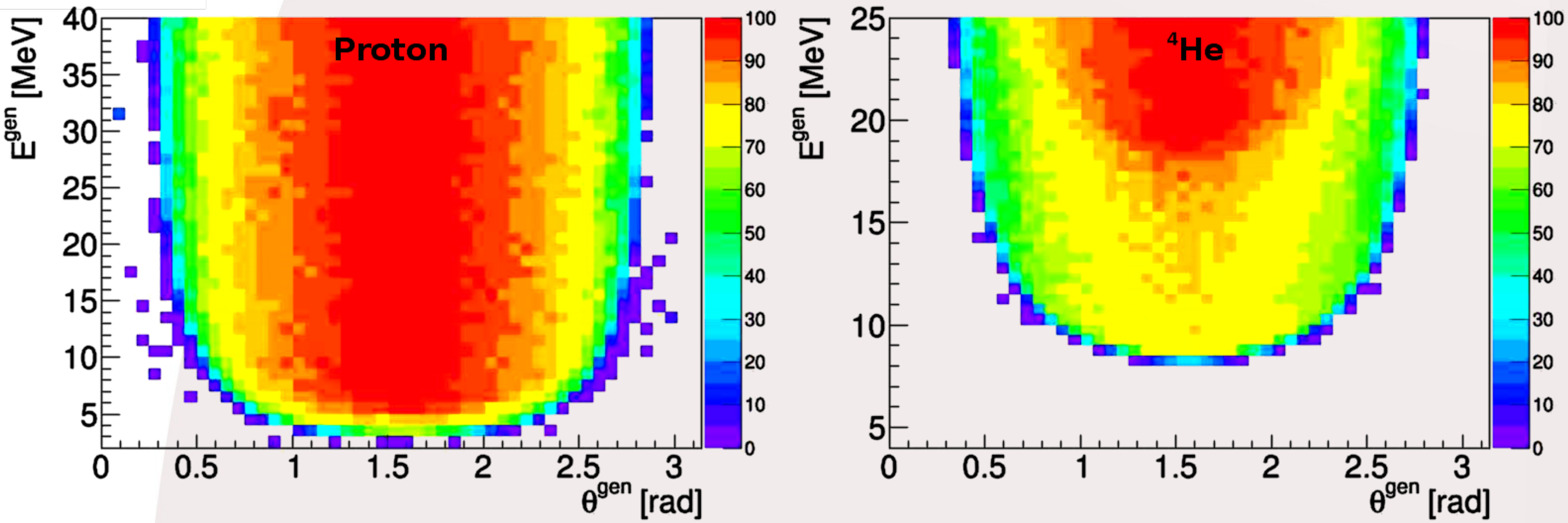


- **A Low Energy Recoil Tracker**
  - Replace the CLAS12 silicon vertex tracker (SVT) and the first layer of micromegas
- **GEANT4 simulation**
  - To define the characteristics of the wire chamber
- **Hyperbolic drift chamber**
  - Stereo angles significantly complicate the mechanics
  - We tested electronic options
    - → first prototype used DREAM Front-End Board
- **Scintillators for TOF and total energy measurement**
  - Advanced GEANT4 simulations have been performed
- **Work in Progress**
  - Choice of material to be optimized for several components
    - We focused on main challenges to demonstrate that we can build a working detector
    - Optimization of different parameters is underway
  - Integration of electronics and other elements
    - We have less channels than micromegas to read, so we do not expect this to be a major challenge



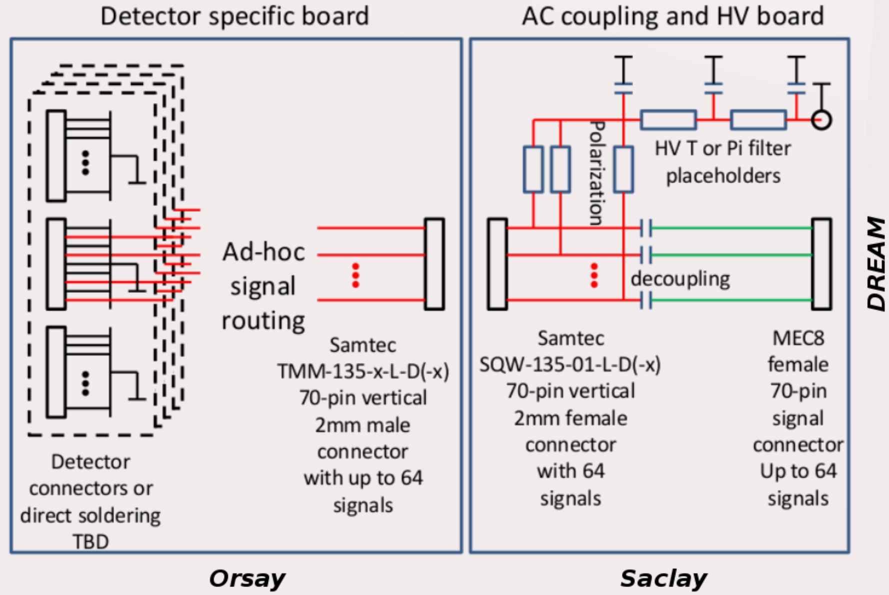
Test with a 2mm wire gap on a curved surface

Detection Capabilities from Simulation

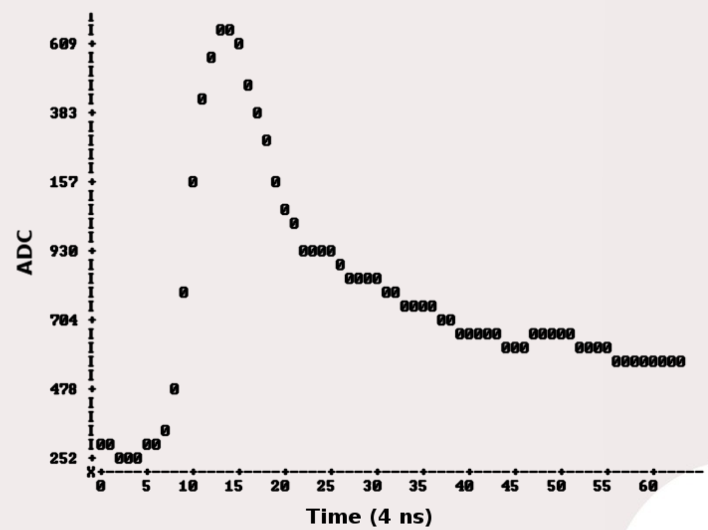


- **Capabilities for very low momentum detection**
  - As low as 70 MeV/c for protons and 240 MeV/c for ^{4}He
  - Detection at large angles in forward and backward directions (25° from the beam)
  - Most of these limits are due to recoils being stopped in the target
  - Target has 6 mm radius with 25 µm kapton walls and 3 atm pressure
- **Capabilities to handle high rates**
  - Small distance between wires leads to short drift time <250 ns (5 µs in a similar RTPC)
  - This translate into 20× less accidental hits
  - Allows to be integrated in the trigger allowing for significantly reduced DAQ rate

First Prototype Tests



- **Mechanical structure**
  - We tested 3D printed titanium for the very complex pieces
  - Carbon is envisioned for the forward part
- **Wire installation**
  - The 2 mm gap appears to be conservative and can be achieved
- **Electronics test**
  - In collaboration with CEA Saclay we tested their DREAM front end chip
  - First test at Orsay has been performed with a single cell
  - Resolution appears to be well under 10 ns reported in the proposal
    - Resolution will be driven by the spread of the drift electrons in the gas
    - Further studies are needed to determine the resolution



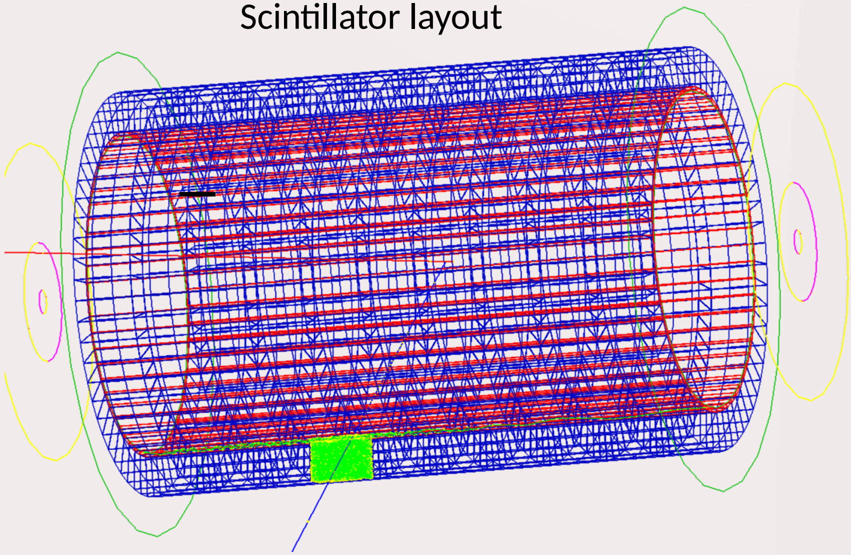
SiPM and Scintillators

- **Scintillator design**
  - Combination of a thin layer and thick tiles
    - ^{3}He and ^{4}He will stop in the first layer
    - p, ^{2}H and ^{3}H will go through and stop in the second layer
  - Thin layer is 2mm × 9mm × 30cm with SiPM at both ends
  - Thick tiles are 20mm × 9mm × 3cm with a SiPM in the back

- **Radiation damage**
  - We expect radiation at the level of ≲krad
  - Scintillators are significantly damaged at ~Mrad levels
  - SiPM studies based on work from Hall-D
    - Indicate that we should have only small effects
    - A more refined simulation to estimate the precise neutron rates on SiPM is in progress

- **Radiation levels are not expected to be an issue for either scintillators or SiPMs**

Scintillator layout



Silicon Photo-multiplier (SiPM)

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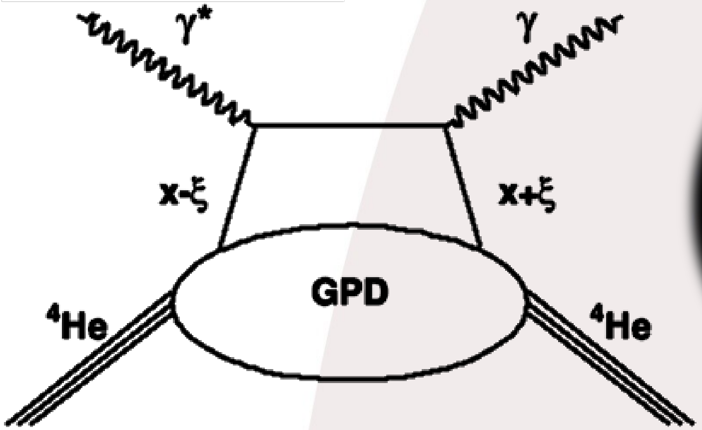
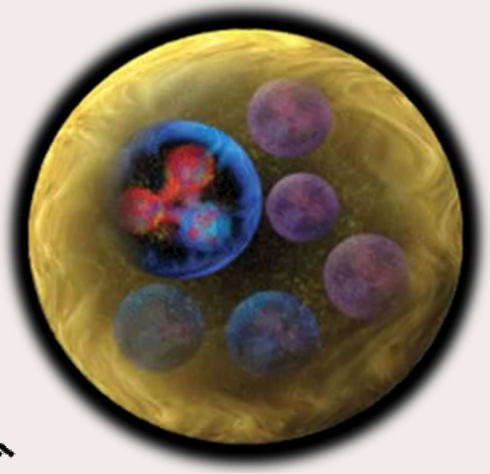
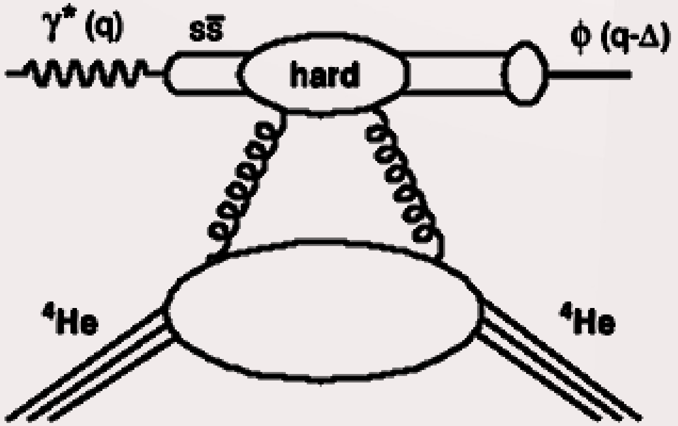
Nuclear GPDs





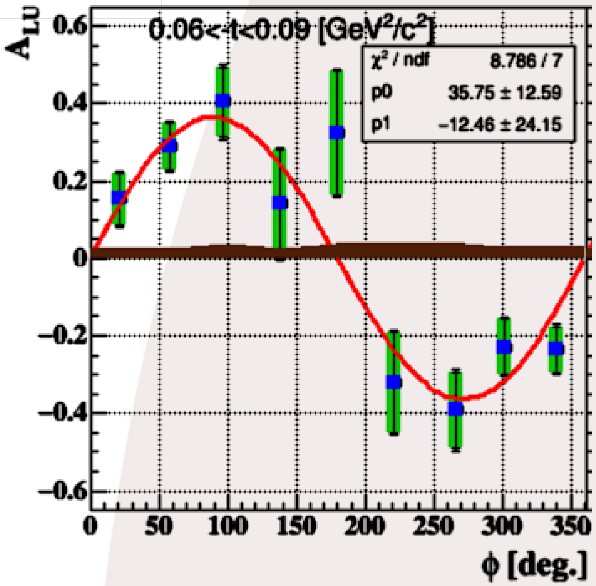


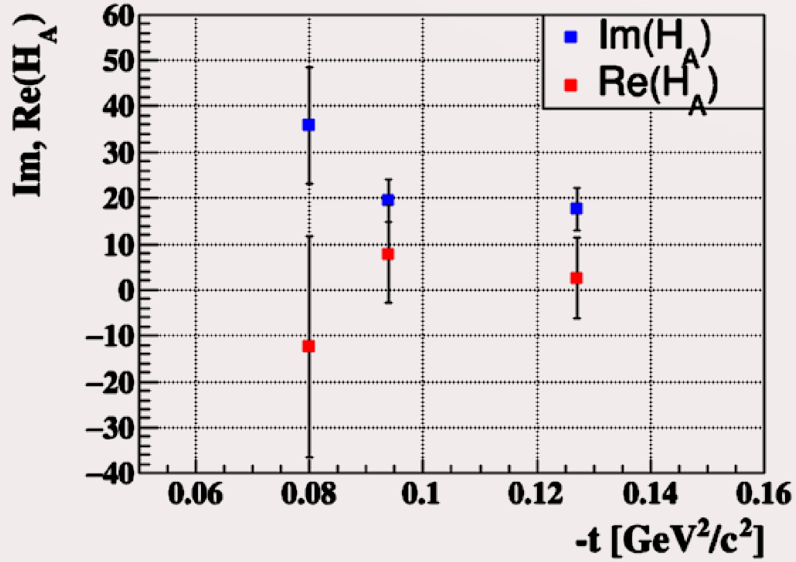
- **Studying ^{4}He nuclear structure in term of quarks and gluons**
  - Spin-0 makes for much simpler extraction of GPDs
    - Allows for an immediate and simple model independent extraction of the GPD H!
    - And this is true for all H_q, H_g and H_T !
  - It is important to ensure the coherence by detecting the recoil nucleus

    A. Kirchner and D. Mueller, Eur. Phys. J. C32 (2003) 347
- **A new take on nuclear physics**
  - Study nuclei beyond the sum of nucleons
  - Sensitive to the non nucleonic degrees of freedom of nuclei
  - A direct access to quark and gluon distribution in nuclei
  - A window into the Electron-Ion Collider (EIC) physics program

    RD and S. Scopetta, Eur.Phys.J. A52 (2016) no.6, 159

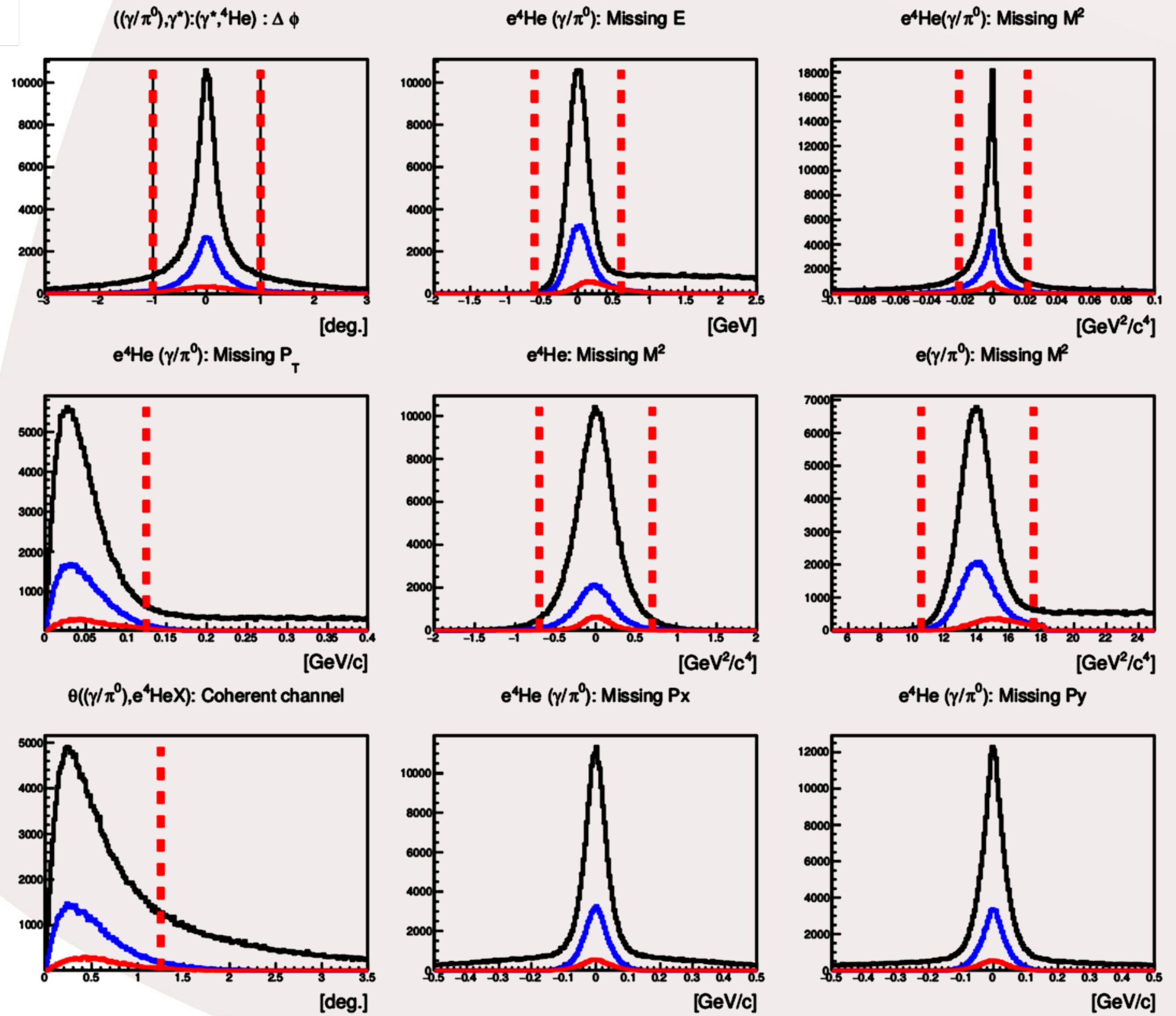
Our CLAS Measurement





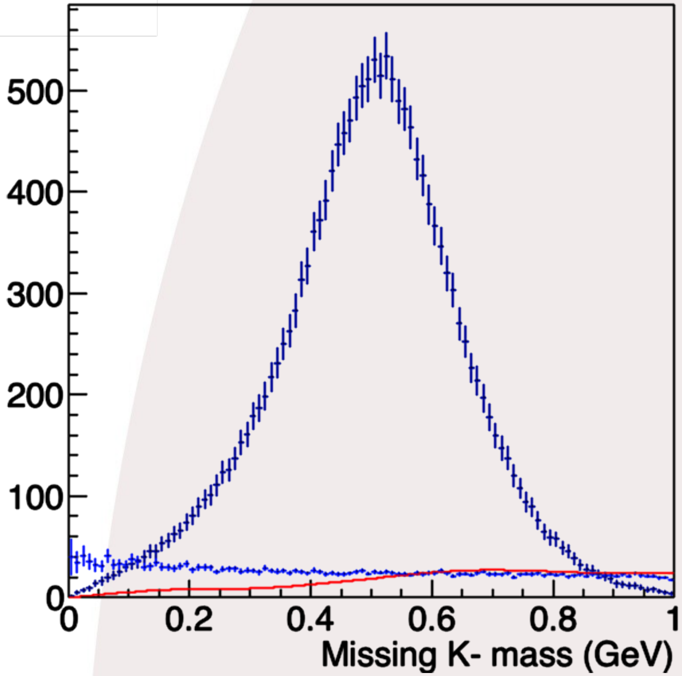
- **We have preliminary results from CLAS (E08-024) experiment**
  - First measurement of its kind
  - Larger asymmetries than for a proton target
  - Limited statistics and kinematic coverage
- **Lesson learned**
  - Higher energy will allow to get more cross section in the deeply virtual regime
  - Faster recoil detector will allow for higher luminosity

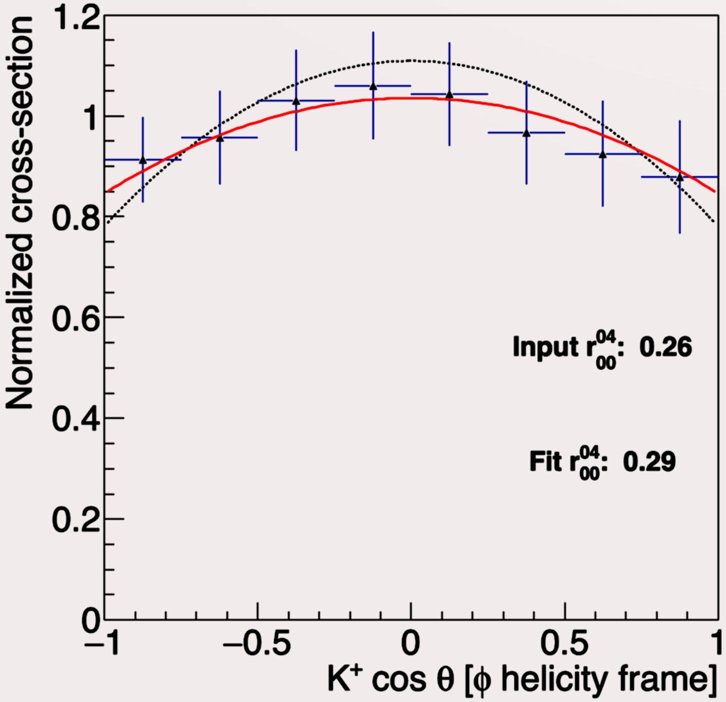
DVCS Exclusivity



– All final state particles are detected
– The very good resolution of all detectors allows for very tight exclusivity cuts

Deeply Virtual ϕ Production

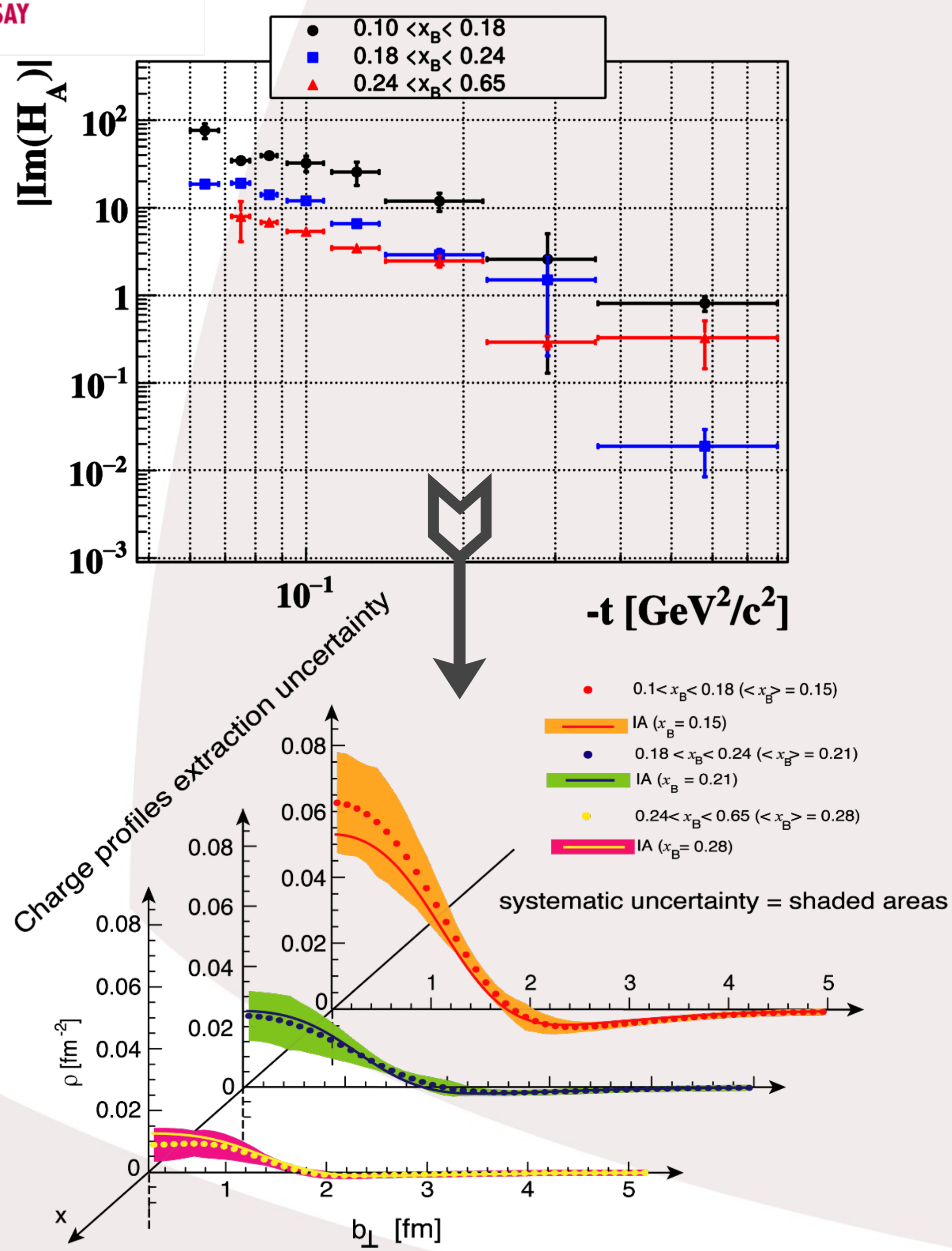


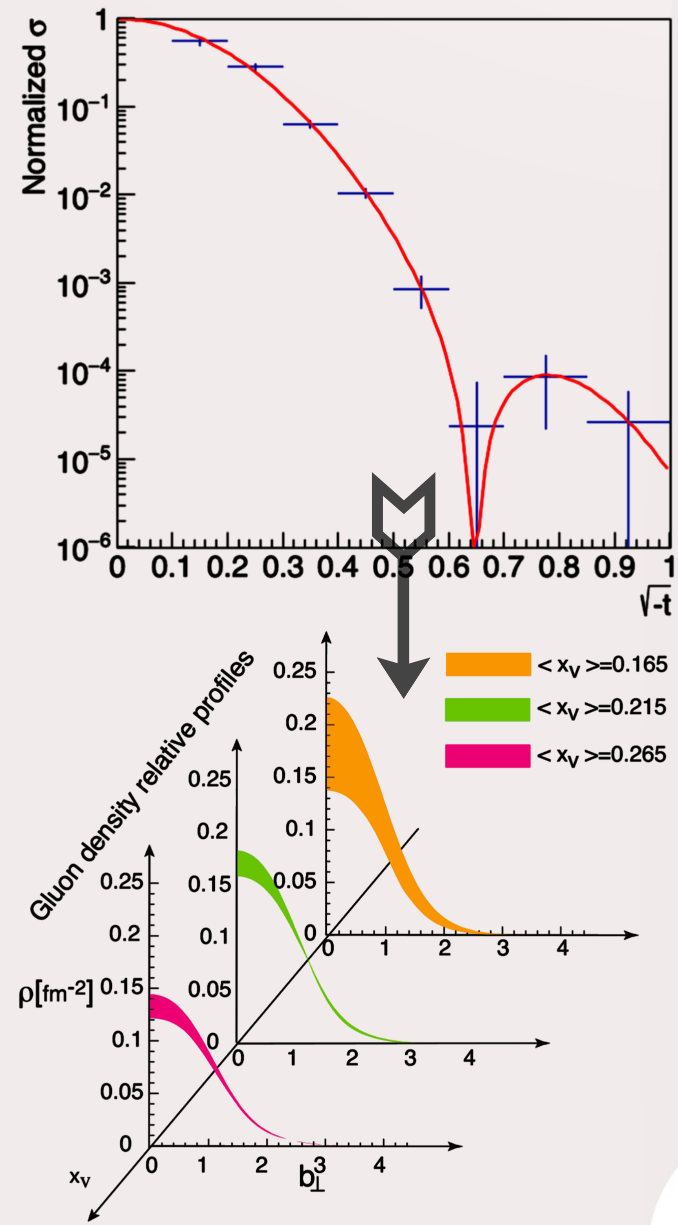


- **Exclusivity is insured by reconstructing the missing mass of a K^-**
  - Very sensitive to ALERT resolution
  - Background is reduced by requiring the detection of ^4He
- **Longitudinal cross section extracted from cosθ**
  - Can then be directly related to gluon distribution

$$|\langle H_g \rangle|(t) \propto \sqrt{\frac{d\sigma_L}{dt}(t - t_{min}) \Big/ \frac{d\sigma_L}{dt}(0)}$$

Projections for Coherent Processes





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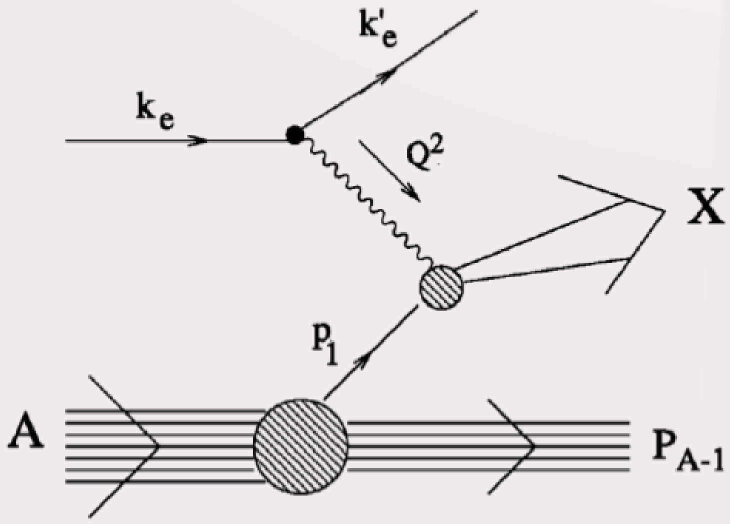
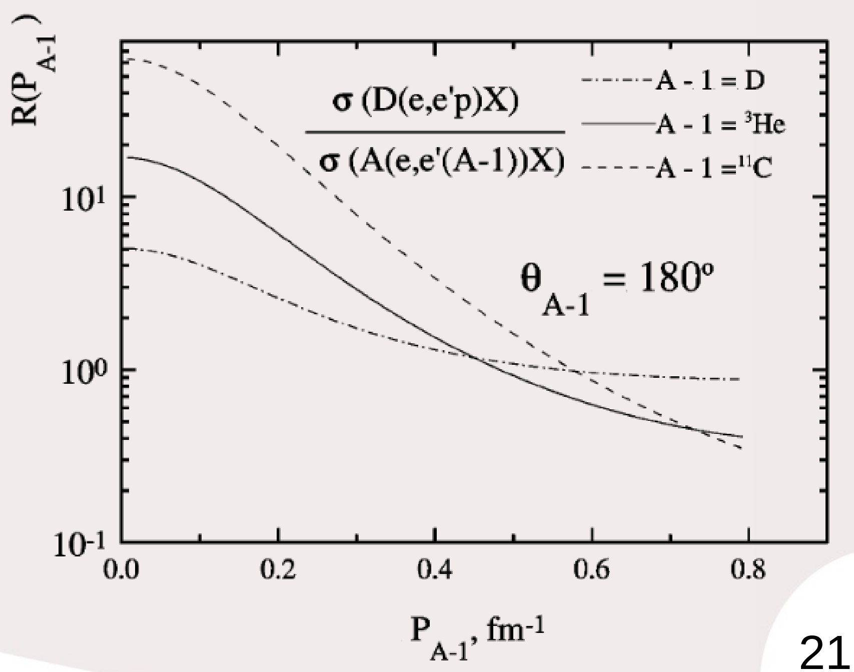
Testing the Spectator Mechanism

- **Spectator recoil for deuterium target**
  - The nucleon inside the nucleus which does not interact with the virtual photon and other hadronic products of the reaction
  - Its detection can be used to control FSIs
  - Used by CLAS successfully for neutron structure function measurement (Bonus run)

- **Spectator recoil for ^{4}He target**
  - The detection of the recoil nucleus (A-1) intact gives an extra indication that FSI is small
  - The Fermi distribution extends to higher momentum





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  - **Tagged EMC**
  - Tagged DVCS
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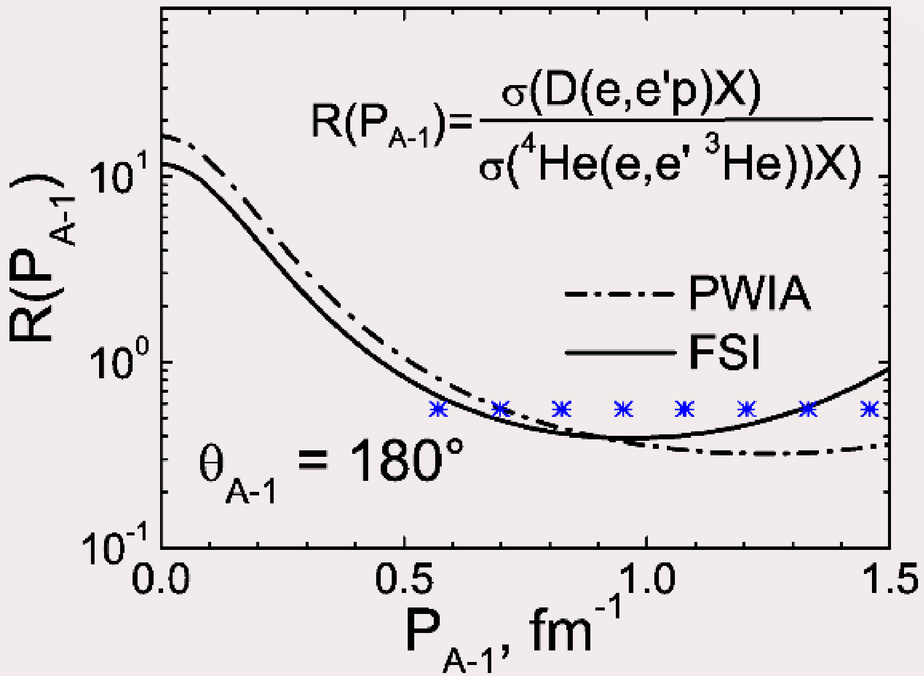
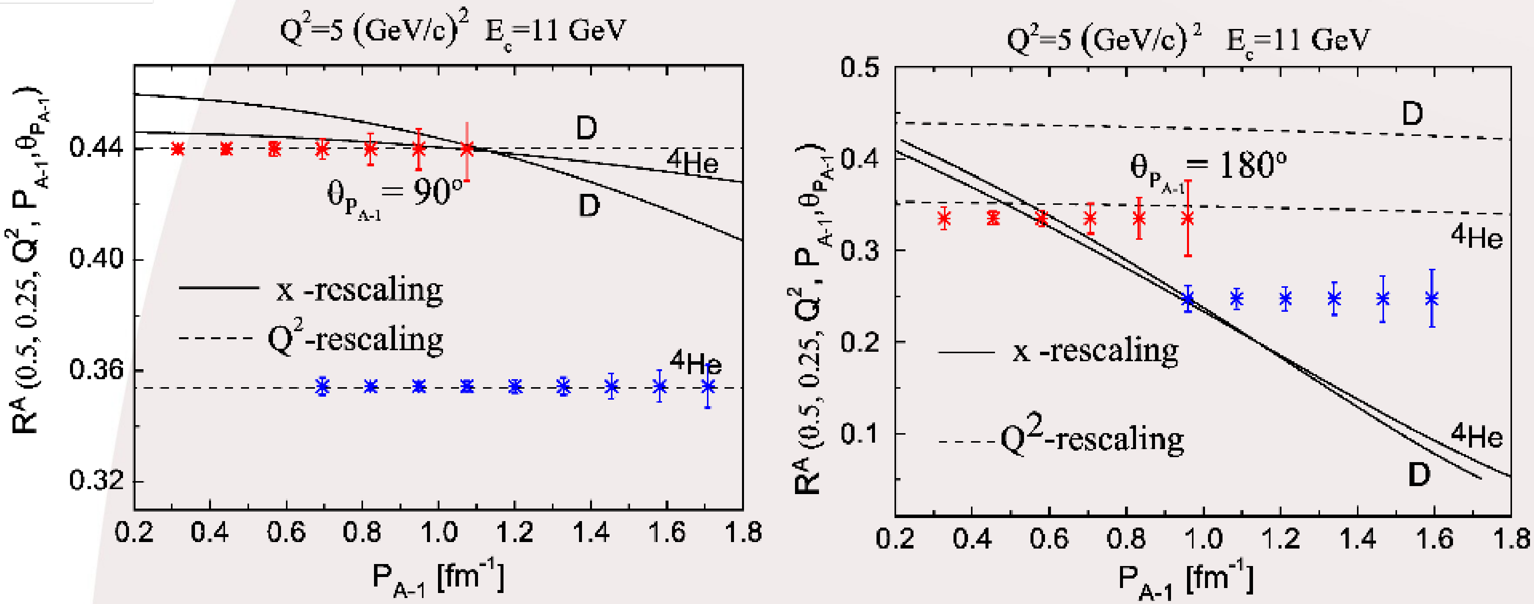
Testing the Spectator Model



- **First step is to test FSI models**
  - Can be tested in large momentum and angle range with very good precision
  - Comparison of Helium and Deuterium targets
  - First measurement of its kind on ^{4}He

C. Ciofi degli Atti, L. P. Kaptari, and S. Scopetta, Eur. Phys. J. A5, 191 (1999)

x or Q^2-Rescaling ?

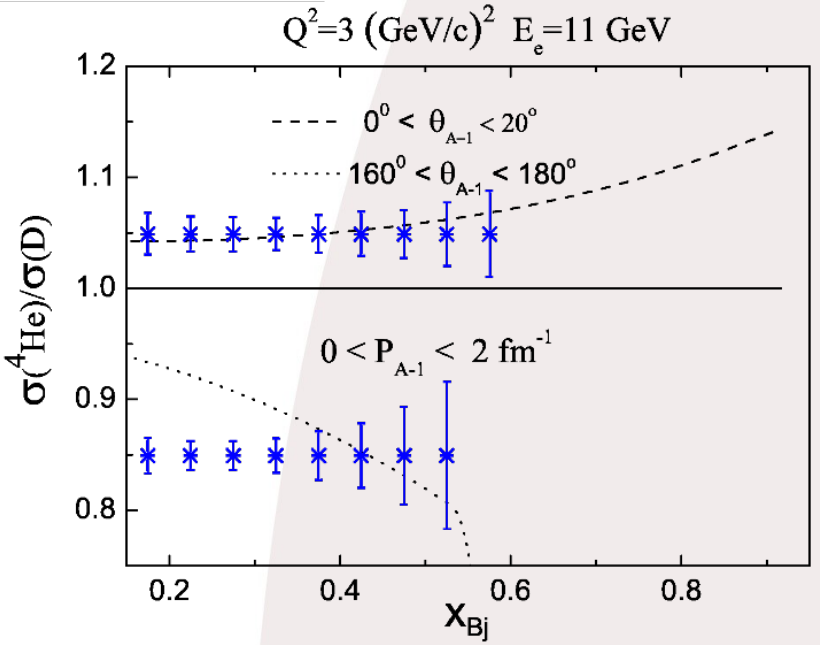


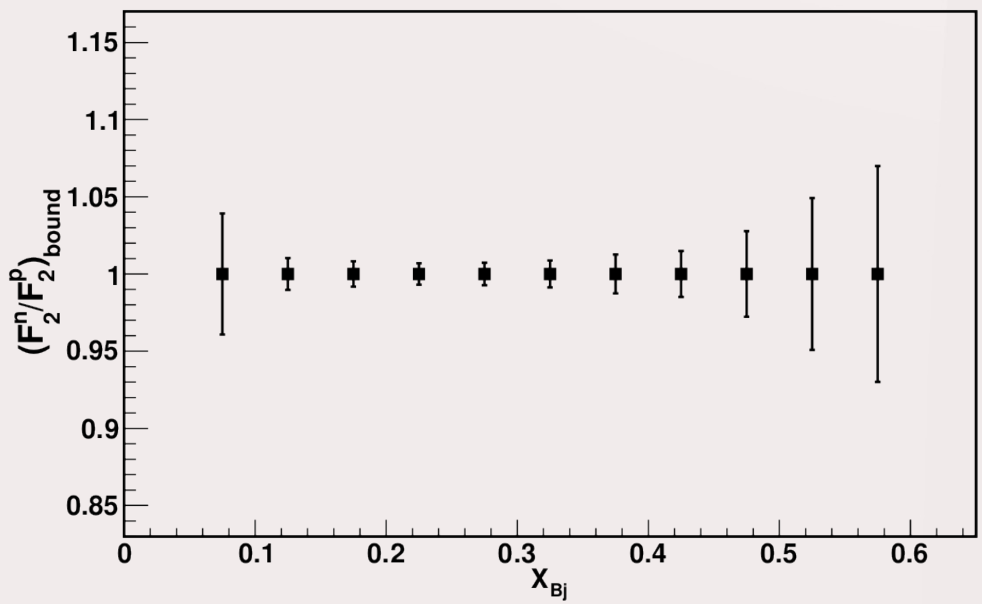
- **The nucleon virtuality is directly linked to the spectator momentum**
- **Rescaling models behave differently with tagged measurements**
  - It is impossible to differentiate x and Q^2 rescaling with inclusive measurements but they give very different signature in tagged measurements
  - Comparison of ^2H to ^4He is particularly interesting
    - It conserves the nucleus isospin symmetry
    - ^4He is a light nuclei with a sizable EMC effect
    - The two rescaling effects are cleanly separated by the comparison between the two nuclei
    - They complement each other in spectator momentum coverage

C. Ciofi degli Atti et al. Eur. Phys. J., vol. A5 (1999) 191

C. Ciofi degli Atti et al. Phys.Rev. C76 (2007) 055206

More Tests of the EMC Models





- **Tagged DIS gives many other opportunities to test the EMC models**
  - In binding model, the EMC effect is due to the cancellation of much larger effects that can be separated with spectator detection
- **Tagged DIS can also be used for flavor selection**
  - We can test how the d/u ratio changes in the nuclear medium

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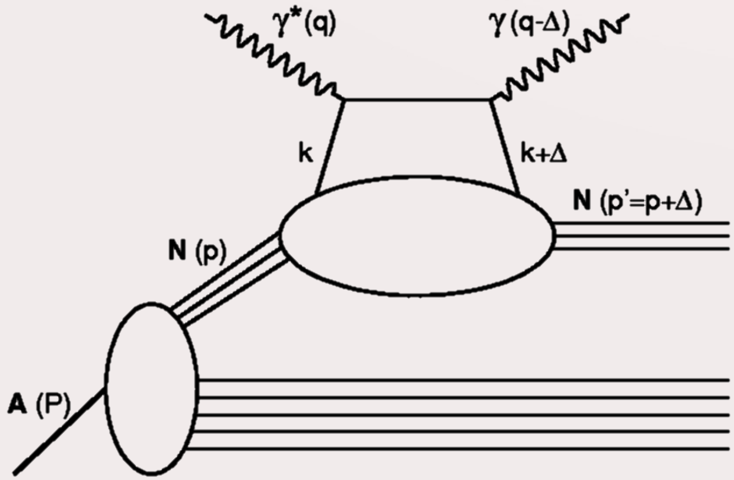
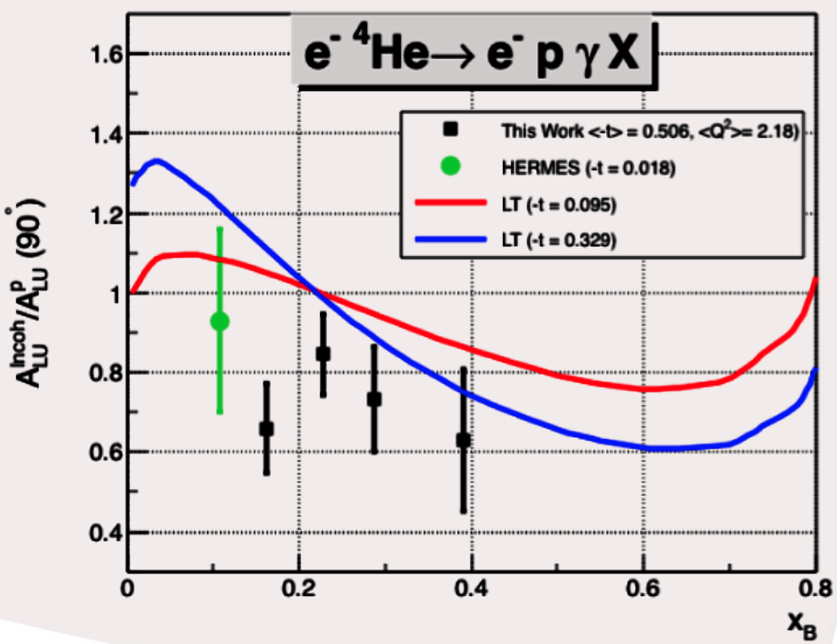
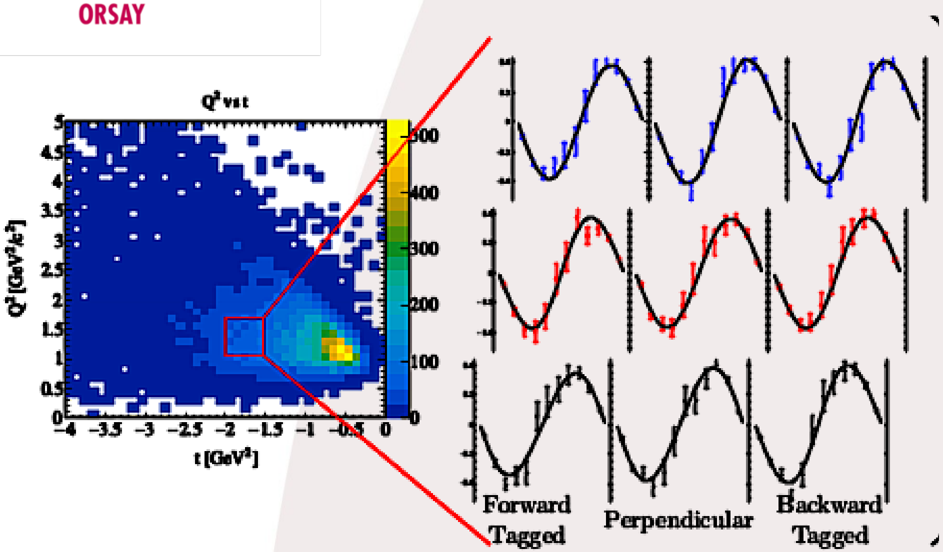
From Incoherent DVCS to Tagged DVCS

- **Incoherent nuclear DVCS measurement in CLAS (E08-024)**
  - **e + ^{4}He → e + γ + p (+ X)**
  - Successful measurement
  - With surprising results
    - We need more statistics and a way to control FSI effects
- **We can get a handle on FSI**
  - **e + ^{4}He → e + γ + p + ^{3}H**
    - Over-constrained measurement ensure full control of FSI including at the zero momentum transfer
    - Can also be directly compared to free proton to understand bound nucleon modification



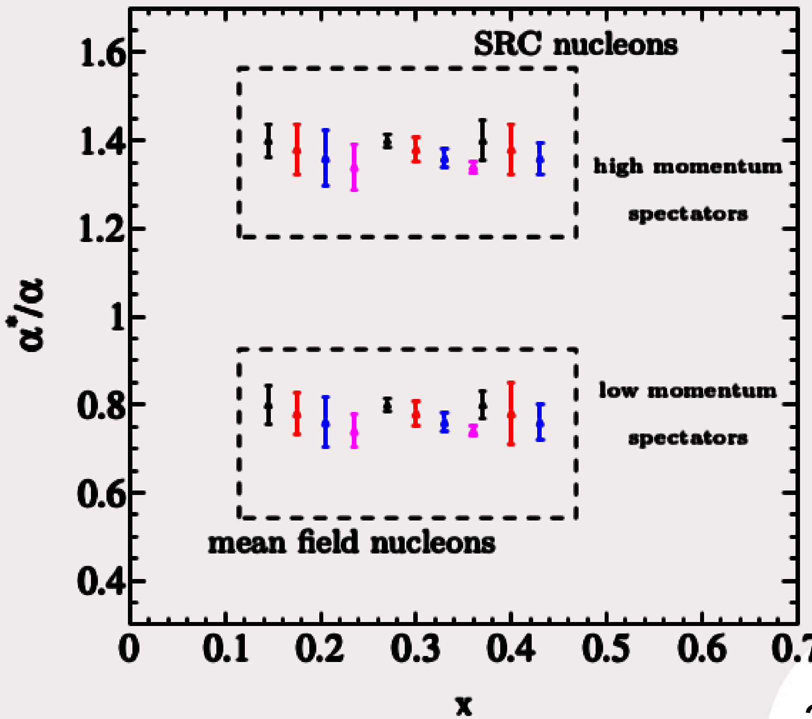


Tagged DVCS Measurements



Bin						
x		0.05	0.25	0.35	0.5	0.8
Q^2	[GeV²]	1	1.5	2.0	3.0	10
t	[GeV²]	0	0.75	1.5	2.5	6.0
θ_s	[degrees]	0.0	50	100	180	
P_s	[GeV/c]	0.0	0.2	0.45	1.0	

- **Projections of neutron ratios**
  - e + ^{2}H → e + γ (+ n) + p
  - e + ^{4}He → e + γ (+ n) + ^{3}He
- **Coverage in spectator momentum and angle**
  - Together with proton studies gives a handle on FSI effects
- **High statistics allow for multi-dimensionnal binning leading to:**
  - Comparison of same spectator momentum in different nuclei (α*/α)
  - Measurement at different spectator momenta: mapping from mean field to SRC nucleon regimes



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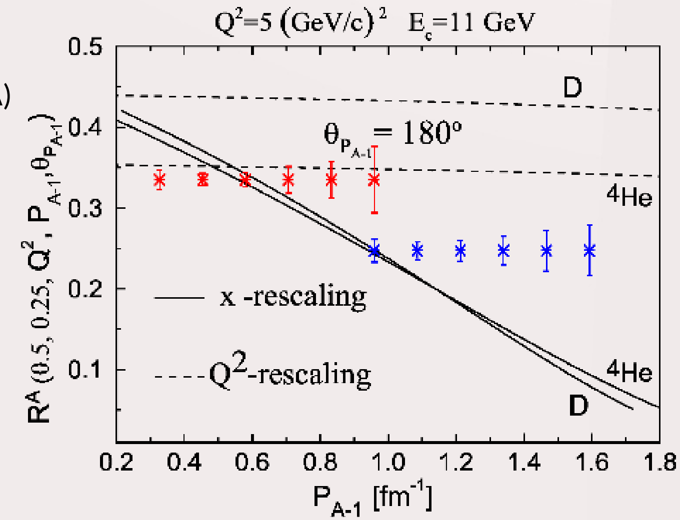
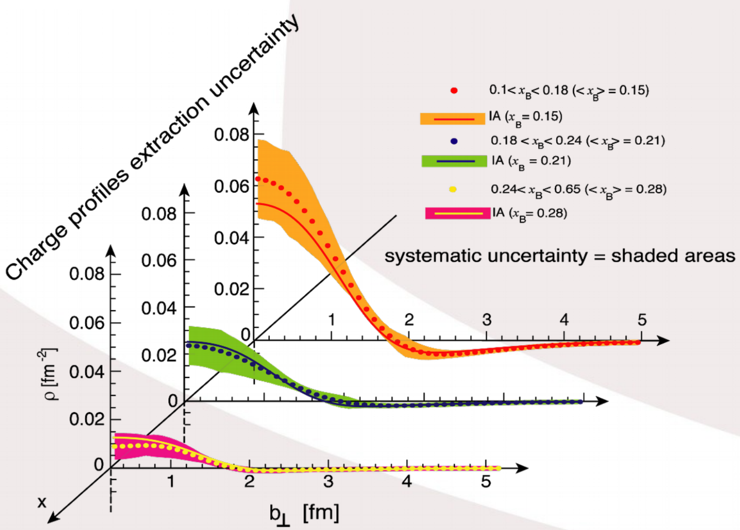
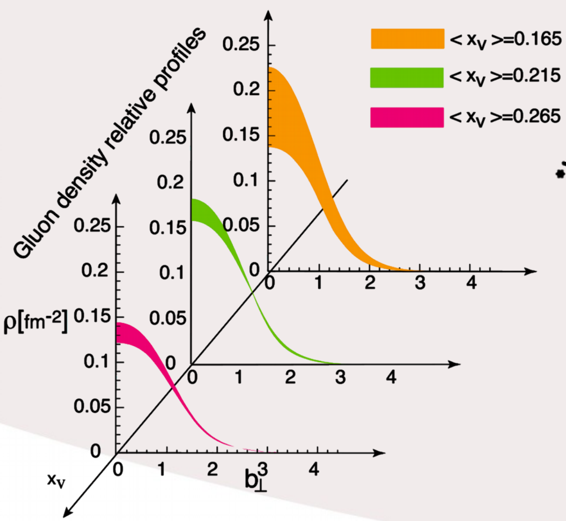
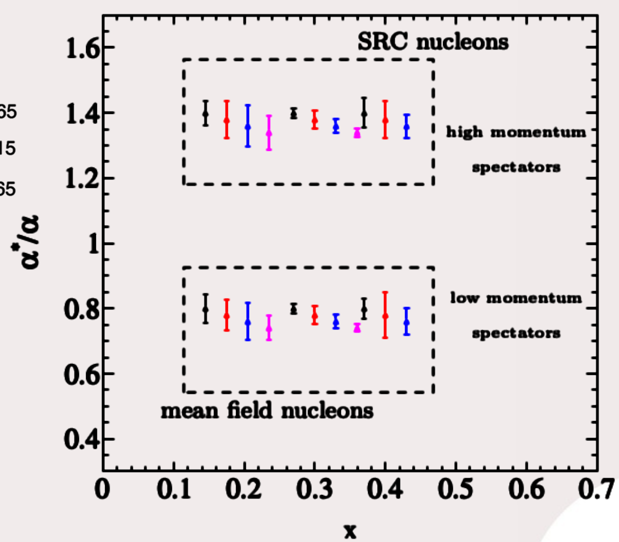
Summary

- **We will bring the study of the QCD structure of Nuclei to the next level**
  - With Nuclear GPDs, we are mapping the fundamental structure of nuclei (PR12-16-011A)
- **We will significantly advance our understanding of nuclear effects**
  - Tagged EMC will give a new insight into the EMC effect (PR12-16-011)
  - Tagged DVCS will explore the 3D structure of bound nucleons (PR12-16-011B)
- **These are also highlights of the EIC physics program**
  - We will provide first measurements at high x
  - Complemented by many other measurements (PR12-16-011C)
- **Funding for the ALERT detector**
  - Initial funding for wire chamber R&D and prototype were provided by IPN Orsay
  - Funding for detector construction (pending a favorable outcome for the PAC) will be pursued from France/Europe (wire chamber) and from the DOE-NP (ANL) for the scintillators, SiPM and readout









Beam Time Request

ALERT run group will need 55 days of beam time

- This request is driven by the tagged EMC and nuclear GPDs measurements
  - The luminosity will be limited by occupancy in the ALERT detector for tagged measurements
  - Higher detection threshold will be used to run at high luminosity for coherent measurements on ^{4}He
- All other interesting physics including Tagged DVCS will need no additional beam time
  - All beam time requested, except commissioning, needs a high polarization to measure beam spin asymmetries in DVCS measurements

Measurements	Particles detected	Targets	Beam time request	Luminosity
Commissioning	p, d, ^{4}He	H and He	5 days	Various
Tagged EMC (PR12-16-011)	p, ^{3}H, ^{3}He	^{2}H and He	20 + 20 days	3.10^{34} cm^{-2}s^{-1}
Nuclear GPDs (PR12-16-011A)	^{4}He	He	extra 10 days on He	6.10^{34} cm^{-2}s^{-1}
Tagged DVCS (PR12-16-011B)	p, ^{3}H, ^{3}He	^{2}H and He	20 + 20 days	3.10^{34} cm^{-2}s^{-1}
Additional Topics (PR12-16-011C)	p, d, ^{3}H, ^{3}He	^{2}H and He	20 + 20 + (10) days	$3(6).10^{34}$ cm^{-2}s^{-1}
TOTAL			55 days	

Outline

- Physics Introduction
- ALERT Detector
- Coherent Measurements
- Tagged Measurements
- Summary & Beam Time Request
- **Erratum and TAC review**

The Erratum

- **We made a mistake calculating the beam current**
  - Beam current request should be 500/1000 nA
    - With this beam current only the projections for the nuclear GPD proposal are affected
  - The aluminum windows are mentioned because it contributes significantly to the luminosity. It is not used for physics
  - We had some confusion about nuleon vs nuclei luminosity
    - You received an erratum for the nuclear GPD proposal projections
- **Can Hall-B beam dump handle this current?**
  - Probably not. It would need to be upgraded for currents above 450 nA
  - If that upgrade is not possible, we can use a higher pressure target (~6 atm)
    - The impact will have to be evaluated for tagged measurements, which require low momentum threshold

Measurements	Particles detected	Targets	Beam time request	Luminosity*	Beam Current
Commissioning	p, d, ^{4}He	H and He	5 days	Various	Various
Tagged EMC	p, ^{3}H, ^{3}He	^{2}H and He	20 + 20 days	3.10^{34} cm^{-2}s^{-1}	500 nA
Tagged DVCS	p, ^{3}H, ^{3}He	^{2}H and He	20 + 20 days	3.10^{34} cm^{-2}s^{-1}	500 nA
Nuclear GPDs	^{4}He	He	extra 10 days on He	6.10^{34} cm^{-2}s^{-1}	1000 nA
Additional Topics	p, d, ^{3}H, ^{3}He	^{2}H and He	20 + 20 + (10) days	$3(6).10^{34}$ cm^{-2}s^{-1}	500 (1000) nA
TOTAL			55 days		

TAC Review Summary

- The proposed detector would require the inner CLAS12 Micromegas be removed so that the ALERT detector could be installed.
- Though the experiment is already reducing the luminosity from the maximum CLAS12 luminosity , they nevertheless are requesting a longer straw target then previously developed. It would seem a safer path to use a previously used straw length (or smaller) then to continue to push for an even longer straw cell target.
- The luminosity limitation is due to the estimated occupancy in the drift chamber. It was not clear that backgrounds from the target cell wall were taken into account as it is clear the 12 GeV CEBAF beam has longer tails than the 6 GeV beam. As straw type cells can have a slight bend, it again is important that the length of the cell is not pushed beyond necessarily to avoid scraping of the tail of the beam.
- Details of the design need to be finalized and a final layout need to be shown including the how the cables and front end electronics are to be located and showing that it can all fit in the space allowed.

- **Answer to technical concerns**
  - We are aware that the inner layer of the Micromegas detector will have to be removed with the SVT, this is not a problem at all (same applies to approved E12-06-113)
    - → We do not use this detector
  - We are aware of issues linked to straw targets and we have tried to be more conservative than Bonus12 (E12-06-113) → see slide #39 for details
  - Final design and layout are going to be worked out if approved but we do not see any showstoppers
    - → We have a limited number of channel compared to micromegas but same electronics

TAC Review Summary

- The downstream end window of the recoil detector is critical as multiple scattering of forward particles will degrade the tracking/momentum resolution. It is not obvious from the proposal to learn how this problem is addressed.
- Also, the details of the electronics need to be finalized with a clear realistic concept of how to include the needed trigger electronics into the general plan for the CLAS12 trigger with the ALERT detector.
- The scintillators in the recoil detector are planned to be read out using SiPM photo sensors. These sensors are very sensitive to neutron radiation, in particular at low energy (thermal). With a Helium target the flux of neutrons will be orders of magnitude higher than with a regular Hydrogen target. Feasibility studies on using SiPM photo sensors in such an environment are needed.

- **The down stream window is indeed an issue**
  - In the proposed experiments only high energy photons and electrons go through this part of the ALERT detector
  - Their resolution is slightly reduced by the material (0.25 mrad per cm of carbon)
  - In the present design we plan to build it with few mm of carbon, which we found to be acceptable.
- **We now performed first tests of our prototype wire chamber**
  - Saclay engineers built an interface card to use DREAM for our drift chamber
  - We tested it and the DREAM cheap appears to work perfectly fine for us
- **We looked into radiation damage based on Hall-D studies**
  - We found that radiation will likely increase dark current
  - But the dose is small enough to stay under control
  - We plan to refine our estimations before our final design

Theory Review Summary

- **Tagged EMC, PR12-16-011 by T. Rogers**
  - "To summarize, the experiment will likely have a large impact on the theoretical picture of the EMC effect."
- **Nuclear GPDs, PR12-16-011A by J. W. Van Orden**
  - "The production quark and gluon distributions for the nucleus rather than just a constituent nucleon eliminates the need to make any assumptions about the character of nucleons in the nucleus and would provide some very interesting results."
- **Tagged DVCS, PR12-16-011B by I. Balitsky**
  - "The experiment is proposed in a run group with two other measurements aimed at understanding of the structure of ^{4}He and I think it should be pursued."
  - About Fig. 1.4 and zero momentum transfer limit, it is not clearly stated in the text, but we also test this effect when looking at results in the form of Fig. 1.5
- **Other topics, PR12-16-011C by R. Schiavilla**
  - "The present proposal is part of a comprehensive program to study the partonic structure of the 4He nucleus through measurements of DVCS and DVMP"

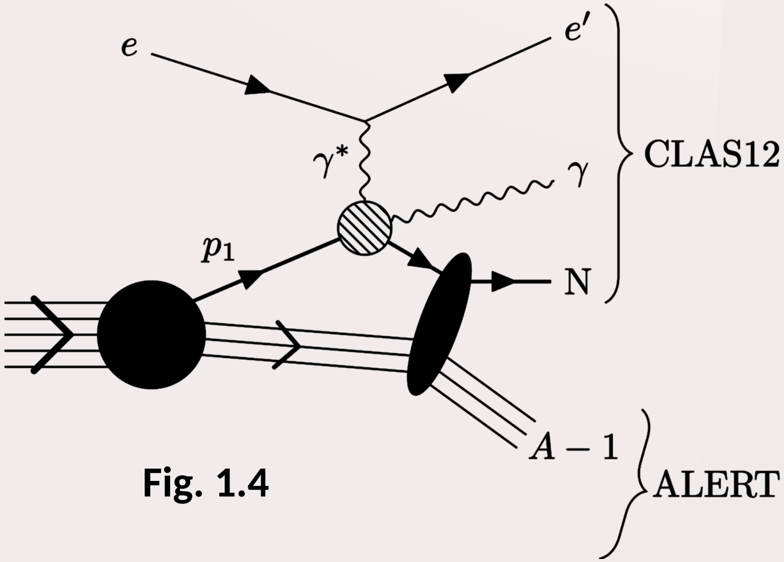


Fig. 1.4

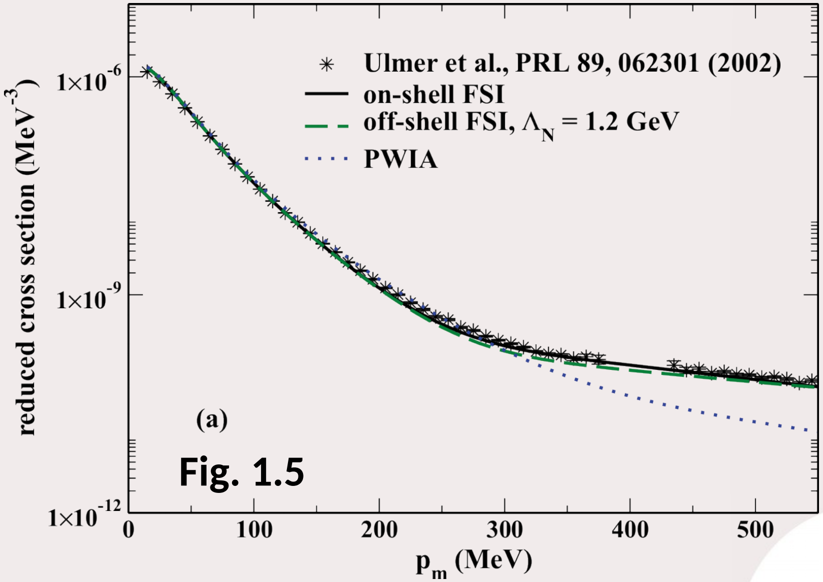
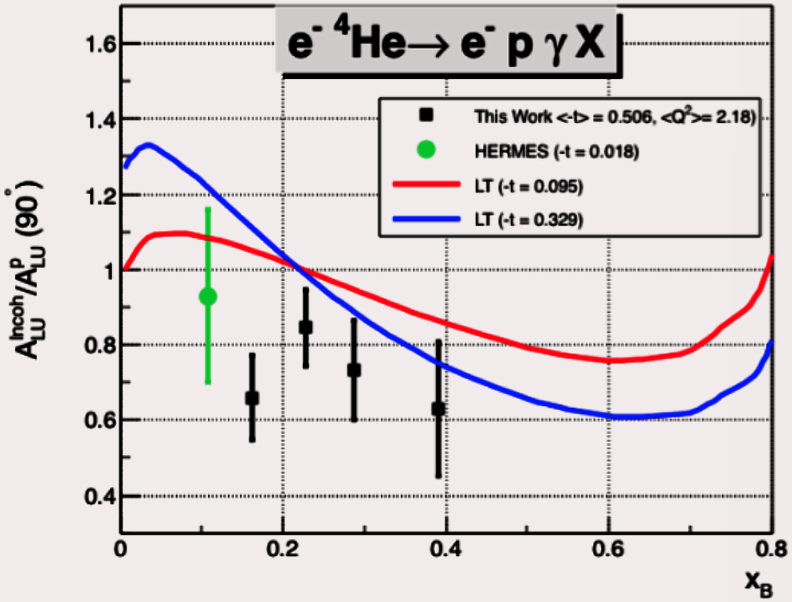


Fig. 1.5

Backup Slides

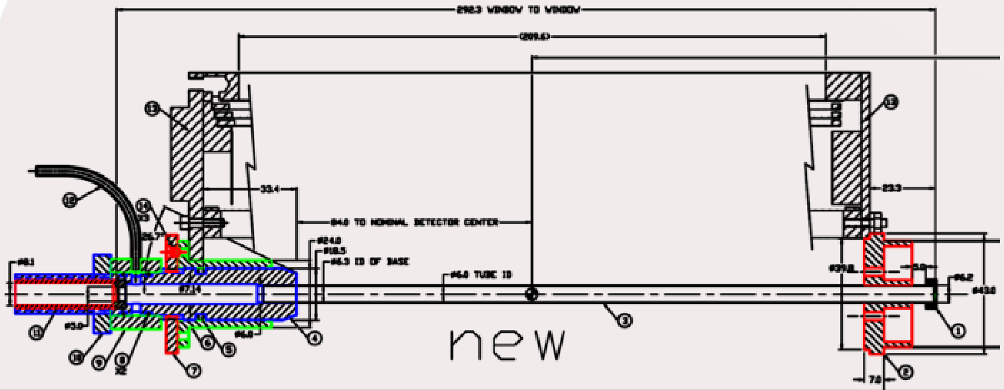
The Quasi-Free Neutron DVCS

- **Complementary to PR12-11-003**
  - Resolution on the photon and neutron does not allow to reconstruct the direction of the low momentum spectator
  - Detecting the spectator gives unique handle on FSI effects
  - This is the only way to control FSI
  - Allows to control Fermi motion as well
    - → gives a better handle on *t*



- **Different systematics**
  - Detecting both proton and neutron is unrealistic in term of statistics
  - So we will get a more important background from π^0
  - Our reach is limited by the tight selection on a backward spectator
- **Altogether this measurement will help significantly in the interpretation of the data of PR12-11-003**

The Straw Target



Experiments	Length	Kapton thickness	Maximum pressure
CLAS targets	30 cm	27 μm	6 atm
Bonus12 (PR12-06-113) target	42 cm	30 μm	7.5 atm
JLab test target 1	42 cm	30 μm	3 atm
JLab test target 2	42 cm	50 μm	4.5 atm
JLab test target 3	42 cm	60 μm	6 atm
Our proposed target	35 cm	25 μm	3 atm

- **Beam scrapping issue raised by TAC**
  - It is indeed an issue and we are more conservative than BoNuS12 (PR12-06-113)
    - We use a radius of 6 mm instead of 3 mm
  - HPS run showed (at different energies) that beam spot can be smaller than specifications and has very limited halo
- **Kapton thickness**
  - It seems that previous target pressure is not acceptable anymore and we probably will have to use slightly thicker target walls
    - This is mostly due to stricter safety standards

Comparison between ALERT and RTPC

- **Luminosity of previous Hall-B experiments with RTPCs was limited by the front-end readout of the RTPC (due to long drift times)**
  - EG6 ran at $1x10^{34}$ $cm^{-2}s^{-1}$ (6 atm, 20 cm, 150 nA)
- **BONUS12 will have improved RTPC readout**
  - Proposal quotes an increase to $2x10^{34}$ $cm^{-2}s^{-1}$ (7.5 atm, 40 cm, 200 nA)
  - This is still limited by RTPC, because CLAS12 can go as high as $1x10^{35}$ $cm^{-2}s^{-1}$
- **Recoil tracker Particle Identification**
  - $^{3}H/^{3}He$ fundamentally unresolveable with a TPC
  - Even other nuclear PID proved difficult
- **Allows recoil detection in trigger**
  - For inclusive CLAS triggers, ~90% have no reconstructed nuclear recoil tracks
- **Plans for ALERT**
  - Run at $3x10^{34}$ and $6x10^{34}$ $cm^{-2}s^{-1}$ (limited by ALERT occupancy)
  - conservative limits; expect up to 5% occupancy at $1x10^{35}$ $cm^{-2}s^{-1}$
  - Provides good discrimination between all of p, ^{2}H, ^{3}H, ^{3}He, ^{4}He

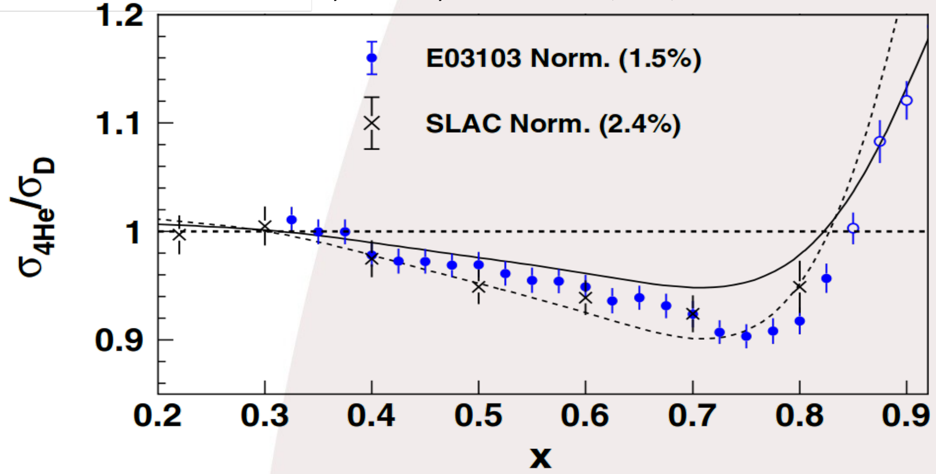
All luminosities above are per nucleon

Additional Topics (PR12-16-011C)

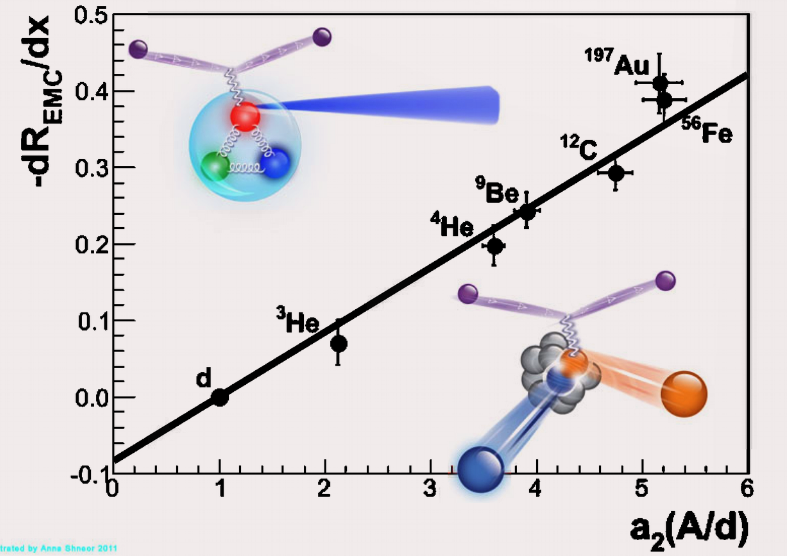
- **We identified a number of other measurements that can be done with the data accumulated with the ALERT detector**
  - *Coherent DVCS and DVMP off deuteron*
  - *Deep virtual π^0 production off ^{4}He*
  - *Three body break-up of ^{4}He in both DIS and DVCS*
  - Semi-inclusive measurements off deuteron to study π cloud of the nucleon
  - Meson spectroscopy in ^{4}He coherent production
    - → Extension of E-07-009
    - → Necessitate very thin forward detector window
  - Tagged Nuclear form factors
  - Role of Δs in short range correlations
  - Tagged hadronization and medium modified fragmentation functions
  - Medium modification of the transverse momentum dependent parton distributions

EMC: The Most Prominent Nuclear Effect

J. Seely et al. Phys.Rev.Lett. 103 (2009) 202301

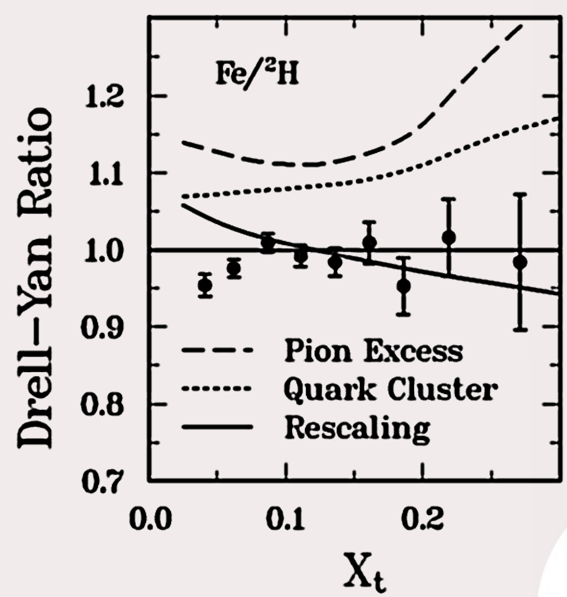


L.B. Weinstein et al., Phys.Rev.Lett. 106, 52301 (2011)



- **Do nuclear pions play a role?**
  - Drell-Yan experiment showed otherwise…
- **Is it x or Q^2-rescaling?**
  - Q^2-rescaling by modifying QCD in medium
  - x-rescaling due to the binding
- **Is there a dependence on nucleon virtuality?**
  - Hint from nucleon-nucleon Short Range Correlations (SRC)
  - Tagging the spectator of the reaction might help with the answer

D.M. Alde et al. Phys. Rev. Lett. 64, 2479 (1990)



n-DVCS is a sensitive probe of **medium modifications**

Enhanced sensitivity through modified (spin) structure functions and form factors

$$A_{LU,n}^{\sin\phi} \propto \mathrm{Im}(F_1^n \mathcal{H}^n - \frac{t}{4M^2} F_2^n \mathcal{E}^n + \frac{x_B}{2}(F_1 + F_2)^n \tilde{\mathcal{H}}^n)$$

- First term $\rightarrow$ suppressed by F_1^n
- Second term $\rightarrow$ Ji's sum rule and quark OAM
- Third term $\rightarrow$ polarized EMC Effect?

Connection to polarized EMC Effect

$$\mathrm{Im}\left((F_1 + F_2)^n \tilde{\mathcal{H}}^n\right) = G_M^n(t)\,\mathrm{Im}(\tilde{\mathcal{H}}^n(\xi,\xi,t))$$

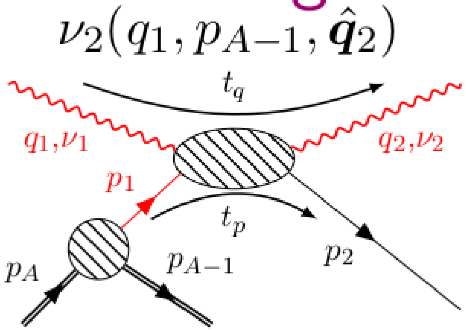
The ratio in the *forward limit* is

$$\frac{\text{bound } n}{\text{quasi-free } n} \longrightarrow \frac{\mu_{n^*}}{\mu_n}\frac{g_1^{n^*}(x)}{g_1^n(x)}$$

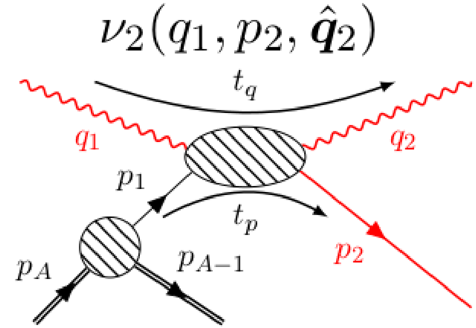
where g_1^n is the neutron's spin structure function.

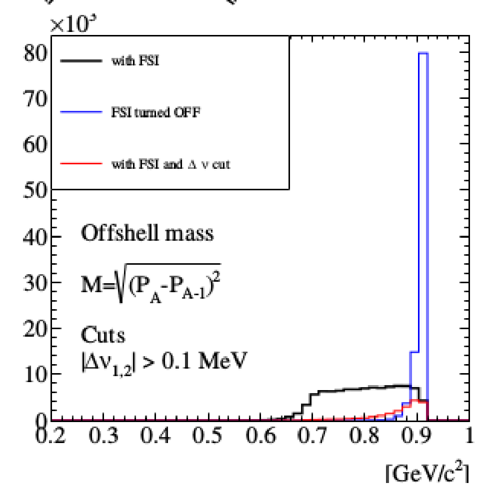
n-DVCS on nuclei presents a **uniquely sensitive measure of medium modifications**

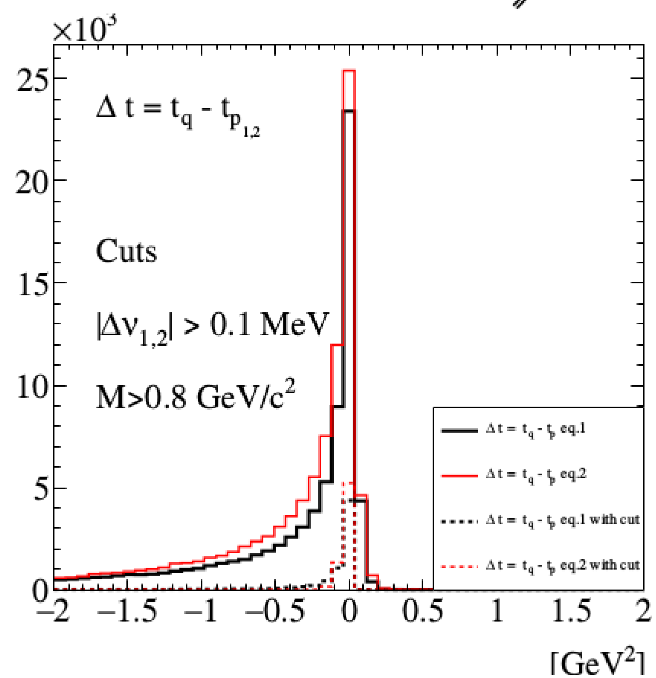
FSIs: Using the extra information

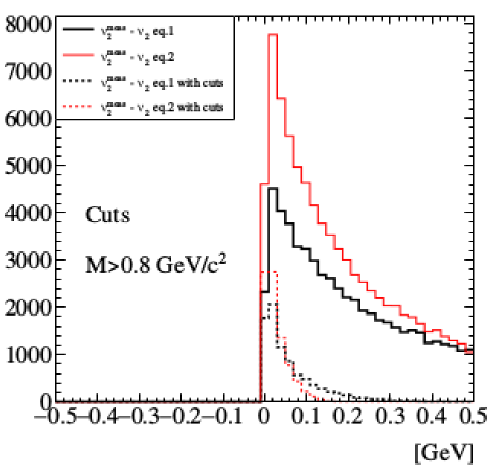


- Calculate real photon energy 2-different ways
- Measure photon energy too!









- Significantly reduce events with FSI
- With FSI a difference appears in $\Delta\nu = \nu^{\text{measured}} - \nu^{\text{eq.1}}$ and $\Delta\nu = \nu^{\text{measured}} - \nu^{\text{eq.2}}$