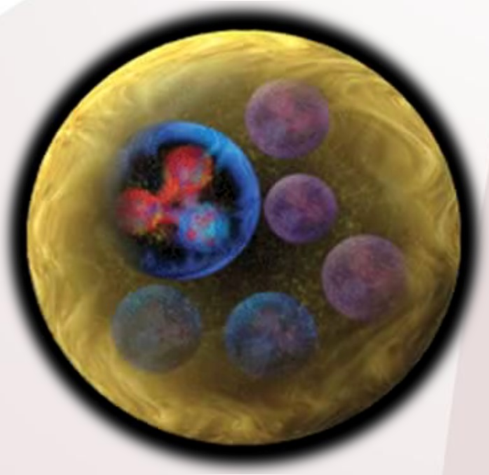
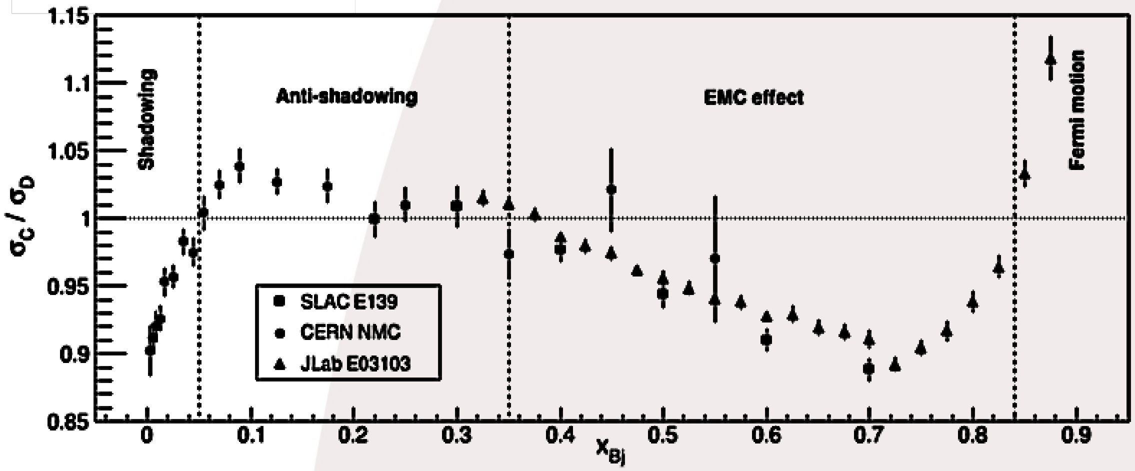


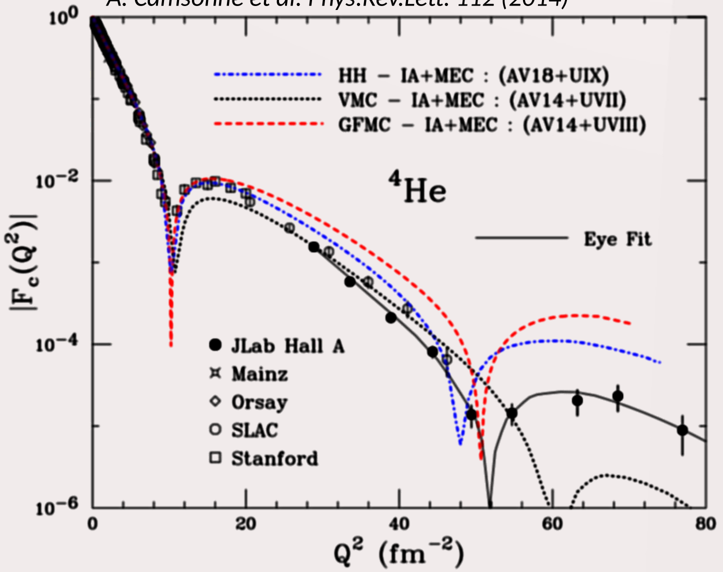
Tagging at JLab 12 and EIC

Raphaël Dupré

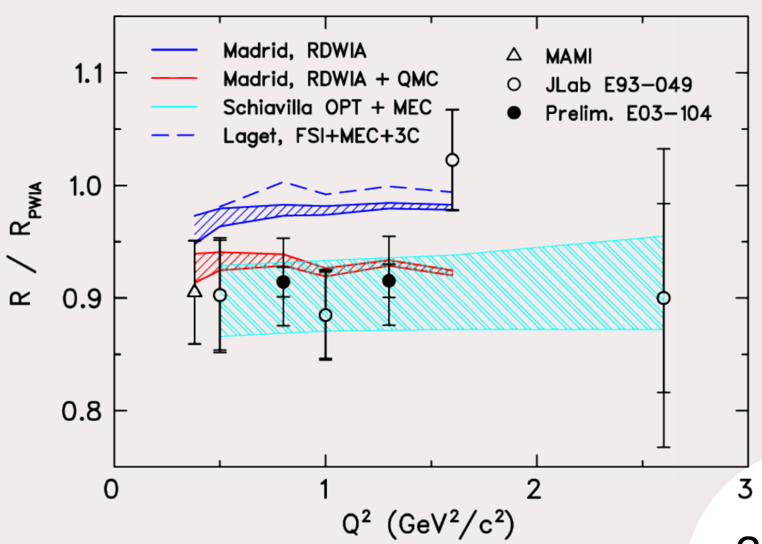
Lessons from the Past



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



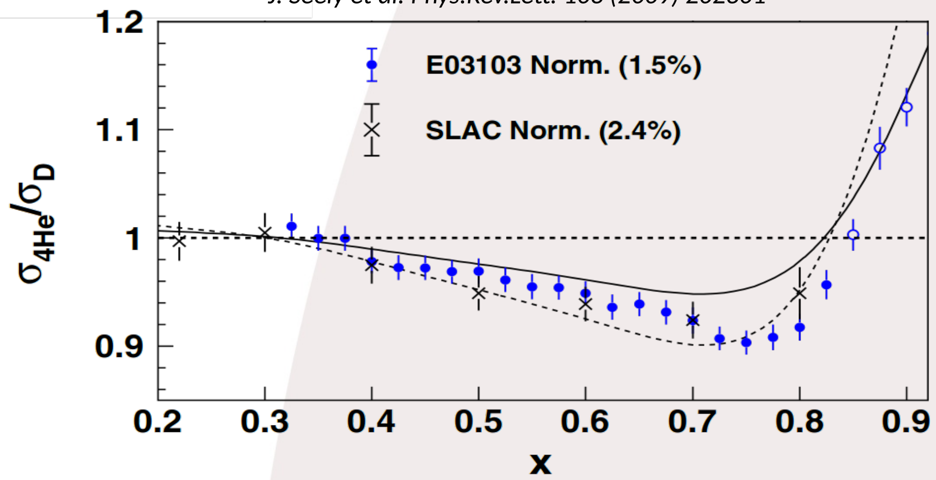
S. Strauch et al. Phys.Rev.Lett. 91 (2003) 052301



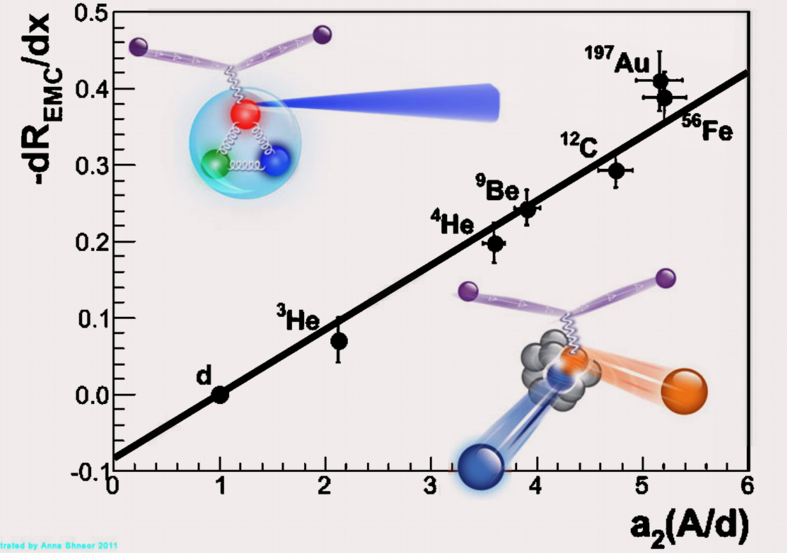
- **Nuclear Parton Distribution Functions (PDFs)**
  - We did not expect a significant effect
    - Binding is only at the level of MeVs
    - Several effects were discovered: shadowing, EMC…
- **Nuclear Form Factors (FFs)**
  - Reveal the transverse structure of nuclei
  - Mostly interpreted in term 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

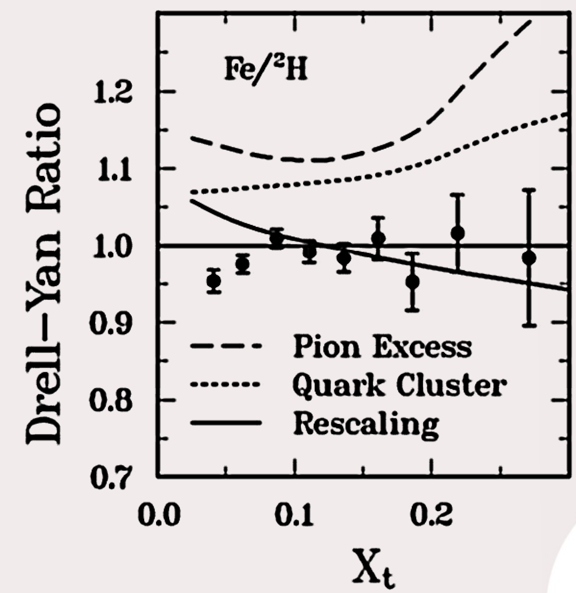


L.B. Weinstein et al., Phys.Rev.Lett. 106, 52301 (2011)



- **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)



Why Tagged Measurements

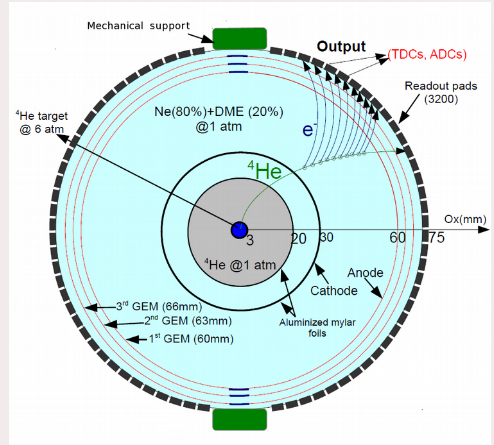
- **The EMC effect remains a mystery**
  - To explore possible links between the EMC effect and the intra nuclear dynamic
  - It is a semi-inclusive measurement in which we have control over the final state interactions

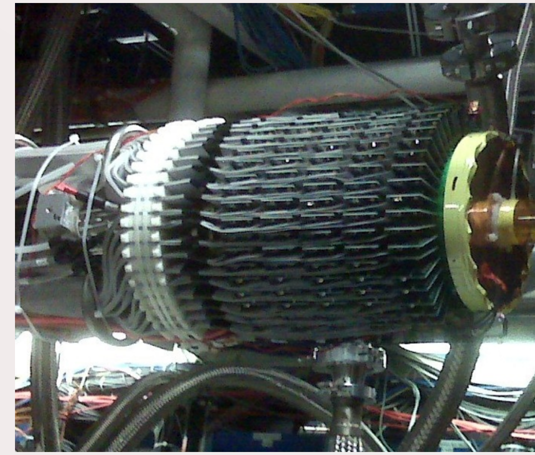
- **Tagged measurements give access to virtuality**
  - The virtuality or off-shellness of the struck nucleon is linked to its momentum in the nucleus
  - It is the way to make a direct link between the nucleus configuration and its modification

- **Nuclear measurements are often plagued with FSI effects**
  - Tagging of low momentum backward fragments is the safest way to suppress this problem

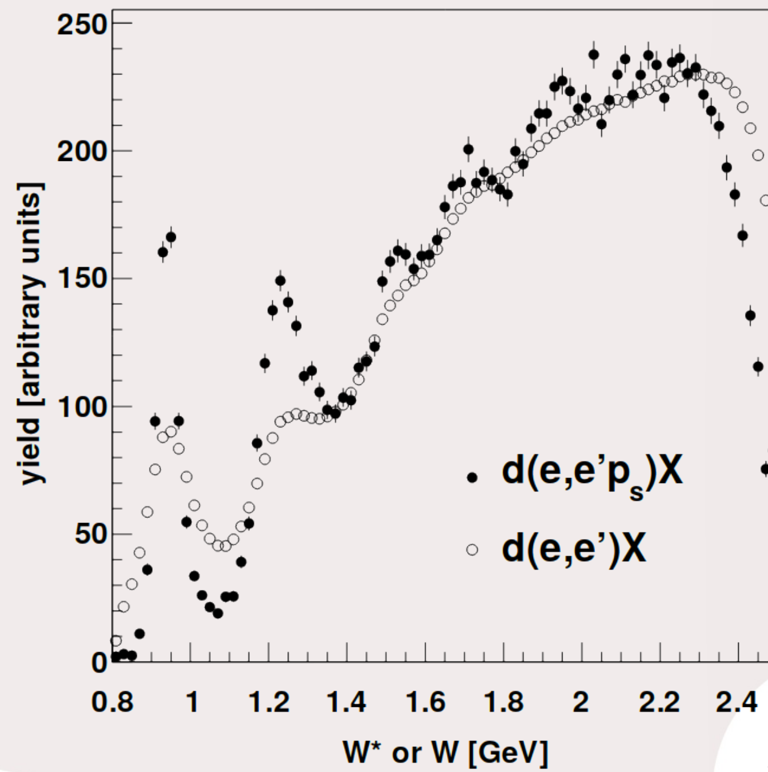
Past experience of tagging

- **Spectator have been “detected” by missing energy and momentum**
  - Done for a long time
  - But results were not always very good
  - Not possible for DIS





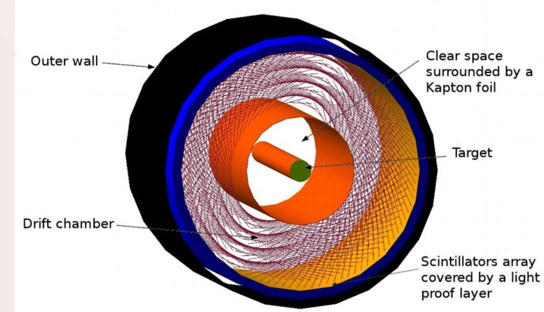
- **Bonus result brought a big change**
  - Directly measure the spectator
  - Best illustration in this inclusive graph

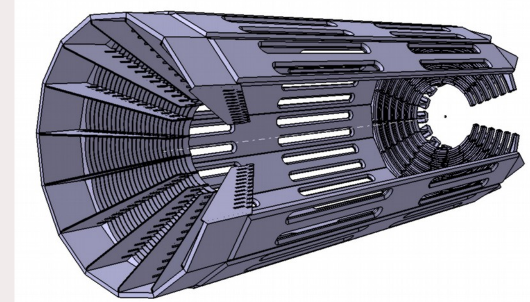


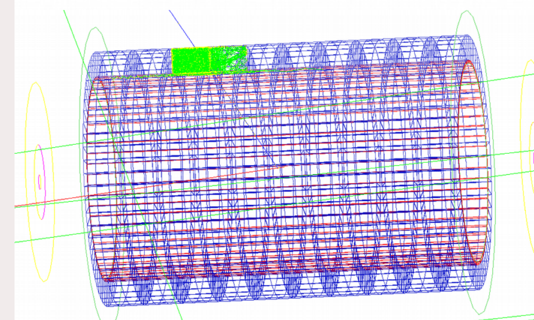
- **Performed using a small radial TPC placed directly around the target**
  - Similar detector used to measure low energy α for coherent helium DVCS
  - This technology is now under control but is limited in rate and luminosity

The ALERT Run group

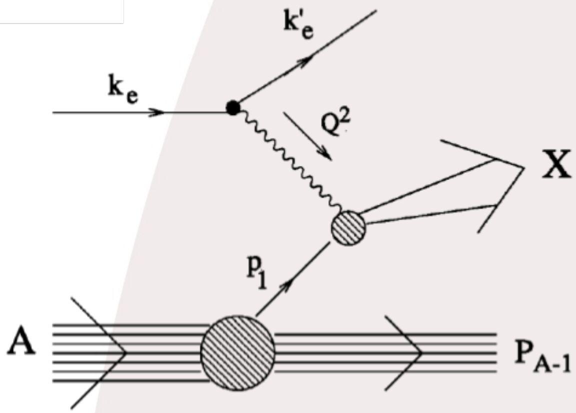
- **Construction of a new faster detector for recoil measurement**
  - To be placed in the center of CLAS12 (Hall-B)
  - With deuterium and helium target
  - Measure from ~100 to 300 MeV light nuclei
- **Many experiments planned (tagged and not tagged)**
  - Partonic Structure of Light Nuclei (E-12-17-012)
  - Tagged EMC Measurements on Light Nuclei (E-12-17-012A)
  - Spectator-Tagged Deeply Virtual Compton Scattering on Light Nuclei (E-12-17-012B)
  - And many other possible experiments (E-12-17-012C)
    - Tagged quasi-elastic
    - …
- **Detector is being designed and prototypes build**
  - We expect to run the experiments sometime around 2021

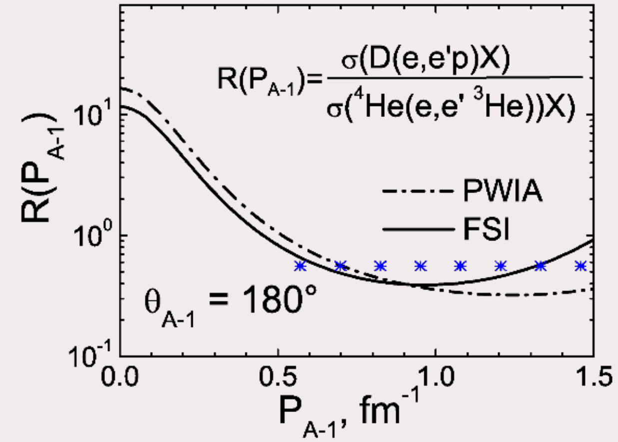






Testing the Spectator Model



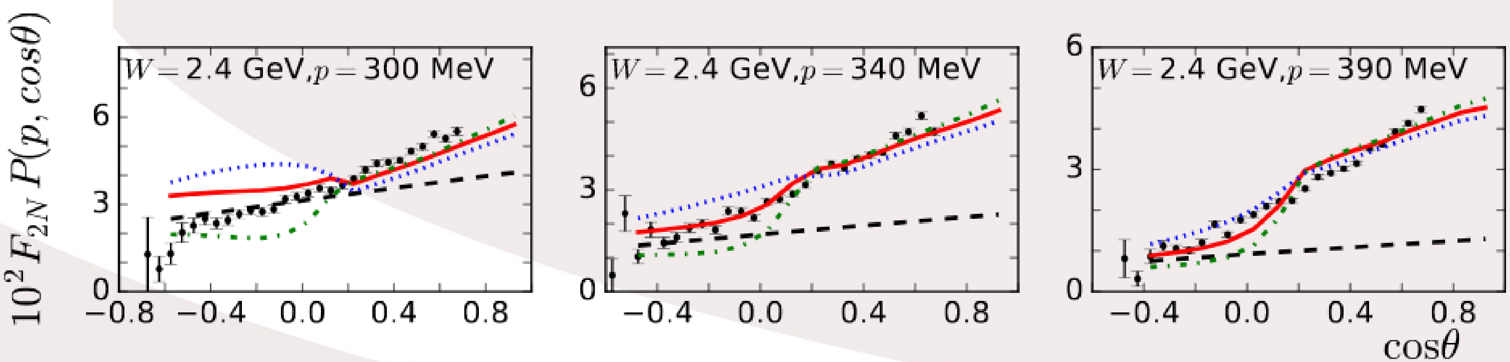


- **First step is to test FSI models**
  - Can be tested in large momentum and angle range with very good precision
    - This measurement will provide strong constraints for theoretical calculations

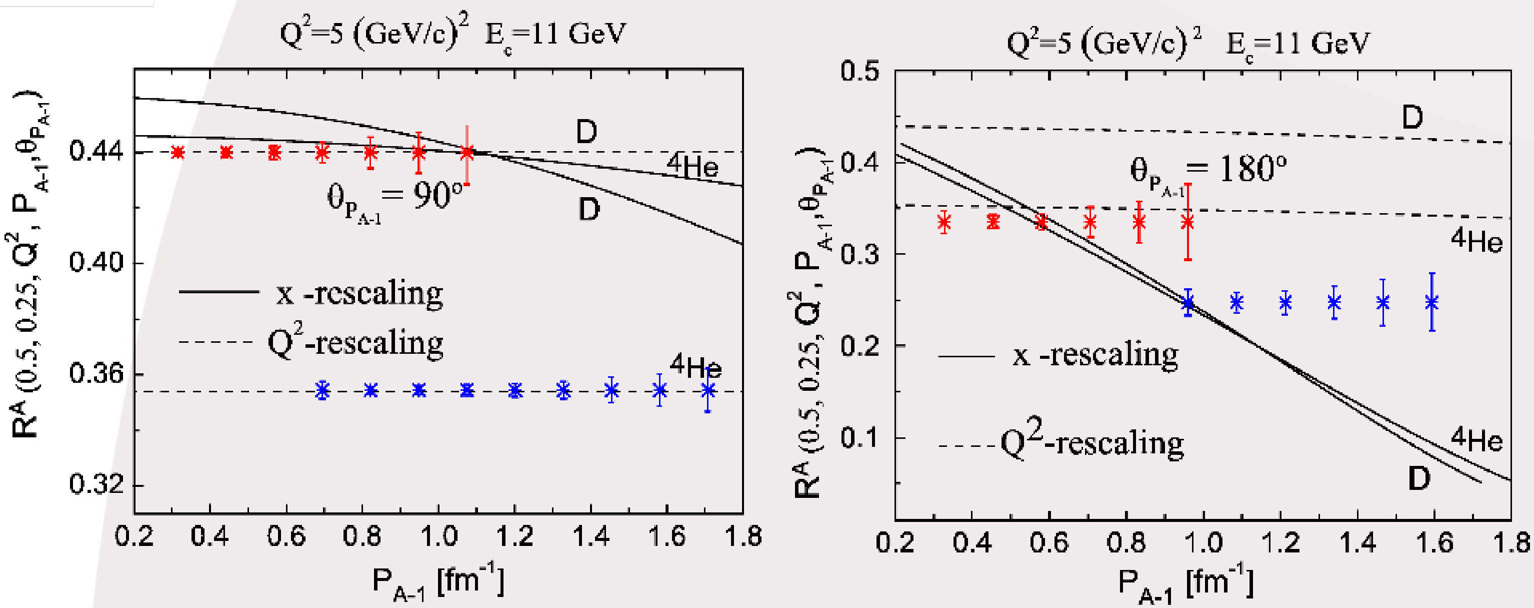
see M. Strikman, C. Weiss, arXiv:1706.02244 - W. Cosyn, M. Sargsian, arXiv:1704.06117

  - 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 ?

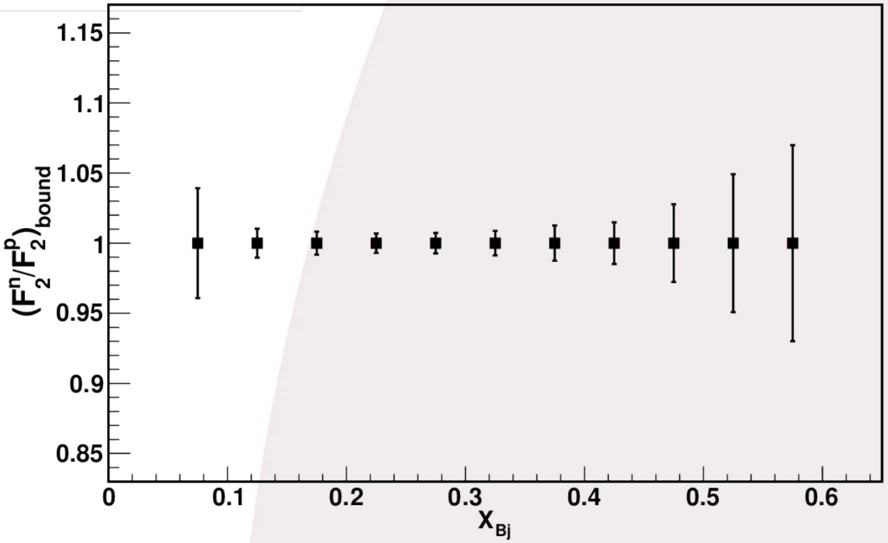


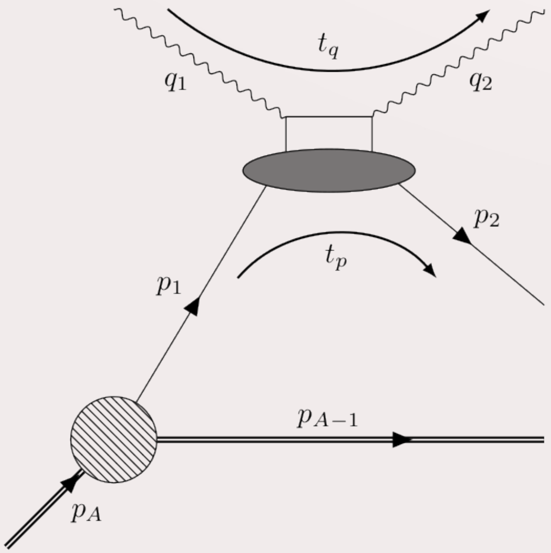
- **The nucleon virtuality is directly linked to the spectator momentum**
- **Rescaling models behave differently with tagged measurements**
  - It is impossible to differentiate x and Q^2 rescaling with inclusive measurements but they give very different signature in tagged measurements
  - Comparison 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 Tagging Observables

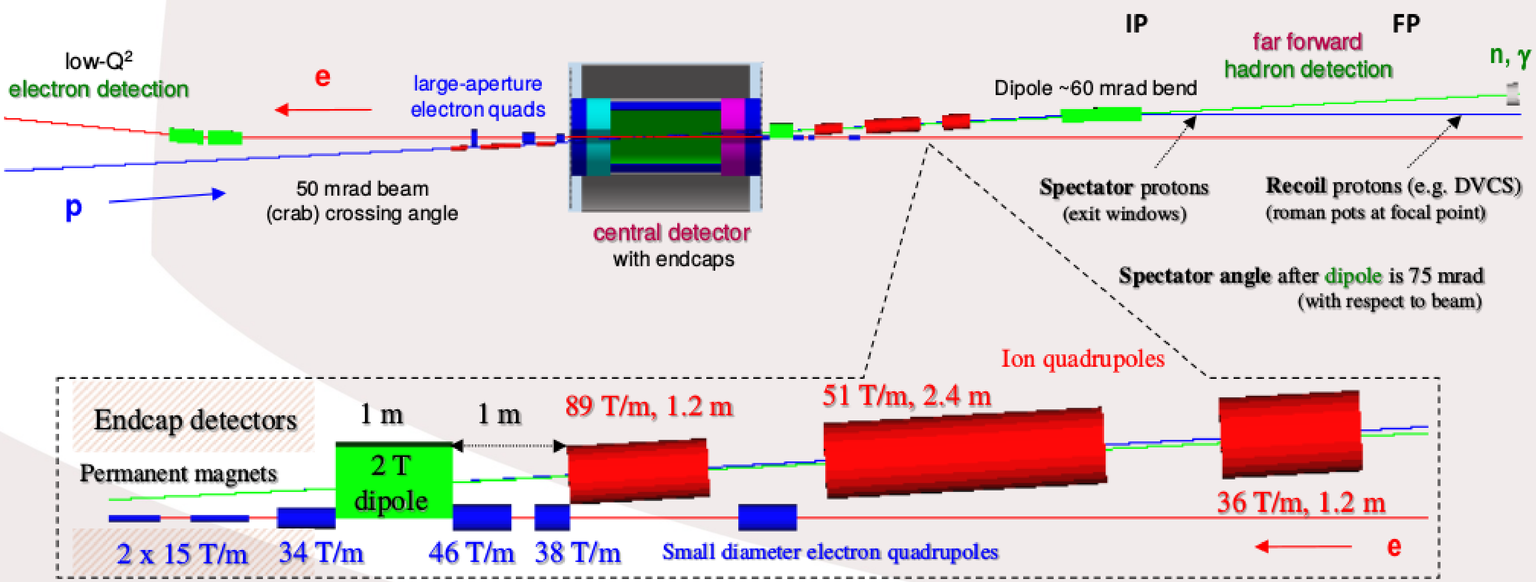




- **Many other tagged measurement and observables have been proposed**
  - Most of them are accessible with ALERT
- **Allows to separate the proton and neutron contributions**
  - Approved only in symmetric nuclei (D, ^{4}He) now, but could be extend to heavier targets (Li, B, …)
- **We can tag many other processes in nuclei**
  - Quasi-elastic, DVCS … (See W. Armstrong Talk)

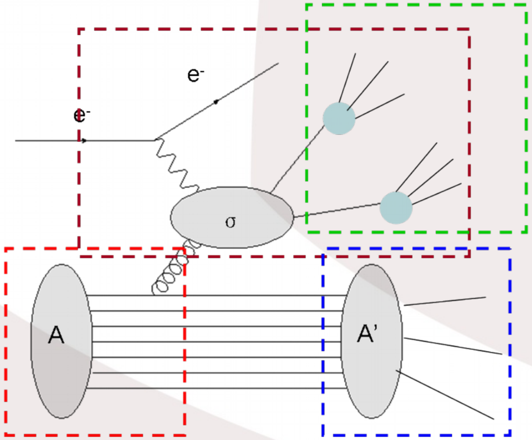
At the EIC

- **Tagging simplifies tremendously in a collider kinematic**
  - Detection close to the beam line
  - No minimum energy
    - Beam rigidity does the trick
  - Access to neutron tagging as well
    - Zero degree calorimeter
- **We can do all the measurements described before at the EIC**

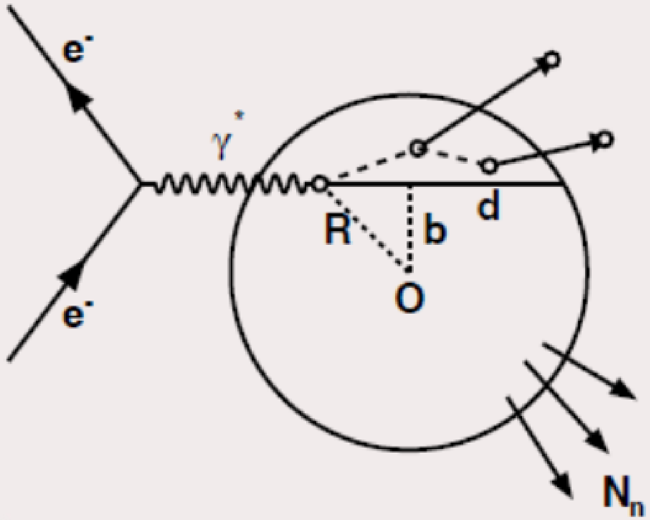


From tagging to nuclear break up

- **When going to heavier nuclei nuclear break up gets more complicated**
  - Moving from two body to many body system
  - Can we still understand what is going on?
- **Nuclear fragments can be indicative of many things**
  - Evaporation and short range correlated pairs from the nuclei
    - Problem: they are not necessarily from the nucleons directly involved in the main scattering
  - Centrality of the interaction
    - Problem: What do we actually call centrality here?
- **Activity in JLab has started to study these questions**
  - Mainly for EIC, but also with interest in JLab 12 possibilities



- PYTHIA
- Energy loss
  - Will add heavy quarks and gluons emission
- Nuclear evaporation
  - Will add a new module for the soft gluons
- Nuclear structure
  - Partons
  - Nucleons



In collaboration with: Jefferson Laboratory, Brookhaven National Laboratory, Argonne National Laboratory, Hampton University, Old Dominion University, Universidad Técnica Federico Santa María, ...

Existing Data at EIC like Energy

➔ There is some data to explore this question !

- ➔ E665 experiment at Fermi Lab
- ➔ μ-D (6000 events) and μ-Xe (2000 events)
- ➔ 490 GeV beam energy

Z. Phys. C 65, 225–244 (1995)

ZEITSCHRIFT FÜR PHYSIK C
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Nuclear shadowing, diffractive scattering and low momentum protons in μXe interactions at 490 GeV

E665 Collaboration

M.R. Adams[6], M. Aderholz[11], S.Aïd[9,a], P.L. Anthony[10,b], M.D. Baker[10], J. Bartlett[4], A.A. Bhatti[13,c], H.M. Braun[14], W. Busza[10], T.J. Carroll[11], J.M. Conrad[5], G. Coutrakon[4,d], R. Davisson[13], I. Derado[11], S.K. Dhawan[15], W. Dougherty[13], T. Dreyer[1], K. Dziunikowska[8], V. Eckardt[11], U. Ecker[14,a], M. Erdmann[1,e], A. Eskreys[7], J. Figiel[7], H.J. Gebauer[11], D.F. Geesaman[2], R. Gilman[2,f], M.C. Green[2,g], J. Haas[1], C. Halliwell[6], J. Hanlon[4], D. Hantke[11], V.W. Hughes[15], H.E. Jackson[2], D.E. Jaffe[6,h], G. Jancso[11], D.M. Jansen[13,i], K. Kadija[11,†], S. Kaufman[2], R.D. Kennedy[3], T. Kirk[4,j], H.G.E. Kobrak[3], S. Krzywdzinski[4], S. Kunori[9], J.J. Lord[13], H.J. Lubatti[13], D. McLeod[6], S. Magill[6,j], P. Malecki[7], A. Manz[11], H. Melanson[4], D.G. Michael[5,k], W. Mohr[1], H.E. Montgomery[4], J.G. Morfin[4], R.B. Nickerson[5,l], S. O'Day[9,m], K. Olkiewicz[7], L. Osborne[10], V. Papavassiliou[15,j], B. Pawlik[7], F.M. Pipkin[5,*], E.J. Ramberg[9,m], A. Röser[14,o], J.J. Ryan[10], C.W. Salgado[4], A. Salvarani[3,p], H. Schellman[12], M. Schmitt[5,q], N. Schmitz[11], K.P. Schüler[15,r], H.J. Seyerlein[11], A. Skuja[9], G.A. Snow[9], S. Söldner-Rembold[11,s], P.H. Steinberg[9,*], H.E. Stier[1,*], P. Stopa[7], R.A. Swanson[3], R. Talaga[9,j], S. Tentindo-Repond[2,t], H.-J. Trost[2,u], H. Venkataramania[15], M. Wilhelm[1], J. Wilkes[13], Richard Wilson[5], W. Wittek[11], S.A. Wolbers[4], T. Zhao[13]

[1] Albert-Ludwigs-Universität Freiburg i. Br., Germany
[2] Argonne National Laboratory, Argonne, IL USA
[3] University of California, San Diego, CA USA
[4] Fermi National Accelerator Laboratory, Batavia, IL USA

Existing Data

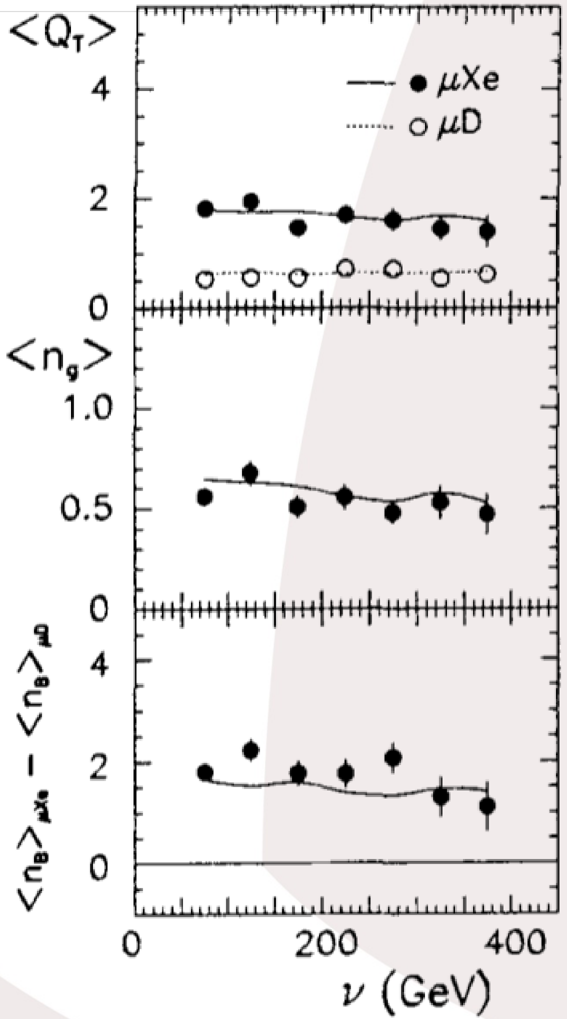


Fig. 2. Average total hadronic net charge $\langle Q_T \rangle$, average number of grey tracks $\langle n_g \rangle$ and difference of average charged backward multiplicities $\langle n_B \rangle_{\mu Xe} - \langle n_B \rangle_{\mu D}$ in μXe and μD scattering as a function of the leptonic energy transfer ν. The lines represent the predictions of the VENUS model

- **Kinematics**
  - **Low x (0.002 → 0.1)**
  - **$Q^2 > 1$ GeV^2 / W > 8 GeV**
  - **Hadrons measured from p > 200 MeV/c**
- **Grey Tracks (n_g)**
  - **Energy deposit significantly higher than MIP**
  - **200 < p < 600 MeV**
- **Total hadronic net charge (Q_T)**

Which observable is most relevant?

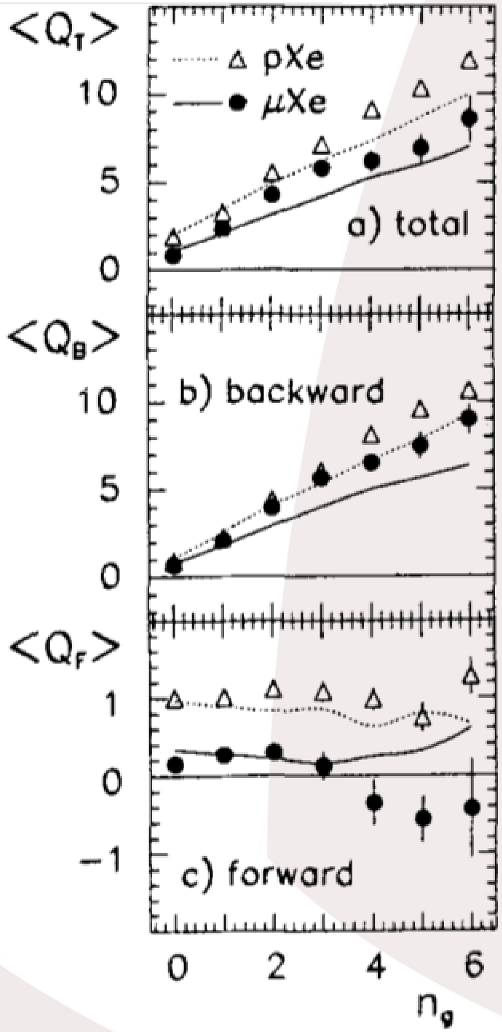


Fig. 6. Average hadronic net charge as a function of the number n_g of grey tracks for μXe and pXe scattering, in the total rapidity region ($\langle Q_T \rangle$) and in the backward ($\langle Q_B \rangle$) and forward ($\langle Q_F \rangle$) hemispheres. The lines represent the predictions of the VENUS model

- ➔ **Three correlated observables :**
  - ➔ **Total charge**
  - ➔ **Backward charge**
  - ➔ **Grey tracks**

- ➔ **Which should we use ?**

- ➔ **Which can we measure best in a collider ?**

Grey Tracks

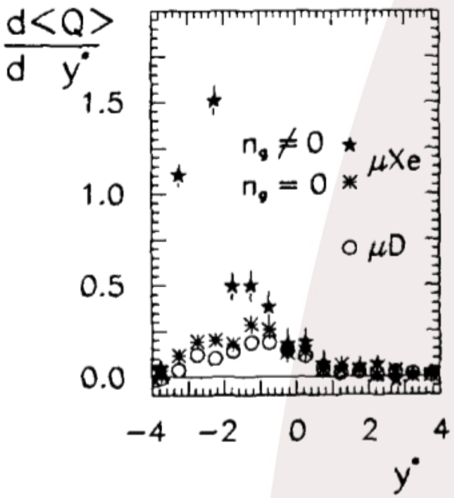


Fig. 3. Average hadronic net charge $d\langle Q\rangle/dy^*$ as a function of y^*, in μD events and in μXe events with ($n_g \neq 0$) and without ($n_g = 0$) grey tracks

- ➔Xe similar to deuterium when no Grey tracks are observed (with 75% efficiency) !
  - ➔ We are close to the spectator case

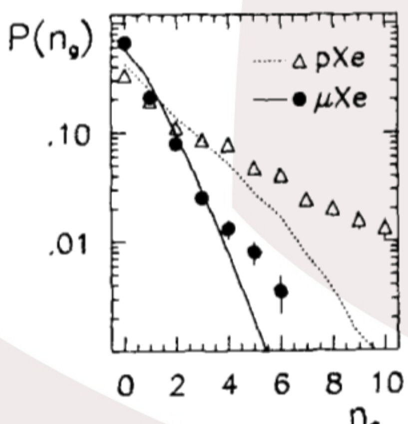


Fig. 5. Multiplicity distribution $P(n_g)$ of grey tracks for μXe and pXe scattering. The lines represent the predictions of the VENUS model

- ➔ Number of Grey tracks to be expected
  - ➔ 0 and 1 Grey tracks represent 90% of the events → Luminosity at EIC will allow to go further

Enhancement of Nuclear Effects

➔ **Requesting Grey tracks enhance the nuclear effects !**

➔ **Example for hadronization studies:**

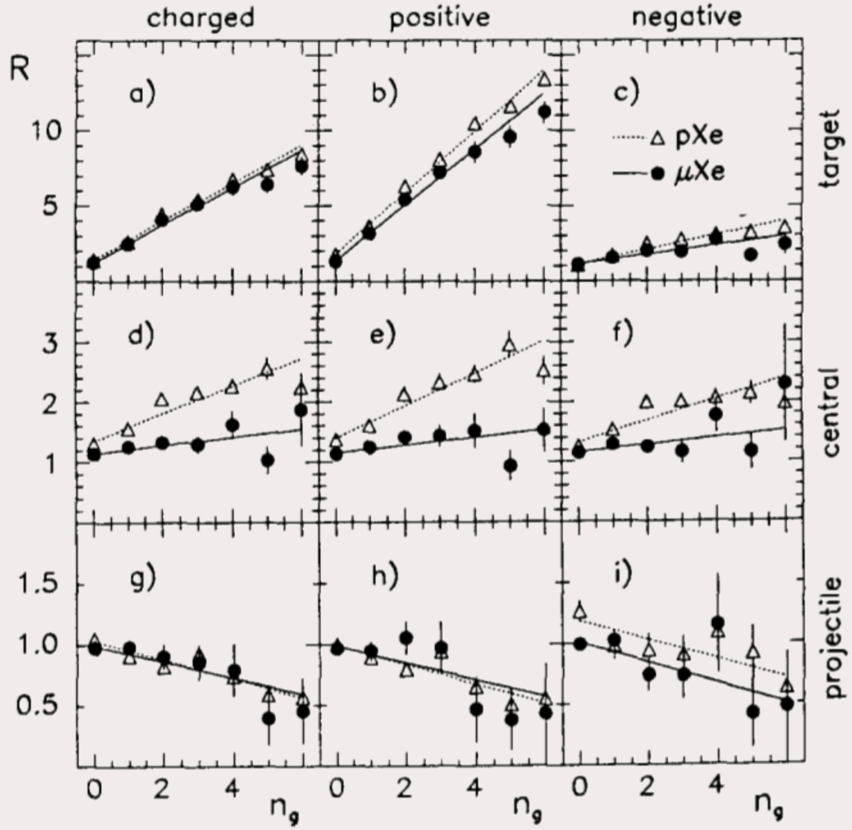
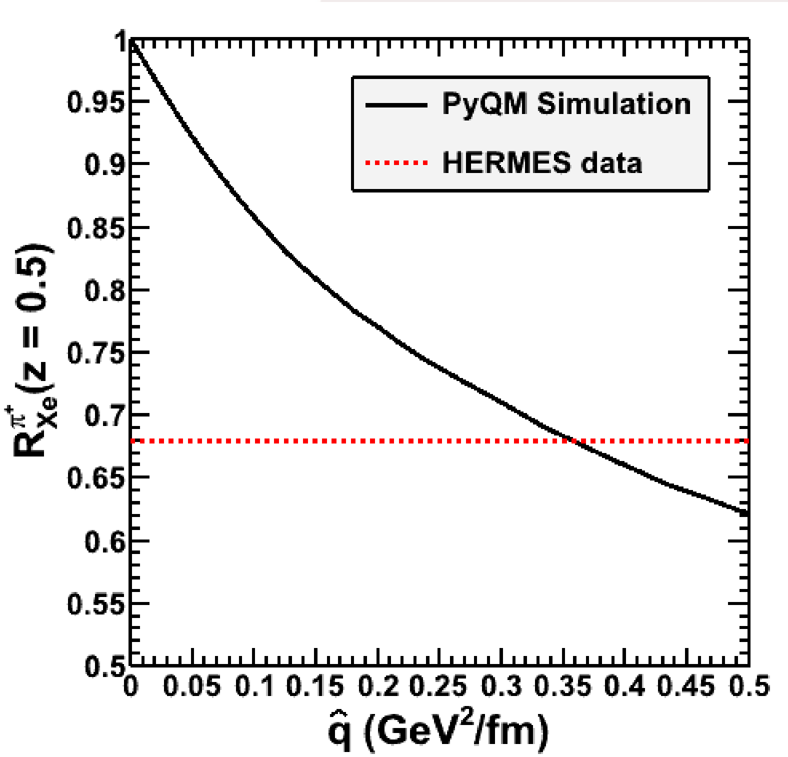
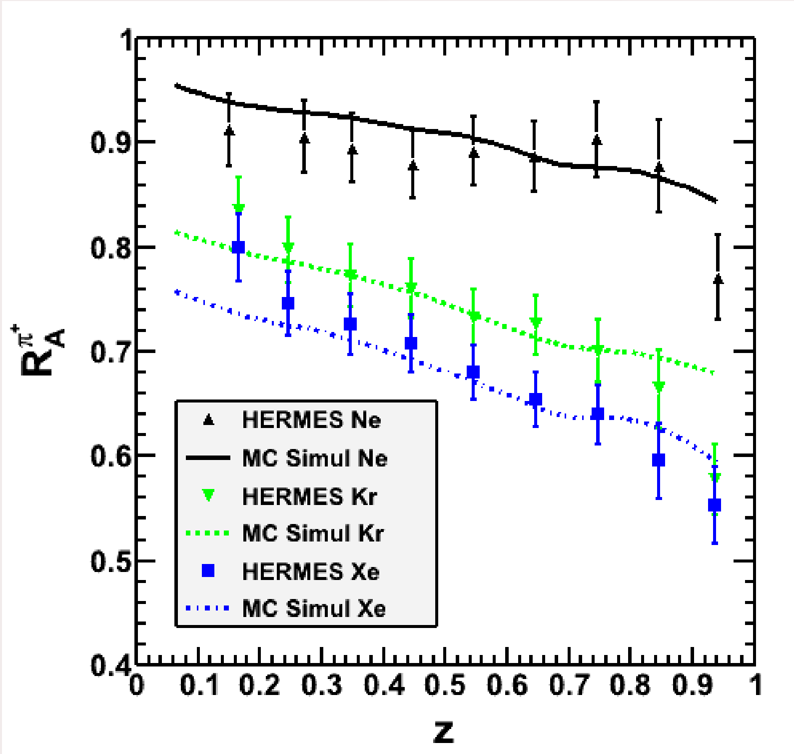


Fig. 10. Multiplicity ratio $R(n_g)_{\mu Xe}$ (full circles) and $R(n_g)_{pXe}$ (open triangles) as a function of the number n_g of grey tracks. The plots are for all charged, for positive and negative hadrons, and for three rapidity intervals (target, central, projectile). The lines are the results of straight-line fits to the data points

Attenuation for HERMES with PyQM

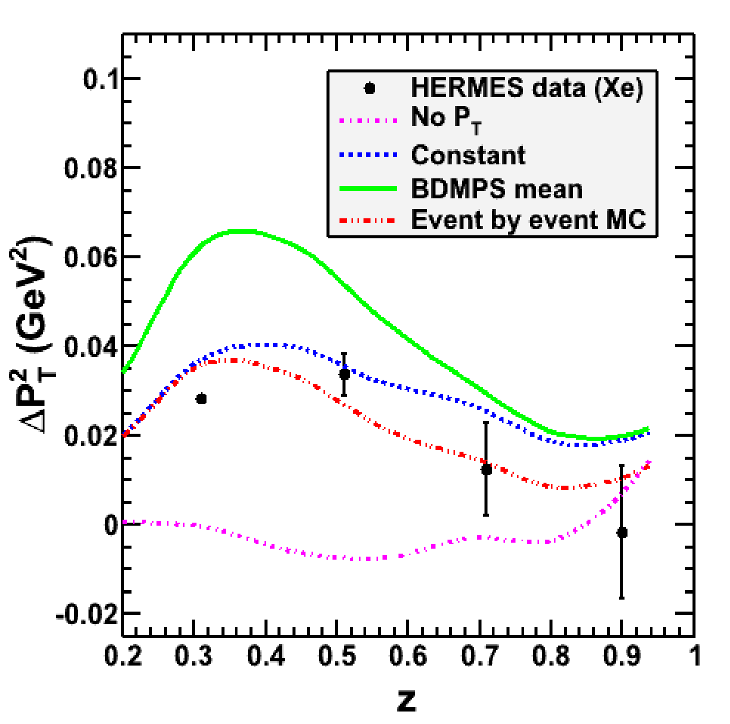




- **Good description with qhat = 0.36 GeV²/fm**
  - Single parameter model
- **Not consistent with observed transverse momentum?**
  - Known to be of the order of 0.03 GeV² for multi-femtometer sized nuclei

Transverse Momentum

- **The transverse momentum can be implemented in many ways**
  - No transverse momentum added
  - Constant addition based on q hat
  - BDMPS formula linking energy loss to transverse momentum
  - Event by event adapted from Salgado&Wiedmann
- **Strong reduction from q to actual hadron transverse momentum**
  - A natural z^2 factor
  - A strong bias from “absorbed” hadrons
  - A small bias from the lower parton energy
- **This will be improved in the Beagle framework and connected to the nuclear remnants**
  - The goal is to describe E665 data measuring slow nuclei out of the nucleus
  - See Mathieu’s talk



Summary

- **Tagging to understand the EMC effect**
  - Tagging provides new observables to understand the EMC effect
    - New observables are the way to resolve the EMC conundrum
  - Tagging links the nuclear dynamic to the partonic structure
  - We have a program at JLab 12 GeV
  - It can be extended and improved at an EIC
    - Study of shadowing ?
- **Moving to nuclear break up**
  - Past data show that it works, but we need solid Monte-Carlo to analyze it
  - It can be useful for many processes, which need to be specifically analyzed
    - Hadronization, shadowing, EMC effect?
  - We are looking also at what can be done in JLab 12 GeV

    (with already approved hadronization beam time)