超前方物理(宇宙線以外)と検出器要求性能

後藤雄二（理研）

2019年10月30日

トピックス

- Physics review
  - HERA: R. Ciesielski (Rockefeller U.)
  - GPD: S. Fazio (BNL)
  - CGC: H. Mantysaari (U. of Jyvaskyla)
- Spectator tagging
  - Ch. Weiss (JLab)
  - Z. Tu (BNL)
- Geometry tagging
  - M. Baker IMDBPADS)
  - B. Schmookler (Stony Brook U.)
  - W. Chang (BNL & CCNU)
- Short range correlation and EMC effect
  - M. Stirkman (Penn State U.)
  - F. Hauenstein (Old Dominion U.)
  - P. Nadel-Turonski (Stony Brook U.)
- Event generator
  - Noon: M. Broz (Czech Technical U.)
- Neutron structure
- np wave function of deuteron
- Isotope tagging
- Spectroscopy

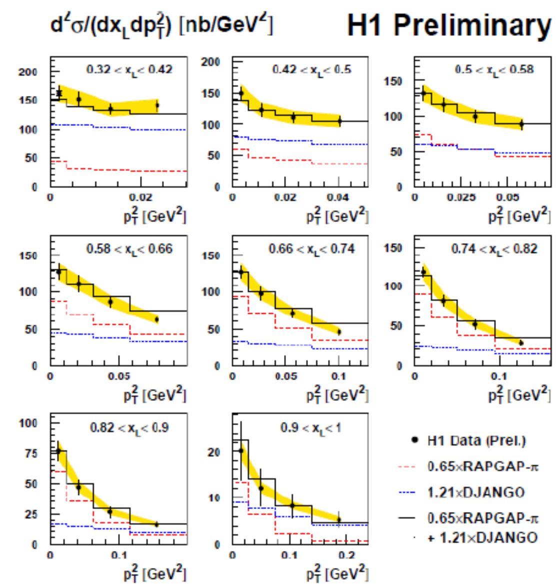
HERA zero-degree detectors

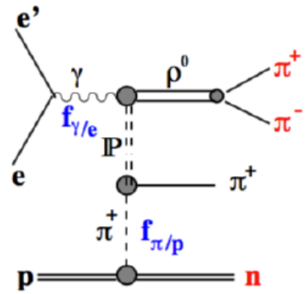
- R. Ciesielski (Rockefeller U.)
- Luminosity monitor @ HERA-I & HERA-II
  - Electron tagger @ 44m
- ZEUS
  - BPC (Beam Pipe Calorimeter)
  - FPC (Forward Plug Calorimeter)
  - LPS (Leading Proton Spectrometer)
- H1
  - FPS (Forward Proton Spectrometer)
  - VFPS (Very Forward Proton Spectrometer)
  - FNC (Forward Neutron Calorimeter)
- Leading baryons
- Proton dissociation taggers

HERA zero-degree detectors

LN in DIS

p_T^2 dependence in bins of x_L

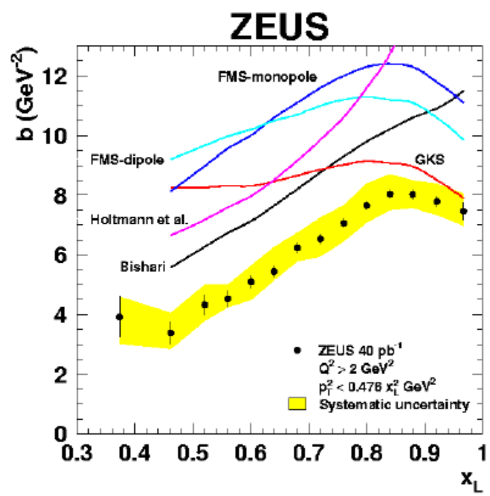


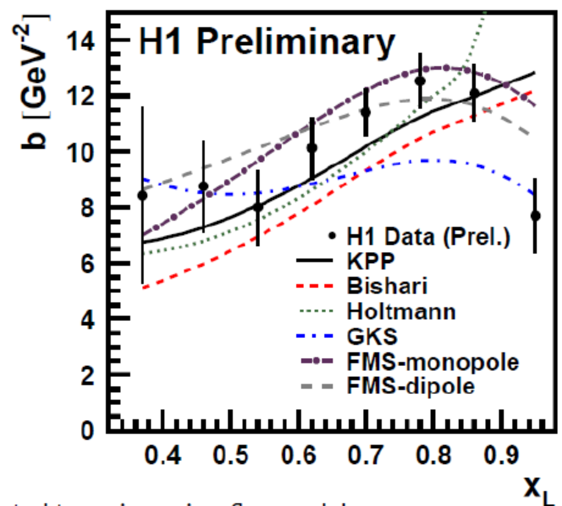


$$d\sigma_{\gamma^* p\to nx} = f_{\pi/p}(x_L, t)\times d\sigma_{\gamma^*\pi\to X}$$

The distribution of p_T^2 (=t) is defined solely by the pion flux

<u>Sensitivity to the pion flux</u>





Slope of exponential p_T^2 dependence compated to various pion-flux models

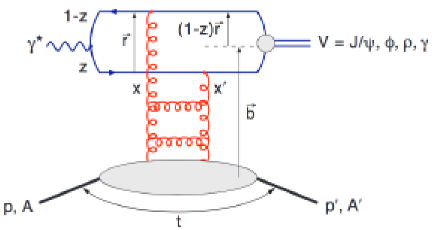
18

GPD studies with exclusive processes at EIC

- S. Fazio (BNL)
- Impact of proton acceptance
- Imaging the gluons in nuclei
  - Coherent part and incoherent part
- Measuring neutron via spectator tagging
- Luminosity & detector requirements

GPD studies with exclusive processes at EIC

Imaging the gluons in nuclei



Diffractive physics in eA

→ Measure spatial gluon distribution in nuclei

→ Reaction: e + Au → e′ + Au′ + J/ψ, φ, ρ

→ Momentum transfer $t = |p_{Au} - p_{Au'}|^2$

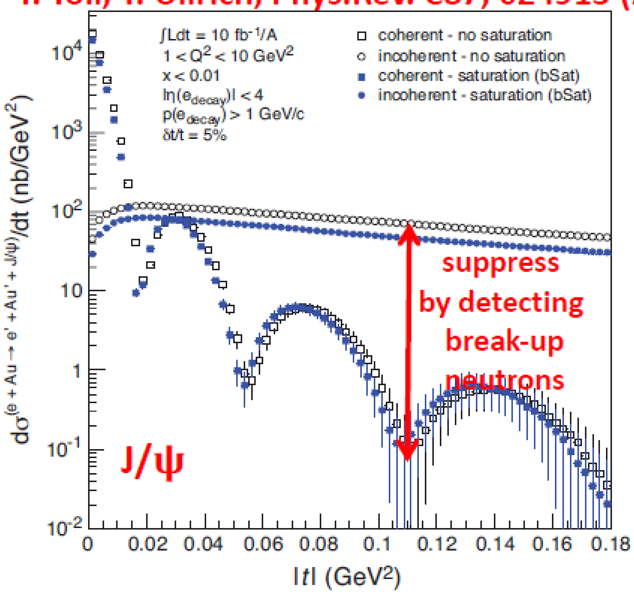
Hot topic:

- ➢ Lumpiness of source?
- ➢ Just Wood-Saxon+nucleon $g(b_T)$

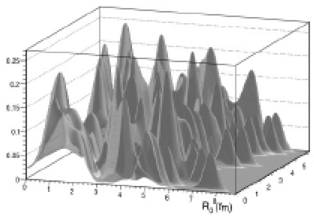
❑ coherent part probes "shape of black disc"

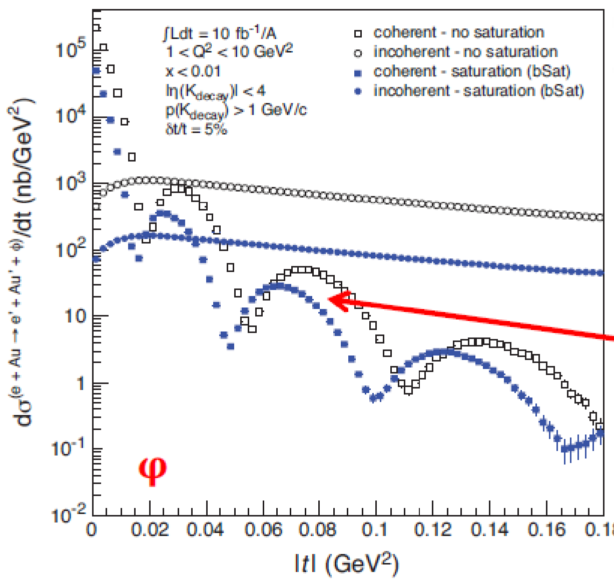
❑ incoherent part (large *t*) sensitive to "lumpiness" of the source [= proton] (fluctuations, hot spots, ...)

T. Toll, T. Ullrich, Phys.Rev. C87, 024913 (2013)



possible Source distribution with $b_T^g = 2$ GeV^{-2}





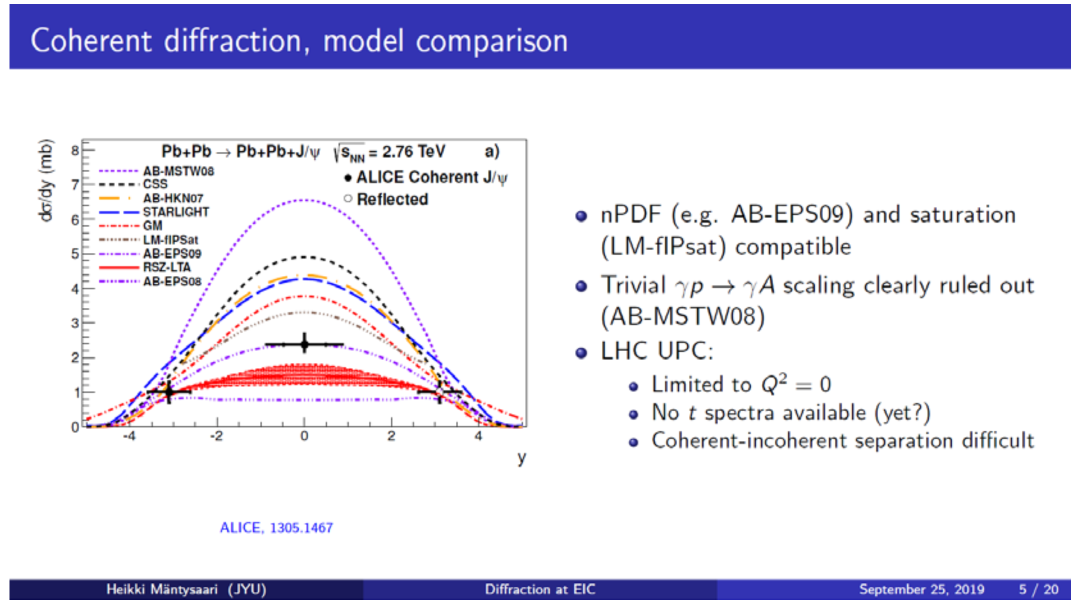
Sensitive to saturation effects!

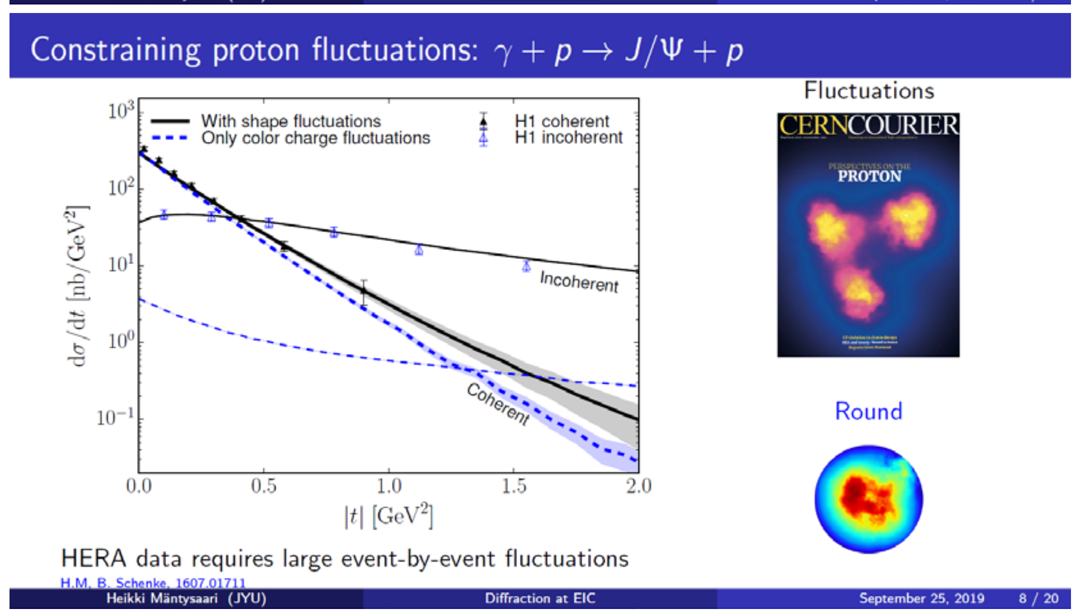
Coherent requires forward scattered nucleus needs to stay intact

→ Veto breakup through neutron detection

Diffractive vector meson and dijet production from CGC at EIC

- H. Mantysaari (U. of Jyvaskyla)
- Coherent-incoherent separation





Spectator tagging with EIC

- Ch. Weiss (JLab)
- Free neutron structure extraction
- Neutron spin structures
  - S wave & D wave
- Nucleon interactions
  - EMC/SRC at large x
  - Diffraction and shadowing at small x

Spectator tagging with EIC

Tagging: Detection requirements

14

Proton $p_{p\perp} = 0 \ldots 200$ MeV neutron struct, diffraction $\Delta p_{p\perp} = 10\text{–}20$ MeV

$0 \ldots 1$ GeV SRC, interactions

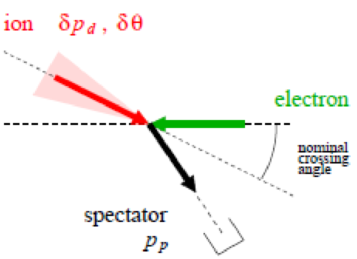
$p_{p\|} = (0.5\text{–}1.5) \times p_{D\|}$ $\Delta p_{p\|}/p_{p\|} \lesssim 0.01$

Neutron $p_{n\perp} = 0 \ldots$few 100 MeV $\Delta p_{n\perp} = ?$

$p_{n\|} = (0.5\text{–}1.5) \times p_{D\|}$ $\Delta p_{n\|}/p_{n\|} = ?$

- Forward protons from deuteron breakup have 1/2 rigidity of deuteron beam
- Forward detector design → Talk tomorrow

Intrinsic momentum spread in ion beam

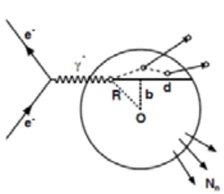


- Transverse momentum spread $\sigma \sim$ few 10 MeV
- Smearing effect $\boldsymbol{p}_{pT}(\text{vertex}) \neq \boldsymbol{p}_{pT}(\text{measured})$, can partly be corrected by convolution
- Significant systematic uncertainty in tagged neutron structure measurements. Correlated, x and Q^2-indpendent. JLab LDRD

Particle production and physics at zero degrees in eA

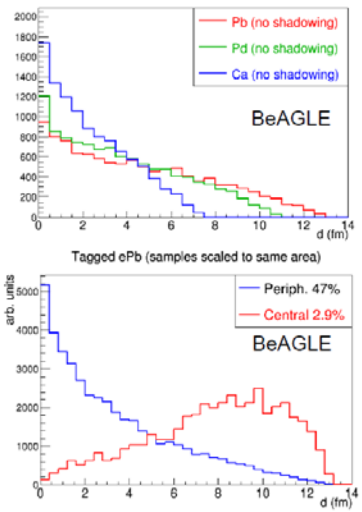
- M. Baker IMDBPADS)

Geometry tagging vs. A-scan



Intra-nuclear cascading increases with d (forward particle production)

Leads to evaporation of nucleons from excited nucleus (very forward)



<d> increases w/ A, but all nuclei have a lot of “skin” (low d events).

ZDC tagging allows more distinctive low d and a high d samples

Also high T(b) samples.

24-SEPT-2019 MDB -Zero Degrees 15

e+A geometry tagging summary

- e+A is different than A+A
- We will NOT have detailed plots vs. "centrality" with 10 meaningful bins like in A+A.
- We CAN remove the e+"skin" collisions and enhance nuclear effects substantially.
- We CAN make meaningful, rather tight, cuts on the high Thickness (central) events.
- A fancy ZCAL is not needed for this.
- Forward charged particles add value.

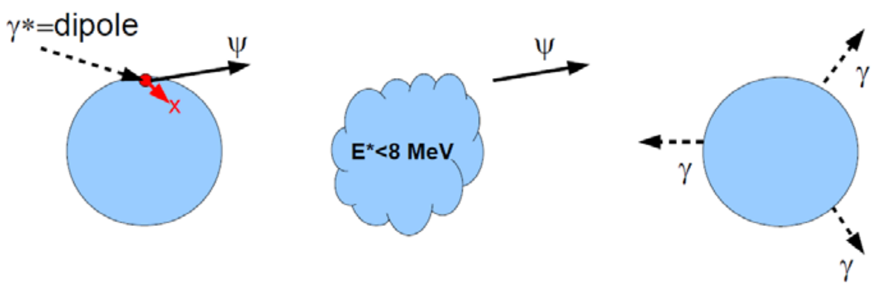
24-SEPT-2019 MDB -Zero Degrees 16

Particle production and physics at zero degrees in eA

Don't forget forward photons

• Problems vetoing incoherent diffractive events at low |t| due to events where the struck nucleon is reabsorbed:

$e + {}^{208}Pb_{82} \rightarrow e' + {}^{208}Pb_{82} + J/\psi + \gamma + \gamma + \gamma\ldots$



Cartoons in Ion Rest Frame

Many primary particles go forward in e+A

- Reconstructing, not just counting or tagging, forward particles is important for a lot of physics in e+A (see all the talks in this meeting!).
- Three quick examples
  - $e+D \rightarrow e'+J/\psi+n+p$
  - Quasi-elastic e+N collisions with SRCs in e+A
  - Target remnant jet in regular DIS

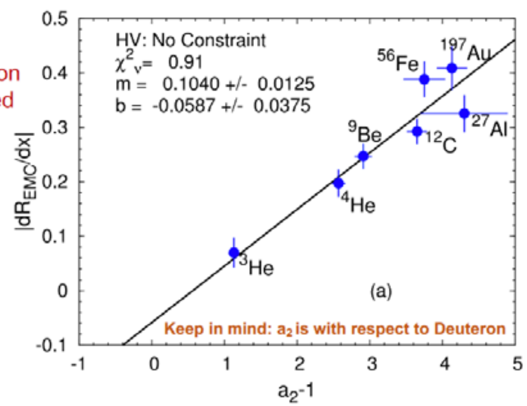
- Geometry tagging
  - Collision geometry and breakup determination in eA collisions by Wan Chang (BNL & CCNU)
  - EIC kinematic reconstruction simulation studies by Barak Schmookler (Stony Brook U.)

Short range correlation and EMC effect

- Probing SRC via deuteron breakup at EIC
  - Z. Tu (BNL)

EMC vs SRC

How much nucleon PDF gets modified



Effect of nuclear density?

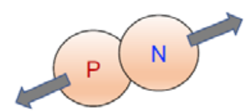
How strong (many) the SRCs (pairs) are
(e.g., the probability of selecting a pair of SRC nucleons in A)

A strong correlation between the two effects

4

One hypothesis

- SRC is the ultimate cause of the EMC effect.
  - Experiments (Jlab) have shown it is an universal ~20% of nucleons are in SRC pairs, starting from A > 12.
  - These SRC pairs have high momentum (e.g., > 400-600 MeV/c), and spatially very close to each other.
  - Nucleon PDF could be **significantly** modified for these pairs, but not modified for other nucleons.
  - Almost all (>90%) of these SRC pairs are found to be similar to a quasi-deuteron at its high momentum tail.



- ➢ How well do we understand the baseline, **deuteron**?
- ➢ "Simplest" SRC pair to be studied.

6

- SRC and EMC experimental overview and simulation studies
  - F. Hauenstein (Old Dominion U.)

SRC measurements: opportunities and challenges at EIC

- M. Stirkman (Penn State U.)

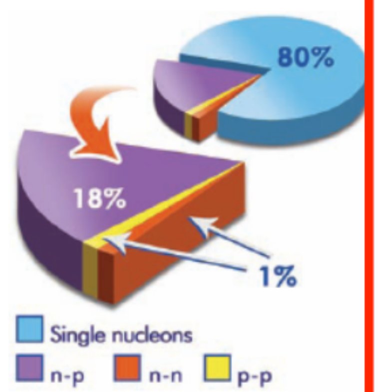
Due to the findings of the last few years at Jlab and BNL SRC are not anymore an elusive property of nuclei !!

Summary of the findings

Practically all nucleons with momenta k≥300 MeV belong to two nucleon SRC correlations
BNL + Jlab +SLAC

Probability for a given proton with momenta 600> k > 300 MeV/c to belong to pn correlation is ~ 18 times larger than for pp correlation
BNL + Jlab

Probability for a nucleon to have momentum > 300 MeV/c in medium nuclei is ~20 — 25%
BNL + Jlab 04 +SLAC 93



The average fraction of nucleons in the various initial-state configurations of ^{12}C.

In heavy nuclei protons have in average higher momenta than neutrons.

The findings confirm our predictions based on the study of the structure of SRC in nuclei (77-93), add new information about isotopic structure of SRC.

Different probes, different kinematics - the same pattern of very strong correlation - Universality is the answer to a question: "How to we know that (e,e'pN) is not due to meson exchange currents?"

14

Experimental SRC/EMC studies

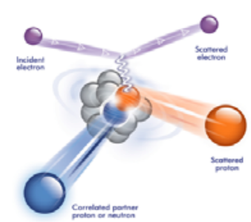
- P. Nadel-Turonski (Stony Brook U.)
- Opportunities and challenges at EIC
  - in a broader context of forward detection requirements

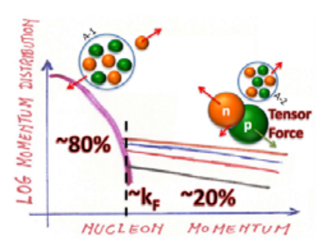
Forward detection – processes and requirements

- Which processes drive the near-beam (small p_T) acceptance?
  - Coherent diffraction on light nuclei (detecting recoiling ion for clean signal)
  - DIS and (in)coherent diffraction on medium- and heavy nuclei (detecting residual nucleus)
- Which processes drive the "large" angle (p_T) acceptance?
  - Tagging of spectator protons from nuclei
  - Exclusive production of photons (DVCS) and mesons (DVMP) on the proton at large t at *low energies*
  - Detection of photons and neutrons from nuclei (cone with line-of-sight)
- Which processes drive the resolution?
  - Magnetic spectrometer: tagging of protons from nuclei (spectators have p ~ Fermi momentum)
  - Hcal (ZDC): tagging of neutrons from exclusive charged meson production on the proton and spectator neutron tagging (*e.g.*, for reactions on the proton in deuterium)
  - EMcal: Photons from nuclear de-excitations (coherent diffraction and rare isotopes)

5

But SRCs are not a process – so where do they fit in?





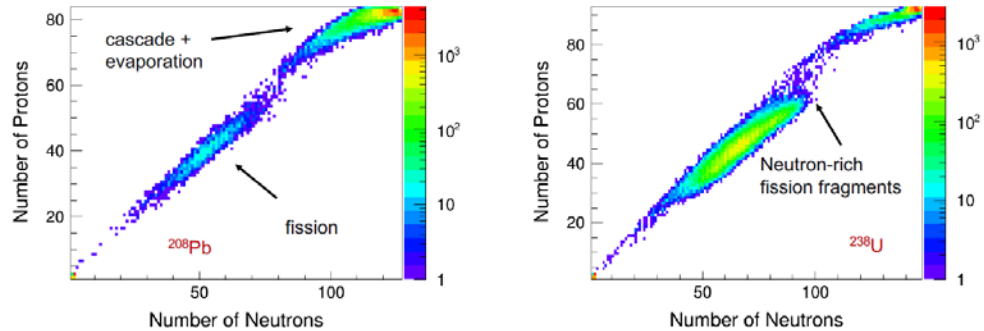
- Deuterium
  - As **spectator tagging on the nucleon** -> *talk by C. Weiss*
    but with sufficient acceptance for high-p_T tail
  - Additional p_T for the struck nucleon will depend on process and kinematics, but can be substantial -> *talk by F. Hauenstein*
- Light ions
  - A-2 fragment(s) easy to detect, except for Z=A/2
  - The latter is, however, a very important case (d, ^{10}B, etc) with detection challenges similar to **coherent processes**
- Heavy ions
  - Tagging and identification of heavy fragments needed.
  - Similar to measurements of **rare isotopes at the EIC** and helpful for **coherent diffraction** on heavy ions.

8

Experimental SRC/EMC studies

- Nuclear fragments

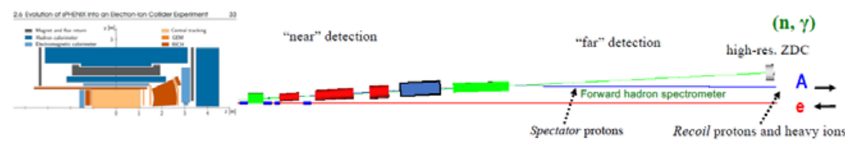
Nuclear fragments produced in eA reactions at the EIC



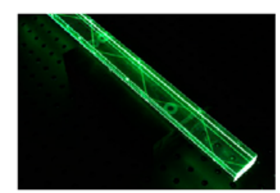
- Fragment detection ("tagging") is needed to, for instance, reconstruct the Fermi momentum of the struck nucleon

18

Detection and identification of the produced nuclei



- Detection of nuclei with rigidities (A/Z) close to that the beam require a dedicated "far" spectrometer where the beam is small and dispersion large.
- But to identify the ion we need both A/Z and an independent measurement of Z. The requirement for sensitivity in Z^2 is 2% in order to identify heavy residual nuclei down to A-1.
- A "mini-DIRC" can produce 100,000 photons (<< 1% error) in a few mm of fused silica.
- R&D in progress (Generic Detector R&D for an EIC program).



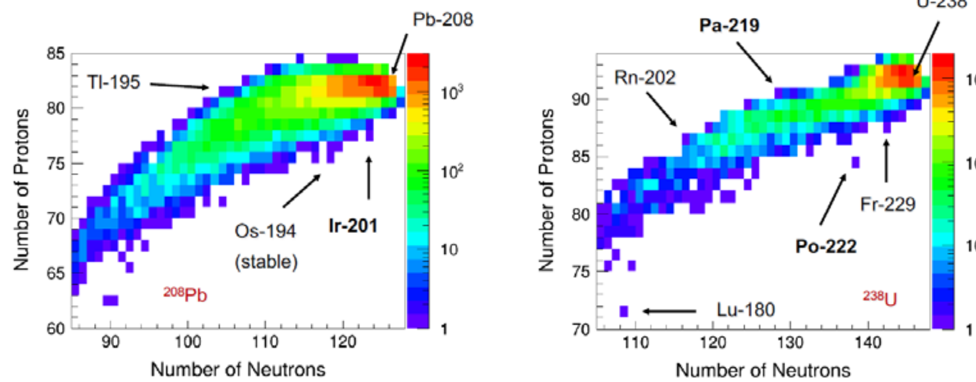
A "mini-DIRC" inside a Roman pot at the downstream focus can identify ions to ~1% in Z^2

19

Experimental SRC/EMC studies

- Isotope tagging

Nuclei from ^{208}Pb and ^{238}U (1s of simulated beam time at the EIC)

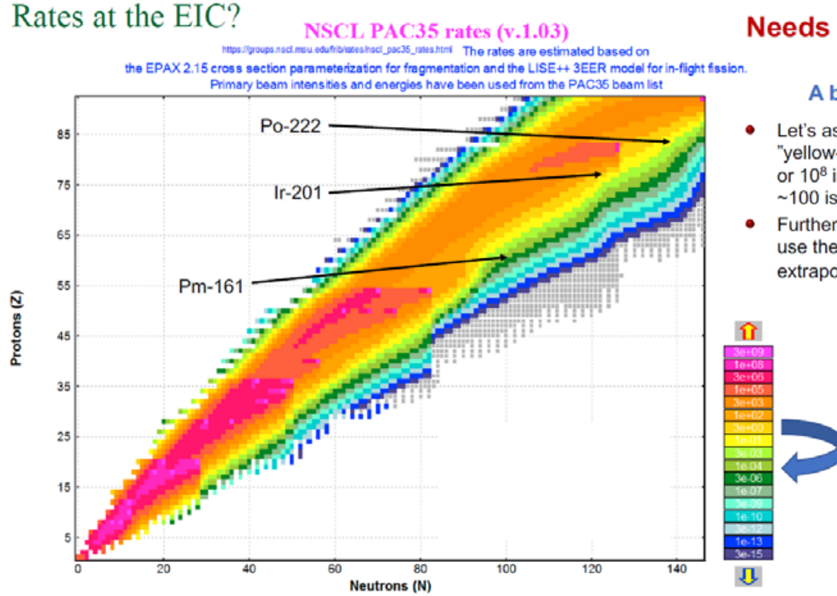


- ^{208}Pb (left) produces mainly heavy isotopes from evaporation
- ^{238}U (right) produces fewer, but heavier isotopes from evaporation. It also produces very neutron-rich fission fragments (medium-mass nuclei have fewer neutrons).

29

Rates at the EIC?

Needs further studies!



A bold extrapolation

- Let's assume that we have one "yellow-orange" event per second, or 10^8 in a year, distributed over ~100 isotopes of interest
- Further, lets assume that we can use the FRIB rate estimates for the extrapolation.
- Then, if we want to accumulate a total of 10,000 events for the isotopes of interest, in a year we can move from the orange-yellow to light green (although for ^{161}Pm we are there in 1 minute)

31