Nuclear Effects in BeAGLE

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Collaborators and Advisors

Benchmark eA Generator for LEptoproduction

Also works for photoproduction $Q^2<1$ GeV^2

BeAGLE (or PyQM) programmers underlined. **Active programmers bolded.**

- A. Accardi, E. Aschenauer, N. Armesto, **MDB**, W. Chang, R. Dupré, M.Ehrhart, I. Friscic, F. Hauenstein, O. Hen, D. Higinbotham, C. Hyde, A. Jentsch, J.H. Lee, V. Morozov, P. Nadel-Turonski, D. Nguyen, J. Pybus, **C. Robles**, A. Schmidt, B. Schmookler, A.Sy, T. Toll, T. Ullrich, **Z. Tu**, C. Weiss, **L. Zheng.**

- Advice from: M. Strikman, R. Venugopalan

Some Nuclear Effects

	In BeAGLE	Improvable	In talk
• Parton distribution functions	✓		
• Parton saturation (CGC etc.)			
• Short-range correlations	✓ (GCF)		
• "Fermi motion"	✓		
• Partonic (or "dipole") MS	✓		
• Partonic gluon radiation	✓		
• Medium-modified hadronization			
• Formation times	✓		
• Hadronic Cascade	✓		
• Nuclear evaporation, breakup	✓		
• Photonic de-excitation of A*	✓		

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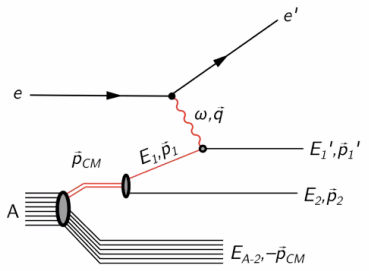
BeAGLE Structure



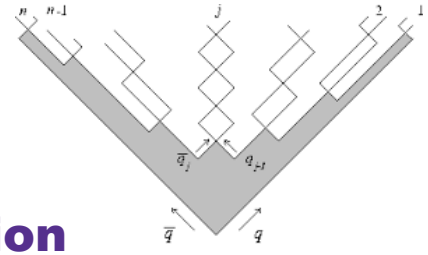
Primary interaction treated by **PYTHIA6** for the hard collision.

Glauber handled by BeAGLE

PyQM: Nuclear Geometry + optional gluon radiation in medium.

Hadronization handled by **PYTHIA6.**

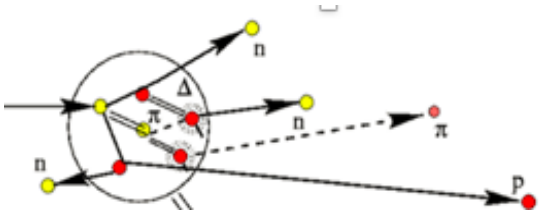
Primary interaction



Cascade process handled by **DPMJET.**

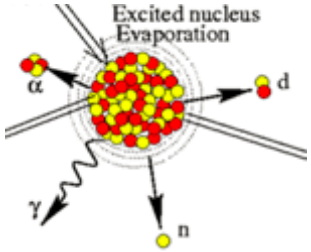
Formation time. Stochastic.

Hadronization



Nuclear remnant evaporation and break up by **FLUKA.**

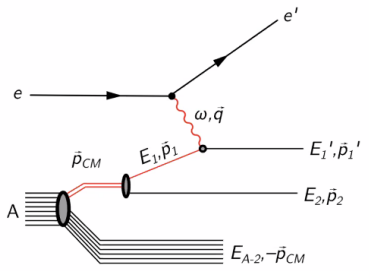
Intra-nuclear cascade



Nuclear remnant evaporation & breakup

BeAGLE Structure

OR we could use: GCF,
MILOU(not yet implemented) etc...



Primary interaction

PyQM: Nuclear Geometry + optional gluon radiation in medium.

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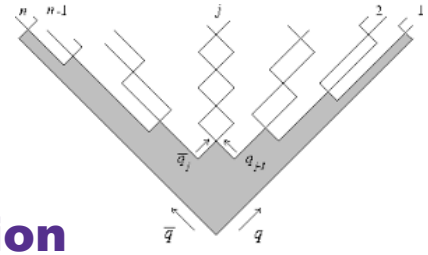

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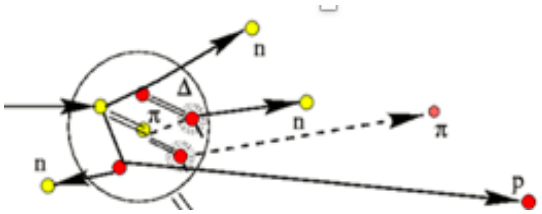

Intra-nuclear cascade

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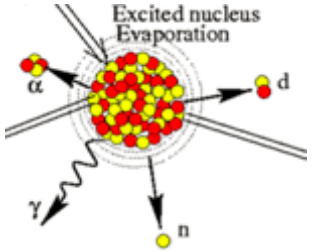
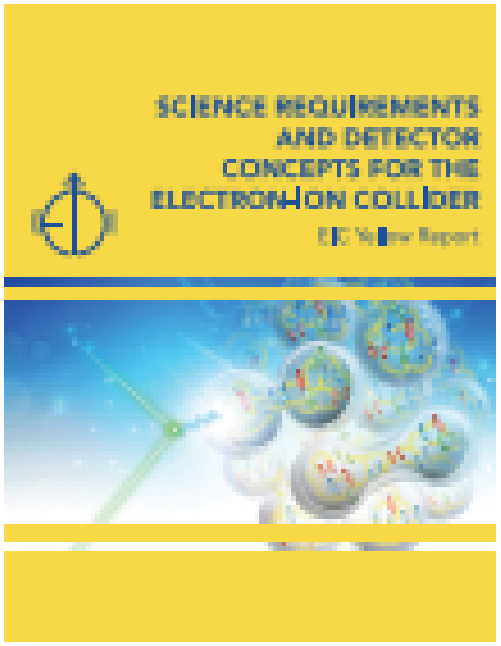


Nuclear remnant evaporation & breakup

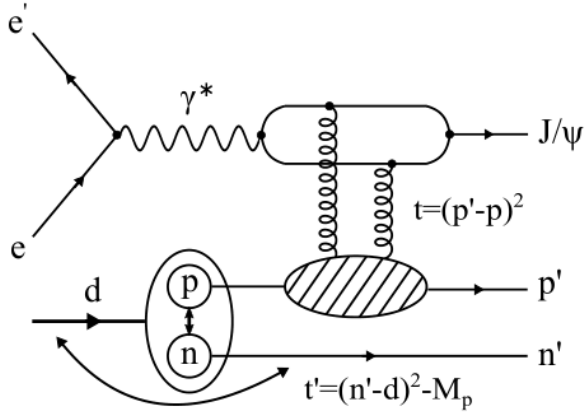
BeAGLE has actually been USED



"Sartre and Beagle are two examples of Monte-Carlo event generators whose development was substantially boosted by the [EIC R&D] program. Both were extensively used in the context of this report."

- BeAGLE has been essential for Forward Detector / IR design and integration.
- Still being used now for proposals and the IP8 design iterations.
- BeAGLE (or its functionality) is essential to being able to understand the target fragmentation region and far-forward physics (in ion direction) at the EIC (and maybe JLAB).

One example from the Yellow Report



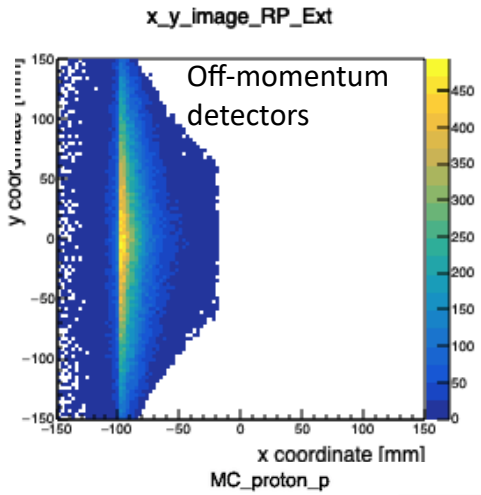
18 x 110 GeV e+D Neutron spectator case.

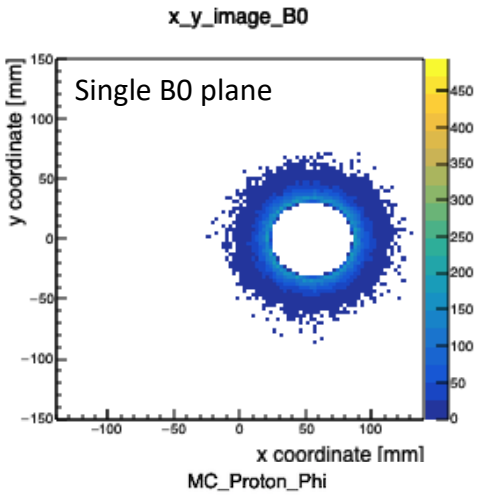
Incoherent diffractive J/psi production off bound nucleons.

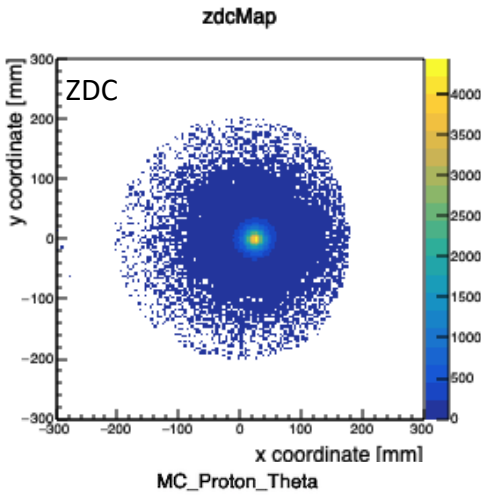
Well optimized detector!!

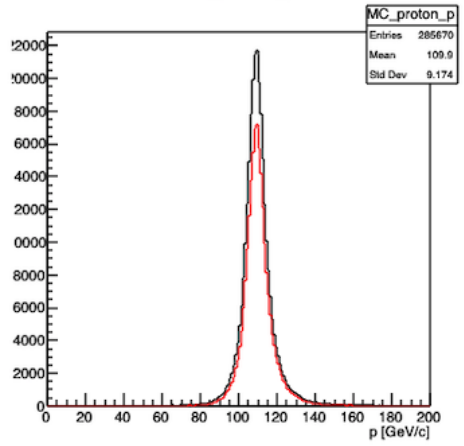
See also:

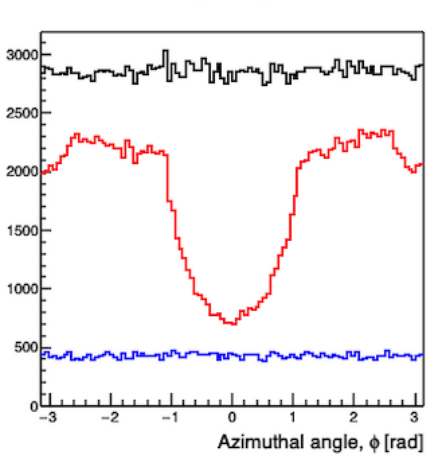
Phys. Lett. B811 (2020) 135877

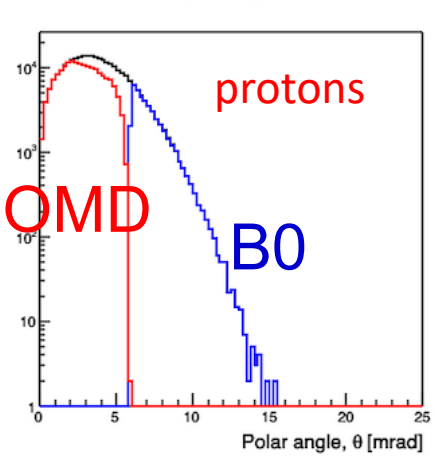






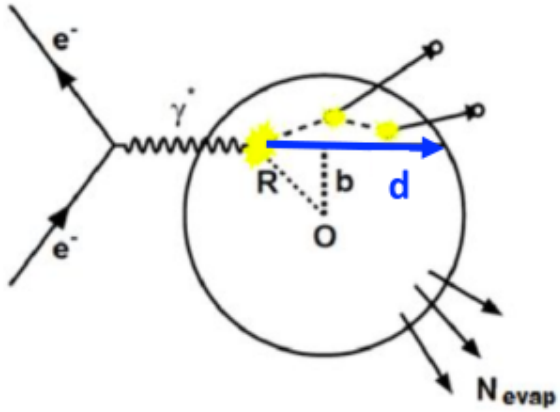




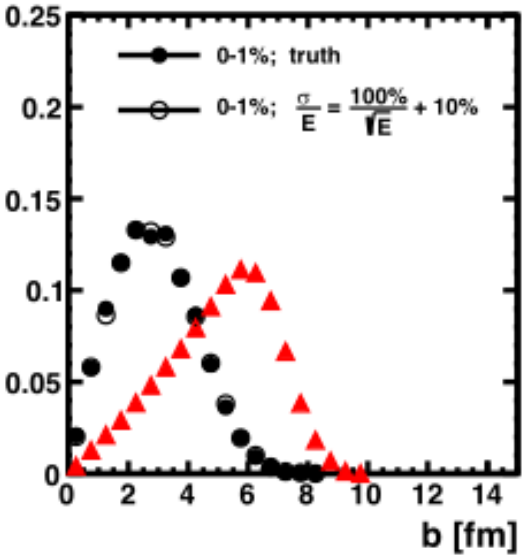


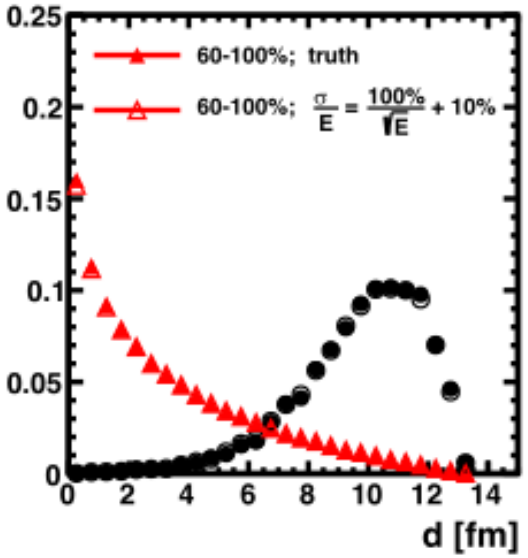
Centrality tagging – another example

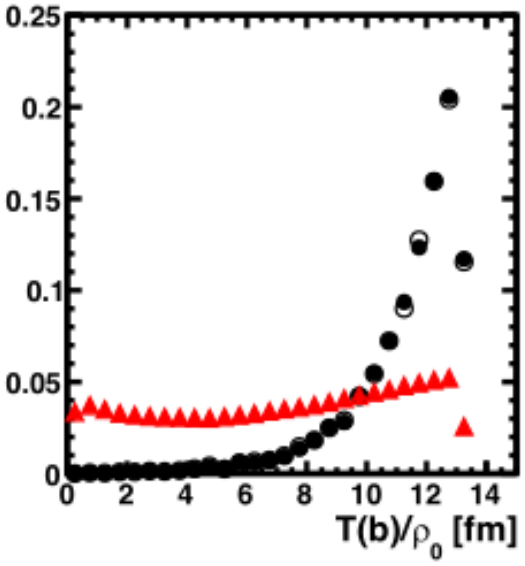
e+Pb collisions at the EIC



The b, d, $T(b)/\rho_0$ comparison between **central** and peripheral collisions.



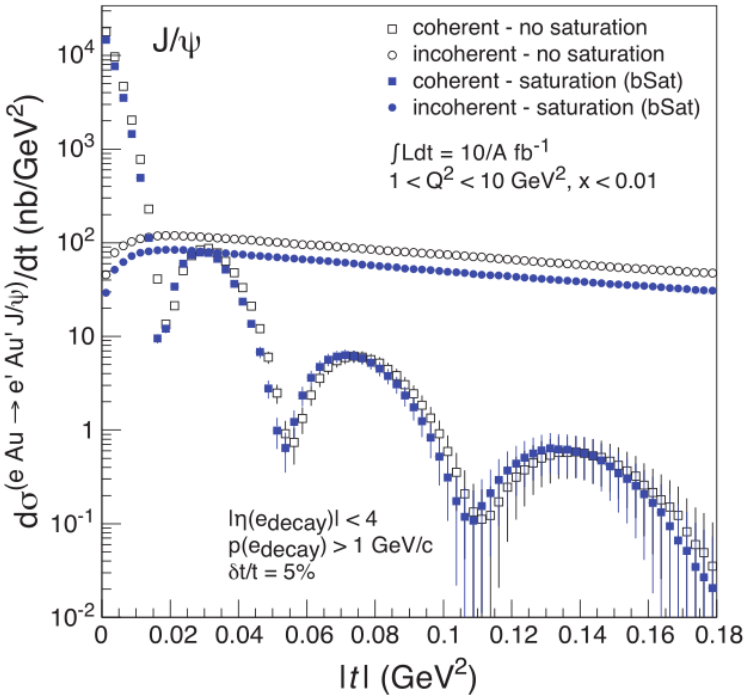




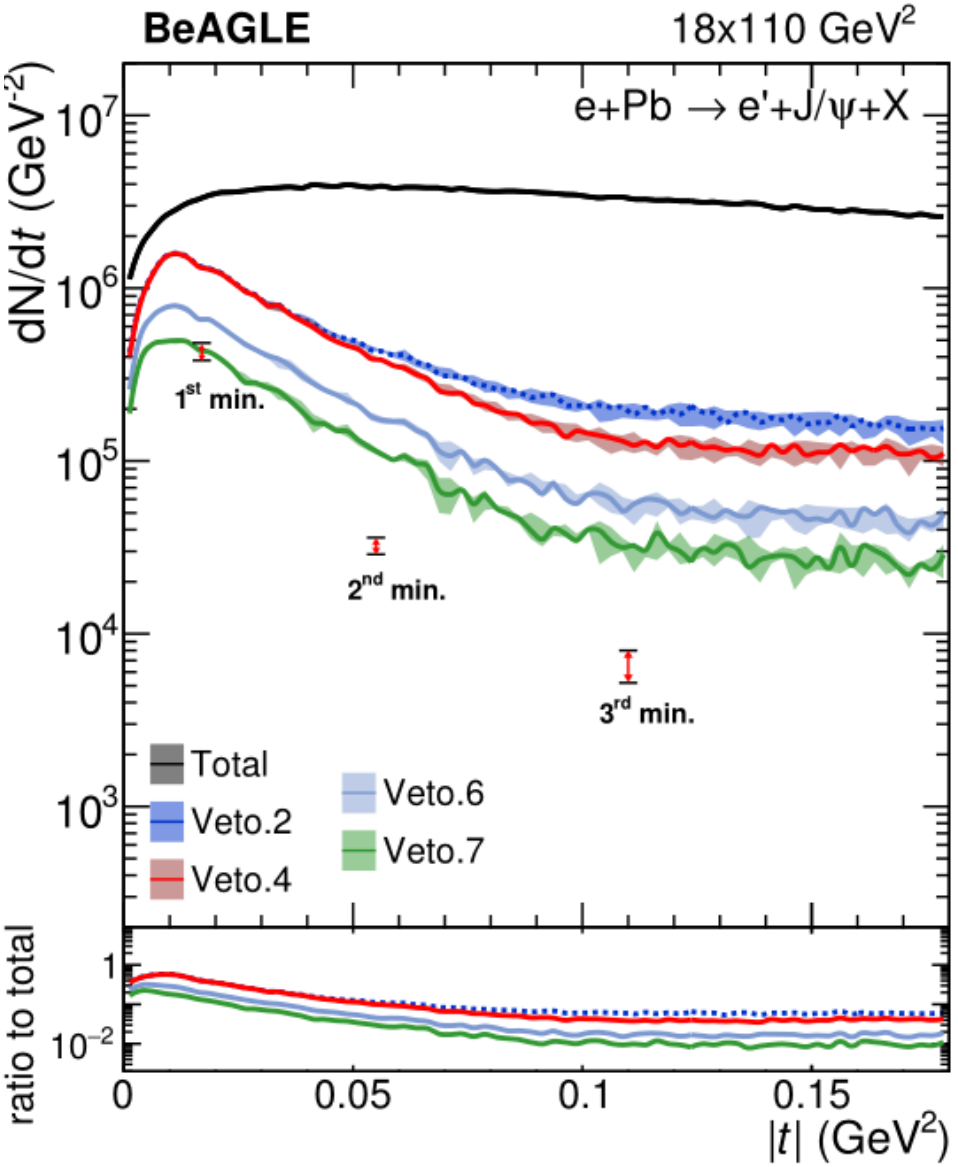
- The true distribution and the smeared one are almost identical.
- A higher resolution calorimeter is not required for this analysis.

Veto tagging of incoherent J/ψ diffraction

Sartre: Toll, Ulrich
PRC **87** (2013) 024913



Chang et al. arXiv:2108.01694v2 [nucl-ex]



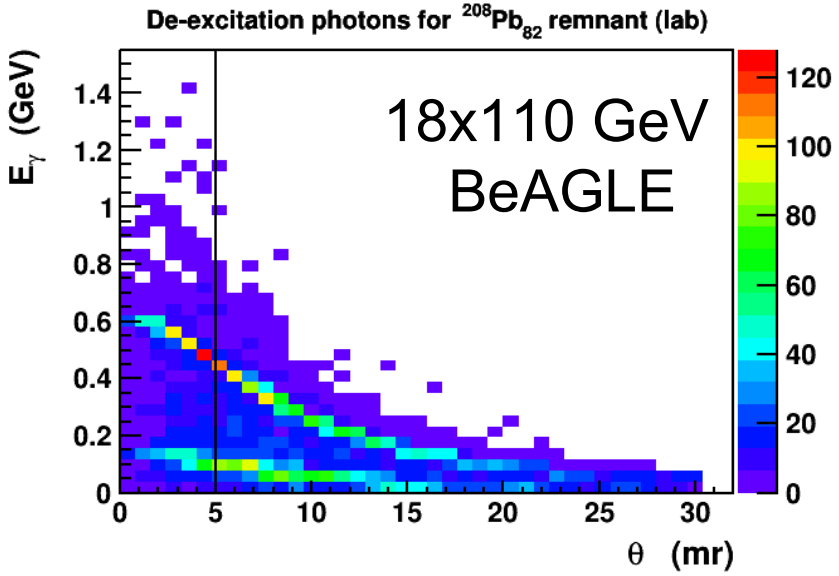
Incoherent,
No sat.
No veto

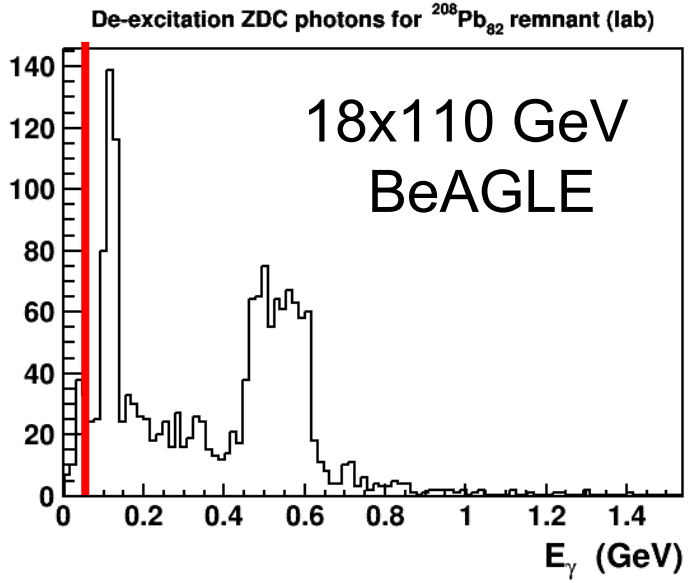
VETO ON:

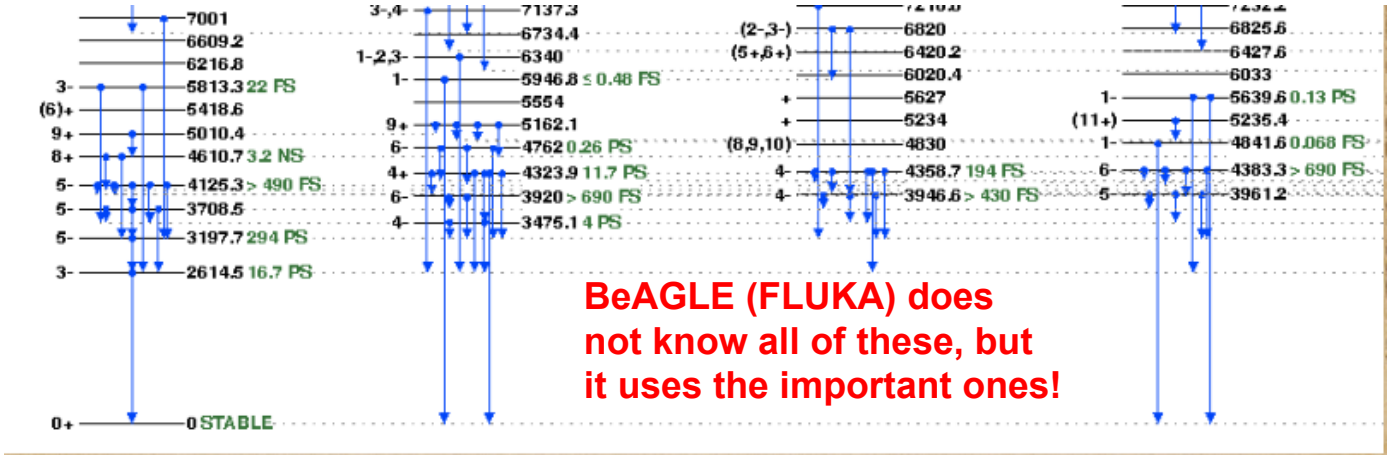
Main + ZDC
& RP + OMD
& B0 incl. γ
& ZDC γ

Simulation challenge in e+A: nuclear detail

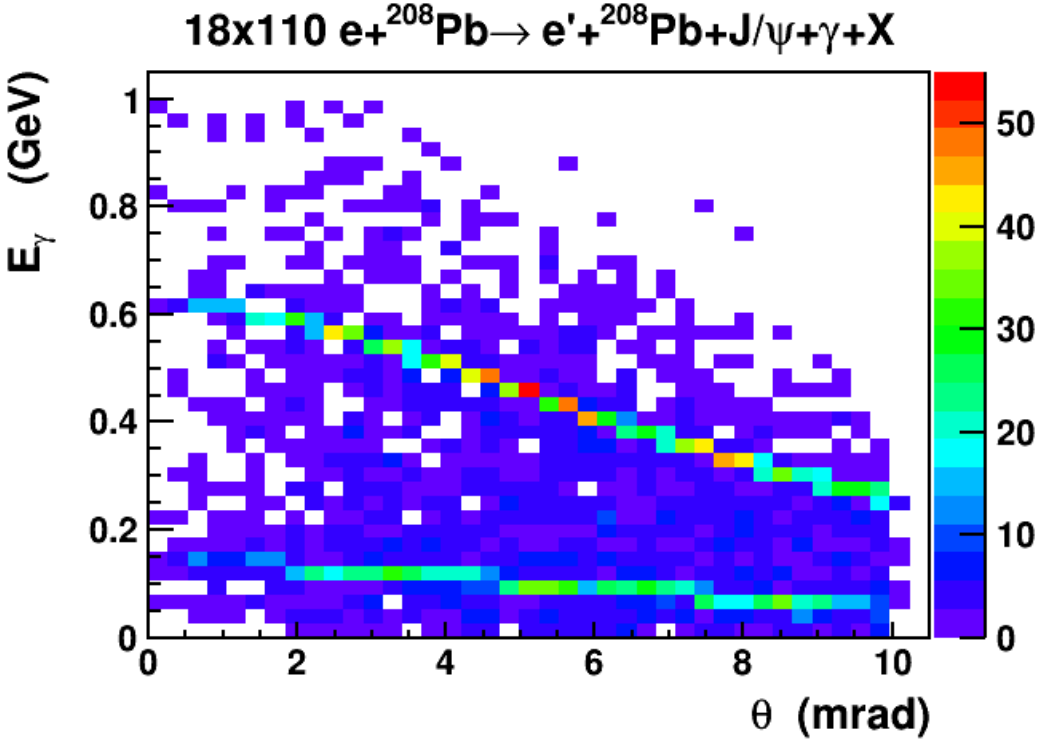
One example: de-excitation photons from $^{208}Pb_{82}$ following
e+Pb $\rightarrow$e'+Pb*+J/ψ $\rightarrow$e'+Pb+γ+γ+γ+J/ψ in (collider) lab frame



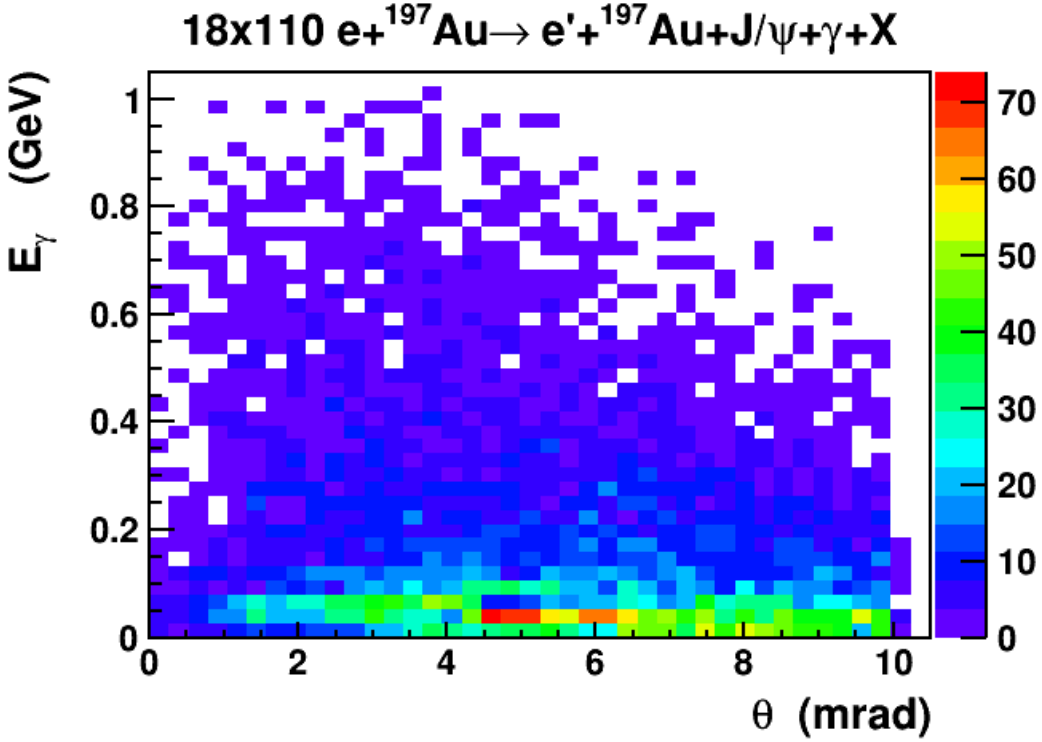




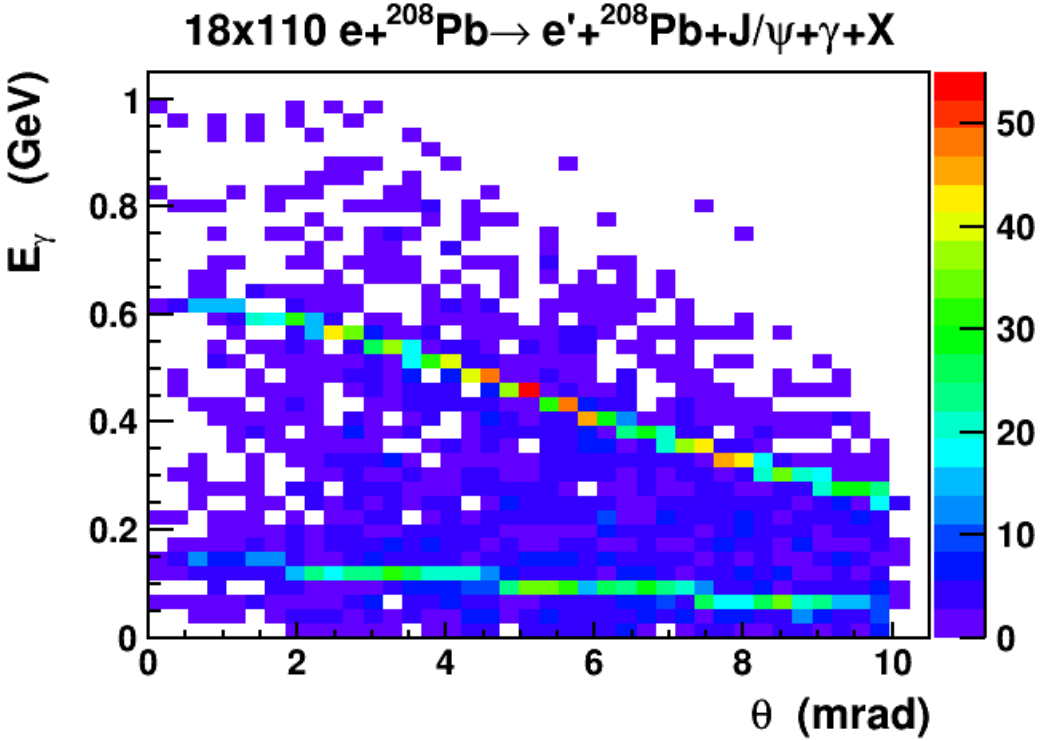
Photons from $^{208}Pb_{82}$ vs. $^{197}Au_{79}$



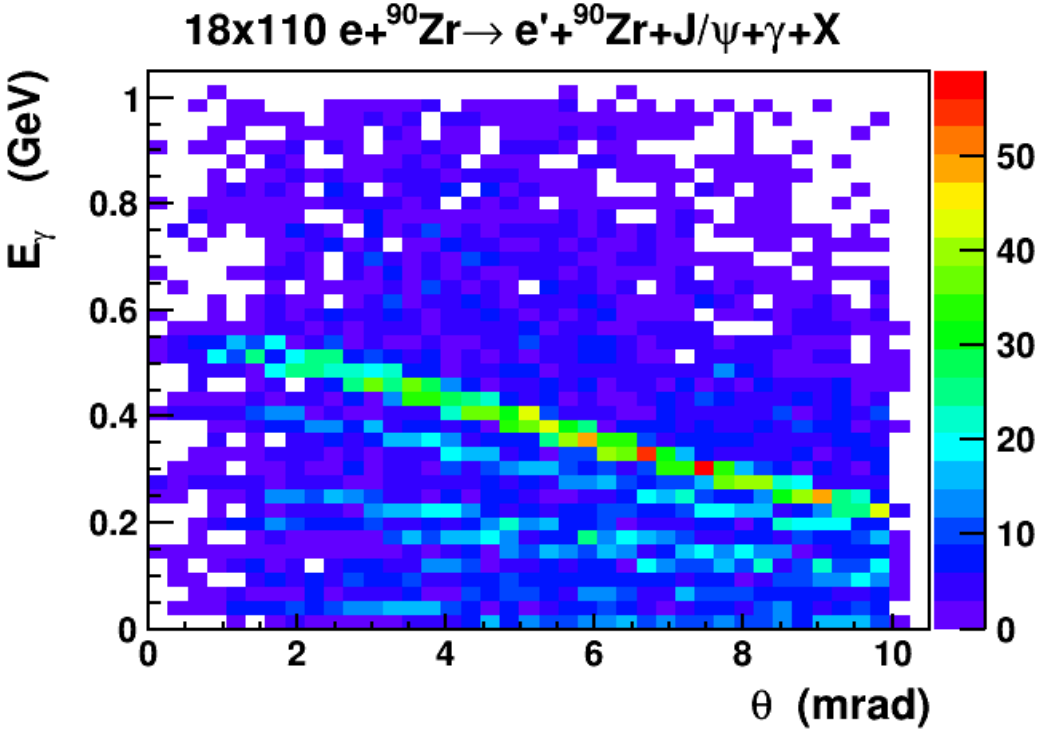
Pb much better than Au!



Photons from $^{208}Pb_{82}$ vs. $^{90}Zr_{40}$

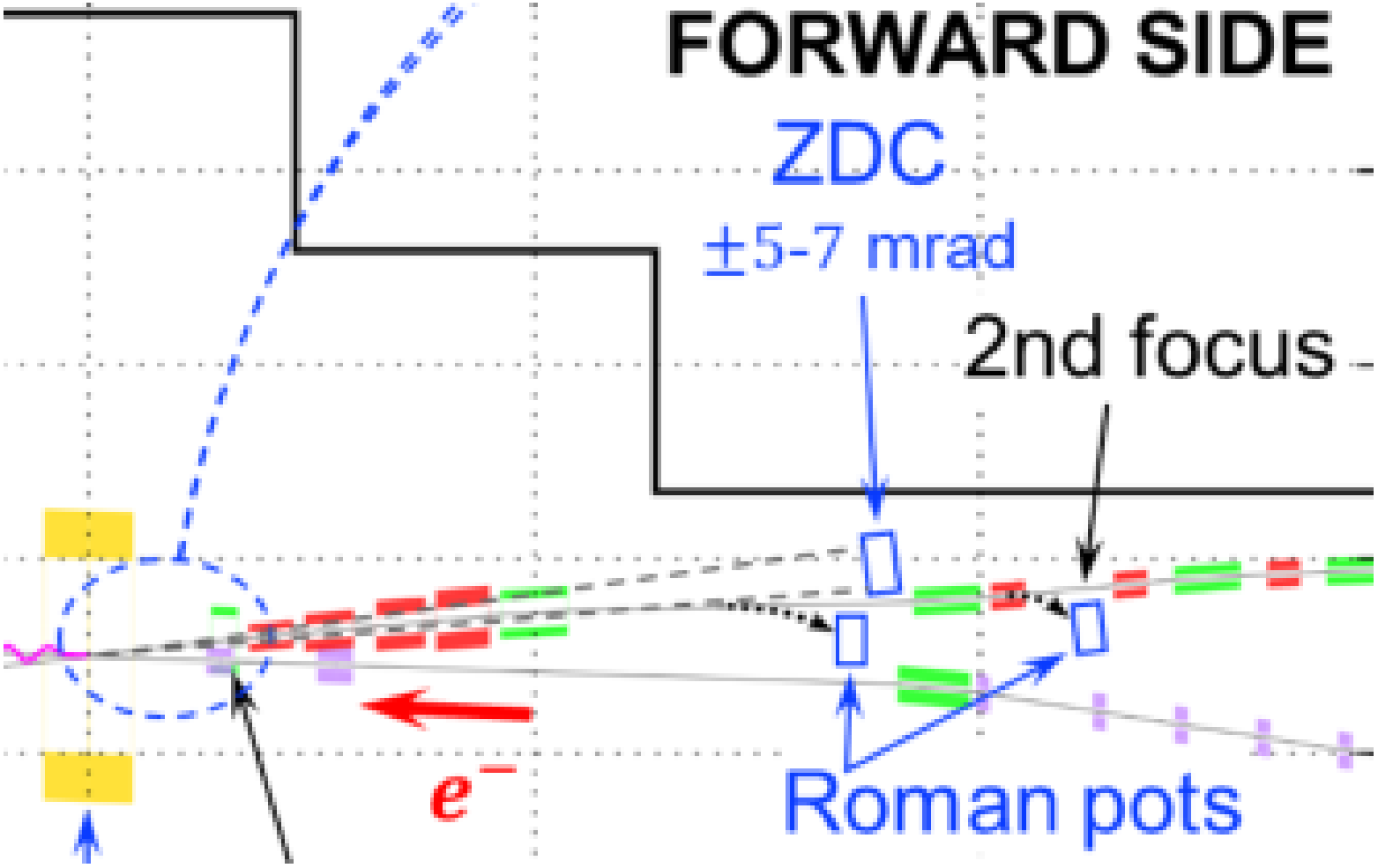


Pawel Nadel-Turonski suggested that ^{90}Zr might be similar to ^{208}Pb… Yes.

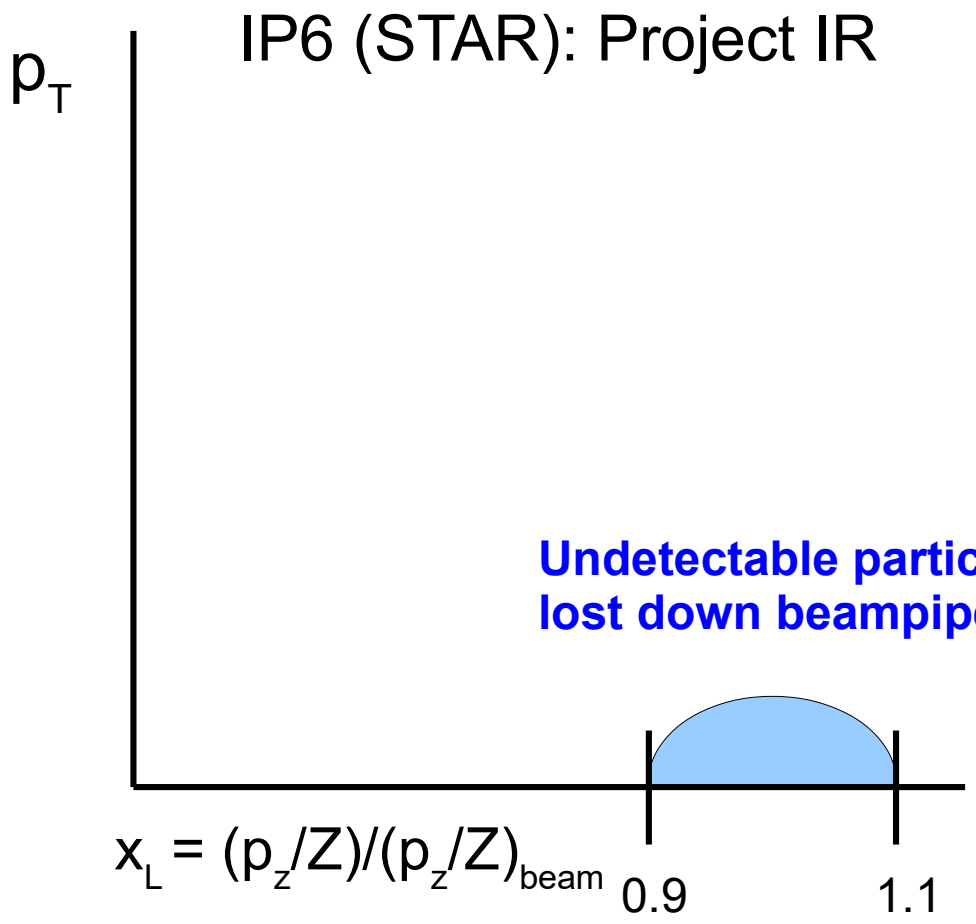


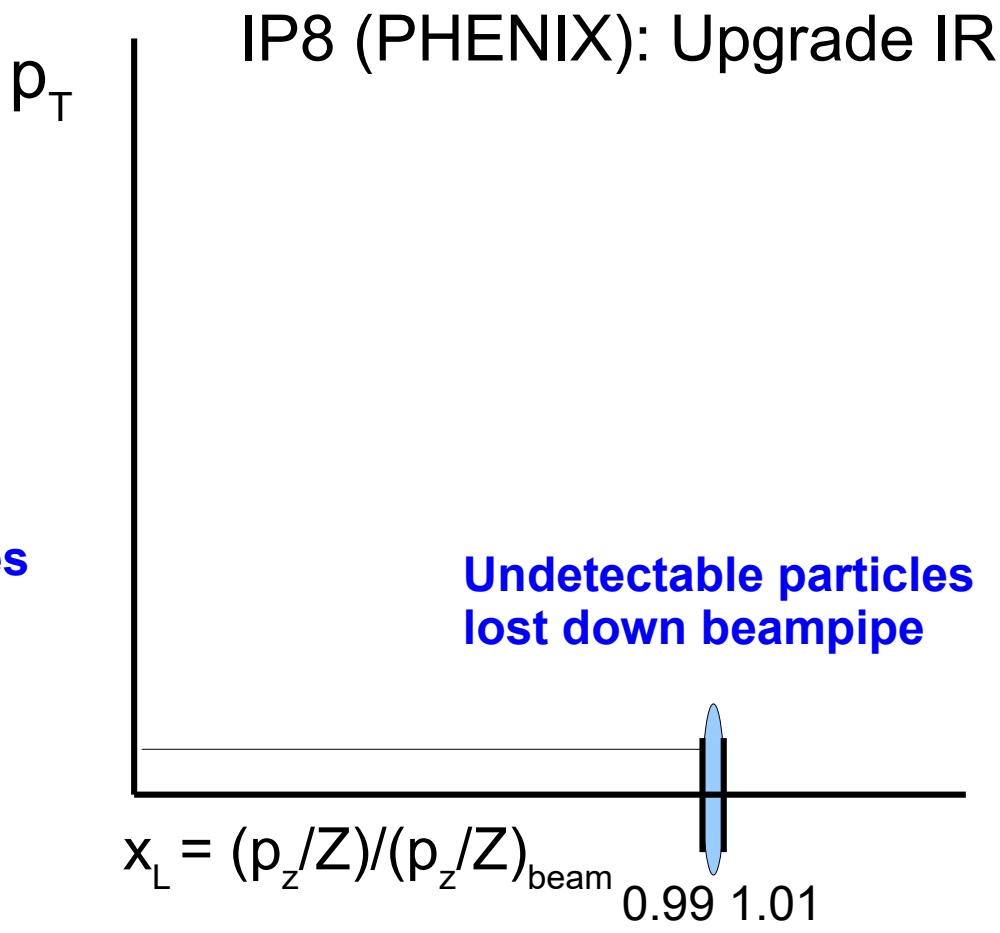
Ongoing Design: Secondary focus at IP8

Allows the detection of particles with rigidity, p/Z, near the beam.
Dispersion path to cause separation of particles.
Focus to allow the Roman pot to be close to pick up the separation.

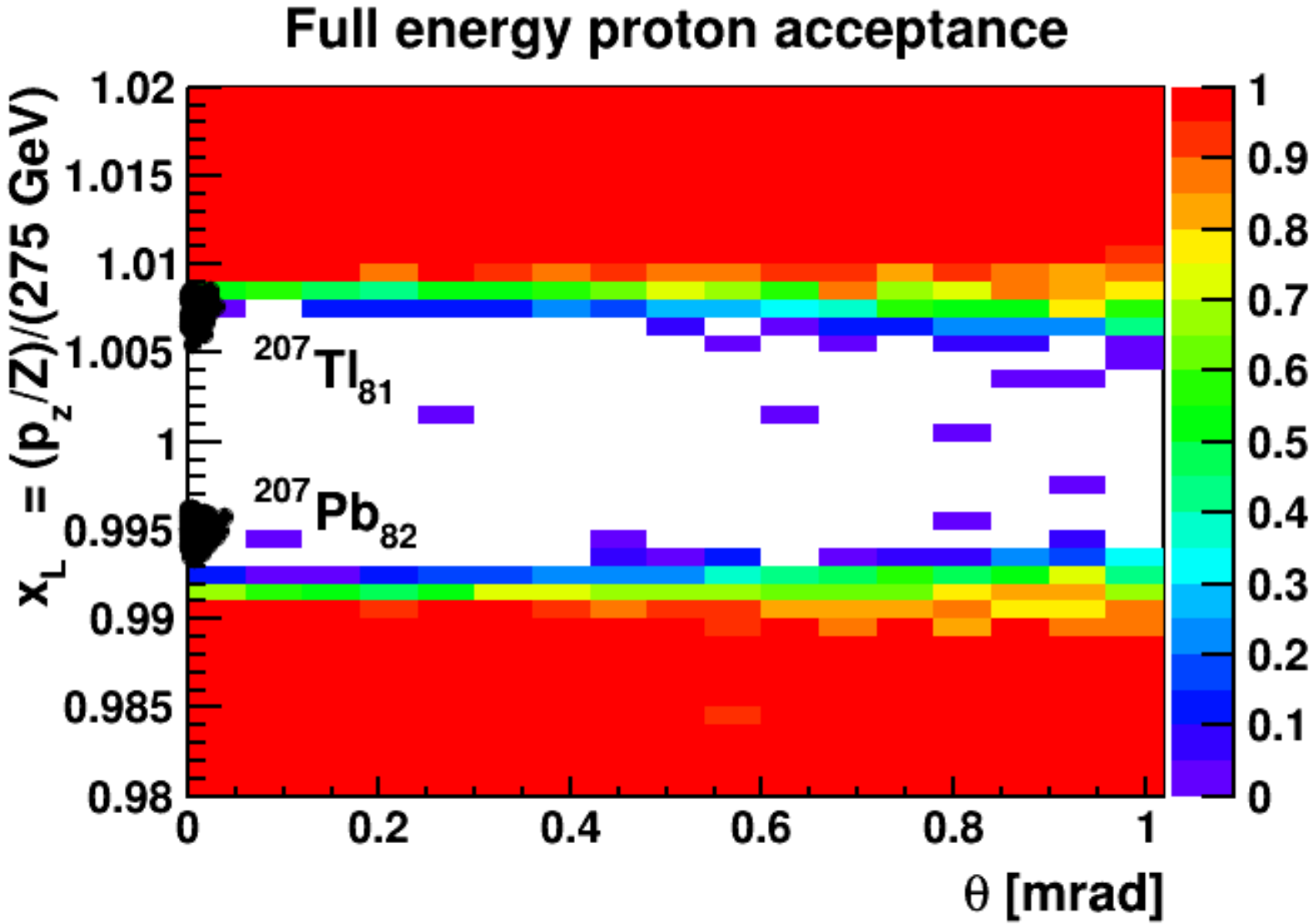


Schematic effect of secondary focus



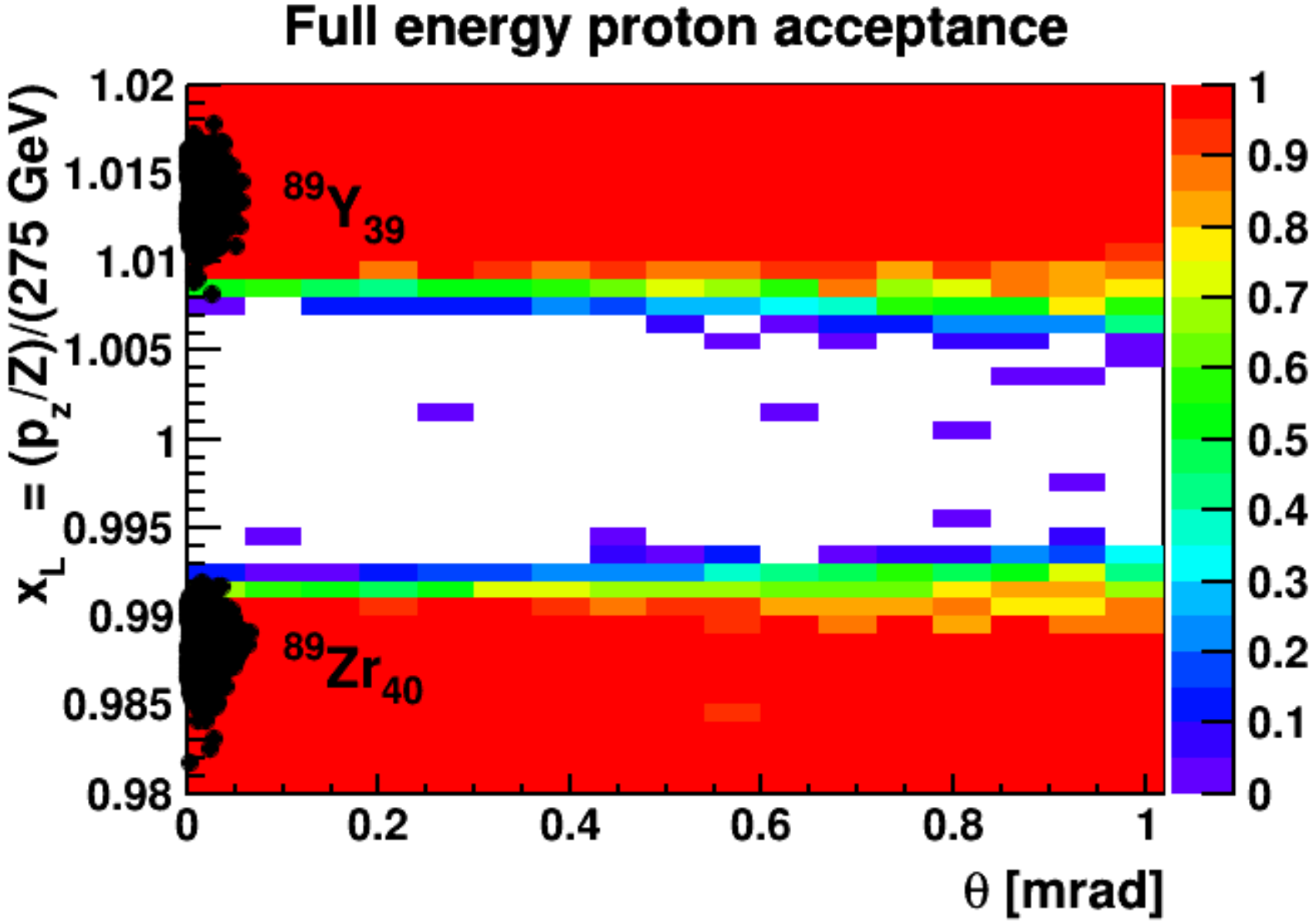


A-1 from e+^{208}Pb J/ψ incoh. Diff. in BeAGLE



CAVEAT : ep acceptance assumed to carry over to ePb.

A-1 particles from e+^{90}Zr J/ψ diffraction

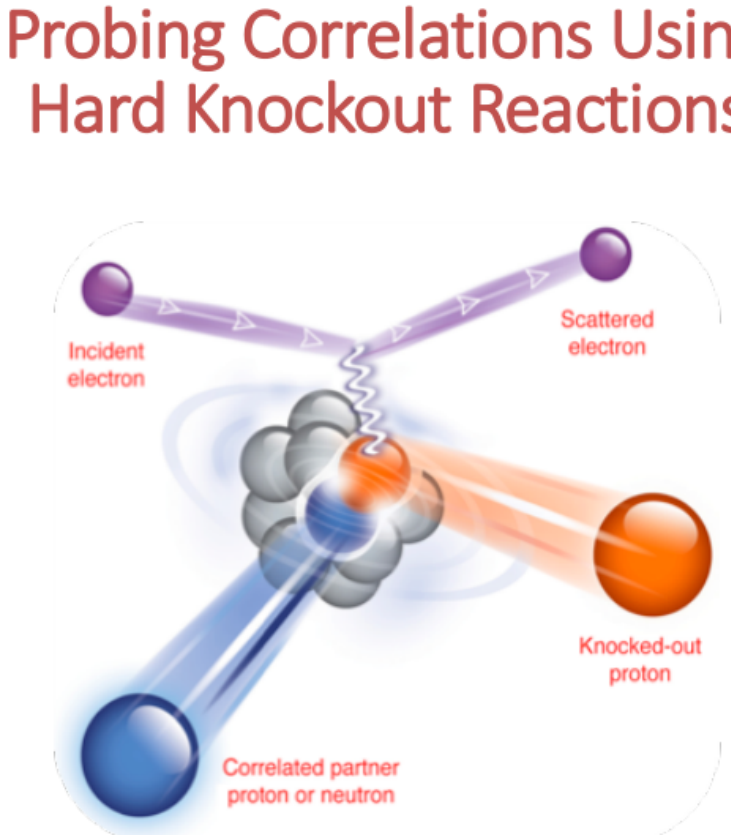


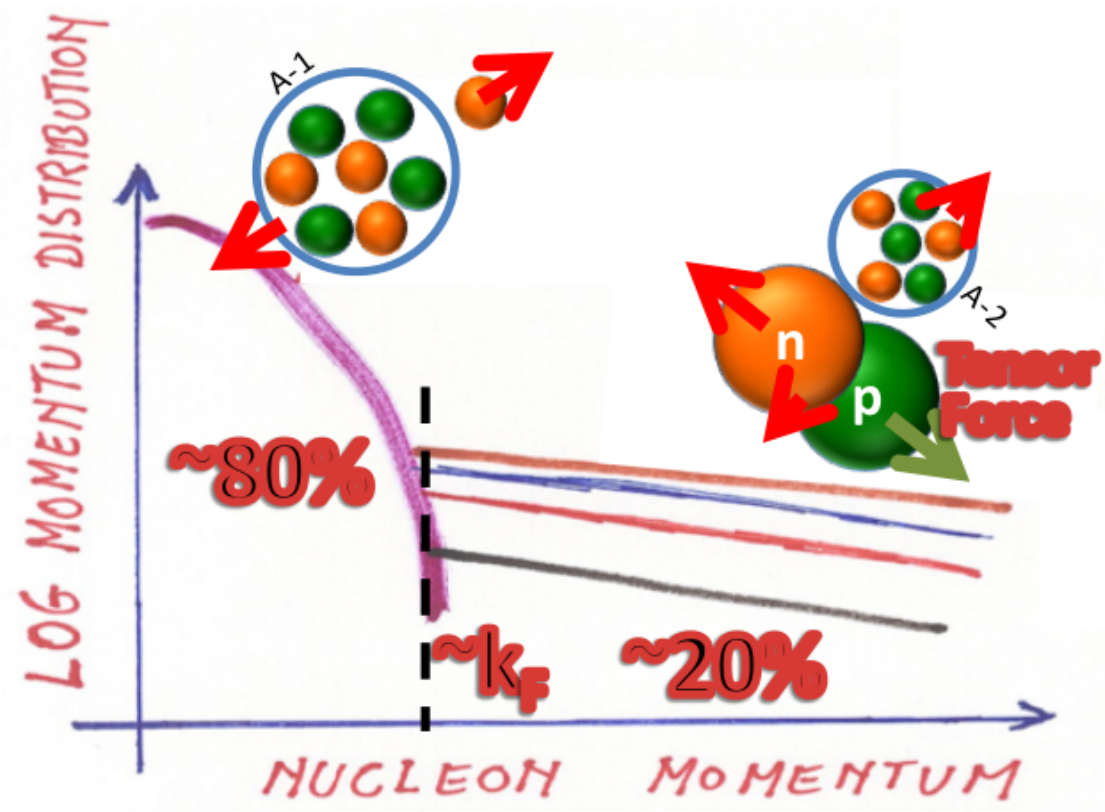
CAVEAT : ep acceptance assumed to carry over to eZr

What's next for BeAGLE?

- Still important for EIC detector/IR design
  - Optimization (IP8 and real-world IP6)
  - Exploration of physics possibilities (tagging!)
- Down to JLAB energies? Why?
  - That's where the data is and more data is planned!
    - See talks at October 2021 meeting:"Exploring QCD with Tagged Processes" https://indico.ijclab.in2p3.fr/event/7455/
  - Tune BeAGLE to better trust EIC predictions.
    - BeAGLE formation time parameter is badly constrained for eA – E665 data is tricky to use.

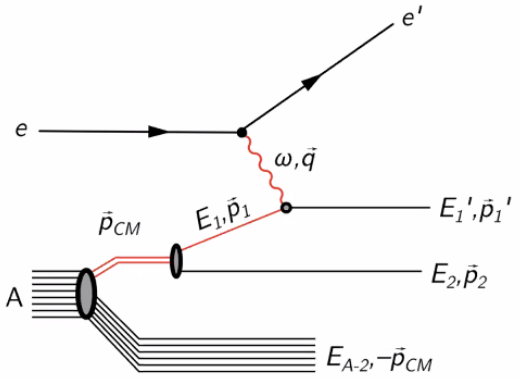
Short-range correlations (quasielastic)





Figures from Or Hen

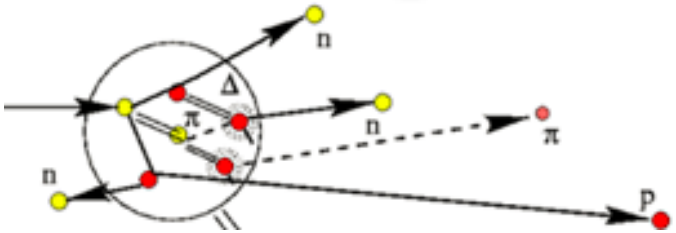
BeAGLE as an afterburner!



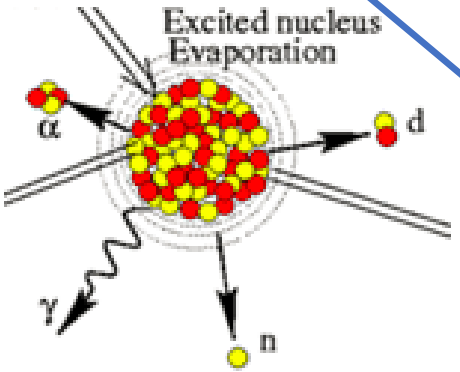
Primary interaction input from **GCF!** for the hard collision.

Primary interaction

Cascade process handled by **DPMJET.**



Intra-nuclear cascade

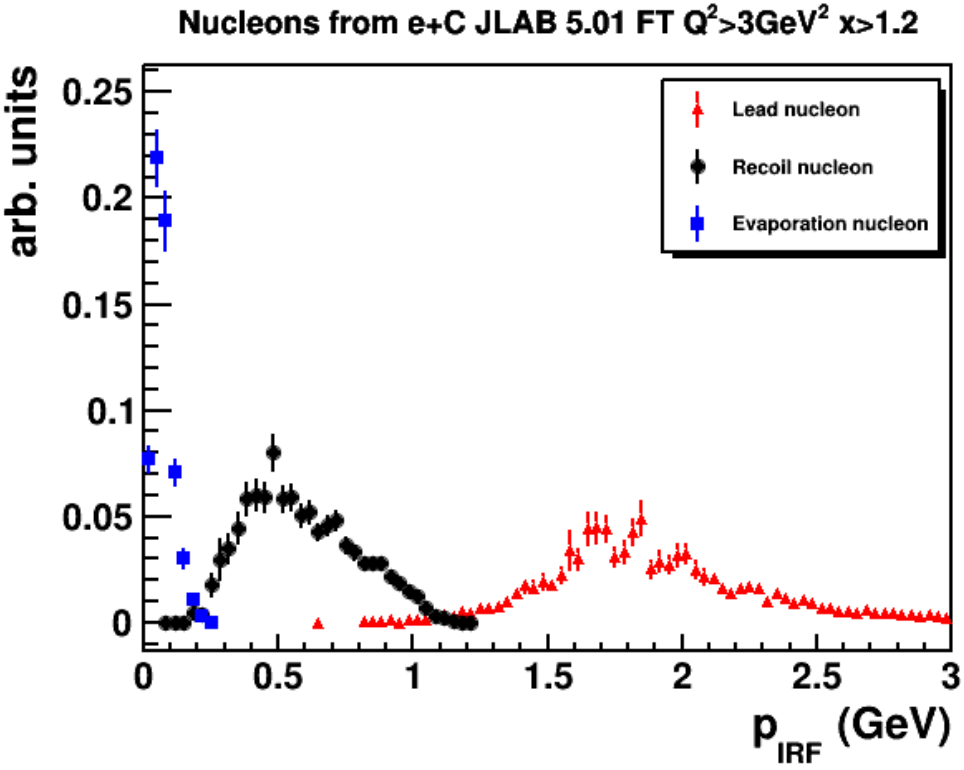


Nuclear remnant evaporation and break up by **FLUKA.**

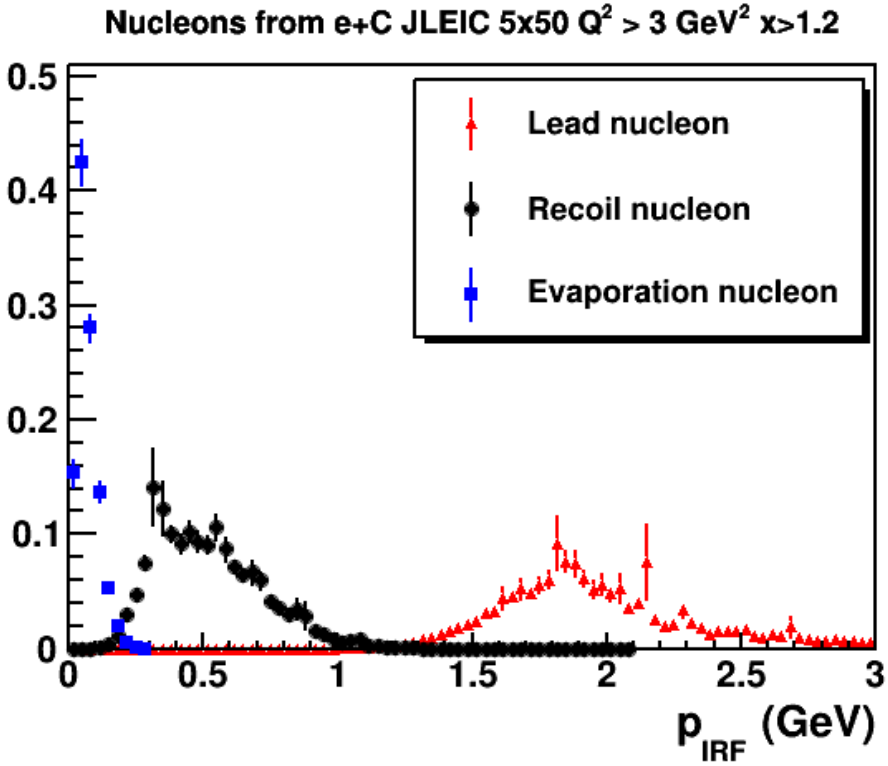
Nuclear remnant evaporation & breakup

GCF+BeAGLE w/o IntraNuclear Cascade

JLAB 5.01 GeV FT e+C
Q^2>3 GeV^2, x>1.2



EIC 5x50 e+C
Q^2>3 GeV^2, x>1.2



Lead and recoil nucleons are distinct.
Evaporation nucleons should not confuse us.

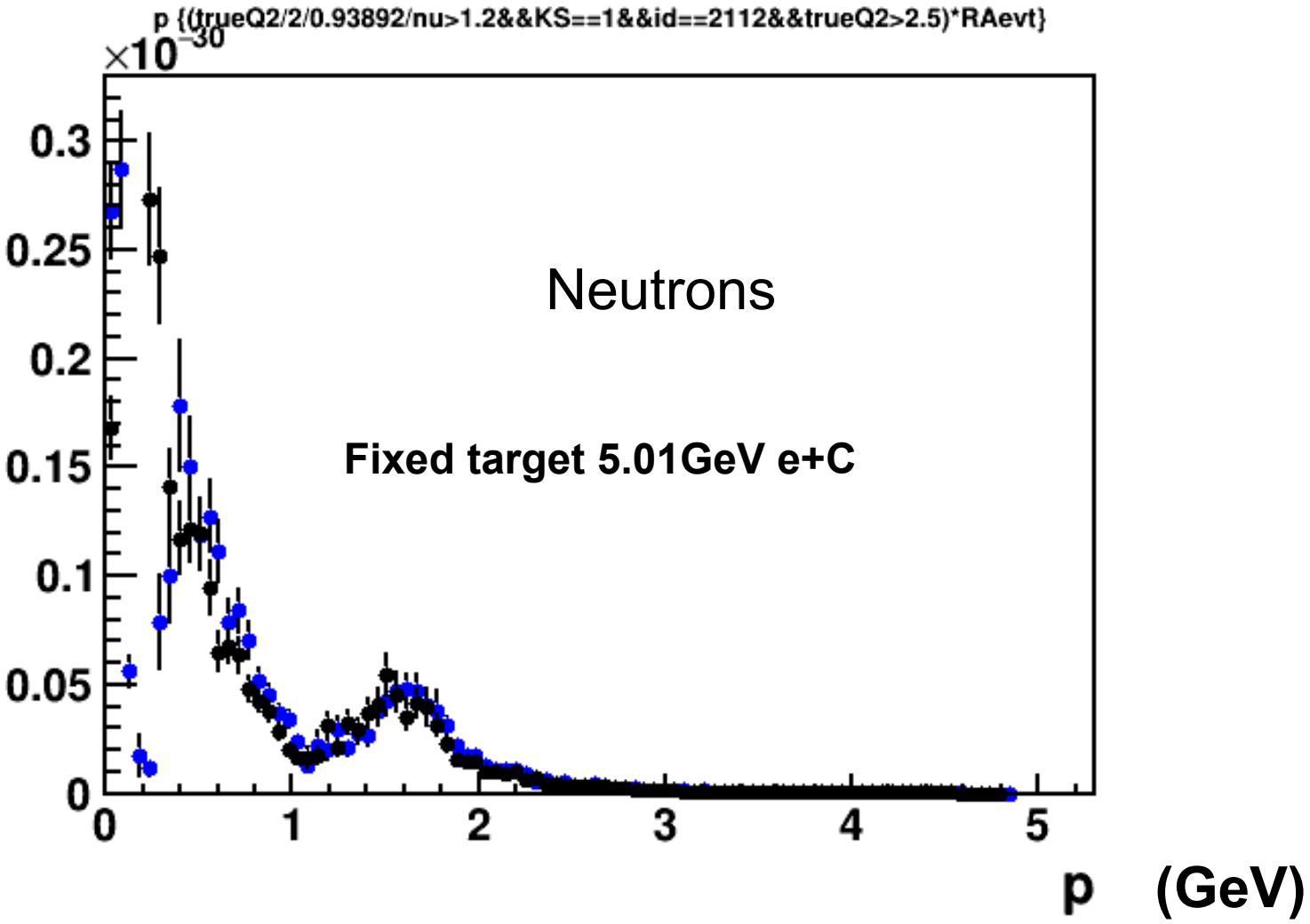
GCF + BeAGLE

- Intranuclear cascade (in DPMJET) can:
  - 1) Scatter our original pair nucleons
  - 2) Knock out additional nucleons
  - 3) Make it harder to define the "recoil" nucleon
    - e.g. recoil neutron strikes an additional spectator neutron and they scatter in a 2→2 process. Do we consider one of the outgoing neutrons a scattered version of the recoil nucleon? Which one?
  - 4) Create pions or other secondary particles...

Lead nucleon largely unaffected by this FSI

Blue is no INC x>1.2, Q^2>2.5 GeV^2

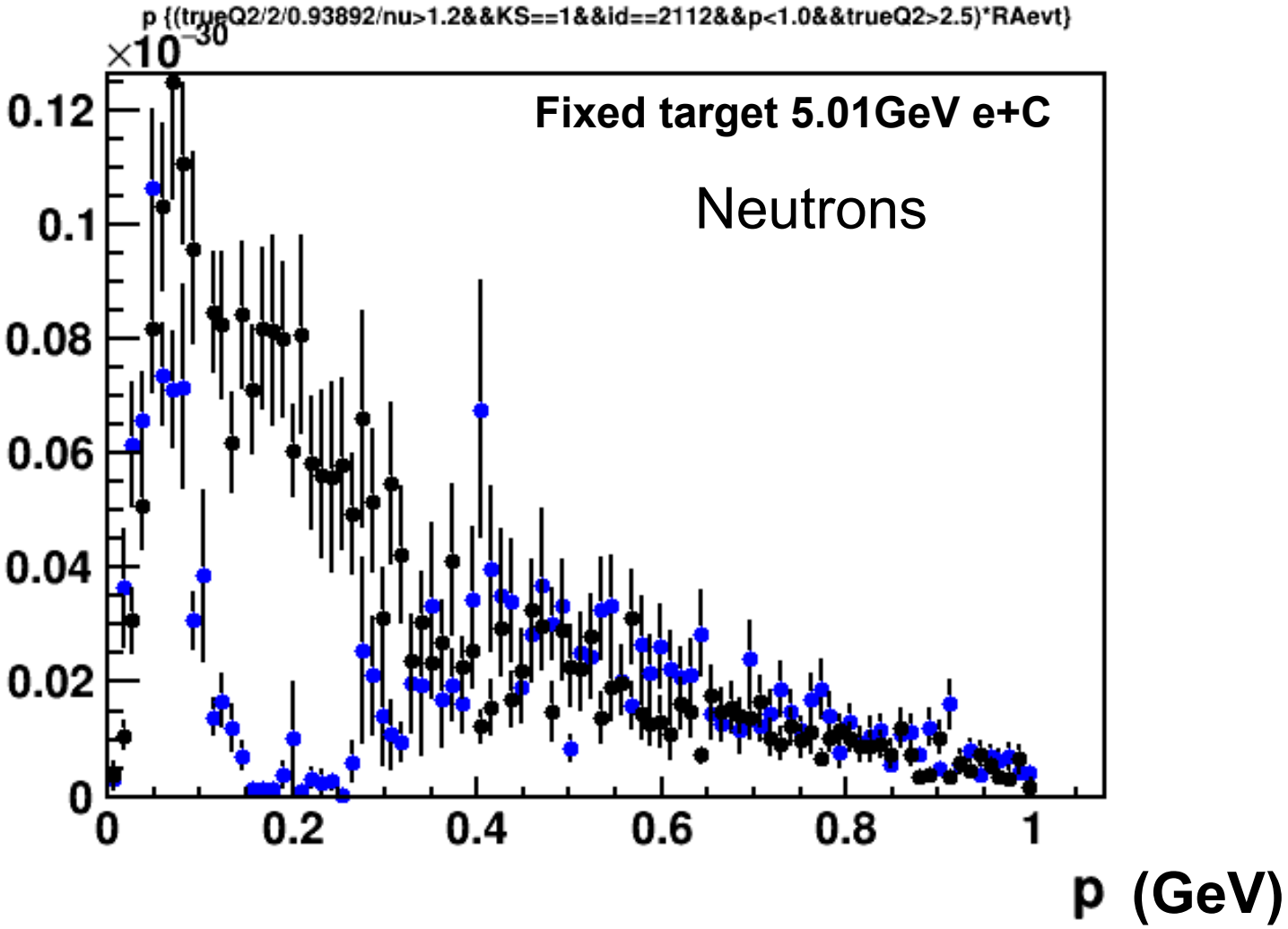
Black is full BeAGLE x>1.2, Q^2>2.5 GeV^2



Low momentum excess washes out peak

Blue is no INC x>1.2, Q^2>2.5 GeV^2

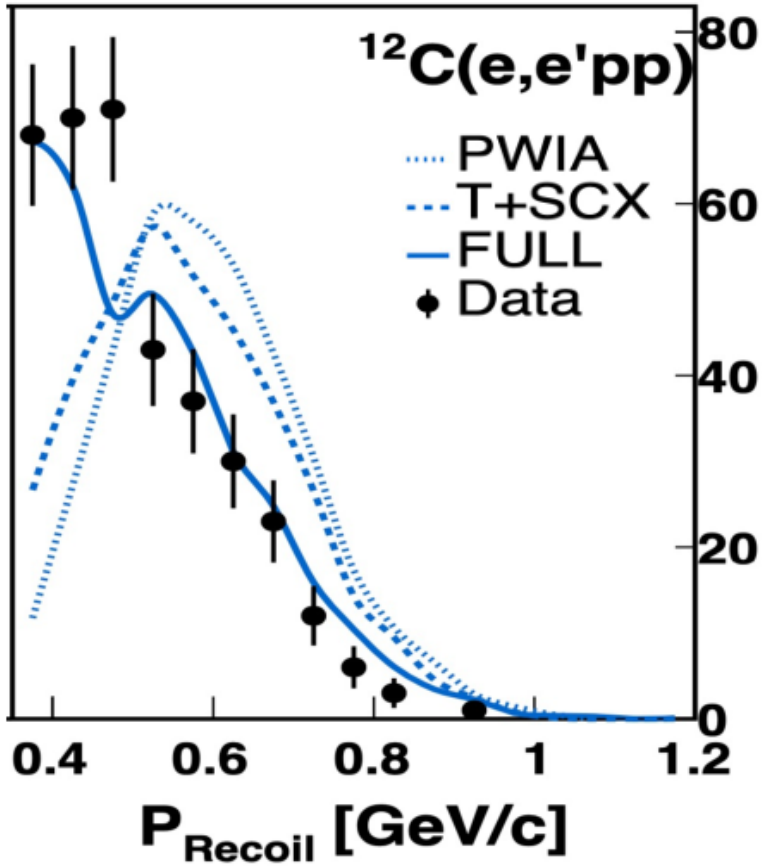
Black is full BeAGLE x>1.2, Q^2>2.5 GeV^2



Simpler eGENIE transport model at JLAB:

https://indico.jlab.org/event/428/timetable/#20210325.detailed

Plot from Natalie Wright talk:
"Transport Estimations of Final State Interaction Effects on Short–range Correlation Studies"
@ 3rd Workshop on Quantitative Challenges in EMC and SRC Research



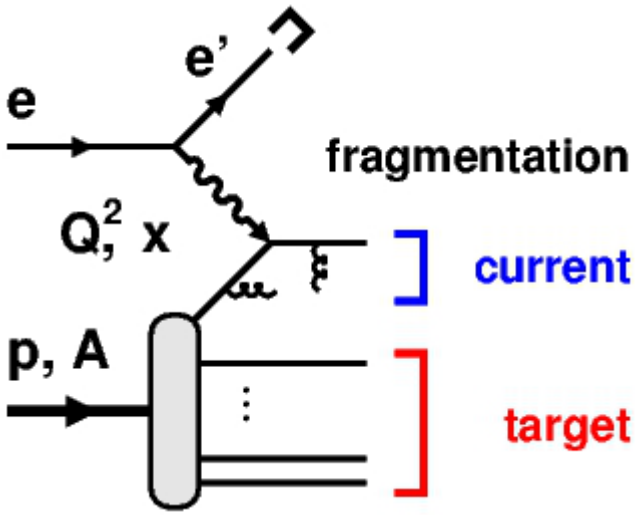
eGENIE allows a single hadron hadron scatter instead of a cascade, but is otherwise similar to BeAGLE.

Transport FSI: Excess nucleons at low end of recoil peak.
Washing out the peak.

FLUKA: Selected slides from Alfredo Ferrari

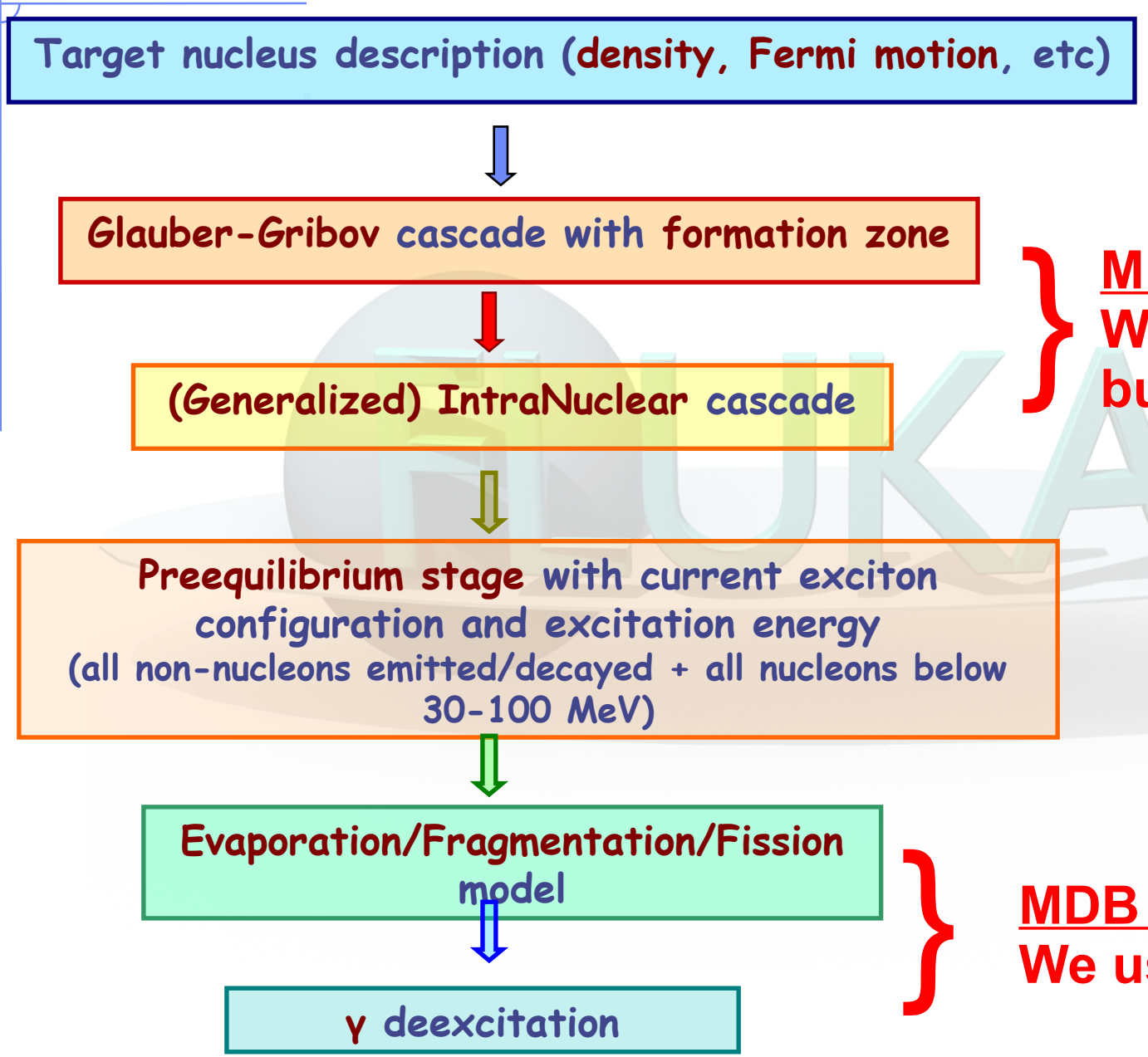
CFNS Ad-Hoc Workshop:

Target Fragmentation Physics with EIC
Sept. 2020



https://indico.bnl.gov/event/9287/timetable/#20200930.detailed

FLUKA (PEANUT) modeling of nuclear interactions



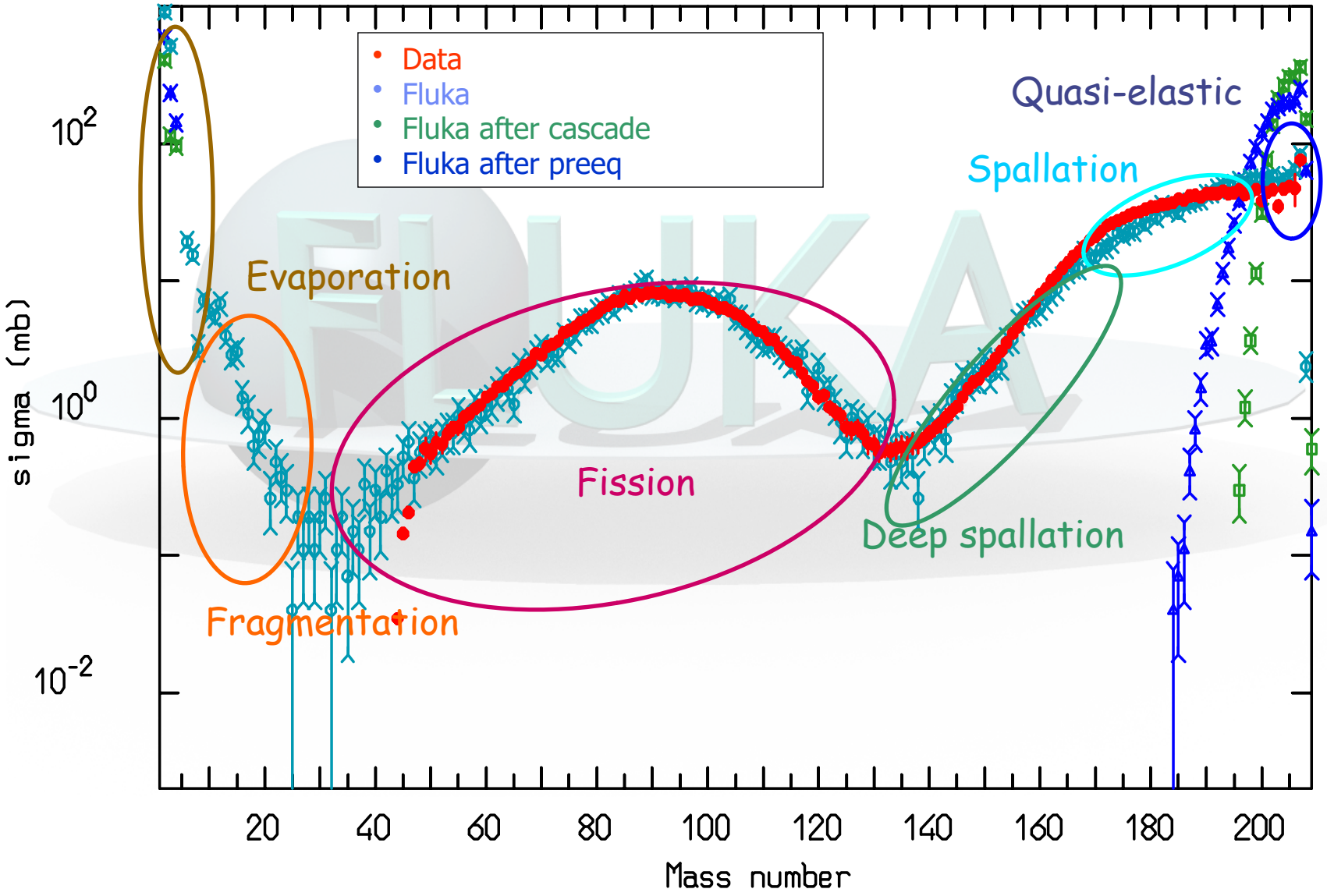
MDB:
We do this in BeAGLE.

MDB BeAGLE note:
We do this w/ DPMJET, but outside FLUKA

MDB BeAGLE note:
We use this part.

Example of fission/evaporation

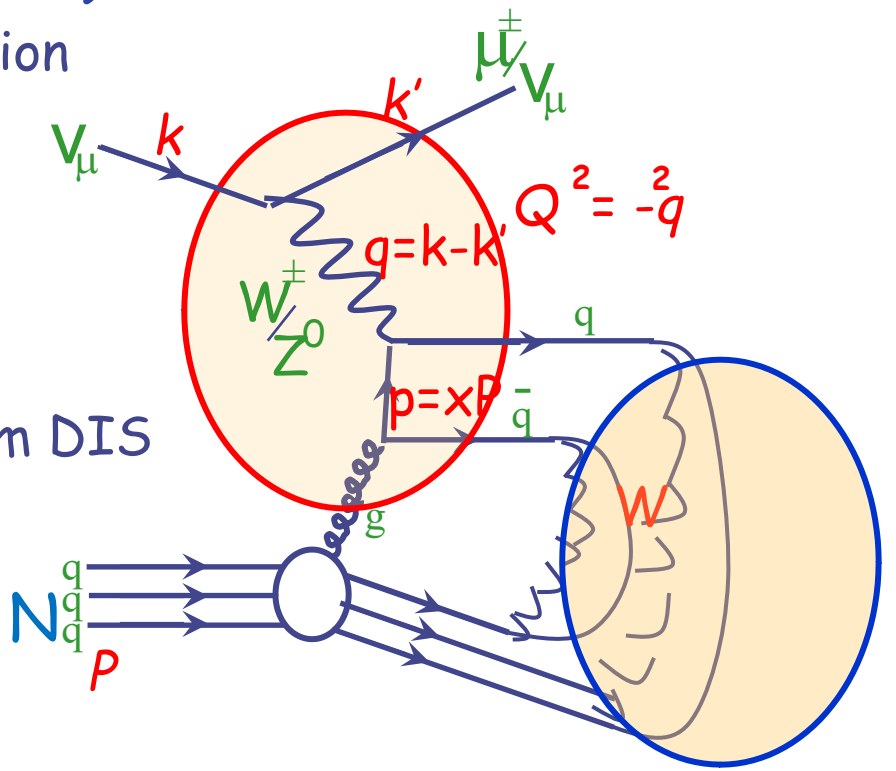
1 A GeV ^{208}Pb + p reactions Nucl. Phys. A 686 (2001) 481-524



(Anti)Neutrinos in FLUKA:

Acta Phys.Polon. B40 (2009) 2491-2505
CERN-Proceedings-2010-001 pp.387-394.

- **νN QuasiElastic (from ~0.1 GeV upward):**
  - Following Llewellyn Smith formulation
  - Lepton masses accounted for
- **νN Resonance production**
  - From Rein-Sehgal formulation
  - Keep only Δ production
  - Non-resonant background term from DIS



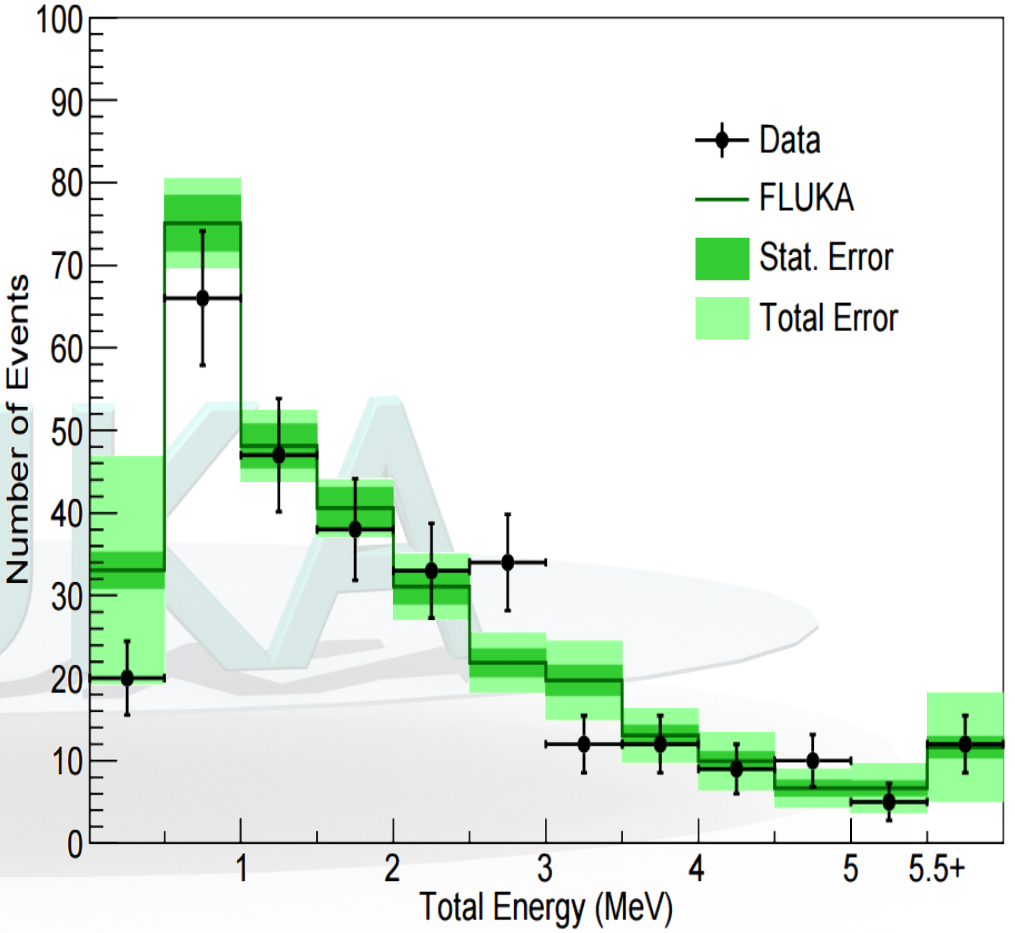
Hadronization

- **νN Deep Inelastic Scattering**
  - NunDIS model (developed ad hoc for FLUKA)
  - Chains from νN DIS: → FLUKA hadronization
- **νN interactions** embedded in PEANUT for **νA** (Initial State and Final State effects)

MDB note:
Very similar to BeAGLE, but uses more of FLUKA

γ de-excitation application: neutrinos+neutrons

- Detector: **ARGONEUT** operated in the **NuMi** beam, in front of the Minos near detector. Small **LAr** chamber
- One of the measurements: ***de-excitation gamma-rays from neutrino interactions***
- Background to this search: mainly ***photons from unseen neutrons*** generated in the neutrino interaction
- Simulations with FLUKA, internal neutrino generator + ***fully correlated pointwise*** low-energy ***neutron σ's*** for Ar



Total reconstructed γ energy in an event for neutrino data and **FLUKA** MC events. Events with no reconstructed energy are not included

Phys. Rev. D **99**, 012002 – Published 7 January 2019

Questions:

- How can we help in general?
- Would a Peanut interface to a eN generator (similar to the built-in one for Nundis) be of help?
- What about formation time for DIS events?
- …

Thanks for your attention

Using FLUKA – we should say yes!

- Benefits:
  - They will do a lot of the work!
  - Well-developed code with long-term support.
  - Worked well for neutrino community
- Issues
  - e-DIS is not as pointlike as ν-DIS & SRC needed.
  - Black box.
  - Needs person-power on EIC side + substantial consulting & support from a semi-expert (MDB or perhaps L. Zheng, N. Armesto)

Conclusions

- BeAGLE has been critical for studying tagging in eA at the EIC.
  - EIC detector/IR IP6 work winding down.
  - IP8 design and fine-tuned IP6 design still active
- Applying BeAGLE to JLAB could be interesting.
  - Validate/tune nuclear effects in BeAGLE
  - Can be applied to incoherent DVCS, SRCs etc.
- Longer-term
  - BeAGLE may be useful as an afterburner.
  - FLUKA-based replacement (tested w/ BeAGLE)

EXTRAS

BeAGLE(Pythia) Target Fragmentation Tune

PYTHIA tune for ZEUS e+p

Slide: Wan Chang et al. DIS, Apr. 2021

$e^+p \rightarrow e^+Xp$ (27.5 GeV x 820 GeV)

Cuts on Event level:

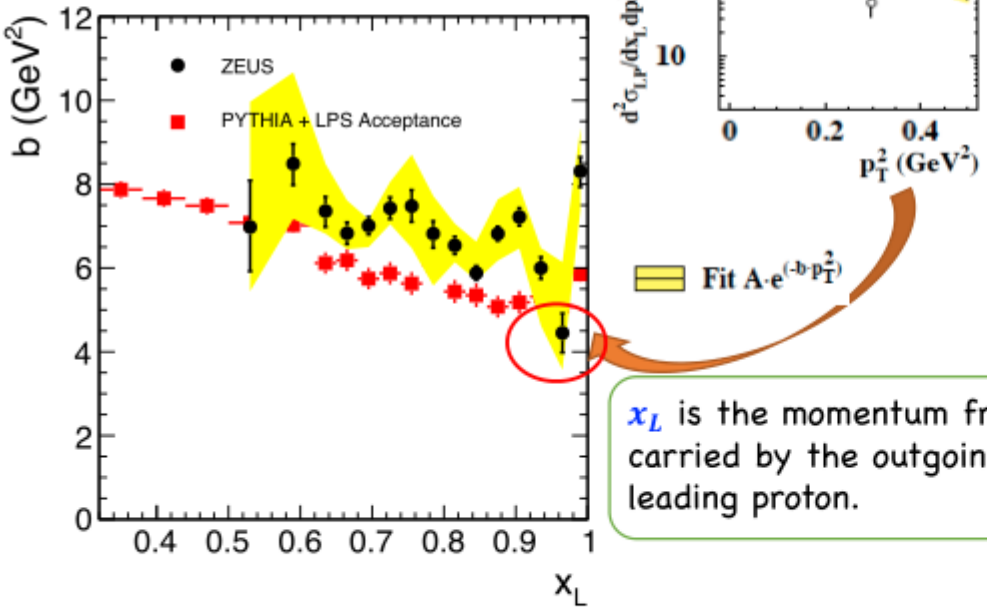
$x_L > 0.32$

$p_T^2 < 0.5\ \mathrm{GeV}^2$

$Q^2 > 3\ \mathrm{GeV}^2$

$45 < W < 225\ GeV$

LPS trigger conditions and acceptance were required, dropped tracks very close to beamline or the edge of LPS detectors.

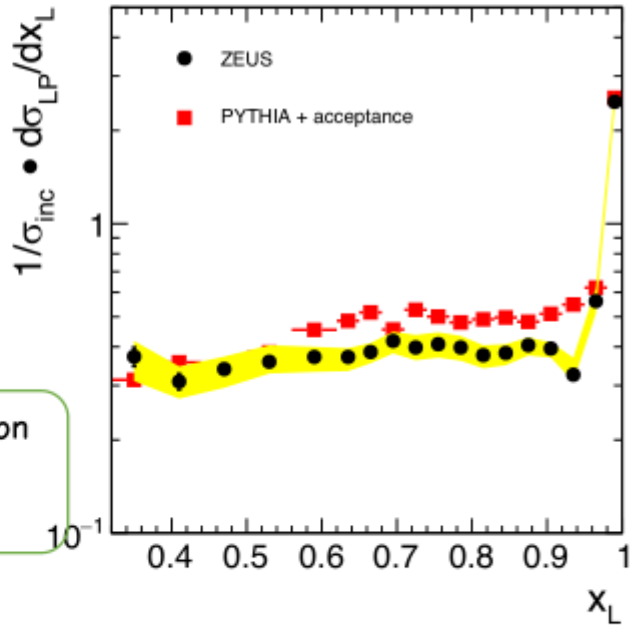


Fit $A \cdot e^{(-b \cdot p_T^2)}$

x_L is the momentum fraction carried by the outgoing leading proton.

JHEP 0906:074,2009

The leading proton production rate:



We have a good PYTHIA tune for target fragmentation for ep.

Remaining improvement would require a full GEANT simulation for the Hera Interaction Region

Tuning Pythia/BeAGLE target fragmentation

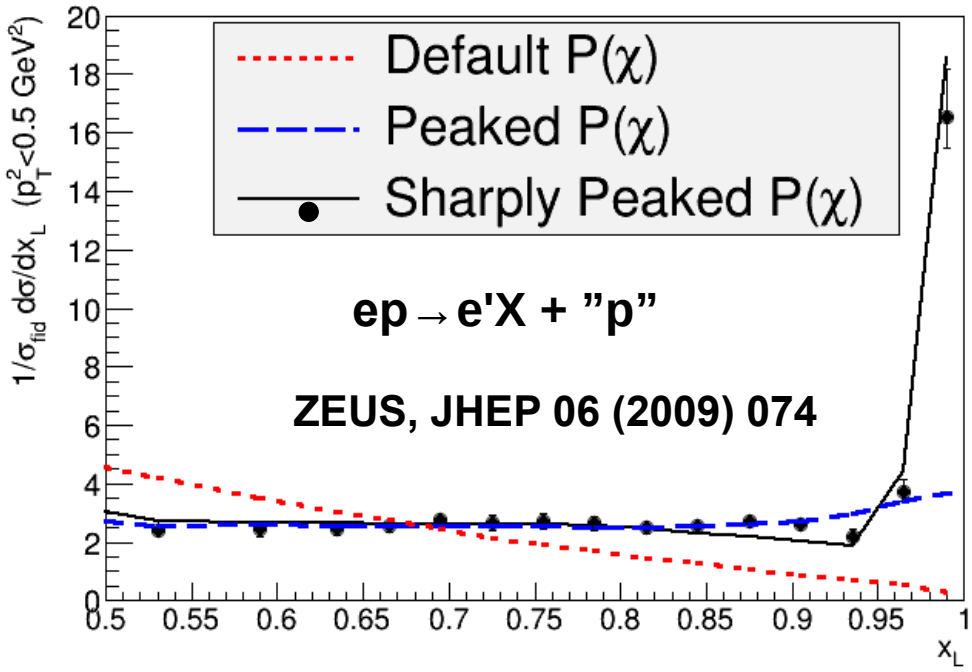
Non-trivial beam remnant clusters fragment into diquark+meson or baryon+quark. The p_L fraction carried by baryon/diquark is called χ.

Tuned P(χ) to better match ZEUS.

	P(χ)
Default	Frag. function
Peaked	$10(1-\chi)^9$
Sharply	$76(1-\chi)^{75}$

In the end we used P(χ) = 7(1-χ)^6
Matches both p & n in hadron-going direction.

σ_{fid} = σ for h+ 0.5<x_L<0.89, p_T^2<0.5 GeV^2

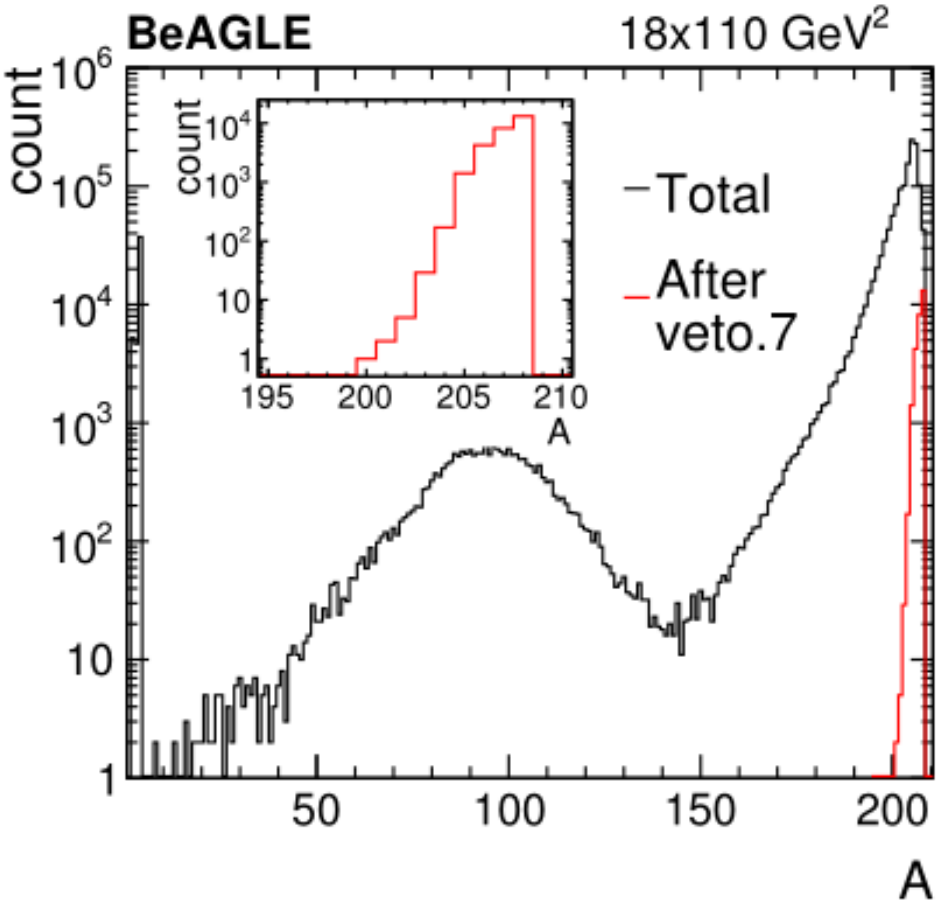


We tune using the p_T distribution as well.

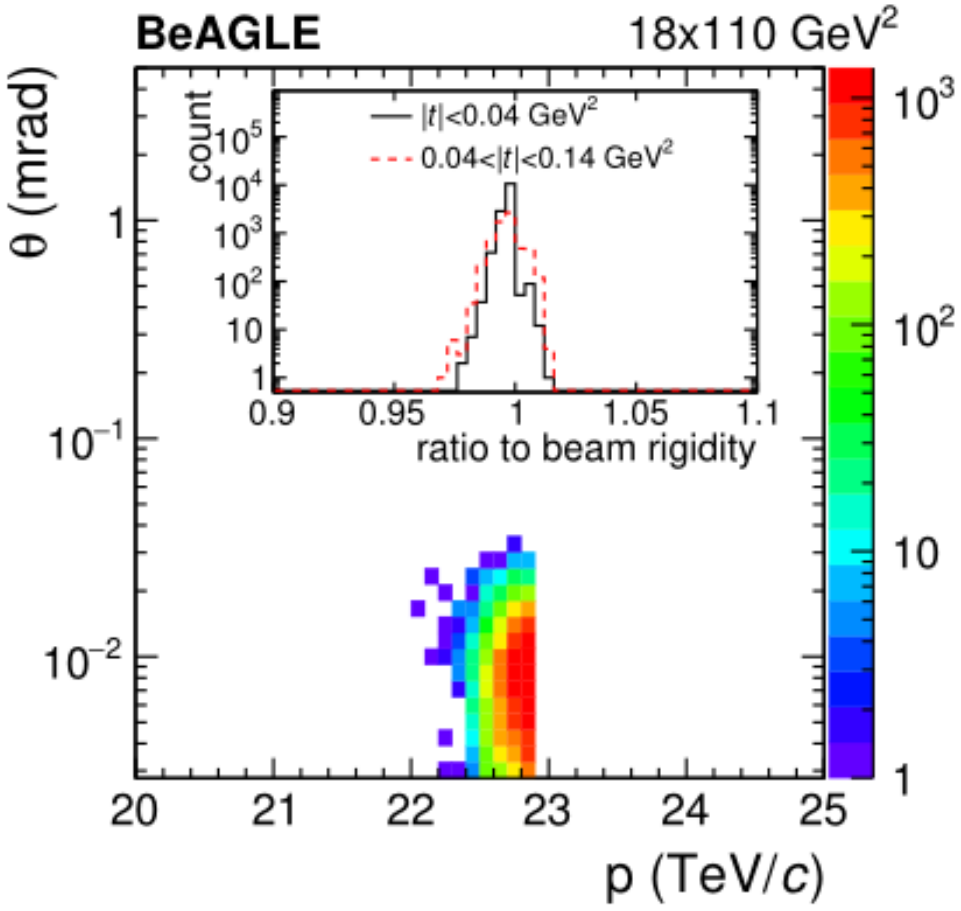
A look at e+Pb events that are HARD to cut

BNL BeAGLE Task Force: Aschenauer, MDB, **Wan Chang**, Jentsch, Lee, Tu, Zheng

STUDY FOR IR6 after cuts on forward protons, neutrons, and photons.

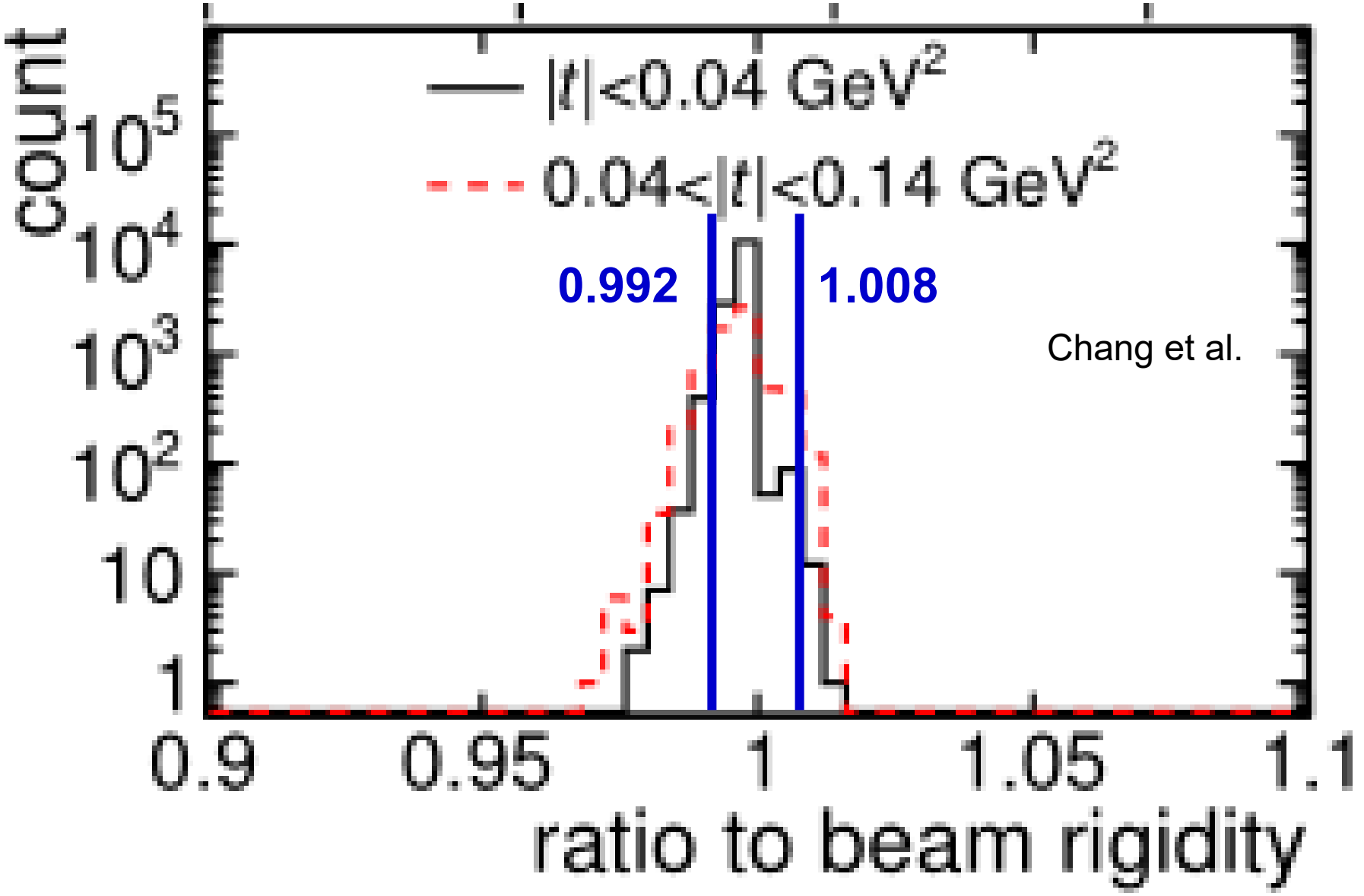


(a)



(b)

Zoom in for rigidity of remnants



IP8 plots from Rolf's talk (from Alex Jentsch)

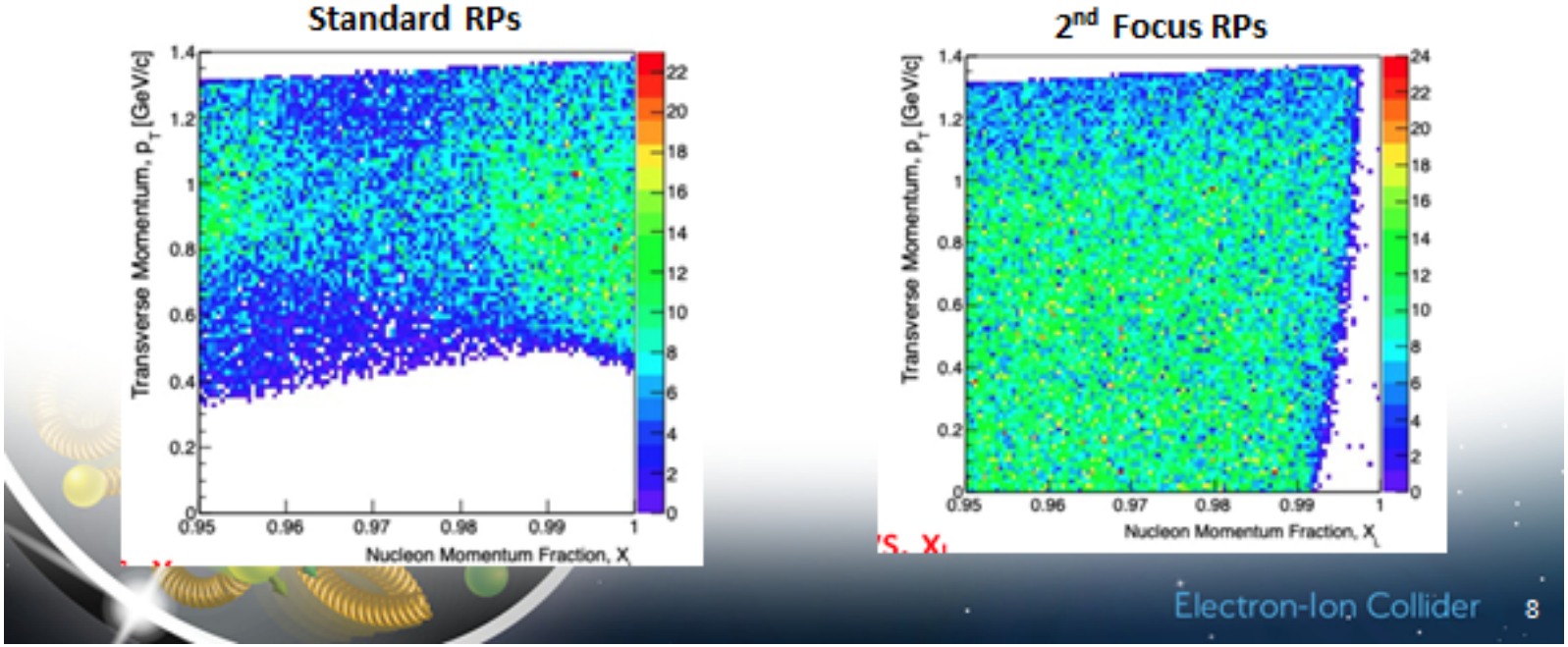
https://jleic-docdb.jlab.org/cgi-bin/private/DisplayMeeting?sessionid=269 F 7/2

Status of IR-8

- All material to simulate physics at 18 GeV x 275 GeV has been posted at https://indico.bnl.gov/event/10974/contributions/51160/
  - Detailed Read-Me how to use all the provided information

x_L acceptance at IP-8:

the most recent optics info was used



Tight geometry cuts are meaningful!