eRD17: BeAGLE

A Tool to Refine Detector Requirements for eA

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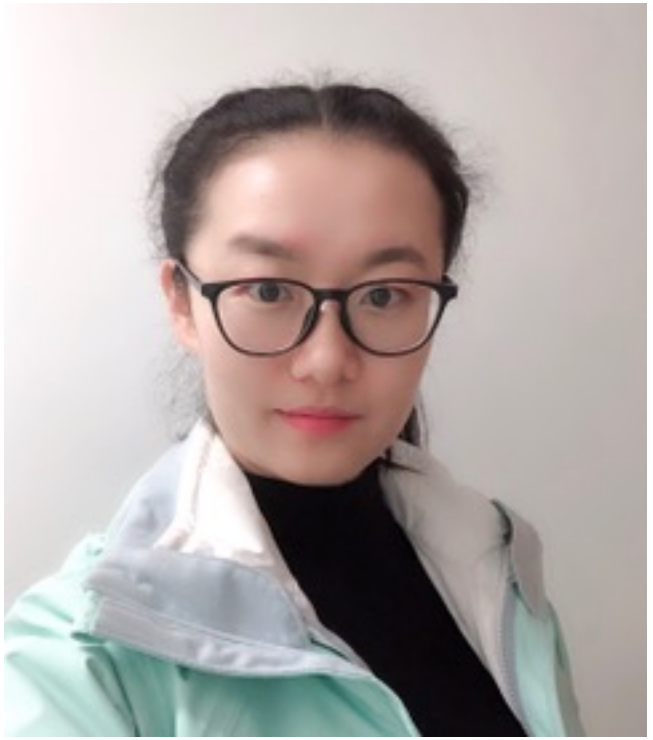
Reminder: New collaborators since 1 yr. ago

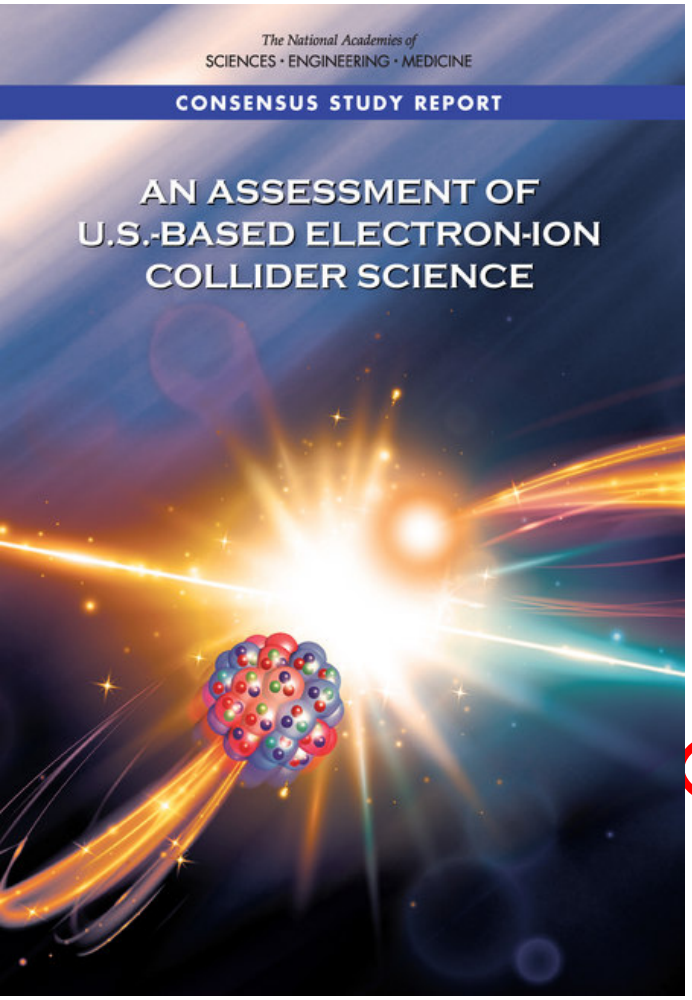
Zhoudunming (Kong) Tu
- Goldhaber Fellow @ BNL
- Funding in Place (BNL/CFNS)
- BeAGLE developer.
- Co-PI of eRD17 project now.



Wan Chang
- Student at CCNU (a la Liang)
- Elke is her co-advisor
- Resident at BNL
- Experienced BeAGLE user
- Funding requested to engage in more extensive BeAGLE work.

NAS Report – R&D requirements chapter

Chapter 4: Accelerator Science, Technology, and Detectors Needed for a U.S.-Based Electron-Ion Collider



An EIC must enable the following:

- Extensive center-of-mass energy range, from ~20-~100 GeV, upgradable to ~140 GeV, to map the transition in nuclear properties from a dilute gas of quarks and gluons to saturated gluonic matter.
- Ion beams from deuterons to the heaviest stable nuclei.
- Luminosity on the order of 100 to 1,000 times higher than the earlierelectron-proton collider Hadron-Electron Ring Accelerator (HERA) at Deutsches Elektronen-Synchrotron (DESY), to allow unprecedented three-dimensional (3D) imaging of the gluon and sea quark distributions in nucleons and nuclei.
- Spin-polarized (~70 percent at a minimum) electron and proton/light-ion beams to explore the correlations of gluon and sea quark distributions with the overall nucleon spin. Polarized colliding beams have been achieved before only at HERA (with electrons and positrons only) and Relativistic Heavy Ion Collider (RHIC; with protons only).
- One or more interaction regions, which integrate the detectors into the collider and preserve the extensive kinematic coverage for measurements.

Forward physics in e+A is different than e+p

- Diffractive J/ψ and ϕ production to study spatial distribution of gluons in the nucleus: G(b).
- Centrality tagging to enhance <T(b)> or effective $A^{1/3}$ for:
  - Enhanced saturation scale Q^2_s
  - Study of medium interaction/modification of jets.
- Deuteron spectator p tagging to study e+"n".
- High "k" spectator tagging
  - e+D: study deuteron wavefunction / p+n interaction
  - e+A: short-range NN correlations in nuclei

Forward detection in e+A is different too!

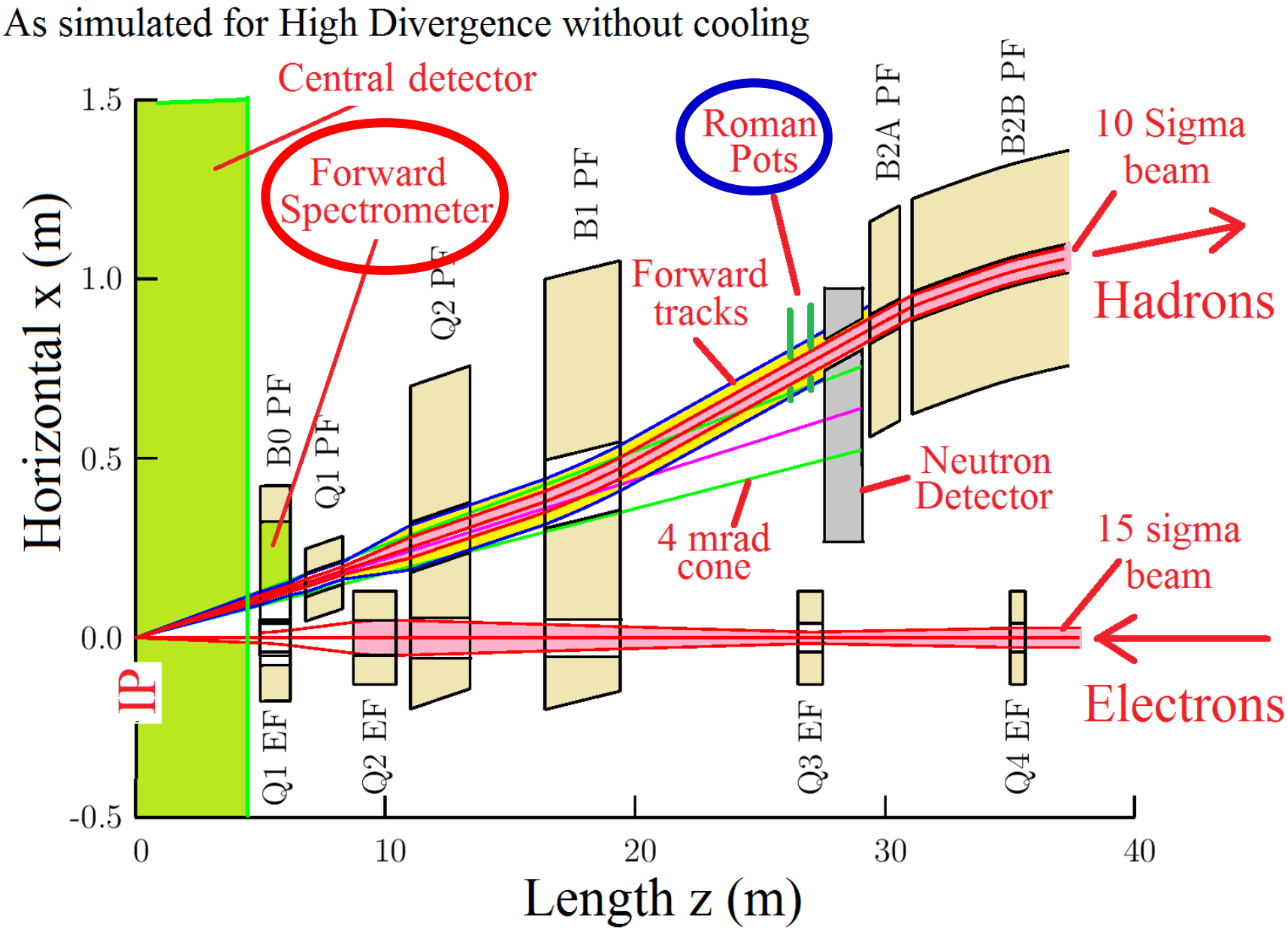
Even for the same physics (e.g. DVCS)

- Protons with $y \sim y_{beam}$ and $p_T \sim 0$ travel with the beam in e+p.
- In e+A, $y \sim y_{beam}$ and $p_T \sim 0$ neutrons, protons, & the beam diverge significantly. (mostly good!)
- Nuclear remnants A'≠A also diverge from the beam, but less significantly...
- All of this needs study with BeAGLE.

Priorities (committee-driven)

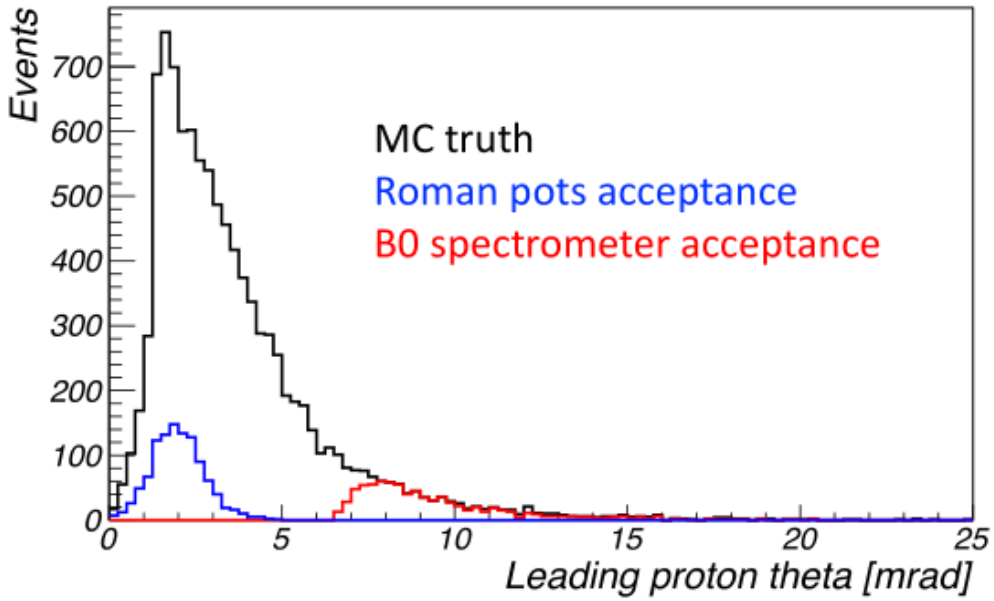
- First: Implementing or supporting studies which impact the forward detector/IR interface.
- Second: Technical improvements and validation/tuning of BeAGLE
  - Debug & cleanup.
  - Adding RAPGAP for better diffraction.
  - Tuning to E665 streamer chamber data.
- Third: Implementing or supporting studies of the effect of detector quality on physics.
  - E.g. How cutting edge does the ZCAL need to be?

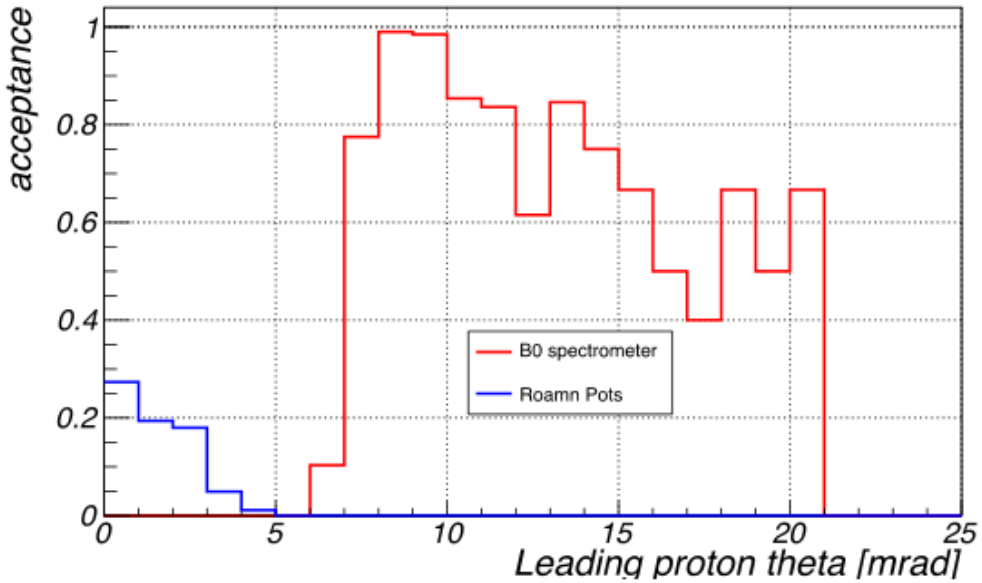
Forward Detector Elements

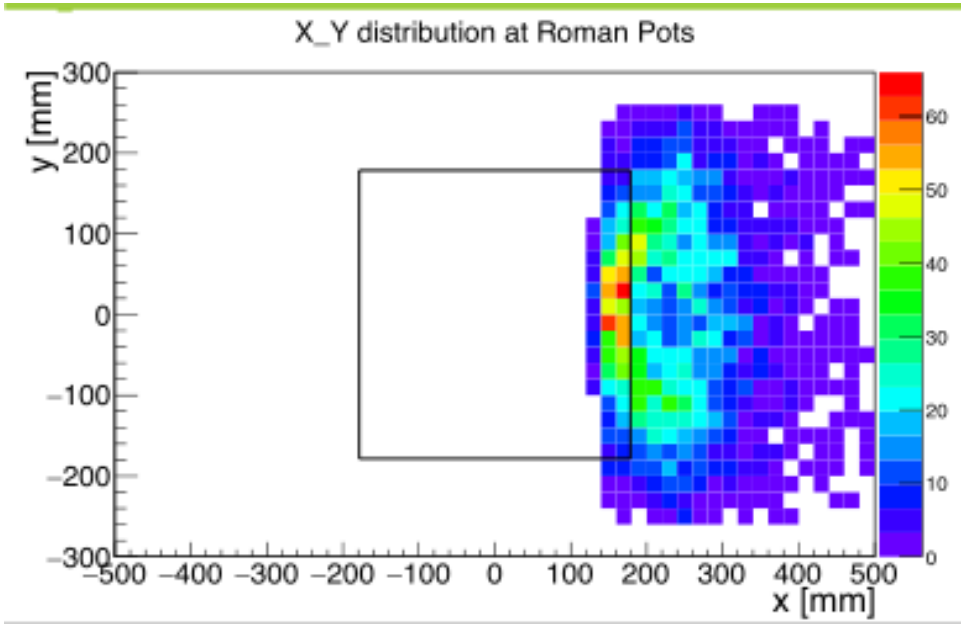


eRHIC Forward Detector Acceptance Studies

Forward protons in e+Pb J/ψ incoh. diffractive events at eRHIC

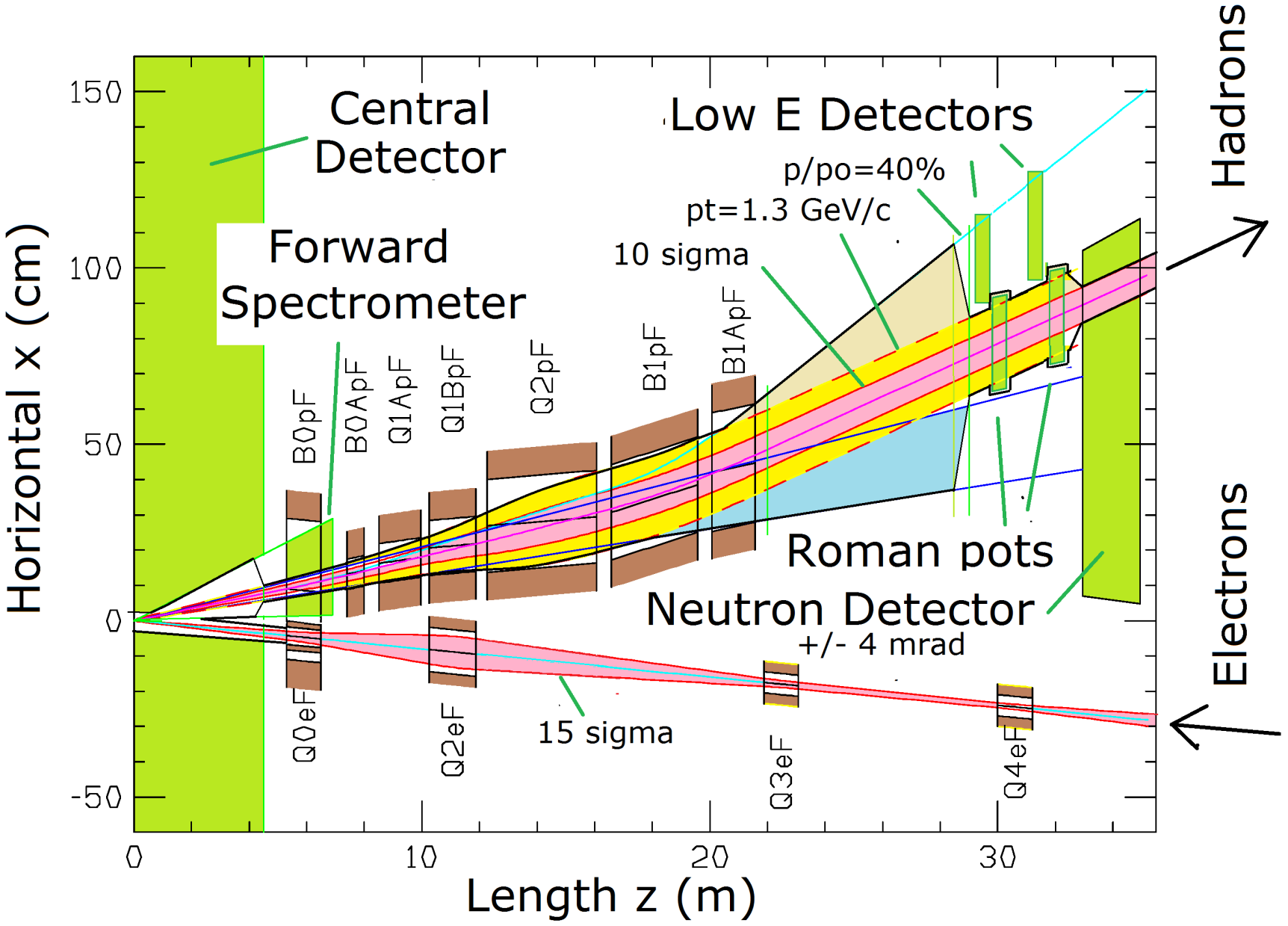






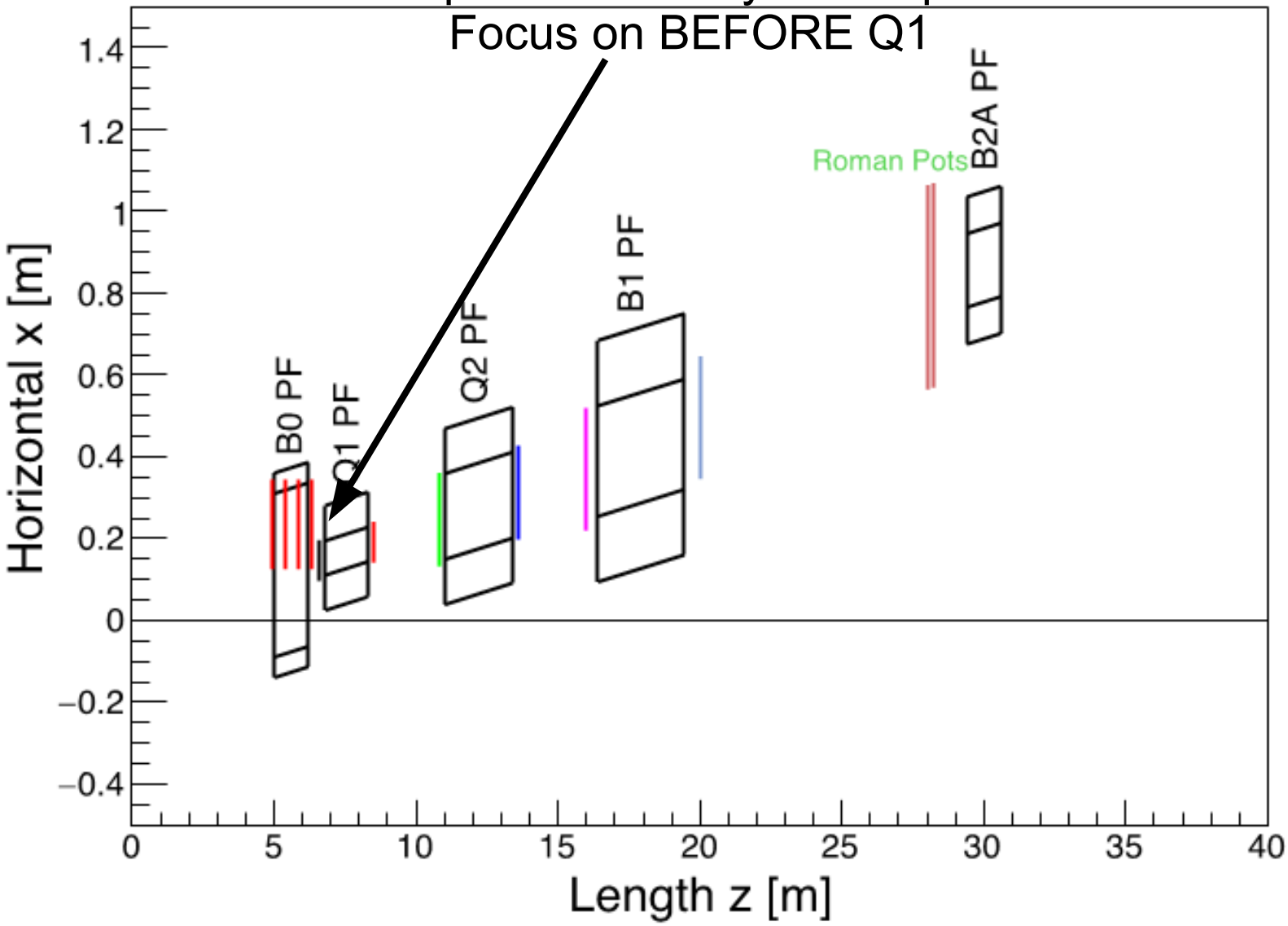
Issue 1:
Roman pots were optimized for e+p. Must move them for e+A – and claim real estate.

Forward Detector /IR (updated design)

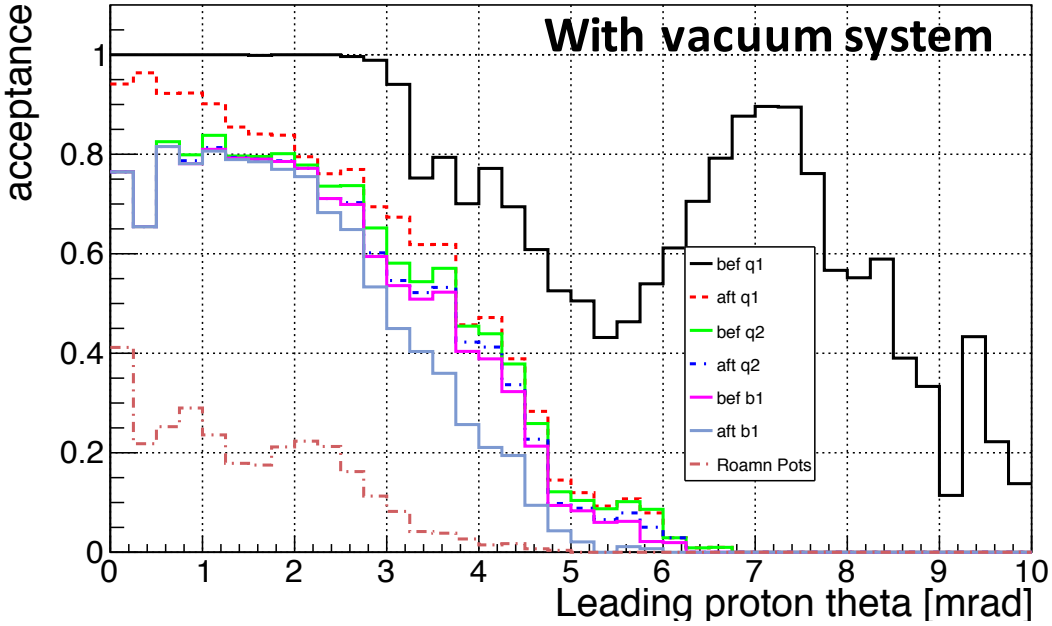


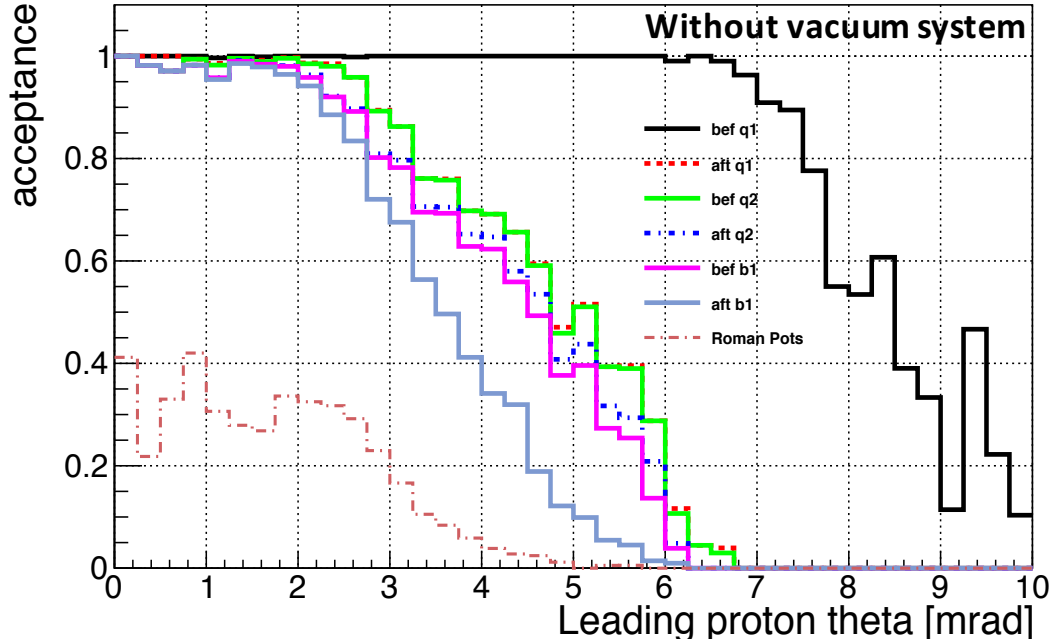
Forward IR Apertures Study

Ideal detector planes to study where protons are lost.



Forward Acceptance Issue #2





Vacuum chamber impeding aperture!

Need to optimize vacuum chamber between main detector and B0.

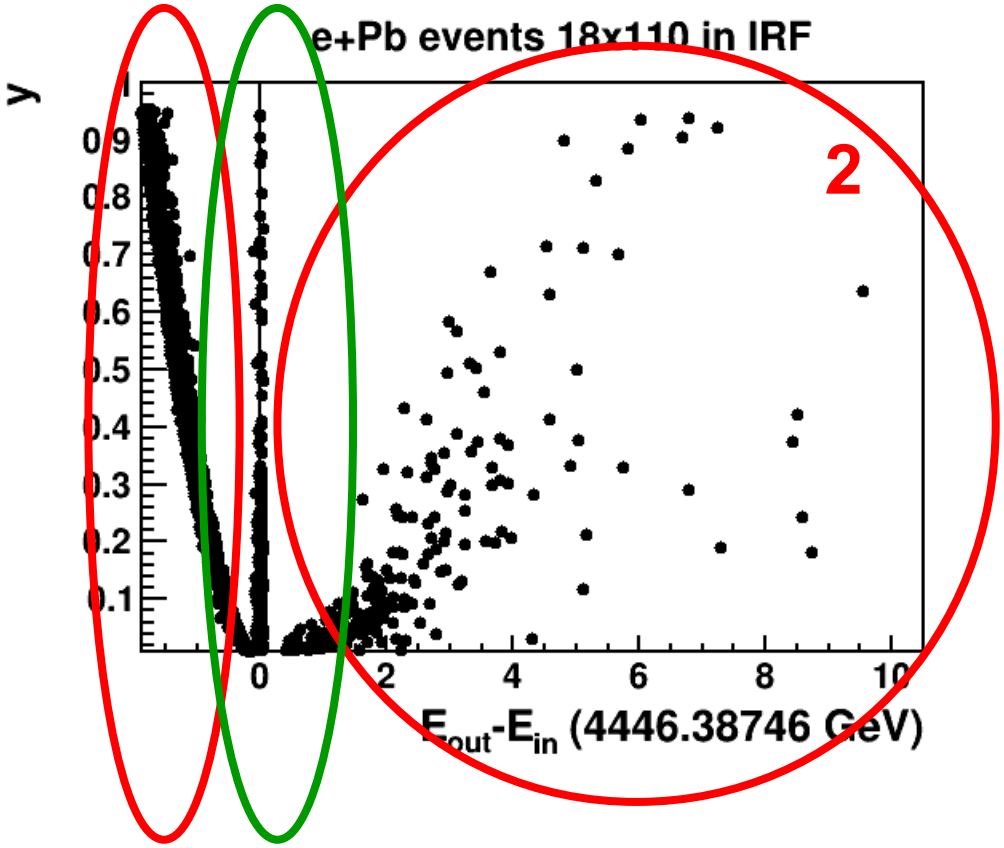
Priority 1 (BeAGLE for Detector/IR issues)

- These ongoing eRHIC studies represent a huge strategic success for eRD17.
- This type of study was the POINT of the whole exercise wrt EIC R&D.
- Similar discussions arising for JLEIC w/ pushback from accelerator physicists:
  - Can we reduce magnet apertures? What is the physics advantage of forward particles in the 5-10mr region?
- Very urgent! The time is now (really yesterday)!

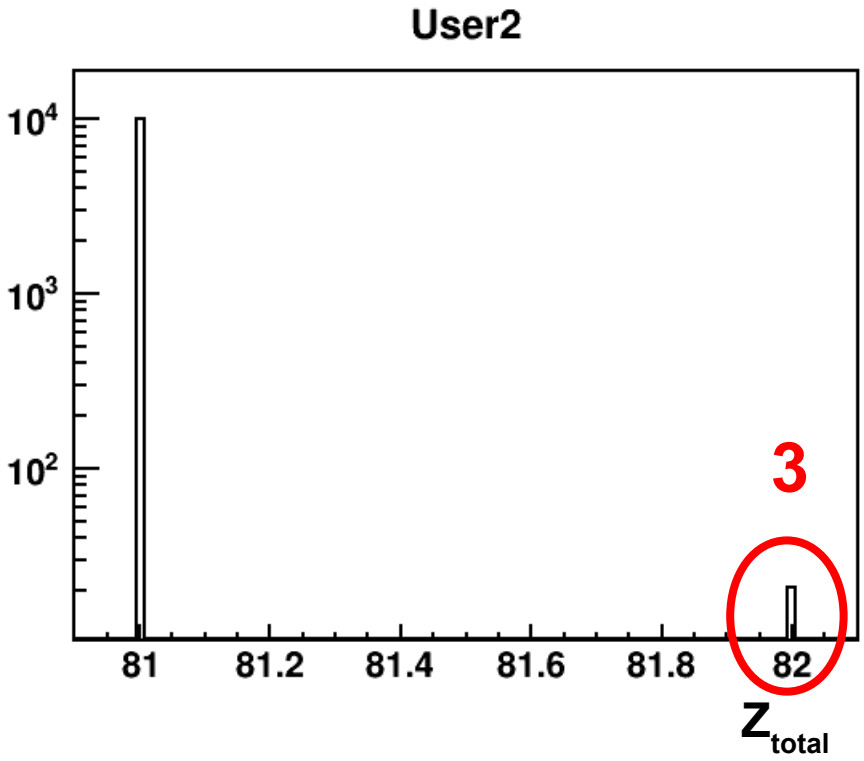
Energy (& charge) nonconservation bugs!

The problem(s) in order of frequency:
1: 95% 2: 2.5% 3: 0.2%

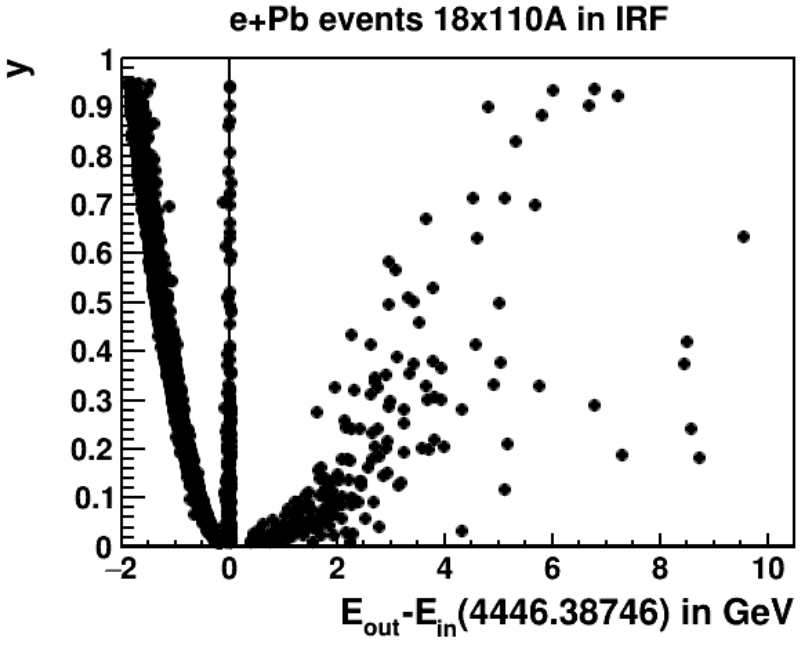
1 $E_{out} - E_{in}$ **should be zero**

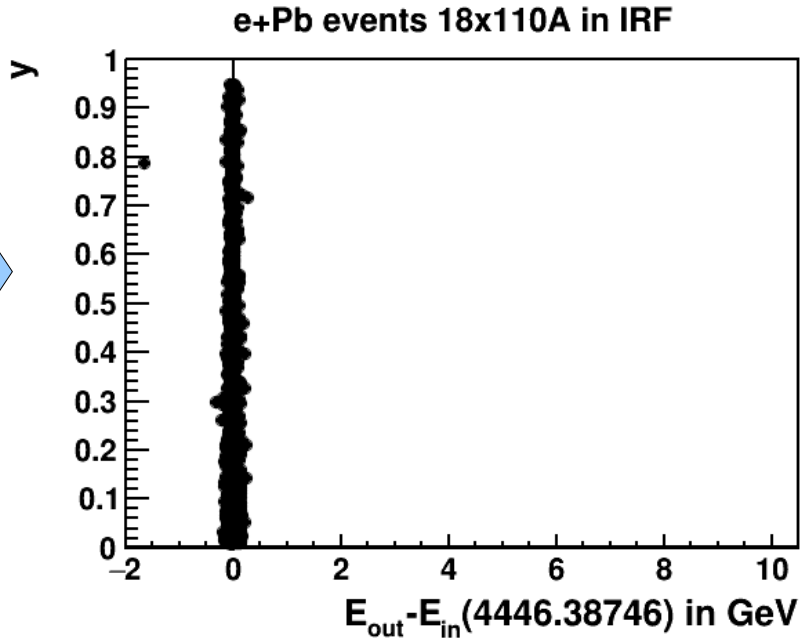


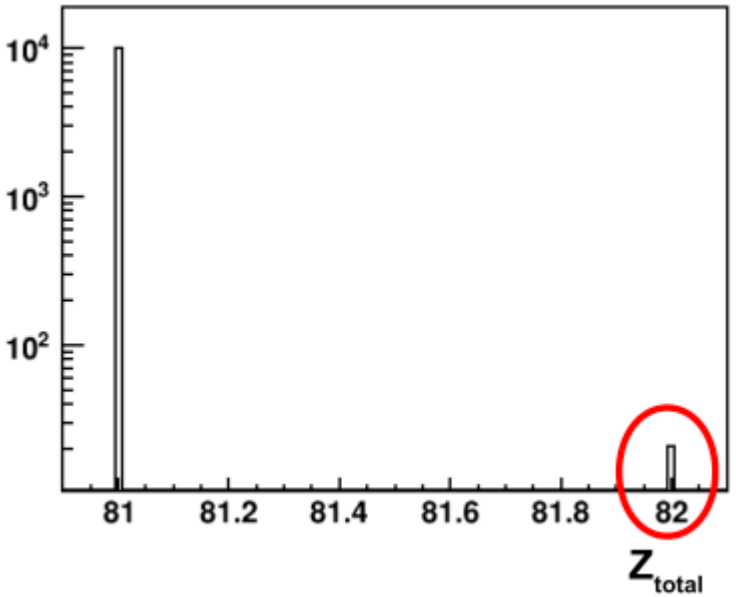
$e^- + {}^{208}Pb_{82}$ **should add up to 81**

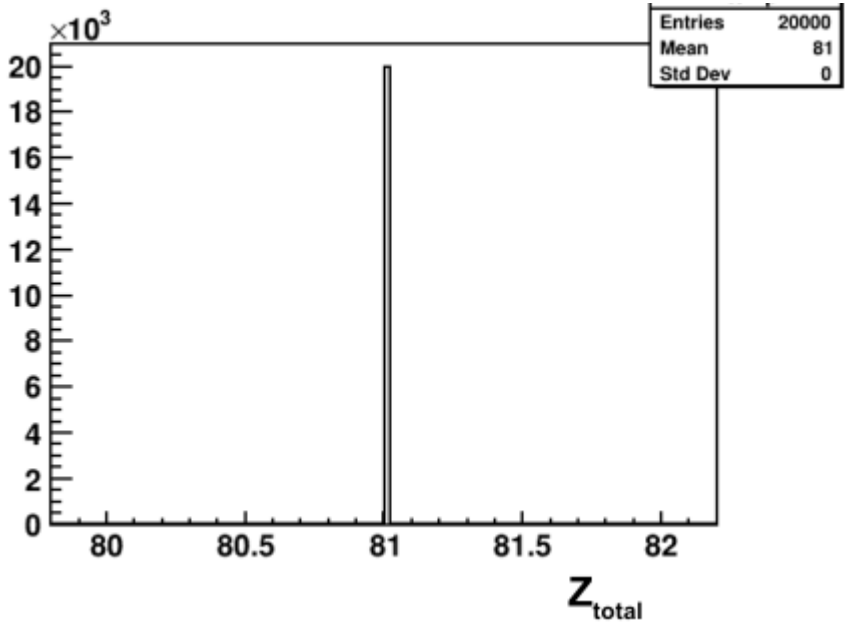


Conservation laws restored (mostly)

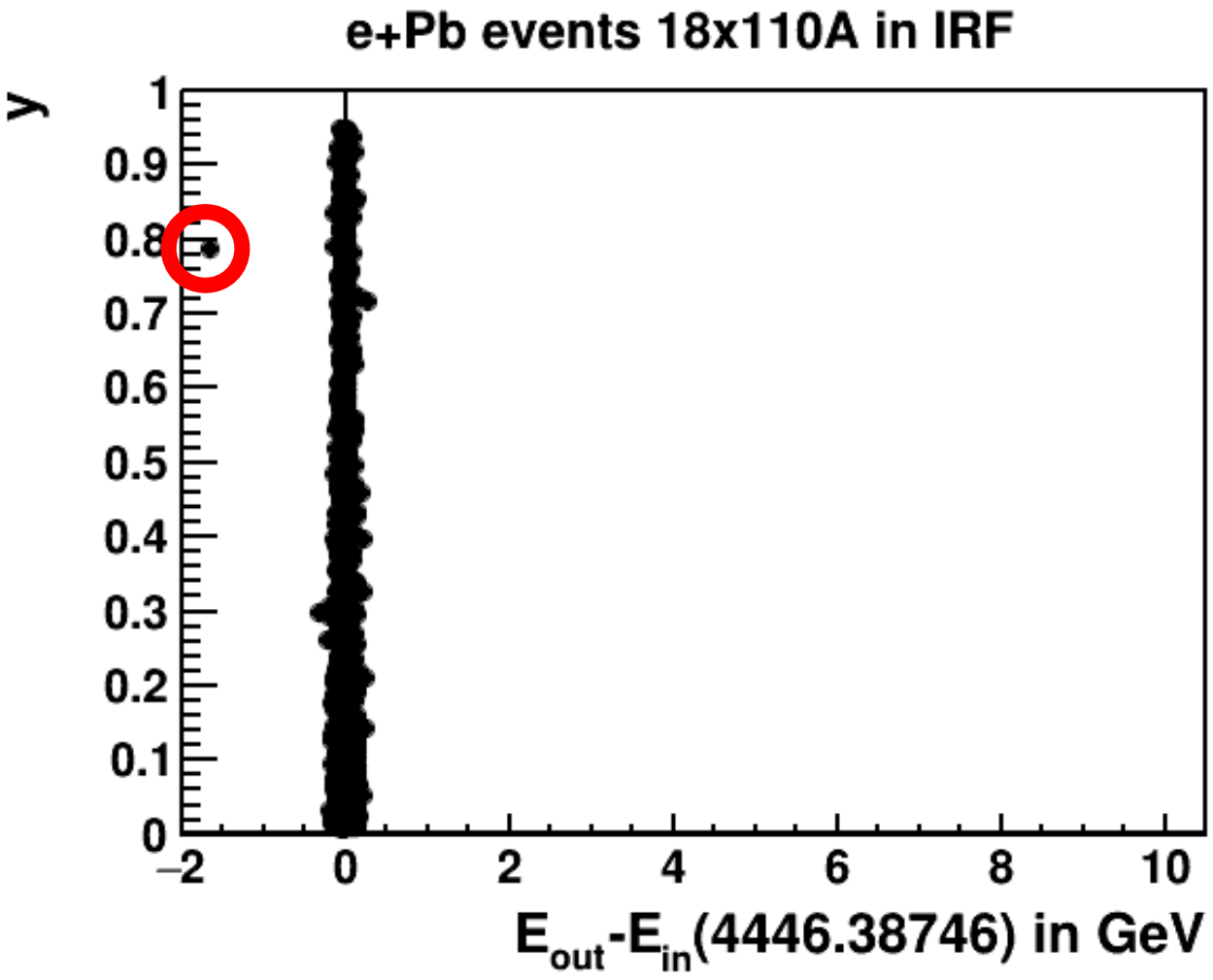








One bad event out of 10000 still to fix...



Annoying, but not highest priority right now.

Event is Pythia proc. 68:
$\gamma^* \rightarrow V$
V+N collision is $gg \rightarrow gg$

Followed by intranuclear cascade…

Priority 2: Technical Progress

Feature added or error corrected	01/2019	06/2019	07/2019
1-8,10,13-17,20-22. Completed BeAGLE tasks.	YES	YES	YES
9. Shadowing coherence length	NO	NO	NO
11a. Effective σ_{dipole} for J/ψ averaged over x & Q^2	YES	YES	YES
11b. Effective σ_{dipole} for ϕ averaged over x & Q^2	YES	YES	YES
11c. Eff. $\sigma_{dipole}(x,Q^2)$ for V=ψ,ϕ,ρ,ω from Sartre (ePb)	NO	NO	NO
11d. Use correct $R_{diff}^{(A=208)}(x,Q^2)$ for V from Sartre	NO	NO	NO
11e. Improved σ_{dipole} for V, if necessary	NO	NO	NO
12a. Understand E665 Event Trigger (& Q^2 dist.)	NO	Started	Started
12b-?. Tune to E665 μA Streamer Chamber data	NO	NO	NO
18. Tune the t distribution for multiple scattering.	NO	NO	NO
19a. Release α version BeAGLE/RAPGAP	YES	YES	YES
19b. Release β version BeAGLE/RAPGAP	YES	YES	YES
19c. Fix charge non-conservation bug (DPMJET-F)	NO	YES	YES
19d. Fix lost energy bug (DPMJET-F)	NO	YES	YES
19e. Fix excess energy bug (DPMJET-F?)	NO	NO	YES
19f. Release tested version BeAGLE/RAPGAP	NO	NO	NO
19g. Extend RAPGAP to include e+n (w/ H. Jung)	NO	NO	NO
22a. Update relative nucleon mom. dists. for e+D	YES	YES	YES
22b. Variety of well-motivated distributions for e+D	NO	NO	YES
23a. Put e+D on mass-shell (ad-hoc)	YES	YES	YES
23b. Put e+D on mass-shell, light-cone prescription	NO	NO	NO
24. Fix J/ψ & ϕ to decay outside the nucleus	NO	YES	YES

Started

bugs fixed

added

fixed

Priority 2: Technical Progress & Plans

Feature added or error corrected	01/2019	06/2019	07/2019
1-8,10,13-17,20-22. Completed BeAGLE tasks.	YES	YES	YES
9. Shadowing coherence length	NO	NO	NO
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24. Fix J/ψ & ϕ to decay outside the nucleus	NO	YES	YES

Started, high priority now

bugs fixed

high priority now

added

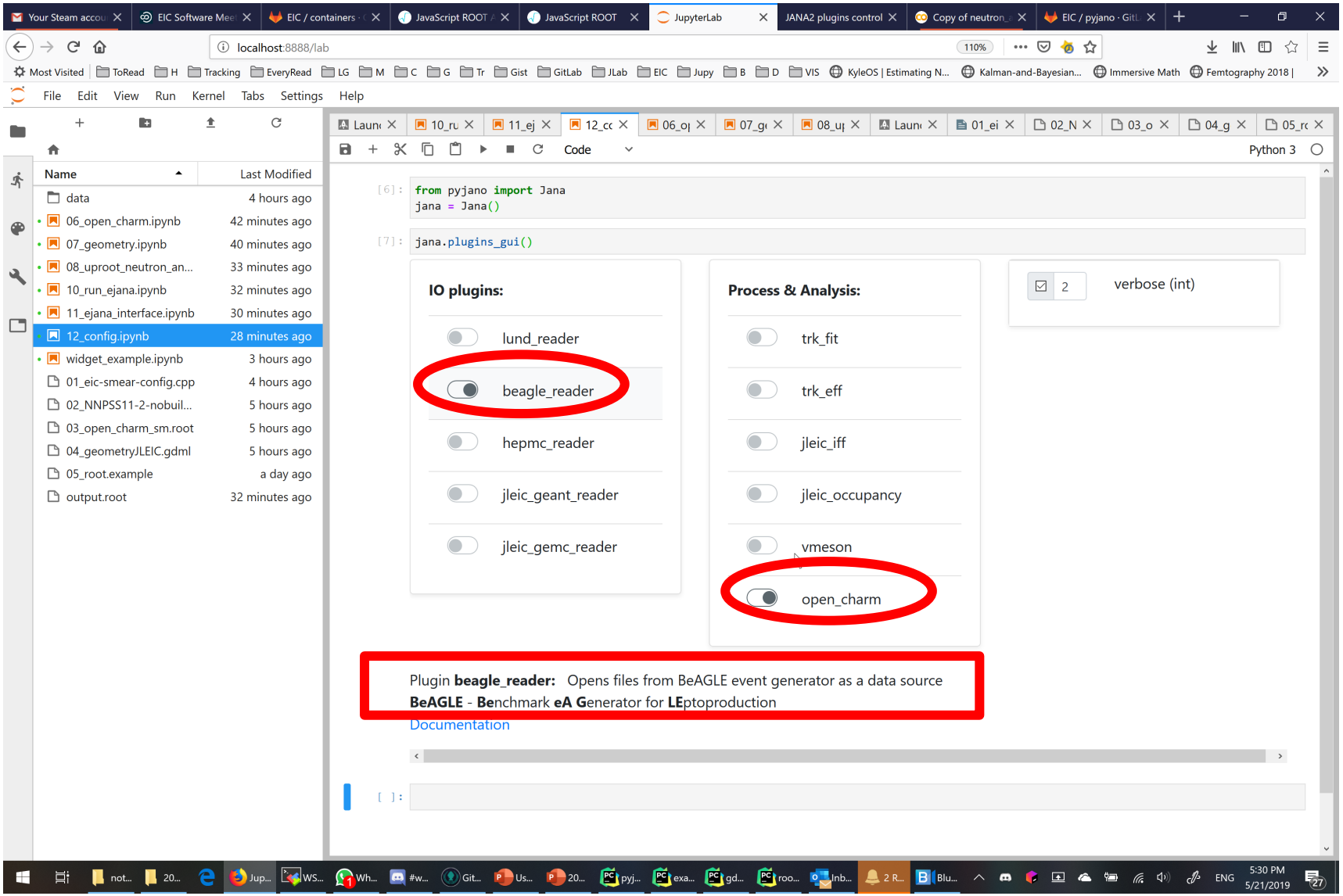
high priority now

fixed

BeAGLE expertise is becoming widespread!

Dmitry Romanov: EPIC – Entry Point for EIC Simulation and Analysis

Talk yesterday: EIC Software Meeting on Det. & Phys. Sim. https://indico.bnl.gov/event/6336/



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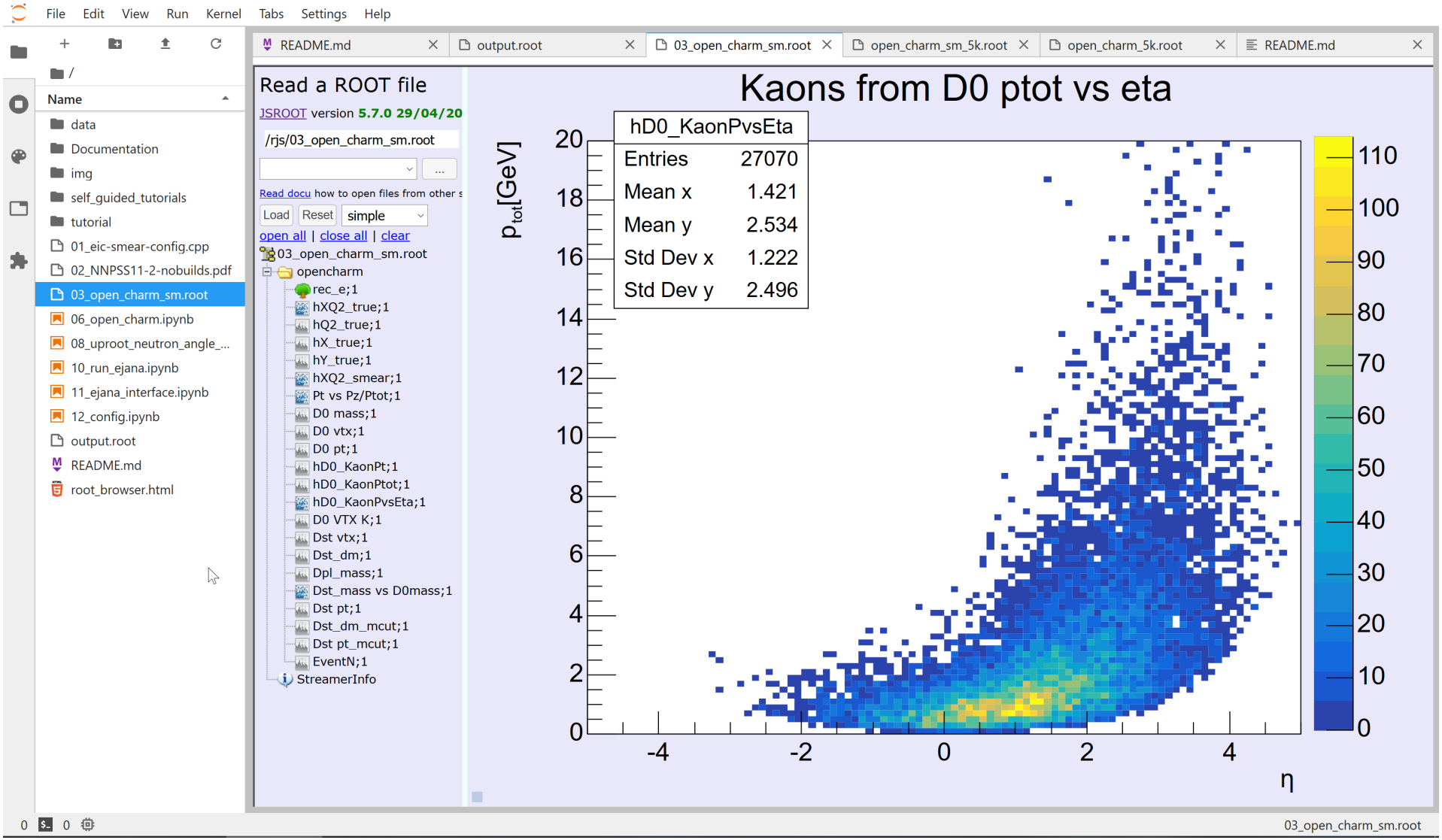


Response to Committee Recommendations

January 2019 Committee Report:

The proponents are responsive to committee recommendations and suggestions; in particular, they addressed the committee recommendations made in July as follows:

> *Spreading BeAGLE expertise more widely*: as well as increasing awareness of the project by attendance at workshops and conferences, they have taken the very important step of clear documentation of the program on GIT such that anyone can now run it.
>
> *Accelerating the work*: they propose to retain the student Chang by paying for her accommodation, should funds be granted. This request is supported by the committee.
>
> *Addressing continuity*: There is a growing base of developers and this is welcomed by the committee. Baker is available at 25% for eRD17. The funding for this both now and in the future is essential.

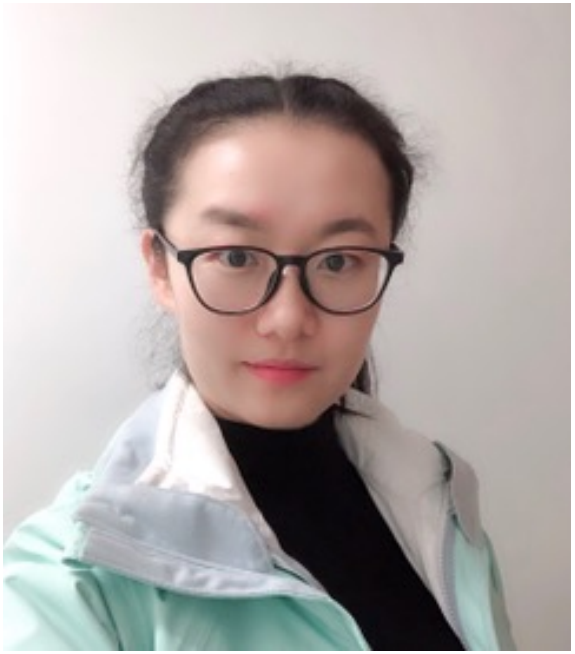
- Point 1 (widespread expertise): EPIC project at JLAB (for JLEIC / EIC) implemented BeAGLE in a general framework with NO developer input.

- Current proposal in line with points 2 (Chang) and 3 (Baker) above.
  - 3 months accomodation for Chang (0.5 FTE 50% covered by BNL)
  - Support for Baker @ 0.25 FTE

Accelerating the Work

Wan Chang, supervised by Elke, working on a day-to-day basis with Kong Tu with support from Baker is now a proven formula!

Plan: Use this approach for BeAGLE tuning.



No funds were available for committee-suggested FY2019 Supplemental Proposal.

FY2020 proposal

Wan Chang – travel support (per diem + housing only)

0.5 FTE x 50% split w/ BNL = 3 months x $5000/month

FY2020 Budget Proposal

Person	Institution	Effort (FTE-year)	Cost to Proposal	Remarks
E. Aschenauer	BNL	0.05	\$0	cost covered by BNL
M.D. Baker	MDBPADS[18]	0.25	\$65,520	
W. Chang	CCNU/BNL	0.50	\$0	salary covered by CCNU
J.H. Lee	BNL	0.05	\$0	cost covered by BNL
Z. Tu	BNL	0.20	\$0	cost covered by BNL
L. Zheng	CUGW	0.10	\$0	salary covered by CUGW
TOTAL:		1.15	\$65,520	

Table 2: Personnel Budget Breakdown for FY2019

Item	Cost
Personnel:	\$65,520
Chang per diem and housing	\$15,000
Zheng Travel	\$6,000
Other Travel	\$1,500
TOTAL:	\$88,020

Table 3: Total Budget Breakdown for FY2020

Proposal in line with committee recommendataions.

External Support

- Salaries from home institutions (for eRD17):
  E. Aschenauer, W. Chang, J.H. Lee, Z. Tu, L. Zheng
  Leverage: 1.15 FTE vs. 0.25 FTE
- Baker support (synergistic) also from:
  JLAB LDRD: "Short-range correlations in medium-to-heavy nuclei at JLEIC"
  MDB, F. Hauenstein, D. Higinbotham (PI), O. Hen, C. Hyde, V. Morozov, ZT, P. Nadel-Turonski, LZ
  - Also collaborating with BNL/SBU SRC effort:
    A. Deshpande, B. Shmookler (postdoc), T. Ullrich
  - Synergy is technical + physics input

Impact of reduced budget

Funding Level	%Funding	Baker FTE	Travel	Result
$88,020	100%	0.25 FTE	$22.5k travel	FY2020 goals completed
$70,420	80%	0.25 FTE	$5k travel	Goals may slip
$52,810	60%	0.20 FTE	$0 No travel	Unlikely to finish in FY2020

Table 4: Impact of Reduced Funding in FY2020

- Forward Detector/IR design is very advanced.
- Many studies in progress at both laboratories.
- Need to understand how well these designs address critical e+A physics goals as well as any tradeoffs.
- A validated/tuned BeAGLE is quite urgent and should not be delayed.

FY2020 Milestones

- January 2020
  - BeAGLE cleanup
  - Full RAPGAP installation
  - Submit a paper
- April 2020
  - Compare BeAGLE to E665 Data
- September 2020
  - Tuning complete

Conclusions

- BeAGLE is used at both labs to understand detector acceptances and requirements.
- BeAGLE expertise is growing rapidly.
  - Accessible and version-controlled.
  - Users are accomplishing things that the developers only find out about later.
- BeAGLE validation w/ RAPGAP & E665 data is progressing, but delayed.
  - As suggested by the committee in July 2018 & January 2019, we propose an additional $15k in student housing/per diem to accelerate the effort.

Extras

E665 triggered data vs. raw BeAGLE

Events information

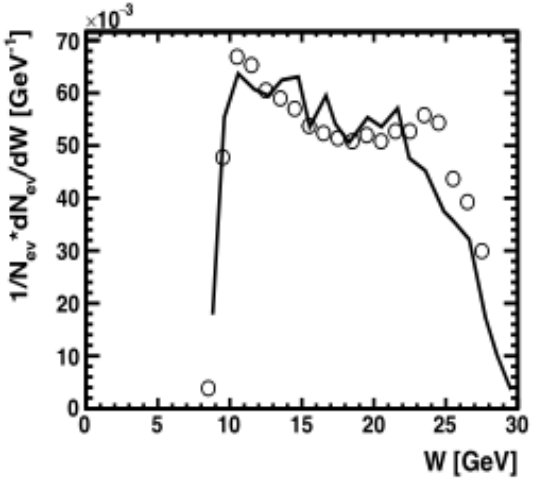
Z. Phys. C 61, 179-198(1994)

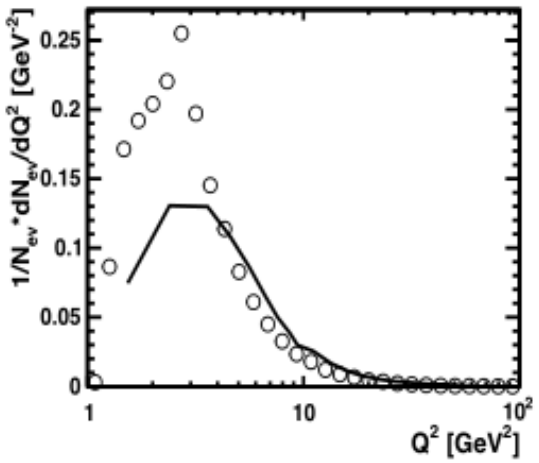
Data sample:

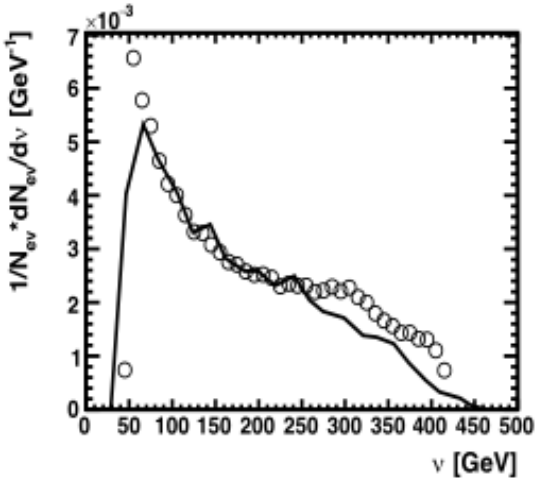
μ^++Xe
Beam momentum:
490 GeV × 0GeV

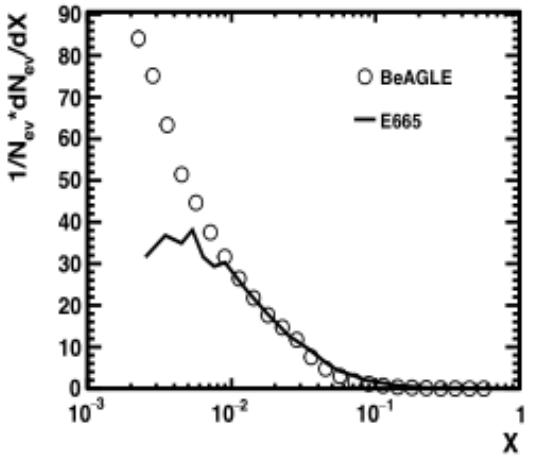
$0.1 < y < 0.85$
$1.0 < Q^2$<100
0.0035 rad < θ < 6.29 rad
8<W<30 GeV
X>0.002

40K events

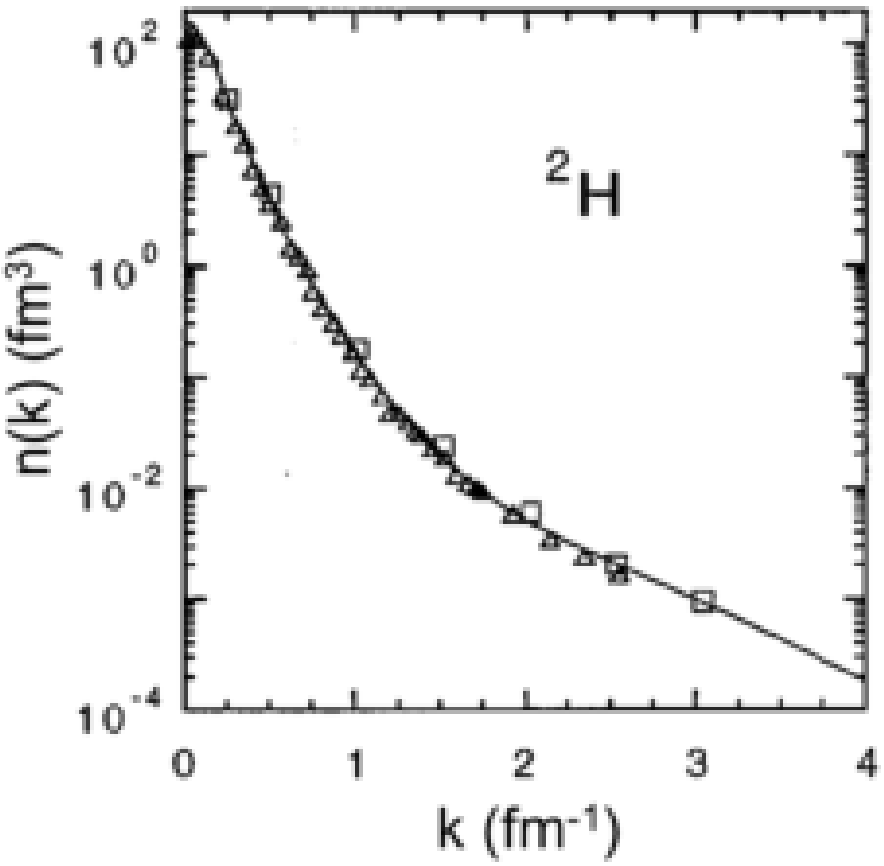








High k tails of nucleons in the deuteron



Hen et al., RMP 89 (2017)045002 Fig. 4
adapted from Fig. 1 of
Ciofi degli Atti, Simula, PRC 53 (1996) 1689

Variable k = nucleon momentum wrt deuteron cm: generalized "Fermi momentum".

$n(k) = k^{-2}\, dN/dk = \int d\Omega (d^3N/dk^3)$

$fm^{-1} \sim 197$ MeV

The curve is theory. Squares & triangles are data from:

C. Ciofi degli Atti et al., PRC 43 (1991) 1153;
M. Berheim et al.: NPA 365 (1981) 349;
S. Turck-Chieze et al.: PLB 142 (1984) 145.

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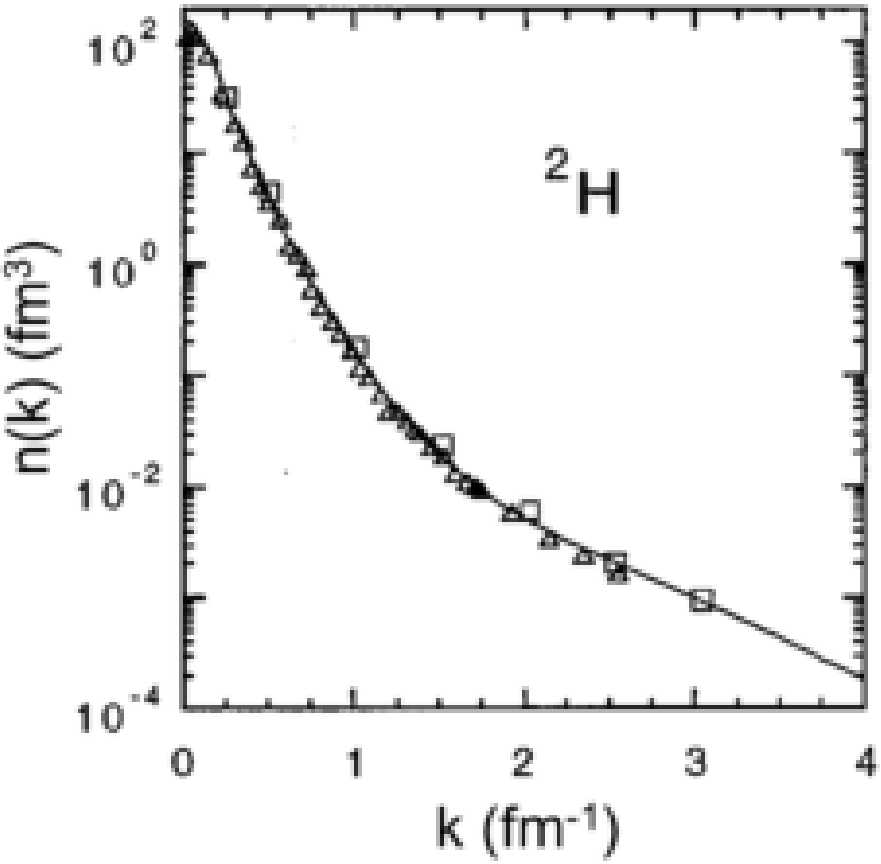

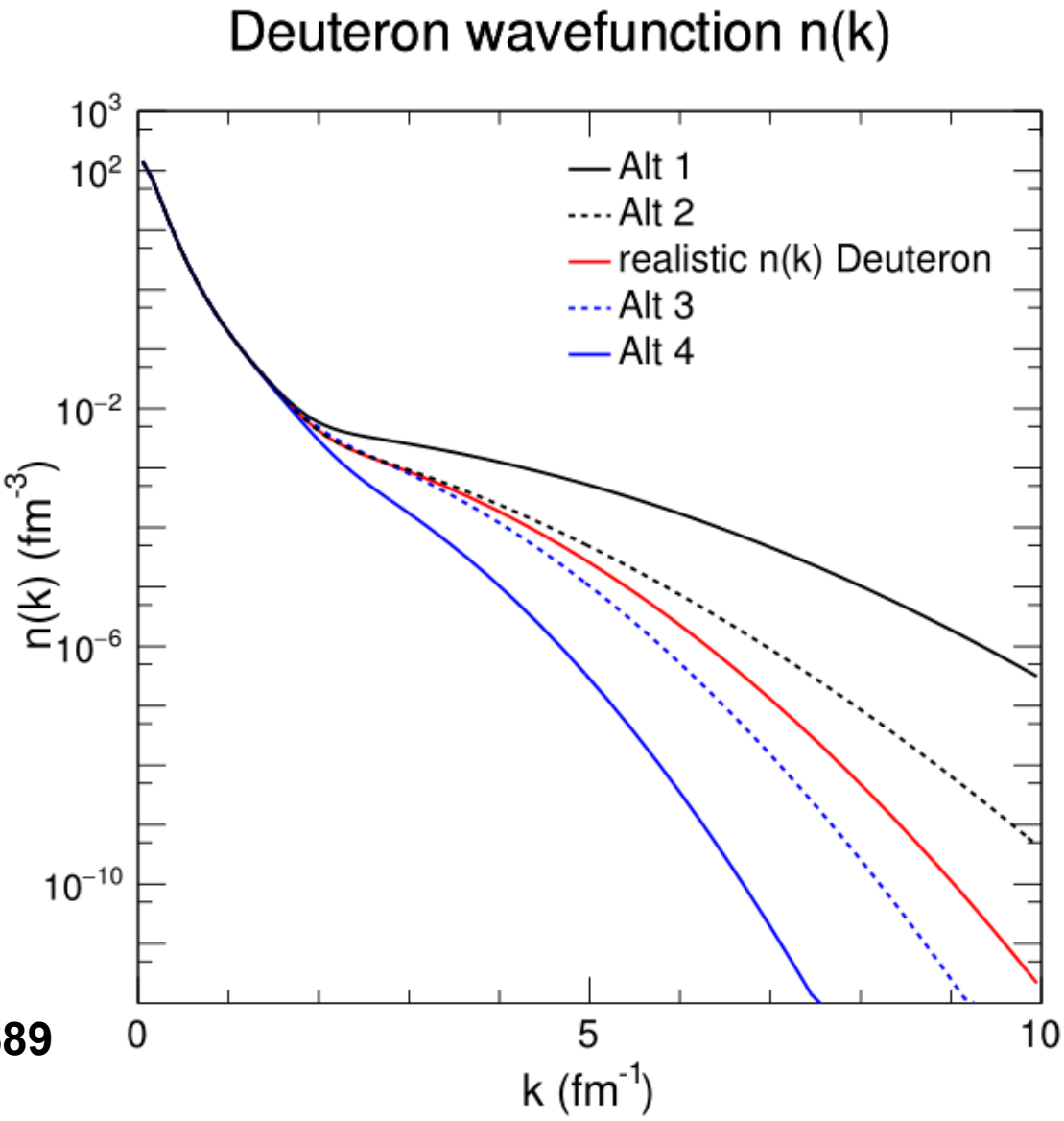

Hen et al., RMP 89 (2017)045002 Fig. 4
adapted from Fig. 1 of
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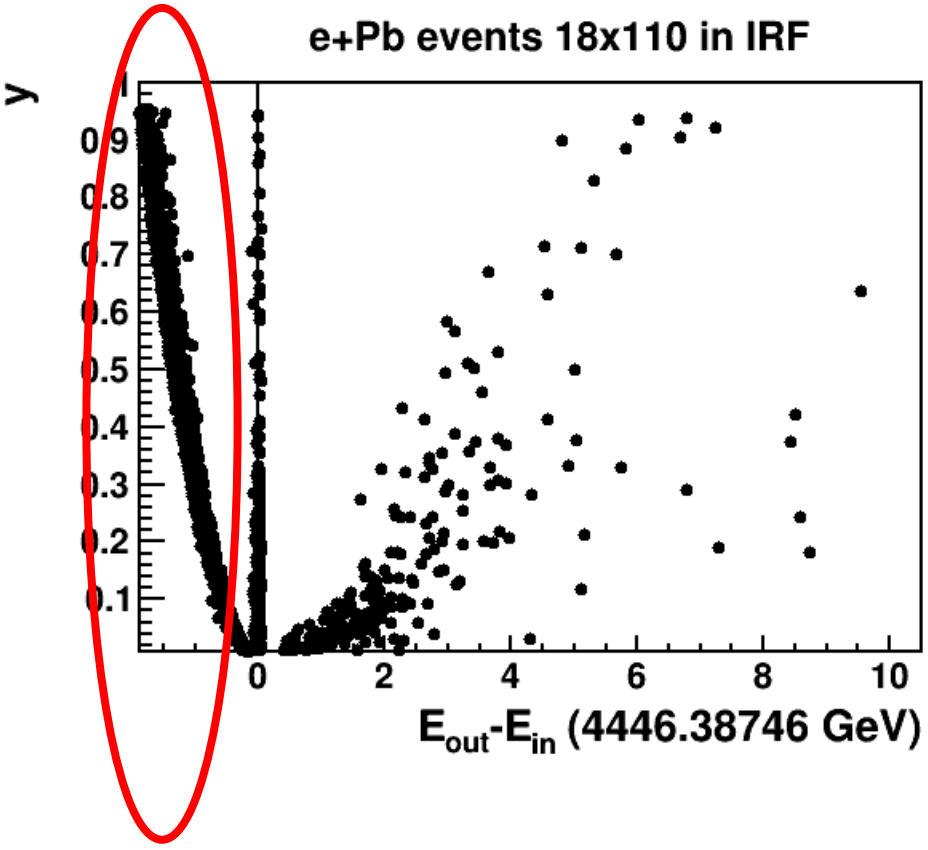
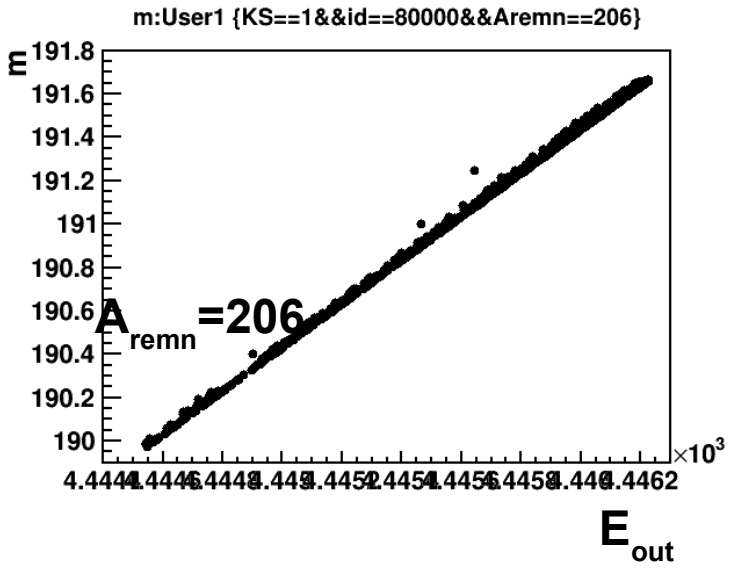
Energy loss bug

Type 1 events are due to a bug in DPMJET-F. A perfectly valid excited remnant has it's 3-momentum scaled to a slightly incorrect value, leading to an inconsistent description in terms of p^{μ},M, E*. This confuses Fluka which returns the final ground state nuclear remnant with the wrong mass, e.g.:

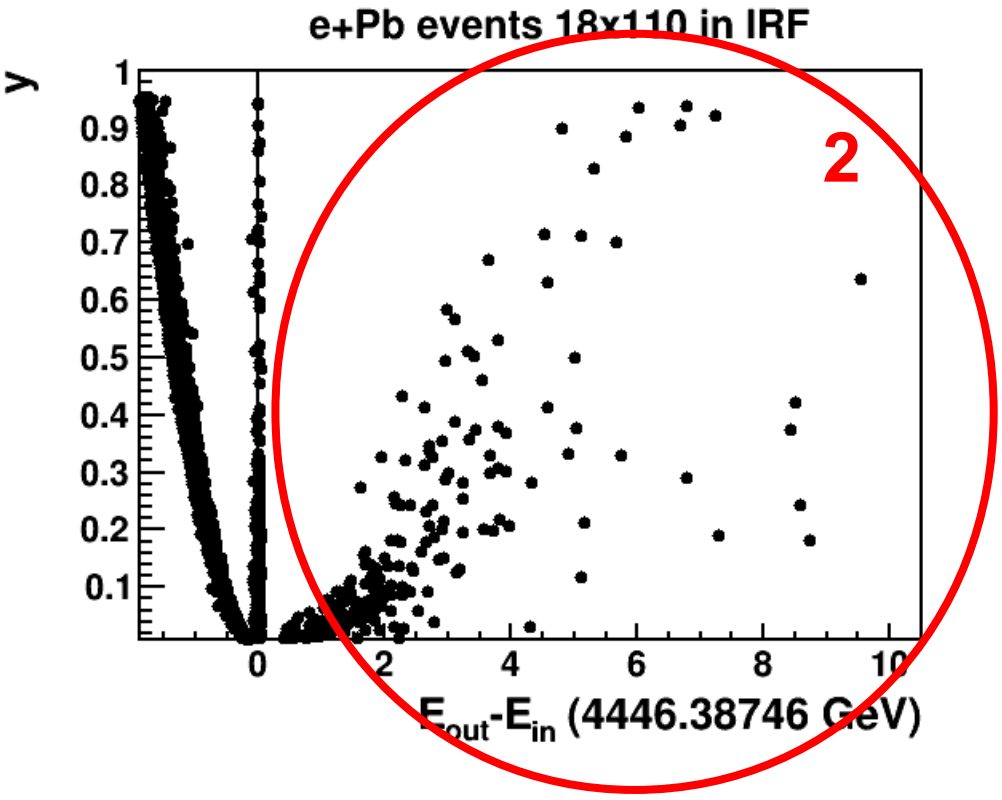
1





Energy gain bug

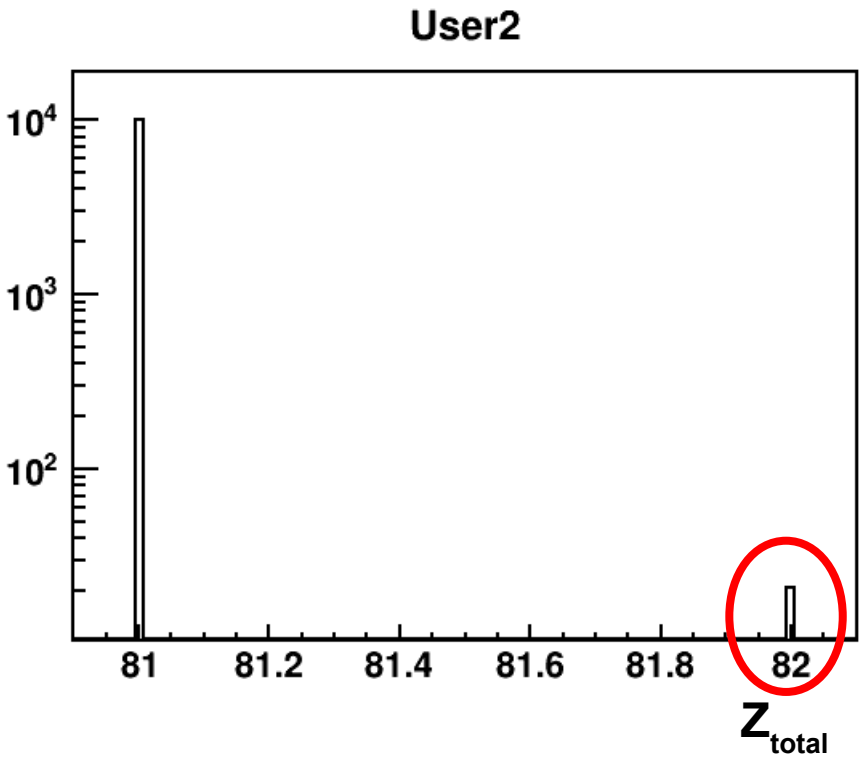
Type 2 is caused by a bug in BeAGLE during an intranuclear cascade. A low energy meson in the ion rest frame can sometimes be put back into the Pythia subevent which is in the γ^*+N HCMS frame without first applying the proper boost.



BeAGLE charge conservation bugfix

Cause: Incorrect handling of hypernuclei in DPMJET-F.

e- + $^{208}Pb_{82}$ should add up to 81



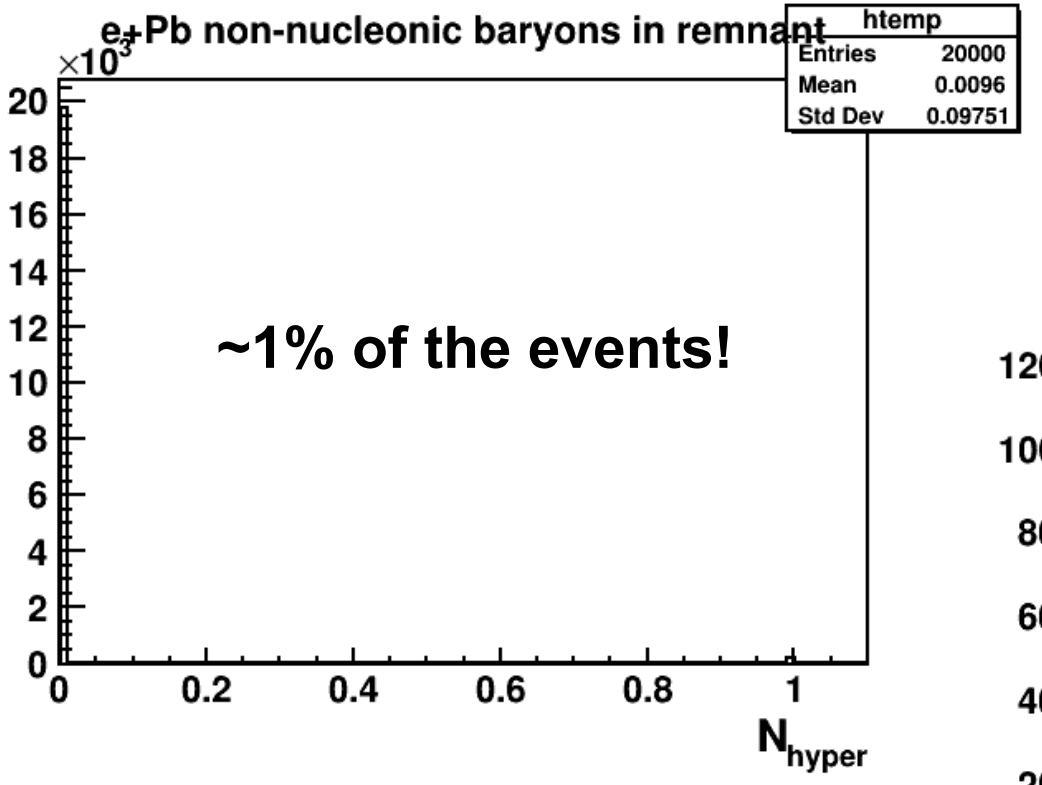
DPMJET-F assumes all nucleons which are not Z=+1 are Z=0. So nucleons like Σ^- are treated as n's.

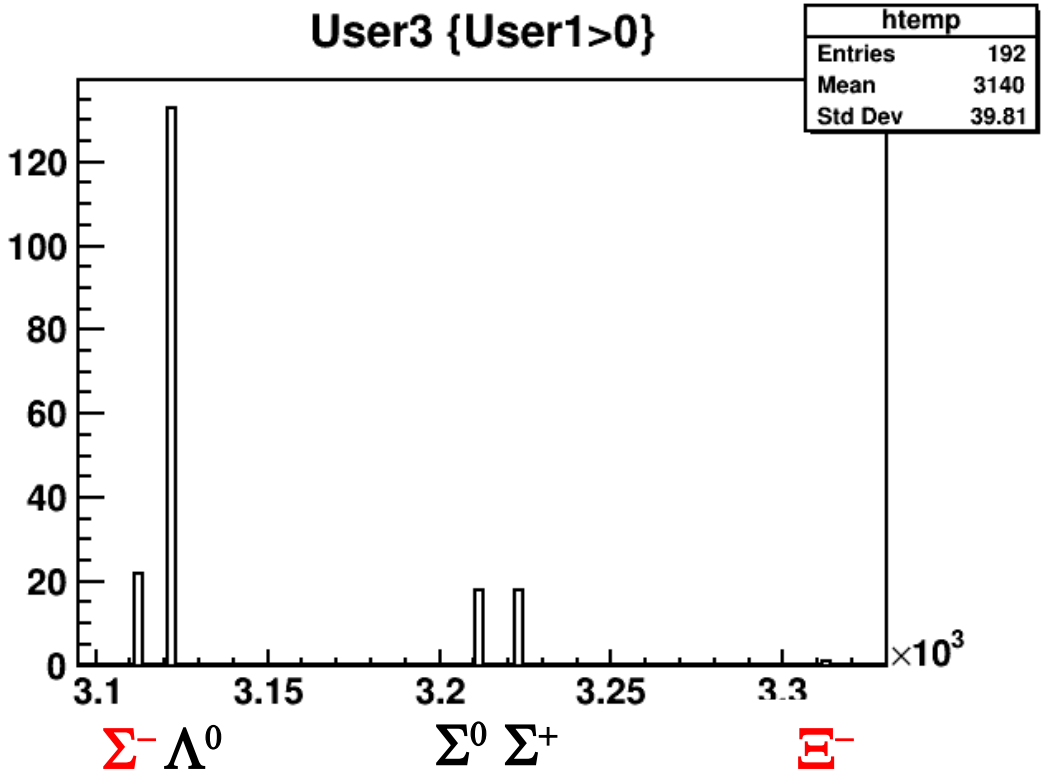
DPMJET, and therefore BeAGLE, has no provision for hypernuclei. FLUKA does, but we aren't using it.

We fixed the charge counting, but remnant has no strangeness, just the excess E*.

Proper handling of hypernuclei would be interesting, but would take time!

Hypernuclei in inelastic 18x110 e+Pb





All events have the correct Zsum now...