eRD17: BeAGLE

A Tool to Refine Detector Requirements for eA

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Outline

- Impact of COVID-19
- Project overview: FY2016-FY2020
  - Progress and Accomplishments since January
- Proposal for FY2021
  - Focus on implementing key "benchmark processes"
  - Bottom-up basis for needed effort.
  - Proposed (new) funding level similar to FY2020
  - Baker effort increases from 0.25 FTE to 0.45 FTE

Impact of COVID-19

- Zheng & Chang are based in Wuhan!
  - Safe and productive, but in China, not @ BNL.
  - Must work around internet latency issues & lack of in-person meetings (for all of us!).
- Temporary slowdown of E665-fitting and GEANT-based forward proton & neutron detection studies, but back on track now.
  - More frequent ZOOM meetings.
  - Alex Jentsch (BNL postdoc) joined effort!
- Travel funding carryover: $28,500
  - Includes FY2019 (Zheng visa issues)

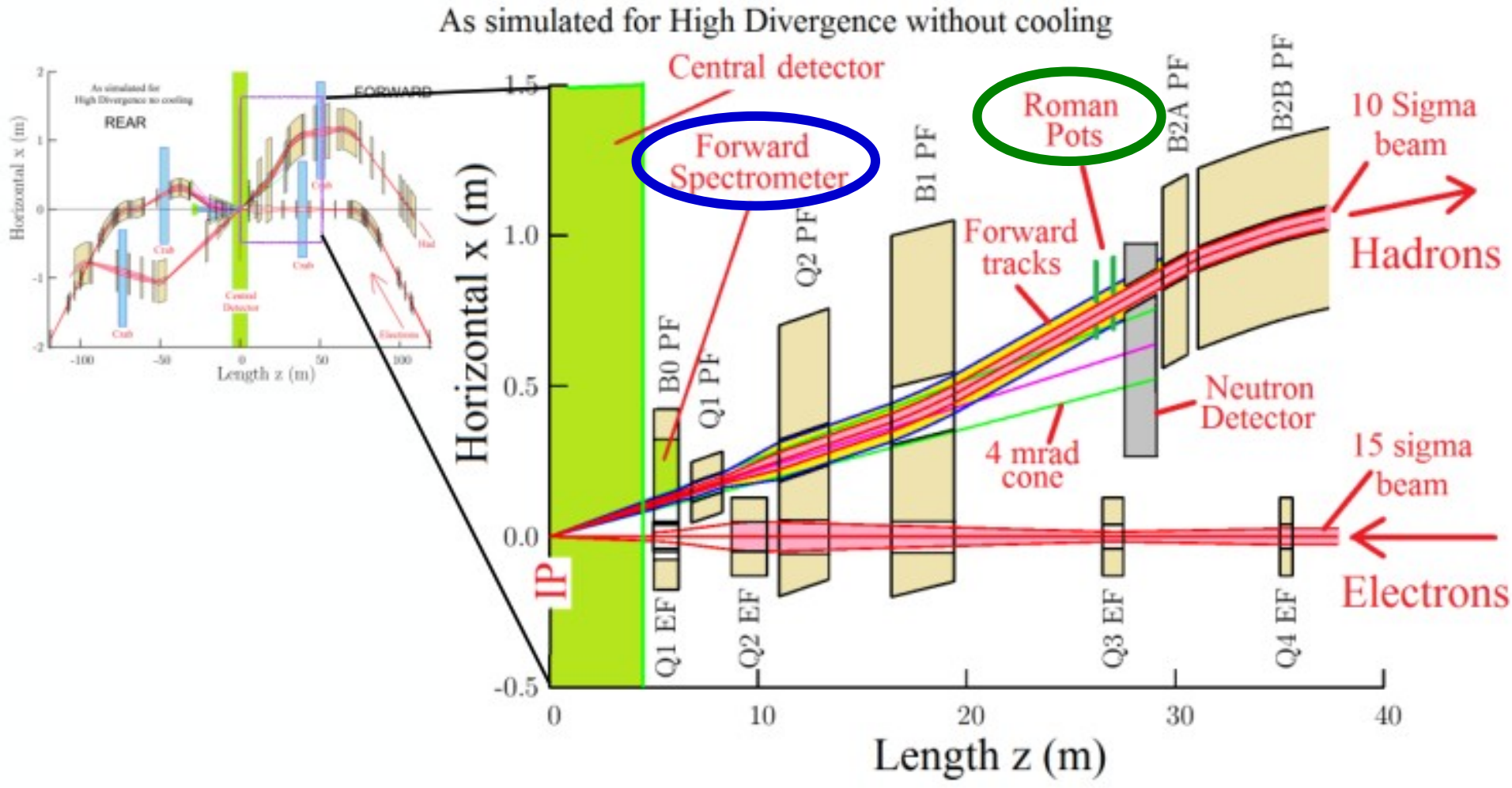
Alexander Jentsch

- Key person in eRD24 also.
- Research Associate, BNL
- Quickly became a leading expert on full GEANT simulation of forward detectors based on actual EIC accelerator IR design.
- Many talks in a wide variety of different Yellow Report working group meetings.
- Co-convener of YR Detector Working Group subgroup: Far-Forward Detectors

EIC R&D Project 17 (BeAGLE, the Saga)

- Initial Proposal (FY2016-2017) was somewhat narrow in focus.
- Key advice from committee Day 1 (July 2015):
  - "The committee encourages regular interaction between the developer and the expected user community".
- All feedback suggested that a more ambitious program was needed in the out years!
  - Forward Detector/IR design critical.
  - Supported by EIC R&D as well as JLAB LDRD and even a bit by MITLNS(!)

EIC IR design 2 years ago (BNL)

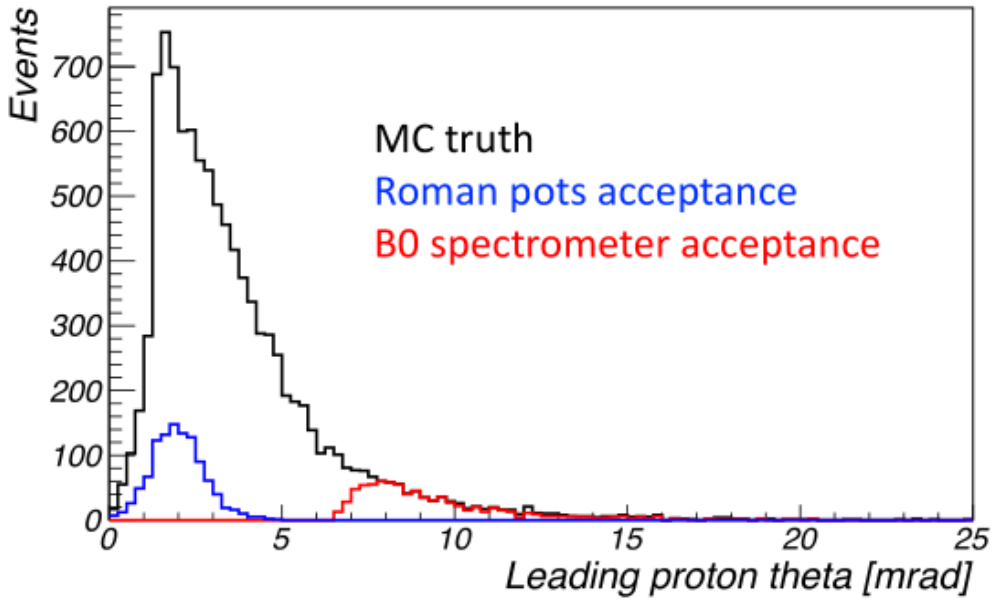


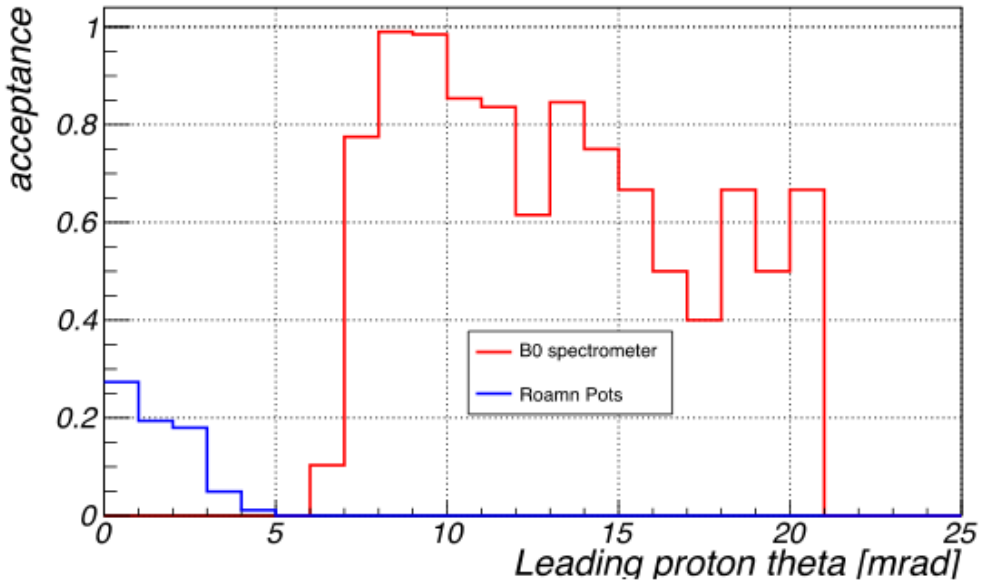
- Integrating requirements for hadron beam direction
  - Forward Detector (6 - 20 mrad)
  - Neutron detector ZDC (0 to 4 mrad)
  - Roman Pots (sensitive 1 to 5 mrad)

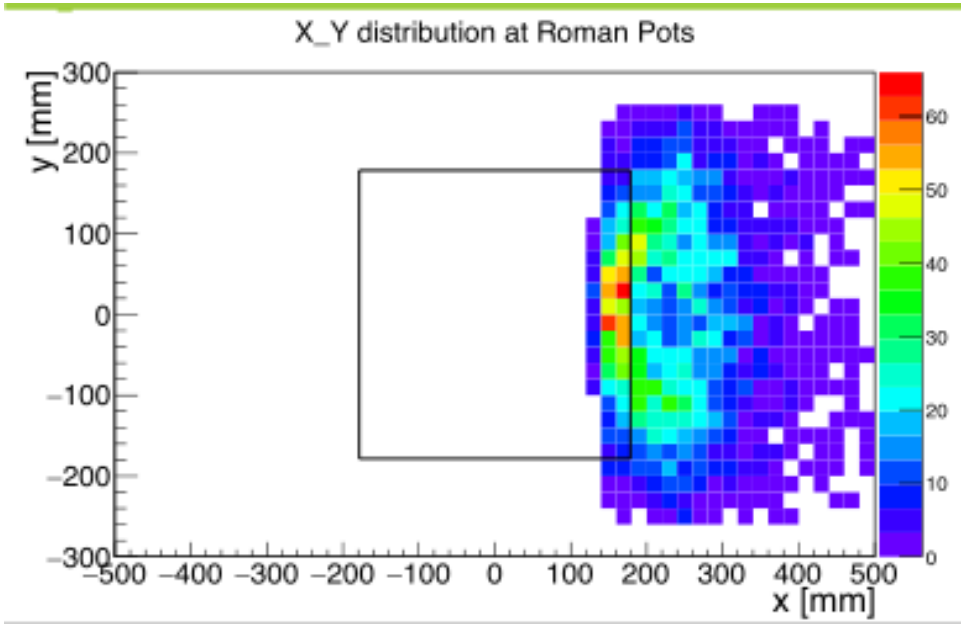
Good design for e+p

BeAGLE based studies from 1 year ago...

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

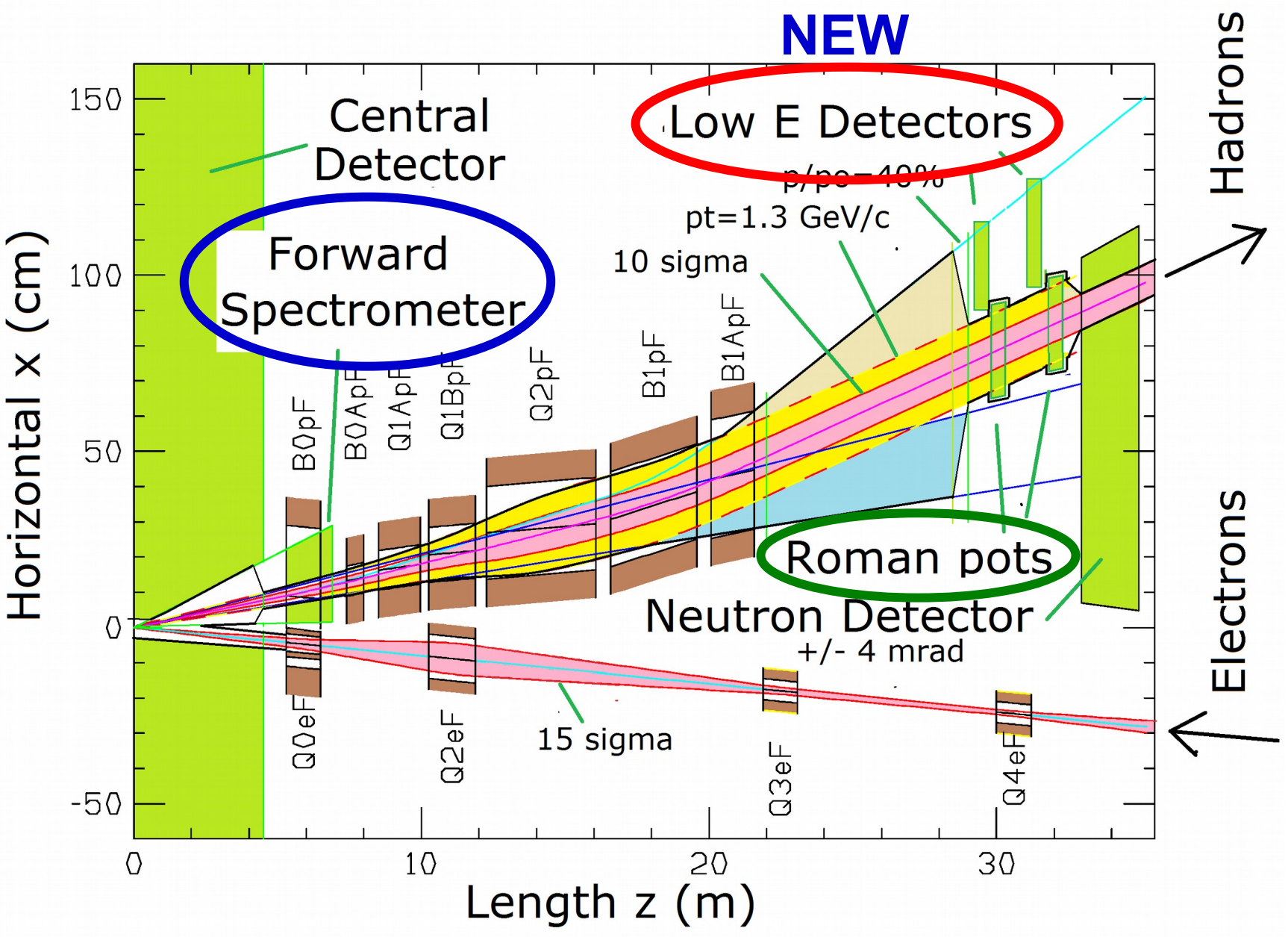






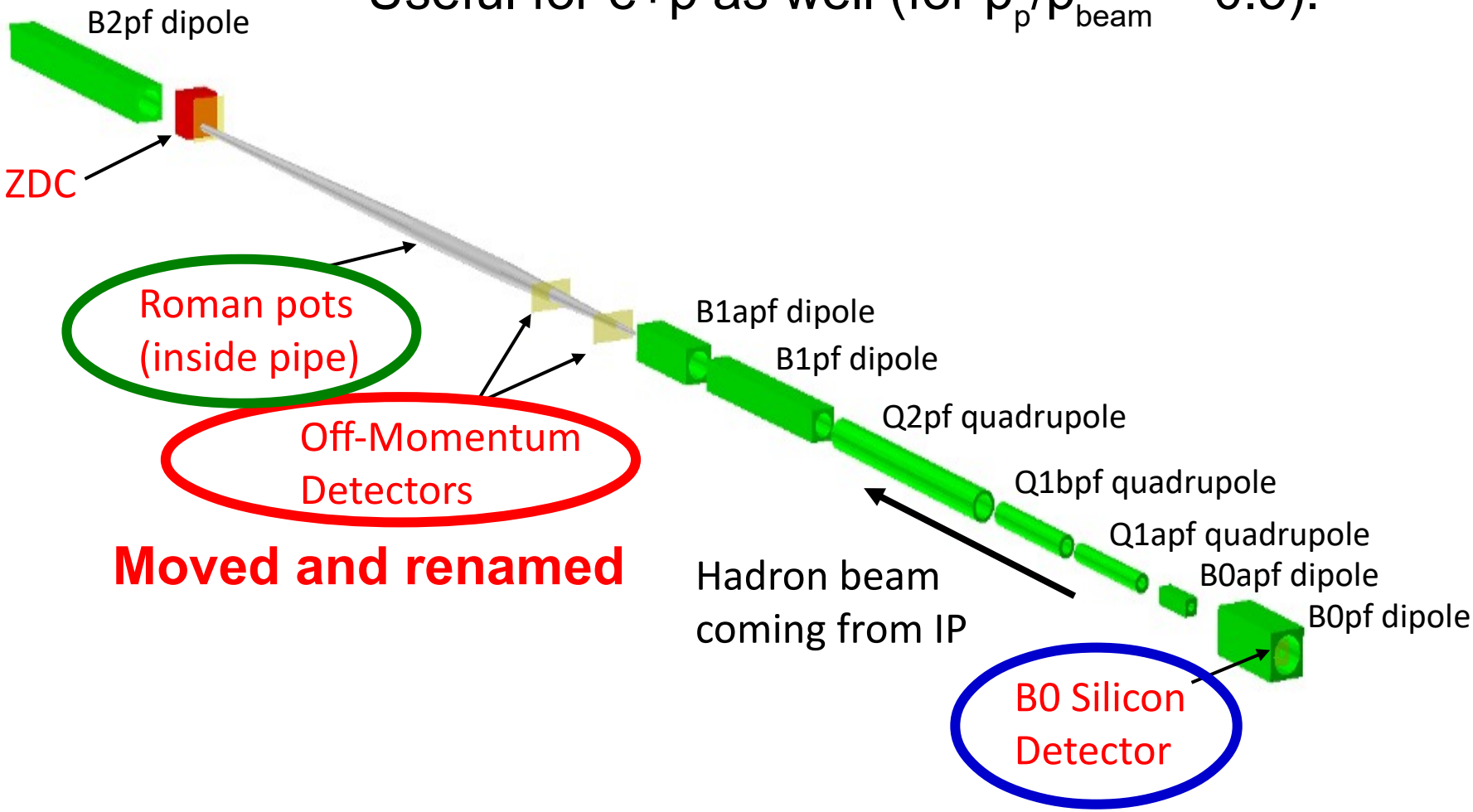
Roman pots were optimized for e+p. Need something else for e+A – claim real estate!

Forward Detector /IR (updated 1 year ago)

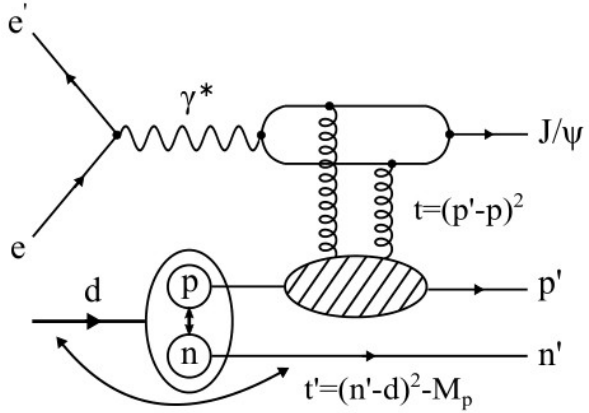


Latest Design being studied and optimized

Off-Momentum Detectors (formerly low E Detectors):
Essential for forward protons in e+A
Useful for e+p as well (for p_p/p_{beam} ~ 0.5).



BeAGLE in Action for the Yellow Report



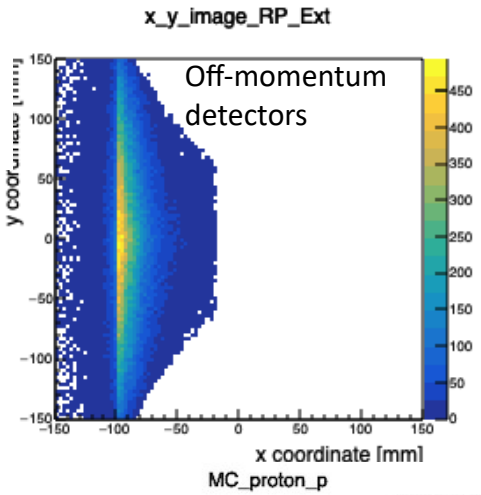
18 x 110 GeV e+D Neutron spectator case.

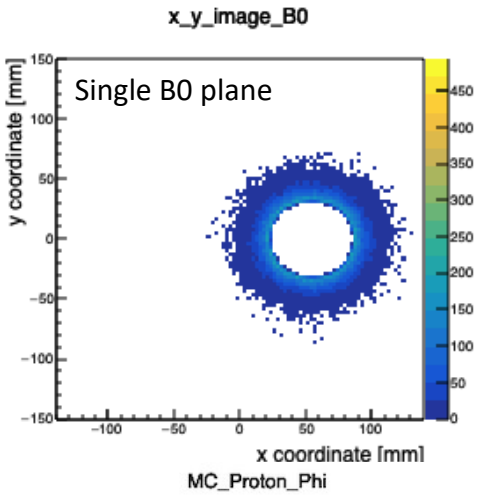
Incoherent diffractive J/psi production off bound nucleons.

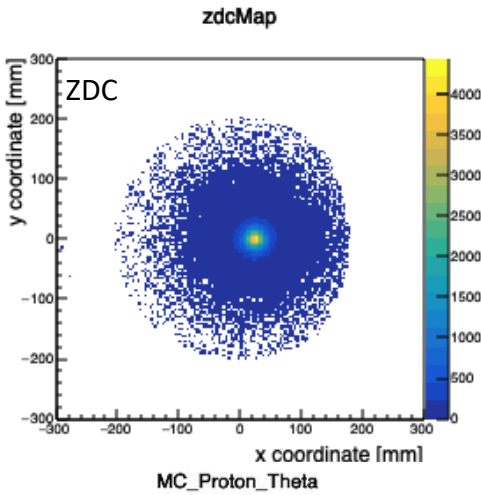
Well optimized detector!! **(for this process...)**

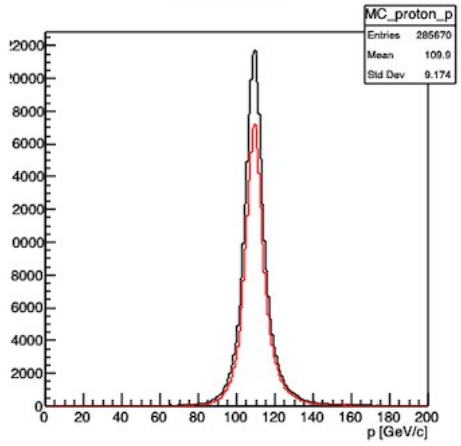
See arXiv:2005.14706

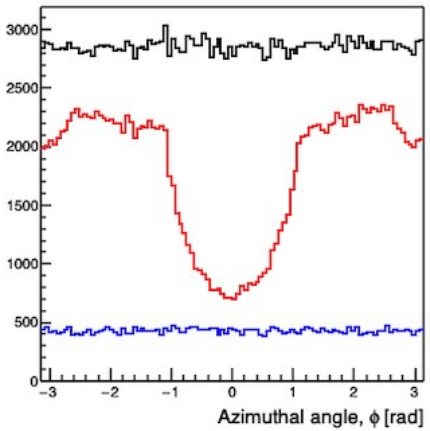
First publication from BeAGLE

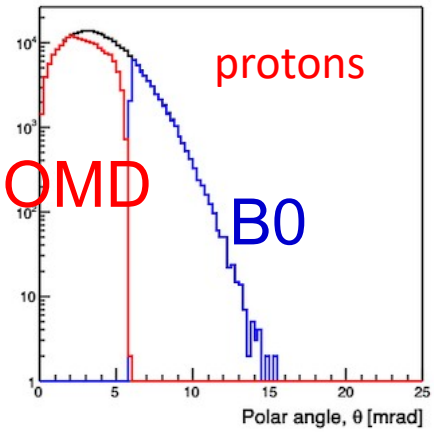












BeAGLE in Action for the Yellow Report

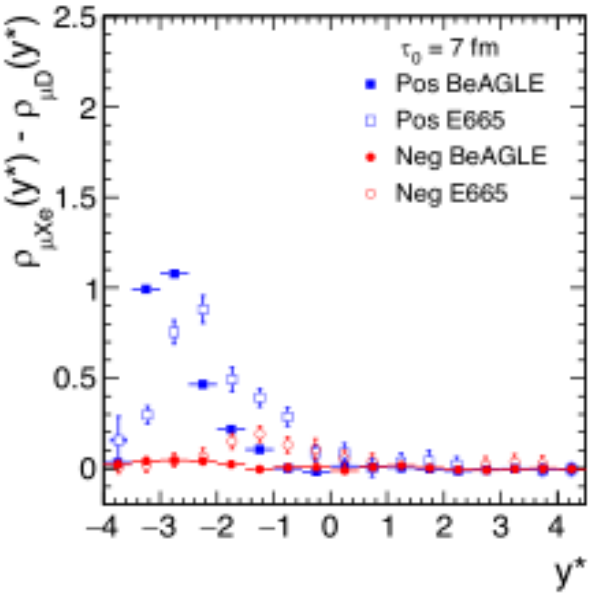
- Having the ability to study detector acceptances from e+A events has been crucial to understanding what additional detectors will be needed in the far-forward region to ensure delivery of the full EIC physics program.
  - BeAGLE has been instrumental to the successful Yellow Report studies that are ongoing, and which will be used for design and construction of the EIC detectors.
  - Just look through talks from last week's EICUG meeting on the Yellow Report status: "Exclusive Reactions WG" and the "Diffractive Reactions and Tagging WG"

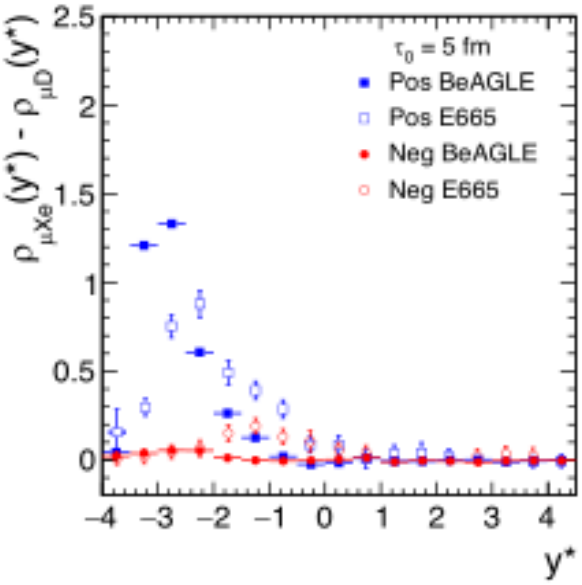
Comparison to E665

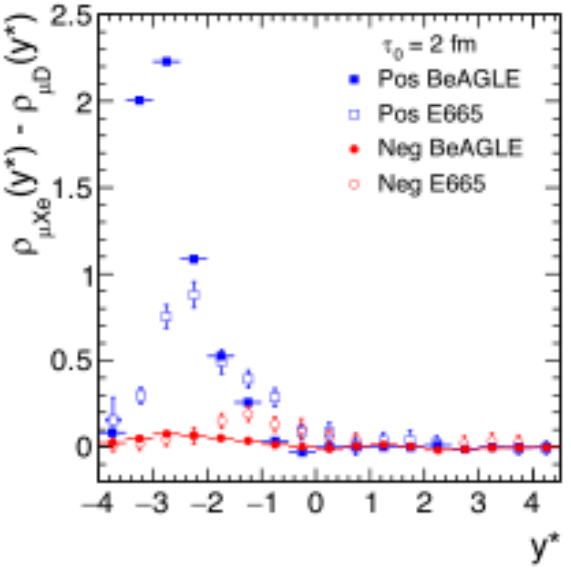
$$\rho_{\mu Xe}(y^*) - \rho_{\mu D}(y^*)$$

y* = rapidity in γ*N cm with γ* along +z

Difference of the normalized cms-rapidity distributions between muXe and muD scattering, for positive (blue) and negative hadrons (red) with different tau0:







- Amount of INC “protons” is right for τ_0=7fm/c & wrong for 2 fm/c, confirming a similar conclusion from the neutrons.
- Longitudinal momentum (y*) distribution is shifted by ~ 0.6 units.

Project Summary so far (FY2016-2020)

- The project has been a success!
  - Thanks to the committee and JLAB! Without it we would be flying blind regarding eA.
    - Released BeAGLE version.
    - Submitted paper (and more to come).
    - Used heavily during the Yellow Report process
    - Providing insight into Forward Detector/IR design and tradeoffs.
- Key Committee Recommendation (Jan. 2020)
  - "... would like to see an implementation of a selected set of benchmark channels ... for designing the EIC detectors".

Identifying the key benchmarks

Benchmark e+A processes for Detector/IR optimization using BeAGLE (or BeAGLE + GCF)

Incoherent diffractive V = (J/ψ or ϕ) production:

$e + Pb \rightarrow e' + V + X$	veto tagging for coherent diff. (gluon distribution and saturation)
$e + Pb \rightarrow e' + J/\psi + X$	comparison to e+D or e+p for nucleon "shape" studies in nuclei
$e + Pb \rightarrow e' + J/\psi + X$	geometry tagging for nucleon "shape" studies in nuclei

Short-range correlation studies A = (C or Pb e.g.):

$e + D \rightarrow e' + J/\psi + n + p$	Kinematically tagged deuteron tail (SRC) studies at any x
$e + C \rightarrow e' + J/\psi + (NN)_{SRC} + X$	Kinematically tagged SRC correlation studies at any x
$e + D \rightarrow e' + n + p$	Quasi-elastic deuteron studies
$e + C \rightarrow e' + (NN)_{SRC} + X$	Quasi-elastic SRC studies [higher Q^2, better detector(?)]
$e + A \rightarrow e' + (NN)_{SRC} + X$	SRC-tagged DIS studies in EMC region $0.2<x<0.8$
$e + A \rightarrow e' + X$ w/ SRC veto	SRC-vetoed DIS studies in EMC region $0.2<x<0.8$

Quasi-neutron DIS with proton spectators:

$e + D \rightarrow e' + p + X$	Measure quasi-free neutron structure function
$e + D \rightarrow e' + n + X$	Isospin inverse to confirm that proton SF extraction works
$e + {}^3He \rightarrow e' + p + p + X$	Access to neutron spin structure function
$e + {}^3H \rightarrow e' + n + n + X$	Isospin inverse to confirm spin proton SF extraction

Geometry tagged DIS:

$e + Pb \rightarrow e' + X$

Identifying the key benchmarks

with advice from the YR diffraction and tagging WG.
Important physics, challenging to the detector.

Benchmark e+A processes for Detector/IR optimization using BeAGLE (or BeAGLE + GCF)

Incoherent diffractive V = (J/ψ or ϕ) production:	
$e + Pb \rightarrow e' + V + X$	**veto tagging for coherent diff. (G distribution and saturation)**
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$e + D \rightarrow e' + n + p$	Quasi-elastic deuteron studies
$e + C \rightarrow e' + (NN)_{SRC} + X$	Quasi-elastic SRC studies [higher Q^2]
$e + A \rightarrow e' + (NN)_{SRC} + X$	**SRC-tagged DIS studies in EMC region 0.2<x<0.8**
$e + A \rightarrow e' + X$ w/ SRC veto	**SRC-vetoed DIS studies in EMC region 0.2<x<0.8**
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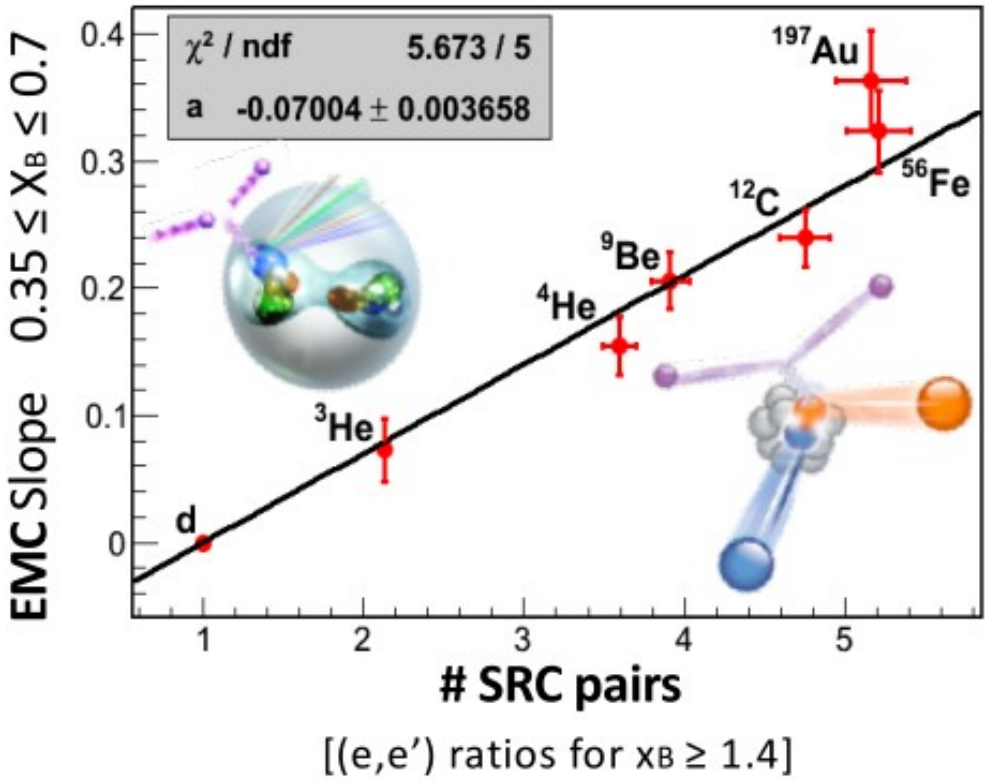
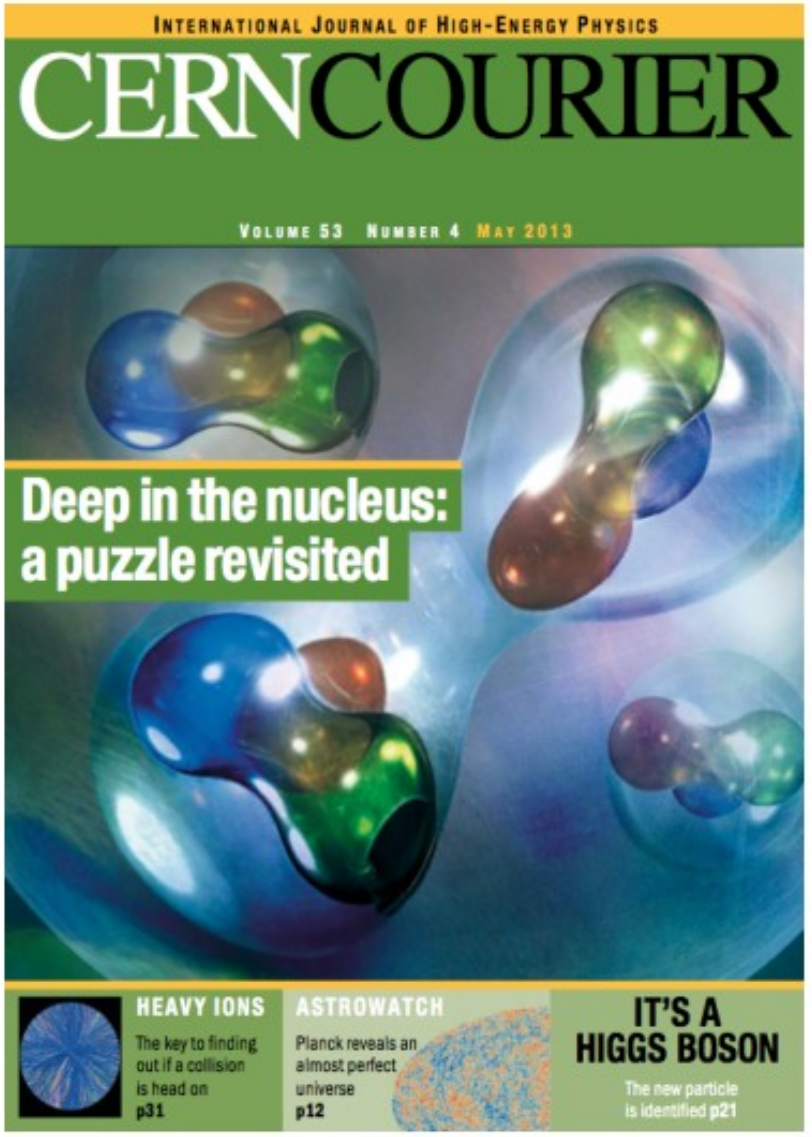
Geometry tagged DIS:	
$e + Pb \rightarrow e' + X$	

Is the EMC effect caused by SRCs?

Or Hen, INT Workshop July 2018



[(e,e') ratios for $x_B \geq 1.4$]



Higinbotham, Miller, **Hen**, and Rith. CERN Cour. 53N4, 35 (2013)

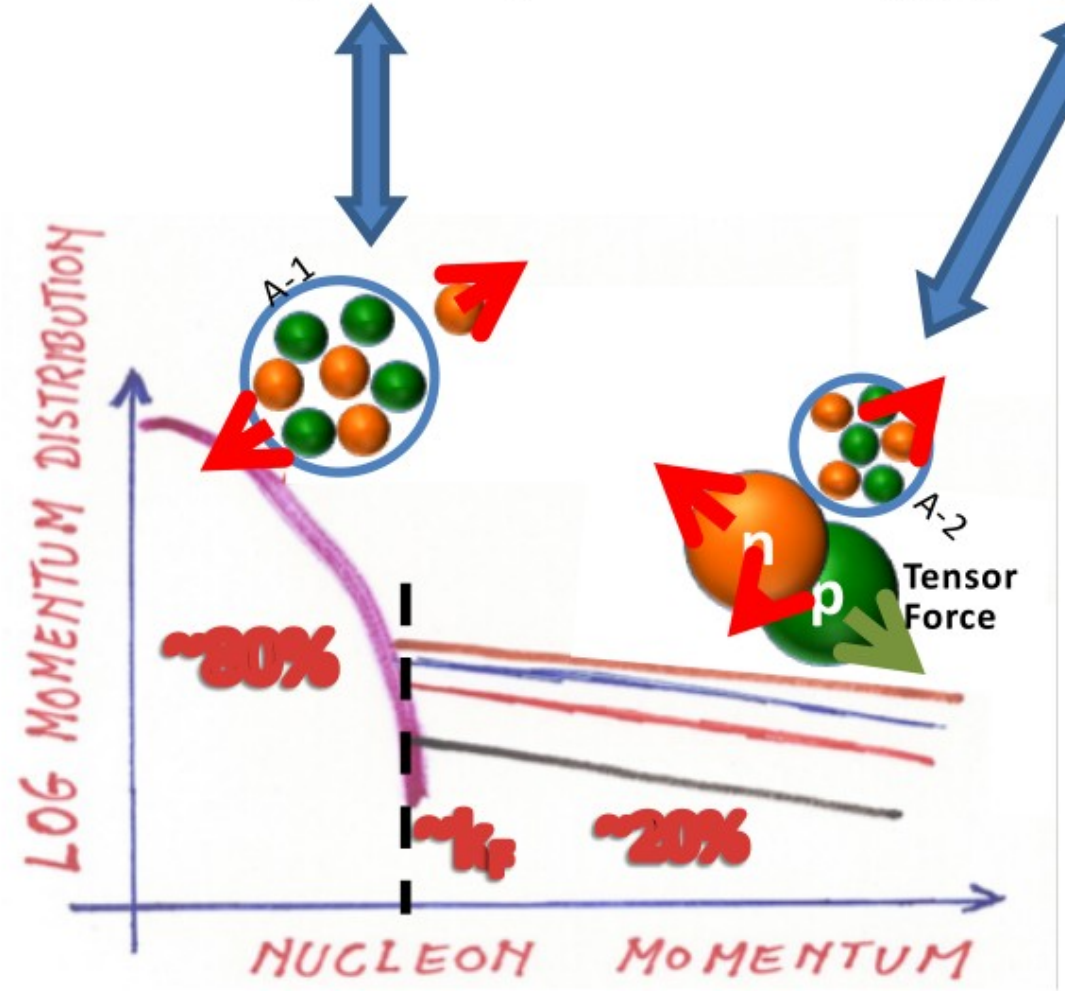
Simple idea: non-SRC nucleons ≈ free

Or Hen, INT Workshop July 2018

Bound = 'quasi Free' + Modified SRCs

$$F_2^A = ZF_2^p + NF_2^n + n_{SRC}^A\left(\Delta F_2^p + \Delta F_2^n\right)$$

$$\Delta F_2^N = F_2^{N*} - F_2^N$$



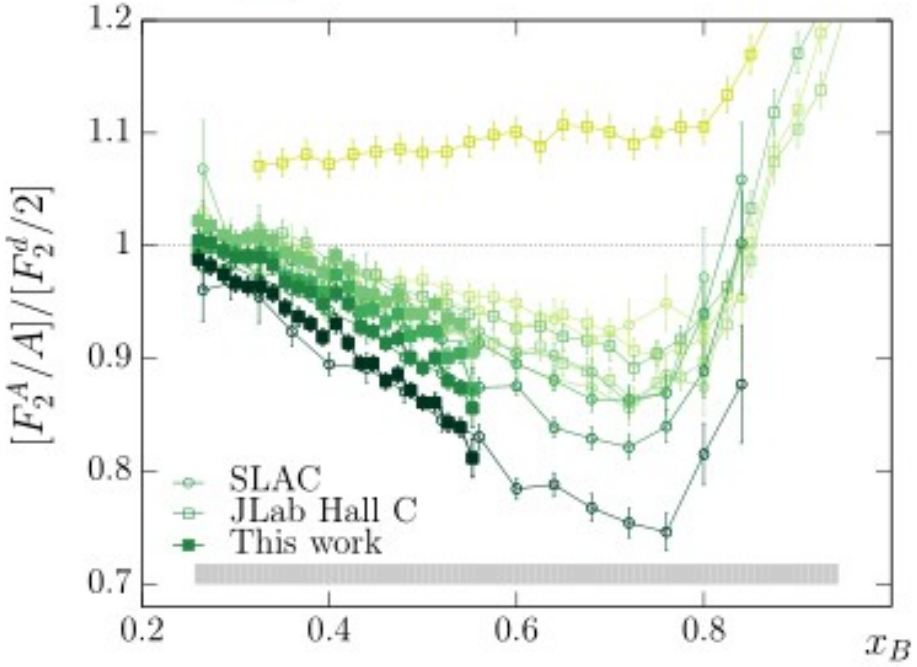
Idea is consistent with data!

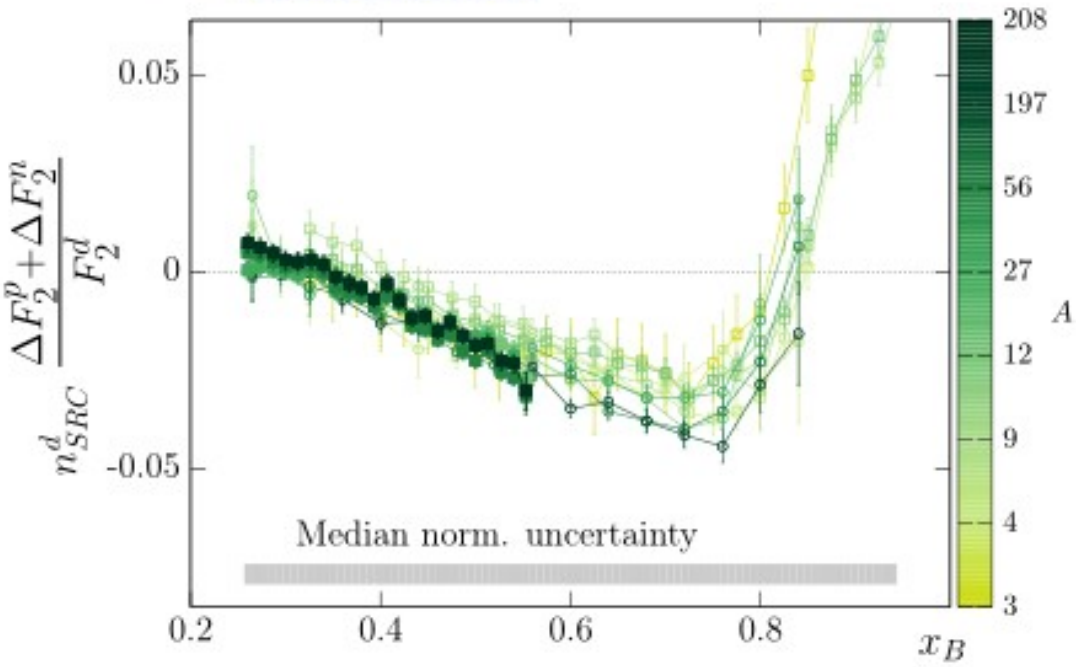
Or Hen, INT Workshop July 2018

$$\frac{F_2^A}{F_2^d} = \left(n_{SRC}^A - N n_{SRC}^d\right)\frac{\Delta F_2^p + \Delta F_2^n}{F_2^d} + (Z-N)\frac{F_2^p}{F_2^d} + N$$

A Dependent — A Dependent

Universal!





Schmookler, Duer, and Schmidt et al., submitted (2018)

$$\Delta F_2^N = F_2^{N*} - F_2^N$$

Tagging SRC vs. Non-SRC is more direct

In the simplest model:

Events without SRC have $F_2(A)=F_2(D)$

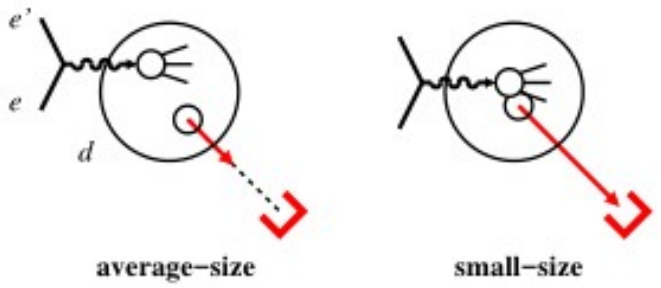
Events with SRC show a universal modification.

Tagged EMC studies with EIC*

From Christian Weiss

- Recoil momentum dep of tagged structure fns

  What momenta/distances cause modification?
  Connection with NN short-range correlations?
  Separate EMC $\leftrightarrow$ FSI?



How well can we tag SRCs?

- Identified w/ Yellow Report WG as one of the 4 key benchmark e+A measurements for EIC.
- Answer: WE DON'T KNOW!!
- Natural tool to develop
  - GCF-DIS for cross-sections in SRC region
  - Upgraded BeAGLE for
    - Nuclear response and $F_2(A)=F_2(D)$ in non-SRC region
    - quark fragmentation & nuclear response in SRC region
      - Existence proof: GCF-QE + BeAGLE
  - GEANT for detector response.

Benchmarks & Status/Plans

- $e + D \rightarrow e' + J/\psi + n + p$
  - Fix small momentum non-conservation
  - Add off-shell structure functions
- $e + Pb \rightarrow e' + V + X$ (diffractive veto)
  - Understand INC using E665 (DIS) data (& LHC p+A UPC?) & tune if possible.
- $e+A \rightarrow e' +(NN)_{SRC} +X$
  - Upgrade BeAGLE to handle this.
- $e + {}^{3}He \rightarrow e' + p + p + X$
  - Debug ^{3}He in DPMJET-F (treats pp as a nucleus?)

BeAGLE Development Crucial in FY2021

- BeAGLE is widely used and has proven essential in forward detector/IR design.
- As suggested by the committee, we identified a few "benchmark processes" which are most important to study.
- More work is needed on BeAGLE to implement some of those processes and understand all of them.
- Tuning & quantifying uncertainty still ongoing.
- We are really running out of time to finalize the IR. The next year is crucial!

The Community View of BeAGLE

- Yellow Report WG Conveners identified BeAGLE development as essential.
  - Letter from "Diffraction and Tagging Physics" WG
  - Similar positive feedback from conveners in Detector WGs: "Far-Forward Detectors" & "Forward Detector/IR Integration"
- BeAGLE development is also critical for IR optimization through "project baselining (CD2)" in Sept. 2022.
  - See e-mail from Elke Aschenauer, co-Associate Director for the Experimental Program of EIC.

FY2021 Budget Proposal

Person	Institution	Effort (FTE-year)	Cost to Proposal	Remarks
M.D. Baker	MDBPADS[6]	0.45	$93,000	
W. Chang	CCNU/BNL	0.50	$0	salary covered by CCNU
A. Jentsch	BNL	0.20	$0	cost covered by BNL
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:		1.50	$93,000	

Table 1: Personnel Budget Breakdown for FY2021 (new money)

Based on a zero-baseline or bottom-up review of what is needed: Baker at max capacity for the next year. No travel.

For reference, FY2020 approved budget (new money) was $88,020

Impact of Reduced Funding

FY2021 Funding	Total Funding (incl. carryover)	%Funding	Baker FTE	Result
$93,000	$121,500	100%	0.45 FTE	Project goals completed
$74,400	$102,900	80%	0.38 FTE	Goals may slip
$55,800	$ 84,300	60%	0.31 FTE	Unlikely to finish in FY2021

Table 3: Impact of Reduced Funding in FY2021

We are applying full travel money carryover of $28,500 to support the Baker subcontract.

Chang will continue to work from China w/o travel support.

External Support

- Salaries from home institutions (for eRD17):
  W. Chang, A. Jentsch, J.H. Lee, Z. Tu, L. Zheng
  Leverage: 1.50 FTE vs. 0.45 FTE supported
- Some JLAB and MITLNS support in FY2020, not currently planned for FY2021.

FY2021 Milestones

- November 21, 2020: BeAGLE results at YR meeting.
- January 2021: Benchmark channels in good enough shape to be used in YR (possibly in preliminary form).
- May 2021: BeAGLE improved as needed for the baselining.
- Sept. 2021: BeAGLE tuned as well as possible & uncertainties quantified.

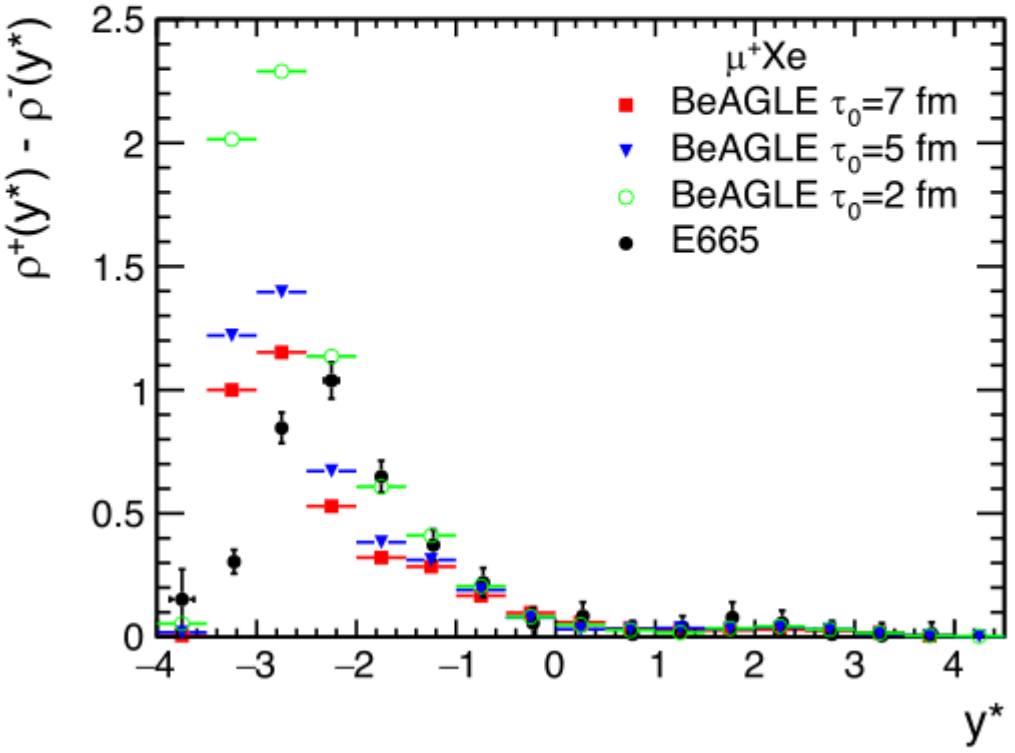
Conclusions

- BeAGLE has been an invaluable "tool to refine detector requirements in eA".
  - Forward detector / IR design improved significantly.
  - Widely used for eA simulations in Yellow Report
- Project scope continues to grow.
  - Driven by the community need (and committee suggestions).
- Focused push on benchmark processes and IR design support still essential and urgent.
  - As suggested by the committee in January.

EXTRAS

Another view of E665 data

The normalized cms-rapidity distribution of hadronic net charge for muXe:



y* = rapidity in γ*N cm with γ* along +z