Update on IR-8 Simulation

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What's New

- Received eAu 110 GeV IR-8 lattice study from Randy (JLab)
  - Updated lattice for ePb 18×110 xml file
  - Recalculate 10σ safe-distance cut at RPSF
- Made changed in D2EIC GitHub repository (Kong approved)
- Added nuclear fragments distribution
- Updated vetoing efficiency for ePb 18×110 GeV^2
  - Maybe too good to be true ☺

IR-8 Magnet Layout

- IP-8 information in machine coordinate
  - Position = (0.65 m, 0.0 m, -0.2975 m)
  - HSR crossing angle = 0.024 rad
  - ESR crossing angle = -0.011 rad

- Layout versions
  - ep: 18×275 GeV^2, 10×275 GeV^2, 10×100 GeV^2, 5×41 GeV^2
  - eAu: 18×110 GeV^2

- Reference
  - ep: https://wiki.bnl.gov/eic-detector-2/images/4/42/IR8_magnet_layout_2023_12_11.xlsx
  - eAu: will ask Elke to help uploading file on wiki page (currently attachment in email)

IR-8 Forward Magnet Elements

Comparisons between **ep 18×275 GeV²** and **eAu 18×110 GeV²** in machine coordinate

☺
D: Dipole
Q: Quadrupole

Forward Elements		Length [m]	R_{inner} [cm]	R_{outer} [cm]	Dipole field B_y [T]	Quadrupole field [T/m]		X_{center} [m]	Z_{center} [m]	θ_{center} [rad]
		ep & eAu	ep & eAu	ep & eAu	ep & eAu	ep	eAu	ep & eAu	ep & eAu	ep & eAu
BXSP01	D	~1.2	24.5	34.5	1.3	0	0	~0.80	~6.1	-0.011
BXSP01A	D	0.6	9	19	0	0	0	~0.84	~7.9	~0.022
QFFDS01A	Q	2	~6.13	~17.2	0	-64.31170472	-64.30890888	~0.88	~9.6	~0.022
QFFDS01B	Q	1.8	~8.93	~22.2	0	-41.88696776	-41.9504432	~0.94	~12	~0.022
QFFDS02A	Q	2.6	~12.24	~27.8	0	32.70356741	32.70400401	~1.01	~15.2	~0.022
QFFDS02B	Q	2.6	~14.24	~34	0	28.24710469	28.25142843	~1.08	~18.3	~0.022
BXDS01A	D	~5.0	17	27	~4.6	0	0	~1.17	~22.6	~0.018
BXDS01B	D	~2.6	5.5	15.5	~-4.6	0	0	~1.13	~39.4	~0.004
Y07_QD1	Q	1.1	4	14	0	20.29616569	20.36907321	~1.16	~42.2	~0.01
MPOT1 (2nd focus)		0	0	4	0	0	0	~1.19	~45.2	~0.01

Optimized for 110 Au
Beam rigidity of 110 Au and 275 p is same, but beta functions at IP is different

IP-8 Beam Parameters and 10σ Cut

From EIC CDR table 3.5 and Randy's eAu study

☺ RPSF: Roman Pot at Secondary Focus

eAu 18 GeV on 110 GeV	Momentum Dispersion ($D_{\text{secondary focus}}$)	Emittance X (ϵ_x*) [mm]	Emittance Y(ϵ_y*) [mm]	Beta function X (β_x secondary focus) [mm]	Beta function Y (β_y secondary focus) [mm]	Momentum spread $(\Delta p/p)$*
Old ep 18 on 275 GeV^2	0.382	43.2e-6	5.8e-6	2289.454596	4538.713168	6.2e-4
New ep 18 on 275 GeV^2	**0.465446718**	43.2e-6	5.8e-6	**498.013008**	**3392.376638**	6.2e-4
New eAu 18 on 110 GeV^2	**0.467582853**	43.2e-6	5.8e-6	**565.292559**	**1870.555797**	6.2e-4

$$\sigma_{x,y} = \sqrt{\epsilon_{x,y}\beta(z)_{x,y} + (D_{x,y}\frac{\Delta p}{p})^2}$$

where
ϵ : Emittance at z=0
β : Beta function at z=RPSF
D : Momentum dispersion at z=RPSF
$\frac{\Delta p}{p}$: Momentum spread at z=0

1σ calculation	$1\sigma_x$	$1\sigma_y$
ep β @ IR-8 RPSF (Old)	0.314867	0.1629770
Wan's IR-8 Study	0.328283	0.085217
ep β @ IR-8 RPSF (new)	**0.146677**	**0.140271**
eAu β @ IR-8 RPSF (new)	**0.156271**	**0.104160**

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Sample

- BeAGLE **v1.03.02** ePb 18×110 GeV^2 J/ψ production from Kong
- Passed onto "afterburner" with IP-8 eAu configuration
  - All events have **beam crossing angle** and **beam effects** (angular divergence and momentum spread)

- In following figures
  - All variables (t, p, and θ) are **true MC info** extracted from "afterburned" file

Nuclear Breakups Distribution

BeAGLE **v1.01.01**

Phys. Rev. D 104, 114030

produced particle	rate
only neutron	7.66%
only proton	0%
only photon	3.25%
neutron and proton	3.19 %
neutron and photon	44.24 %
proton and photon	2.27 %
neutron, proton and photon	39.39 %

TABLE II. Summary of particles produced in incoherent J/ψ production in BeAGLE.

BeAGLE **v1.03.02**

Nuclear Breakups at Final State	Number of Events
Only Neutrons	7.86 %
Only Protons	0.0001 %
Only Photons	3.45 %
Neutrons + Protons	3.18 %
Neutrons + Photons	45.41 %
Protons + Photons	1.85 %
Neutrons + Protons + Photons	38.25 %

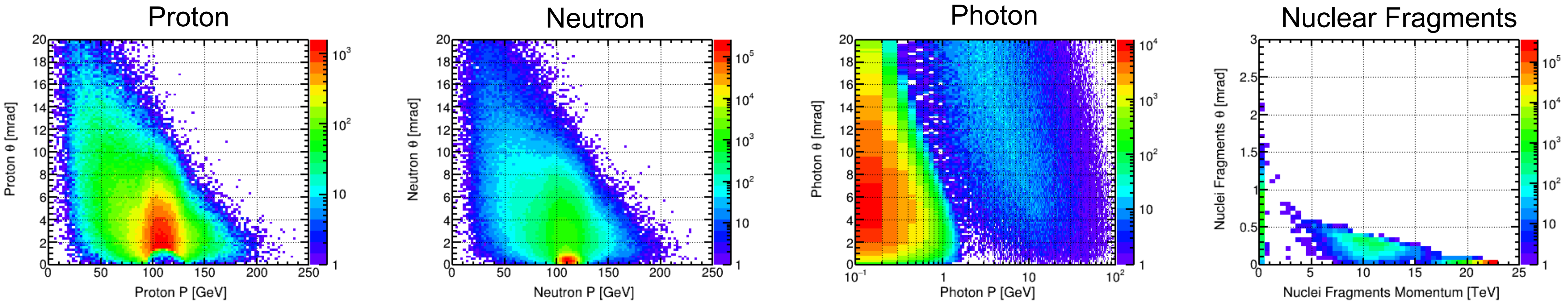
About **95 %** of events have **neutrons**

Nuclear Breakups Distribution

	Nuclear Breakups at Final State	Number of Events
Generated Level	Only Neutrons	0 %
	Only Protons	
	Only Photons	
	Only Fragments	0.000818881 %
	Neutrons + Protons	0 %
	Neutrons + Photons	
	Protons + Photons	
	Fragments + **Neutrons**	**7.86044 %**
	Fragments + Protons	0.00013648 %
	Fragments + Photons	3.44749 %
	Neutrons + Protons + Photons	0 %
	Fragments + **Neutrons** + Protons	**3.17958 %**
	Fragments + **Neutrons** + Photons	**45.4081 %**
	Fragments + Protons + Photons	1.85217 %
	Fragments + **Neutrons** + Protons + Photons	**38.2513 %**

About **95 %** of events have **neutrons** and **the rest have fragments** can be vetoed by RPSF

Nuclear Breakups Distribution

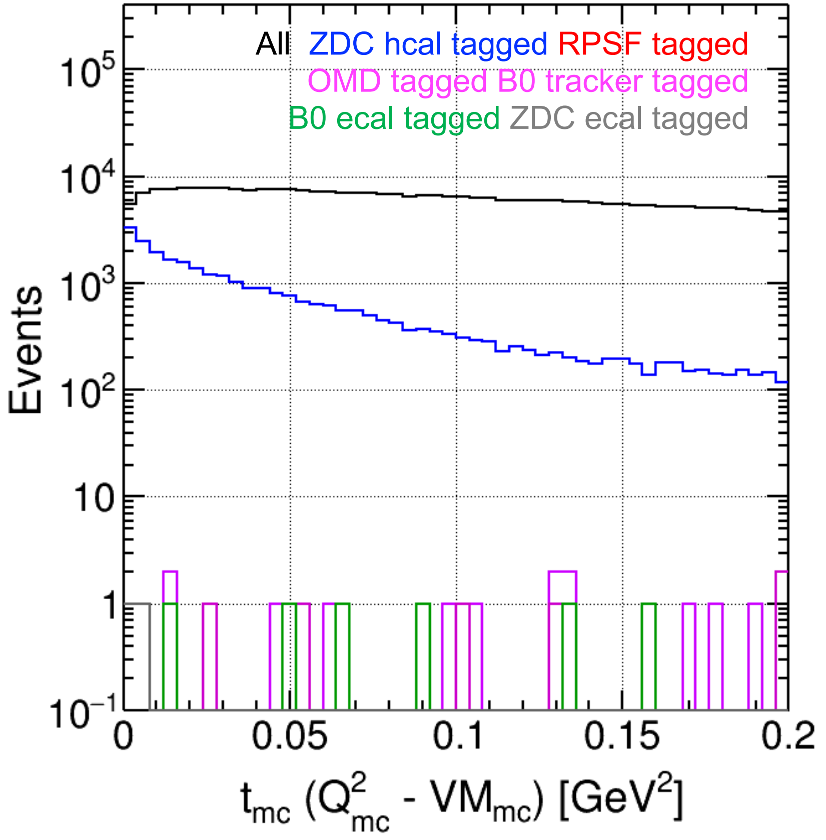


Approach – Vetoing Efficiency

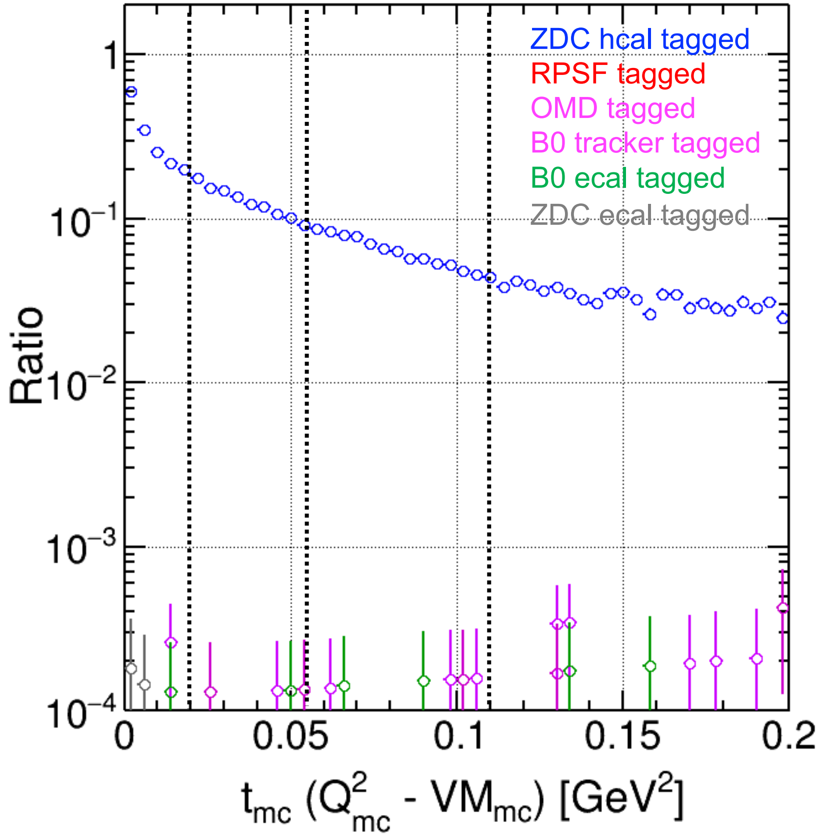
- Understand background to coherent J/ψ production
- Looked at **$1 < Q^2 < 10$**
- Discarded events having **more than one electron in final state with η < -1**
- Used **10σ safe distance cut** based on **eAu β @ IR-8 RPSF** (**new**)
- **Tagged events for nuclear breakups tagging purpose**
  - ZDC Hcal: **any registered RAW hits**
  - RPSF: **one layer (closet to 2nd focus)** has registered RAW hits outside **10σ** safe distance
  - OMD: **two layers** (actual four layers as redundancy) have registered RAW hits
  - B0 Tracker: **at least two out of four layers** have registered RAW hits
  - B0 Ecal: **energy** of all hits greater than **100 MeV**
  - ZDC Ecal**: energy** of all hits greater than **100 MeV**

t Distribution and Vetoing Efficiency

Veto inefficiency for incoherent events



Coherent diffractive minima



Found to be enough to suppress incoherent contribution at three minima

Vetoing efficiency is > 99.99% at all three minima

Remaining (Non-Vetoed) Events

Veto Selections	Surviving Events	
	ep β @ IR-8 RPSF	eAu β @ IR-8 RPSF
All events	998,161	997,820
Events with one scattered electron identified and $\|\eta_{J/\psi}\| < 4$ and 1 < Q^2 < 10	732,707 (100.0 %)	732,455 (100 %)
ZDC HCAL tagged	41,880 (**5.71579 %**)	41,848 (**5.71339 %**)
+ RPSF tagged	94 (**0.0128291 %**)	71 (**0.00969343 %**)
+ OMD tagged	93 (0.0126927 %)	71 (0.00969343 %)
+ B0 tracker tagged	51 (0.00696049 %)	30 (0.00409581 %)
+ B0 ecal tagged	27 (0.00368497 %)	17 (0.00232096 %)
+ ZDC ECAL tagged	15 (**0.0020472 %**)	4 (**0.000546109 %**)

With 10σ safe distance cut based on ***eAu β @ IP-8 RPSF (New)***

4 of 997,820 events were NOT vetoed

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Remaining (Non-Vetoed) Events

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- Veto.1: no activity other than e^- and J/ψ in the main detector ($|\eta| < 4.0$ and $p_T > 100$ MeV/c) ;
- Veto.2: Veto.1 and no neutron in ZDC;
- Veto.3: Veto.2 and no proton in RP;
- Veto.4: Veto.3 and no proton in OMDs;
- Veto.5: Veto.4 and no proton in B0;
- Veto.6: Veto.5 and no photon in B0;
- Veto.7: Veto.6 and no photon with $E > 50$ MeV in ZDC.

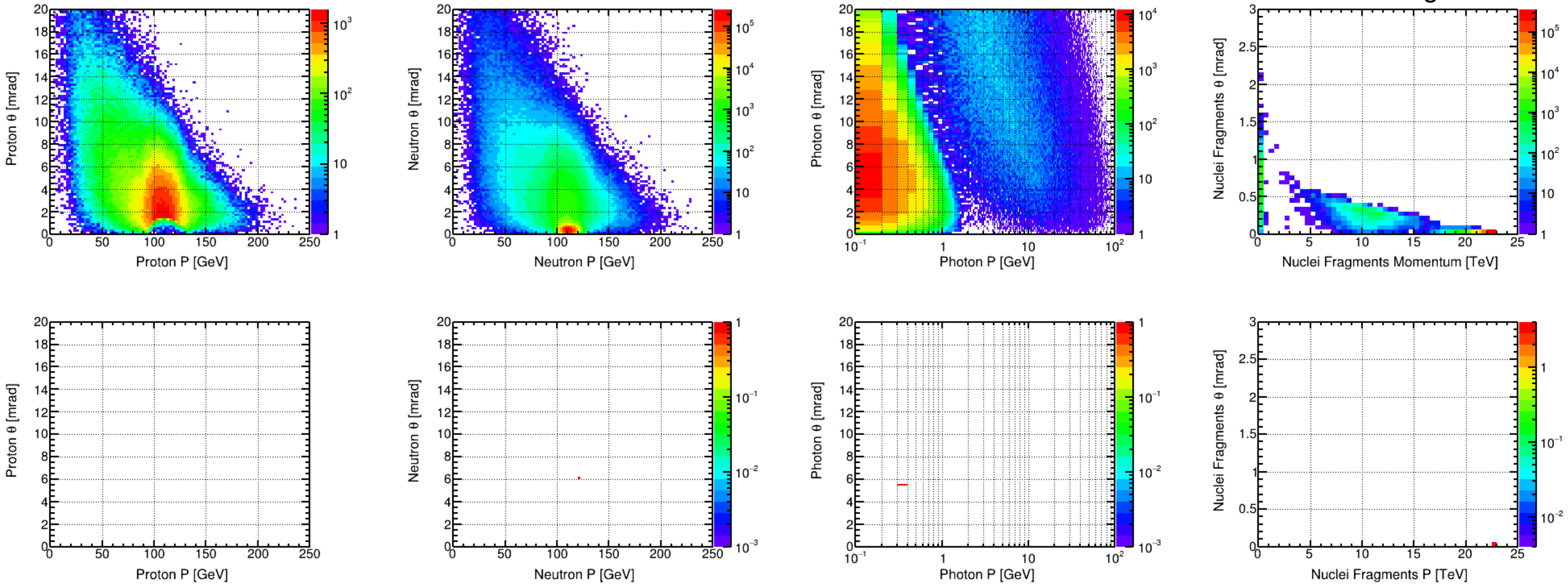
Survived Event Ratio				
Material	Without beam pipe	Beryllium	Aluminum	Stainless Steel
Total events	100 %	100 %	100%	100%
Veto.1	86.9%	86.9%	86.9%	86.9 %
Veto.2	5.81%	9.73%	9.85%	17.2%
Veto.3	5.81%	9.73 %	9.85%	17.2%
Veto.4	5.09%	8.77%	8.89%	15.73%
Veto.5	4.32%	6.22%	5.97%	10.18%
Veto.6	2.29%	3.32%	3.18%	5.68%
Veto.7 ($E_{\text{photon}} > 50$ MeV)	1.06%	2.05%	2.46%	5.58%
Veto.7 ($E_{\text{photon}} > 100$ MeV)	-	2.18%	-	-

TABLE III. Summary of the percentage of events surviving the different vetoing steps for incoherent events assuming no beam pipe and different beam pipe materials of beryllium, aluminum, and stainless steel.

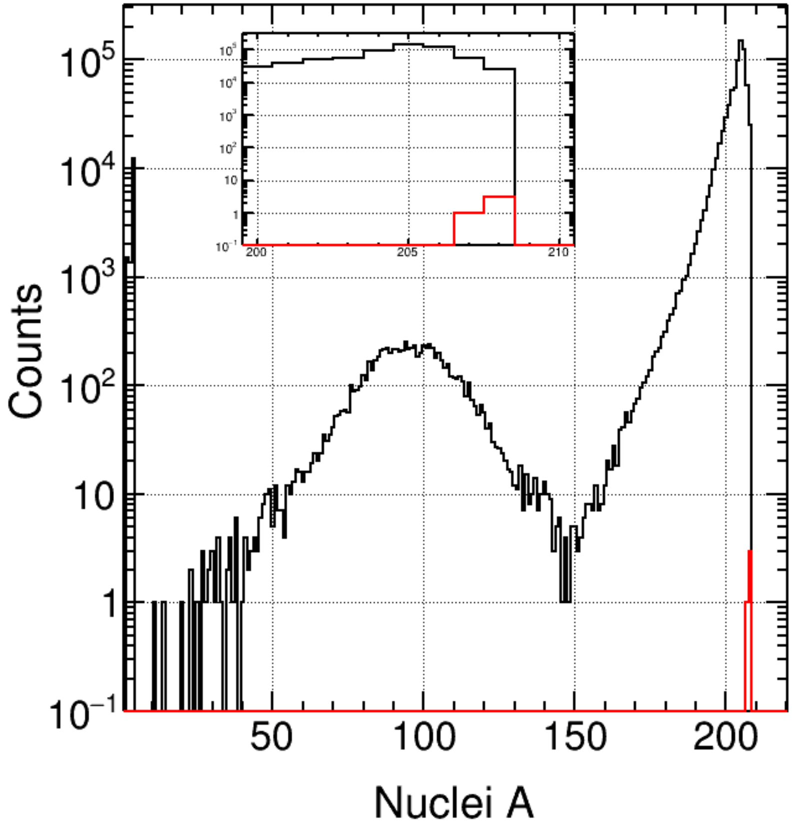
Veto Selections	Surviving Events
	eAu β @ IR-8 RPSF
All events	997,820
Events with one scattered electron identified and $\|\eta_{J/\psi}\| < 4$ and 1 < Q^2 < 10	732,455 (100 %)
ZDC HCAL tagged	41,848 (**5.71339 %**)
+ RPSF tagged	71 (**0.00969343 %**)
+ OMD tagged	71 (0.00969343 %)
+ B0 tracker tagged	30 (0.00409581 %)
+ B0 ecal tagged	17 (0.00232096 %)
+ ZDC ECAL tagged	4 (**0.000546109 %**)

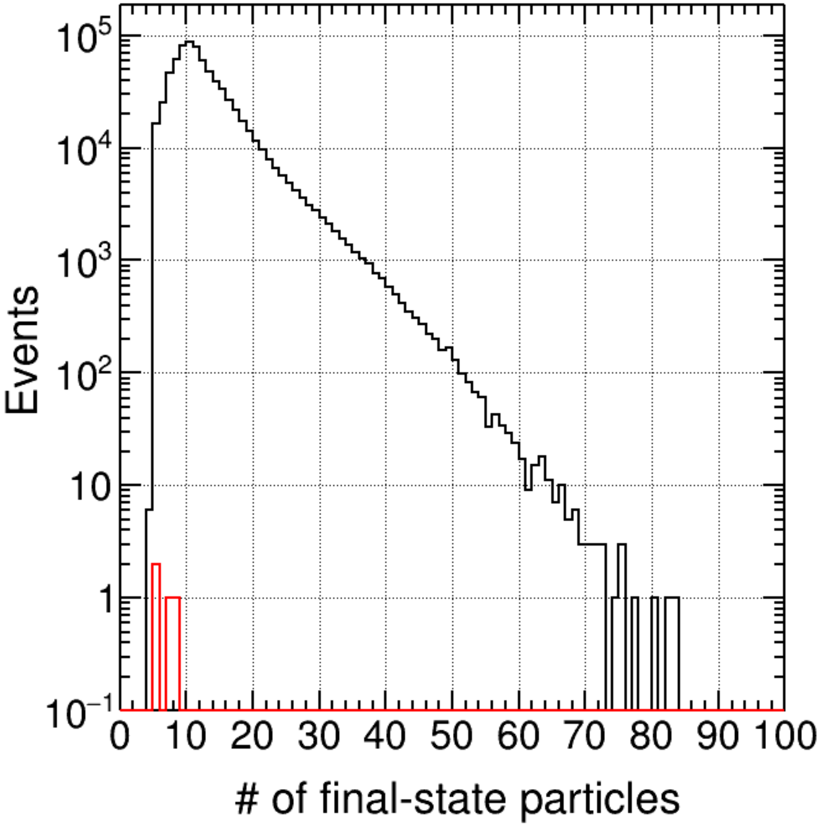
Remaining (Non-Vetoed) Events

Proton | Neutron | Photon | Nuclear Fragments



Remaining (Non-Vetoed) Events





Remaining events have high mass nuclear remnants (A = 208 and 207 for Pb) and low particle multiplicity

Summary

- So far, used 275 GeV proton for 110 GeV Au because beam rigidity is same and no 110 GeV Au lattice is available
  - Noted that beta functions at IP is different and acceptance might suffer
- In terms of lattice fields, scaled from 275 GeV proton according beam energy configuration. Should I use each optimized version of lattice for 100 GeV and 41 GeV protons?
- Updated IR-8 lattice for 110 GeV Au in D2EIC GitHub
  - Optimized in quadrupole fields (focusing point at secondary focus)
  - New lattice for another beam configuration (eAu 41×5 GeV^2) will be available shortly
- Will include a simplified beam pipe (+ material) design to quantify impact on vetoing efficiency

BackUp Slides

EIC Beam Parameters for ep

EIC CDR

Table 3.3: EIC beam parameters for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling. High divergence configuration.

Species	proton	electron	proton	electron	proton	electron	proton	electron	proton	electron
Energy [GeV]	275	18	275	10	100	10	100	5	41	5
CM energy [GeV]	140.7		104.9		63.2		44.7		28.6	
Bunch intensity [10^{10}]	19.1	6.2	6.9	17.2	6.9	17.2	4.8	17.2	2.6	13.3
No. of bunches	290		1160		1160		1160		1160	
Beam current [A]	0.69	0.227	1	2.5	1	2.5	0.69	2.5	0.38	1.93
RMS norm. emit., h/v [μm]	5.2/0.47	845/71	3.3/0.3	391/26	3.2/0.29	391/26	2.7/0.25	196/18	1.9/0.45	196/34
RMS emittance, h/v [nm]	18/1.6	24/2.0	11.3/1.0	20/1.3	30/2.7	20/1.3	26/2.3	20/1.8	44/10	20/3.5
β^*, h/v [cm]]	80/7.1	59/5.7	80/7.2	45/5.6	63/5.7	96/12	61/5.5	78/7.1	90/7.1	196/21.0
IP RMS beam size, h/v [μm]	119/11		95/8.5		138/12		125/11		198/27	
K_x	11.1		11.1		11.1		11.1		7.3	
RMS $\Delta\theta$, h/v [μrad]	150/150	202/187	119/119	211/152	220/220	145/105	206/206	160/160	220/380	101/129
BB parameter, h/v [10^{-3}]	3/3	93/100	12/12	72/100	12/12	72/100	14/14	100/100	15/9	53/42
RMS long. emittance [10^{-3}, eV·s]	36		36		21		21		11	
RMS bunch length [cm]	6	0.9	6	0.7	7	0.7	7	0.7	7.5	0.7
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Max. space charge	0.007	neglig.	0.004	neglig.	0.026	neglig.	0.021	neglig.	0.05	neglig.
Piwinski angle [rad]	6.3	2.1	7.9	2.4	6.3	1.8	7.0	2.0	4.2	1.1
Long. IBS time [h]	2.0		2.9		2.5		3.1		3.8	
Transv. IBS time [h]	2.0		2		2.0/4.0		2.0/4.0		3.4/2.1	
Hourglass factor H	0.91		0.94		0.90		0.88		0.93	
Luminosity [10^{33}cm^{-2}s^{-1}]	1.54		10.00		4.48		3.68		0.44	

EIC Beam Parameters for eAu

EIC CDR

Table 3.5: EIC beam parameters for e-Au operation for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling.

Species	Au ion	electron	Au ion	electron	Au ion	electron	Au ion	electron
Energy [GeV]	110	18	110	10	110	5	41	5
CM energy [GeV]	89.0		66.3		46.9		28.6	
Bunch intensity [10^{10}]	0.08	6.2	0.05	17.2	0.05	17.2	0.036	17.2
No. of bunches	290		1160		1160		1160	
Beam current [A]	0.23	0.227	0.57	2.50	0.57	2.50	0.41	2.50
RMS norm. emit., h/v [μm]	5.1/0.7	705/20	5.0/0.4	391/20	5.0/0.4	196/20	3.0/0.3	196/20
RMS emittance, h/v [nm]	43.2/5.8	20.0/0.6	42.3/3.0	20.0/1.0	42.3/3.0	20.0/2.0	68.1/5.7	20.0/2.0
β^*, h/v [cm]]	91/4	196/41	91/4	193/12	91/4	193/6	90/4	307/11
IP RMS beam size, h/v [μm]	198/15		196/11		197/11		248/15	
K_x	0.077		0.057		0.056		0.061	
RMS $\Delta\theta$, h/v [μrad]	218/379	101/37	216/274	102/92	215/275	102/185	275/377	81/136
BB parameter, h/v [10^{-3}]	1/1	37/100	3/3	43/47	3/2	86/47	5/4	61/37
RMS long. emittance [10^{-3}, eV·s]	16		16		16		16	
RMS bunch length [cm]	7	0.9	7	0.7	7	0.7	11.6	0.7
RMS $\Delta p/p$ [10^{-4}]	6.2	10.9	6.2	5.8	6.2	6.8	10	6.8
Max. space charge	0.007	neglig.	0.008	neglig.	0.008	neglig.	0.038	neglig.
Piwinski angle [rad]	4.4	1.1	4.5	1.2	4.5	1.5	5.8	1.2
Long. IBS time [h]	0.33		0.36		0.36		0.85	
Transv. IBS time [h]	0.81		0.89		0.89		0.16	
Hourglass factor H	0.85		0.85		0.85		0.71	
Luminosity [10^{33}cm^{-2}s^{-1}]	0.52		4.76		4.77		1.67	

Surviving (Non-Vetoed) Events

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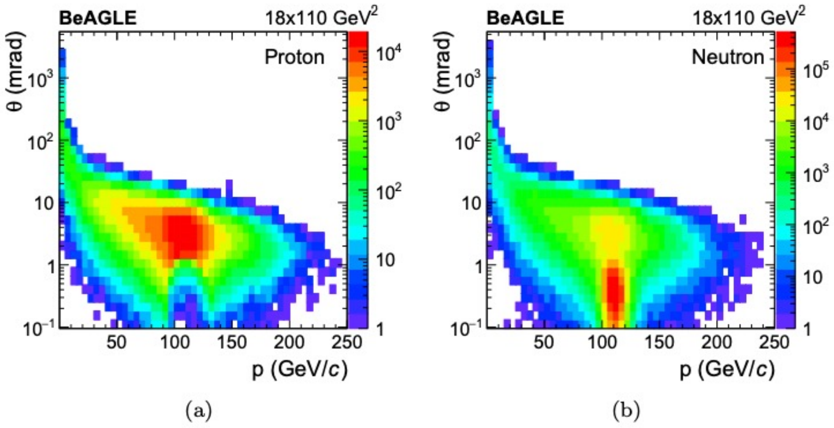

FIG. 3. The scattering angle as function of the total momentum of (a) protons, (b) neutrons, and (c) photons for incoherent events before any veto was applied.

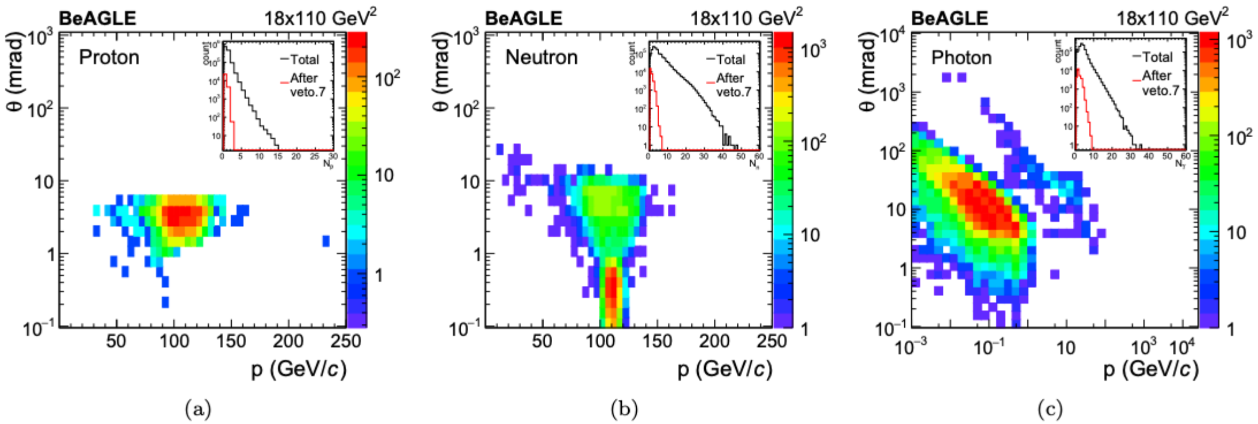

FIG. 5. The scattering angle as function of the total momentum for (a) protons, (b) neutrons, and (c) photons after veto.7. The insert at each panel shows the particle multiplicity distributions, for both the MC truth level (total) and after applying all cuts to veto the incoherent events.

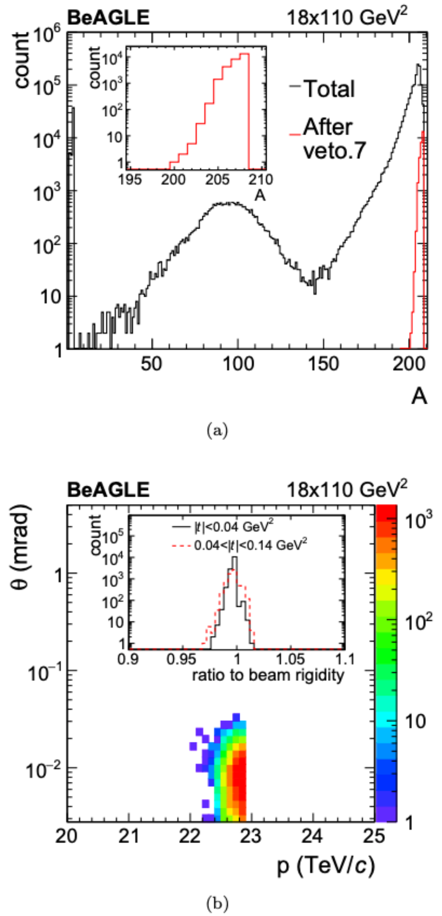

FIG. 6. (a) The mass number distribution for nuclei of total and surviving events after veto.7. (b) The scattering angle versus total momentum for nuclei of surviving events after veto.7, the insert shows the ratio of the residual nuclei rigidity to that of the nuclear beam.