2024 EIC User Group Early Career Workshop

Vetoing Efficiency of Incoherent Diffractive Vector Meson Production at the Second Interaction Region at the EIC

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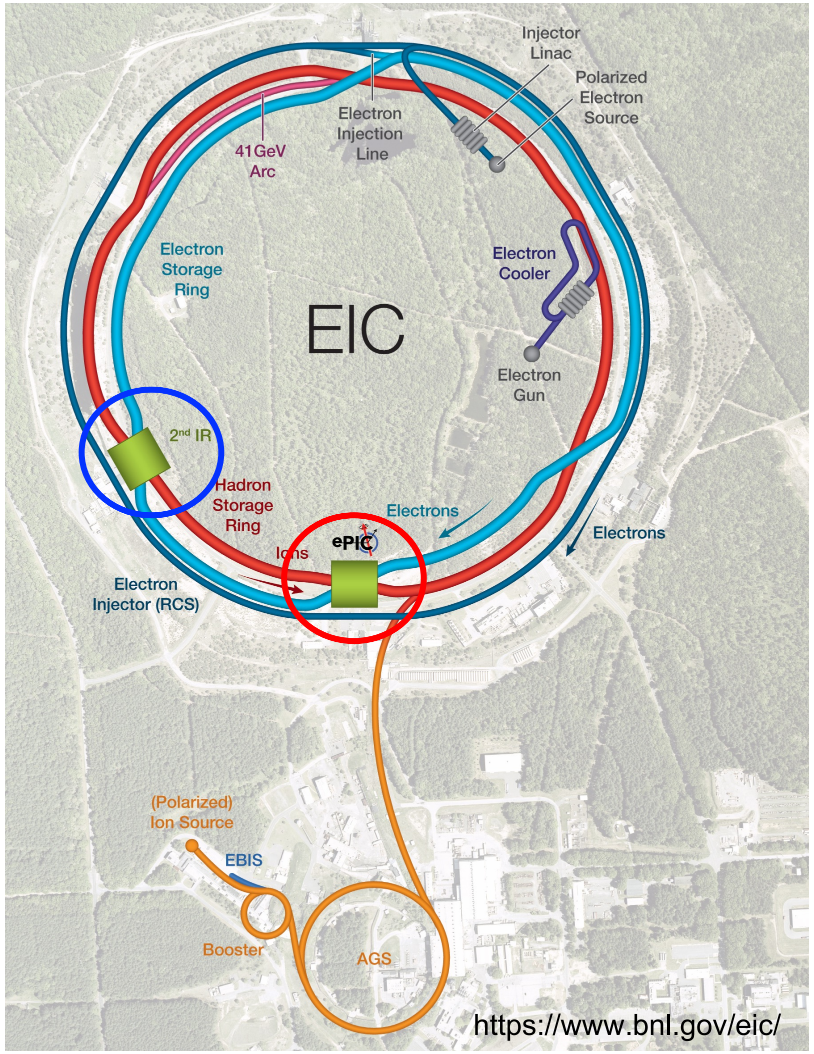
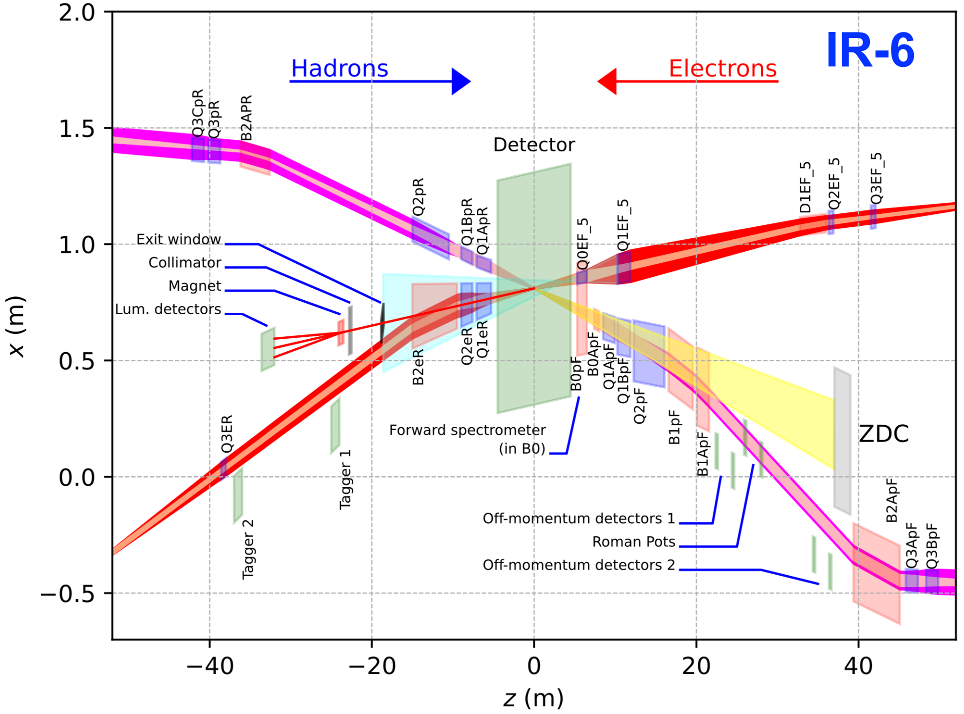
EIC 2nd Detector Motivation



- EIC Design
  - Two interaction points (IP-6 and IP-8)
  - Two interaction regions (IR-6 and IR-8)
- **Detector 1,** called **ePIC,** located at **IP-6**
- Can accommodate the **second detector** and a **second interaction region**
- **A general-purpose collider detector** to support full EIC program (**complementarity**)
  - **Cross-checks & control of systematics**
  - Subdetector technologies
  - Magnetic field
  - **Broaden physics program (different physics focuses)**

EIC Interaction Regions

Requires specialized detectors integrated in the interaction region over 80 m



Crossing angle: **25 mrad**

IR-Design:
0.2 GeV < p_T < 1.3 GeV

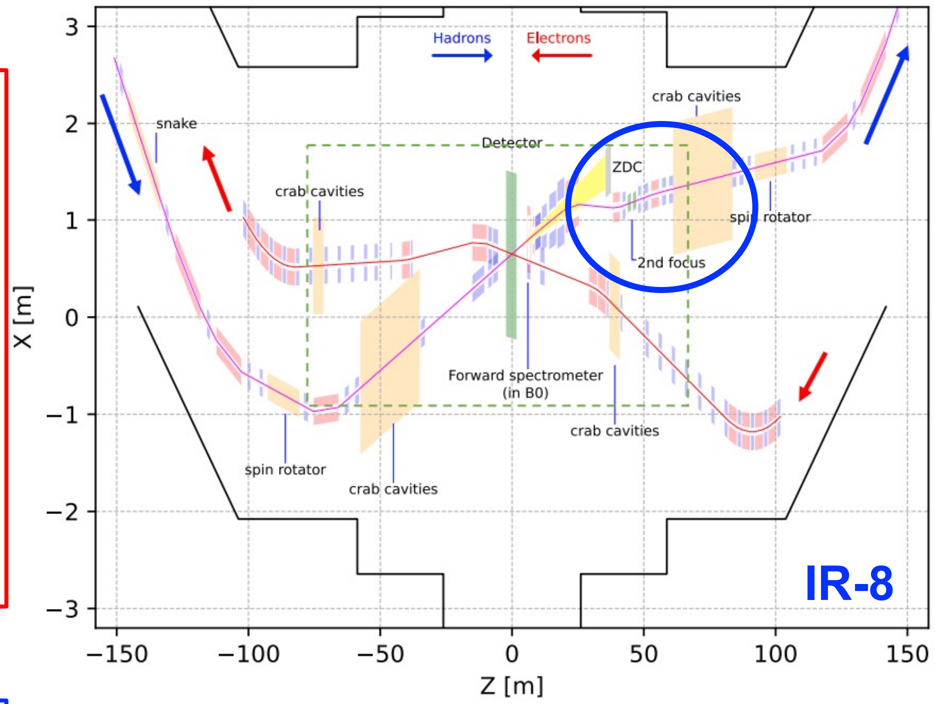
Same
Accelerator highlights and challenges

Shared luminosity between both IRs

Center-of-mass energy coverage

Different
Blind spots

Far-forward detector acceptances



Crossing angle: **35 mrad**

IR-Design:
2nd "beam optics" focus
comes with challenges (ex. magnet design) in accelerator machine

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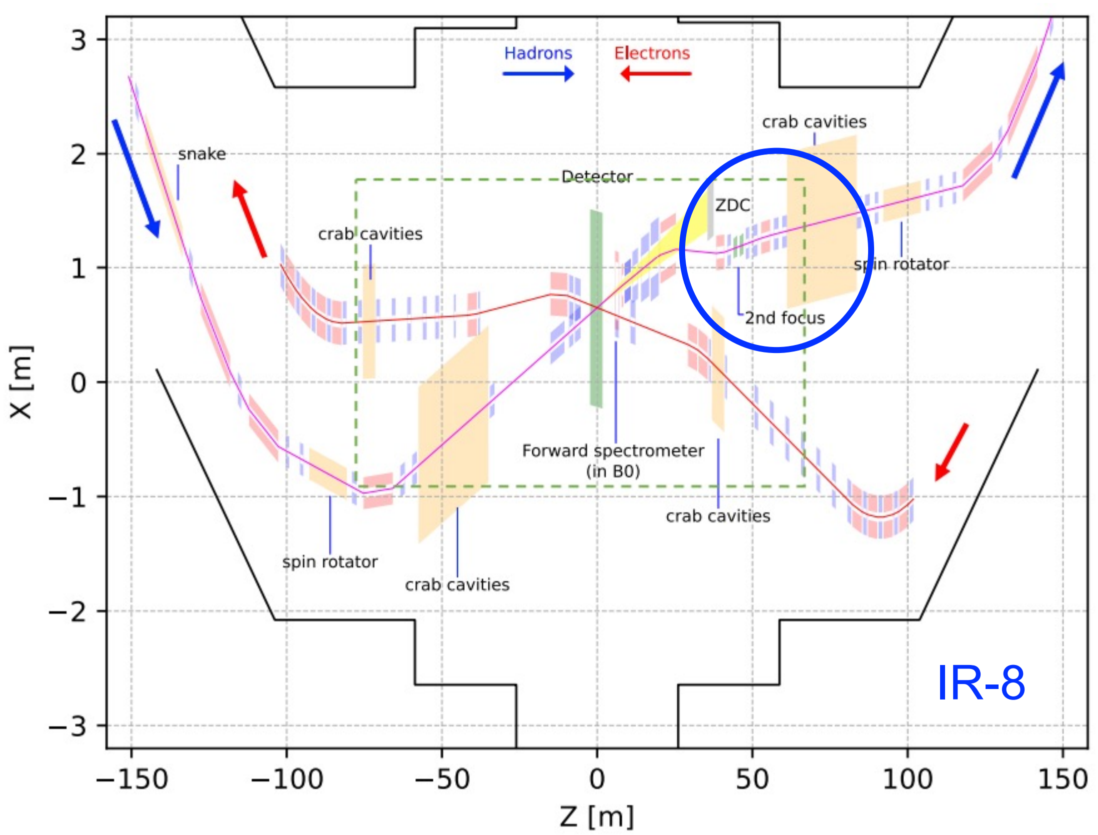
IR Concept – 2nd Focus in Far-Forward

- By **adding additional magnets to focus beam ~ 45 m downstream from interaction point** under challenges the chromaticity budget needs to be listed
- This is NOT the detector design, but it is the **machine design that the detector can be benefit from**
- 2nd focus enables
  - Higher probability to **detect low p_T (< 250 MeV) particles**
  - Detects near-beam particles that get out of the beam envelop
- **Complementary to ePIC: exclusive, tagging, and diffractive physics analysis**



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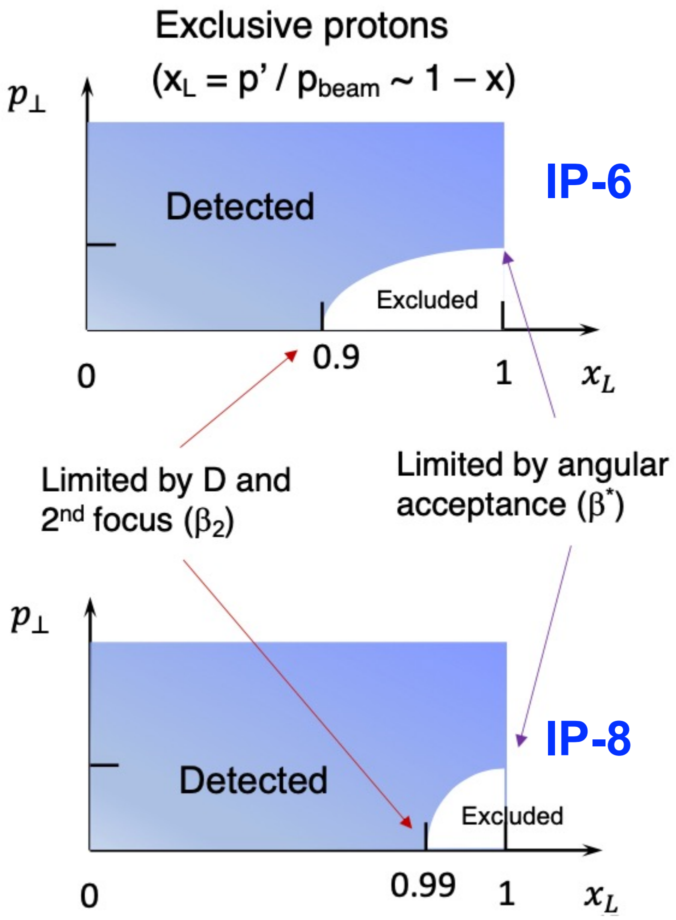
Physics Opportunities with 2nd Focus

- 2nd focus at IR8 greatly improves **forward acceptance**
- Complementarity with Detector 1 (ePIC) @ IR-6
- **Excellent low-p_T acceptance** for protons and light nuclei from exclusive reactions **at very low t**
- **Detection of target fragments** makes it possible
  - To veto breakup to study coherent process
  - To study final state when breakup occurs
- Coherent diffraction on heavy nuclei by vetoing breakups
- Adding PID idea? rare isotopes detection and identification of heavy fragments



Order-of-magnitude improvement in forward acceptance

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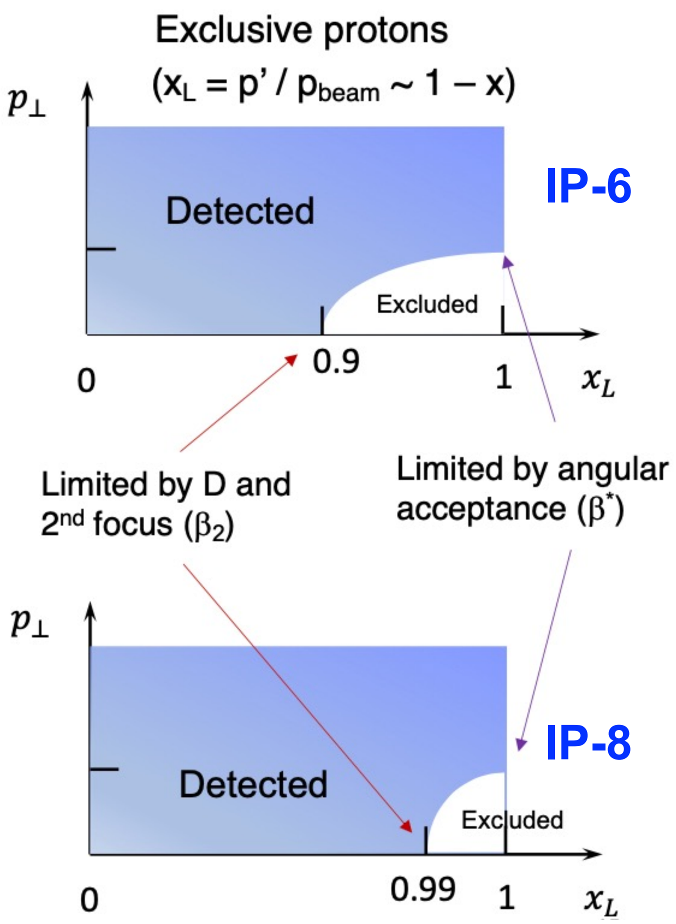
- Coherent diffraction on heavy nuclei by vetoing breakups
- Adding PID idea? rare isotopes detection and identification of heavy fragments
- **Today, show study on capabilities of separating coherent (nucleus stays intact) from incoherent (nucleus breaks up) diffractive events by tagging far-forward nuclear fragments**



Order-of-magnitude improvement in forward acceptance

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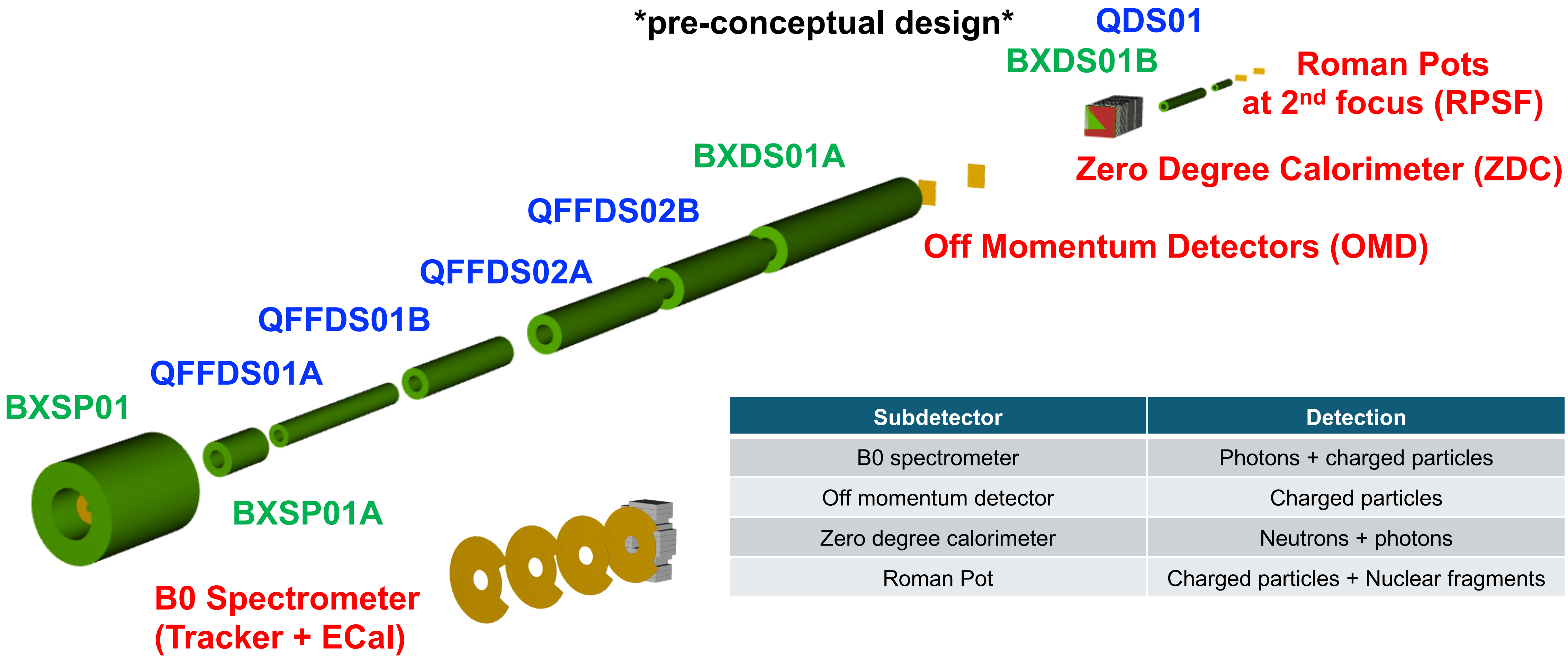
Far-Forward Detector – Layout

Implemented in **proposed IR-8 Forward Hadron Lattice** and required far-forward detectors

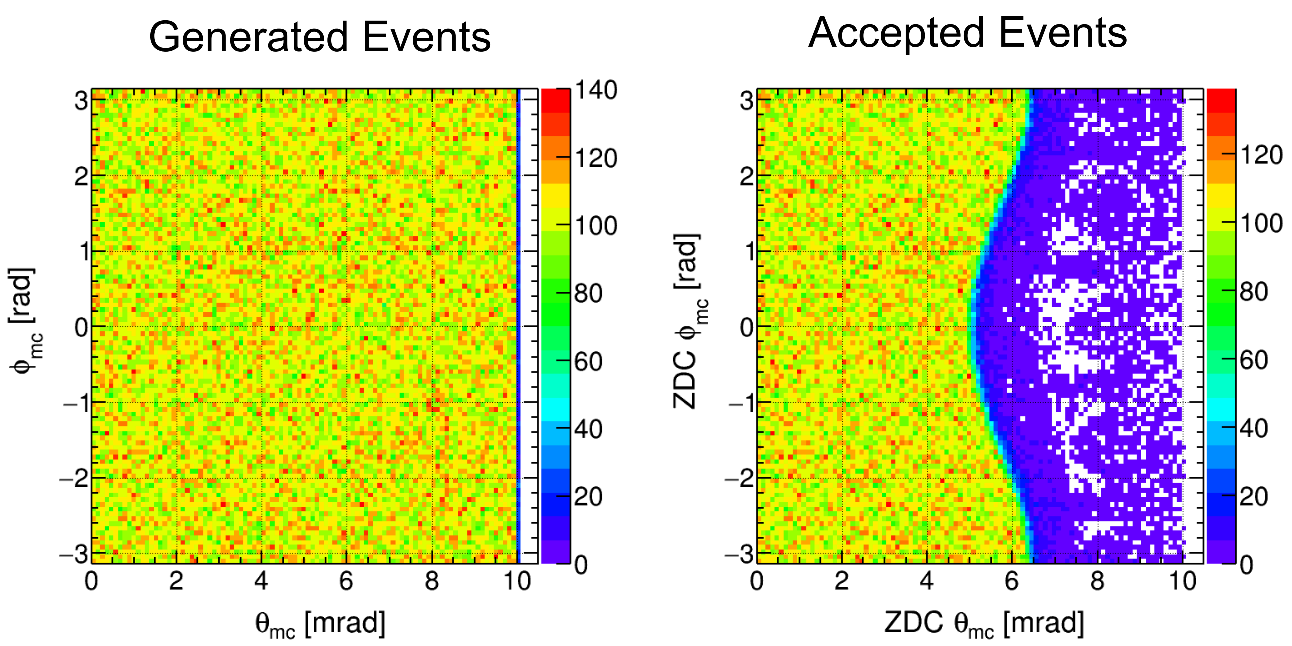
pre-conceptual design



Subdetector	Detection
B0 spectrometer	Photons + charged particles
Off momentum detector	Charged particles
Zero degree calorimeter	Neutrons + photons
Roman Pot	Charged particles + Nuclear fragments

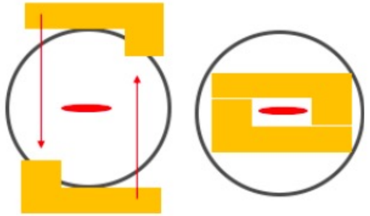
Far-Forward Detector – Acceptance

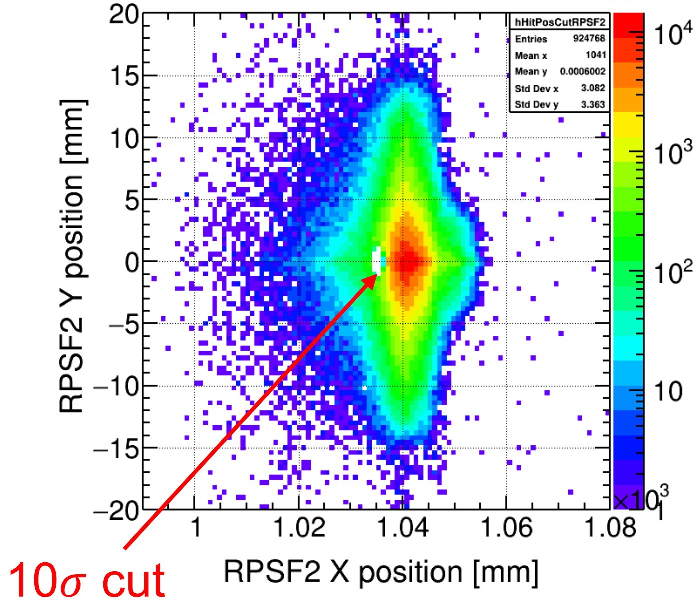
Zero Degree Calorimeter



- ZDC < 5 mrad uniformly ~100 %
- Exit window material impact on neutron acceptance

Roman Pot (@ 2nd focus)





ep DVCS
18×275 GeV^2

- Windows on pots depending on the **beam optics (transverse beam size)**

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

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

☺ RPSF: Roman Pot at Secondary Focus

Approach – Vetoing Efficiency

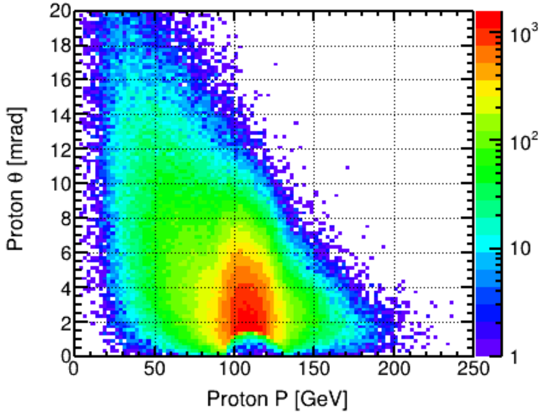
- To understand **impact of 2nd focus on suppression of incoherent contribution** (background to coherent J/ψ production)
- Used **BeAGLE** v1.03.02 ePb 18×110 GeV^2 J/ψ production (**1 < Q^2 < 10**)
  - **Incoherent events** $\boldsymbol{ePb \rightarrow e' + J/\psi(ee/\mu\mu) + X}$
- Applied **10σ safe distance cut** based on **eAu @ IR-8 Roman Pot at 2nd focus**
- **Tagged events for nuclear breakup 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**

Nuclear Breakups Distribution

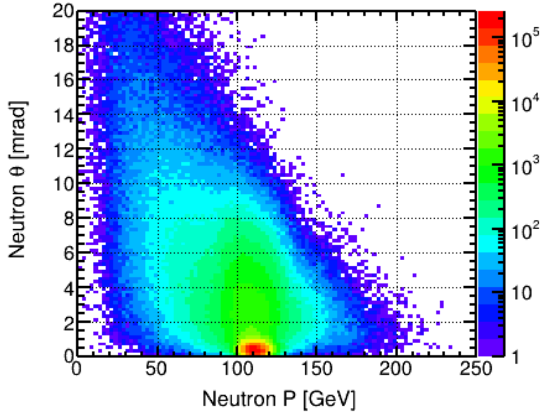
Nuclear Breakups at Final State	Number of Events
Only Neutrons	7.86 %
Only Protons	0.0001 %
Only Photons	3.45 %
Neutrons + Protons	3.18 %
Neutrons + Photons	45.41 %
Protons + Photons	1.85 %
Neutrons + Protons + Photons	38.25 %

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

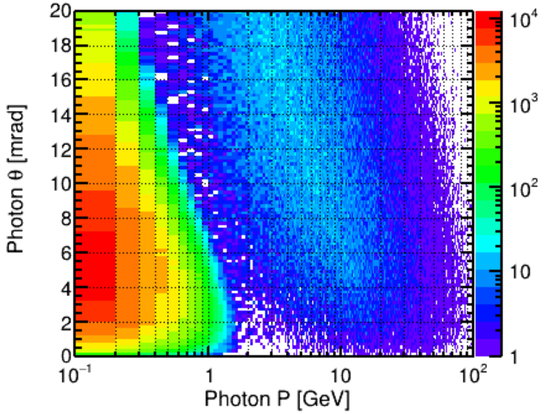
Proton



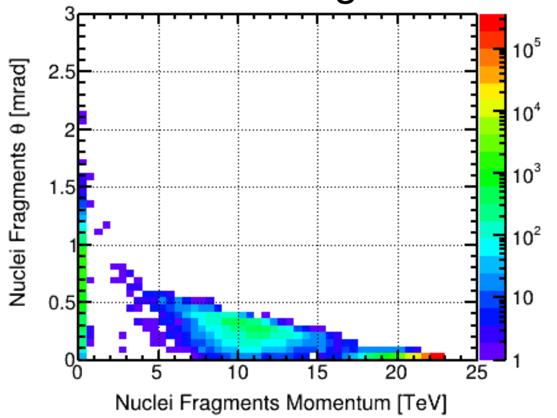
Neutron



Photon

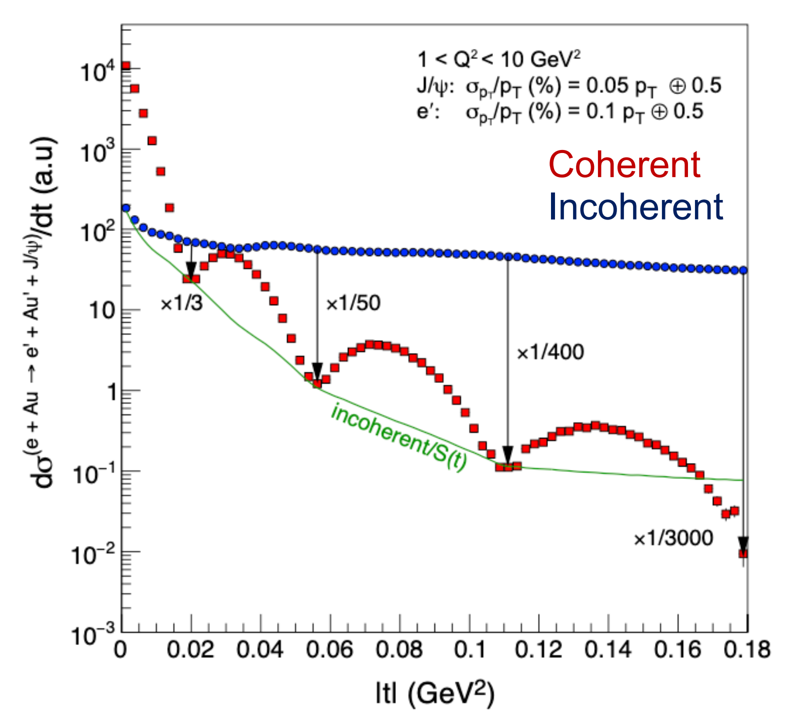


Nuclear Fragments



Far-Forward Detector – Incoherent Veto

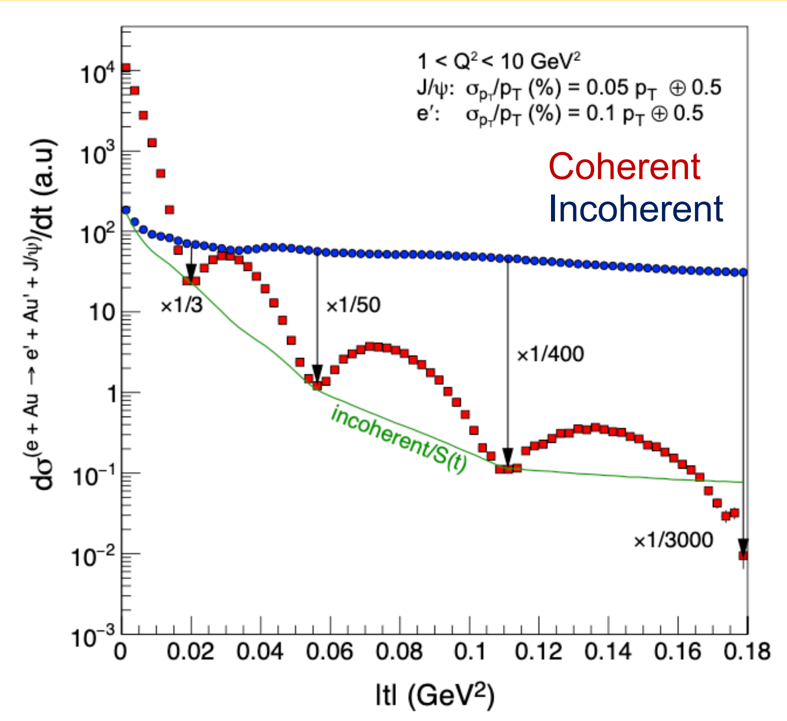
Reference from EIC YR p.352



At position of third diffractive minimum, **rejection factor for incoherent events better than 400:1 must be achievable (0.0025 % inefficiency)**

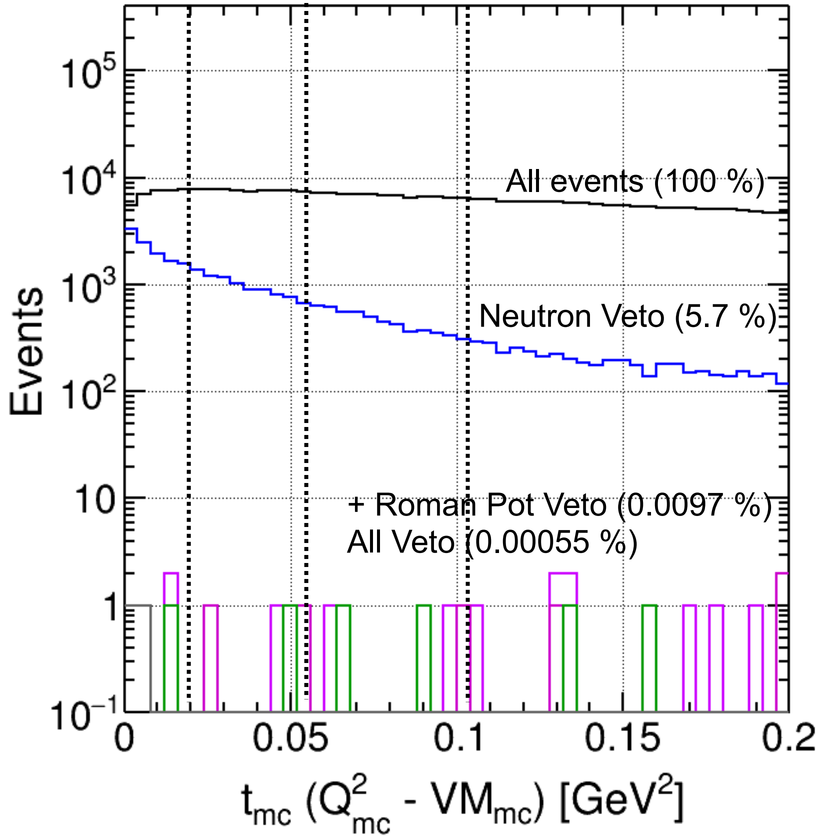
Far-Forward Detector – Incoherent Veto

Reference from EIC YR p.352



At position of third diffractive minimum, **rejection factor for incoherent events better than 400:1 must be achievable (0.0025 % inefficiency)**

Veto inefficiency for incoherent events



ZDC hcal tagged (neutrons)

RPSF tagged (protons, nuclear fragments)

OMD tagged (charged particles)

B0 tracker tagged (charged particles)

B0 ecal tagged (photons)

ZDC ecal tagged (photons)

Vetoing power $> 10^3$

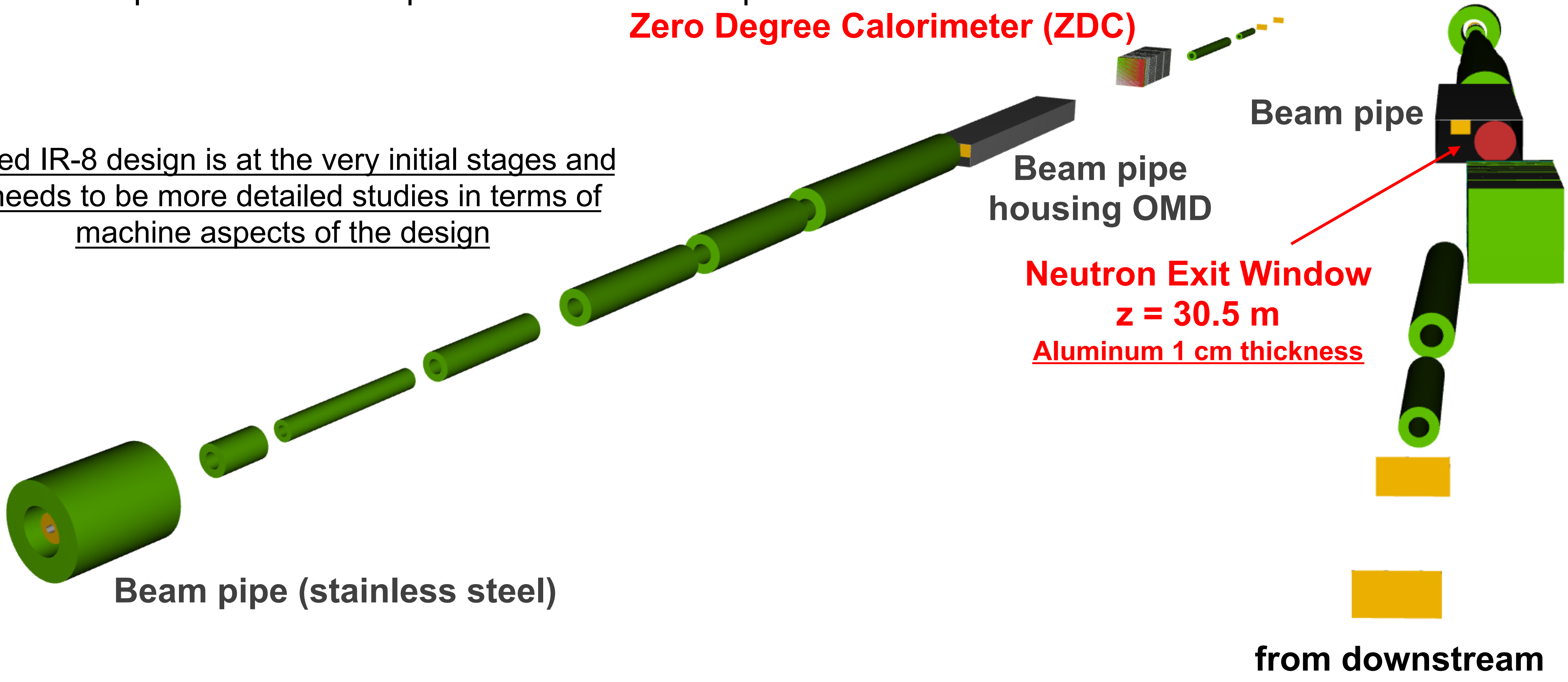
Found to be enough to suppress incoherent contribution at three minima

Vetoing efficiency is ≫ 99.99%

Simplified Beam Pipe Implementation

Proposed pre-conceptual design of IR-8 Forward Hadron Lattice
To evaluate impact on materials placed before ZDC in particular

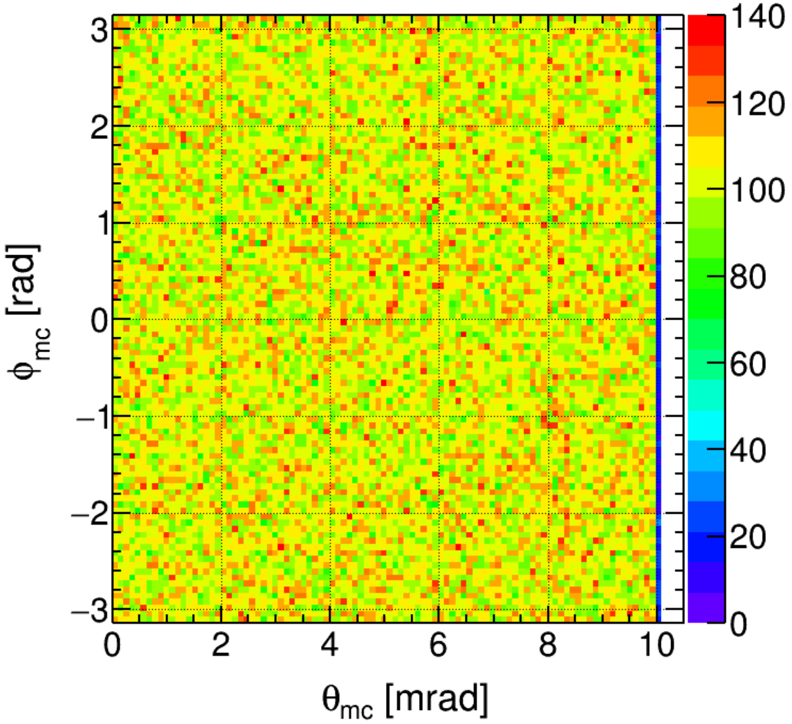
<u>Noted IR-8 design is at the very initial stages and it needs to be more detailed studies in terms of machine aspects of the design</u>



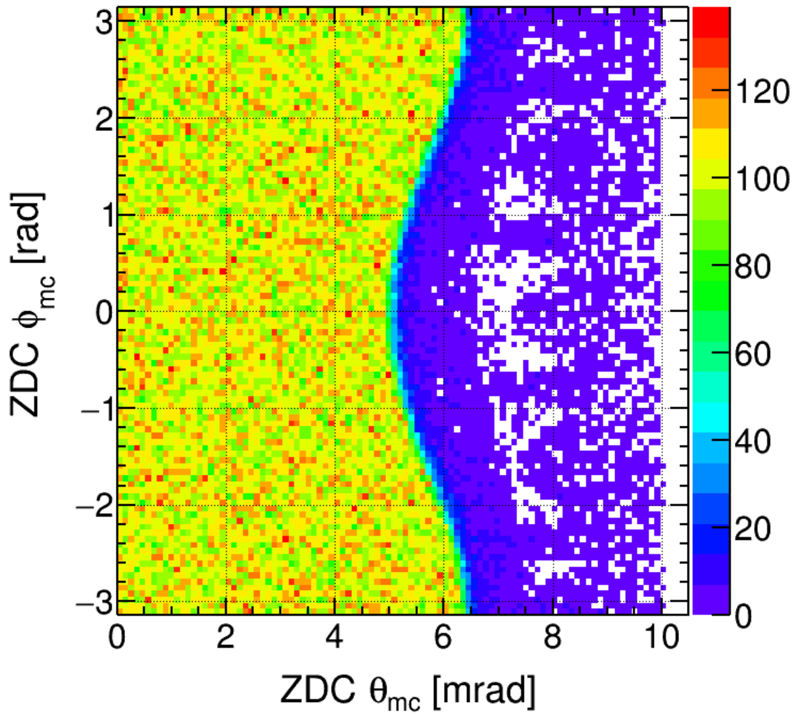
Detector Acceptance Comparison: ZDC

Single Neutron E = 275 GeV and 0 < θ_{MC} < 10 mrad

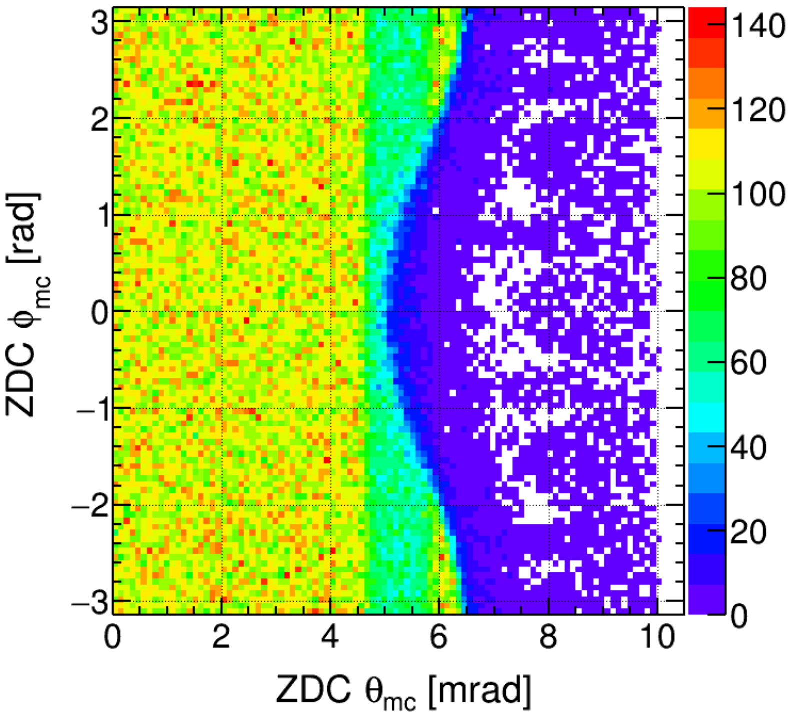
Generated



Accepted
without beam pipe/exit window



Accepted
with beam pipe/exit window

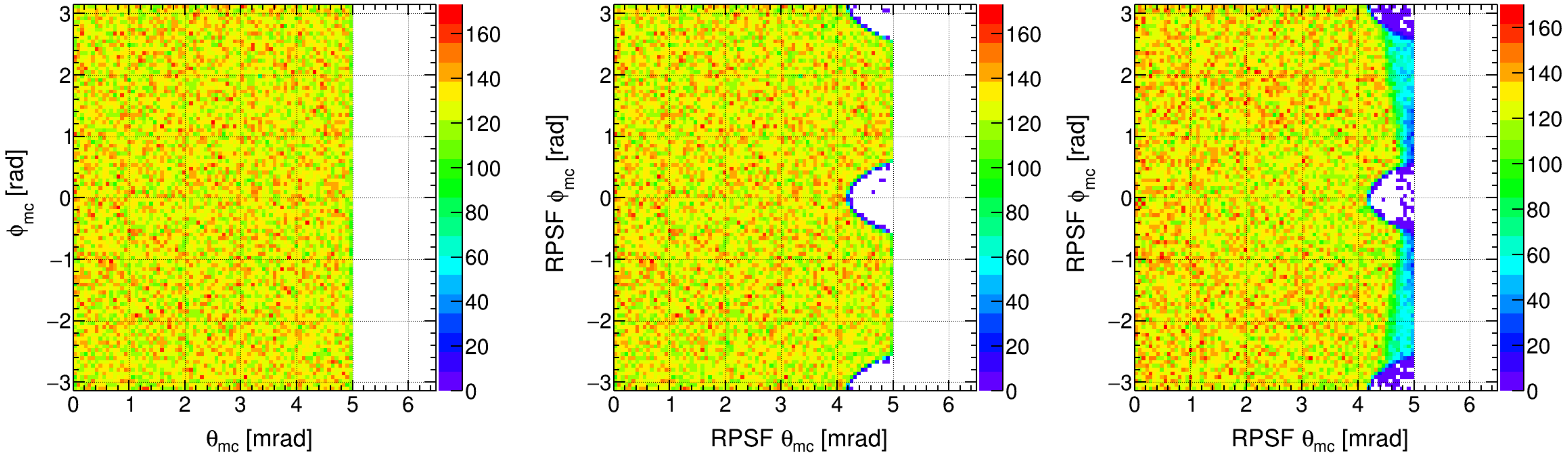


In total, about **99.96 % (97.2 % with beam pipe/exit window)** events were accepted.
Full acceptance in θ_{MC} changed from up to 5 mrad to 4.5 mrad

Detector Acceptance Comparison: RPSF

Single Proton E = 275 GeV and $0 < \theta_{MC} < 5$ mrad

Generated | **Accepted without beam pipe** | **Accepted with beam pipe**



In total, about **95.3 % (91.7 % with beam pipe)** events were accepted.
However, **full acceptance up to 4.2 mrad stays the same**

Vetoing Efficiency Comparison

Veto Selections	Surviving Events	
	Before Beam Pipe/Exit Window	After Beam Pipe/Exit Window
All events	997,820	998,161
Events with one scattered electron identified and $\vert\eta_{J/\psi}\vert < 4$ and $1 < Q^2 < 10$	732,455 (100 %)	732,707 (100 %)
ZDC HCAL tagged	41,848 (**5.71339 %**)	42,476 (**5.79713 %**)
+ RPSF tagged	71 (**0.00969343 %**)	66 (**0.00900769 %**)
+ OMD tagged	71 (0.00969343 %)	64 (0.00873473 %)
+ B0 tracker tagged	30 (0.00409581 %)	30 (0.00409441 %)
+ B0 ecal tagged	17 (0.00232096 %)	19 (0.00259312 %)
+ ZDC ECAL tagged	4 (**0.000546109 %**)	10 (**0.0013648 %**)

Each event has multiple neutrons and in principle if one of them is detected, it is tagged
Nuclear fragments can be captured at roman pot at secondary focus

Summary and Outlook

- To explore physics opportunities by taking full advantage of 2^{nd} focus
  - Implemented **pre-conceptual design of IR-8 hadron beamline** geometry and its field configuration + **required far-forward detectors**
- Using BeAGLE incoherent events (ePb 18×110 GeV^2 J/ψ production), evaluated vetoing power by tagging nuclear fragments using far-forward detectors
  - **Found to be enough to suppress incoherent contribution at three diffractive minima**
  - Shown that it can **achieve vetoing efficiency of ≫ 99.99 %** (i.e. vetoing power ~ 10^3)
  - With exit window implementation, shown not much difference in vetoing efficiency
- Possible physics cases with improved forward acceptance, in particular of low p_T
  - **Access low t** where one can probe large impact parameter b (pion cloud) → change of transverse spatial distribution of gluons or quarks with x allows to help us to **better understand mechanism of confinement**
  - Provide possibility for **constraining diffractive longitudinal structure function (F_L^D)**; Reggeon and Pomeron → enables to **study two Reggeon and Pomeron contributions at the same machine** and may opens new opportunity to study separate from one contribution to another

Backup Slides

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 ($D_{secondary\ focus}$)	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
ep β @ IR-8 RPSF (new)	**0.146677**	**0.140271**
eAu β @ IR-8 RPSF (new)	**0.156271**	**0.104160**

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**

Remaining (Non-Vetoed) Events

Phys. Rev. D 104, 114030

- 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 %**)
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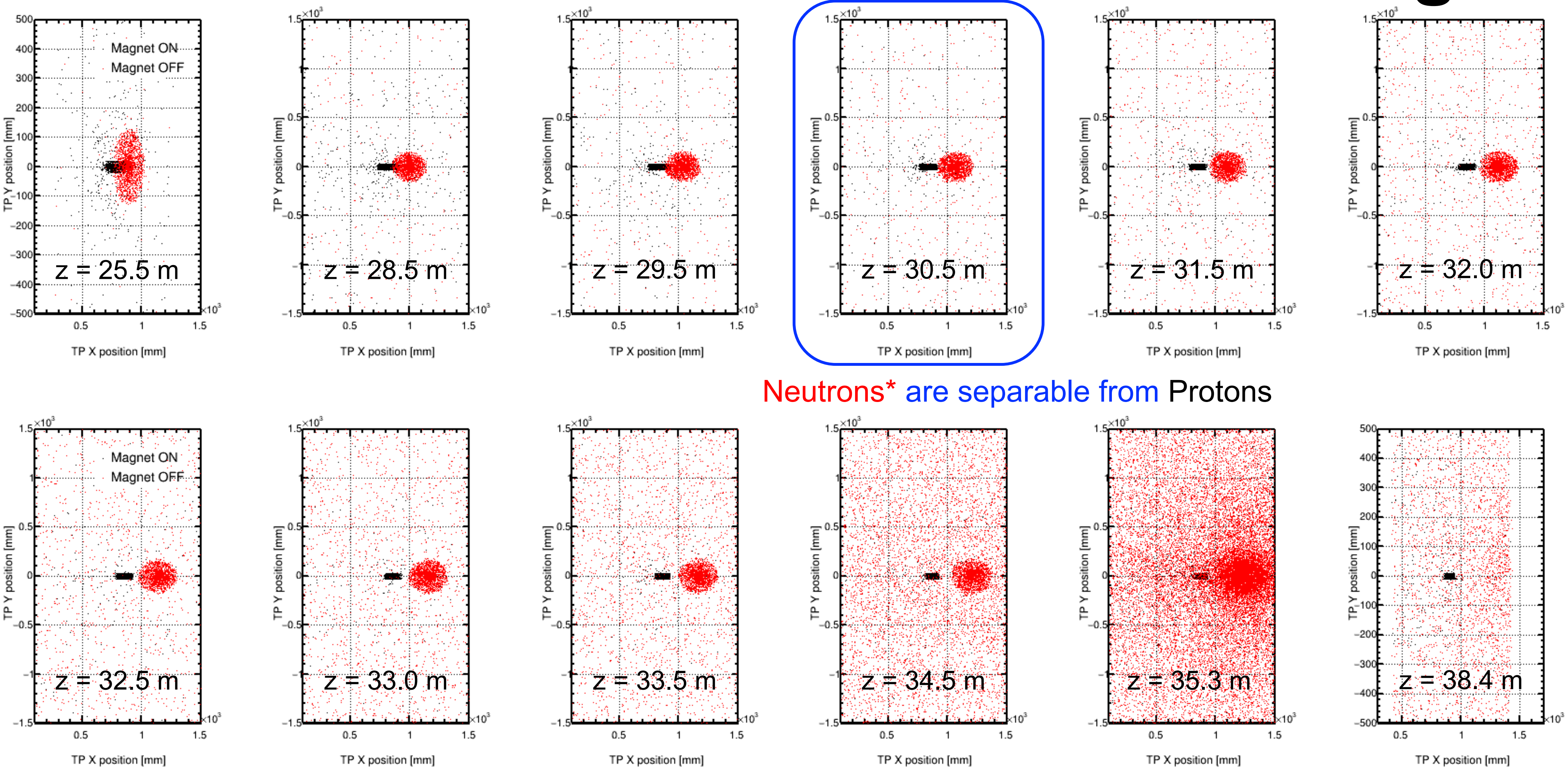
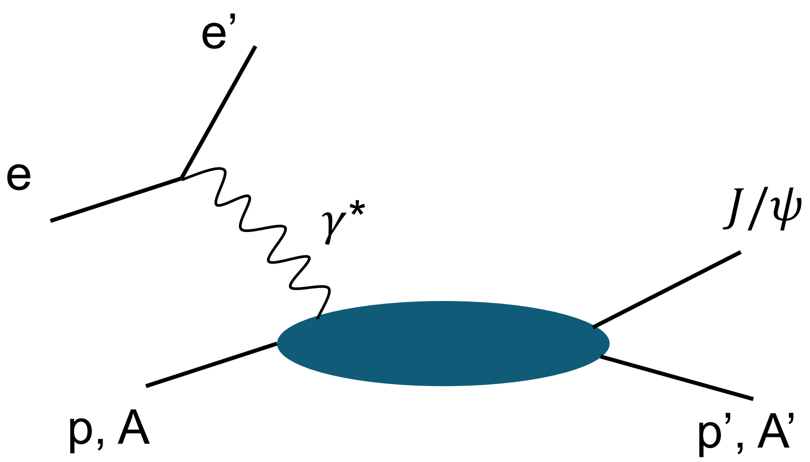
Hit Positions of Protons w/ & w/o Magnets

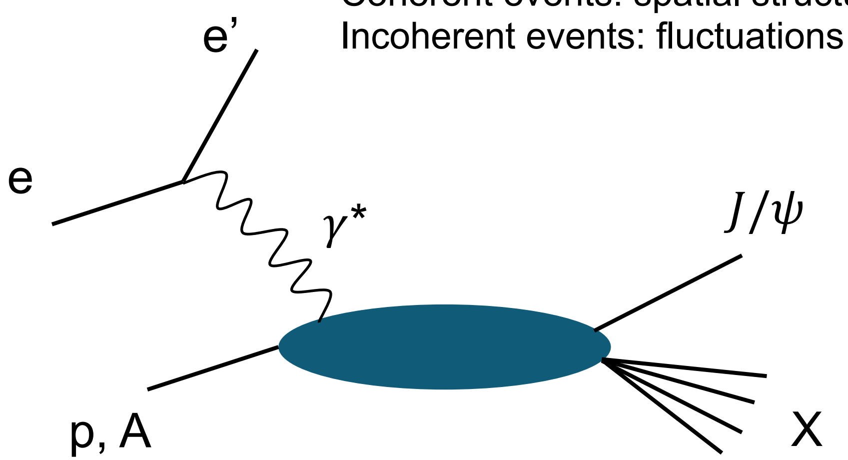


Diffractive Physics Program

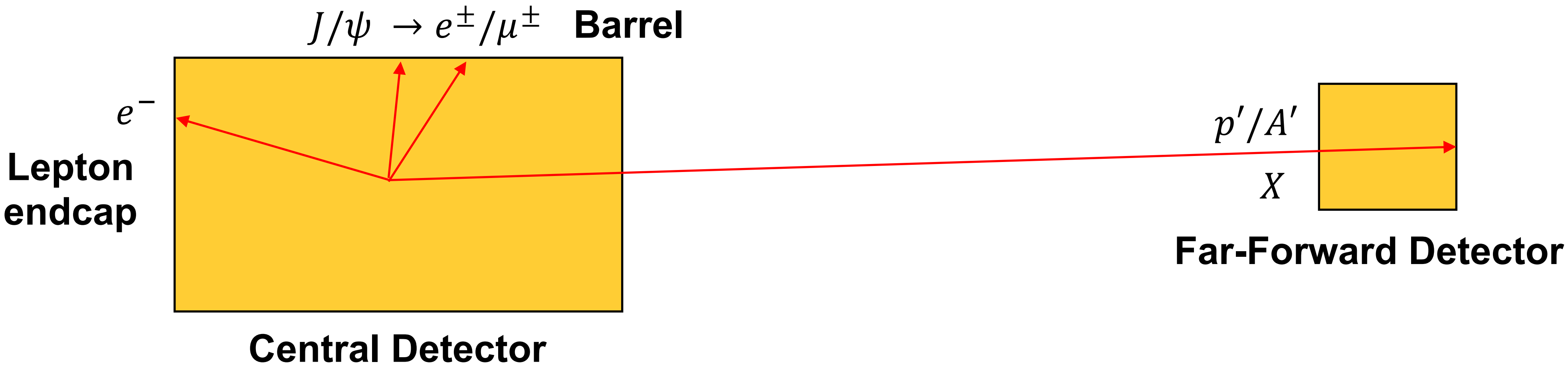
Coherent events: spatial structure of gluons (mean)
Incoherent events: fluctuations



Coherent – Target stays intact

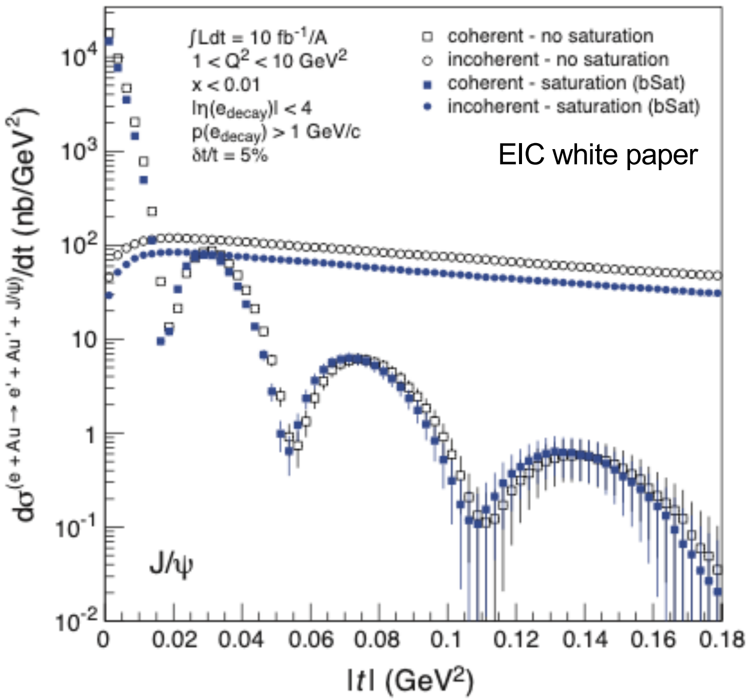


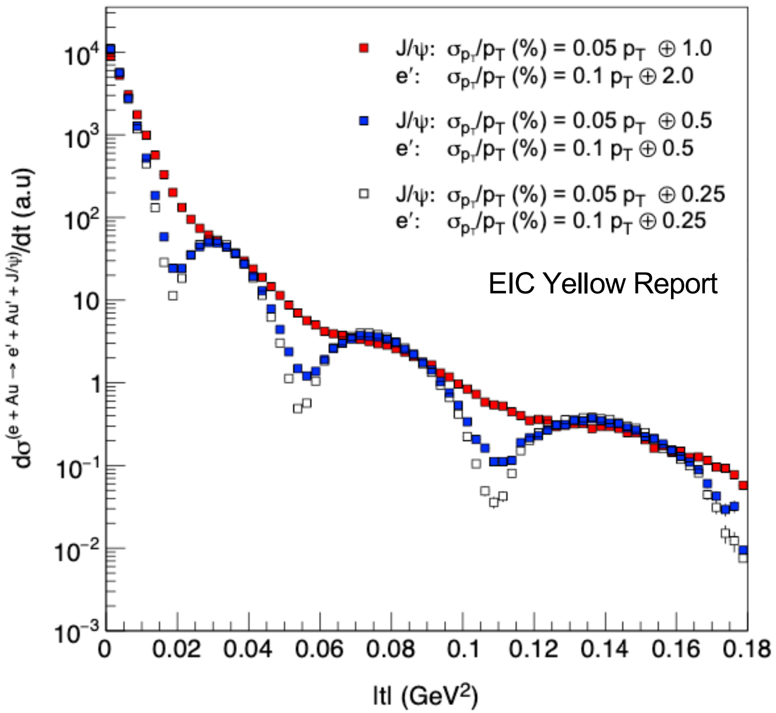
Incoherent – Target breaks up

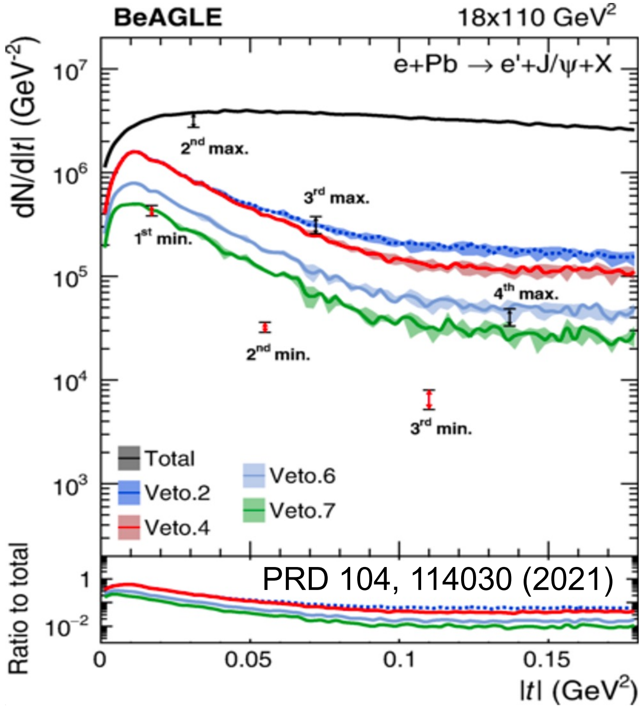


Diffractive Physics Program

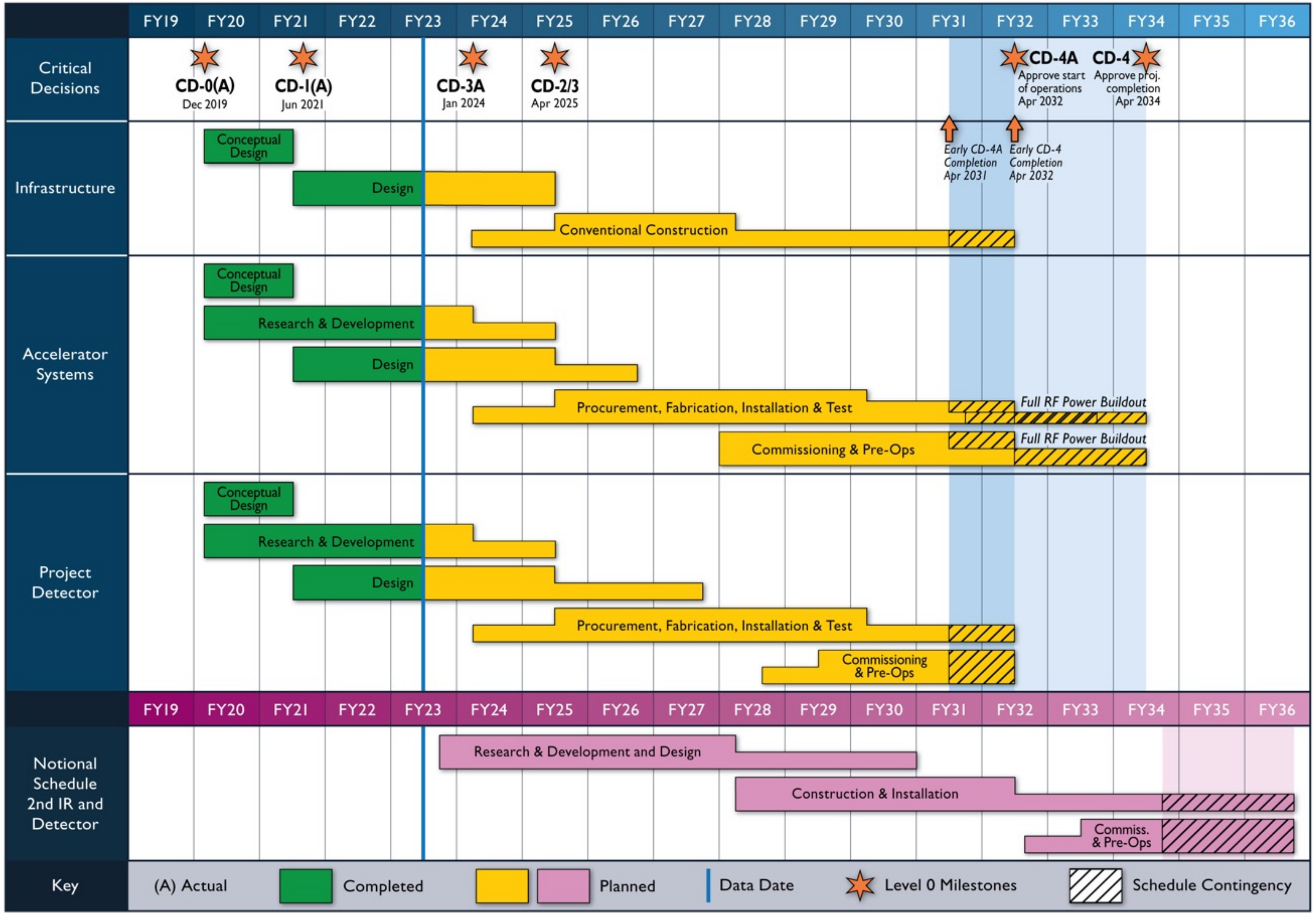
- Experimentally, **measured spectra** in vector meson production contain **sum of coherent and incoherent processes**
  - Low t – coherent events dominate, but **higher t – incoherent events dominate**
  - Measuring coherent events is **very challenging → tagging nuclear breakups and vetoing incoherent events instead**
  - **Tracking resolution (p_T in particular)** allows to measure position of dip patterns







EIC 2nd Detector Timeline



Reference schedule for 2nd IR and detector from EICUG meeting July 2023

← EIC 2nd detector

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