Tagging incoherent vector-meson production events at ePIC

Mathias Labonté

Exclusive diffractive and tagging meeting
May 5, 2025

Outline

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1. Motivation and Good-Walker paradigm

2. Details, BeAGLE dataset

3. Incoherent event tagging efficiency study

   How well can we tag incoherent events at ePIC?

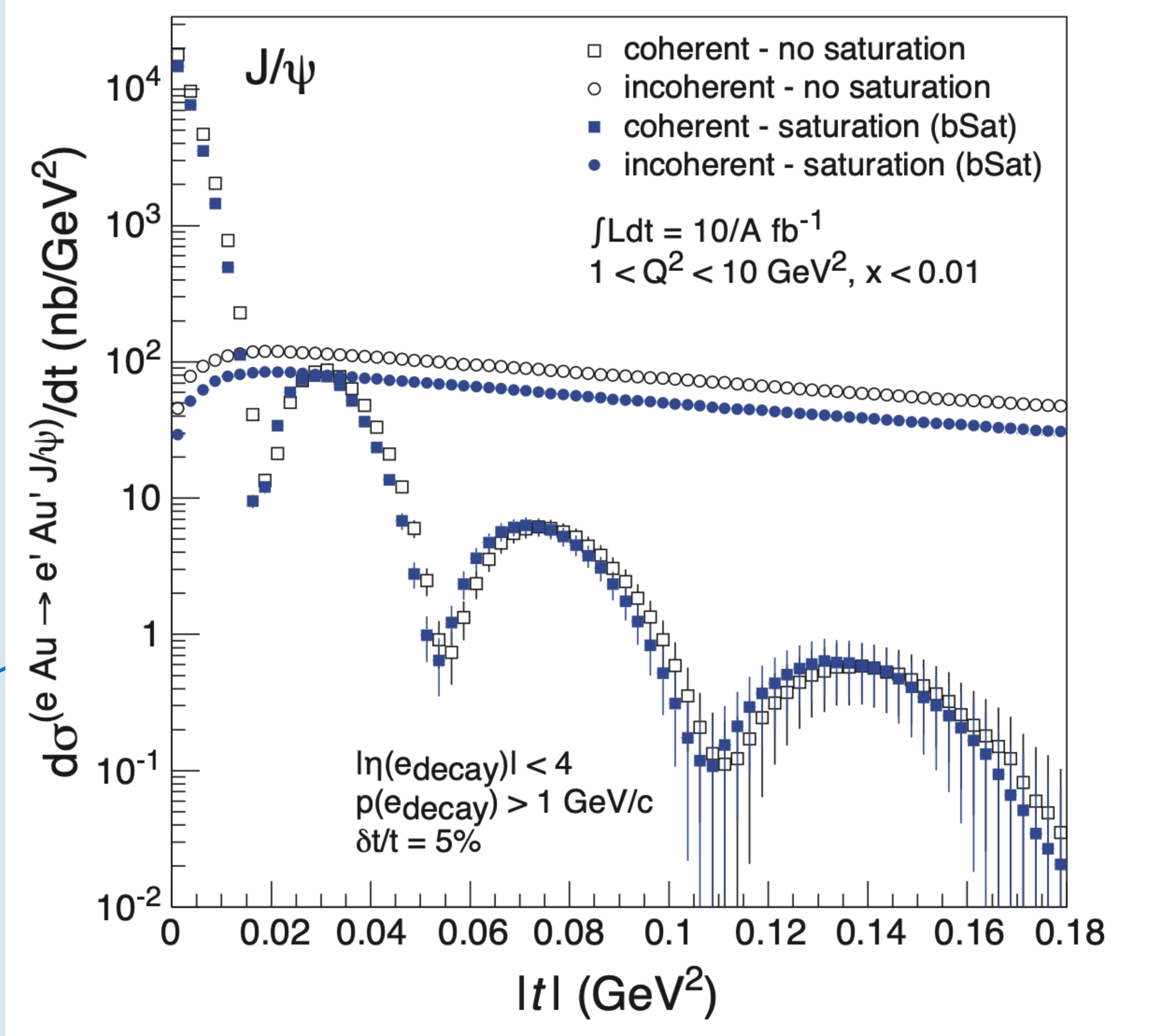
4. Comparisons between Pb and Au

Good-Walker paradigm

- Coherent exclusive vector meson production events are sensitive to the transverse gluon distribution within the nucleus
- Incoherent events are sensitive to event-by-event fluctuations
- Even nuclear excitations are incoherent, and the Good-Walker paradigm breaks down
- Measuring these photons coming from nuclear de-excitations can serve as a means of tagging incoherent events

Physics goals at the EIC

- Measure coherent vector-meson production to learn about the distribution of gluons in the nucleus
- Requires us to be able to efficiently tag incoherent events
- Tagging efficiency required at the third diffractive minimum: 99.8%



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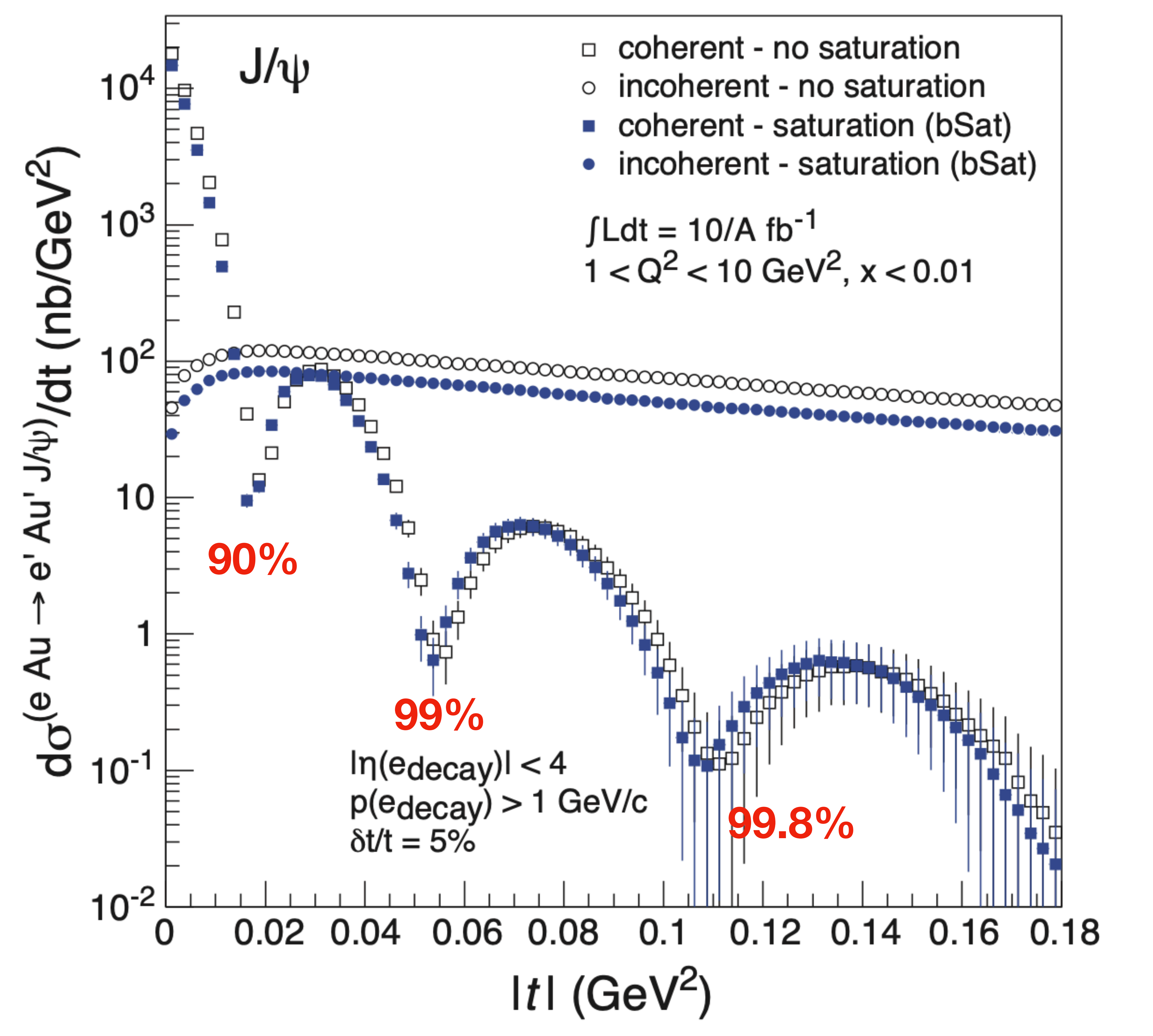

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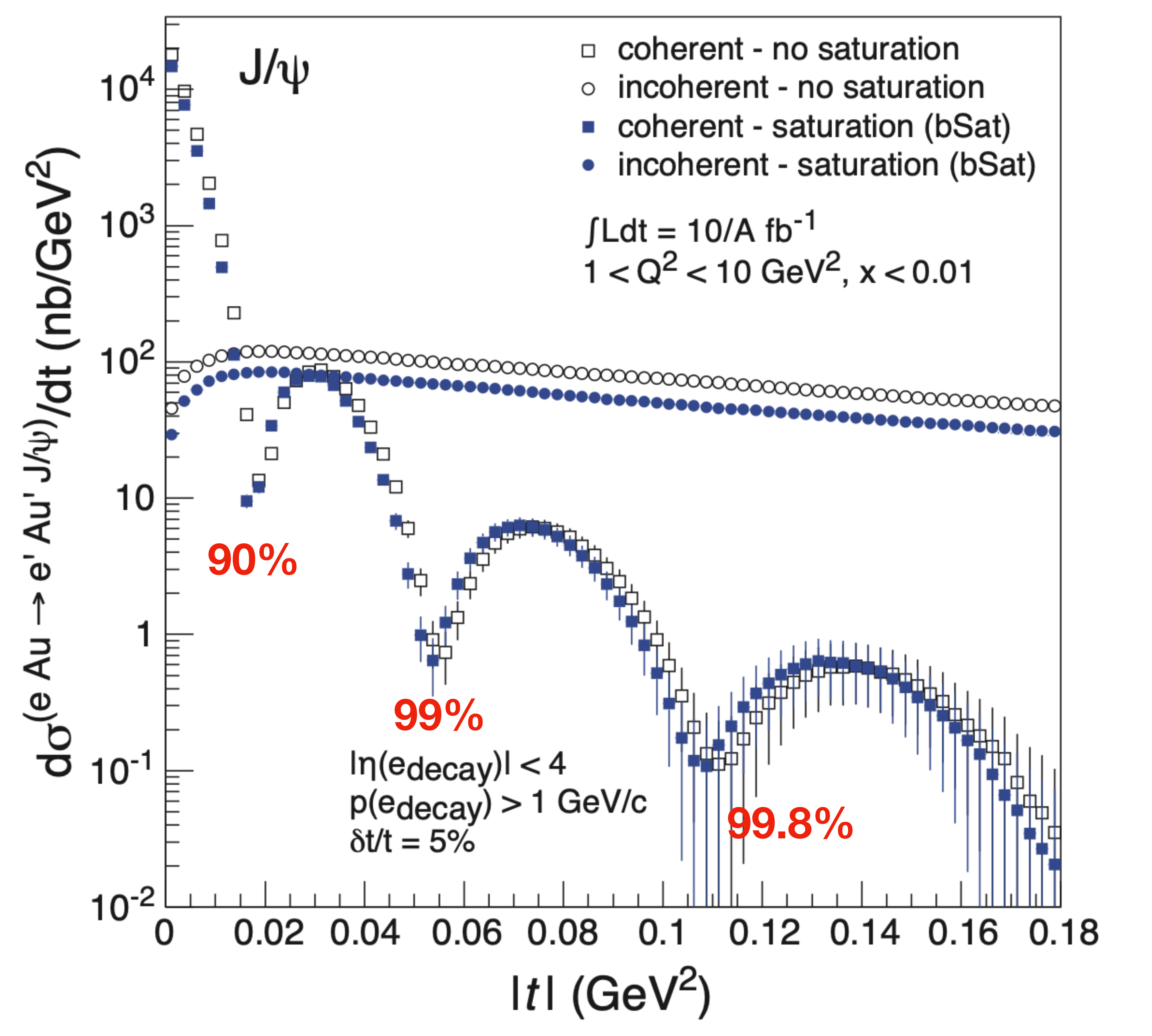

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EIC Early Science Program

	Species	Energy	Luminosity (fb^{-1})
Year 1	e+Ru or e+Cu	10x115	1
Year 2	e+d	10x130	9
	e+p	10x130	1
Year 3	e+p	10x130	5
Year 4	e+Au	10x130	0.5
	e+p	10x250	4
Year 5	e+Au	10x100	0.4
	e+^{3}He	10x166	4

Gold and Lead

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- From a partonic perspective, Au and Pb are similar (Woods-Saxon distributed nuclei and similar shadowing)
- But they have differences in their nuclear shells, giving differences in the gamma spectrum emitted from de-excitation
- The Good-Walker paradigm breaks down even in any case where there is some change to the nucleus
- The first excited state of Au (77 KeV) is much lower than than Pb (2.6 MeV), and decays much slower

Excited Nuclear States for Au-197 (

Energy levels

Au excited states

E^* [keV]	$2J^\pi$	μ	Q	$T_{1/2}$ or Γ_{cm}
0.0[a]	3^+	+1.145746(9)	+0.547(16)	Stable
77.351(2)	1^+	+0.420(3)		1.91(1) ns
268.788(10)	3^+			15.4(13) ps
279.00(5)[A]	5^+	+0.53(5)		18.6(15) ps
409.15(8)[B]	11^-	⟨+⟩5.98(9)	+1.68(5)	7.73(6) s
502.52(13)	5^+	+3.0(5)	+3.0(5)	1.77(+19-12) ps
547.5(2)[a]	7^+	+0.53(7)		4.61(+19-13) ps
583.86(17)[C]	⟨7^-⟩			
736.84(15)	7^+	+1.7(5)	+1.7(5)	1.09(+13-9) ps
767.09(23)[B]	⟨15^-⟩			
855.6(2)[A]	9^+	+1.5(5)	+1.5(6)	2.67(+25-15) ps
882(5)				
888.11(20)	1^+			
935.96(14)	⟨5^+⟩			
947.86(20)[C]	⟨9^-⟩			
1003.56(21)*	⟨13^-⟩			
1045.05(16)	⟨7^+⟩			
1059.67(21)*	⟨9^+⟩			
1118.80(19)*				
1150.54(16)	3^+,5^+			
1217.28(22)	⟨3^+⟩			
1220(10)				
1231.7(3)[a]	11^+	+2.0(10)		0.91(1) ps
1242.02(22)	⟨1^+⟩			

Gold and Lead

Excited Nuclear States for Pb-208 (Lead)

Energy levels

Pb excited states

E^* [keV]	J^π	E_n [keV]	ℓ_n	Γ_n [meV]	Γ_n^1 [meV]	Γ_γ^2/Γ [eV]	$B(E1)$	$T_{1/2}$ or Γ_{cm}
0.0								Stable
2614.52(1)	3^-							16.7(3) ps
3197.71(1)	5^-							294(15) ps
3475.08(1)	4^-							4(3) ps
3708.45(1)	5^-							<100 ps
3919.97(1)	6^-							>690 fs
3946.58(1)	4^-							>430 fs
3961.16(1)	5^-							≤18 ps
3995.44(1)	4^-							>690 fs
4037.44(1)	7^-							>690 fs
4045(5)	$5^-,6^-$							
4051.13(1)	3^-							326(+28-21) fs
4085.52(4)	2^+					0.45(3)	2434(168)	0.80(4) fs
4106(3)	$\langle 3^- \rangle$							
4125.35(1)	5^-							>490 fs
4144(5)*	X^+							
4159(4)	$\langle 2^+ \rangle$							
4180.41(1)	5^-							319(35) fs
4206.28(1)	6^-							>690 fs
4229.59(2)	2^-							333(28) fs
4254.80(2)	3^-							97(7) fs
4261.87(1)	4^-							>520 fs
4296.56(1)	5^-							201(+49-35) fs
4318(12)	$2^+,5^-$							
4323.95(1)	4^+							11.7(+1.5-1.8) ps
4358.67(1)	4^-							194(21) fs
4383.29(2)	6^-							>690 fs
4403(2)	$3^-,4^+$							
4423.65(2)[A]	6^+							>110 fs

States are shorter lived and higher minimum threshold

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Event Generation

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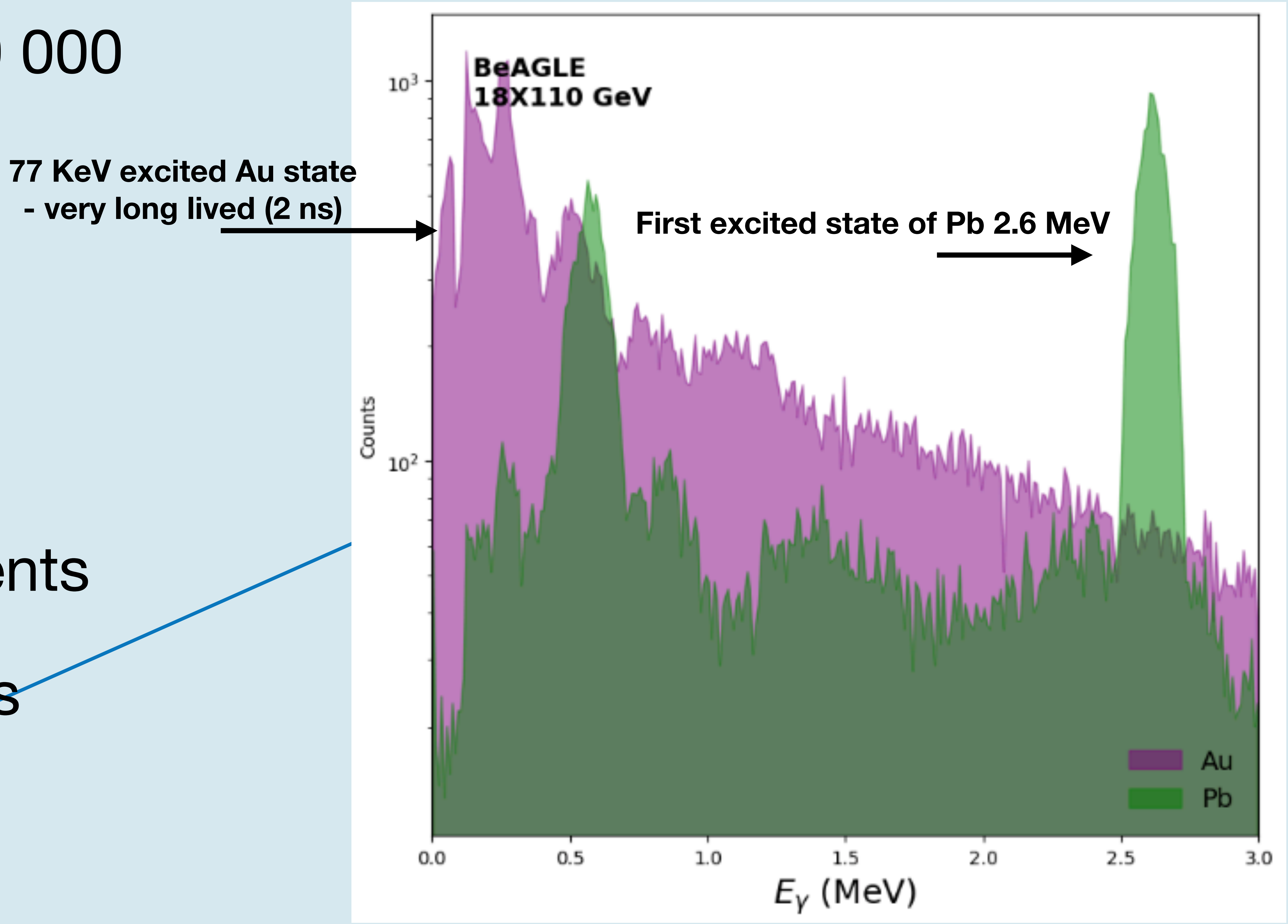
- Use BeAGLe to generate ~ 20 000 events with J/Ψ production
    - e+Pb 18x110 GeV
    - e+Au 18x110 GeV
- Calculate our ability to veto incoherent VM production events
- Is there a target species that is preferred for VM production?

(In target rest frame)



Event Generation

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- Use BeAGLe to generate ~ 300 000 events with J/Ψ production
  - e+Pb 18x110 GeV
  - e+Au 18x110 GeV
- Calculate our ability to veto incoherent VM production events
- Paper from 2021, try to reproduce the different veto efficiencies

Investigation of the background in coherent J/ψ production at the EIC

Wan Chang,[1,2,*] Elke-Caroline Aschenauer,[2,†] Mark D. Baker,[3,‡] Alexander Jentsch,[2,§] Jeong-Hun Lee,[2] Zhoudunming Tu,[2,4,¶] Zhongbao Yin,[1] and Liang Zheng[5]

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[2] *Department of Physics, Brookhaven National Laboratory, Upton, NY 11973, U.S.A.*
[3] *Mark D. Baker Physics and Detector Simulations LLC, Miller Place, NY 11764, U.S.A.*
[4] *Center for Frontiers in Nuclear Science, Stony Brook, NY 11794, U.S.A.*
[5] *School of Mathematics and Physics, China University of Geosciences, Wuhan 430074, China*
(Dated: August 10, 2021)

- 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.

Percentage of surviving events

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- Veto.5: Veto.4 and no proton in B0;
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- Veto.7: Veto.6 and no photon with $E > 50$ MeV in ZDC.

e+Pb 18×110 GeV

Veto Stage	This study (%)	Paper (%)
Veto 1	85.0682	86.9
Veto 2	5.128	5.81
Veto 3	5.128	5.81
Veto 4	5.1062	5.09
Veto 5	4.639	4.32
Veto 6	0.7818	2.29
Veto 7	0.2204	1.06

- The difference in surviving events could come from different BeAGLE versions, slightly different detector models, no crabbing effect
- No reconstruction here

Comparison to Gold

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- A first look shows that Au performs similarly to Pb
- But we have to remove the long-lived states (crude cut; remove particles with $E_\gamma < 409\ \mathrm{KeV}$)
- Not perfect because higher states could decay into an intermediate state that is short lived

Percentage of surviving events

Veto Stage	Au (%)		Pb (%)	
	This study	Paper	This study	Paper
Veto 1	85.019	N/A	85.0682	86.9
Veto 2	5.919	N/A	5.128	5.81
Veto 3	5.919	N/A	5.128	5.81
Veto 4	5.8964	N/A	5.1062	5.09
Veto 5	5.2898	N/A	4.639	4.32
Veto 6	0.2614	N/A	0.7818	2.29
Veto 7	0.0748	N/A	0.2204	1.06

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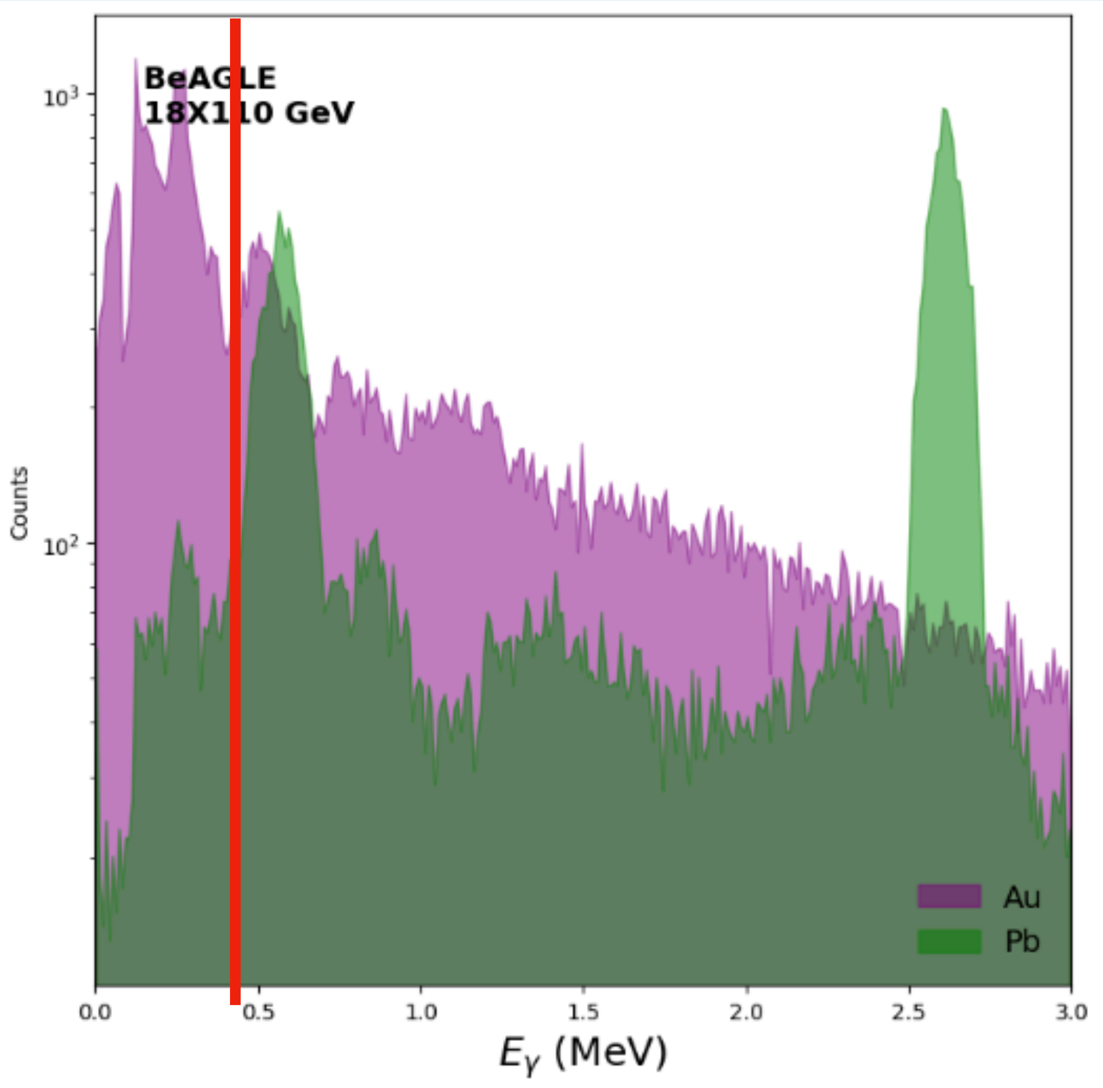
Percentage of surviving events

Veto Stage	Au (%)		Pb (%)	
	This study	Paper	This study	Paper
Veto 1	85.129	N/A	85.0682	86.9
Veto 2	5.9234	N/A	5.128	5.81
Veto 3	5.9234	N/A	5.128	5.81
Veto 4	5.9004	N/A	5.1062	5.09
Veto 5	5.2922	N/A	4.639	4.32
Veto 6	4.7106	N/A	0.7818	2.29
Veto 7	3.8448	N/A	0.2204	1.06

Much higher after we cut the Au states



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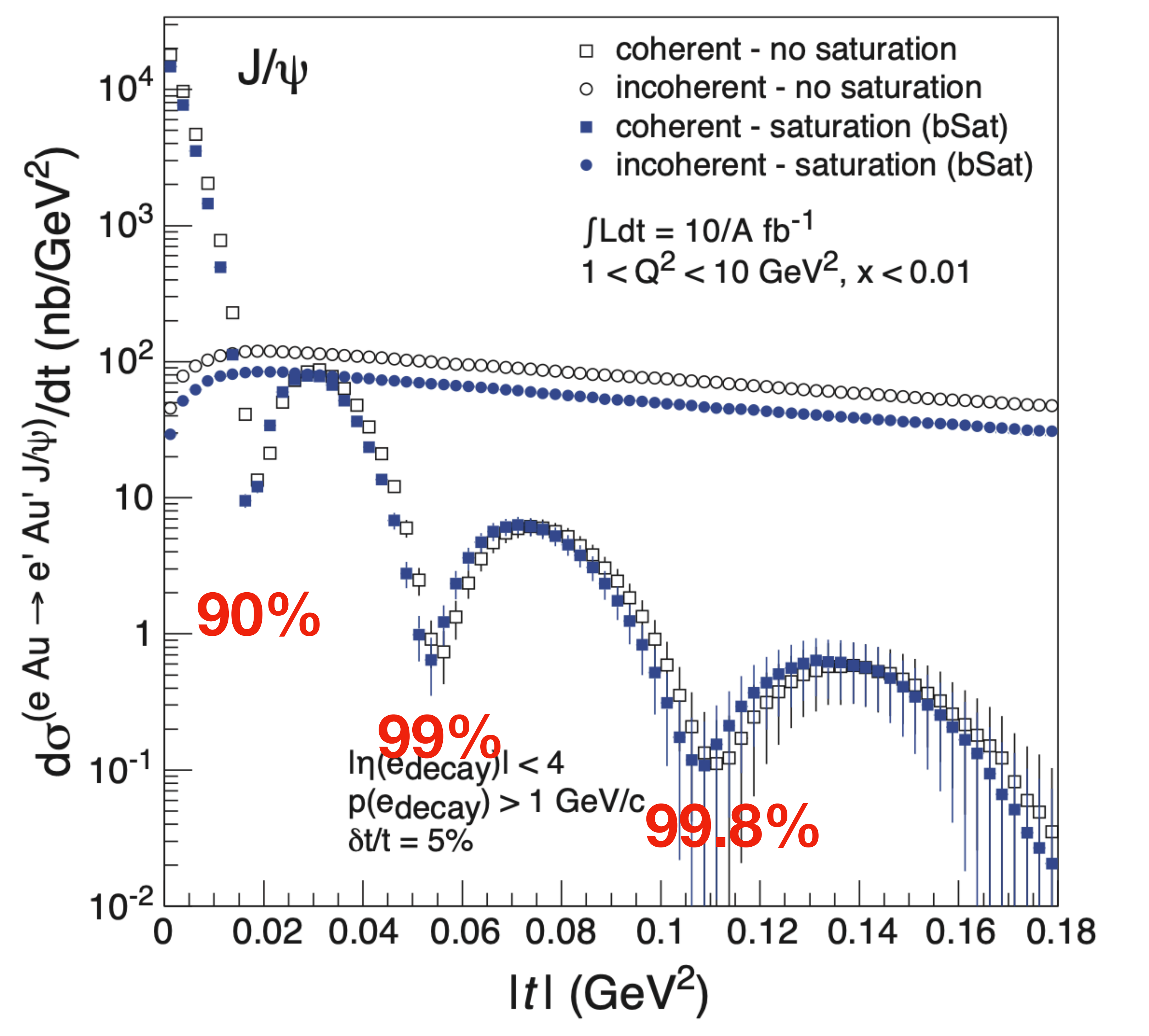

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Step 7 for $0.1 < \|t\| < 0.12$	**1.814**	—	**0.041**	—

- For the third diffractive minimum, we need a veto efficiency of 0.2%
- Pb is close to this target, but Au is not after removal of the excited states
    - This is before considering detector effects

Conclusion

- A first look shows us that we might not be able to reconstruct the third diffractive minimum with a Au beam
- Pb seems to perform better
    - Using a crude cut to eliminate the long lived states
    - Should investigate further how to best do this
- Could use studies like this to motivate ion species during the early physics program
- **Next steps**
    - Reconstruction?
    - More differential studies in t