Tagging coherent vector-meson production events at the EIC

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Outline

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

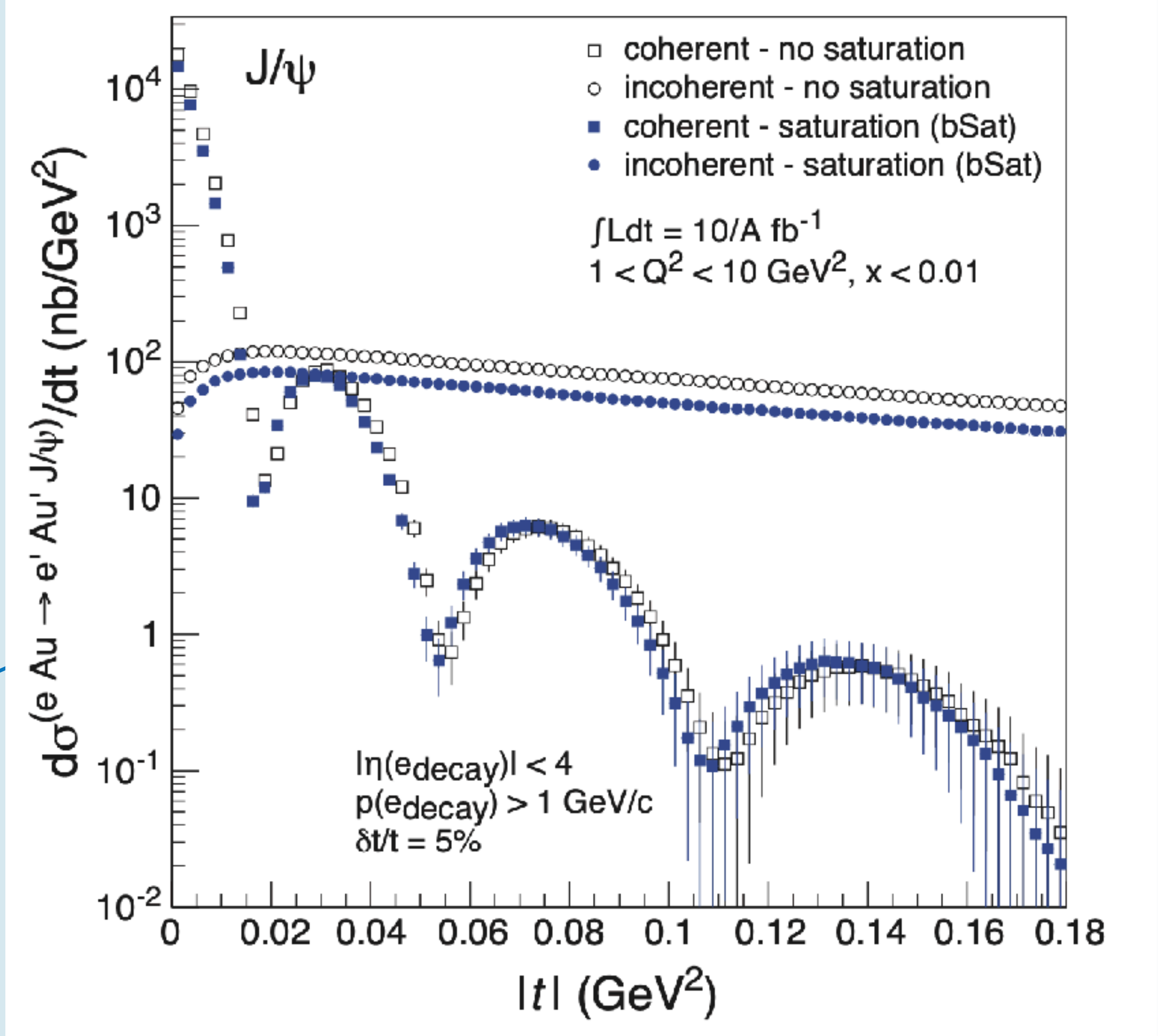
- Coherent exclusive vector meson production events are sensitive to the transverse gluon distribution within the nucleus
- Incoherent events are sensitive to event-by-event fluctuations
- Even nuclear excitations are incoherent, and the Good-Walker paradigm breaks down
- Measuring these photons coming 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%



T. Toll and T. Ullrich, Phys. Rev. C 87, 024913 (2013), arXiv:1211.3048 [hep-ph].

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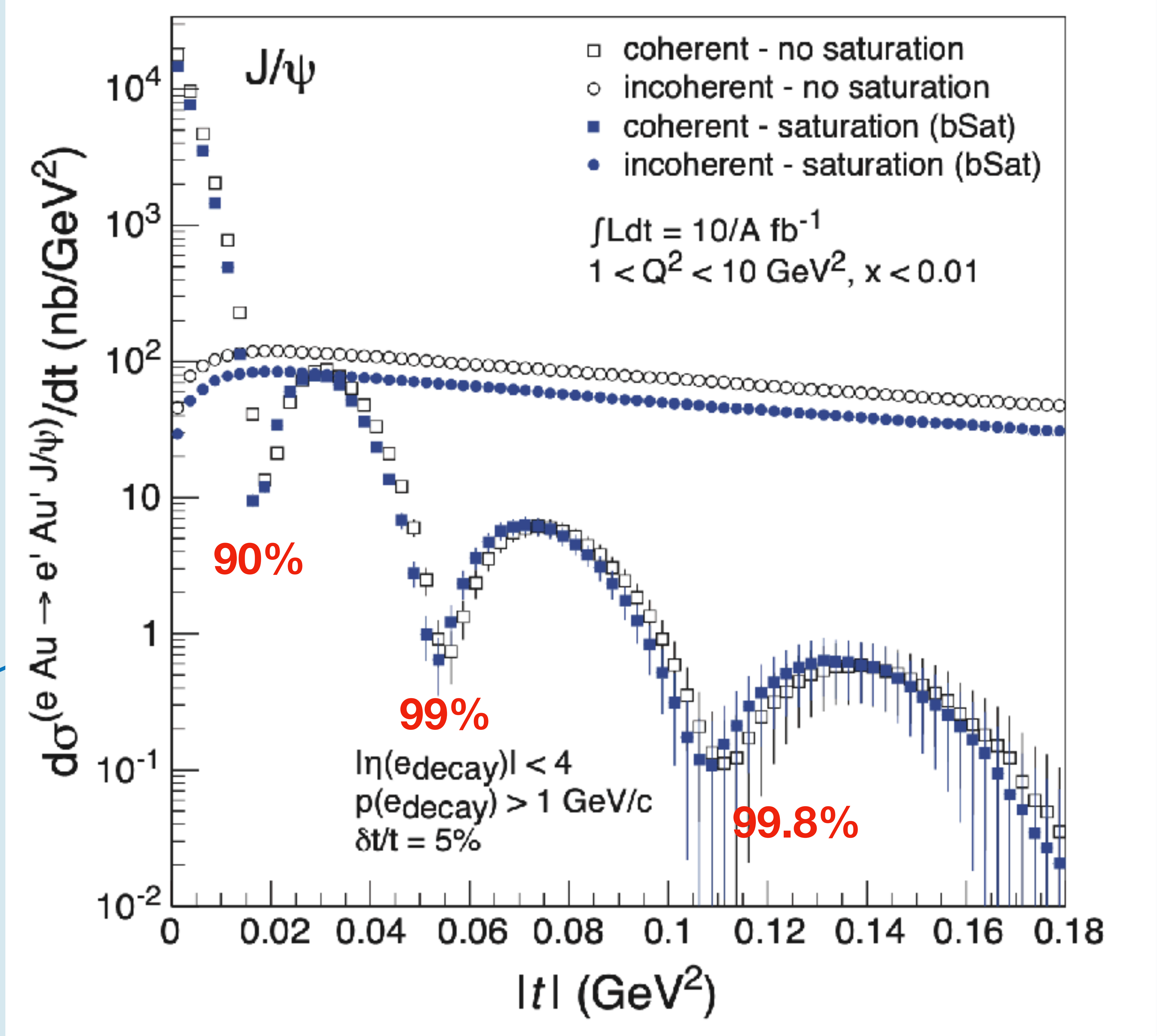

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Slide from Rosi Reed's talk yesterday

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
- 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

Au excited states

Energy levels

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]	$\langle 7^- \rangle$			
736.84(15)	7^+	+1.7(5)	+1.7(5)	1.09(+13-9) ps
767.09(23)[B]	$\langle 15^- \rangle$			
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)	$\langle 5^+ \rangle$			
947.86(20)[C]	$\langle 9^- \rangle$			
1003.56(21)*	$\langle 13^- \rangle$			
1045.05(16)	$\langle 7^+ \rangle$			
1059.67(21)*	$\langle 9^+ \rangle$			
1118.80(19)*				
1150.54(16)	$3^+,5^+$			
1217.28(22)	$\langle 3^+ \rangle$			
1220(10)				
1231.7(3)[a]	11^+	+2.0(10)		0.91(1) ps

Gold and Lead

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Excited Nuclear States for Pb-208 (Lead)

Pb excited states

Energy levels

E^* [keV]	J^π	E_n [keV]	ℓ_n	Γ_n [meV]	Γ_n^l [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)	(3^-)							
4125.35(1)	5^-							>490 fs
4144(5)*	X^+							
4159(4)	(2^+)							
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

Excited Nuclear States for Au-197 (

Au excited states

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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
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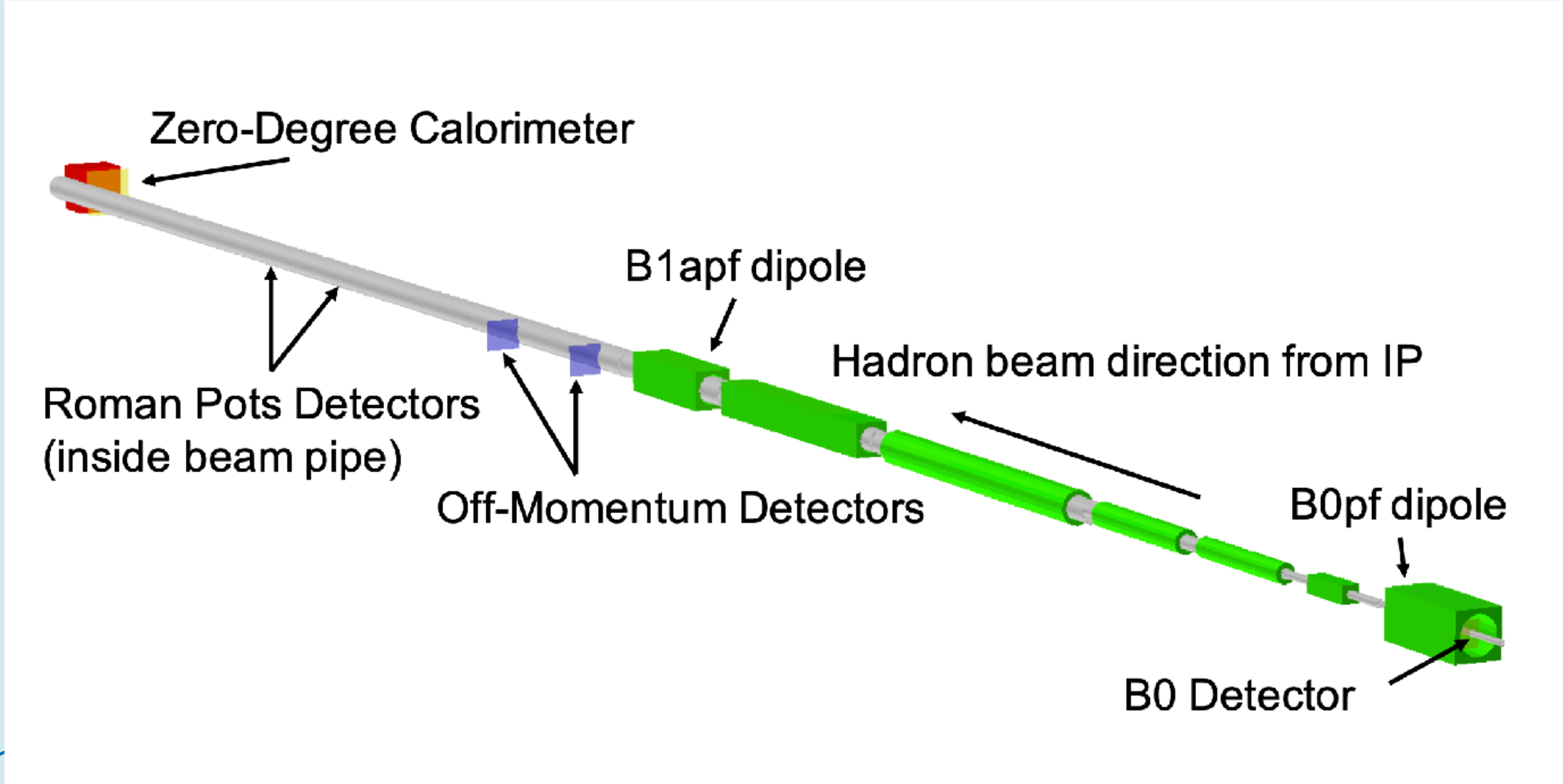
1150.54(16)	$3^+,5^+$			
1217.28(22)	(3^+)			
1220(10)				
1231.7(3)^a	11^+	+2.0(10)		0.91(1) ps
1242.02(22)	(1^+)			

Detecting the photons from nuclear decay

- Photons will be boosted and wind up mostly in the B0 and ZDC
- Will have EM calorimetry in these detectors



Event Generation

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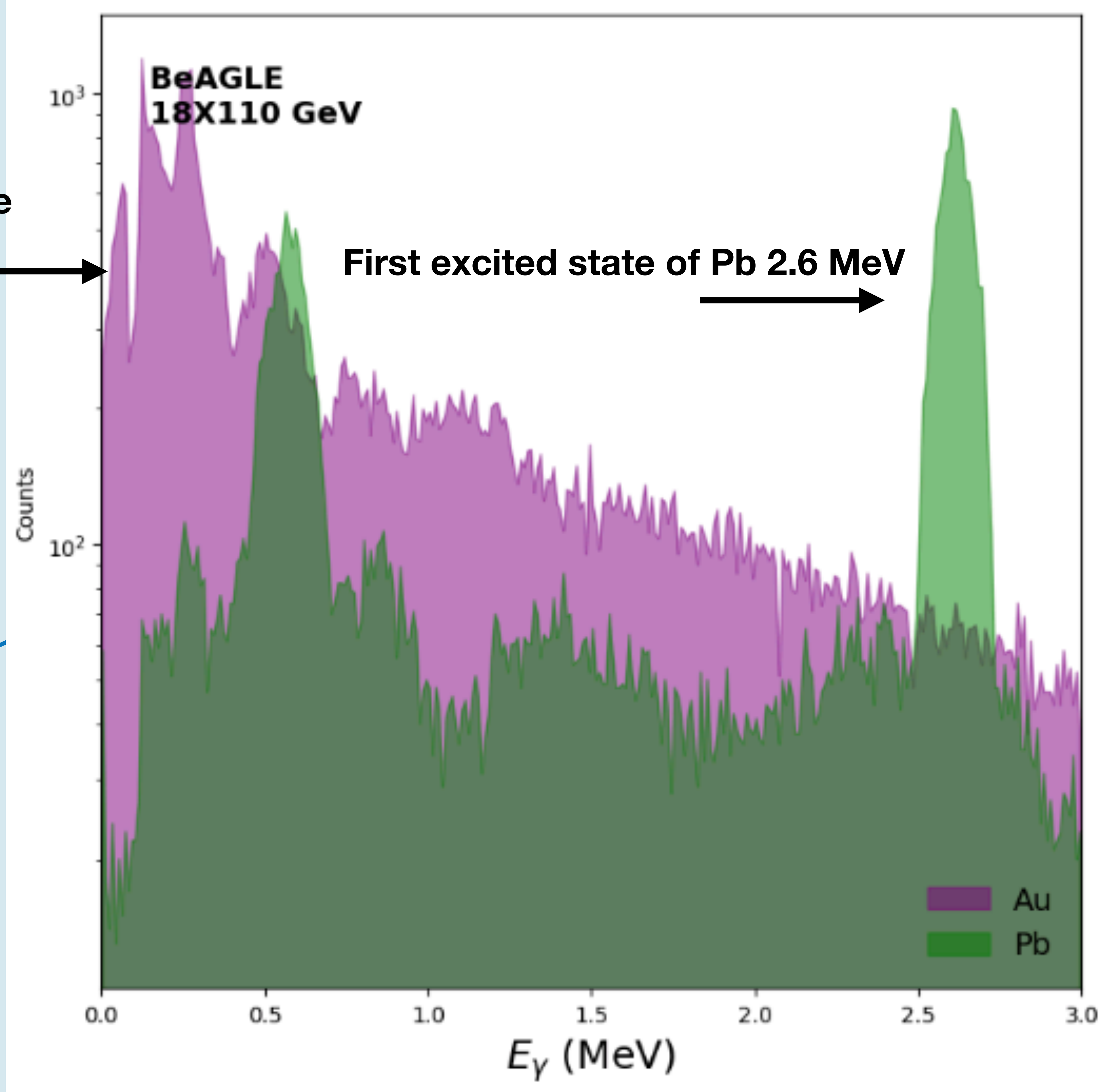
- Use BeAGLe to generate ~ 20 000 events with J/Ψ production
  - e+Pb 18x110 GeV
  - e+Au 18x110 GeV
- Force the nucleus to remain intact (ARemn = 208, 197)
- Select only photons whose parent ID is a nucleus
- Is there a target species that is preferred for VM production?

(In target rest frame)

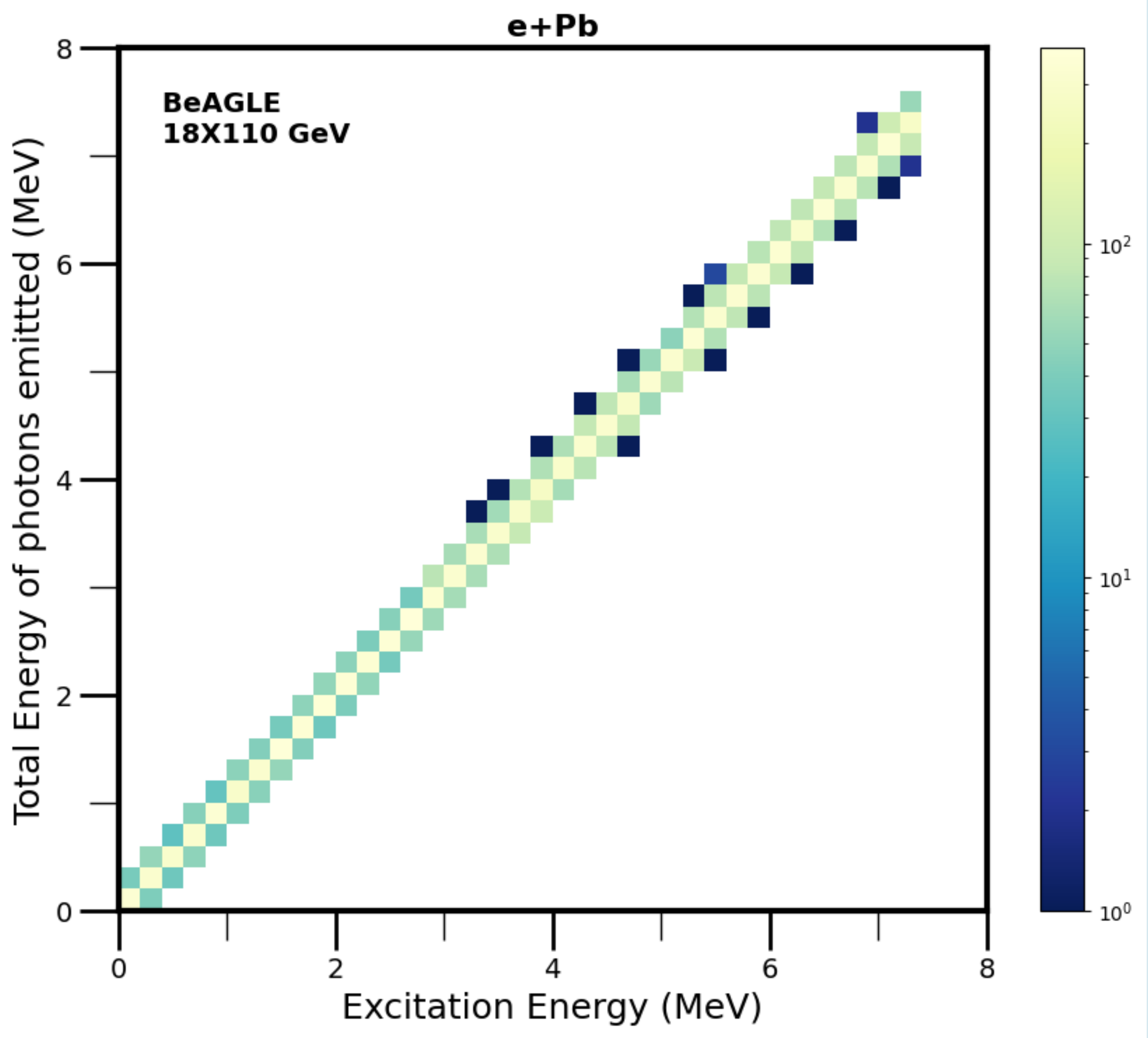


Excitation energy

- We can then plot the excitation energy against the total energy of diffractive photons in the event

- Very well correlated

- Can conclude we are properly selecting photons coming from nuclear excitations



How well can we tag incoherent events?

How many of photons do we see in ZDC?

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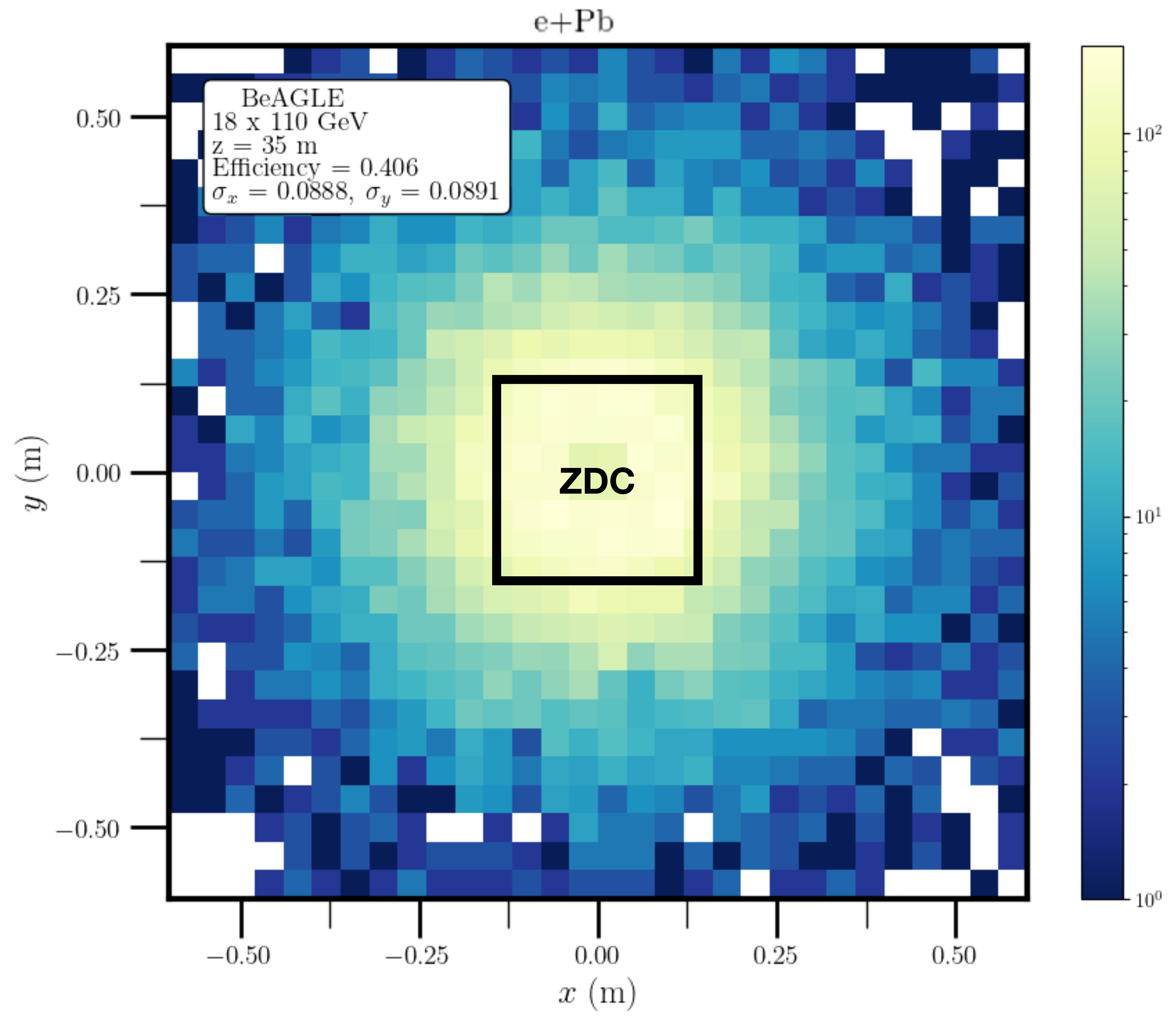
- Select on the plane $Z = 35$ m
- Select photon with highest η in each event
- Effective area of ZDC: 17x17 cm
- Can tag around 40% of events as incoherent in fiducial region of ZDC

$$\text{Efficiency} = \frac{\text{\# of events with photon in ZDC acceptance}}{\text{\# of total events}}$$



How many photons do we see in B0?

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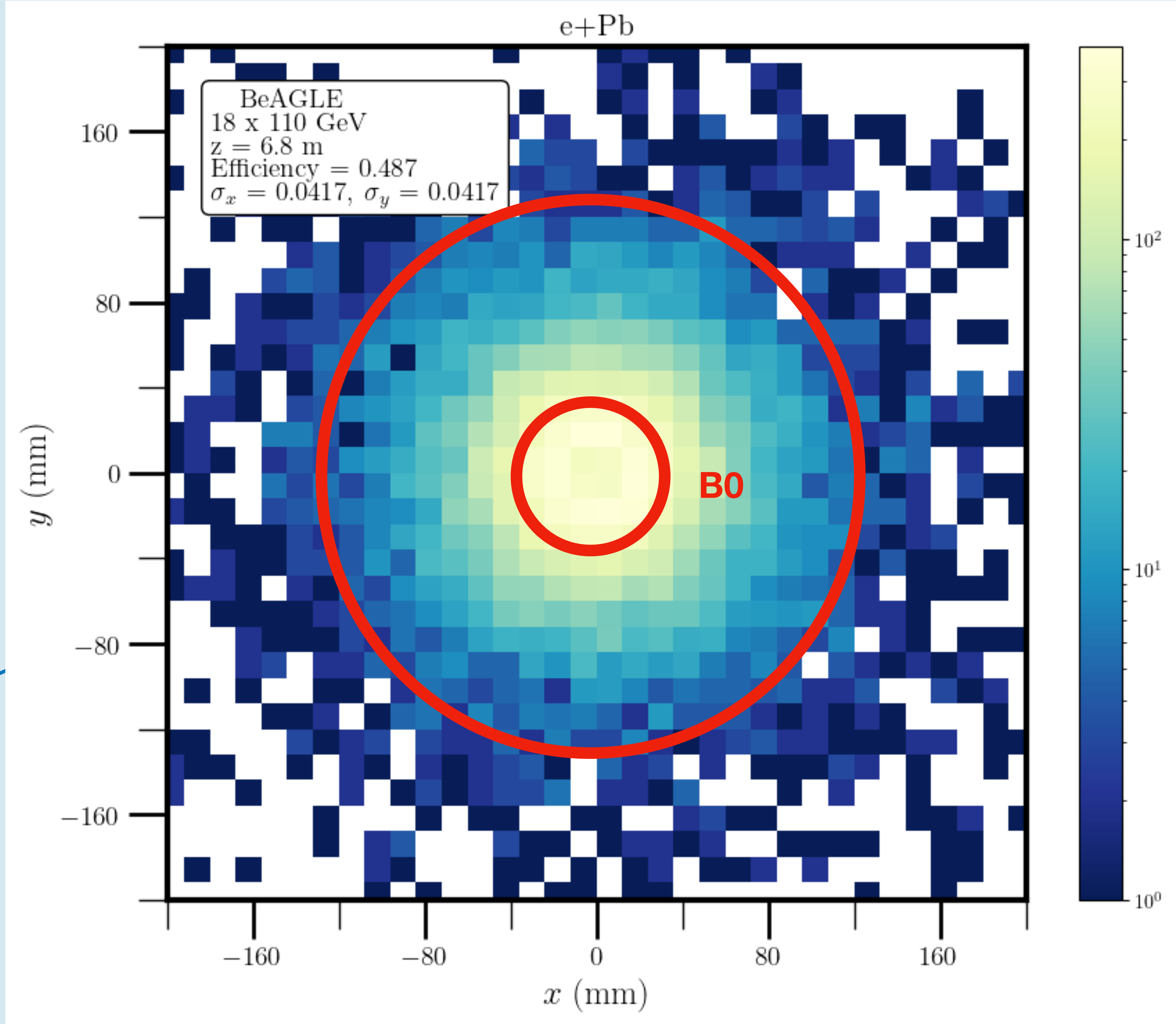
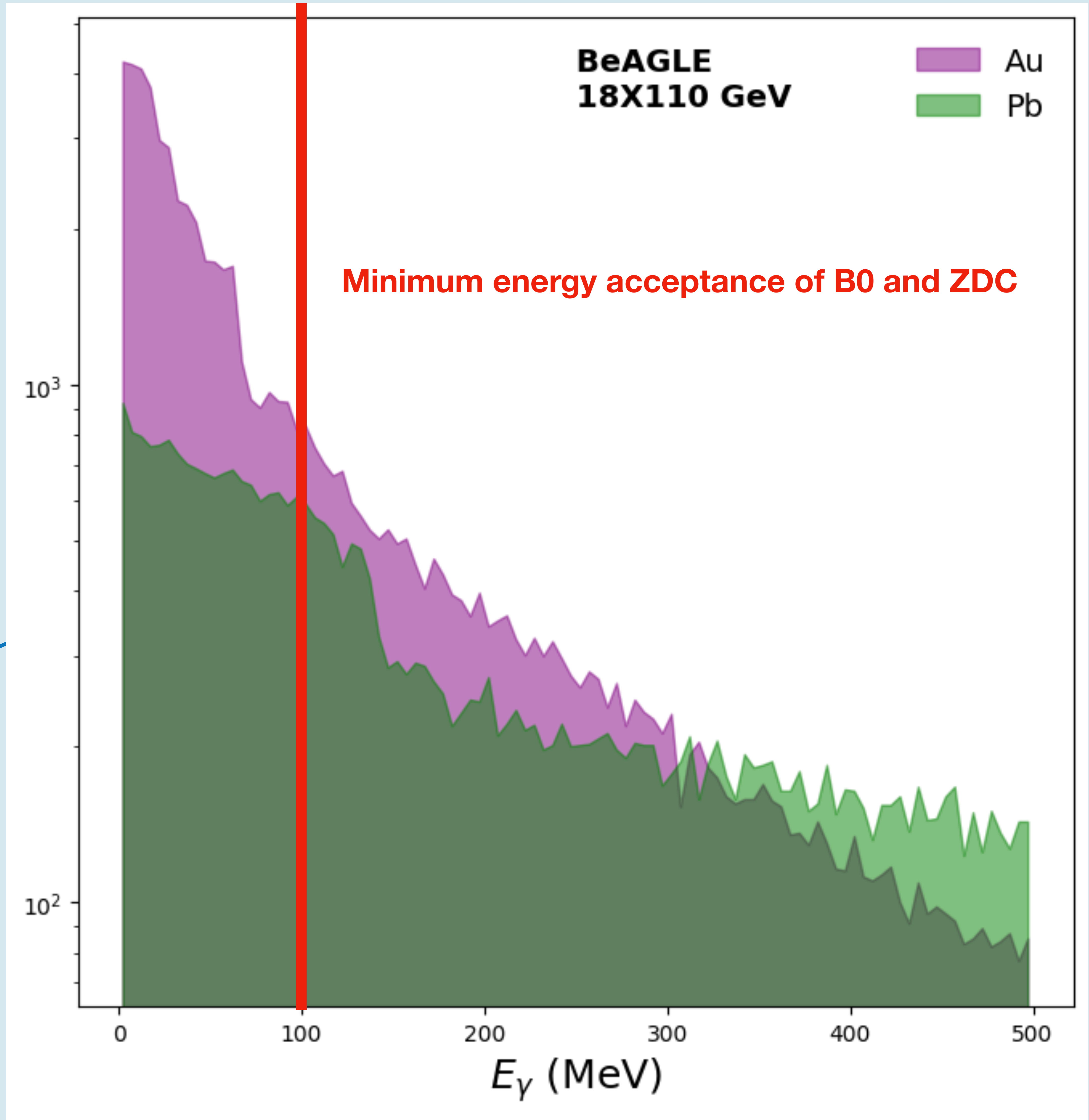
- We catch around half of the photons in the B0 at the z = 6.8 m plane
- Inner radius: 40 mm
- Outer Radius 150 mm
- Have not accounted for irregular geometry
- We see around a 50% incoherent event tagging efficiency in the B0



Accounting for minimum energy threshold

- The ZDC and B0 will be able to see photons with energies (roughly) greater than 100 MeV
- Select photon with the highest η whose energy in the lab frame is greater than 100 MeV



What about with gold?

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- Gold has some excited states that are very long lived
- 77 KeV → 1.91 ns
- 409 KeV → 7.73 s
- The nucleus will travel far down the beampipe before it emits these photons
- If we want to make a similar plot, we should first cut them out

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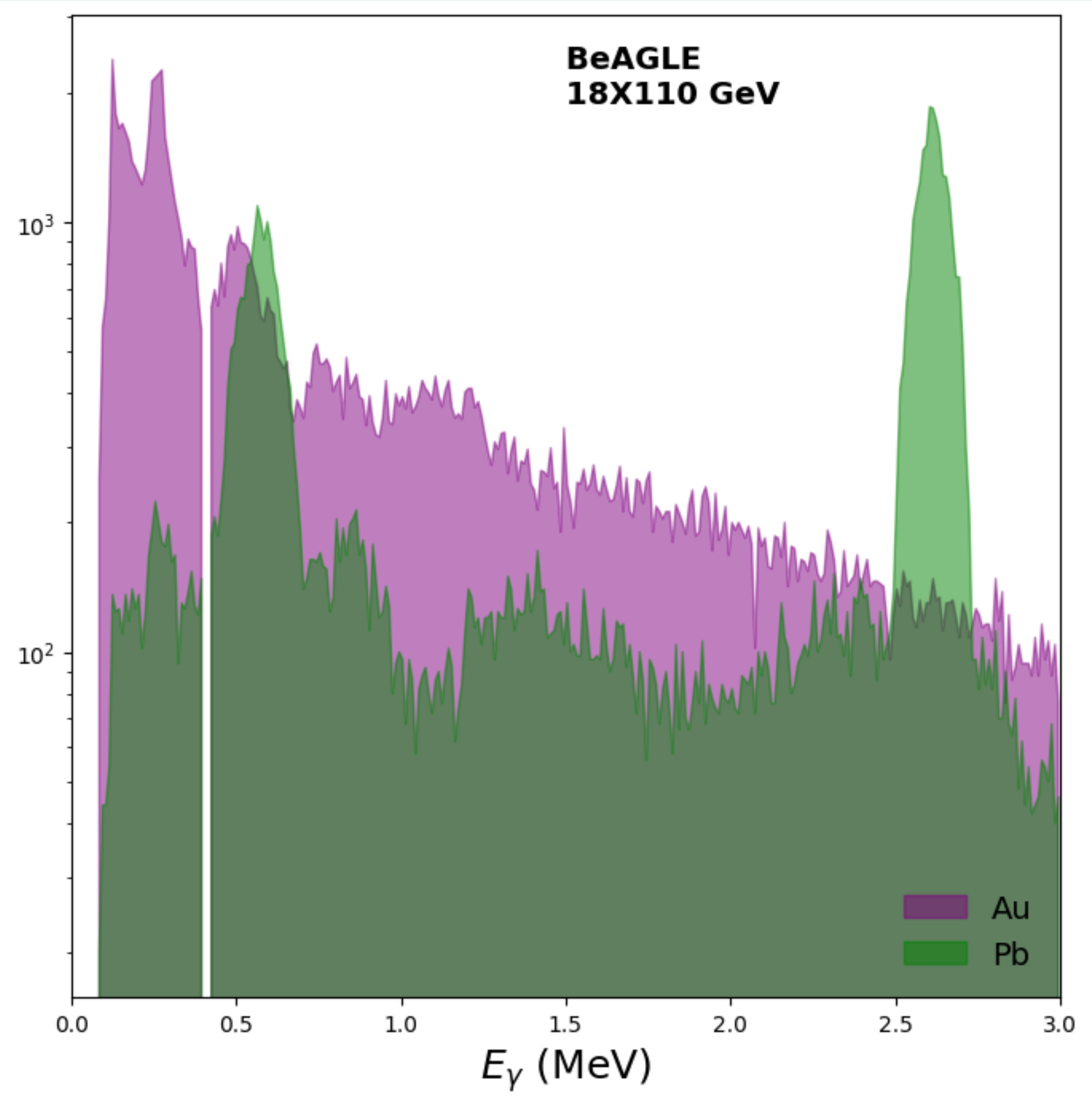
- For 409 KeV peak, have not accounted for decays to higher energy levels

(In target rest frame)



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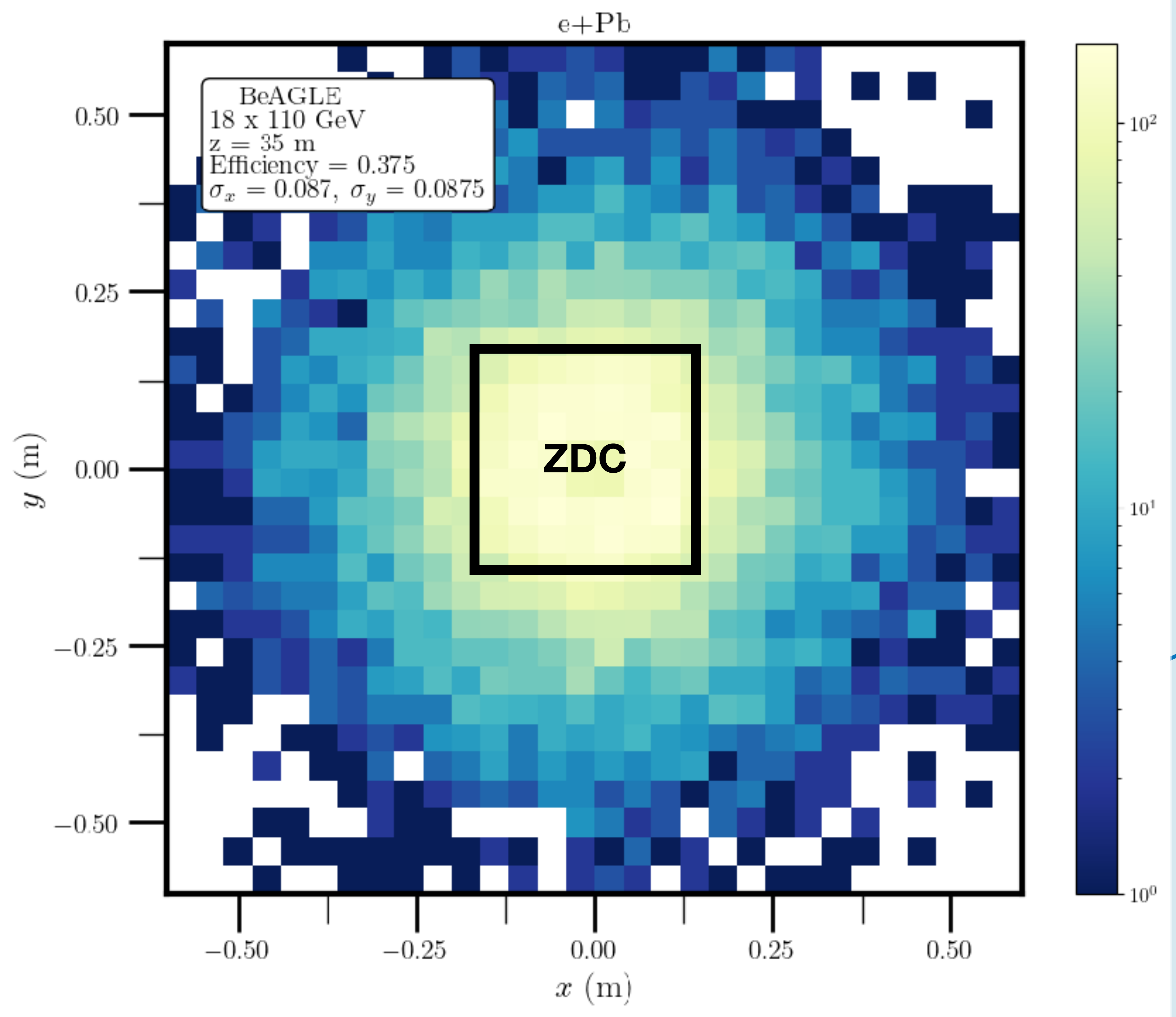
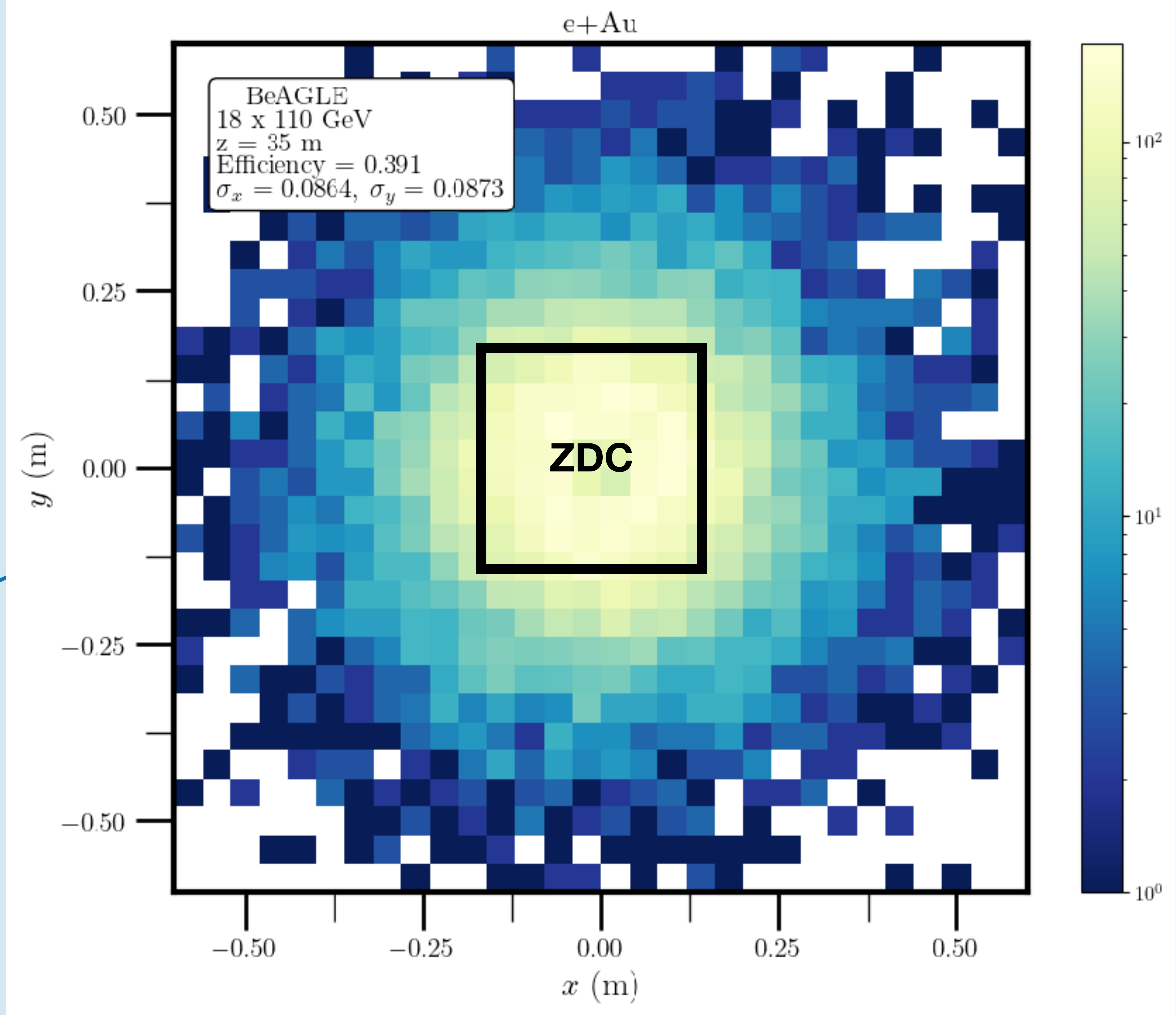
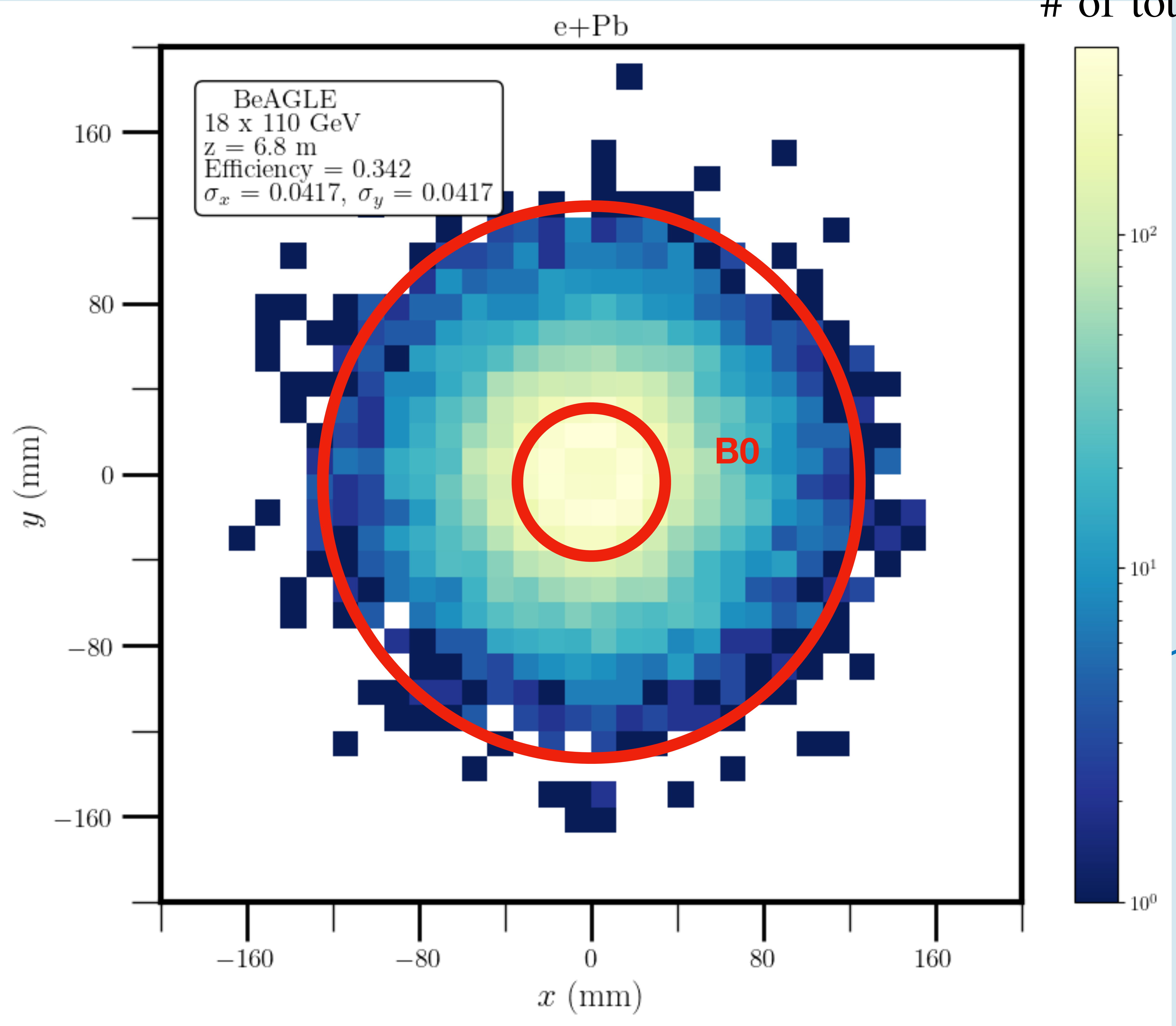


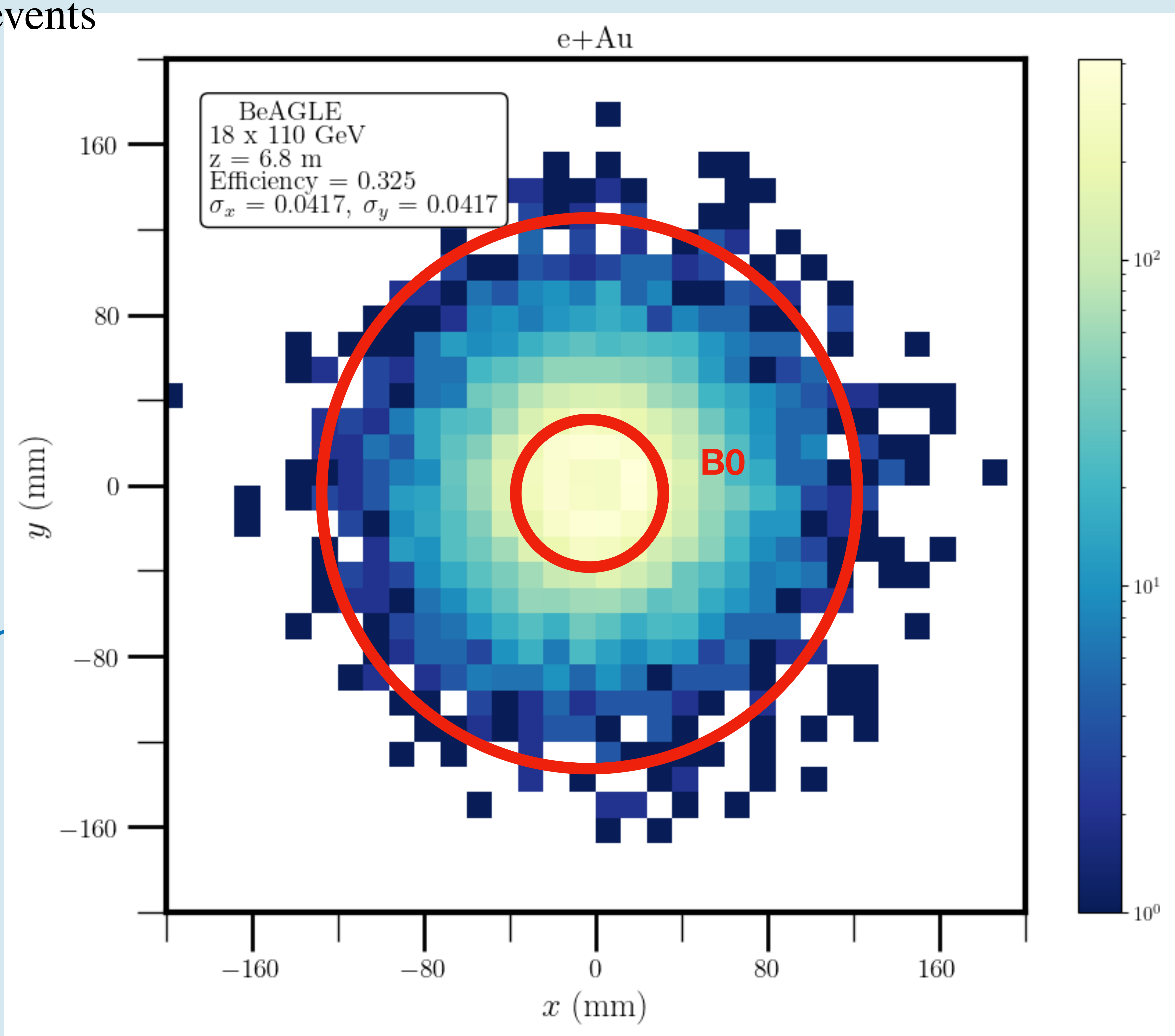


***WITH minimum energy requirement $E_\gamma > 100\ \text{MeV}$

How many photons do we see in B0?

$$\text{Efficiency} = \frac{\#\text{ of events with photon in B0 acceptance}}{\#\text{ of total events}}$$





*****WITH minimum energy requirement** $E_\gamma > 100\ \text{MeV}$

Conclusion and Next steps

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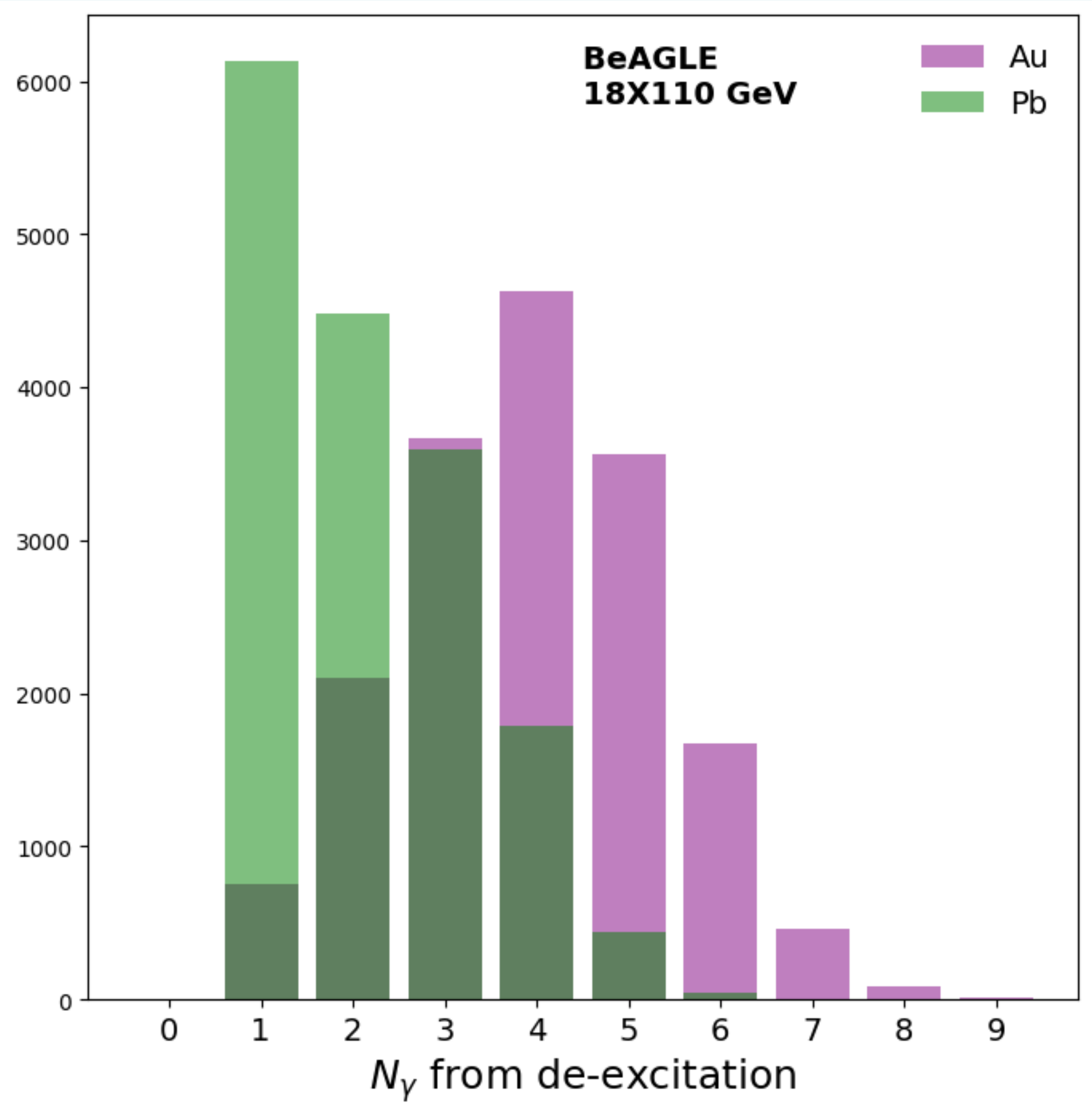
- It is critical to tag incoherent events when studying vector meson production
- Au spectrum has some longer lived states that wont decay within ePIC acceptance
- We showed some studies of *only* events where the nucleus remains intact but is still incoherent
    - Next open the analysis to all classes of collisions
- Can then see if Au or Pb will satisfy the 99.8% veto efficiency at the third diffractive minimum

Backup

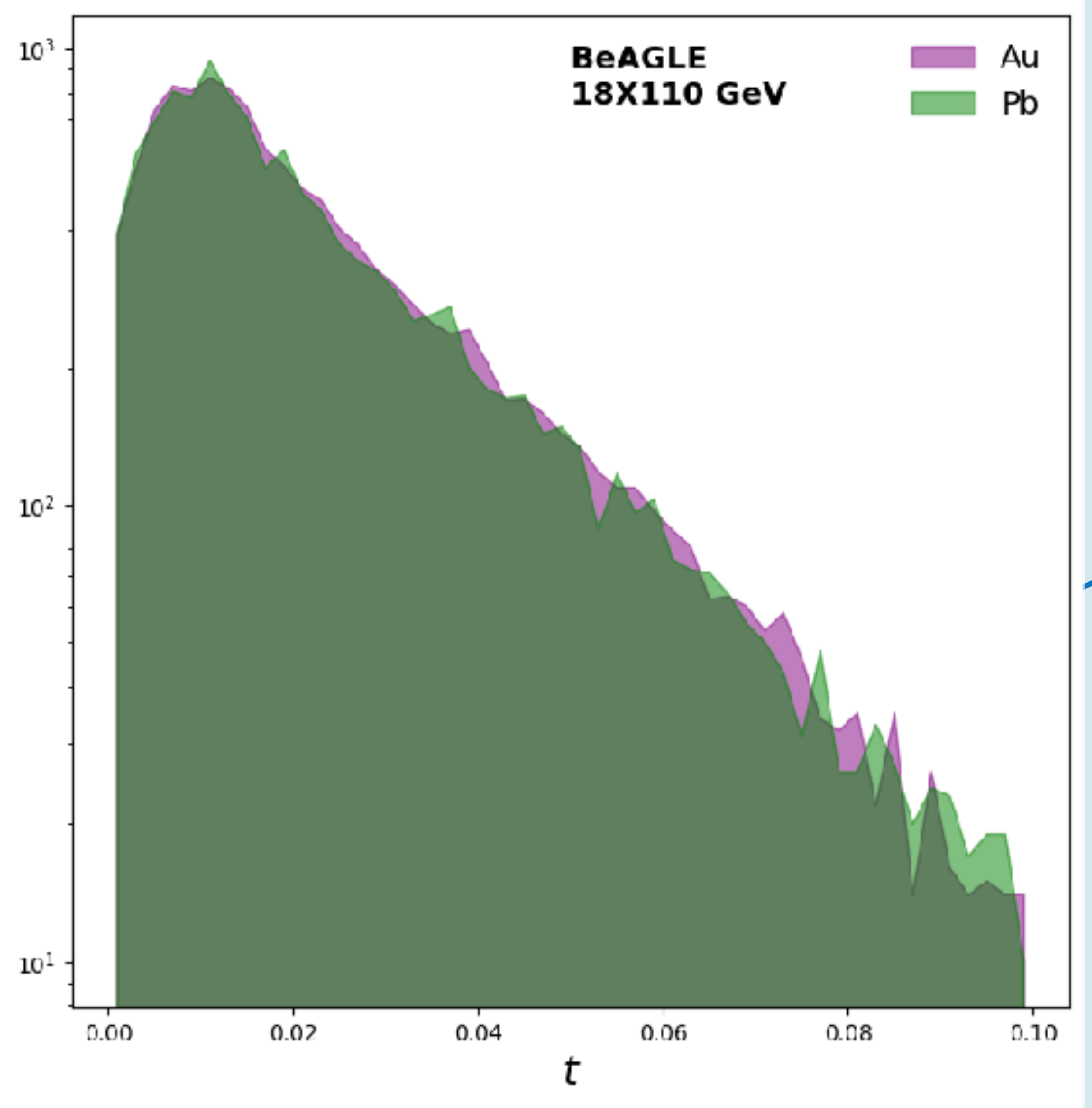
Number of photons in each event

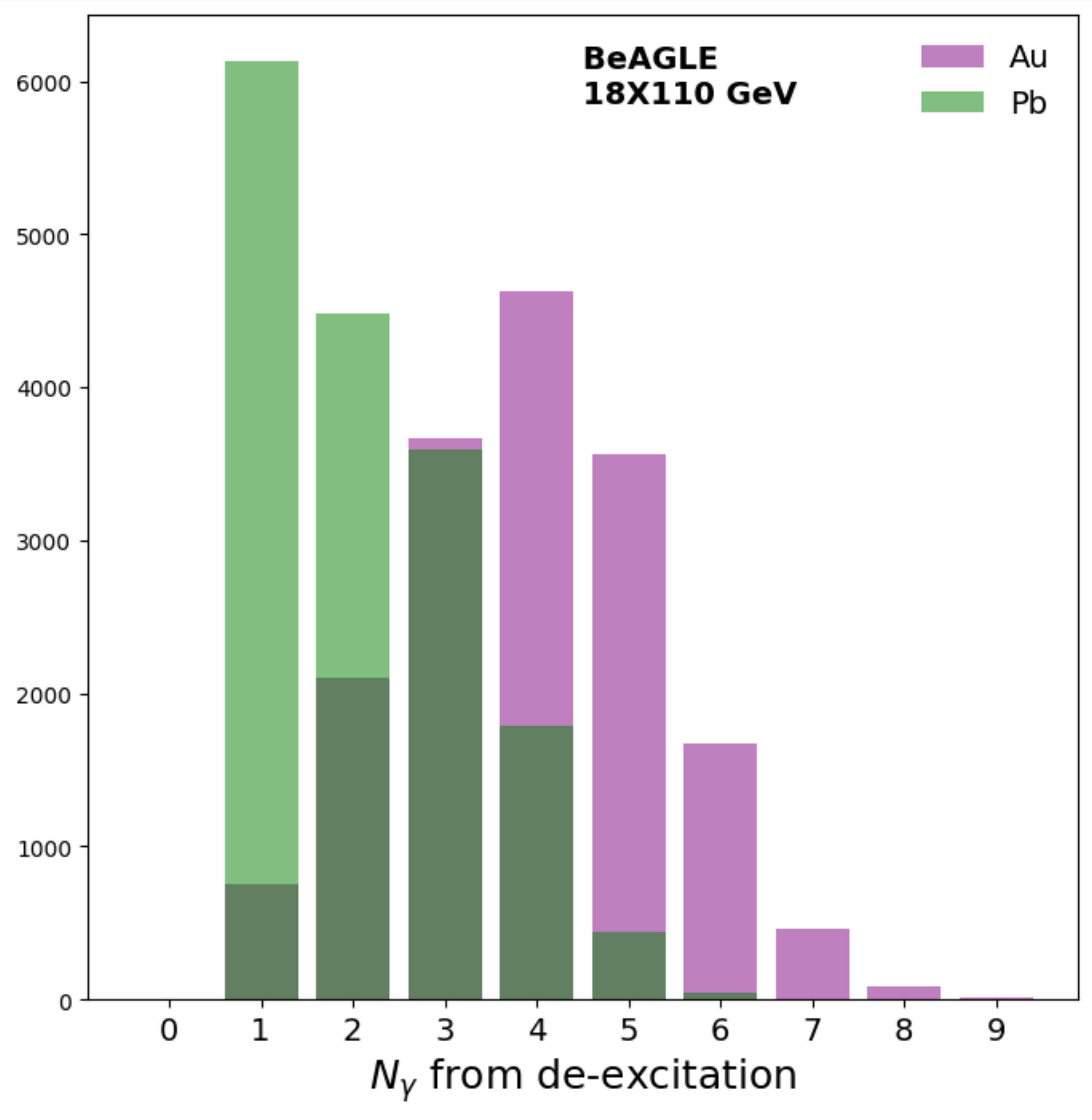
- We see Pb typically emits 1 photon, Au around 5 or 6



Number of photons in each event

- We see Pb typically emits 1 photon, Au around 5 or 6
- How does this plot behave as a function of *t*?





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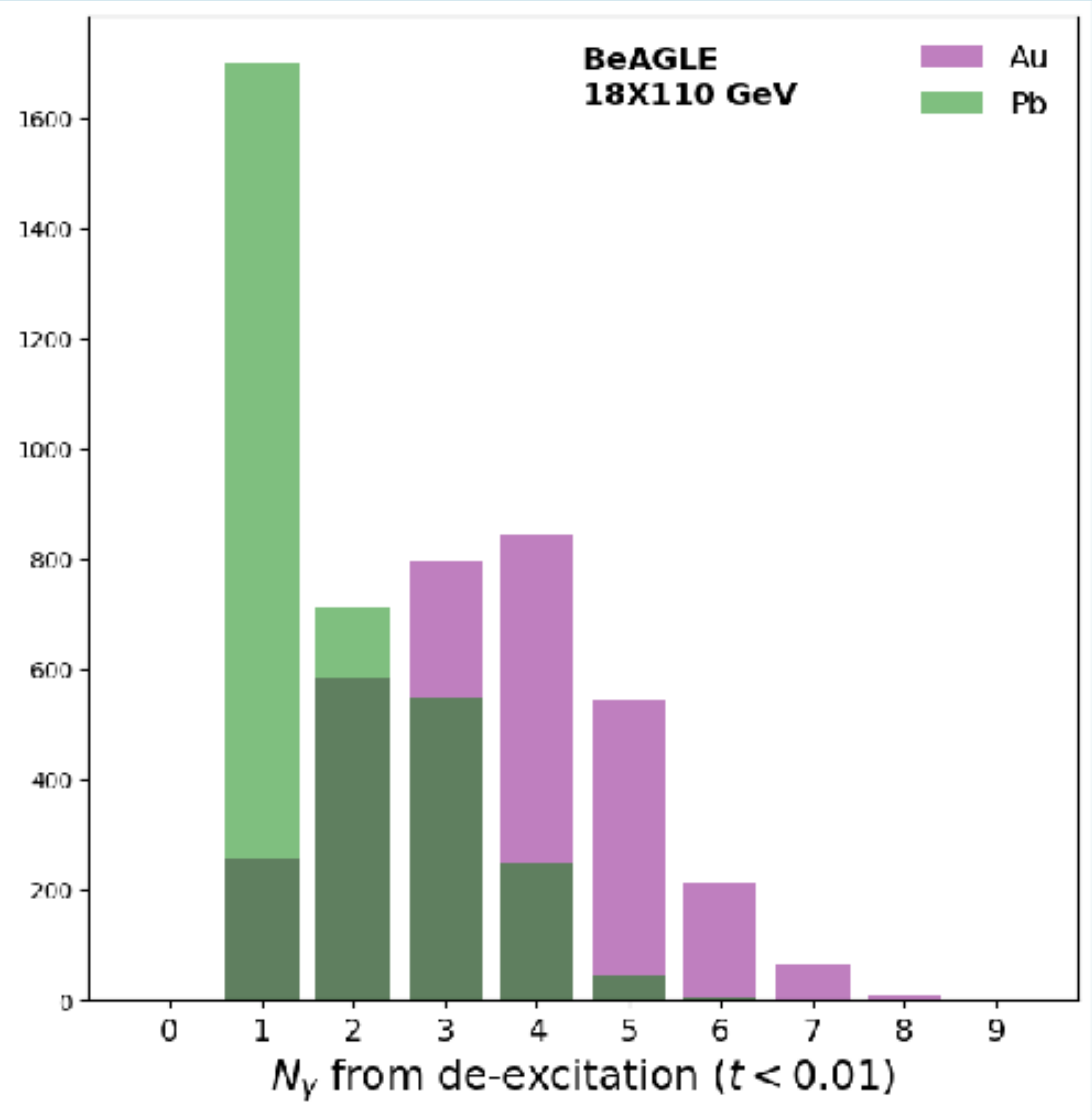

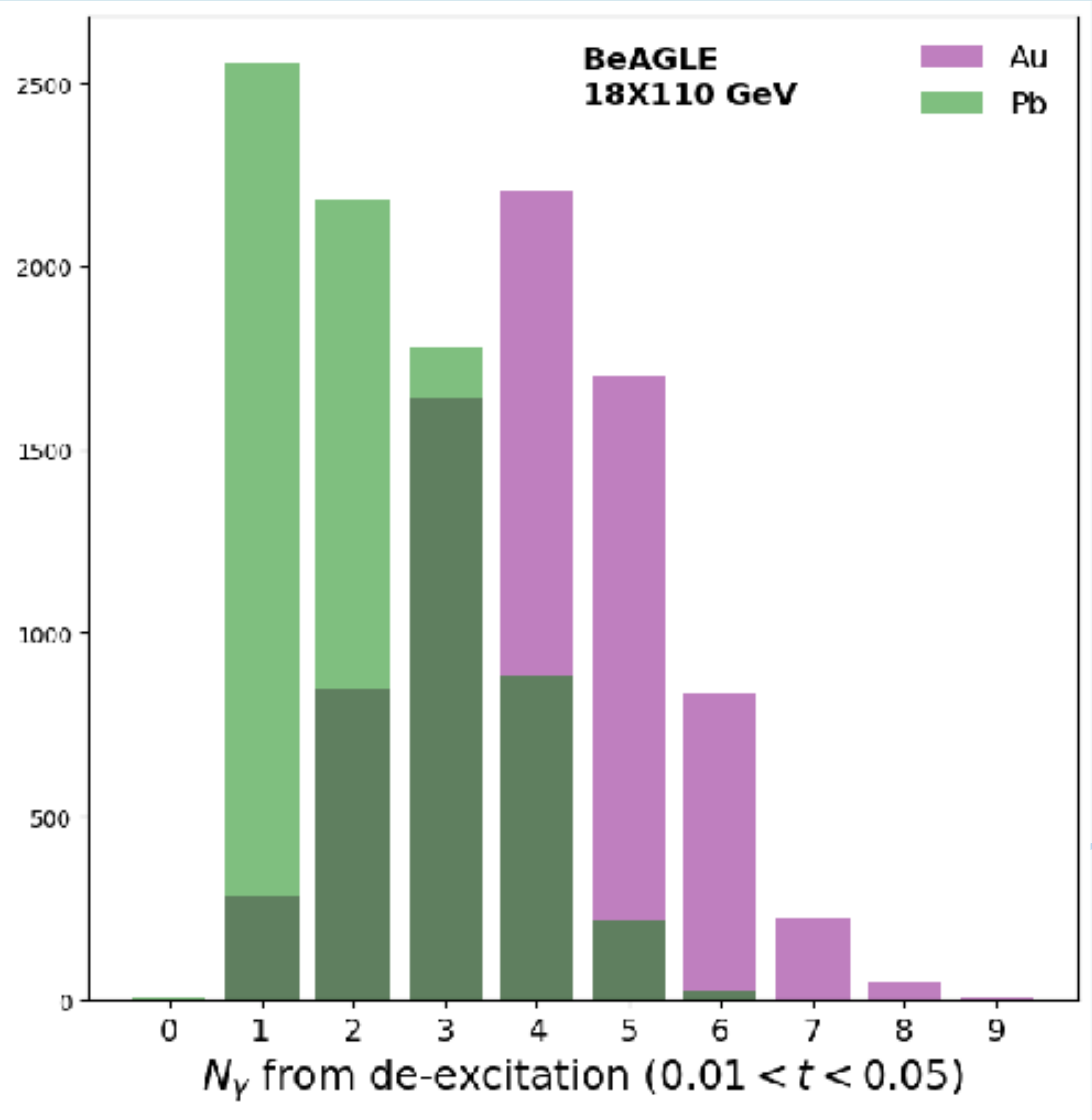

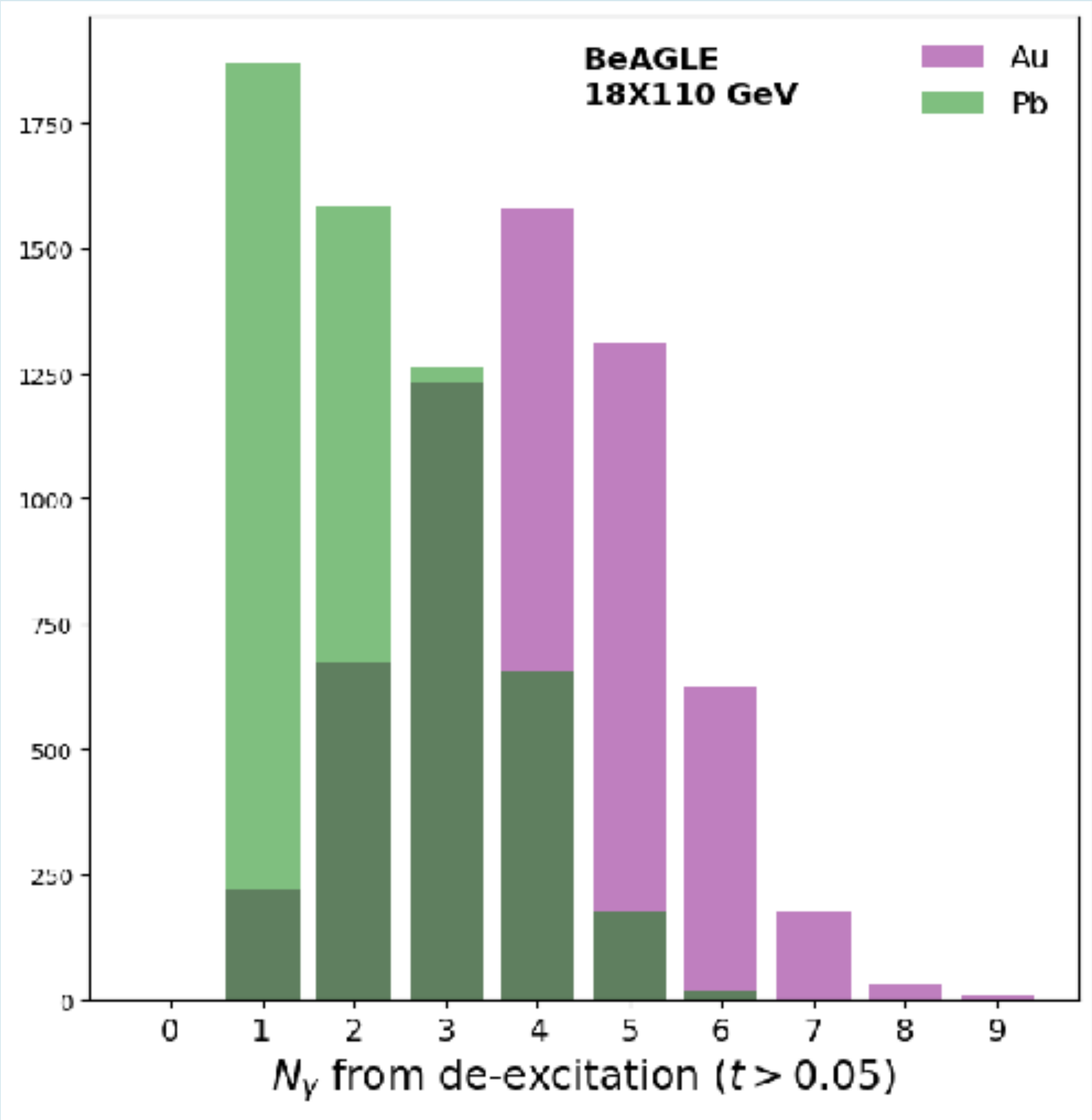

- As t increases, the collision becomes more violent and we produce more photons