Direct measurement of Gluon Saturation with UPC

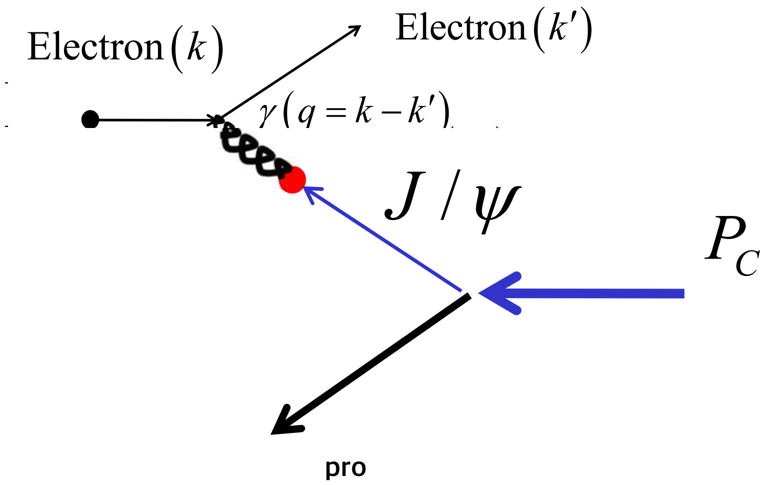
Yongsun Kim

Sept 2, 2022

CeNUM workshop

Elliptic and triangular flow of charmonium states in heavy ion collisions	*Prof. Sungtae Cho*	
Inha University	09:30 - 09:55	
CENuM for the CMS heavy-ion program	*재범 빅*	
Inha University	09:55 - 10:20	
Simulation for Heavy IoN Collision with Heavy-quark and ONia	*Jinjoo Seo*	
Inha University	10:20 - 10:45	
Break: Break (br)		
Inha University	10:45 - 11:00	
Remarks on the recent UPC and heavy quark results in CMS	*Prof. 용선 김*	
Inha University	11:00 - 11:25	
Study of upsilon(1S) flow in pPb collision system with the CMS detector	*기수 이*	
Inha University	11:25 - 11:50	
Measurement of excited state Upsilons in PbPb collision with CMS	*수환 이*	
Inha University	11:50 - 12:15	

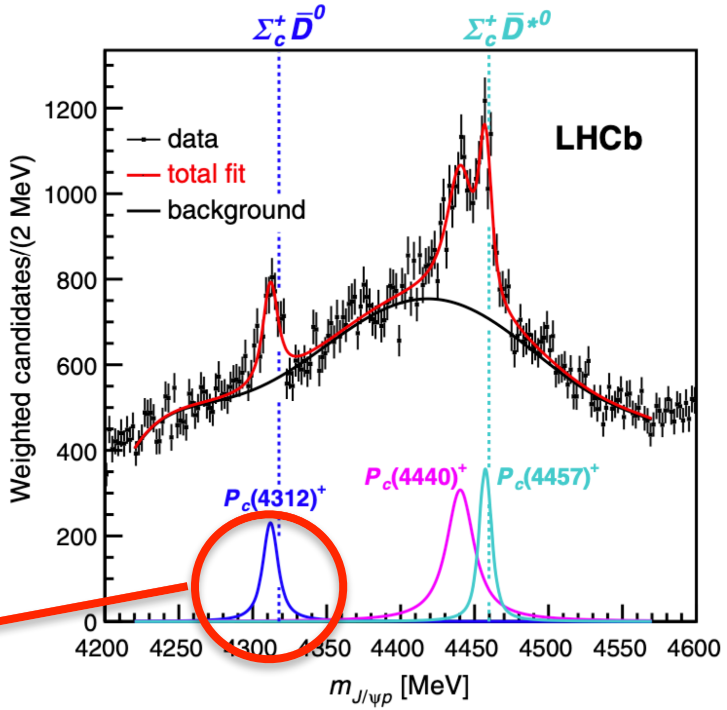
Cross section of P_c(4312) in EIC



- Vector meson dominance model
- Z.Phys. A356 (1996) 193-206, Klingl et al.
- Currents and Mesons (1969), Sakurai

$$\mathcal{L}_{\rm int} = \begin{cases} \frac{g_{JpP_c}}{m_{J/\psi}} \bar{\psi}_p \sigma^{\mu\nu} F^J_{\mu\nu} \psi_{P_c} & J^P = \frac{1}{2}^+, \\ \frac{g_{JpP_c}}{m_{J/\psi}} \bar{\psi}_p \gamma_5 \sigma^{\mu\nu} F^J_{\mu\nu} \psi_{P_c} & J^P = \frac{1}{2}^-, \\ \frac{g_{JpP_c}}{m_{J/\psi}} \bar{\psi}_p \gamma_5 \gamma^{\mu} F^J_{\mu\nu} \psi^\nu_{P_c} & J^P = \frac{3}{2}^+, \\ \frac{g_{JpP_c}}{m_{J/\psi}} \bar{\psi}_p \gamma^{\mu} F^J_{\mu\nu} \psi^\nu_{P_c} & J^P = \frac{3}{2}^-. \end{cases}$$

J^P	$\frac{1}{2}^+$	$\frac{1}{2}^-$	$\frac{3}{2}^+$	$\frac{3}{2}^-$
g_{JpP_c}	0.379	0.169	1.47	0.599



Cross section of $P_c(4312)$ in EIC

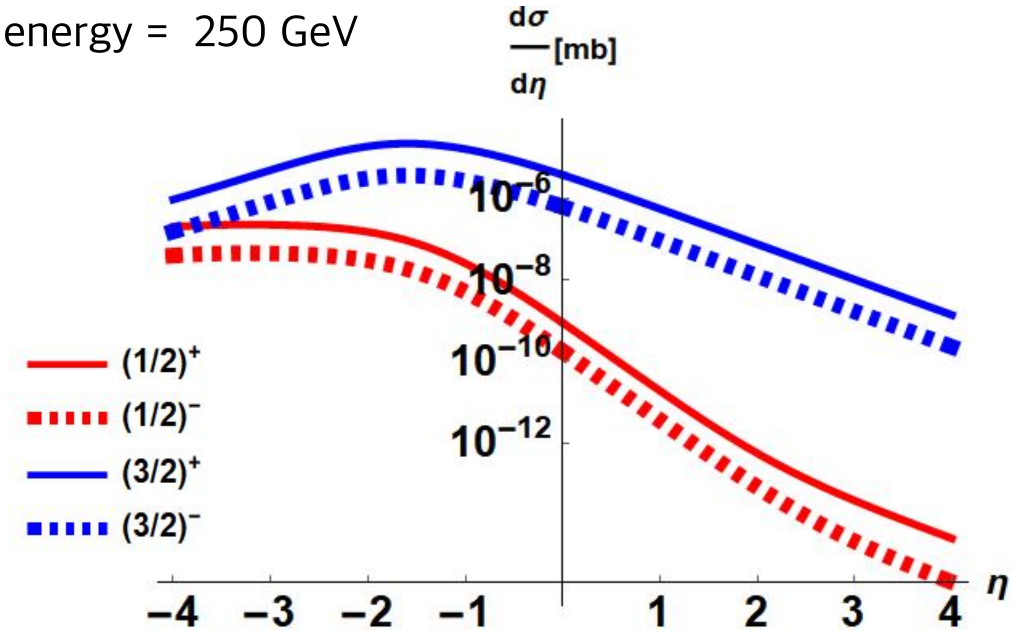
	e	p	$^{3}He^{2+}$	$^{197}Au^{79+}$
Energy, GeV	15.9	250	167	100
CM energy, GeV		122.5	81.7	63.2
Bunch frequency, MHz	9.4	9.4	9.4	9.4
Bunch intensity (nucleons), 10^{11}	0.33	0.3	0.6	0.6
Bunch charge, nC	5.3	4.8	6.4	3.9
Beam current, mA	50	42	55	33
Hadron rms norm. emittance, μm		0.27	0.20	0.20
Electron rms norm. emittance, μm		31.6	34.7	57.9
Beta*, cm (both planes)	5	5	5	5
Hadron beam-beam parameter		0.015	0.014	0.008
Electron beam disruption		2.8	5.2	1.9
Space charge parameter		0.006	0.016	0.016
rms bunch length, cm	0.4	5	5	5
Polarization, %	80	70	70	none
Peak luminosity, 10^{33} $cm^{-2}s^{-1}$		1.5	2.8	1.7

Peak lumi updated to 10^{34} $cm^{-2}s^{-1}$ => 10 fb^{-1} per month is

Cross section of $P_c(4312)$ in EIC

Electron energy = 16 GeV

Proton energy = 250 GeV



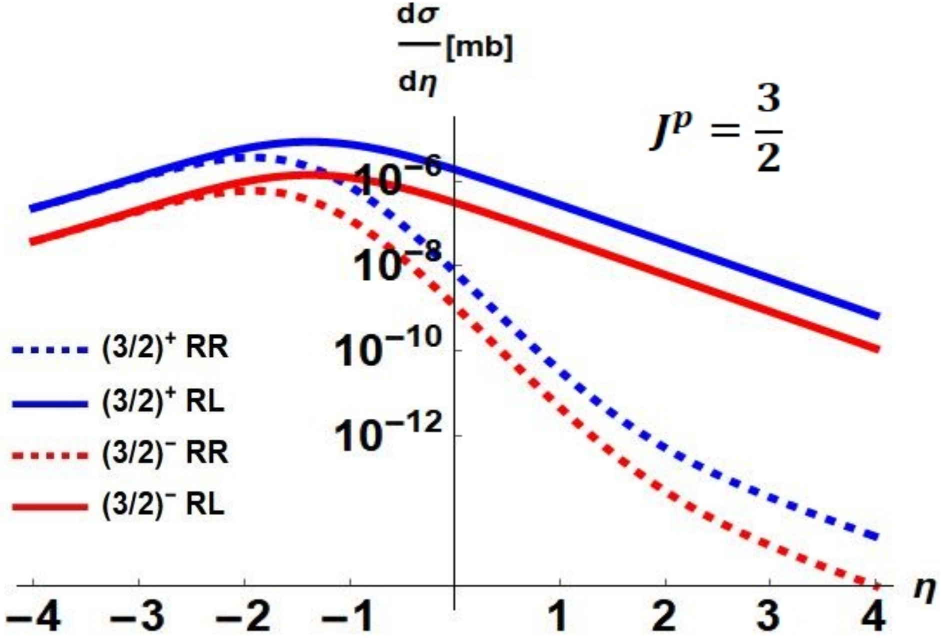
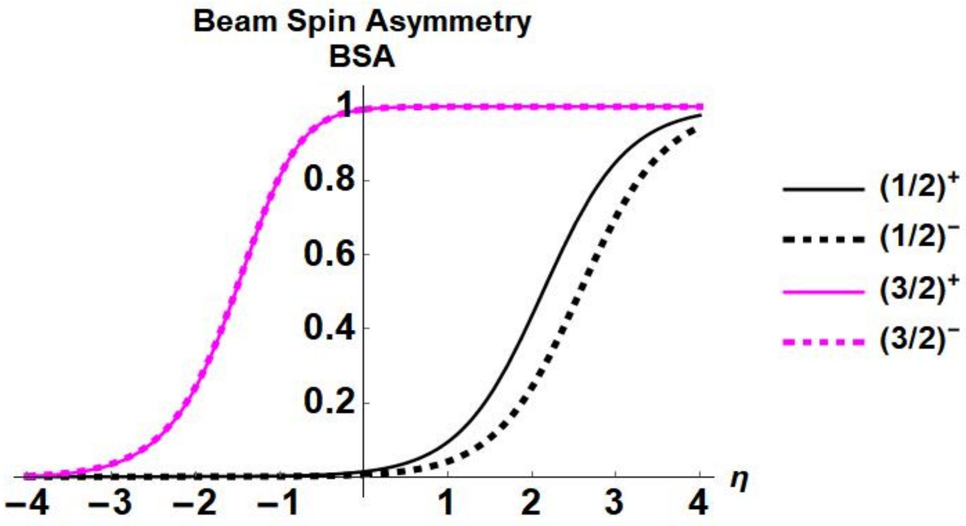


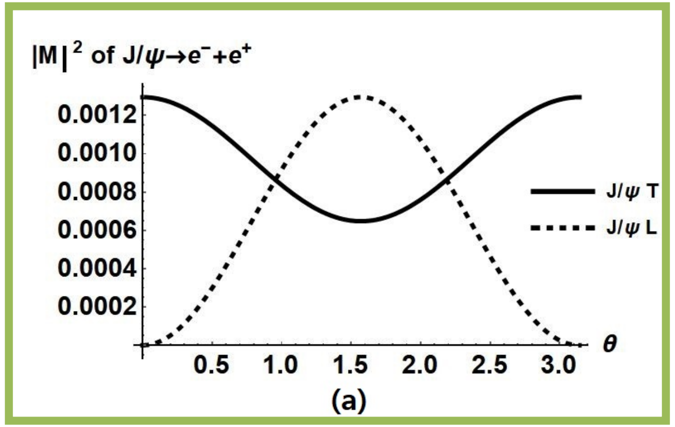
TABLE II. Expected number of $P_c(4312)$ produced at the EIC with 10 fb^{-1}.

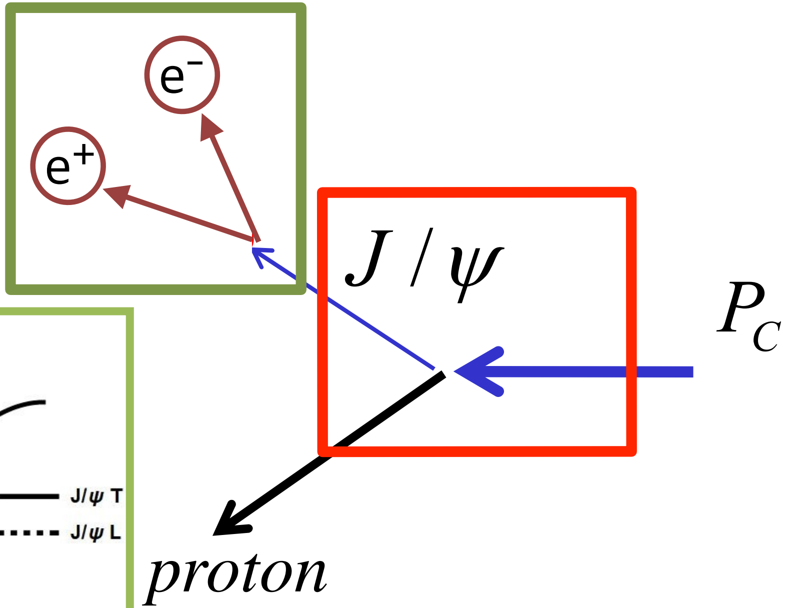
J^P of P_c	$\frac{1}{2}^+$	$\frac{1}{2}^-$	$\frac{3}{2}^+$	$\frac{3}{2}^-$
Yield	5.09×10^6	1.01×10^6	4.51×10^8	7.46×10^7

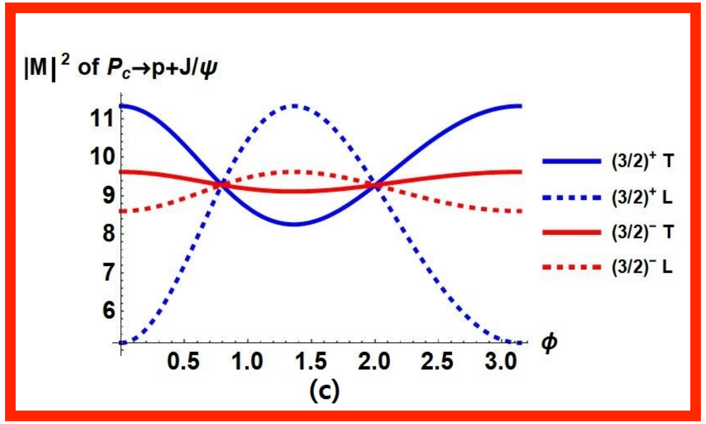
Cross section of $P_c(4312)$ in EIC



$$BSA\ (\eta) = \frac{d\sigma/d\eta\ [RL] - d\sigma/d\eta\ (RR)}{d\sigma/d\eta\ [RL] + d\sigma/d\eta\ [RR]}$$







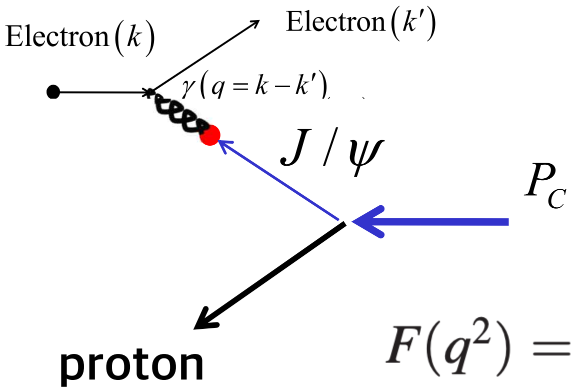
- BSA says the spin
- angular correlation says the parity

Total number of $P_c(4312)$

than for the negative parity. With one month of operation at the EIC in its nominal condition, millions of $P_c(4312)$'s are expected to be measured via $p + e^+ + e^-$ channel. This calculation can be generalized for other

TABLE II. Expected number of $P_c(4312)$ produced at the EIC with 10 fb^{-1}.

J^P of P_c	$\frac{1}{2}^+$	$\frac{1}{2}^-$	$\frac{3}{2}^+$	$\frac{3}{2}^-$
Yield	5.09×10^6	1.01×10^6	4.51×10^8	7.46×10^7

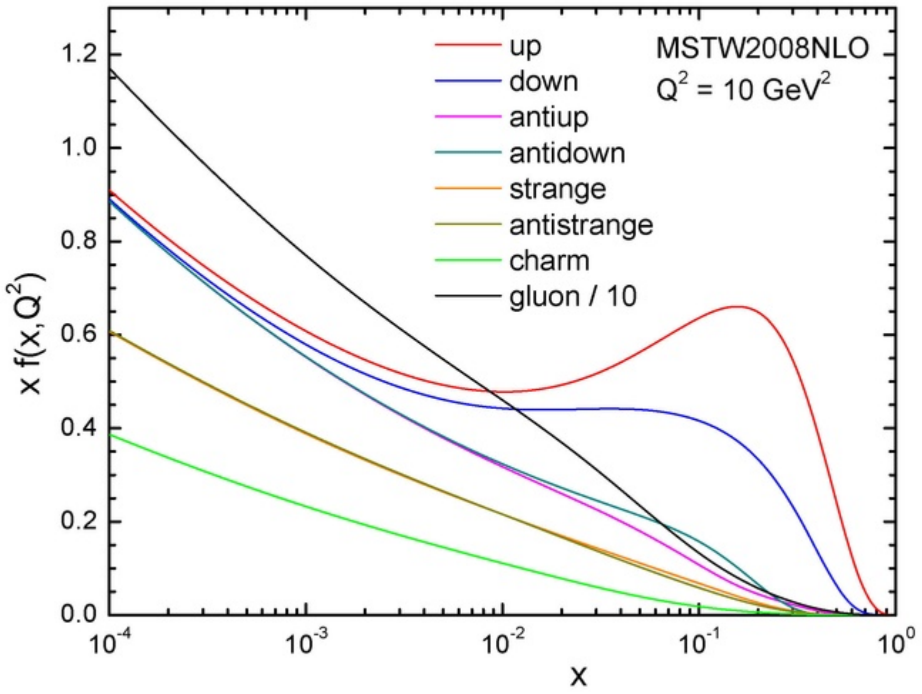


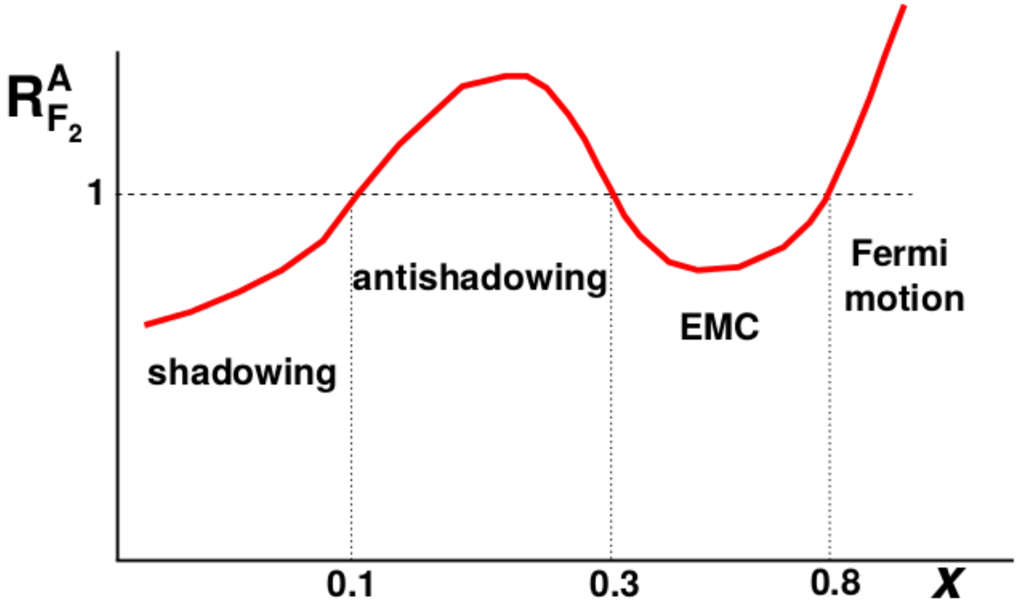
$$F(q^2) = \frac{m_{J/\psi}^2 - \Lambda^2}{q^2 - \Lambda^2}$$

parity. With one month of operation at the EIC in its nominal condition, an experimentally measurable number of $P_c(4312)$'s are expected to be produced via the $p + e^+ + e^-$ channel. This calculation can be generalized

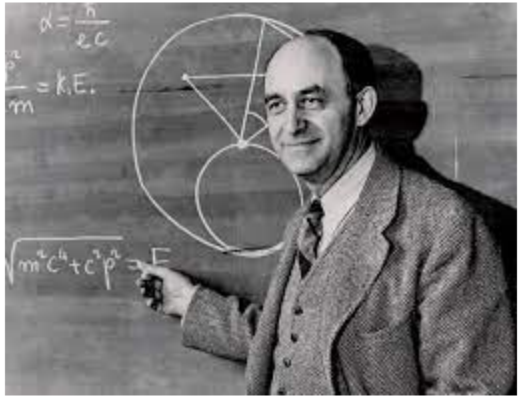
TABLE II. Expected number of $P_c(4312)$ produced at the EIC with 10 fb^{-1}.

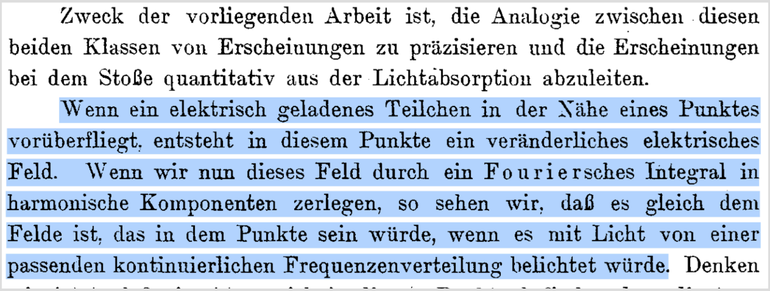
J^P of P_c	$\frac{1}{2}+$	$\frac{1}{2}-$	$\frac{3}{2}+$	$\frac{3}{2}-$
Yield	5.67×10^3	1.13×10^3	4.32×10^4	7.15×10^3


up
down
antiup
antidown
strange
antistrange
charm
gluon / 10
MSTW2008NLO
$Q^2 = 10\ GeV^2$
$x\ f(x,Q^2)$
x
1.2
1.0
0.8
0.6
0.4
0.2
0.0
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}

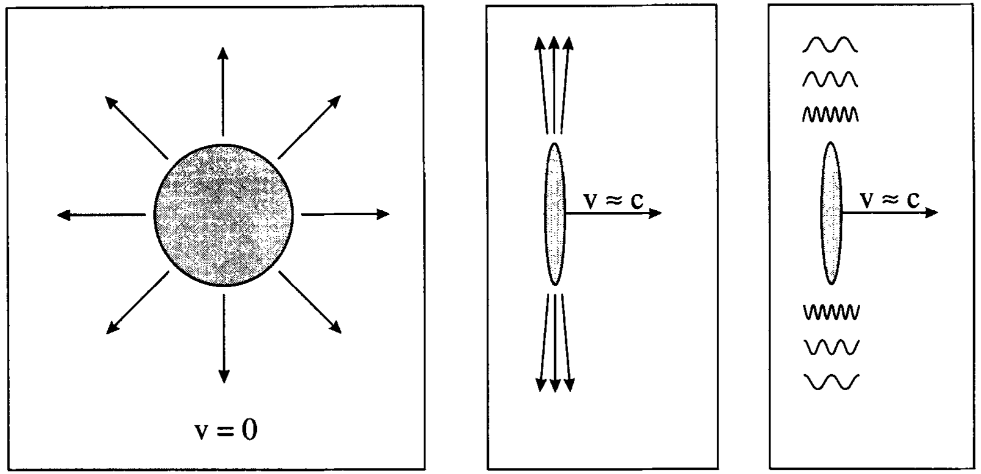

$R^A_{F_2}$
1
shadowing
antishadowing
EMC
Fermi motion
0.1
0.3
0.8
x

Equivalent Photon Approximation




Zweck der vorliegenden Arbeit ist, die Analogie zwischen diesen beiden Klassen von Erscheinungen zu präzisieren und die Erscheinungen bei dem Stoße quantitativ aus der Lichtabsorption abzuleiten.

Wenn ein elektrisch geladenes Teilchen in der Nähe eines Punktes vorüberfliegt, entsteht in diesem Punkte ein veränderliches elektrisches Feld. Wenn wir nun dieses Feld durch ein Fouriersches Integral in harmonische Komponenten zerlegen, so sehen wir, daß es gleich dem Felde ist, das in dem Punkte sein würde, wenn es mit Licht von einer passenden kontinuierlichen Frequenzenverteilung belichtet würde. Denken



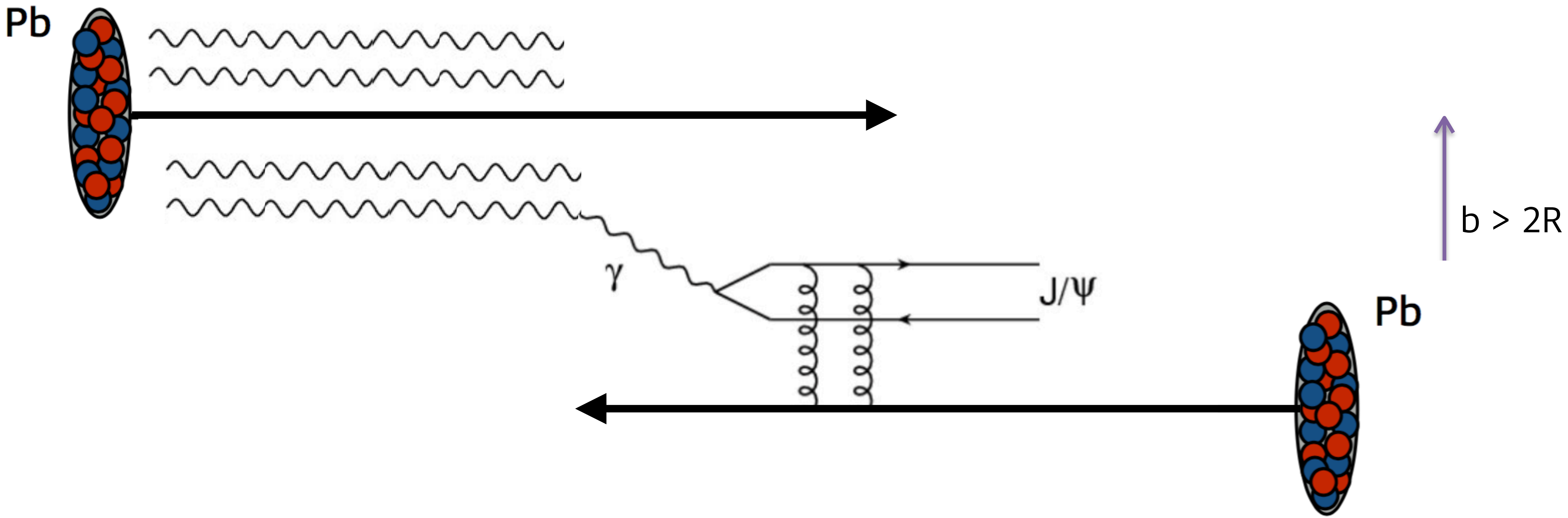
Nuovo Cim.,2:143-158,1925 (arXiv:hep-th/0205086 in English)

- Trajectory of fast moving charged particle is equivalent to a flux of photons (Fermi, 1924)
- Later, this method was extended to relativistic regime by Weizsacker[1] and Williams[2]
- At LHC photon energy can reach to 80 GeV, and at RHIC 3 GeV
- We can practice high energy γ + (p or A) and $\gamma + \gamma$ collisions by triggering non-hadronic collisions

[1] Z. Phys. 88, 612 (1934)

[2] Kgl. Danske Videnskab. Selskab Mat.-Fys. Medd. 13, 4 (1935)

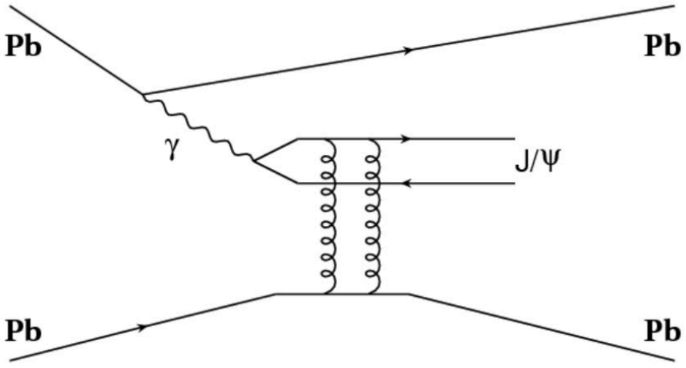
Vector meson production in UPC

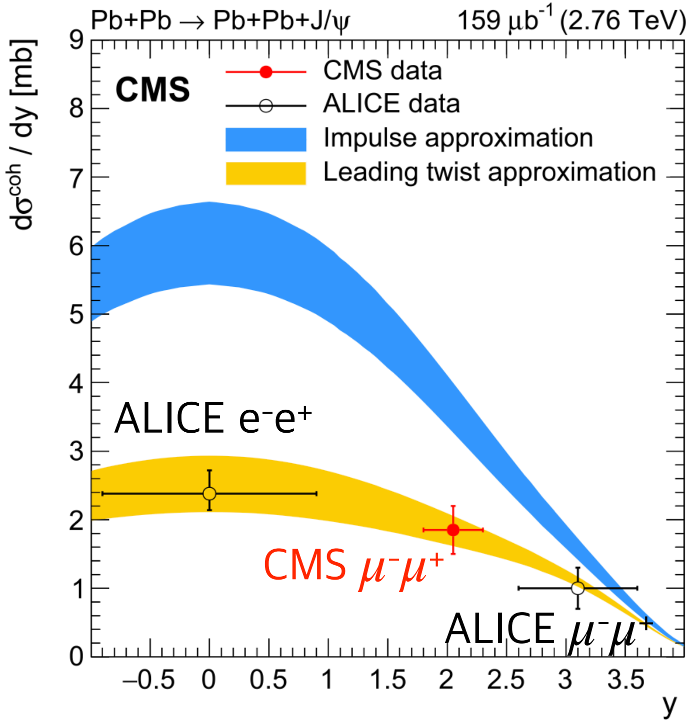


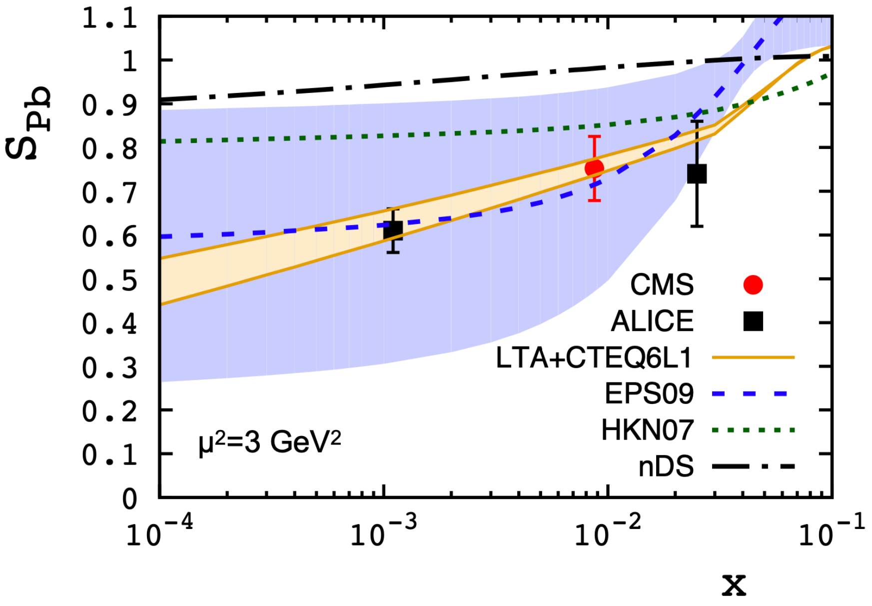
Ultra Peripheral Collision (UPC)

- quasi-elastic and diffractive collision
- No energy deposit in forward calorimeters
- Occasionally neutrons are emitted from excited ions

Ultra peripheral collision

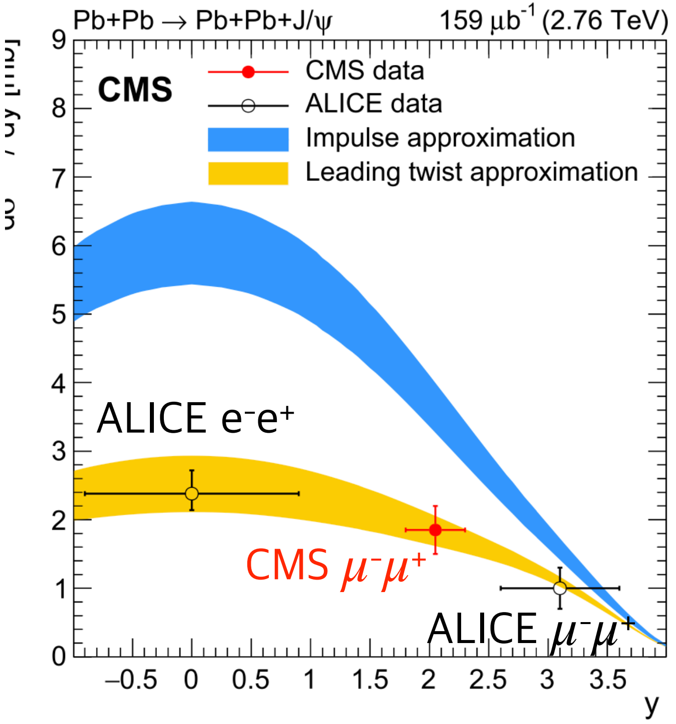


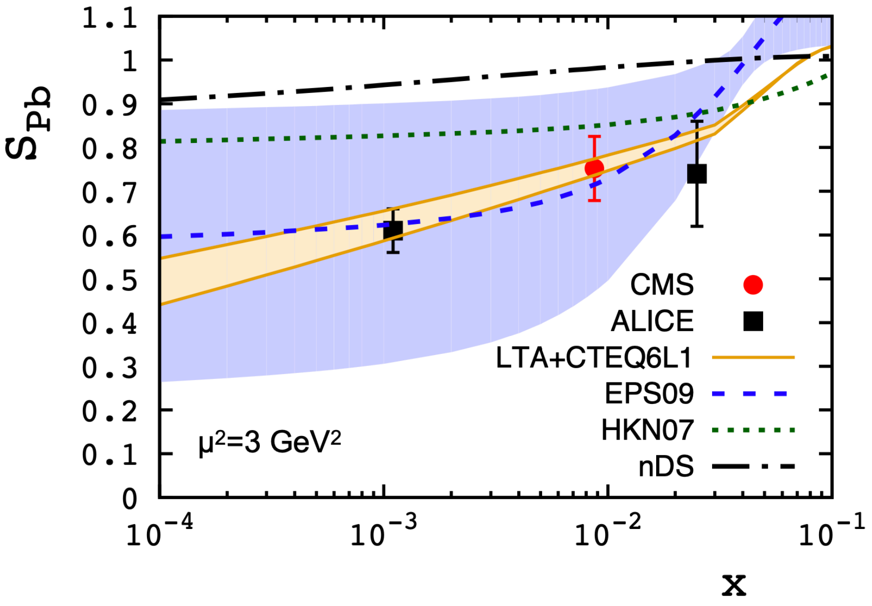




Ultra peripheral collision

- $y = \ln\left(\frac{2\omega}{M_{J/\psi}}\right)$
  - y is the rapidity of the J/ψ
  - ω is the photon energy
- $x = \left(\frac{M_{J/\psi}}{\sqrt{s_{NN}}}\right) e^{\mp y}$
  - Bjorken-x
- $W_{\gamma Pb}^2 = M_{J/\psi}^2 / x$
  - Centre-of-mass energy of the photon–target system





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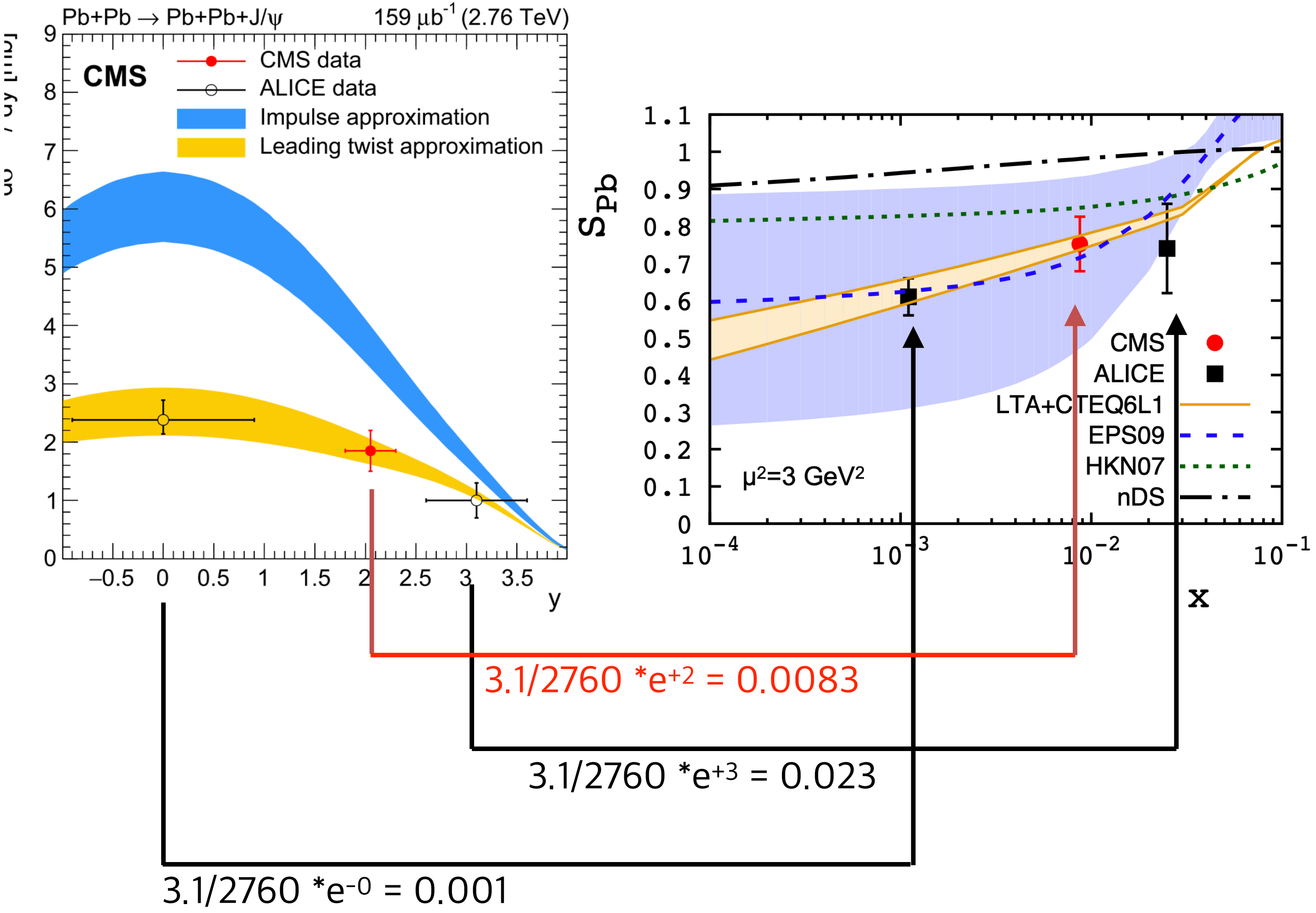
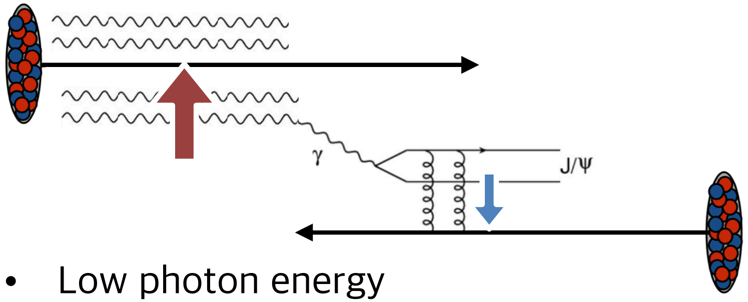


Ultra peripheral collision

$$x = \frac{m}{\sqrt{s_{NN}}} e^{+y}$$

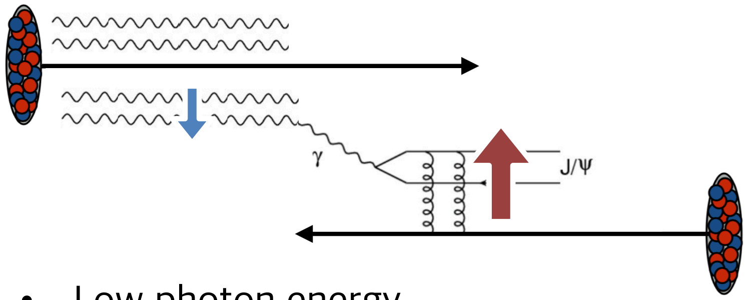
$$w = \frac{m}{2} e^{-y}$$



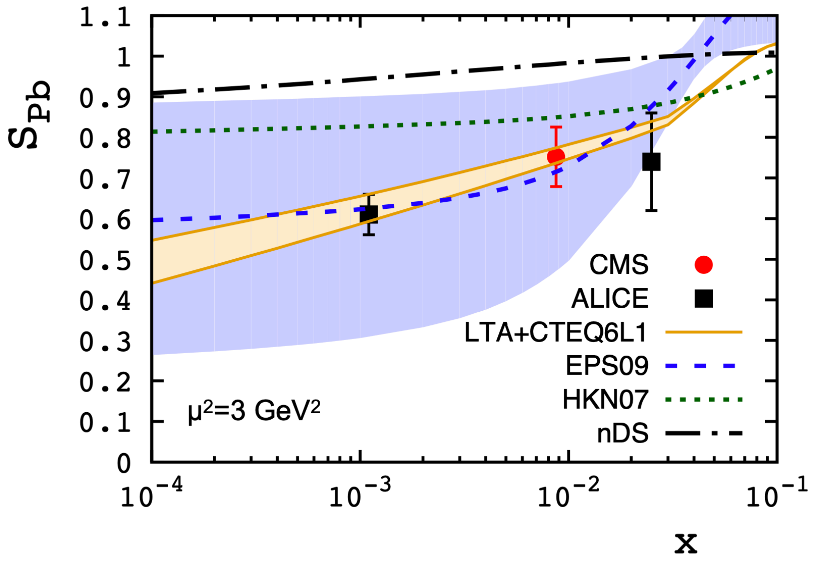
- Low photon energy
- High x in target

$$x = \frac{m}{\sqrt{s_{NN}}} e^{-y}$$

$$w = \frac{m}{2} e^{+y}$$



- Low photon energy
- High x in target

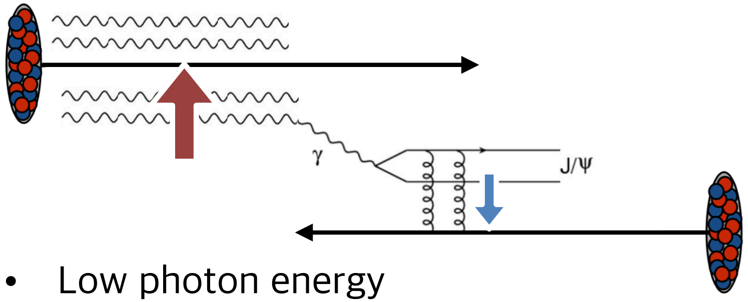


From SINam's note

Ultra peripheral collision

$$x = \frac{m}{\sqrt{s_{NN}}} e^{+y}$$

$$w = \frac{m}{2} e^{-y}$$



- Low photon energy
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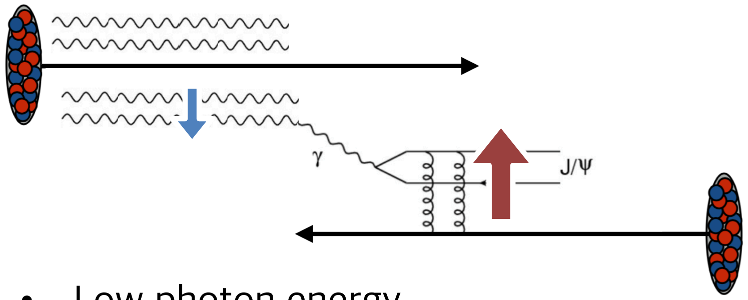
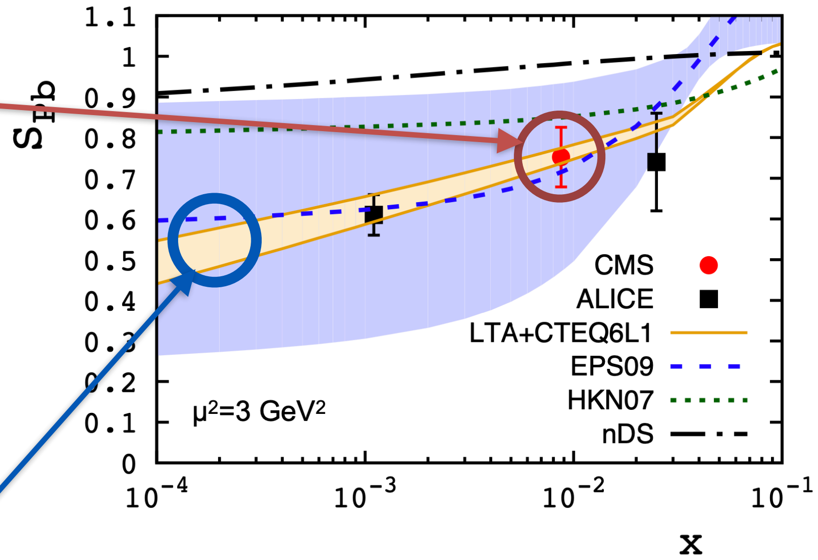
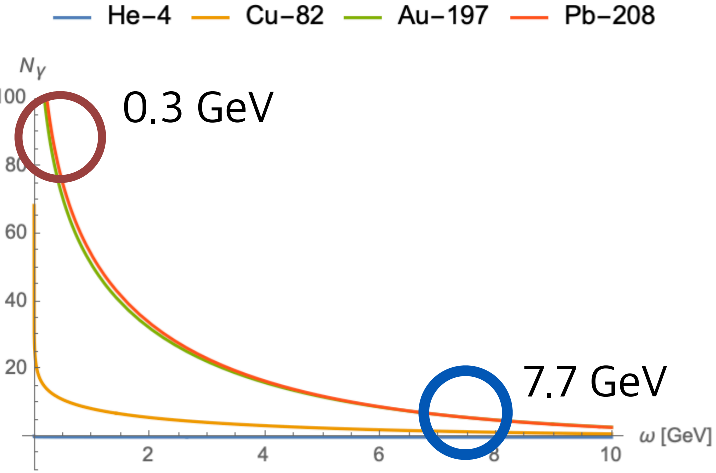


- Low photon energy
- High x in target



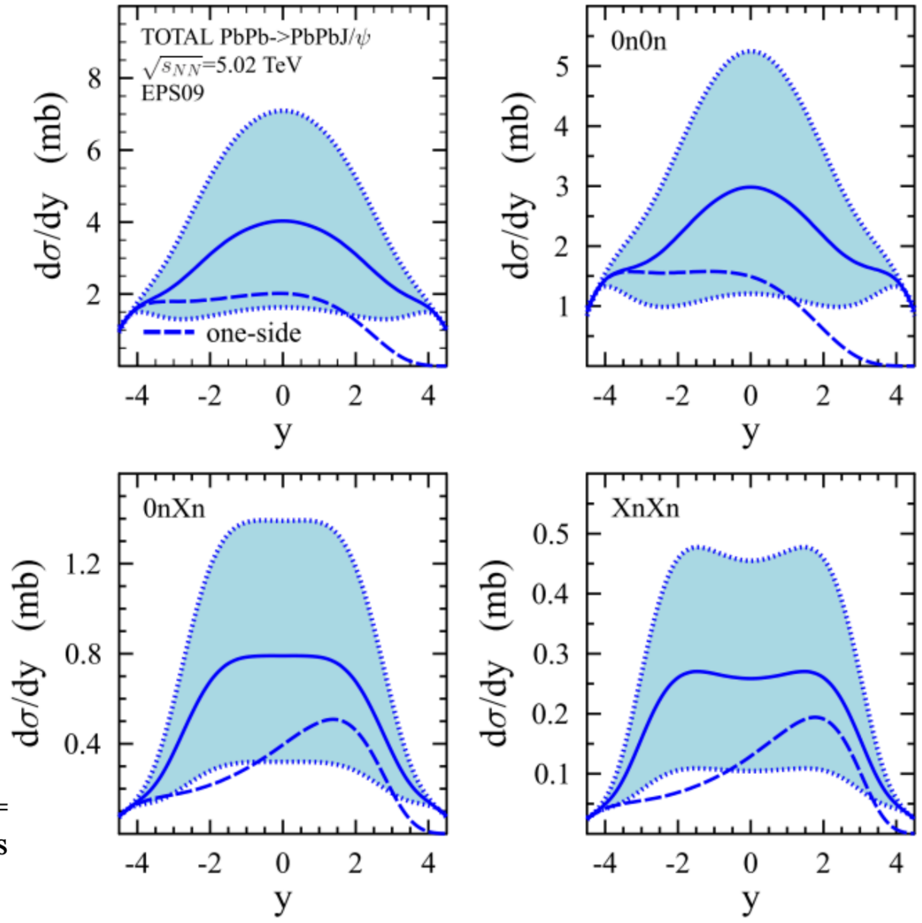


From SINam's note

A novel solution: Neutron tagging

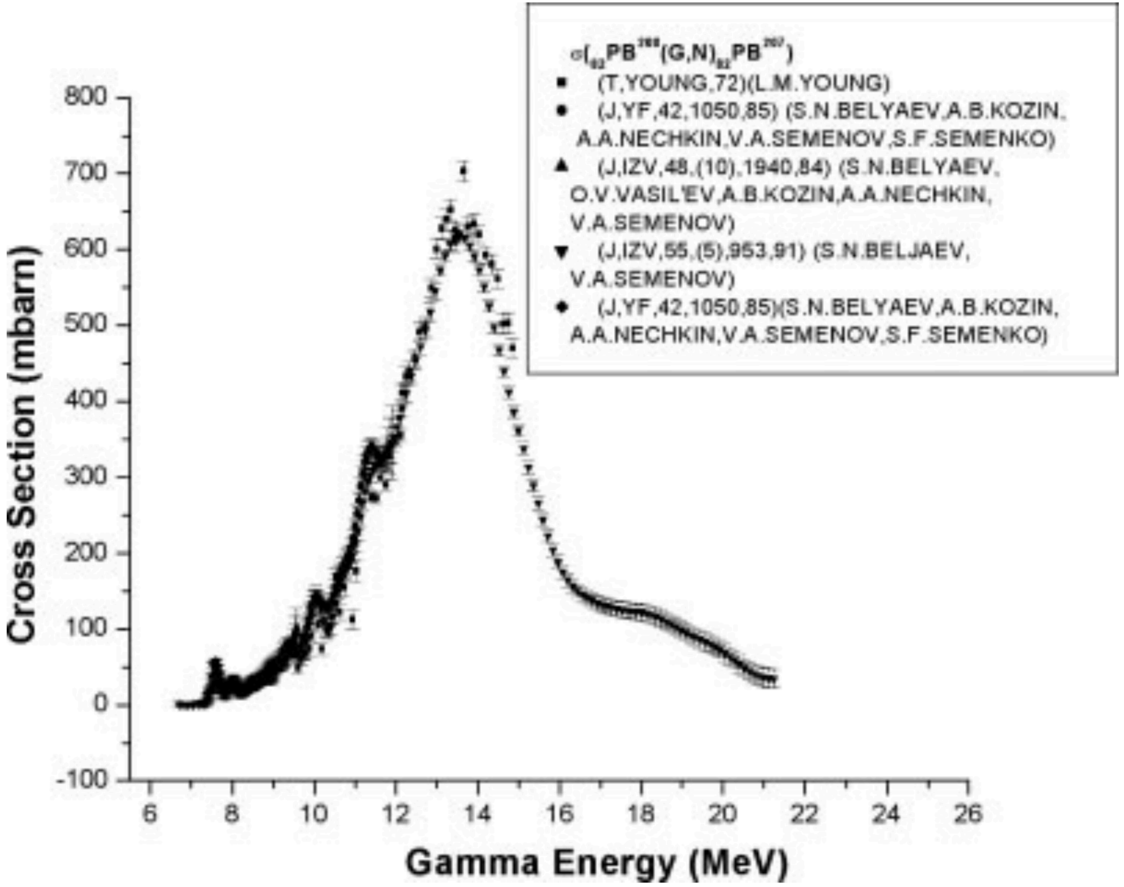
- Proposed by V. Guzey, M. Strikman, and M. Zhalov https://arxiv.org/abs/1312.6486
- High photon flux → Additional ion excitation → Emitting Neutrons
  - 0n0n: **No** neutron on both ZDC
  - 0nXn: At least **one** neutron on **one** ZDC
  - XnXn: At least **one** neutron on **both** ZDC

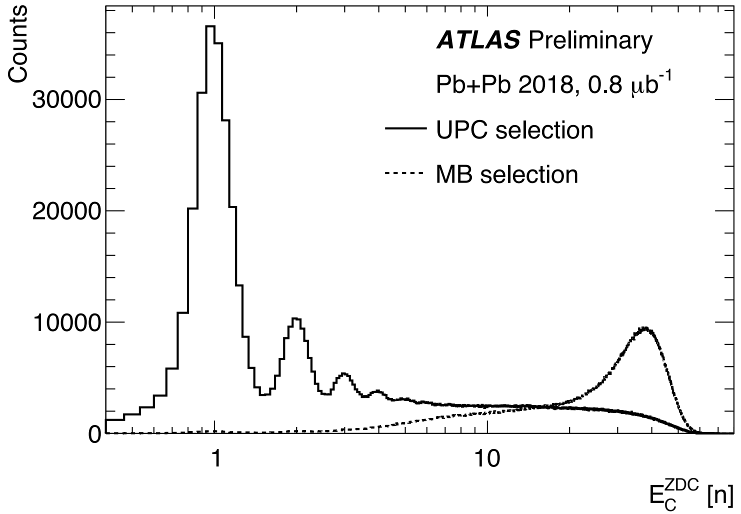
$$y = \ln\left(\frac{2\omega}{M_{J/\psi}}\right)$$

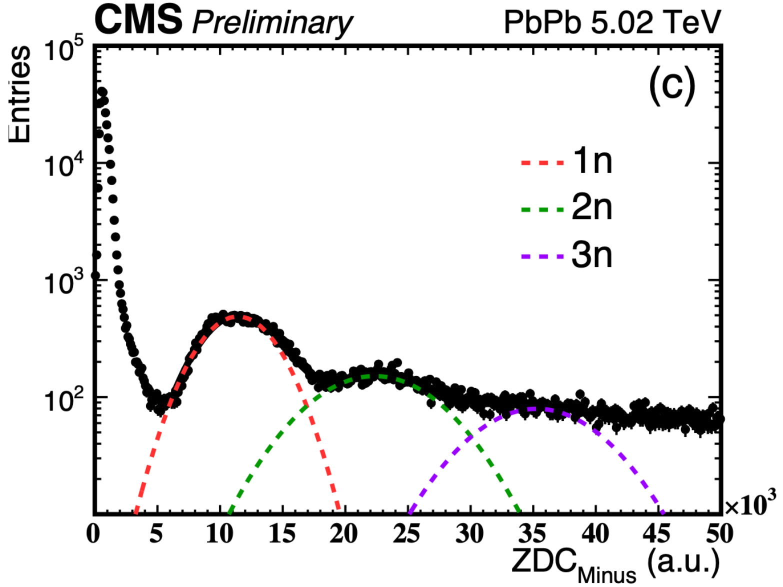


Cross section as a function of the J/ψ rapidity y at √sNN = 5.02 TeV: areas show the uncertainties. The dashed curves labeled "one side" show the contribution of the first term.
https://journals.aps.org/prc/abstract/10.1103/PhysRevC.93.055206

Impact parameters of photo-interaction

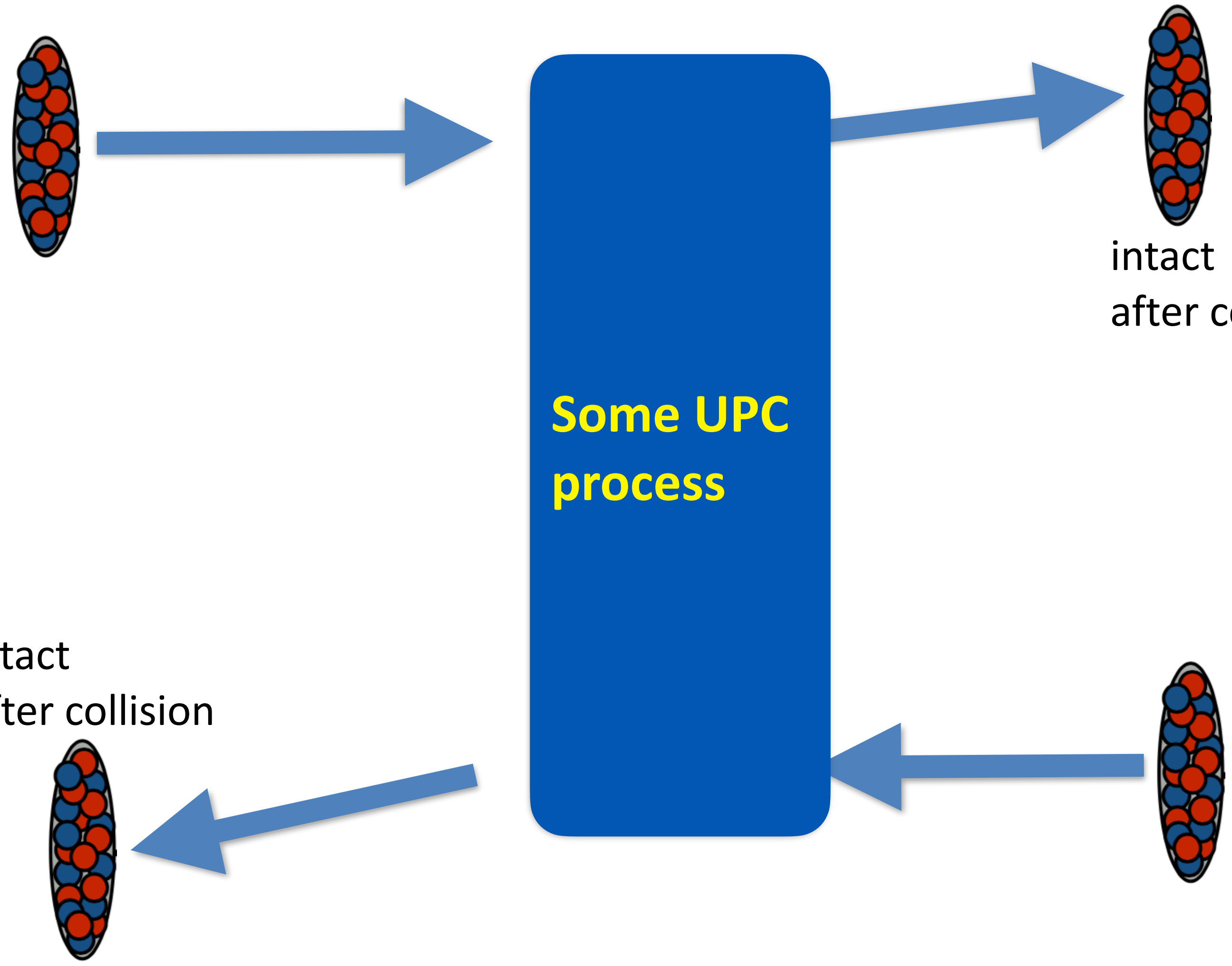


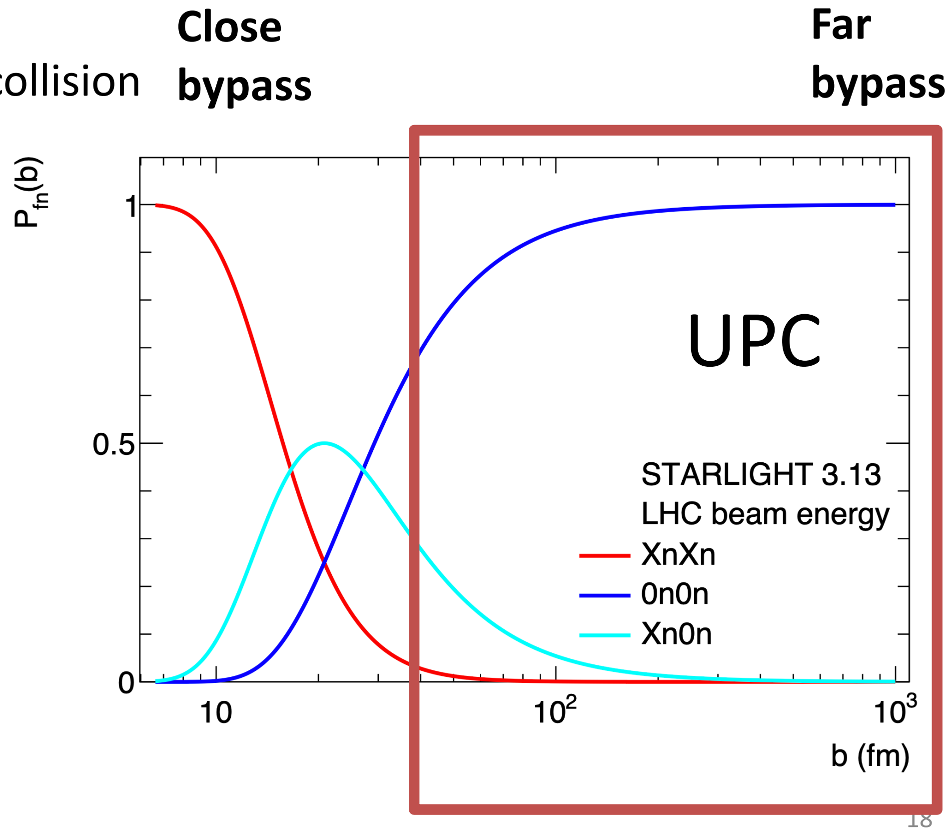




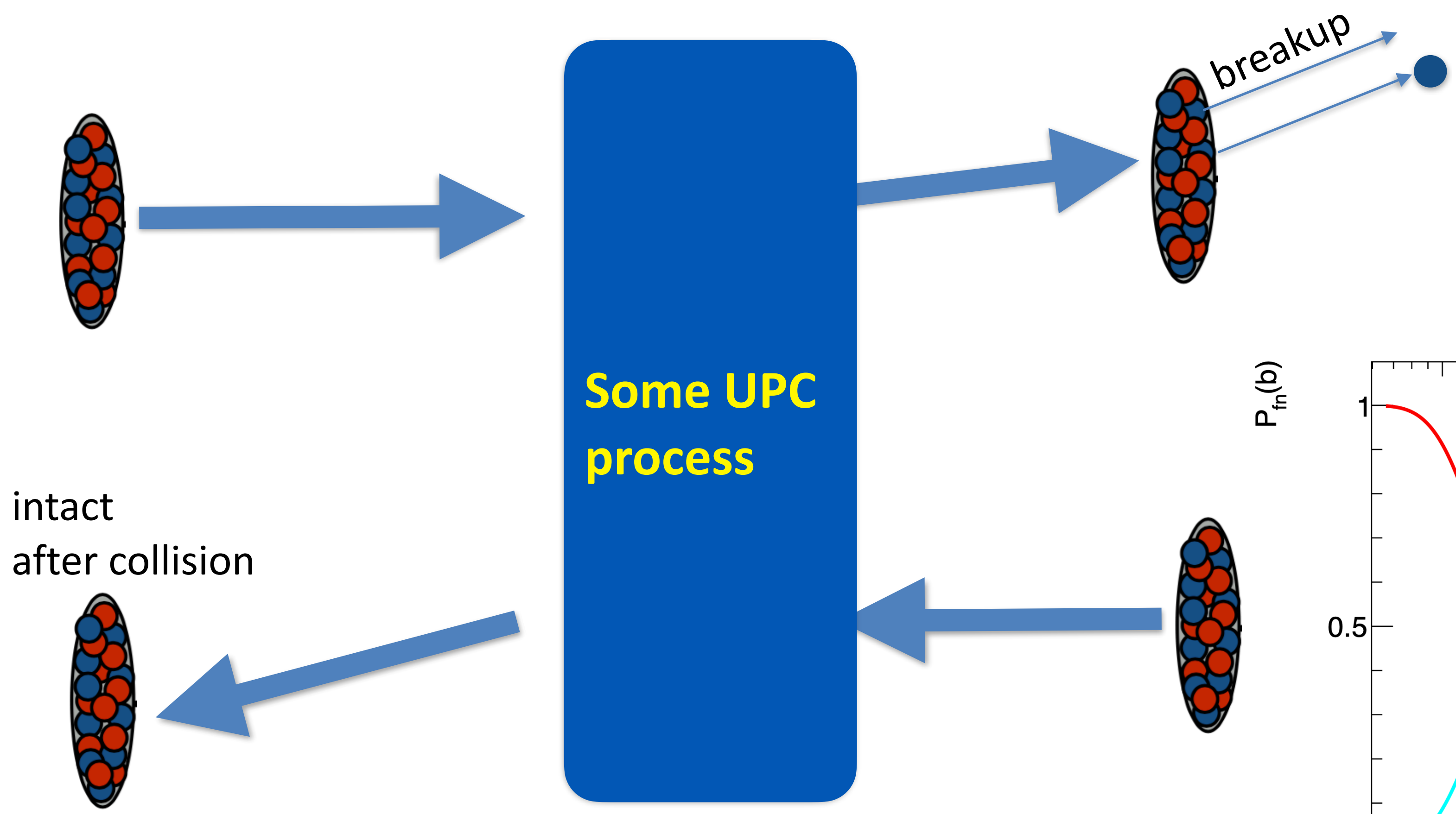
- **Giant dipole resonance** knocks out neutrons
- Measured by Zero Degree Calorimeters

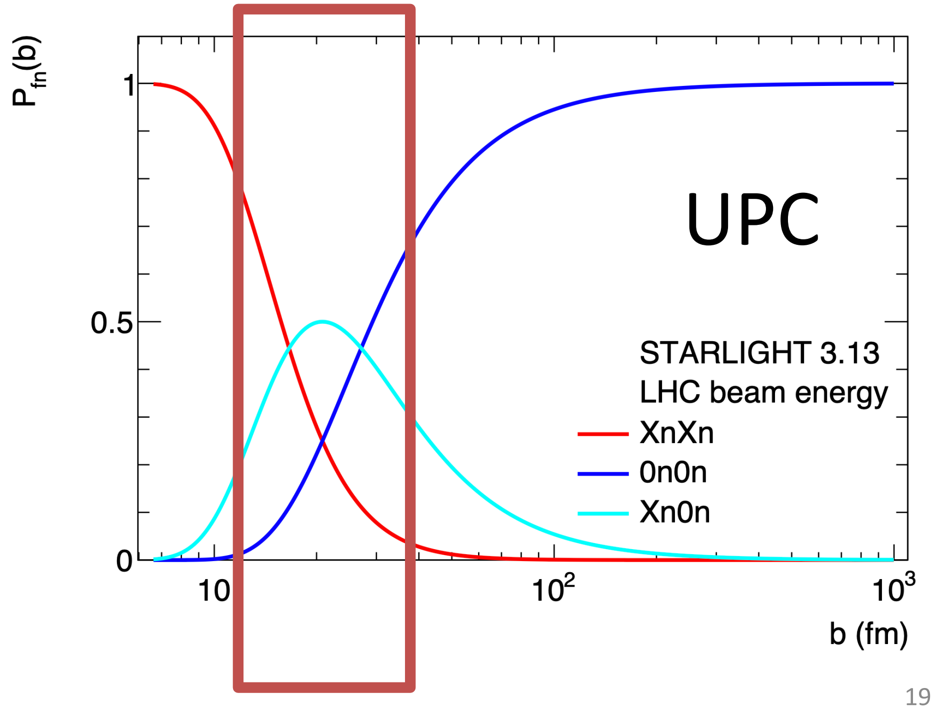
UPC depending on Impact parameter



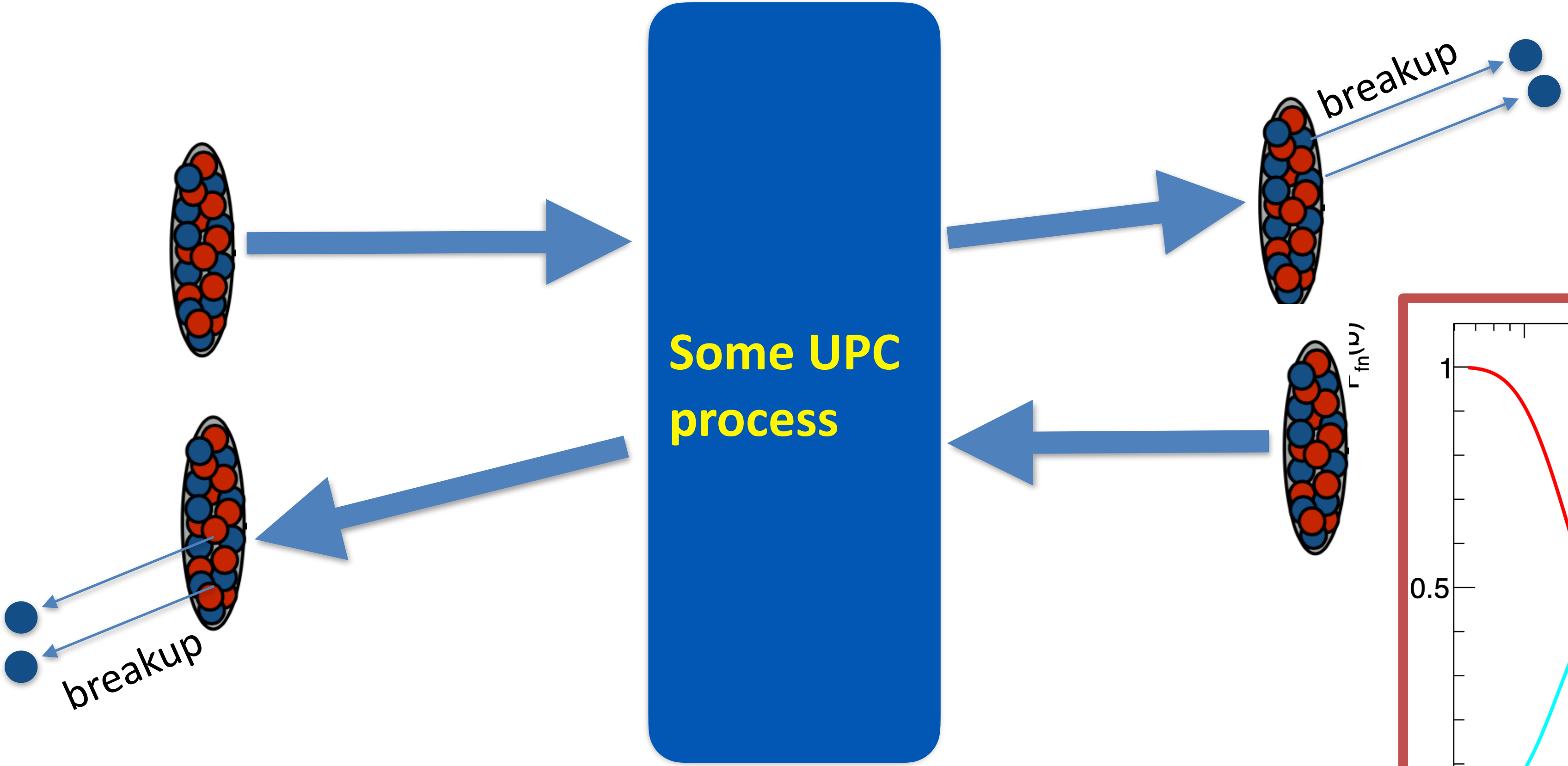


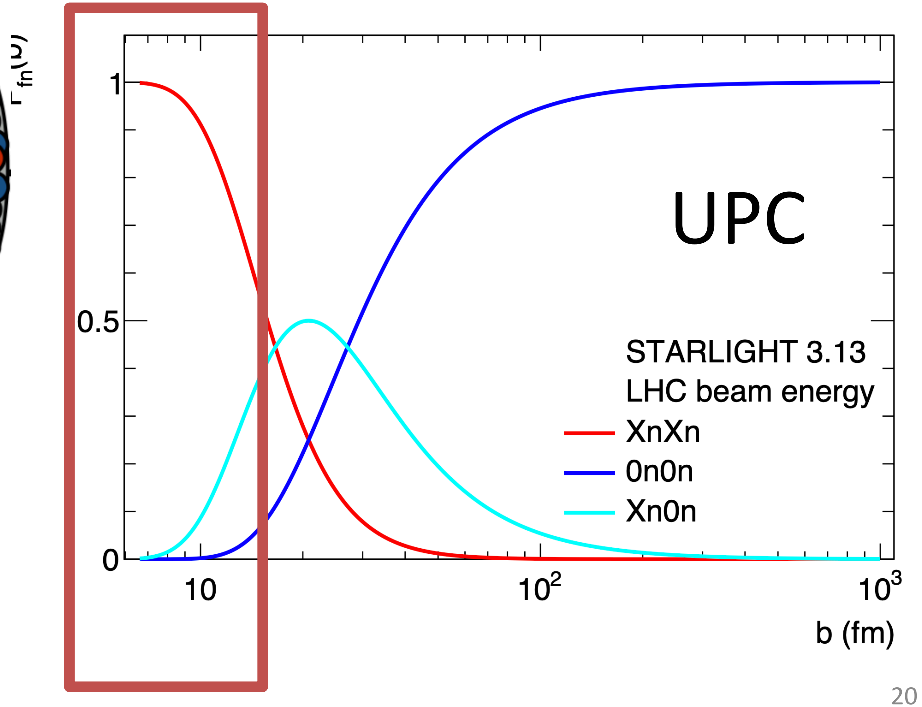
UPC depending on Impact parameter





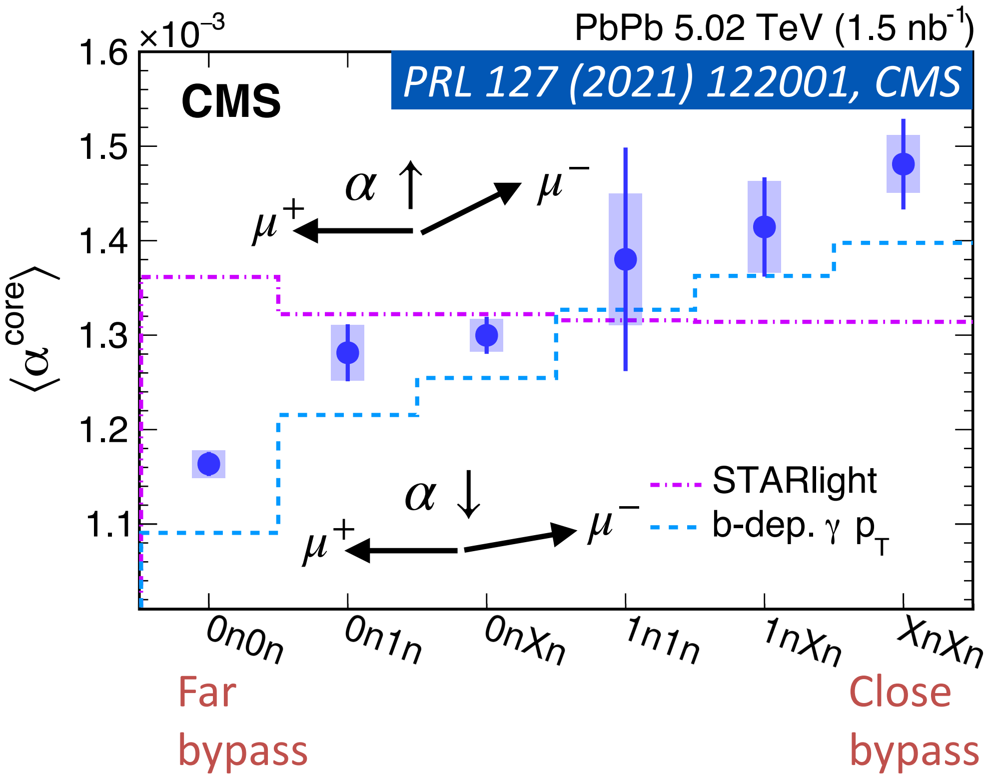
UPC depending on Impact parameter

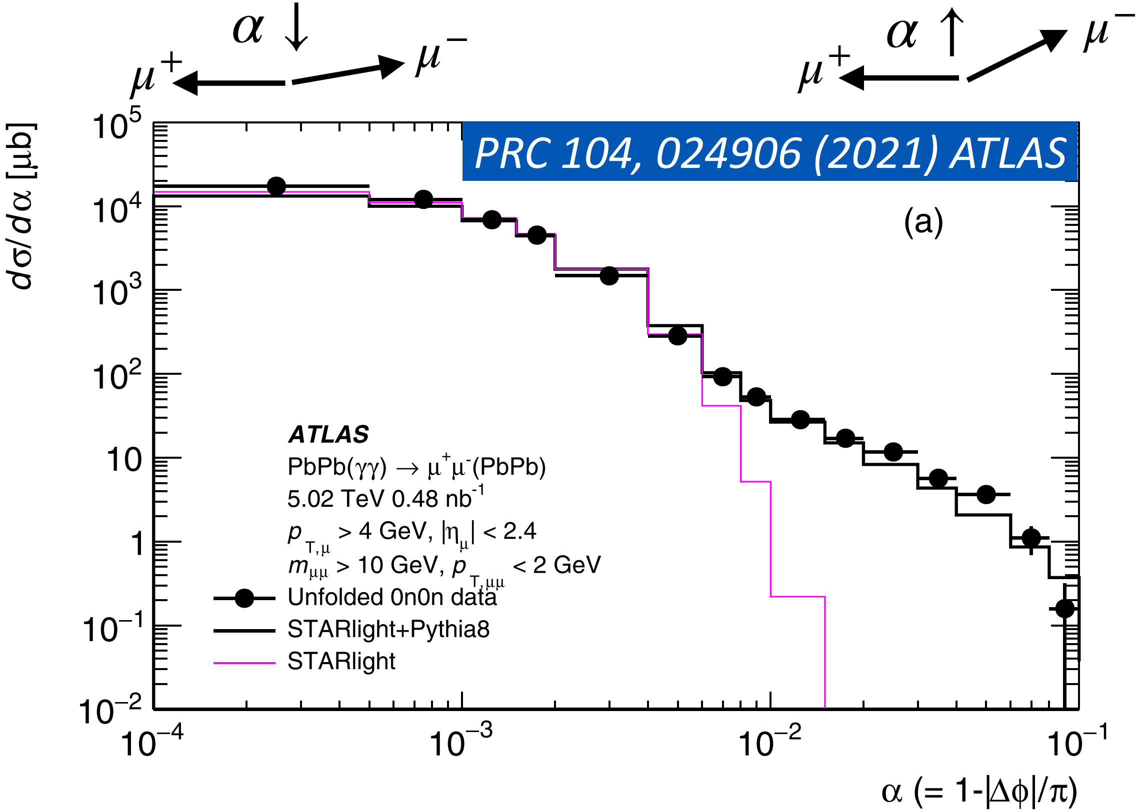




Neutron emission can be a proxy for the centrality among UPC

Dimuon acoplanarity in UPC by Rice group





- Photo-produced dimuon pairs had acoplanarity depending on the impact parameter
- Theory compatible with data when the b-dependnt photon p_T is considered *[arXiv.2006.07365]*

Solving high energy contribution

$$\frac{d\sigma^{0n0n}_{AA\to AA'J/\psi}}{dy} = N^{0n0n}_{\gamma/A}(\omega_1)\cdot\sigma_{\gamma A\to J/\psi A'}(\omega_1) + N^{0n0n}_{\gamma/A}(\omega_2)\cdot\sigma_{\gamma A\to J/\psi A'}(\omega_2)$$

$$\frac{d\sigma^{0nXn}_{AA\to AA'J/\psi}}{dy} = N^{0nXn}_{\gamma/A}(\omega_1)\cdot\sigma_{\gamma A\to J/\psi A'}(\omega_1) + N^{0nXn}_{\gamma/A}(\omega_2)\cdot\sigma_{\gamma A\to J/\psi A'}(\omega_2)$$

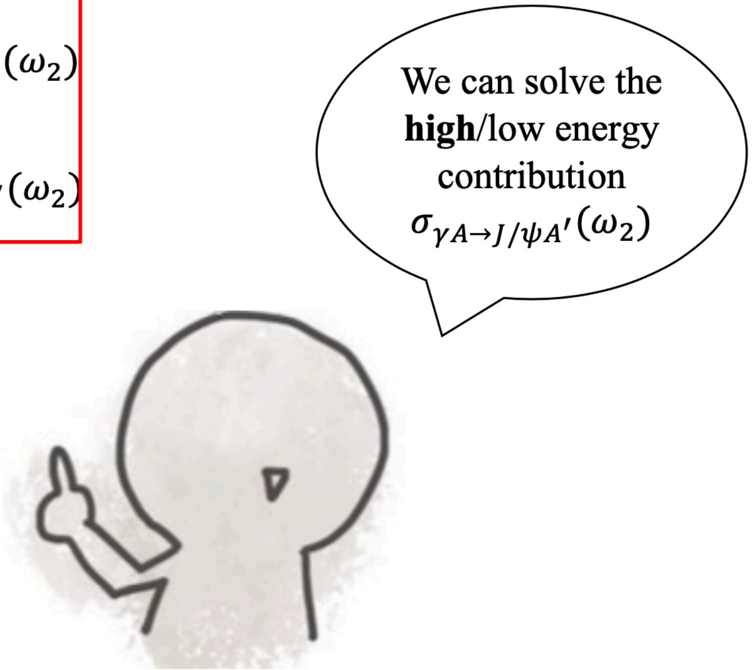
$$\frac{d\sigma^{XnXn}_{AA\to AA'J/\psi}}{dy} = N^{XnXn}_{\gamma/A}(\omega_1)\cdot\sigma_{\gamma A\to J/\psi A'}(\omega_1) + N^{XnXn}_{\gamma/A}(\omega_2)\cdot\sigma_{\gamma A\to J/\psi A'}(\omega_2)$$

Measured

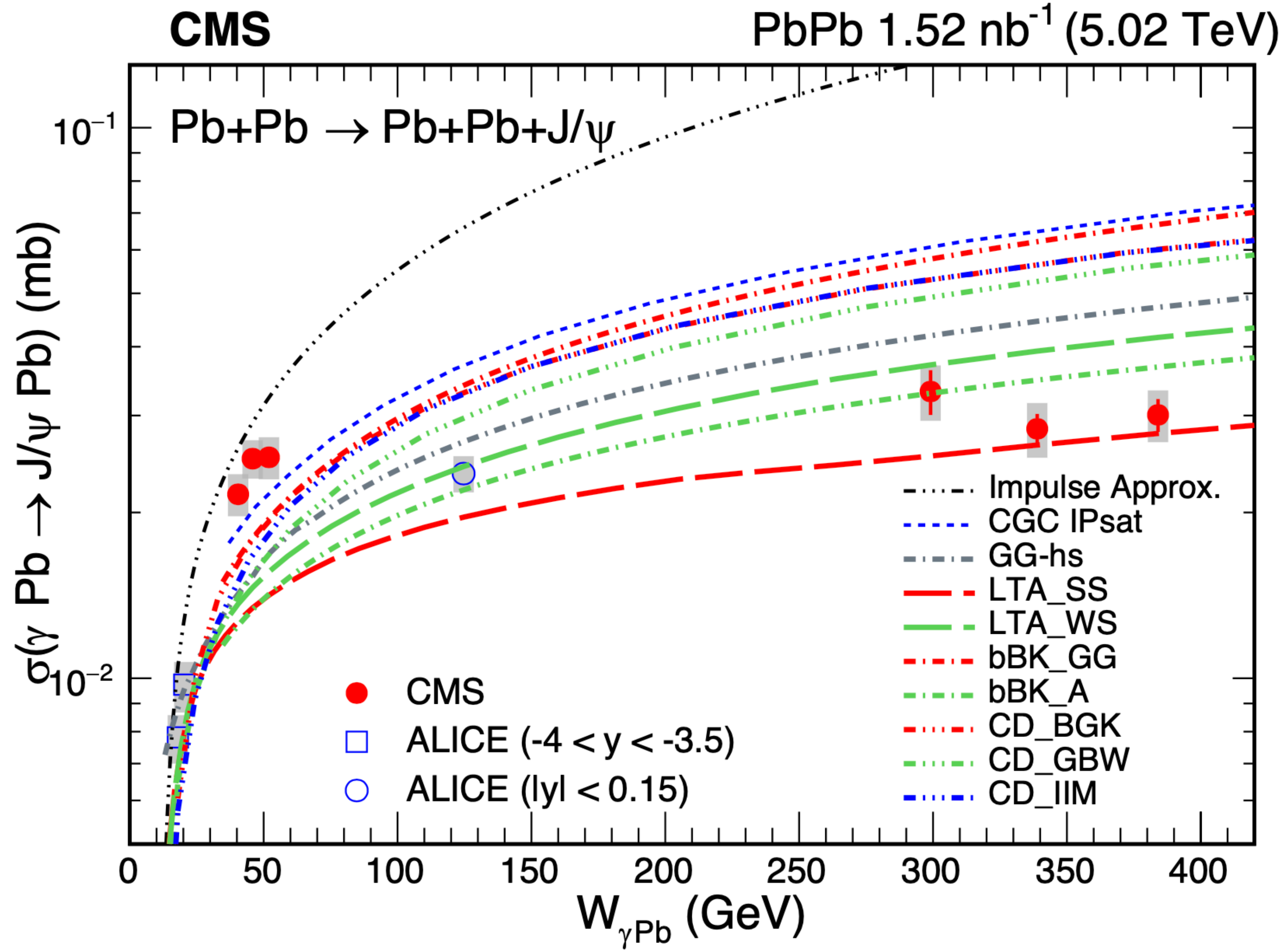
StarLight

Solve

Let get $\frac{d\sigma}{dy}$ first!



Preliminary result



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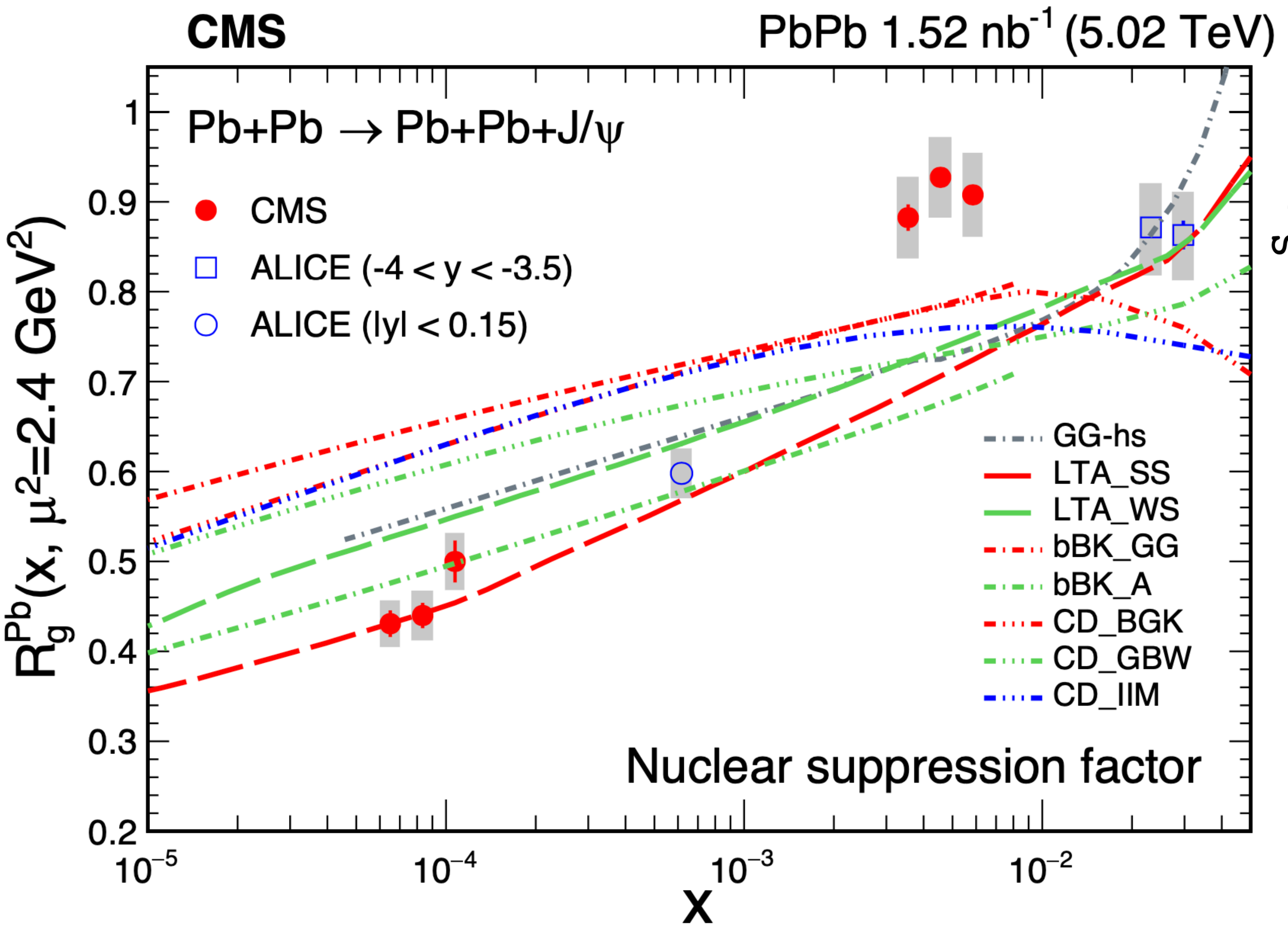
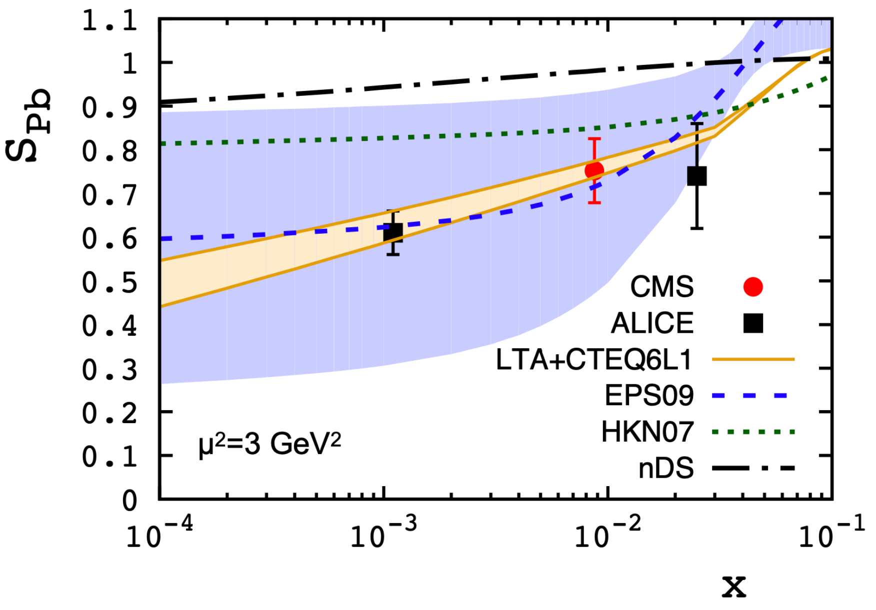


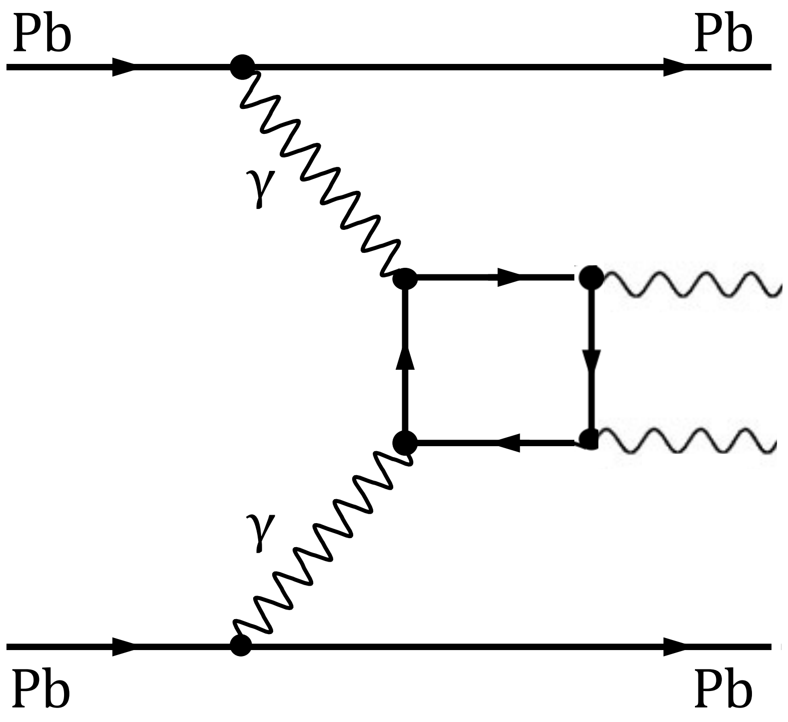


Take home message

- Let’s keep finding new observables!
- Surprise might be right under our nose.

- backup

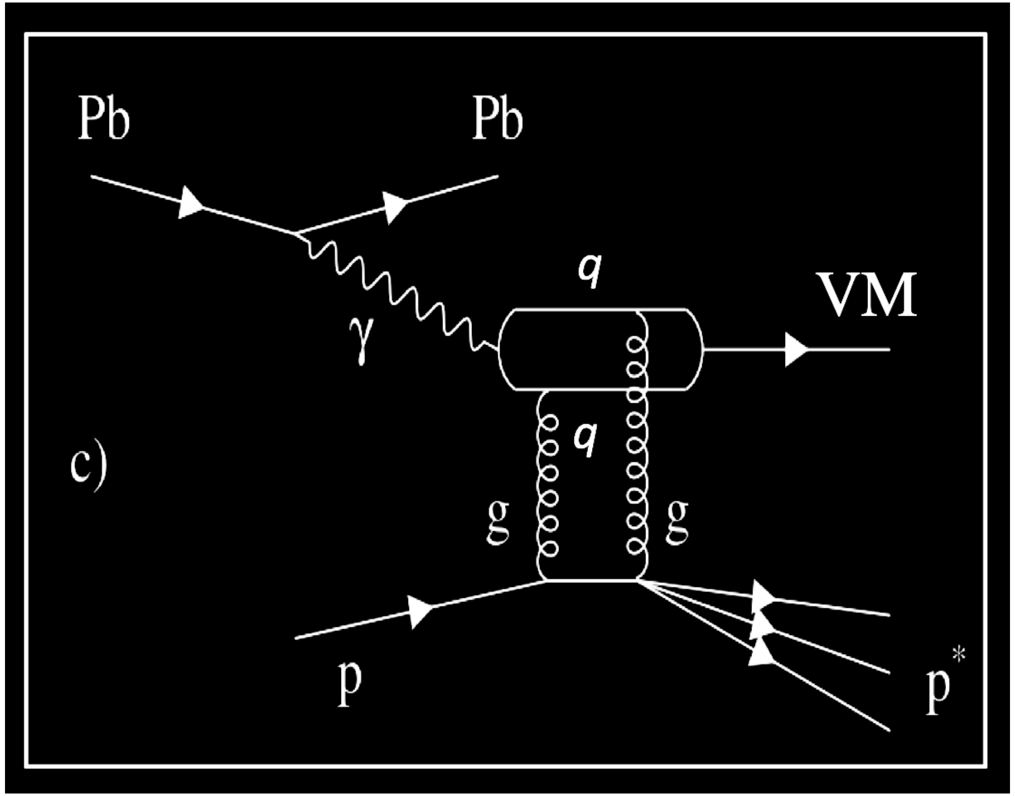
Validation of Photon flux

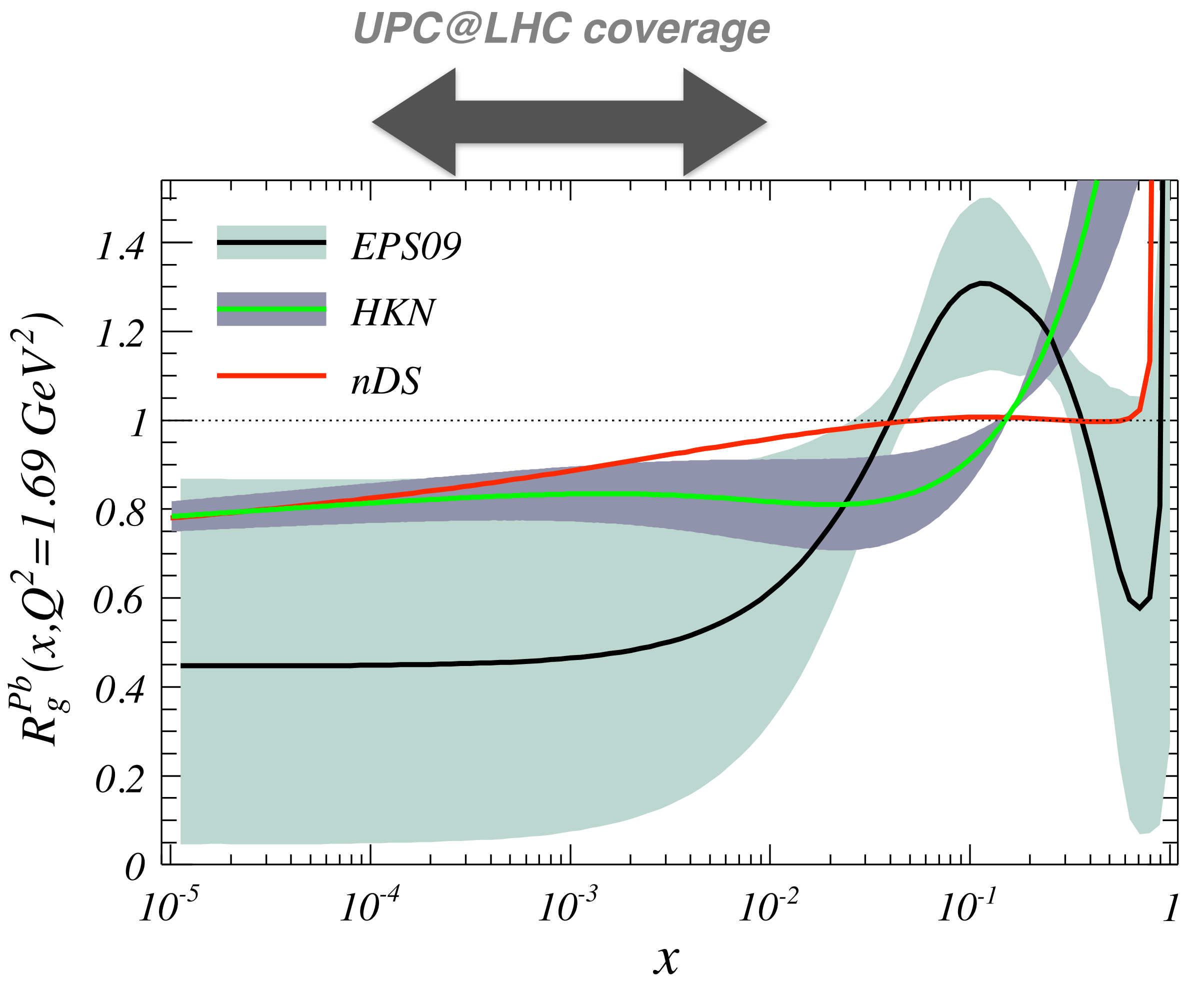


- Is our understanding of QED in UPC perfect?

Vector meson in γ + p(Pb)

- $\rho(770)$, J/ψ, $\psi(2S)$, Υ(nS), ϕ
- Test for pQCD and nuclear structure





Cross section of $\gamma\gamma \rightarrow \mu\mu(ee)$ in PbPb UPC

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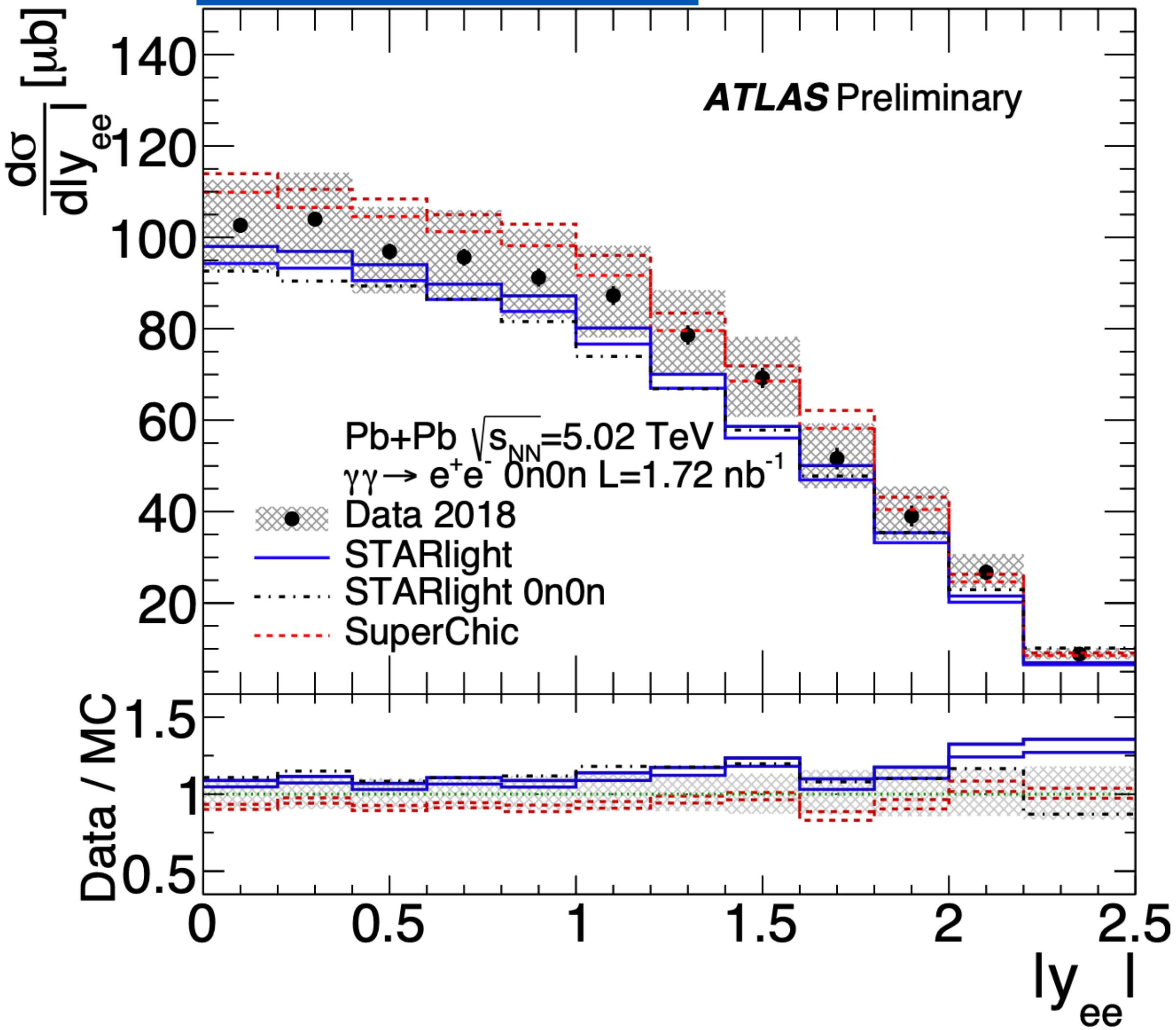

- Cross section is proportional to the incoming photon flux
- Thus useful for calibration of photon flux
- SuperChic and STARLIGHT calculate inclusive cross section within uncertainties