



Observation of b dependence of $\mu^+ \mu^-$ acoplanarity in ultra-peripheral PbPb collisions

Shuai Yang (for the CMS collaboration)

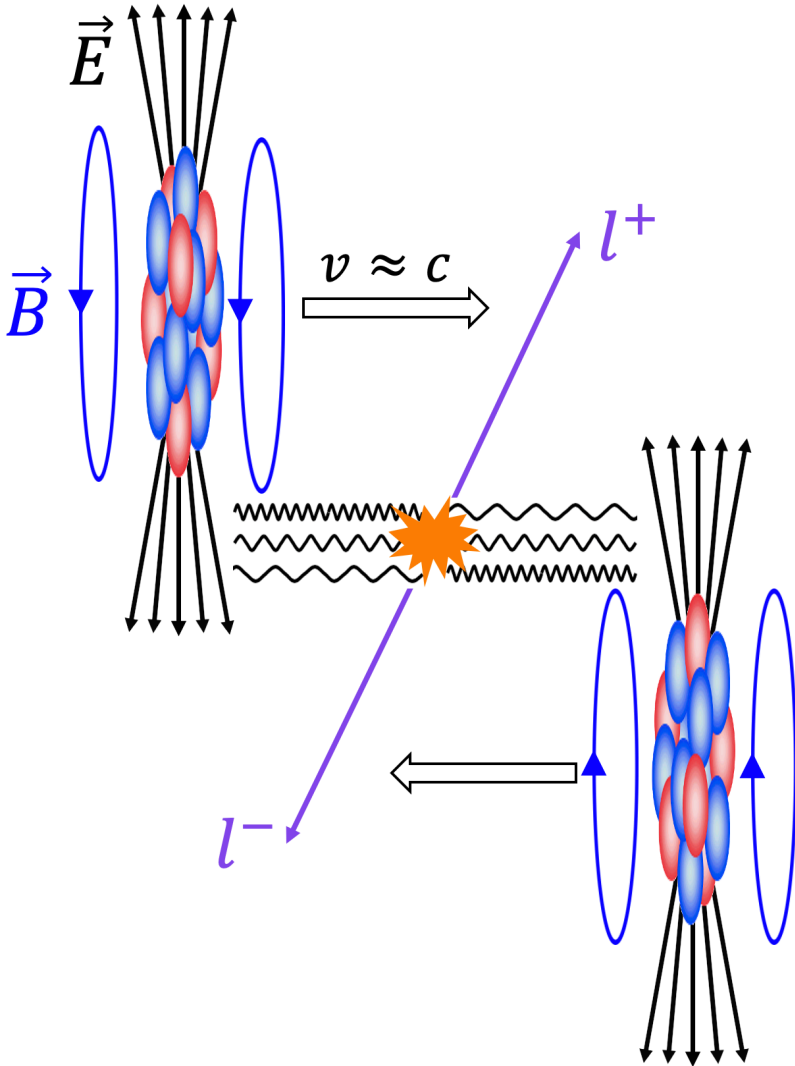
Rice University

IS2021

The VIth International Conference on the
INITIAL STAGES
OF HIGH-ENERGY NUCLEAR
COLLISIONS



Photon-photon interactions



➤ Photon kinematics

- $p_T < \frac{\hbar}{R_A}$ ($\mathcal{O}(30)$ MeV @ LHC)

➤ Equivalent photon approximation

- Photon $p_T(\mathbf{b})$ (X)

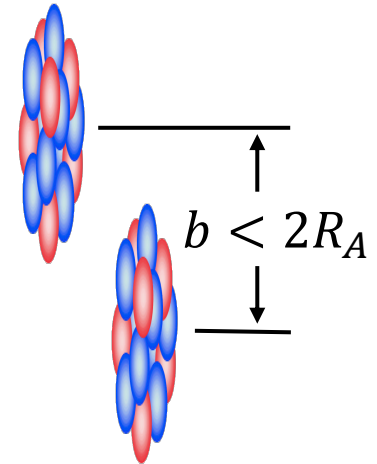
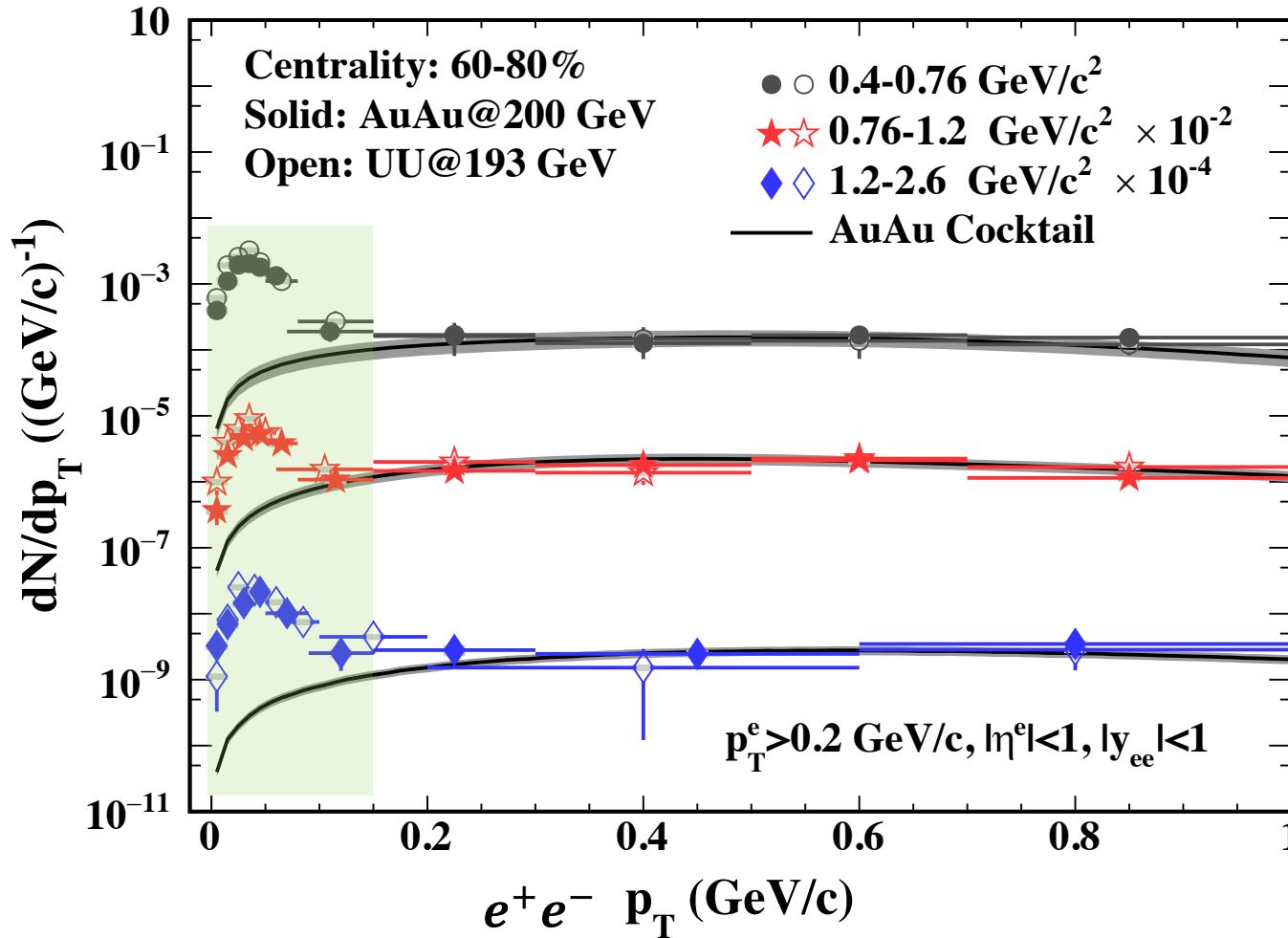
➤ Distinctive $l^+ l^-$ feature

- Exclusive production
- Concentrated at low p_T (back-to-back)

Observed in hadronic collisions

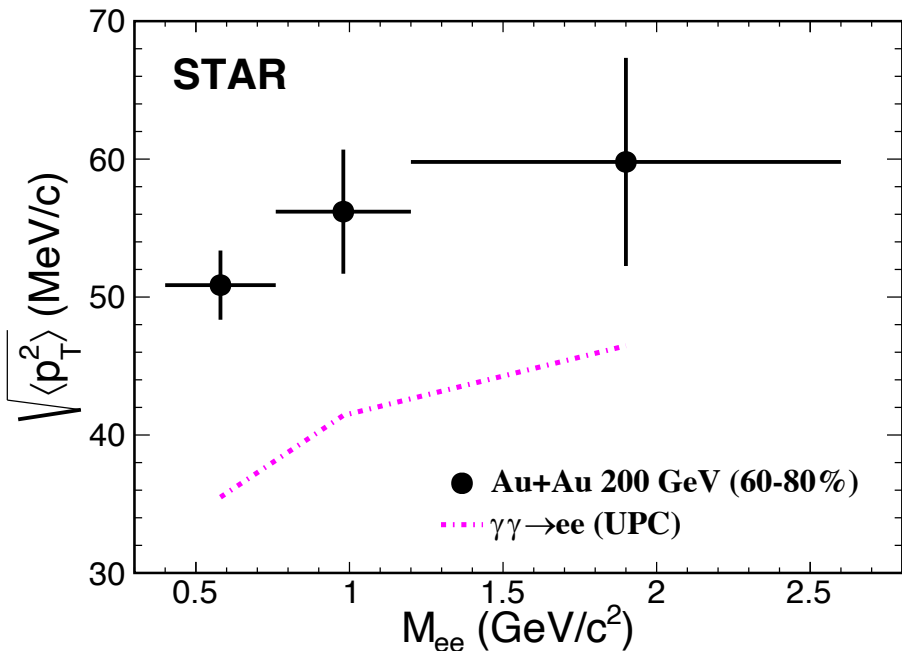


STAR, PRL 121 (2018) 132301

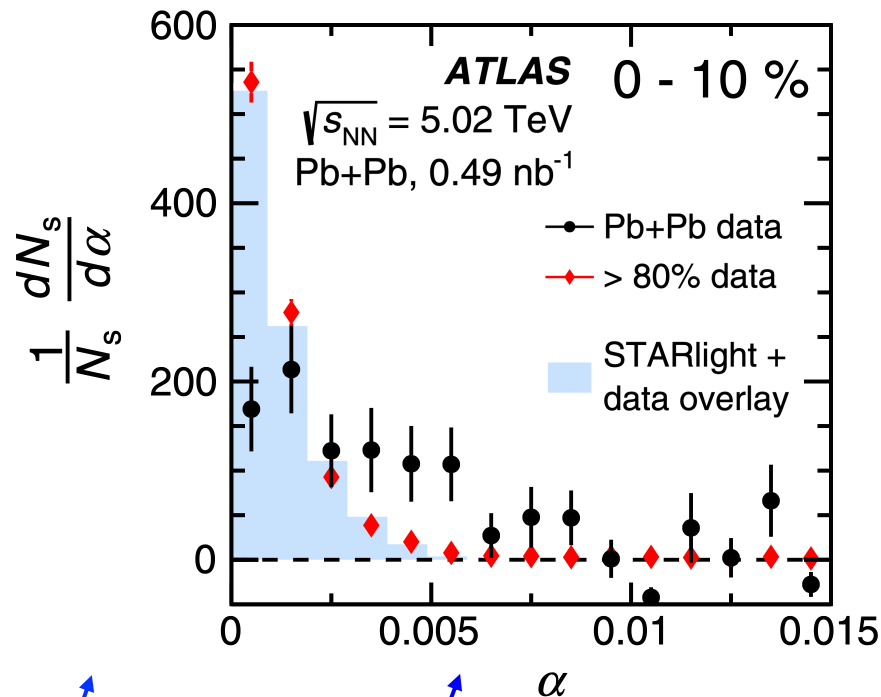


Modification of lepton pairs

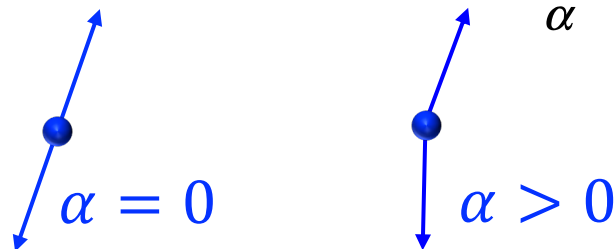
STAR, PRL 121 (2018) 132301



ATLAS, PRL 121 (2018) 212301



$$\alpha = 1 - \frac{|\phi^+ - \phi^-|}{\pi}$$



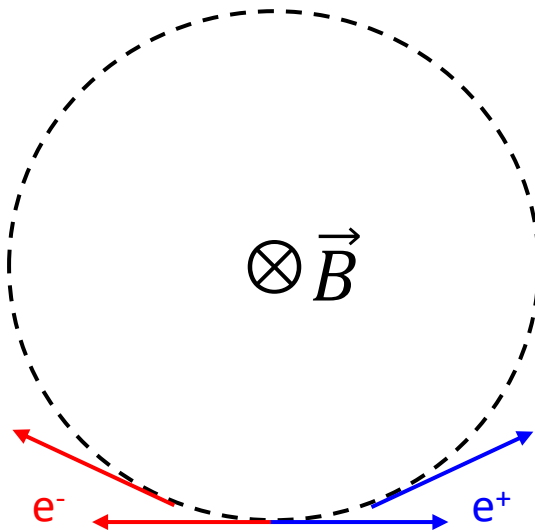
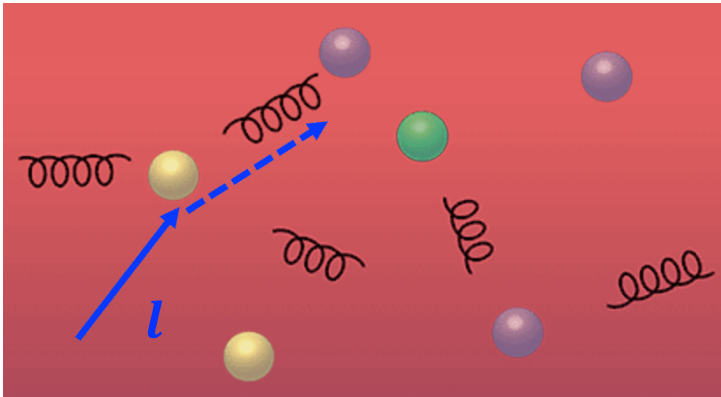
➤ Back-to-back correlation becomes weaker towards central collisions

Puzzle of the physics origin

STAR, PRL 121 (2018) 132301

ATLAS, PRL 121 (2018) 212301

Final-state effect?



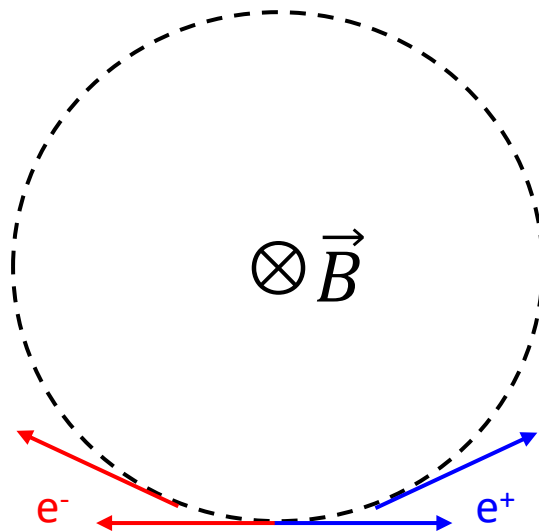
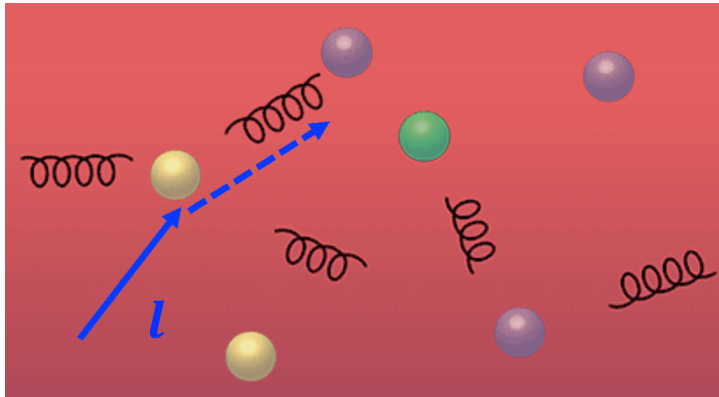
Puzzle of the physics origin



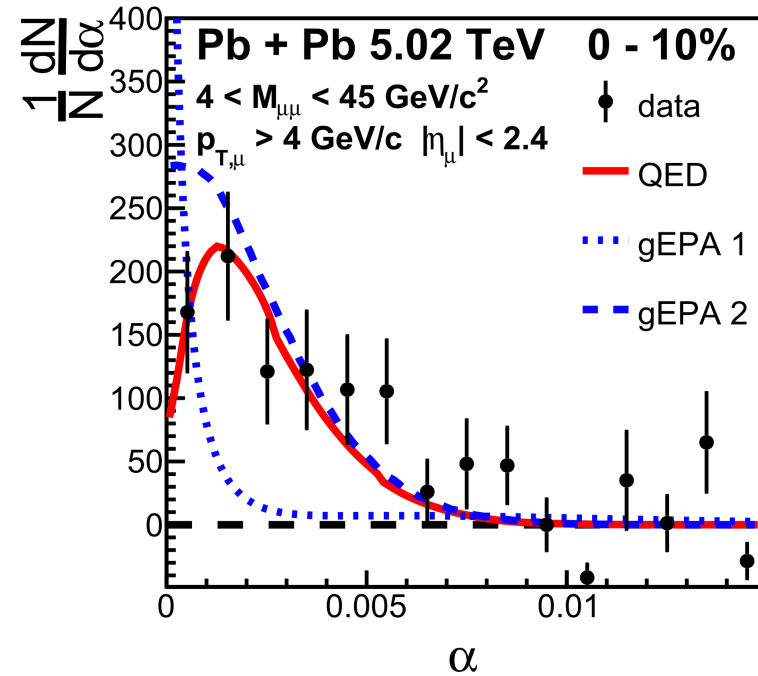
STAR, PRL 121 (2018) 132301
 ATLAS, PRL 121 (2018) 212301

Zha et al., PLB 800 (2020) 135089

Final-state effect?

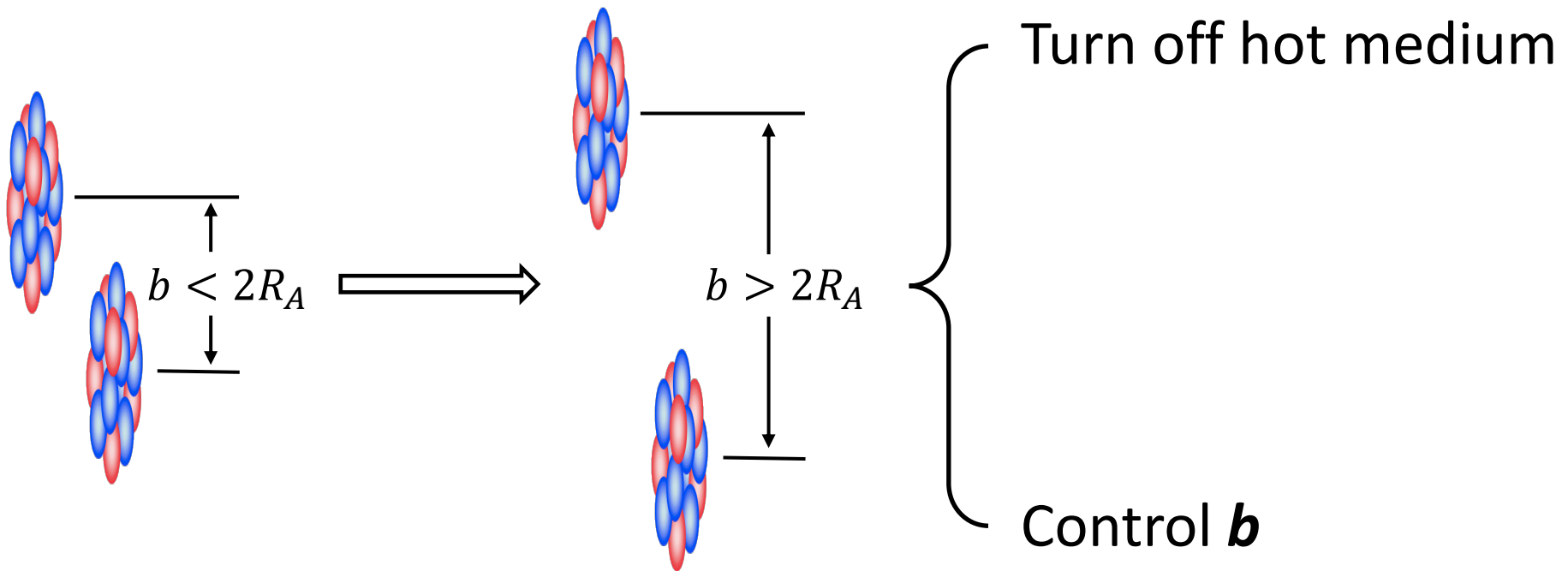


Initial-state effect?

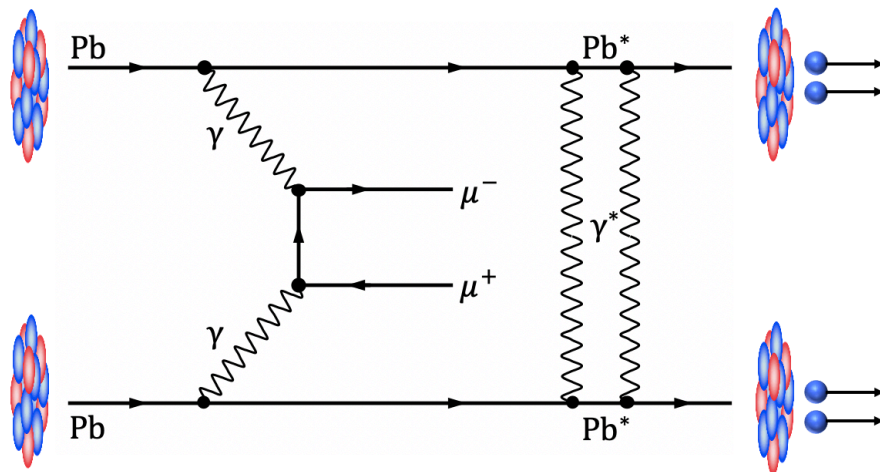


- Described by lowest-order QED without medium effect
- b dependence of initial photon p_T

Experimentally explore the puzzle



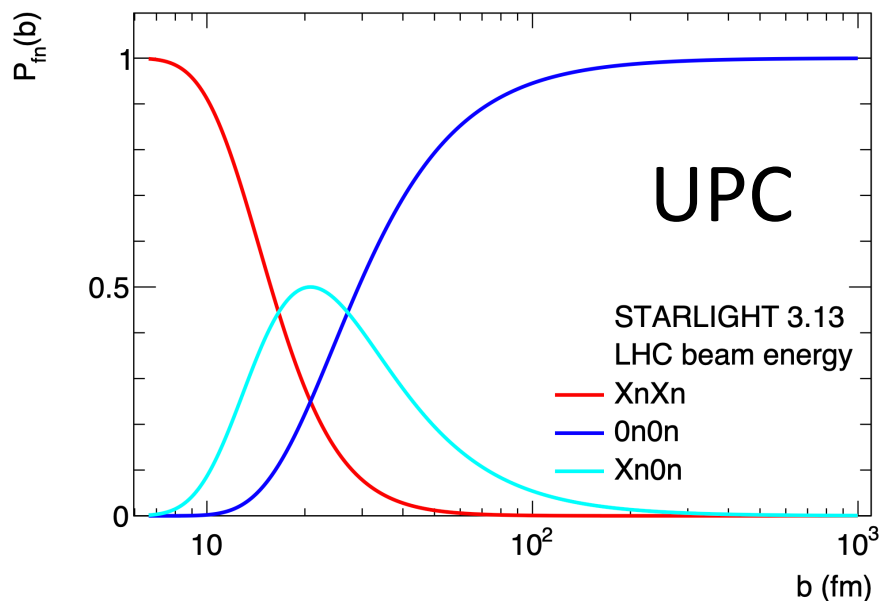
Control “centrality” in UPC



$$N(k) = \int d^2b N(k, b) P_{0\text{had}}(b) P_1(b) P_2(b)$$

, where $P_i(b) \propto 1/b^2$

Klein and Steinberg, *Ann. Rev. Nucl. Part. Sci.* 70 (2020) 323



➤ Bearing analogy to centrality

- $b_{XnXn} < b_{0nXn} < b_{0n0n}$

The CMS detector



CMS DETECTOR

Total weight : 14,000 tonnes
 Overall diameter : 15.0 m
 Overall length : 28.7 m
 Magnetic field : 3.8 T

STEEL RETURN YOKE
 12,500 tonnes

SILICON TRACKERS
 Pixel (100x150 μm) $\sim 16\text{m}^2 \sim 66\text{M}$ channels
 Microstrips (80x180 μm) $\sim 200\text{m}^2 \sim 9.6\text{M}$ channels

SUPERCONDUCTING SOLENOID
 Niobium titanium coil carrying $\sim 18,000\text{A}$

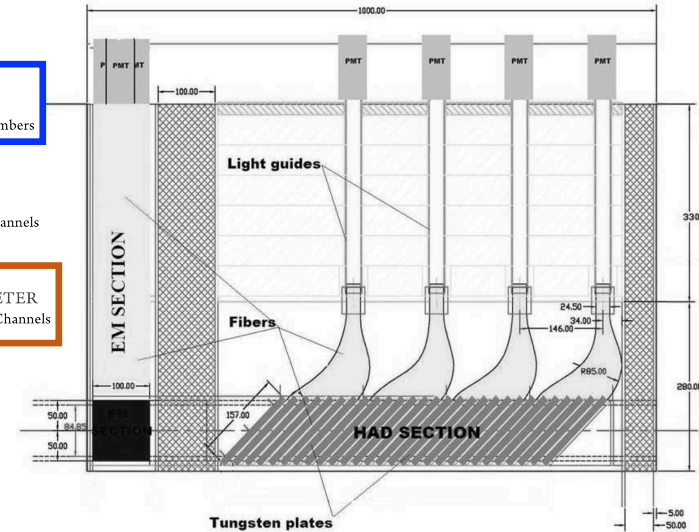
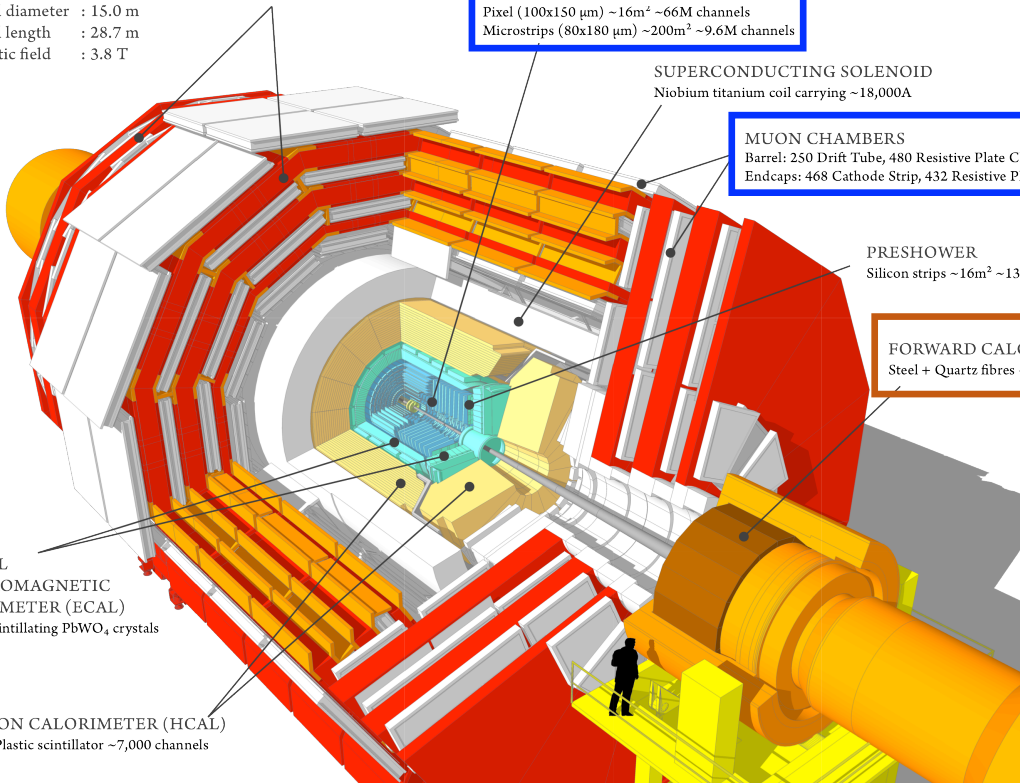
MUON CHAMBERS
 Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
 Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
 Silicon strips $\sim 16\text{m}^2 \sim 137,000$ channels

FORWARD CALORIMETER
 Steel + Quartz fibres $\sim 2,000$ Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
 $\sim 76,000$ scintillating PbWO_4 crystals

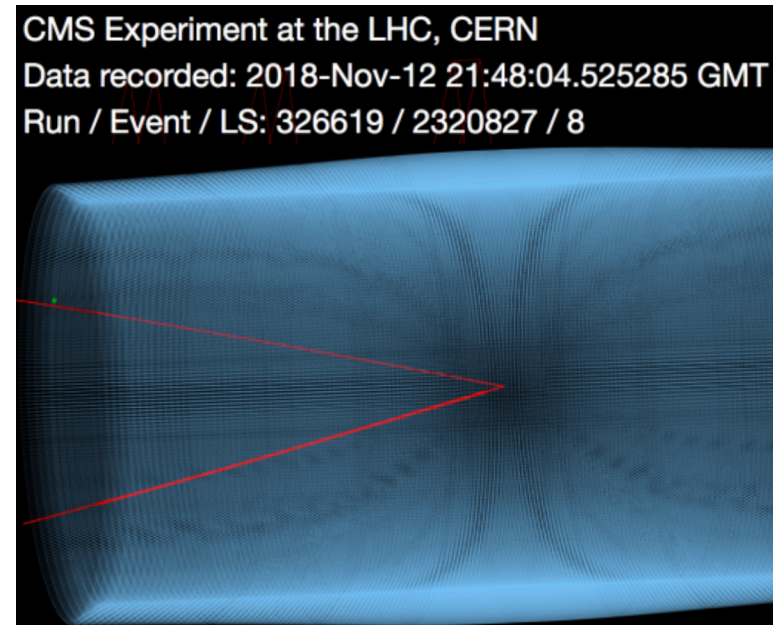
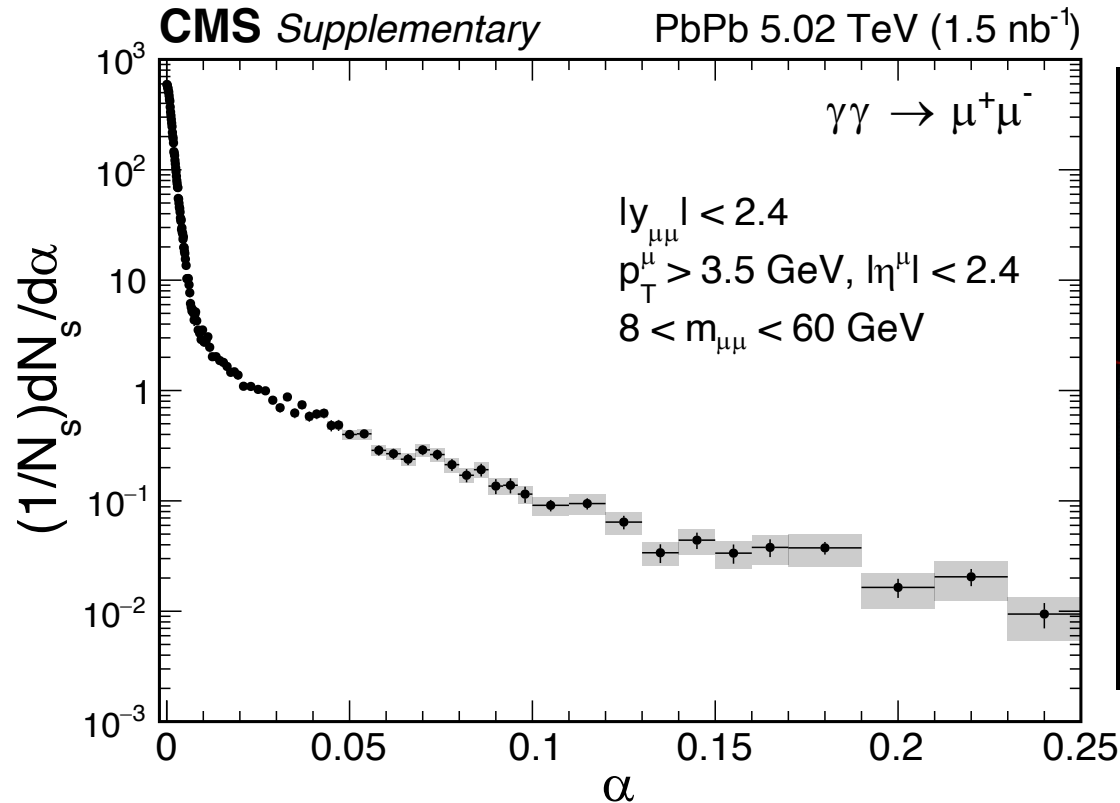
HADRON CALORIMETER (HCAL)
 Brass + Plastic scintillator $\sim 7,000$ channels



Zero Degree Calorimeter
 $|\eta| > 8.3$, $\sim 140\text{m}$ from IP

- HF: reject hadronic collisions
- Tracker + Muon chamber: muon identification
- ZDC: Neutron detection

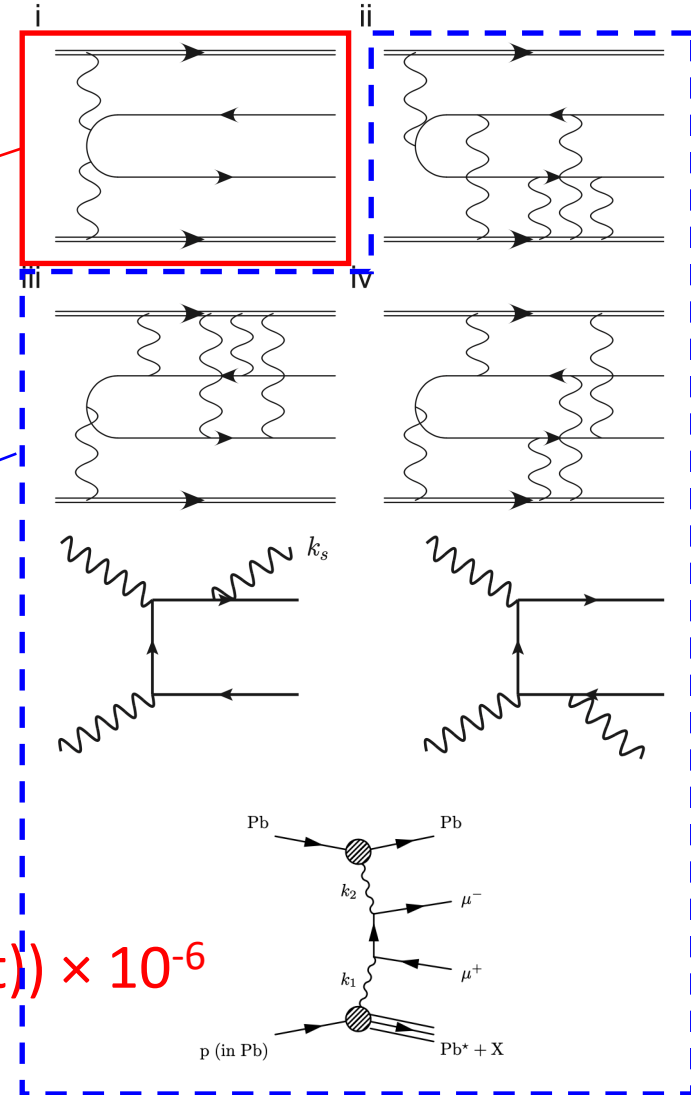
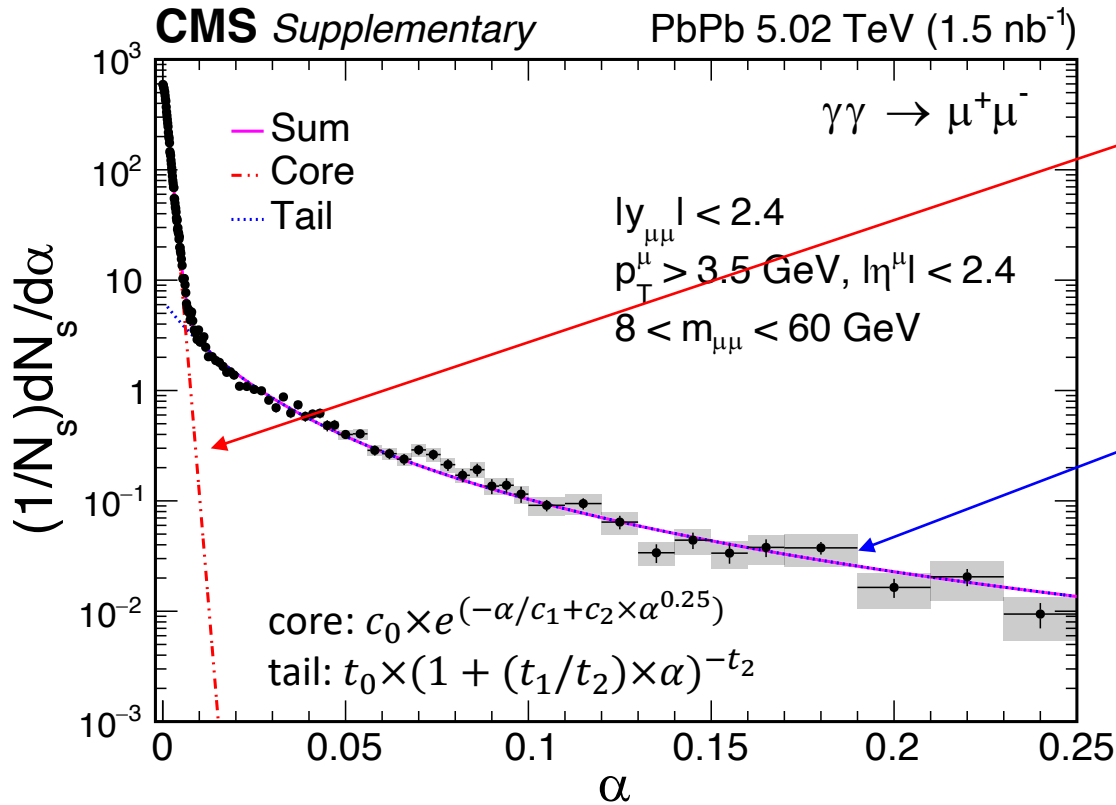
α distribution in UPC



➤ **Narrow core + Long tail**

$$\alpha = 1 - \frac{|\phi^+ - \phi^-|}{\pi}, \alpha \propto p_T^{l^+l^-}$$

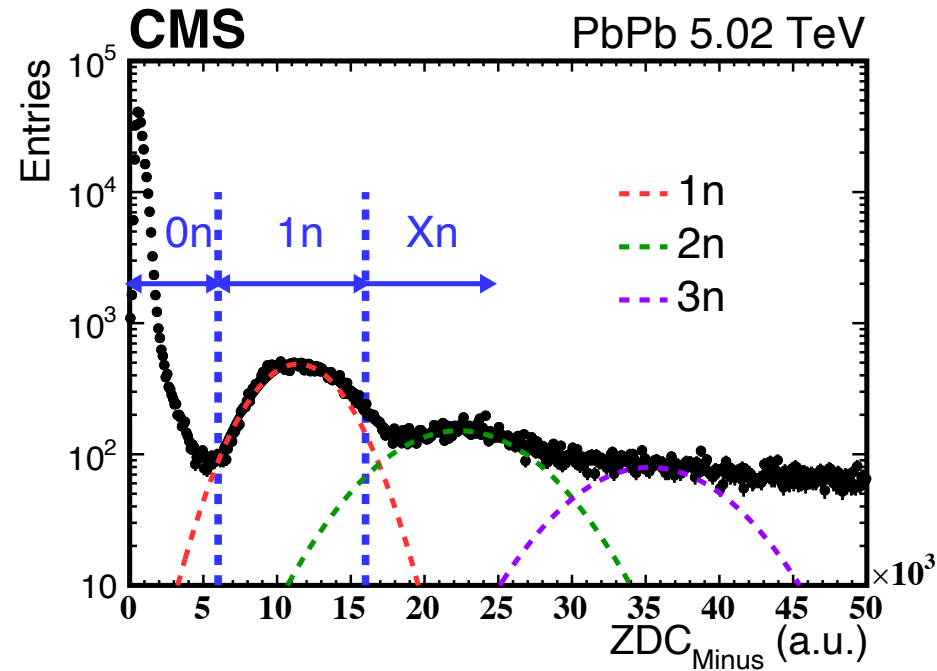
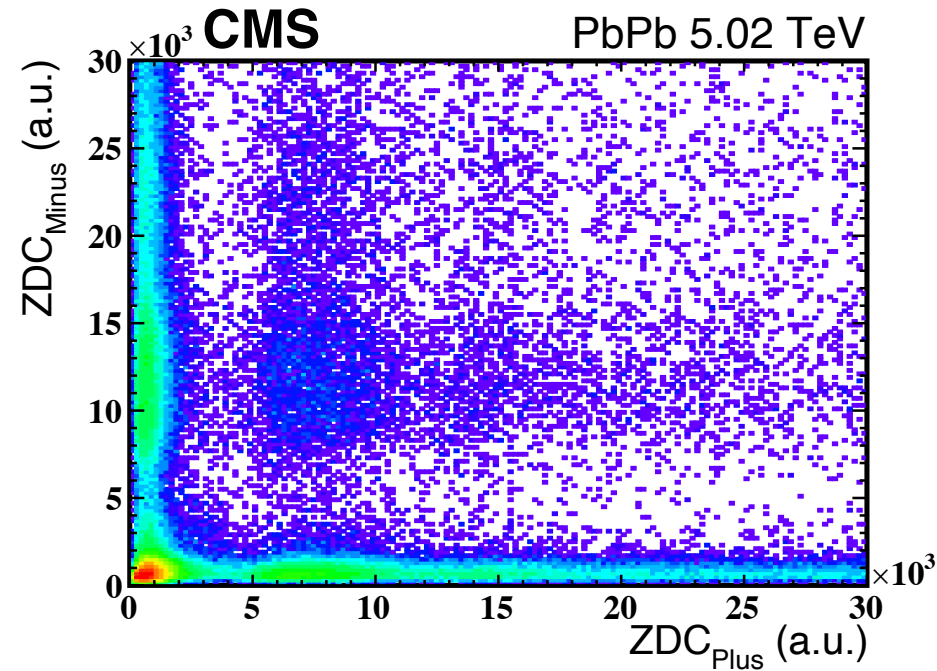
α distribution in UPC



➤ Decouple α spectrum:

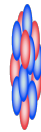
- Data: $\langle \alpha^{\text{core}} \rangle = (1227 \pm 7 \text{ (stat)} \pm 8 \text{ (syst)}) \times 10^{-6}$
- STARlight: 1350×10^{-6}

Determine neutron multiplicity

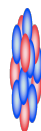


➤ Straight cut to disentangle neutrons

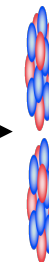
- 0n0n, 0n1n, 0nXn, 1n1n, 1nXn, XnXn ($X \geq 2$)



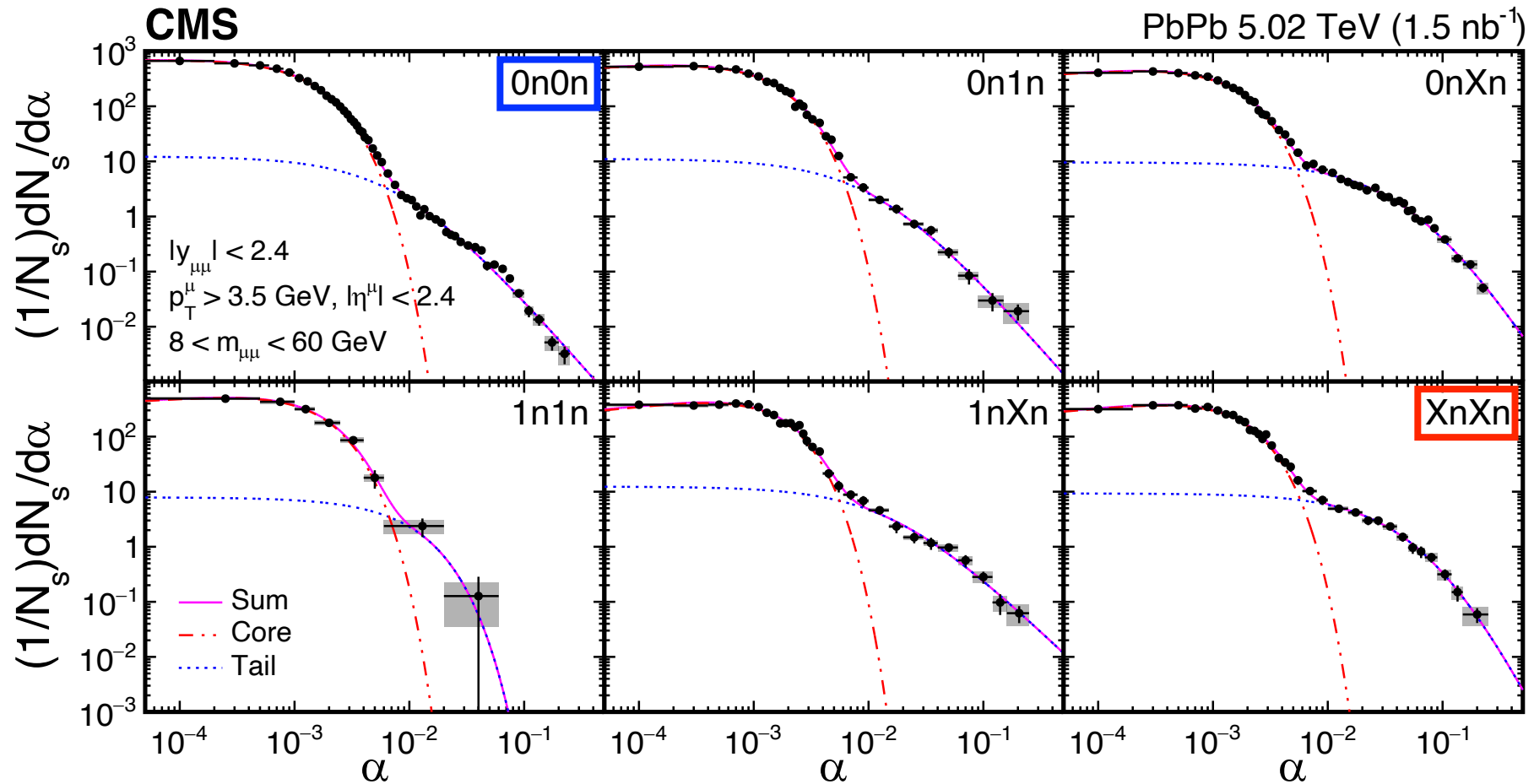
Fewer neutrons



More neutrons



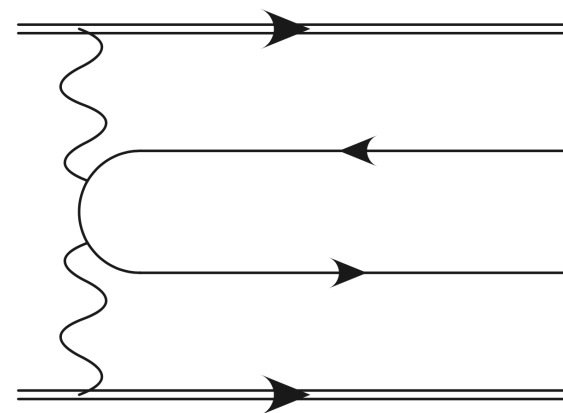
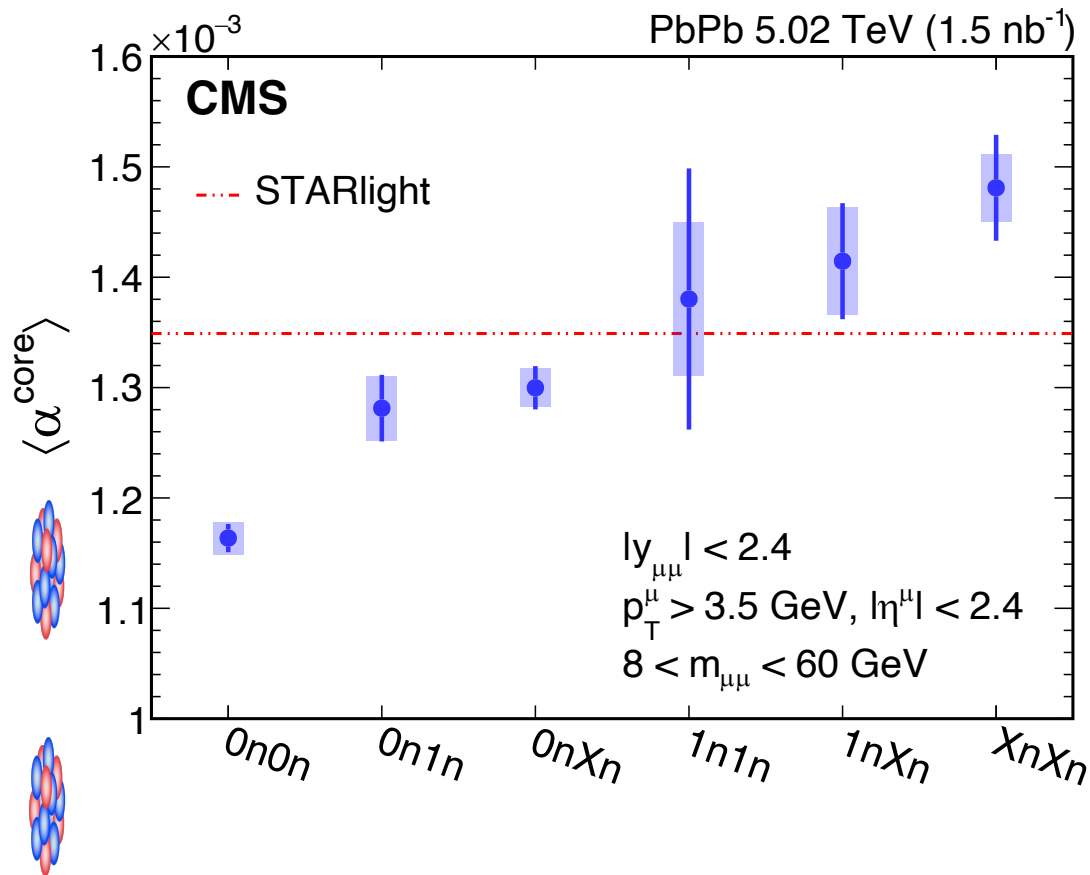
α spectrum vs. neutron multiplicity



➤ **0n0n (fewer neutrons) \Rightarrow XnXn (more neutrons)**

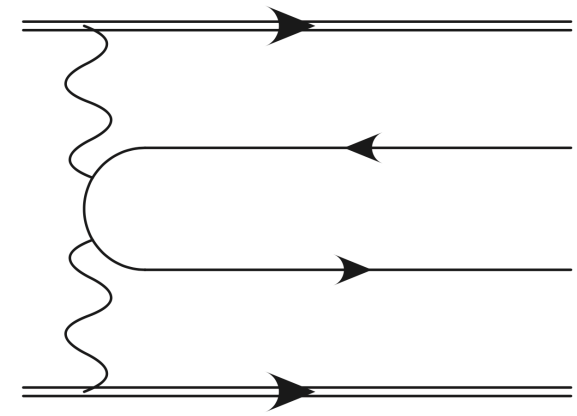
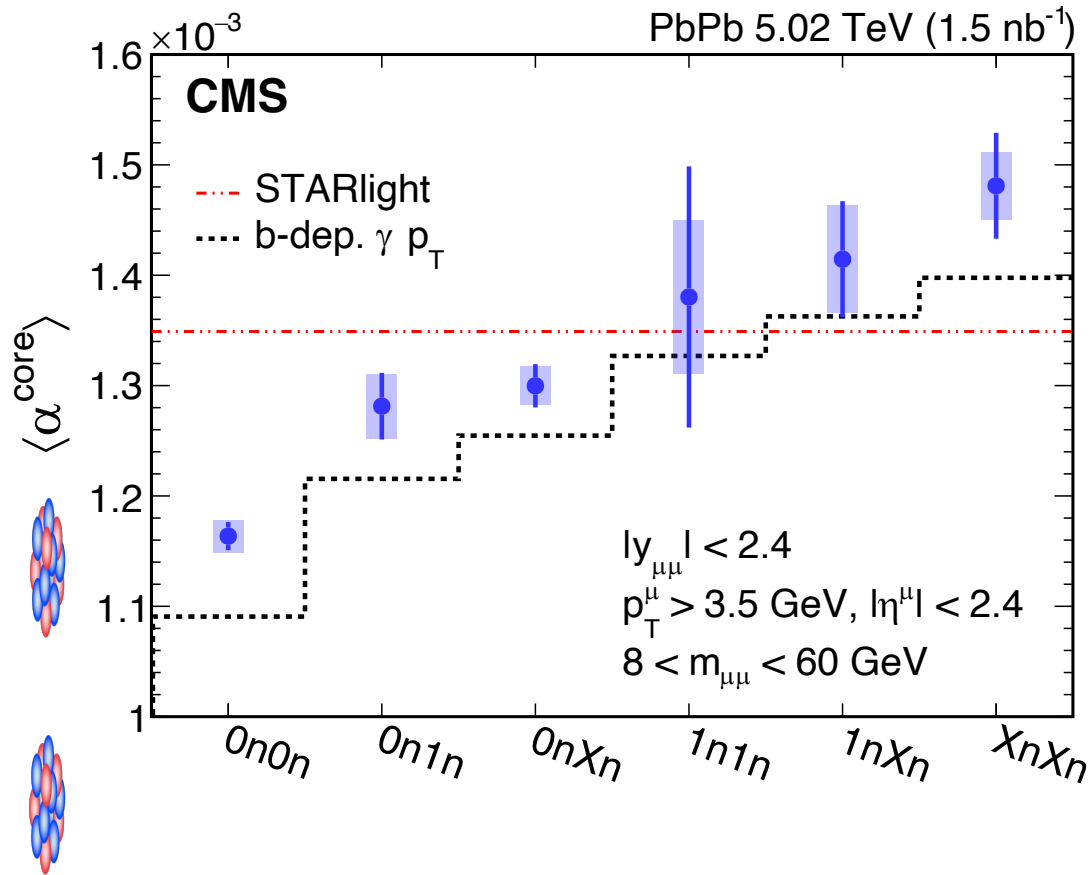
- Tail contribution becomes larger
- Seems has depletion in the very small α

$\langle \alpha^{\text{core}} \rangle$ vs. neutron multiplicity



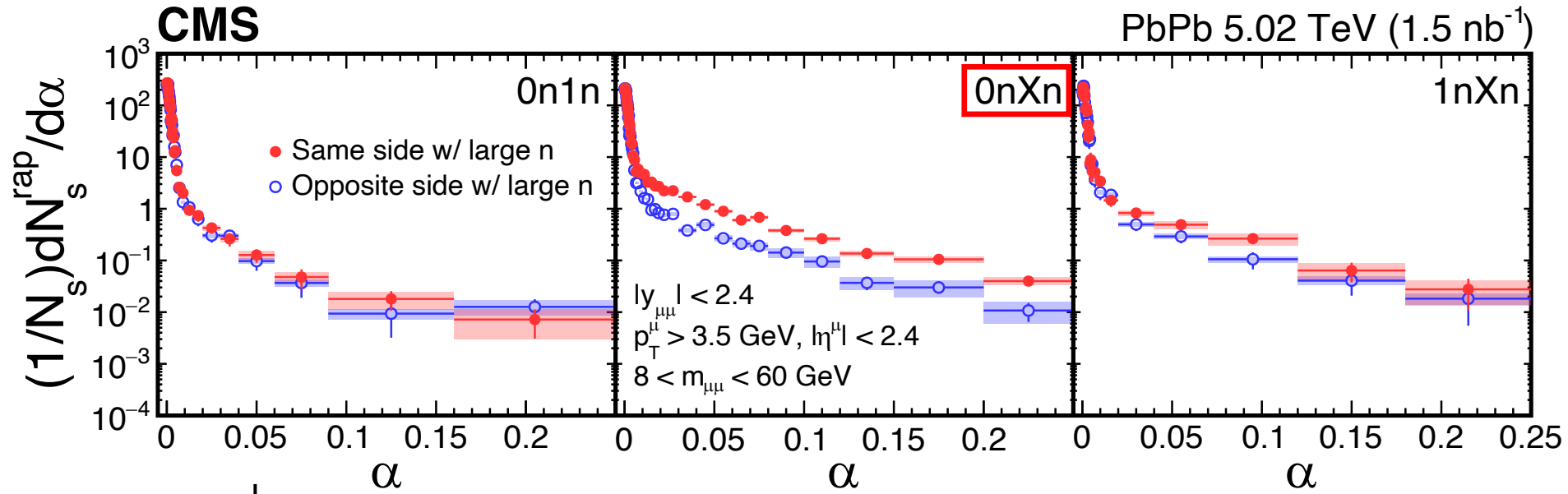
- Strong (5.7σ) neutron multiplicity dependence of $\langle \alpha^{\text{core}} \rangle$
 - b dependence of initial photon p_T

$\langle \alpha^{\text{core}} \rangle$ vs. neutron multiplicity



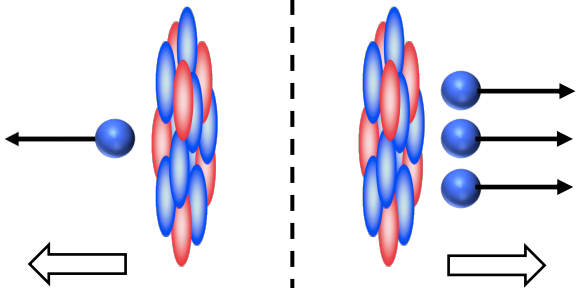
- Strong (5.7σ) neutron multiplicity dependence of $\langle \alpha^{\text{core}} \rangle$
 - b dependence of initial photon p_T
 - Qualitatively described by a leading order QED model

Rapidity dependence of α spectrum



Opposite

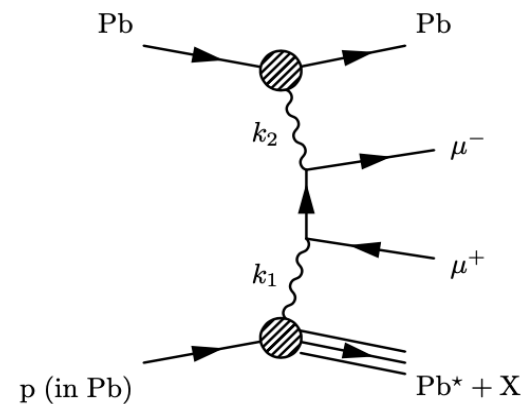
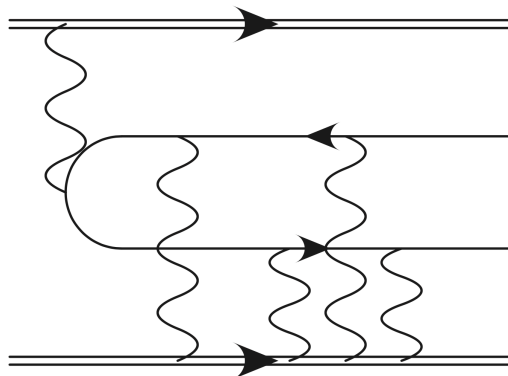
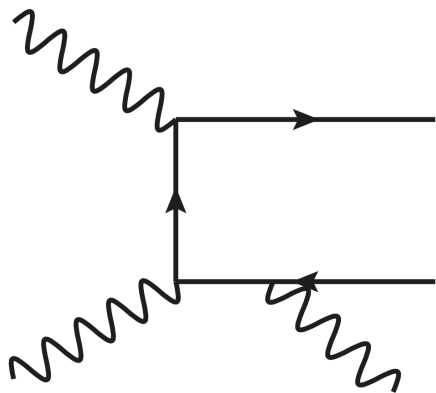
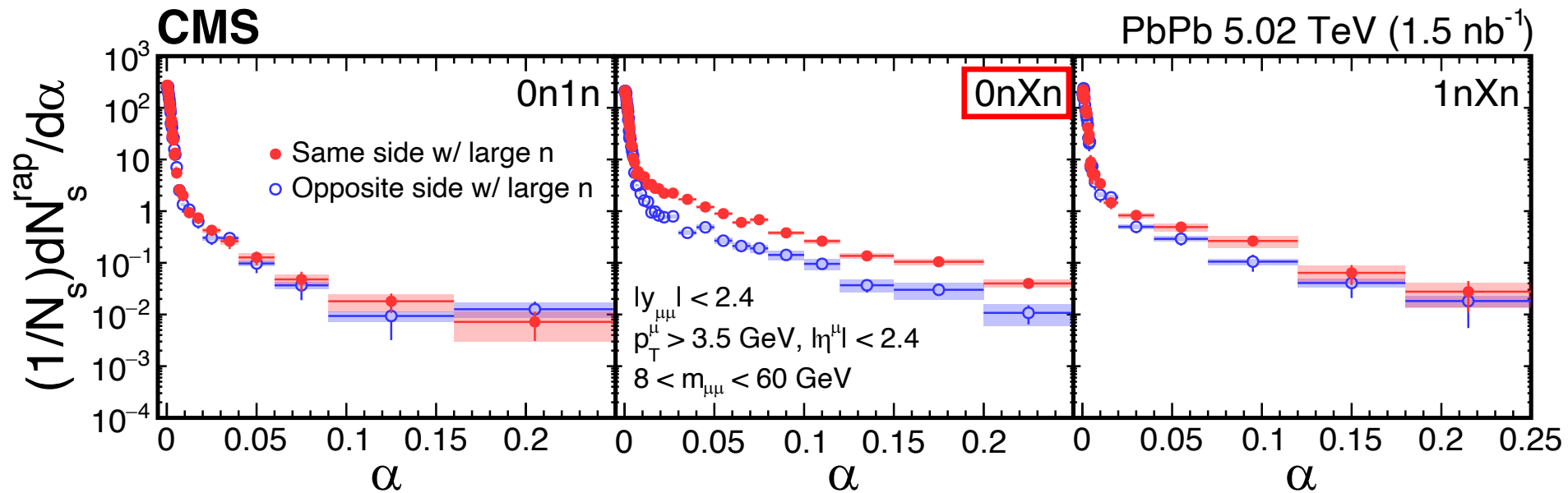
Same



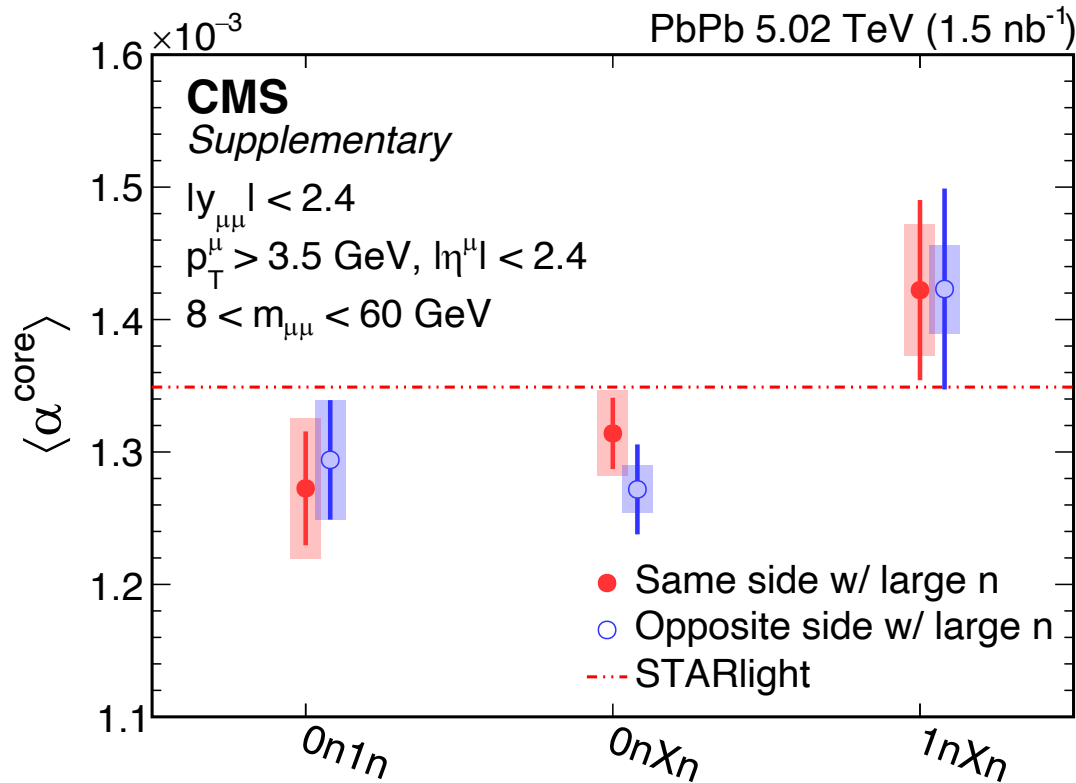
➤ In 0nXn, the tail contribution

- Same y hemisphere > Opposite y hemisphere

Rapidity dependence of α spectrum



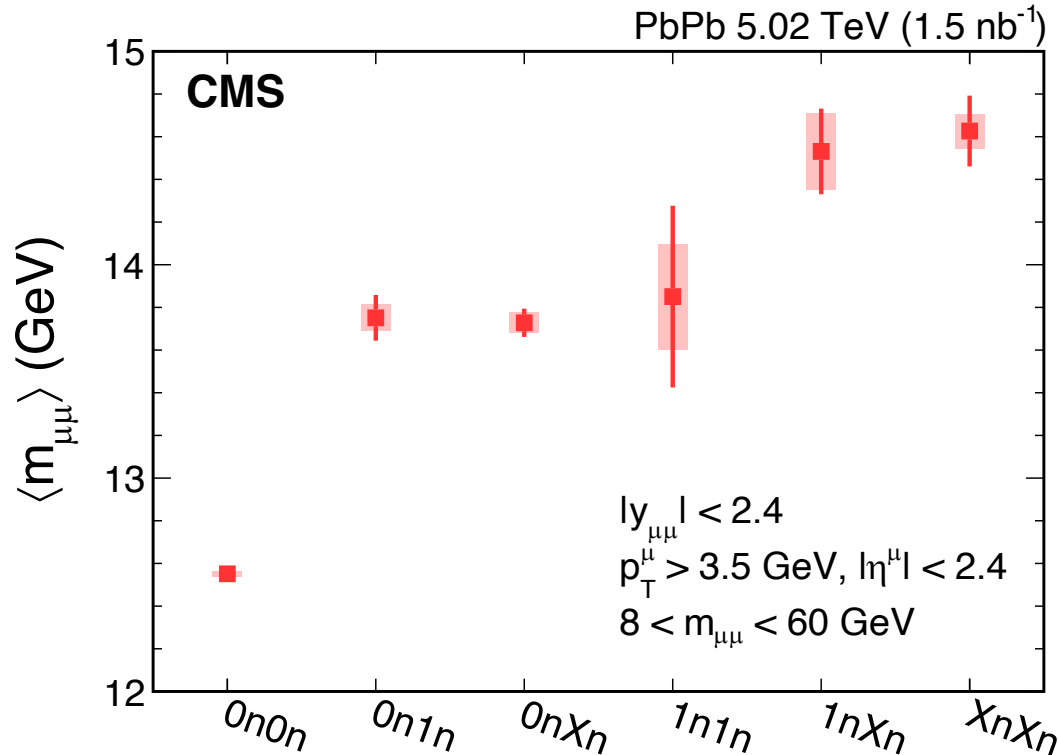
Rapidity dependence of $\langle \alpha^{\text{core}} \rangle$



➤ $\langle \alpha^{\text{core}} \rangle$ has no rapidity dependence

- Core dominantly comes from LO $\gamma\gamma$ scattering

$\langle m_{\mu\mu} \rangle$ vs. neutron multiplicity

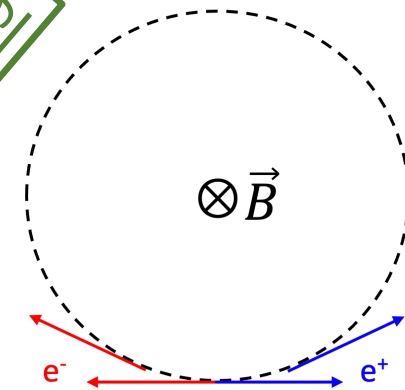
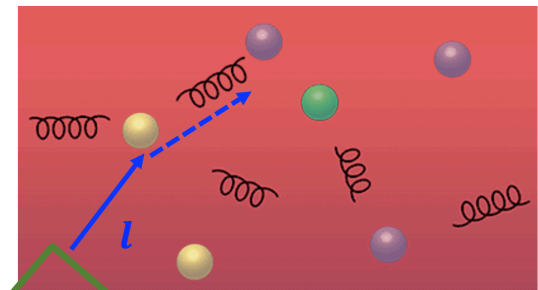
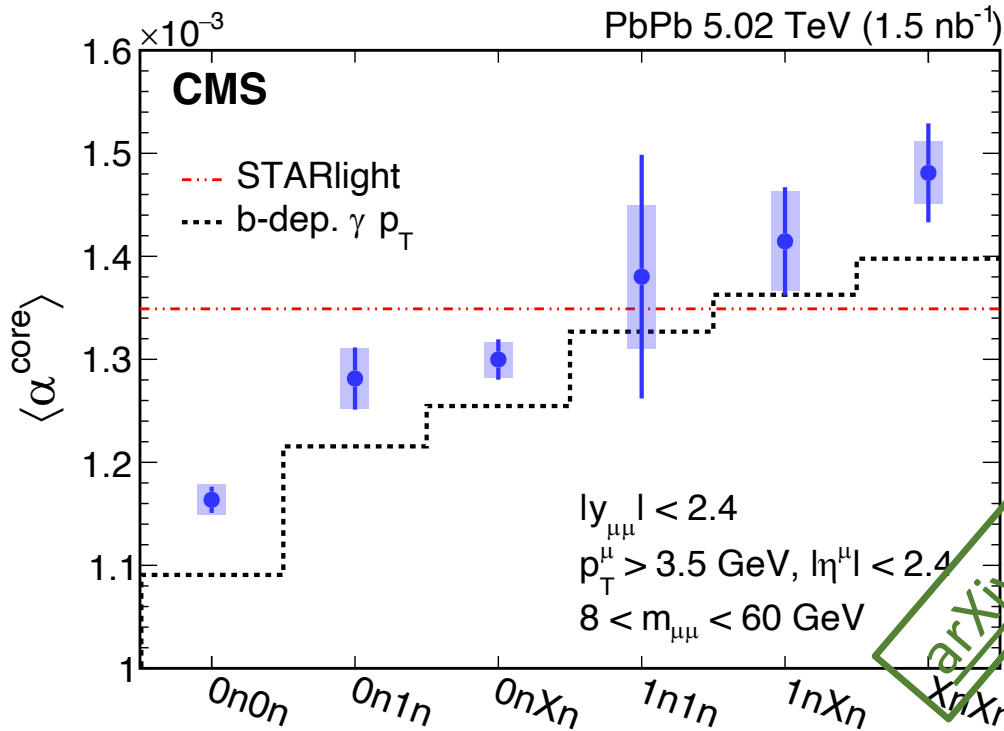


- Strong neutron multiplicity dependence of $\langle m_{\mu\mu} \rangle$
 - Deviation from constant: $\gg 5\sigma$
 - **b** dependence of initial photon energy

Summary



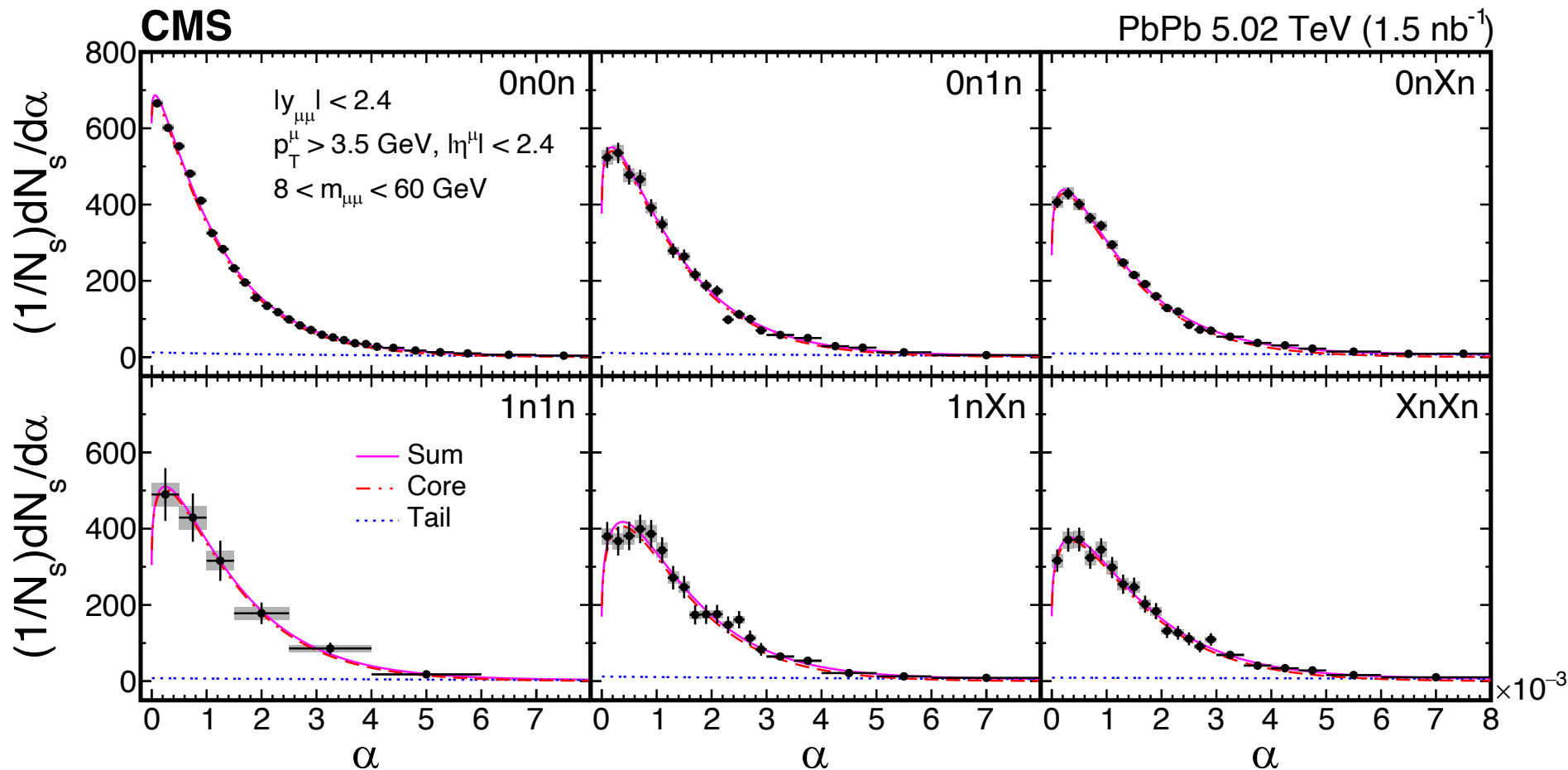
- Observed strong b dependence of $\langle \alpha^{\text{core}} \rangle$ for the first time
 - b dependence of photon p_T
 - Constrain initial photon induced models
 - Controllable baseline for searching final-state EM effects



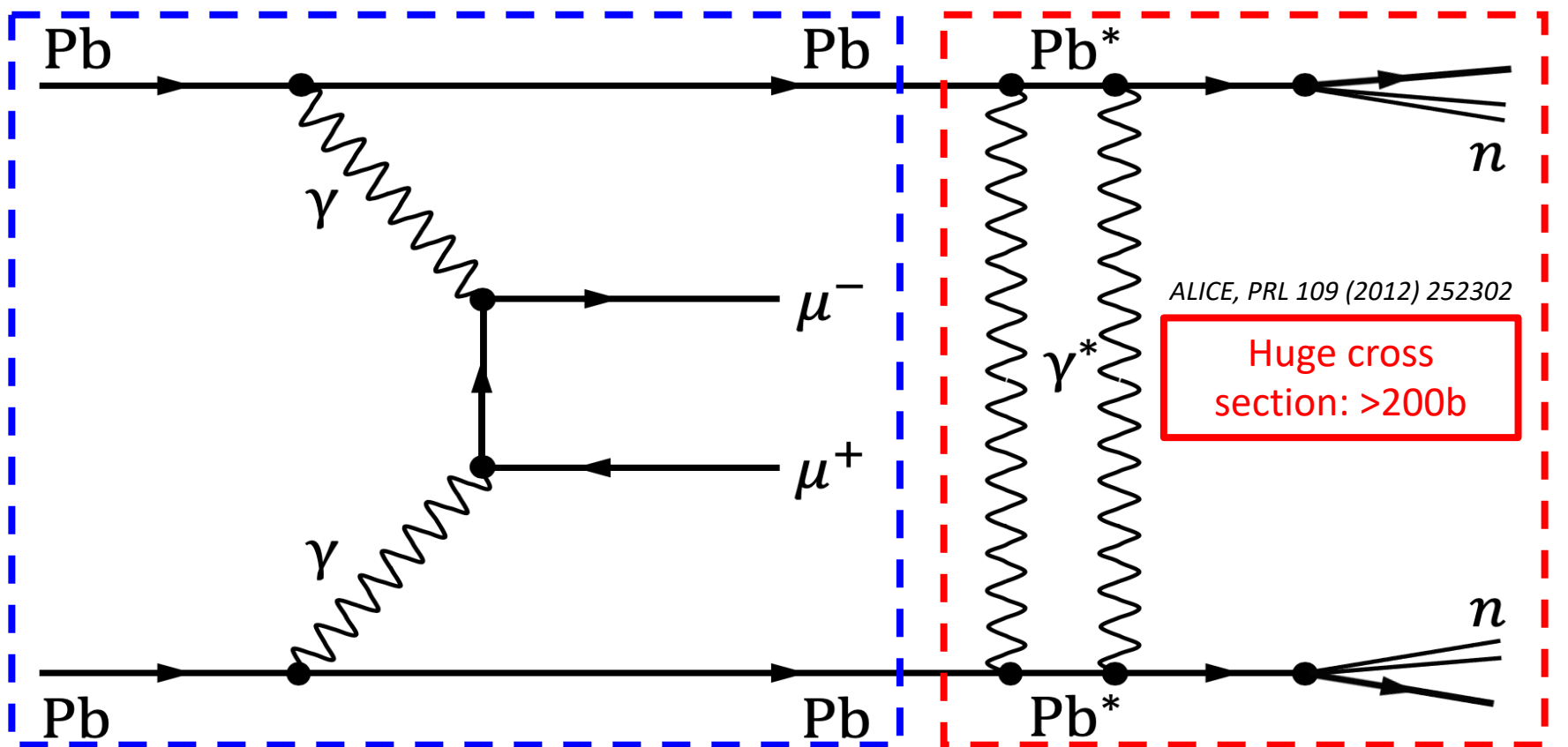


Backup

Zoom in of α spectrum



Dissociative pileup



ALICE, PRL 109 (2012) 252302

Huge cross section: $>200b$

$\gamma\gamma \rightarrow \mu^+\mu^-$ with / without neutron emitting

EM dissociation without any $\gamma\gamma \rightarrow \mu^+\mu^-$

different collisions

$\gamma\gamma \rightarrow \mu^+\mu^-$ with neutron multiplicity migration