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

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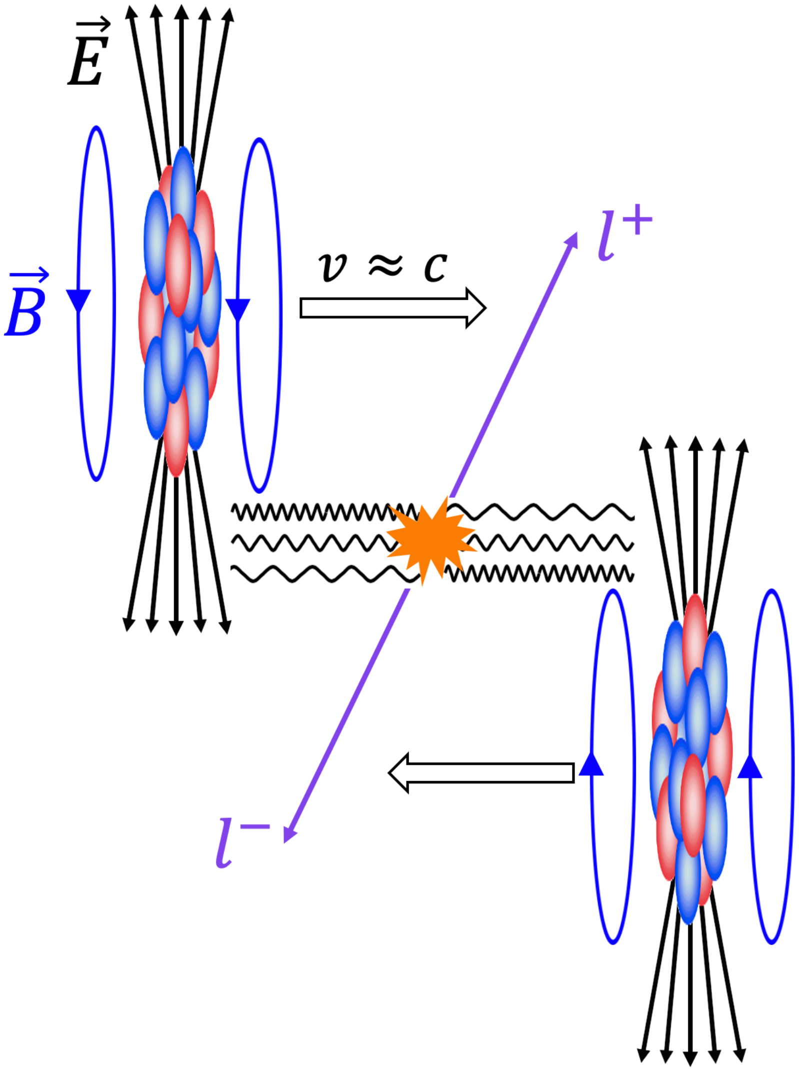
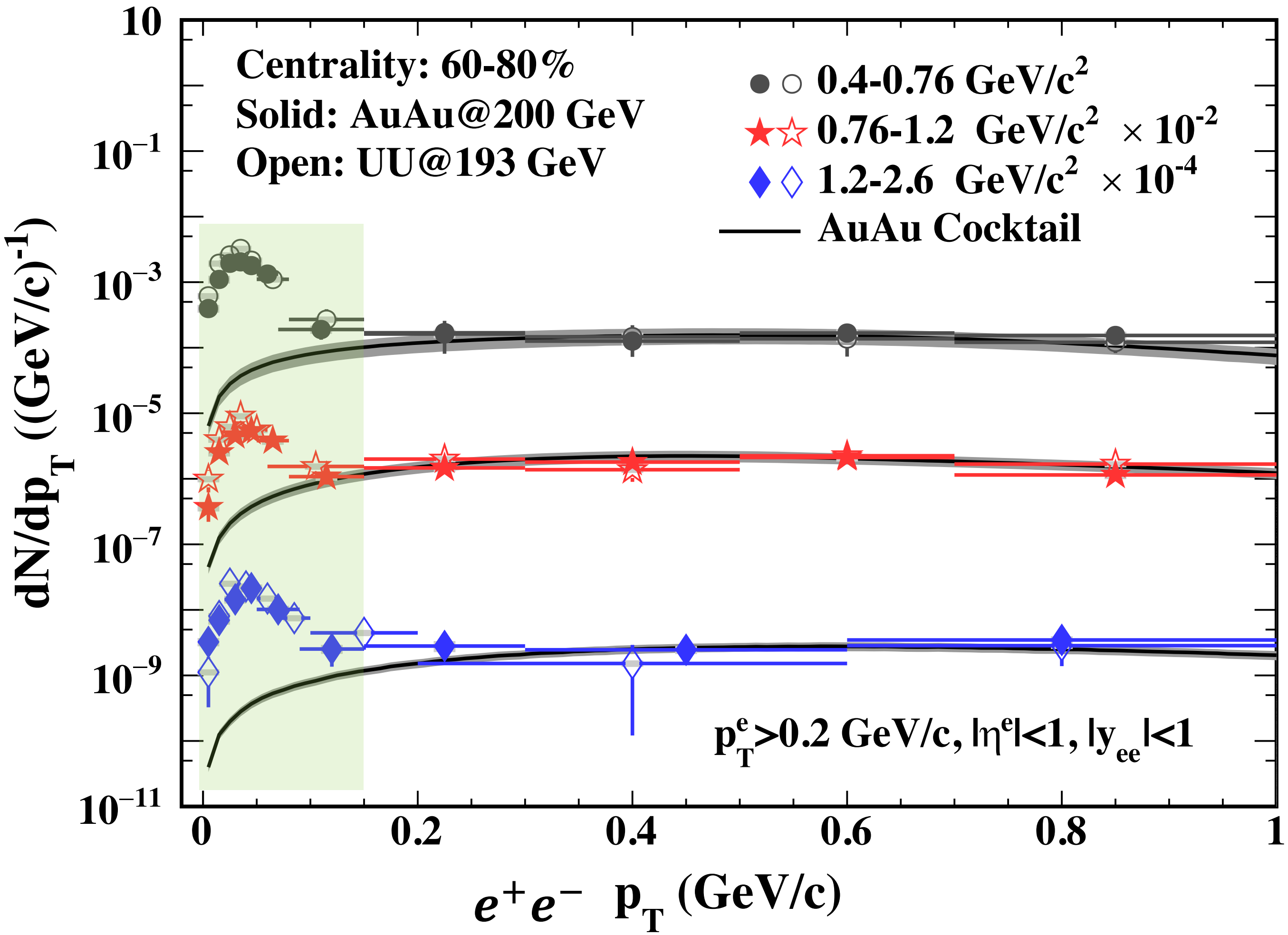
Photon-photon interactions

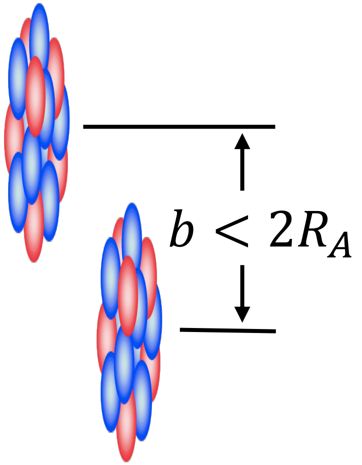


- **Photon kinematics**
  - $p_T < \frac{\hbar}{R_A}$ ($\mathcal{O}$(30) MeV @ LHC)
- **Equivalent photon approximation**
  - Photon $p_T(\boldsymbol{b})$ (X)
- **Distinctive l^+l^- feature**
  - Exclusive production
  - Concentrated at low p_T (back-to-back)

Observed in hadronic collisions

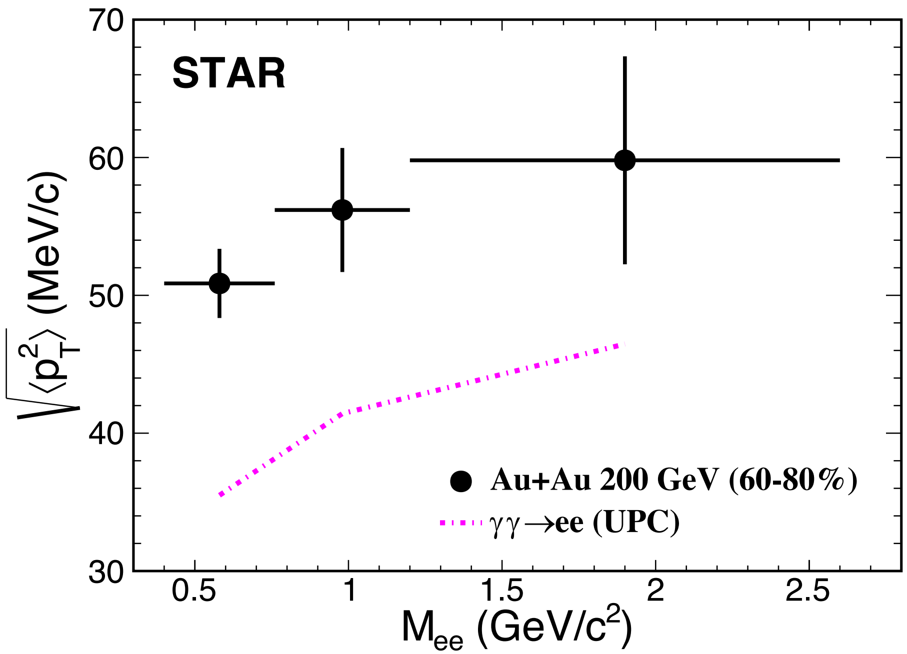
STAR, PRL 121 (2018) 132301



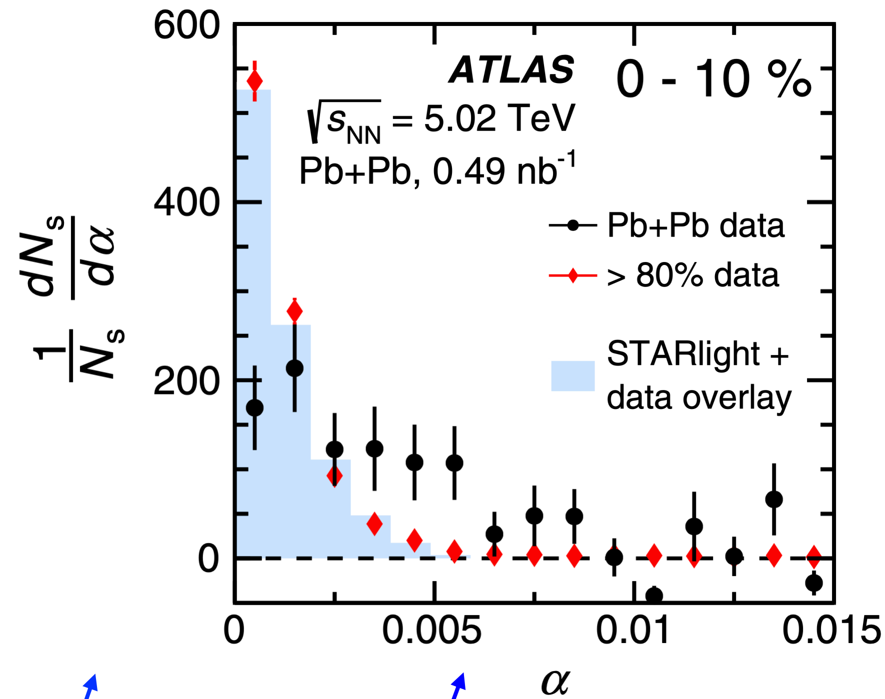


Modification of lepton pairs

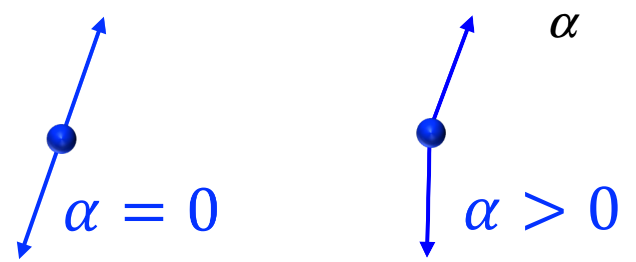
STAR, PRL 121 (2018) 132301



ATLAS, PRL 121 (2018) 212301



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

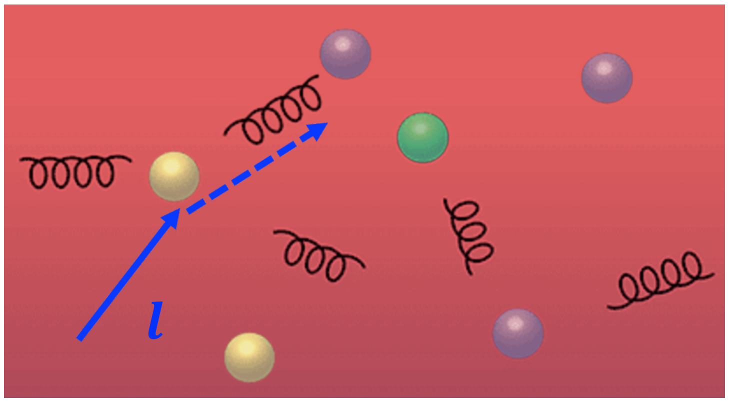


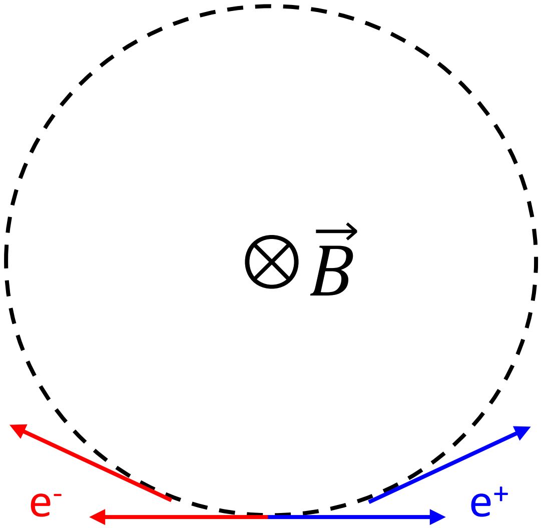
- ➢ Back-to-back correlation becomes weaker towards central collisions

Puzzle of the physics origin

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

Final-state effect?



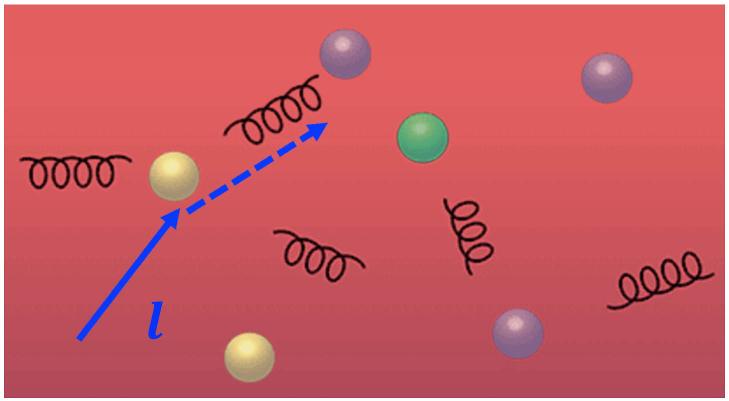


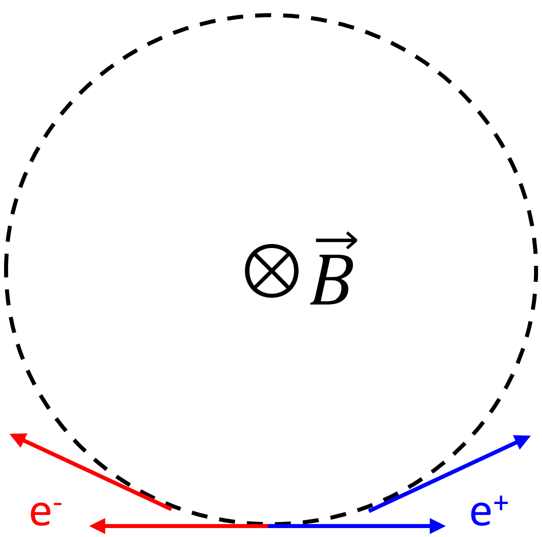
Puzzle of the physics origin

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

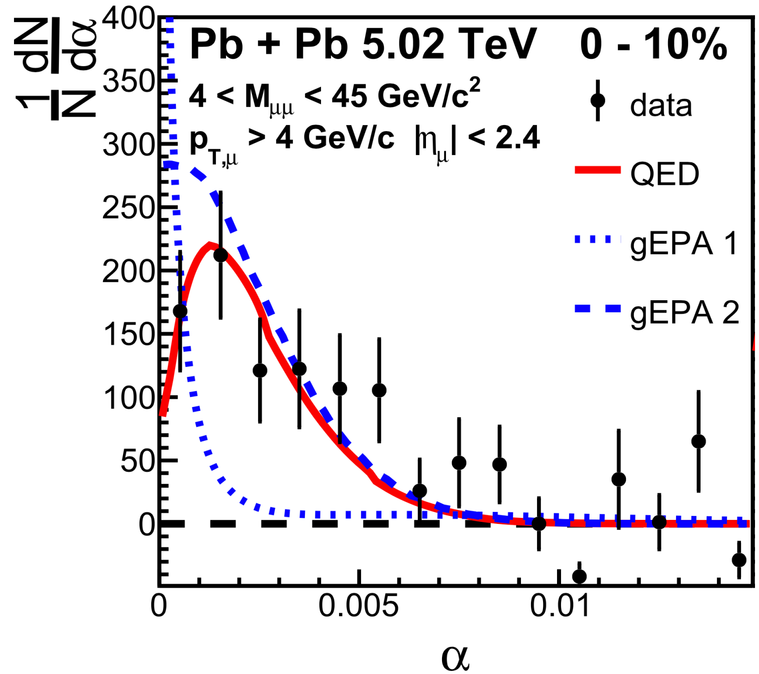
Zha et al., PLB 800 (2020) 135089

Final-state effect?



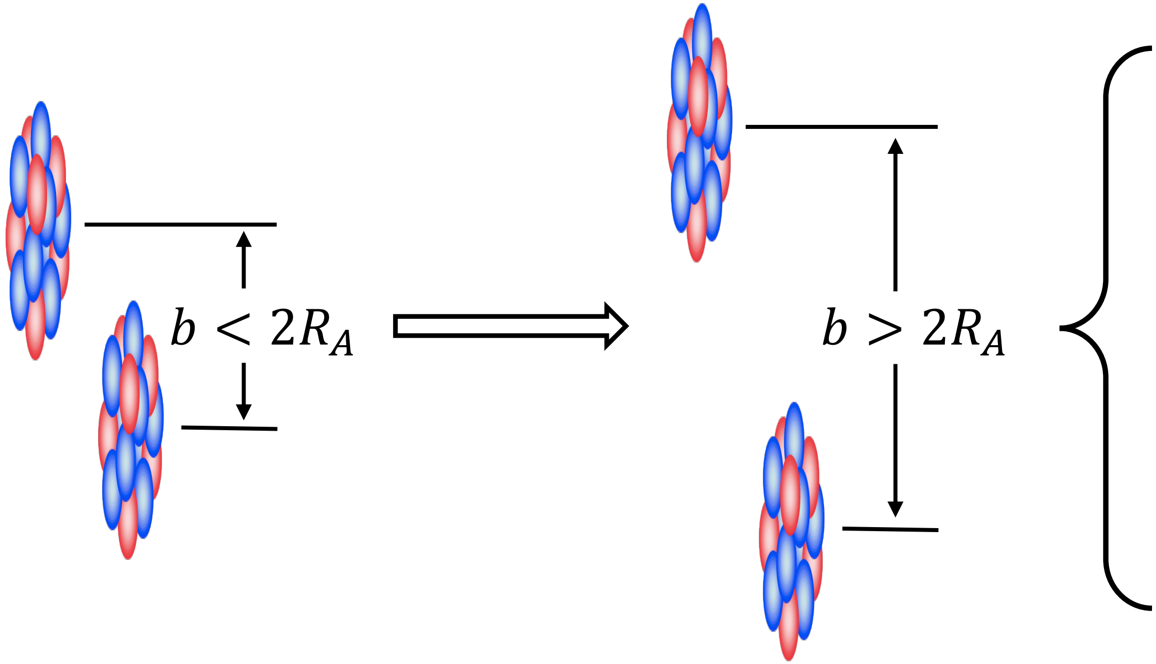


Initial-state effect?



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

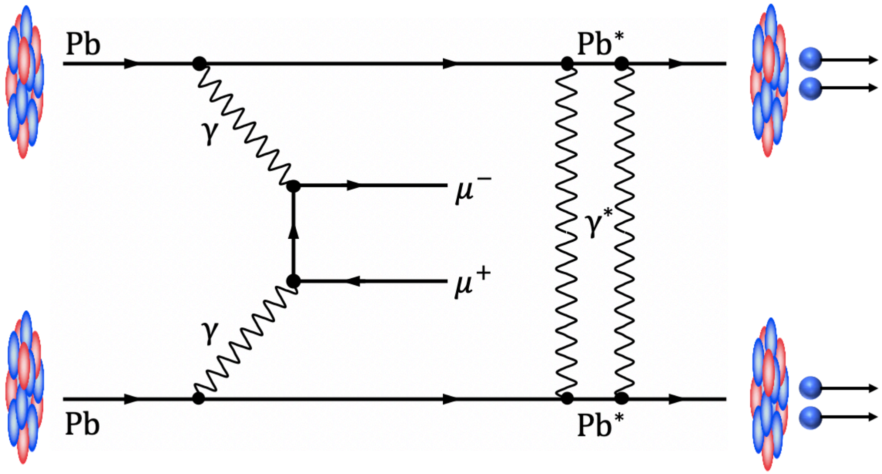
Experimentally explore the puzzle



Turn off hot medium

Control ***b***

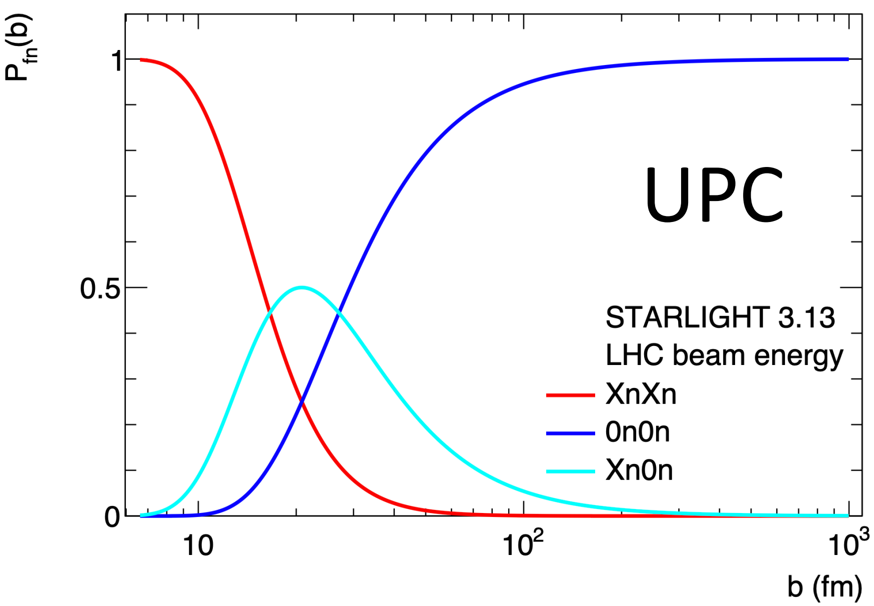
Control "centrality" in UPC



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

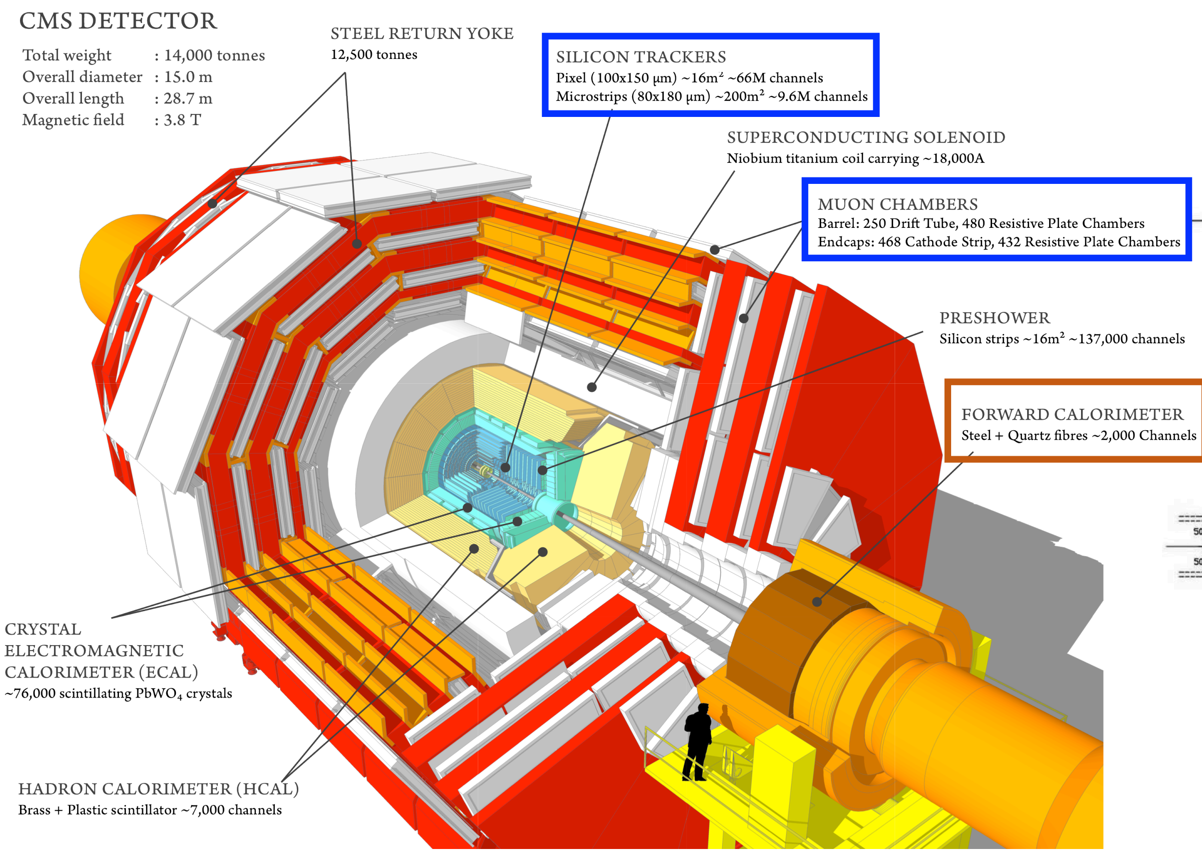
$$N(k) = \int d^2b N(k,b) P_{0\mathrm{had}}(b) P_1(b) P_2(b)$$

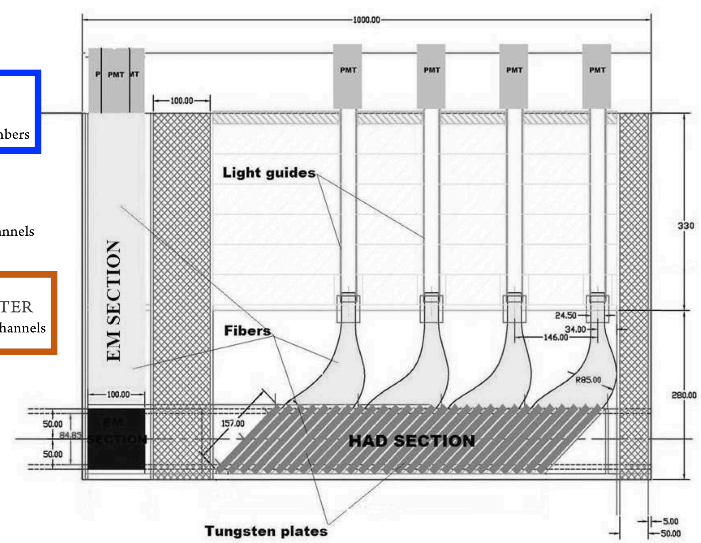
, where $P_i(b) \propto 1/b^2$



- Bearing analogy to centrality
  - $b_{XnXn} < b_{0nXn} < b_{0n0n}$

The CMS detector

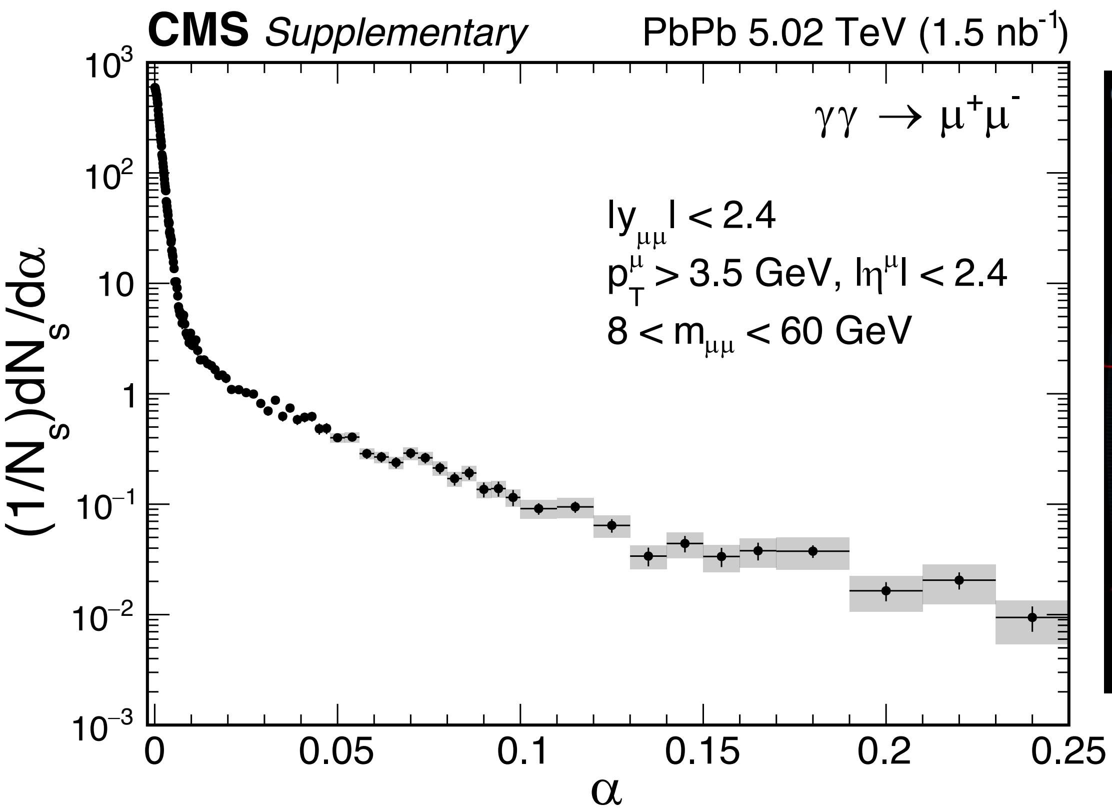


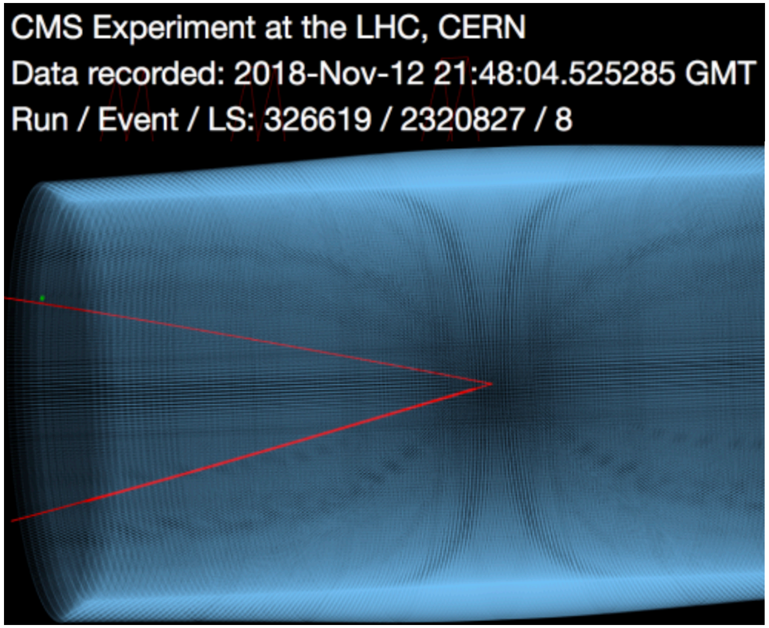


Zero Degree Calorimeter
$|\eta|>8.3$, ~140m from IP

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

α distribution in UPC

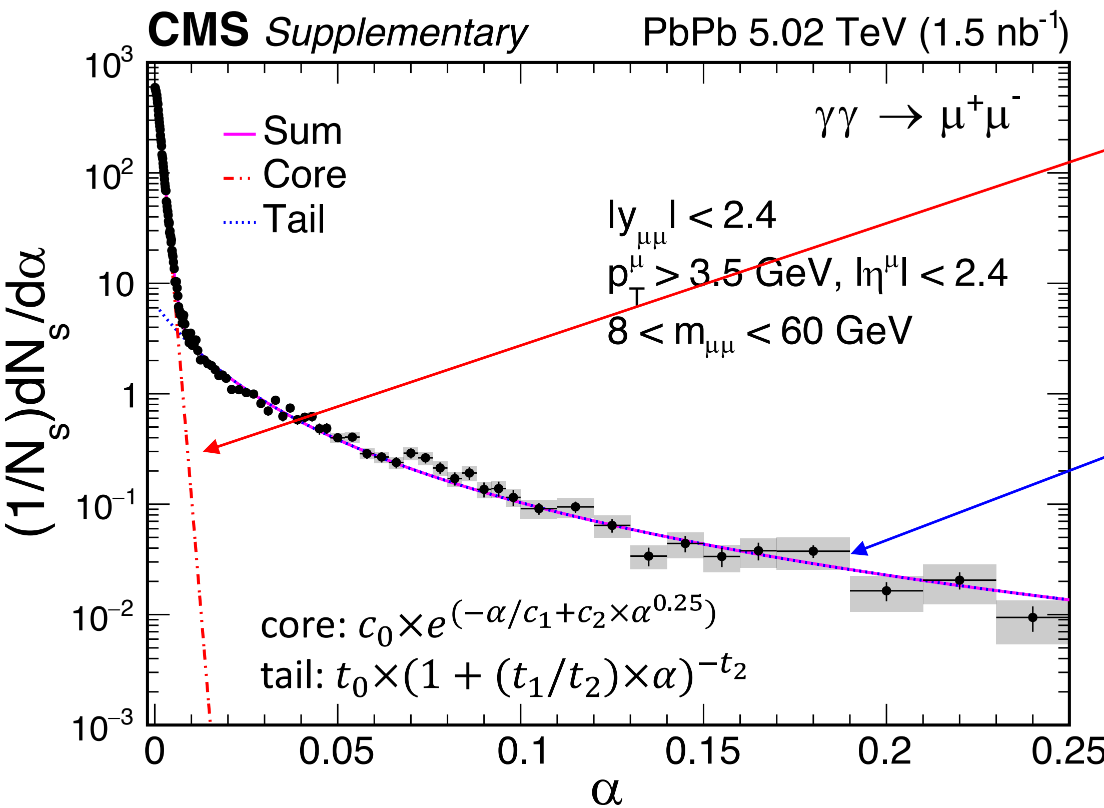


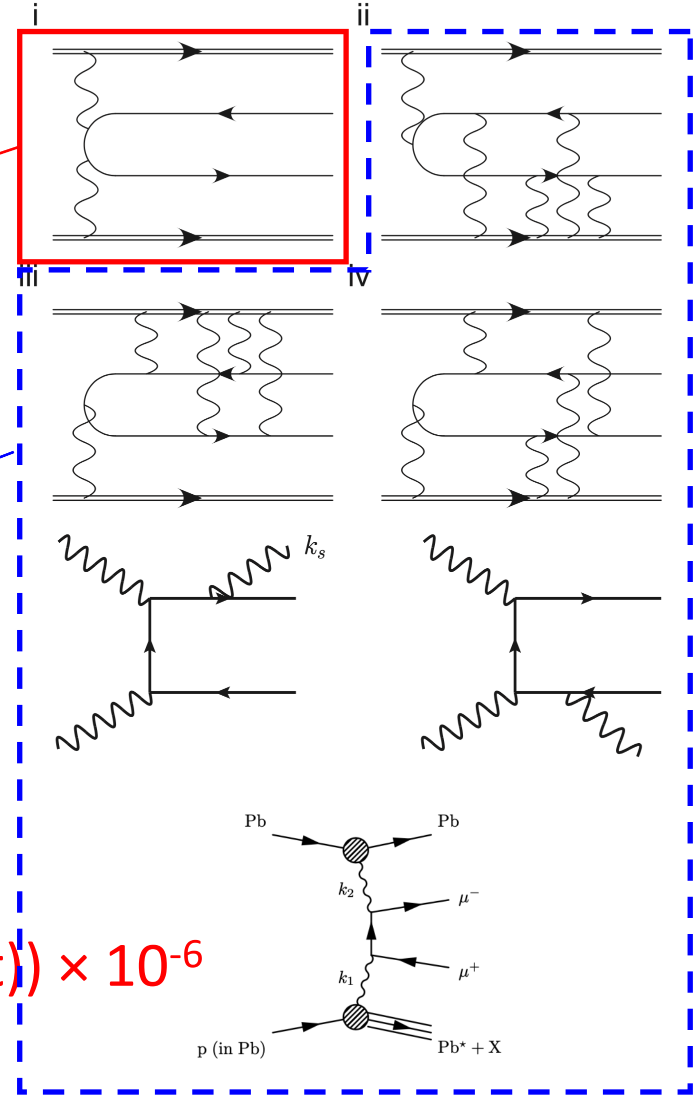


- Narrow core + Long tail

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

α distribution in UPC

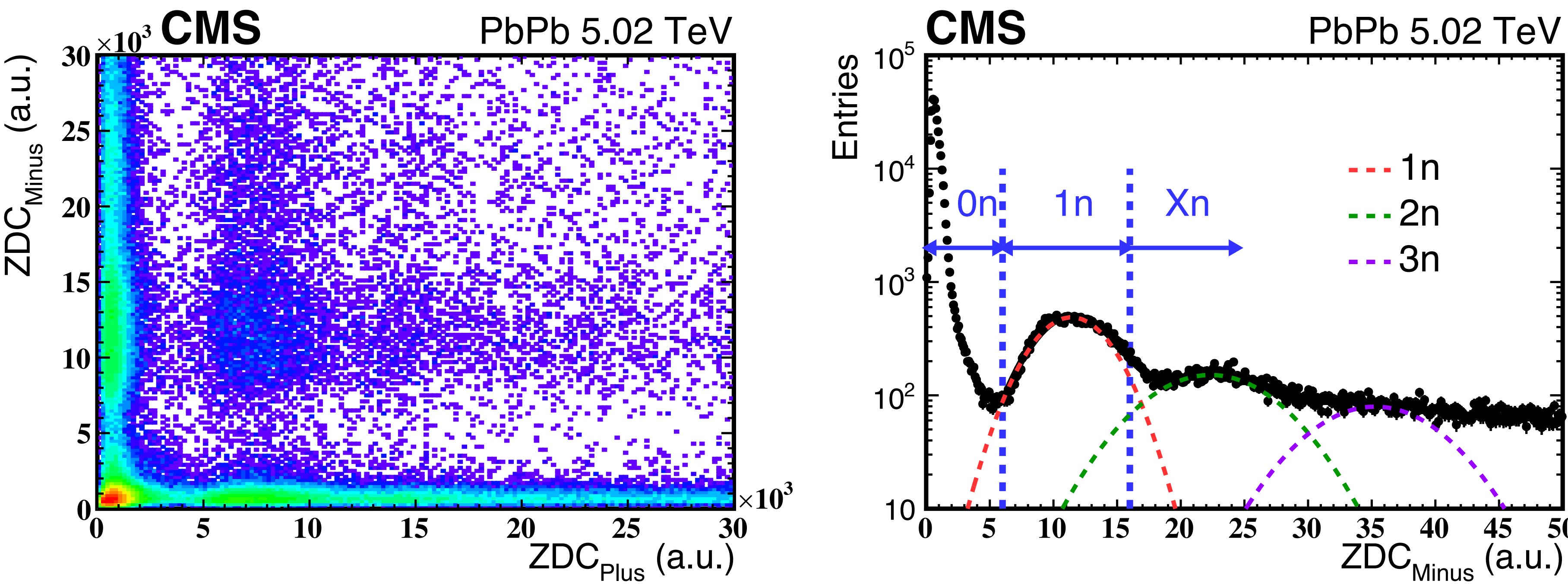




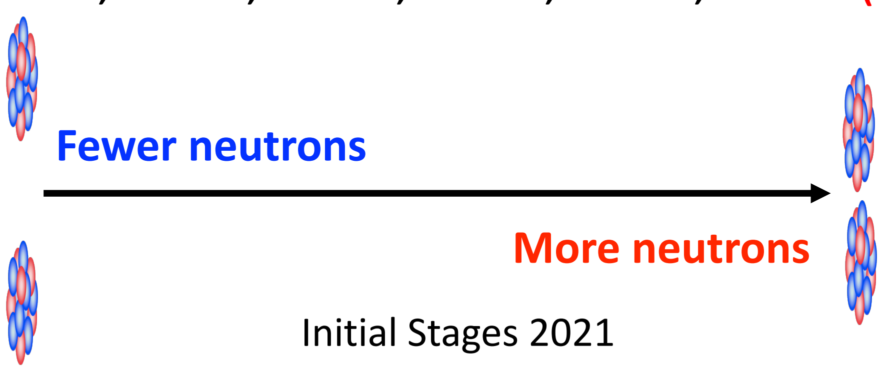
➢ Decouple α spectrum:

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

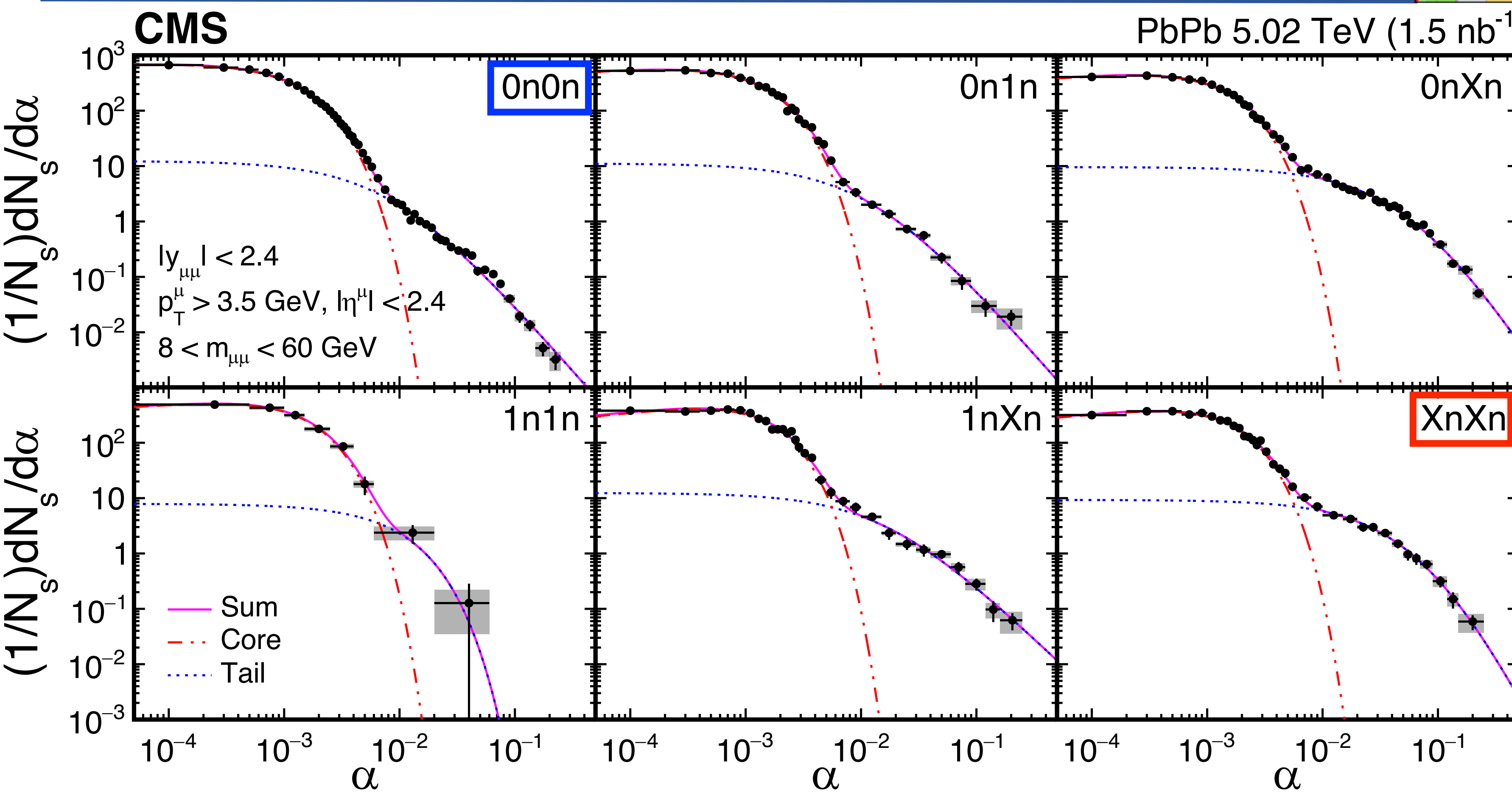
Determine neutron multiplicity



- Straight cut to disentangle neutrons
  - 0n0n, 0n1n, 0nXn, 1n1n, 1nXn, XnXn (X≥2)

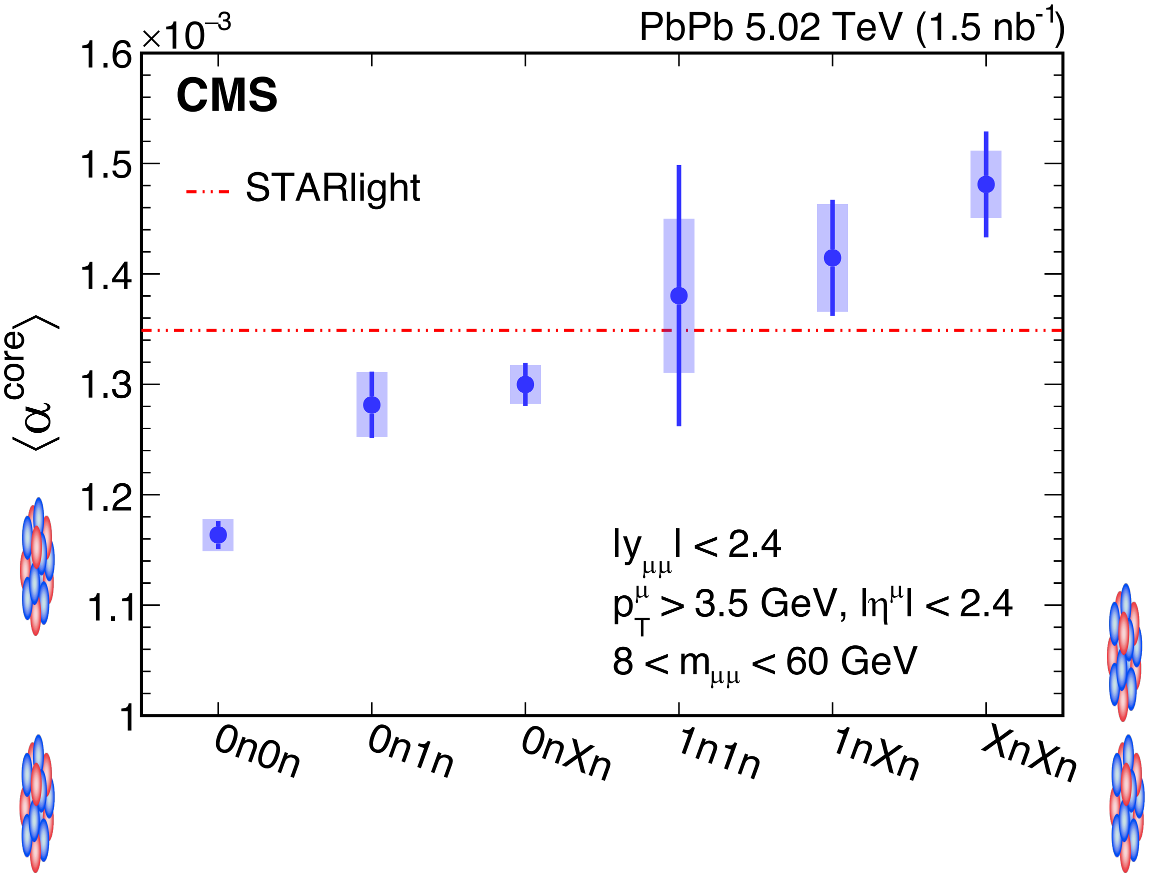


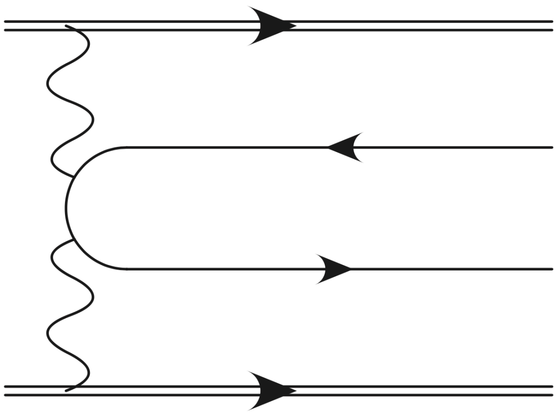
α spectrum vs. neutron multiplicity



- 0n0n (fewer neutrons) $\Longrightarrow$ XnXn (more neutrons)
  - Tail contribution becomes larger
  - Seems has depletion in the very small α

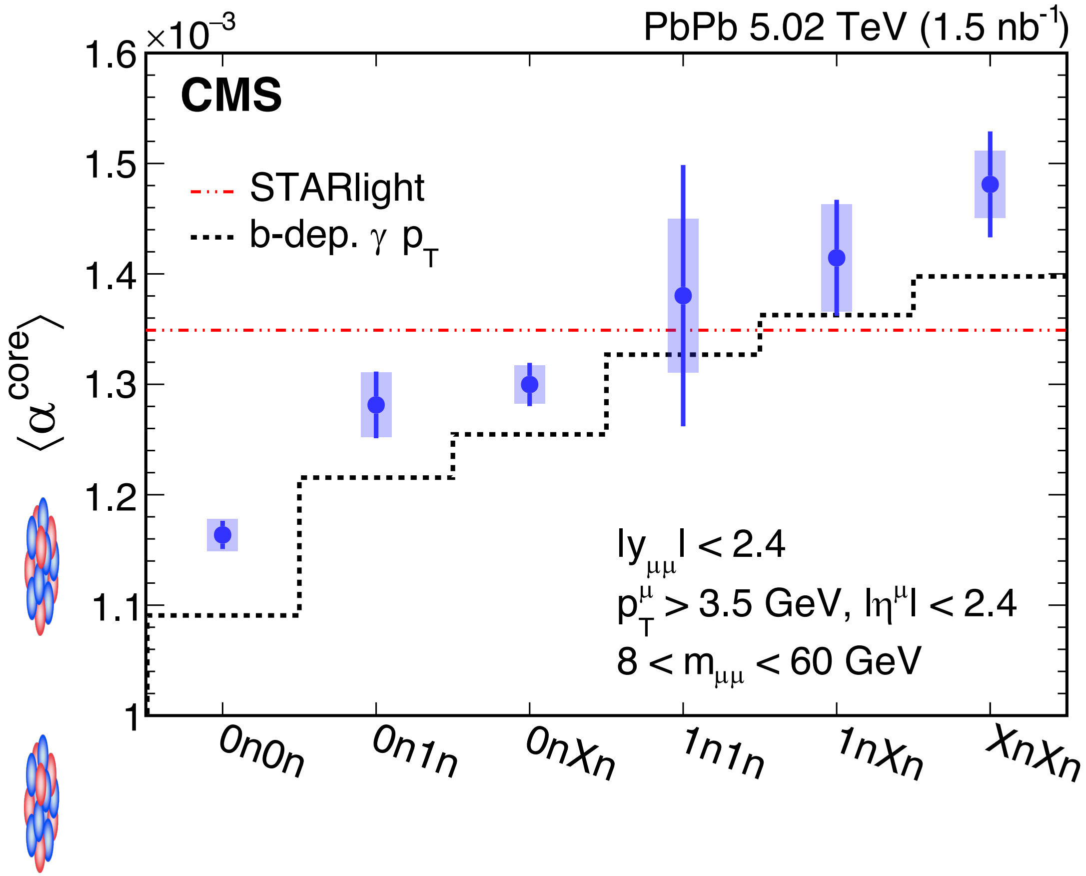
$\langle \alpha^{core} \rangle$ vs. neutron multiplicity

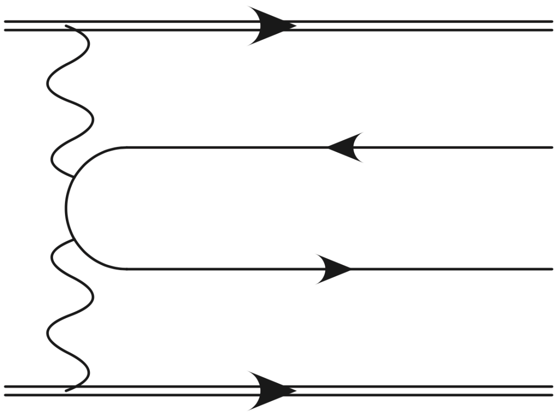




- ➢ Strong (5.7 σ) neutron multiplicity dependence of $\langle \alpha^{core} \rangle$
  - ***b*** dependence of initial photon p_T

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

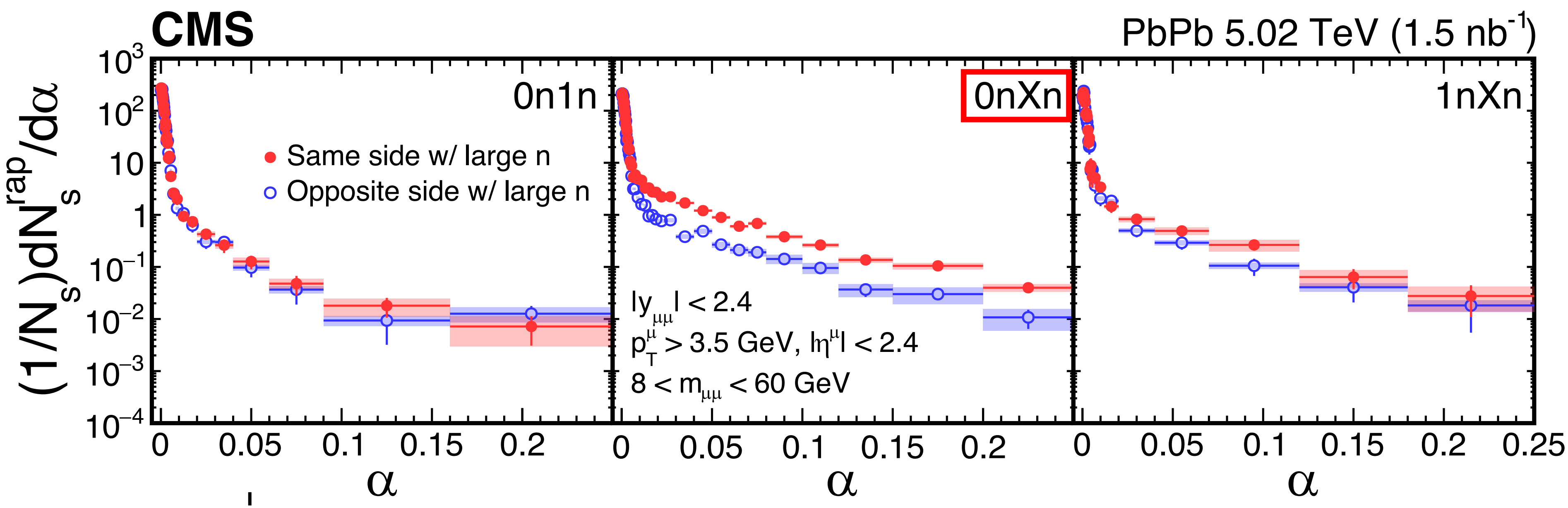


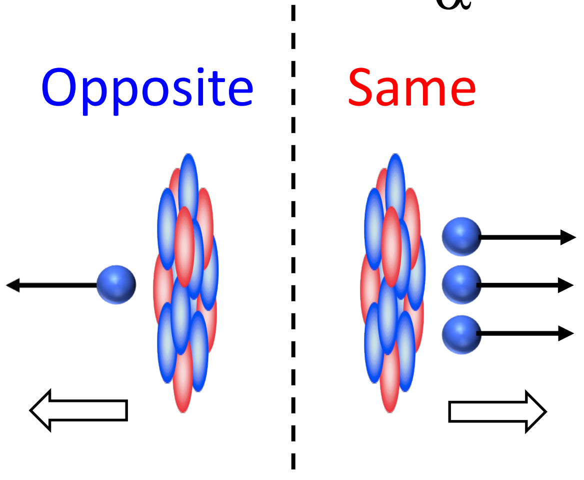


- ➢ Strong (5.7 σ) neutron multiplicity dependence of $\langle \alpha^{core} \rangle$
  - ***b*** **dependence of initial photon p_T**
  - Qualitatively described by a leading order QED model

Brandenburg et al., arXiv: 2006.07365

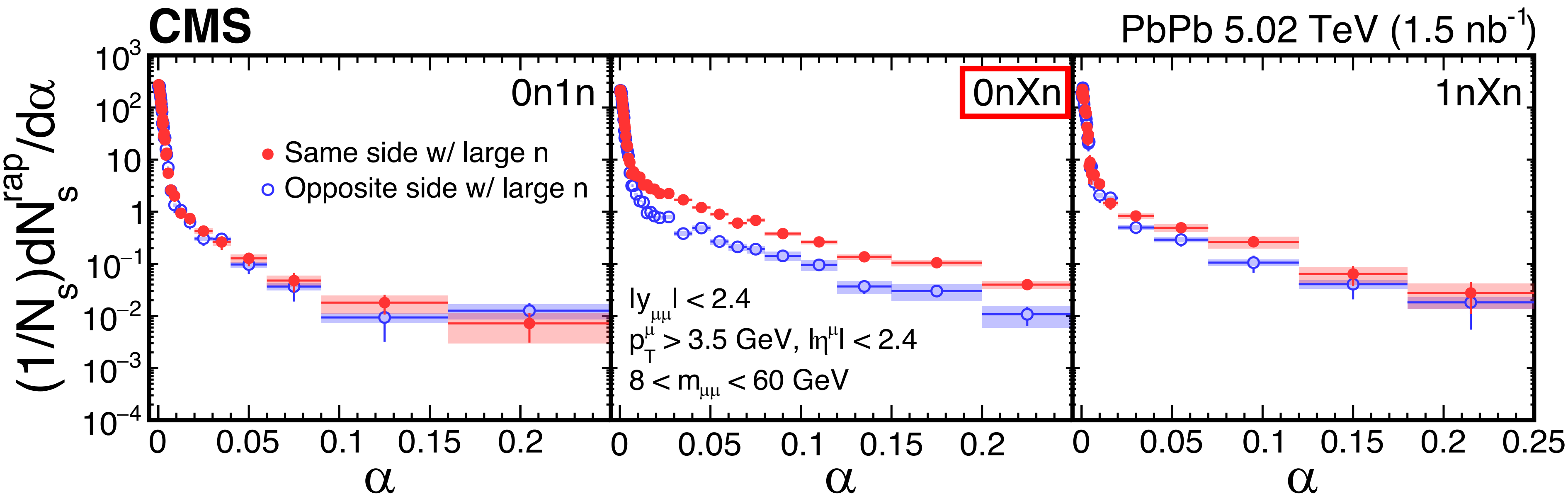
Rapidity dependence of α spectrum

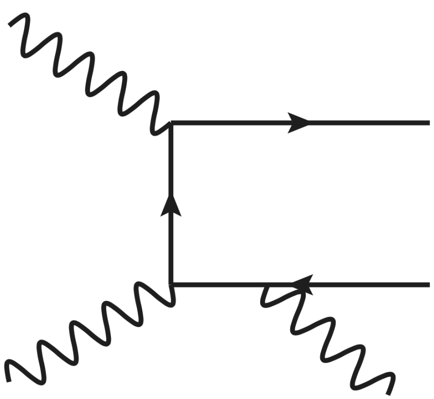


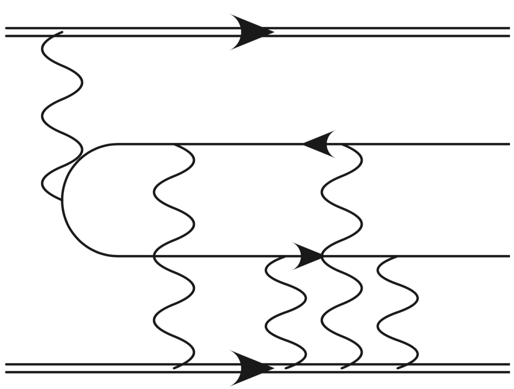


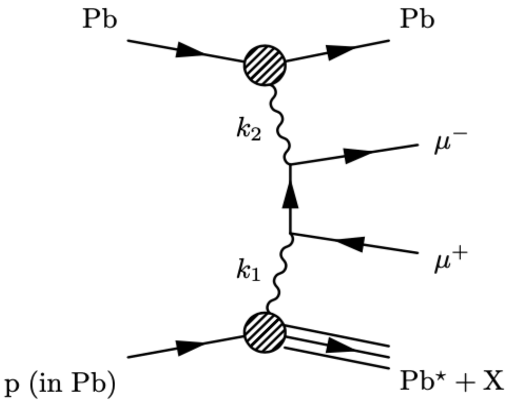
- In 0nXn, the tail contribution
  - Same y hemisphere > Opposite y hemisphere

Rapidity dependence of α spectrum



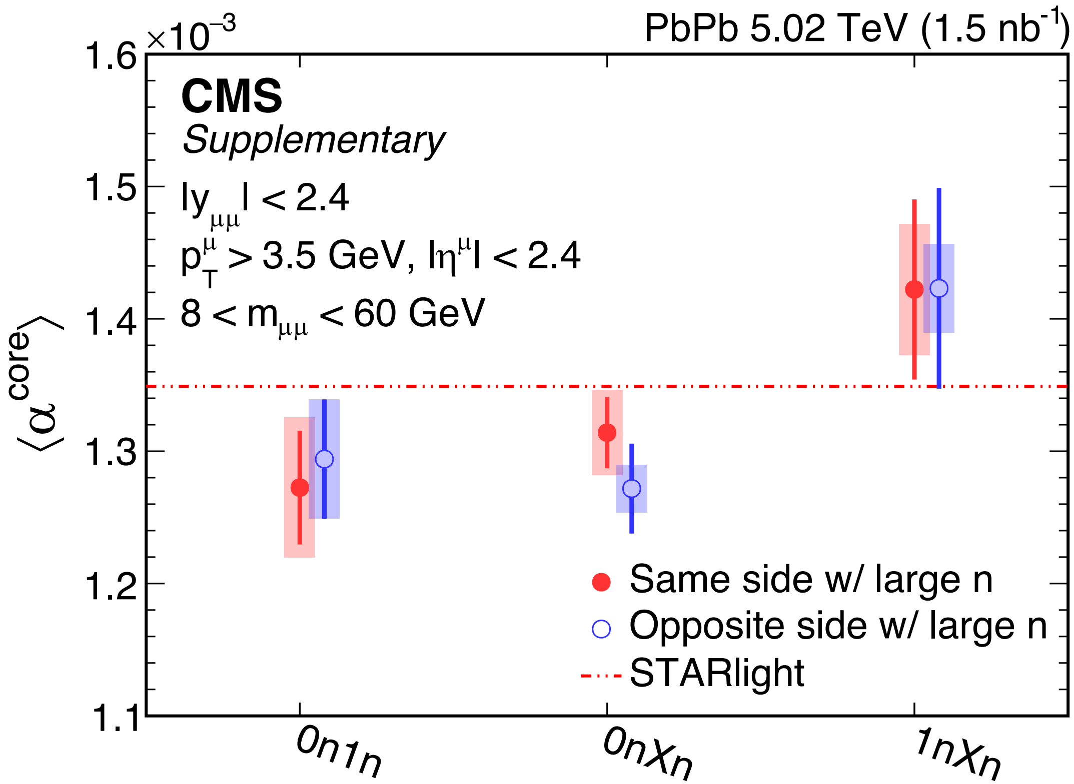






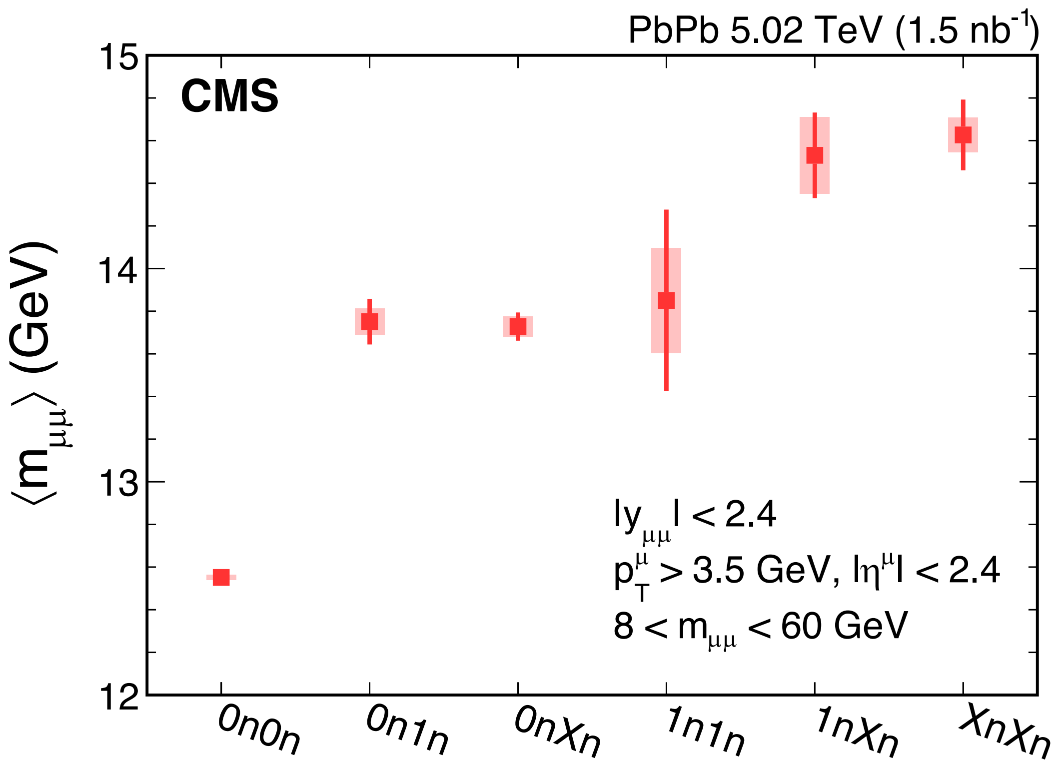
ATLAS, arXiv:2011.12211

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

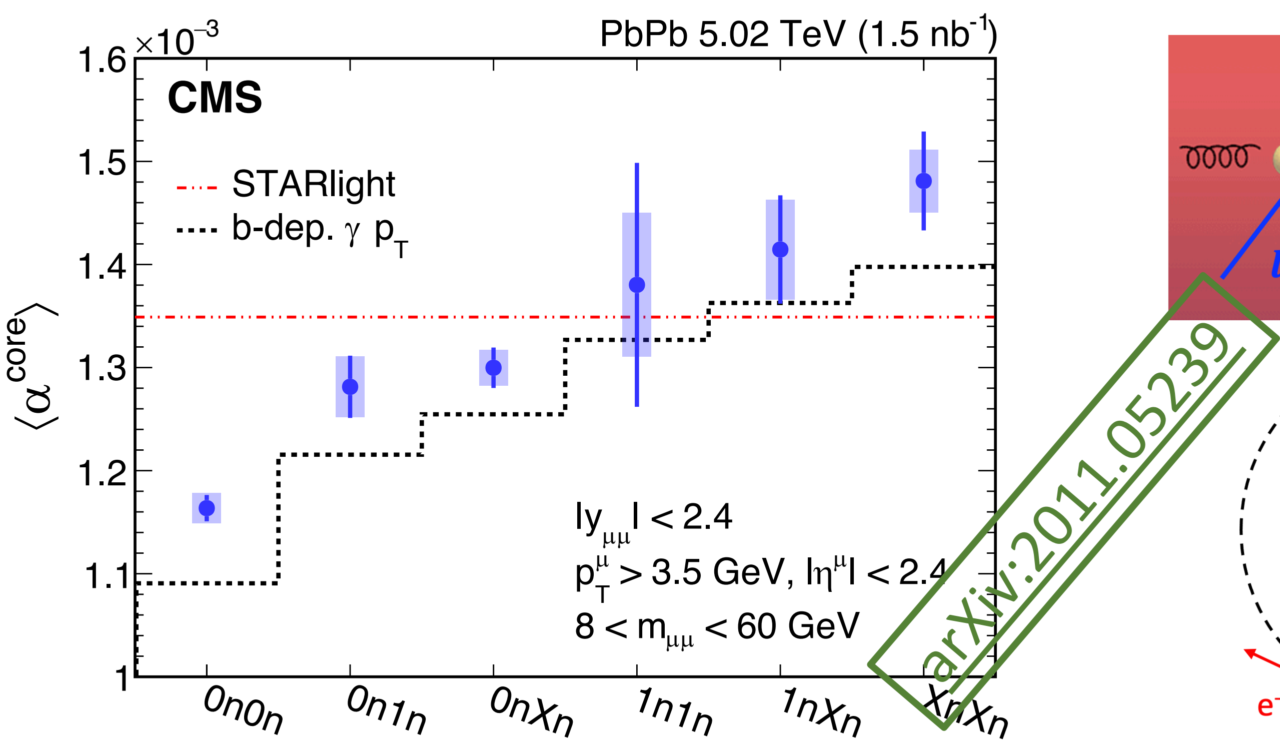
$\langle m_{\mu\mu} \rangle$ vs. neutron multiplicity

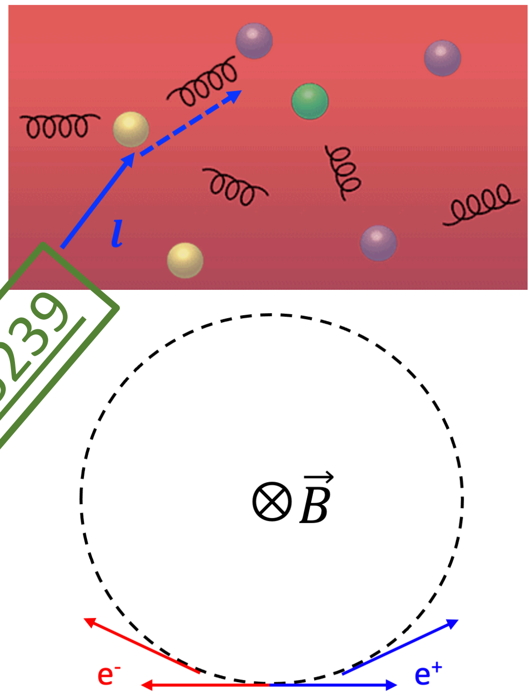


- Strong neutron multiplicity dependence of $\langle m_{\mu\mu} \rangle$
  - Deviation from constant: $\gg 5\sigma$
  - ***b*** dependence of initial photon energy

Summary

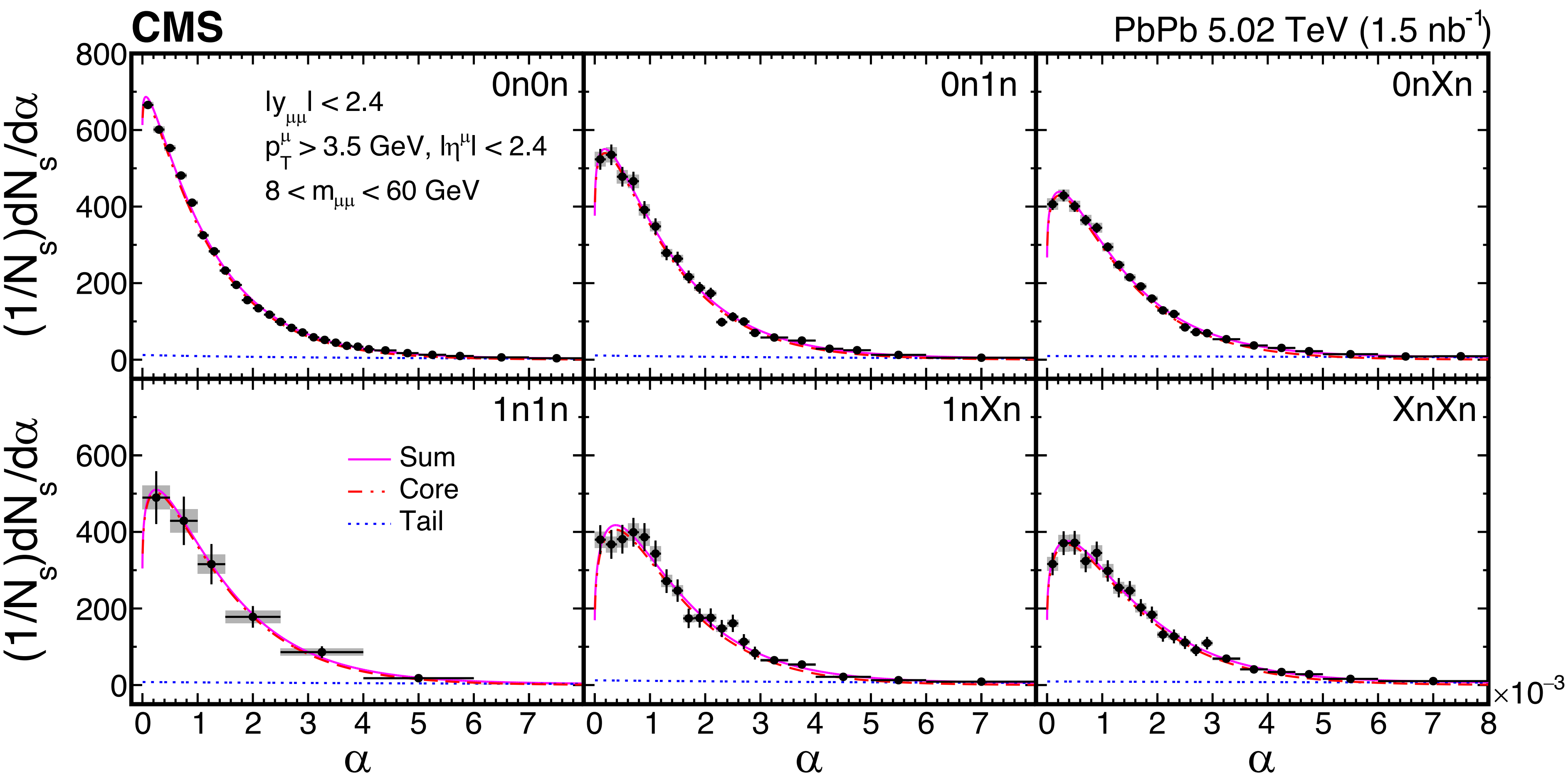
- Observed strong ***b*** dependence of $\langle \alpha^{core} \rangle$ for the first time
  - ***b*** dependence of photon p_T
  - Constrain initial photon induced models
  - Controllable baseline for searching final-state EM effects



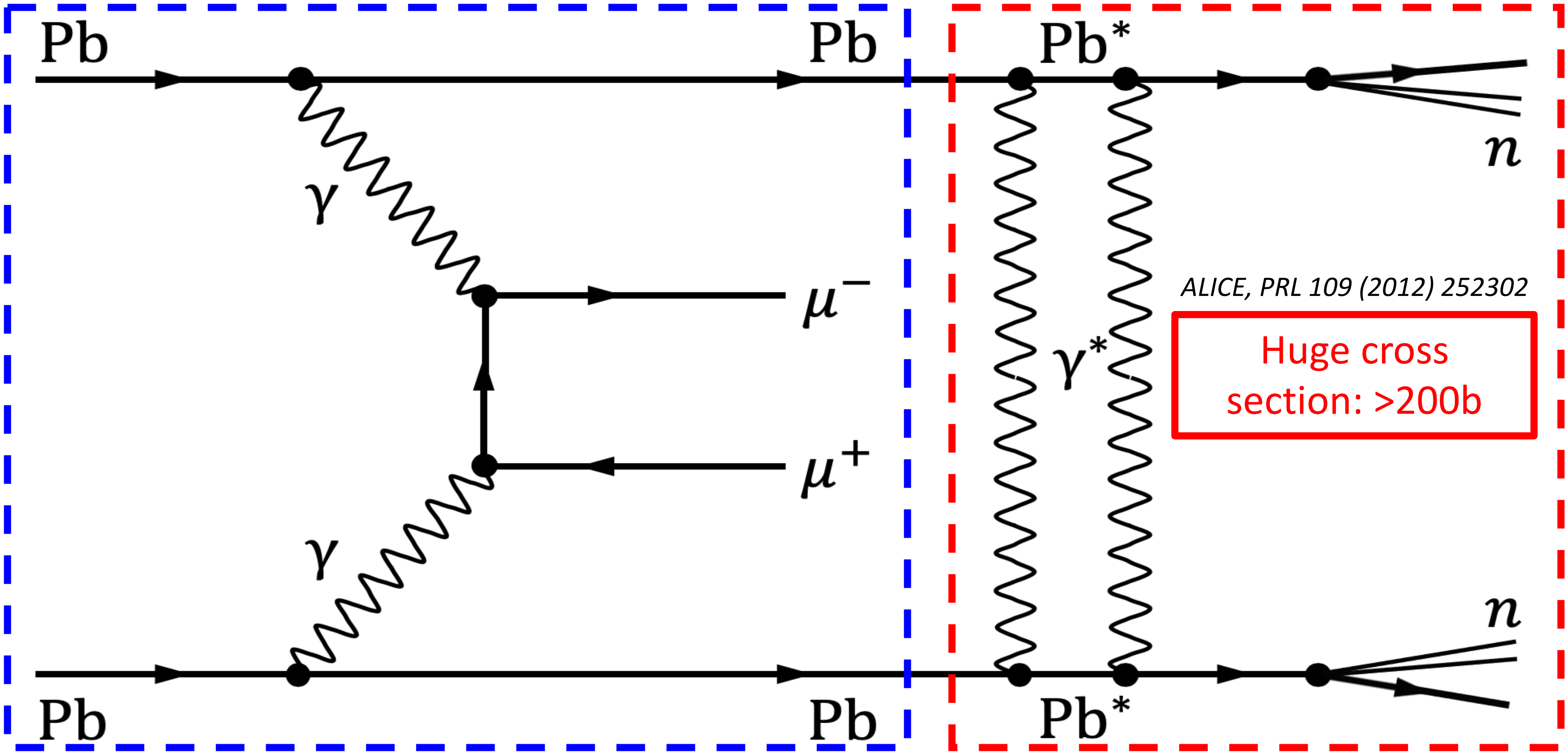


Backup

Zoom in of α spectrum



Dissociative pileup



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

different collisions

EM dissociation **without any** $\gamma\gamma\longrightarrow\mu^+\mu^-$

$\gamma\gamma\longrightarrow\mu^+\mu^-$ **with neutron multiplicity migration**