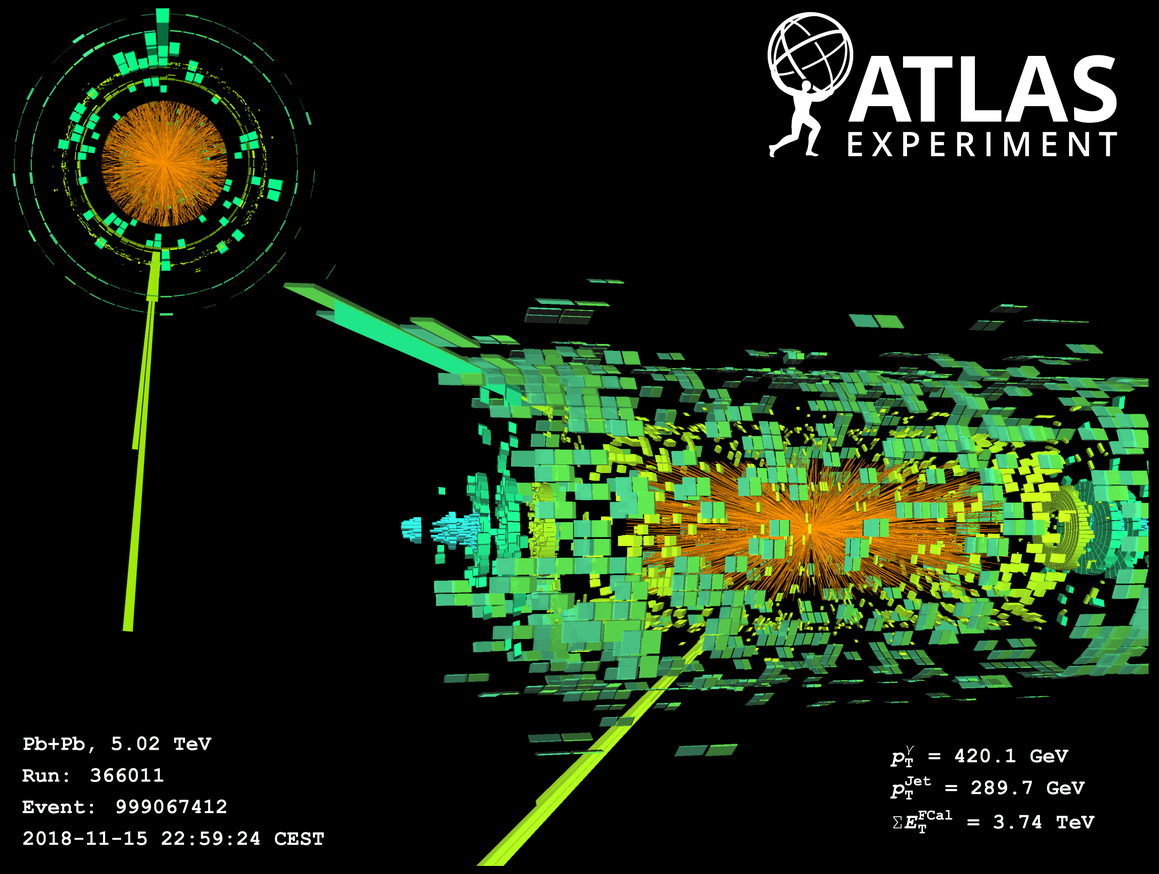
Recent ATLAS measurements in heavy-ion collisions



Lydia Beresford on behalf of the ATLAS Collaboration

Windows on the Universe

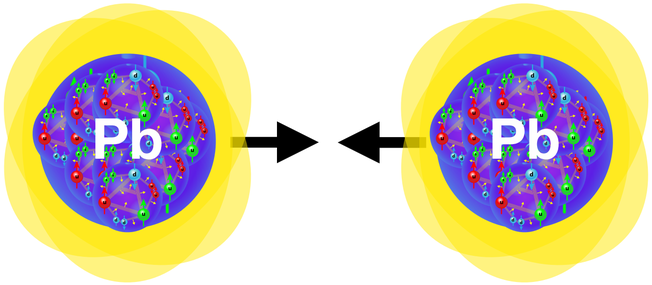
9th August 2023

Overview

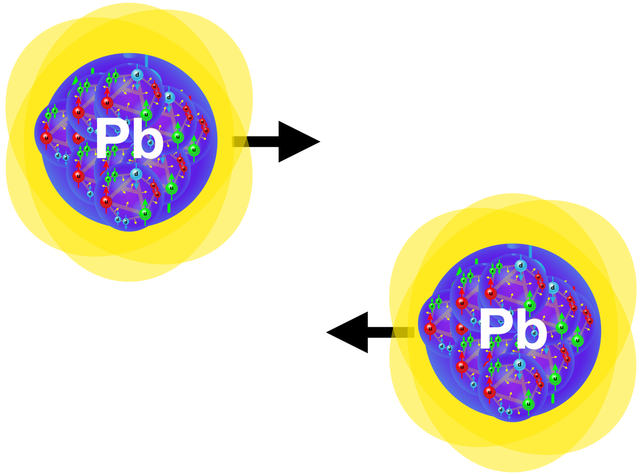
Very broad physics programme in ATLAS heavy ion group: Pb, Xe, p, photon

Today will focus mainly on recent Pb+Pb results for hard processes:

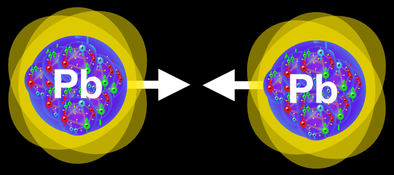
Head-on collisions



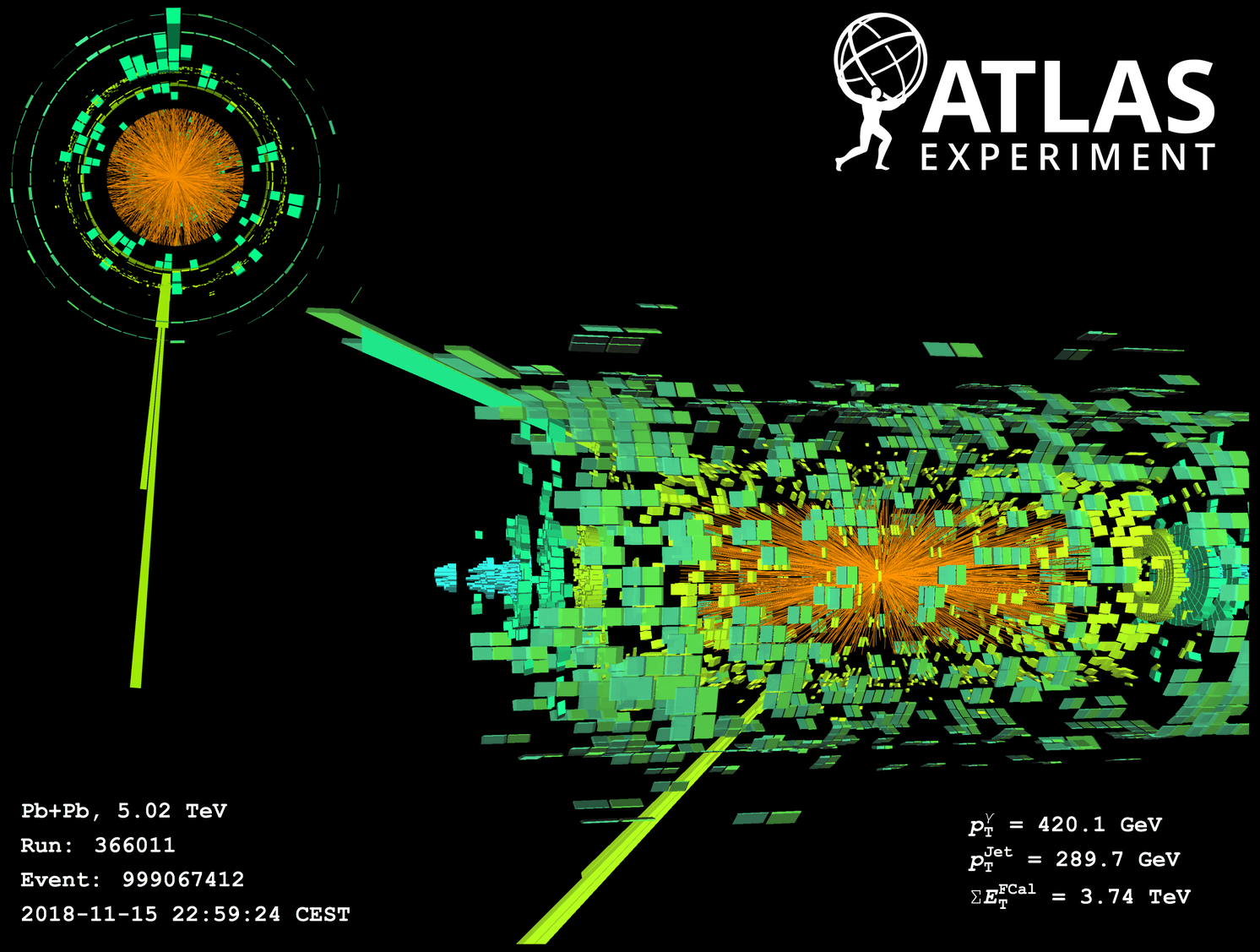
Ultra-peripheral collisions



Head-on collisions



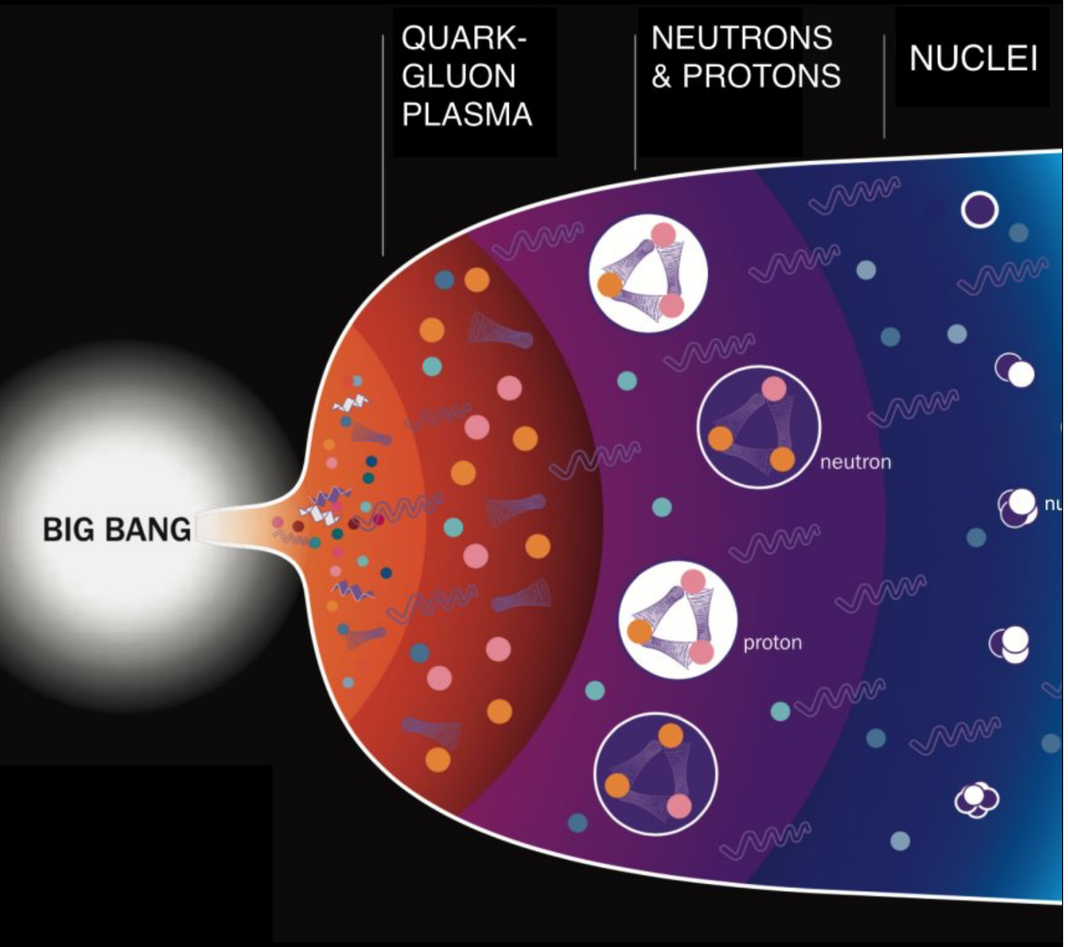
ATLAS EXPERIMENT



Pb+Pb, 5.02 TeV
Run: 366011
Event: 999067412
2018-11-15 22:59:24 CEST

p_T^{γ} = 420.1 GeV
p_T^{Jet} = 289.7 GeV
$\sum E_T^{FCal}$ = 3.74 TeV

Quark Gluon Plasma (QGP)



https://twitter.com/QM2018

LHC heavy ion collisions can produce hot, dense, medium with free colour charges

→ **Quark Gluon Plasma (QGP)**

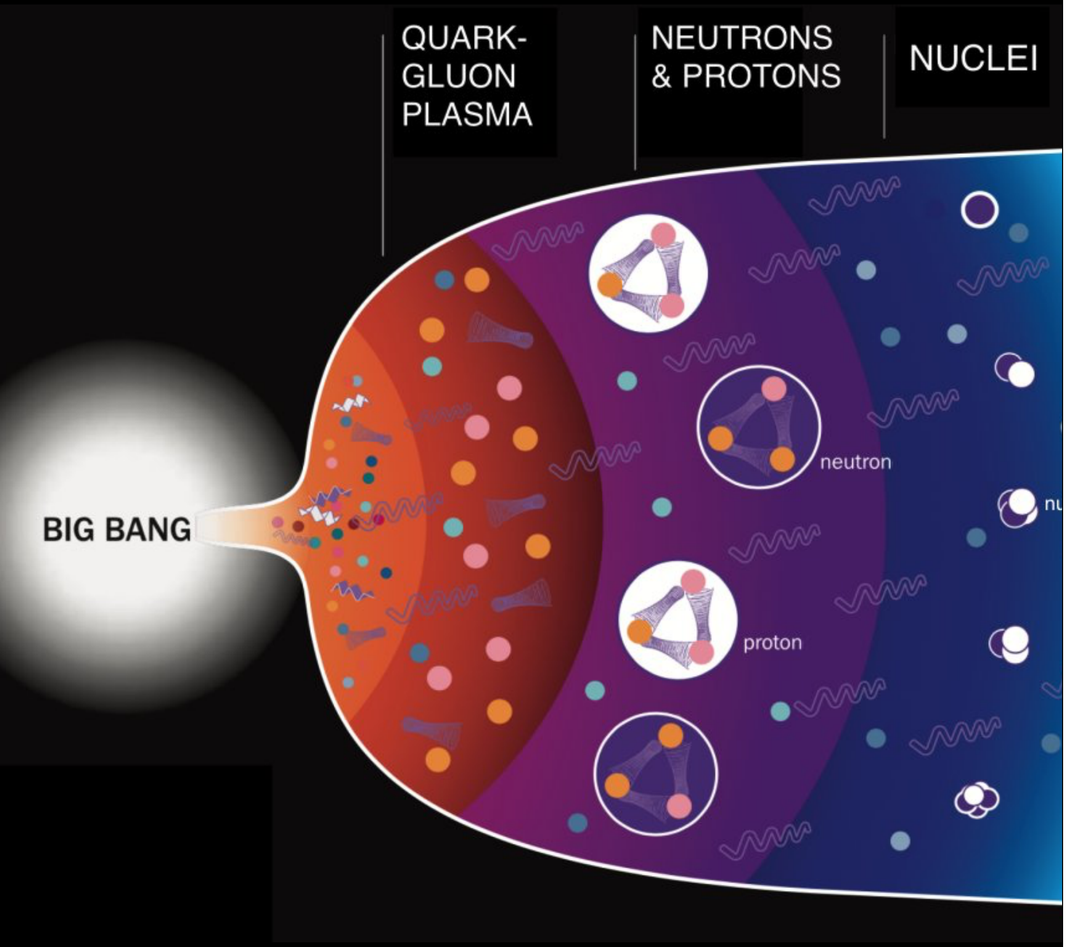
High momentum partons strongly interact in QGP & lose energy (gluon radiation & scattering) before hadronising

→ **Jet quenching**

Binding potential of quarkonia e.g. $\Upsilon(b\bar{b})$ can be modified in QGP (colour screening by QGP constituents)

→ **Suppression of Quarkonia**

Quark Gluon Plasma (QGP)



https://twitter.com/QM2018

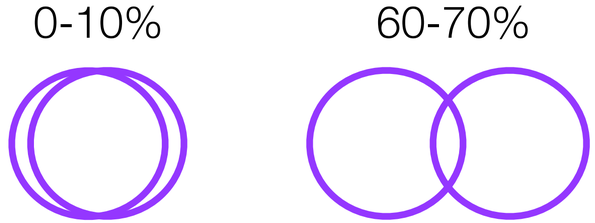
Quantify yield suppression relative to proton-proton

→ **Nuclear modification factor:**

$$R_{AA} = \frac{N(Pb\,Pb)}{N_{Coll} \times N(p\,p)}$$

$R_{AA} < 1$ → Suppression

Suppression stronger for more central collisions (larger QGP volume)



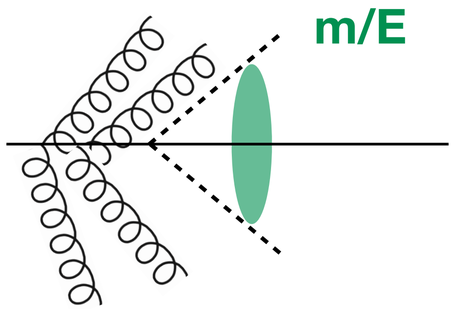
B-jets

EPJC 83 438 (2023)

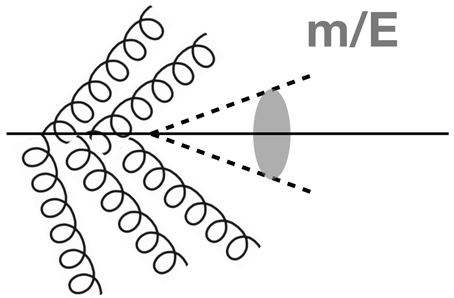
Goal: study mass & colour-charge dependence (quark vs gluon) of jet energy loss

Mass dependence: “dead-cone effect”

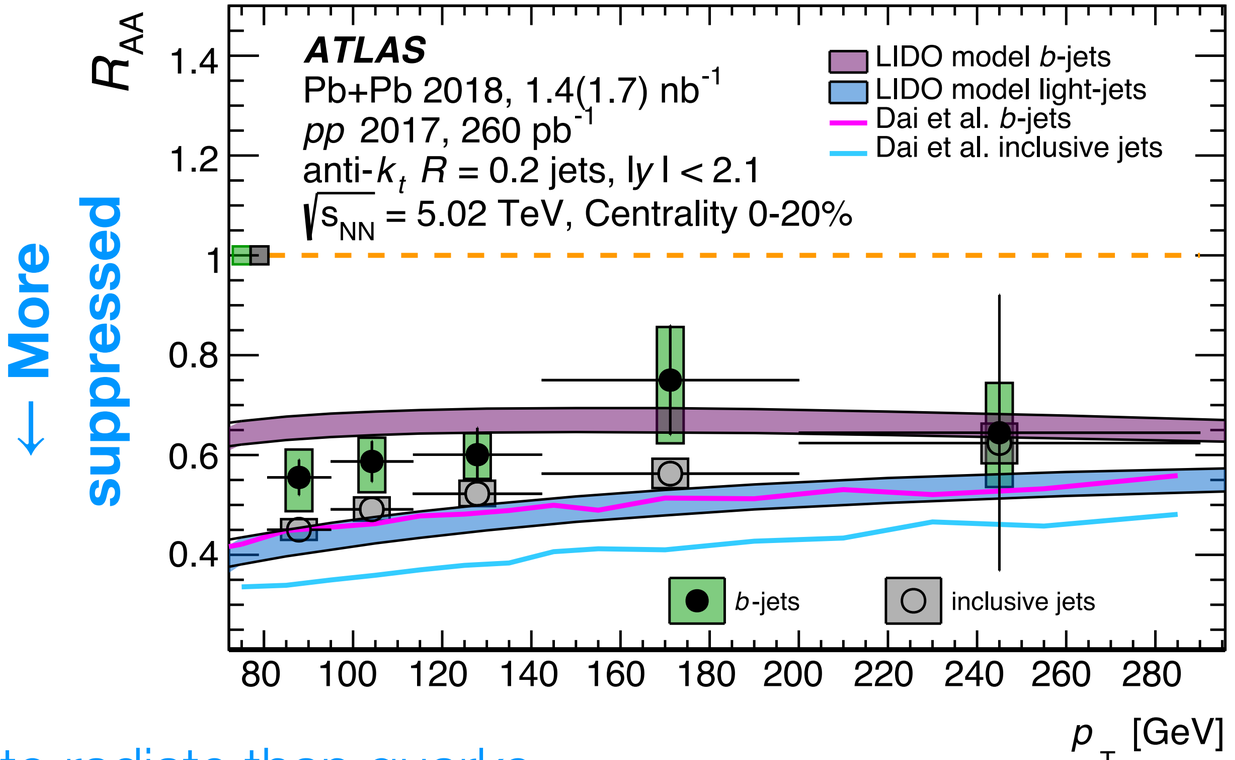
Heavy quark jets



Lighter quark jets



Radiation suppressed in $\theta <$ m/E



Colour-charge dependence: Gluons more likely to radiate than quarks

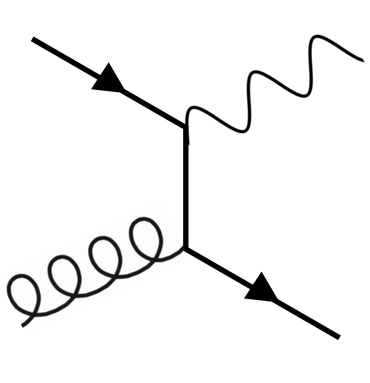
Utilise semi-leptonic decay of b-hadron, correct for missing neutrino energy

B-jets ~20% less suppressed than inclusive jets in central collisions

Photon-tagged jet

2303.10090

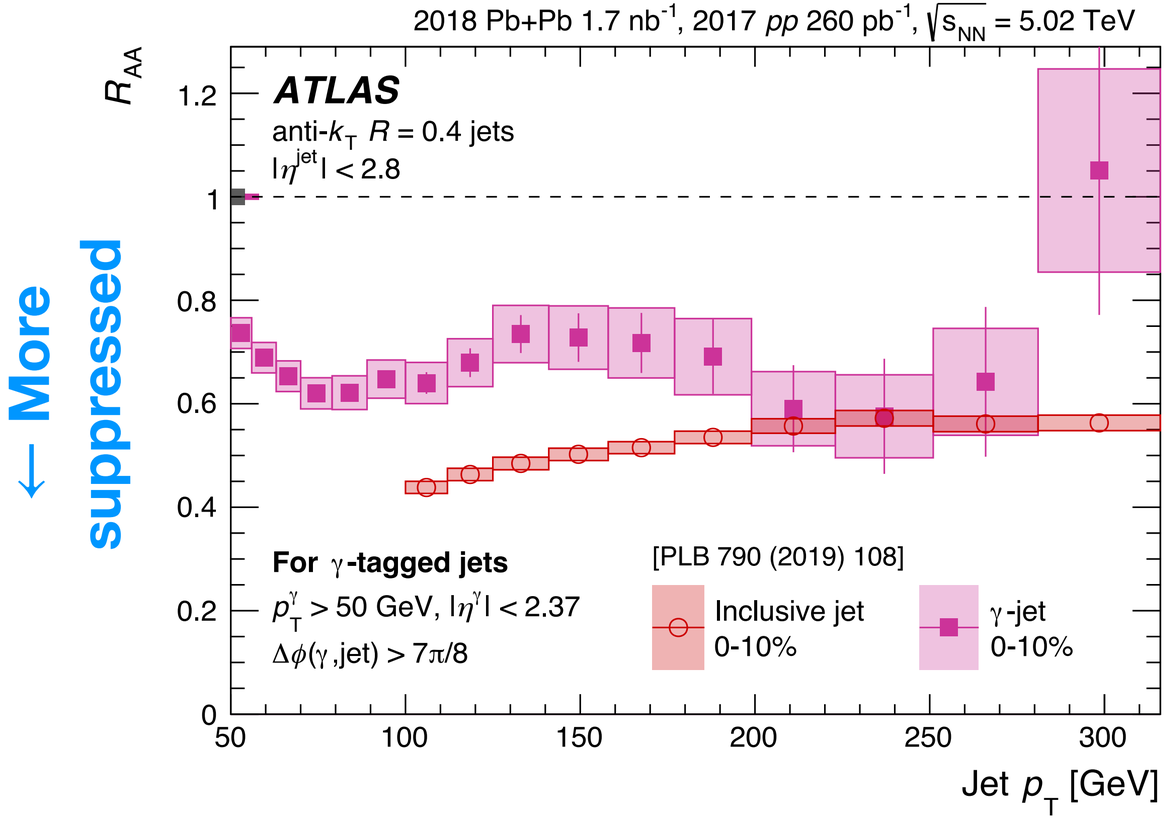
Goal: isolate colour-charge dependence (quark vs gluon) of jet energy loss



γ $p_T > 50$ GeV

q $p_T > 50$ GeV

Quark-initiated jets dominate



Quark-enhanced photon-tagged jets less suppressed than inclusive jets

Other factors: p_T spectra steepness, isospin, nPDF effects → Use S_{loss} to reduce impact (see backup)

→ **Strong confirmation of more jet quenching for gluon jets than quark jets**

Jet substructure

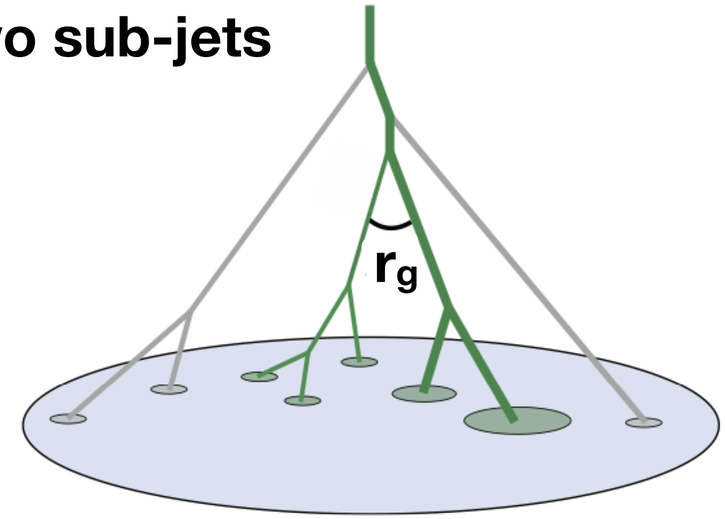
PRC 107 054909

Goal: study splitting-angle dependence of jet energy loss

Anti-kt jets (R=0.4) re-clustered with Cambridge-Aachen algorithm

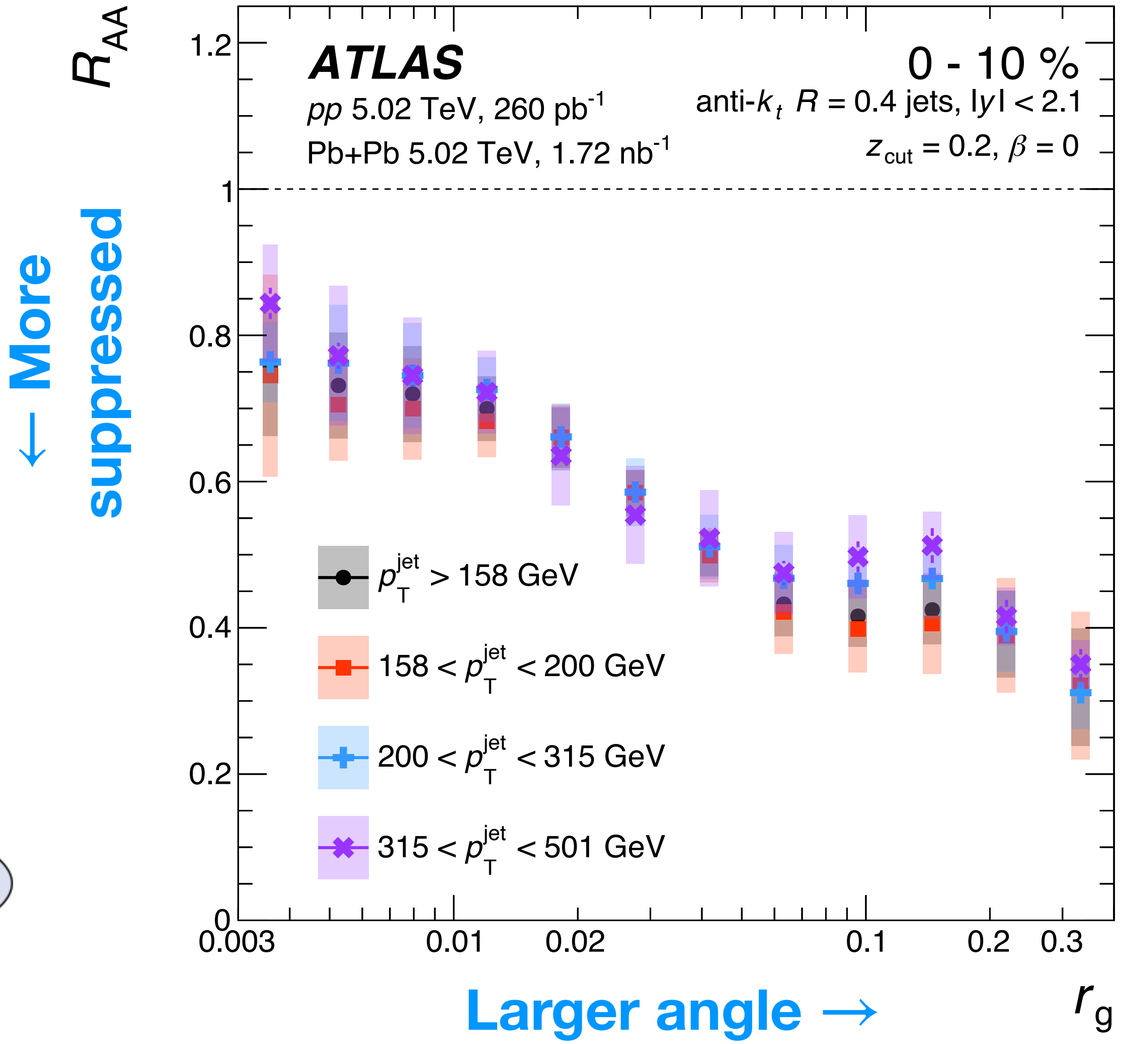
Groom using soft-drop procedure
→ Identify first hard splitting

r_g= angle between two sub-jets



PLB 833 (2022) 137390

Extended study to large radius jets, see: 2301.05606



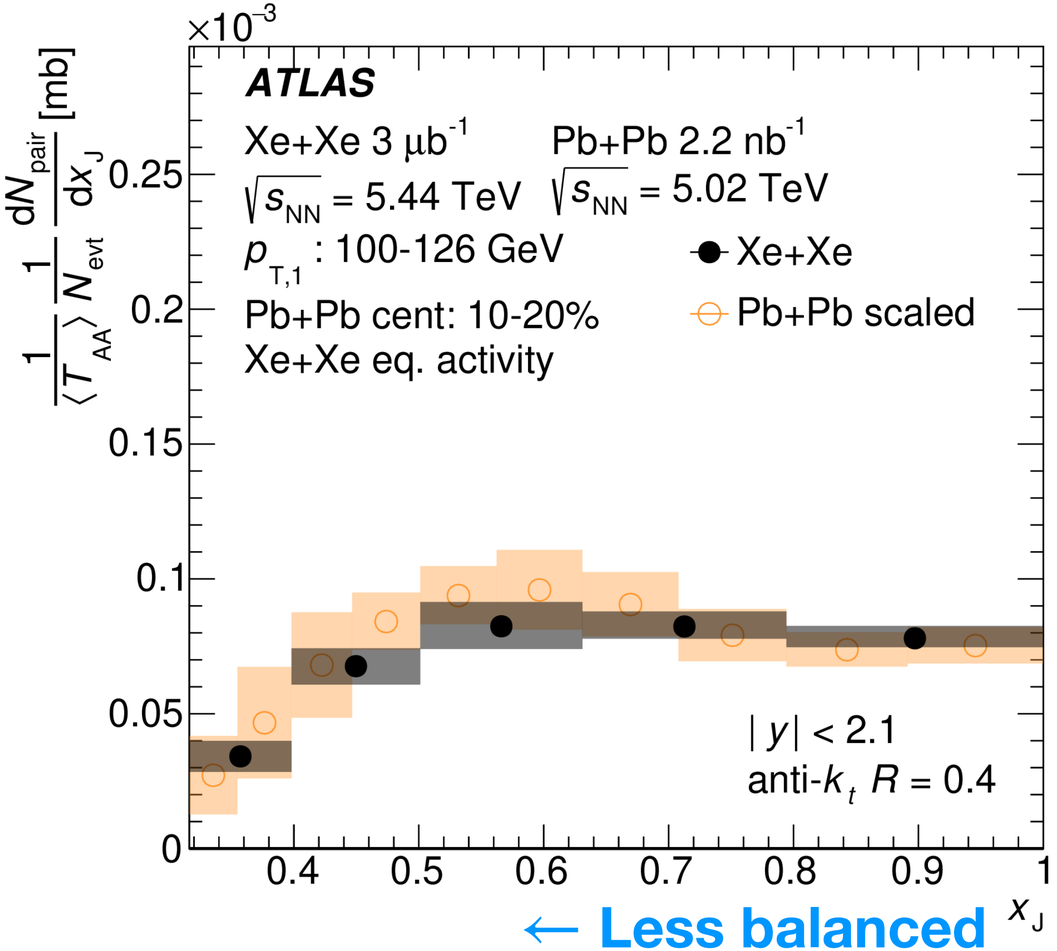
Dijet asymmetry in Pb+Pb and Xe+Xe

PRC 107 054908

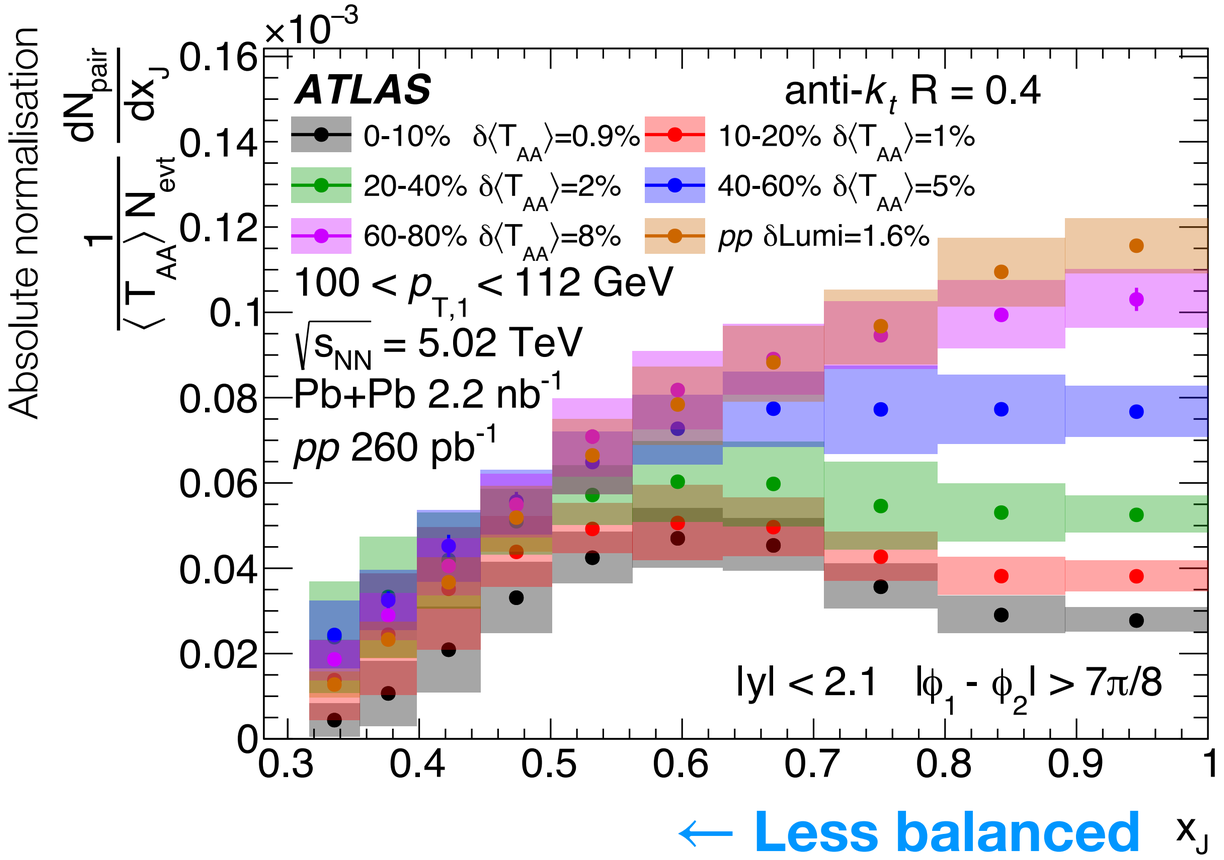
2302.03967

Transverse momentum balance: $x_J = \frac{p_{T2}}{p_{T1}}$

Balanced dijets more suppressed



← Less balanced



← Less balanced

Xe+Xe results consistent with Pb+Pb results after correcting for different centre-of-mass energy

Upsilon production

PRC 107 054912

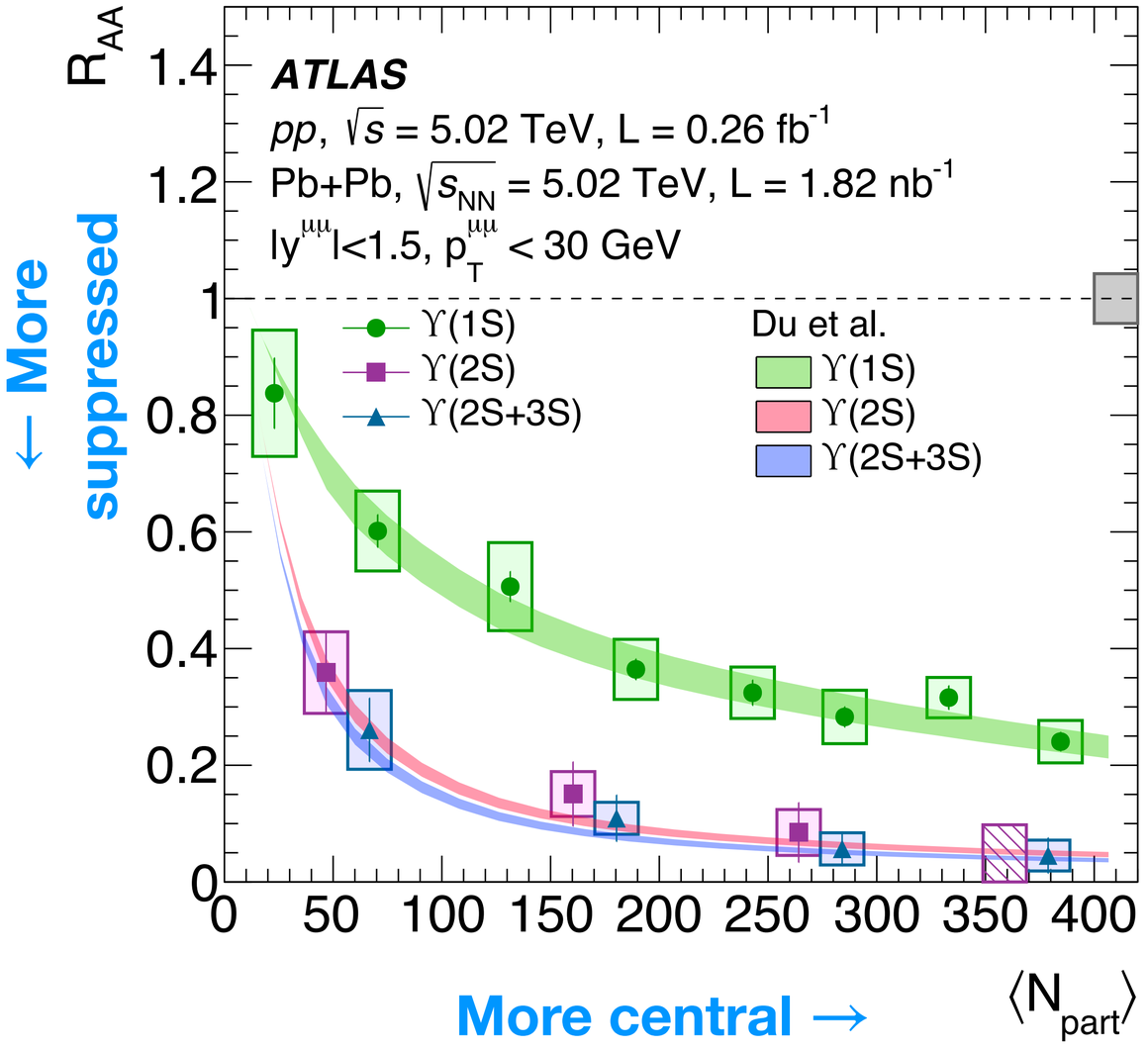
Goal: study upsilon production in the QGP

Pb+Pb: Sequential suppression of $\Upsilon(b\bar{b})$ states

→ Excited states dissolve at lower QGP temperature

Also seen in p+Pb collisions

What about pp?



Upsilon production in proton-proton

ATLAS-CONF-2022-023

Study (PU subtracted) <N_{ch}> as function of Υ p_T for **1S**, **2S** & **3S**

At Υ p_T < 30 GeV:

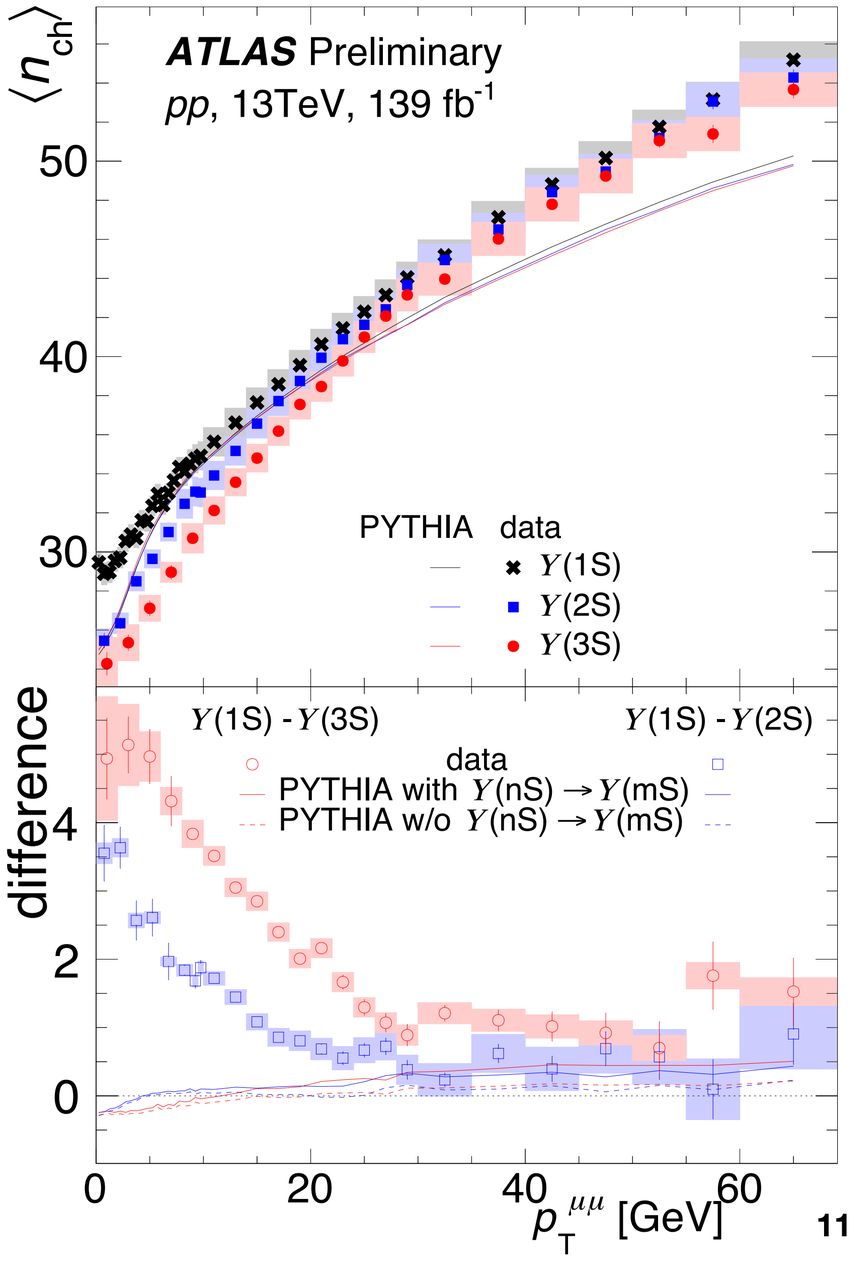
- Higher N_{ch} for **1S** than for **2S** & **3S**
- Not predicted by Pythia MC

Suggests correlation between UE & hard process

Sequential suppression?

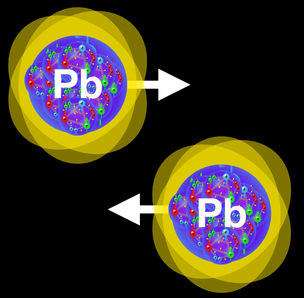
Other soft QCD effect e.g. colour reconnection?

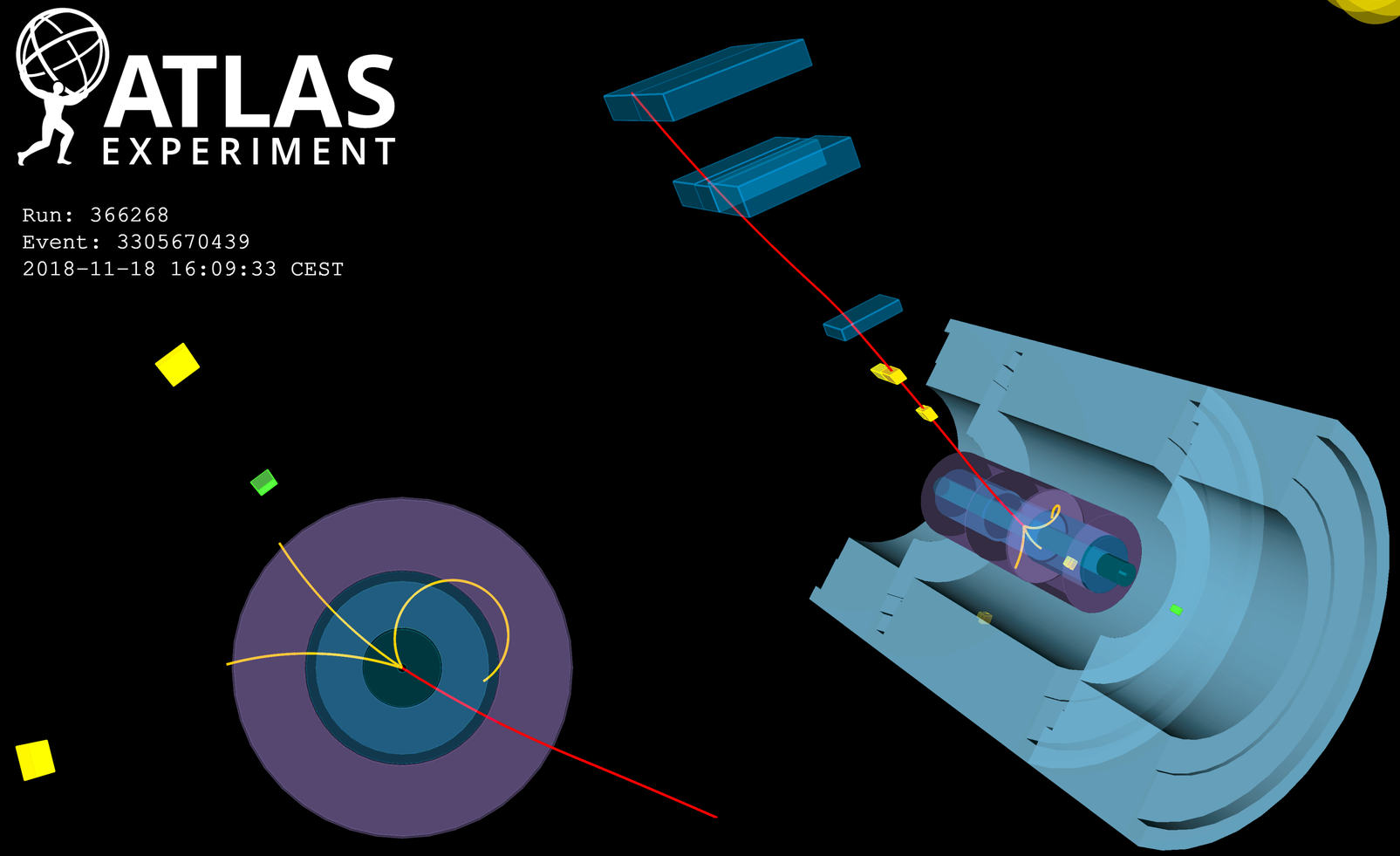
…



<n_{ch}> = Mean number of charged particles with 0.5 < p_T < 10 GeV & $|\eta|$ < 2.5

Ultra-peripheral collisions (UPC)





$\gamma\gamma \rightarrow ee$

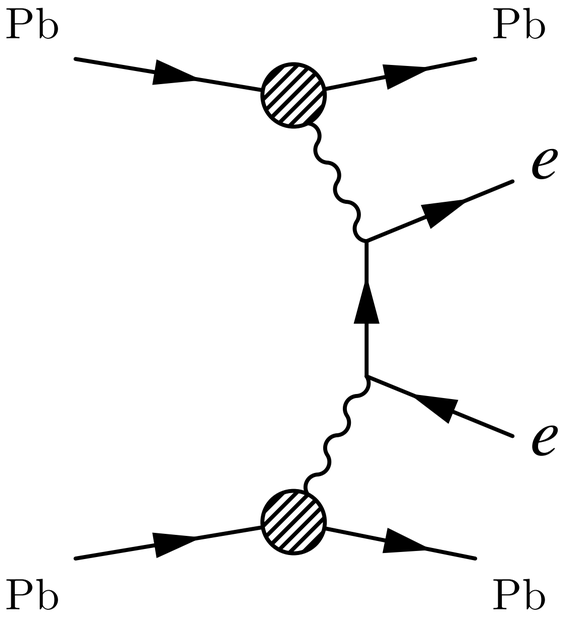
$\gamma\gamma \rightarrow ee$: JHEP 06 (2023) 182

$\gamma\gamma \rightarrow \mu\mu$: PRC 104 024906

Goal: Improve our understanding of photon-flux

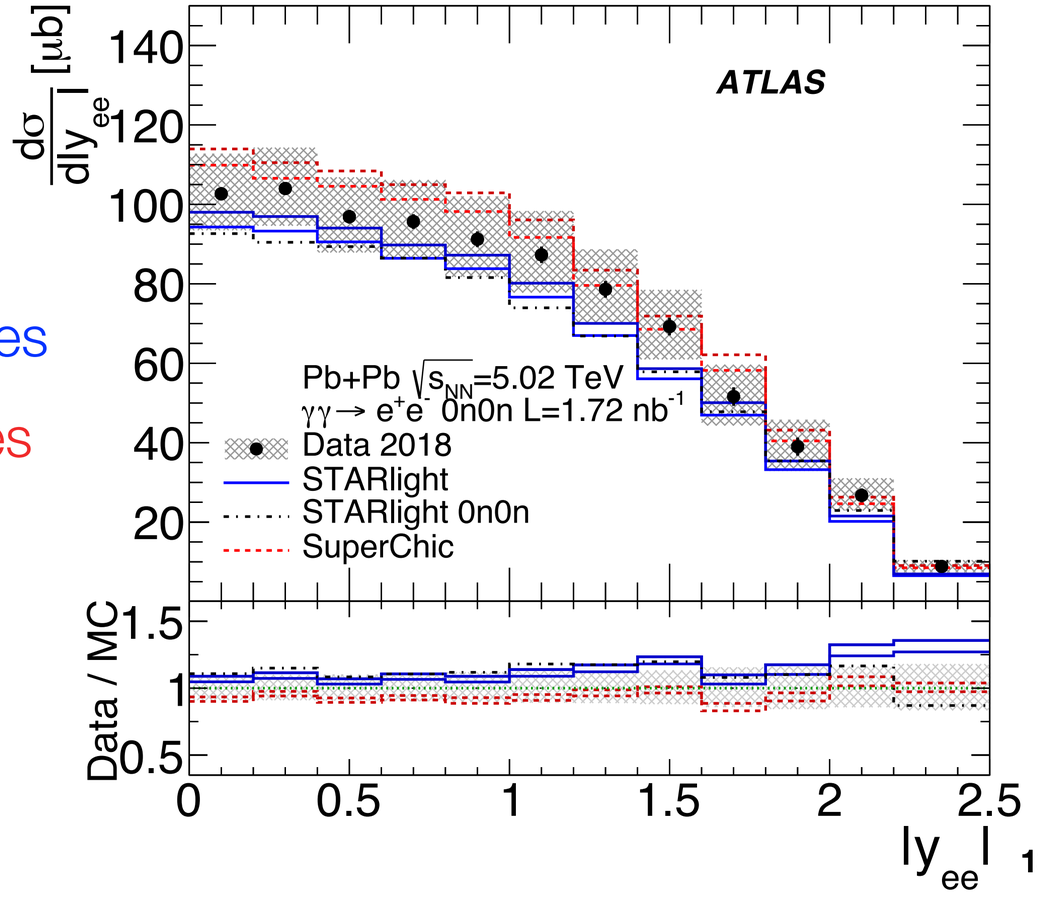
Use Zero Degree Calorimeter (ZDC) to categorise events

→ No neutrons on either side (0n0n) targets both Pb ions remaining intact



STARlight underestimates

SuperChic overestimates

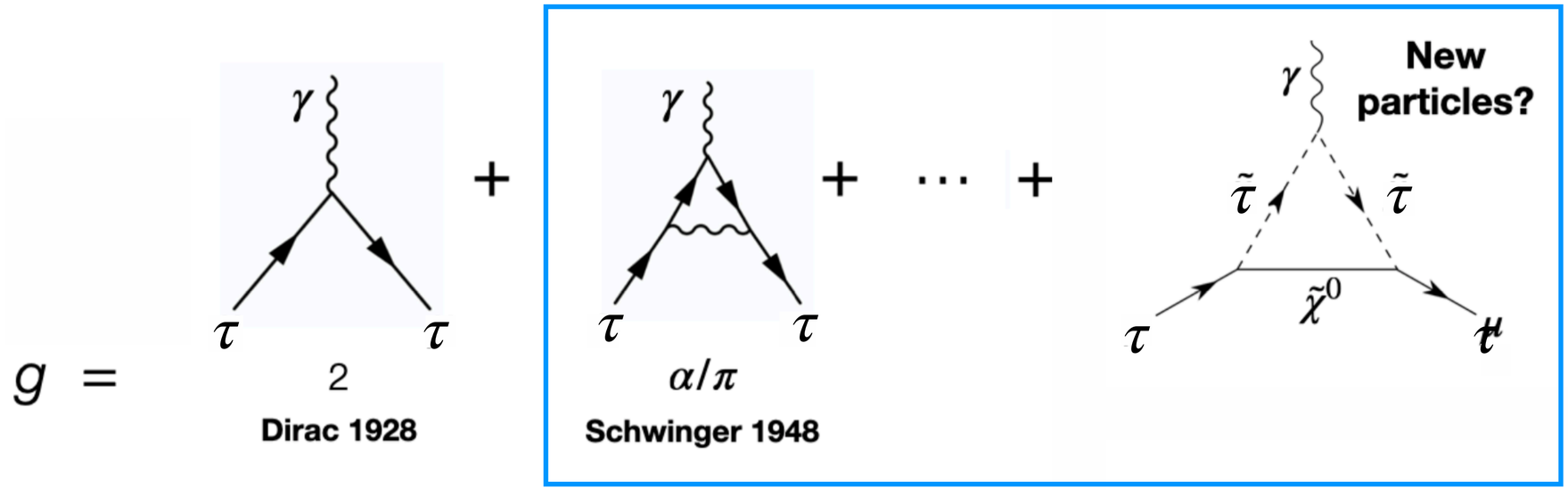


$\gamma\gamma \to \tau\tau$: Tau g-2

2204.13478

Goal: measure the tau anomalous magnetic moment

Spin 1/2 charged particles **magnetic moment:** $\boldsymbol{\mu} = g \dfrac{q}{2m} \mathbf{S}$



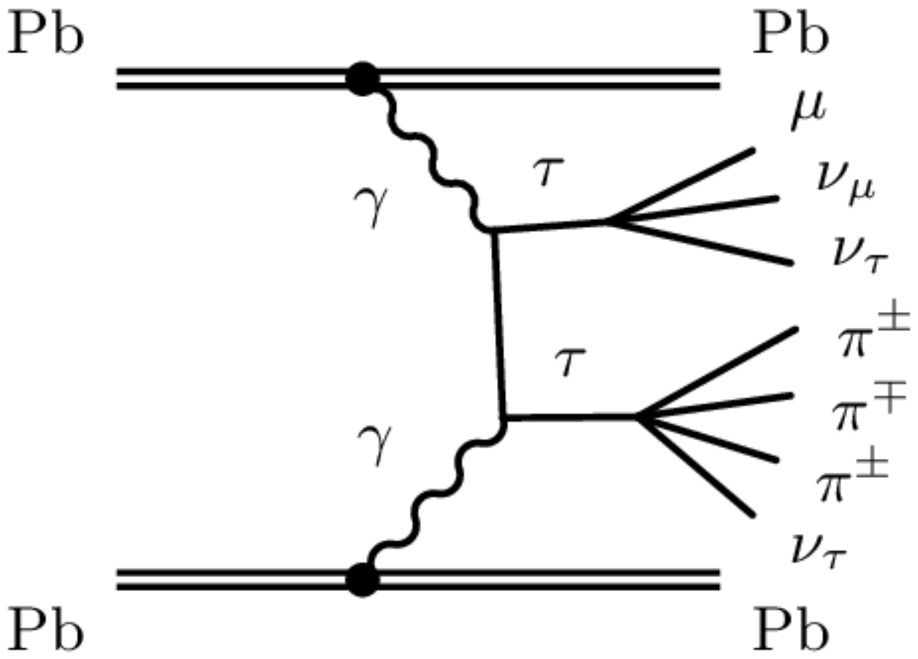
Anomalous magnetic moment ('g-2'): $a = \dfrac{(g-2)}{2}$

$\gamma\gamma \rightarrow \tau\tau$: Tau g-2

2204.13478

Goal: measure the tau anomalous magnetic moment

$\gamma\gamma \rightarrow \tau\tau$ **cross-section** sensitive to tau g-2



Additional sensitivity:

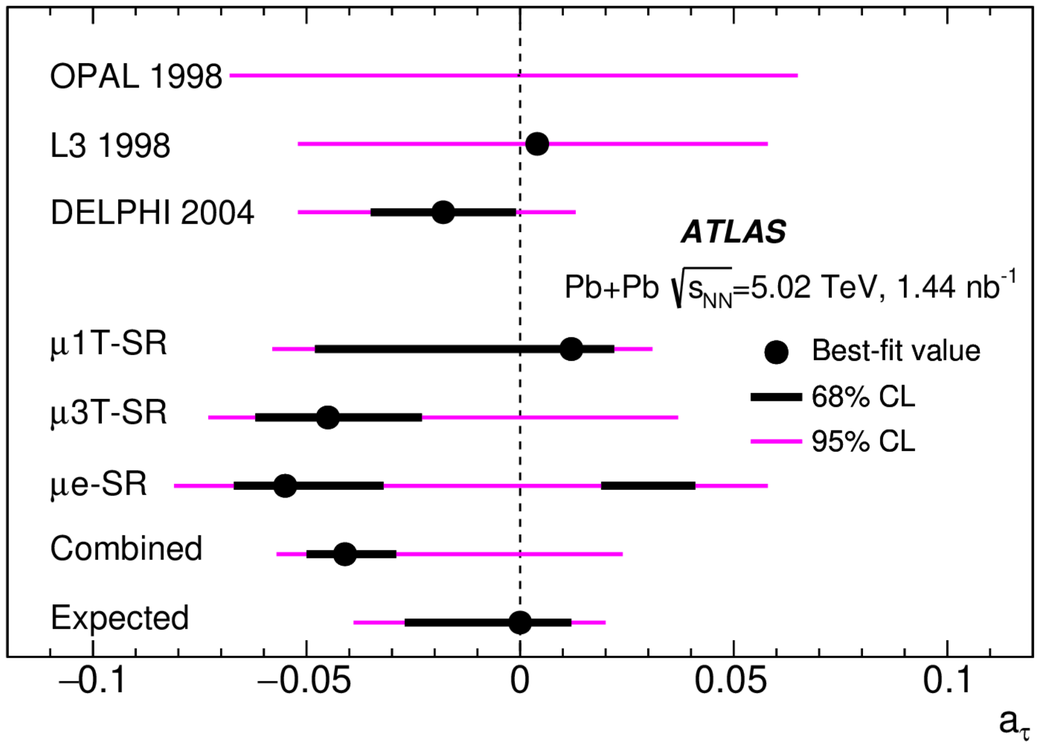
- Measure **differentially** in muon p_T
- Constrain photon-flux in $\gamma\gamma \rightarrow \mu\mu$ control region

$\gamma\gamma \rightarrow \tau\tau$: Tau g-2

2204.13478

ATLAS & CMS set first new constraints on a_τ since 2004

First measurements of τ leptons in heavy ion collisions



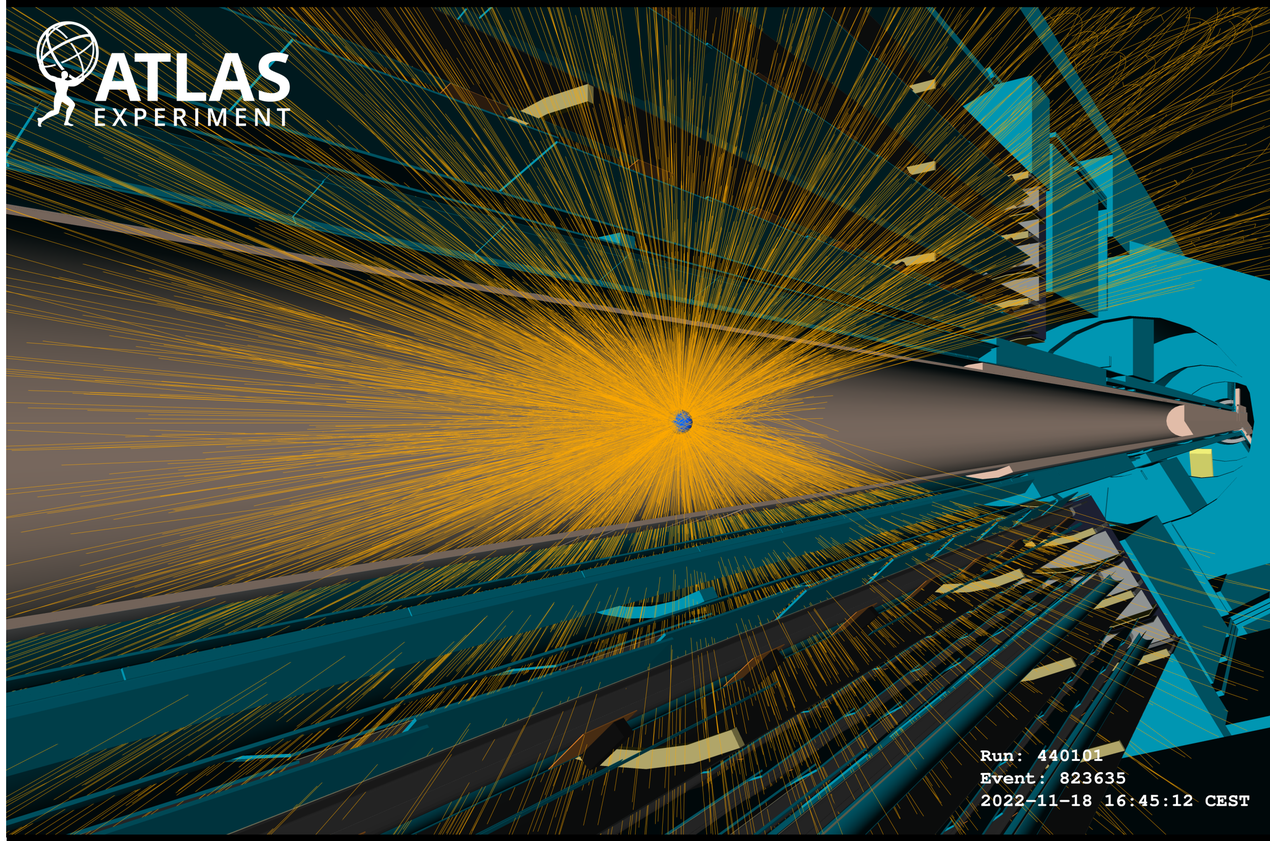
Constraints competitive with DELPHI

Statistical uncertainty dominates → Will improve with more data!

Summary

- **New studies of jet energy loss dependence on initiating parton:**
  B-jets, photon-tagged jets, substructure, dijets
- **Sequential suppression of Υ states in Pb+Pb collisions**
- **Interesting correlations between UE & Υ production in proton collisions**
- **UPC measurements improve our understanding photon flux & constrain tau g-2**

Expect to at least double Pb+Pb dataset in 2023!



Heavy ion collision November 2022

$\sqrt{s_{NN}}$ = 5.36 TeV