PHYSICS WITH THE ATLAS ZDC: HADRONIC AND EM PROCESSES

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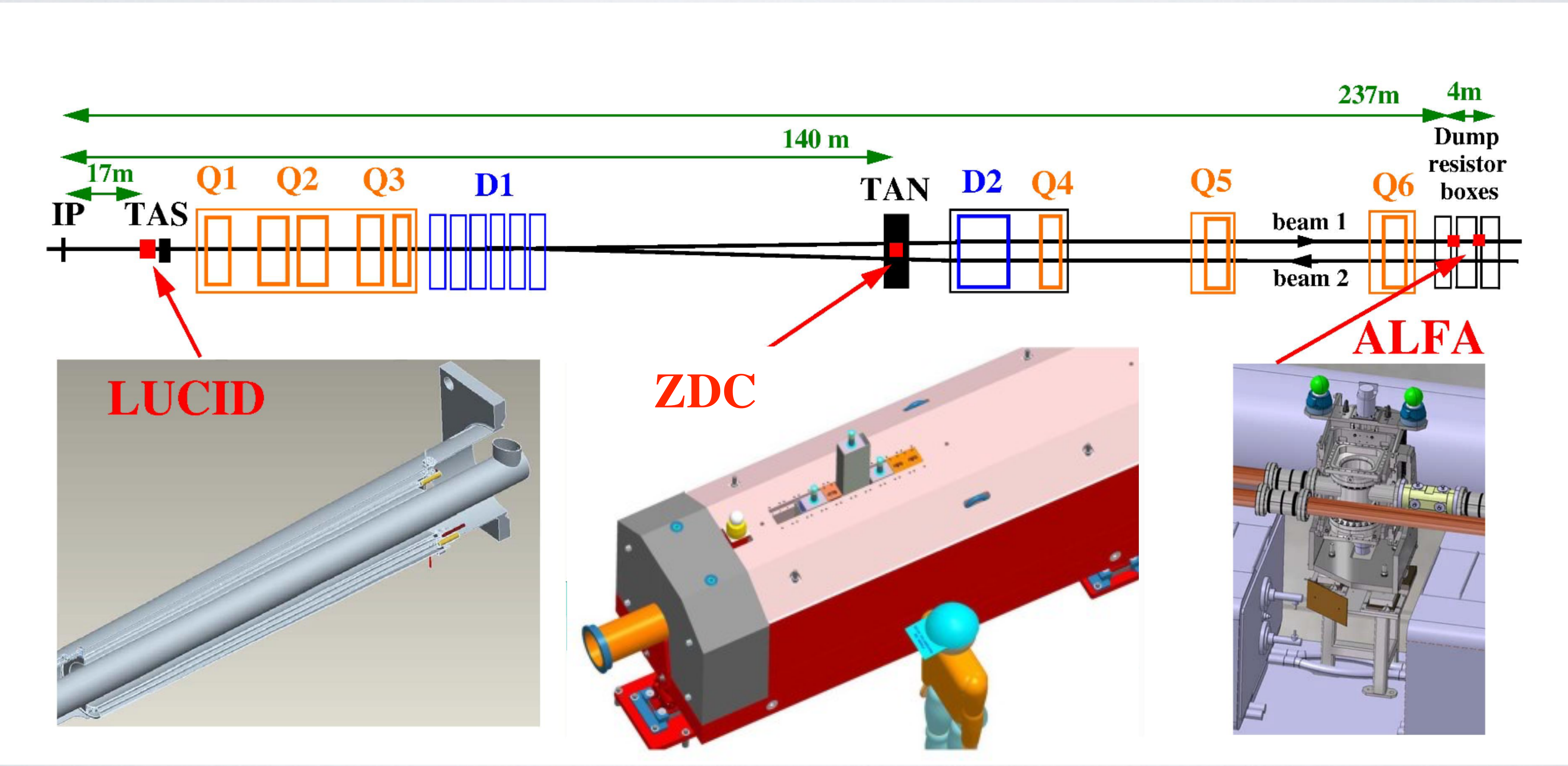
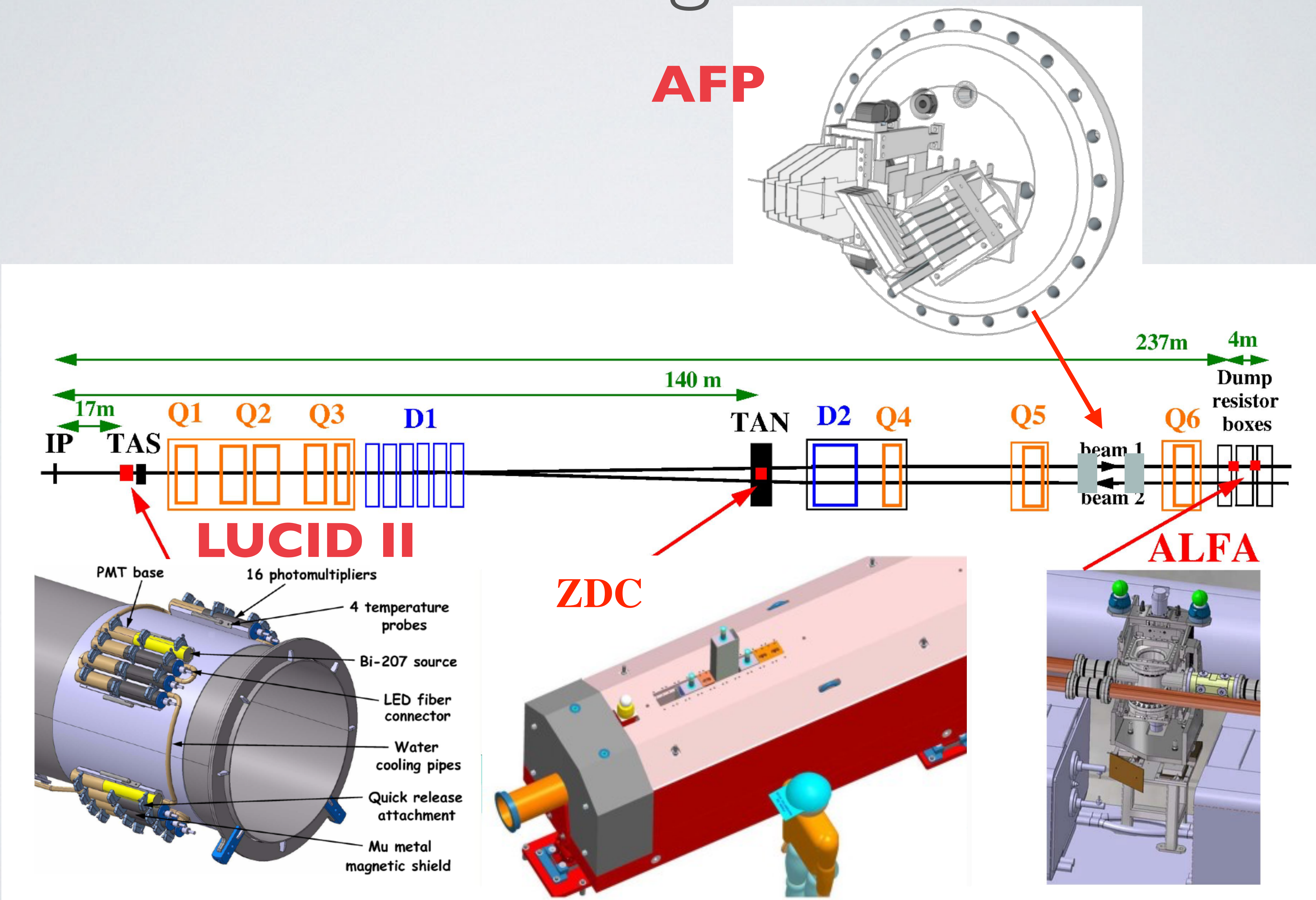
Forward Physics And Instrumentation From Colliders To Cosmic Rays, SBU
19 October 2018

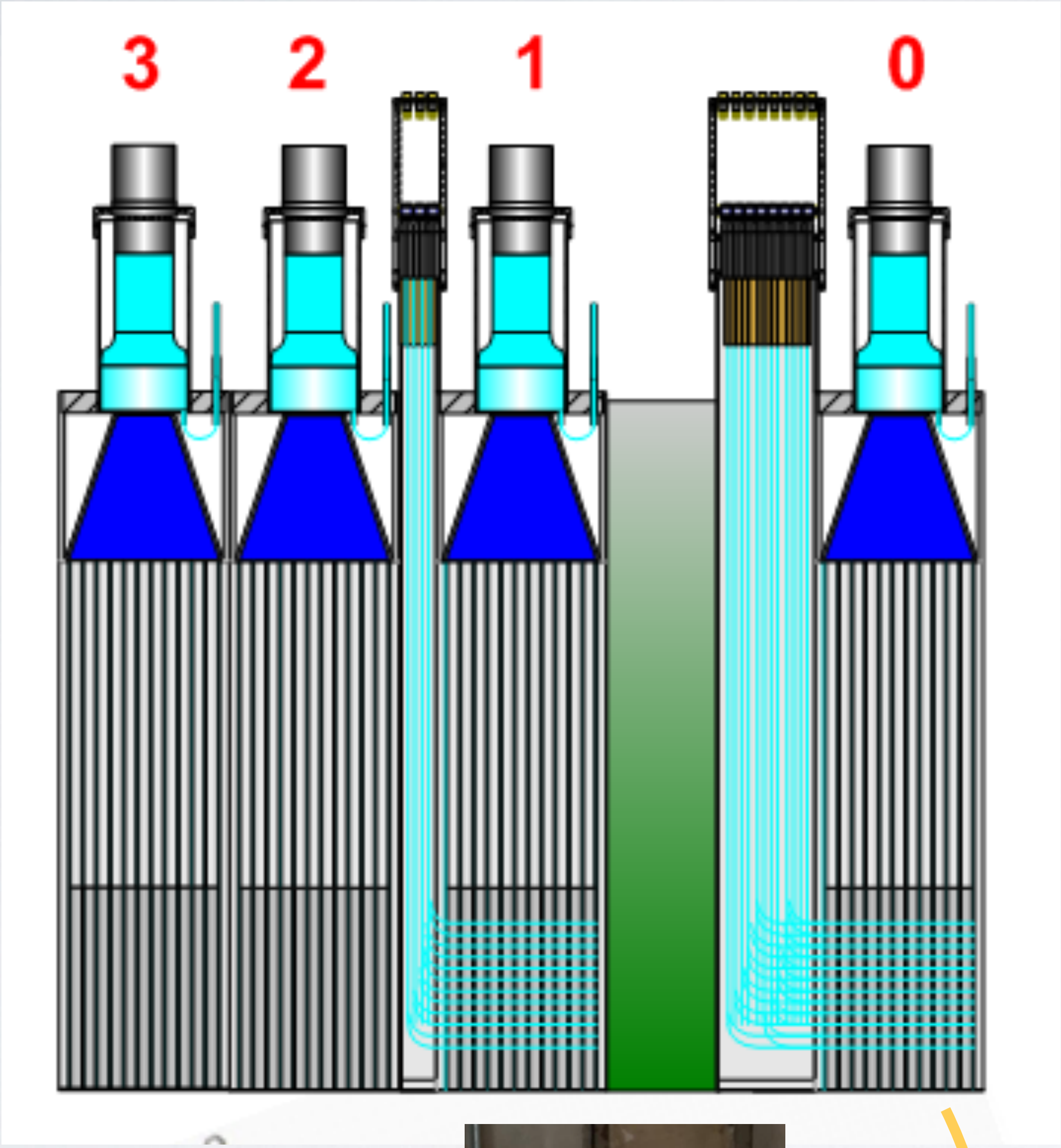
ATLAS forward region: Run 1



ATLAS forward region: Run 2



ATLAS ZDC Design

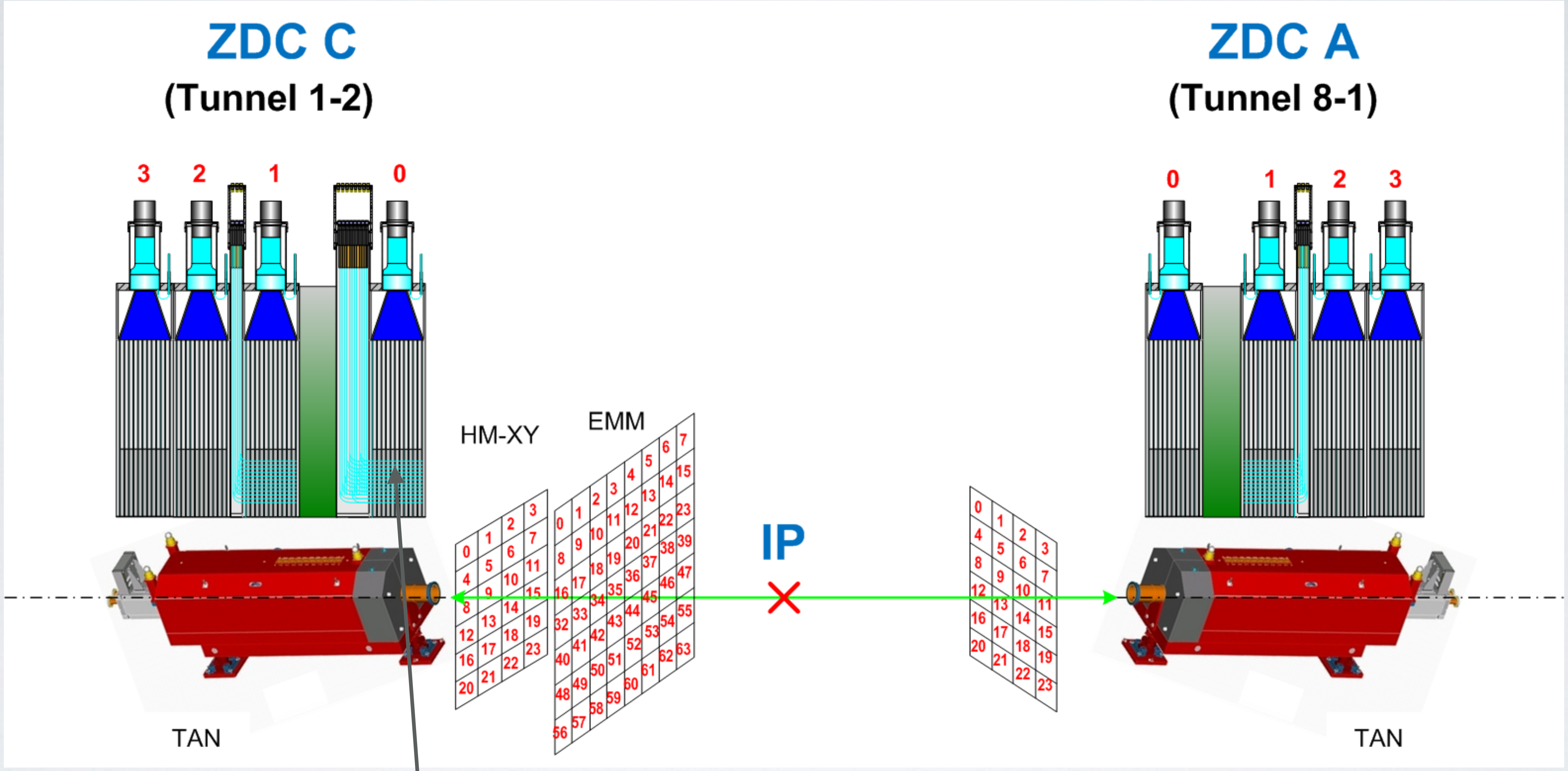


Full ZDC detector has **4** modules, each with depth of **1** nuclear interaction length

Showers produce Cerenkov light in d=1.5mm **vertical quartz** rods (GE214) sandwiched between 1cm **tungsten** plates

Some spatial information provided by 1mm longitudinal bent rods, read out by 10mm R1635 PMTs:
EM module has 8x8 grid
HadXY module has 8x10 grid, grouped into 24 regions

ATLAS ZDC in Run 1&2

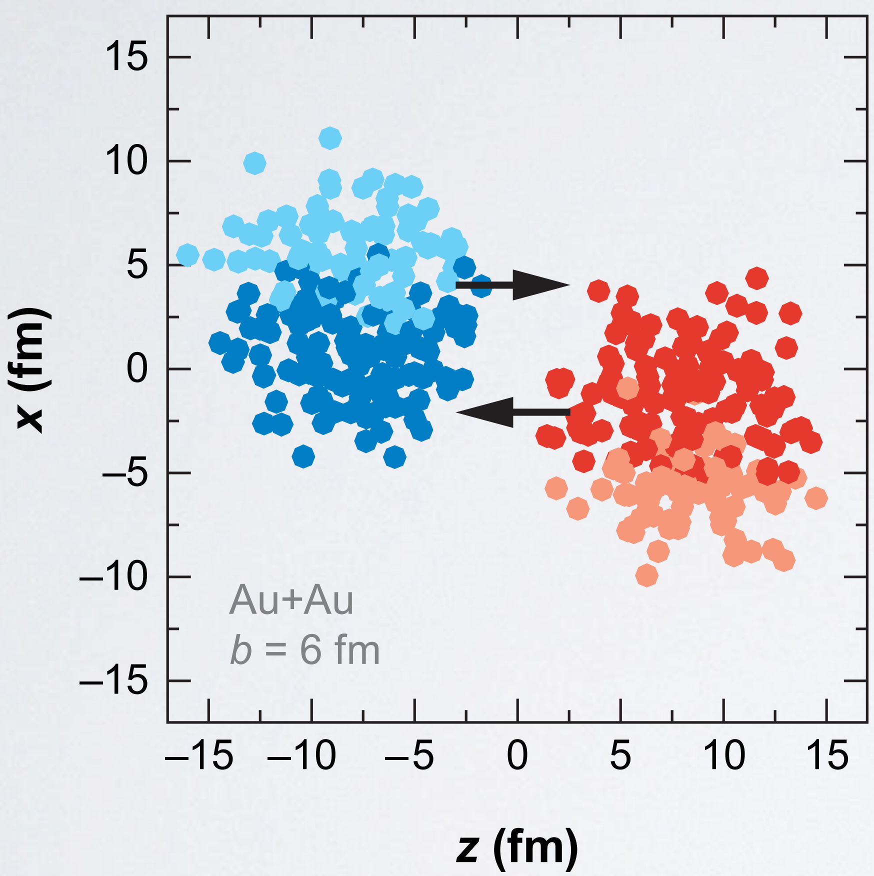


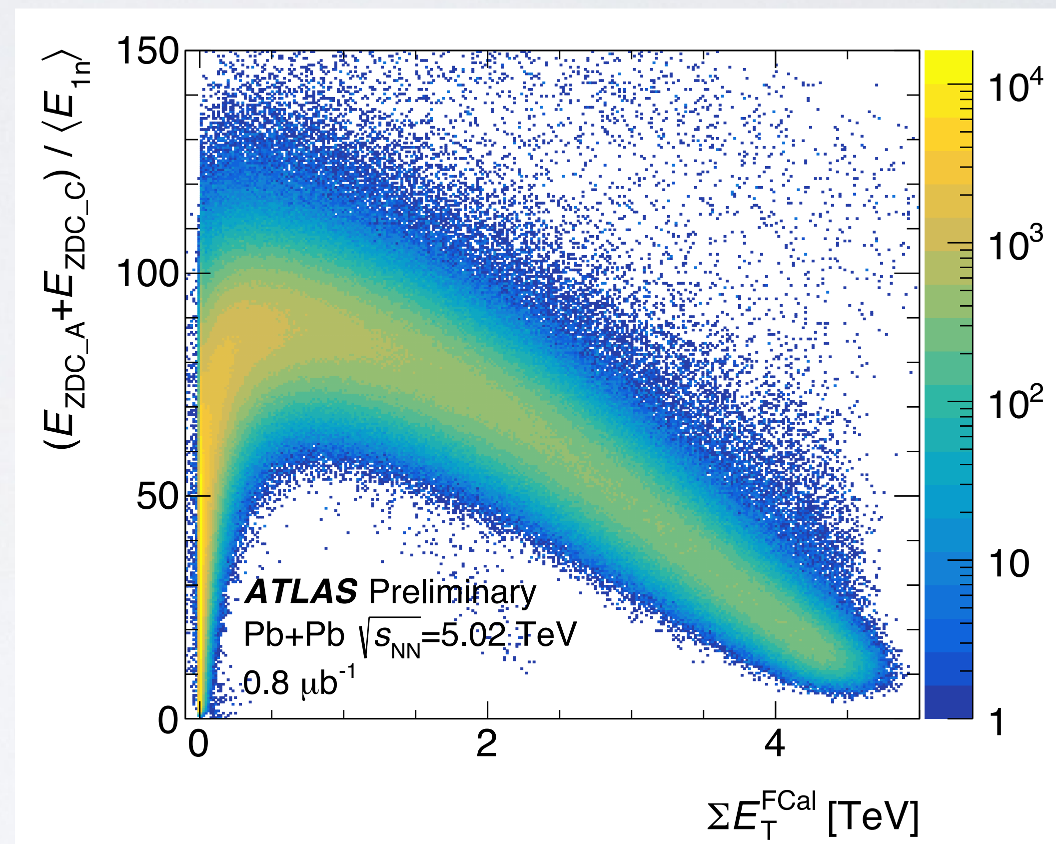
In 2013 and 2016 p+Pb running,
LHCf replaced segmented EM module

2011 pp running damaged quartz,
so all rods replaced for 2013 & 2015 running

ATLAS ZDC: goals

- Primary purpose: event triggering and centrality confirmation in hadronic heavy ion collisions

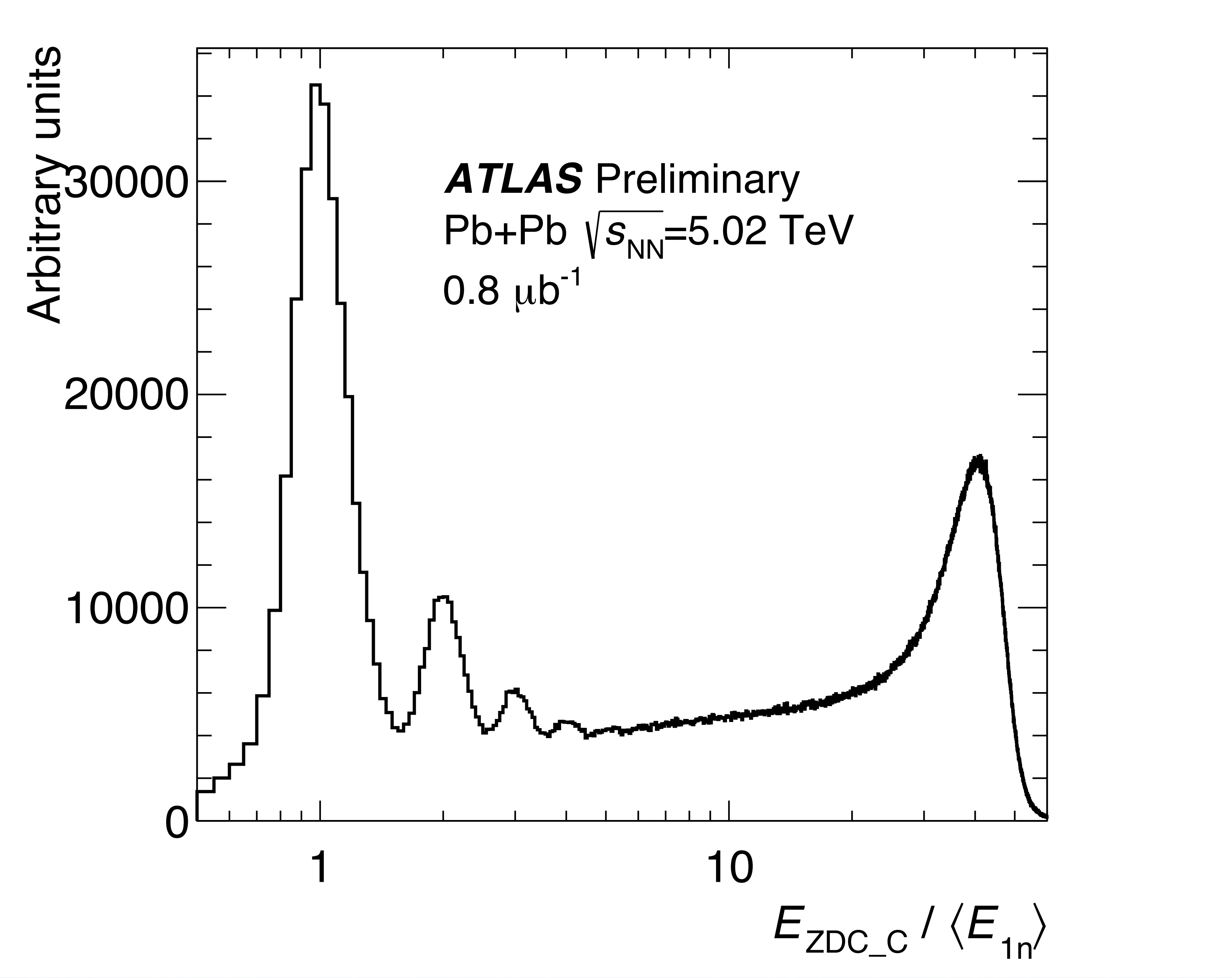




Coincidence of ZDCs suppresses ultraperipheral EM processes.
Strong correlation between ZDC energy & forward calorimeter E_T confirms basic assumptions of centrality analysis in Pb+Pb.

Essential for triggering on hadronic heavy ion collisions.

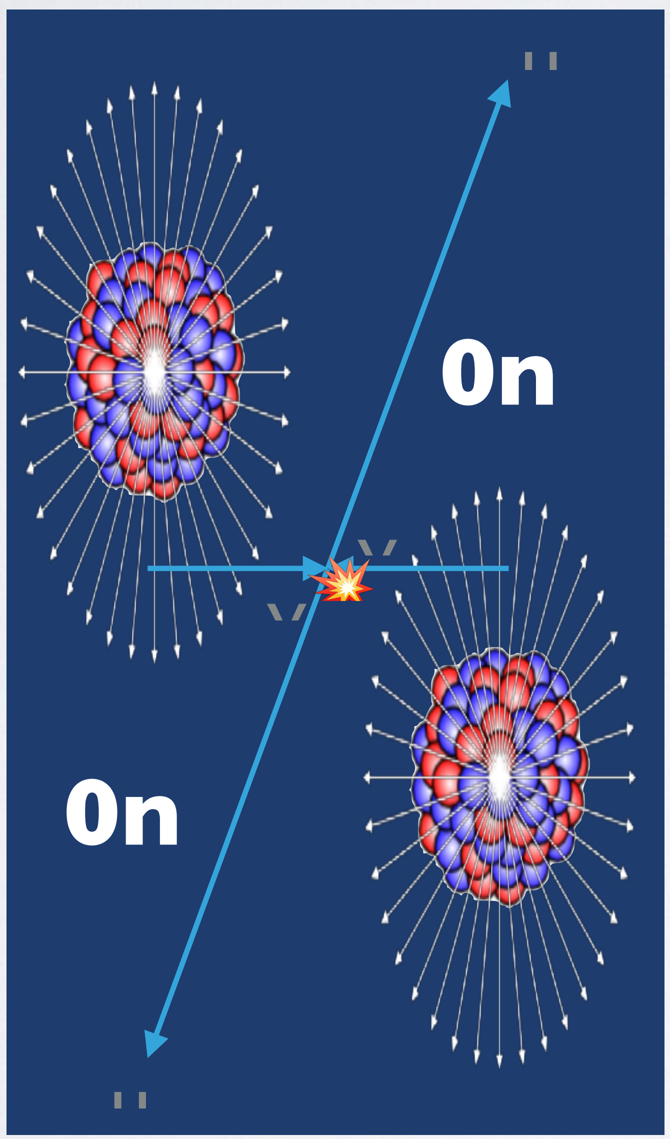
Single ZDC spectrum



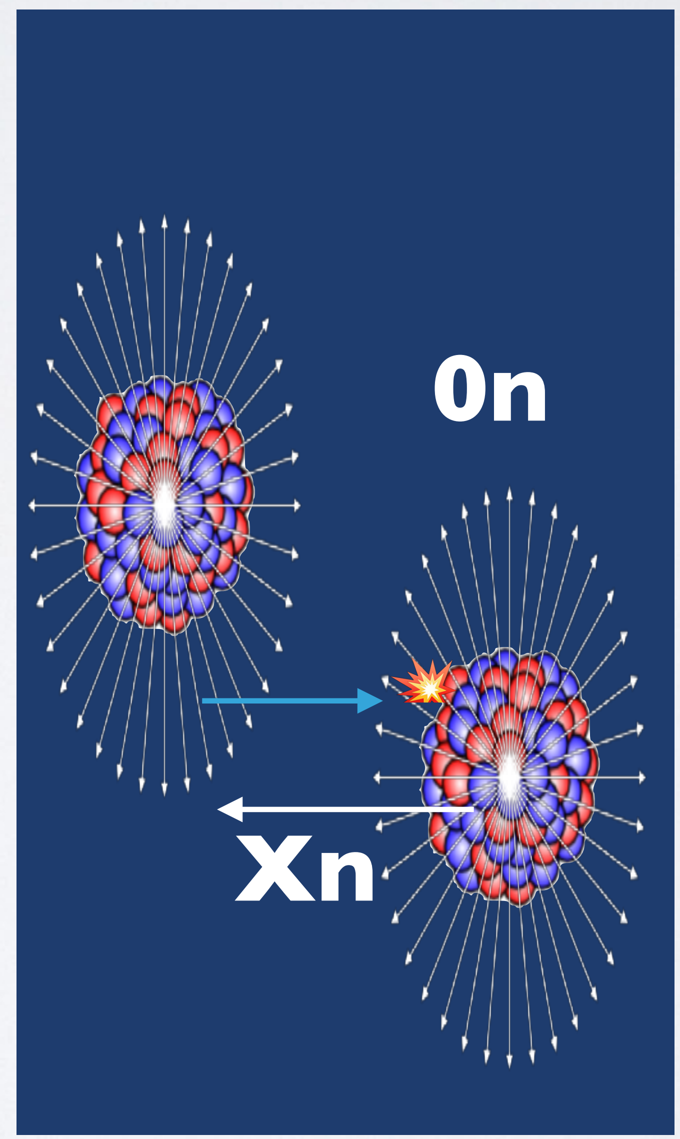
σ/E_{1n} ~ 16%: 4+ neutrons clearly visible, and then continuum, which ends where ZDC-FCal correlation turns over

ATLAS ZDC: goals

- Vetoing on ZDC coincidence enhances EM processes!
  - *gamma-gamma and gamma-nucleus processes*

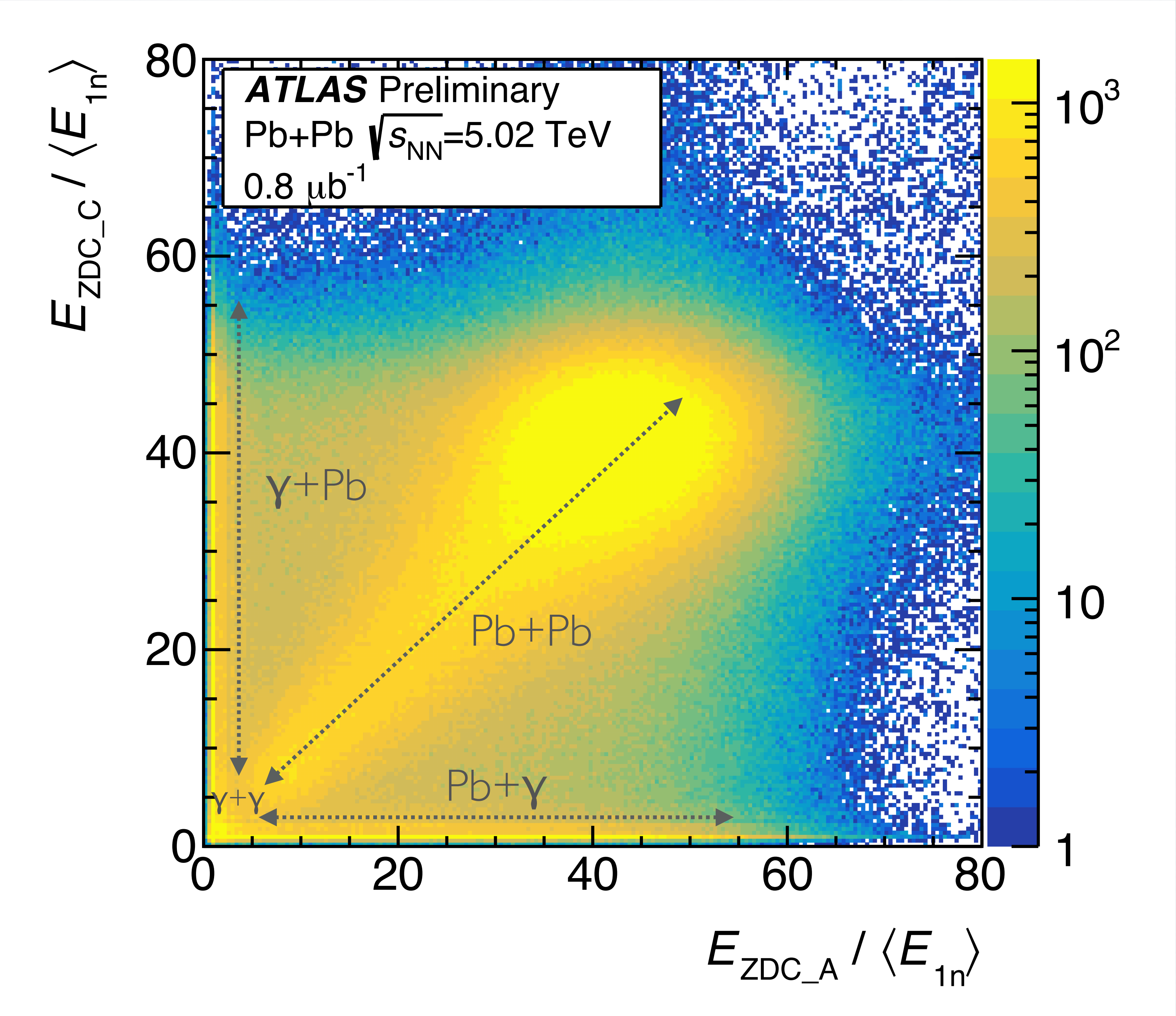


no ZDC signal



single-arm ZDC

Distinguishing EM processes



ZDC topology roughly distinguishes γ+γ (0 ZDC), γ+Pb (1 ZDC), Pb+Pb (2 ZDC)

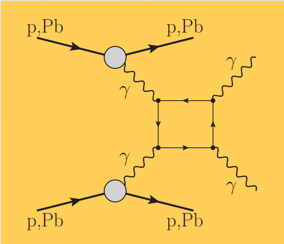
Practical considerations

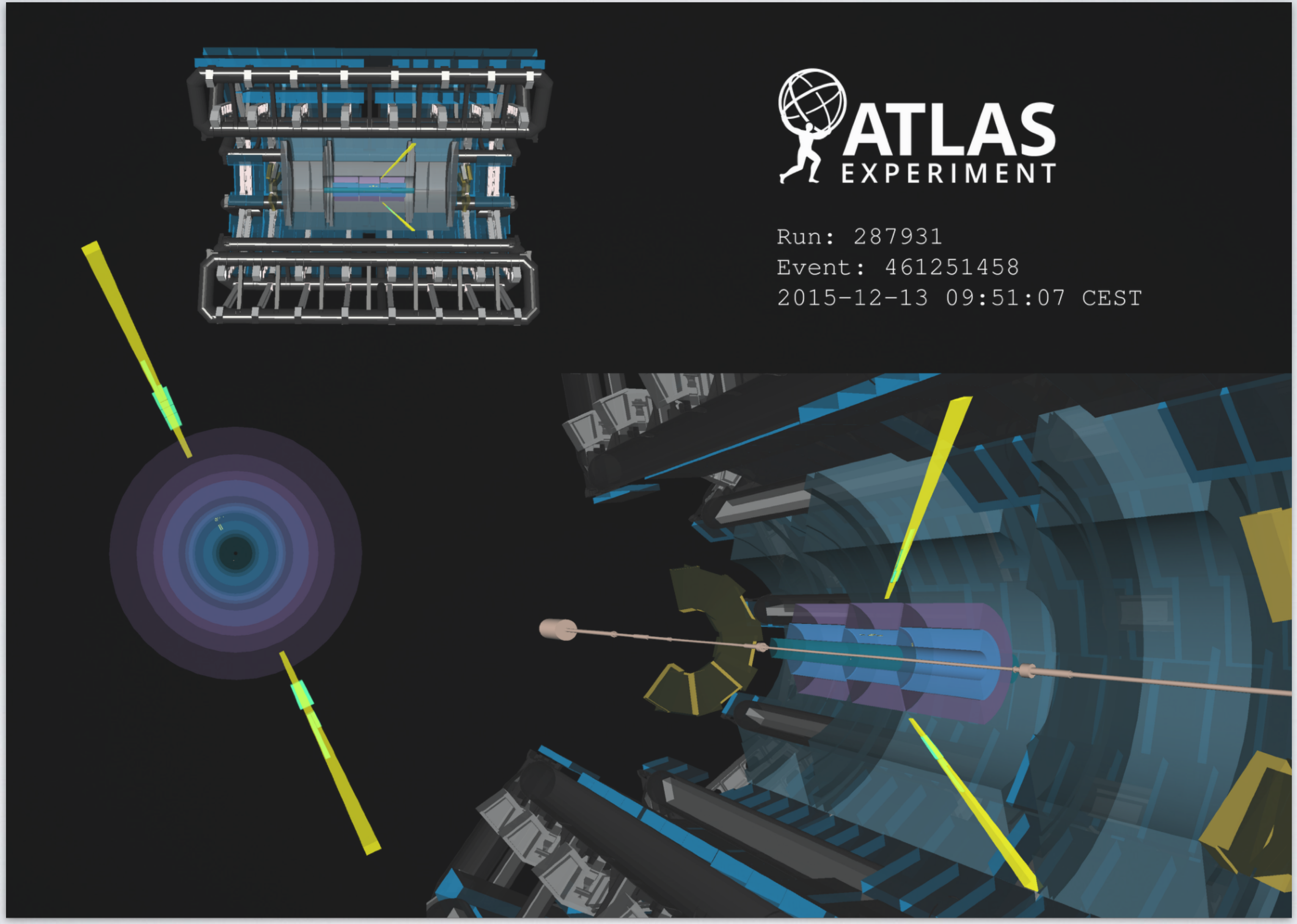
- Additional soft photon exchange
  - *Even in* **γγ** *UPC processes (no neutrons), STARLIGHT predicts breakup occurring O(30%) of the time, depending on* $M_{\mu\mu}, Y_{\mu\mu}$
  - *Detailed nuclear fragmentation not available*

- In time pileup
  - μ = *(interactions / bunch crossing)* = $\sigma_{in}\ L\ /\ N_{bunches}\ f_{LHC}$
  - σ_{in} *known to be ~7.7b (nuclear geometry),* $\mu \sim 0.005$
  - *However, for ZDCs, one needs to use* σ_{EMD}
  - σ_{EMD} *~ 190 b (ALICE, 2.76 TeV), 205 b (RELDIS, 5.02 TeV)*
  - *Thus, pileup is increased by 200/7.7 ~ 26,* $\mu \sim 0.13$

Observed ZDC topology is not sufficient for final results if desired precision is <15%

γγ processes: light-by-light





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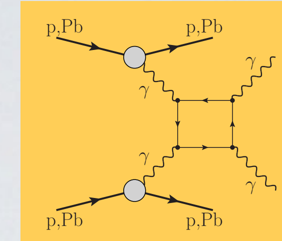
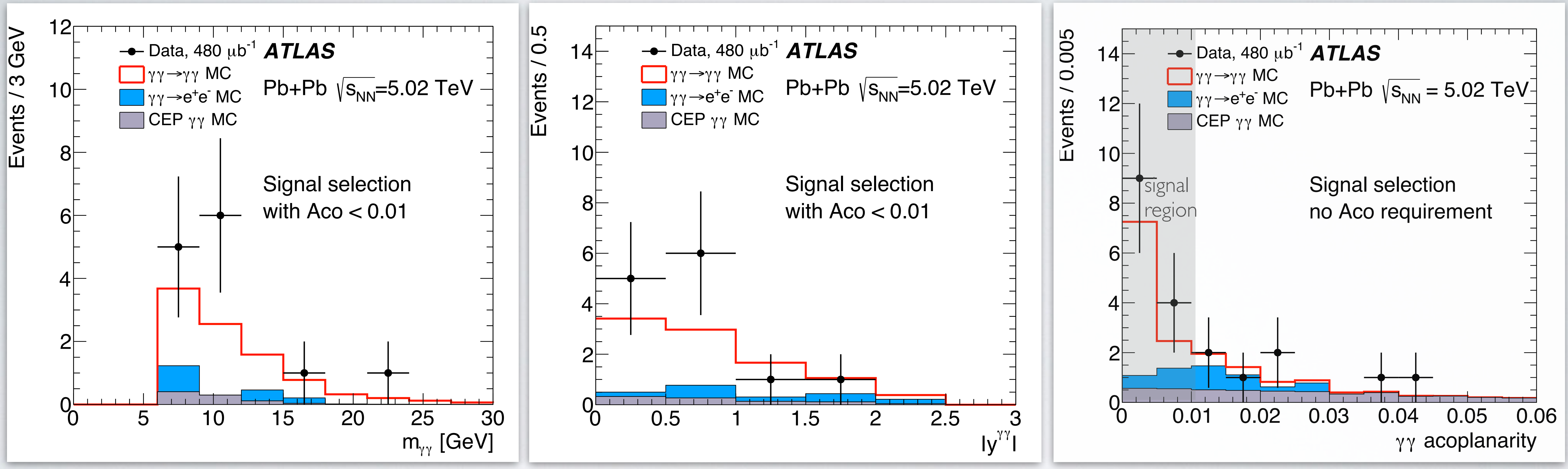




Invariant masses out to 20-25 GeV,
Pair rapidity out to 2

Clear enhancement at low acoplanarity

ARTICLES

PUBLISHED ONLINE: 14 AUGUST 2017 | DOI: 10.1038/NPHYS4208

nature physics

OPEN

Evidence for light-by-light scattering in heavy-ion collisions with the ATLAS detector at the LHC

ATLAS Collaboration†

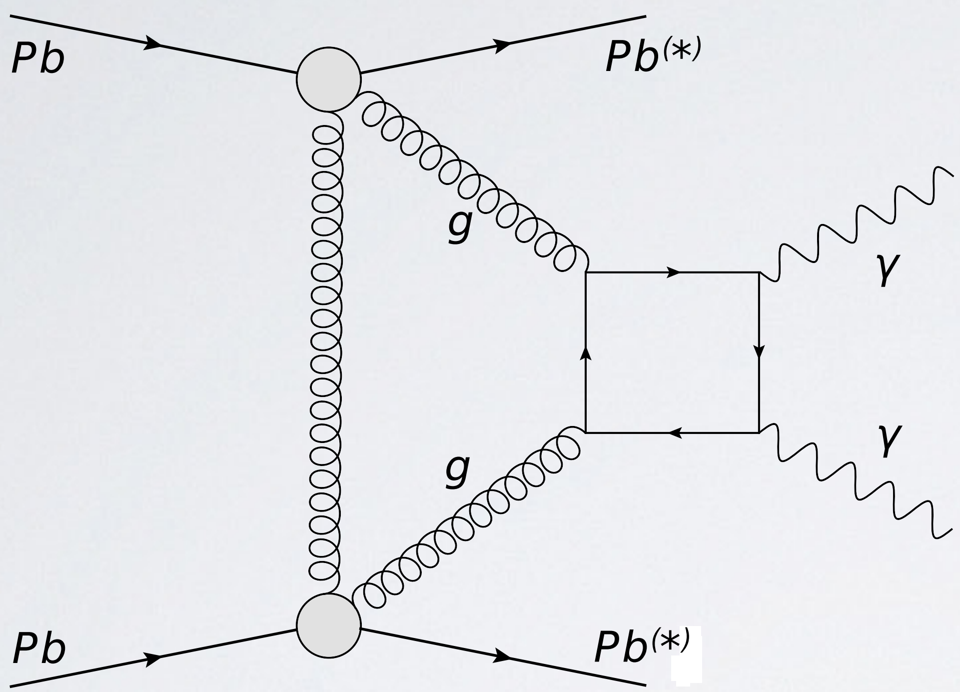
$\sigma_{fid} = 70 \pm 24$ (stat.) ± 17(syst) nb

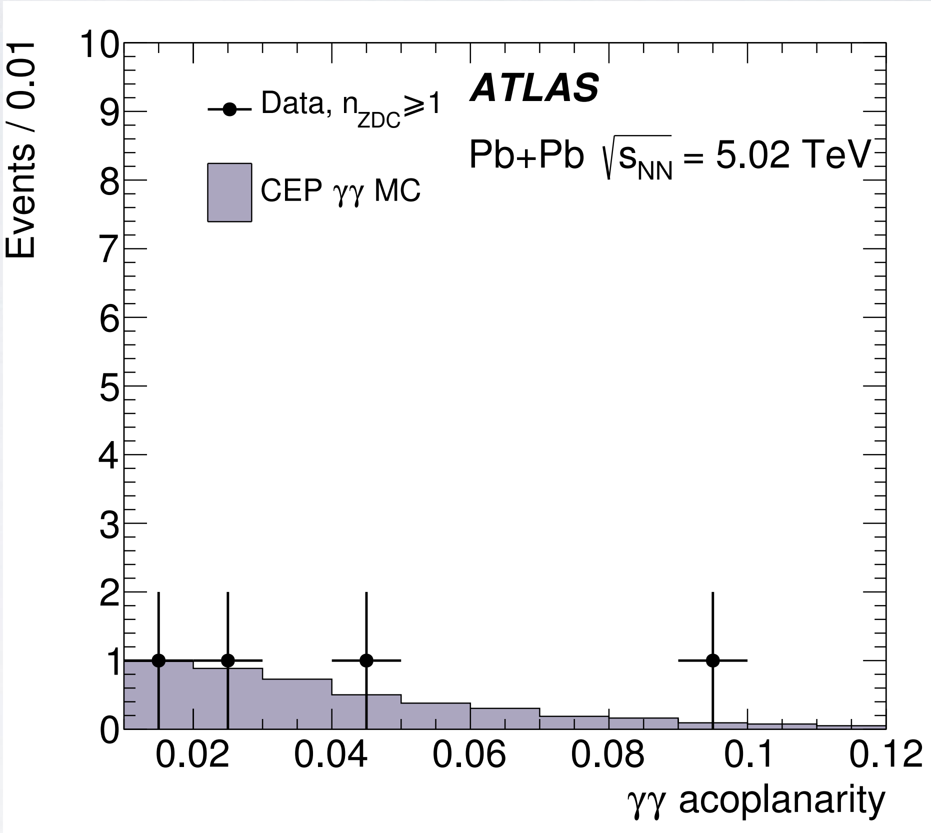
4.4σ significance observed
3.8σ expected

Looking forward to improvements in 2018!

ATLAS ZDC in light-by-light

Supplemental material at
http://dx.doi.org/10.1038/nphys4208

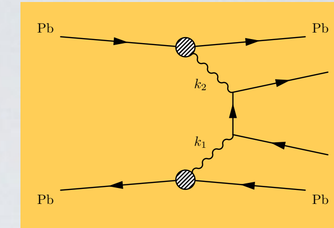


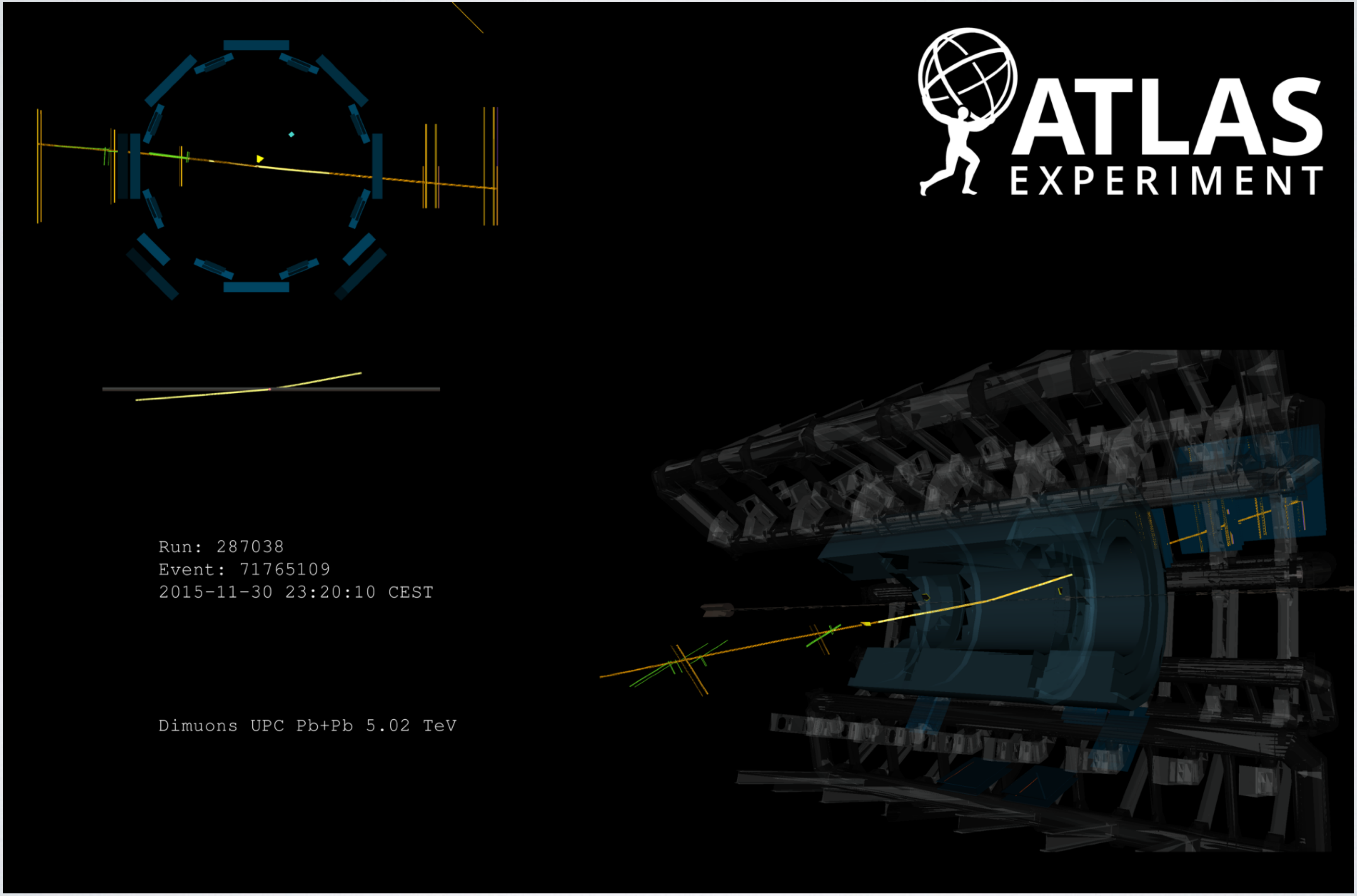


Light-by-light is pure γγ → no neutron production (modulo soft exchange)
background processes involving gluon exchange → neutrons in ZDC

Events with ZDC activity show broad acoplanarity distribution
validates use of expectations from SuperChic CEP

$\gamma\gamma$ processes: dileptons





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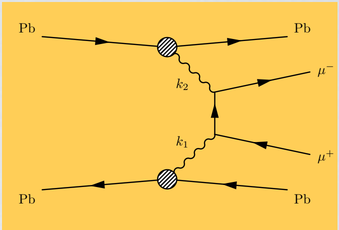
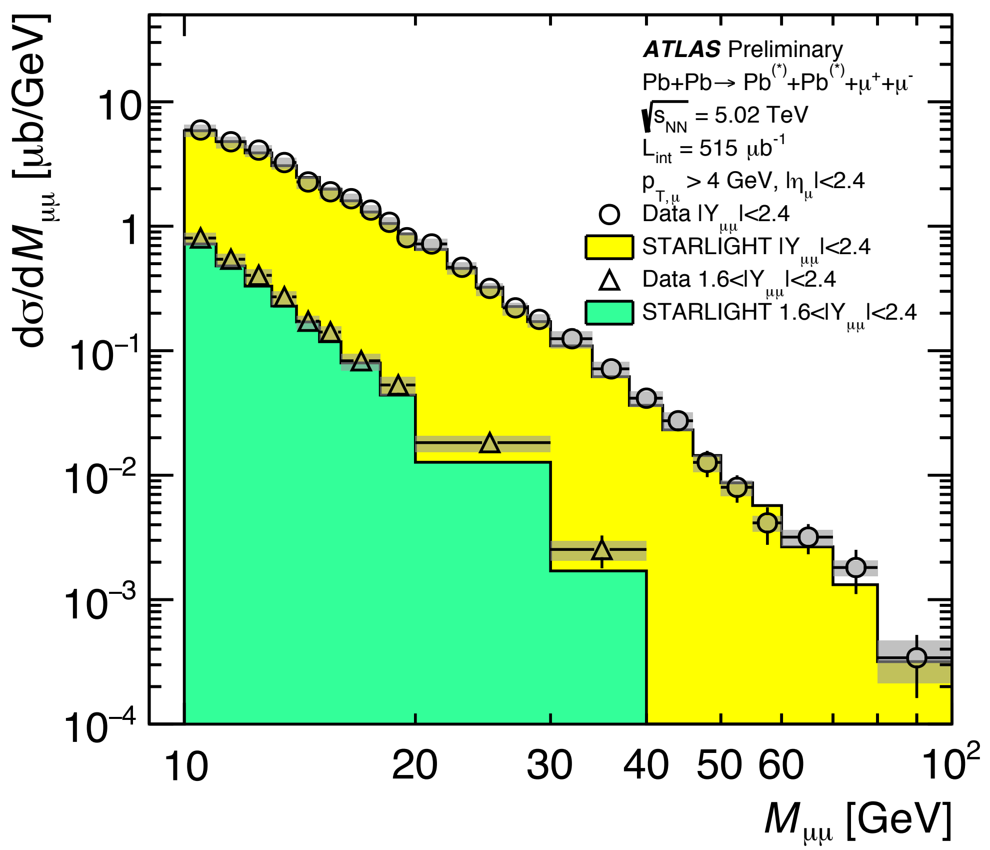
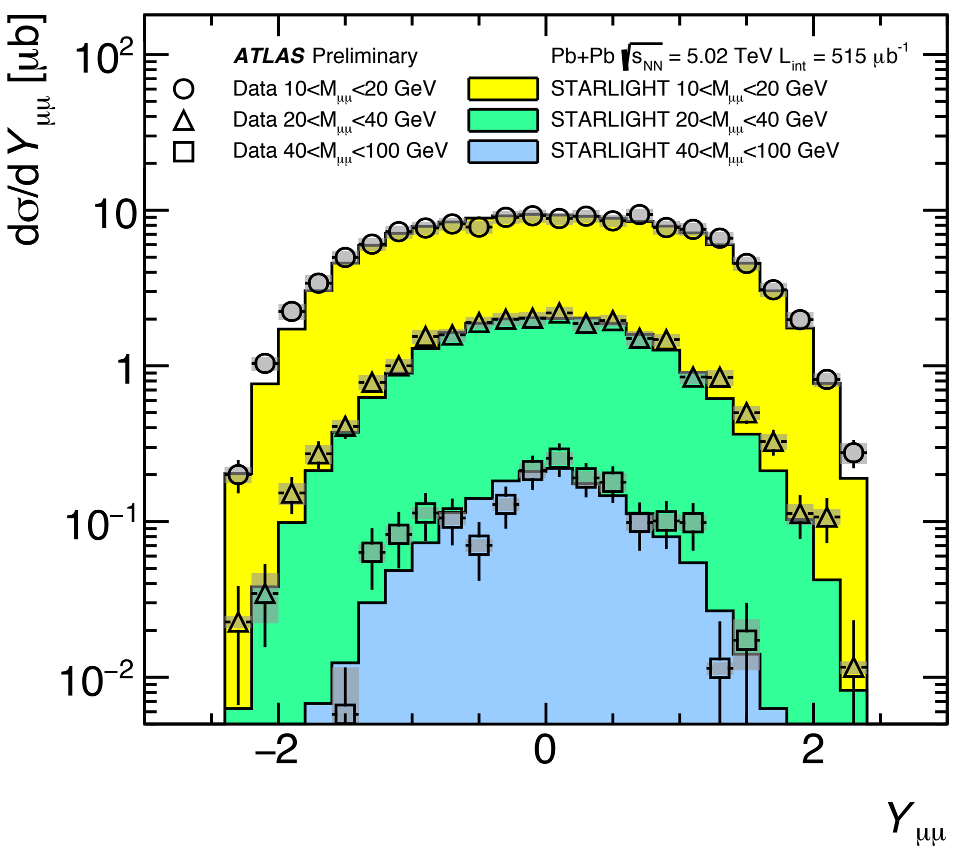


ATLAS-CONF-2016-025



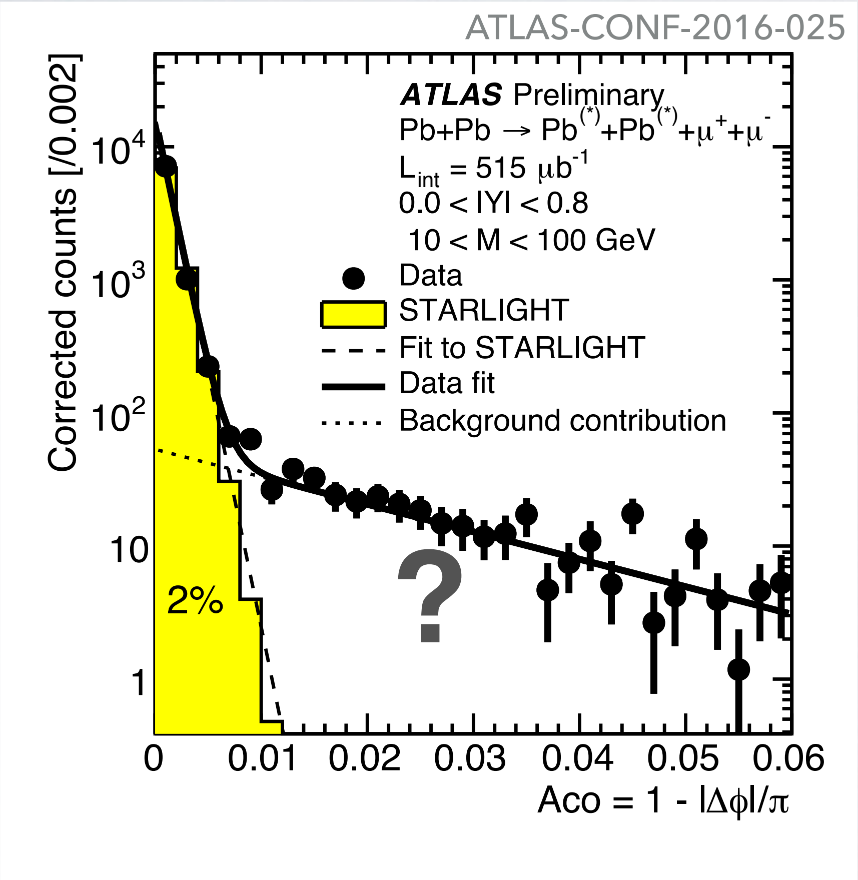


Trigger on muon + E_T < 50 GeV + 2 forward gaps

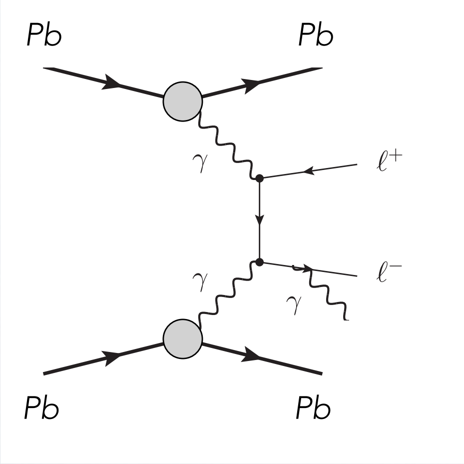
Select on 2 opposite charge muons and no other tracks in |η|<2.5

After all corrections: good agreement of μμ cross sections with STARLIGHT 1.1

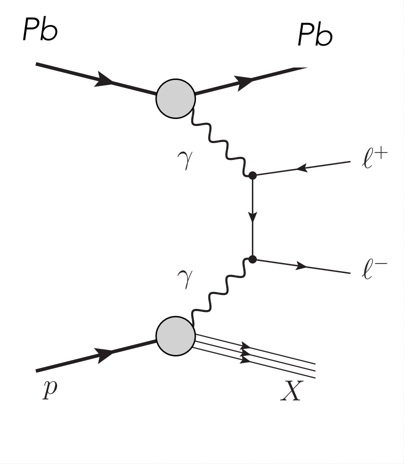
ZDC for dilepton production



NLO QED



dissociation



Pure γγ, but with better statistics than light-by-light: clean environment to study impact of soft photon exchange

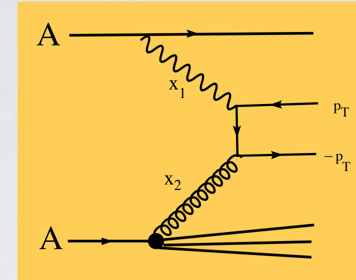
Also can study backgrounds:
Data shows clear, irreducible Aco tails, while simulated STARLIGHT provides only back-to-back dilepton production

Could expect contributions from NLO QED diagrams as well as dissociative processes

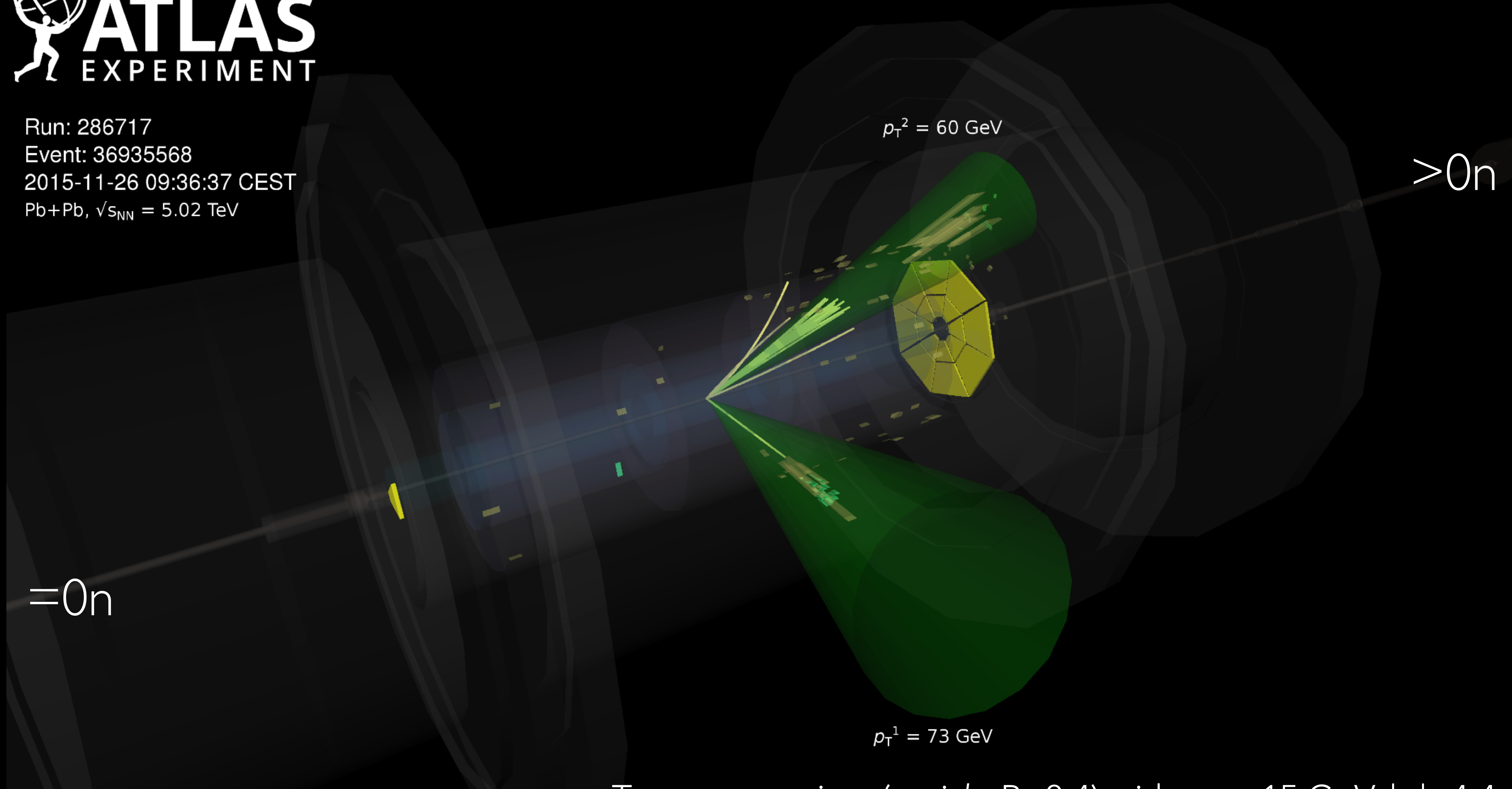
Similar to CEP, dissociative processes involve hard exchange and should lead to nuclear breakup

Work in progress, coming soon.

Photonuclear dijets

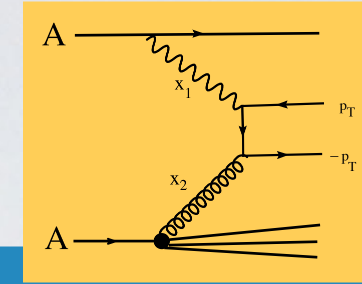


exclusive 1-arm ZDC used to trigger on these events



Two or more jets (anti-k_T R=0.4) with p_T > 15 GeV, $|\eta|$<4.4
At least one with p_T > 20 GeV, $|\Delta\phi|_{12}$ > 0.2, m_{jets} > 35 GeV

Photonuclear dijets

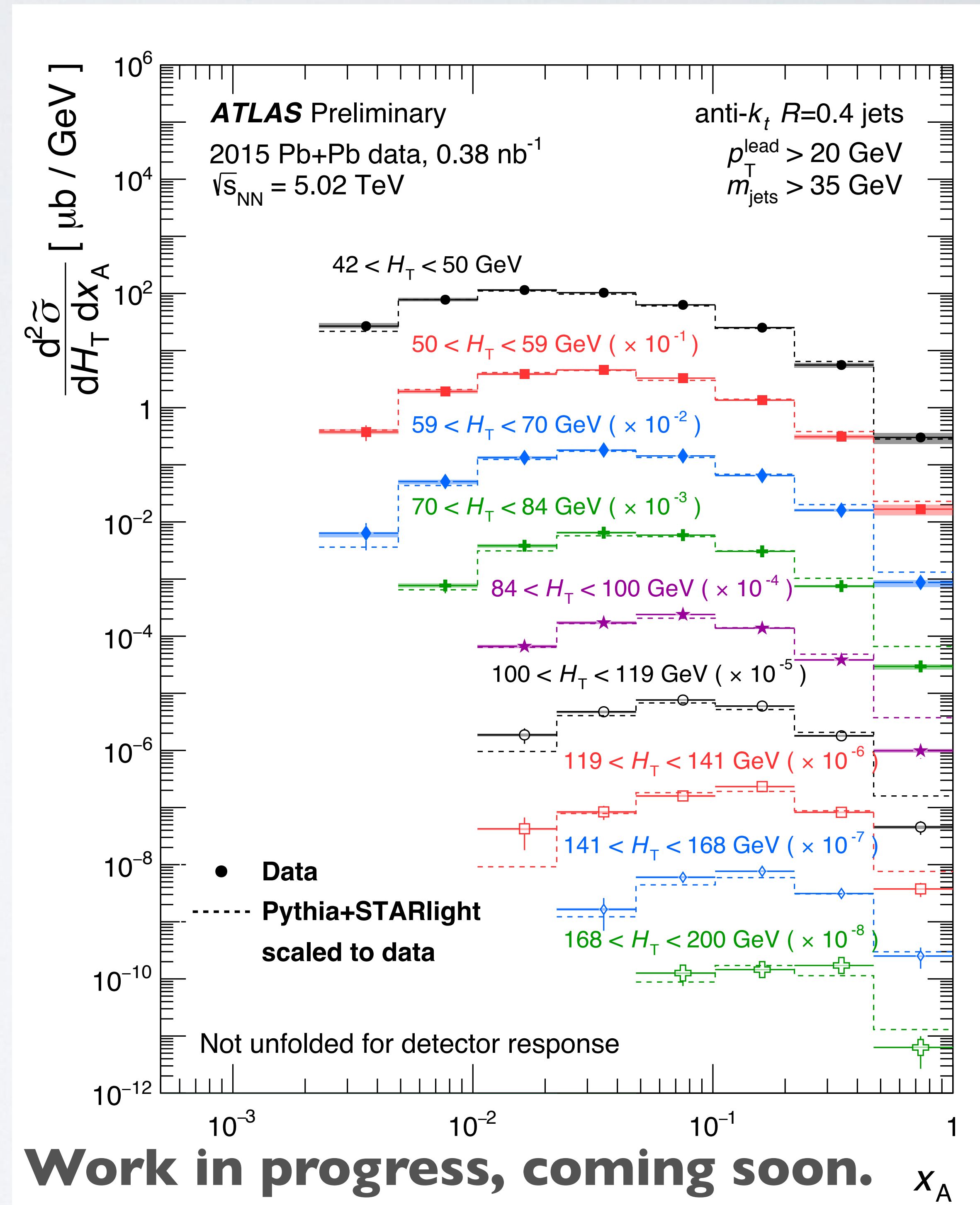


jet variables: $H_\mathrm{T} \equiv \sum_i p_{\mathrm{T}\,i}\,,\;\; x_\mathrm{A} \equiv \frac{m_\mathrm{jets}}{\sqrt{s}} e^{-y_\mathrm{jets}}$

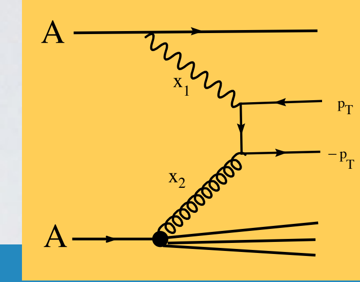
gap selection to reject γγ while accepting resolved photon production.

Need to also include diffractive contributions w/o ZDC trigger

A. Angerami, QM18



Photonuclear dijets



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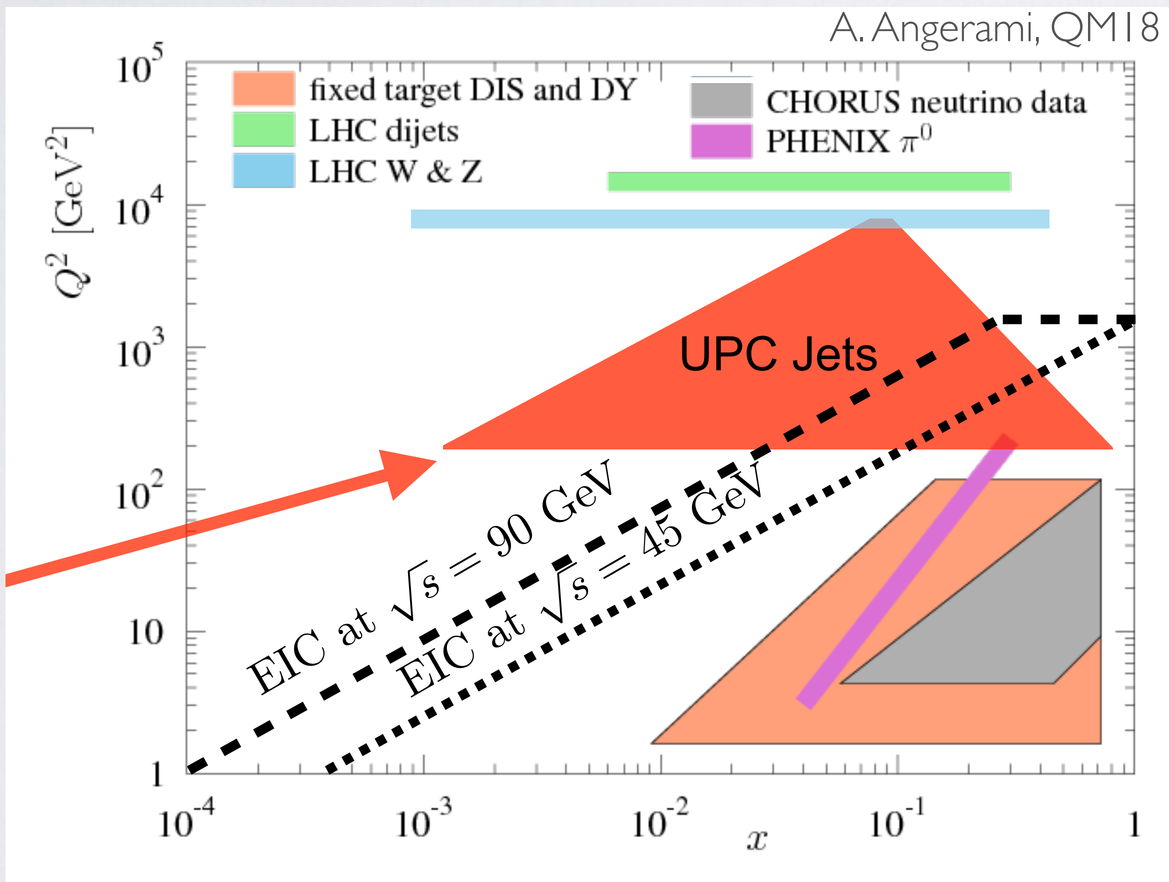
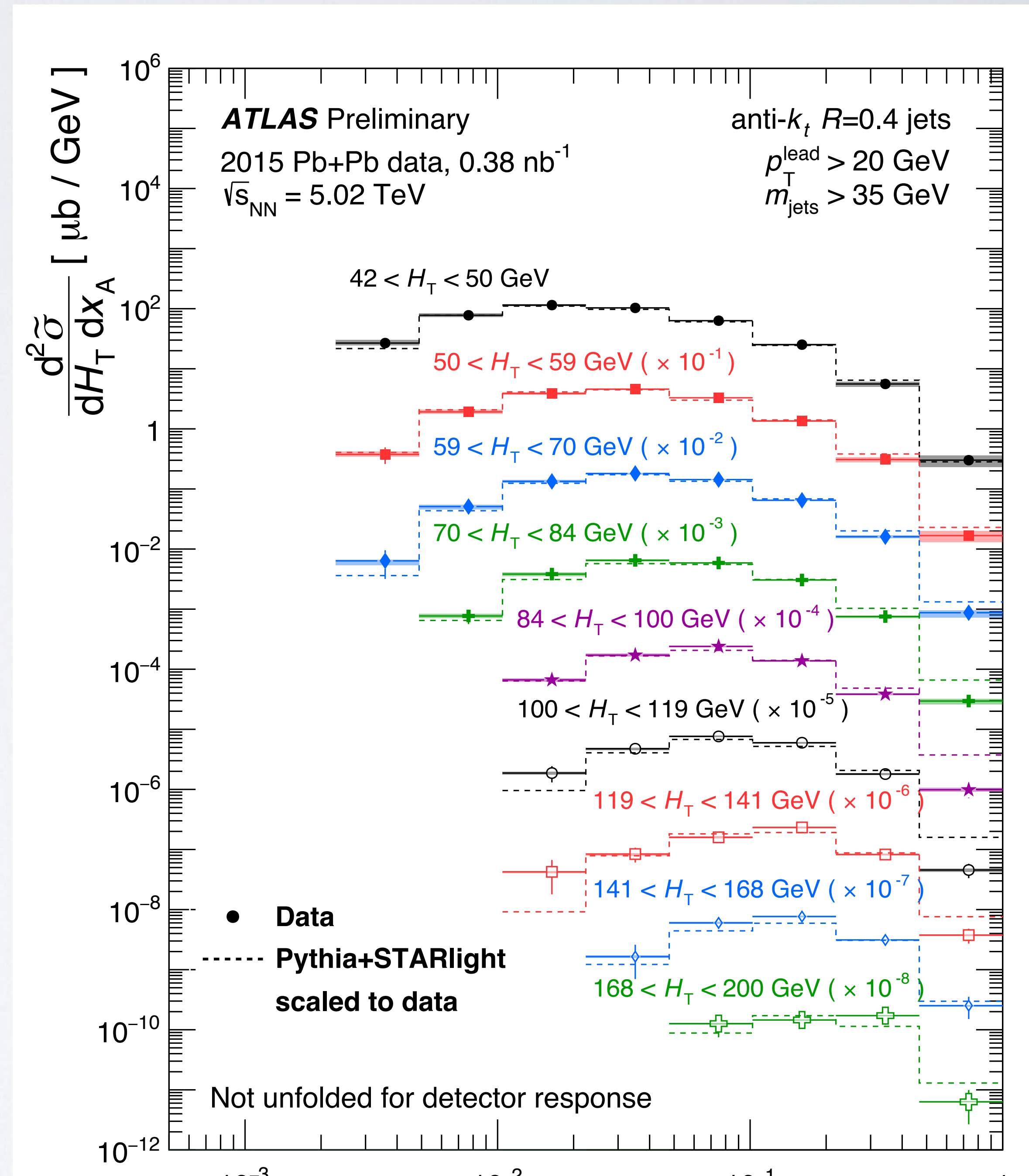


Some overlap with EIC: access to eA physics



Work in progress, coming soon.

Conclusions

- ZDC plays a central role in ATLAS HI program
  - *Distinguishes between hadronic and EM induced reactions*
  - *Central role in minbias & UPC trigger schemes*
- Use cases of ATLAS ZDC discussed for
  - *Event selection/centrality confirmation*
  - *Characterizing backgrounds in light-by-light*
  - *Studying soft photon exchange and backgrounds in UPC dilepton production*
  - *Selection of photonuclear dijet events*
- Upgrade design underway for Runs 3/4:
  - *joint R&D efforts between ATLAS & CMS*
  - *Discussed in detail in next talk*