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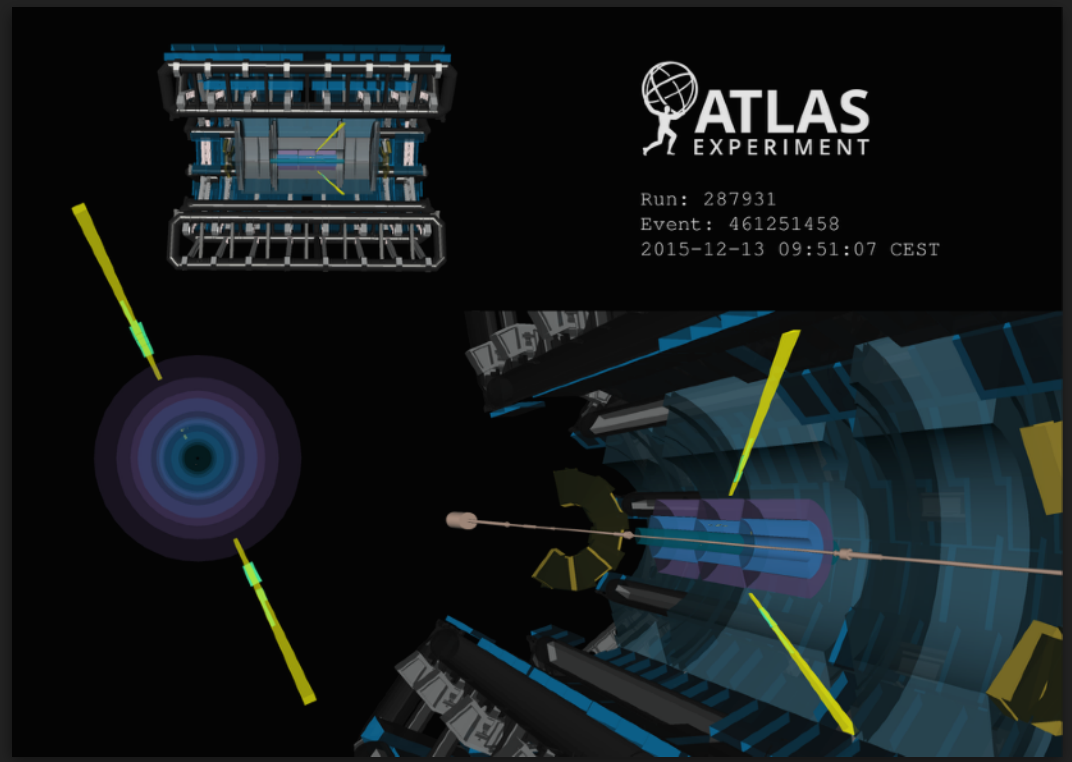
NYGAVIK
GOTHI
HELGALA
TERRA NOBILIVM
FELBORG
HORV PISCIV CAPITIBVS VTVNTVR LOCO LIGNO
FISCA
STEK

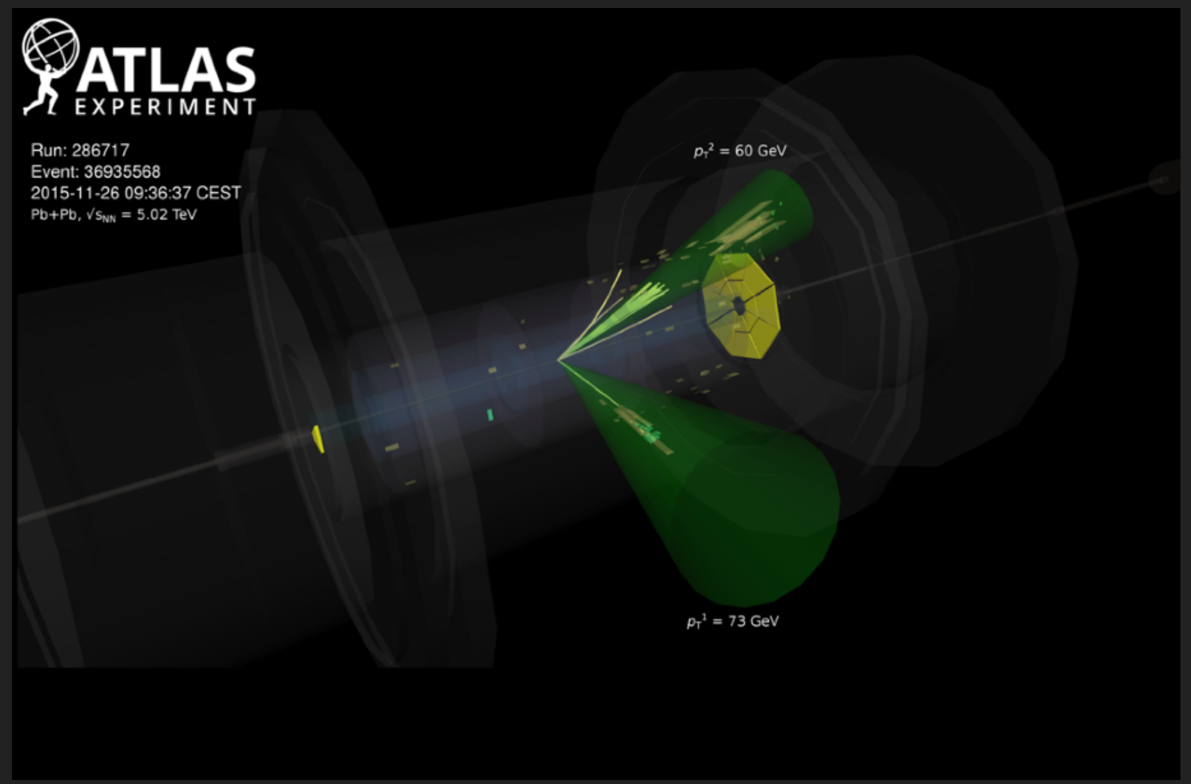
with 16:9 format

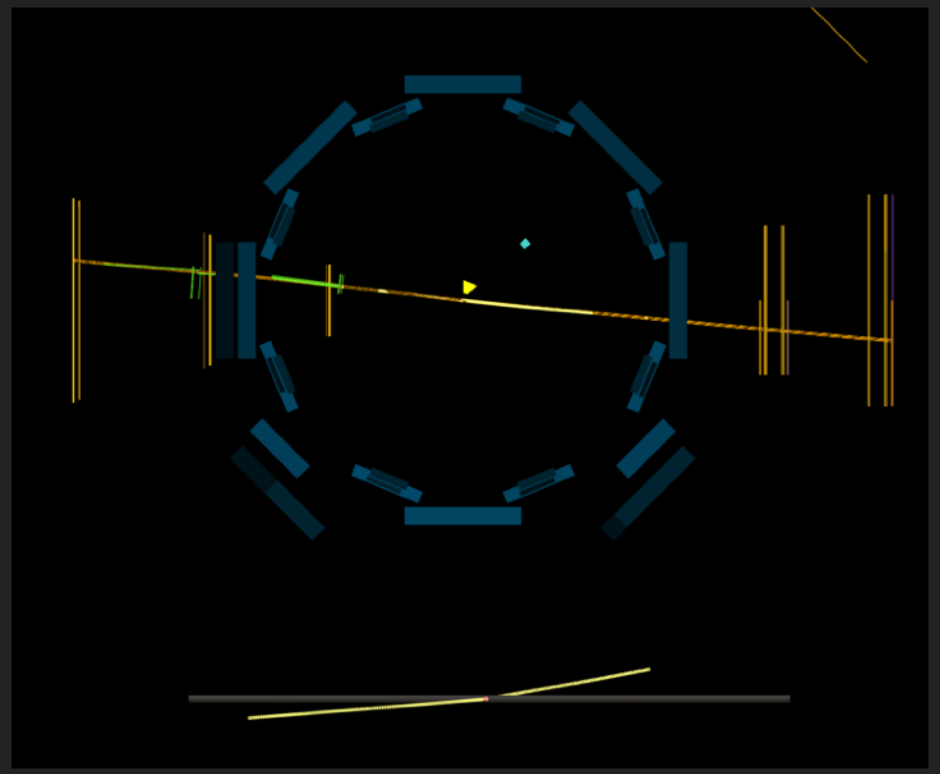
…here be dragons…

…& there be dragons!

ATLAS EXPERIMENT





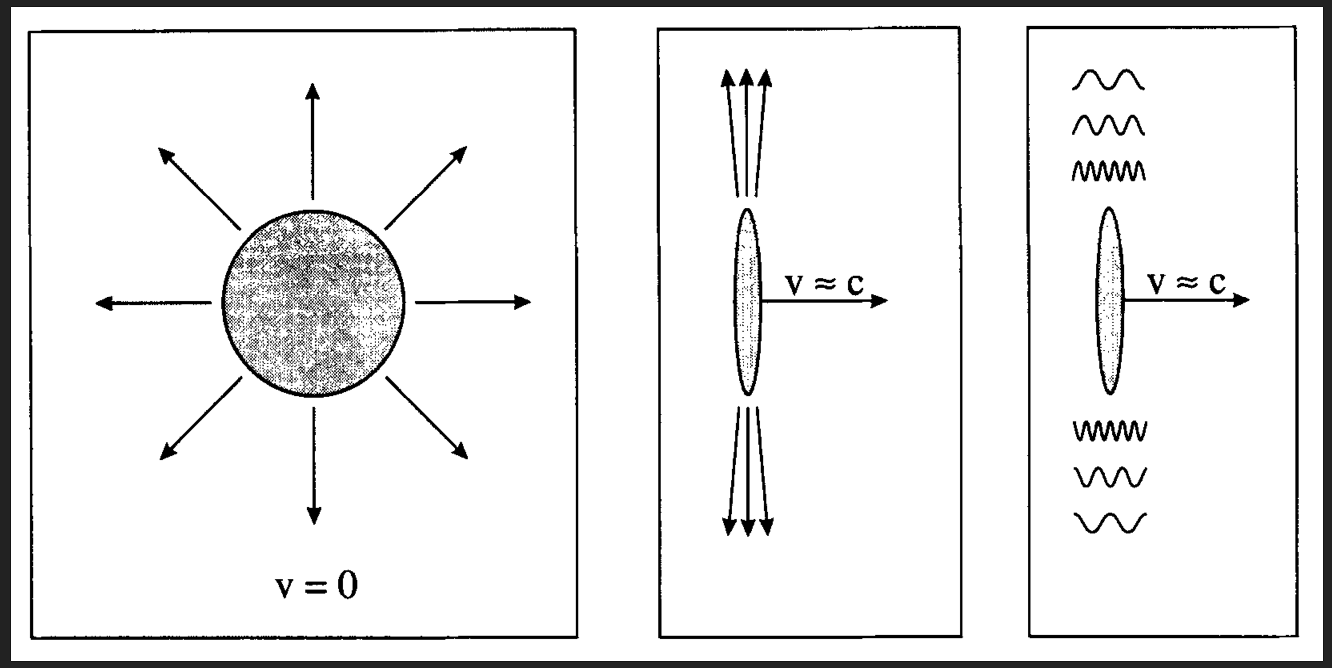


PETER STEINBERG, BNL FOR THE ATLAS COLLABORATION

ELECTROMAGNETIC PROCESSES WITH QUASIREAL PHOTONS IN PB+PB COLLISIONS: QED, QCD, AND THE QGP

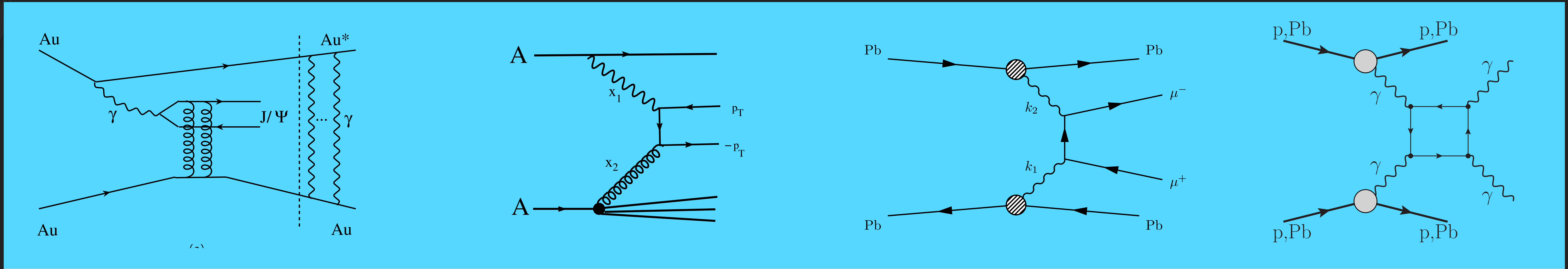
💡 🌈 🔥

QUASI-REAL PHOTONS FROM LEAD-NUCLEI



- Boosted nuclei are intense source of quasi-real photons
  - Typically treated using EPA (Weiszacker-Williams)
  - Quantize classical field
- Photons with E≲(ℏc/R)γ are produced coherently (Z^2)
  - Up to ~80 GeV for Pb+Pb @ 5.02 TeV, 1.4 TeV for p+p!

Experiments at RHIC & LHC have begun a systematic investigation of UPC, including:

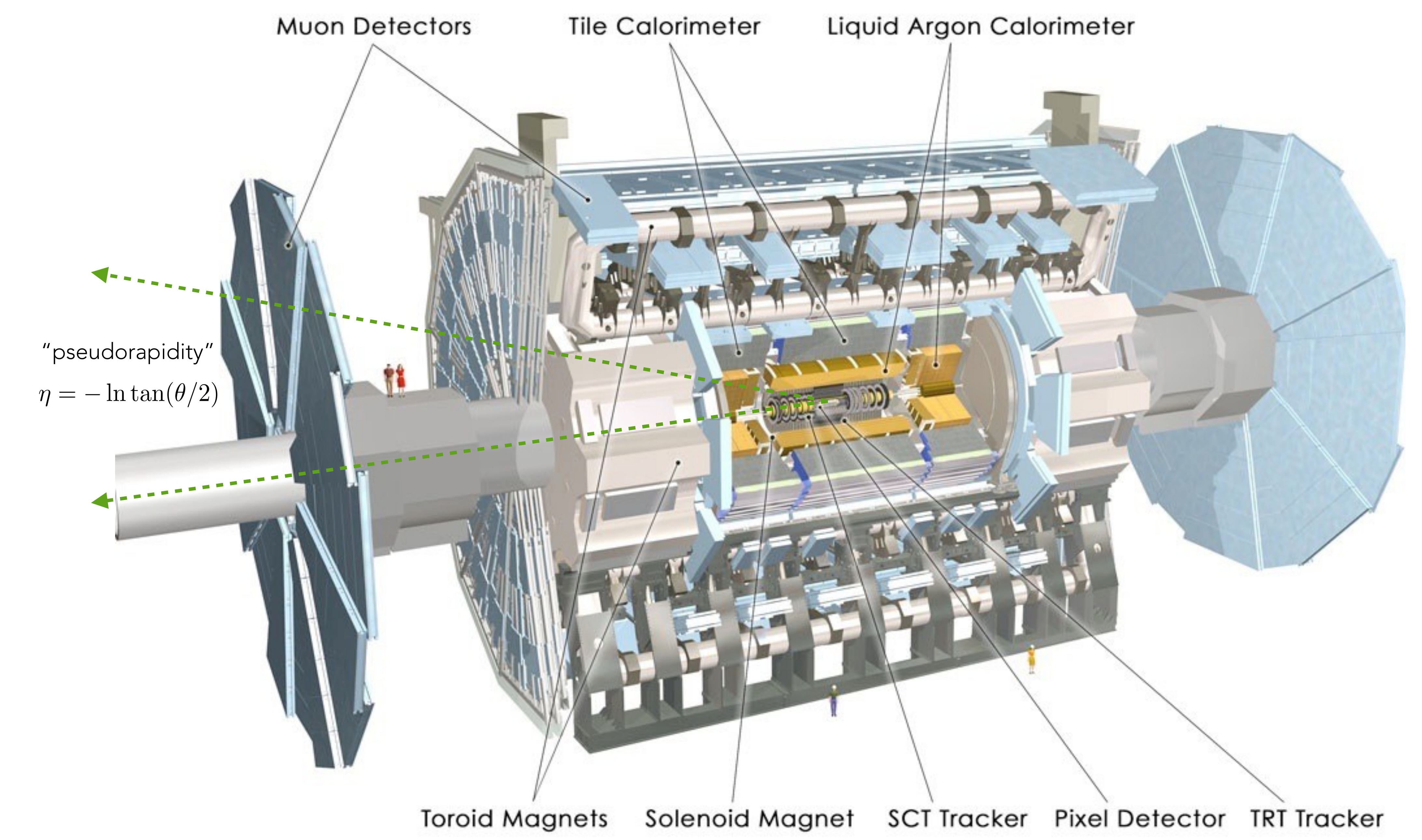


Photon-pomeron*:*
production of vector mesons
(sensitivity to nPDF)

Photo-nuclear*:*
jet photoproduction
(probe nPDF directly)

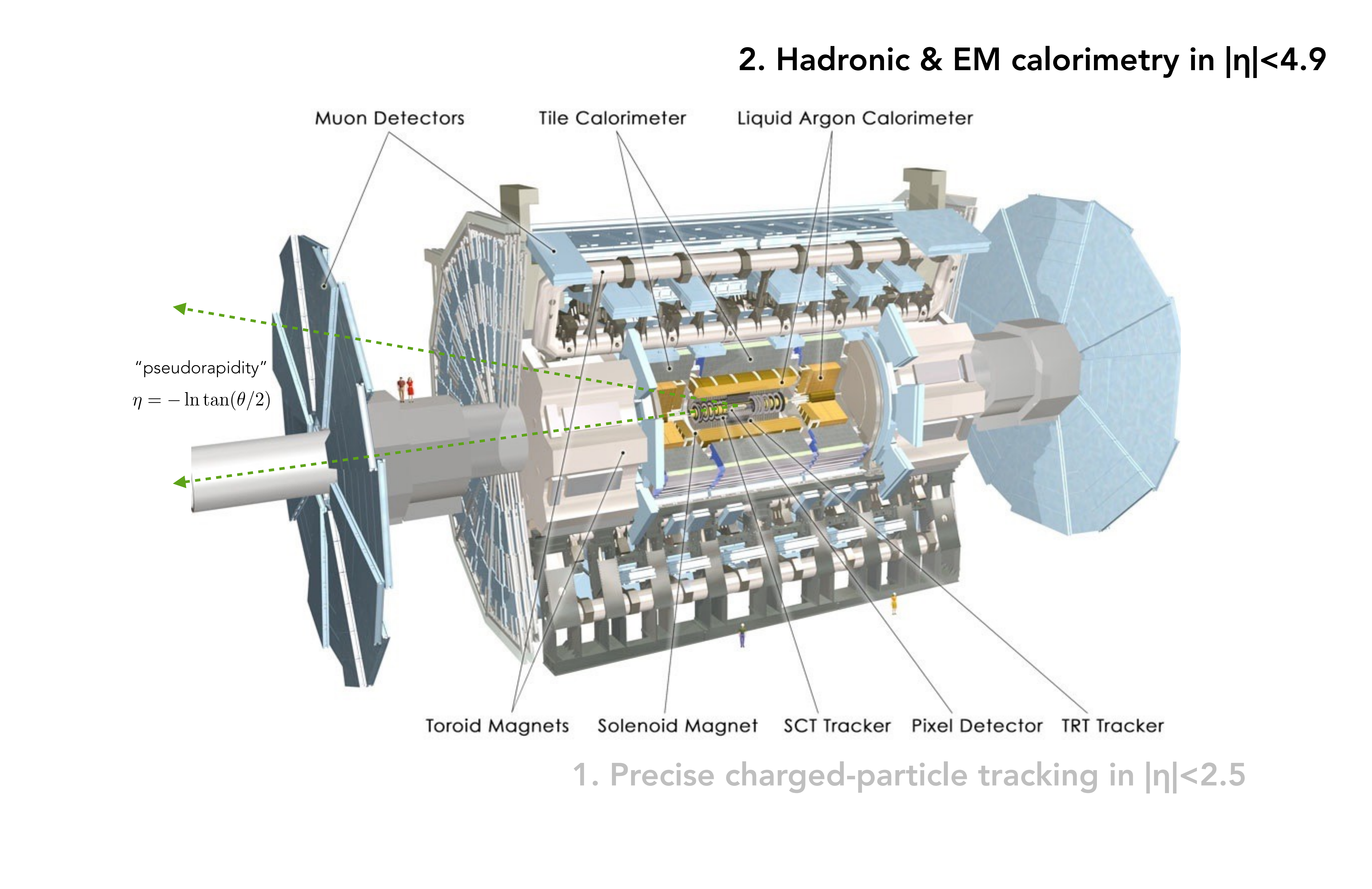
Photon-photon*:*
dilepton, ***diphoton!***
(& other exclusive states)

ATLAS DETECTOR



1. Precise charged-particle tracking in |η|<2.5

ATLAS DETECTOR

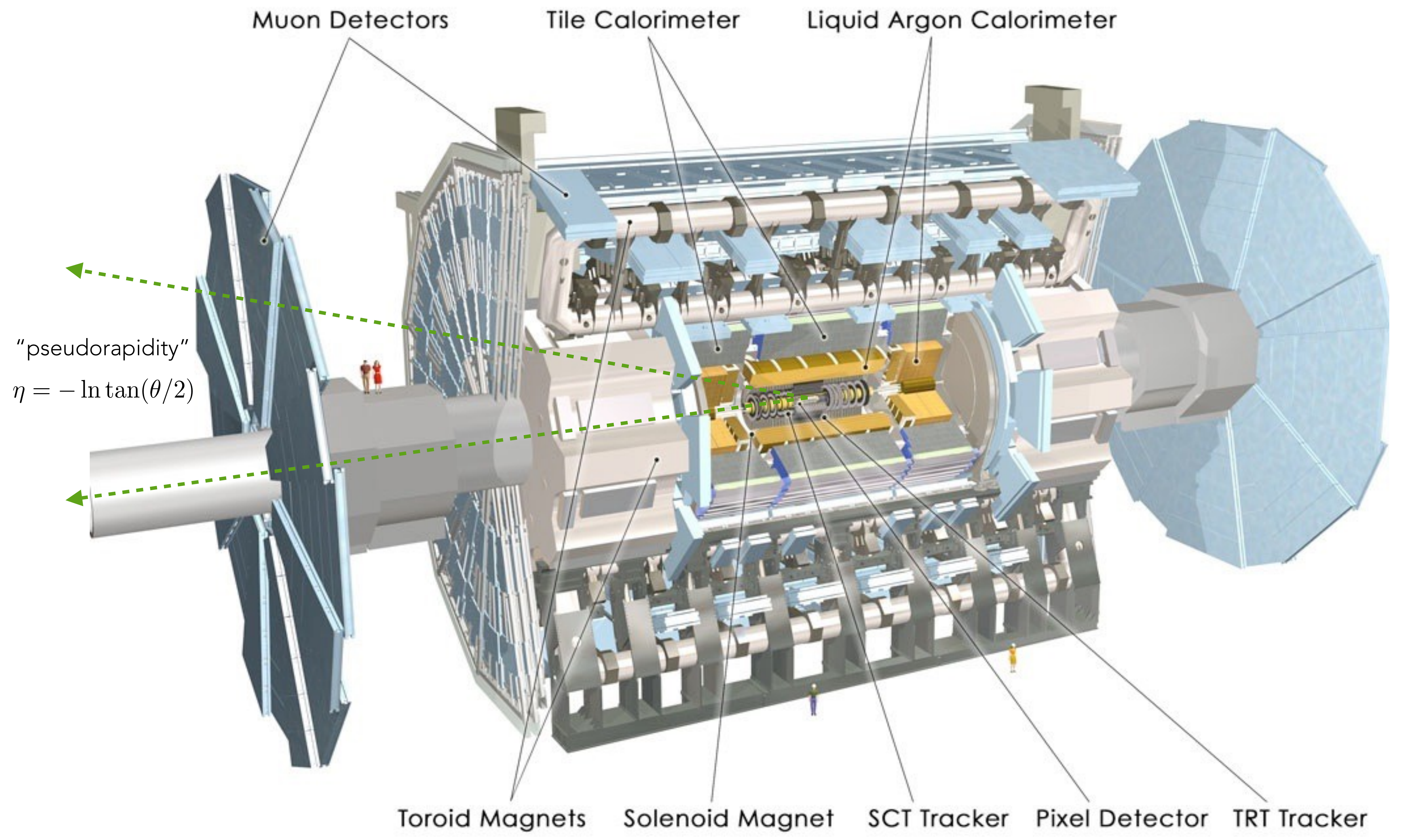


ATLAS EXPERIMENT

ATLAS DETECTOR

3. Precise μ tracking in |η|<2.7

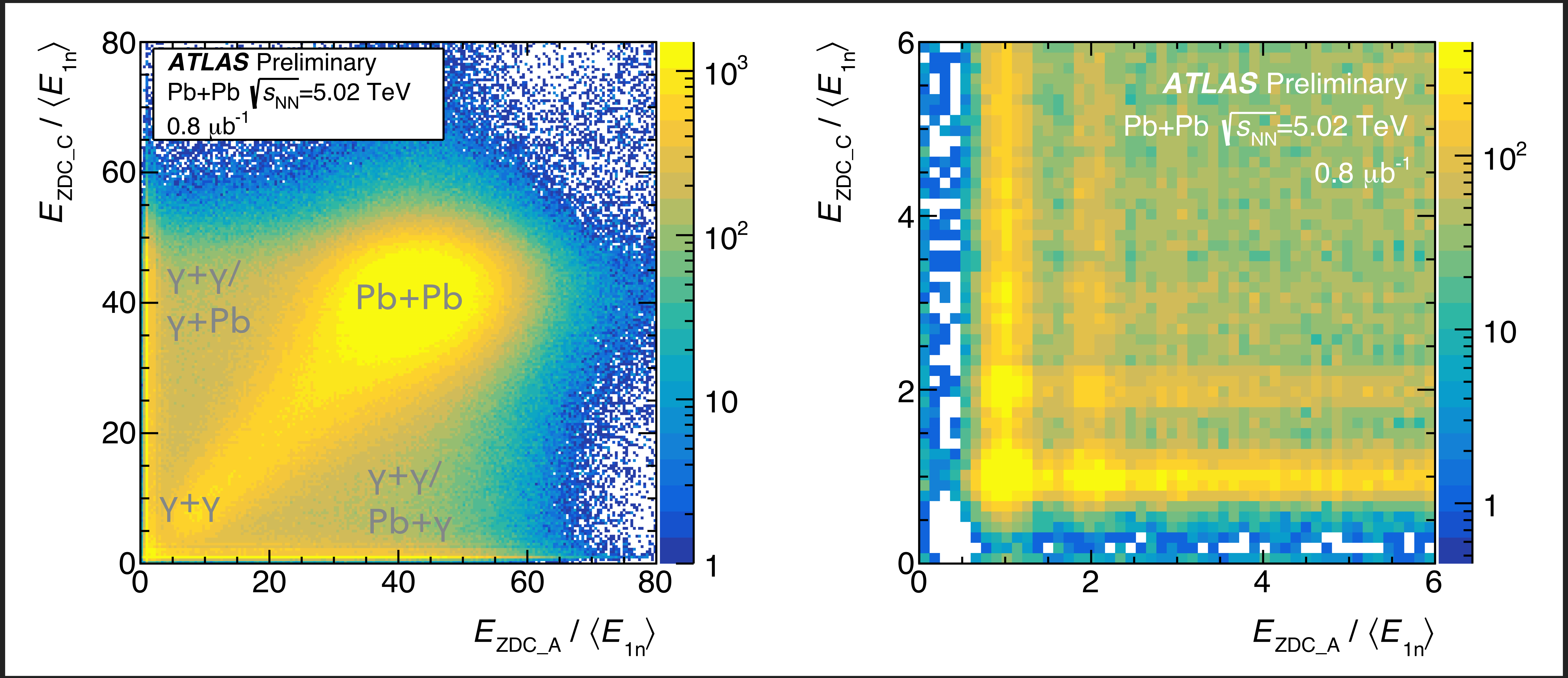
2. Hadronic & EM calorimetry in |η|<4.9

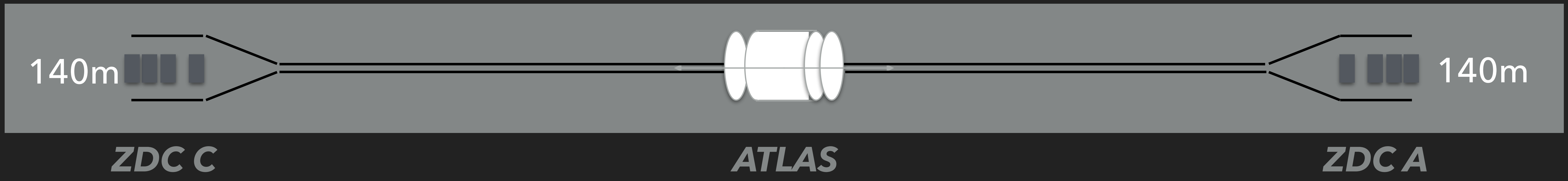


1. Precise charged-particle tracking in |η|<2.5

Exclusive final-states require a fully-hermetic detector!

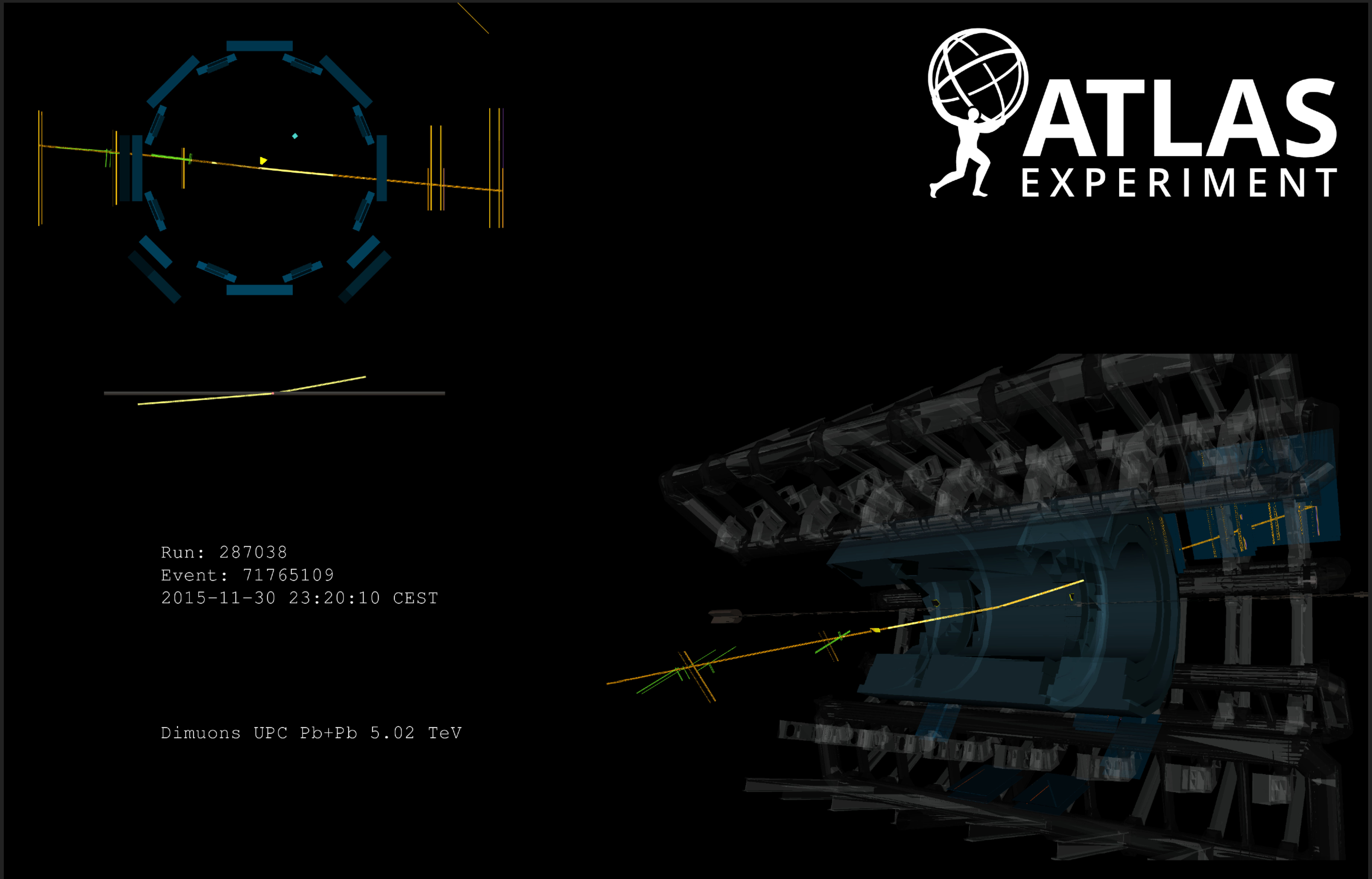
ZERO DEGREE CALORIMETERS





https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/HION-2015-001/

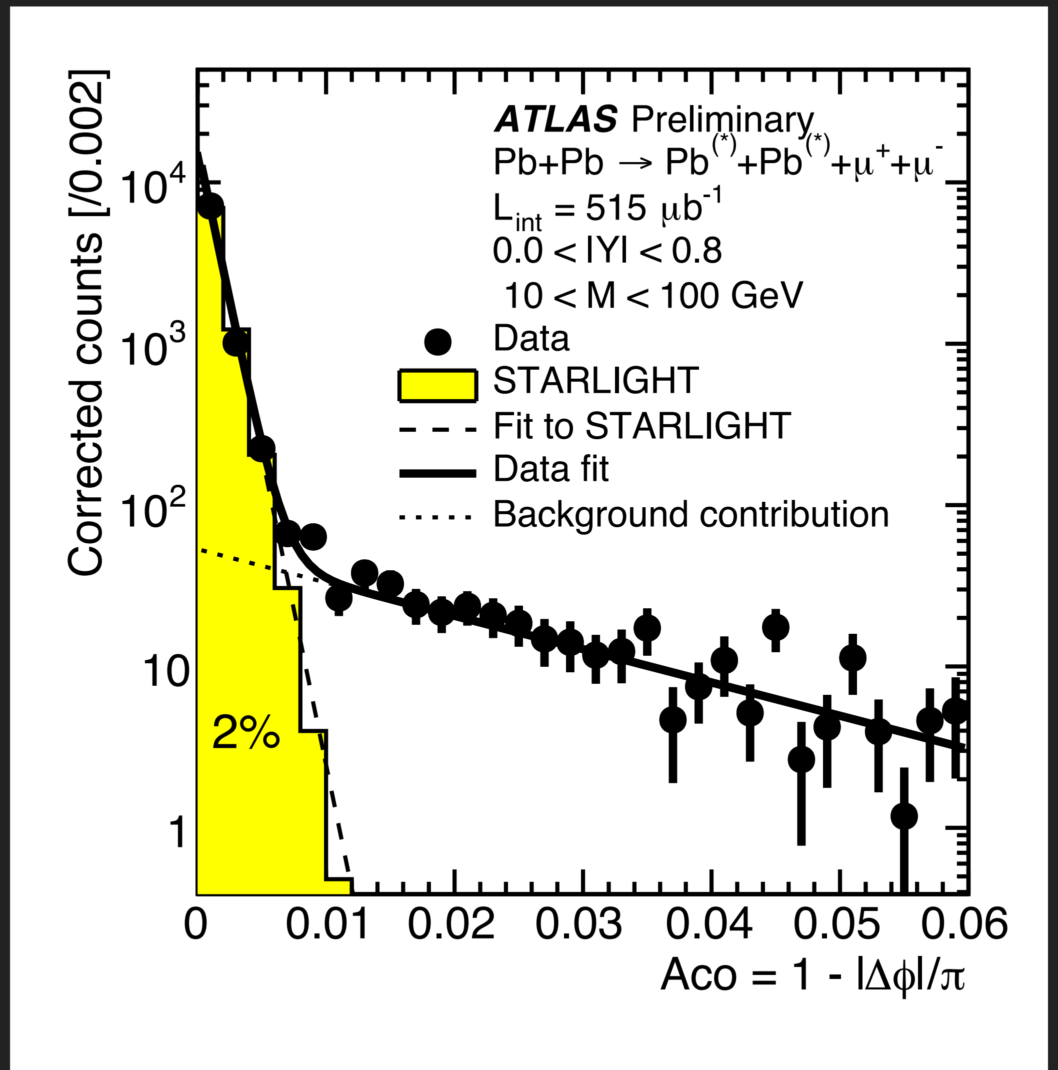
M=173 GEV EXCLUSIVE DIMUON EVENT

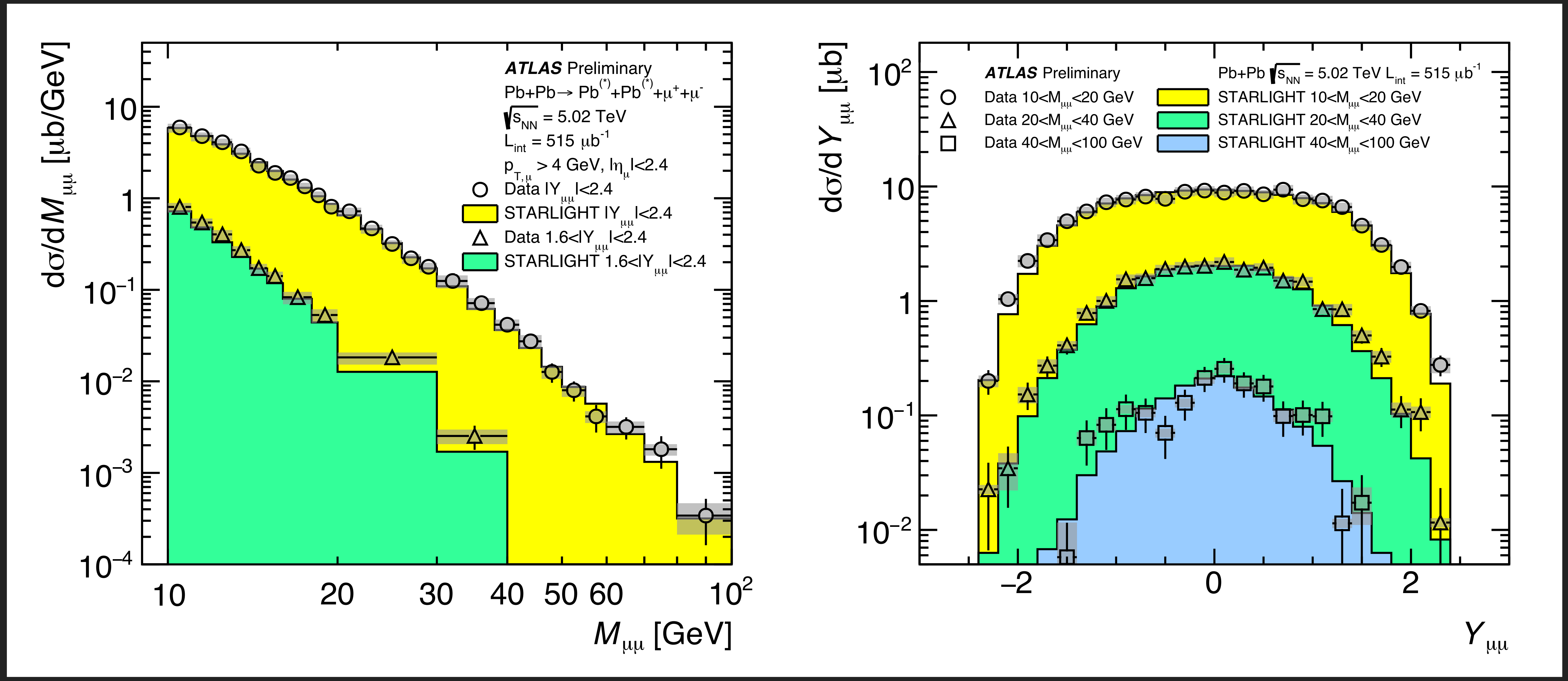


ATLAS EXPERIMENT

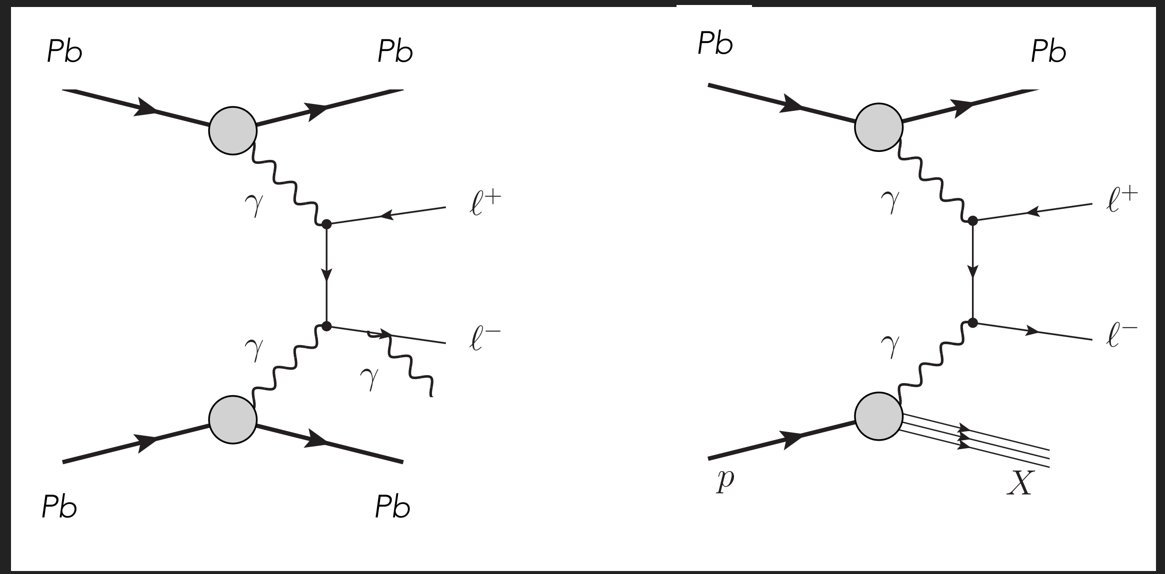
EXCLUSIVE DIMUON PRODUCTION

ATLAS-CONF-2016-025





NLO QED dissociation

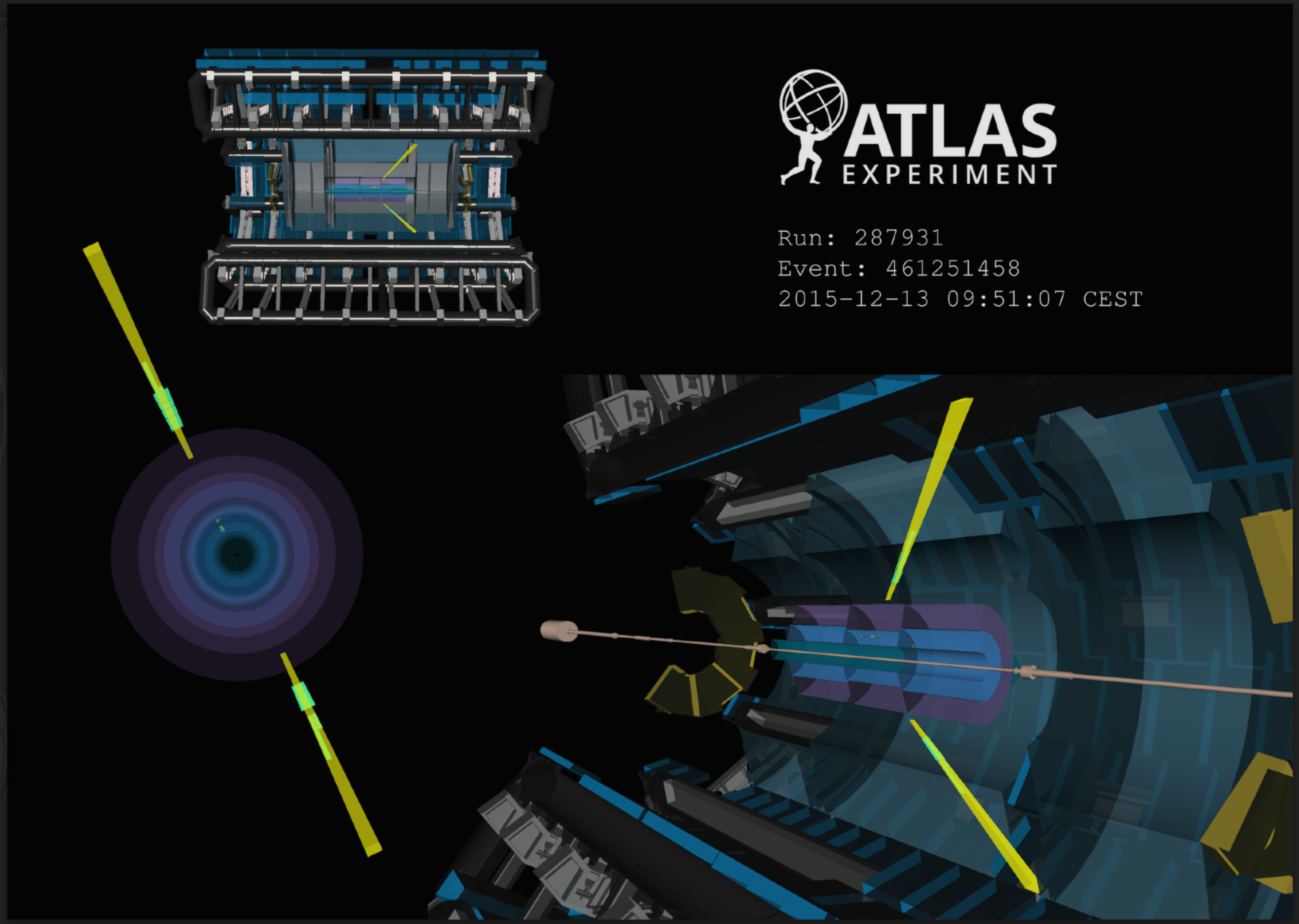


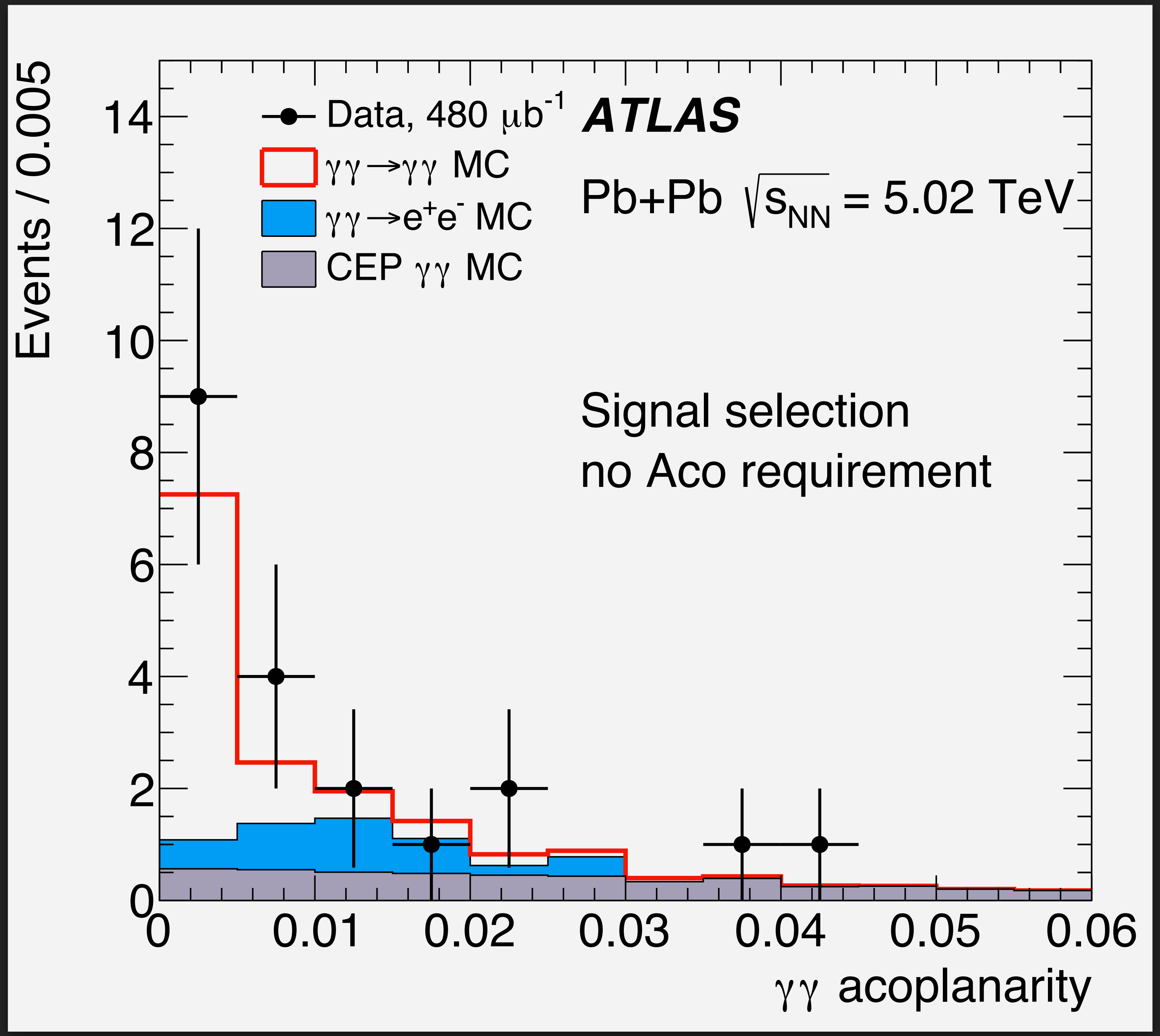
Exclusive dimuon event distributions corrected for trigger, reco & vertex efficiency, systematics cover whether long Aco tails are all signal or all background

STARLIGHT 1.1 provides good description of fully-corrected dimuon distributions, with hint of small excess at high $Y_{\mu\mu}$ (but NB missing physics: e.g. higher-order QED)

LIGHT-BY-LIGHT SCATTERING

https://doi.org/10.1038/NPHYS4208





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

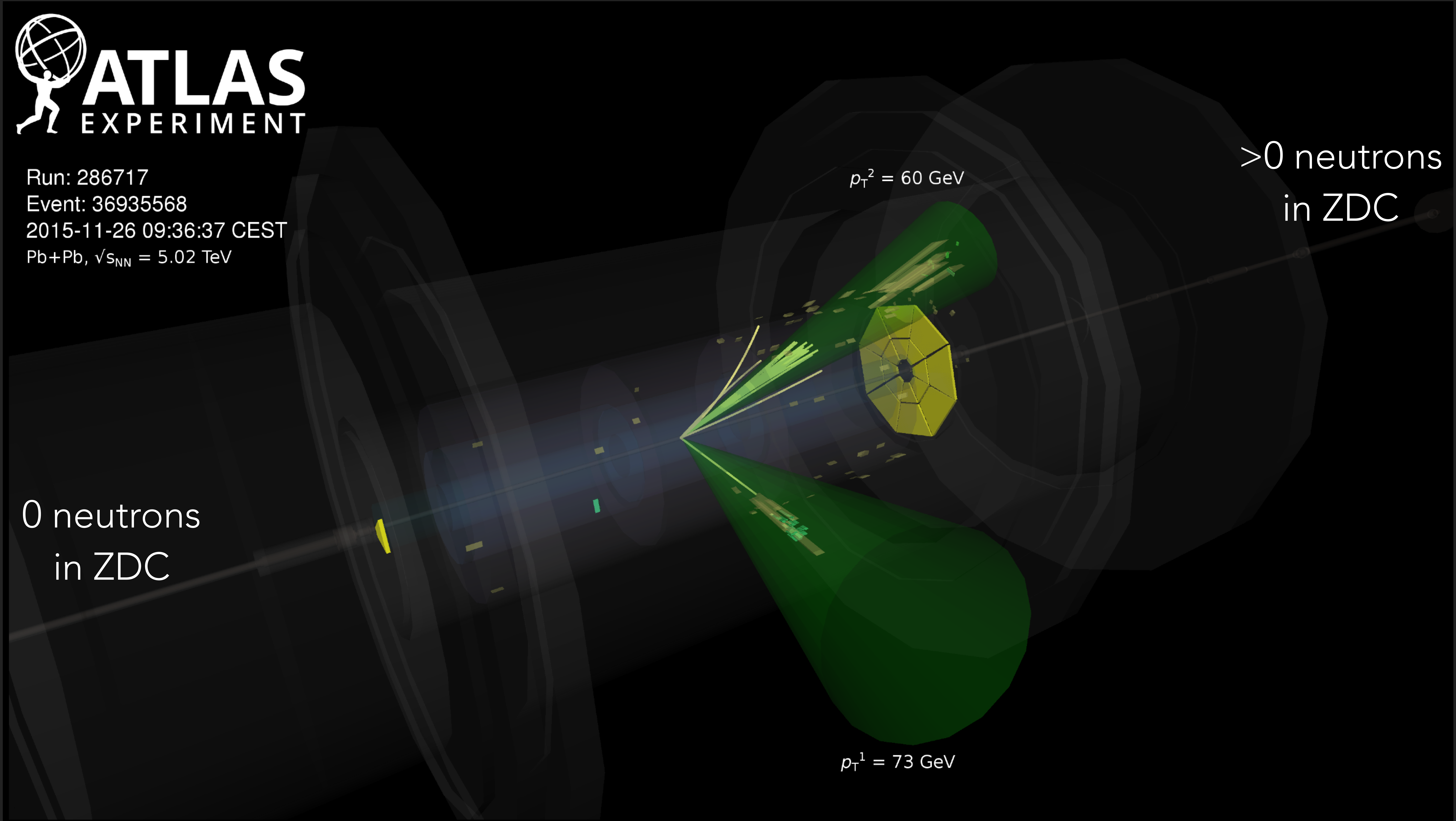
ATLAS Collaboration†

σ_{fid} = 70±24 (stat.) ±17(syst) nb

4.4σ significance observed
3.8σ expected

PHOTONUCLEAR DIJETS

ATLAS-CONF-2017-011

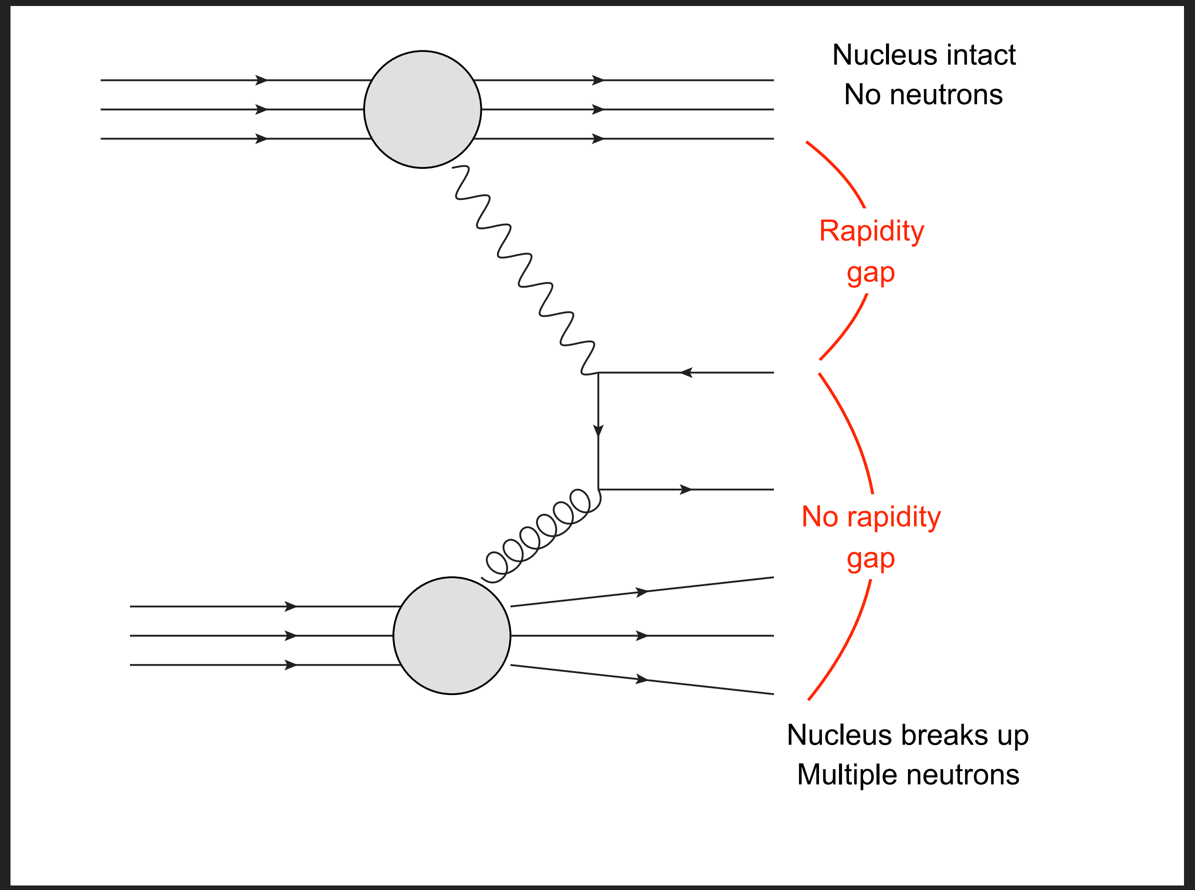


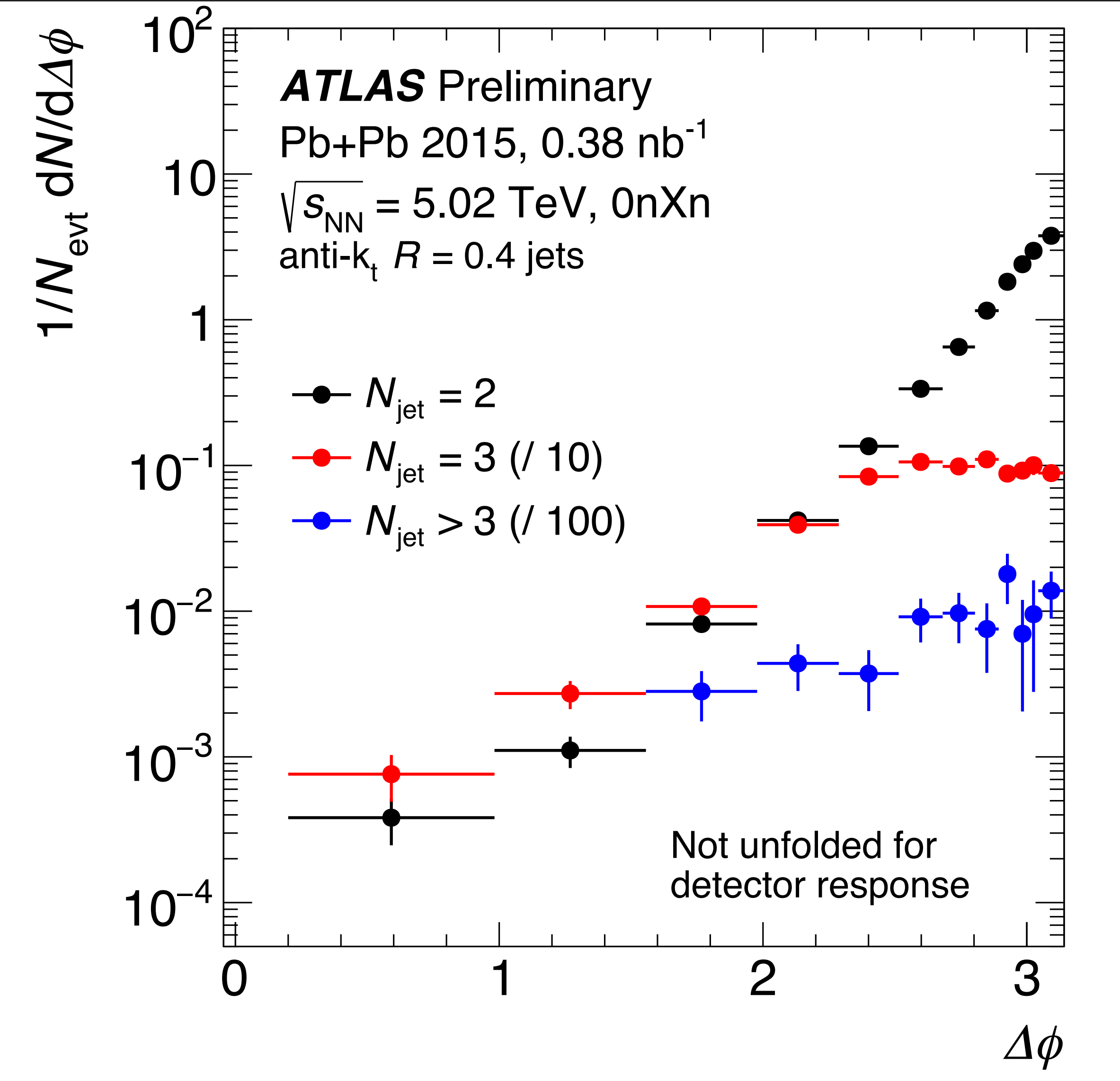
Two or more jets (anti-k_T R=0.4) with p_T > 15 GeV, $|\eta|$<4.4
At least one with p_T > 20 GeV, $|\Delta\phi|_{12}$ > 0.2, m_{jets} > 35 GeV

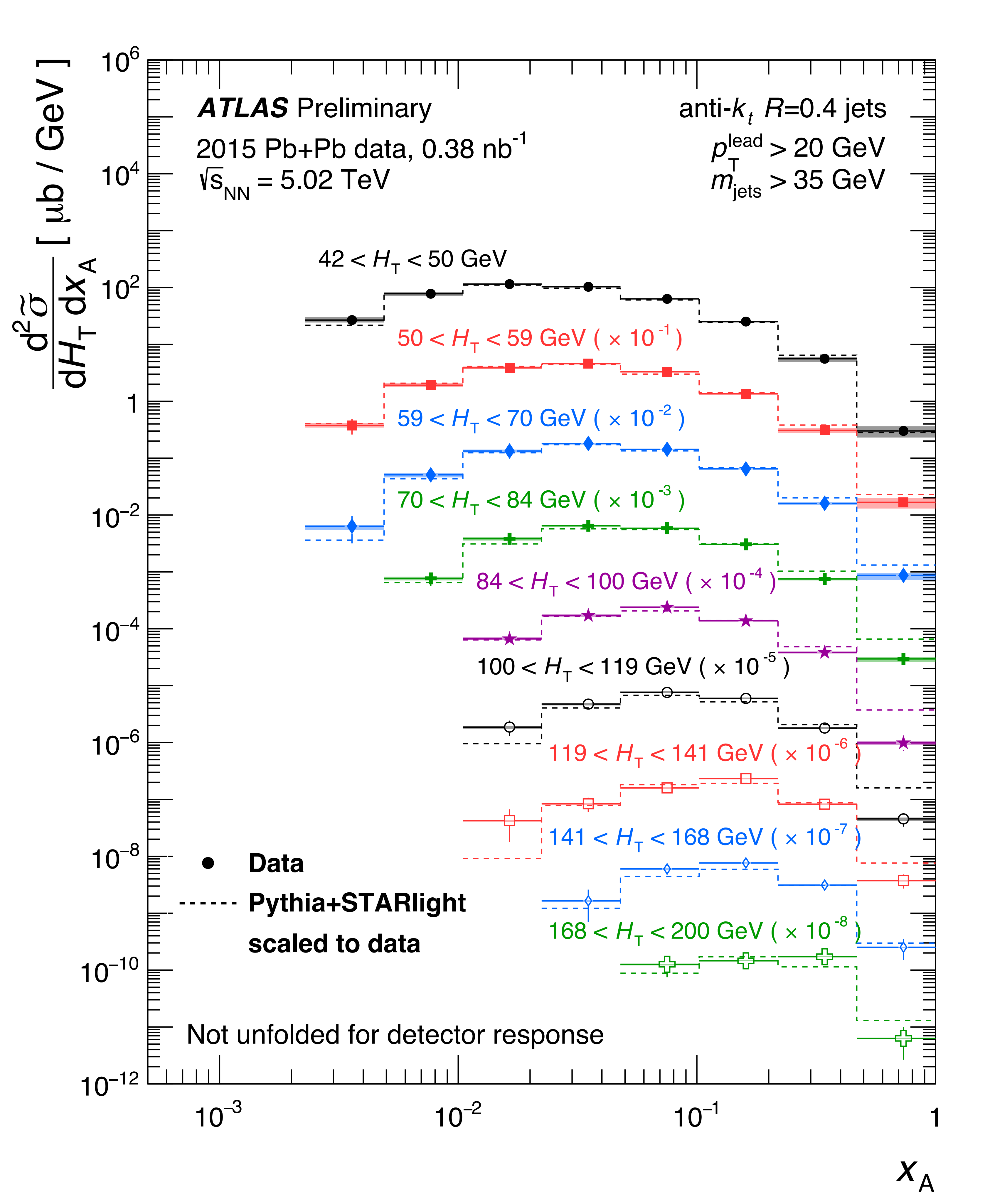
ATLAS EXPERIMENT

PHOTONUCLEAR DIJETS

jet variables: $H_T \equiv \sum_i p_{T\,i}\,, \quad x_A \equiv \frac{m_{\rm jets}}{\sqrt{s}} e^{-y_{\rm jets}}$







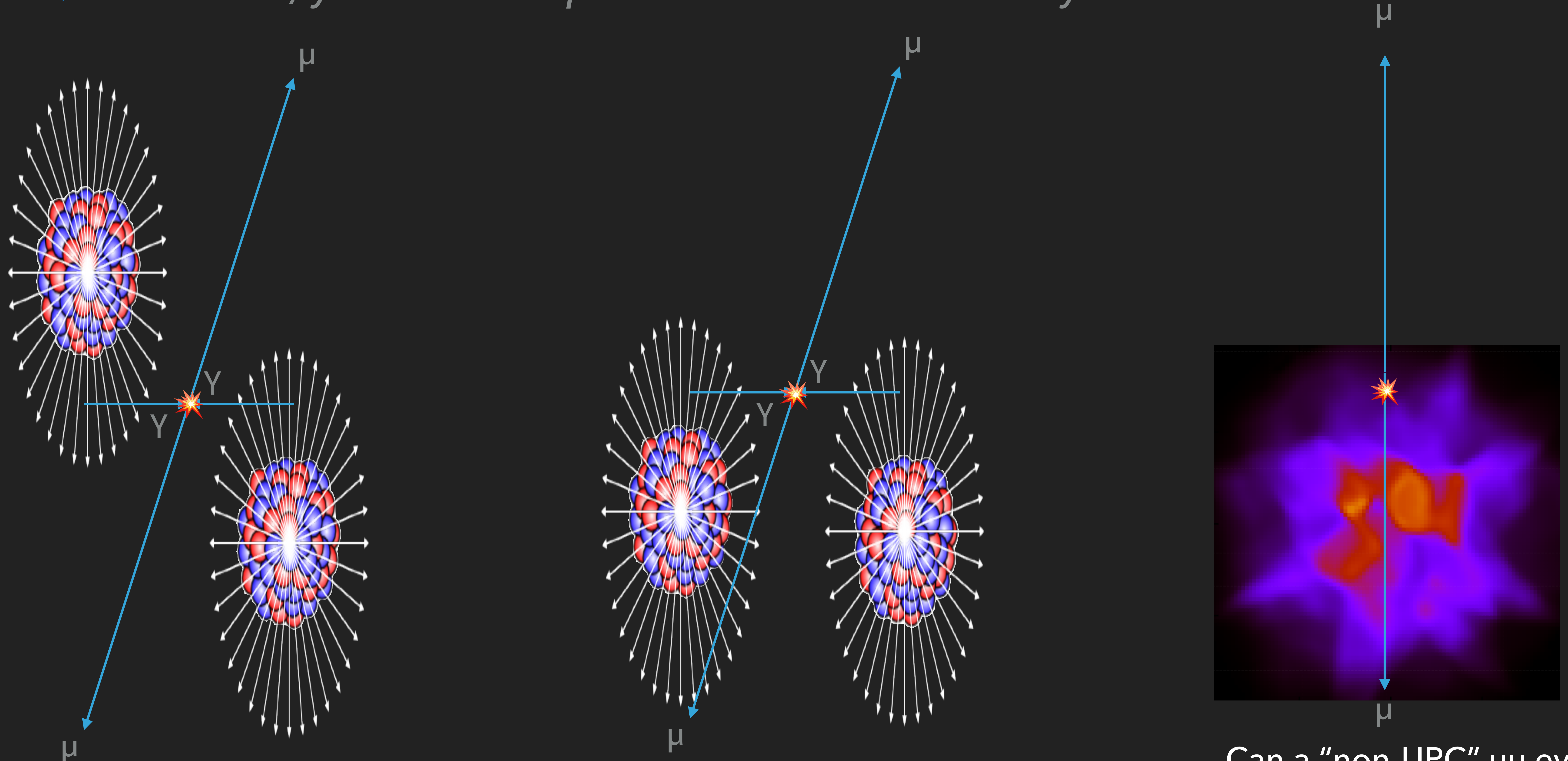
ATLAS-CONF-2017-011

Excellent agreement with PYTHIA6 reweighed to STARLIGHT

UPC DIMUONS IN "NON-UPC" EVENTS

ATLAS-HION-2018-11

- UPC dimuon rates calculated assuming the nuclei "miss"
  - *However, you can still produce them when they don't!*



Can a "non-UPC" μμ event "see" the QGP?

More details in poster by A. Angerami

EVENT AND MUON SELECTION

- Trigger
  - *Dimuon trigger, each with 4 GeV at L1, and 4 GeV in HLT*
- Muon selection
  - *Tight selection, p_T>4 GeV, $|\eta|$<2.4*
  - *Selections on transverse and longitudinal impact parameter < 1.5 mm*
- Pair requirement
  - *Opposite sign pairs with $4 < M_{\mu\mu} < 45$ GeV*
- Trigger & reconstruction efficiencies determined using J/Ψ
  - *Applied to each muon as $w^{-1} = \epsilon_{trig}\epsilon_{reco}$*

ANALYSIS STRATEGY

- Acoplanarity: difference in azimuthal angle (cf. UPC dimuons)

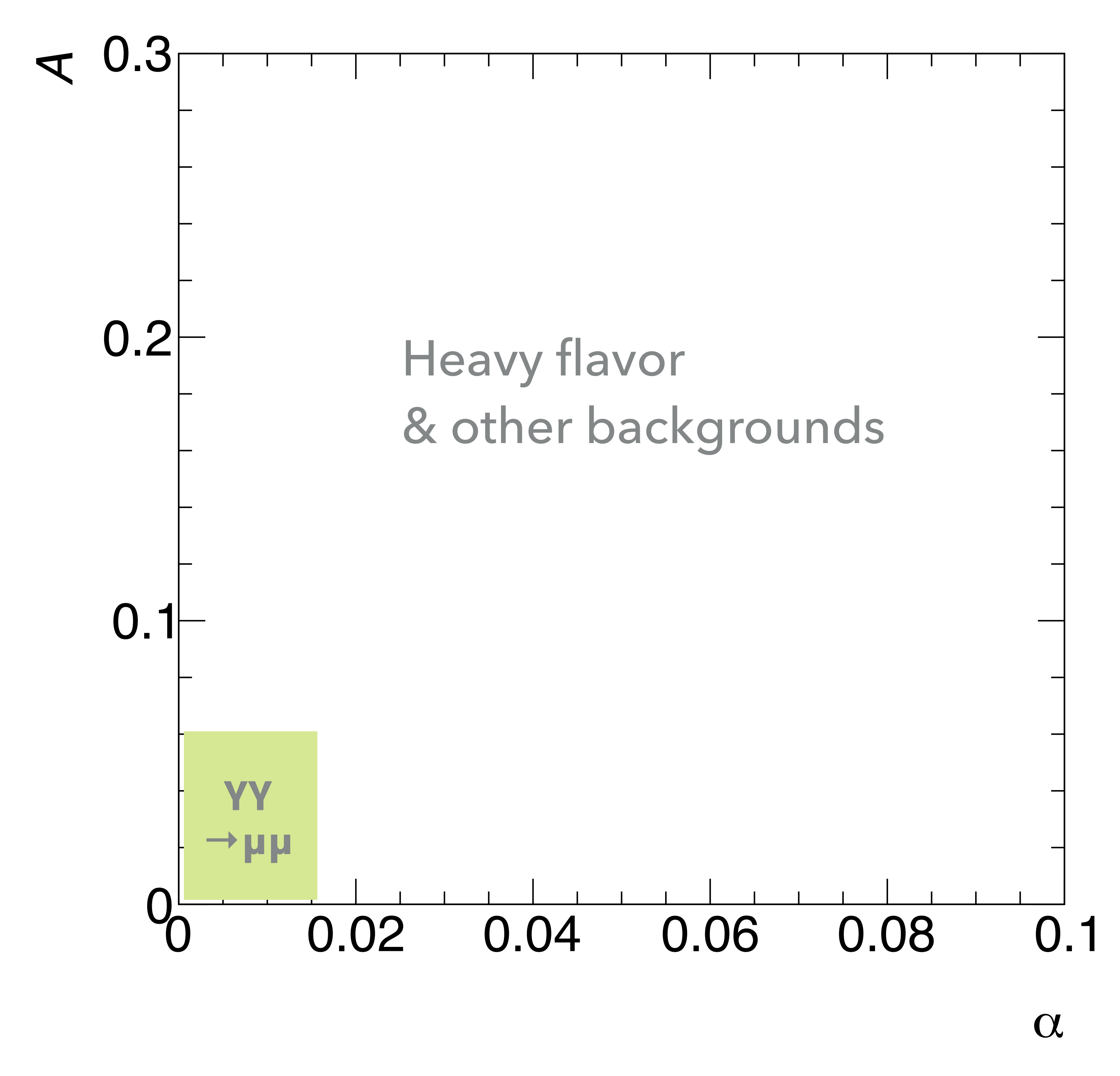
$$\alpha \equiv 1 - \frac{|\phi^+ - \phi^-|}{\pi}$$

- Asymmetry: difference in transverse momentum, divided by sum

$$A \equiv \left|\frac{p_T^+ - p_T^-}{p_T^+ + p_T^-}\right|$$

- Combined impact parameter, larger for HF decays

$$d_{0\,\mathrm{pair}} \equiv d_0^+ \oplus d_0^-$$



Decompose measured spectra for A and α to isolate contribution from signal μμ

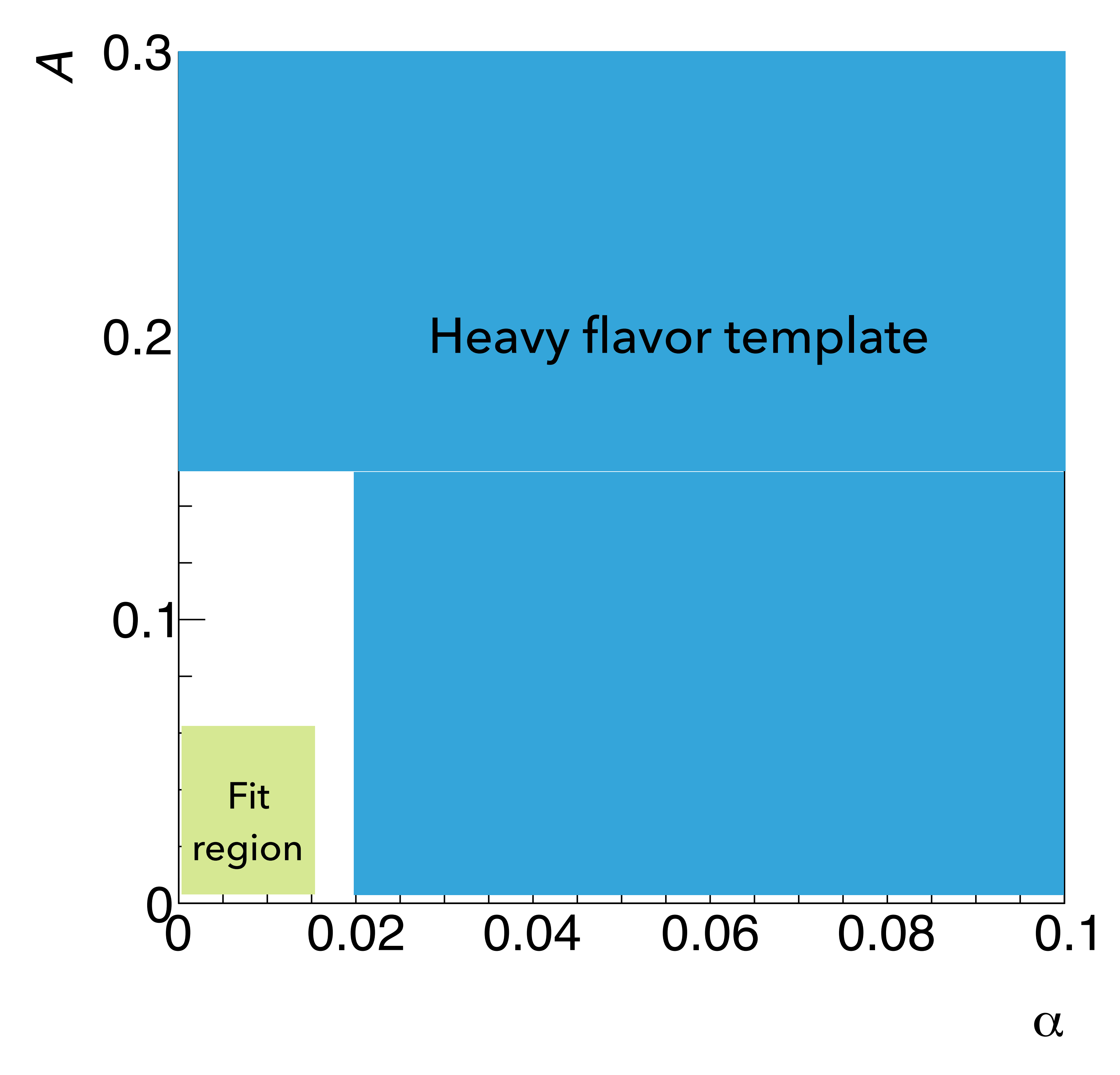
Heavy flavor dimuons have a clear signature of larger impact parameters

BACKGROUND FRACTION FROM TEMPLATES

For each centrality selection:

- Create HF templates in $d_{0,\text{pair}}$, by selecting α>0.02 & A>0.15
  - *Use PYTHIA8 template for centralities with low statistics*
- Signal template by fully simulated STARLIGHT 1.1
- Fit to form:

$$\mathcal{F}(d_{0\,\text{pair}}) \equiv f\,\mathcal{S}(d_{0\,\text{pair}}) + (1-f)\,\mathcal{B}(d_{0\,\text{pair}})$$



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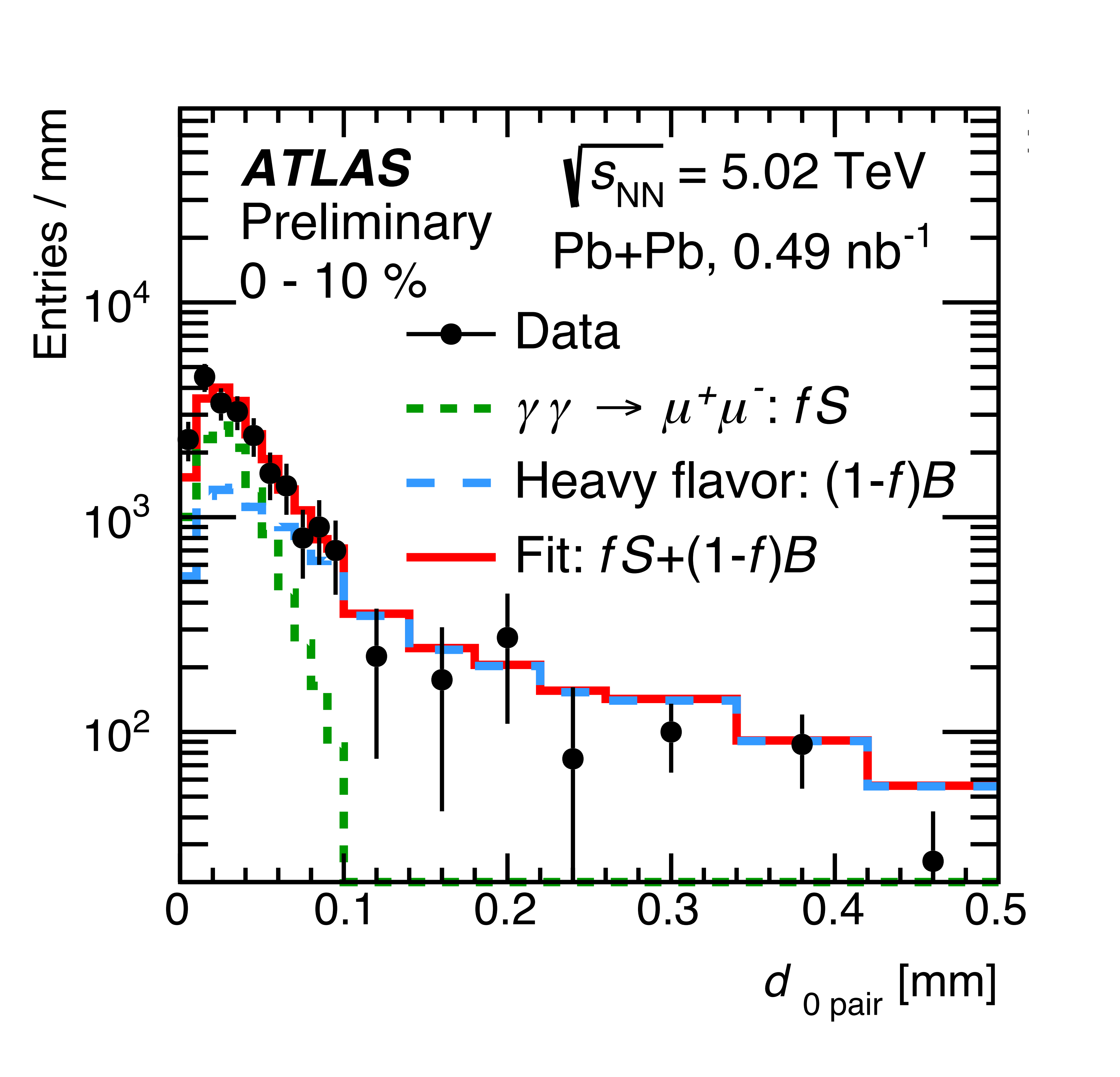

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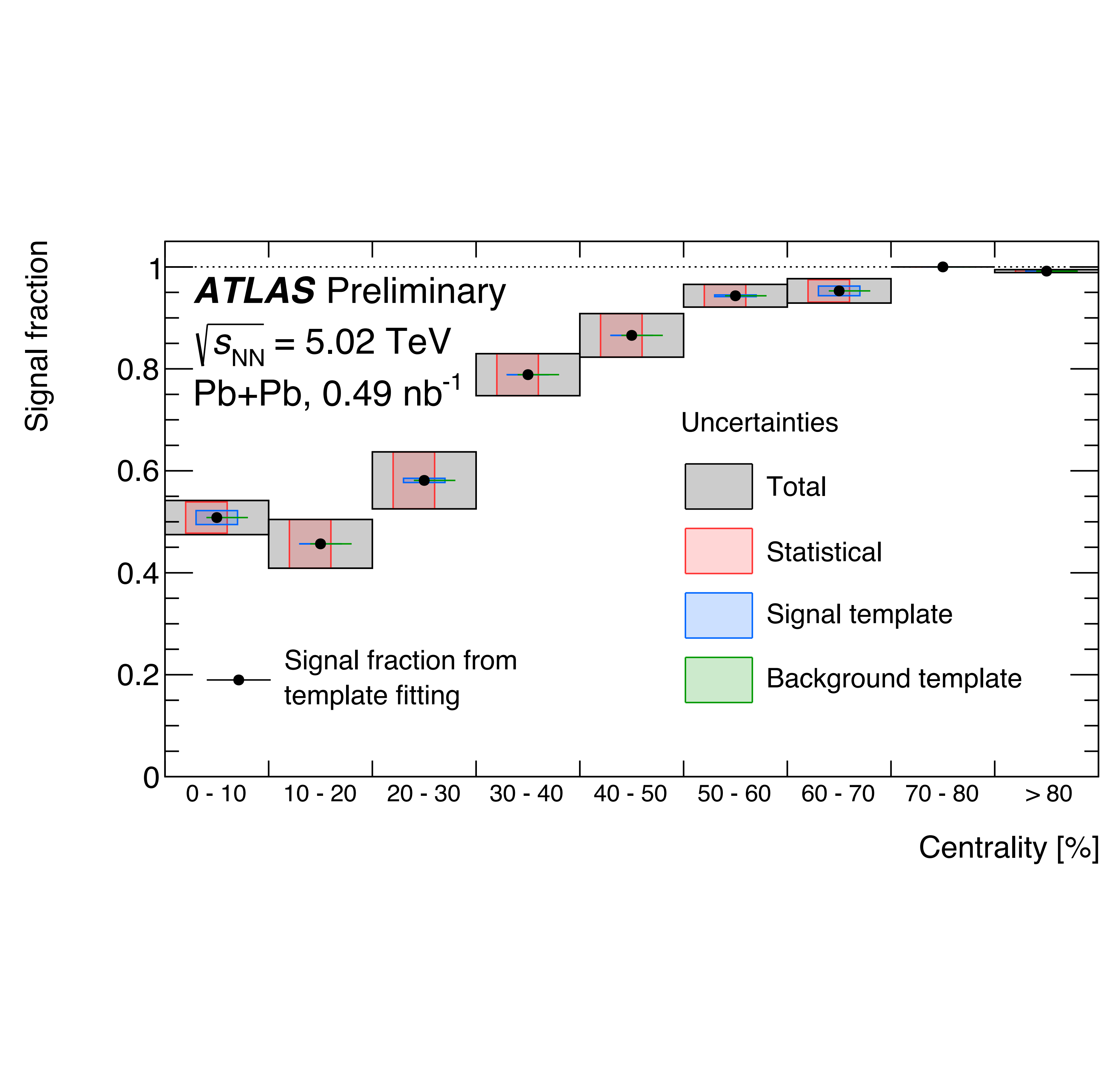


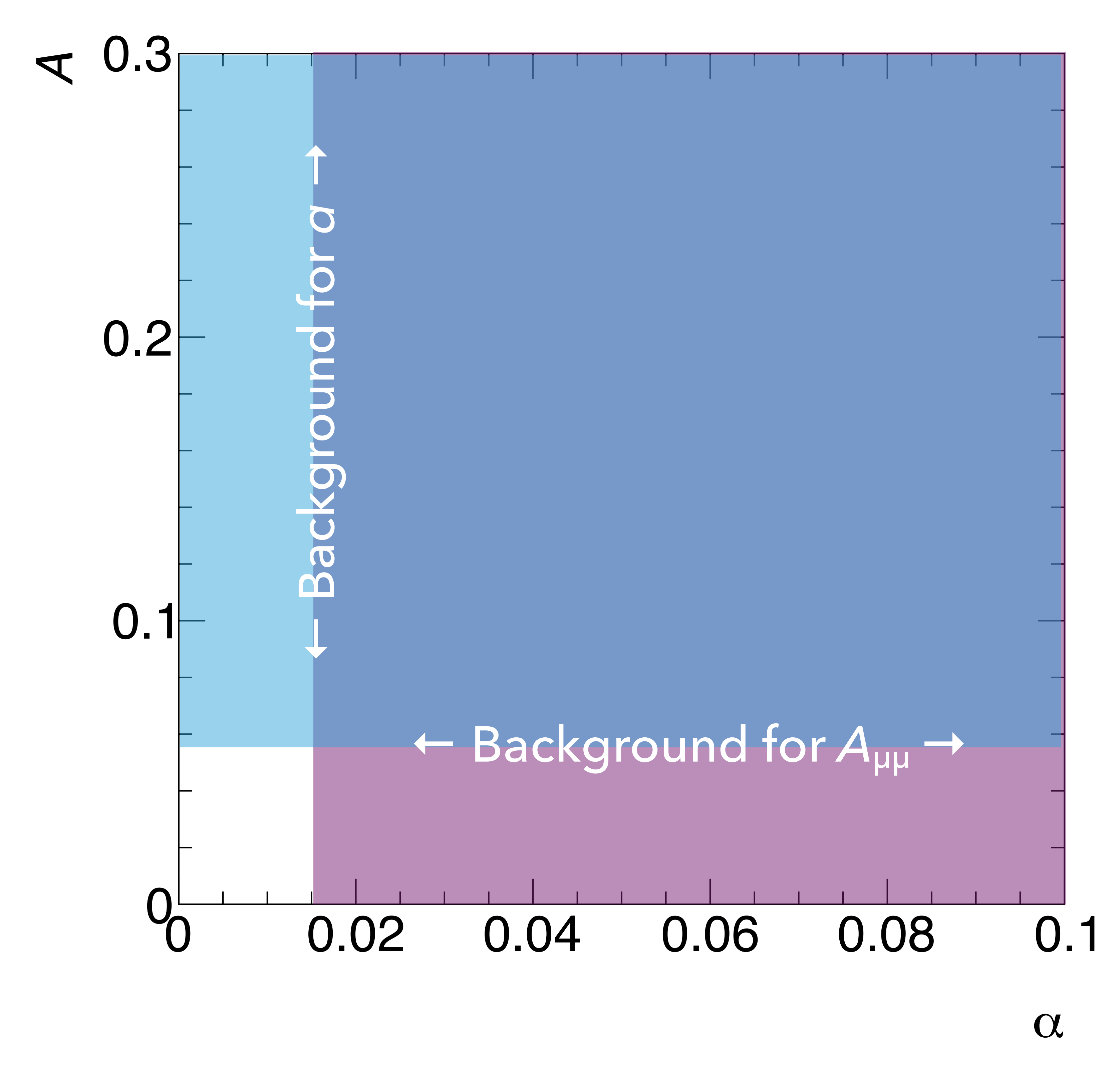
Signal fraction ~100% in >80% (mainly UPC)
Decreases for more central events (N_{coll} scaling)
Uptick in 0-10% most-center (jet quenching)

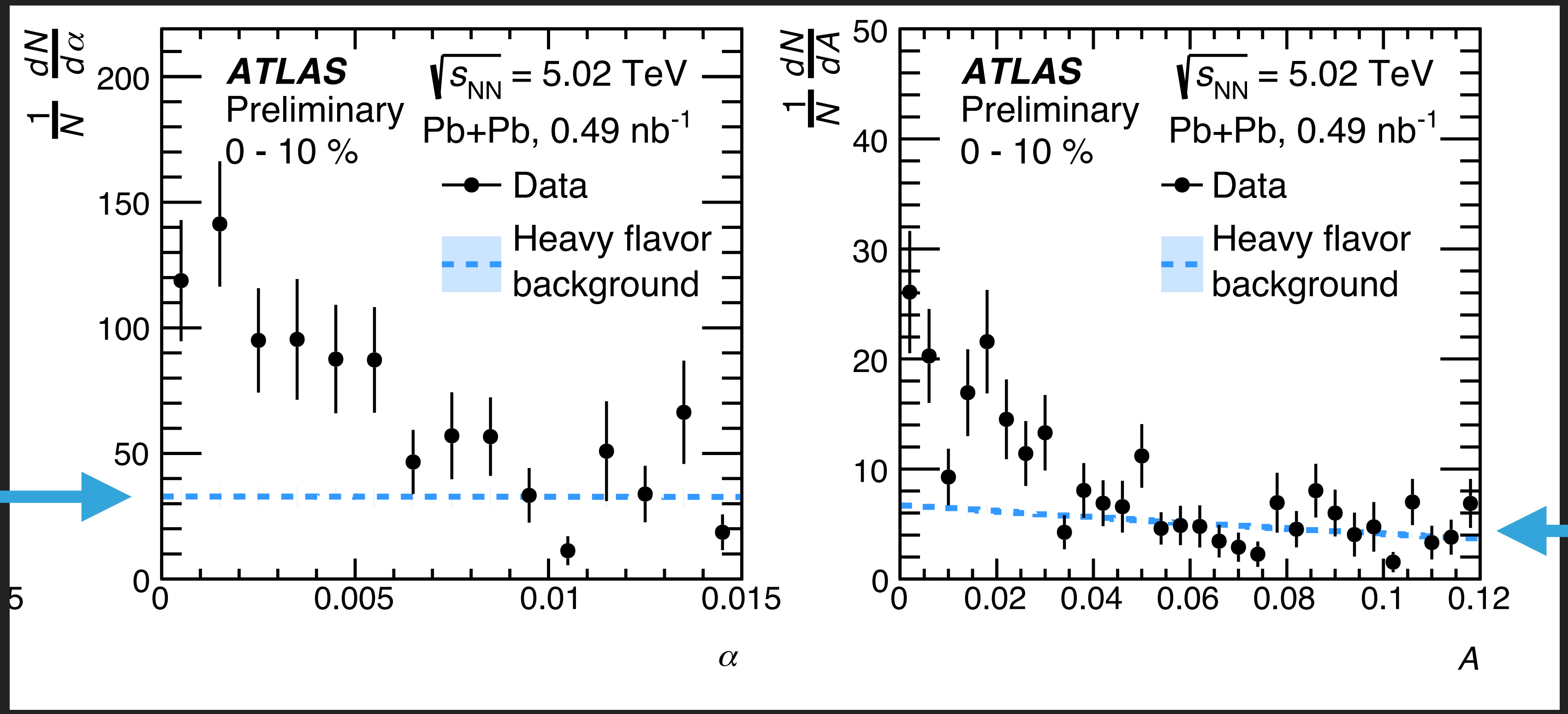
BACKGROUND TEMPLATES BY CUT INVERSION

For each centrality selection:

- BG Template for A: $\alpha > 0.015$
- BG Template for α: $A > 0.06$

- Fit to 2nd order polynomial
  - *systematics by const. & linear fits*

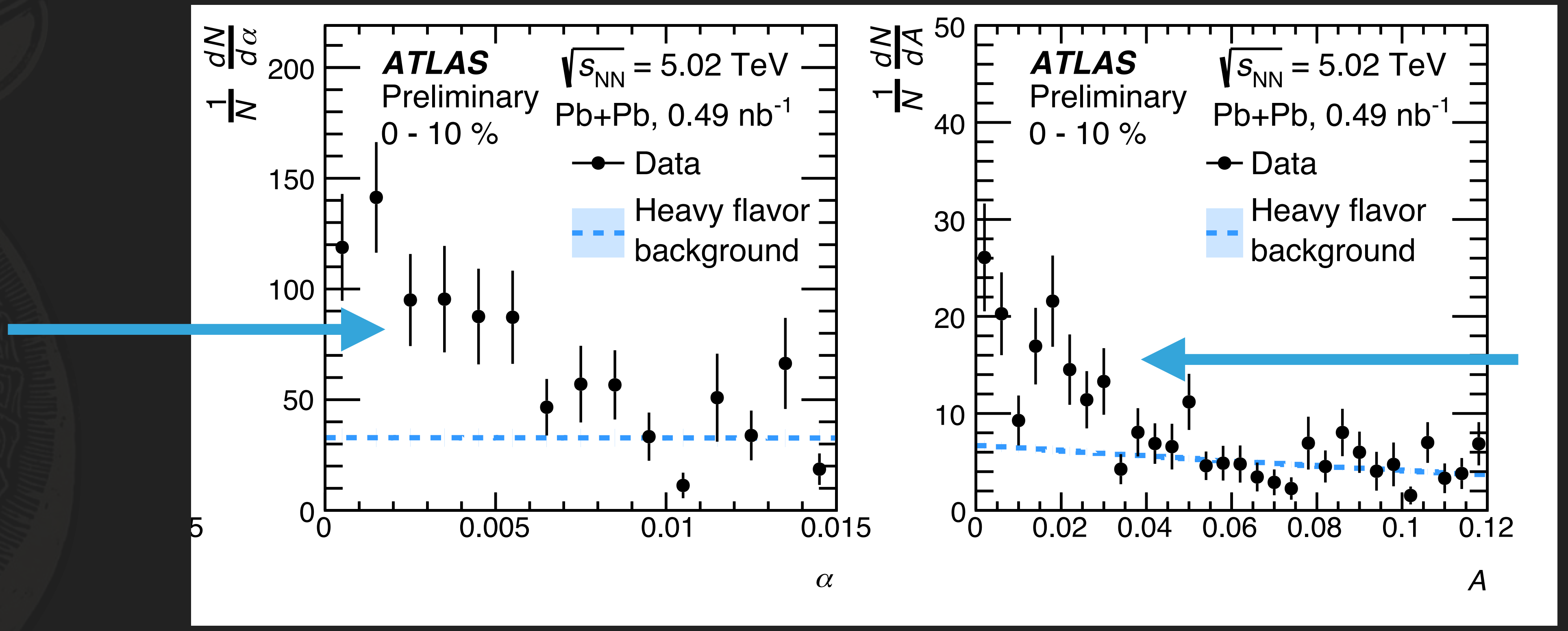


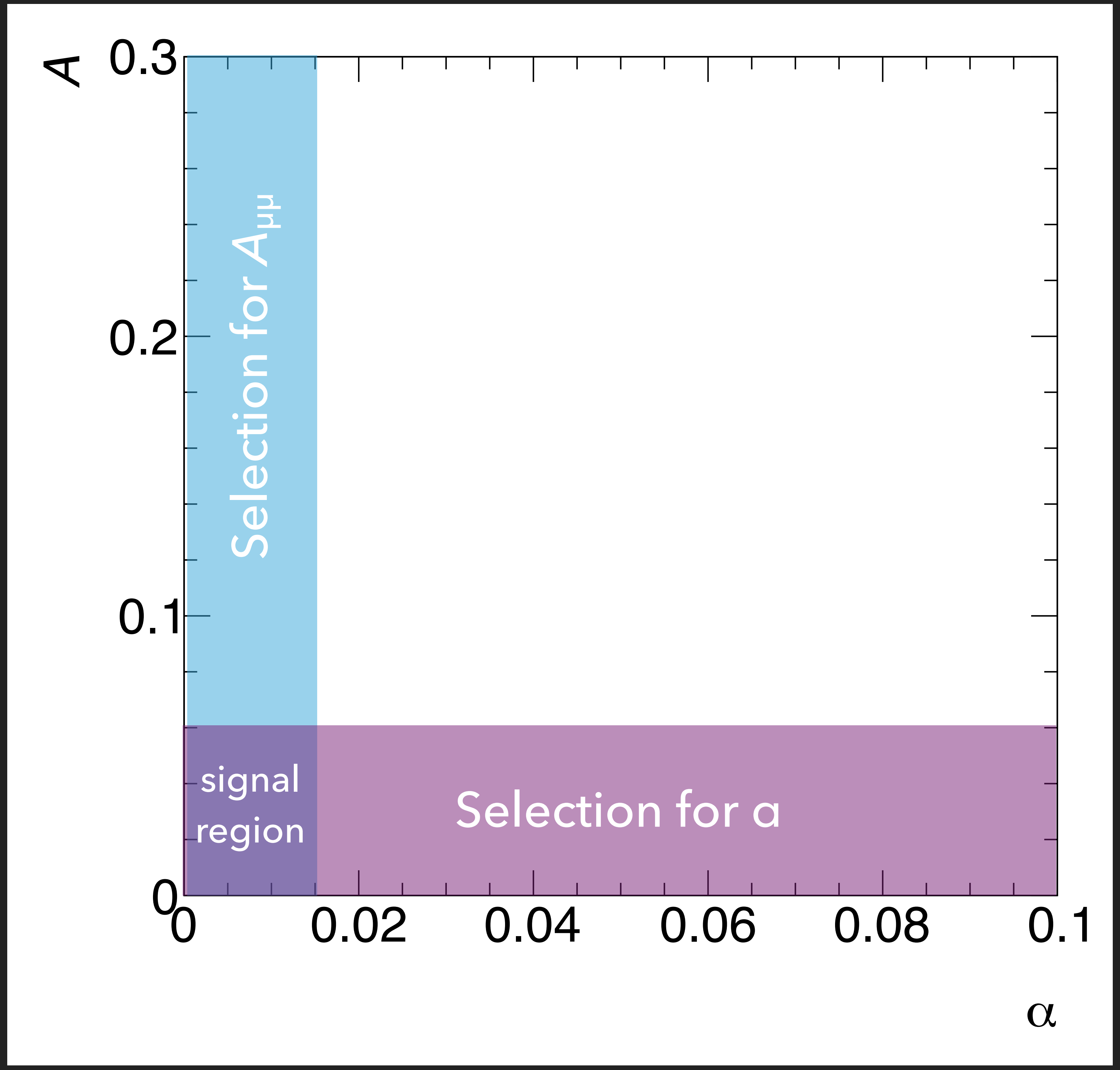


BACKGROUND EXTRACTION

For each centrality selection:

- Now focus on signal region
  - Select $A_{\mu\mu}<0.06$ to study α
  - Select $\alpha<0.015$ to study A
- Normalize BG templates to signal fraction and subtract

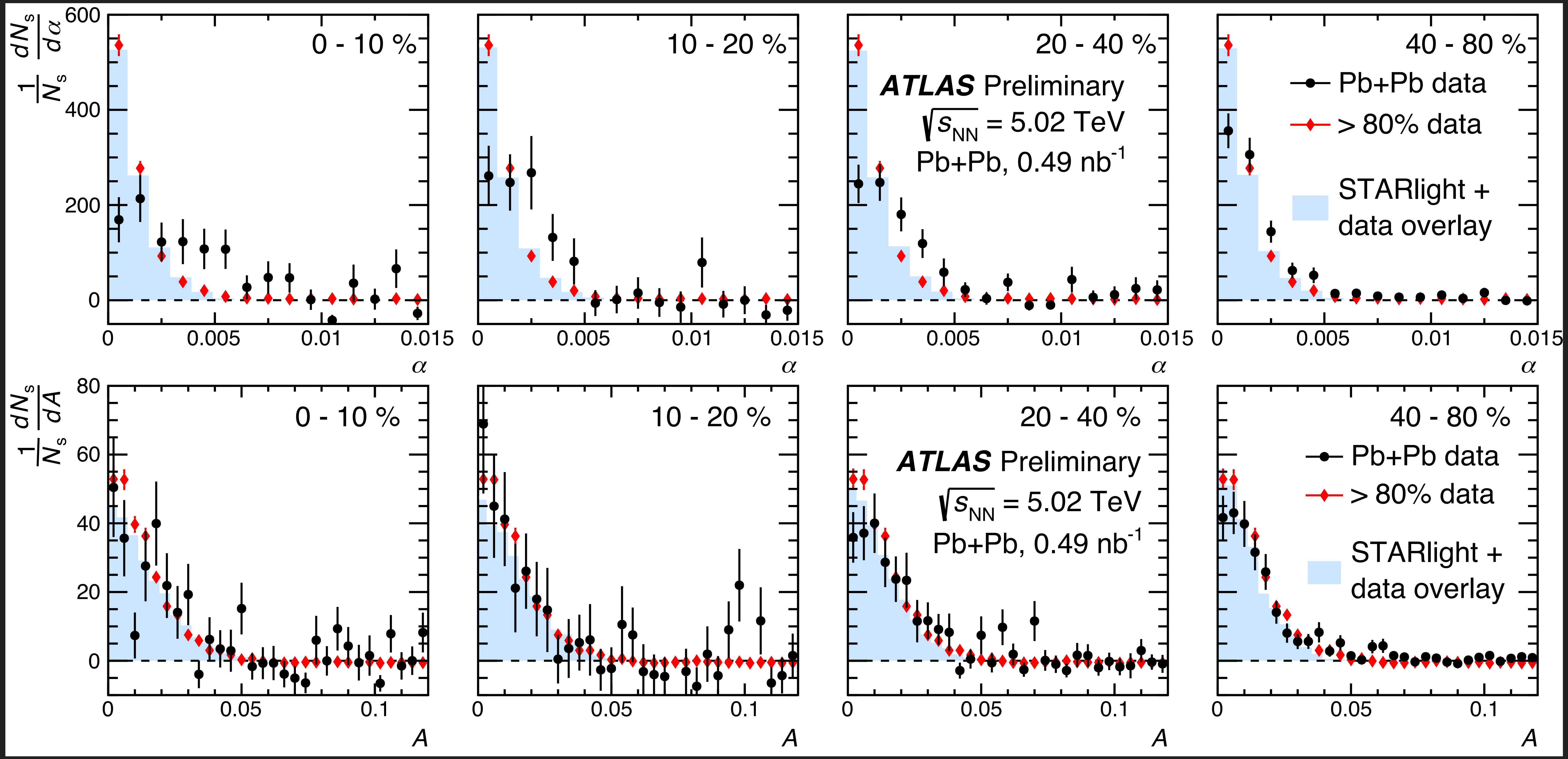




CORRECTED SIGNAL DISTRIBUTIONS

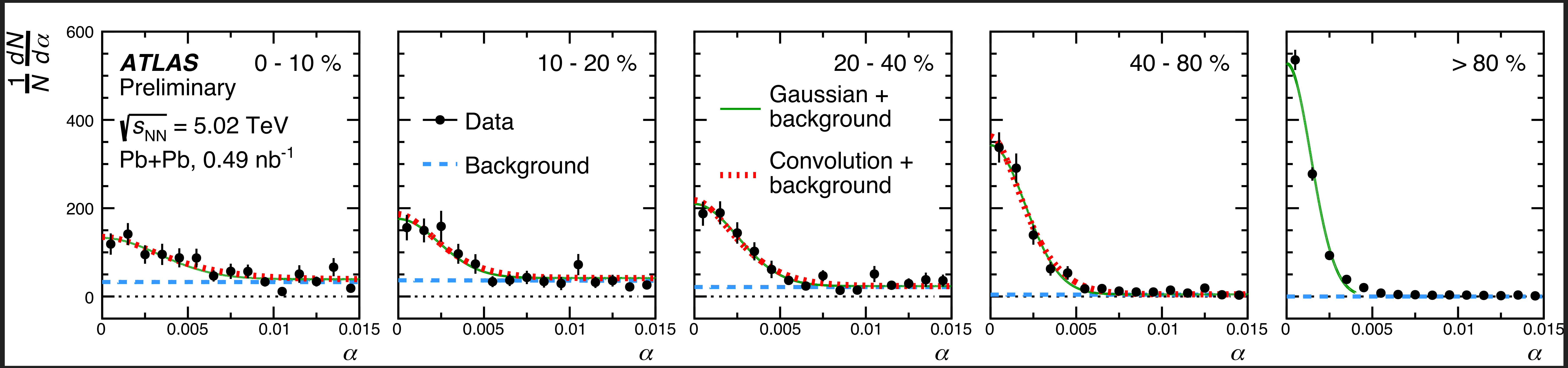
α

A

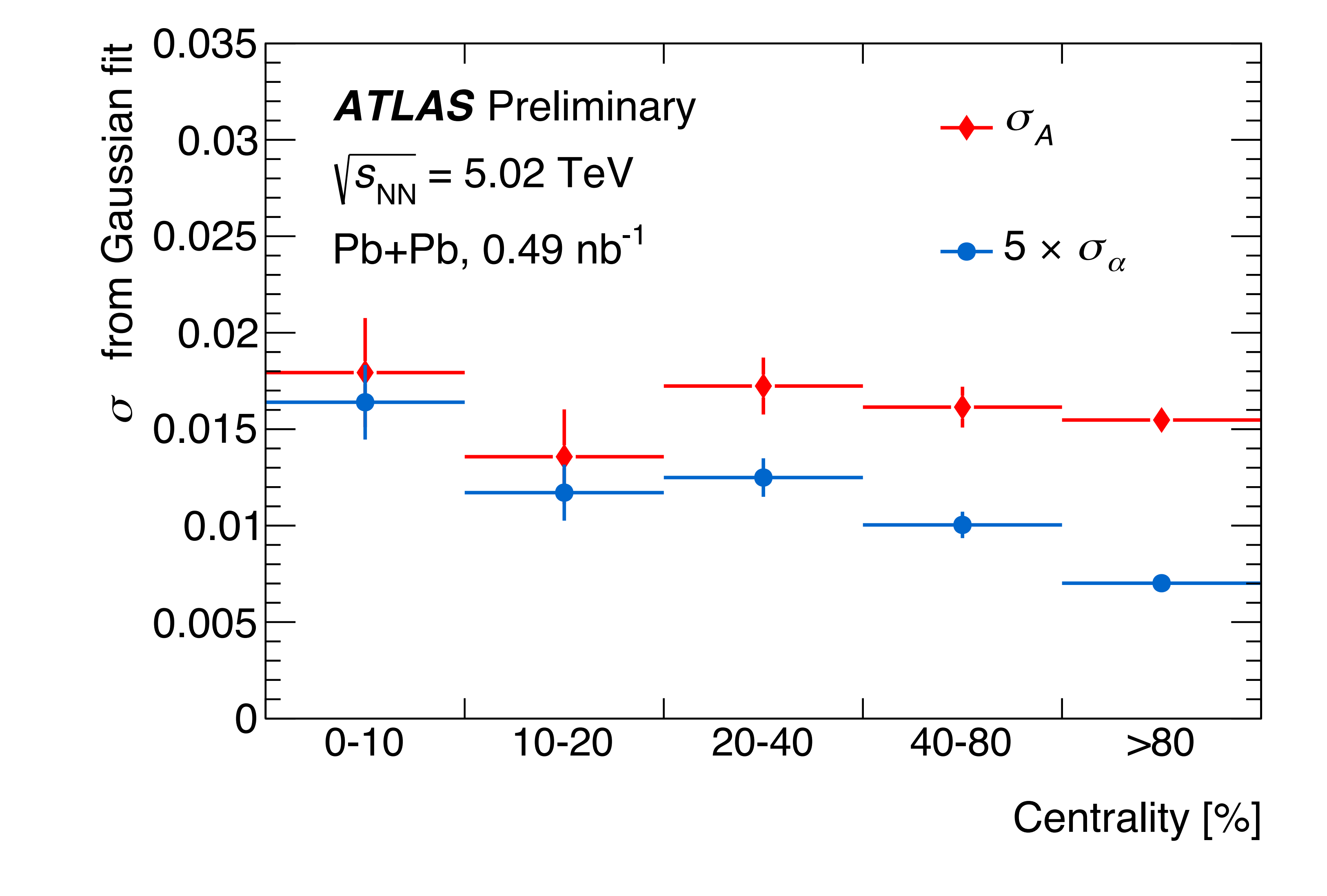


- Simulated STARLIGHT events show no centrality-dep. broadening
- HF-determined backgrounds saturate tails
  - *No obvious contribution from Drell-Yan, Υ, or dissociative processes*

FITS TO DIMUON ACOPLANARITY



- Fit width of signal distributions using Gaussian + background template
  - *Alternate fit convolving over σ(p_T)*
- α width clearly grows with centrality
  - *No sensitivity to asymmetry distributions*



ATLAS EXPERIMENT

EXTRACTING RMS k_T FROM DIMUON DISTRIBUTIONS

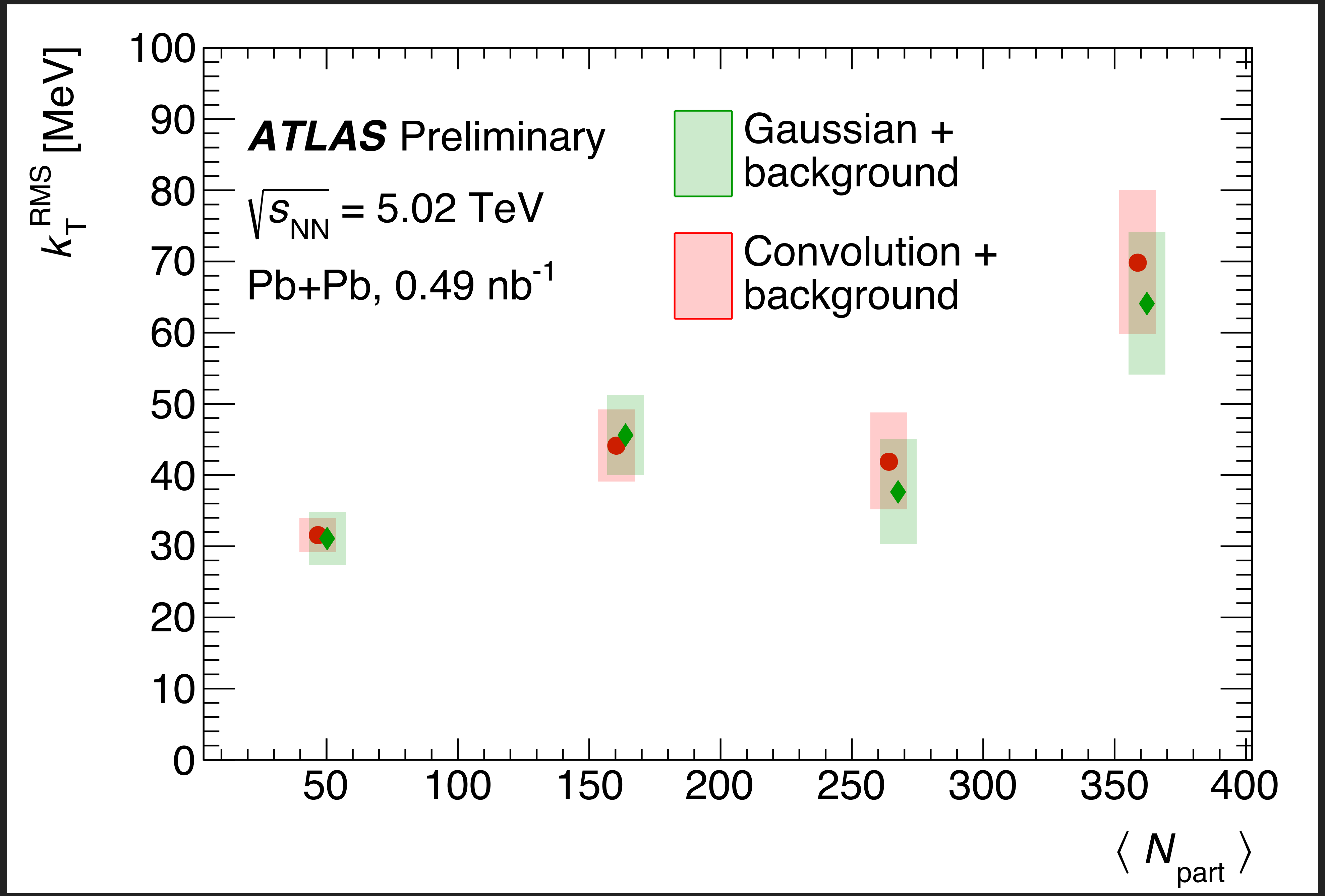
- Assume broadening from small transverse momentum imparted to each muon

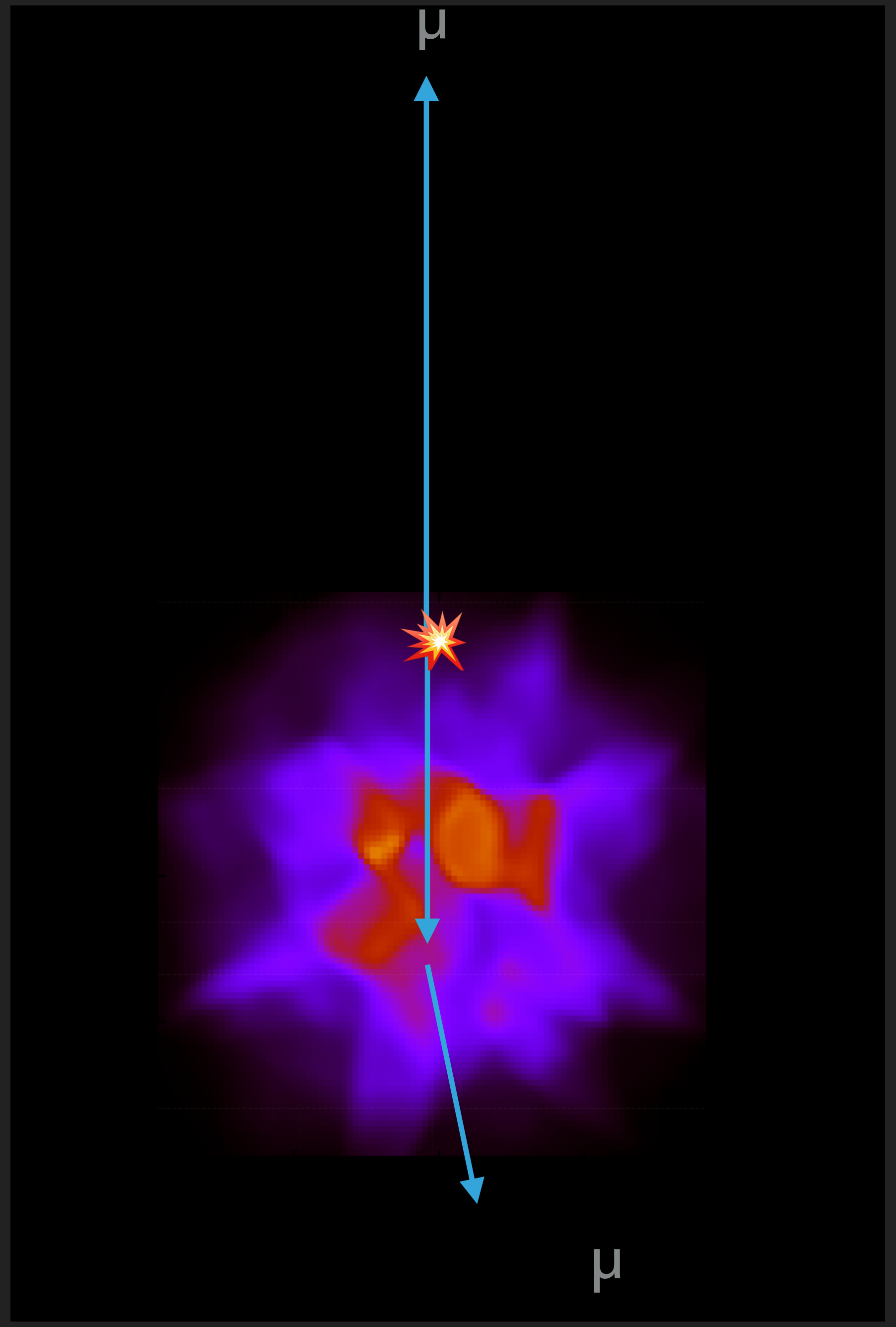
$$\langle \alpha^2 \rangle = \langle \alpha^2 \rangle_0 + \frac{1}{\pi^2} \frac{\left\langle \vec{k}_T^2 \right\rangle}{\left\langle p_{T\,avg}^2 \right\rangle}$$

- $\langle k^2_T \rangle$ extracted using
  - *$\langle \alpha^2 \rangle$ from centrality-dependent σ*
  - *Nominal variance $\langle \alpha^2 \rangle_0$ from fit to >80% centrality (UPC)*
  - *Nominal $p^2_{T,avg}$ from fits to measured distributions*

Centrality [%]	$\langle N_{part} \rangle$	$p_{T\,avg}^{RMS}$ [GeV]	Gaussian fit			Convolution fit
			$\sigma_A(\times 10^2)$	$\sigma_\alpha(\times 10^3)$	k_T^{RMS} [MeV]	k_T^{RMS} [MeV]
0 – 10	359	7.0 ± 0.1	$1.79^{+0.10}_{-0.09}$	$3.3^{+0.4}_{-0.4}$	64^{+10}_{-10}	70^{+10}_{-10}
10 – 20	264	7.7 ± 0.4	$1.36^{+0.12}_{-0.10}$	$2.3^{+0.3}_{-0.3}$	38^{+7}_{-7}	42^{+7}_{-7}
20 – 40	160	7.4 ± 0.3	$1.72^{+0.04}_{-0.04}$	$2.5^{+0.2}_{-0.2}$	46^{+6}_{-6}	44^{+5}_{-5}
40 – 80	47	6.8 ± 0.3	$1.61^{+0.01}_{-0.01}$	$2.0^{+0.1}_{-0.1}$	31^{+4}_{-4}	32^{+2}_{-2}
> 80	-	7.0 ± 0.3	$1.55^{+0.01}_{-0.01}$	$1.54^{+0.02}_{-0.02}$	-	-

FITS TO EXTRACT RMS k_T

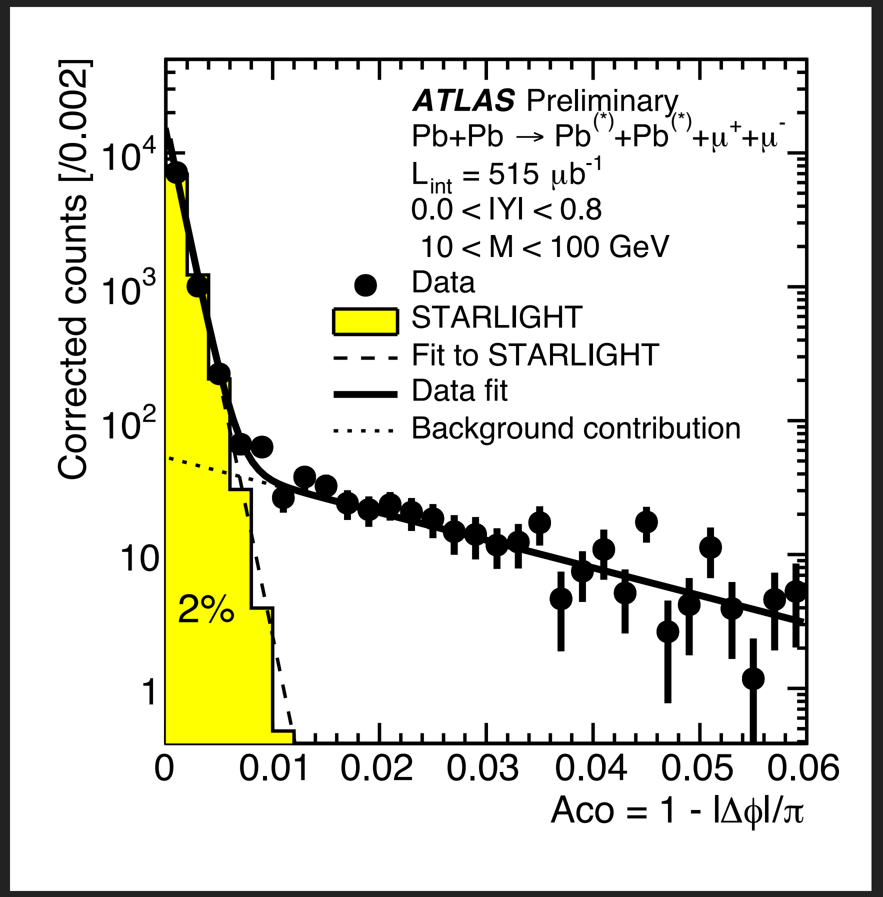




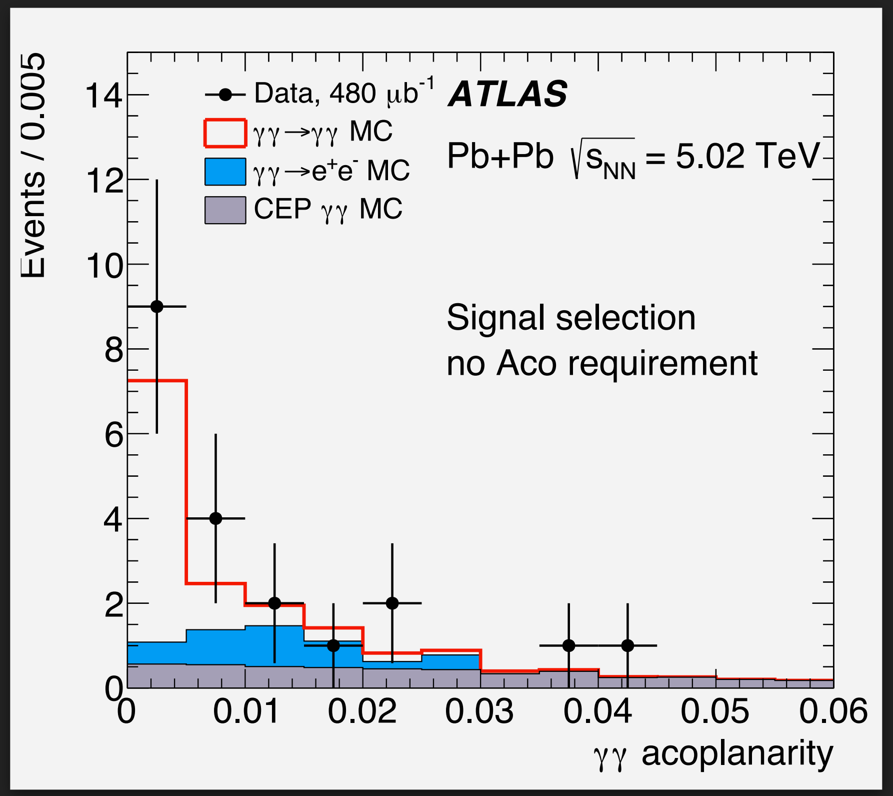
- Additional per-muon RMS k_T beyond that found for >80% centrality (UPC)
- Small in absolute terms, but grows systematically with centrality
- In most central events $\langle k_T \rangle$ ~ 70 MeV
- Specific “tomographic” interpretation hinges on whether there are additional mechanisms for influencing muons in the context of a heavy ion collision.

CONCLUSIONS

- EM-induced processes in Pb+Pb collisions in ATLAS teaches us about :



💡 QED



ATLAS EXPERIMENT

CONCLUSIONS

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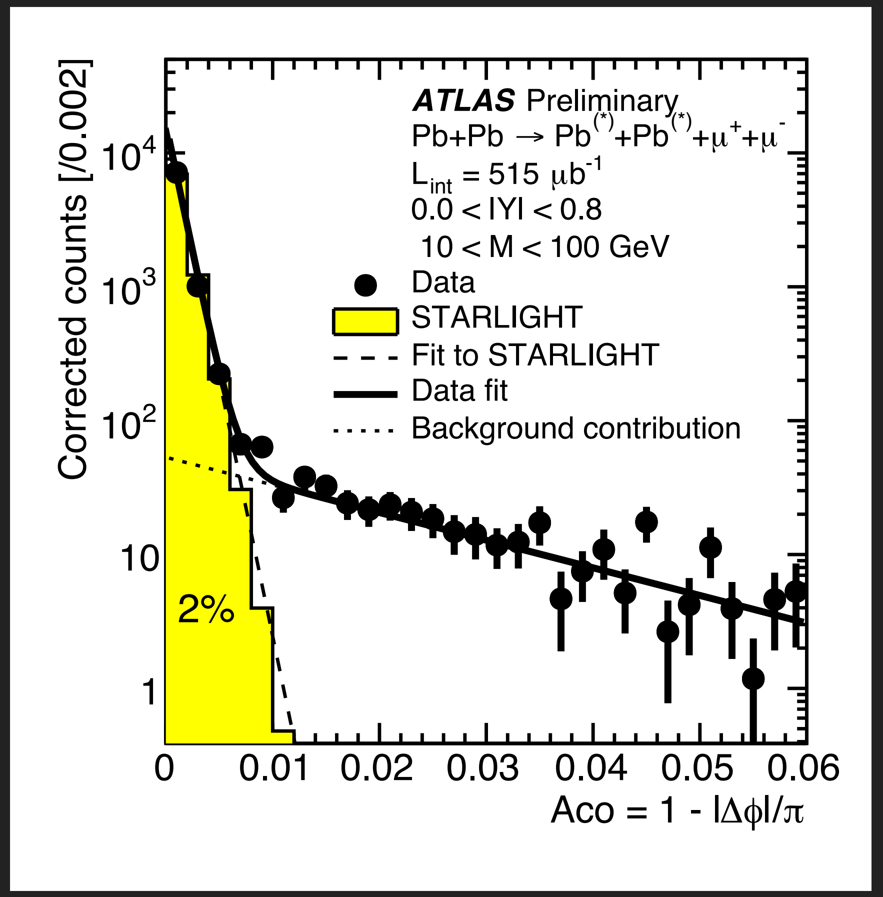
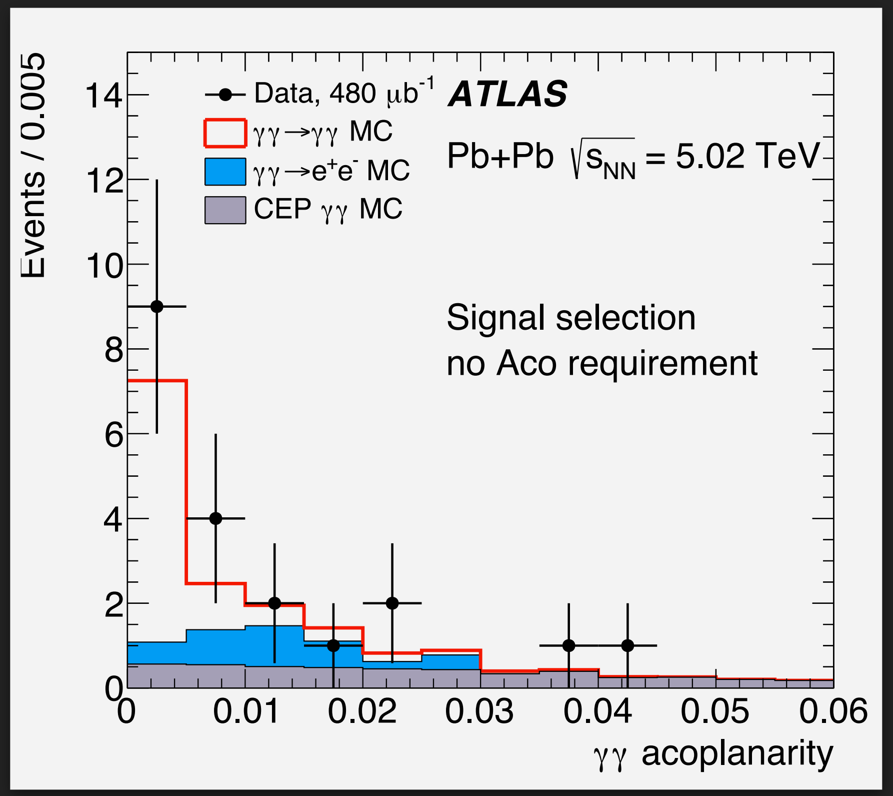
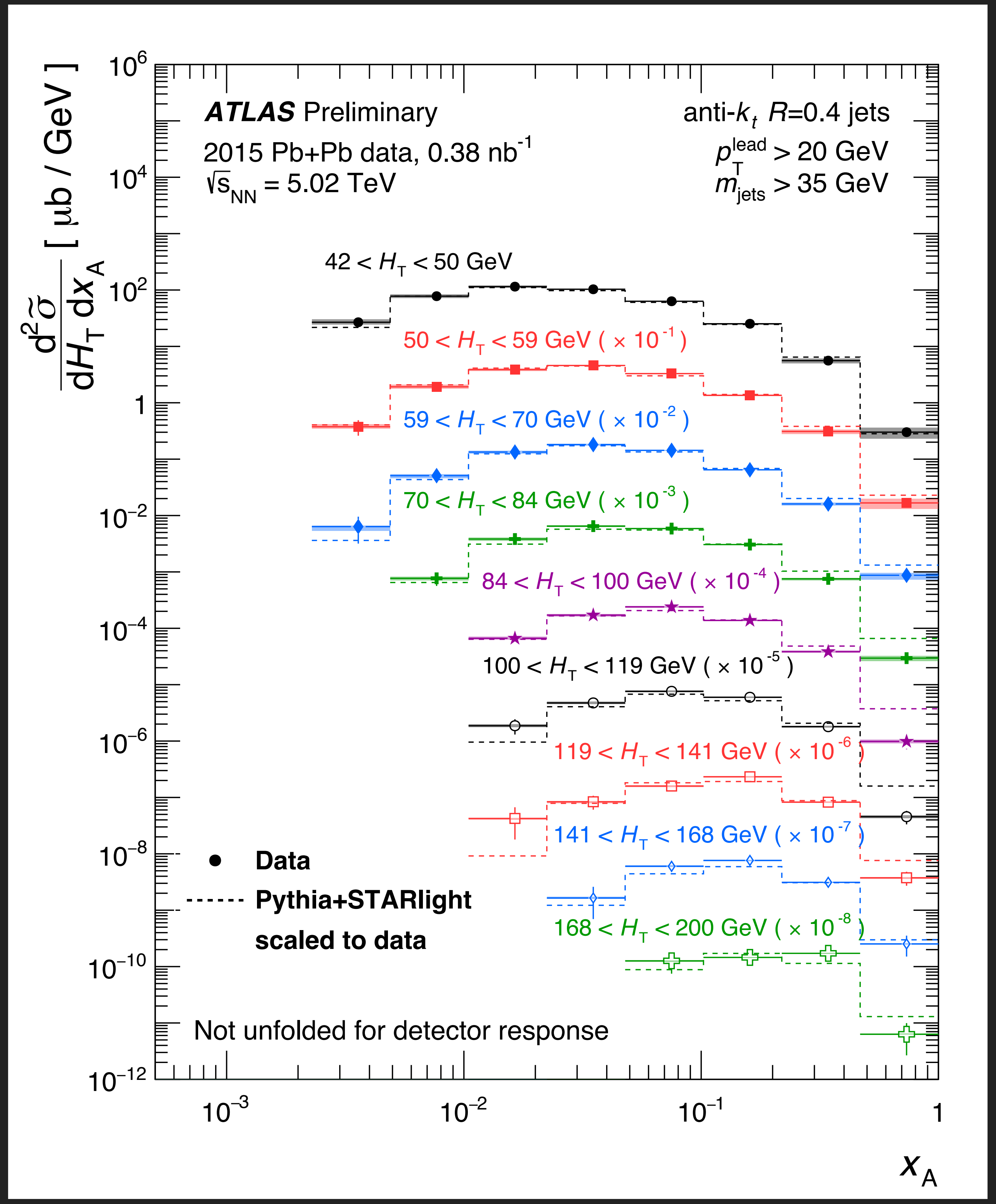


QED





QCD

CONCLUSIONS

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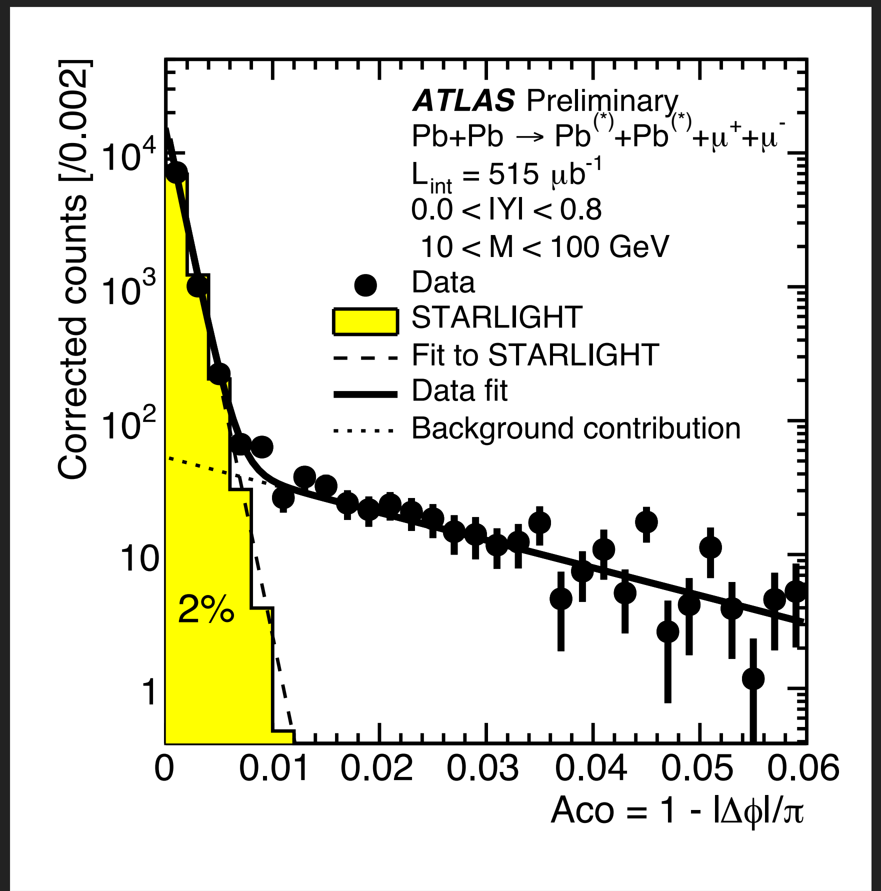
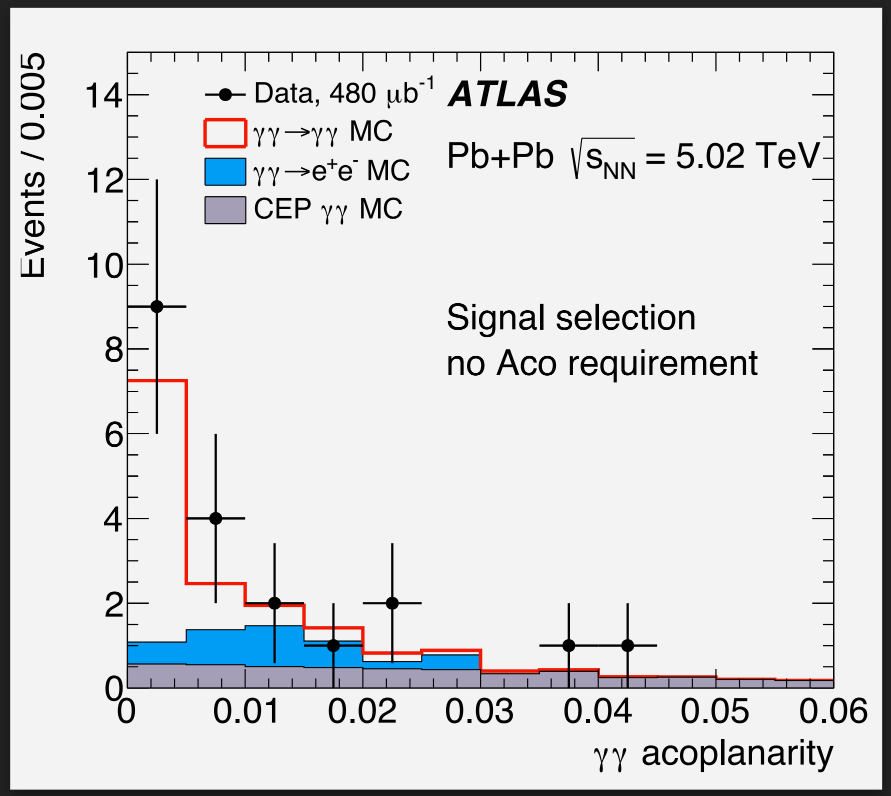
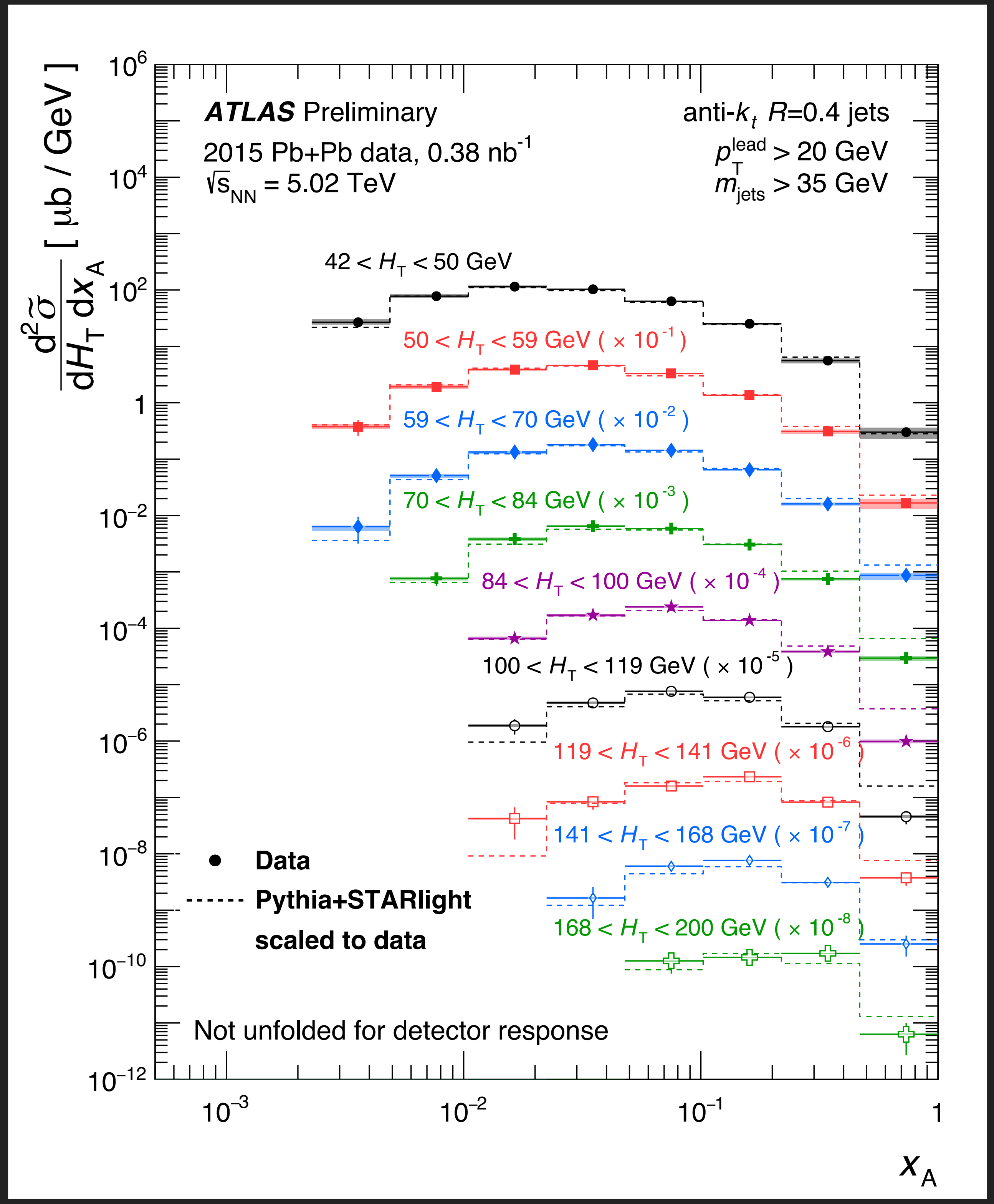


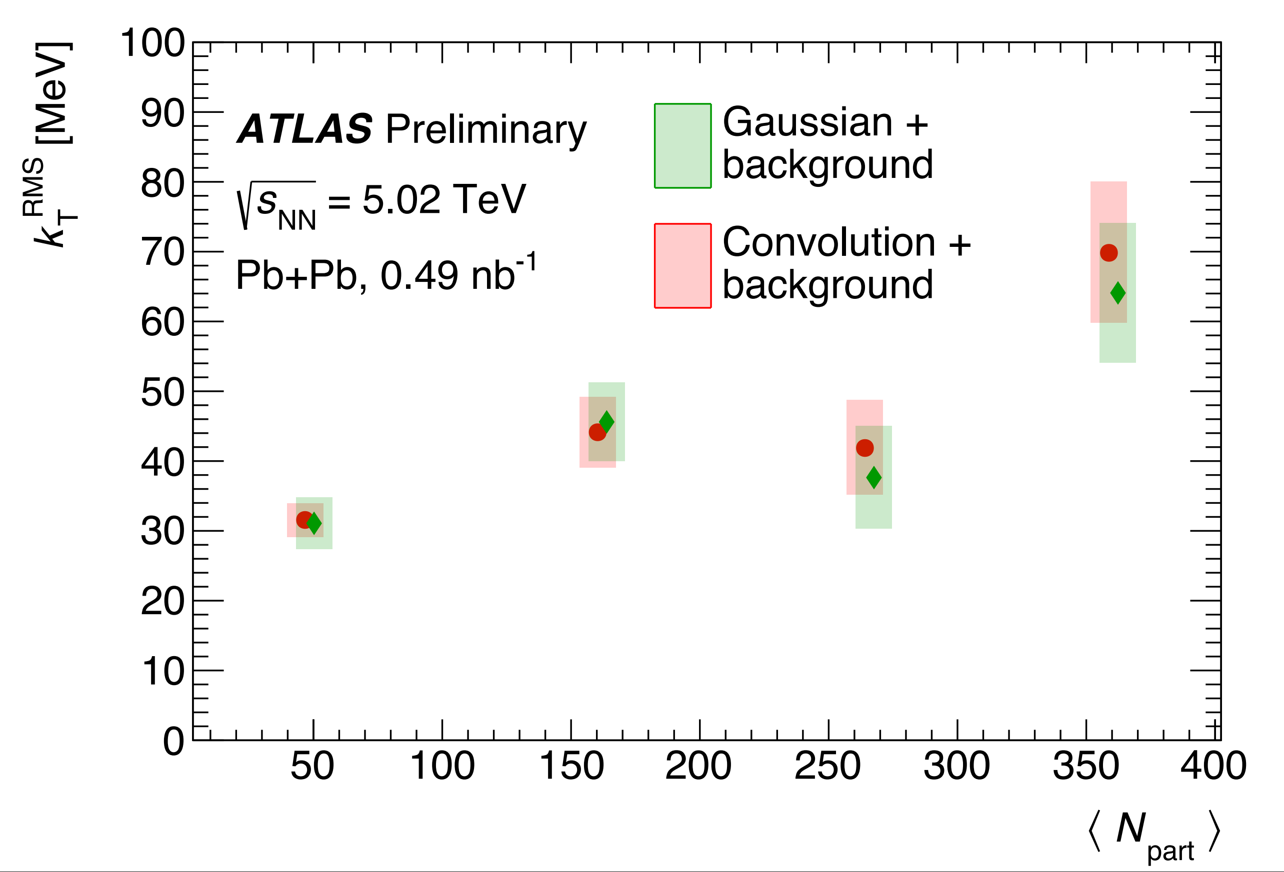
QED

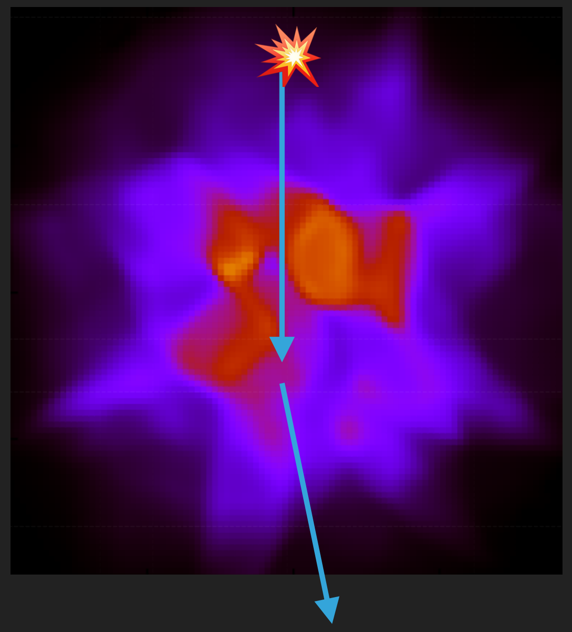




QCD

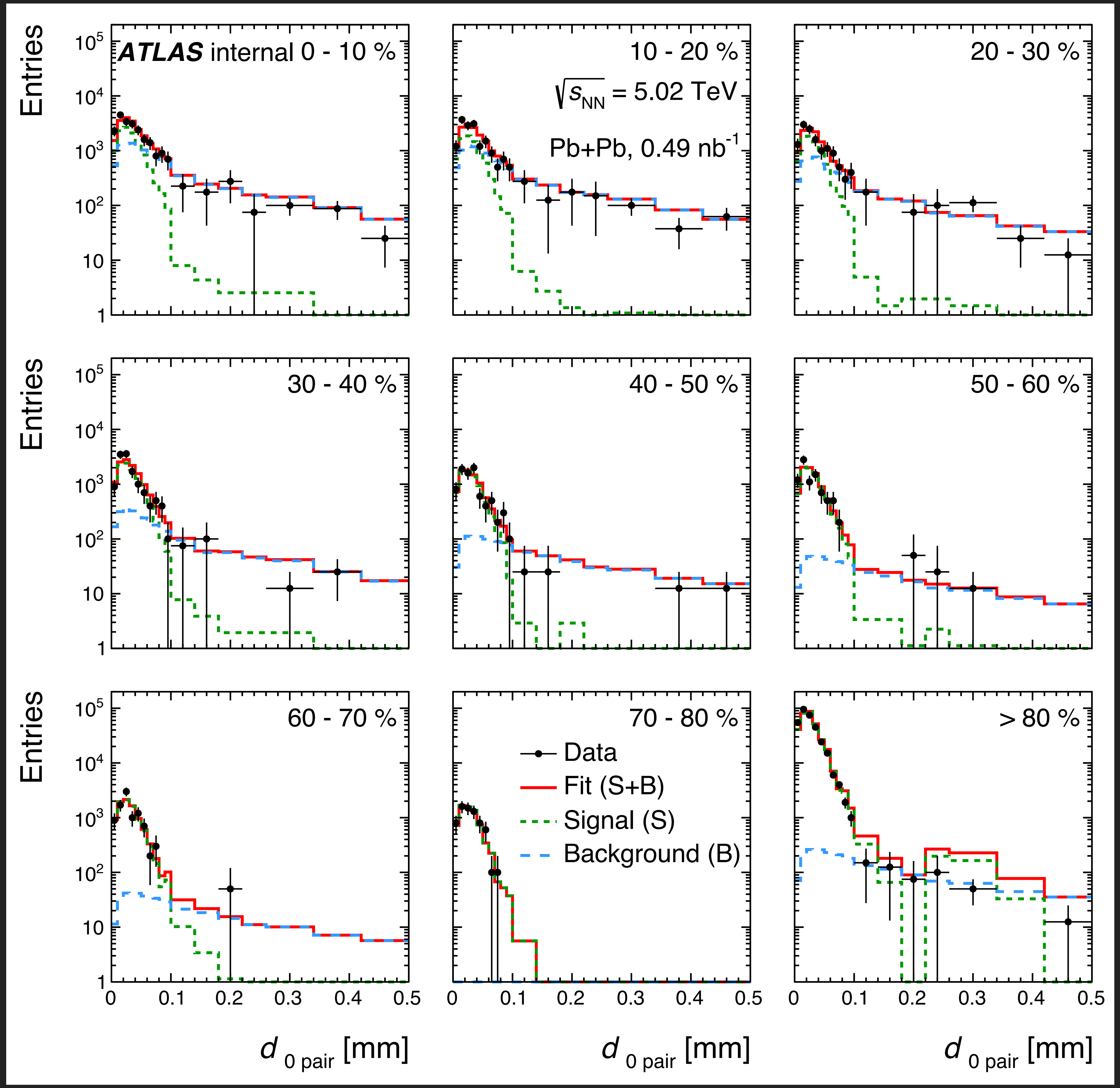
QGP?



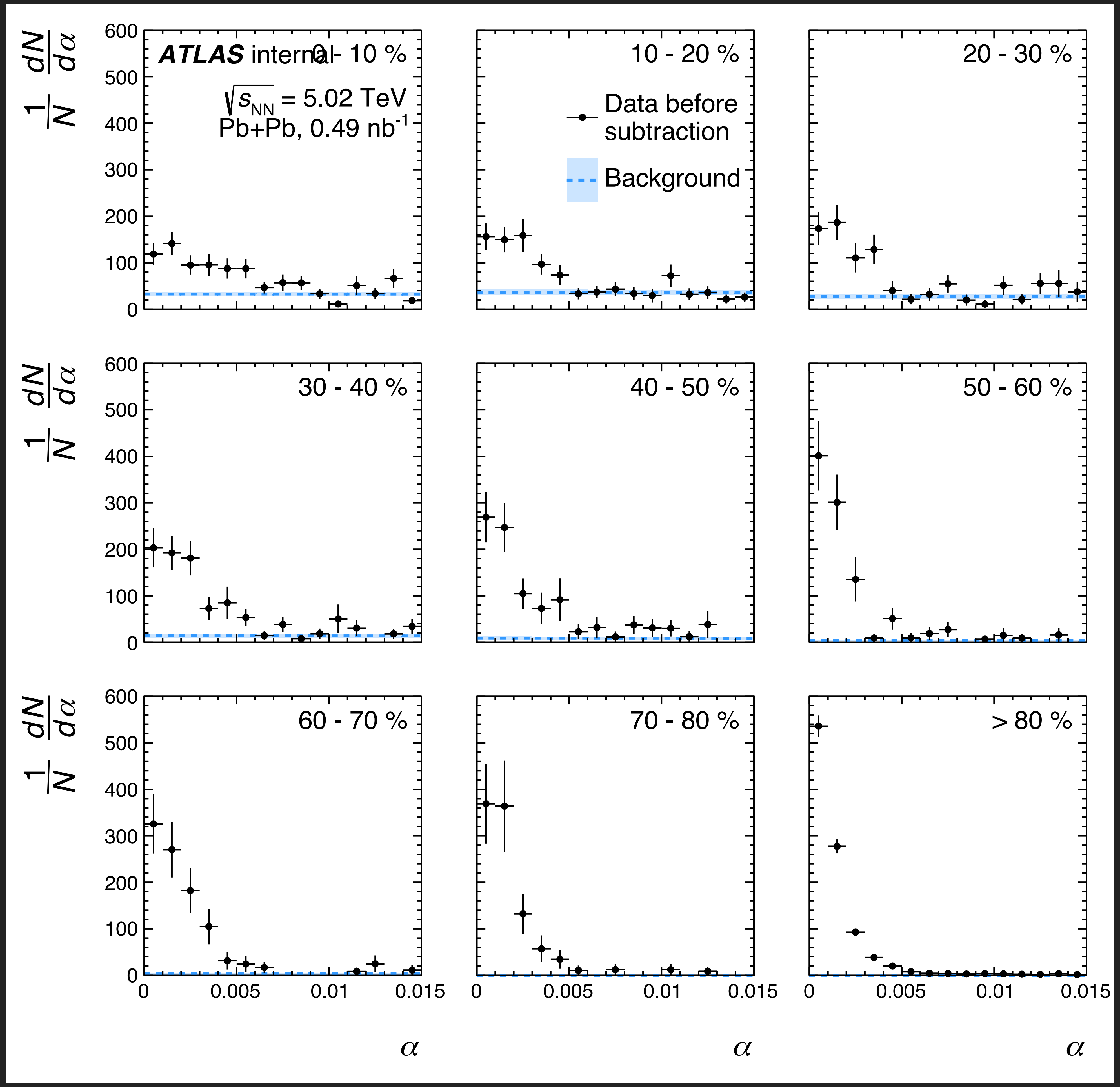


EXTRA SLIDES

BACKGROUND FITS VS. CENTRALITY

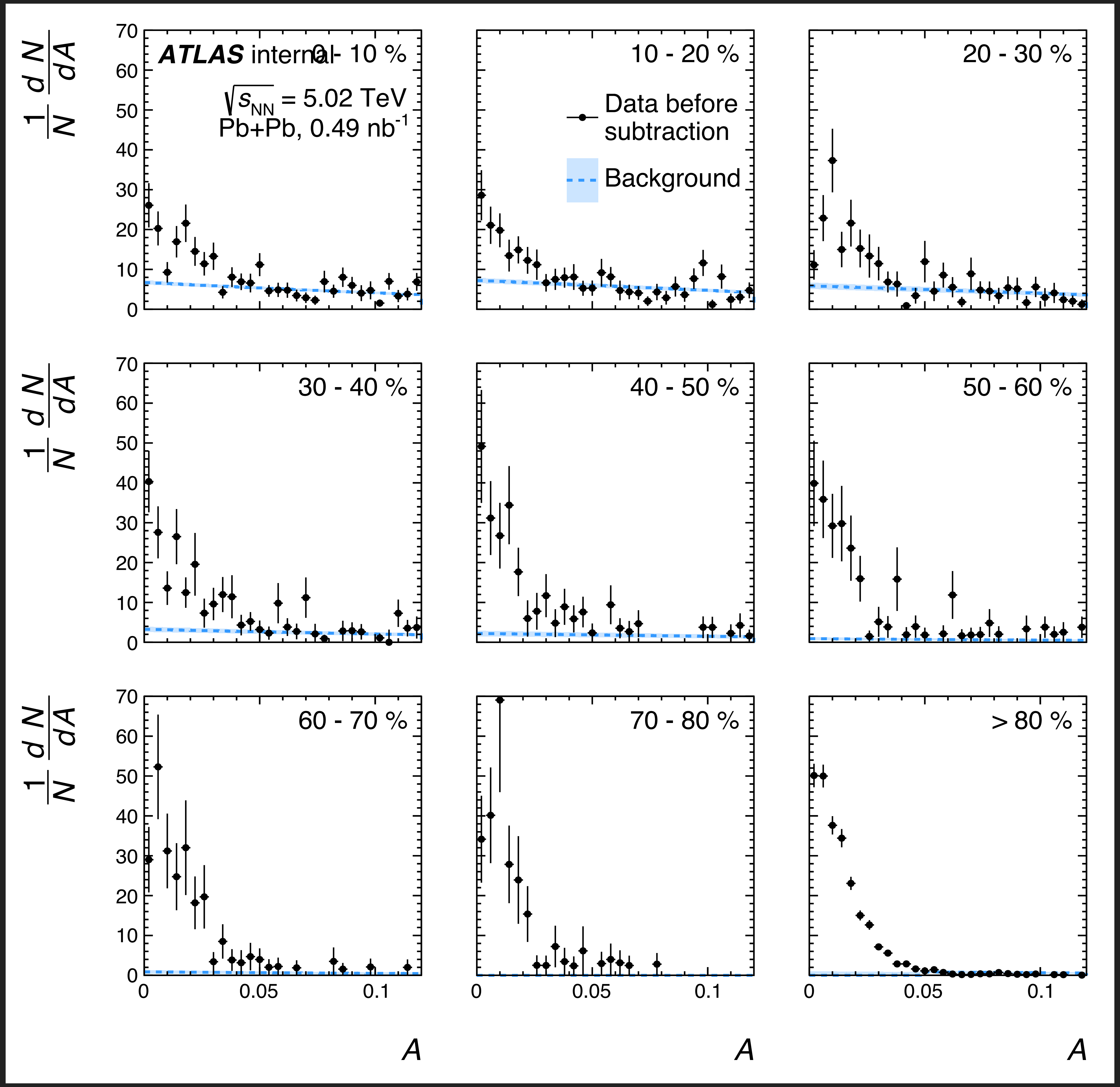


ACOPLANARITY DISTRIBUTIONS VS. CENTRALITY FOR α<0.015



HF background saturates tails

ASYMMETRY DISTRIBUTIONS VS. CENTRALITY FOR A<0.06



HF background saturates tails