Recent soft QCD results from ATLAS and LHCf

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on behalf of the ATLAS and LHCf collaborations

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ATLAS EXPERIMENT

UNIVERSITÉ DE GENÈVE

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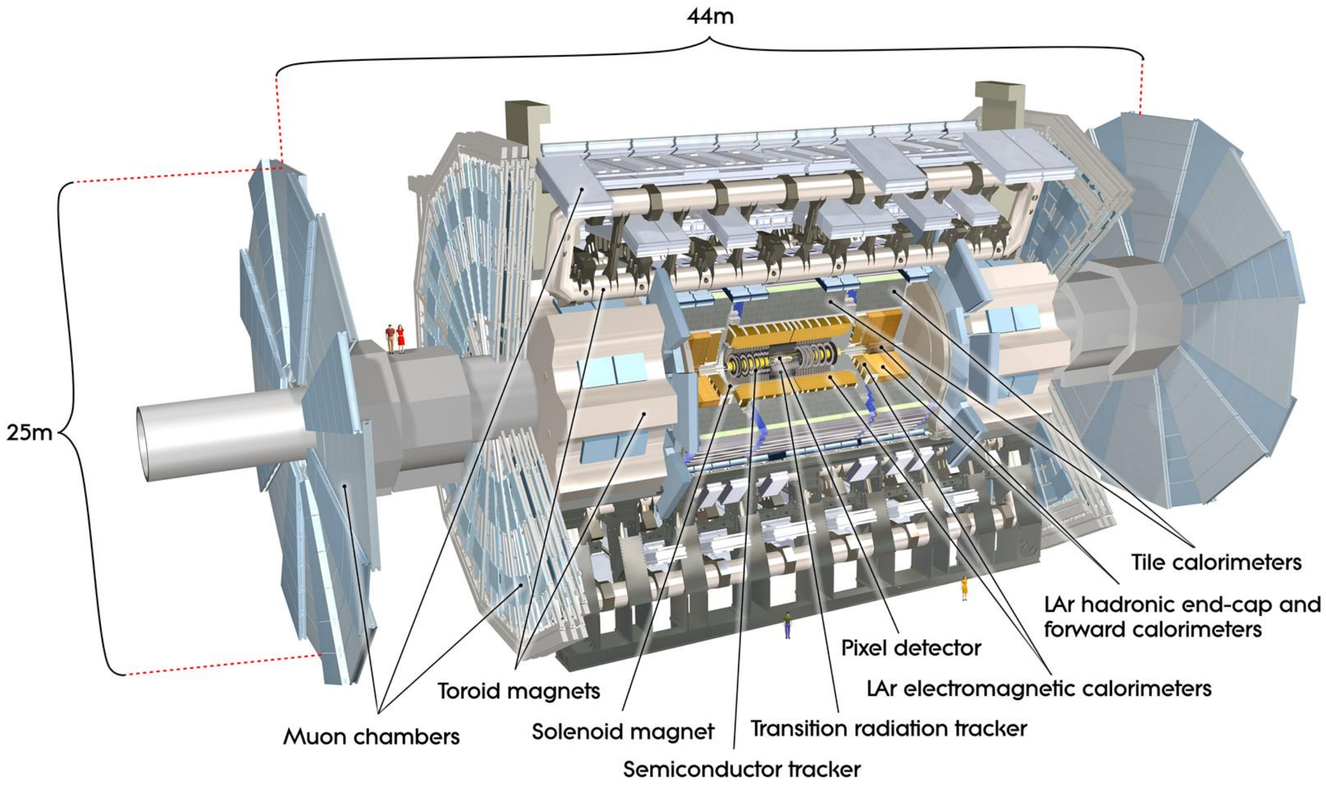
The ATLAS experiment

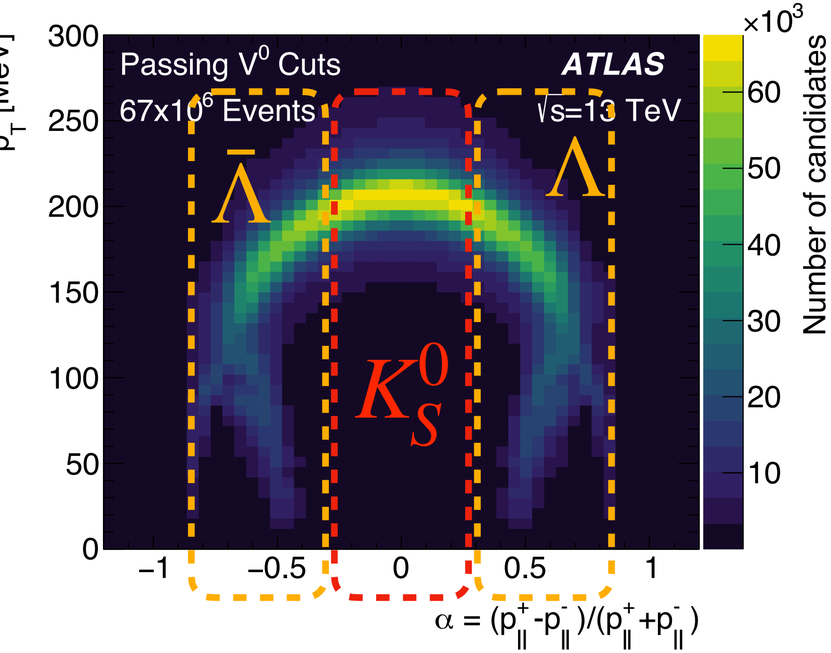
- General purpose LHC detector
- Wide physics program targeting multiple processes
  - Precision measurements
  - Searches for new physics
- Excellent probe for hadronic central physics
  - Combined calorimetry + tracking
- Charged particles in forward region more challenging due to lack of tracker
  - Will change for HL-LHC!

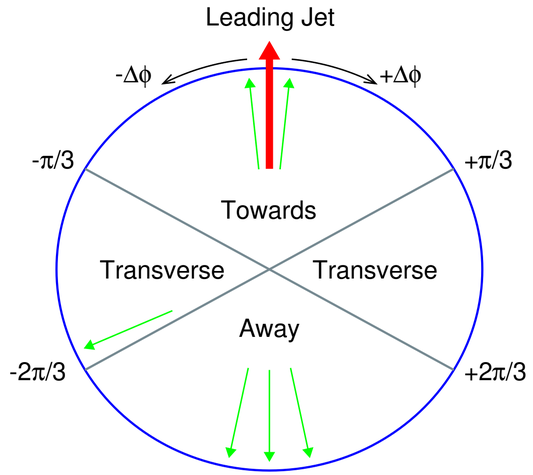


Underlying event with strange hadrons

arXiv:2405.05048

- K_S^0 and $(\Lambda + \bar{\Lambda})$ production studied in 2015 low pile-up *minimum bias* data
  - Study the underlying event in a clean environment
  - Important for the modelling of MPI hadronization and color-reconnection
- Strange hadron decays reconstructed with displaced vertices
  - Dedicated V^0-finder algorithm to identify two-body decay vertices
  - Further selections on hadron candidates for a high-purity sample
- Divide transverse plane into three regions based on leading jet
  - Minimum bias data → dijet events
  - Towards and Away: sensitive to fragmentation effects
  - Transverse: most sensitive to UE





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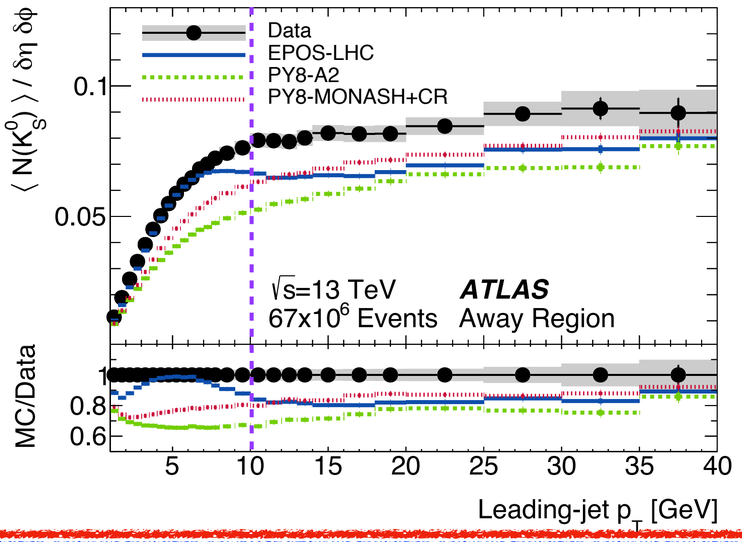
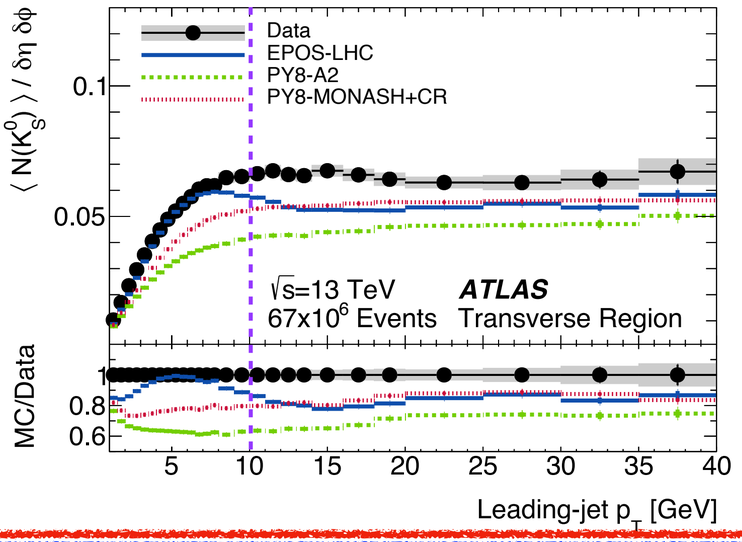
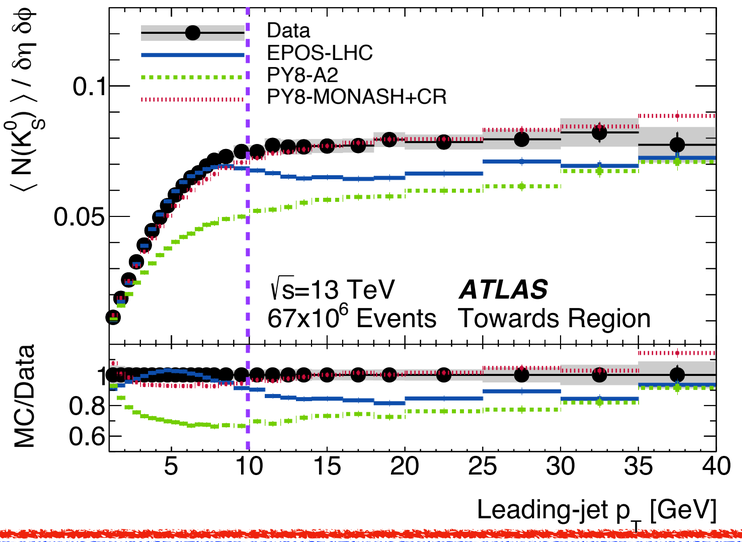
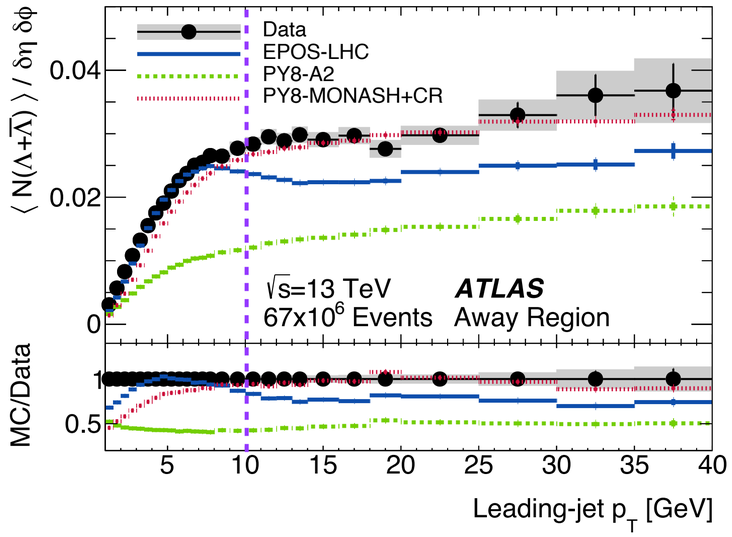
K^0_S production

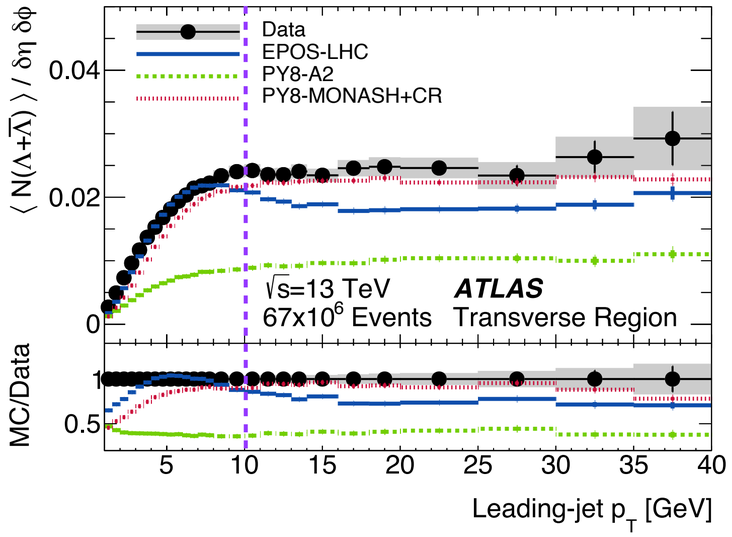


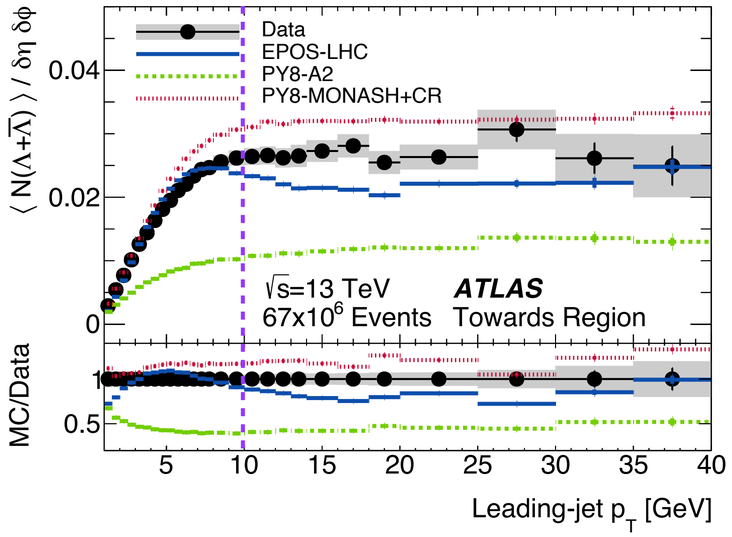




$(\Lambda + \bar{\Lambda})$ production







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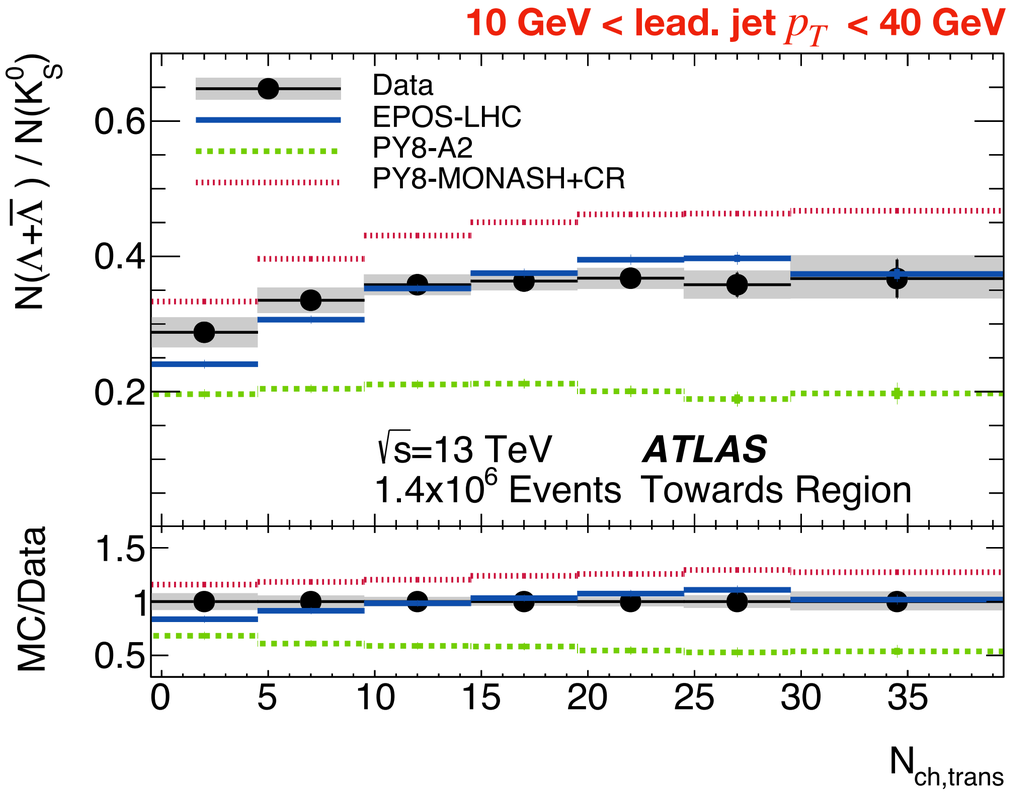
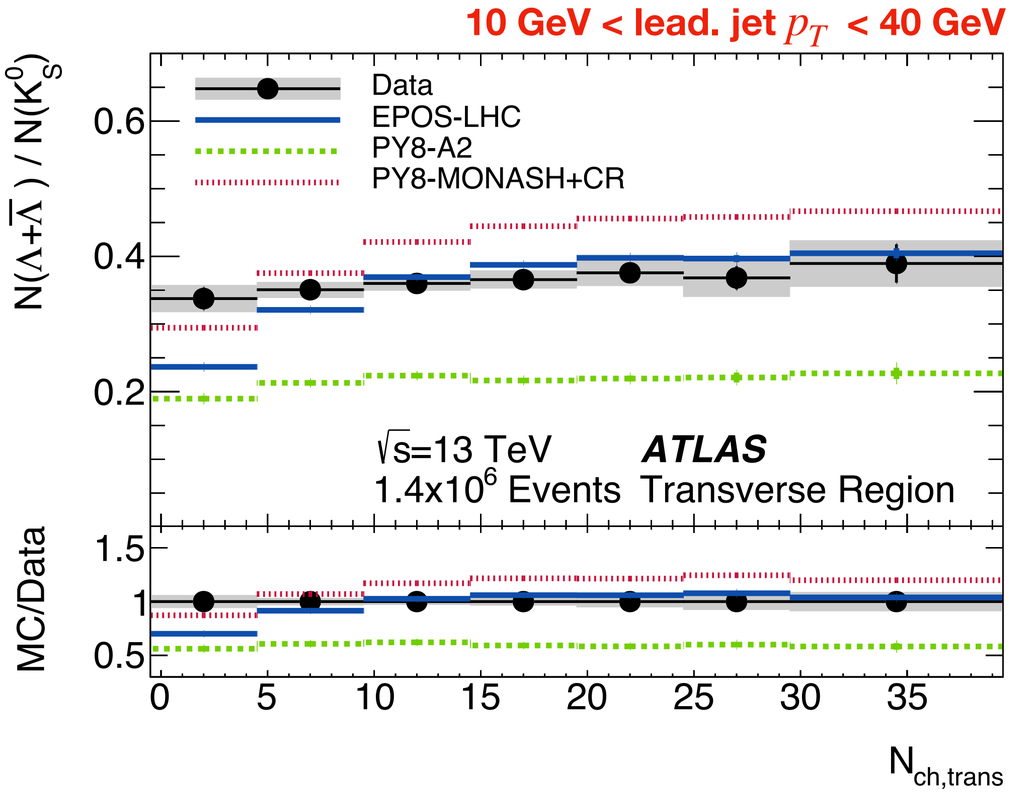




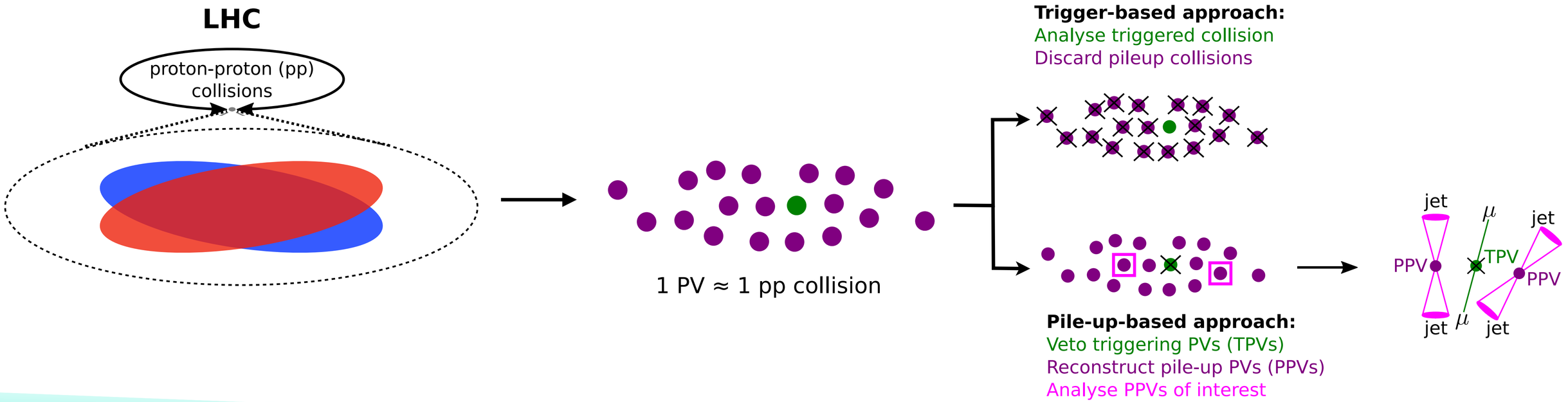
- Weak dependence with total charged activity in the transverse direction
- No model can completely account for all regimes observed
  - Pythia8 + A2 tunes predicts correct shape but yields are ~40% off!

Using pile-up collisions for physics

arXiv:2407.10819

- In each Bunch Crossing (BC) there are multiple *independent* pp interactions
- Once the data is recorded, we reconstruct each pp interaction in a BC as Primary Vertices (PVs)
  - Standard ATLAS approach: find the PV that fires the trigger, suppress everything else
  - Alternative approach: find the PV that fires the trigger, remove it and use everything else for physics
- All interactions in a given BC are uncorrelated: pile-up interactions are not biased by the trigger selection

➡ Access to low-momentum jets for physics studies!



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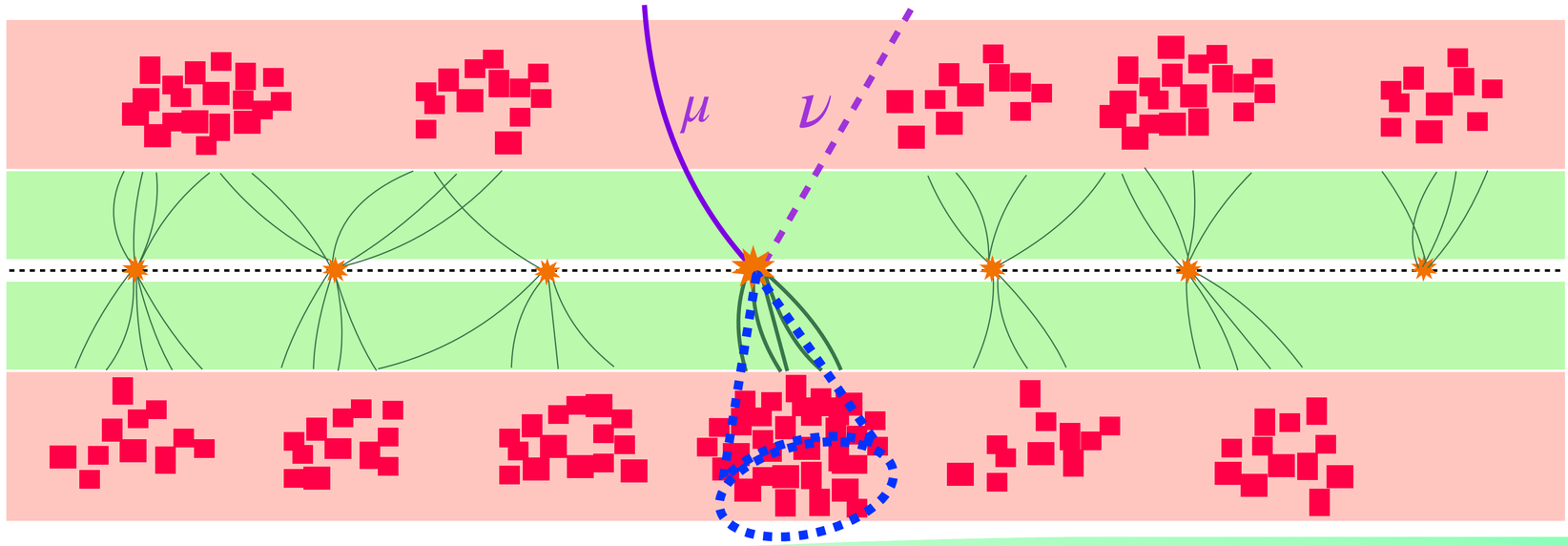

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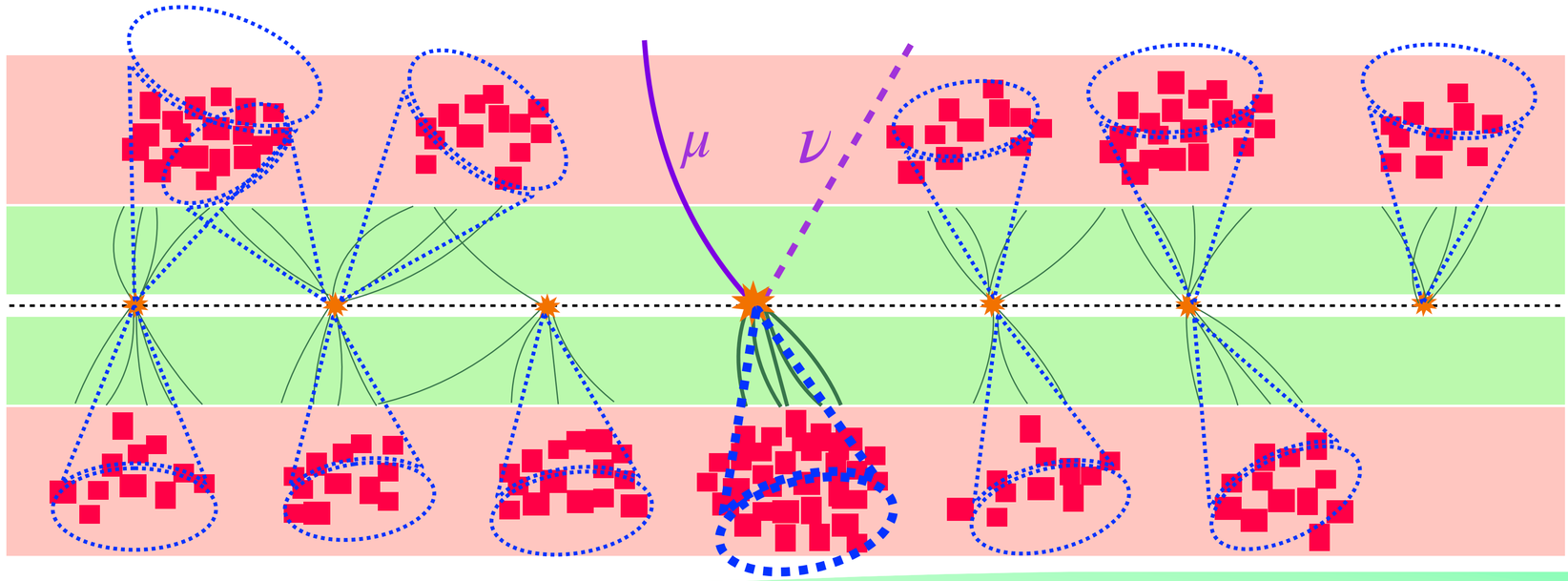
- Key ingredients:
  - Reconstruct jets from all primary vertices in the BC



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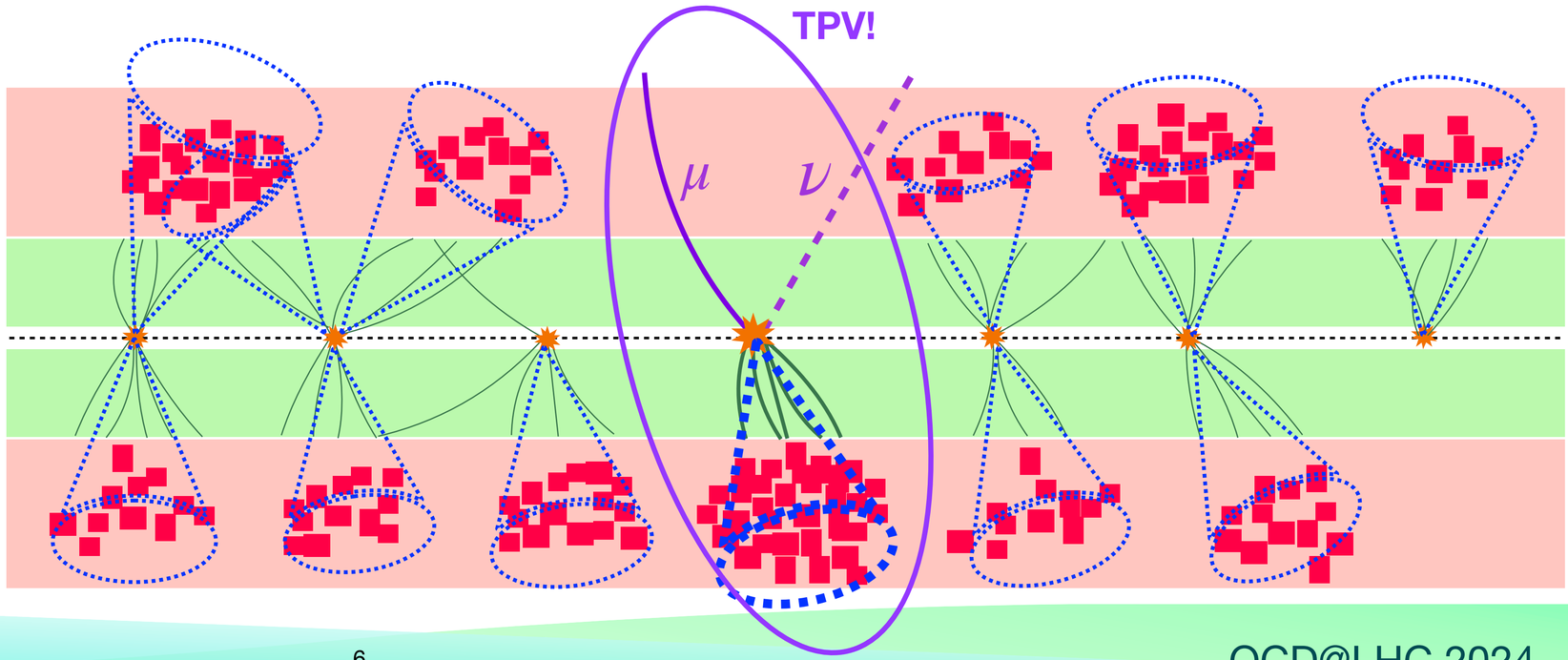
- Key ingredients:
  - Reconstruct jets from all primary vertices in the BC
  - Identify and remove the **Triggering Primary Vertex (TPV)** and <u>all objects associated to it</u>



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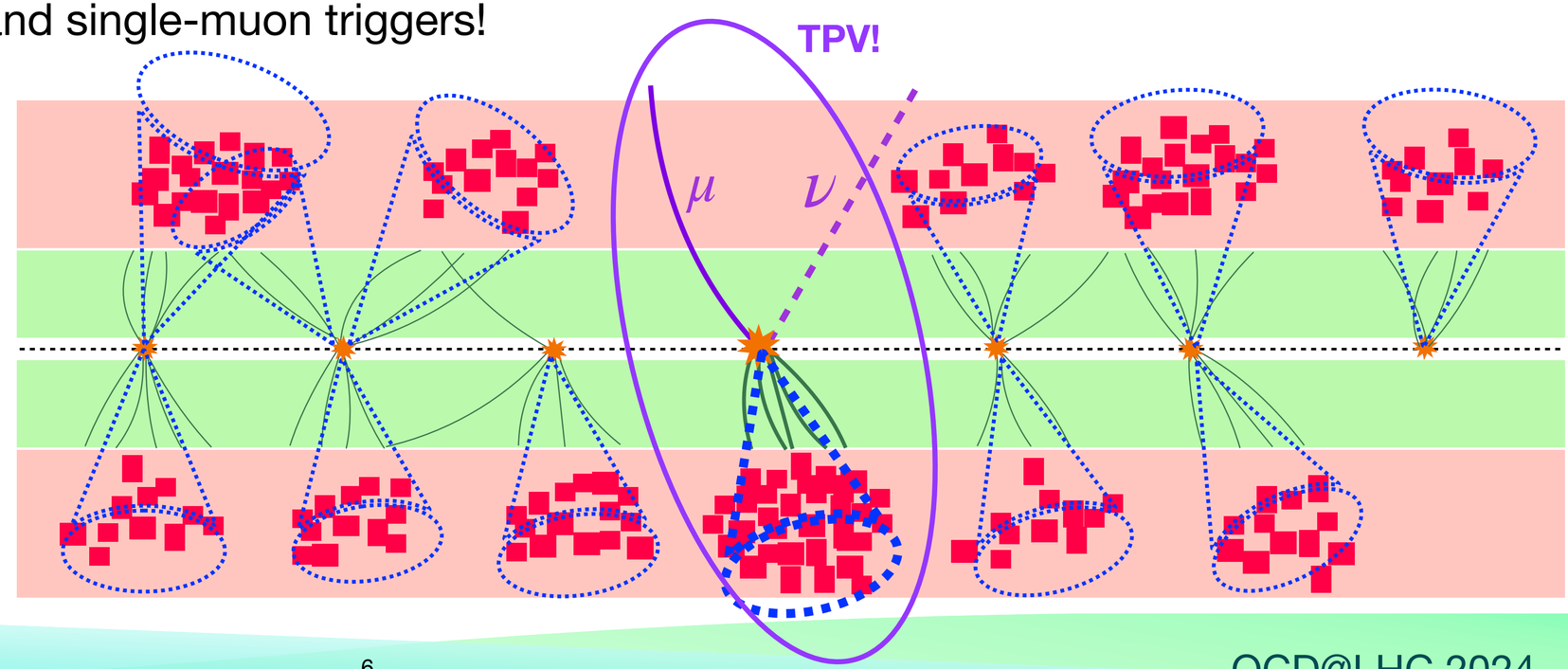
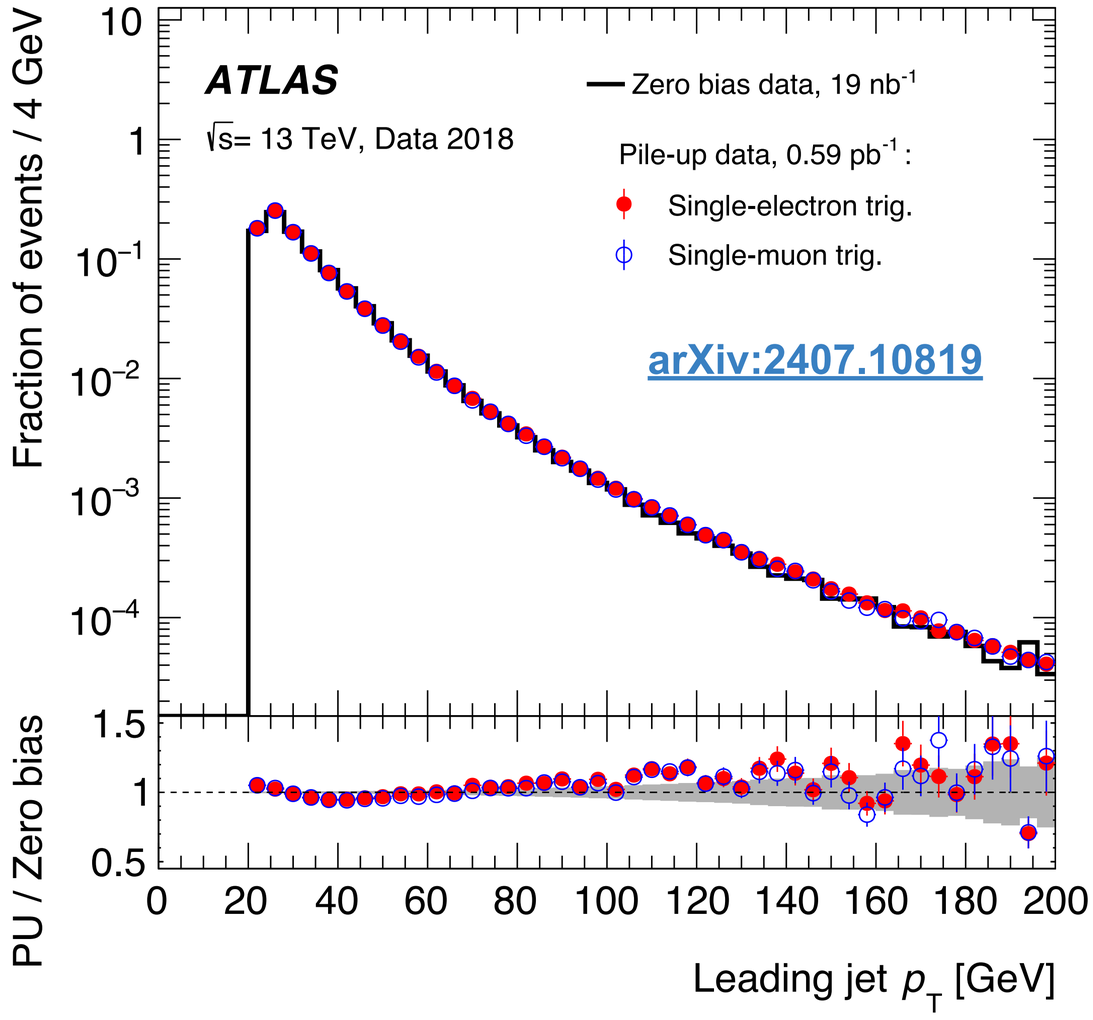
- Key ingredients:
  - Reconstruct jets from all primary vertices in the BC
  - Identify and remove the **Triggering Primary Vertex (TPV)** and all objects associated to it
- TPV identification depends on the signature triggered on
  - Find a single responsible physics object for firing the trigger
  - It must be possible to match the triggering object to a PV — charged objects
- Perfect signature: single-electron and single-muon triggers!



Using pile-up collisions for physics

- TPV-removal process is essential for trigger-unbiased dataset
- **Dataset validation:** compare the pile-up data to *zero bias* data
  - Study single-electron and single-muon triggered-data independently
  - Good agreement with reference
  - Excellent agreement between them



Using pile-up collisions for physics

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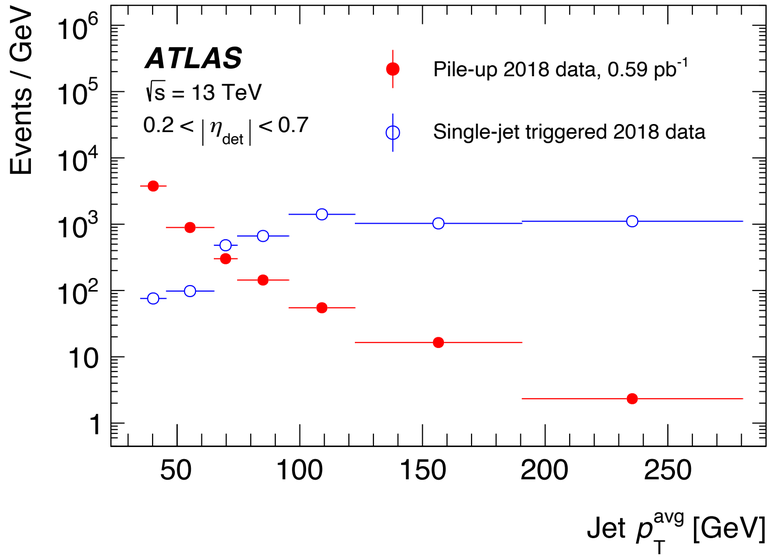
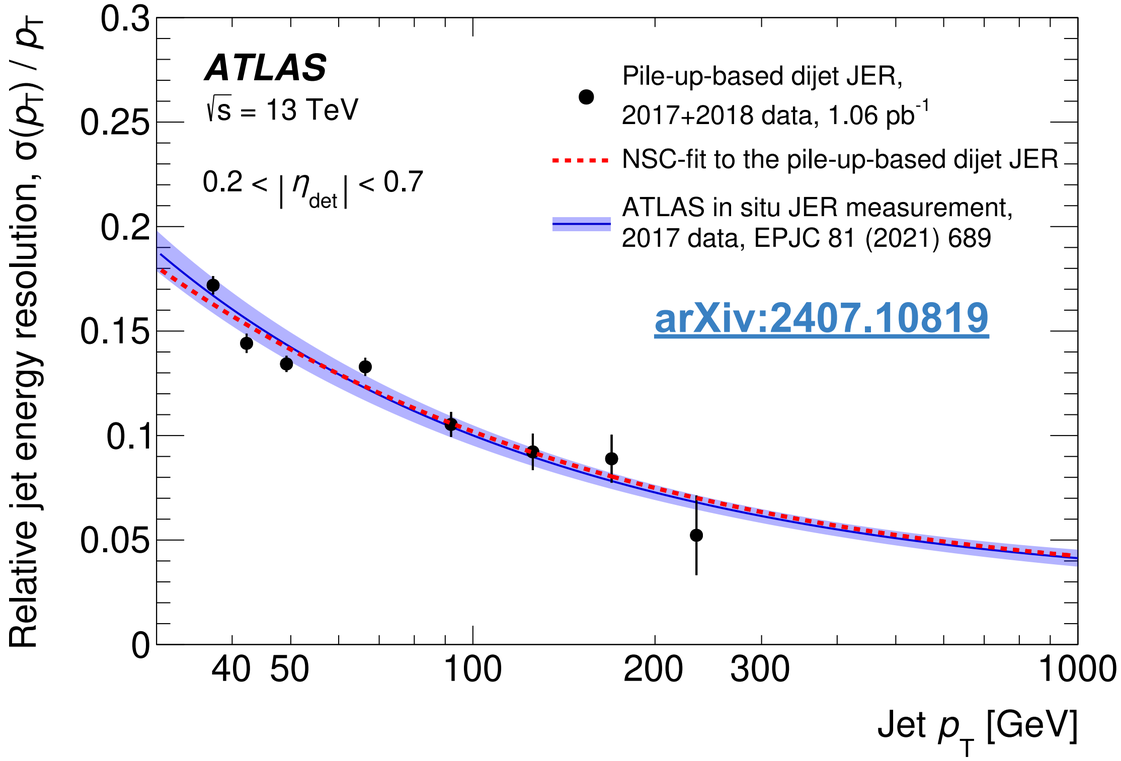
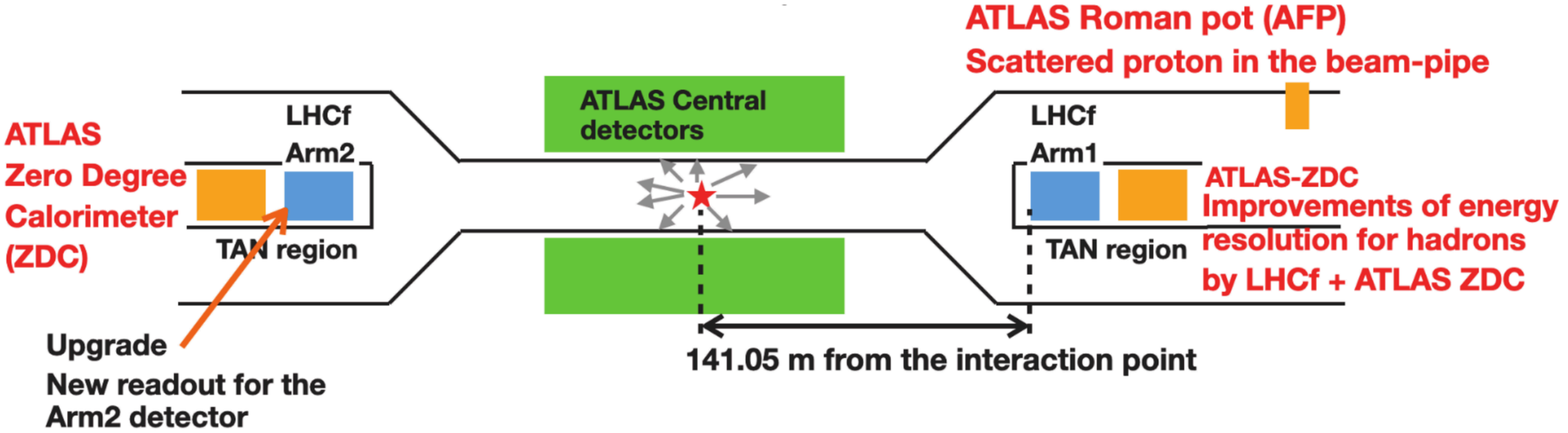
- **Dataset validation:** compare the pile-up data to *zero bias* data
  - Study single-electron and single-muon triggered-data independently
  - Good agreement with reference
  - Excellent agreement between them
- Jet Energy Resolution measurement at low jet p_T
  - Imbalance in low-energy dijet systems
  - Good agreement with standard JER extraction, improving (stat-only) accuracy up to 40%
  - First physics result with the dataset, more to come!





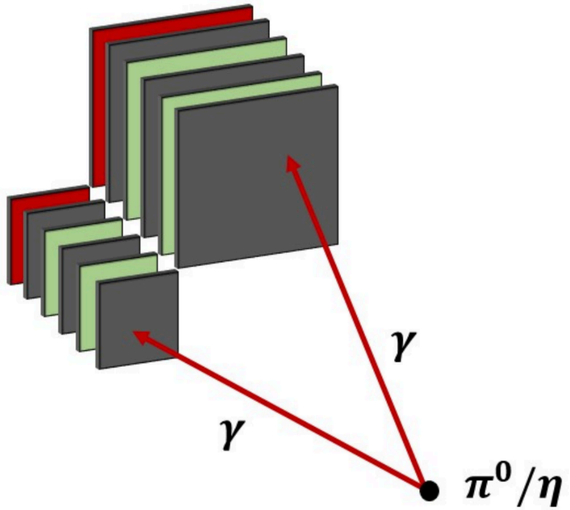
The LHCf experiment

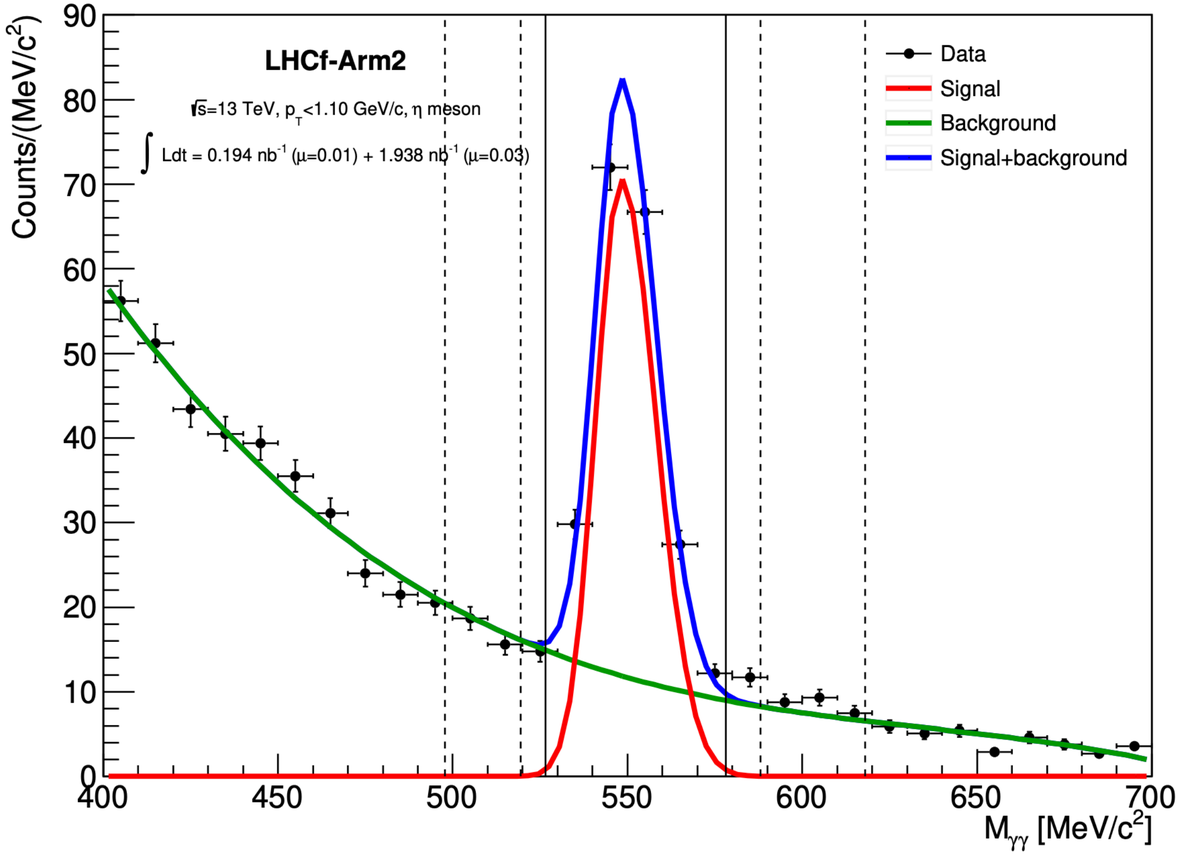
- LHC experiment optimized for neutral particle detection in the forward region → $|\eta| > 8.4$
  - Two independent detectors — Arm1 & Arm2 — at about 140 meters from ATLAS IP
- 2 towers of sampling and position-sensitive calorimeters per detector
  - 44 radiation lengths // 1.6 hadronic interaction length
- Dedicated data-taking runs, possible to complement with ATLAS detector information



Forward η-meson production rate measurement

- First observation of $s-$hadrons in the forward region with 2015 low-pileup data and Arm2 detector
- Reconstruct $\eta \rightarrow \gamma\gamma$ decays at the IP
  - Require each photon to hit a different tower → remove large backgrounds with multi-hit veto
  - Corrections to account for detector and selection effects applied
- Functional fit to data to extract the background component





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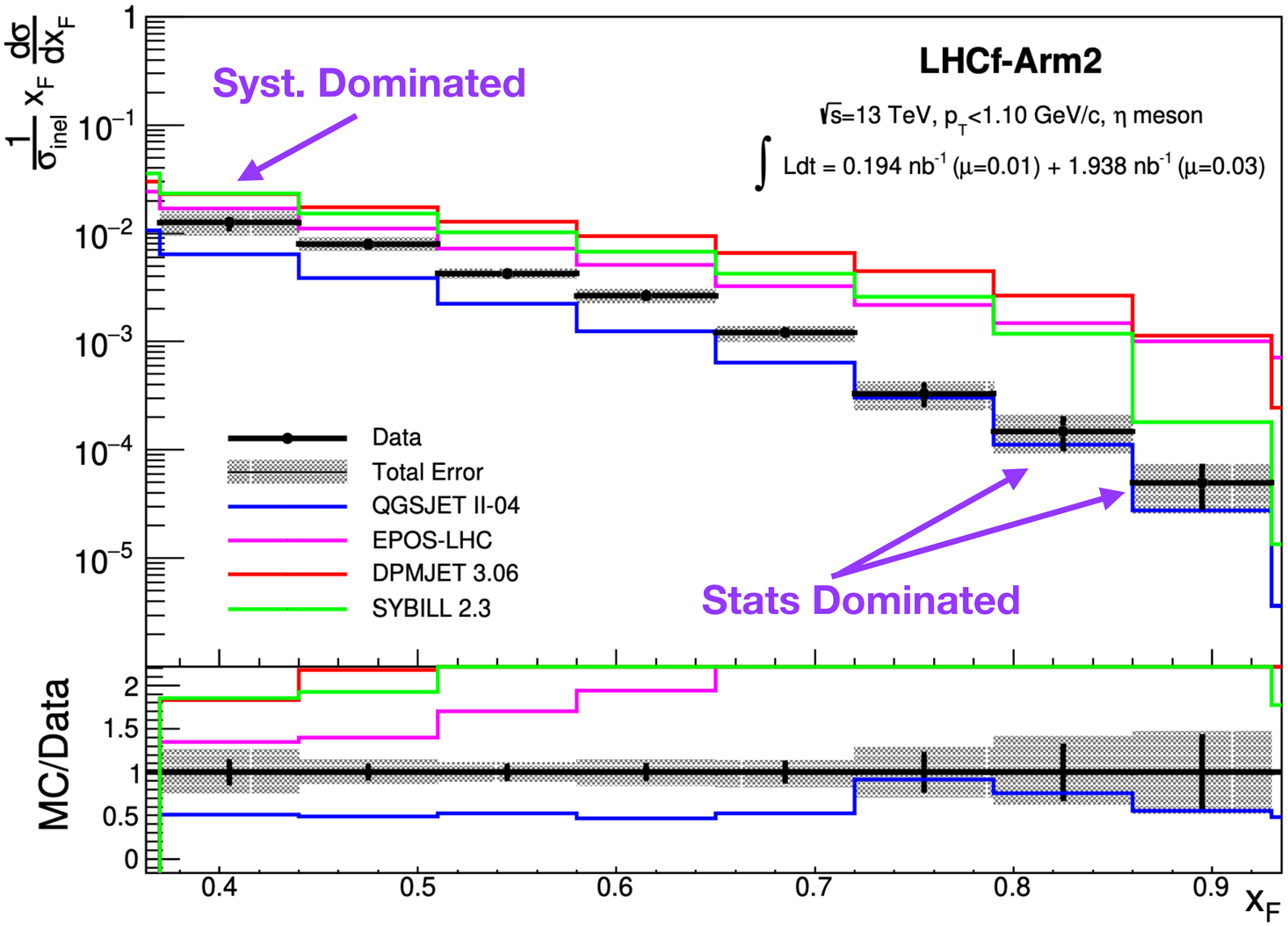
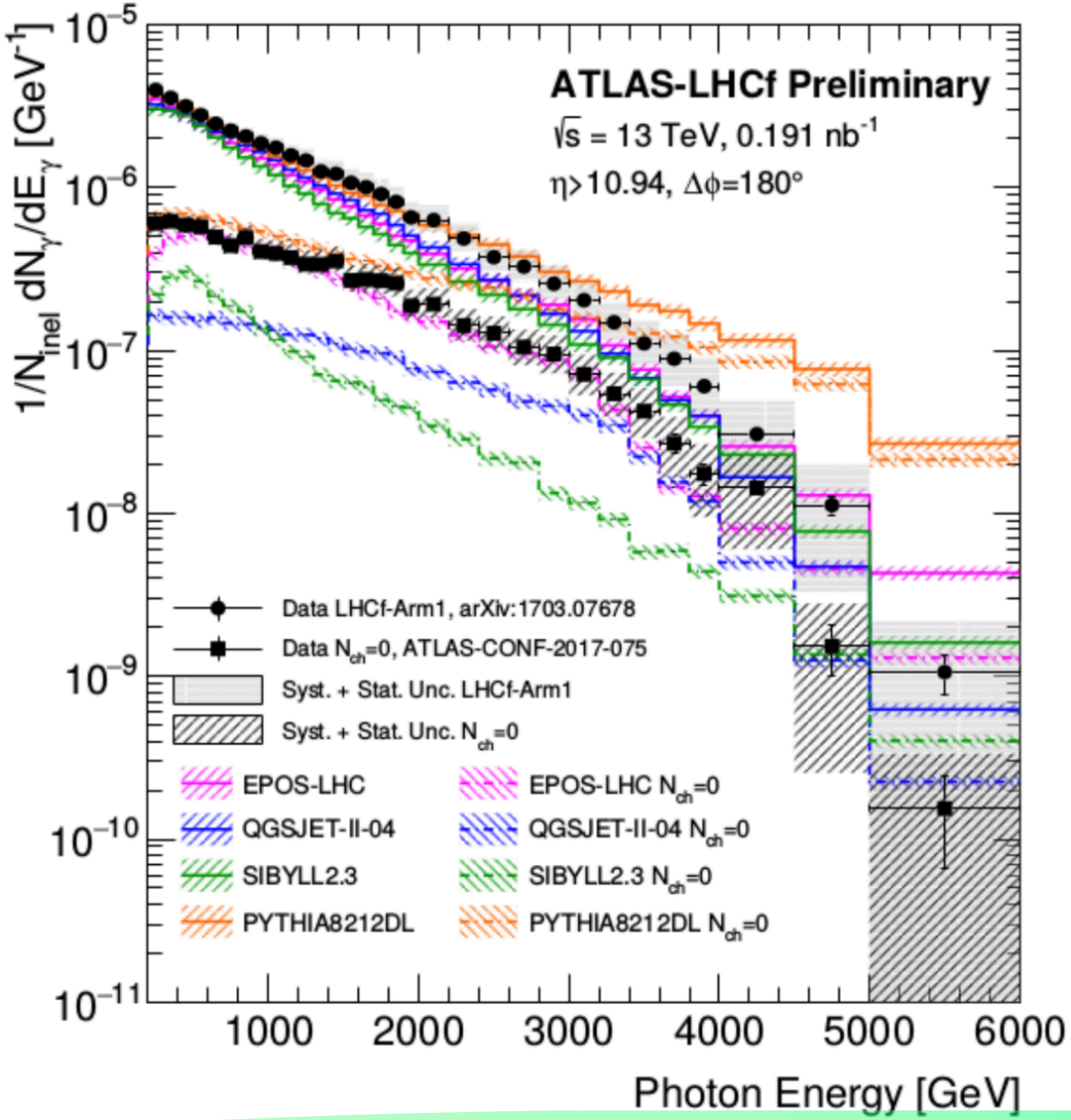


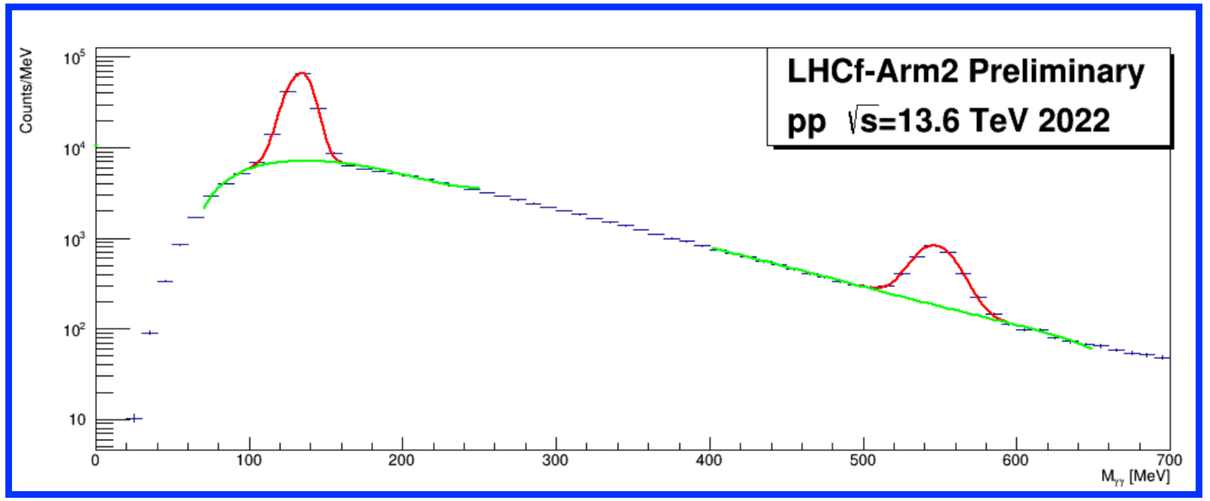
- None of the models considered can reproduce the data
- QGSJET II-04 gets close, with a similar shape but a factor 2 off in the normalisation
- The rest of the models overestimate the data by more than a factor 2

Diffractive collisions with ATLAS + LHCf

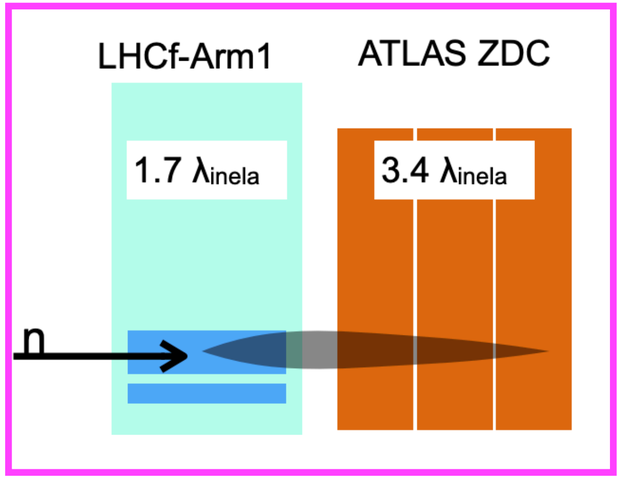
- Study photon production in pure diffractive events with the ATLAS + LHCf combined 2015 data
  - Tracker in ATLAS allows the selection of collisions with large rapidity gaps $\rightarrow \Delta\eta > 5$
- Selection of low-mass diffractive events: $M_X \lesssim 50$ GeV
- EPOS-LHC model best for ATLAS selection, Pythia8 for LHCf
- Final results in place and paper currently under internal review!

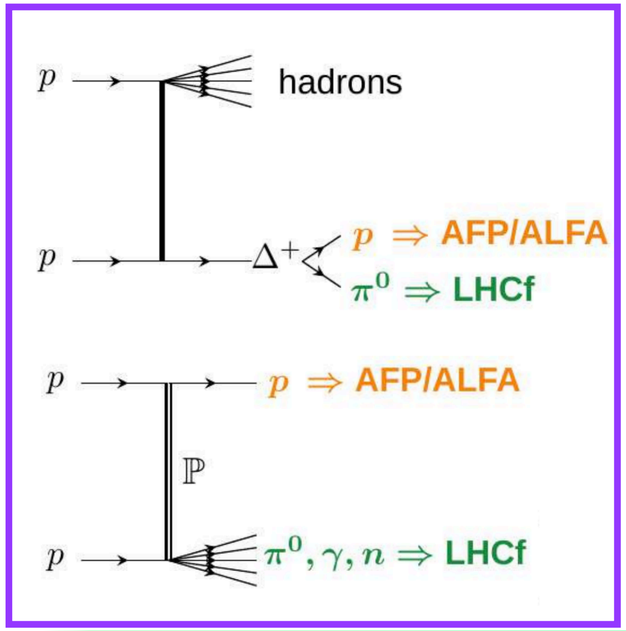


LHCf operations in LHC Run-3



- **New data sample** collected in 2022 at $\sqrt{s} = 13.6$ TeV
  - 300M events recorded vs 40M events in 2015 sample
- Combined performance with ATLAS sub-detectors for
  - **Better neutron energy resolution** — LHCf + ATLAS ZDC
  - **Tagging scattered protons** — LHCf + ATLAS RPs
- Physics targets:
  - π^0, η and K_S^0 production with increased precision
  - 1-π exchange processes
  - Search for Δ^+ resonance in forward region
  - Detailed studies of dissociative diffractive events





Summary

- A number of new results from ATLAS and LHCf collaborations on soft QCD measurements
  - New technique to access low-energy hadronic physics
  - Underlying event studies with s—hadrons
  - First observation and production rate measurement of η—mesons in the forward region
  - Combined operations of both experiments for precise results with Run-2 and Run-3 data on the way
- Important interplay among all results, with no model being able to describe all results at once
- More results from both collaborations to come, stay tuned!

Thanks for your attention!