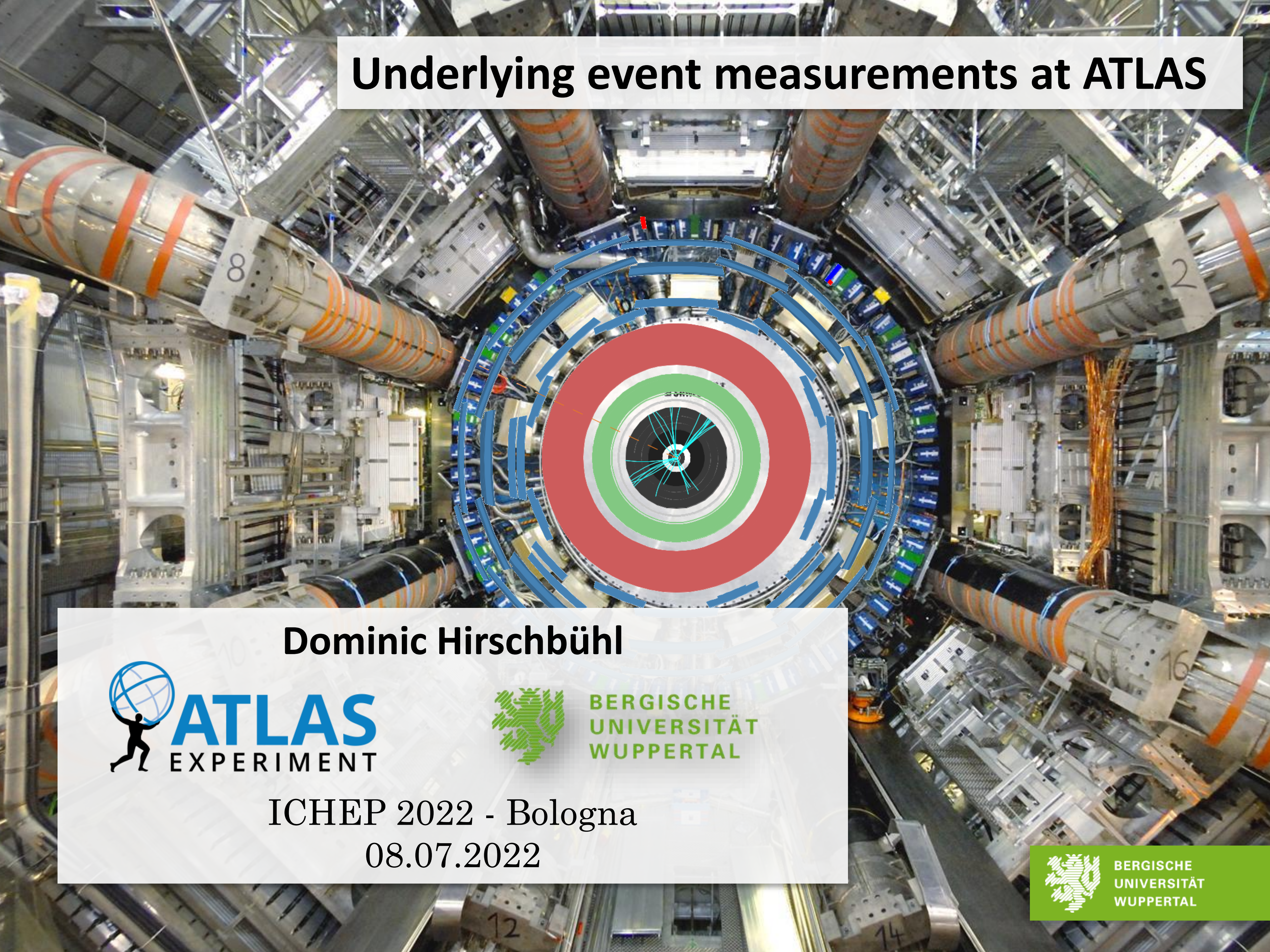
Underlying event measurements at ATLAS



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ATLAS EXPERIMENT

BERGISCHE UNIVERSITÄT WUPPERTAL

ICHEP 2022 - Bologna

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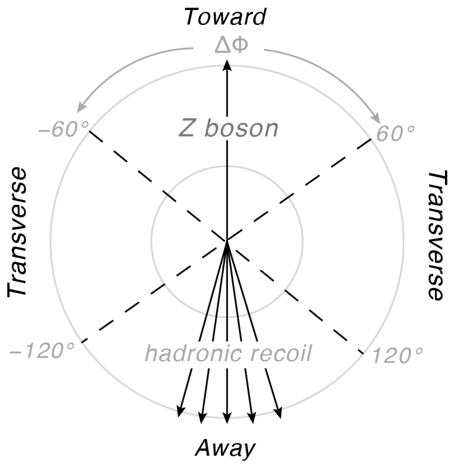
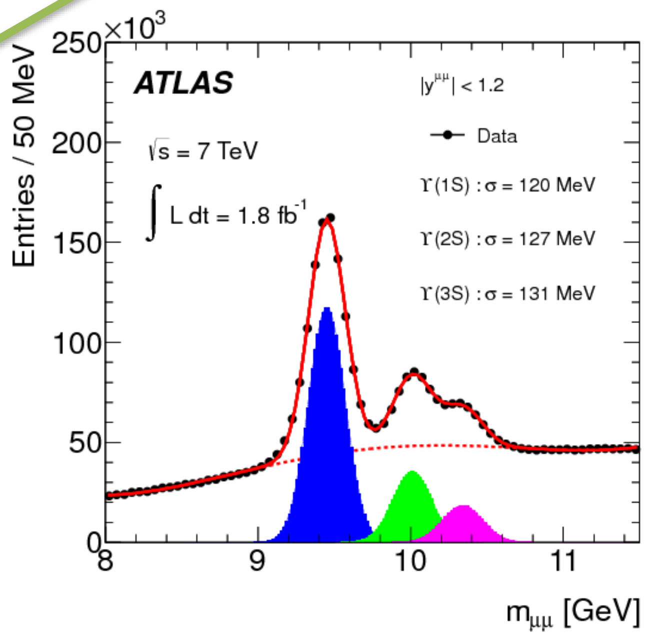
Overview

Measurement of distributions sensitive to the underlying event in inclusive Z boson production in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector
Eur. Phys. J. C 79 (2019) 666

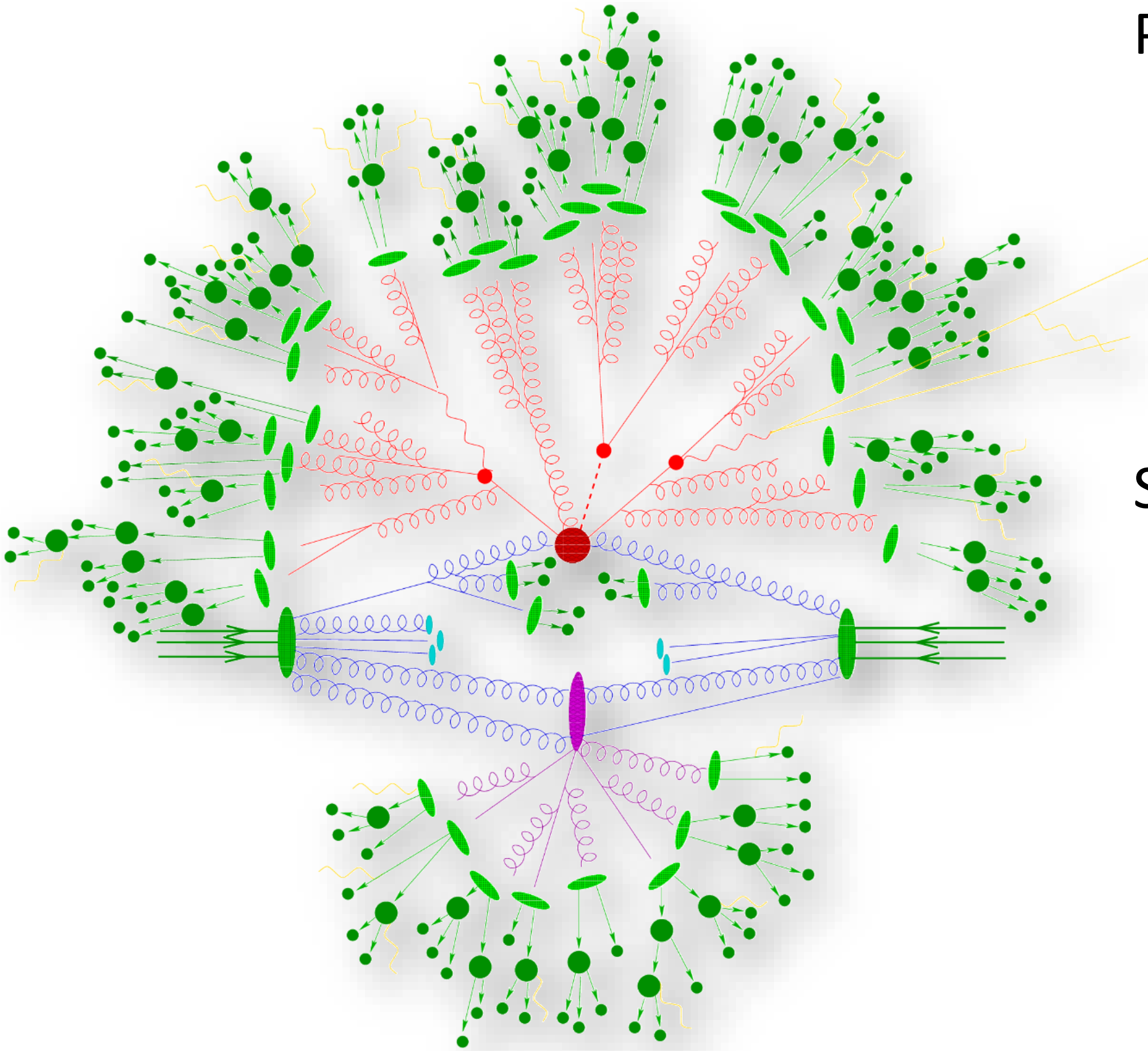


New!



Correlation of Υ meson production with the underlying event in pp collisions measured by the ATLAS experiment
ATLAS-CONF-2022-023

Introduction



Perturbative physics:

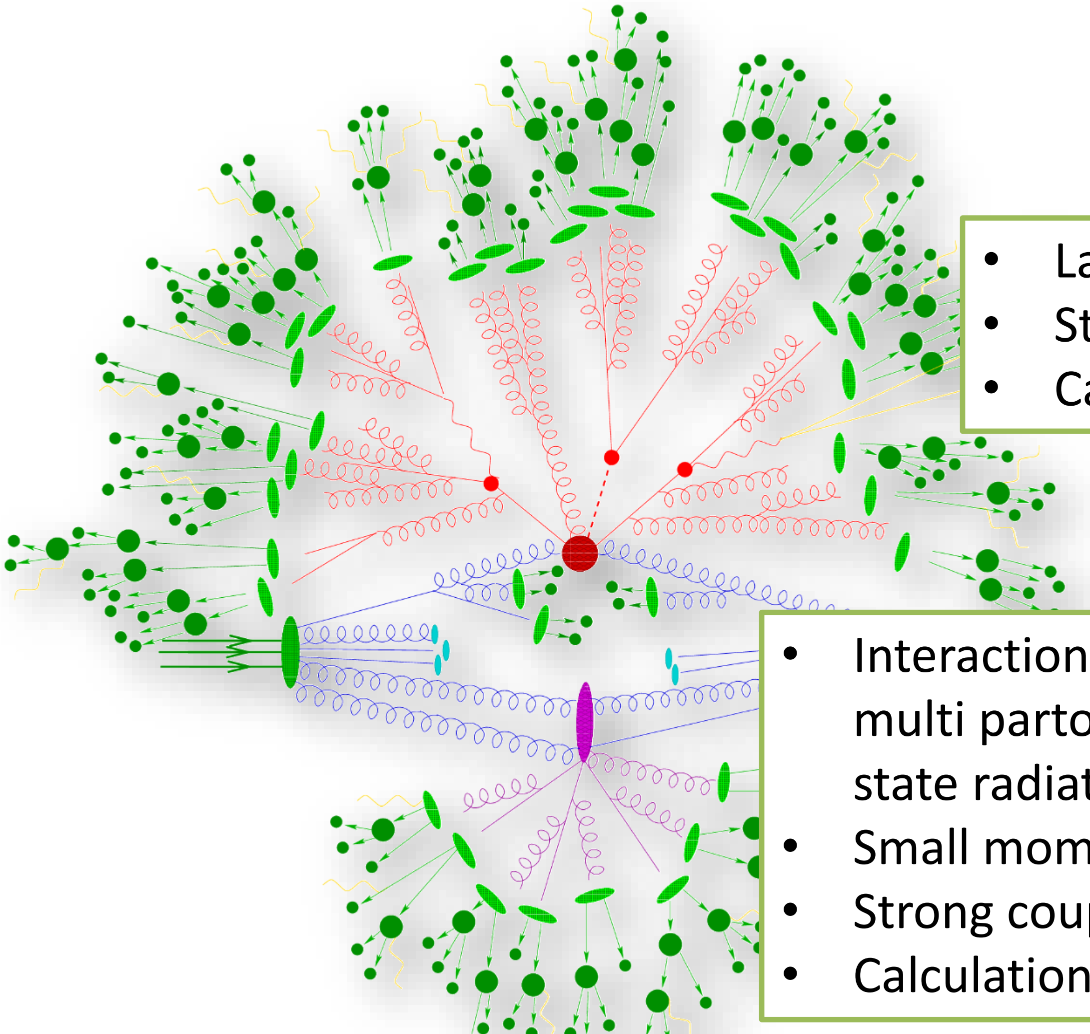
- Hard scattering
- Prompt decays

- Parton shower / QED radiation

Soft physics:

- Underlying event
- Hadronisation
- Hadron Decays

Introduction



Perturbative physics:

- Hard scattering
- Prompt decays

- Large momentum transfer,
- Strong coupling constant is small,
- Calculation using perturbatively QCD.

Soft physics:

- Underlying event

- Interaction between proton remnants, multi parton interactions(MPI), initial and final state radiation.
- Small momentum transfer
- Strong coupling constant diverges
- Calculation using phenomenological models.

No sharp boundary between the hard processes and UE.

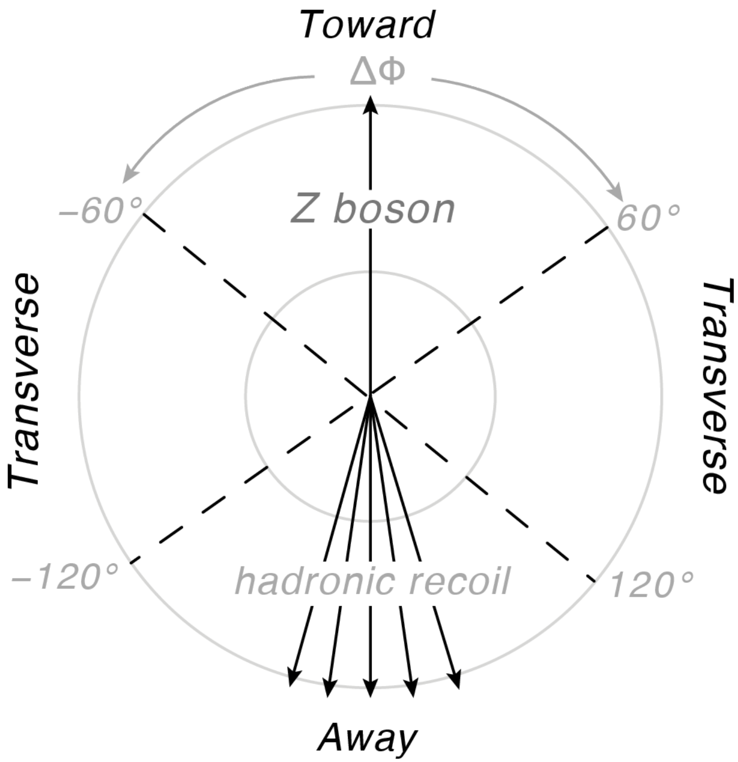
The underlying event

Activity accompanying the hard scatter

- Is not distinguishable from the hard scatter on an event-by-event basis
- Can be probed using topological observable
- Can include contributions from multi-parton interactions

Drell-Yan processes

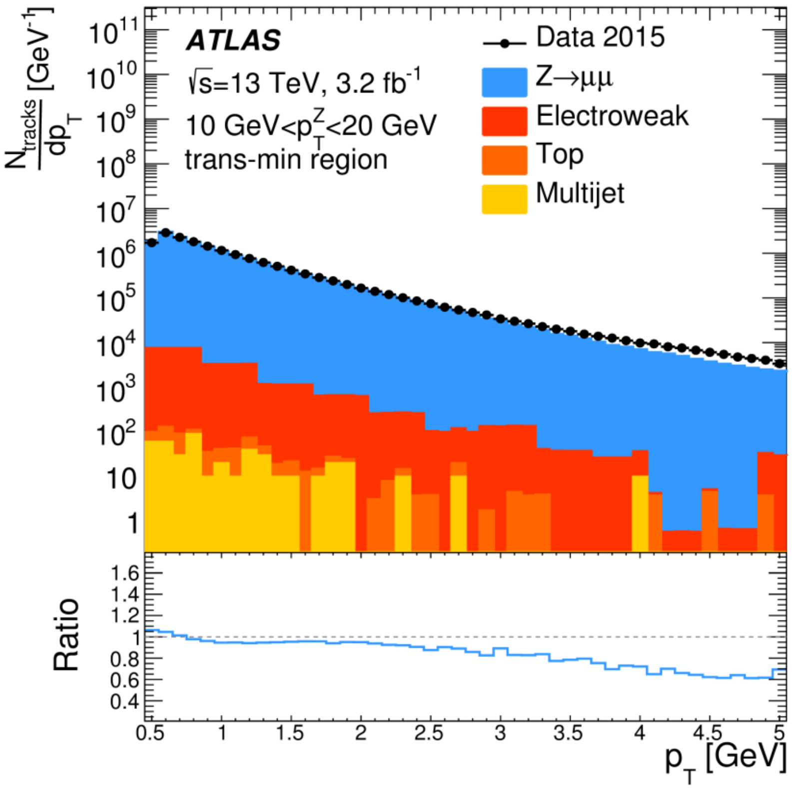
- Provide a clean environment
- Here: $qq \to Z \to \mu^+\mu^-$
  with initial-state radiation (ISR) to give a balancing jet
- No final-state radiation!
- Kinematic distributions in the transverse regions sensitive to soft production models



Analysis setup

Event selection

- Exactly 2 muons with $p_T > 25$ GeV and $|\eta| < 2.4$
- Muons must be from primary vertex and not from heavy quark decays
- 66 GeV < $m_{\mu\mu}$ < 116 GeV to reduce backgrounds
- **Tracks: $\boldsymbol{p_T > 0.5}$ GeV and $\boldsymbol{|\eta| < 2.5}$**



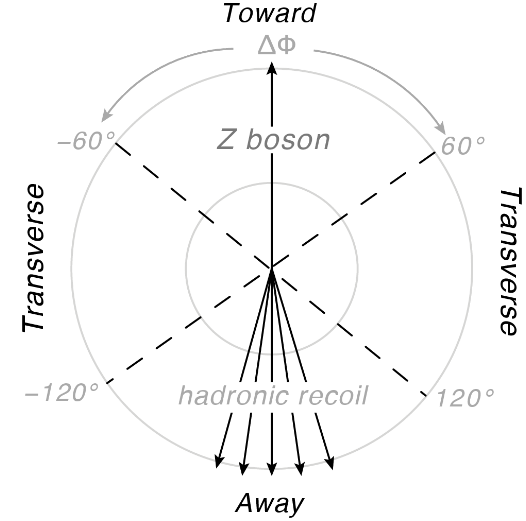
Background

- Assessed using MC
  - $Z \rightarrow \tau\tau$
  - $Z \rightarrow t\bar{t}$
  - $WW \rightarrow \mu\nu\mu\nu$
- Assed data driven
  - Multijet background

Analysis strategy

Four regions:

- Toward (Z direction),
- Away (jet direction),
- Transverse max./min with greater/lesser $\sum p_T$



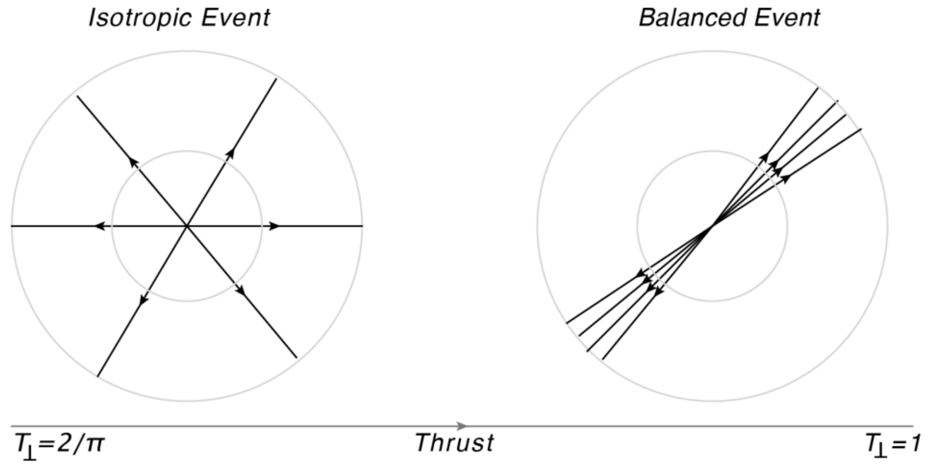
Observables, normalised to angular width of each region:

(using all particles in event, except muons.)

- Normalised charged particle p_T distribution
- N_{ch}: Charged particle multiplicity
- $\Sigma\, p_T$ of charged particles
- Mean p_T of charged particles

Studied in 8 bins of $p_T(Z)$ and two bins of transverse thrust:

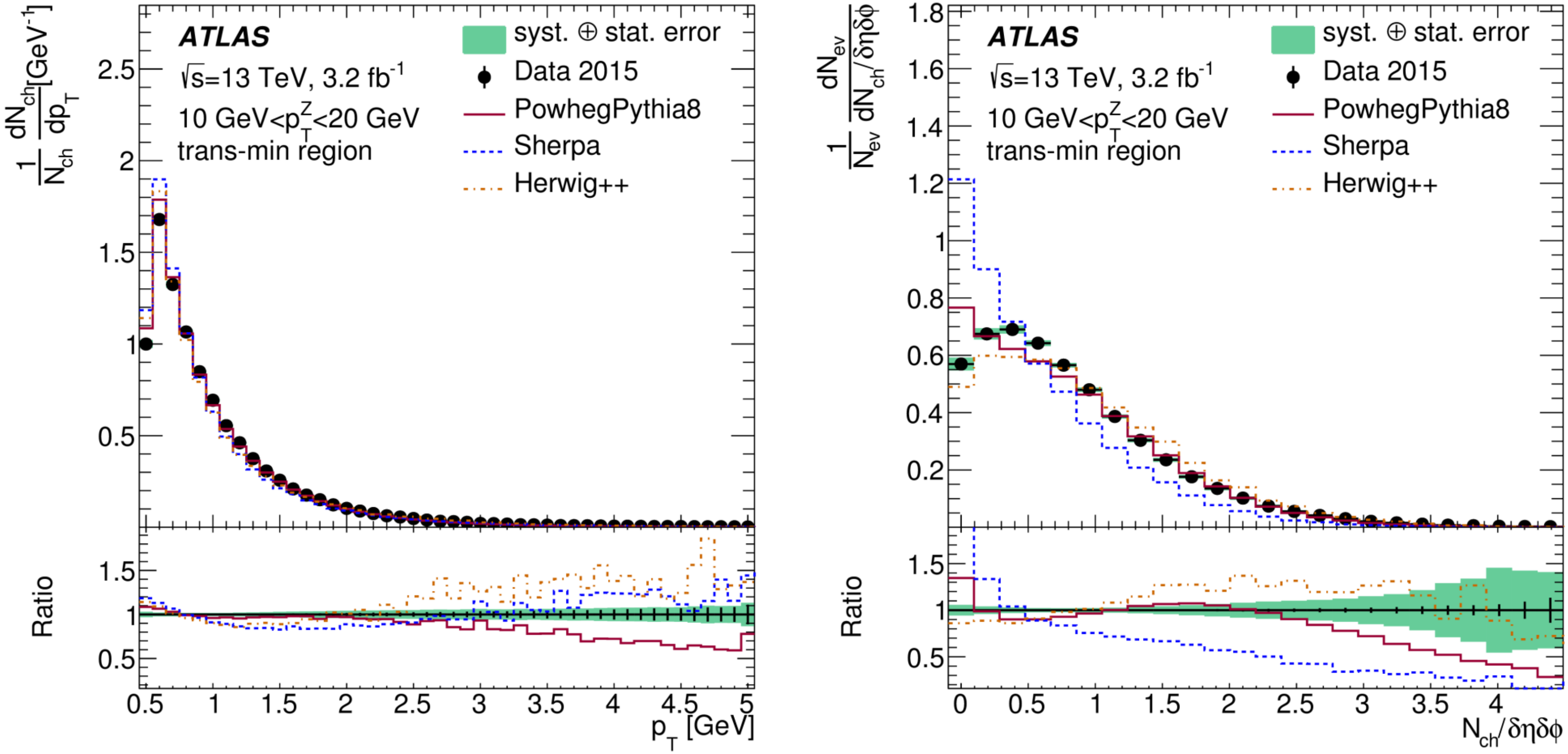
$$T_\perp = \frac{\sum_i |\vec{p}_{\mathrm{T},i} \cdot \hat{n}|}{\sum_i |\vec{p}_{\mathrm{T},i}|}$$



Low thrust
→sensitive to MPI

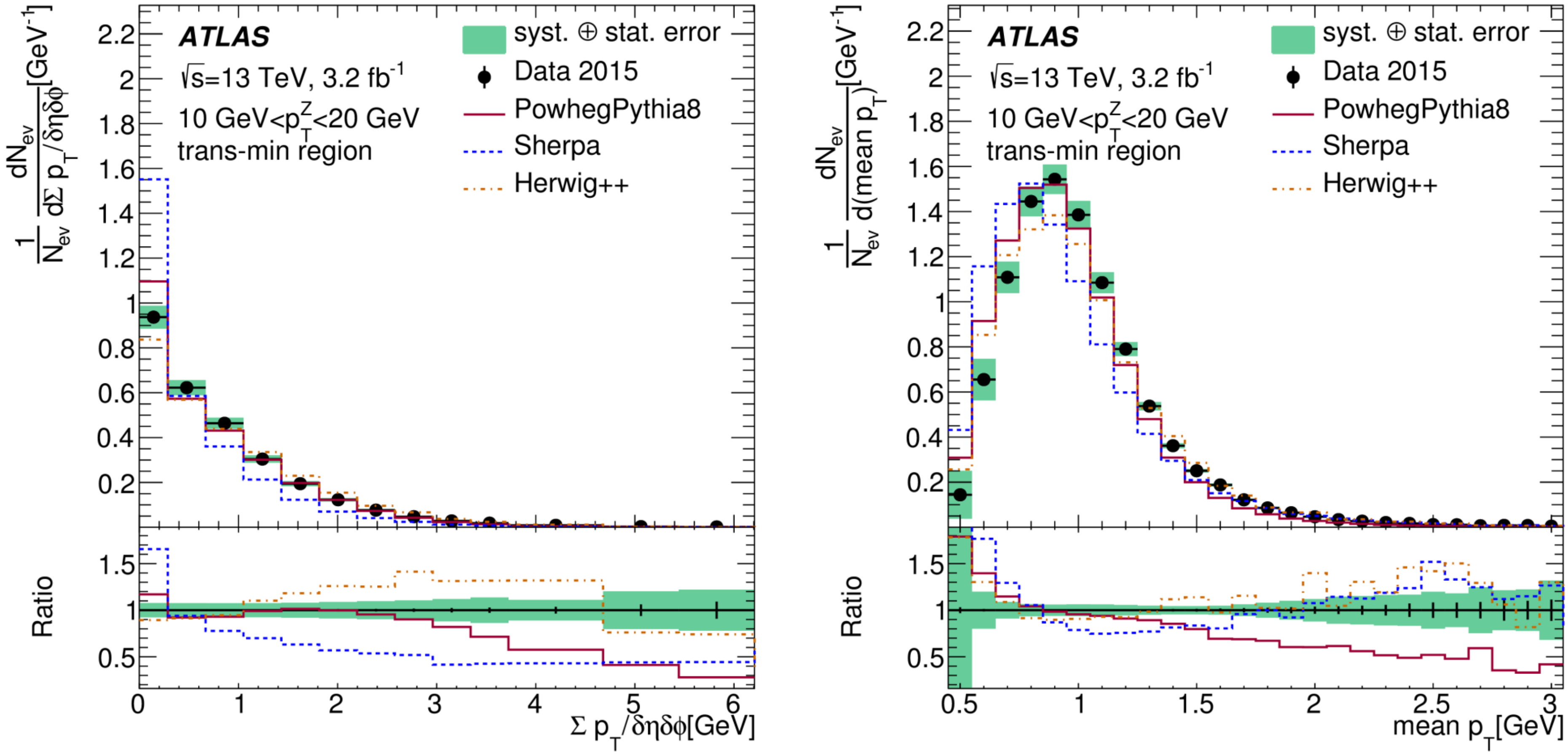
High thrust
→jet, ISR

Results



Systematic uncertainties are small and mainly detector-related.
Sherpa has worst agreement for N_{ch}

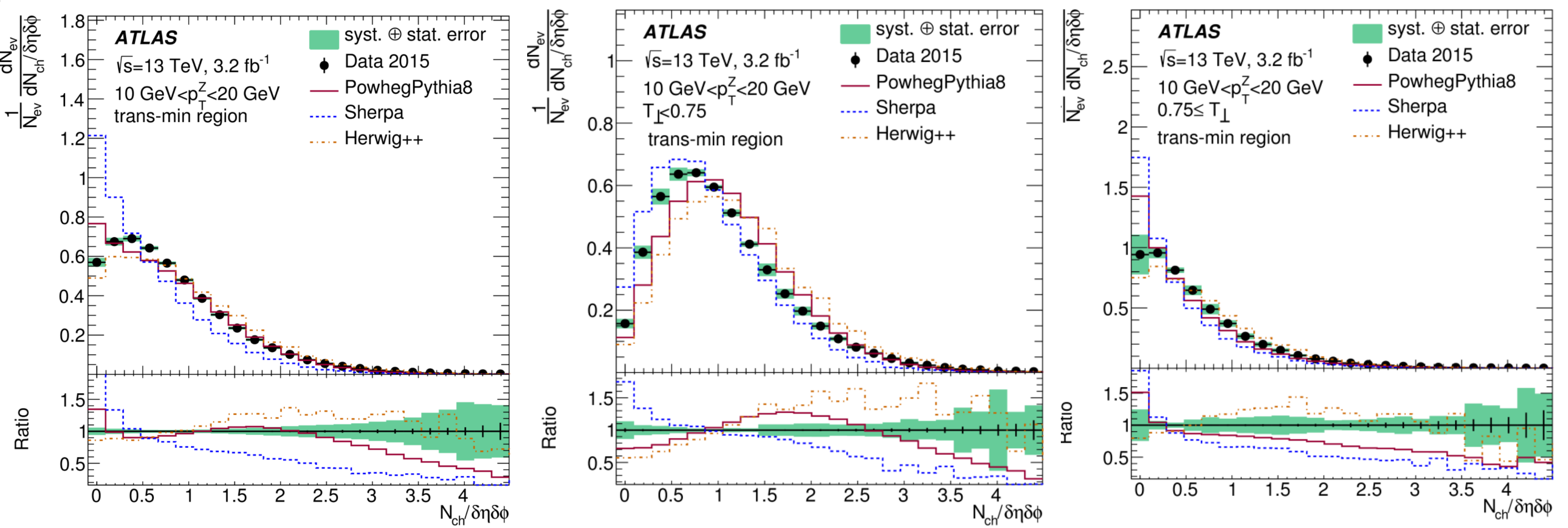
Results



- $\sum p_T$ best described by Herwig++
- mean p_T not well modelled by Pythia8
- Same trends for higher $p_T(Z)$

Different Thrust regions

Inclusive | low thrust $T_\perp < 0.75$ | high thrust $T_\perp \geq 0.75$



- N_{ch} for low quite different than for high Thrust
- Agreement is worst for both splittings

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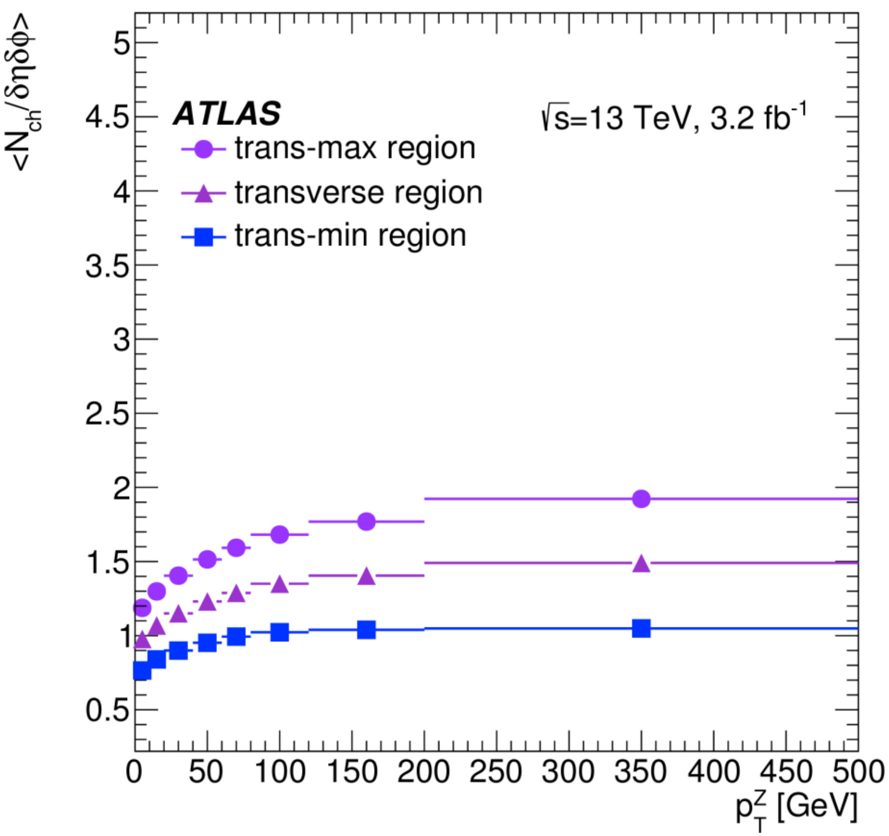
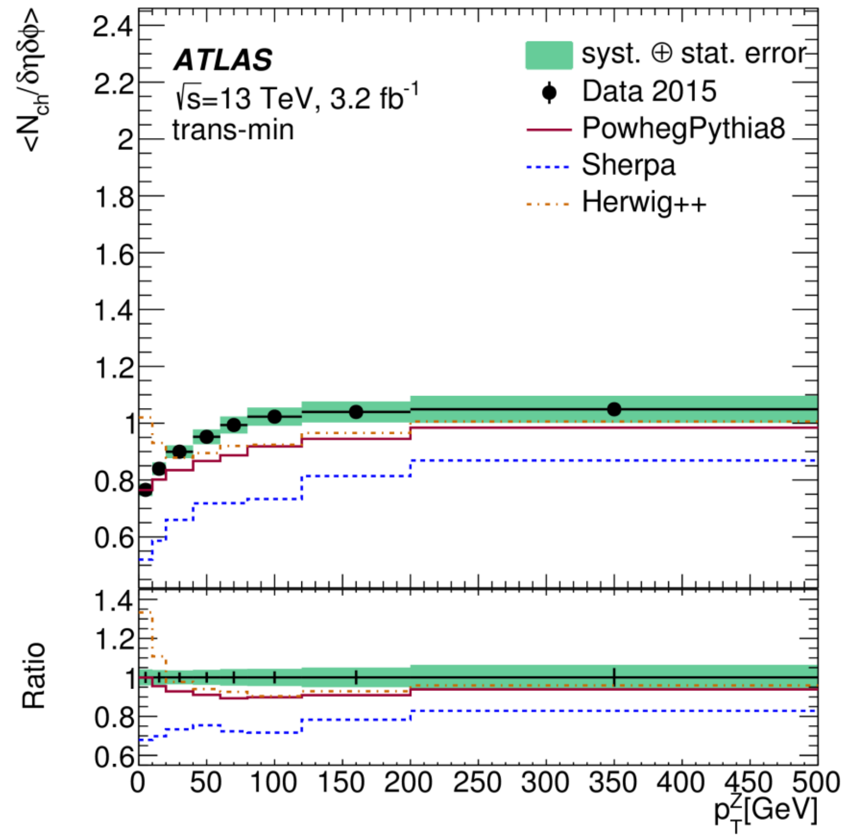
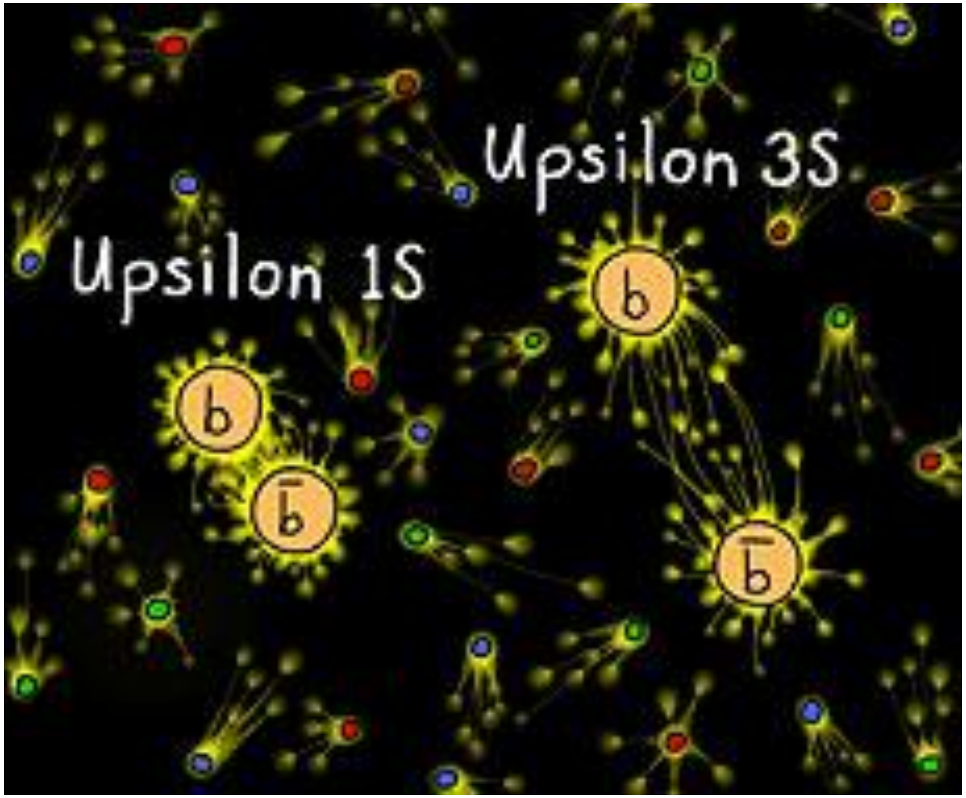
Charged particle multiplicities





N_{ch} is poorly described, but Pythia8 and Herwig++ are better then Sherpa
→ important ingredient for further MC generator tunings

Correlation of Υ meson production with the underlying event in *pp* collisions measured by the ATLAS experiment ATLAS-CONF-2022-023



Introduction and Motivation

- In heavy ion physics UE may reflect the conditions of the quark-gluon plasma formation

- Correlations between processes characterized by different momentum scales and correlations between "hard" and "soft" particle production relatively unexplored
  - Many studies of small systems demonstrating quark-gluon plasma-like signatures in soft physics → not many using hard probes

- CMS observed a decrease of the ratio of yields $\Upsilon(nS)$ / $\Upsilon(1S)$ as a function of multiplicity and studied the effect in different sphericity intervals (JHEP04(2014)103, JHEP11 (2020) 001).
  → **It was suggested that the decrease in the ratios is an UE effect.**

- Search for modification of the UE (soft) for different Upsilon states (hard) in pp collisions by measuring

$$\boldsymbol{n_{ch}},\ \ \boldsymbol{dn_{ch}/dp_T} \text{ and } \boldsymbol{dn_{ch}/d\Delta\phi}\text{, where } \boldsymbol{\Delta\phi = \phi^{\Upsilon} - \phi^{ch}}$$

Analysis strategy

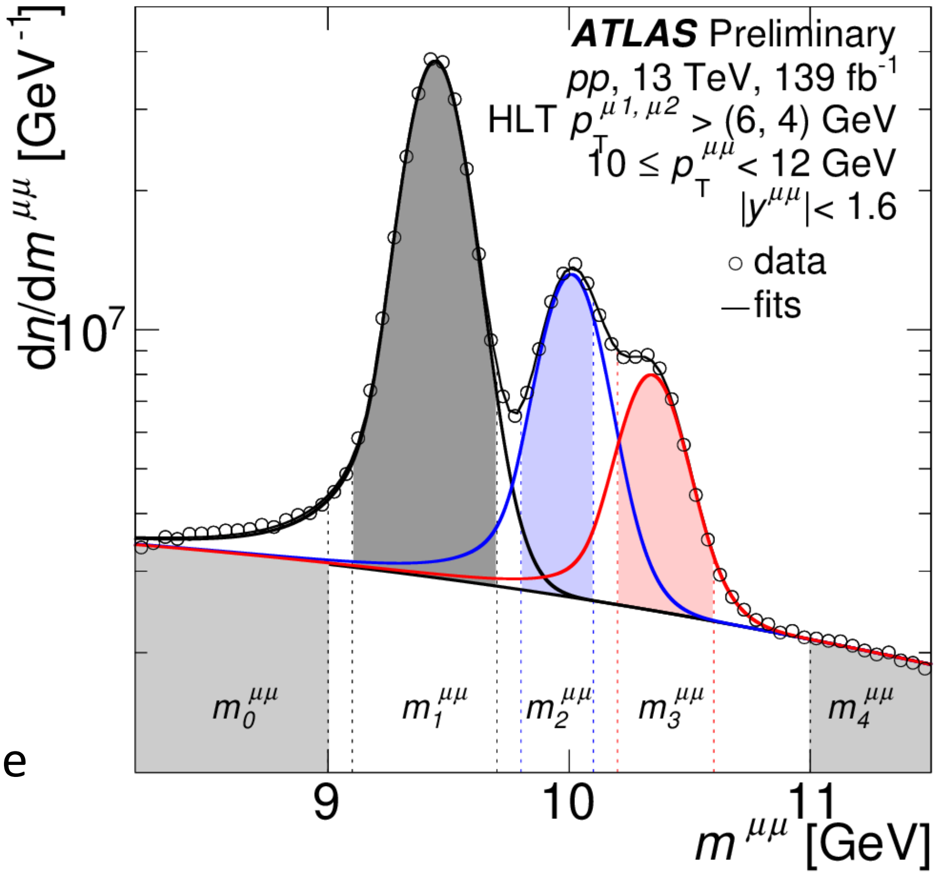
Full Run 2 dataset

- Di-muon trigger
- $\Upsilon \to \mu\mu$ events with
  - $8.2 \leq m^{\mu\mu} < 11.8$ GeV
  - $|y^{\mu\mu}| < 1.6.$

- Charged particle tracks:
  $0.5 < p_T < 10$ GeV and $|\eta| < 2.5$

- Υ candidates in 5 mass regions
  → signal + background fits

- Background in the 'upper-mass' and 'lower-mass' regions are similar in shape
  → sideband subtraction

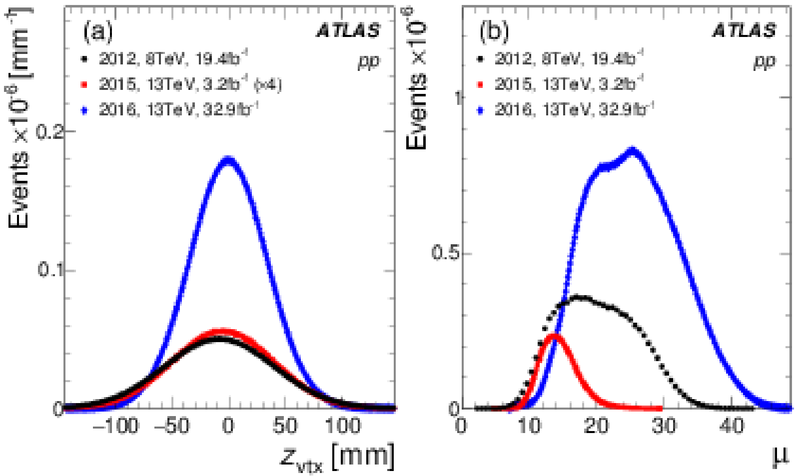


Pile-up subtraction

Pileup subtraction using **event mixing technique** developed for Eur. Phys. J. C (2020) 80:64

The main idea:

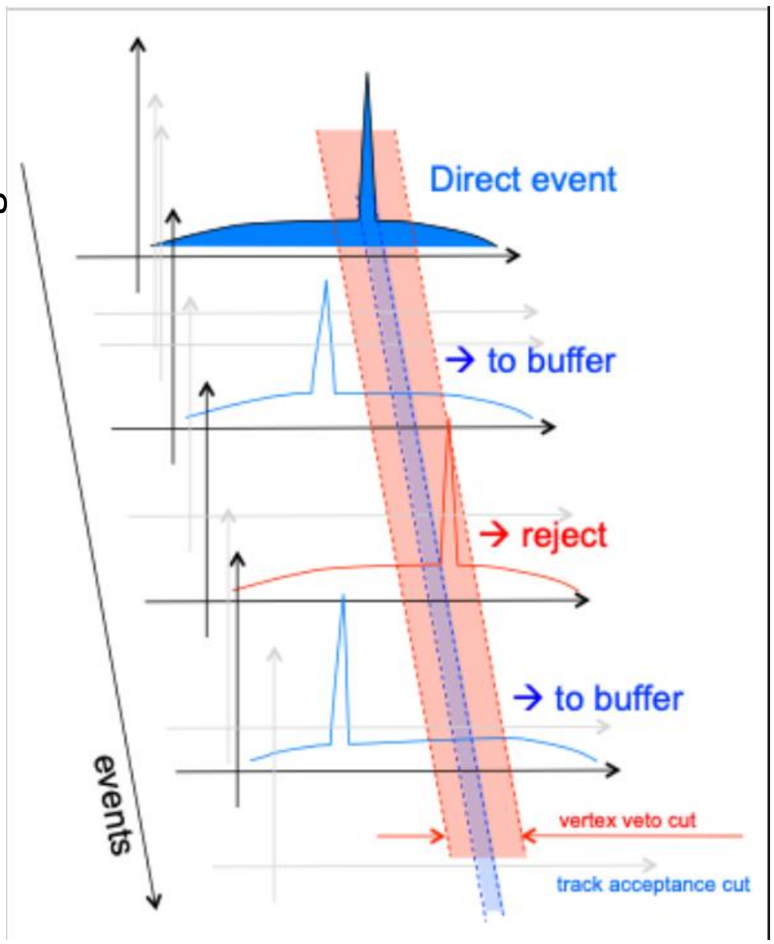
n_{trk} in a randomly placed window is proportional to the interaction density
Interaction density is defined by μ and size of the interaction diamond RMS(z_{vtx})



Since the z_{vtx} distribution is stable over the LHC fill, one can measure the n_{trk} in a window placed at the same location in another event with the same μ.

Pile-up subtraction

Stolen from Yasha Aizenberg



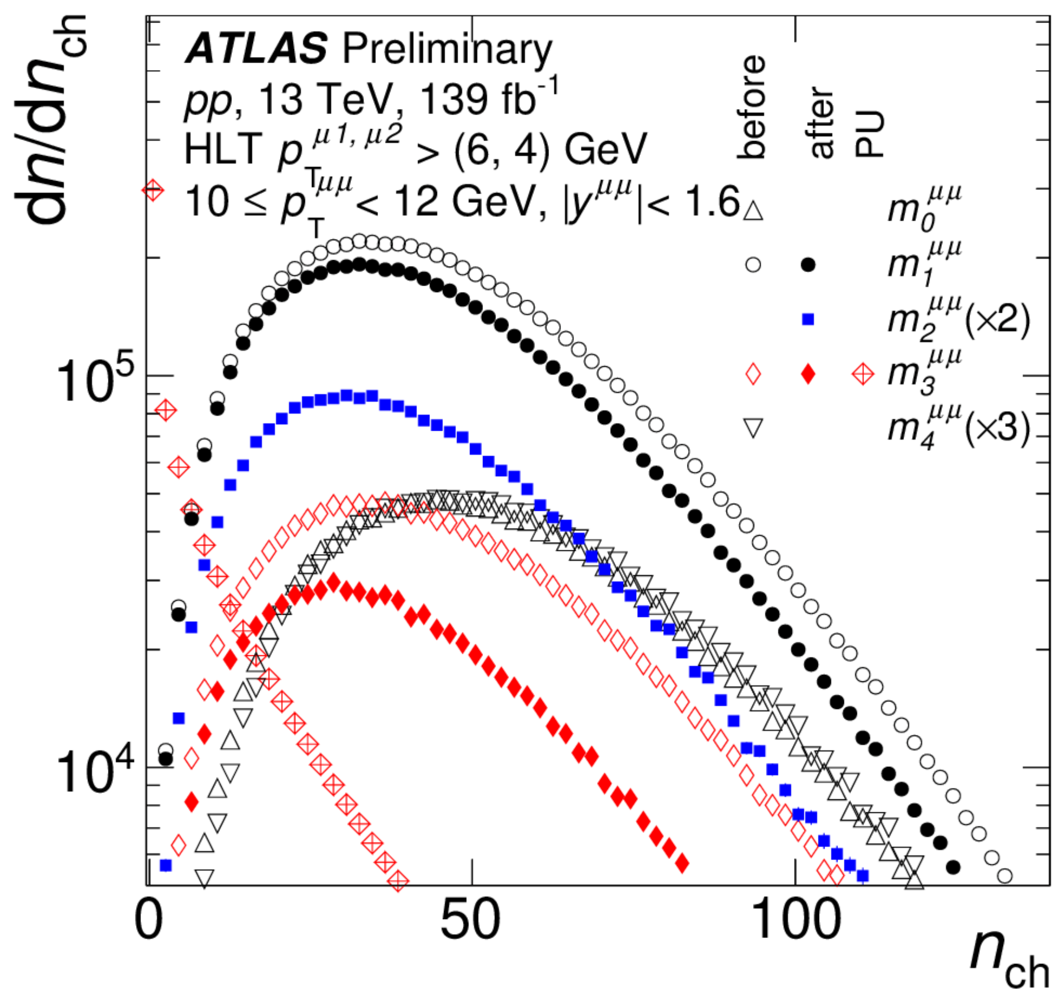
- Select a certain event from the events sample → Direct event
- Search for events with the same μ in the same run
- Discard events, where the vertex in the other event is within **15mm** of the Direct event
- Tracks are selected to Mixed events, if they satisfy vertex pointing in longitudinal plane $|\boldsymbol{\omega}| = \left|\left(z_0^{trk} - z_{vtx}\right)\sin\theta\right| < 0.75\ \mathbf{mm}$, w.r.t. vertex of the Direct event
- Repeat procedure 20 times
- Accepted number of pile-up events:

$$\nu \equiv \langle n_{\mathrm{trk}}^{\mathrm{bkg}} \rangle = 2\omega_0 \left.\frac{\mathrm{d}^2 n_{\mathrm{trk}}^{\mathrm{mix}}}{\mathrm{d}\omega\, \mathrm{d}\bar{\mu}}\right|_{\bar{z}_{\mathrm{vtx}}=0} \mathrm{Gauss}(\bar{z}_{\mathrm{vtx}})\bar{\mu},$$

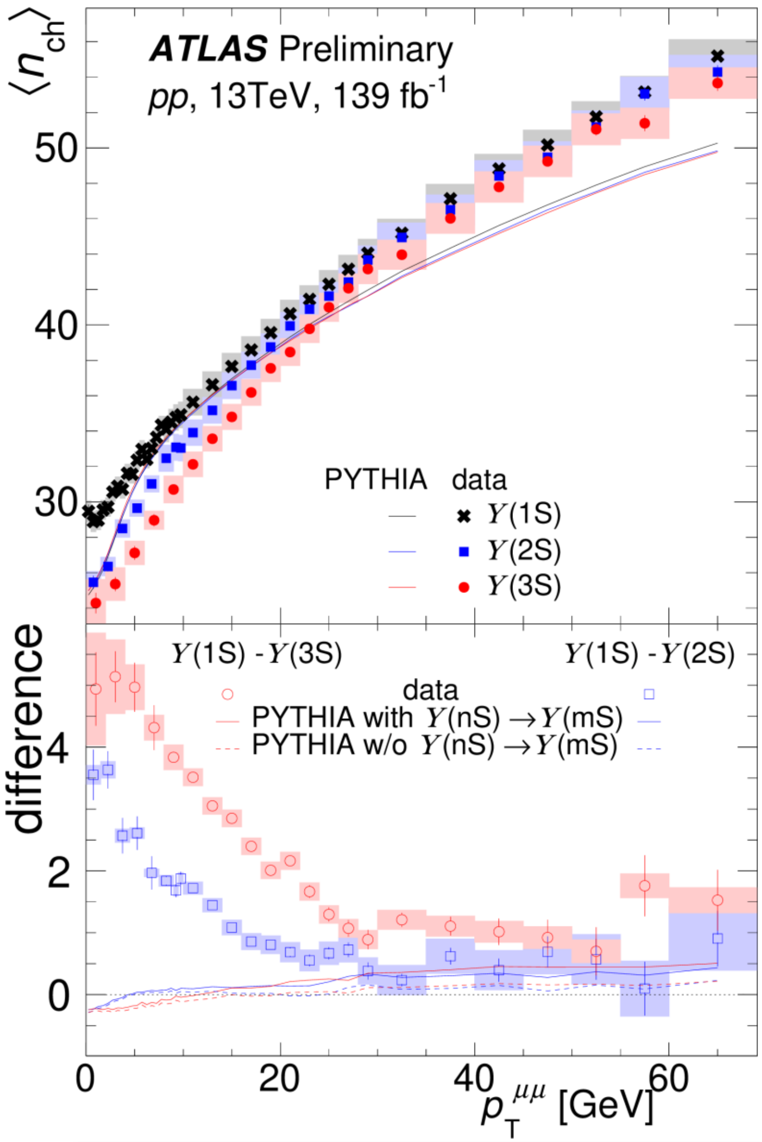
0.75mm   Particle production in pp collisons

n_{ch} distributions for Υ states

- Open markes before, full markers after background subtraction
- Pileup contribution identical for different states
  → only shown for $\Upsilon(3S)$)
- Different Υ states have different averages

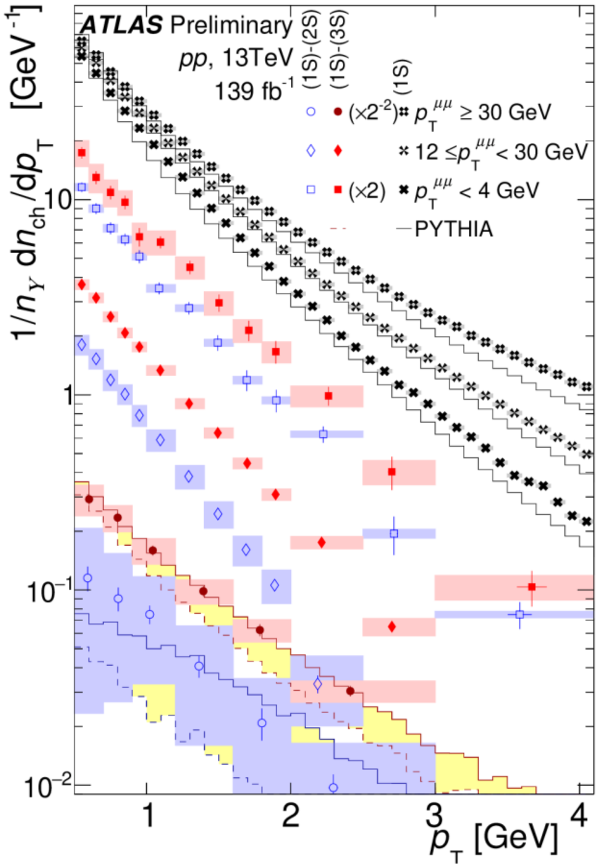


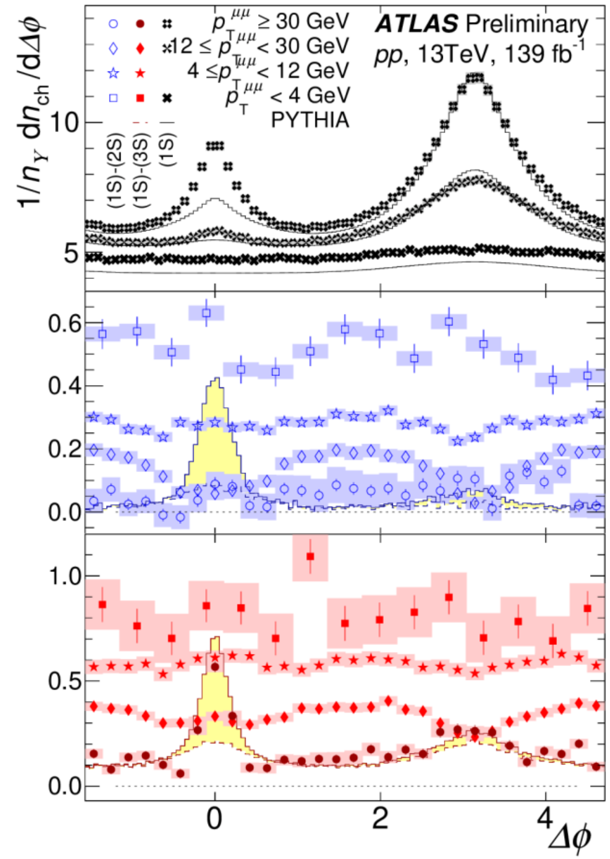
Mean values of n_{ch} distribution



- Observed a strong difference in the n_{ch} distributions
- Effect strongest at $p_T^{\mu\mu} = 0$
  - $\Upsilon(1S) - \Upsilon(2S)$: 3.6 ± 0.4
  - $\Upsilon(1S) - \Upsilon(3S)$: 4.1 ± 1.1
- Feed-down of states, mass differences, systematic uncertainties cannot explain the effect

Kinematic Distributions of $\Upsilon(1S)$-$\Upsilon(nS)$





- Subtracted p_T distributions are consistent in shape with the UE and cannot be described by additional jet activity
- For $\Upsilon(3S)$ at $p_T^{\mu\mu} > 30$ GeV → peaks around $\Delta\phi = 0$ and $\Delta\phi = \pi$.
  Likely explained by feed-down decays $\Upsilon(nS) \rightarrow \Upsilon(1S), \chi_b(mP) \rightarrow \Upsilon(nS)$

Conclusion

UE in Z+jet events:

- All tested generators show significant deviations with data for predicting UE activity
- Herwig++ qualitatively performs best
- Important ingredient for future MC generator tuning efforts

UE in Υ meson production:

Significant difference in the charged particle multiplicity is observed

- $\Upsilon(1S)$: $< n_{ch} > = 29.5 \pm 0.7$
- $\Upsilon(2S)$: 12% less
- $\Upsilon(3S)$: 17% less

Differences are strongly momentum-dependent

→ reduced for higher $p_T^{\mu\mu}$