First Run 2 Soft QCD Results from ATLAS

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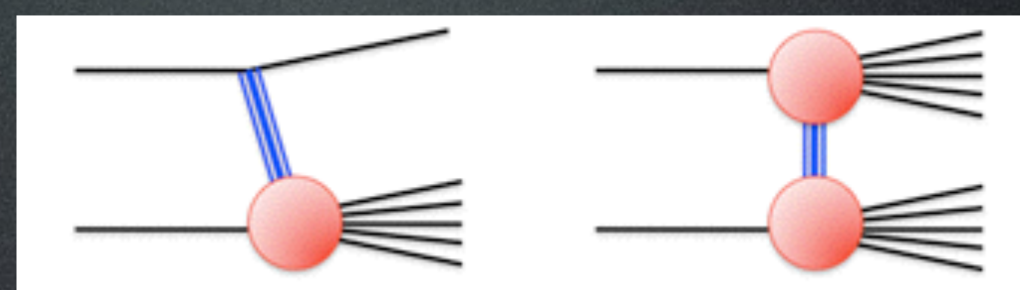
South African Institute of Physics Meeting
July, 2016

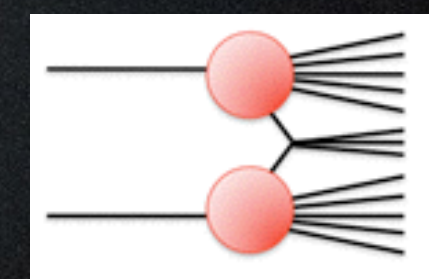
Soft-QCD

$$\sigma_{total} = \sigma_{el} + \sigma_{inel}$$

Soft-QCD

$$\sigma_{total} = \sigma_{el} + \sigma_{sd} + \sigma_{dd} + \sigma_{nd}$$





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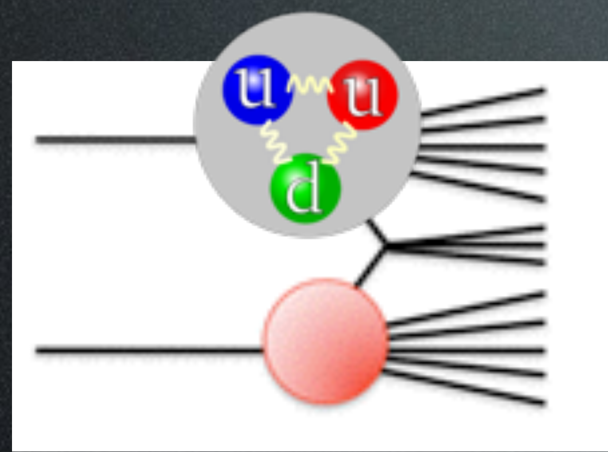
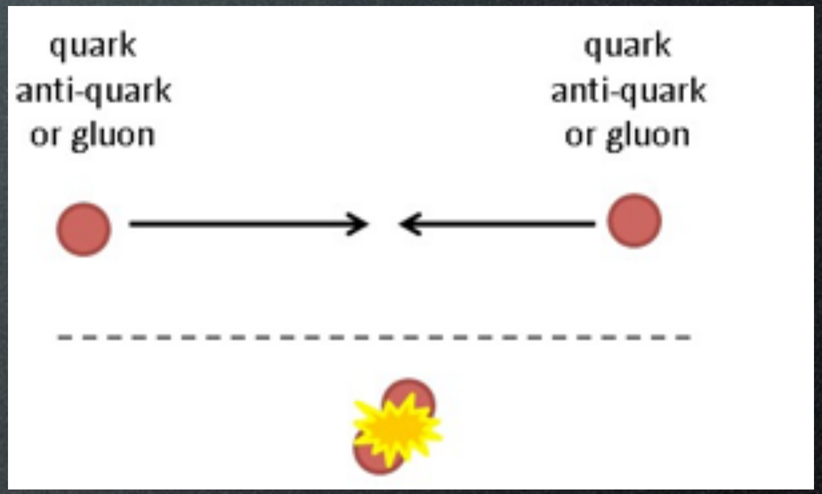
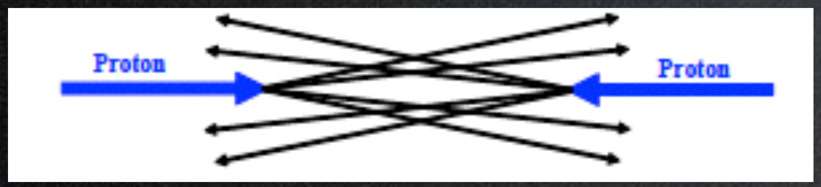


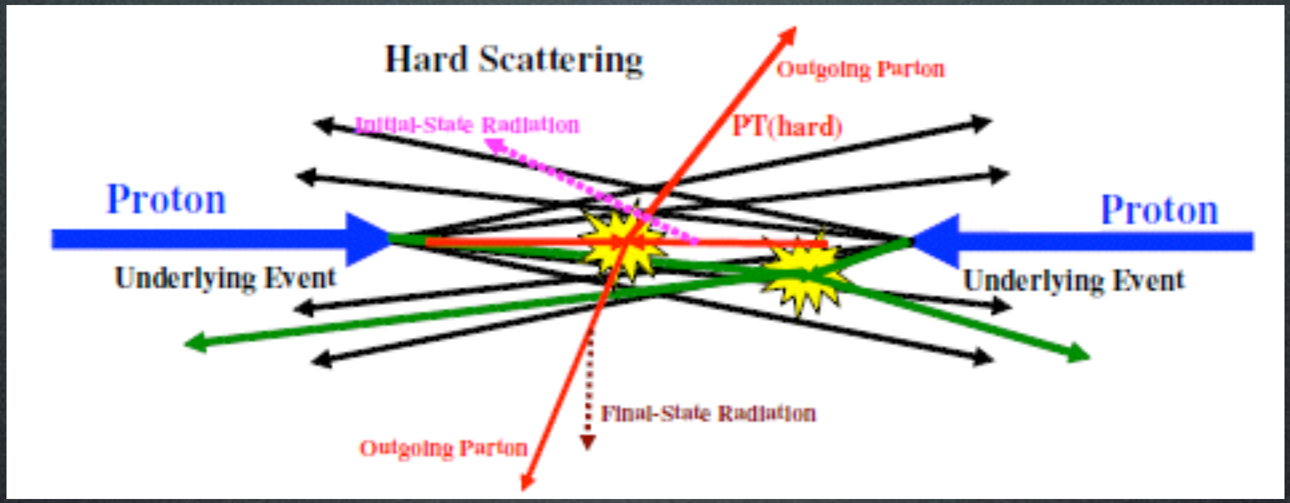


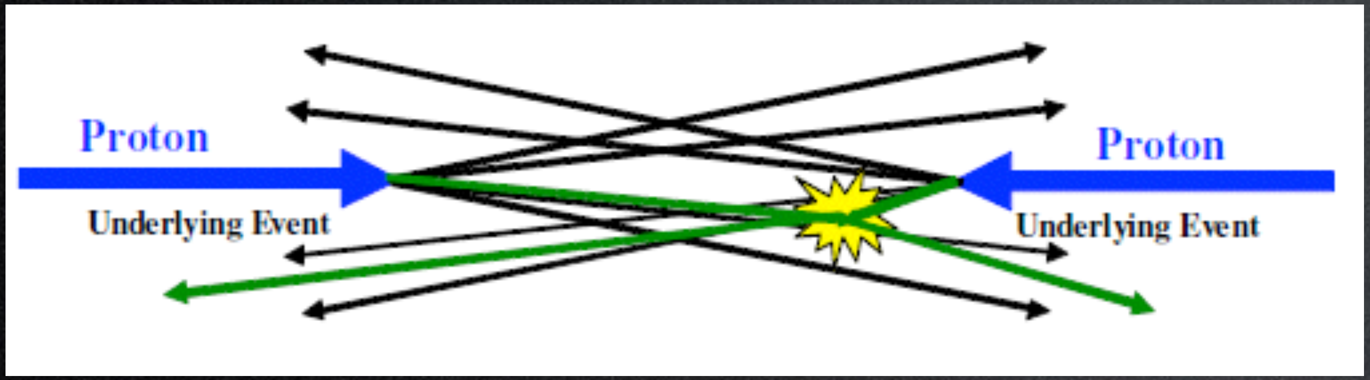
Interesting part!

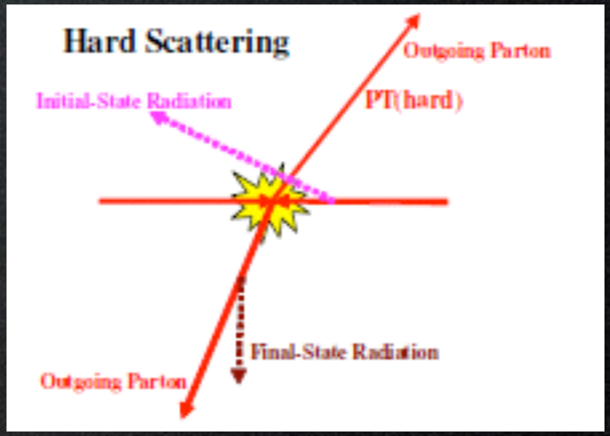


No hard scatter

Soft-QCD







Underlying event = BBR+ MPI+ (ISR+FSR)

BBR: Beam-beam remnants
MPI: Multiple Parton interactions
ISR/FSR: Initial/Final state radiation

Glossary

- Minimum-bias (MB): Pretty much everything, exact definition trigger dependent.
- Underlying event (UE): background to events with an identified hard scatter (more like the actual interesting events we want to look at)
- Pileup (PU): (uncorrelated) separate collisions within the same/different bunch crossing we can't differentiate because of our finite detector resolution (more like "isotropic" min-bias events).

Soft QCD

- Pedestal activity to all physics processes
- Not perturbative processes
- Cant subtract the contribution on an event-by-event basis
- Modelled in Monte Carlo Generators

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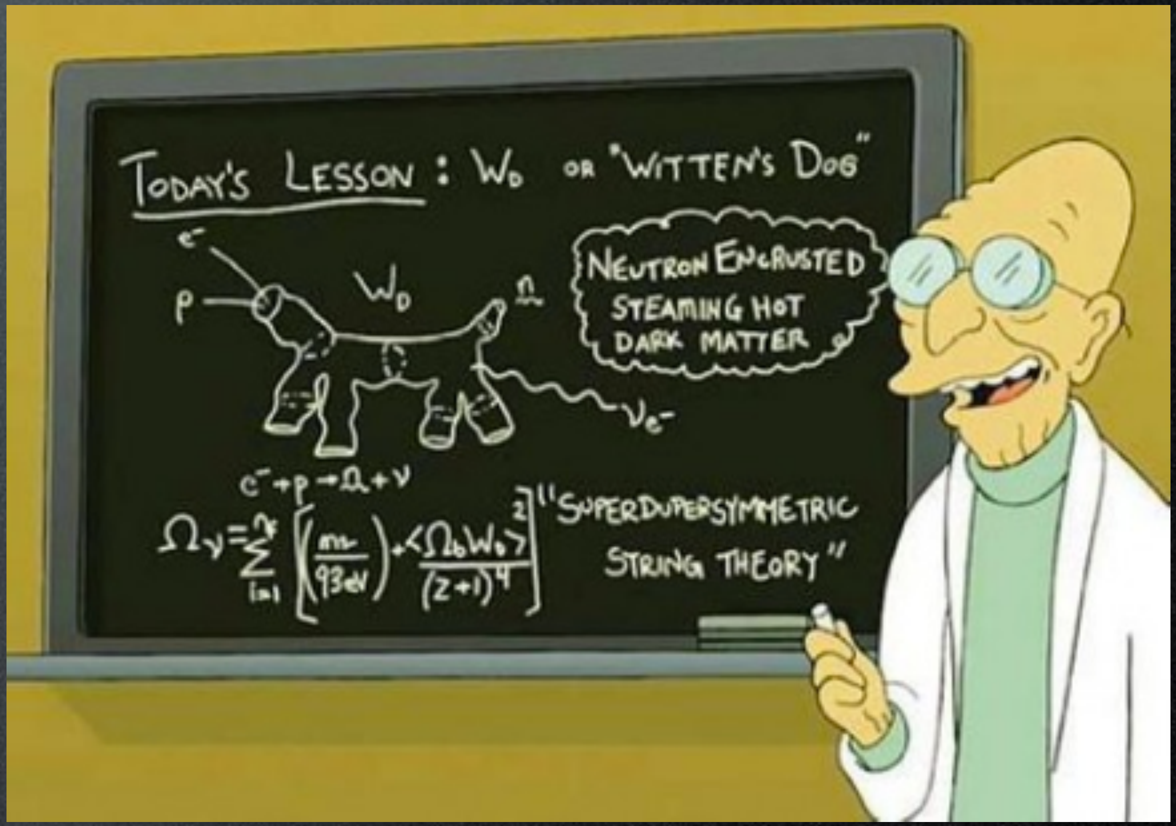
Detour: Event Generators

- We want realistic simulation of the collision events. To devise analysis strategy, background model, study/remove detector effect, etc.

- The hard scattering part can be calculated theoretically (in some order) .

- The soft part is not calculable, so we use phenomenological models implemented in Monte

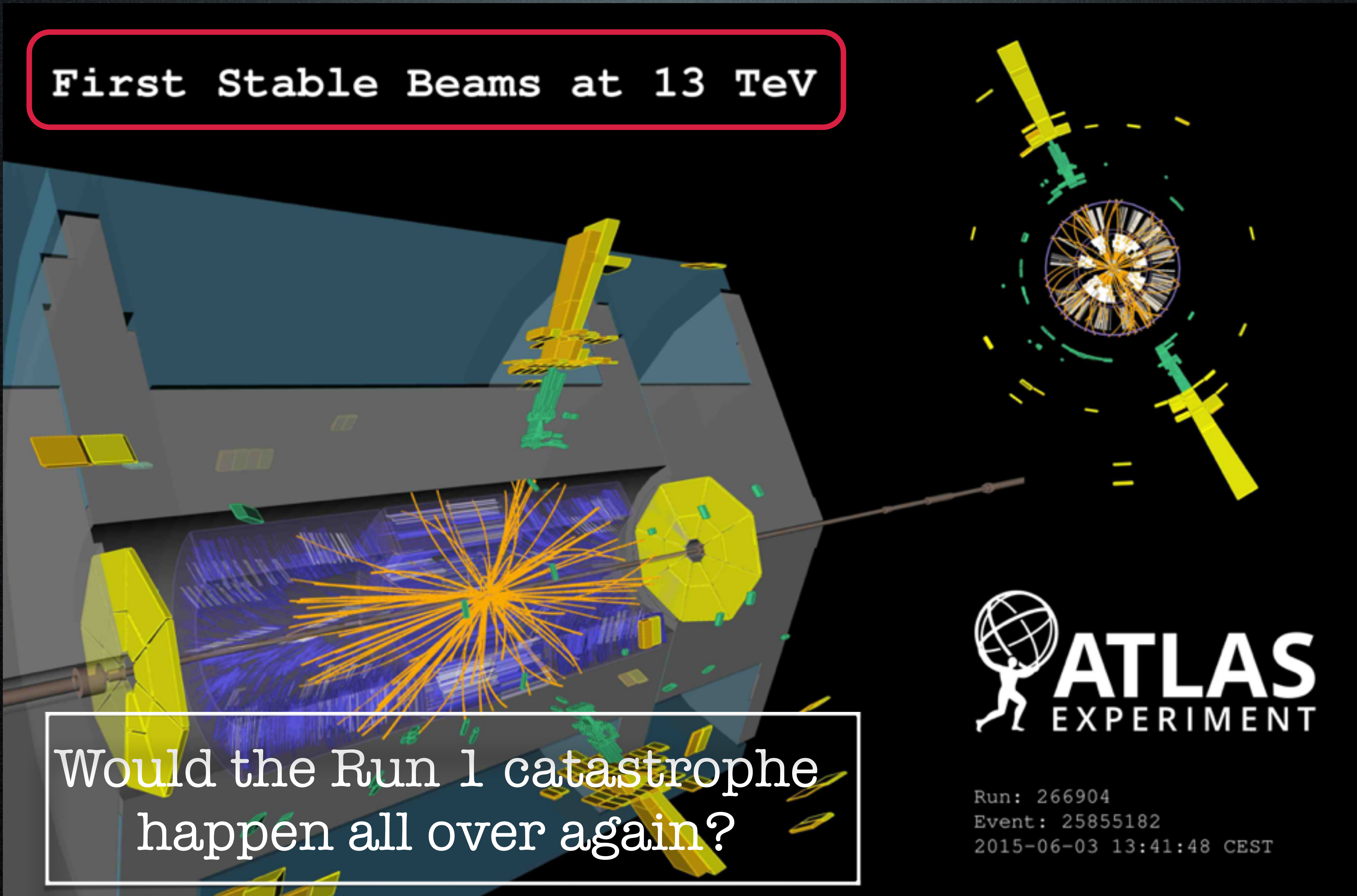


Actually two step process, but not going to discuss detector simulation!

Tuning

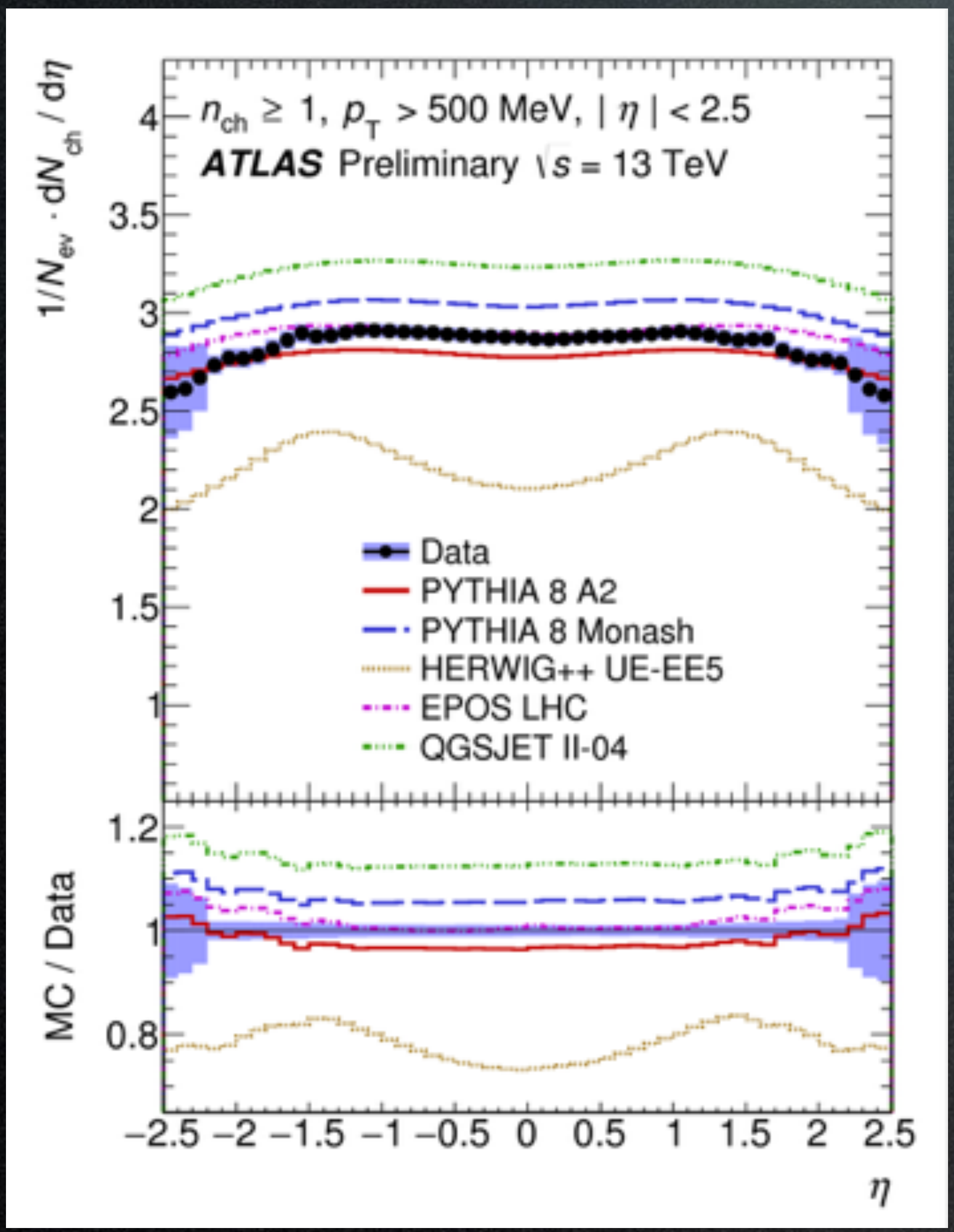
- Ultimate goal: models need to describe real data.
- "Free" parameters control all these aspects of the models, which cannot be derived analytically.
- A bunch of correlated (or anti-correlated) parameters describe one aspect, so have to change them simultaneously.

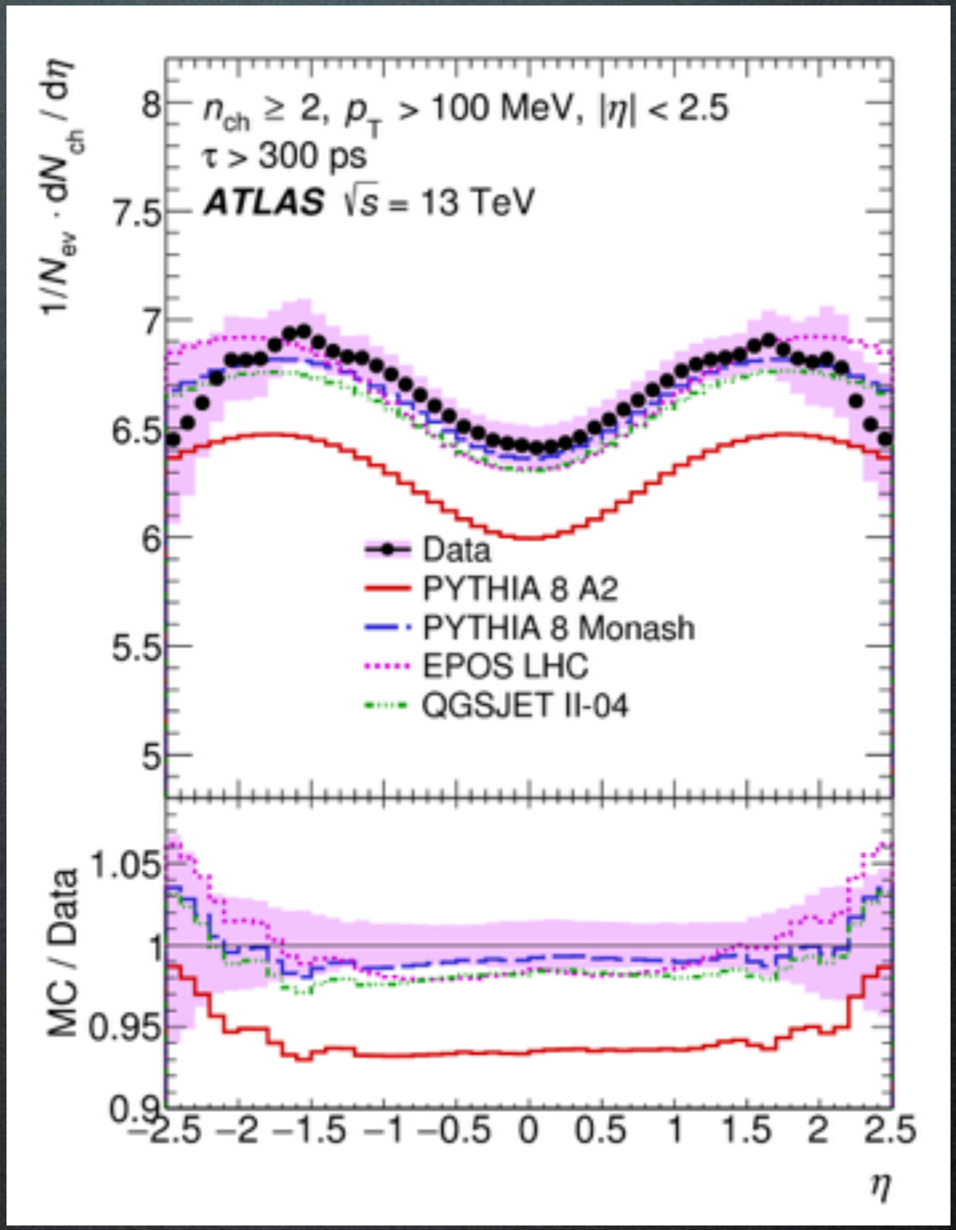
Tune: A particular optimized parameter setting in a particular MC generator to match the simulation with available data. Differ according to which datasets are included.



Would the Run 1 catastrophe happen all over again?

Charged Particle Distributions



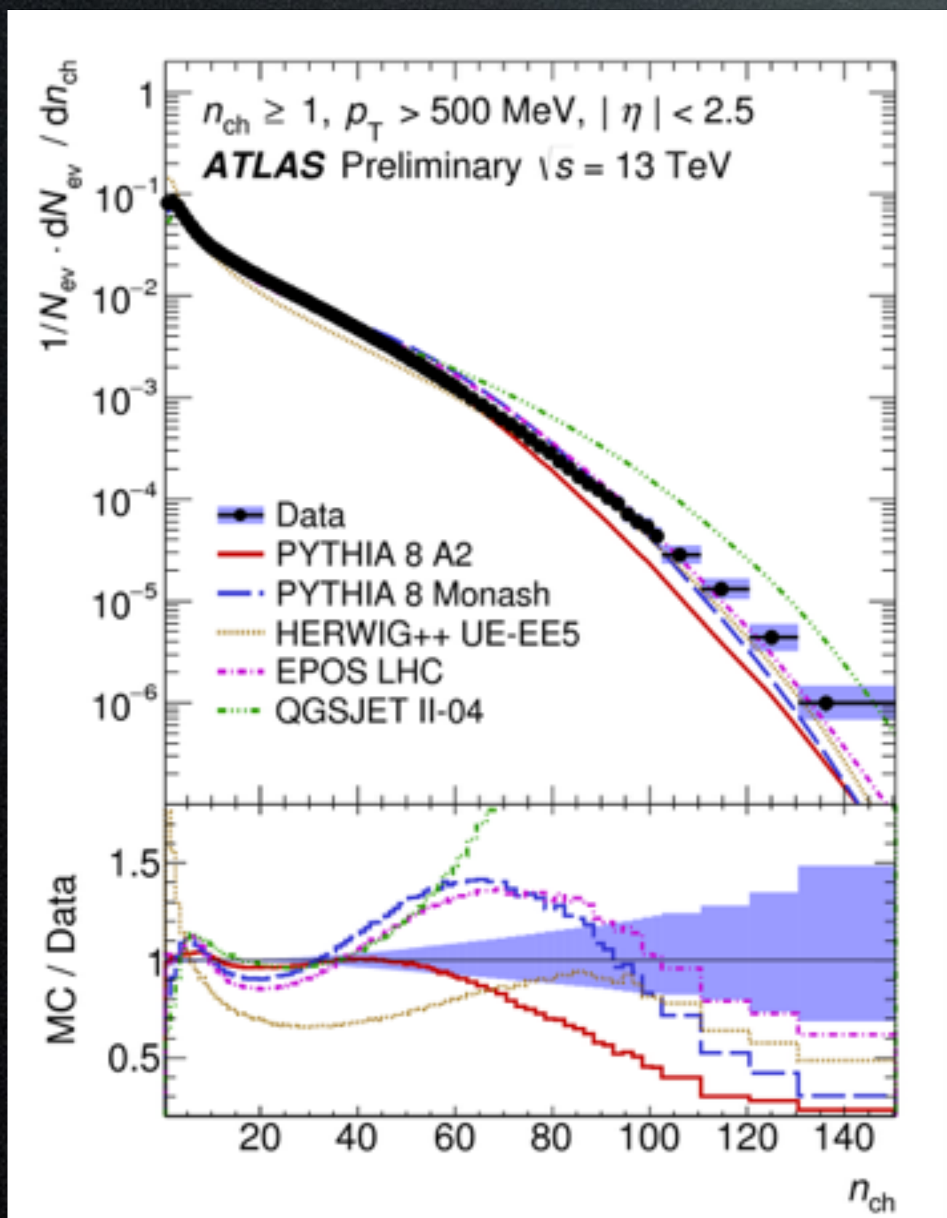


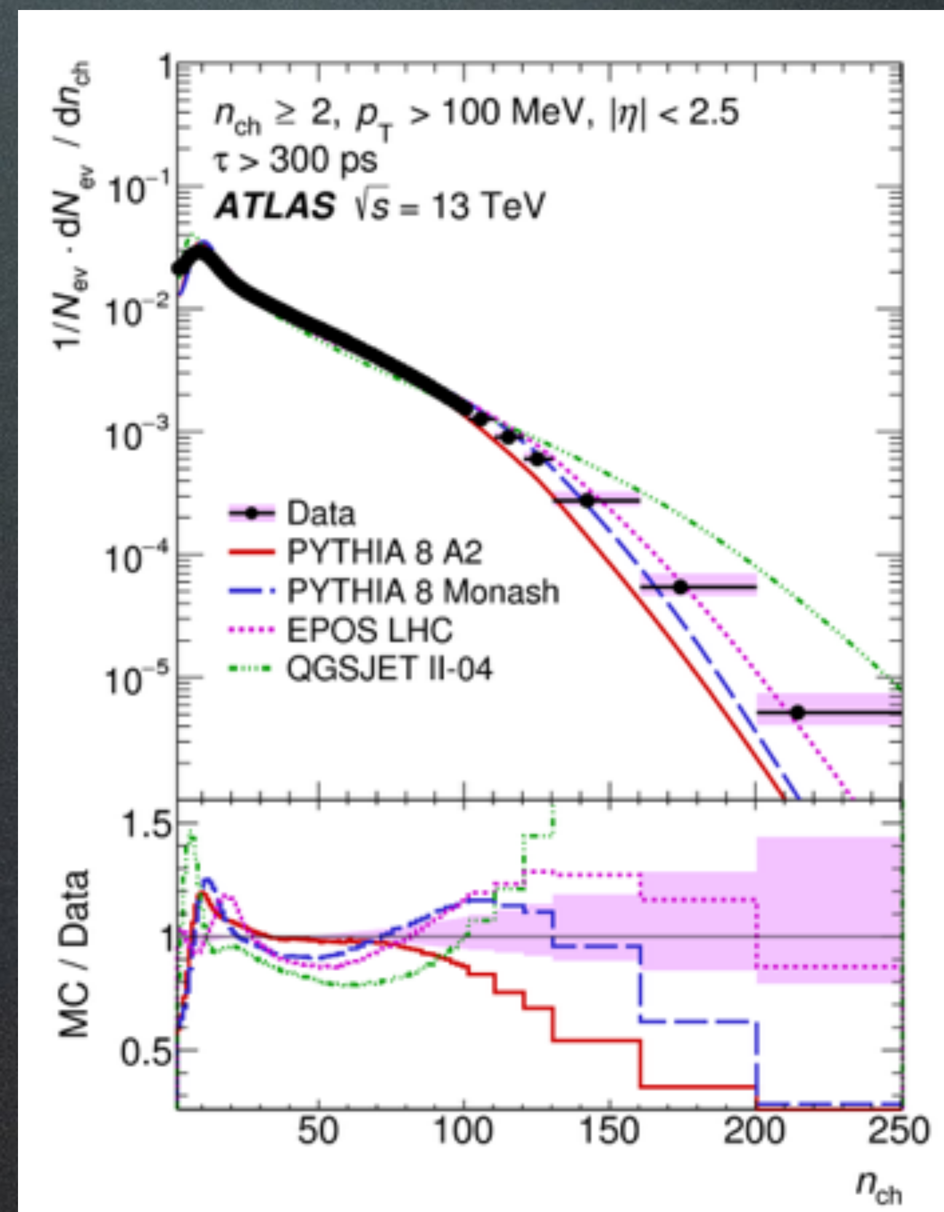
Pythia8 tunes and Epos do well for left, only A2 is bad on right

Physics Letters B (2016), Vol. 758, pp. 67-88

arXiv:1606.01133

Charged Particle Distributions





Similar trends, none of the models do well over the whole range

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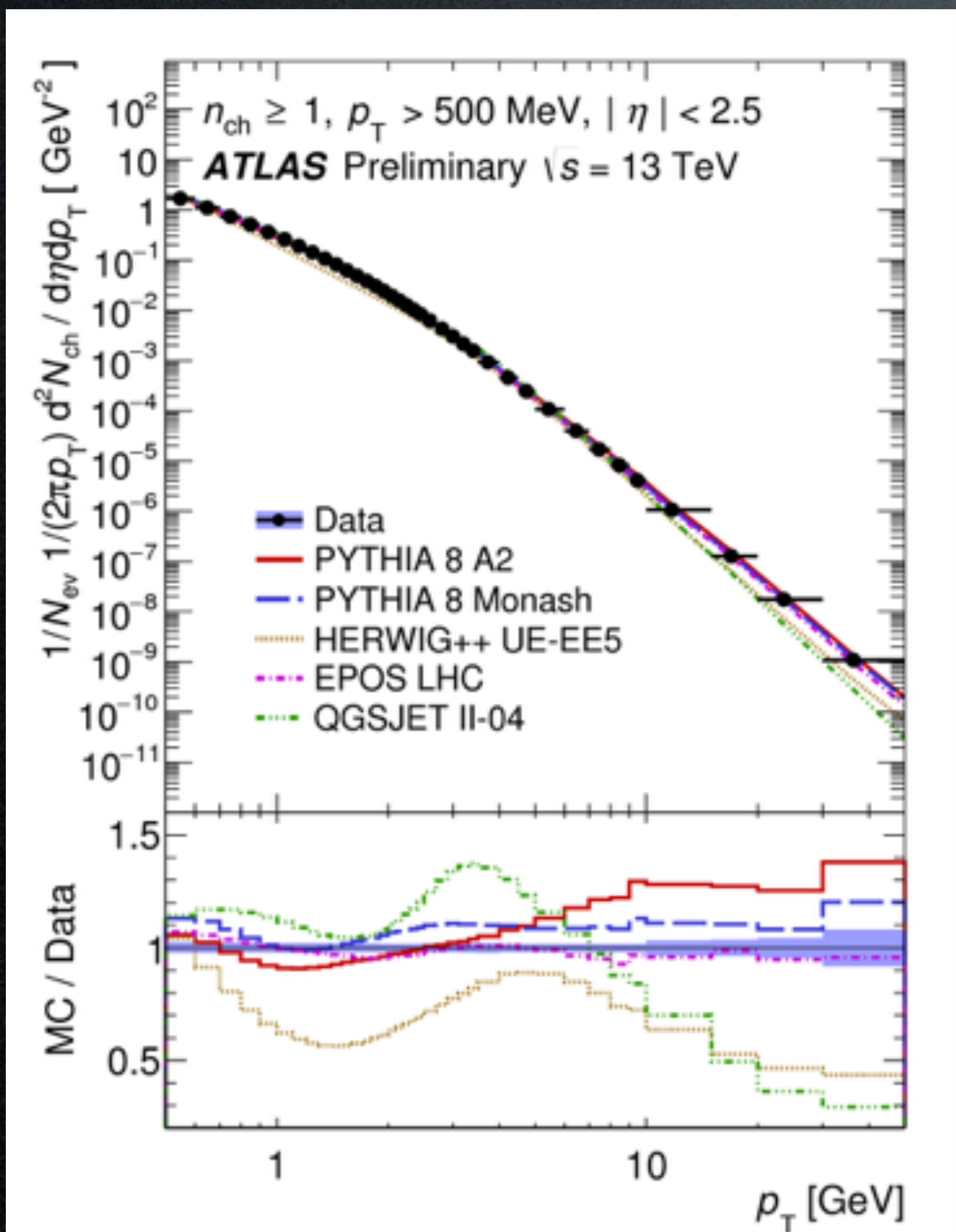
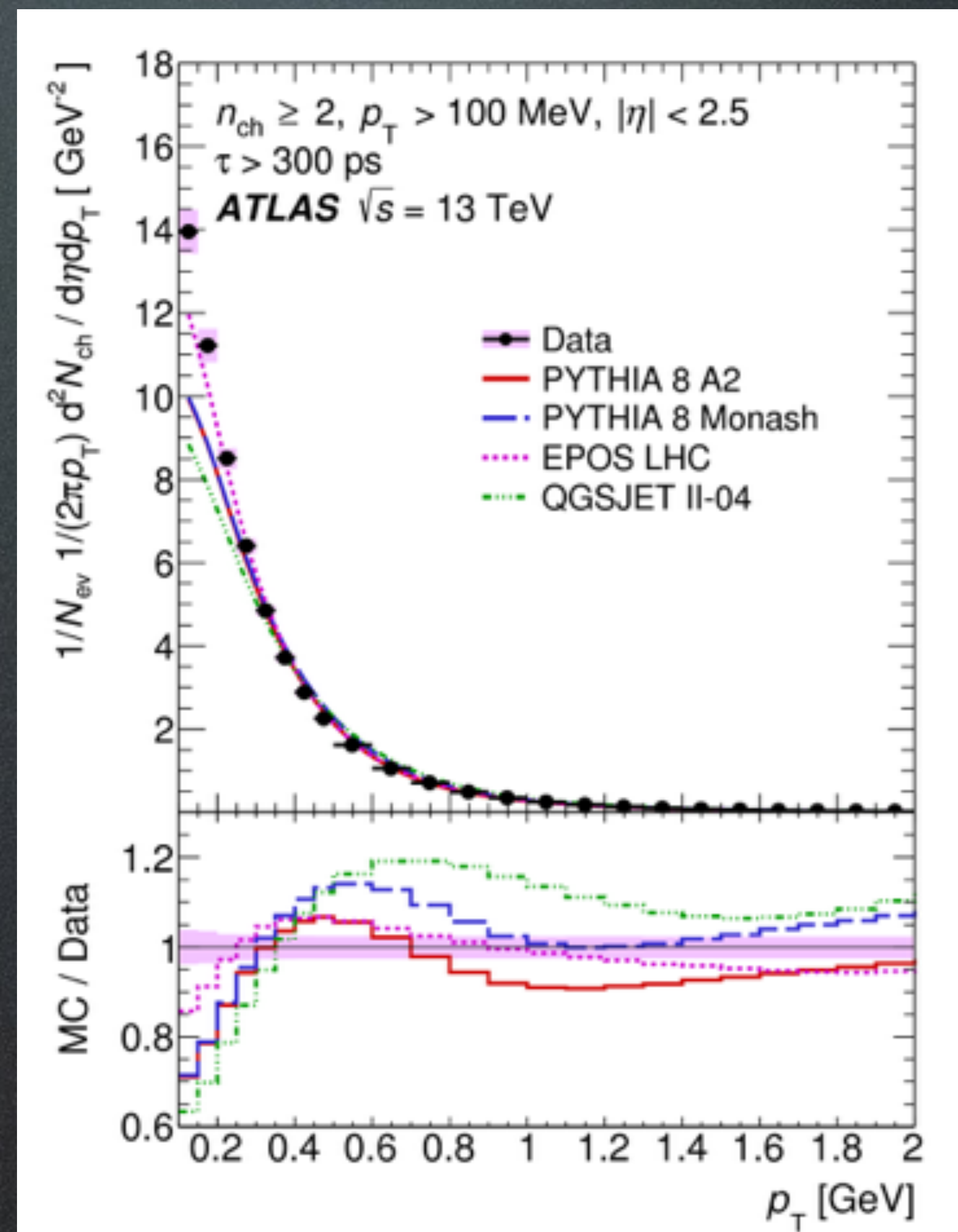
Charged Particle Distributions





Epos is best for both, A2 and Monash are competitive

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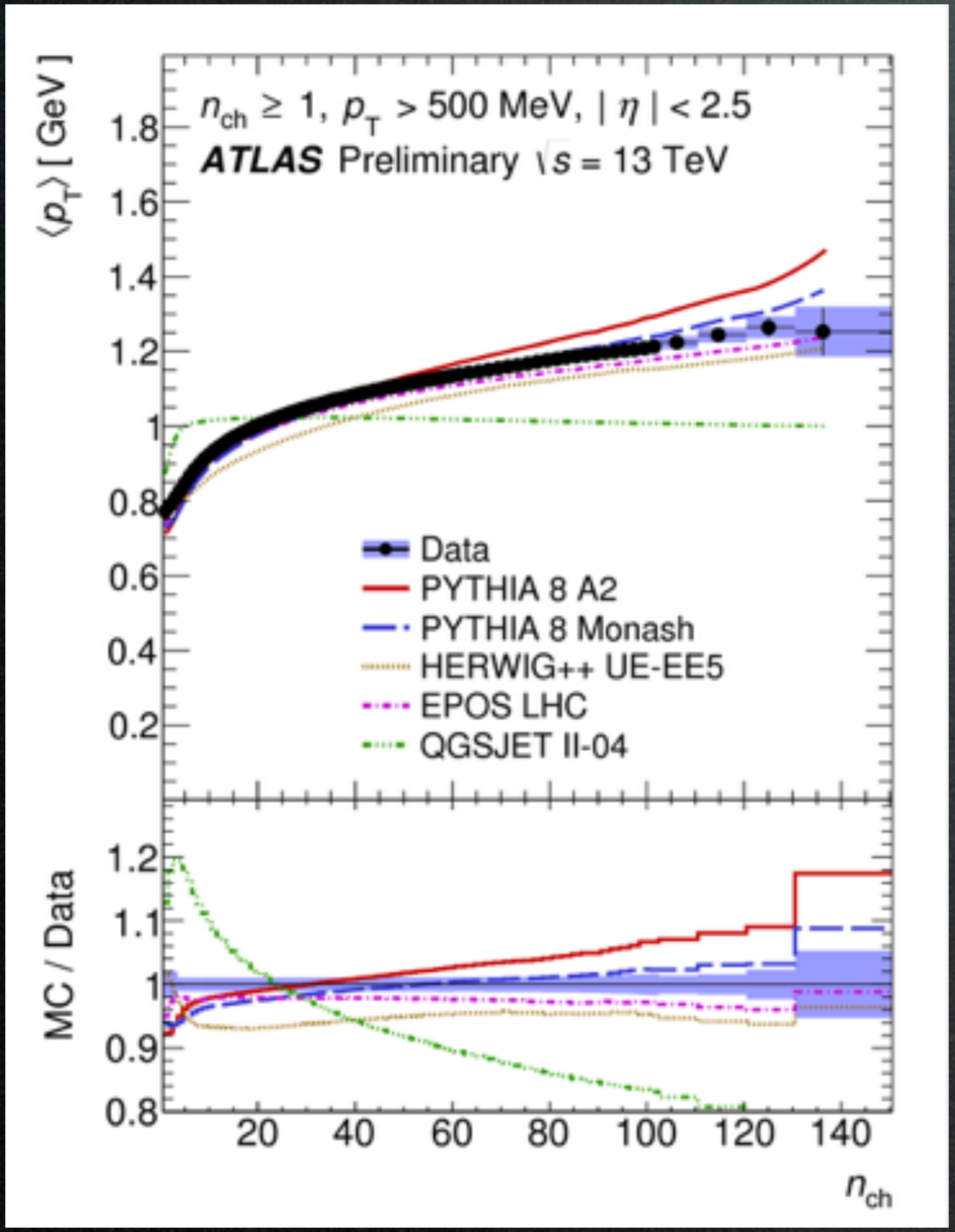
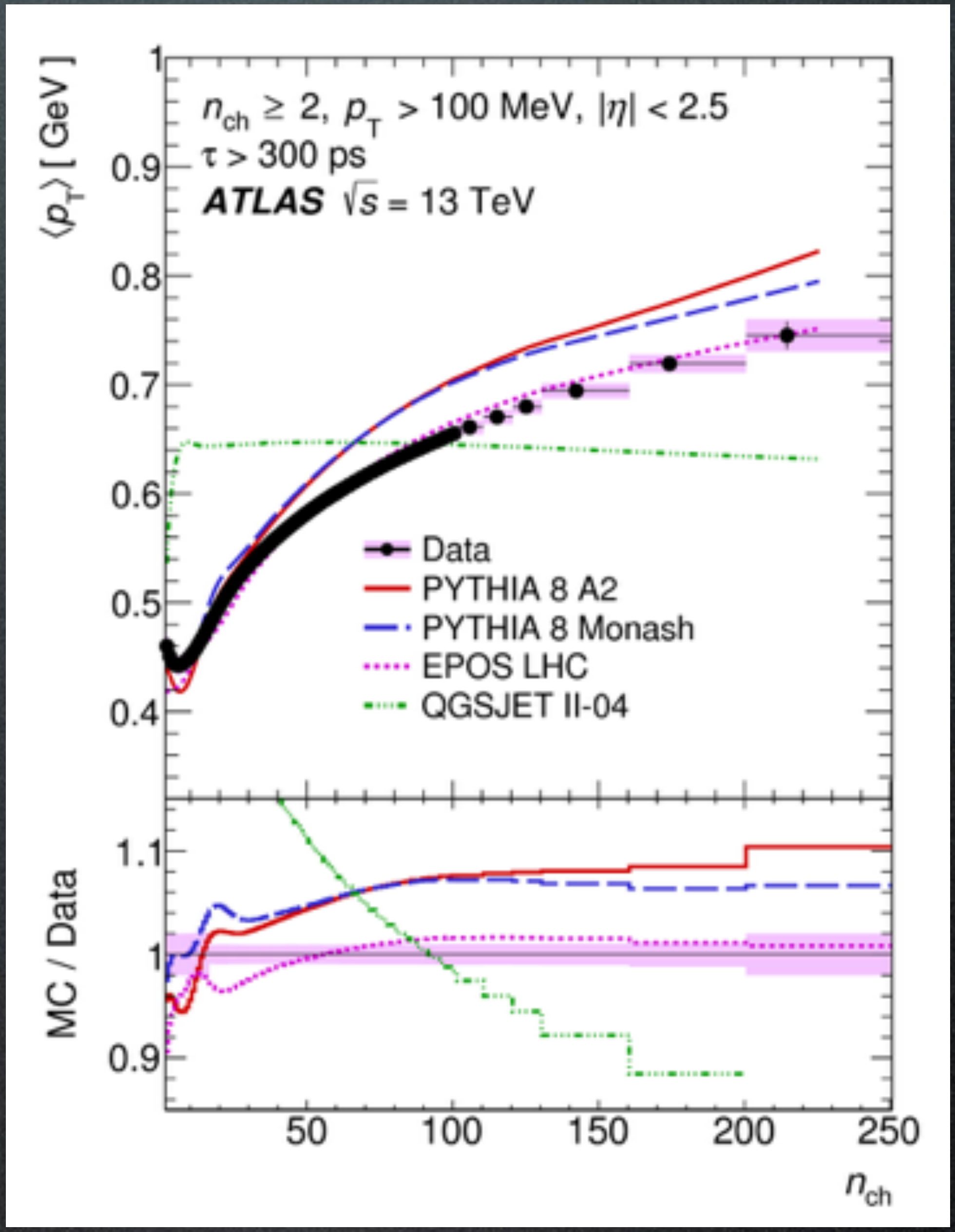
Charged Particle Distributions



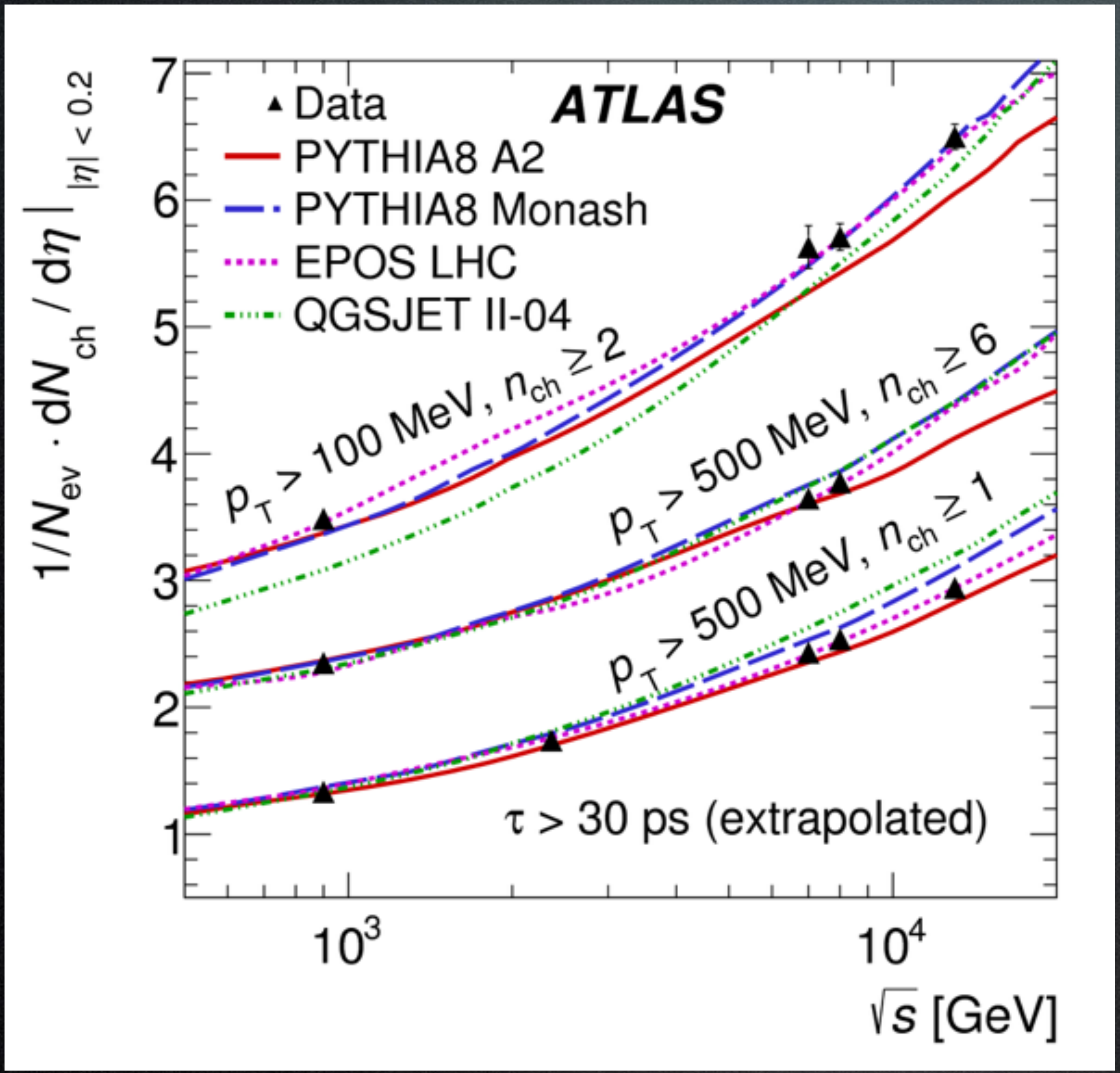


Correlation depends on colour reconnection

Physics Letters B (2016), Vol. 758, pp. 67-88

arXiv:1606.01133

Dependence on E.C.M



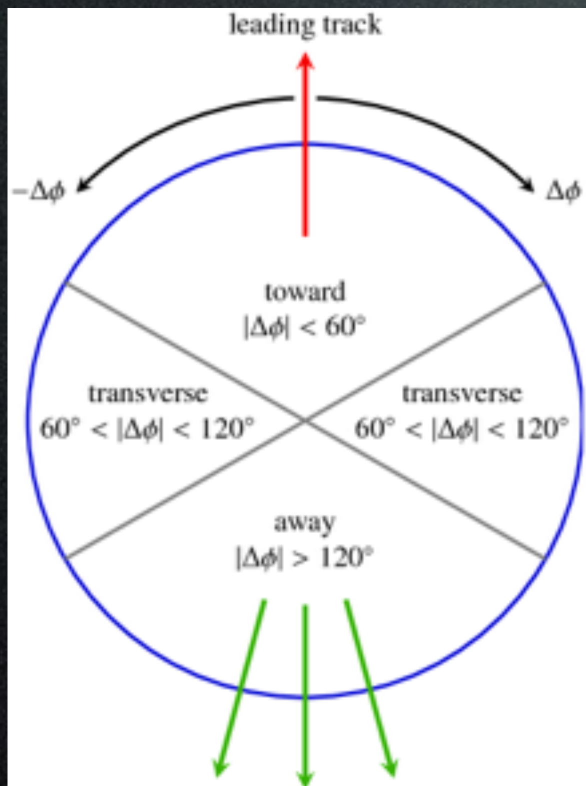
About 20% increase from going from 7 to 13 TeV

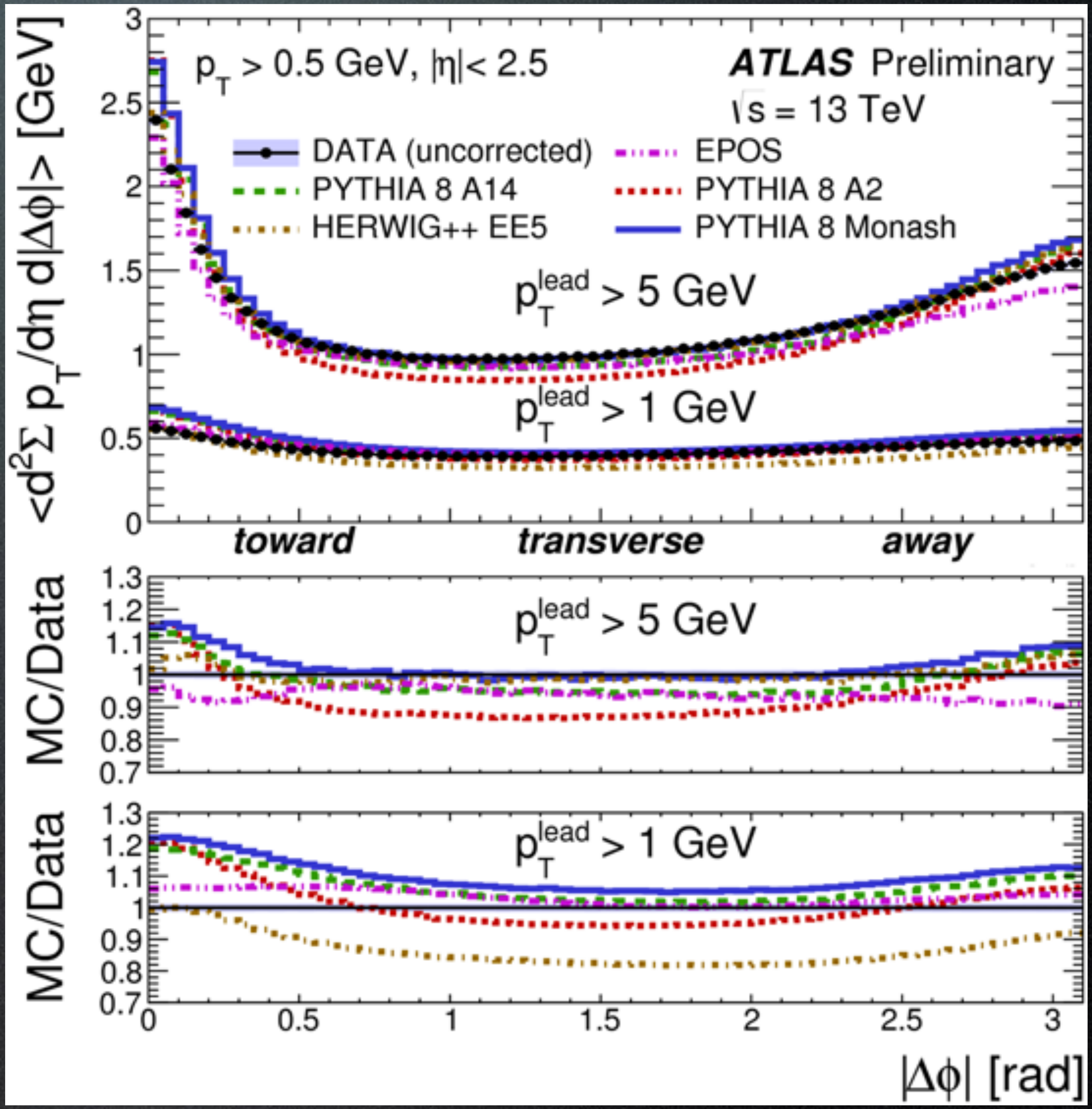
Most models get the trend right

arXiv:1606.01133

Underlying Event

Underlying Event

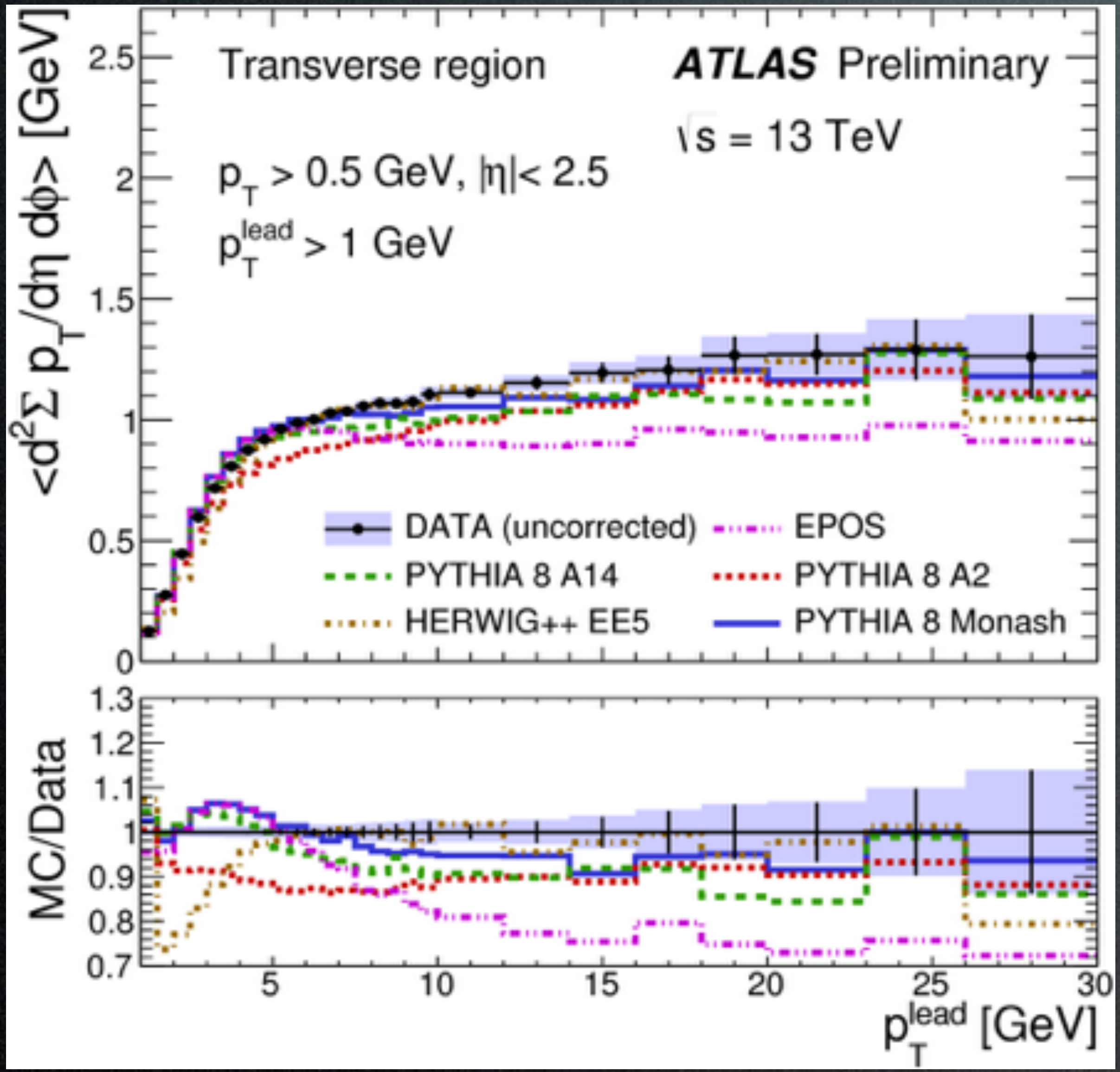


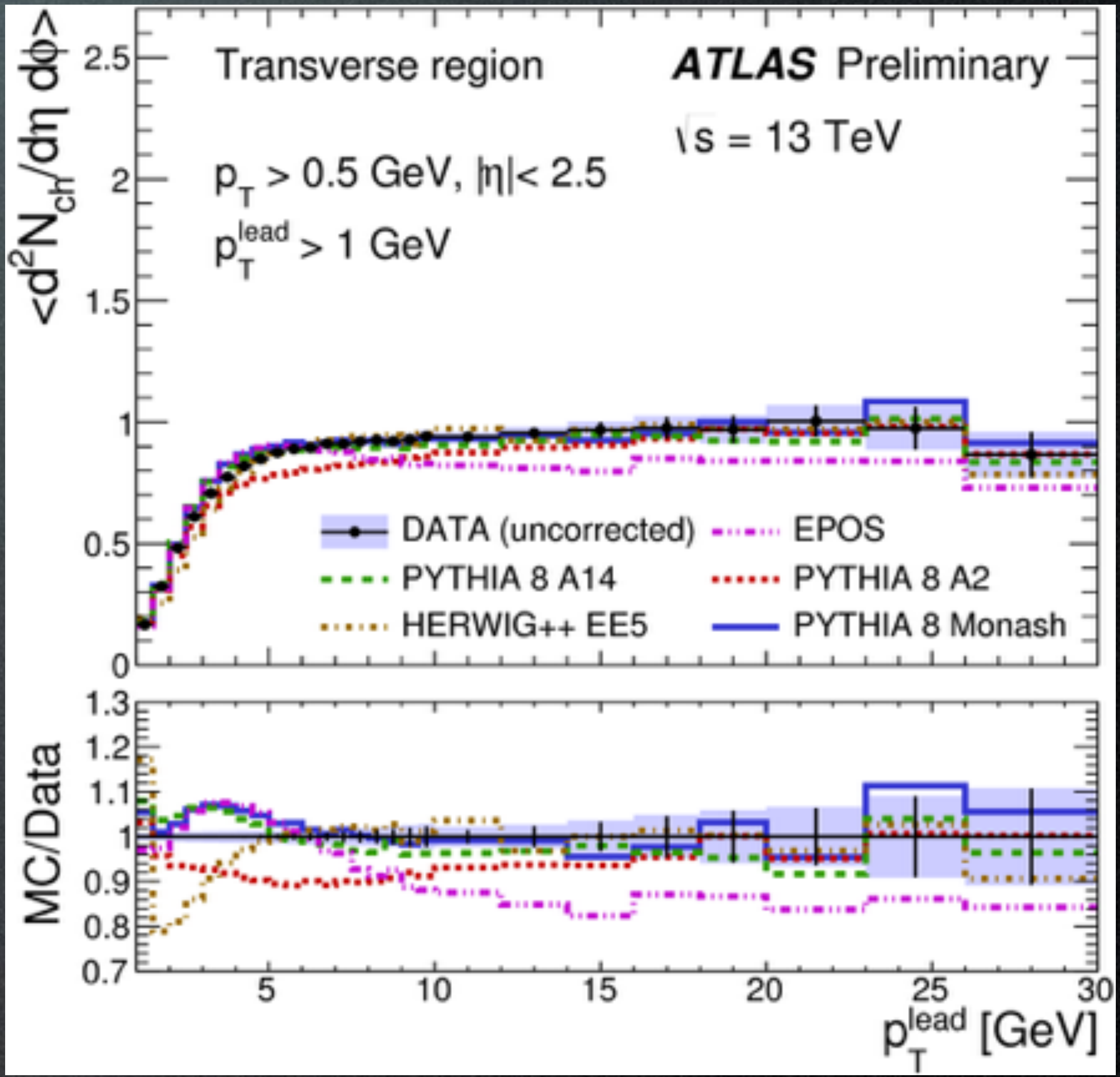


Overall decent agreement, MB tunes do better for lower lead p_T, while UE tunes for higher

ATL-PHYS-PUB-2015-019

Underlying Event





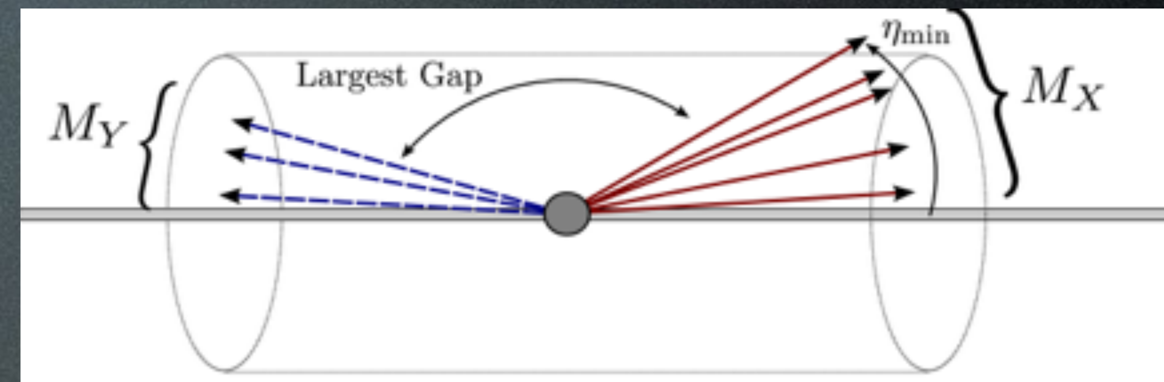
Tunes get the energy extrapolation roughly right

ATL-PHYS-PUB-2015-019

Inelastic pp Cross-Section

Require two MBTS hits

Constrain diffractive events fraction by hit on one side



Define using the larger mass:

$$\boxed{\tilde{\xi} = \frac{\tilde{M}_X^2}{s}}$$

Calculated essentially by a counting experiment

Data-based Estimations

Total Events

BG Subtraction

Migration of Small ξ into the fiducial

$$\sigma_{\mathrm{inel}}(\tilde{\xi} > 10^{-6}) = \frac{N - N_{\mathrm{BG}}}{\epsilon_{\mathrm{trig}} \times L} \times \frac{1 - f_{\tilde{\xi}<10^{-6}}}{\epsilon_{\mathrm{sel}}}$$

MC-based Corrections

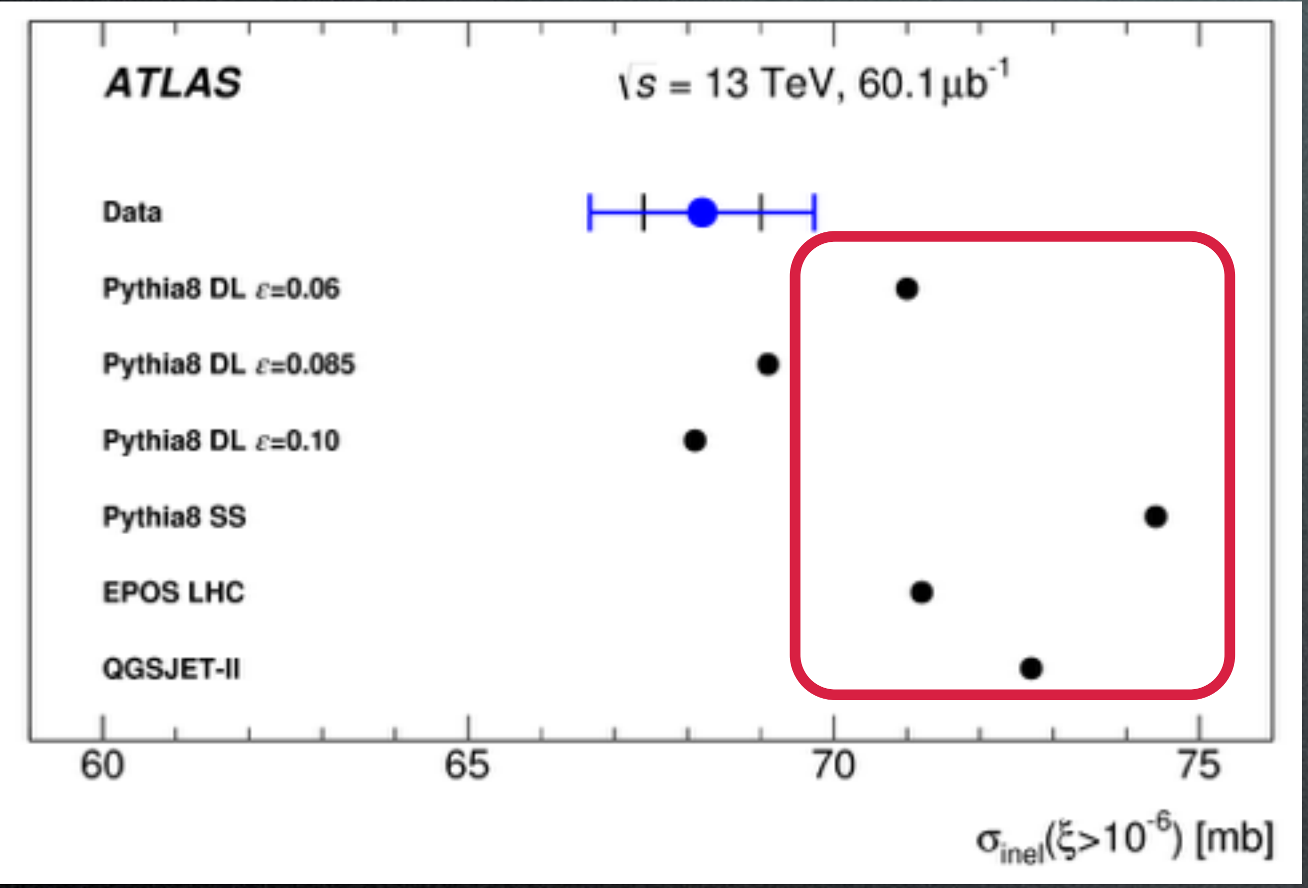
Trigger Eff.

Luminosity

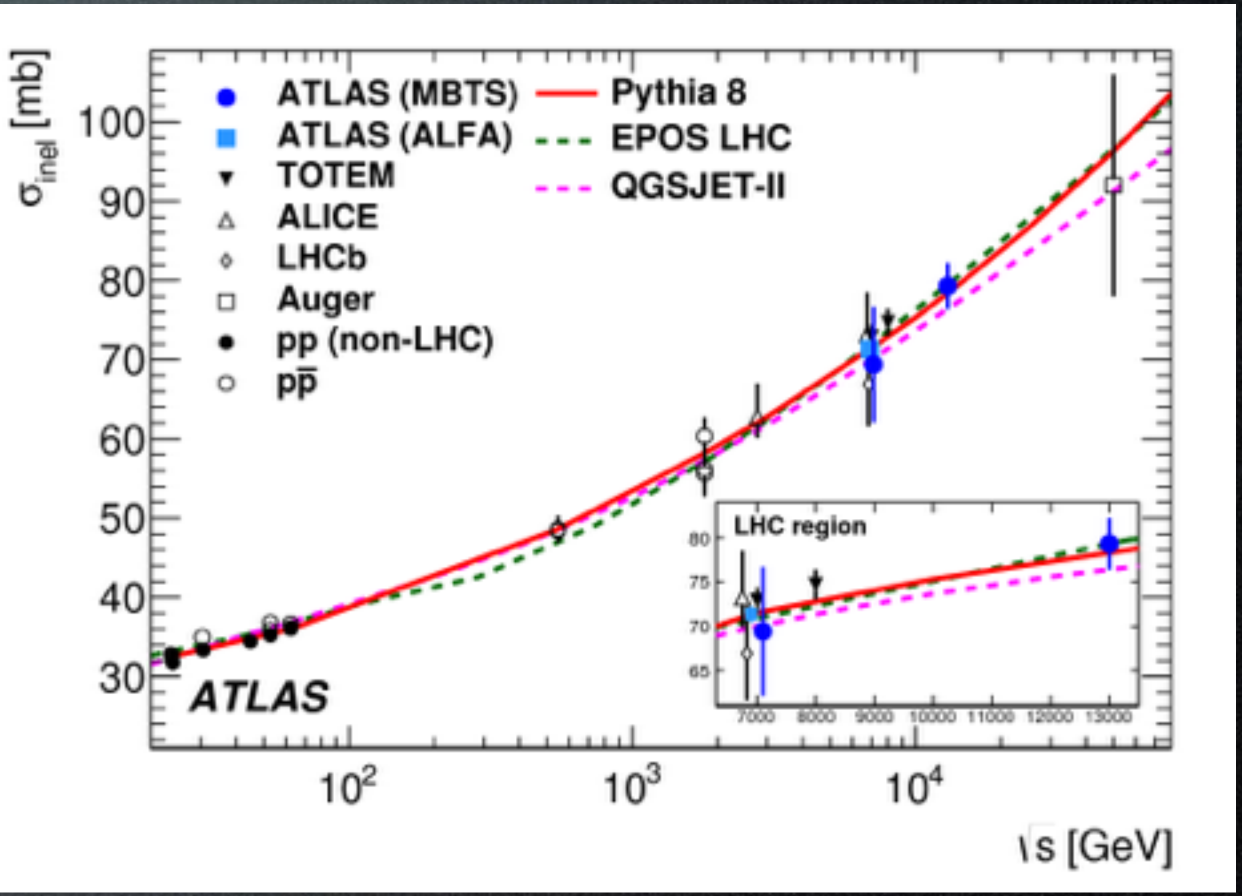
Fiducial Acceptance

Inelastic pp Cross-Section

Fiducial



Total



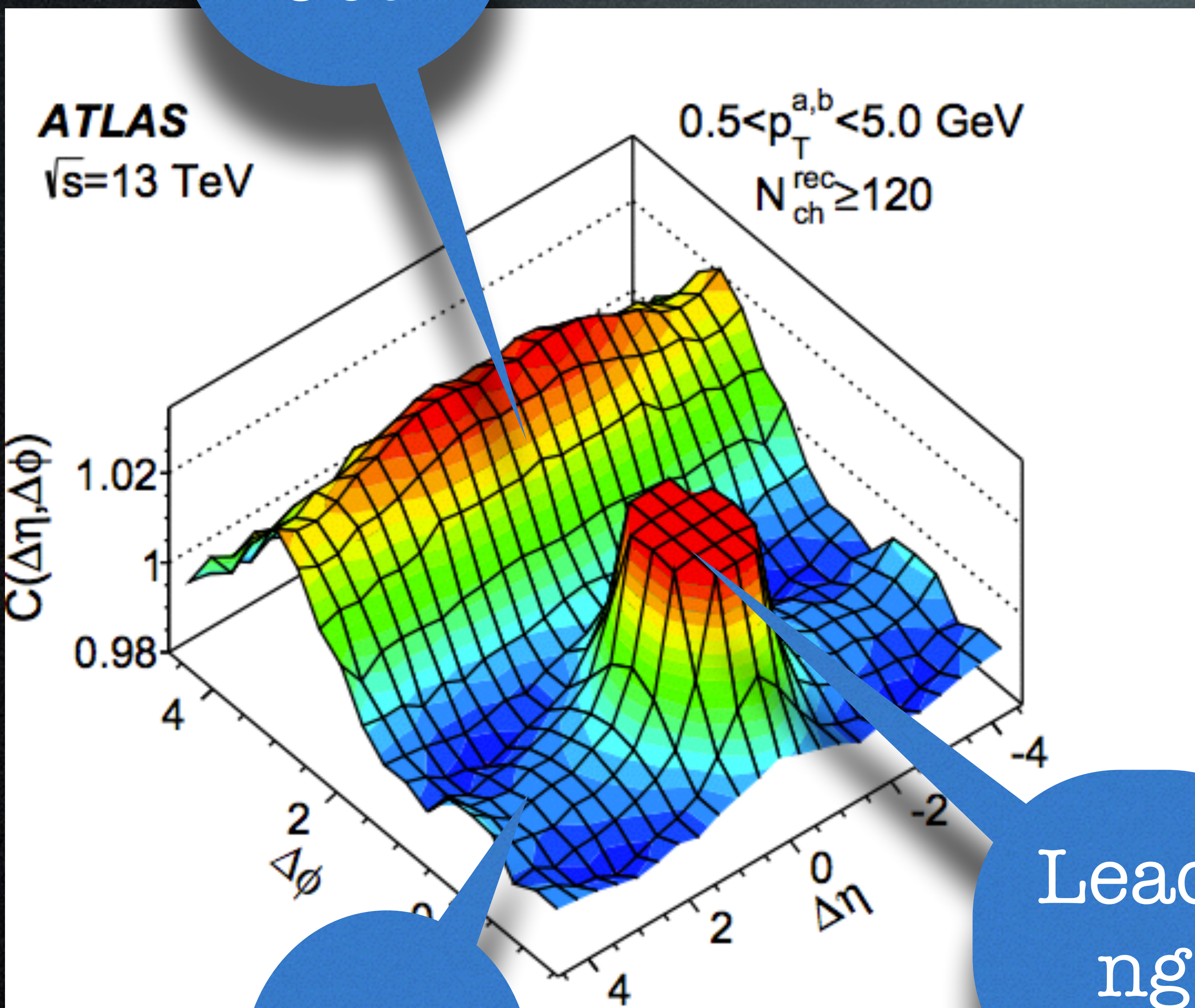
Extrapolated to total inelastic cross-section using MC models

Largest uncertainty on luminosity

arXiv:1606.02625

The Ridge

First ATLAS Run 2 paper



In high multiplicity events there is an enhancement in the particle production at Δφ ≈ 0 over wide range of Δη

First seen in HI collisions, also at TeV by CMS

Needs dedicated HM trigger

Summary

- Soft QCD is fun (and useful).
- Tuning is fun too, but hard to get everything right.
- Generators contain a lot under their hood, and it is good to have some understanding of it.
- The improved modelling of low p_T processes is feeded back to full event generation, where it affects high p_T part of the event, especially for precision measurements.

Supporting Material

NEW PREDICTIONS (10 years)

1. QCD tests & applications will greatly improve, incorporating NLO, NNLO,...and a theory of fragmentation and hadronization.
2. Atlas and CMS will discover a candidate Higgs particle.
3. There will be convincing evidence for Susy particles.
4. Plans will be underway to build a LC (at Cern) to explore the superworld and the US will join CERN.
5. There will be direct detection of the Dark Matter wind.
6. Alice will see a crossover to the perturbative quark-gluon plasma.
7. Some new Z mesons will be discovered.
8. Gravitational waves and B modes will be observed.
9. String theory will start to be a **theory** with predictions.
10. We will have a plausible explanation of why Λ is so small.

David Gross at EPS 2011

A Note on the Models

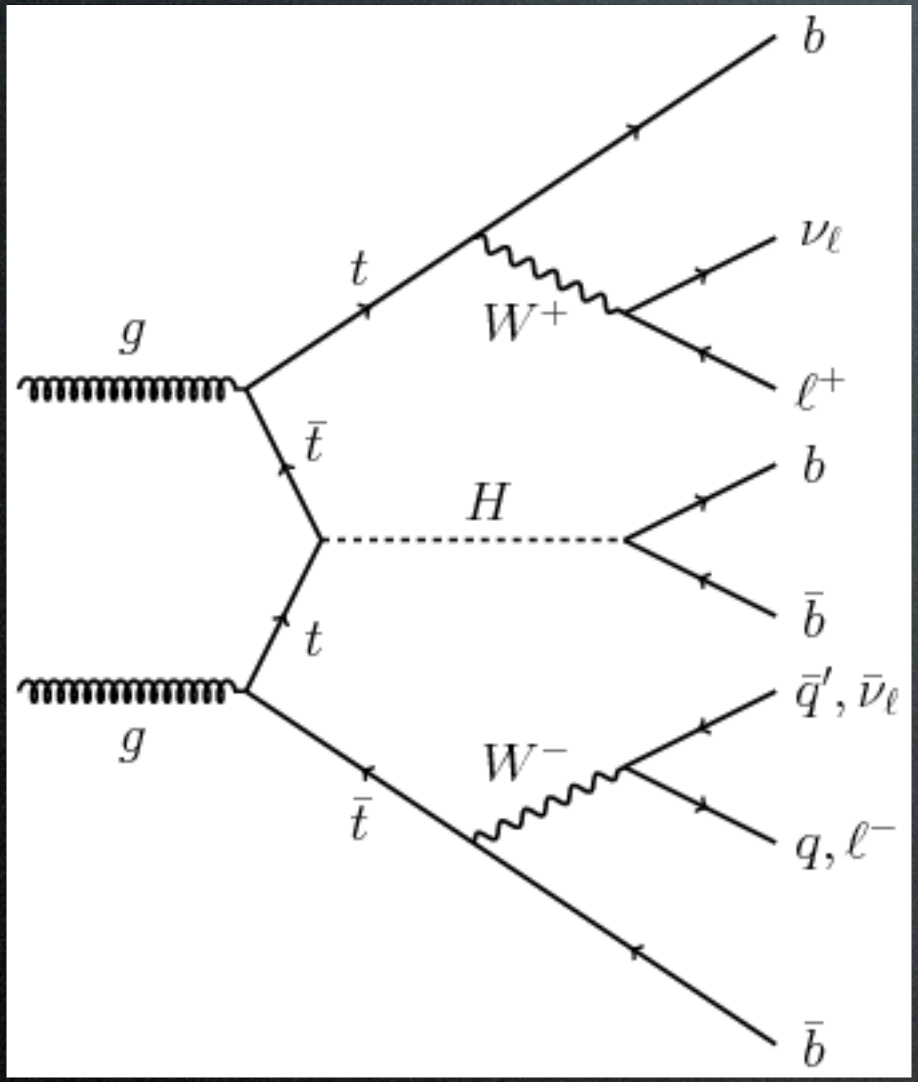
"The predictions of the model are reasonable enough physically that we expect it may be close enough to reality to be useful in designing future experiments and to serve as a reasonable approximation to compare to data. We do not think of the model as a sound physical theory . . . "

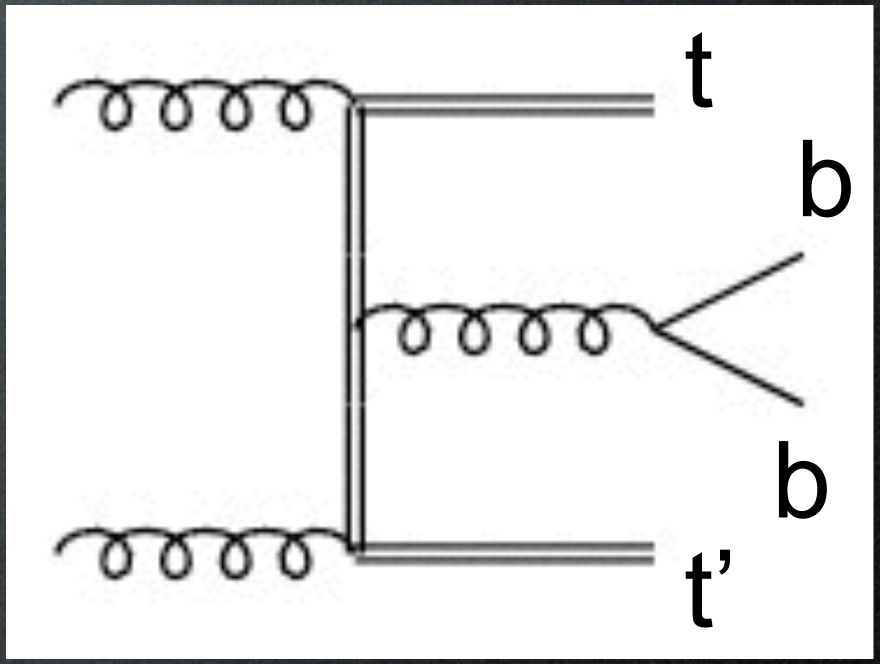
– Richard Feynman and Rick Field, 1978

Monte Carlo Models

- Leading order/Parton shower models: Trying to build up a complex 2->N final state by showers.
- Pieces of a Parton-Shower MC Generator: (2->2 hard scattering), ISR, FSR, MPI, Fragmentation, Hadronization.
- Examples: Pythia, Herwig family.
- Higher order/Multileg generators: Sherpa, Alpgen, MC@NLO, Madgraph, Powheg ...
- Generators used mostly for a specific process: Phojet (diffraction), HIJING (heavy ion), AcerMC (top), JHU (spin and polarization information)...

One of the hardest measurements:



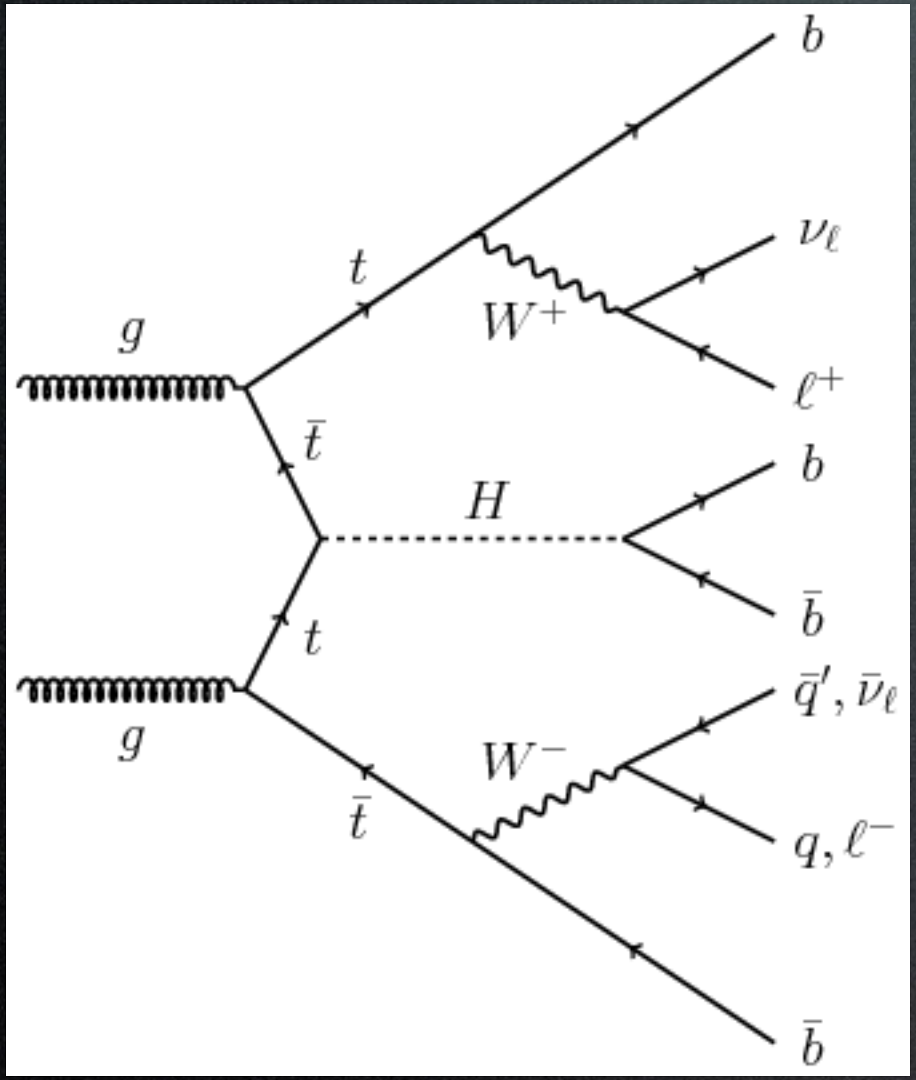


Signal: ttH(bb)

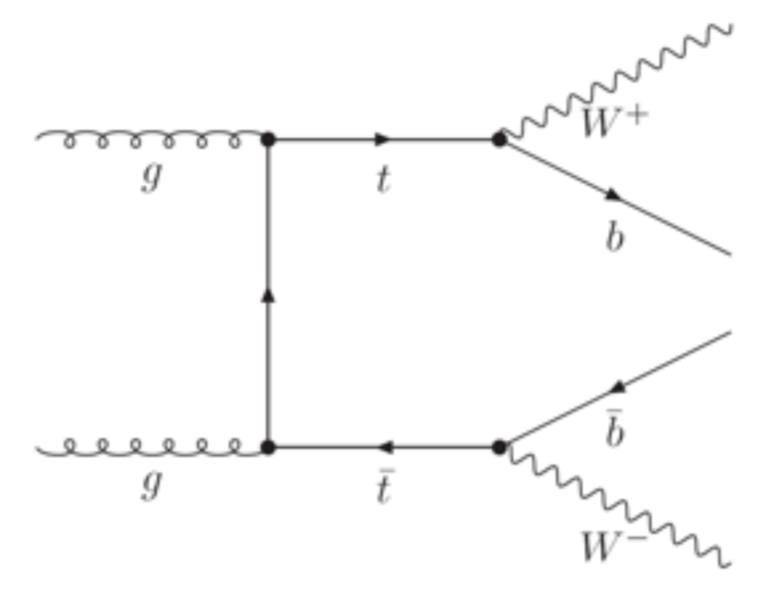
BG: ttbb

important for measuring Yukawa couplings

One of the hardest measurements:



Signal: ttH(bb)



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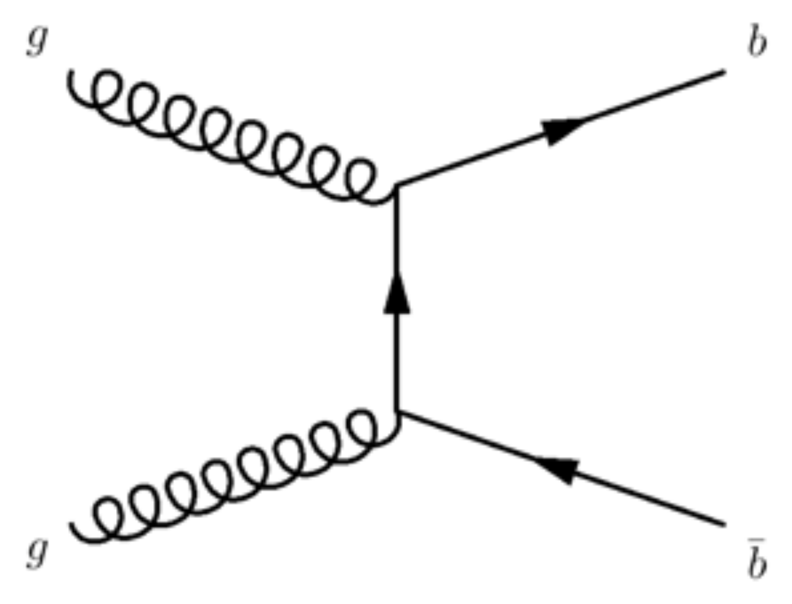
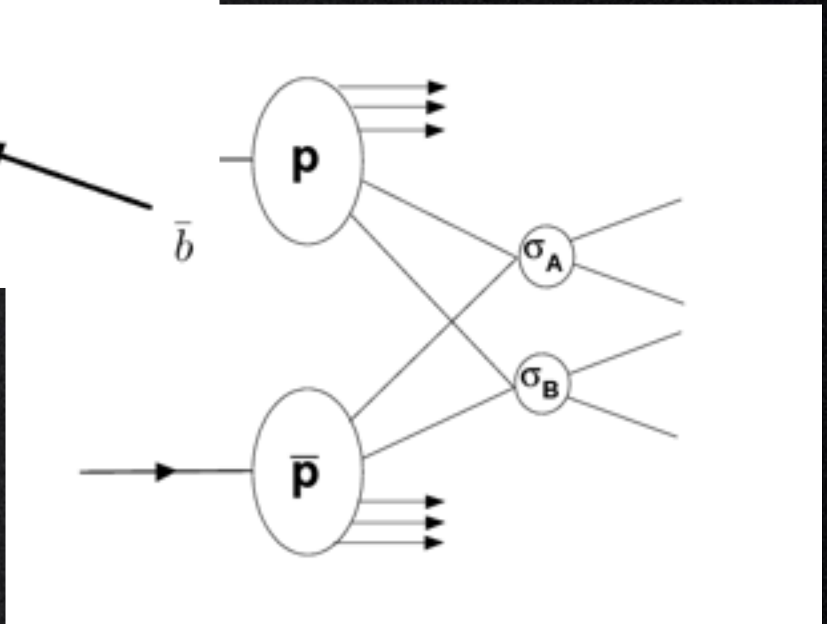
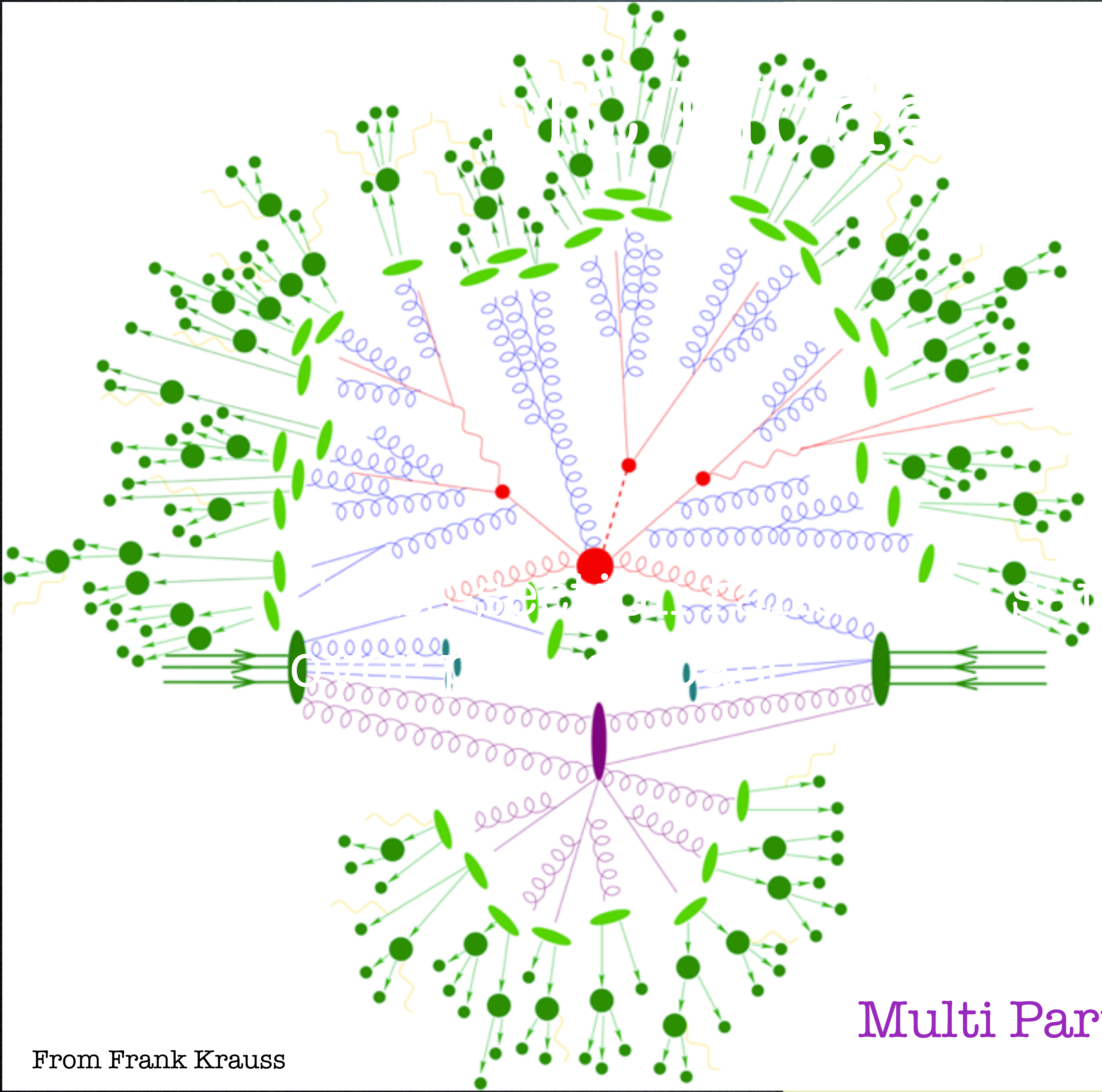


(DPI) bb





Hard Process

Parton Shower

Hadronization

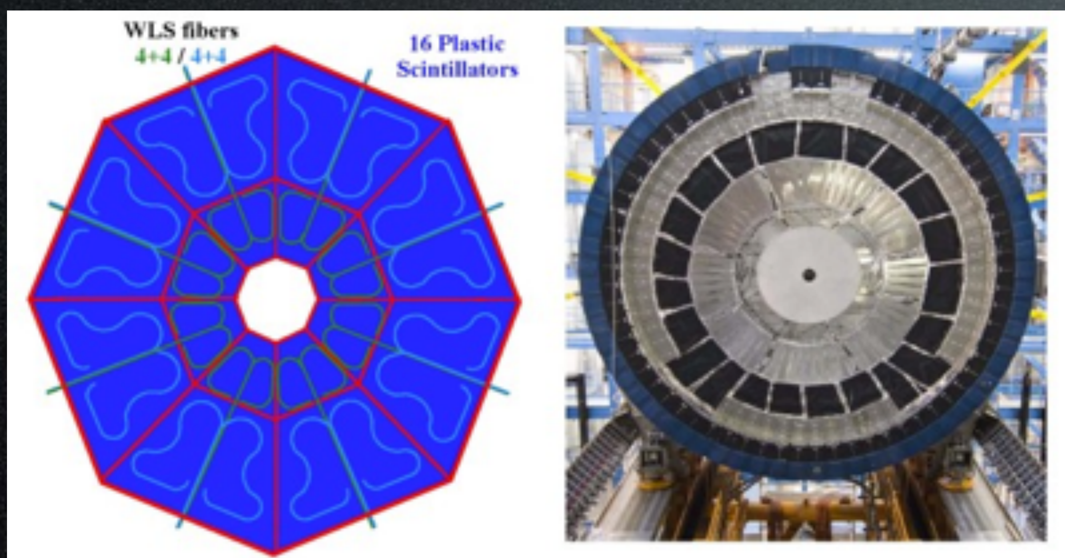
Decays

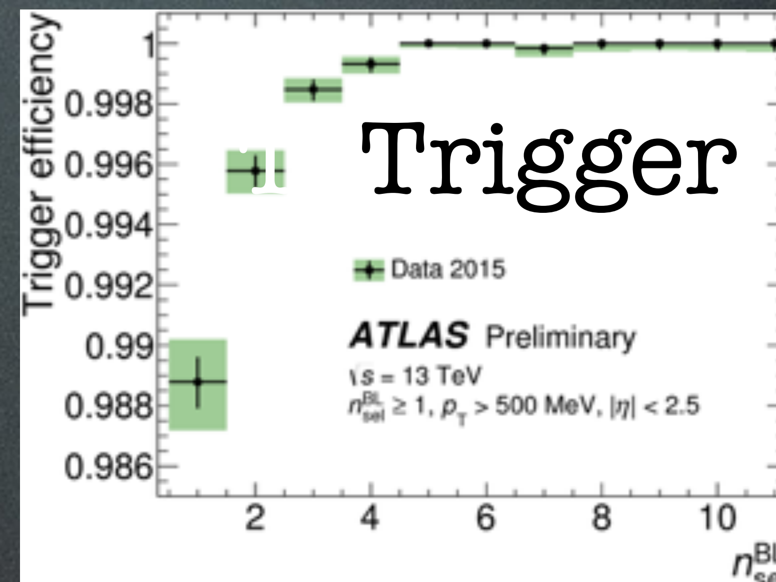
Multi Parton Interaction

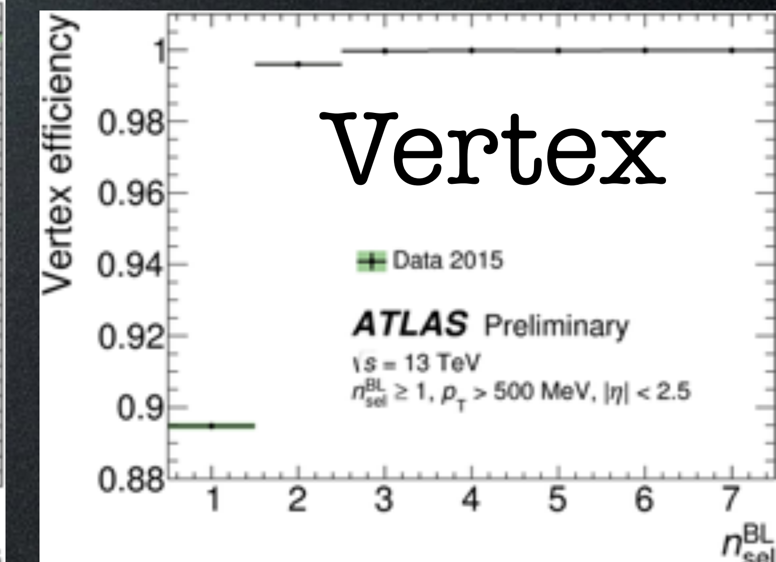
From Frank Krauss

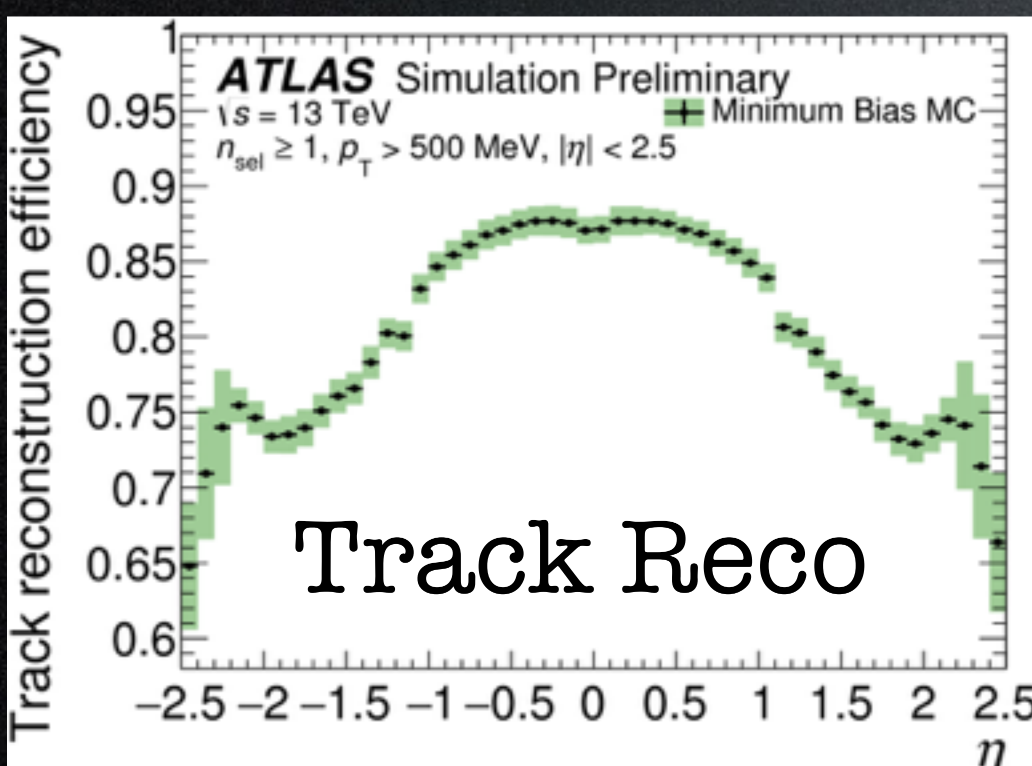
Charged Particle Distributions

MBTS - single side hit required









About 10M events, using low μ run

Tracks with $p_T > 0.5$ GeV and $|\eta| < 2.5$

Remove primary charged particles with $30 < \tau < 300$ ps (strange baryons)