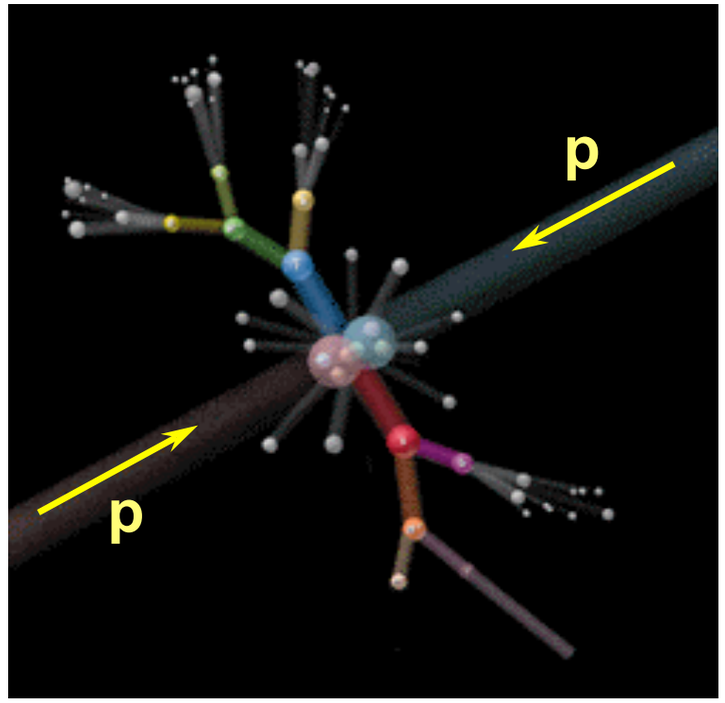
Minimum Bias studies with early data: ATLAS plans.

Arthur Moraes

University of Glasgow

Hadron–hadron collisions

- Essentially all physics at high-energy hadron colliders are connected to the interactions of quarks and gluons (small & large transferred momentum).
  - Hard processes (high-p_T): well described by perturbative QCD
  - Soft interactions (low-p_T): require non-perturbative phenomenological models



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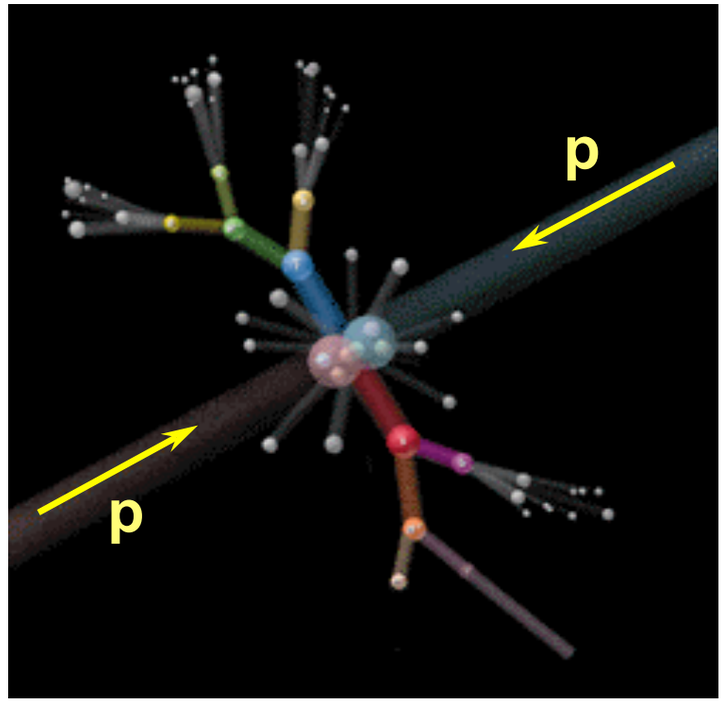

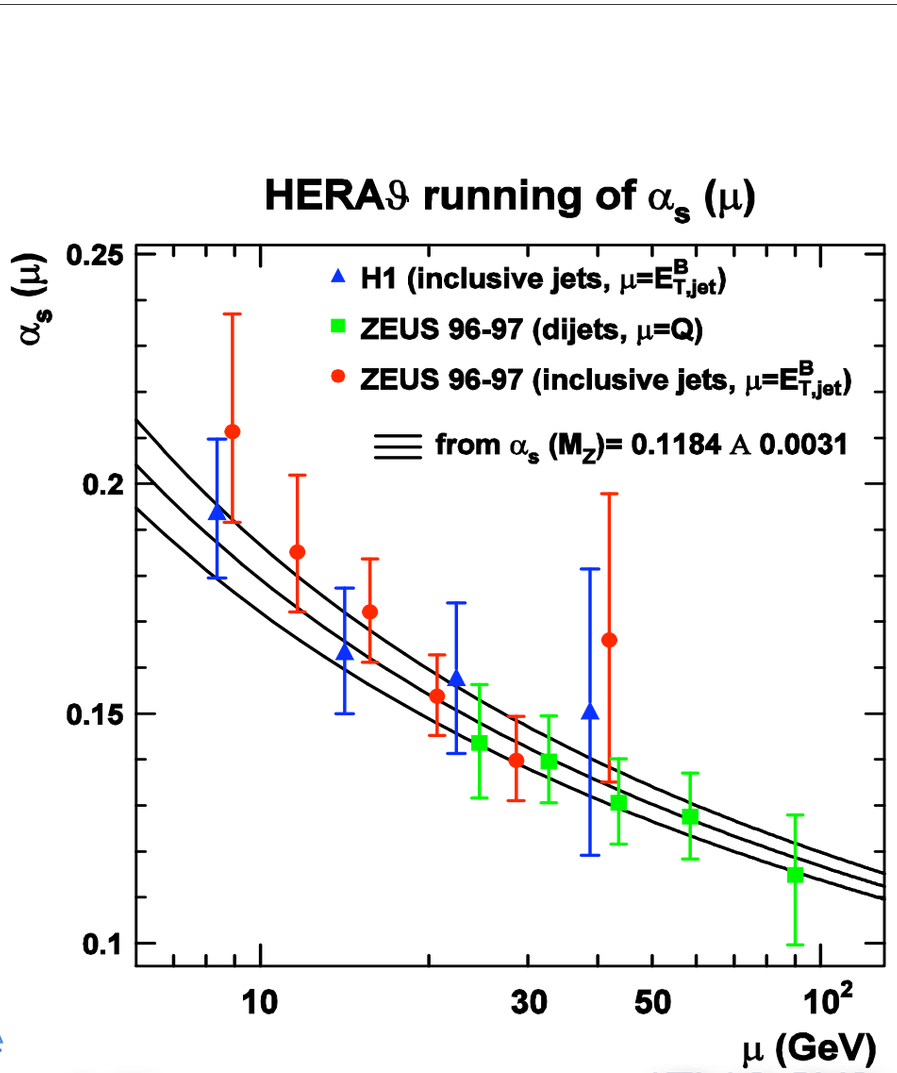

Soft Interactions: Problems with strong coupling constant, $\alpha_s(Q^2)$, saturation effects,…

- **Inelastic hadronic events** are dominated by **"soft"** partonic interactions.
- On average, inelastic hadron–hadron collisions have low transverse energy, low multiplicity.

Minimum bias studies: from few pb^{-1} to ~$10pb^{-1}$

- assume data with “reasonable” quality
- flexibility with respect to the c.m. energy
- low luminosity is ideal as the effect of overlapping proton-proton collisions is removed (or at least reduced)!
- **“Early” measurements ≠ “Easy” measurements!**

Global characteristics of LHC collisions: minimum bias events

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- "All" LHC experiments will be measuring and analyzing minimum bias interactions with the early data.

- What are the general processes we expect to encounter?

$$\sigma_{tot} = \sigma_{elas} + \sigma_{inel}$$

$$= \underbrace{\sigma_{elas}}_{\sim 25-30\%} + \underbrace{\sigma_{ND} + \sigma_{SD} + \sigma_{DD}}_{\sim 75-80\%}$$

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$$= \sigma_{elas} + \sigma_{ND} + \sigma_{SD} + \sigma_{DD}$$

~25-30%

~75-80%

- Accumulating events for analysis is only constrained by the allocated trigger bandwidth!

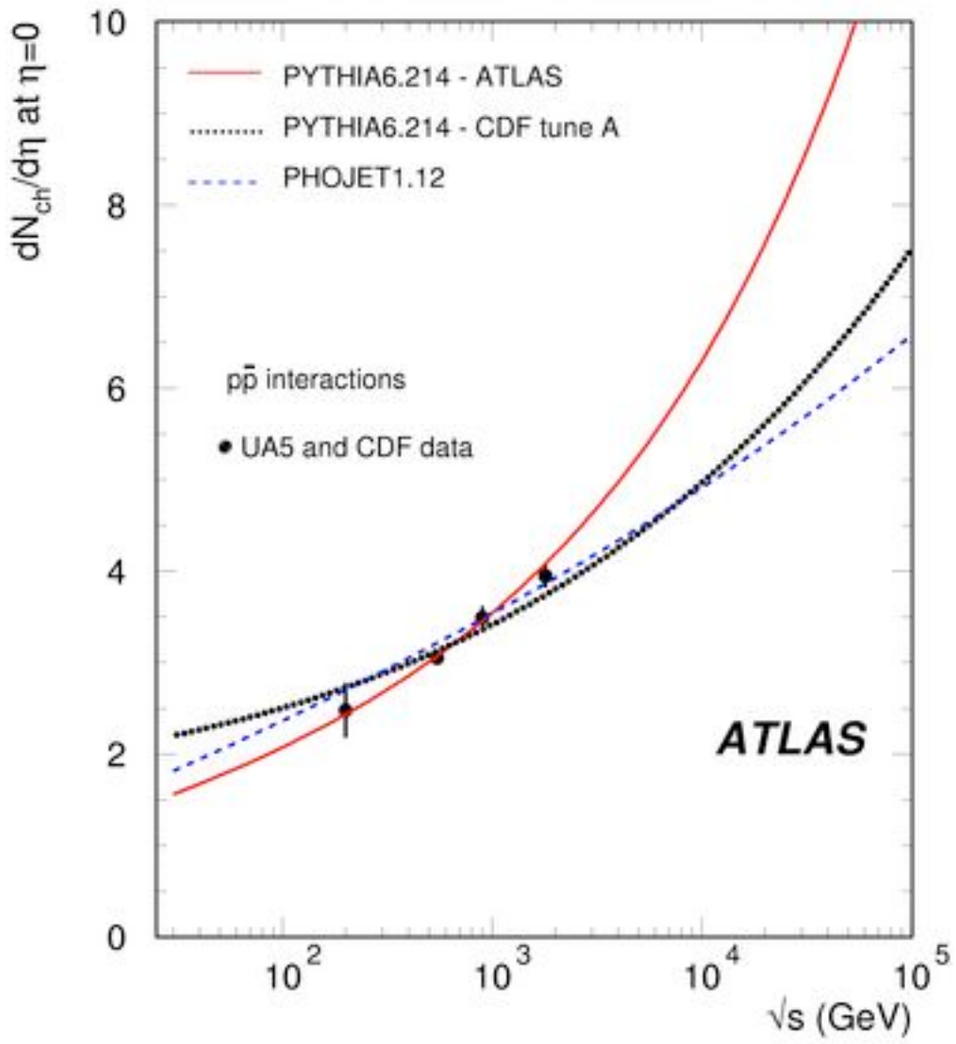
  * $N_{events} = \sigma \times \mathcal{L}$

    N_{MB} ➠ ~tens of billions of "minimum bias" events for $\mathcal{L} = 1 pb^{-1}$

- Low luminosity is ideal as the effect of overlapping proton-proton collisions is removed (or at least reduced)!

LHC Predictions: pp collisions at √s=14TeV

Charged particle density: minimum bias



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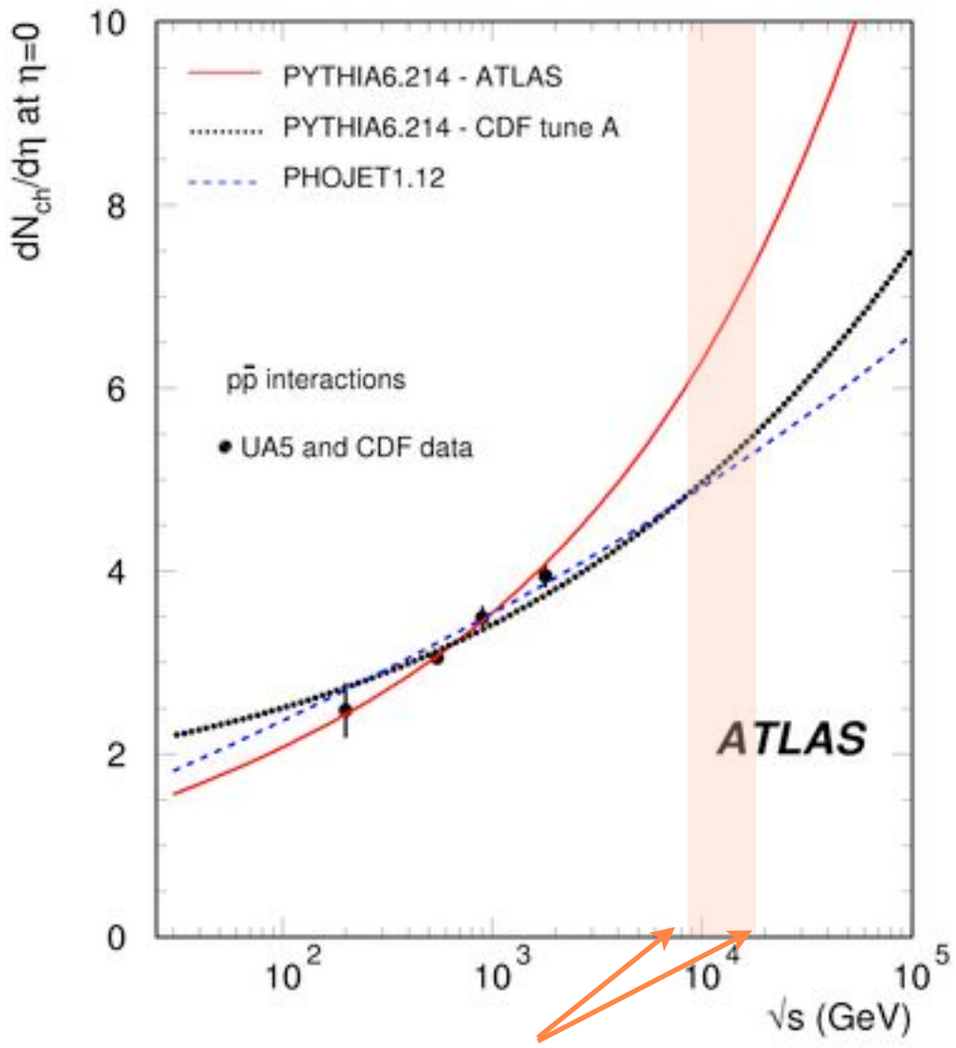

c.m. between 8 – 14TeV

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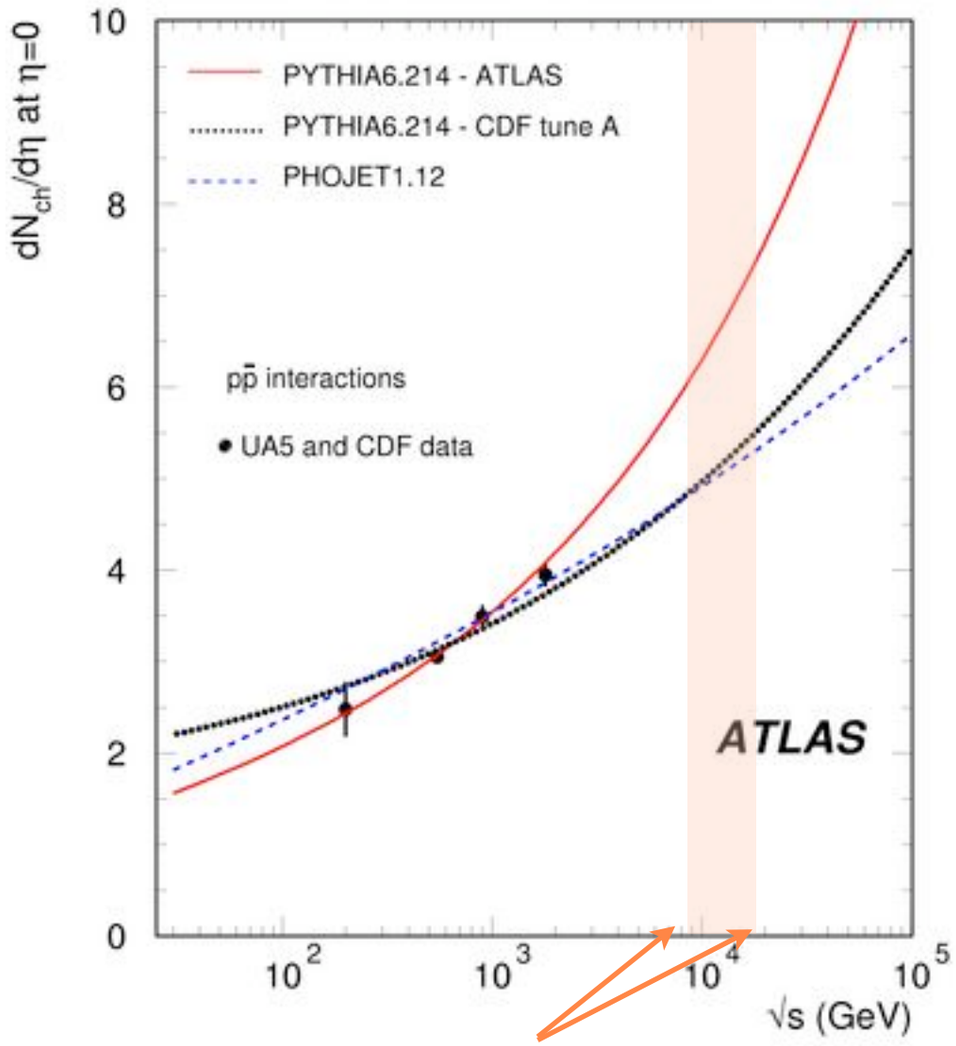
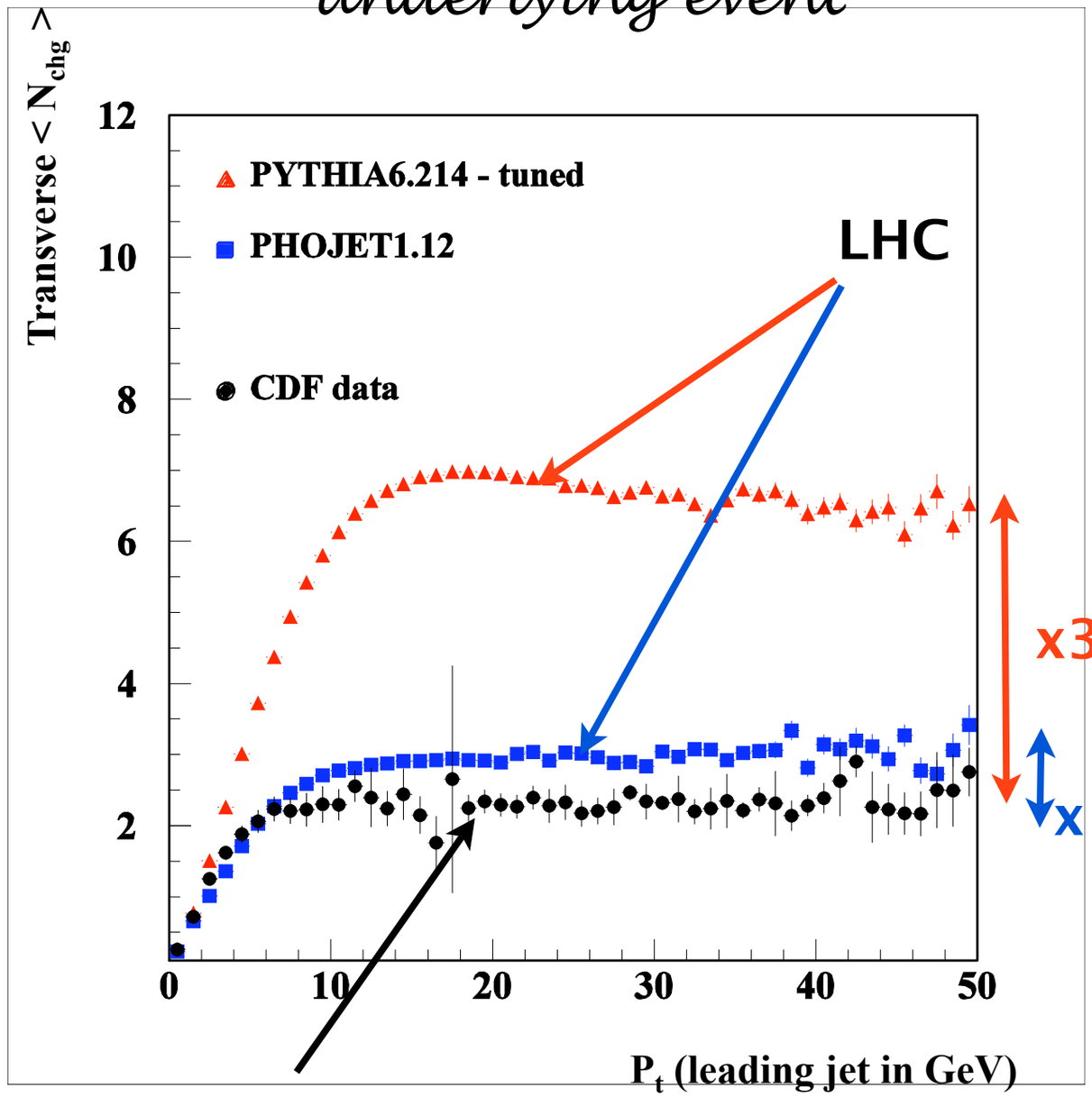


c.m. between 8 – 14TeV

Charged particle density: underlying event



Tevatron

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LHC Predictions: pp collisions at √s=14TeV

Observable	PYTHIA6.214 – tuned	PHOJET1.12	Δ%
σ_{tot} (mb)	101.5	119.1	17.3
σ_{elas} (mb)	22.5	34.5	53.3
σ_{NSD} (mb)	65.7	73.8	12.3
Minimum bias Predictions			
$\langle n_{chg} \rangle$	91.0	69.6	30.7
$dN_{chg}/d\eta$ plaeau	~ 7.0	~ 5.5	27.3
for $\lvert\eta\rvert<2.5$	6.8	5.1	33.3
$dN_{chg}/d\eta$ at $\eta = 0$	0.55	0.64	16.3
$\langle pT \rangle$ at $\eta = 0$ (GeV)	158.4	115.1	37.6
n_{tot} ($\lvert\eta\rvert<15$)	60.9	45.5	33.8
n_{tot} ($\lvert\eta\rvert<2.5$)			
Underlying Event Predictions			
$\langle N_{chg} \rangle$ $pT_{ljet} > 10$ GeV	~ 6.5	~ 3.0	~ 115
$\langle pT_{sum} \rangle$ $pT_{ljet} > 10$ GeV	~ 7.5	~ 3.5	~ 115
$dN_{chg}/d\eta$ $pT_{ljet} > 10$ GeV	~ 29.0	~ 13.3	~ 125
UE/Min-bias $pT_{ljet} > 10$ GeV	~ 4	~ 2	~ 100

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Minimum bias measurements with "early" LHC data

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- "All" LHC experiments will be measuring and analyzing minimum bias interactions with the early data.
  - ATLAS (public) report on minimum bias studies:

    ATLAS Collaboration, *Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics*, CERN-OPEN-2008-020, Geneva, 2008.

- Common steps:
  - Triggering on minimum bias collisions
  - Reconstructing tracks / calorimeter clusters
  - Correcting back for detector effects (efficiencies & acceptances)

Triggering on minimum bias events

(strategy for low luminosity runs!)

What do we want in our final minimum bias sample?

- **most of the inelastic events** (with as little or "minimum" bias as possible).
- **later to be distilled into non-single diffractive inelastic events.**

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(strategy for low luminosity runs!)

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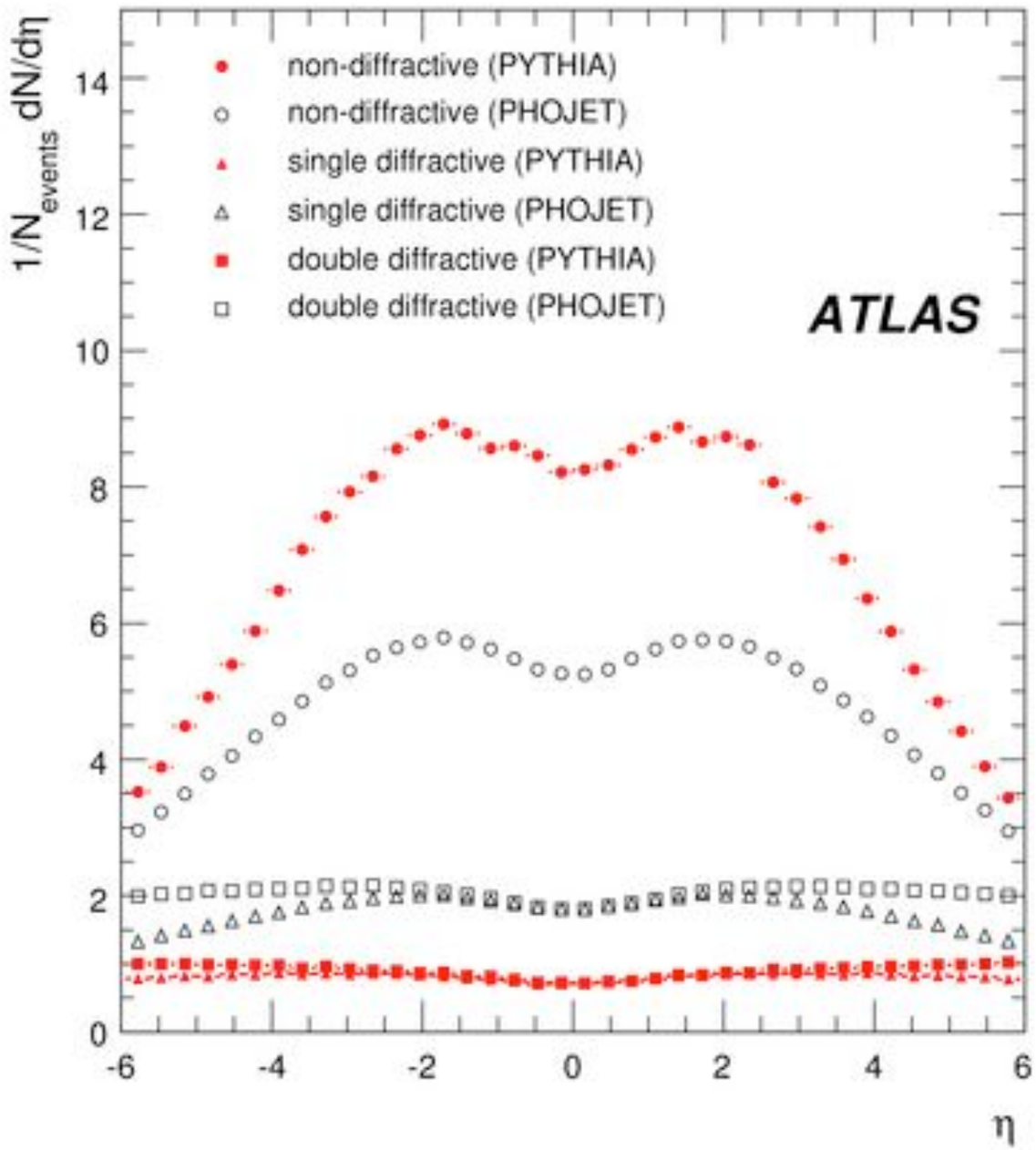
- **later to be distilled into non-single diffractive inelastic events.**

What do we need to separate?

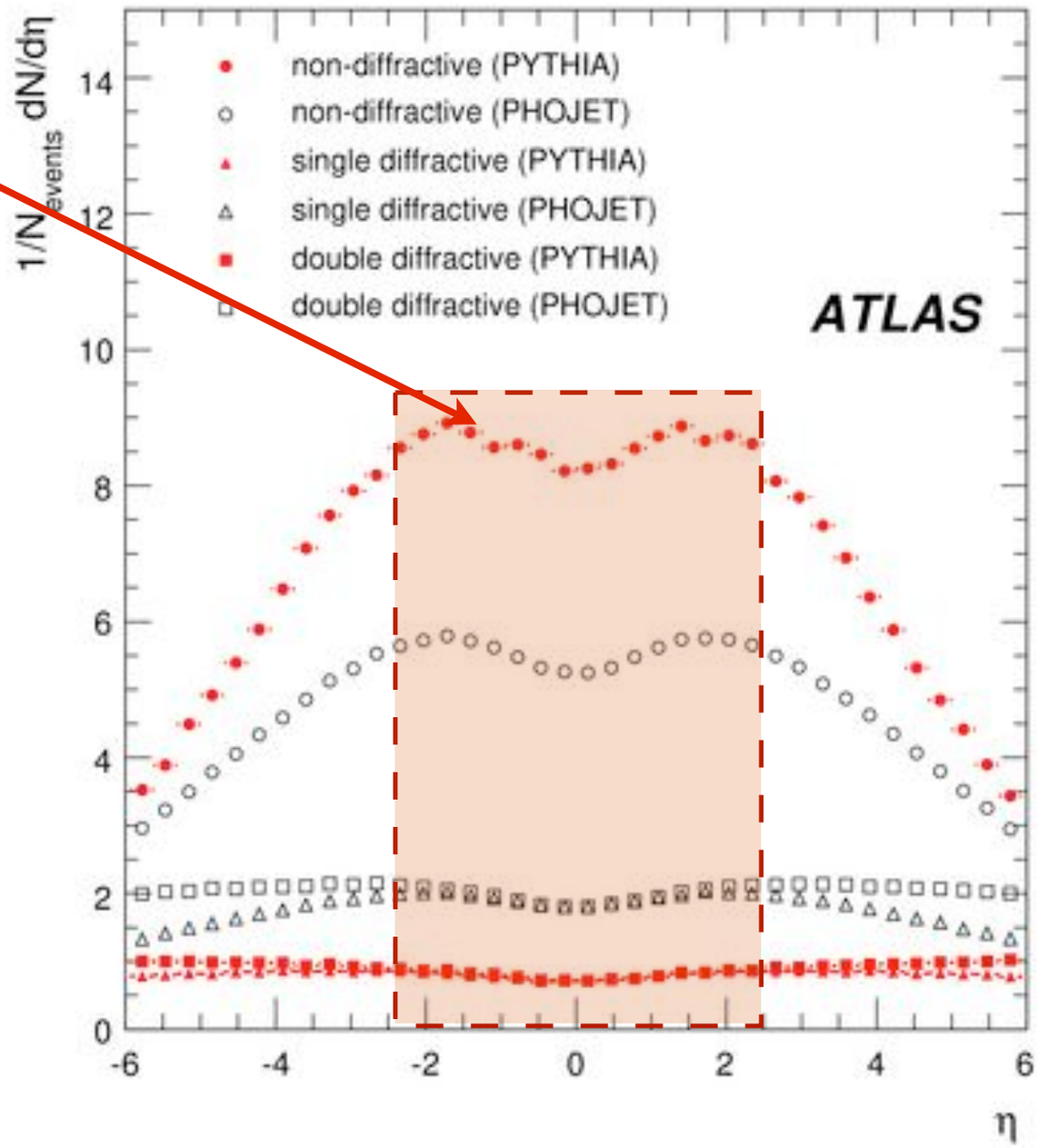
- **Empty events** (for initial runs with bunch spacing of 75ns, most bunch crossings are expected to be empty at $L=10^{31}cm^{-2}s^{-1}$)**;**
- **Beam-gas;**
- **Beam-halo;**
- **Pile-up** (not so much of a big issue early on, but important for $L\sim10^{33}cm^{-2}s^{-1}$ and greater).

Triggering on minimum bias events



Triggering on minimum bias events

Inner detector space points



Triggering on minimum bias events

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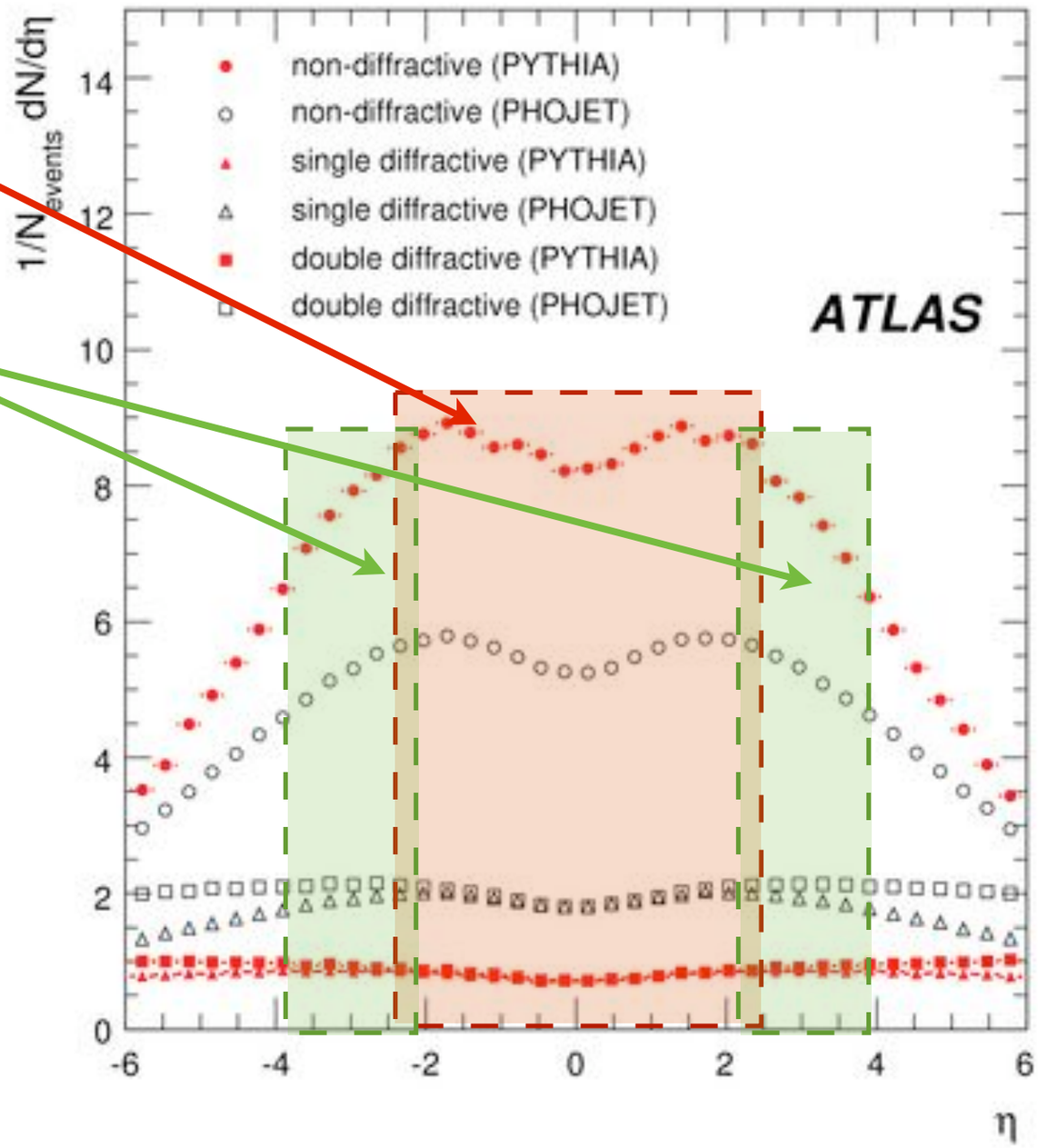
Minimum bias trigger scintillators



Triggering on minimum bias events

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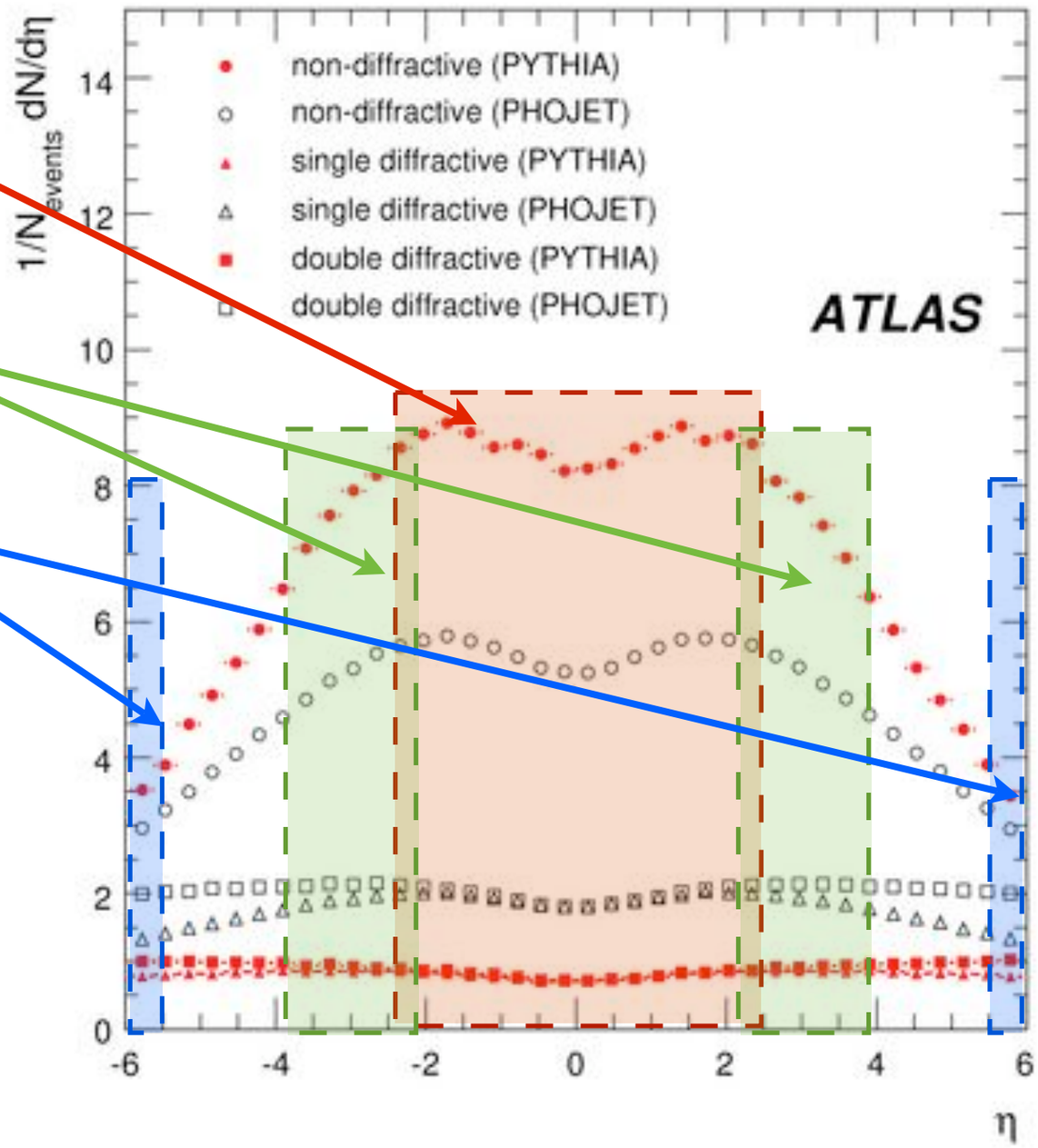
Inner detector space points

Minimum bias trigger scintillators

Cerenkov detector (LUCID)

Zero degree calorimeter (ZDC)
8.3 → ∞



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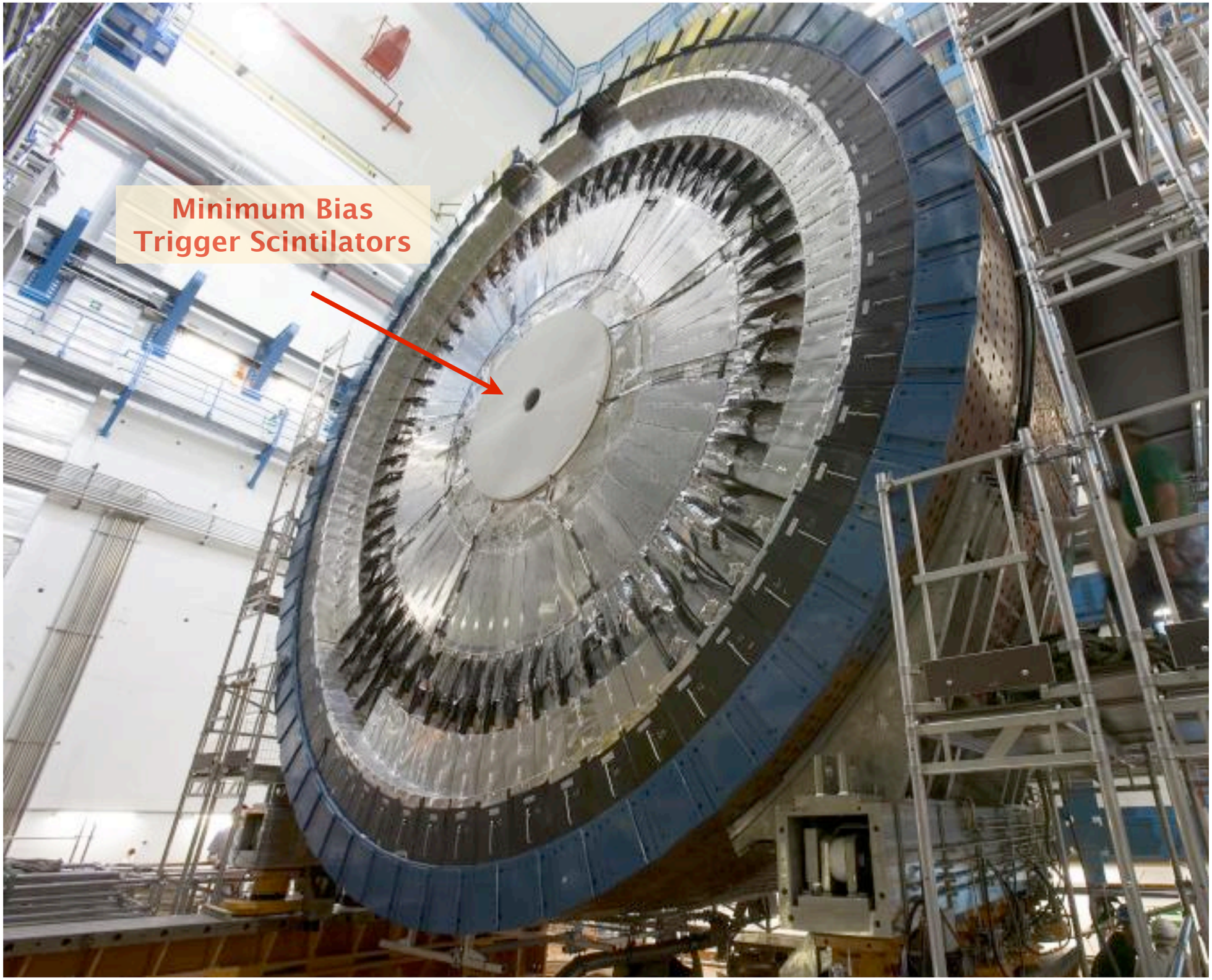
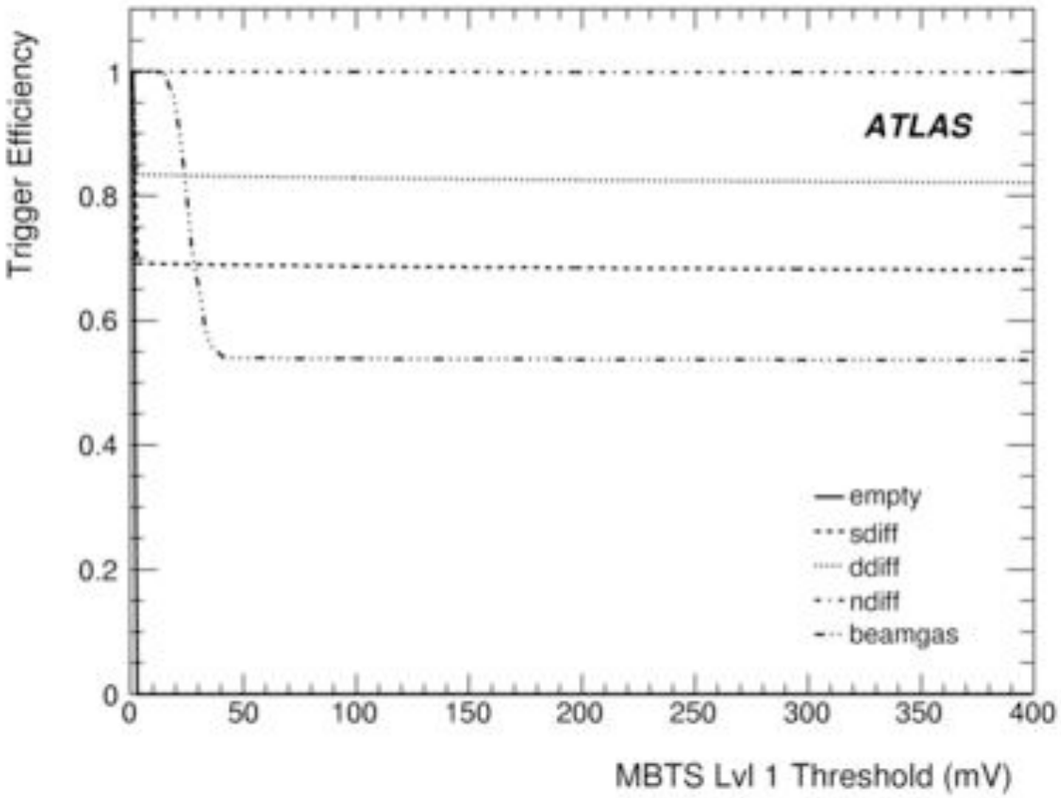
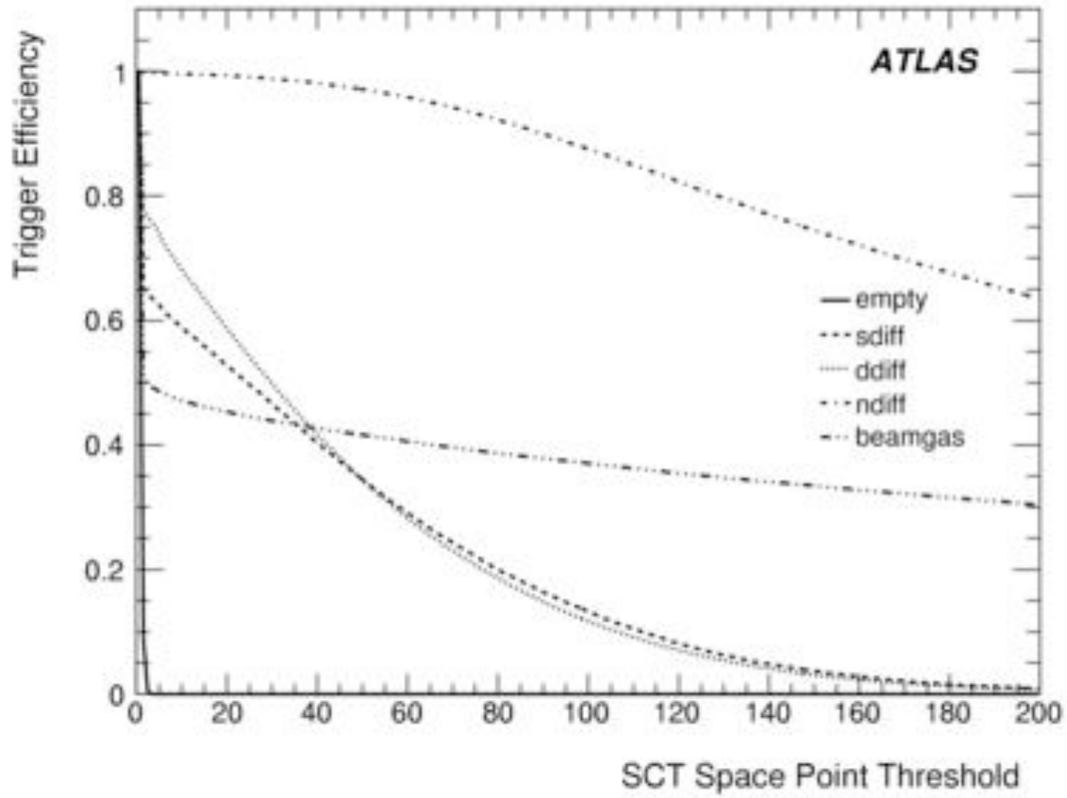


Trigger efficiency



- MBTS L1 trigger efficiency for the MBTS_2 configuration



- Trigger efficiency as a function of the number of pixel spacepoints

ATLAS Collaboration, *Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics,* CERN-OPEN-2008-020, Geneva, 2008.

Process	MBTS_2	Spacepoint
non-diffractive	100%	100%
double diffractive	83%	66%
single diffractive	69%	57%
Beam gas	54%	47%

- MBTS≥2 (of 32). Threshold set from cosmic data
- Space point (SP) trigger. SCT≥3 and Pixel≥12

Diffractive events in minimum bias samples

("soft" diffraction)

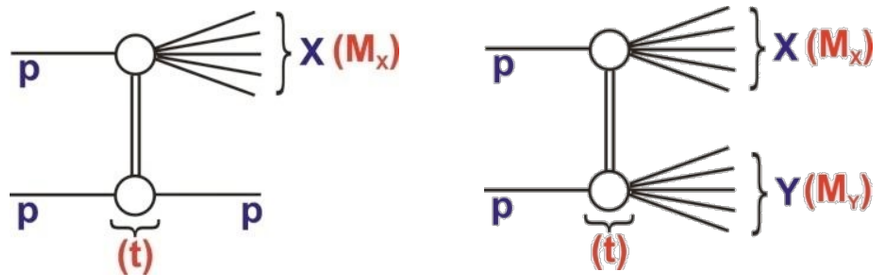
- We are planning to measure the diffractive mass distributions of single and double diffractive events.

- The diffractive component of inelastic events is ~25% of the inelastic cross-section.

- High-η triggers (MBTS, BCM, LUCID, ZDC) are essential!

- Earliest experience in identifying gaps.

- Very attractive measurement for early data!



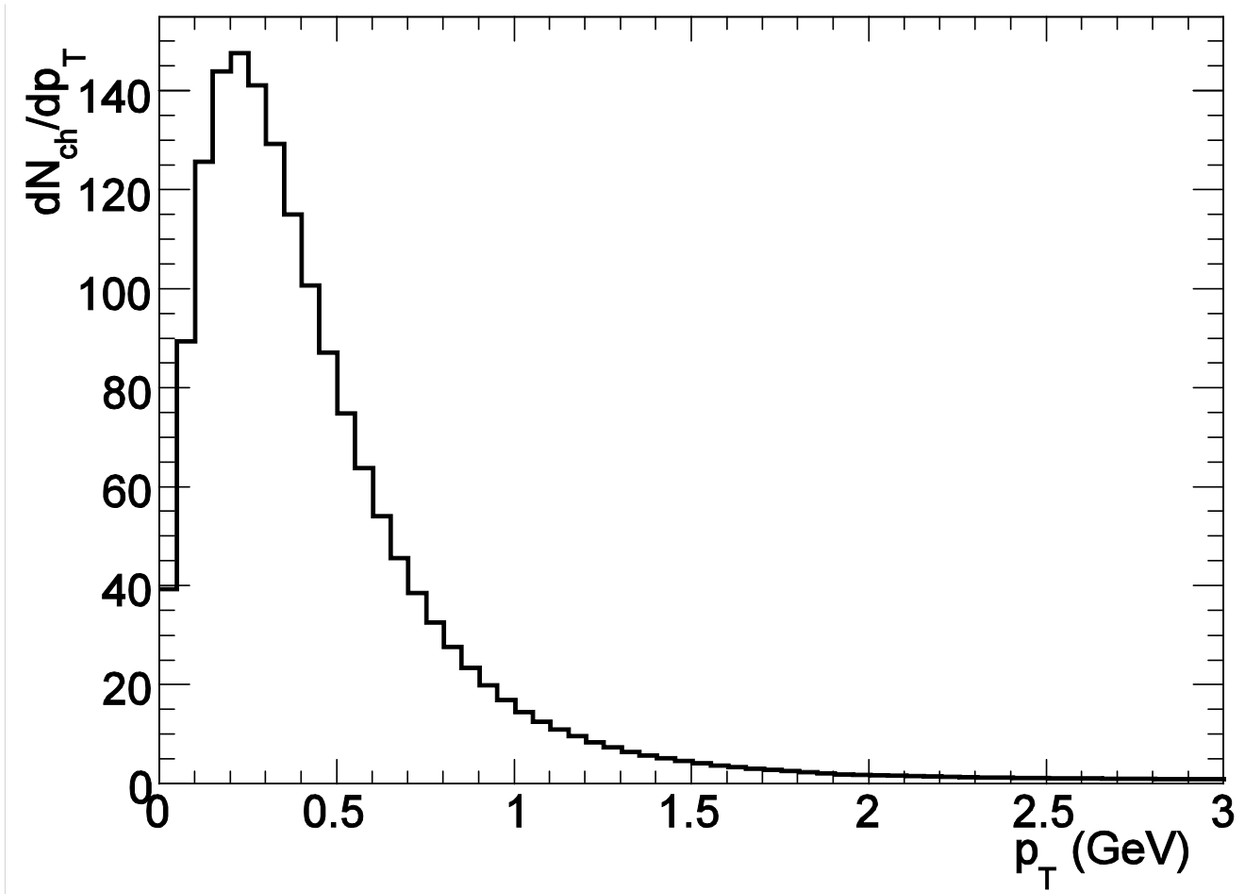
What do we plan to measure?

- Invariant mass of dissociated system(s):
M_X (M_X and M_Y for double-diffraction)

- **Diffractive events have a very characteristic shape!**

Event reconstruction:

- The goal is to reconstruct the event and recover all charged particles;
- Major challenge: reconstruction of low-p_T tracks (p_T<500 MeV)
- Low-p_T reconstruction software & strategy to estimate low-p_T tracking efficiency from data are **essential** to get dN/dη comparable to past measurements!



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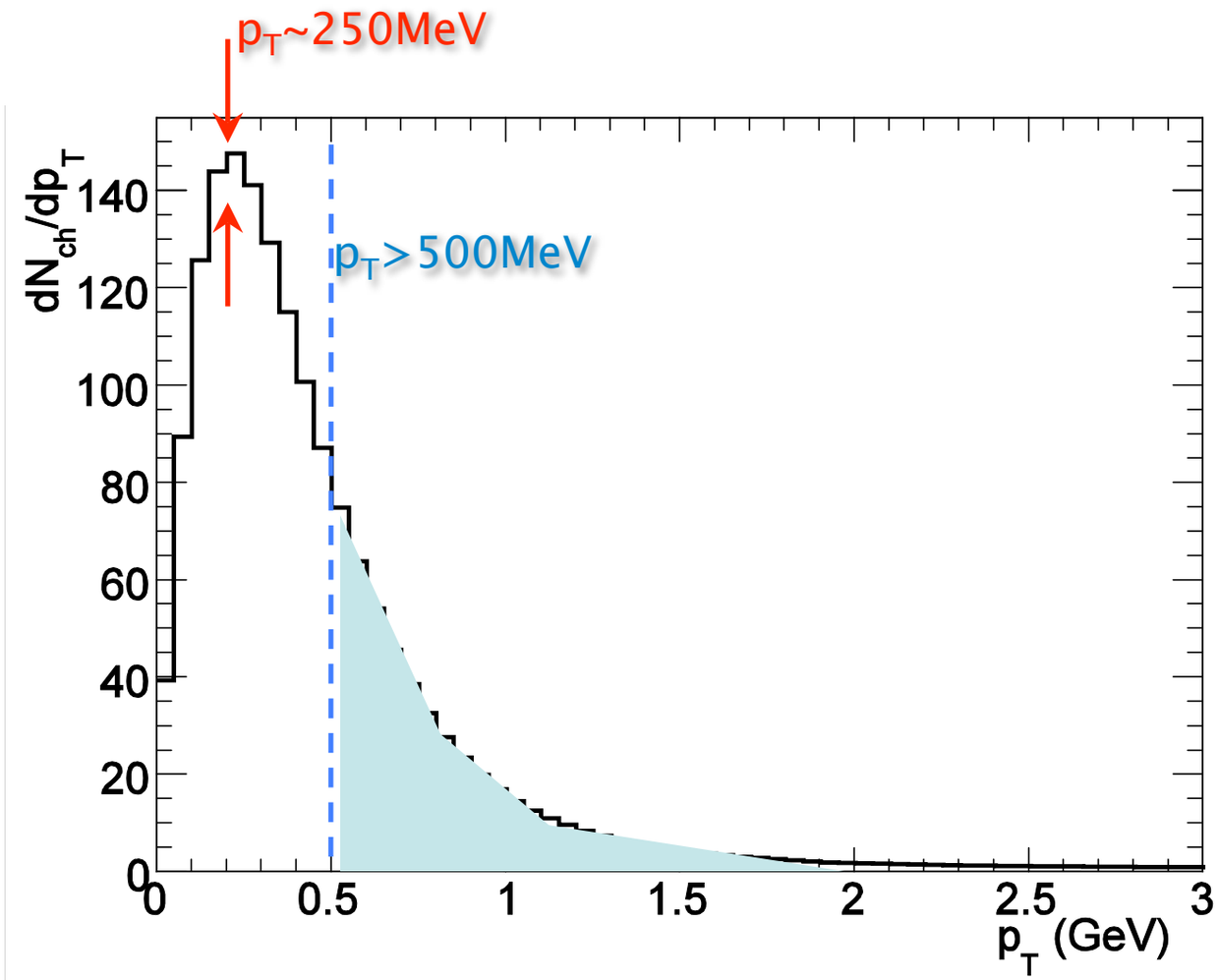

- Work is being done to push this limit to p_T ~ 100 – 200 MeV;
- Avoid large extrapolation factors for measurements such as $dN_{ch}/d\eta$.

Global characteristics of LHC collisions: minimum bias events

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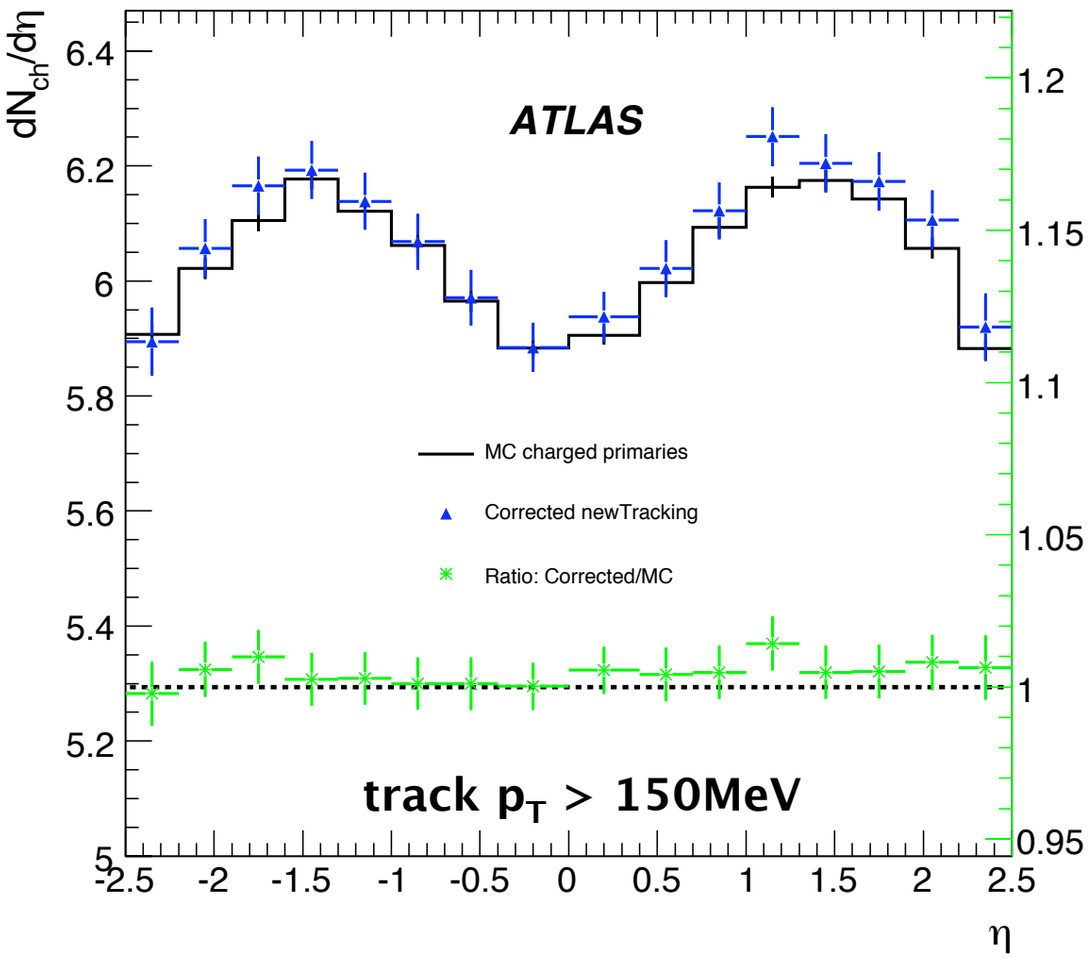
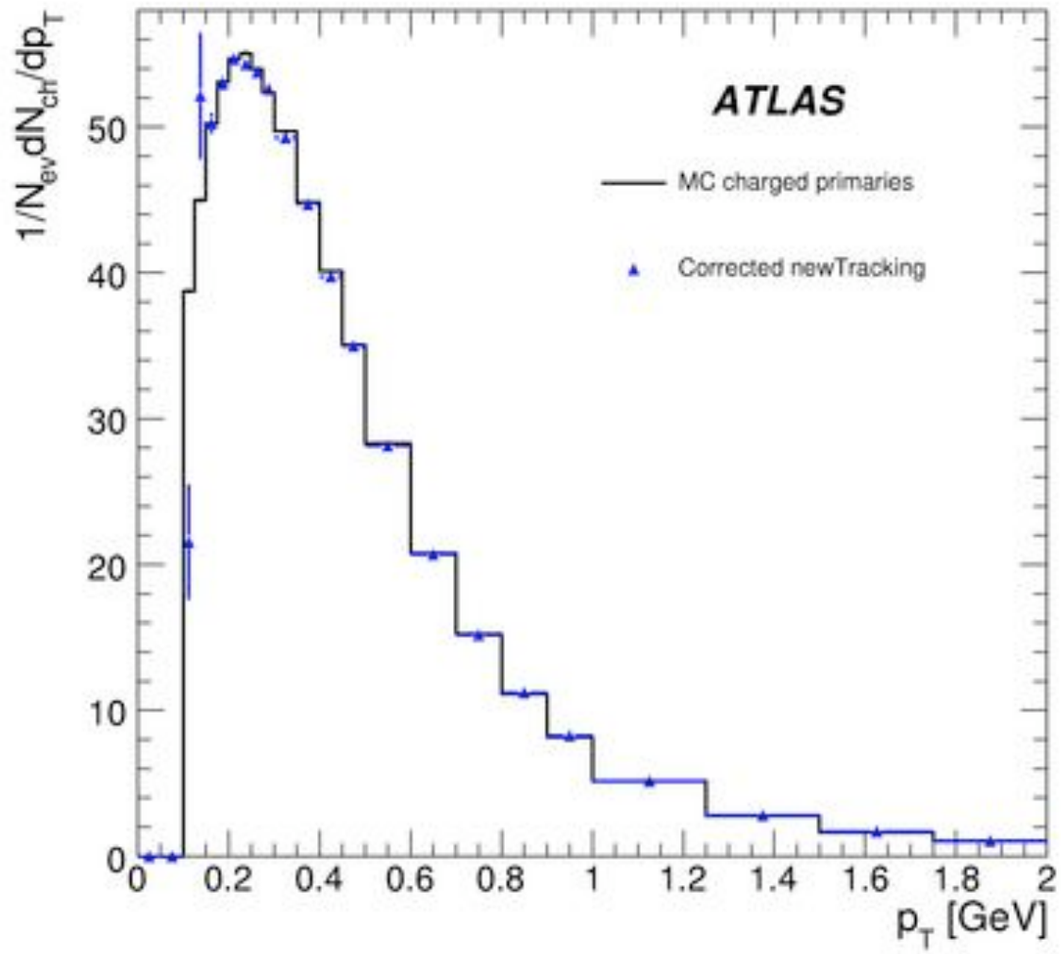
- physics with < 1 pb^{-1}

Charged particle density in pseudorapidity



p_T spectrum of charged particles



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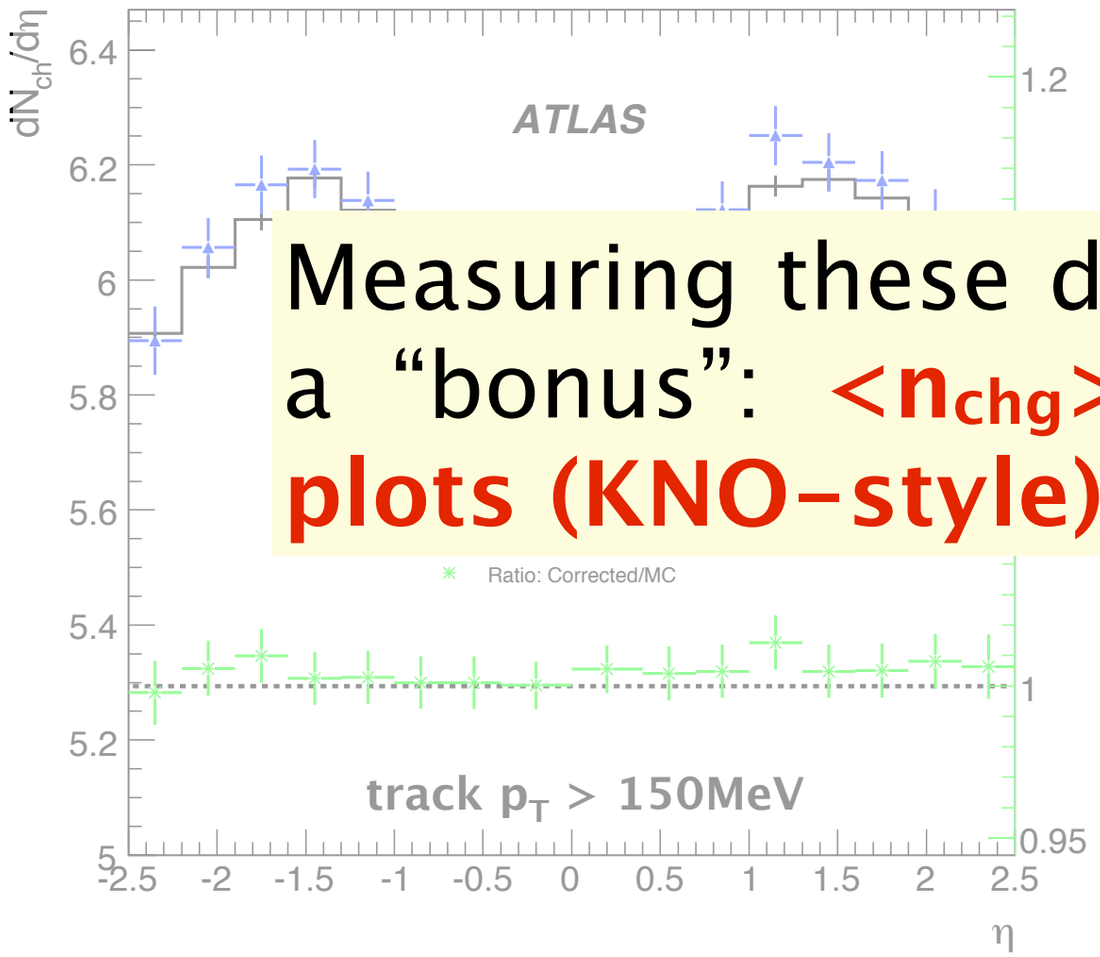

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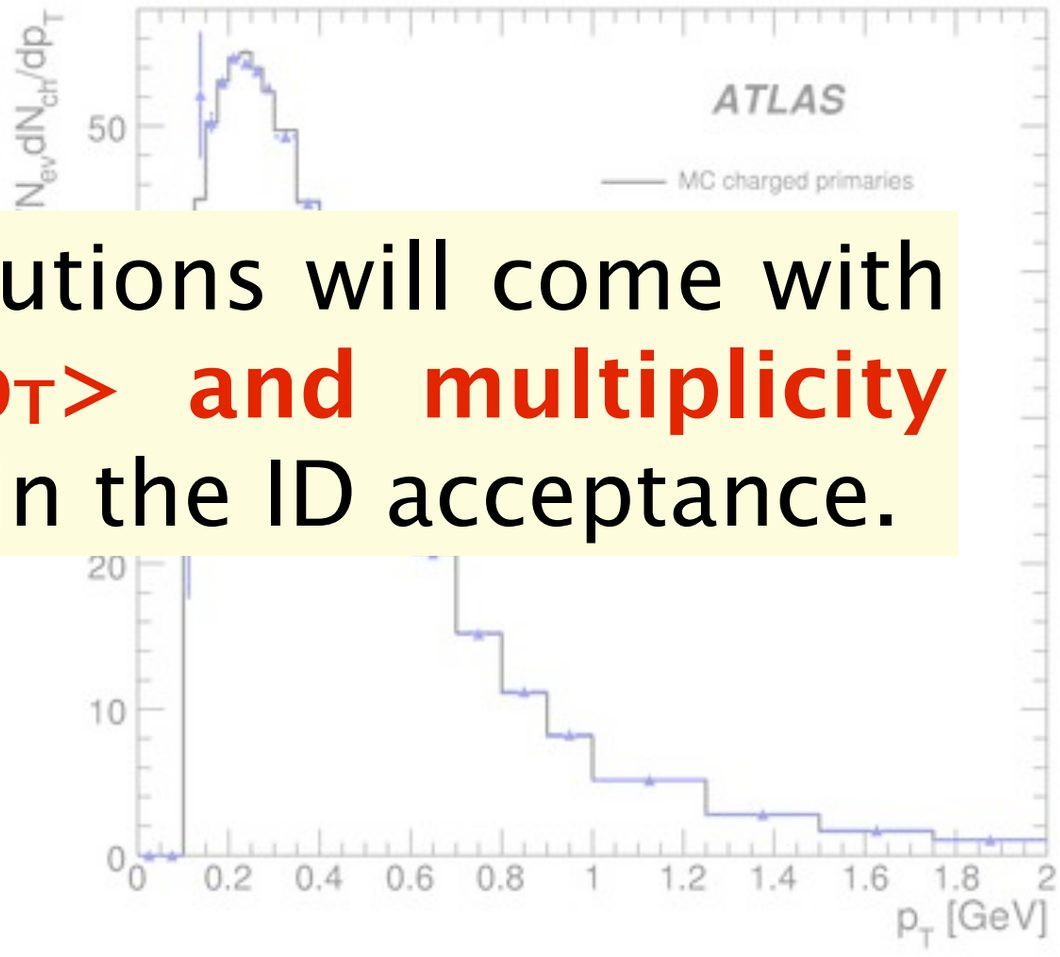

Measuring these distributions will come with a "bonus": **$<n_{chg}>$, $<p_T>$ and multiplicity plots (KNO-style)** within the ID acceptance.

ATLAS Collaboration, *Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics*, CERN-OPEN-2008-020, Geneva, 2008, to appear.

Reconstructing minimum bias events

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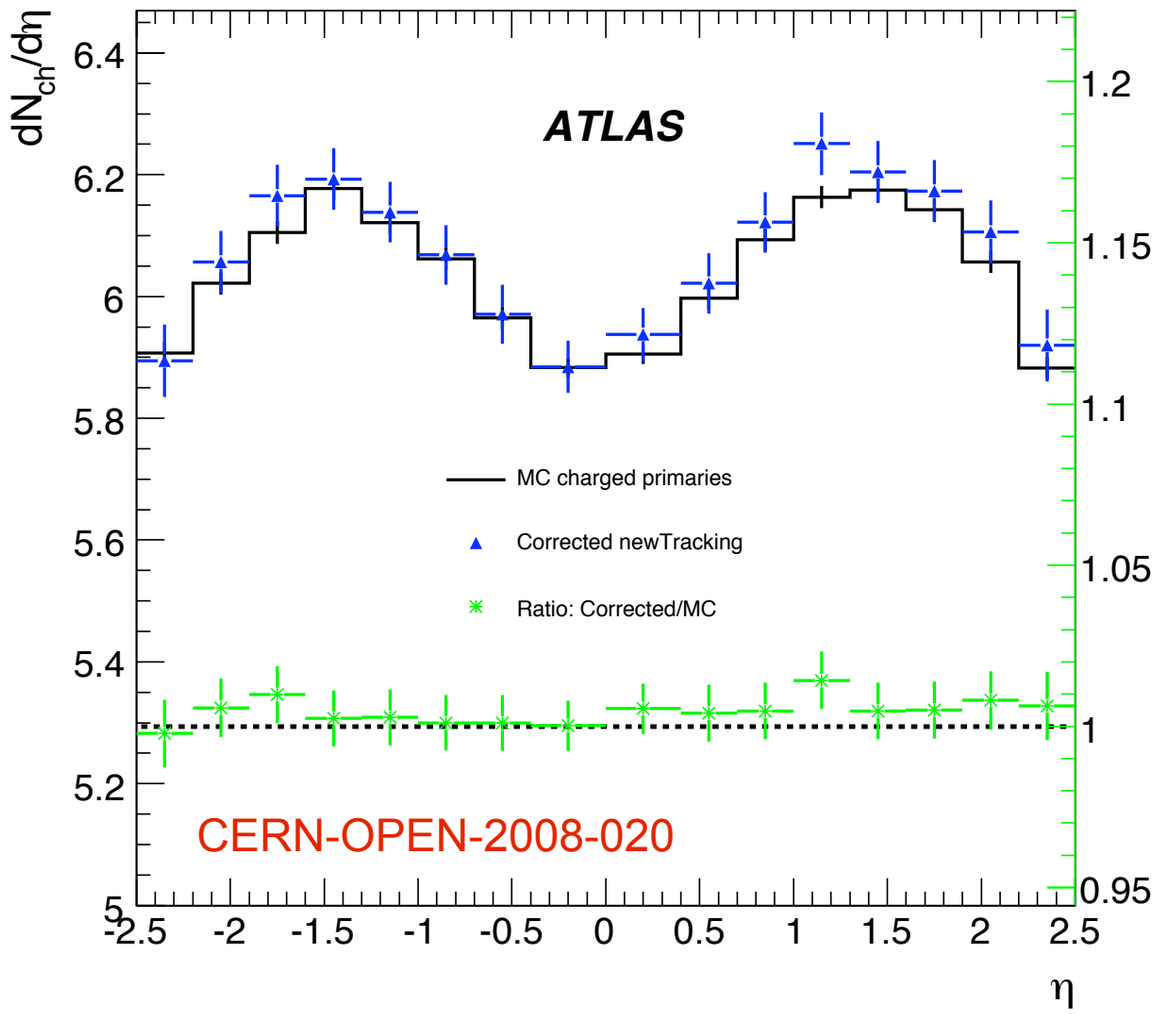
MC charged primaries & track p_T > 150MeV



Summary of systematic uncertainties

Track selection cuts	2%
Mis-estimate of secondaries	1.5%
Vertex reconstruction	0.1%
Mis-alignment	6%
Beam-gas & pile-up	1%
Particle composition	2%
Diffractive cross-sections	4%
Total:	**8%**

- Reconstructed distribution for non-single diffractive inelastic events (for p_T > 150MeV)
- This can be directly compared to previous measurements from UA5 and CDF for example.

Corrections:
- Track-to-particle correction
- Vertex reconstruction correction
- Trigger bias

“Tuning” MC generators:

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What is the strategy?

- Let experimental data guide you! (experimentalist’s bias...)

  Gather as many measurements as possible about the physics you want to describe.

- Start by calibrating generators to describe average / global properties.

  for example: $\langle n_{chg} \rangle$, $\langle p_T \rangle$, $dN/d\eta$, ...

- Identify “specialized” distributions to tune particular model components.

  for example: dN/dp_T in the UE (sensitive to ISR), KNO plots in MB (sensitive to hadronic matter distribution), ...

- Use measurements taken at different c.m. energies

  a good model should be able to reproduce data from earlier colliders “BEFORE” it can be used to generate predictions for higher energies!

- Never lose sight of the physics!

  if parameter choices point to selections outside the physics reach of the generator, then the model needs to be changed!

ATLAS example can be found in: EPJ C 50, 435 (2007)

Tuning MC generators:

- LHC studies on the calibration of MC models have evolved considerably from the time of the Detector & Physics Performance TDRs (1999...).
- Minimum bias distributions (from the ATLAS TDR):

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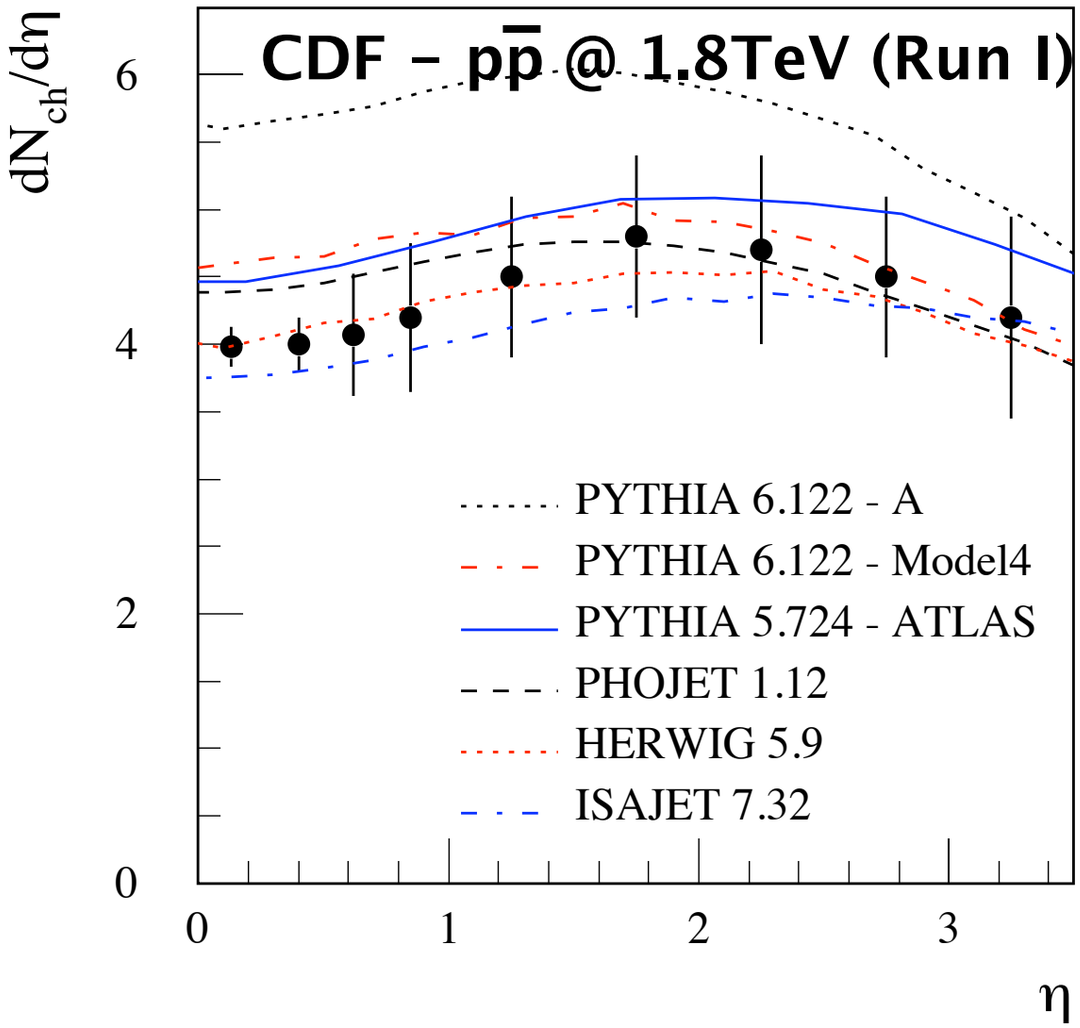

ATL-PHYS-99-019

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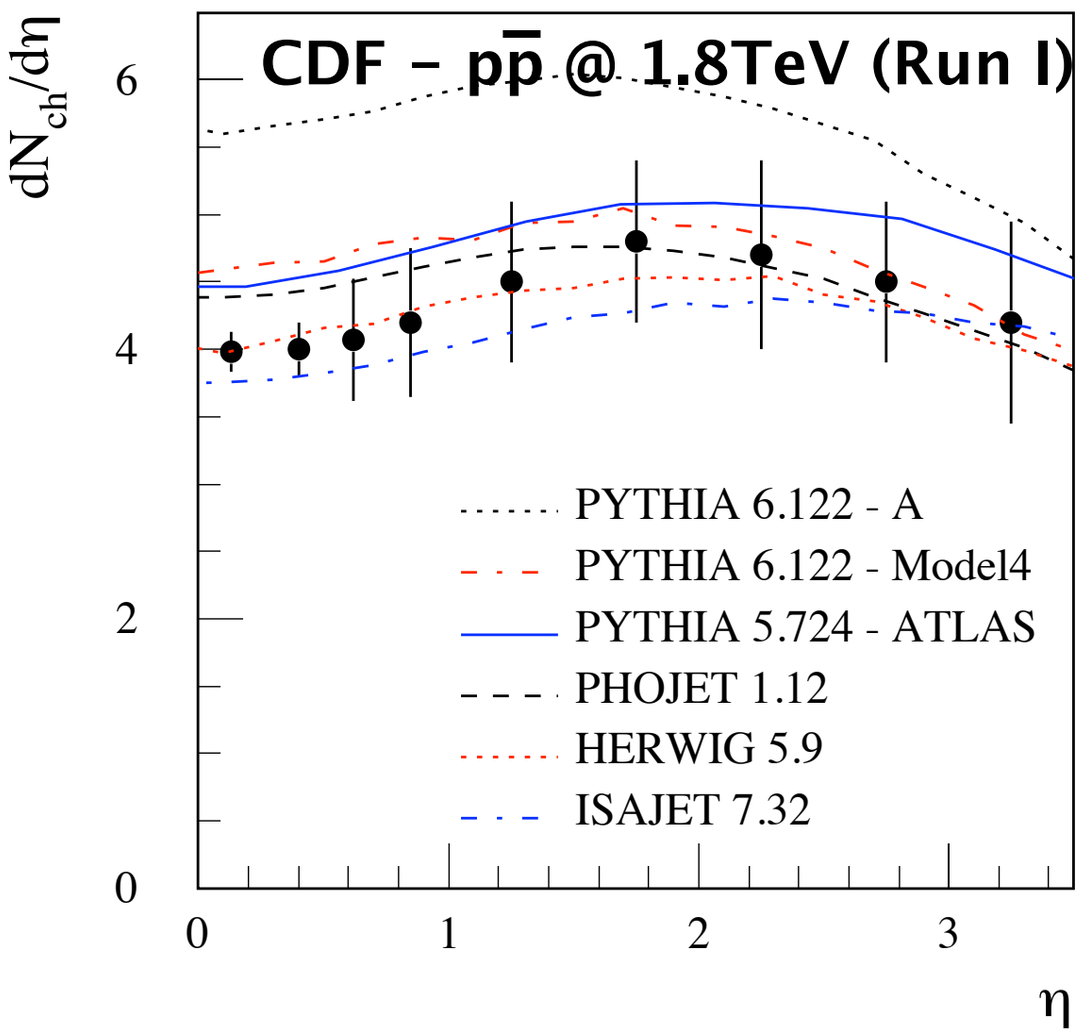

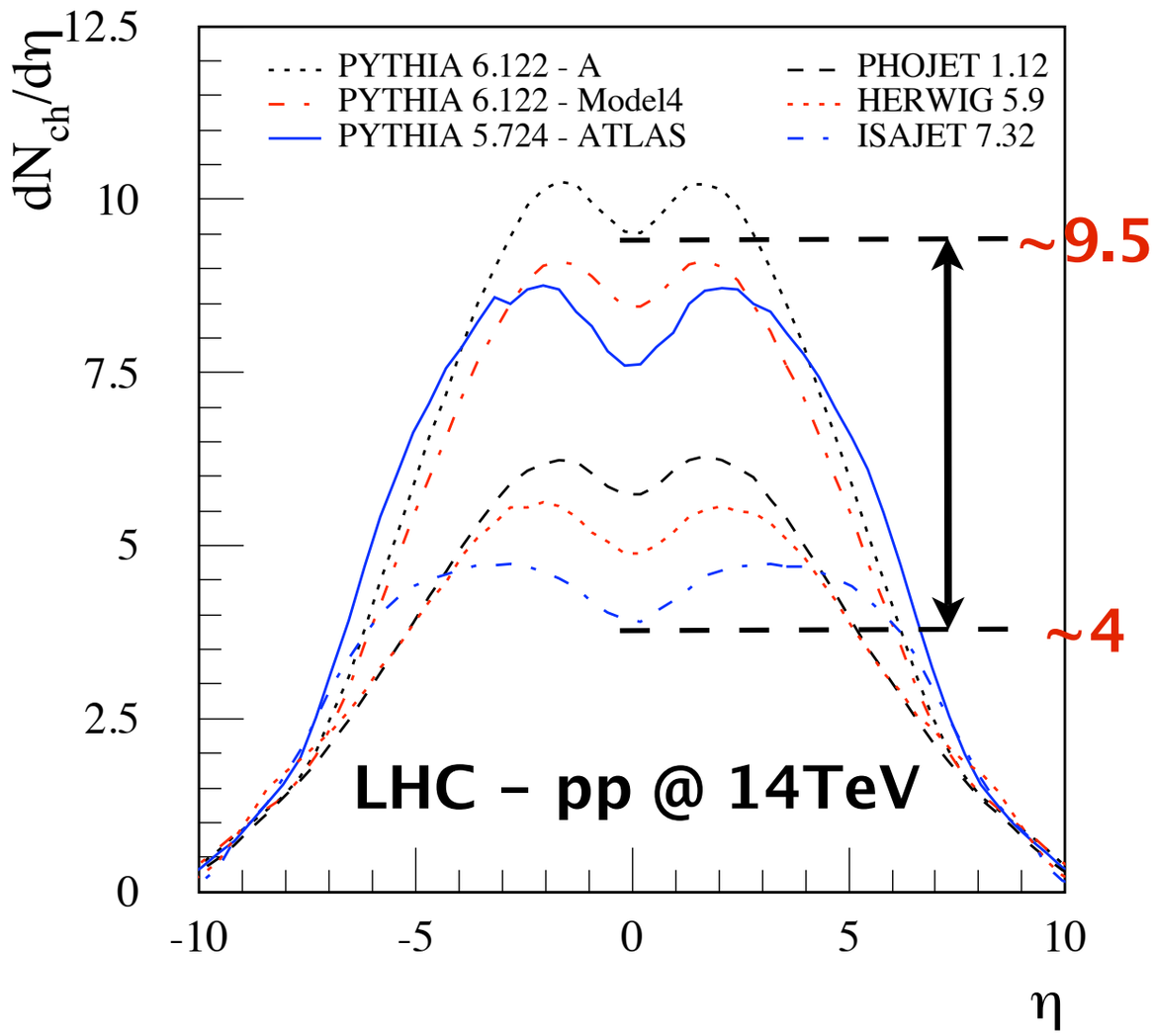

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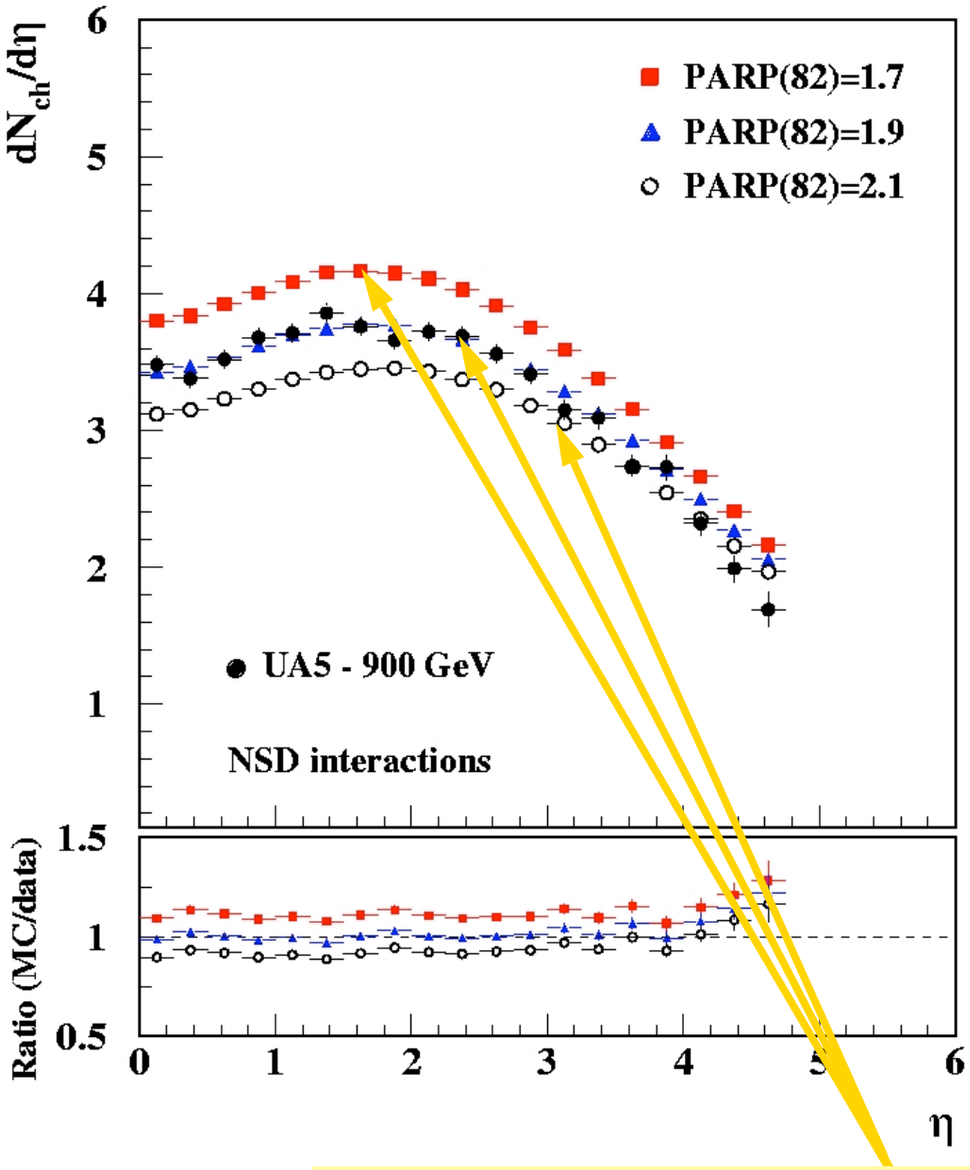
Tuning models to minimum-bias data
(practical examples...)



Lower p_T cut-off determines the average particle density.

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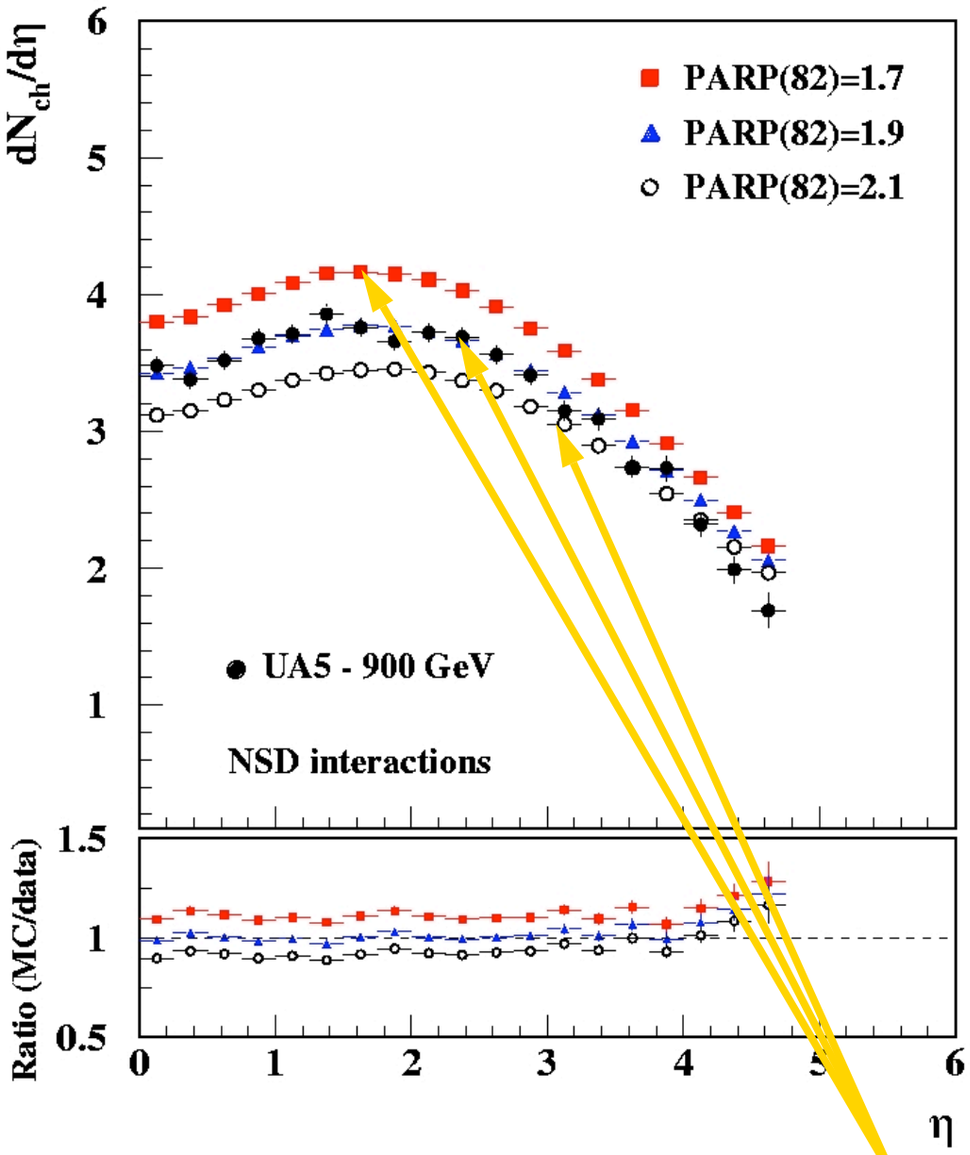

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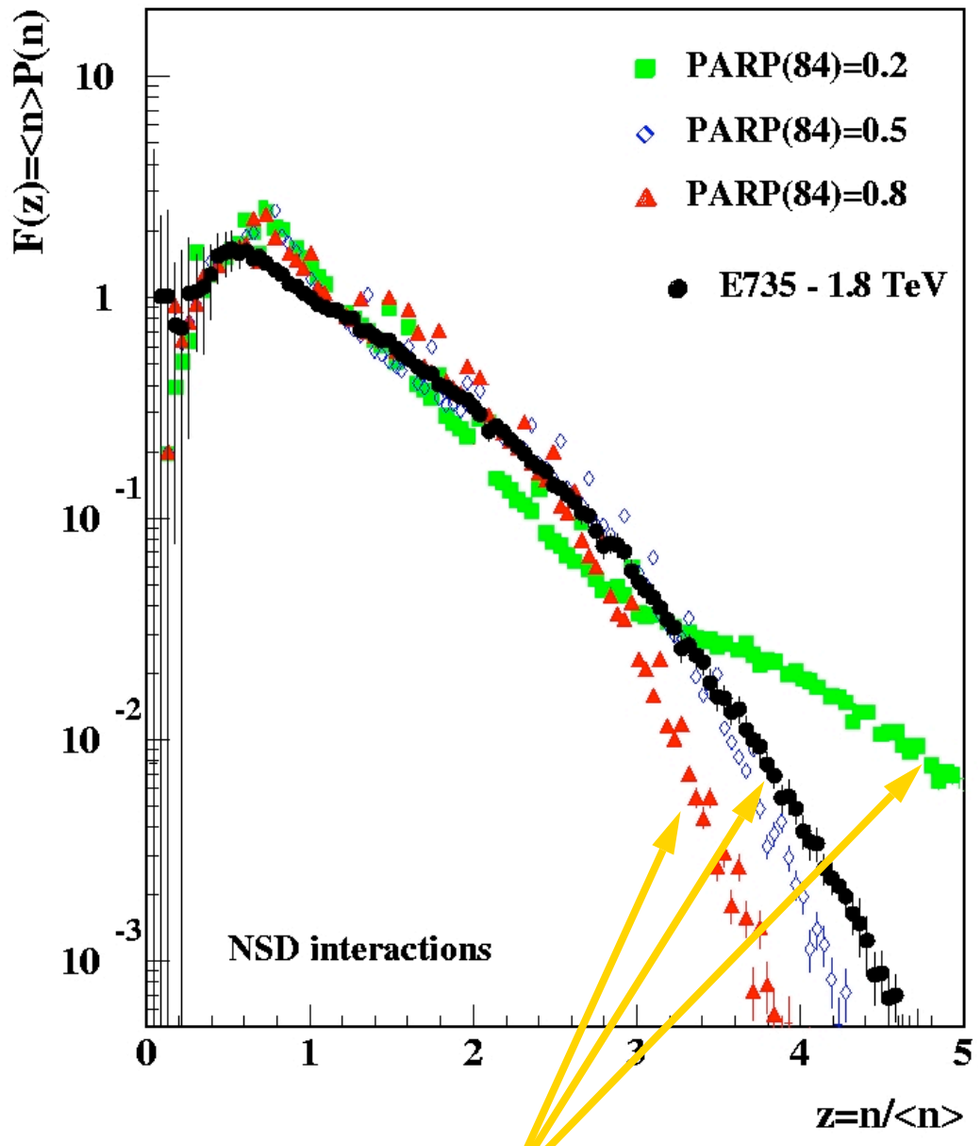
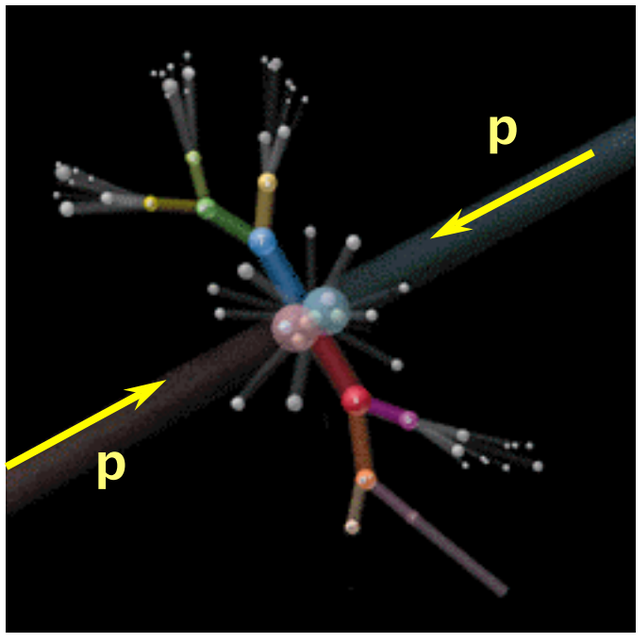


High-multiplicity events are described differently by each tuning.

"Minimum bias" vs. the underlying event: aren't they the same?

- **The underlying event:** All particles from a single particle collision except the process of interest.

  – Sometimes, the underlying event can also be defined as everything in the collision except the hard process (high-Q^2).



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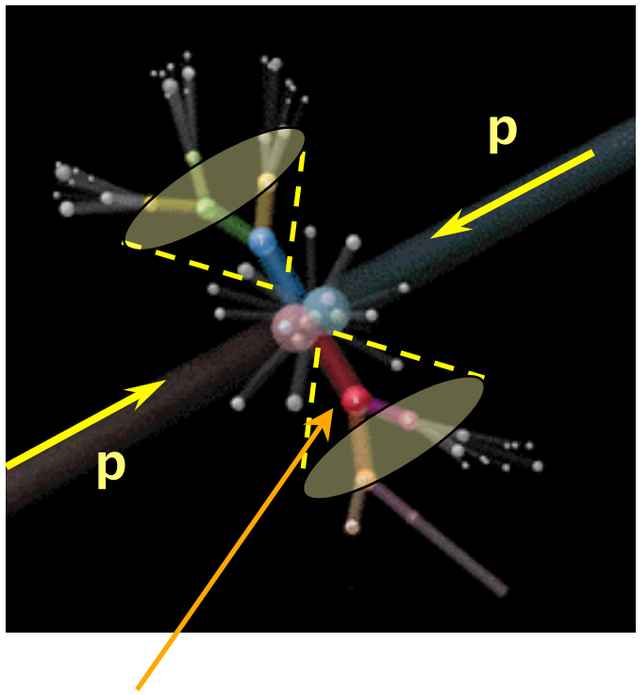

Process of interest (eg. high p_T jets, top-anti-top pair, Z boson)

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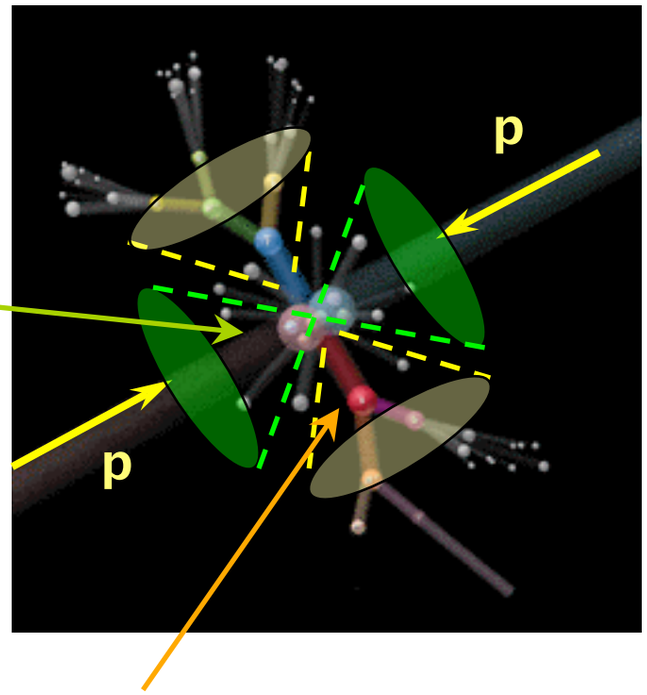

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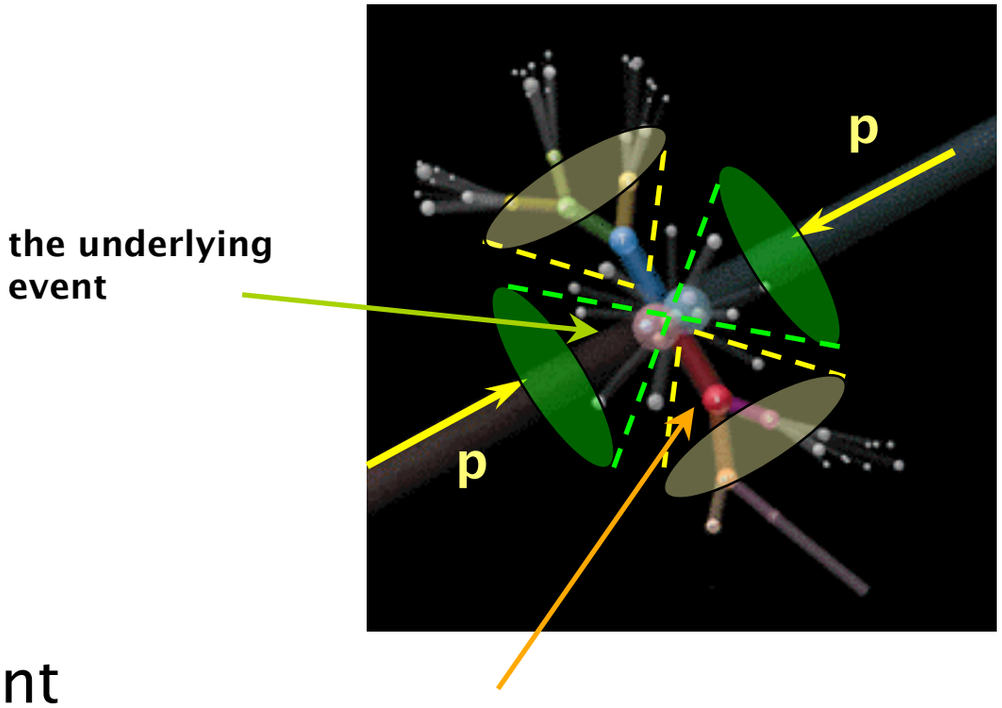
- **Common mis-conception**: in the pre-Tevatron era, the activity in the underlying event (particle multiplicity, p_T^{sum}, ...) was assumed to be **“approximately”** the activity measured in minimum bias events.



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...going forward to higher luminosities

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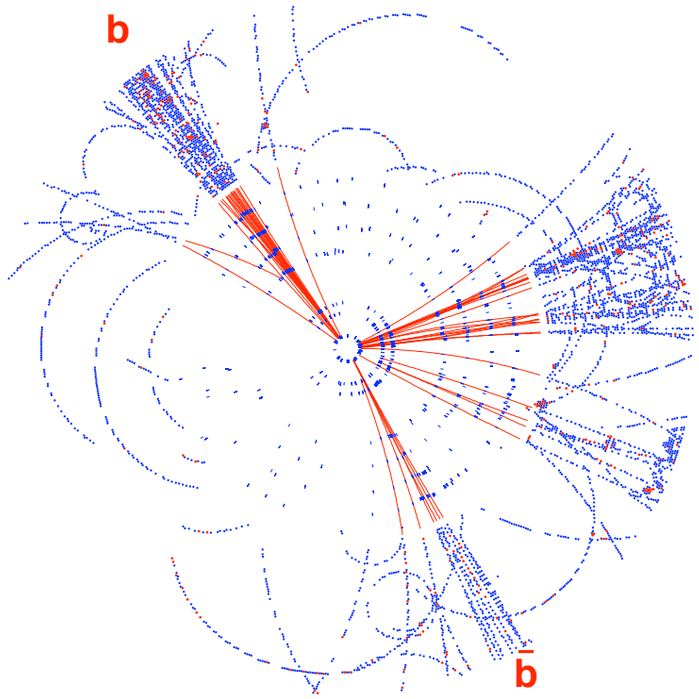
ATLAS Barrel Inner Detector

$H \rightarrow b\bar{b}$

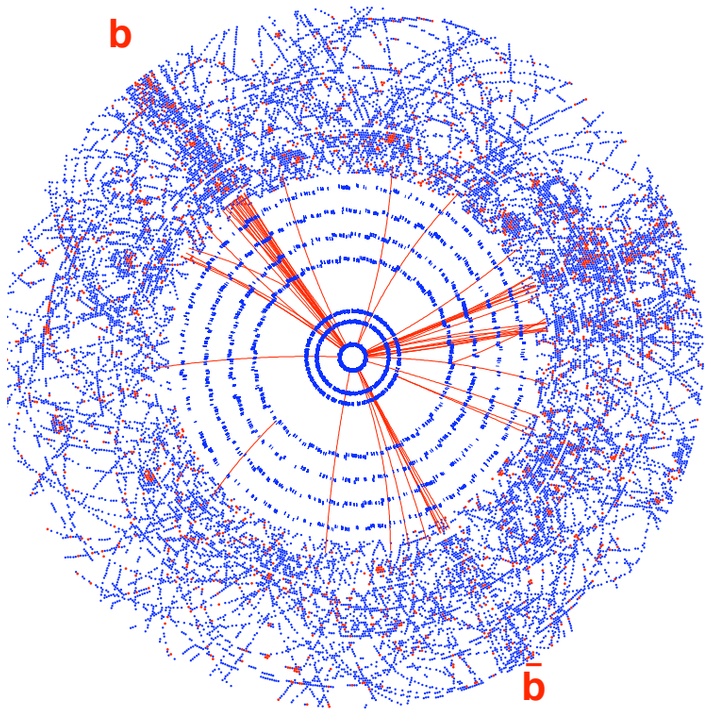
Low-luminosity

$L=10^{33}\ cm^{-2}s^{-1}$



$L=10^{34}\ cm^{-2}s^{-1}$

High-luminosity
(LHC design)



...going forward to higher luminosities

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Low-luminosity

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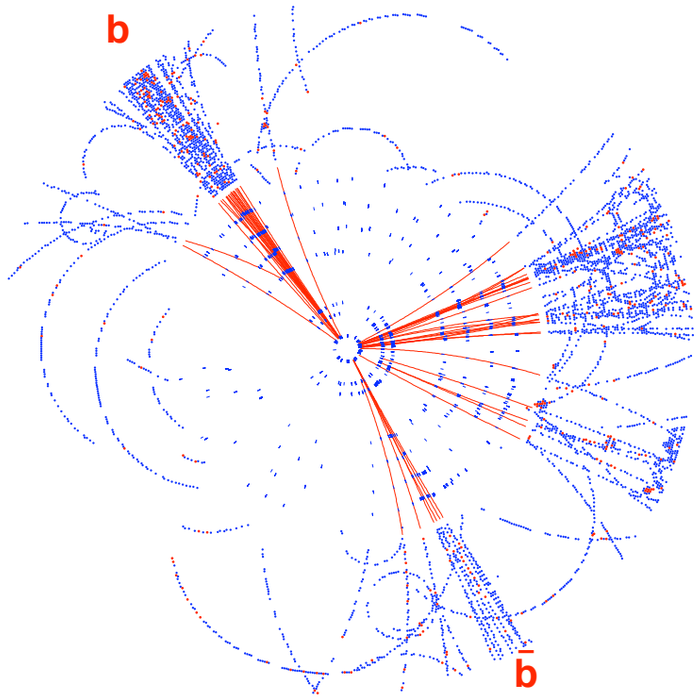

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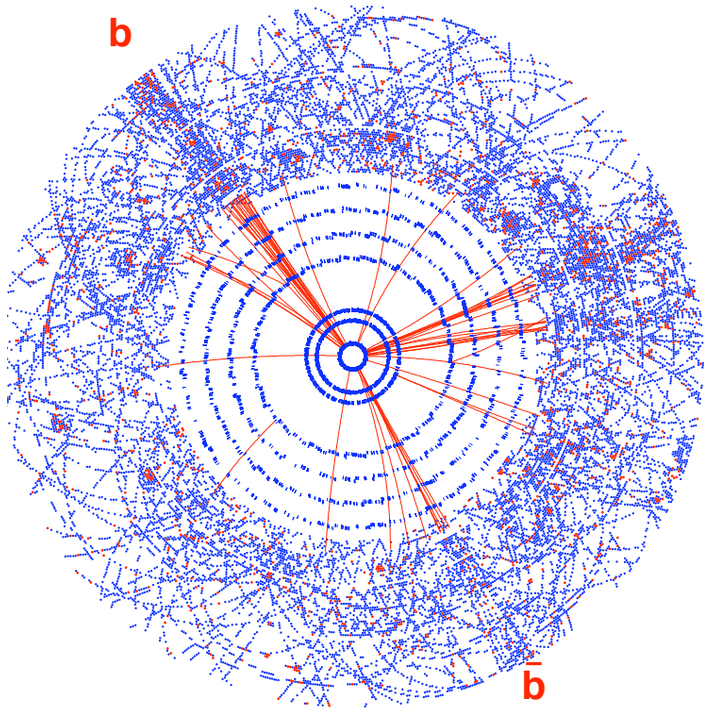


- Understanding of single inelastic collisions is essential.
- High-luminosity environment: can have up to 23 – 25 minimum bias pp collisions per bunch-crossing, ie ~1000 extra tracks!
- SLHC: from 2017(?), luminosity 10x greater than design value ($L_{SLHC} = 10^{35}\ cm^{-2}\ s^{-1}$)
  - higher event rates
  - better statistics & signal significance
  - sensitivity for smaller cross-sections
- Understanding multiple pp collisions will be essential for most of the discovery channel both in the Higgs and Supersymmetry sectors!

Summary

- **The search for "New Physics" at the LHC will begin with the understanding the detector and the hadronic environment in LHC collisions.**

- **Several QCD studies are being designed to take advantage of the data as it becomes available at the LHC** (potentially the first physics papers!)**.**
  - Most measurements can be "adapted" to different colliding energies
  - Global characterization of LHC collisions: minimum bias measurements

- **ATLAS is not only exceptionally well designed to find new physics (ie. Higgs and SUSY) but will also deliver very precise and detailed measurements of the entire event through its tracker and calorimeter (including low-p_T tracks).**

- **"Early" measurements ≠ "Easy" measurements!** Remember: brand new physics environment & new technologies.

Backup

Planned measurements for minimum bias interactions

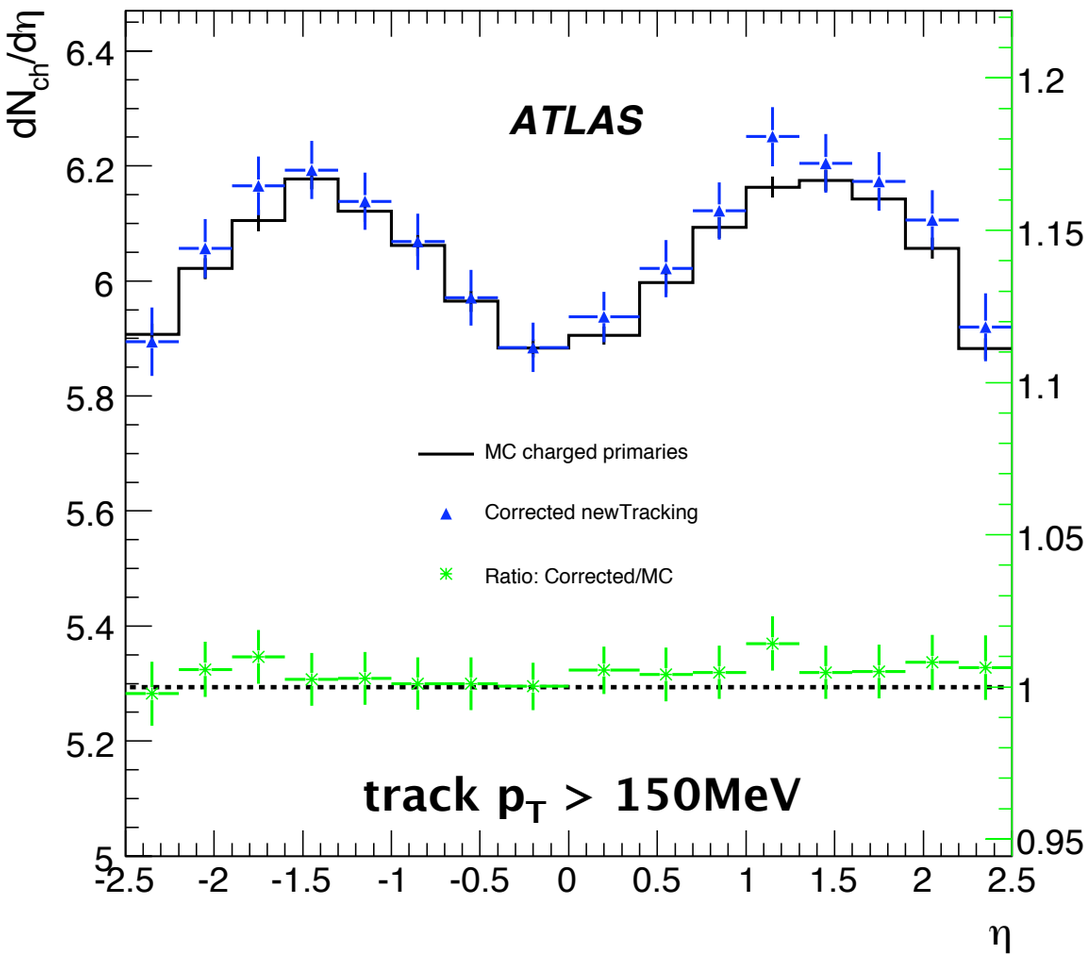
- At the LHC, studies on minimum-bias and the underlying event **are planned to be done early on**.
  - Charged particle multiplicity $dN/d\eta$ and dN/dp_T : ~10K events (triggered)
  - Charged particle multiplicity distributions (KNO) : ~400K events
  - $\langle P_T \rangle$ vs n_{chg}: ~1M events
  - UE distributions (E_T up to 150GeV) : ~10M minimum bias events

Global characteristics of LHC collisions: minimum bias events

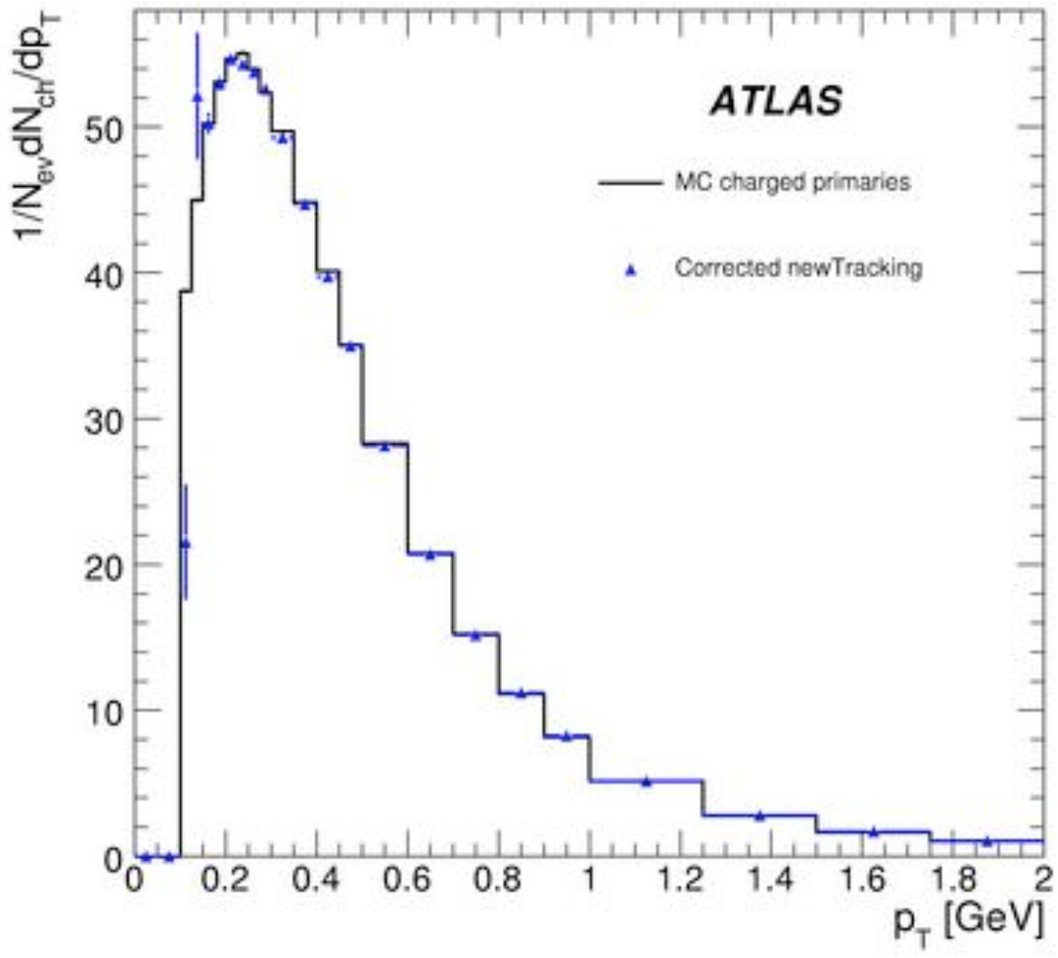
University of Glasgow

- physics with < 1 pb^{-1}

Charged particle density in pseudorapidity



p_T spectrum of charged particles



ATLAS Collaboration, *Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics,* CERN-OPEN-2008-020, Geneva, 2008, to appear.