Minimum Bias and Underlying event studies at CMS

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on behalf of the CMS QCD group

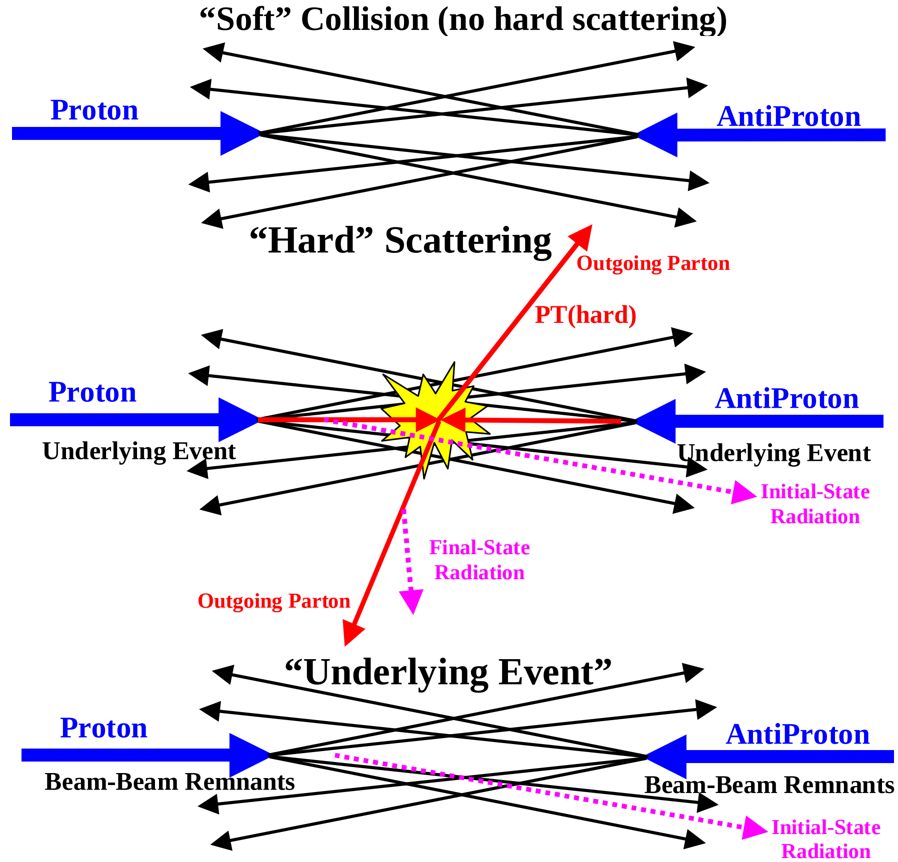
DIS09: XVII International Workshop on Deep-Inelastic Scattering and Related Subjects

Why Min Bias data?

- Typical p-p collision free of non-collision background
  - Dominated by low pt QCD processes
  - Also σ_{nd} ~2/3 σ_{tot}, = 75 mb
- At High lumi, pile up will consist of many min bias events

$$< N_{\text{int}} >= L_{inst} \cdot \sigma_{tot} / f \approx 19$$

- Soft component superimposed on hard scatters (UE event) is not identical to MB but has same phenomenology



Model multi-parton interactions and its interplay with PDFs, parton showers, beam remnants and hadronisation across 2 orders of magnitude in sqrt(s) in combination with as many different hard processes and in as many relevant observables possible

MPI Models and tunes

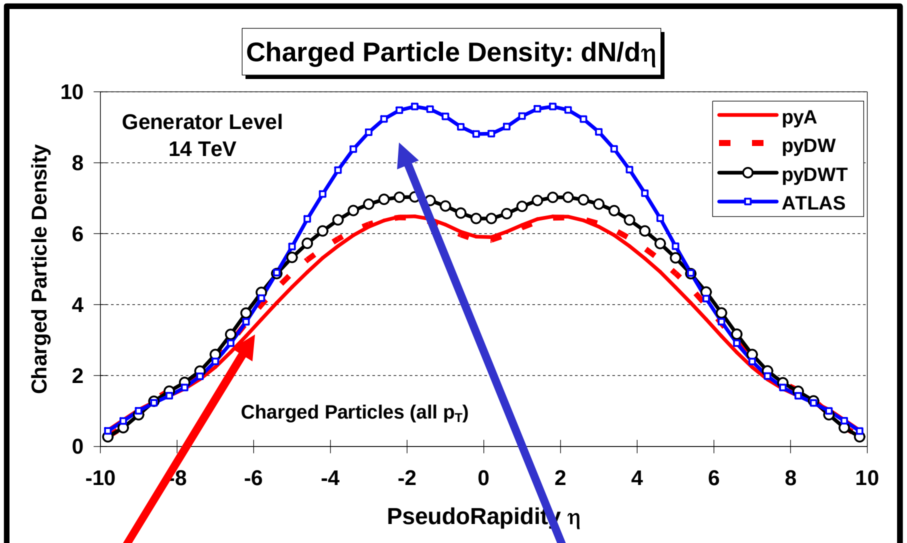
T. Sjöstrand and M. Van Zijl, Phys. Rev. D 36 (1987) 2019

Extensive studies by Rick Field et al. in CDF using Tevatron data

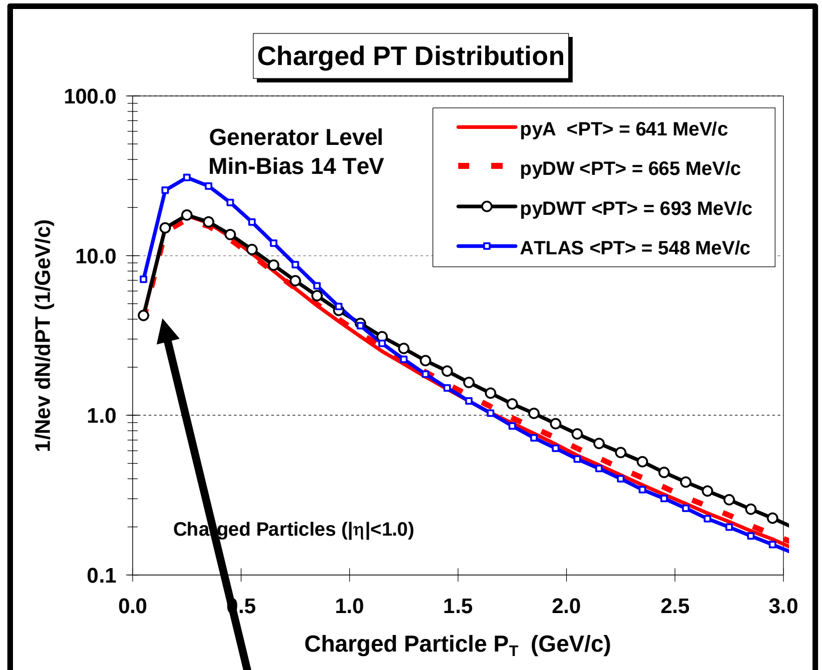
http://www.phys.ufl.edu/~rfield/cdf/

- **Pedestal effect: amount of MPI increases with P_T scale of hardest scatter**
- **Can not be explained by tuning up the Initial state showers**
- **Model with varying impact parameter of 'cored' hadron densities works best**
- **$dN_{ch}/d\eta$ in UE is at least 2x that of soft min bias collision**
- **MPI depend sensitively on PDFs**
- **UE is similar in Z, W prompt γ and dijet events**
- **Many models and tunes agree at Tevatron energies, but diverge at 14 TeV**

LHC extrapolations



R. Field et al., CMS NOTE 2006-067



TuneA
- CDF RUNI tune on UE
- Double core MI model
- Pythia 6.2+CTEQ5L

Tune DW
- Includes DY data
- D0 dijet $\Delta\phi$

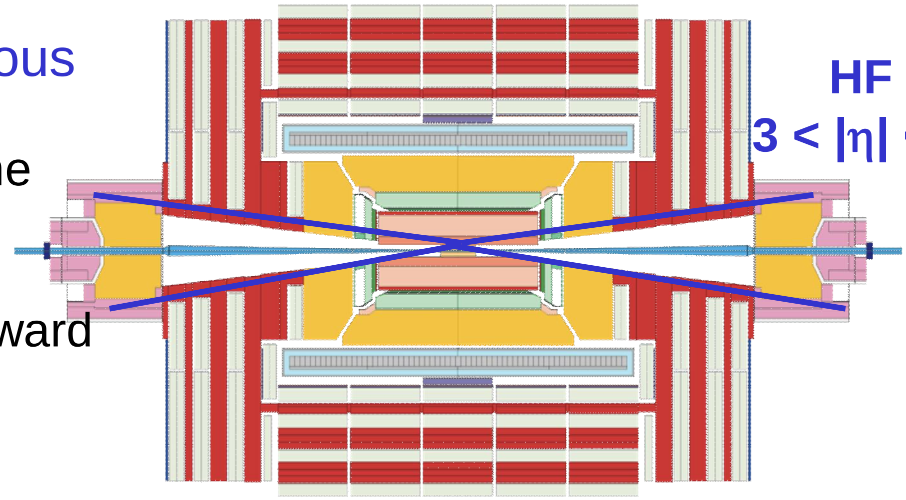
ATLAS tune
- A. Moraes et al.
- MB & UE over large $\sqrt{s}$
- Pythia default energy evolution of p_{t0}

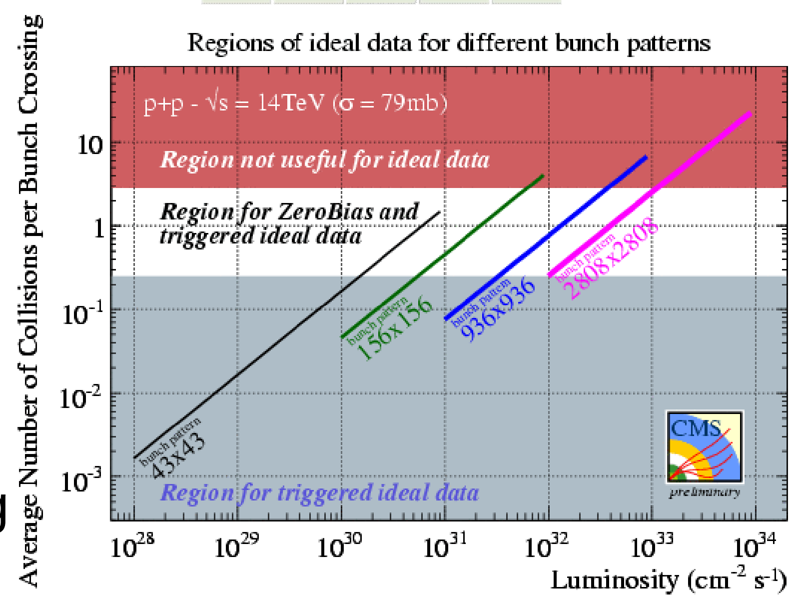
Tune DWT
- Like tune DW
- Same energy evolution as ATLAS

Other tunes exist!

CMS min bias data

- Several level 1 (hardware trigger) strategies depending on instantaneous lumi:
  - Zero bias: beam bunch crossing time
    100% efficient for all data, but not effective at startup conditions
  - Min bias HF single: single sided forward hadron calorimeter
    efficiency: 81% non diffractive
    15% diffractive
  - Min Bias HF double: double sided forward hadron calorimeter
    efficiency: 47.5% non diffractive
    0.6% diffractive
  - Zero bias + 1 Pixel Track: at 900GeV
    efficiency: 99% non diffractive
    ~60% diffractive
- 'Ideal data':
  One single collision per bunch crossing (no pile-up)

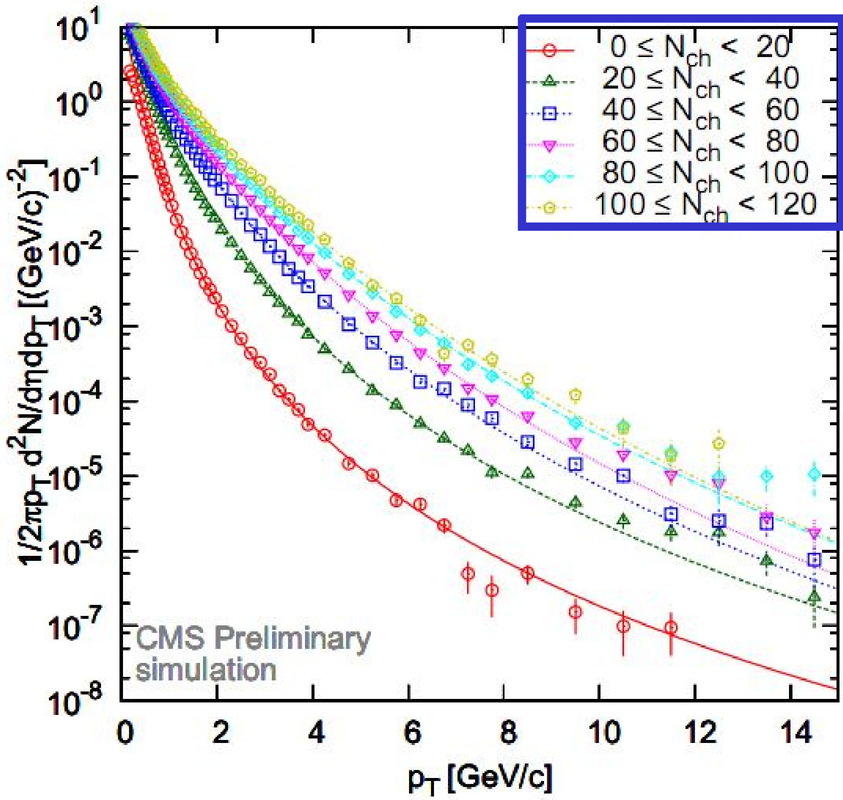




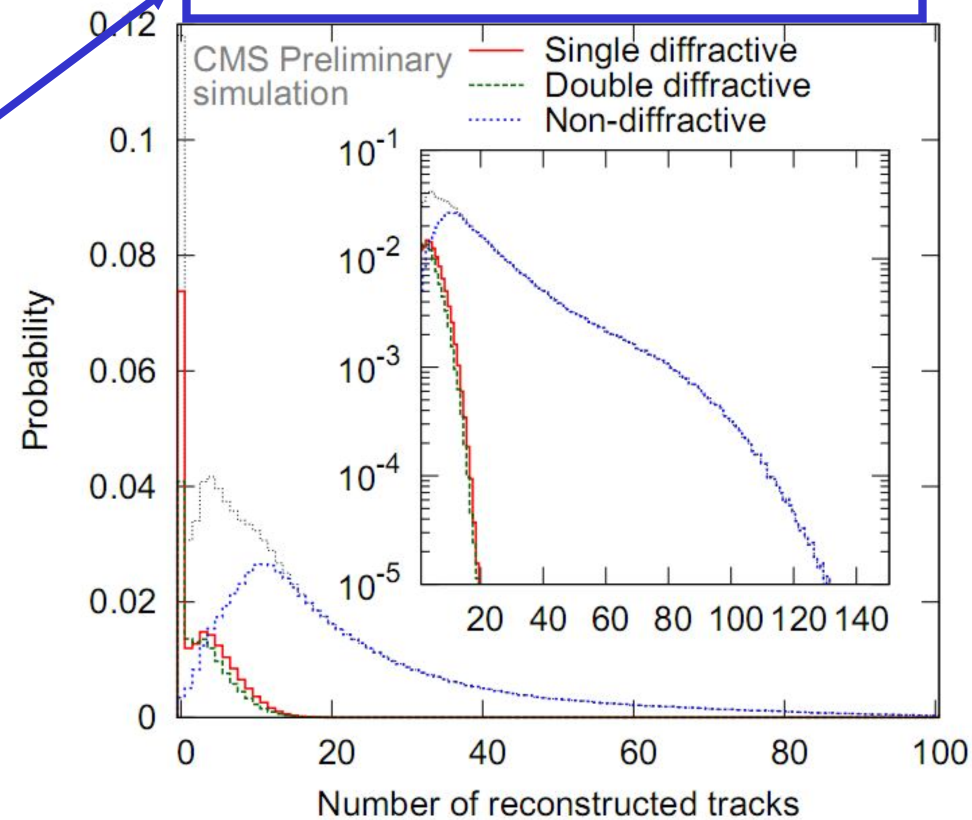
CMS PAS QCD_07_002

CMS min bias multiplicities

p_t spectrum in various multiplicity bins



Number of reconstructed tracks

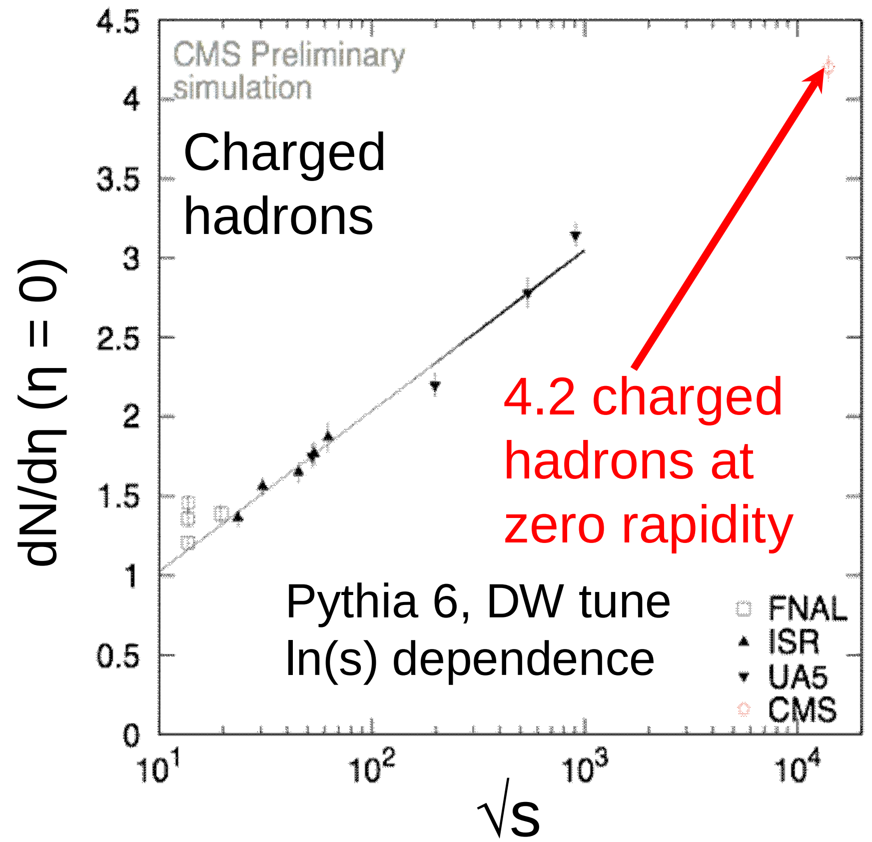


Extend p_t range of track reconstruction to reduce extrapolation uncertainties to low p_t
Proto-tracks based on pixel detector hit triplets extend reconstructed p_t range to p_t>100 MeV

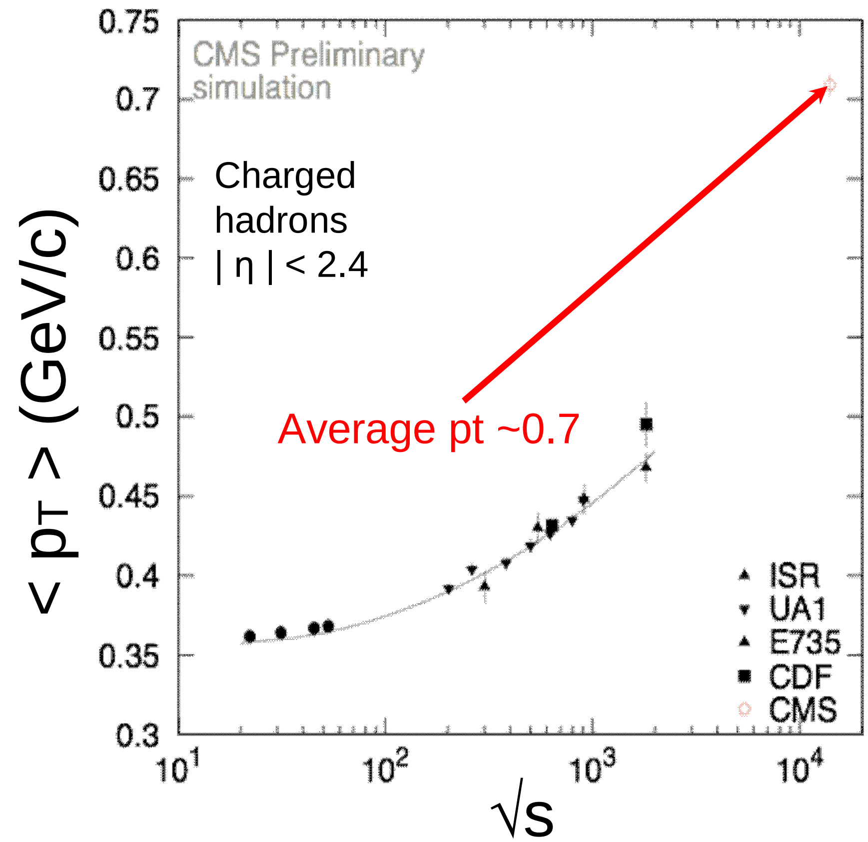
More details in single and identified particle spectra in Luca Mucibello's talk!

Energy evolution

<u>*Multiplicity in central region :*</u>

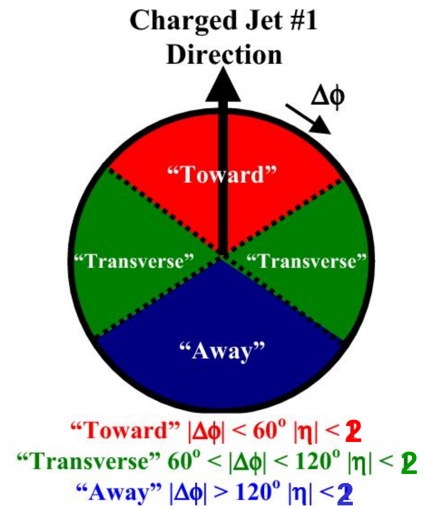


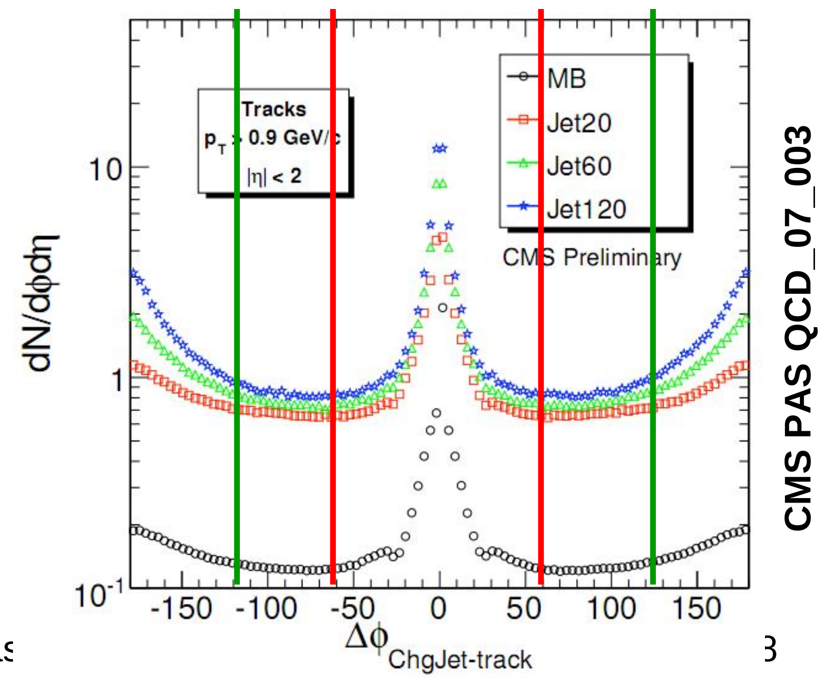
<u>*Average p_T :*</u>



Underlying event

- Analysis strategy builds on Tevatron experience (R. Field e.a.)
- Combination of MB and jet triggers based on leading calo jet
  - P_T(calo) > 20, 60, 120 GeV/c
- Charged jets: iterative cone with R=0.5 applied on charged particles with p_t >0.5 GeV/c and $|\eta|$<2
  - Standard CMS track reco (pt > 0.9 GeV/c) adapted and re-optimized (50% more charged tracks)
  - Startup alignment precision taken into account
- 3 main regions of interest wrt leading charged jet: toward, transverse, away
- 2 main density observables in each region:
  - Charged particle density: $dN/d\eta d\phi$
  - Scalar sum of charged p_t: $dp_t^{sum}/d\eta d\phi$



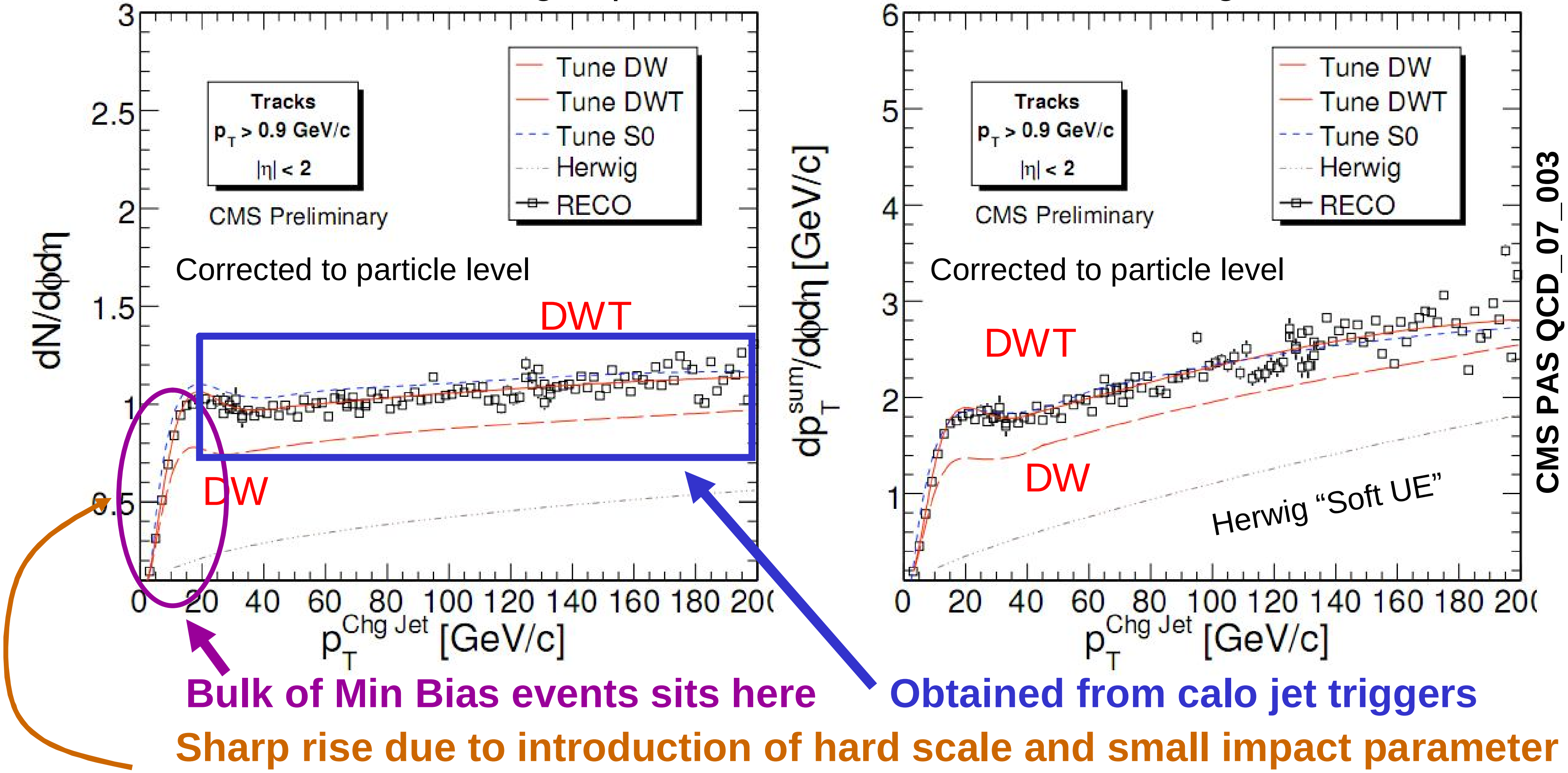


CMS UE observables

$\int L\,dt = 100\ pb^{-1}$

Standard tracking with $p_t > 0.9$ GeV

Charged particle densities in Transverse region



Bulk of Min Bias events sits here

Obtained from calo jet triggers

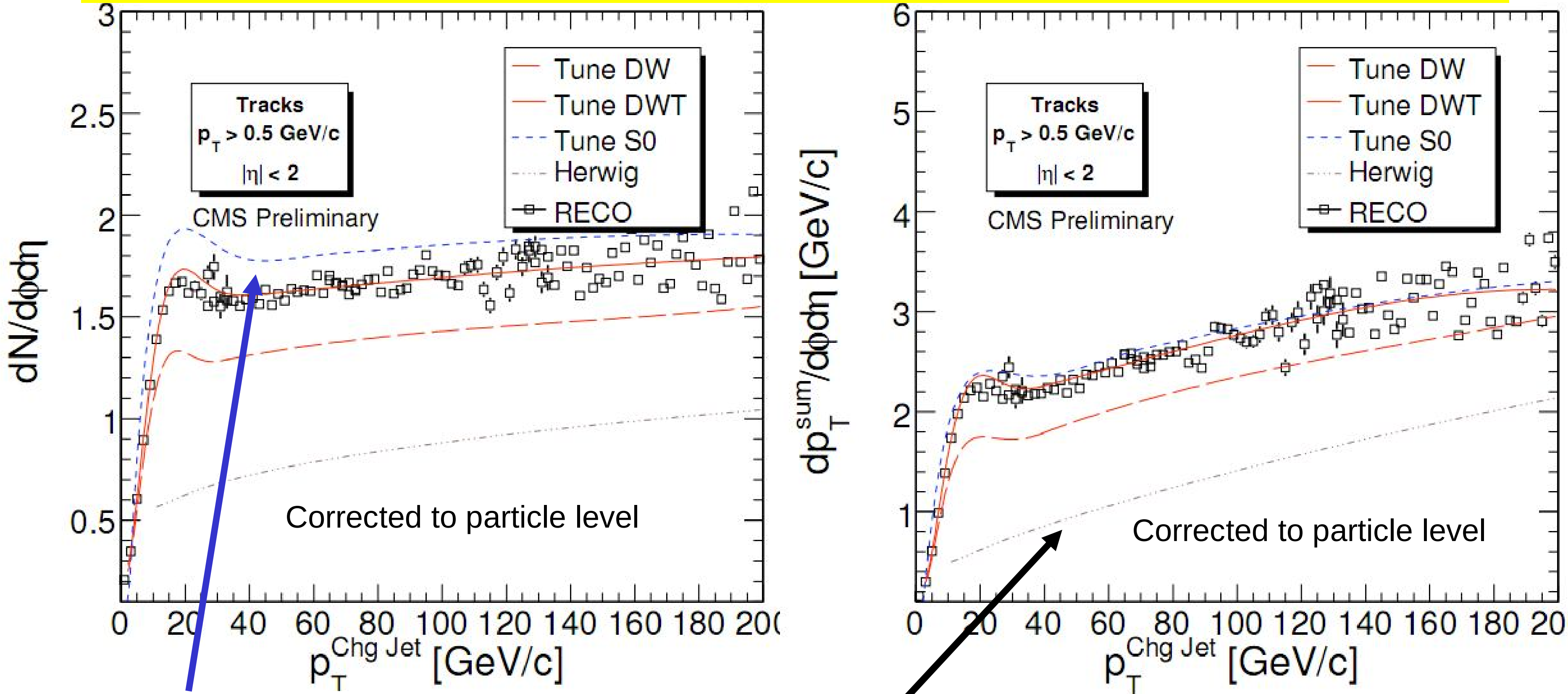
Sharp rise due to introduction of hard scale and small impact parameter

Saturating at P_T^{ChgJet}~10 GeV, then smooth rise due to more ISR

CMS UE observables

$\int L\,dt = 100\ pb^{-1}$ Charged partcile densities in Transverse region

Significant improvement in sensitivity when extending tracking to $p_t > 0.5$ GeV



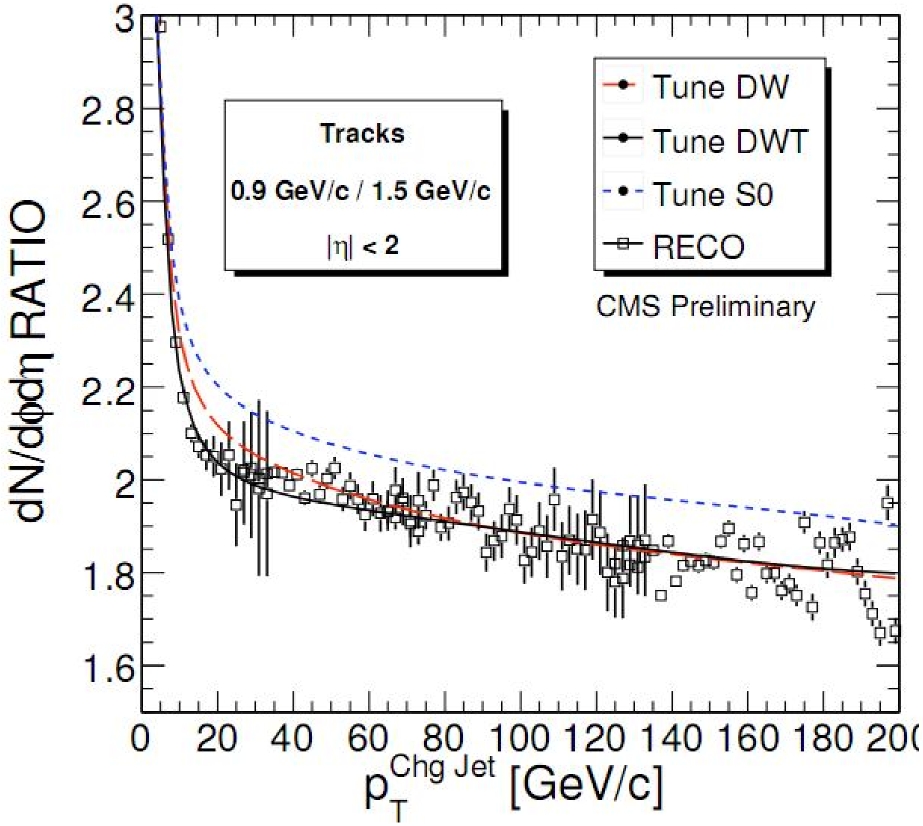
CMS PAS QCD_07_003

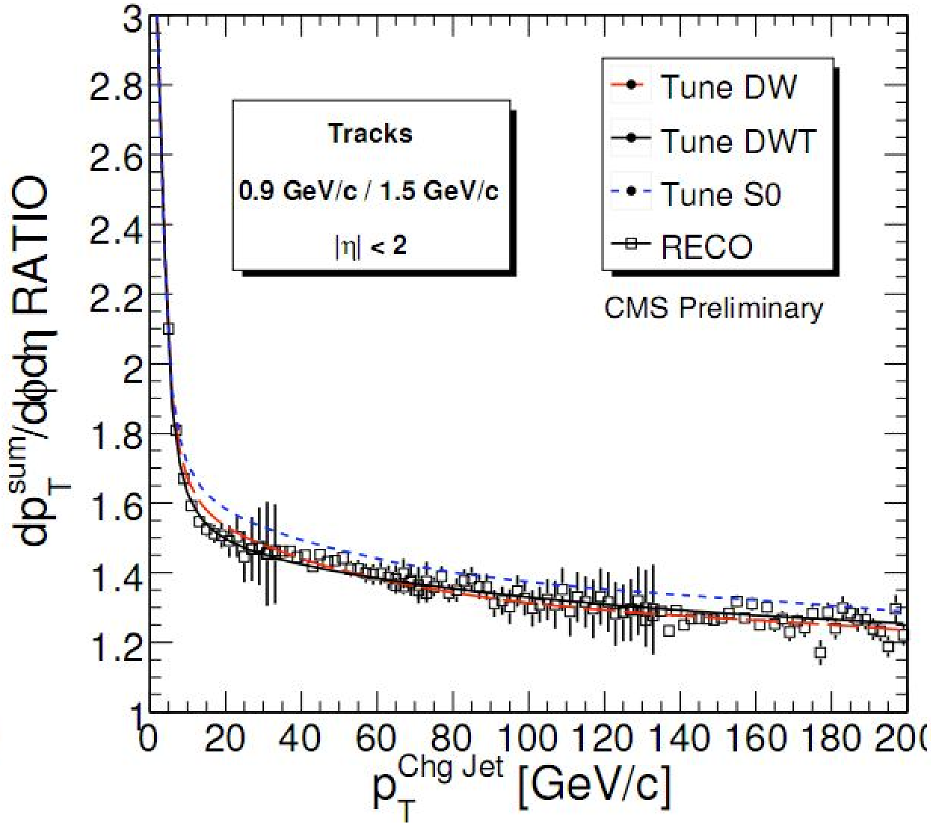
S0 tune
- **Pt ordered Pythia showers**
- **New MI model**
- **Color reconnection model**
- **Tuned to agree with Tune A (CDF data**

HERWIG without MI
- **Cluster fragmentation**
- **Explicit angular ordering**
- **NO Multiple Interactions reference point**

Density ratios

- Ratio of density profiles using tracks with pt>0.9 GeV/c wrt. tracks with pt>1.5 GeV/c
- Unsensitive to identical correction factors for these subsets of tracks
- Can be used to compare with particle level generator outputs





Conclusion

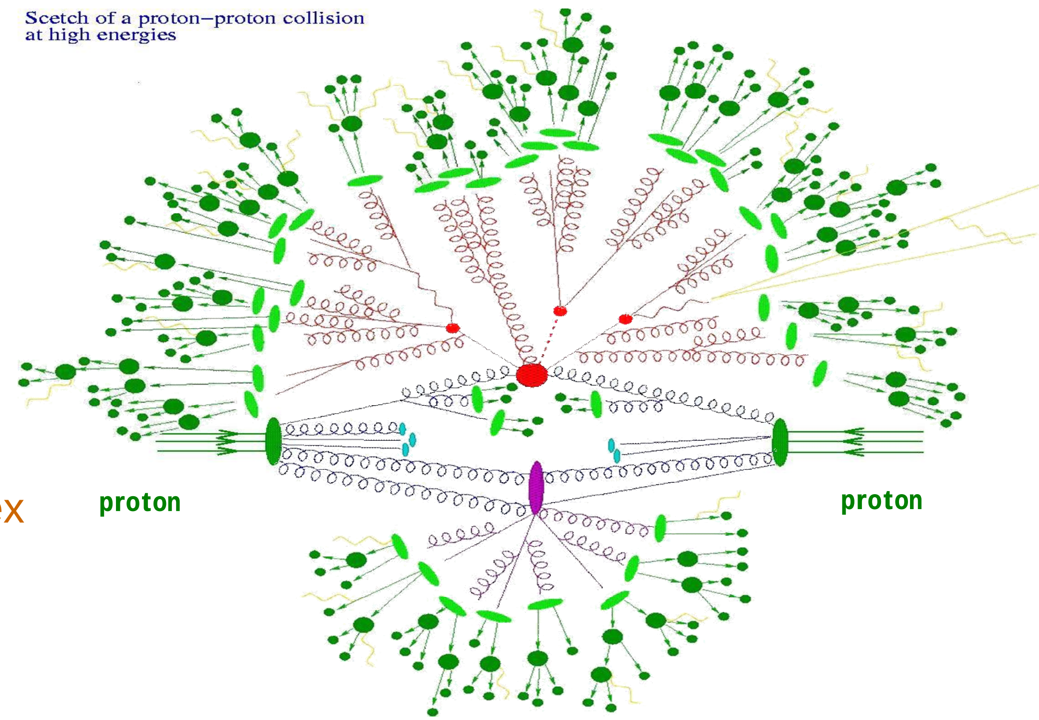
- CMS had several zero bias & min bias trigger menus at hand with efficiencies ranging from 100% - 48%
- CMS has approved analyses for ‘standard’ Min. bias and UE measurements
  - Include deep level of understanding of our tracking and track detector performance
- Will take advantage of several energy and luminosity scenarios: 900 GeV, 10 TeV and 14 TeV at 10^{27}-10^{34} cm^{-2} s^{-1}
- New complementary measurement ideas are being tested (DY, γ+3jets, correlations, ...)
- Many recent initiatives started on tuning of many models, but as T. Sjöstrand says:

  As to tunes, it feels appropriate to remind of Mark Twain's "everybody talks about the weather, but nobody does anything about it."

The Long version

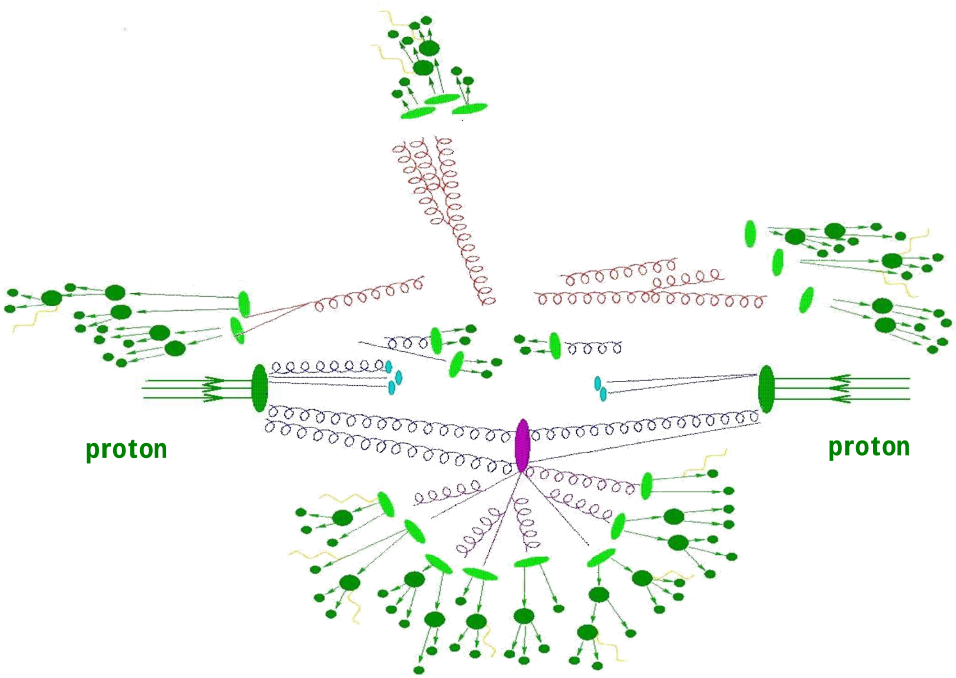
Min bias vs. underlying event

- Min bias event (MB): a typical p-p collision free of non-collision background
  - Dominated by low pt QCD processes
- Min bias trigger: trigger that samples all p-p interactions in their natural composition
  - Based on minimal hadronic activity originating from one vertex
  - Same efficiency for all non diffractive inelastic processes (~2/3 $\sigma_{tot,}$ = 2/3 * 100 mb)
- Pile up: At LHC, many MB occur in one bunch crossing



$$< N_{\text{int}} >= L_{inst} \cdot \sigma_{tot} / f \approx 19$$ At nominal LHC luminosity

Min bias vs. underlying event



Both MB and UE can be treaded consistently by a small number of tunable models

Underlying event (UE): all particles that are not produced by hard scatter between two partons in one p-p collision

- Initial & Final state showers
- Beam remnants
- Multiple parton interactions

UE is not a MB event superimposed on high pt parton-parton scatter

- connection between multiple parton interactions and impact parameter (or Pt scale)

  'Pedestal effect'
- correlations due to QM, momentum & flavor, rescattering

Why min bias at LHC

- Fundamental understanding of hadron-hadron interactions and multiparticle production mechanisms
  - What can be safely factorised
  - Color Flow
  - Correlations & fluctuations
  - Rescatters
  - Connection between non-diffractive, diffractive, heavy ions
- Monte Carlo modeling and tuning:
  - Many models agree equally well with some datasets
  - Some models more thoroughly tested than others
  - Large extrapolation uncertainties to 14 TeV
- As we probe smaller x, do we enter new regimes ?
  - Connections with PDF's
  - saturation
  - diffraction
- Some 'high-profile' measurements are sensitive to underlying event behavior
  - missing Et, jet veto, forward jets, rapidity gaps, ...
- As commissioning tool for our new detectors
  - Occupancy, noise, calibration, alignment

What needs to be modeled

- P-P interaction is often (unrightfully) factorised in
  - Hard central interactions (pQCD: matrix el)
  - Parton showers (pQCD: DGLAP + P_t generation)
  - Structure functions (LO, NLO, one parton vs multi-parton)
  - Fragmentation (models, jet universality)
  - Beam remnants (pQCD + models)
  - Multiple parton interactions (models)

Level of understanding

Of key importance when trying to understand MB data
But unmistakeably related to other bullets in this list

Multiple Parton interactions

- Realisation from experiment: ISR, Tevatron, ...
  - Some p-p collisions exhibit 2 or more (semi-) hard parton-parton scatters
- Realisation from theory: below pt scale of ~2GeV the parton-parton cross section exceeds the total p-p cross section

Amount of parton-parton interactions
Is Poisson process with mean

$$< N_{\mathrm{int}} >= \frac{\sigma_{\mathrm{int}}(p_{t_{\mathrm{min}}})}{\sigma_{nd}}$$

Modeling MPI

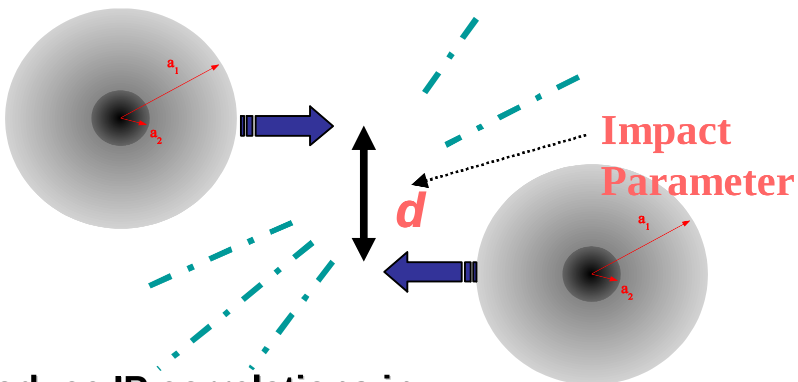
Basic idea   T. Sjöstrand and M. Van Zijl, Phys. Rev. D 36 (1987) 2019

- Theoretical fact: differential 2→2 cross section diverges as $p_t \to 0$
- Solution: Introduce cut-off p_{t0} to ensure finite and calculable results

→ Screens color and evolves with center of mass energy as s^{α}

$$\frac{d\hat{\sigma}}{dp_t^2} \propto \frac{\alpha_s^2(p_t^2)}{p_t^4} \rightarrow \frac{\alpha_s^2(p_t^2 + p_{t0}^2)}{\left(p_t^2 + p_{t0}^2\right)^2}$$

Pythia MPI Model with Varying impact parameter between the colliding hadrons: hadronic matter is described by double Gaussians



Introduce IP correlations in Multiple Parton Interactions → **Describe Tails!**

- Independent MPI: Poisson process, with minimal 1 interaction
- Make Poisson broader by impact parameter based average number of MPI
- All generators use this model, but differ in choice of p_{t0} and subsequent showers
- Currently only way to get N_{ch} and p_{tch} correct over wide energy range

Tuning (his)tory

Tune A

- R. Field et al. Round 2002
- CDFI “Evolution of charged jets”
- Pythia 6.2 and CTEQ5L
- Tunes MI model and ISR params
- Min bias and jet data for UE
- Predicts enough particles, but too little energy in UE
- Agreed with Tevatron RUNII as well
- N_{ch}-<p_t> correlations due to color connections

Tune AW

- Round 2005, builds on A
- Problem with lower end of PT spectrum of Z bosons
- Changes in intrinsic KT and ISR parameters
- MI parameters not affected
- More ‘complete’ tune than A

Tune DW

- summer 2006, Builds on AW
- Includes D0 dijet $\Delta\phi$ results
- Change in one ISR param

Tune DWT

- ATLAS optimizes tune for sqrt(s) dependence
- Tune DW modified to give same energy dependence

Tune S0,S1

- New Pythia showers (6.4) ordered in p_t rather than m^2
- Modified MI model that includes ISR showers
- Color reconnection models driven by top mass systematics studies
- tuned to agree with tune A on limited observables

Recent MI workshop in Perugia

Workshop's conclusions:

Big dichotomy in pp Physics

✓ Traditional MB & UE measurements and their impact on MC/MPI Tuning (unavoidable at the LHC start-up)

✓ Conceptual progress, Ideas for a MPI factorization theorem, New MPI models with increasing level of correlation effects, double scattering and complementary σ_{eff} measurements with mini-jets.

✓ Slowly moving toward a scenario where these different measurements can be used at the same time to constraint the models

HI, pp and diffractive communities clearly still speak different languages (although they often refer to the same physics processes).

Don't forget that here we should focus on MPI at the LHC…

✓ For example: How rapidity gap suppression connects to MPIs ?

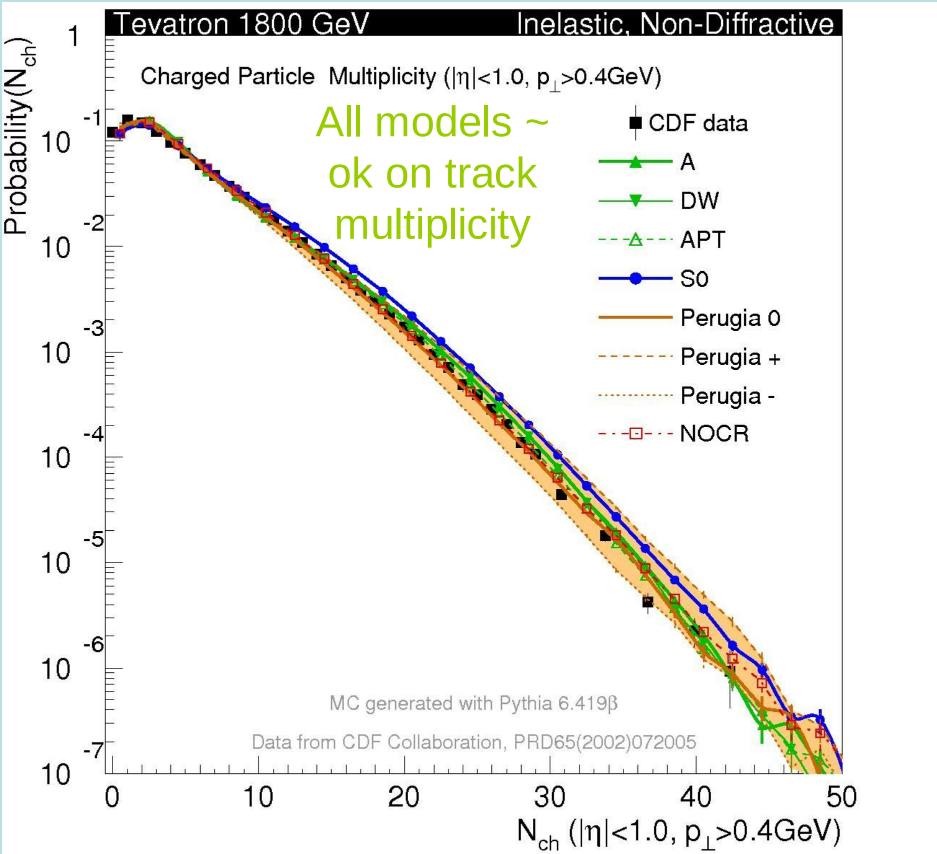
✓ But this is precisely why we want to have these MPI@LHC workshops

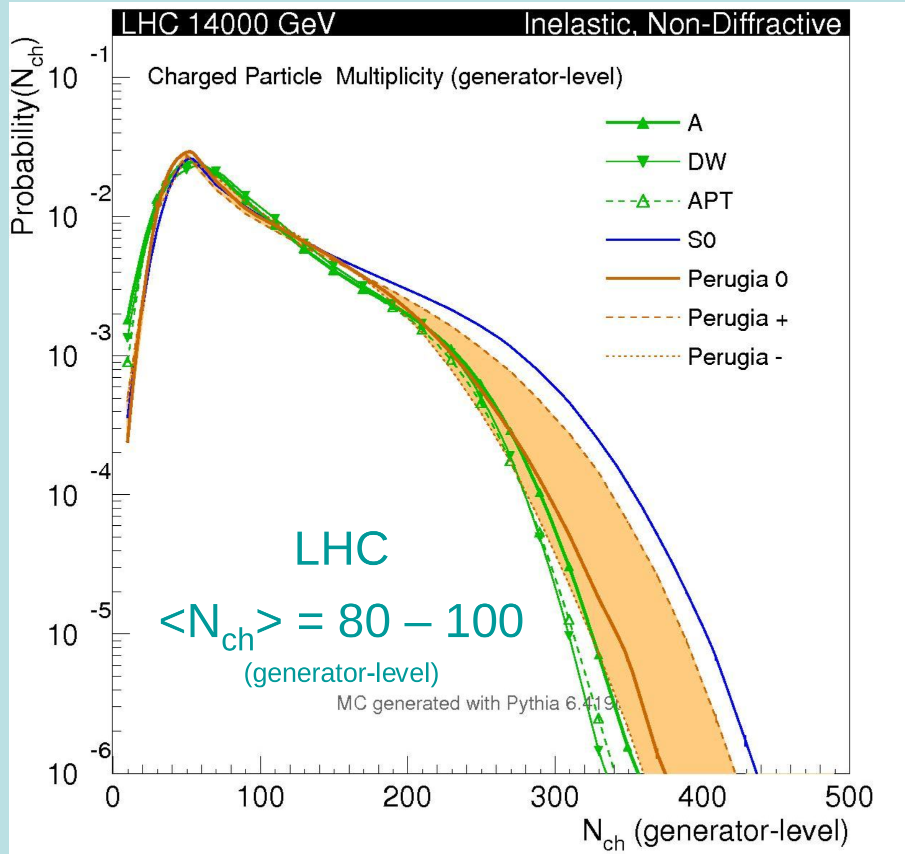
http://www.pg.infn.it/mpi08/

Charged particle multiplicities

P. Skands: Perugia MPI@LHC'08 workshop

- Perugia tunes of new model, using Tevatron 630/1800/1960 GeV data
  - + min/max variations
  - + LEP tuned fragmentation pars from Professor, courtesy H. Hoeth (see talk)

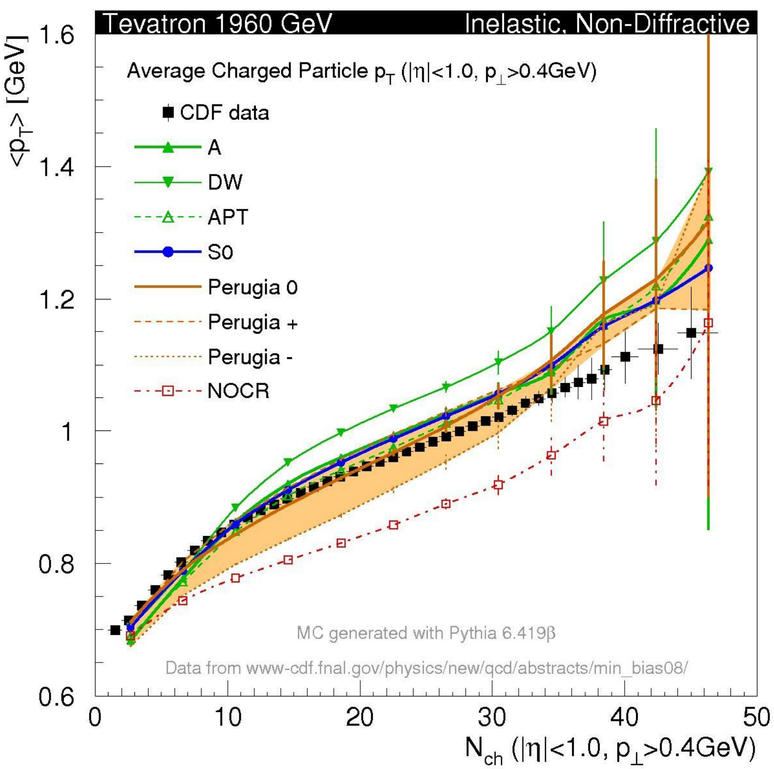




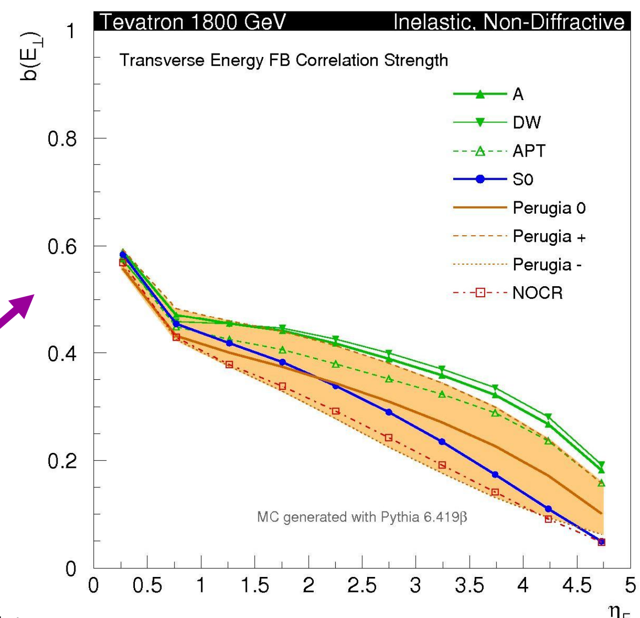
Data from CDF, Phys. Rev. D 65 (2002) 072005

Need to cover

N_{ch} vs $<p_t>$



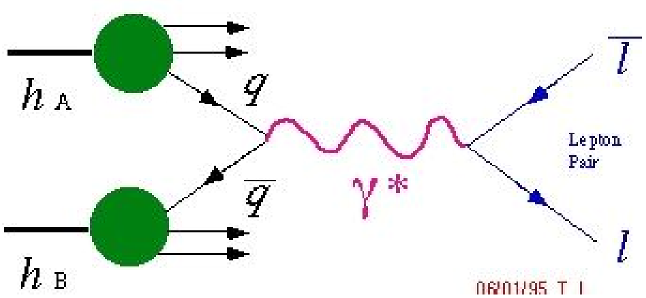
- Sensitive to new p_t ordered shower scheme in Pythia
- Seems to favor significant color reconnections
- Large extrapolation uncertainties at high N_{ch} and high $<p_t>$

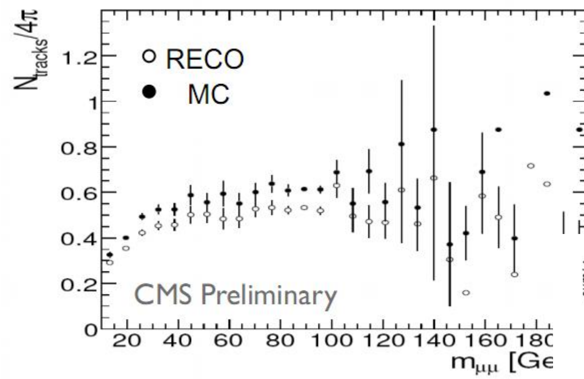


Forward-backward correlations!

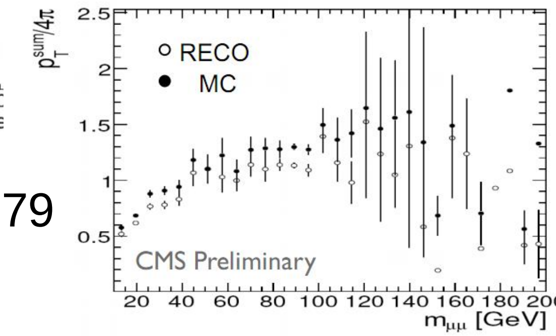
Other observables

DY or Z^0 events





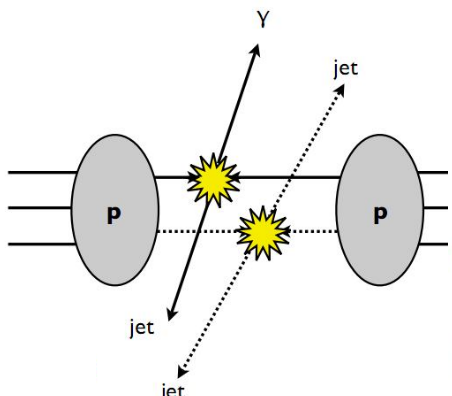
Similar densities in transverse region



CMS Physics TDR: J. Phys. G: Nucl. Part. Phys. **34** 995-1579

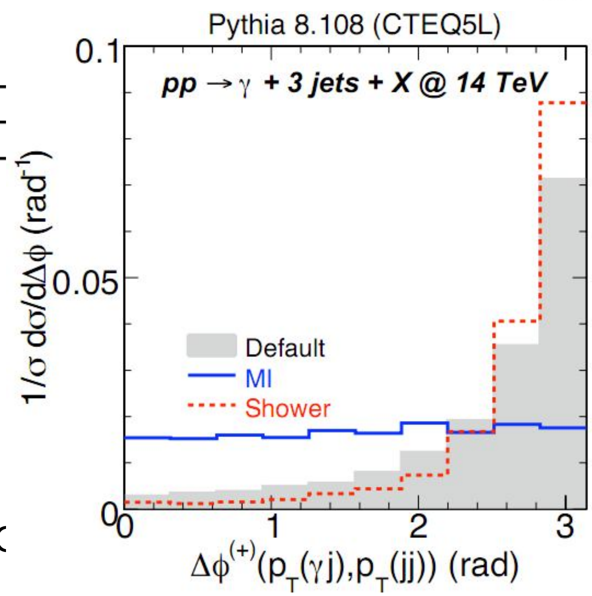
Double-parton-scattering in γ+3 jet

(or same sign W boson production)



Best balanced pair given by:

$$\min\left(\frac{|\vec{p}_{Ti}+\vec{p}_{Tj}|^2}{|\vec{p}_{Ti}|+|\vec{p}_{Tj}|}+\frac{|\vec{p}_{Tk}+\vec{p}_{Tl}|^2}{|\vec{p}_{Tk}|+|\vec{p}_{Tl}|}\right)$$



Pythia Tunes

Parameter (PYTHIA v 6412+)	A	ATLAS	DW	DWT	S0
UE parameter 1 PARP(83)	0.5	0.5	0.5	0.5	1.6
UE parameter 2 PARP(84)	0.4	0.5	0.4	0.4	n/a
UE total gg fraction PARP(86)	0.95	0.66	1.0	1.0	n/a
ISR infrared cutoff PARP(62)	1.0	1.0	1.25	1.25	(= PARP(82))
ISR renormalisation scale prefactor PARP(64)	1.0	1.0	0.2	0.2	1.0
ISR Q^2 [illegible] factor PARP(67)	4.0	1.0	2.5	2.5	n/a
FSR model MSTJ(41)	2	2	2	2	(p_T − *ordered*)
FSR Λ_{QCD} PARJ(81)	0.29	0.29	0.29	0.29	0.14

Table 3.1: PYTHIA parameters, divided into main categories: UE (underlying event), ISR (initial state radiation), FSR (final state radiation), BR (beam remnants), and CR (colour reconnections). The UE reference energy for all models is PARP(89)=1800GeV, and all dimensionful parameters are given in units of GeV.