Characterization of underlying event in CMS experiment at LHC

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On behalf of CMS collaboration

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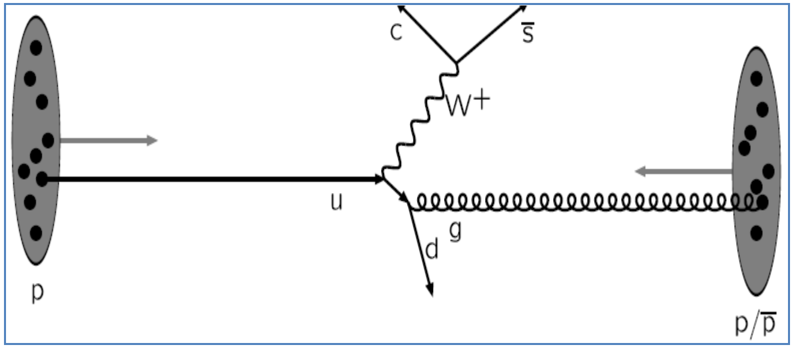
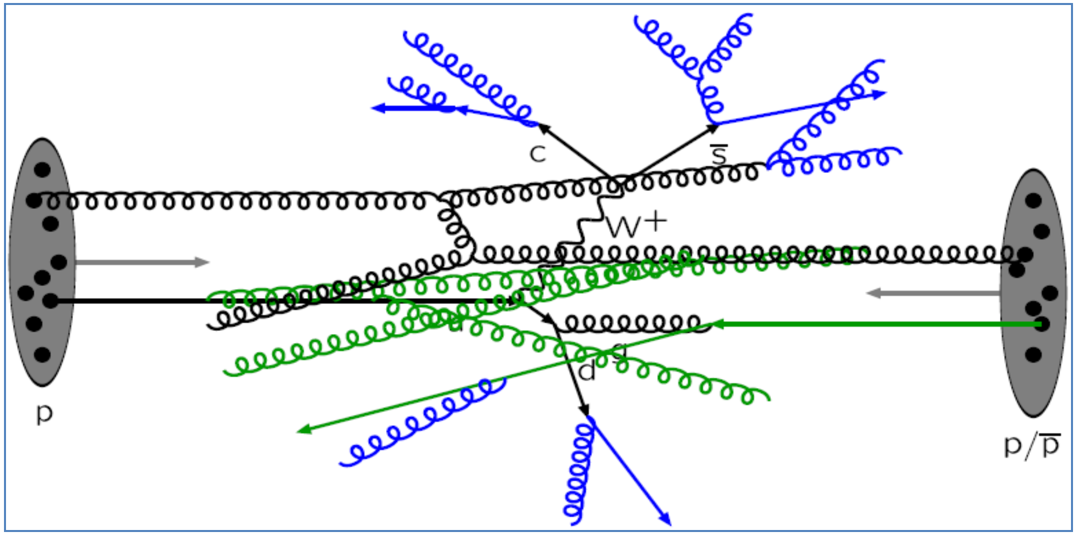
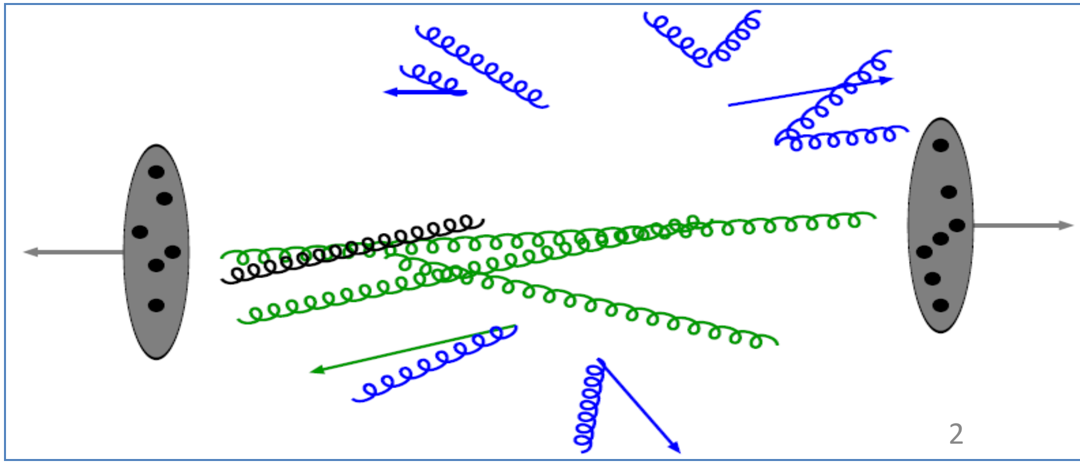
Hard collision and UE







Underlying event in hadronic collisions

Underlying event (UE): everything in single particle collision except the hard process of interest (may be hard or soft).

Components of UE:

- Initial and final state radiations (assuming only the leading order process is studied in the experiment!)
- Beam-beam remnants
- Multiple parton interactions

Charged multiplicity in minimum bias events at UA5, Tevatron experiments could be explained better by introducing the concept of multi-parton interaction along with parton shower + hadronization.

UE is essentially semi-hard interaction, with typical scale ~ 1-2 GeV (to be compared with soft interaction scale of Λ_{QCD} ~ 0.2 GeV)

➔ needs phenomenological models for description

➔ parameters in the models need adjustments

➔ ***TUNING* of monte carlo event generators**

Importance of UE in future

Any hard scatter process is essentially embedded with UE

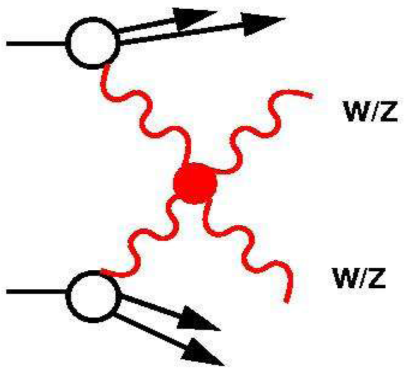
➔ *we need to have good idea of the activity for events at similar energy.*

In many interesting weak processes hard jets are not anticipated in the central region of the detector, eg.,

1. Search for Higgs produced in Vector Boson Fusion decaying to leptons
2. Vector boson scattering

→Jet veto efficiency is highly sensitive to the model of UE

→Minijets can also arise from uncorrelated multi-parton interactions



Isolation criteria of leptons, photon crucially depends on the activity in the environment they are in.

- It also acts as reference to hard p-p and heavy ion collisions.

Multiparton interactions

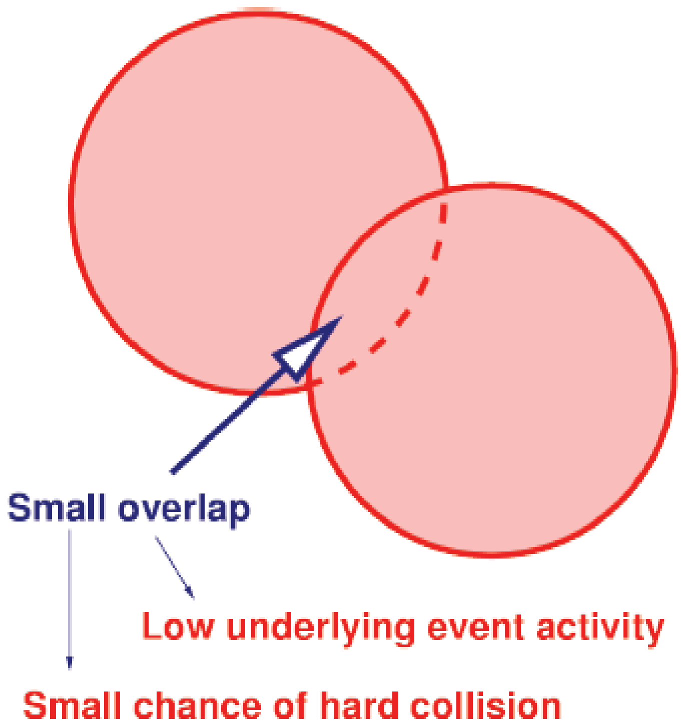
When two protons collide, the number of interactions (<n>) depends on the impact parameter (b)

➔hence the matter distribution inside hadrons is introduced.

Small b ➔ hard scatter, more interactions, ie, larger <n>

➔ more activity from underlying event than minimum bias process.

different models of UE corresponds to variations in matter distribution and other parameters



$$\sigma_{\mathrm{hard}}(p^2_{\perp\mathrm{min}}) = \int_{p^2_{\perp\mathrm{min}}} \frac{d\sigma_{\mathrm{hard}}(p^2_{\perp})}{dp^2_{\perp}} dp^2_{\perp}$$

$p_{T,min}$ is adjusted to fit experimental data.

UE inversely proportional to $p_{T,min}$

Multiple interaction parameters in Pythia

Extrapolation from lower energy ➔ $$p_{T0} = PARP(82)\left(\frac{\sqrt{s}}{\sqrt{s_0}}\right)^{PARP(90)}$$

MSTP(81)=1	multiple interactions
MSTP(82)=4	complex scenario + double Gaussian matter distribution
PARP(82)=1.8	$p_{t_{min}}$ parameter
PARP(84)=0.5	core radius: 50% of the hadronic radius
PARP(89)=1.0	energy scale (TeV) used to calculate $p_{t_{min}}$
PARP(90)=0.16	power of the energy dependence of $p_{t_{min}}$

	TUNE	PAPR(82)(GeV/c)	PARP(89)(TeV)	PARP(90)	PDF
Pythia 6 →	D6T	1.8	1.96	0.16	CTEQ6L1
→	Z1	1.932	1.8	0.275	CTEQ5L
Pythia8 →	tune 1	2.15	2	0.24	CTEQ5L
→	Tune 4C	2.085	1.8	0.19	CTEQ6L

Current CMS TuneZ2* : 1.927 1.8 0.225 CTEQ6L

Measurement of underlying event

Main observable: hadronic activity as a function of separation in azimuth $\Delta\phi$ between the leading *object* and any charged track.

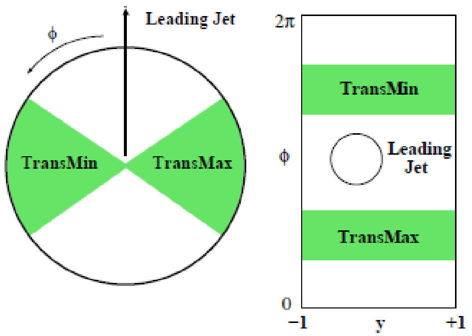
- study topological variation of activity in terms of sensitive variables:

1. density of charged particle multiplicity: $d^2N/d\eta\, d(\Delta\phi)$

2. density of scalar p_T sum: $d^2(\Sigma\, p_T)/d\eta\, d(\Delta\phi)$

3. average transverse momentum: $<\Sigma\, p_T>/<N_{ch}>$

- Angular regions defined wrt the hard object:



1. Away ($|\Delta\phi| > 120^0$) : hard-scattering component which balances the leading object

➔ away region will have effects of radiation

2.Transverse ($60^0 < |\Delta\phi| < 120^0$) : **best suited for UE studies**

3. Towards ($|\Delta\phi| < 60^0$) : can be suitable, as in case of Drell-Yan process, once the hard scattering component is completely removed by ignoring the leptons

CMS efforts for understanding UE

2 types of final states identified to pick up the hard interaction event

a) hadronic final state:

→ analysis based on jets reconstructed from charged tracks

→ event shape

b) Drell-Yan dimuon system with large enough invariant mass: $m_{l+l-} \sim M_Z$

→ UE is completely extracted by removing the muons from hard scatter

- Confine tracks within $|\eta| < 2$ or 2.4 and pT > 0.5 or 0.25 GeV/c
- Confine charged track jets $|\eta| < 1.9$, pT > 5 GeV/c

NEW

Only a limited flavour of wide range of topics studied:

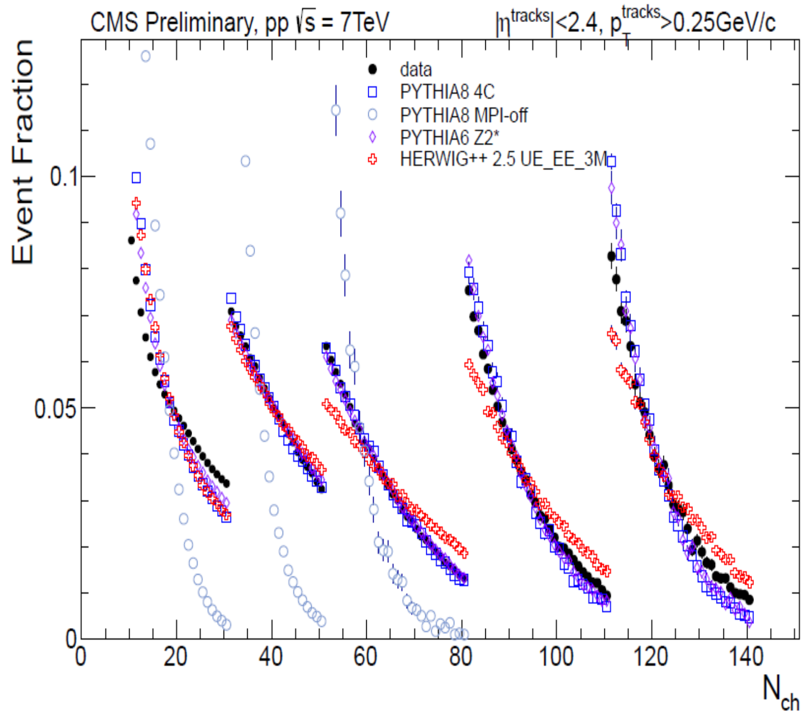
1) Activities as a function of multiplicity of charged tracks **(FSQ-12-022)**
2) Comparison of UE activity at different energies **(FSQ-12-020)**
4) Activities in forward rapidity **(FWD-11-003, JHEP 04(2013) 072)**
3) Strangeness production **(QCD-11-010)**
4) Drell-Yan events **(QCD-10-040, EPJC 72 (2012) 2080)**
5) Using transverse momentum of Z in DY process **(SMP-12-025)**

CMS Physics Analysis Summary (PAS), publicly available

Hard and soft particles as a function of particle multiplicity

CMS PAS FSQ-12-022

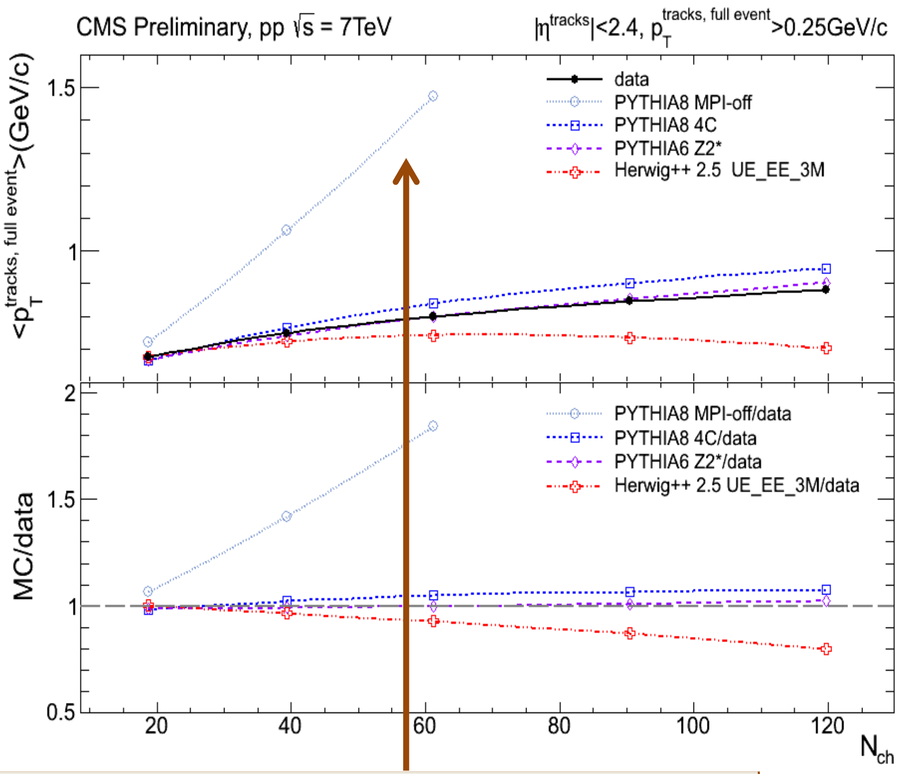
- Bulk properties of minimum bias events → reasonably described by Pythia.
- However differential distributions does not match data very well. *e.g.*,tail of charged particle multiplicity ➔ incomplete understanding of inelastic scattering ?
- Different mechanisms of multiparticle production in p-p collision can be probed via study of jets and UE properties as a function of particle multiplicity.

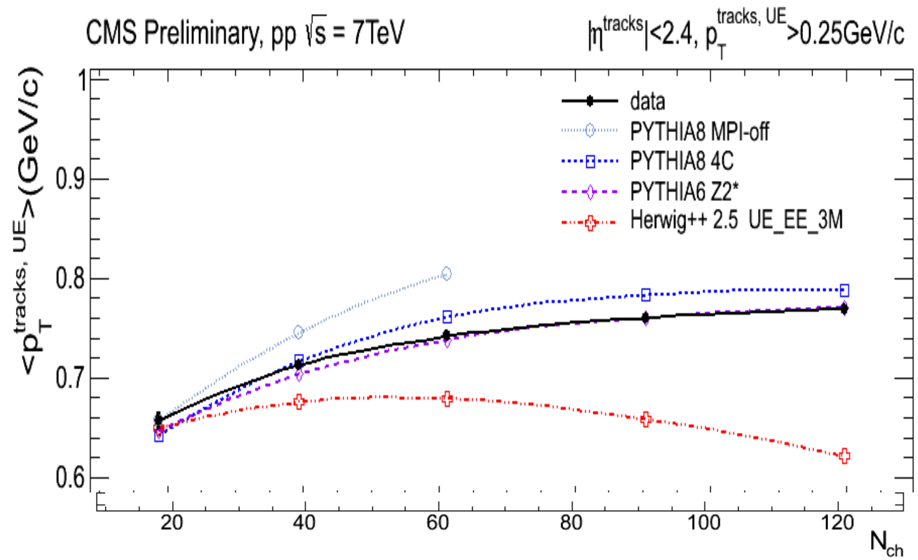


Charged particle multiplicity in 5 bins covering a range of multiplicity (similar to classification of centrality in heavy ion collisions)

- **Data are not described at all by MPI-off tunes.**
- **Pythia (semihard MPI modeling) is better than Herwig (softer MPI modeling)**

Average charged-particle p_T as a function of multiplicity

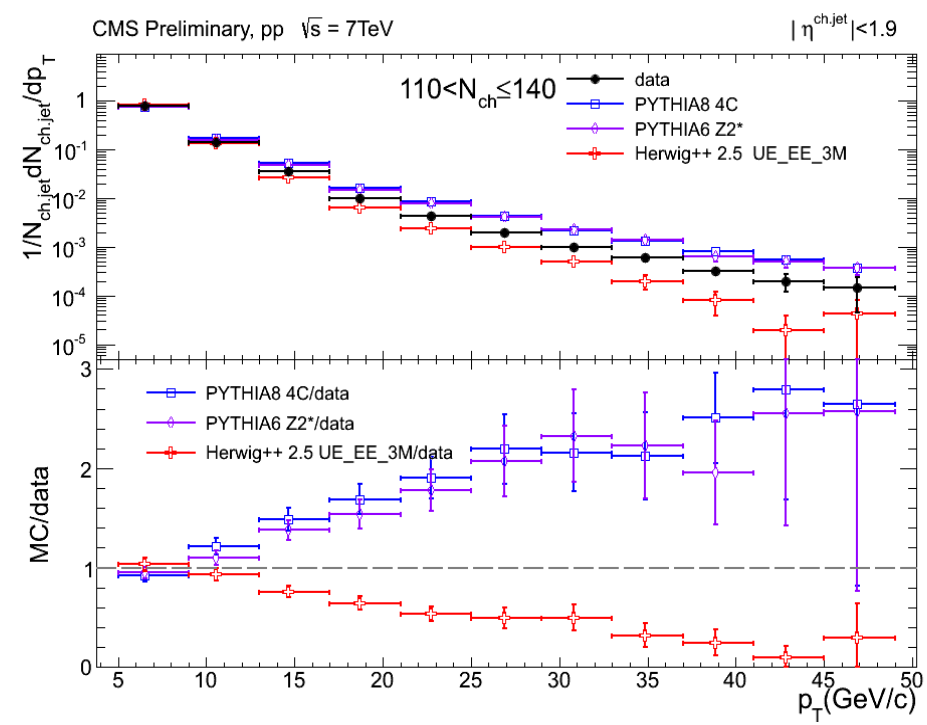




MPI has to be accounted for!

Herwig does worse job than Pythia in describing dependence of multiplicity.

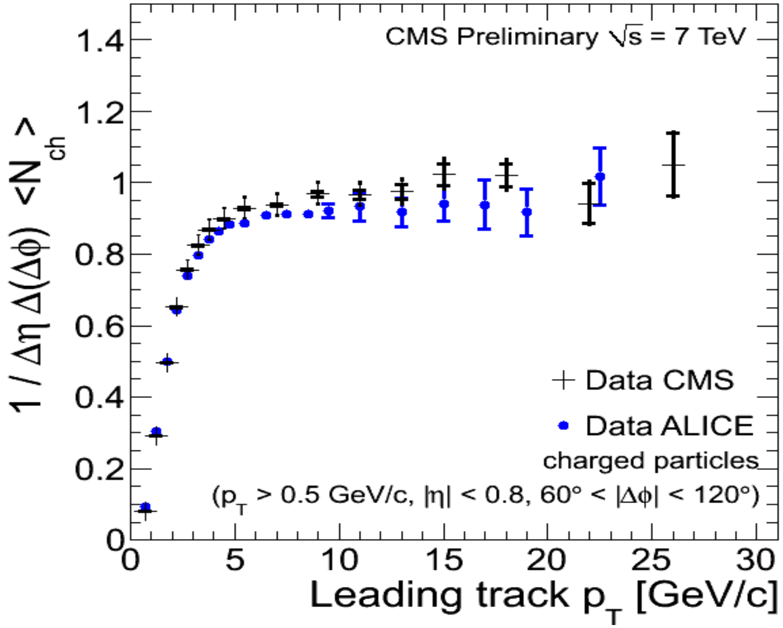
With increasing p_T the description of Pythia differs more from that of Herwig

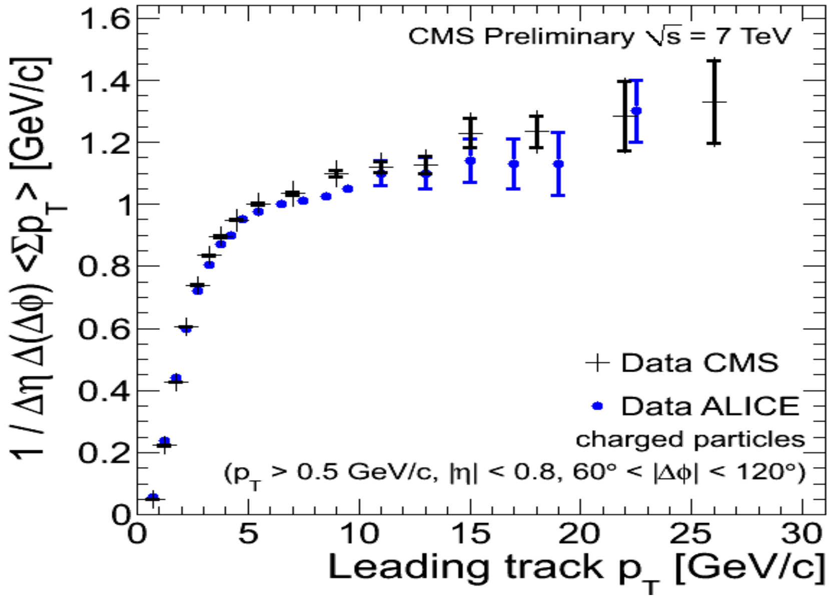


CMS PAS FSQ-12-022

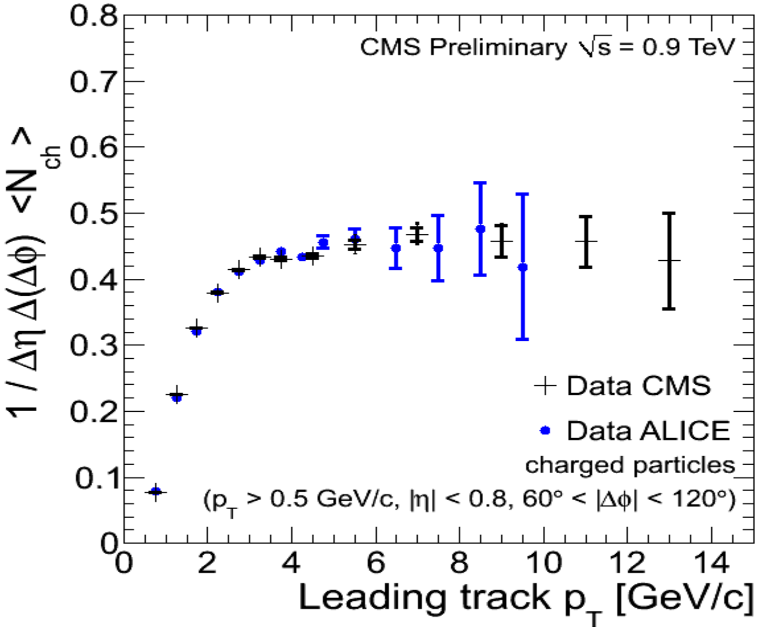
Comparison of CMS measurements with ALICE

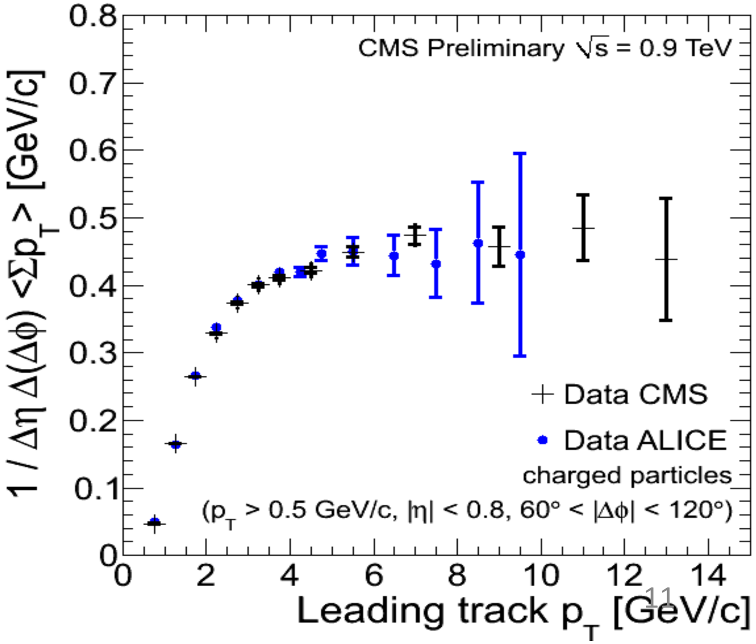
PAS FSQ-12-022





No difference within uncertainties.





Charged particle activity as a fn. of √s

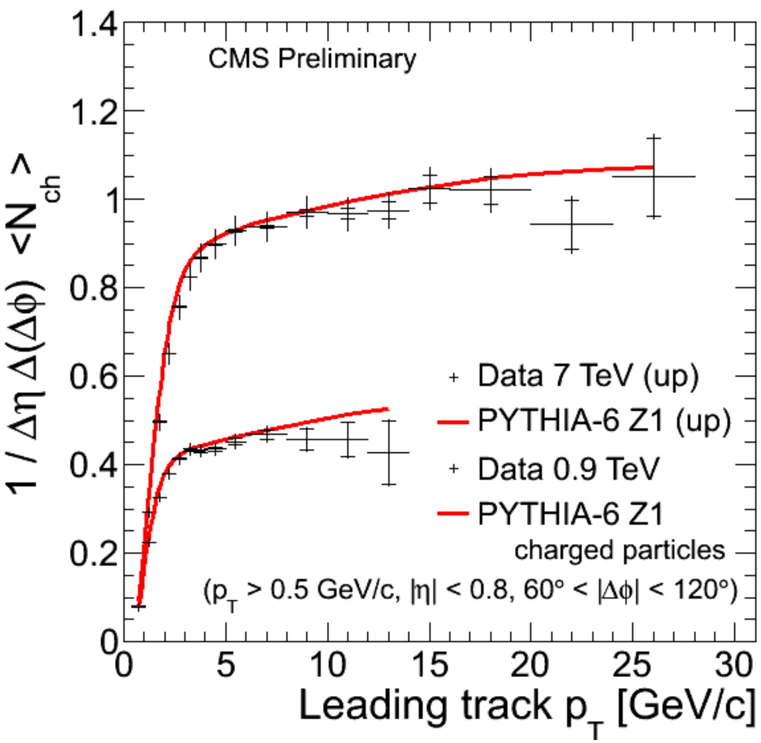
Comparison of measurements with various monte carlo predictions

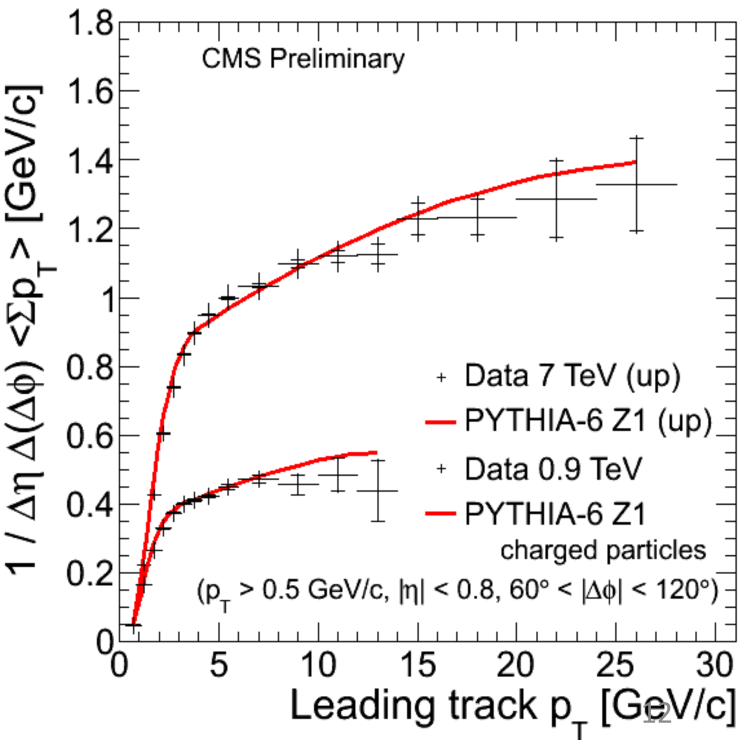
➔ get extra constraints for the tuning parameters

➔ better understanding for the underlying event phenomena.

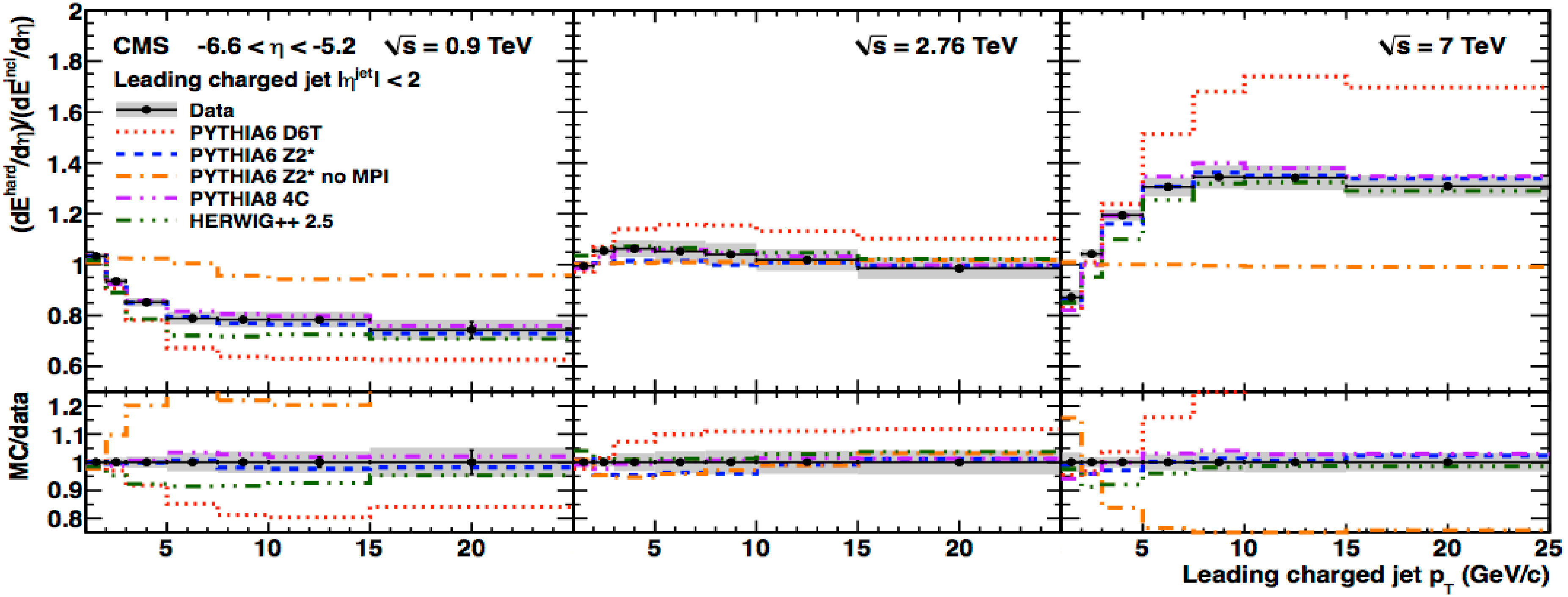
FSQ-12-020

- Significant increase in the average multiplicity and the scalar sum p_T followed by slower rate of increase due to saturation of MPI
- Activities increase with √s





UE in forward rapidity at various √s



Ratio of energies in the forward direction:

- events with charged particle jet in central region wrt inclusive events
- As a function of central jet p_T
- As a function of √s

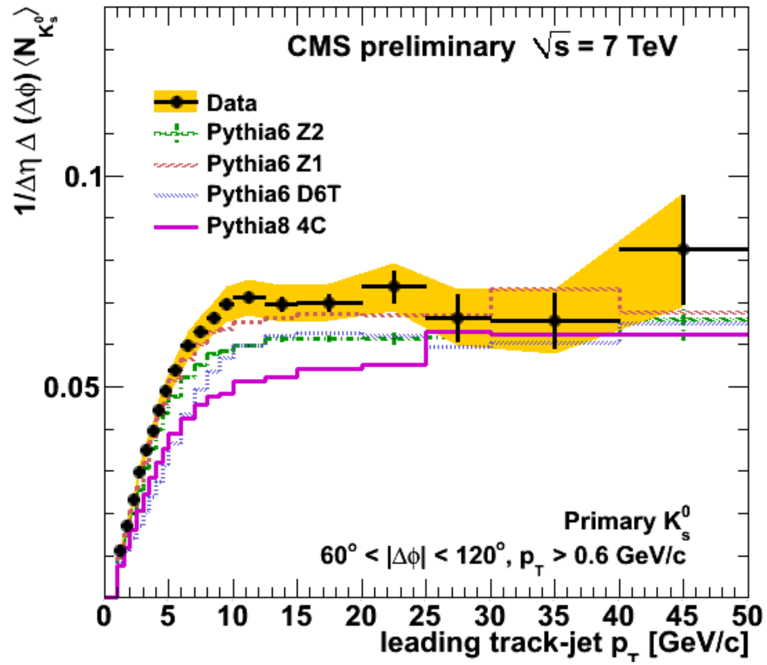
JHEP 04(2013) 072

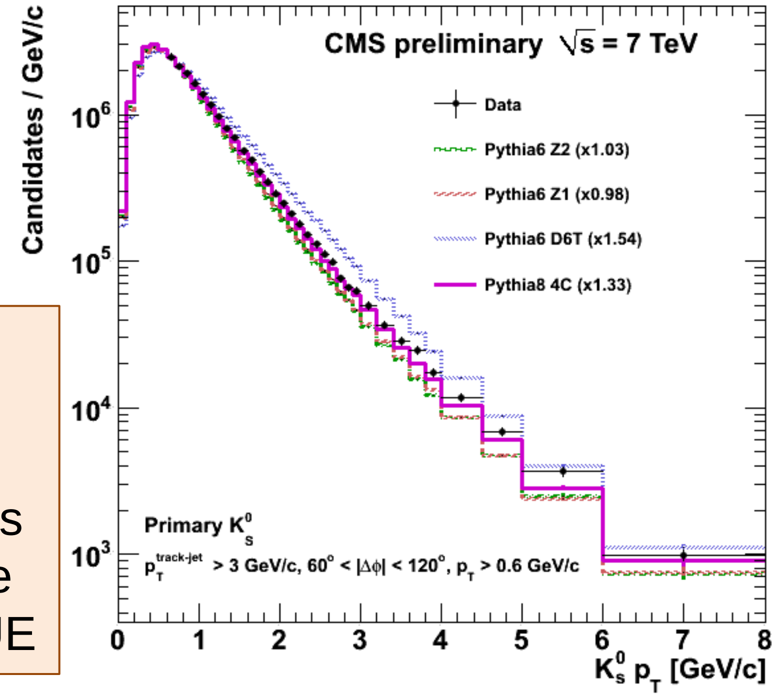
➔ At lower √s, the remnants have lower energy if a hard central object is demanded in the event.

➔ At higher √s, initial steep increase followed by features of saturation

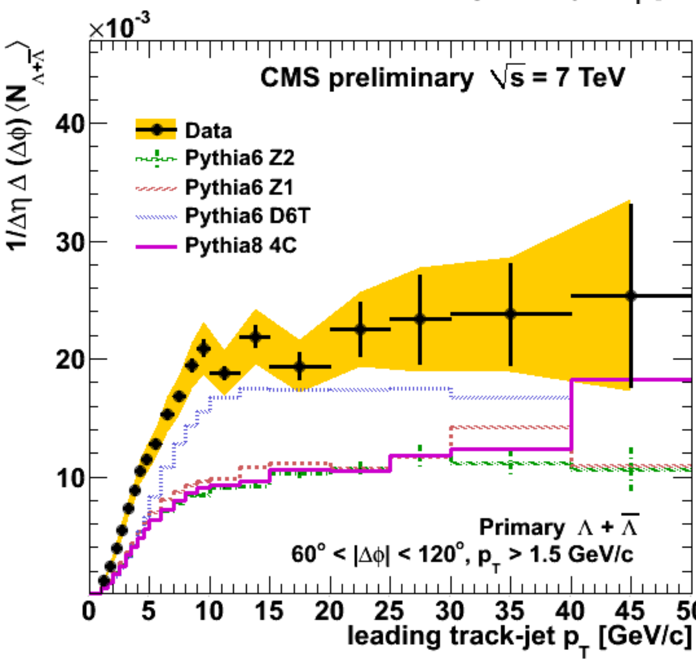
➔ Transition region reflected in flat spectrum

Strange particle production in UE



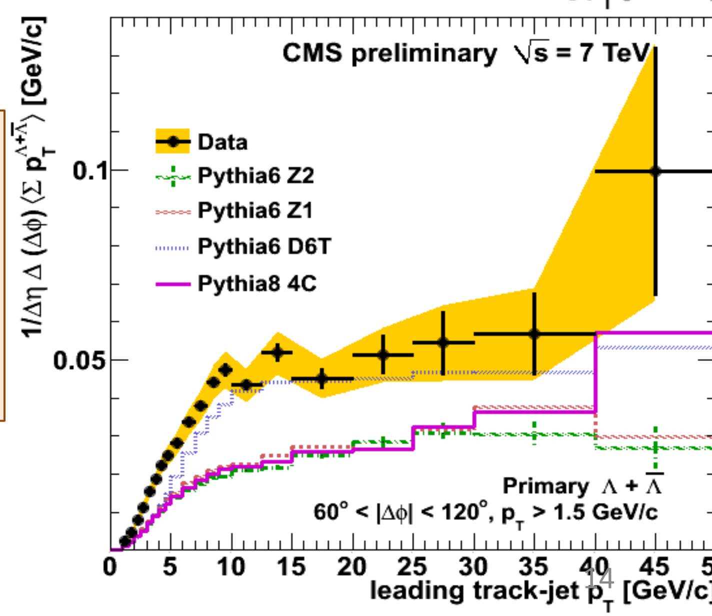


Monte carlos underestimate productions of strange particles both in inclusive events and in UE



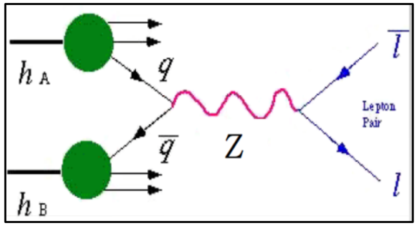
For baryons (Λ_S) data-MC agreement is worse than for mesons (K_S) for all the UE variables.

QCD-10-007

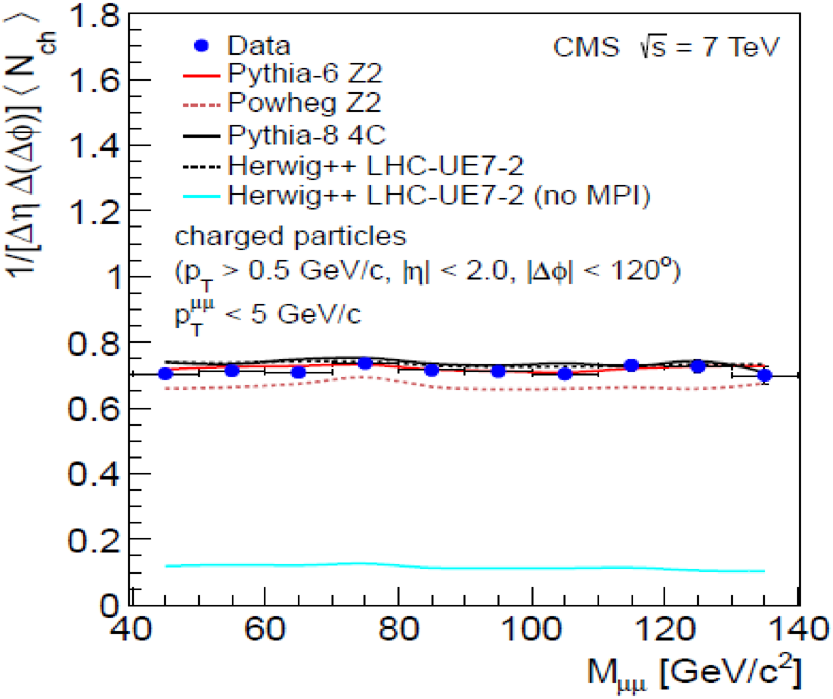


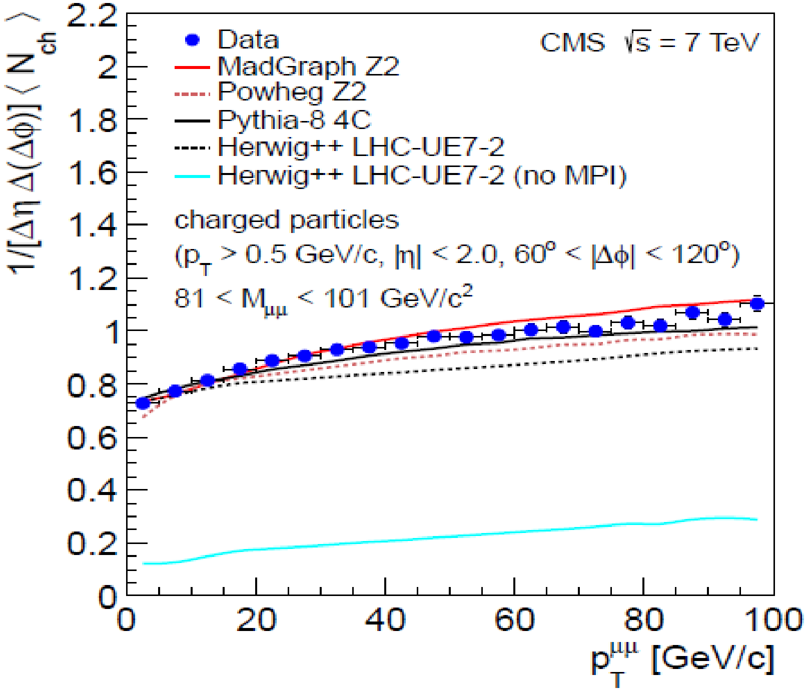
Drell-Yan process and underlying events

- UE kinematics is studied as function of invariant mass and transverse momentum of the dimuon system.
- Require small recoil to study UE as a function of energy scale ($M_{\mu\mu}$)
- Around Z resonance, UE dependence on $P_T^{\mu\mu}$ ➔ contribution from radiation.



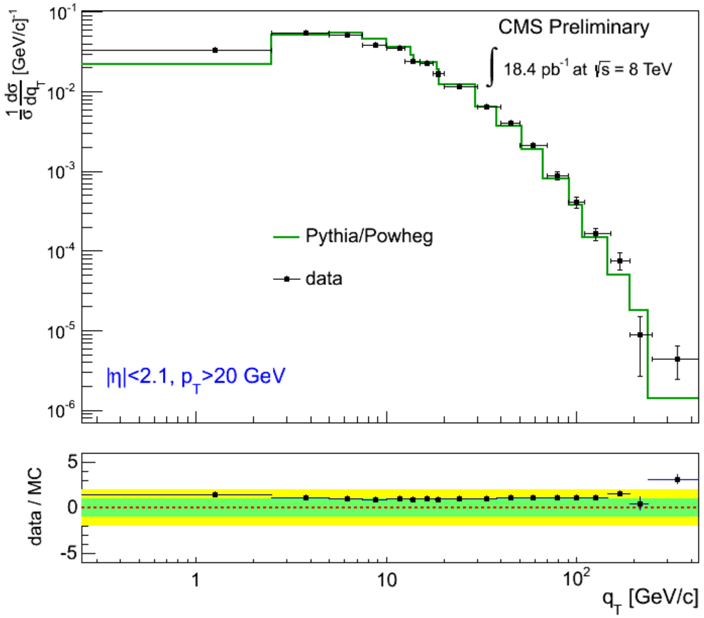
EPJC 72 (2012) 2080)

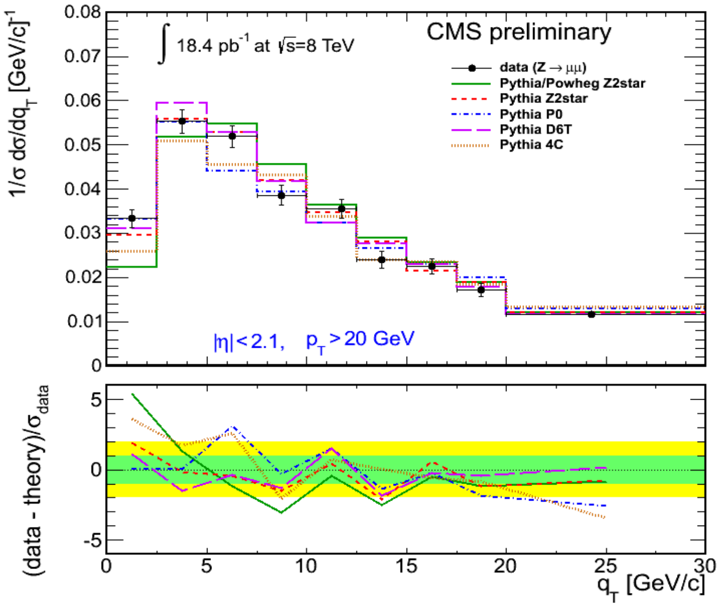




- No dependence on energy scale ($M_{\mu\mu}$) as MPI saturates at these scale
- Tunes derived from other analyses describe UE in DY ➔ **universality**

Study of UE using transverse momentum spectrum of Z





Use Drell-Yan process further.

Non-zero transverse momentum of Z boson (q_T)

a) low q_T region due to UE

b) high q_T region due to higher order corrections.

Present result uses low luminosity data (pile up event ~ 5) at 8TeV, $\mathcal{L}$~ 19 pb $^{-1}$

➔ poor discriminating power for different models.

Analysis of full data set at 8 TeV on-going

➔accuracy of measurement will have the potential for discriminating different tunes.

SMP-12-025

Conclusion

Study of underlying event at LHC is essential

- to understand the soft and semihard interactions in a collision
- to prepare for precision studies as well as for searches

CMS has a vibrant programme to address the relevant issues.

- LHC phase1 data has been extremely useful to understand the underlying event activities.
- Phenomenological models for soft hadronic interactions have been tuned with early data.
- No single modeling of multi-parton interaction in monte carlos is able to describe all features.

Looking forward to operations at LHC(13/14 TeV) to confirm the $\sqrt{s}$-evolution of the semi-hard parton interactions, and improve our understanding of the UE.

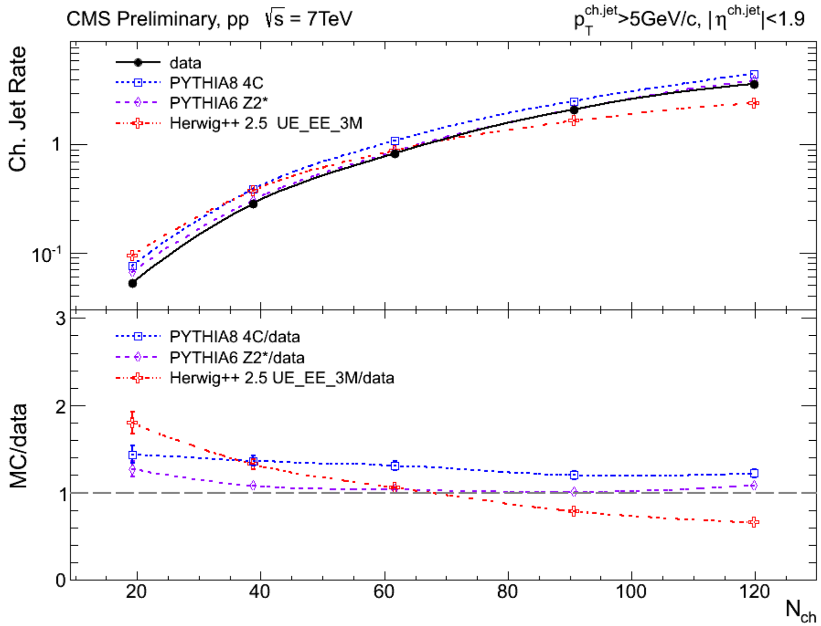
backup

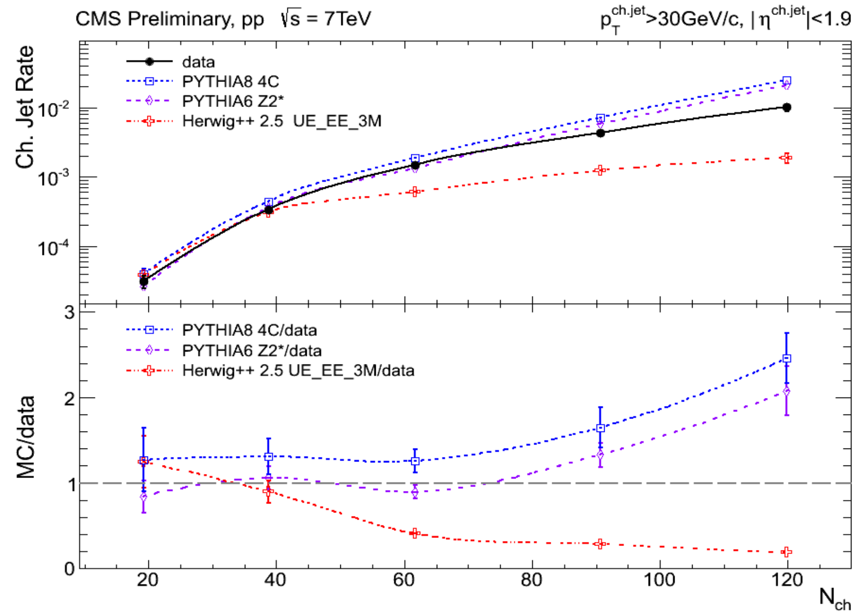
Experimental details

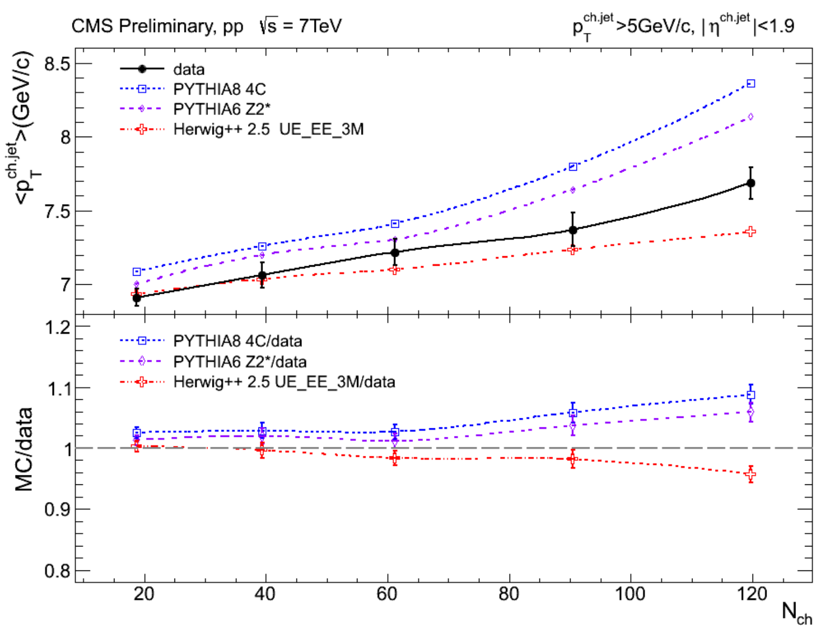
HF coverage |h|<5.2
Impact parameter resolution along z ~ 10 cm
δp_T = 0.7% @ 1 GeV

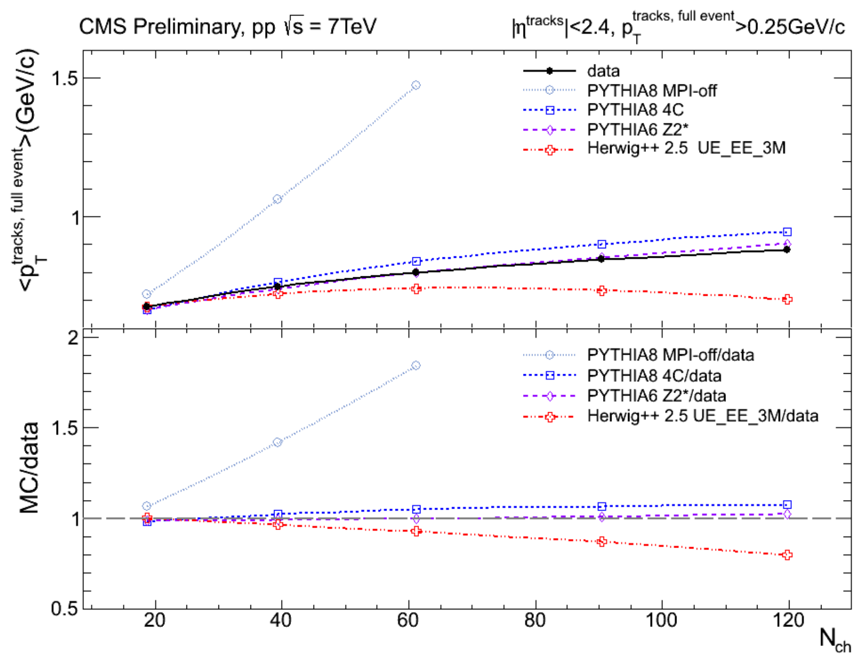
Data used for multiplicity study collected during low PU operation in 2010 ~ 3.18 /pb
Fraction for events with 2 primary vertices reconstructed as one or which share associated tracks < 0.2%
Negligible contribution from diffractive evnets.
Mean multiplicity of events ~ 24,
charged track jet |h| <1.9, pT> 5GeV
Eff. For trigger and event selection = 87%, 100% for nch > 10, 30

Jet activity as fn. multiplicity with varying threshold for jet p_T



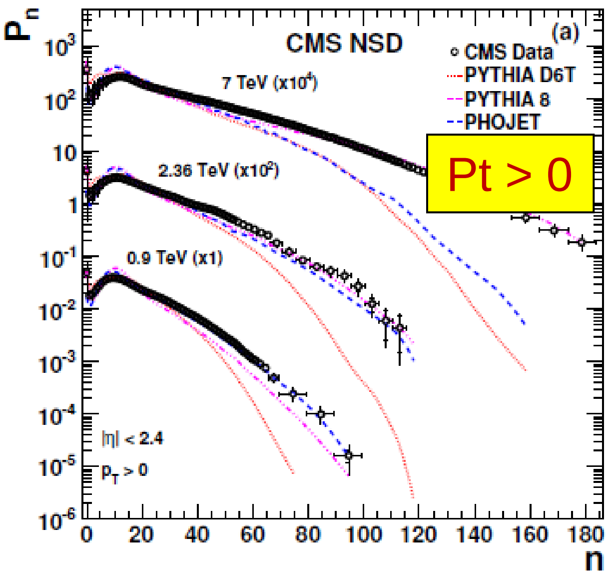


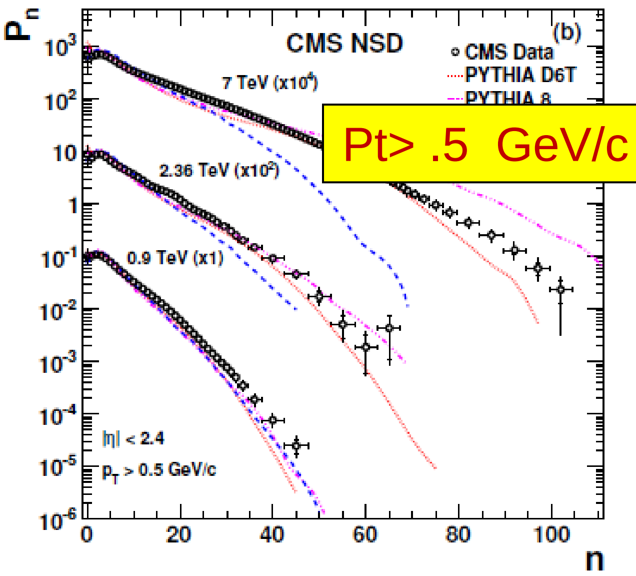




History

charged multiplicity in minimum bias events at UA5, Tevatron experiments could be explained better by introducing the concept of multi-parton interaction along with parton shower + hadronization.





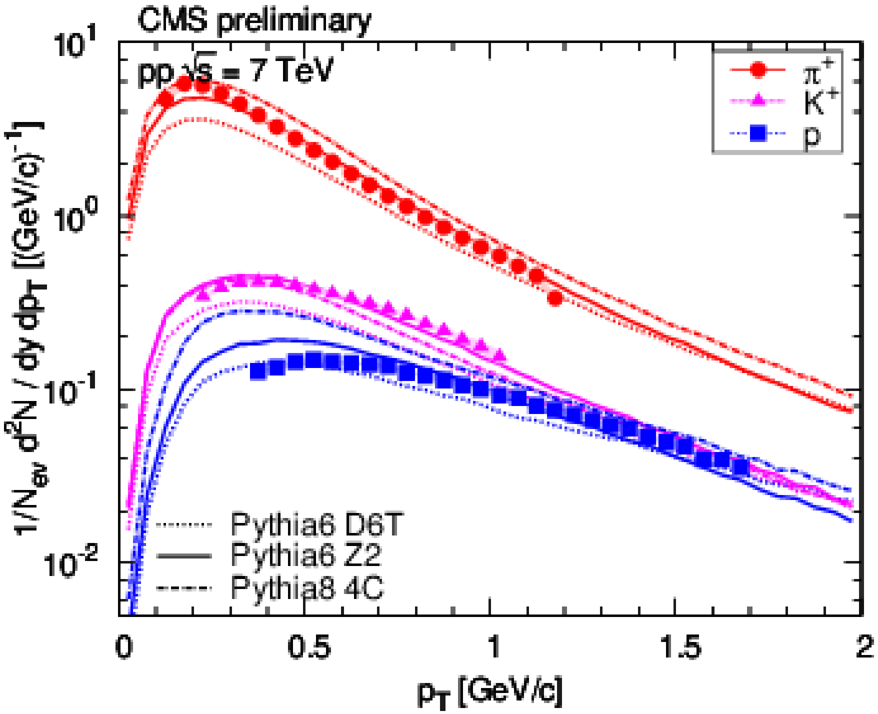
The descriptions based on lower energy data do not work very well at LHC energies.

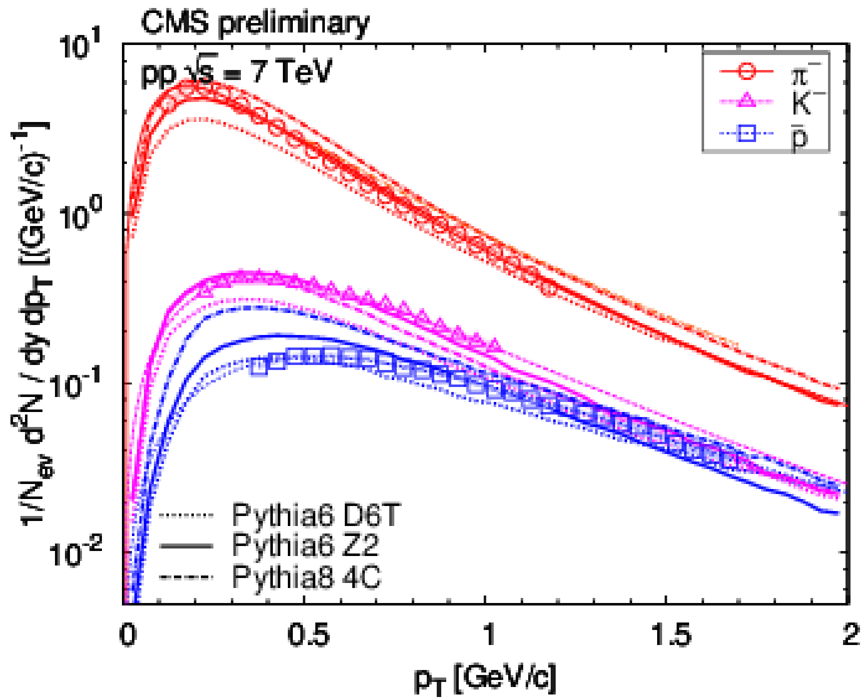
Tuning of monte carlo event generators made the situation better

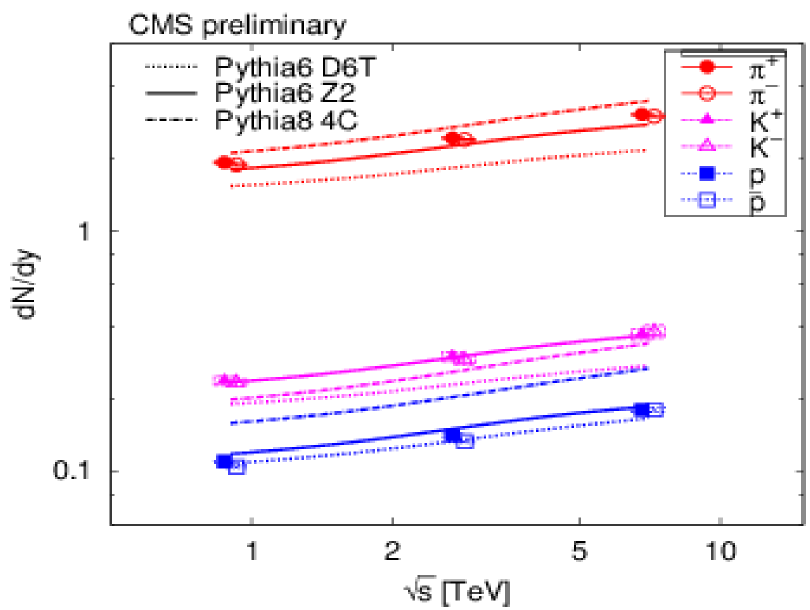
No single model of soft interactions in monte carlo is able to describe all features

➔ Lot of studies at LHC underline the importance of understanding the UE processes with much better accuracy.

Spectra of charged particles

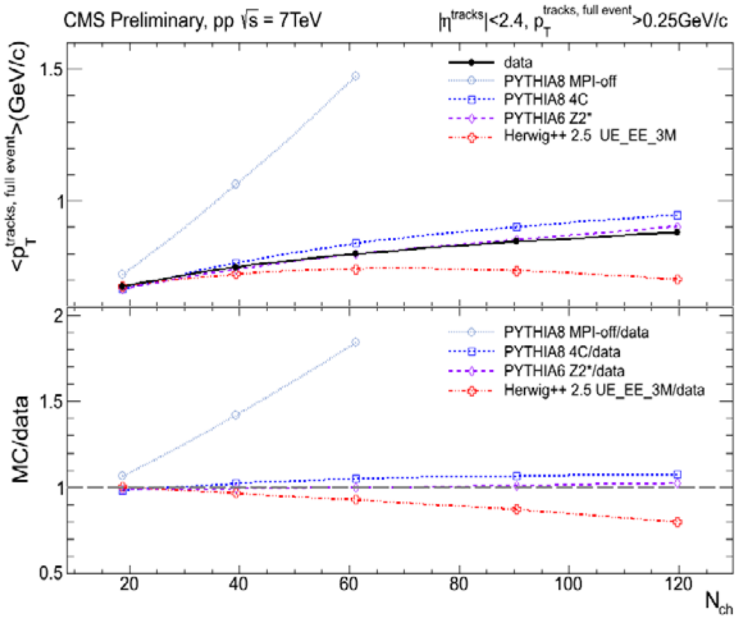


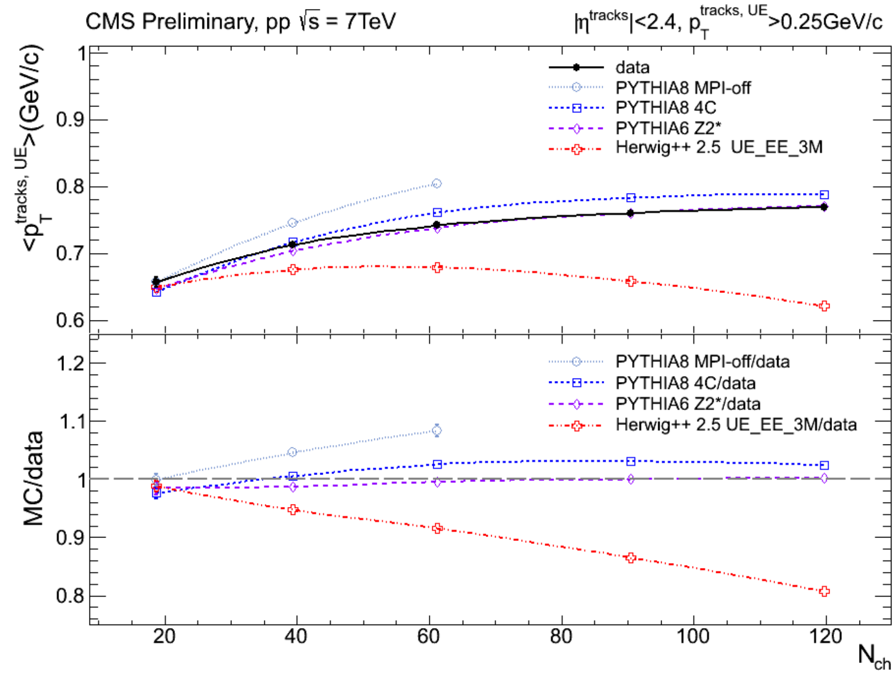


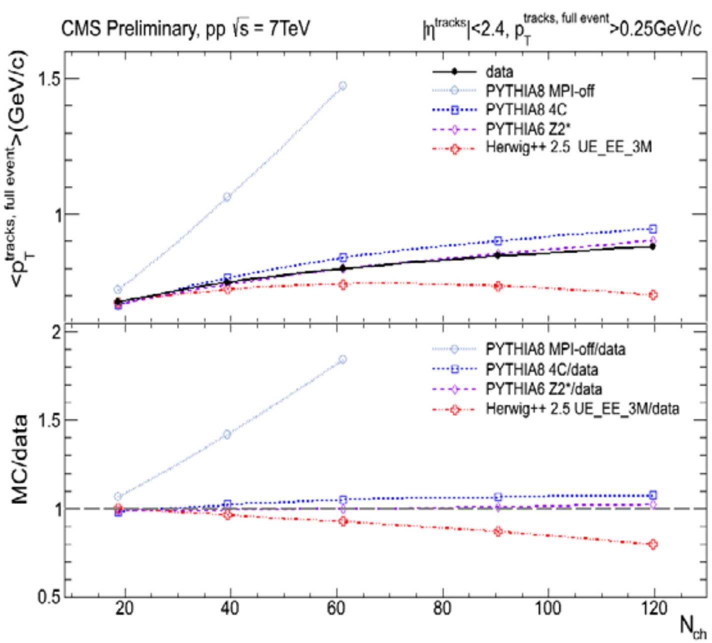


CMS-PAS-FSQ-12-014

Properties of charged particles from jets and from UE

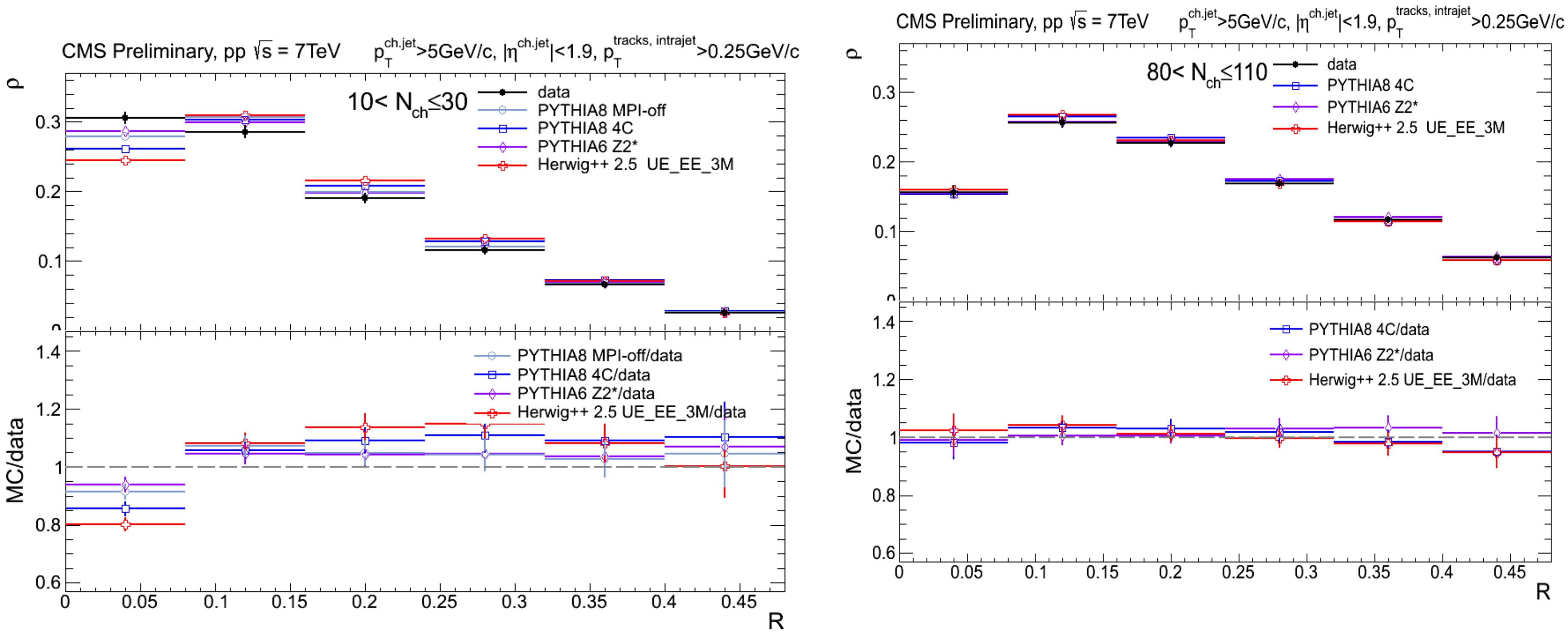






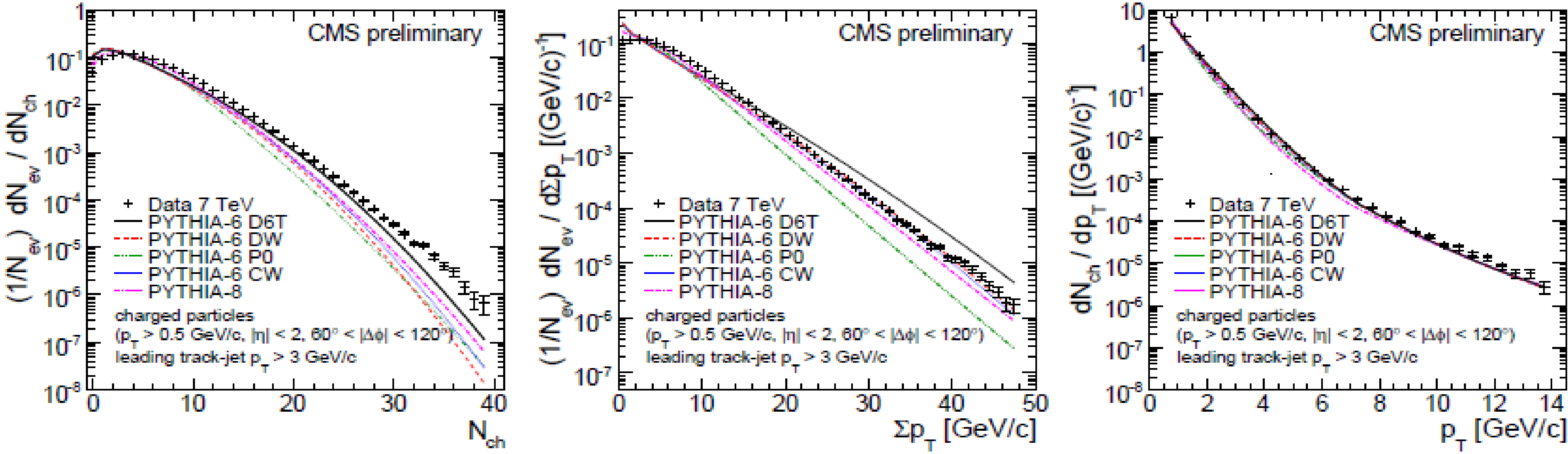
Mean transverse momentum of intrajet charged vs. corrected charged-particle multiplicity

Jet p_T density as a fn of distance from jet axis

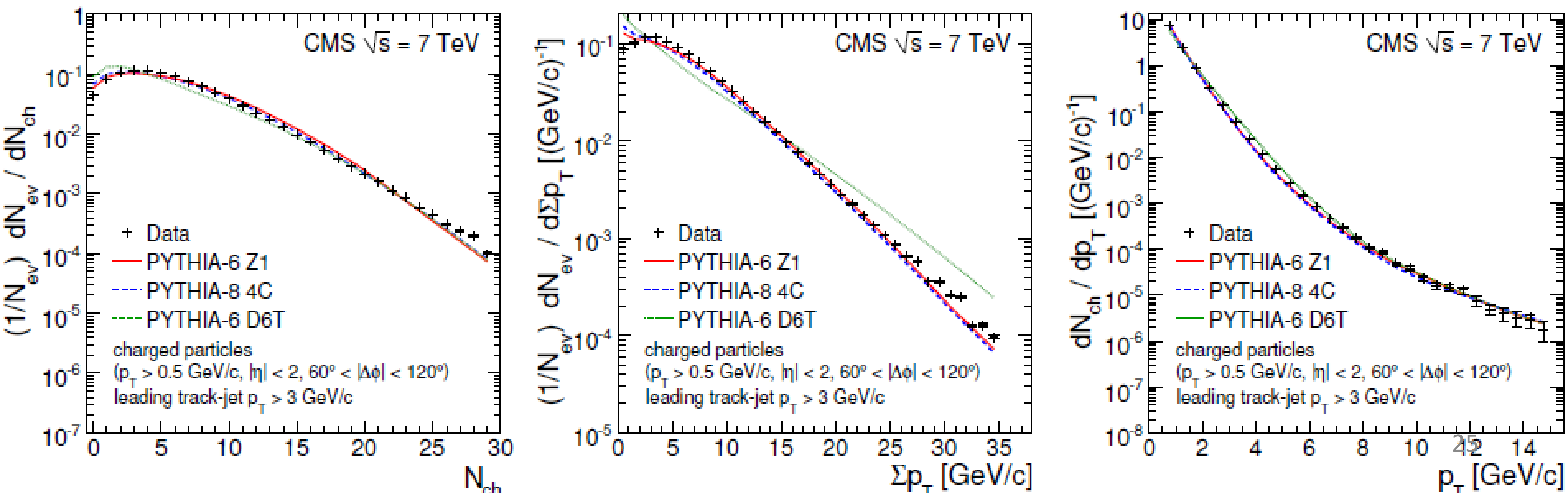


CMS PAS FSQ-12-022

Measurement of minimum bias events in CMS

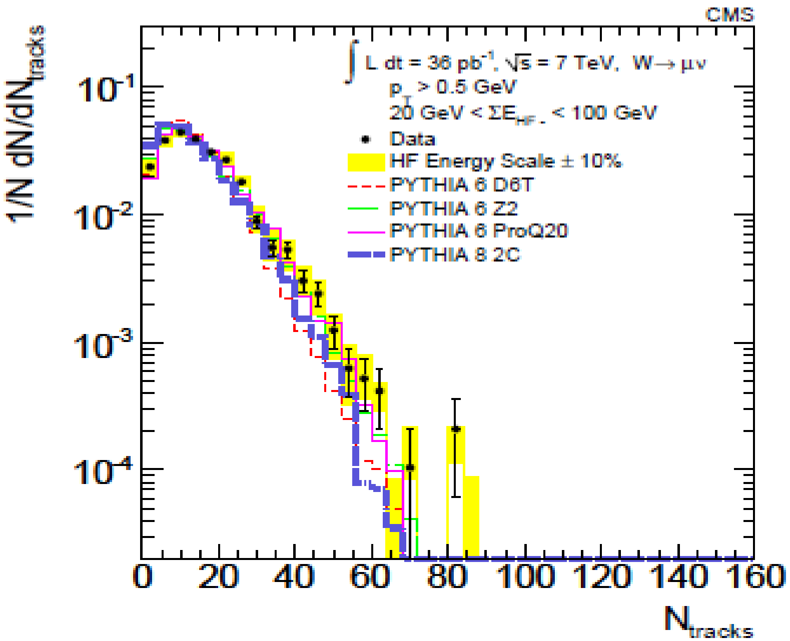


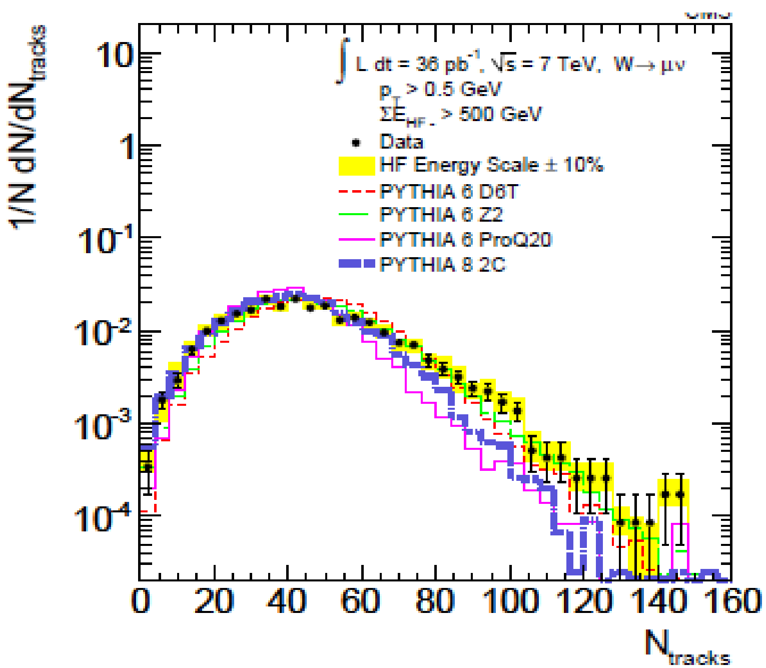
Tuning of monte carlo generators made the situation better



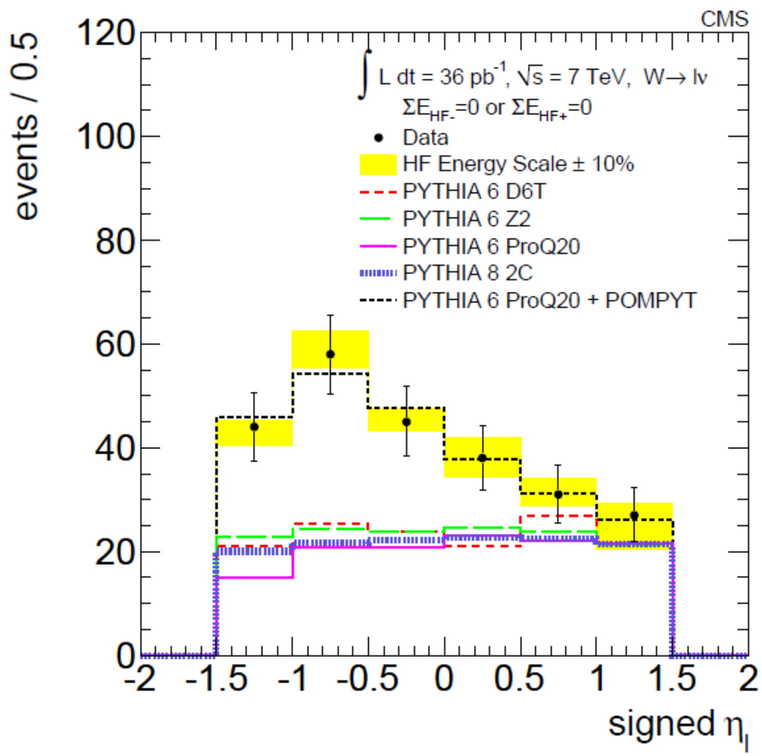
UE activity in forward region

CMS-PAS-FWD-11-003





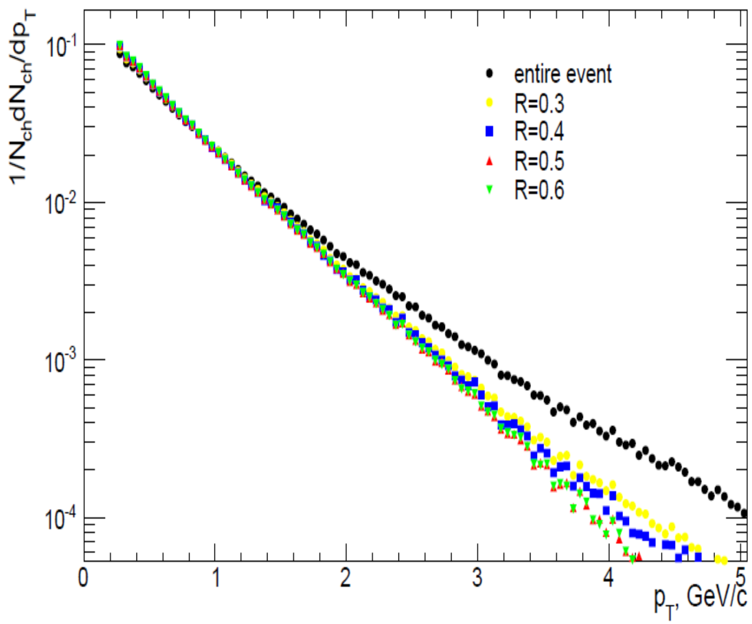
- Measure energy flow in forward direction 3 <|η|<4.9 for W/Z events
- Correlation of activity in central region.
- Look for large rapidity gap events
- Presence of diffraction ➔ lepton and gap i n the same hemisphere.



Correction for charged tracks

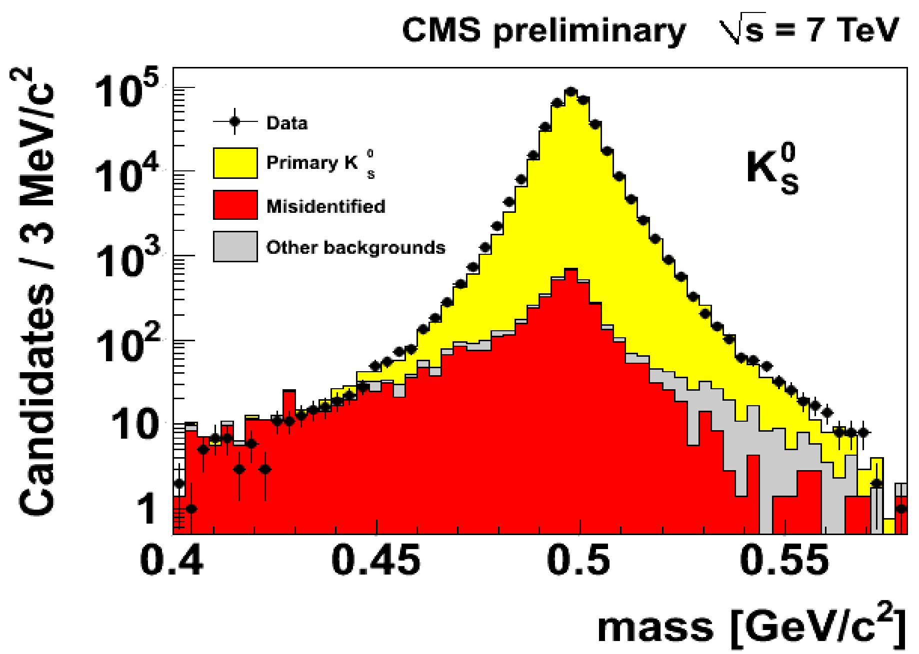
$$N_{\rm ch}^{\rm true}(\eta, p_{\rm T}) = N_{\rm ch}^{\rm reco}(\eta, p_{\rm T})\frac{1 - fake(\eta, p_{\rm T})}{eff(\eta, p_{\rm T})}$$

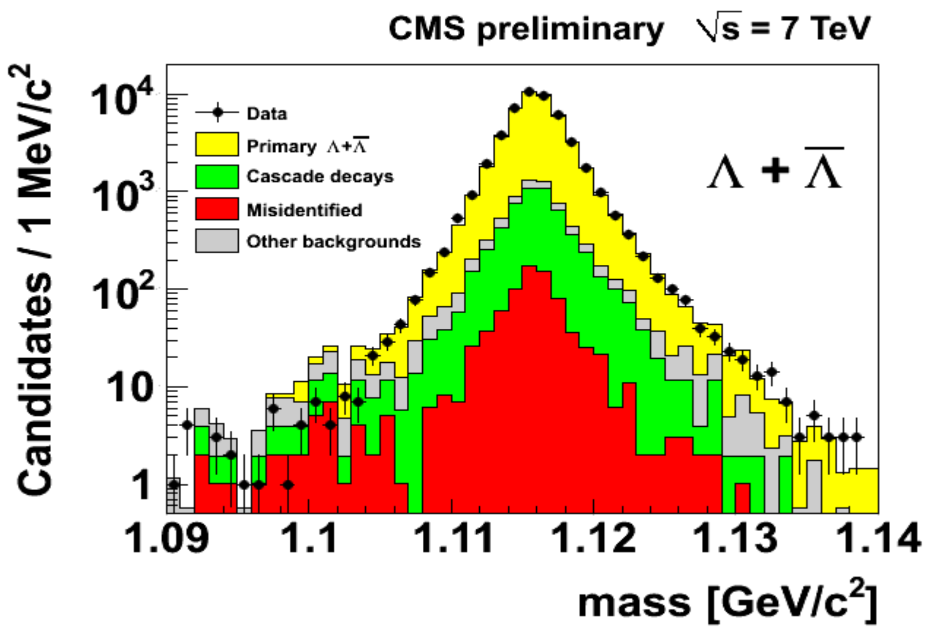
simulation

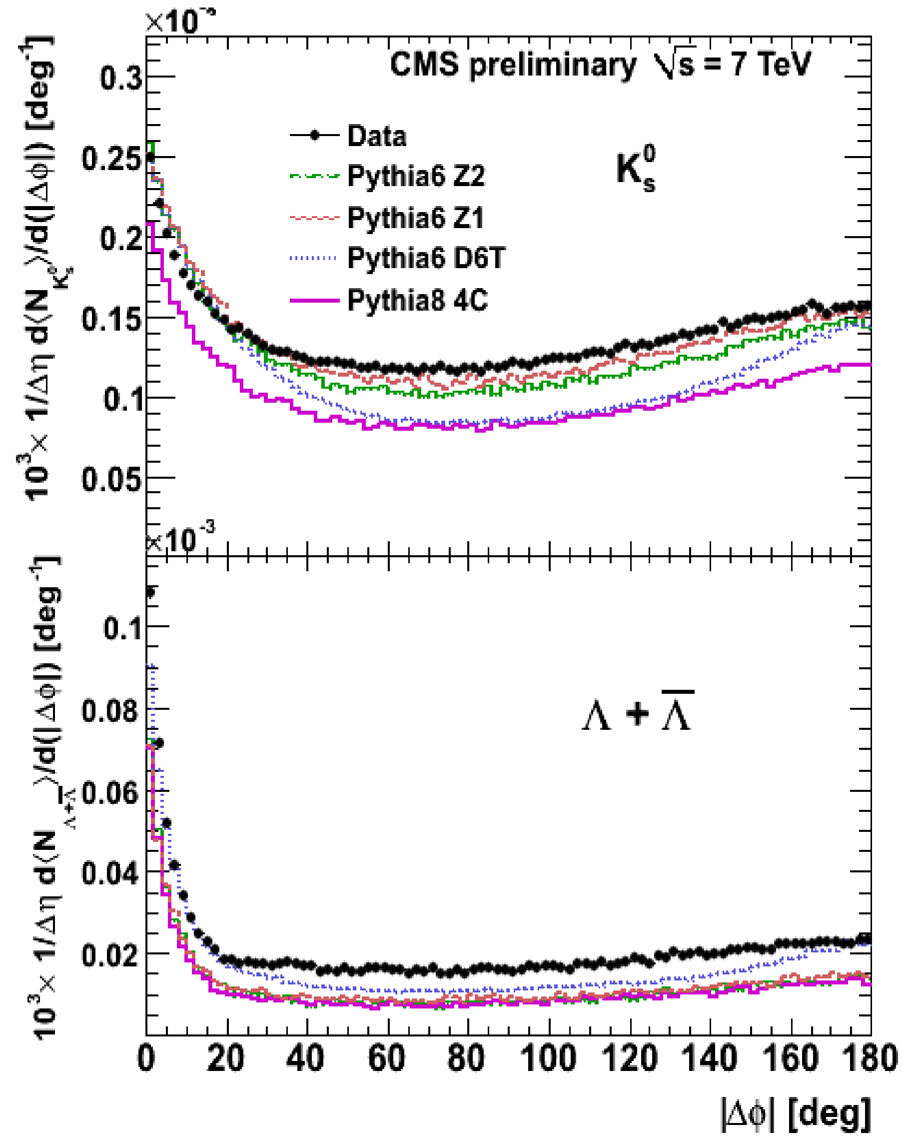


Dependence of p_T spectrum on the radius of the jet-defining cones .

Strange particle production in CMS







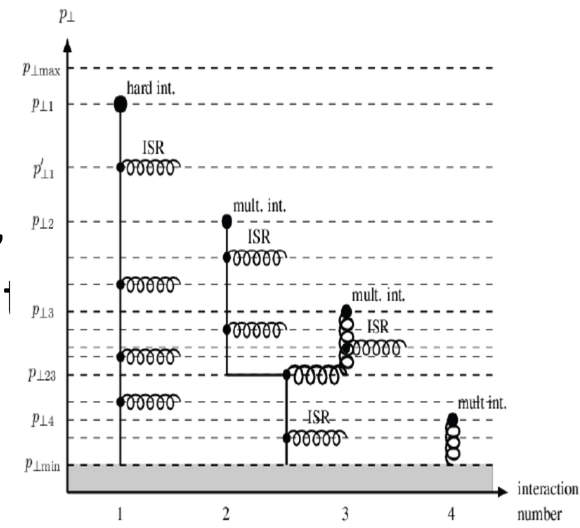
Uncorrected average production

Multiple interaction in Pythia

To calculate hard scatter cross-section $d\sigma/dp_T^{\,2}$
→introduce a cutoff value:

$$1/\hat{p}_T^4 \rightarrow 1/(\hat{p}_T^2 + \hat{p}_{T_0}^2)^2$$

→ evaluate hard scatter cross-section for a given b, above threshold which is matched to experiment data and extrapolated at LHC energies.



$$\hat{p}_{T_0}(\sqrt{s}) = \hat{p}_{T_0}(\sqrt{s_0}) \cdot (\sqrt{s}\,/\,\sqrt{s_0})^{\epsilon},$$

Simulation in pythia-8 all interactions simulated in decreasing order of p_T. ISR is p_T ordered over all interactions.

Tuning refers to adjustment of values $\hat{p}_{T_0}$ ϵ etc. , and description of matter distribution inside the proton.

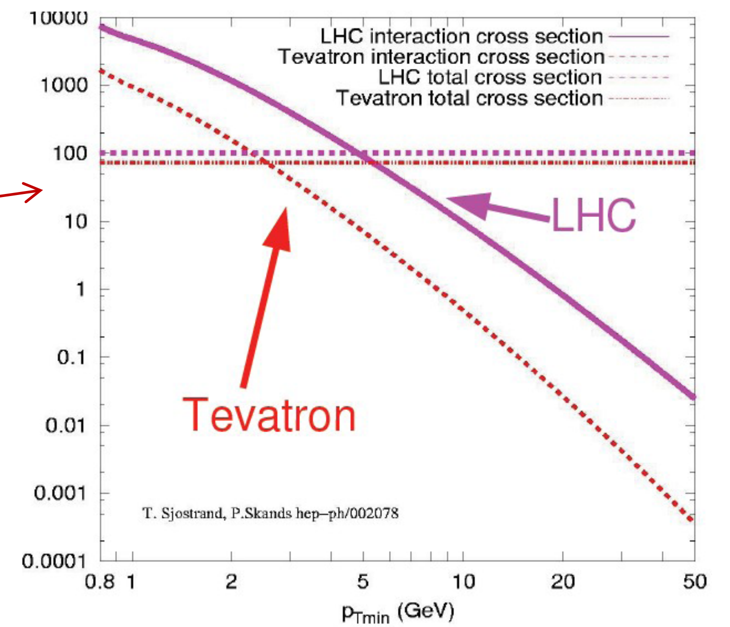
Partonic cross-sections

$$\sigma(p_1 + p_2 \to j_1 + j_2 + X) \;=\; f(x_1,\mu^2) \otimes f(x_2,\mu^2)\; \hat{\sigma}(x_1 p_1 + x_2 p_2 \to j_1 + j_2)$$

- partonic cross-section

$$\sigma_{\mathrm{hard}}(p^2_{\perp \mathrm{min}}) = \int_{p^2_{\perp \mathrm{min}}} \frac{d\sigma_{\mathrm{hard}}(p^2_\perp)}{dp^2_\perp} dp^2_\perp$$

- diverges faster than $1/p^2_{\perp \mathrm{min}}$



- Interaction rate exceeds total inelastic, non-diffractive cross-section!

➔ happens in the perturbative range,

➔ above λ QCD

➔ more than one 1 interaction per event

➔ **multiple partonic interaction**

➔ **need modelling** ➔ **tuning**

$$\langle n \rangle = \frac{\sigma_{\mathrm{hard}}(p_{\perp \mathrm{min}})}{\sigma_{nd}}$$

Average number of semihard interactions per event >1 for LHC