CMS Minimum Bias Results

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On behalf of the CMS Collaboration

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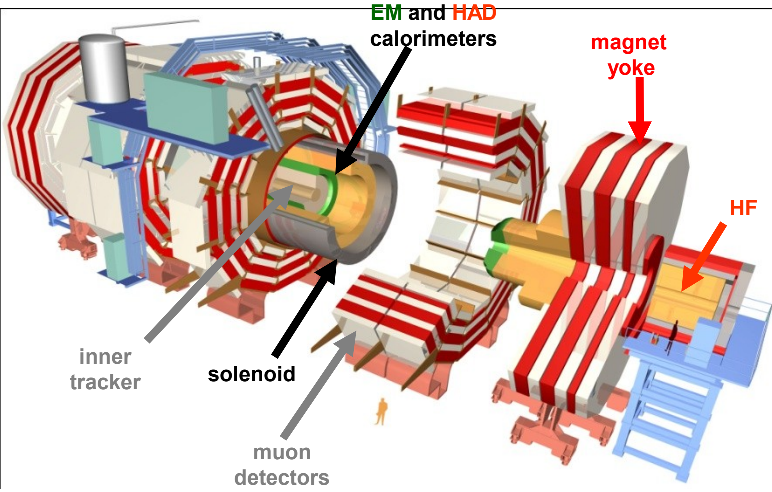
The main question

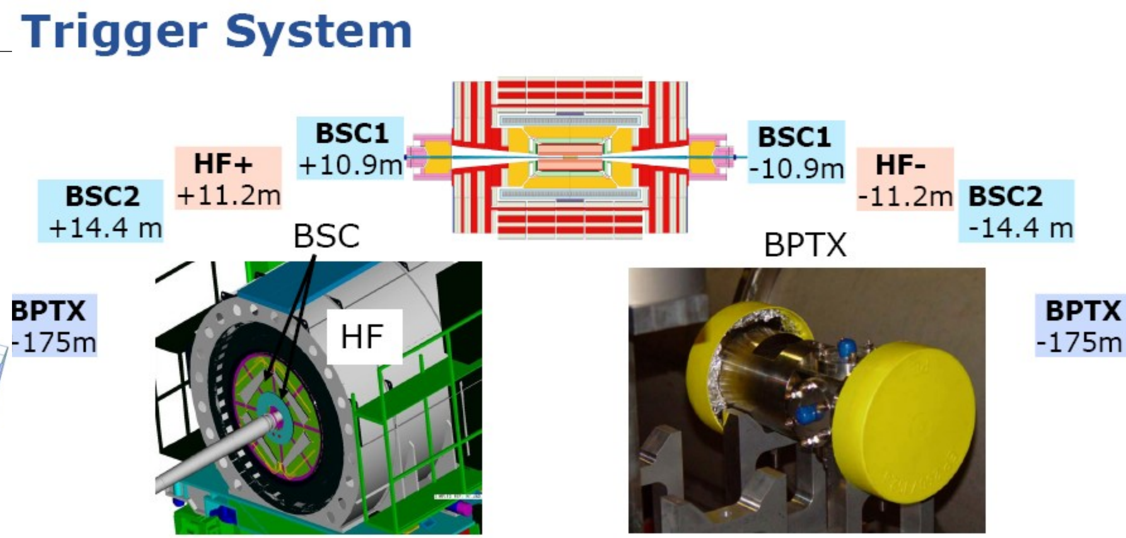
- Can multiparticle production at highest collider energies be described by combining:
  - Integrated (N)NLO PDF's based on linear evolution equations
  - NNLO matrix elements
  - A simple geometric interpretation of multiple parton interactions (MPI)
  - String fragmentation and color neutralisation of beam remnants

Possible extensions

- Take into account transverse degrees of freedom
- Non-linear effects at high gluon densities: gluon saturation at very small x
- More detailed modeling of color flow and MPI
- Collective effects when reaching high energy densities

CMS minimum bias triggers





Trigger :

- any hit in the beam scintillator counters (BSC)

  AND

- filled bunch passing the beam pickups (BPTX)

Offline event selection :

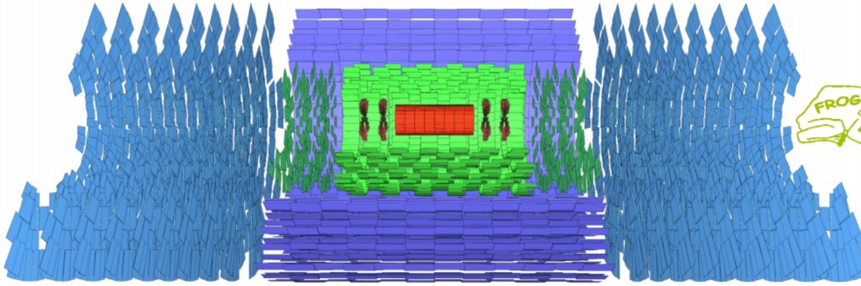
- ≥ 3 GeV in both sides of the HF
- rejection of the beam halo using BSC timing
- beam induced background rejection (pixel cluster shapes)
- at least a reconstructed vertex near the collision point

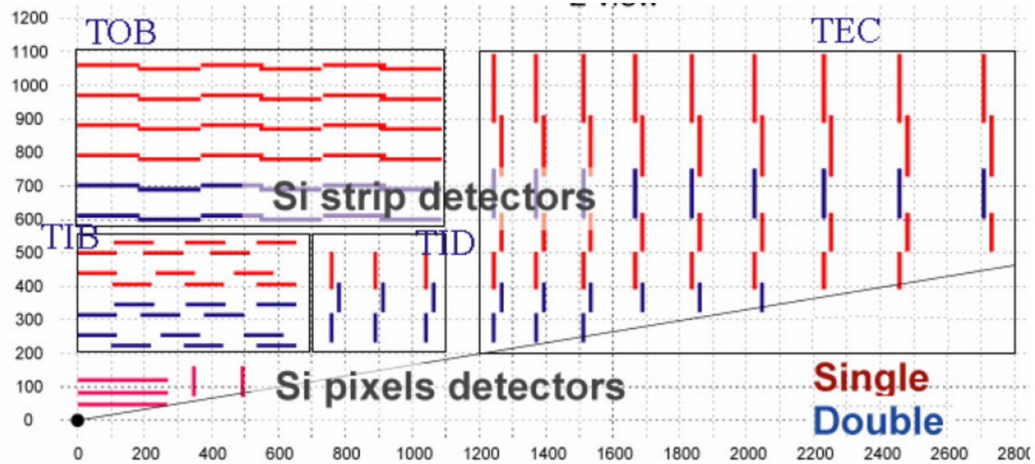
Sample composition at 7 TeV

Proces	Fraction	Efficiency
SD	19.2%	26.7%
NSD	80.8%	86.3%

Pythia definitions

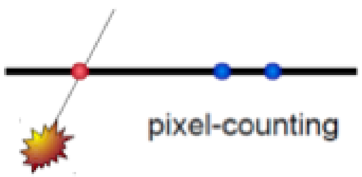
Charged particle reconstruction

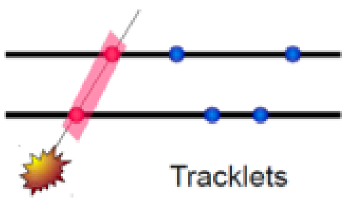


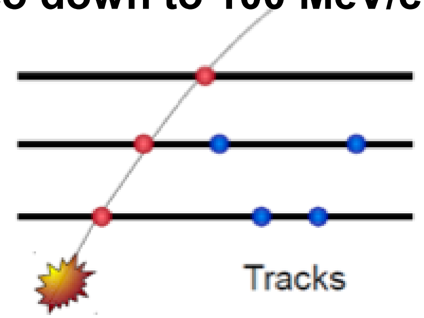


CMS Silicon tracker

- 9.6 M Si strips, 66 M pixels
- Hit reconstruction efficiency > 99%
- >97% of all channels operational
- coverage of $|\eta|<2.4$ with ≥ 10 strips ≥ 3 pixels
- p_t reco down to 100 MeV/c with 3 pixels







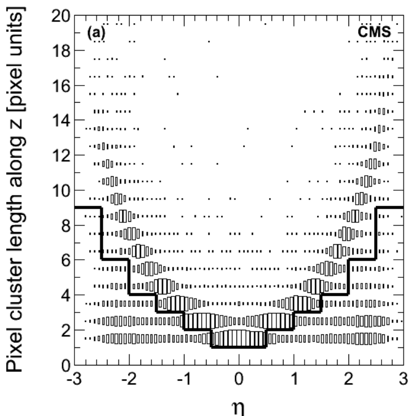
- Pixel Counting
  - # clusters/layer
  - Largest acceptance: pt>30 MeV/c
  - Insensitive to alignment
  - most sensitive to bg: detector noise, loopers

- Tracklets
  - 2 out of 3 pixel layers
  - data driven bg subtraction
  - pt> 50 MeV/c

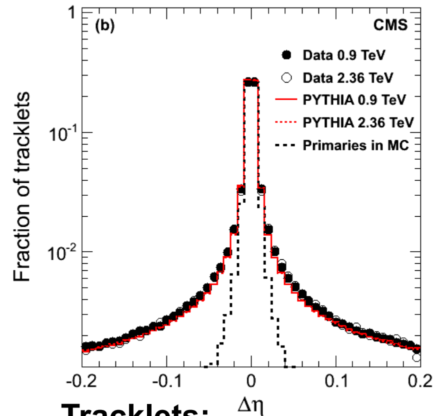
- Tracks
  - Very robust
  - Low bg
  - p_t> 100 MeV/c: ε>70% and bg < 5% fakes at lowest p_t

Pseudorapidity density

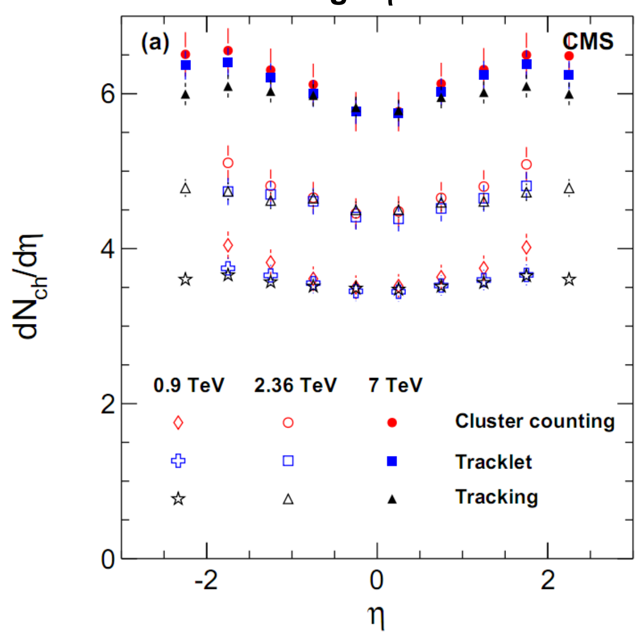
V. Khachatryan et al., JHEP 02 (2010) 041
V. Khachatryan et al., Phys. Rev. Lett. 105 (2010) 022002



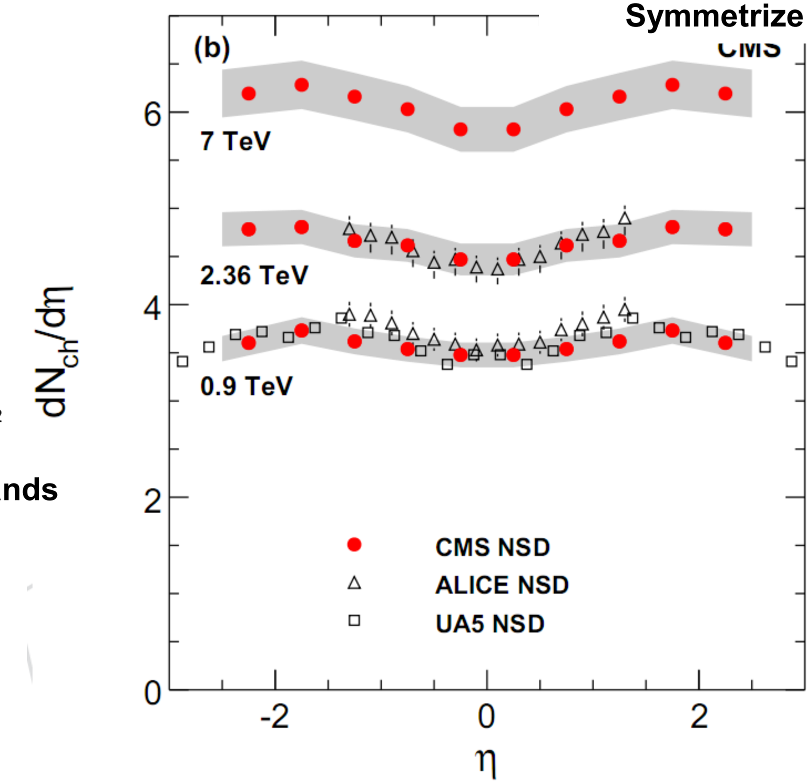
Cluster counting:
eliminate short clusters at large η



Tracklets:
Estimate bg from sidebands

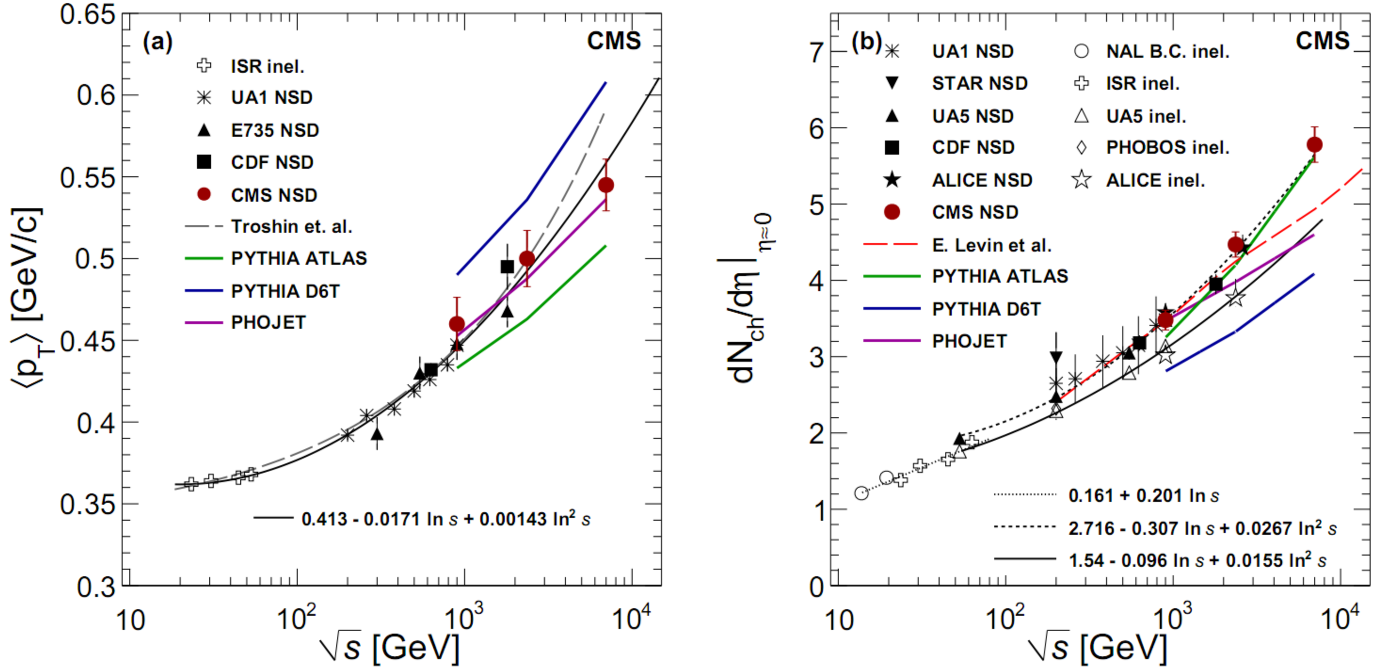


Average all methods
&
Symmetrize



All measurements in agreement with other experiments, however densities are higher than most MC models (see later).

Energy dependence of single particle spectra



CMS Coll, JHEP02(2010)041

CMS Coll., Phys. Rev. Lett. 105 (2010) 022002

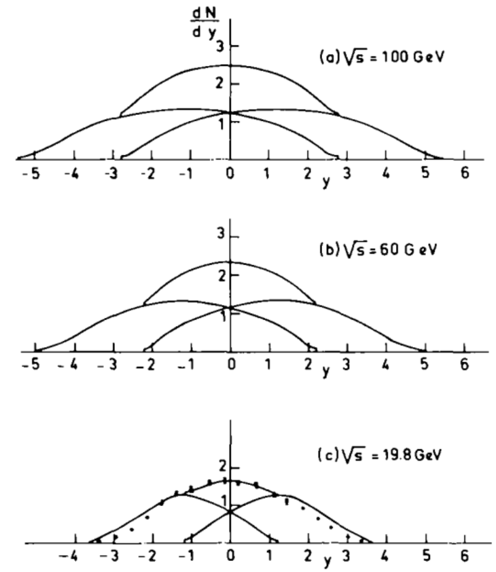
Most event generators are not able to describe simultaneously both energy evolution in $\rho(0)$ and $<p_T>$

Why do these quantities rise and why faster than ln(s) ?

Pre-QCD Answers

Central rapidity density

- Feynman scaling implies that width of plateau increases as ln(s) but height remains the same: seen in low energy e+e- and h-h
- QCD radiation violates Feynman scaling at high energies
- But, even when assuming Feynman scaling, the possibility of creating more strings in <u>multiple parton scatters</u> gives rise of $\rho(0)$ stronger than ln(s)

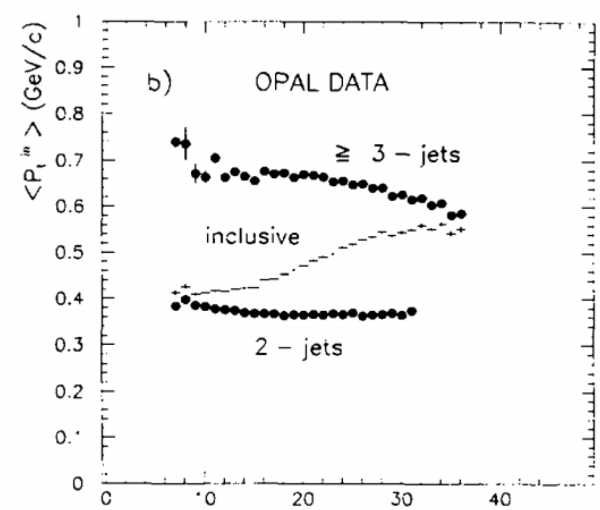


A. Capella et al., PLB81 (1979) 68
A. Capella and J. Tran Thanh Van, PLB114(1982) 450

Average p_t

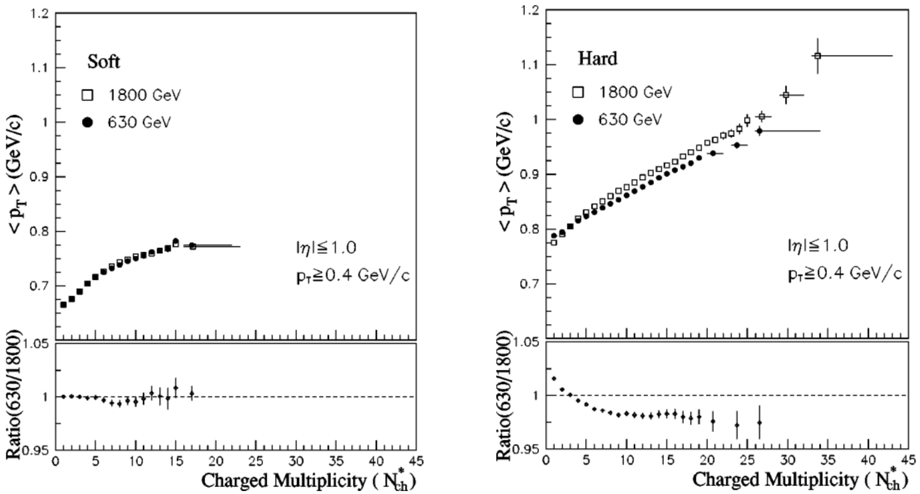
- $< p_t >$ is energy independent for soft processes
- Rise is due to
  - production of jets in hard scatters
  - And <u>multiple soft interactions</u>

F. Bopp, P. Aurenche and J. Ranft, Phys.Rev.D33 (18671986)

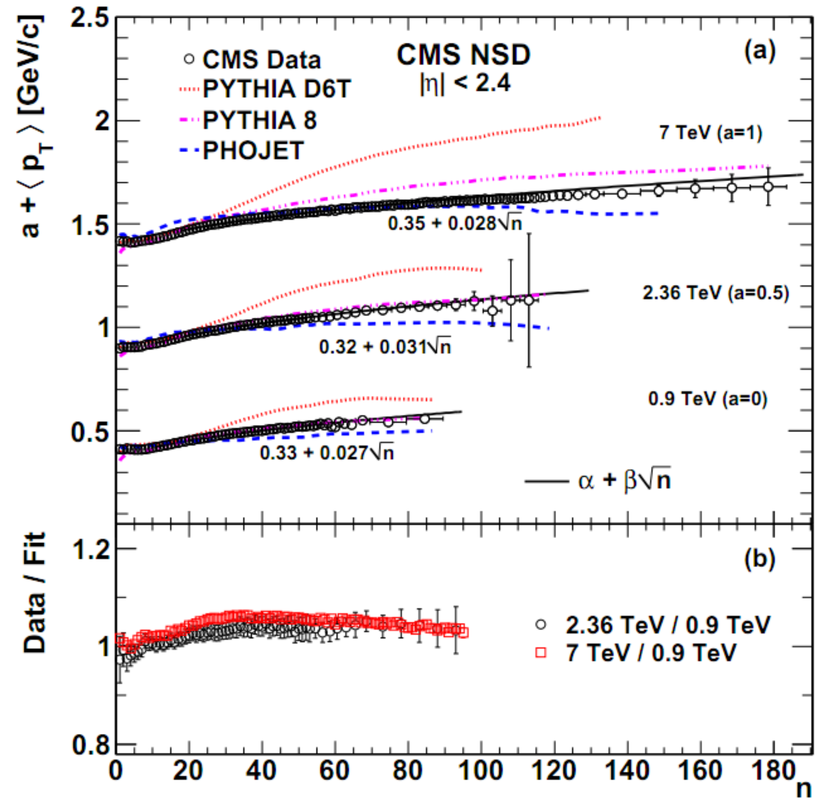


OPAL Coll., PLB320 (1994) 417

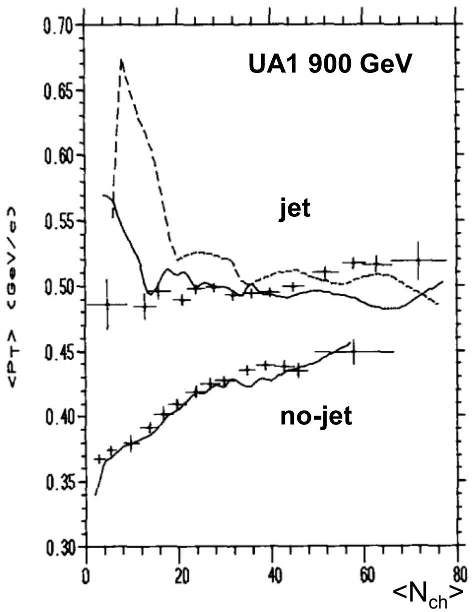
Correlate the two



CDF Coll., Phys. Rev. D65 (2002) 072005



CMS Coll., Submitted to JHEP (2010), arXiV

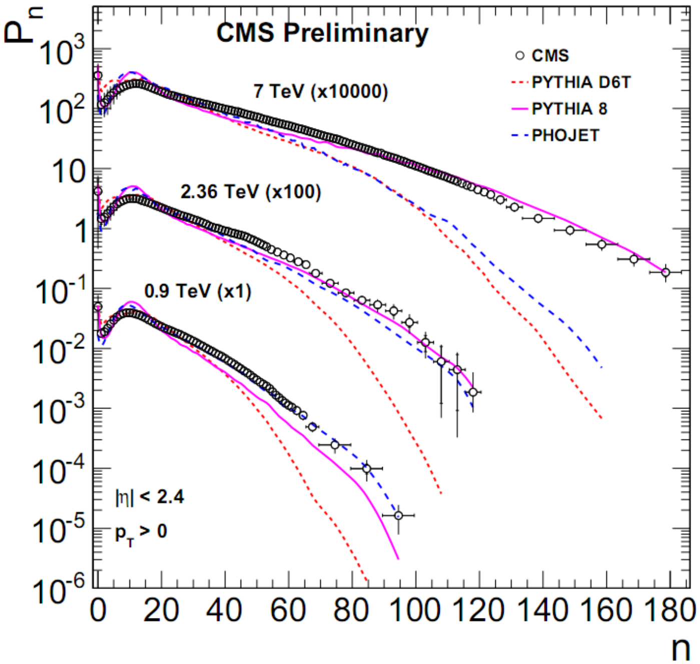


?

T. Sjostrand and M Van Zijl, PLB188 (1987) 149

- Separation between soft and hard events, clearly indicates that not everything is explained by perturbative jet production
- The scaling with energy is remarkable, especially for the soft events
- Very sensitive to details of MPI modeling: gg vs qq

Multiplicities



CMS Coll., Submitted to JHEP (2010), arXiV

- Dedicated minimum bias tracking extending to p_T=100 MeV/c up to |η|<2.4
- Unfolded up to primary hadron level
- Extrapolated to p_T>0 (2% correction)
- Cross-checked with tracklets and B=0T data

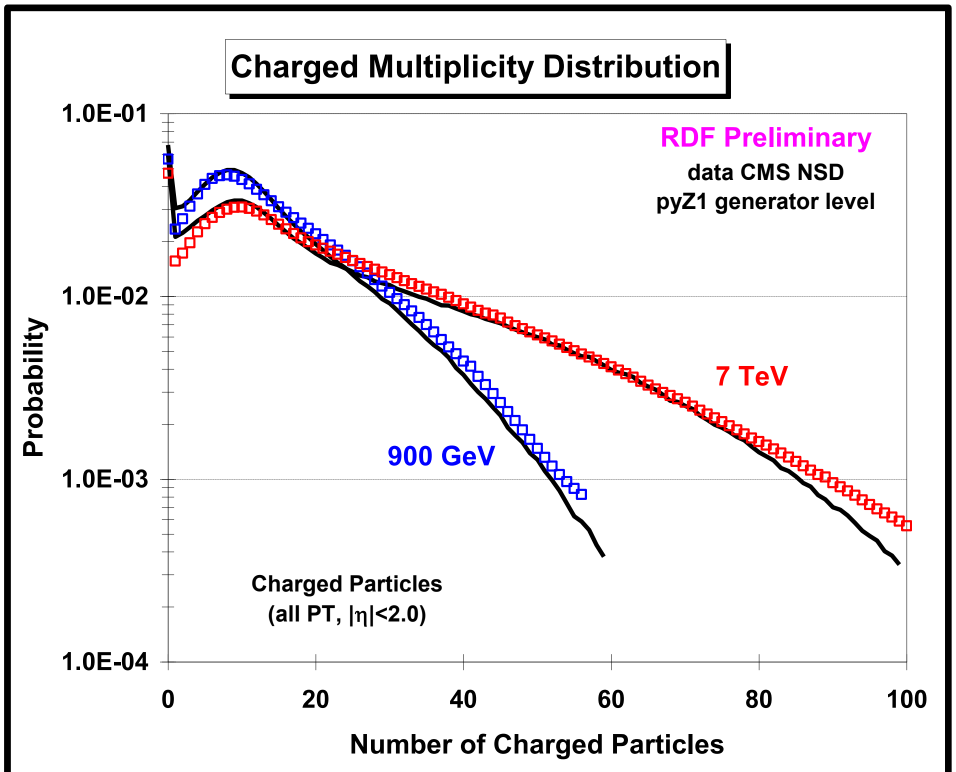
$\sqrt{s}$ (TeV)	$\langle n \rangle$			
	Data	PYTHIA D6T	PYTHIA 8	PHOJET
0.9	$17.9 \pm 0.1^{+1.1}_{-1.1}$	14.7	14.9	17.1
2.36	$22.9 \pm 0.5^{+1.6}_{-1.5}$	16.7	17.8	18.7
7	$30.4 \pm 0.2^{+2.2}_{-2.0}$	21.2	25.8	23.2

- Shape of the multiplicity distribution (MD) reveals information on the dynamics and stochastic nature (correlations) of particle production
- More Pythia Tunes (P0, ProQ20, DW) exist but are omitted for clarity
- No Monte Carlo is able to describe all multiplicities at all energies
- In general all MC's generate too many high pT particles (by tuning up the MPI)

Recent MC Tuning efforts

LHC wide working group on analysis of MB data and tuning of MC generators to MB and UE measurements

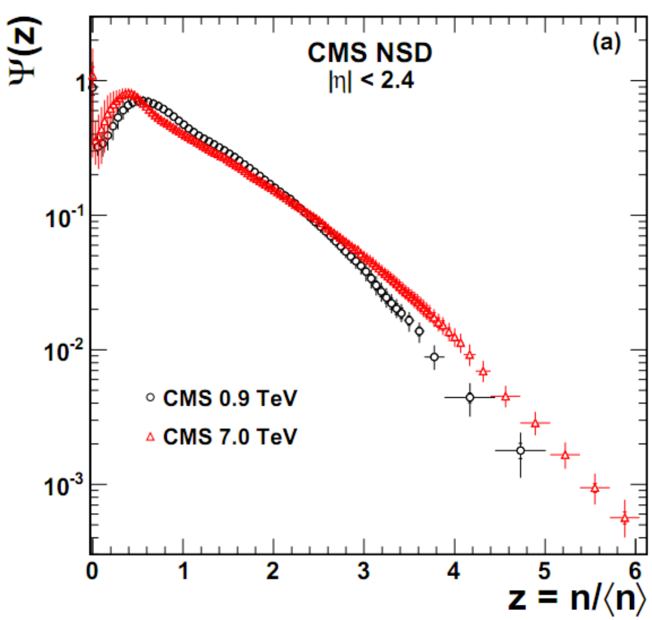
http://lpcc.web.cern.ch/LPCC/index.php



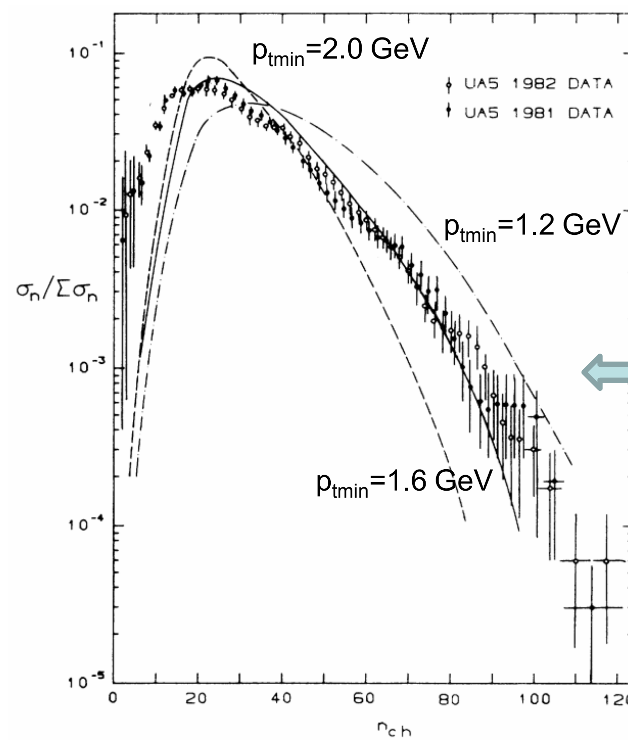
- New CMS Pythia 6.4 (pt-ordered showers) tune by R.Field based on UE observables
- Main parameters related to MPI model in Pyhthia
- Predictions of this new tune compared with MB multiplicity data
- Works much better than older (Tevatron tunes)
- Still fail to describe the highest multiplicity tails

Multiplicities and KNO scaling

- KNO Scaling is not a consequence of Feynman scaling, but of hadrons produced by the self-similar branching of a single string assuming a fixed coupling constant
- Strong KNO scaling violation in intermediate-range pseudorapidity intervals is an indication of multiple (soft) interactions



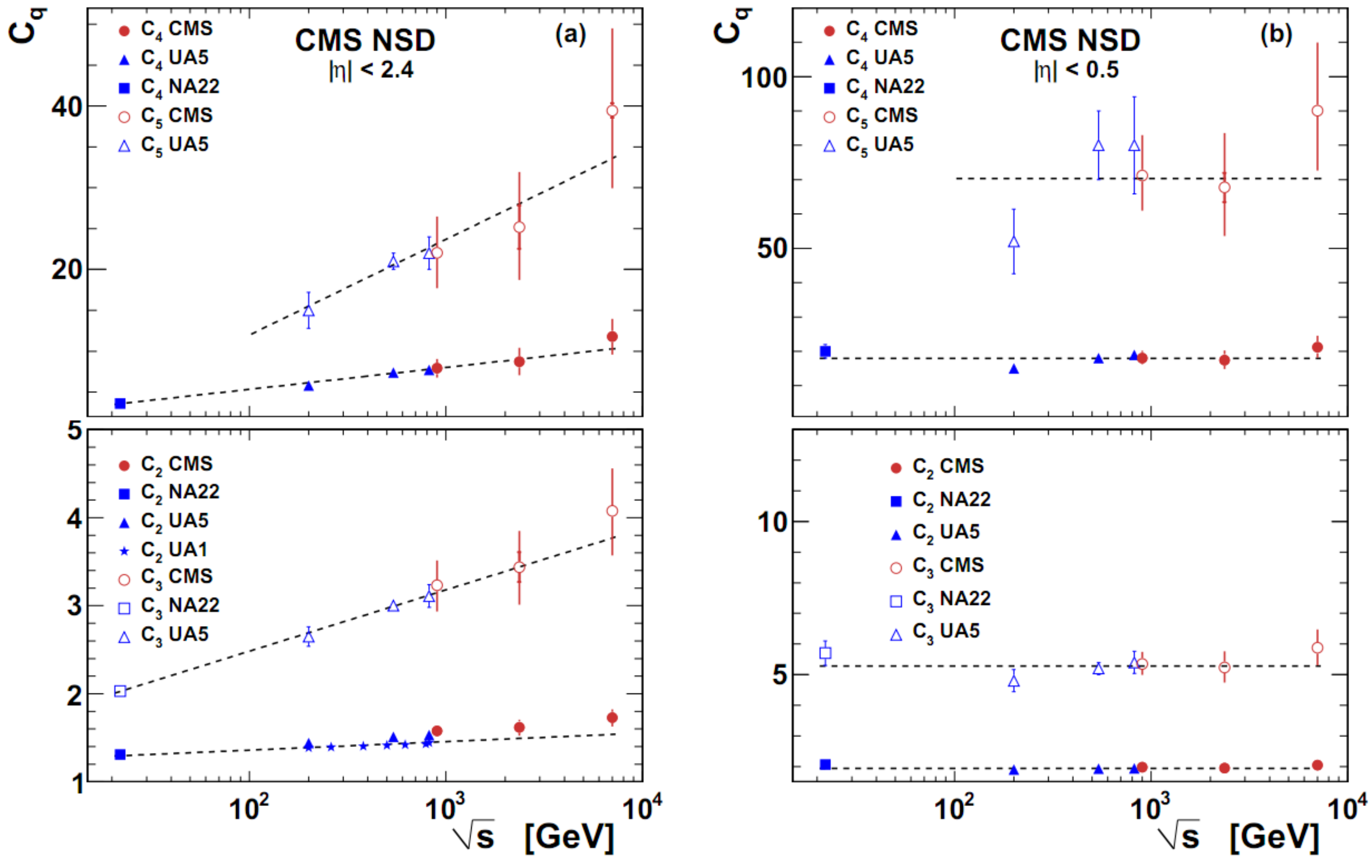
CMS Coll., Submitted to JHEP (2010), arXiV



Interpretation of UA5 540 GeV data:
T. Sjostrand and M. van Zijl, Phys. Rev. D36(1987) 2019

Average number of Interactions increases with decreasing p_{tmin}: 0.56, 1.01, 2.11

KNO scaling in small rapidity intervals



$$C_q = \frac{\langle n^q \rangle}{\langle n \rangle^q}$$

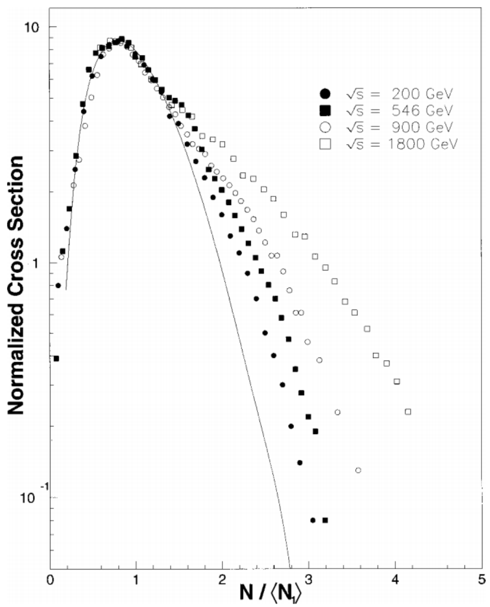
Increase with s indicates KNO scaling violation

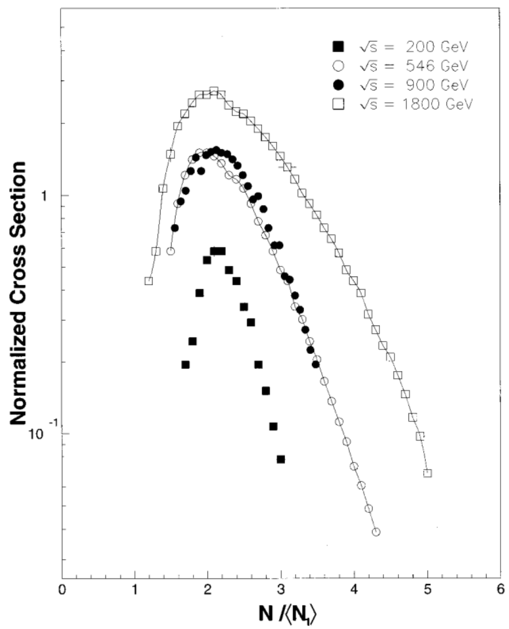
KNO scaling holds for small rapidity intervals (as seen by ALICE)

Negative Binomial Distribution

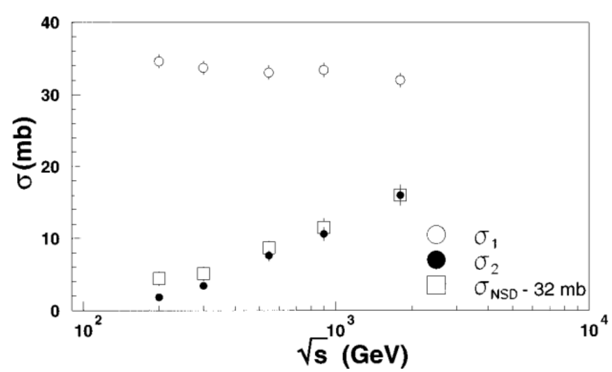
- Single NBD distribution corresponds to completely chaotic (gaussian) system in which all higher order correlations can be expressed in terms of two-particle correlations
- Single NBD's are observed in e+e-, low energy h-h and in very small phase domains (single string events)
- SppS andTevatron data indicate multiple NBD structure in h-h at high energies in intermediate size rapidity ranges

S.G. Matinyan and W. D. Walker, Phys. Rev. D59 (1999) 034022

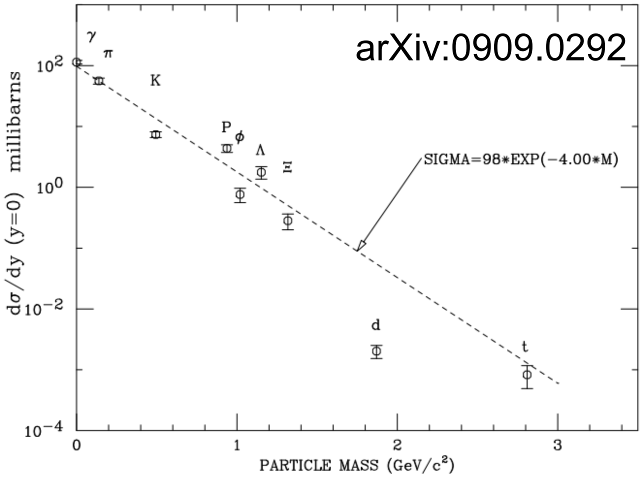


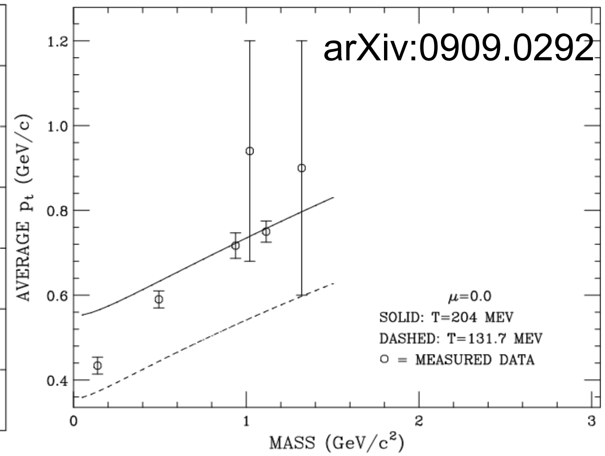


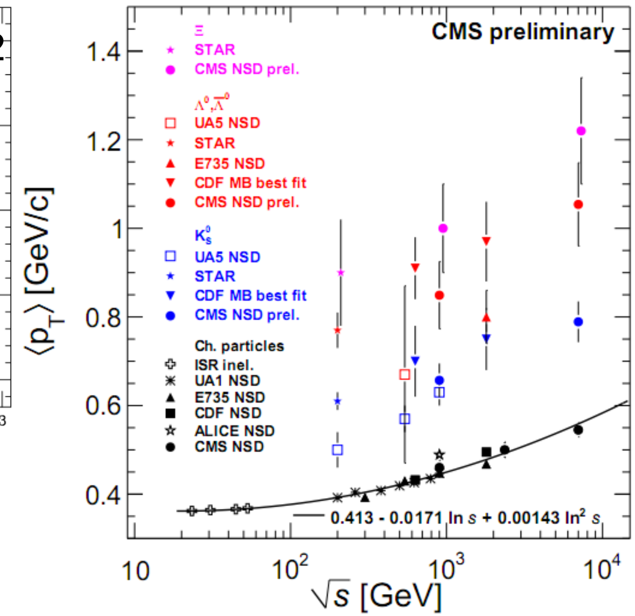
- **Subtract ISR component from data at Higher energies**
- **Integrate remaining fraction to derive cross section for second parton-parton interaction**
- **This cross section saturates around 1 TeV**



Identified particles



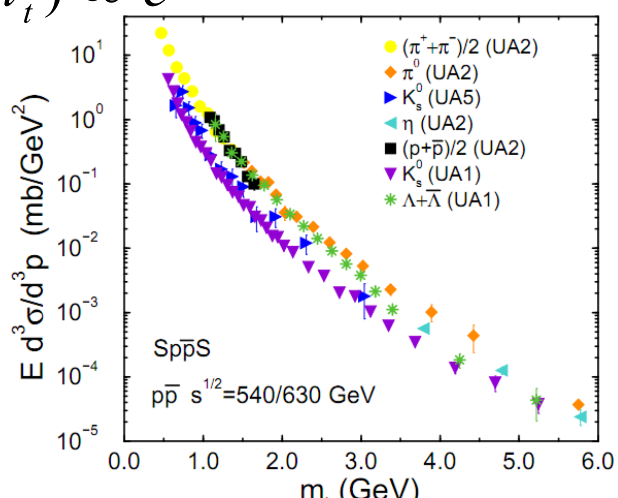




CMS PAS QCD-10-007

Schwinger tunneling in a color flux tube (string):

$$P(m_t) \propto e^{-\pi m_t^2/\kappa}$$

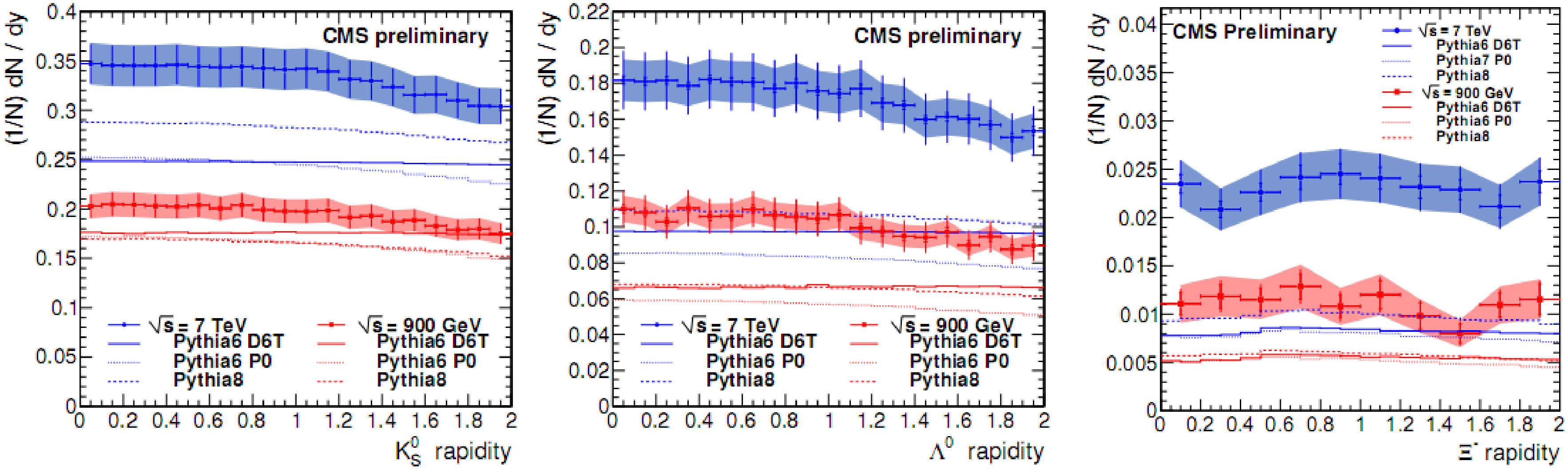


J. Schaffner-Bielich et al. nucl-th/0202054

- Heavy quarks are suppressed
- Suppression is fairly independent of CM energy
- <pt> increases for heavier particles (H. Satz, Phys. Rev. D17 (1978) 914)
- What would happen if κ depends on sqrt(s) or multiplicity …. ?

Strangeness production

CMS PAS QCD-10-007



Pythia underestimates the production yield of Strange particles at all energies

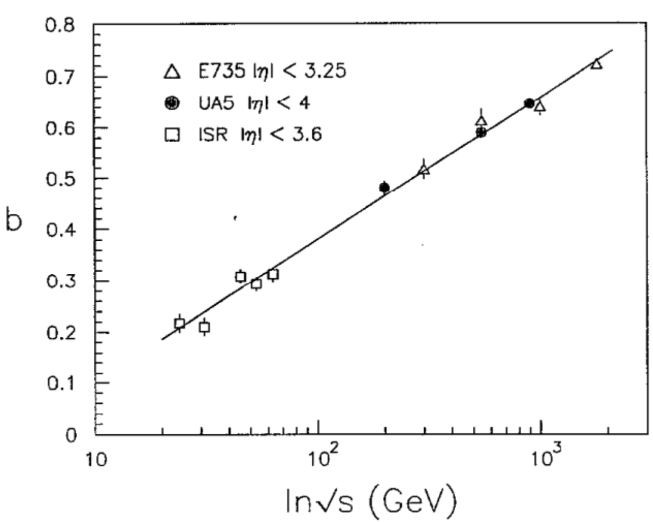
And

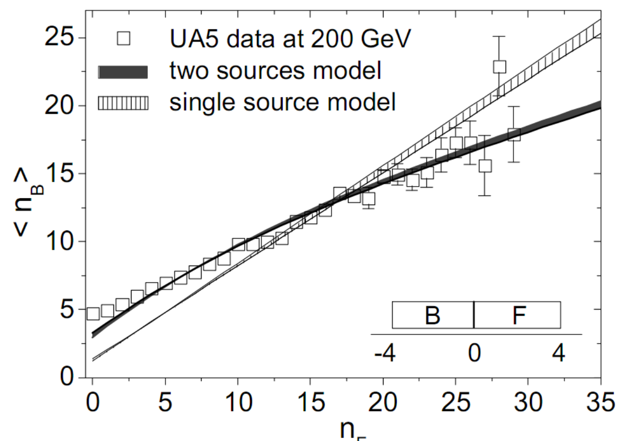
Also underestimates the large increase of the production cross section (1.7 K^0-Λ, 2.1 Ξ) between 0.9 and 7 TeV

Two-particle correlations

- String fragmentation introduces short range order in rapidity
- Decay of resonances imposes short range two-particle correlations
- CMS has measured cluster size of 2.5-2.75 (900 GeV – 7 TeV) by means of short range rapidity correlations that can not be explained by resonances alone (CMS Coll, J. High Energy Phys., 09: 091, 2010.)
- Long-range rapidity correlations arise naturally from a fluctuating number of extra particle production sources: strength ~ $<k^2> - <k>^2$ (A. Capella and J. Tran Thahn Van, Z. Phys. C18 (1983) 85.
- Additional , unexpected same side, long range rapidity correlations observed by CMS (see X. Janssen's talk)

E735 Coll, PLB 353 (1995) 155





A. Bzdak, arXiV: 0906.2858

Increase of F-B correlation strength with energy
Is an indication of increasing MPI at high energies

Conclusion and outlook

- Many complementary measurements give insights in:
  - The existence of MPI's
  - The amount of MPI's
  - Their dynamics, and hardness scale
- Some of these measurements have not yet been performed at the LHC (jet-nojet, F-B, multi component, K/pi, …)
- Interesting to compare results of min bias (# of MPI and cross sections) with direct measurements of double hard processes
- Eventually we will get a more complete description of soft multihadron production and will understand the universality and growth of total inelastic cross section (and relate it to the diffractive one)

Backup

CMS Detector

Magnetic field of 3.8 Tesla

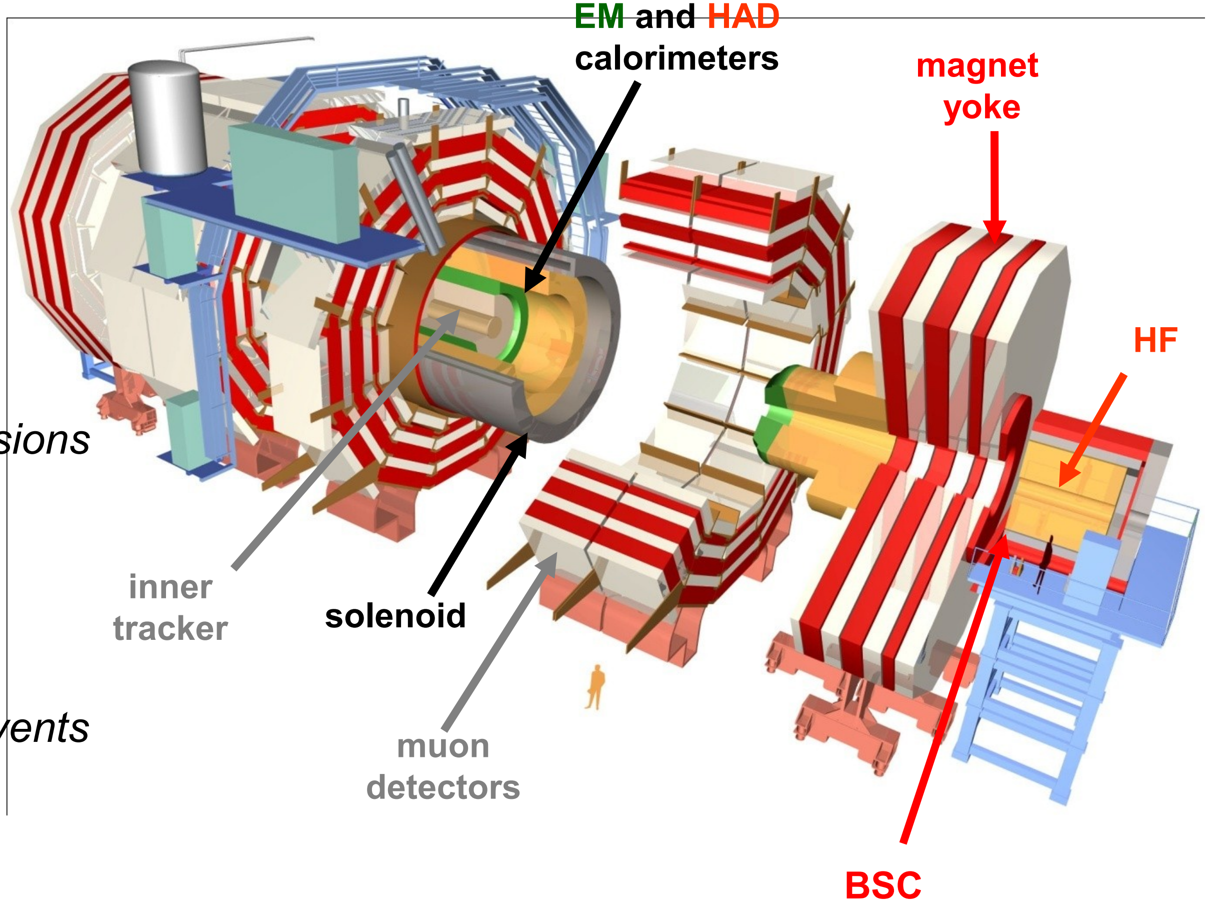
Acceptance of tracker is $|\eta| < 2.5$

Acceptance of BSC is $3.23 < |\eta| < 4.65$

- *Used to trigger on real collisions*

Acceptance of Forward Calorimeter (HF) is $2.9 < |\eta| < 5.2$

- *Used to reject mainly SD events*

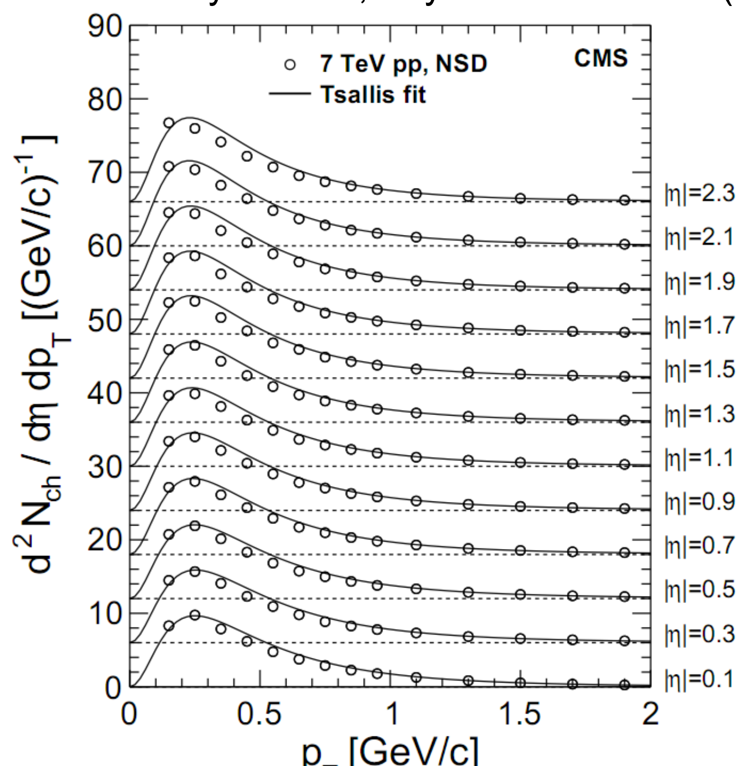


Transverse momenta

Differential yield of charged hadrons in the range $|\eta| < 2.4$ in 0.2-unit-wide bins of $|\eta|$ in NSD events.

V. Khachatryan et al., JHEP 02 (2010) 041

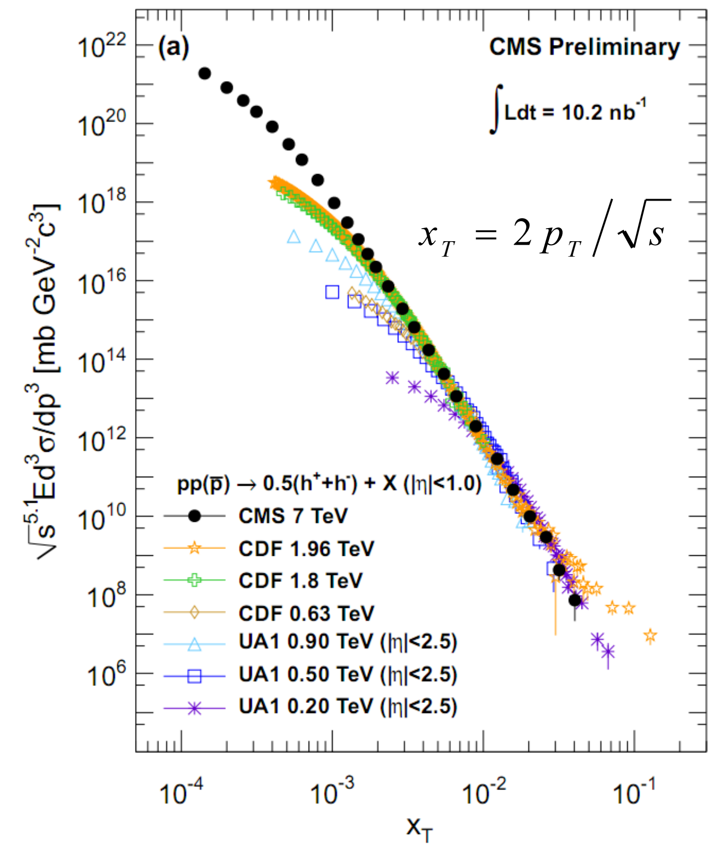
V. Khachatryan et al., Phys. Rev. Lett. 105 (2010) 022002



Tsallis fit gives good description

$$E\frac{d^3N_{ch}}{dp^3} = \frac{1}{2\pi p_T}\frac{E}{p}\frac{d^2N_{ch}}{d\eta dp_T} = C(n,T,m)\frac{dN_{ch}}{dy}\left(1+\frac{E_T}{nT}\right)^{-n}$$

CMS PAS QCD-10-008



Measured tracks up to 140 GeV/c

$\frac{\Delta p}{p} \le 10\%$ for p<1TeV

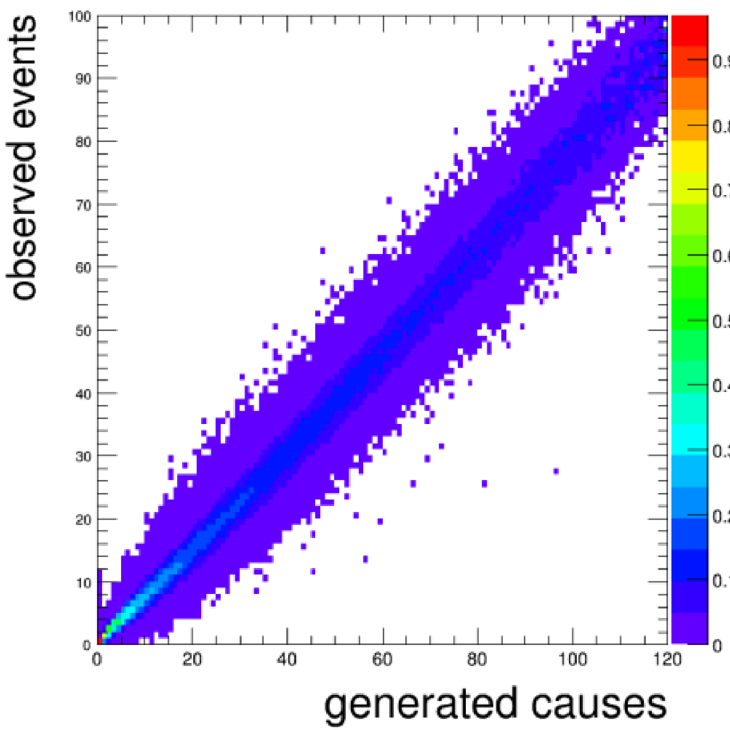
Power law scaling:

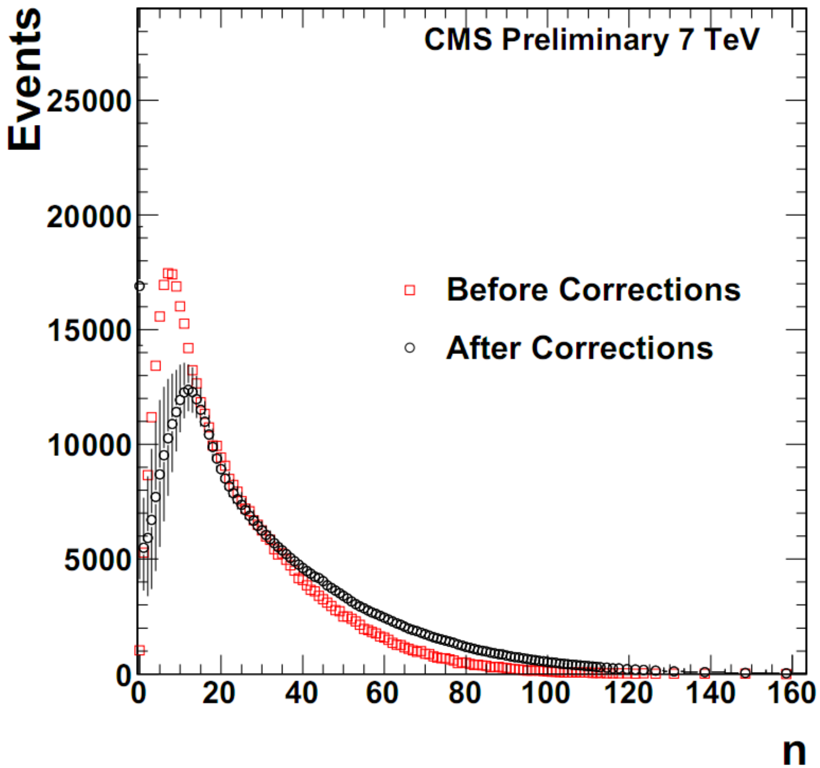
$$E\frac{d^3\sigma}{dp^3} = F(x_T)/\sqrt{s}^{\,n(x_T,\sqrt{s})}$$

n≅5-6

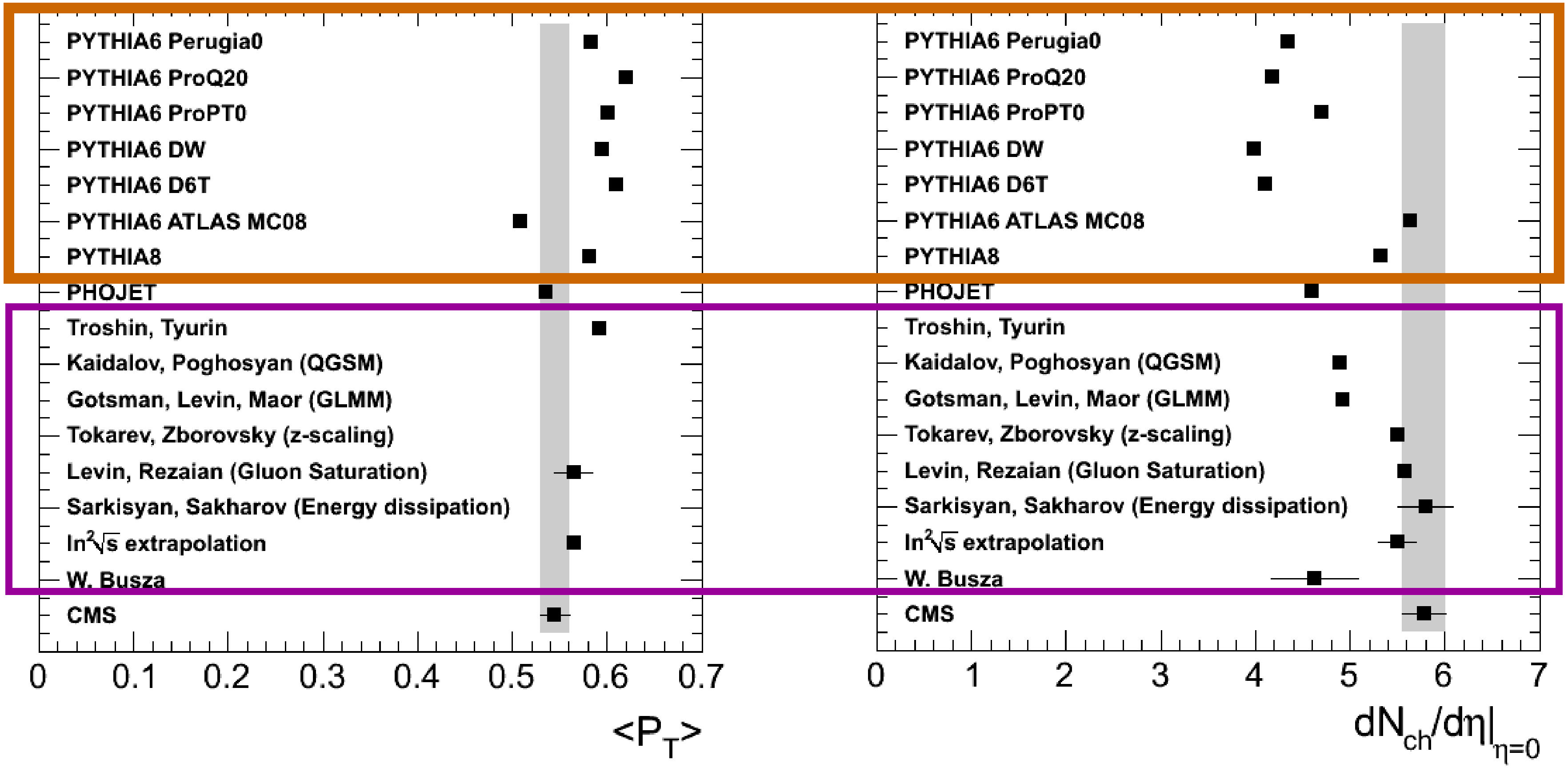
Unfolding

P(E|C) probabilities matrix
{in hypothesis of full efficiency (eff=1.) for each "cause", vertical rows are normalized to 1.}
from migration matrix of MinBias track reconstruction @10TeV





Model Comparisons



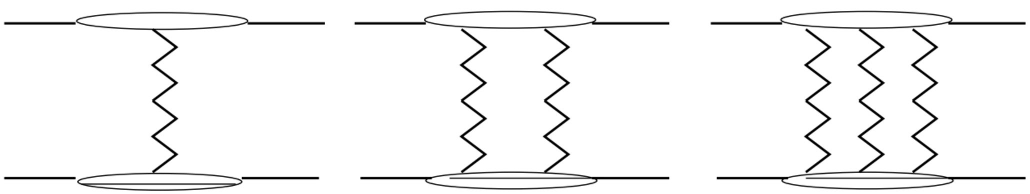
Most PYTHIA tunes overestimate <Pt> and underestimate dN/dη

Some analytical models are spot on

Cross sections, Pomerons and MPI

- ☞ Universal rise of the cross section, $\sigma_{tot} \sim s^{\varepsilon}$, violates unitarity at high s
- ☞ $\sigma_{el} \leq \frac{1}{2}\, \sigma_{tot}$ (black disk geometrical limit)
- ☞ $\sigma_{SD} / \sigma_{tot}$ is observed to be fairly constant

$\Rightarrow$ Multi-Pomeron exchanges $\Leftrightarrow$ Multi Parton interactions



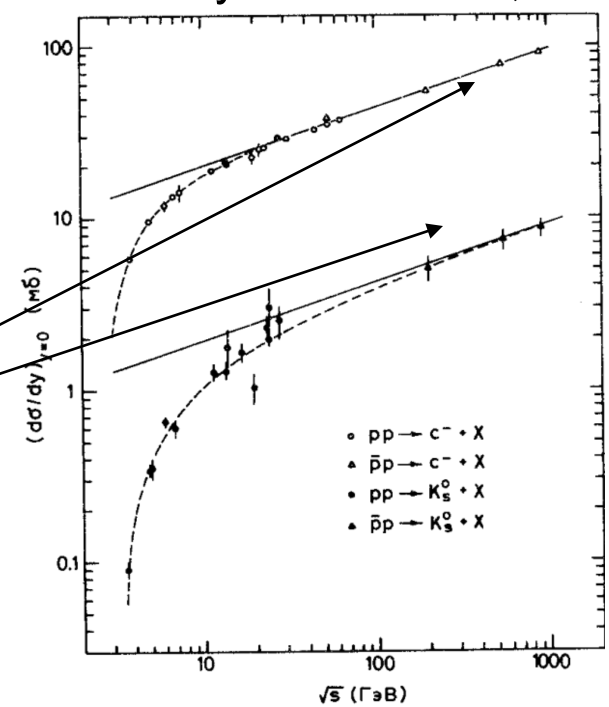
(a) (b) (c)

R. Engel: $\sigma_{tot} = \sum_{n=1}^{\infty} (-1)^n \sigma^{(n)}$

$$\left. \frac{d\sigma}{dy} \right|_{y=0} = \alpha . s^{\Delta} \quad \text{at high s}$$

With $\Delta = 0.170 \pm 0.008$

From Phys. Lett. **B215**, 417, 1988



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

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

Modeling MPI

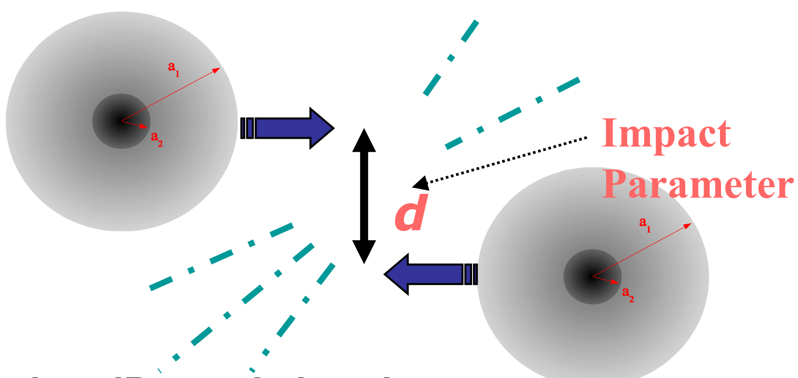
Basic idea T. Sjöstrand and M. Van Zijl, Phys. Rev. D 36 (1987) 2019

- 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}

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

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

Motivations

- ☞ Minimum bias=typical p-p collision free of non-collision background
  - ➢Dominated by low pt QCD processes (non –perturbative)
  - ➢Also σ_{nd} ~2/3 σ_{tot}, = 75 mb

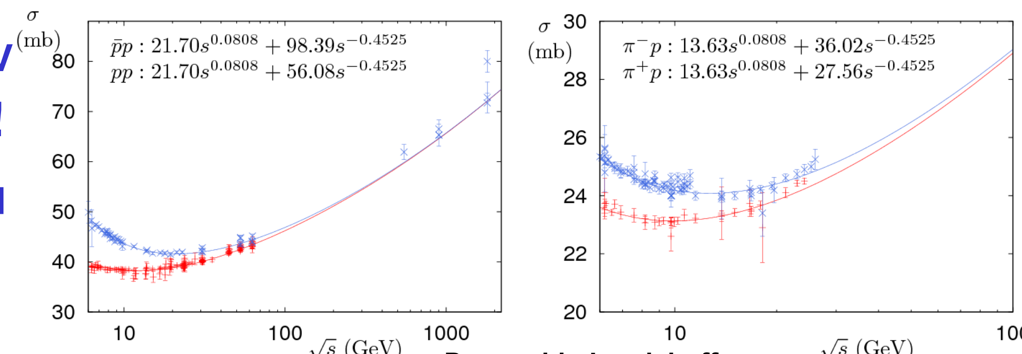
☞At High lumi, pile up will consist of many min bias events (O(20)).

☞Soft component superimposed on hard scatters (UE event) is <u>not identical</u> to MB but has same phenomenology

☞ As reference to heavy ion runs at 2.76*ATeV

But also to learn about the physics !

☞ At high s, all hadron hadron (and γ*p at fixed low Q) cross sections grow in a similar way
  - ☞ Many indications of universality

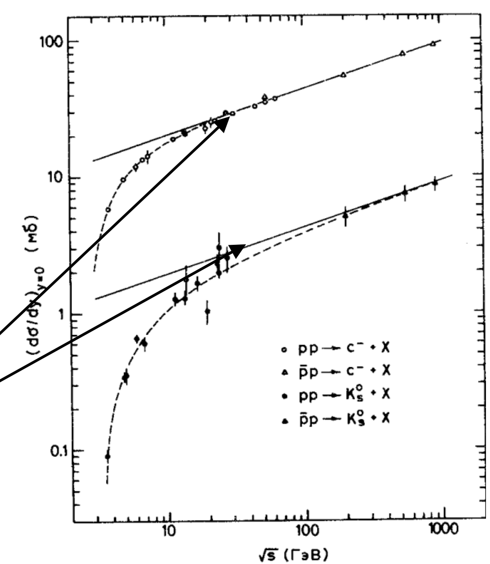


Donnachie-Landshoff

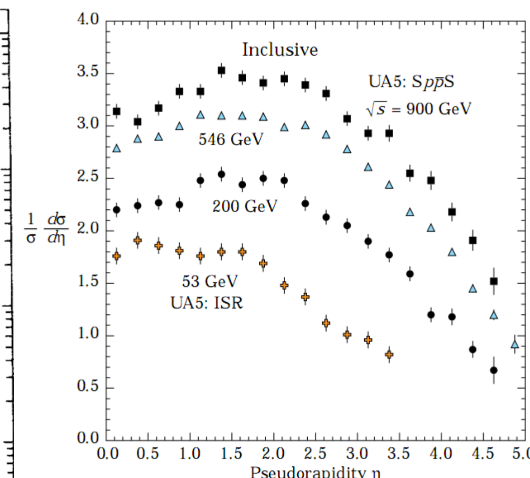
☞ σ_{tot} and σ_{inel} are not easy measurements, but inclusive single particle spectra and multiplicities are

☞ Precision of present day measurements do not allow discrimination between power law (regge-Type) behavior, s^{ε} , or fits by log(s) or $\log^2(s)$ or $e^{\sqrt{(\log s)}}$

$$\left.\frac{d\sigma}{dy}\right|_{y=0} = \alpha . s^{\Delta}$$



Uvarov-Schlapnikov-Likhoded



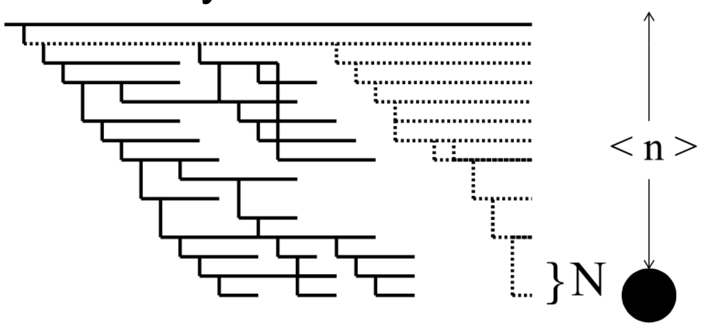
Multiplicities

☞ Universal high s behavior of σ_{tot}, independent of the particle species is an important observation, calling for a deeper understanding

☞ Related to number of dipoles in parton shower

☞ Contains information on particle production mechanism, short range order and QM symmetrisation effects

Feynman & Gribov



$$\sigma_{tot} \approx 0.5 \cdot \delta \cdot \langle n \rangle$$

$$\sigma_{diff+el} \approx \frac{\delta^2}{4} \langle n^2 \rangle$$

- **Accelerated parton radiates soft 'wee' partons**
- **Wee partons forget the identity of their parent hadron**
- **Hadron-hadron collisons are to first order an interaction of 2 'wee' partons**
- **interaction probability of two wee partons (nowadays called color dipoles) is INDEPENDENT of s in LO QCD**
- **s dependence comes from the probability distribution of wee partons P(n)**

If P(n) is Poissonian.

⇔ Good & Walker formalism, based on unitarity!

Explains also t-slope of inelastic events