Overview of Soft QCD and diffractive physics at LHC

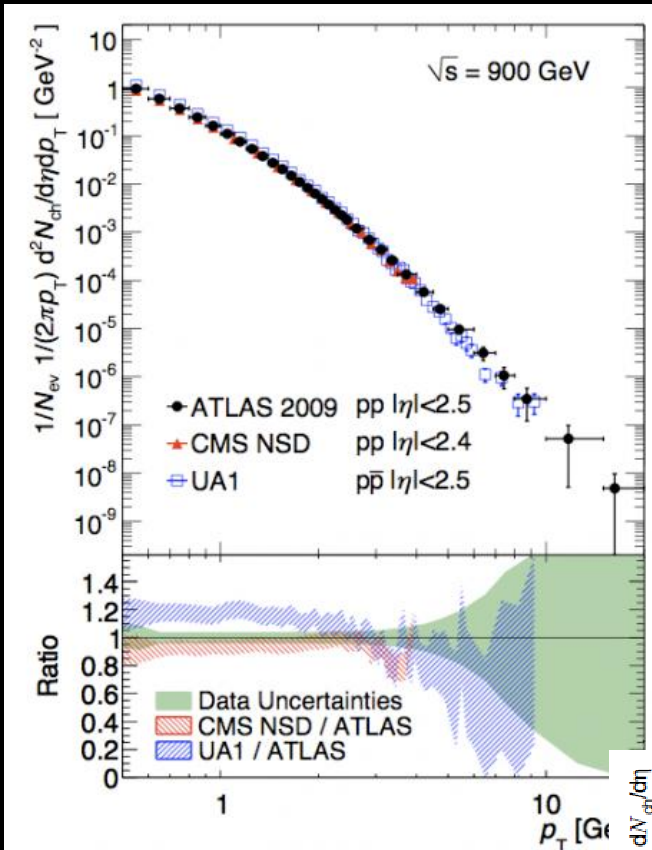
E. Scapparone
PLHC2012,
June 5, 2012

- Soft QCD processes: inclusive and exclusive measurements;
- Strange mesons/baryons → the MC tuning;
- The inelastic cross section;
- Diffraction (from scintillators to calorimetry);
- A lot of results from ALICE, ATLAS EXPERIMENT, CMS, LHCb, TOTEM :

  not a comprehensive review;

Inclusive production

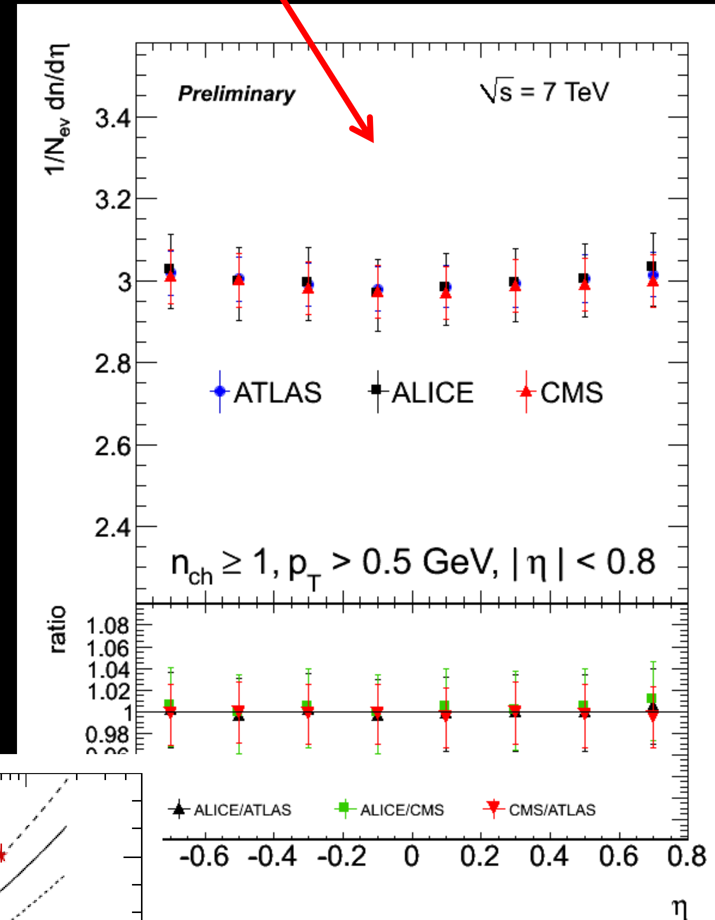
Nice agreement between experiments..(MB&UE WG)

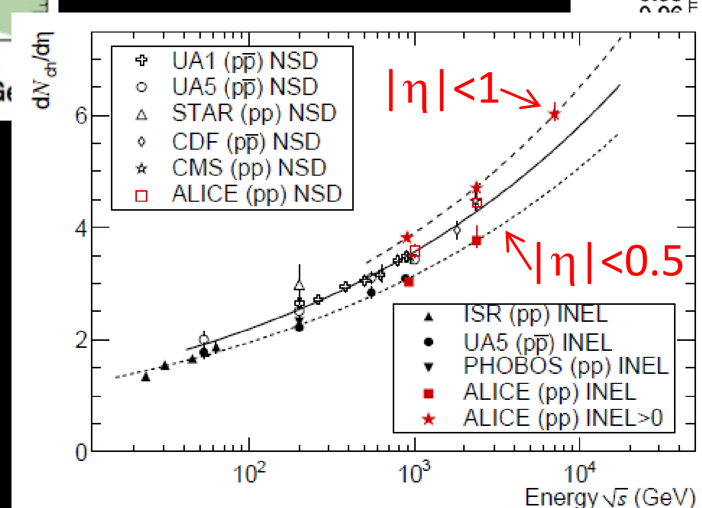


Phys. Lett. B688 (2010) 21

dN/dη →

← dN/dp$_t$

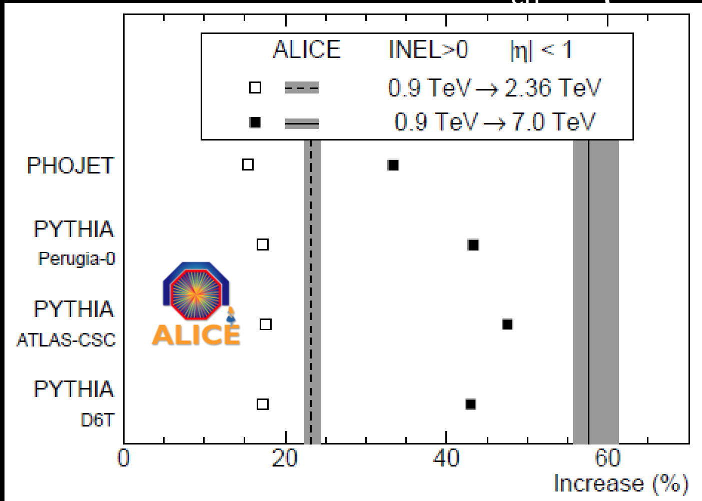


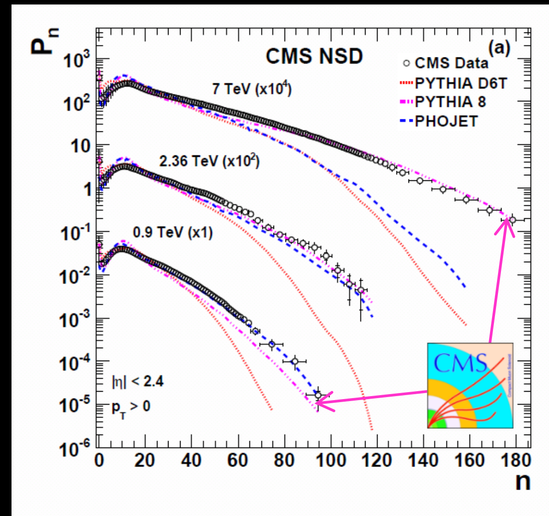


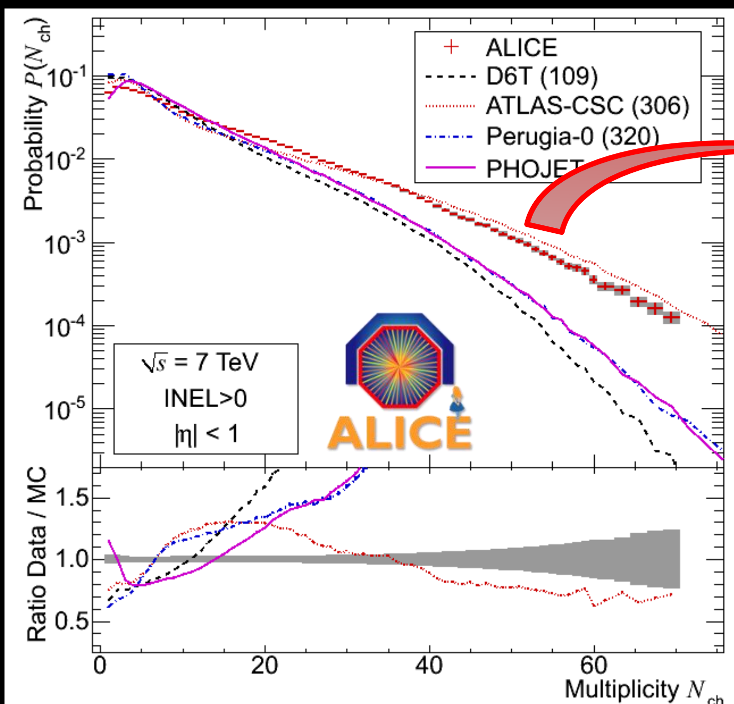
EPJ C68 (2010) 345

..but the comparison with MCs is another story…

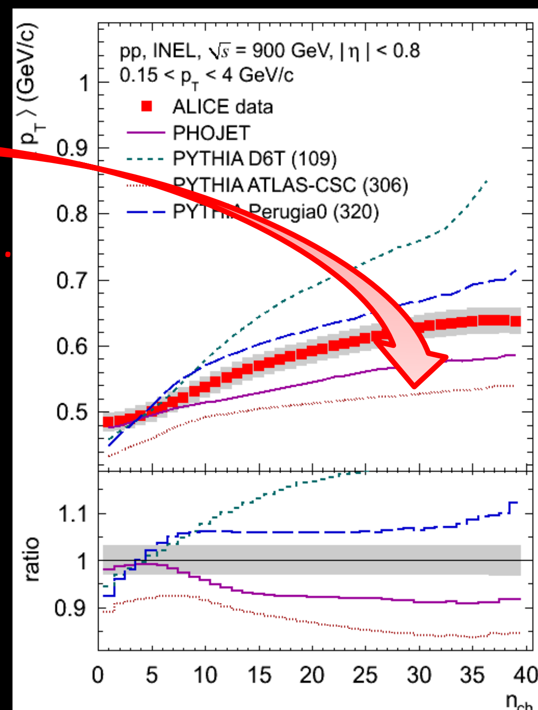
Relative increase in $dN_{ch}/d\eta$







but..



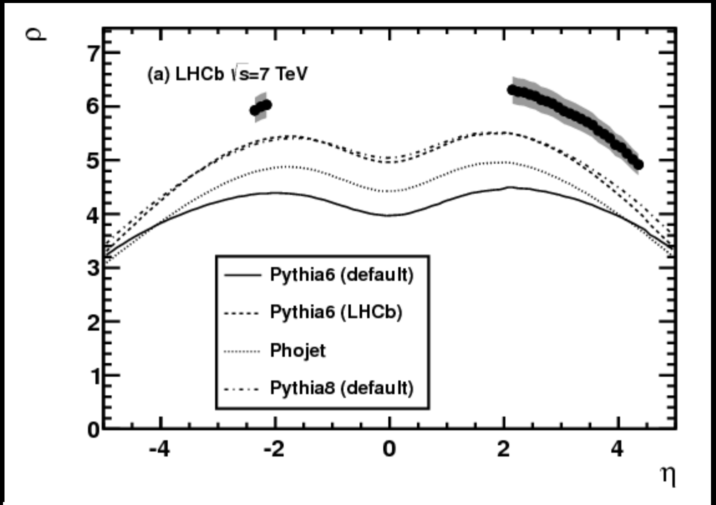
EPJ C68 (2010), 89
EPJ C68 (2010), 345

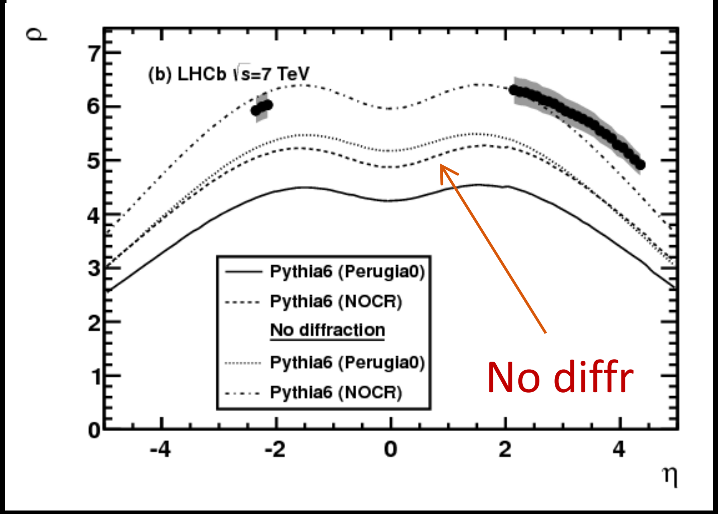
The forward region → LHCb

$-2.5 < \eta < -2$ or $2 < \eta < 4.5$

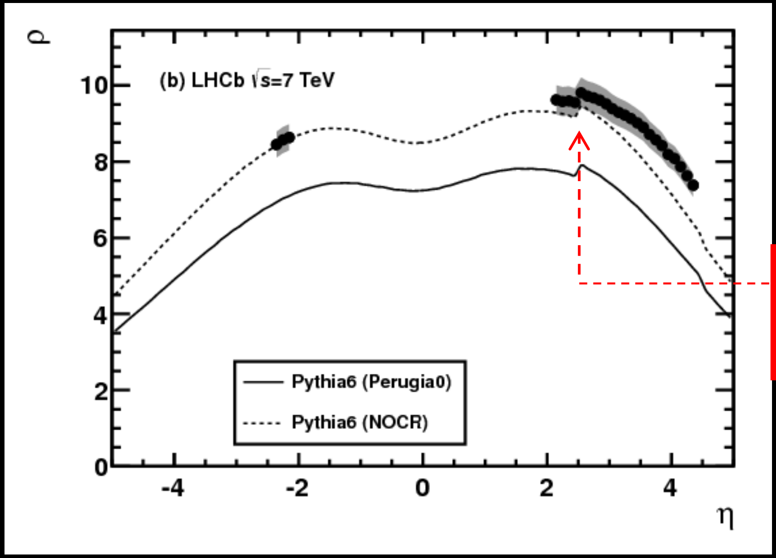
N > 1 in the $2 < \eta < 4.5$ region

EPJ C72 (2012) 1947





At least: 1 track in $2 < \eta < 4.5$ (asimmetry) with $p_t > 1$ GeV/c



Artefact of the event selection for the hard events

The models (default or tuned) underestimated the charged particle production (as in the central region)

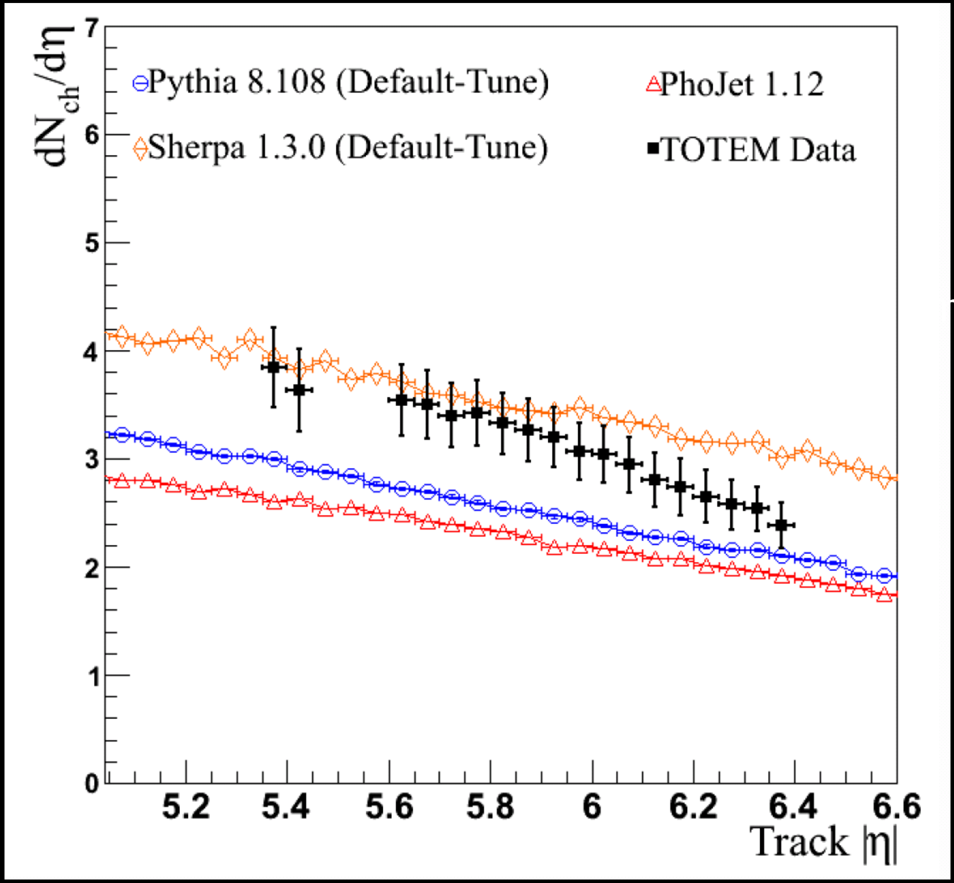
Not forward enough?

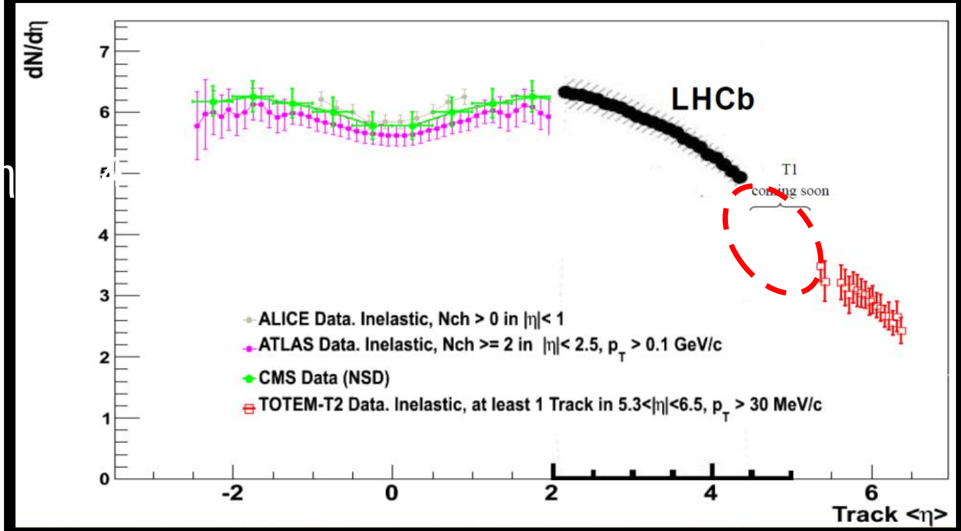
TOTEM ($5.3 < \eta < 6.4$)

$\sqrt{s}$ = 7 TeV p_T >40 MeV/c $N_{ch} \geq 1$

Europhysics Lett. 98 (2012) 31002

T2 GEM detector
(13.5 m from IP)





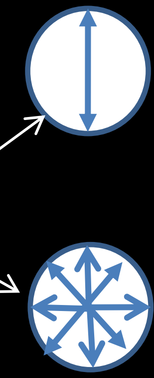
R. Orava, at **"Exclusive and diffractive processes in high energy proton-proton and nucleus-nucleus collisions, (2012)"**

Sherpa by T. Gleisberg et al, JHEP, 0902:007 (2009)

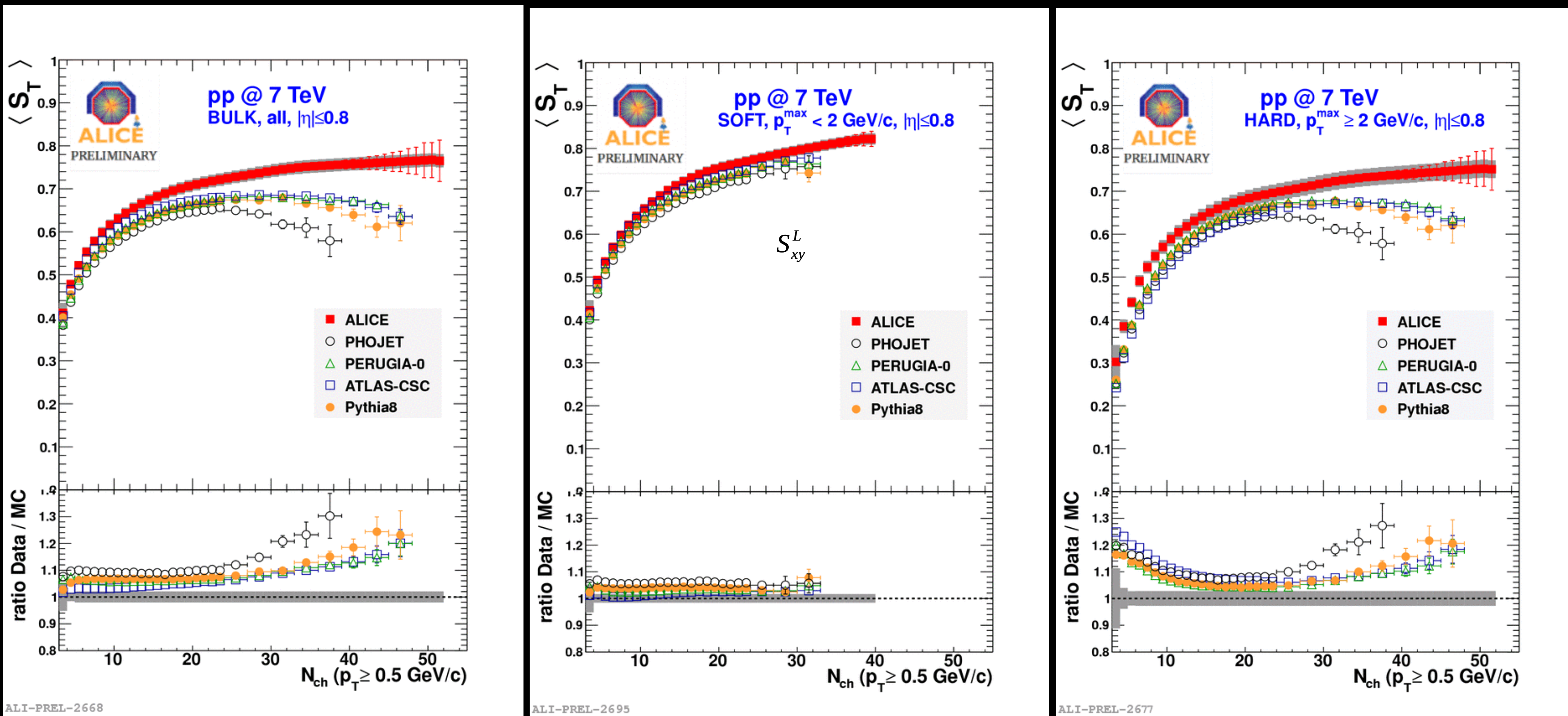
Event transverse sphericity

$$\mathbf{S^L_{xy}} = \frac{1}{\sum_i p_{Ti}} \sum_i \frac{1}{p_{Ti}} \begin{pmatrix} p_{xi}{}^2 & p_{xi}p_{yi} \\ p_{xi}p_{yi} & p_{yi}{}^2 \end{pmatrix}$$

$$S_\perp = \begin{cases} = 0 & \text{“pencil-like” limit} \\ = 1 & \text{“isotropic” limit} \end{cases}$$

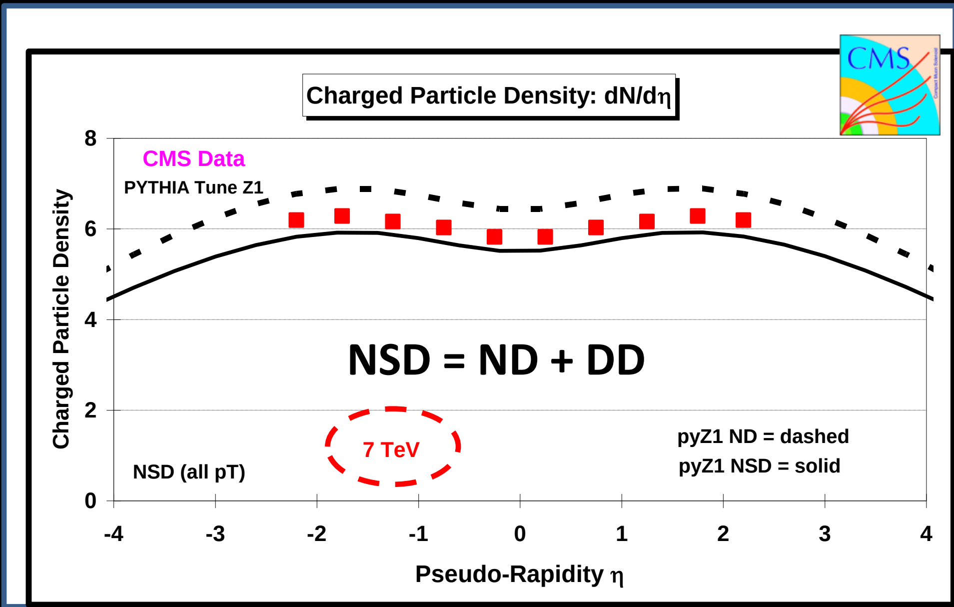


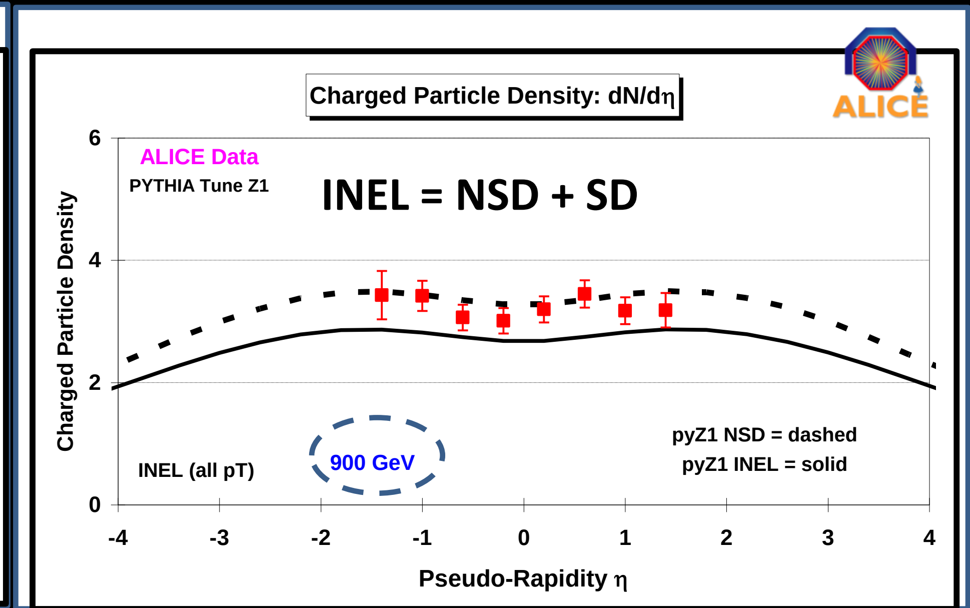
$S_T = 2\lambda_2/(\lambda_1+\lambda_2)$, with λ_1 , λ_2 eigenvalues of the $\mathbf{S^L_{xy}}$ tensor



It's not just a question of rate, charged multiplicity and p_T: events are more spherical, than in MC. Most of the discrepancy comes from hard events.

The search for the ideal tuning (= ) ongoing:





R. Field, NW-Argonne Higgs Workshop, Chicago May 16, 2012

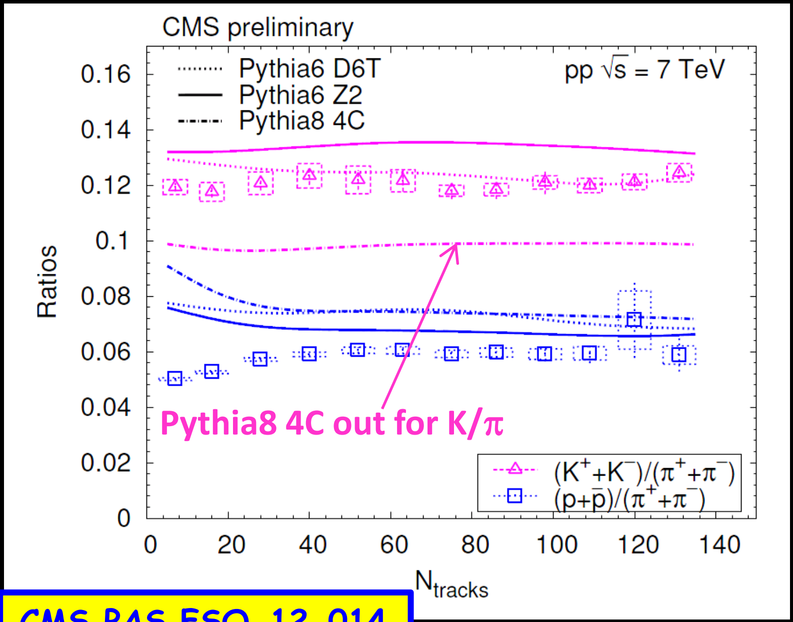
➡ **The LPCC MB&UE Working Group has suggested several MB&UE "Common Plots" the all the LHC groups can produce and compare with each other.**

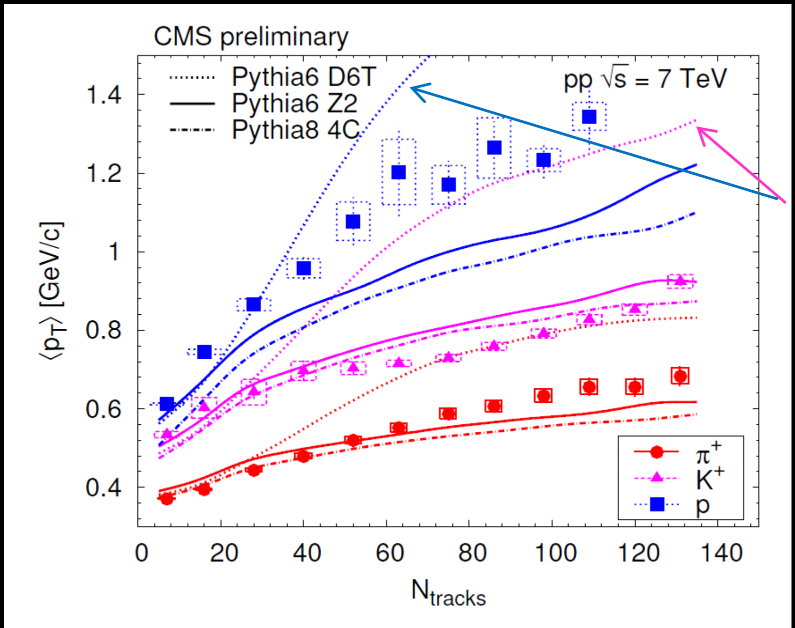
Inclusive measurement summary:

- a wide η interval covered at LHC, the region 4 < η < 5.4 to be filled by TOTEM T1;
- good agreement between the experiments in the overlapping regions;
- default tunes cannot reproduce the data; few tuning do their job better, although not perfectly (Pythia Z1) yet.
- But what about the single hadron (i.e. different quark) tuning ?

Exclusive production

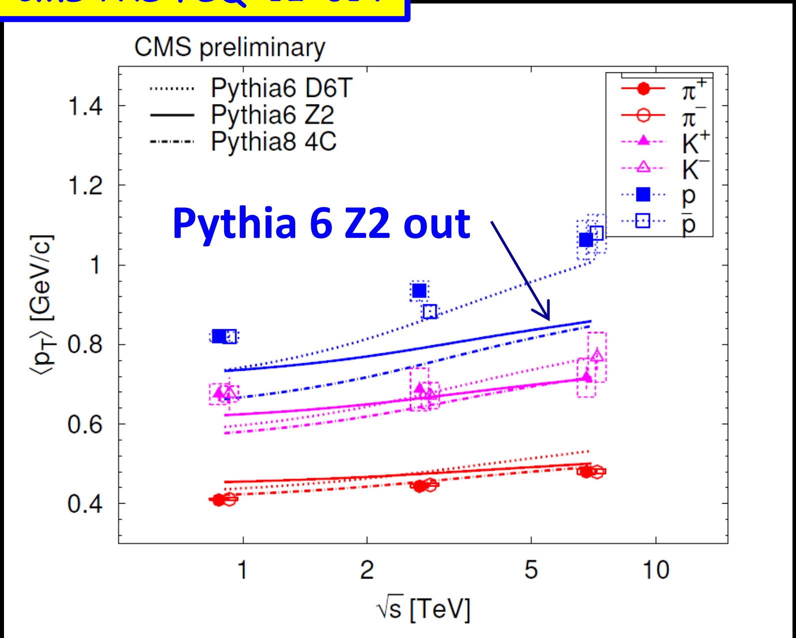
s-quark: soft events, but their modelling is a hard job…..

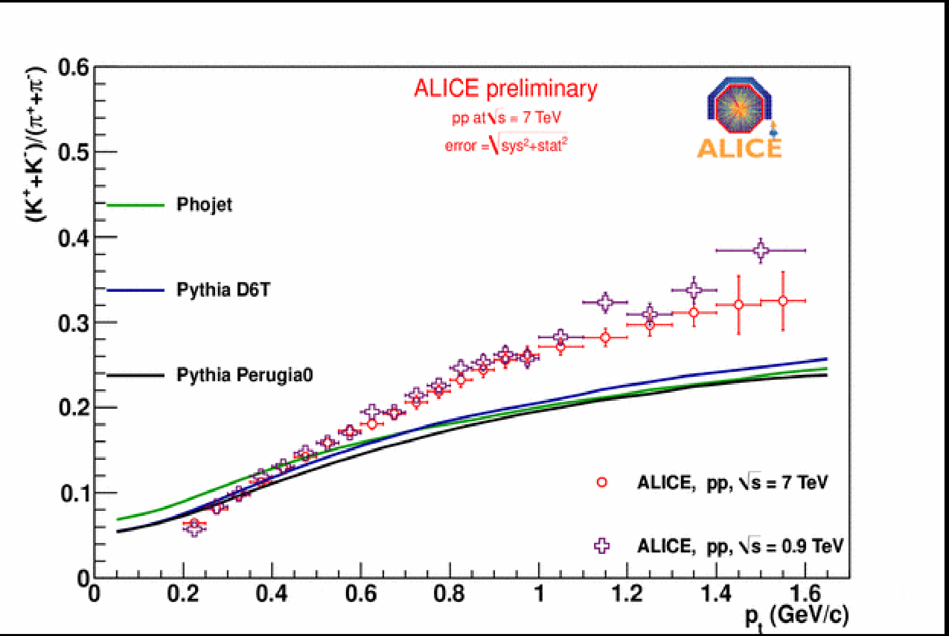




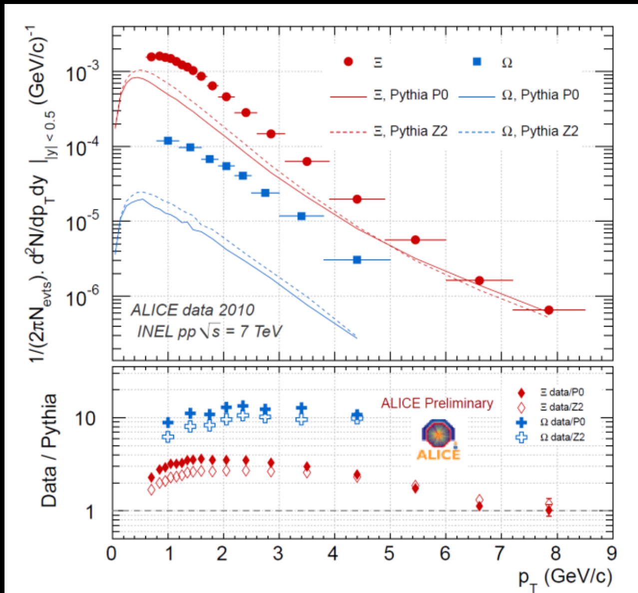
Pythia D6T too hard

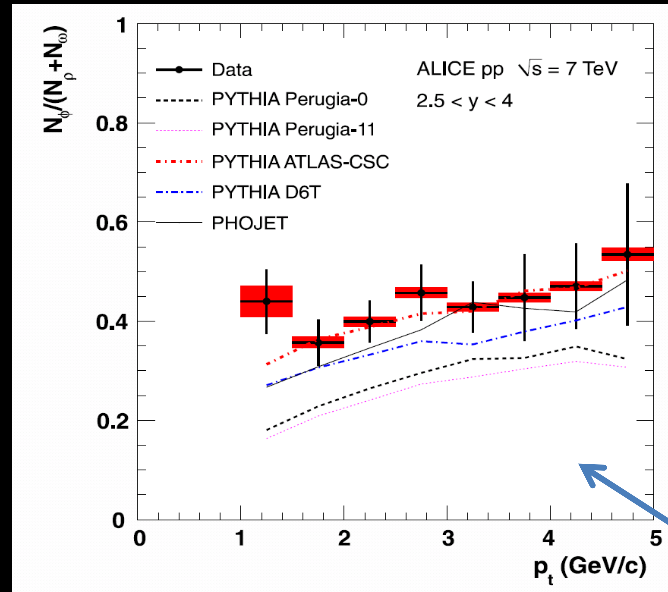
CMS PAS FSQ-12-014





(ss,sss) → Φ,Ξ, Ω, Ξ/Ω

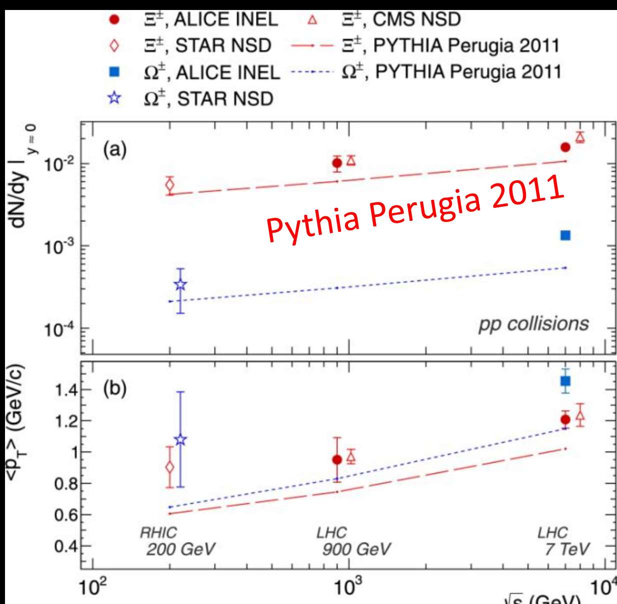


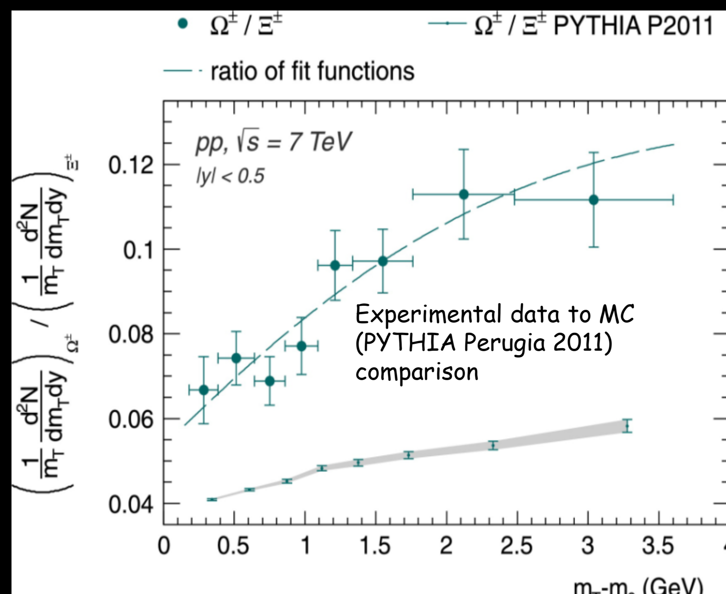


DATA $\sigma_\rho/\sigma_\omega$ =1.15 ±0.20±0.12

PYTHIA/Perugia-0	1.03
PYTHIA/Perugia-11	1.03
PYTHIA/ATLAS-CSC	1.05
PYTHIA/D6T	1.04
PHOJET	1.08

Perugia-0, Perugia-11 and D6T tunes systematically underestimate this ratio, while PHOJET, ATLAS-CSC ~ OK



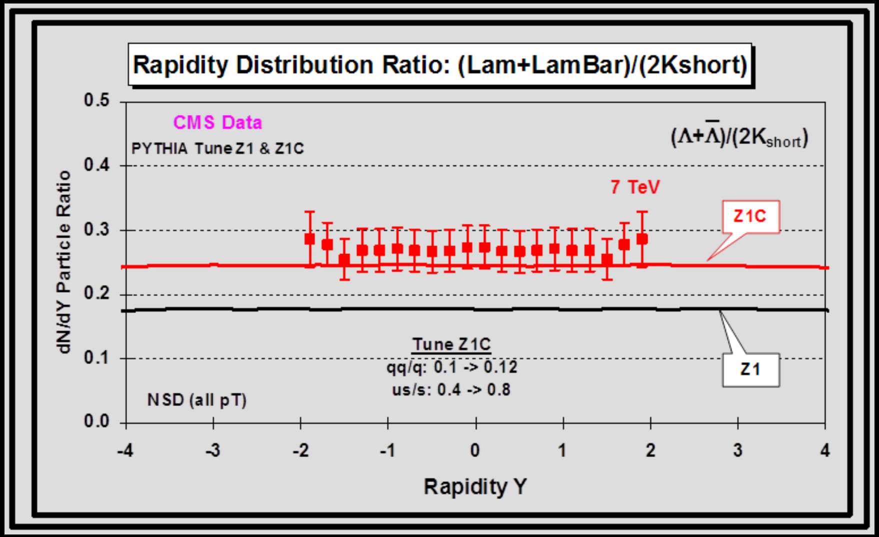


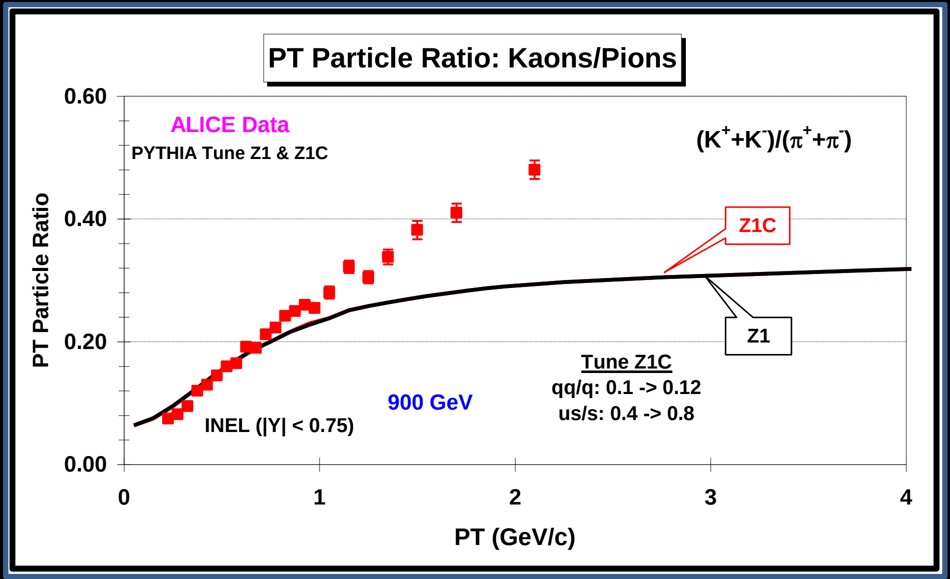
Phys. Lett. B710 (2012) 557

Phys. Lett. B 712(2012) 309

Several tunes were tested, among them PYTHIA Z2, Perugia 2011 and Perugia 0 tunes. These tunes were several times to an order of magnitude below the measured multi-strange spectra and yields (up to a factor 4 for $\Xi^{\pm}$, **15 for $\Omega^{\pm}$**).

Any hope to reproduce the s quark at LHC ? → Z1/Z1C tunings





- PYTHIA Z1/Z1C does not describe correctly the p_T distributions of heavy particles (MC too soft);
- PYTHIA Z1 could give problems with LEP data;
See the talk by R. Field @ QCD@LHC, St. Andrews, Scotland, August 25, 2011.

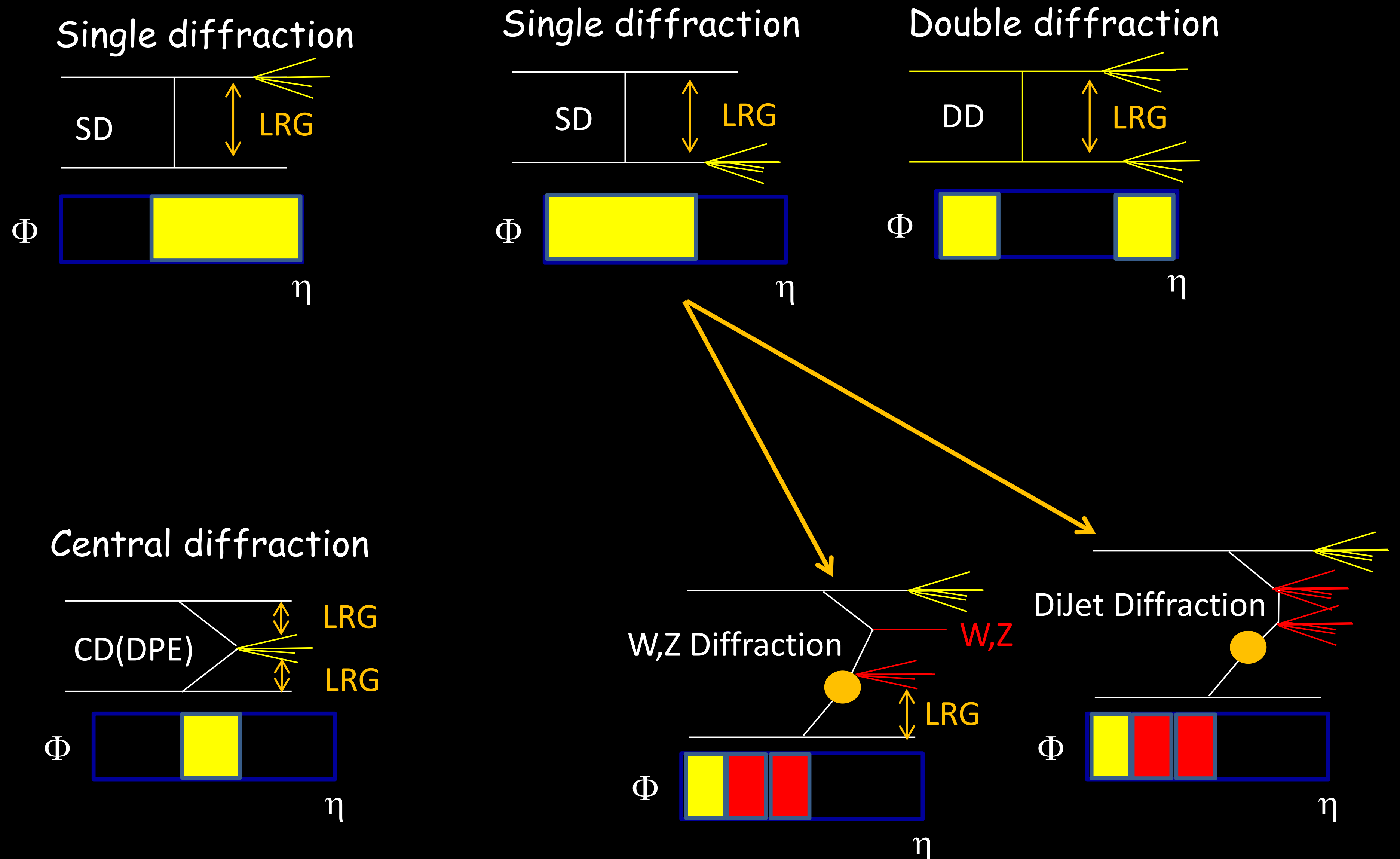
Why tuning is a so difficult task:

- Tuning has to work both for Minimum Bias(MB) and Underlying Events(UE);
- A lot of different mechanisms at work;
- It's easy to modify a given parameter to reproduce an observable; it's difficult to find a single tuning for LEP, CDF, LHC data and for the different LHC energies….

At the moment a large abundance of tunings (Z1, Z2, Z2f, D6T, Perugia 0, Perugia 11,ATLAS CSC, C4,4Cf,…). Most of them reproduce at least few observables, none of them reproduce all the observables.

A big effort ongoing…… A difficult task. Moreover "yes but you have to include diffraction too, that is difficult to be tuned"….so, let's give a look !

..and now diffraction !



probes the quark content of the Pomeron

Diffractive processes are a relevant fraction of the total cross section σ_{tot} → their understanding is mandatory for a full MB and UE modeling

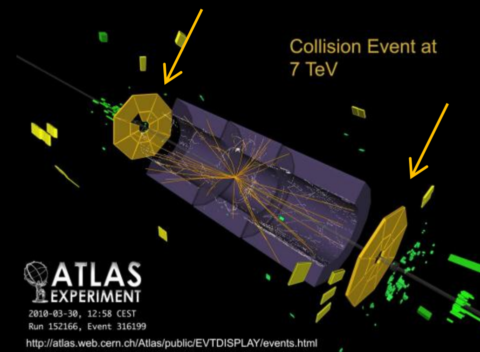
but

- Going from experimental observables to physics quantities requires MC → results often model dependent;
- Diffraction physics requires low pile up runs;
- Experimental challenge: most of the proton excitation remains into the beam pipe;
- Smooth transition from DD to Non Diffractive (ND);
- Small contribution from CD (DPE): modelling not trivial;

Two tecniques: - beam proton tagging or (requires roman pots, limited η)
- large rapidity GAP (widely used)

The INEL cross section

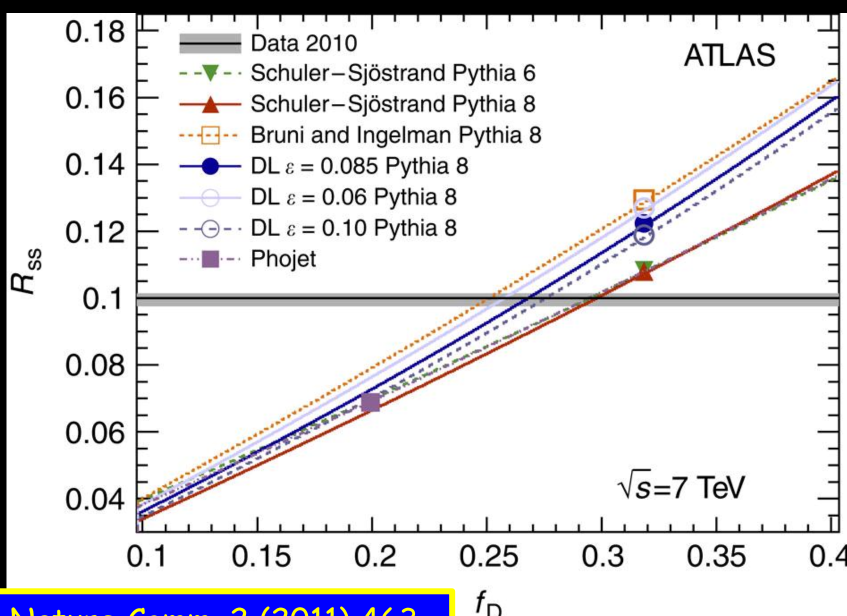
MBTS(Minimum Bias Trigger Scintillator)
±3.6 m from the IP, $2.1 < |\eta| < 3.8$



intact p: $\eta = 8.85$(@7 TeV)
X system: $\eta_X < 3.8$
$\rightarrow \Delta\eta \leq 12.2$

$\xi \sim e^{-\Delta\eta} > 5 \times 10^{-6}$
$\xi = M_x^2/s \rightarrow M_X > 15.7$ GeV

The first commandment: constrain the diffraction



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Single sided event ratio $R_{ss} = N_{SS}/All$

MC generators predict < 1% of the ND process pass the single-sided event selection, whereas 27–41% of the SD and DD processes pass the single-sided selection. sensitive to the relative fraction of diffractive events $R_{ss} = N_{SS}/All$.

$$R_{ss} = (10.02 \pm 0.03(\text{stat}) \pm^{+0.1}_{-0.4} (\text{sys.}))\%$$

$$f_D = (\sigma_{SD} + \sigma_{DD} + \sigma_{CD})/\sigma_{inel} = (26.9\ ^{+2.5}_{-1.0})\%$$

MC rescaling: Pythia 8 + the Donnachie and Landshoff tuning (DL) is the ATLAS Ref. model: $F_D(DL)=26.9$ %

Beam gas events

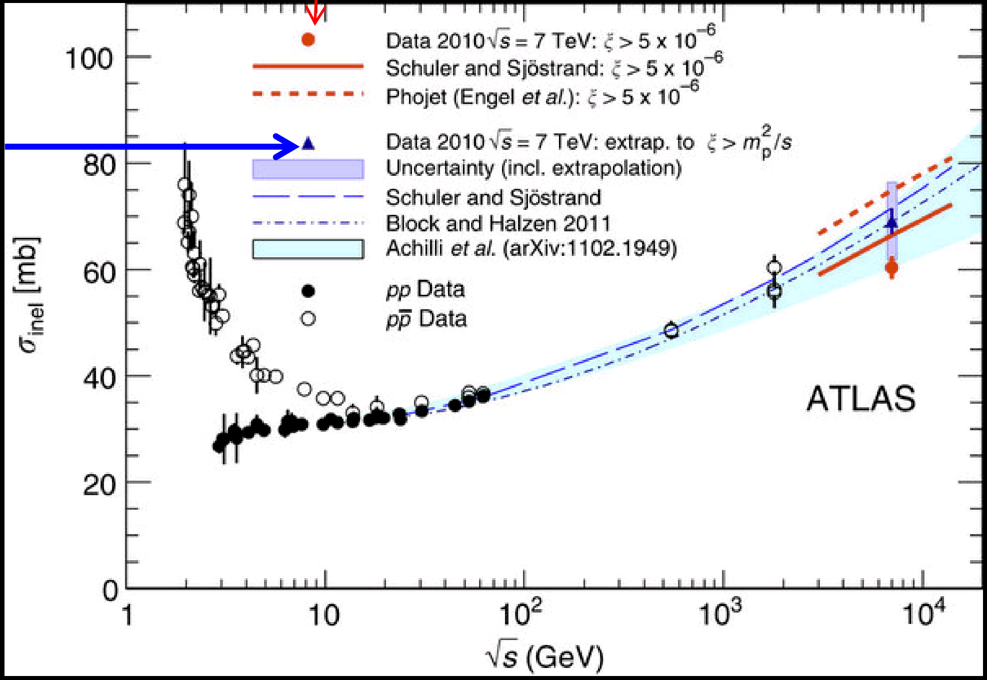
$$\sigma_{inel}(\xi > 5\cdot 10^{-6}) = \frac{(N-N_{back})\cdot(1-f_{\xi<5\cdot 10^{-6}})}{\varepsilon_{trig}\cdot \mathscr{L} \cdot \varepsilon_{sel}} = (60.3 \pm 0.05(stat) \pm 2.1(lumi))\ mb$$

Going from $\xi > 5\cdot 10^{-6}$ to the full range → $\varepsilon(\xi > 5\cdot 10^{-6}) = (87\pm 10)\%$, ranging from

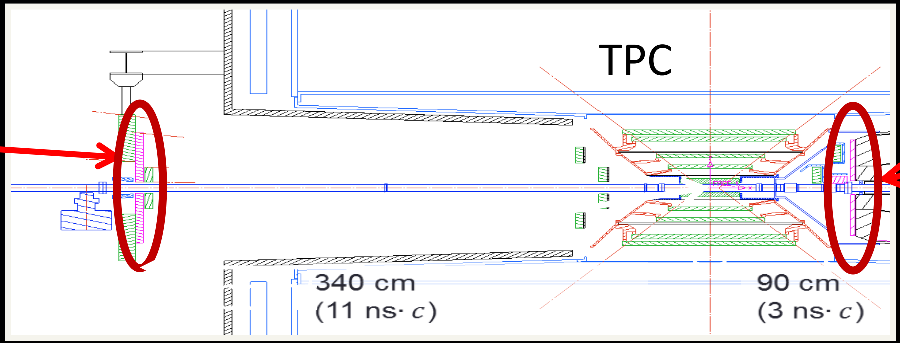
- 79% (Ryskin et al., EPJ C71(2011) 1617)
- 96% (Phojet)

Central value by Donnachie and Landshoff(DL), $d\sigma_{SD}/d\xi \sim 1/\xi^{1+\varepsilon}$, $\alpha'=0.35$GeV/c and $\varepsilon=0.085$, $\alpha(t) = \alpha(0)+\alpha' t$.

$\sigma_{inel} = (69.1 \pm 2.4(stat) \pm 6.9(lumi))\ mb$



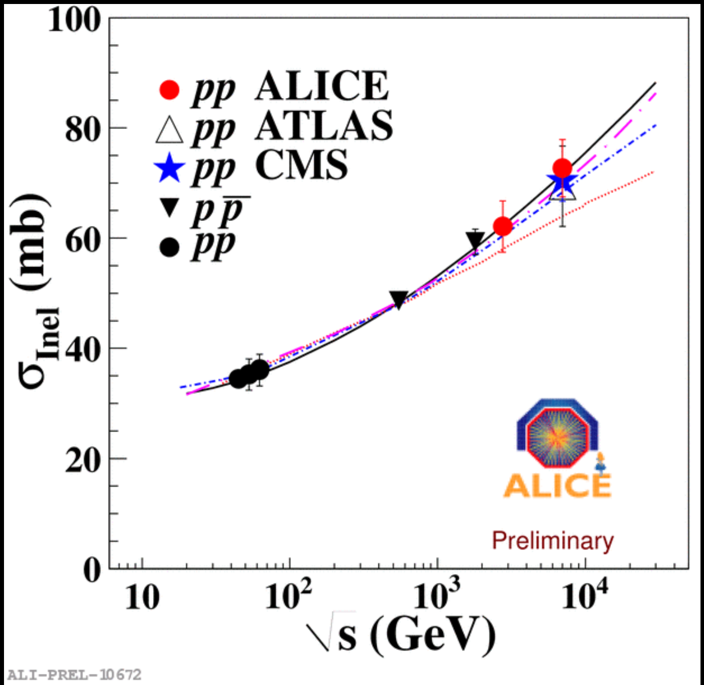
Nature Comm. 2 (2011) 463



Consider the trigger made of V0A.and.V0C (V0-and) → σ by VdM scan. Then V0-and/inel by SD and DD tuned MC ε=(0.745 ± 0.010) @ 7 TeV

Preliminary ALICE result arXiv: 1109.4510 :

σ =(72.7 ± 1.1 (model) ± 5.1 (lumi)) mb @ 7 TeV



ATLAS EXPERIMENT σ = (69.1 ± 2.4 (stat) ± 6.9 (model)) mb (1)

CMS σ = (64.5 ± 1.1(sys) ± 1.5 (model) ± 2.6 (lumi)) mb (2)

TOTEM σ = (73.5± 0.5 (stat) $^{+1.8}_{-1.3}$ (sys) mb (3)

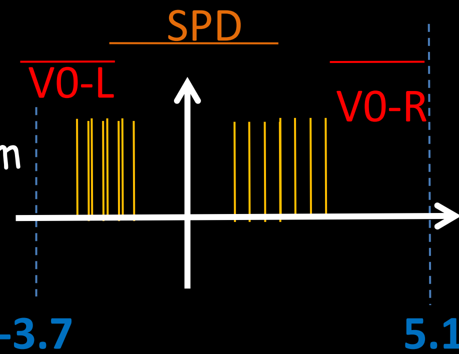
ATLAS-CMS/ALICE results agree if the same model is used to extract ε (ATLAS use the DL model, ALICE model has a $1/M_x$ steeper scaling)

(1) Nature Comm. 2 (2011) 463
(2) CMS PAS QCD-11-002
(3) EPL 96 (2011) 21002

→ σ_{INEL} ~ (70±5) mb at $\sqrt{s}$=7 TeV

MC tuning of σ_{SD}, σ_{DD}

Measure $N_{\text{1 arm trigger}} / N_{\text{2 arm trigger}}$

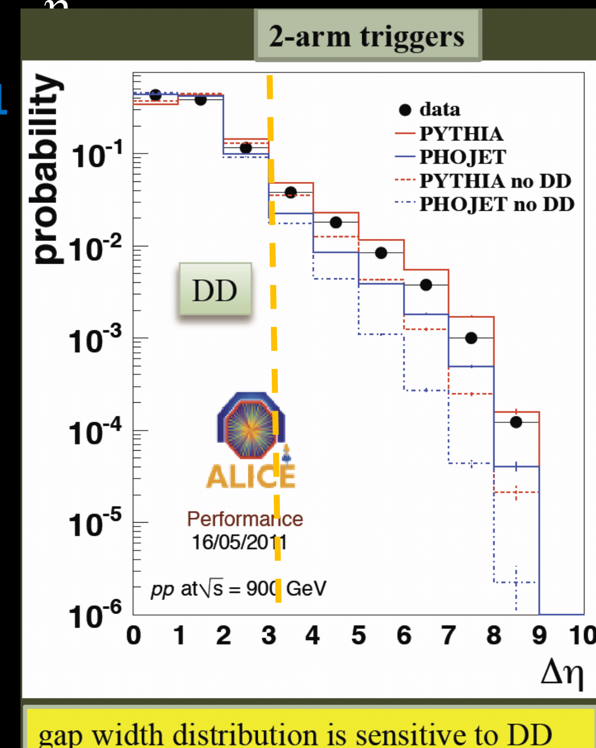


ε_{SD} → Prob. SD triggered as 1 arm, 2 arm
ε_{NSD} → Prob. NSD triggered as 1 arm, 2 arm
Vary σ_{SD}/σ_{NSD} to reproduce exp data
→ SD fraction fixed

Phytia overestimates
PHOJET underestimates DD

Events with $\Delta\eta>3$ → DD

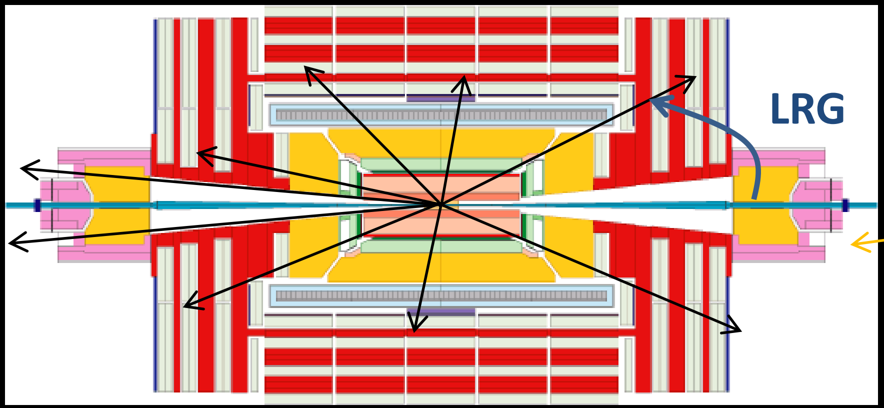
Can be used to tune
DD fraction in MC
(~8% at 7 TeV) → DD fraction fixed



$\sqrt{s}$ = 0.9 TeV	$\sqrt{s}$ = 2.76 TeV	$\sqrt{s}$ = 7 TeV
$\sigma_{SD}/\sigma_{Inel} = 0.202 \pm 0.034$ (*sys*)	$\sigma_{SD}/\sigma_{Inel} = 0.187 \pm 0.054$(*sys*)	$\sigma_{SD}/\sigma_{Inel} = 0.201 \pm 0.039$ (*sys*)
$\sigma_{DD}/\sigma_{Inel} = 0.113 \pm 0.029$ (*sys*)	$\sigma_{DD}/\sigma_{Inel} = 0.125 \pm 0.052$(*sys*)	$\sigma_{DD}/\sigma_{Inel} = 0.122 \pm 0.036$ (***sys***)

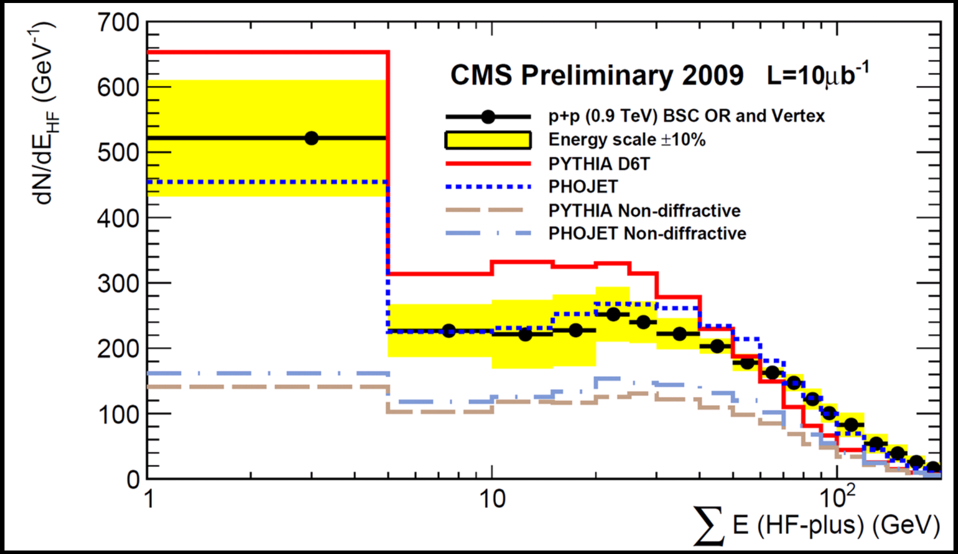
Understanding diffraction....
...the advantage of the calorimetry.

CMS (forward calorimetry @ work)

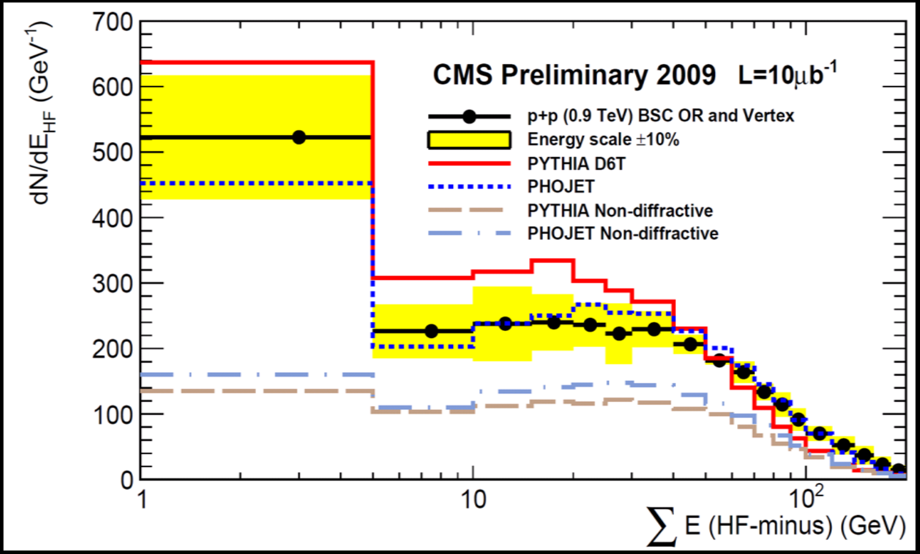


Hadronic Forward calorimeters

E(HF-minus) < 8 GeV



E(HF-plus) < 8 GeV



PYTHIA D6T overestimates SD; spectrum too soft.
PHOJET underestimates SD, but agrees in the higher part

CMS-FWD-010-001

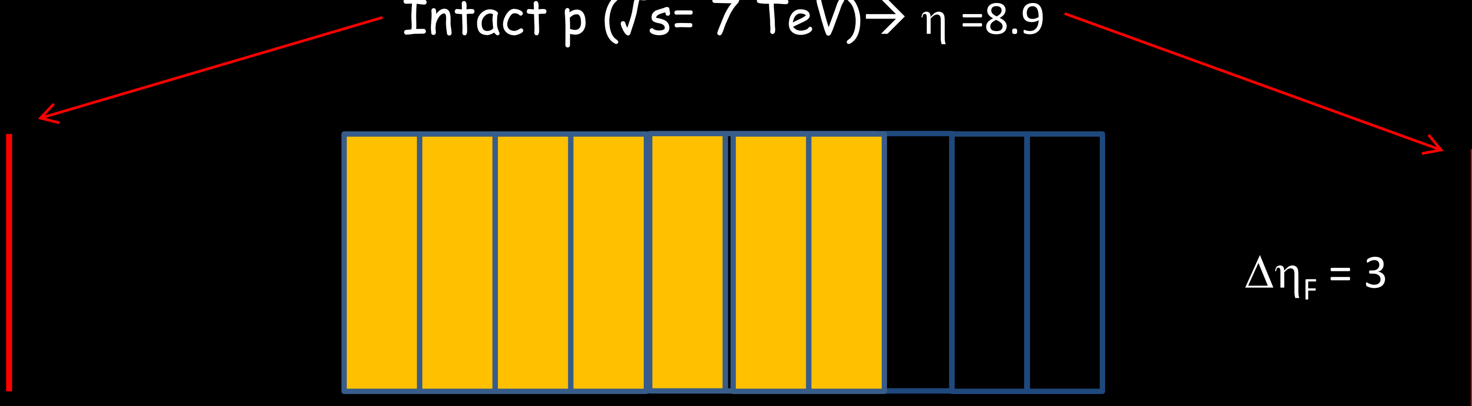
Rapidity gap cross section

Analysis based on: EMCAL, Fcal, η region considered $-4.9 < \eta < 4.9$,

An η slice is active when (track with $P_t > 200$ MeV OR at least 1 calorimeter cell fired)

Forward gap: starting from the η edge(± 4.9), select the largest <u>consecutive</u> set of empty slices

Intact p ($\sqrt{s}$= 7 TeV)→ η =8.9

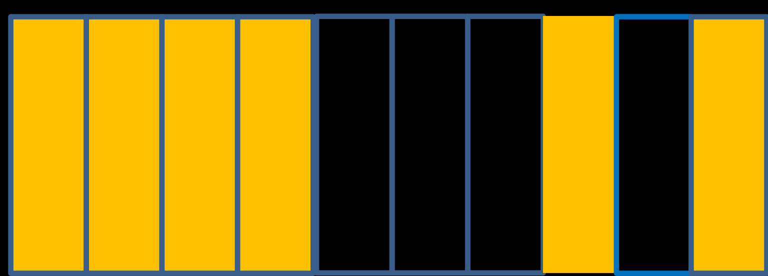


$\Delta\eta_F = 3$

$\Delta\eta = 4 + \Delta\eta_F$

$\Delta\eta = -\ln \xi$

-4.9 4.9



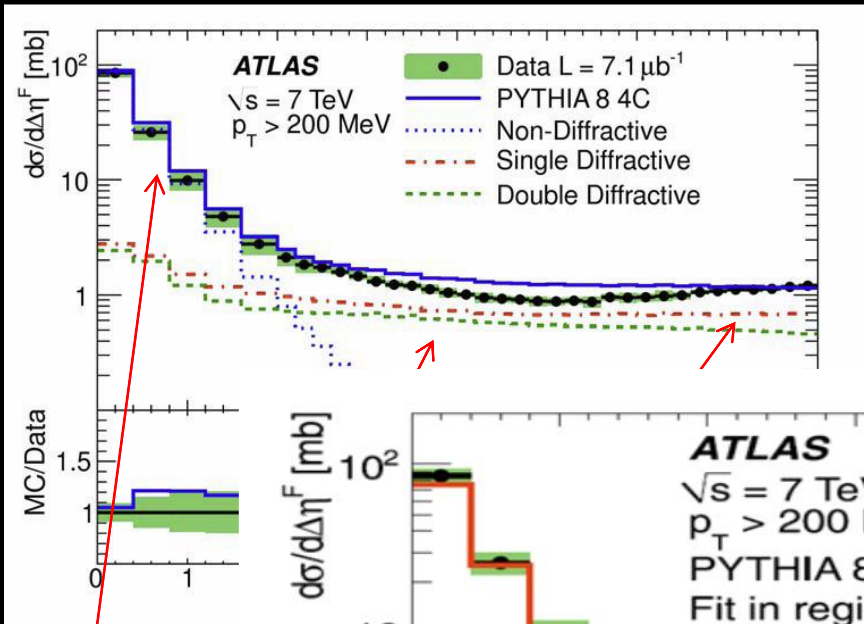
$\Delta\eta_F = 0$

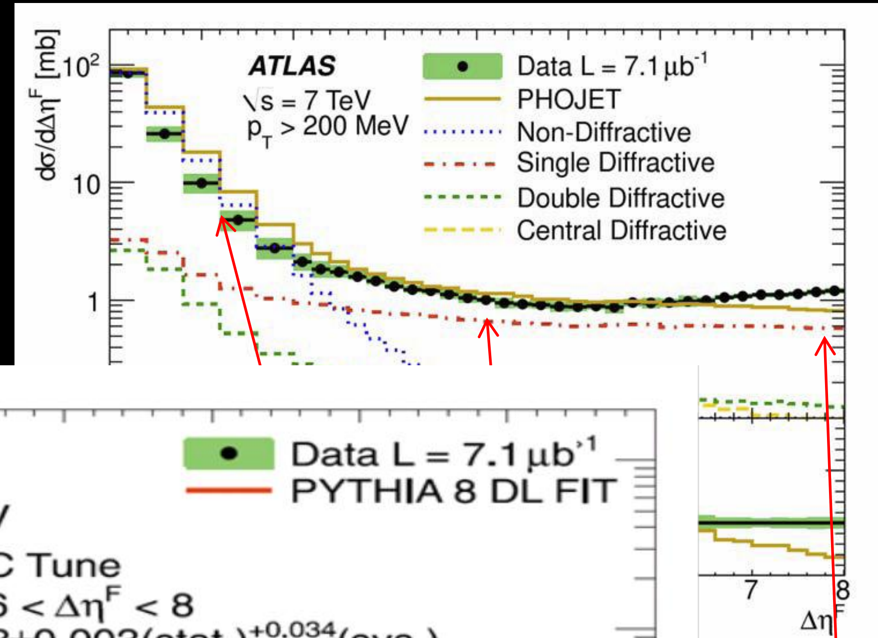
-4.9 4.9

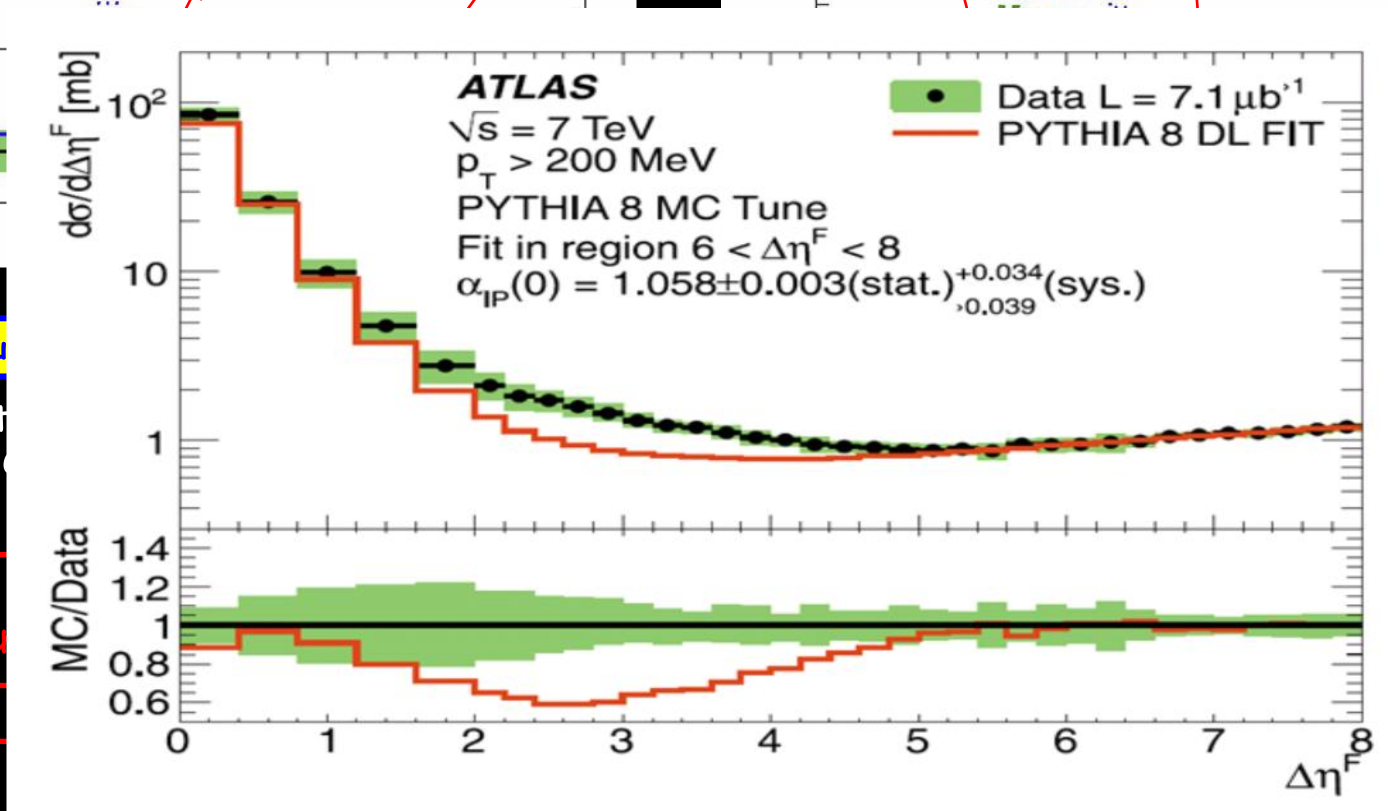
ND → $\Delta\eta_F \sim 0$

Diffractive events: large $\Delta\eta_F$

Eur. Phys. Jour. C72(2012)1926







Eu

Pyt
PHO

ND do

PYTHIA σ_{IN} overall overestimate or just right DD decreases in PHOJET ?

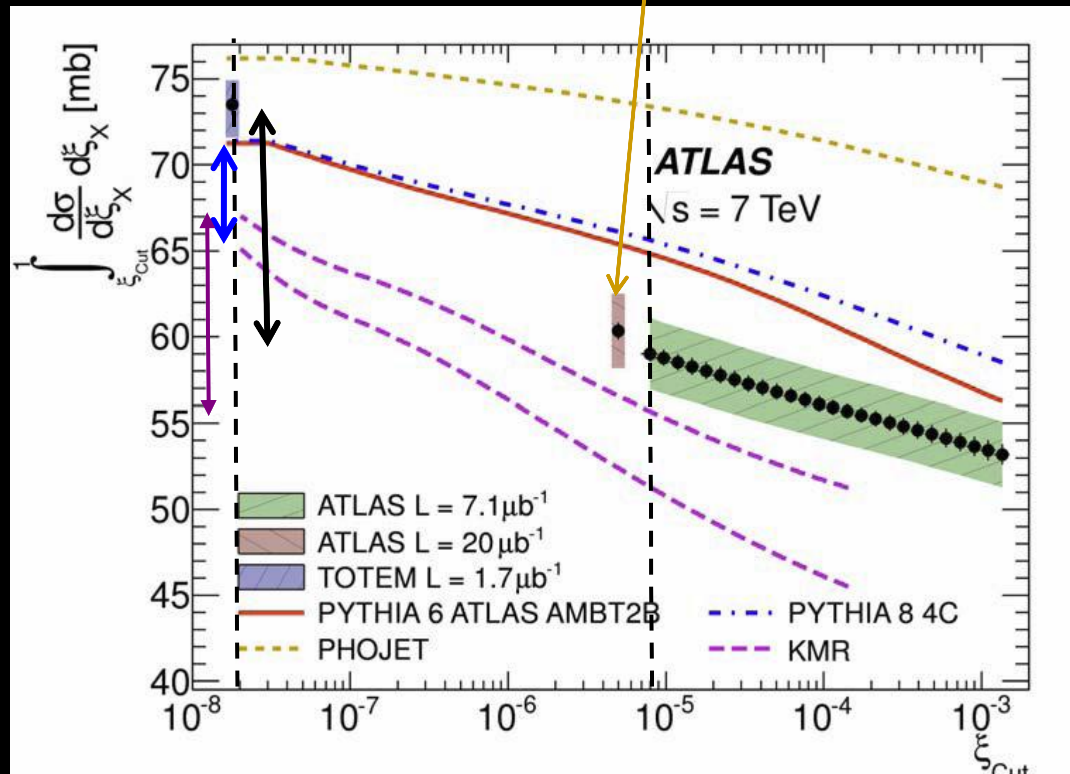
DD decreases too much at large $\Delta\eta_F$ in PHOJET, rise not reproduced (SD+DD) dynamics

$\Delta\eta \sim -\ln\xi = -\ln M_x^2/s$

More on σ_{inel}

$$\int_0^{\Delta\eta^F_{Cut}} \frac{d\sigma}{d\Delta\eta^F} d\Delta\eta^F \longleftrightarrow \int_{\xi_{cut}}^{1} \frac{d\sigma}{d\xi_x} d\xi_x$$

Previous measurement from MBST



Comparing the cross section at $\xi > 8 \cdot 10^{-6}$ and at $\xi > 2 \cdot 10^{-8}$

ATLAS-TOTEM $(14.5^{+2.0}_{-1.5})mb$

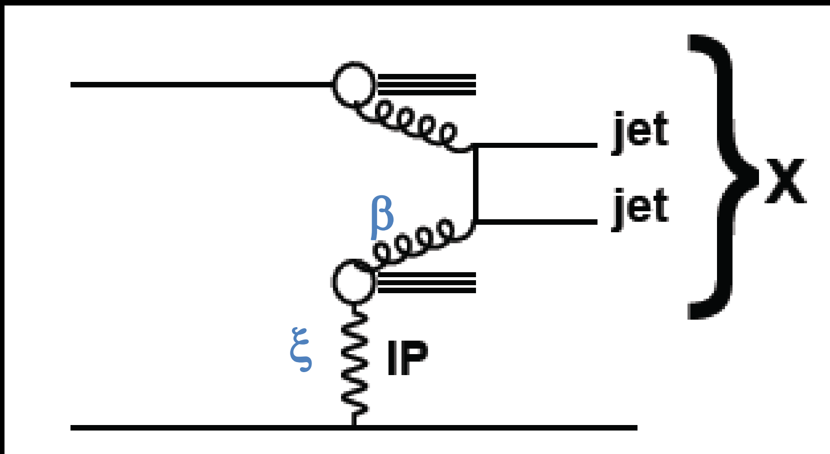
Pythia ~ 6 mb

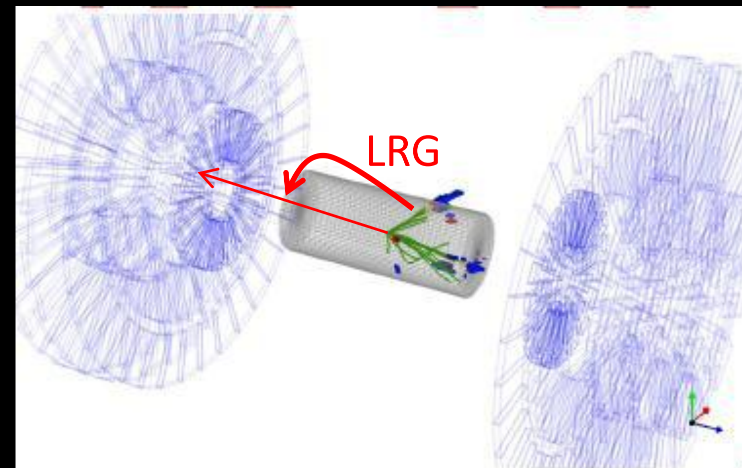
KMR (Ryskin) ~ 12 mb

The contribution to the σ_{inel} from $\xi < 8 \cdot 10^{-6}$ larger than predicted by most models

Diffractive events with a hard parton-parton scattering

Search for diffraction with a hard scale (signature: no hadronic activity in a wide η range)





Study of diffractive structure function:

$\sigma(pp \rightarrow ppX) \sim F_{jj} \times F_{jj}^{D} \times \sigma(ab \rightarrow jj) \rightarrow \sigma_{SD}/\sigma_{ND} = F_{jj}^{D} / F_{jj}$ exp known

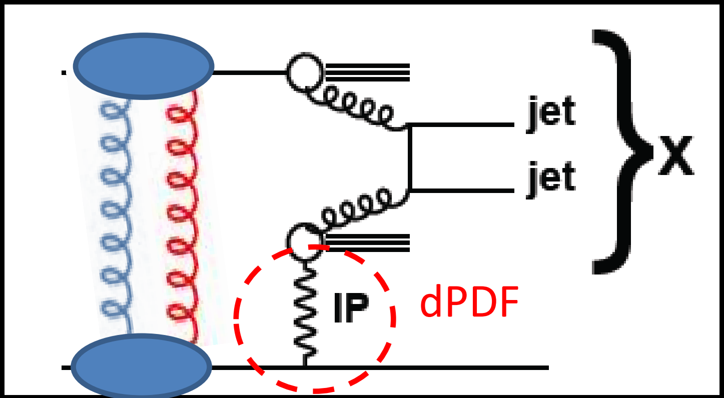
Trigger on $E_t > 6$ GeV. Jets with $P_t > 20$ GeV and $-4.4 < \eta < 4.4$. $\mathscr{L}=2.7\ nb^{-1}$

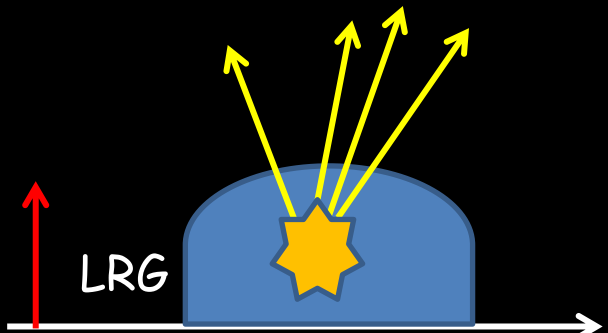
Particle flow object (particle candidates obtained by combining tracking + calorimetry with $\eta_{min} > -3$, $\eta_{max} < 3$) → gap of > 1.9 η unit in HF,

results presented as a function of

$\tilde{\xi}^{\pm} = C\,\Sigma\,(Ei \pm pzi)/\sqrt{s}$ $\quad 0.5*(\xi^{-} + \xi^{+}) \sim \xi = M^2_x/s$, $C \sim 1.45$ (from MC)

Diffraction at HERA



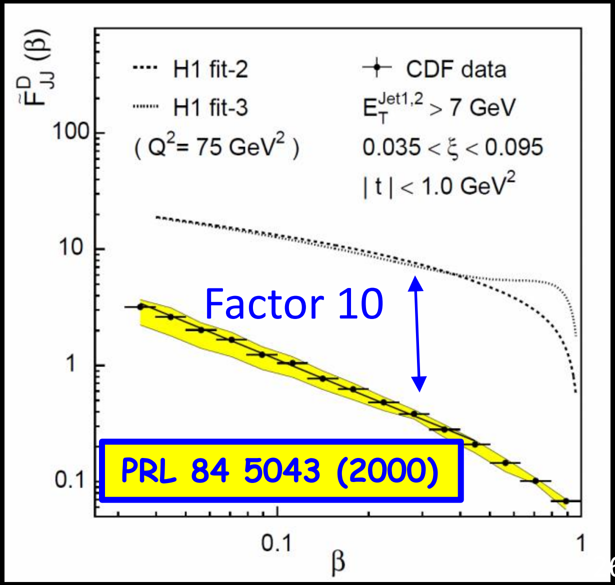


Two step process: Pomeron emission+ Hard scattering

$\sigma \sim F_{jj} \times F_{jj}^{D} \times \sigma(ab \rightarrow jj)$ (hard scattering)

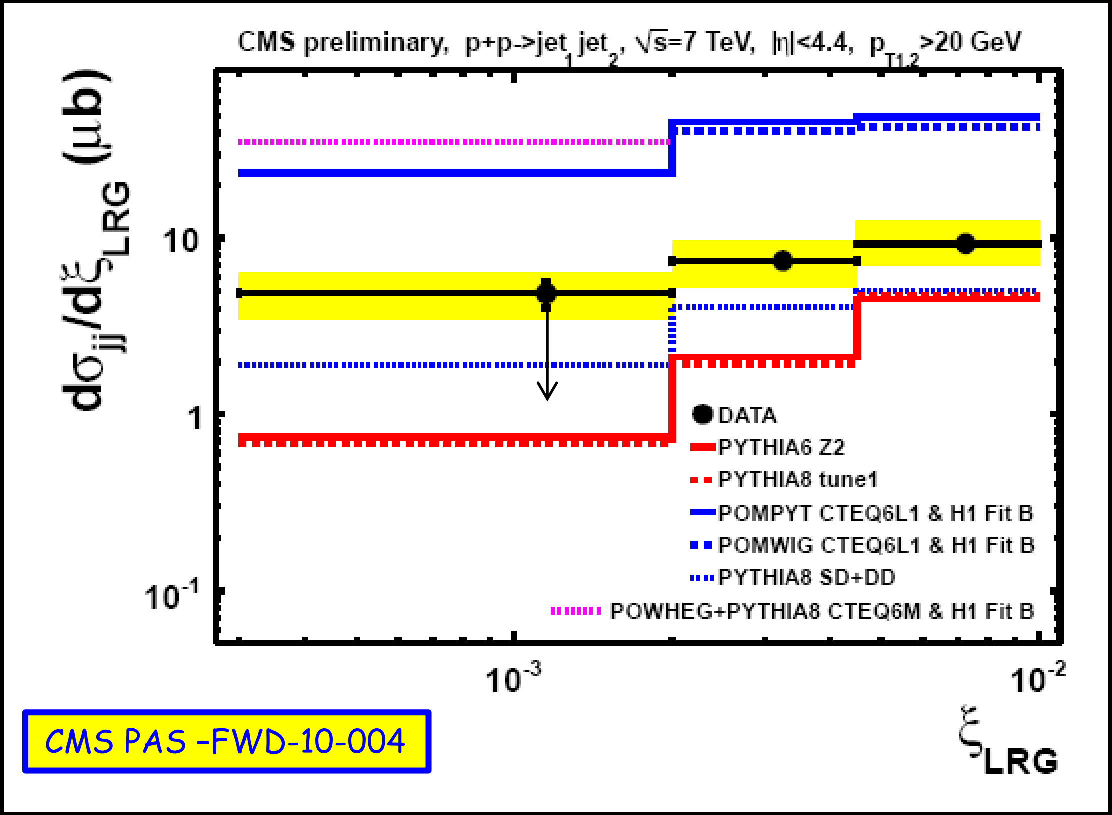
Diffraction at CDF

Factorization broken: soft interaction/rescattering the rapidity gap: $\sigma \propto \langle s^2 \rangle$



At LHC RGS prediction 5-25 %

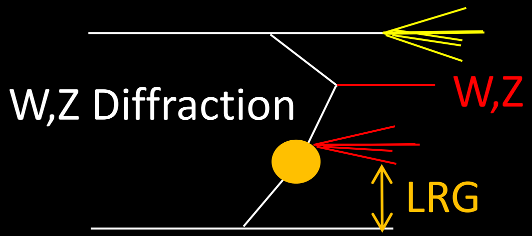
PYTHIA/POMPYT:
Same diffractive parton distribution,
but different pomeron flux



- MC not including diffraction (PYTHIA 8, Z2) cannot reproduce data at low $\tilde{\xi}$:
- Pythia 8 (SD + DD) is not enough; same dPDF than POMPYT/POMWIG, but different IP flux;
- POMPYT/POMPYT (SD) ( ) needed at low x, but their normalization higher at low $\tilde{\xi}$;
- RGS(Rapity Gap Survival):

Data: includes p excited into low mass undetected in the forward region;
POMPYT: does not include RGS, but the dPDF includes a p dissociative contribution;
RGS upper limit: data/POMPYT = (0.21±0.07)

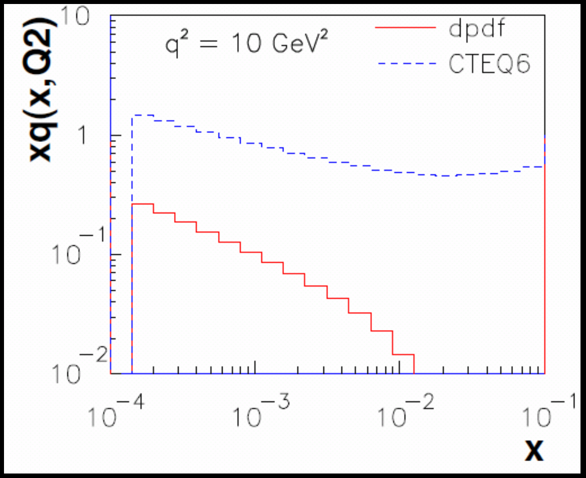
Diffractively produced W

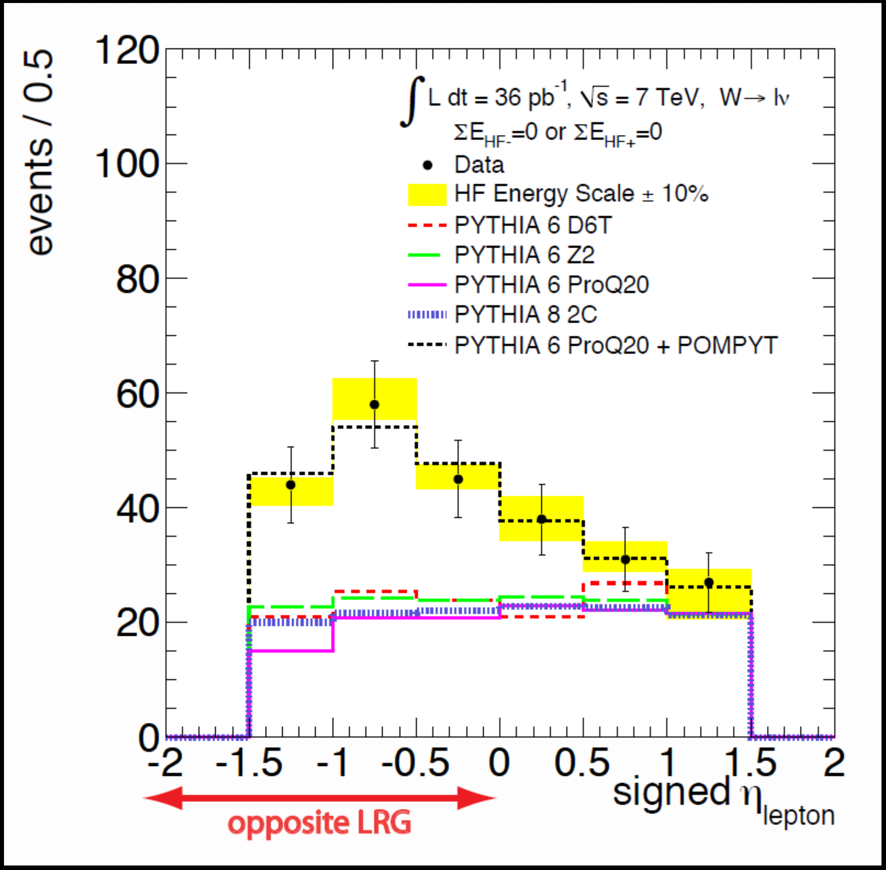


One central and isolated lepton (η < 1.4) with p_T > 25 GeV,
pt miss > 30 GeV: 32,000 ev
HF+ or HF- with no energy (1.9 gap): ~ 300 ev → ~ 1%

Select events with no energy in one side:
Lepton and the gap in the same hemisphere → η_{lept} >0
Lepton and the gap in opposite hemisphere → η_{lept} <0

Asimmetry (not reproduced by Pythia):
dPDF smaller x wrt PDF → produced W boosted in the direction of the parton with the
Largest x → opposite to the gap



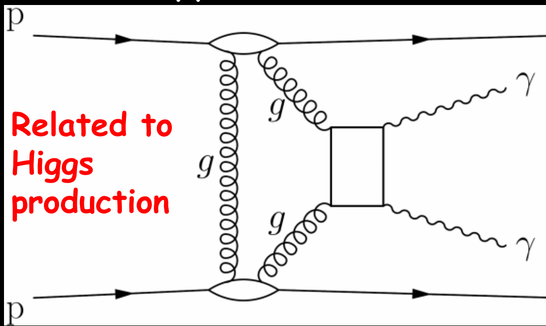


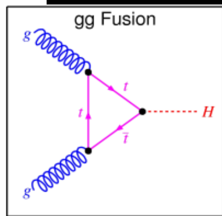
Best fit diffraction component:
(50.0 ±9.3 (stat.) ± 4.2 (syst.)) %

W with LRG fraction: (1.46 ± 0.09(stat)±0.38(syst.))%

Central exclusive production:

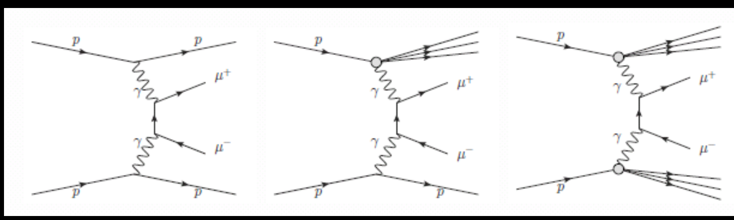
$\gamma\gamma$ search

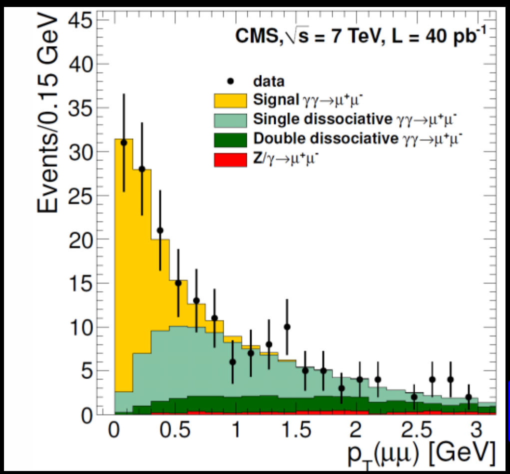




CDF: $\sigma(E_T>2.5\text{ GeV}, |\eta|<1) = (2.48^{+0.4}_{-0.35}\text{ (stat) }^{+0.4}_{-0.35}\text{ (sys)) pb}$

CMS: $\sigma(E_T>5.5\text{ GeV}, |\eta|<2.5) < 1.3\text{ pb (95\% C.L.)}$





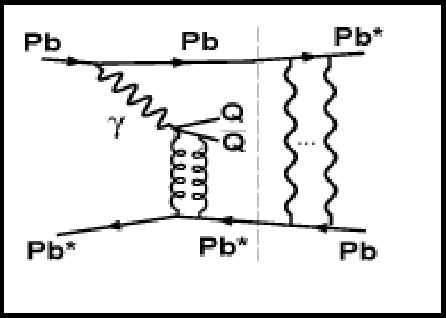
$M_{inv} > 11.5$ GeV,
$p_T > 4$ GeV and $|\eta| < 2.1$,
DY cut: μ vertex separated
> 2mm from any additional tracks

$$\sigma = (3.38 \pm^{0.58}_{0.55}\text{ (stat)} \pm 0.16\text{(sys)} \pm 0.14\text{(lumi)) pb}$$

$\sigma_{DATA}/\sigma_{MC}$:

$$\sigma = 0.83 \pm^{0.14}_{0.13}\text{ (stat)} \pm 0.04\text{(sys)} \pm 0.03\text{(lumi)}$$

Ultra peripheral Collisions (UPC): ongoing analysis for heavy meson production in Pb-Pb collisions (J/Ψ, Υ): access to the the nuclear gluon structure function, $\sigma_{J/\Psi,\Upsilon} \propto |x\cdot g(x,q^2)|^2$



J/Ψ, Υ production allows the measurement of the gluon shadowing in the nucleus

Conclusions

- Impressive amount of work from the LHC experiments on soft QCD/diffractive physics;

- In general good agreement between experimental results;

- A MC tuning, reproducing simultaneously all the observables still missing. Strange hadron production modeling requires more work;

- Inelastic cross section measured: (70±5) mb at $\sqrt{s}$=7 TeV: results are model dependent;

- Diffraction process study shows significant advance: few of them nicely constrained (SD ~ 20%, DD ~ 10-15 %), CD still missing;

- Calorimetry is performing nicely in the forward physics, providing exciting results;

- A lot of new results coming;

BACKUP

ALICE-ATLAS UE