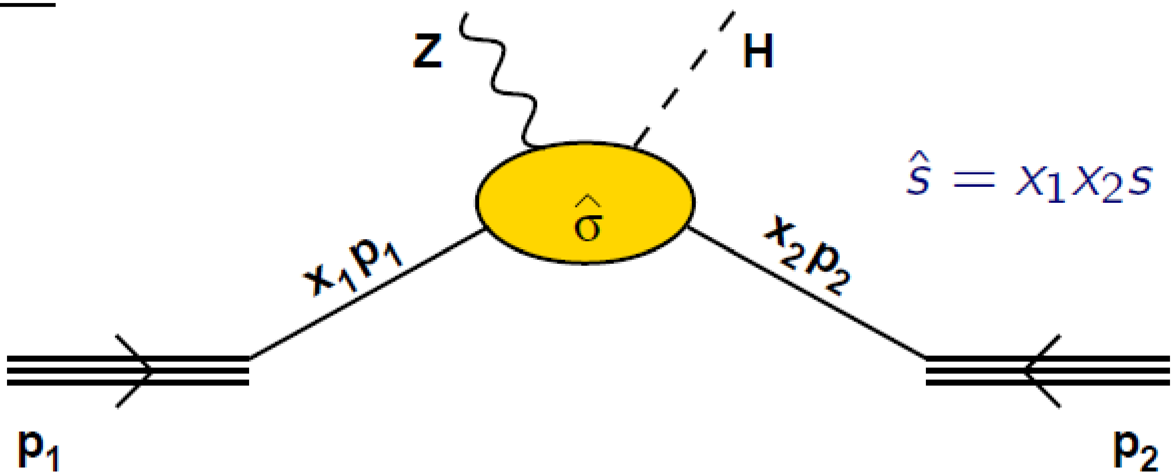
4. Hadron-hadron collisions

Factorization



$\hat{s} = x_1 x_2 s$

$$\sigma = \int dx_1 f_{q/p}(x_1, \mu^2) \int dx_2 f_{\bar{q}/\bar{p}}(x_2, \mu^2)\, \hat{\sigma}(x_1 p_1, x_2 p_2, \mu^2)$$

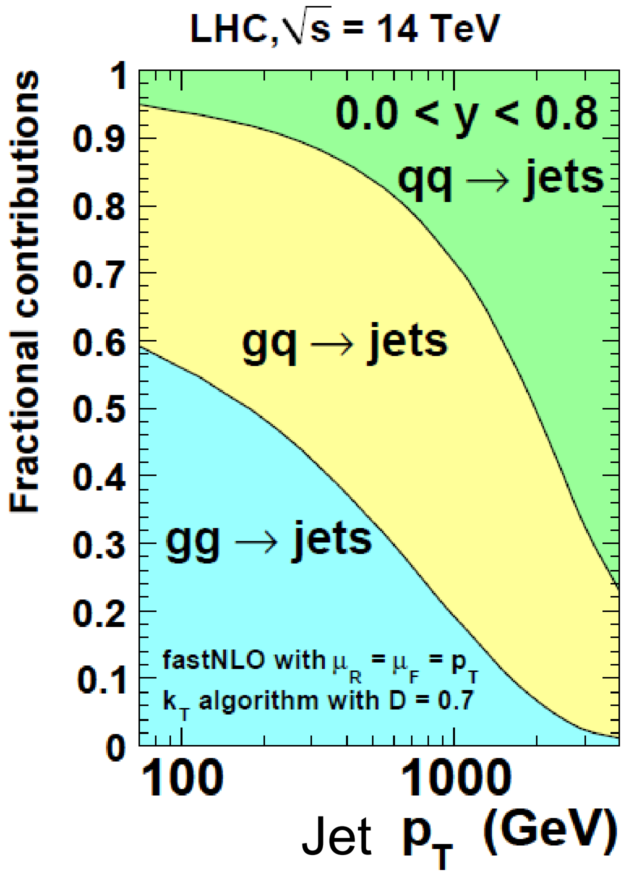
factorization scale

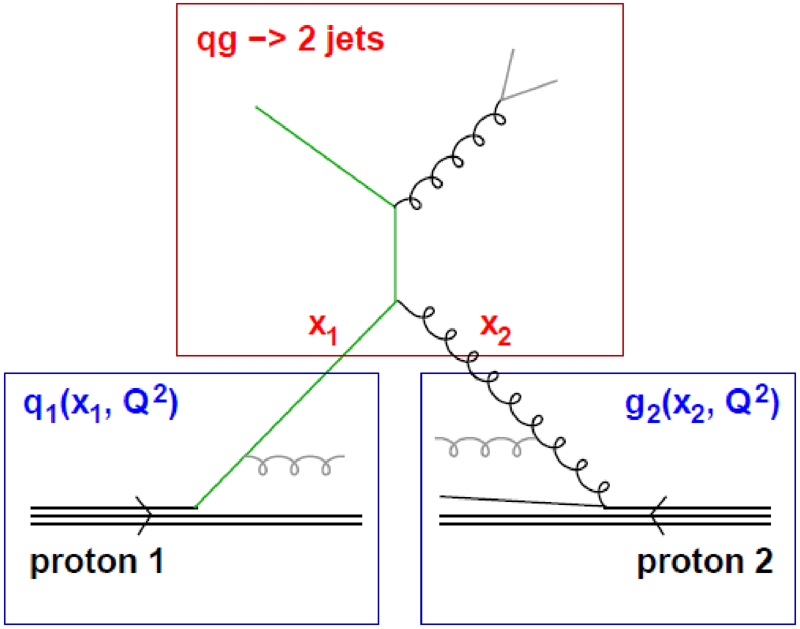
Total cross section is factorized into a “hard part” and into a “normalization” from process independent parton distribution functions.

For all cross section estimation the knowledge of the PDF is necessary.

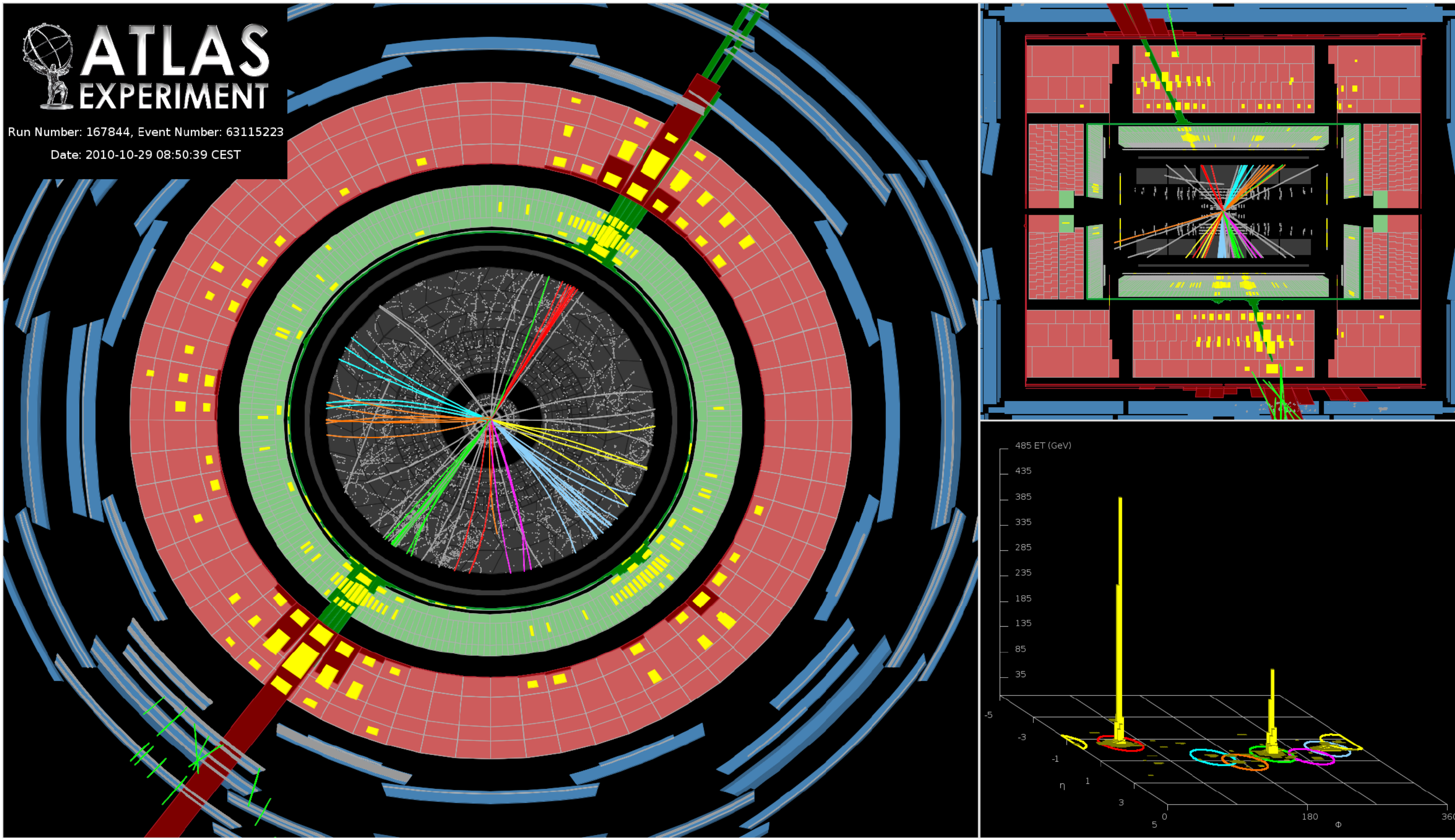
Example process: jet production in pp

Jet production in proton-proton collision is an excellent test of PDFs, in particular of gluon PDF, since there are large direct contributions from $gg \to gg$ and $qg \to qg$:



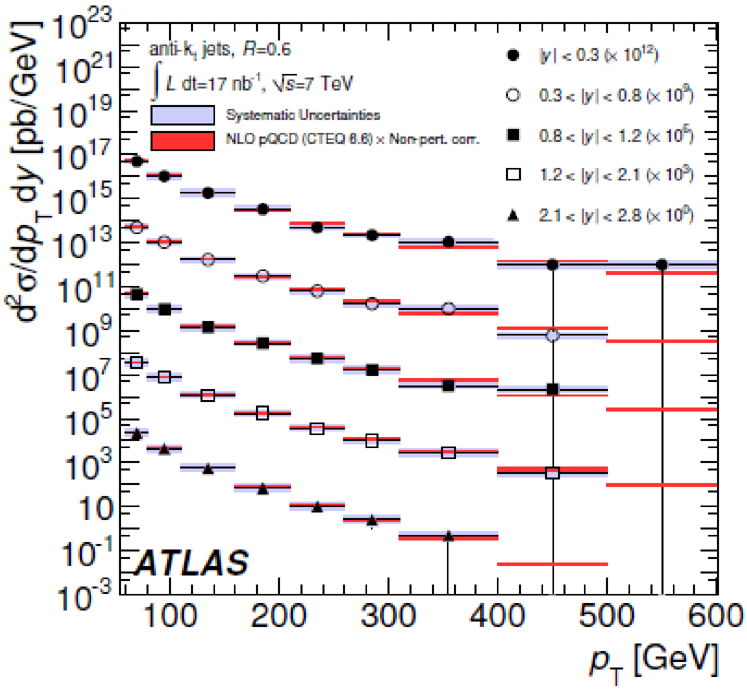


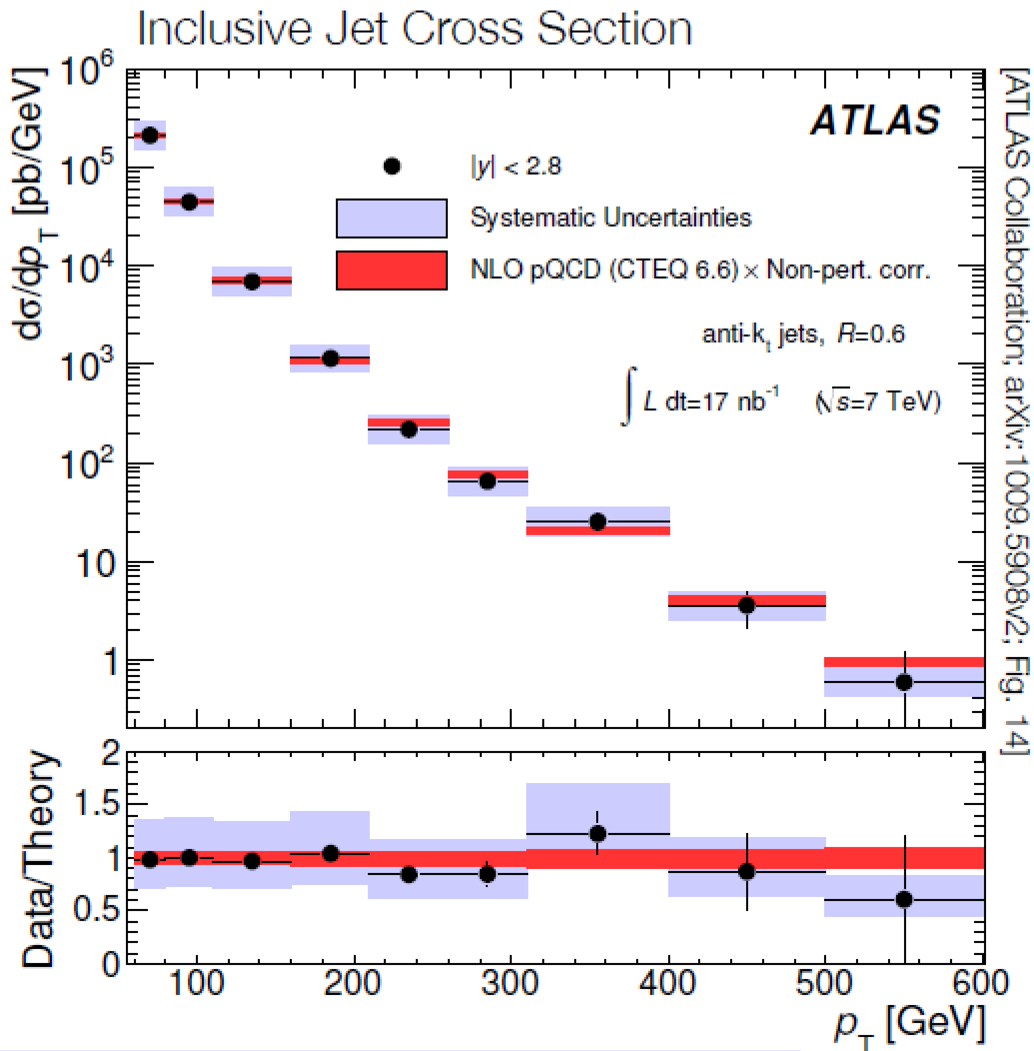
$$\sigma_{pp \to 2\,jets} = \sigma_{qg \to 2\,jets} \otimes q_1 \otimes g_2 + \cdots$$


ATLAS
EXPERIMENT
Run Number: 167844, Event Number: 63115223
Date: 2010-10-29 08:50:39 CEST
485 ET (GeV)
435
385
335
285
235
185
135
85
35
-5
-3
-1
η
1
3
5
0
180
Φ
360

Inclusive jet production

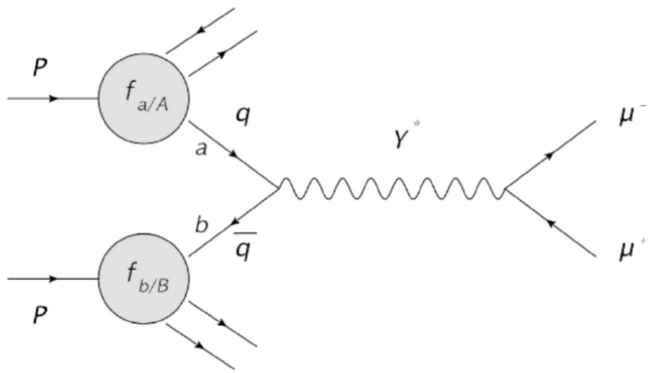
Jet algorithm: anti-k_t w/ R=0.6



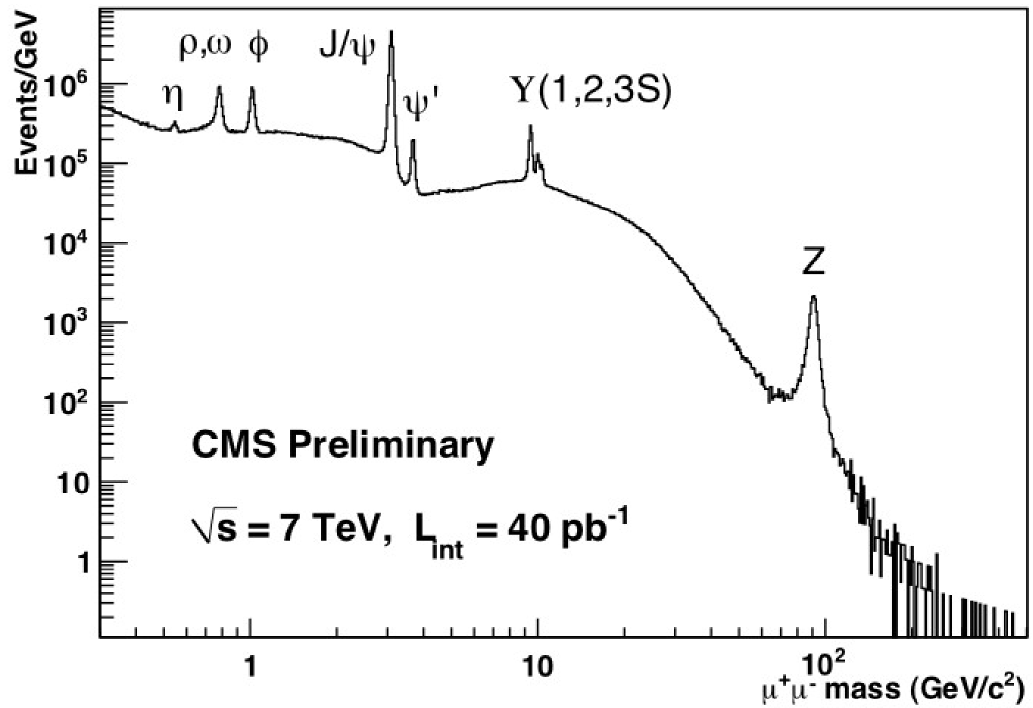


Inclusive jet production well described with known PDFs

Simplest process: Drell-Yan production

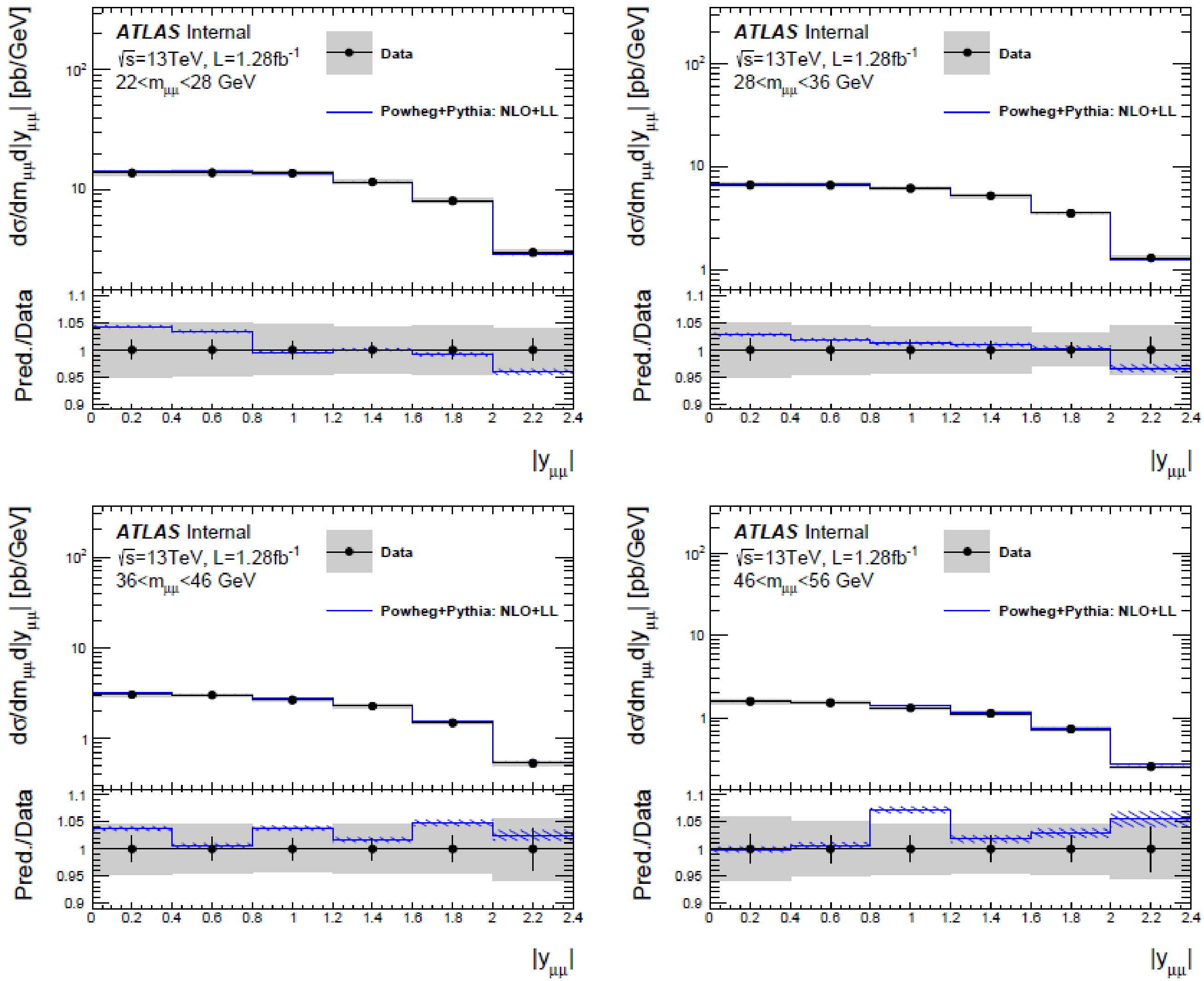


$$\hat{\sigma}\left(q(p_1)\bar{q}(p_2) \to l^+l^-\right) = \frac{4\pi\alpha^2}{3\hat{s}}\frac{1}{N_c}Q_q^2$$



These kind of processes can also be used to improve PDFs.

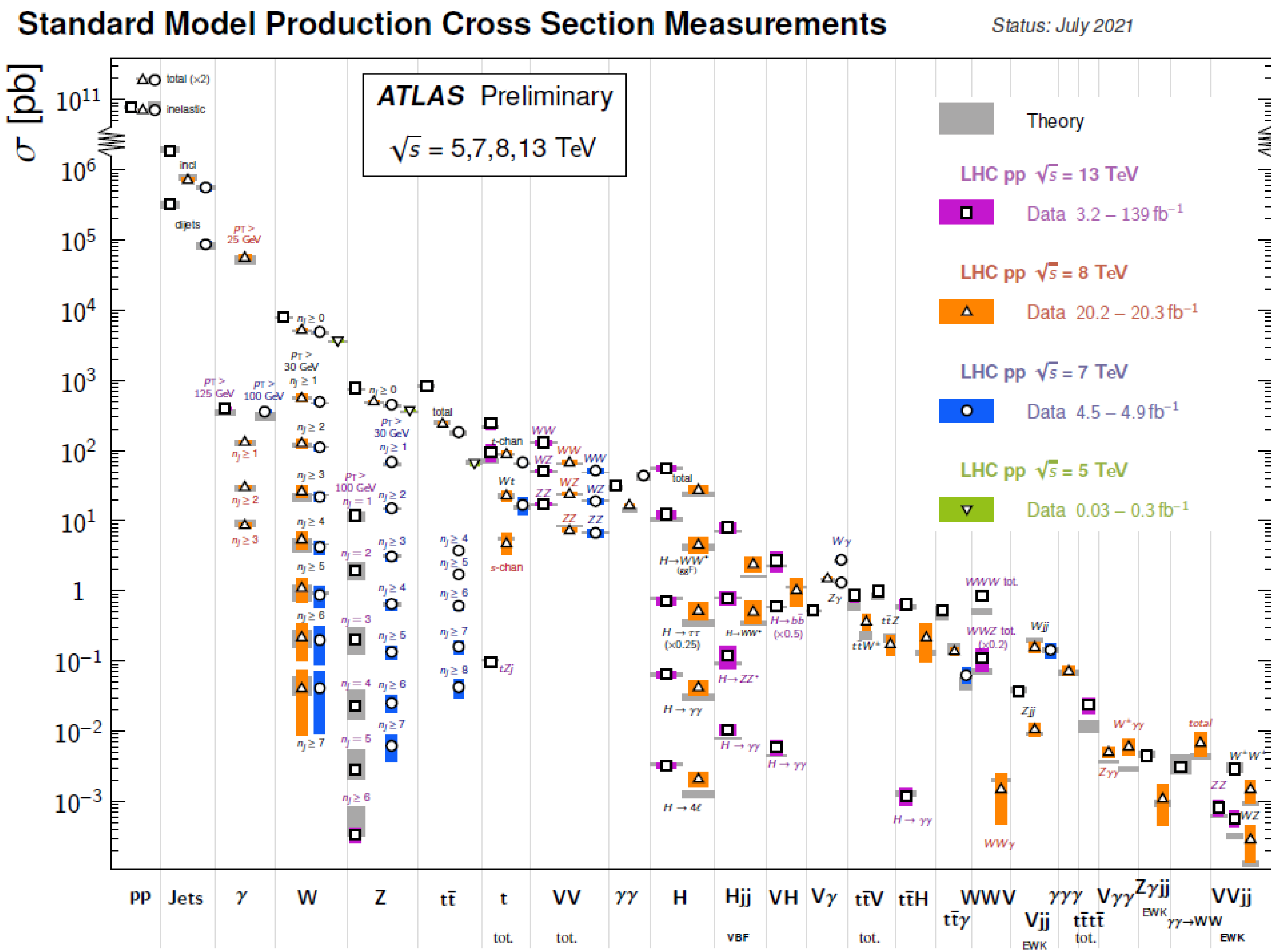
Measured pp $\rightarrow \mu\mu X$: excellent agreement w/ predictions.



Alessandro Guida, PhD Thesis, 2022

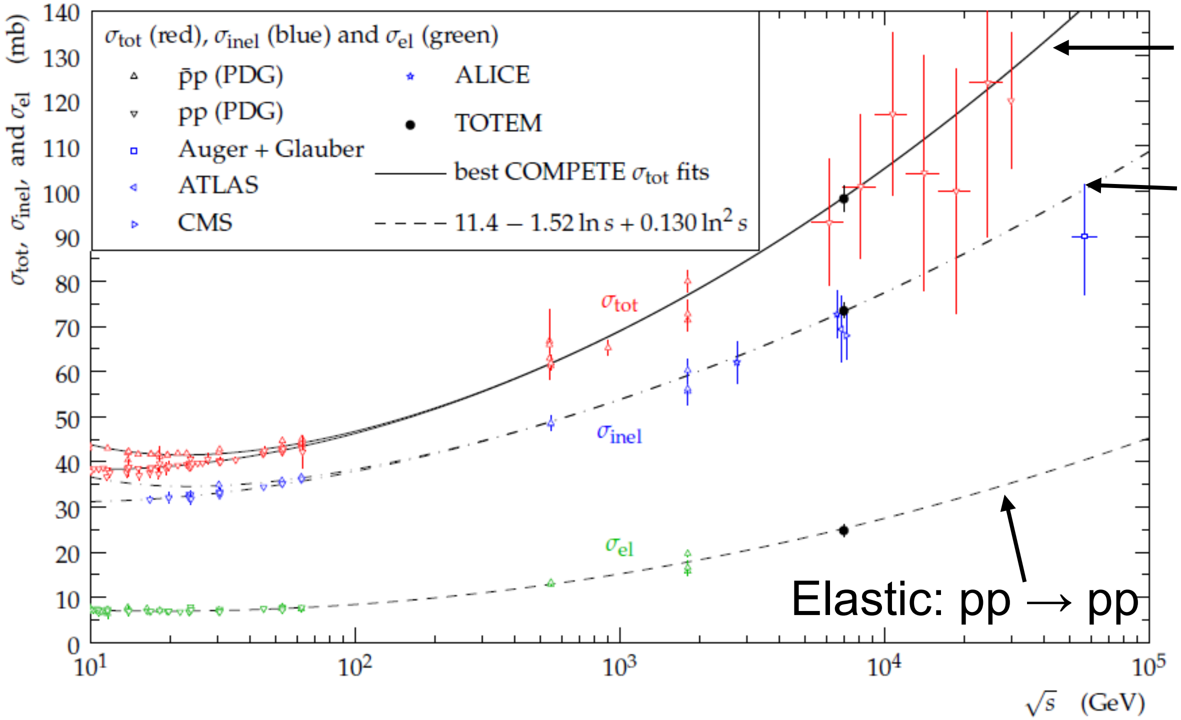
Predicted at measured cross sections at LHC

ATL-PHYS-PUB-2021-032



Impressive achievement of theoretical and experimental physics.

Remark: total pp cross section



Total = elastic + inelastic

Inelastic: pp → X_1X_2, Xp

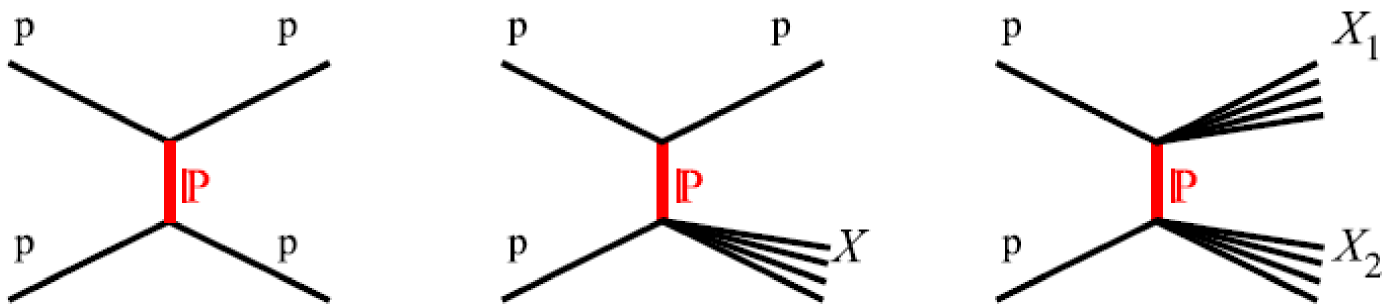
(smallest fraction = hard scattering)

Experiment	σ_{INEL} (mb) @ 7 TeV
ALICE	$73.2^{+2.0}_{-4.6}$(model) $\pm$ 2.6(lumi)
ATLAS	69.4 $\pm$ 6.9(model) $\pm$ 2.4(exp)
CMS	68.0 $\pm$ 4.0(model) $\pm$ 2.0(syst) $\pm$ 2.4(lumi)
TOTEM	$73.5^{+1.8}_{-1.3}$(syst) $\pm$ 0.6(stat)

The hadron-hadron cross section can be decomposed into elastic and inelastic contributions (including diffractive and non-diffractive topologies), each of which can be described by non-perturbative pheno-menological models, based on general principles such as unitarity and analyticity

Closer look to the elastic and diffractive process

Elastic and diffractive (single or double diffractive)



+ central-diffractive

$\sim 20\% \, \sigma_{inel}$ $\sim 14\% \, \sigma_{inel}$ @7 TeV

<u>Regge theory (phenomenological):</u>

Describes single and double diffractive scattering by an exchange of an color singlet object with the quantum numbers of the vacuum: Pomeron. The Pomeron also dominates the elastic scattering at high energies.

Single Diffraction (SD) is similar to elastic scattering except that one of the protons breaks up, producing particles in a limited rapidity region. In Double Diffraction (DD), both protons break up. In SD events there is a rapidity gap between the proton and the broken-up proton (same in DD)

Completely different than in hard scattering of partons → color string