Electroweak and QCD aspects in V+Jets

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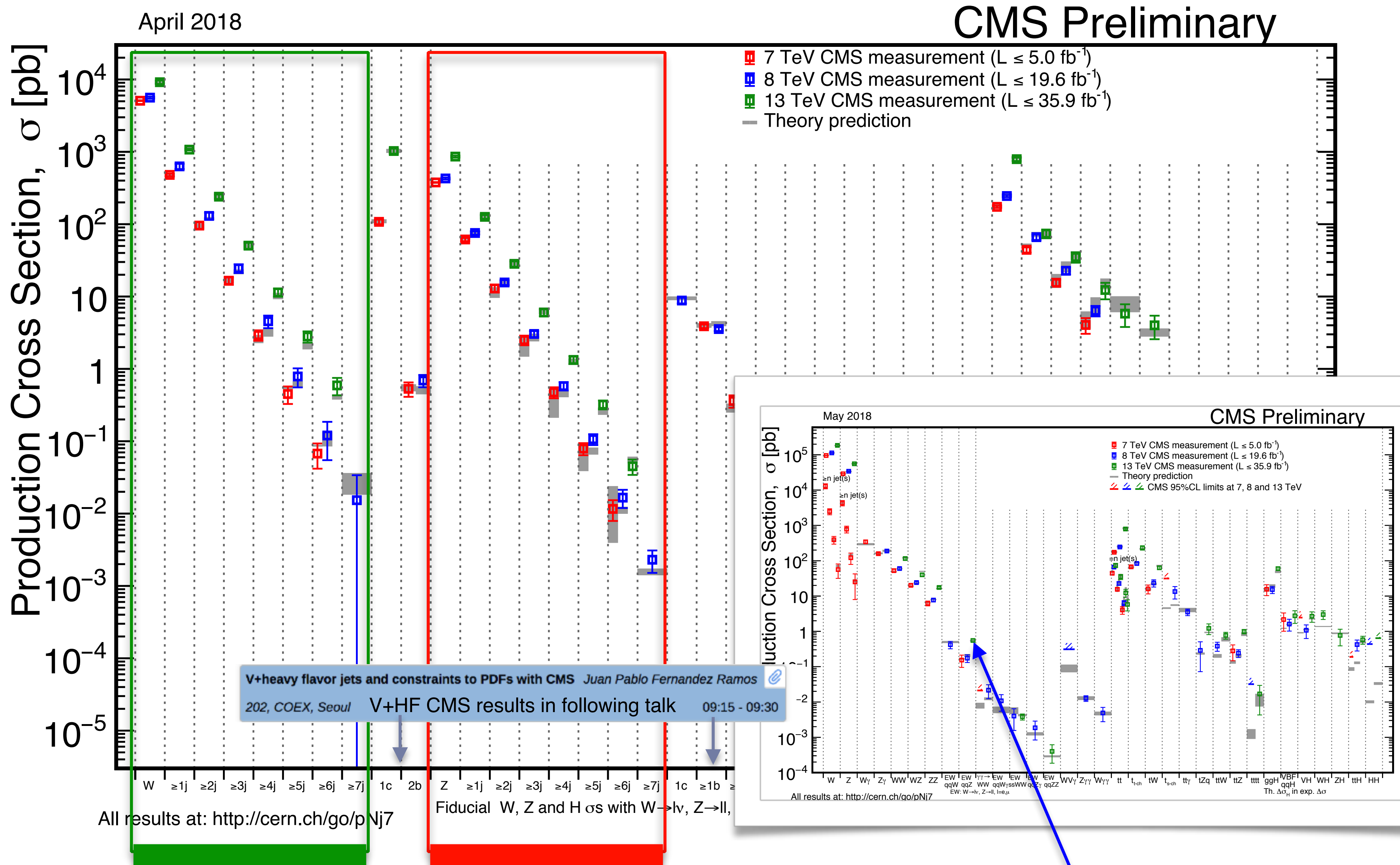
CMS



Here:

W+Jets

Phys. Rev. D 96 (2017) 072005
2015 data

Z+Jets

arXiv:1804.05252
2015 data

+γ+Jets

arXiv:1807.00782
2015 data
Submitted: 3 July

+EWK Z + 2 Jets

arXiv:1712.09814
2016 data
Accepted (EPJC): 5 July

Motivation

- Precision measurements of [differential] V+Jets production cross sections stringent tests of SM predictions
  - sensitive to higher order (QCD and EWK effects)
  - sensitive to non perturbative effects (e.g. particle emission, parton shower)
  - also targeting explicitly EWK production mode (VBF, soft QCD modeling)
- Comparison of the measurements with predictions motivates additional Monte Carlo (MC) generator development and improves our understanding of the prediction uncertainties.

- V+jets is dominant background for:
  - Top quark measurements
  - Higgs physics
  - VH ($H \rightarrow bb$)
  - Searches for new physics

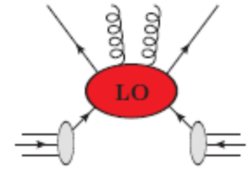
Here:

W+Jets	Z+Jets	+γ+Jets	+EWK Z + 2 Jets
Phys. Rev. D 96 (2017) 072005 2015 data	arXiv:1804.05252 2015 data	arXiv:1807.00782 2015 data Submitted: 3 July	arXiv:1712.09814 2016 data Accepted (EPJC): 5 July

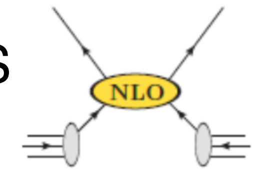
Theoretical predictions for W/Z+jet cross sections

MADGRAPH5_AMC@NLO + Pythia8

- LO: up to 4 partons; kT-MLM merging ME—>PS
- NNPDF3.0 LO PDF, CUETP8M1 Pythia8 tune



- NLO: up to 2 partons; FxFx jet merging ME—> PS
- NNPDF3.0 NLO PDF, CUETP8M1 Pythia8 tune



GENEVA 1.0-RC2 (GE) (for Z+jet only)

- NNLO matrix elements + NNLL resummation
- PDF4LHC15 NNLO, CUETP8M1 Pythia8 tune

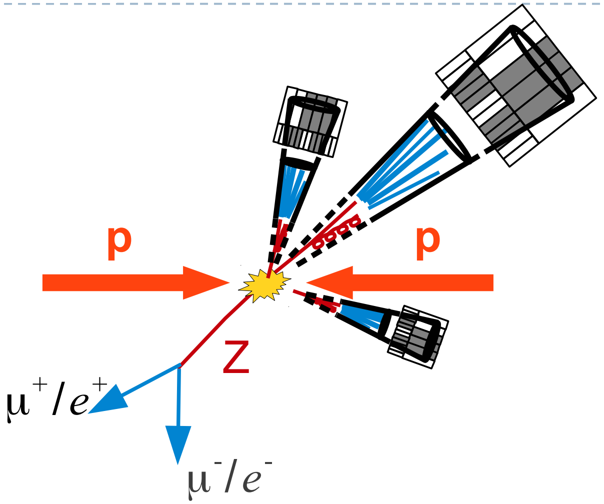
Z/W+1 jet fixed order NNLO

- Correction for hadronization and multiple parton interaction computed with NLO MG5 aMC+Pythia8 as differential scaling factors; CT14 (Z)/ NNPDF 3.0 NNLO (W)

Samples	*0j*	*1j*	*2j*	*3j*	*4j*	*>4j*	*Cross section [pb]*
LO MG5_aMC	*LO*	*LO*	*LO*	*LO*	*LO*	*PS*	*5787*
NLO MG5_aMC	*NLO*	*NLO*	*NLO*	*LO*	*PS*	*PS*	*5931*
Geneva	*NLO*	*NLO*	*LO*	*PS*	*PS*	*PS*	*5940*
Z/W+1@NNLO	*-*	*NNLO*	*NLO*	*LO*	*-*	*-*	*134.6*

arXiv:1804.05252

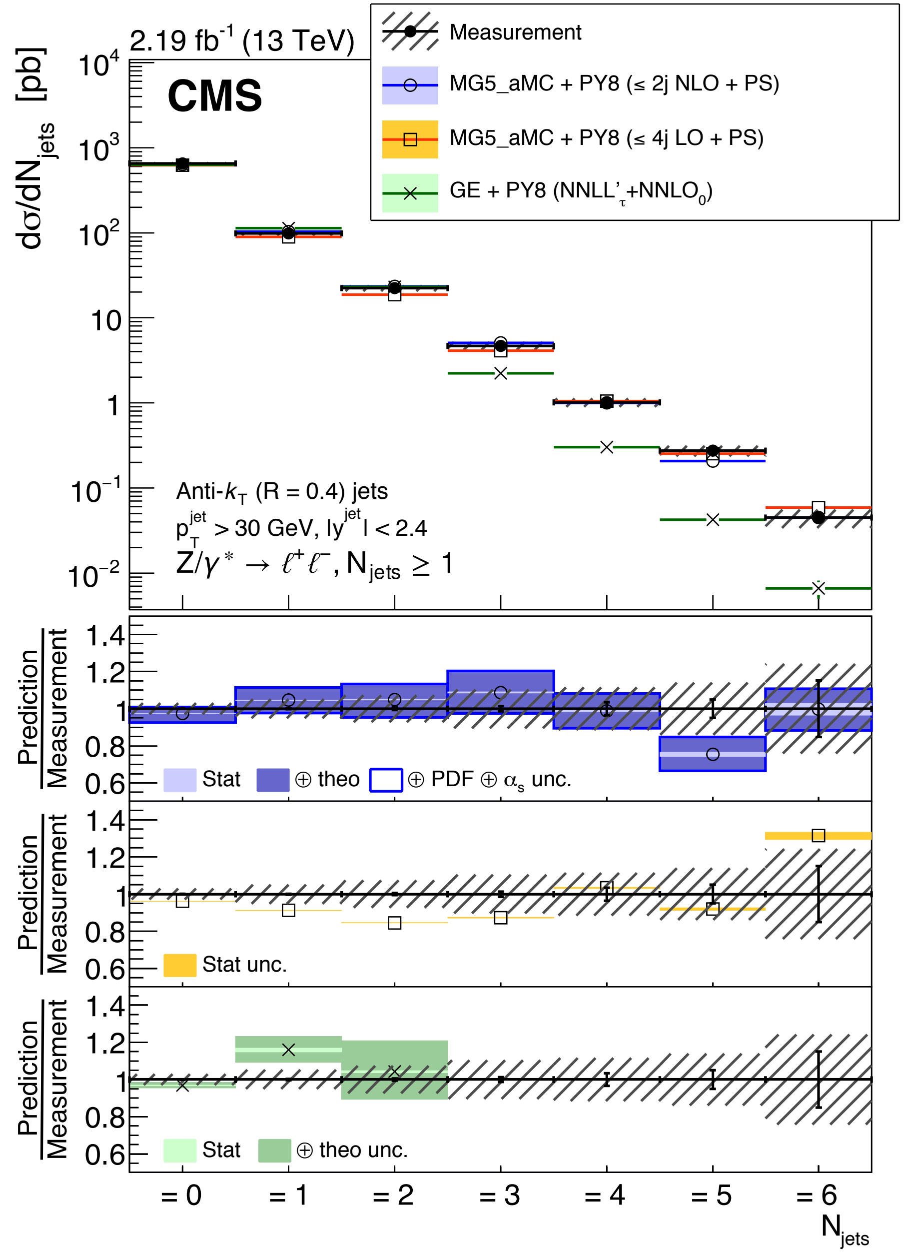
Differential Z+jet cross sections



- leptons: p_T>30 GeV; |η|<2.4
- m(ll)=91±20 GeV
- p_T(jet)>30 GeV; |η|<2.4; ΔR(jet,l)>0.4

- pp collisions 2015: 2.19/fb
- Backgrounds estimated from simulation
- ttbar dominant background at high jet multiplicities

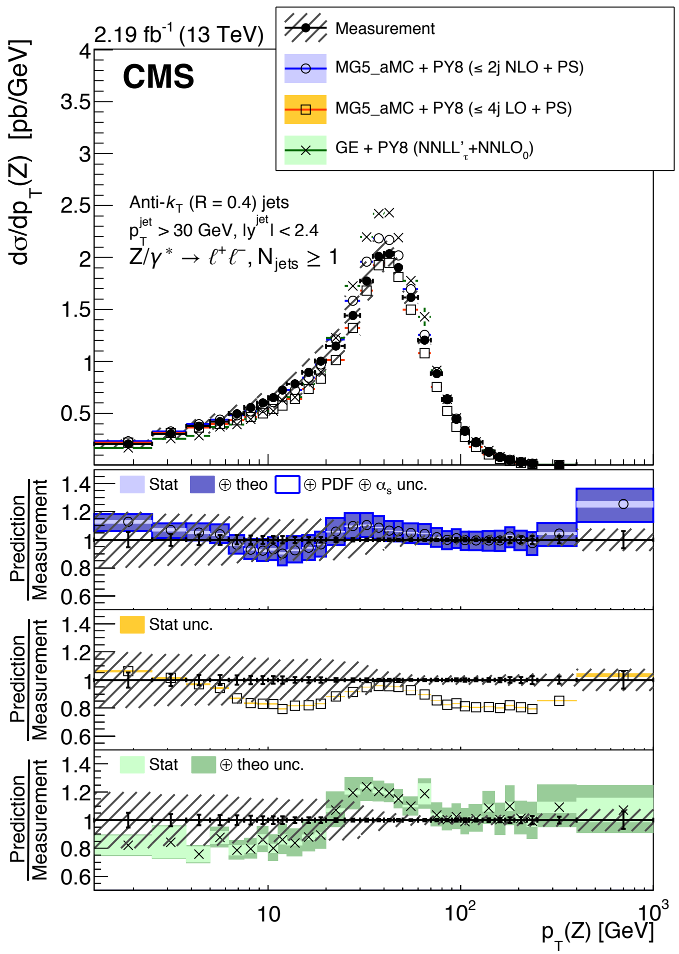
- Unfolding to generator level for many observables: N_{Jets}; p_T(jet1/2/3); y(jet1/2/3); HT; p_T balance; jet-Z balance (JZB)

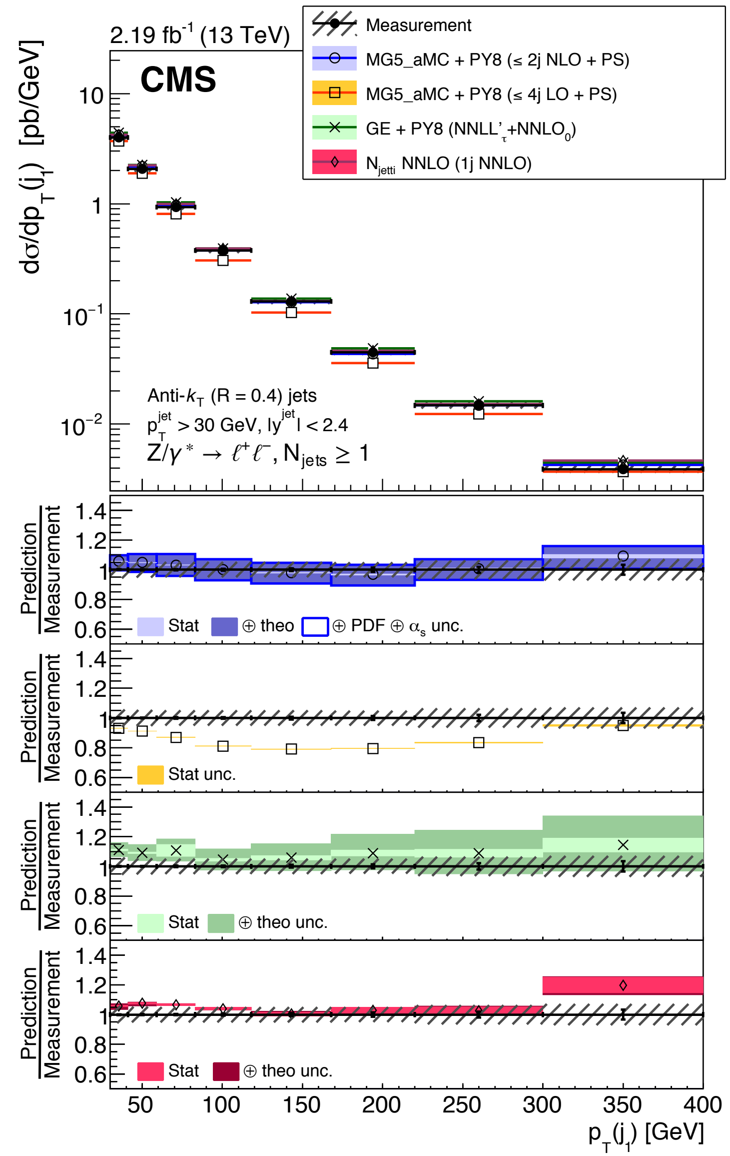


Z+Jets

arXiv:1804.05252

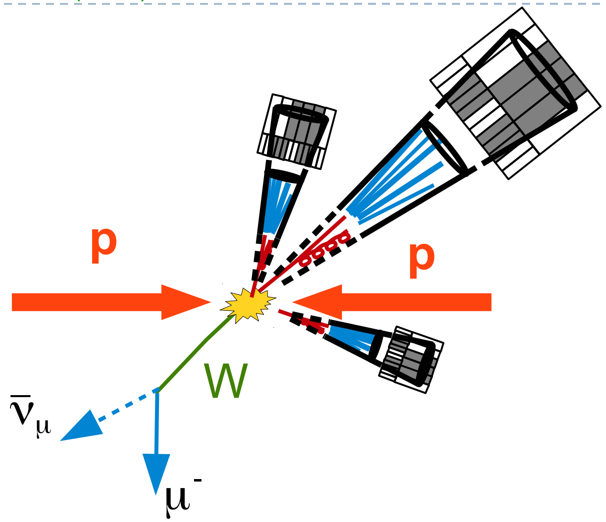
Differential Z+jet cross sections





- GE: shape at low $p_T(Z)$ and p_T(jet1) dependence well modelled
- LO MG5_aMC: significant differences
- NLO MG5_aMC and Z+1@NNLO: NLO needed to describe measurement

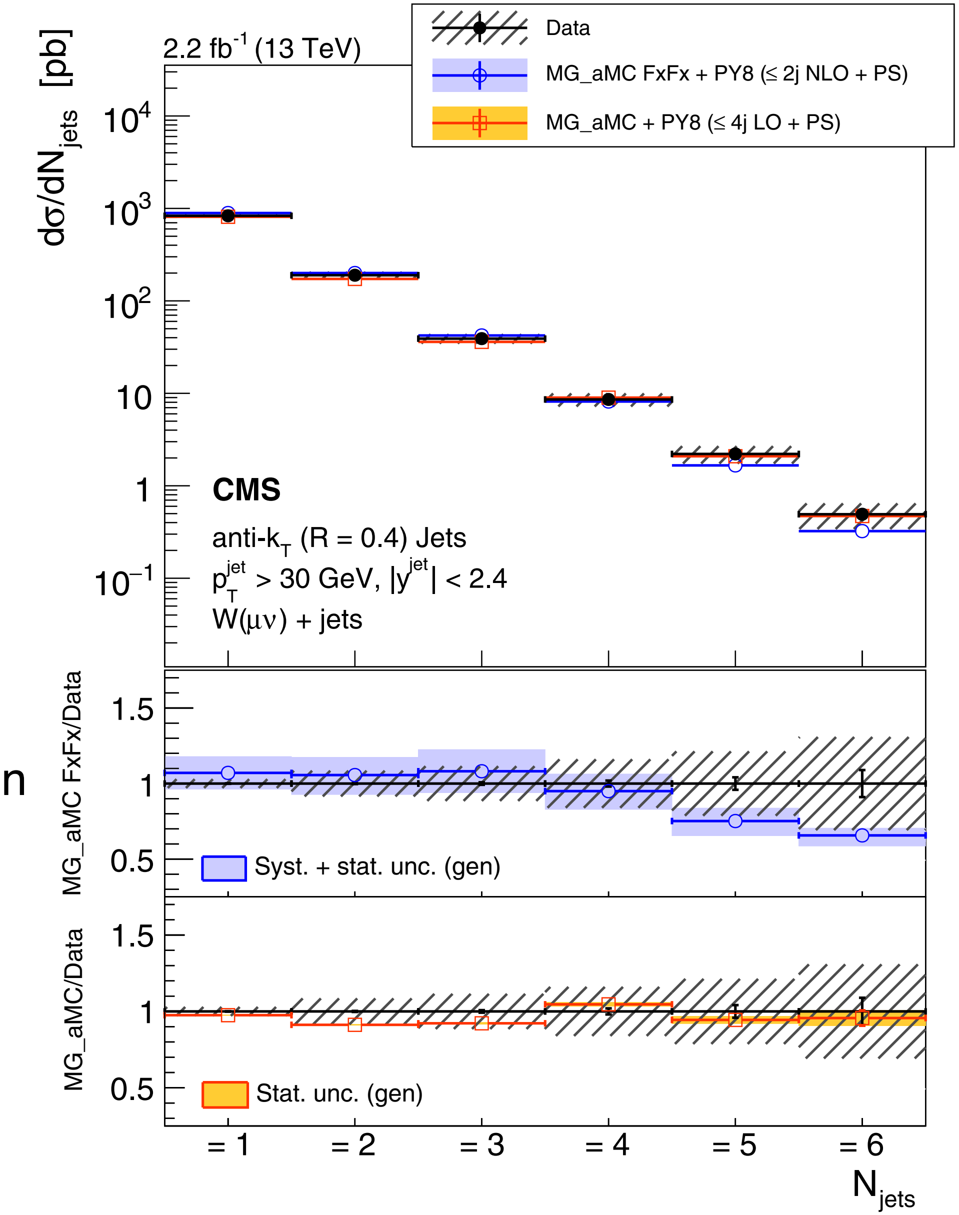
Differential W+jet cross sections



- $p_T(\mu)$>30 GeV; |η|<2.4; M_T> 50 GeV
- p_T(jet)>30 GeV; |η|<2.4; ΔR(jet,l)>0.4

- pp collisions 2015: 2.2/fb
- Backgrounds estimated from simulation (QCD multijet data-driven)
- ttbar dominant background at high jet multiplicities

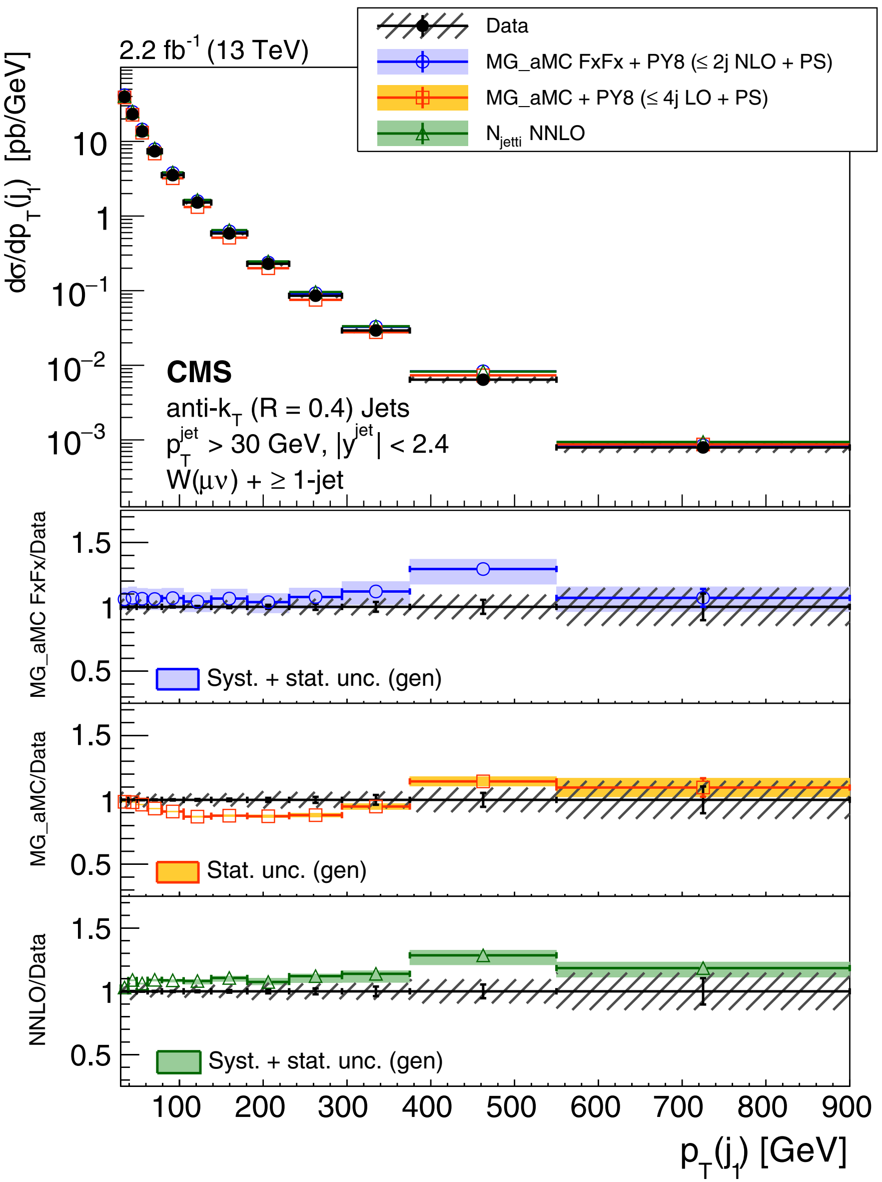
- Unfolding to generator level for many observables: N_{Jets}; p_T(jet1/2/3/4); y(jet1/2/3/4); HT; ΔΦ(μ,jet1/2/3/4); ΔR(μ,closest jet)

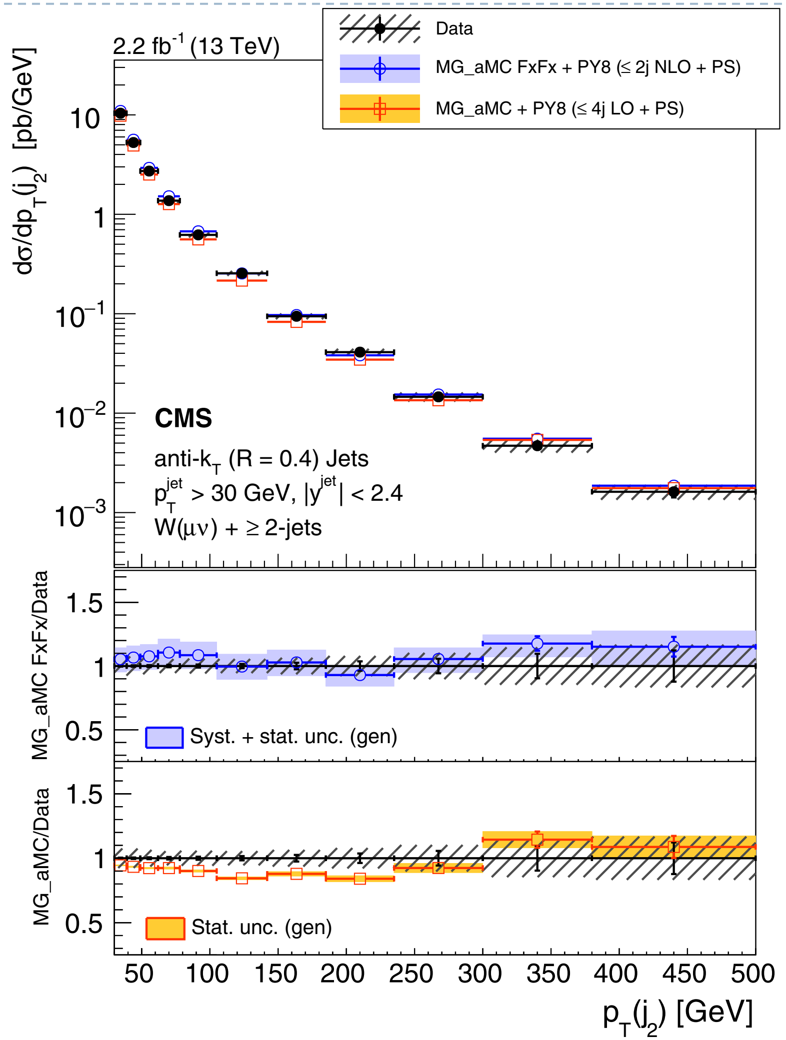


W+Jets

Phys. Rev. D 96 (2017) 072005

Differential W+jet cross sections





- NLO MG5_aMC : Overall best description
- LO MG5_aMC: underestimating at low jet p_T
- W+1@NNLO: better description of shape for p_T of leading jet than LO

W+Jets

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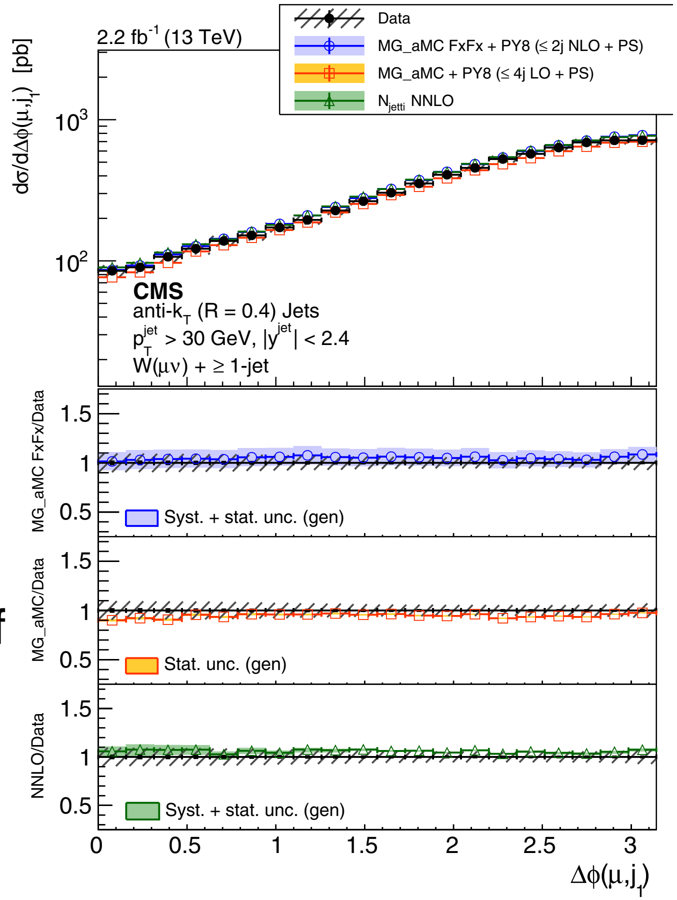
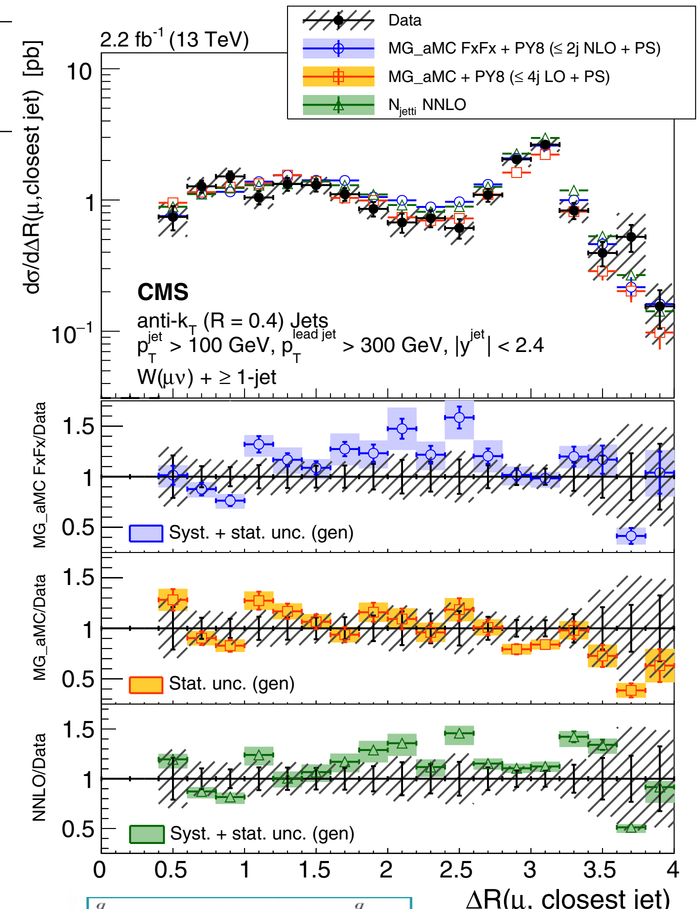
Differential W+jet cross sections

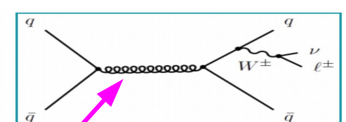
Angular observables

- $\Delta\Phi(\mu,\text{jet1})$: sensitive to the implementation of particle emissions and other (non) perturbative effects modeled by PS algorithms in event generators
- $\Delta R(\mu,\text{closest jet})$: probes contribution of electroweak radiative processes to W+jets

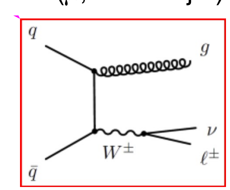
- Decent modelling of angular observables by all predictions: LO MG5_aMC, NLO MG5_aMC, W+1@NNLO





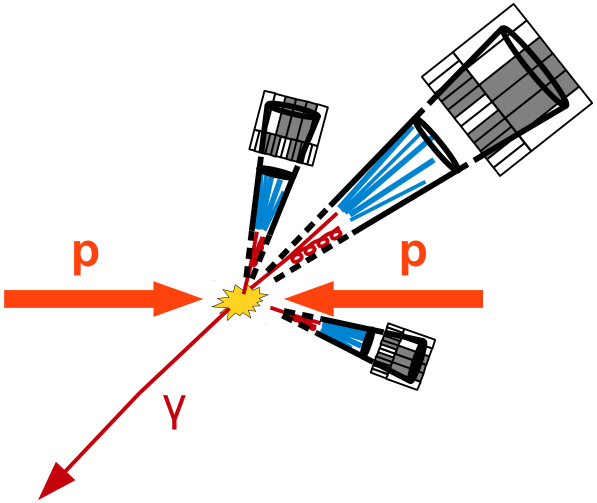


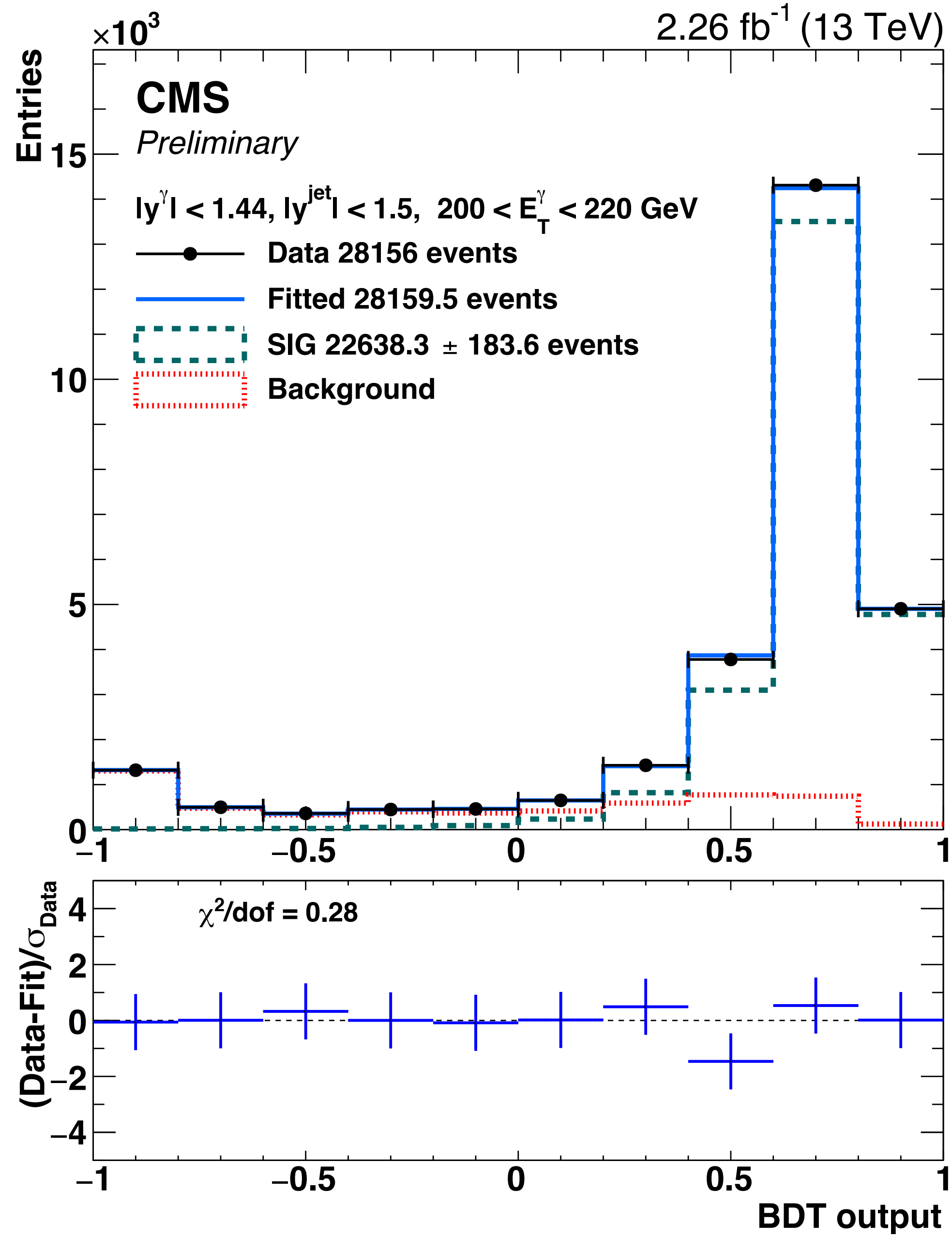
small ΔR: collinear



Large ΔR: W balanced by hadronic recoil

Differential γ+jet cross sections

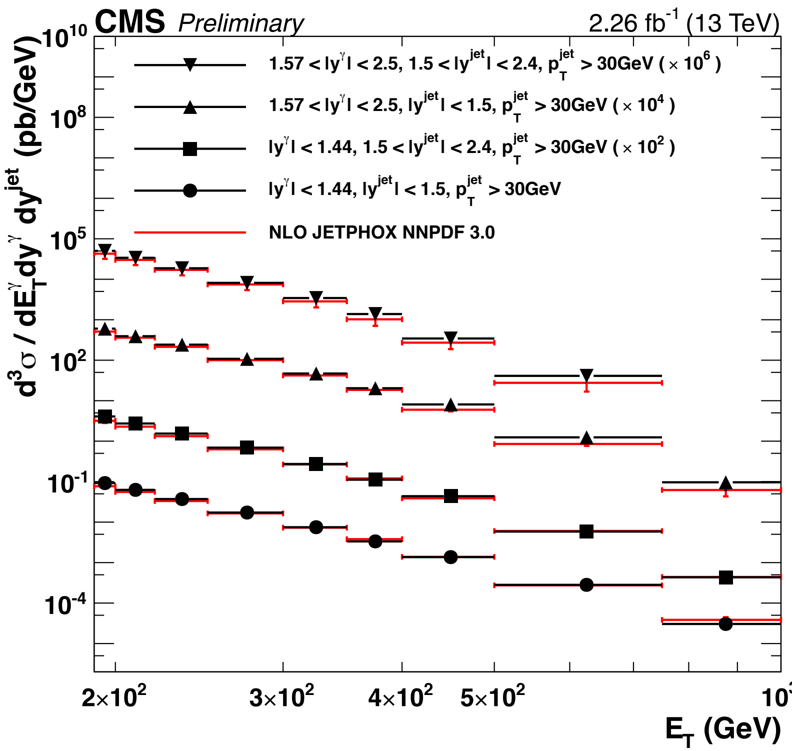


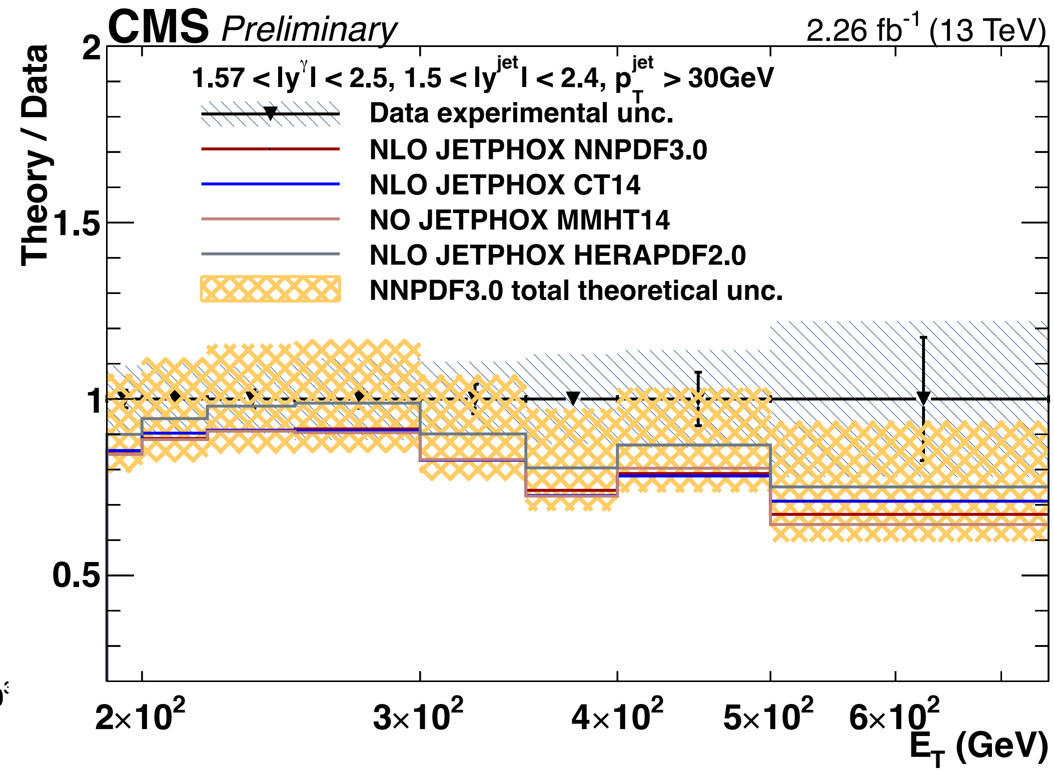


- Photon yields are extracted using the shape of BDT distributions.
- Template for background taken from control region
- Measured inclusive (+ jets) cross sections double (triple) differential in photon E_T , y, (rapidity of the highest pT jet), are compared to NLO QCD calculations (Jetphox 1.3.1)

arXiv:1807.00782

Differential γ+jet cross sections



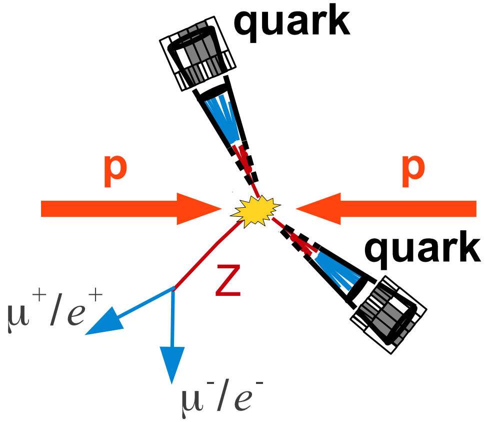


- Cross-sections in agreement with NLO (Jetphox 1.3.1) within uncertainties, in all kinematic regions.

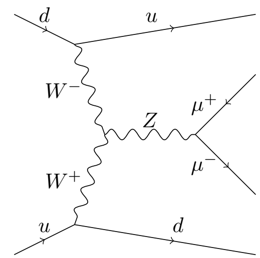
- Expect sensitivity to gluon PDFs over a wide range of (x,Q^2)
- The ratio of the theoretical predictions to data with different PDF sets is studied. Observed differences are small, and within theoretical uncertainties.
- With precise NNLO calculations these measurements could be used to constraint the gluon and other PDFs.

arXiv:1712.09814

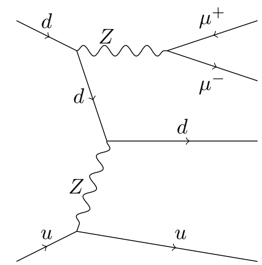
Electroweak Z+2 jets



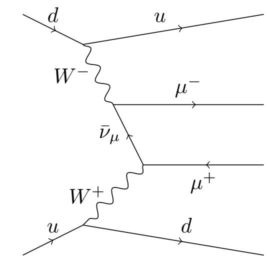
Electroweak production:



Vector Boson Fusion



Bremsstrahlung-like



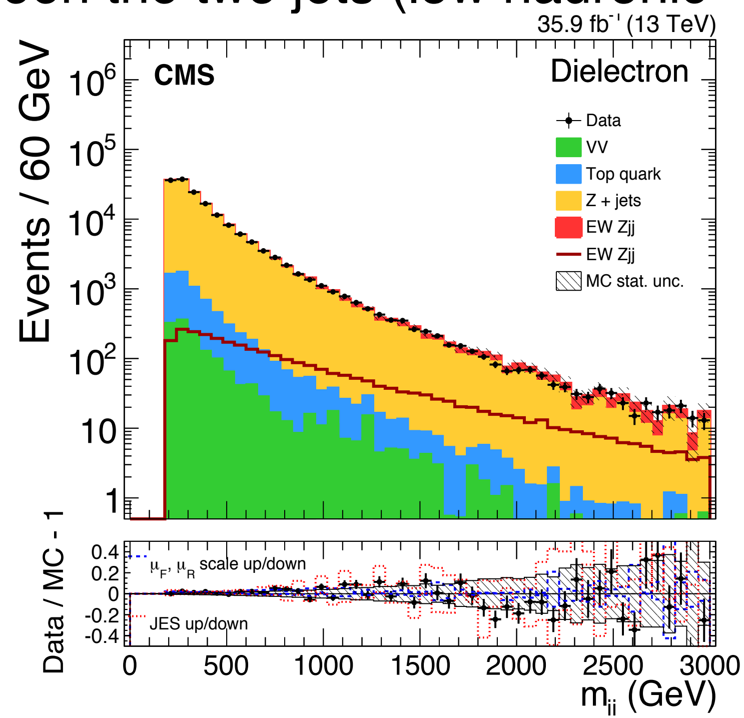
Multiperipheral Collision

Properties of EW Zjj signal events:

- well-separated jets in rapidity with large m_{jj}, and central decay of Z boson
- suppressed color flow in the region between the two jets (low hadronic activity in the rapidity interval)

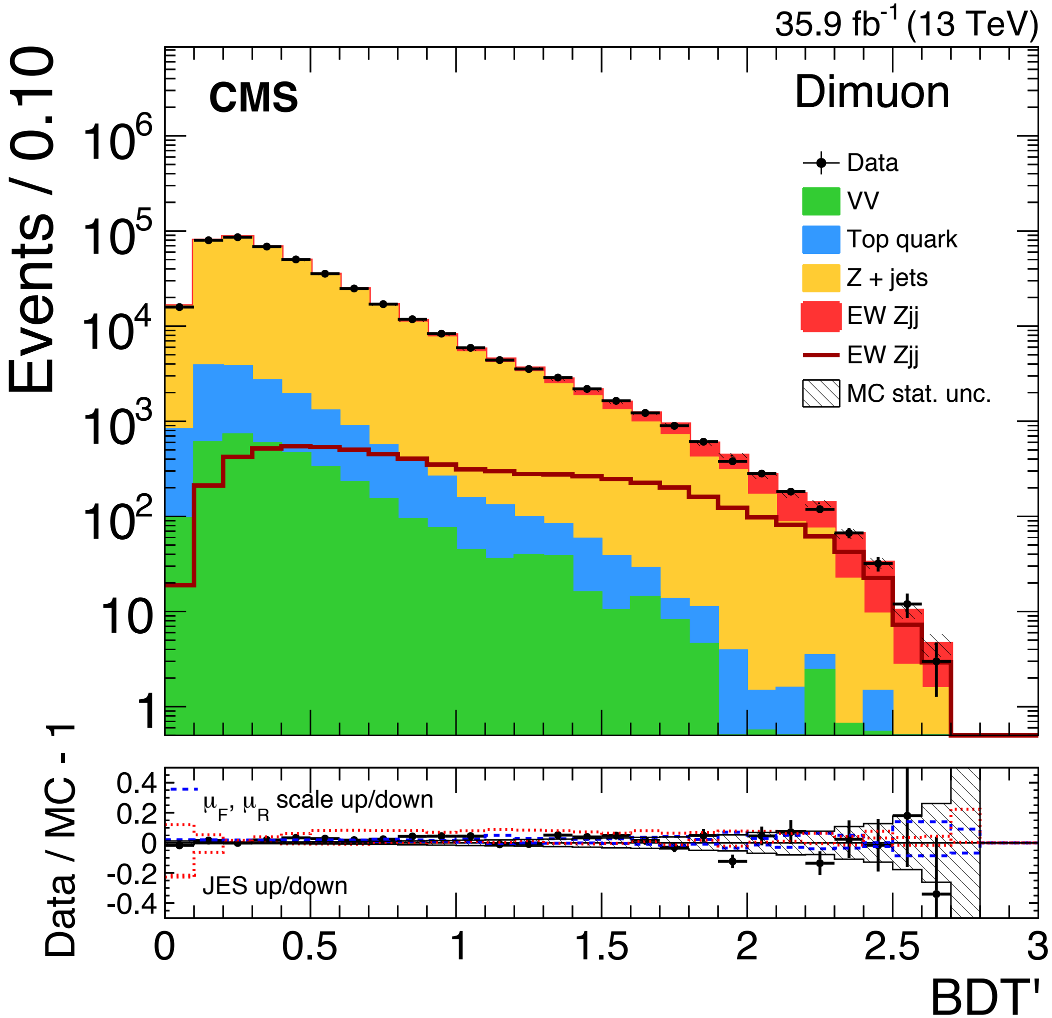
Basic event selection:

- $p_T(j) > 25$ GeV; $m_{jj} > 120$ GeV; $p_T(l1/l2) > 30/20$ GeV; $m(ll)=91\pm15$ GeV
- BDT with many input observables for signal extraction



- pp collisions 2016: 35.9/fb
- The first observation for this process at 13 TeV

Electroweak Z+2 jets



Discriminating observables used in BDT

m_{jj}, $\Delta\eta_{jj}$, $R(p_T^{\text{hard}})$, $z^*(Z)$, p_{Tjj}, quark/gluon likelihood (QGL) of the two tagging jets

$$R(p_T^{\text{hard}}) = \frac{|\vec{p}_{Tj_1} + \vec{p}_{Tj_2} + \vec{p}_{TZ}|}{|\vec{p}_{Tj_1}| + |\vec{p}_{Tj_2}| + |\vec{p}_{TZ}|}$$

$$y^* = y_Z - \frac{1}{2}(y_{j1} + y_{j2})$$

$$z^* = \frac{y^*}{\Delta y_{jj}}$$

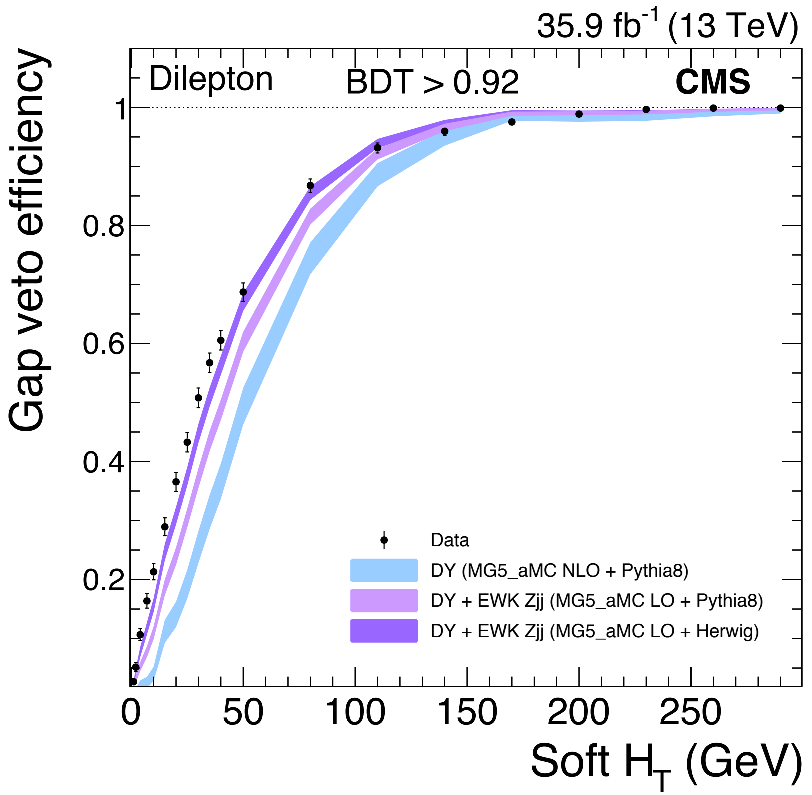
- Simultaneous fit of EW and QCD component in the signal (high BDT) and control (low BDT) regions

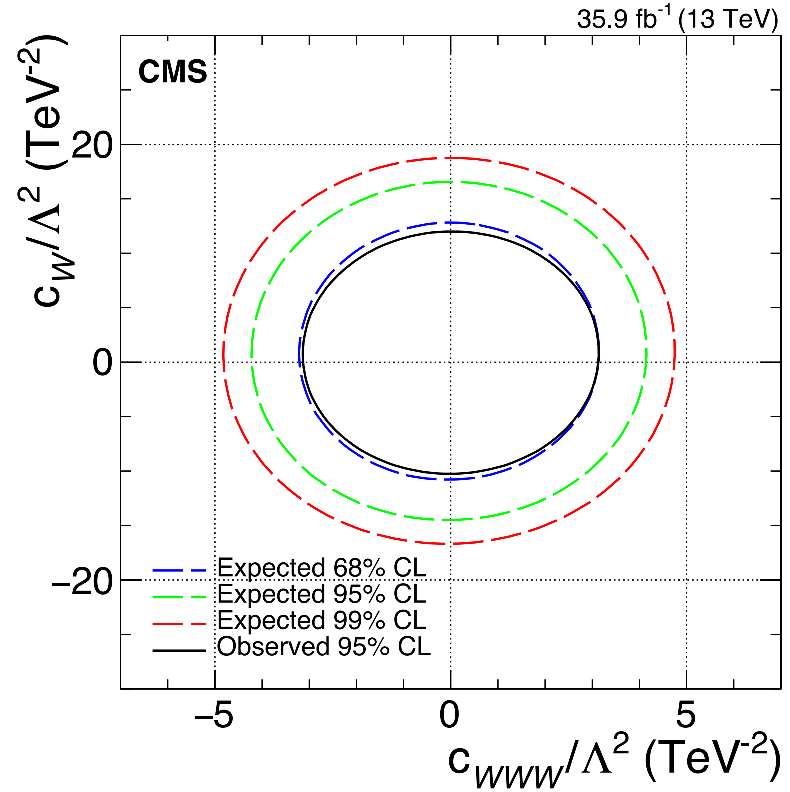
Result: σ(EW lljj)=552±19(stat)±55(syst) fb

MG5_aMC+PYTHIA 8: σ(SM LO EW Z(*ll*)+2-jets)=543±24 fb

arXiv:1712.09814

Electroweak Z+2 jets



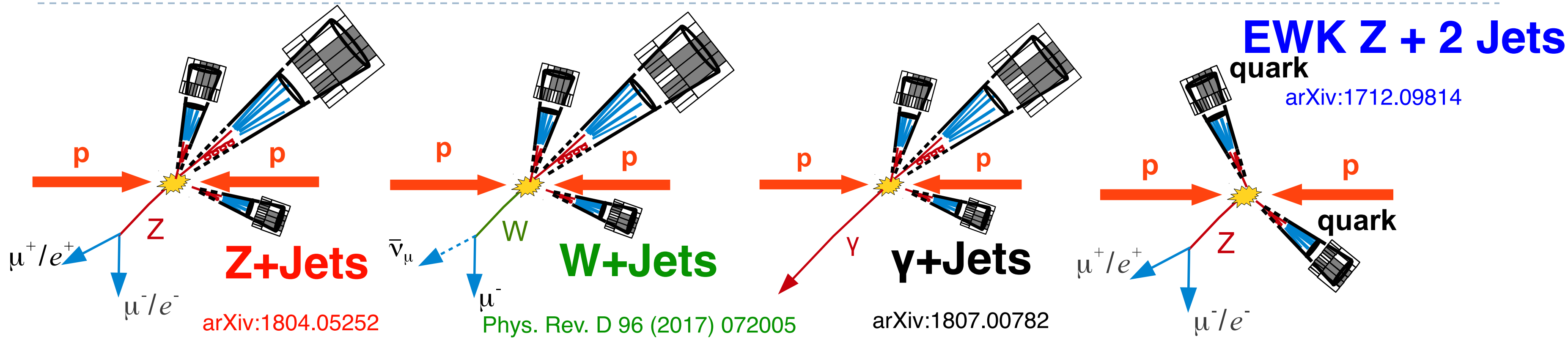


Gap veto efficiency: fraction of events with a measured gap activity below a given threshold

- Data disfavour background only predictions
- Bkg+Signal model with Herwig does much better at low gap activity values

- Limits on anomalous trilinear gauge couplings
- No evidence for aTGC is found. The most stringent constraints on cWWW to date are extracted

Conclusions



Z/W/γ+Jets

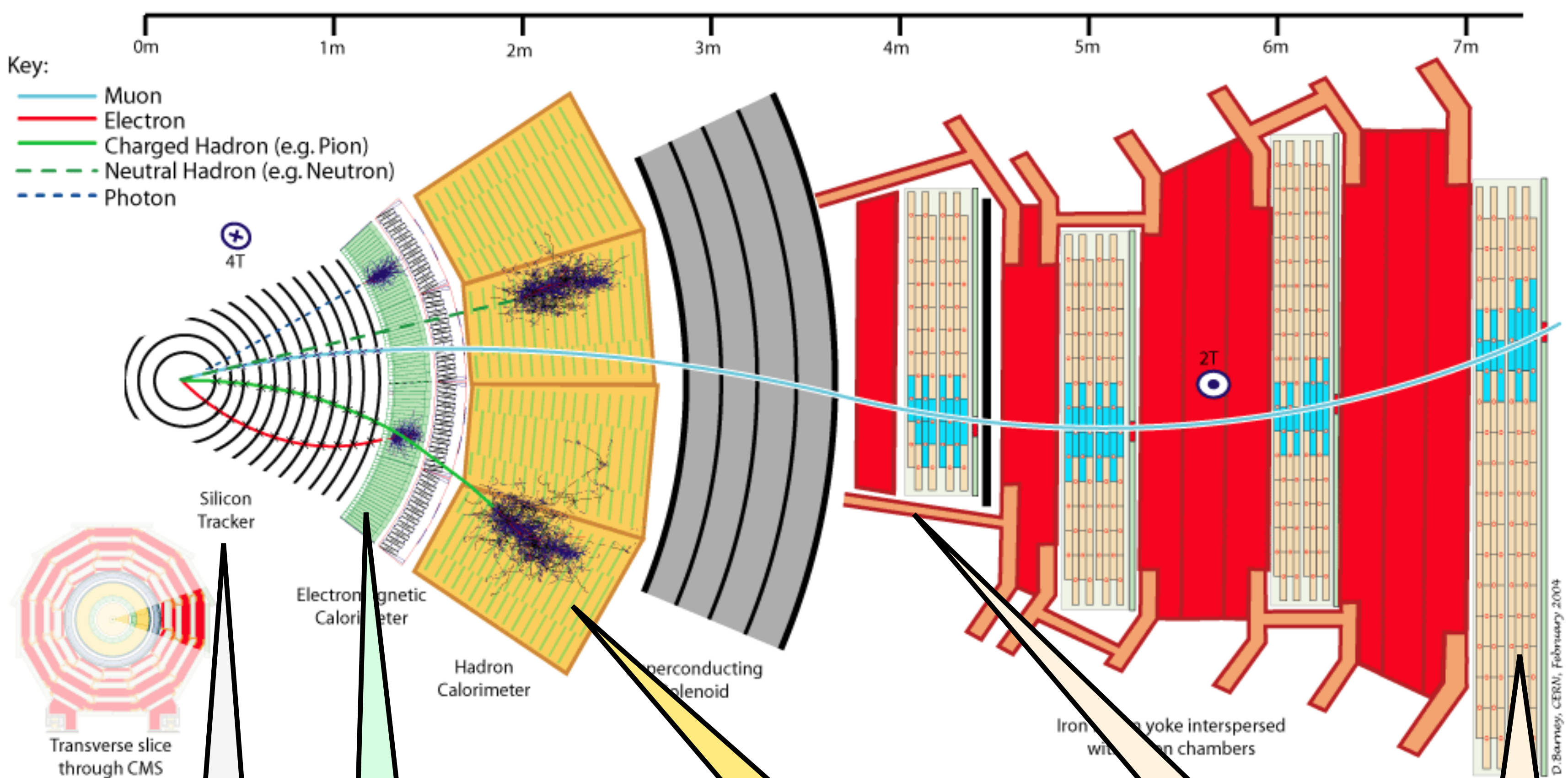
- Differential cross section measurements are stringent tests of SM predictions; **high experimental precision**
  - NLO essential to describe jet multiplicity, transverse momentum of the leading jet and Z boson
  - Fixed order NNLO predictions available with significantly reduced theory uncertainties for W/Z
- γ+Jets: PDF constraints possible with measurements and improved NNLO predictions

EWK Z+2jets

- First observation of the EW Zjj production at 13 TeV
  - 10% prec. of σ measurement; in agreement with SM prediction
  - stringent limits on aTGC and constraints on gap activity modelling

Backup

Particle Flow (PF) approach



Silicon Tracker

Position, momentum of charged particles : **$e^{\pm}$, $\pi^{\pm}$, $\mu^{\pm}$**

Electromagnetic Calorimeter

Position & ID, energy of **$e^{\pm}$, γ, π^{0}**

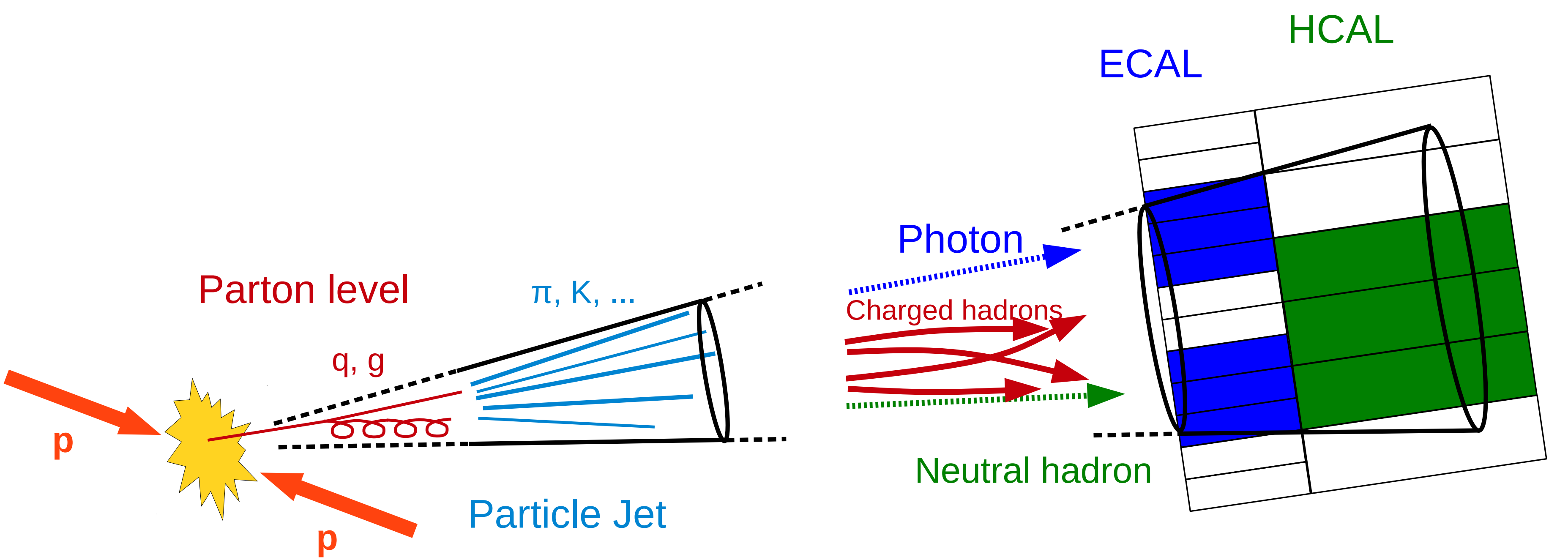
Hadron Calorimeter

Energy of hadrons : **p, n, $\pi^{\pm}$, K ..**

Muon Chambers

Position & momentum of **$\mu^{\pm}$**

Particle Flow (PF) approach



W/Z jet multiplicity distributions (pre-unfolding)