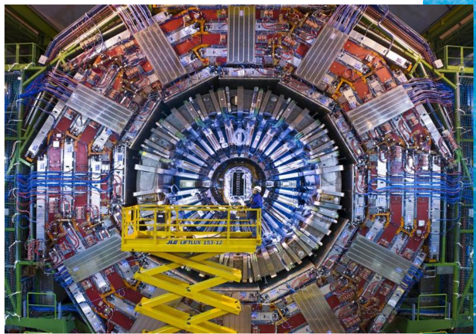
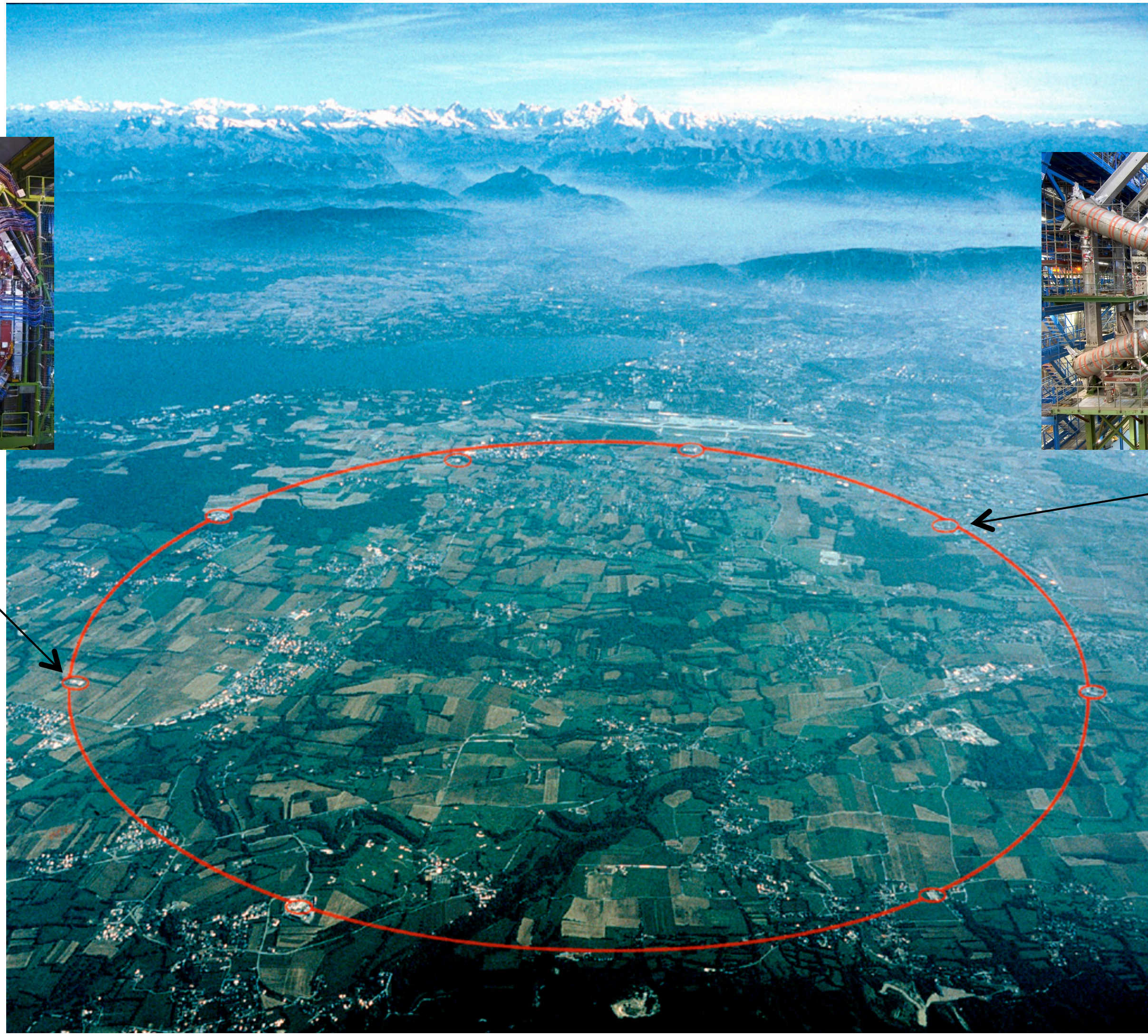
Recent Results on (multi)jet production Measurements with the ATLAS and CMS experiments

Matthias Weber (UCLA)

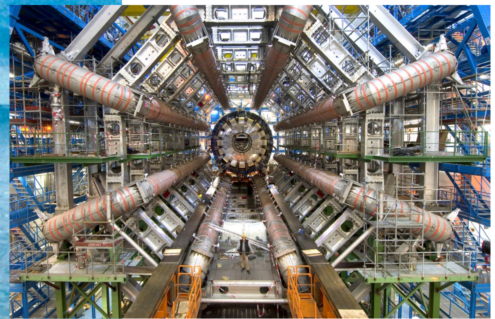
on behalf of the ATLAS & CMS collaborations

CMS





ATLAS

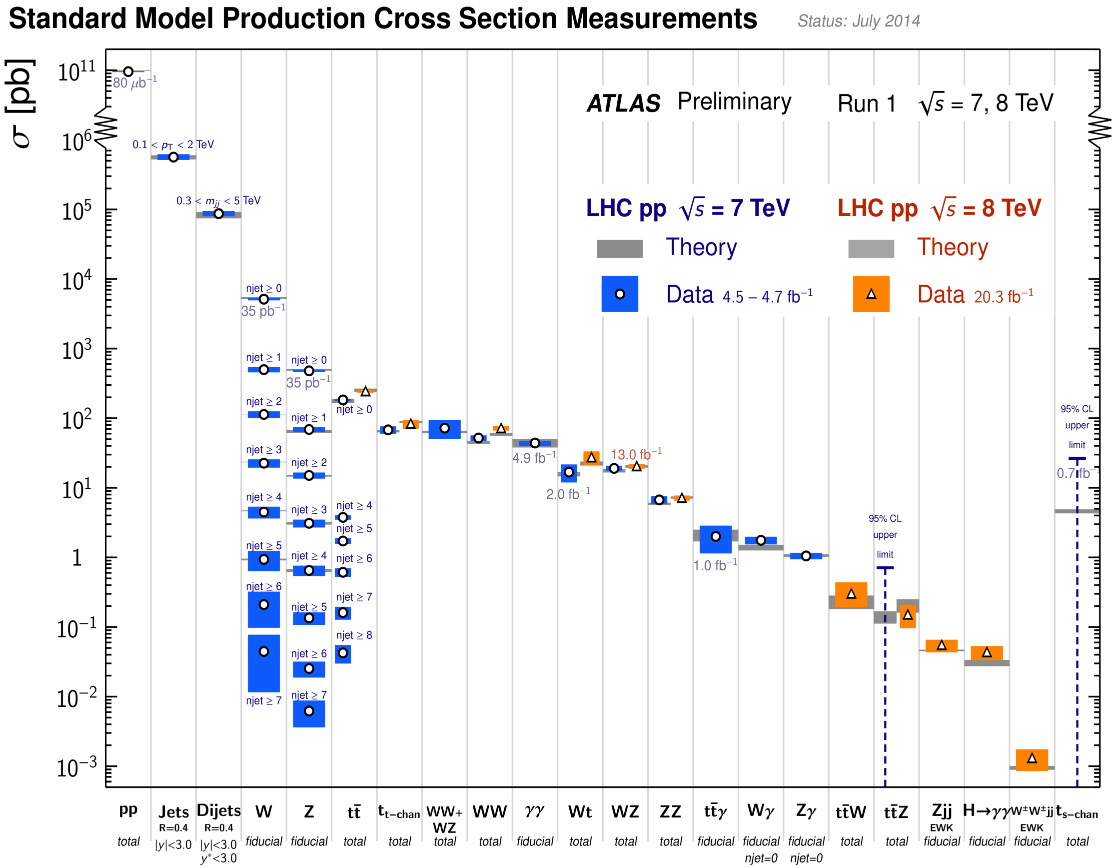


(Multi)Jets: Outline

- Jet properties
  - Jet energy corrections
  - Rejection of pileup jets
  - Quark/gluon jet discrimination
  - Jet pull
- Measurement of jet cross-sections
- Multi-jet measurements
- Vector bosons and jets: Z over photon p_T ratio

Jets: Motivation

- Good understanding of jets crucial for many experimental signatures
- Test perturbative QCD calculations and MC predictions over several orders of magnitude
- Study parton distribution functions
- High precision measurements
  - Very small background rates
  - Small experimental uncertainty

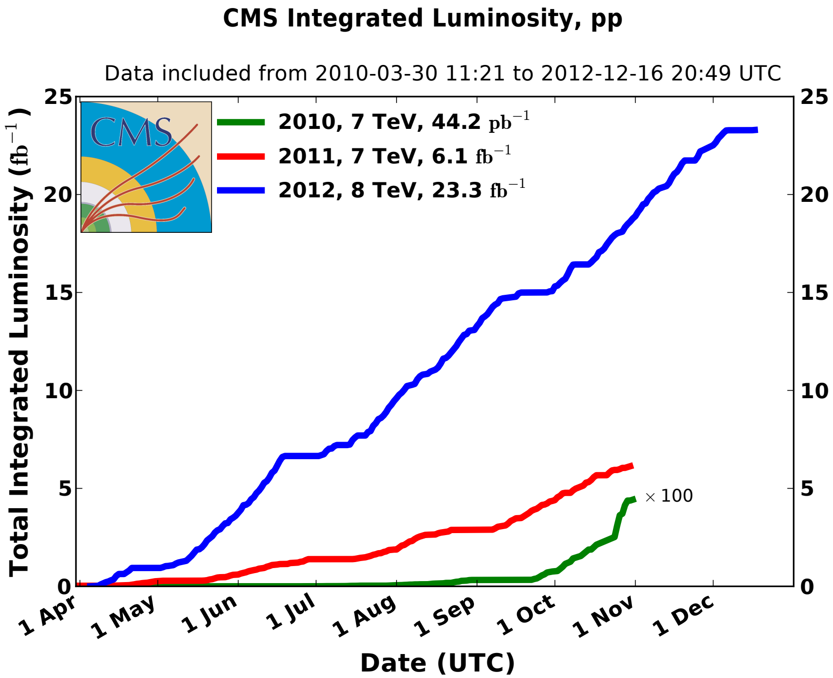


Study extreme kinematic selections interesting for new physics with high precision

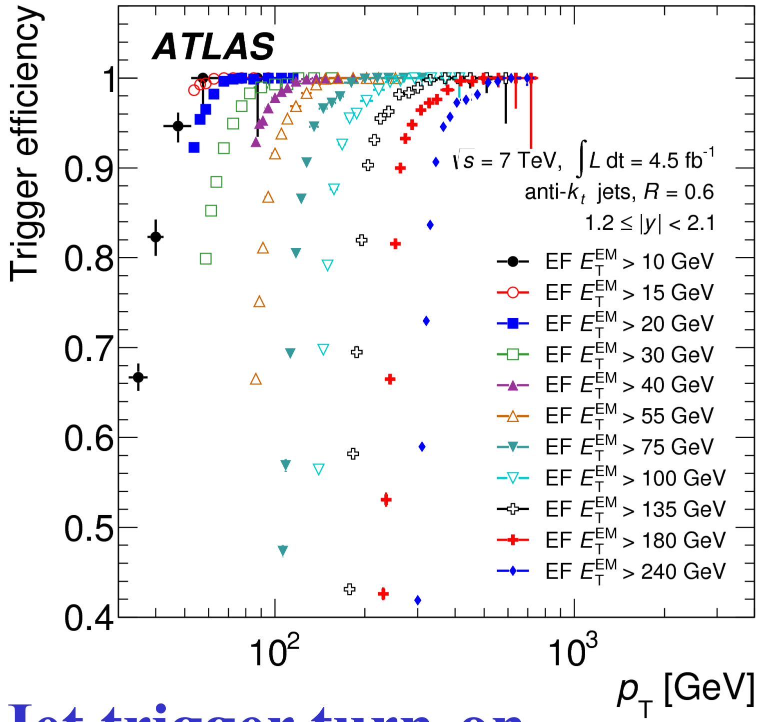
- Final state with jets (and leptons) major background for Higgs, SUSY, Exotica

Data sample and trigger

- Huge integrated luminosity delivered to both experiments, over 20 fb^{-1} in 2012 at 8 TeV



recorded intergrated lumi



Jet trigger turn-on

- In order to cope with the large rate, need to filter events by different triggers
- Need to combine several trigger streams for retrieving full spectrum
- Determine trigger turn on and prescales for physics spectrum

Jet Properties

Jet calibration sequence

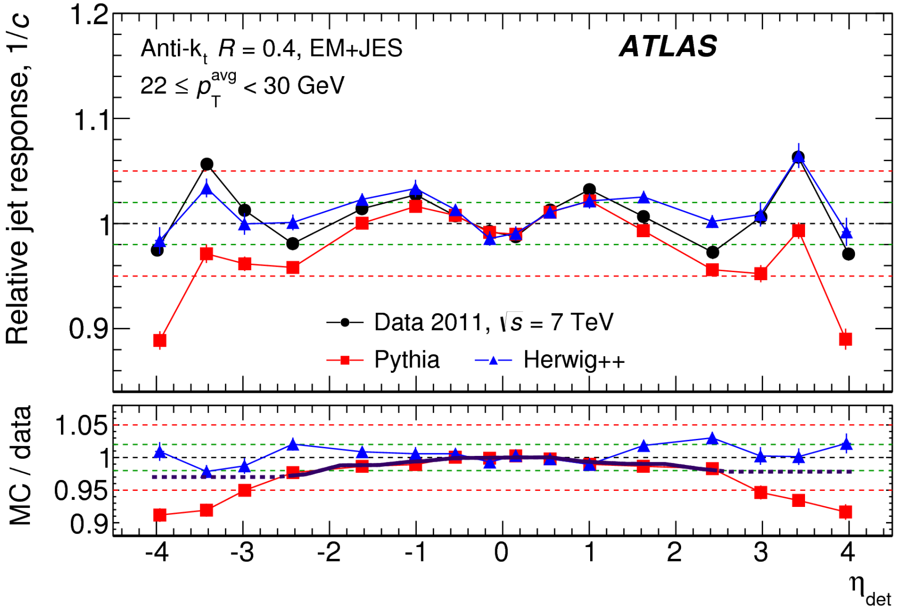
Both ATLAS and CMS calibrate jets in a factorized approach (shown for ATLAS)

- The first step corrects for jet energy due to pileup: additional events in the same collision as the hard scatter we are interested in
- The MC JES calibration includes correction in η and p_T of the jet

- In situ correction performed on data in dijet-balancing to correct the η dependence of the response
- Correction in p_T derived from leptonic Z plus jets and γ plus jets events (MET projection fraction and p_T balancing)
- For high p_T jets use multijets where 1 single hard jet is balanced by multiple (calibrated) low p_T jets

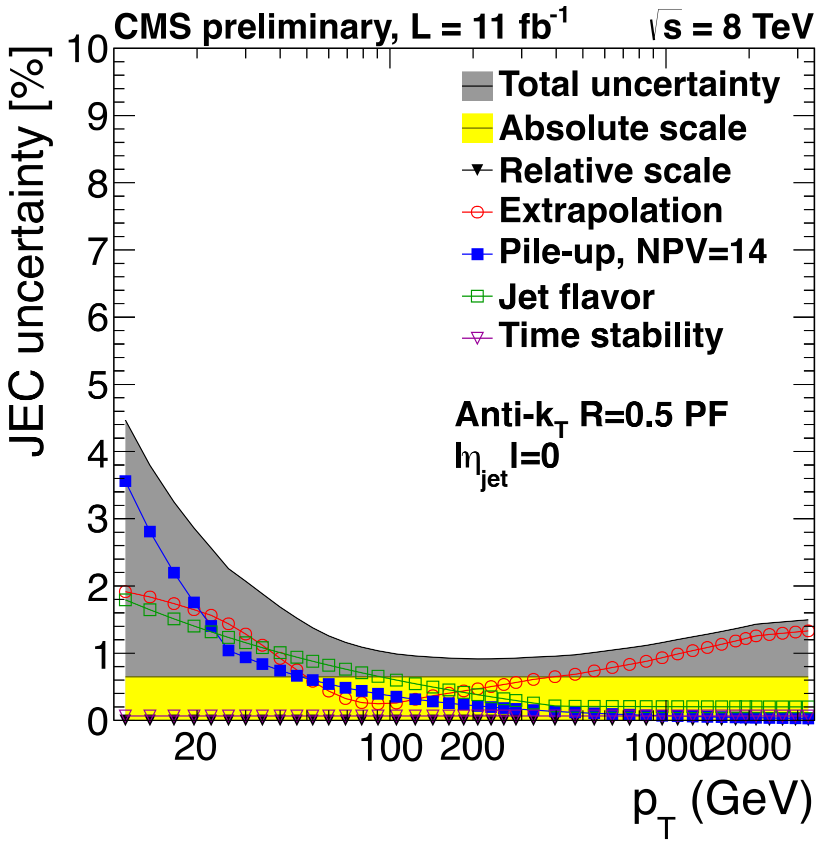
Jet calibration results

ATLAS intercalibration of jets



Systematics of this calibration step mostly through modelling of 3rd jet radiation in different MCs

CMS uncertainy of JEC



For central jets uncertainty below 2% → allows measurements with high precision

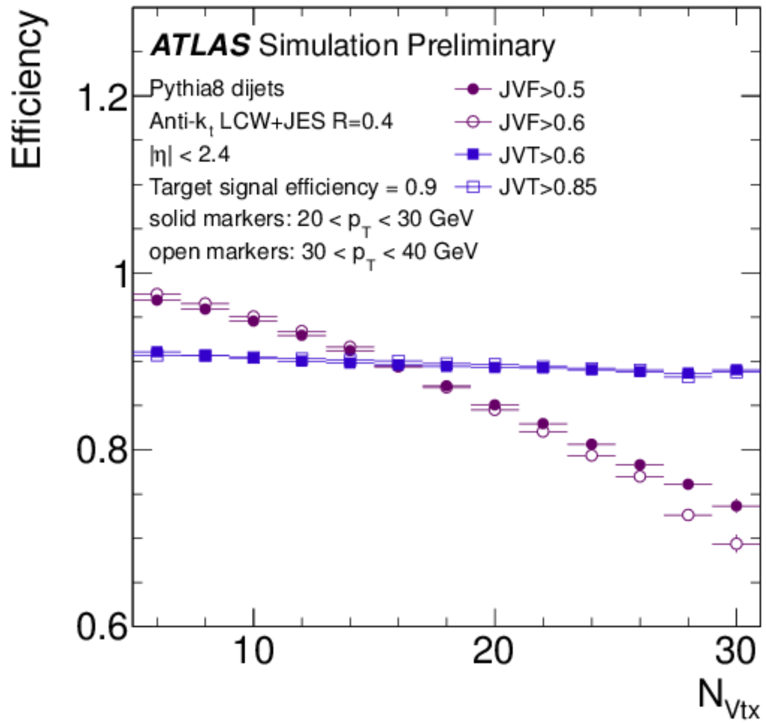
arxiv:1406.0076

CMS-DP-2013-011

Pileup jet rejection

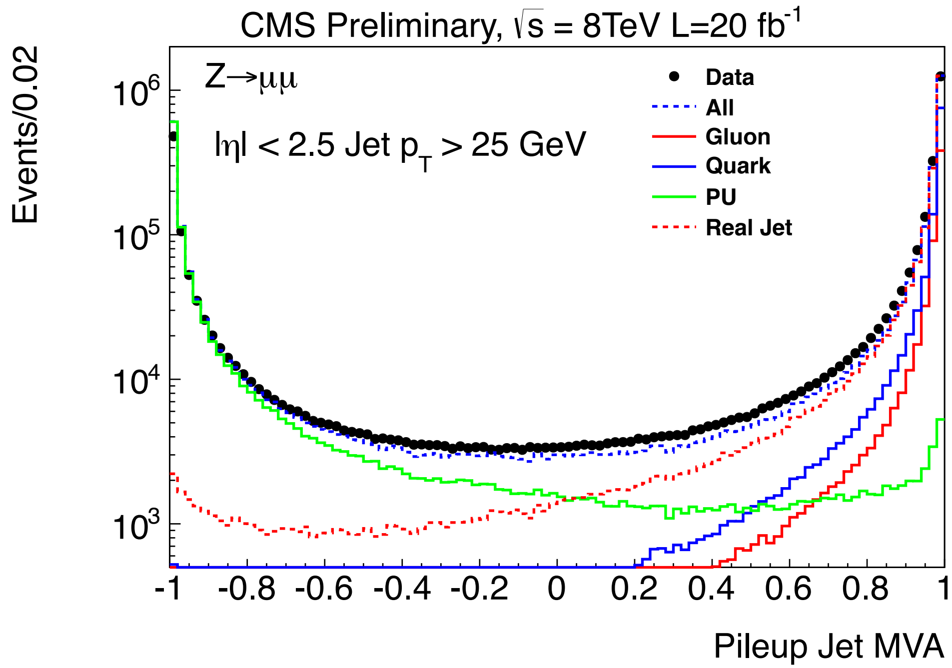
Jet Vertex fraction, PV_0 vertex with track $\Sigma\, p_T^2$

$$\mathrm{JVF} = \frac{\sum_k p_T^{\mathrm{trk}_k}(\mathrm{PV}_0)}{\sum_l p_T^{\mathrm{trk}_l}(\mathrm{PV}_0) + \sum_{n\geq 1}\sum_l p_T^{\mathrm{trk}_l}(\mathrm{PV}_n)}$$



As alternative MVA combination of two other track based variables, very stable vs N_{vtx}

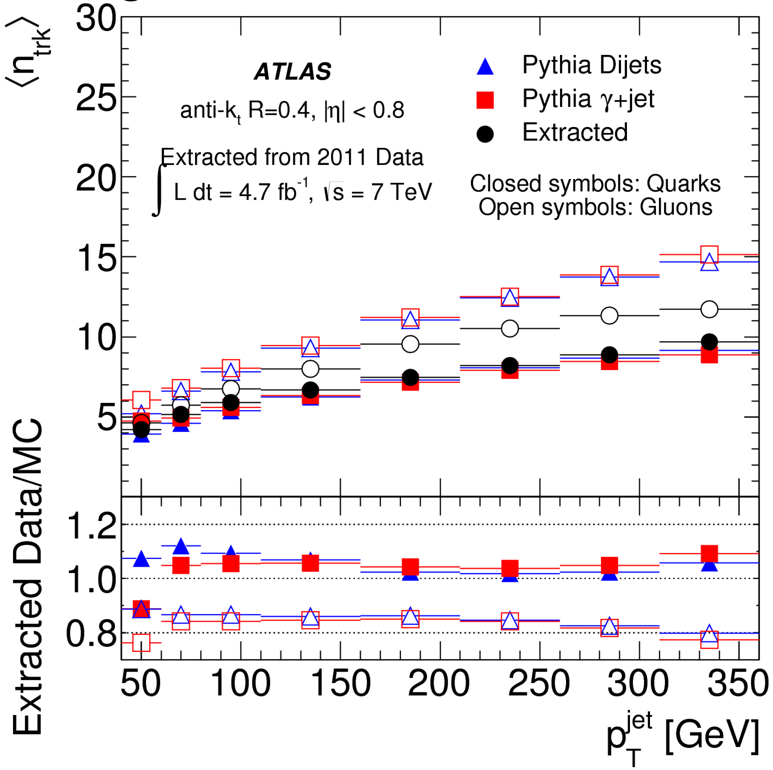
CMS pileup ID MVA based with several track driven input variables (similar to JVF) and jet shower shape variables



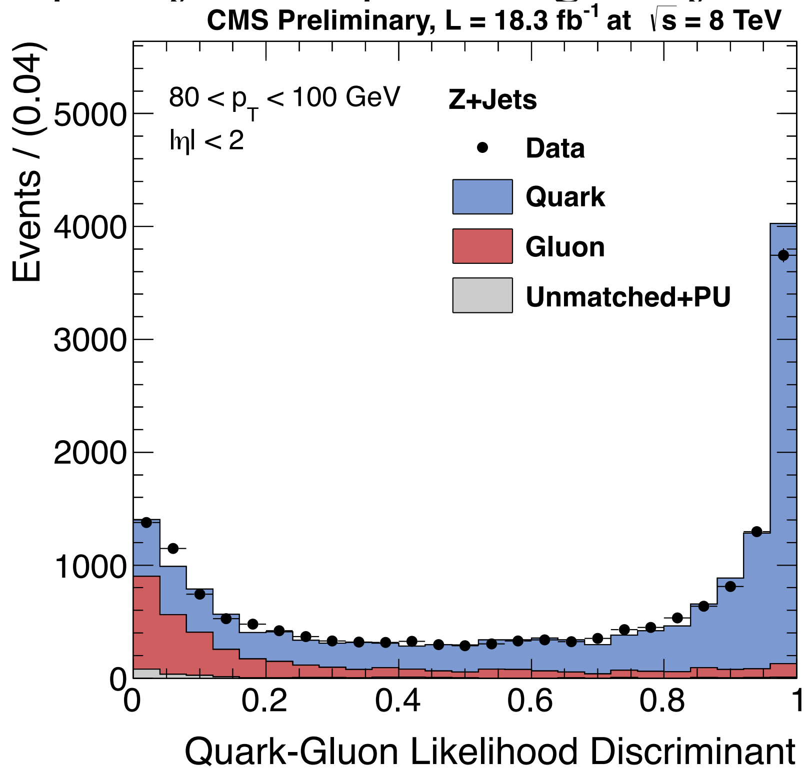
For central jets reach signal efficiency of 99%, PU jet rejection of 90-95 % for p_T>30 GeV

Quark/gluon jet discrimination

Try to build discriminator based on different characteristics between gluon and quark jets, e.g. fewer constituents or narrower shape of quark jets compared to gluon jets



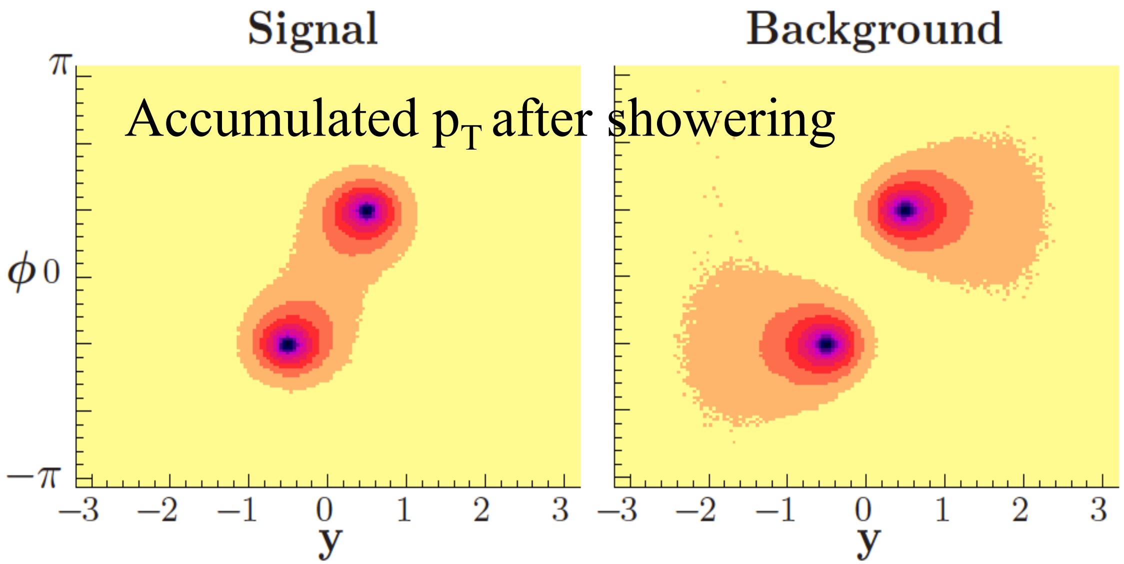
Average n_{track} templates extracted from data compared to pythia from dijets (gluon) and γ+jets (quark dominated)



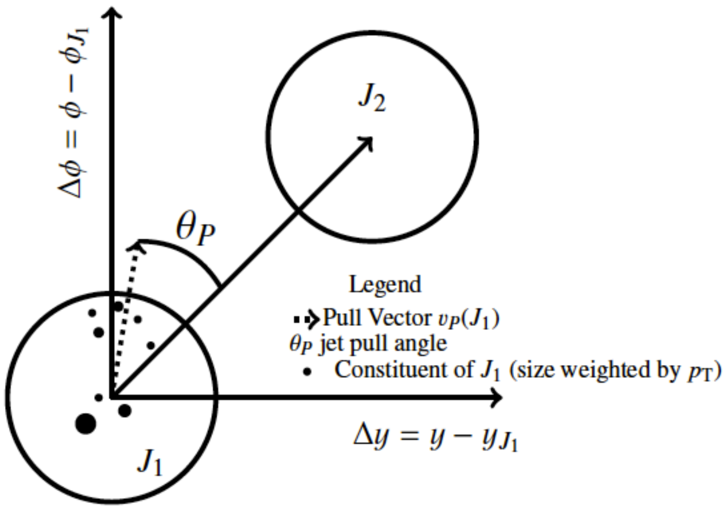
Performance of tagger and input variables evaluated using dijets and Z+jets

Jet pull

Jet pull handle to study color connection between jets, can be used to discriminate between jets originating from color singlets (Higgs) and color octets (e.g. gluons)



PRL 105, 022001 (2010)



Definition jet pull vector:

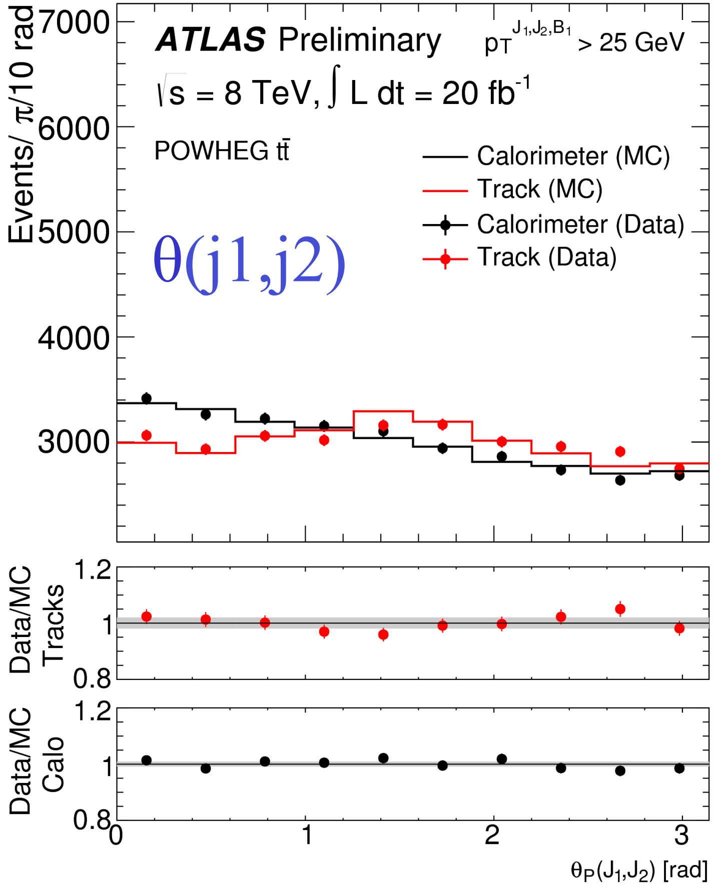
$$v_P(J) = \sum_{i \in J} \frac{p_T^i |\vec{r}_i|}{p_T^J} \vec{r}_i$$

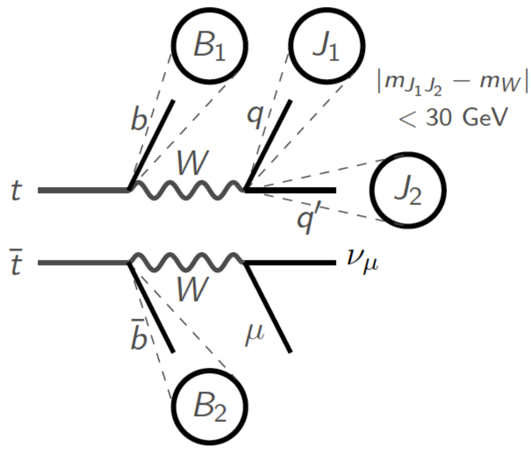
$$\vec{r}_i = (\Delta y_i, \Delta\phi_i)$$

Vectors of constituents relative to jet axis

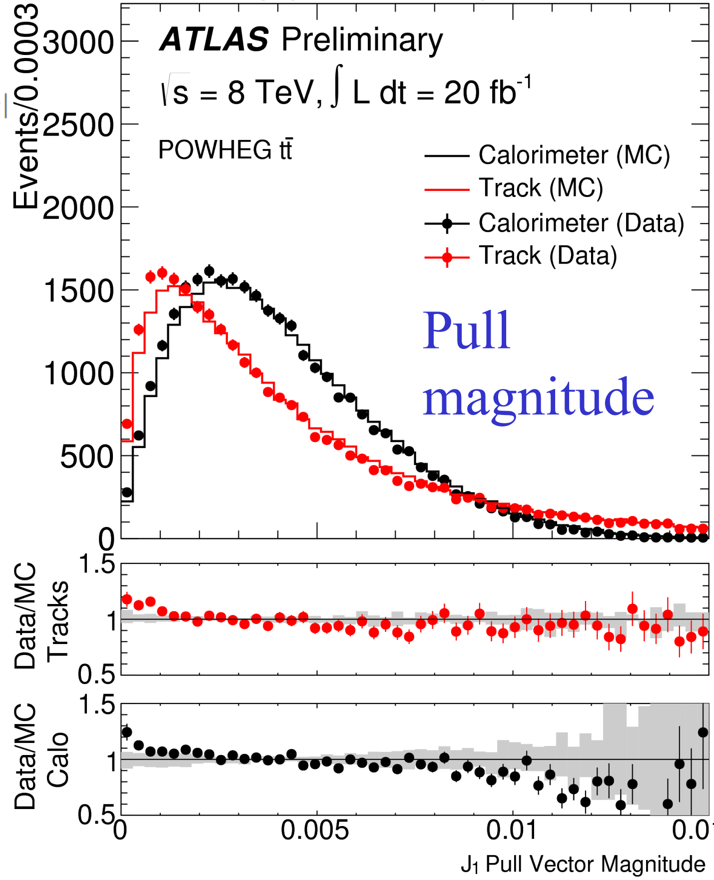
Jet pull in semi-leptonic ttbar events

Measure angle between jet pull vector of jet1 and vector connecting jet1 and jet2





j1,j2 quark jets from W

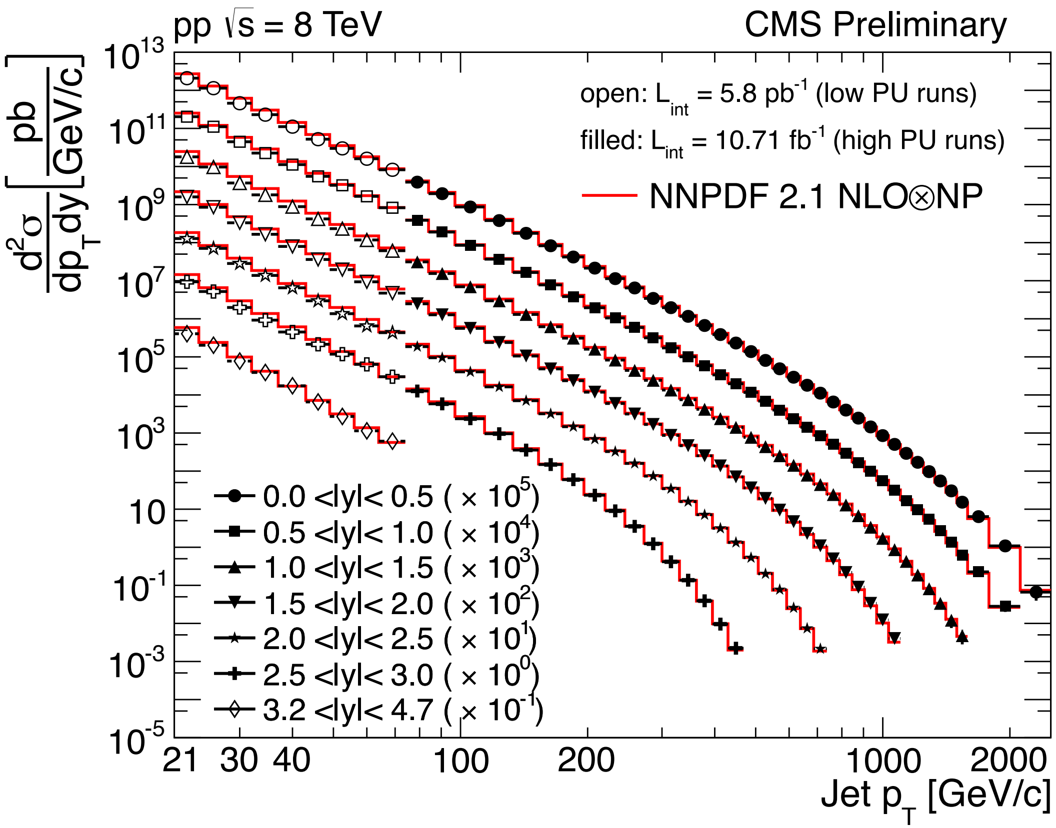


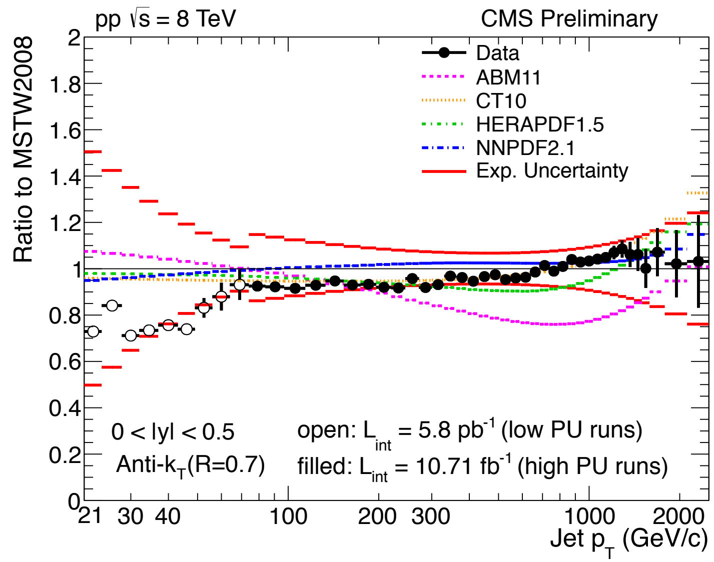
Good agreement between MC and data for both measurement types (tracks and calorimeter input

ATLAS-CONF-2014-048

Jet Cross-sections

Inclusive jet cross-section at 8 TeV



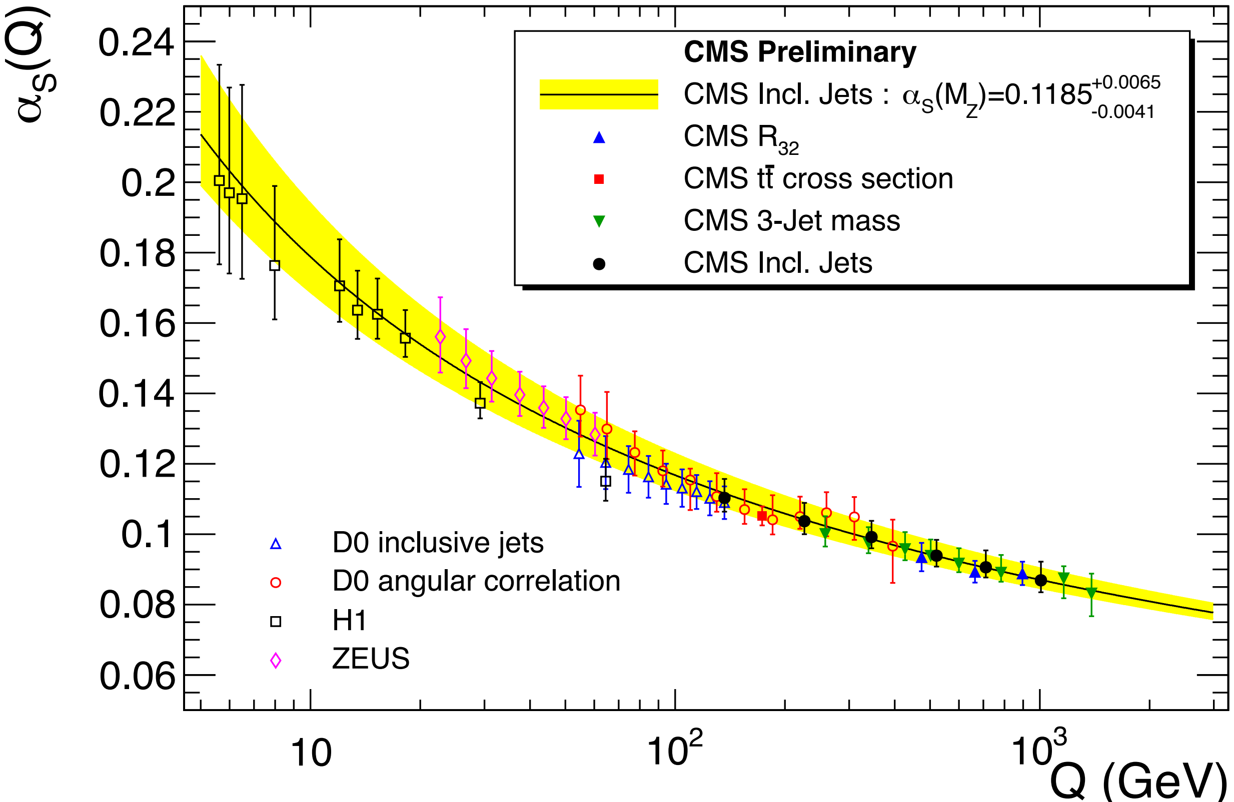


Inclusive jet p_T cross-section at 8 TeV in 7 rapidity bins from 20 to 2500 GeV, over 15 orders of magnitude.

Dedicated low pile-up runs needed for precise measurement at low p_T

Compared to NLO predictions with several PDF sets

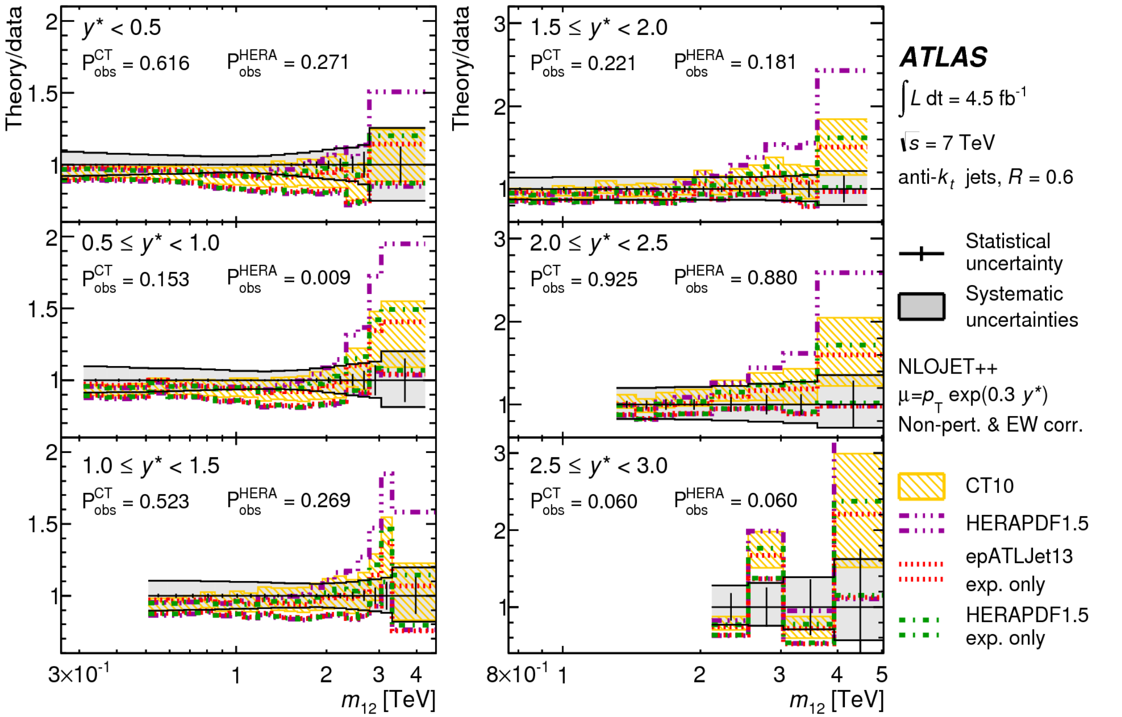
α_S extraction from jet results

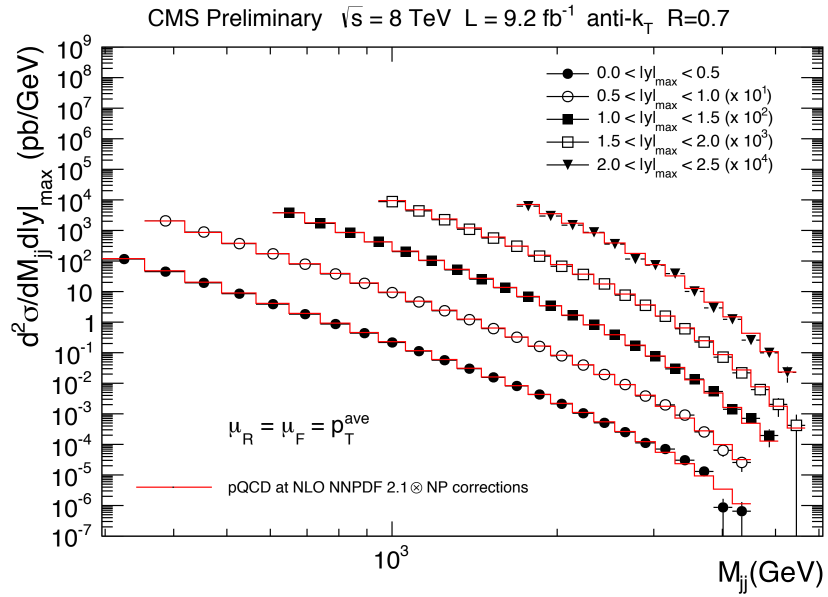


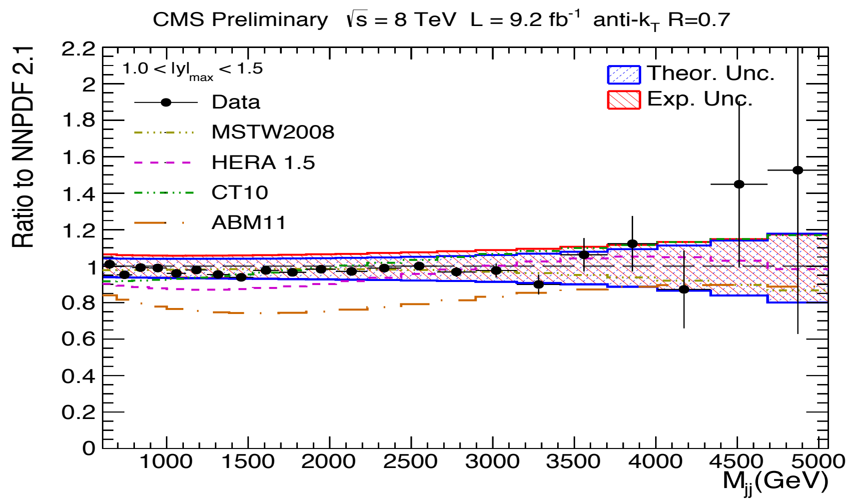
Extract α_S from CMS 7 TeV inclusive jet measurement with jet p_T's up to 2 TeV within η to 2.5, result in agreement with world average:

$$\alpha_S(M_Z) = 0.1185 \pm 0.0019\,(\mathrm{exp.}) \pm 0.0028\,(\mathrm{PDF}) \pm 0.0004\,(\mathrm{NP})^{+0.0055}_{-0.0022}\,(\mathrm{scale})$$

Dijet mass cross-section







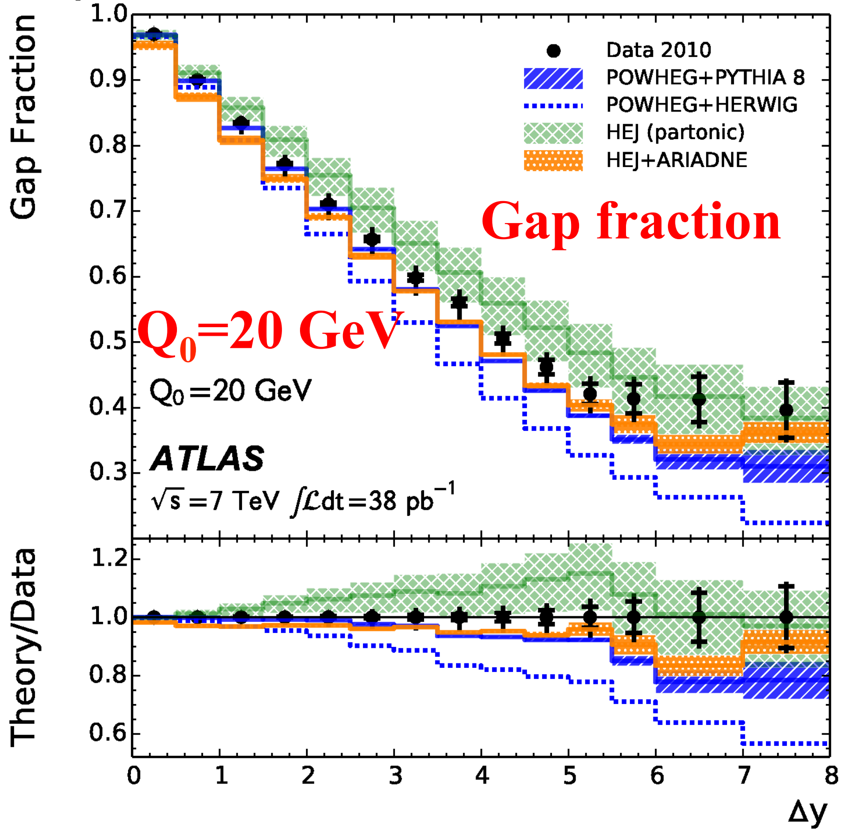
Double differential dijet mass cross-section agrees with NLO pQCD predictions for most PDF sets (both 7 and 8 TeV), disagreement with ABM11 PDF, HERA 1.5 slightly off in some bins

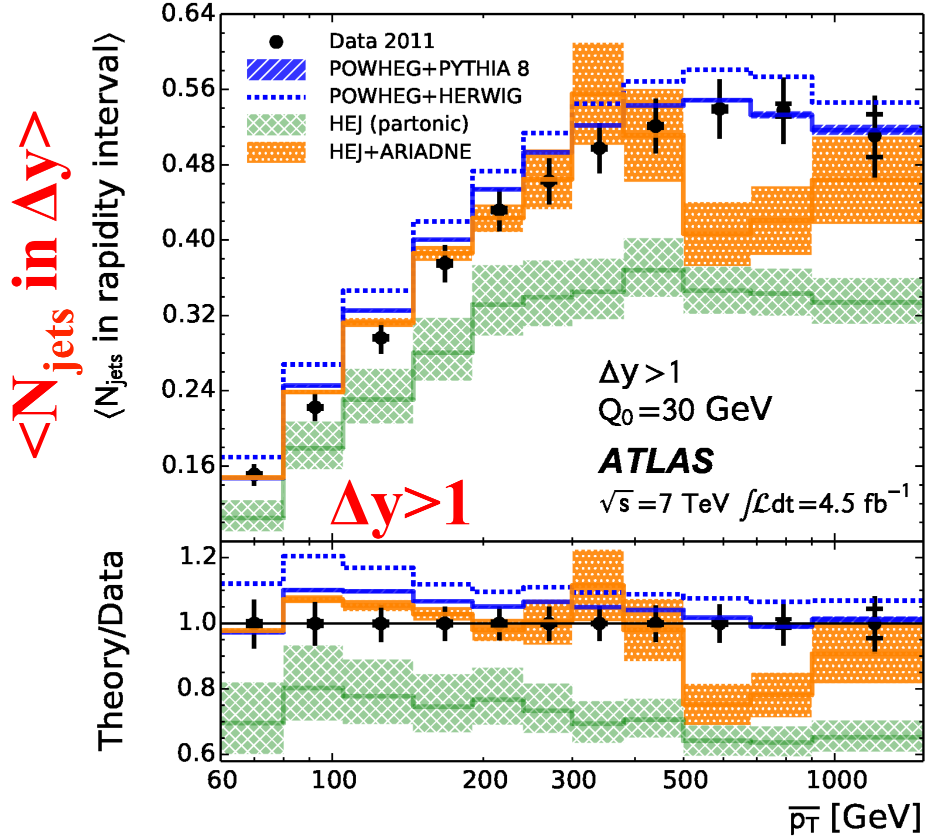
Experimental and theory uncertainties similar

Dijet studies (ATLAS, 7 TeV)

Jet vetoes in dijet events, Δy rapidity difference between two leading jets

Gap fraction: events without additional jets with $p_T > Q_0$ vs total number of events

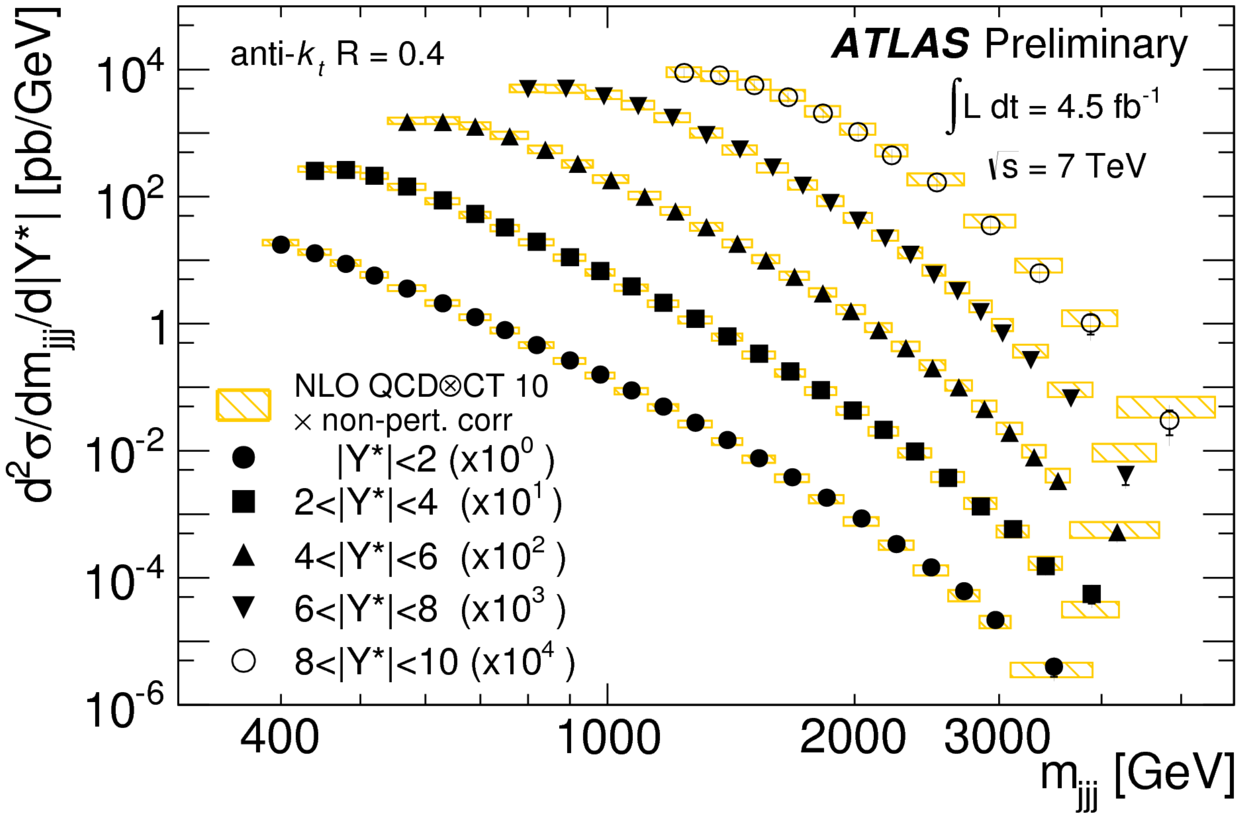




POWHEG+PYTHIA 8 and HEJ+ARIADNE provide best descriptions in general, HEJ parton level and POWHEG+Herwig off

arXiv:1407.5756

Three jet cross-section



Y* defined as

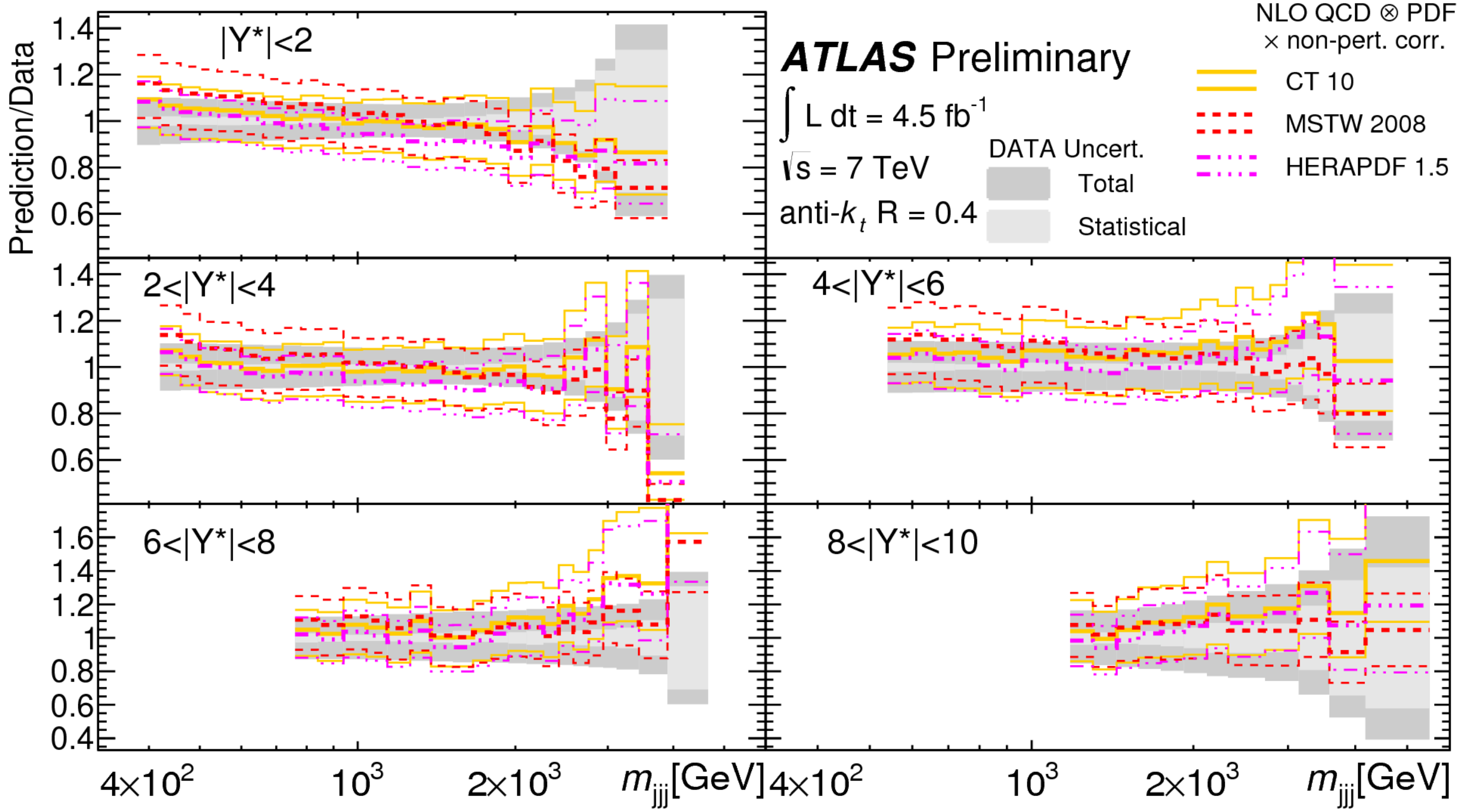
$$Y^* = |y_1 - y_2| + |y_2 - y_3| + |y_1 - y_3|$$

Measured as double differential over 7 orders of magnitude

three-jet masses range between 380 GeV up to 5 TeV

Distribution sensitive to both jet transverse momenta and azimuthal correlation, compared to several PDF sets

Three jet cross-section: ratios



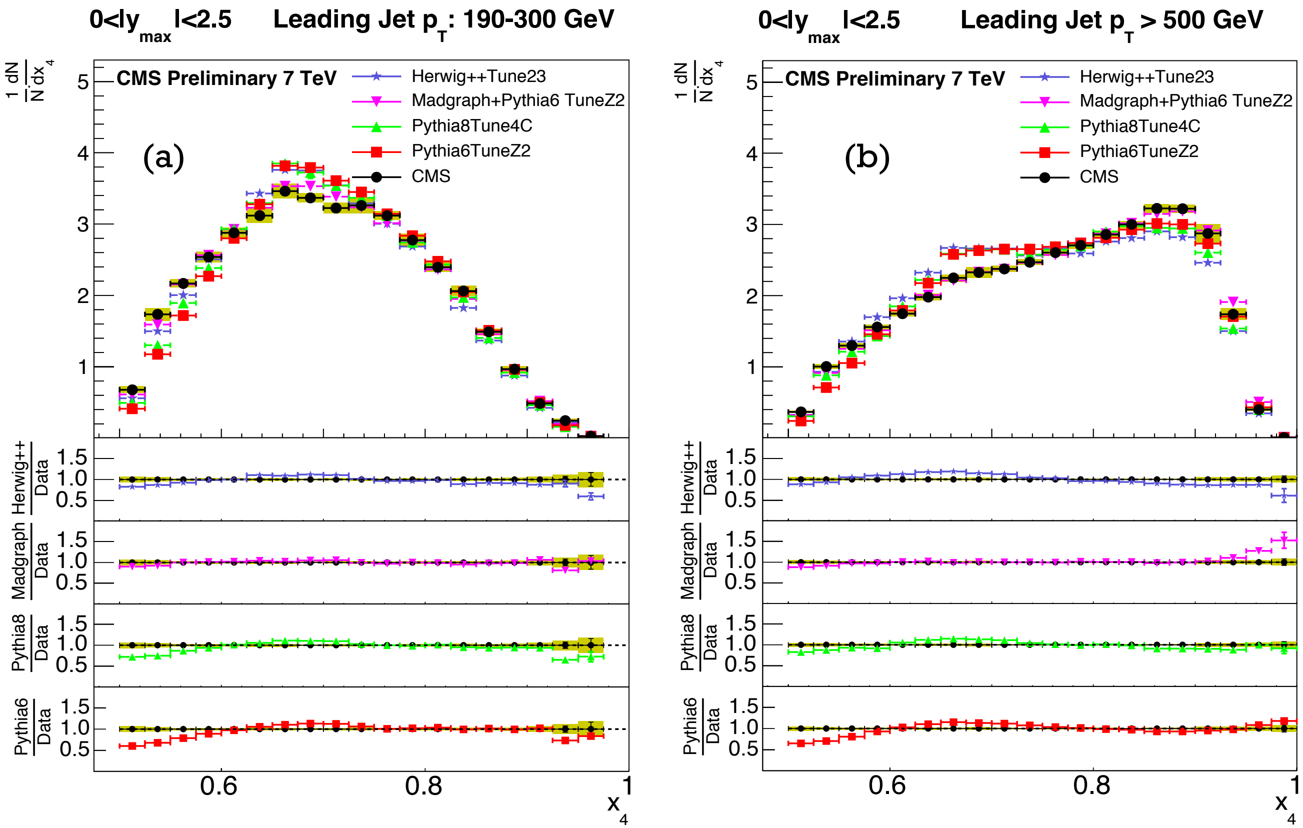
Good quality description of NLOJET++ with CT10, MSTW08 and HERAPDF 1.5 for 0.4 jets across the full range

Multijets (CMS, 7 TeV)

Inclusive 3 and 4 jet events, jet momenta scaled to centre of mass system:

Measure scaled jet energies and angles

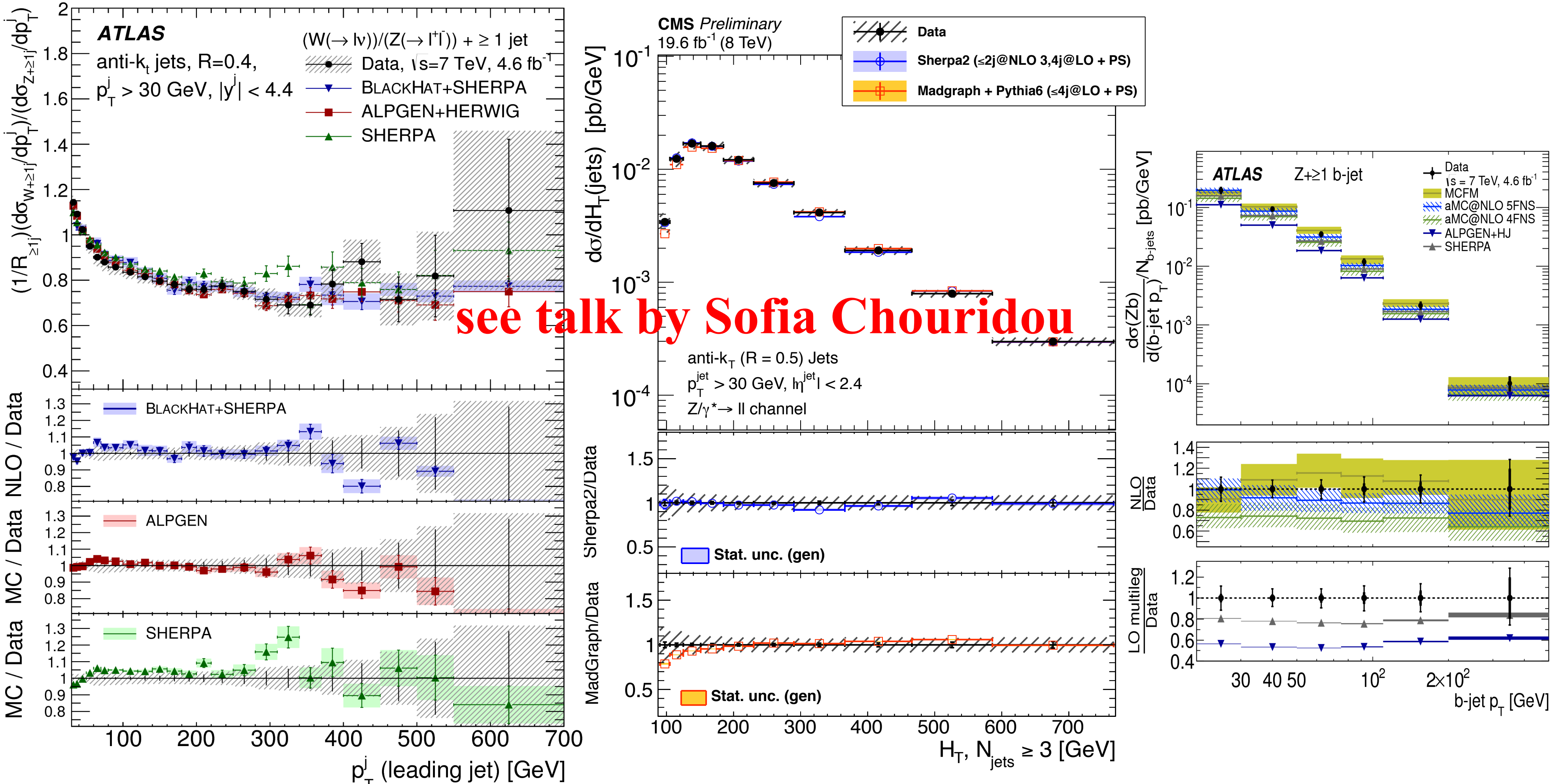
$x_4 = E_{j2}/\sqrt{s}$ scaled energy of second leading jet in centre of mass systeam



Comparison with different MC predictions. MadGraph provides good description, LO +PS predictions from Pythia 6 & 8 and Herwig++ are off at more than 10 % for most of the range

Vector bosons plus jets

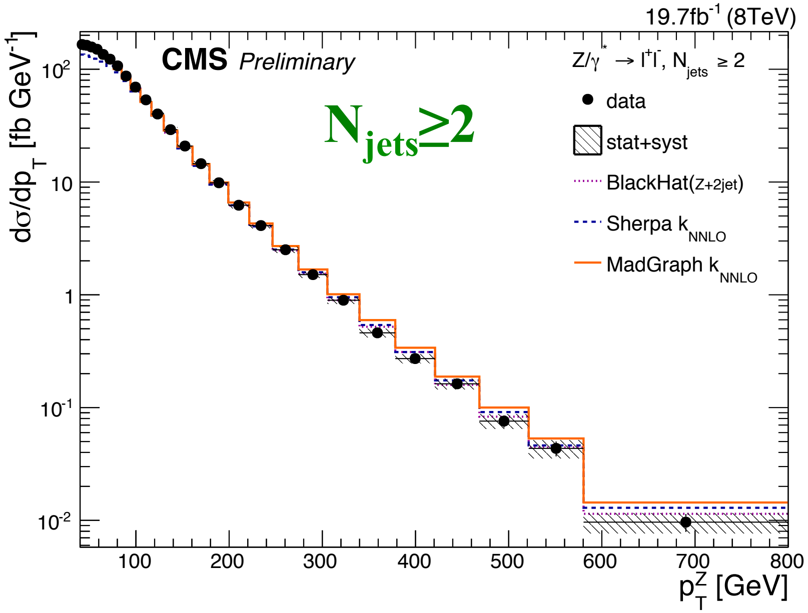
W and Z+(heavy) jets, W/Z + jets ratios



see talk by Sofia Chouridou

Several high precision measurements in V+(heavy) jets by both experiments → more details about most of these in following talk by Sofia Chouridou

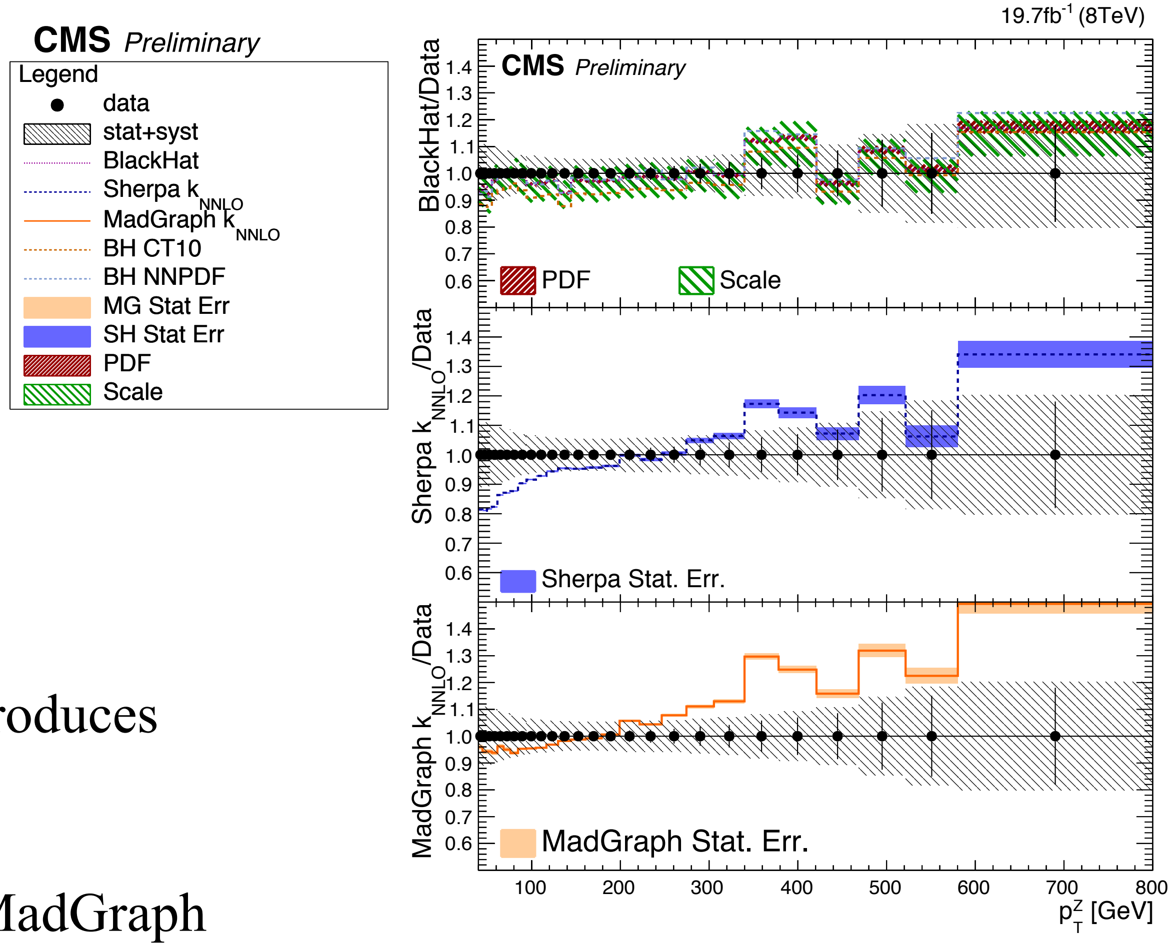
Z+jets cross-section at 8 TeV



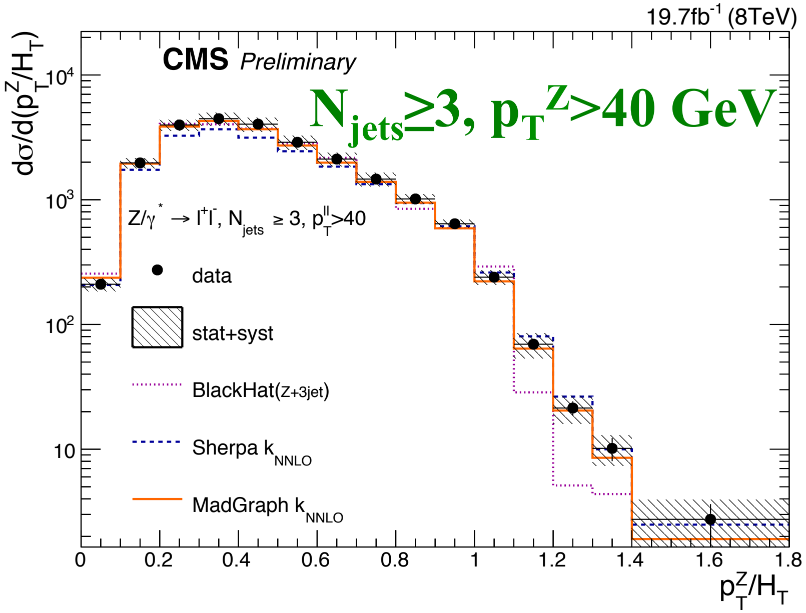
Z transverse momentum for $N_{jet}\geq 2$:

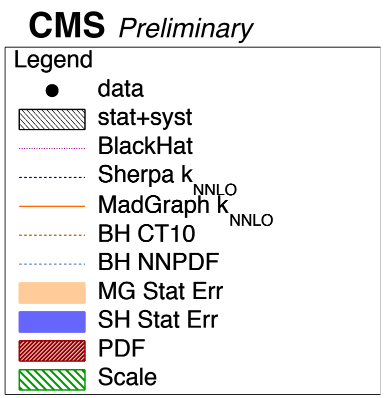
NLO prediction from BlackHat reproduces shape, 5-10 % lower for most bins

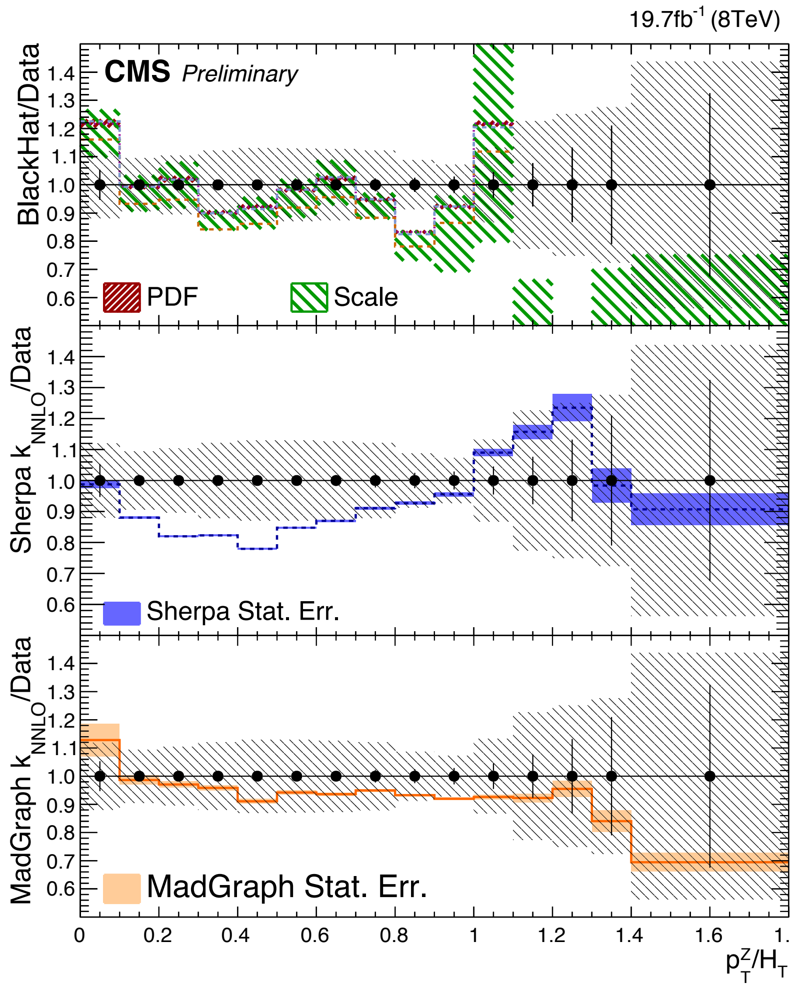
LO multileg+PS from Sherpa and MadGraph scaled to NNLO show trend vs data



Ratio p_T^Z/H_T







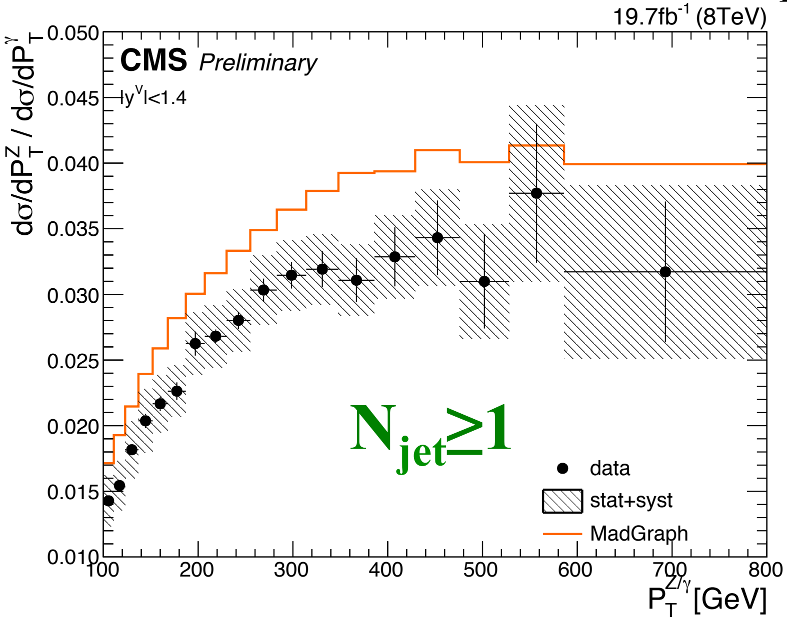
Ratio of p_T^Z vs jet scalar sum H_T for $N_{jet} \geq 3$:

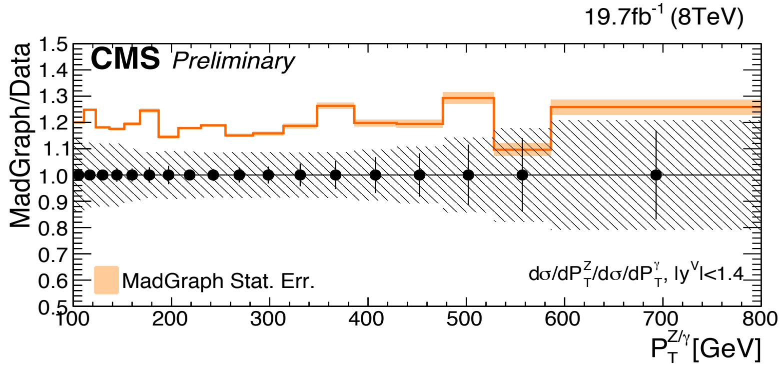
NLO prediction from BlackHat reproduces bulk of distribution

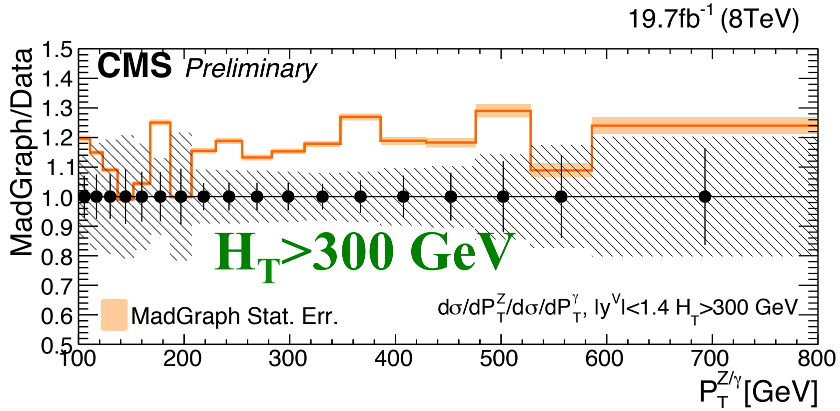
Need parton shower to reproduce full distribution, MadGraph gives best prediction

Z/photon plus jets cross-section ratio

Transverse momentum cross-section ratio of Z over photon plus jets in barrel
In full hadronic searches photon p_T spectrum used to describe high end tail of $Z \rightarrow \nu\nu$







Ratio measured in several phase-spaces, same conclusion for all:

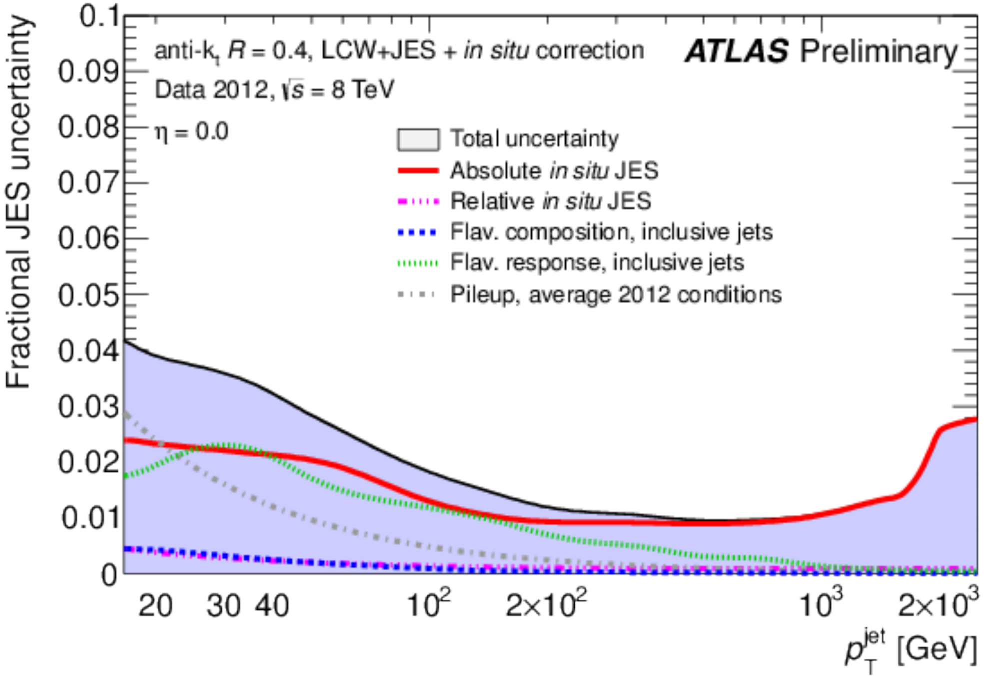
- Plateau reached around $p_T^V \sim$ 300-350 GeV
- MadGraph predicts correct shape, but scale off by 20 % (LO cross-sections used)
- Trend of MC/Data ratio for p_T of the boson same for both processes, ratio itself OK
- k-Factor for photons needs to be higher

Summary

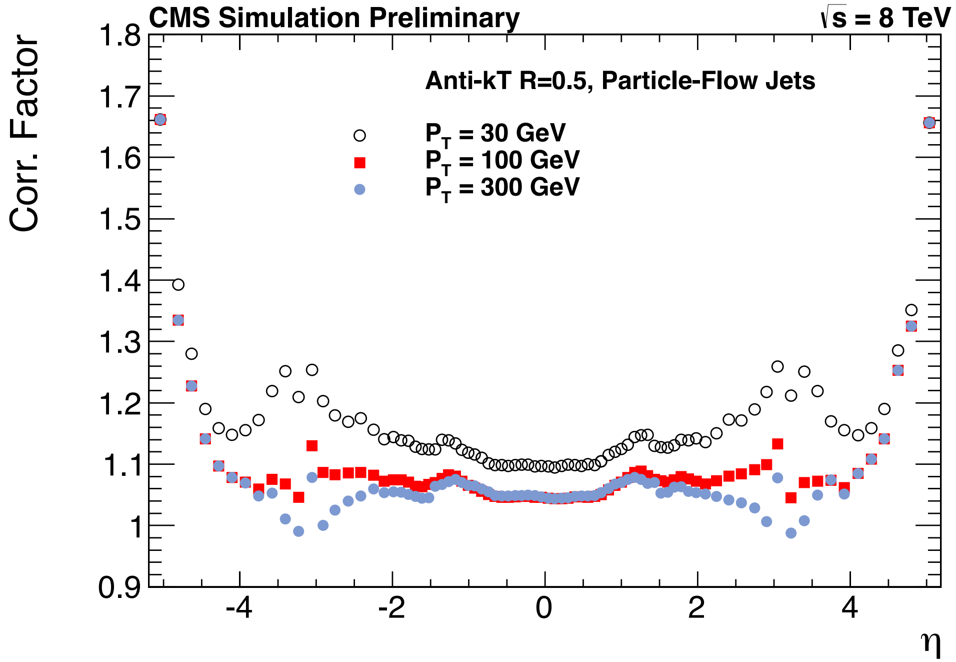
- Jet calibration performed by both ATLAS and CMS in data driven ways with high precision
- Good agreement of jet property measurements between data and MC
- Data-driven quark/gluon taggers have been developed and validated
  - Can be used in future measurements for signal-background rejection in signatures with quark decays
- Performance of jet pull studied by ATLAS in ttbar events
- Inclusive jet momentum distributions in agreement with NLO predictions
- Multijet measurement by CMS shows good agreement with MadGraph multileg LO+PS prediction
- First measurement of Z/photon plus jet transverse momentum ratio at CMS
  - Good shapewise agreement with LO MadGraph prediction
  - Scale underestimated by roughly 20 %
  - Input for future SUSY hadronic studies
- Vast and rich jet measurements performed by ATLAS and CMS in run I, more exciting times to look forward to in run II

BACKUP

Jet calibration



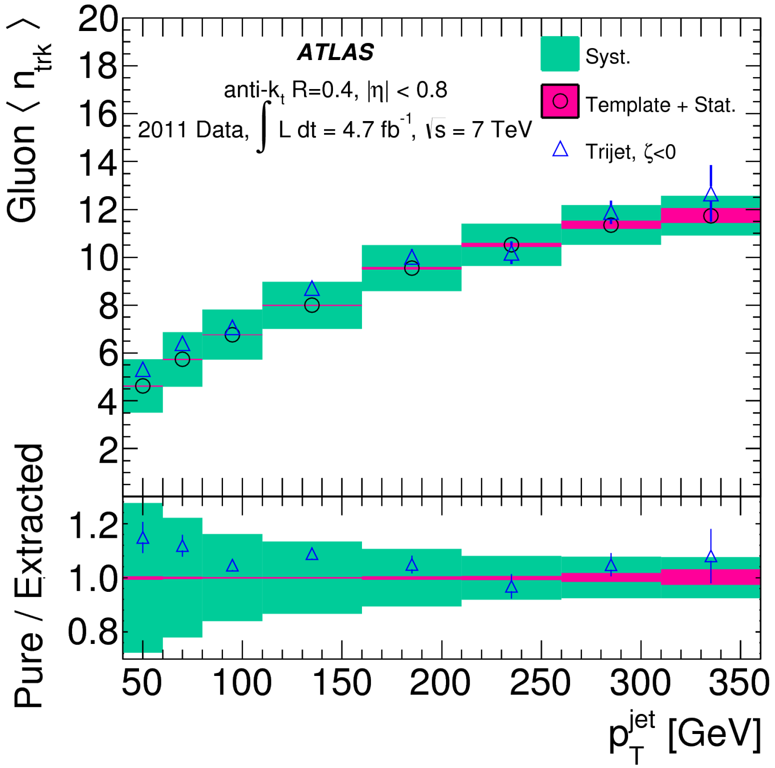
Summary of the all JES uncertainties at ATLAS

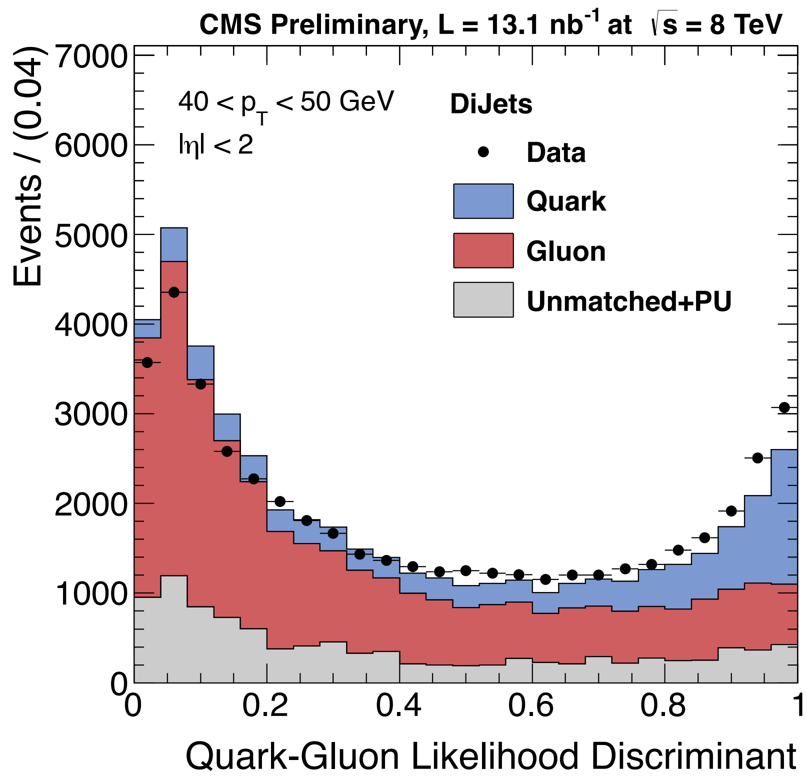


CMS correction factors derived from MC for 8 TeV anti-k_T jets (R=0.5)

Quark/gluon jet templates vs data

Validate gluon extracted n_{trk} template
In gluon jet enriched trijet data sample





Discriminator performance of the quark-gluon tagger in dijet data compared to dijet MC from Pythia

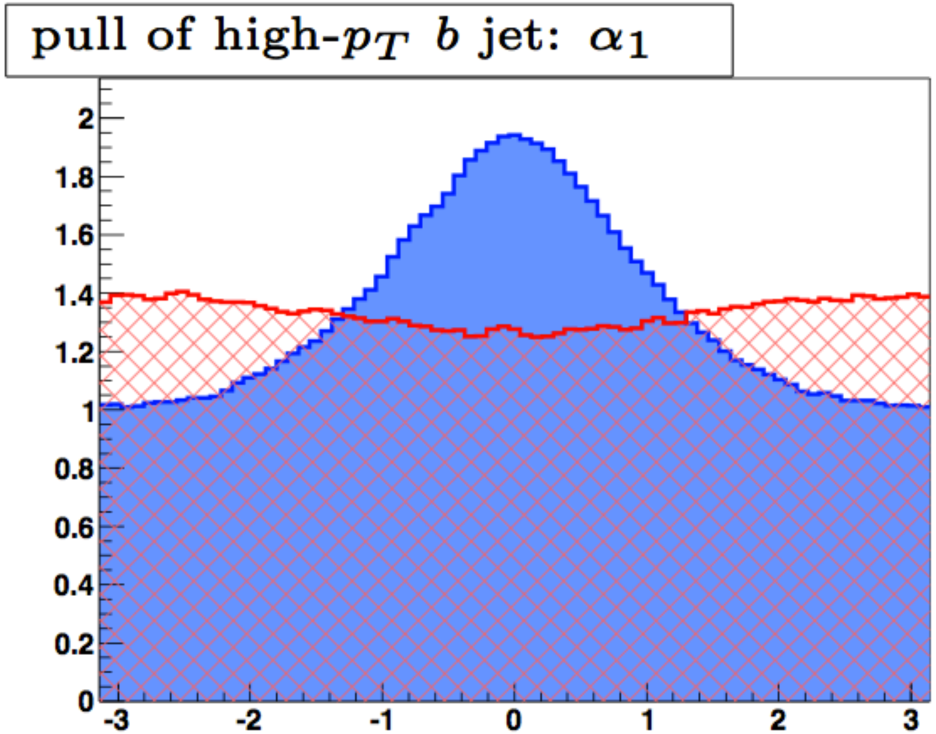
arXiv:1405.6583

CMS-JME-13-002

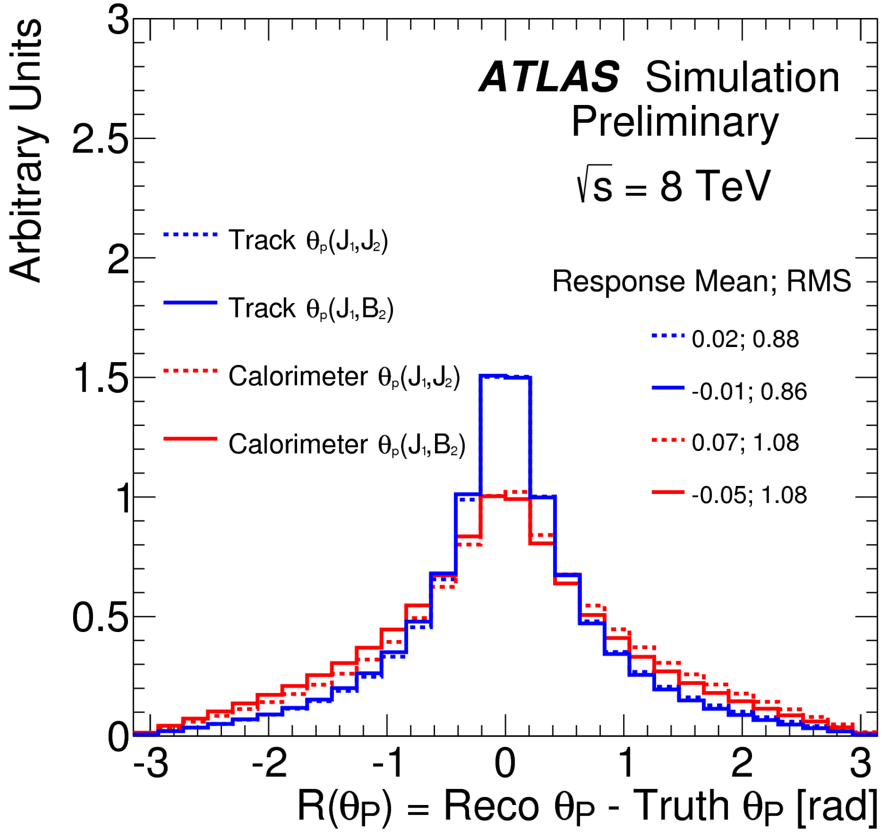
Jet pull: background discrimination for ZH

Theory paper **JHEP04(2011)069:** use pull vectors to discriminate between ZH→Z bbar Signal and gg →Z bbar background

θ(j1,j2) of ATLAS named α_1 in paper



Red: background, blue signal

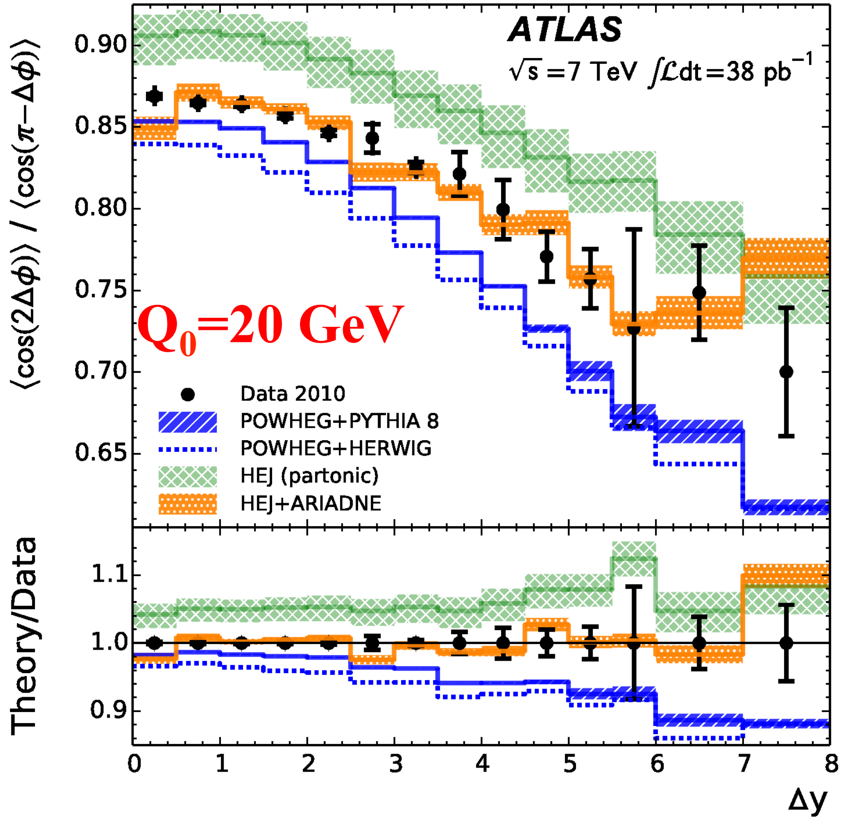


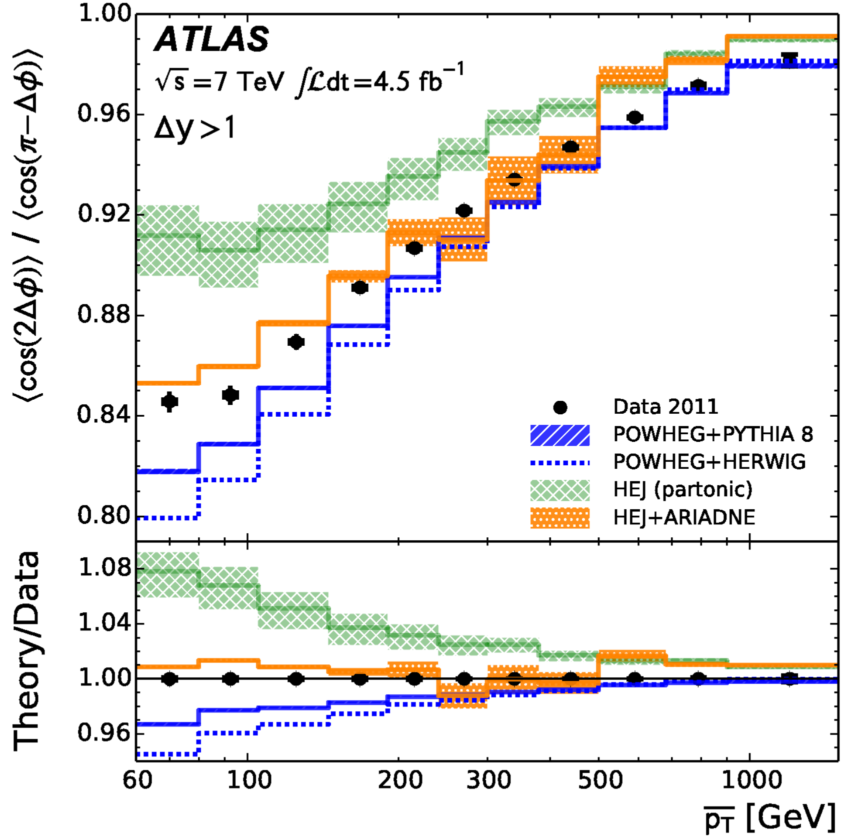
For good discrimination, good resolution of measurement essential

Dijet studies (ATLAS, 7 TeV)

Jet vetoes in dijet events, Δy rapidity difference between two leading jets

Gap fraction: events without additional jets with $p_T > Q_0$ vs total number of events

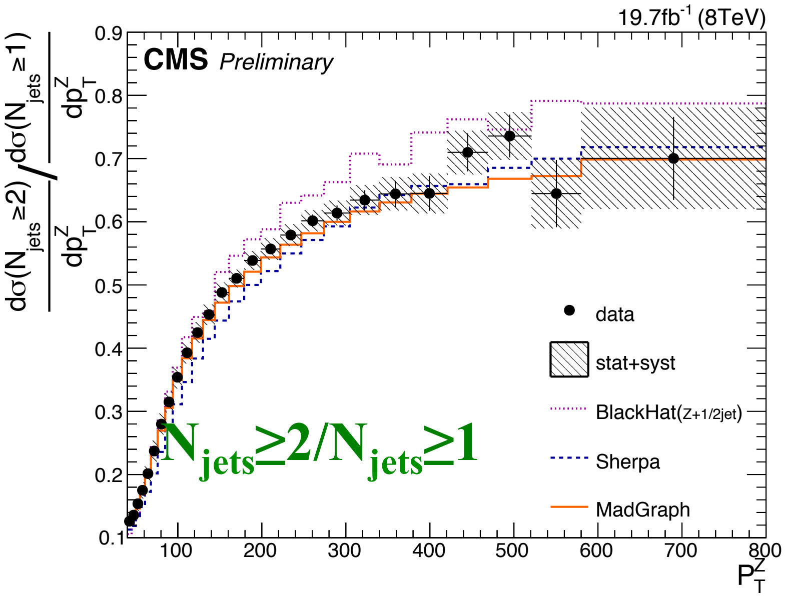


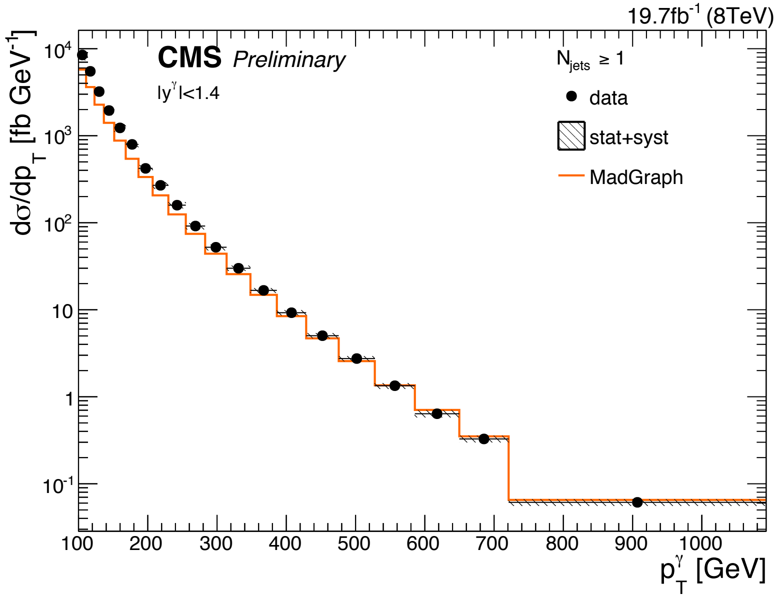


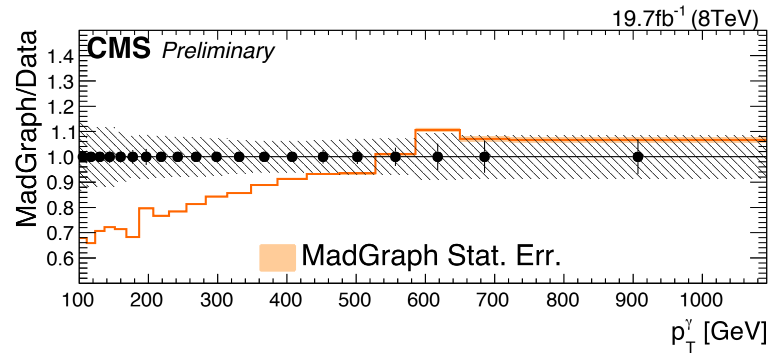
HEJ+ARIADNE (BKFL PDF evolution) provides best description of angular variable, POWHEG (DGLAP PDF evolution) performs worse for angular decorrelation study

arXiv:1407.5756

photon+jets cross-section at 8 TeV







p_T^Z 2 over 1 jet ratio predicted only perfectly by MadGraph, BlackHat OK in shape, but off in scale

Same trend in MadGraph/Data ratio for photon p_T^γ than for p_T^Z, no k-Factor applied for scale