QCD with LHC *pp* collisions

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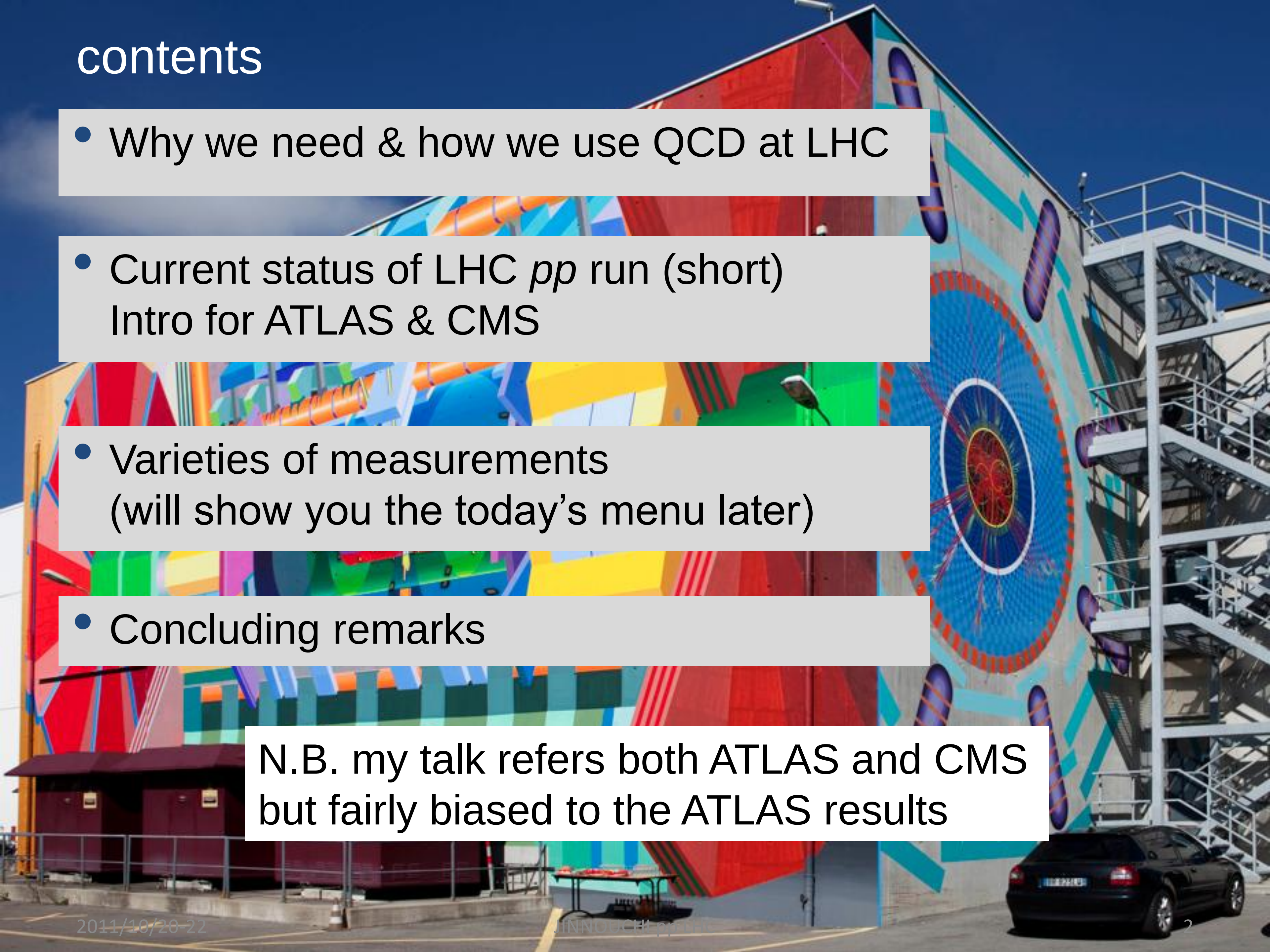
Future Directions in High Energy QCD

RIKEN Wako

2011/10/20-22



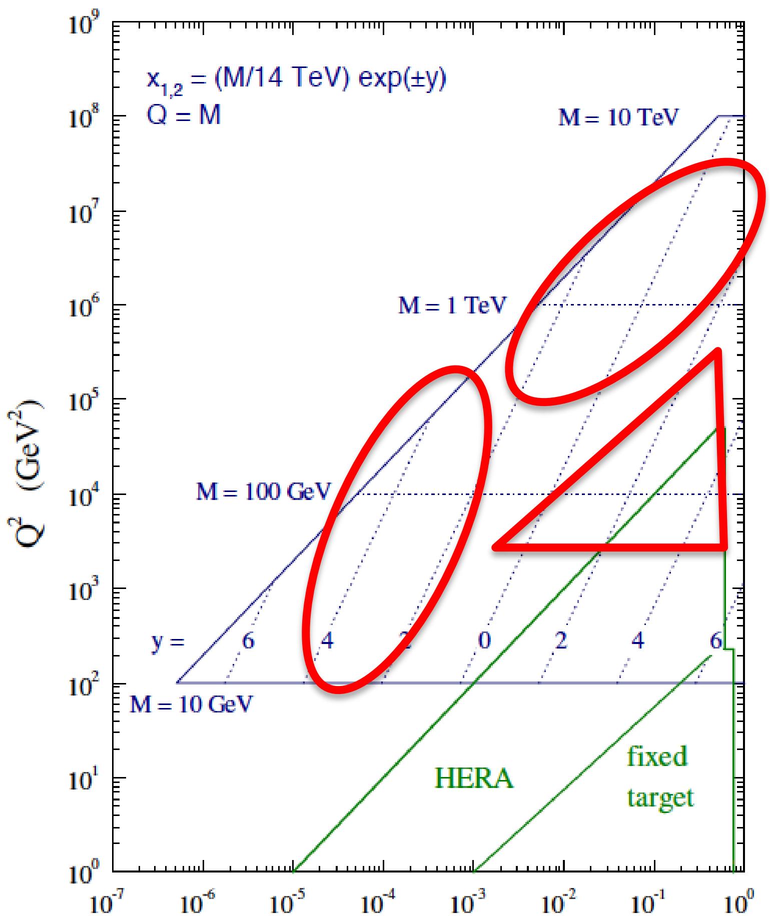
contents

- Why we need & how we use QCD at LHC
- Current status of LHC *pp* run (short)
  Intro for ATLAS & CMS
- Varieties of measurements
  (will show you the today's menu later)
- Concluding remarks

N.B. my talk refers both ATLAS and CMS
but fairly biased to the ATLAS results

QCD studies in TeV scale

- What's so special with QCD at LHC
  - 3.5 - 7.0 times higher CM energy than Tevatron – possibility to explore very high Q^2 & very low-x
  - More prec om new generation
    - Increas roved particle ID
    - tested nely tuned/checked
  - Better inte
    - Develc
      - ✓ Hi
      - ✓ Ne
      - ✓ Tr interactions, etc
    - Develc
- Inheriting huge ther experiments (Tevatron, HEF
  - Benefit of ıer extension

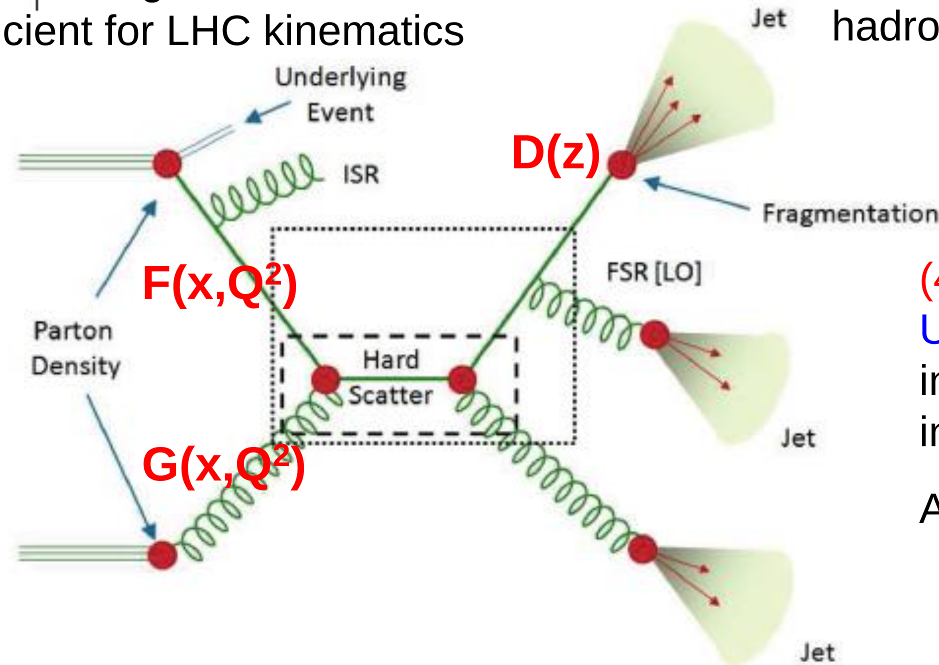


What LHC can do for QCD

refining/expanding knowledge on the QCD event for “LHC era”

(2) Initial state $F(x,Q^2),G(x,Q^2)$
PDF : non-perturbative nature
(experimentalists’ territory)
Current existing PDFs will not be sufficient for LHC kinematics

(3) Final state $D(z)$
Fragmentation : non-perturbative nature
(experimentalists’ territory)
Validation of the parton shower+ hadronization model



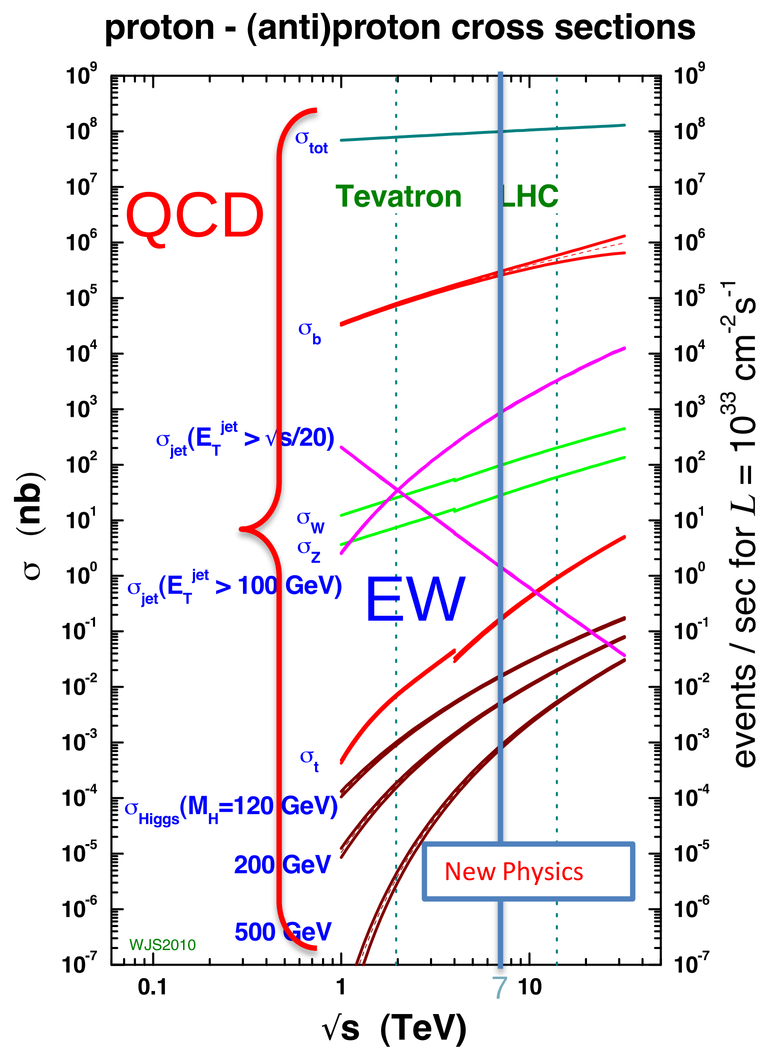
(4) Bound state physics
Underlying Events: Spectator partons in proton participate as multiple interactions

Also some resonance studies

(1) Hard scattering Cross Section : perturbative (theorists’ territory)
LO calculation is not often sufficient to describe data
Verification of NLO, NNLO by measurements (experimentalists’ territory)

What QCD does for LHC

- QCD itself is a fundamental physics subject at LHC
  - go beyond the other experiments, distinguishing the *'state of the art'* theories is a primary motivation
- On practical side, the top priority of LHC is the Beyond Standard Model
  - QCD processes dominates the LHC *pp* collisions
  - A possible signal from BSM is buried in the huge cross section of the QCD events (Background)
  - BSM signal events contain QCD processes (PDF, jets, UE)



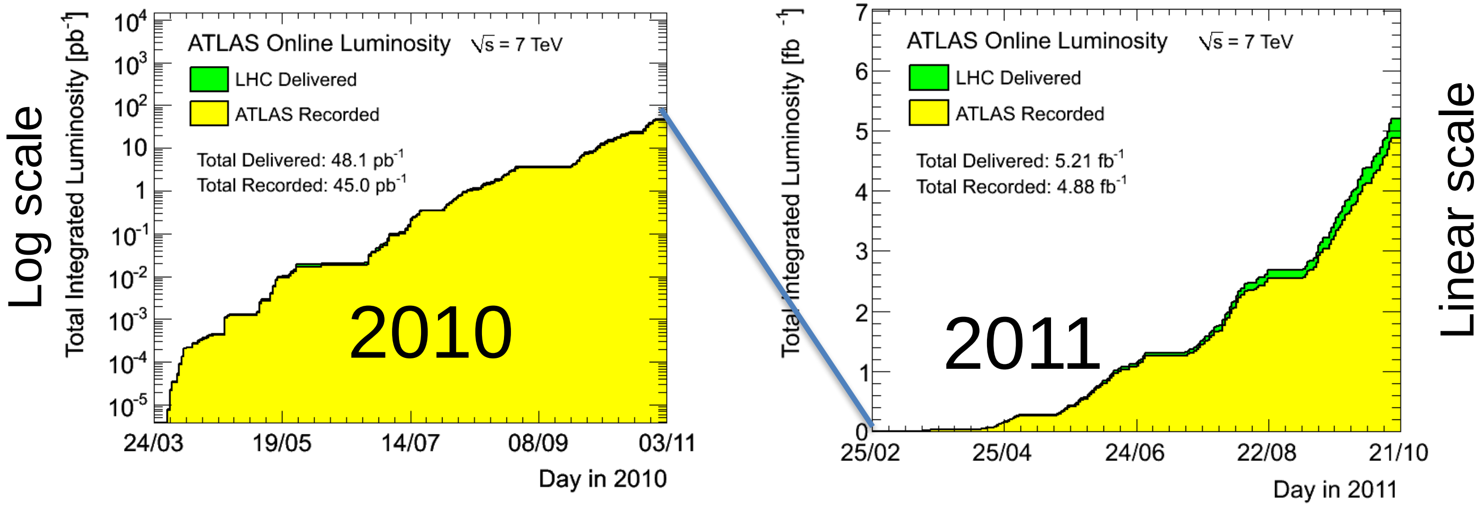
→ understanding/controlling of QCD is an indispensable step towards new physics

Brief Overview of the LHC *pp* run

&

Detectors (ATLAS/CMS)

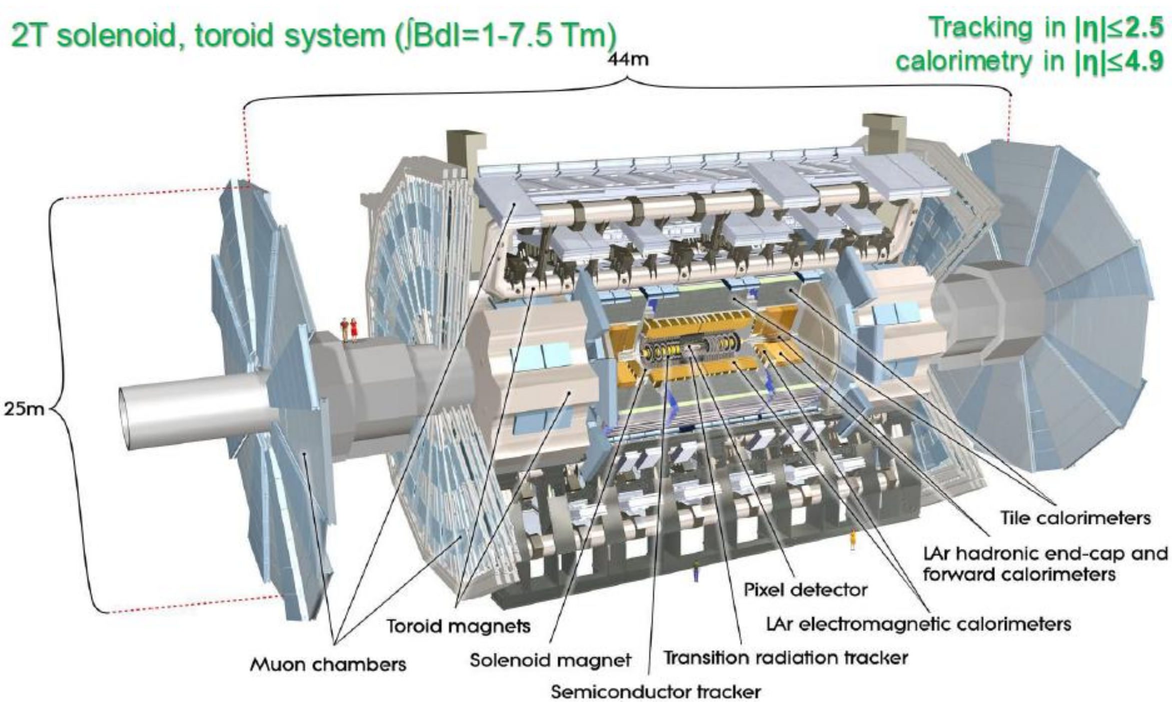
LHC (*pp*) past and today

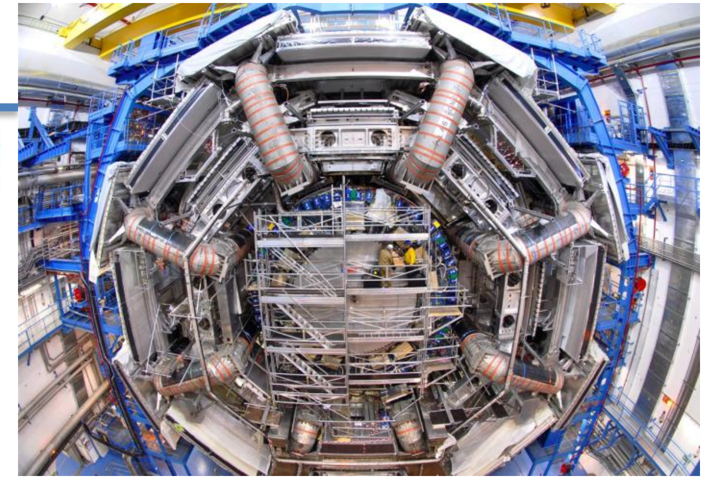


- In 2010
  - First 7TeV pp collisions started from March
  - 48 pb^{-1} pp collisions delivered (45pb^{-1} recorded by ATLAS)
- In 2011
  - Peak luminosity 3.59 x $10^{33}cm^{-2}s^{-1}$
  - ~ 4.88(5.21) fb^{-1} data recorded(delivered) (this morning, 10 days left for 2011 *pp* runs)
  - Possibly reach > 5 fb^{-1} during 2011
  - 1380 bunches, 50nsec spacing, 1.4E11 p/ bunch

LHC will run in 2012 then long shutdown / will restart at higher energy

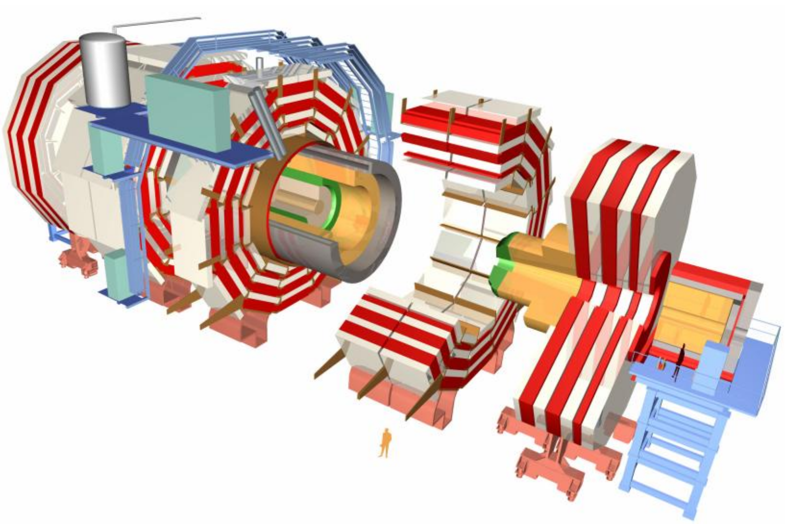
ATLAS

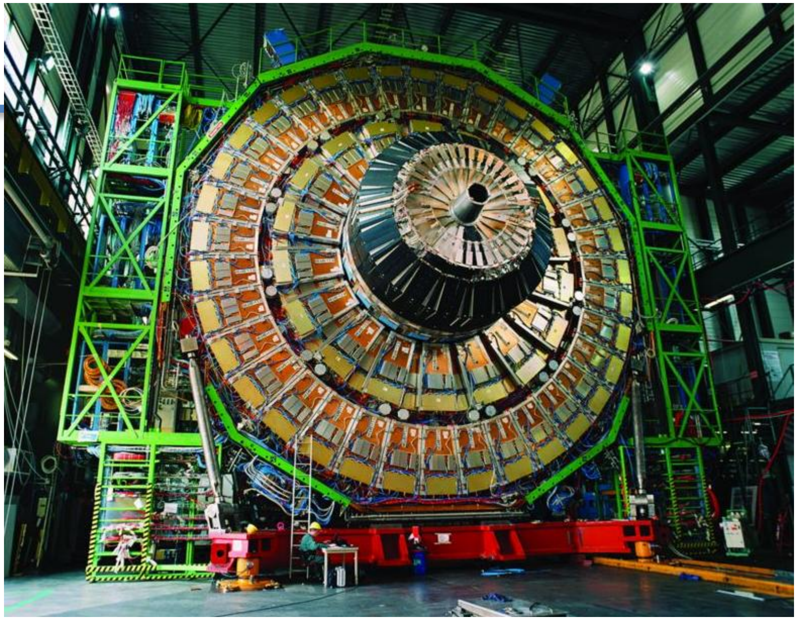




- Gigantic general purpose detector with well balanced performance (resolutions/acceptance)
- Emphasis on lepton measurements
    - 2T solenoid for inner tracker
    - Air core (less MS) + Toroid magnet (forward acceptance) for outer muon system
- Accordion shape LAr calorimeters for fine lateral + longitudinal EM shower shape

CMS (comparison to ATLAS)





- Compact but Heavy
  - H=15m L=22m (half of ATLAS)
  - W=12,500 ton (twice of ATLAS, mainly from SC magnet steel yoke)
- EMCal: $PbWO_4$ scintillator
  - Excellent energy resolution
- Solenoid: 4T (most outer layer)
  - gain tracking resolution, with shorter lever arm
  - Not enough HCAL thickness

Resolutions (@p_T=100GeV)

	ATLAS	CMS
e, gamma	1.5%	0.9%
muon	2-3%	2-3%
Jets	8%	12%

Recent Measurements

Covered topics in this talk

2010 data (~35pb^{-1}) had low pile-up (~2.2 interactions/bunch crossing)
very recent public results are shown here, but based on 2010 data

Uncertainties of the collected luminosity = 3.4%

[1] Hard Scatterings - perturbative nature -

- Jets (Single, Double, Multiple)
- Photon (Single, Double)
- B-jets
- W/Z + jets productions
- many others (not covered)

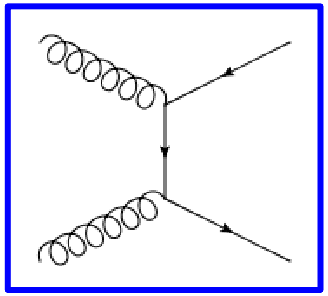
[2] soft QCD - non perturbative nature -

- Charged particle multiplicities in minimum bias events
- Multiple parton interactions (underlying events)
- many others (not covered)

[3] QCD at very high energy

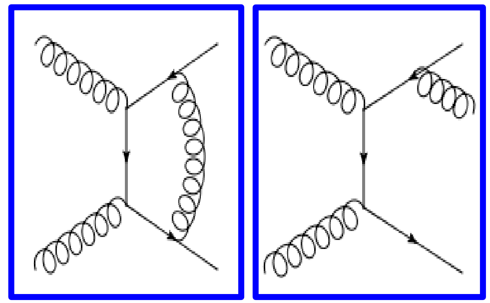
QCD predictions

LO



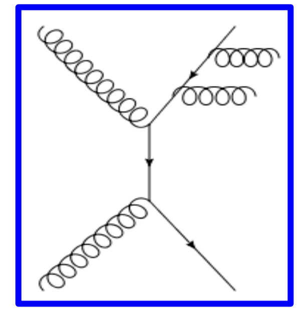
Tree level

NLO



Up to 1-loop

LL summation

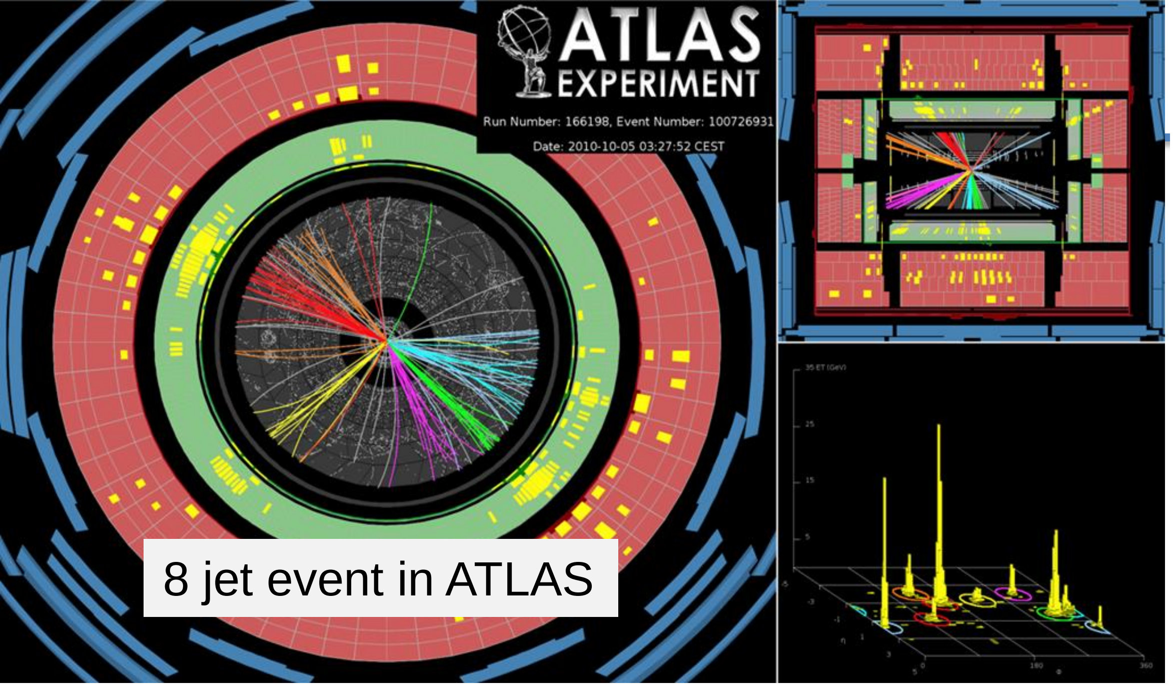


Parton shower
(emits gluons in soft/collinear approximation)

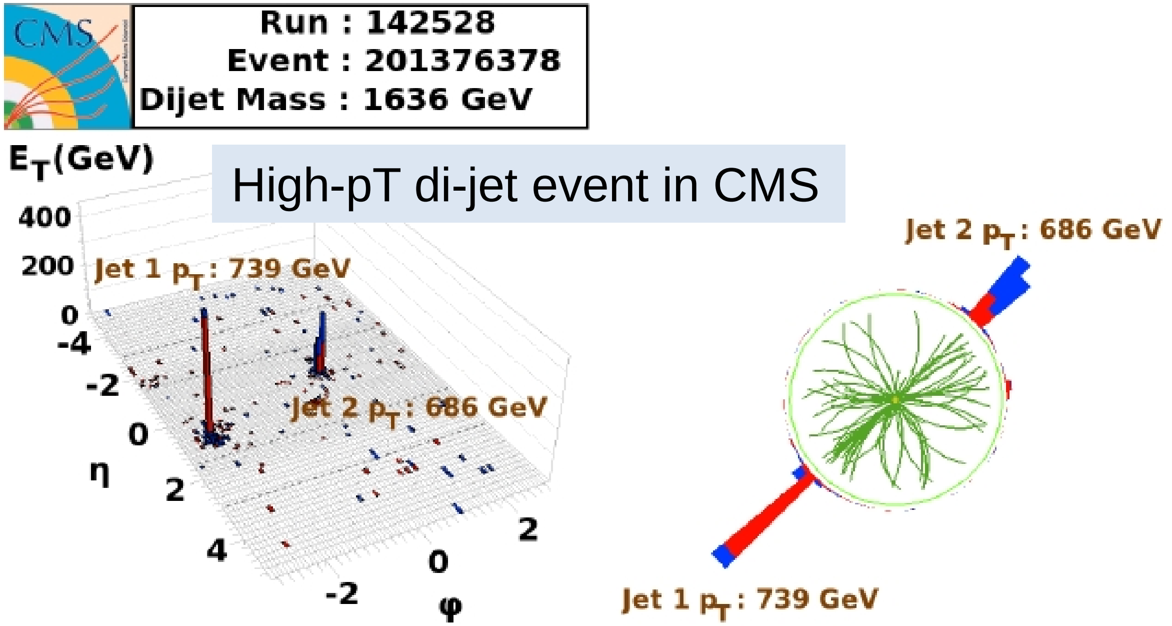
- LO MC: ***Pythia, Herwig*** generic package LO process + shower + fragment
- NLO parton: ***NLOJet++, MCFM, DIPHOX, JETPHOX*** only partons in final state (just pQCD part)
- NLO MC: ***MC@NLO, POWHEG*** hard process computed at NLO, shower performed by PYTHIA/HERWIG
- Higher order tree level MC: **ALPGEN, SHERPA** computation of all tree level diagrams of multi parton emissions, require parton matching btw ME and PS, missing loop effect
- NNLO parton: **FEWZ,** etc

Perturbative QCD Topics

JETS

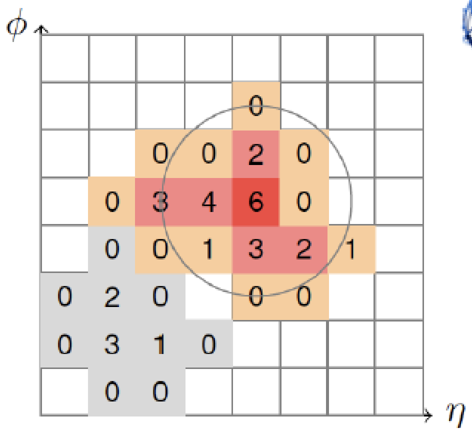


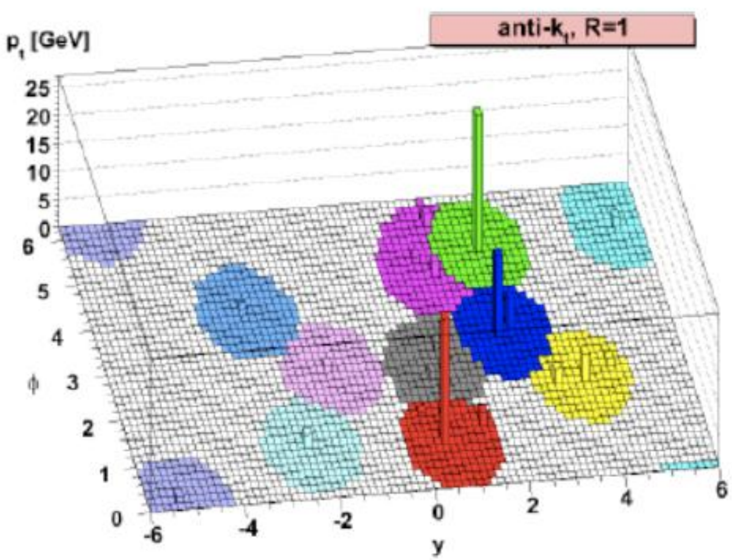
8 jet event in ATLAS



High-pT di-jet event in CMS

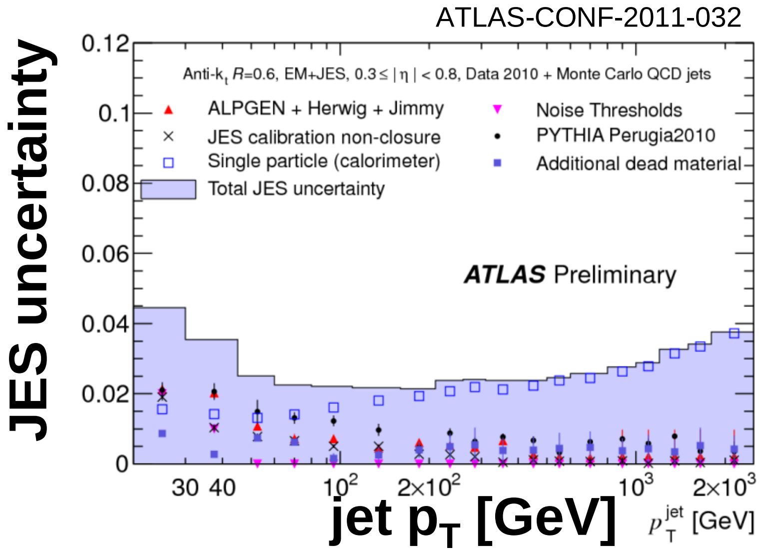
Jet reconstruction in LHC

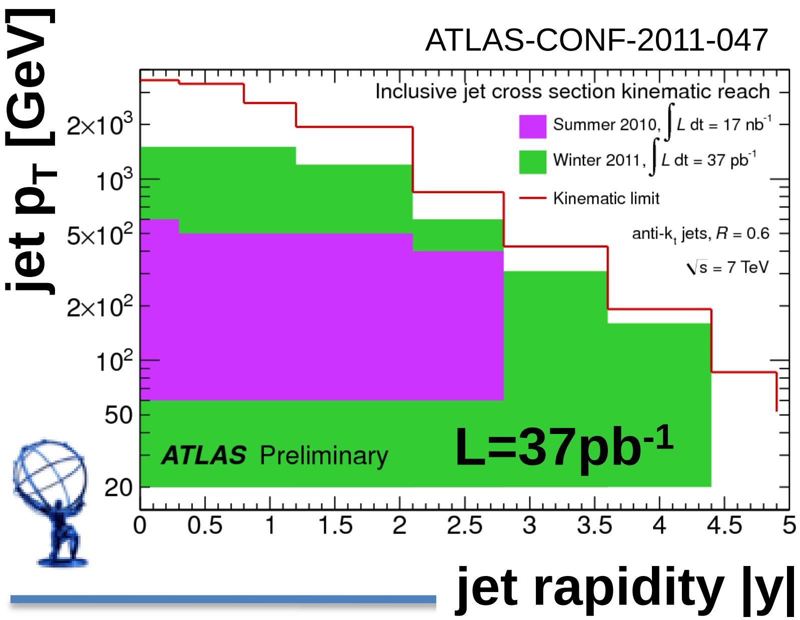




- Calorimeter Cell clustering
  - 3-D topological clusters
    - start with seed (>4 ʃ)
add neighboring cells (>2σ)
add all adjacent cells (>0)
- Jet Reconstruction
  - combine the clusters using anti-k_T algorithm (infrared & collinear safe)
R=0.4, 0.6 (or 1.0)
  - infrared safe : essential for NLO comparison
  - cone shape : pileup subtraction
- Calibration
  - response corrections: hadronic components (compensation), inactive volume, out of cone leakage, pile-up
  - EM calib → JetEnergyScale calib
MC-based correction function in jet E, η bins

Jet performance





Jet Energy Scale uncertainties
(from 2010 data)

- 2.5% for ~100GeV central jets
- Calorimeter response to the single particle is dominant component (reduced significantly from in-situ meas.)

Unfolding for detector effects

- restoring effects (resolution, efficiency)
- bin-by-bin correction was used

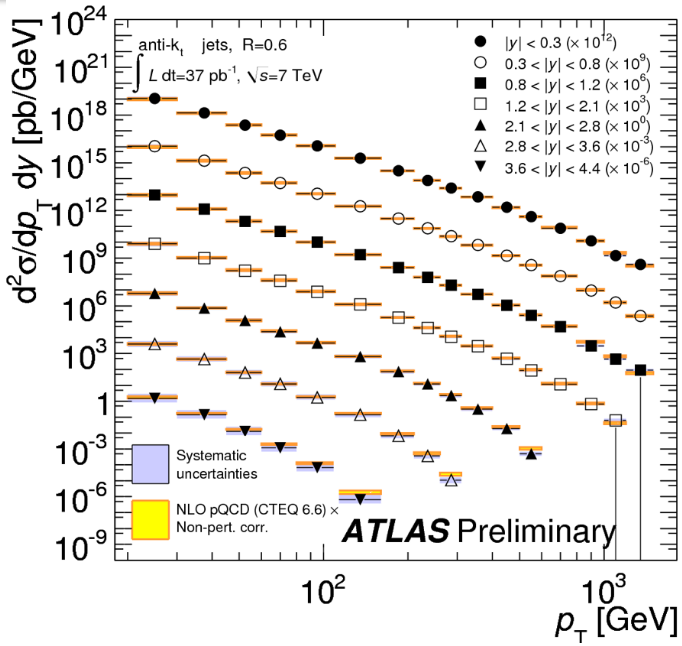
Jet kinematics : phase space reach

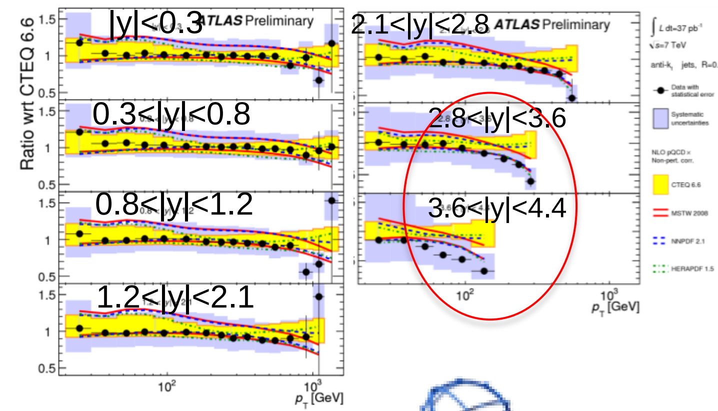
- Kinetic range of full 2010 data (green)
- With a few 10 pb^{-1} of data, the reach in jet pT at the LHC is already twice of other experiments
- Forward jet measurement cover up to |y| = 4.4
- p_T range goes up to > 1TeV

Inclusive jet cross section

important input for PDF determination

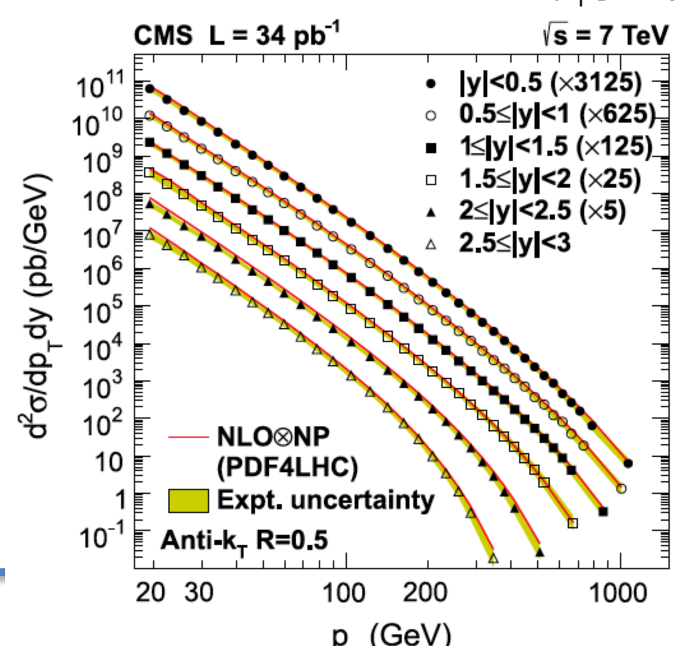
- p_T>1TeV, |y|<4.4 cross section vary by 10^{10} over the pT range measured
- Both expts. Compare with NLOJET++ & NP corrections
- Baseline PDFs
  - CTEQ6.6 (ATLAS)
  - PDF4LHC(CMS)

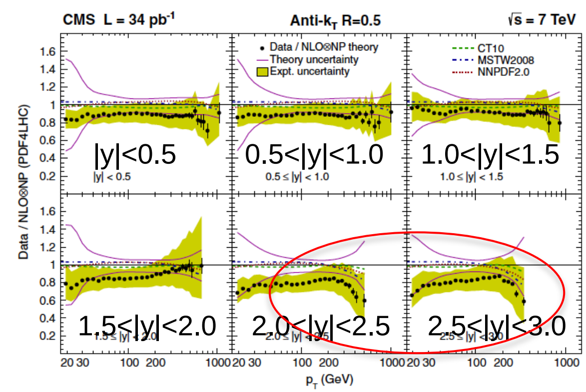




ATLAS-CONF-2011-047

- Experimental systematic uncertainties ~10-20%
- Both experiments agree with predications within uncertainties
- possibly some deviation in the far forward + at high p_T
- tough region for theory and measurement

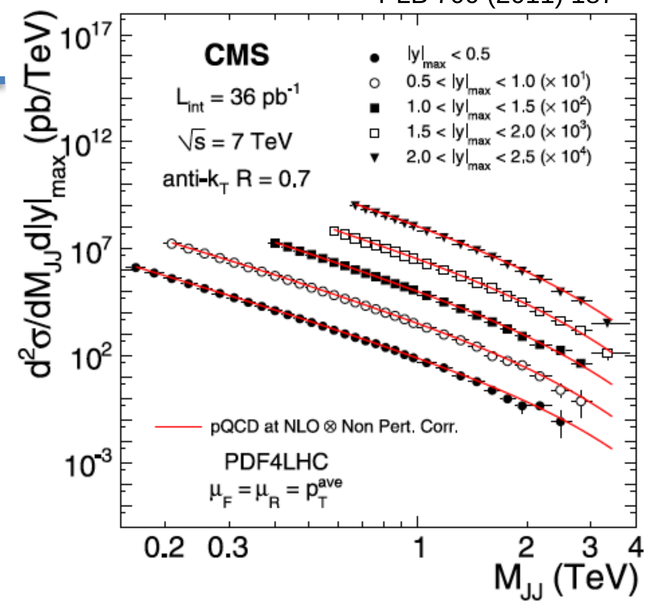




Phys.Rev.Lett.107(2011)132001

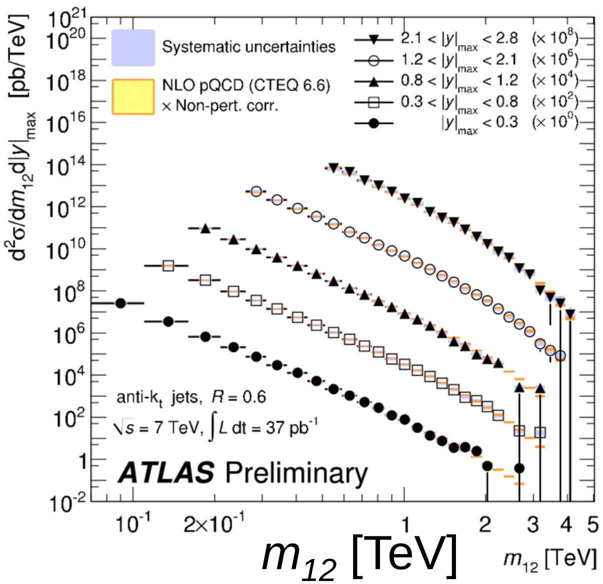
Dijet production

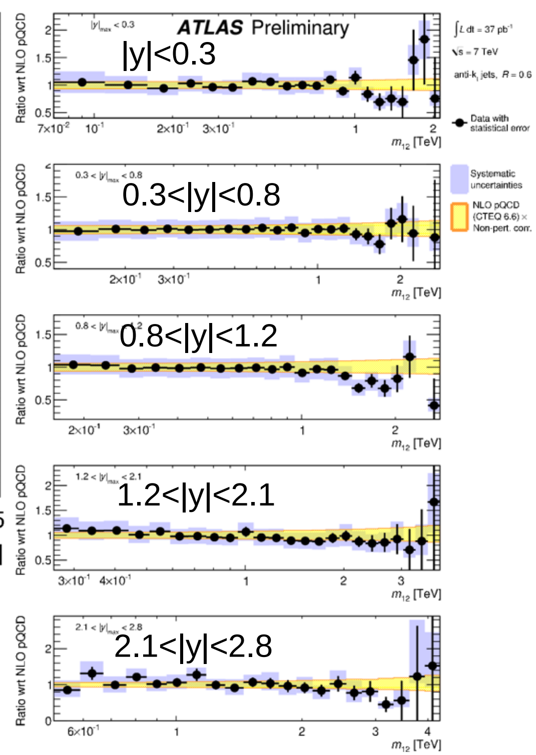
PLB 700 (2011) 187

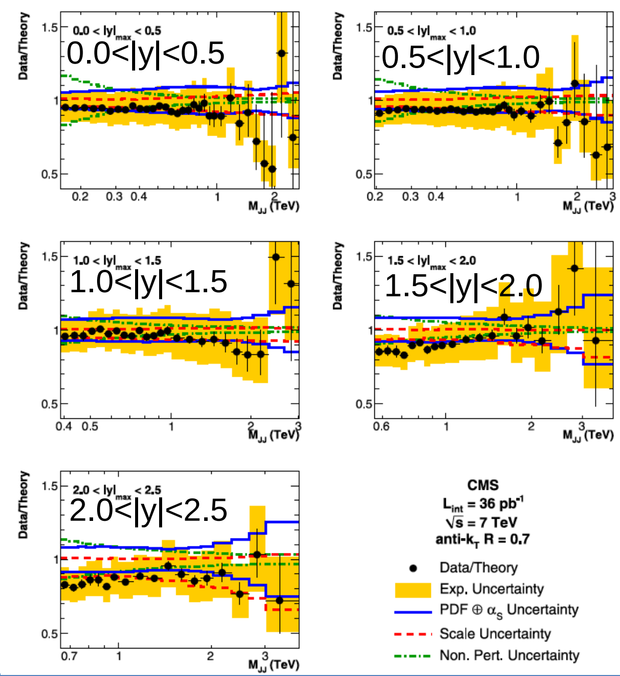


more emphasis on Matrix Element structure

- Dijet measurements from both ATLAS/CMS
  - Cross section as a function of M_{JJ} and $|y|_{max}$
  - Varies by ~7 orders of magnitude
  - M_{JJ} range up to 4.1 TeV
  - Data vs. predictions in good agreement within uncertainties 10-15%



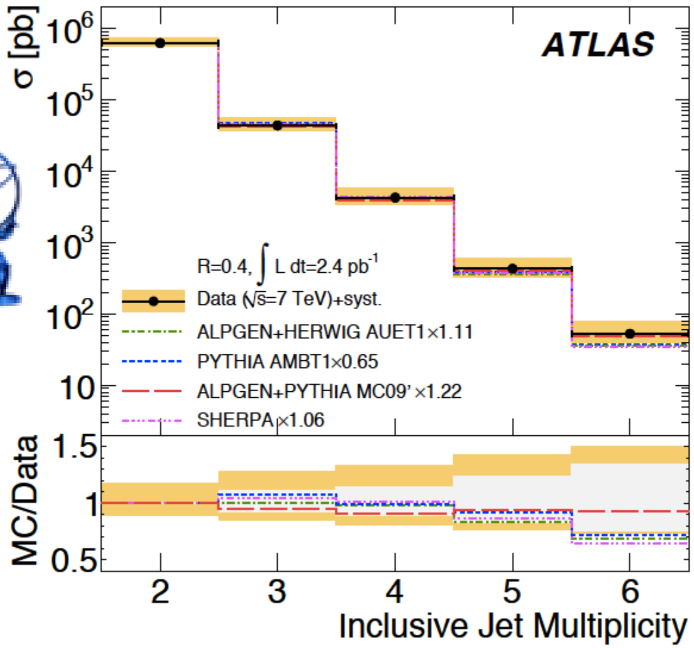




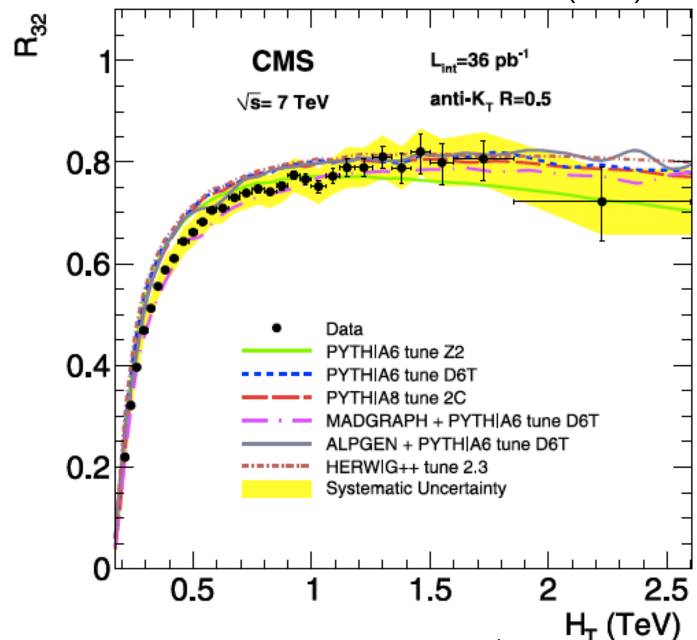
ATLAS-CONF-2011-047

Multi-jet Cross sections

arXiv:1107.2092



PLB702 (2011)336



$$\left(d\sigma_{3j} / d\sigma_{2j}\right) \text{ vs. } H_T \quad \left(H_T = \sum_{i=1}^{n} p_{Ti}\right)$$ all jets p_T>50GeV

multi-leg LO ME + PS play a crucial rule for representing the high jet multiplicity

result for σ_{nj}
leading jet p_T>80GeV
other jets p_T>60GeV all |y|<2.8
MC scaled to 2-jet cross section
Dominant systematics JES

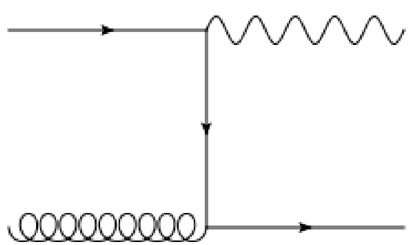
all LO MC (2→2(or n)) reproduce the main features

p_T>50GeV |y| <2.5 jets
ratio rises with increasing H_T
(as the phase space opens)

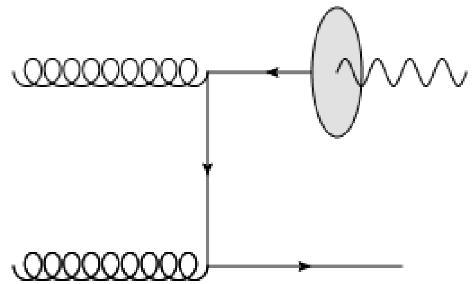
MadGraph (LO ME+PS) agrees well
(differ from ALPGEN by ME-PS matching parameters)
[in ATLAS, ALPGEN+Pythia good agreement]

Isolated prompt photons

- Prompt photon production is very important to understand at LHC (irreducible BG for Higgs, SUSY, UED searches)
- Big emphasis on EM calorimeter performance
- SM photons are from either Direct or Parton Fragmentation



Typical dominant 'direct' production (signal)

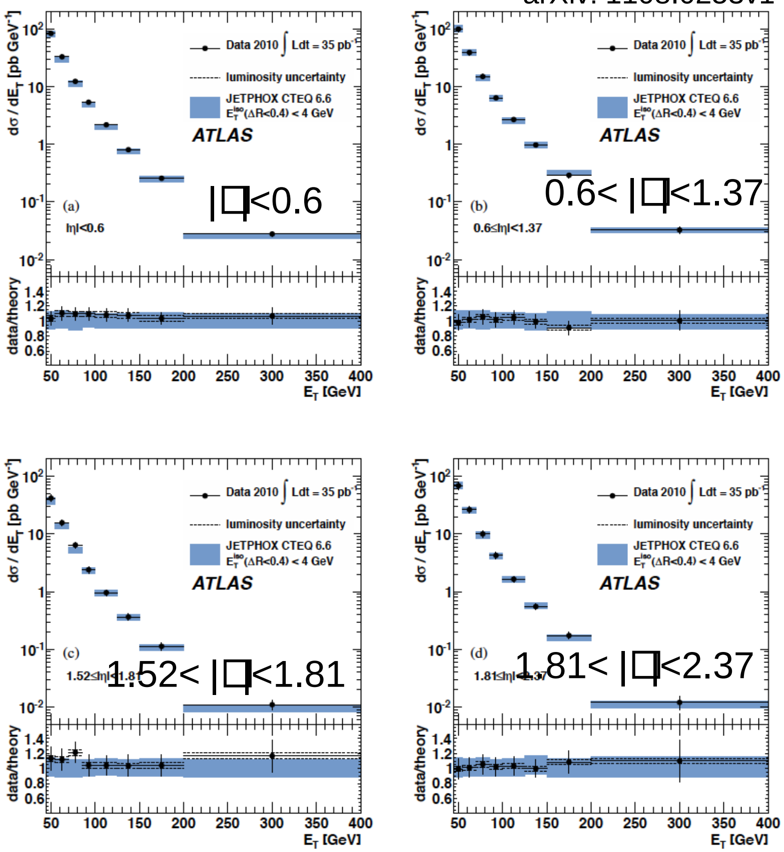


Typical fragmentation production (background)

- direct production is dominated by qg→qγ, sensitive to gluon PDF
- Both components implemented in NLO MC (JETPHOX)
- parton-level isolation cut dR=0.4 around photon (for MC comparison)

Single photon inclusive distribution

arXiv: 1108.0253v1



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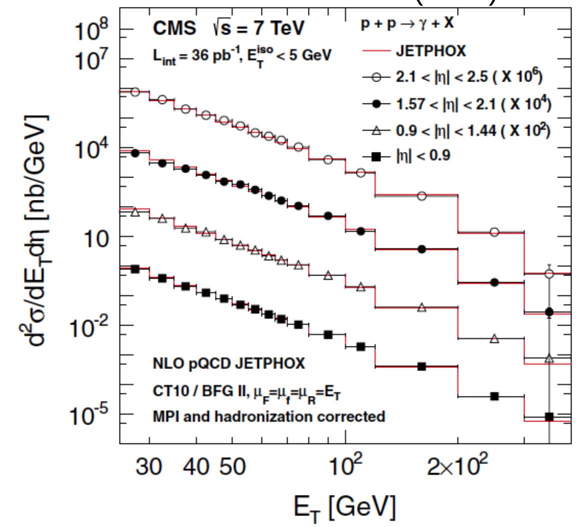
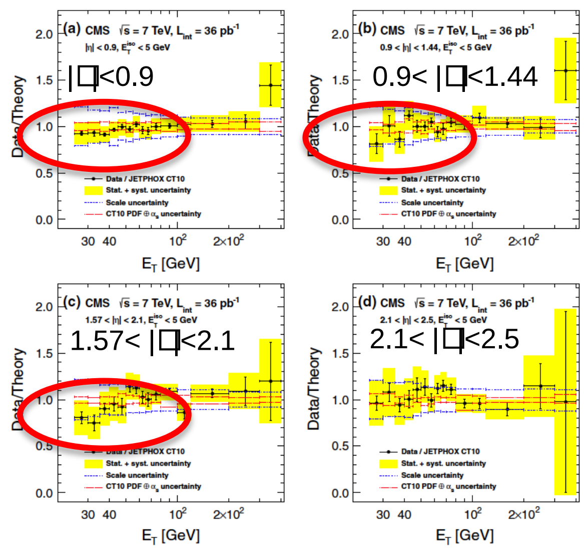




prediction tend to be higher at low E_T (similar tendency in ATLAS p_T>15GeV ATLAS-CONF-2011-058)

ATLAS 45 < photon E_T < 400GeV

- JETPHOX + CTEQ6.6
- Isolation condition E_T < 4GeV in cone 0.4
- Systematics dominant :
  - direct/fragmentation fraction
  - pileup, shower shape (MC/data)

CMS 25 < photon E_T < 400GeV

- JETPHOX + CT10 PDF

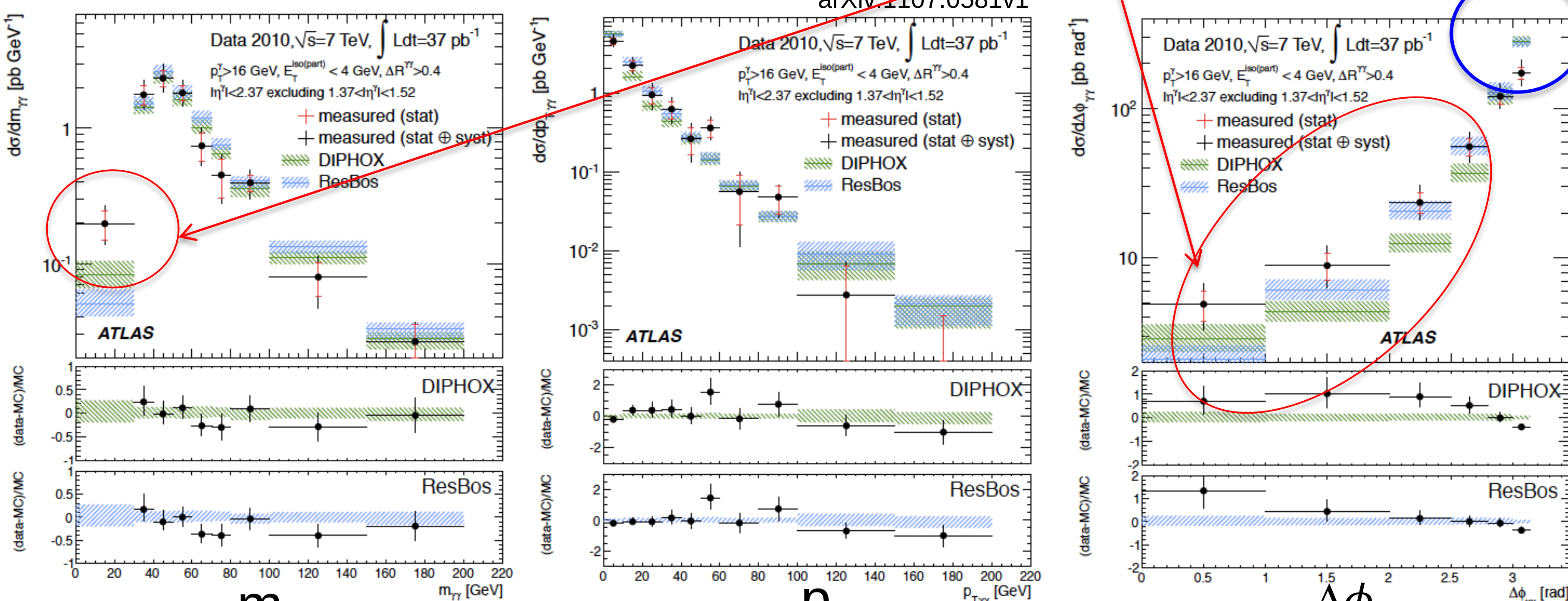
di-photon measurements

- |eta|< 2.37 except 1.37 < |eta| < 1.52
- di-photon E_T > 16 GeV
- di-photon two isolation cones separate i.e. $dR_{\gamma\gamma}$>0.4
- Isolation energy E_T^{ISO}<3GeV: tight selection
- backgrounds estimated with data-driven, subtracted

sensitive to soft gluon emission (need NLO)

sensitive to the fragmentation model

arXiv:1107.0581v1



$m_{\gamma\gamma}$ $p_{T\gamma\gamma}$ $\Delta\phi_{\gamma\gamma}$

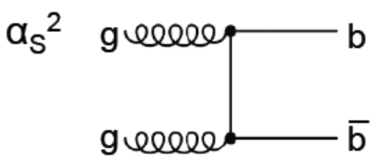
both NLO MC good agreements

data is broader than NLO MC

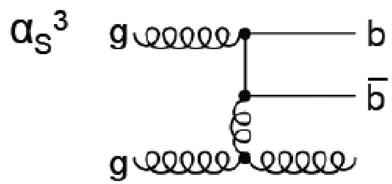
b-jets productions

Substantial background in many BSM searches

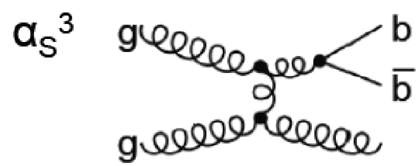
- Major production modes



flavor creation (LO)



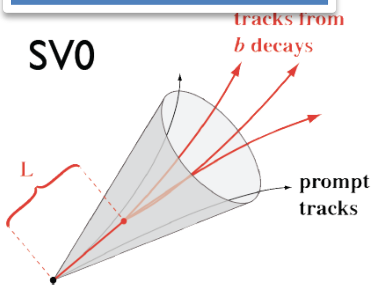
flavor excitation (NLO)



gluon splitting (NLO)

- b-tagging algorithm in use for 2010 data

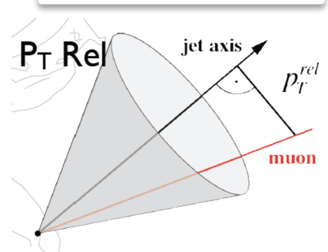
Main method



The displaced vertex is given by the long decay length of the B meson

SV0 reconstructs the secondary vertex from the charged decay products

alternative
(for b-tag eff. measurement)



Muons from semi-leptonic B decays have a large angle w.r.t. the jet axis

p_T^{rel} is used to tag b-jets

- Operation point

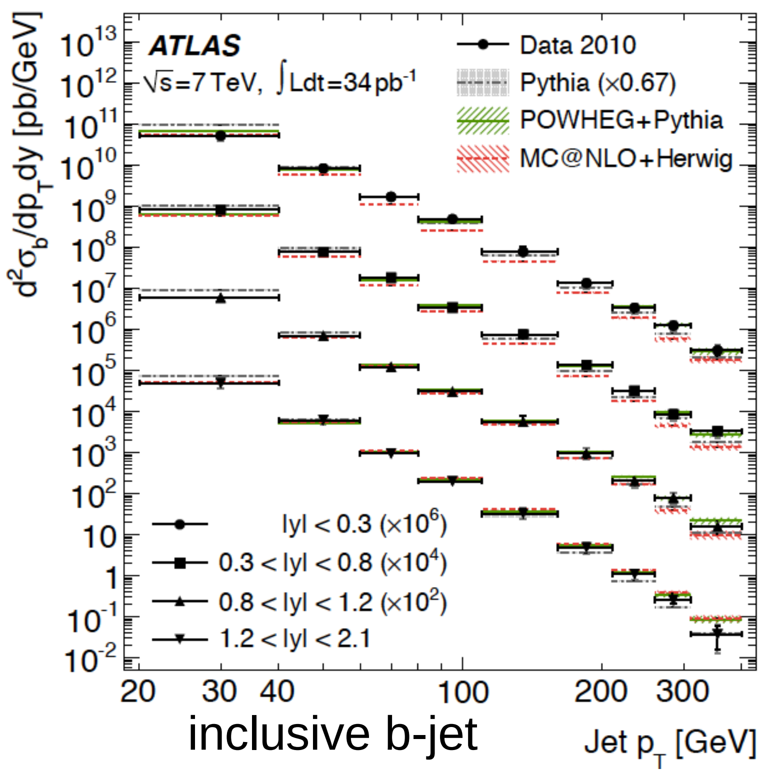
    in default, 50% b-tagging efficiency is chosen

b-jet cross sections

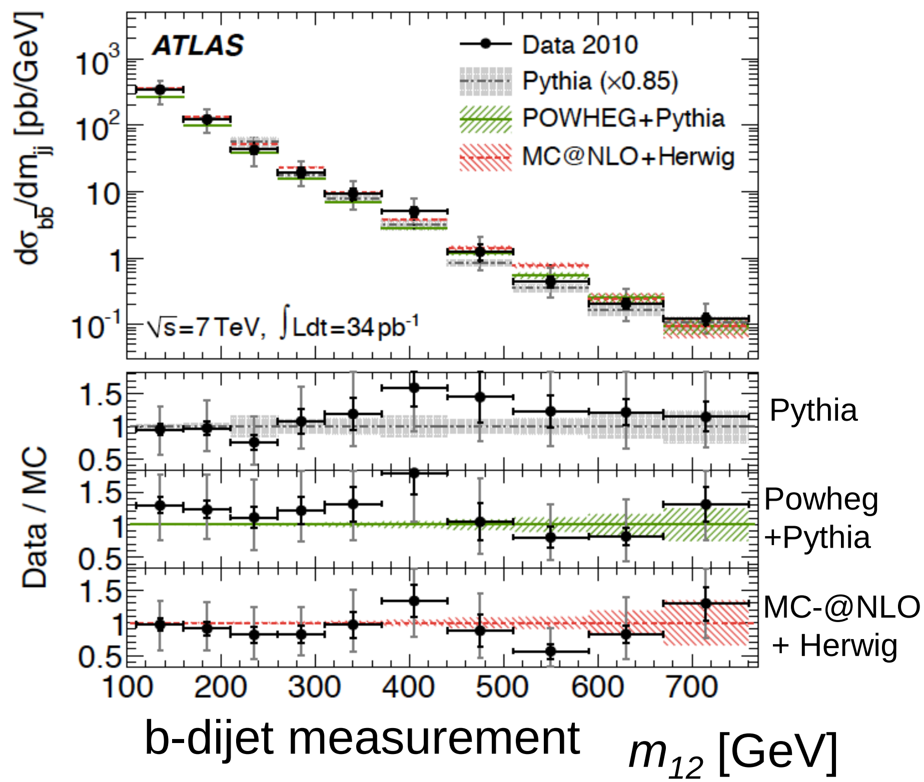
- Jet anti-k_T algorithm dR=0.4
- $|y_{jet}| < 2.1$
- for di-jet p_T(jet) > 40GeV
- compared to NLO MC
- systematics dominant: b-jet energy scale, b-tagging eff/purity uncertainties

- POWHEG+Pythia shows good agreement while MC@NLO+Herwig significantly different in inclusive b-jet measurement
- all three show good agreement for b-dijets

arXiv:1109.6833v1



inclusive b-jet

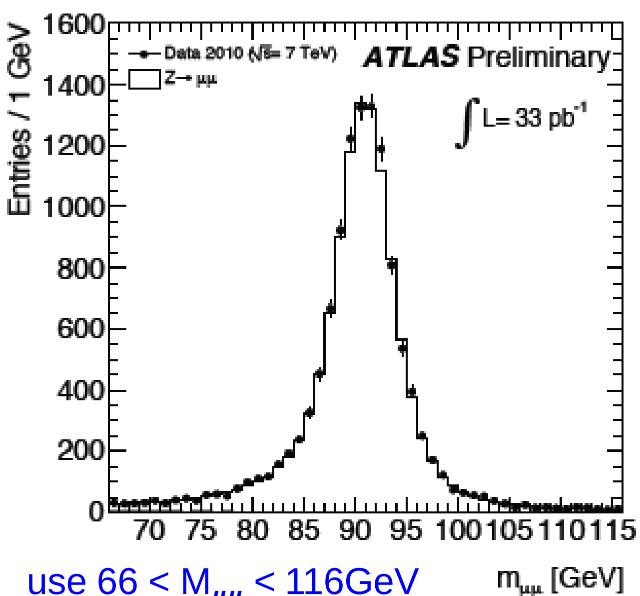


b-dijet measurement

QCD + Electro-Weak (W/Z)

- EW gauge boson produced with n-jets
- bosons produced via qq interaction, while jets are from higher order QCD terms
- stringent test of pQCD

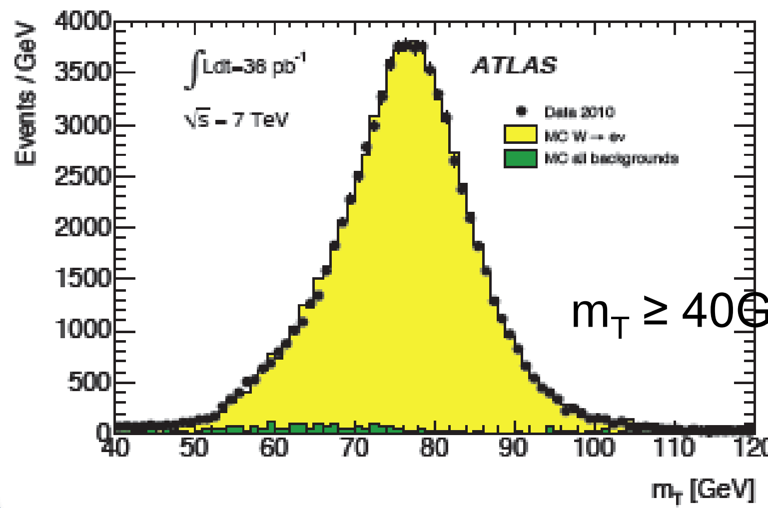
Z identified with the M_{INV} of the di-lepton system



use $66 < M_{\mu\mu} < 116$GeV

W p_T of ν from missing E_T
Reconstruct transverse mass

$$M_T = \sqrt{2 p_T^{\ell} E_T^{Miss} \left(1 - \cos\left(\phi_{\ell} - \phi_{EtMiss}\right)\right)}$$



$m_T \geq 40$GeV

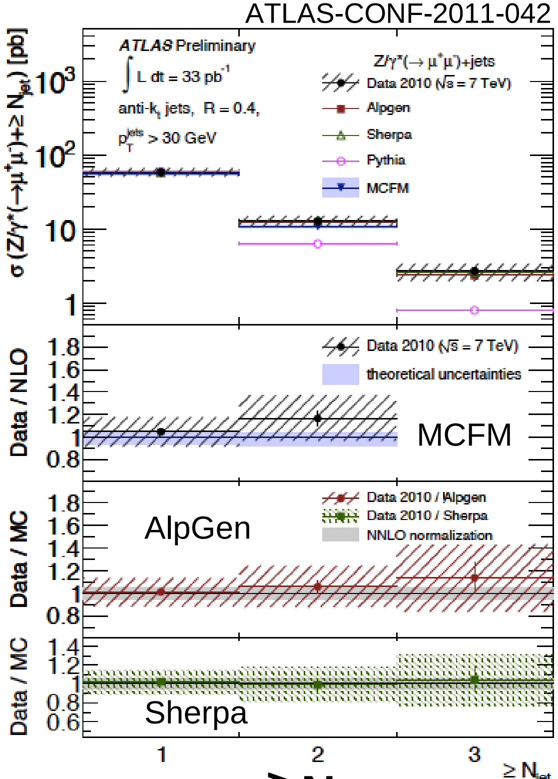
- EtMiss measurement affected by pileup
- reproduce the pile-up conditions by N primary vertices weighted MB events

Z + jets

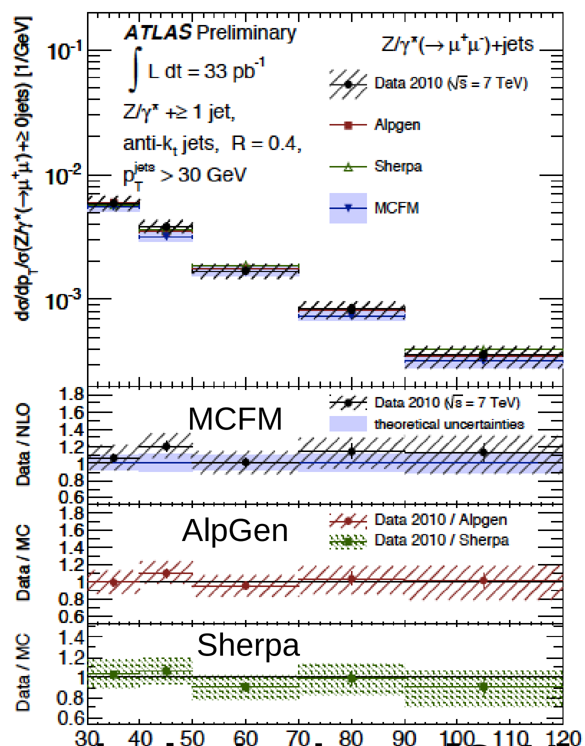
Just as multi-jets case, LO ME+PS MCs crucial for the jet multiplicity, and jet kinematics

- Alpgen / Sherpa in good agreement with data
  multi-parton ME, normalized to NNLO cross section
- MCFM (NLO ≤ 2) also consistent
- Pythia (2⟹2) disagrees from Njet ≥ 2

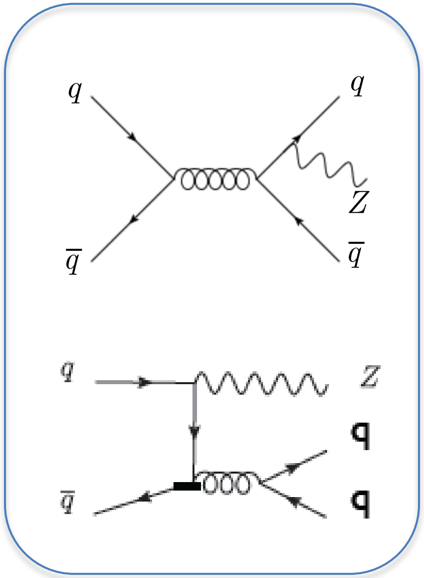
ATLAS-CONF-2011-042



≧N_{JET}



inclusive jet p_T [GeV]

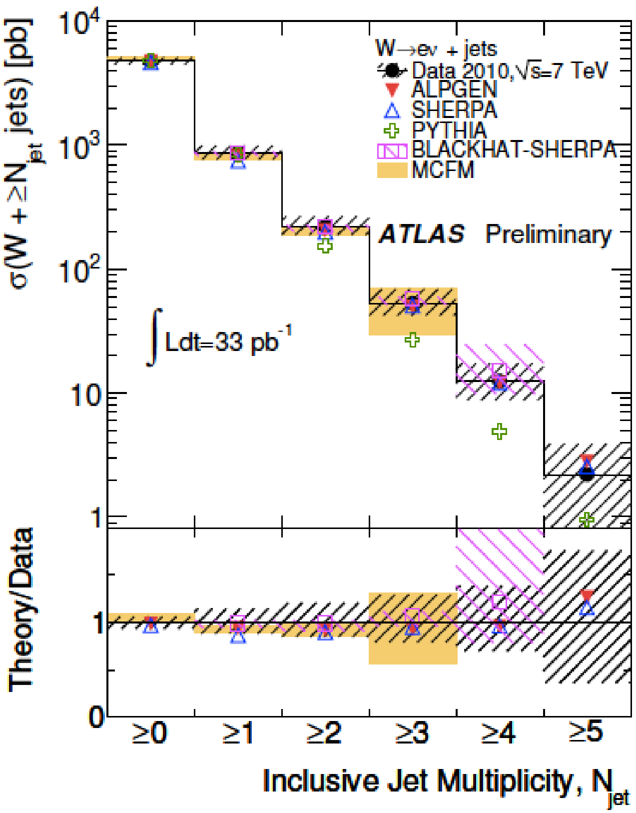


[Selection]
isolated leptons :
$p_T(e,\mu)$ > 20GeV, $|\eta|(e,\mu)$ < (2.47,2.4)
anti-k_T jets :
dR=0.4, p_T>25GeV $|y|$< 2.1
opposite sign (same flavor) leptons 66 < $M_{\ell\ell}$<116GeV

W + jets

Significant BG for $t\bar{t}$, single *top* measurement, also for Higgs and beyond SM searches

Pythia LO : disagree from N_{jet} = 2 and more
Alpgen/Sherpa : multi-parton ME, normalized to NNLO cross section
MCFM : NLO up to 2jet, LO at 3jet
BlackHat-Sherpa : NLO up to 3jet, LO at 4jet



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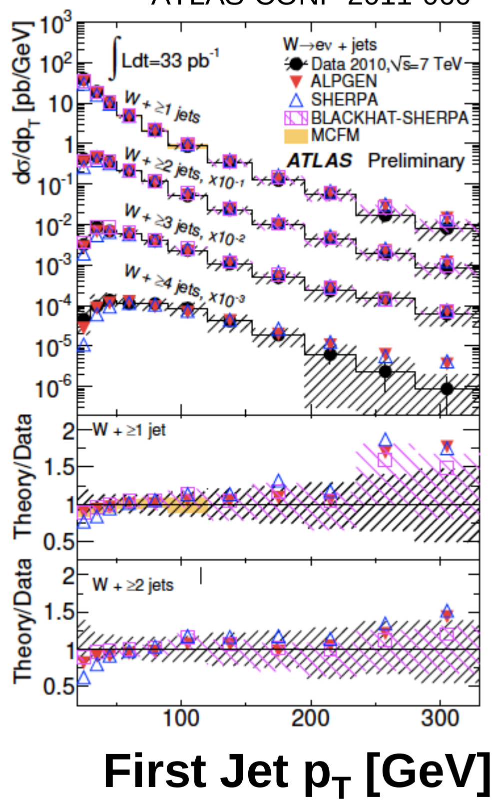
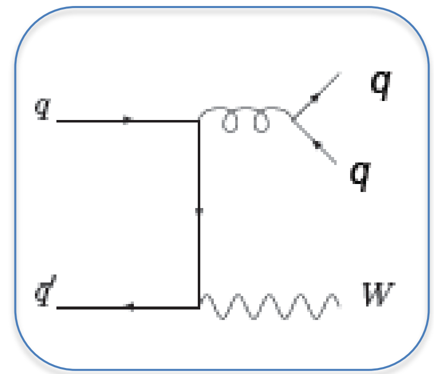


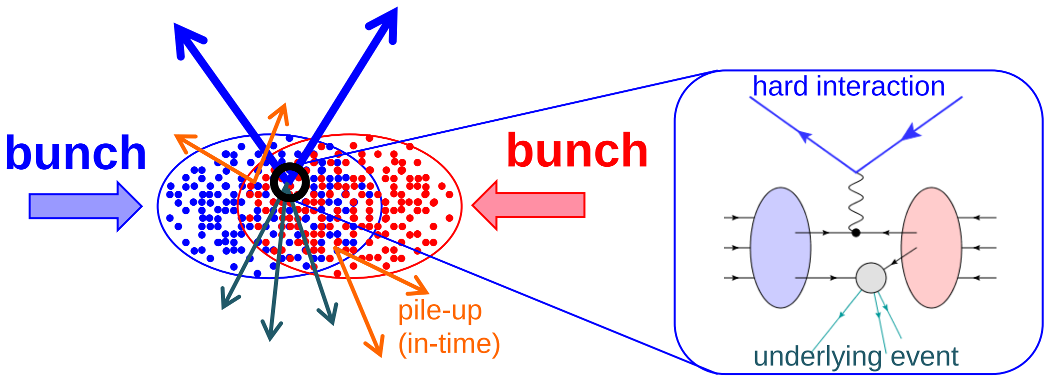


[Selection]
isolated lepton :
$p_T(e,\mu)$ > 20GeV, $|\eta|(e,\mu)$ < (2.47,2.4)
EtMiss > 25GeV, M_T>40GeV
anti-k_T jets :
dR=0.4, pT>20GeV |y|< 2.8

similar results for muon channel

Non-perturbative QCD Topics

MB(minimum bias) & UE(underlying event) in LHC



- Important topics for LHC
  - MB : major BG for detectors as a pile-up (in-time)

    interactions /bunch crossing = 2.2 (2010)→ 5.8 (2011)→ ~23 (design)
    in MC, average # weighted simulated events overlaid on hard process
  - UE : each interaction accompanies multi-parton interactions
- Modeling in Pythia and Herwig/Jimmy
  - difficult to describe both MB/UE with the same parameters
    → separate tunes prepared
  - ever lasting tuning efforts on going

Minimum bias events

AMBT1 : the first tune based on ATLAS MB data (0.9 and 7.0TeV)
diffractive reduced phase space (Nch≧6, pT > 500MeV, |eta|<2.5)

→ recent tune obtained separately for **MB (AMBT2)** and **UE (AUET2)**

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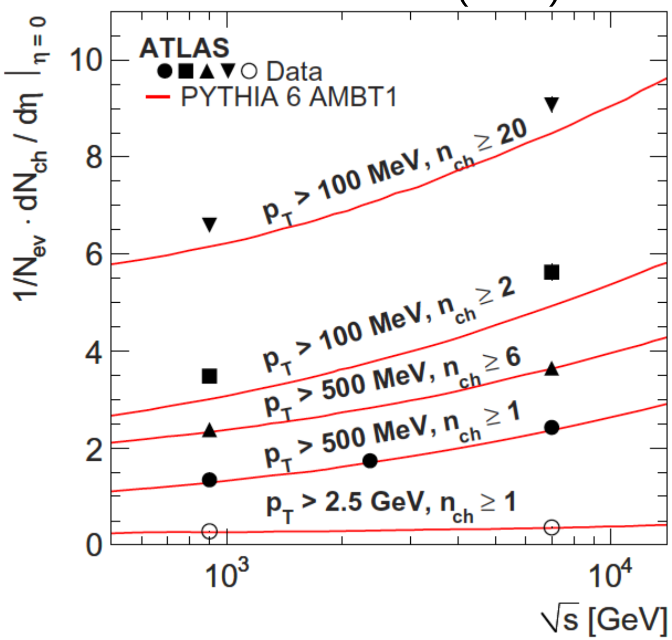
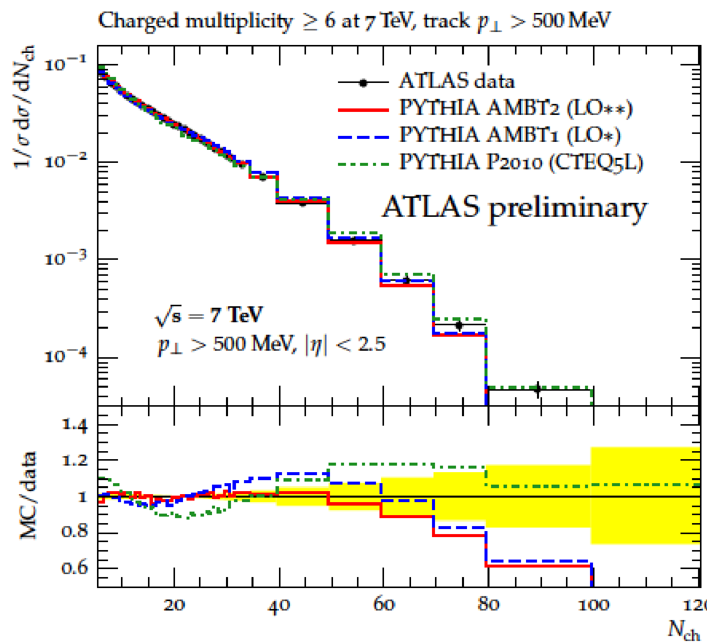




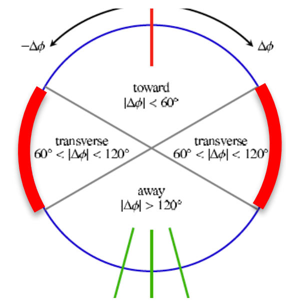
particle density vs. √s
low p_T (diffractive domain) is not described well by MC, p_T > 500MeV are OK

# of charged particle distribution
AMBT2 improved in high stat. region
(p_T dist. is not improved; not shown here)
still room for progress !

Underlying events

- look at properties in 60 degree azimuthal wedge perpendicular to leading track

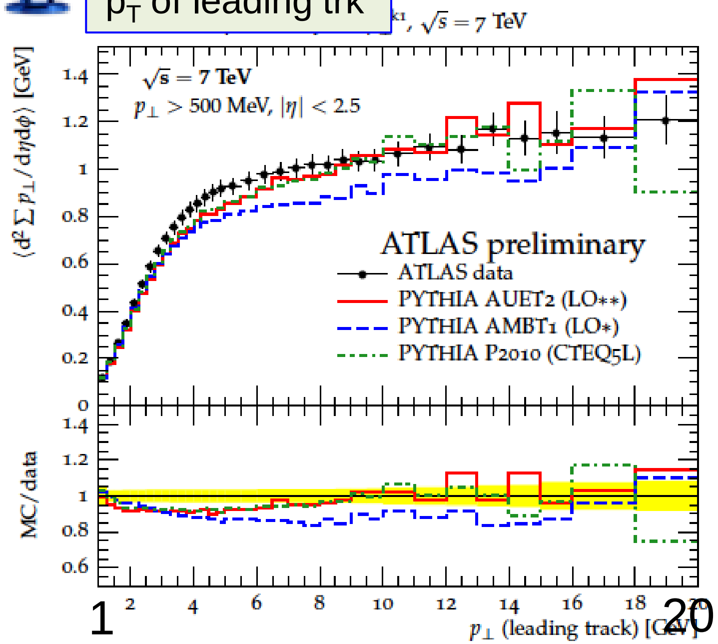
leading track (hard interaction)



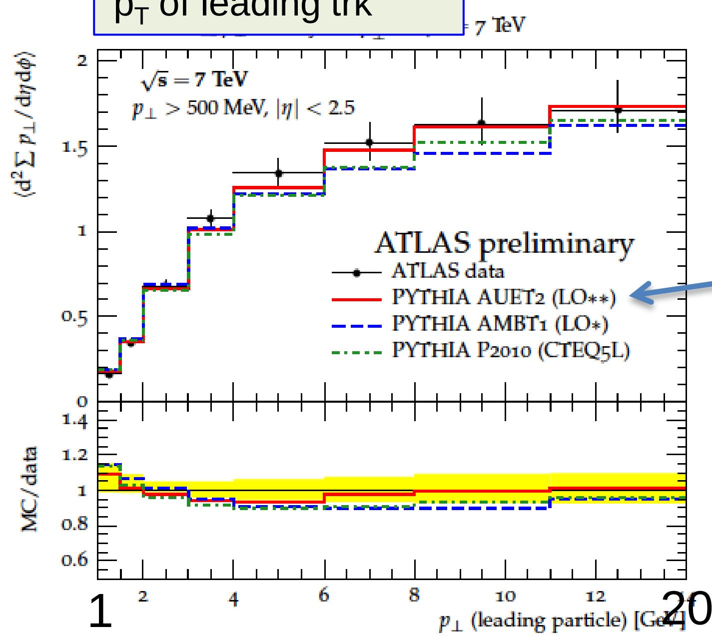
transverse (UE)

N_{chg} density vs. p_T of leading trk

ATL-PHYS-PUB-2011-008



<pT> of chg trks vs. p_T of leading trk



tuned to UE only

good improvement of **AUET2 (red)** over **AMBT1(blue)**

Rapid rise with p_T, plateau above ~5GeV

On going work for

- various MCs, PDFs e.g. PYTHIA8(C++)

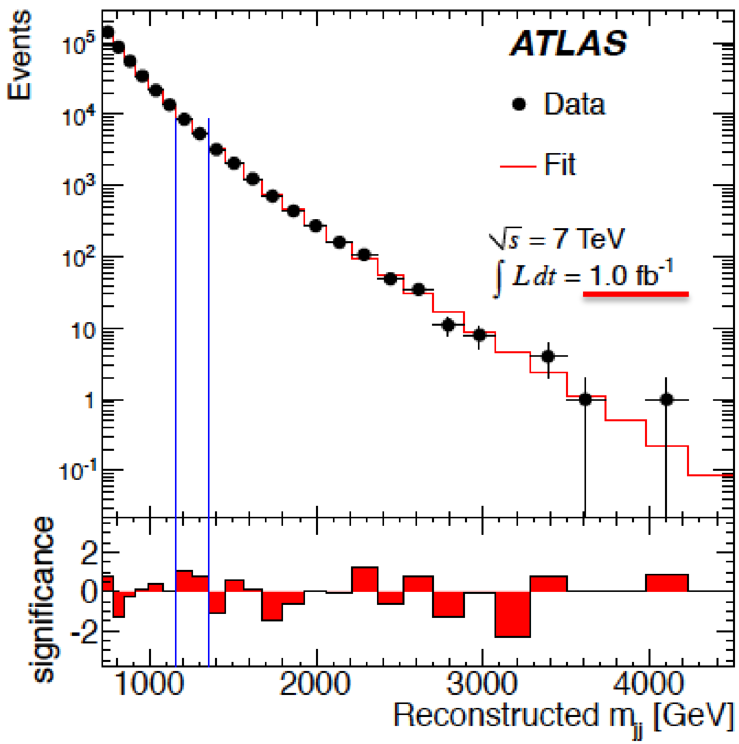
QCD at very high energy

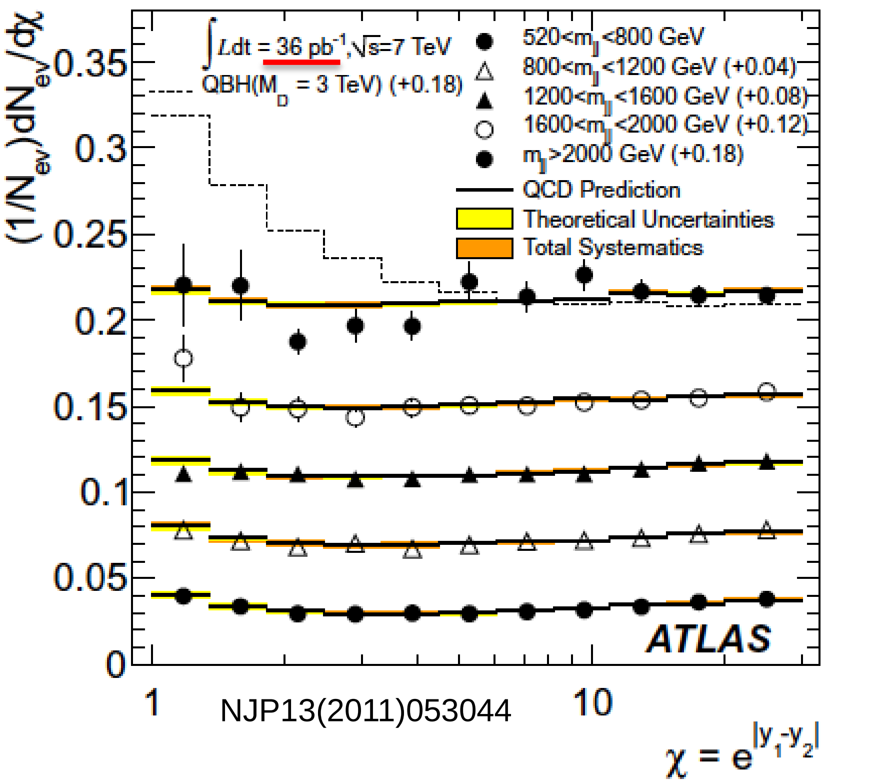
Di-jet resonance search

- resonance search is the first thing one should try for BSM with early data (robust quantity, which do not require super accurate JES)
- useful way to confirm the QCD modeling & detectors are sound and still at very high energy

with this variable χ, one expects peak around 1 for heavy resonant particle (back to back jets)

arXiv:1108.6311





NJP13(2011)053044

good description up to M_{jj} > 3TeV
so far no luck yet, need higher statistics for higher tail and angular correlation

Concluding remarks

- A stunning number of successful measurements for many QCD channels from both ATLAS and CMS
- Inherited powerful knowledge (MC, Jets algorithm, analysis techniques) accelerated the quick interpretation of new results
- Most QCD predictions in good agreement with measurements
- Current precision is 10-15% on data and theory measurement side will be improved with large statistics of 2011/2012 data
    - more systematic studies, more understanding on detector
- Will expand our understanding in the new kinematic regimes
- Aiming at 5fb^{-1} updates/publications for winter 2012

That's All
!! Thank you for listening !!

EXTRA SLIDES

ATLAS Data Quality

ATLAS Detector Status

as of 2011/10/05

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	96.4%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.8%
Tile calorimeter	9800	96.2%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k100	99.0%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	97.7%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	97.9%

Operational fractions very high (> 97%)

high good quality data (>98% except LAr)

luminosity weighted fraction of good quality data during LHC stable beam runs, L=2.33fb^{-1} (3/13-8/13)

Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.9	100	90.0	91.3	94.8	98.2	99.5	99.7	99.9	99.6	99.6	99.4

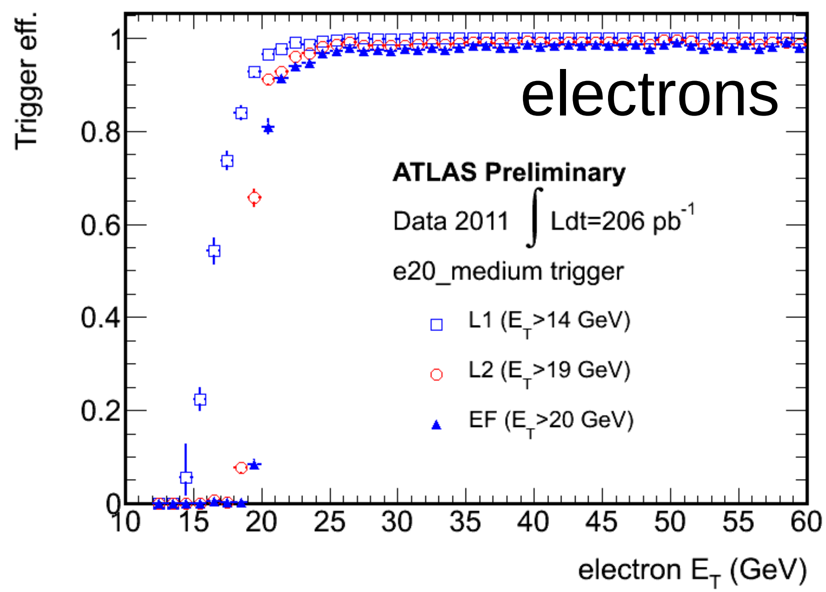
Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and August 13th (in %). The inefficiencies in the LAr calorimeter will largely be recovered in the future.

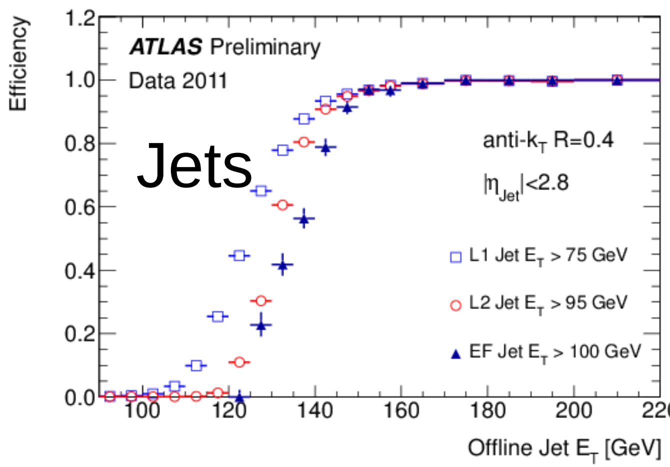
Upgrade & long shutdown (LS) plan (as of today)

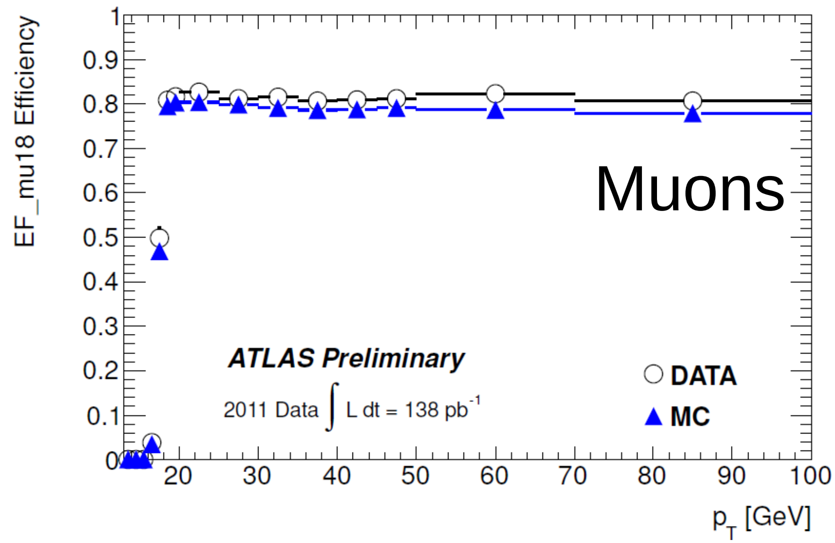
- LS1: 2013 – 2014 shutdown 24month physics-to-physics
  - Machine : mainly splices consolidation and repairs
  - ATLAS : IBL, Pixel new SQP, new LVPS for tile/lar, FTK, etc....
- RUN : 2015-2017
  - $\sqrt{s}$ ~ 13-14TeV, β^*=0.55m, L~1x10^{34} → ~50fb^{-1}
- LS2: 2018 shutdown (Phase-I): ~1 year
  - Machine : injectors (LINAC4) and collimators
  - ATLAS : L1 trigger (topological, more granular), Muon Small Wheels, etc
- RUN : 2018-2021
  - L~2x10^{34} → 300fb^{-1}
- LS3: 2022-2023 shutdown (Phase-II): ~2years
  - Machine : new inner triplets, crab cavities
  - ATLAS : new tracker, new calorimeter electronics, new FCAL, etc
- RUN : 2024 -
  - L~5x10^{34} → up to 3000fb^{-1}

ATLAS Trigger performance

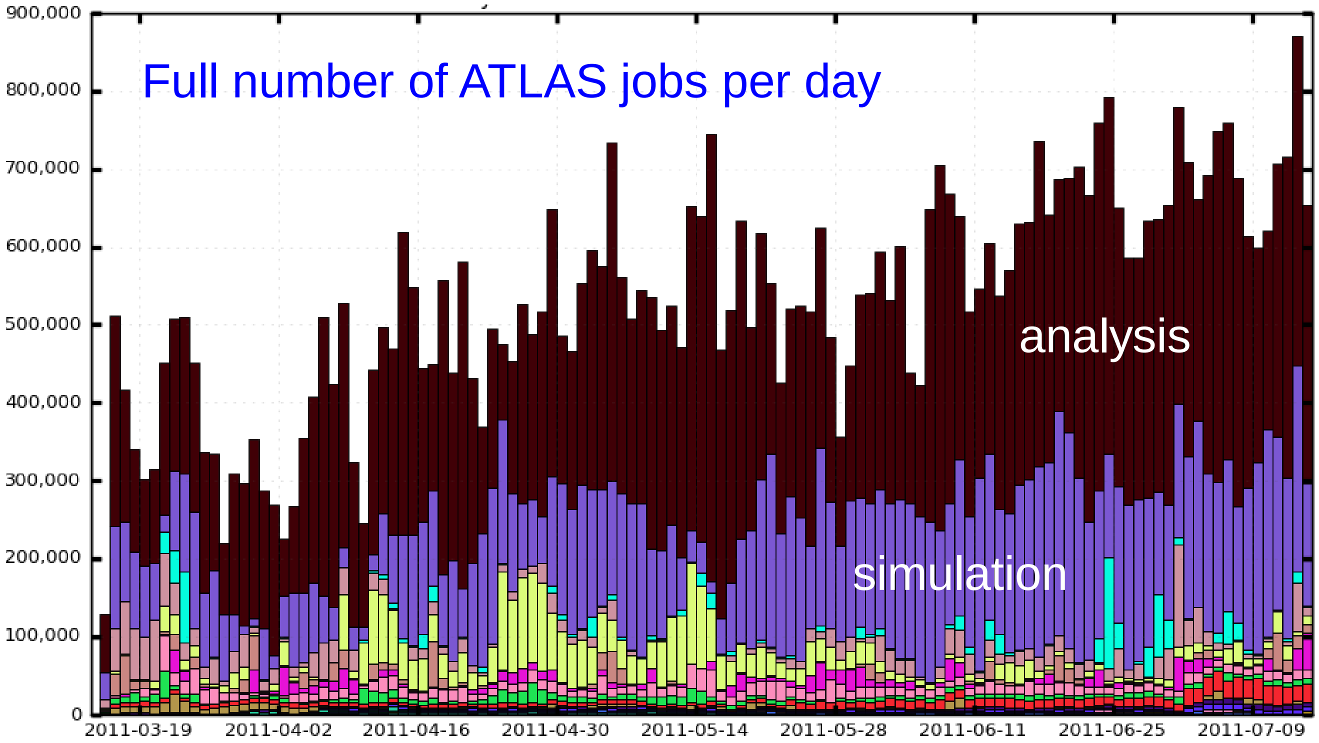
- High level trigger menu : software based, continuous update with luminosity
- $3 \times 10^{33} cm^{-2} s^{-1}$ menu
  - Prescaled triggers
    - Electrons pT>22GeV
    - Muons pT>20GeV
    - Jets pT>240GeV
    - EtMiss > 60GeV
    - (Di)photons pT> 80(20)GeV
- $5 \times 10^{33} cm^{-2} s^{-1}$ menu
  - Even tighter menus planned







Data preparation and computing

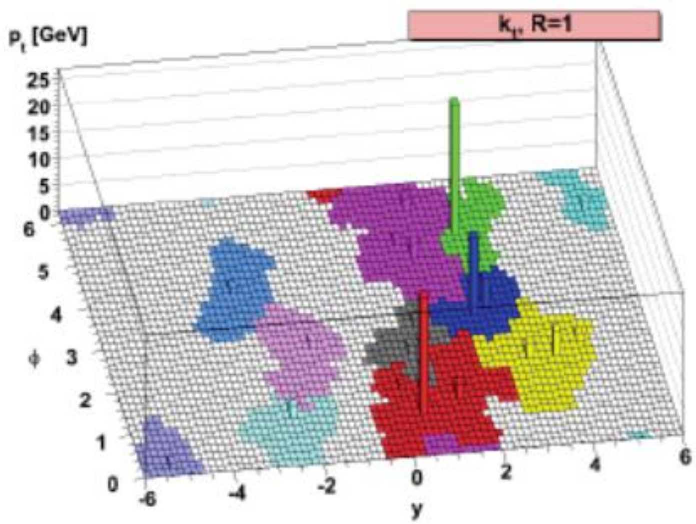


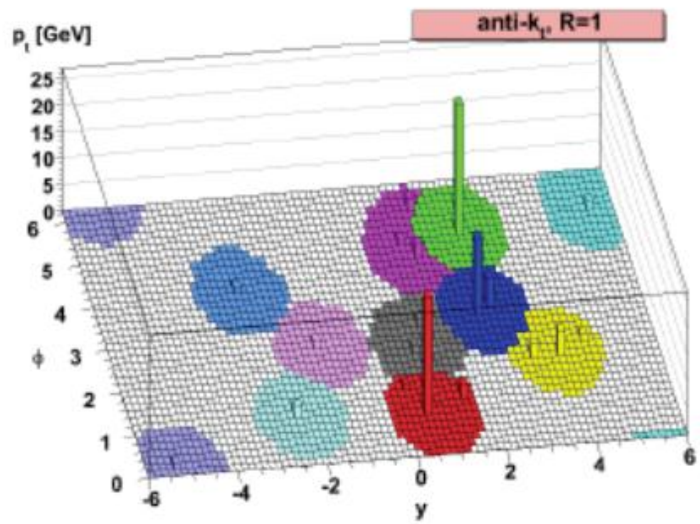
2011.03 2011.07

- Raw data are reconstructed at Tier-0 site (CERN) within 2days
- Calibration and data quality performed for physics analysis
- Data are ready for analysis on the grid within a week
- Up to 800k jobs/day are processed on Tier-1 and Tier-2 sites
  - Analysis, Simulation, Reprocessing, various productions

k_T and anti-k_T Jet algorithms

- define for each proto-jet its "beam distance" $d_{iB} = k_{Ti}^n$
  and for each pair of pro-jets their "separation"
  $d_{ij} = \min(k_{Ti}^n, k_{Tj}^n)\frac{\Delta R_{ij}^2}{R^2}$ where $\Delta R_{ij}^2 = (y_i - y_j)^2 + (\varphi_i - \varphi_j)^2$
  and R^2 is a specified size scale of order unity
- if $d_{ij} < d_{iB}$ combine proto-jets *i* and *j*; otherwise, define *i* as a jet and remove it from the list
- *k_T* algorithm corresponds to *n* = 2 (favors clustering of soft proto-jets)
- anti-*k_T* corresponds to *n* = -2 (favors clustering of hard proto-jets)
- both algorithms are infrared and collinear safe

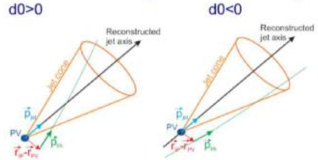




advanced *b*-taggings

IP-based algorithm: ***IP3D***

It signs the transverse and longitudinal impact parameters of tracks with respect to the primary vertex:



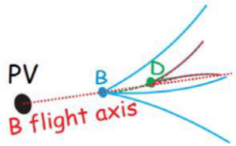
SV-based algorithm: ***SV1***

It reconstructs the inclusive vertex formed by the decay products of the *b*-hadron, including products of the eventual subsequent *c*-hadron decay.

It takes advantage of different properties of the SV:

Multi-vertex fit algorithm: ***JetFitter***

This algorithm tries to reconstruct the full *b*-hadron decay chain (*b*→*c*→…) including vertex topologies with single tracks (under hypothesis that *b*- and *c*-hadron decays lie on the same line)

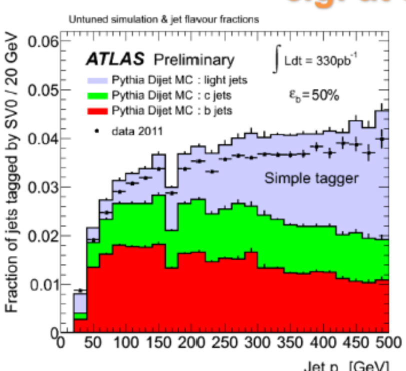


It also takes advantage of the different properties of these vertices:

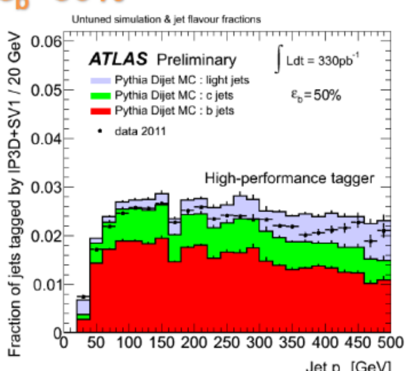
for QCD jet events:

fraction of light jets incorrectly tagged as b-jets
is substantially reduced with the advanced taggers

***e.g.* at ε_b=50%**

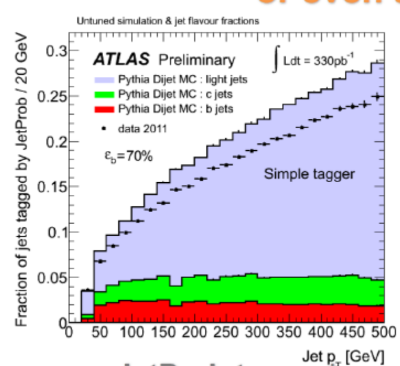


SV0 tagger*

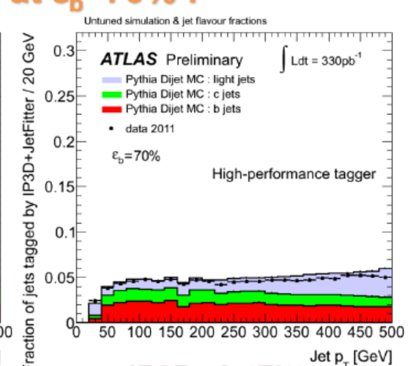


IP3D+SV1

or even at ε_b=70% !

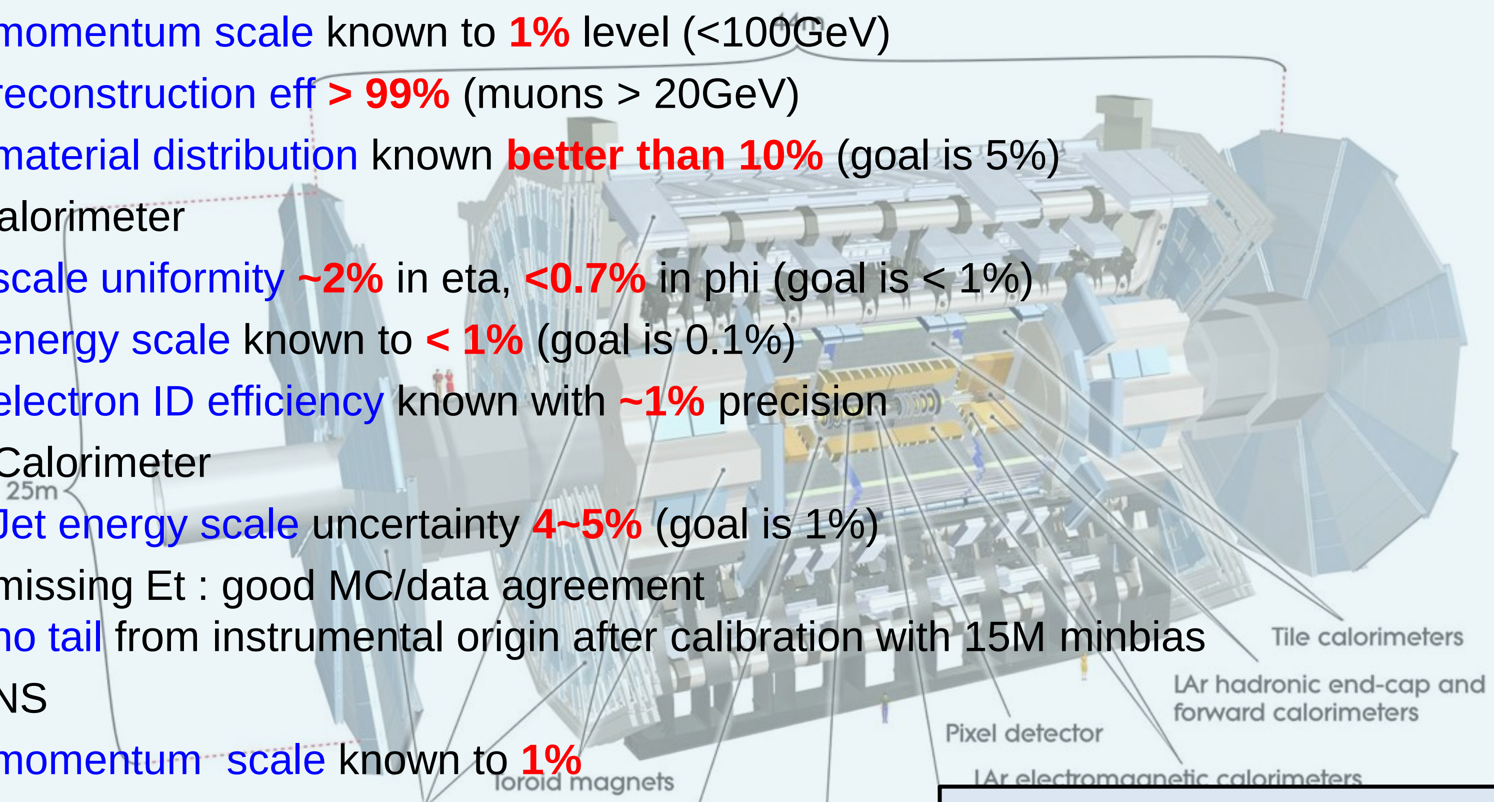


JetProb tagger*



IP3D+JetFitter

ATLAS detector performance in 2010



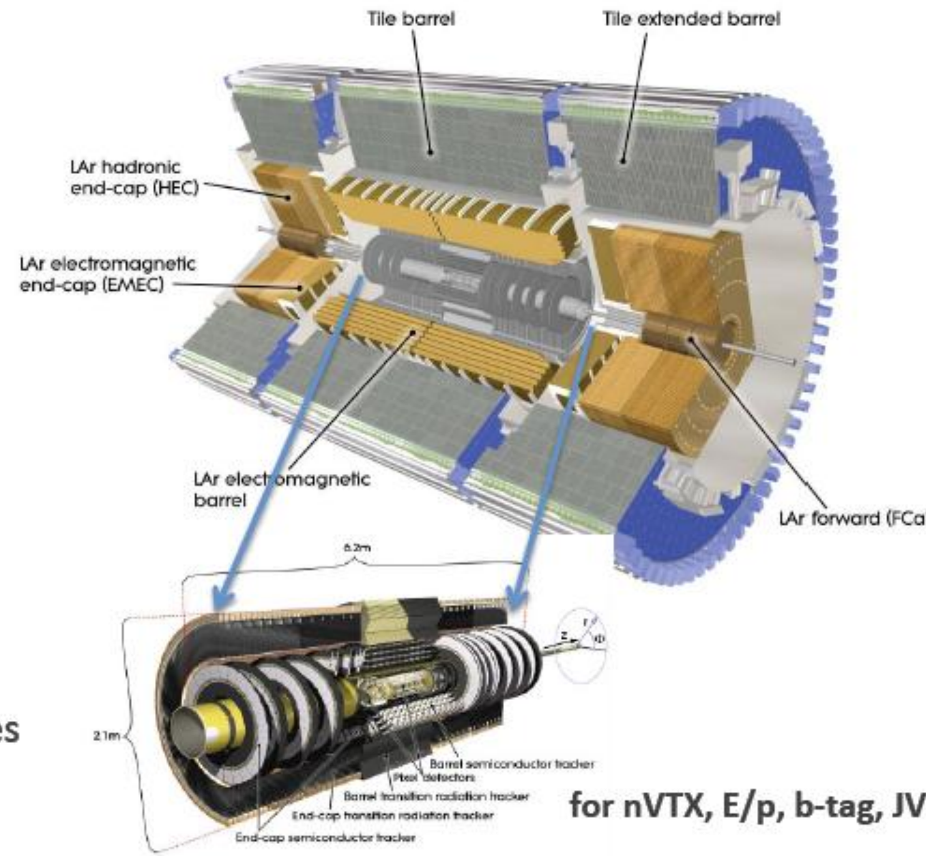
- Inner detector
  - momentum scale known to **1%** level (<100GeV)
  - reconstruction eff **> 99%** (muons > 20GeV)
  - material distribution known **better than 10%** (goal is 5%)
- EM Calorimeter
  - scale uniformity **~2%** in eta, **<0.7%** in phi (goal is < 1%)
  - energy scale known to **< 1%** (goal is 0.1%)
  - electron ID efficiency known with **~1%** precision
- HAD Calorimeter
  - Jet energy scale uncertainty **4~5%** (goal is 1%)
  - missing Et : good MC/data agreement
    no tail from instrumental origin after calibration with 15M minbias
- MUONS
  - momentum scale known to **1%**
  - momentum resolution known to **rel. 10%**
  - reconstruction eff known to **1-2%** (goal is 1%)
- Trigger / Data GRID transfer →
- Luminosity 2010 (Van der Meer scan)
  - final uncertainty 3.2% (most of the papers used the previous estimation 11%)

Rate (2010/ design)
Bunch crossing: 1MHz/40MHz
Level-1: 20kHz / 75kHz
Level-2: **3.5kHz** / 2kHz
EF: **300Hz** / 200Hz
GRID: **1-4GB/s** / 2GB/s

ATLAS calorimeter and inner detectors

Sampling Calorimeters

- High granularity
- Longitudinal segmentation (3-4)
- Non-compensating
  (jet calibration performed offline)
- Coverage



for nVTX, E/p, b-tag, JVF,...

EM: LAr(act.) / Pb(abs.)
$|\eta| < 1.475$ (barrel)
$1.375 < |\eta| < 3.2$ (endcap)

HAD
Barrel region $|\eta|<1.4$:
Organic scintillator(act.) / steel(abs.) tiles
Endcap region $1.4<|\eta|<3.2$: LAr/Cu

FORWARD
$3.2<|\eta|<5.0$
LAr/Cu (EM) and LAr/W (HAD)

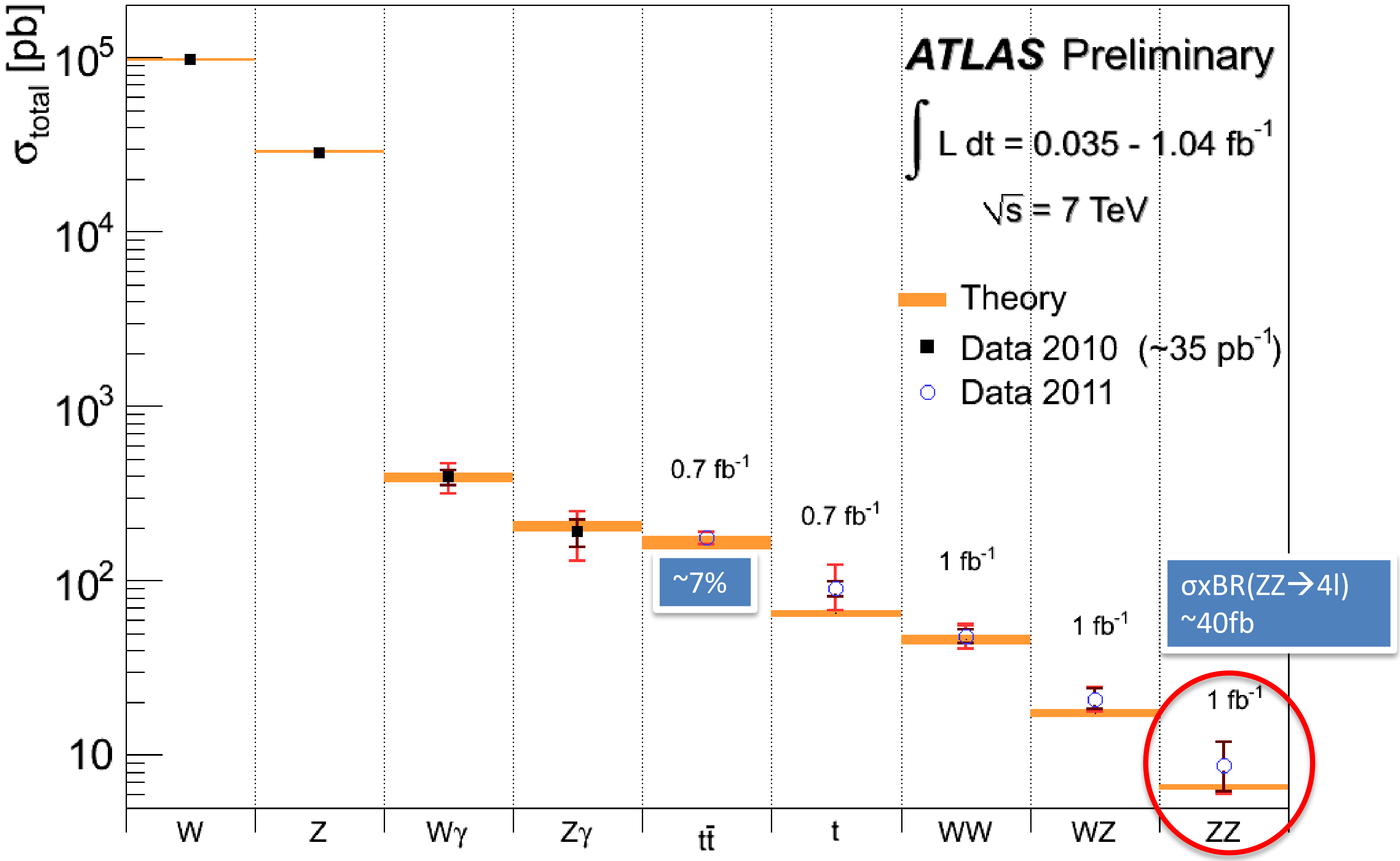
Inner Detector

Pixel detectors, semiconductor tracker (SCT), transition radiation tracker (TRT)

87M readout channels, coverage up to $\eta = 2.5$
Immersed in 2T solenoidal magnetic field

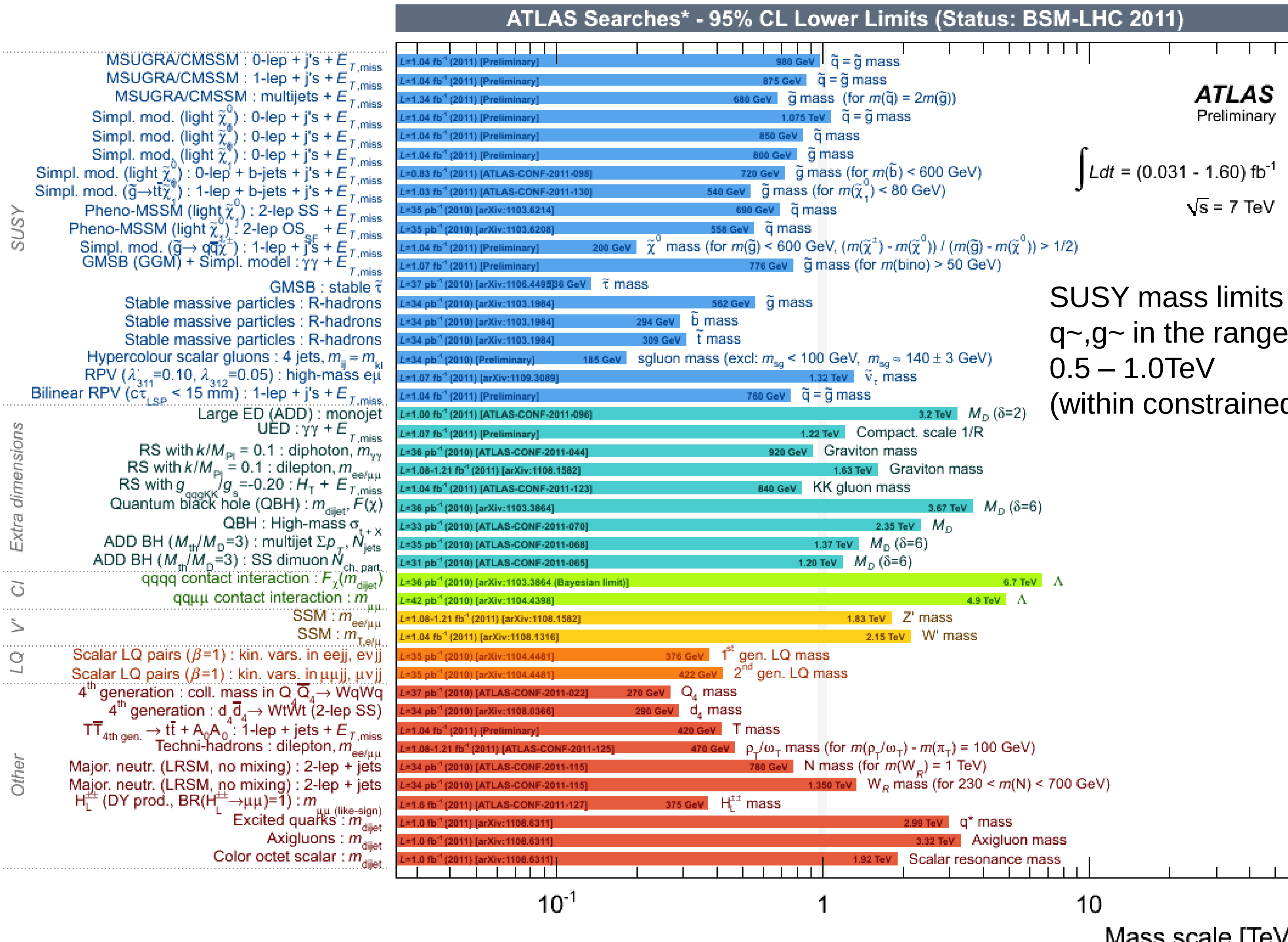
Summary of SM measurements

inner error: stat
outer error: total



Measuring cross-sections down to few pb (~40fb including BR)

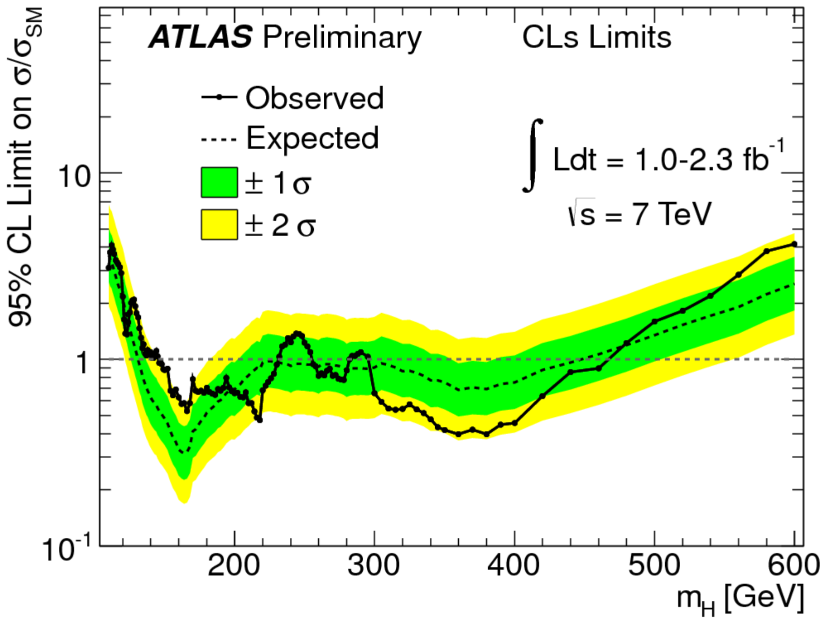
Summary of BSM searches

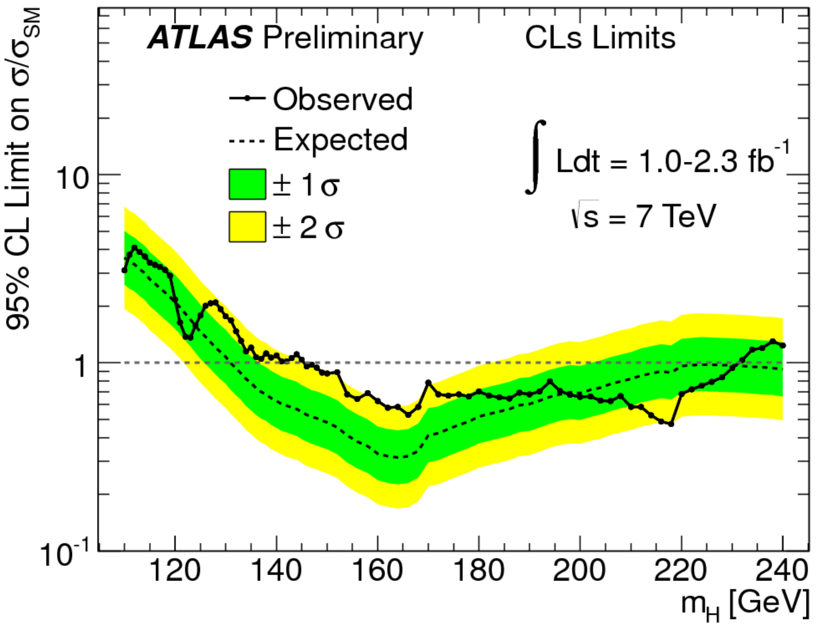


SUSY mass limits on q~,g~ in the range 0.5 – 1.0TeV (within constrained models)

*Only a selection of the available results leading to mass limits shown

Summary of Higgs searches (all channels combined)





- Excluded by ATLAS at 95% CL
  - 146 – 466 GeV except 232-256, 282-296 GeV
- Expected to be excluded (if no signal) at 95% CL
  - 131 – 447 GeV
- the best motivated low mass region (EW fit: m_H<161 GeV 95%CL) still open to exploration