Summary … not complete and biased

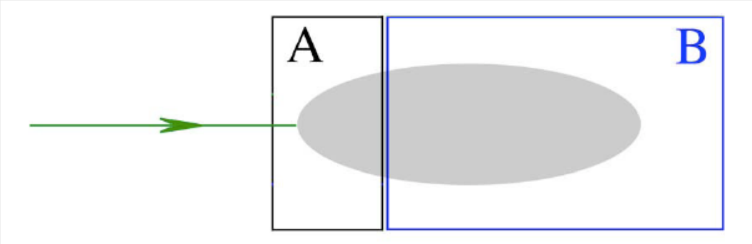
Jet reconstruction and spectroscopy

C.Roda – Universita` and INFN Pisa

Effects of calorimeter peculiarities on the Jet Energy Scale

R.Wigmans

- Pitfalls of calibration methods – expecially - for hadronic showers



- A/B = 1 paradigma: calibrate the different segments in the same way
  - e/h difference in calo sections (if you privilege em than you pay in hadron…)
- Need for a precise MC for hadronic showers to help improving calibration
- Most important: check your calibration checks with data

Wigmans

An attractive option for improving the quality of hadron calorimetry:

Use Čerenkov light!! *Why?*

Hadron showers < *em* component (π^0) / *non-em* component (mainly soft *p*)

Calorimeter response to these components not the same *($e/h \neq 1$)*

Čerenkov light almost exclusively produced by em component
(~80% of non-em energy deposited by non-relativistic particles)

→ DREAM (Dual REAdout Method) principle:
Measure f_{em} event by event by comparing Č and dE/dx signals

Future calorimeters aim at a resolution good enough to disentangle hadronic decays of Z from W

Jet definitions: constraints

SNOWMASS accords (FermiLab, 1990)

G.Soyez, P.Loch, S.Hartmut, P.Gianluca, G.Velev

Several important properties that should be met by a jet definition are [3]:

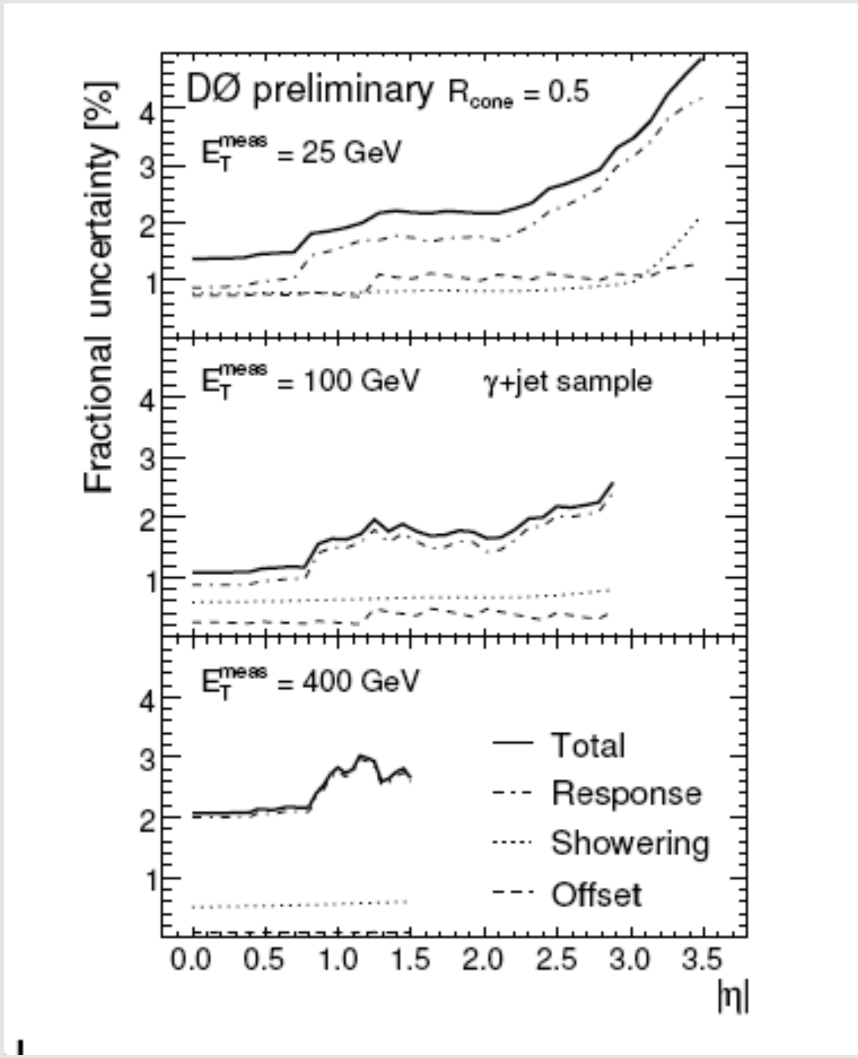
1. Simple to implement in an experimental analysis;
2. Simple to implement in the theoretical calculation;
3. Defined at any order of perturbation theory;
4. Yields finite cross section at any order of perturbation theory;
5. Yields a cross section that is relatively insensitive to hadronization.

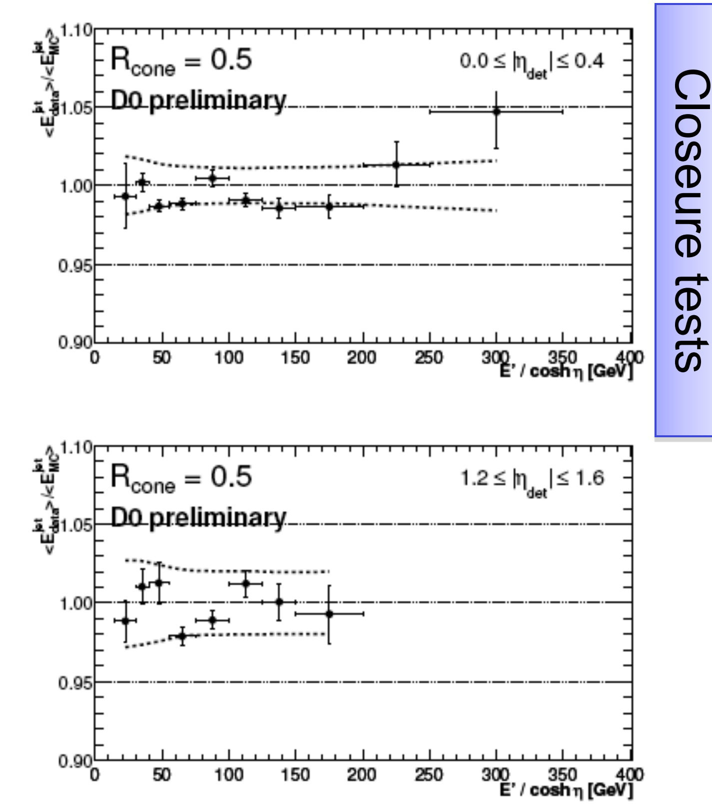
20 years later, these are only recently satisfied!!!

Experiment	CDF	D0	ATLAS	CMS
Input Detector signals	Towers	Towers	Towers, 3D clusters	Towers
Jet algorithm	Cone (JetClu) 0.4, 0.7	Midpoint 0.5, 0.7	**anti-kT 0.4, 0.6**	**anti-kT 0.5, 0.7**
Calibration	Pametrization + data driven	Mostly data driven + MC	Simple MC based, Local, Global	CaloJets, Calo+Track, Particle Flow

Jet Energy Scale uncertainty – D0

G.Petrillo



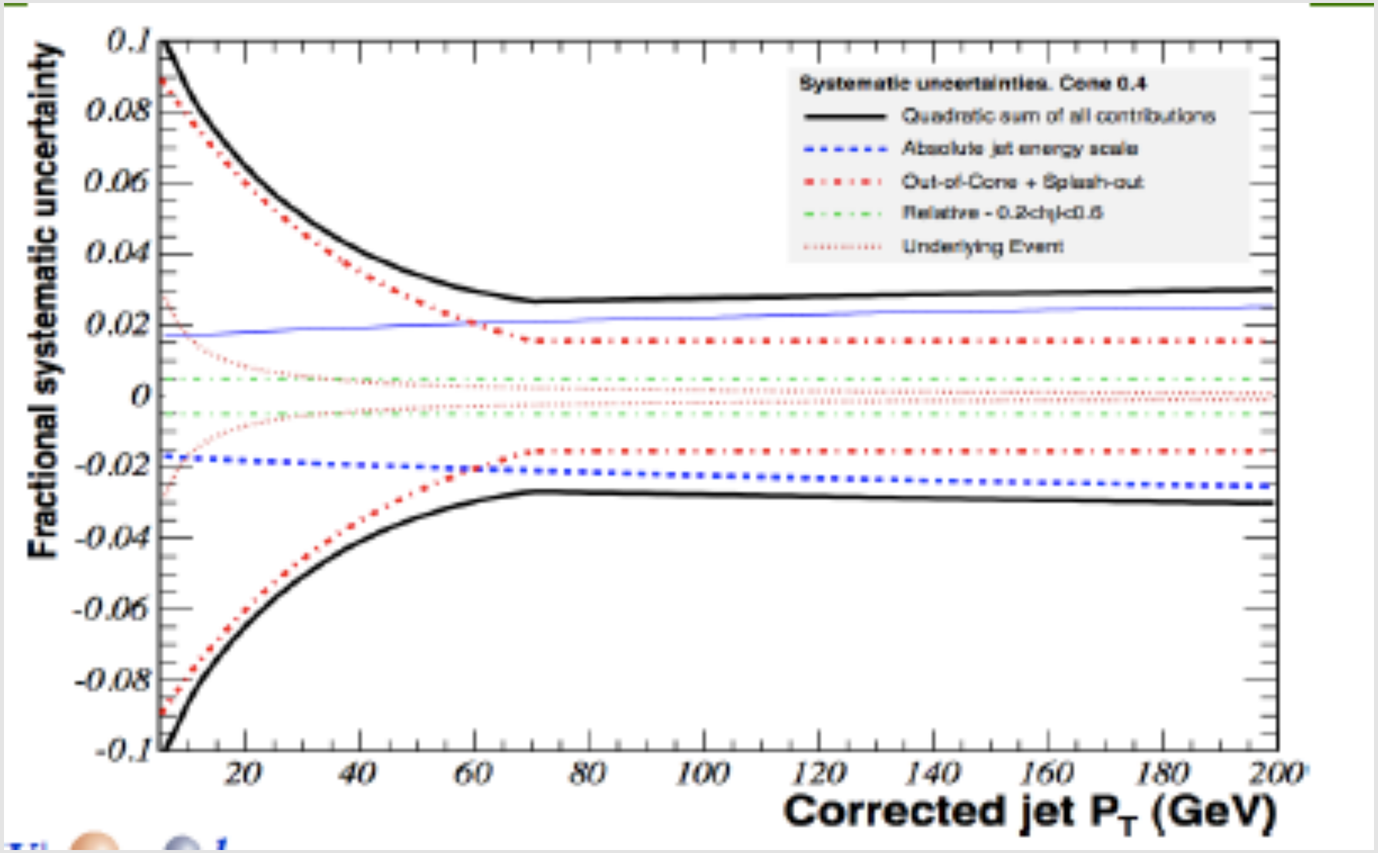


Closeure tests

- for a sizeable number of analyses the consistency of JES between data and simulation is *more important* than the correctness of its absolute scale

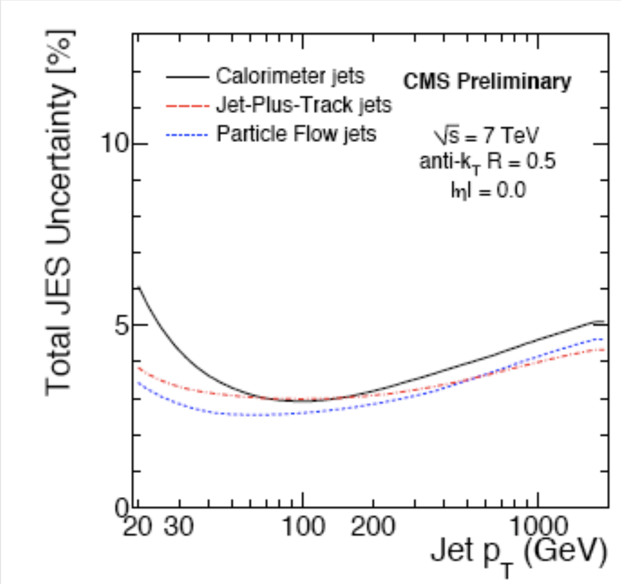
CDF Jet Energy Scale Uncertainty

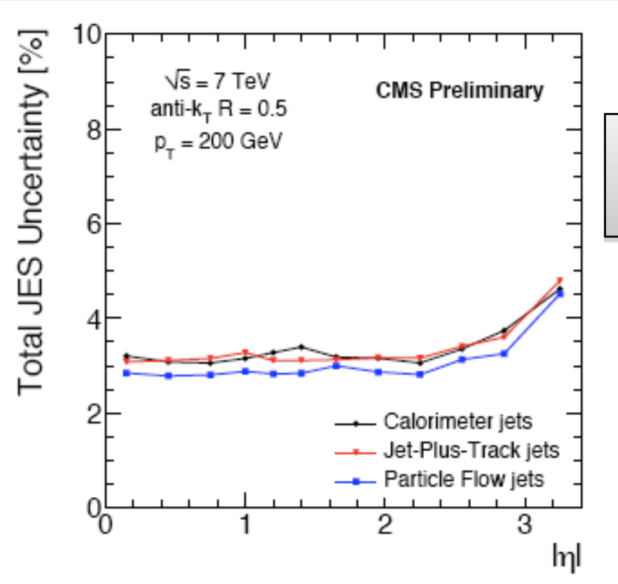
G.Velev



Jet Energy Scale uncertainty – LHC

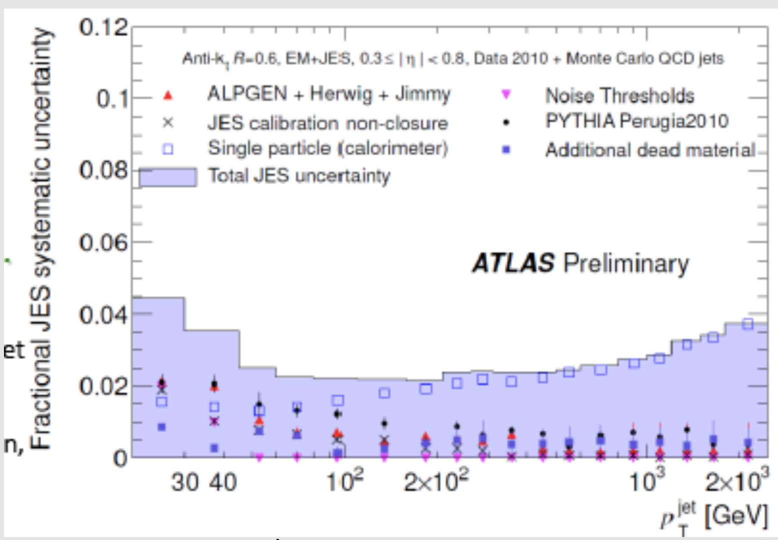
K.Kousouris

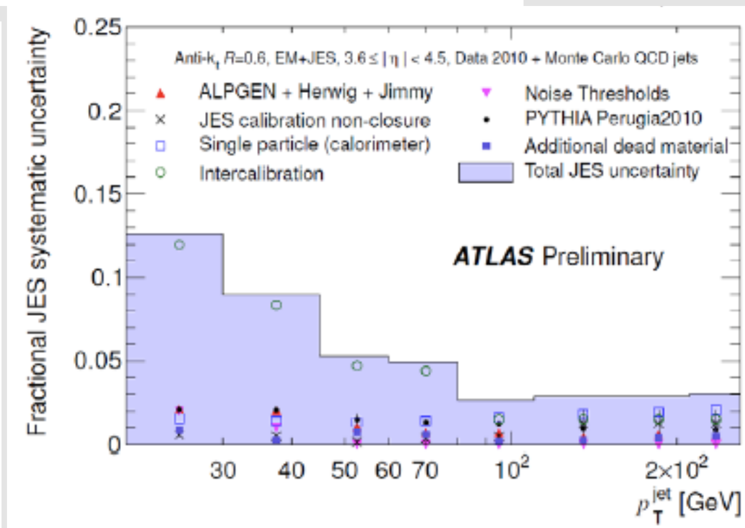




New version on full Data sample soon

P.Loch

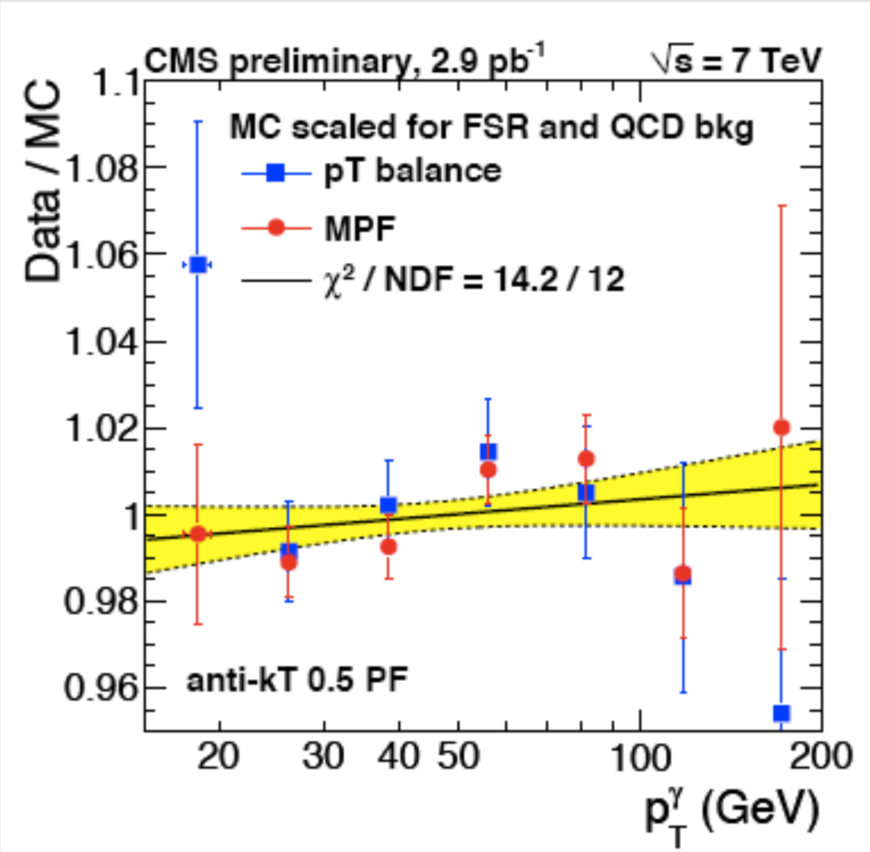


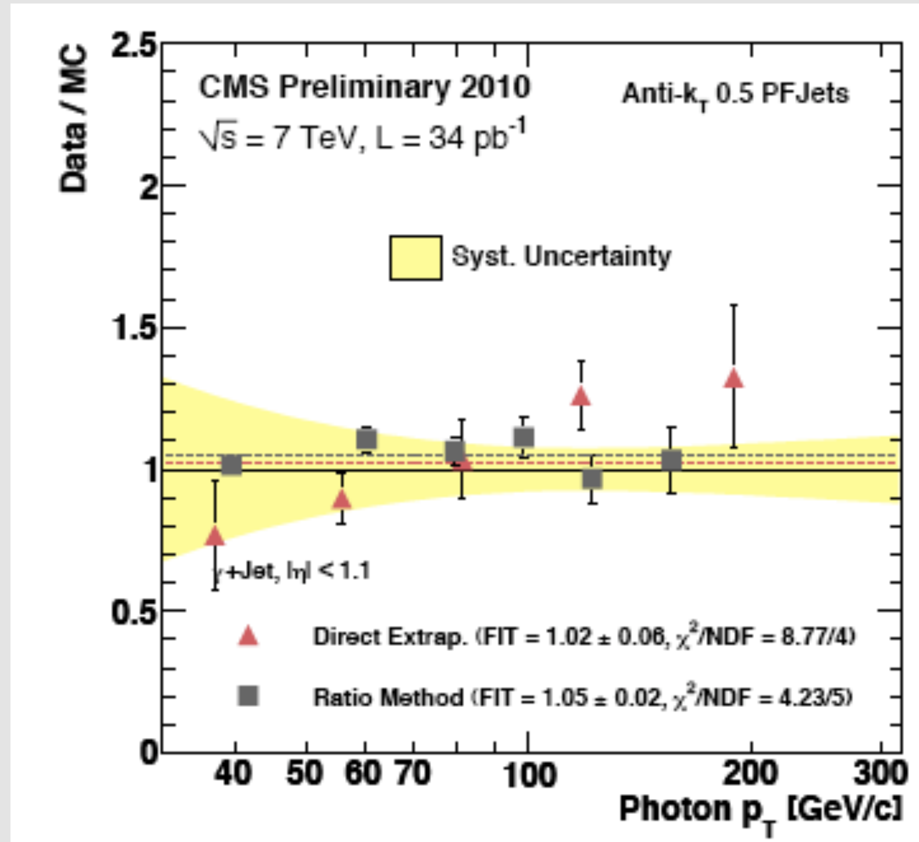


JES In-situ measurements CMS

H.Stadie

Gamma-Jet events MPF and pT balance



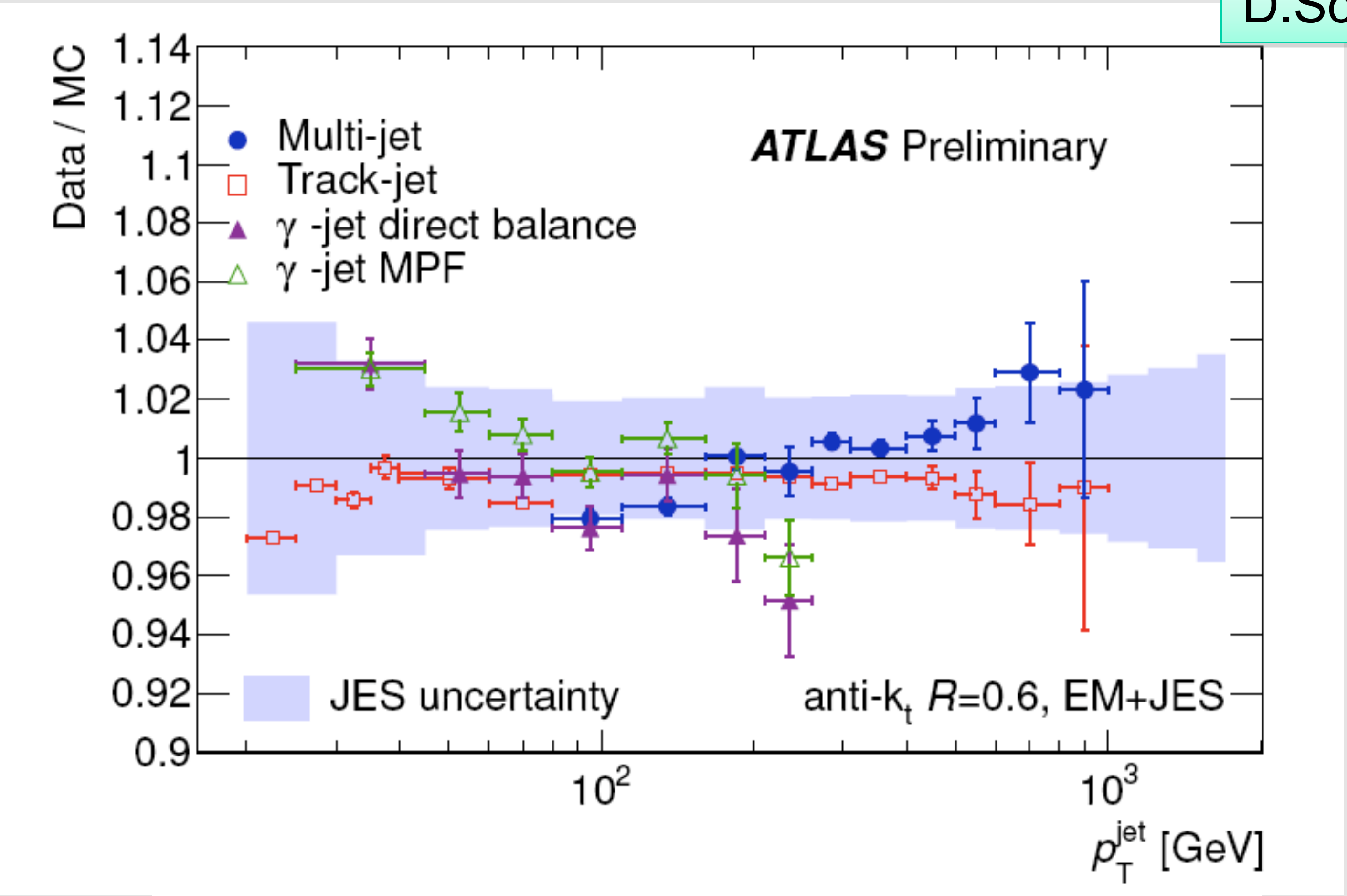


Absolute scale
Shift used for correction

Energy resolution

In-situ JES measurements ATLAS

D.Schouten



JES uncertainty for jets in barrel region, with $N_{PV} = 1$

Road to these results

JES uncertainty at few percent level in a few months….

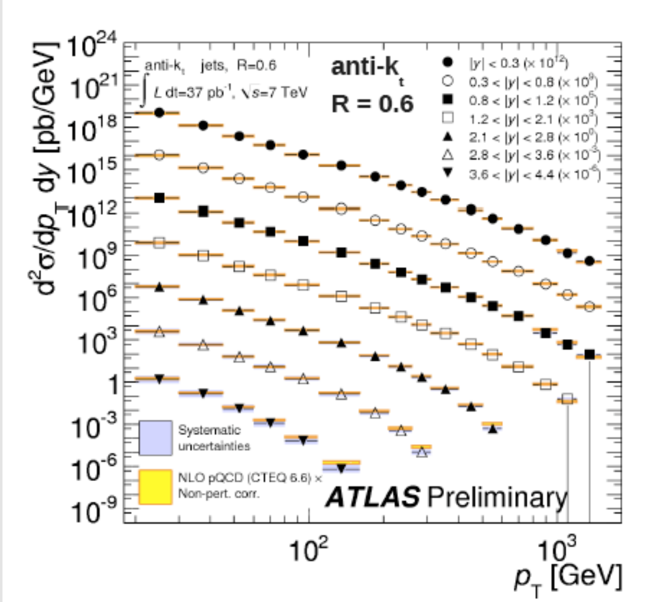
How we got there ? … hard work +

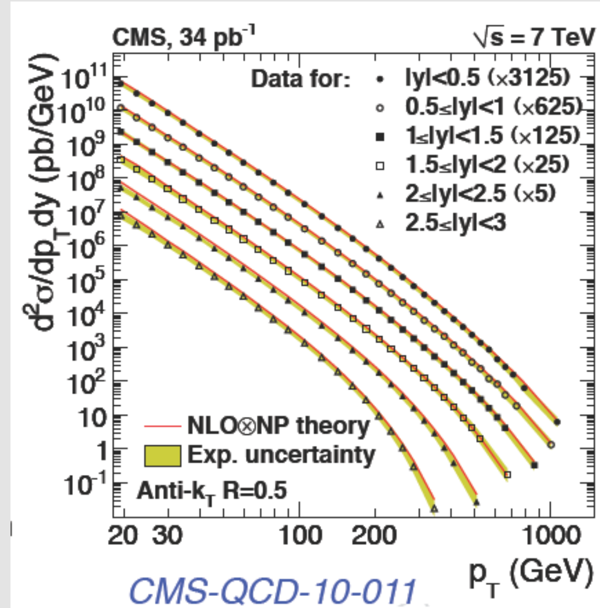
Learnt from previous experiments, Tevatron experience was a great input for LHC

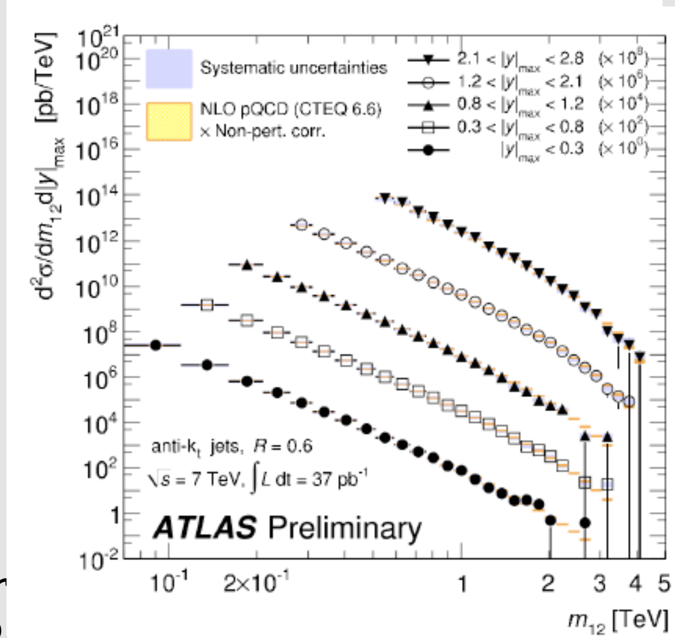
Years of Test Beam to understand the details of our detectors

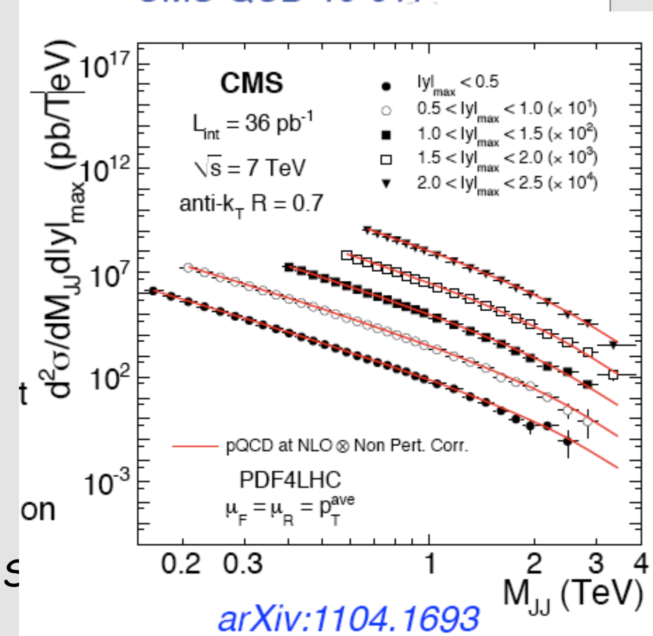
QCD measurements - LHC

ATLAS, F.Vives

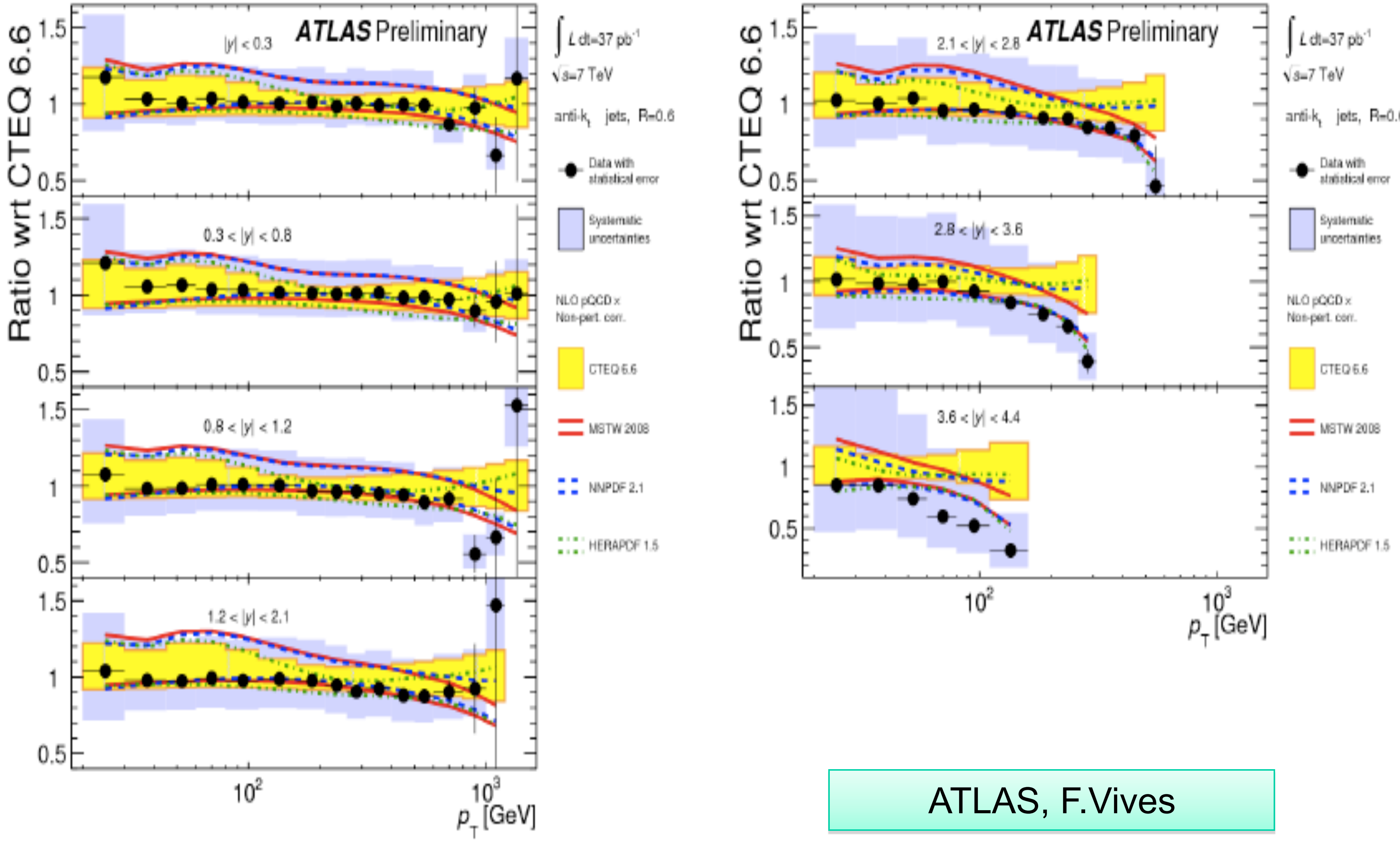




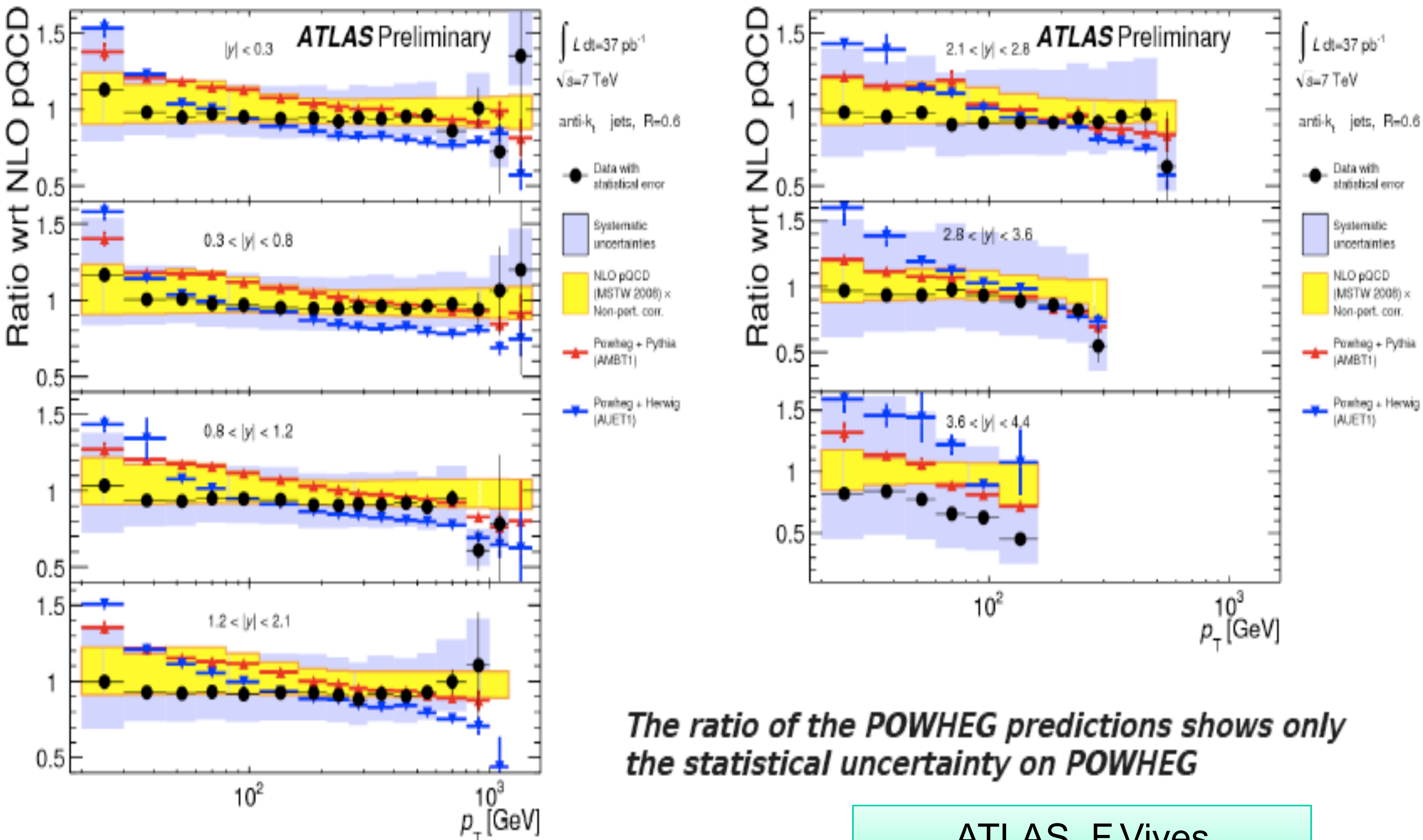




CMS, K.Kousouris

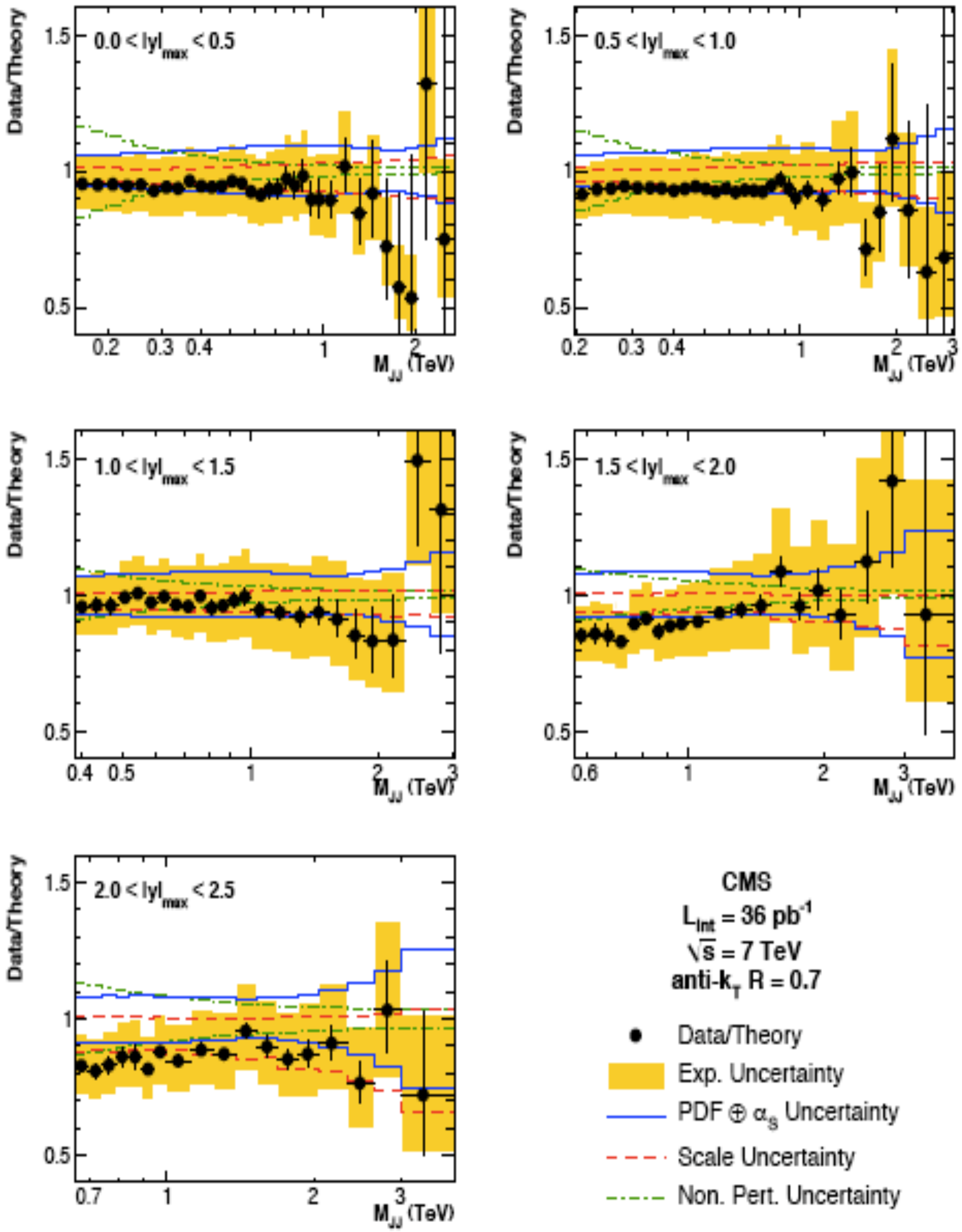


ATLAS, F.Vives



The ratio of the POWHEG predictions shows only the statistical uncertainty on POWHEG

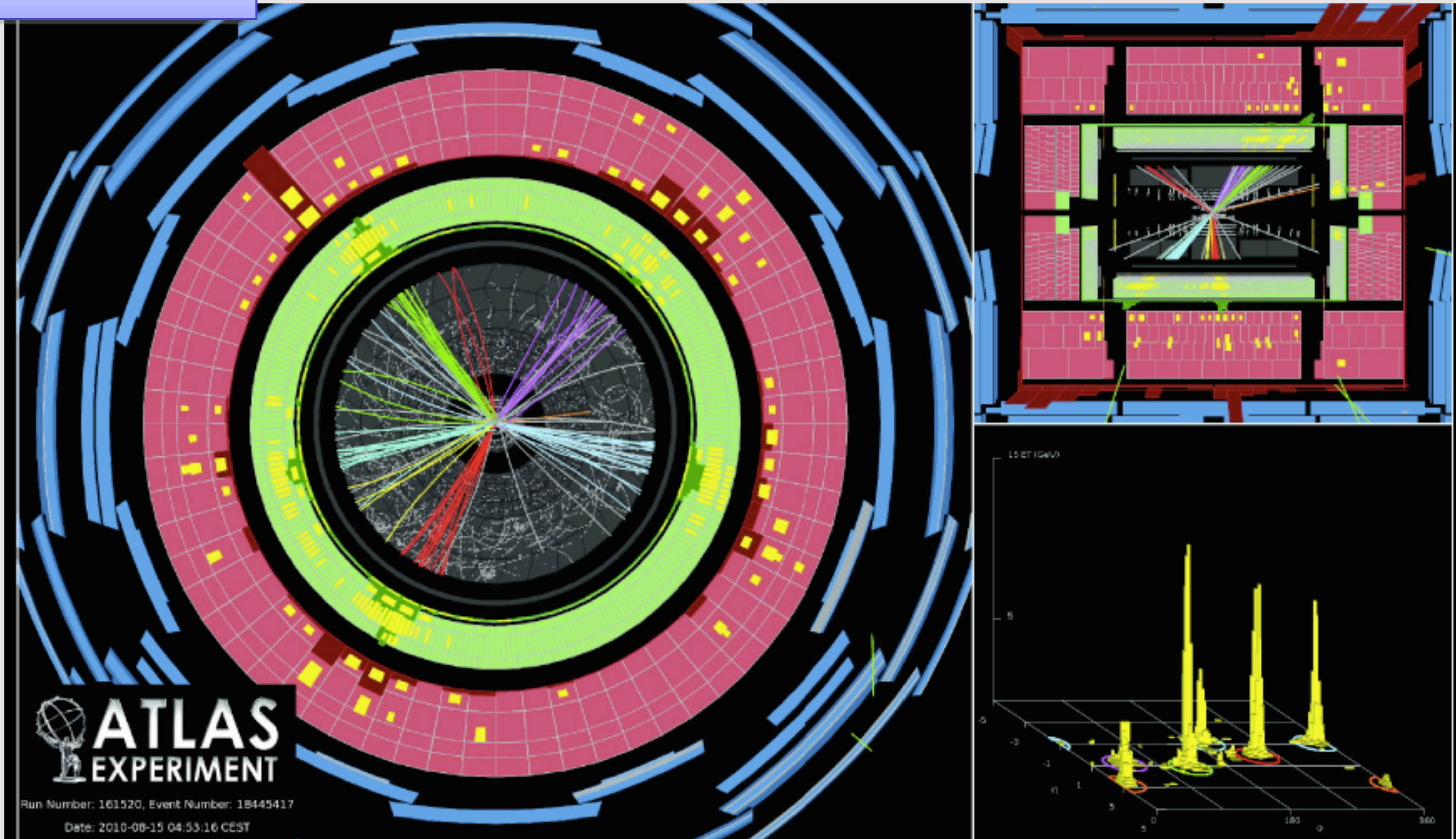
ATLAS, F.Vives



CMS - K.Kousouris

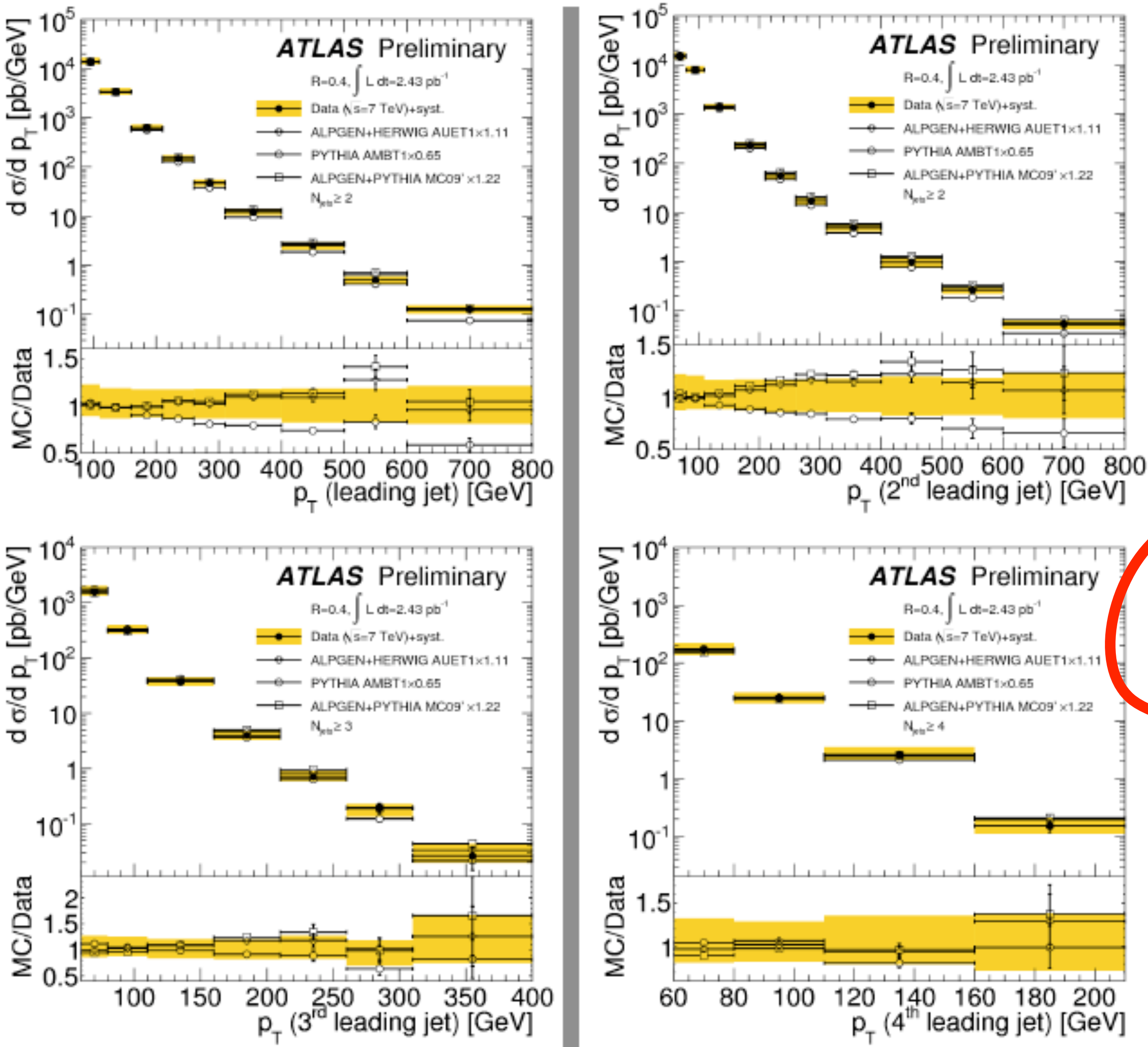
- ✦ **Data and theory are compatible in the entire phase-space of the measurement**
- ✦ **Similar trend with the inclusive jets**
  - but not directly comparable due to the different jet size

Z.Zinonas



Event display of a **six-jet** event, reconstructed with the anti-k_t 0.4 algorithm, satisfying the multi-jet analysis requirements. The yellow towers represent the transverse energy deposited in the calorimeter projected on a grid of η and φ

Differential Cross-Section Vs Jet pT



Measurement uncertainty is ~10-20% across *pT* and increasing up to 30% for the pT^{4th}

The JES uncertainty remains the dominant uncertainty in the measurement

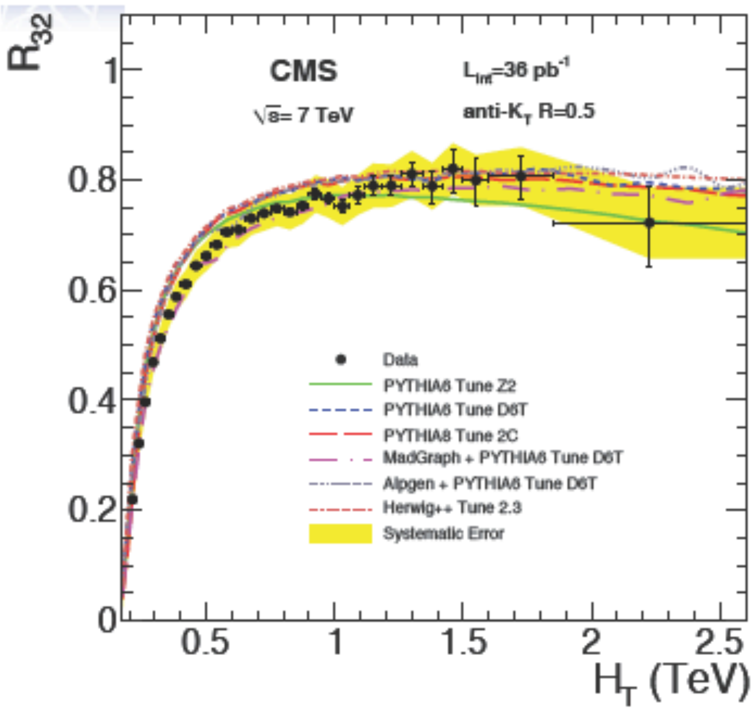
Good agreement between data and ALPGEN (all tunes) within the systematics ✔

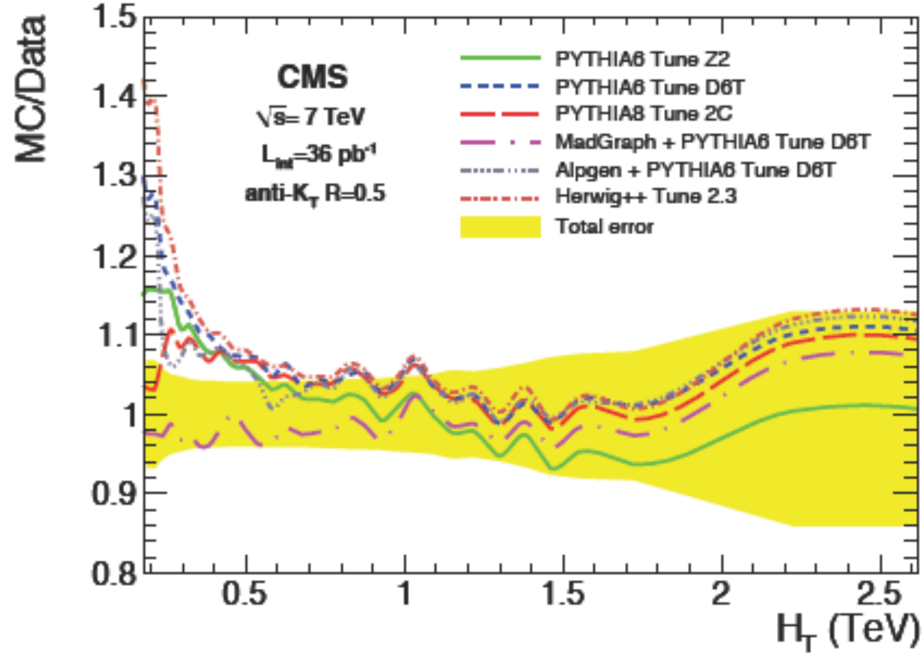
Steeper shape of PYTHIA than that of the data

PYTHIA undershoots the multi-jet cross-section

3j/2j Cross-Section Ratio

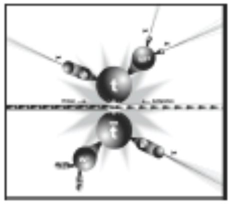
CMS-QCD-10-012



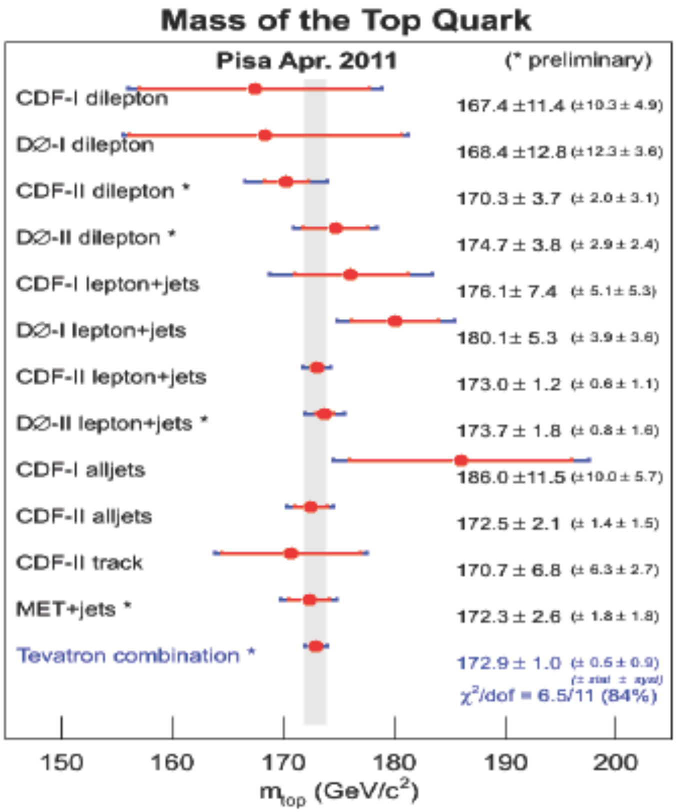


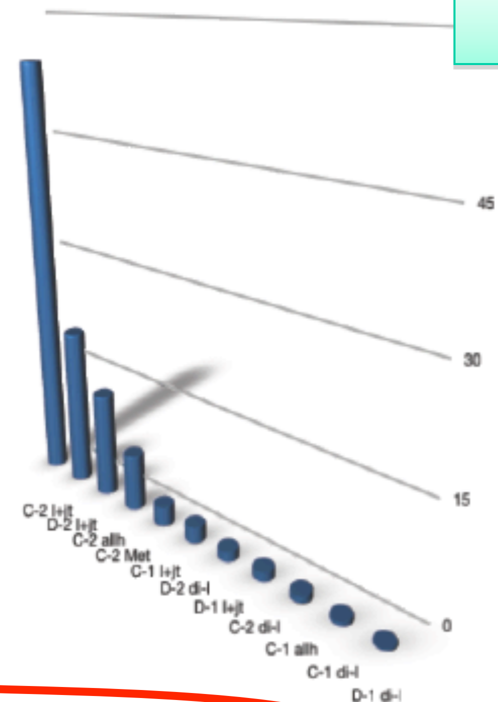
- **Ratio of cross sections (3j/2j), vs H_T**
  - insensitive to experimental uncertainties
  - the NLO calculation for the given setup is affected by large scale uncertainties
  - can be used for the α_S measurement (in a different setup)
- **Comparison to QCD MC generators**
  - all generators agree for $H_T > 0.7$ TeV with significant deviation at low values
  - Madgraph is in excellent agreement with the data in the entire H_T range

CDF&DØ Combination – Pisa 2011*



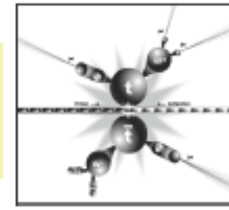
G.V.Velev





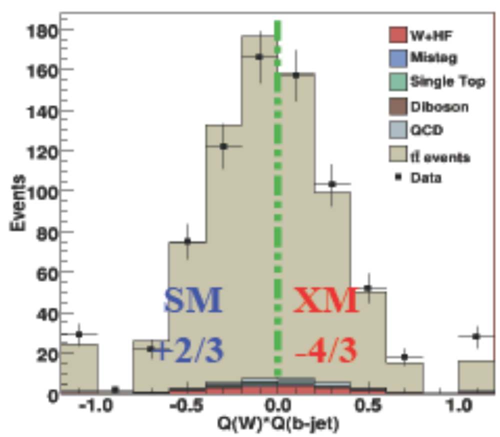
- $\Delta M_{top}/M_{top} = 0.63\%$

$M_{top} = 172.7 \pm 1.1$ (stat+syst) GeV/c^2

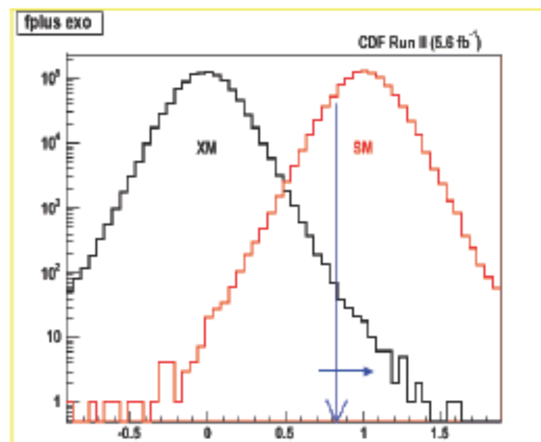


Top Charge

- Lepton + jets events with two b tags
- Use kinematic fit in to choose best combination of W^+b and W^-b
- Flavor tag *b* jets using soft leptons or jet charge
- Compare probabilities for Q=+2/3 vs. -4/3 solutions



NEW!



$$Q_{b-jet} = \frac{\sum_i q_i \cdot (\vec{p}_i \cdot \hat{a})^x}{\sum_i (\vec{p}_i \cdot \hat{a})^x}$$

x = weighting factor

$\hat{a}$ = jet axis

$\vec{p}_i$ = track momentum

Compare to MC trials
Consistent with SM at 13% CL
Only 0.014% of trials for XM have fit metric >0.83

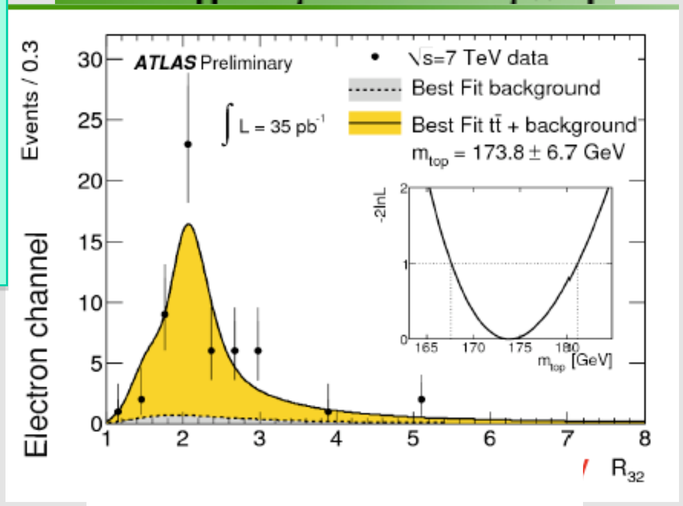
Exclude Q_{top} = -4/3 @ 95 % CL

CMS and ATLAS Top mass measurement

A.Neusiedl

ATLS - Semi leptonic channel

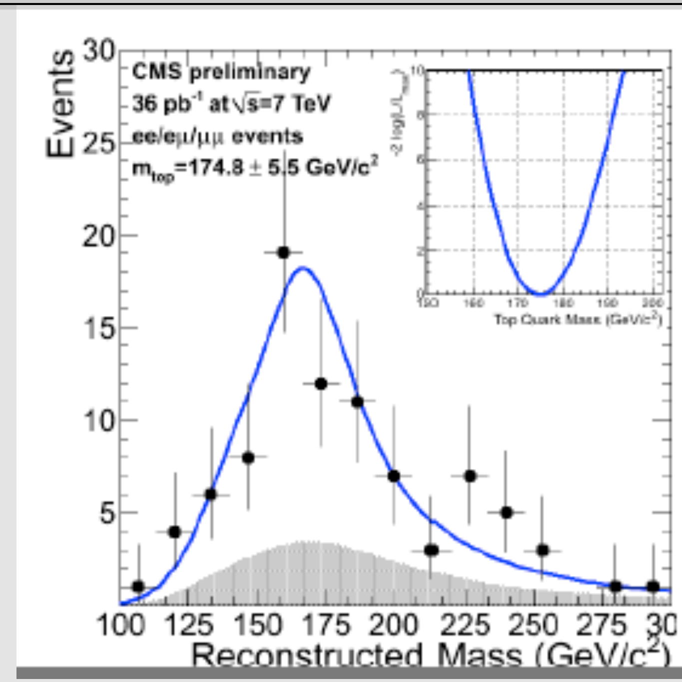
1-D fit of $R_{32} = \frac{m_{top}^{reco}}{m_W^{reco}}$



m_{top} = (169.3 ± 4.0 ± 4.9) GeV

CMS - Dilepton channel

R.Chierici

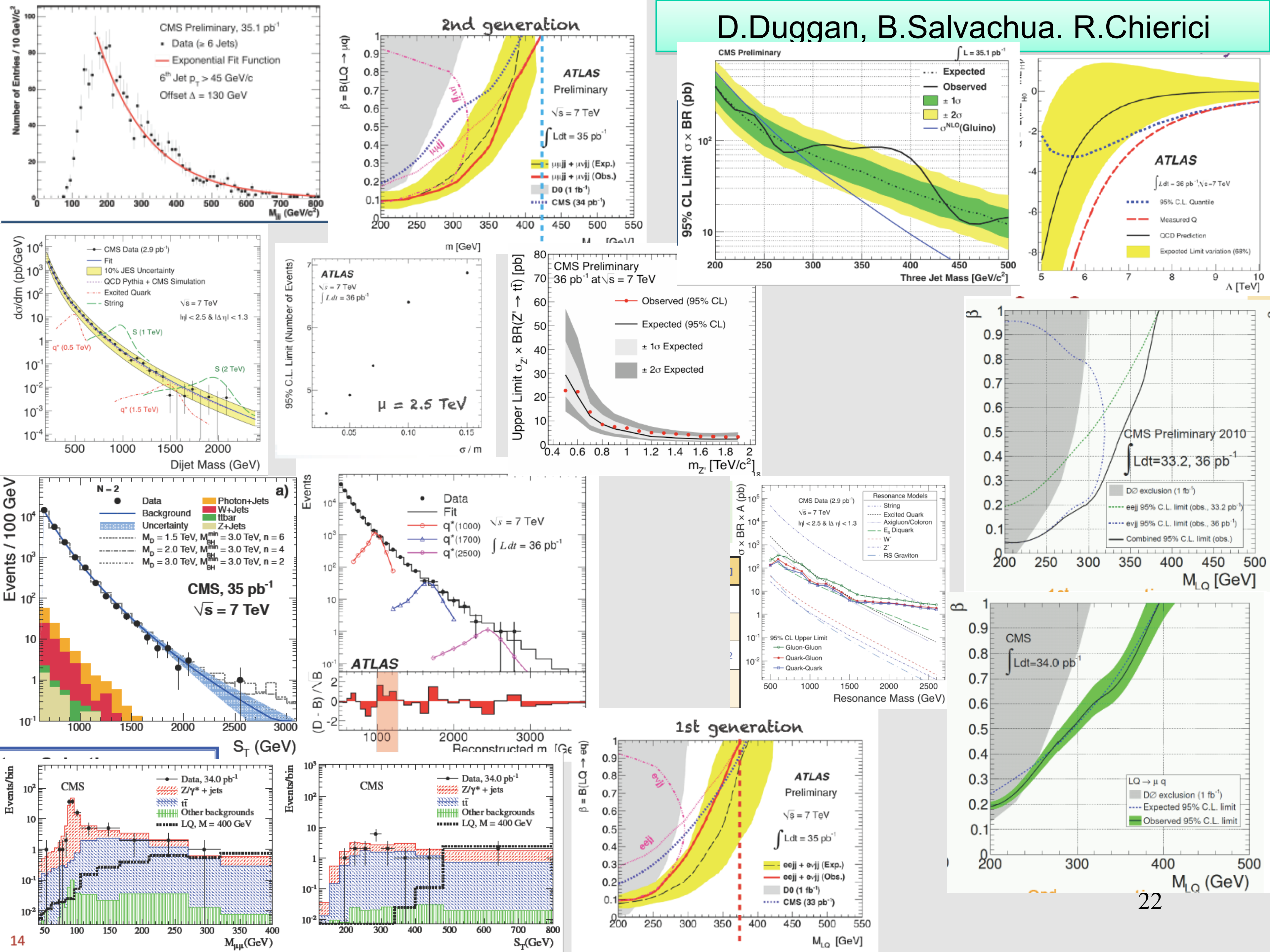


combined 175.5 ± 4.6(*stat*) ± 4.6(*syst*)

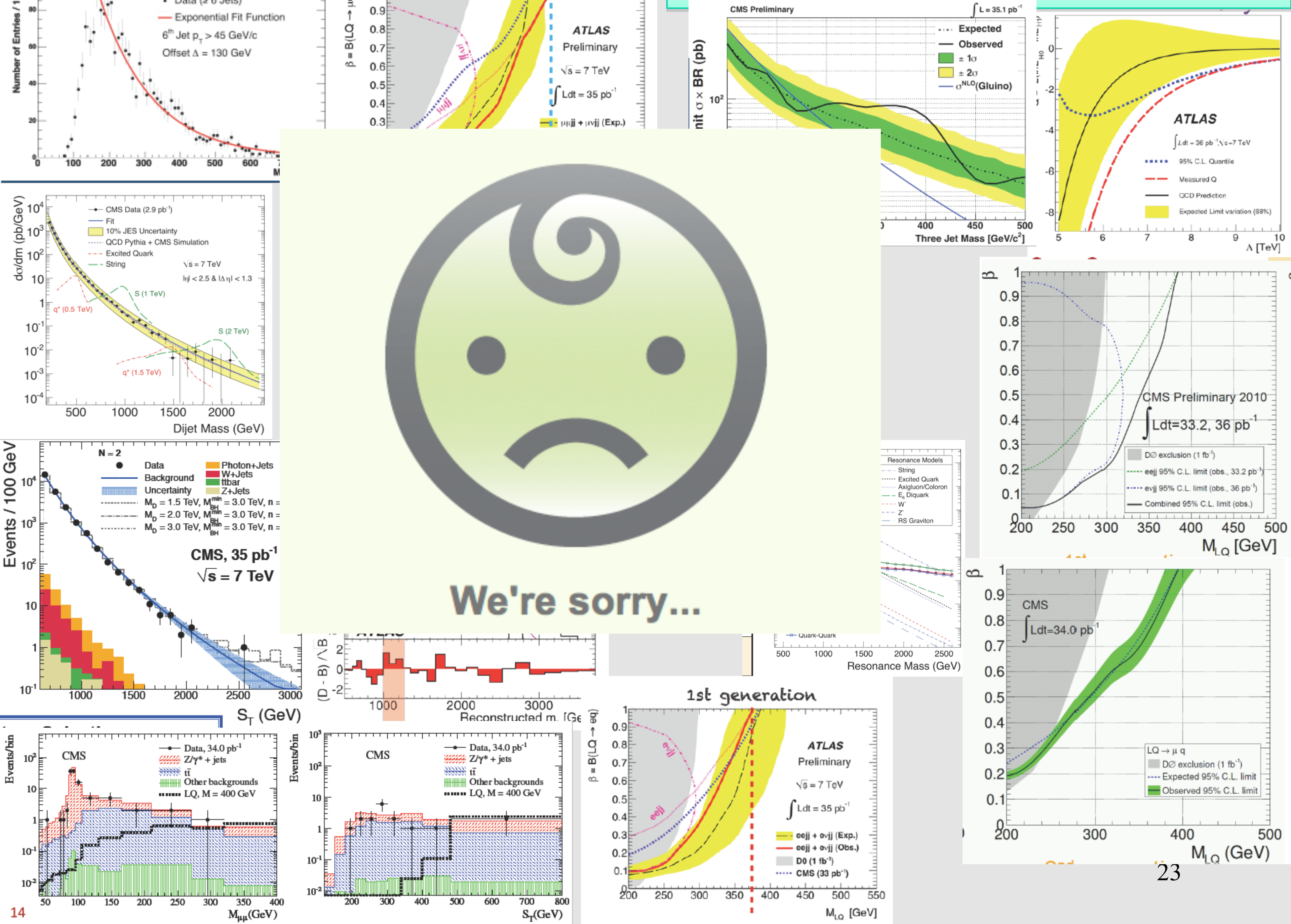
Largest experimental syst uncertainty: b-jet and JES

Jets for Searches for new physics …

D.Duggan, B.Salvachua. R.Chierici



D.Duggan, B.Salvachua. R.Chierici



What we have not found yet …

Leptoquarks

Forth generation quark

Black holes

Quark compositness

Axigluons

…..

However ….

D.Duggan
B.Salvachua

		Observed Lower Limits (TeV)		
		Tevatron	**Atlas**	**CMS**
Dijets	Excited quarks (q*)	1.32	2.64	1.58
	Axigluons/Colorons	1.25	2.1	1.52
	String resonances	1.6	--	2.5
	E_6 diquarks	0.63	--	1.6
	Randall-Meade QBH (n = 6)	--	3.67	--
	Contact Interactions I	2.9	9.5*	5.6
Multijets	Gluinos (RPV decays)	0.144	--	0.280
Leptons (MET) + jets	1^{st} Generation LQ (b =1)	0.299	0.376	0.384
	2^{nd} Generation LQ (b =1)	0.316	0.422	0.394
WWbb / WWjj	4^{th} Generation Heavy Quark (Q_4)	$m_{u4} > 0.356$ $m_{d4} > 0.372$	0.270	0.361
Jets, Leptons, Photons and MET	Semi-Classical QBH (n=6, Planck Scale=1.5 TeV)	--	--	4.5

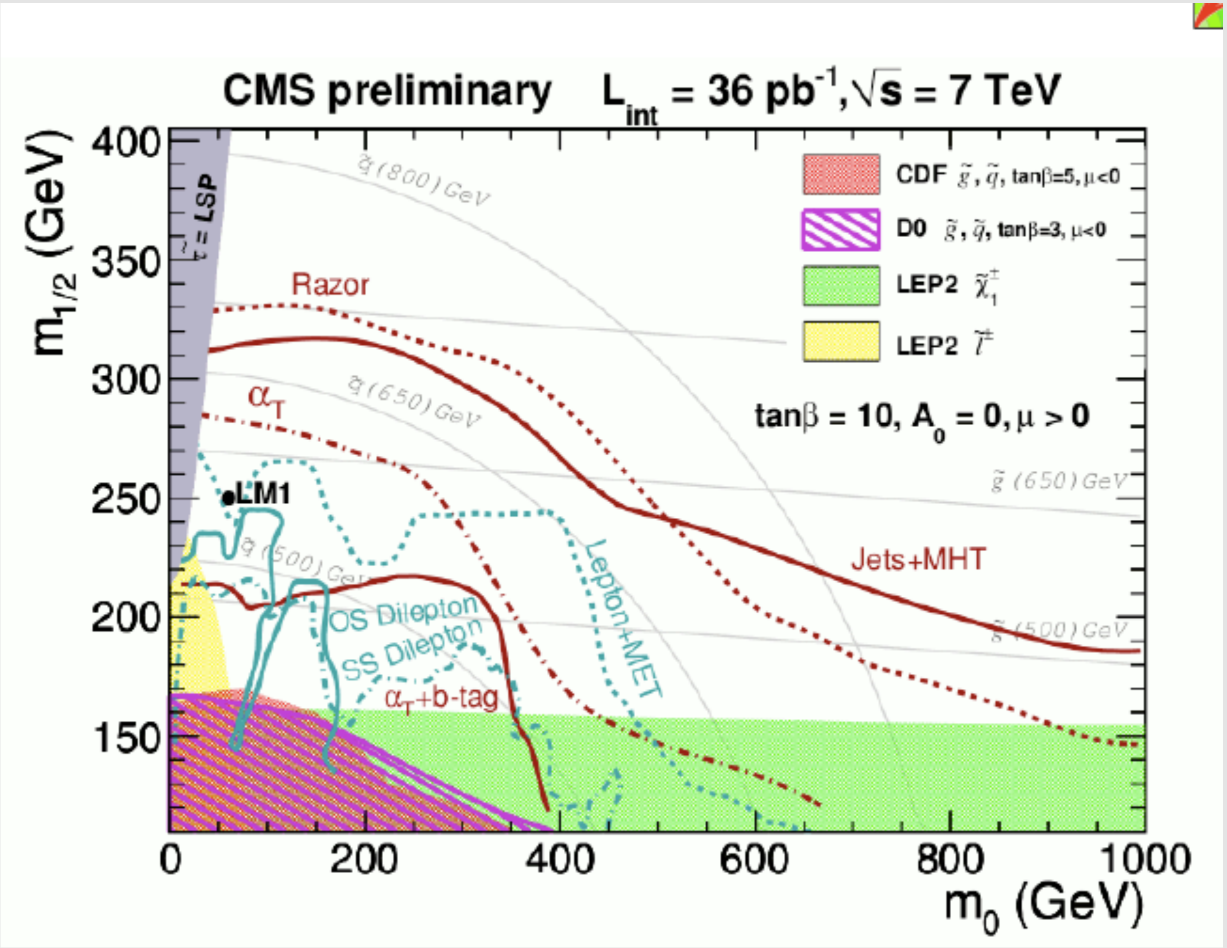
* Bayesian Limit = 6.7 TeV

SUSY searches in CMS

R.T.D' Agnolo

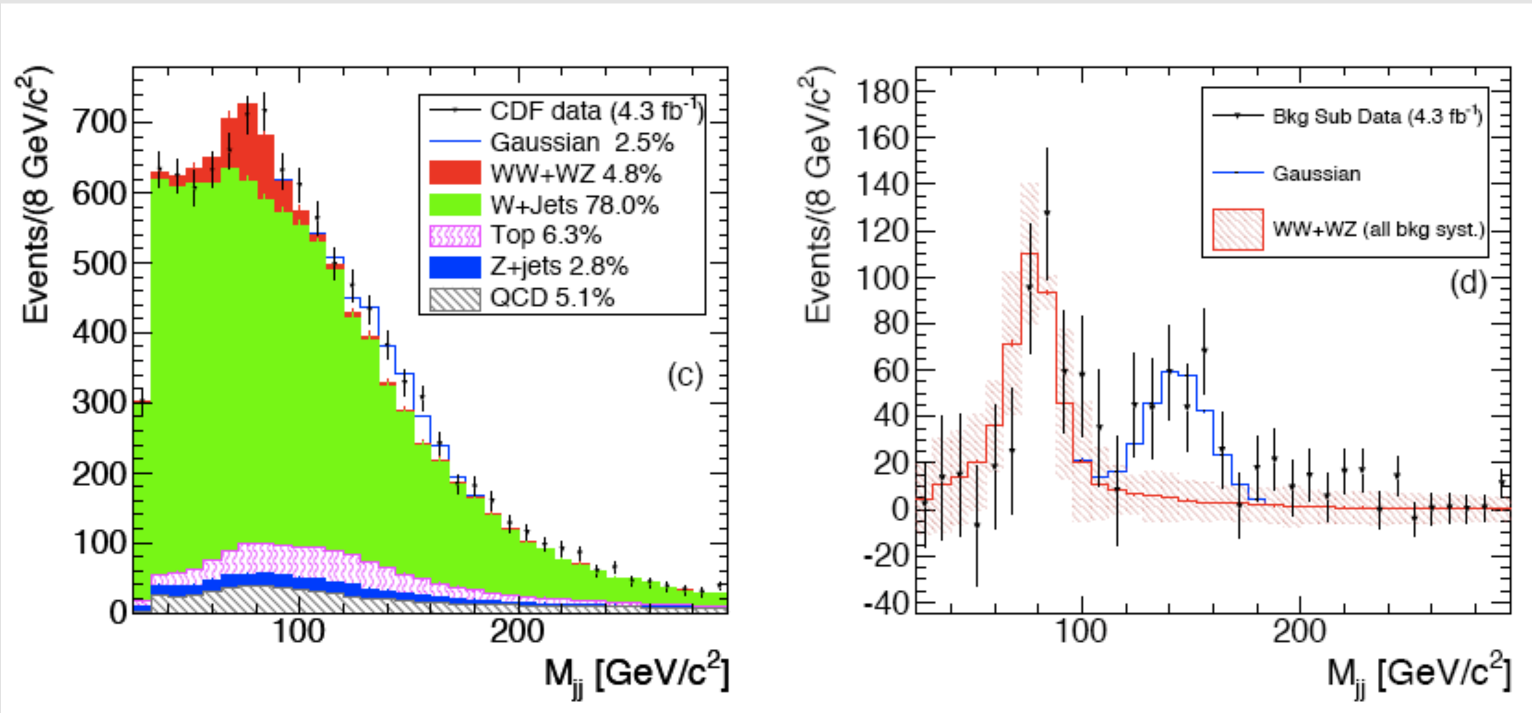
CMS presented the razor method: data driven approach for background estimate -> will improve as statistics increases

2011 will be the year that will teach us a lot on SUSY – discover or exclude the SUSY



The plots that everybody are discussing in these days…

Invariant Mass Distribution of Jet Pairs Produced in Association with a W boson in pp Collisions at √s = 1.96 TeV

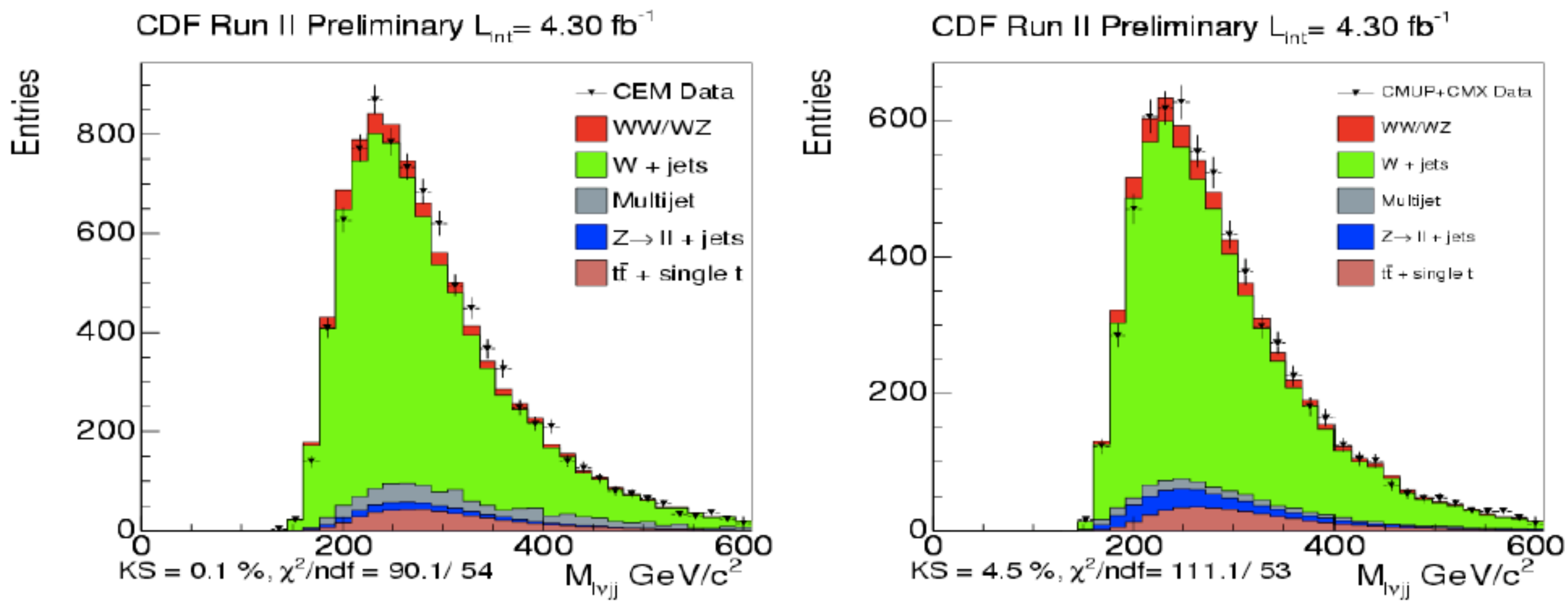


$$\sigma_{\mathrm{resolution}} = \sigma_W \sqrt{\frac{M_{jj}}{M_W}} = 14.3\ \mathrm{GeV/c^2},$$

	Electrons	Muons
Excess events	156 ± 42	97 ± 38
Excess events / expected diboson	0.60 ± 0.18	0.44 ± 0.18
Mean of the Gaussian component	144 ± 5 GeV/c^2	

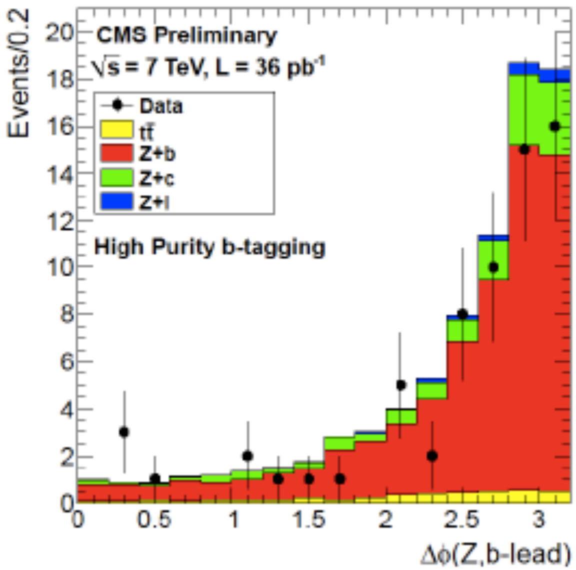
Resonant production

- Finally, to investigate the possibilities of a parent resonance or other quasi-resonant behavior, we consider the $M_{(\mathrm{lepton},\nu,jj)}$ and the $M_{(\mathrm{lepton},\nu,jj)}$-$M_{jj}$ distributions for events with M_{jj} in the range 120-160 GeV/c^{2}and to investigate the Dalitz structure of the excess events, the distribution of $M_{(\mathrm{lepton},\nu,jj)}$-$M_{jj}$, in bins of M_{jj}.
- The distributions are compatible in shape with the background-only hypothesis in all cases.



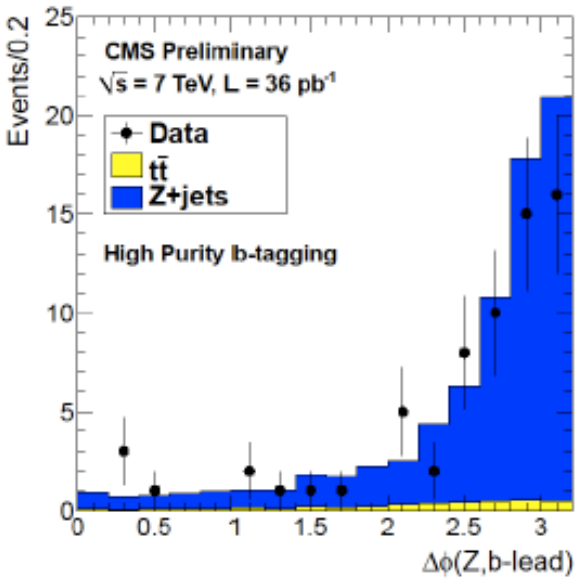
b-jet, gluon jets, light quark jets…

CMS - Z+b-jets



MadGrah
Fixed-flavour

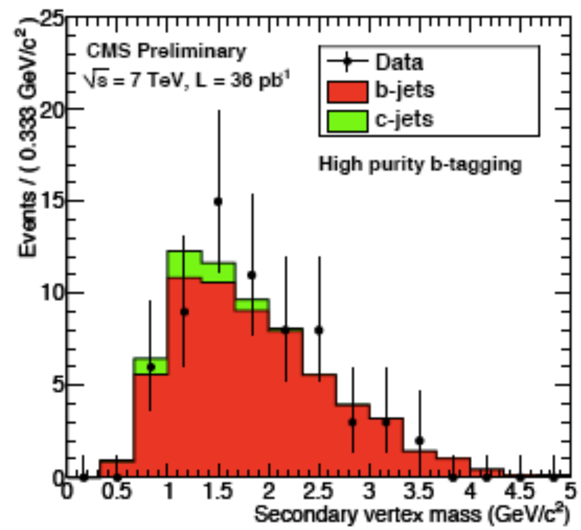
No distinction between schemes (limited statistics in the tails)



MadGrah
Variable-flavour

M.Nespolo

J.Piedra



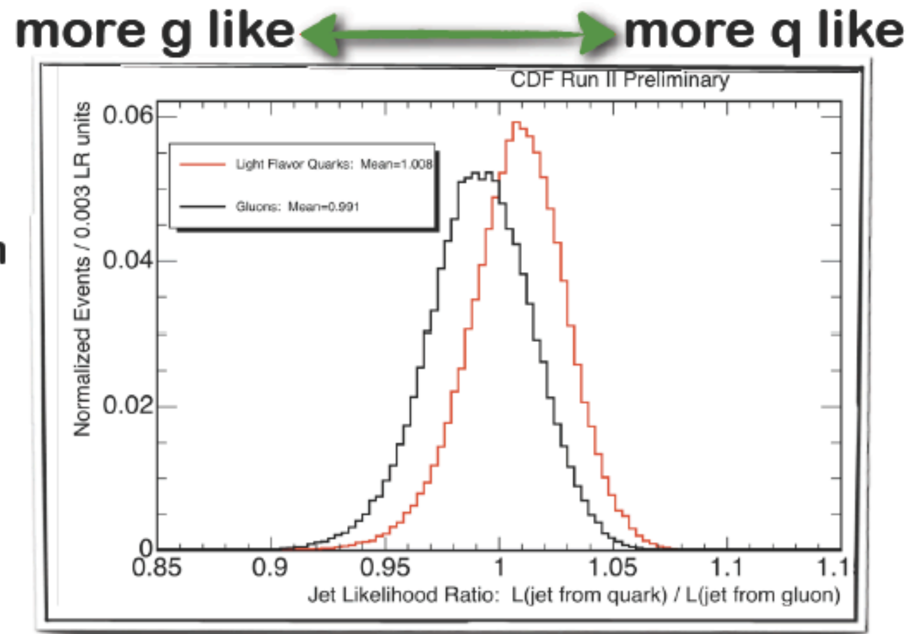
High purity sample of b jets

20

alk

Separating quark from gluon jets

The likelihood ratio (LLR)



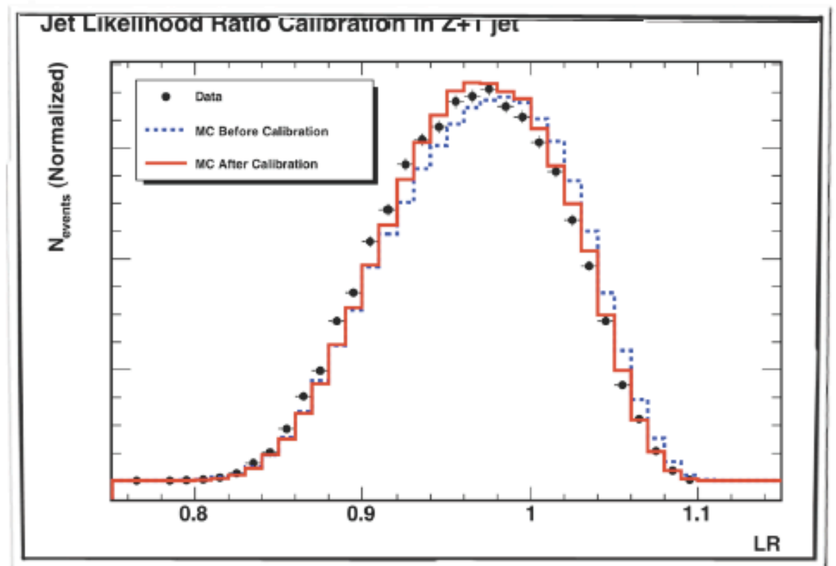
- Quarks and gluons look different enough
- Separate on a statistical basis

Not enough for a straight cut but useful in a multivariate analysis

Separating quark from gluon jets

Check in Z+1 jet

- Still not the "signal" region
  - Large stats sample
  - Check how the calibration worked
- A bit off but much better agreement
  - This final difference can be used to asses systematics

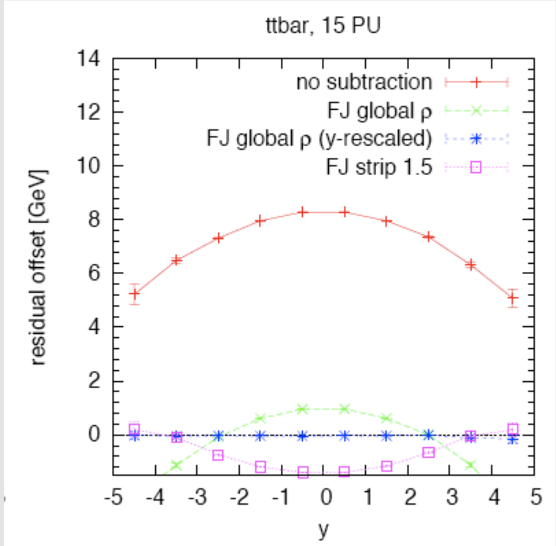


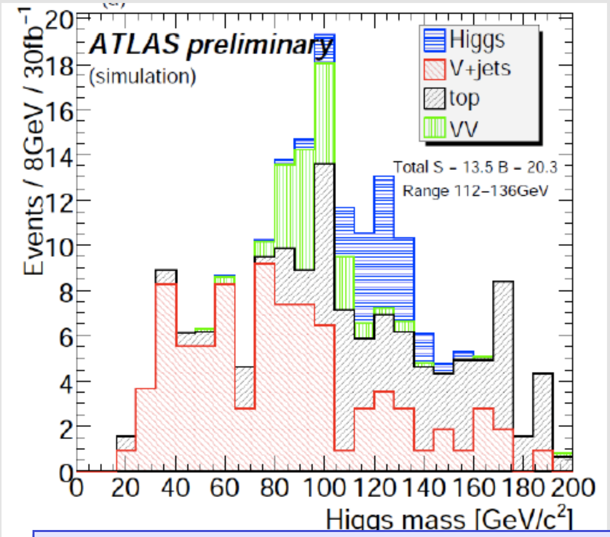
We now have a q/g separator which MC can described quite well

Jets in their habitat - Soyez

New or current important challenges:

- Pile-up, UE
  - Pollution from soft events: use of JetArea
  - Modification of hard jets: use anit-kT rigidity
- Sub-structure: find the jets from boosted particle decay
  - Recluster: keep most of hard part (perturbative) and remove UE
  - Disentagle QCD from signal (W->qq, H->bb…)

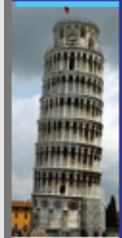




WH->lnubbar

Effect Of Pile-Up On Jet Shapes

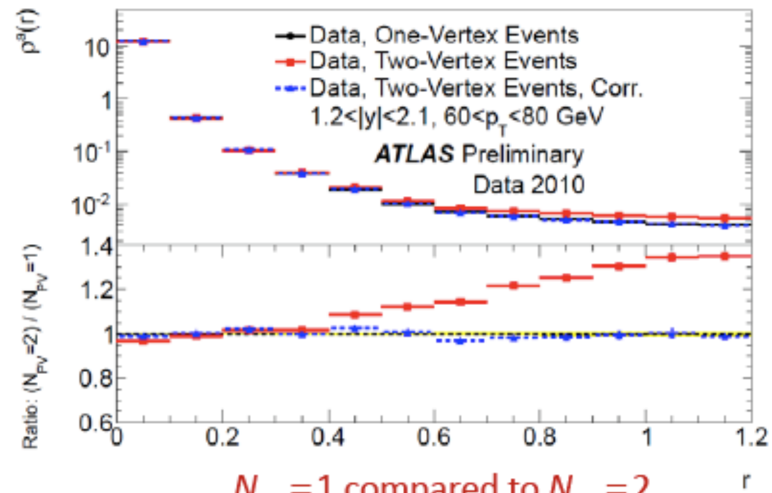
P. Loch
U of Arizona
April 18, 2011



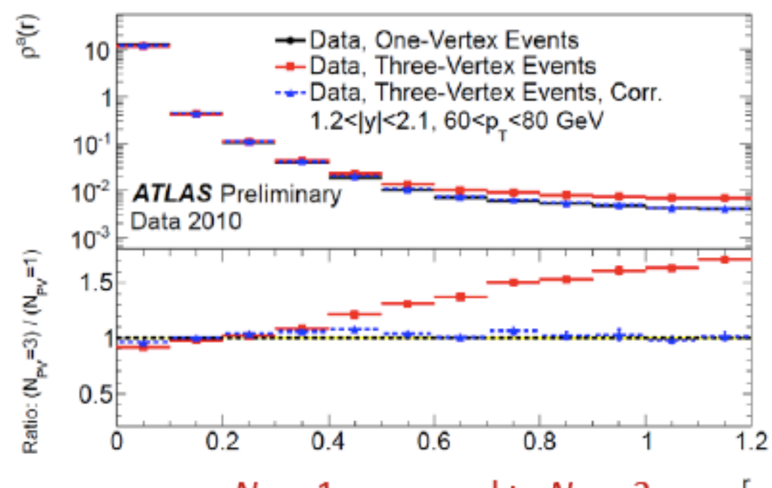
Pile-up in jets

- Average additional energy in jet is corrected
  - See offset correction earlier!
- η – dependence of average corrections can be applied inside jet and near jet as well
  - Reduces sensitivity of jet shape measurement on pile-up
  - Shape is measured as relative pT density in annulus of width δr and radius r around jet axis

$$\rho^a(r) = \frac{1}{\pi\left[(r+\delta r)^2-(r-\delta r)^2\right]} \times \left\langle \frac{p_T(r-\delta r/2, r+\delta r/2)}{p_T(0,R)} \right\rangle$$



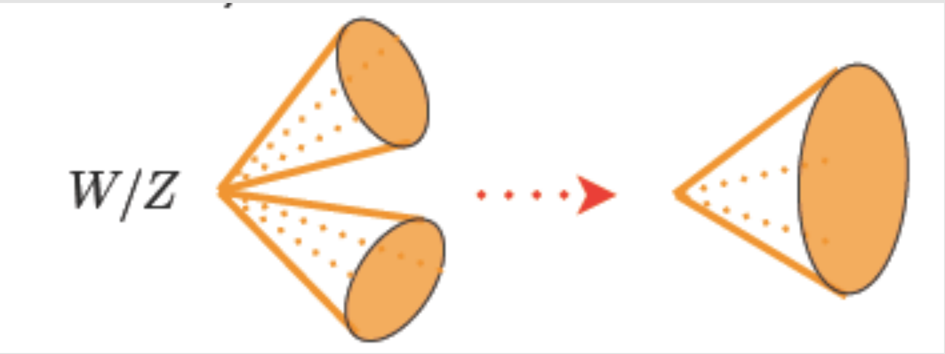
$N_{PV}=1$ compared to $N_{PV}=2$

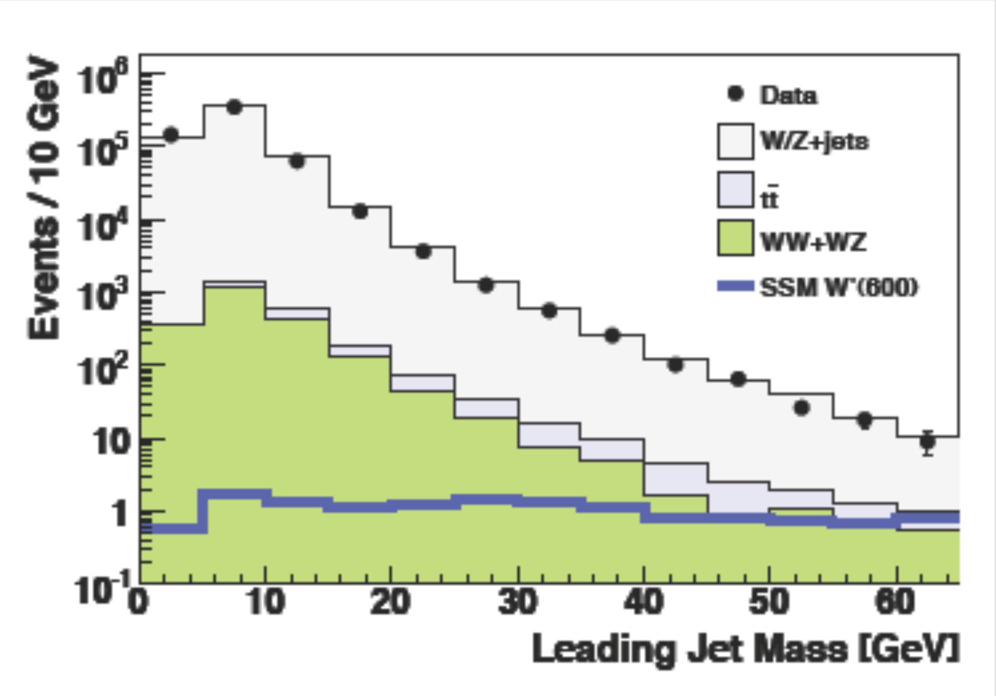


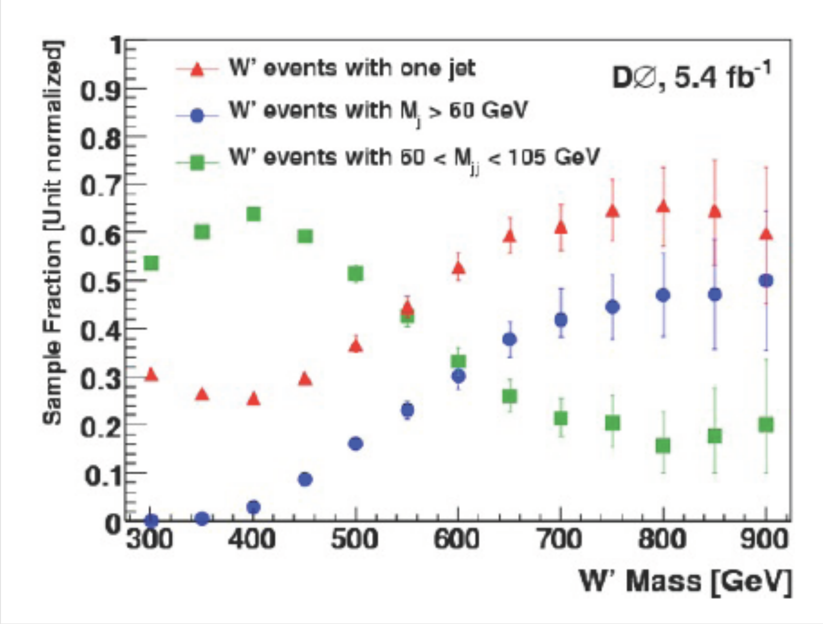
$N_{PV}=1$ compared to $N_{PV}=3$

(*all plots from* ATLAS-CONF-2011-030)

Boosted W/Z in D0 – T.Gadfort





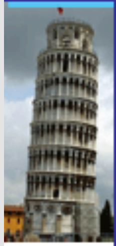


Need Control sample to check energy scale

Can go to a more refined splitting

First Look At Jet Substructure

P. Loch
U of Arizona
April 18, 2011



Pisa Workshop on Jet Reconstruction & Spectroscopy at Hadron Colliders

April 18-19, 2011 Pisa, Italy

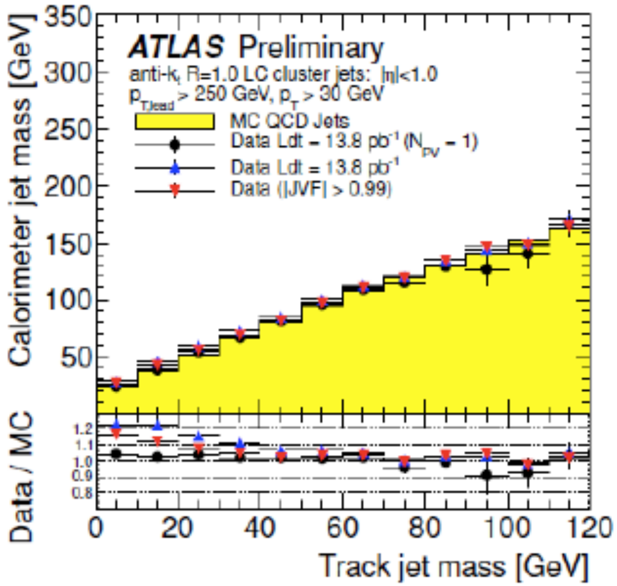
Motivation

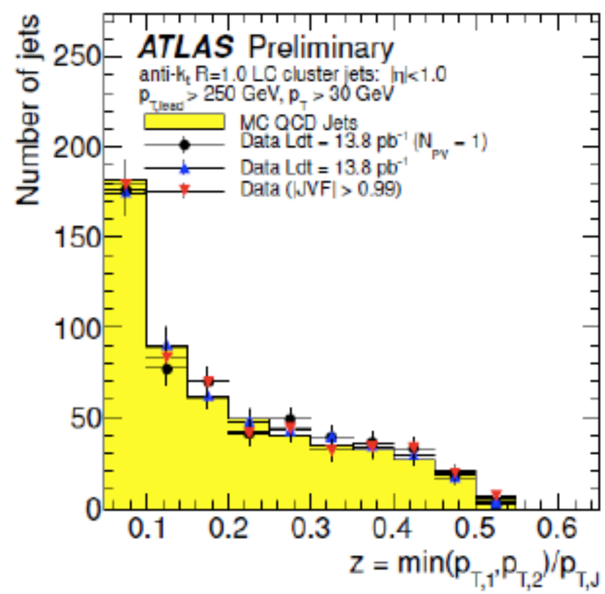
Looking for boosted heavy particles

- All decay products are reconstructed in one jet
- Two-prong (like W→qq or new heavy particle Q* →qq/gg) and three prong (e.g., t →qqb) decay structure can be reconstructed using jet substructure tools at particle level
- Need to understand experimental limitations introduced by detectors

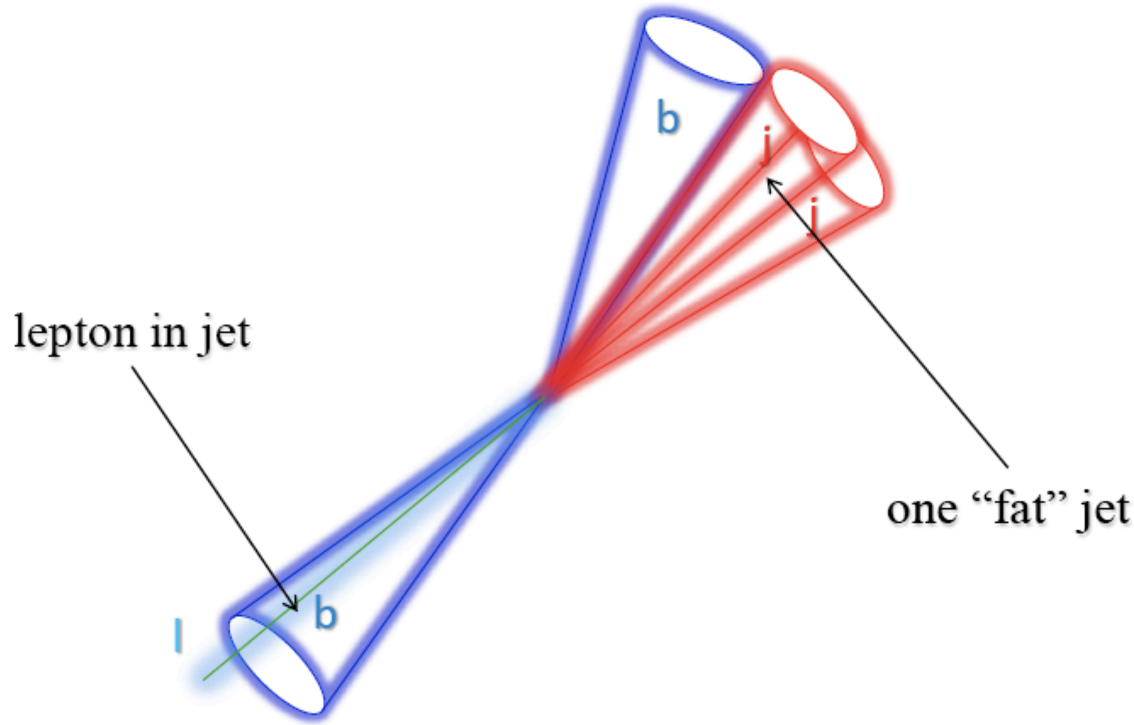
First look at calorimeter cluster jets

- Jet mass reconstruction becomes especially meaningful if jet source is heavy particle
- Pile-up may generate additional mass and worsen single jet mass resolution
  - Use vertex constraint track jet mass as unbiased reference scale for mass reconstruction
- Sub-jet kinematics well modeled
  - Little effect from pile-up so far





Boosted tops !



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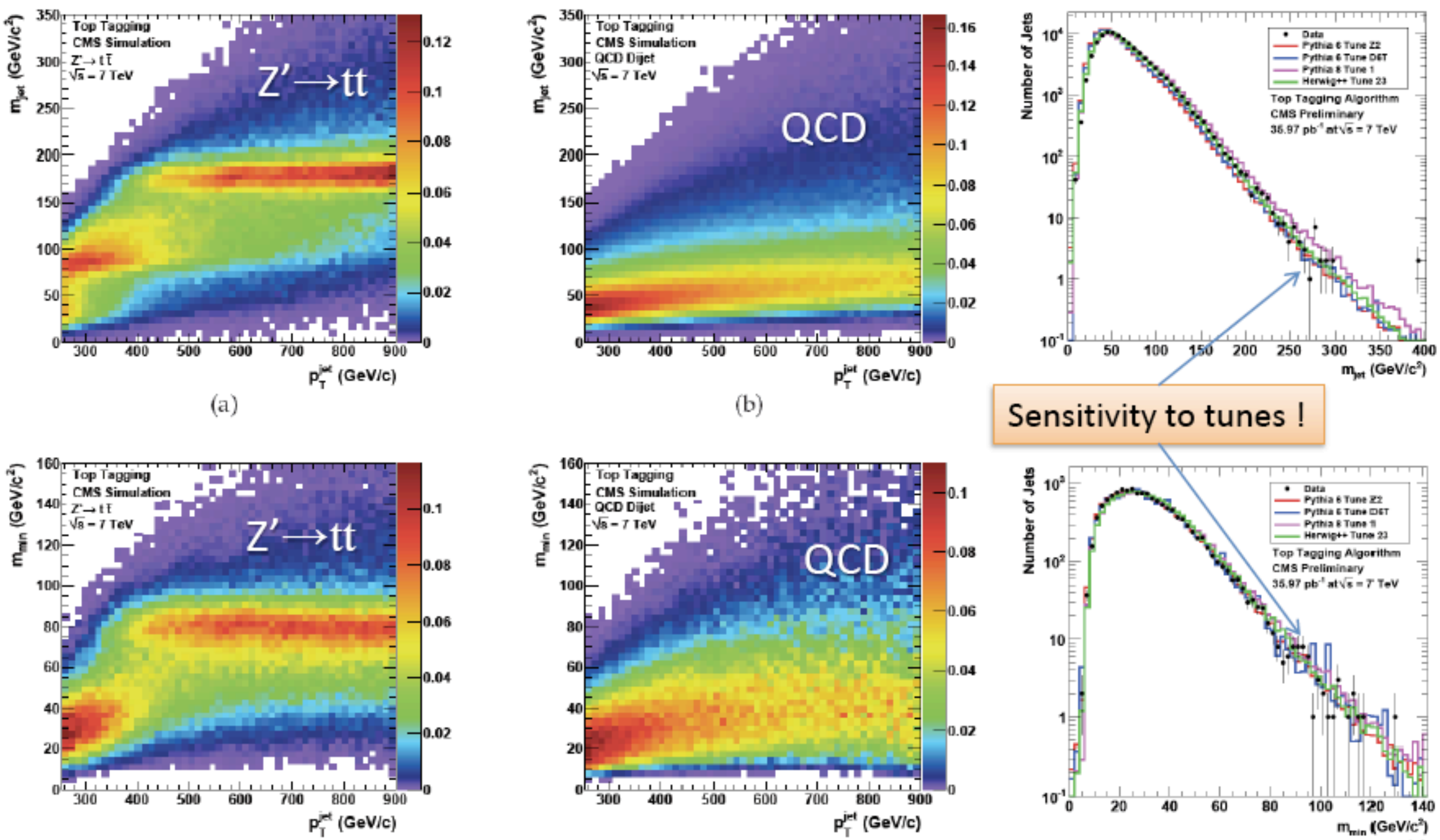
m_{jet} and m_{min}

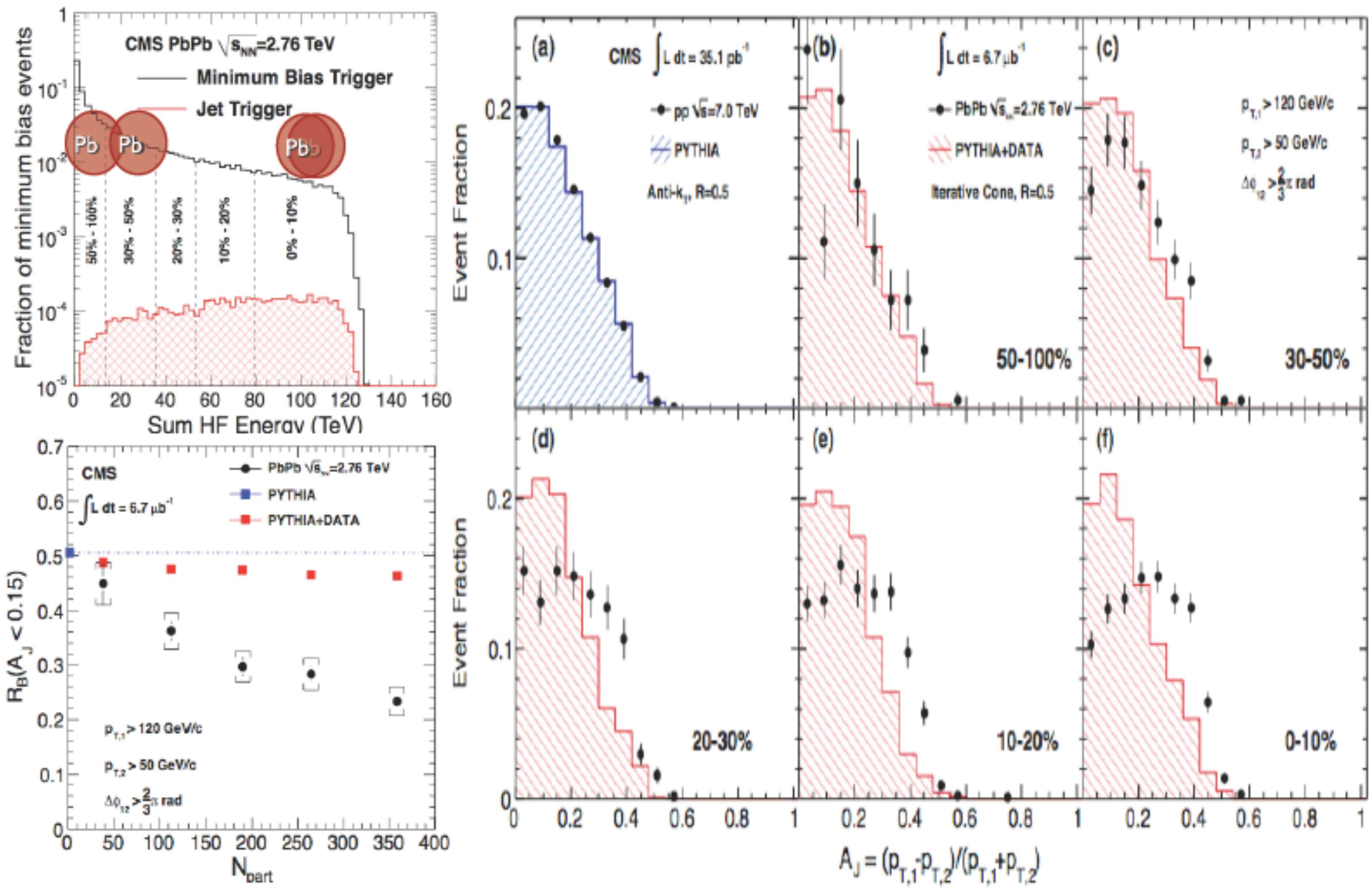
R.Chierici

- Main variables for the top tagging already well understood in QCD data



One more challenge: jets in Pb-Pb collisions

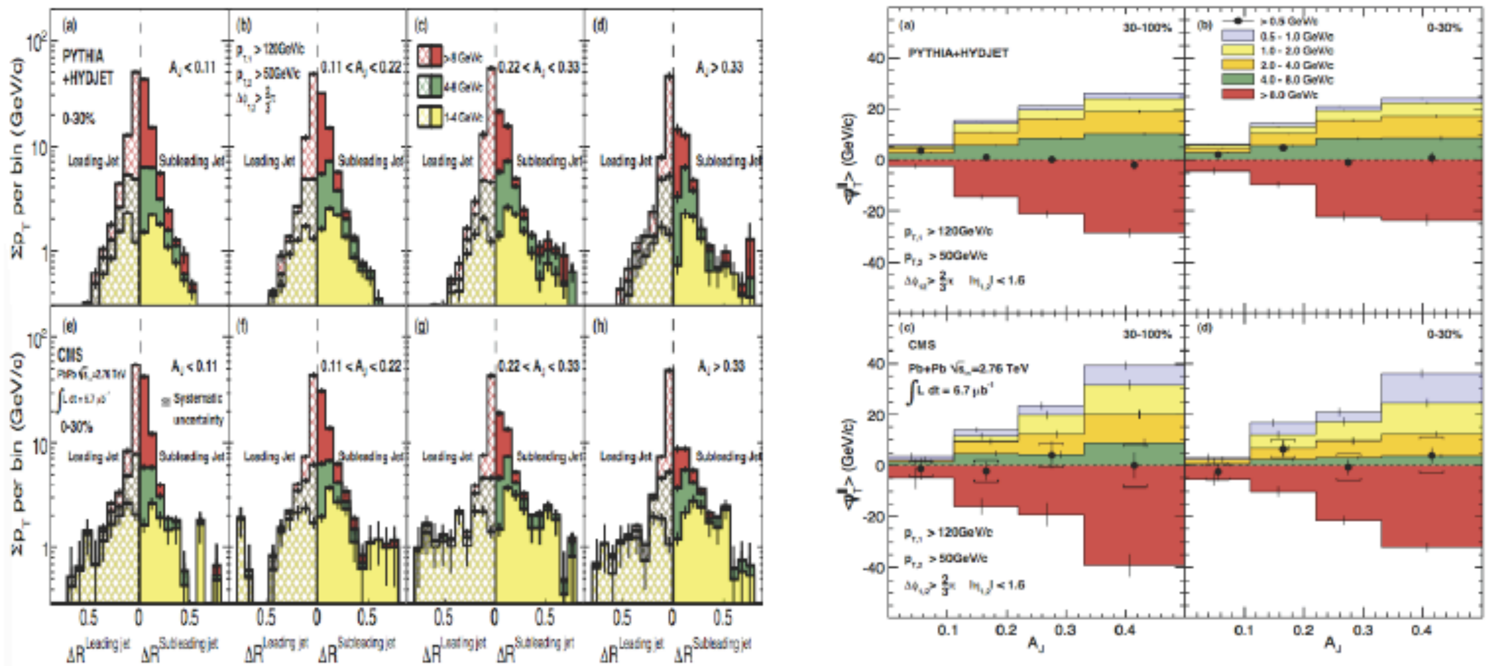
direct observation of Jet-quenching



R.Tenchini

One more challenge: jets in Pb-Pb collisions

First detailed understanding of jet quenching



The phenomenon of jet quenching in Heavy-Ion collisions is now described in detail and fully understood.

The di-jet momentum balance is fully recovered if we consider the low p_T tracks distributed over a wider angular range wrt the jet axis.

arXiv:1102.1957 ; CERN-PH-EP-2011-001.

R.Tenchini

My list of challenges

- Jet energy scale uncertainty improvement
- b-jets scale
- Jet resolution
- Triggering on hadronic states
- Robustness against pile-up
- Jets in Pb-Pb collisions
- Jet substructure
- Jet size optimization
- Jet ID: gluon vs light quarks
- Keep improving detector simulation

Backup

What is important for physics

- What is important for physics:
  - JES uncertainty
  - Resolution
  - b tagging – missing items from talks ?
  - Trigger
- Next steps: improve hadronic calibration
- Questions:
  - Flavour dependence - Kostas
  - Noise contribution - Wigman

Ingredients for the

Experience from previous experiment

TB detector understanding

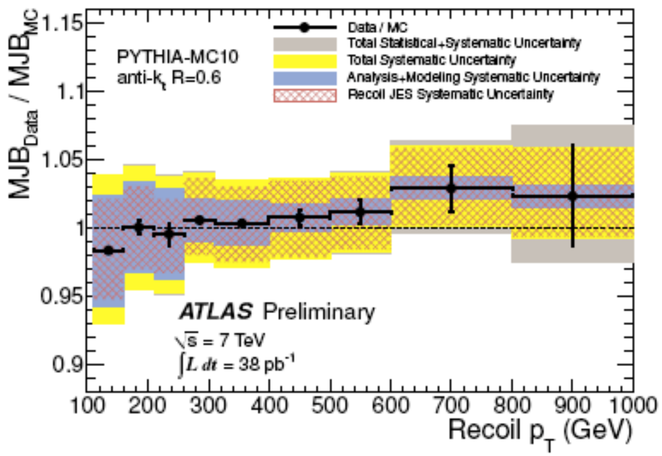
Questions to Alberto

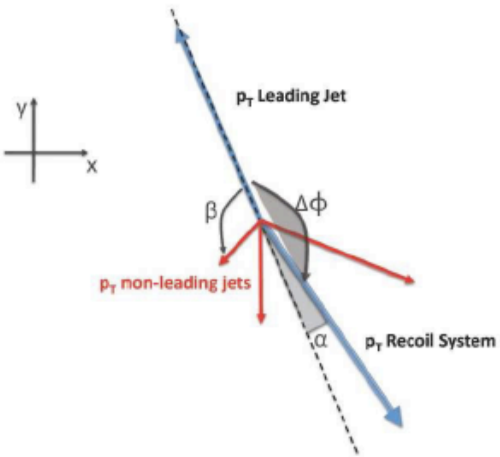
- WW normalization to NLO
- Shift in Mjj from JES and from Bkg
- Checking the JES from top is not really fair since the event types are different
- Different fragmentation (?)
- ttbar spectrum

MJB D.Schouten

QCD Multijet Balancing

- extrapolate γ + jet to high p_T using events where a high p_T jet recoils against an $N > 1$ jet system





multijet analysis

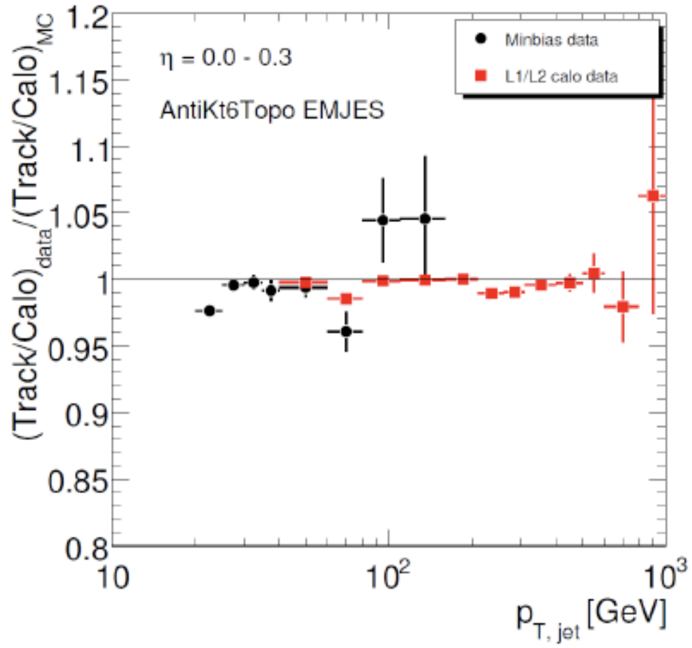
- $\Delta\phi(lead, recoil) > \pi - 0.3$, $\Delta\phi(lead, closest\ recoil) \equiv \beta > 1$
- require $A = p_T^{j_2} / p_T^{recoil} < 0.6$
- exhaustive list of systematics: recoil JES, ISR & FSR, nearby jets, flavor

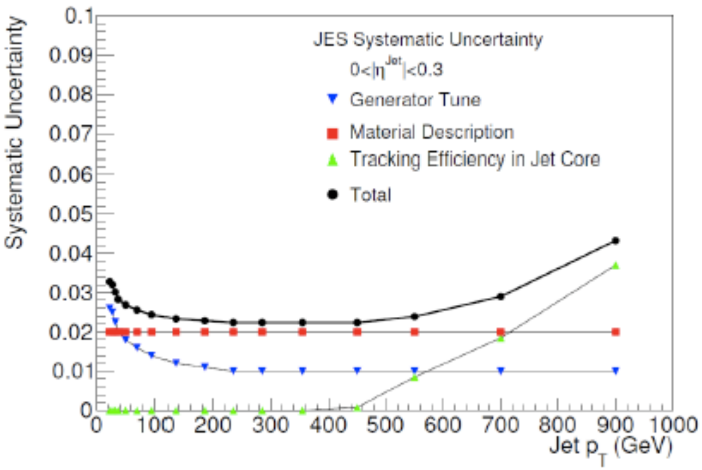
Track ↔ Calorimeter Jet

Despite uncertainties in jet fragmentation, ratio of charged to total energy is highly constrained.

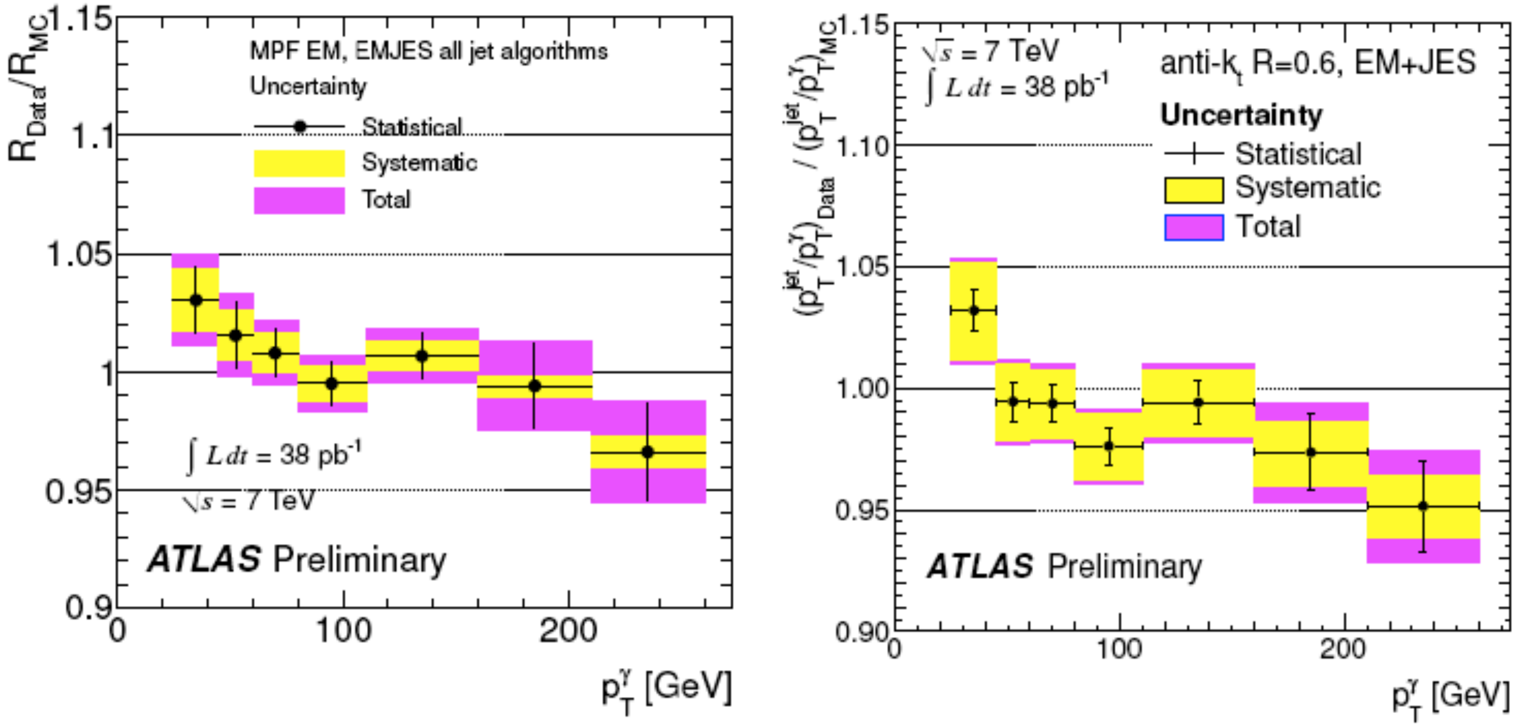
Trackjet analysis

- construct jets from selected tracks and match to jets from calorimeter clusters
- compare distribution of p_T^{track}/p_T^{calo} with Pythia dijet simulation





γ + Jet

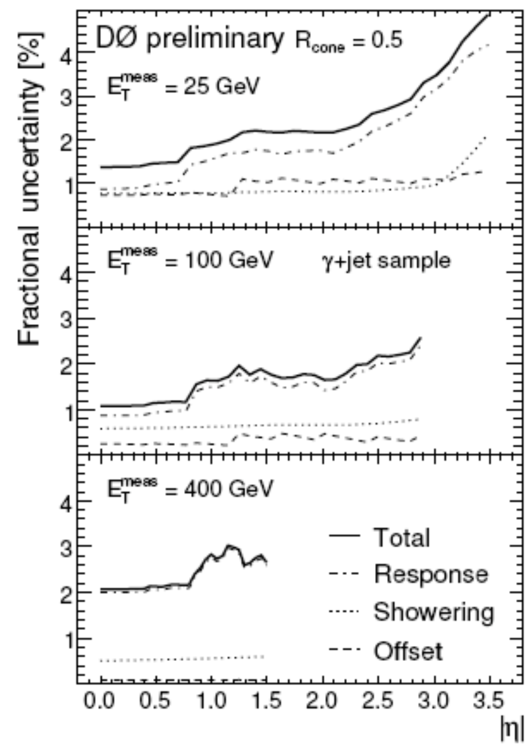


Monte Carlo : Data comparison for MPF and direct balance, versus p_T^{γ}

D0 - Petrillo

Jet Energy Scale uncertainty

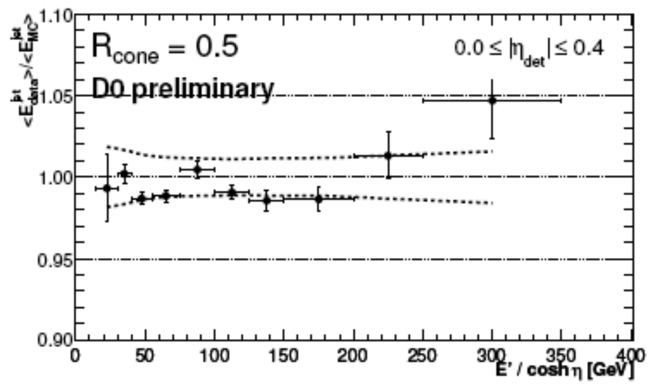
- at the end of the Jet Energy Scale measurement, dozens of sources of uncertainty can and have been identified and included
- the largest contribution to the uncertainty comes from the largest component of the correction, the *response*
- a few of the contributions can be reduced by expanding the simulation samples, much more by collecting and analysing more data
- as time goes, detector performances change, as do accelerator's: it is not always possible to combine additional data to the existing measurement

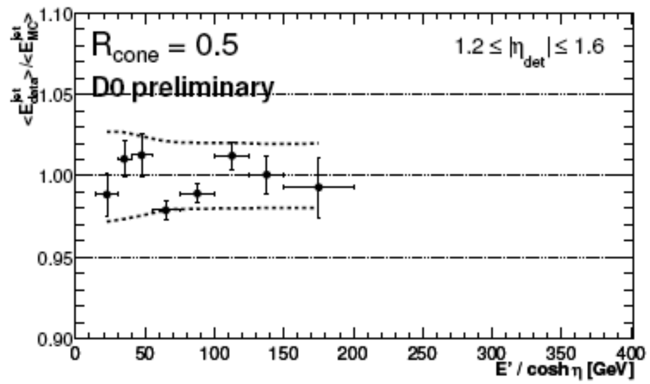


D0 - Petrillo

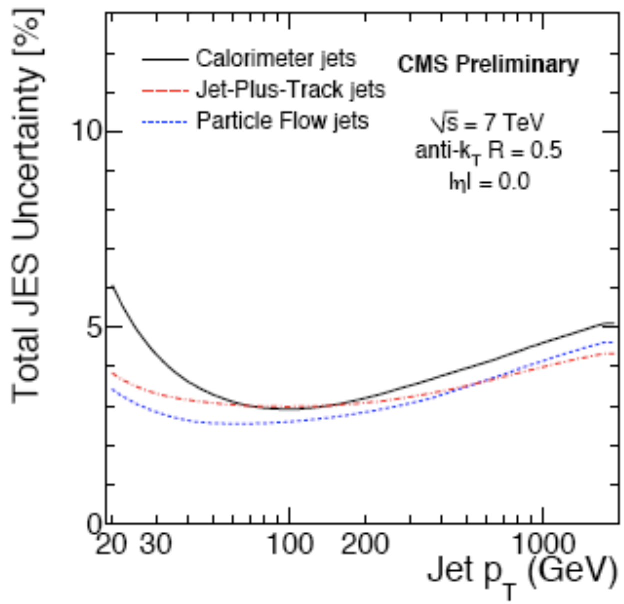
Comparison between data and simulation

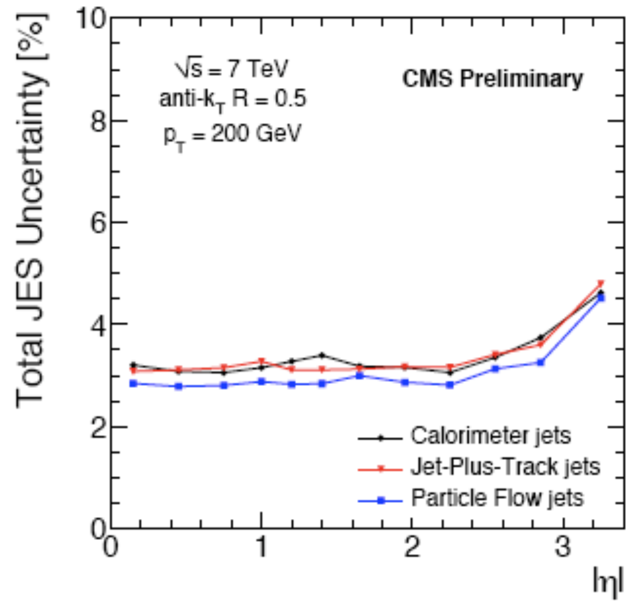
- for a sizeable number of analyses the consistency of JES between data and simulation is *more important* than the correctness of its absolute scale
- consistency is verified on a γ+jets sample
- the simulated sample is contributed by both γ+jets and QCD processes, proportionally to the estimated purity in data





Jet Energy Scale Uncertainty





- ✦ **Total jet energy scale uncertainty: 3-5% for all jet types**
  - estimated with the first 3 pb^{-1} of data
  - significantly improved (by a factor ~2) after using the entire sample (currently under review by CMS -- JINST paper to be submitted soon)
- ✦ **Uncertainty dominated by the high-p_T extrapolation**
  - beyond the p_T reach of the photon+jet sample

THE UNIVERSITY OF ARIZONA.

Jet Energy Scale Uncertainties

P. Loch
U of Arizona
April 18, 2011

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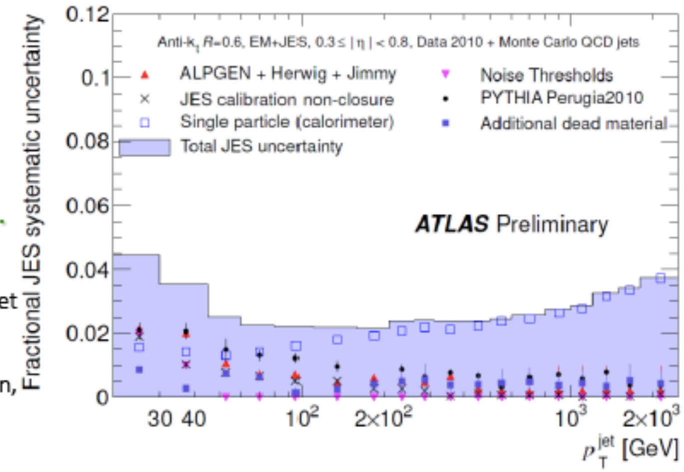
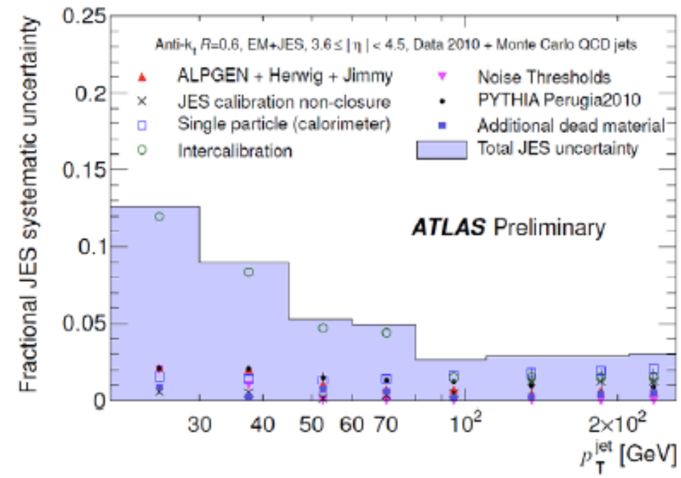
Contributions to systematic JES uncertainties in central region of ATLAS

- [MC] Non-closure of calibration
  - See previous slide
- [MC] model dependencies
  - Apply calibrations from reference sample to…
    - Different response simulation/Geant4 shower model
    - Detector description variations/material budget & alignment
    - Alternative physics simulation with different underlying event, fragmentation/hadronization, parton shower model…
- [MC,data] calorimeter response
  - Charged hadrons 0.5 < p < 20 GeV (see next slide)
    - E/p from isolated tracks in collisions
  - Charged hadrons 20 < p < 350 GeV
    - Test beam experiments
  - Basic energy scale and EM response
    - Z → ee in collisions
  - Neutral hadrons
    - Estimates from MC (conservative)
  - High energy particles in jet (p > 400 GeV)
    - Estimates from MC (conservative)

Extrapolation to end-cap and forward regions

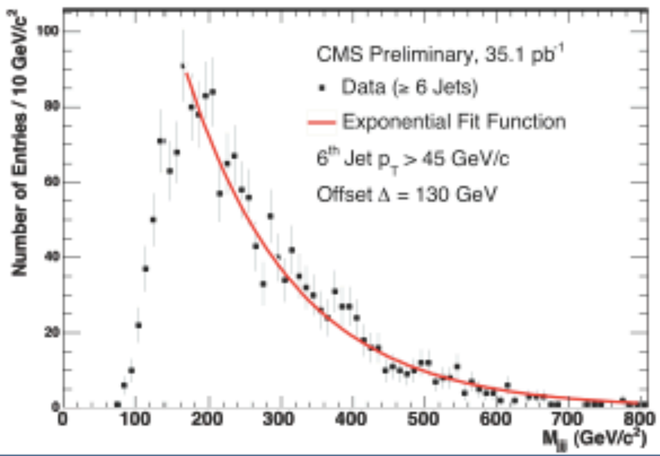
- [data] p_T balance in QCD di-jet events
  - Constraints the forward energy scale





(*all plots from* ATLAS-CONF-2011-032)

Three Jet Resonances in Multi-Jet Events

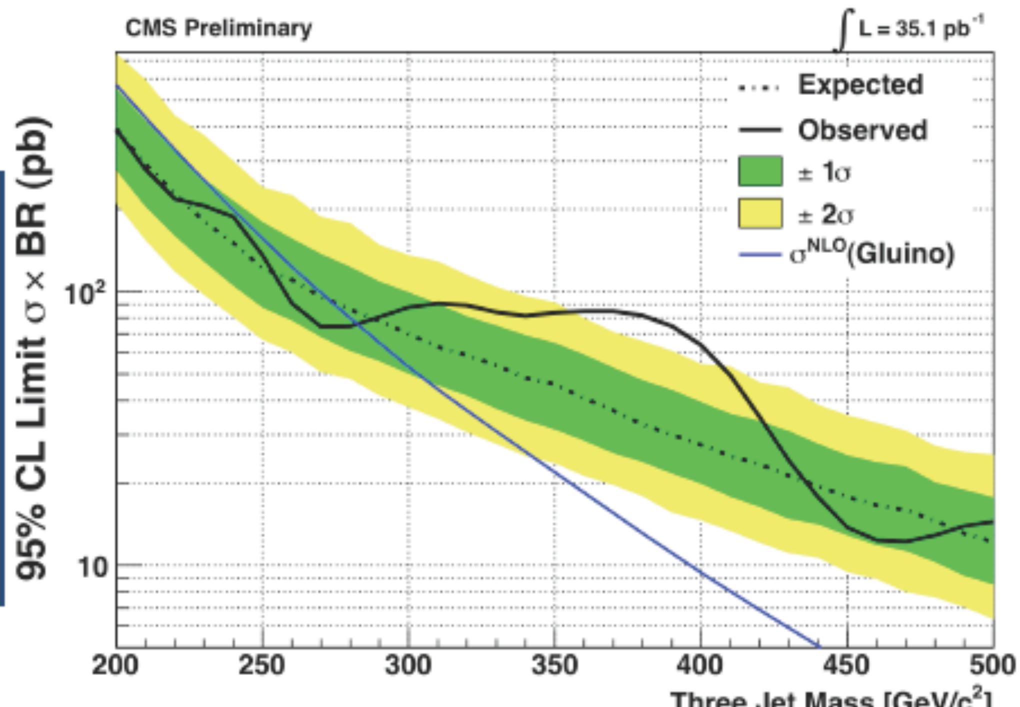


Exclusion for gluino RPV decay:

Observed: $200 < M_g < 280$ GeV/c^2
Expected: $200 < M_g < 270$ GeV/c^2

Largest excess seen at 390 GeV/c^2 → significance of 1.9σ (with look-elsewhere effect)

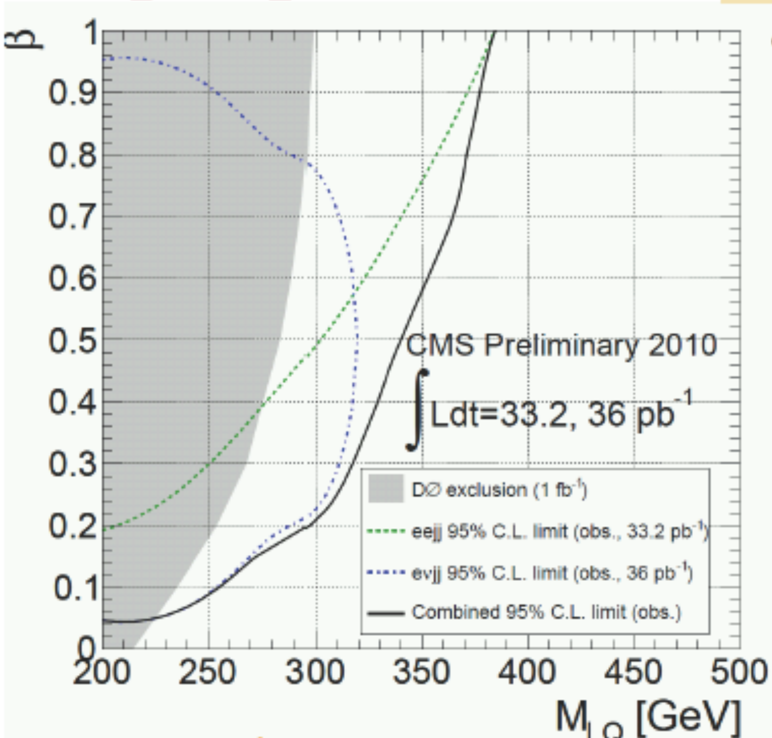
- **1st limits from the LHC**
- **Highest limits to date on gluino RPV decays!**



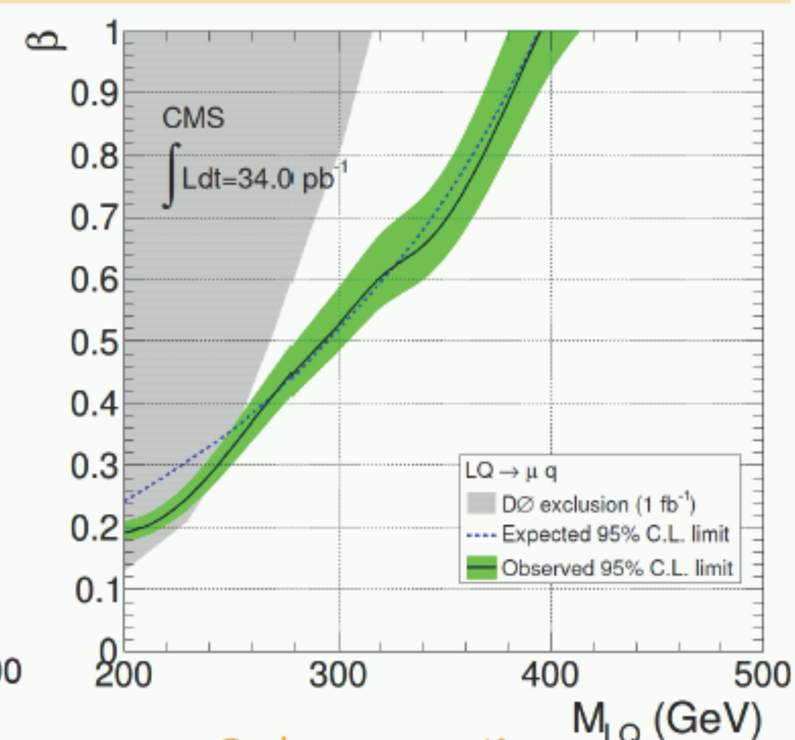
EXO-11-001

Leptoquark limits

Limits for both 1st and 2nd generation Leptoquarks outperform Tevatron limits for all but very low β



1st generation



2nd generation

New combined limits:
M_{LQ1} > 384, 340 GeV/c², β = 1, 0.5

New limit from the μμjj channel:
M_{LQ2} > 394 GeV/c²

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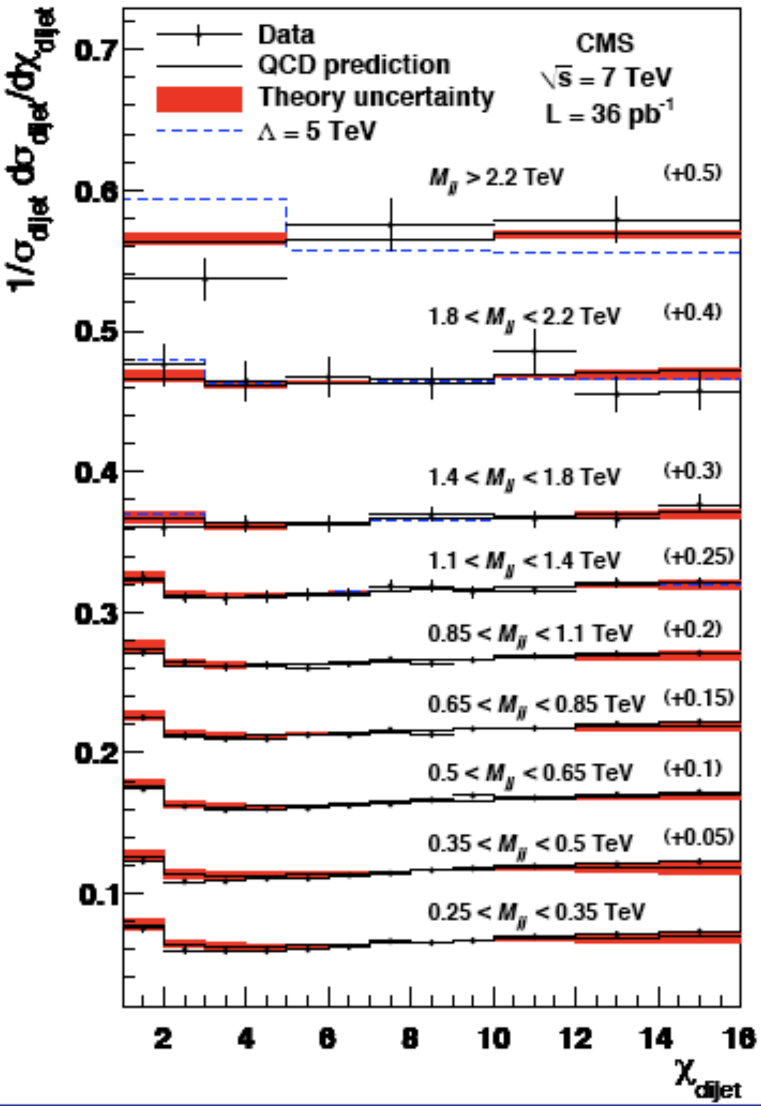
Dan Duggan 18/4/2011

Dijet Angular Distributions (II)

arXiv:1102.2020v1



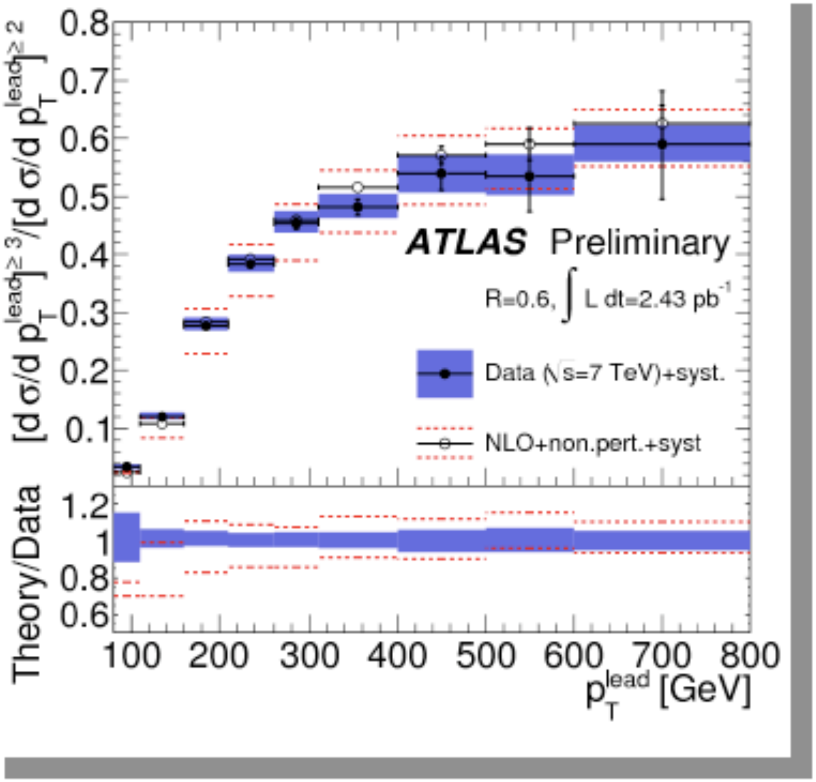
$$\chi = e^{|y_1 - y_2|} \approx \frac{1 + |\cos\theta^*|}{1 - |\cos\theta^*|}$$

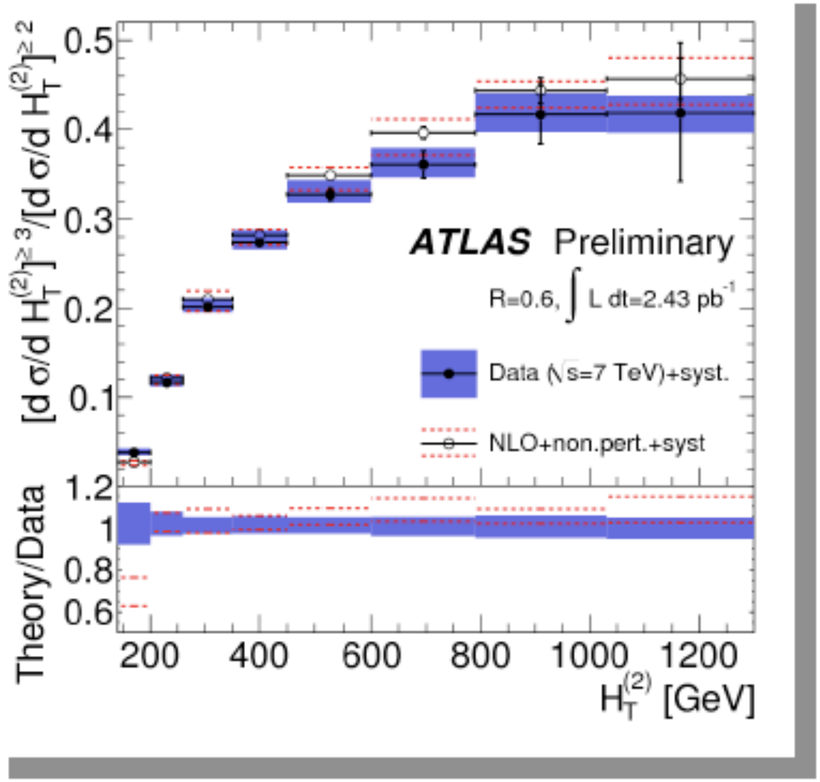
- ✦ **Normalized dijet cross section, as a function of χ, in mass bins**
  - χ is the preferred angular variable because QCD shape is relatively flat vs χ
  - using anti-k_T PF jets with R=0.5
  - 36 pb^{-1}
  - χ range: $1 < \chi < 16$
  - 9 dijet mass bins
- ✦ **Experimental uncertainties**
  - cancellation of many uncertainties (absolute JES, luminosity)
  - relative JES vs y, resolution
- ✦ **Theory uncertainties**
  - scale unc. dominates (5-9%)
  - non-perturbative correction unc. up to 4% at low masses
  - not sensitive to the PDFs

3-to-2 jet Differential Cross-section Ratios

NLO pQCD Theory

Experimental results compared to NLO pQCD calculations with the MSTW2008nlo PDF set





Anti-k_t 0.6 jets:

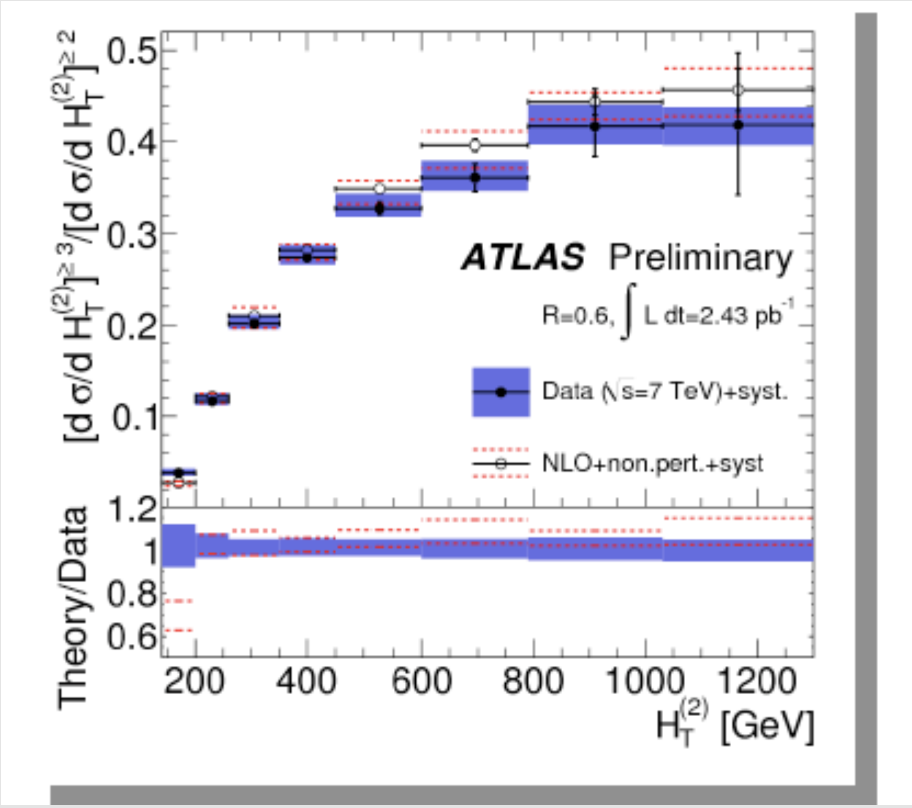
less sensitive to theoretical scale uncertainties

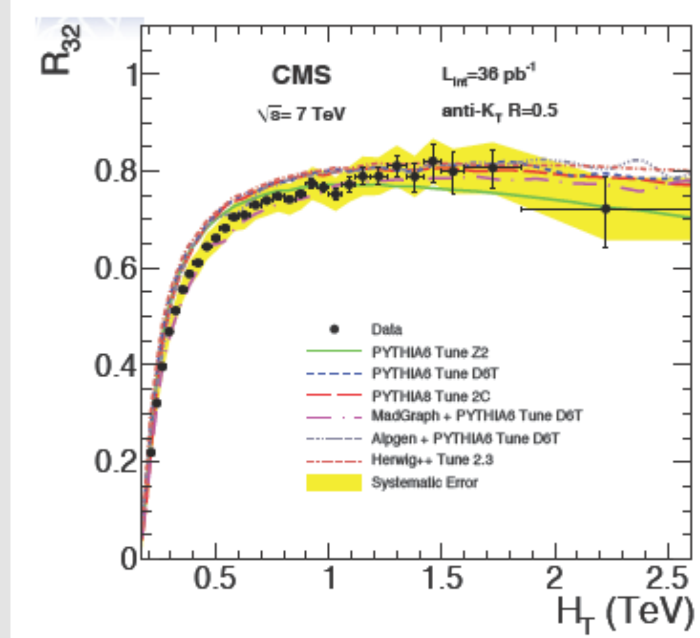
→ Data measurement uncertainties ~5%

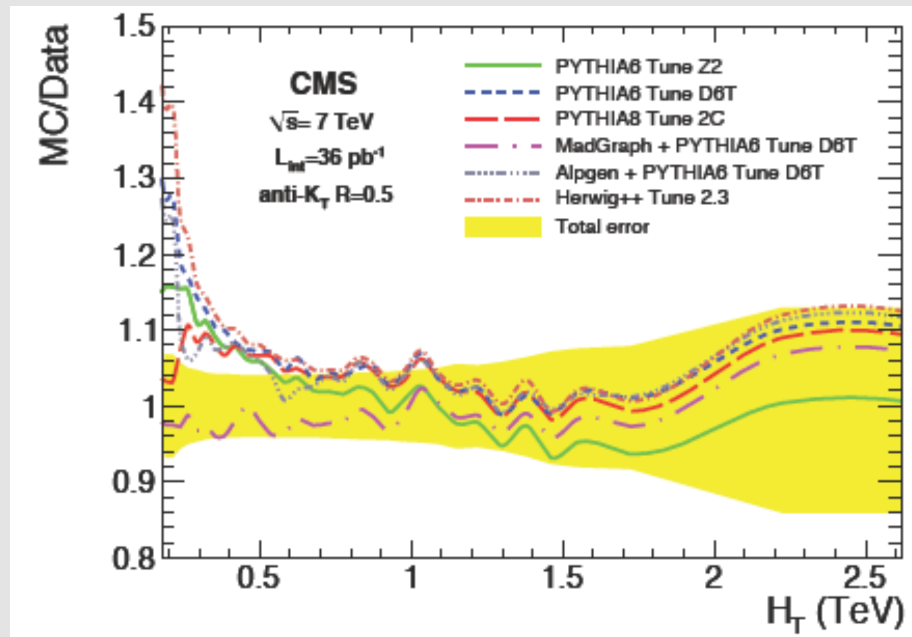
→ Theory prediction uncertainties ~5%

Reduced experimental uncertainties ✔

A possible good candidate for the α_s fit ✔







Next steps: measurements of alpha-strong

Invariant Mass Distribution of Jet Pairs Produced in Association with a W boson in pp Collisions at √s = 1.96 TeV

- Assuming only background contributions, and systematic errors, the probability to observe an excess larger than in the data is 7.610^{-4} corresponding to 3.2 standard deviations
- No excess in Z+jets however statistic not enough
- Signal is compatible with a W plus a particle of mass 150 GeV
- (Cross-section)x(BR jet jet) ~ 4pb
- not compatible with WH->lnubbar: (Cross-section)x(BR bb) = 39 fb
- b-jets ratio in excess region (120-160 GeV) is compatible with side band regions
- Decay from heavier particle ? For the moment no evidence of a resonance produced by lepton,nu,jj

- Good characterization of the multi-jet topologies
  - with multiplicity up to **6 jets**
  - for jet ***pT*s** up to **800 GeV/c**
  - for event H_T up to **1.6 TeV**