Z, W+Jets, ttbar+Jets and W+ heavy flavours at the CMS

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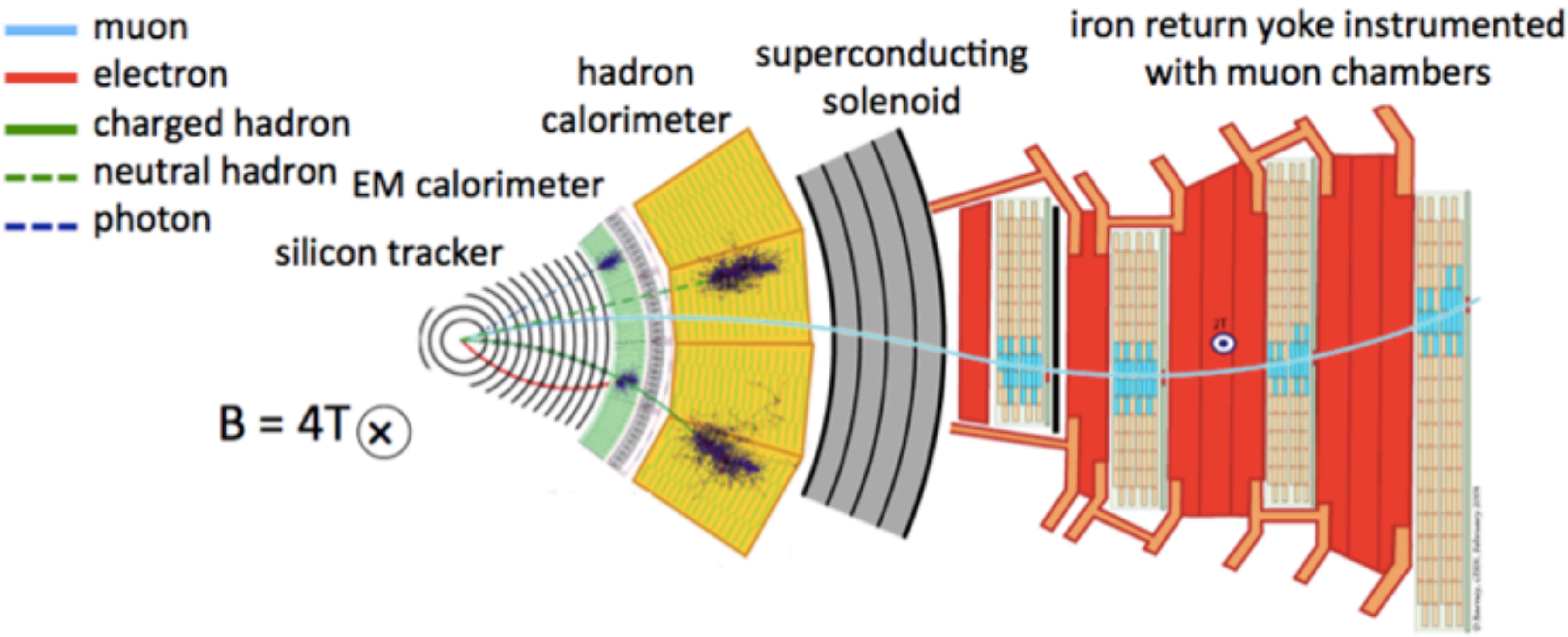
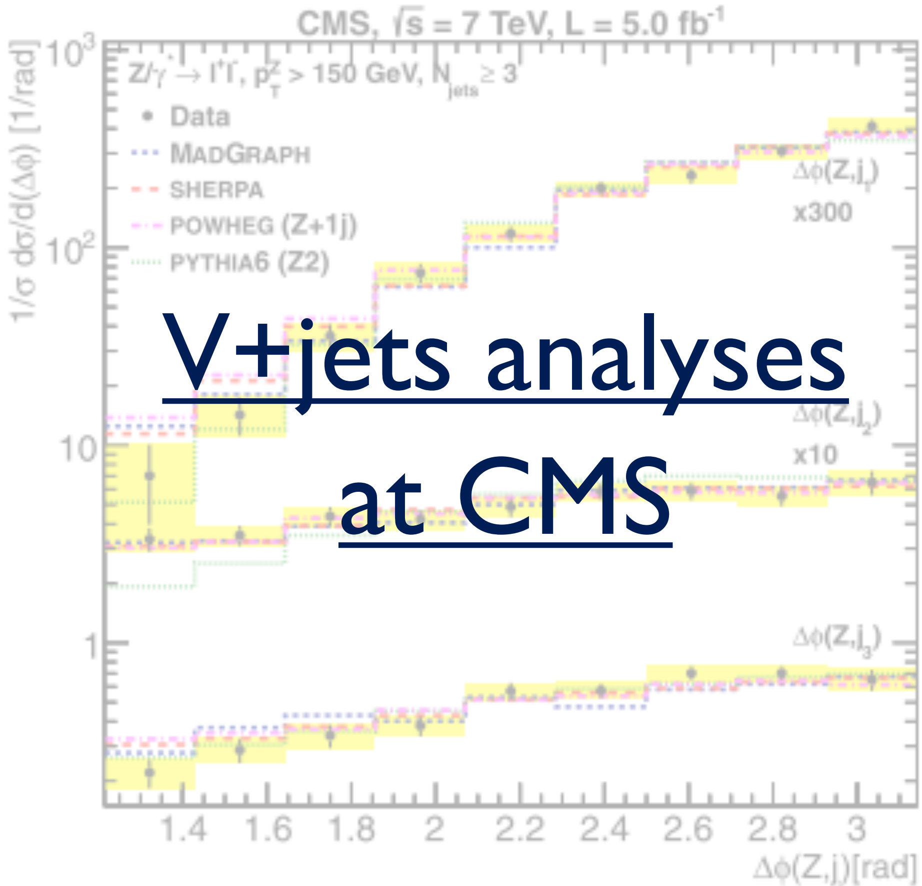
CMS Detector and Particle Flow



- Significant improvement due to Particle Flow Algorithm that uses information from all sub-detectors
  - muons, electrons, photons, charged and neutral hadrons
  - the list is used to reconstruct higher level objects like jets, MET
    - electrons: tracks matched to clusters in EM calorimeter
    - muons: minimum ionizing tracks, penetrate deep into muon system
    - jets / H_T: constructed with combined tracking + calo info
    - MET: constructed with combined tracking + calo info, hermetic detector

V+jets analyses at CMS



Azimuthal Correlation and Event Shape

Phys. Lett. B 722 (2013) 238

- Data: 5.0/fb taken at 7 TeV from 2011 data

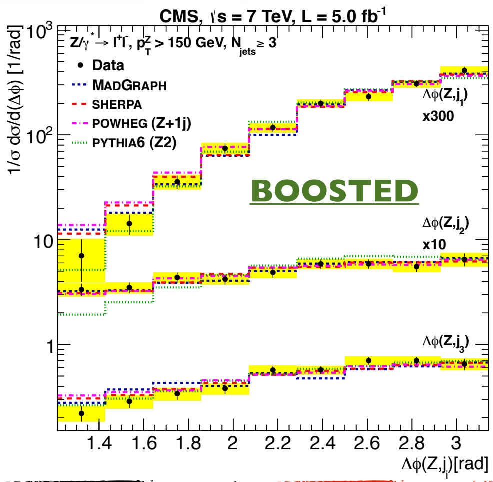
- MC "Signal" (named "Z+Jets"):
  - MadGraph (up to the fourth jets + pythia)
  - SHERPA (up to the fourth jet)
  - PYTHIA6 Z2
  - POWHEG (Z+1J NLO)
- MC Backgrounds:
  - ttbar
  - W+Jets
  - dibosons (WW,WZ,WW)

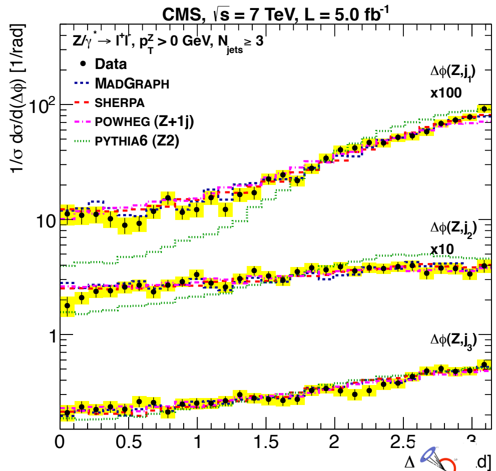
- Studies published by the Tevatron (D0) and ATLAS: extended the frontier to higher jet multiplicity (three jets)
- Theory/data comparison for boosted Z bosons (p_T>150 GeV) -> **phase space very critical for searches for new phenomena** based on large imbalanced system (New)
- First study of variables categorizing the topological structure of Z+Jets ("Event Shapes") suitable to **tune parton shower** or fragmentation functions. (New)
- Differential cross section as a function of:
  - azimuthal angles $\Delta\Phi(Z,J_i)$ i = 1,2,3, ; $\Delta\Phi(J_i,J_k)$ i,k = 1,2
  - transverse thrust τ

A. Banfi, G.P. Salam, G. Zanderighi, JHEP 0408 (2004) 062

$$\tau_\perp \equiv 1 - \max_{\vec{n}_\tau} \frac{\sum_i |\vec{p}_{T,i} \bullet \vec{n}_\tau|}{\sum_i p_{T,i}}$$

Results

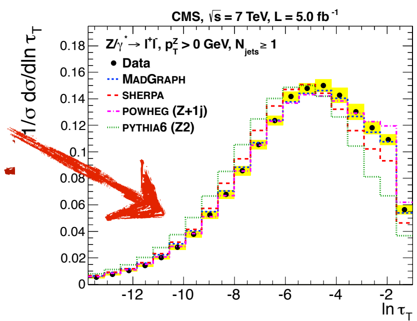


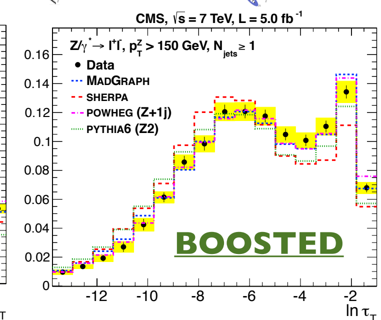


ΔΦ(Z,Ji) as a function of the Jet Multiplicity, with/without the Z(Pt)>150 GeV cut

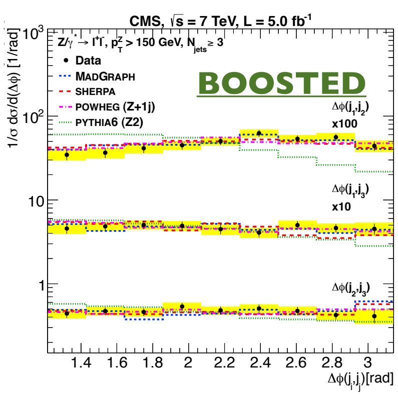
ΔΦ(Ji,Ji) as a function of the Jet

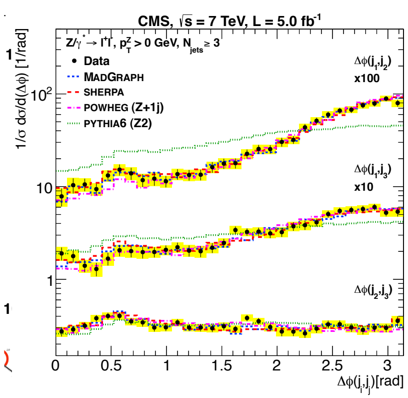
Thrust variable





- Overall the measured distributions agree within uncertainties with MadGraph
- Sherpa 10% overshoot
- For $Z(P_T) >$ 150 GeV, system more isotropic

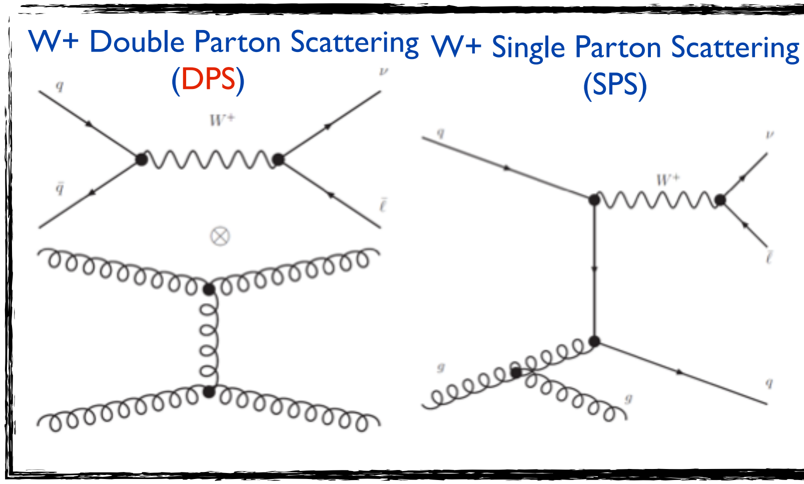




- MadGraph agrees with data
- Sherpa & Pythia differs in the thrust (smaller values)

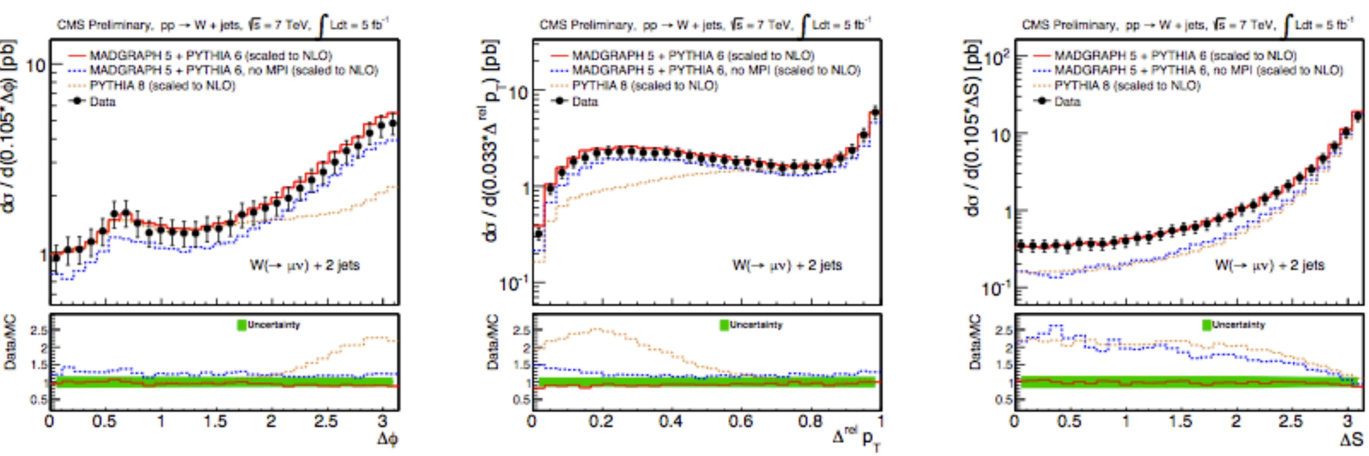
Double Parton Scattering in W+2j

- Data: 5.0/fb taken at 7 TeV from 2011 data
  - Jet $P_T > 20$, $|\eta| < 2.4$
- Valuable information on the spatial structure of the hadrons and multi-parton correlations in the hadronic wave-function
- W boson decaying into a muon and neutrino plus two jets.
- DPS kinematics quite different than SPS: can construct variable sensible towards DPS.



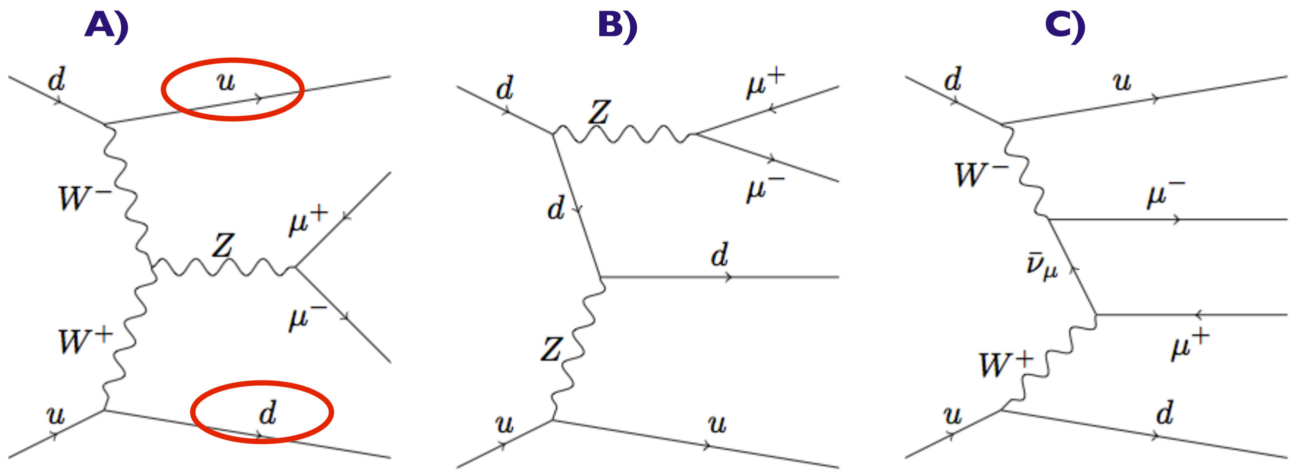
- Variable sensible to DPS are:
  - ΔΦ: azimuthal separation between the two selected jets
  - $$\Delta^{\mathrm{rel}}\, p_T = \frac{|\vec{p}_T(j1) + \vec{p}_T(j2)|}{|\vec{p}_T(j1)| + |\vec{p}_T(j2)|}.$$
  - $$\Delta S = arccos\left(\frac{\vec{P}_T(\mu, \not{E}_T).\vec{P}_T(j1, j2)}{|\vec{P}_T(\mu, \not{E}_T)|.|\vec{P}_T(j1, j2)|}\right)$$

PAS-FSQ-12-028



- DPS-sensitive distributions are quite nicely described by MADGRAPH (particle level)
- Prediction without MPI do not describe the data in a proper way

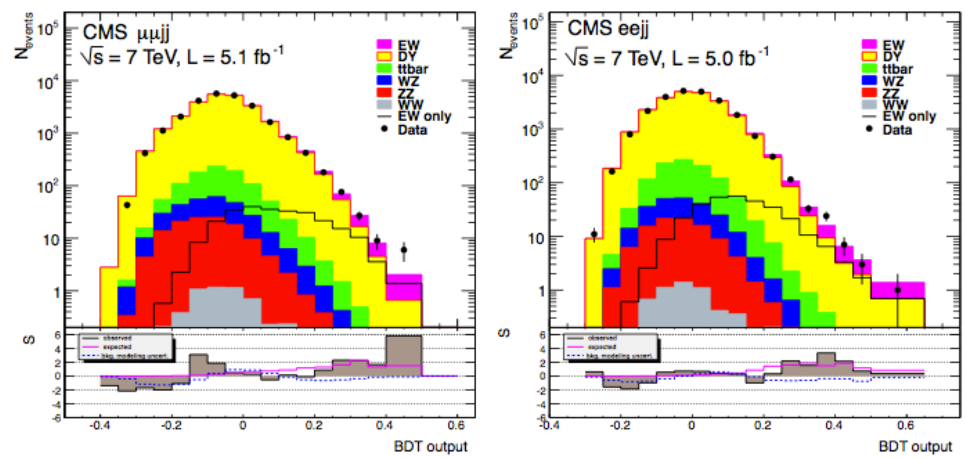
EW production of Central Z



- 3 diagrams: (A) VBF process, (B) bremmstralung, (C) multi peripheral process

arXiv: 1305.7389

- Important foundation of the more general study of vector boson fusion (VBF) processes
- Studied EW Z boson production in association with 2 jets (P_T>20 GeV), Z bosons decaying in electrons or muons
- Signal extracted using multivariate analysis in the two channels. A boosted decision tree with decorrelation is trained on several variables



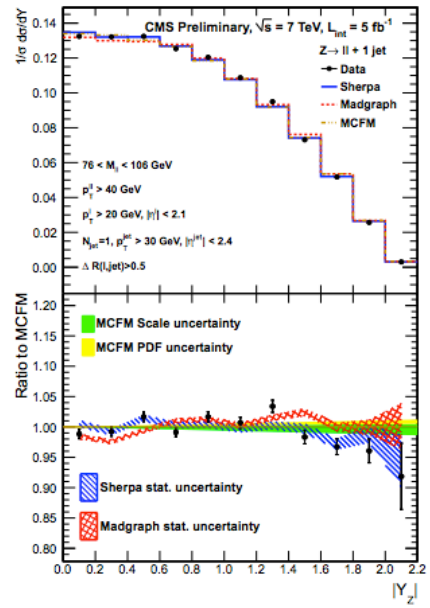
$$\sigma_{\text{VBFNLO}}(\text{EW}\ \ \ell\ell\text{jj}) = 166\ \text{fb}$$

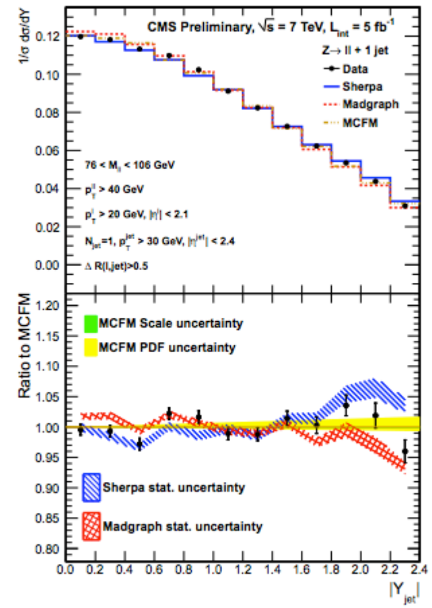
$$\sigma^{\text{EW}}_{\ell\ell\ (\ell=\text{e},\mu)} = 154 \pm 24\,(\text{stat.}) \pm 46\,(\text{exp. syst.}) \pm 27\,(\text{th. syst.}) \pm 3\,(\text{lum.})\ \text{fb}$$

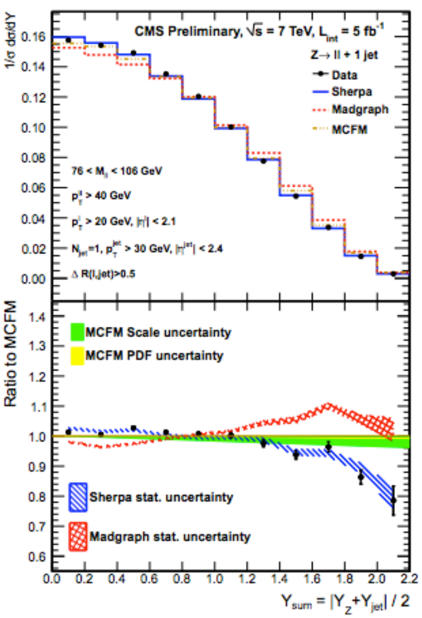
Z+1 jet and gamma+1 j rapidity distribution

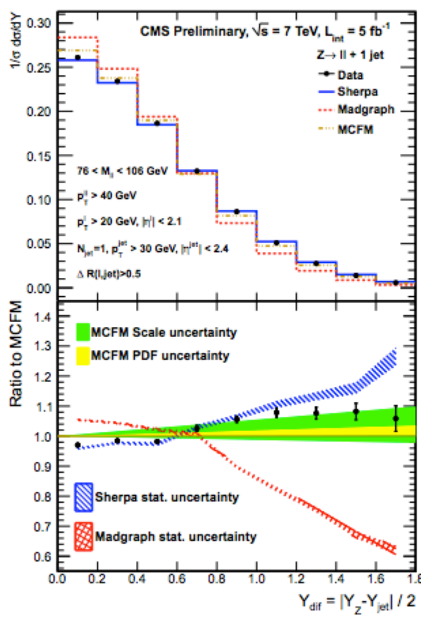
CMS-PAS-SMP-12-004

- Event with only 1 jet (pt>30, eta <|2.4|)
- Polar scattering angle θ* can be written in terms of measured quantities Y_V and Y_{jet}:
  - $\cos\theta^* = \tanh(Y_V) / \beta^*$
  - $Y_{diff} = | Y_V - Y_{jet} | /2$
    - ($Y_{sum} = | Y_V + Y_{jet} | /2$)



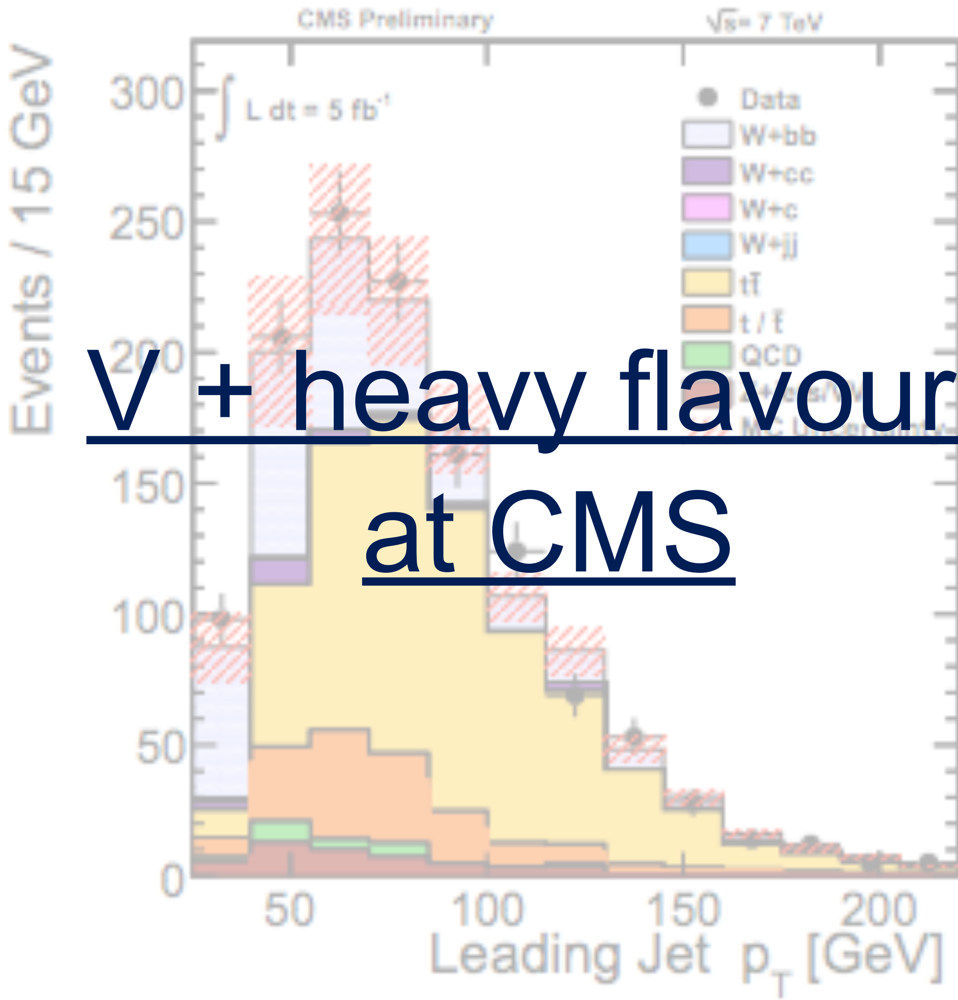






- Basic quantities Y_z and Y_{jet} are in agreement with the MC predictions.
- The derived quantities Y_{sum} and Y_{diff} are in general agreement with MCFM
- SHERPA better description of Y_{sum} and Y_{diff}

V + heavy flavours at CMS



Z →b, bb Cross Section

- The cross section for the production of a Z/γ* boson in association with at least 1 hadron-level b is given by:

$$\sigma_{\text{hadron}}(Z/\gamma^* + \mathrm{b}, Z/\gamma^* \to \ell\ell) = \frac{N(\ell\ell + \mathrm{b}) \times (\mathcal{P} - f_{\mathrm{t\bar{t}}})}{\mathcal{A}_\ell \times \mathcal{C}_{\text{hadron}} \times \varepsilon_\ell \times \varepsilon_{\mathrm{b}} \times \mathcal{L}}$$

- **A_l**: Acceptance (Sherpa,MCFM)
- **ε_b**: B-tagging efficiency (MC correct to match data)
- **ε_l**: Lepton efficiency
- **C_{hadron}**: Correction factor for detector resolution (comparison event yield/generator level)

- **Purity (P)**: estimated from the secondary vertex mass distribution, extracting the P from data using a template trained on MC.
- **F_{tt}** is the fraction of tt events, because real b arise from tt.
  tt extrapolated from sideband

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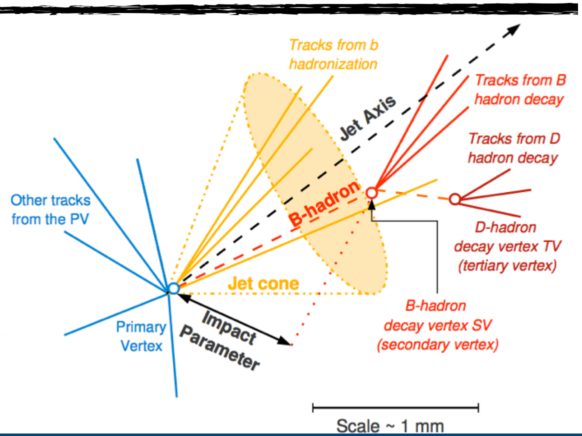

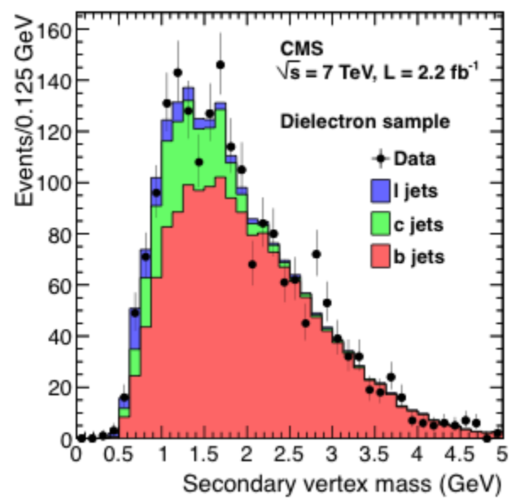

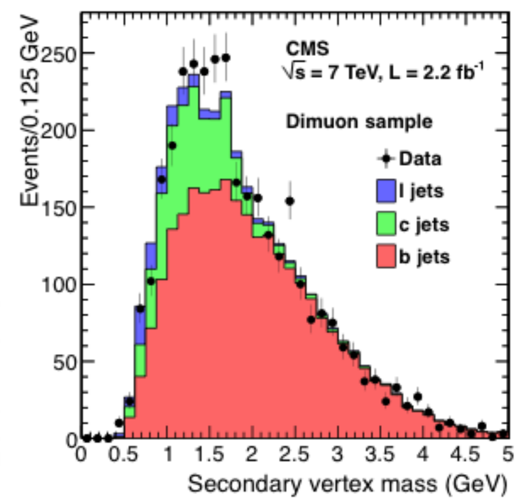

Results

- Final Cross section is Z+b is:

$$\sigma_{hadron}(Z/\gamma^* + b, Z/\gamma^* \to ll) = 5.84 \pm 0.08(stat) \pm 0.72(syst)^{0.25}_{-0.55}\ \text{pb}$$

$$\sigma^{MCFM}_{parton} = 4.73 \pm 0.54\ \text{pb}$$

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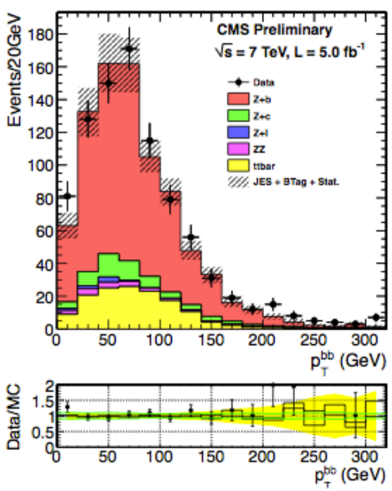
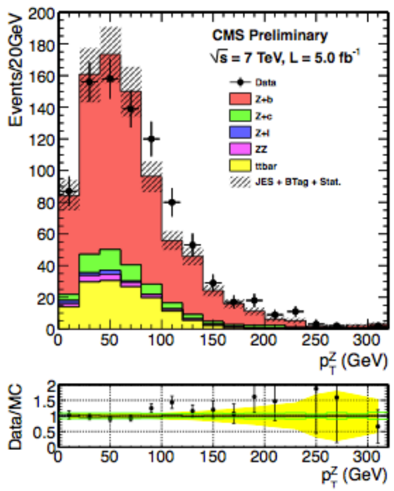
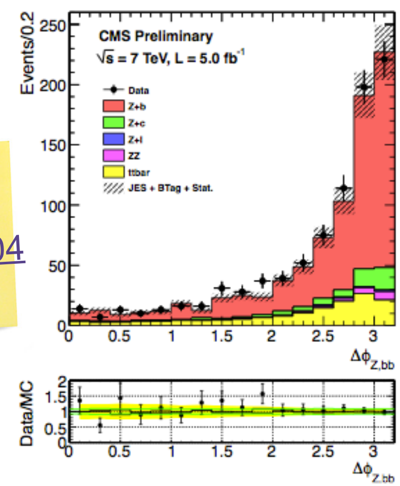
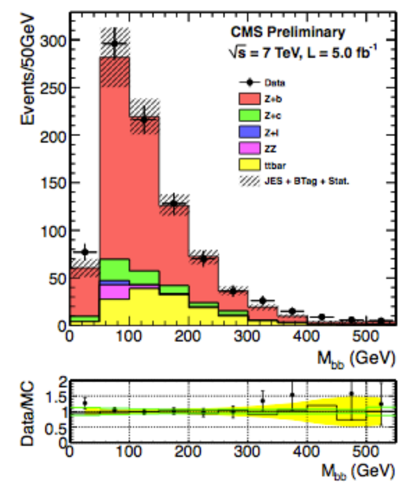
- Cross section for one Z boson in association with exactly one or at least two b quarks





CMS-PAS-SMP-13-004



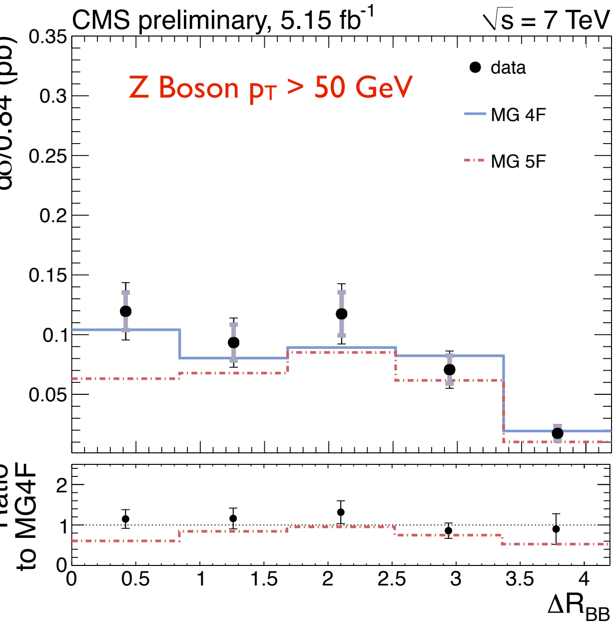


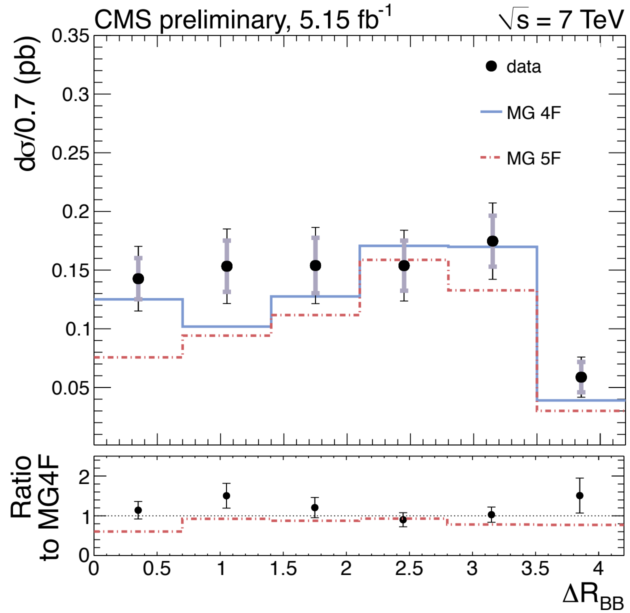
Multiplicity bin	Measured	MadGraph 5F	MadGraph 4F
σ(Z($\ell\ell$)+1b) (pb)	$3.52 \pm 0.02 \pm 0.20$	3.66 ± 0.02	3.11 ± 0.03
σ(Z($\ell\ell$)+2b) (pb)	$0.36 \pm 0.01 \pm 0.07$	0.37 ± 0.01	0.38 ± 0.01
σ(Z($\ell\ell$)+b) (pb)	$3.88 \pm 0.02 \pm 0.22$	4.03 ± 0.02	3.49 ± 0.03
σ(Z($\ell\ell$)+b)/σ(Z($\ell\ell$)+j) (%)	$5.15 \pm 0.03 \pm 0.25$	5.35 ± 0.02	4.60 ± 0.03

Good agreement at particle level with MADGRAPH (different calculation scheme)

Comparison of kinematic properties show potential limitation of the MC generator (Matrix Element + Particle Shower al LO)

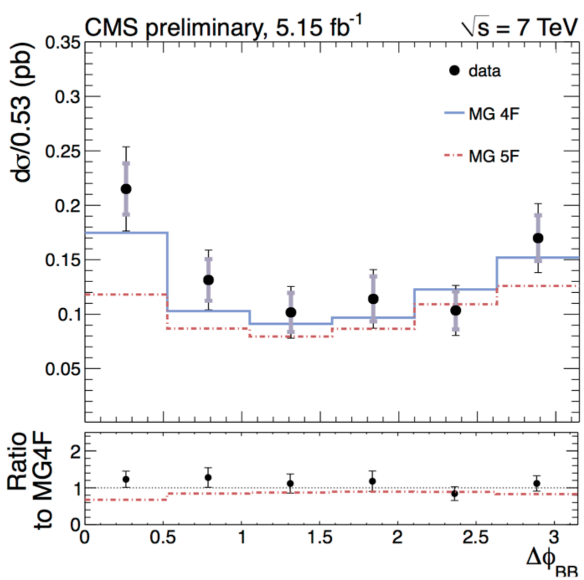
Angular correlation between B hadrons produced in association with a Z

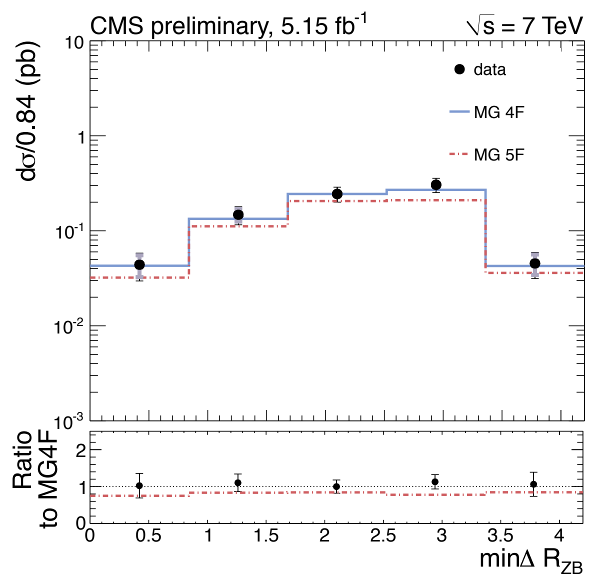


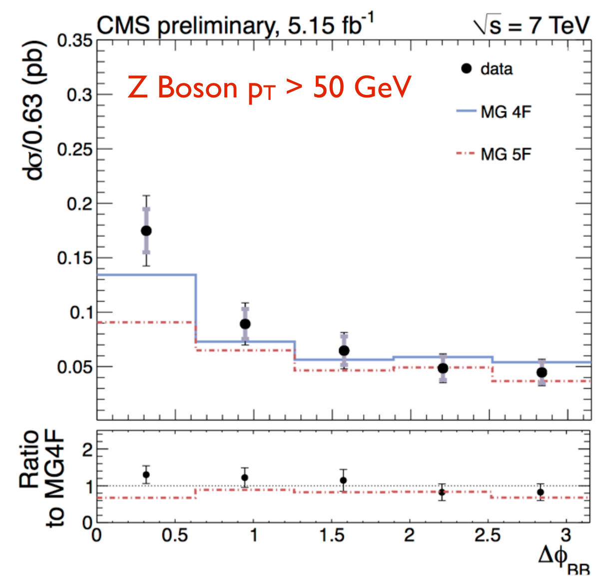


PAS-EWK-11-015

- BB angular separation demand good angular resolution
- Method based on an inclusive secondary vertex finder (IVF) has been used



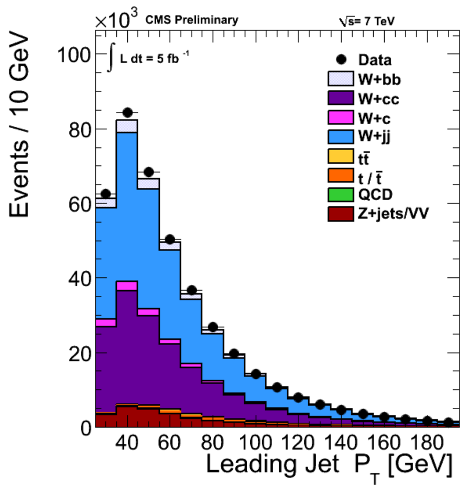


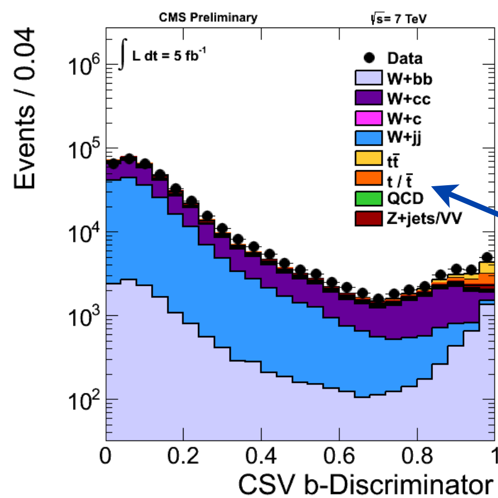


Production Cross Section of W Bosons in association with 2 b jets

CMS-PAS-SMP-12-026

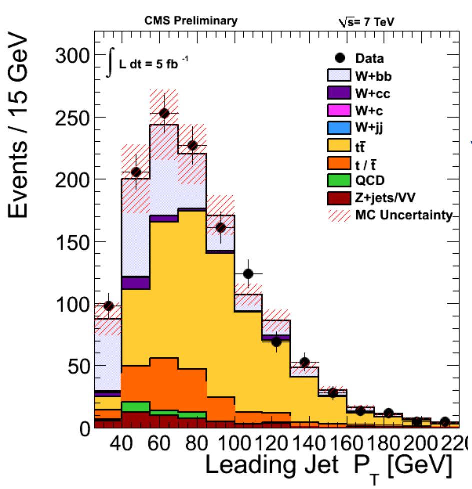
- Data: 7 TeV data (5.0/fb)
- Test for pQCD and for MC generators. Also background for new Physics and Higgs
- Jet P_T >25 GeV, $|\eta| < 2.5$; $W \to \mu\nu$ only, requiring exactly 2 b jets (using combined secondary vertex CSV b-tagging algorithms).





Backgrounds are taken from simulation, except QCD, obtained from data (inverting the selection).

Initial yields taken from data, in estimates based on control regions or from simulation



- CSV algorithm working point with maximum reduction of W+jets(u,d,c,s,g) is used.
- Final b yields are extracted using a binned maximum likelihood

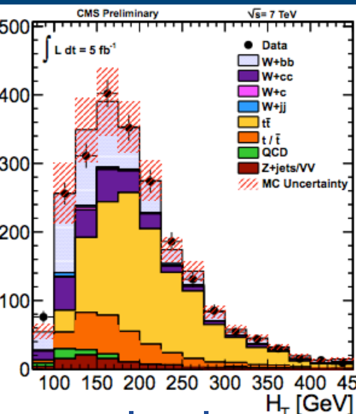
Process	Prediction	Fitted Yield
$W+b\bar{b}$	332 ± 66	300 ± 60
$W+c$, $W+c\bar{c}$	21 ± 4	20 ± 4
W+usdg	1.5 ± 0.2	1 ± 1
Z+jets	31 ± 3	32 ± 3
$t\bar{t}$	596 ± 35	647 ± 52
Single top	160 ± 13	170 ± 13
WW, WZ	19 ± 3	17 ± 3
QCD	33 ± 17	33 ± 16
Total	1194 ± 78	1220 ± 82
Observed Events	1230 ± 35	

Results

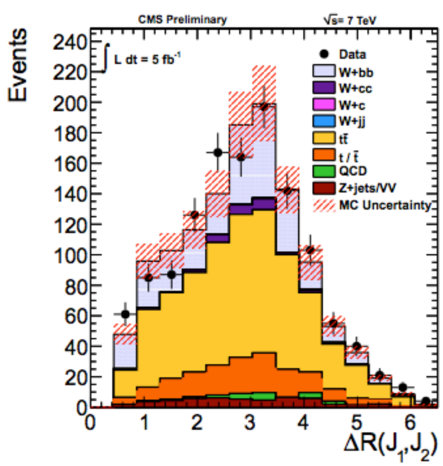
$$\sigma(pp \to W + b\bar{b}) = \frac{N_{Data} - N_{Bckg}}{\mathcal{L}_{int}\,\epsilon_{sel}}$$

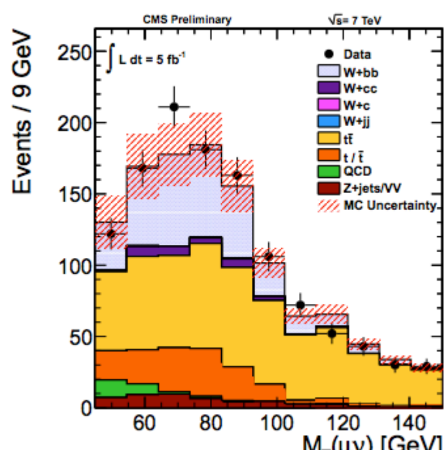
ε evaluated using MadGraph

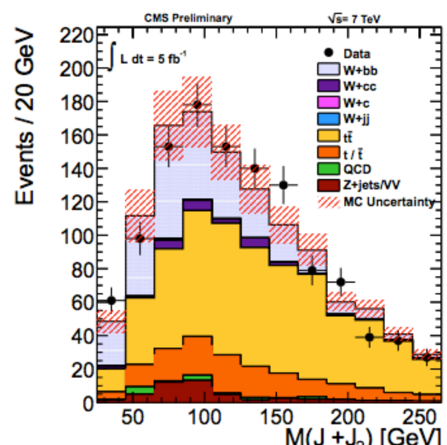
$$\sigma(pp \to W + b\bar{b}, p_T^b > 25\text{ GeV}, |\eta^b| < 2.4) \times \mathcal{B}(W \to \mu\nu, p_T^\mu > 25\text{ GeV}, |\eta^\mu| < 2.1) =$$
$$= 0.53 \pm 0.05\,(\text{stat.}) \pm 0.09\,(\text{syst.}) \pm 0.06\,(\text{theo.}) \pm 0.01\,(\text{lum.})\text{ pb.}$$

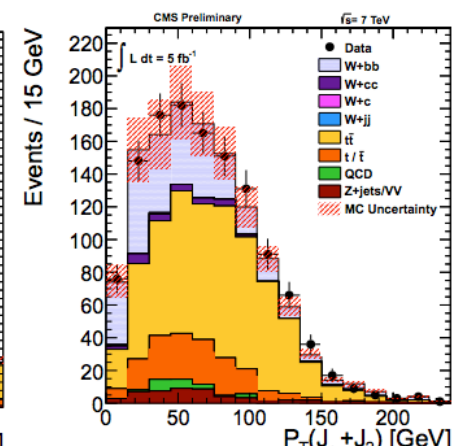


- Hadronization correction factor 0.92±0.01 (final-state particle → parton-level cross section) is estimated with MADGRAPH +PYTHIA.
- The measured values can be compared to the NLO cross section of 0.52 ± 0.03 pb calculated with MCFM
- Also the kinematics of the bb system is exploited. The observed distributions are well described by the simulation.



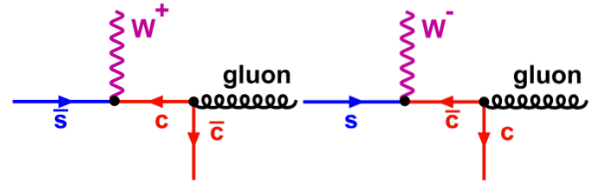






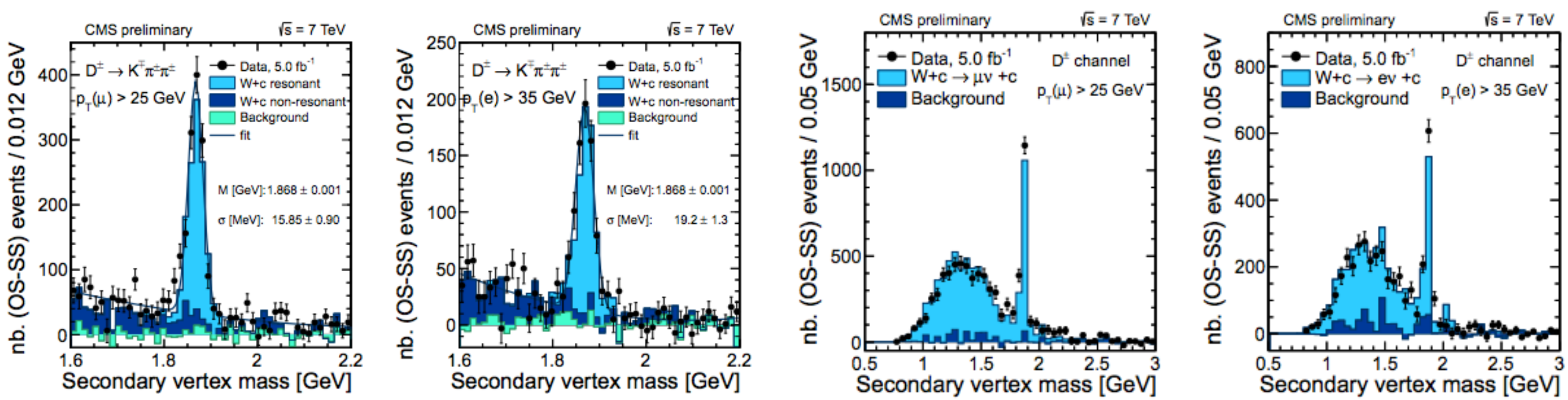
Associated Charm Production in W Final states

- Data: 7 TeV data (5.0/fb)
- Jet P_T >25 GeV, $|\eta|$ < 2.5



- W+c provides direct access to the strange quark content of the proton at the electroweak scale
- Precise measurements may reduce the uncertainties on the strange parton density function (PDF). Improving PDF knowledge is essential for many future precision analyses.
- Study of pp→ W + c + X:
  - W boson is detected as W→ lν
  - Jets originating from a c(anti c) quark are identified using one of the three following signatures:
    - displaced secondary vertex with 3 tracks and inv.mass consistent with $D^+ \to K^-\pi^-\pi^-$ ($D^- \to K^+\pi^-\pi^-$)
    - displaced secondary vertex with 2 tracks and inv.mass consistent with $D^0 \to K^-\pi^+$ associated to a previous $D^{*+}(2010) \to D^0\pi^+$ at the primary vertex
    - semileptonic decay leading to a well identified muon

CMS-PAS-SMP-12-002



Results

$$\sigma(W+c) = \frac{N_{sel} - N_{bkg}}{\mathcal{L}_{\rm int}\, \mathcal{B}\, \mathcal{A}\, \epsilon}$$

$$\mathcal{B} \equiv \mathcal{B}(c \to D^{*+}(2010); D^{*+}(2010) \to D^0\pi^+; D^0 \to K^-\pi^+) = (0.622 \pm 0.020)\%$$

$$\mathcal{B} \equiv \mathcal{B}(c \to D^+ \to K^-\pi^+\pi^+) = (2.08 \pm 0.10)\%$$

$$\mathcal{B} \equiv \mathcal{B}(c \to \ell) = (9.11 \pm 0.49)\%$$

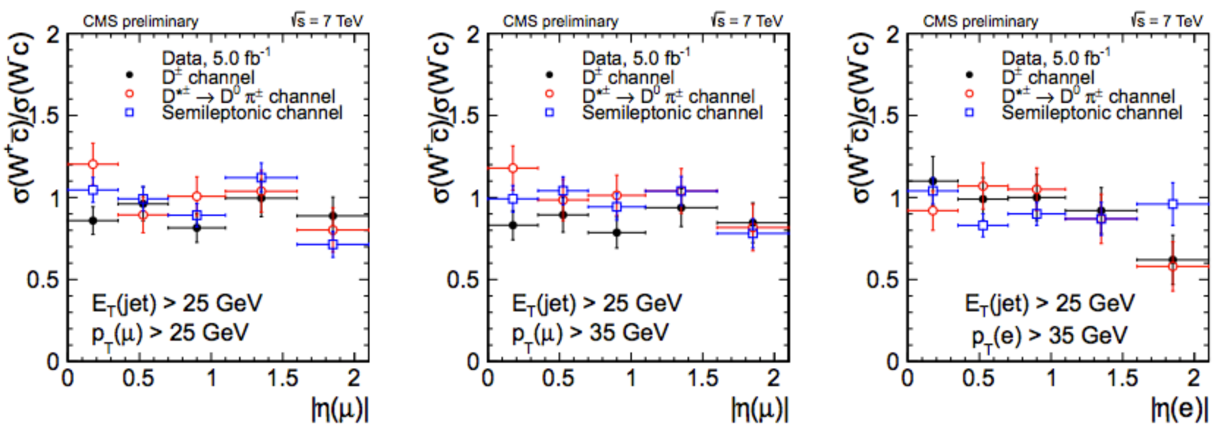
$W \to \mu\nu$, $p_T^\mu > 25\,\mathrm{GeV}$				
Final state	$(S+B)_{\rm data}$	$S_{\rm data}$	$\mathcal{A}\epsilon$ [%]	$\sigma(W+c)$ [pb]
$D^\pm$	1502 ± 62	1203 ± 91	11.1 ± 0.3	103.6 ± 7.8 (stat.) $\pm$ 8.1 (syst.)
$D^{*\pm}(2010)$	318 ± 21	309 ± 23	8.5 ± 0.4	116.9 ± 8.7 (stat.) $\pm$ 10.0 (syst.)
$c \to \mu$	14215 ± 196	9867 ± 237	20.4 ± 0.2	106.5 ± 2.6 (stat.) $\pm$ 9.6 (syst.)
Average				107.7 ± 3.3 (stat.) $\pm$ 6.9 (syst.)

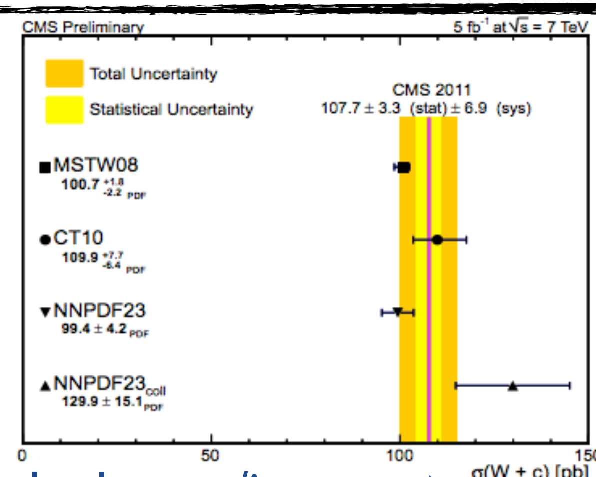
$$\frac{\sigma(pp \to W^+ + \bar{c} + X)}{\sigma(pp \to W^- + c + X)}(p_T^\mu > 25\ \mathrm{GeV}) = 0.954 \pm 0.025\ (\mathrm{stat.}) \pm 0.001\ (\mathrm{syst.}),$$

$$\frac{\sigma(pp \to W^+ + \bar{c} + X)}{\sigma(pp \to W^- + c + X)}(p_T^\mu > 35\ \mathrm{GeV}) = 0.947 \pm 0.026\ (\mathrm{stat.}) \pm 0.002\ (\mathrm{syst.}),$$

$$\frac{\sigma(pp \to W^+ + \bar{c} + X)}{\sigma(pp \to W^- + c + X)}(p_T^e > 35\ \mathrm{GeV}) = 0.93 \pm 0.03\ (\mathrm{stat.}) \pm 0.01\ (\mathrm{syst.}),$$

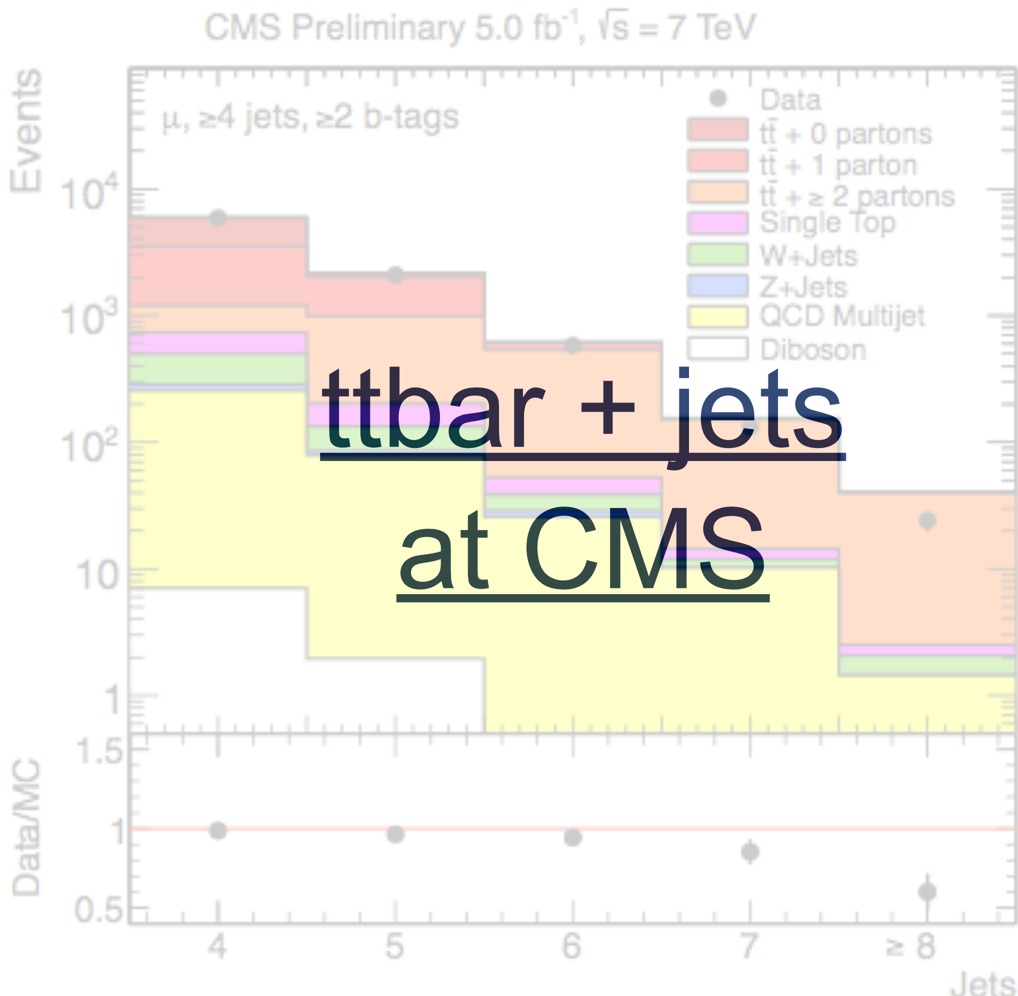
$$\frac{\sigma(pp \to W^+ + \bar{c} + X)}{\sigma(pp \to W^- + c + X)}(p_T^\ell > 35\ \mathrm{GeV}) = 0.939 \pm 0.019\ (\mathrm{stat.}) \pm 0.005\ (\mathrm{syst.}).$$





- Normalized differential cross section as a function of the lepton/jet η
- Comparison of the theoretical predictions for σ(W + c) computed with MCFM and several PDF

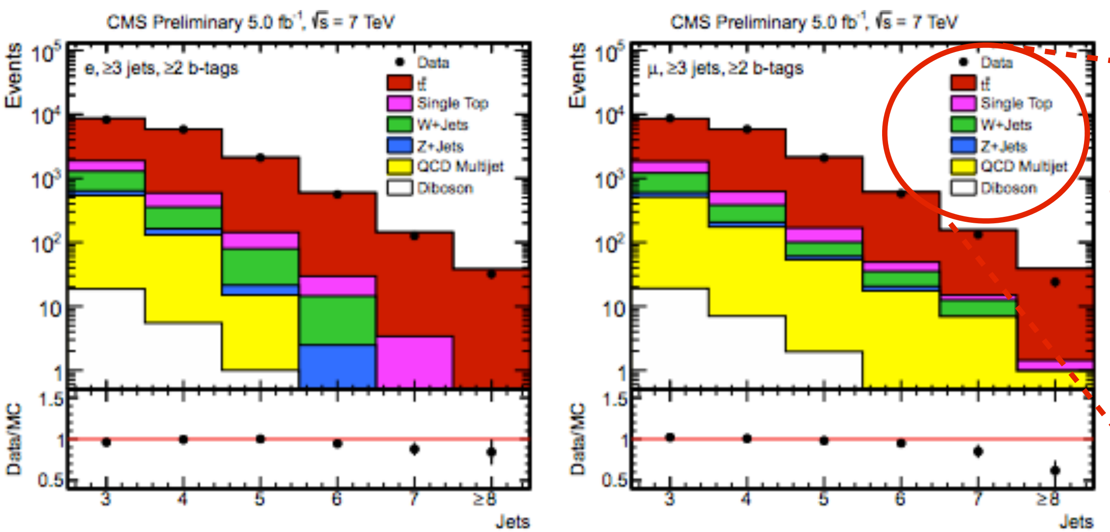
ttbar + jets at CMS



Jet Multiplicity in top pair events (1 lepton)

- Data: 5.0/fb taken at 7 TeV from 2011 data
- Events selected requiring one isolated electron/muon with p_T > 30 GeV and at least 3 jets (p_T >35, within η < |2.4|)
- Background to Higgs and SUSY. Very useful to constrain initial state radiation (ISR) and to provide test of pQCD
- Jets from bottom quarks are tagged with an algorithm which combines reconstructed secondary vertices and track-based lifetime information, the Combined Secondary Vertex Medium (CSVM)
- MADGRAPH generator was generated with up to three additional partons in addition to the jets from ttbar decay

CMS-PAS-TOP-12-018

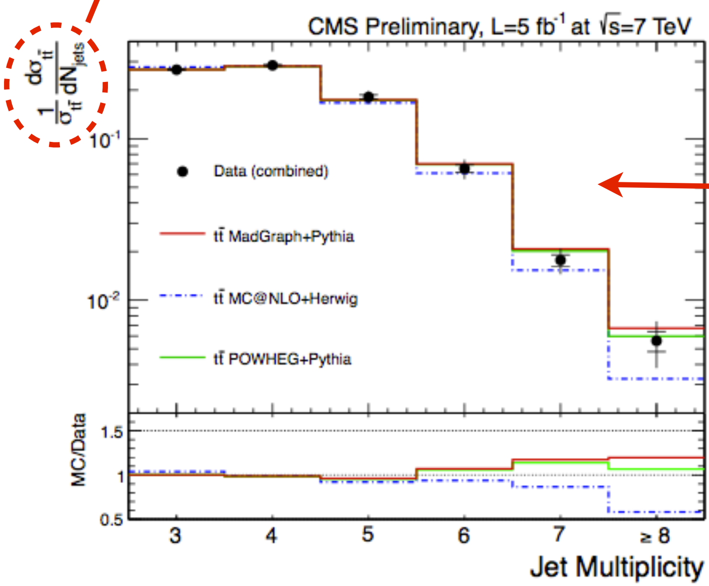


- MC samples are used for Z+jets, single top and di-bosons.
- Data-driven method used for W +jets(using charge asymmetry and heavy flavor correction) and QCD (inverting selection criteria using signal and sideband region)

- Main systematics are: Jet Energy Correction and resolution, Q^2 scale variation (biggest contribution), background description, ME/PS matching, PDF

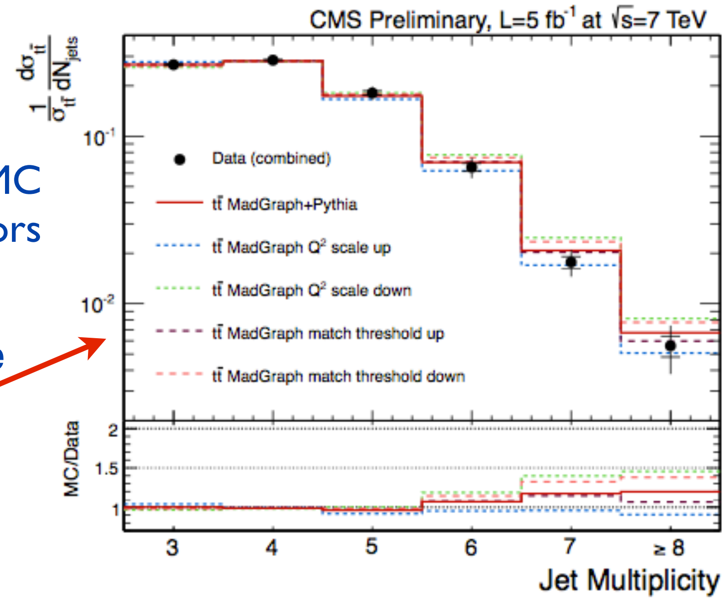
Results

$$\frac{d\sigma}{\sigma_{t\bar{t}}\cdot dN_{\text{jets}}} = \frac{1}{\sigma_{t\bar{t}}^{\text{measured}}} \times \boxed{\frac{d\sigma_{t\bar{t}}^{\text{measured}}}{dN_{\text{jets}}}} \rightarrow \boxed{\frac{d\sigma_{t\bar{t}}^{\text{measured}}}{dN_{\text{jets}}} = \frac{N^i_{\text{data}} - N^i_{\text{bkg}}}{\Delta^i_X \boxed{\cdot\, \epsilon^i \cdot} \mathcal{L}}} \qquad \boxed{\epsilon^i = \frac{N^i_{\text{rec}}}{N^i_{\text{gen}}}}$$



Different MC generators

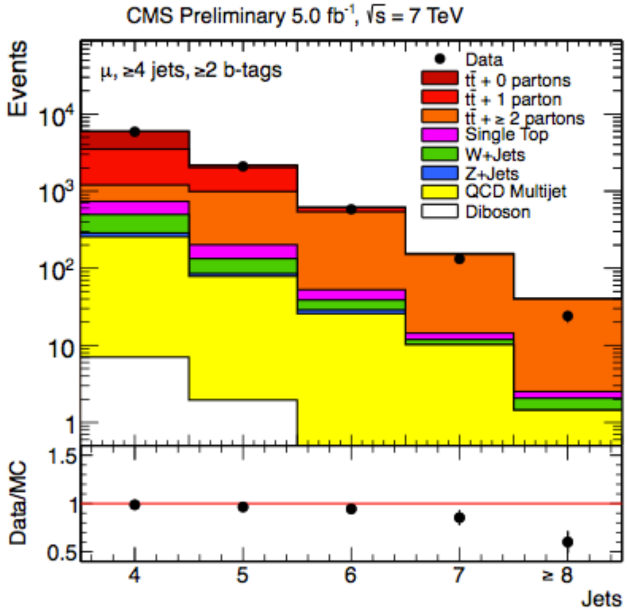
Different Q scale and ME-PS matching threshold



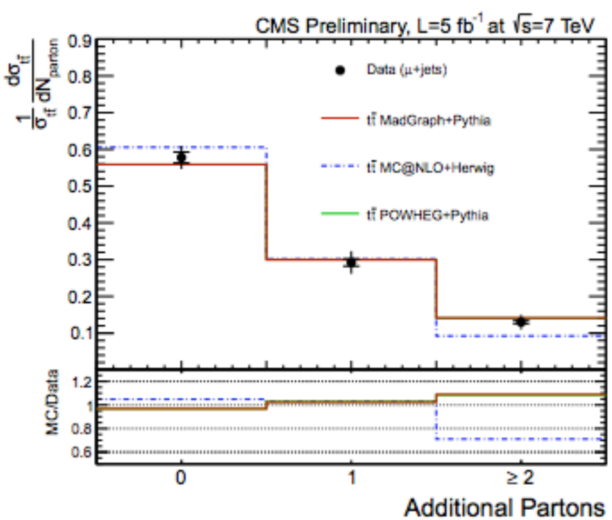
$\frac{d\sigma}{\sigma_{t\bar{t}}\cdot dN_{\text{jets}}}$	$N^{\text{gen}}_{\text{jets}} = 3$	$N^{\text{gen}}_{\text{jets}} = 4$	$N^{\text{gen}}_{\text{jets}} = 5$	$N^{\text{gen}}_{\text{jets}} = 6$	$N^{\text{gen}}_{\text{jets}} = 7$	$N^{\text{gen}}_{\text{jets}} \geq 8$
Data (e+jets)	0.261 ± 0.013	0.287 ± 0.011	0.179 ± 0.016	0.068 ± 0.012	0.019 ± 0.004	0.006 ± 0.002
Data (μ+jets)	0.273 ± 0.014	0.281 ± 0.011	0.169 ± 0.018	0.066 ± 0.009	0.017 ± 0.003	0.004 ± 0.002
Madgraph MC	$0.268 \pm 8 \times 10^{-5}$	$0.281 \pm 8 \times 10^{-5}$	$0.174 \pm 6 \times 10^{-5}$	$0.070 \pm 4 \times 10^{-5}$	$0.021 \pm 2 \times 10^{-5}$	$0.007 \pm 1 \times 10^{-5}$

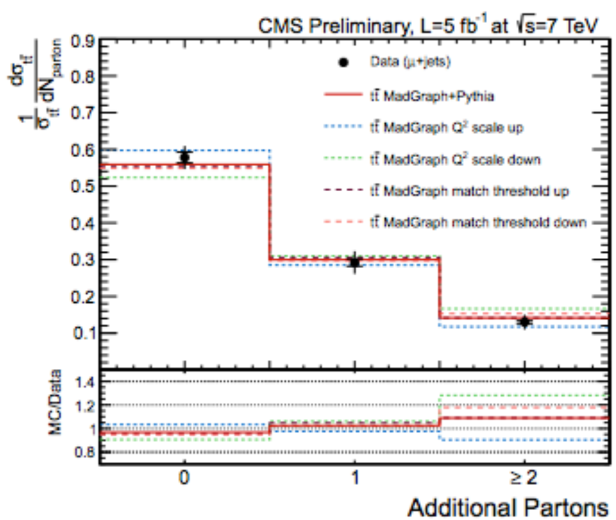
- Good agreement with various generators and scales is found (except small discrepancy MC@NLO and MADGRAPH Down at high jet multiplicity)

Results (2)



- Alternative method to extract information about additional radiation in ttbar: cross section as a function of the number of hard partons radiated in addition to the decay products
- “Additional jet” is defined as those jets in the phase space which are not identified by the kinematic reconstruction as part of the ttbar system
- Additional partons relies on the jet definition and the matching jet/parton. GenJets with ΔR>0.5 are required for additional radiation.



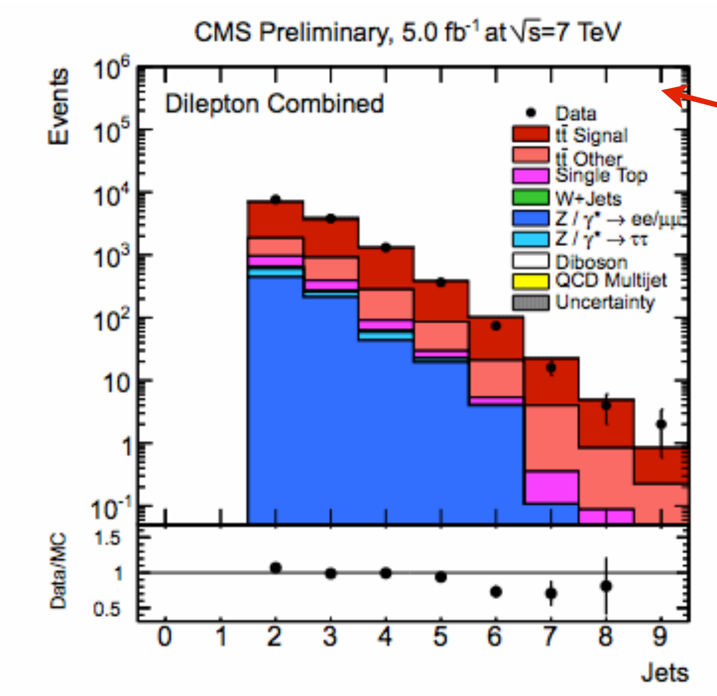


process	Normalized Cross-Section
$t\bar{t}+0$ parton	$0.578 \pm 0.015(stat.) \pm 0.028(syst.)$
$t\bar{t}+1$ parton	$0.292 \pm 0.010(stat.) \pm 0.029(syst.)$
$t\bar{t}+\geq 2$ partons	$0.130 \pm 0.004(stat.) \pm 0.019(syst.)$

Excellent agreement between data and MC predictions!

Jet Multiplicity in top pair events (2 leptons) @ 7 TeV

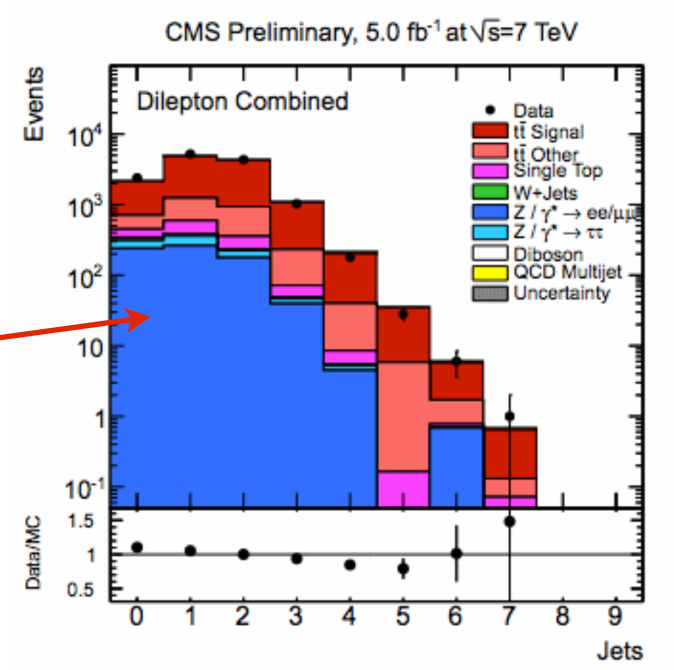
- In this channel, at leading order, only two charged leptons and two b-jets are produced, and the presence of additional jets can be attributed to higher order QCD effects.
- Events are selected if there are at least two isolated leptons (electrons or muons) and two jets (at least one is identified as b-jet).
- A kinematic reconstruction method is used to determine the top-quark pair kinematic properties and to identify the two b-jets originating from the decays of the two top quarks



Threshold jet P_T 30 GeV

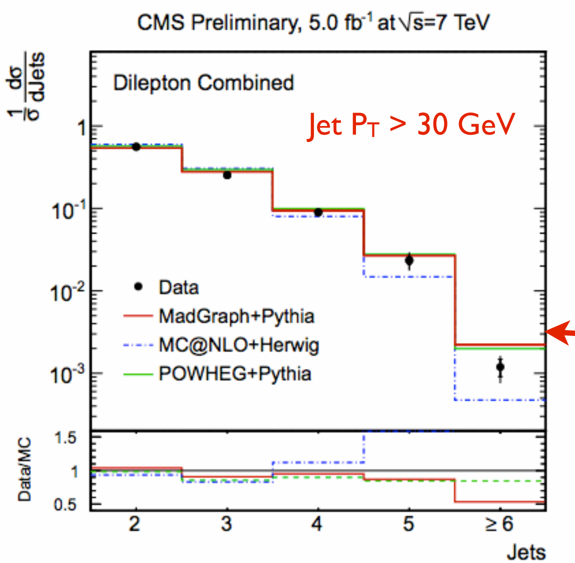
Threshold jet P_T 60 GeV

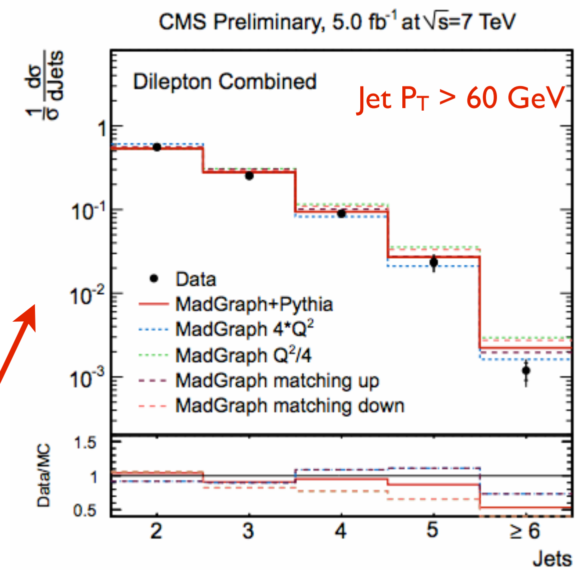
CMS-TOP-12-023



Results

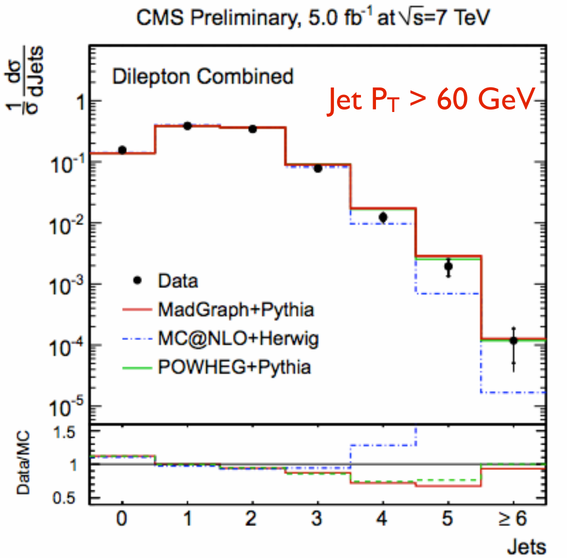
- Detector effects are corrected using unfolding method

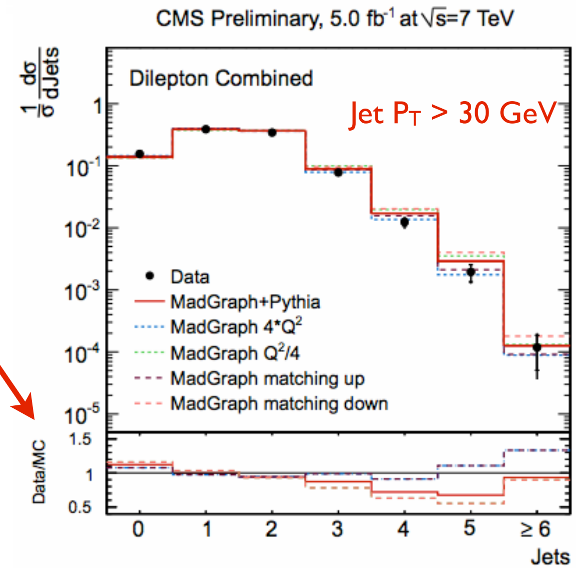




Different MC generators

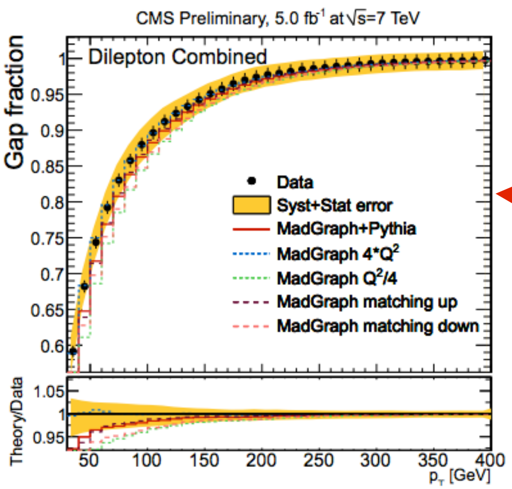
Different Q scale and ME-PS matching threshold





Other Results

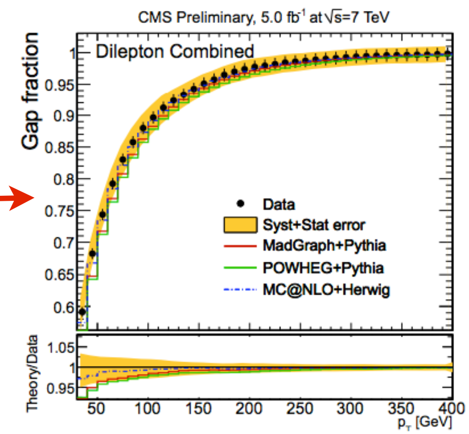
- An alternative way to investigate the jet activity arising from quark and gluon radiation is to determine the fraction of events that do not contain an additional jet above a given threshold



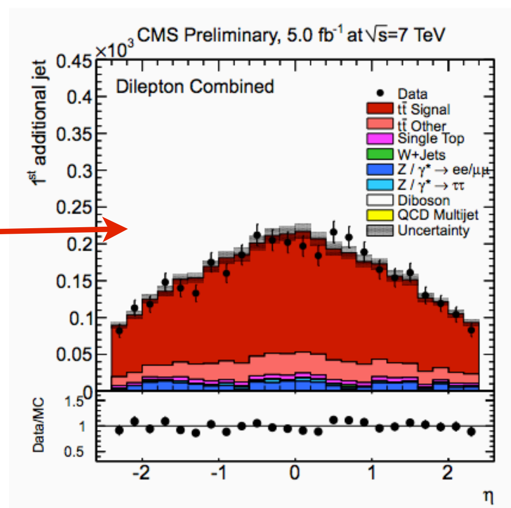
Different Generator

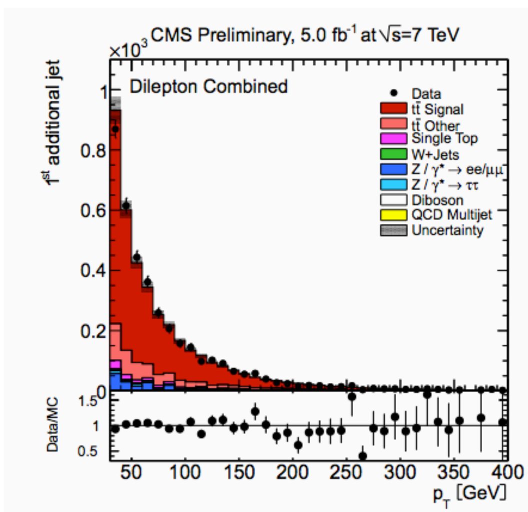
$$f(p_T) = \frac{N(p_T)}{N_{total}}$$

Different Scaling

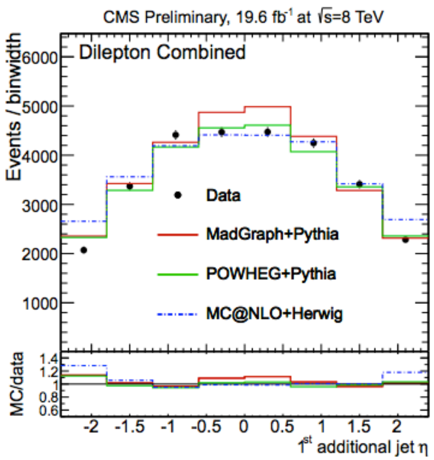


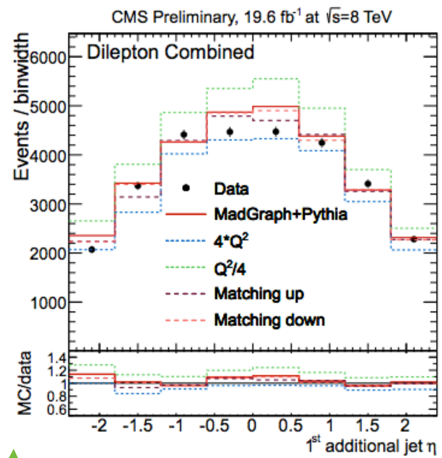
- Other measurements:
  - Distribution of the rapidity and the transverse momentum of the first leading additional reconstructed jets compared to signal and background simulated samples.





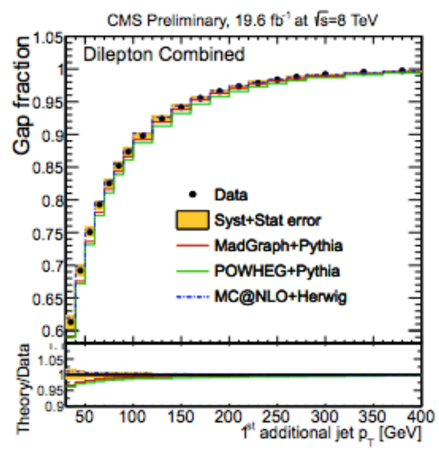
Jet Multiplicity in top pair events (2 leptons) @ 8 TeV

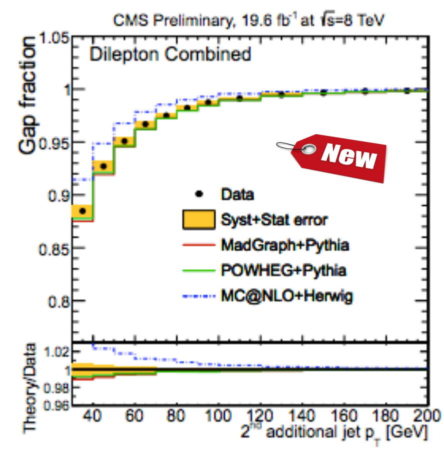




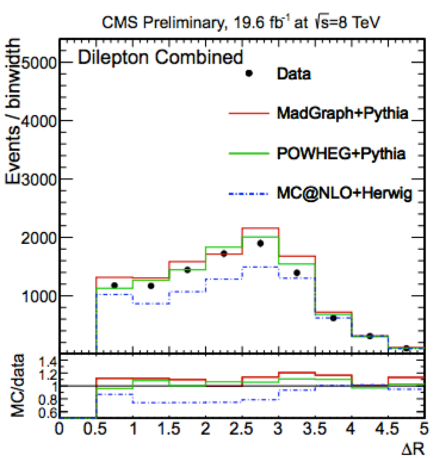
- Same observables as for the 7 TeV, with 3 pt thresholds

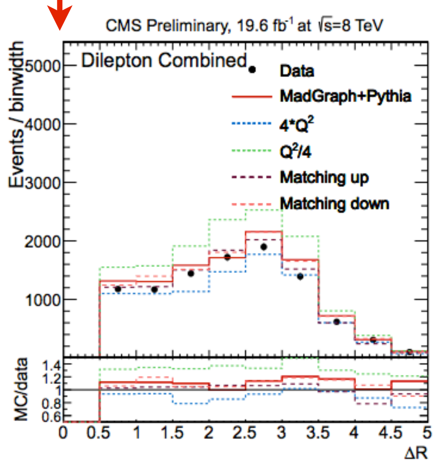
CMS-PAS-TOP-12-041

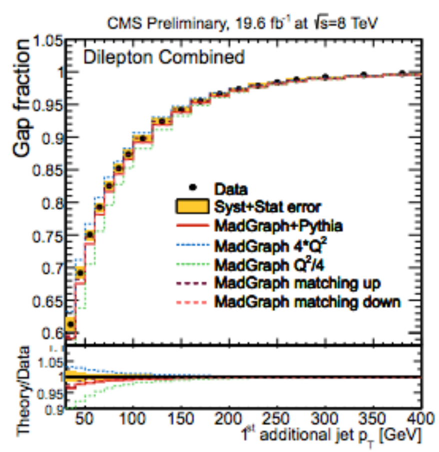


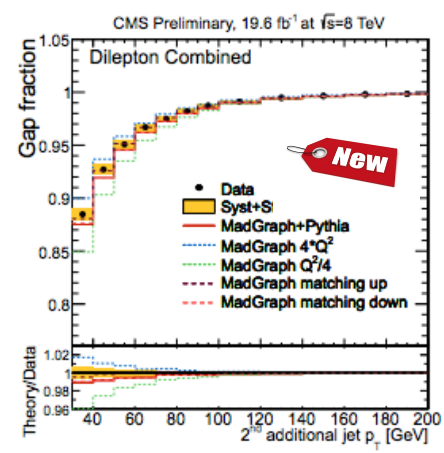


- New: Measurement of the additional jet eta and DeltaR between first and second additional jet

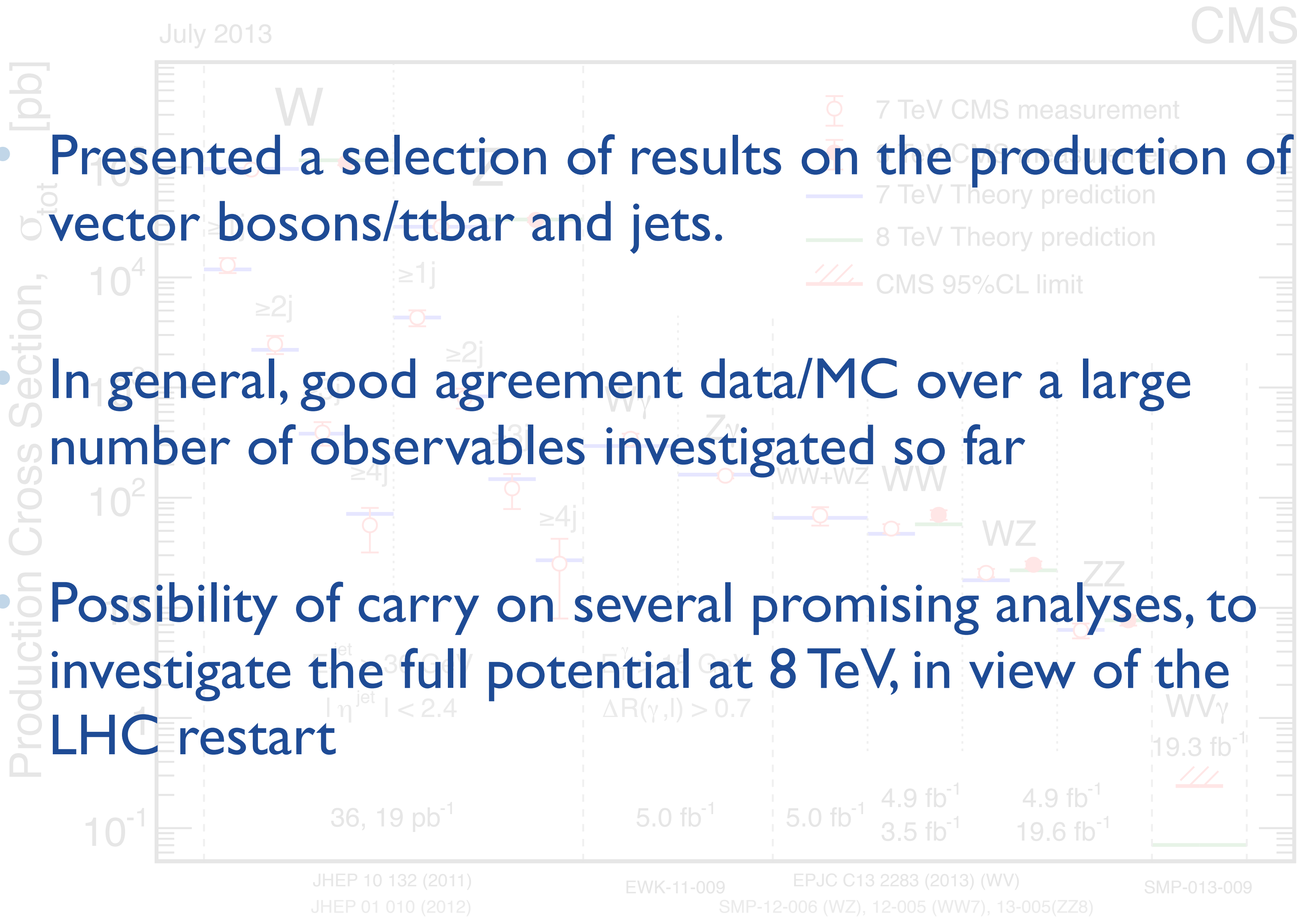








Conclusions

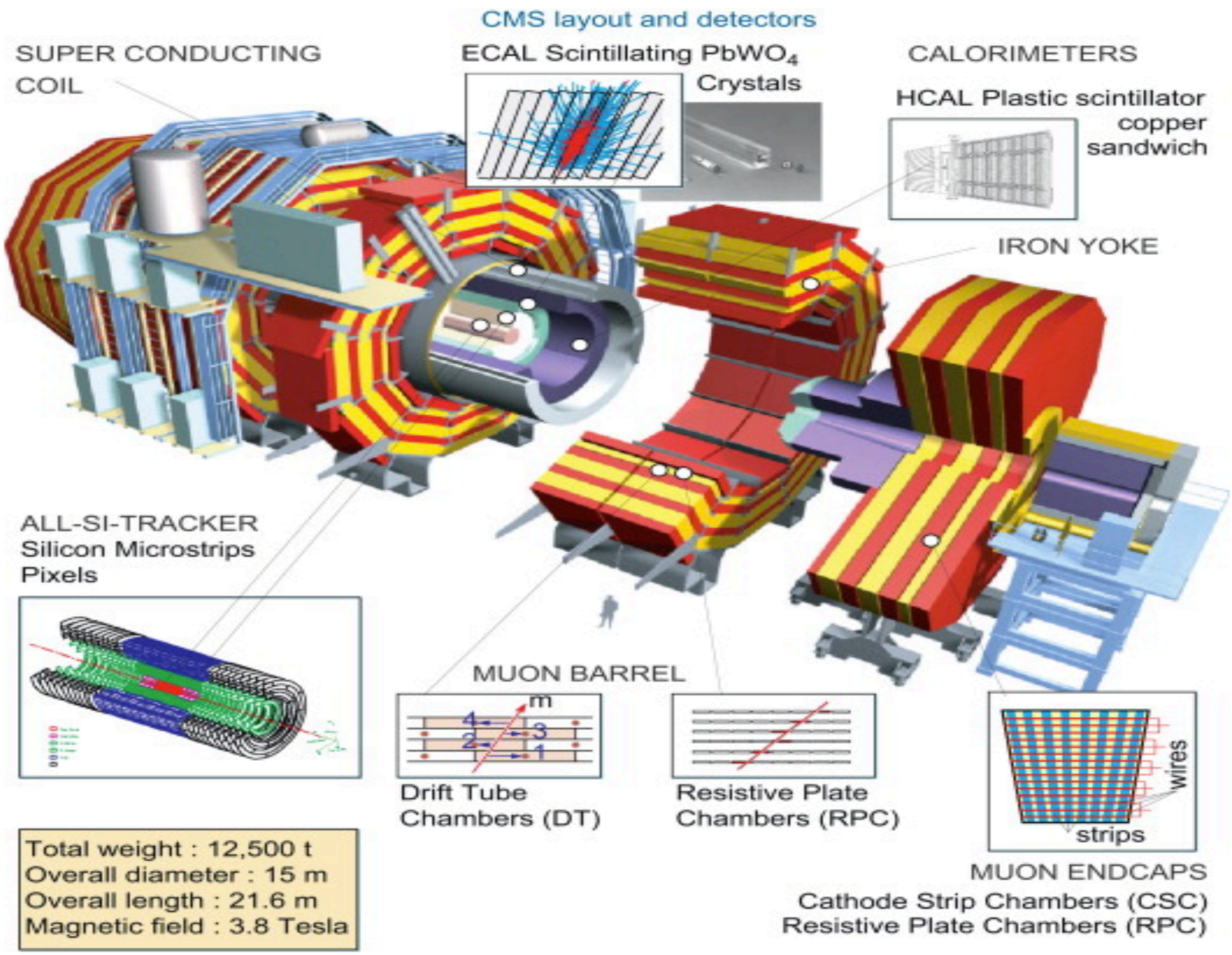


- Presented a selection of results on the production of vector bosons/ttbar and jets.
- In general, good agreement data/MC over a large number of observables investigated so far
- Possibility of carry on several promising analyses, to investigate the full potential at 8 TeV, in view of the LHC restart

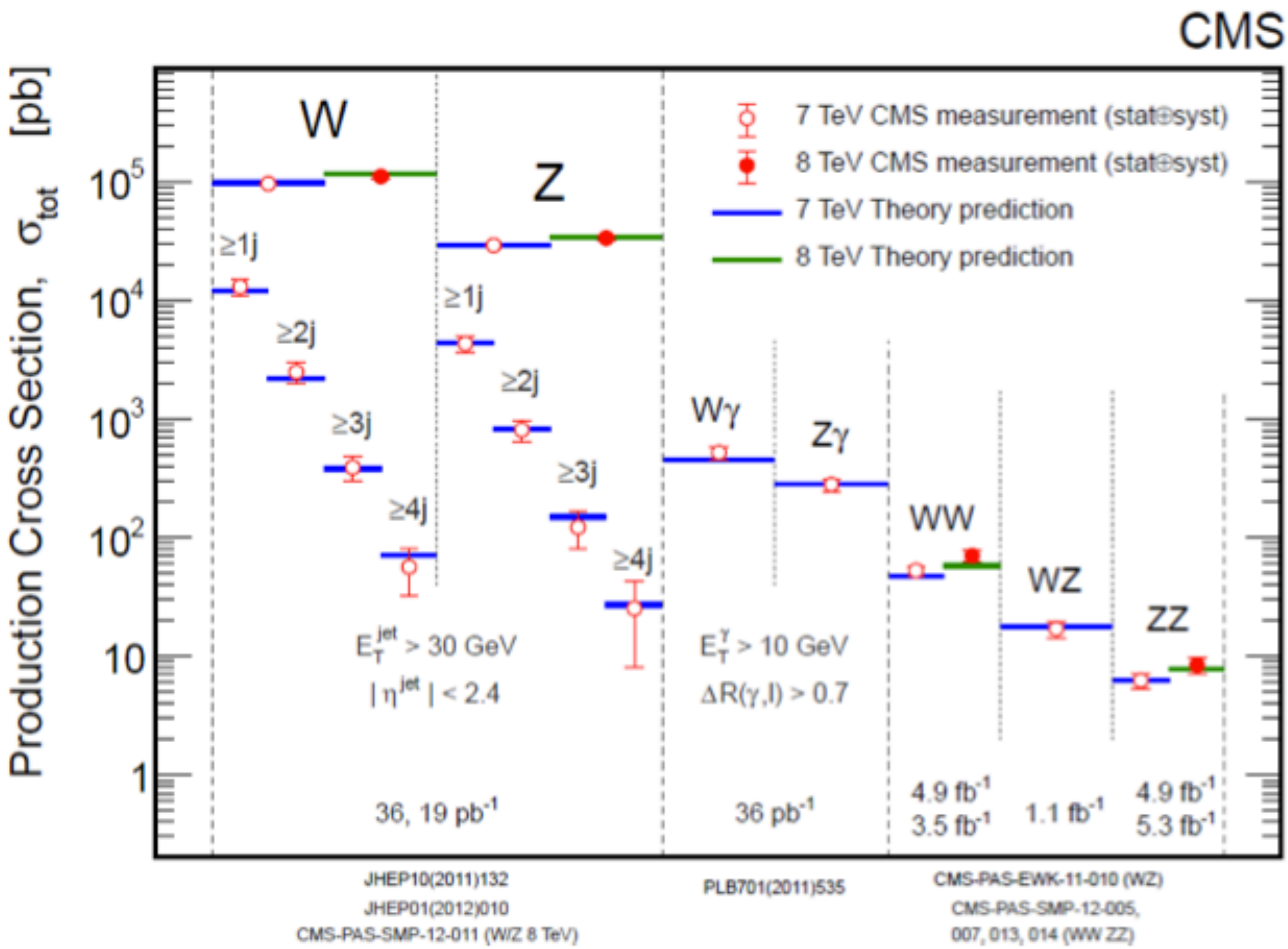
Backup

Backup

CMS Detector



Standard Model @ CMS

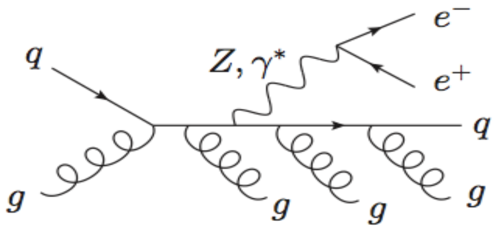


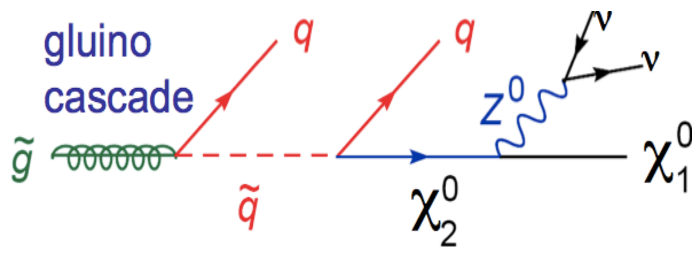
Physics Motivations in V+jets

The associated production of a boson and jets is a test of the Standard Model (SM)

- Test the perturbative Quantum Chromodynamics predictions (pQCD)
    - NLO calculation available for the Z/W boson
    - Data driven method to tune different theoretical models of the process

- SM Background to New Physics processes
    - Huge variety of processes involving multiple jets in searches
    - SUSY (gluino cascades), Dark Matter, 4th generation





- SM Background to Higgs Physics (HZ with H to bb pair, ZZ to lepton+jets...)

- Constraints to Parton Density Function (PDF), at various center of mass energies

Other motivations for V+jets

- Can be also useful for detector calibrations:
  - Jets recoiling against a Z can be utilized to calibrate the jet energy

- It is an important test bench to probe a wide number of MC generators:
  - Leading Order (LO) MC + Matching Parton Shower (PS):
    - Alpgen, MadGraph, Sherpa
  - Fixed Order Next-to-Leading Order (NLO):
    - aMC@NLO, BlackHat
  - Fixed Order NLO + PS:
    - Powheg, Pythia (Z+>=1 Jet)

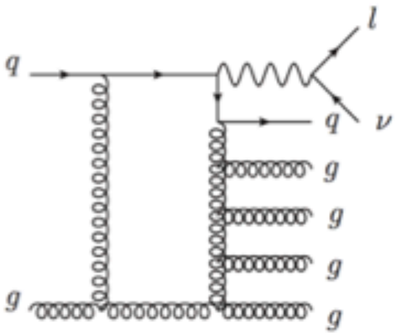
	3+ years ago	today
W/Z	NNLO	NNLO
V+1j	NLO	NLO+PS
V+2j	NLO	NLO
V+3j	LO	NLO
V+4j	LO	NLO
V+5j	LO	NLO soon

Review of MC in the market

- LO matrix element + matching to parton shower (PYTHIA, HERWIG)
  - **ALPGEN**, **MADGRAPH**, **SHERPA** (CKKW or MLM matching)
- Fixed-order NLO calculation
  - **Blackhat-Sherpa**: NLO up to Z + ≥4 jets W + ≥5 jets

NEW

  - **Rocket + MCFM**: NLO up to W/Z + ≥3 Jets
  - **MCFM**: NLO up to W/Z + ≥2 Jets
- Fixed-order NLO + parton shower for Z+ ≥1 Jet
  - **POWHEG** + **PYTHIA**
- Resummation
  - **HEJ**: all-order resummation of perturbative contribution of wide angle emission (for ≥2 Jets)
- Approximate NNLO for Z+ ≥1 Jet
  - **LOOPSIM+MCFM**, JHEP 1009 (2010) 084
- NLO QCD ⊗ NLO EW
  - JHEP 1106 (2011) 069



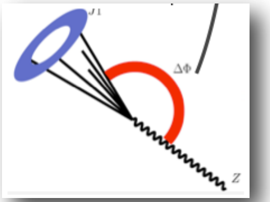
Event Shape Observables

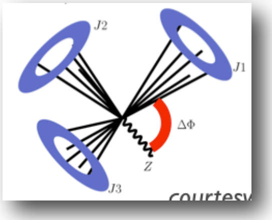
- Differential cross section as a function of:
  - azimuthal angles $\Delta\Phi(Z,J_i)$ i = 1,2,3
  - $\Delta\Phi(J_i,J_k)$ i,k = 1,2,3
  - transverse thrust

A. Banfi, G.P. Salam, G. Zanderighi, JHEP 0408 (2004) 062

$$\tau_\perp \equiv 1 - \max_{\vec{n}_\tau} \frac{\sum_i |\vec{p}_{T,i} \bullet \vec{n}_\tau|}{\sum_i p_{T,i}}$$

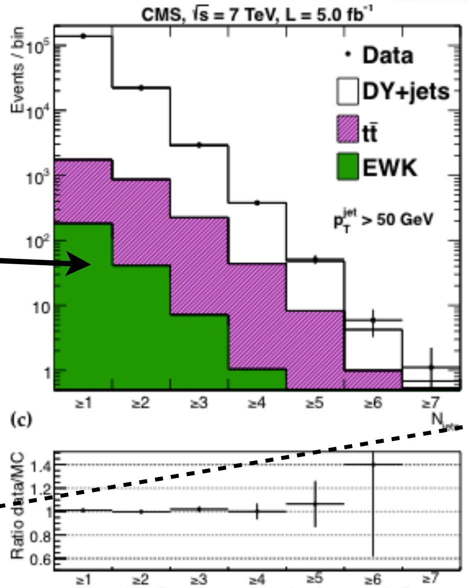
Pencil-like: $\tau_\perp \sim 0$ Spherical: $\tau_\perp \sim 1-2/\pi$

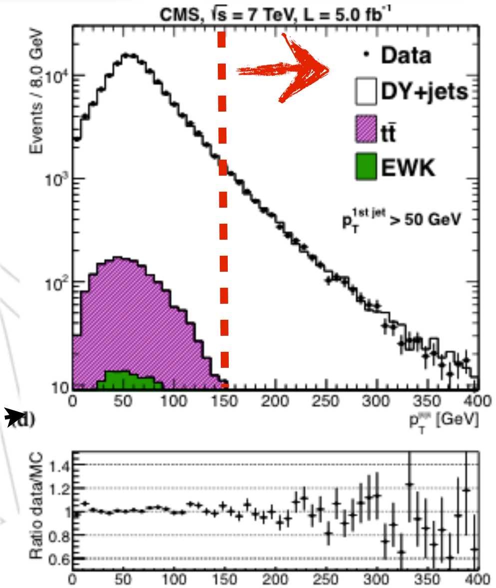




In the limit of a **perfectly balanced** (pencil-like) Z + 1 Jet tends to **zero**. With additional jets, the value increases. The largest possible value is reached in the limit of a spherical, homogeneously-distributed event.

To investigate the dependence of the topological properties on the complexity of the final state, events categorized as a function of the Jet Multiplicity.





Measurement performed also in the boosted regime ($Z(P_T)$ >150 GeV)

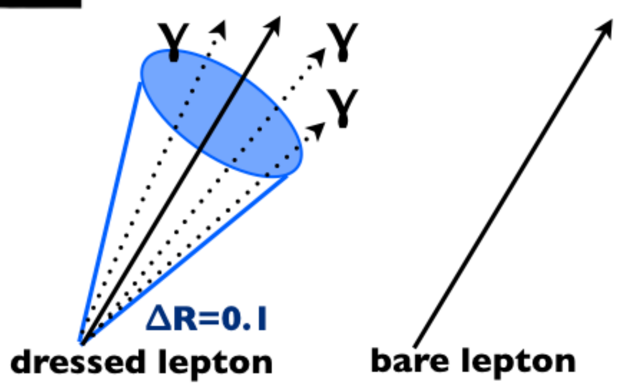
Unfolding Strategy

- In order to measure cross sections, the following quantities have to be evaluated:

$$\frac{d\sigma}{dx} = \frac{(N_{data} - N_{bkg})}{\varepsilon \times L \times \Delta x}$$

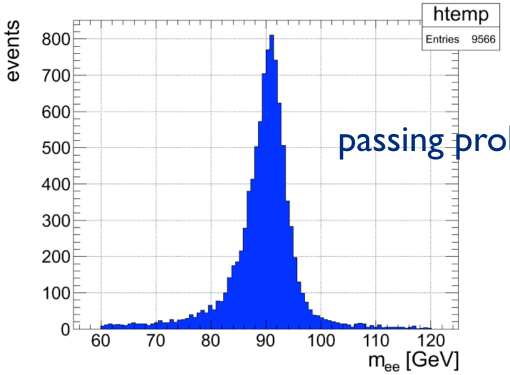
- Estimate background contribution and efficiencies
- Unfold in order to bring back results at particle level

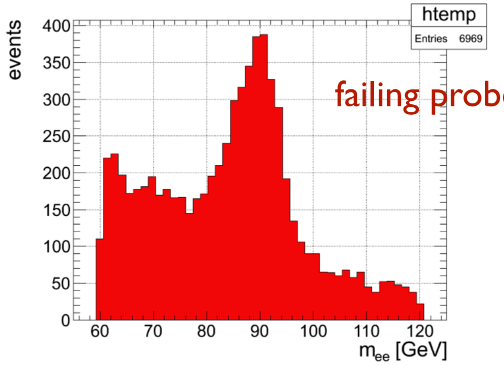
- Apply photon and lepton recombination

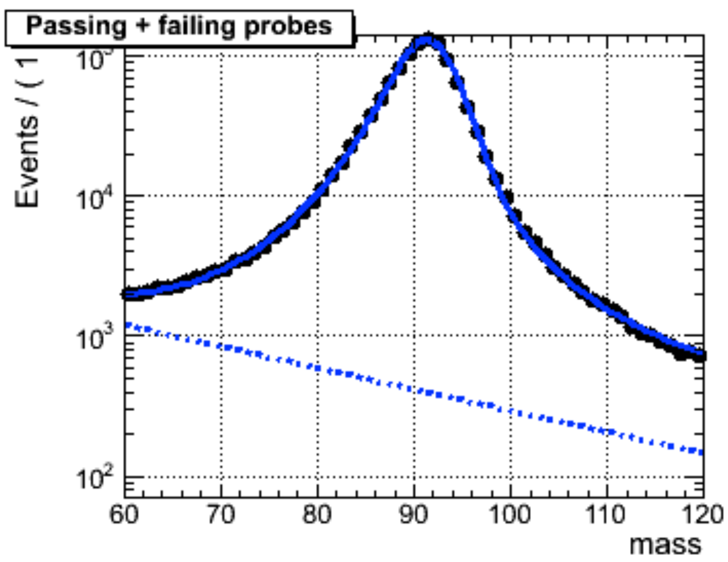


Tag And Probe (TAP) Method

- Efficiencies evaluated with the data driven Tag & Probe method:
  - select Z candidates sample by requiring a “tag” electron with very tight requirements
  - the second "probe" electron is used to test the event selection efficiency. The invariant mass of the two electrons is then computed in a window around the Z mass
  - filled different distributions for **passing** and **failing**







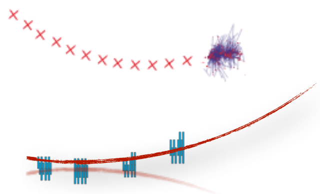
$$\varepsilon = \frac{n_{signal}^{(pass)}}{n_{signal}^{(pass)} + n_{signal}^{(fail)}}$$

- Perform a **simultaneous** fit to the “passing” and “failing” distributions to extract the efficiencies

Event and Jet Selection

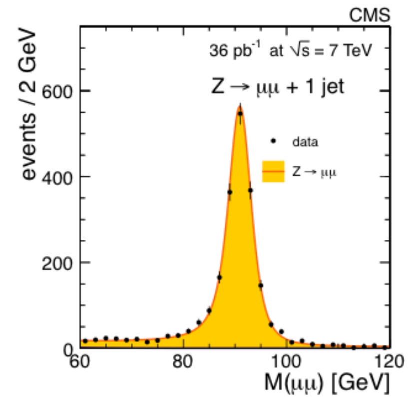
Leptons

- Electrons: p_T > 20 GeV, $|\eta|$<2.4 (no crack)
- Muons: p_T > 20 GeV, $|\eta|$<2.4
- Subtract PU ("ρ Fast Jet Method")
- Isolation Criteria



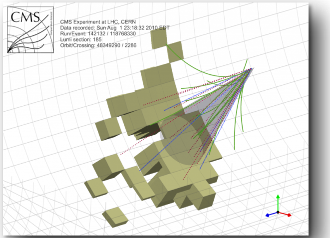
Bosons

- Z: Lepton opposite charge, cuts on lepton invariant mass
- W: cut on missing energy (using M_T variable)

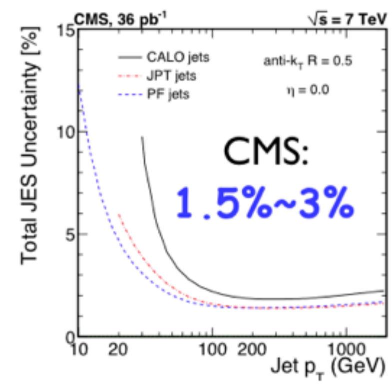


$M_T=\sqrt{(2p_{TL}\not{E}_T\,(1-\cos\Delta\Phi))}$

Jets Selection



- Correct for the Jet Energy Scale
- Anti-KT jets in $|\eta|$ < 2.4 (2.1) ΔR=0.5
- Separation lepton-jet required



Rho Fast-Jet Method

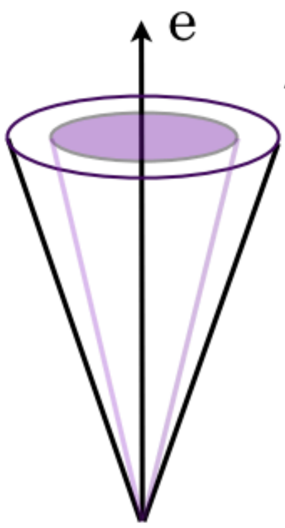
Isolation

$$Iso = [\sum_{ECAL,HCAL,TRK}^{\Delta R<0.3} E_T] - p_T^e$$

Isolation pile-up corrected

Rho FastJet Method

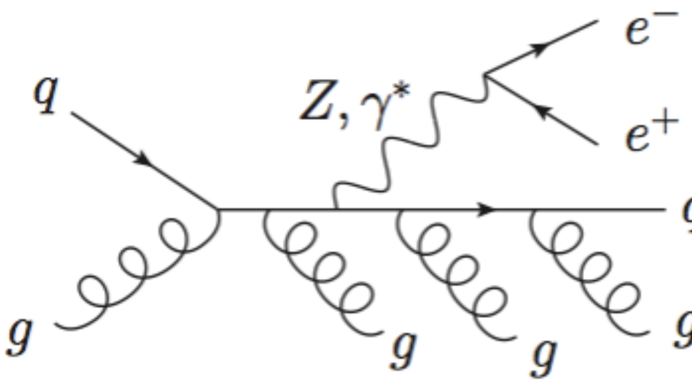
$$Iso_{PUR} = Iso - \rho S$$



$\Delta R = [(\Delta \eta)^2 + (\Delta\phi)^2]^{1/2}$

- ϱ = *energy density*
  energy per unit of area
  in the jet
  (PU energy event by event)

- S = *effective area*
  jet area weighted with
  iso dependence wrt vtxs

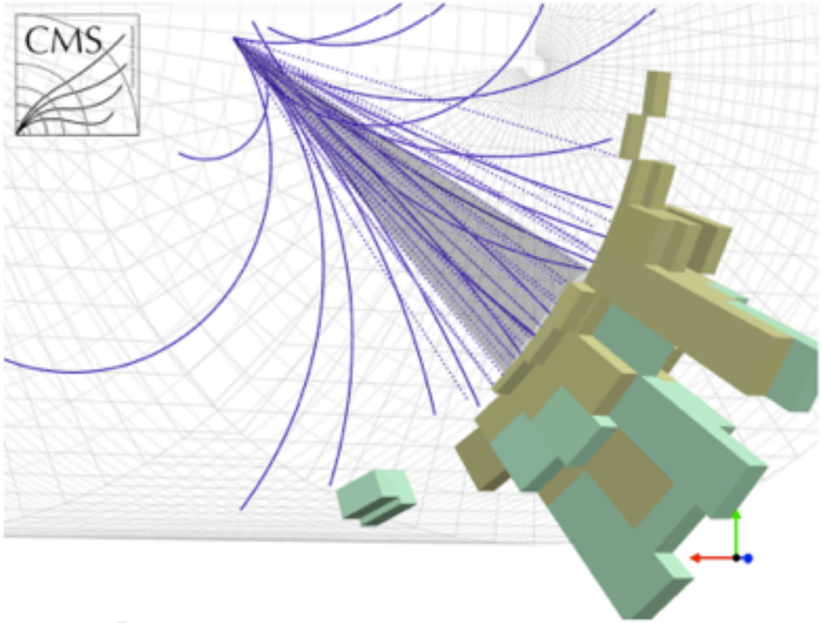


isolated electrons

jet energy

Jet Energy Corrections

Jet reconstruction in CMS: Particle Flow
combines information from all CMS sub-detectors



- simply:
  Jets energy is difficult to measure.

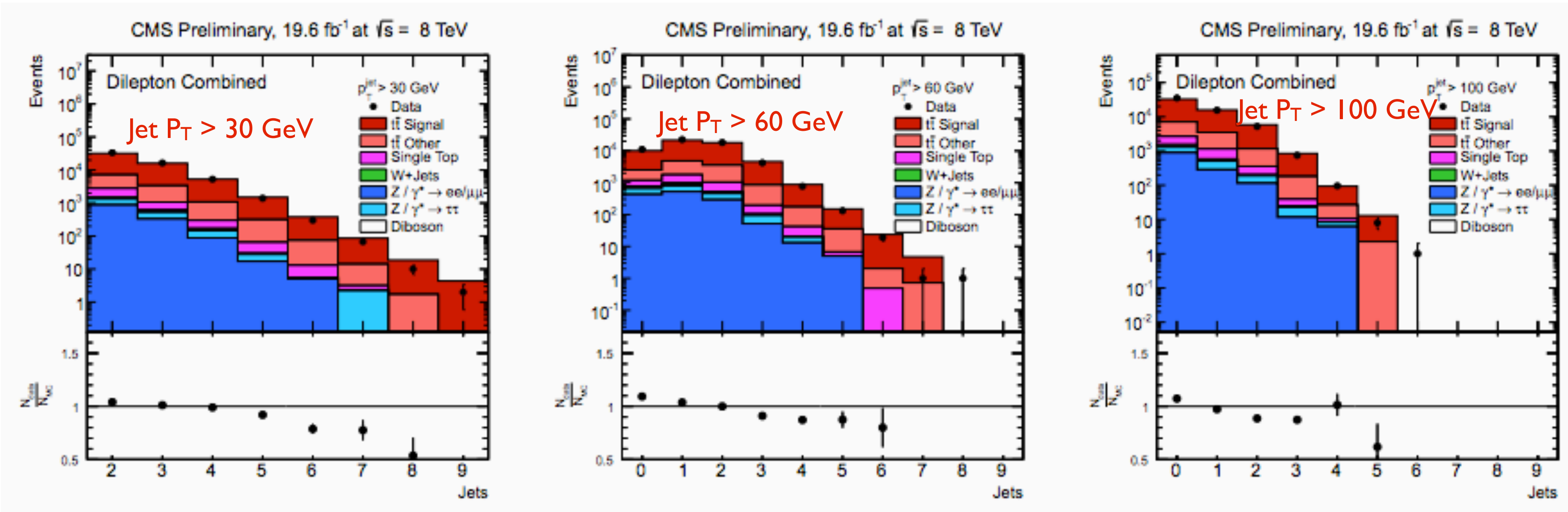
- Main issue: correct the jet energy

HCAL response
In CMS decompose correction into indipendent factor then apply in a fixed sequence (levels)

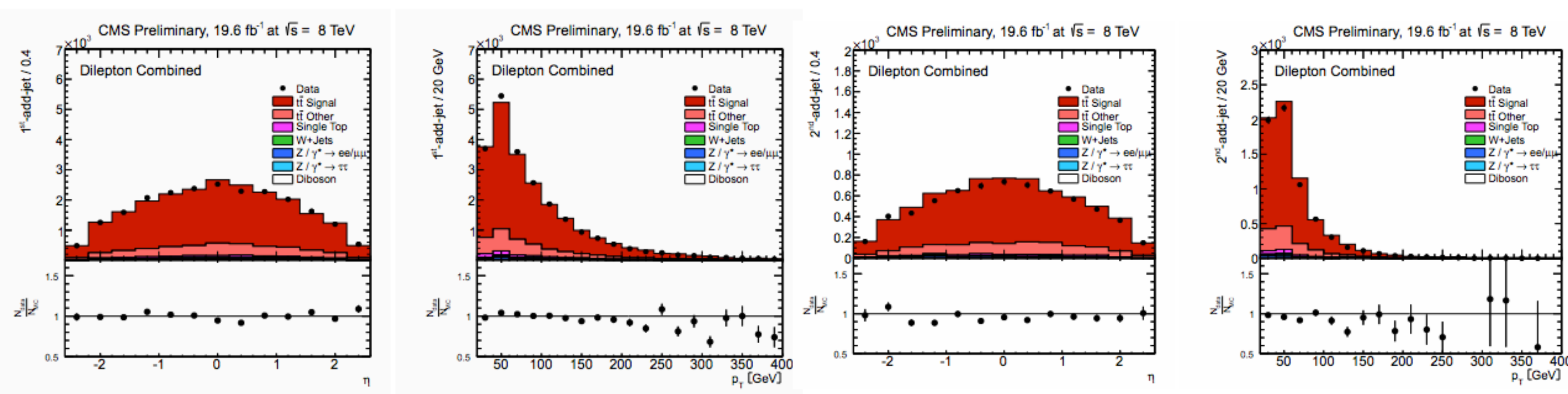
RECO JET → CALIB JET

LVL1	Offset	pile-up removal
LVL2	Relative	jet response uniform with η
LVL3	Absolute	CaloJet pT uniform to particle level
LVL4	EM	jet response in e.m. energy component
LVL5	Flavour	flavour dependence
LVL6	Parton Jet	<CaloJet pT = parton pT>

Jet Multiplicity in top pair events (2 leptons) @ 8 TeV

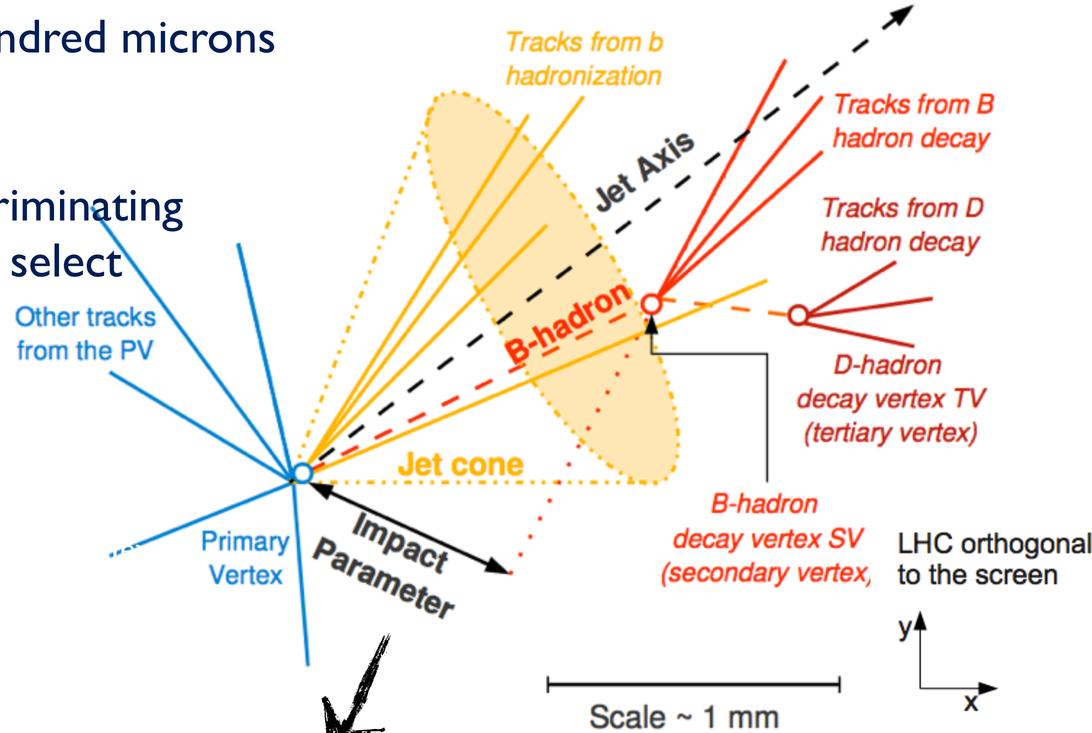


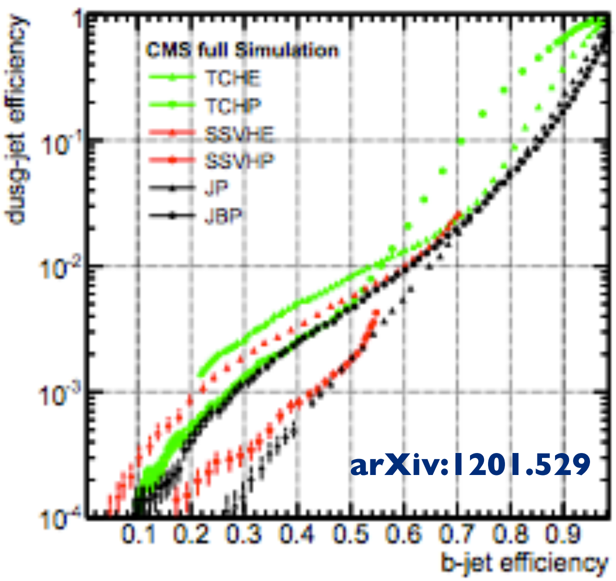
- Same observables as for the 7 TeV, with 3 pt thresholds

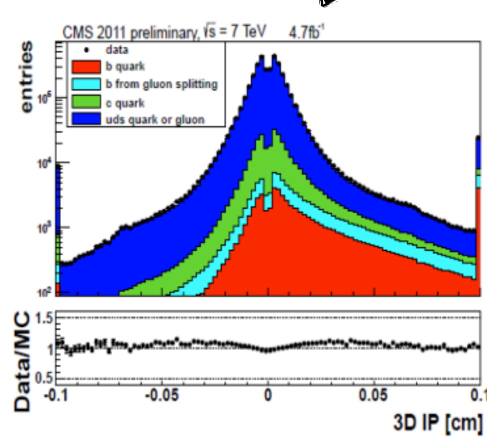


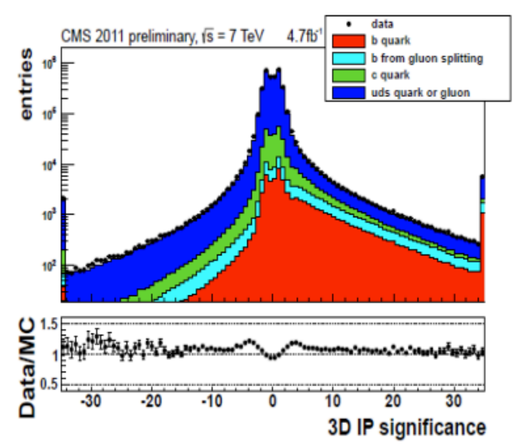
B Tagging in a nutshell

- Typical IP order of magnitude is few hundred microns (IP uncertainty ~10-100 um)
- Use Track IP significance $S = IP / \sigma_{IP}$
- In the SSV algorithm S is used as a discriminating variable on which the user can cut on to select different regions in the efficiency versus purity phase space.









Analysis Working Point: (mis)tagging fakes (udsg) jets estimated to be 1%