Searches with heavy quarks at CMS

-Search for Resonances in TTbar Mass Spectrum (PAS-TOP-10-007)
-Search for a Heavy Bottom-like Quark (hep-ex:1102.4746)

Nicolas Beaupère, Lyon le 20/04/2011

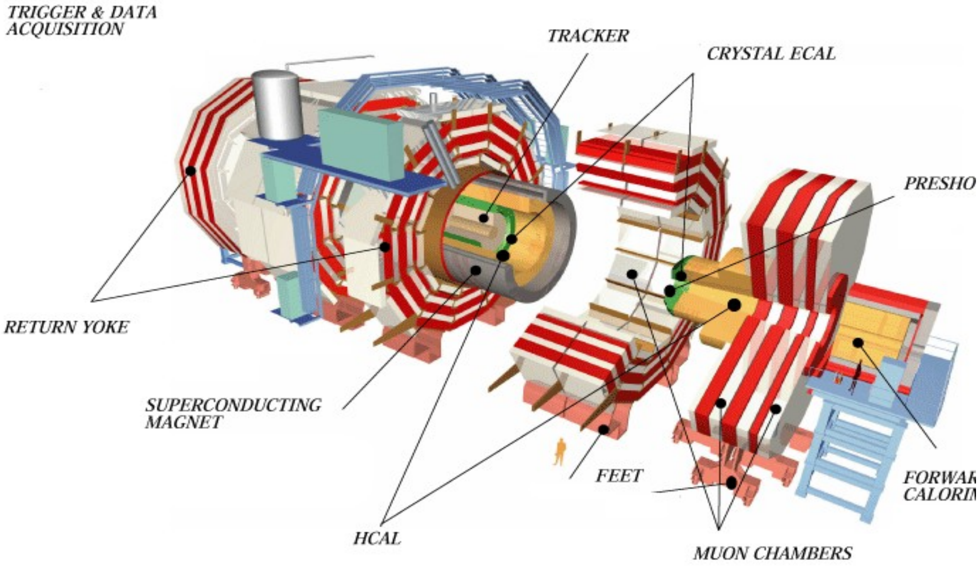
CMS detector

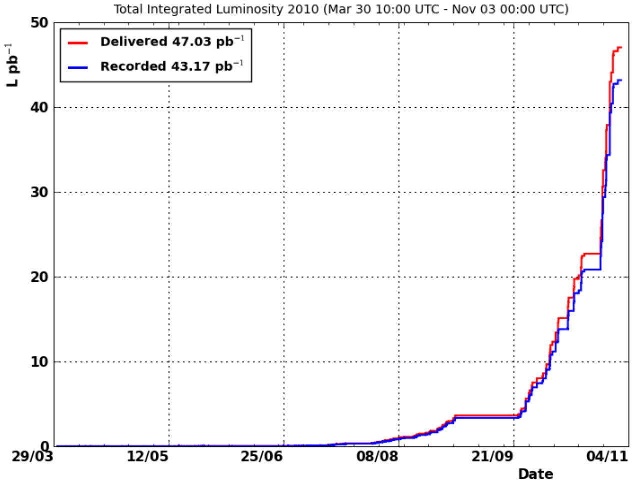
Main LHC features :

- $\sqrt{s} = 7\,TeV$
- $\mathcal{L} = \frac{N^2 k_p f}{4\pi\sigma_x\sigma_y}$

→ max = 2.5×10^{32} $cm^{-2}.s^{-1}$

N : nb of proton per bunch ~ 10^{11}
k_p : nb of bunchs → max = 348
f : collision frequency → max = 150 ns
σ : transverse section of bunch



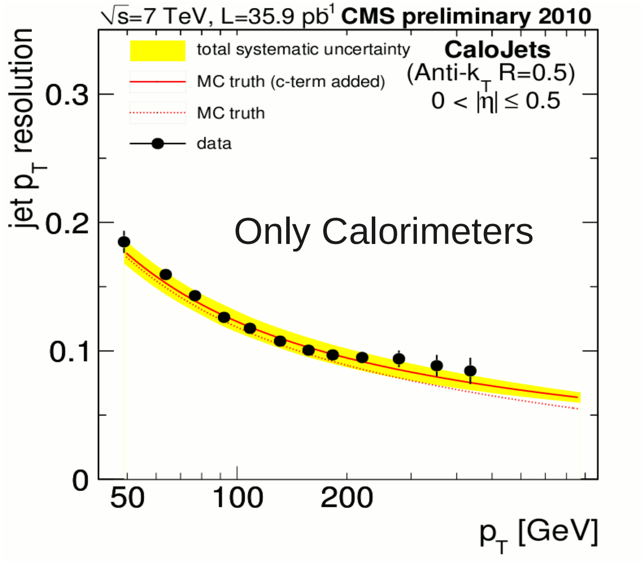


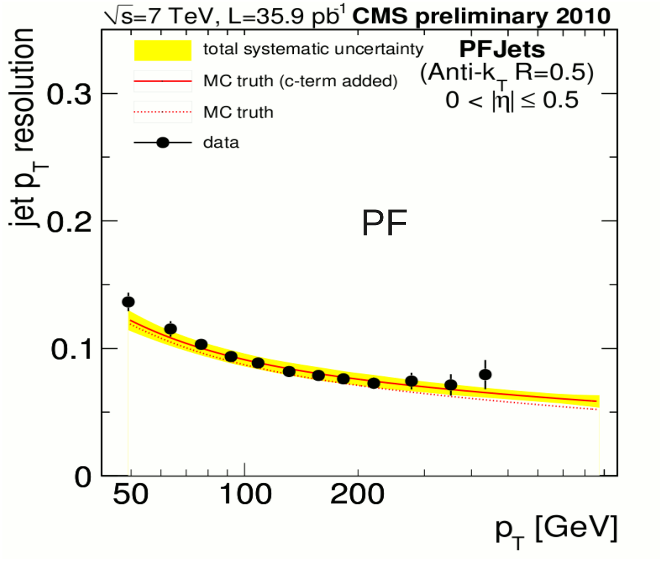
These two analyses used 36 ($M(t\bar{t})$) and 34 ($b'\bar{b}'$) pb^{-1} of 2010 LHC run

CMS detector : Physics objects

Particle flow algorithm :

- Algorithm which attempts to reconstruct all particles in the event
- Use information of all sub-detectors
- Reconstructs higher level physics objects (jets, MET, Tau) with :
  ⇒ better resolution





Outline

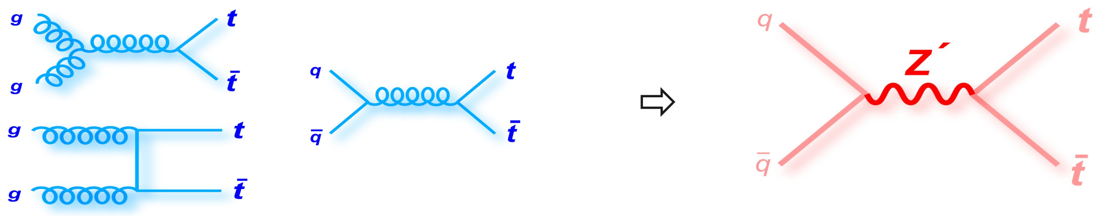
- Signal and background modeling
- Event selection
- m(ttbar) reconstruction
- Background estimation
- Data-MC comparison
- Systematic uncertainties
- Result

$t\bar{t}$ analysis

-Search for Resonances in TTbar Mass Spectrum (PAS-TOP-10-007)

Motivation

- Extensions of Standard Model predict :



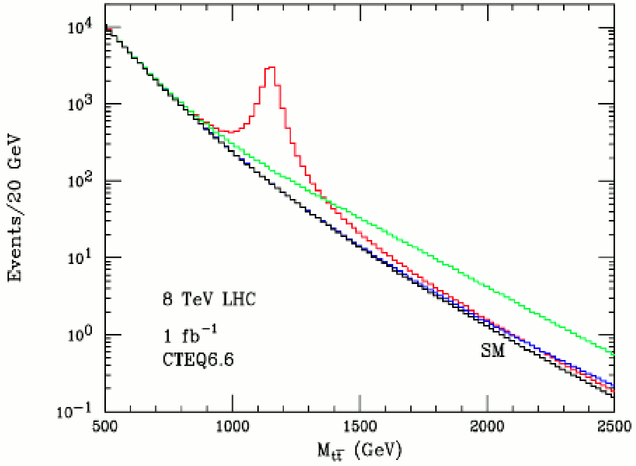
- Each top quark decays to b quark and W boson :

$$t\bar{t} \longrightarrow bW^{+}\bar{b}W^{-}$$

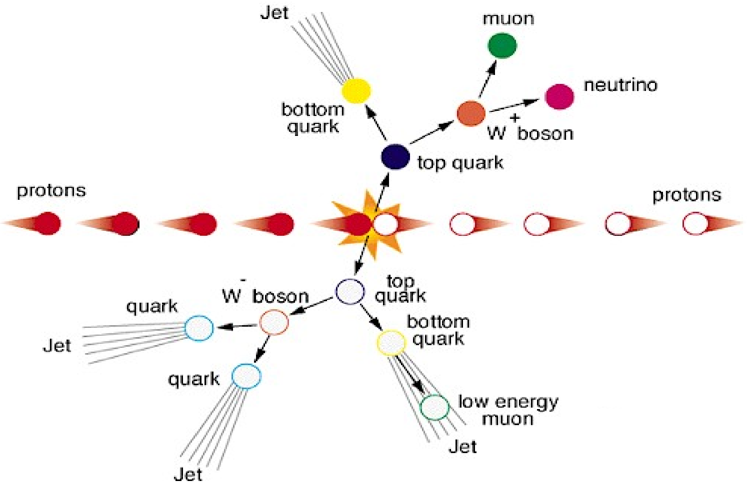
- One W boson decaying hadronically

- The other W decaying into a lepton + neutrino

Semi-leptonic channel



Axigluon model inspired by CDF top charge asymmetry
Y. Bai et al, arXiv:1101.5203v1



Experimental signature :

- 4 or more hard jets (2 from b quarks)
- 1 hard lepton
- Missing transverse energy

Motivation

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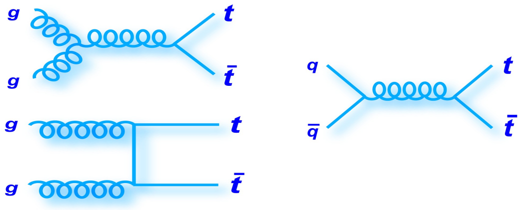
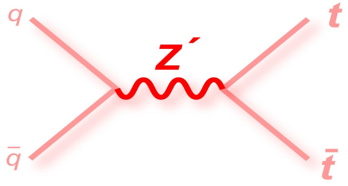


⇨



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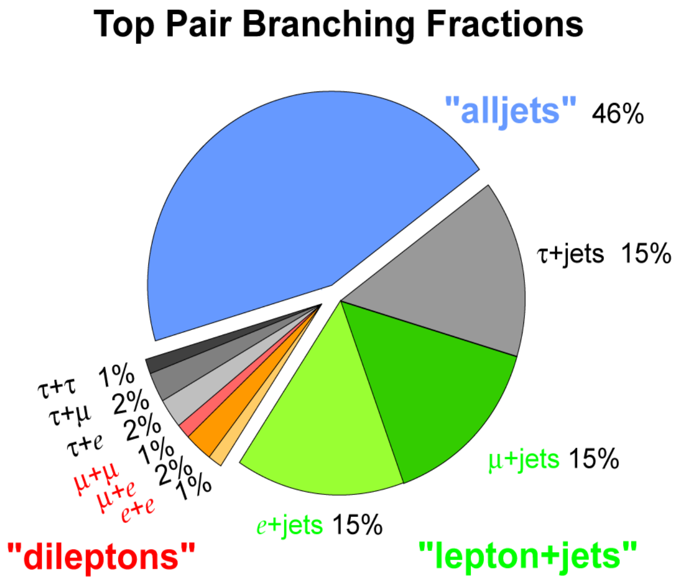
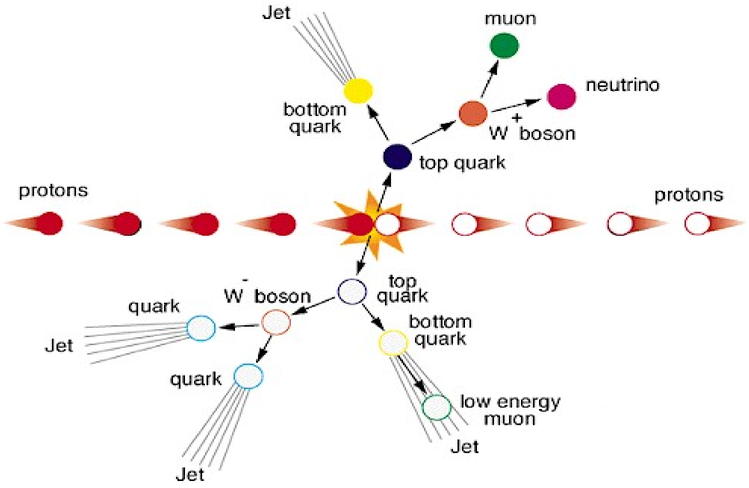




Signal and Background modelling

Z' signal into ttbar decay : MadGraph
mass range [0.5-2] TeV and narrow width set to 1% of its mass ⇨ **Generic resonance**

W/Z boson + jets : MadGraph
→ matched with parton shower via the MLM algorithm (hep-ph/0602031)

QCD multi-jet : Pythia6

SM top quark pair : MadGraph
MC@NLO to provide a cross check

Single top : MadGraph

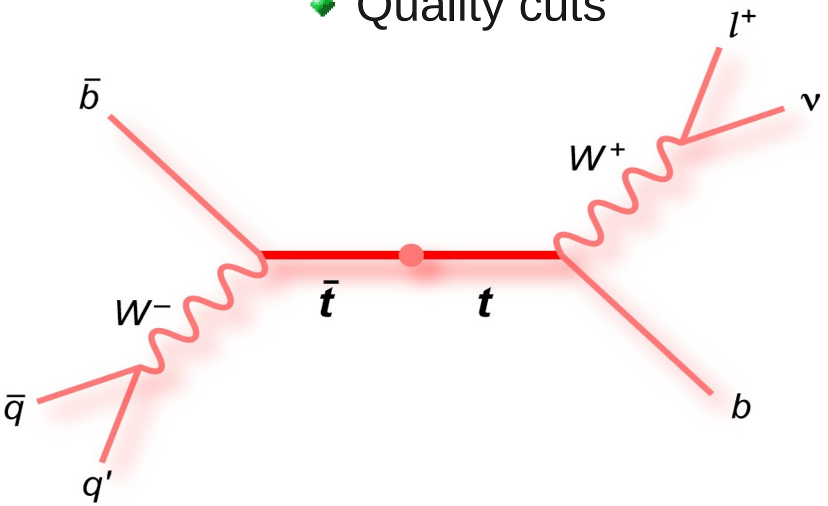
All the MC events are simulated with CMS reconstruction software

Remark : MadGraph, Pythia6 and MC@NLO use CTEQ6L PDFs

ttbar selection

Only one isolated lepton

- Pt > 20 (30) GeV for μ(e)
- $|\eta|$< 2.1 (2.5) for μ(e)
- Quality cuts

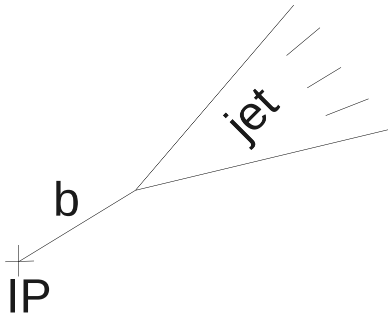


MET > 20 GeV

At least 3 jets

- Pt > 70, 50, 30 GeV
- $|\eta|$ < 2.4
- Corrected for detector response
- Quality cut

- b-tagging :
  - use secondary vertex algorithm to flag jets from b quarks



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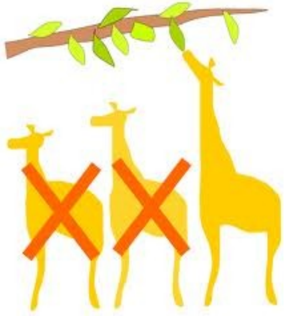

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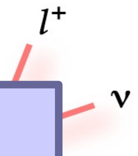

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Final selection step

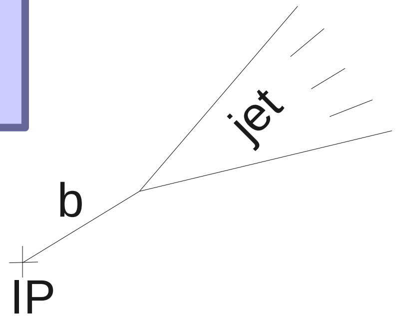
divide events in 8 categories :

- 3 jets with 1 b-tagging
- ⩾4 jets with 0 b-tagging
- ⩾4 jets with 1 b-tagging
- ⩾4 jets with 2 b-tagging

⇒ x 2 (muons/electrons)

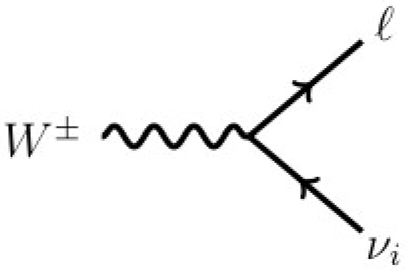
- b-tagging :

  - use secondary vertex algorithm to flag jets from b quarks



M(ttbar) reconstruction

3 steps :



- neutrino reconstruction :
  W decays to lepton + undetected neutrino
  → use W Mass (80.4 GeV) constraint to compute neutrino longitudinal momentum

- jet - parton (b quarks and quarks from W) association :
  Compute χ^2 for each possible combination
  Use lowest χ^2 to match :

$$\chi^2 = \Sigma\, \chi_i^2 = \Sigma \frac{(x_i^{meas} - x_i^{ref})^2}{\sigma_i^2}$$

b-tagging also used to increase jet association efficiency
⇨ Association is correct in 80 % of events in simulation

χ^2 terms
Leptonic Top Mass
Hadronic Top Mass
Hadronic W Mass
Pt of ttbar System
Fraction of Total Ht in Selected Jets

- kinematic fit to optimize the selected object variables :

Optimized variables	Constraints parameters
Neutrino : (Px,Py,Pz)	W mass = 80.4
Lepton : E	Top mass = 172.5
Jets : E	

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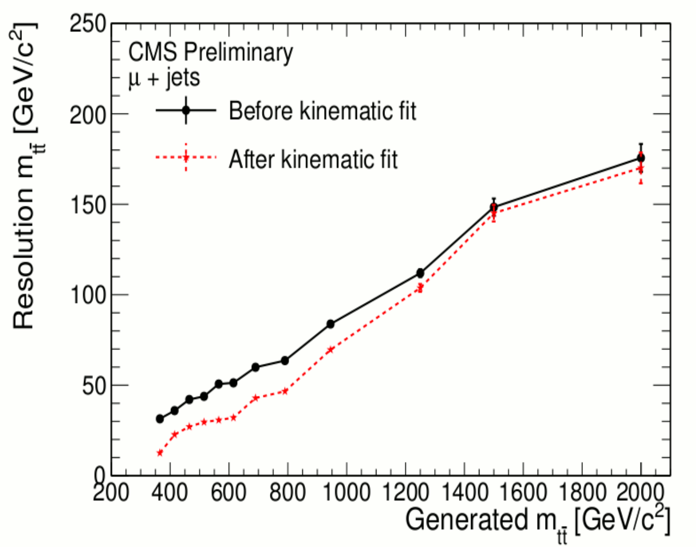

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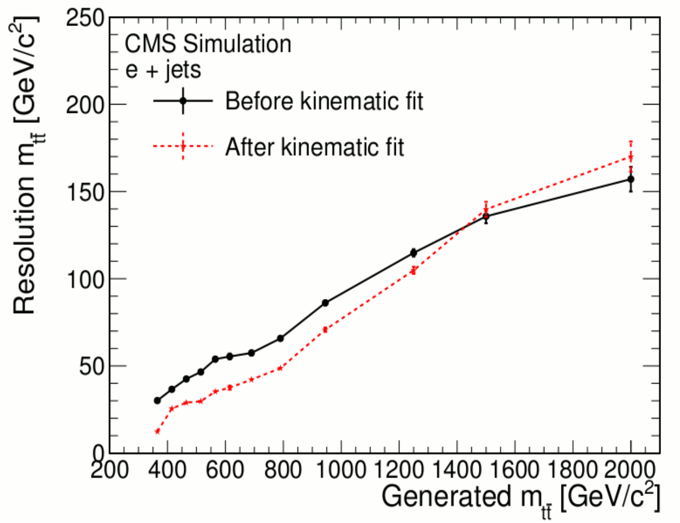

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Background estimate

Important part of the analysis to then extract Signal from Background

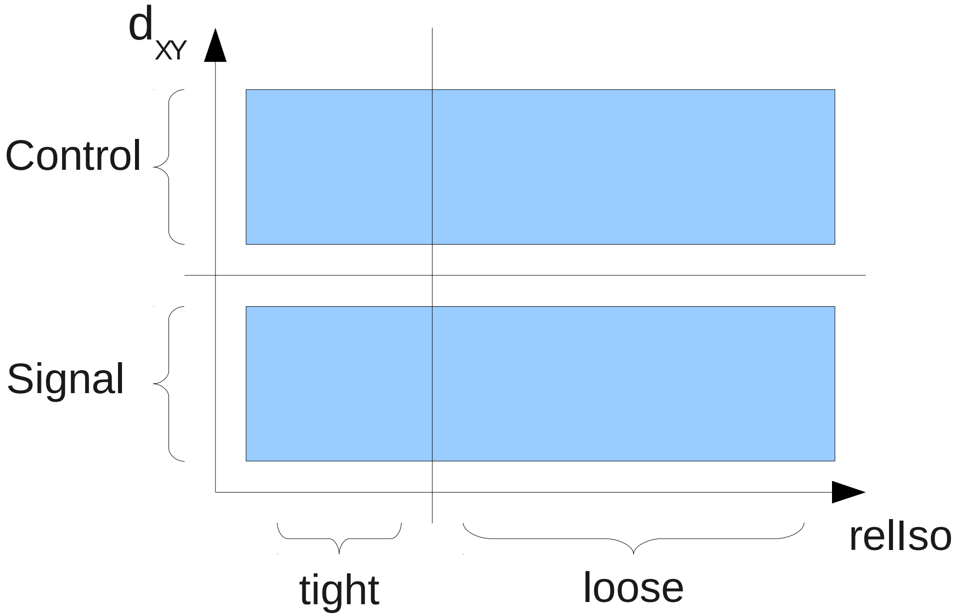
- QCD multi-jet events :

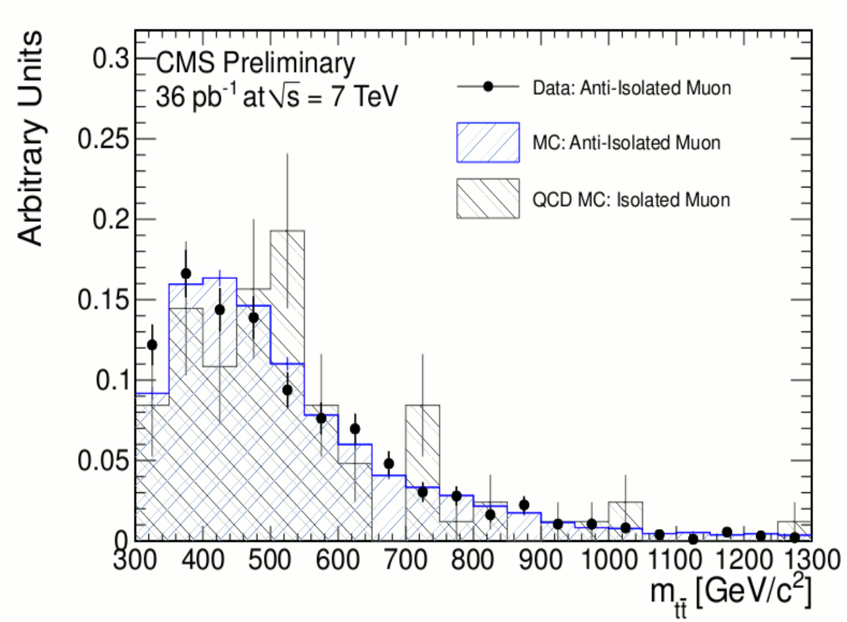
  Data driven estimate with Matrix method :

  - QCD efficiency from control region

  - Number of QCD events from :

$$N^{QCD}_{tight} = \epsilon_{QCD} \frac{\epsilon_{W+Jets} N^{total}_{loose} - N^{total}_{tight}}{\epsilon_{W+Jets} - \epsilon_{QCD}}.$$

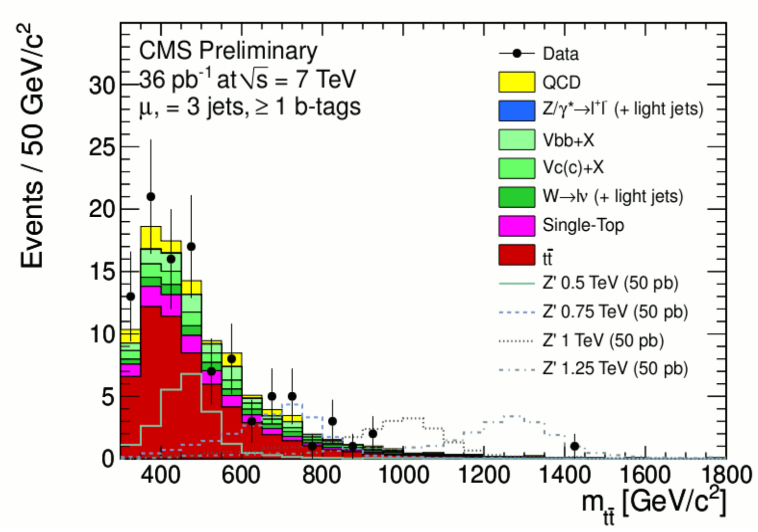


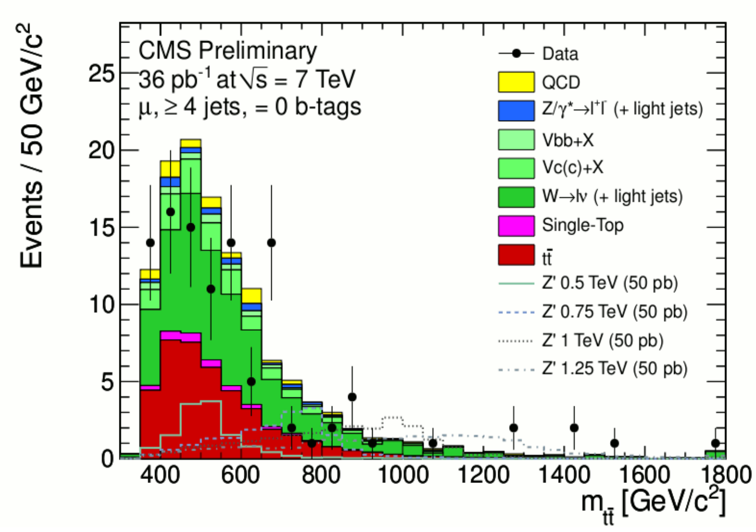


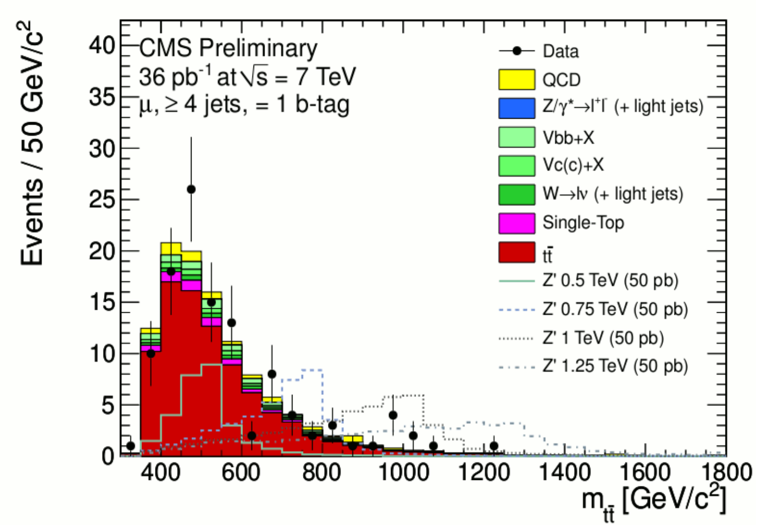
- W + jets events
- Top pair events
- Single top, ...

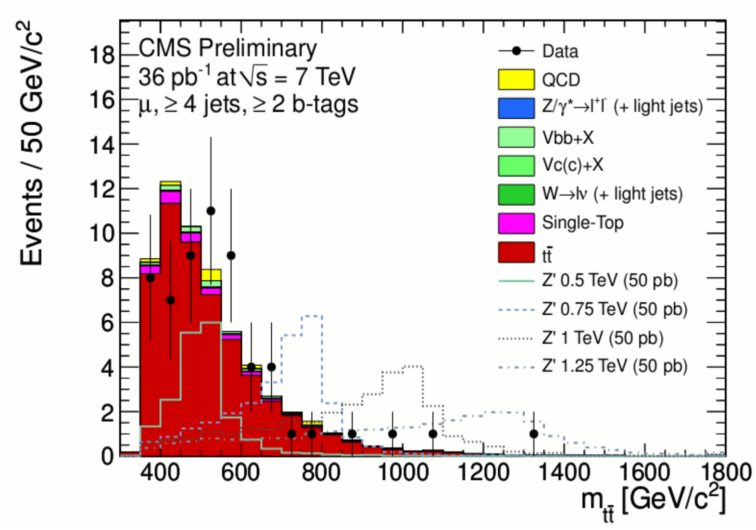
Obtained from simulation (using theoretical cross-section)

Data – MC comparison : Muon channel



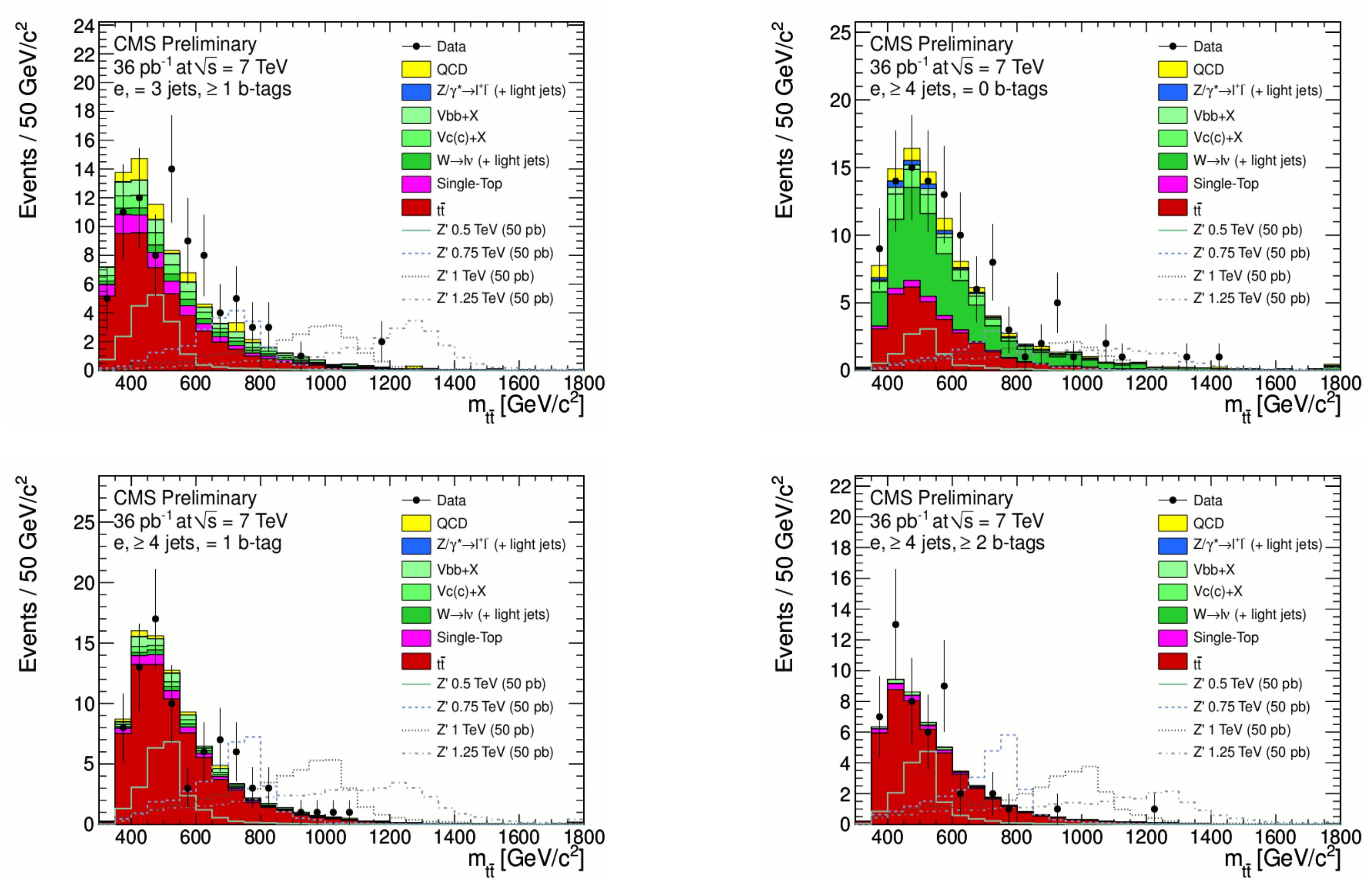






Yield	tt	W/Z+LF	W/Z+HF	Single-top	QCD	Data	Sum BG
μ4j2t	51.6±0.4	0.1±0.0	2.4±0.2	2.0±0.0	1.0±1.0	58±7.6	57.1±1.1

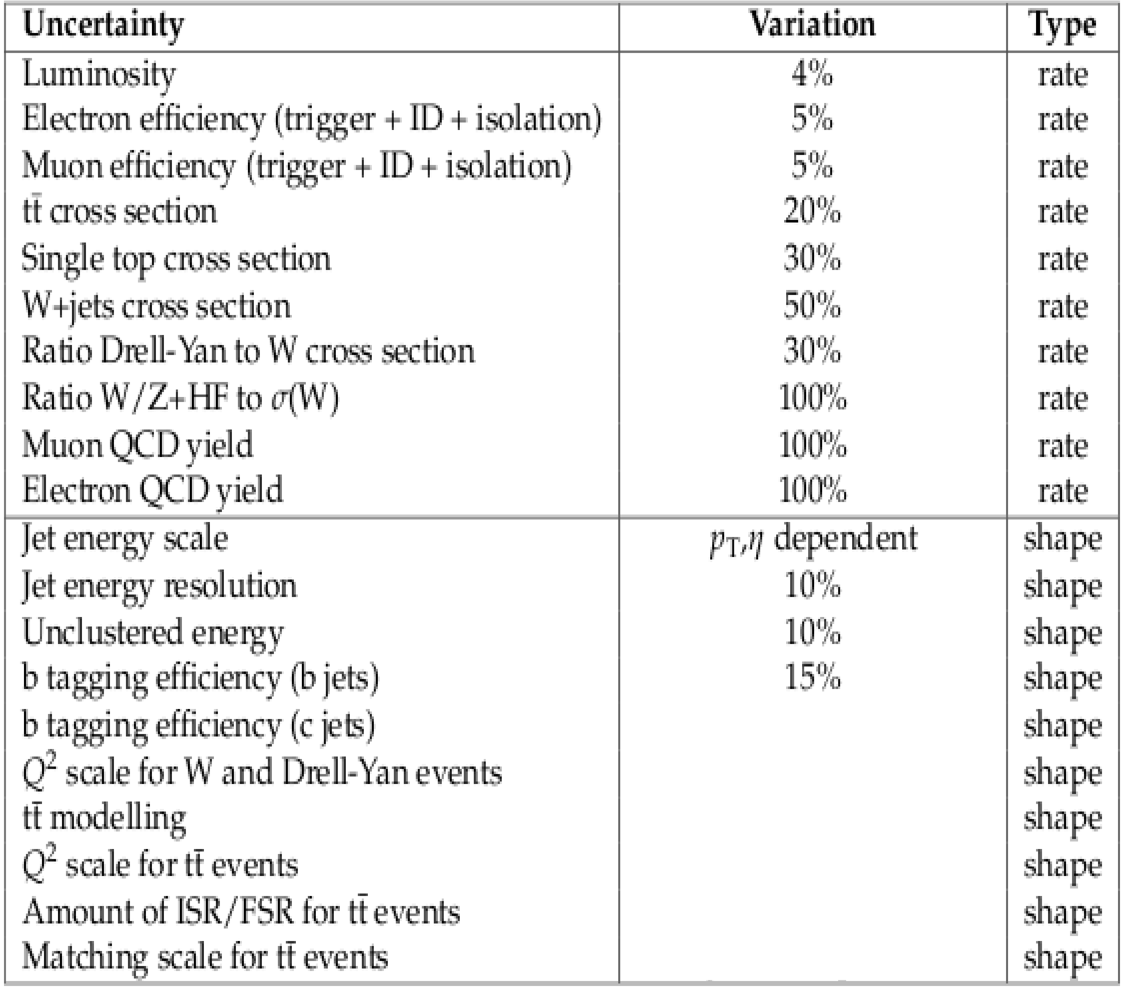
Data – MC comparison : Electron channel



Yield	tt	W/Z+LF	W/Z+HF	Single-top	QCD	Data	Sum BG
e4j2t	40.9±0.4	0.1±0.0	2.1±0.2	1.5±0.0	0.1±0.1	50±7.1	44.6±0.5

Systematic Uncertainties

2 different types :



Uncertainty	Variation	Type
Luminosity	4%	rate
Electron efficiency (trigger + ID + isolation)	5%	rate
Muon efficiency (trigger + ID + isolation)	5%	rate
$t\bar{t}$ cross section	20%	rate
Single top cross section	30%	rate
W+jets cross section	50%	rate
Ratio Drell-Yan to W cross section	30%	rate
Ratio W/Z+HF to $\sigma(W)$	100%	rate
Muon QCD yield	100%	rate
Electron QCD yield	100%	rate
Jet energy scale	p_T,η dependent	shape
Jet energy resolution	10%	shape
Unclustered energy	10%	shape
b tagging efficiency (b jets)	15%	shape
b tagging efficiency (c jets)		shape
Q^2 scale for W and Drell-Yan events		shape
$t\bar{t}$ modelling		shape
Q^2 scale for $t\bar{t}$ events		shape
Amount of ISR/FSR for $t\bar{t}$ events		shape
Matching scale for $t\bar{t}$ events		shape

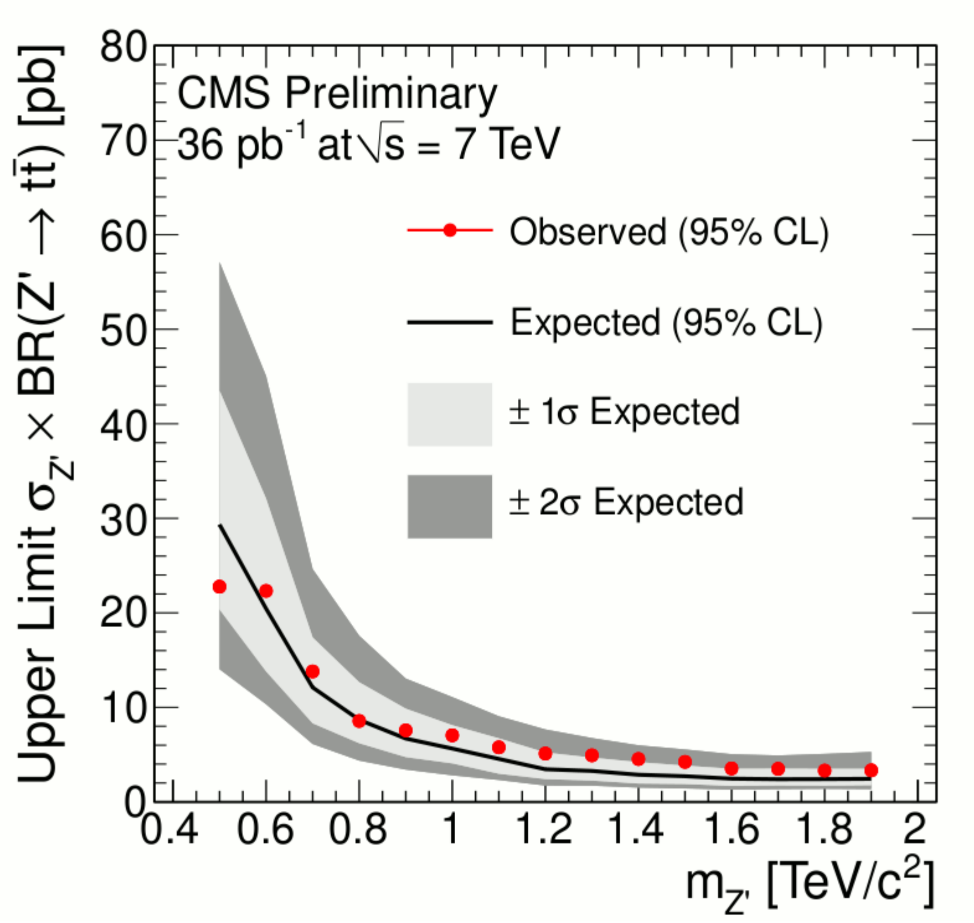
Use data Tag and probe method with Z + jets events

Theoretical uncertainties

Experimental uncertainties

Result : limit Curve for Z' production

Expected and observed upper limits



$$\begin{aligned} n_k(m_{t\bar{t}}, \vec{\sigma}^r, \vec{\sigma}^s) &= N_k^{signal}(\vec{\sigma}^r, \vec{\sigma}^s) \cdot \mathrm{pdf}^{\,signal}(m_{t\bar{t}}, \vec{\sigma}^s) \\ &+ \sum_i N_{ki}^{background}(\vec{\sigma}^r, \vec{\sigma}^s) \cdot \mathrm{pdf}^{\,background}(m_{t\bar{t}}, \vec{\sigma}^s), \end{aligned}$$

- Bayesian method → limit curve of 95% CL :
  - Expected curve from background-only pseudo experiments
  - Observed points (red) are from data

No significant excess

$b'\bar{b}'$ analysis

-Search for a Heavy Bottom-like Quark (hep-ex:1102.4746)

Preamble

Reasons :

- Indirect bounds on the Higgs boson mass can be relaxed (PhysRevD.76.075016)
- Additional generation of quarks can be relevant for the baryon asymmetry of the Universe (arxiv:hep-ph/9903387)

Decay channel :

$$b'\bar{b}' \rightarrow tW^-\bar{t}W^+ \rightarrow bW^+W^-\bar{b}W^-W^+$$

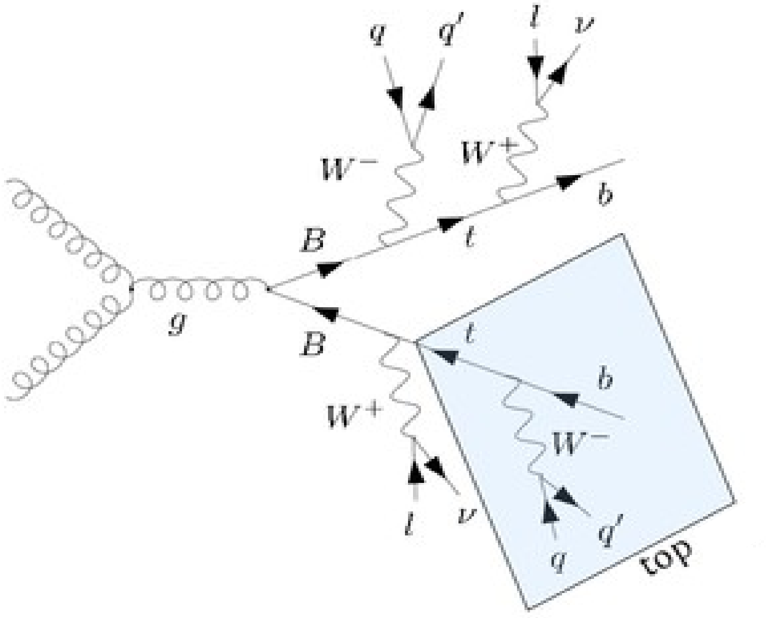
Observed decay chain contains :

- 2 same-sign isolated leptons

or

- 3 isolated leptons

Leptons ⇨ electrons and muons



Physics objects (leptons, jets, MET) :

- defined and selected as in the previous analysi

Remark : CDF experiment already set a upper limit of 338 GeV at 95% CL on b' mass (PhysRevLett.104.091801)

event selection

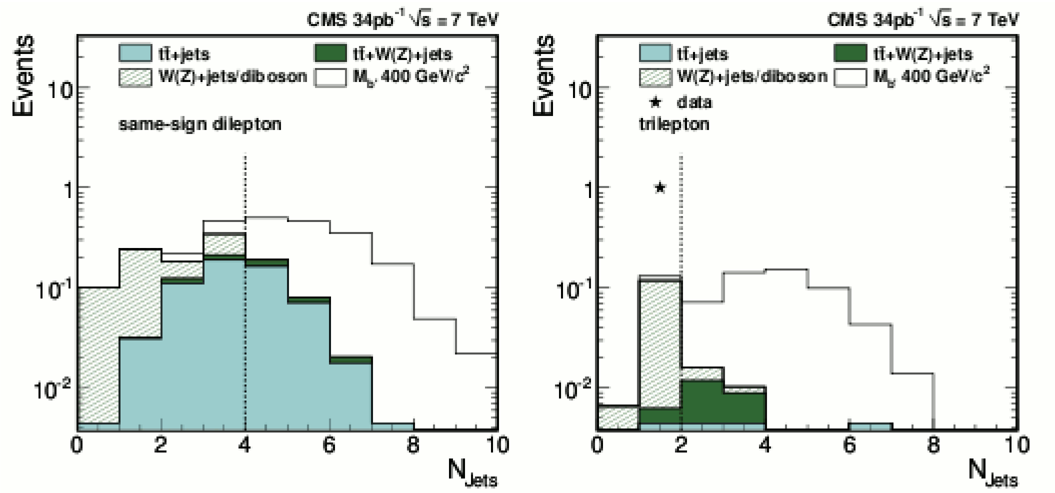
Events :

- 2 same-sign leptons + ⩾ 4 jets

or

- 3 leptons + ⩾ 2 jets

- Reject background from Z decay : $|M(l^{+}l^{-}) - M(Z)| \leqslant 10$ GeV
- Reject background from charge misidentification : $|M(e^{\pm}e^{\pm}) – M(Z)| \leqslant 10$ GeV
- ΣPt(objects) + MET > 350 GeV

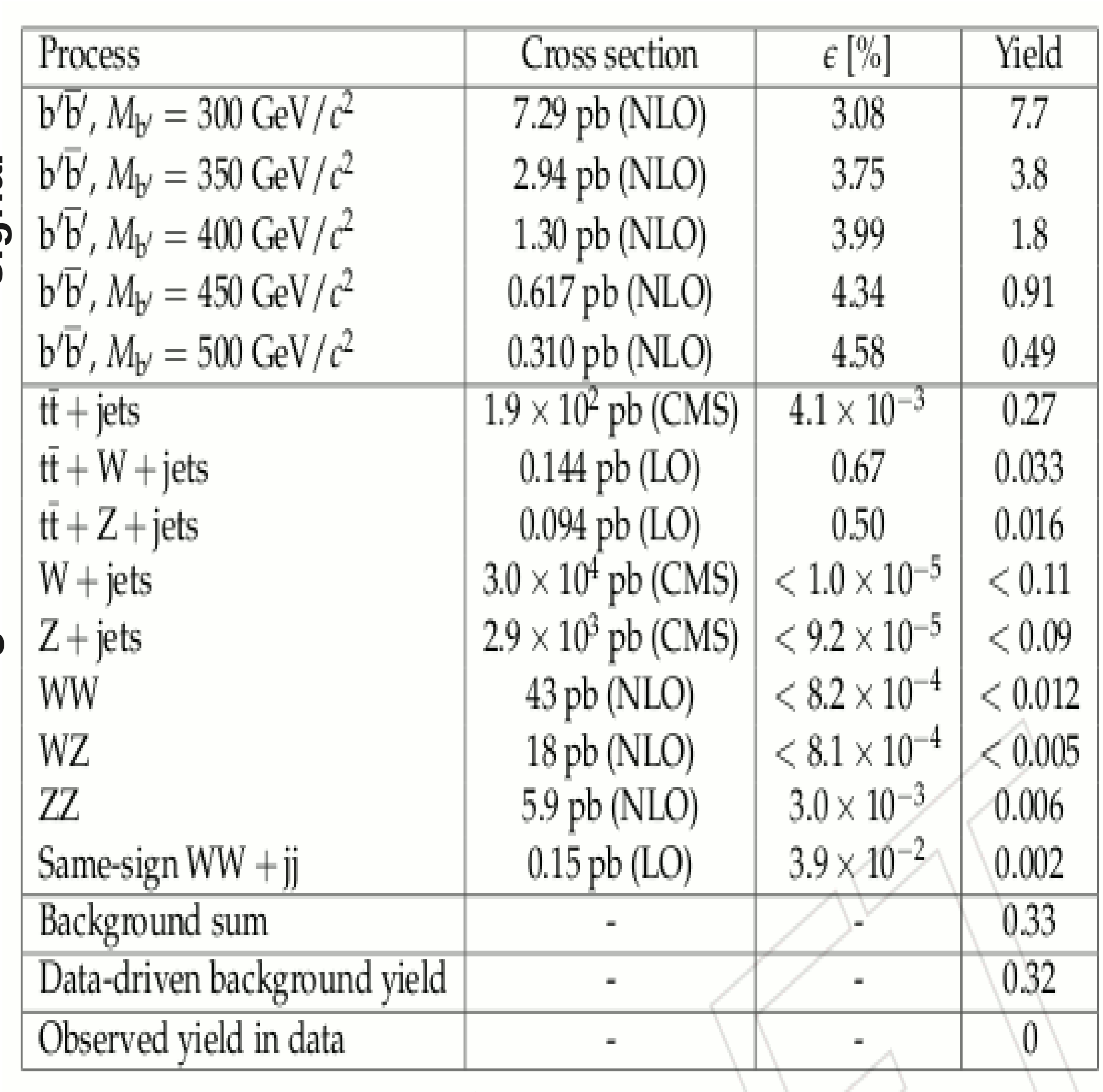


No events after all selection

Signal and background estimate

signal

background



Process	Cross section	ϵ [%]	Yield
$b'\bar{b}'$, $M_{b'} = 300\ \mathrm{GeV}/c^2$	7.29 pb (NLO)	3.08	7.7
$b'\bar{b}'$, $M_{b'} = 350\ \mathrm{GeV}/c^2$	2.94 pb (NLO)	3.75	3.8
$b'\bar{b}'$, $M_{b'} = 400\ \mathrm{GeV}/c^2$	1.30 pb (NLO)	3.99	1.8
$b'\bar{b}'$, $M_{b'} = 450\ \mathrm{GeV}/c^2$	0.617 pb (NLO)	4.34	0.91
$b'\bar{b}'$, $M_{b'} = 500\ \mathrm{GeV}/c^2$	0.310 pb (NLO)	4.58	0.49
$t\bar{t}$ + jets	1.9×10^2 pb (CMS)	4.1×10^{-3}	0.27
$t\bar{t}$ + W + jets	0.144 pb (LO)	0.67	0.033
$t\bar{t}$ + Z + jets	0.094 pb (LO)	0.50	0.016
W + jets	3.0×10^4 pb (CMS)	$< 1.0 \times 10^{-5}$	< 0.11
Z + jets	2.9×10^3 pb (CMS)	$< 9.2 \times 10^{-5}$	< 0.09
WW	43 pb (NLO)	$< 8.2 \times 10^{-4}$	< 0.012
WZ	18 pb (NLO)	$< 8.1 \times 10^{-4}$	< 0.005
ZZ	5.9 pb (NLO)	3.0×10^{-3}	0.006
Same-sign WW + jj	0.15 pb (LO)	3.9×10^{-2}	0.002
Background sum	-	-	0.33
Data-driven background yield	-	-	0.32
Observed yield in data	-	-	0

MadGraph/MadEvent

Max contribution

Normalized to the measured CMS cross-section

MadGraph at LO cross-section

MCFM NLO cross-section

MadGraph at LO cross-section

Data-Driven

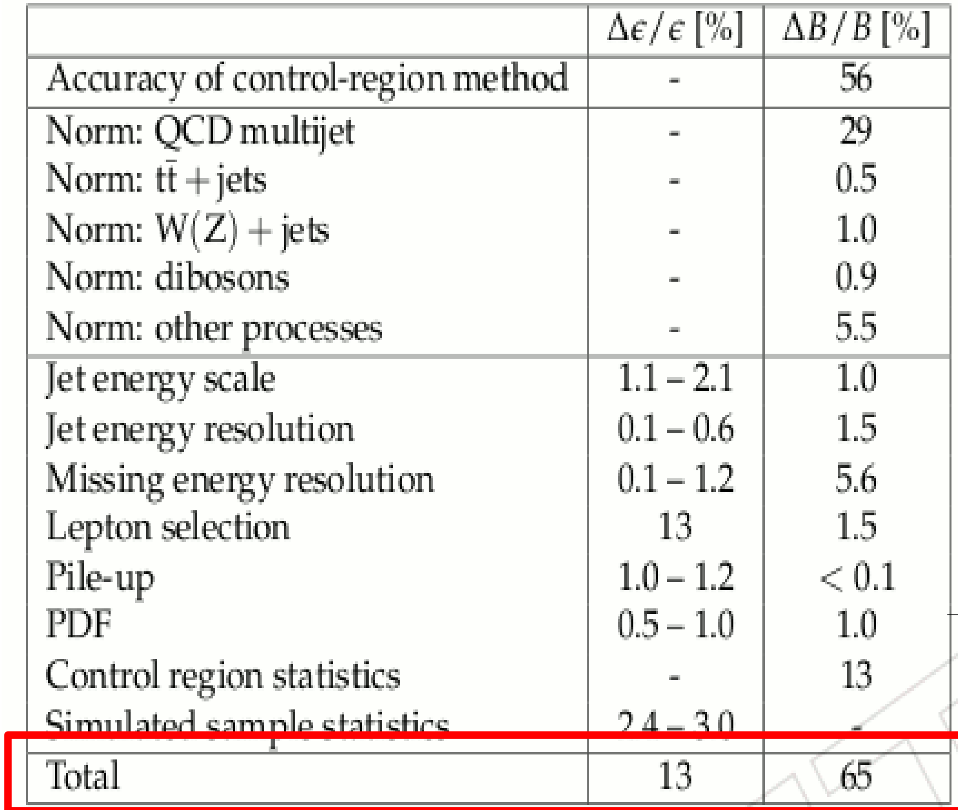
Very small background contribution

Relative systematic uncertainties

Cross-section : $$\sigma = \frac{N^{data} - B}{L.\epsilon}$$

Uncertainty on integrated luminosity = ±11%

Signal Background



	$\Delta\epsilon/\epsilon$ [%]	$\Delta B/B$ [%]
Accuracy of control-region method	-	56
Norm: QCD multijet	-	29
Norm: $t\bar{t}$ + jets	-	0.5
Norm: W(Z) + jets	-	1.0
Norm: dibosons	-	0.9
Norm: other processes	-	5.5
Jet energy scale	1.1 – 2.1	1.0
Jet energy resolution	0.1 – 0.6	1.5
Missing energy resolution	0.1 – 1.2	5.6
Lepton selection	13	1.5
Pile-up	1.0 – 1.2	< 0.1
PDF	0.5 – 1.0	1.0
Control region statistics	-	13
Simulated sample statistics	2.4 – 3.0	-
Total	13	65

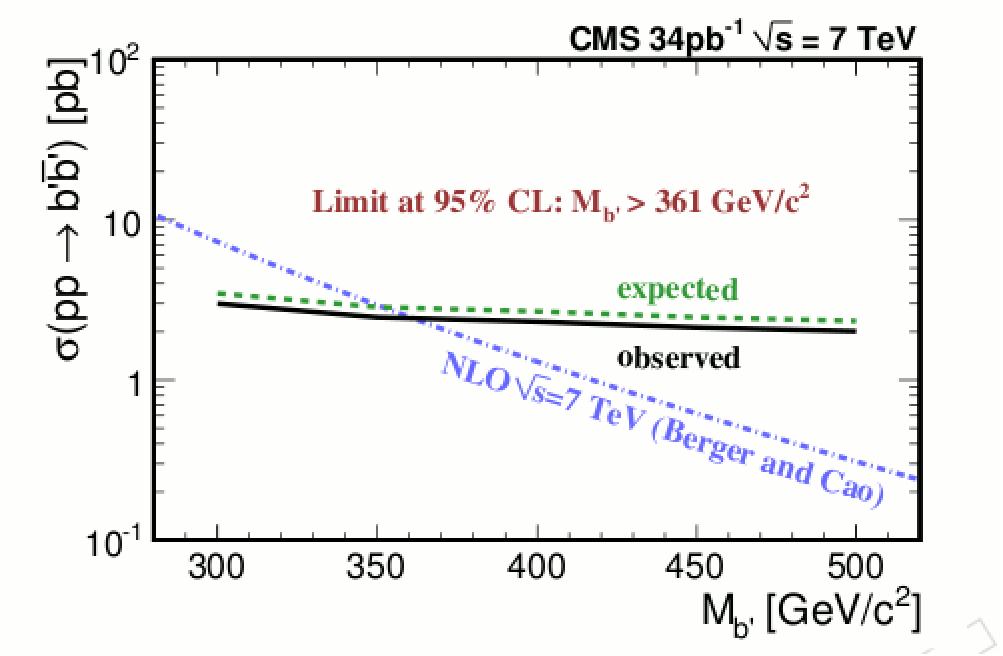
CTEQ6

(Summed in quadrature)

Results

Upper limits on b' cross-section :

- Bayesian method

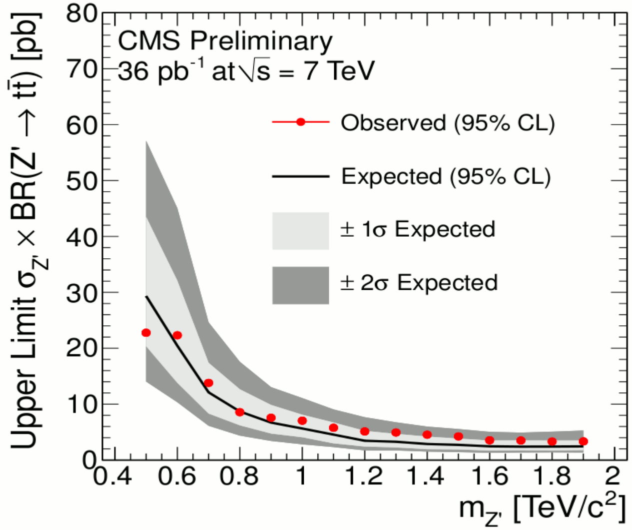


From 255 to 361 GeV excluded at 95% CL

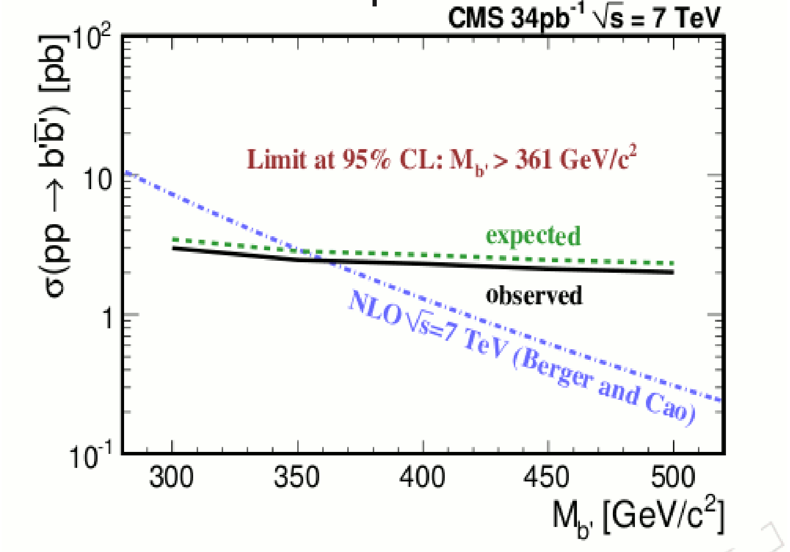
Remark : M(W) + M(top) ≃ 80 + 175 = 255 GeV → kinematic limit

Conclusion

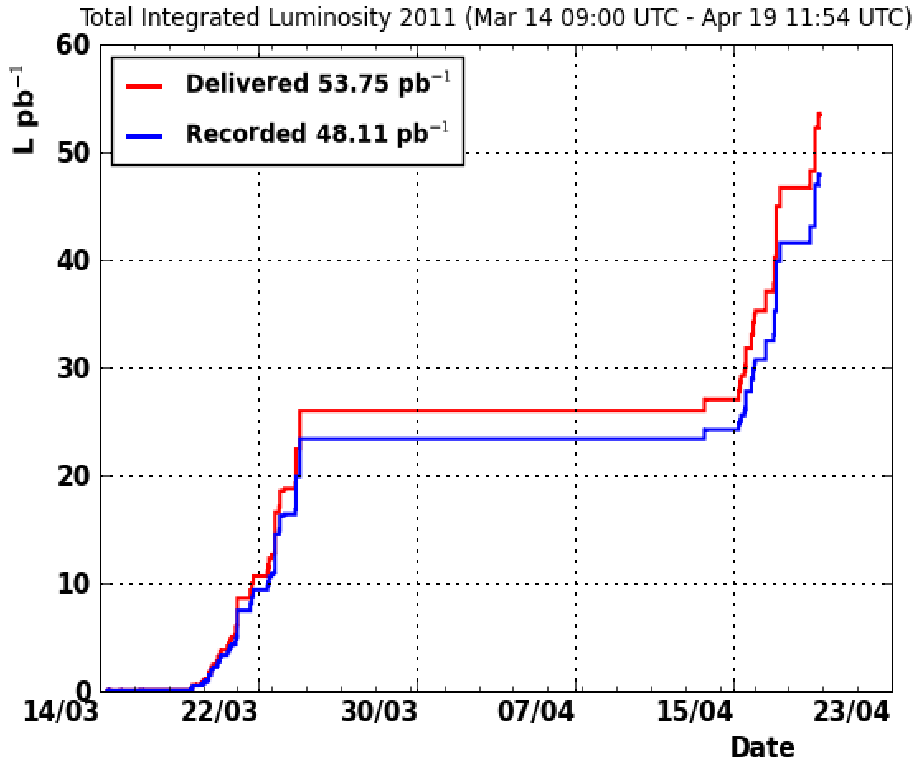
PAS-TOP-10-007



ArXiv:hep-ex:1102.4746



- Two results competitive with previous measurements
- will be improved with the increase of luminosity



ttbar selection

<u>Muon trigger :</u> muon candidate with Pt > 9 and 15 GeV $\rightarrow \varepsilon \sim 94\ \%$
<u>Electron trigger :</u> ECAL cluster with Et > 10 and 22 GeV $\rightarrow \varepsilon \sim 99\ \%$

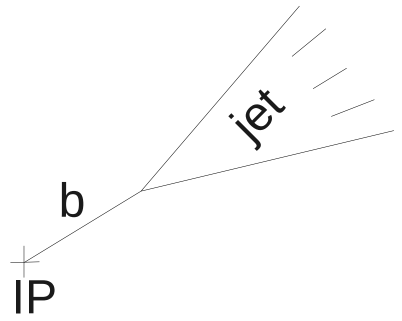
- <u>Lepton :</u>
  - Muons :
    - - Muon chambers
    - - Silicon tracker
    - - Good quality tracks
    - - Consistent with primary vertex
    - - Pt, $|\eta|$
  - Electrons :
    - -high quality candidate
    - - Pt, $|\eta|$

- <u>Isolated leptons :</u> (between leptons and jets)
  - - Ratio of all hadronic activity and lepton Et in a cone with $\Delta R < 0.3$ must be less than 10%

- <u>Lepton veto :</u>
  - - only one isolated lepton candidate
  - - Z → ee veto (for electron part of the analysis)

- <u>Jets :</u>
  - - 3 jets from anti-k_T algorithm with correction relative and absolute ($\Delta R < 0.5$)
  - - leading Pt >70 GeV
  - - second Pt > 50 GeV
  - - last Pt > 30 GeV
  - - $|\eta|$

- <u>Met :</u>
  - - Et_{miss} > 20 GeV



- b-<u>tagging :</u>
  - - used secondary vertex algorithm to flag jets from b quark

Physics object selection

Muons :

- Used global fit of trajectories with hits in the tracker (pixel and strip) and in the muon system
- Pt, $|\eta|$
- Track consistent with primary vertex

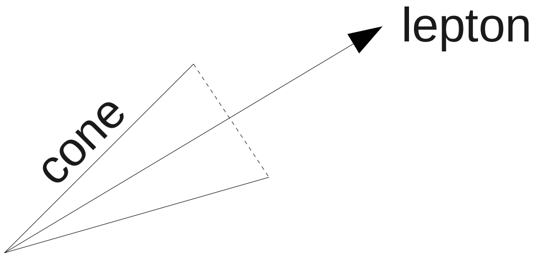
Electrons :

- Pt, $|\eta|$
- Track consistent with primary vertex
- ID variables : - Ratio between HCAL and ECAL energy
  - Shower width in η
  - Distance between calorimeter shower and particle trajectory in the tracker

⇨ reject background from hadronic jets and keep 85% of events from W or Z decays

Isolation : (to select lepton from W → lν)

- $\Delta R < 0.3$
  - Muons : $\Sigma Pt < 20$ %
  - Electrons : $\Sigma Pt < 9(6)$ % Barrel (End-Cap)



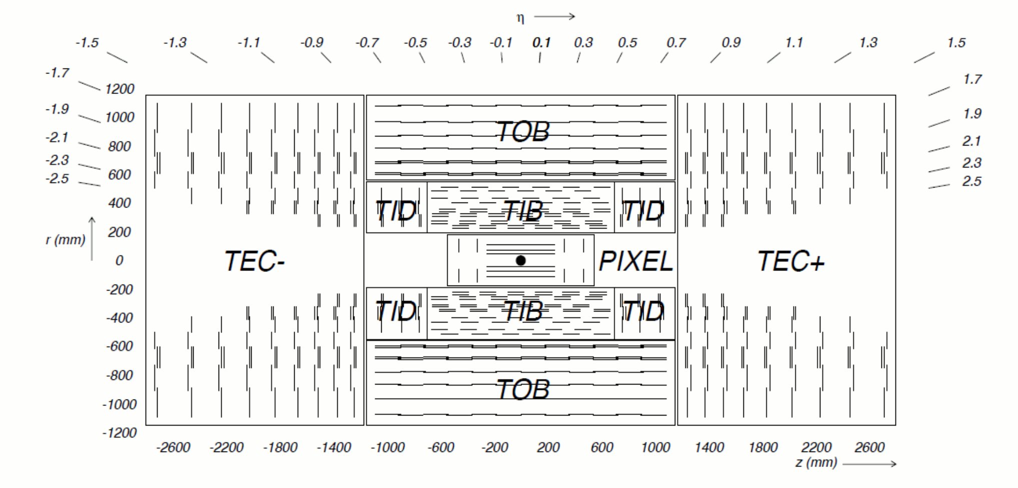
Jets :

- Anti-k_T algorithm $\Delta R < 0.5$
- Pt, $|\eta|$

back-up

Some useful variables :

η=-ln[tan(θ/2)] with θ the angular angle in transvers plan



back-up

Particle flow (PF) in CMS :

- Algorithm which attempt to reconstruct all particles in the event
- Use all information of sub-detector
- Permit higher level physics objects (jets, MET, Tau)

Particles reconstructed by PF :

- Muons, electrons, photons, neutral and charged hadrons

Fundamental elements to build PF particles :

- Charged-particle tracks
- Calorimeter cluster (ECAL & HCAL)
- Muon tracks

⇒Recommendation : high efficiency and low fake rate

PF Algorithm :

- Iterative tracking
- Calorimeter clustering
- Link between :
  - tracker track and calorimeter cluster
  - tracker track and muon track in muon system
  - ECAL and HCAL