First top quark results at the LHC

Andrea Giammanco
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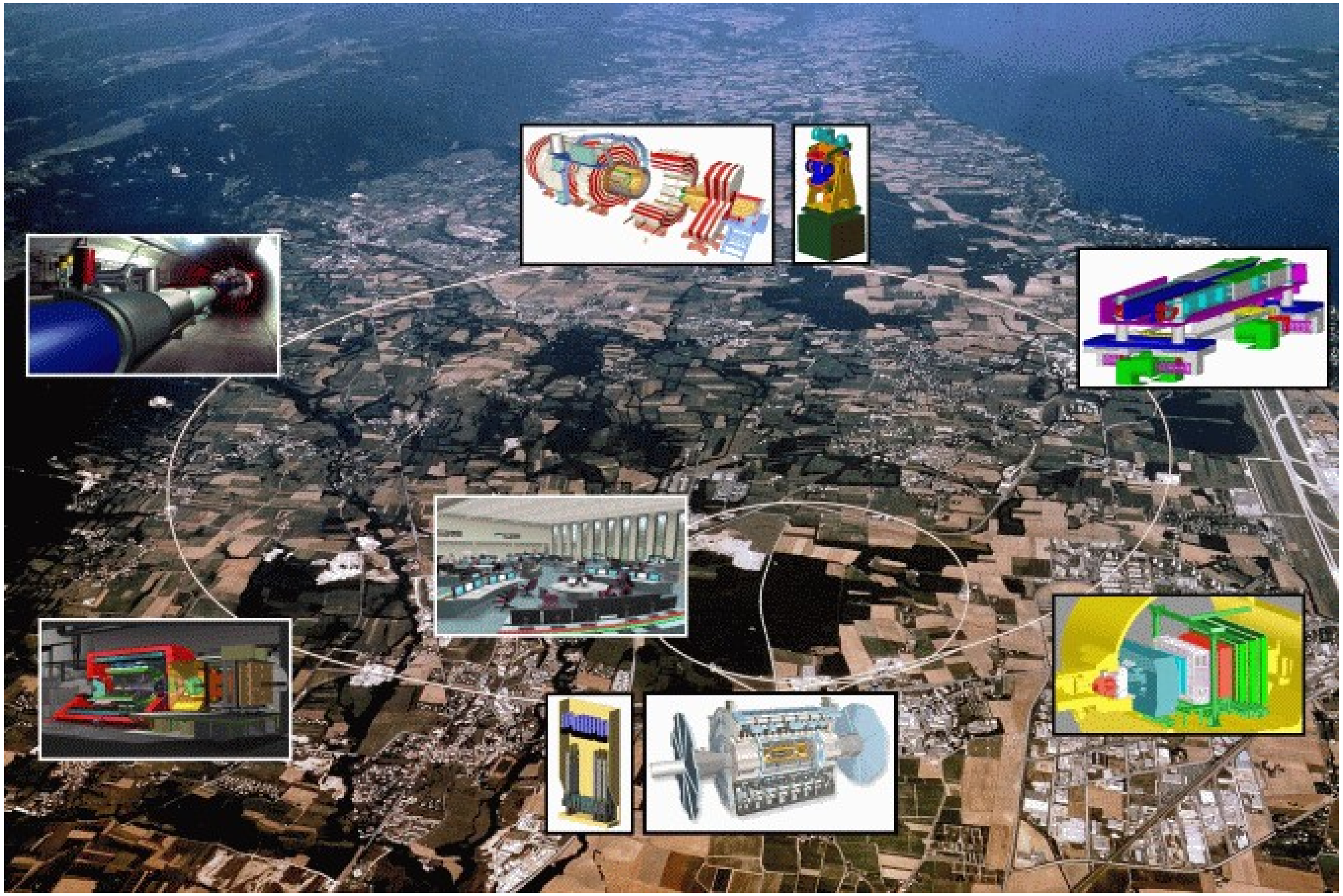
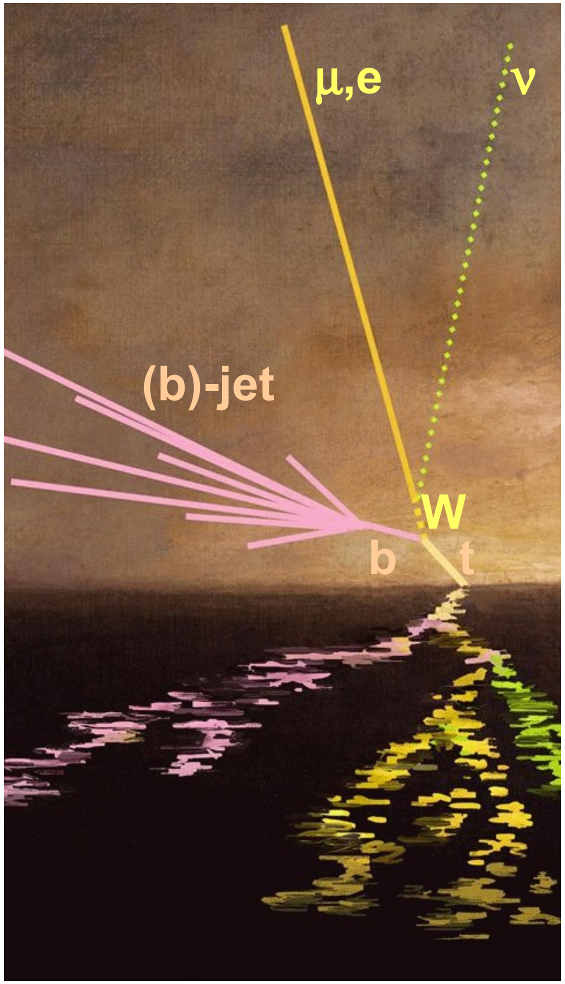
on behalf of the ATLAS & CMS collaborations

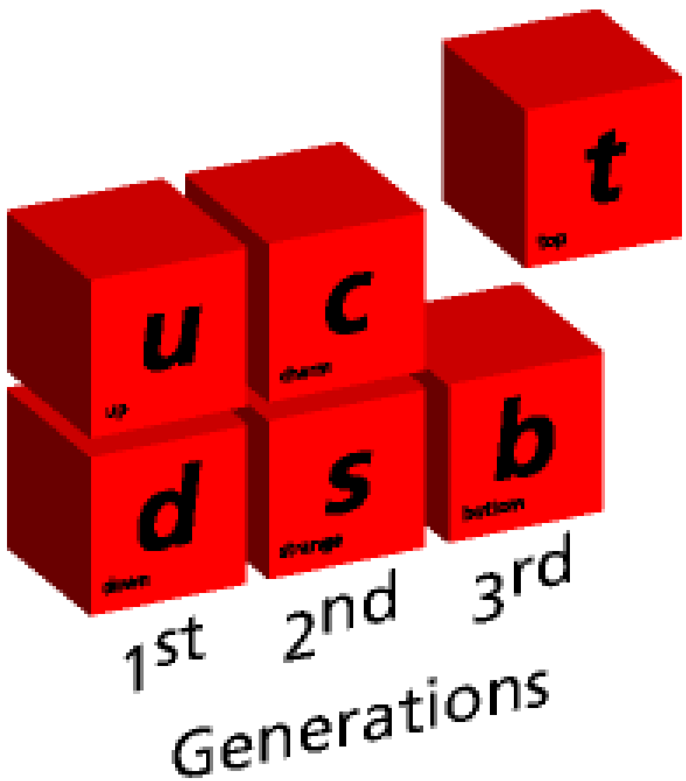




F. Ligabue & B.R. Haydon

GDR Terascale, Nov.3, 2010

Outline



- Intro: what's so interesting about the top quark
- The first European top quarks
- The first cross section at 7 TeV
- What's coming next


NATURE VOL 310 12 JULY 1984

NEWS AND VIEWS

CERN comes out again on top

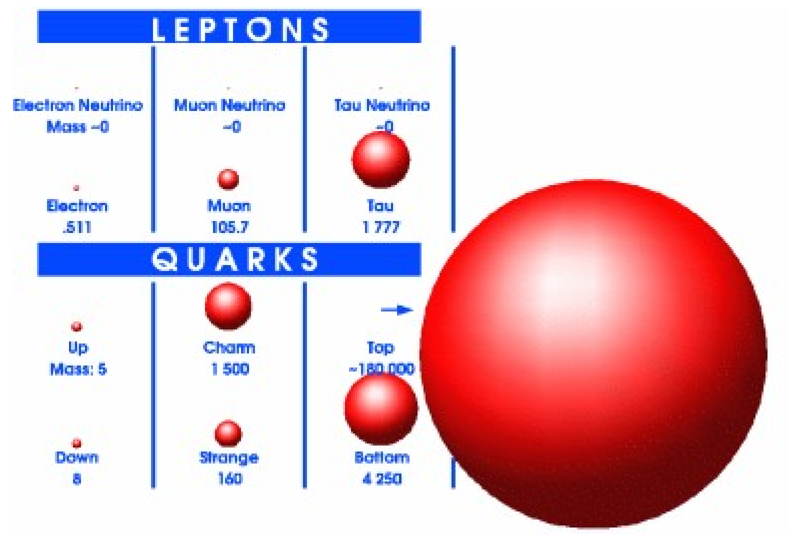
With the discovery of the electroweak bosons ($W^{\pm}$ and Z^0) in the bag, CERN now announces the discovery of the quark called top. *What will come next?*

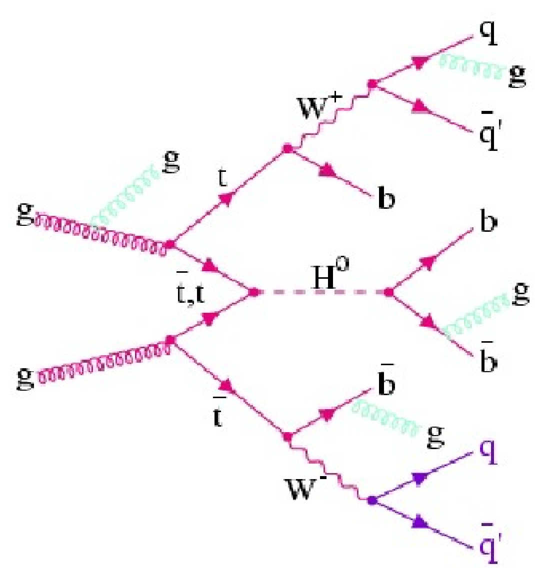
Why studying the top quark?
(conservative point of view)

- It exists
  - But it's the less known quark: room for improvement
  - It is noise to many new physics signatures
  - Its mass is already precise enough (<1%) to make it useful as a *"standard candle"* for jet energy scale extraction
  - Assuming BR($t \rightarrow b$)~1 as in the SM, a high-purity top selection will be used to extract b-tagging efficiency
- $M_t > M_W$: this means that the W is not virtual
  - Γ proportional to G_F, not G_F^2. Result: $\tau_{decay} < \tau_{hadr}$
    - $\tau_{decay} < \tau_{hadr} \rightarrow$ we probe a "naked" quark
    - $\tau_{decoherence} (> \tau_{hadr}) > \tau_{decay} \rightarrow$ polarization is preserved
    - powerful probe of new physics

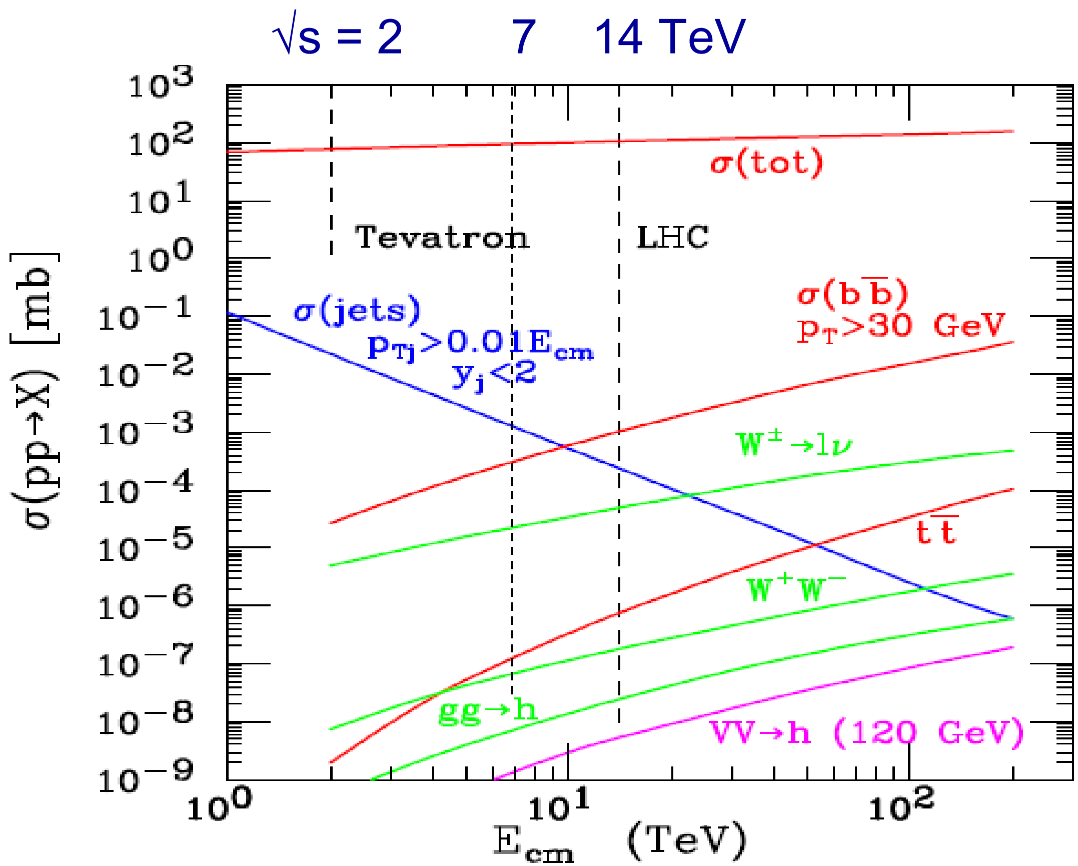
Why studying the top quark?
(less conservative point of view)

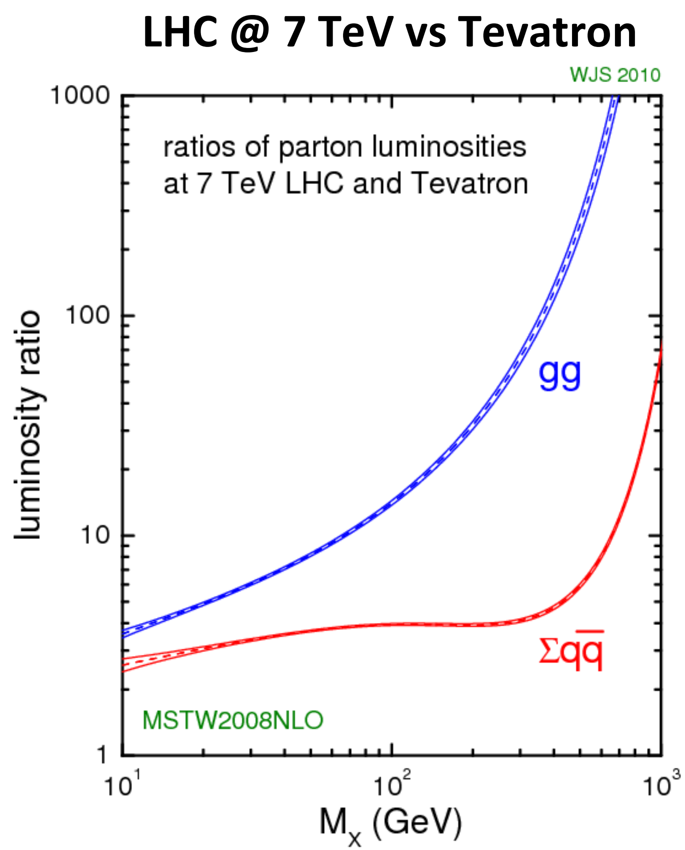
- It's the highest mass SM particle: Higgs coupling to the top is the strongest among the fermions
  - Key to the mass hierarchy mystery?
    - Who ordered a 170 GeV monster??
    - Numerology: can y_t~1 be a coincidence?
  - New particles may decay preferentially into top, especially in models which try to explain this “coincidence”
  - Top may decay into new particles or participate to new processes (e.g., FCNC enhanced by SUSY)
    - At least one guaranteed by SM: $t\bar{t}H$





From Tevatron to LHC

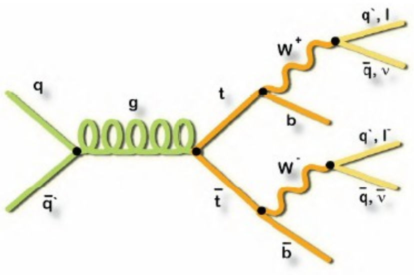




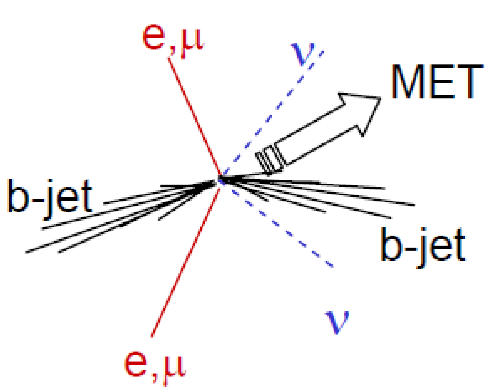
x20 gain in parton luminosity @ M_{top}

8000 top pairs / experiment @ LHC in 50 pb^{-1}, exactly as 1 fb^{-1} @ Tevatron.
Tevatron exp's still have an edge in systematics-dominated measurements; in statistics-limited ones, LHC is going to take the lead by sheer brute force

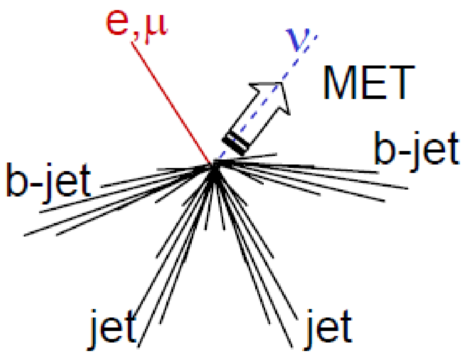
Simple event selections for early data



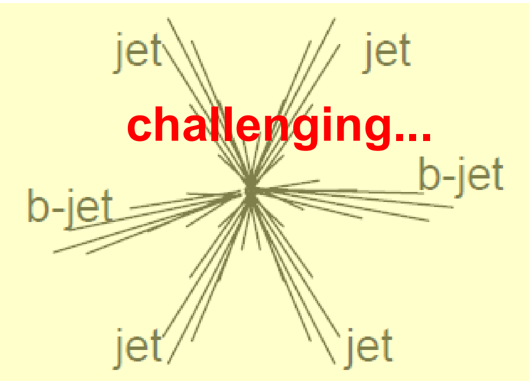
- Dileptons
  - 2μ || 2e || eμ, isolated
  - At least 2 central jets
  - Z veto in 2μ and 2e
  - High MET
- Lepton+jets
  - 1μ || 1e, isolated
  - At least 4 central jets
  - High MET
  - Alternative analyses w/ and w/o b-tagging



dileptons
(BR~5%)



lepton + jets
(BR~30%)

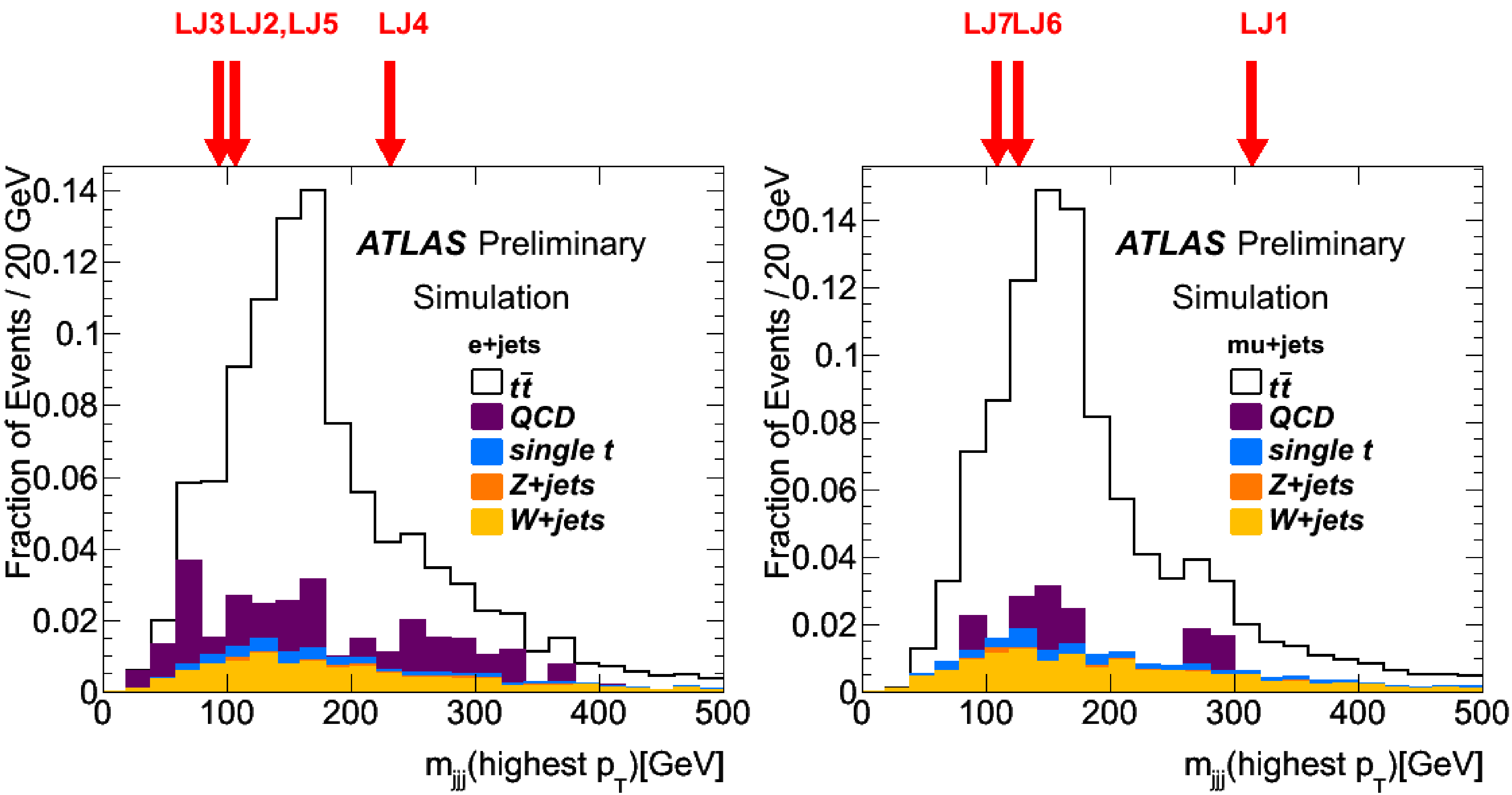


all hadronic
(BR~46%)

Summer conferences

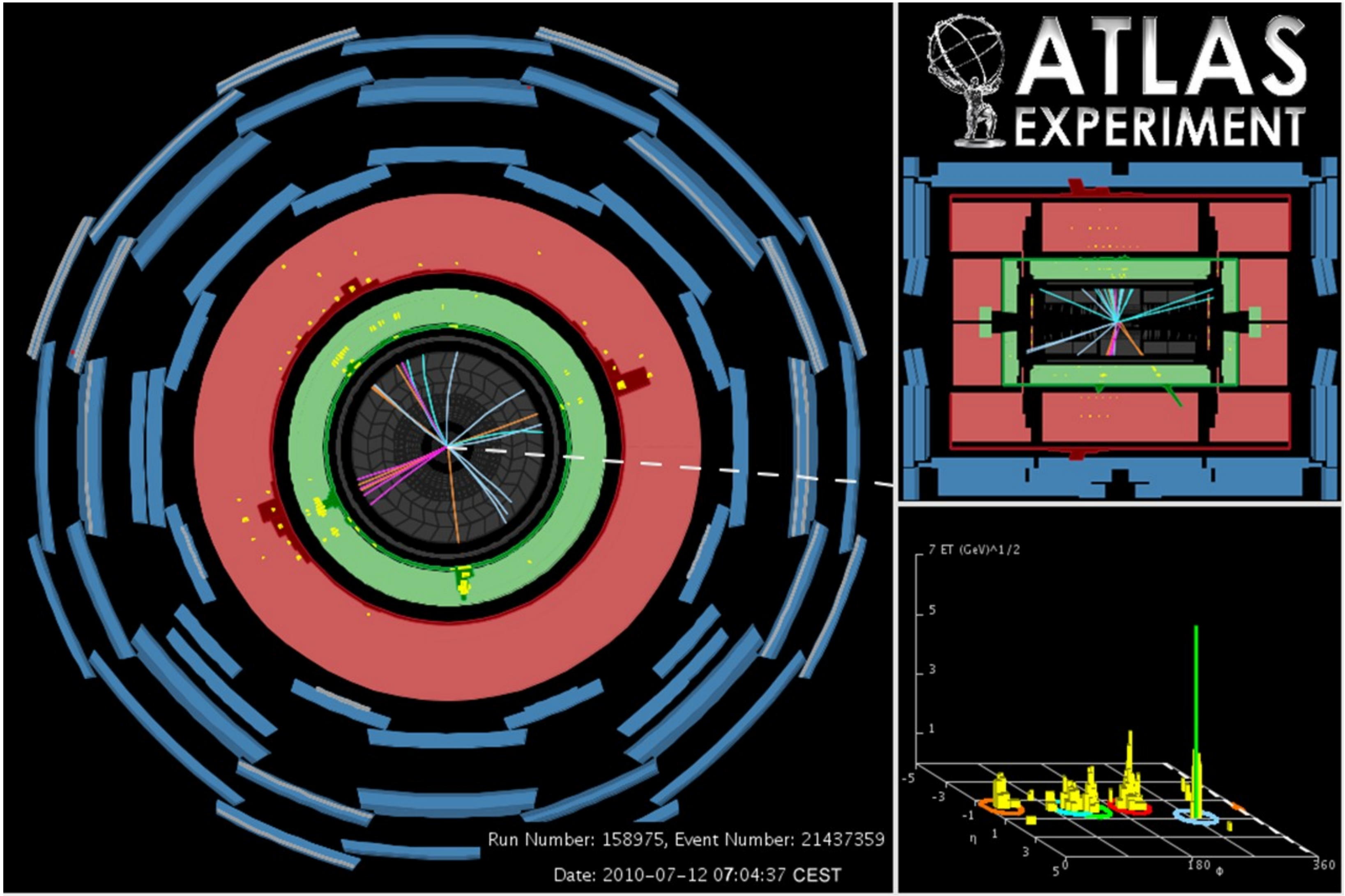
First top candidates: ATLAS

ATLAS-CONF-2010-063
ATLAS-CONF-2010-087



e+jets candidate (LJ2)

ATLAS-CONF-2010-063
ATLAS-CONF-2010-087



Summer conferences

First top candidates: ATLAS

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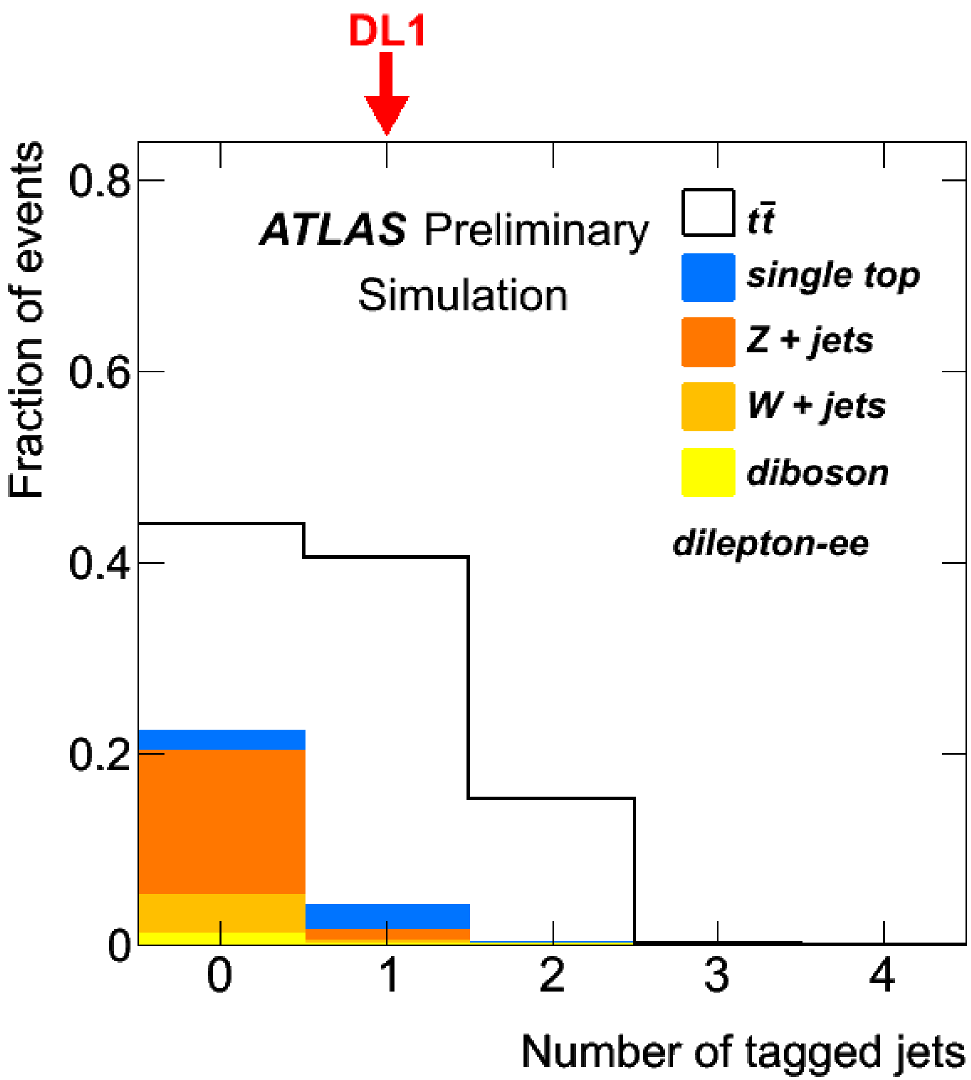
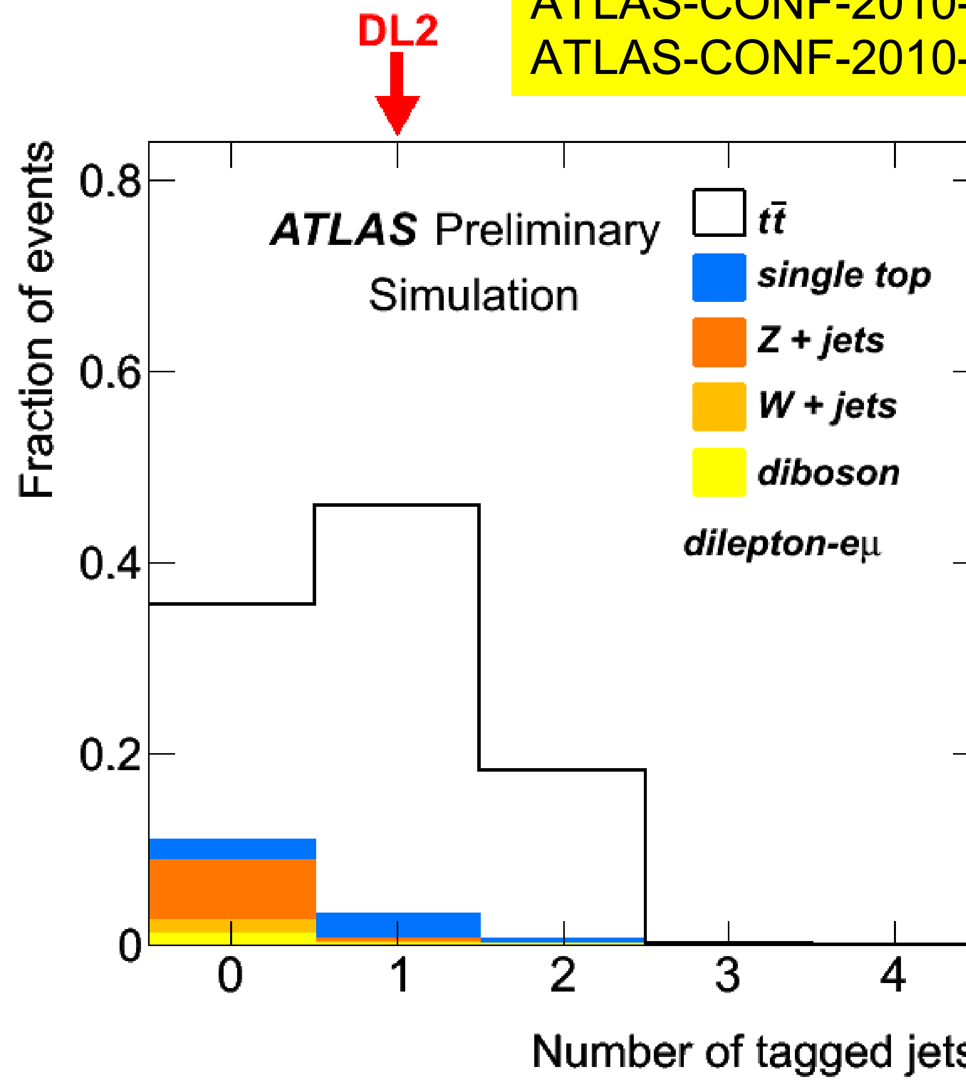
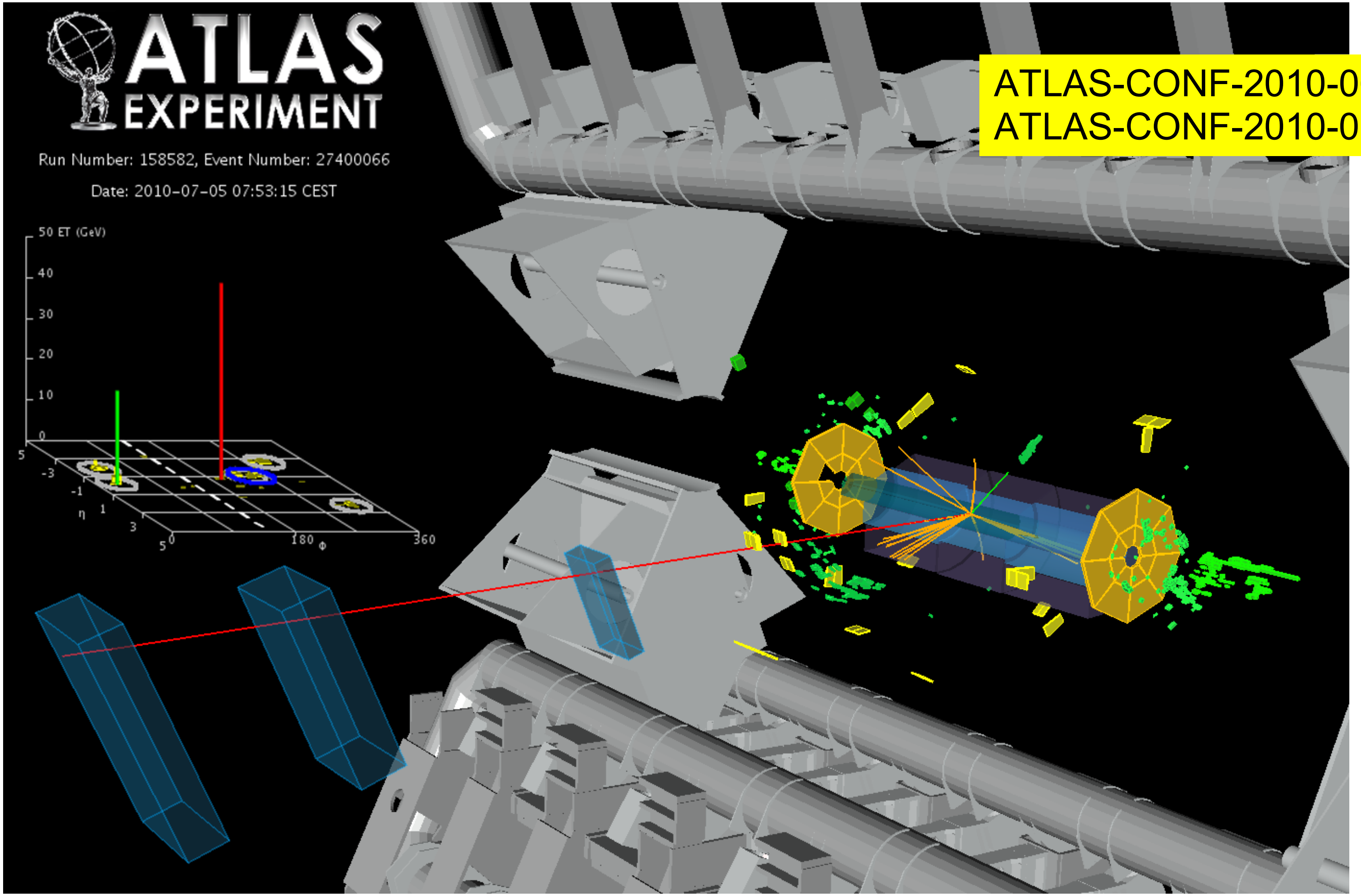




eμ candidate (DL2)

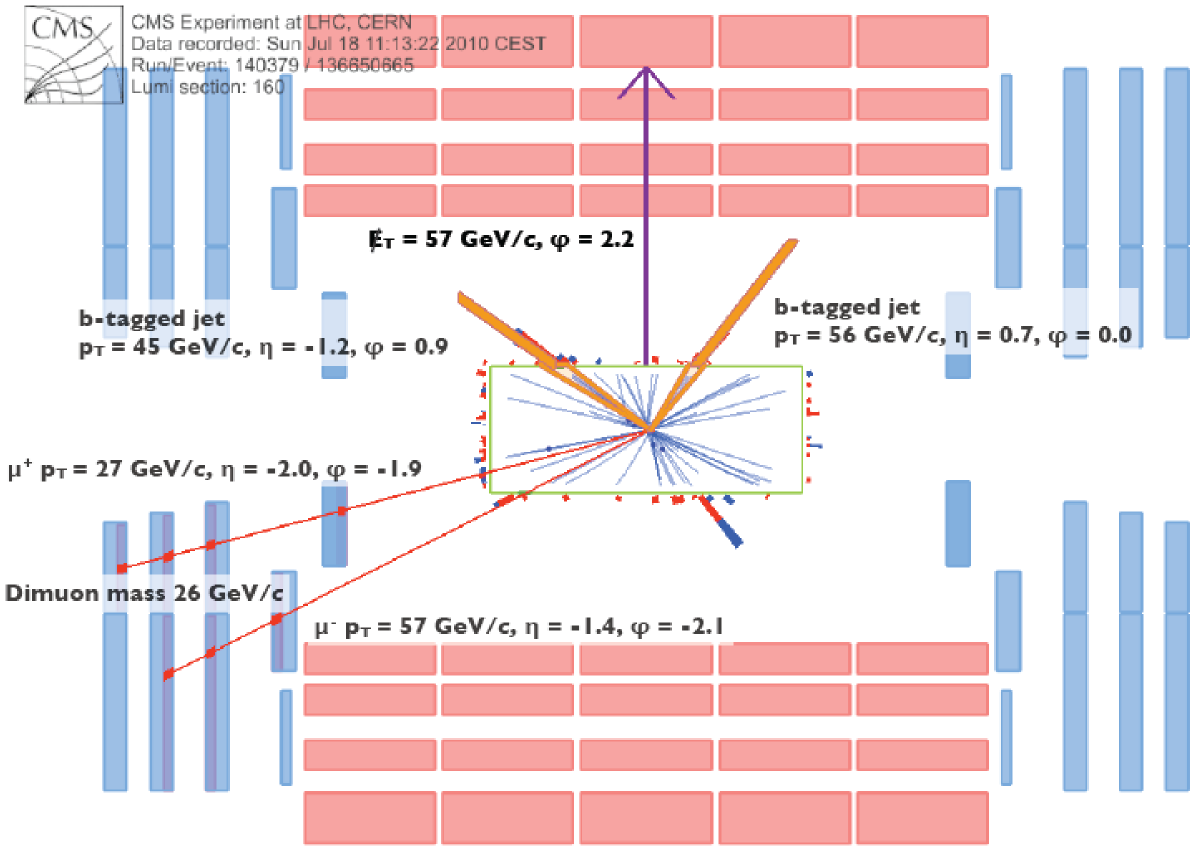


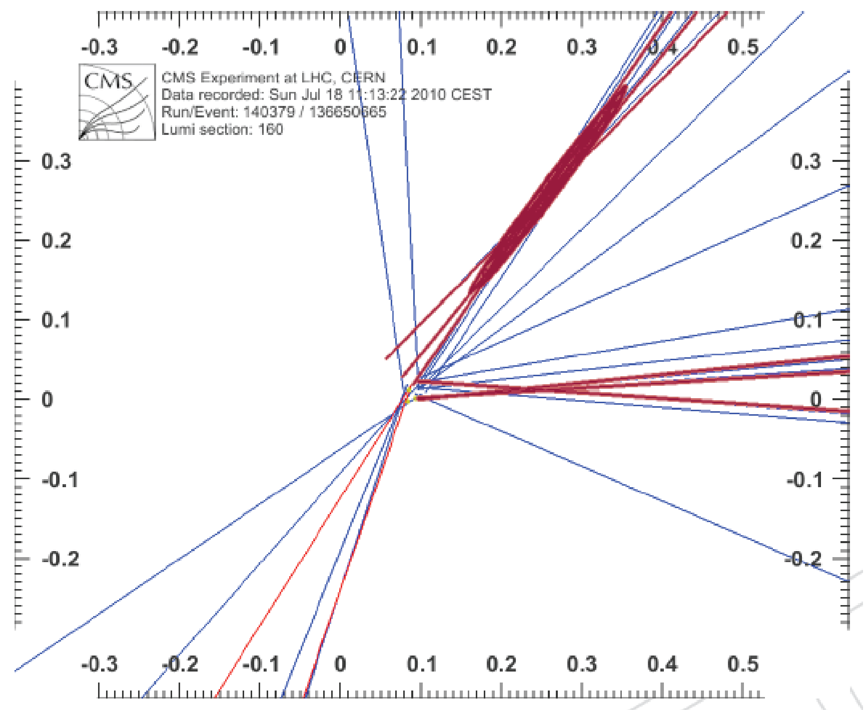
ATLAS-CONF-2010-063
ATLAS-CONF-2010-087

Summer conferences

First top candidates: CMS

CMS-TOP-10-004

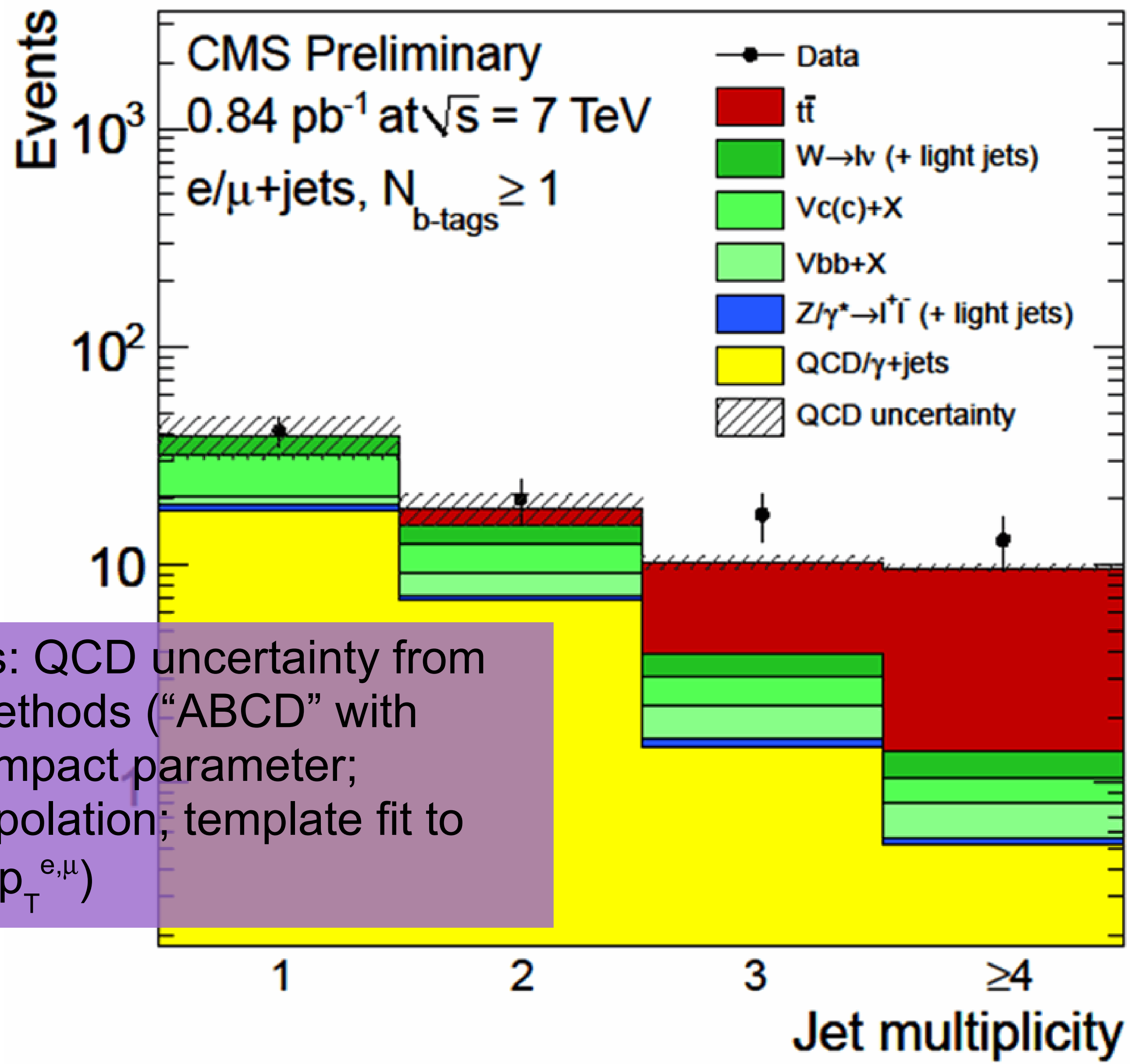




Candidate tt→WbWb→lνblνb with 2 muons (far from Z peak), 2 jets and large missing energy; muons and jets belong to the same primary vertex; clear secondary vertices in jets

First top candidates: CMS

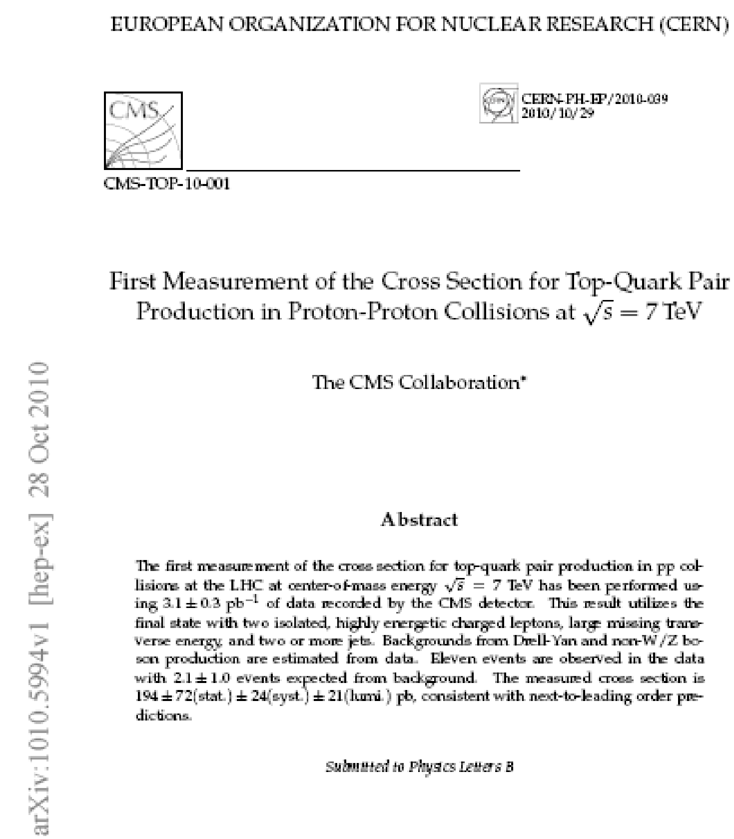
CMS-TOP-10-004



Hashed bands: QCD uncertainty from data-driven methods ("ABCD" with isolation and impact parameter; isolation extrapolation; template fit to MET or MET+$p_T^{e,\mu}$)

First cross section at 7 TeV

- CMS just submitted the very first cross section paper at 7 TeV
  - arXiv:1010.5994 [hep-ex]
  - More plots in CMS-TOP-10-001
  - Based on the first **3.1/pb**
  - In the cleanest channel: dileptons
  - Lepton+jets will follow asap
- The ATLAS collaboration will follow very soon
- More detailed publications with the full 2010 dataset (~40/pb)



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2010-039
2010/10/29

CMS-TOP-10-001

First Measurement of the Cross Section for Top-Quark Pair Production in Proton-Proton Collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration*

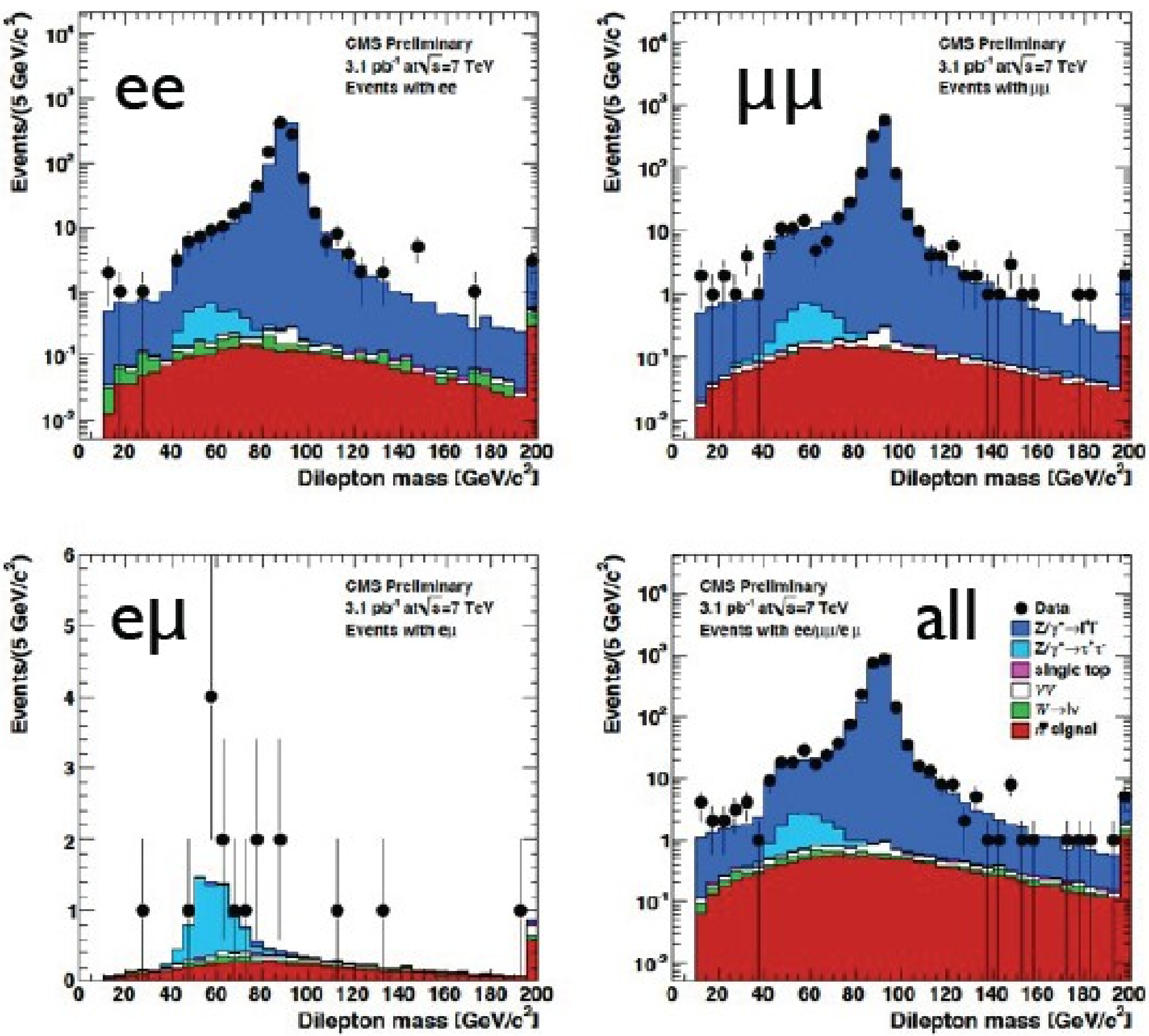
arXiv:1010.5994v1 [hep-ex] 28 Oct 2010

Abstract

The first measurement of the cross section for top-quark pair production in pp collisions at the LHC at center-of-mass energy $\sqrt{s} = 7$ TeV has been performed using 3.1 ± 0.3 pb^{-1} of data recorded by the CMS detector. This result utilizes the final state with two isolated, highly energetic charged leptons, large missing transverse energy, and two or more jets. Backgrounds from Drell-Yan and non-W/Z boson production are estimated from data. Eleven events are observed in the data with 2.1 ± 1.0 events expected from background. The measured cross section is $194 \pm 72(\text{stat.}) \pm 24(\text{syst.}) \pm 21(\text{lumi.})$ pb, consistent with next-to-leading order predictions.

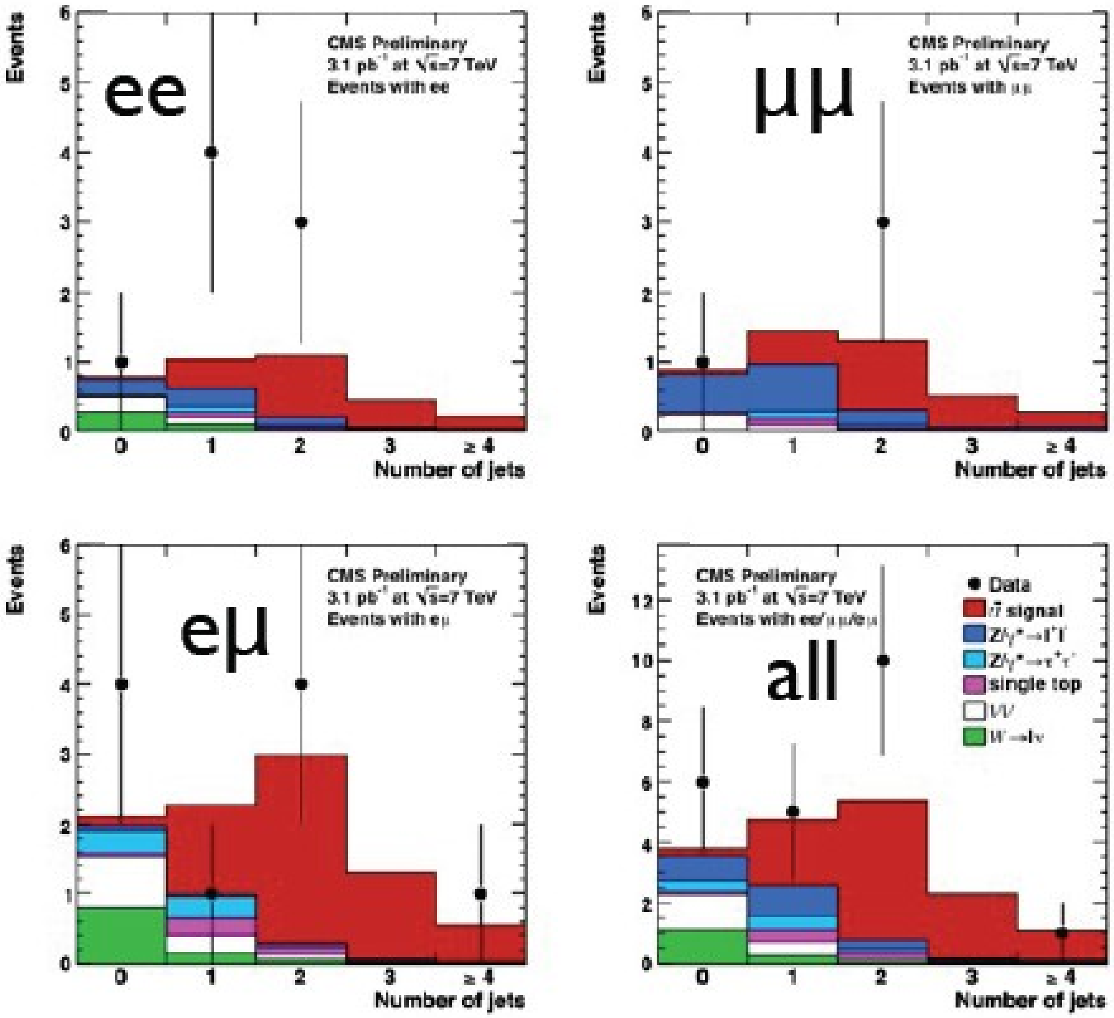
Submitted to Physics Letters B

First selection step: 2 good isolated leptons



- Sample dominated by $Z \rightarrow ee, \mu\mu, \tau\tau$
- Z veto in 2μ and 2e
  - M_{ll}<76 GeV, >106 GeV
- MET selection
  - Using track-corrected MET (tcMET)
  - tcMET > 30 GeV, ee,$\mu\mu$
  - tcMET > 20 GeV, eμ

Full selection, data vs MC



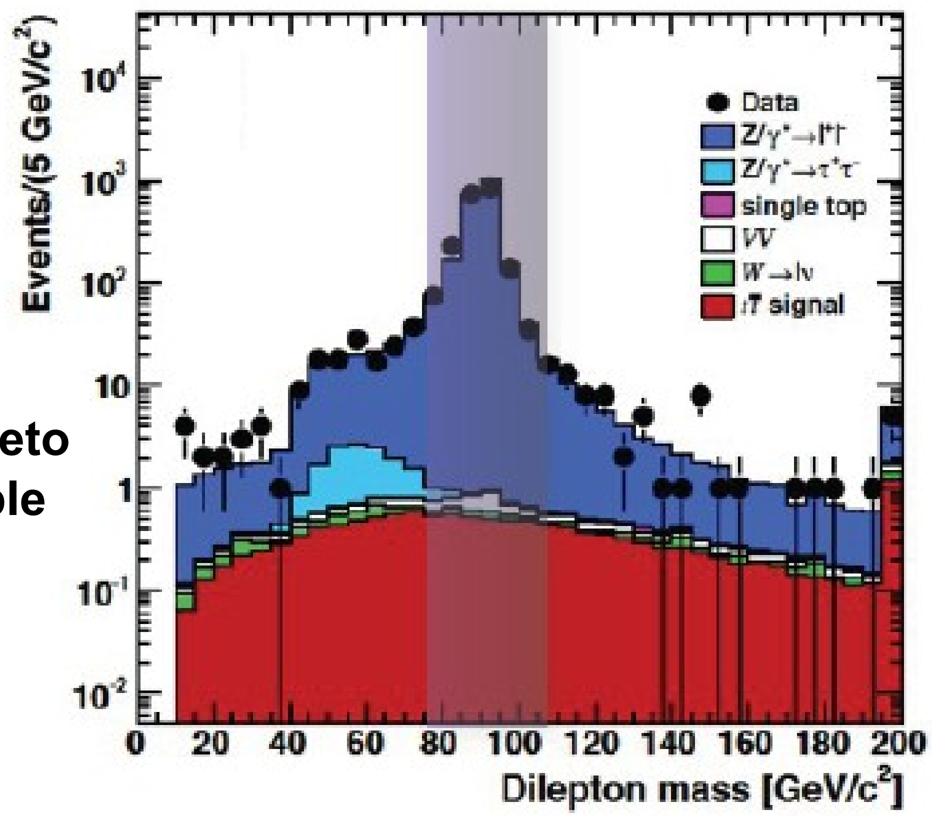
Number of track-corrected jets after Z-veto and MET cut

Full selection, ≥2 jets:

Process	ee	$\mu\mu$	$e\mu$	all
Dilepton $t\bar{t}$	1.50	1.68	4.48	7.65
VV	0.03	0.03	0.08	0.13
Single top - tW	0.05	0.05	0.15	0.25
Drell-Yan $\tau\tau$	0.04	0.07	0.07	0.18
Drell-Yan $ee, \mu\mu$	0.14	0.28	0.01	0.43
Non-dilepton $t\bar{t}$	0.05	0.01	0.09	0.15
W+jets	0.03	< 0.01	0.06	0.09
Total simulated	1.8	2.1	4.9	8.9
Data	3	3	5	11

Background estimation: γ*/Z+jets

- Drell-Yan events are the largest residual background in ee,μμ
- Survive thanks to "fake" MET
- MC: trust M_{ll} shape more than MET



From MC — **Non-DY events in Z-veto region: use eμ sample**

$$N_{\rm out}^{e^+e^-,{\rm exp}} = R_{\rm out/in}^{e^+e^-}\left(N_{\rm in}^{e^+e^-} - 0.5N_{\rm in}^{e^\pm\mu^\mp}k_{ee}\right)$$

$$k_{ee} = \sqrt{\frac{N_{\rm in}^{e^+e^-,loose}}{N_{\rm in}^{\mu^+\mu^-,loose}}},$$

$$^{*}R_{out/in} = N^{out}_{DY\ MC}/N^{in}_{DY\ MC}$$

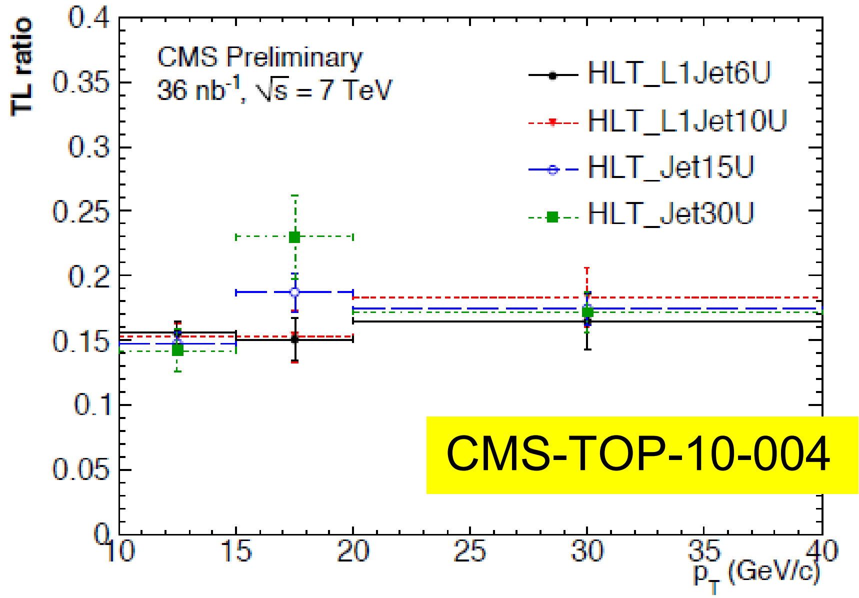
...and the same for $N_{out}^{\mu\mu}$

Background estimation: QCD, W+jets, non-dileptonic $t\bar{t}$

- MC estimates of events with fake/non-prompt leptons depend crucially on the detector simulation
- We extract them from data:
  - We define a "Fakeable Object" (FO), with similar but looser selection than our muon / electron candidates
  - We define a scale factor, Tight-to-Loose (TL) ratio, in η, p_T bins
  - We derive TL from a lepton-triggered sample requiring an offline jet passing some threshold

$$N_{nn}^{QCD} = \sum_{i,j} \frac{TL_i TL_j}{(1-TL_i)(1-TL_j)} N_{\overline{nn}}^{ij}$$

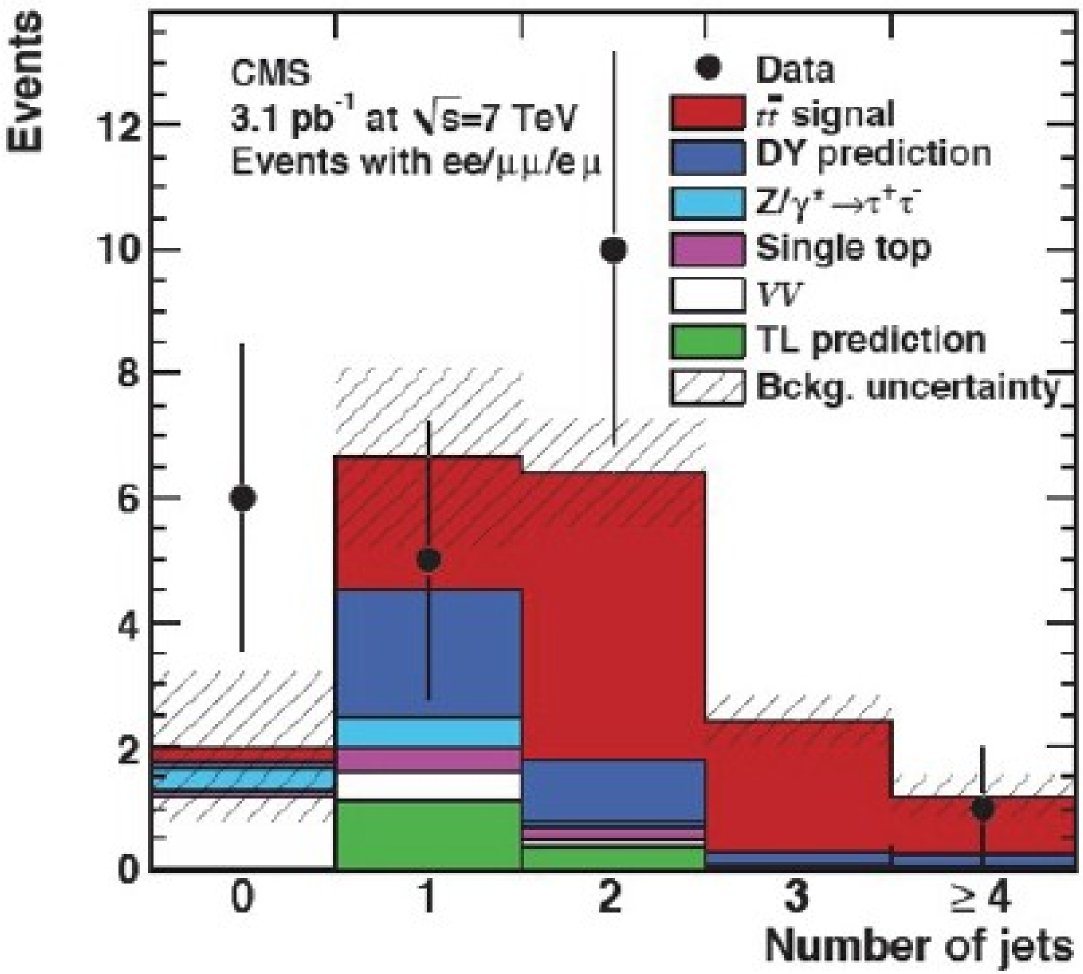
$$N_{nn}^{WJets} = \sum_{i,j} \frac{TL_i}{(1-TL_i)} N_{\overline{n}n}^{ij}$$



TL ratio for electrons

Final result

$$\sigma(\mathrm{pp} \to \mathrm{t\bar{t}}) = 194 \pm 72(\mathrm{stat.}) \pm 24(\mathrm{syst.}) \pm 21(\mathrm{lumi.})\ \mathrm{pb}$$



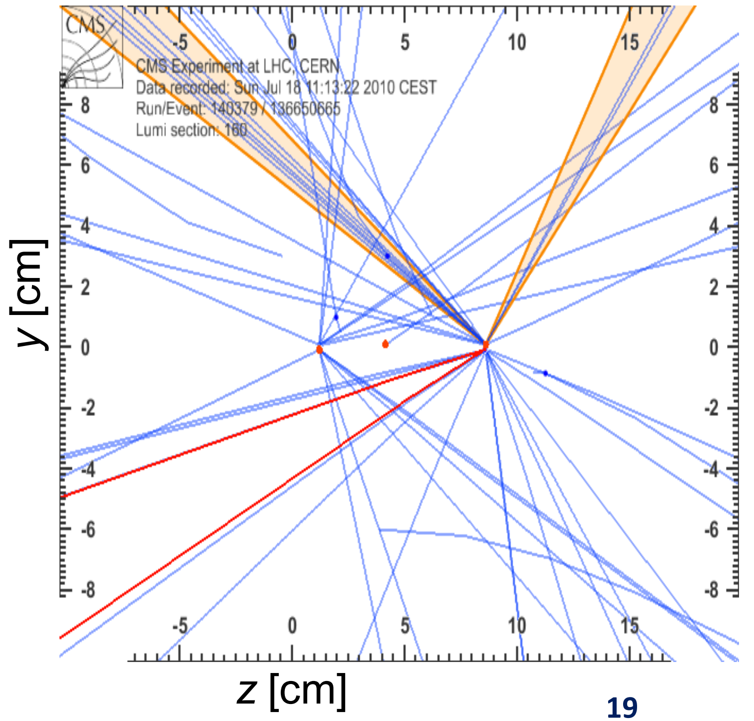
- All dileptonic channels combined
- In this plot: backgrounds from data-driven estimates (see later in this talk), apart from single top and VV, taken from MC scaled to NLO, and $Z \to \tau\tau$ to NNLO
- Hashed bands: background uncertainty

Compare with NLO expectation: $157.5^{+23.2}_{-24.4}$ pb

from MCFM, with M_t=172.5 GeV, uncertainty from scale variations, PDF (MSTW, CTEQ, NNPDF), α_S (PDF4LHC prescriptions)

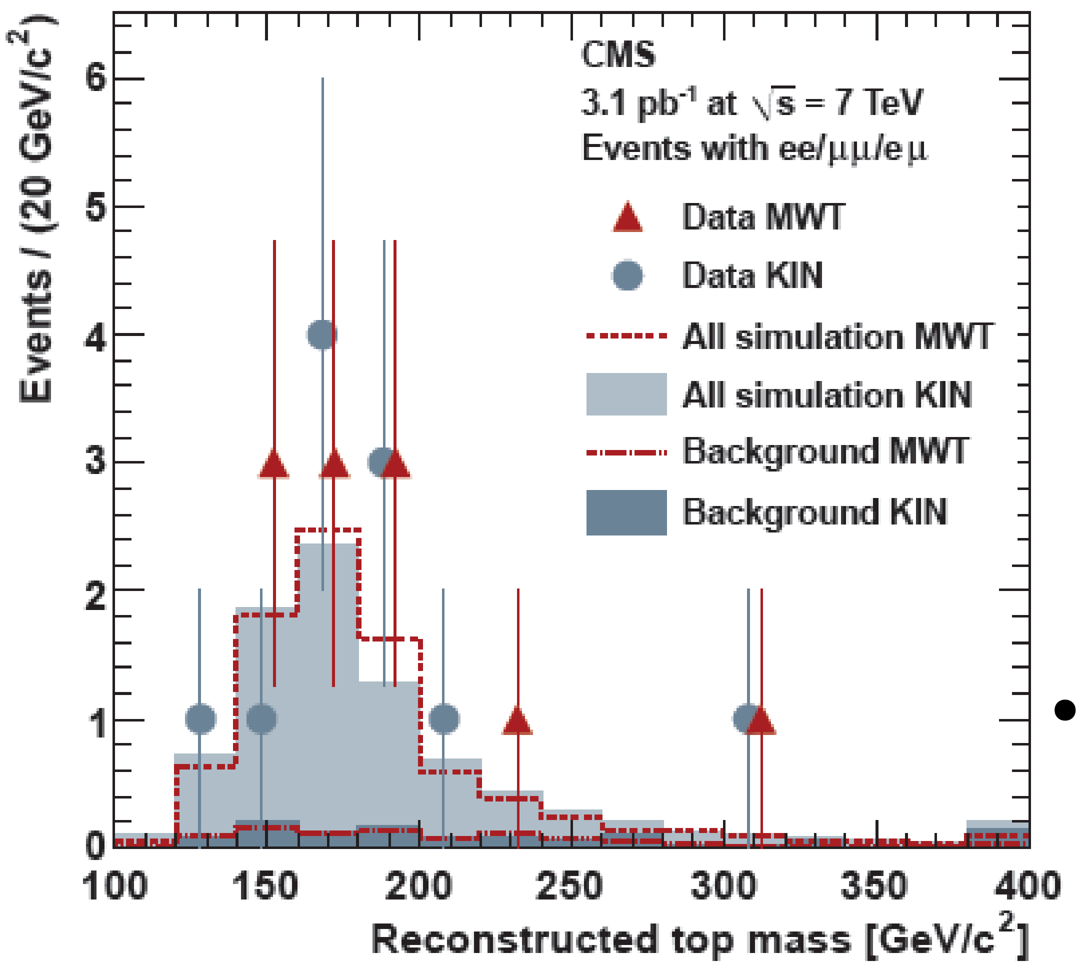
Maximize redundancy: alternative dileptonic analysis

- Standard top analyses rely to a large extent on calorimetry; we also explored a track-based jet clustering
  - Momentum is degraded (neutrals are lost), but no resonance is reconstructed in this final state, so we care for the number of jets, not for their 4-momenta
  - We have a very precise primary vertex reconstruction; taking only tracks compatible with the hardest primary vertex we are insensitive to "pile up"
- No MET cut
- Very similar results (see backup)



A $t\bar{t}$ candidate + 2 additional primary vertices

How top-like are these events: top mass estimation



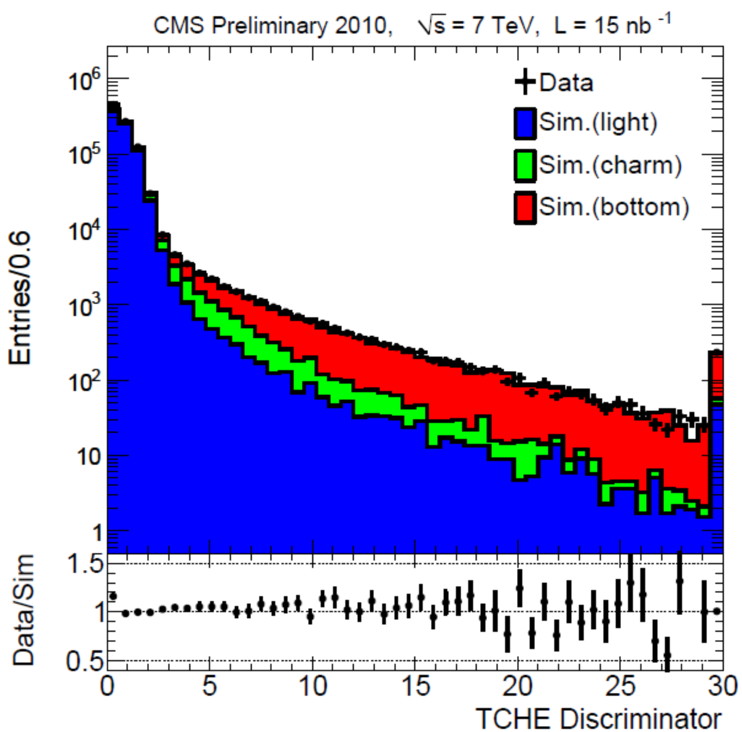
Dalitz & Goldstein, PRD 45, 1531 (1992)

- Matrix Weighting (MWT):
  - P and M_W constraints yield, for each M_t hypothesis, 2 ellipses in P_x/P_y (for top and antitop); their intersections are the solutions
  - Solution weights calculated from Prob($E_l^*|M_t$) and Bjorken x_1, x_2
  - Take M_t with largest weight sum
- Full Kinematic method (KIN):
  - Fully specify kinematics: adding P_z^{ttbar}, randomly thrown from a Gaussian (w/ width from MC)
  - Take M_t with most solutions

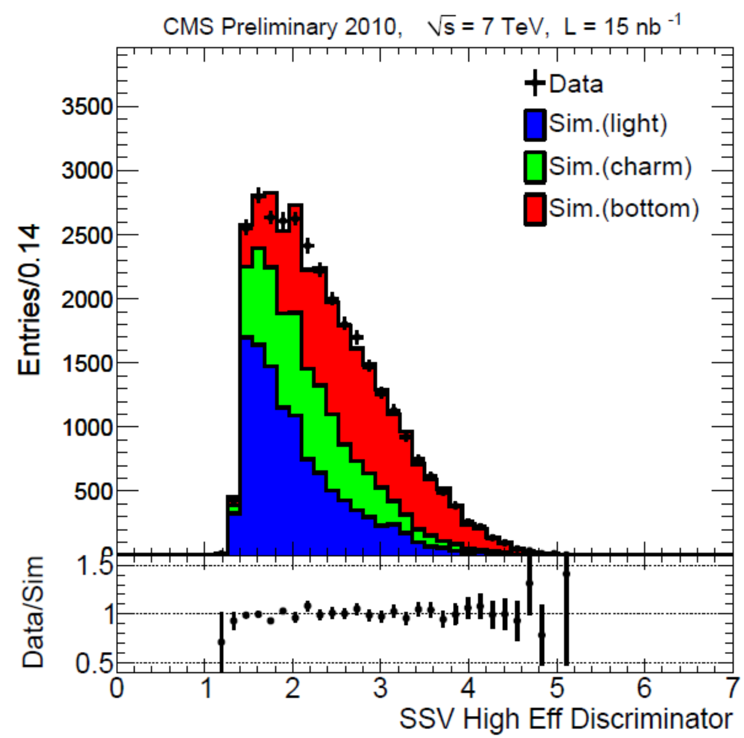
A look at b-tagging

CMS-BTV-10-001

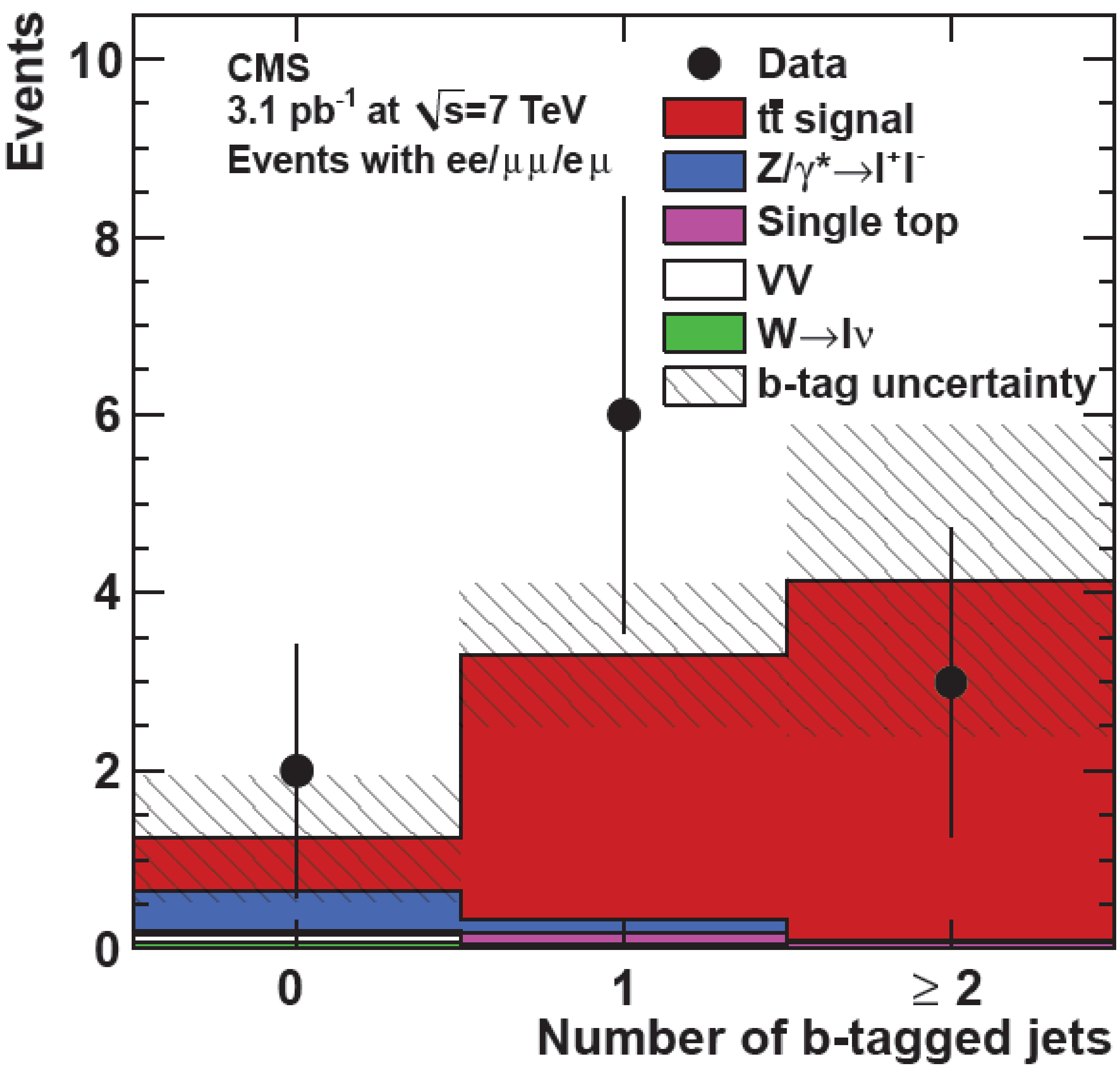
- “Track counting” tagger
  - Uses IP significance of n-th track as discriminator



- Secondary vertex tagger
  - Uses discriminator based on 3D flight distance

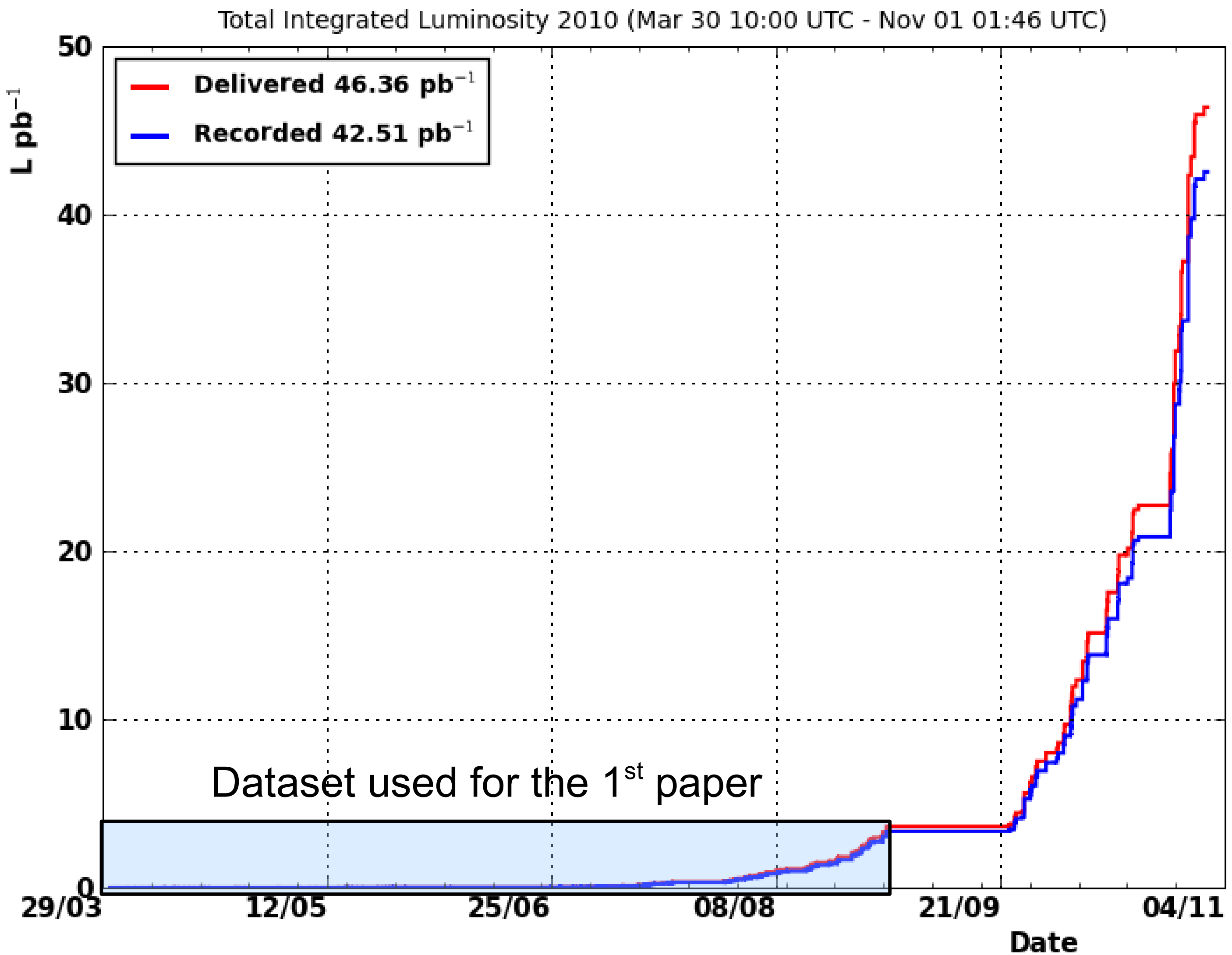


How top-like are these events: number of b-tagged jets



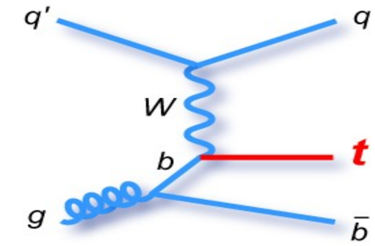
- Track counting tagger
  - At least 2 tracks with impact parameter significance >1.7σ
- Working point chosen such to give 10% mistagging probability for a light jet
- Roughly 80% efficiency for b-jets from top
- Hatched bands: uncertainty on the data/MC scale factor

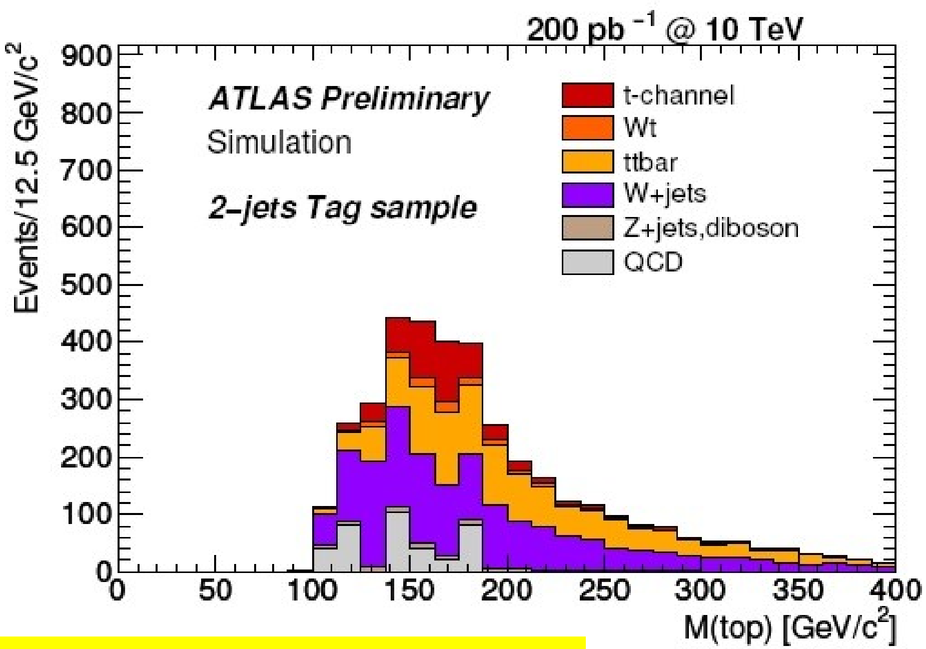
End of the 2010 pp run at 7 TeV



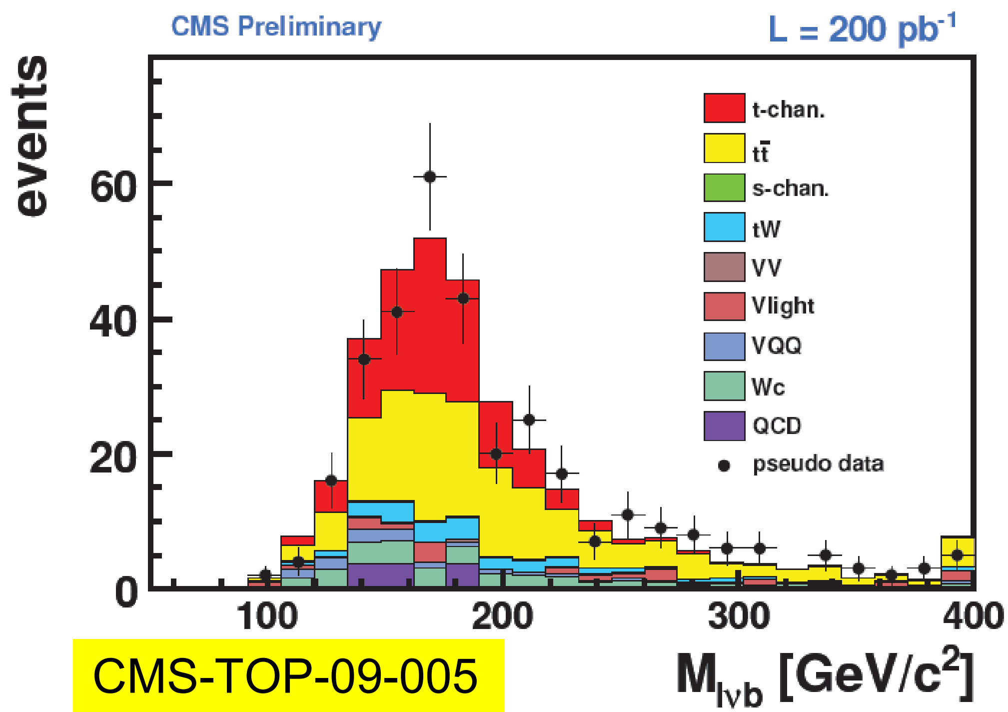
LHC goal for 2011: 1/fb. Discussion about ramping to 8 TeV

Coming soon: single top





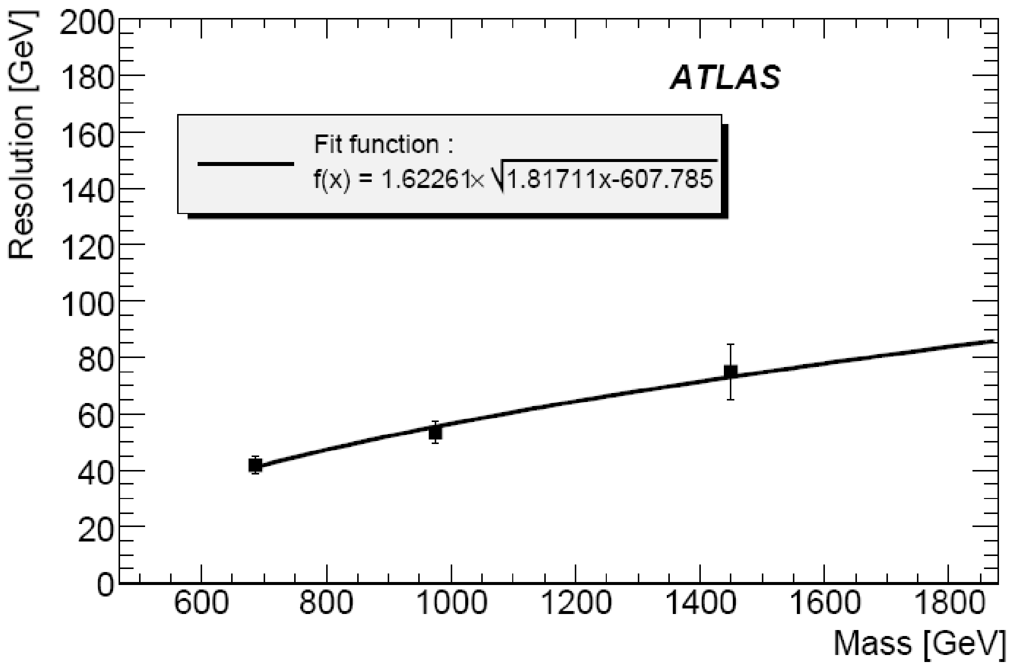
ATL-PHYS-PUB-2010-093



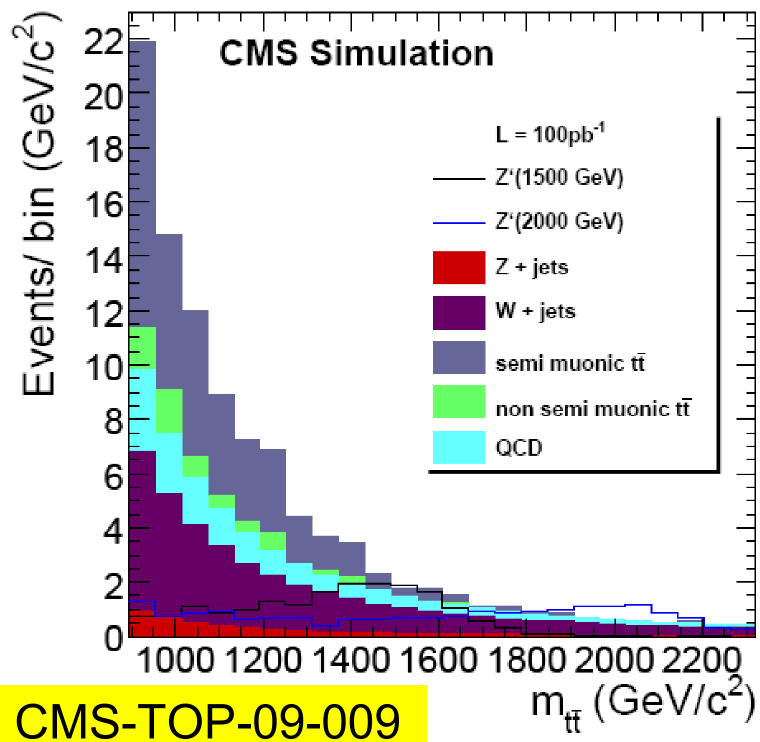
CMS-TOP-09-005

- Plots from MC studies with 200/pb @ 10 TeV assumption
- ATLAS & CMS have ambitious goals:
  - Confirm Tevatron's discovery with 2010 dataset
  - Competitive $|V_{tb}|$ precision with 2011 dataset

Coming soon: $X^0 \to t\bar{t}$ search (e.g., Z')



CERN-OPEN-2008-20, arXiv:0901.0512



CMS-TOP-09-009

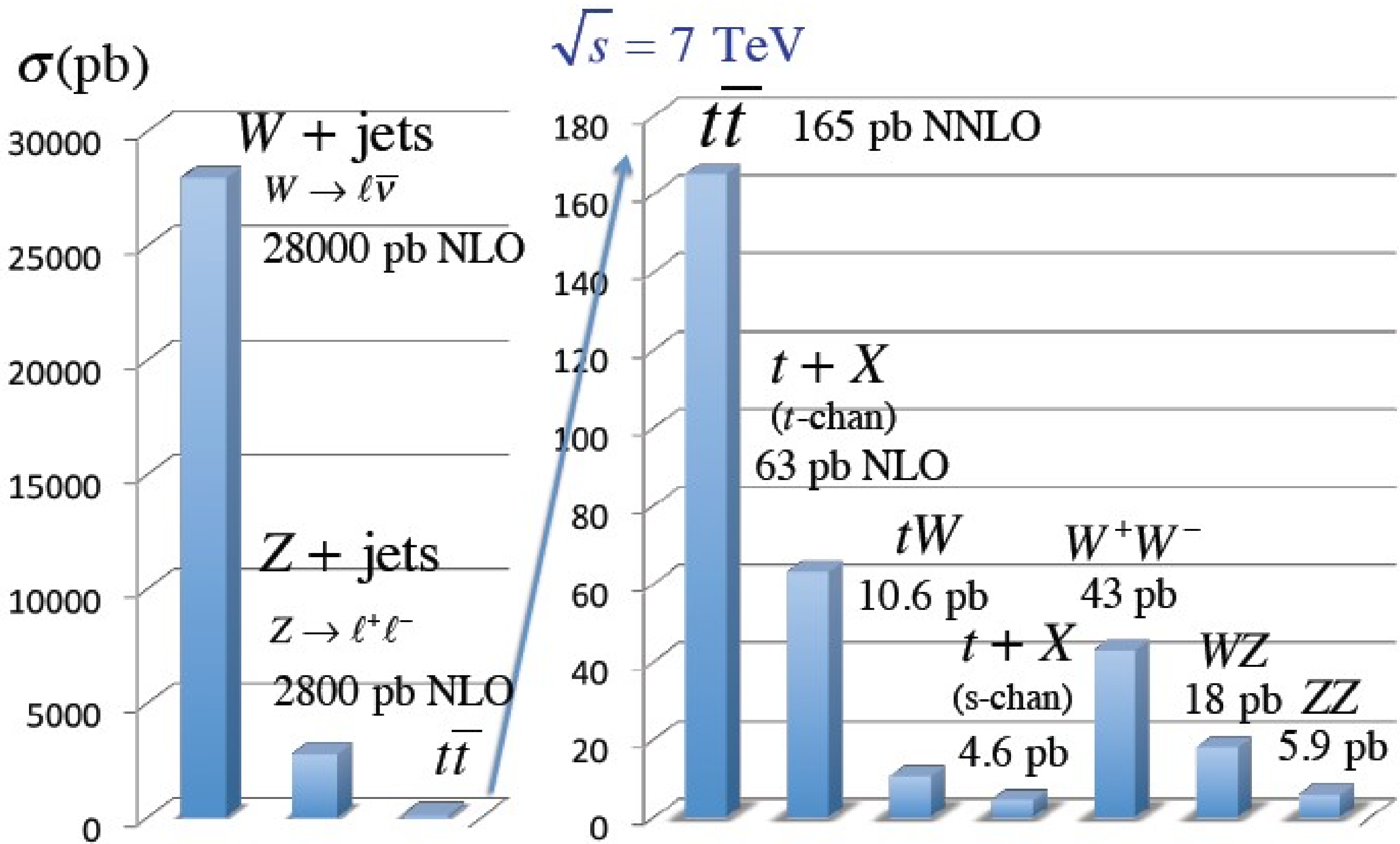
- Plots from MC studies with 14 and 10 TeV assumptions
- 1/fb @ 7 TeV: limits in $M_{Z'}$ range 1-3 TeV can be improved
- Challenge: top quark boost makes reconstruction tougher

Conclusions & Outlook

- LHC is starting to compete with Tevatron on top quark physics
  - Higher c.o.m. energy, and different production mechanism: gluon-gluon more than quark-antiquark
- Very first ttbar cross section at 7 TeV from CMS with 3.1/pb (dileptonic final states)
  - 37% statistical error, 39% stat+syst
  - Errors comparable w/ first CDF and D0 papers in Run II
- Rich program for top physics with 1/fb @ 7 TeV
  - ...or 8 TeV? Final decision at Chamonix, Jan.2011
  - Single top, $X^0 \rightarrow t\bar{t}$ search, mass, BR($t \rightarrow b$), ...

Backup

Black Hole / Strangelet CRASH Button
CMS
ABORT
In case of imminent world destruction:
break glass and push CMS abort button



Slide stolen to J.Richman

Lifetime and other times
(thanks to Fabio Maltoni)

$\tau_{had} \approx h/\Lambda_{QCD} \approx 2\bullet 10^{-24}$ s
$\tau_{top} \approx h/\,\Gamma_{top} = 1/(G_F\, m_t^3\, |V_{tb}|^2/8\pi\sqrt{2}) \approx 5\bullet 10^{-25}$ s
(with h=6.6 10^{-25} GeV s)

(Compare with $\tau_b \approx (G_F^2\, m_b^5\, |V_{bc}|^2\, k)^{-1} \approx 10^{-12}$ s)

Spin-flips are due to CHROMOMAGNETIC interactions, which are mediated by dimension 5 operators:

$$\mathcal{L}_{\rm mag} = \frac{C_m}{4m_t}\bar{Q}_v G_{\mu\nu}\sigma^{\mu\nu}Q_v \;\Rightarrow\; \tau_{\rm flip} \simeq h\left(\frac{\Lambda^2_{QCD}}{m_t}\right)^{-1} >> \tau_{\rm had}$$

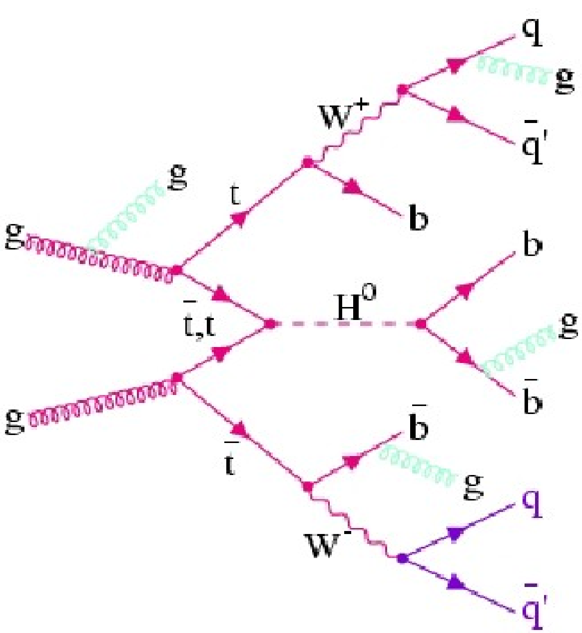
If, for instance, $V_{tb} \sim 0.3$, then top would start hadronizing into mesons and still conserve its spin!

[Falk and Peskin, 1994]

Top as a background

(two examples, and a lesson from history)

- $t\bar{t}H \rightarrow t\bar{t}b\bar{b}$
  - Need to study $t\bar{t}jj$ kinematics
- $\tilde{t}\bar{\tilde{t}} \rightarrow t\bar{t}\tilde{\chi}\tilde{\chi}$
  - Need to control tails of MET

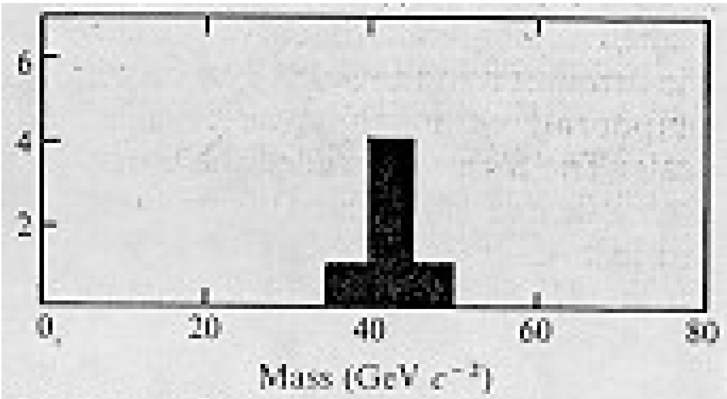


- 1984: UA1 “finds” the top!
  - And mono-jets the same year
  - Culprits: in both cases, extra jets in W/Z events

NATURE VOL 310 12 JULY 1984 — NEWS AND VIEWS

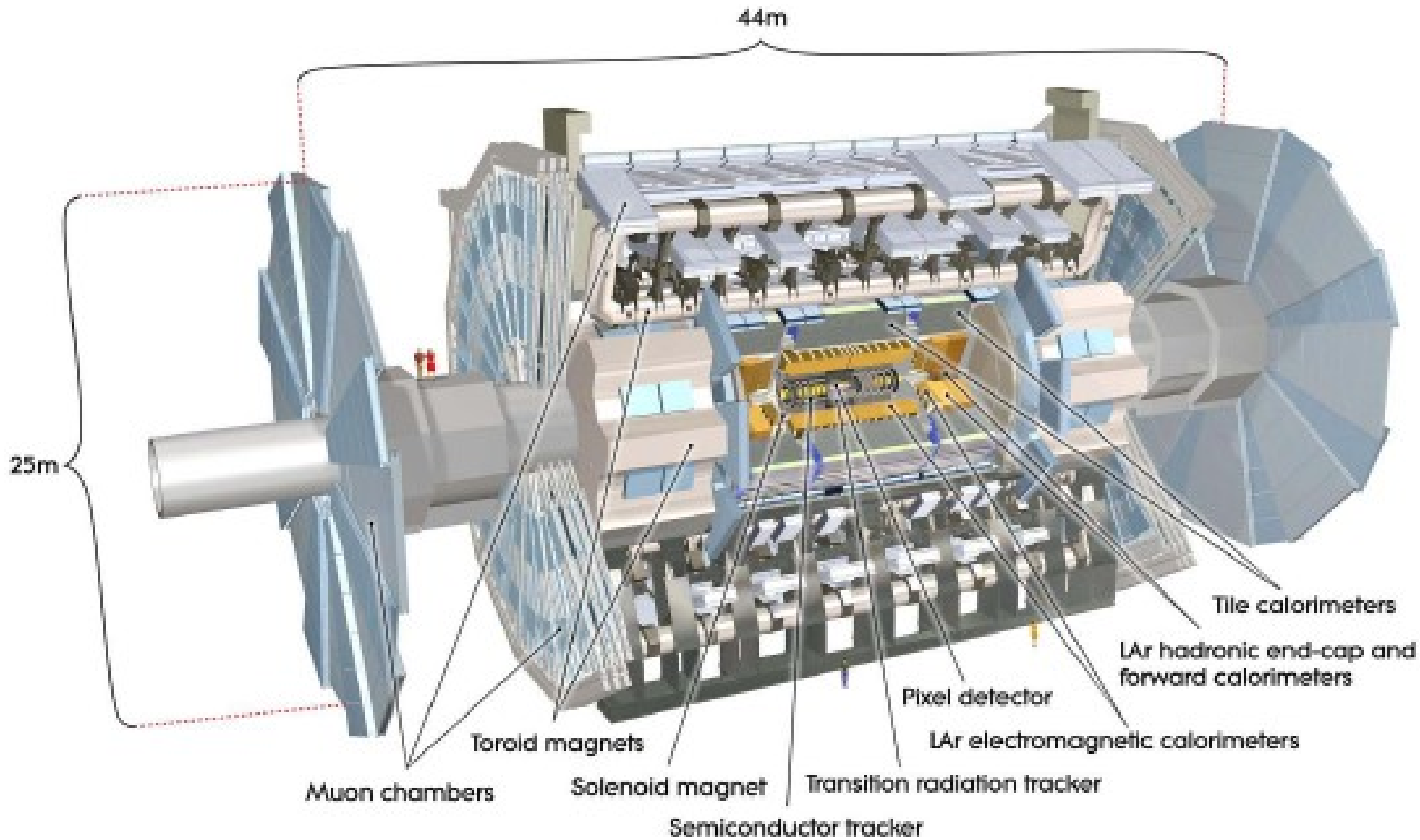
CERN comes out again on top

With the discovery of the electroweak bosons ($W^\pm$ and Z^0) in the bag, CERN now announces the discovery of the quark called top. What will come next?

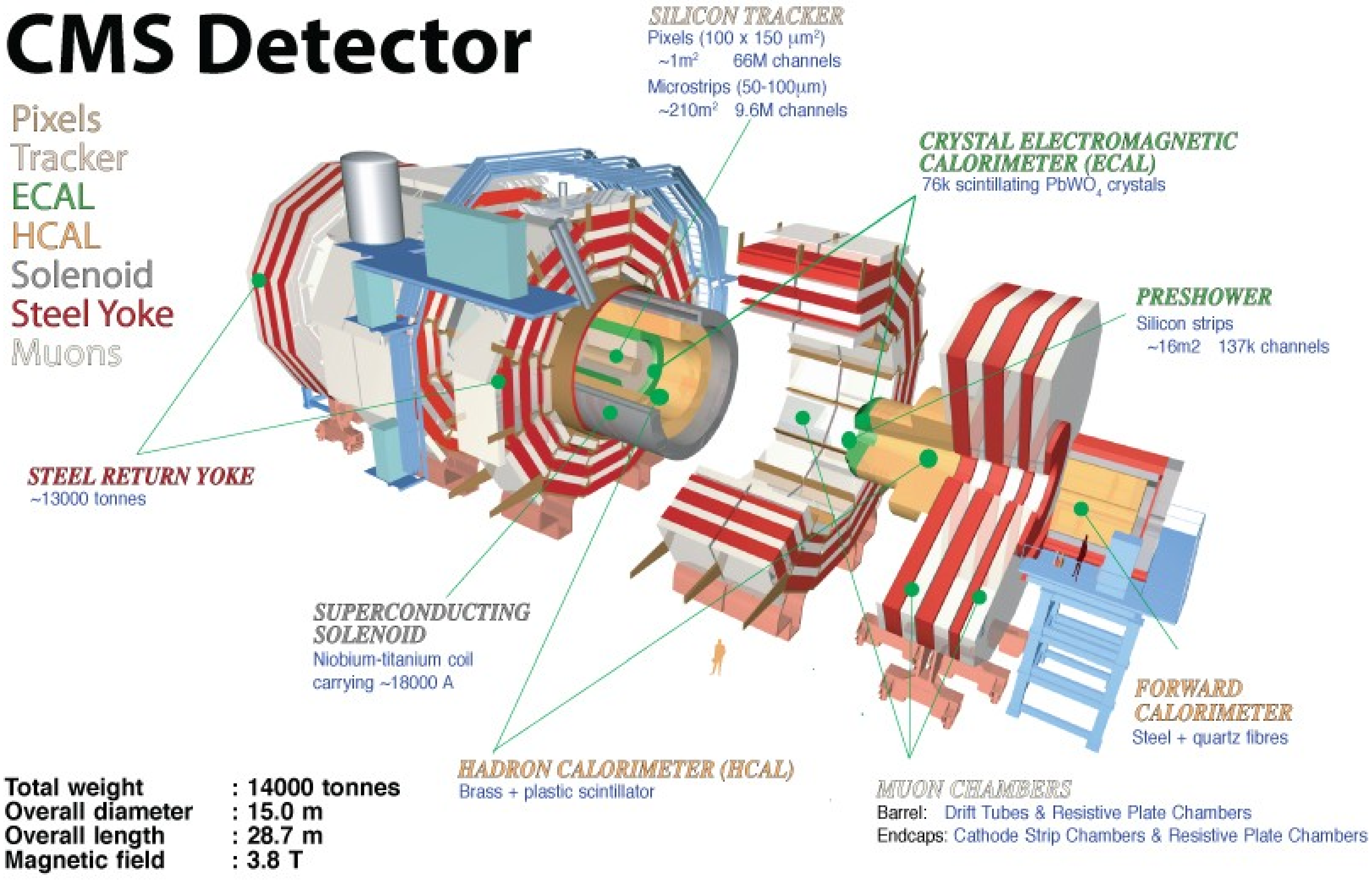


Distribution of measured top quark mass.

ATLAS detector

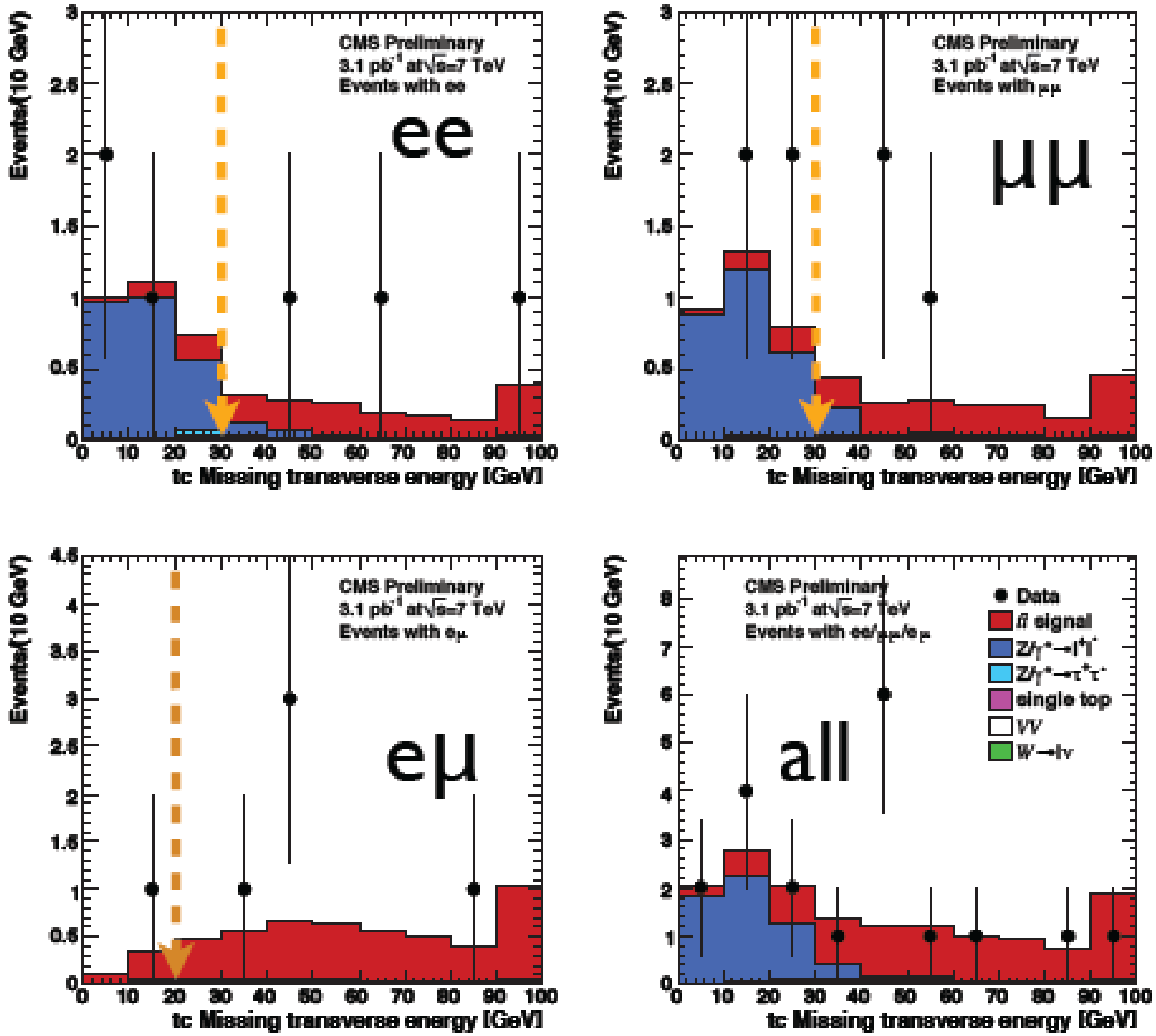


CMS detector



MET cut

CMS-TOP-10-001



Background estimation: QCD, W+jets, non-dileptonic tt

CMS-TOP-10-001

- QCD: start from the number of events with two FO leptons, correct by TL:

$$N_{nn}^{QCD} = \sum_{i,j} \frac{TL_i TL_j}{(1-TL_i)(1-TL_j)} N_{nn}^{ij}$$

- W+jets: start from events with 2 tight and 2 FO leptons, correct by TL and real dileptons:

$$N_{nn}^{Wj,raw} = \sum_{j} \frac{TL_j}{(1-TL_j)}$$

$$N_{nn}^{Wj} = N_{nn}^{Wj,raw} - 2N_{nn}^{QCD} - \Delta_{signal}$$

Estimation of Δ_{signal}

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- Using Z events from data
- Count events passing numerator selections, corrected by a Spillage Rate (SR)

$$\Delta_{signal} = N_{nn} \cdot SR_{\ell\ell'}$$

$$SR_{ee} = \frac{1}{N_{nn}^{Zee}} \sum_{i,j} \frac{TL_j}{(1-TL_j)}$$

- Similarly for $SR_{\mu\mu}$; instead, $SR_{e\mu}=(SR_{ee}+SR_{\mu\mu})/2$

Systematic uncertainties

Source	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$	all
Lepton selection	7.1%	5.2%	4.4%	4.4%
Energy scale	3.8%	4.0%	3.4%	3.7%
ISR/FSR	1%	1%	1%	1%
Decay model	2%	2%	2%	2%
Branching fraction	1.7%	1.7%	1.7%	1.7%
Subtotal (no backgrounds, no luminosity)	8.6%	7.1%	6.2%	6.4%
Backgrounds	50%	40%	$^{+10}_{-5}$%	15%
Total without luminosity	50%	40%	$^{+12}_{-8}$%	16%
Integrated luminosity	11%	11%	11%	11%

- Lepton sel.: from tag&probe with Z, MC used for Z/tt difference
- Energy scale: jets and hadronic part of MET scaled by ±5%
- ISR/FSR, decay model: by comparing various MC samples
- PDF uncertainty: <0.5% impact
- Backgrounds: mostly data-driven, see later in this talk

Selected events (standard analysis)

Table 6: Expected signal and background contributions compared to the number of events observed in data passing full signal selection. Contributions from $Z/\gamma^\star \rightarrow e^+e^-, \mu^+\mu^-$ and events with non-W/Z leptons are estimated from data. All other contributions are estimated from simulation. Systematic uncertainty prior to backgrounds as given in Table 5 is reported for the signal expectation. The contribution from the non-W/Z leptons in the $e^\pm\mu^\mp$ final state is truncated at zero for the purpose of obtaining the total background estimate in $e^\pm\mu^\mp$ final state, it is an intermediate estimate and is allowed to be negative to obtain the total in all modes combined.

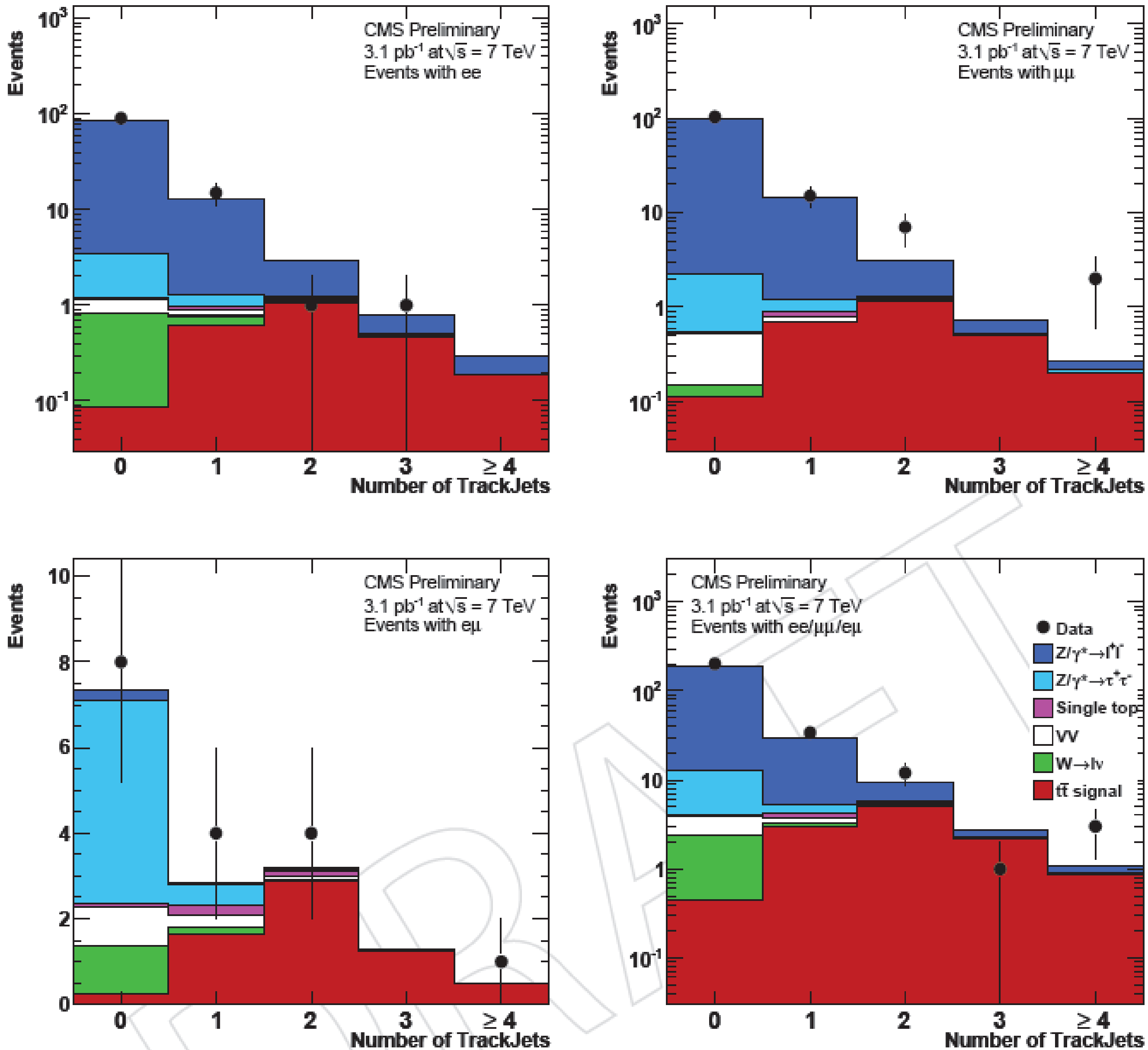
Source	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$	All
Dilepton $t\bar{t}$	1.5 ± 0.1	1.7 ± 0.1	4.5 ± 0.3	7.7 ± 0.5
VV	0.03 ± 0.02	0.03 ± 0.02	0.08 ± 0.04	0.13 ± 0.07
Single top	0.05 ± 0.03	0.05 ± 0.03	0.15 ± 0.08	0.25 ± 0.13
$Z/\gamma^\star \rightarrow \tau^+\tau^-$	0.04 ± 0.02	0.07 ± 0.03	0.07 ± 0.04	0.18 ± 0.09
$Z/\gamma^\star \rightarrow e^+e^-, \mu^+\mu^-$	$0.8 \pm 0.4 \pm 0.4$	$0.6 \pm 0.4 \pm 0.3$	N/A	$1.4 \pm 0.5 \pm 0.5$
Events with non-W/Z leptons	$0.3 \pm 0.4 \pm 0.2$	$0.1 \pm 0.2 \pm 0.2$	$-0.3\,^{+0.4}_{-0.1}\,^{+0.2}_{-0.1}$	$0.1 \pm 0.5 \pm 0.3$
Total backgrounds	1.2 ± 0.7	0.8 ± 0.6	$0.3\,^{+0.4}_{-0.1}$	2.1 ± 1.0
Data	3	3	5	11

Selected events (track-jets, no MET)

Table 7: Summary of the number of selected events and estimated signal and background for events with two isolated and identified leptons with oppositely signed charges, passing Z-veto and having at least two track-jets. All backgrounds and uncertainties are estimated in the same way as for the main analysis. The systematic uncertainty on the $Z/\gamma^{\star}$ estimate is 25%, reflecting no missing energy requirement which is the main source of uncertainty on this estimate.

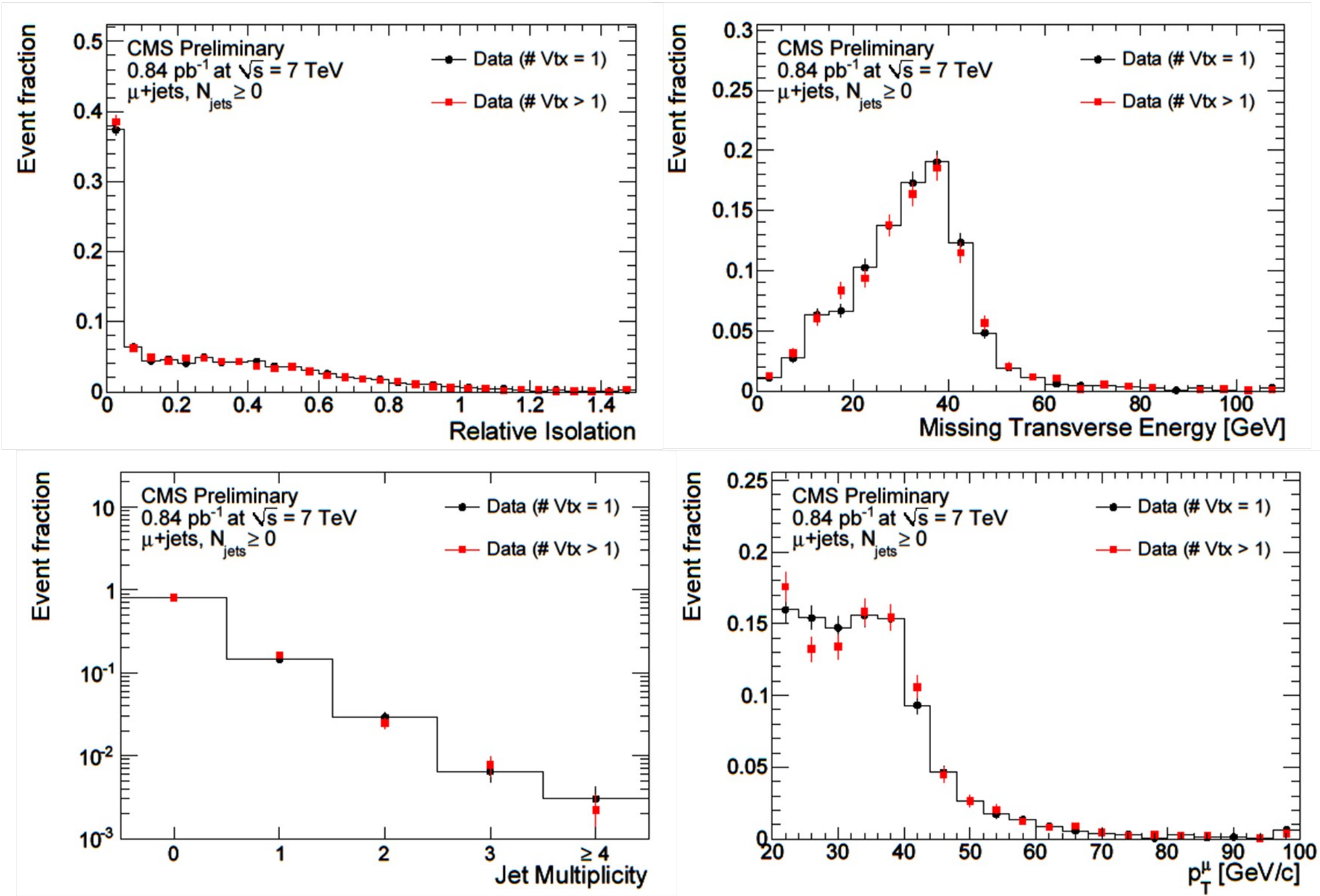
Mode	e^+e^-	$\mu^+\mu^-$	$e^{\pm}\mu^{\mp}$	all
Events in data	2	9	5	16
$Z/\gamma^{\star}$ estimate	2.0 ± 0.7	2.4 ± 0.7	-	4.4 ± 1.3
QCD estimate	0.3 ± 0.4	0.3 ± 0.2	0.0 ± 0.2	0.5 ± 0.5
Wjets estimate	-0.5 ± 0.7	-0.2 ± 0.4	-0.1 ± 0.6	-0.8 ± 1.0
Background from simulation	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.6 ± 0.3
Total backgrounds	2.2 ± 0.9	2.6 ± 0.8	0.3 ± 0.5	5.1 ± 1.6
Signal from simulation	1.7 ± 0.1	1.9 ± 0.1	4.6 ± 0.3	8.2 ± 0.5

Track-jets


CMS Preliminary
3.1 pb-1 at √s = 7 TeV
Events with ee
Events with μμ
Events with eμ
Events with ee/μμ/eμ
Events
Number of TrackJets
0
1
2
3
≥ 4
Data
Z/γ*→l+l-
Z/γ*→τ+τ-
Single top
VV
W→lν
tt̄ signal

Sensitivity to pile-up

CMS-TOP-10-004



First top candidates: ATLAS

ATLAS-CONF-2010-063
ATLAS-CONF-2010-087

ID	Run number	Event number	Channel	p_T^{lep} (GeV)	E_T^{miss} (GeV)	m_T (GeV)	m_{jjj} (GeV)	#jets $p_T > 20$ GeV	#b-tagged jets
LJ1	158801	4645054	μ+jets	42.9	25.1	59.3	314	7	1
LJ2	158975	21437359	e+jets	41.4	89.3	68.7	106	4	1
LJ3	159086	12916278	e+jets	26.2	46.1	62.6	94	4	1
LJ4	159086	60469005	e+jets	39.1	66.7	102	231	4	1
LJ5	159086	64558586	e+jets	79.3	43.4	86.7	122	4	1
LJ6	159224	13396261	μ+jets	29.4	65.4	64.1	126	5	1
LJ7	159224	13560451	μ+jets	78.7	40.0	83.7	108	4	1

ID	Run number	Event number	Channel	p_T^{lep} (GeV)	E_T^{miss} (GeV)	H_T (GeV)	#jets $p_T > 20$ GeV	#b-tagged jets
DL1	155678	13304729	ee	55.2/40.6	42.4	271	3	1
DL2	158582	27400066	$e\mu$	22.7/47.8	76.9	196	3	1