Top at LHC

top pair production

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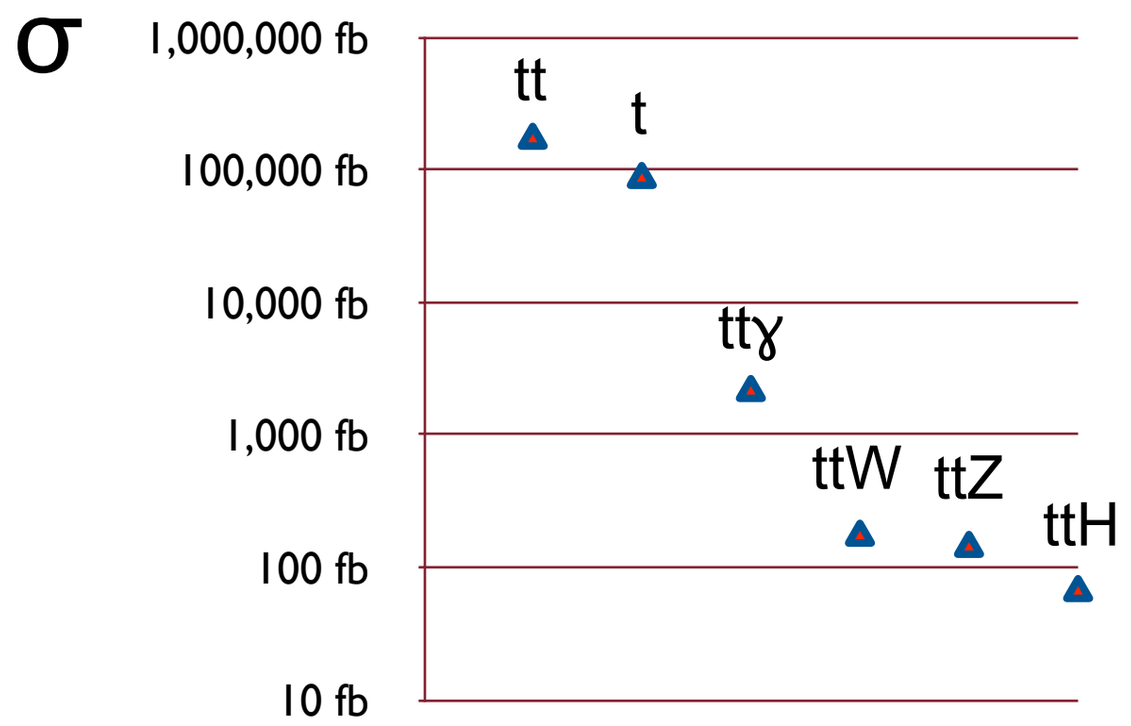
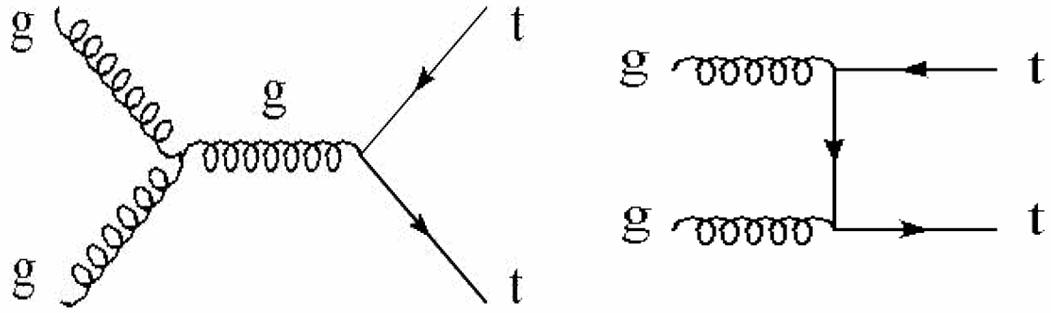
INTERESTING PHYSICS WITH TOP

- Strong sector
  - ttbar production
- Electromagnetic interaction
  - ttbar + photon
- Electroweak sector
  - ttbar + W/Z
- Elctroweak symmetry breaking
  - ttbar + Higgs production
  - precise measurement of coupling constants to Higgs



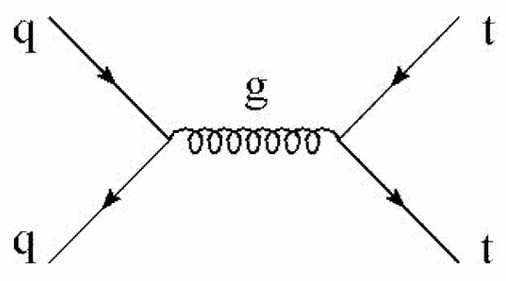
T-TBAR PRODUCTION

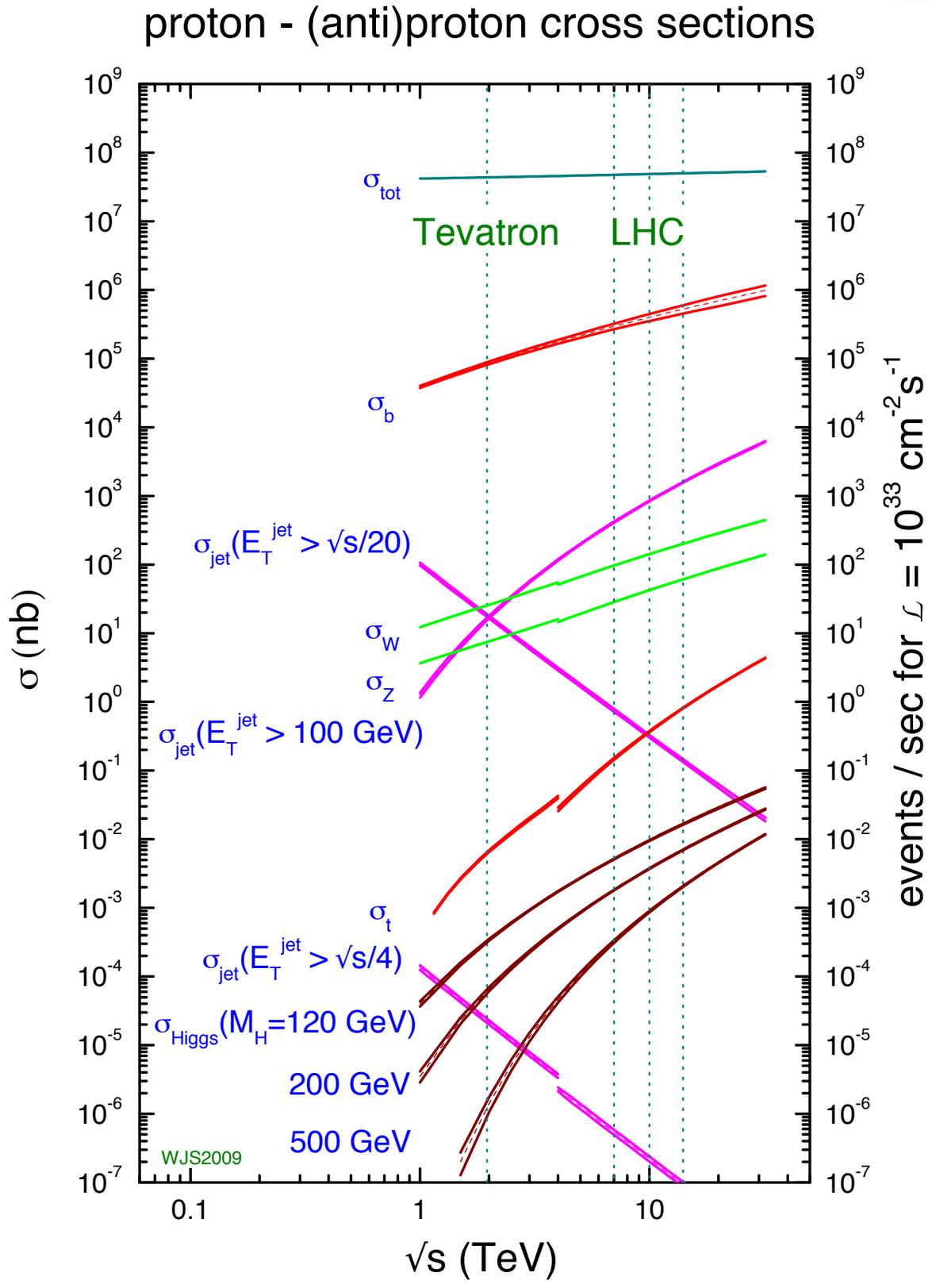
- gluon-gluon fusion dominates at LHC: > 80% of cross section



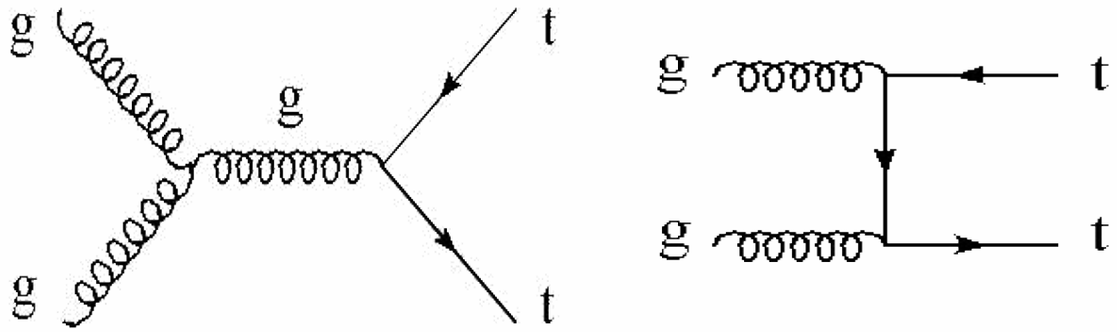
	Tevat	LHC(7)	LHC(14)
gg	~10%	~85%	~90%
qq	~90%	~15%	~10%

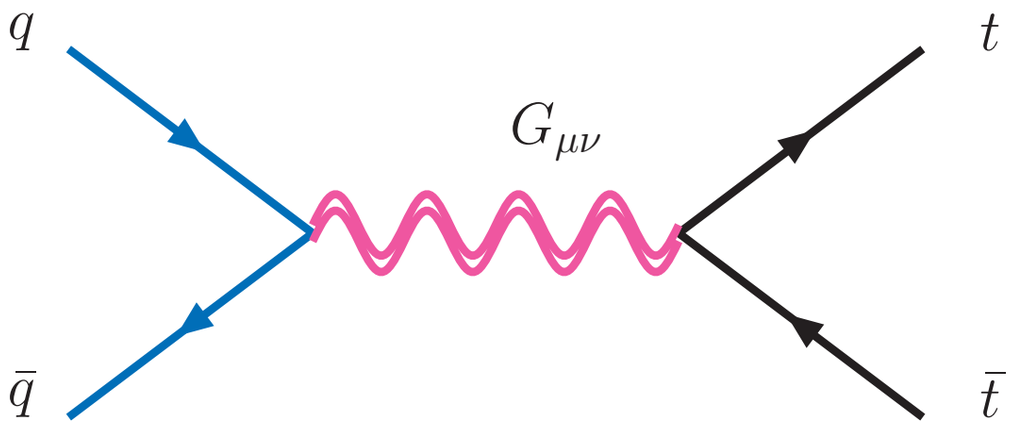
- At Tevatron 90% cross section due to quark-antiquark diagram

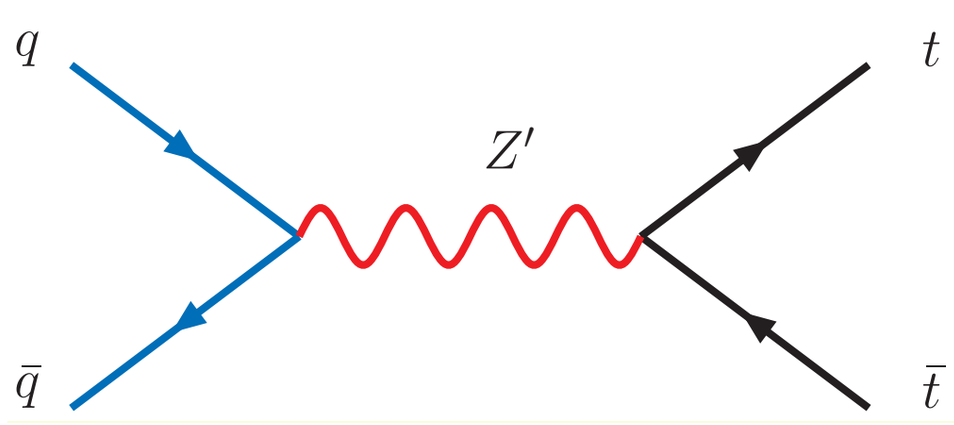




New Physics in T-Tbar







- New heavy resonances could enhance cross section with visible invariant mass peak

T-TBAR CROSS SECTION

√s(TeV)	xsec (pb)	Rate at $10^{33}cm^{-2}\ s^{-1}$
1.96 ($p\bar{p}$)	~7	
7 (pp)	~165	0.2Hz
14 (pp)	~900	0.9Hz

Top Factory!

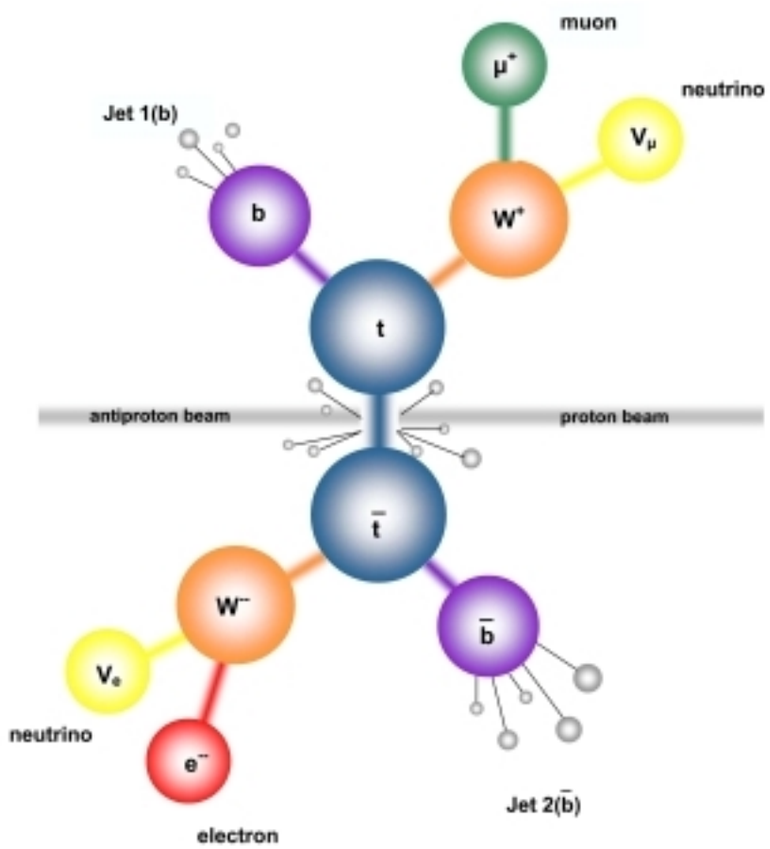
for $\int Ldt$ =1 fb^{-1} @ 7TeV, expect $16 \cdot 10^4$ events

Tevatron (lower energy collider): $\int Ldt$ =9.4 fb^{-1} on tape, expect ~ $6.6 \cdot 10^4$ events

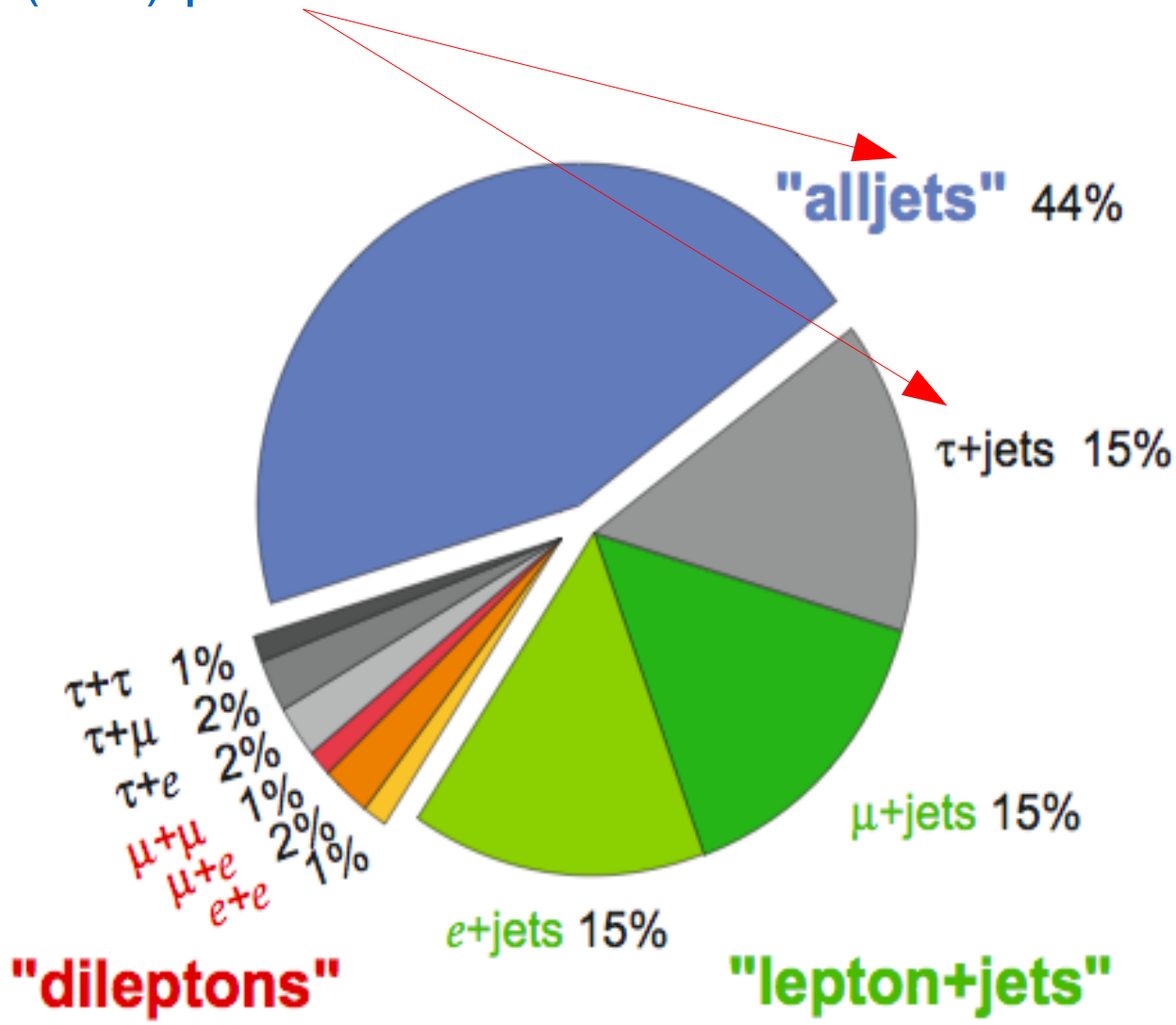
- b-tagging critical at Tevatron but not necessarily at LHC
  - very useful but given large sample top measurement feasible also without tagging

- Development of top tagging to recognize top topology

T-TBAR FINAL STATES



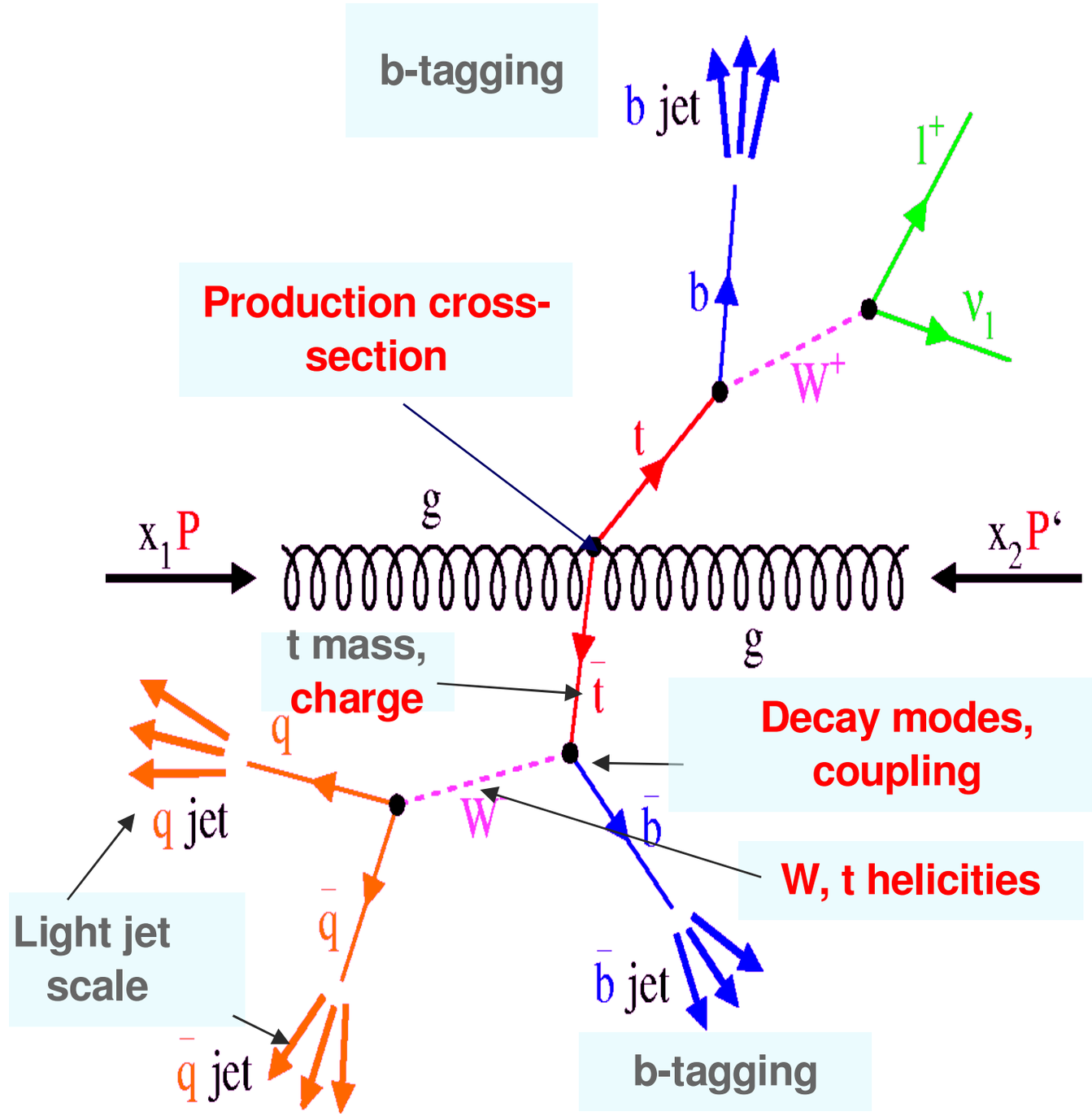
tt final states not considered in the Top rediscovery at LHC in analyses up to O(100) pb^{-1}



tt final states (l=e,μ)

- Full hadronic **45%**: 6 jets
- Semileptonic **30%**: ℓ + MET + 4jets
- Dileptonic **11%**: 2ℓ +MET + 2jets

T-TBAR TOPOLOGY

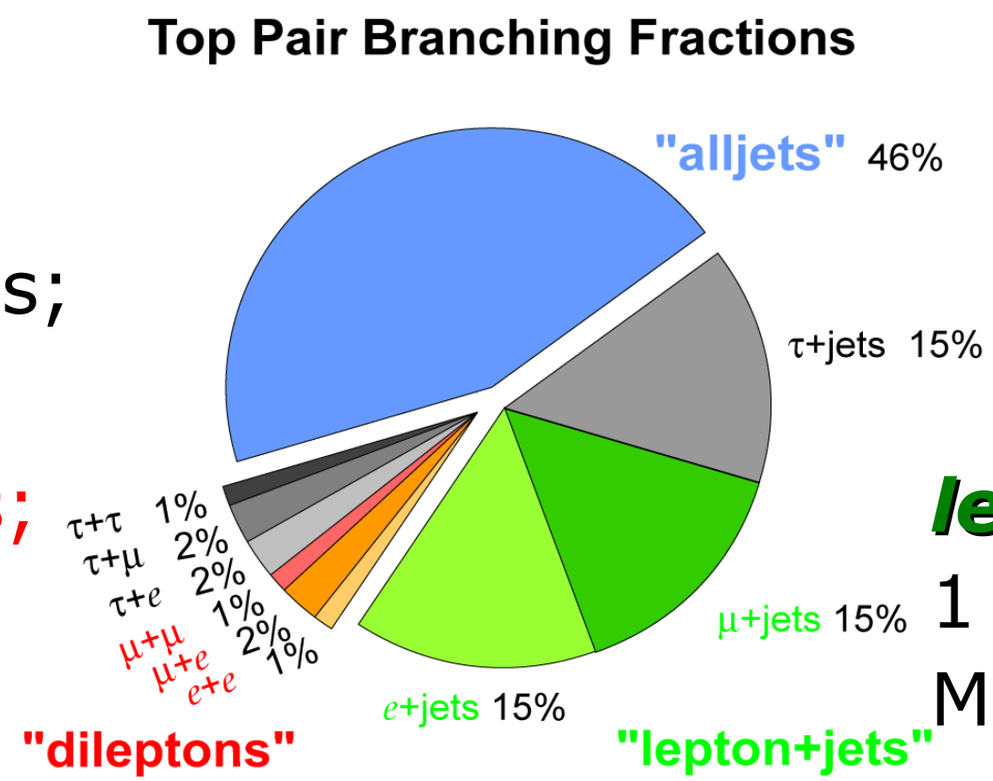


T-TBAR SIGNATURES

$t\bar{t} \rightarrow W^+bW^-\bar{b}$: Final states are classified according to W decay

$B(t \rightarrow W^+b) = 100\%$

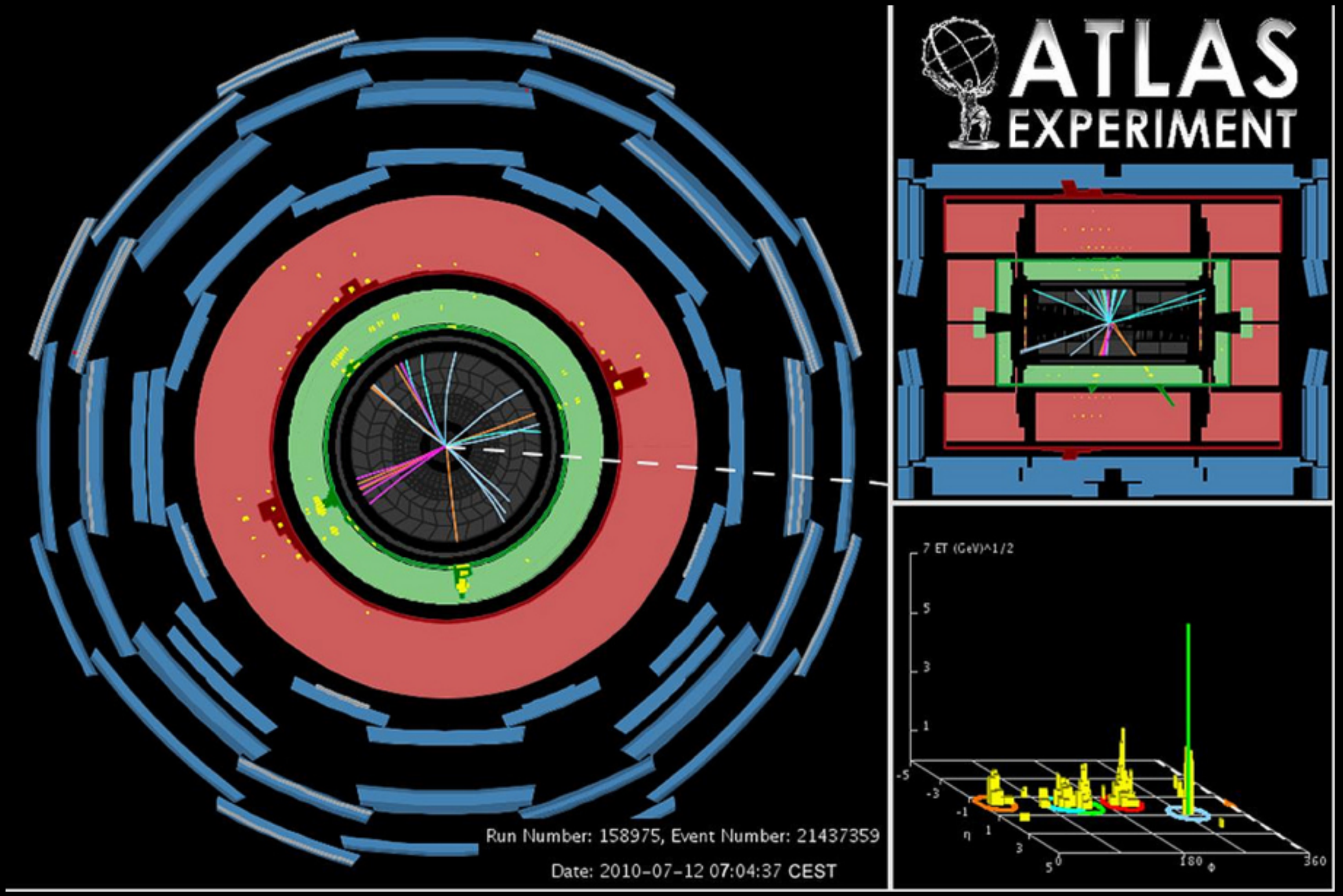
pure hadronic:
≥6 jets (2 b-jets)



dilepton:
2 isolated leptons;
High missing E_T
from 2 neutrinos;
2 b-jets

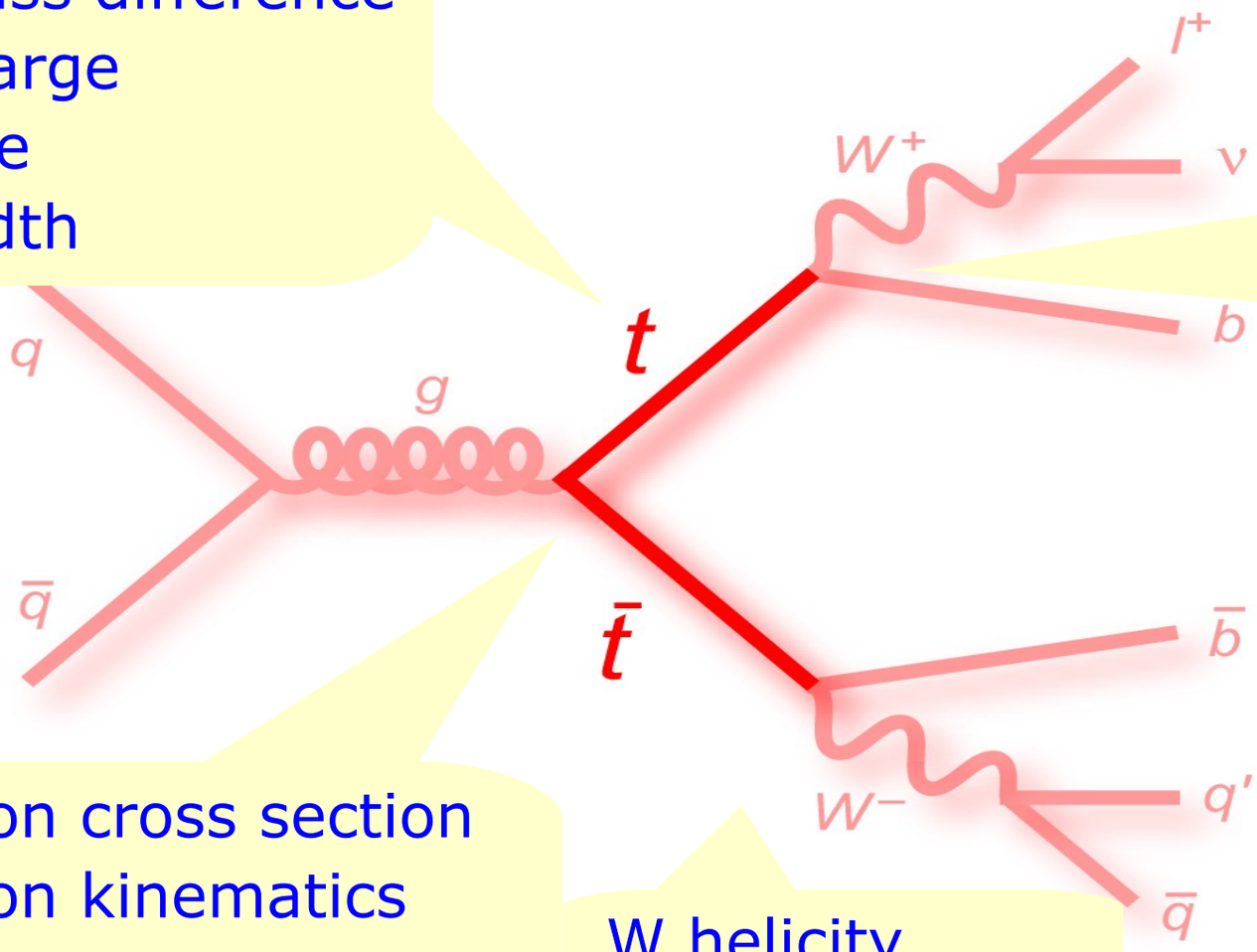
lepton+jets:
1 isolated lepton;
Missing E_T from neutrino;
≥4 jets (2 b-jets)

T-TBAR CANDIDATE AT LHC



Top Measurements

Top mass
Top mass difference
Top charge
Lifetime
Top width



Branching ratios
$|V_{tb}|$
Anomalous coupling
New/Rare decays

Spin correlation
Charge asymmetry
Color Flow

Production cross section
Production kinematics
Production via resonance
New particles

W helicity

s- & t- channel production, properties and searches in single top events

Top Measurements

$M_t = 173.3 \pm 1.1$ GeV/c^2

$M_t - M_{tbar} = -3.3 \pm 1.7$ GeV/c^2

$\Gamma_t < 7.5$ GeV at 95% CL

Exclude q = -4/3 at 95%CL

No evidence for SUSY stop

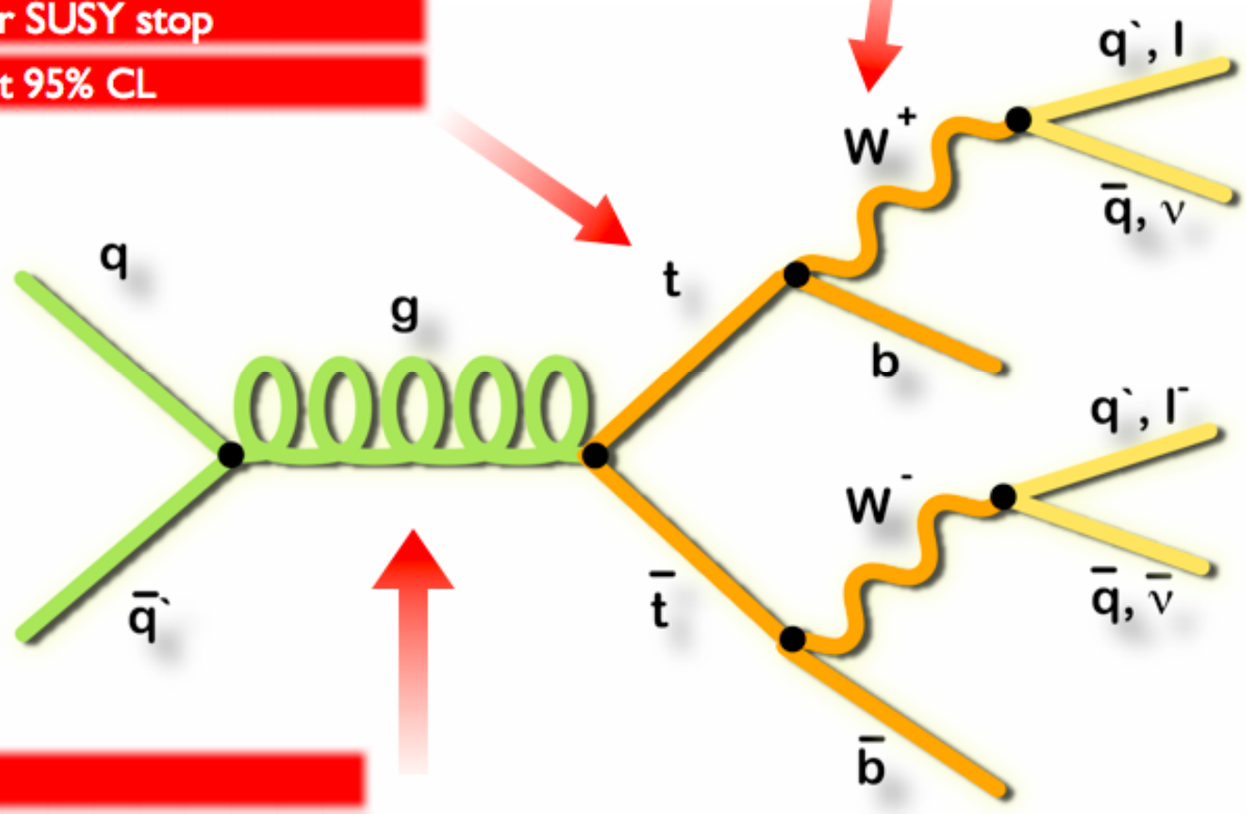
$M_{t'} > 335$ GeV at 95% CL

Vtb = 0.91 ± 0.11 (exp) ± 0.07 (theory)

No evidence for charged Higgs

BR(t→Zq) < 3.7% at 95% CL

$F_0 = 0.62 \pm 0.11$ & $F_+ = -0.04 \pm 0.05$



$\sigma_{ttbar} = 7.5 \pm 0.5$ pb

$\sigma_{singletop} = 2.8 + 0.5$ pb

$\sigma_{ttbar+j} = 1.6 \pm 0.5_{sys}$ pb

$M_{Z'} > 900$ GeV at 95% CL

$M_{W'} > 800$ GeV at 95% CL

$M_{b'} > 372$ GeV at 95% CL

$F_{gg} = 0.07\ ^{+0.15}_{-0.07}$ (stat+sys)

$A_{fb} = 0.475 \pm 0.114$

Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

Measurement of Top Cross Section

- Trigger requirements: single lepton trigger
  - at least one electron with p_T > 15 GeV OR
  - at least one muon with p_T > 9 GeV
- Signal Selection
  - isolated leptons: little activity around candidate lepton
    - reject fakes from jets
  - lepton pairs with opposite charge: ee, μμ, eμ
    - 15 GeV veto around Z mass
    - M_{ll} > 10 GeV: reject Jpsi and other low mass resonances
  - Missing transverse energy
    - caused by neutrinos in semileptonic W decay
  - At least 2 jets
    - at least 2 b quarks in final state
- Main sources of backgrounds

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

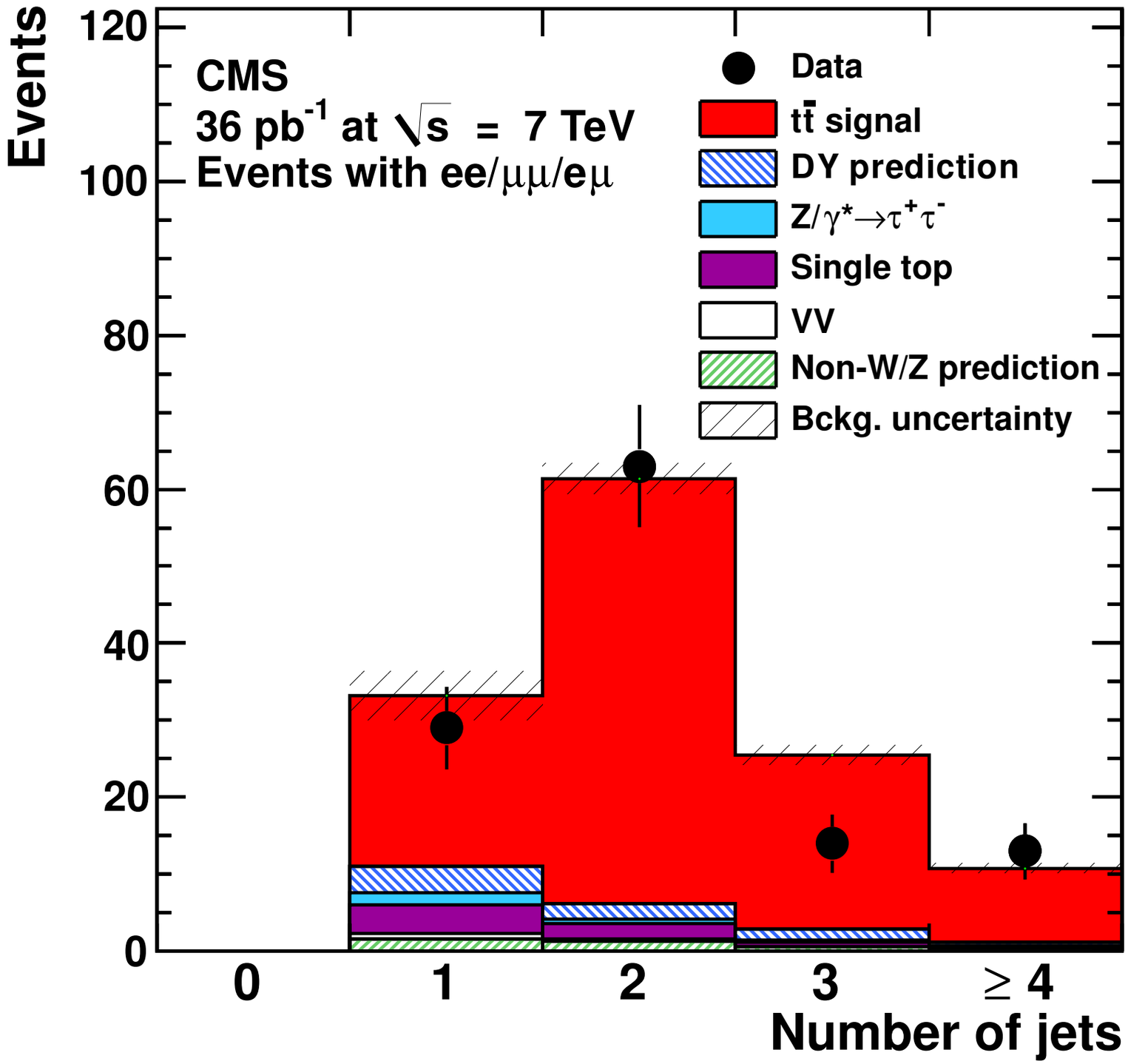
JHEP 07 (2011) 049

Final state	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
At least two jets, no b-tagging requirement			
Events in data	23	28	60
Simulated backgrounds	1.4 ± 0.3	1.5 ± 0.3	5.2 ± 1.2
$Z/\gamma^\star \to e^+e^-/\mu^+\mu^-$	3.0 ± 1.8	7.4 ± 4.1	–
Non-W/Z	1.1 ± 1.4	0.6 ± 1.1	1.4 ± 1.6
All backgrounds	5.5 ± 2.3	9.5 ± 4.3	6.7 ± 2.0
Total acceptance $\mathcal{A}$ (%)	0.259 ± 0.021	0.324 ± 0.025	0.928 ± 0.057
Cross section (pb)	$189 \pm 52 \pm 29$	$159 \pm 45 \pm 39$	$160 \pm 23 \pm 12$
At least two jets, at least one b-jet			
Events in data	15	24	51
Simulated backgrounds	0.7 ± 0.2	0.8 ± 0.3	2.5 ± 0.7
$Z/\gamma^\star \to e^+e^-/\mu^+\mu^-$	0.7 ± 0.7	2.6 ± 1.8	–
Non-W/Z	0.9 ± 1.2	0.3 ± 0.8	0.5 ± 1.1
All backgrounds	2.3 ± 1.4	3.8 ± 2.0	3.0 ± 1.4
Total acceptance $\mathcal{A}$ (%)	0.236 ± 0.022	0.303 ± 0.028	0.857 ± 0.068
Cross section (pb)	$150 \pm 46 \pm 22$	$186 \pm 45 \pm 25$	$156 \pm 23 \pm 13$
One jet, no b-tagging requirement			
Events in data	8	10	18
Simulated backgrounds	1.6 ± 0.4	1.9 ± 0.4	3.6 ± 0.9
$Z/\gamma^\star \to e^+e^-/\mu^+\mu^-$	0.2 ± 0.3	5.2 ± 4.3	–
Non-W/Z	0.3 ± 0.5	0.1 ± 0.4	1.3 ± 1.3
All backgrounds	2.1 ± 0.7	7.1 ± 4.3	4.9 ± 1.5
Total acceptance $\mathcal{A}$ (%)	0.058 ± 0.007	0.074 ± 0.008	0.183 ± 0.024
Cross section (pb)	$282 \pm 135 \pm 45$	$107 \pm 119 \pm 163$	$200 \pm 65 \pm 35$

Data Driven Background Estimate

- Drell-Yan background
  - count N_{rej} events rejected by Z veto in data
  - count N_{passMC} simulated Drell-Yan events retained by Z veto
  - count N_{failMC} simulated Drell-Yan events rejected by Z veto
  - Estimate N_{DY} of residual background events in signal sample as $N_{DY} = N_{rej} \times N_{passMC} / N_{failMC}$
- Non-W/Z lepton background: events with real leptons not produced in W/Z decays
  - define a Tight lepton selection for signal
  - Define a Loose selection with relaxed requirements
  - use non-W/Z events (e.g. multijet QCD) to measure $R_{TL} = N_T/N_L$ where
    - N_T: number of non-W/Z leptons passing tight selection
    - N_L: number of non-W/Z leptons passing loose selection
    - count number of N_{loose} dilepton events failing tight and passing loose selection
    - Determine $N_{bkg} = N_{loose} \times R_{TL}$
- 50% systematic uncertainty of background determination
  - calibration effects. dependency of Drell-Yan background on tight requirements
  - contamination of bkg sample by EW events; flavor differences between multijet QCD sample and real background

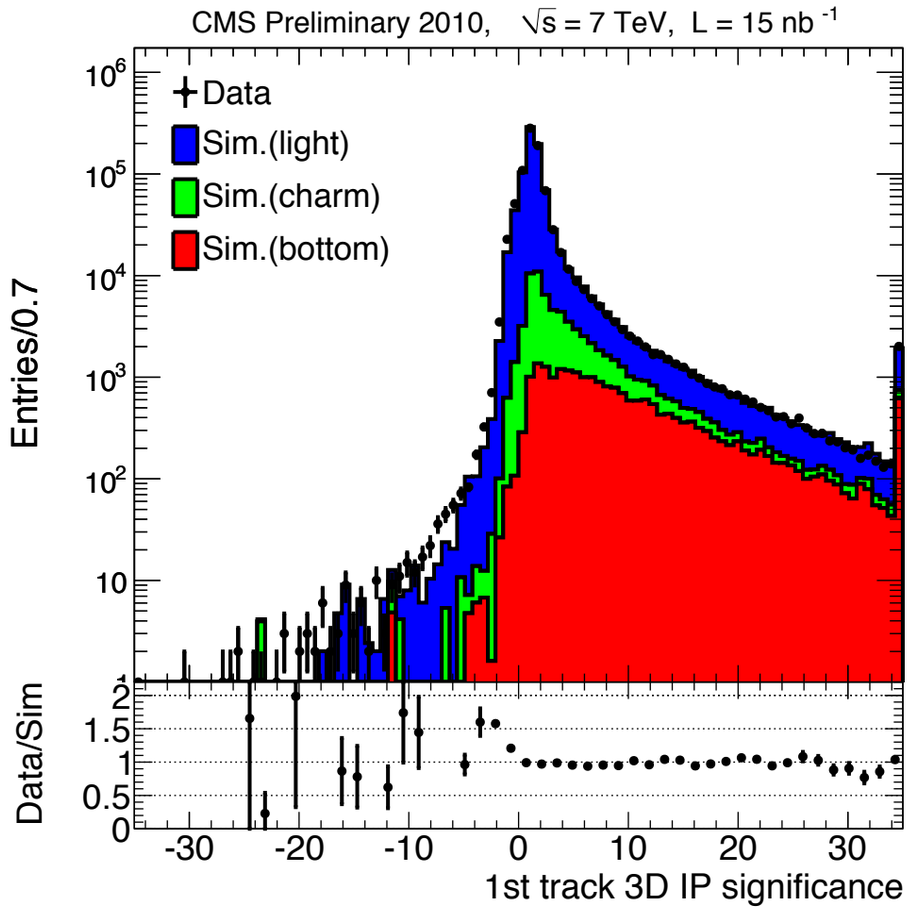
JET MULTIPLICITY



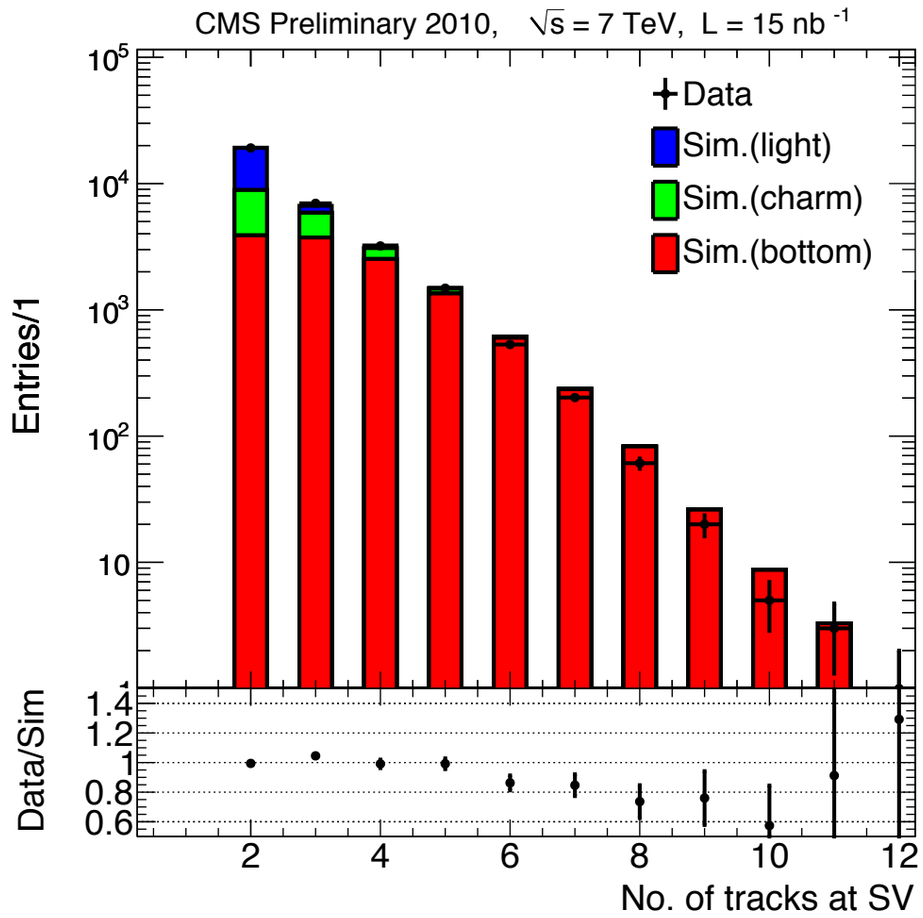
B-TAGGING

- Exploit presence of at least 2 tracks with large impact parameter
- 80% efficient on signal
- 10% fake rate estimates on QCD multijet with no b-quark

Impact parameter significance

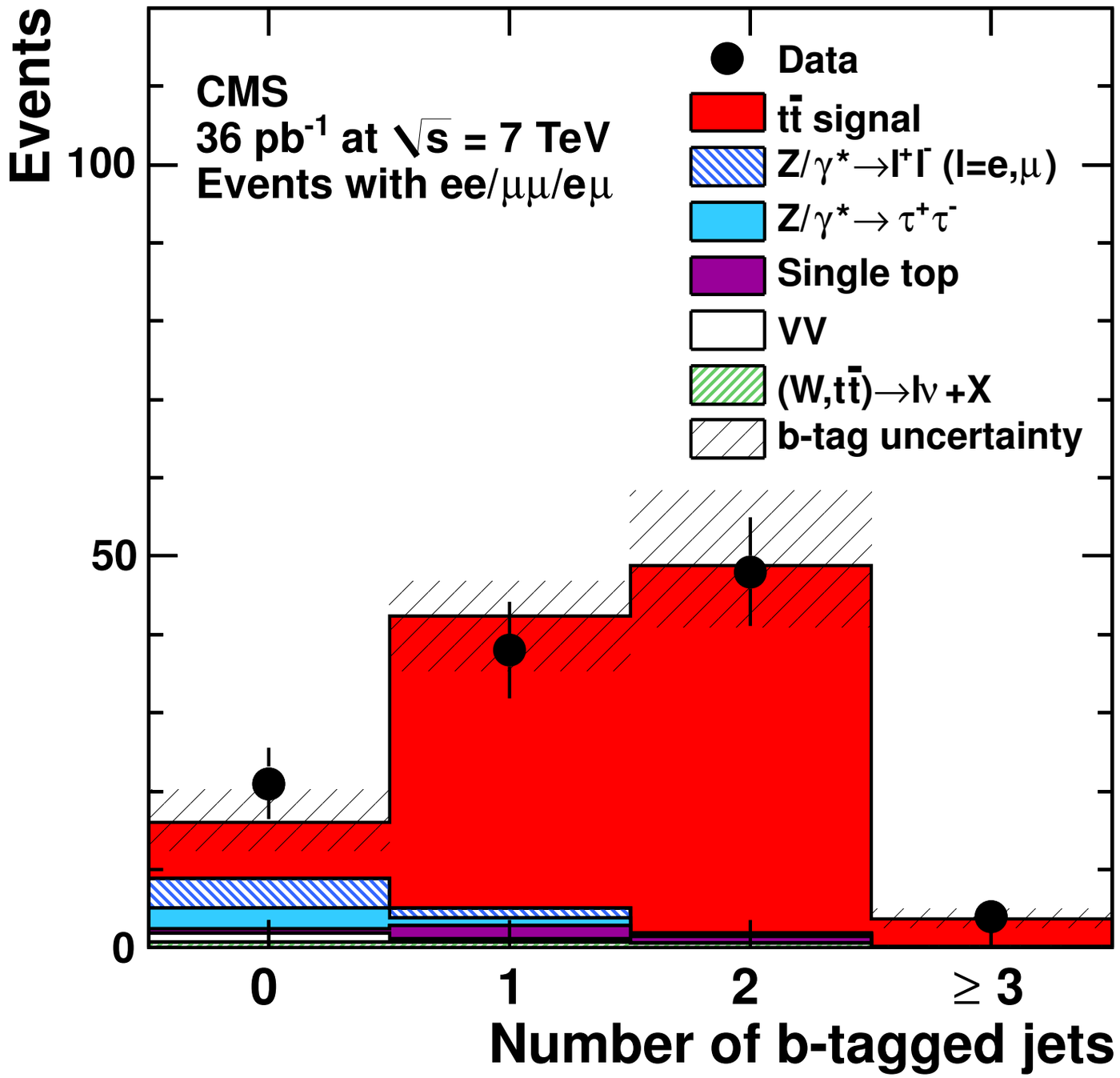


Number of tracks in Secondary Vertex

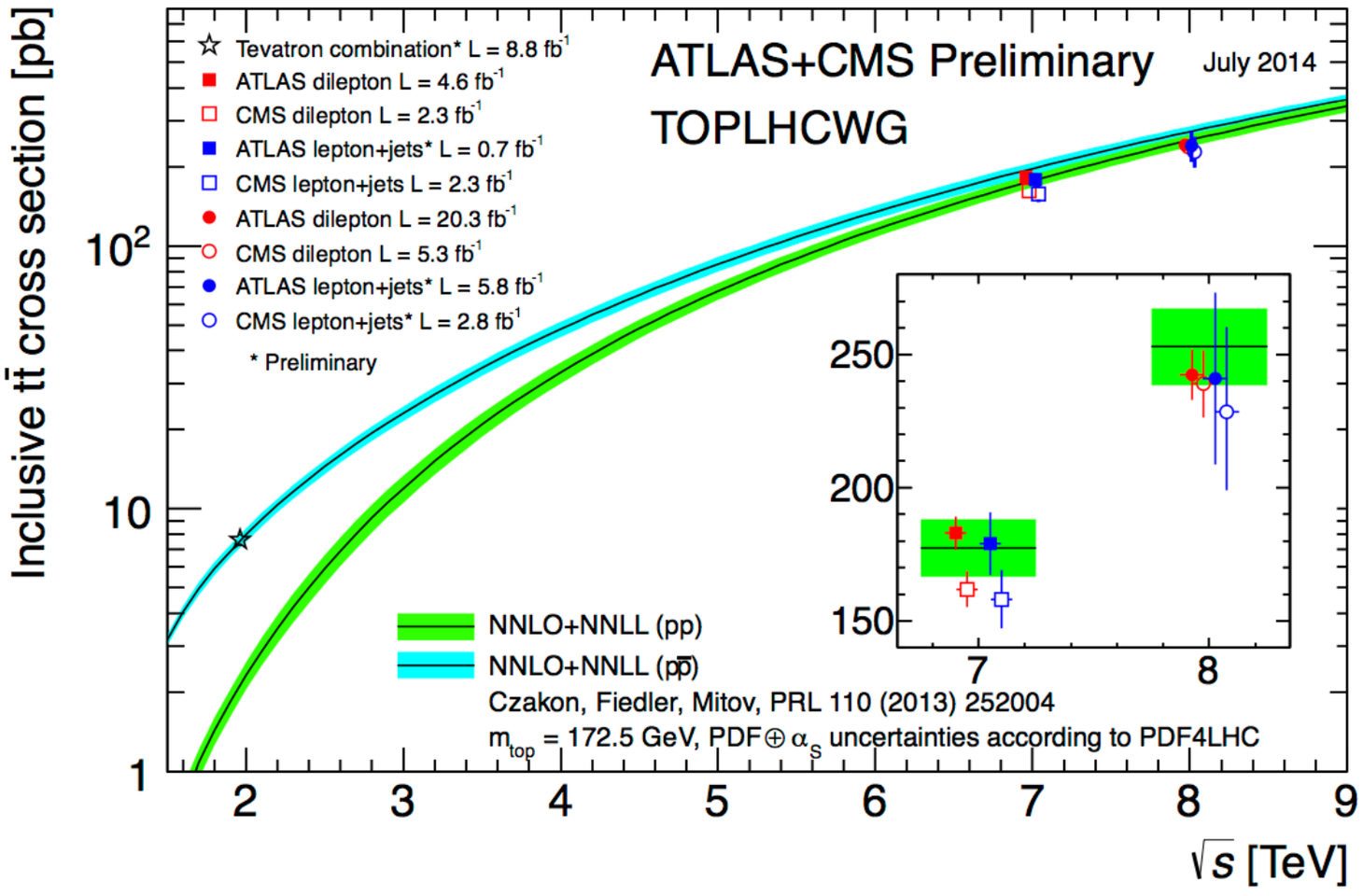


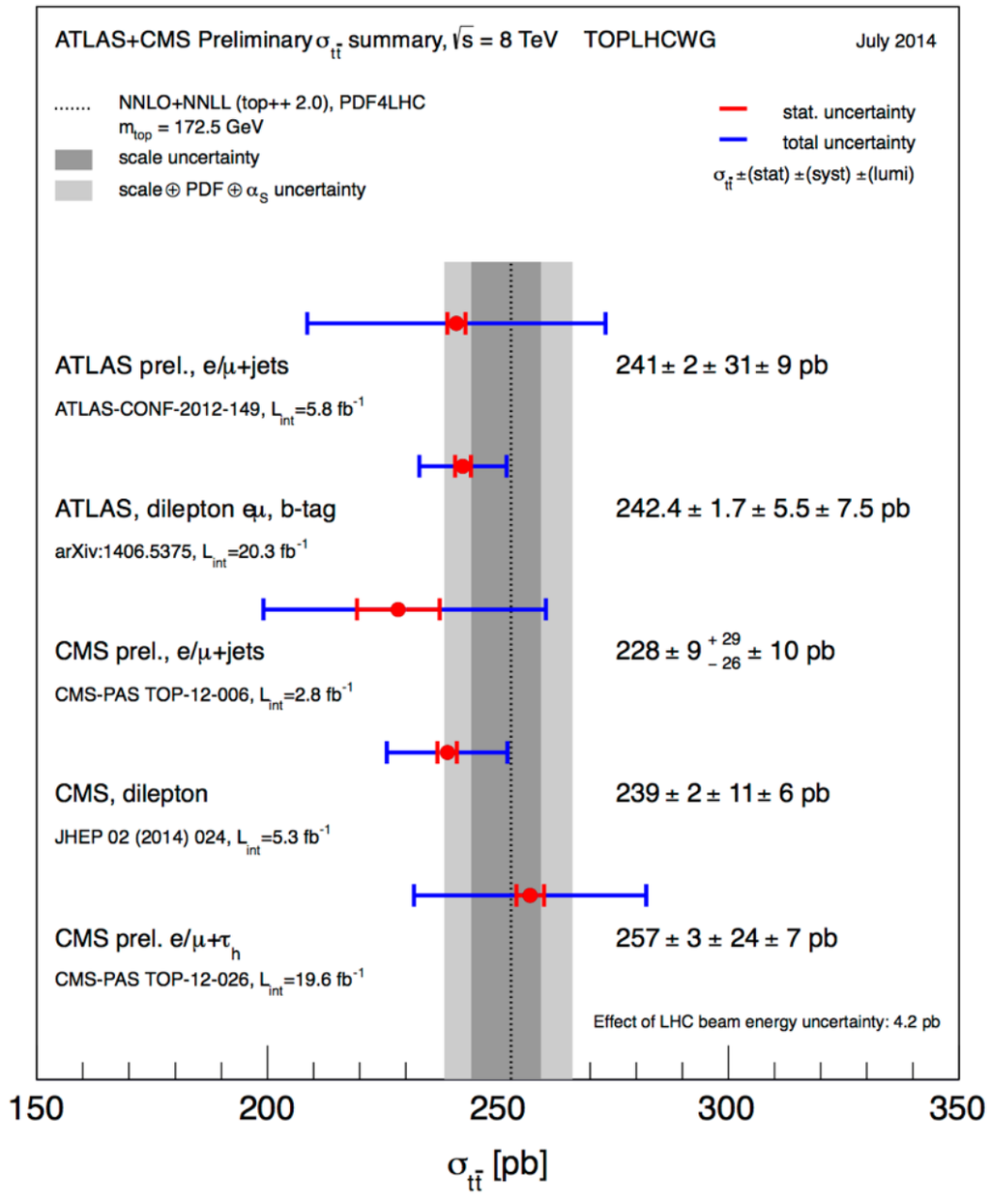
- Outstanding performance of b-tagging so early in data taking
  - Ask Tevatron folks how long took them before relying on b-tagging!

B-TAG MULTIPLICITY



TTBAR CROSS SECTION





TOP @ 13 TeV

Result

$\sigma_{t\bar{t}} = 749 \pm 57\ (\text{stat}) \pm 79\ (\text{syst}) \pm 74\ (\text{lumi})\ \text{pb}$ 16%

8% 11% 10%

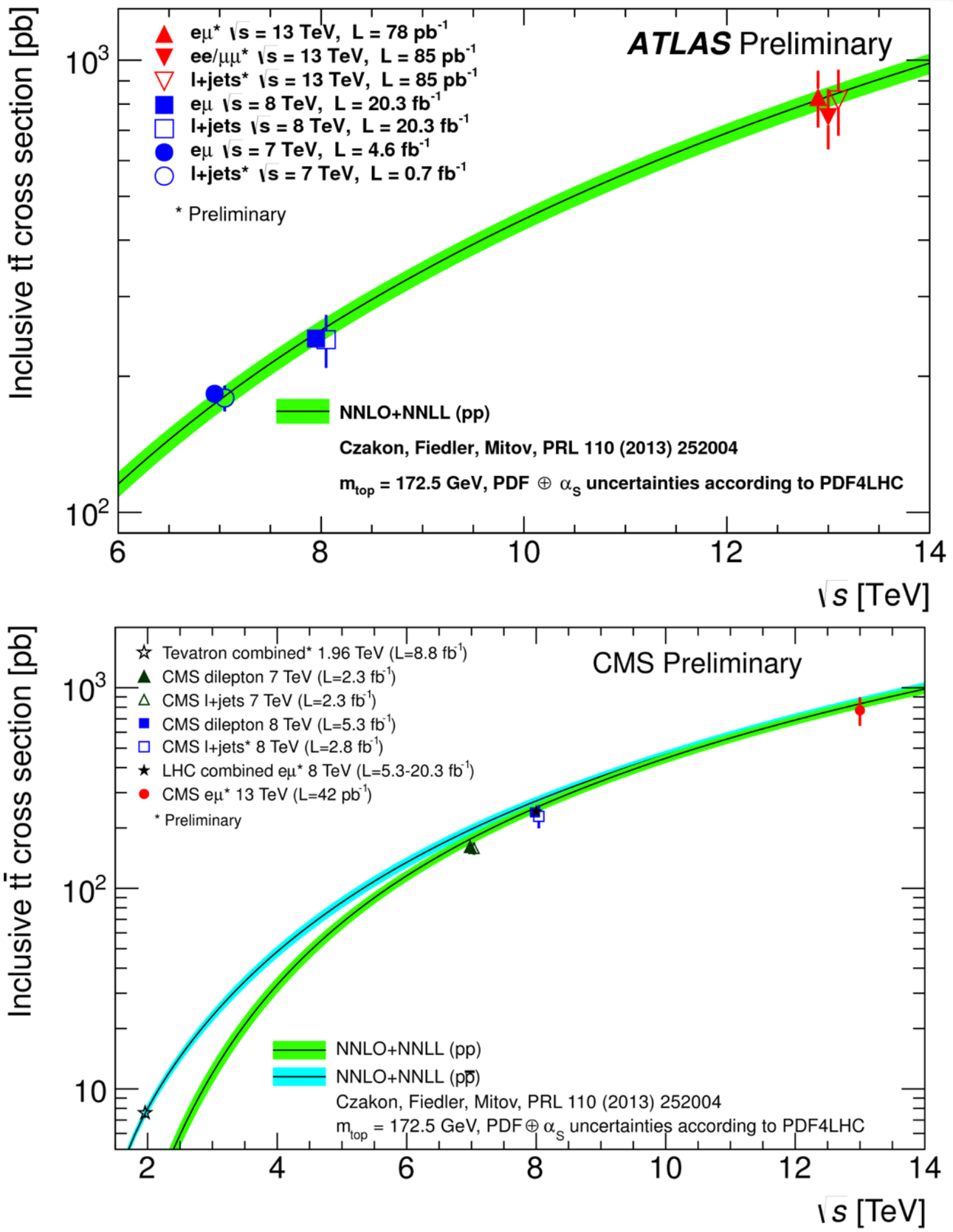
Theory NNLO+NNLL prediction

$832^{+40}_{-46}\ \text{pb}$ at $m_t = 172.5\ \text{GeV}$

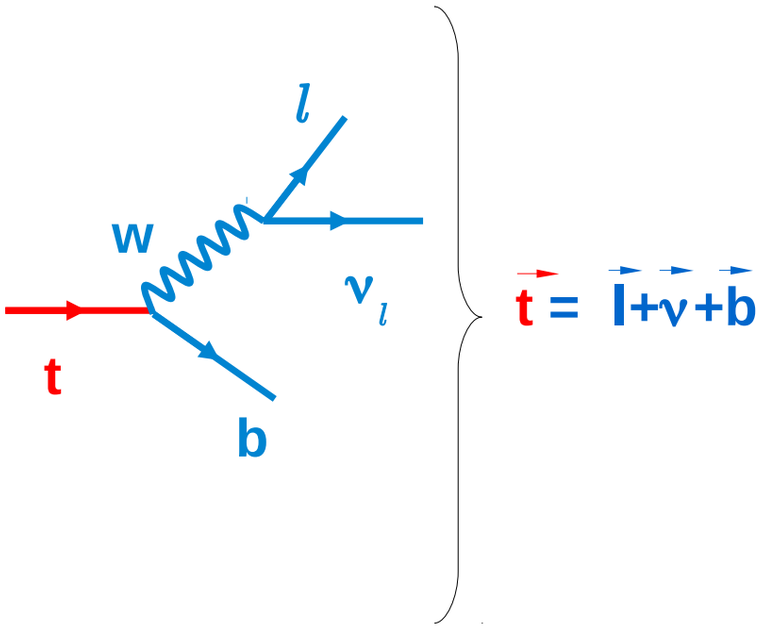
For comparison: eμ + b-jets

$\sigma_{t\bar{t}} = 829 \pm 50\ (\text{stat}) \pm 56\ (\text{syst}) \pm 83\ (\text{lumi})\ \text{pb}$ 14%

6% 7% 10%



TOP MOMENTUM RECONSTRUCTION



Reconstructed taking 4 momenta of the lepton, the b-tagged jet and the MET:

1) take $(p_{x,\nu}, p_{y,\nu}) = (MET_x, MET_y)$

2) constrain the mass of the lν pair to the PDG value of m_W : **get 2nd order equation in $p_{z,\nu}$**

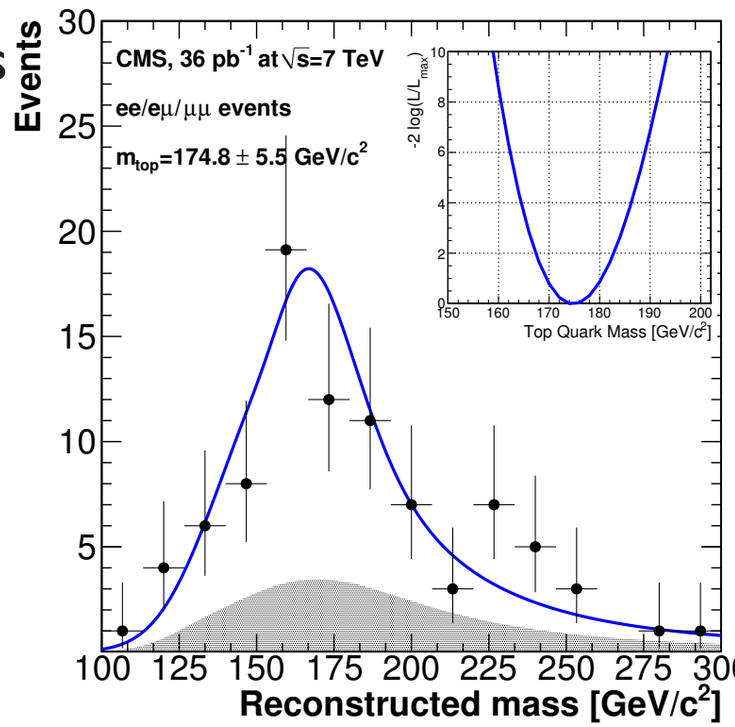
3)two real solutions:take the one with lowest $|p_{z,\nu}|$

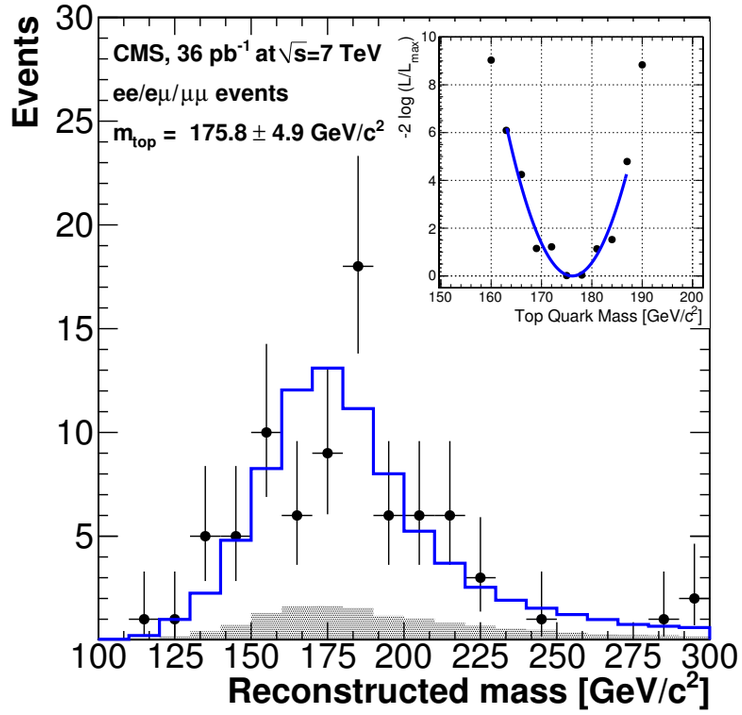
4)two imaginary solutions: put discriminant to 0. In this case eq. 1) is not valid anymore, but **we can still impose 2.**

5)Chose $p_{x,\nu}, p_{y,\nu}$ with minimum distance from the MET in the p_x/p_y plane

Top Mass Reconstruction

- Insufficient kinematic constraints due to 2 missing neutrinos
- Numerical methods available to estimate best combination of jets and leptons in tt candidates
- Use known detector resolutions and generate ensemble of jet momenta and MET based on measured values
- Matrix-element Weighting Method (MWT)
  - assume different values of top mass
  - for each value compute likelihood of mass being compatible with jet momenta and MET
  - Choose solution with highest likelihood to assign top mass

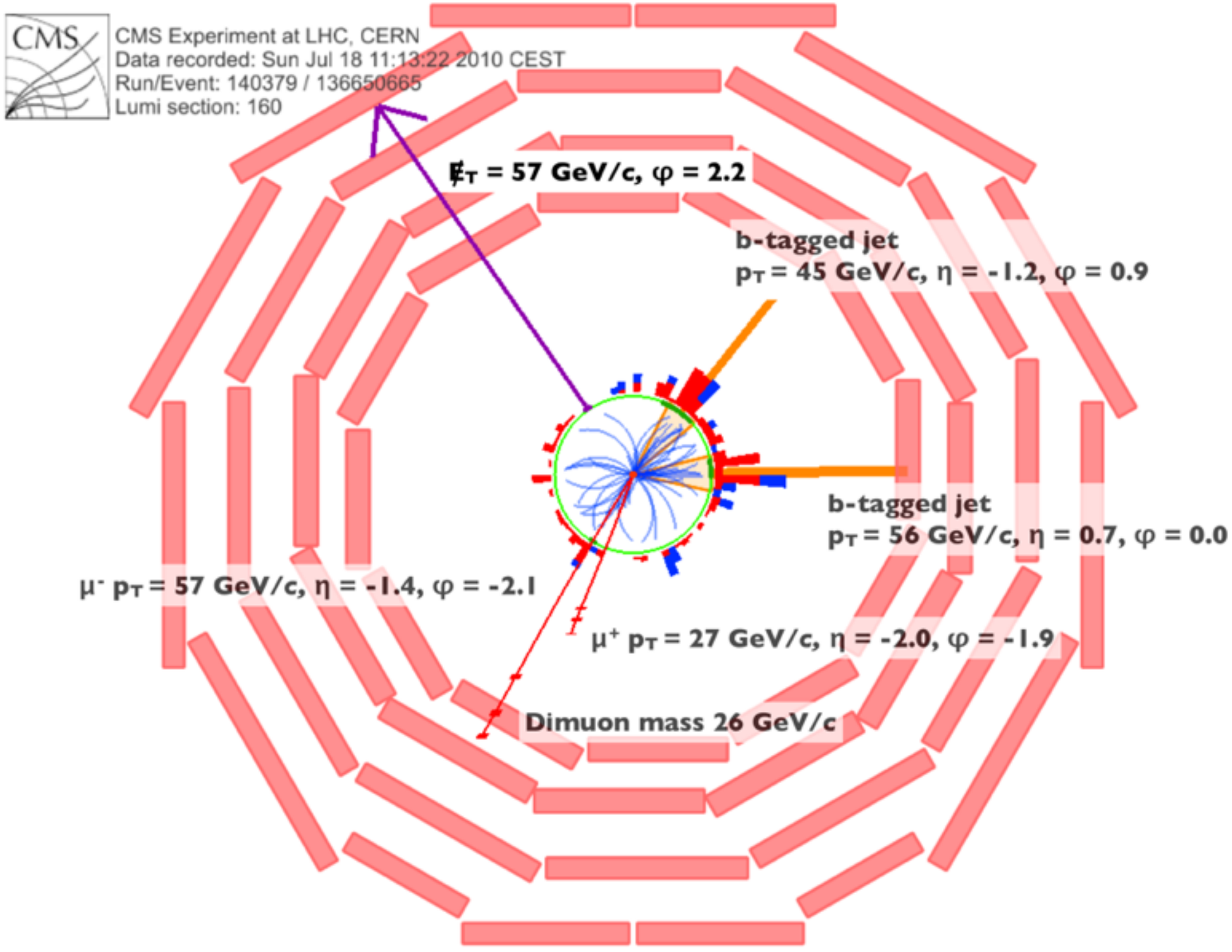




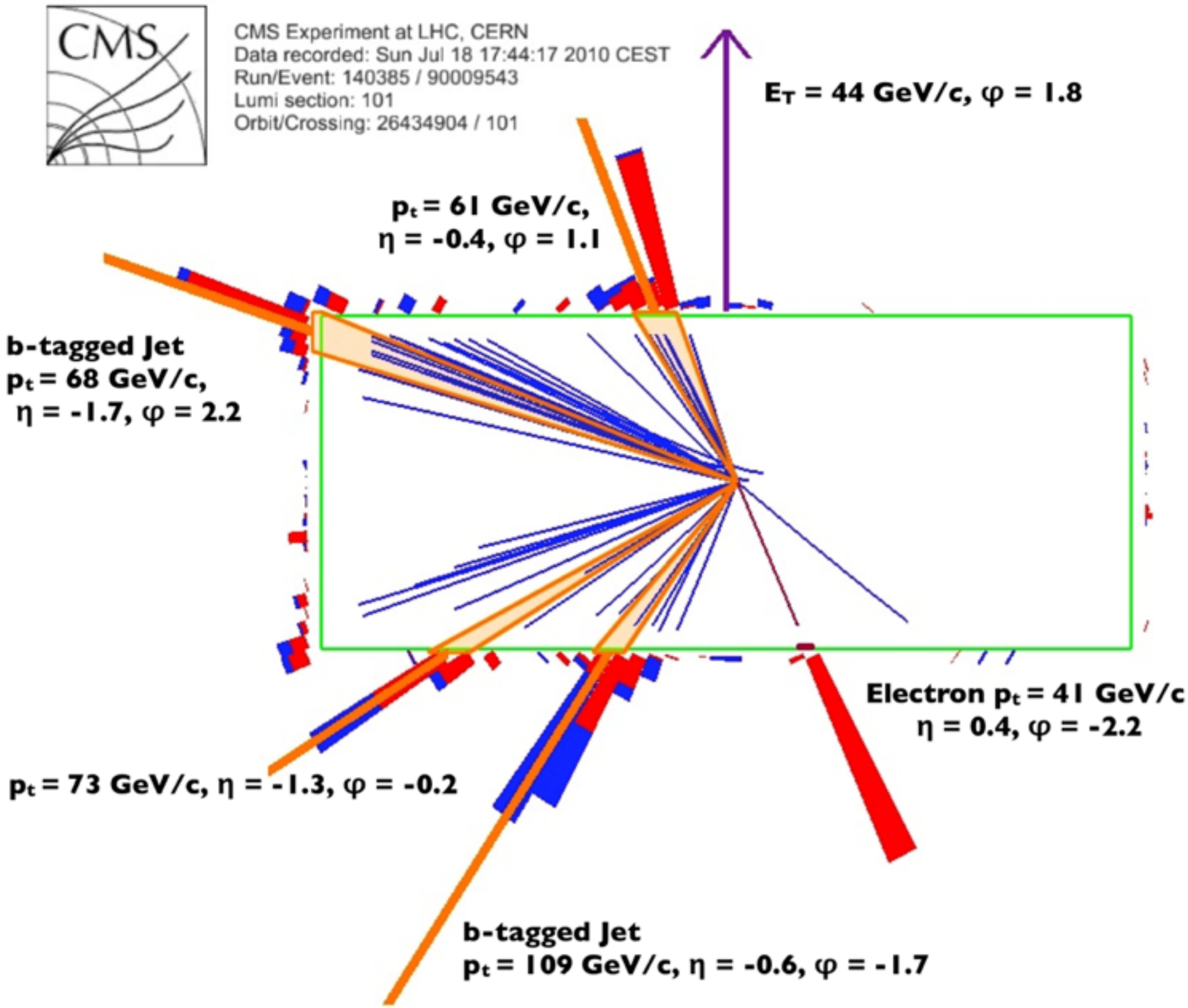
$$\chi^2 = \frac{\left(m_{jj}^{(1)} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(m_{jj}^{(2)} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(m_{jjb}^{(1)} - m_t^{rec}\right)^2}{\Gamma_t^2} + \frac{\left(m_{jjb}^{(2)} - m_t^{rec}\right)^2}{\Gamma_t^2} + \sum_{i=1}^{6} \frac{\left(p_{T,i}^{fit} - p_{T,i}^{meas}\right)^2}{\sigma_i^2}$$

$$\sigma(\mathrm{pp} \to \mathrm{t\bar{t}}) = 168 \pm 18\,(\mathrm{stat.}) \pm 14\,(\mathrm{syst.}) \pm 7\,(\mathrm{lumi.})\ \mathrm{pb}$$

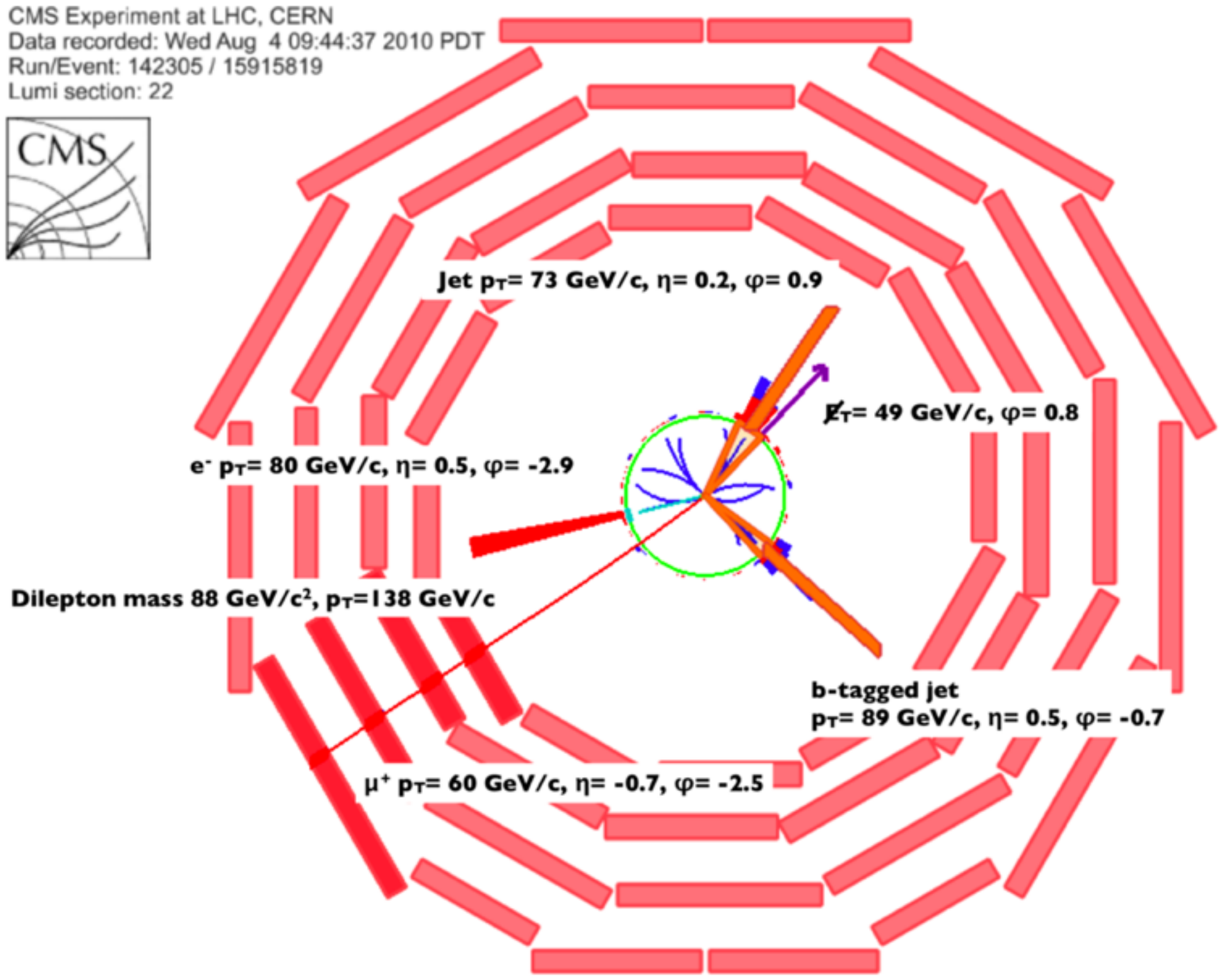
μμ + JETS CANDIDATE



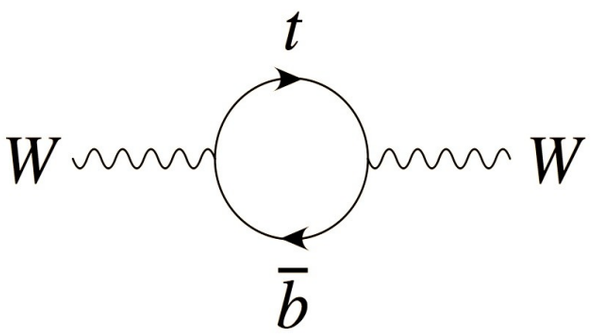
e + JETS CANDIDATE

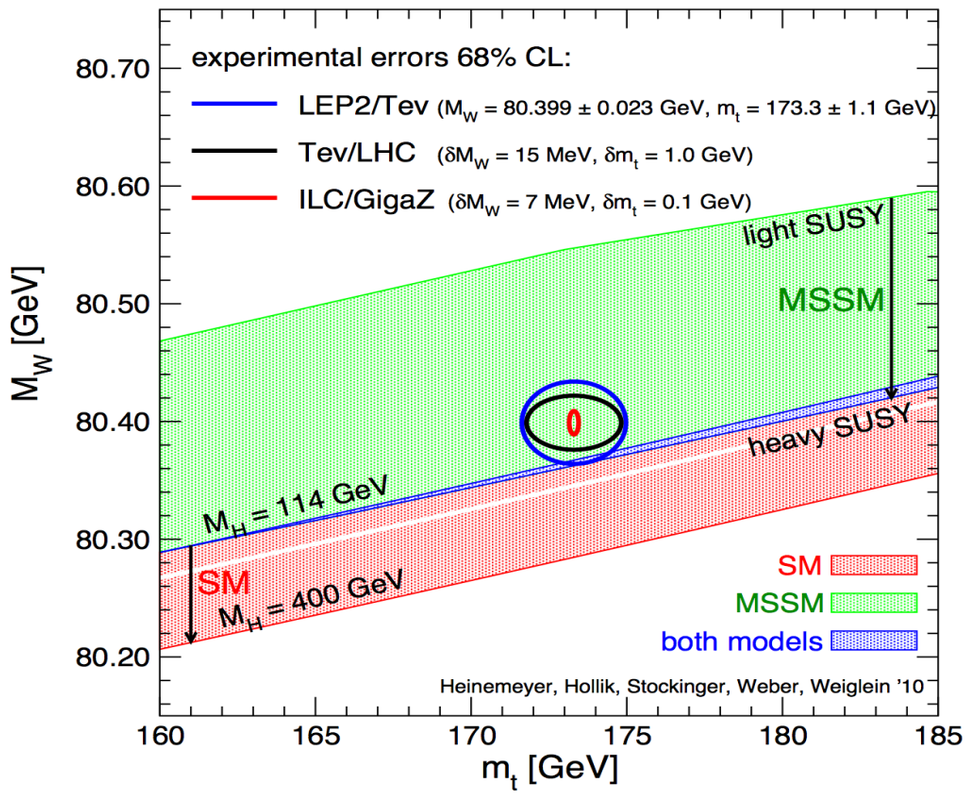


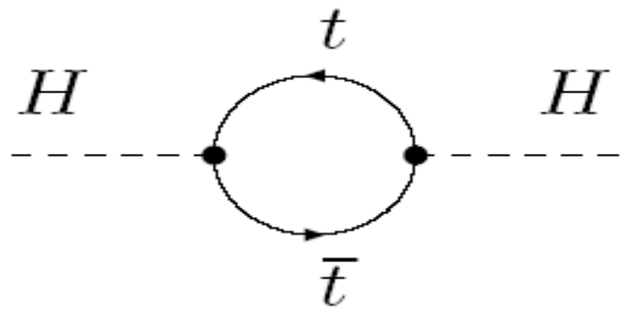
eμ + JETS CANDIDATE



Top Mass

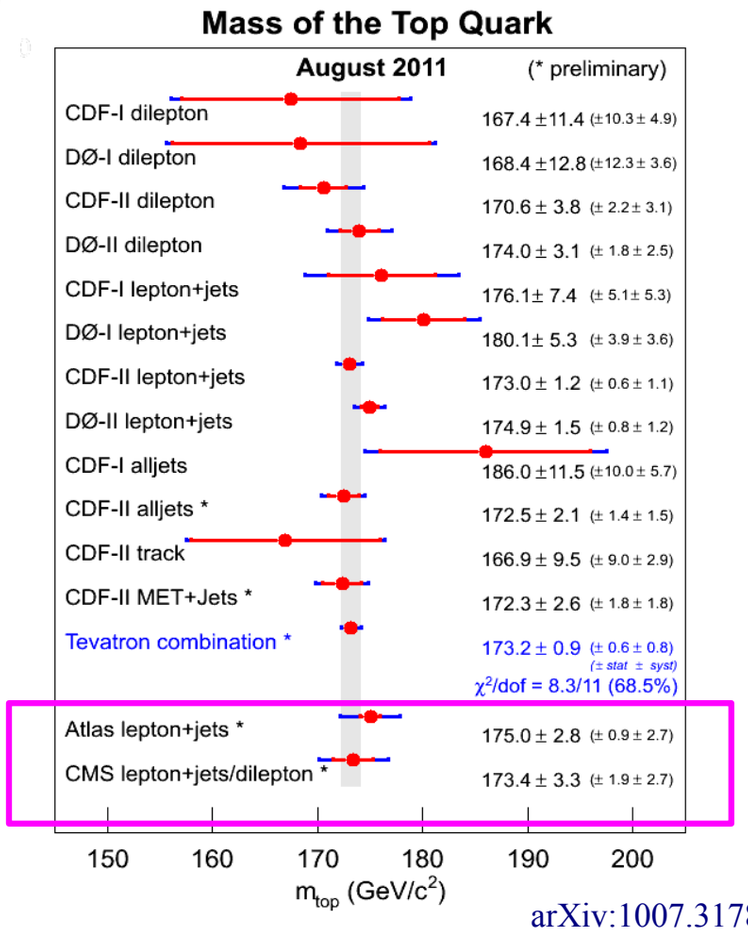






- Free parameter of Standard Model
- Together with W mass provide constraint on Higgs mass
- Several methods used for measurement
  - Template method, ideogram, matrix element

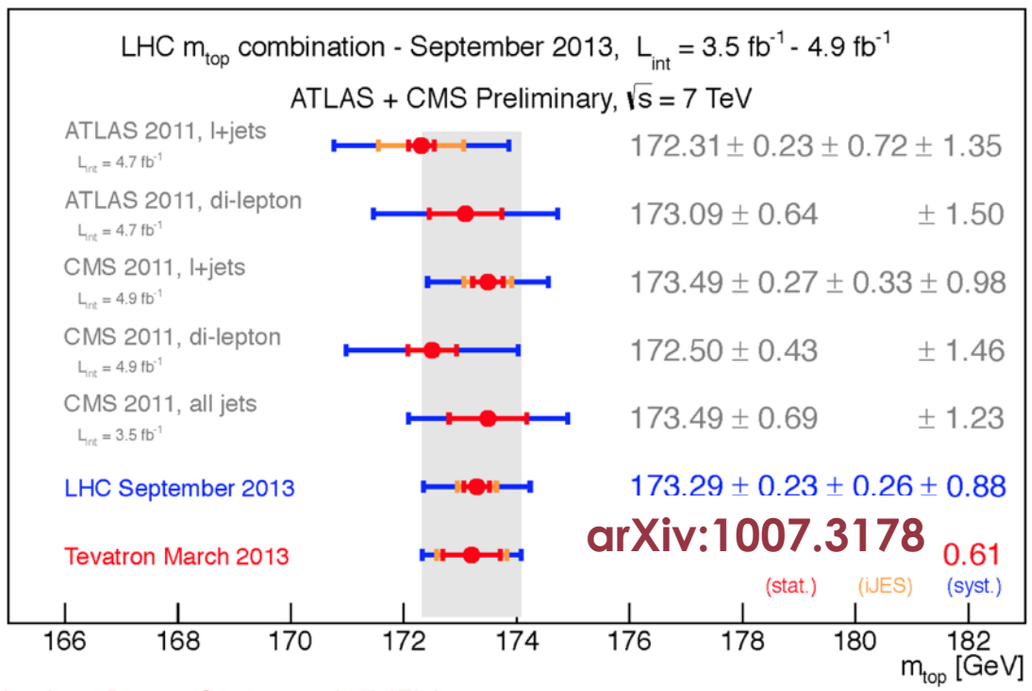
Top Mass World Average



arXiv:1007.3178

- Systematics limited!
  - Main effort for experiments: detailed understanding of systematics
  - Main systematics at Tevatron: JES-related
  - Main systematics at LHC: JES-related and ISR/FSR

- Tevatron combination: first time uncertainty below 1GeV!



$$\mathcal{M}_\rho = \begin{array}{c} \begin{matrix} \text{ATLAS } l\text{+jets} & \text{ATLAS di-}l & \text{CMS } l\text{+jets} & \text{CMS di-}l & \text{CMS all jets} \end{matrix} \\ \begin{pmatrix} 1.00 & & & & \\ 0.63 & 1.00 & & & \\ 0.26 & 0.35 & 1.00 & & \\ 0.18 & 0.25 & 0.64 & 1.00 & \\ 0.16 & 0.24 & 0.55 & 0.75 & 1.00 \end{pmatrix} \end{array} \begin{matrix} \text{ATLAS } l\text{+jets} \\ \text{ATLAS di-}l \\ \text{CMS } l\text{+jets} \\ \text{CMS di-}l \\ \text{CMS all jets} \end{matrix}$$

Top mass at LHC: PAS-TOP-13-005

Top Mass Measurement