Top Quark at LHC

2011-2012 Intercollegiate PostGraduate Course in Elementary Particle Physics

London, UCL Bloomsbury Campus
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Outline

- **Why top quark?**

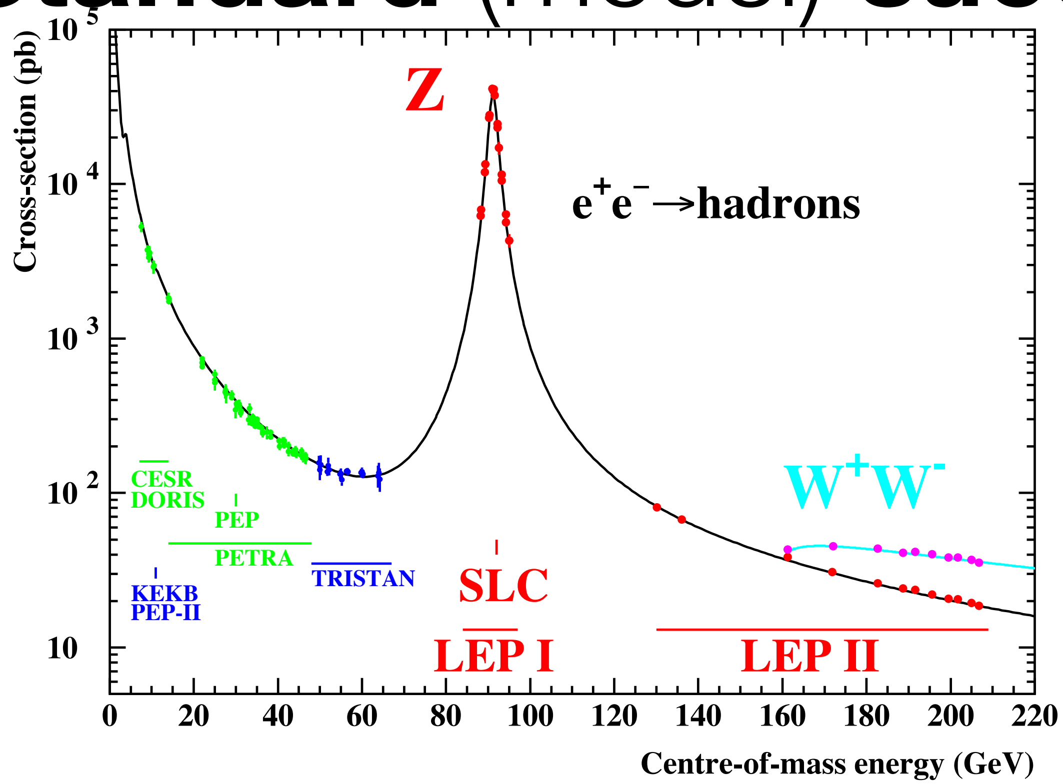
- **The tools of the trade**
  - **LHC:** a top factory at work
  - **The ATLAS and CMS detectors**: top observers

- Measuring **top quark production**
  - top pair
  - single top

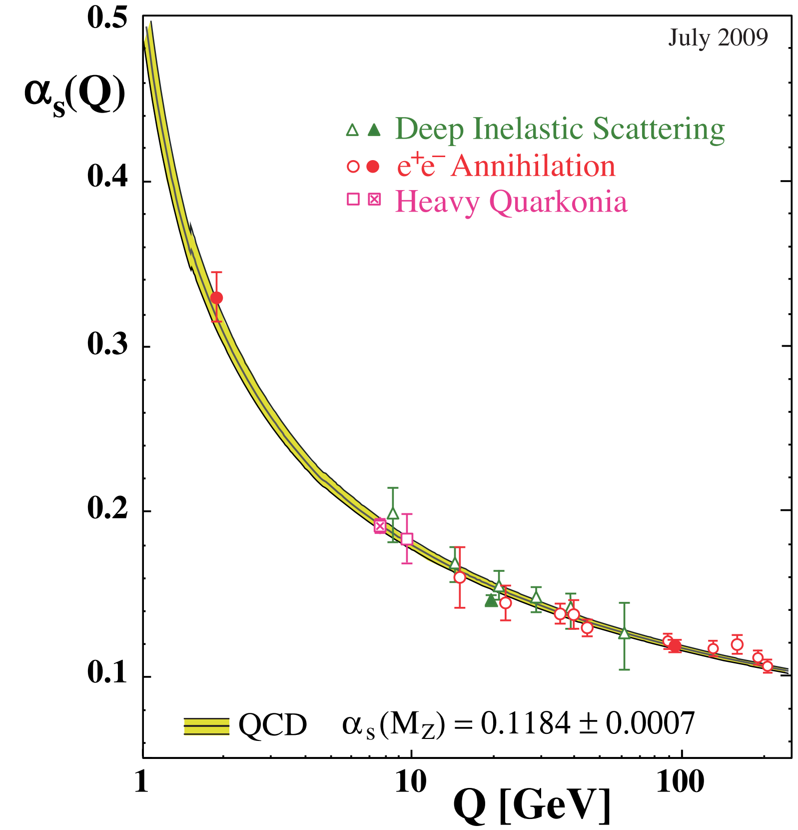
- Top Properties
  - Top mass
  - Angles: spin correlations (production)

- Top pair production as a **window on new physics**
  - Resonances in $t\bar{t}$

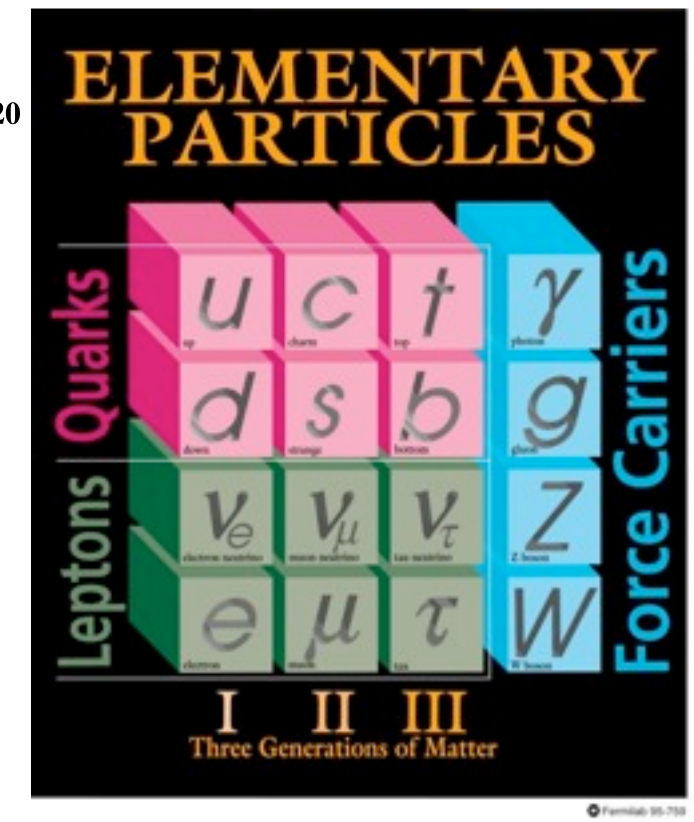
Standard (model) **successes**

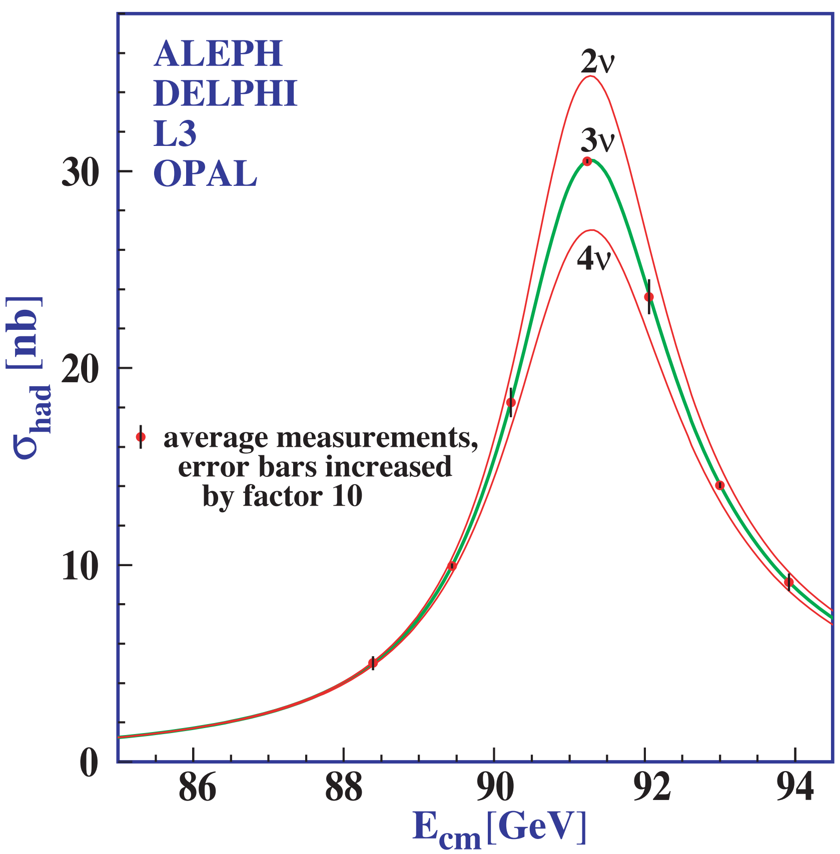


W, Z, bosons unify Electro-weak force

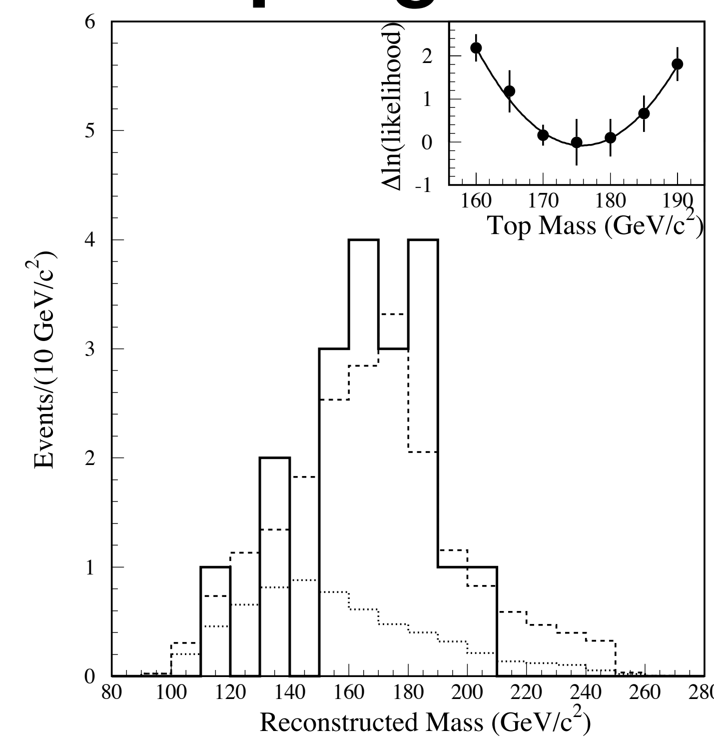


Strong coupling runs





a quick (biased) selection..



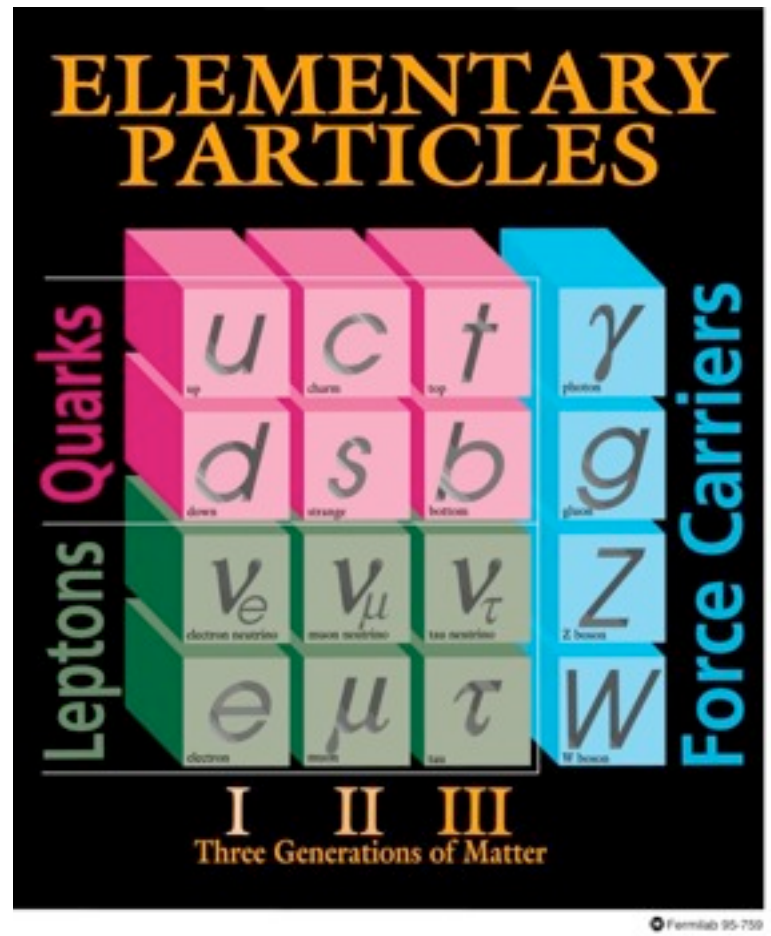
only 3 standard neutrinos

Top quark is found

Standard (model) **questions**

- ***How is gravity incorporated?***

- **What is the origin of mass?**



- ***Why 3 generations with different quantum numbers ?***

- ***Why different forces (ranges, strengths)?***

- ***What accounts for the energy balance of the universe?***

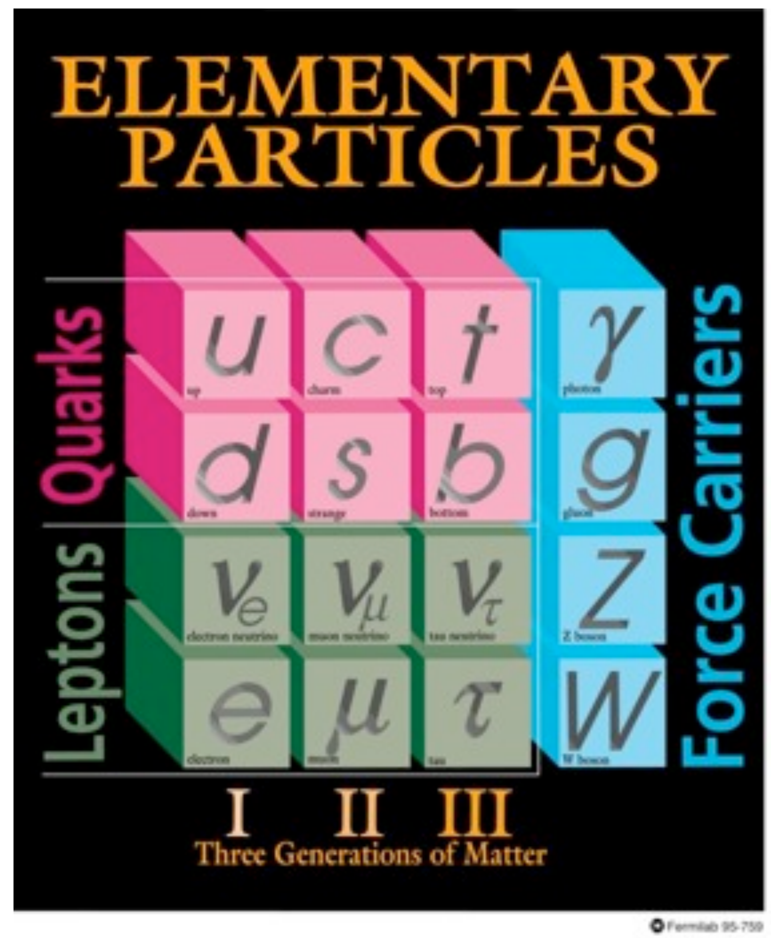
Standard (model) **questions**

- ***How is gravity incorporated?***

Quantum gravity
Extra dimensions...

- **What is the origin of mass?**

Higgs, SuperSymmetry, New Strong forces..



- ***Why 3 generations with different quantum numbers ?***

4th generation...?

- ***Why different forces (ranges, strengths)?***

String theory..

- ***What accounts for the energy balance of the universe?***

Dark matter, Dark energy...

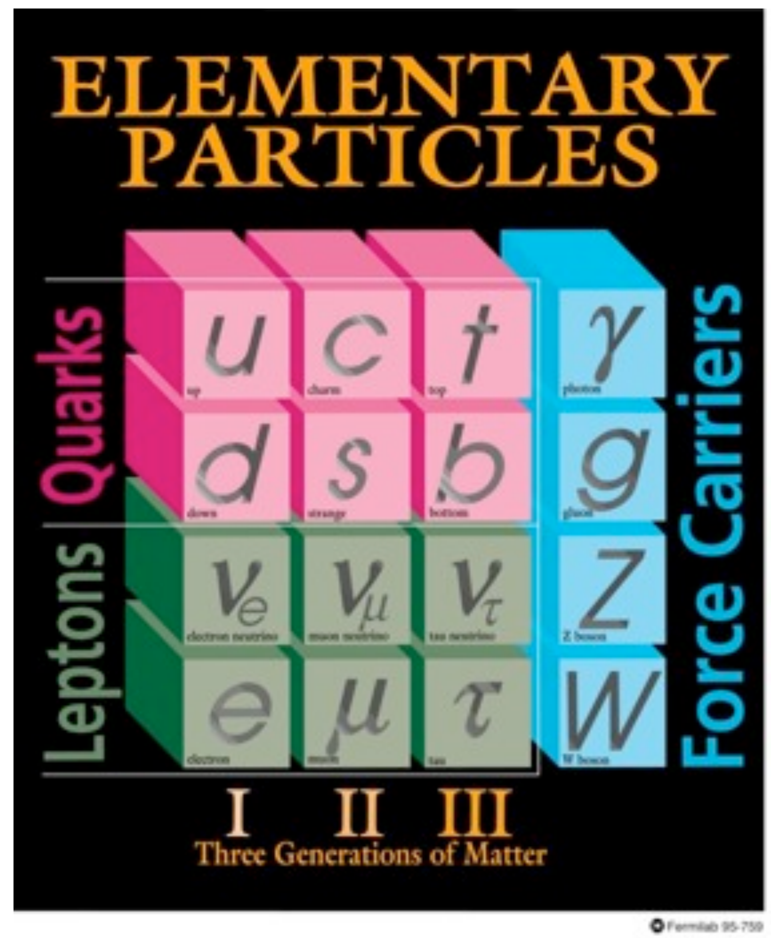
Standard (model) **questions**

- **What is the origin of mass?**

Higgs, SuperSymmetry, New Strong forces..

- ***How is gravity incorporated?***

Quantum gravity
Extra dimensions...



- ***Why 3 generations with different quantum numbers ?***

4th generation...?

- ***Why different forces (ranges, strengths)?***

String theory..

- ***What accounts for the energy balance of the universe?***

Dark matter, Dark energy...

From bottom to top: a history of expectations

One needs top because

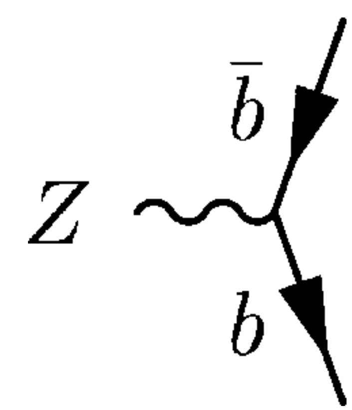
No flavour changing neutral currents: no b iso-singlet

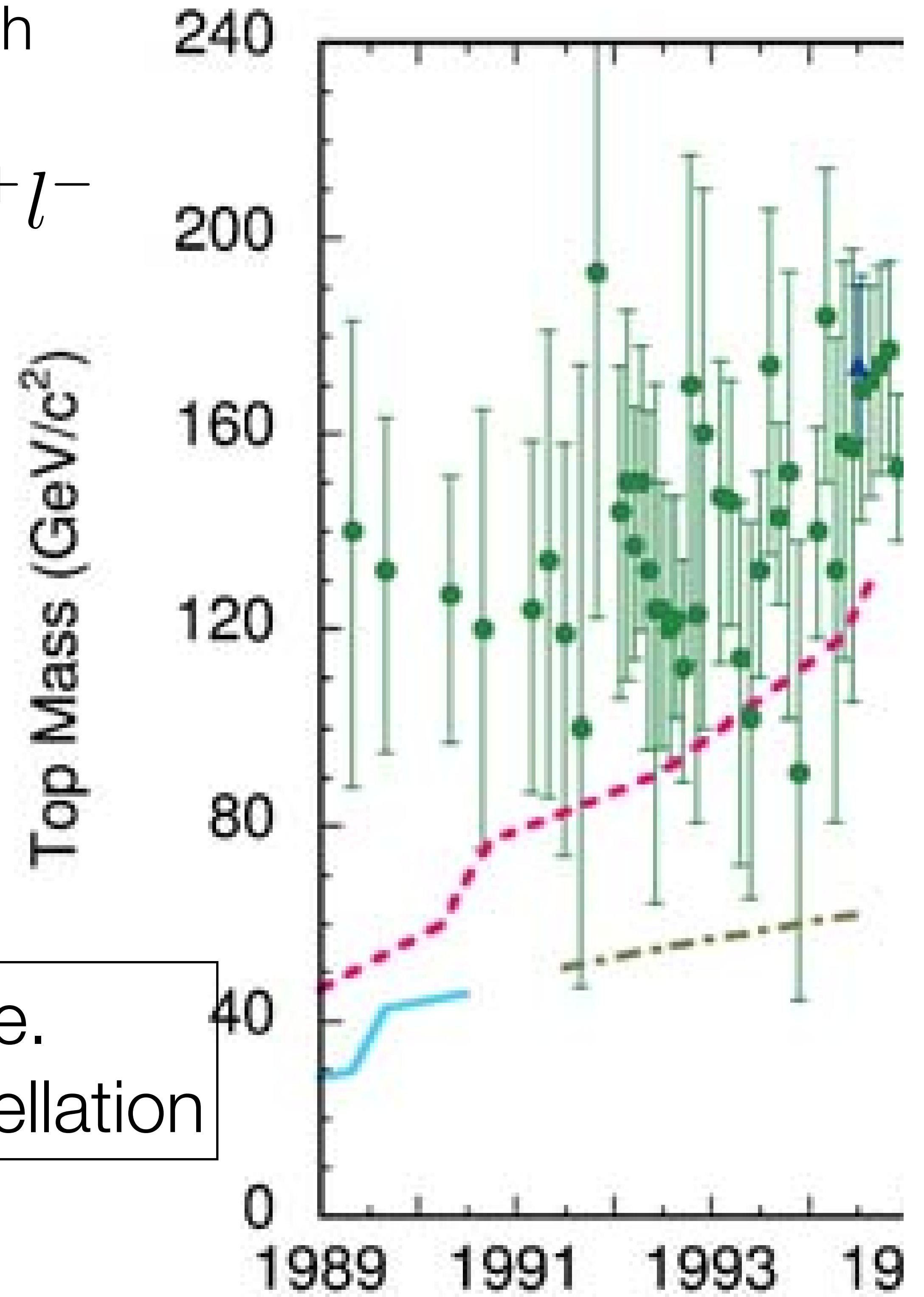
$$\begin{bmatrix} c \\ s' \end{bmatrix}_L \quad b'_L$$

b couples to s only with neutral mediator

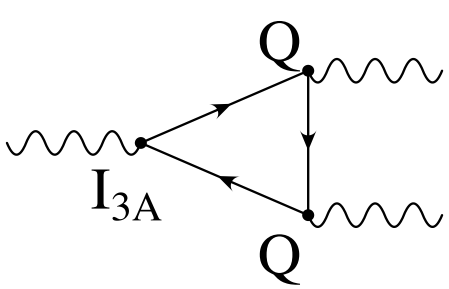
$$b \longrightarrow s + l^+ l^-$$

I_3 = -1.2 for b quark required by Z width in $b\bar{b}$ decay. Need additional quark, isospin partner of b, with I_3 = +1.2





No triangular fermion loops anomalies i.e. additional quark required for lept.-ferm. cancellation



$$\sim \sum_L I_{3A} Q^2 = -\sum_L I_3 \left[I_3 + \frac{1}{2} Y \right]^2$$

$$\sim \sum_L Y \sim \sum_L Q$$

1995: top is discovered!

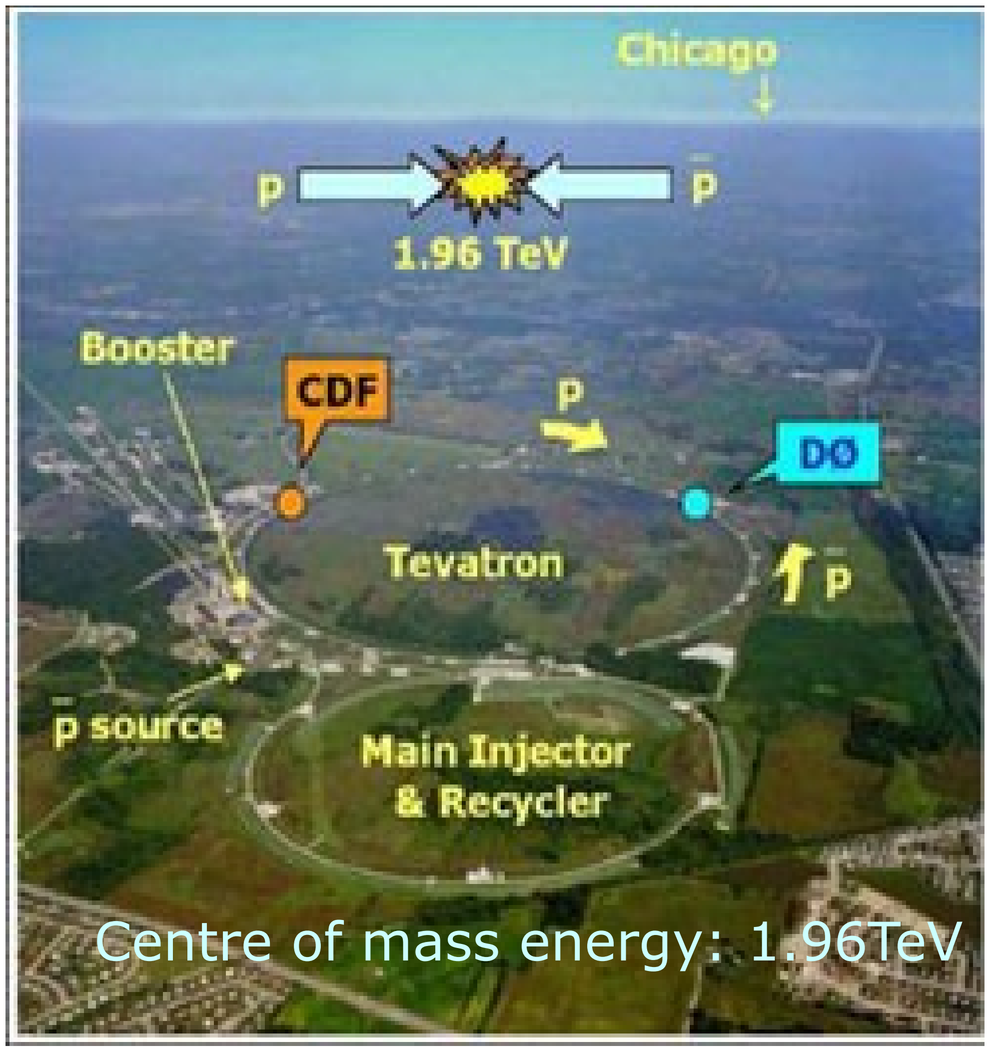
$\sqrt{s} = 1.8$ TeV

m

$m_{top} = 176 \pm 8(\text{stat.}) \pm 10(\text{sys.})\ \text{GeV/c}^2$

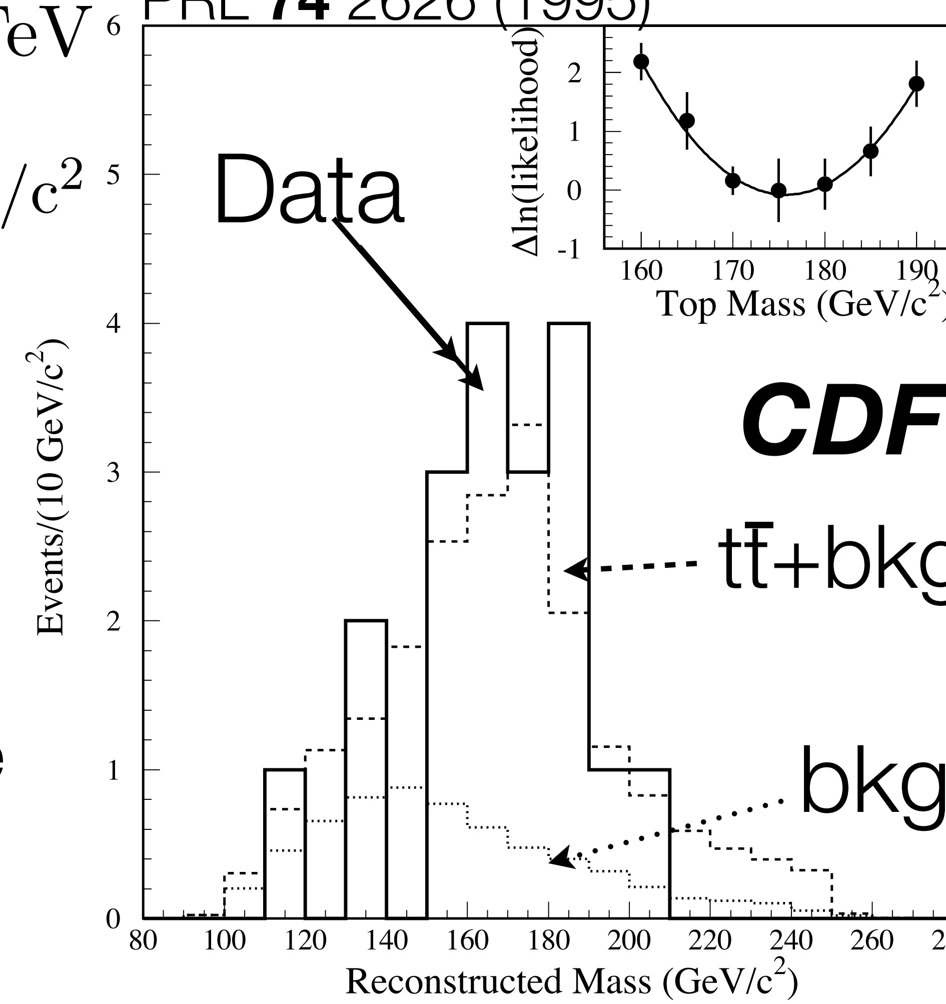
$\sigma_{t\bar{t}} = 6.8^{+3.6}_{-2.4}$ pb.

p$\bar{\text{p}}$ collisions



19 sel. events
exp bkg:6.9
4.8 s.d.significance

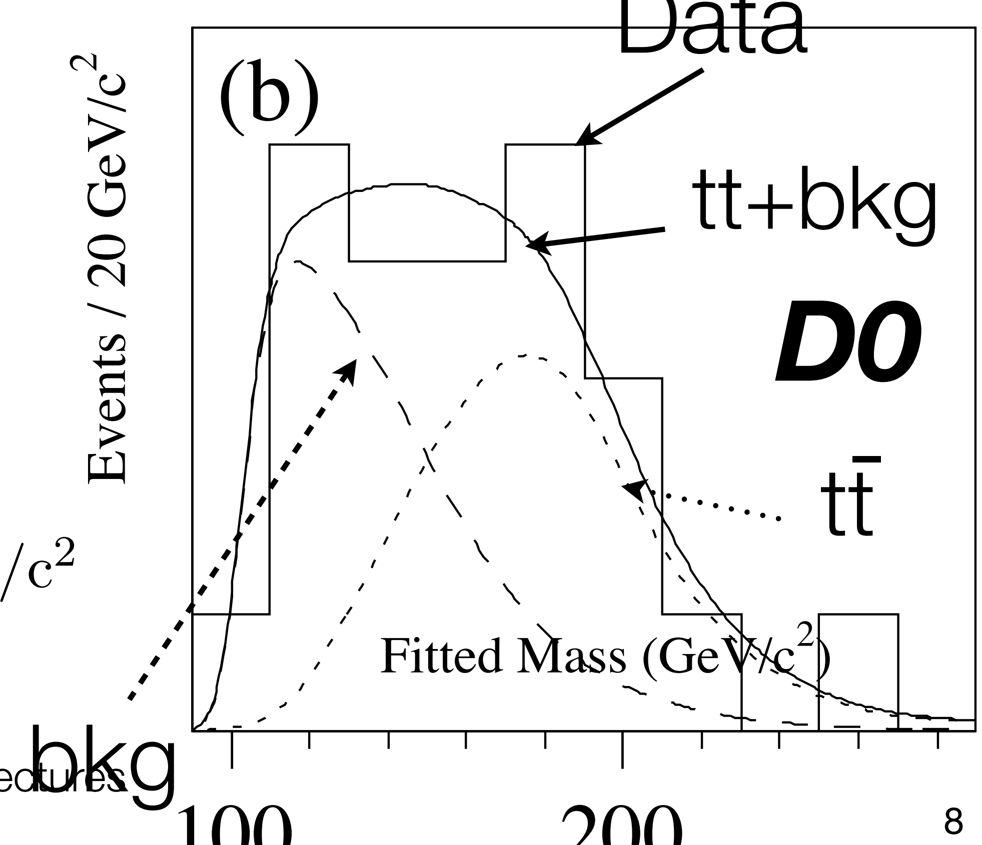
PRL **74** 2626 (1995)



mass from
lkl fit to shape

17 sel. events
exp bkg: 3.8
4.6 s.d. significance

PRL **74** 2632 1995

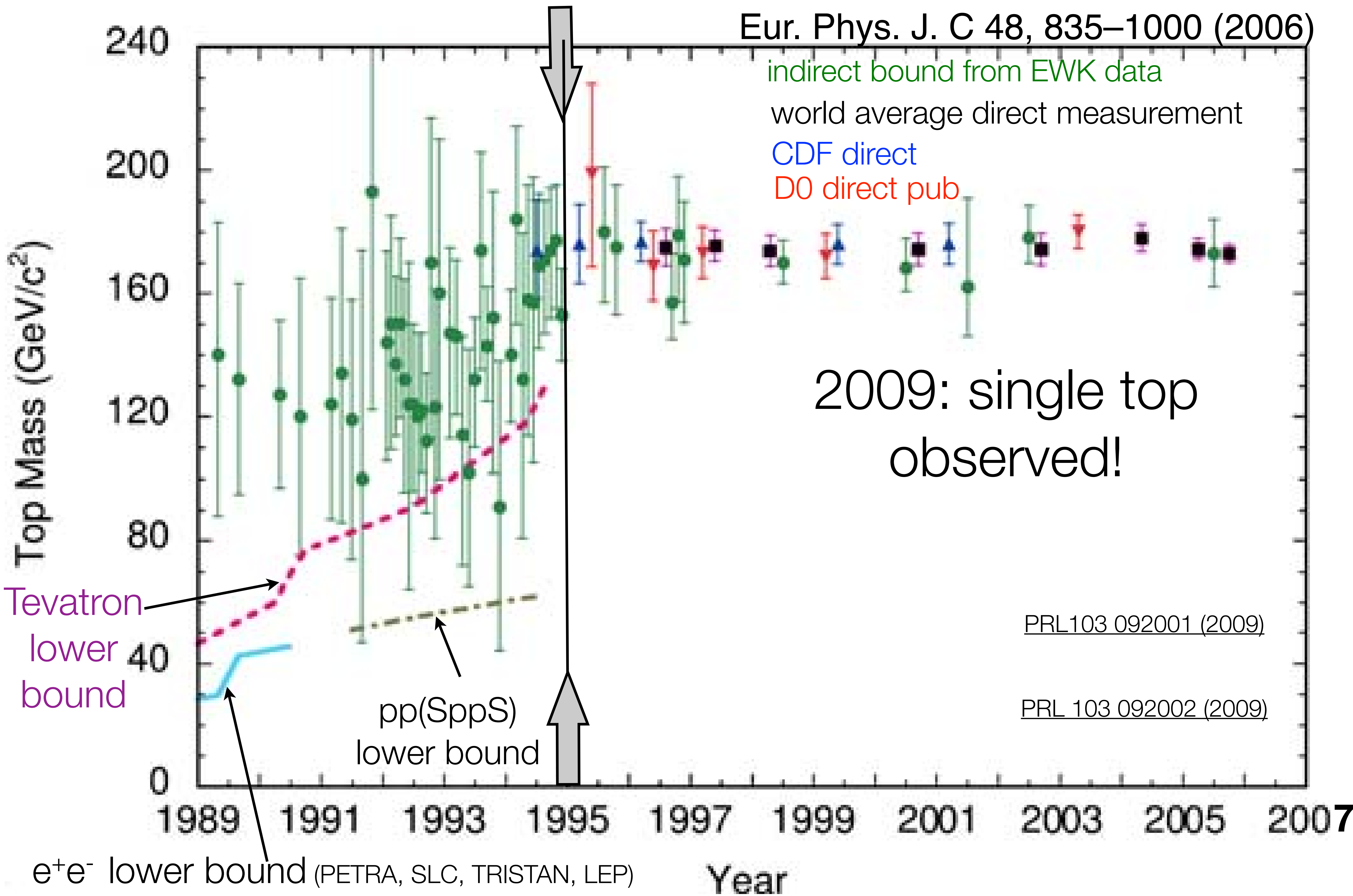


$m_{top} = 199^{+19}_{-21}\ (\text{stat.}) \pm 22\ (\text{syst.})\ \text{GeV/c}^2$

$\sigma_{t\bar{t}} = 6.4 \pm 2.2$ pb.

From bottom to top: the global picture

A.Quadt

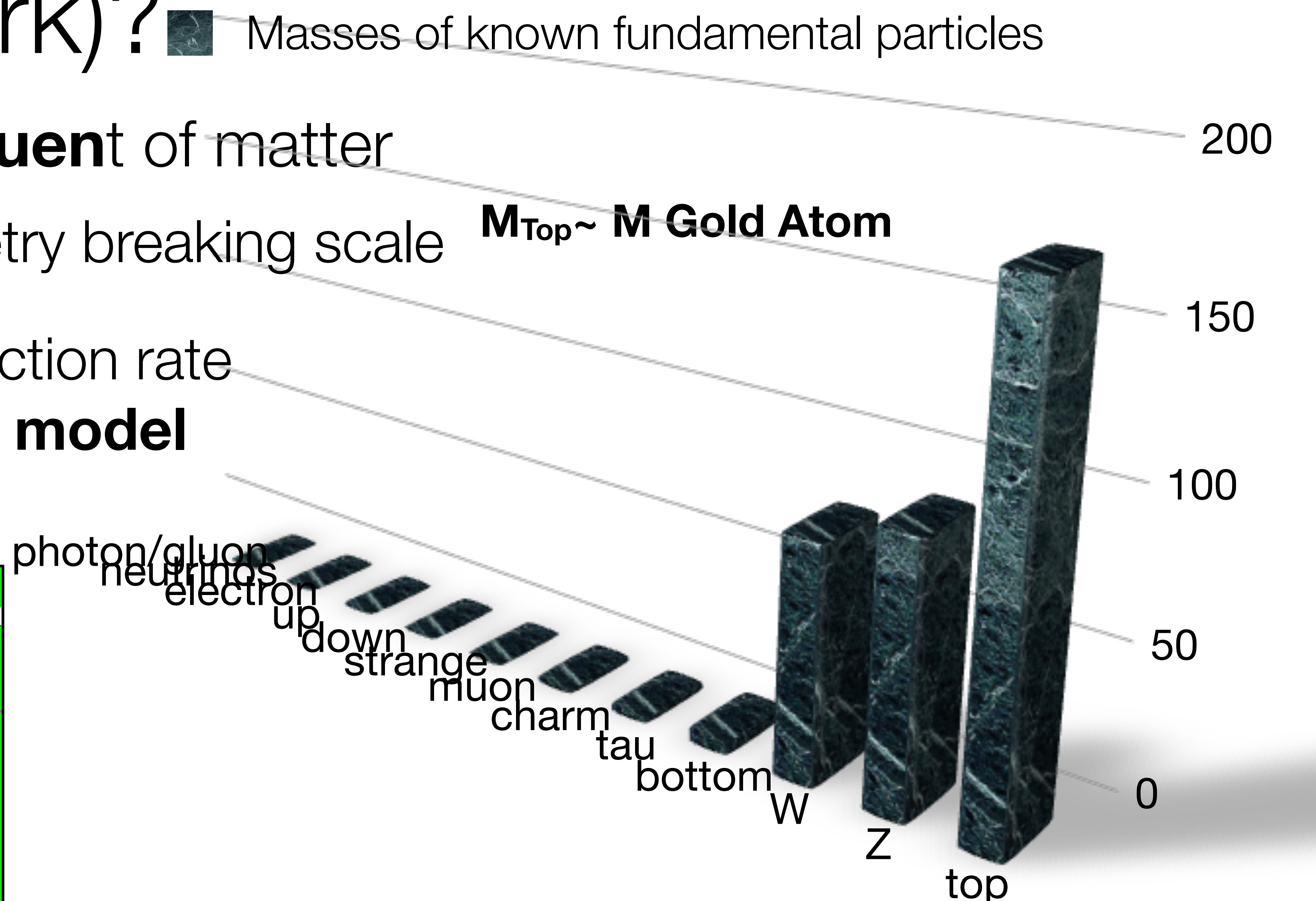


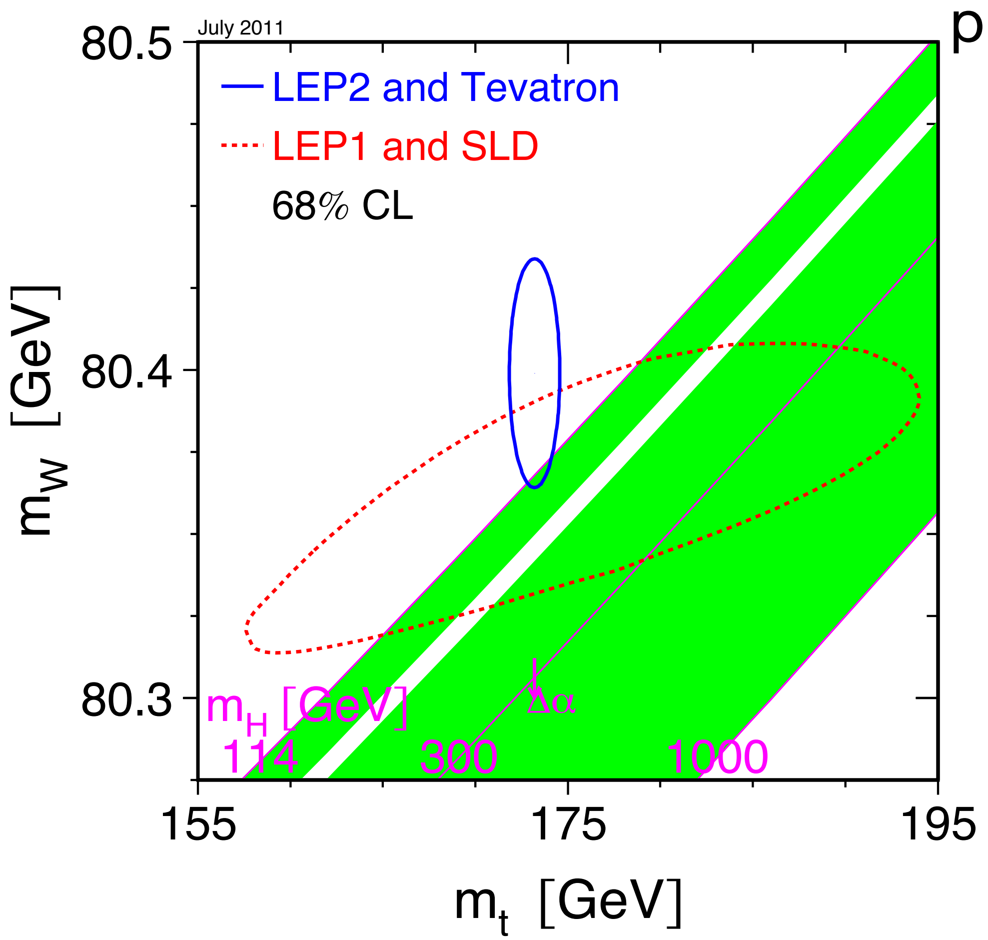
Why Top (quark)?

Most massive constituent of matter

M_{top}~ electroweak symmetry breaking scale

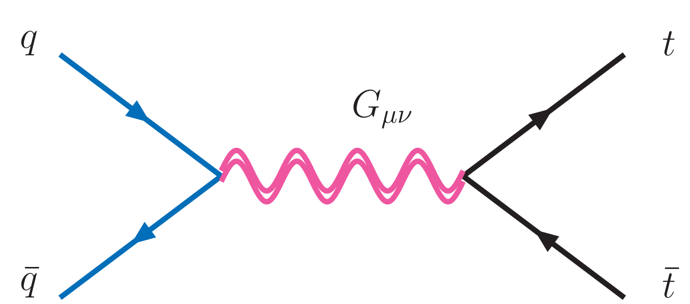
Decay and strong production rate are **tests of standard model**

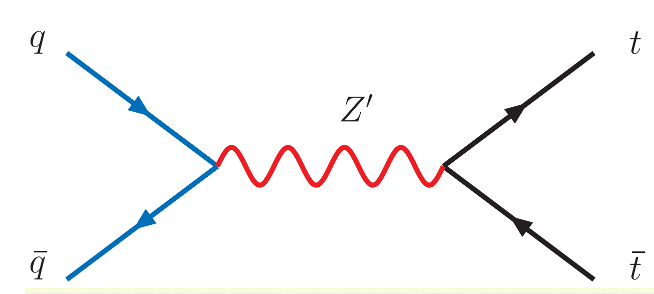




Various scenarios with **direct/indirect coupling to new physics:** from extra dimensions to new strong forces

Background to possible **new physics** (Higgs, SUSY)

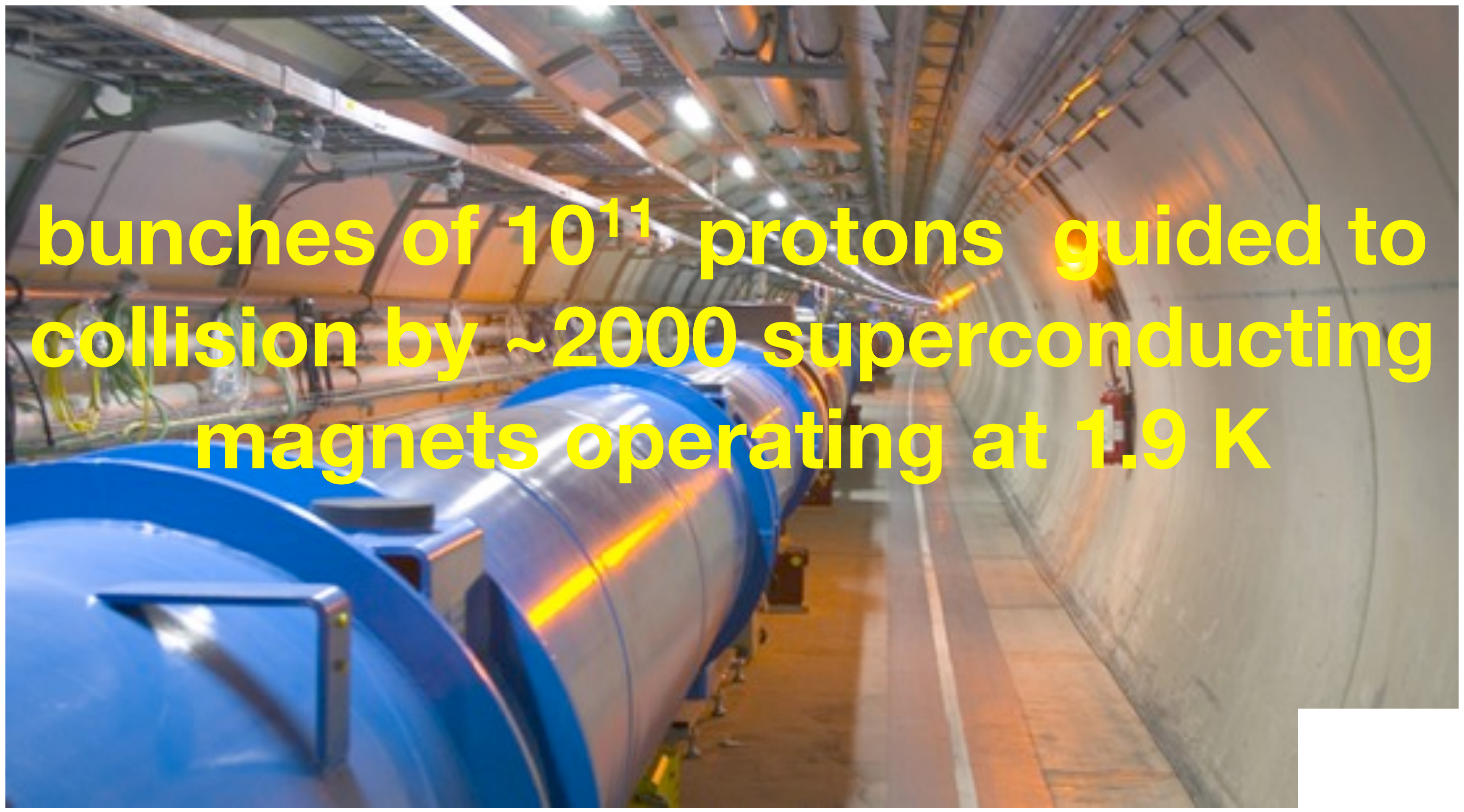


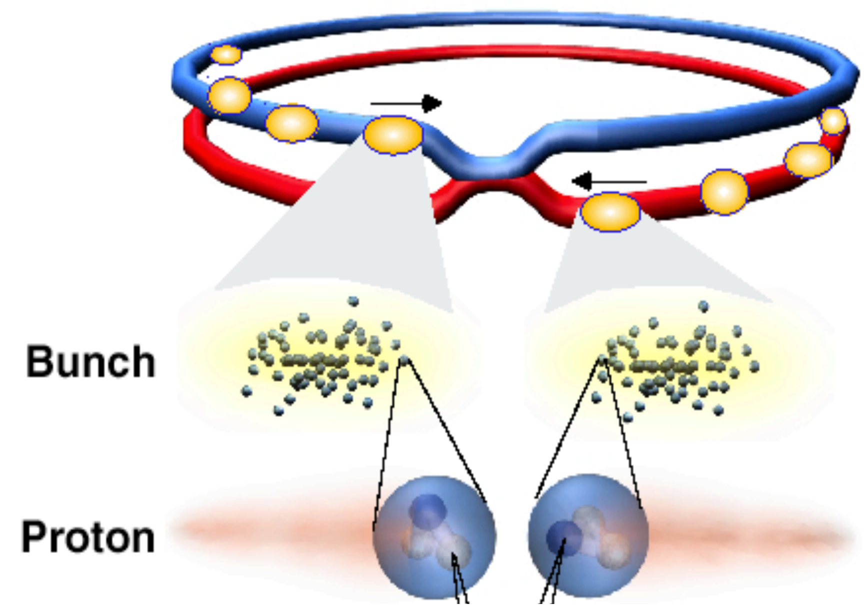


LHC : a *Top* producer

counter-rotating high intensity proton bunches colliding at center of mass energy (E_{cm}) = 7 TeV in 27 Km tunnel

eventually: E_{CM}=14TeV (7 TeV per beam, design value)





$$\mathcal{L} \propto \frac{N_1 N_2 n_b}{\sigma^2}$$

Key parameters:

- N_i = bunch intensity
- n_b = number of bunches
- σ = colliding beam size

dN_{events}/dt = ***Luminosity*** * cross section

$N_{events}(\Delta t) = \int_{\Delta t} L dt$ * cross section

LHC : a *Top* producer

counter-rotating high intensity proton bunches colliding at center of mass energy (E_{cm}) = 7 TeV in 27 Km tunnel

E_{cm}(Tevatron)= 1.96 TeV

$$\mathcal{L} \propto \frac{N_1 N_2 n_b}{\sigma^2}$$

' parameters:

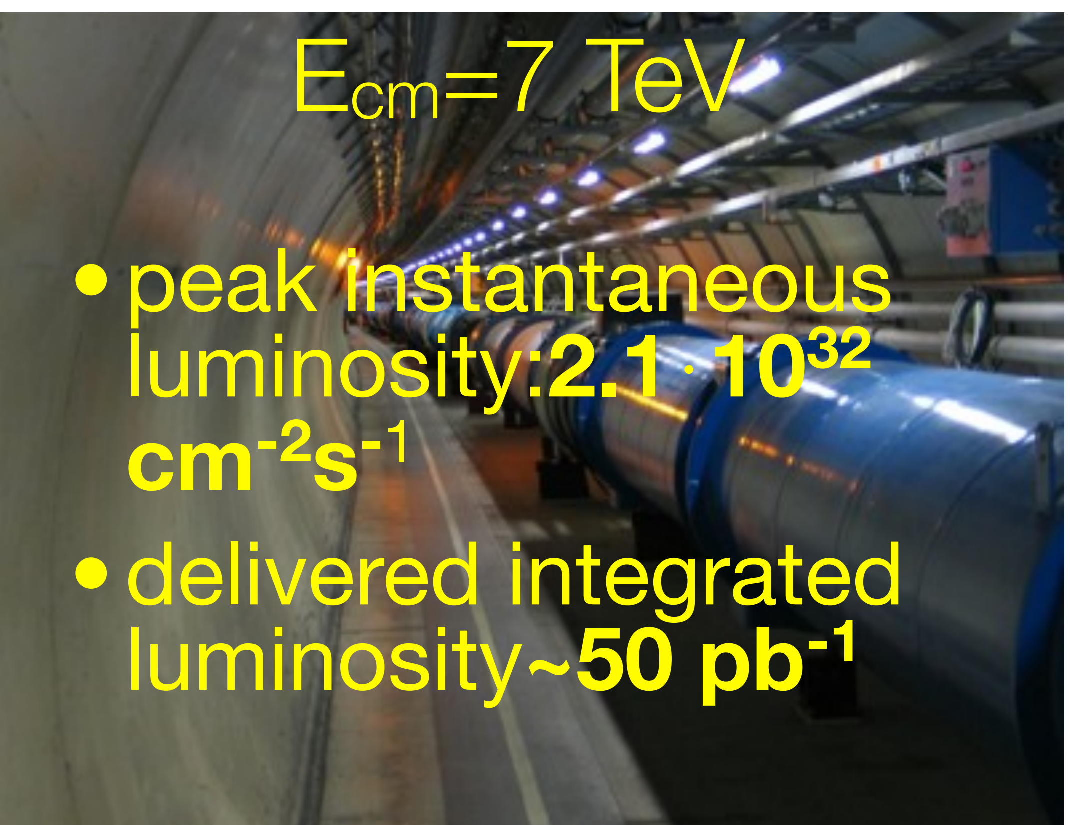
N_i = bunch intensity

n_b = number of bunches

σ = colliding beam size

Ad maiora..

2010



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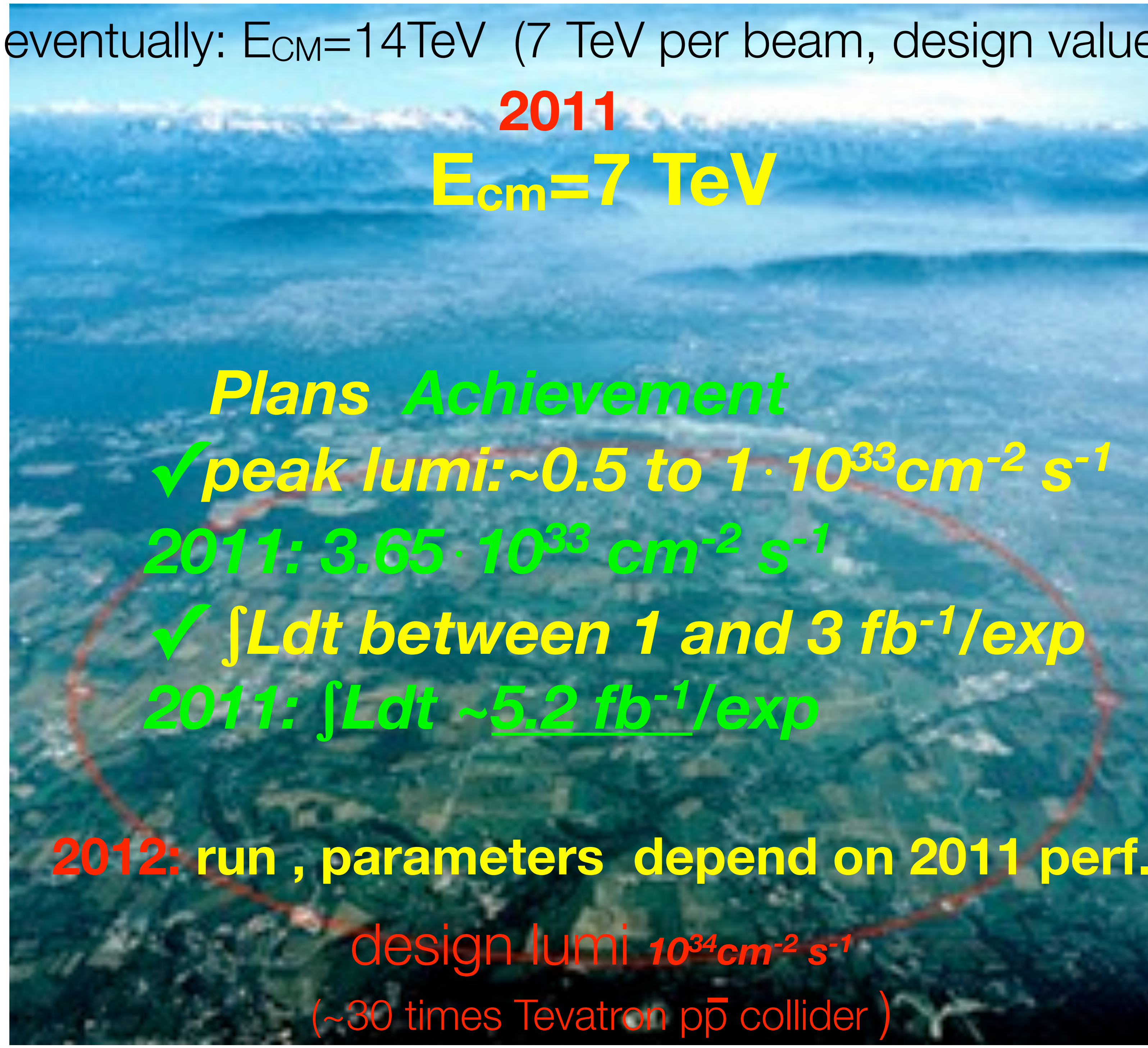
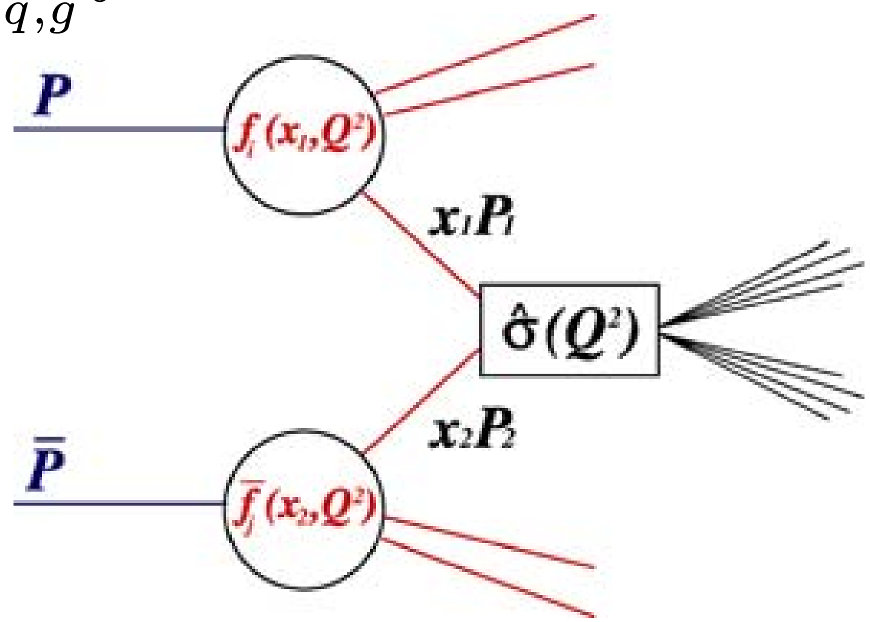


$N_{events}(\Delta t)$= ***∫Ldt*** * cross section

Top quark @ LHC: production(I)

$$\sigma^{t\bar{t}}(\sqrt{s}, m_t) = \sum_{i,j=q,\bar{q},g} \int dx_i dx_j f_i(x_i,\mu^2) \bar{f}_j(x_j,\mu^2) \hat{\sigma}^{ij\to tt}(\rho, m_t^2, x_i, x_j, \alpha_s(\mu^2), \mu^2)$$



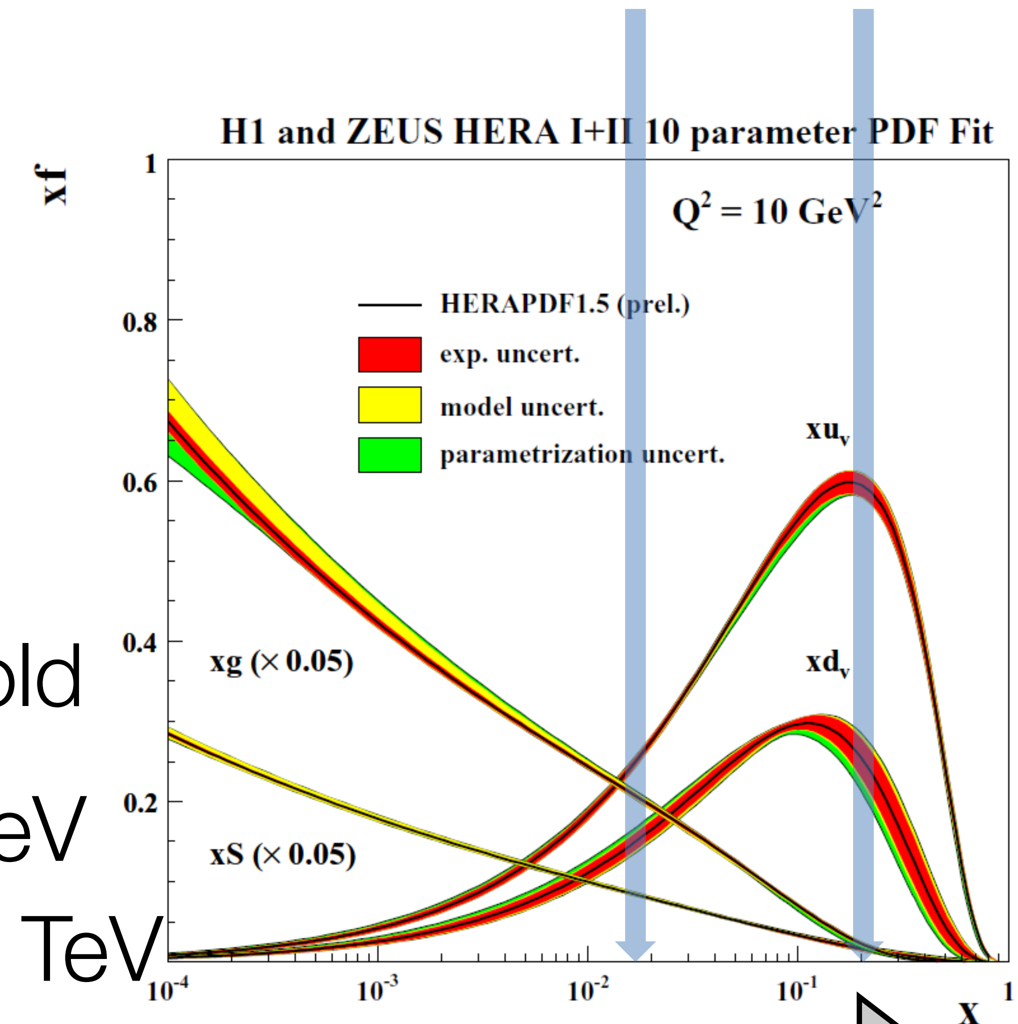
	LHC(14)	LHC(7)	Tev(1.9)
gg	~90%	~85%	~10%
qq	~10%	~15%	~90%

To produce tt

$\hat{s} \geq 4m_t^2$ ⇨ $x_i x_j = \hat{s}/s \geq 4m_t^2/s.$

$f_i(x)$ falls with larger x ⇨ typical $x_i x_j$ near threshold

⇨ $x \approx \frac{2m_t}{\sqrt{s}}$ = 0.19 @ Tevatron √s=1.8 TeV
0.18 @ Tevatron √s=1.96 TeV
0.048 (0.025) @ LHC with √s=7 (14 TeV)



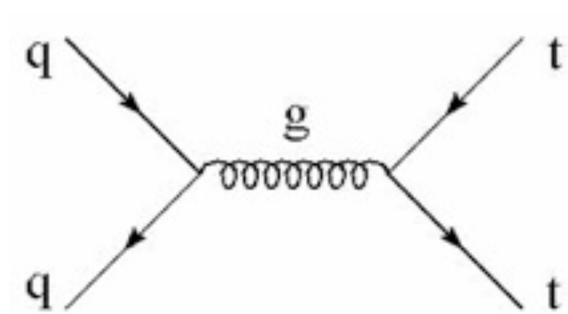
Top quark @ LHC: production

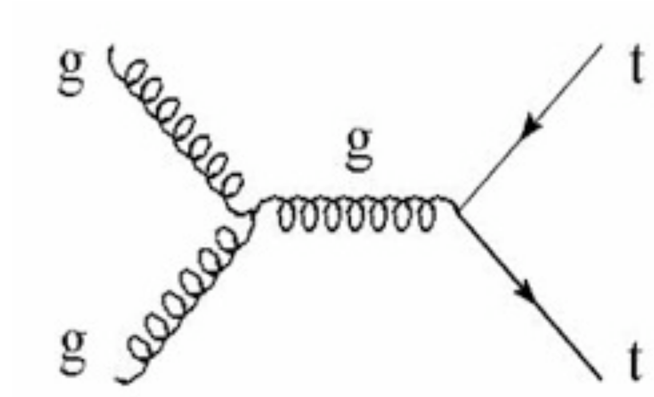
probe low x in pdfs → gluon fusion dominated

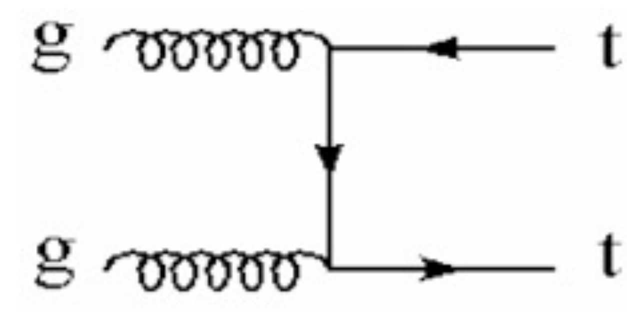
	Tevat	LHC(7)	LHC(14)
gg	~10%	~85%	~90%
qq	~90%	~15%	~10%

top pairs: strong

Aliev et al 2011
Beneke et al 2010
Langefeld Moch Uwer 2009
Moch,Uwer 2008





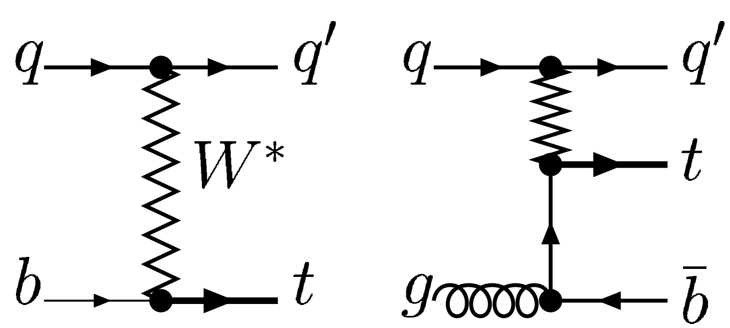


$$\sigma = 165^{+11}_{-16}\ pb$$

single top: electroweak

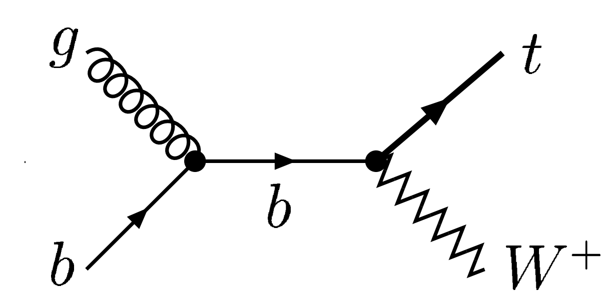
Kidonakis 2010

t chan



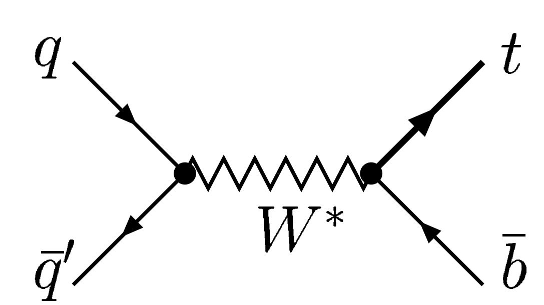
$$\sigma = 64^{+3}_{-3}\ pb$$

Wt chan



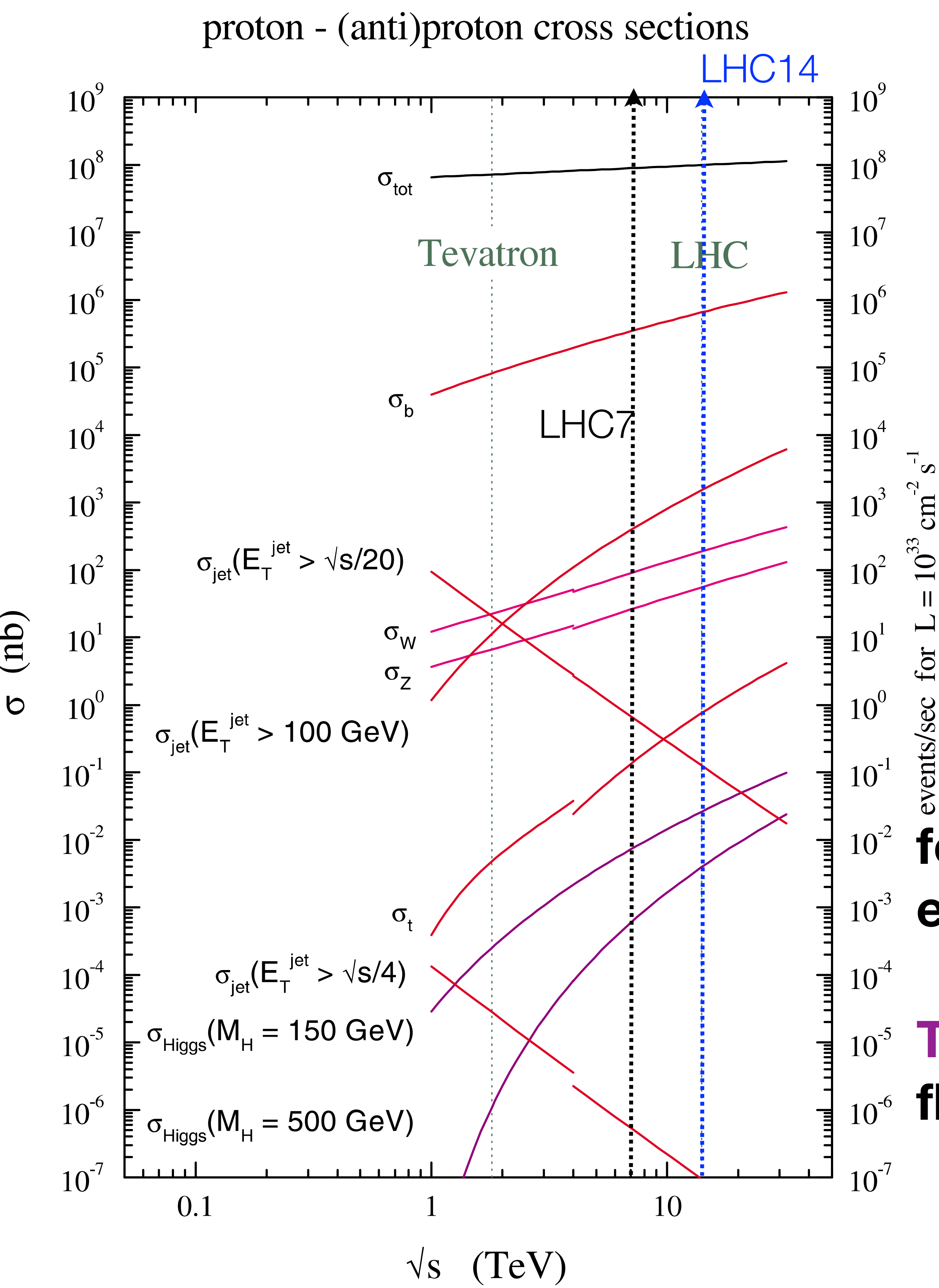
$$\sigma = 15.7^{+1.3}_{-1.4}\ pb$$

s chan



$$\sigma = 4.6 \pm 0.3\ pb$$

Top @ LHC: in the context



$t\bar{t}$ cross section

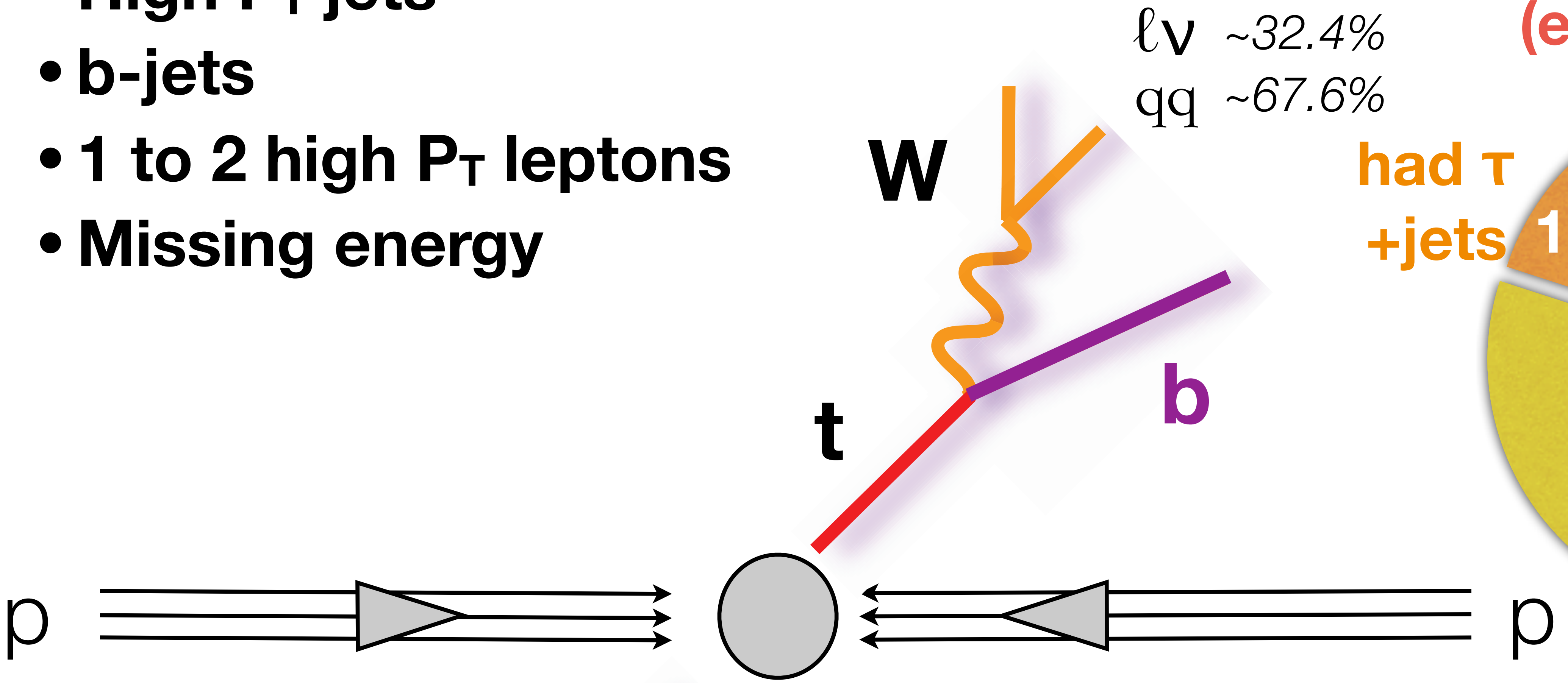
$\sqrt{s}$(TeV)	xsec (pb)	Rate at L= 10^{33}cm^{-2} s^{-1}
1.96 ($p\bar{p}$)	~7	
7 (pp)	~165	0.2Hz
14 (pp)	~900	0.9Hz

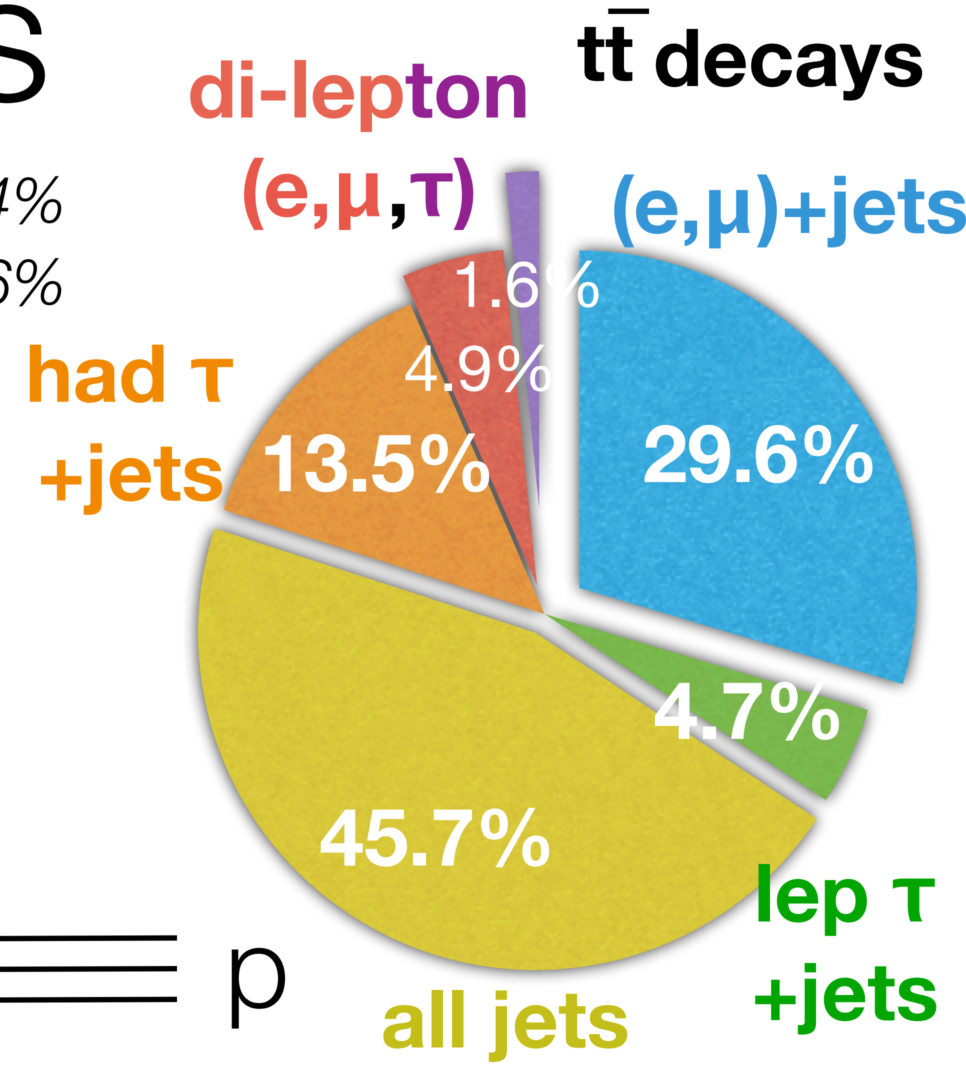
for $\int Ldt$ = 1 fb^{-1} @ 7TeV, expect $1.6 \cdot 10^4$ events

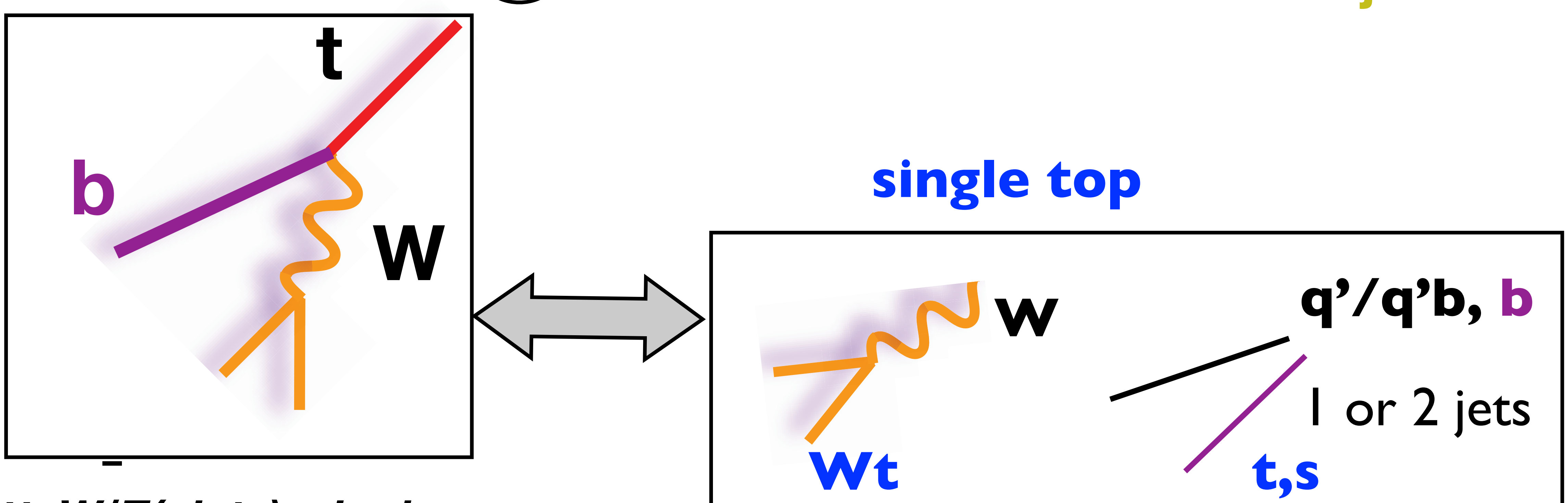
Tevatron (lower energy collider): $\int Ldt$ =9.4 fb^{-1} on tape, expect ~ $6.6 \cdot 10^4$ events

Top signatures

- **High P_T jets**
- **b-jets**
- **1 to 2 high P_T leptons**
- **Missing energy**





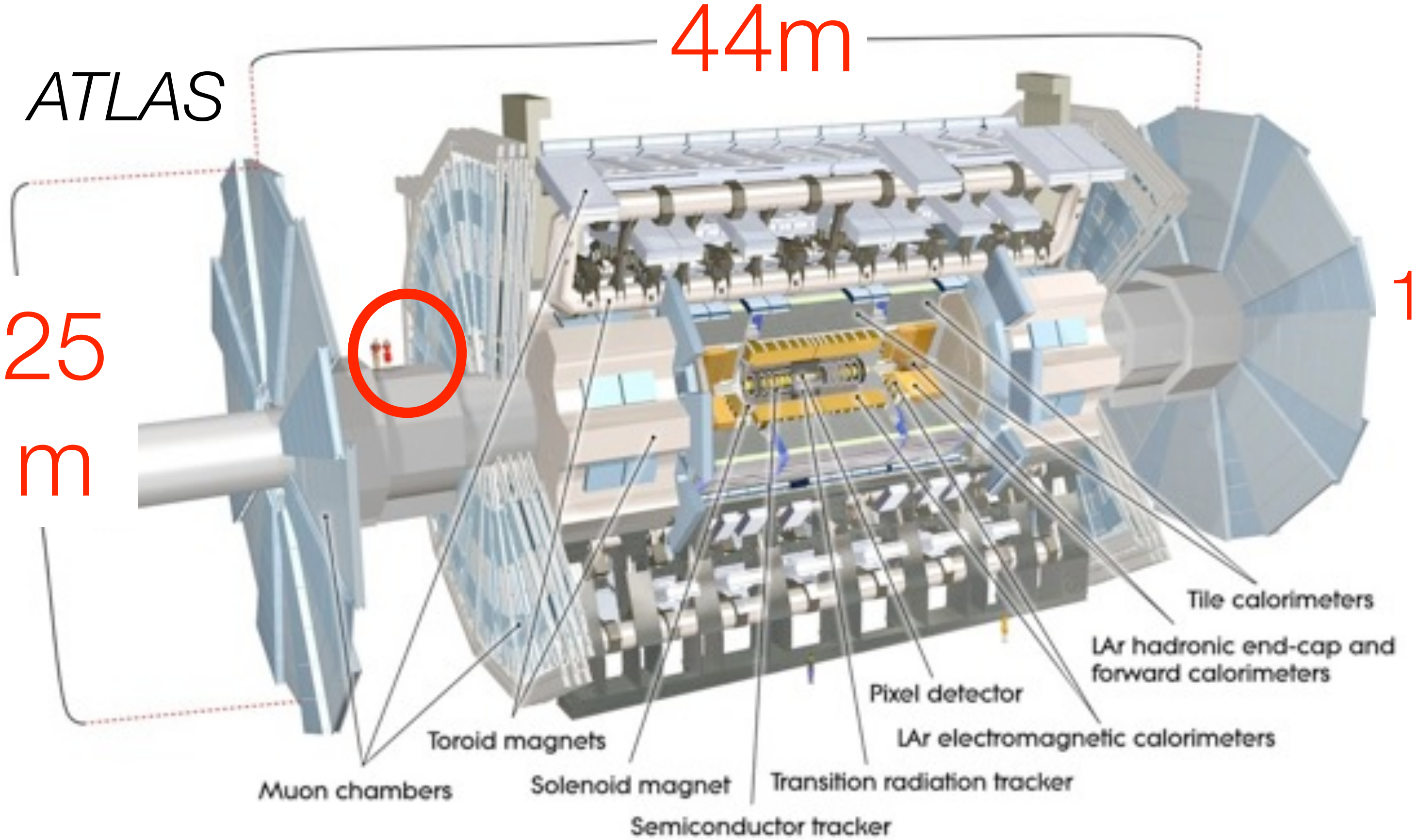


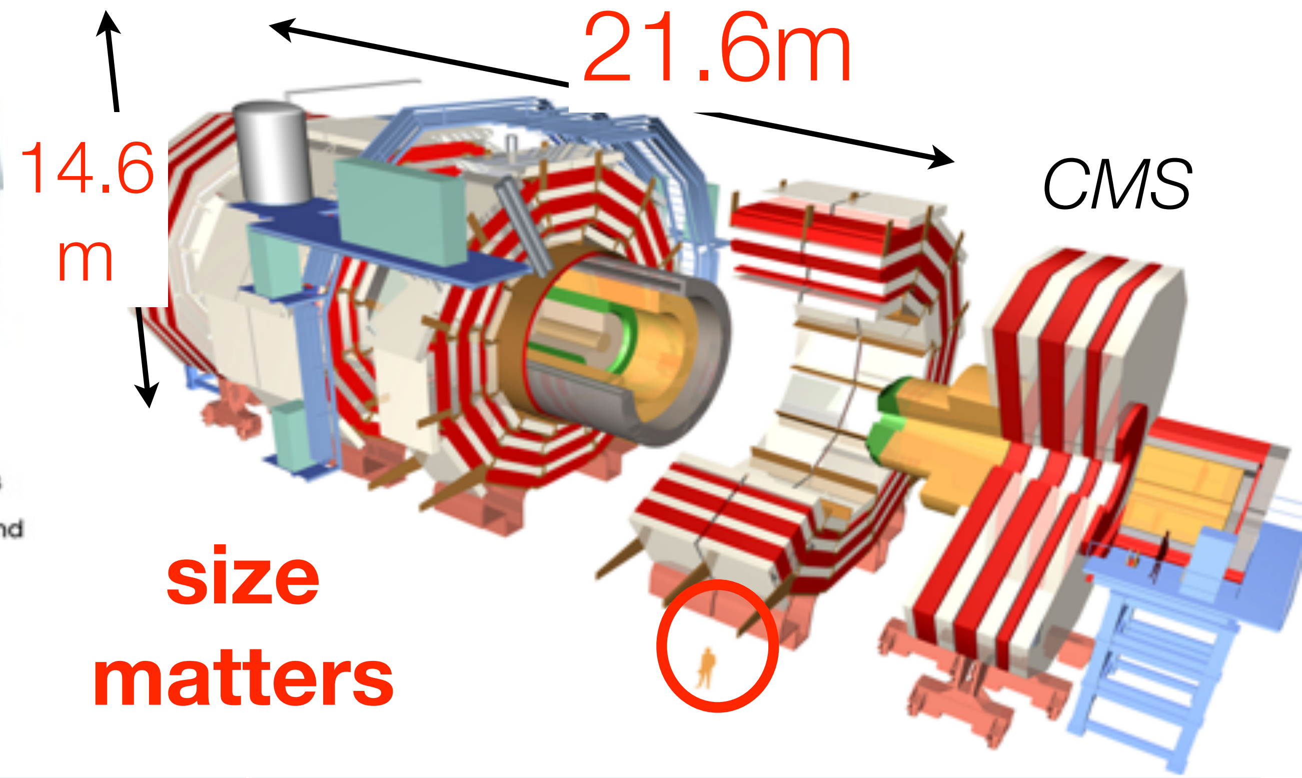
bkgs_tt: W/Z(+jets), single top, QCD, Di-bosons

bkgs_single_t: tt +some bkgs_tt

ATLAS & CMS: *Top* observers

3 (ATLAS) or 2(CMS) trigger levels for event selection



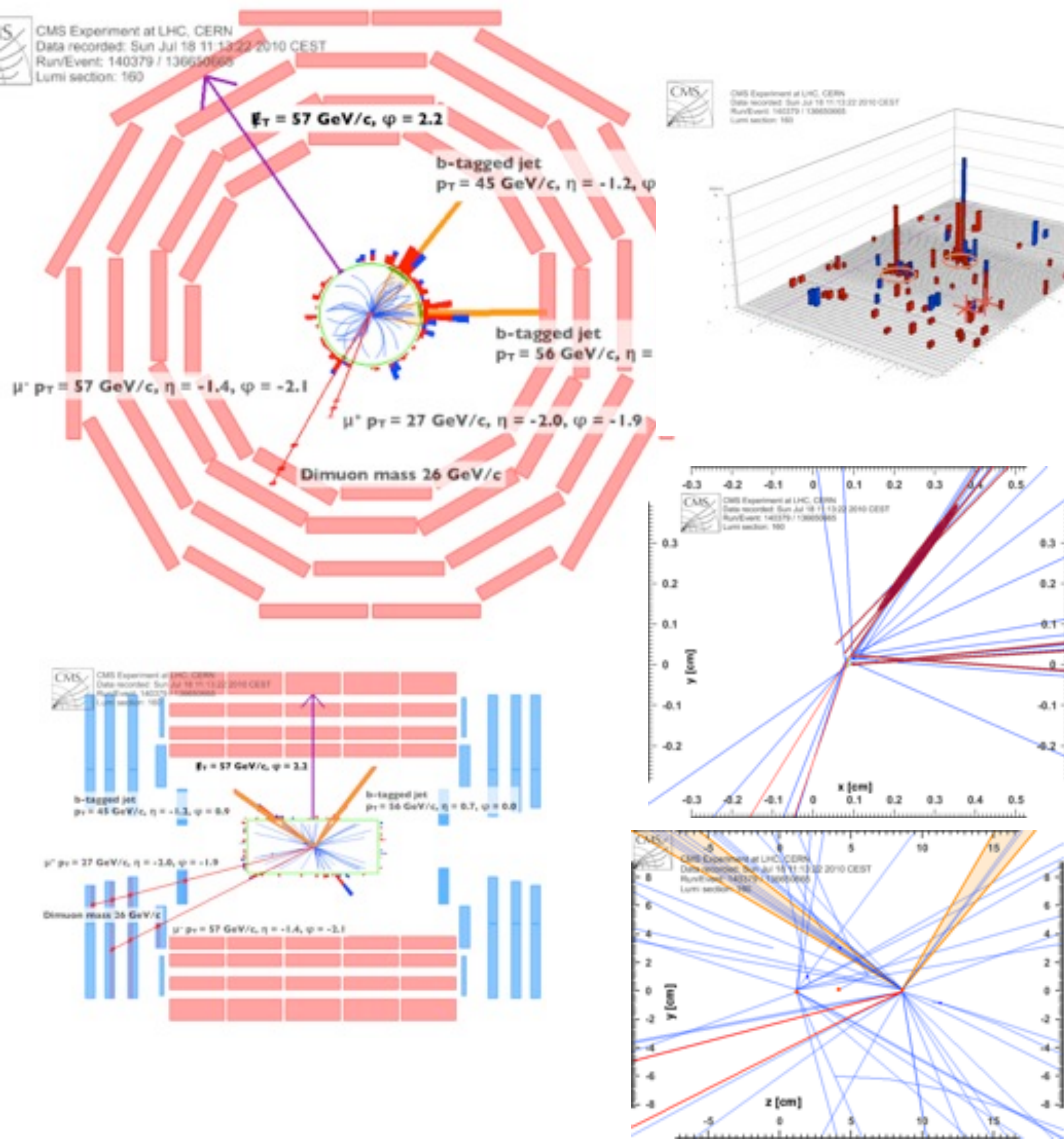


size matters

	ATLAS	CMS
Magnetic field	2 T solenoid + toroid (0.5 T barrel 1 T endcap)	4 T solenoid + return yoke
Tracker	Si pixels, strips + TRT $\sigma/p_T \approx 5\text{x}10^{-4} p_T + 0.01$	Si pixels, strips $\sigma/p_T \approx 1.5\text{x}10^{-4} p_T + 0.005$
EM calorimeter	Pb+LAr σ/E ≈ 10%/√E + 0.007	PbWO4 crystals σ/E ≈ 2-5%/√E + 0.005
Hadronic calorimeter	Fe+scint. / Cu+LAr/W+LAr (10λ) σ/E ≈ 50%/√E + 0.03 GeV (central)	Cu+scintillator (5.8λ + catcher)/Fe+quartz fibres σ/E ≈ 100%/√E + 0.05 GeV
Muon	$\sigma/p_T \approx$ 2% @ 50GeV to 10% @ 1TeV (ID+MS)	$\sigma/p_T \approx$ 1% @ 50GeV to 5% @ 1TeV (ID+MS)
Trigger	L1 + RoI-based HLT (L2+EF)	L1+HLT (L2 + L3)

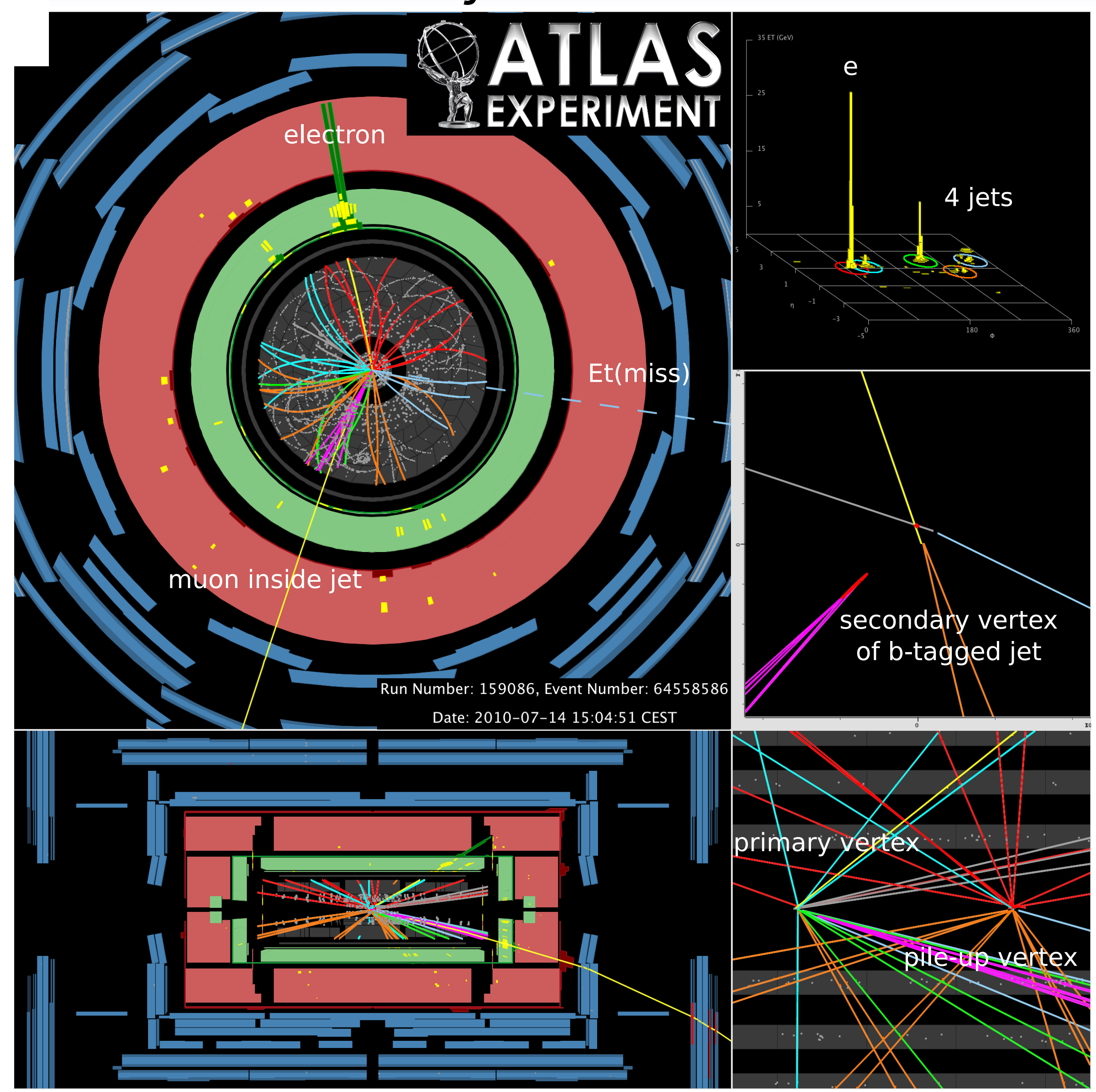
ATLAS and CMS: *Top* observers.....

Top events are real commissioning tool: full detector at play!!



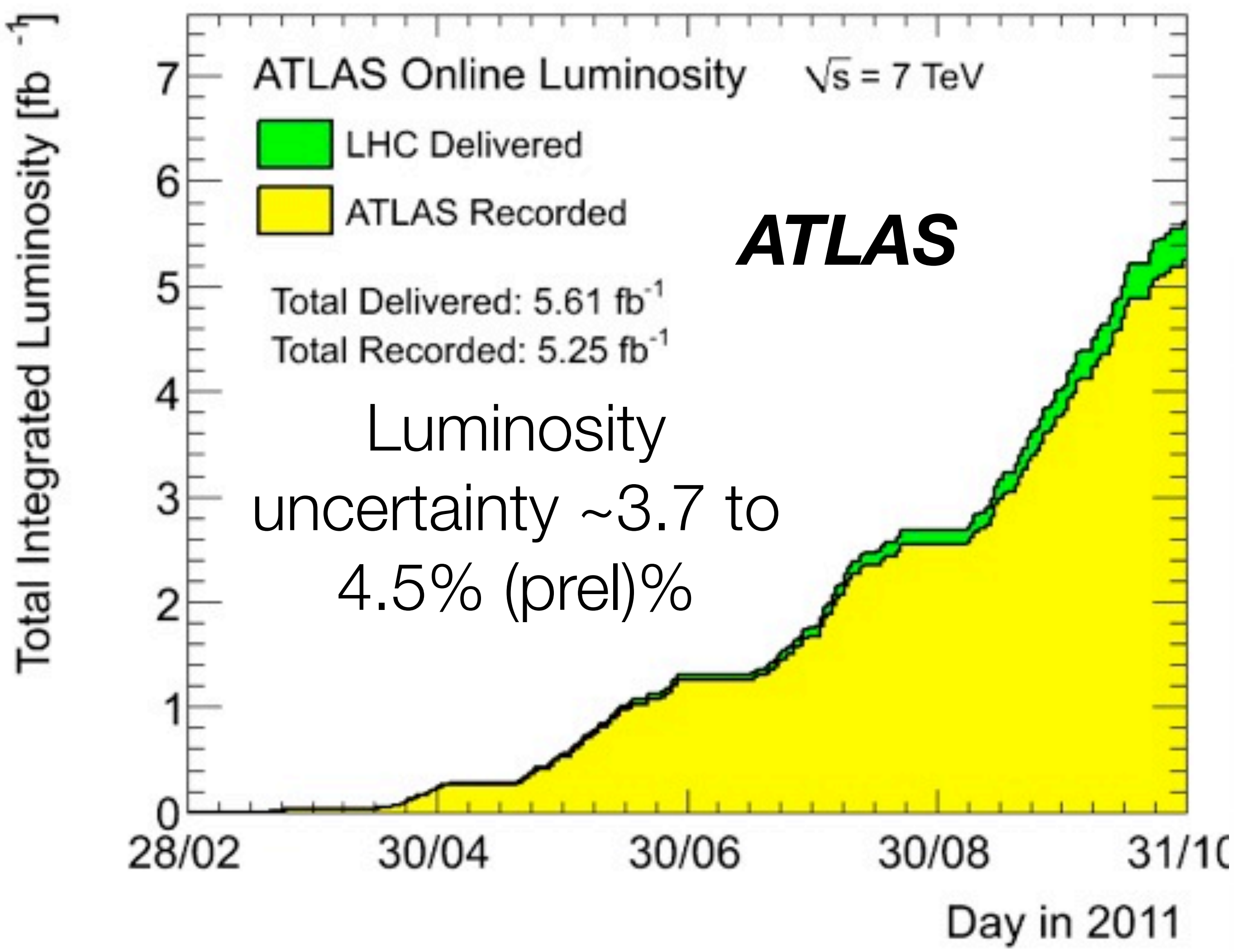
di-lepton (μμ+jets) candidate

e+jets candidate



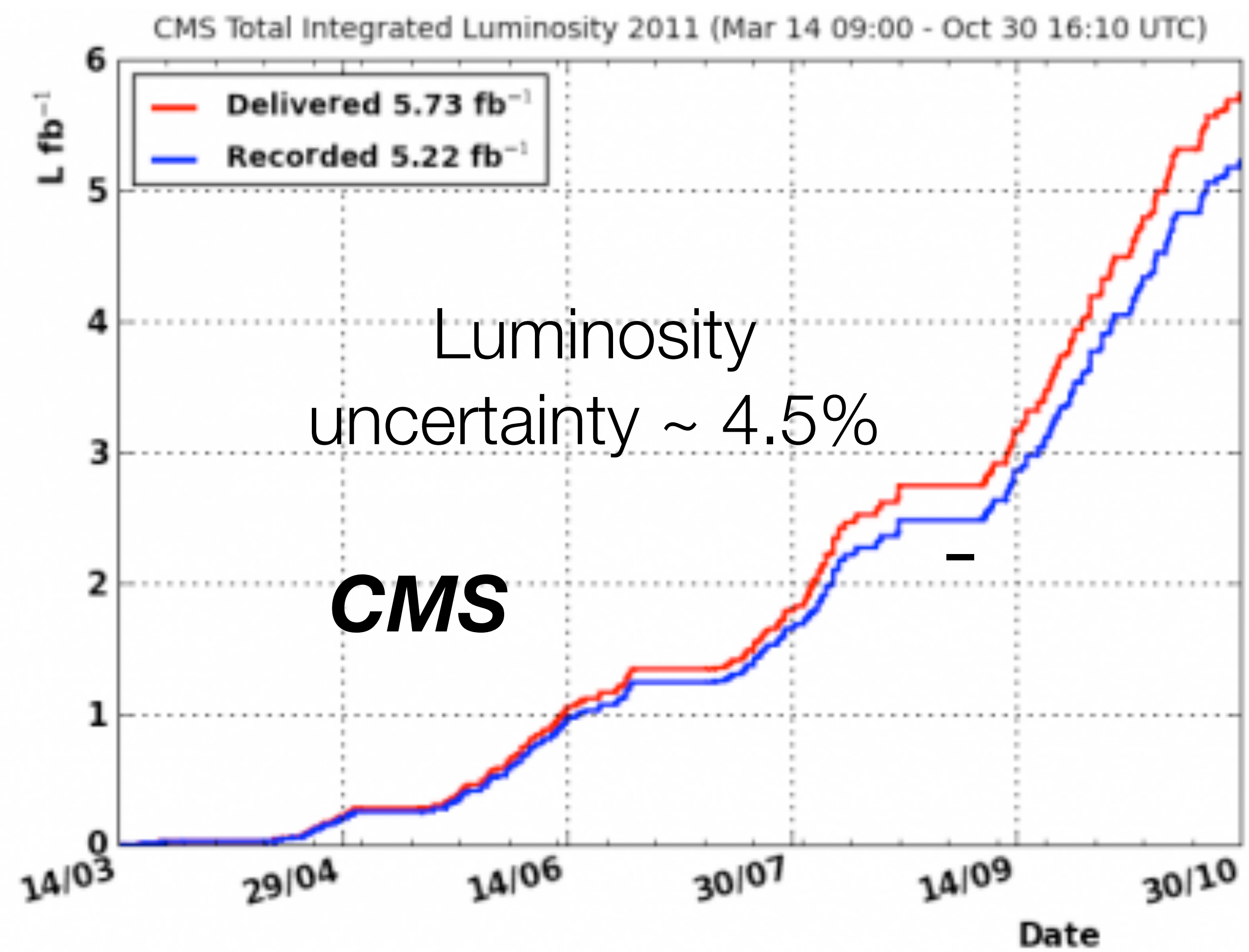
...with excellent data taking performance

2011



Analyses use 36 pb^{-1}(2010) and 0.2 to 1.14 fb^{-1} (2011)

2011



ATLAS (2010)

Total Recorded (Delivered) Lumi:
45.0 (48.1) pb^{-1}
Lumi uncertainty~3.4%

Data sample for first top paper~3 pb^{-1}

CMS (2010)

Total Recorded (Delivered) Lumi:
47.03 (43.17) pb^{-1}
Lumi uncertainty~4%

Ingredients I : leptons

A=ATLAS,C=CMS

* A=$|\eta_{cluster}| \notin$ [1.37,1,52]

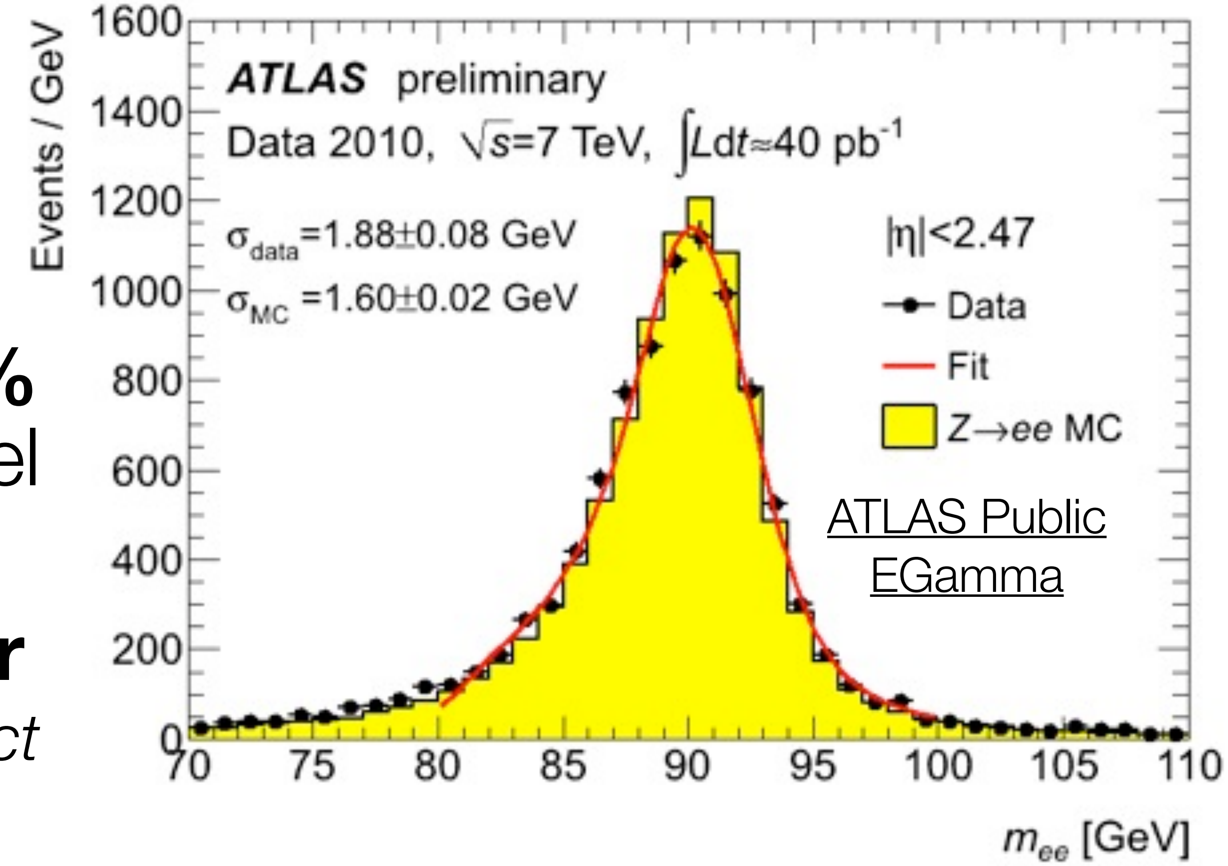
* C=$|\eta_{cluster}| \notin$ [1.44,1,57]

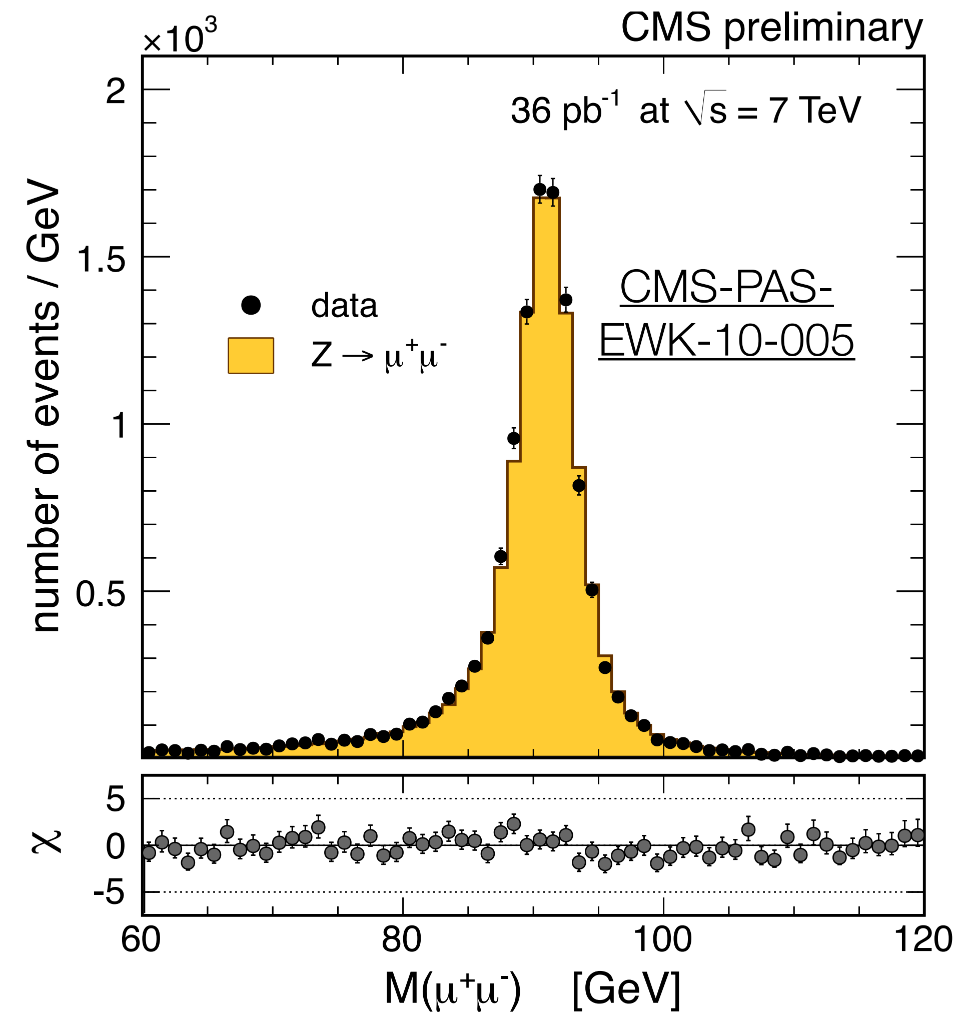
Electrons

- (A) E **scale** *from data known* ***at*** **0.3 to 1.6%** up to 1 TeV (C) ECAL **scale** known **at** level of **0.6% to 1.5%**
- isolated **central*combination of shower shape , track/calo-cluster match** *(correct for Bremsstrahlung, veto conversions)*
  - $|\eta_{cluster}|$<2.4 (A) or 2.5(C), p_T>25(A) or 30(C) GeV
  - **remove duplicate** *close-by (ΔR< 0.2)* **jets** (A) ***or*** *reco* **objects** *(with Particle Flow(PF))*

- **Muons**
  - **p_T scale known at ≈<1%**
  - **isolated central combined fitted track from primary vertex**
    - ❖$|\eta_{track}|$<2.5 (*A*) <2.1(*C*), p_T>20 GeV
    - ❖**suppress heavy flavour decays**: no μ with ΔR< 0.4 (A) or 0.3 (C) from a jet

scale factors to correct small data/MC mismatch

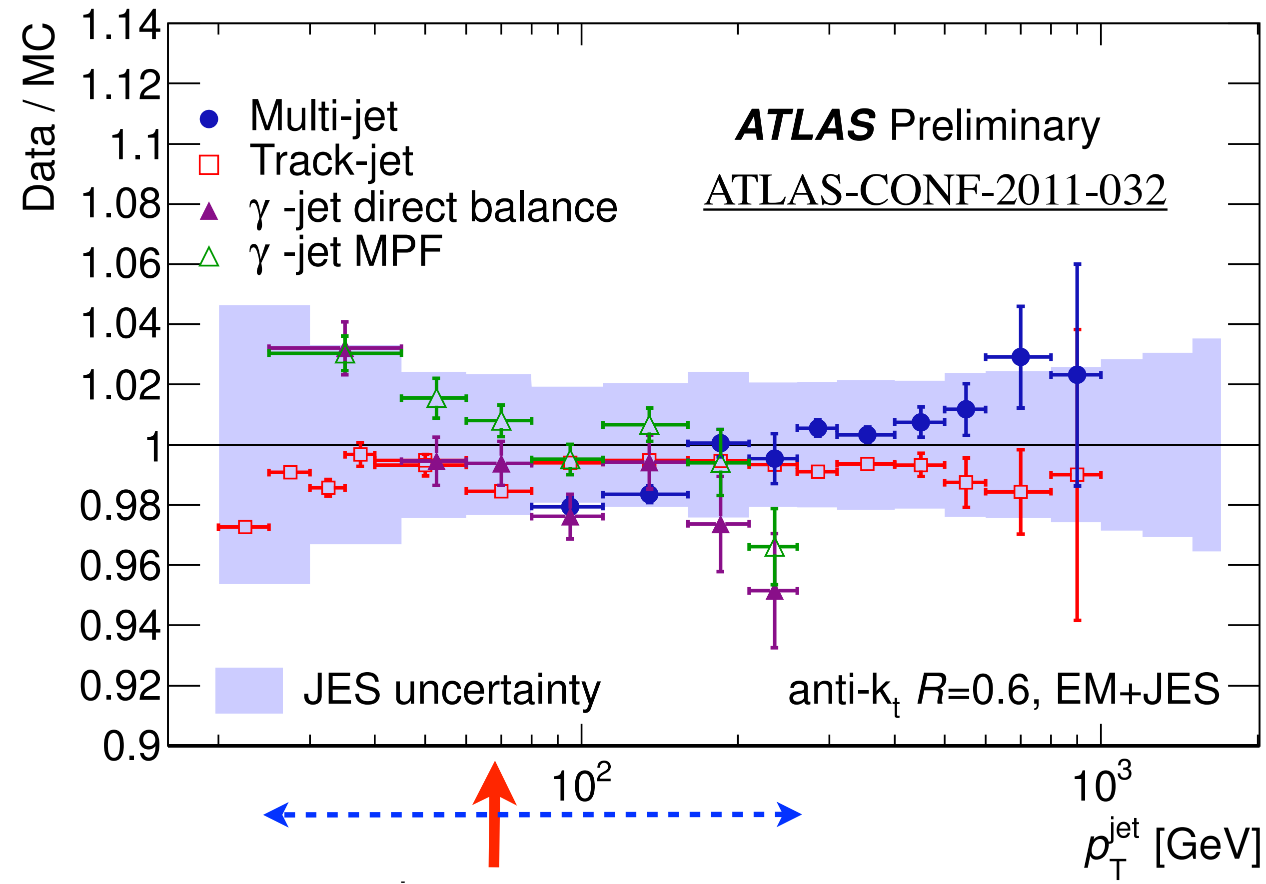




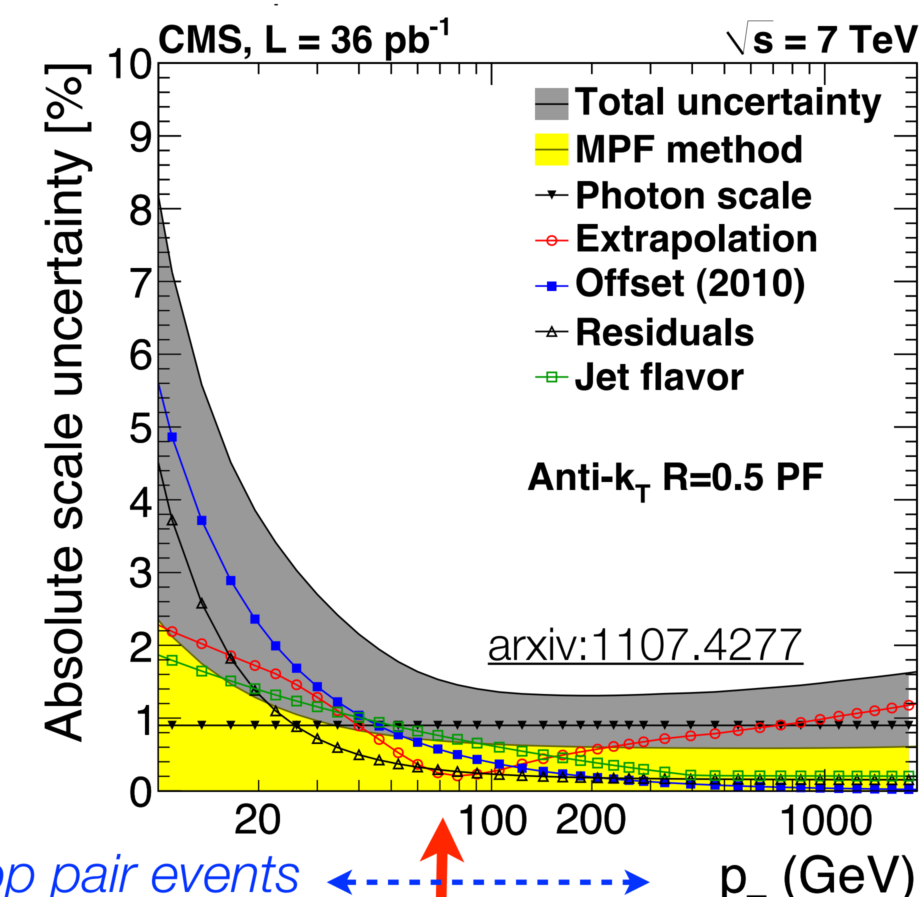
Ingredients II : jets

A=ATLAS,C=CMS

- **Reco**: particle flow objects (C) or 3d calo clusters(A)→ **anti-k_T algorithm** (R=0.4(A),0.5(C))
  - p_T > 25(*A*) or 30(*C*) GeV
  - $|\eta_{jet}|$ <2.4(*A*) or 2.5 (*C*)



- **Calibrate jet energy scale** with (η,p_T) dependent weight ***from simulated "true" jet kinematics***+ *pile-up offset correction*



- **Scale uncertainty:** *between 2% to 8% in* $\boldsymbol{p_T}$ *and* η
  - Contributions from physics modelling, calo response, det simulation
  - in-situ validation

jet p_T range in single lept top pair events

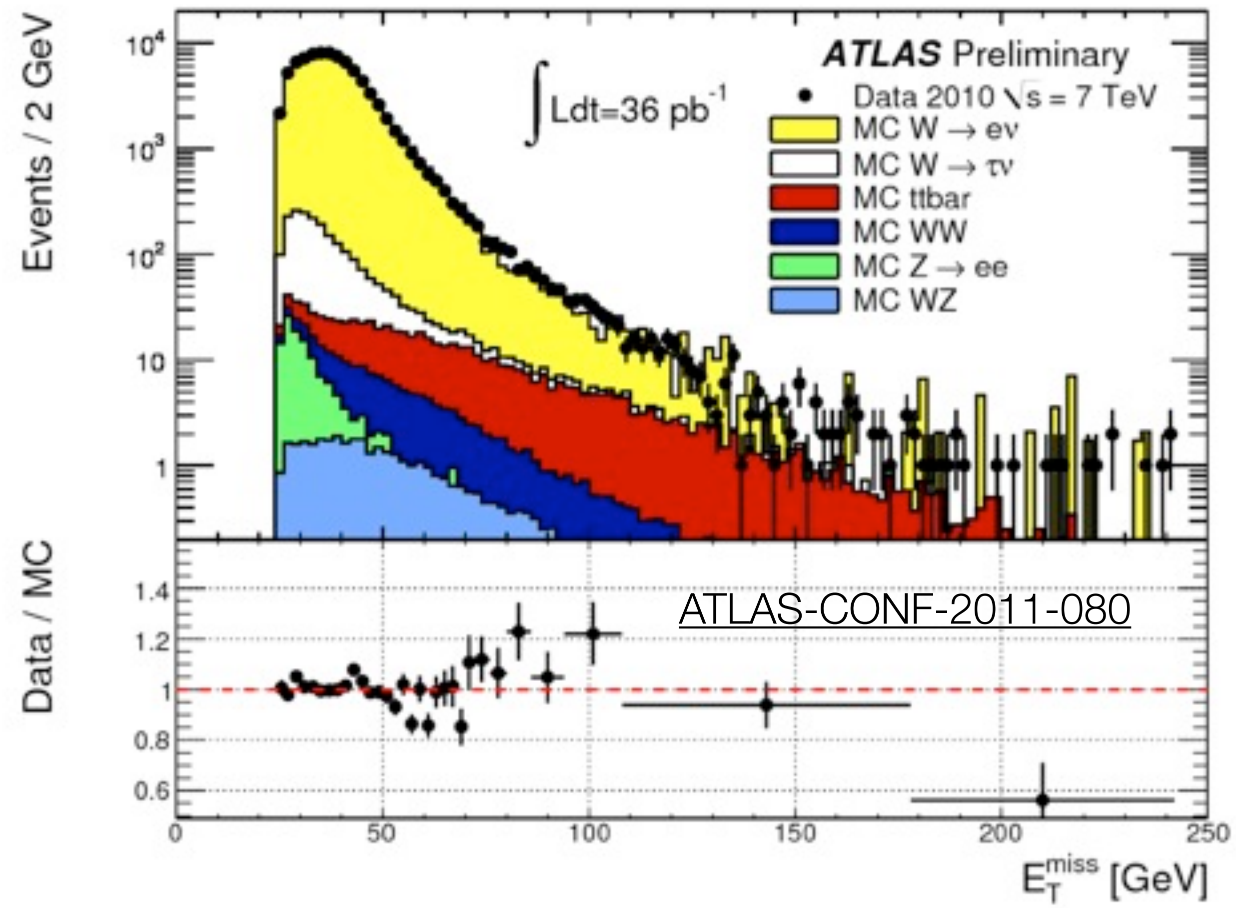
~average jet p_T in single lept top pair events

Ingredients III: missing transverse energy (E_T^{miss})

A=ATLAS,C=CMS

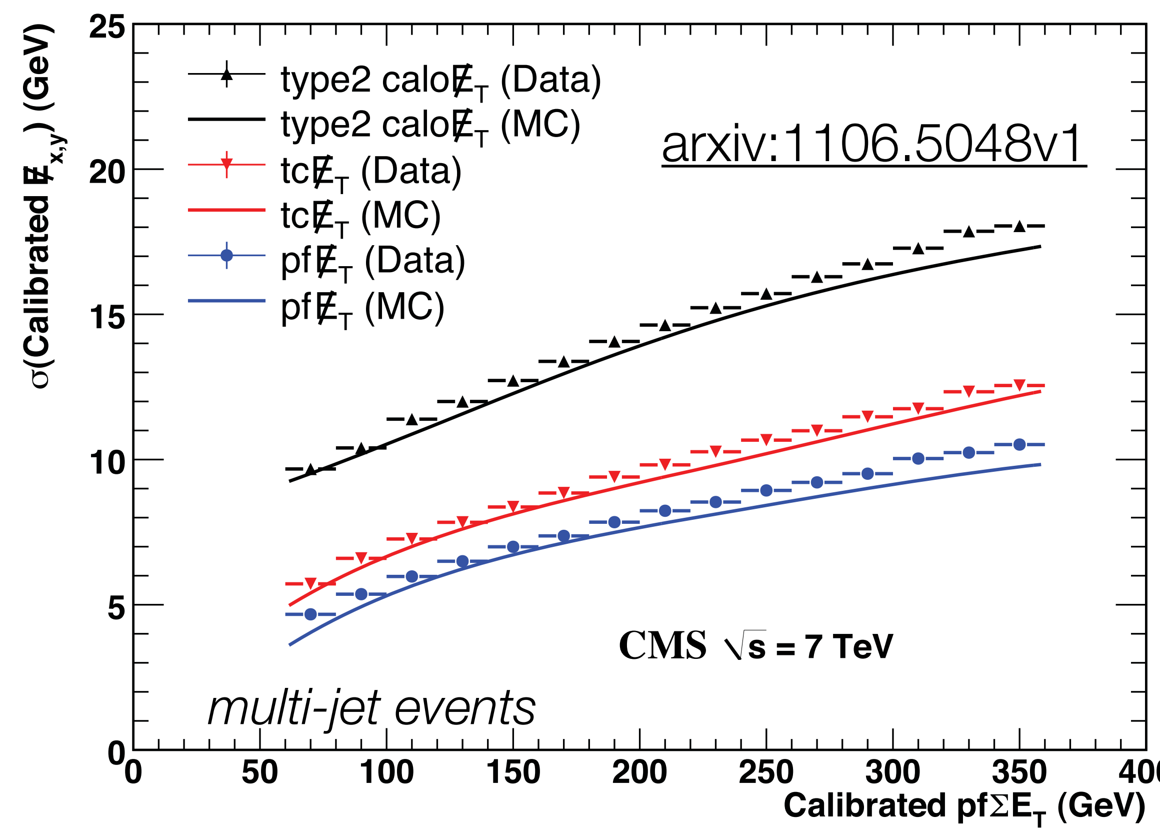
- **Negative vector sum** of
  - A: **energy in calorimeter cells,** projected in transverse plane **associated with high p_T object + μ** mom. + dead material loss
  - C: energy/momentum from 1) PF **particle flow objects** or 2) **Calo** towers + μ or 3) **TC**: **Track +Calo**, no double counting

  projected in transverse plane



- Cells/towers/tracks are **calibrated according to association** to high p_T object (electron, photon,tau, jet, muon)

- *Calo cells with overlapping association are counted once*



Selecting top pairs - single lepton

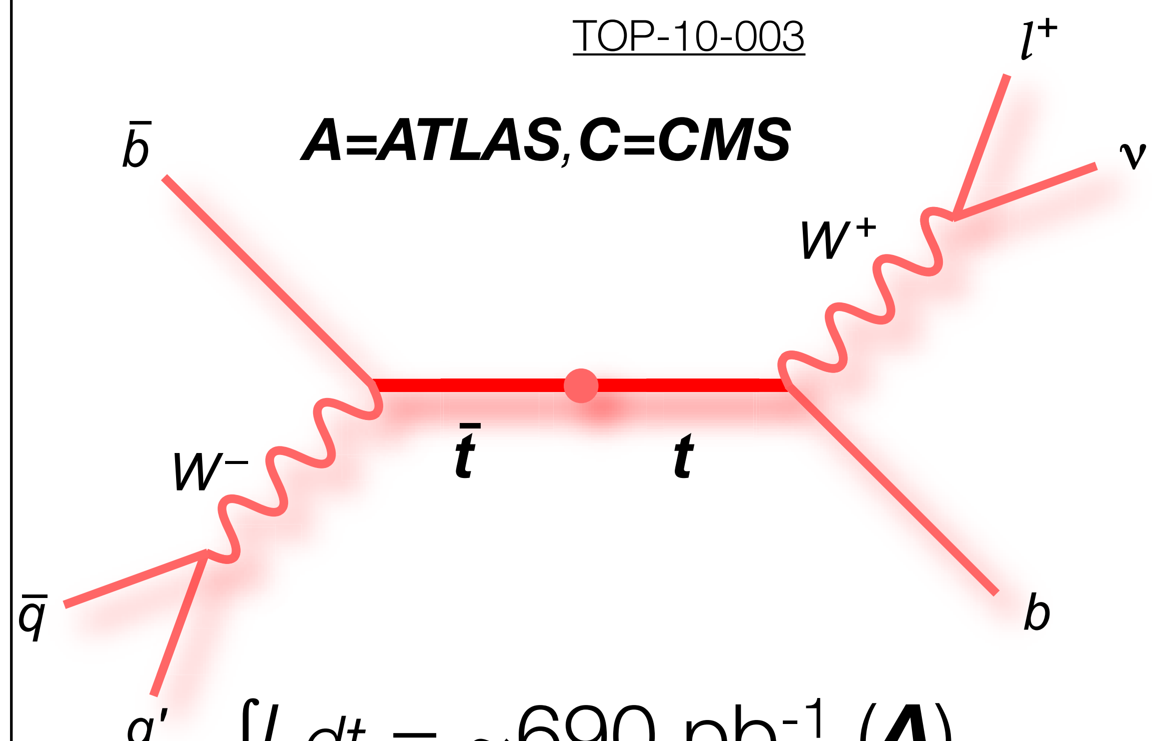
NEW! ATLAS-CONF-2011-121

arxiv:1106.0902

TOP-10-003

- **Trigger on** high p_T **single lepton (e,μ)**
- Good collision and no jet from noise/ out-of-time activity
- **≥ 1** high p_T central **lepton, reject di-leptons**
  - ***A: exactly one lepton***
  - ***C: ≥ 1 electron, reject if |m(ee) -M$_Z$| <15 GeV for any ee pair,*** *no lower p_T μ* ***OR only one μ,*** *no lower E_T e*
- **≥ 3** central high p_T **jets**

- ***A*: high E_T^{miss} and large transverse leptonic W mass** (M_T^W) * **to reduce** QCD bkg
  - *E_T^{miss} > 35 (25) GeV for e (μ) chan*
  - *M_T^W > 25 GeV (60GeV - E_T^{miss}) for e (μ) chan*



$\int L dt$ = ~690 pb^{-1} (**A**) (2011), 36 pb^{-1} (**C**) *(2010)*

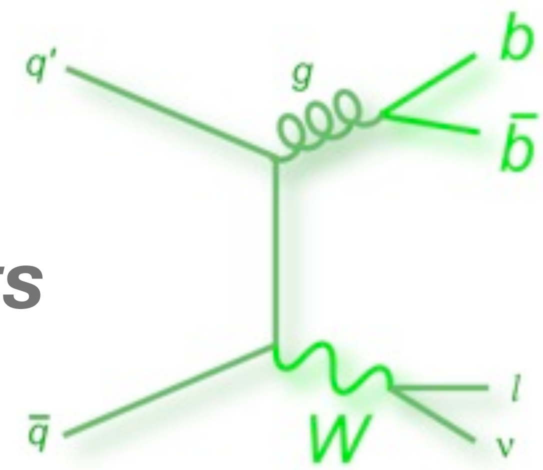
	A		C	
	e	**μ**	**e**	**μ**
tt bkg	5232 18920	7478 33482	325 948	408 757
TotEx	**24152**	**40960**	**1273**	**1165**
Data	**23824**	**41137**	**1611**	**1487**

$$* = \sqrt{2 p_T^{\ell} p_T^{\nu} (1 - \cos(\phi^{\ell} - \phi^{\nu}))}$$

Backgrounds estimates - single lepton

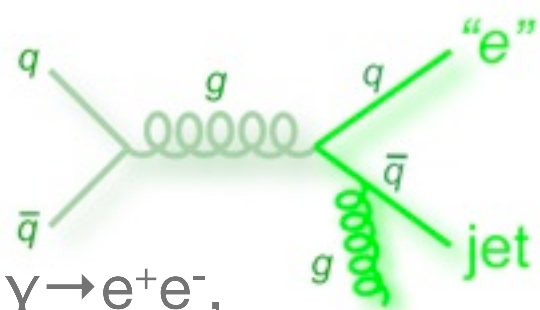
A=ATLAS,C=CMS

- ***W+jets***



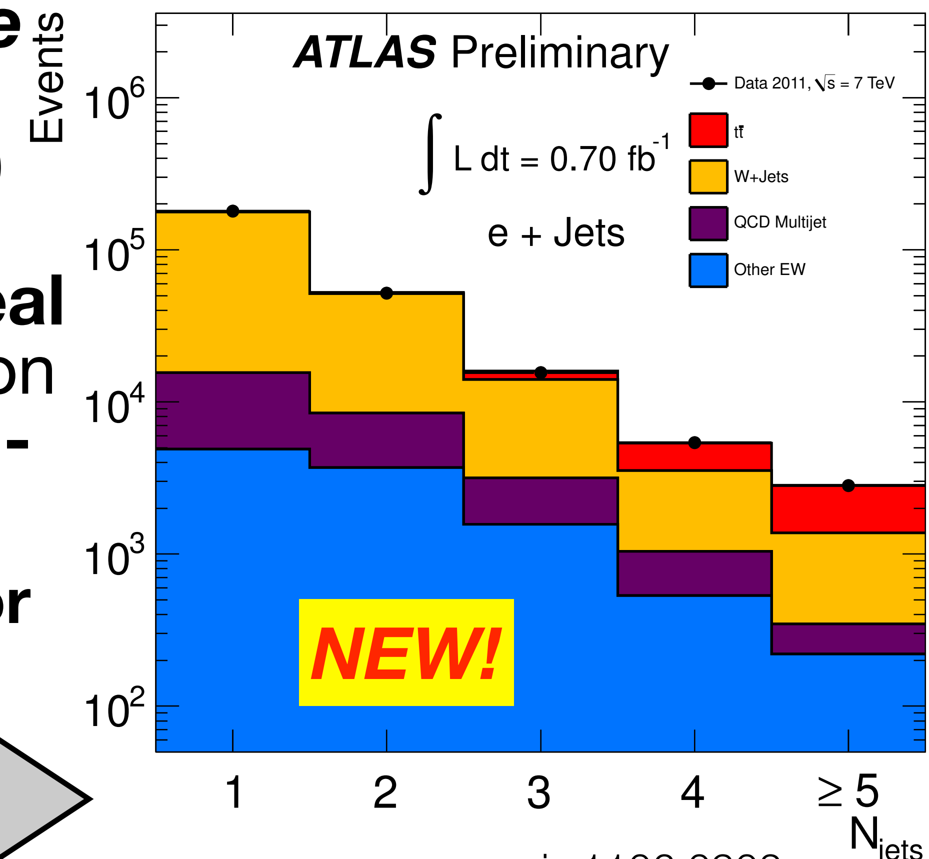
- *simulated shape*
- ***normalization from charge asymmetry of W prod*** *before b-tag **(A)**,floating(**C**)*
- A:Combine **isol. prob for real and fake** lep in control region **with N(isol. lep) and N(non-iso lep)→isolated fake lep**
- C:**shape from non-isolated or failing el-ID/quality, floating norm.**

- ***QCD***



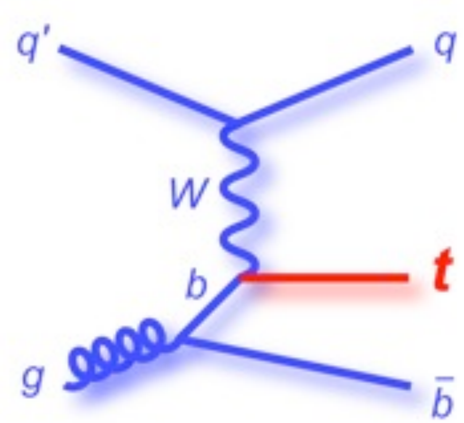
mis-id jets,$\gamma \rightarrow e^+e^-$, non-prompt leptons (b/ c-decays)

ATLAS-CONF-2011-121

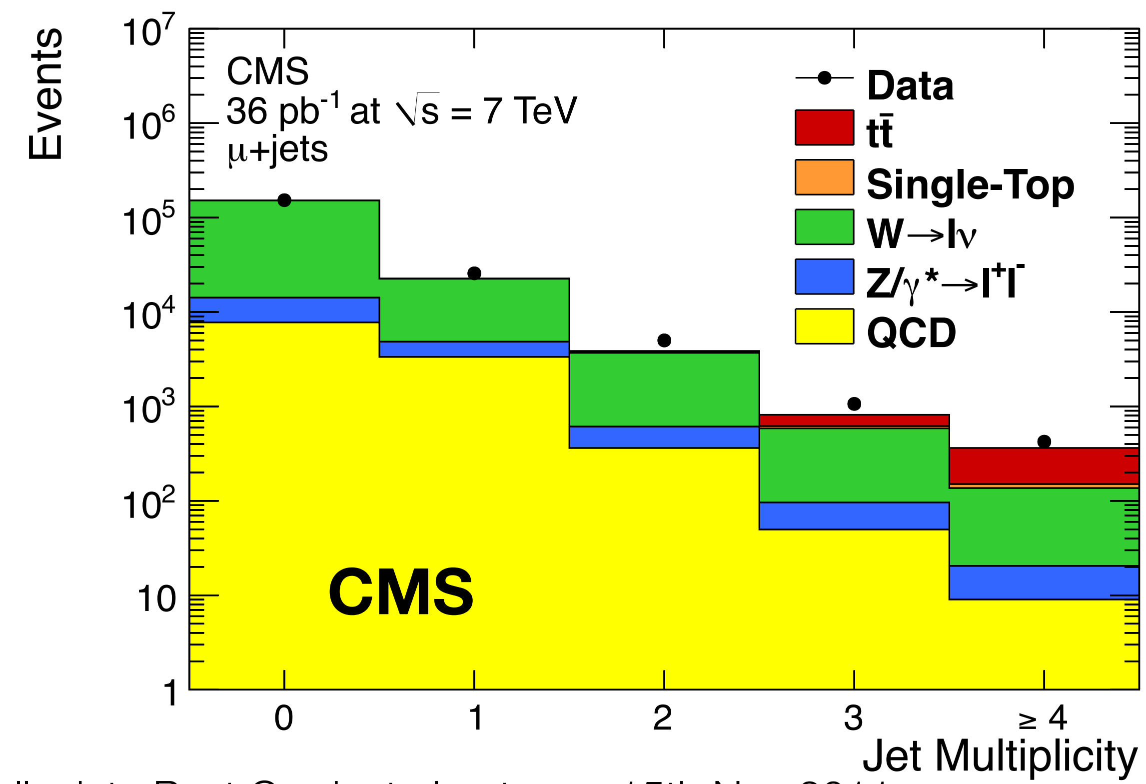


arxiv:1106.0902

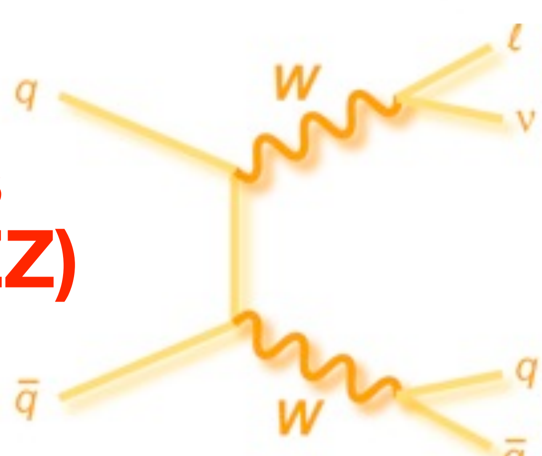
- **Single top**



Simulated shape+ rate set to SM (A), floating (C)



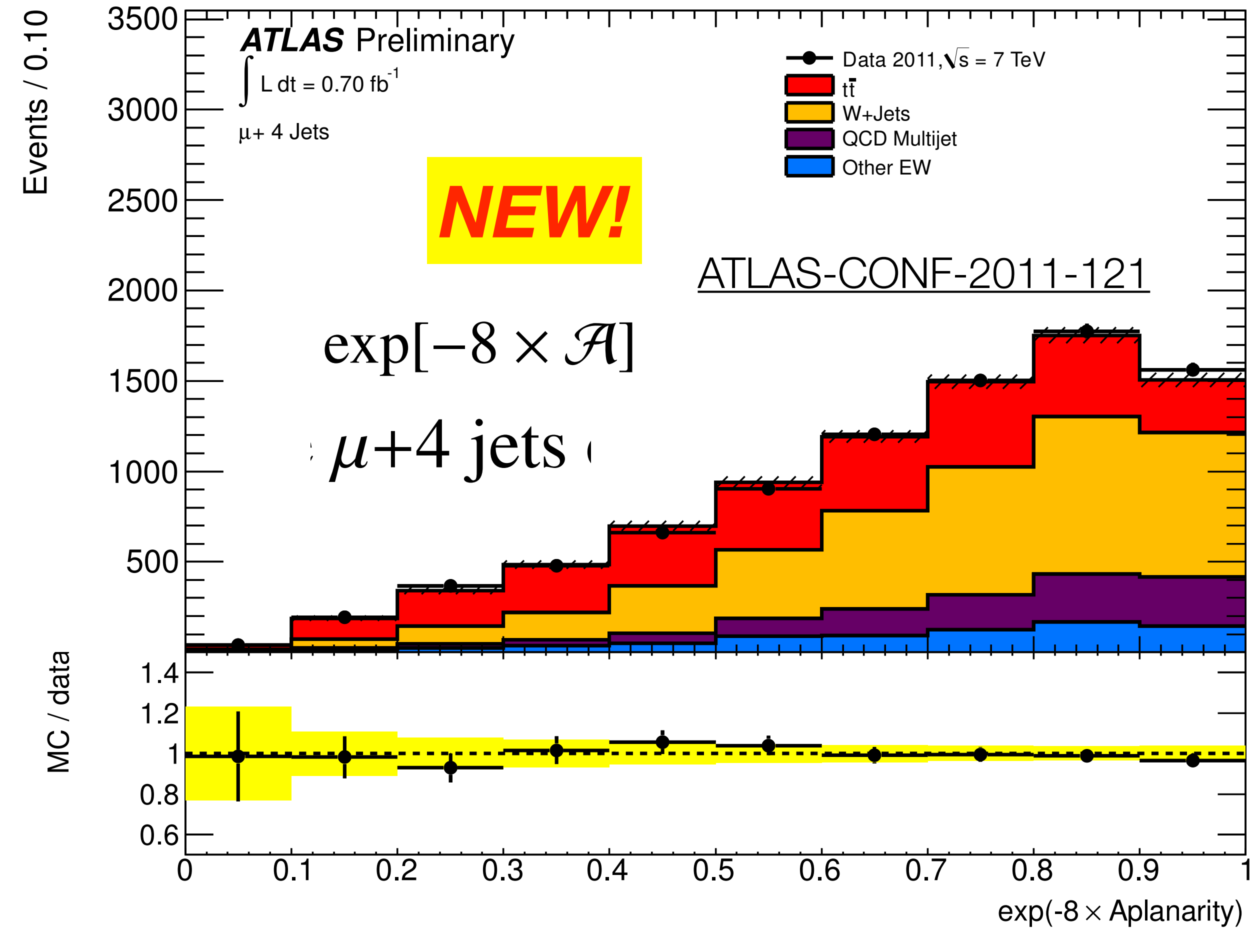
- **Di-bosons (WW,WZ,ZZ)**

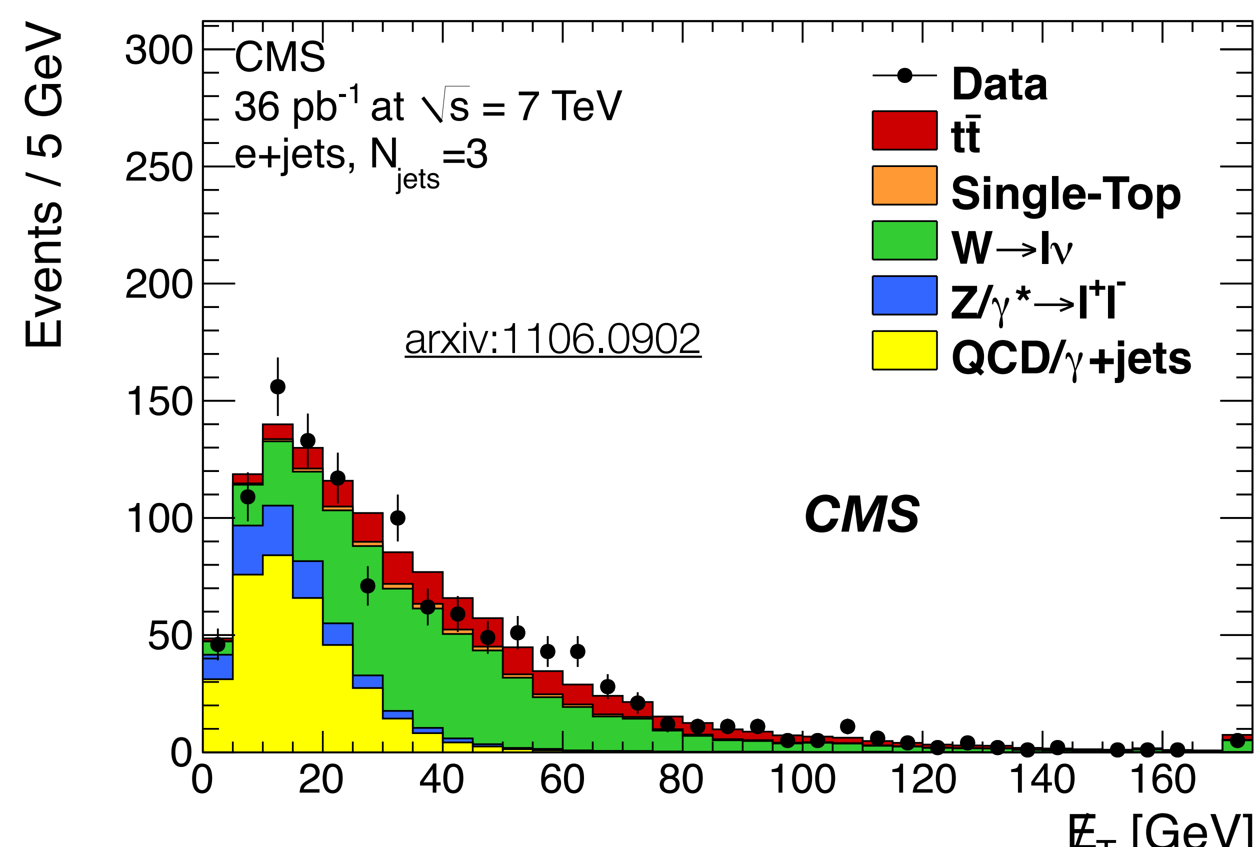


σ_{tt} - single lepton

A=ATLAS, C=CMS

- **Build discriminant from** signal+ bkg **templates of**
  - ***A*: lepton η, p_T of highest p_T jet aplanarity** (←*top is more spherical*), **$H_{T,3p}$,** ratio of transverse to longitudinal activity (←*top is more transverse)*
  - ***C*: E_T^{miss} for 3-jet bin** (*vs QCD*)**, M3 for ≥ 4-jet bin,** mass of 3-jet system with highest vectorially combined p_T





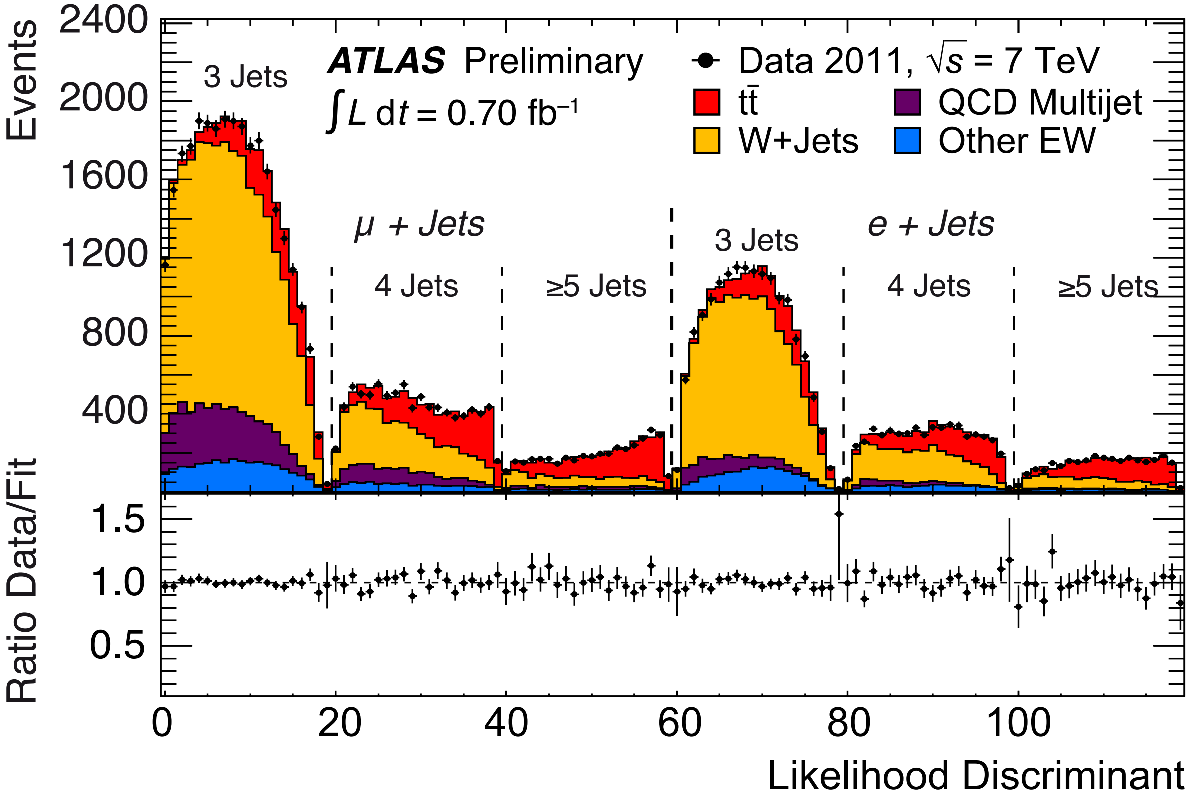
- **Extract σ_{tt} ,σ_{bkg} by binned likelihood fit of discriminant** to data in ***A*:** 3, 4 and **≥ 5**-jet bins, ***C***: 3 and **≥4-jet bins**

σ_{tt} and syst. uncertainties - single lepton

(e, μ combined)

A=ATLAS, C=CMS

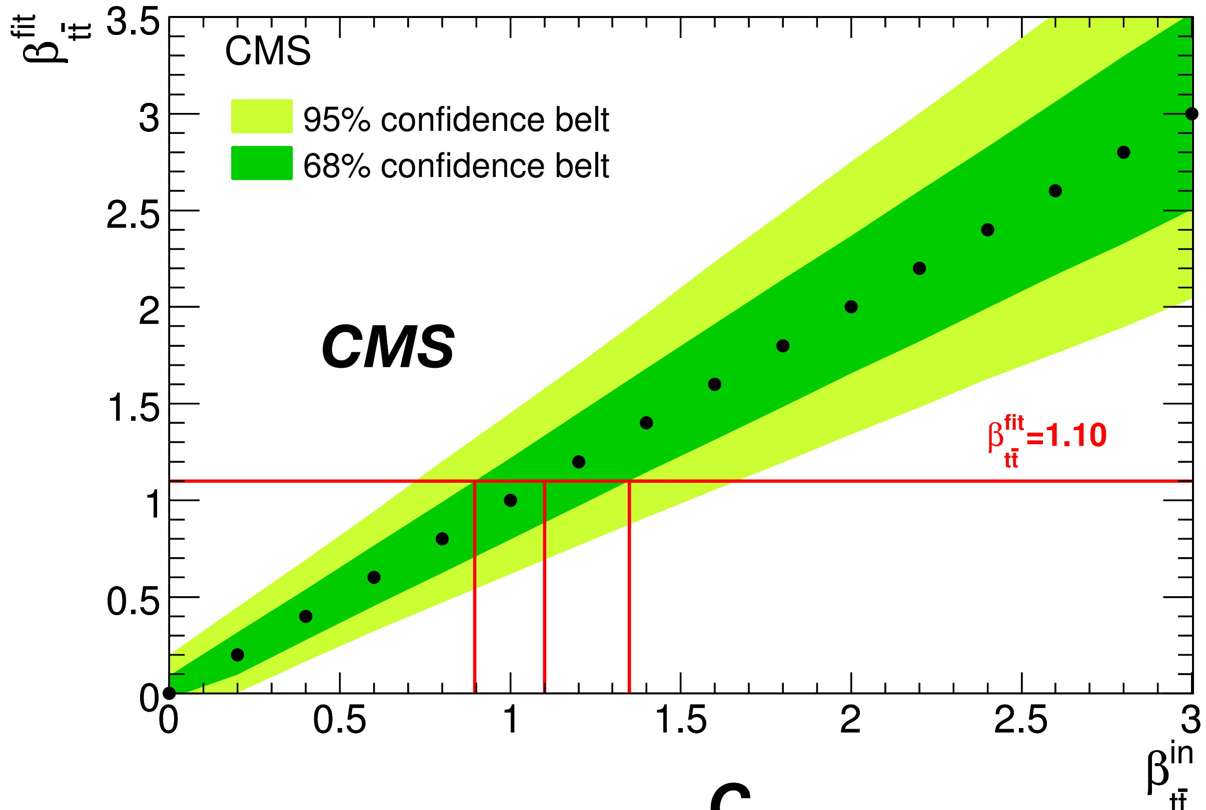
ATLAS-COM-CONF-2011-132



A

$$\sigma_{t\bar{t}} = 179.0 \pm 3.9\,(\text{stat}) \pm 9.0\,(\text{syst}) \pm 6.6\,(\text{lumi})\ \text{pb}$$ ***NEW!***

arxiv:1106.0902

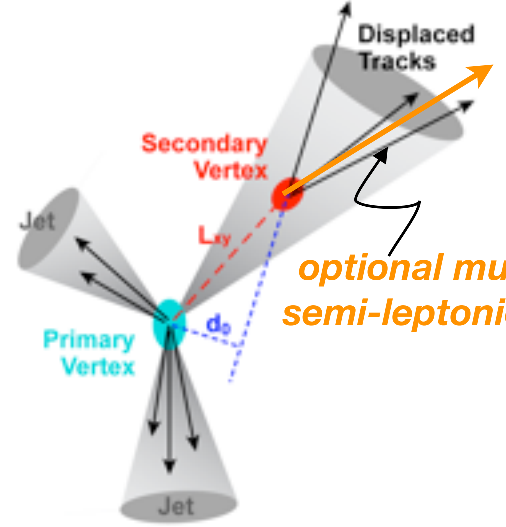


C

$$\sigma_{t\bar{t}} = \mathbf{173 \pm 14(stat)\ ^{+36}_{-29}\ (syst) \pm 7(lumi)}\ \text{pb}$$

- **most syst uncertainties part of lkl fit** as Gaussian nuisance parameters→reduction in JES,ISR/FSR (20% to 70% of initial value)
- still syst-dominated: generator ~3% lepton scale~2%
- δσ/σ=6.6% (stat~0.5%, sys~5%)

- syst included in pseudo exp to derive **Neyman CL belt for max lkl fit**
- syst-dominated (JES~18%, factorization scales~7%)
- δσ/σ~23% (stat~8%, sys~21%)



Ingredients IV : enter b-jets

A=ATLAS, C=CMS

B-hadrons~ long lifetime ~observable flight (few mm)

Tagging

d_0/σ_{d_0}

$L_{3D}/\sigma_{L_{3D}}$

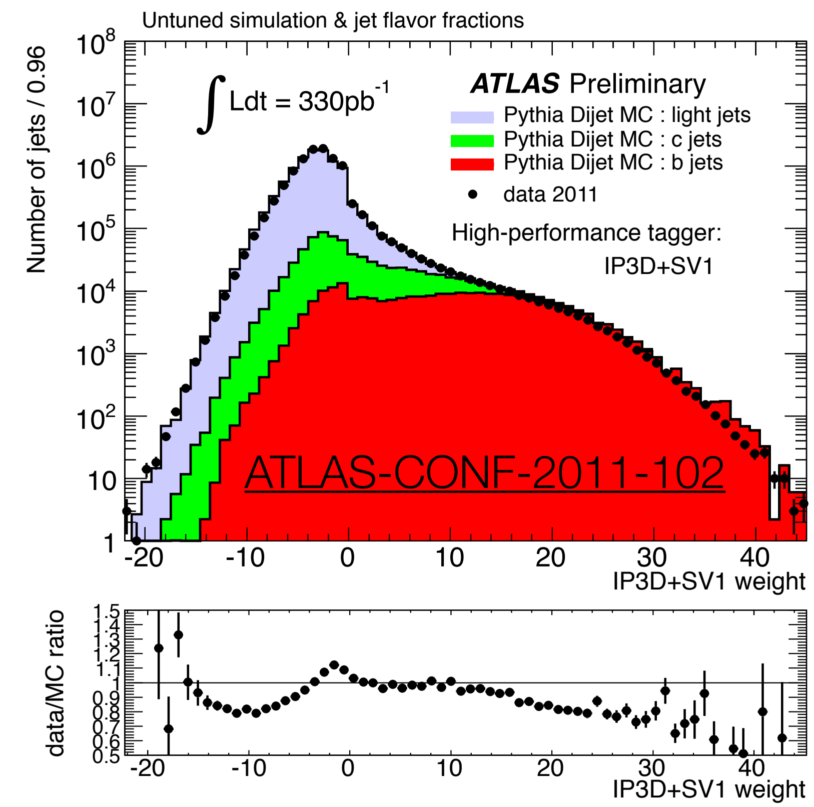
- **A**: (1) jet prob from **track impact parameter** (IP) (2) **3D decay length** significance of sec. vertex (SV) (3) **Neural net** *with 1), 2) + mass of SV tracks +* N_{2track} *vertices+* E_{SV}*(tracks)/*E_{PV}*(tracks)*
- **C**:(1) 3D **SV decay length significance** *(&* $N_{tracks}>3$*)* (2) **track IP** signif. & ≥2 or 3 high **IP** signif. tracks

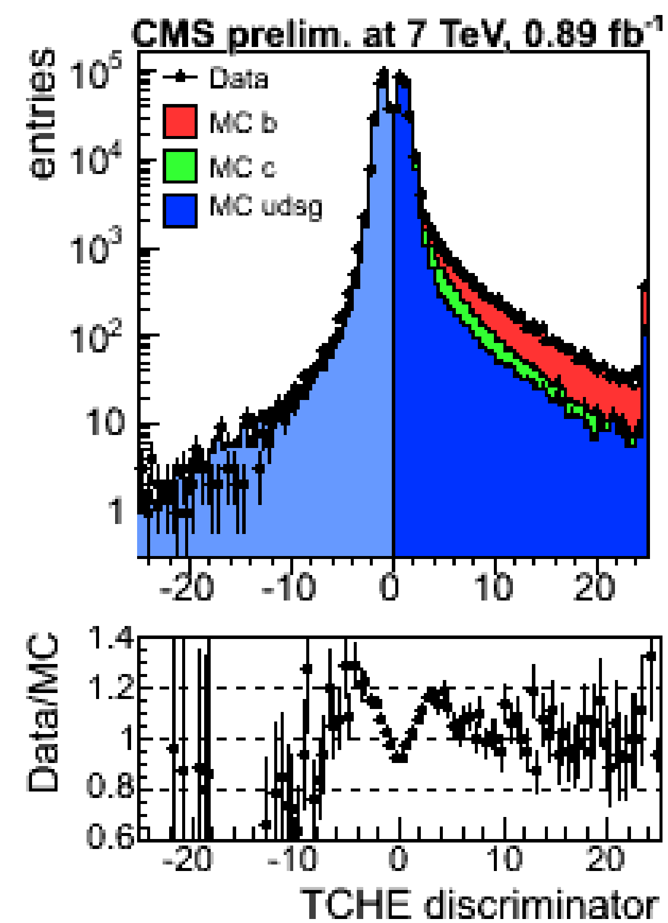
Performance

- **Efficiency: fit fraction** of b-jets in sample with muons in jets, *count # b-tagged*
- **Mis-tag rate**: **from SV properties** (*invariant mass of tracks (A), rate of negative decay length / impact par significance (A,C))*

Efficiency/mis-tag : from **80%/10%** (track/NN based) to **40%/0.1%** (SV based)

p_T dependent scale factors to correct MC





CMS-PAS-BTV-11-001

shape comparison

σ_{tt} - single lepton *with b-tag*

A=ATLAS, C=CMS

$\int Ldt$ = **36 pb^{-1}** (***A***)(2010) **0.8 to 1.1fb^{-1}** (***C***) *(2011)*

- Standard single lepton selection + large **E$_T$^{miss}** and M_T^W
- Bkg shapes/normalization as no-btag

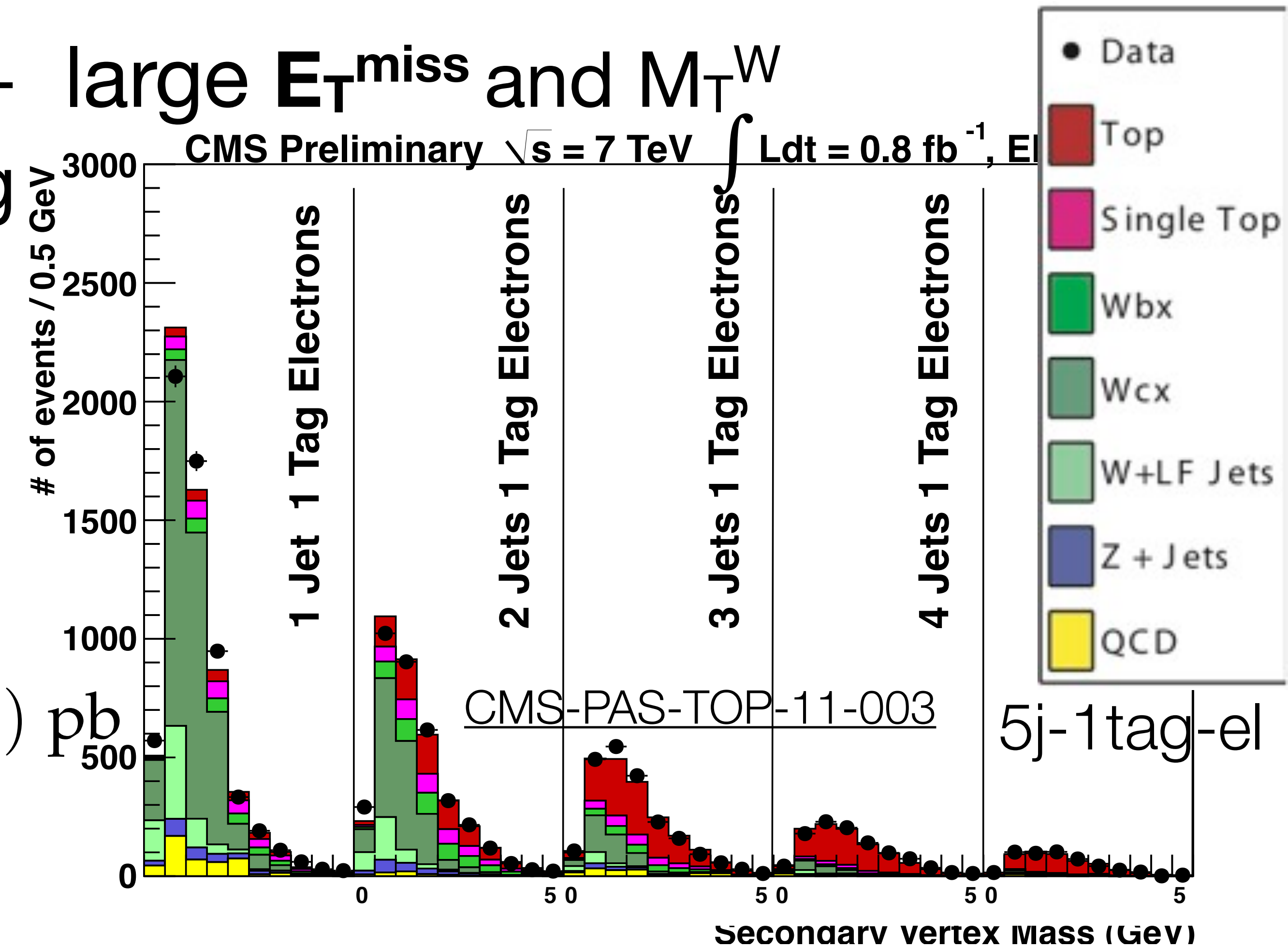
C

- **≥ 1 b-tagged** central high p_T **jet**

Max lkl fit to secondary vertex mass in 2d plane of (N_{jet}, $N_{b\text{-}jet}$)

$$\sigma_{t\bar{t}} = 164.4 \pm 2.8(\text{stat.}) \pm 11.9(\text{syst.}) \pm 7.4(\text{lum.})\ \text{pb}$$

$\delta\sigma/\sigma$~9%

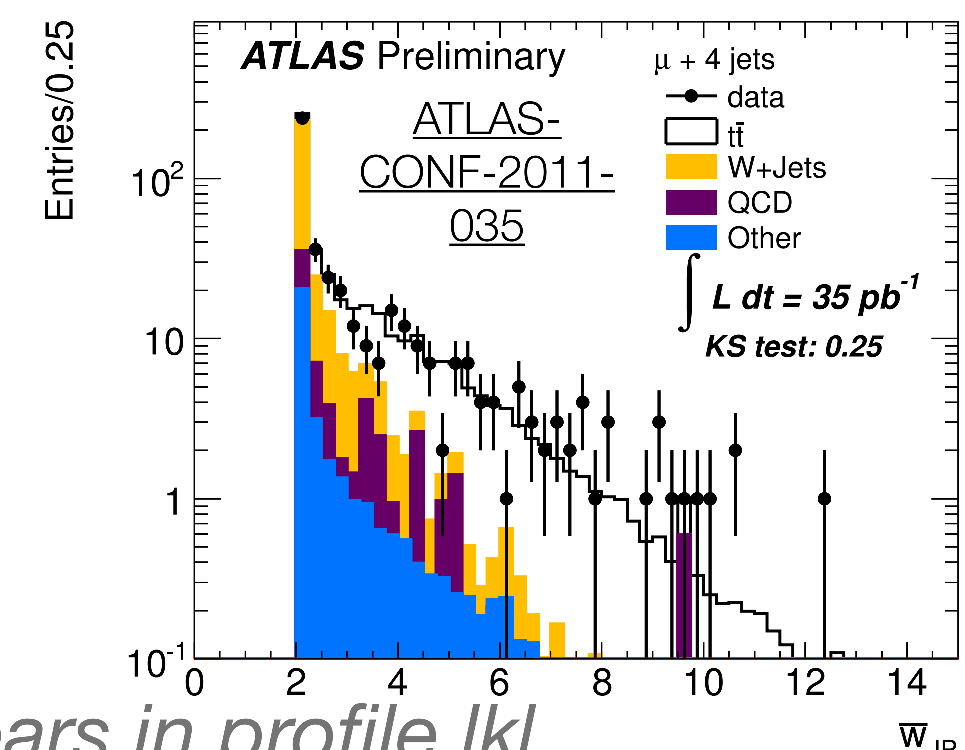


A

- Max lkl fit of 4-variable discriminant
- replace leading jet p_T with **average** of two largest **jet b-tagging** probability (←*top has more b-jets)*

$\sigma_{t\bar{t}}$ =**186 ±10 (stat) ± $^{21}_{-20}$ (syst) ±6 (lumi) pb**

$\delta\sigma/\sigma$~13%



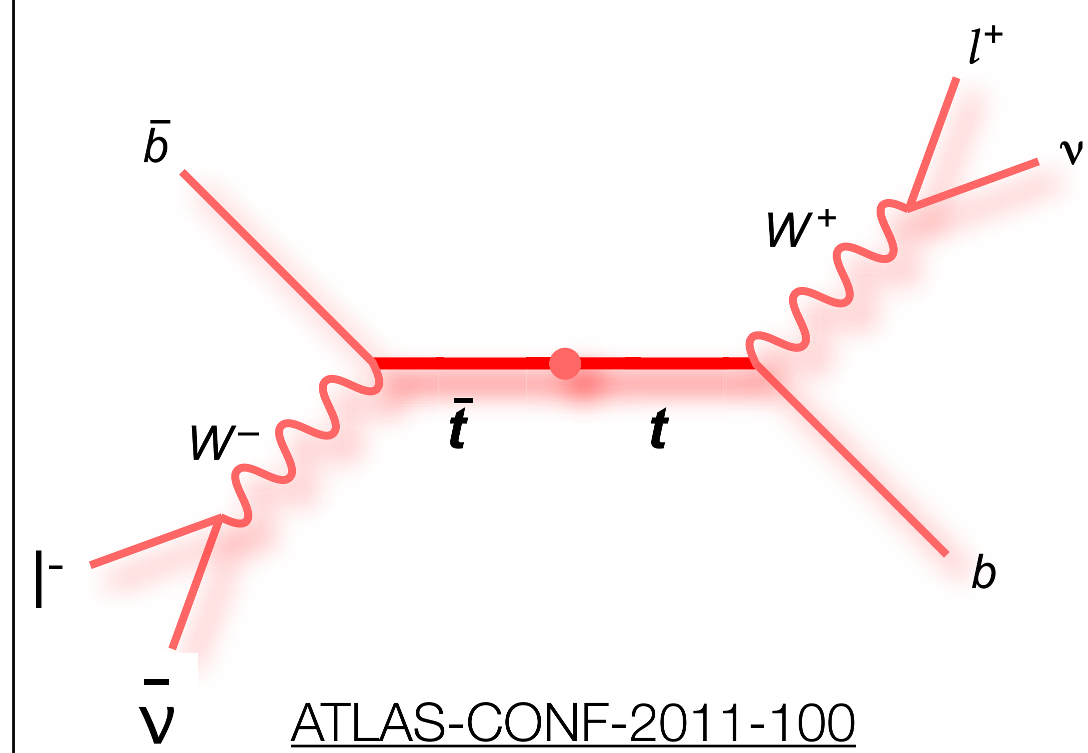
A,C: Syst uncertainties fitted *as nuisance pars in profile lkl*

Selecting top pairs : di-lepton

A=ATLAS, C=CMS

- Vertex and quality cuts
- After single (A,C) lepton and di-el (C) trigger (A), **exactly (A) or at least (C) two opposite sign** high p_T central **leptons (ee, eμ, μμ)**
- **≥ 2 central** high p_T **jet**
- High E_T^{miss} **for (ee, μμ)** *(at least >30 GeV)* **or transverse activity (eμ)**
  - *$H_T = \sum_{jets,lepts} |p_T|$ (A) or $\sum_{lept}$ transv. mass(C)*
- **for (ee, μμ) veto low di-lep mass** *(<15(A),12(C) GeV)* & **Z-like***(mass window)* **events**
- *if* **≥ 1 b-tag,** *relax E_T^{miss}*

(2011) $\int L dt$ = **0.7 pb^{-1}** (***A***), **1.14 fb^{-1}** (***C***)



ATLAS-CONF-2011-100

CMS-TOP-11-005 **NEW!**

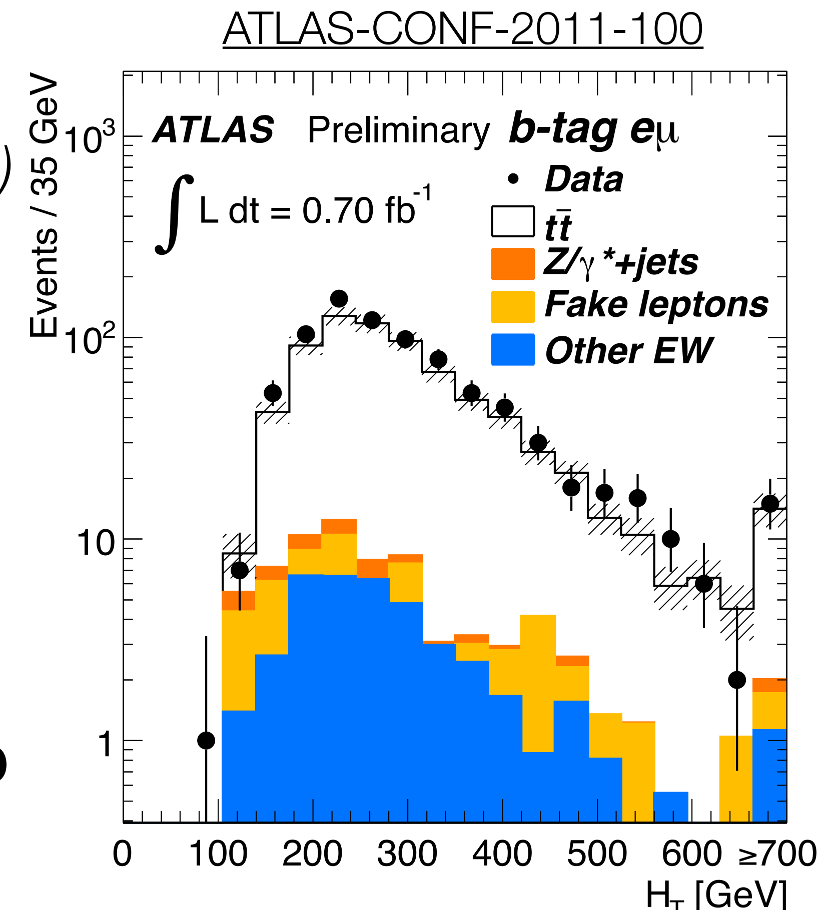
Backgrounds

Z/γ*+jets
QCD, Di-bosons
single lepton

Di-lepton σ_{tt} - main backgrounds

A=ATLAS,C=CMS *(2011)* $\int L dt$ = **0.7 pb^{-1}** (***A***), **1.14 fb^{-1}** (***C***)

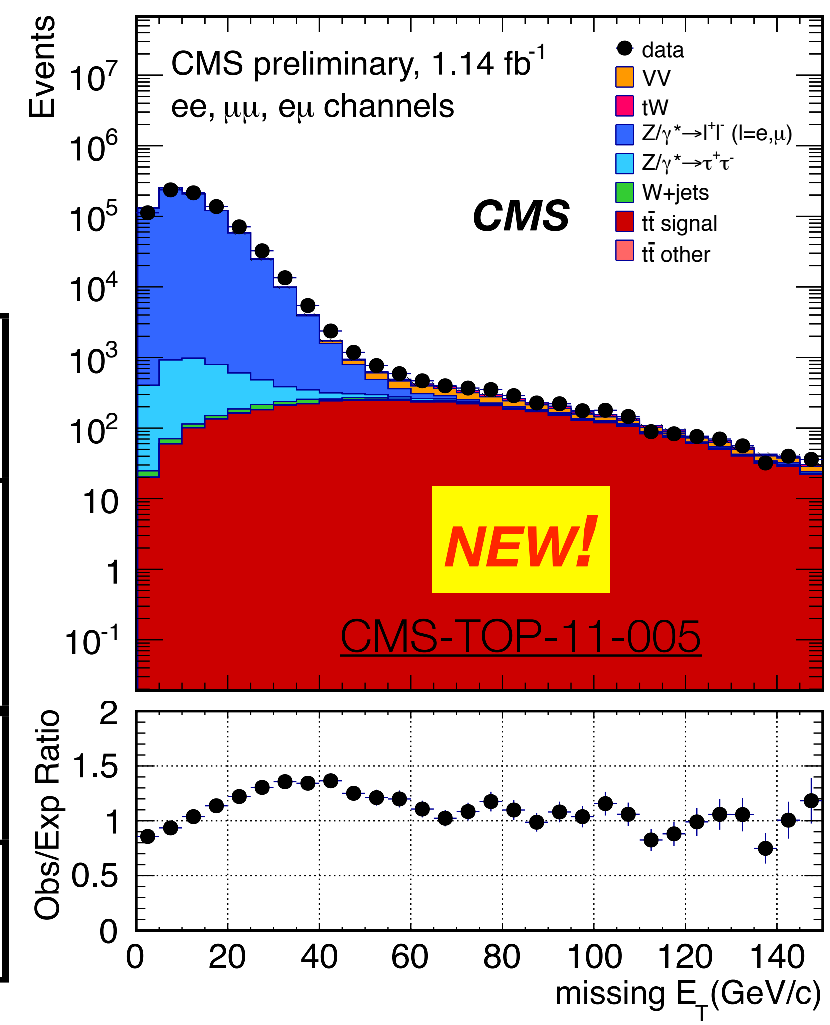
- "Fake" leptons from data
  - Get **probability** for **loose** "fake" (A, C) and real (A) leptons ***to be in signal region (A)*** **← control samples** enriched with real (in Z window) or "fake" (low E_T^{miss}) leptons **(A)**, multi-jet single loose lepton sample **(C)**
  - **Combine** with **N(di-lep)** for **all loose/tight** pairs (A) **or only loose pair** *(fail tight)* **(C)→fake tight** (i.e. signal) **lep**



- Z/γ* bkg (ee, μμ) : **scale** non-Z/γ*-bkg-subtracted **data in** Z-mass window **control region with ratio** of N(Z/γ*) in signal region to control region **from simul.**

≥1-btag

	ee (A)	ee(C)	μμ(A)	μμ(C)	eμ(A)	eμ(C)
tt	167	427	314	559	666	1487
Bkg	25	78	45	100	68	141
Tot Exp	**192**	**505**	**359**	**659**	**734**	**1628**
Data	**202**	**589**	**349**	**688**	**823**	**1742**



Di-lepton σ_{tt} results

A=ATLAS,C=CMS

- **Include** estimated **background**
- **Cross section from likelihood fit** combining channels and including systematics as nuisance parameters

A

no b-tag $\sigma_{t\bar{t}} = 171 \pm 6(\text{stat.})^{+16}_{-14}(\text{syst.}) \pm 8(\text{lum.})$ pb.

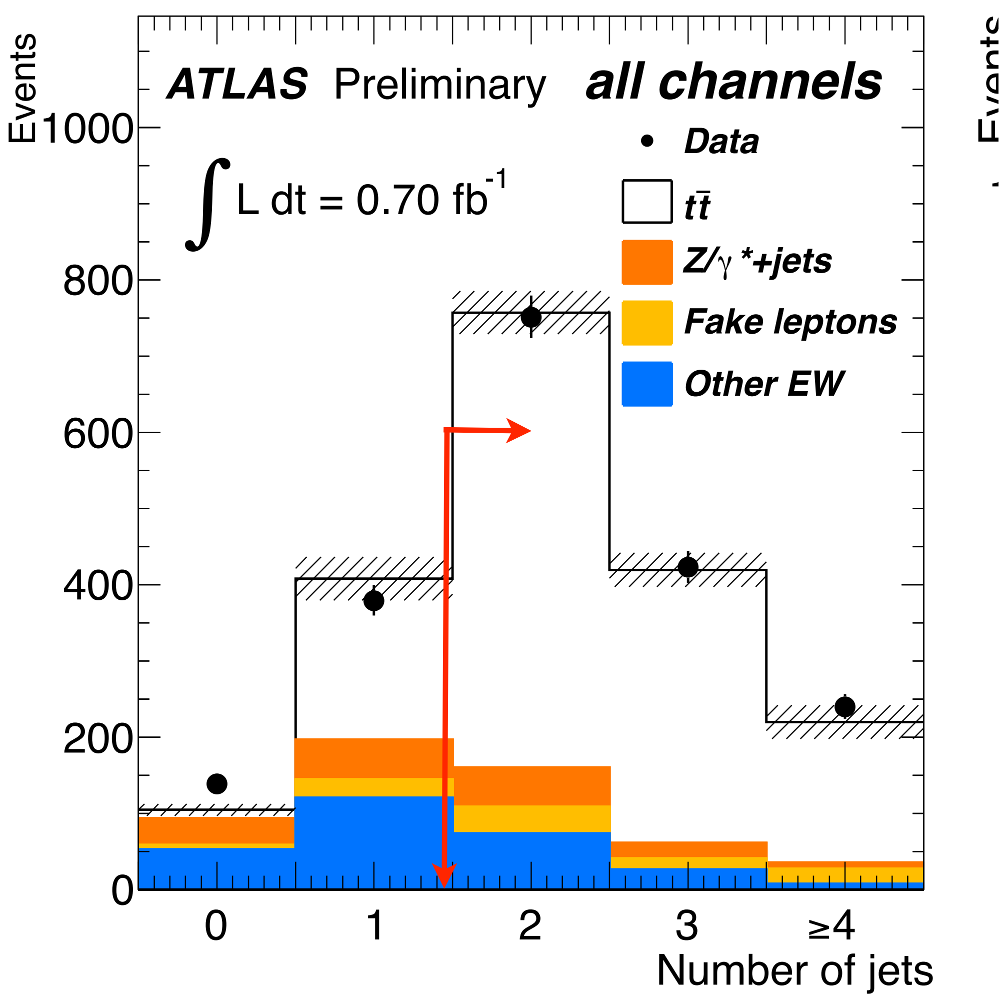
b-tag $\sigma_{t\bar{t}} = 177 \pm 6(\text{stat.})^{+17}_{-14}(\text{syst.})^{+8}_{-7}(\text{lum.})$ pb.

δσ/σ~11% (no-tag) and b-tag)

C

δσ/σ~11% ***NEW!***

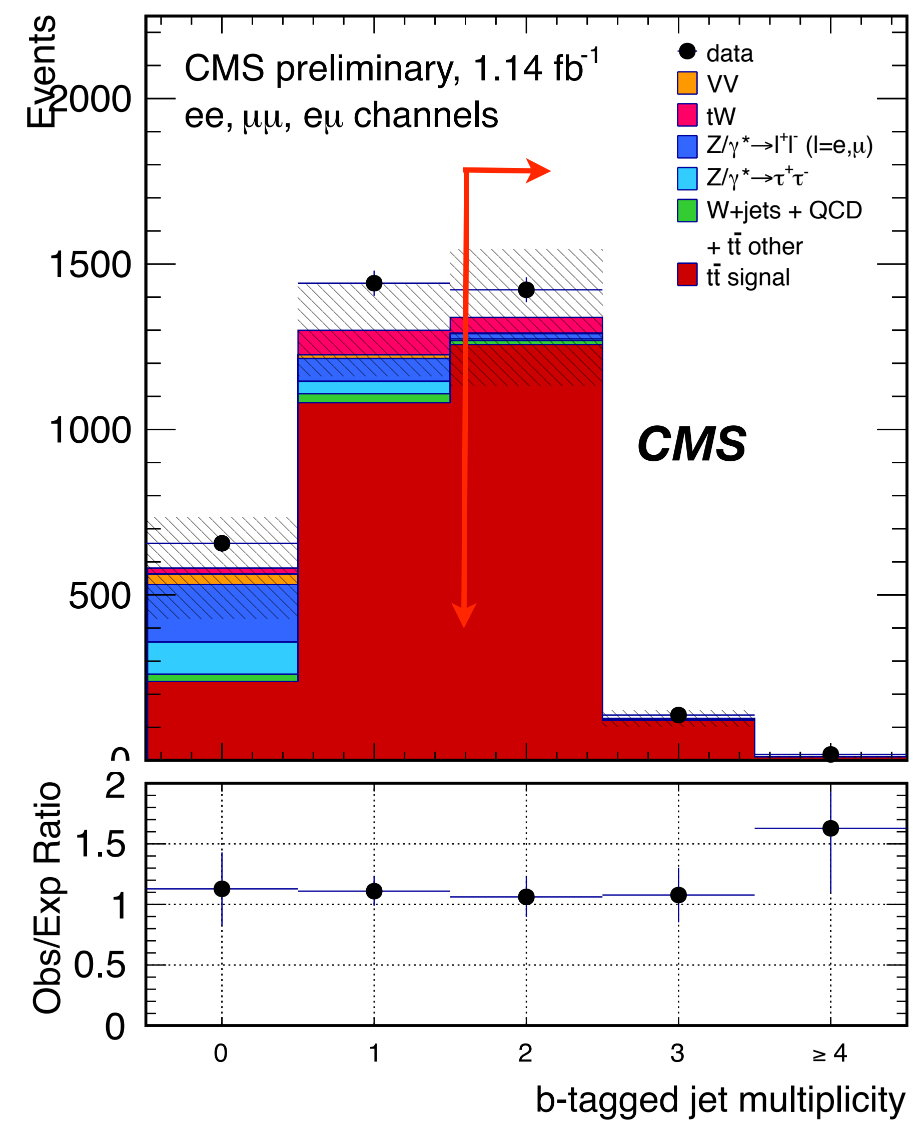
169.9 ± 3.9(stat.) ± 16.3(syst.) ± 7.6(lumi.) pb



distributions after all cuts, except N_{jets}

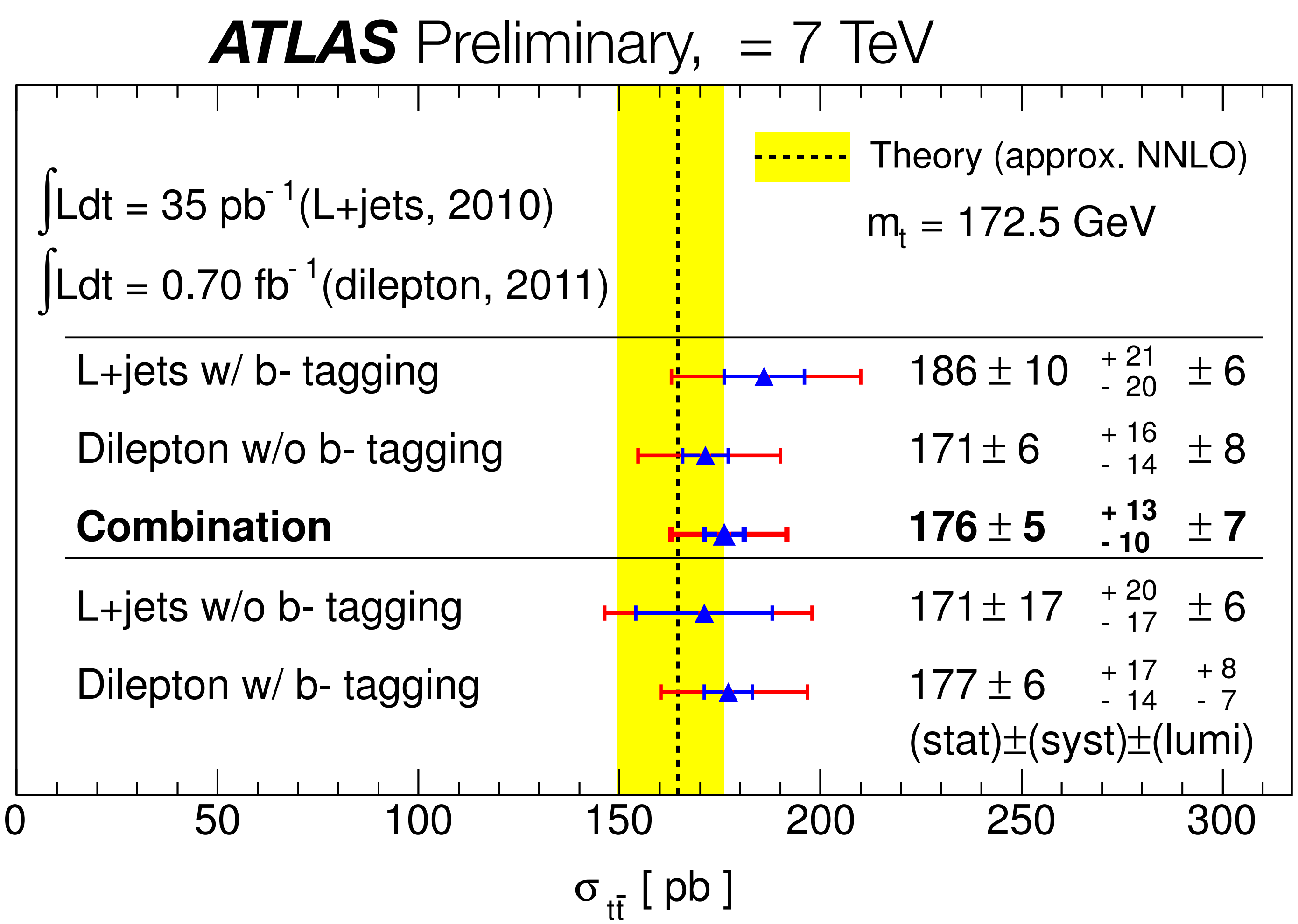
syst dominated!

JES~5% (A),
b-tag~4-5% (A-tag,C)
C: pile-up~5%,lep sel~4%
A:ISR~2.6%

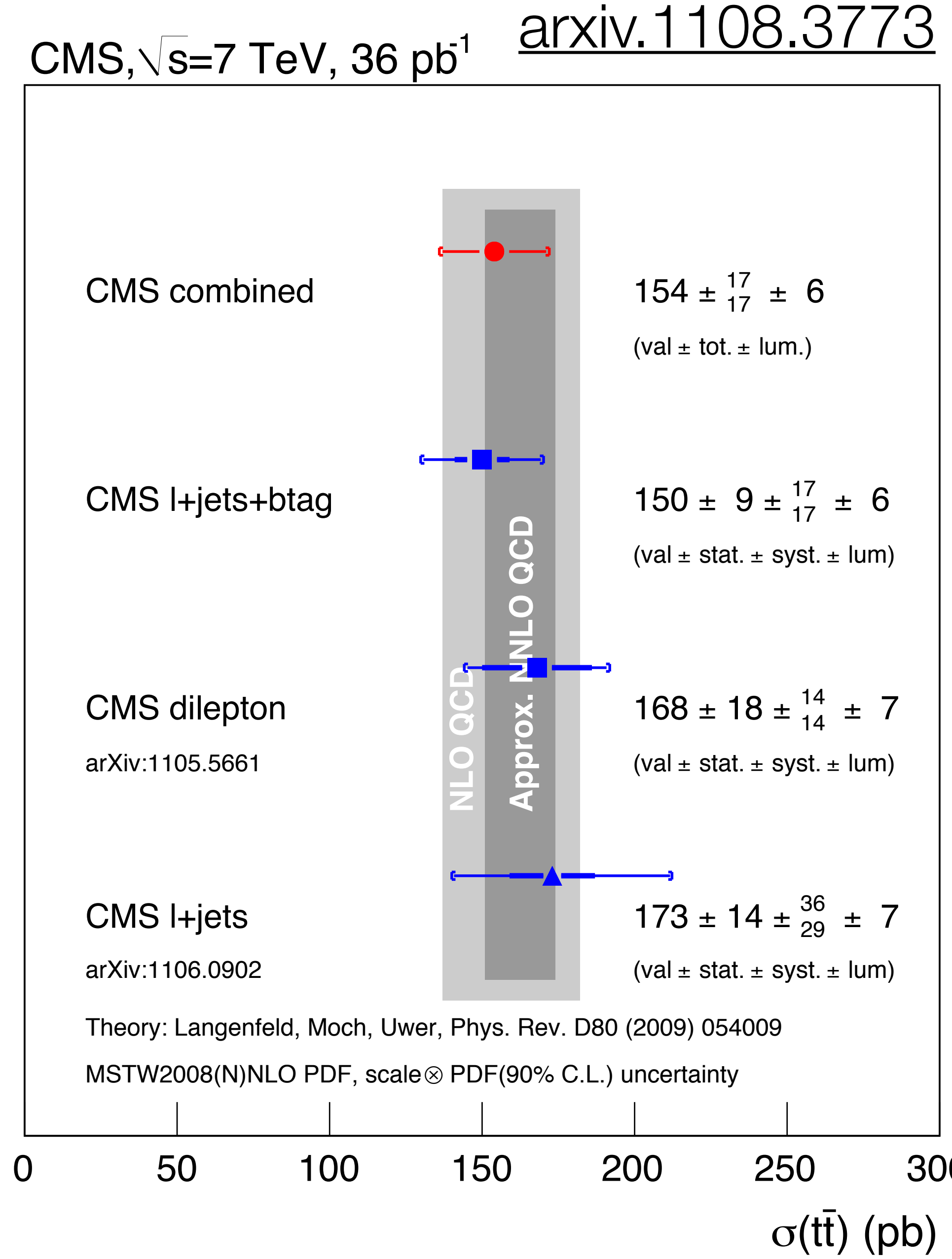


Combined top pair cross section results

ATL-CONF-2011-108



arxiv.1108.3773



L+jets w/o b-tagging **σ=179 ±3.9 ± 9.0 ±6.6 pb**

(∫Ldt = 0.7fb⁻¹ 2011)

(∫Ldt = 1.14fb⁻¹ 2011) dilepton **σ=169.9 ±3.9 ± 16.3 ±7.6 pb**

NEW! (∫Ldt = 0.8 to 1.1fb⁻¹ 2011) L+jets+btag **σ=164.4 ±2.8 ± 11.9 ±7.4 pb**

- Combined uncertainty is ~**10% dominated by systematics. Comparable to theory**
  - **ATLAS:** $176 \pm 5^{+13}_{-10} + 7$ pb ←
  - **CMS** : $154 \pm 10^{+17}_{-17} + 6$ pb

*do not include **NEW** results*

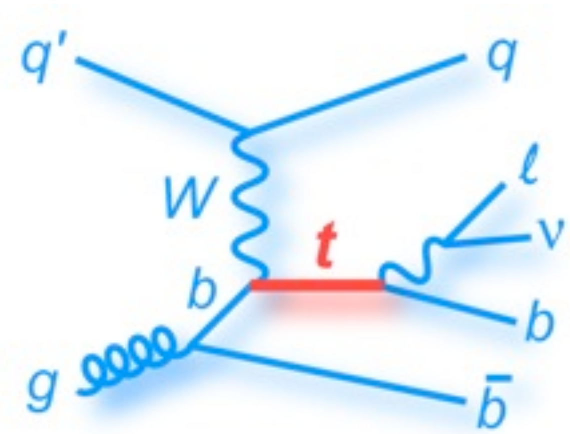
σ_t - Single top - t chan

$\int L dt$ = **0.7 fb^{-1}** (***A***) *(2011)*, ~**36 pb^{-1}** (***C***) *(2010)*

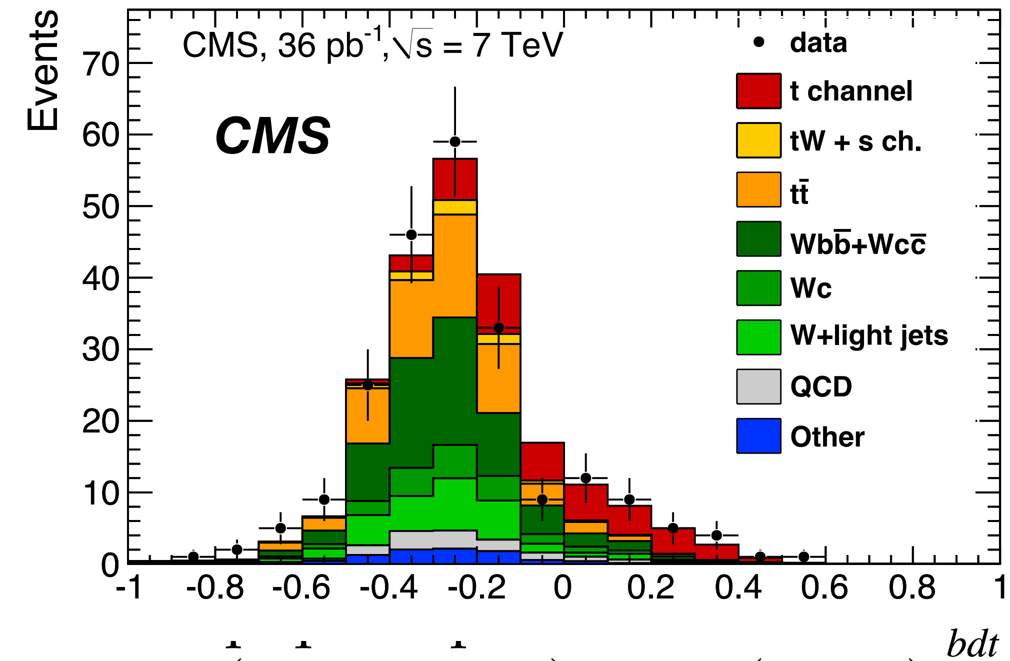
t-chan: $q\ell\nu b(b)$

A=ATLAS**, **C=CMS

- Exactly **1 high p_T central lepton** (e,μ), **high E_T^{miss}** (A) and M_T^W(A,C), require **exactly 2** (A,C) or **3 jets** (A) **in |η|<4.5**(A) or **5**(C)
  - *2 samples: pre-tag,1 b-tag (A,C),>=1b-tag (C)*
  - ***QCD and W+jets norm from data***



arxiv:1106.3052



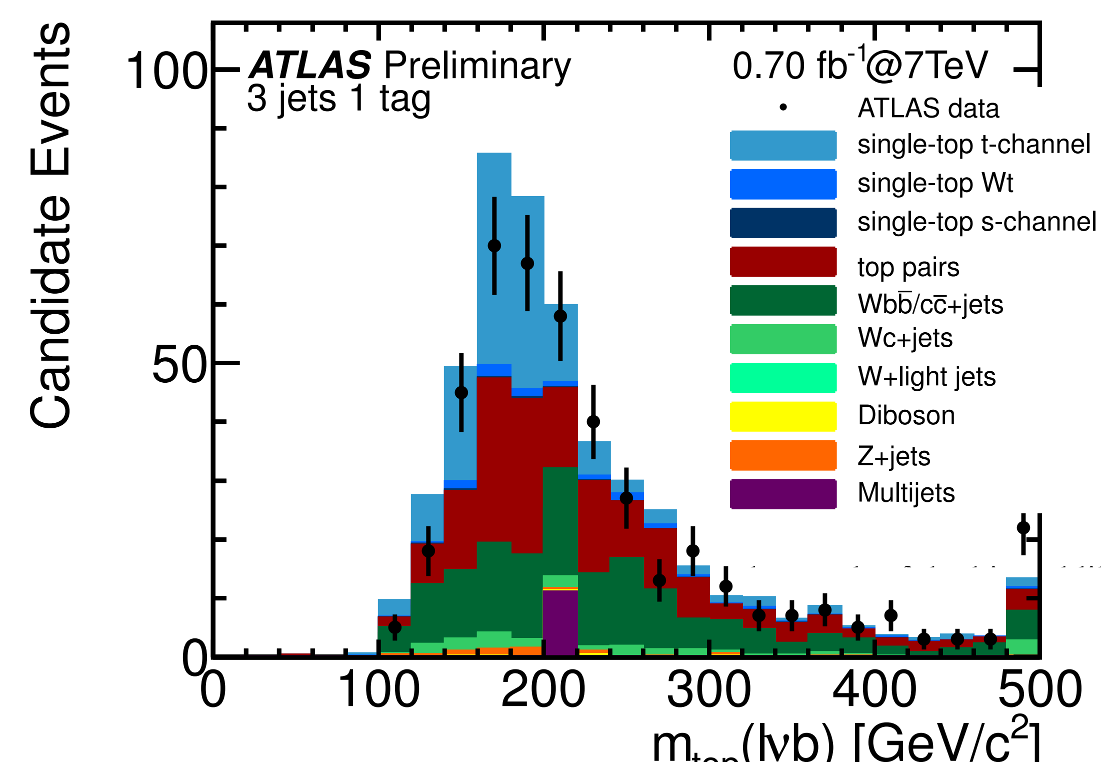
$83.6 \pm 29.8\ (\text{stat.} + \text{syst.}) \pm 3.3\ (\text{lumi.})$ pb,

δσ/σ~36%

- **C**: **combine 2 results**: **2D-max lkl fit** to *lepton-untagged jet angle & η of untagged jet* + **Bayesian estimate** from BDT
- **A**: **cut/count on angular jet var.,top mass and H_T**, *confirmed by max Lkl fit to neural network discriminant (13 var.)*

syst dominated!

ATL-CONF-2011-101



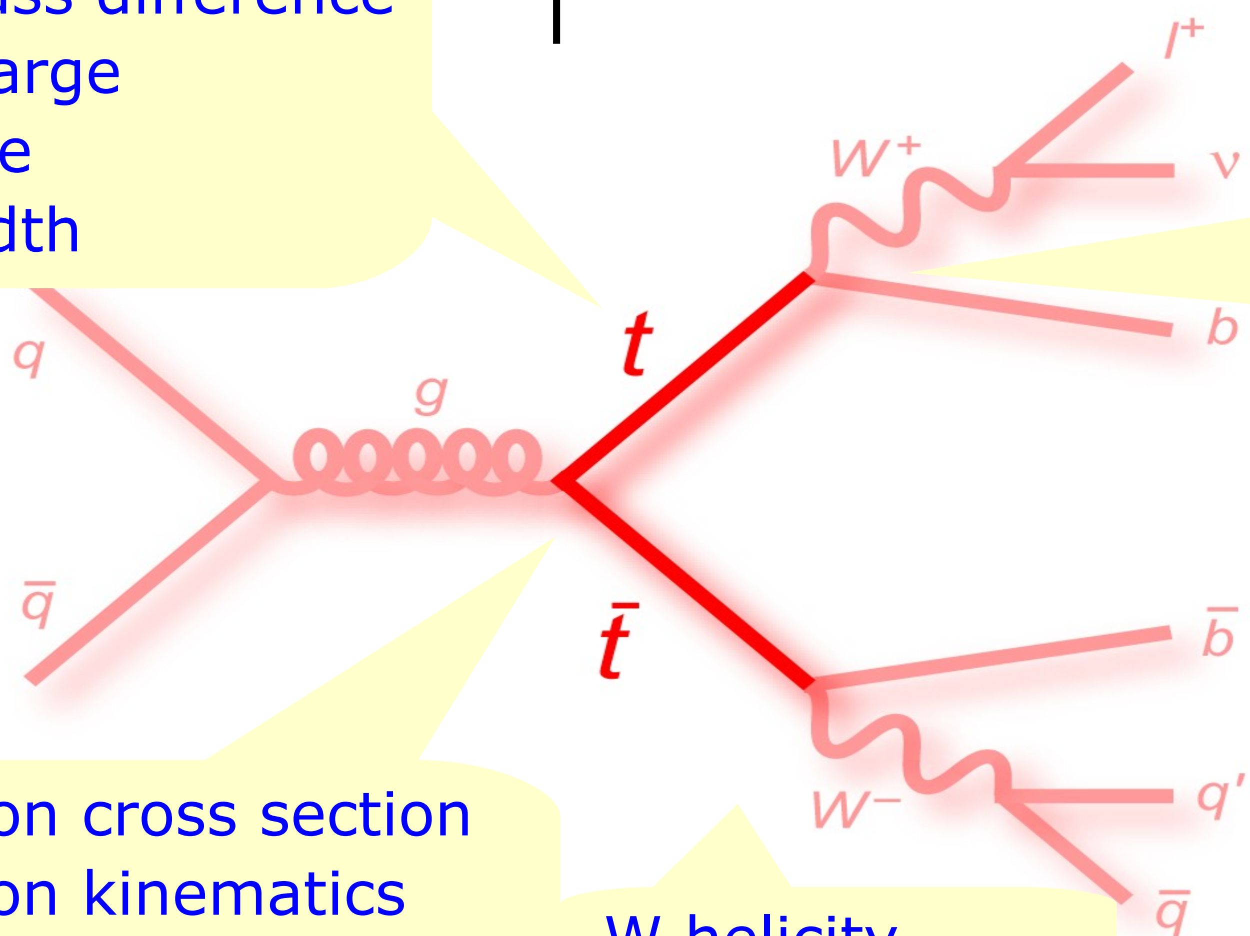
$$\sigma_t = 90^{+9}_{-9}(\text{stat})\,^{+31}_{-20}(\text{syst})$$ δσ/σ~36%

Y Peters
PIC2011

All we study about the Top

Top mass
Top mass difference
Top charge
Lifetime
Top width

1



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

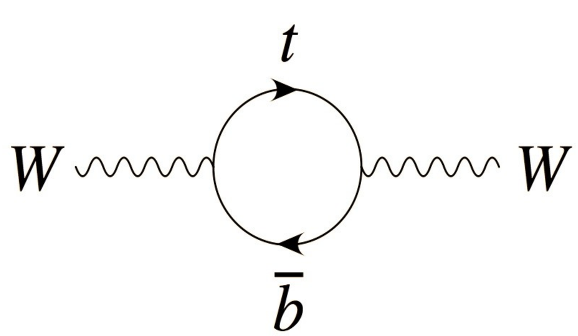
W helicity

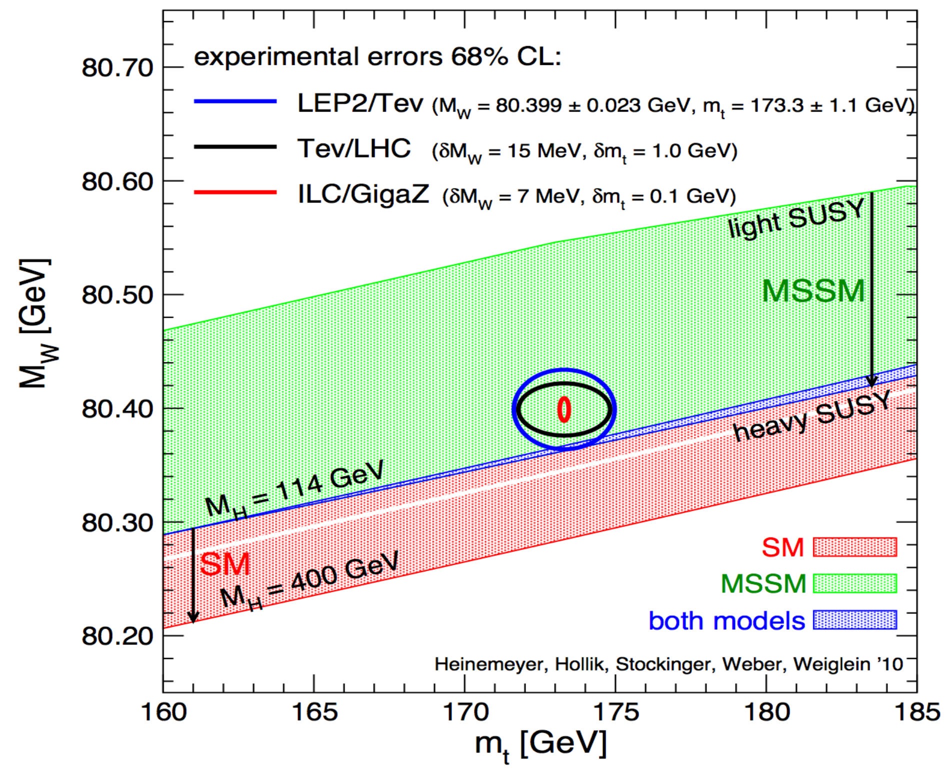
s- & t- channel production, properties and searches in single top events

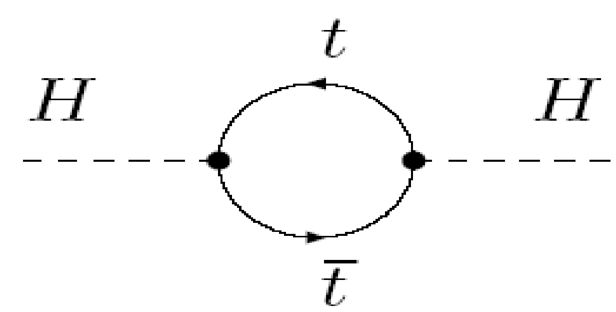
Y Peters
PIC2011

Top Quark Mass

- Free parameter of the SM
- Together with W mass: puts constraint on Higgs mass





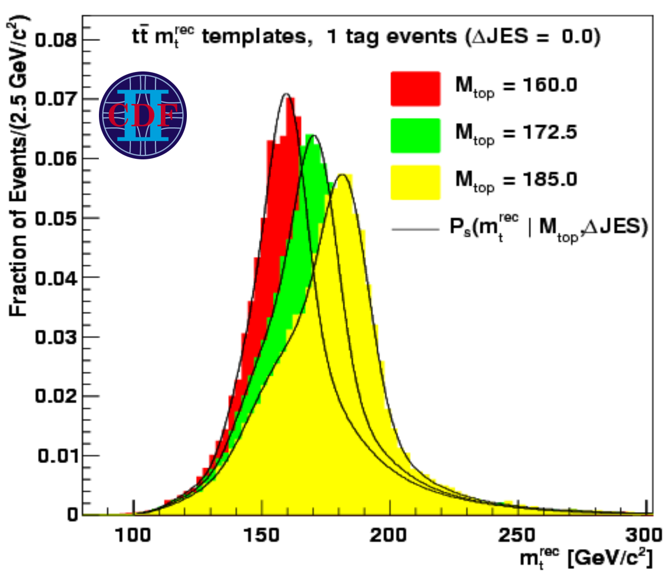


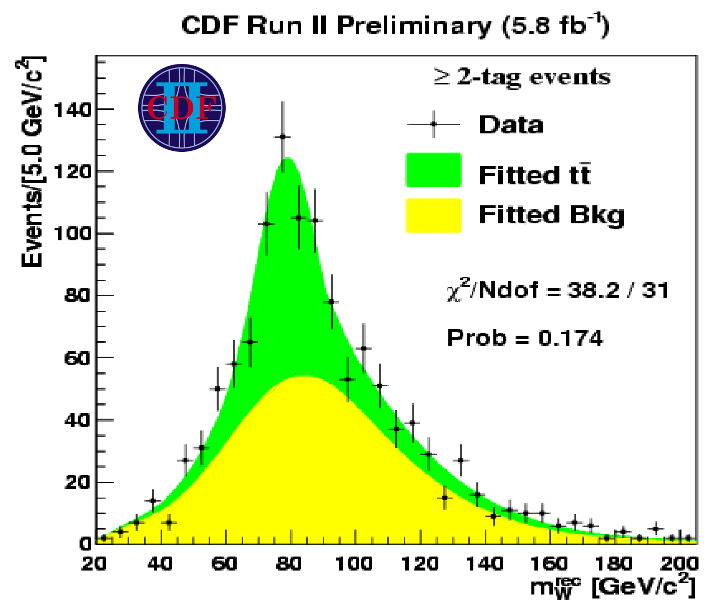
- Measurement done with several methods:
  Template method, ideogram, matrix element, etc.
  - Methods also used for other analyses, e. g. W helicity & spin correlations

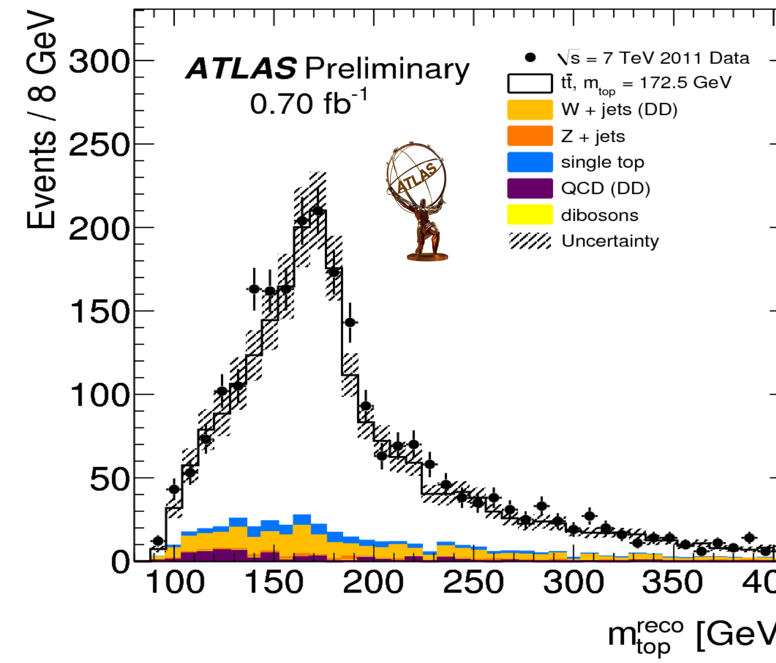
MANCHESTER 1824

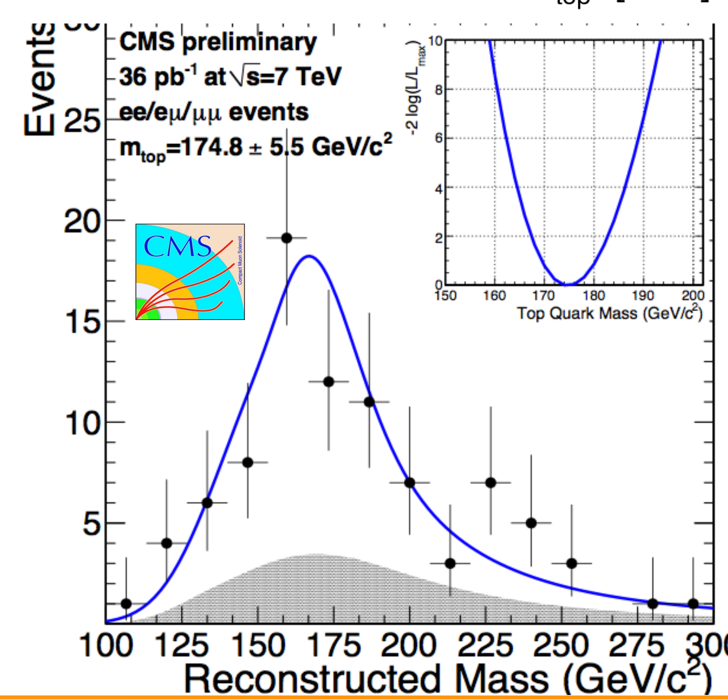
Top Quark Mass: Template Method

- Construct mass dependent template, fit to data
- Alljets and l+jets: Take info from hadronically decaying W mass to constrain jet energy scale





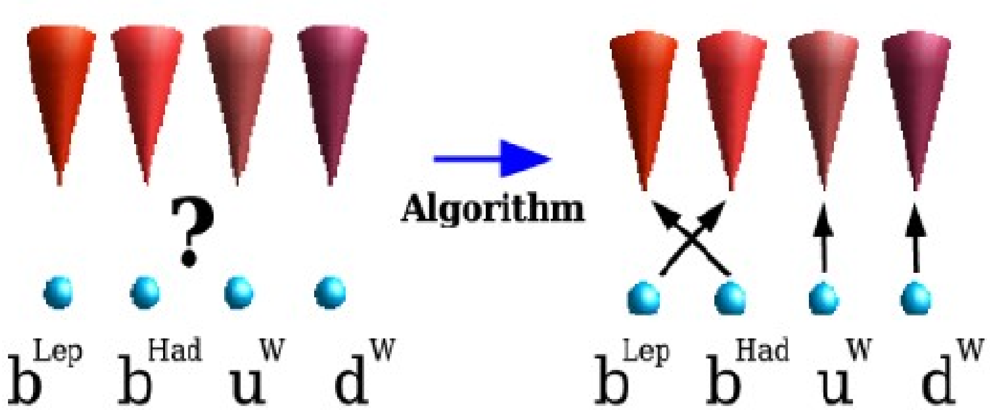


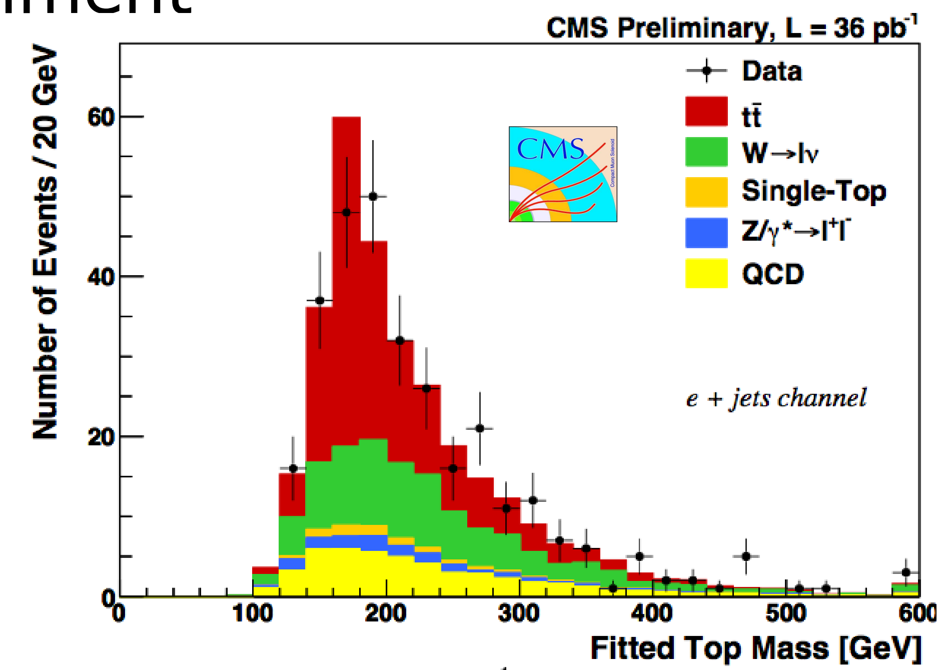


- Dilepton: Construction of templates more complicated due to presence of two neutrinos
  - Neutrino weighting, Matrix Weighting,...

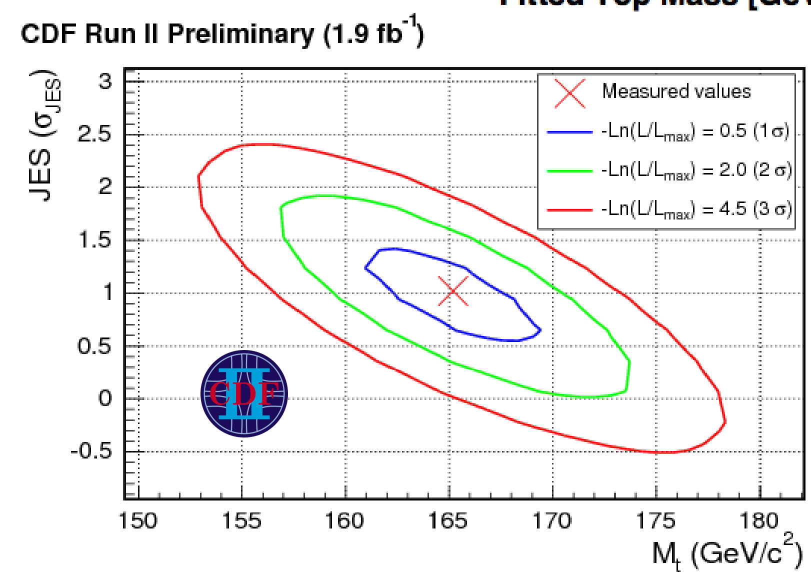
Top Quark Mass: Ideogram

- Use kinematic fit to reconstruct complete kinematics of the event → yields fitted m_t for each jet to quark assignment





- Calculate event likelihood as function of m_t
- Used in l+jets & alljets

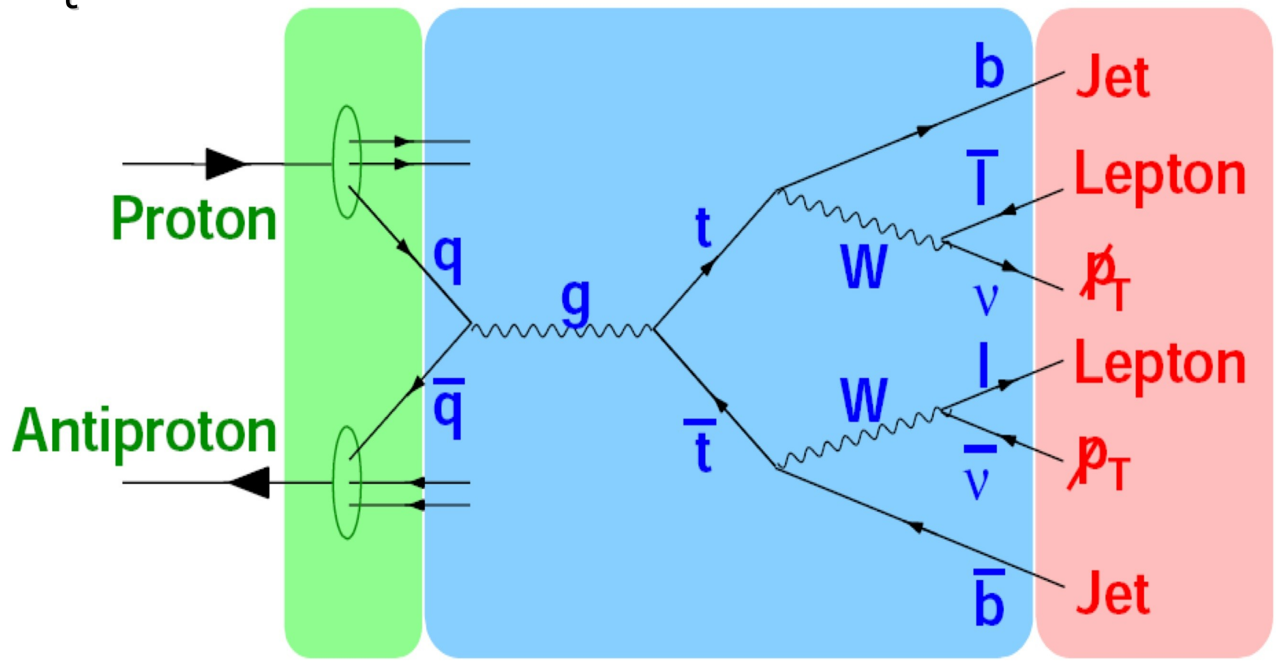


MANCHESTER 1824

Top Quark Mass: Matrix Element Method

- Use full event kinematics → most precise method
- For each event calculate probability to belong to certain top mass

$P_{sig}(x;m_t) \propto \int$ PDF x Matrix element x Transfer function



- Perform likelihood fit of event probabilities
- Probability depends on top mass (& JES for in-situ fit)
- Used in l+jets & dilepton final states

MANCHESTER 1824

Most Recent Mass Results

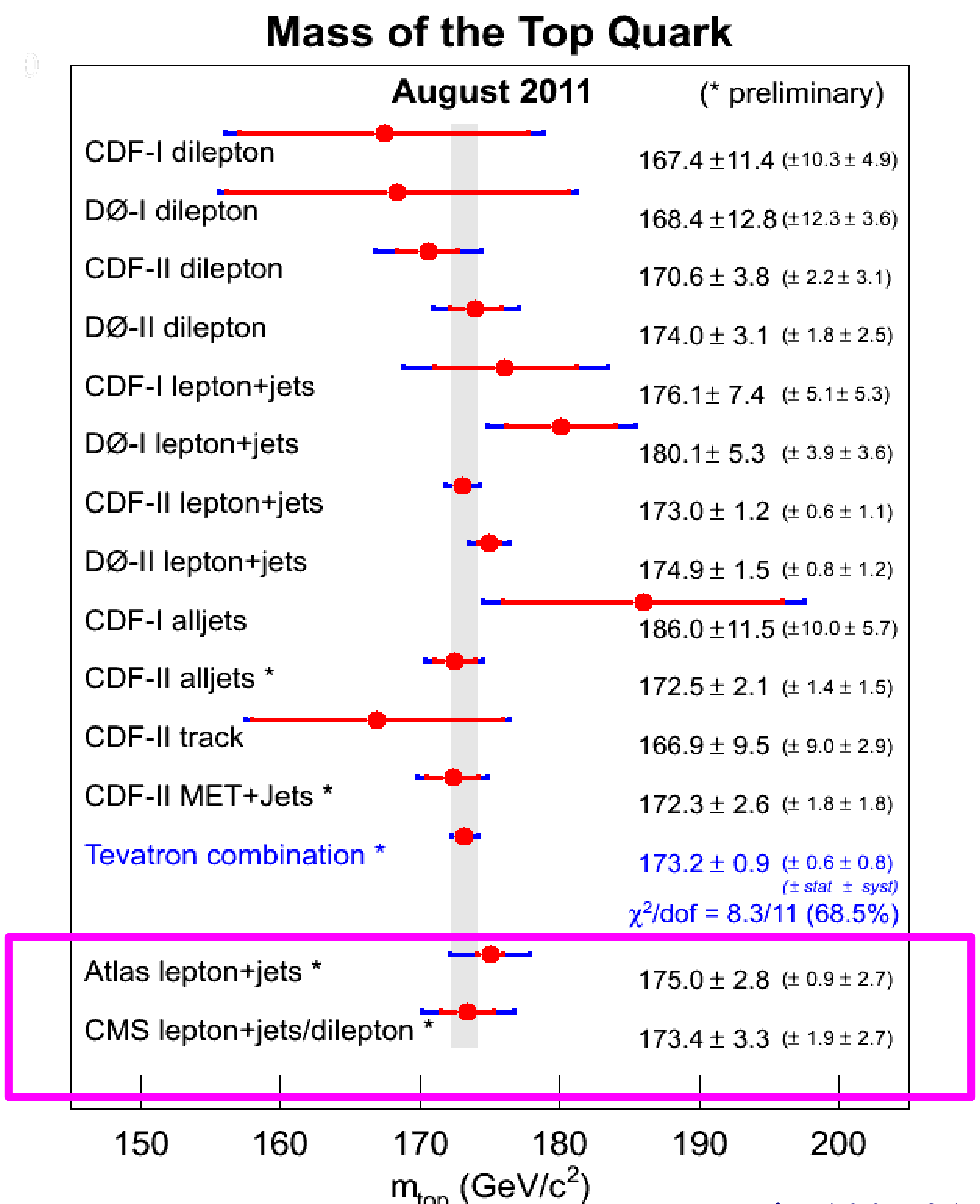
NEW

- Template:
  - CDF (alljets), 5.8fb^{-1}: m_t=172.5±2.0(stat+syst)GeV
  - CDF (dilepton), 5.6fb^{-1}: m_t=170.3±3.7(stat+syst)GeV
  - Atlas (l+jets), 0.7fb^{-1}: m_t=175.9±0.9(stat)±2.7(syst)GeV
  - CMS (dilepton), 36pb^{-1}: m_t=175.5±4.6(stat)±4.6(syst)GeV
- Ideogram:
  - CMS (l+jets), 36pb^{-1}: m_t=173.1±2.1(stat)$^{+2.8}_{-2.5}$(syst)GeV
- Matrix Element technique:
  - DØ (l+jets), 3.6fb^{-1}: m_t=174.9±1.5(stat+syst)GeV
  - DØ (dilepton), 5.4fb^{-1}: m_t=174.0±3.0(stat+syst)GeV
  - CDF (l+jets), 5.6fb^{-1}: m_t=173.0±1.2(stat+syst)GeV

Y Peters PIC2011

All consistent
Systematics limited

Top Quark Mass: Combinations



arXiv:1007.3178

Y Peters PIC2011

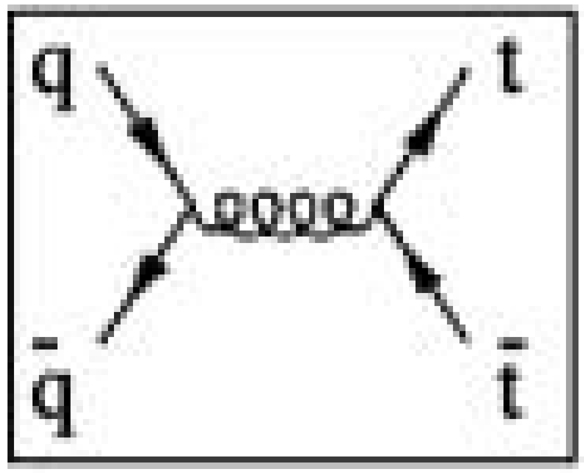
- Systematics limited!
  - Main effort for experiments: detailed understanding of systematics
  - Main systematics at Tevatron: JES-related
  - Main systematics at LHC: JES-related and ISR/FSR
- Tevatron combination: first time uncertainty below 1GeV!

Top spin correlation

$^{2L+1}S_J$

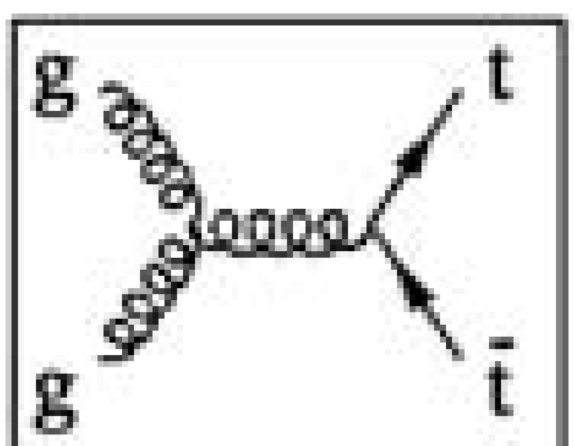
- Top quark decays before hadronization: $1/\Gamma_{top} < 1$ fm → top polarization preserved in angular dist of decay products

massless fermions: fixed helicity=chirality + QCD conserves chirality



dominant at Tevatron

tt is produced unpolarized

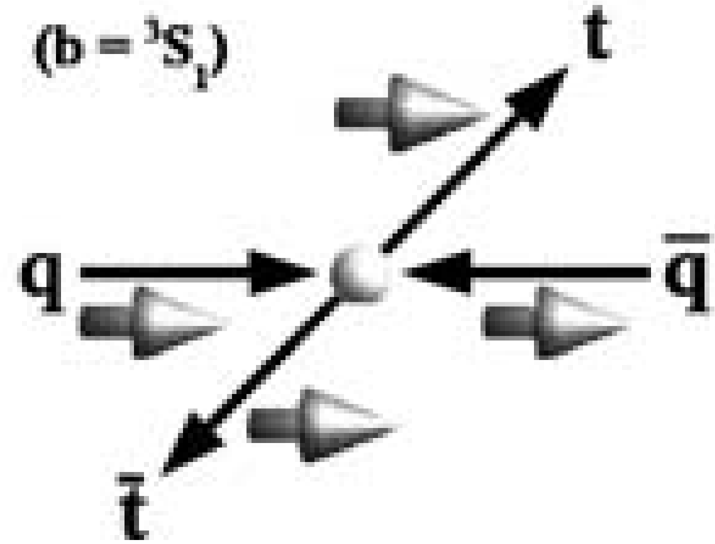


dominant at LHC

if m -> 0
chirality -> helicity = projection of spin along direction of motion

$s \sim 2m_{top}$

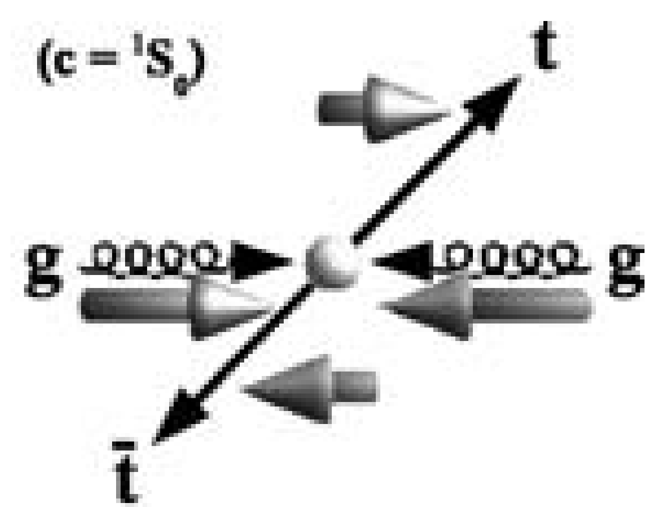
mostly $^3S_1$



L=0,J=1 → **parallel** spins *along given axis*

opposite helicity

mostly $^1S_0$

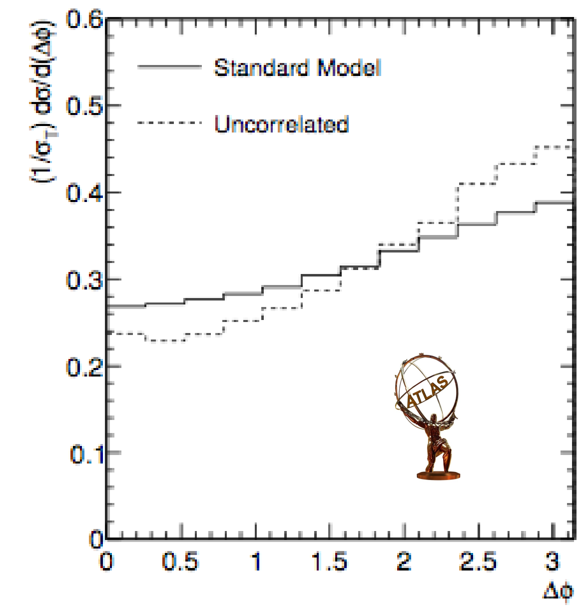


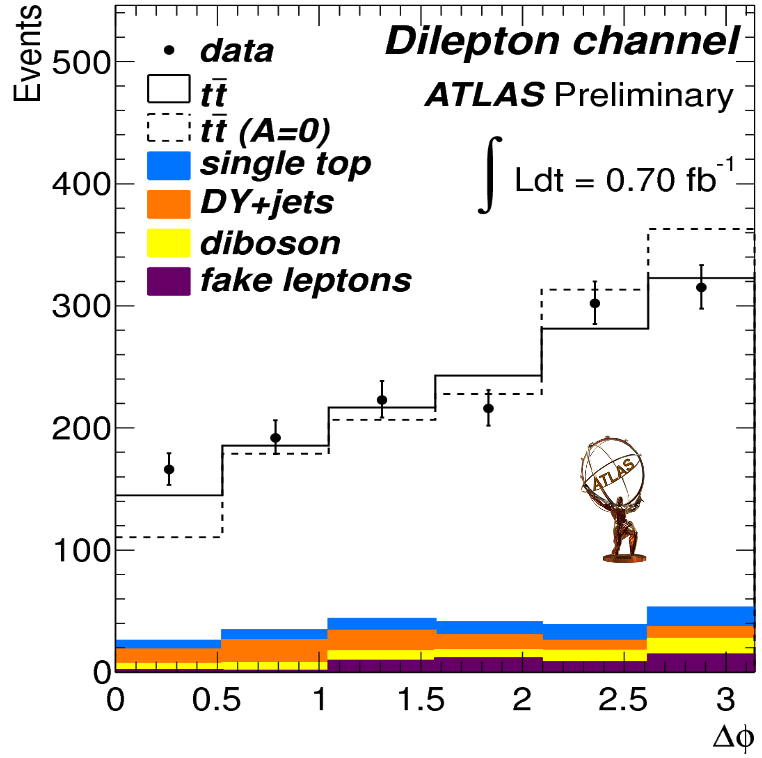
L=J=0 → anti-**parallel** spins *along given axis*

same helicity

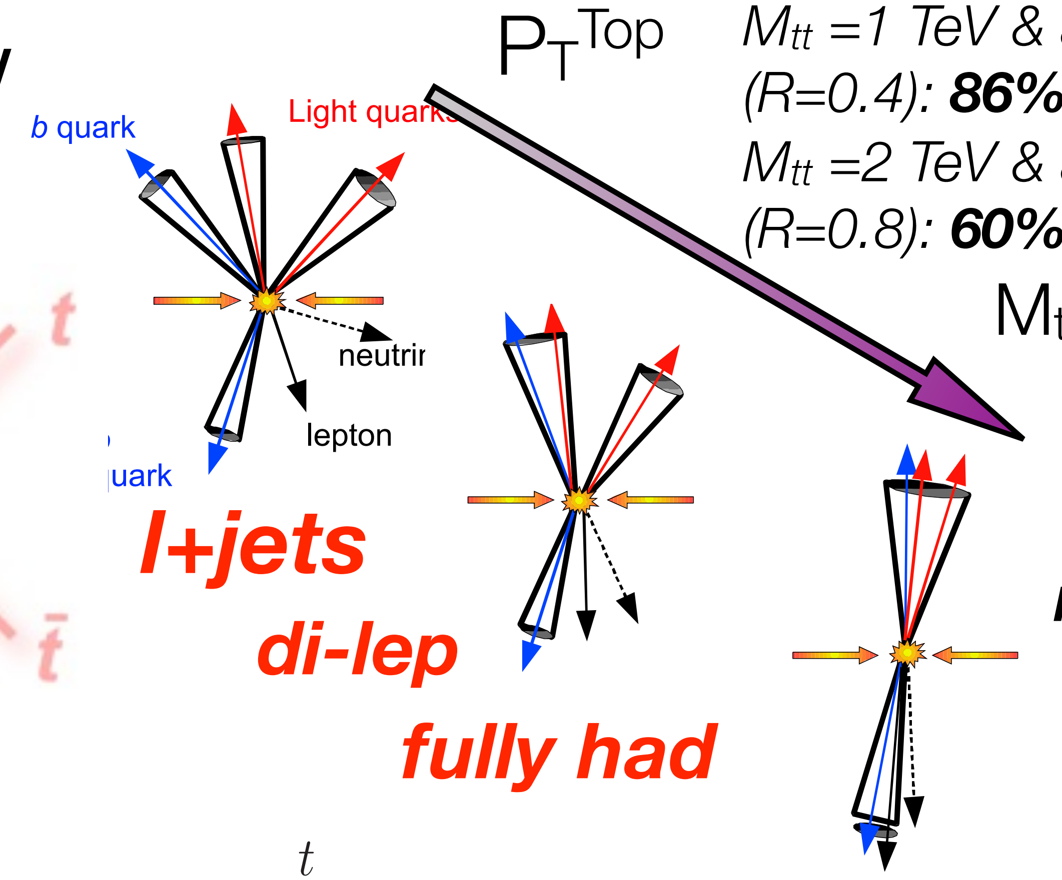
$t\bar{t}$ Spin Correlations at LHC

- LHC: 85% gg → $t\bar{t}$: dominated by like helicity gluons at low √s
- Simple variable in dilepton channel: $\Delta\phi=|\phi_{l+}-\phi_{l-}|$
  - No kinematic fit needed!
- Result of template fit: $f=1.06\pm0.21(stat)^{+0.40}_{-0.27}(syst)$
  - Main systematics: ISR; modeling of signal
  - Corresponds to $C_{helicity}=0.34^{+0.15}_{-0.11}$ (SM: $C_{helicity}=0.32$)
- Agreement with SM
- Already dominated by systematics





Top production as a window on new physics

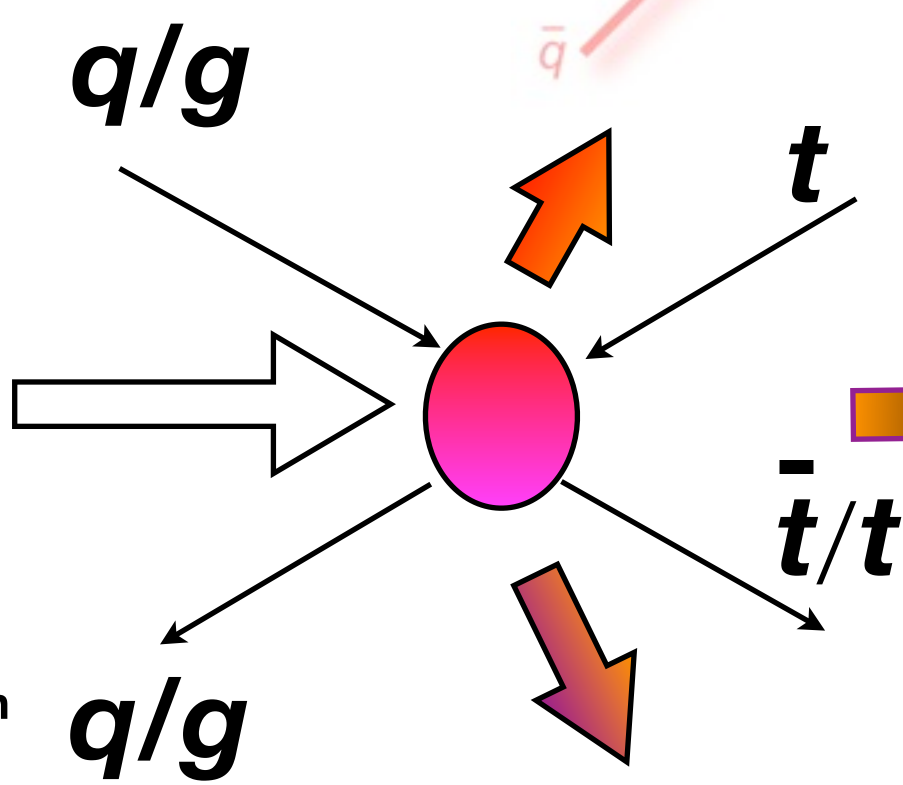


M_{tt} =1 TeV & anti-k_T (R=0.4): **86% resolved**
M_{tt} =2 TeV & antikt (R=0.8): **60% boosted**

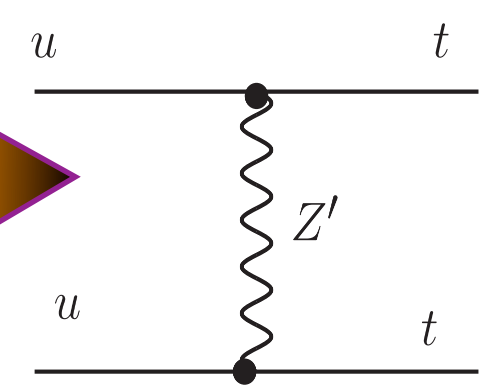
l+jets
di-lep
fully had

For ΔR=0.8, M_{tt} ~1.7 TeV, P_T ~600 GeV

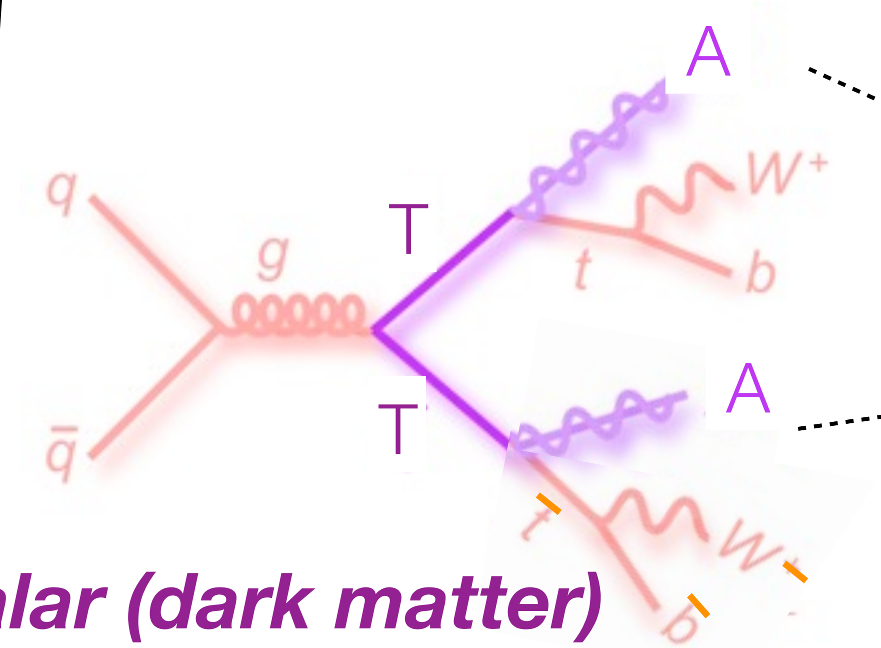
KK Gluon



Production cross section
Resonant production
Production kinematics
Spin polarization



FCNC-induced same sign top pair



tt+E_T^{miss}

top partner + stable scalar (dark matter)

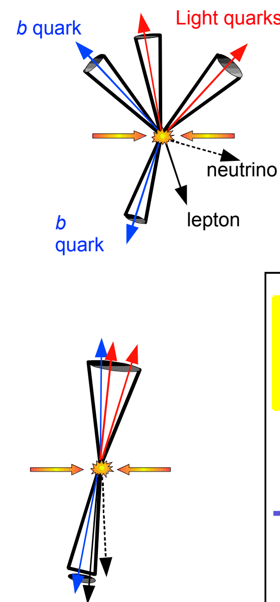
exotic 4th gen, stop to top neutralino, UED, little higgs, leptoquarks

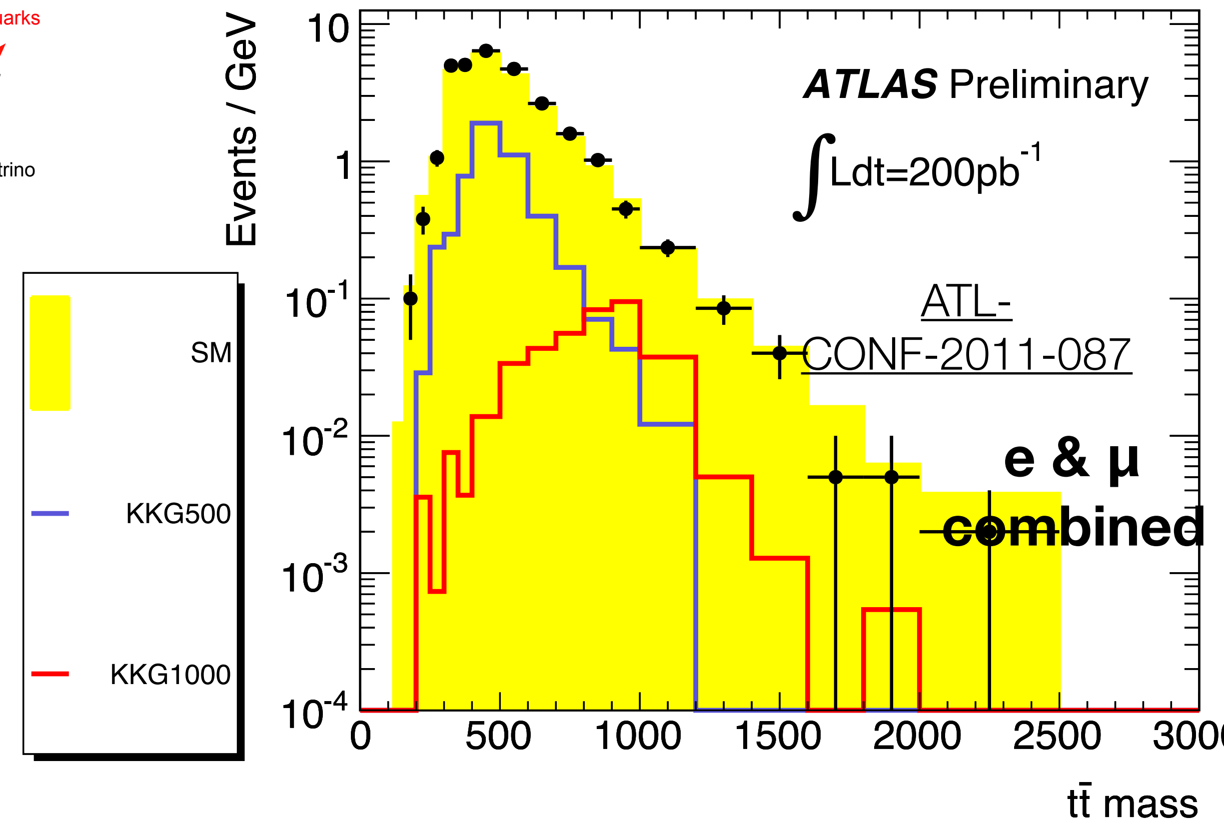
Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ - single-lepton

A=ATLAS, C=CMS

(2011) $\int L dt$ = **0.2 fb^{-1}** (***A***) **1.14 fb^{-1}** (***C***)

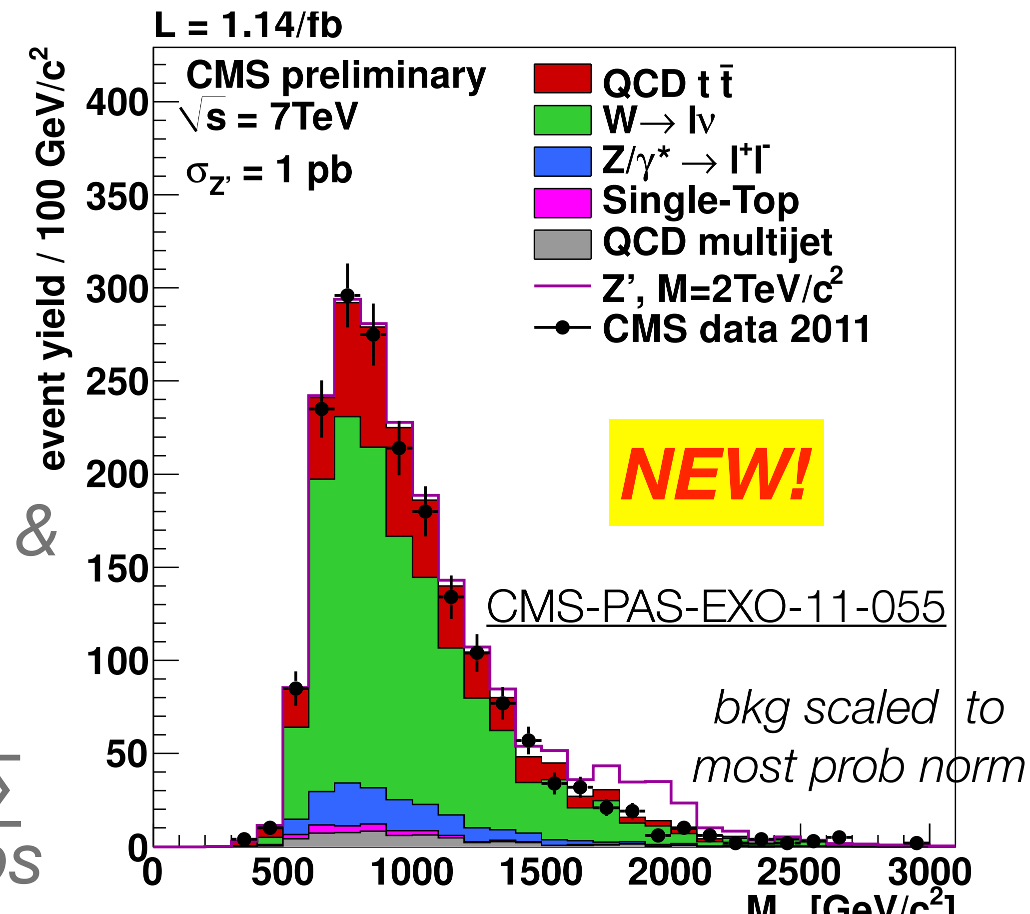
- **A**: **standard single lep** (e μ)
  sel: ≥4 jets, ≥1 b-tag
- **C**: **single μ, *boosted top sel.***
  - **≥ 2 jets with** p_T>50 GeV, **lead jet p_T>250 GeV**
  - **one non-iso μ** with ΔR>0.5 from closest jet OR p_T rel. to jet >15 GeV
  - **high $p_{T,lep}$+E_T^{miss}** >150 GeV





- Data-driven **QCD** (*jet template method normalize to low E_T^{miss} (A),shape from ev. failing mu 2D cut (C)),* **W+jets normalization (A)** (*extrapol. from N_{jet} in W+jets-enriched sample)*

- **Reconstruct leptonic W** *from E_T^{miss}, lepton & W mass*, **then $M_{t\bar{t}}$**
  - ***sum leptonic W to** (A) **4** leading p_T **jets** or (C) **jets giving back-to-back top-jets** ←minimal ∑ ΔR (lep/b-jet, leptonic top) & max ΔR betw. tops*



Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ -single lepton

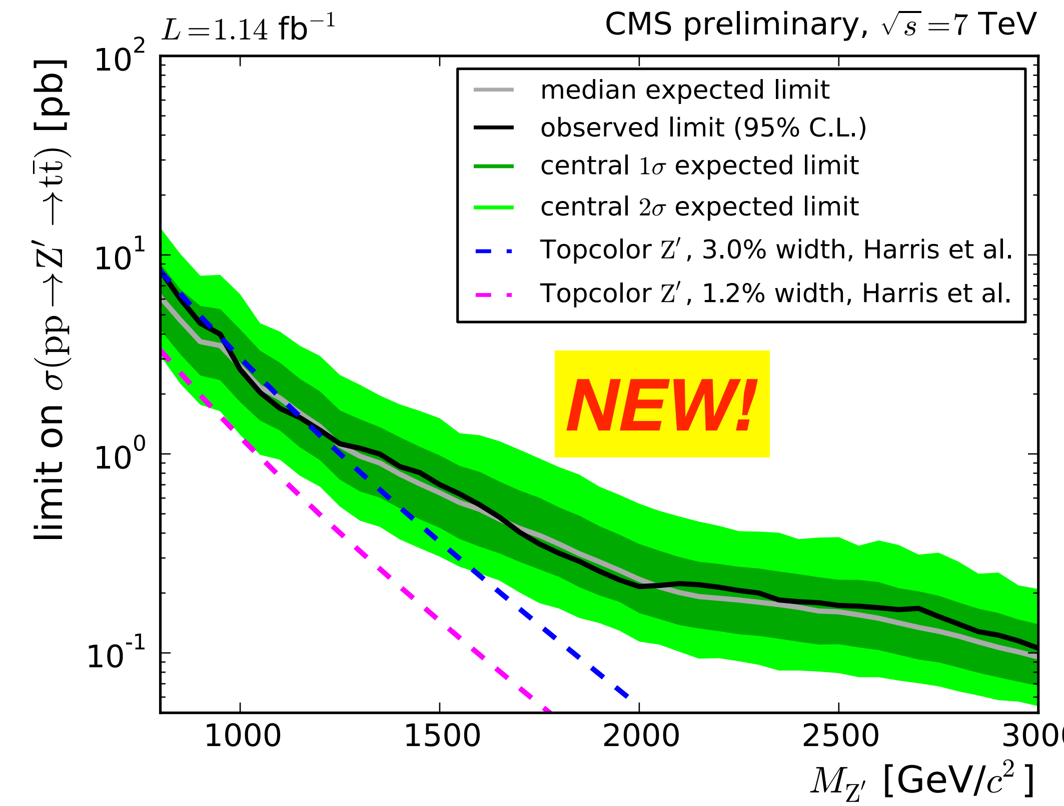
A=ATLAS, C=CMS

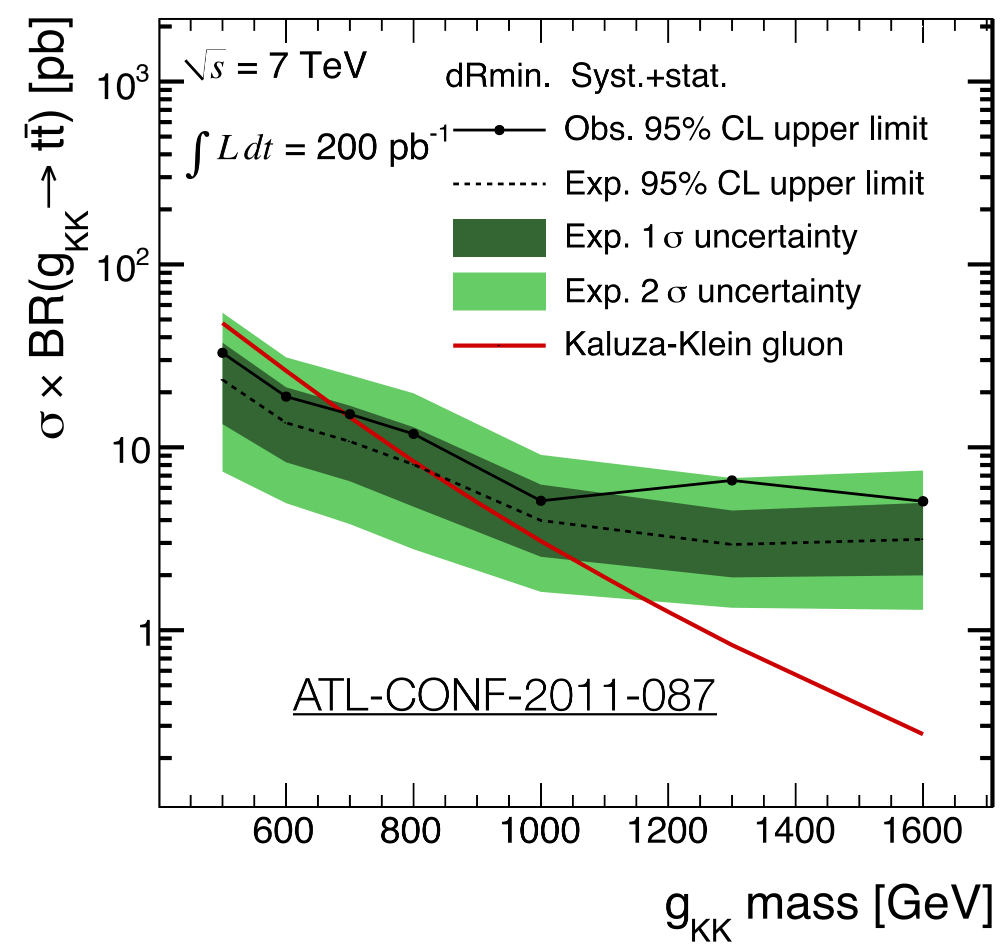
- No excess found → **95% Bayesian credible interval for Z' & RS KKGluon σ*BR, including systematics** *as integrated (CMS), averaged(A) nuisance pars.*

- Upper observed (expected) limit at **95% prob on Z' σ*BR (with $\Gamma_{Z'}/m_Z \sim 1\%$)**
  - C:**sub-pb for** $m_{Z'}$>1.3 TeV, <0.2 pb for $m_{Z'}$> 2.3 TeV
  - A: **38 (40) pb** *for $m_{Z'}$=500 GeV* **to 3.2 (5) pb** *for $m_{Z'}$=1.3 TeV*

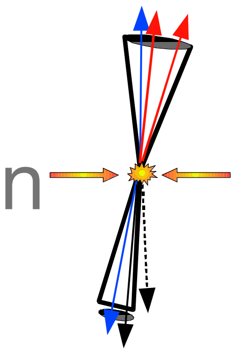
- C: For **Z' with 3% width exclude 805 GeV** <$m_{Z'}$< **935 GeV** and **960 GeV** <$m_{Z'}$< **1060 GeV** at 95% CL

- A: KK Gluons with masses < **650 GeV are excluded with 95%prob**

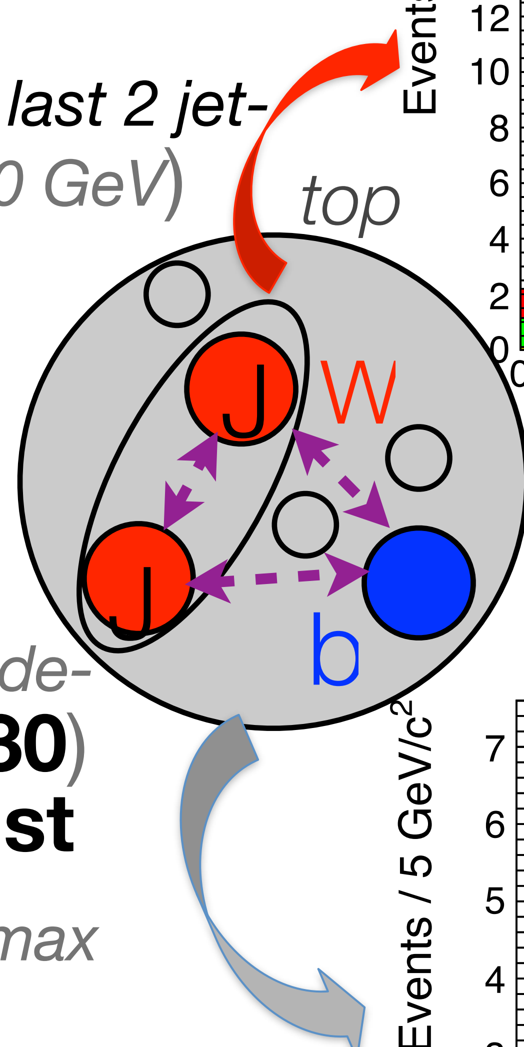




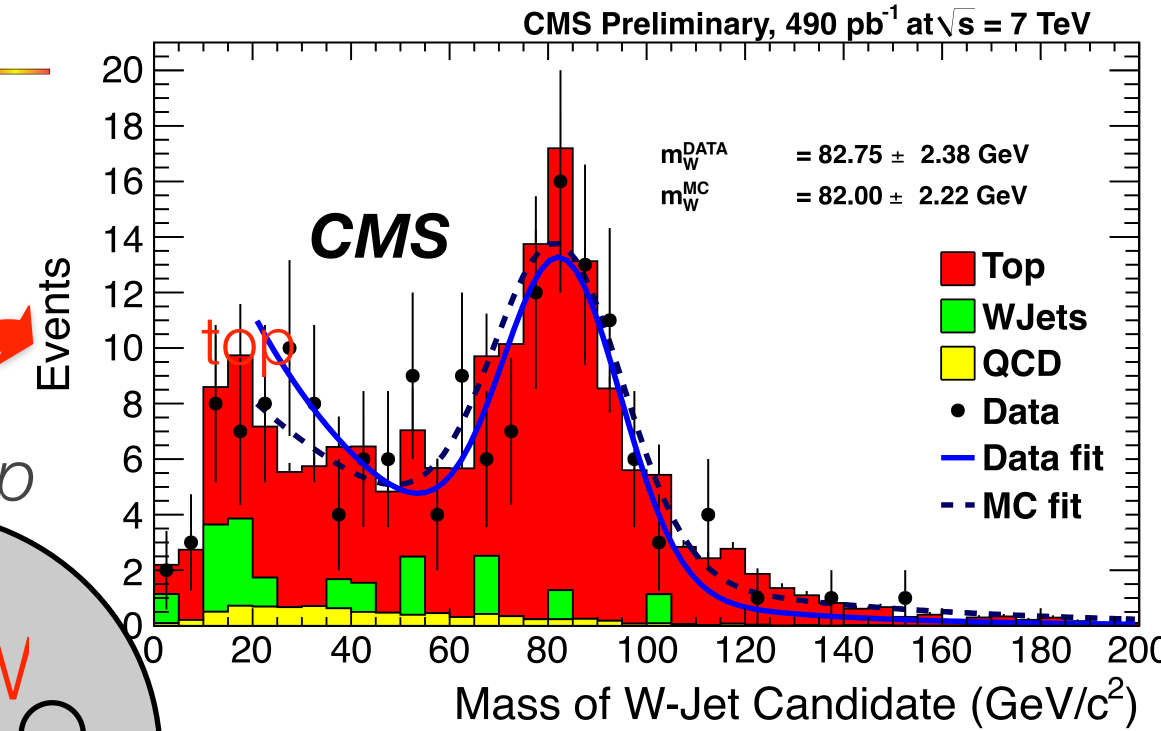
Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ - fully hadronic



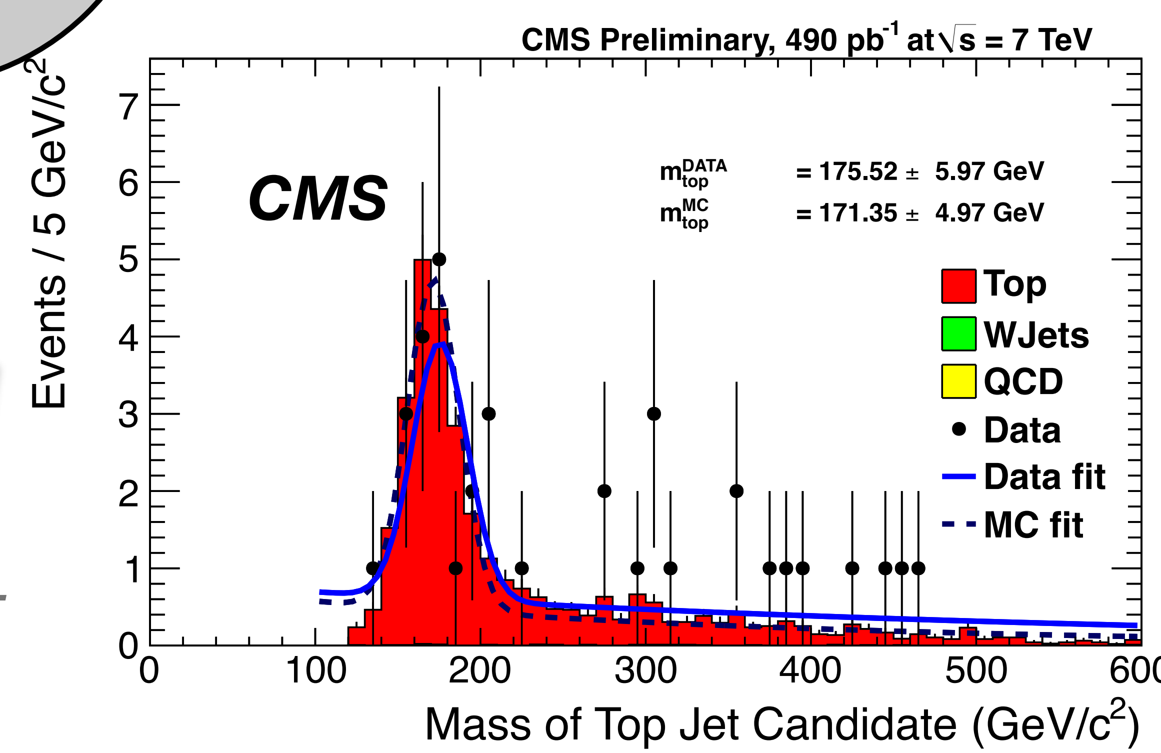
- *Trigger on ≥ 1 jet with p_T>200 GeV*
- **“1+1”: ≥ 2** R=**0.8** Cambridge-Aachen **(CA) jets**
  - **p_T>350 GeV & large Δφ** *>2.1*
  - **top-tagged** (*m_{jet} ~m_{top}* ,*$N_{sub\text{-}jets}$ in last 2 jet-making steps* ≧ *3, min($m_{2\ sub\text{-}jets}$) > 50 GeV*)
- **“1+2”: ≥3 R=0.8 CA jets**
  - **leading top-tagged jet** with **p_T>350 GeV**
  - **2nd**(3rd) **pruned** *(discard soft,wide-angle clusters)* **jet** with **p_T>200 (30)** GeV, **large Δφ***>2.1(1.7)* **from 1st**
  - **j2 is W-tag** (*m_{jet} ~m_W,2 sub-jets,max ($m_{sub\text{-}jet}$)/m_{jet} <0.4*), **m(j2,j3)~m_{top}**
- Data-driven **QCD: weight 1-**top or W-**tag control sample *with mis-tag prob*** ← *anti-tag (fail top tag cuts) & probe in semi-lep evs*



$\int Ldt$ = **0.89 fb^{-1}** *(2011)*



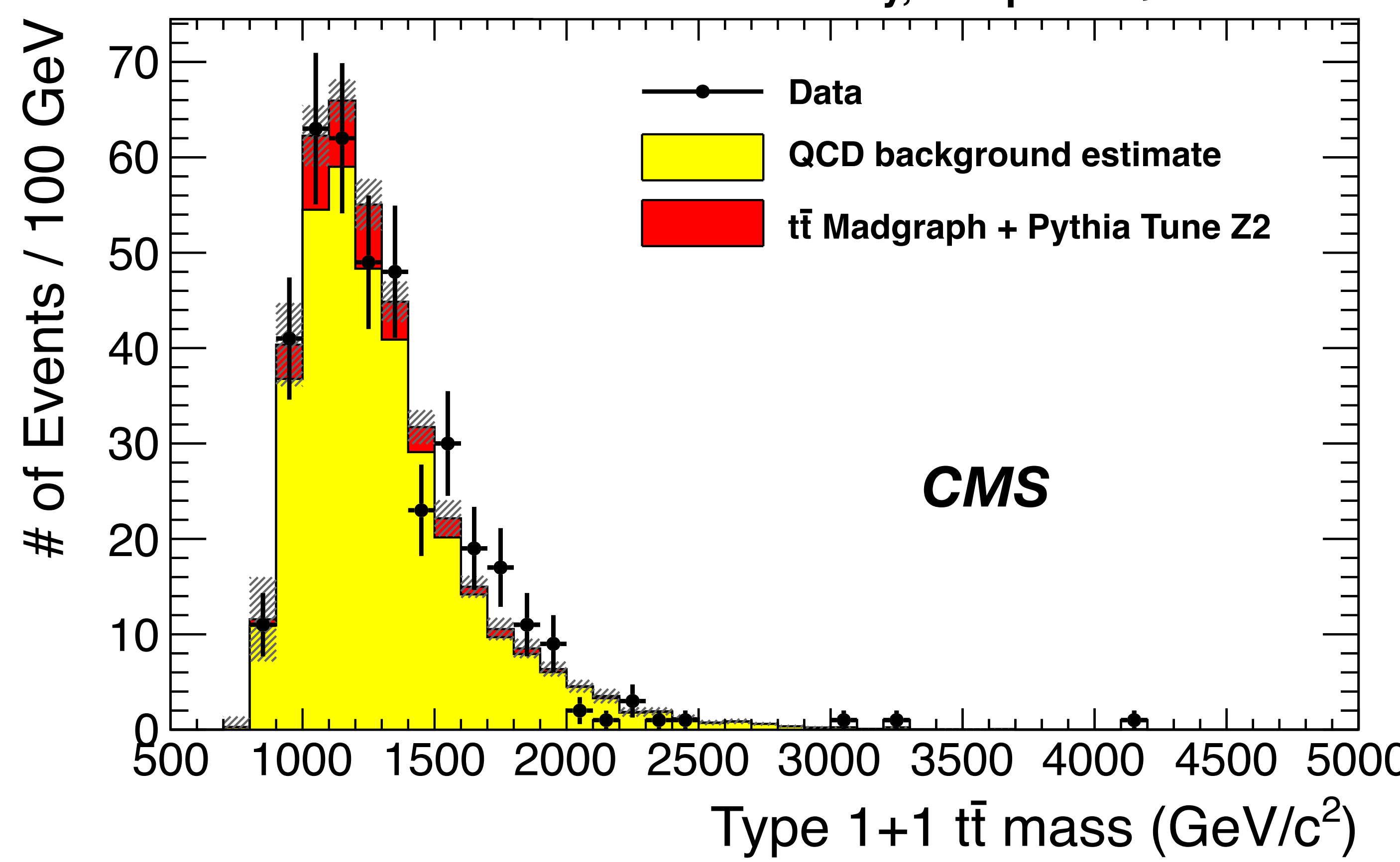
validation in boosted-W semi-lep events CMS-PAS-EXO-11-006



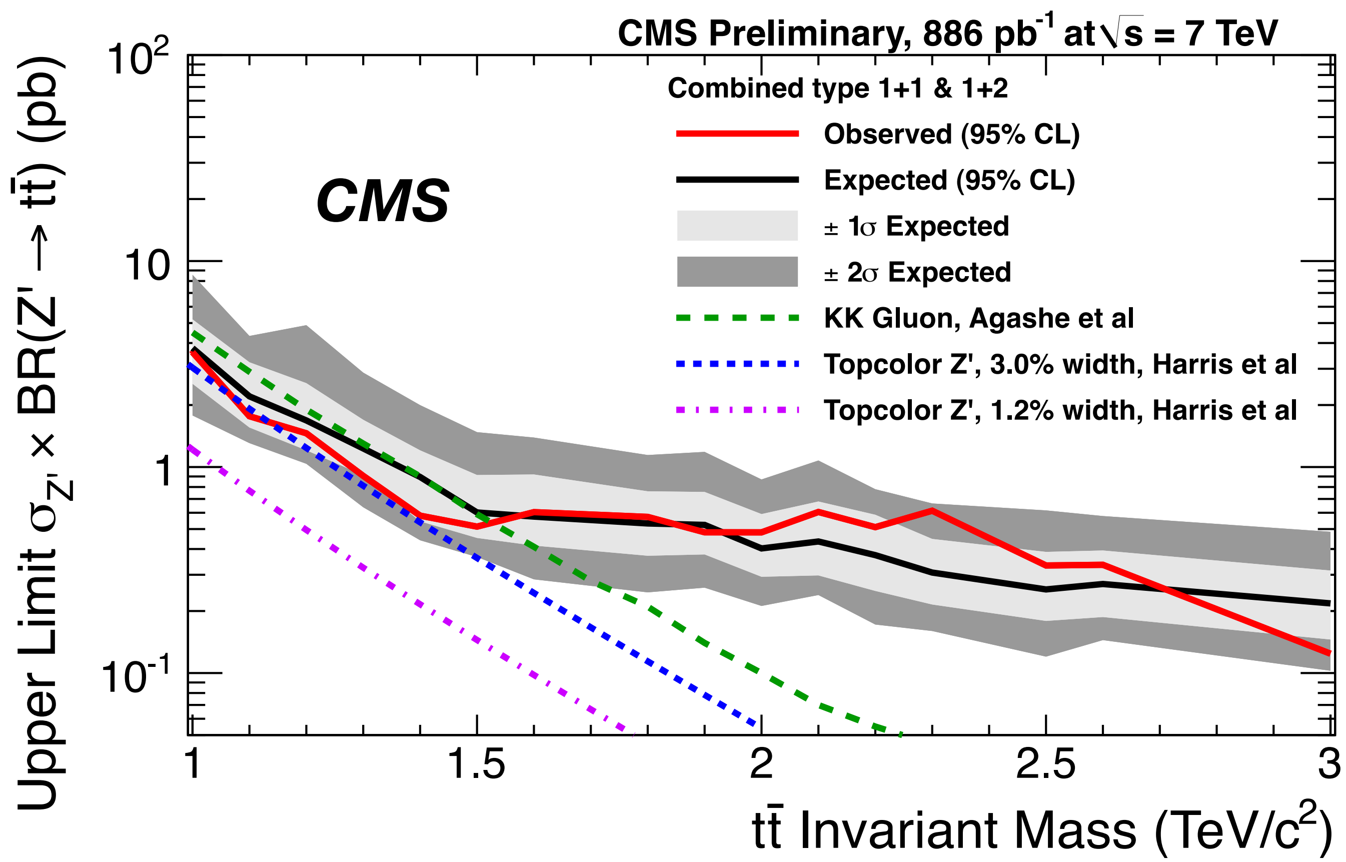
Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ - fully hadronic

$\int L dt = \sim$ **0.89 fb^{-1}** *(2011)*

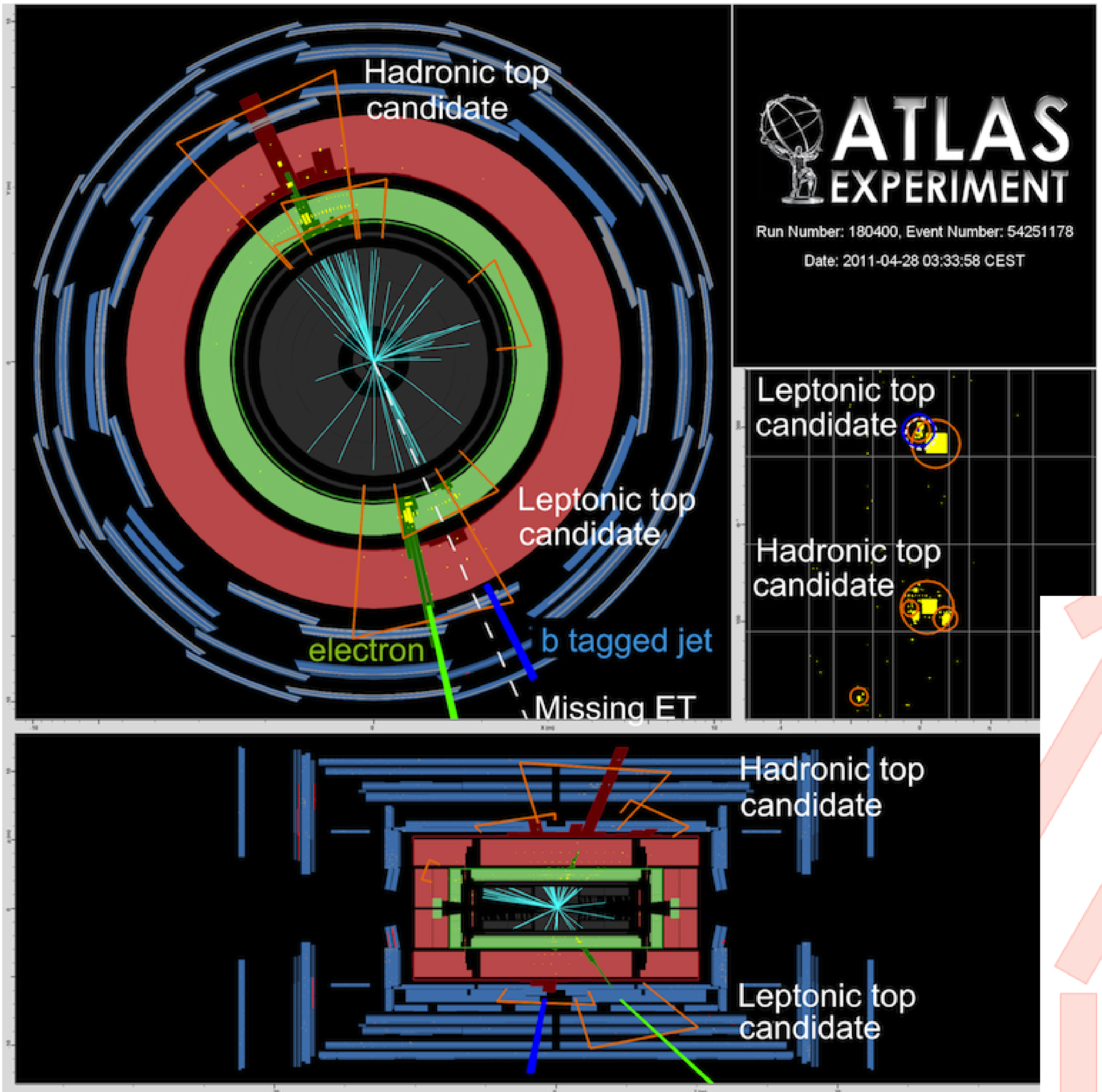
- **M_{tt}: sum top jets** in "1+1", **sum top jet, Wjet and closest jet** in "1+2"
  - QCD: **sum tag(s) & probe jet,** random m_{probe} around m_{top}



- No excess found→**95% Bayesian credible interval for Z'/RS KKGluon σ****BR*** **including systematics** *as integrated nuisance pars.*
- **Sub-pb limit on Z' σ*BR**
- **exclude 1 TeV<$m_{KKGluon}$<1.5 TeV @ 95%CL**



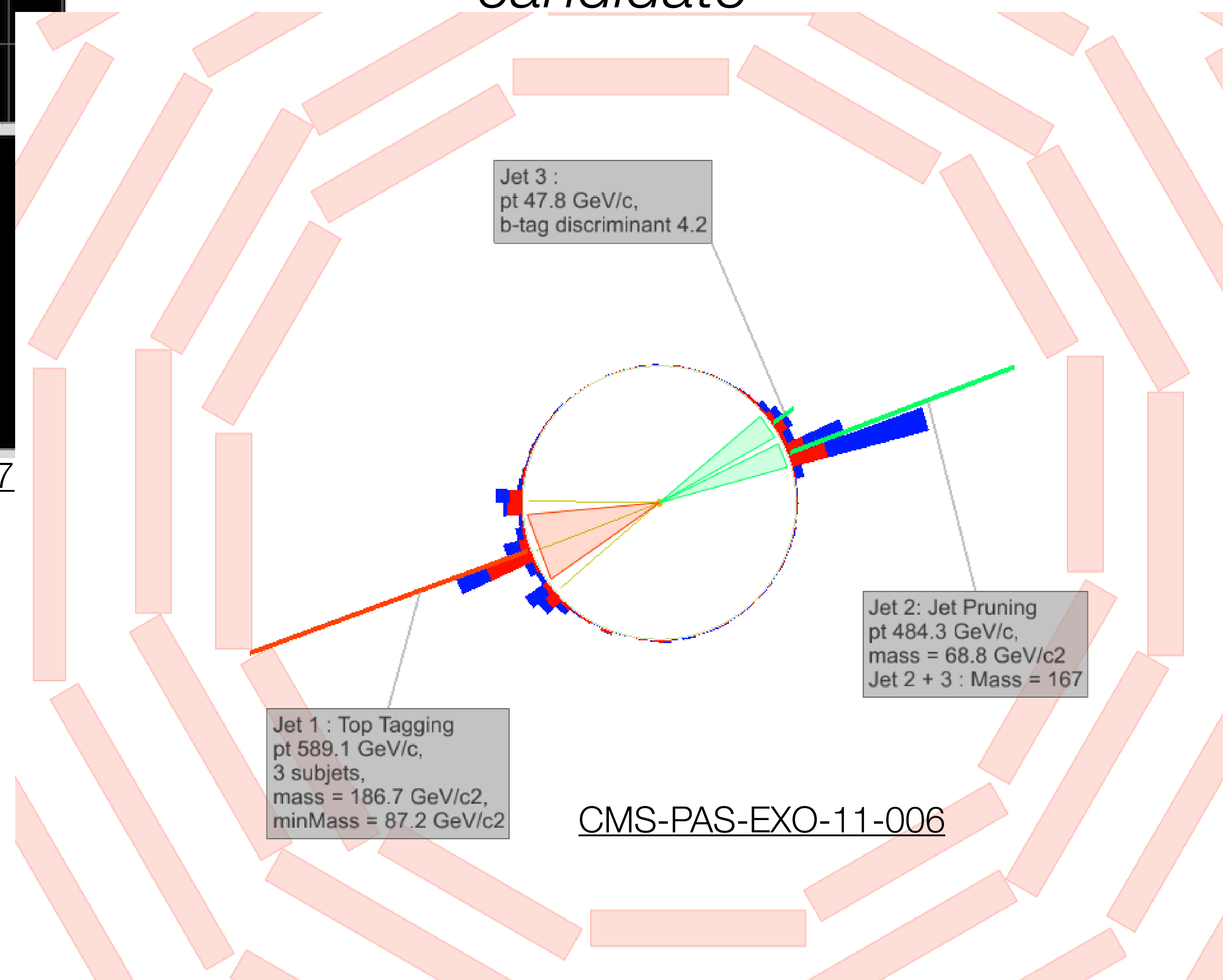
Search for excess in top pair production vs $M_{t\bar{t}}$



ATL-CONF-2011-087

semi-leptonic di-top-jet candidate

fully hadronic di-top-jet candidate



Conclusions

- **Top analysis at LHC is in full swing** thanks to the combined performance of LHC & detectors: **a very rich program is already underway.**
- **Top pair production cross section is measured** in nearly all expected final states. It is **consistent with the standard model at $\sqrt{s}$=7 TeV** and **most precise channels**/combination are
  - **systematics dominated**
  - entering the realm of **precision physics**: $\delta\sigma/\sigma$ <~10% comparable with theory uncertainty
- **Single top production is clearly observed** in the t-channel; need more data to observe it in Wt and s-channel.
- **Top properties** are rapidly reaching precision level with **m_{top} already syst dominated**
- The rapidly **increasing data-set and detector understanding** is quickly opening **unprecedented phase space for new physics searches linked to top production** *ranging from resonances to*

Additional (useful) references

- A. Quadt, Top quark physics at hadron colliders, Eur. Phys. J. C 48, 835–1000 (2006) DOI 10.1140/epjc/s2006-02631-6
- A J,. Khun, Theory of Top Quark Production and Decay, http://arxiv.org/abs/hep-ph/9707321v1
- S Willembrock,THE STANDARD MODEL AND THE TOP QUARK, http://arxiv.org/abs/hep-ph/0211067v3
- Chris Quigg, Top-ophilia,FERMILAB-FN-0818-T

and references therein

BACK-UP

Math Appendix : Mass, P_T and DR

As we know that for any 4-momentum

$$E = m_T \cosh y \ , \ p_x \ , \ p_y \ , \ p_z = m_T \sinh y$$

where $m_T^2 = m^2 + p_x^2 + p_y^2$. and

$$y = \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z} \right) = \ln \left(\frac{E + p_z}{m_T} \right) = \tanh^{-1} \left(\frac{p_z}{E} \right) .$$

The invariant mass M of the two-particle system

$$M^2 = m_1^2 + m_2^2 + 2[E_T(1)E_T(2) \cosh \Delta y - \boldsymbol{p}_T(1) \cdot \boldsymbol{p}_T(2)] \ ,$$

where $E_T(i) = \sqrt{|\boldsymbol{p}_T(i)|^2 + m_i^2}$,

This can be re-written as

$M^2 = m_1^2 + m_1^2 + 2[E_T(1) E_T(2) \cosh(Dy) - p_T(1) p_T(2) \cos(DPhi)$

where DPhi =Phi(2)-Phi(1)is the angle between the two momenta in the transverse plane

Now if 1) the masses of the particles are small w.r.t. their momenta and 2) the splitting is quasi collinear i.e. $\cos DPhi \sim 1 - (DPhi)^2/2$ and $\cosh(Dy) \sim 1 + Dy^2/2$, so $E_T(I) \sim p_T(i)$

http://en.wikipedia.org/wiki/Hyperbolic_function

$M^2 \sim 2[p_T(1) p_T(2) (1+Dy^2/2 - 1+ (DPhi)^2/2)]= p_T(1) p_T(2) (Dy^2/2 + (DPhi)^2)= p_T(1) p_T(2)(DR(1,2))^2$

So

Labelling i and j such that $p_{tj} < p_{ti}$ and defining $z = p_{tj}/p_t$

$$(p_t = p_{ti} + p_{tj}),$$

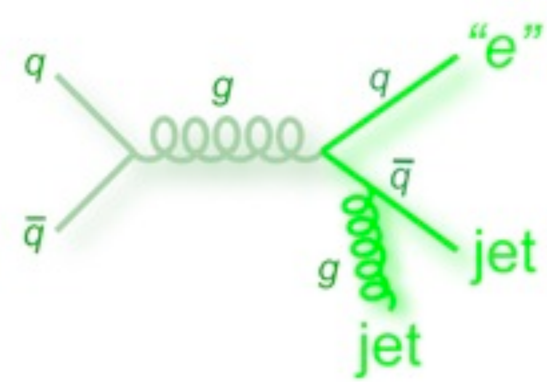
$$m^2 \simeq z(1-z) p_t^2 \Delta R_{ij}^2 \ ,$$

$$d_{ij} = z^2 p_t^2 \Delta R_{ij}^2 \simeq \frac{z}{(1-z)} m^2 \ .$$

Techniques for BKG estimation

Example background estimates: QCD multi-jet -single lep

- “Fake” leptons: mis-id jets, $\gamma \rightarrow e^+e^-$ non-prompt leptons (b/c-decays)



μ channel: matrix method

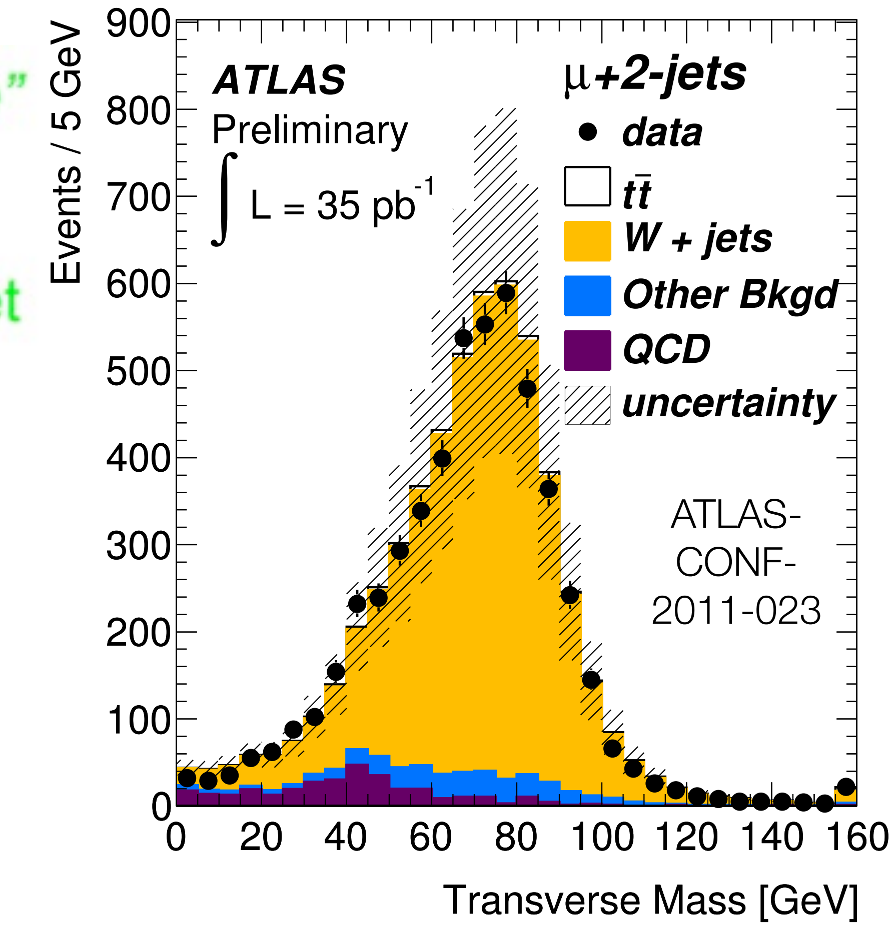
- Measure $N^{standard}$ (isolated-μ) and N^{loose}(non-iso-μ) events and **find standard fake muons** from

$$N^{loose} = N^{loose}_{fake} + N^{loose}_{real}$$

$$N^{standard} = \varepsilon_{fake}\, N^{loose}_{fake} + \varepsilon_{real}\, N^{loose}_{real}$$

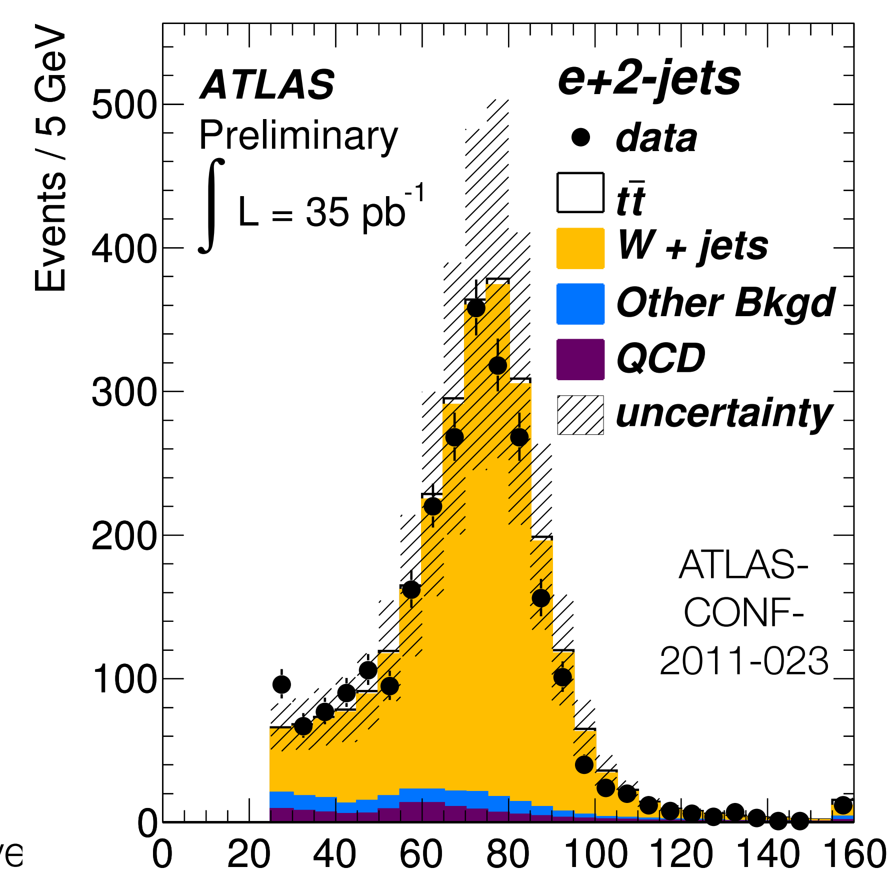
ε_{fake} from low E_T^{miss}, M_T^W and ε_{real} from $Z \rightarrow \mu^+\mu^-$

- Do it in bins of any variable to get proper estimate



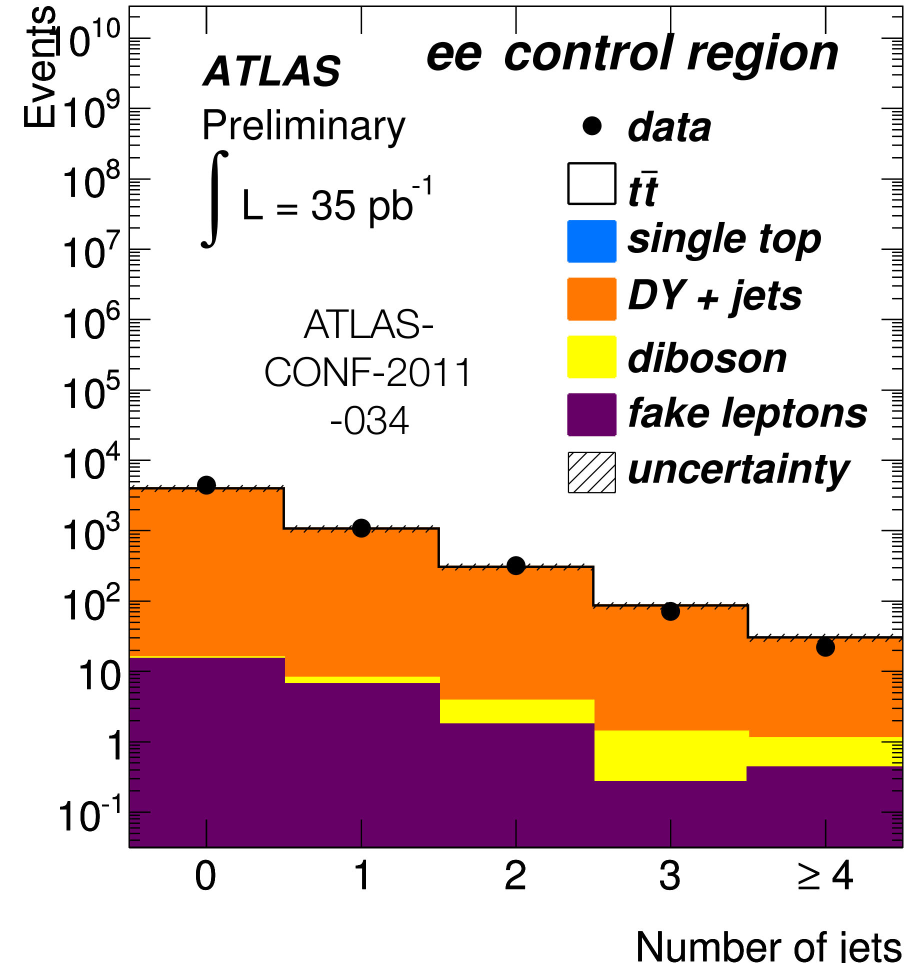
e channel: template method

- **Derive QCD template** from control region (electron fails one/more selection criteria)
- **Normalize by fitting low E_T^{miss} shape** *(QCD template + MC samples)* **to data→extrapolate to** standard region



Example background estimates: QCD multi-jet - di-lepton

- Define tight (standard) and loose lepton samples relaxing
  - calo and track isolation for μ
  - calo isolation, TRT hits, E/p cuts for **e**
- Express measured (Tight,Loose) samples in terms of unknown (**Real**, **Fake**) and estimated probabilities ***r*** ***(f)***: for ***real (fake)*** leptons passing loose also to pass tight cuts
- Extract ***fake*** content by matrix inversion



$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

Measure ***r*** in Z →ll

Measure ***f*** in QCD enriched sample: single loose lepton, low E_T^{miss}

(W+jets subtracted using simulation)

Example background estimates: W+jets - single lepton

ATLAS

pre-tag=all standard cuts, no b-tag requirement
tagged= all standard cuts, including at least 1 b-tag

- Shape from simulation
- Normalization
  - floating parameter to be determined from kinematic fit
  - final normalization from fit, but starting value and variations constrained from data using

$$W_{\geq 4,\mathrm{tagged}} = W_{\geq 4,\mathrm{pretag}} \cdot f_{2,\mathrm{tagged}} \cdot \bar{k}_{2\rightarrow\geq 4}.$$

1: Derive correction to fraction of heavy and light flavour events in the W+2jet bin before b-tagging

N (W+jets,pre-tag, $N_{jets,}$) = N (W+jets,pre-tag, N_{jets}) * [$\sum_{Type} f_{Type,Njets}$] ; $\sum f_{Type,Njets}=1$
Type= Wbb+jets,Wcc+jets,Wc+jets,W+light jets; Njets= jet mult bin (0,1,2,3...)

- Derive N(W+1jet) and N(W+2jet) with 1)standard single lepton selection and 2) subtraction of small backgrounds (tt,single t, di-boson, QCD from data)
- Write N(W+1jet, pre-tag), N(W+2jet, pre-tag) and N(W+2jet, tag) as a function $f_{Type, 2jets}$. Assume fixed $f_{Type,2jets}$ /$f_{Type,2jets}$ + $f_{Wbb,Njets}$ = $f_{Wbb,Njets}$ → Derive $f_{Type,2jets}$
- Compare data-driven $f_{Type,2jets}$ to MC value: derive scaling factors for $f_{Type,2jets}$. Assume scaling $f_{Type,4jets}$ is the same as $f_{Type,2jets}$ .So now ∑ alpha $f_{Type,Njets}$

Example background estimates: W+jets - single lepton (cont)

pre-tag=all standard cuts, no b-tag requirement
tagged= all standard cuts, including at least 1 b-tag

ATLAS

2: Derive pre-tag W+jets normalization W i.e. full selection except for >=1 b-tagged jet

In the proton there are more up (valence) quarks than down (valence) quarks →
($\bar{u}d \rightarrow W^+$)+jets events are more numerous than ($u\bar{d} \rightarrow W^-$)+jets

$$W_{\geq 4,\mathrm{pretag}} = N_{W^+} + N_{W^-} = \frac{(N_{W^+}^{MC} + N_{W^-}^{MC})}{(N_{W^+}^{MC} - N_{W^-}^{MC})}(D^+ - D^-) = \left(\frac{r_{MC}+1}{r_{MC}-1}\right)(D^+ - D^-),$$

$N_{W^+}^{MC}$ ($N_{W^-}^{MC}$) are the number of selected events with a W from MC, **D** is the number of selected events with a positive or negative lepton,
r_{MC} is N_{W^+}/N_{W^-} : it is estimated using ALL the W components and by scaling the heavy and light flavour samples according to point 1

3: Derive tagged W+jets normalization W by scaling pre-tag estimate

$$W_{\geq 4,\mathrm{tagged}} = W_{\geq 4,\mathrm{pretag}} \cdot f_{2,\mathrm{tagged}} \cdot k_{2\rightarrow\geq 4}.$$

Estimate $f_{2,tagged}$ = N(W+jets,2jets,tagged)/N(W+jets,2jets,pre-tag) where N(W+jets,2jets,XX) are obtained from the data with 1) selection 2) small bkg subtraction

Estimate $k_{2\rightarrow\geq 4}$,= $f^{MC}_{tagged,\geq 4jet}/f^{MC}_{tagged,2jet}$
Simulate W+jets events:get fraction of those selected + at least 1 b-tag to simply selected .
Get these fractions for 2 jet bin and 4 jet bin. Get the ratio.

Example background estimates: W+jets - single lepton

ATLAS

- Shape from simulation,
- Normalization
  - floating parameter to be determined from kinematic fit
  - final normalization from fit, but starting value and variations constrained from data

PDFs for up and down quarks are different in proton

W^+ are obtained from ud^+

$$N_{W^+} + N_{W^-} = \frac{(N_{W^+}^{MC} + N_{W^-}^{MC})}{(N_{W^+}^{MC} - N_{W^-}^{MC})}(D^+ - D^-) = \left(\frac{r_{MC} + 1}{r_{MC} - 1}\right)(D^+ - D^-)$$

Additional measurements

Search for excess in $t\bar{t}$ production - di-lepton

$\int L dt$ = **1.04 fb^{-1}** *(2011)*

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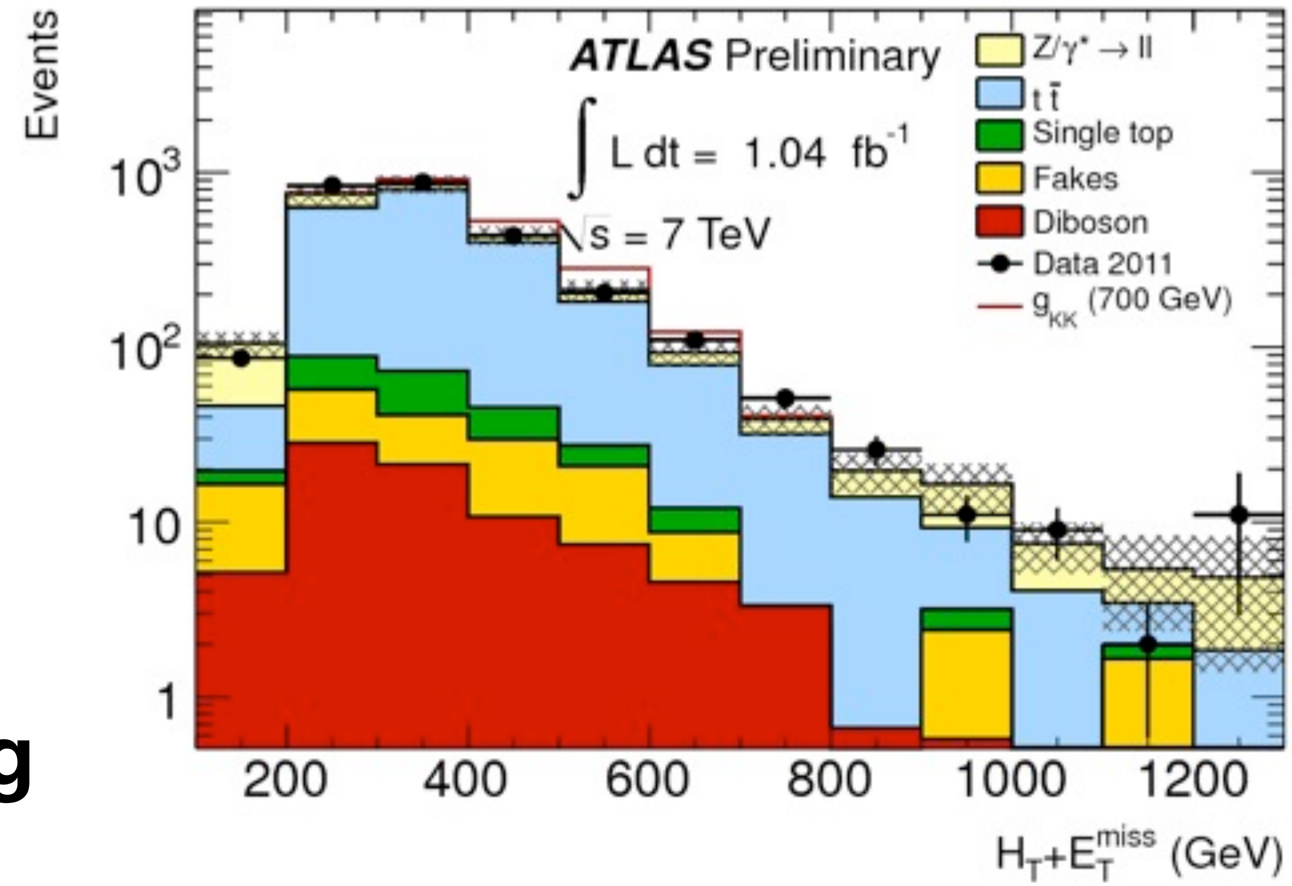
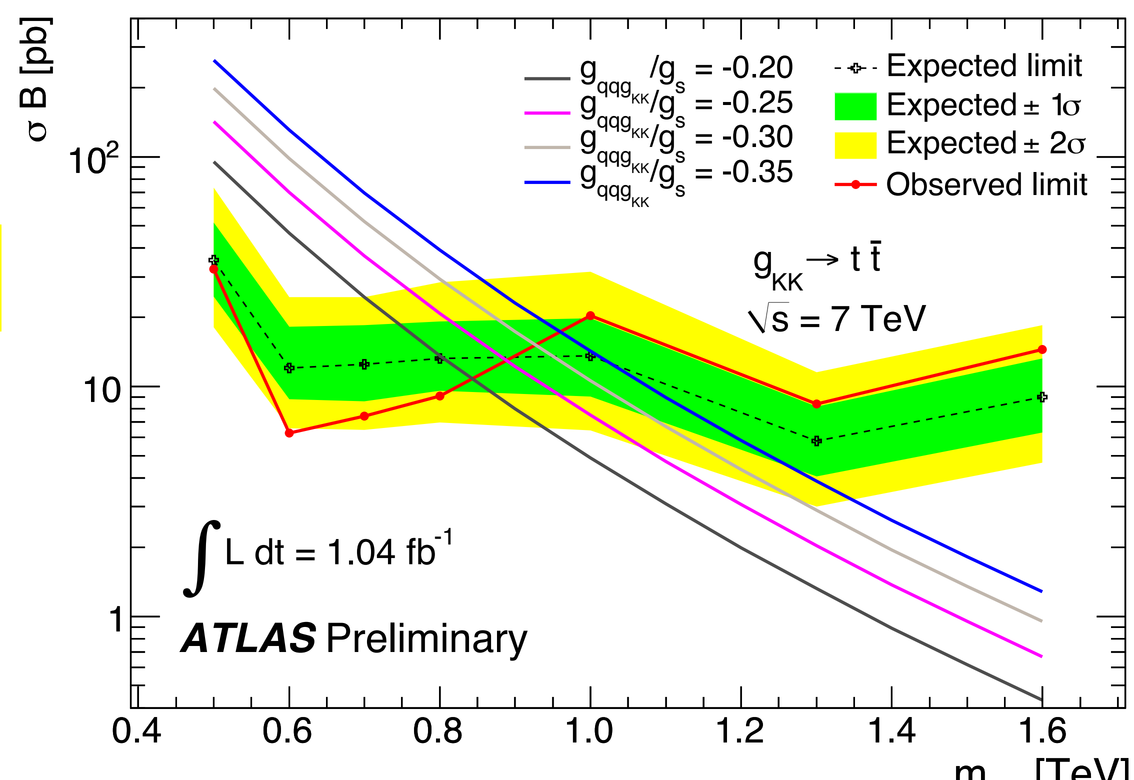
- **Standard: di-lepton selection** (e,) + **data-driven Z/γ*+jets** (*E_T^{miss}-dep Z-window*) and **QCD** bkg estimates



- No excess found in H_T+E_T^{miss} → **95% Bayesian credible interval for RS KKGluon σ*_BR_ including systematics** *as integrated nuisance pars.*



- **Exclude RS KKGluon with M_{KK} below 0.84 TeV** at 95% CL

NEW!

default → (-0.20)

	Mass Limit (TeV)	
$g_{qqg_{KK}}/g_s$	Expected	Observed
-0.20	0.80	0.84
-0.25	0.88	0.88
-0.30	0.95	0.92
-0.35	1.02	0.96

Di-lepton: μ+τ (τ→ *had*) channel **NEW!**

A=ATLAS, C=CMS

Check universality + sensitivity to $t \to H^{\pm}+b \to \tau\nu b$

$\int Ldt$ = ~**1.08 fb^{-1}** (***A***,***C***) *(2011)*

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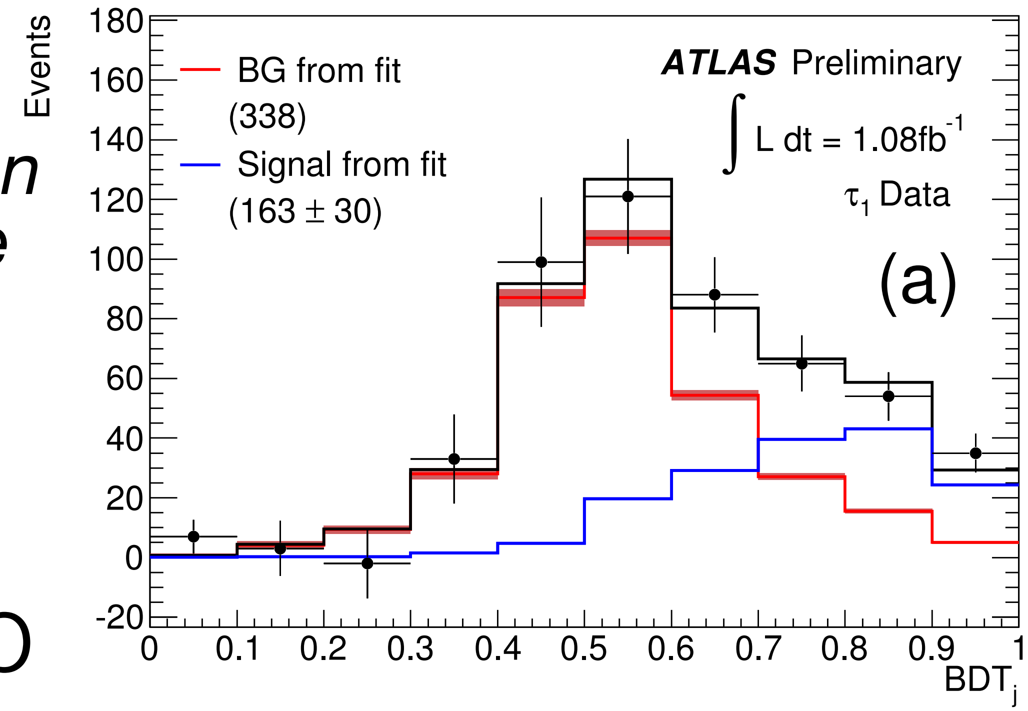
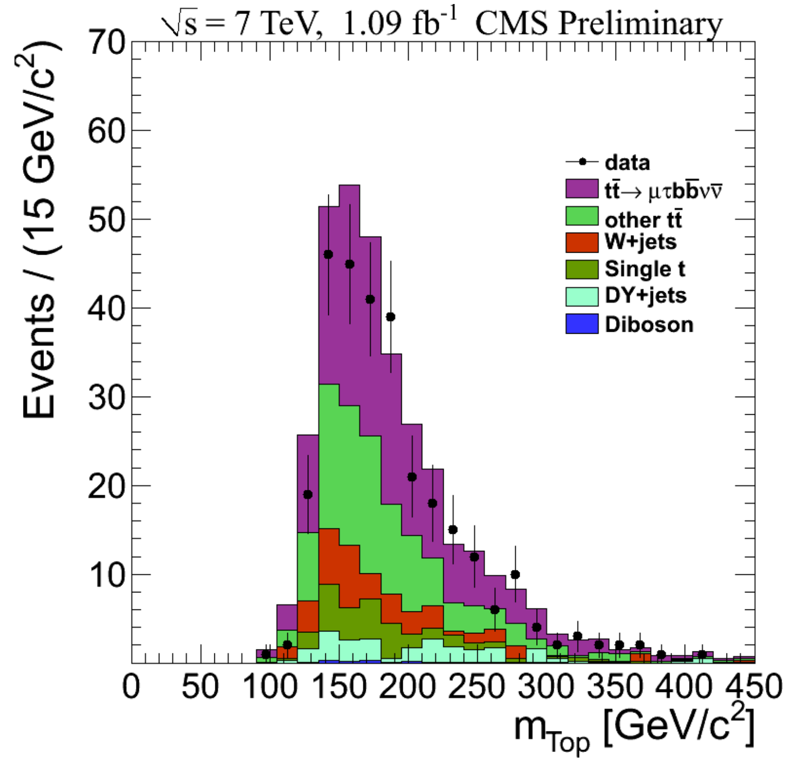
- **One** *central* high p_T **μ, no** low p_T (C) **el**
- **≥1** *jet-seeded* **τ candidate** *(←cut-based algo on particle flow objects (C) or Boosted Decision Tree (BDT) (A))* **with opposite charge to μ (OS)**
- ≥2 jets & ≥1 b-tag
- **large E_T^{miss}** *>40 (C) or 30 (A) GeV* **& H_T**>*200 GeV (A)* update and go to back-up



A $\sigma_{t\bar{t}} = 142 \pm 21\ (\text{stat.}) \pm^{20}_{16}\ (\text{syst.}) \pm 5\ (\text{lumi.})$ pb

δσ/σ~21%

- **Data-driven** *dominant* **tt & W+jets** *(enriched low N_{jet} region (A), weight W+≥3jet with jet fake prob. from average of W+≥1jet & QCD enriched (C),***QCD** *(non-iso mu sample normalized to low E_T^{miss})*
- $\sigma_{tt} = N_{\mu+\tau}$ /A*Lumi. **$N_{\mu+\tau}$ from**
  - C: **bkg-subtracted data**
  - A: **template lkl fit** of difference of **BDT** in OS & SS samples *(cancel most gluon & b-jet fakes)*



C

$\sigma_{t\bar{t}} = 148.7 \pm 23.6(\text{stat.}) \pm 26.0(\text{syst.}) \pm 8.9(\text{lumi.})$ pb

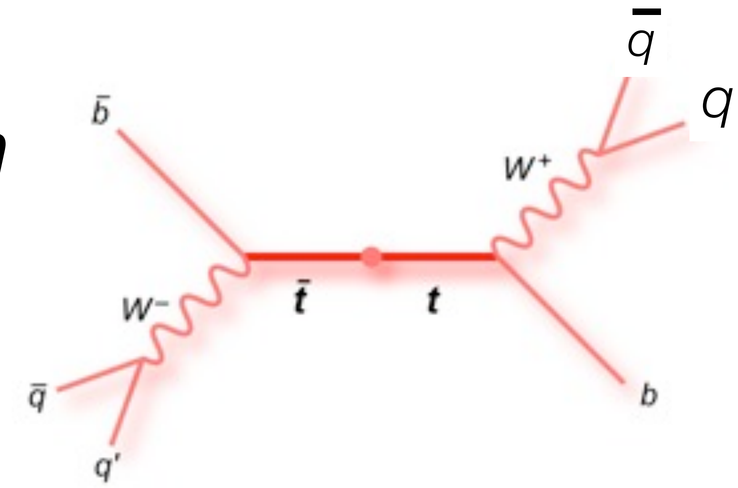
δσ/σ~24%

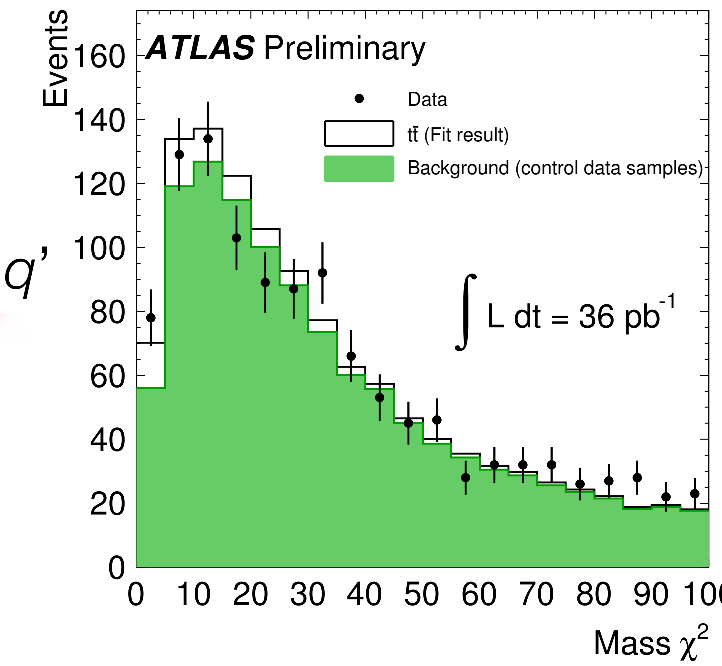
Fully hadronic channel

$\int L dt$ = **35 pb^{-1}** (***A***) (2010), **~1.0 fb^{-1}** (***C***) (2011)

- **≥ 4 jet trigger**, *good jets*
- **≥ 6 high p_T jets, ≥ 2 b-tags**
  - *4 jets with p_T ≥ 60 GeV (A,C), 5th (6th) jet p_T ≥ 50 (40) GeV (C)*
- ***A***: no e or μ, small $E_T^{miss}/\sqrt{E_T^{calo}}$ & large H_T > *300 GeV*
- **Reconstruct with χ^2 kine fit**

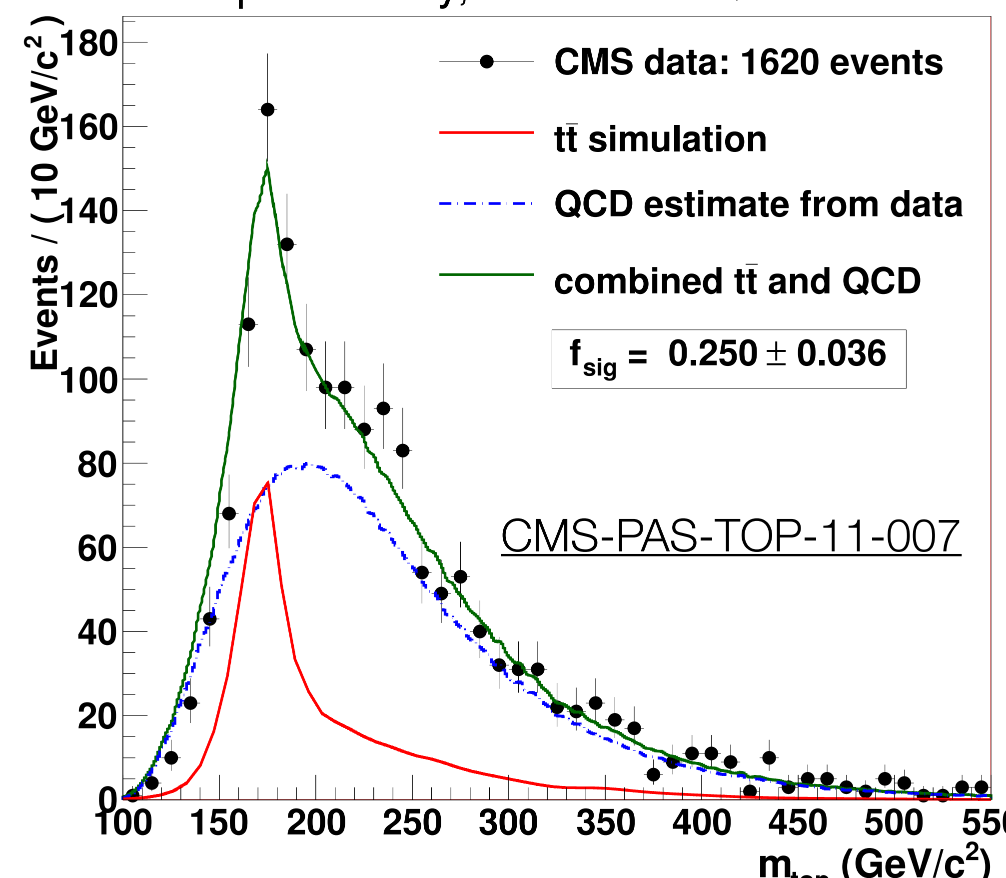
A=ATLAS, C=CMS





95% CL upper limit $\sigma_{t\bar{t}} < 261$ pb.

CMS preliminary, 1.09 fb^{-1} at $\sqrt{s}$ = 7 TeV



- Data-driven **QCD bkg: weight control samples** *>=6 jets no b-tag (C) or 6,5 jets(A)* **with** *data driven* **b-tag prob**

- **N_{tt} from lkl fit to top mass (C)** *checked by neural network discr.* **or χ^2(A)→**σ=N_{tt}/A*Lumi

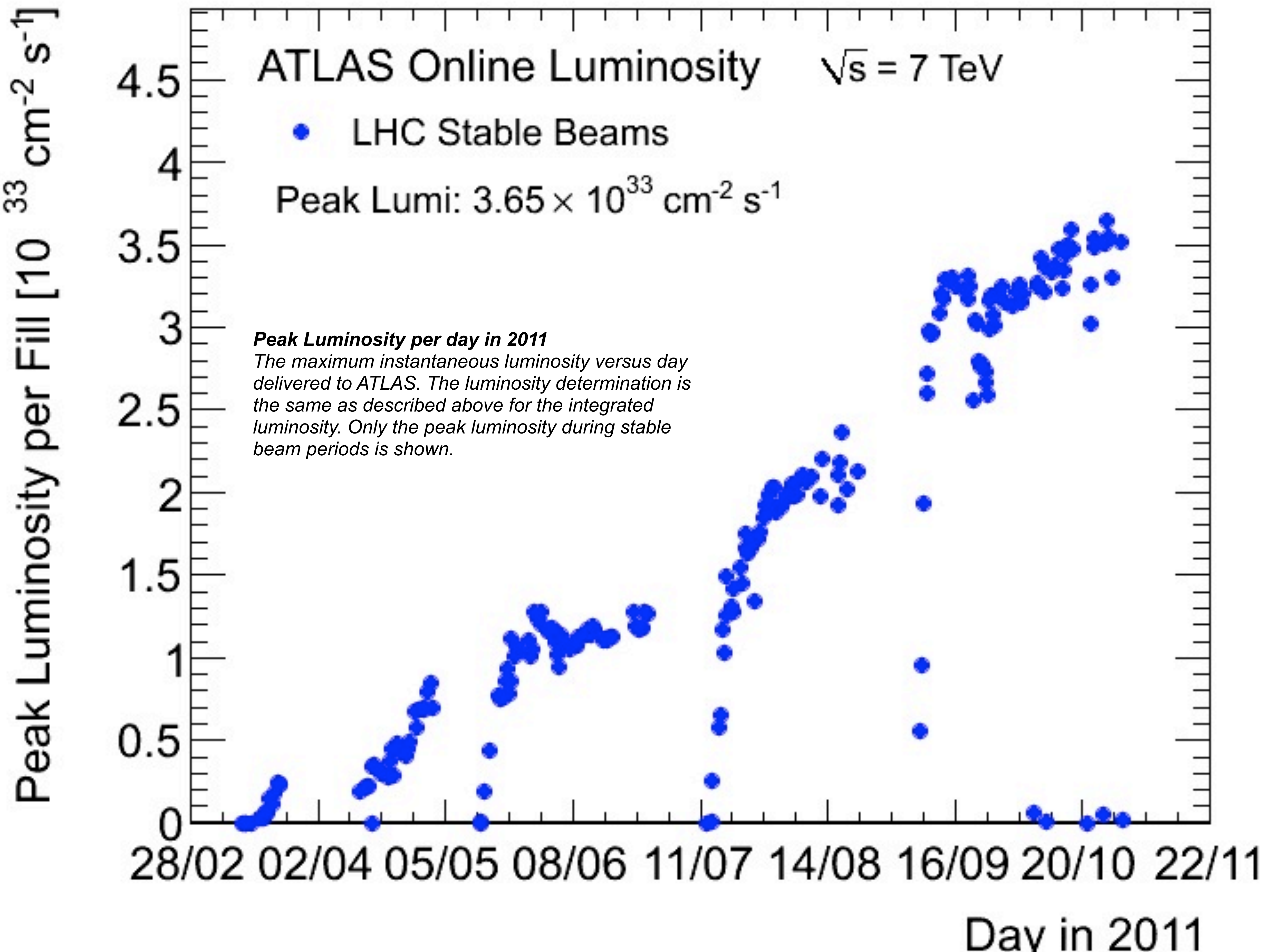
Systematics from pseudo exp. *(dominated by b-tag, jet scale, bkg norm)*

δσ/σ~33%

syst dominated!

$$\sigma_{t\bar{t}} = 136 \pm 20\,(\text{stat.}) \pm 40\,(\text{sys.}) \pm 8\,(\text{lumi.})\ \text{pb}.$$

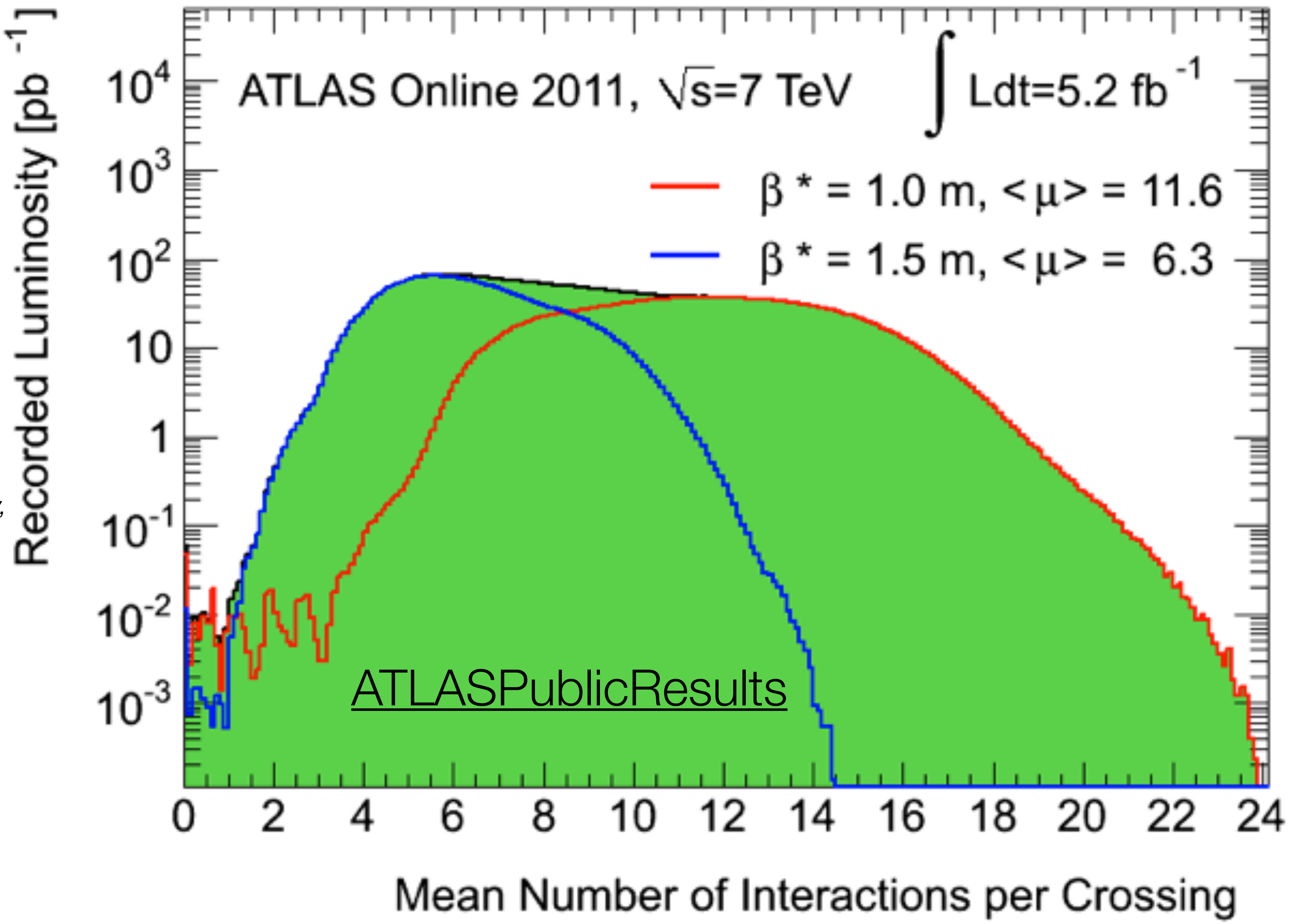
Luminosity,pile-up and simulation



Peak Luminosity per day in 2011
The maximum instantaneous luminosity versus day delivered to ATLAS. The luminosity determination is the same as described above for the integrated luminosity. Only the peak luminosity during stable beam periods is shown.

Number of interactions per crossing at LHC seen by ATLAS - 2011

Number of Interactions per Crossing
Shown is the luminosity-weighted distribution of the mean number of interactions per crossing for 2011. The plot is shown for data taken before and after the September Technical Stop where the beta was reduced from 1.5m to 1.0m. The integrated luminosities and the mean mu values are given in the figure. The mean number of interactions per crossing corresponds the mean of the poisson distribution on the number of interactions per crossing. It is calculated from the instantaneous luminosity as* $\mu = L \times \sigma_{inel} / (n_{bunch} \times f_r)$ *where L is the instantaneous luminosity,* σ_{inel} *is the inelastic cross section which we take to be 71.5 mb,* n_{bunch} *is the number of colliding bunches and* f_r *is the LHC revolution frequency. More details on this can be found in arXiv: 1101.2185. The entries at* $\mu \sim 0$ *arise from pilot bunches that were present during many of the early LHC fills. The luminosity in these bunches is >100 times smaller than in the main bunches resulting in values* $\mu < 0.1$*.*



also see arxiv:1101.2185

Simulation Monte Carlo used in top analyses

A=ATLAS, C=CMS

Generation

- **Top quark : MC@NLO (A), MADGRAPH(C)**
  - xsec is normalized to NNLO effects
  - variationas with ACER (A), POWHEG(A,C)
  - tau decays with TAUOLA
- **Single top : MC@NLO(A), MADGRAPH (C)**
  - t, Wt and s channels
  - normalized to MC@NLO, remove Wt overlaps with tt final state
- **Z/gamma+jets** : **PYTHIA (A)** for Z_tautau, **ALPGEN (A)** for Z to ee and Z to mumu NLO factor of 1.25, MADGRAPH(C)
- **Di-boson** : WW, ZZ: ALPGEN (A) normalized to NLO from MCFM, PYTHIA(C)
- **W+jets**: **ALPGEN** (A), **MADGRAPH**(C)
  - W+n light partons, W+bb, W+cc, W+c

Simulation for pile-up mostly included (from zero to 8 events on av (A))

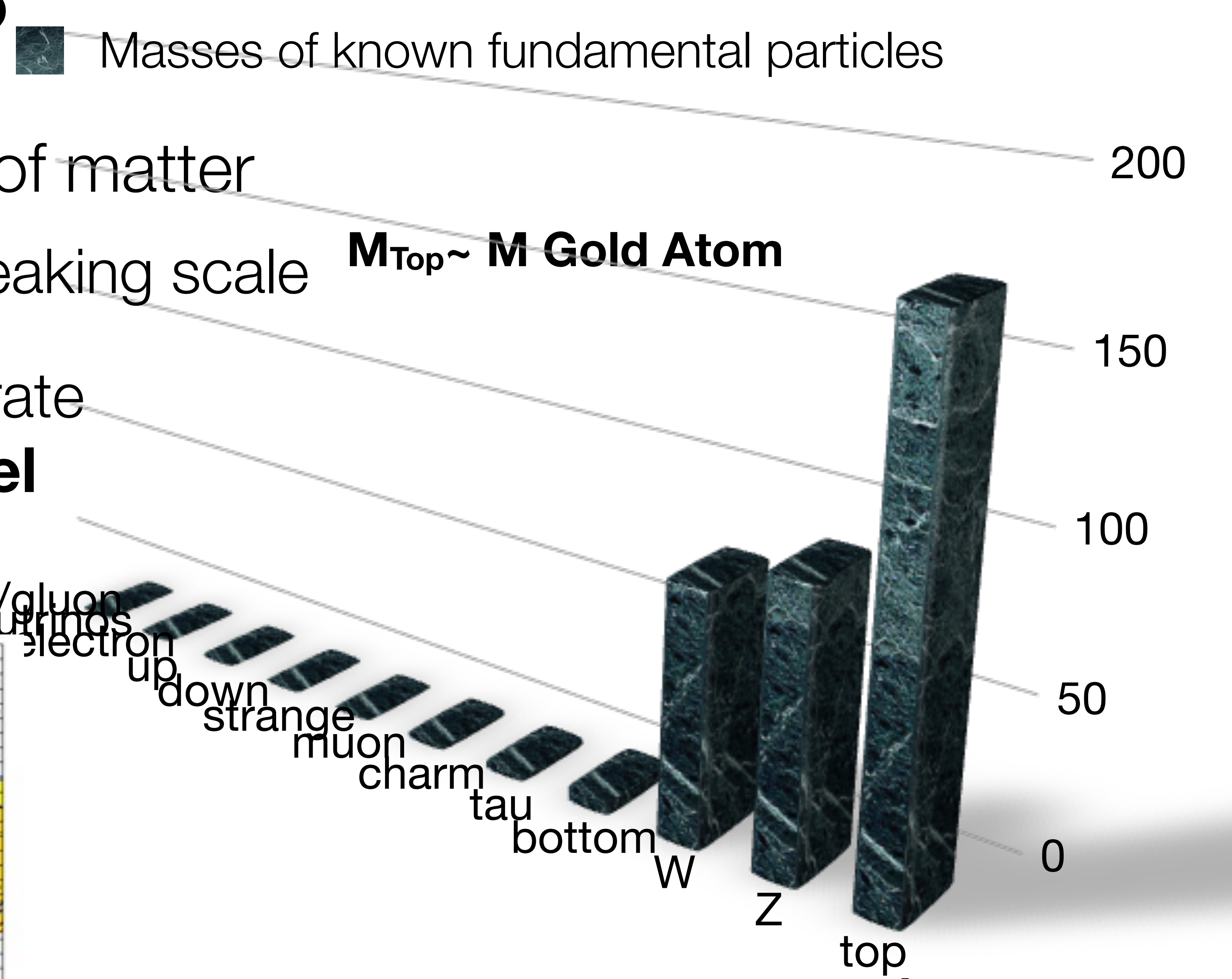
Hadronization

- **HERWIG + JIMMY for underlying event modelling (A), PYTHIA(C)**

Detector

- **GEANT4**

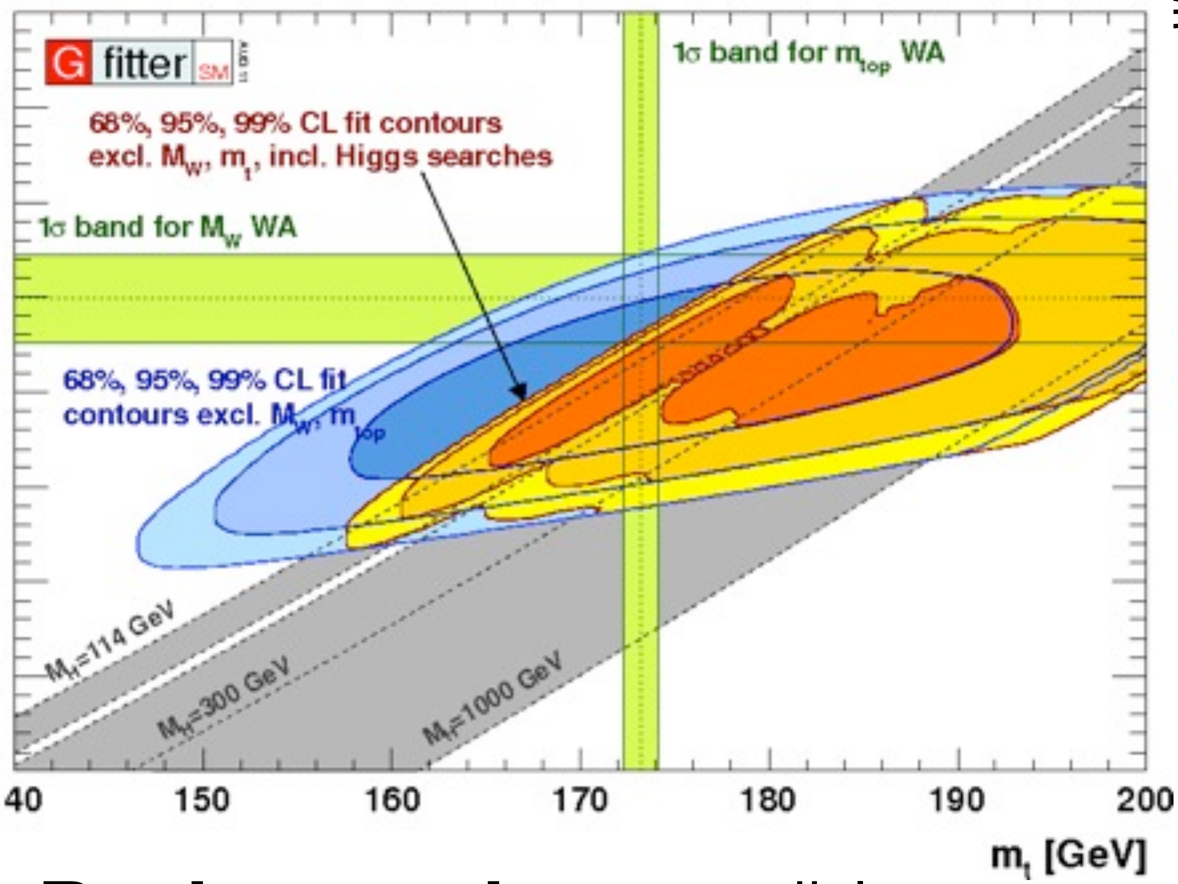
Why Top (quark)?



Most massive constituent of matter

M_{top}~ electroweak symmetry breaking scale

Decay and strong production rate are **tests of standard model**



Various scenarios with **direct/indirect coupling to new physics:**
from extra dimensions to new strong forces

Background to possible **new physics** (Higgs, SUSY)