DAY 2: TRIGGER AND MEASUREMENTS DOUBLING AS SEARCHES

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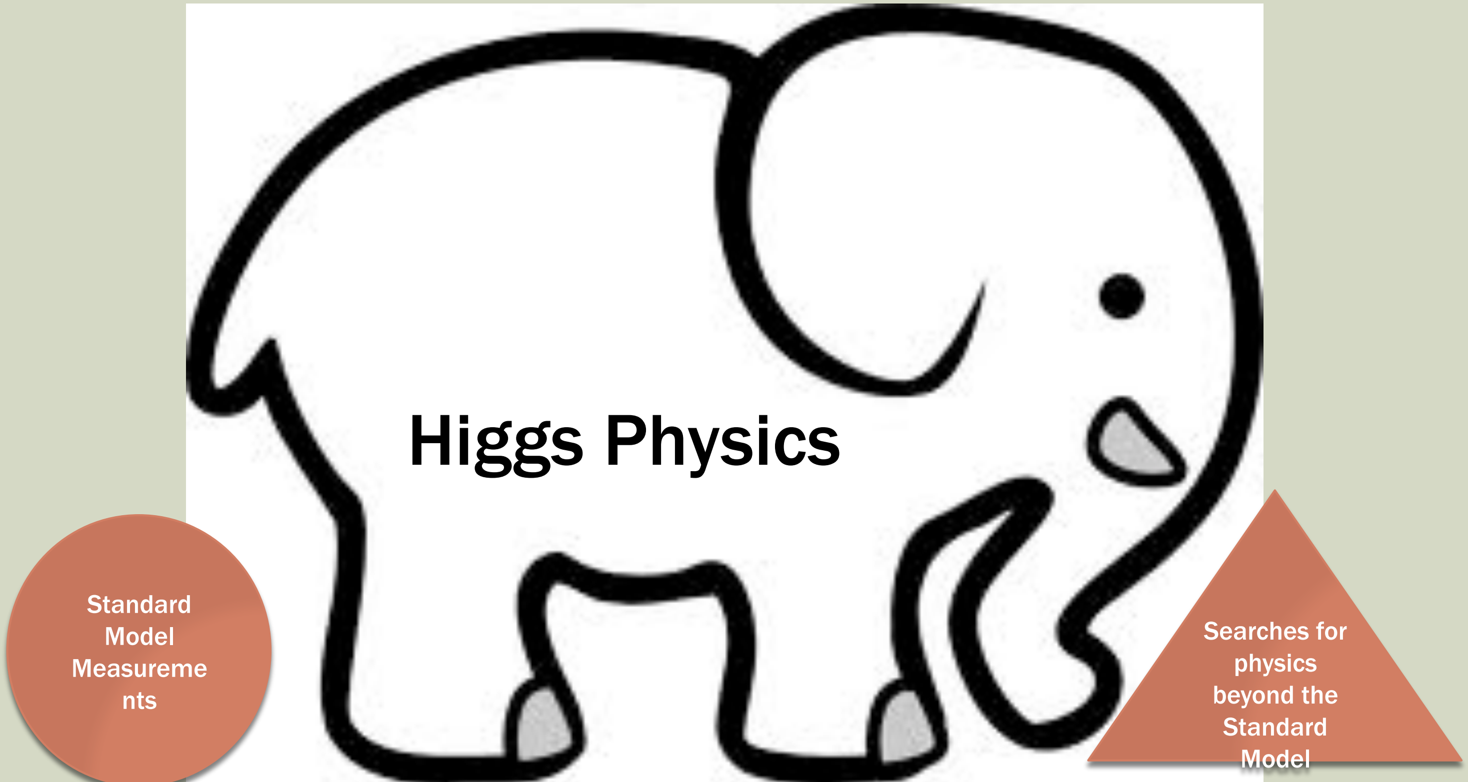
TRIGGER PHILOSOPHY?

Standard Model Measurements

Searches for physics beyond the Standard Model

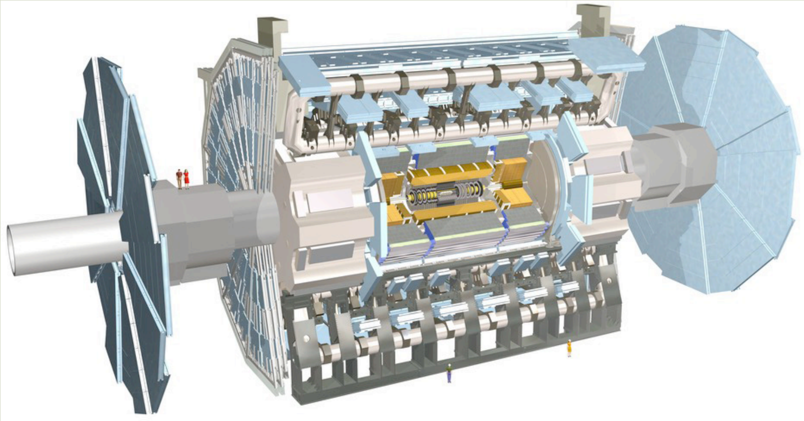
How do experiments support a wide array of measurements and searches?

TRIGGER PHILOSOPHY?



How do experiments support a wide array of measurements and searches?

WE THROW OUT THE VAST MAJORITY OF OUR DATA . . .



protons

protons

40 MHz

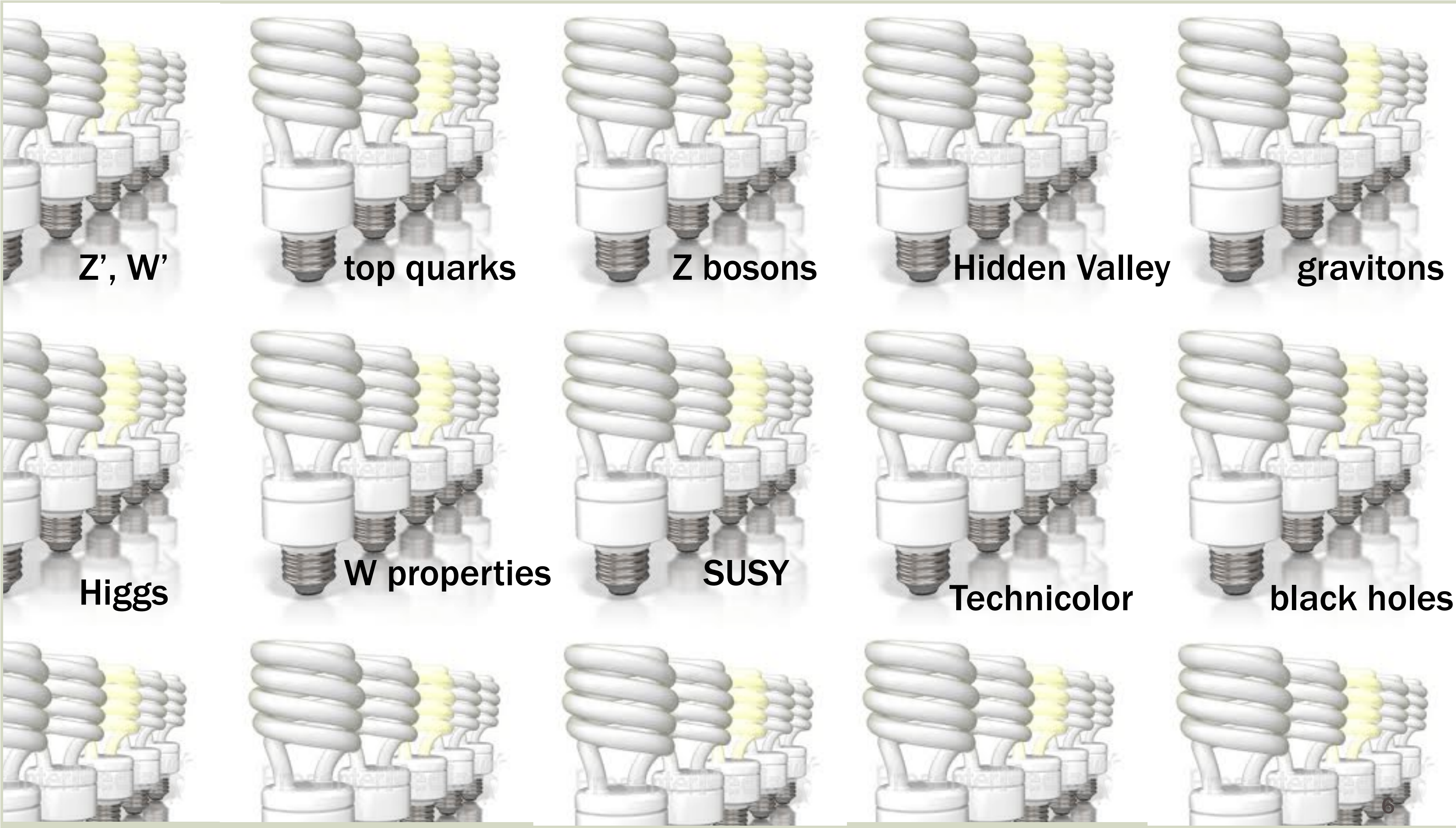
Trigger

800 Hz

Bunches of protons pass through each other every 25 (50) ns,
for 40,000,000 possible opportunities to store data every second
but only O(1000) can be kept for analysis

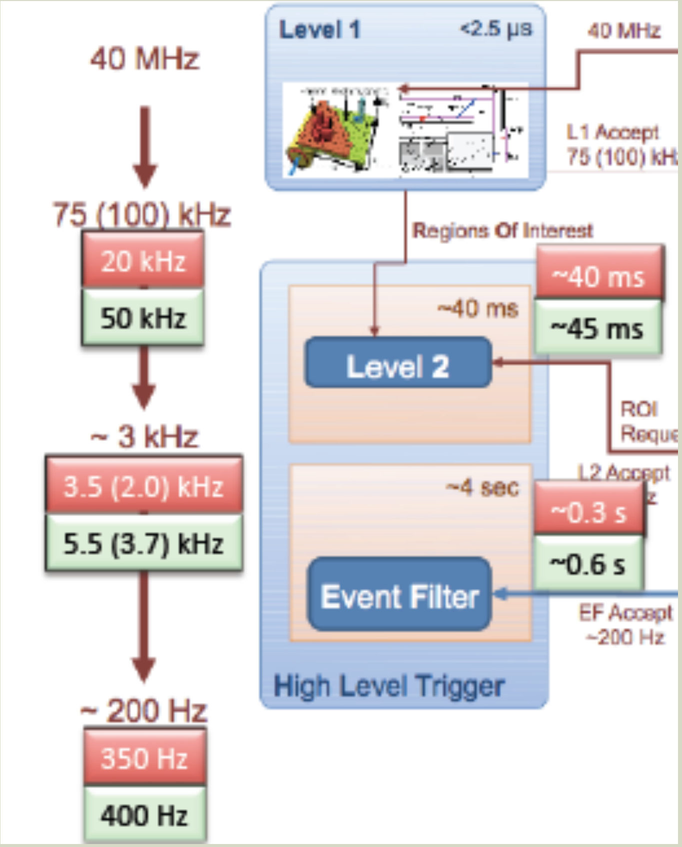
AND PEOPLE ARE PRETTY CREATIVE!

HOW TO BALANCE COMPETING NEEDS?

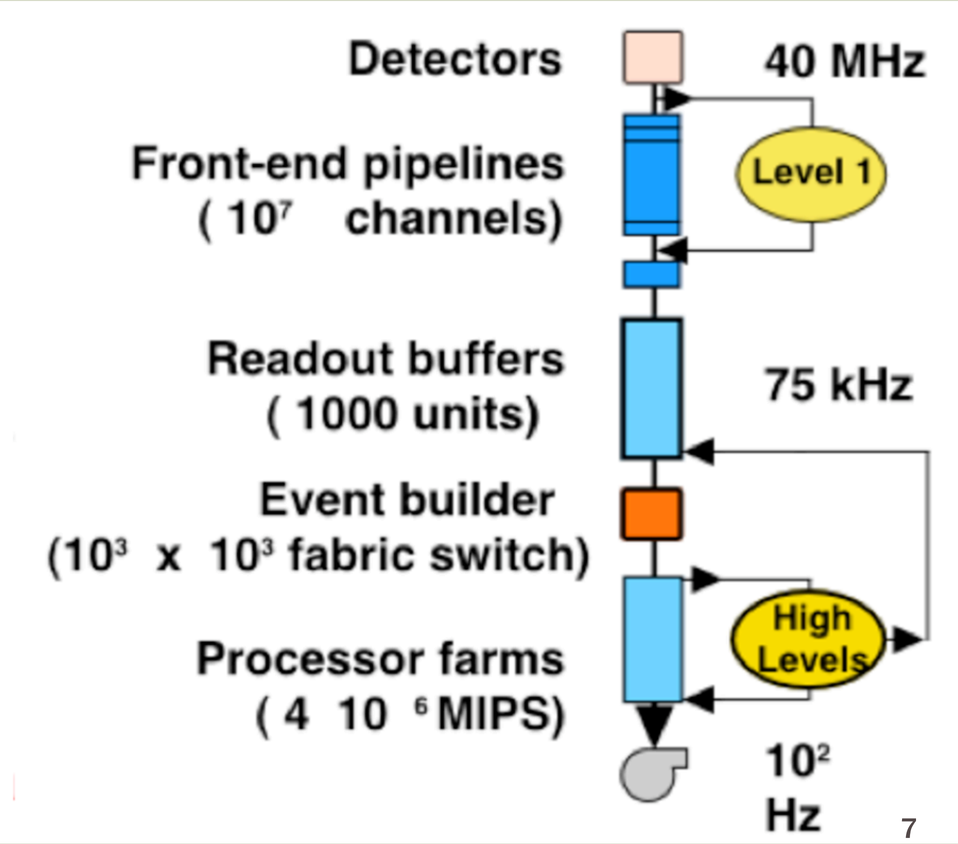


TRIGGER

ATLAS: 3 Levels



CMS: 2 Levels



TRIGGER PHILOSOPHY

- Physics-object based
  - electrons, muons, jets, b-jets, taus,
  - SUM ET, MET
- Reject as early as possible, leaving more time for more complicated decisions
- Need to be able to measure trigger efficiency
  - back-up triggers required?
- Result, ~500 distinct selections at the trigger level

TRIGGER MENU JUGGLING: ATLAS ORGANIZATION

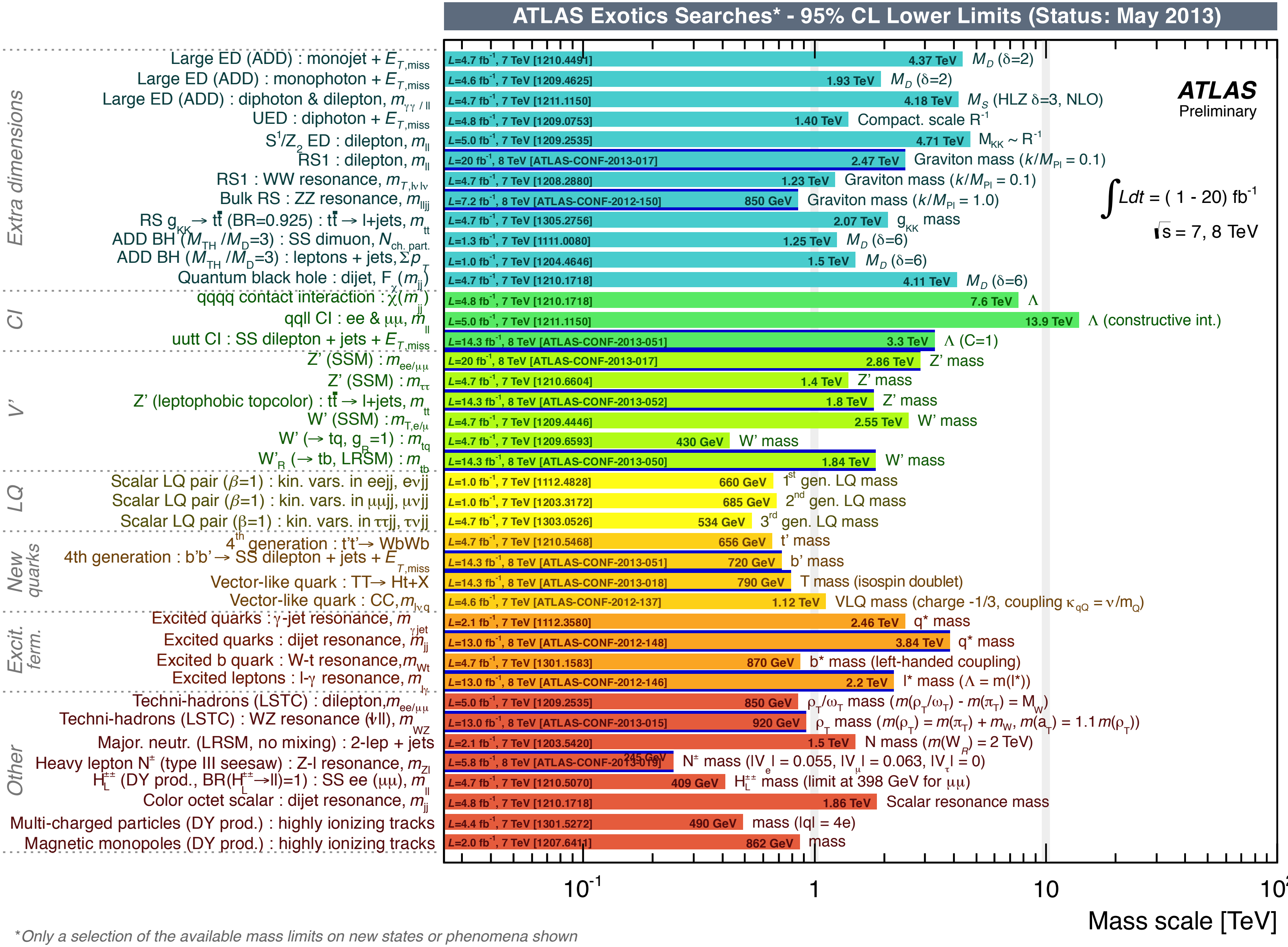
Physics Groups

B Physics
Top
Standard Model
Higgs
SUSY
Exotics
Heavy Ions
Monte Carlo

Combined Performance

e/gamma
Flavour tagging
Jet/MET
Tau
Muon
Inner Tracking

Note: the Exotics group has an "other" category...



SUSY: this is just a representative selection...

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: LHCP 2013

ATLAS Preliminary

$\int \mathcal{L}dt = (4.4 - 20.7)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 7, 8$ TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}dt\ [\mathrm{fb}^{-1}]$	Mass limit		Reference
Inclusive searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.8 TeV	$m(\tilde{q})=m(\tilde{g})$	ATLAS-CONF-2013-047
	MSUGRA/CMSSM	1 e, μ	4 jets	Yes	5.8	$\tilde{q}, \tilde{g}$ 1.24 TeV	$m(\tilde{q})=m(\tilde{g})$	ATLAS-CONF-2012-104
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-054
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 740 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV	ATLAS-CONF-2013-047
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0) = 0$ GeV	ATLAS-CONF-2013-047
	Gluino med. $\tilde{\chi}^{\pm}$ ($\tilde{g}\to q\bar{q}\tilde{\chi}^{\pm}$)	1 e, μ	2-4 jets	Yes	4.7	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0) < 200$ GeV, $m(\tilde{\chi}^{\pm}) = 0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	1208.4688
	$\tilde{g}\tilde{g}\to qqqql\ell(\ell\ell)\tilde{\chi}_1^0\tilde{\chi}_1^0$	2 e, μ (SS)	3 jets	Yes	20.7	$\tilde{g}$ 1.1 TeV	$m(\tilde{\chi}_1^0) < 650$ GeV	ATLAS-CONF-2013-007
	GMSB ($\tilde{\ell}$ NLSP)	2 e, μ	2-4 jets	Yes	4.7	$\tilde{g}$ 1.24 TeV	$\tan\beta < 15$	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ	0-2 jets	Yes	20.7	$\tilde{g}$ 1.4 TeV	$\tan\beta > 18$	ATLAS-CONF-2013-026
	GGM (bino NLSP)	2 γ	0	Yes	4.8	$\tilde{g}$ 1.07 TeV	$m(\tilde{\chi}_1^0) > 50$ GeV	1209.0753
	GGM (wino NLSP)	1 e, μ + γ	0	Yes	4.8	$\tilde{g}$ 619 GeV	$m(\tilde{\chi}_1^0) > 50$ GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0) > 220$ GeV	1211.1167
	GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	$m(\tilde{H}) > 200$ GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale 645 GeV	$m(\tilde{G}) > 10^{-4}$ eV	ATLAS-CONF-2012-147
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	12.8	$\tilde{g}$ 1.24 TeV	$m(\tilde{\chi}_1^0) < 200$ GeV	ATLAS-CONF-2012-145
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	2 e, μ (SS)	0-3 b	No	20.7	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0) < 500$ GeV	ATLAS-CONF-2013-007
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.14 TeV	$m(\tilde{\chi}_1^0) < 200$ GeV	ATLAS-CONF-2013-054
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	3 b	Yes	12.8	$\tilde{g}$ 1.15 TeV	$m(\tilde{\chi}_1^0) < 200$ GeV	ATLAS-CONF-2012-145
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-630 GeV	$m(\tilde{\chi}_1^0) < 100$ GeV	ATLAS-CONF-2013-053
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^{\pm}$	2 e, μ (SS)	0-3 b	Yes	20.7	$\tilde{b}_1$ 430 GeV	$m(\tilde{\chi}_1^{\pm}) = 2\,m(\tilde{\chi}_1^0)$	ATLAS-CONF-2013-007
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	1-2 e, μ	1-2 b	Yes	4.7	$\tilde{t}_1$ 167 GeV	$m(\tilde{\chi}_1^0) = 55$ GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 220 GeV	$m(\tilde{\chi}_1^0) = m(\tilde{t}_1) - m(W) - 50$ GeV, $m(\tilde{t}_1) << m(\tilde{\chi}_1^{\pm})$	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	2 e, μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 150-440 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV, $m(\tilde{t}_1)-m(\tilde{\chi}_1^{\pm}) = 10$ GeV	ATLAS-CONF-2013-048
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	0	2 b	Yes	20.1	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0) < 200$ GeV, $m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0) = 5$ GeV	ATLAS-CONF-2013-053
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e, μ	1 b	Yes	20.7	$\tilde{t}_1$ 200-610 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV	ATLAS-CONF-2013-037
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.5	$\tilde{t}_1$ 320-660 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV	ATLAS-CONF-2013-024
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_1$ 500 GeV	$m(\tilde{\chi}_1^0) > 150$ GeV	ATLAS-CONF-2013-025
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e, μ (Z)	1 b	Yes	20.7	$\tilde{t}_2$ 520 GeV	$m(\tilde{t}_1) = m(\tilde{\chi}_1^0) + 180$ GeV	ATLAS-CONF-2013-025
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e, μ	0	Yes	20.3	$\tilde{\ell}$ 85-315 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e, μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 125-450 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV, $m(\tilde{\ell},\tilde{\nu}) = 0.5(m(\tilde{\chi}_1^{\pm}) + m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-049
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	0	Yes	20.7	$\tilde{\chi}_1^{\pm}$ 180-330 GeV	$m(\tilde{\chi}_1^0) = 0$ GeV, $m(\tilde{\tau},\tilde{\nu}) = 0.5(m(\tilde{\chi}_1^{\pm}) + m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-028
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to \tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 600 GeV	$m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0) = 0$, $m(\tilde{\ell},\tilde{\nu}) = 0.5(m(\tilde{\chi}_1^{\pm}) + m(\tilde{\chi}_1^0))$	ATLAS-CONF-2013-035
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W^*\tilde{\chi}_1^0 Z^{(*)}\tilde{\chi}_1^0$	3 e, μ	0	Yes	20.7	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 315 GeV	$m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0) = 0$, sleptons decoupled	ATLAS-CONF-2013-035
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	0	1 jet	Yes	4.7	$\tilde{\chi}_1^{\pm}$ 220 GeV	$1 < \tau(\tilde{\chi}_1^{\pm}) < 10$ ns	1210.2852
	Stable $\tilde{g}$, R-hadrons	0-2 e, μ	0	Yes	4.7	$\tilde{g}$ 985 GeV		1211.1597
	GMSB, stable $\tilde{\tau}$, low β	2 e, μ	0	Yes	4.7	$\tilde{\tau}$ 300 GeV	$5 < \tan\beta < 20$	1211.1597
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	0	Yes	4.7	$\tilde{\chi}_1^0$ 230 GeV	$0.4 < \tau(\tilde{\chi}_1^0) < 2$ ns	1304.6310
	$\tilde{\chi}_1^0 \to qq\mu$ (RPV)	1 e, μ	0	Yes	4.4	$\tilde{q}$ 700 GeV	1 mm < cτ < 1 m, $\tilde{g}$ decoupled	1210.7451
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e+\mu$	2 e, μ	0	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	$\lambda'_{311}=0.10, \lambda_{132}=0.05$	1212.1272
	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e(\mu)+\tau$	1 e, μ + τ	0	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	$\lambda'_{311}=0.10, \lambda_{1(2)33}=0.05$	1212.1272
	Bilinear RPV CMSSM	1 e, μ	7 jets	Yes	4.7	$\tilde{q}, \tilde{g}$ 1.2 TeV	$m(\tilde{q}) = m(\tilde{g})$, $c\tau_{LSP} < 1$ mm	ATLAS-CONF-2012-140
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	0	Yes	20.7	$\tilde{\chi}_1^{\pm}$ 760 GeV	$m(\tilde{\chi}_1^0) > 300$ GeV, $\lambda_{121} > 0$	ATLAS-CONF-2013-036
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 e, μ + τ	0	Yes	20.7	$\tilde{\chi}_1^{\pm}$ 350 GeV	$m(\tilde{\chi}_1^0) > 80$ GeV, $\lambda_{133} > 0$	ATLAS-CONF-2013-036
	$\tilde{g} \to qqq$	0	6 jets	-	4.6	$\tilde{g}$ 666 GeV		1210.4813
	$\tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	2 e, μ (SS)	0-3 b	Yes	20.7	$\tilde{g}$ 880 GeV		ATLAS-CONF-2013-007
Other	Scalar gluon	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693	1210.4826
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale 704 GeV	$m(\chi) < 80$ GeV, limit of < 687 GeV for D8	ATLAS-CONF-2012-147

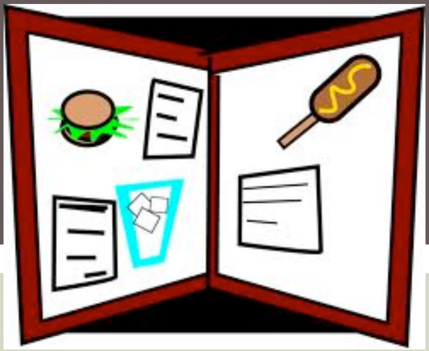
$\sqrt{s} = 7$ TeV full data | $\sqrt{s} = 8$ TeV partial data | $\sqrt{s} = 8$ TeV full data

10^{-1} 1 Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

1 TeV

MAKING THE MENU



- Need low threshold leptons
  - to keep SM (W and Z) and the Higgs is light
  - SUSY cascades can result in lots of low p_T stuff

↓

- Impose isolation requirements
  - this reduces rate for a given threshold, but can become inefficient at higher energy

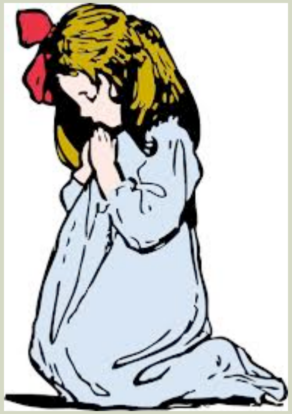
    ↓

    - add higher p_T un-isolated thresholds

- Make multiple object selections (2 electrons, or 1 electron + 1 muon)
  - results in many combinations, could be optimized per “signal” channel with competing interests

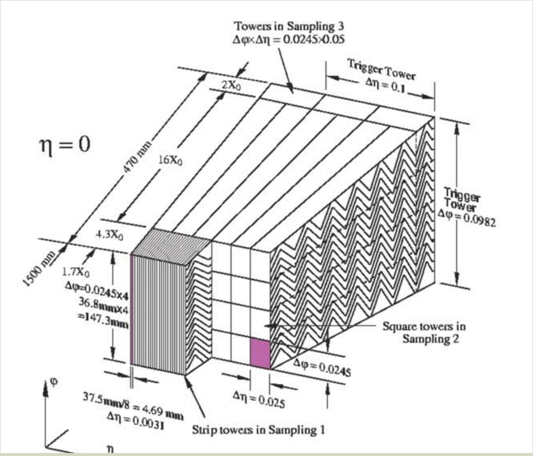
SO, YOU HAVE AN ANALYSIS IDEA?

- Present the analysis to your colleagues
- Propose trigger item
  - Calculate rate (both total and unique)
  - Present plan for measuring efficiency + any back-up trigger needed
  - Present plan for how to adapt with changing conditions
    - should item be pre-scaled? Thresholds increased?
- Bandwidth allocation is driven by priorities of the experiment



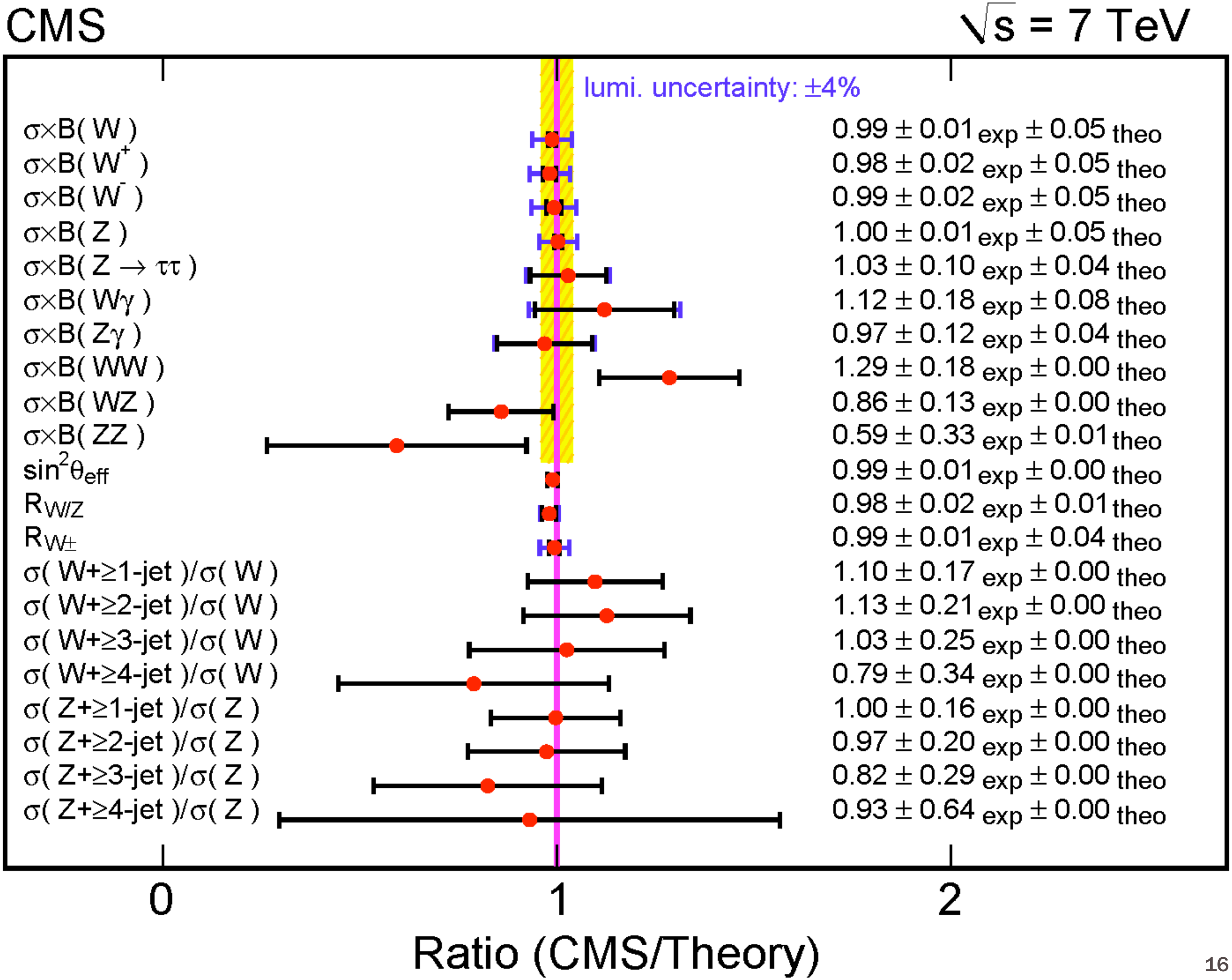
MOVING FORWARD?

- How to cope with additional pile-up for LHC Run 2 and beyond?
  - Add more information or increase the quality of information available
  - ATLAS plans to increase granularity of Level 1 calorimeter information, add topology information at L1, and have fast-tracking input to L2
  - For “Run3”, tracking would likely be added at Level 1



ELECTROWEAK OVERVIEW

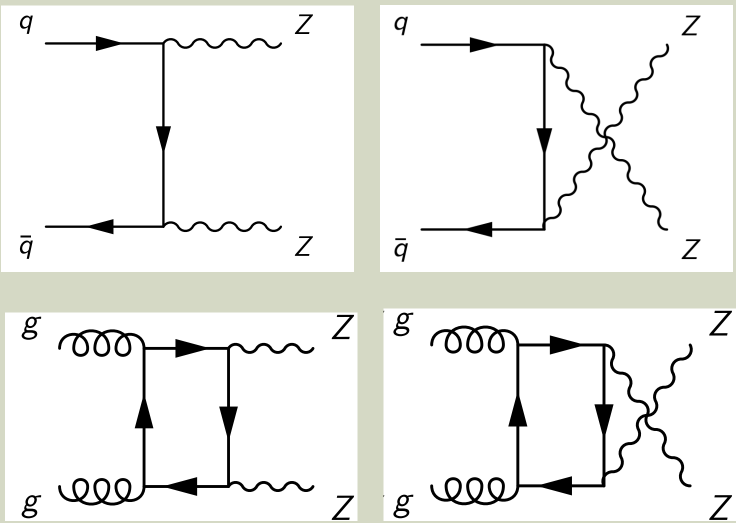
CMS


CMS
√s = 7 TeV
lumi. uncertainty: ±4%
σ×B(W) 0.99 ± 0.01 exp ± 0.05 theo
σ×B(W+) 0.98 ± 0.02 exp ± 0.05 theo
σ×B(W-) 0.99 ± 0.02 exp ± 0.05 theo
σ×B(Z) 1.00 ± 0.01 exp ± 0.05 theo
σ×B(Z → ττ) 1.03 ± 0.10 exp ± 0.04 theo
σ×B(Wγ) 1.12 ± 0.18 exp ± 0.08 theo
σ×B(Zγ) 0.97 ± 0.12 exp ± 0.04 theo
σ×B(WW) 1.29 ± 0.18 exp ± 0.00 theo
σ×B(WZ) 0.86 ± 0.13 exp ± 0.00 theo
σ×B(ZZ) 0.59 ± 0.33 exp ± 0.01 theo
sin2θeff 0.99 ± 0.01 exp ± 0.00 theo
RW/Z 0.98 ± 0.02 exp ± 0.01 theo
RW± 0.99 ± 0.01 exp ± 0.04 theo
σ(W+≥1-jet)/σ(W) 1.10 ± 0.17 exp ± 0.00 theo
σ(W+≥2-jet)/σ(W) 1.13 ± 0.21 exp ± 0.00 theo
σ(W+≥3-jet)/σ(W) 1.03 ± 0.25 exp ± 0.00 theo
σ(W+≥4-jet)/σ(W) 0.79 ± 0.34 exp ± 0.00 theo
σ(Z+≥1-jet)/σ(Z) 1.00 ± 0.16 exp ± 0.00 theo
σ(Z+≥2-jet)/σ(Z) 0.97 ± 0.20 exp ± 0.00 theo
σ(Z+≥3-jet)/σ(Z) 0.82 ± 0.29 exp ± 0.00 theo
σ(Z+≥4-jet)/σ(Z) 0.93 ± 0.64 exp ± 0.00 theo
0
1
2
Ratio (CMS/Theory)

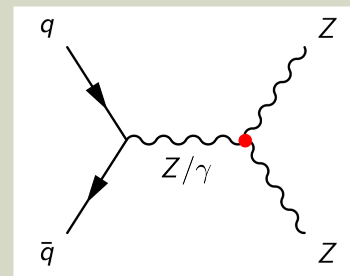
ZZ PRODUCTION

ATLAS

PRODUCTION OF ZZ



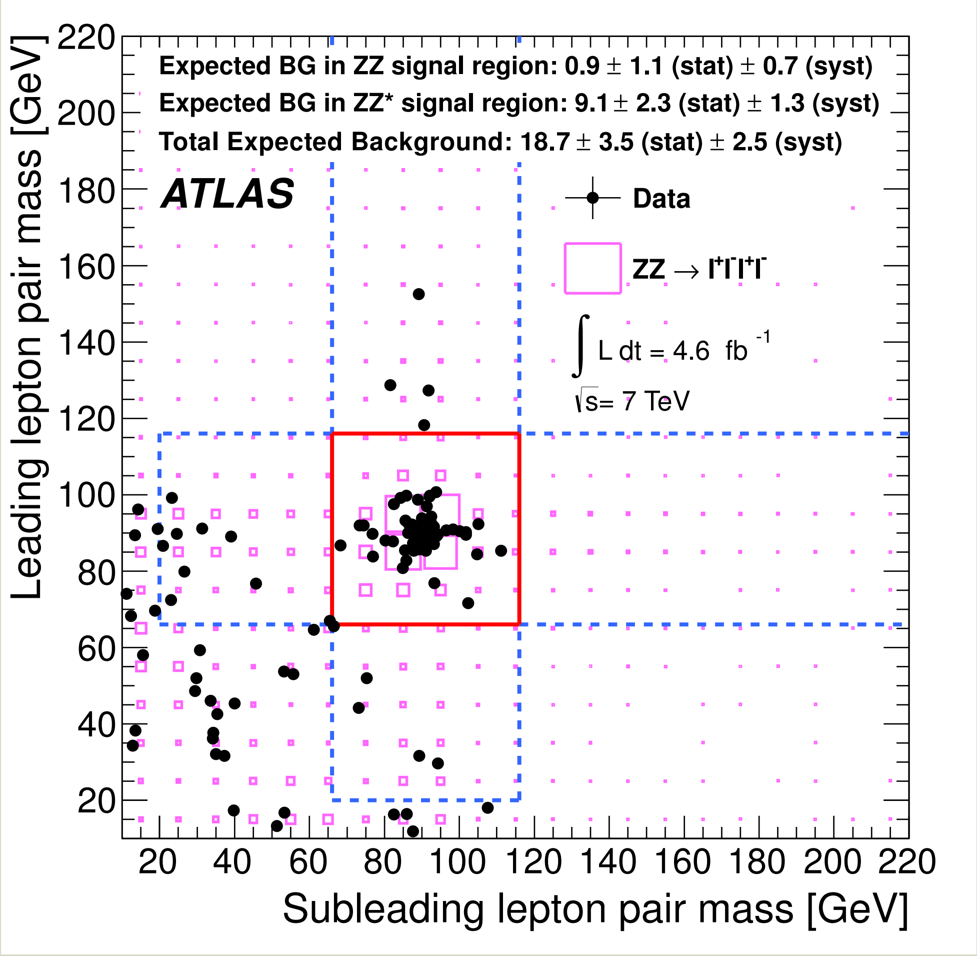
SM does not have neutral triple gauge boson couplings



Predicted ZZ cross section, with NLO and natural Z width: $5.89^{+0.22}_{-0.18}$ pb

Higgs also produces ZZ, but one Z is offshell – "contamination" of this analysis expected at the level of 3%

FOUR CHARGED LEPTON CHANNEL



FIDUCIAL CROSS SECTION

$$\sigma_{ZZ}^{\text{fid}} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{C_{ZZ} \times \mathcal{L}}$$

correction factor: $\dfrac{\text{\# events passing selection}}{\text{\# signal events in fiducial region}}$

Selection	C_{ZZ}
$ZZ \to \ell^+\ell^-\ell'^+\ell'^-$	$0.552 \pm 0.002 \pm 0.021$
$ZZ^* \to \ell^+\ell^-\ell'^+\ell'^-$	$0.542 \pm 0.002 \pm 0.022$
$ZZ \to \ell^+\ell^-\nu\bar{\nu}$	$0.679 \pm 0.004 \pm 0.014$

From data-corrected MC in particular, lepton p_T and resolution

EXTRAPOLATE TO TOTAL PHASE SPACE?

$$\sigma_{ZZ}^{\text{total}} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{A_{ZZ} \times C_{ZZ} \times \mathcal{L} \times \text{BF}}$$

A_{zz} = Acceptance

Branching Fraction

Selection	A_{ZZ}
$ZZ \to \ell^+\ell^-\ell'^+\ell'^-$	$0.804 \pm 0.001 \pm 0.010$
$ZZ \to \ell^+\ell^-\nu\bar{\nu}$	$0.081 \pm 0.001 \pm 0.004$

Keep backgrounds low!!

SYSTEMATICS (AS % OF A OR C)

Source	$ZZ \to \ell^+\ell^-\ell'^+\ell'^-$	$ZZ^* \to \ell^+\ell^-\ell'^+\ell'^-$	$ZZ \to \ell^+\ell^-\nu\bar{\nu}$
	C_{ZZ}		
Lepton efficiency	3.0%	3.1%	1.3%
Lepton energy/momentum	0.2%	0.3%	1.1%
Lepton isolation and impact parameter	1.9%	2.0%	0.6%
Jet+$E_{\mathrm{T}}^{\mathrm{miss}}$ modelling	–	–	0.8%
Jet veto	–	–	0.9%
Trigger efficiency	0.2%	0.2%	0.4%
PDF and scale	1.6%	1.5%	0.4%
	A_{ZZ}		
Jet veto	–	–	2.3%
PDF and scale	0.6%	–	1.9%
Generator modelling and parton shower	1.1%	–	4.6%

BACKGROUNDS

for the 4 ch. lepton channel, backgrounds come from jets faking electrons or muons measured from data (f), and scaled-up from lepton + jets sample (N) corrected for the signal.

	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$	$\ell^+\ell^-\ell'^+\ell'^-$
$(+)\ N(\ell\ell\ell j) \times f$	8.85 ± 0.98	0.21 ± 0.21	10.63 ± 1.06	19.70 ± 1.46
$(-) N(ZZ) \times f$	0.29 ± 0.18	$0.20^{+0.25}_{-0.20}$	0.56 ± 0.28	1.05 ± 0.42
$(-) N(\ell\ell jj) \times f^2$	4.24 ± 0.23	1.10 ± 0.31	4.24 ± 0.23	9.58 ± 0.45
Background estimate, $N(\mathrm{BG})$	4.3 ± 1.4(stat.)	< 0.91	5.8 ± 1.6(stat.)	9.1 ± 2.3(stat.)
	± 0.6(syst.)		± 0.9 (syst.)	± 1.3(syst.)

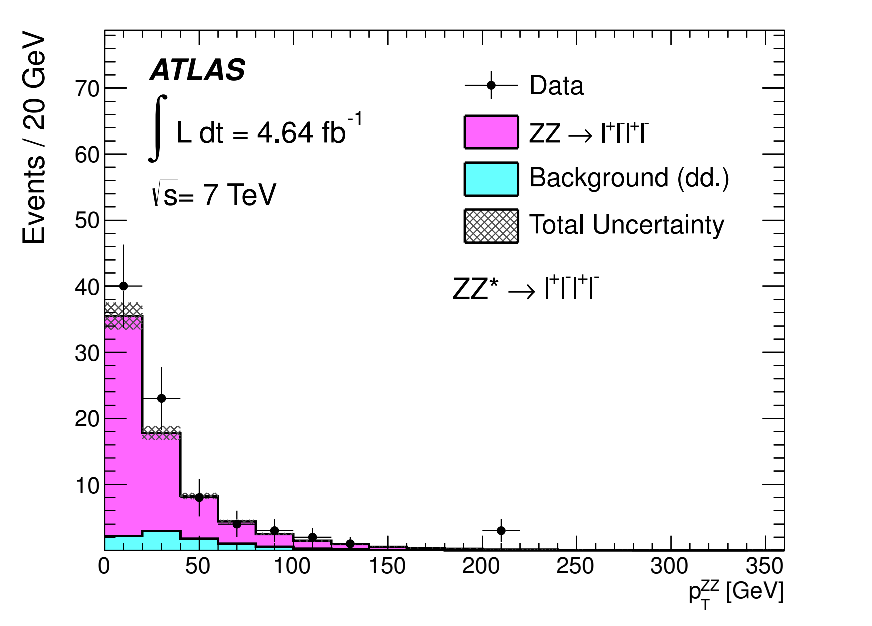
for the channel with neutrinos, the backgrounds are electroweak processes

data-driven → $t\bar{t}$, Wt, WW, $Z \to \tau^+\tau^-$; $Z \to \mu^+\mu^-, e^+e^-$+jets; $W+$ jets

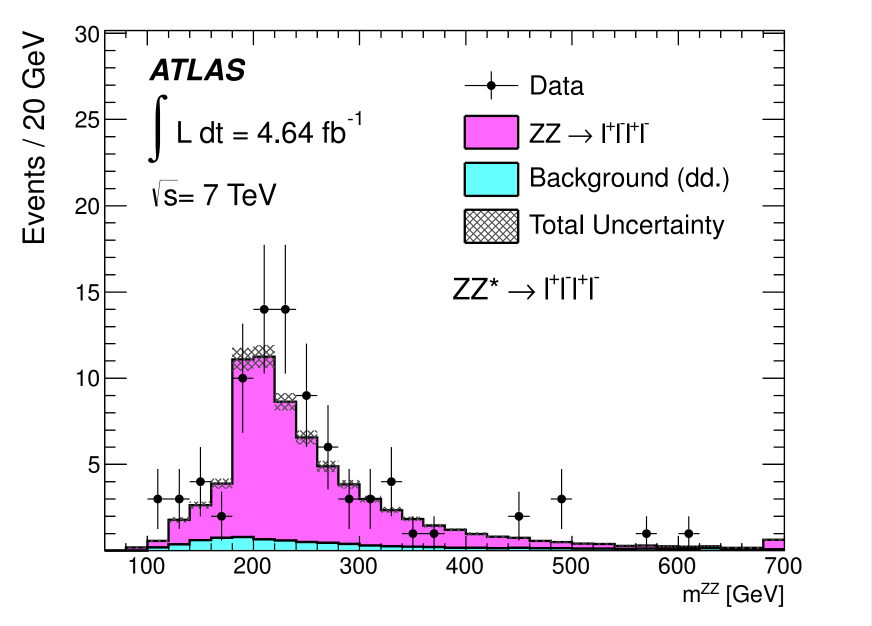
Process	$e^+e^- E_{\mathrm{T}}^{\mathrm{miss}}$	$\mu^+\mu^- E_{\mathrm{T}}^{\mathrm{miss}}$	$\ell^+\ell^- E_{\mathrm{T}}^{\mathrm{miss}}$
$t\bar{t}$, Wt, WW, $Z \to \tau^+\tau^-$	$8.5 \pm 2.1 \pm 0.5$	$10.6 \pm 2.6 \pm 0.6$	$19.1 \pm 2.3 \pm 1.0$
WZ	$8.9 \pm 0.5 \pm 0.4$	$11.9 \pm 0.5 \pm 0.3$	$20.8 \pm 0.7 \pm 0.5$
$Z \to \mu^+\mu^-, e^+e^-$+jets	$2.6 \pm 0.7 \pm 1.0$	$2.7 \pm 0.8 \pm 1.2$	$5.3 \pm 1.1 \pm 1.6$
$W+$ jets	$0.7 \pm 0.3 \pm 0.3$	$0.7 \pm 0.2 \pm 0.2$	$1.5 \pm 0.4 \pm 0.4$
$W\gamma$	$0.1 \pm 0.1 \pm 0.0$	$0.2 \pm 0.1 \pm 0.0$	$0.3 \pm 0.1 \pm 0.0$
Total	$20.8 \pm 2.3 \pm 1.2$	$26.1 \pm 2.8 \pm 1.4$	$46.9 \pm 4.8 \pm 1.9$

DO WE KNOW WHAT WE ARE DOING?

transverse momentum (ZZ)



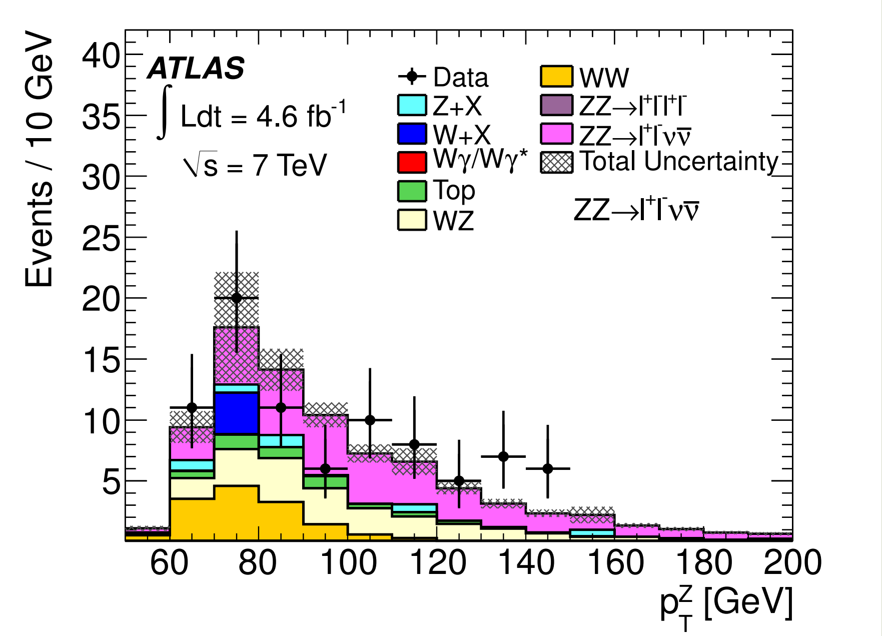
Invariant mass (ZZ)



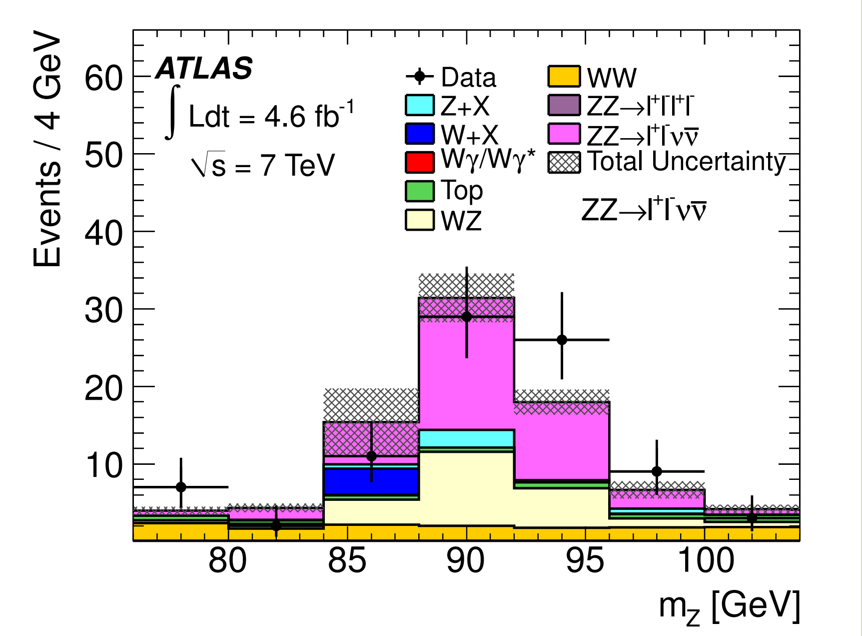
for the $l^+l^-l^+l^-$ channel

WHAT ABOUT FOR THIS CHANNEL?

transverse momentum (ZZ)



Invariant mass (ZZ)

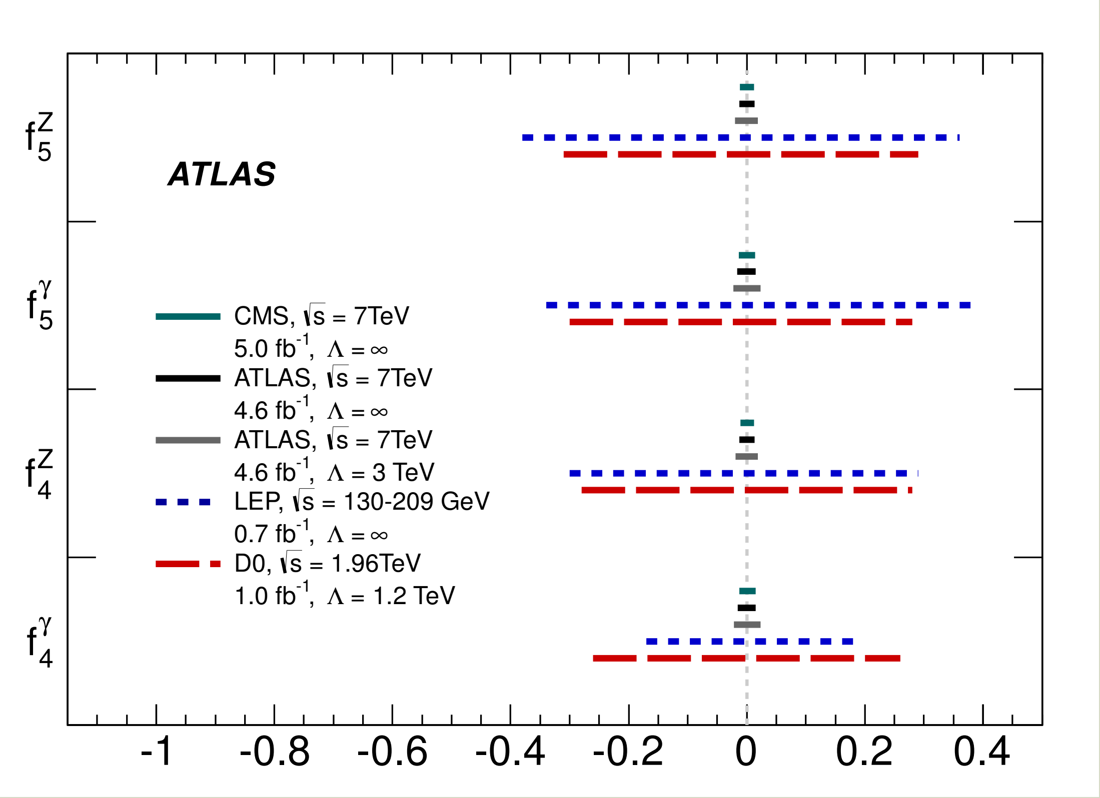


for the channel with two neutrinos

RESULTS

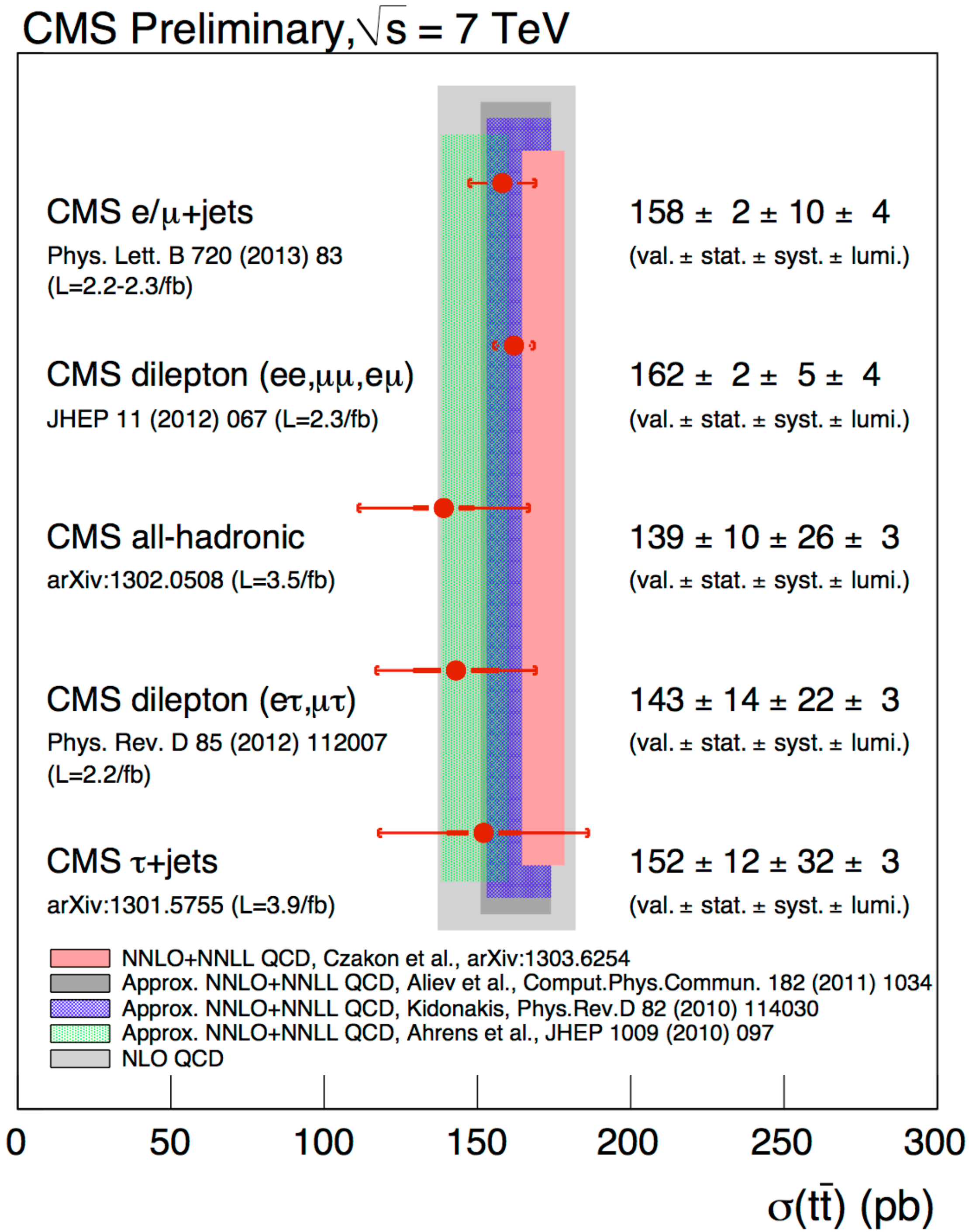
measured:

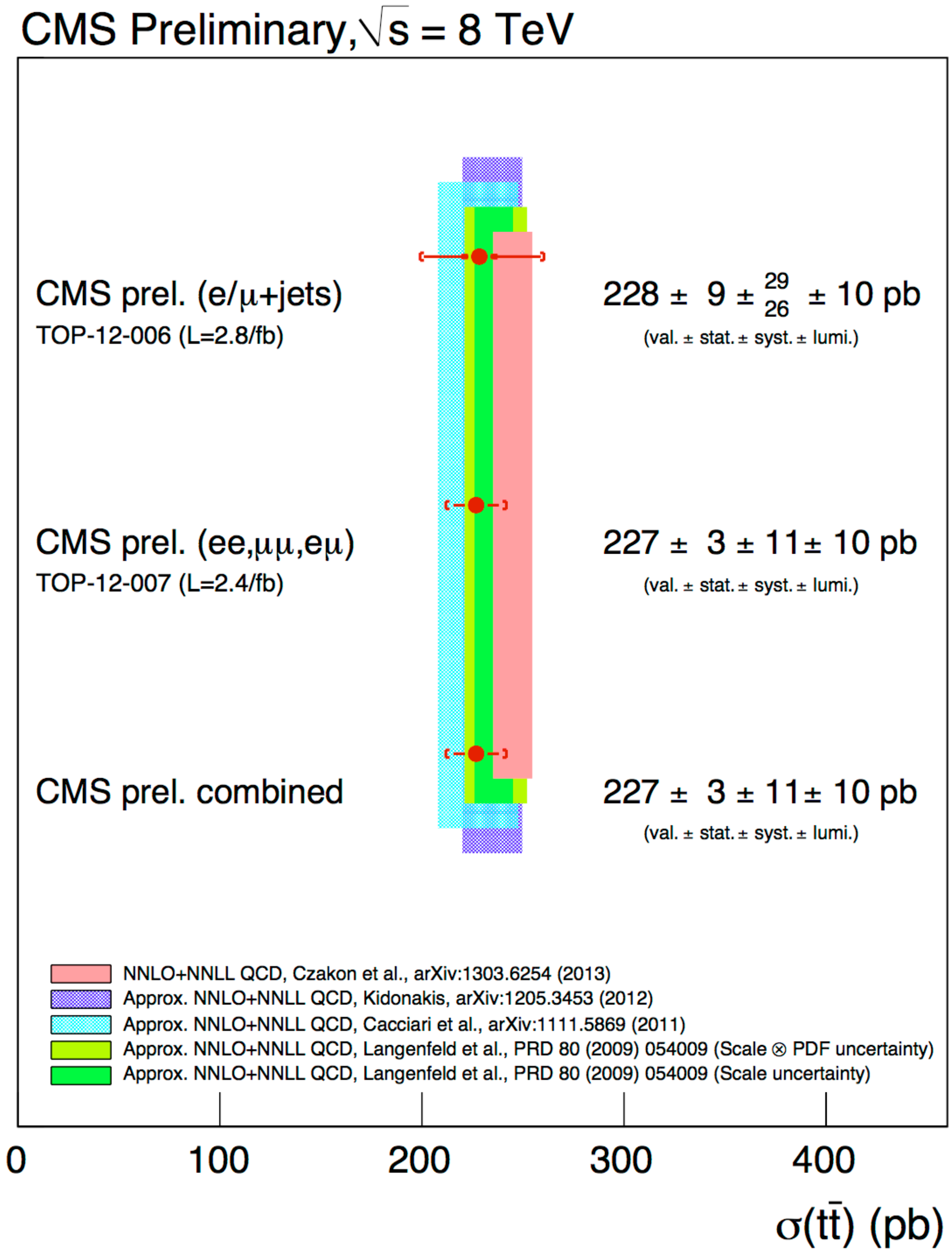
$$\sigma_{ZZ}^{\text{tot}} = 6.7 \pm 0.7\ (\text{stat.})\ {}^{+0.4}_{-0.3}\ (\text{syst.})\ \pm 0.3\ (\text{lumi.})\ \text{pb}.$$

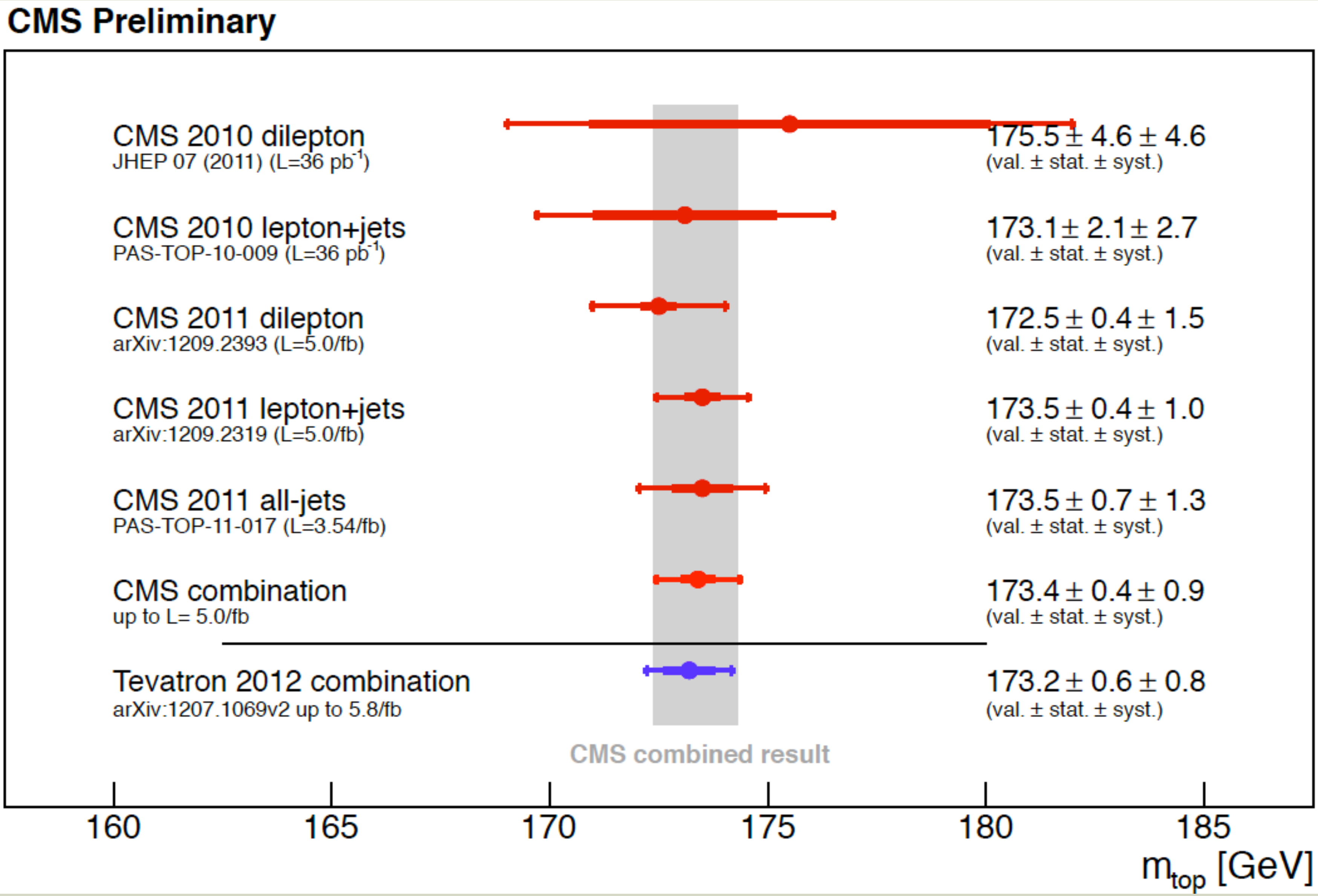


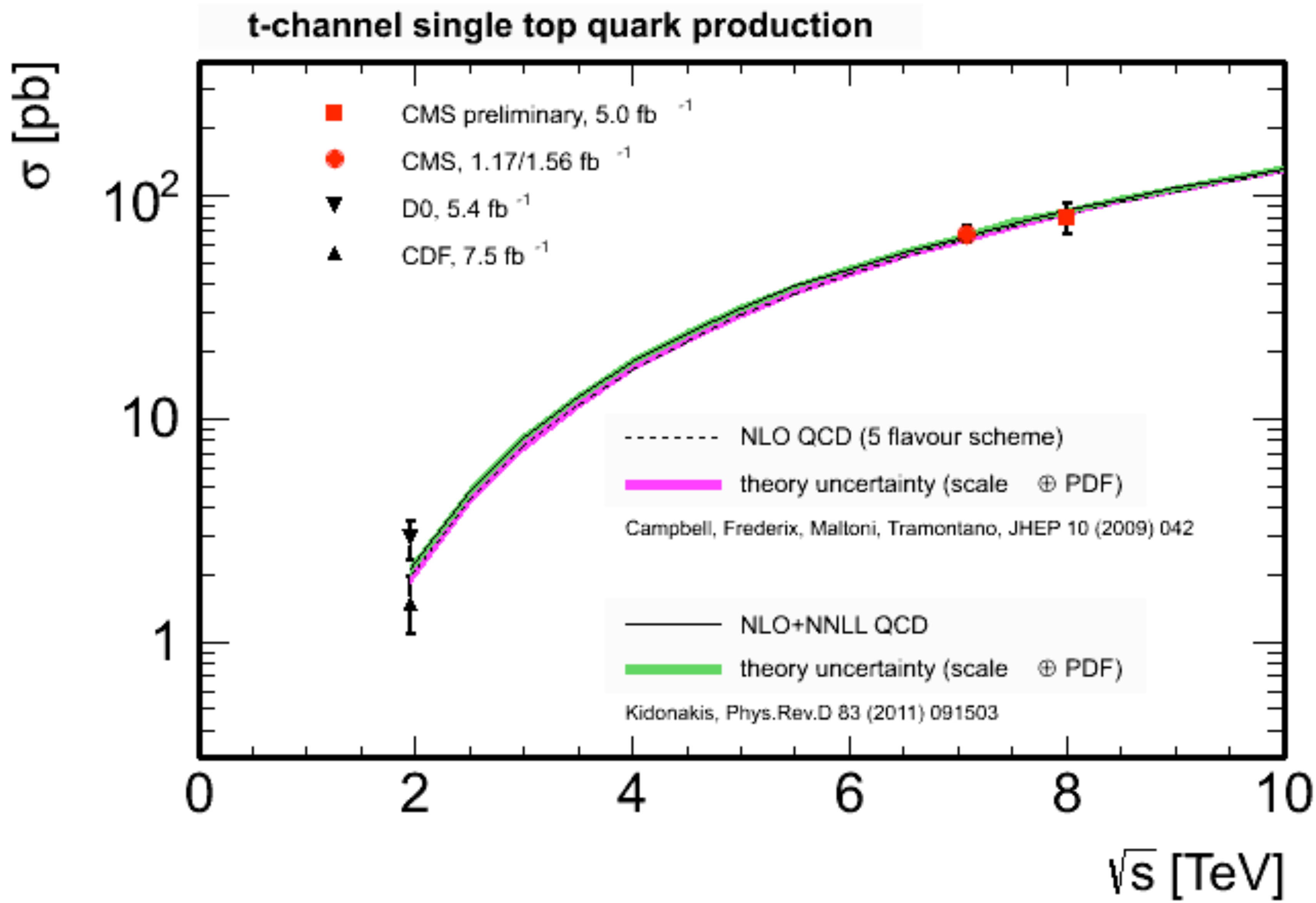
TOP QUARK OVERVIEW

CMS


CMS Preliminary, $\sqrt{s}$ = 7 TeV
CMS e/μ+jets
Phys. Lett. B 720 (2013) 83
(L=2.2-2.3/fb)
158 ± 2 ± 10 ± 4
(val. ± stat. ± syst. ± lumi.)
CMS dilepton (ee,μμ,eμ)
JHEP 11 (2012) 067 (L=2.3/fb)
162 ± 2 ± 5 ± 4
(val. ± stat. ± syst. ± lumi.)
CMS all-hadronic
arXiv:1302.0508 (L=3.5/fb)
139 ± 10 ± 26 ± 3
(val. ± stat. ± syst. ± lumi.)
CMS dilepton (eτ,μτ)
Phys. Rev. D 85 (2012) 112007
(L=2.2/fb)
143 ± 14 ± 22 ± 3
(val. ± stat. ± syst. ± lumi.)
CMS τ+jets
arXiv:1301.5755 (L=3.9/fb)
152 ± 12 ± 32 ± 3
(val. ± stat. ± syst. ± lumi.)
NNLO+NNLL QCD, Czakon et al., arXiv:1303.6254
Approx. NNLO+NNLL QCD, Aliev et al., Comput.Phys.Commun. 182 (2011) 1034
Approx. NNLO+NNLL QCD, Kidonakis, Phys.Rev.D 82 (2010) 114030
Approx. NNLO+NNLL QCD, Ahrens et al., JHEP 1009 (2010) 097
NLO QCD
0
50
100
150
200
250
300
σ(tt̄) (pb)


CMS Preliminary, $\sqrt{s}$ = 8 TeV
CMS prel. (e/μ+jets)
TOP-12-006 (L=2.8/fb)
228 ± 9 ± $^{29}_{26}$ ± 10 pb
(val. ± stat. ± syst. ± lumi.)
CMS prel. (ee,μμ,eμ)
TOP-12-007 (L=2.4/fb)
227 ± 3 ± 11± 10 pb
(val. ± stat. ± syst. ± lumi.)
CMS prel. combined
227 ± 3 ± 11± 10 pb
(val. ± stat. ± syst. ± lumi.)
NNLO+NNLL QCD, Czakon et al., arXiv:1303.6254 (2013)
Approx. NNLO+NNLL QCD, Kidonakis, arXiv:1205.3453 (2012)
Approx. NNLO+NNLL QCD, Cacciari et al., arXiv:1111.5869 (2011)
Approx. NNLO+NNLL QCD, Langenfeld et al., PRD 80 (2009) 054009 (Scale ⊗ PDF uncertainty)
Approx. NNLO+NNLL QCD, Langenfeld et al., PRD 80 (2009) 054009 (Scale uncertainty)
0
100
200
300
400
σ(tt̄) (pb)


CMS Preliminary
CMS 2010 dilepton
JHEP 07 (2011) (L=36 pb-1)
175.5 ± 4.6 ± 4.6
(val. ± stat. ± syst.)
CMS 2010 lepton+jets
PAS-TOP-10-009 (L=36 pb-1)
173.1 ± 2.1 ± 2.7
(val. ± stat. ± syst.)
CMS 2011 dilepton
arXiv:1209.2393 (L=5.0/fb)
172.5 ± 0.4 ± 1.5
(val. ± stat. ± syst.)
CMS 2011 lepton+jets
arXiv:1209.2319 (L=5.0/fb)
173.5 ± 0.4 ± 1.0
(val. ± stat. ± syst.)
CMS 2011 all-jets
PAS-TOP-11-017 (L=3.54/fb)
173.5 ± 0.7 ± 1.3
(val. ± stat. ± syst.)
CMS combination
up to L= 5.0/fb
173.4 ± 0.4 ± 0.9
(val. ± stat. ± syst.)
Tevatron 2012 combination
arXiv:1207.1069v2 up to 5.8/fb
173.2 ± 0.6 ± 0.8
(val. ± stat. ± syst.)
CMS combined result
160
165
170
175
180
185
m_top [GeV]


t-channel single top quark production
σ [pb]
10^2
10
1
CMS preliminary, 5.0 fb^{-1}
CMS, 1.17/1.56 fb^{-1}
D0, 5.4 fb^{-1}
CDF, 7.5 fb^{-1}
NLO QCD (5 flavour scheme)
theory uncertainty (scale ⊕ PDF)
Campbell, Frederix, Maltoni, Tramontano, JHEP 10 (2009) 042
NLO+NNLL QCD
theory uncertainty (scale ⊕ PDF)
Kidonakis, Phys.Rev.D 83 (2011) 091503
0
2
4
6
8
10
$\sqrt{s}$ [TeV]

ASSOCIATED PRODUCTION: TOP QUARK PAIRS AND W/Z

CMS

PRODUCTION

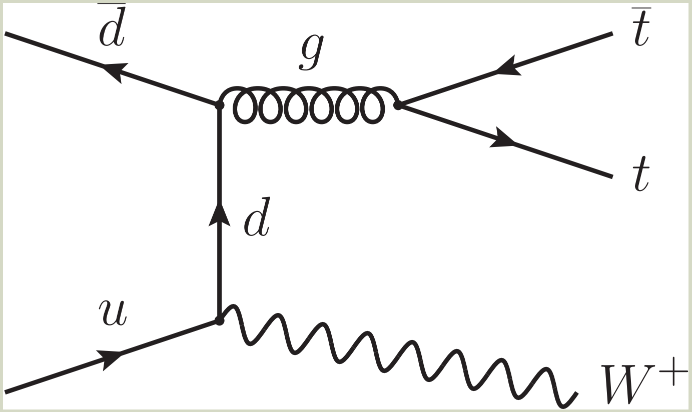
NLO calculation for ttW:

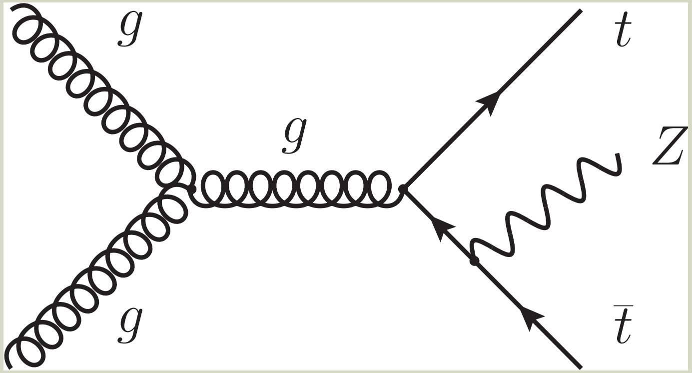
$$0.169^{+0.029}_{-0.051}\,\mathrm{pb}$$

NLO calculation for ttZ:

$$0.137^{+0.012}_{-0.016}\,\mathrm{pb}$$

Most important diagrams for ttV





Testing the SM at the TeV scale!

TRILEPTON ANALYIS

$$pp \to t\bar{t}Z \to (t \to b\ell^{\pm}\nu)(t \to bjj)(Z \to \ell^{\pm}\ell^{\mp}) \qquad (\text{with } \ell = e \text{ or } \mu)$$

TRILEPTON ANALYIS

$$pp \to t\bar{t}Z \to (t \to b\ell^{\pm}\nu)(t \to bjj)(Z \to \ell^{\pm}\ell^{\mp}) \qquad (\text{with } \ell = e \text{ or } \mu)$$

Z provides powerful constraint!
two same-flavor, opposite-sign leptons (pT > 20 GeV)
that give Z mass (81 – 100 GeV)

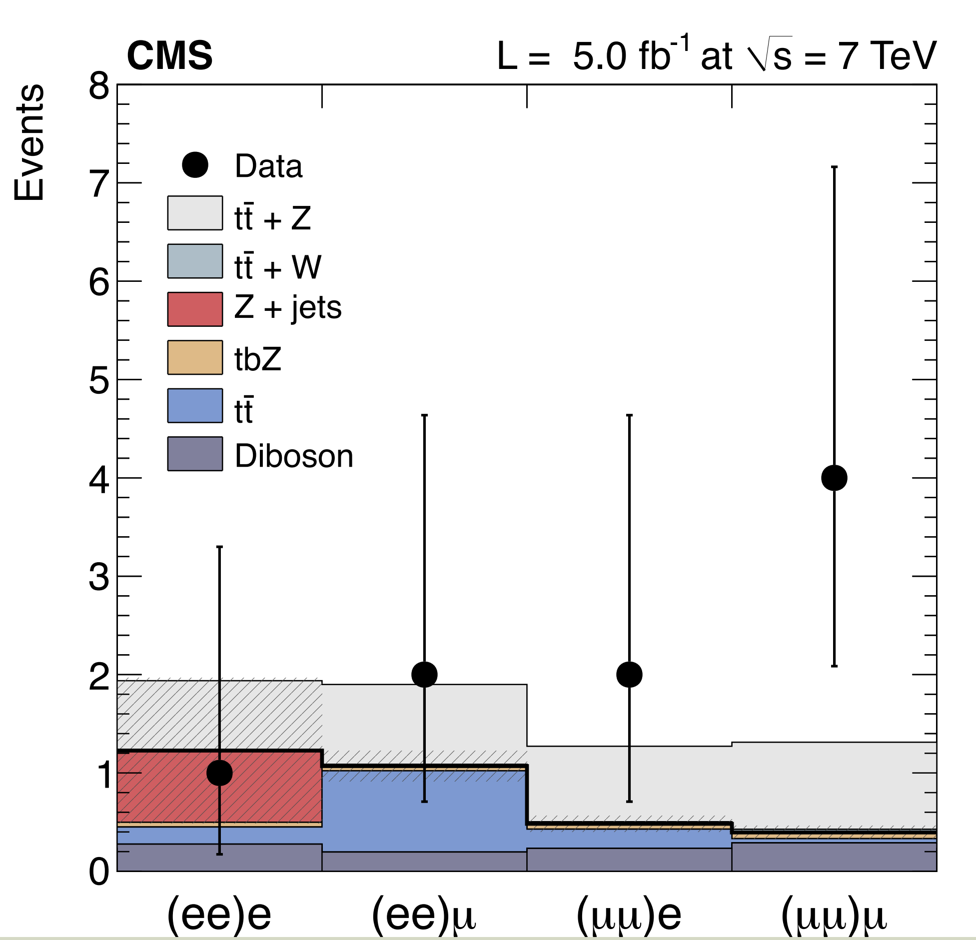
two b-quarks!

three jets, at least two b-tags
additional lepton > 10 GeV

transverse momentum of Z system > 35 GeV

scalar sum of p_T of all jets > 120 GeV

TRILEPTON RESULT



$$\sigma_{t\bar{t}Z} = 0.28^{+0.14}_{-0.11}\,(\text{stat.})\,{}^{+0.06}_{-0.03}\,(\text{syst.})\,\text{pb}$$

SAME-SIGN DILEPTONS (V+TTBAR)

$$pp \to t\bar{t}W \to (t \to b\ell^{\pm}\nu)(t \to bjj)(W \to \ell^{\pm}\nu)$$

$$pp \to t\bar{t}Z \to (t \to b\ell^{\pm}\nu)(t \to bjj)(Z \to \ell^{\pm}\ell^{\mp})$$

SAME-SIGN DILEPTONS (V+TTBAR)

$$pp \to t\bar{t}W \to (t \to b\ell^{\pm}\nu)(t \to bjj)(W \to \ell^{\pm}\nu)$$
$$pp \to t\bar{t}Z \to (t \to b\ell^{\pm}\nu)(t \to bjj)(Z \to \ell^{\pm}\ell^{\mp})$$

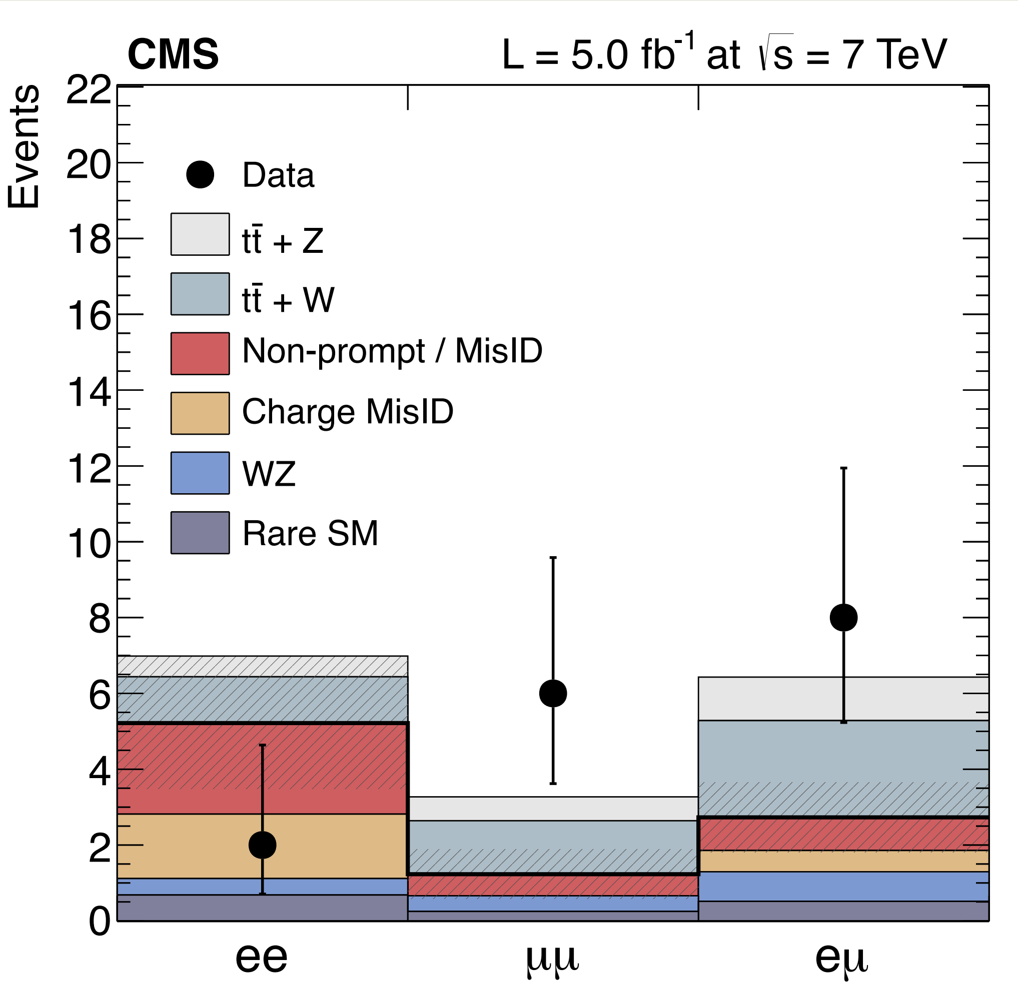
First, we want an orthogonal selection: veto events that pass trilepton analysis cuts

requiring three jets, at least one b-tagged

two same-sign leptons pT > 55 (30) GeV, with invariant mass > 8 GeV

Why is the Z even included in this selection?

SAME-SIGN RESULTS

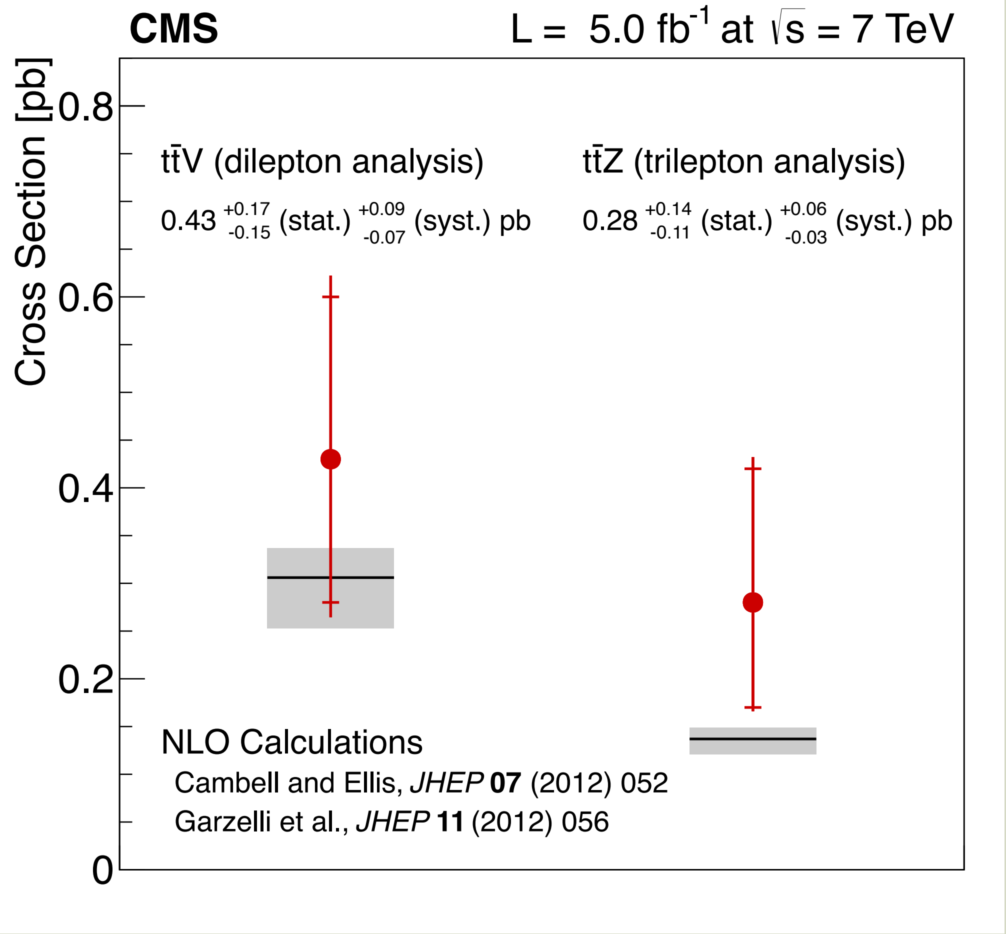


backgrounds are fairly low

ttV can be accessed

$$\sigma_{t\bar{t}V} = 0.43^{+0.17}_{-0.15}\,(\text{stat.})\;^{+0.09}_{-0.07}\,(\text{syst.})\,\text{pb}$$

SUMMARY



CMS
L = 5.0 fb-1 at √s = 7 TeV
Cross Section [pb]
0.8
0.6
0.4
0.2
0
tt̄V (dilepton analysis)
0.43 +0.17 -0.15 (stat.) +0.09 -0.07 (syst.) pb
tt̄Z (trilepton analysis)
0.28 +0.14 -0.11 (stat.) +0.06 -0.03 (syst.) pb
NLO Calculations
Cambell and Ellis, JHEP 07 (2012) 052
Garzelli et al., JHEP 11 (2012) 056

TTBAR RESONANCE SEARCH

ATLAS

USING LEPTON + JETS CHANNEL

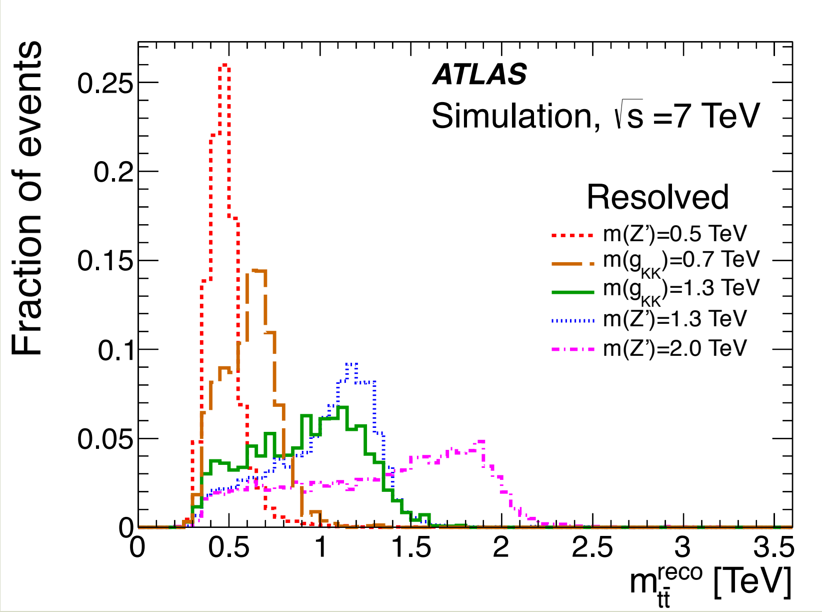
- Resolved
  - Trigger: low p_T single lepton (18 – 22 GeV depending on object)
  - jets assigned via minimization:

$$\chi^2 = \left[\frac{m_{jj} - m_W}{\sigma_W}\right]^2 + \left[\frac{m_{jjb} - m_{jj} - m_{t_h - W}}{\sigma_{t_h - W}}\right]^2 + \left[\frac{m_{j\ell\nu} - m_{t_\ell}}{\sigma_{t_\ell}}\right]^2 + \left[\frac{(p_{\mathrm{T},jjb} - p_{\mathrm{T},j\ell\nu}) - (p_{\mathrm{T},t_h} - p_{\mathrm{T},t_\ell})}{\sigma_{\mathrm{diff}\,p_\mathrm{T}}}\right]^2,$$

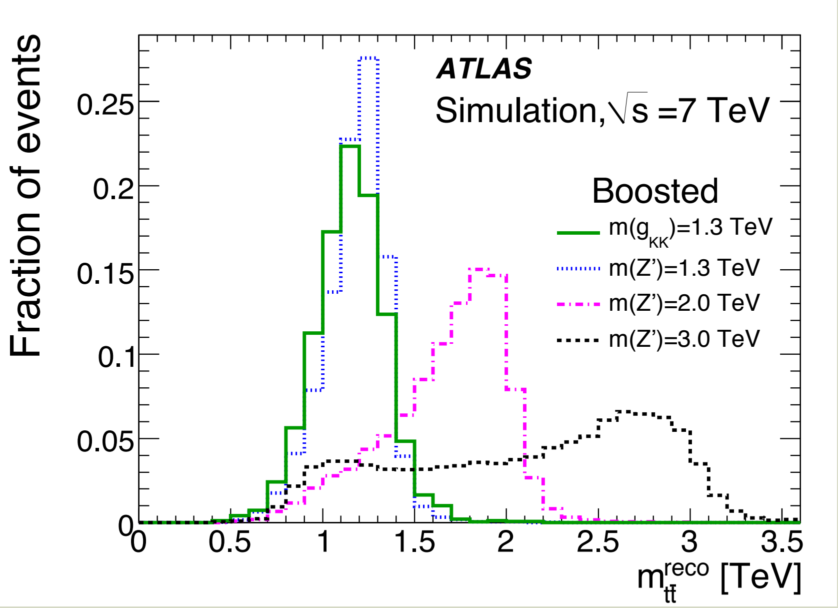
- Boosted
  - Trigger: large (R=1.0) radius high p_T (240 GeV) single jet trigger
  - offline single jet p_T cut is 350 GeV
  - the large jet is taken to have the W-> jets, so missing E_T provides the neutrino information

MASS RECONSTRUCTION (SIMULATION)

Resolved



Boosted

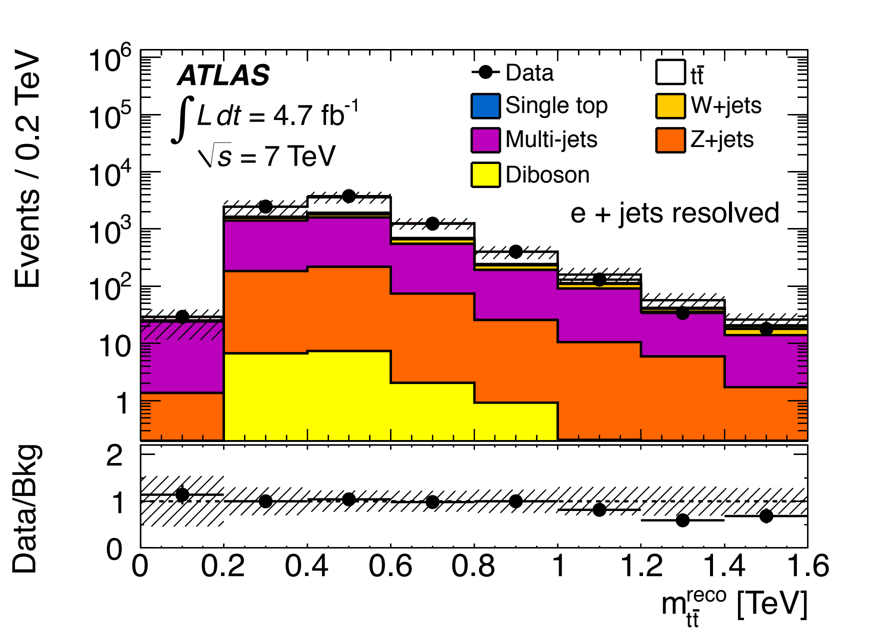


CONTROL REGION: MULTI-JET ENRICHED

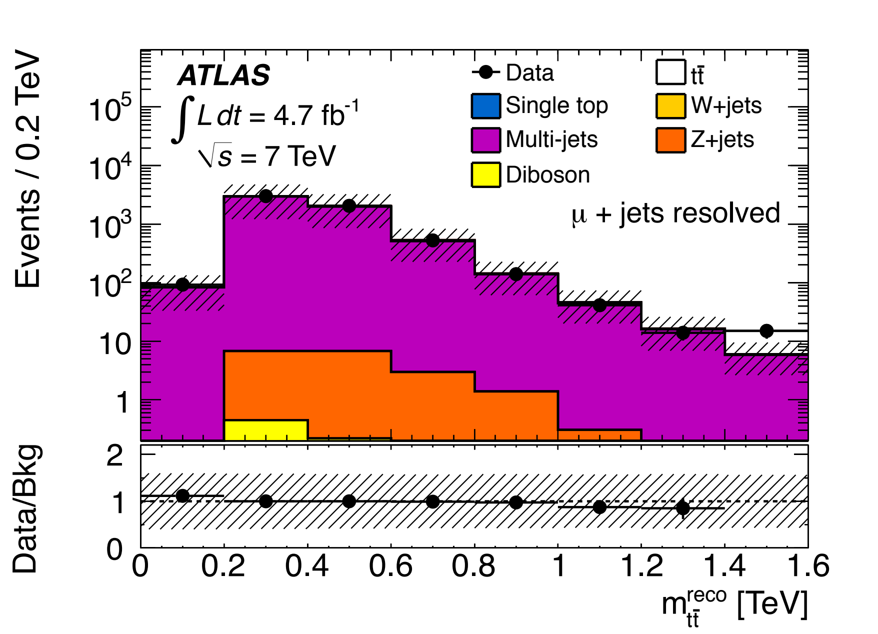
Require Missing ET < 50 GeV and m_T < 50 GeV

For muons, also require significant impact parameter to enrich in heavy flavor

electrons (resolved)



muons (resolved)

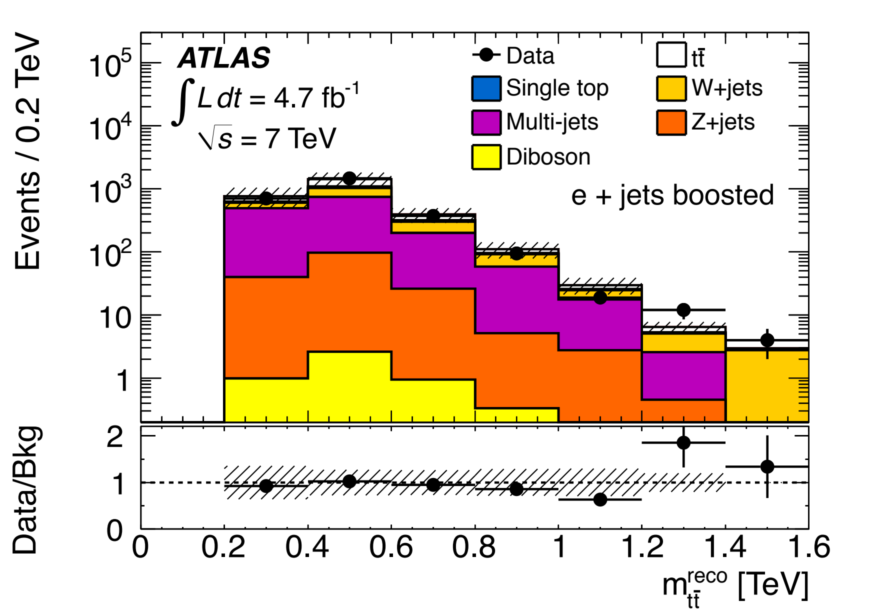


CONTROL REGION: MULTI-JET ENRICHED

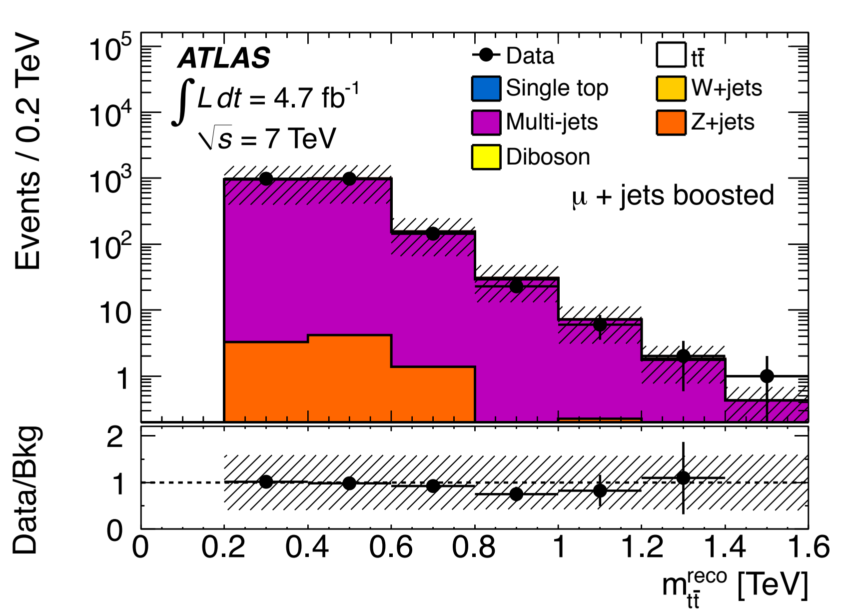
Require Missing ET < 50 GeV and m_T < 50 GeV

For muons, also require significant impact parameter to enrich in heavy flavor

electrons (boosted)



muons (boosted)



Systematic effect	Resolved selection uncertainty [%] tot. bkg.	Resolved selection uncertainty [%] Z'	Boosted selection uncertainty [%] tot. bkg.	Boosted selection uncertainty [%] Z'
Luminosity	3.3	3.9	3.5	3.9
PDF	4.7	3.2	7.3	1.5
ISR/FSR	0.5	–	0.9	–
Parton shower and fragm.	0.1	–	7.4	–
$t\bar{t}$ normalization	8.2	–	9.0	–
$t\bar{t}$ EW virtual correction	1.9	–	4.2	–
$t\bar{t}$ NLO scale variation	1.2	–	8.9	–
W+jets bb+cc+c vs. light	1.7	–	1.1	–
W+jets bb variation	1.3	–	1.1	–
W+jets c variation	0.8	–	0.1	–
W+jets normalization	1.3	–	1.5	–
Multi-jets norm, e+jets	1.7	–	0.4	–
Multi-jets norm, μ+jets	1.0	–	1.1	–
JES, small-radius jets	7.9	3.1	0.6	0.4
JES+JMS, large-radius jets	0.2	4.7	17.3	2.8
Jet energy resolution	1.3	0.7	0.5	0.2
Jet vertex fraction	1.4	1.8	1.9	1.9
b-tag efficiency	3.8	7.9	6.1	3.7
c-tag efficiency	1.2	0.6	0.1	2.6
Mistag rate	1.0	0.3	0.6	0.1
Electron efficiency	0.6	0.7	0.5	0.5
Muon efficiency	0.9	0.9	0.6	0.6
All systematic effects	14.1	11.2	25.4	7.1

Look at 1.6 TeV Z' to evaluate systematics

BACKGROUNDS

uncertainties listed are systematics

from data (Multi-jets e, Multi-jets μ, W+jets)

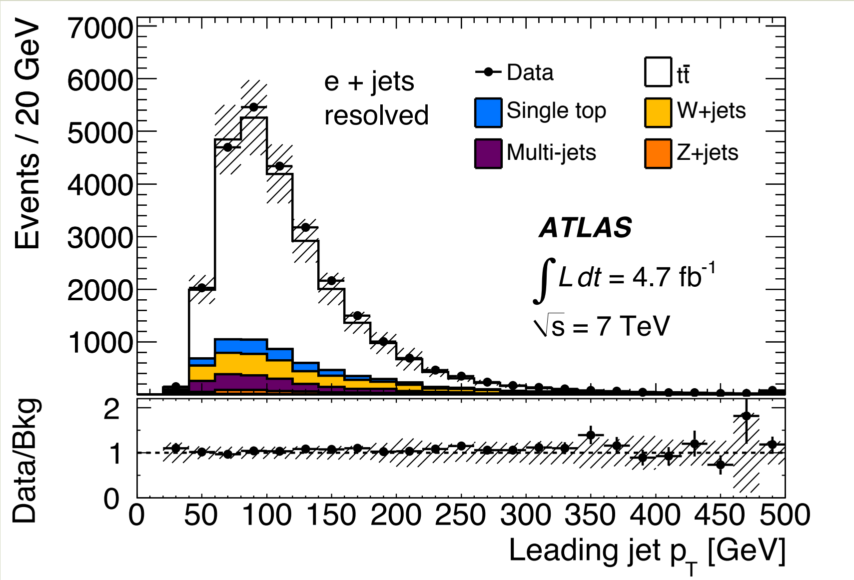
Type	Resolved selection	Boosted selection
$t\bar{t}$	44200 ± 7000	940 ± 260
Single top	3200 ± 500	50 ± 10
Multi-jets e	1600 ± 1000	8 ± 5
Multi-jets μ	1000 ± 600	19 ± 11
W+jets	7000 ± 2200	90 ± 30
Z+jets	800 ± 500	11 ± 6
Dibosons	120 ± 50	0.9 ± 0.6
Total	58000 ± 8000	1120 ± 280
Data	61931	1078

HOW DID WE DO?

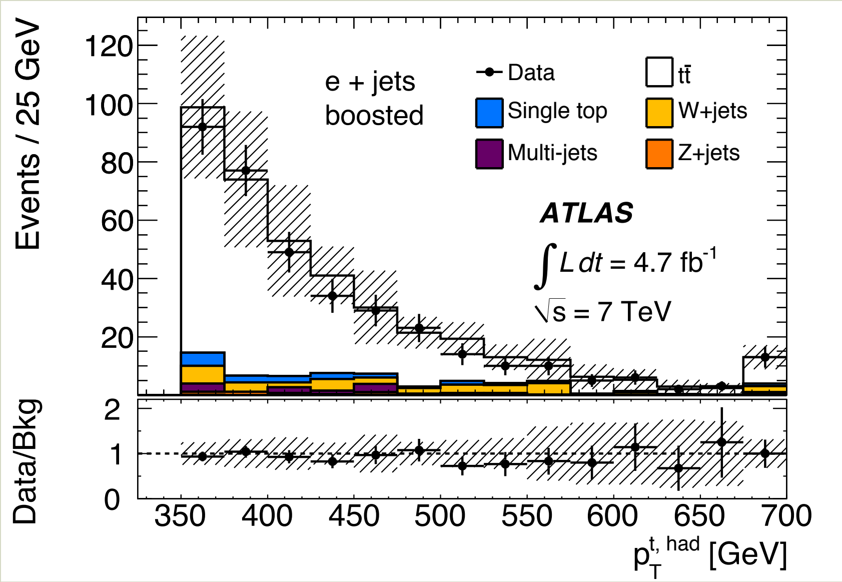
HOW DID WE DO?

electron channel

resolved category: p_T of leading jet



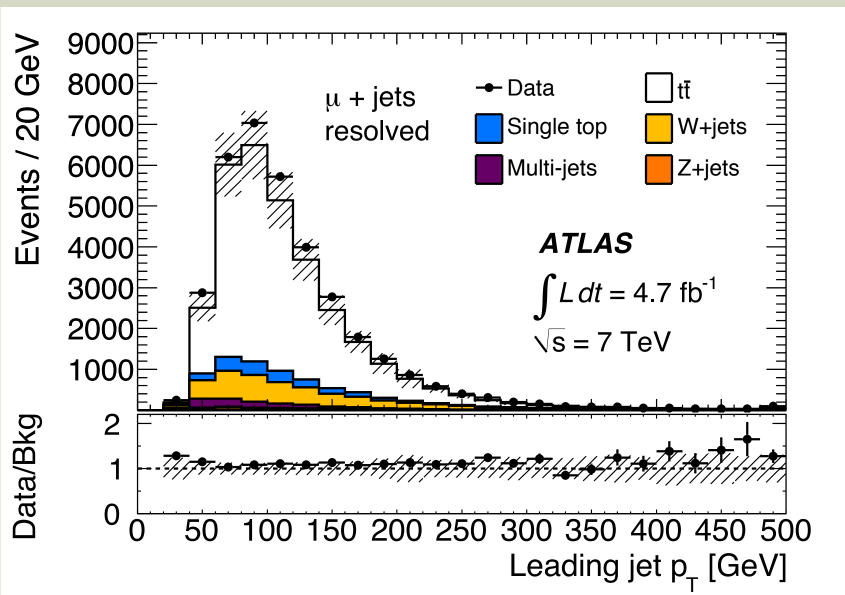
boosted category: p_T of hadronic top candidate (large jet)



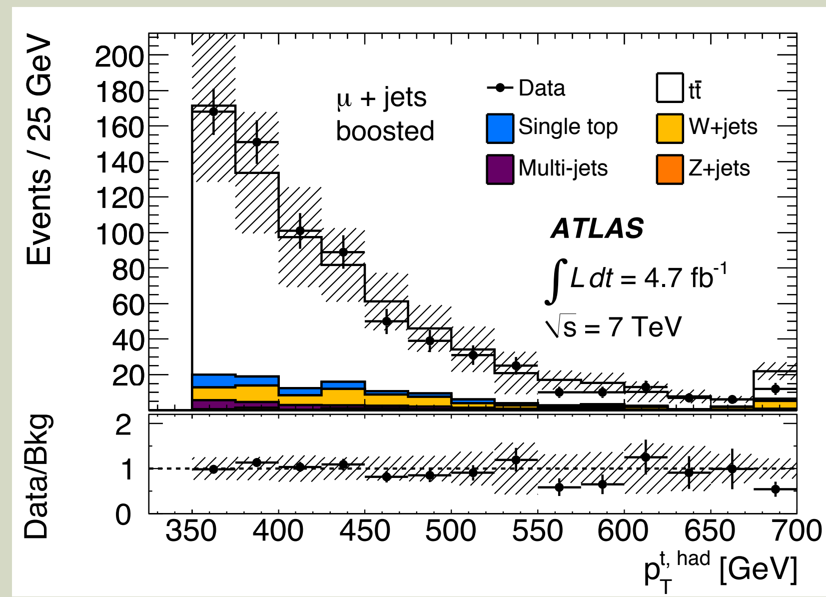
HOW DID WE DO?

muon channel

resolved category: p_T of leading jet

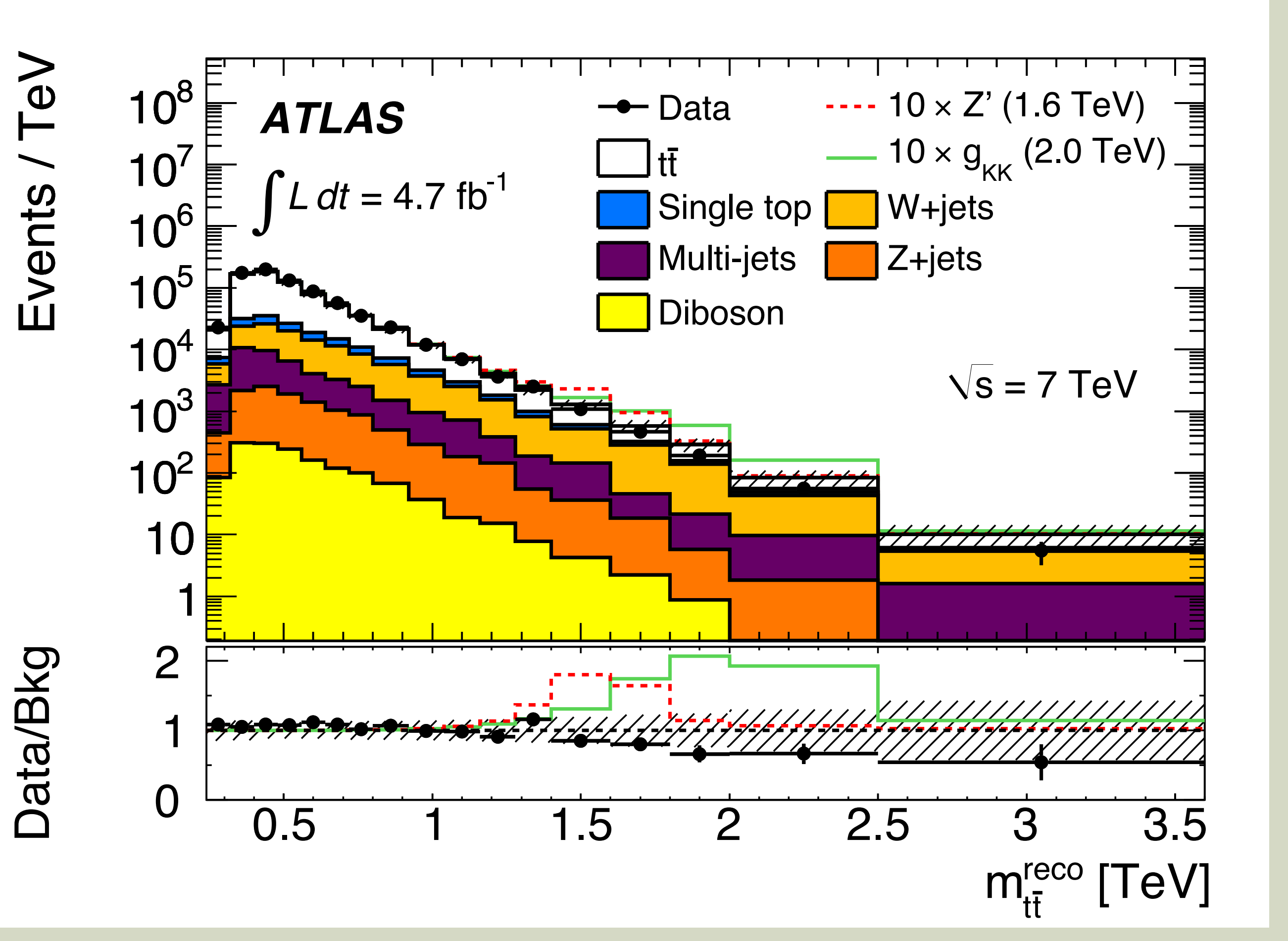


boosted category: p_T of hadronic top candidate (large jet)

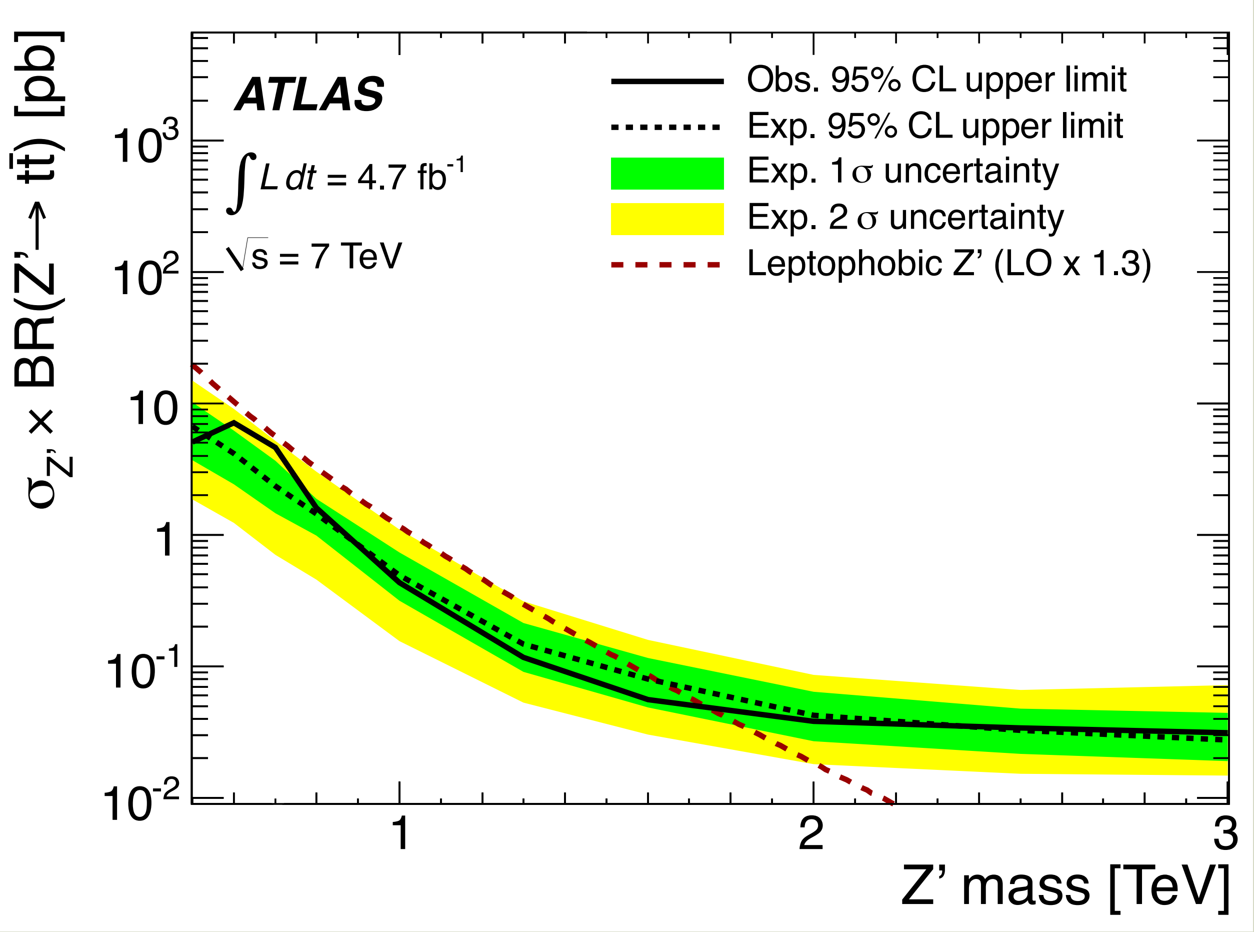


RESULTS: SKIPPING TO THE PUNCHLINE

Both channels, both methods



TRANSLATING RESULTS TO LIMITS: Z'

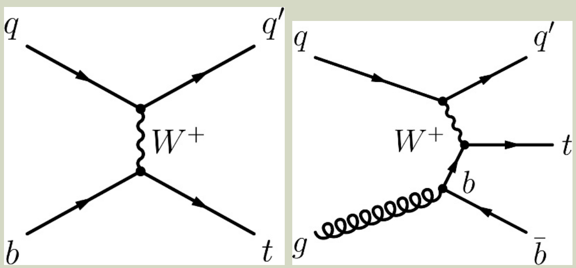


SINGLE TOP T-CHANNEL

CMS

OVERVIEW

leading order t-channel production



two channels: muon and electron

muon channel: 17 GeV trigger

electron channel: 27 GeV trigger
then
25 GeV electron + 30 GeV jet

STATISTICS

Process	Muon yield	Electron yield
t-channel	617 ± 3	337 ± 2
tW channel	107 ± 1	70.2 ± 0.9
s-channel	25.6 ± 0.5	14.7 ± 0.4
$t\bar{t}$	661 ± 6	484 ± 5
W + light partons	92 ± 7	38 ± 4
$Wc(\bar{c})$	432 ± 14	201 ± 9
$Wb(\bar{b})$	504 ± 14	236 ± 10
Z + jets	87 ± 3	13 ± 1
Dibosons	23.3 ± 0.4	10.7 ± 0.3
QCD multijet	77 ± 3	62 ± 3
Total	2626 ± 22	1468 ± 16
Data	3076	1588

normalization from data (annotation bracketing the $Wc(\bar{c})$ and $Wb(\bar{b})$ rows)

data driven (annotation pointing to the QCD multijet row)