Top quark cross section measurement @ ATLAS with dilepton final state

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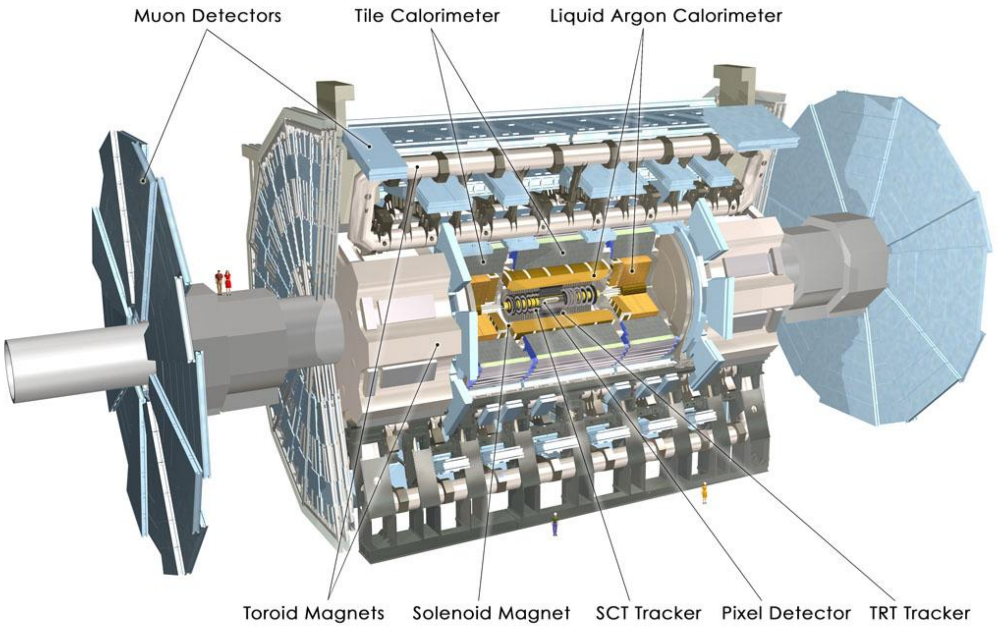
LHC & ATLAS

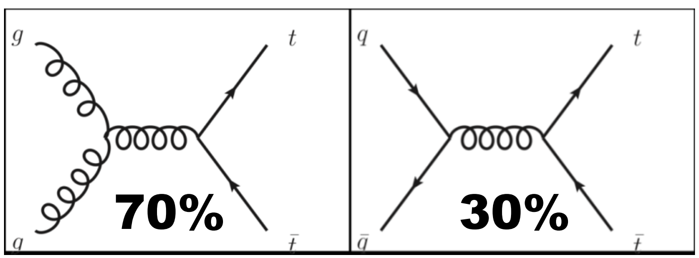
- LHC experiment
  - 陽子-陽子衝突実験
    - 重心系 7 TeV.
    - 2010 年より本格稼働！



- ATLAS detectors.
  - 飛跡検出器
  - カロリメータ (EM/H-Cal)
  - ミューオン検出器

トップクォーク @ LHC

- 標準模型粒子の中で最大質量をもつ素粒子.
  - 172.0 ± 0.9 ± 1.3 GeV/c^2.
- トップクォーク生成 @ LHC
  - NNLO QCD Prediction = 164.6pb.
    - Gluon-gluon fusion (**70%**).
    - Quark-quark annihilation (**30%**).



- トップクォーク対生成断面積の測定、崩壊分岐比の測定
  - 標準模型を超えた物理への感度
    - $H^{+/-}$ production in t quark decay.
    - $qq \rightarrow Z' \rightarrow tt$ production.
  - 標準模型の良いテスト (摂動 QCD の精密検証)

ダイレプトン終状態を用いた解析

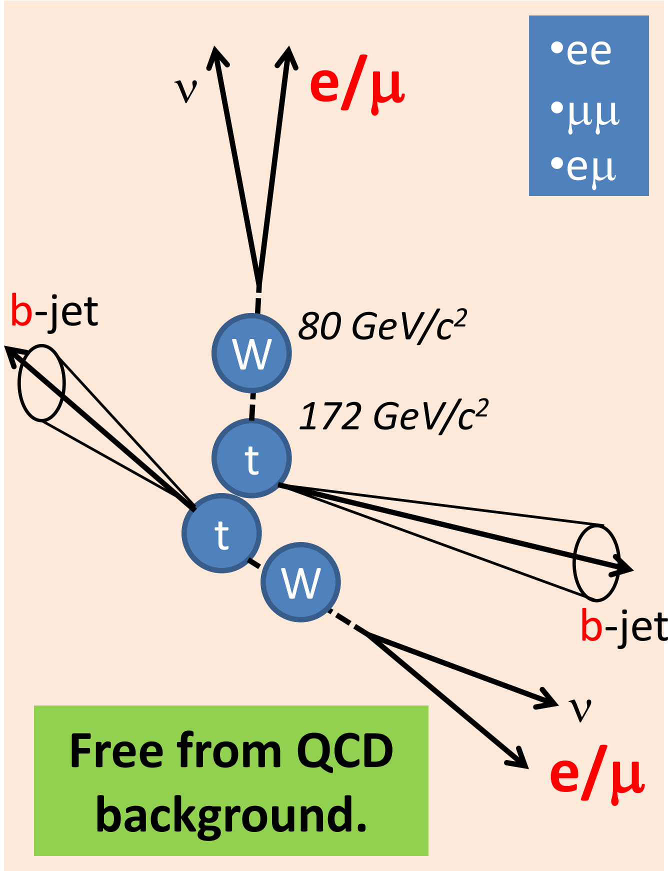
- 候補事象の選別.
  - 2 本のレプトンをタグに信号を検出.
  - 背景事象との分離のための Veto
    - Z不変質量を作るダイレプトン事象
    - 横運動量のアンバランス (Missing ET) が小さい事象
    - ジェットが二本以上ない事象

- **105** Observed events (2010 data)
  - ee **16**, μμ **31**, eμ **58** events.

- 生成断面積の測定

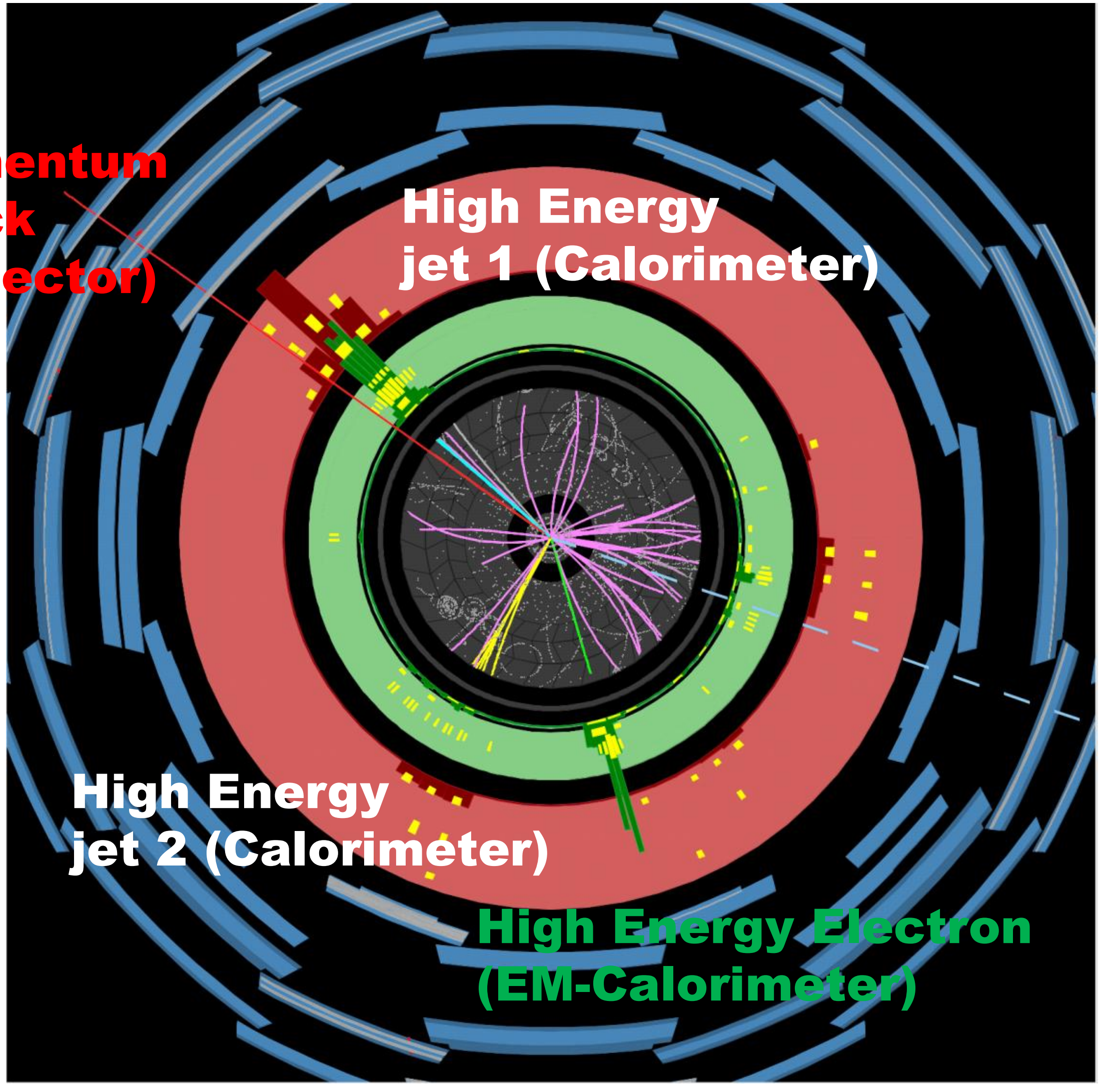
$$\sigma_{tt} \times BR(ll) = \frac{N_{\mathrm{observed}} - N_{\mathrm{background}}}{\mathscr{A}} \times \frac{1}{\mathscr{L}}$$

  - 観測事象数. 背景事象数. 信号事象に対するアクセプタンス. ルミノシティを正確に把握して、評価.

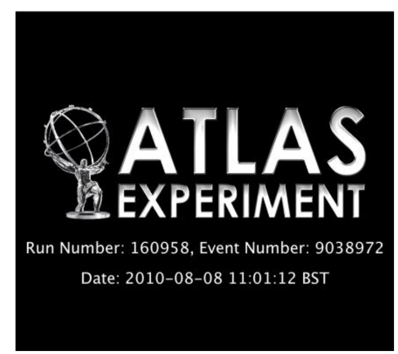


ダイレプトン tt 事象の候補

eμ 候補



Missing ET
(Imbalance of total
transverse energy)



信号事象に対するアクセプタンス評価

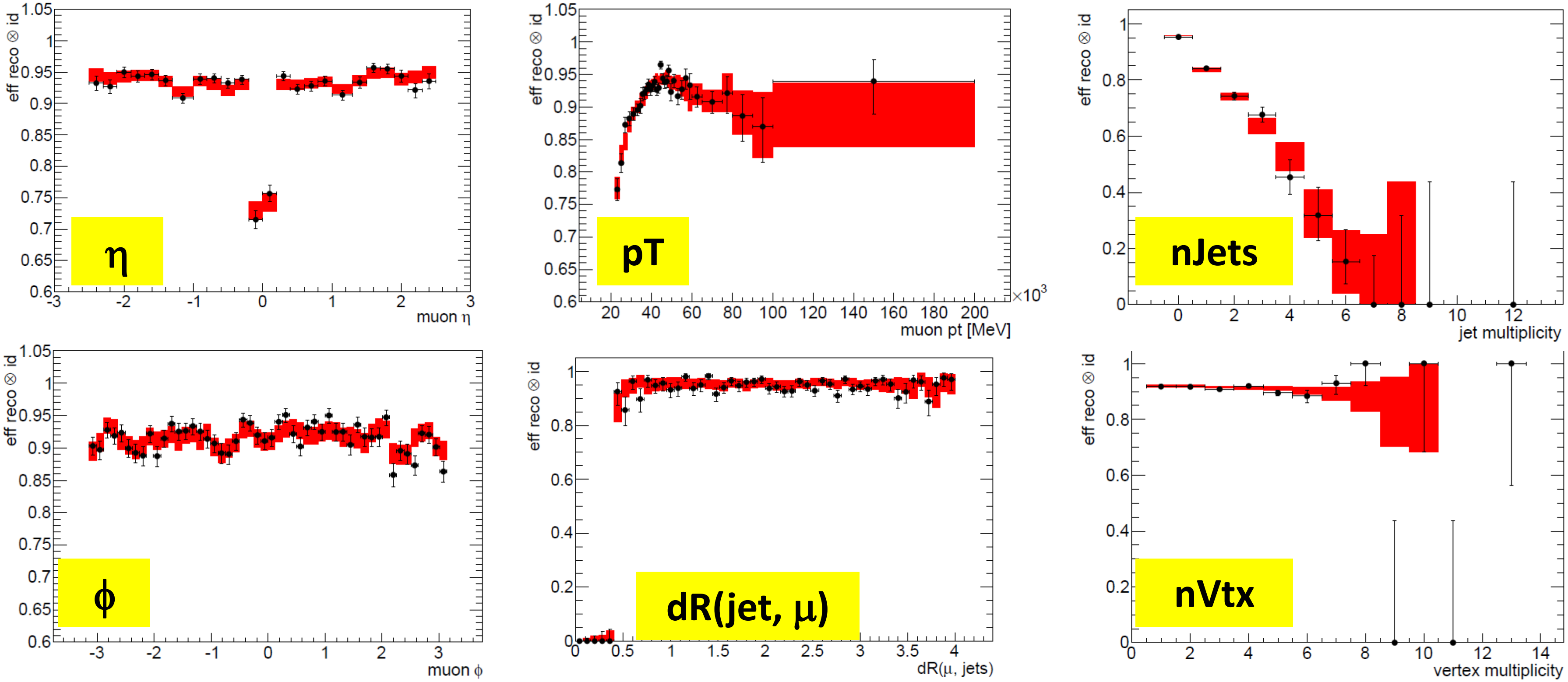
- 検出器の性能を反映したシミュレーションを用いて評価
  - 終状態粒子の運動学的特徴をシミュレーションを用いて評価
  - 検出器性能を実機データから評価.
    - 検出器の検出効率、運動量･エネルギー測定のスケール分解能
- 評価の安定性の確認
  - 検出器の性能評価における不定性
  - シミュレーションのモデリングに対する不定性.

Channel	Acceptance estimation.
Ee	**11.5±1.4%**
μμ	**20.5±1.6%**
eμ	**24.3±1.9%**

アクセプタンス評価の詳細

- レプトンの検出効率 & トリガー効率
  - Z ボソンプロセスを利用して評価.

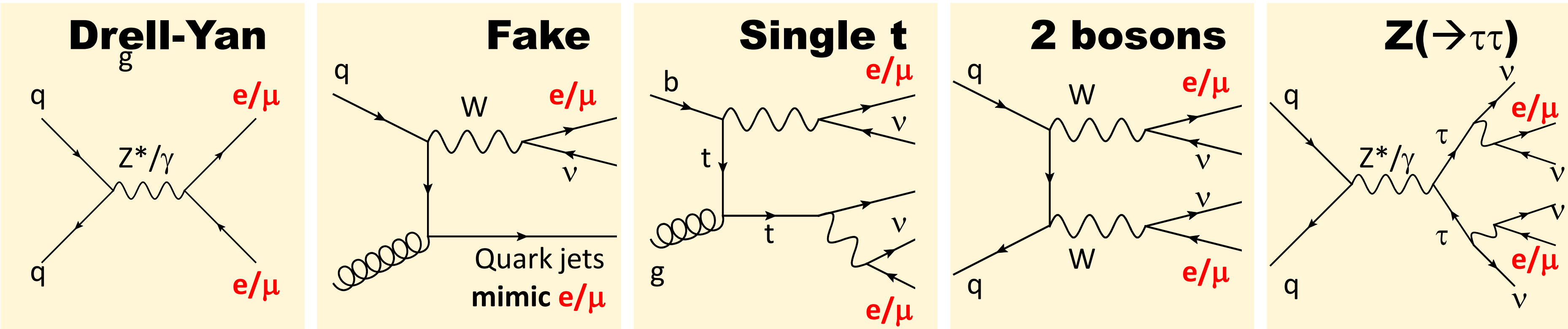
● 実測値, ■ シミュレーション



- モンテカルロ・シミュレーションの記述の妥当性を証明.
- <u>位相空間</u>、<u>事象の”混み具合”</u>によらず、正確に記述 (top 事象でも OK)
- **検出器実機の性能を正確に把握して、高い確度でのアクセプタンス評価を実現**

背景事象数の評価

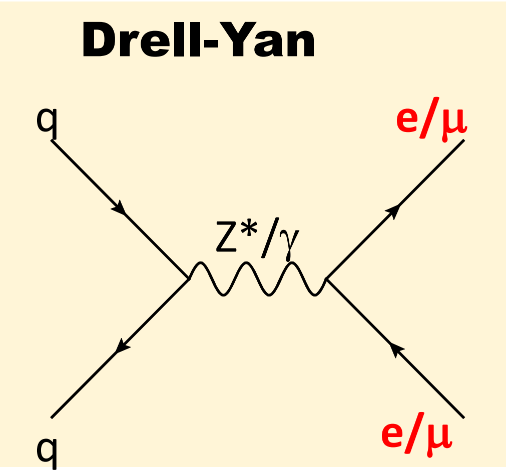
- ダイレプトン解析における背景事象の候補



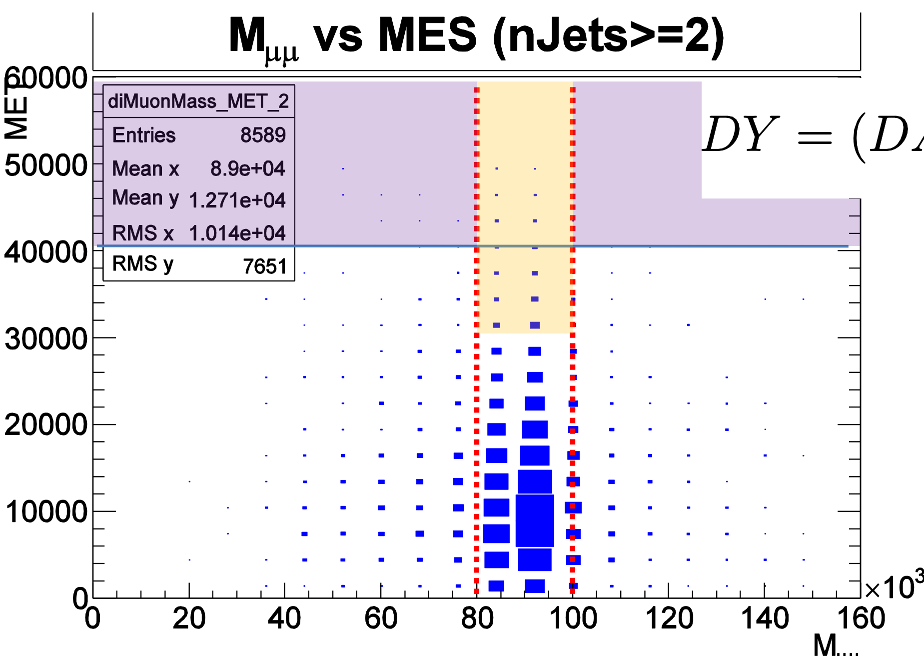
Channel	DY	Fake	Single top	WW/WZ/ZZ	Z(→ττ)
ee	1.1±0.5	0.8±0.8	0.6±0.1	0.5±0.2	0.5±0.3
μμ	3.6±1.8	0.5±0.6	1.3±0.2	0.9±0.3	1.1±0.6
eμ	-	3.0±2.6	2.5±0.4	2.1±0.8	3.2±1.5

- 背景事象数の評価結果
  - ee : **3.5 ± 1.1 events**
  - μμ : **7.4 ± 2.0 events**
  - eμ : **10.8 ± 3.7 events**

背景事象数評価の詳細 (1) DY



- MET の "**mis-measurement rate**" をデータから評価.
  - コントロール領域を定義
    - nJets ≥ 2, Inside Z mass, MET>30GeV.
    - Z*/g purity ≈ 90%
  - コントロール領域の観測事象数を信号領域へ外挿して評価

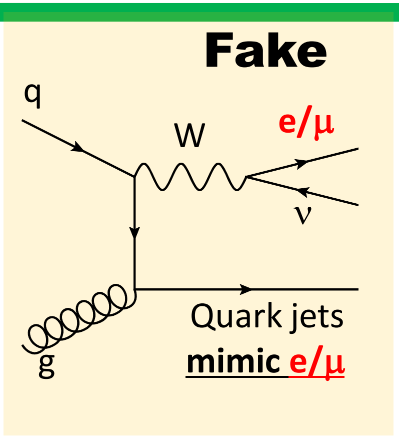


$$DY = (DATA(CR) - MC_{\mathrm{background}}) \times \frac{MC(SR)}{MC(CR)}$$

Channel	Expectation
ee	1.1 ± 0.5
μμ	3.6 ± 1.8

Background estimation details (2)

- レプトンの "**mis-particle-ID rate**" をデータから評価.
  - QCD 2jets 事象を用いて、jet が tight な particle ID を通過する確率を測定. (= fake rate; *f*)

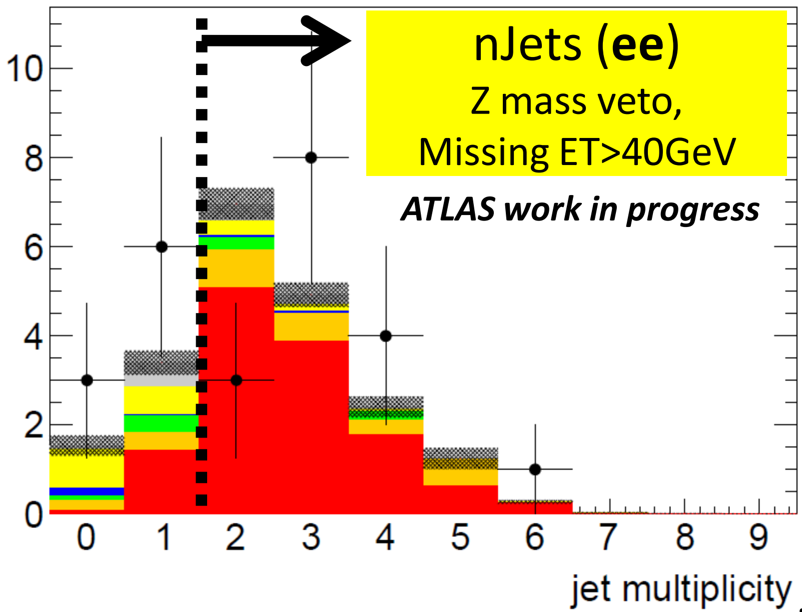


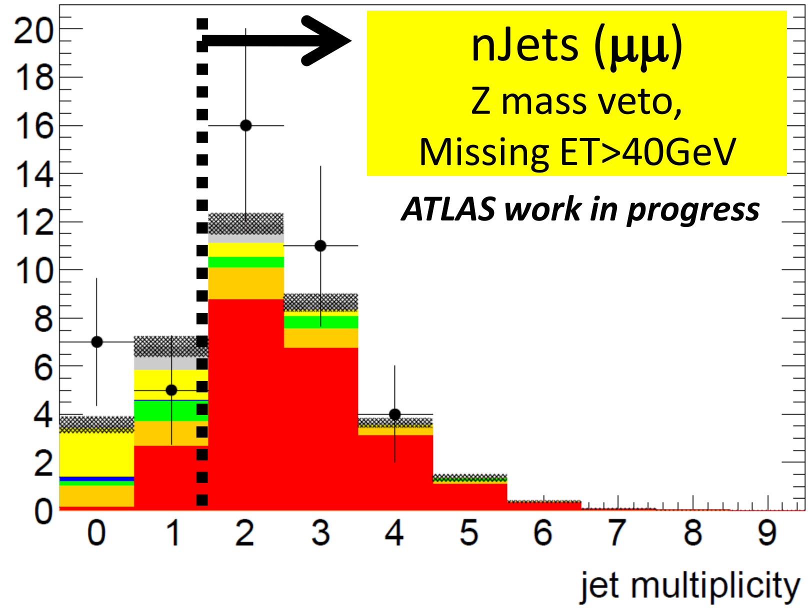
$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

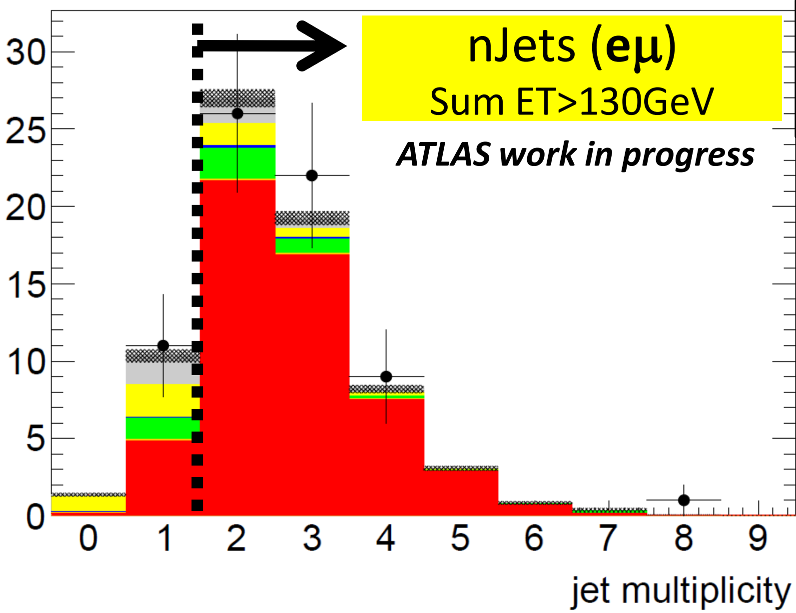
- 連立方程式を解き、選別される事象数を評価
  - $rf \times N_{FR} + fr \times N_{RF}$, (W+jets.) + $ff \times N_{FF}$ (QCD)

	ee	μμ
Expectation	0.8 ± 0.8	0.5 ± 0.6

検出事象数の評価





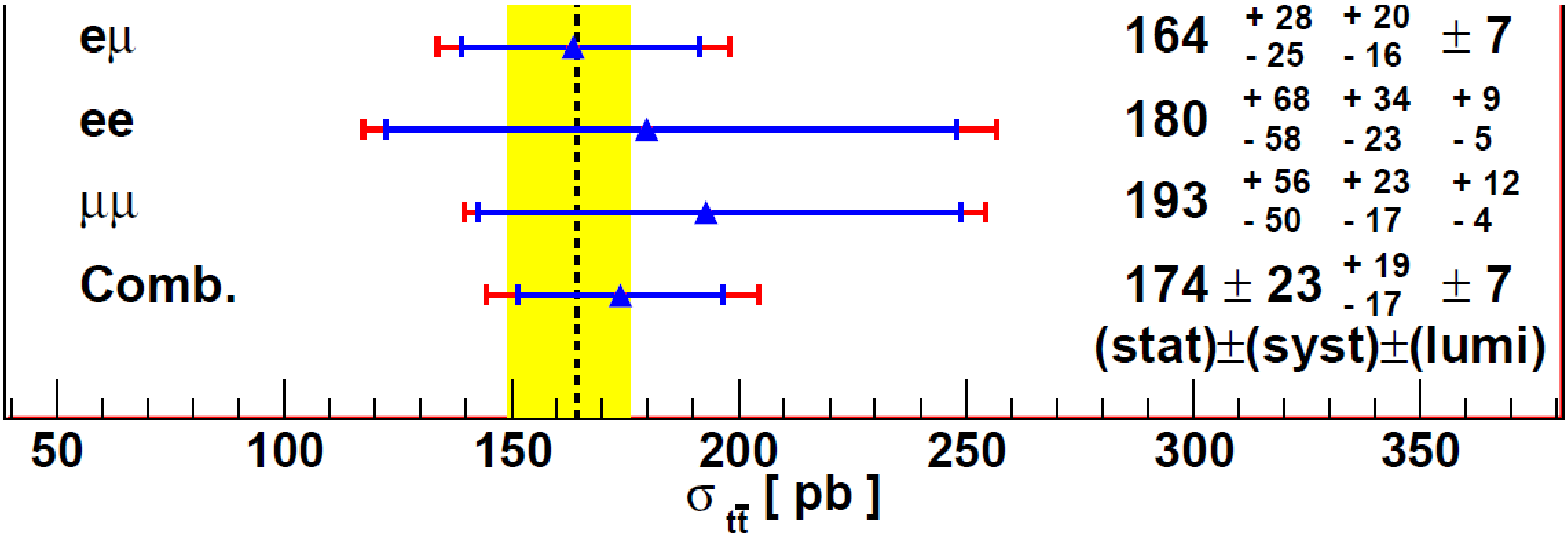


● ATLAS Data (35/pb)
tt Signal, DY, Z(ττ), Single top, WW/WZ/ZZ

	Data	BG	Data-BG	Prediction
ee	**16**	3.5±1.1	**12.5±1.1**	11.4±1.4
μμ	**31**	7.4±1.9	**23.6±1.9**	20.1±1.7
eμ	**58**	10.8±3.5	**47.2±5.3**	47.5±4.1

生成断面積の測定結果

- Results from individual channel analysis.



- 高い精度での測定を実現.
  - 3 チャンネルコンバイン時の 測定の Significance = 5.7σ
- NNLO の計算 (164.6pb) に一致

まとめ

- トップ対生成断面積の測定 @ LHC-ATLAS
  - 検出器の応答を精密に理解.
  - 7 TeV の陽子・陽子衝突における初の精密測定 significance 5.7 σ.

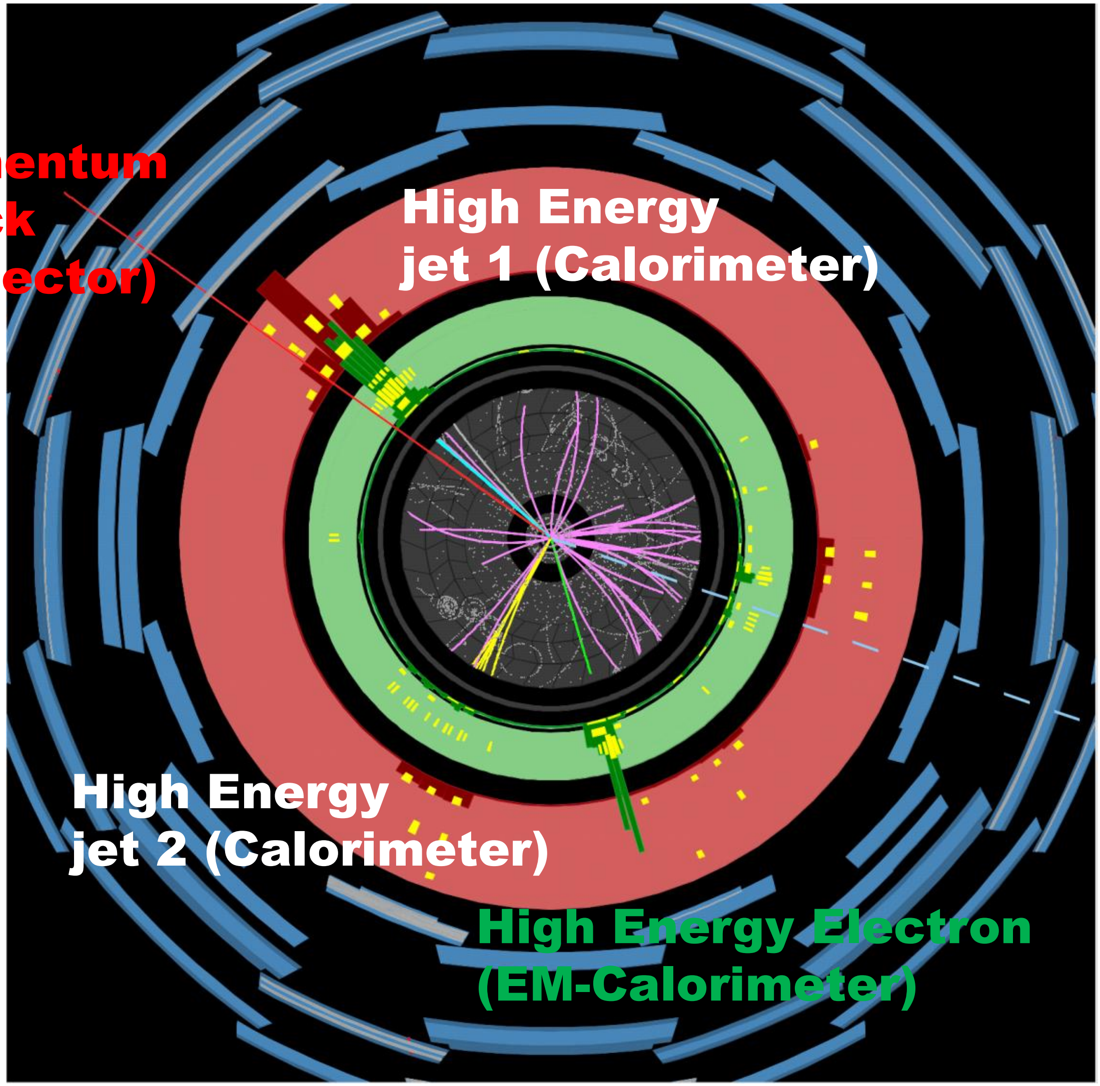
combined	$174.0 \ {}^{+22.6}_{-22.6} \ {}^{+19.1}_{-17.4} \ {}^{+7.0}_{-7.0}$ (*1, *2, *3)

*1 statistics uncertainties, *2 systematic uncertainties, *3 luminosity uncertainties

pQCD の計算と 5.7 σ の有意さで、一致することを証明.

BACK UP SLIDES

Event display of dilepton tt candidate



Top quark pair production candidate event

(e+μ)

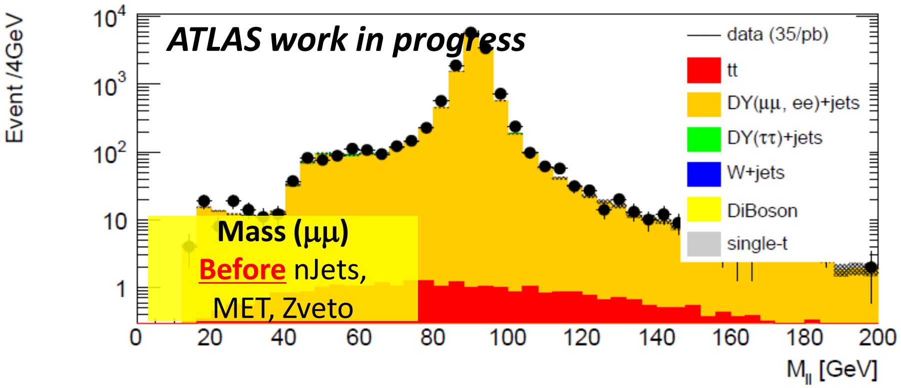
ATLAS EXPERIMENT

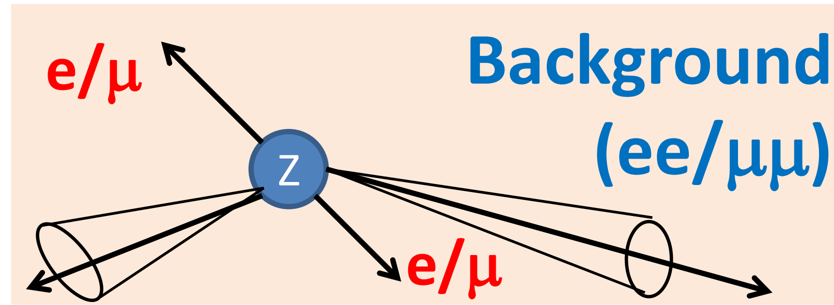
Run Number: 160958, Event Number: 9038972

Date: 2010-08-08 11:01:12 BST

Background physics process

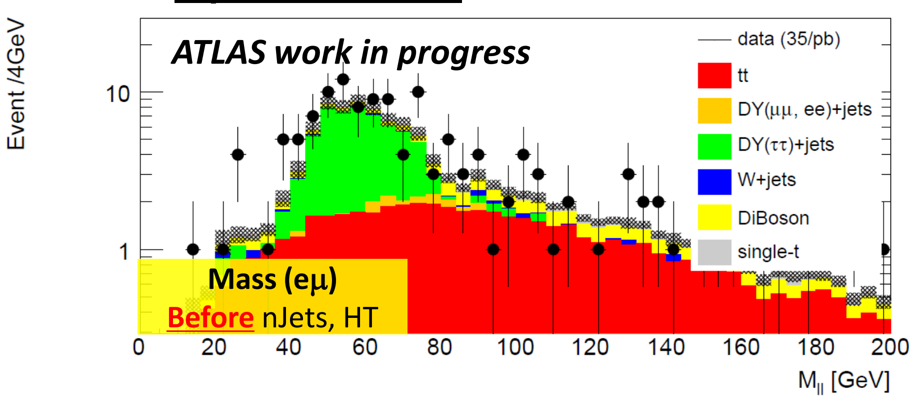
- <u>ee/μμ channel</u>

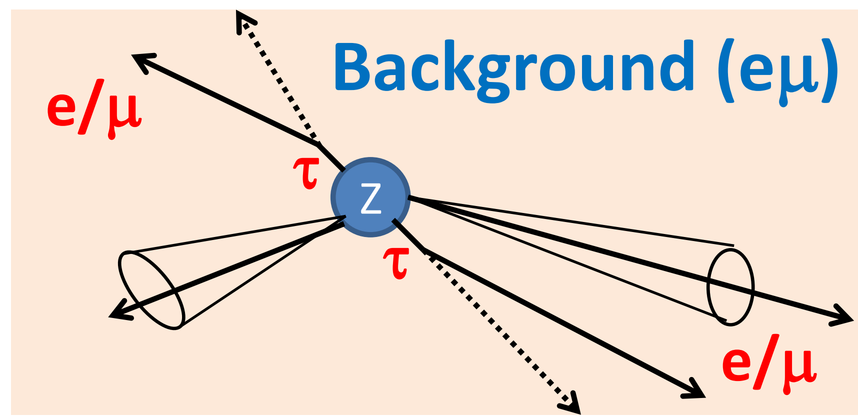




  – Z (DY) physics process dominates. σ(Z→$\mu\mu/ee$)/σ(tt→$\mu\mu/ee$) = **500**
  – Tight cut is required to reject DY .

- <u>eμ channel</u>

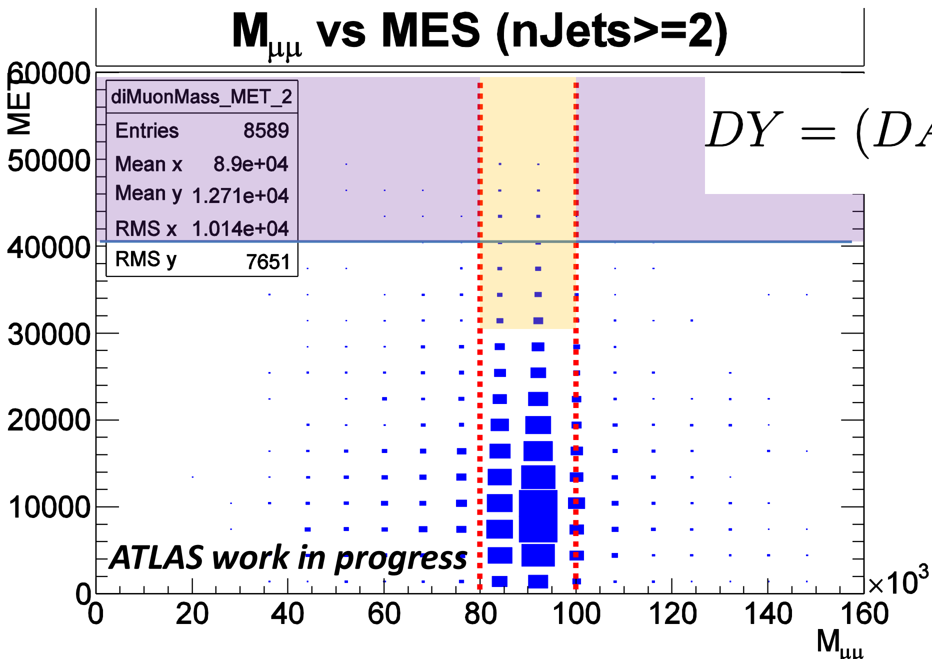




  – Background free. (Z→$\tau\tau$ physics process is the largest BG source.)

Background estimation **Drell - Yan**

- Estimate MET mismeasurement rate, using control region.
  - Control region is defined in Z mass window (Z*/g purity ≈ 90%) with nJets ≥ 2, Inside Z mass, MET>30GeV.
- Estimate the DY contamination in SR.



$$DY = (DATA(CR) - MC_{\text{background}}) \times \frac{MC(SR)}{MC(CR)}$$

Channel	Expectation
ee	1.1 ± 0.5
μμ	3.6 ± 1.8

Background estimation **Fake lepton**

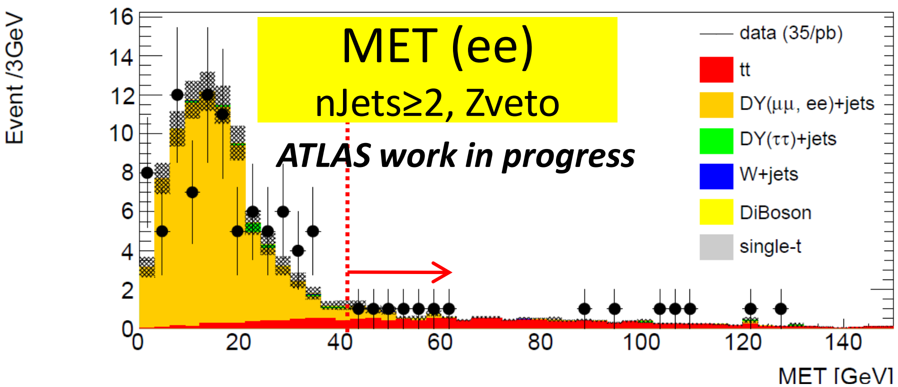
- Measure detection rate for real & fake lepton.
  - Z(→ee/μμ), QCD 2jets events are used to estimate detection rate for real & fake leptons.

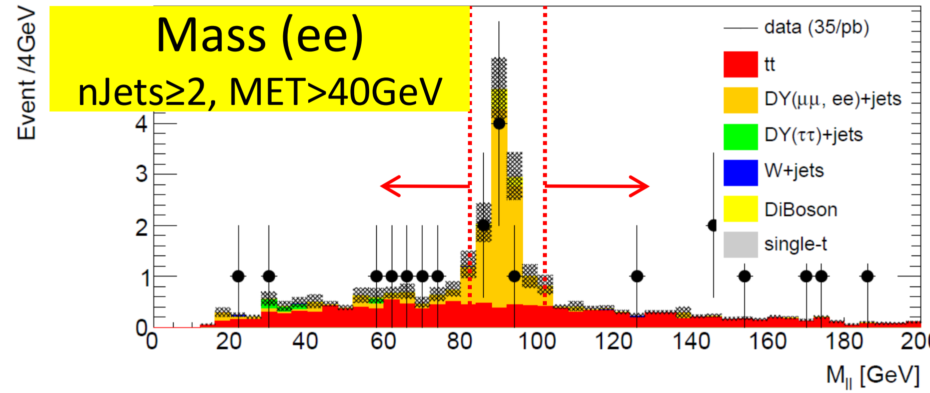
$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

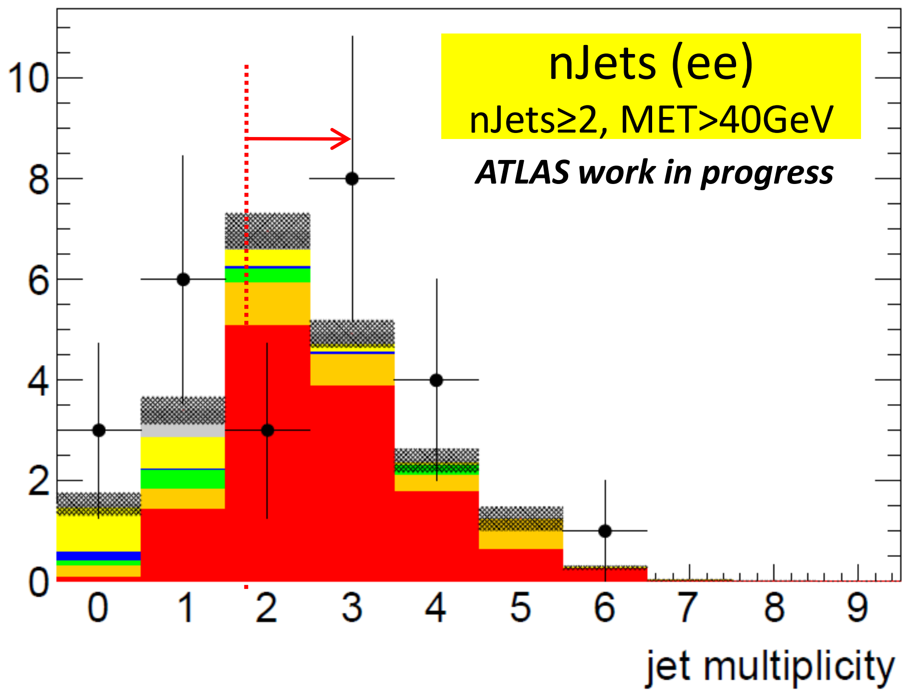
- Solve the equations, and number of events including fakes (N_{FR}, N_{RF}, N_{FF}).
  - N_{FR}, N_{RF}, are corresponding to W+jets.
  - N_{FF}, are corresponding to QCD.

	ee	μμ
Expectation	0.8 ± 0.8	0.5 ± 0.6

Event yield (ee)

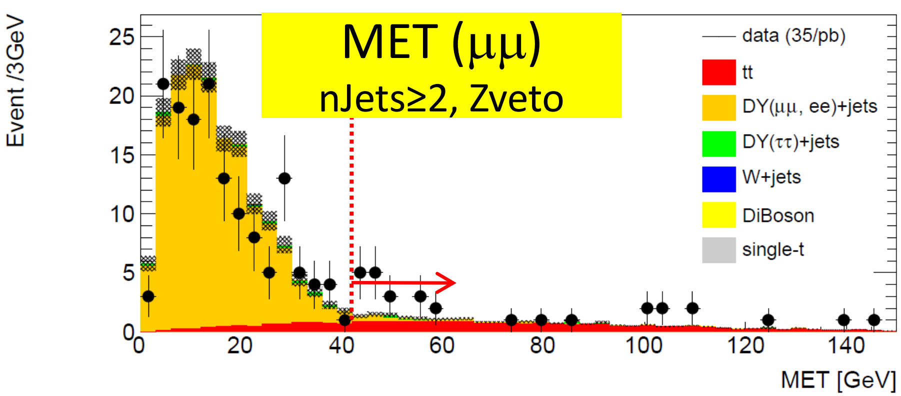


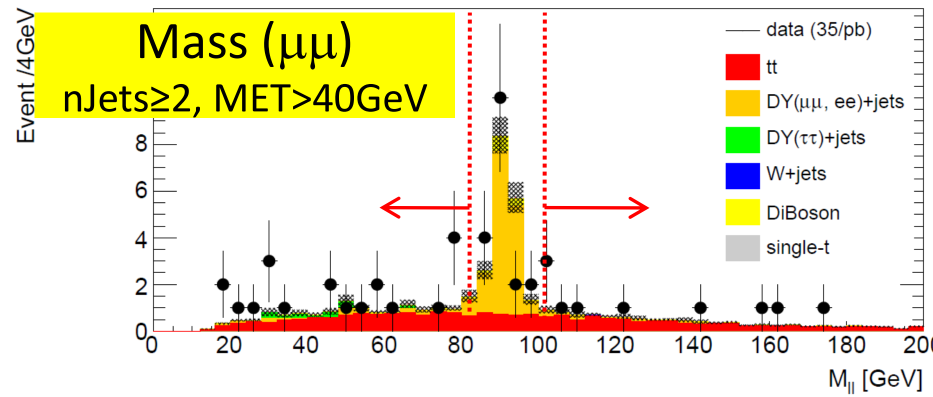


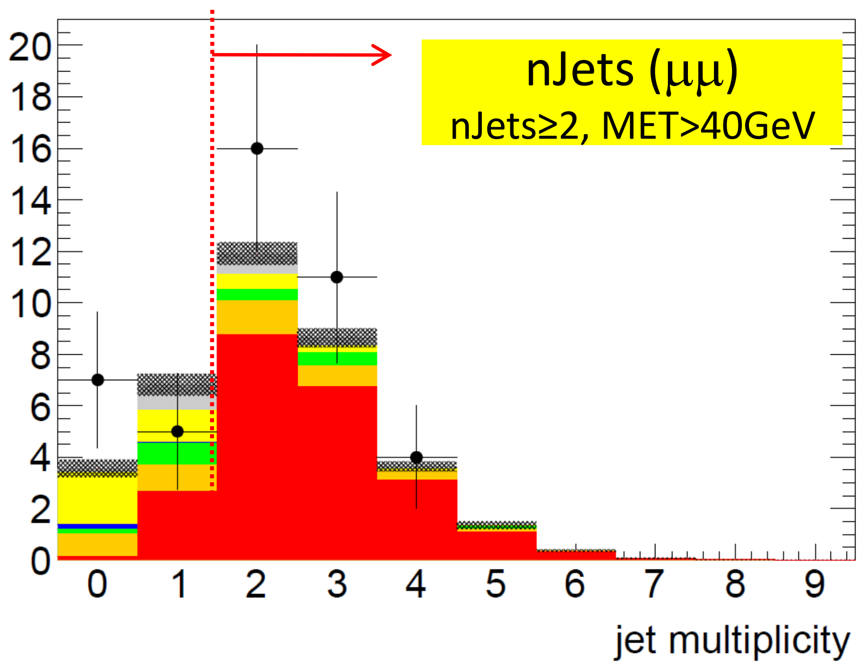


- **16** events observed.
- 14.9±1.7 events expected.
  - 11.4±1.4 signals.
  - 3.5±1.1 backgrounds.

Event yield (μμ)

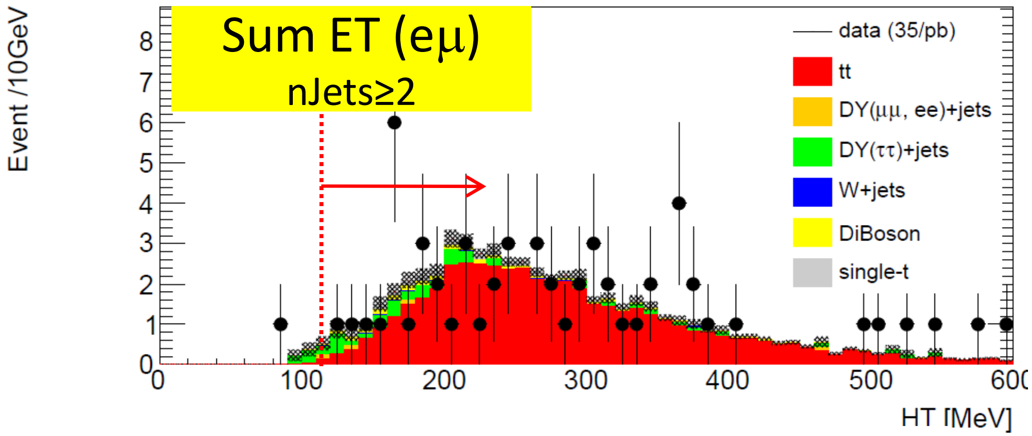


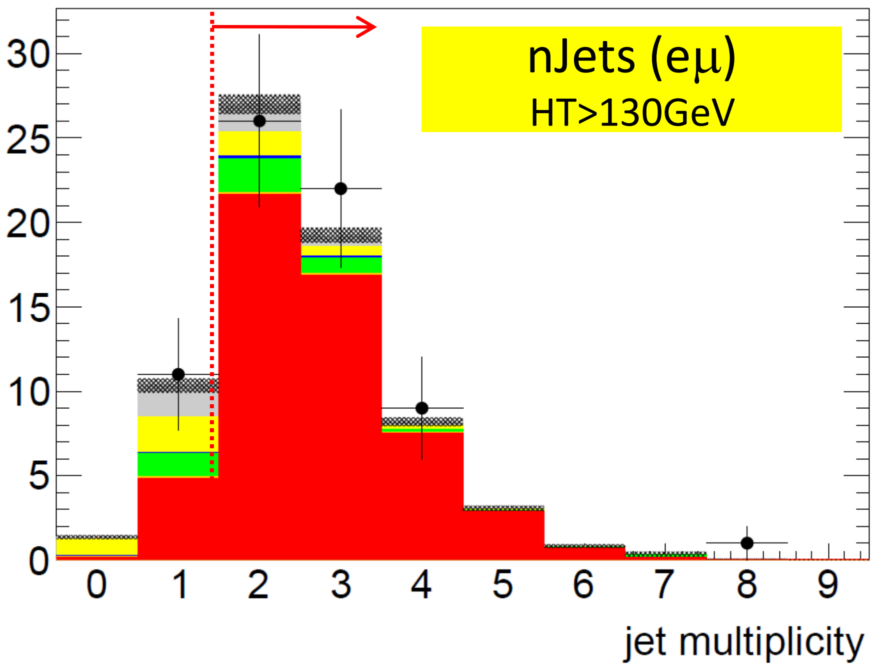




- **31** events observed.
- 27.5±2.5 events expected.
  - 20.1±1.7 signals.
  - 7.4±1.7 backgrounds.

Event yield (eμ)





- **58** events observed.
- 58.3±5.3 events expected.
  - 47.5±4.1 signals.
  - 10.8±3.5 backgrounds.

Event Yield summary

	ee	$\mu\mu$	$e\mu$
Z+jets (DD)	1.1 ± 0.5	$3.6^{+1.8}_{-1.2}$	-
$Z(\rightarrow \tau\tau)$+jets (MC)	0.5 ± 0.3	1.1 ± 0.6	$3.2^{+1.5}_{-1.4}$
Non-Z leptons (DD)	0.8 ± 0.8	0.5 ± 0.6	3.0 ± 2.6
Single top (MC)	0.6 ± 0.1	1.3 ± 0.2	2.5 ± 0.4
Dibosons (MC)	0.5 ± 0.1	0.9 ± 0.2	$2.1^{+0.5}_{-0.3}$
Total (non $t\bar{t}$)	$3.5^{+1.1}_{-1.0}$	$7.4^{+1.9}_{-1.6}$	$10.8^{+3.5}_{-3.2}$
$t\bar{t}$ (MC)	$11.4^{+1.4}_{-1.2}$	$20.1^{+1.6}_{-1.7}$	$47.5^{+3.9}_{-4.1}$
Total expected	$14.9^{+1.7}_{-1.6}$	$27.5^{+2.5}_{-2.4}$	$58.3^{+5.3}_{-5.2}$
Observed	16	31	58

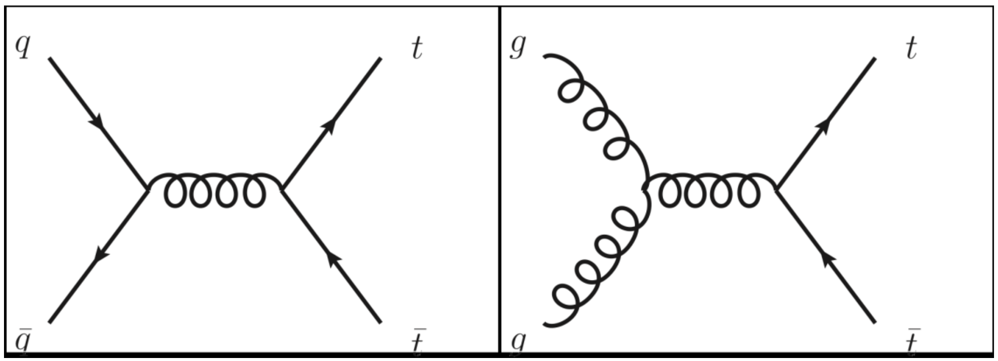
Background estimation

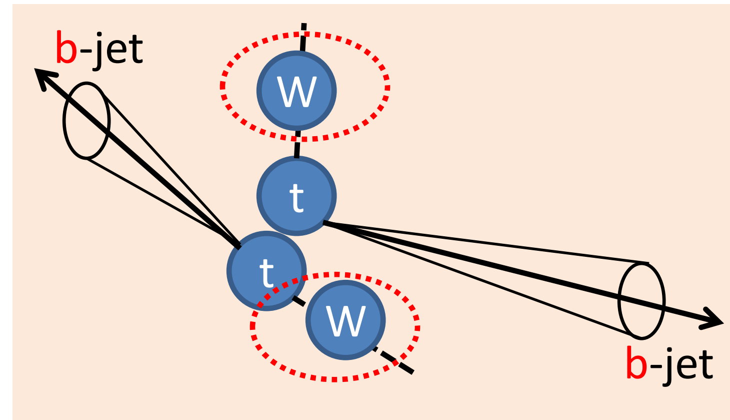
- Categorization of background
  - (1) $Z^*/\gamma(ee)$, $Z^*/\gamma(\mu\mu)$ **Drell - Yan**
    - Pass event selection due to mis-measurement of MET.
  - (2) $W(e\nu)$+jets, $W(\mu\nu)$+jets **Fake lepton**
    - Pass event selection due to mis-particle identification. (jets mimic e/μ)
  - (3) Z ($\tau\tau$) + jets, WW + jets, WZ + jets, Single top
    - Similar event topology with 2 leptons, MET, & jets.

    SM process
- Strategy of estimation
  - (1) & (2) are estimated from **real detector response**.
    - Since it is difficult to reproduce mis-measurement in simulation.
  - (3) are estimated from MC prediction.

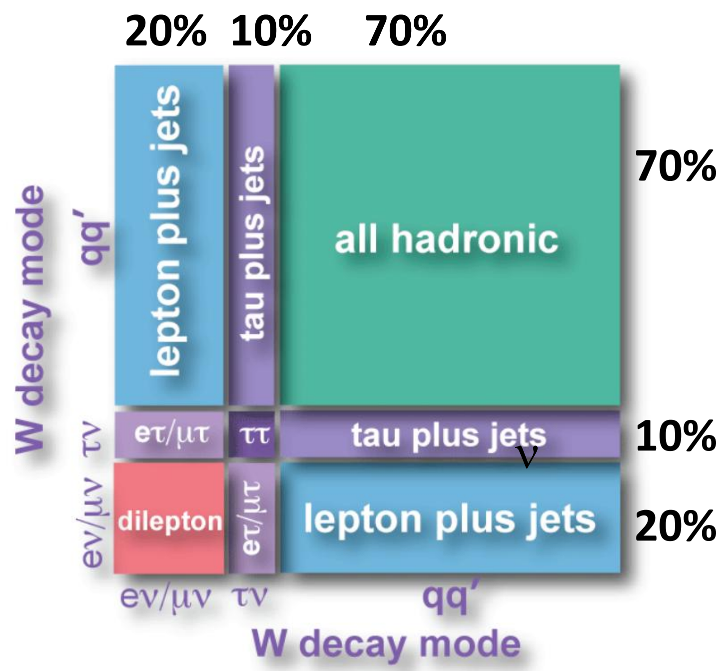
Top quark pair production & decay

- Top quark pair production.
  - **160pb** (NNLO) @ 7TeV
    - gg → tt (70%), qq → tt (30%)





- Final state of tt
  - l + jets : BR = 28%
  - **di lepton : BR = 4%**
  - all jets : BR = 49%
  - tau : BR = 19%

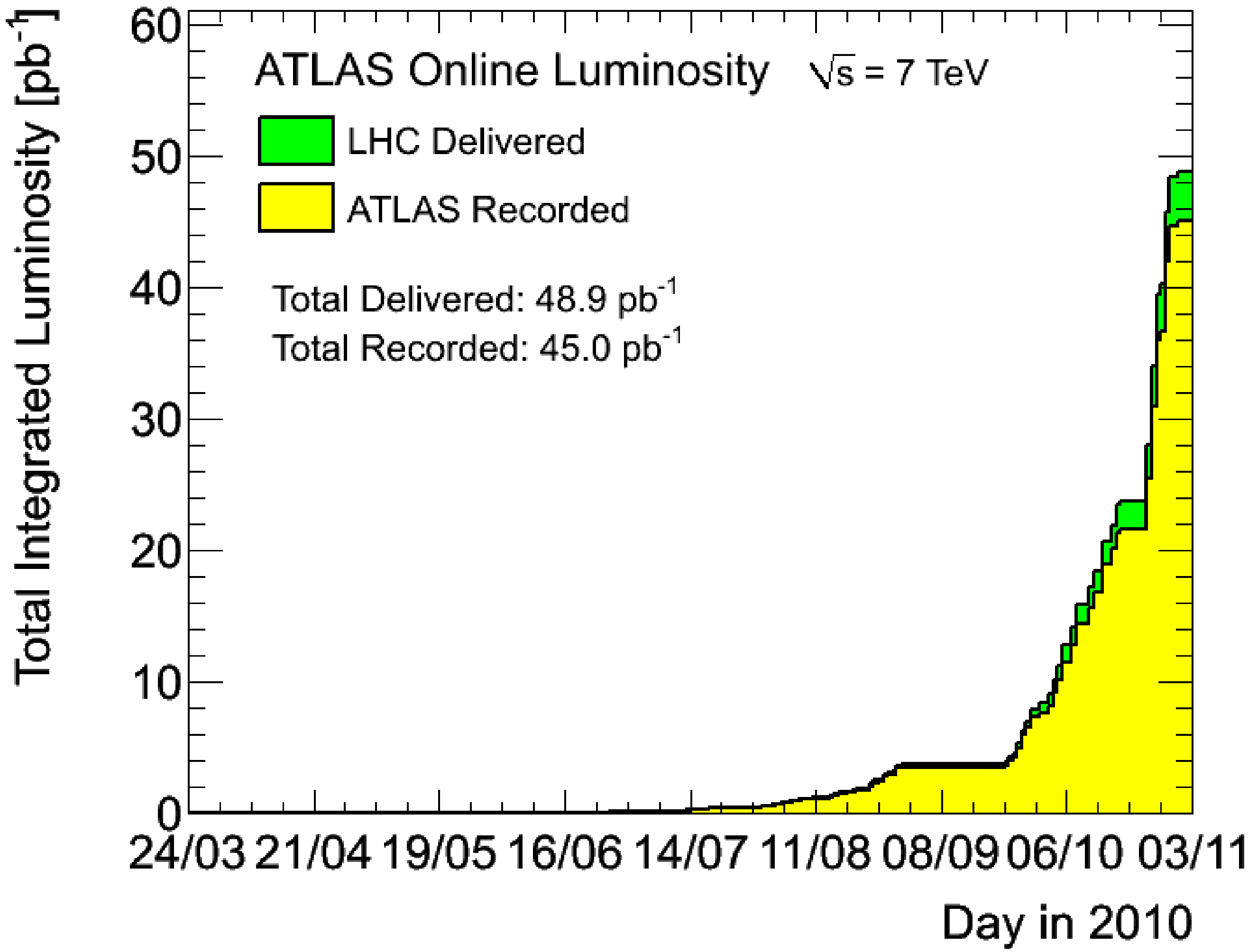


Cross section measurement

$$\sigma_{tt} \times BR(\mu\mu) = \frac{N_{\text{observed}} - N_{\text{background}}}{\mathscr{A}} \times \frac{1}{\mathscr{L}}$$

- Collect & count tt event candidate. ($N_{observed}$)
- Estimate background.($N_{background}$)
- Evaluate acceptance & the stability. (A)
  - Detector performance.
  - Event modeling.
- Measure luminosity (L)

Luminosity


ATLAS Online Luminosity √s = 7 TeV
LHC Delivered
ATLAS Recorded
Total Delivered: 48.9 pb-1
Total Recorded: 45.0 pb-1
Total Integrated Luminosity [pb-1]
0
10
20
30
40
50
60
24/03 21/04 19/05 16/06 14/07 11/08 08/09 06/10 03/11
Day in 2010

Systematic error estimation

	Background	Acceptance	Cross Section
	3.5	0.115	180.0
	Δ Background %	Δ Acceptance %	Δ Cross Section %
Luminosity	+1.2/-1.2	-	-3.4/+3.7
Data Stat	+10.9/-8.7	-	+40.9/-31.9
MC Stat	±8.8	±2.2	±3.4
Pile-up	±0.4	±0.3	±0.2
Fake	±22.6	-	±6.4
DD Method	±8.7	-	±2.2
MC x-sec	+6.9/-6.4	-	-2.1/+2.0
JES	+4.8/-5.9	+7.6/-5.5	-8.3/+7.6
JER	±6.6	±2.6	±0.7
JEF	±0.2	±1.3	±1.3
Mu ID SF	-	-	-
Mu Trig SF	-	-	-
El ID SF	+2.1/-2.1	+5.2/-5.2	-5.5/+6.1
El Trig SF	+0.4/-0.4	+1.0/-1.0	-1.1/+1.1
Mu ES	-	-	-
Mu ER (MS)	-	-	-
Mu ER (ID)	-	-	-
El ES	+0.6/+0.6	+0.5/-0.6	-0.6/+0.4
El Resolution	+0.3/-0.1	-0.0/+0.1	-0.1/-0.1
P.Shower	-	±4.4	±4.4
Generator	-	±1.0	±1.0
ISR	-	±0.1	±0.1
FSR	-	±3.1	±3.1
PDF	-	±2.5	±2.5
Syst. total	+28.0/-28.1	+11.6/-10.4	+14.0/-14.2
Cross Section (observed)	$180.0^{+73.7}_{-57.4}\,^{+25.2}_{-25.5}\,^{+6.6}_{-6.2}$ pb		

	single top	diboson	$Z\tau\tau$
Yield	0.6	0.5	0.5
Uncertainty(%)			
Lumi	±3.2	±3.2	±3.2
JES	+20.1/-11.8	+24.8/-14.2	+20.9/-20.6
JER	±1.3	±0.7	±20.6
JEF	±2.2	±1.6	±0.0
El ID SF	+5.2/-5.2	+5.3/-5.3	+5.5/-5.5
El Trig SF	+1.0/-1.0	+1.0/-1.0	+1.0/-1.0
Mu ID SF	-	-	-
Mu Trig SF	-	-	-
MC xsec	+10.0/-10.0	+5.0/-5.0	+39.6/-39.6
MC Stat	±5.9	±5.1	±44.8
Pile-up	±2.9	±3.9	±5.7
El ES	+0.3/-0.6	-0.8/-1.5	+0.0/+0.0
El ER	-0.6/+0.6	-0.6/-1.0	+0.0/+0.0
Mu ES	-	-	-
Mu ER (MS)	-	-	-
Mu ER (ID)	-	-	-
total (syst + lumi)	+24.3/-18.1	+26.8/-17.7	+67.2/-67.1

ee

Systematic error estimation

	Background	Acceptance	Cross Section
	7.4	0.205	193.2
	Δ Background %	Δ Acceptance %	Δ Cross Section %
Luminosity	+1.3/-1.3	-	-3.5/+3.7
Data Stat	+7.0/-6.3	-	+28.2/-23.5
MC Stat	±8.9	±1.6	±3.2
Pile-up	±1.8	±0.9	±0.4
Fake	±7.7	-	±2.4
DD Method.	±10.8	-	±0.9
MC x-sec	+9.4/-11.6	-	-2.9/+3.5
JES	+5.9/+14.2	+3.2/-4.1	-4.9/-0.3
JER	±6.4	±1.0	±1.0
JEF	±0.1	±1.7	±1.7
Mu ID SF	+0.3/-0.3	+0.7/-0.7	-0.8/+0.8
Mu Trig SF	+0.2/-0.2	+0.3/-0.3	-0.4/+0.4
Ele ID SF	-	-	-
Ele Trig SF	-	-	-
Mu ES	+0.2/+0.4	+0.2/-0.2	-0.2/+0.1
Mu ER (MS)	+1.5/-2.0	-0.0/-0.0	-0.4/+0.6
Mu ER (ID)	+5.5/-2.9	+0.1/+0.1	-1.9/+0.8
El ES	+0.0/+0.0	+0.0/+0.0	+0.0/+0.0
El ER	+0.0/+0.0	+0.0/+0.0	+0.0/+0.0
P.Shower	-	±4.4	±4.4
Generator	-	±0.7	±0.7
ISR	-	±0.9	±0.9
FSR	-	±2.1	±2.1
PDF	-	±1.9	±1.9
Syst. total	+25.0/-21.1	+6.8/-7.3	+8.0/-9.3
Cross Section (observed)	$193.2^{+54.4}_{-45.5}\,^{+15.5}_{-17.9}\,^{+7.2}_{-6.7}$ pb		

	single top	diboson	$Z\tau\tau$
Yield	1.3	0.9	1.1
Uncertainty(%)			
Lumi	±3.2	±3.2	±3.2
JES	+10.0/-9.3	+18.9/-15.7	+24.5/+0.0
JER	±2.5	±2.8	±23.7
JEF	±2.6	±2.3	±0.0
El ID SF	-	-	-
El Trig SF	-	-	-
Mu ID SF	+0.7/-0.7	+0.7/-0.7	+0.7/-0.7
Mu Trig SF	+0.3/-0.3	+0.3/-0.3	+0.3/-0.3
MC x-sec	+10.0/-10.0	+5.0/-5.0	+33.3/-33.3
MC Stat	±4.2	±3.7	±27.9
Pile-up	±2.1	±5.0	±9.3
El ES	-	-	-
El ER	-	-	-
Mu ES	+0.3/-0.2	+1.0/+0.0	+0.0/+0.0
Mu ER (MS)	+0.5/-0.2	+1.1/-0.0	+0.0/+0.0
Mu ER (ID)	+0.2/-0.0	+0.6/+0.3	+0.0/+0.0
total (syst + lumi)	+15.7/-15.2	+21.2/-18.3	+56.1/-50.5

μμ

Systematic error estimation

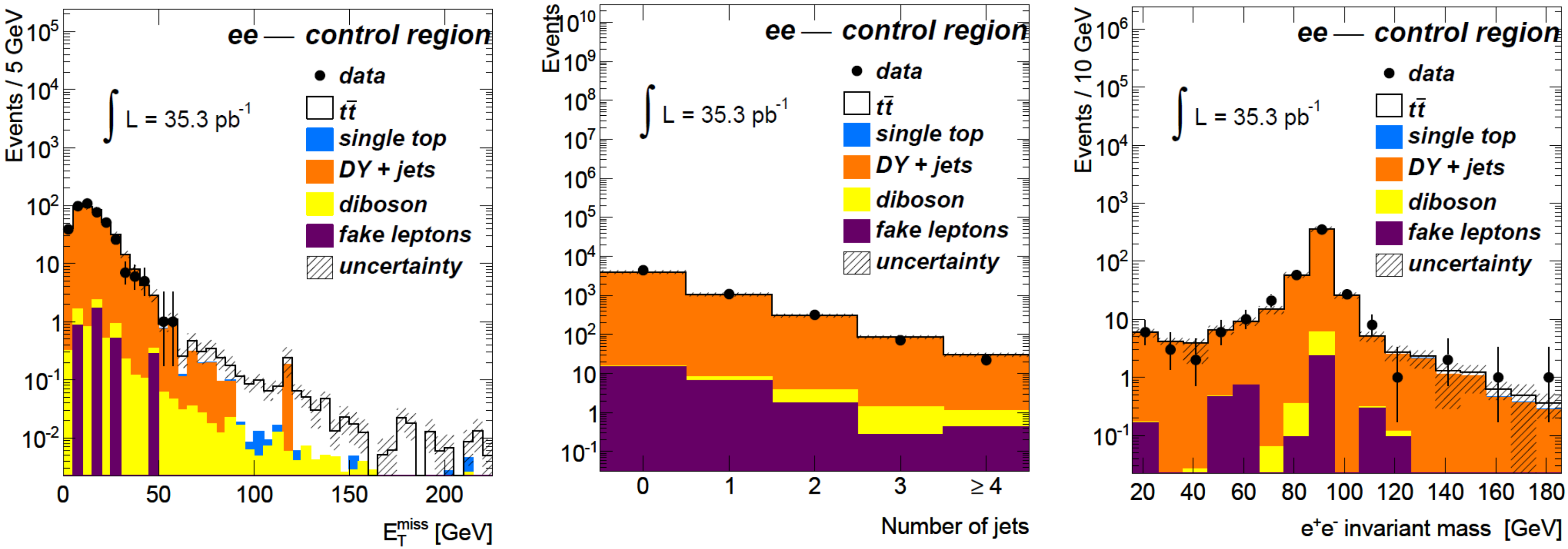
	Background	Acceptance	Cross Section
	10.8	0.243	163.6
	Δ Background %	Δ Acceptance %	Δ Cross Section %
Luminosity	+2.3/-2.3	-	-3.6/+3.9
Data Stat	-	-	+18.3/-16.1
MC Stat	±5.1	±1.1	±1.6
Pile-up	±5.0	±0.6	±1.7
Fake	±23.9	-	±5.5
DD Method (DY)	-	-	-
MC x-sec	+13.7/-13.7	-	-3.1/+3.1
JES	+14.3/-6.7	+1.9/-2.8	-5.1/+4.5
JER	±1.2	±1.3	±1.0
JEF	±2.5	±1.7	±2.3
Mu ID SF	+0.3/-0.3	+0.4/-0.4	-0.4/+0.4
Mu Trig SF	+0.0/-0.0	+0.0/-0.0	-0.0/+0.0
El ID SF	+2.7/-2.7	+3.7/-3.7	-4.1/+4.5
El Trig SF	+0.1/-0.1	+0.1/-0.1	-0.1/+0.1
Mu ES	+0.8/+0.0	+0.1/-0.1	-0.3/+0.1
Mu ER (MS)	+0.0/+0.8	-0.0/-0.0	+0.0/-0.2
Mu ER (ID)	-0.0/+0.1	-0.0/-0.0	+0.0/+0.0
El ES	+0.1/-0.2	+0.1/-0.1	-0.1/+0.2
El ER	-0.0/-0.0	+0.0/+0.0	-0.0/-0.0
P.Shower	-	±5.2	±5.2
Generator	-	±1.2	±1.2
ISR	-	±1.2	±1.2
FSR	-	±1.1	±1.1
PDF	-	±2.2	±2.2
Syst. total	+32.2/-29.6	+7.7/-8.0	+11.3/-11.4
Cross Section	$163.6^{+30.0\ +18.5\ +6.3}_{-26.3\ -18.7\ -5.9}$ pb		

	single top	diboson	$Z\tau\tau$
Yield	2.5	2.1	3.2
Uncertainty(%)			
Luminosity	±3.2	±3.2	±3.2
JES	+12.8/-8.1	+21.9/-11.7	+23.9/-8.7
JER	±0.2	±5.4	±0.3
JEF	±2.2	±1.9	±5.6
El ID SF	+3.7/-3.7	+3.7/-3.7	+3.8/-3.8
El Trig SF	+0.1/-0.1	+0.1/-0.1	+0.1/-0.1
Mu ID SF	+0.4/-0.4	+0.4/-0.4	+0.4/-0.4
Mu Trig SF	+0.0/-0.0	+0.0/-0.0	+0.0/-0.0
MC x-sec	+10.0/-10.0	+5.0/-5.0	+35.2/-35.2
MC Stat.	±3.1	±2.5	±16.9
Pile-up	±3.0	±3.5	±12.4
El ES	+0.2/-0.2	+0.2/-0.5	+0.0/+0.0
El ER	-0.1/+0.1	+0.1/-0.1	+0.0/+0.0
Mu ES	+0.1/-0.0	+0.1/+0.0	+2.7/+0.0
Mu ER (MS)	+0.1/-0.1	+0.0/-0.0	+0.0/+2.7
Mu ER (ID)	-0.1/+0.1	-0.0/+0.2	+0.0/+0.0
total (syst + lumi)	+17.6/-14.6	+24.0/-15.4	+48.2/-42.6

eμ

Control region plots

- Validation of the distribution (ee channel)



Control region plots

- Validation of the distribution ($\mu\mu$ channel)