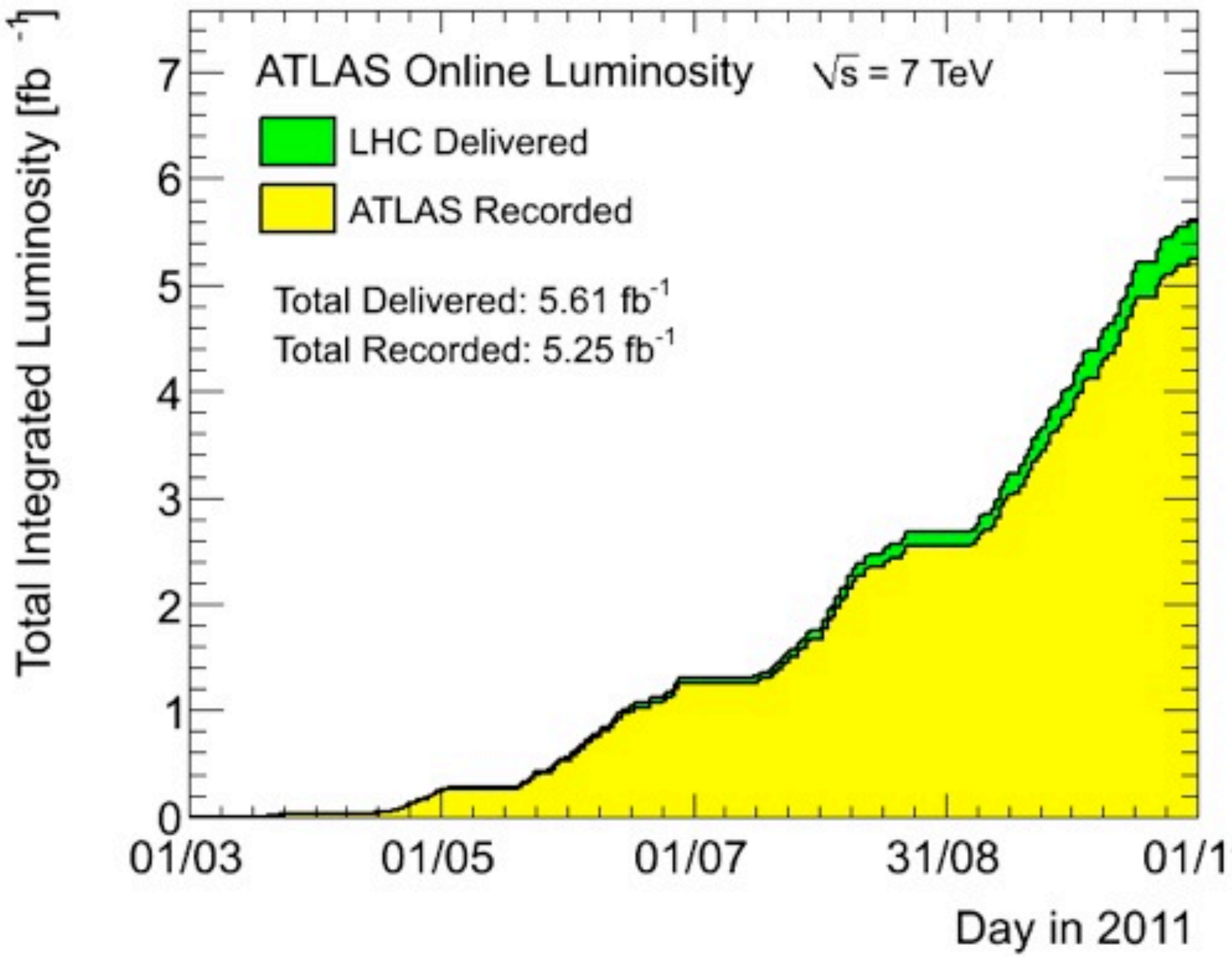
ATLAS実験におけるb-taggingを用いたtop quark対生成断面積の測定

久野・山中研究室合同年末発表会
2011年12月19日

廣瀬穣
山中研究室

Introduction

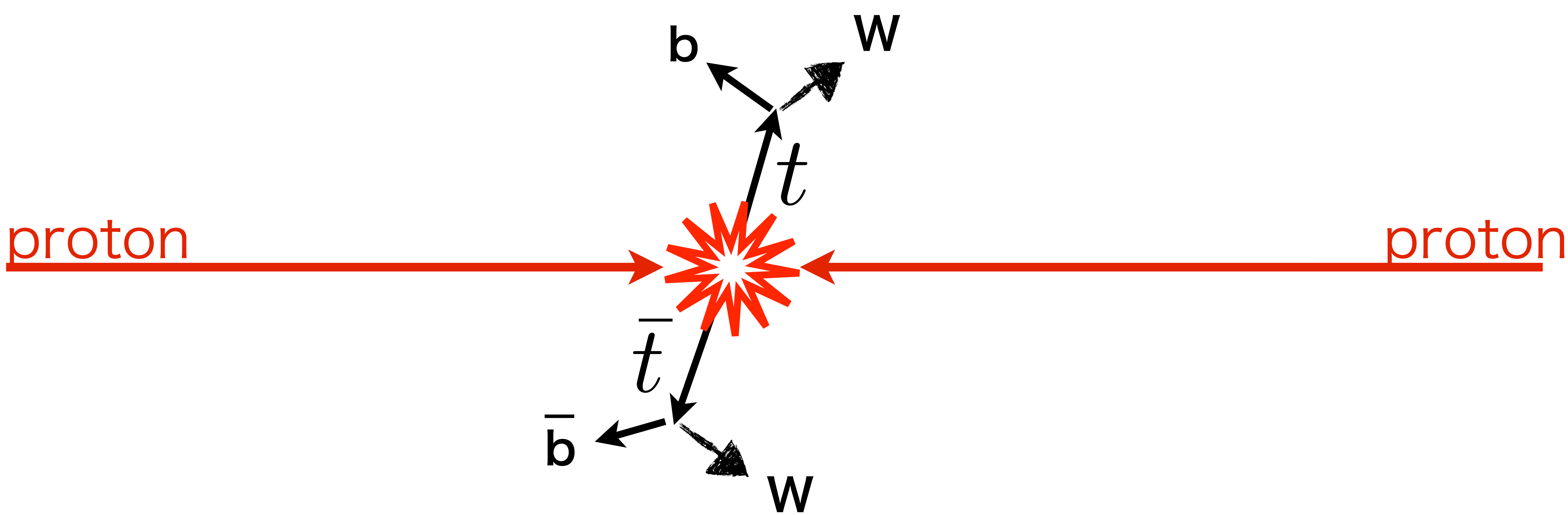
- **Large Hadron Collider(LHC)**
  - Proton-Proton collider
  - $\sqrt{s}$ = 7TeV
- **The ATLAS experiment**
  - General purpose detector.
    - ➡Higgs search.
    - ➡New physics search.



Very smooth operation!!

$t\bar{t}$ production cross-section measurement

- **di-lepton final state (lepton means electron or muon)**



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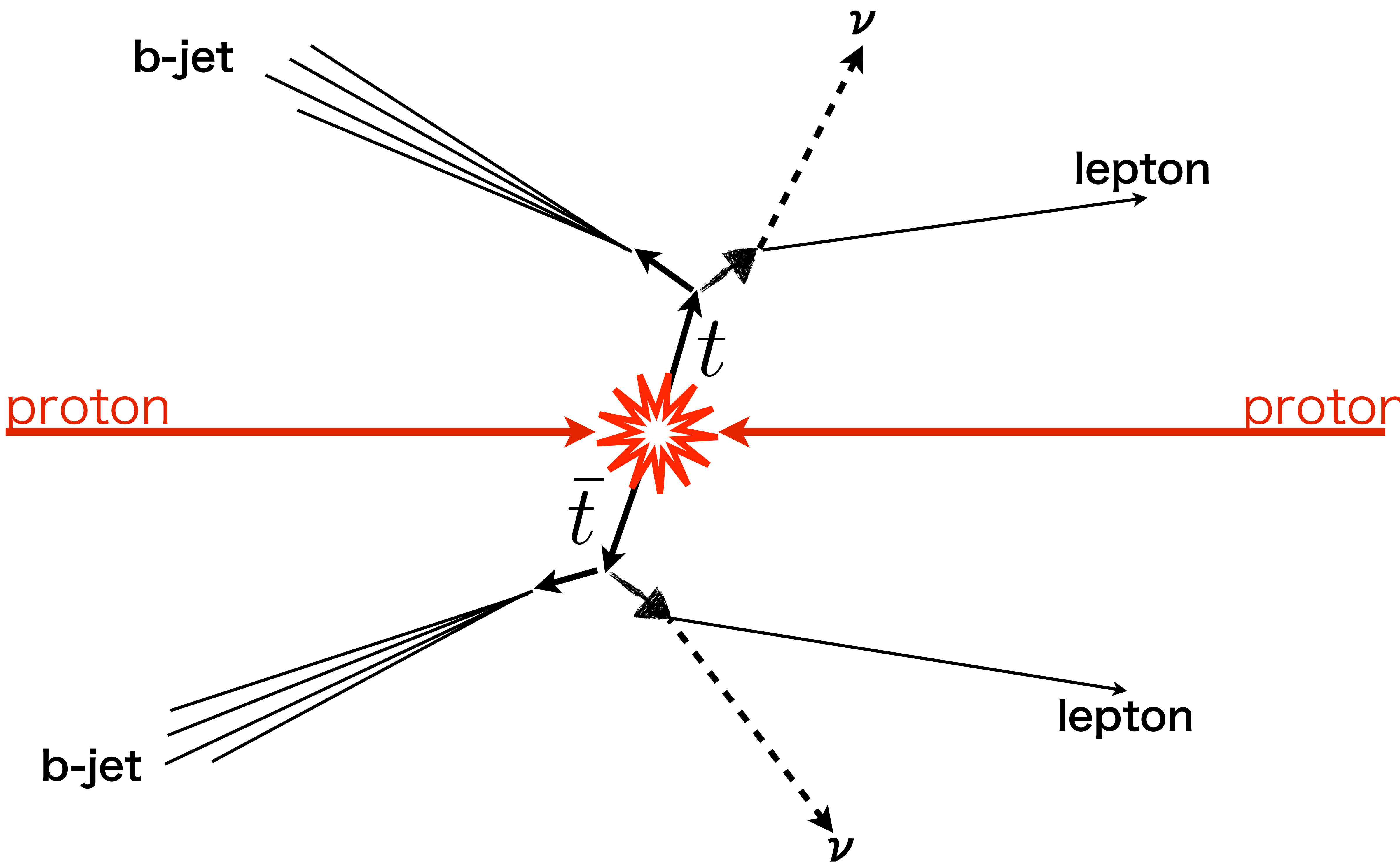

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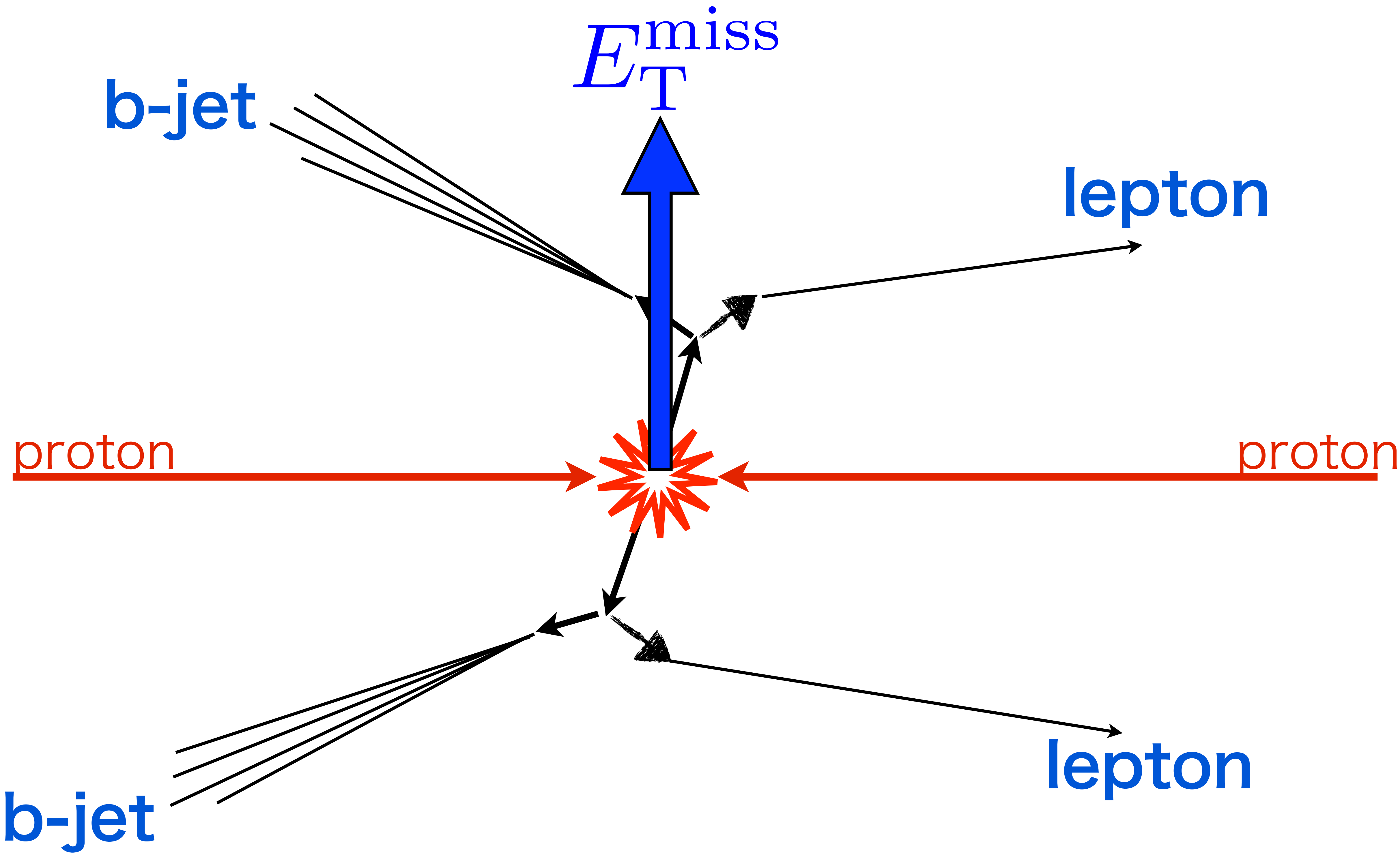

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- **Assumed background sources**
  - Z/γ^* + jets
  - Fake leptons (mainly W+jets)
  - WW, WZ, ZZ + jets
  - single top

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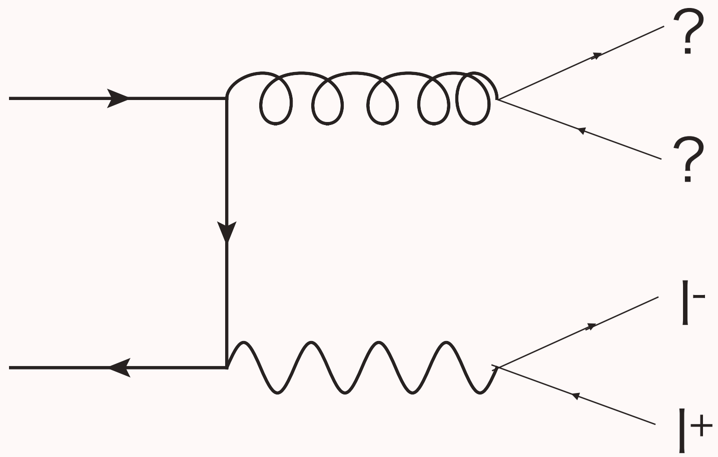
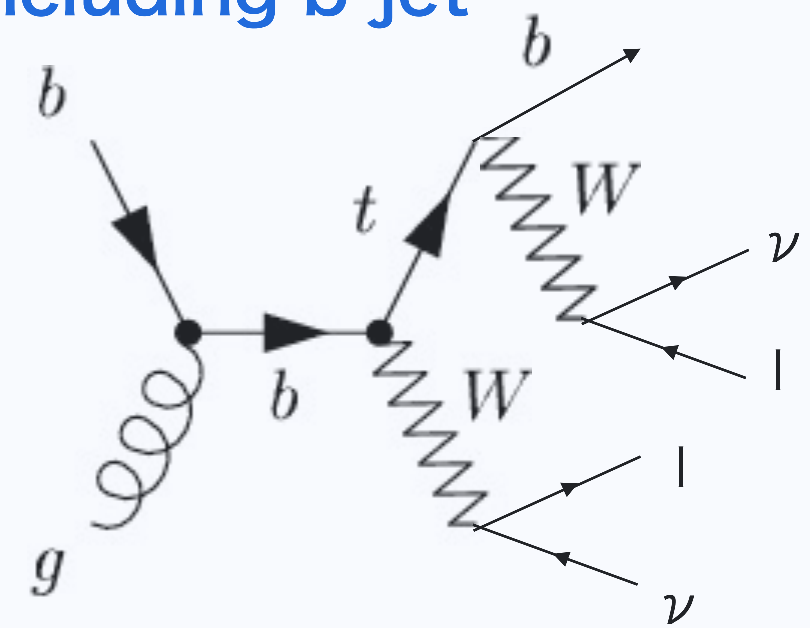
less b-jets(~3%)



including b-jet



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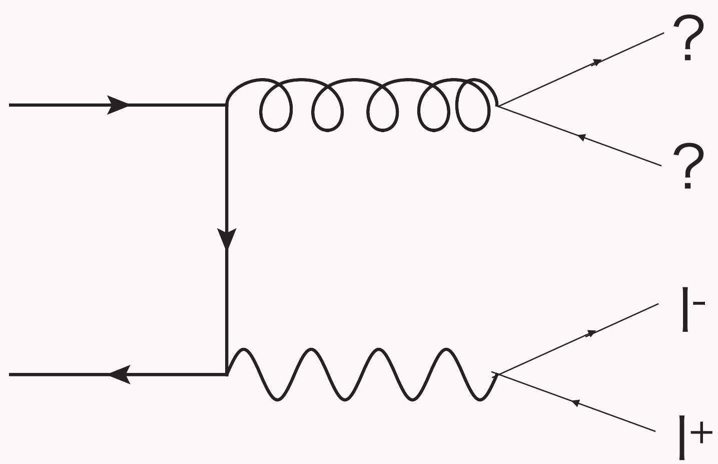
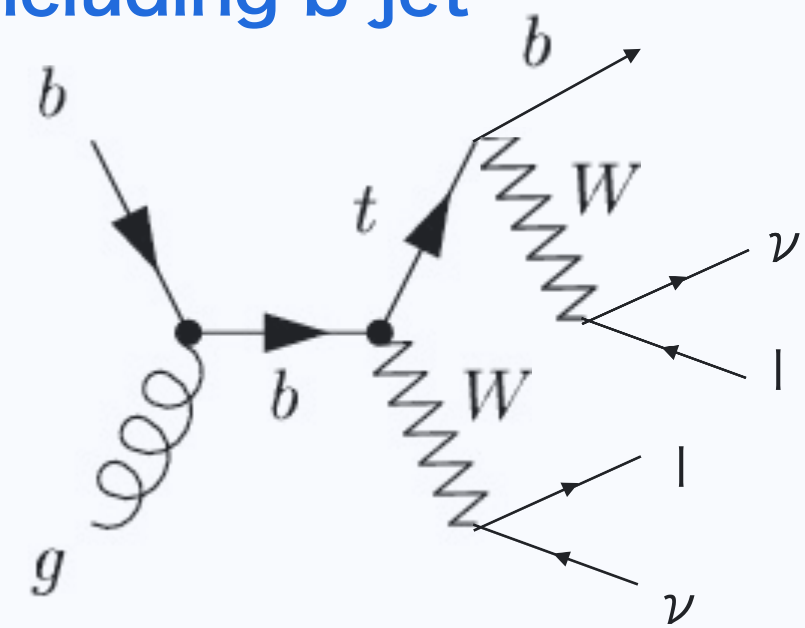


including b-jet



Better S/N ratio can be achieved by b-tagging !!

$t\bar{t}$ production cross-section measurement

- Cut and Count method
  - $\sigma_{t\bar{t}} = \dfrac{N_{obs} - N_{BG}}{\mathcal{A} \times \mathcal{L}}$ ($\mathcal{A}$: acceptance, $\mathcal{L}$: Integrated Luminosity)
  - simple and robust (e.g. multi variate analysis etc...)

- With high purity ttbar sample ...

  1) validate QCD at the highest energy region
  2) understand main background for Higgs/SUSY etc...
  3) can be a good b-quark source for btag calibration

- **Essential step for future analyses in LHC physics !!**

dilepton analysis so far...

- result with 35pb^{-1} of 2010 data
  - $\sigma_{t\bar{t}} = 188 \pm 26(\mathrm{stat.})^{+20}_{-16}(\mathrm{syst.})^{+9}_{-7}(\mathrm{lum.})\ \mathrm{pb.}$
  - precision : ~18% (statistically limited... $\delta_{\sigma_{t\bar{t}}}(stat.) \sim 13\%$)
  - submitted to PLB.
    (arXiv : http://arxiv.org/abs/1108.3699)

- In 2011 data analysis
  - using 0.70 fb^{-1} of data (~20 times more than 2010 !!)
  - not limited by statistics anymore
  - need to suppress systematic uncertainty

Event selection

- **variables for event selection**
  - $E_{\mathrm{T}}^{\mathrm{miss}} > 30\ \mathrm{GeV}(ee, \mu\mu)$, $\sum |E_{\mathrm{T}}| > 110\ \mathrm{GeV}(e\mu)$
  - $|M_{ll} - M_Z| > 5\ \mathrm{GeV}(ee, \mu\mu)$(referred as Z window cut)
  - #jets ≥ 2
  - b-tagging

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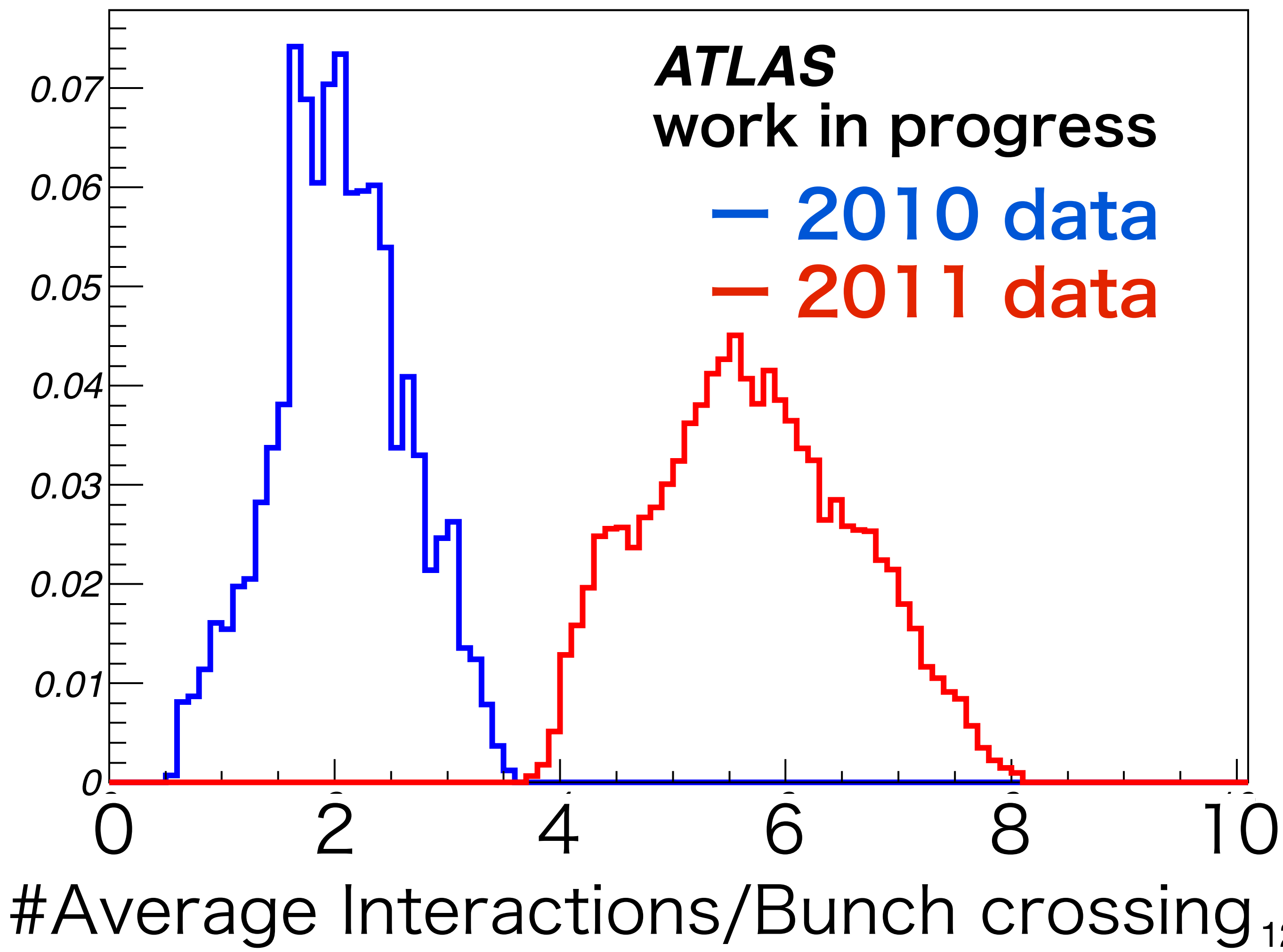
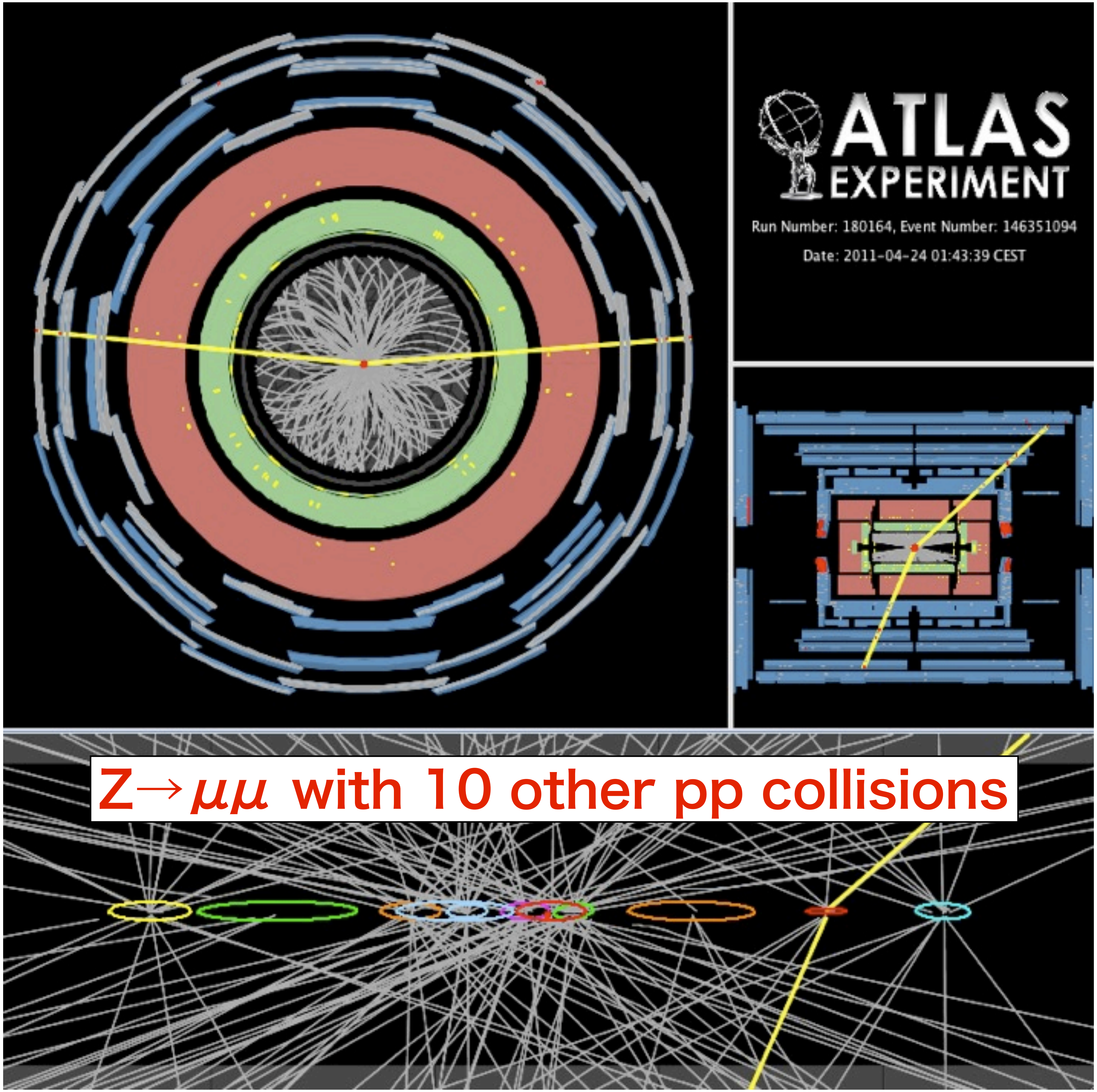
  - $\#\mathrm{jets} \geq 2$
  - b-tagging
- **need re-optimization !!**
  - Due to different detector environment.
  - Observing more underlying events.




ATLAS
EXPERIMENT
Run Number: 180164, Event Number: 146351094
Date: 2011-04-24 01:43:39 CEST
Z→μμ with 10 other pp collisions

b-tagging requirement

- **"at least one"** b-tagged jet with **"high btag efficiency"**
  - help to reduce systematics from btag eff. measurement.
  - $\delta_{\sigma_{t\bar{t}}} \propto 2(1-\varepsilon_b)\delta_{\varepsilon_b}$ (typically $\delta_{\varepsilon_b} \sim 8\%$)

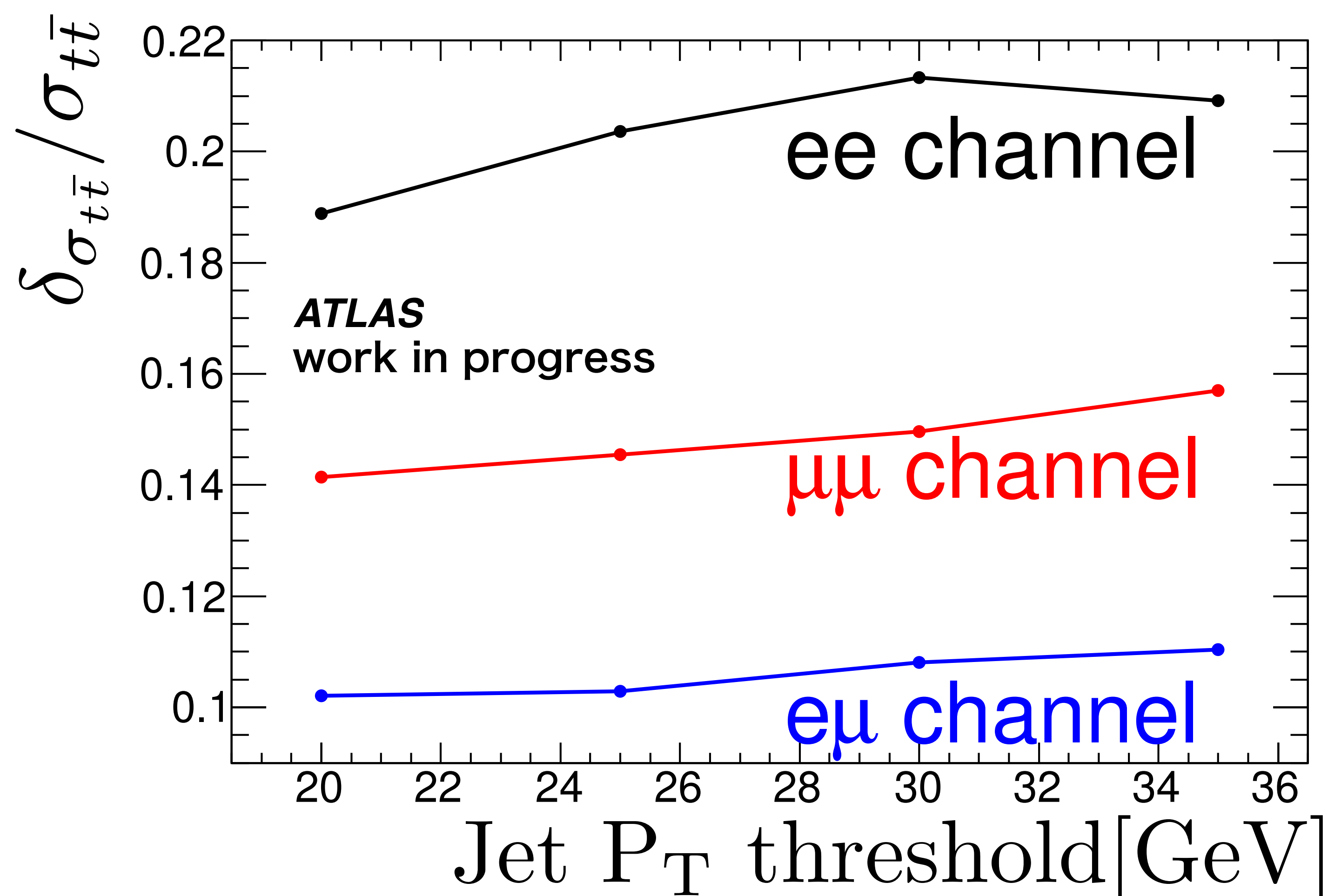
- b-tagging algorithm
  - JetProb : charged track base
  - IP3DSV1 : charged track and secondary vertex base

    ➡so called "advanced tagger"

- JetProb@70% was used for the 2010 analysis.
  - Switched to **IP3DSV1@80%**
  - can reduce $\delta_{\sigma_{t\bar{t}}}$ by ~30%

Jet P_T threshold optimization

- Motivation : not to pick up jets from other pp collisions
- Evaluate $\delta\sigma/\sigma$ with each Jet P_T threshold
  - $\delta\sigma$ is including uncertainty from…
    - ➡ Jet Energy Scale(JES)
    - ➡ btag efficiency measurement
    - ➡ observed event statistics

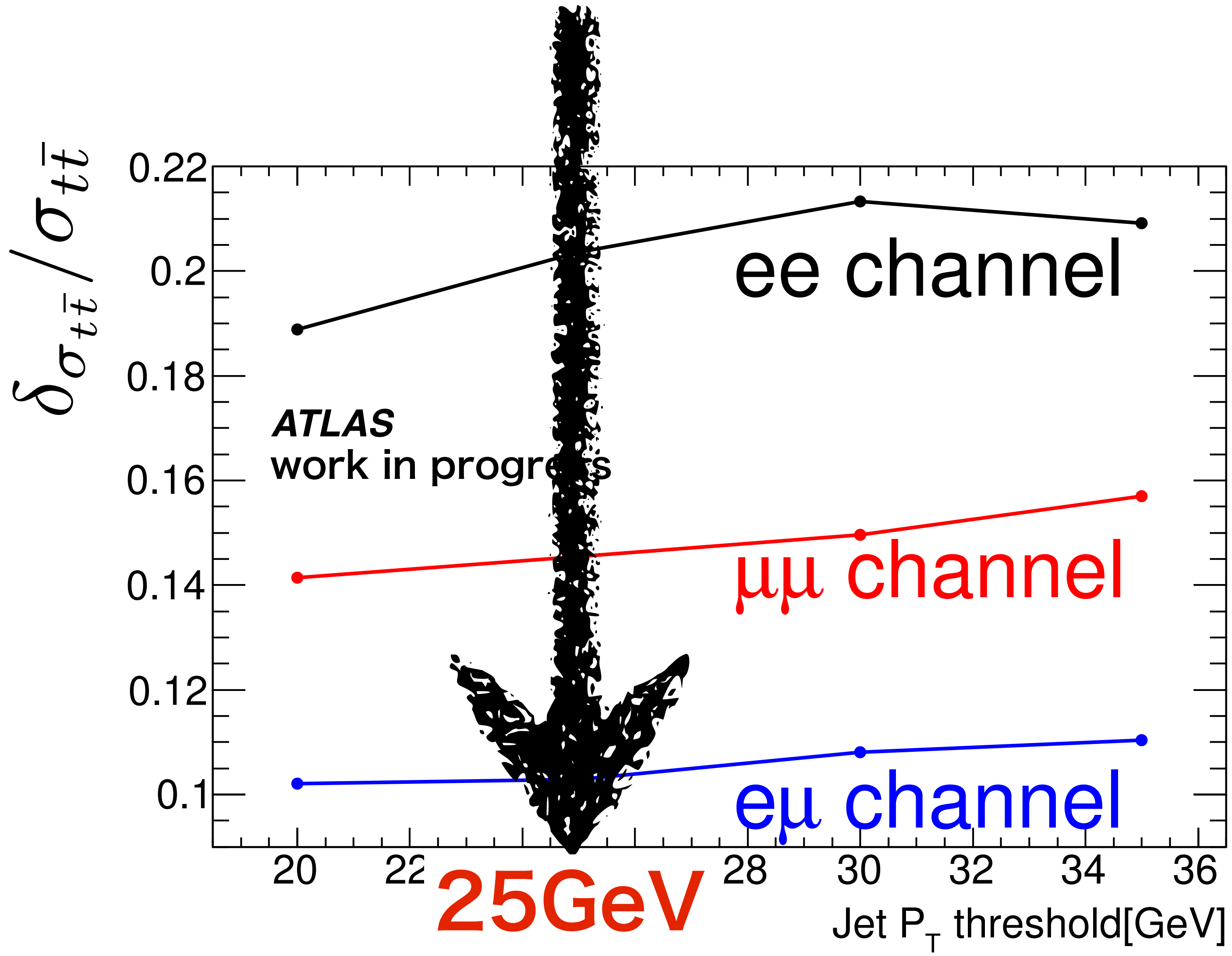


Jet P_T threshold optimization

"Jet P_T > 25GeV" was chosen.

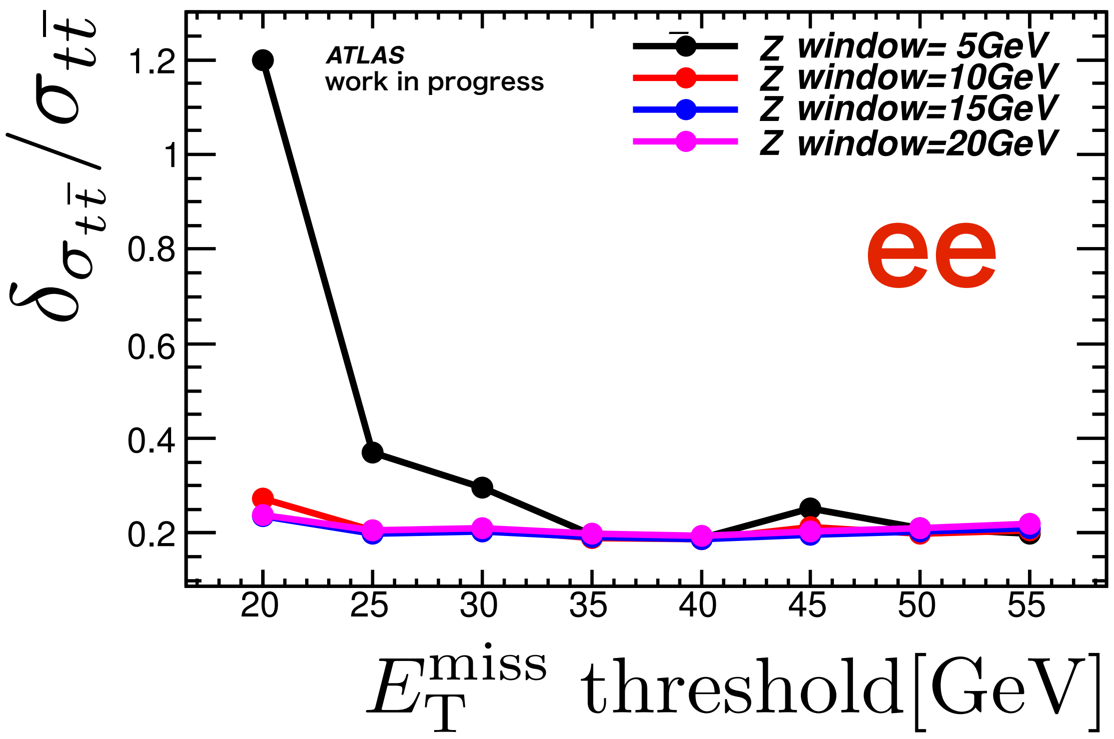
--> Safe for environmental changes

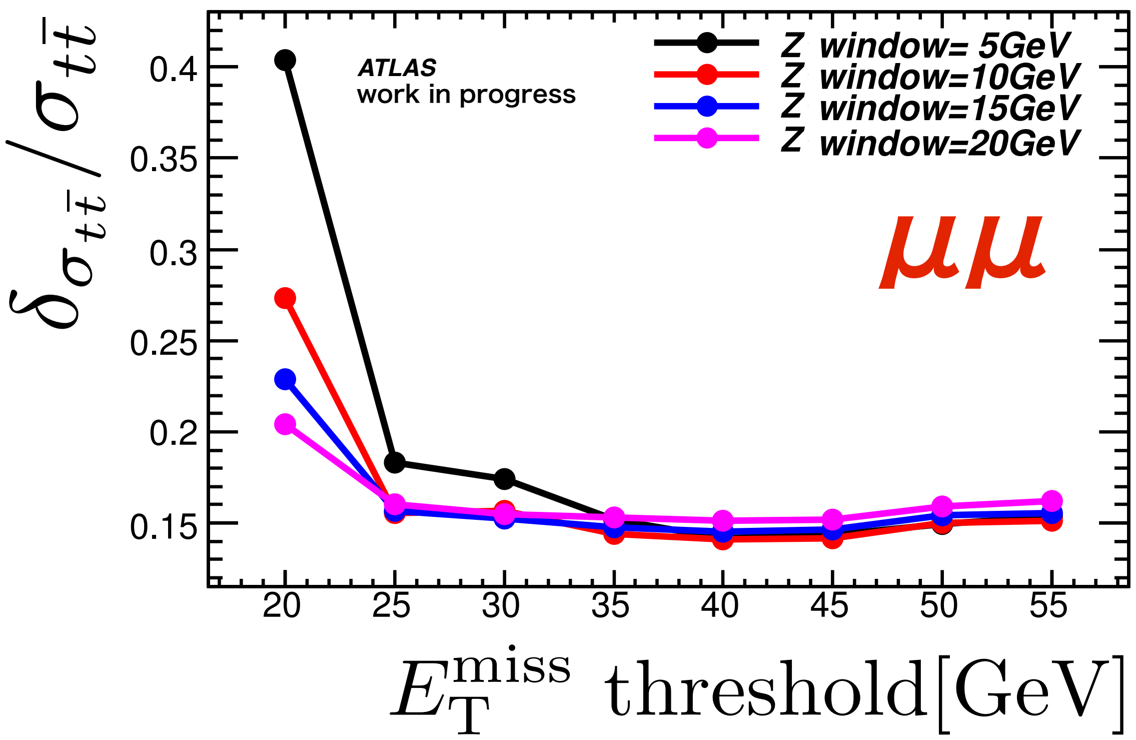
(Luminosity keeps increasing !!)

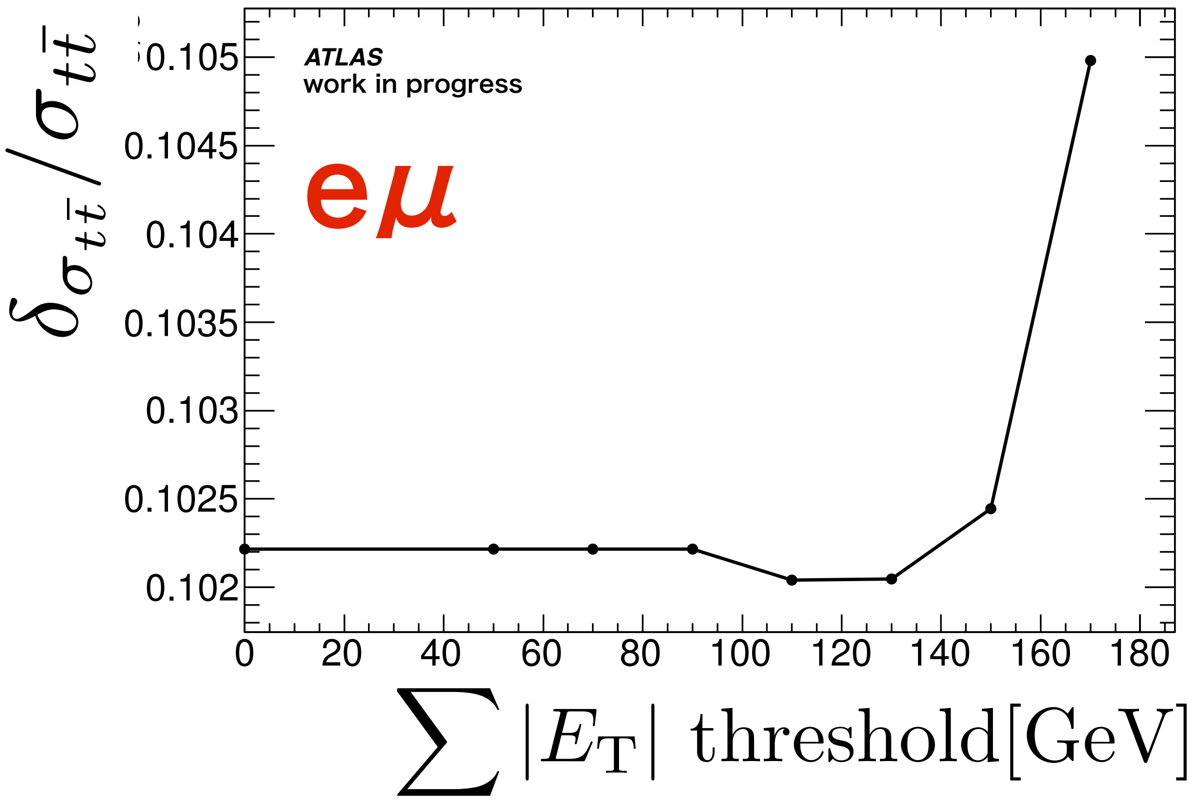


Event selection optimization

- similar approach as previous page.



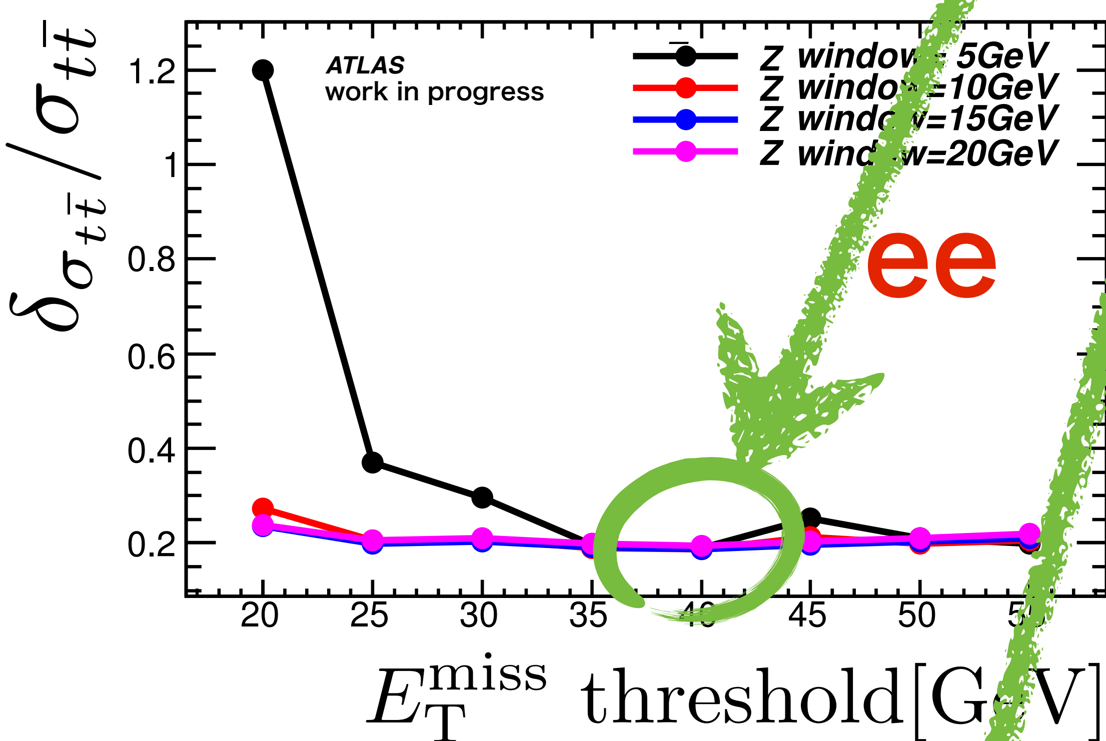


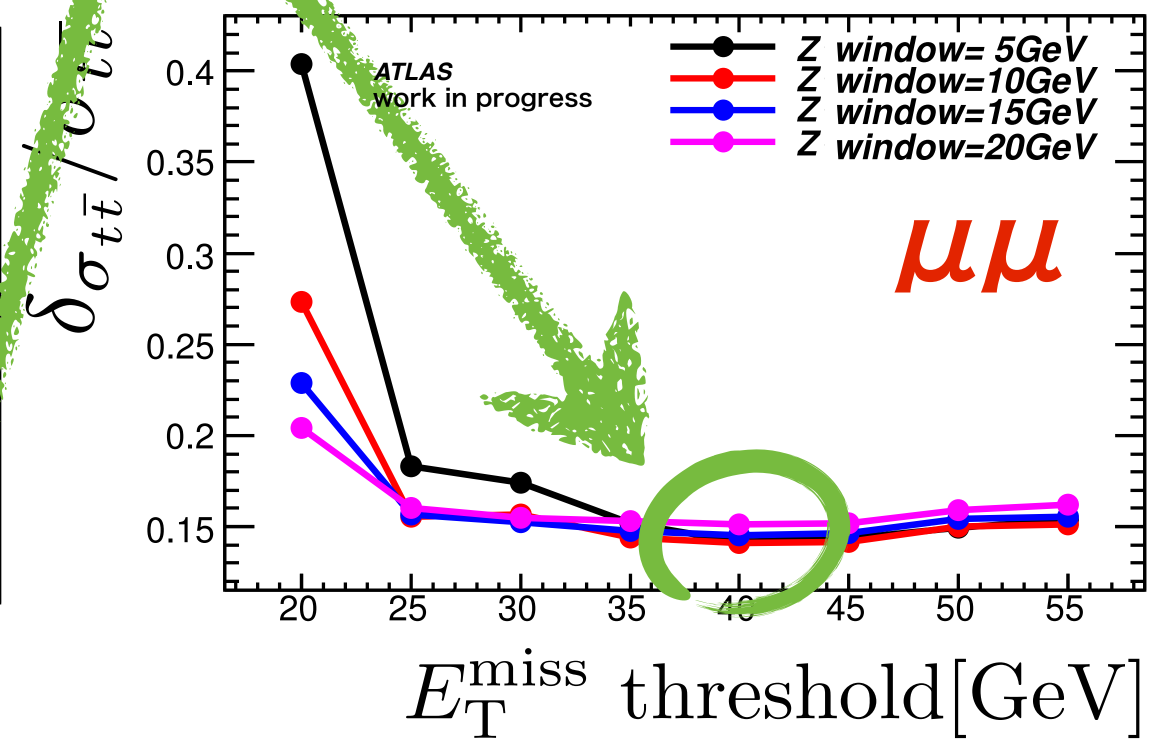


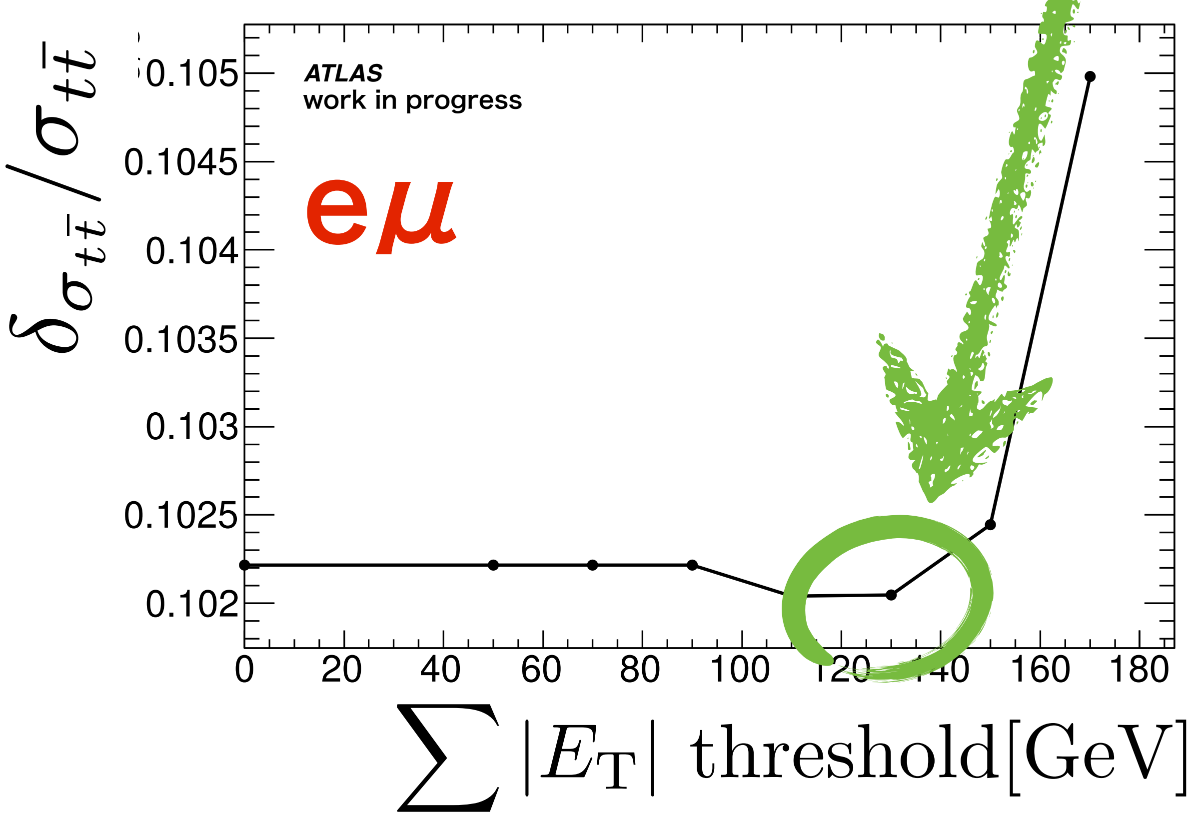
Ev

analyzing with this point

- si







ee/mumu channel

$E_{\mathrm{T}}^{\mathrm{miss}}$ > 40GeV (30GeV)

Z-window = 10GeV (5GeV)

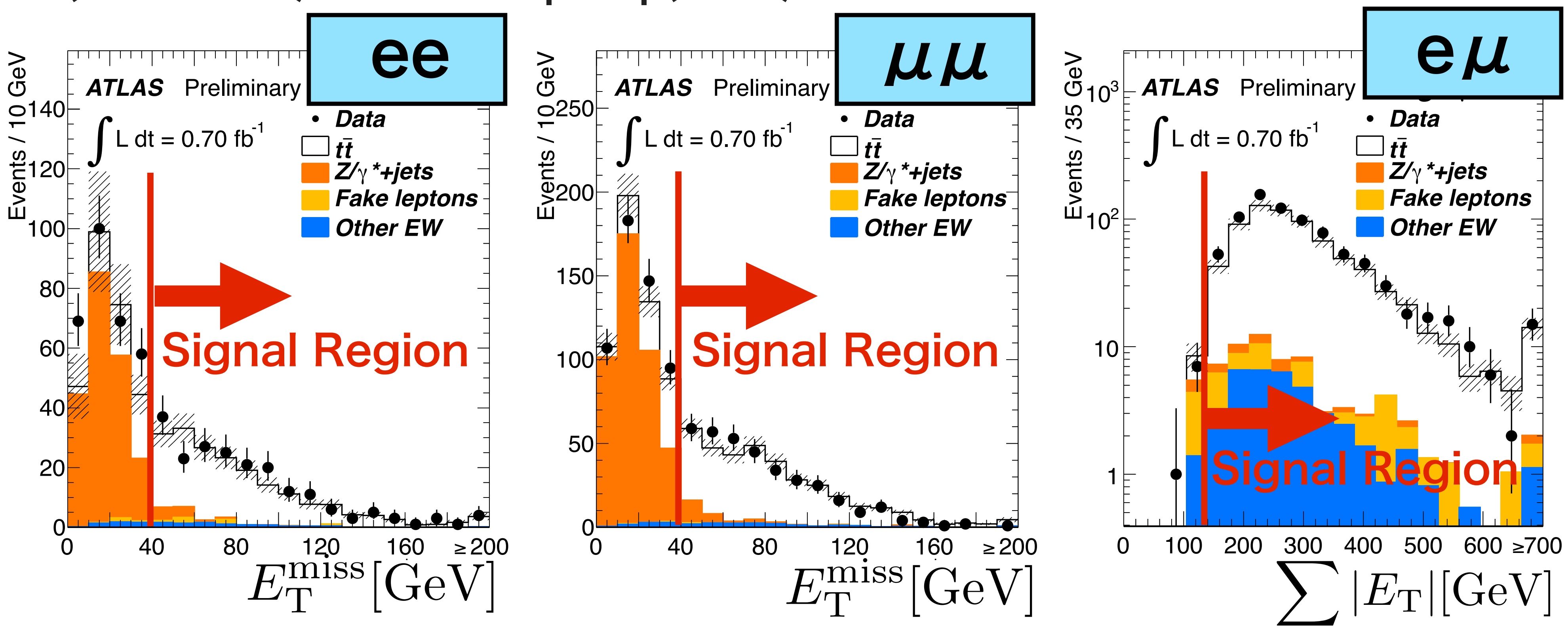
emu channel

$\sum|E_{\mathrm{T}}|$ > 130 GeV (110GeV)

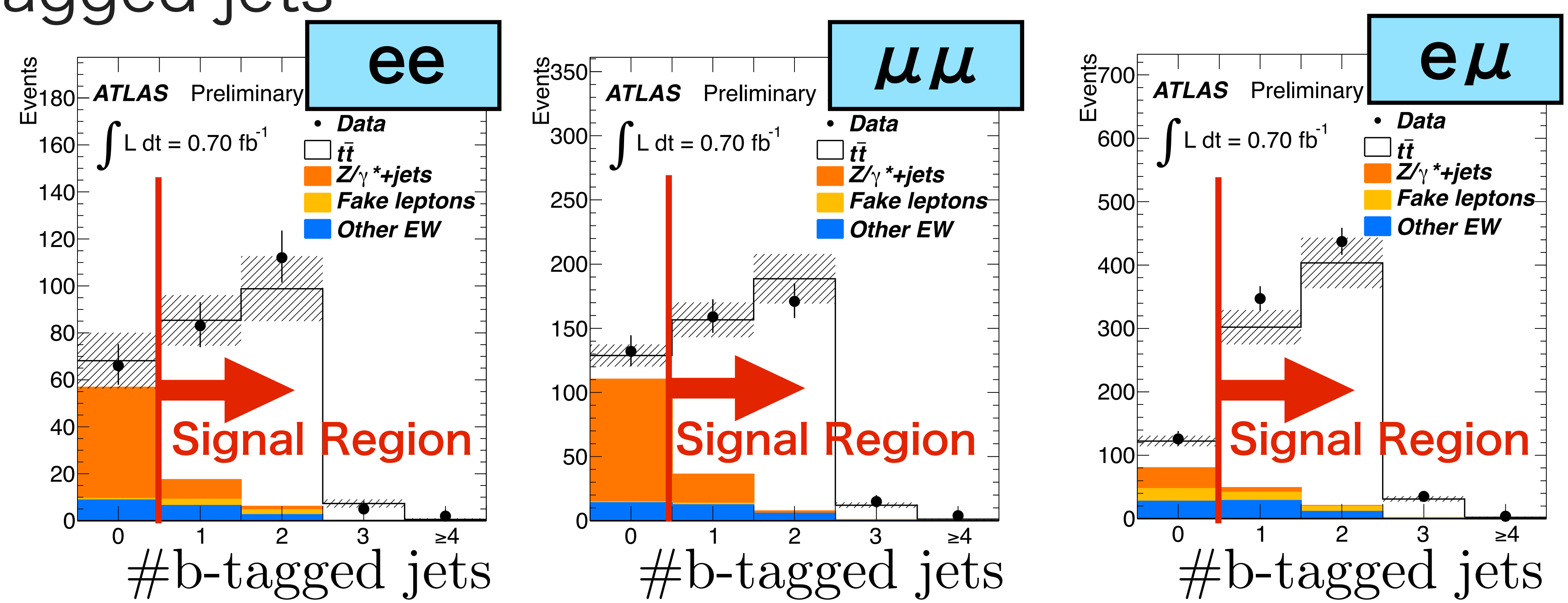
"()" : used in 2010 analysis

Distributions (after requiring all selection)

- E_T^{miss} (ee, $\mu\mu$) and $\Sigma|E_T|$(eμ)



- #b-tagged jets

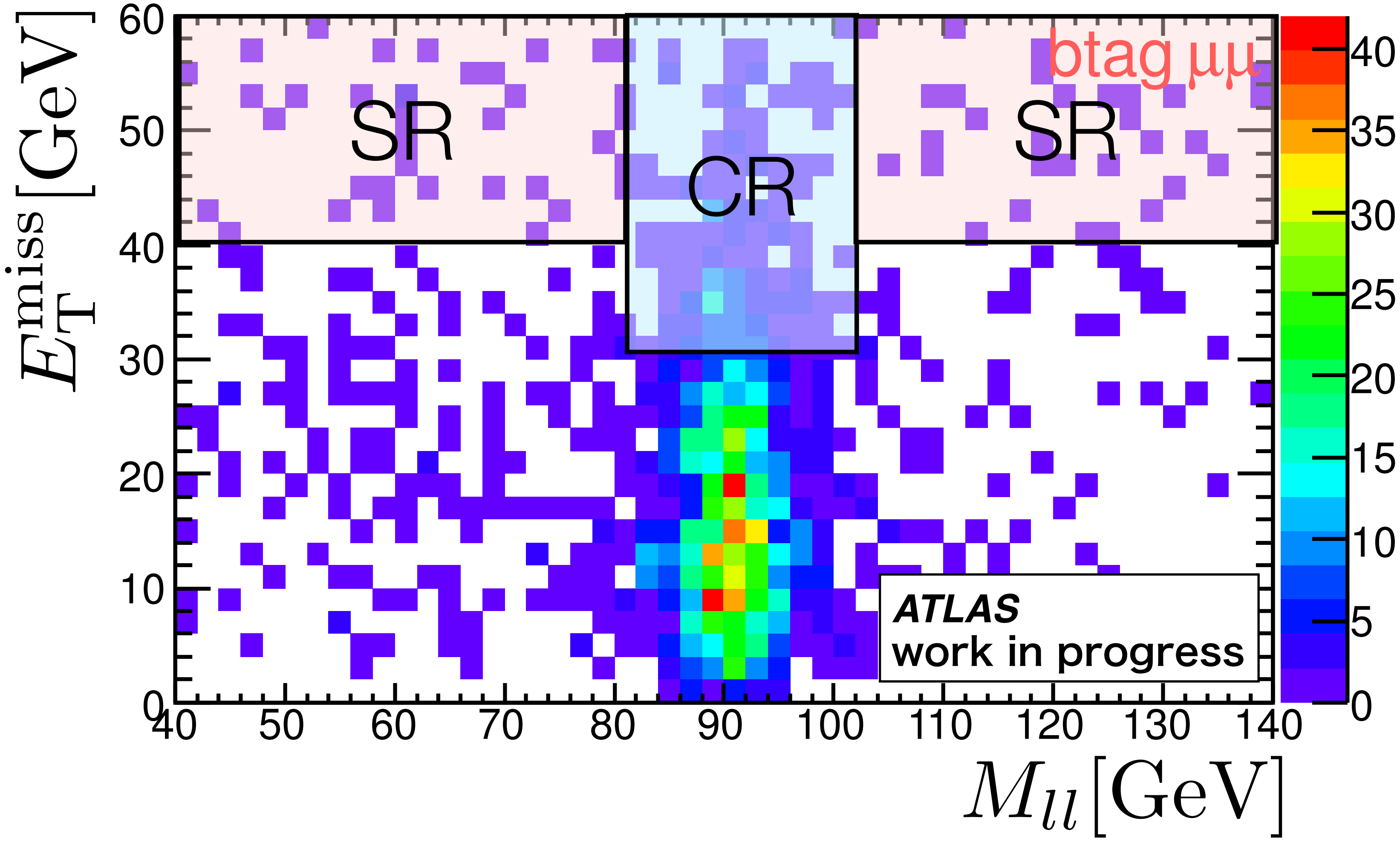


BG estimation from Z/γ^*

- Extrapolate #events in Control Region(CR) to Signal Region(SR)

$$N_{Z/\gamma^*+\text{jets}} = \frac{\text{MC}_{Z/\gamma^*+\text{jets}}(\text{SR})}{\text{MC}_{Z/\gamma^*+\text{jets}}(\text{CR})} \times (\text{Data(CR)-MC}_{\text{other}}(\text{CR}))$$

- CR definition
  - ➡same requirement as signal (including btagging)
  - ➡inside Z-window with high $E_{\mathrm{T}}^{\mathrm{miss}}$



Event yields

Process	Yields(ee)	Yields($\mu\mu$)	Yields($e\mu$)
DY+jets (data driven)	$9.8\ ^{+1.7}_{-1.3}$	$20.3\ ^{+1.8}_{-2.8}$	–
Z→ $\tau\tau$ + jets (MC)	1.8 ± 1.1	7.6 ± 3.5	9.5 ± 4.1
fake leptons (data driven)	7.5 ± 6.5	4.9 ± 3.1	19.8 ± 12.5
Single top (MC)	$7.3\ ^{+1.3}_{-1.1}$	16.2 ± 2.3	33.5 ± 4.7
Dibosons (MC)	2.2 ± 0.7	$2.6\ ^{+0.9}_{-0.6}$	8.8 ± 1.7
Total Predicted (non $t\bar{t}$)	26.0 ± 4.9	$47.7\ ^{+4.5}_{-5.2}$	71.6 ± 14.1
$t\bar{t}$	$159.4\ ^{+17.0}_{-20.5}$	$304.3\ ^{+25.8}_{-34.5}$	$674.5\ ^{+57.0}_{-74.7}$
Total Predicted	$185.4\ ^{+17.5}_{-20.8}$	$352.0\ ^{+26.2}_{-34.9}$	$746.1\ ^{+58.7}_{-76.0}$
Data	201	365	834

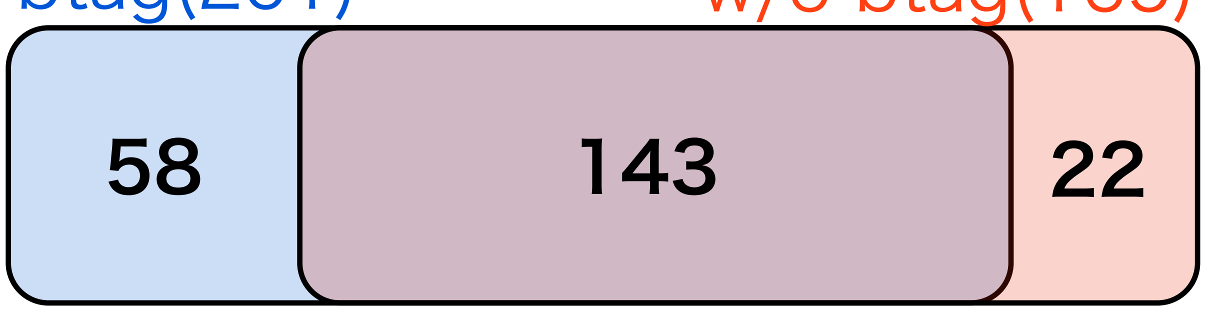
S/N : ee = 6.1(4.9)
$\mu\mu$ = 6.4(4.3)
eμ = 9.4(4.6)

“()”~w/o btag analysis

Overlapping events against the analysis w/o btag with tight cut

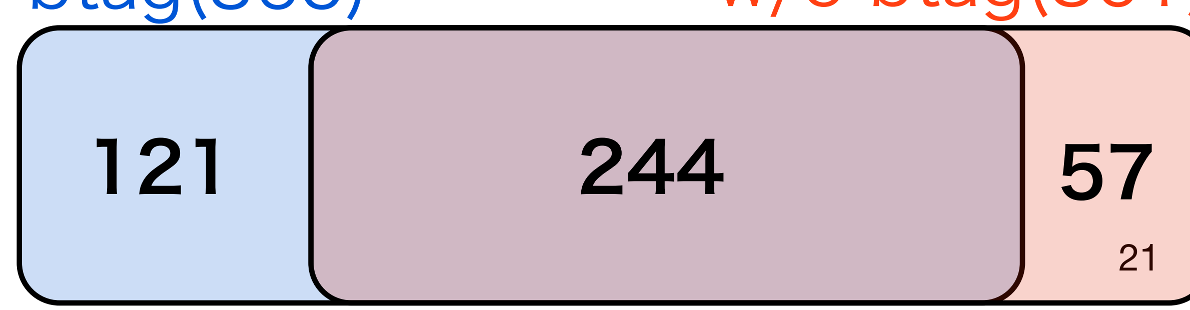
In ee channel

btag(201) w/o btag(165)

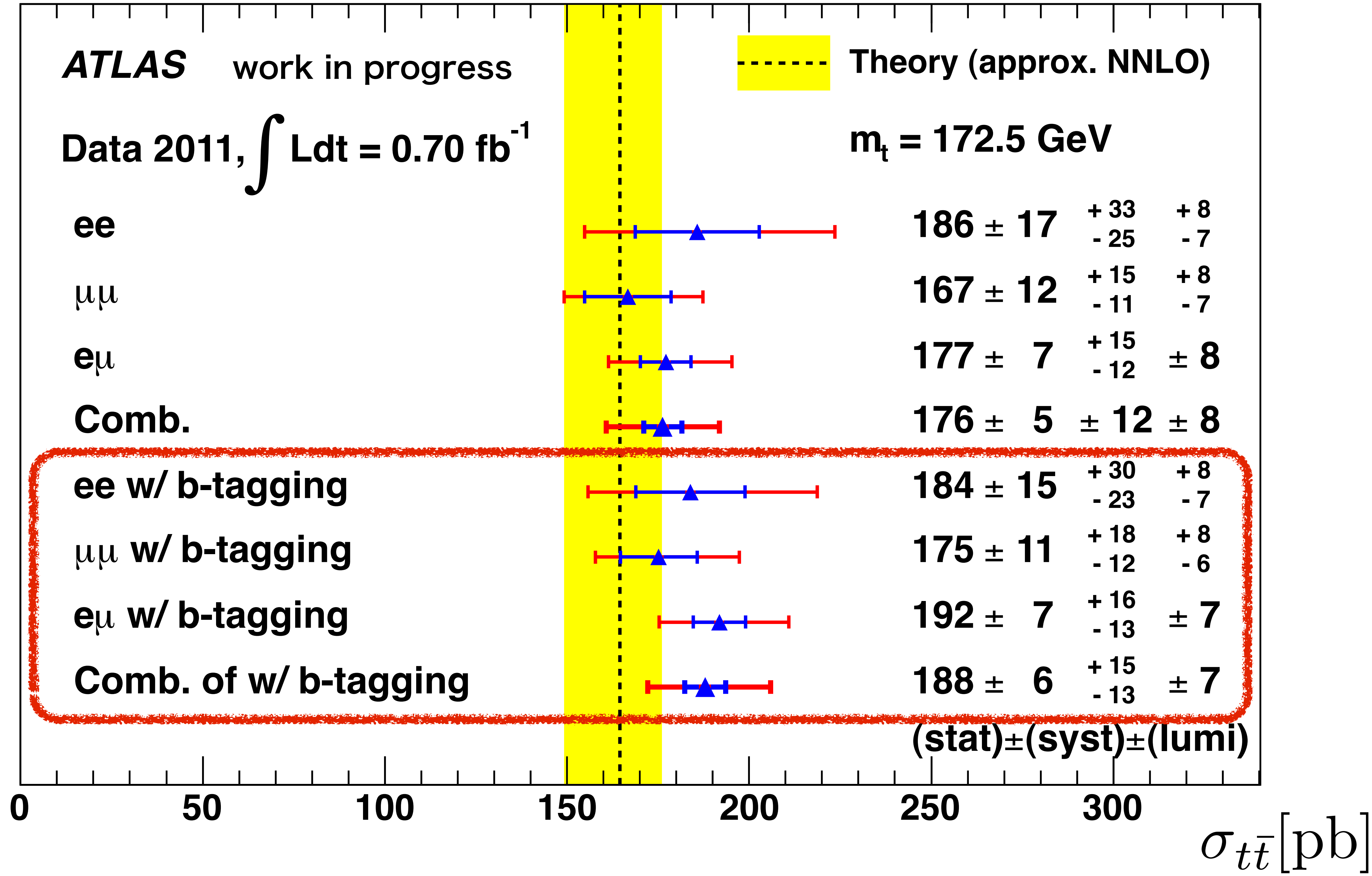


In $\mu\mu$ channel

btag(365) w/o btag(301)



Extracted cross section



consistent result with theory and the analysis w/o b-tagging

Systematic uncertainties

	combined
Uncertainties (%)	$\Delta\sigma/\sigma[\%]$
Data Statistics	-3.0 / 3.0
Luminosity	-3.9 / 3.9
MC Stat.	-0.5 / 0.5
Lepton uncertainties	-2.3 / 2.3
Jet/E_{T}^{miss} uncertainties	-4.5 / 4.5
DY estimation	-0.2 / 0.0
Fake lepton estimation	-1.1 / 1.1
b-tagging uncertainties	-3.1 / 4.1
Generator	-3.7 / 4.1
All syst.(except Lumi)	-6.8 / 8.2
Stat + Syst	-8.4 / 9.7

Data statistics

Luminosity

Jet Energy Scale

btag calibration

Total Uncertainty

~ 9% precision was achieved !!

Conclusions

- **Performed ttbar cross section measurement with b-tagging**
  - using 0.70 fb^{-1} of data
    - ➡enough statistics even for di-lepton final state
  - adopt b-tagging @ 80% efficiency
    - ➡help to suppress systematic uncertainty

- **measured Cross-Section is consistent with NNLO prediction**
  - combined result : $\sigma_{t\bar{t}} = 188 \pm 6(\mathrm{Stat.})^{+15}_{-13}(\mathrm{Syst.}) \pm 7(\mathrm{Lumi.})[\mathrm{pb}]$
    - ➡Precision : ~10% (~18% in 2010 analysis)
  - NNLO prediction : $\sigma_{t\bar{t}} = 165^{+11}_{-16}$ pb. @ Mt = 172.5 GeV

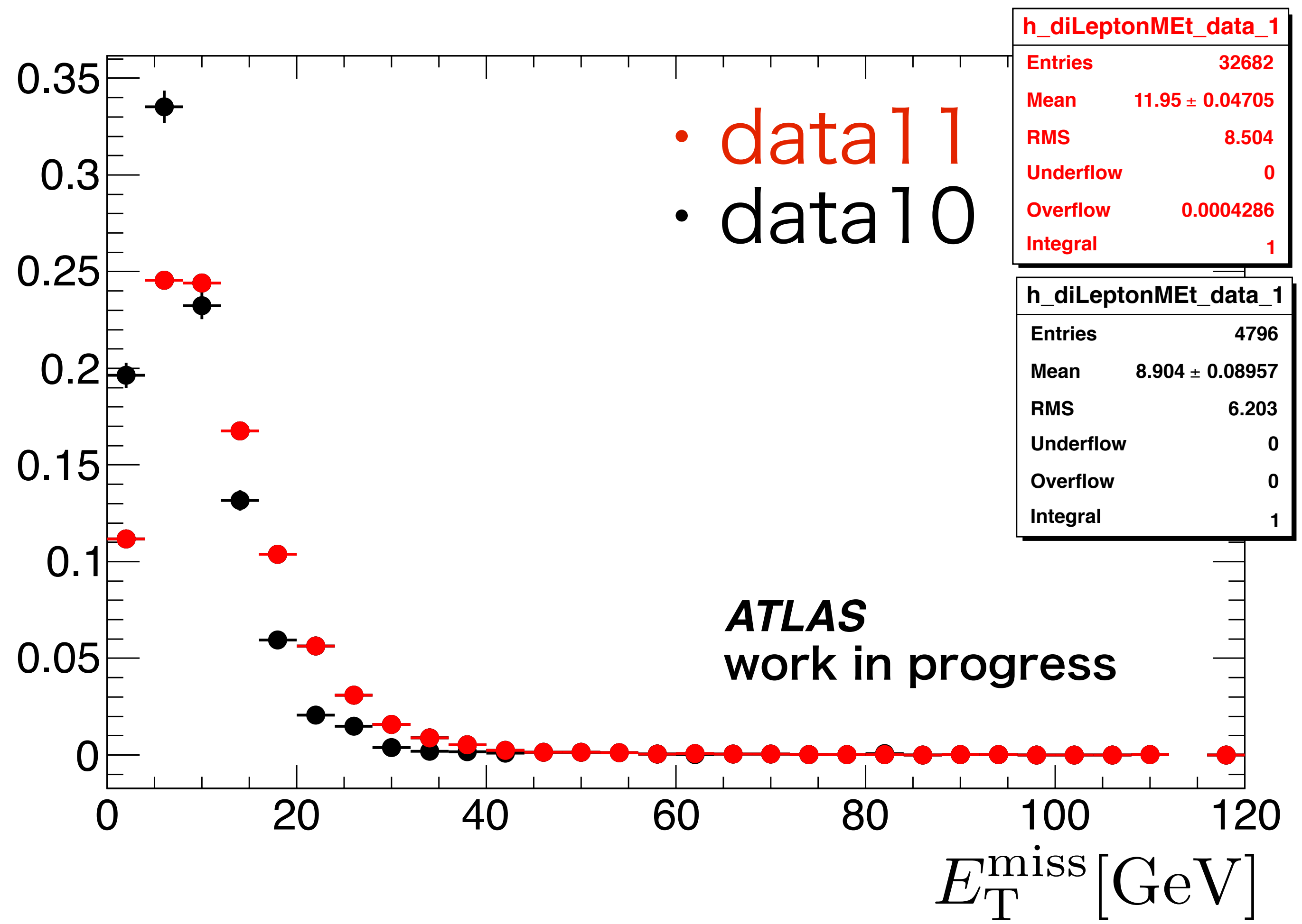
- **Achieved comparable size of uncertainty w.r.t theoretical prediction !!**

backup

Effect of underlying events

- After requiring di-lepton
  - dominated by Z/γ^* + jets events(i.e. basically no MEt)

- $E_{\mathrm{T}}^{\mathrm{miss}}$ resolution got worse due to underlying events.
  - additional energy deposit ⇒ large energy fluctuation in calorimeter



$E_{\mathrm{T}}^{\mathrm{miss}}$ has less rejection power against Z/γ^* events than 2010 !!

b-tagging algorithm

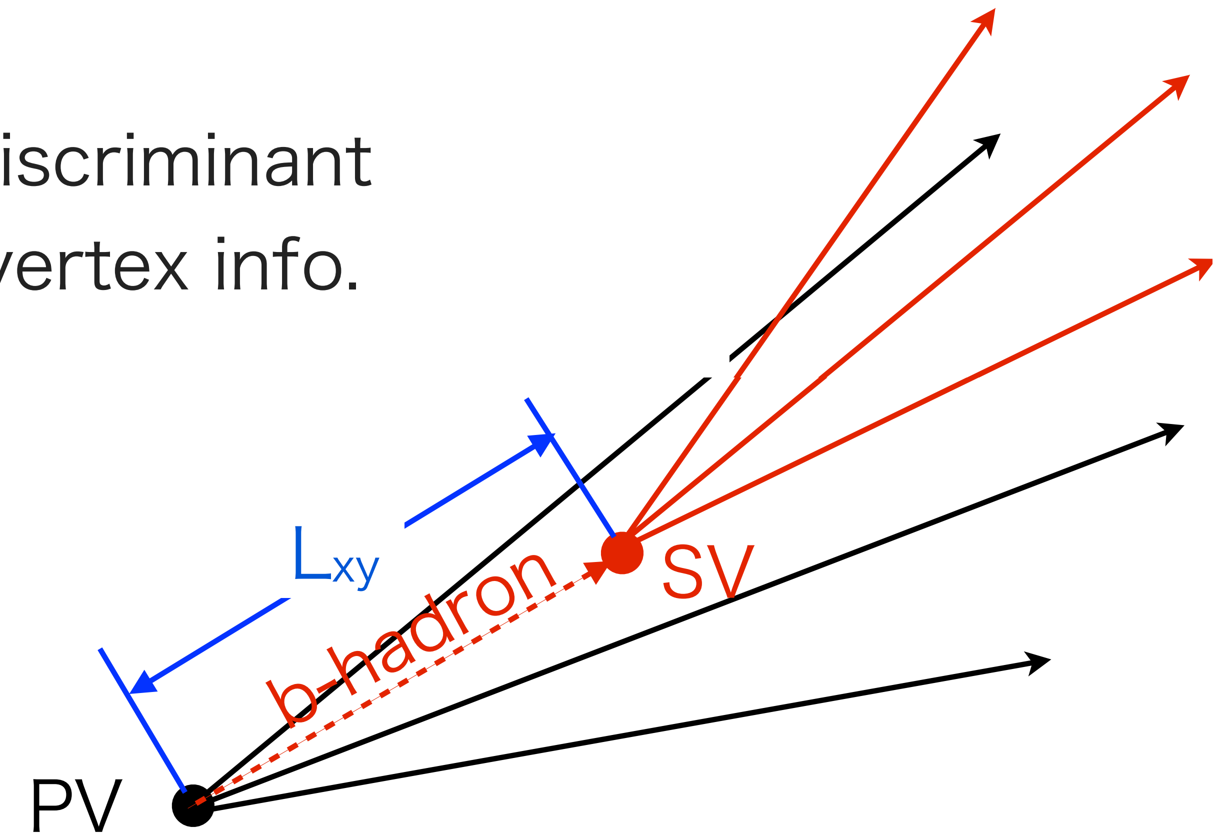
- **JetProb** : charged track base

$$\mathscr{P}_i = \int_{-\infty}^{-|d_0^i/\sigma_{d_0}^i|} \mathscr{R}(x)dx$$: Likelihood of tracks comes from PV

$$\mathscr{P}_{jet} = \mathscr{P}_0 \sum_{j=0}^{N-1} \frac{(-ln\mathscr{P}_0)^j}{j!}$$: Likelihood of jet is light-flavor jet

(where $\mathscr{P}_0 = \prod_{i=1}^{N} \mathscr{P}'_i$ and $\begin{cases} \mathscr{P}'_i = \frac{\mathscr{P}_i}{2} & \text{if } d_0^i > 0 \\ \mathscr{P}'_i = \left(1 - \frac{\mathscr{P}_i}{2}\right) & \text{if } d_0^i < 0 \end{cases}$)

- **IP3DSV1** : log likelihood of various discriminant
  - using both tracks and secondary vertex info.
    - ➡Signed d_0 significance
    - ➡Secondary vertex mass
    - ➡etc...



BG Estimation for Fake Leptons

- **Matrix Method**
  - Define "Tight/Loose" lepton

    ➡count the remaining #events(N_{TT}, N_{LL} etc.)
  - Measure a probability "r" and "f"

    ➡"r(f)" : the probability of a real(fake) lepton which pass the "loose" criteria will pass the "tight" criteria.

    - "r" : measured in Z→ll process
    - "f" : measured in QCD process
  - Solve this matrix...

contribution from fake leptons

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

- **Results** : ee : 7.5 ± 6.5 (Stat.+Syst.)

  $\mu\mu$: 4.9 ± 3.1 (Stat.+Syst.)

  eμ : 19.8 ± 12.5 (Stat.+Syst.)

Uncertainty for Z/γ^* + jets estimation

ee channel

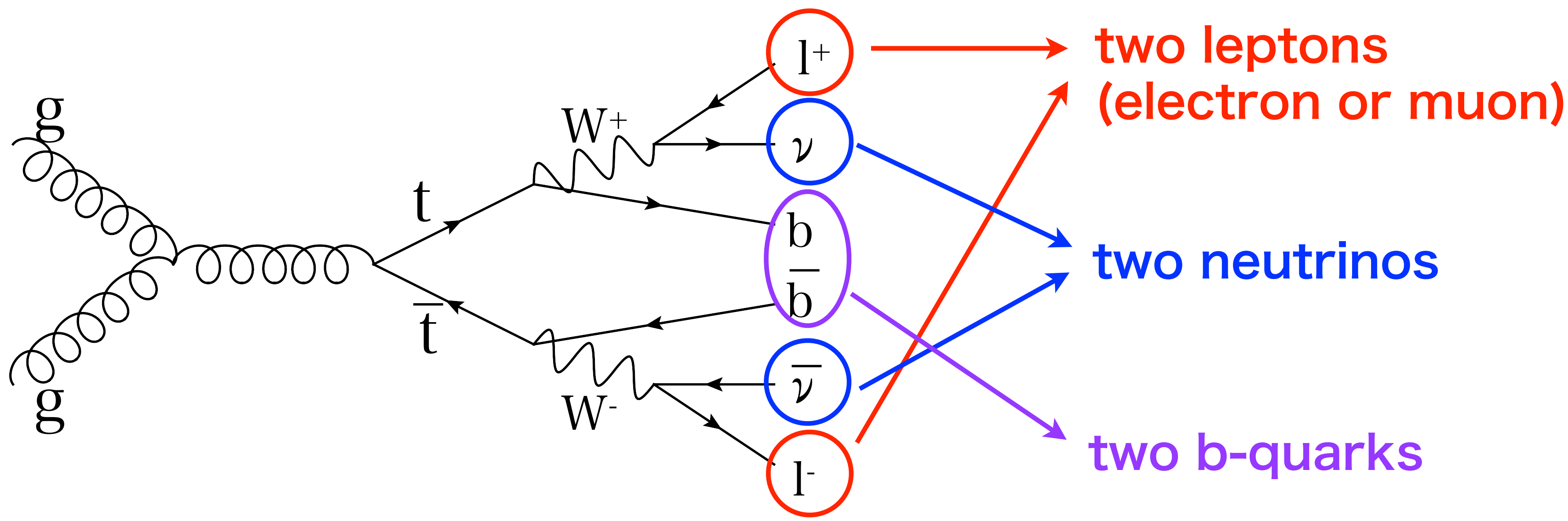
	MC	Data Driven
Expected Yields	11.2	9.8
Uncertainty Source	$\delta N_{DY}/N_{DY}[\%]$	$\delta N_{DY}/N_{DY}[\%]$
Data stat.	-	± 7.4
MC stat.	± 7.0	± 7.0
Method	-	± 5.2
JES	+54.7/-24.0	+10.9/- 0.0
JER	± 15.1	± 1.8
Jet ID SF	± 0.0	± 0.2
SoftJet/CellOut Term.	+ 0.4/- 1.8	+ 0.0/- 2.2
LAr Hole	+ 4.7/- 3.7	+ 3.6/- 1.6
El. ES	± 2.9	± 3.2
El. ER	+ 6.2/- 2.4	+ 4.6/- 1.3
El. ID SF	+ 5.2/- 5.1	± 0.0
El. Trig SF	± 1.9	± 1.7
MC xsec	± 28.8	-
b-tag eff.	± 2.7	± 0.0
l-tag eff.	+ 4.5/- 4.6	± 0.4
Pileup	+ 0.0/- 3.1	+ 0.0/- 2.7
Luminosity	± 3.7	-
Total	+ 65.1/-42.7	+17.3/-13.2

mumu channel

	MC	Data Driven
Expected Yields	21.9	20.3
Uncertainty Source	$\delta N_{DY}/N_{DY}[\%]$	$\delta N_{DY}/N_{DY}[\%]$
Data stat.	-	± 5.5
MC stat.	± 4.6	± 4.6
Method	-	± 0.8
JES	+42.3/-27.2	+ 1.3/-10.0
JER	± 23.6	± 3.8
Jet ID SF	± 0.0	± 0.1
SoftJet/CellOut Term.	+ 0.8/- 0.1	+ 0.6/- 3.2
LAr Hole	+ 2.8/- 1.3	+ 2.1/- 0.0
Mu. ES	+ 0.9/- 0.0	+ 1.0/- 0.0
Mu. ER	± 1.1	± 1.4
Mu. ID SF	± 0.6	± 0.0
Mu. Trig SF	+ 0.2/- 2.0	+ 0.0/- 0.1
MC xsec	± 29.7	-
b-tag eff.	+ 2.9/- 2.8	± 0.1
l-tag eff.	+ 5.1/- 5.2	+ 0.3/- 0.4
Pileup	+ 1.6/- 2.9	+ 0.0/- 2.6
Luminosity	± 3.7	-
Total	+57.5/-47.5	+ 8.7/-13.6

$t\bar{t}$ production cross-section measurement

- **ttbar → di-lepton final state**



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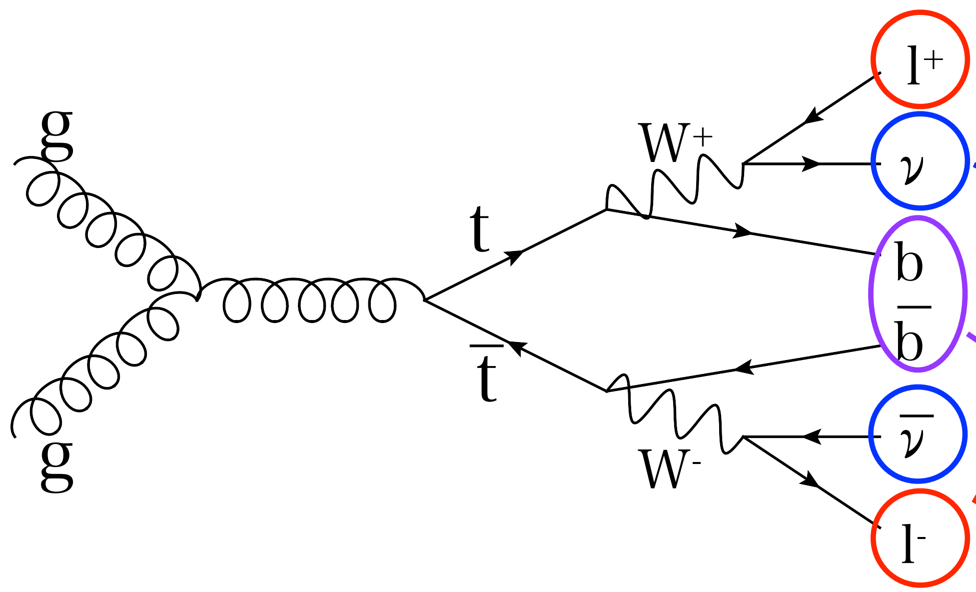

two leptons (electron or muon)

two neutrinos

two b-quarks

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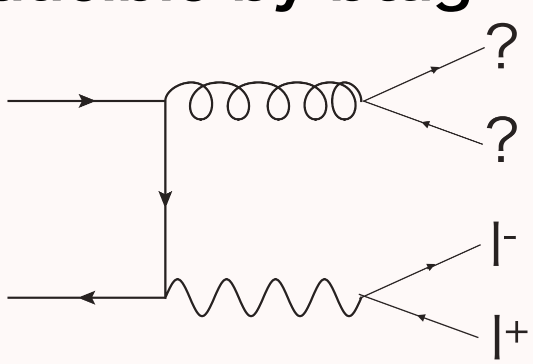
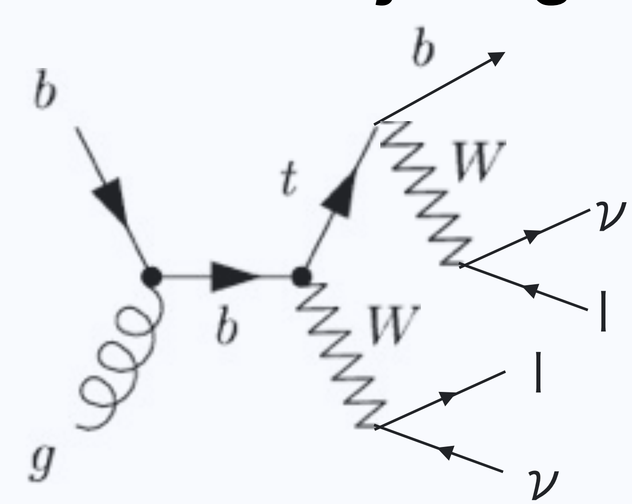
less b-jets(~3%)

reducible by btag



including b-jet

irreducible by btag



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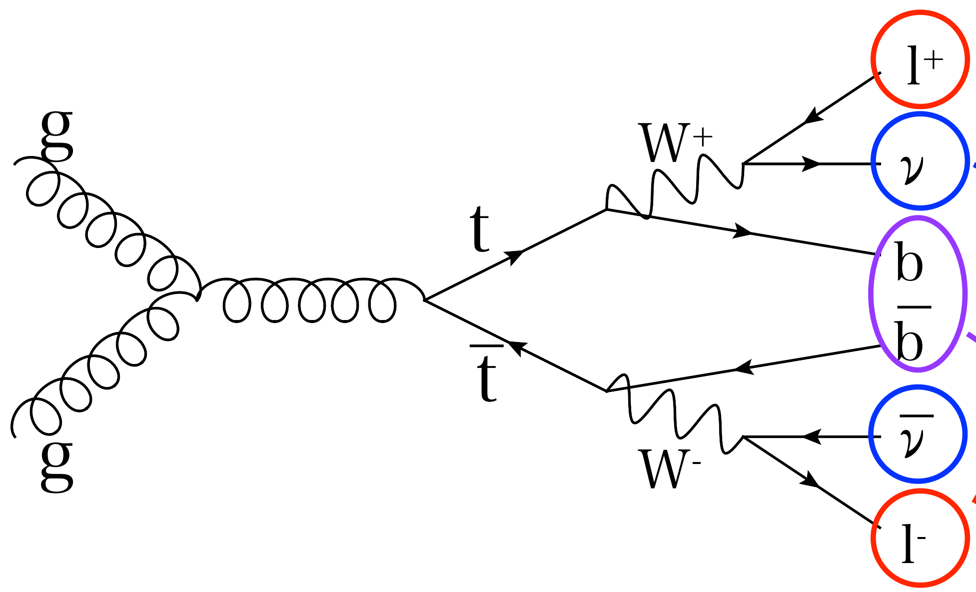

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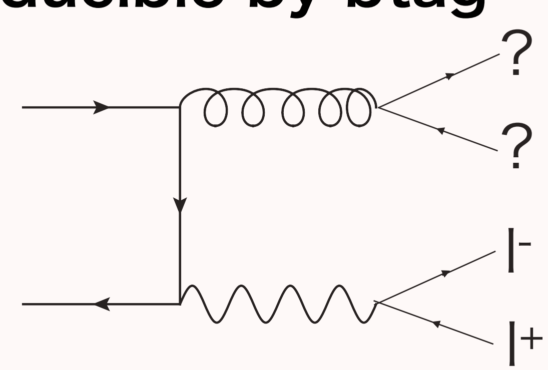
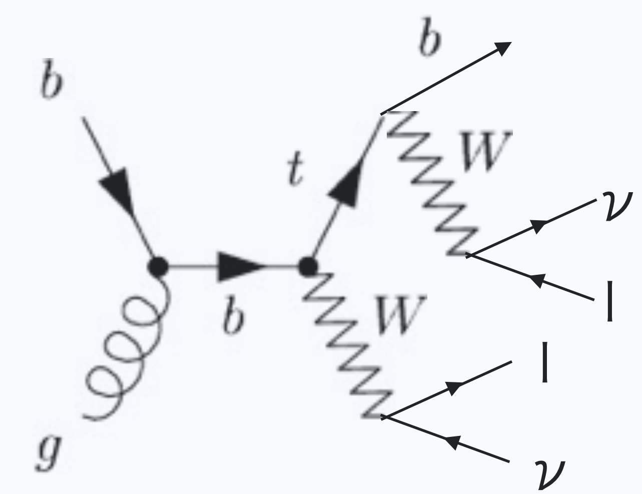


including b-jet

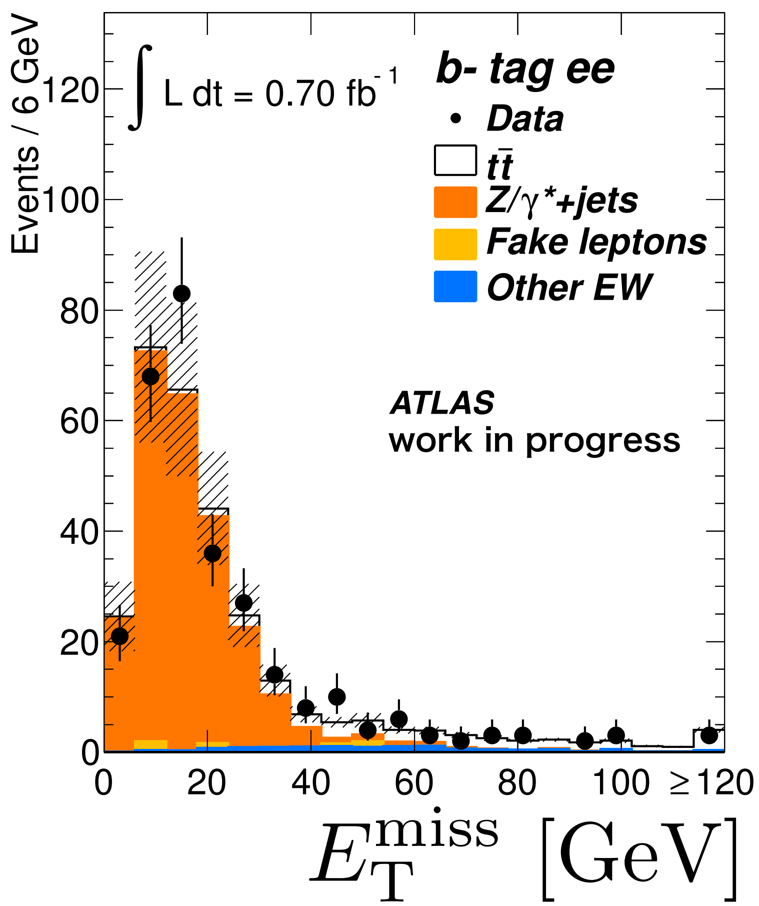
irreducible by btag

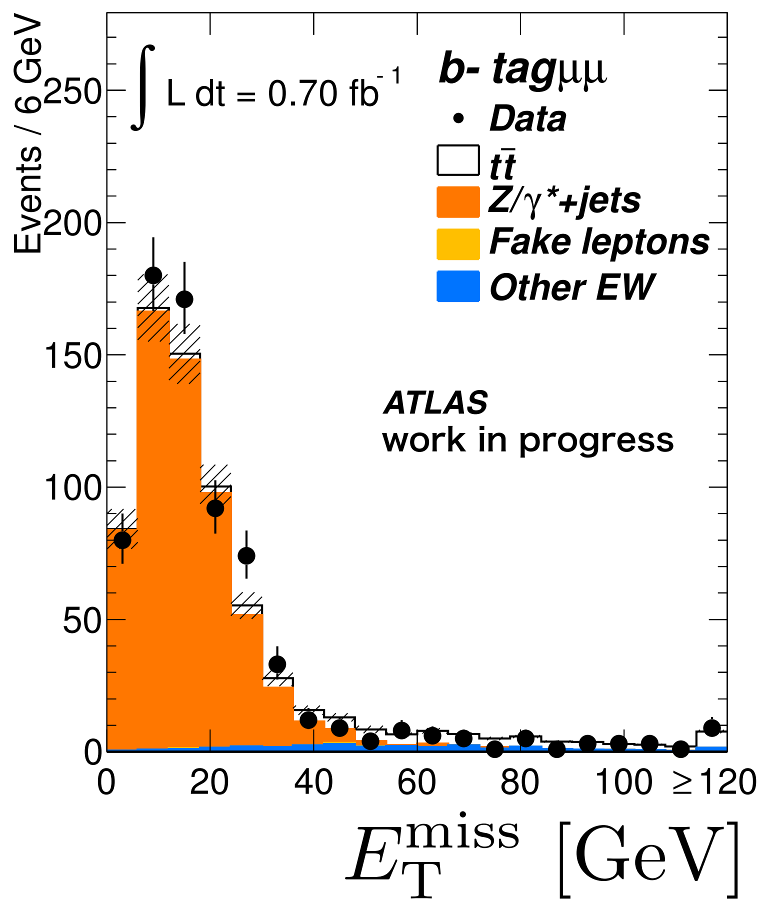


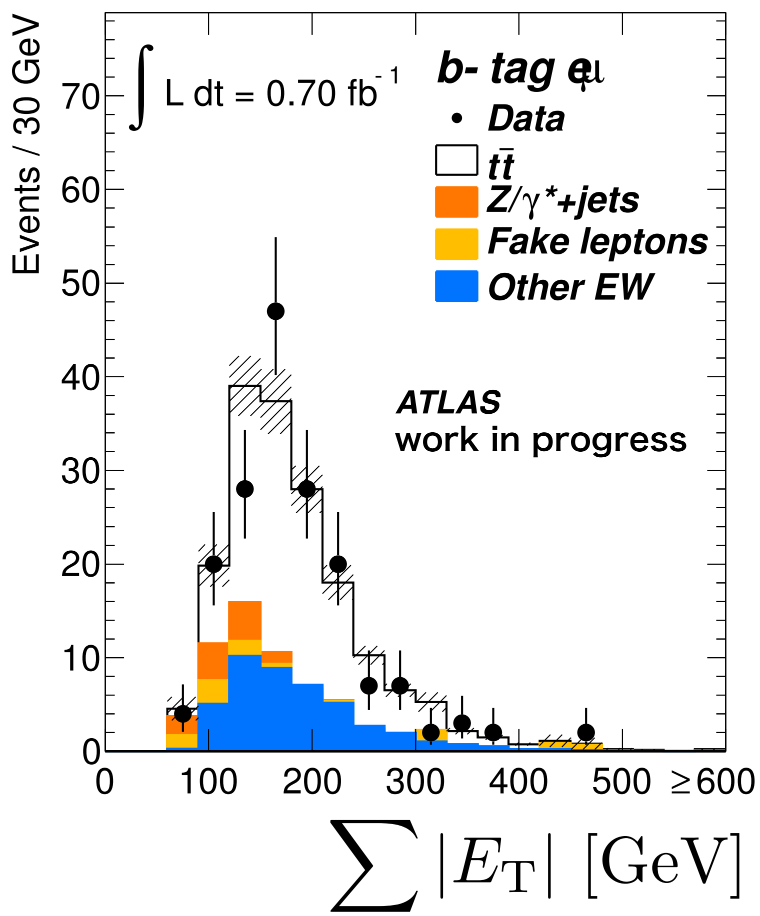
➡ **Better S/B ratio can be achieved by b-tagging !!**

Distributions in Control Region

- After requiring all selection but has only one jet.







Good Agreement !!