Recent results of top quark physics at LHC

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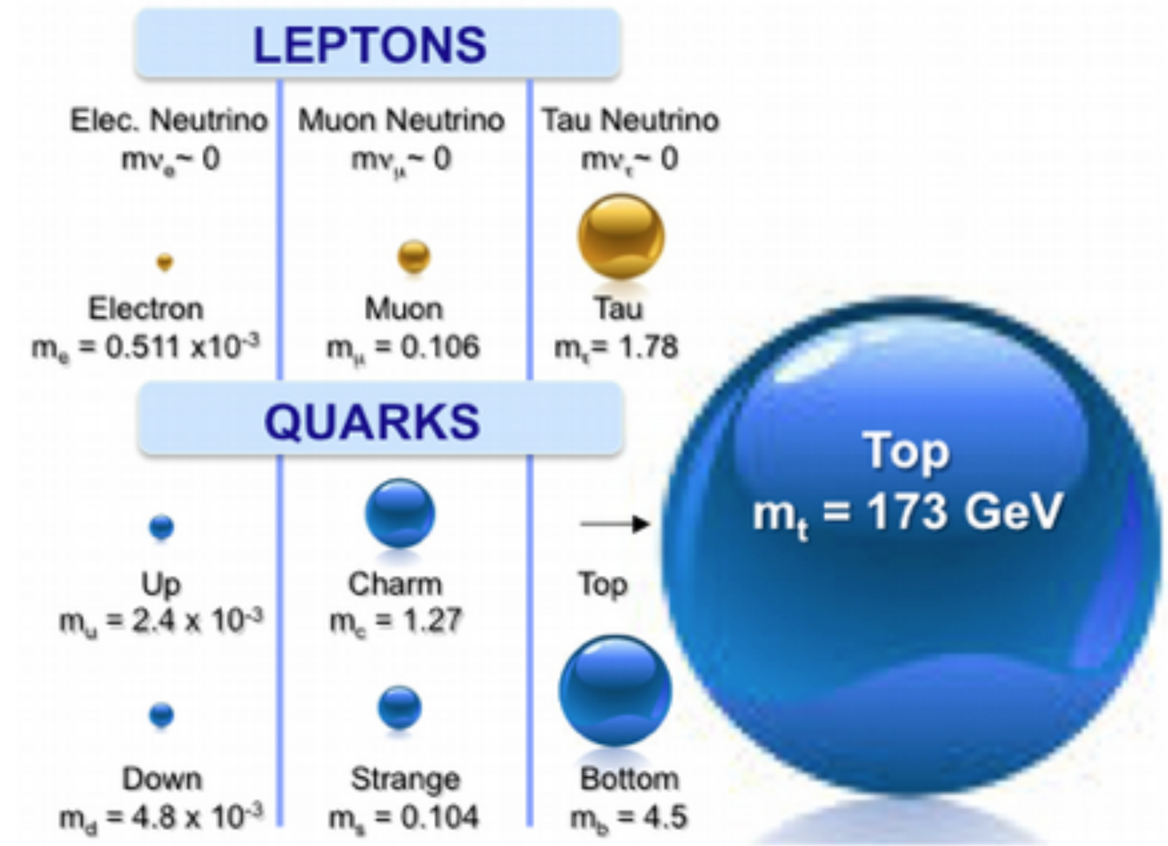
Top quark

Top quark :

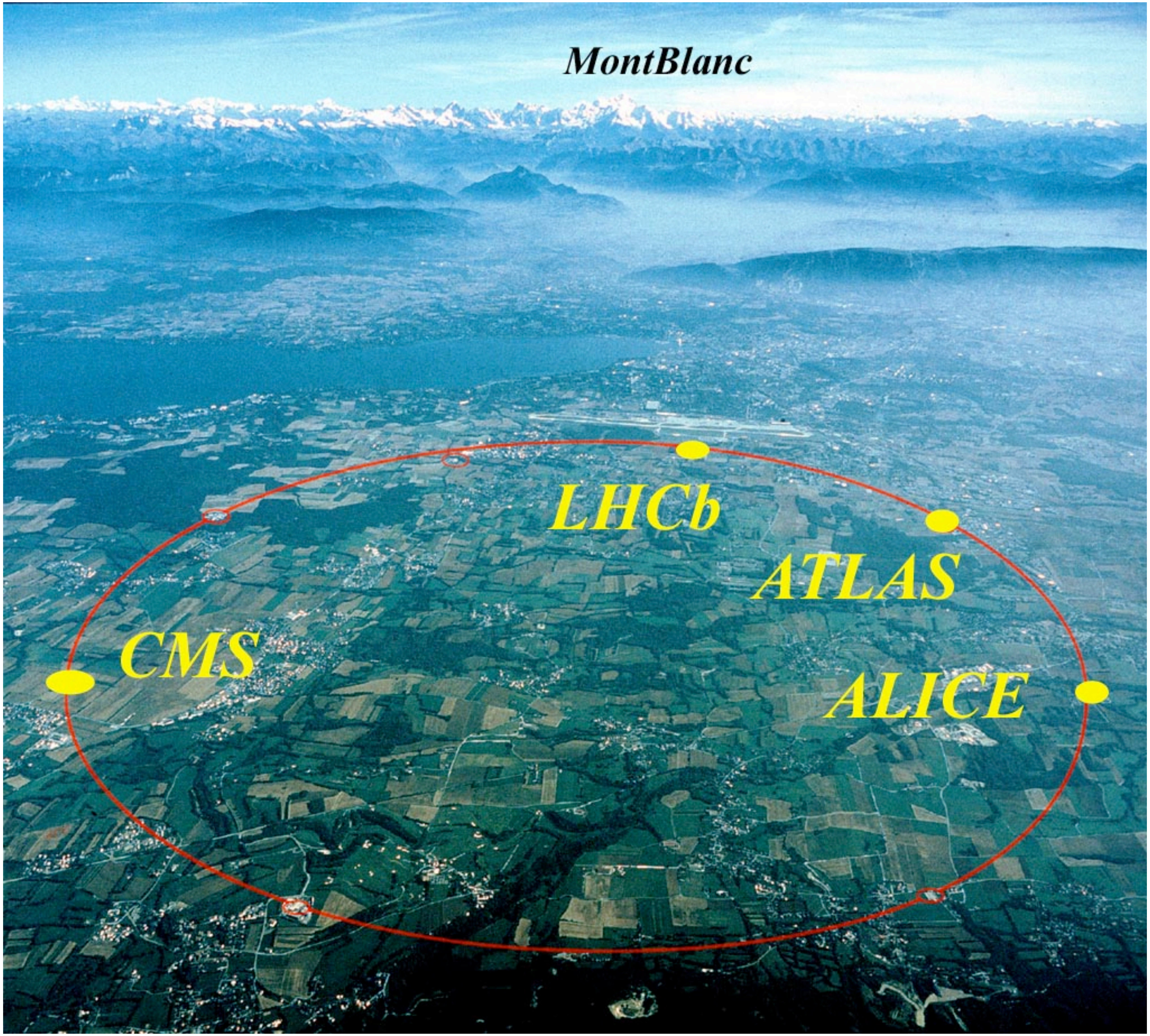
- Discovered in 1995 by Tevatron
- The heaviest particle in SM
  (M_t = 173.21 ± 0.51 ± 0.71 GeV)
  - The coupling with Higgs (Y_t) ~1.
  - Sensitive to new physics BSM
- Short lifetime around ~10^{-25} s
  - Information on a bare quark



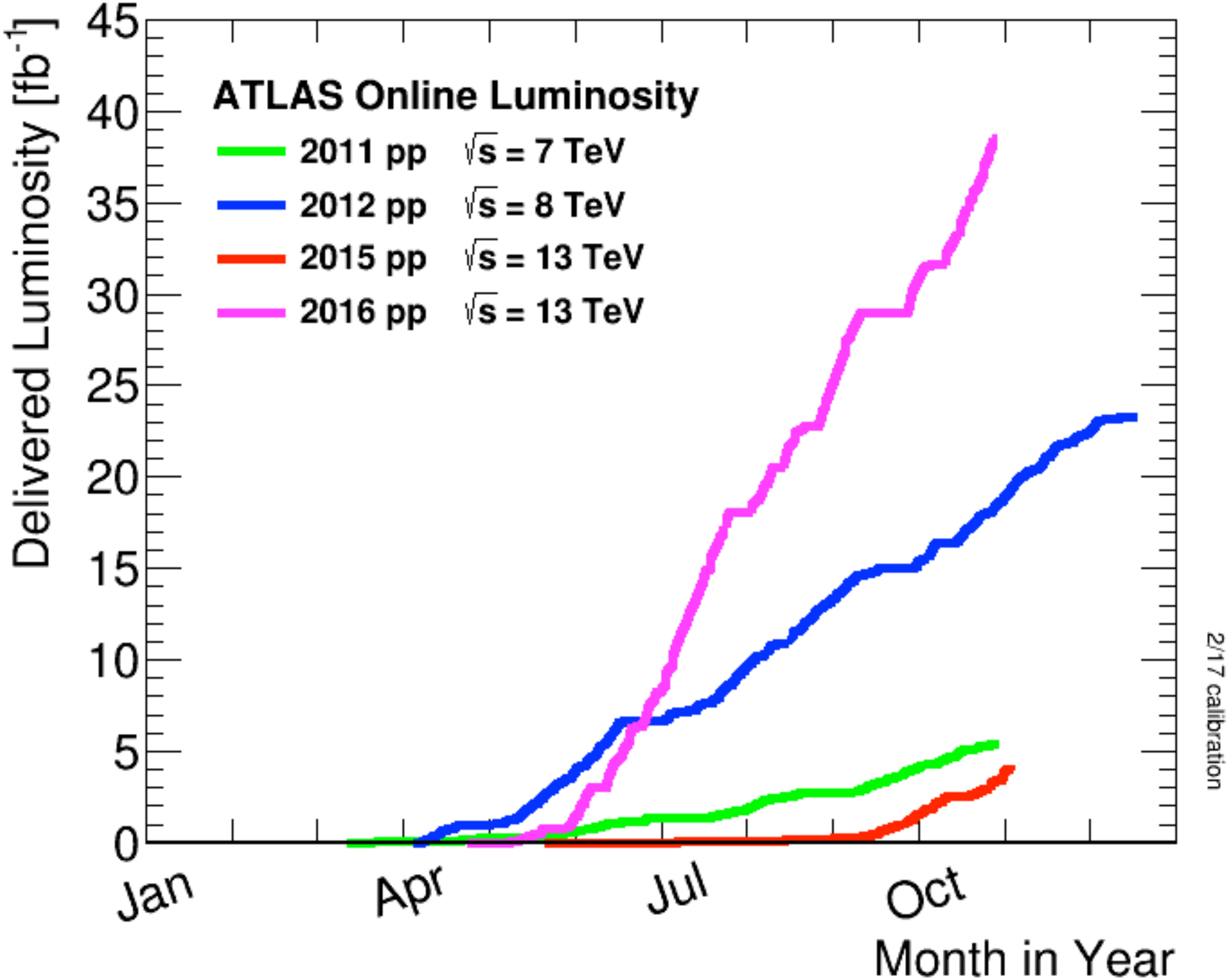
- LHC is the top quark factory experiment
  - ~10 top quark pairs are produced every second in Run 2 LHC

- We can approach not only precision measurement of SM but also the new particle physics phenomenology using top quark as a probe.
  - Test of pQCD at high Q^2 from top quark production
  - Test of electroweak from top quark decay
  - measurements of Higgs-top Yukawa coupling Y_t
  - direct searches of BSM (e.g. stop, g_{KK}, etc.)

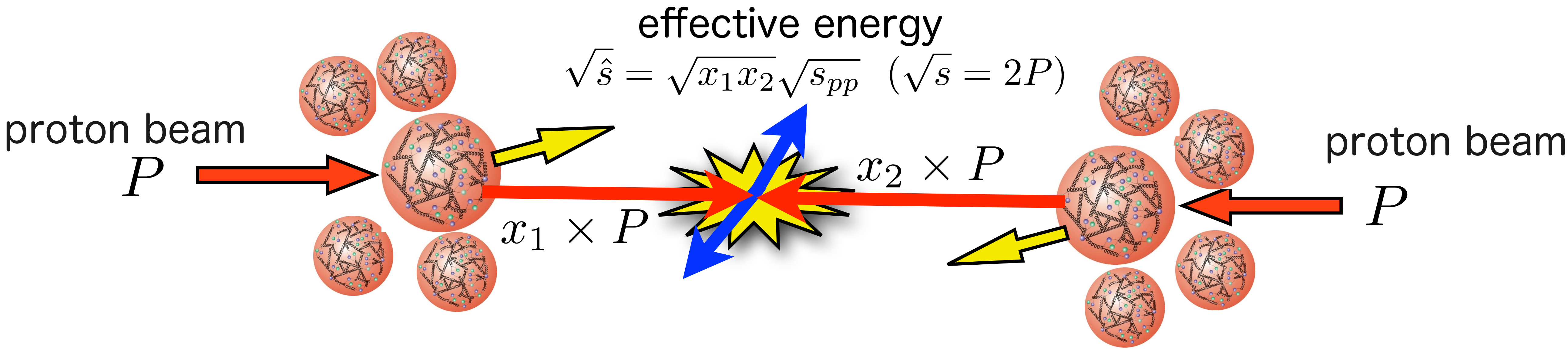
LHC

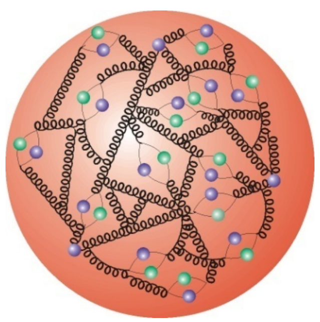


Integrated Luminosity



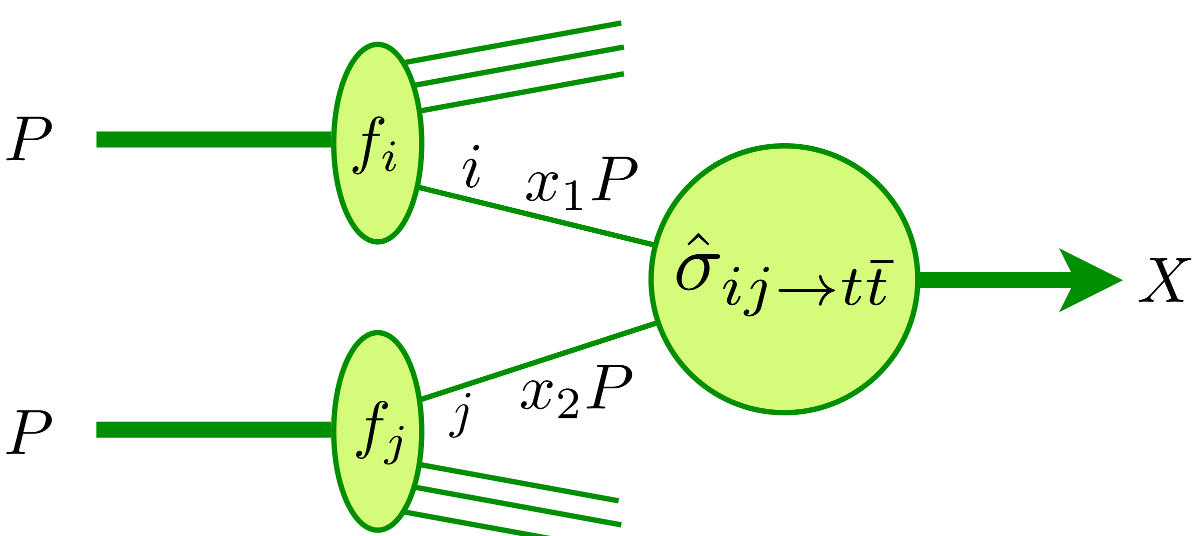
top quark pair production in p-p collision





- A proton consists of not only u-u-d valence quarks but also a lot of sea quarks and gluons → parton
- The cross section cannot be extracted without the knowledge of the parton density.

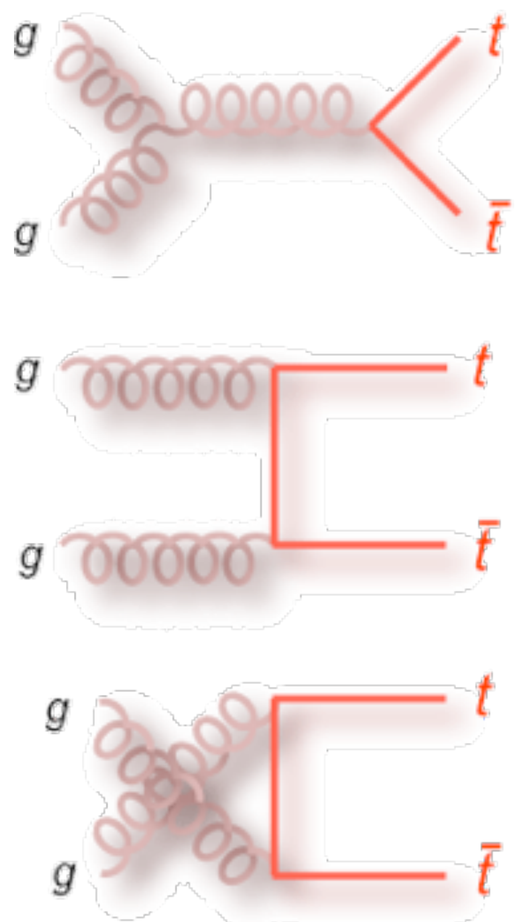
$$\sigma_{pp\to t\bar{t}} = \sum_{ij} \int \mathrm{d}x_1 \int \mathrm{d}x_2 f_i(x_1,\mu) f_j(x_2,\mu) \hat{\sigma}_{ij\to t\bar{t}}(s, \alpha_S(\hat{\mu}), Q/\mu)$$

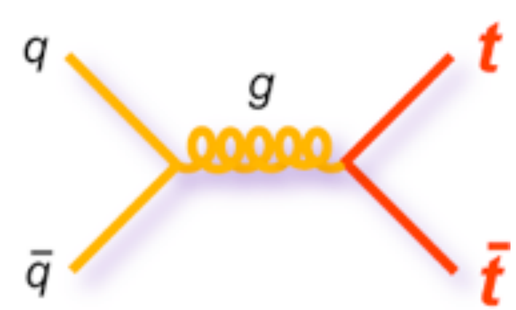


$\hat{\sigma}_{ij\to t\bar{t}}$ parton(i)-parton(j) cross-section → perturbative QCD

$f_i(x,\mu)$ Parton distribution function

top quark pair production at LHC

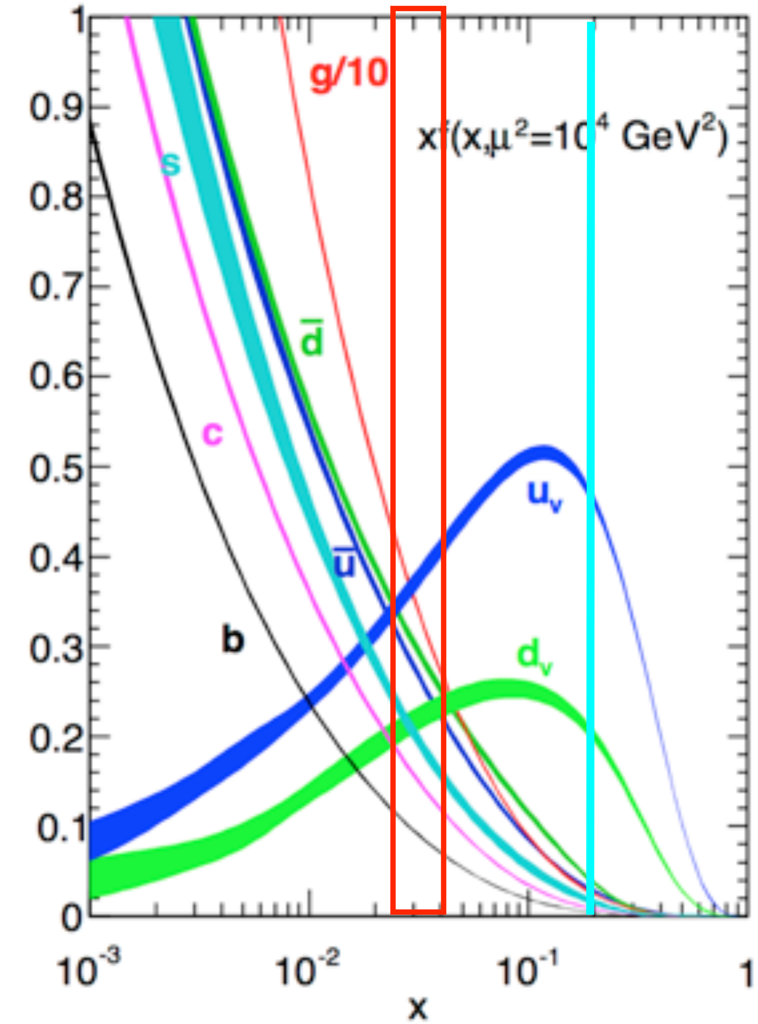




$$\sqrt{\hat{s}} = \sqrt{x_1 x_2}\sqrt{s_{pp}} \qquad x \sim \frac{2m_t}{\sqrt{s}}$$

LHC sensitive to gluonPDF

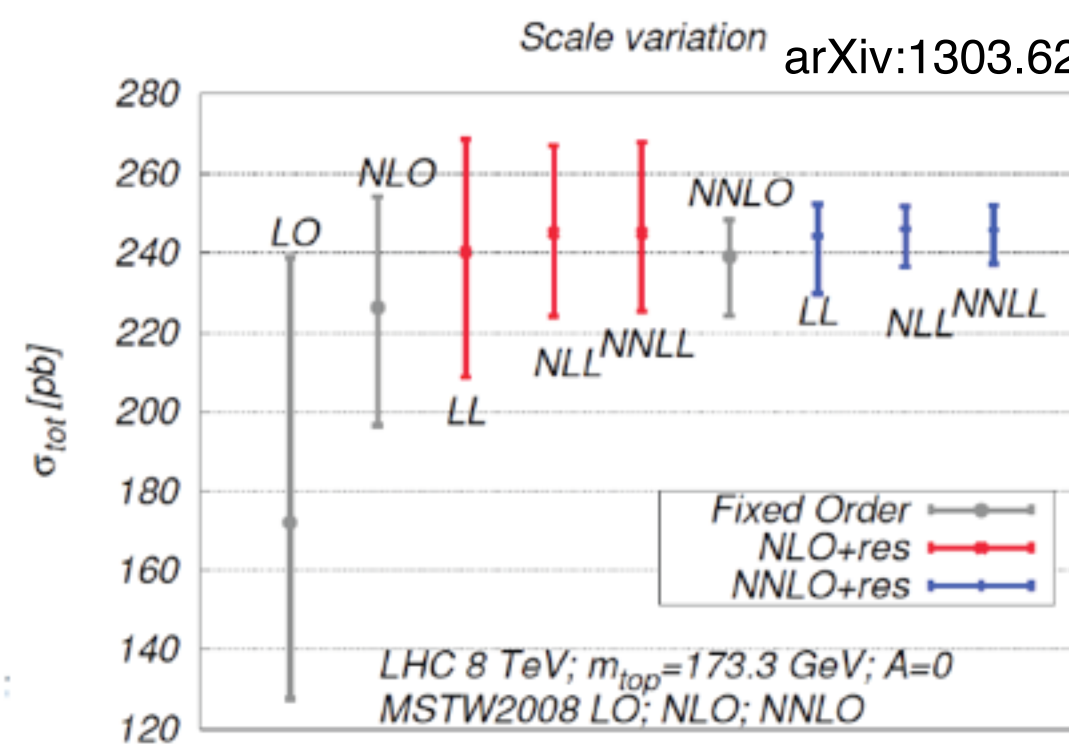
Tevatron sensitive to quark PDF



NNLO+NNLL (m_t=173.3, PDF=MSTW2008nnlo68cl)

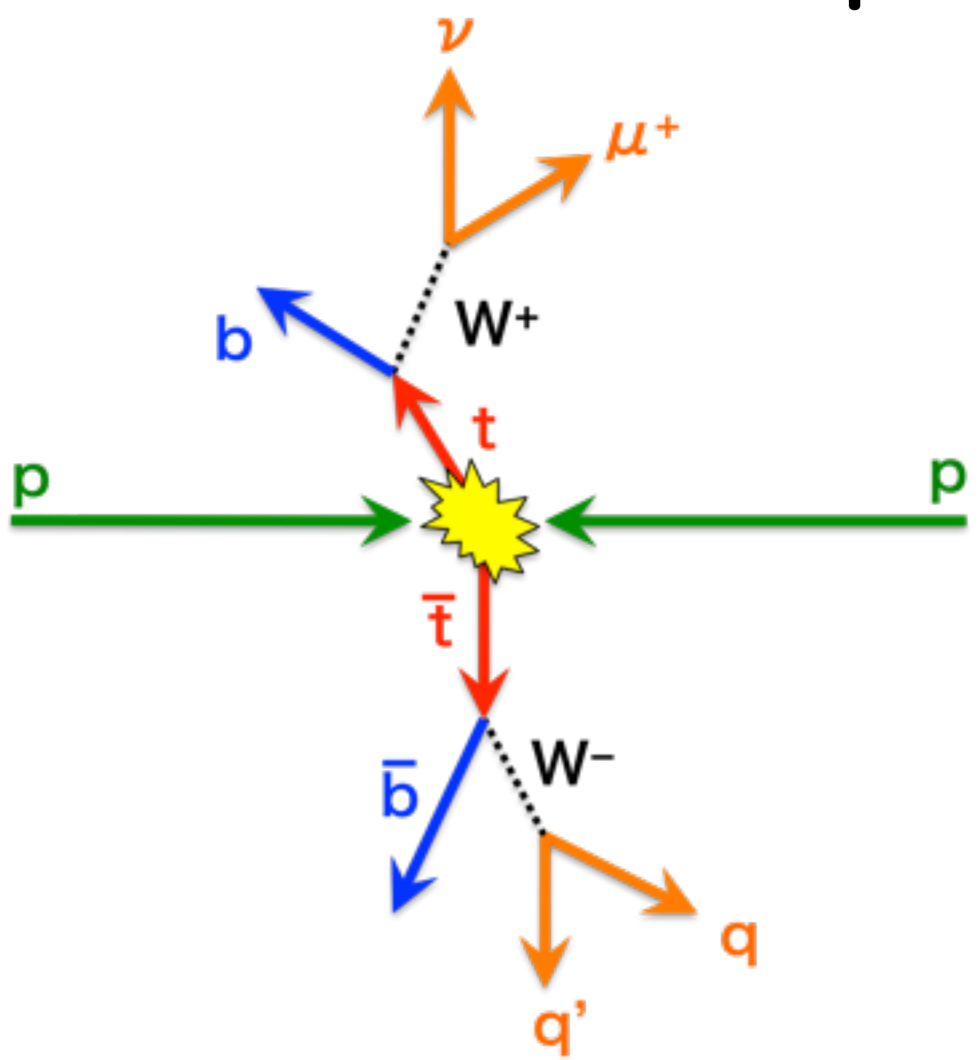
	x	qq : gg	σ_{tt} (pb)	±scale	±pdf
7TeV	0.049	15 : 85	172.0	~3%	3%
8TeV	0.043	12 : 88	245.8	~3%	~2.5%
14TeV	0.025	10 : 90	953.6	~3%	2%
Tevatoron 1.96 TeV	0.18	90 : 10	7.165	~2%	2%

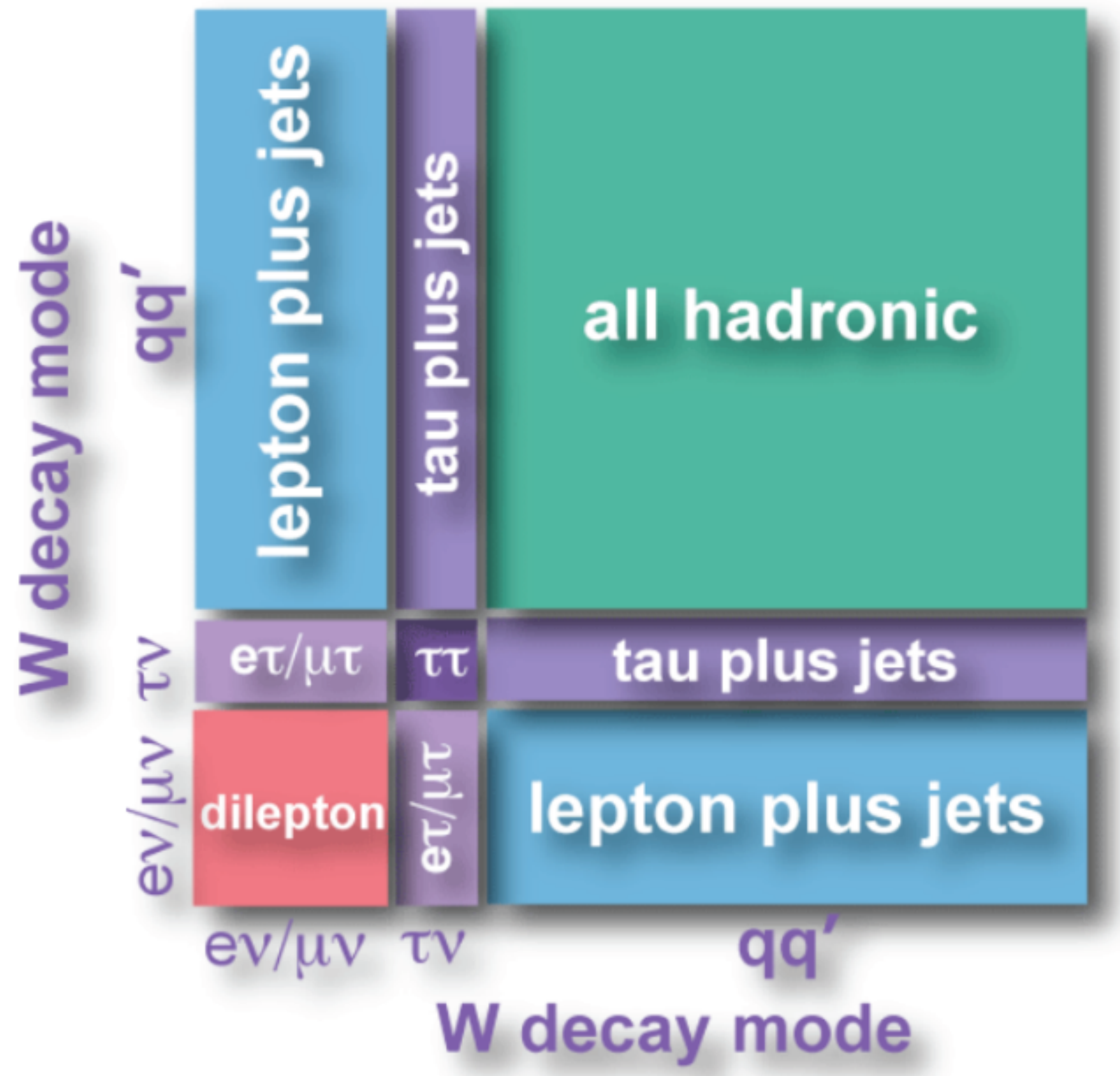
arXiv:1303.6254



arXiv:1303.6254

Top quark decay





Br(t→Wb) ~ 100%

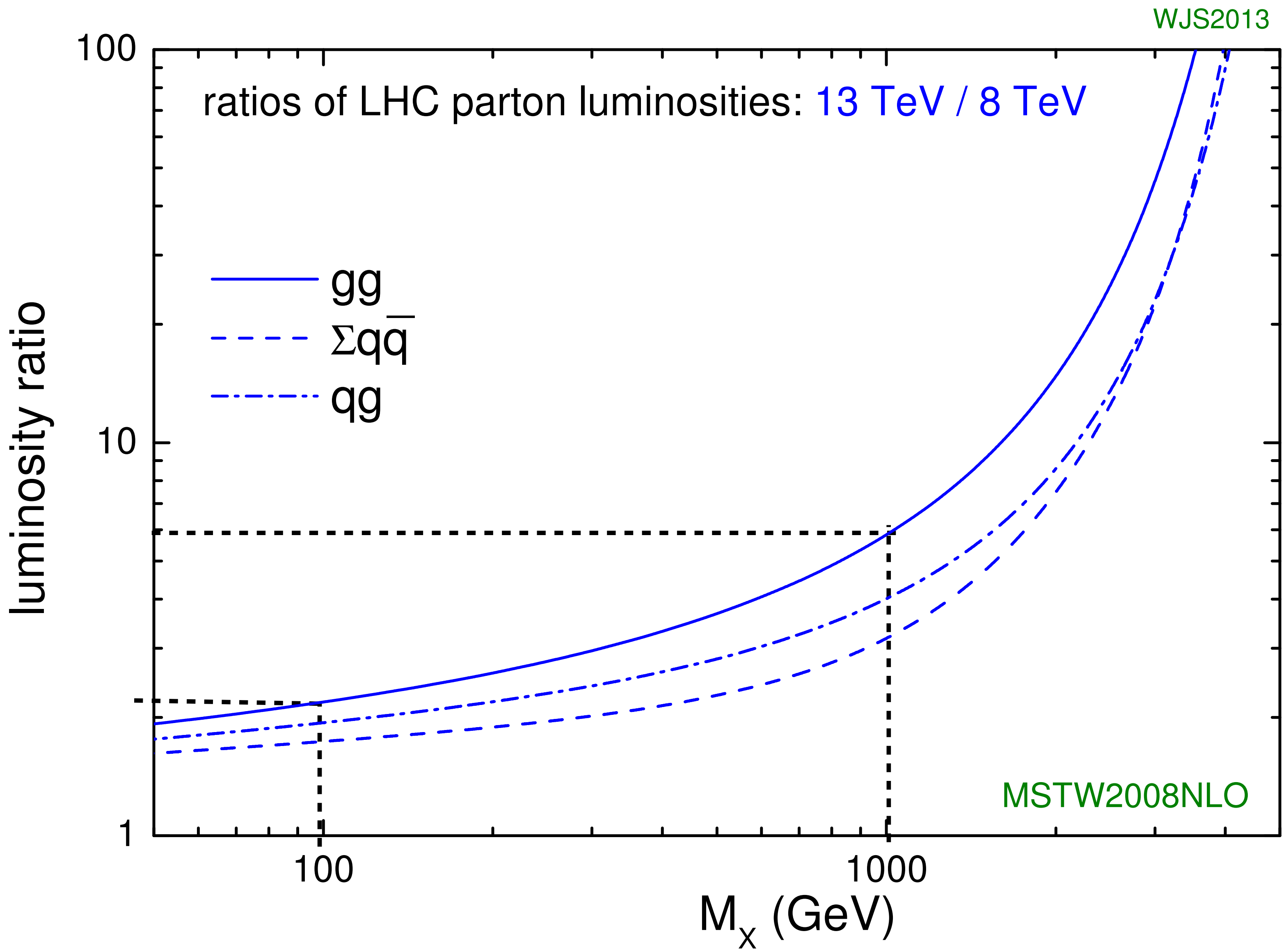
2つのWの崩壊によって、categorizeされる

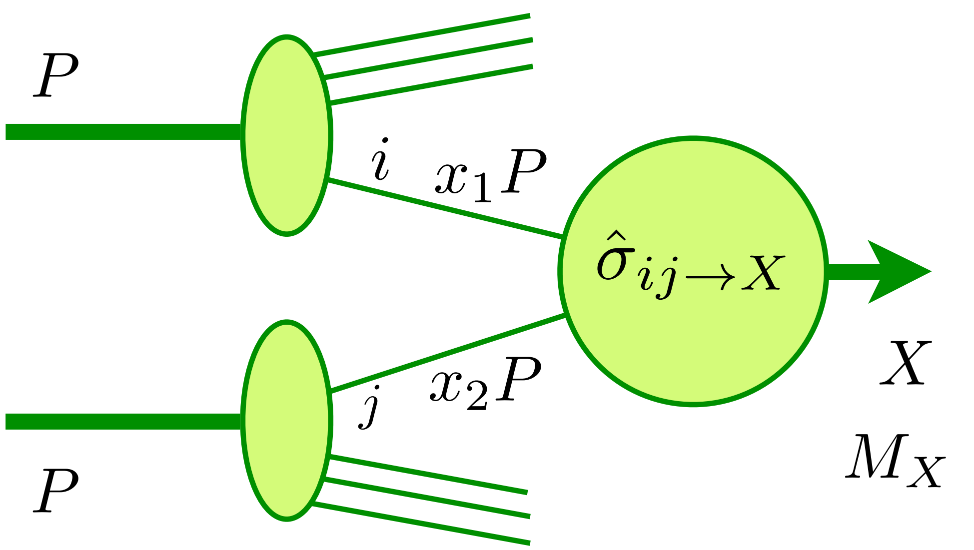
- dilepton 5%
- lepton+jets 30%
- all jets 45%

- tau+X (charged Higgsに感度)
- rare decay (FCNC decayなど)

Advantage of 7TeV→8TeV→13TeV

Heavy particles can be produced more at higher √s





13TeV / 8TeV

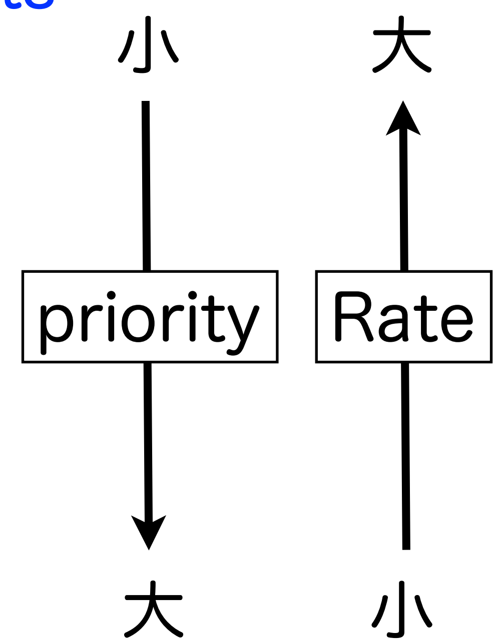
Higgs（100GeV) production　：　x ~2

SUSY（1TeV）production　：x 5-6

proton-proton collision

Many physics projects

- QCD
- B-physics
- Electroweak
- top quark physics
- Higgs physics
- New physics



Mostly low-Q^2 QCD events

Higgs：10^{10} lower than inelastic QCD

Trigger is important

100kHz at L1、100Hz at HLT

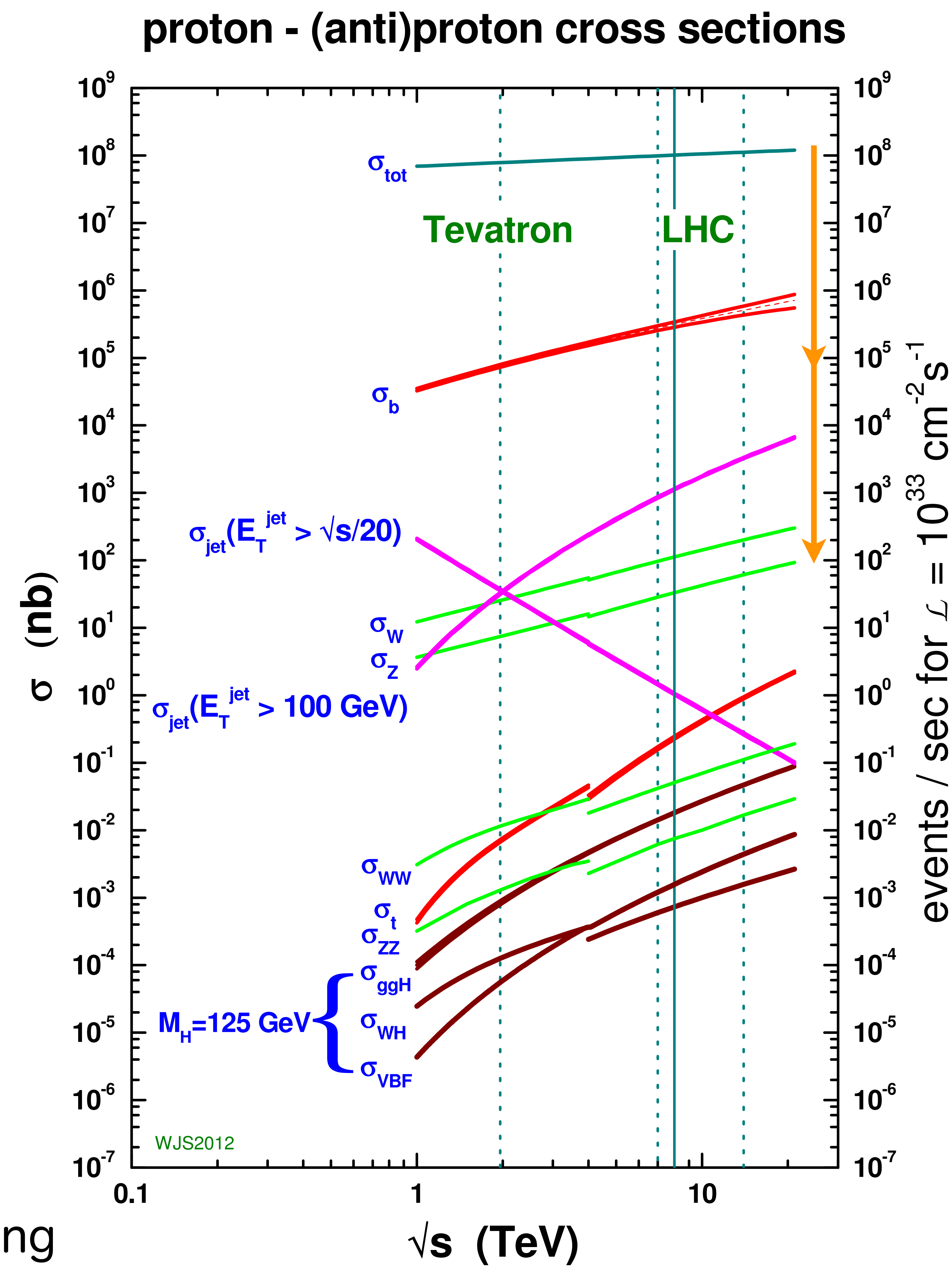
Pileup

Event rate＝σ × L

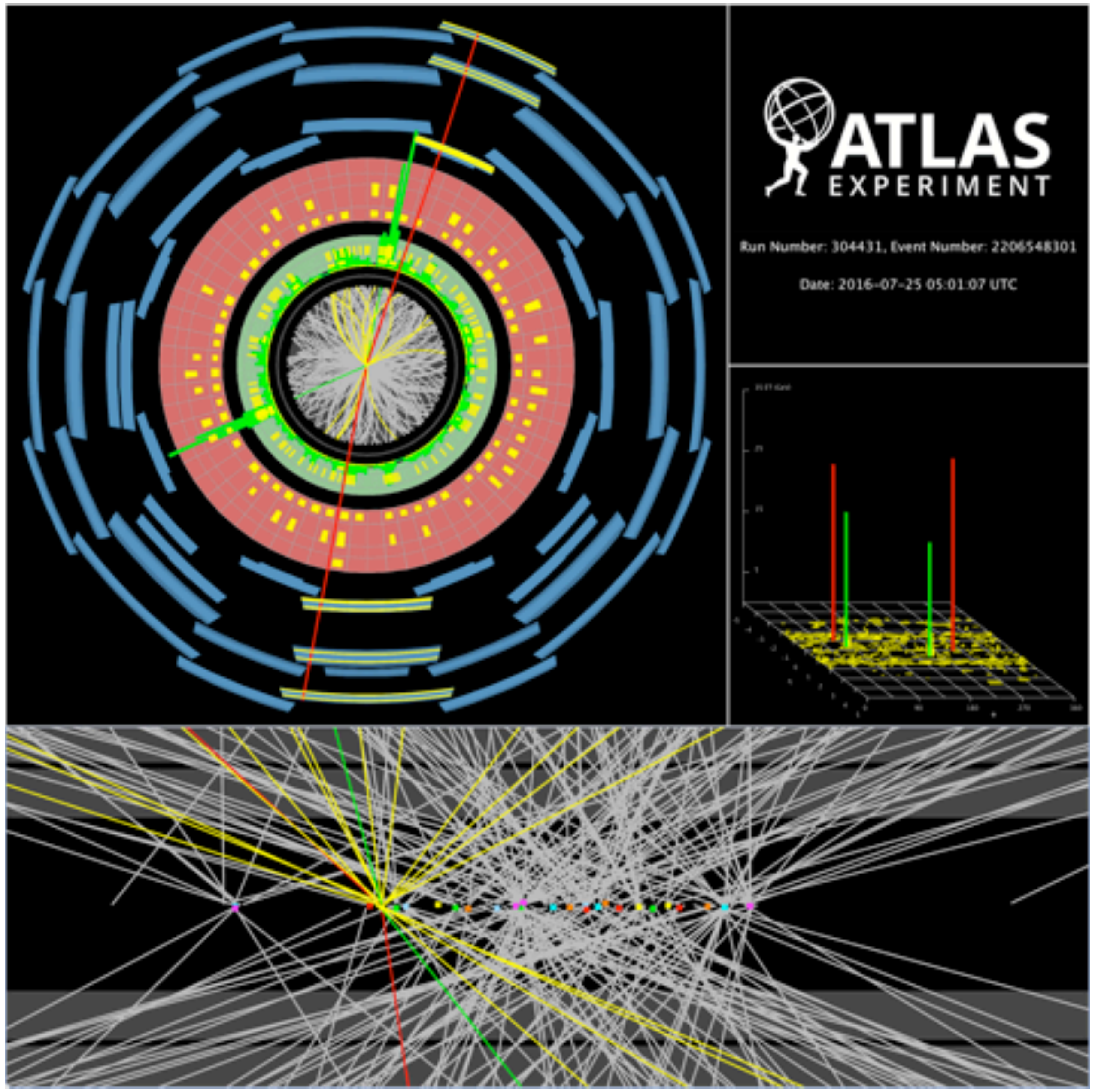
σ_{tot}~100mb
L~$10^{34}cm^{-2}s^{-1}$ } →Event rate 1GHz

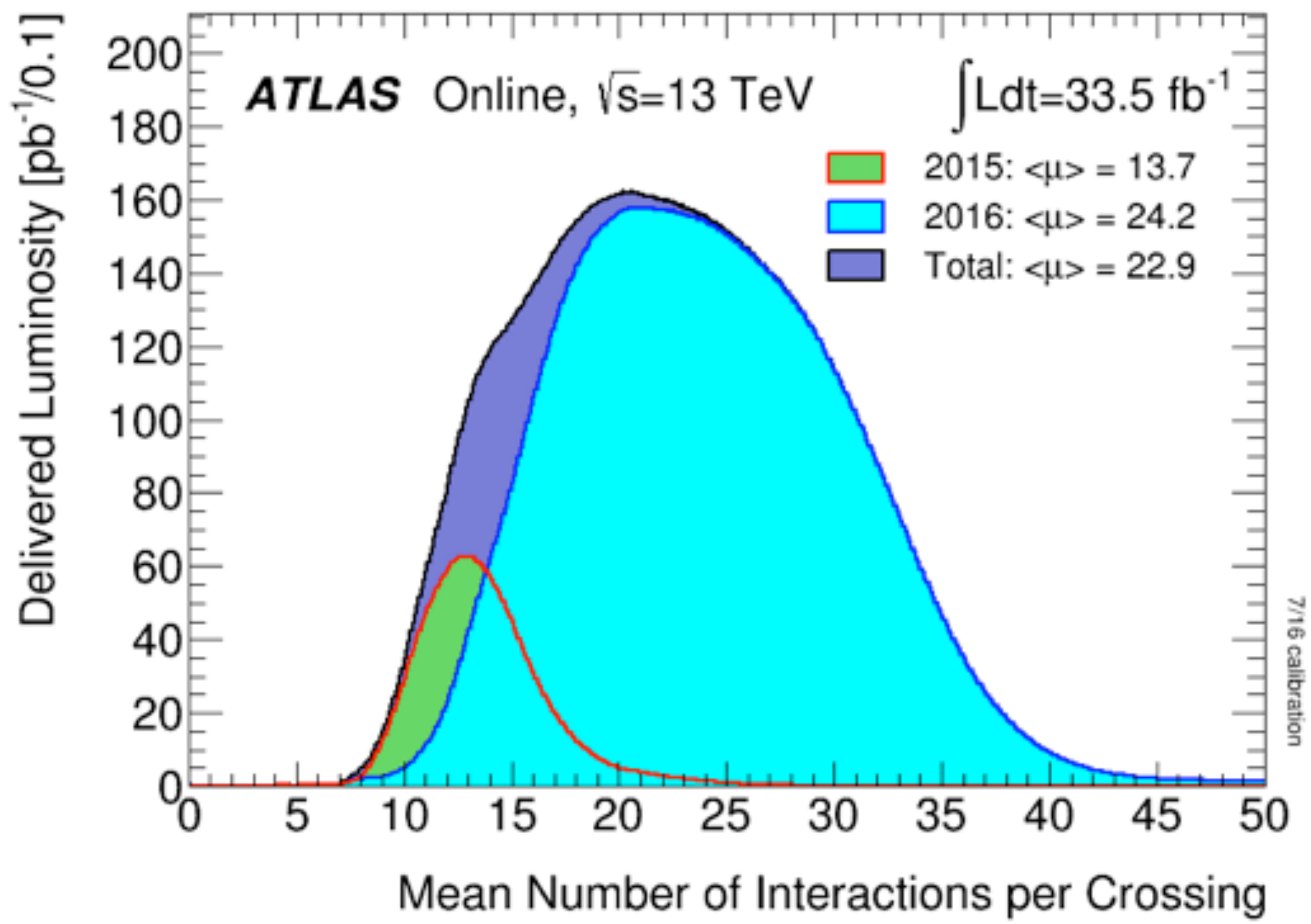
proton crossing rate＝40MHz

→several interactions in one p-p crossing



Pileup


ATLAS
EXPERIMENT
Run Number: 304431, Event Number: 2206548301
Date: 2016-07-25 05:01:07 UTC


ATLAS Online, √s=13 TeV
∫Ldt=33.5 fb⁻¹
2015: <μ> = 13.7
2016: <μ> = 24.2
Total: <μ> = 22.9
Delivered Luminosity [pb⁻¹/0.1]
Mean Number of Interactions per Crossing
7/16 calibration
0
20
40
60
80
100
120
140
160
180
200
0
5
10
15
20
25
30
35
40
45
50

A Toroidal Lhc AppratuS

Calorimeters:
Tile & LAr

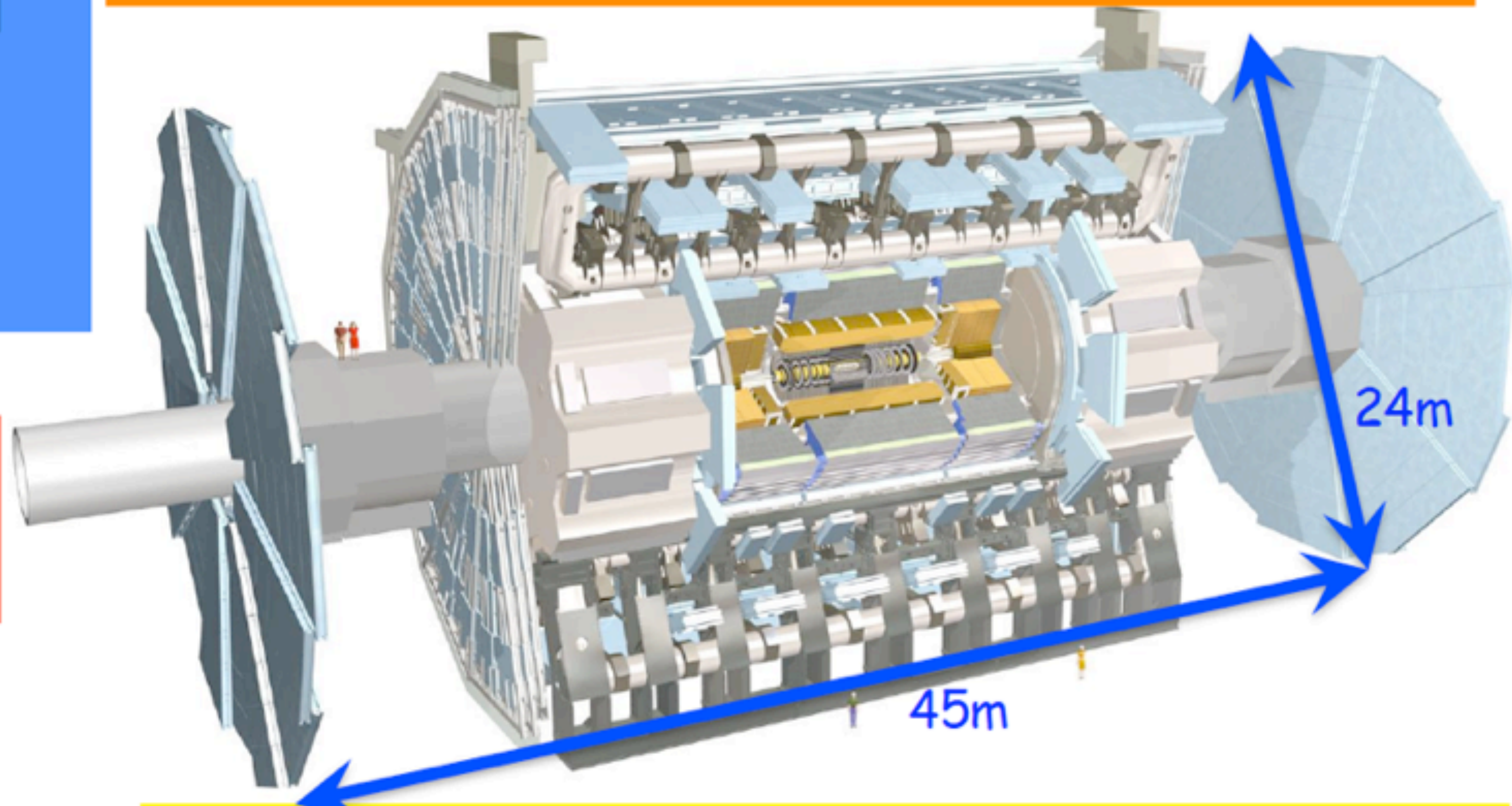
e/γ $\frac{\sigma(E)}{E} = \frac{10\%}{\sqrt{E}} + 0.7\%$

Hadron $\frac{\sigma(E)}{E} = \frac{50\%}{\sqrt{E}} + 3\%$ |η|<3, $\frac{\sigma(E)}{E} = \frac{100\%}{\sqrt{E}} + 10\%$ |η|>3

Muons:

Trigger TGC RPC

Precision CSC MDT



大きさ：24m × 45m
重量：7000 トン
読み出し：160M

Magnets:

Solenoid : 2テスラ

Toroidal :
$\int B \times d\ell$ = 2~6 (T×m)

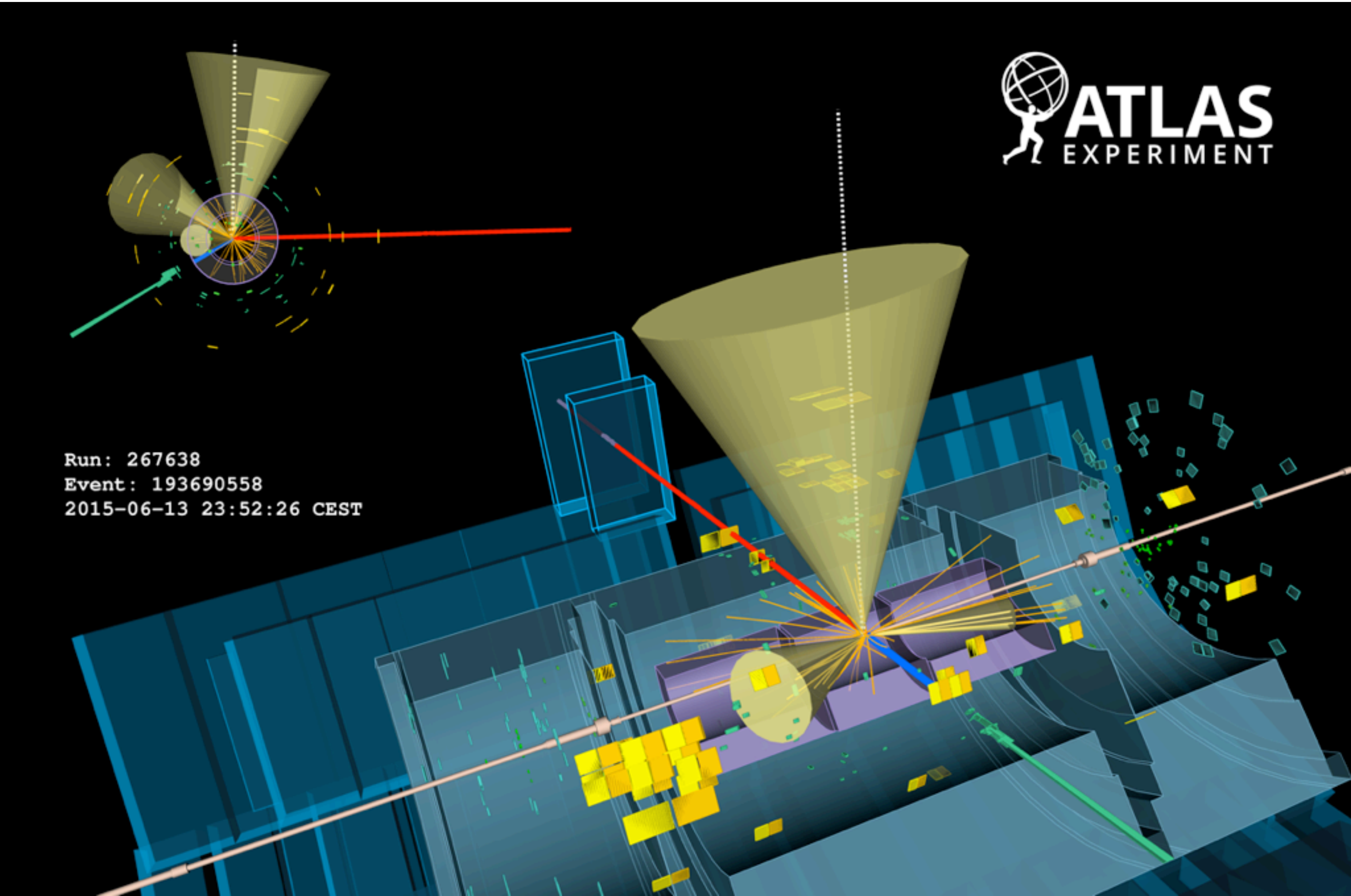
Inner Tracker: $\frac{\sigma}{P_T} = 0.05\% \times P_T + 1\%$ (2% @ 20GeV)

Pixel:
50×400μm²
80M channels

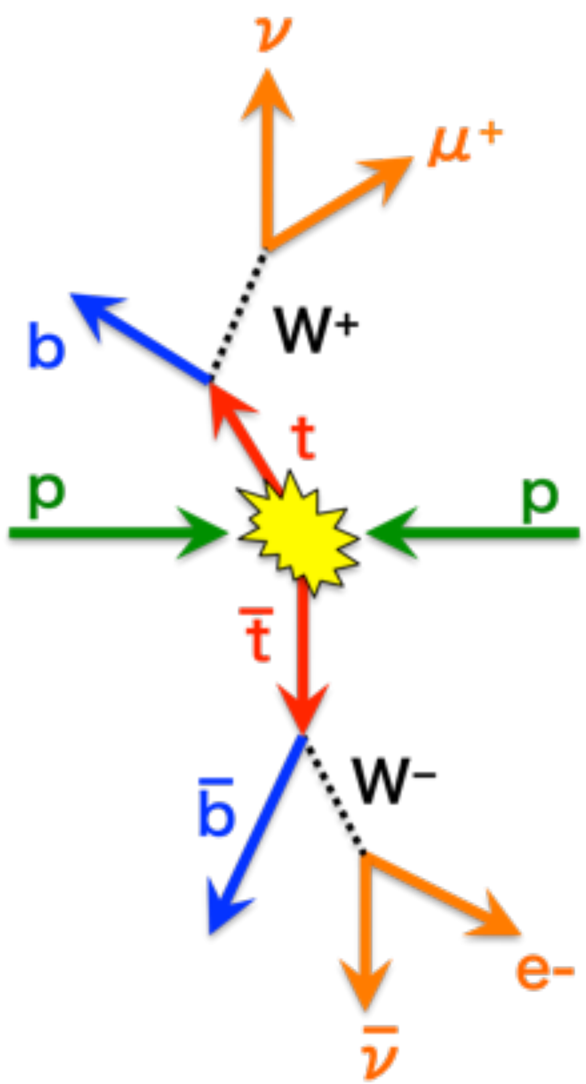
SCT:
80μm × 6cm
7M channels

TRT:
4mm φ straw tube
350k channels

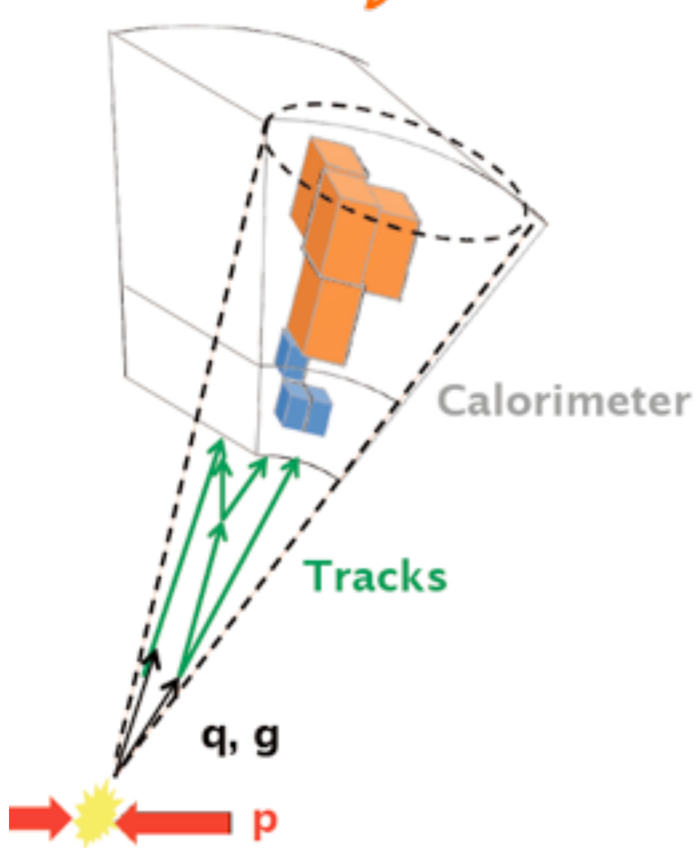
A ttbar candidate event



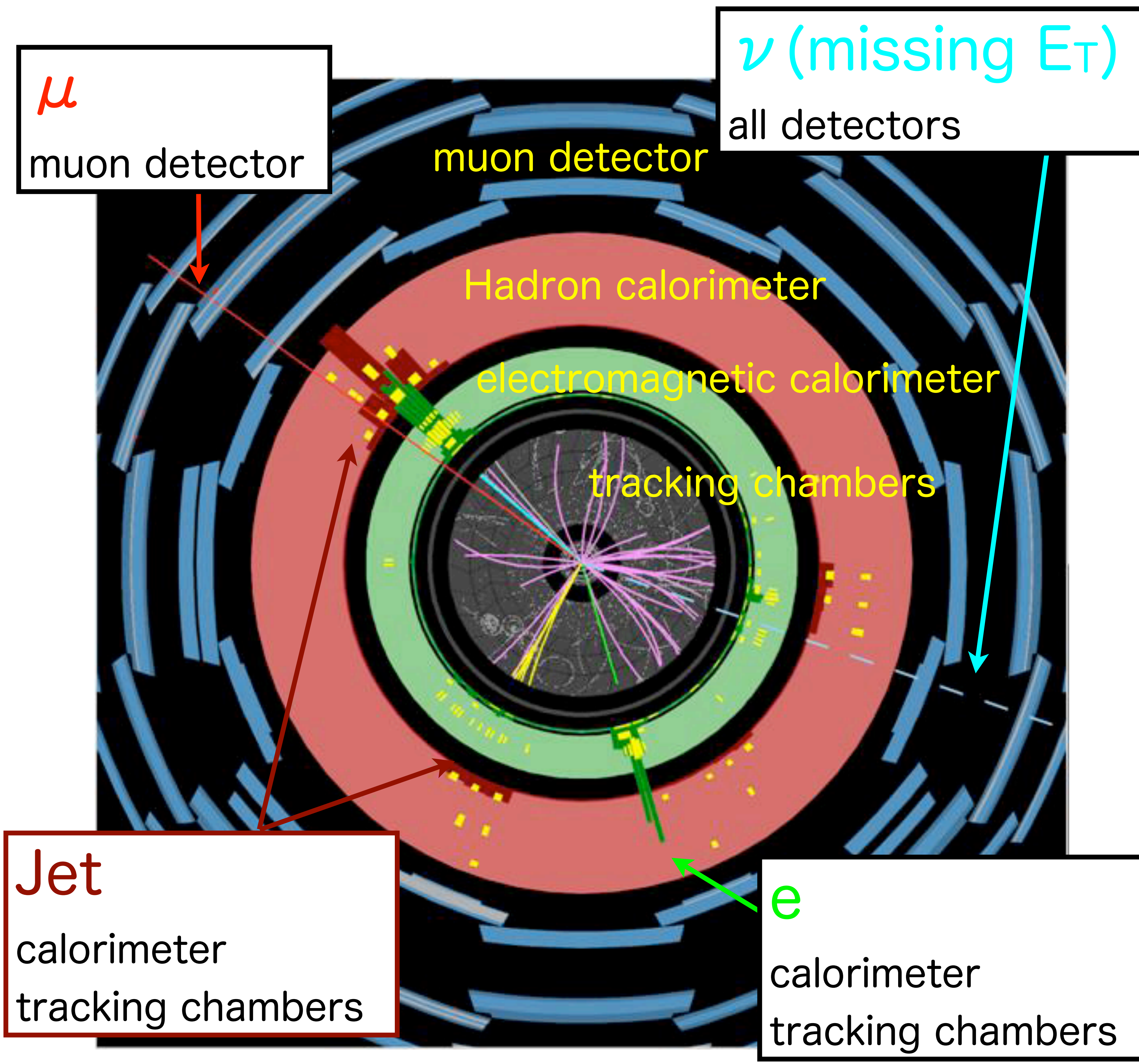
Object ID



ν
μ+
W+
b
t
p
p
t̄
W−
b̄
e-
ν̄



Calorimeter
Tracks
q, g
p



μ
muon detector
ν (missing ET)
all detectors
muon detector
Hadron calorimeter
electromagnetic calorimeter
tracking chambers
Jet
calorimeter
tracking chambers
e
calorimeter
tracking chambers

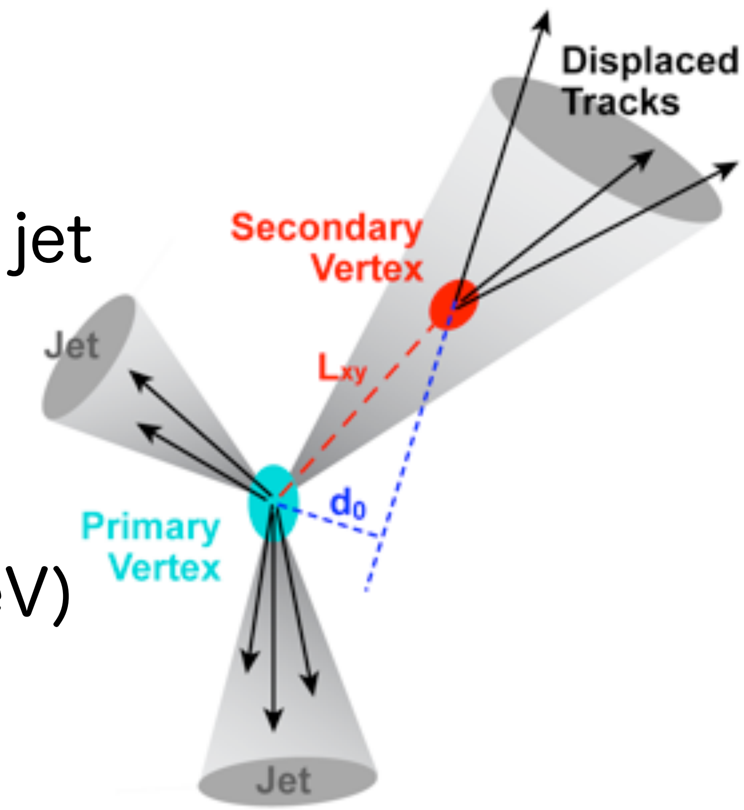
b-jet id & τ-id

b-jet id

large jet multiplicity

large L_{xy}

large d_0 of tracks in jet



$c\tau$ ~500μm

$\beta\gamma$~10 (@P~50GeV)

→ Run 5 mm

τ-jet id

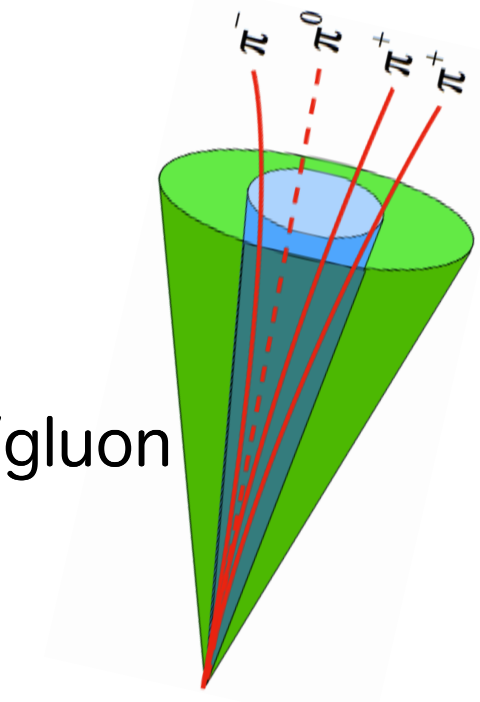
energy :

wider than e/γ

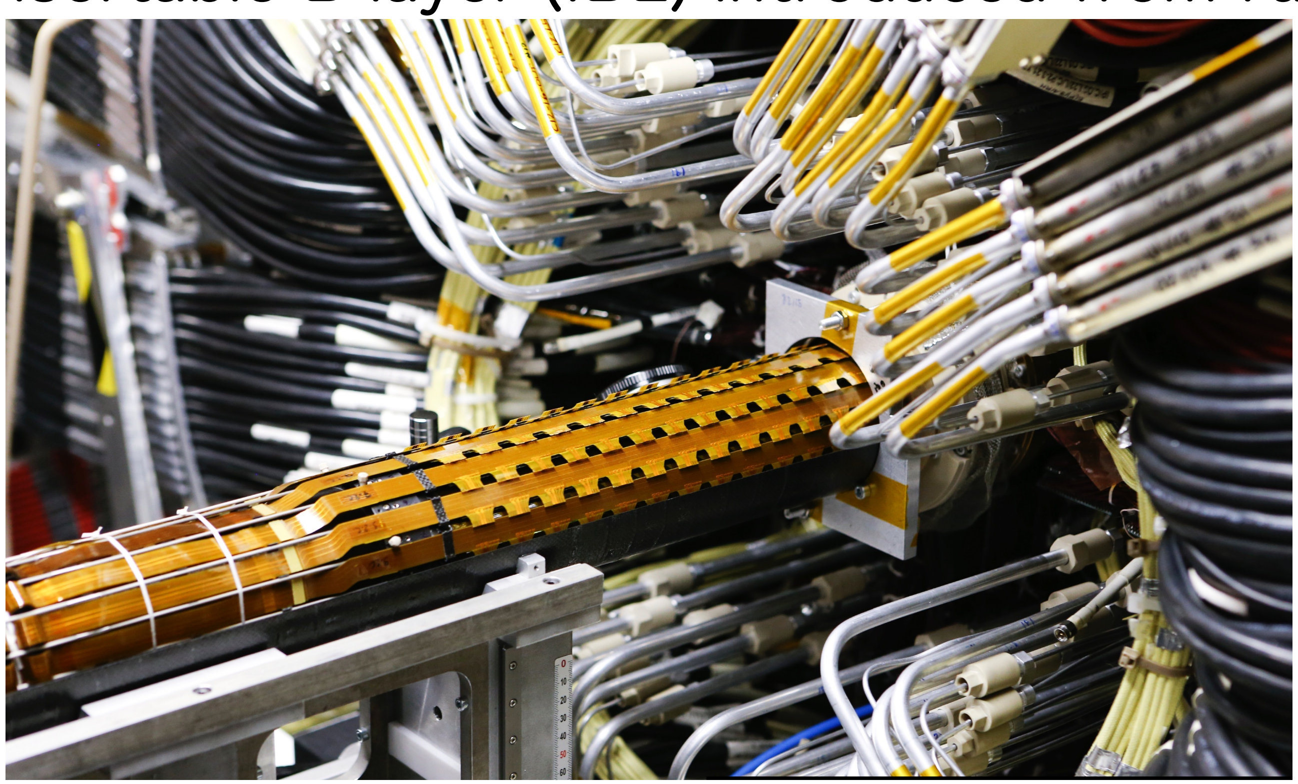
narrower than quark/gluon

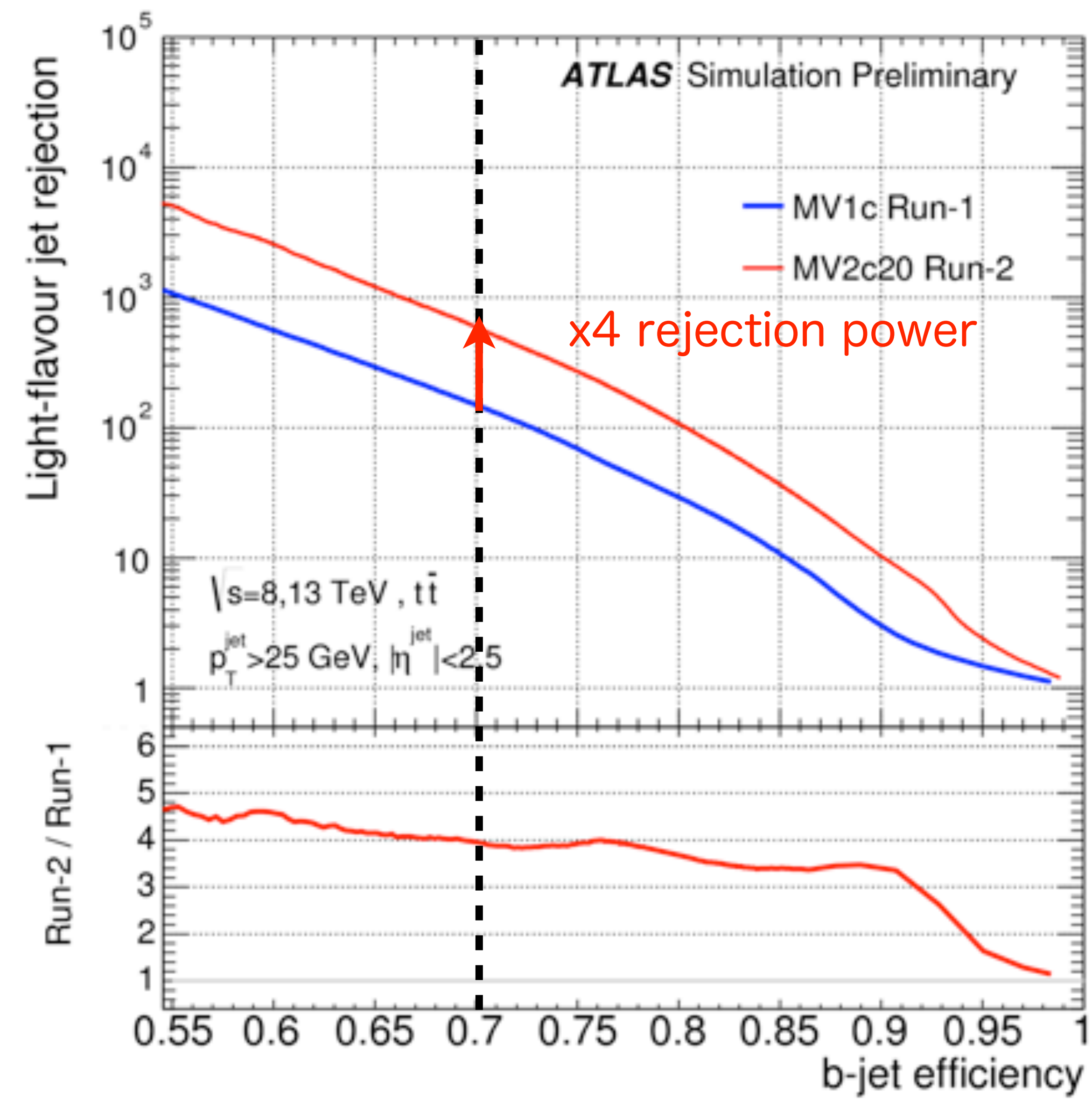
charged particles :

1 or 3, collinear



Insertable B layer (IBL) introduced from run2





Event selection

○ dilepton

- 2 isolated leptons
- Z mass veto (for ee, $\mu\mu$)
- ≧2 jets, at least one jet b-tagged

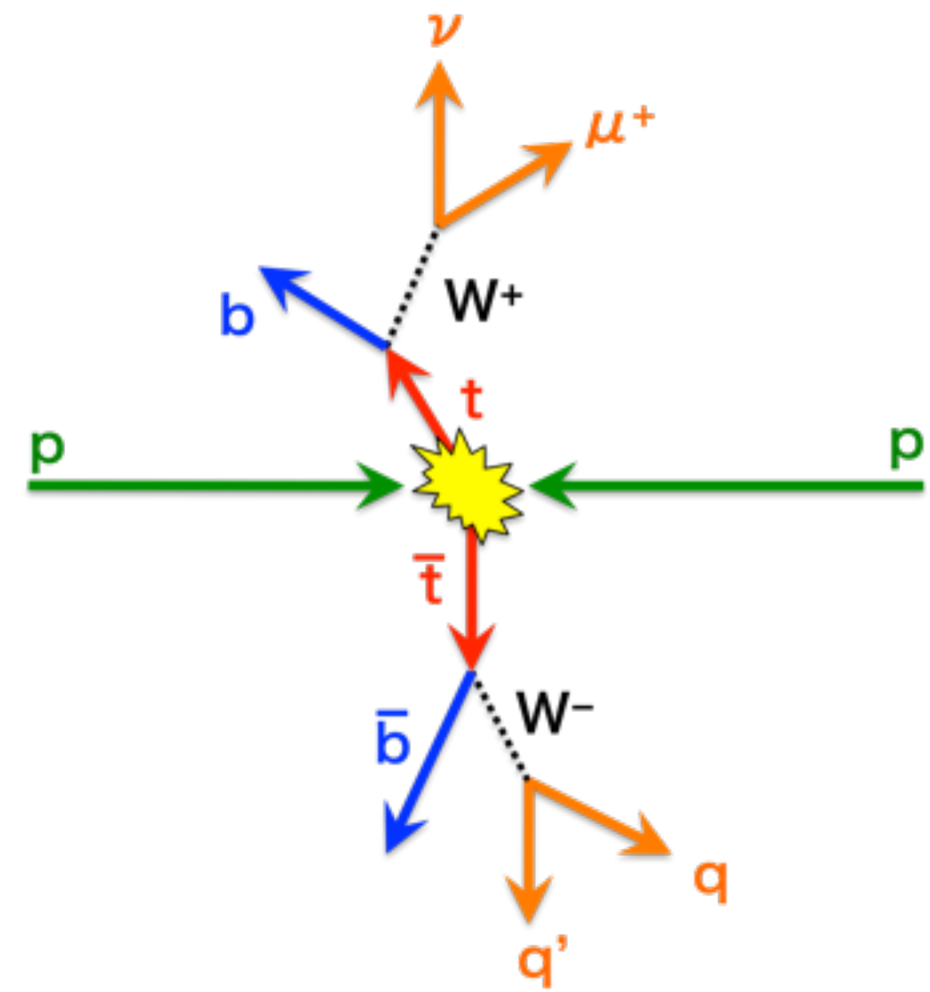
○ single lepton

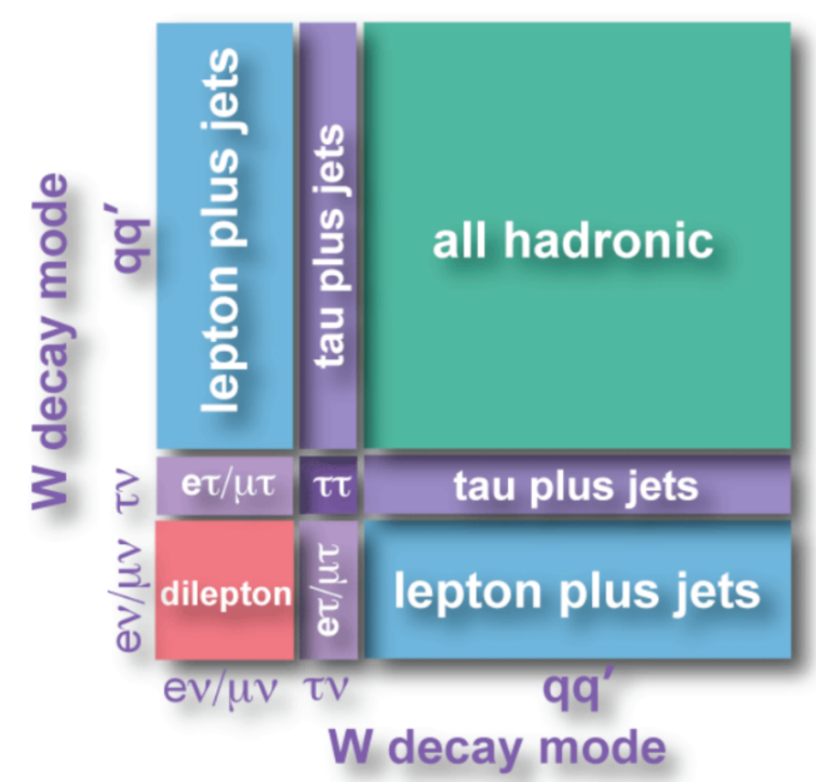
- 1 isolated lepton
- E_T^{miss}, $M_T(W)$でmulti-jet, W+jetsをcontrol
- ≧4 jets, at least one jet b-tagged

○ all-jets

- No isolated lepton
- ≧6 jets, 2 jets b-tagged
- Small E_T^{miss} significance, centrality

b-tag: typically ε=70%,
rejection factor=130 (light quark), 5 (c-quark)

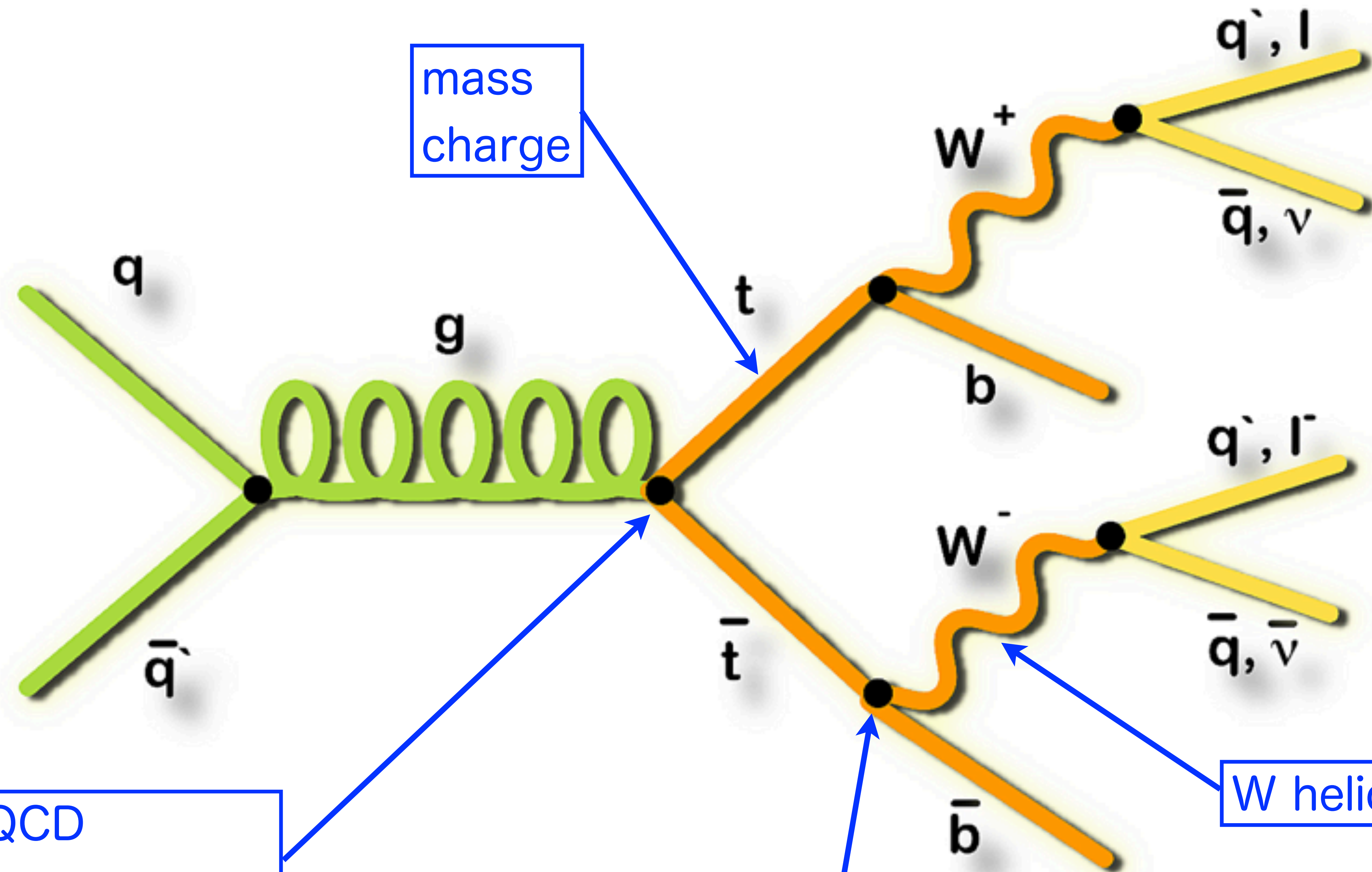




Kinematic fitting

$$
\begin{aligned}
L = \; & \mathcal{B}(\widetilde{E}_{\mathrm{p},1}, \widetilde{E}_{\mathrm{p},2} | m_W, \Gamma_W) \cdot \mathcal{B}(\widetilde{E}_{\mathrm{lep}}, \widetilde{E}_{\nu} | m_W, \Gamma_W) \\
& \mathcal{B}(\widetilde{E}_{\mathrm{p},1}, \widetilde{E}_{\mathrm{p},2}, \widetilde{E}_{\mathrm{p},3} | m_t, \Gamma_t) \cdot \mathcal{B}(\widetilde{E}_{\mathrm{lep}}, \widetilde{E}_{\nu}, \widetilde{E}_{\mathrm{p},4} | m_t, \Gamma_t) \\
& \mathcal{W}(\hat{E}_x^{\mathrm{miss}} | \widetilde{p}_{x,\nu}) \cdot \mathcal{W}(\hat{E}_y^{\mathrm{miss}} | \widetilde{p}_{y,\nu}) \cdot \mathcal{W}(\hat{E}_{\mathrm{lep}} | \widetilde{E}_{\mathrm{lep}}) \cdot \\
& \prod_{\mathrm{i}=1}^{4} \mathcal{W}(\hat{E}_{\mathrm{jet,i}} | \widetilde{E}_{\mathrm{p,i}}) \cdot \prod_{\mathrm{i}=1}^{4} P(\mathrm{tagged} \mid \mathrm{parton\ flavour}),
\end{aligned}
$$

Top quark physics program



mass
charge

test of pQCD
cross section
tt+X production
charge asymmetry
spin-correlation
resonance production

test of EW
Wtb anomalous coupling
rare decay

W helicity

Major background for Higgs and searches

Inclusive cross-section

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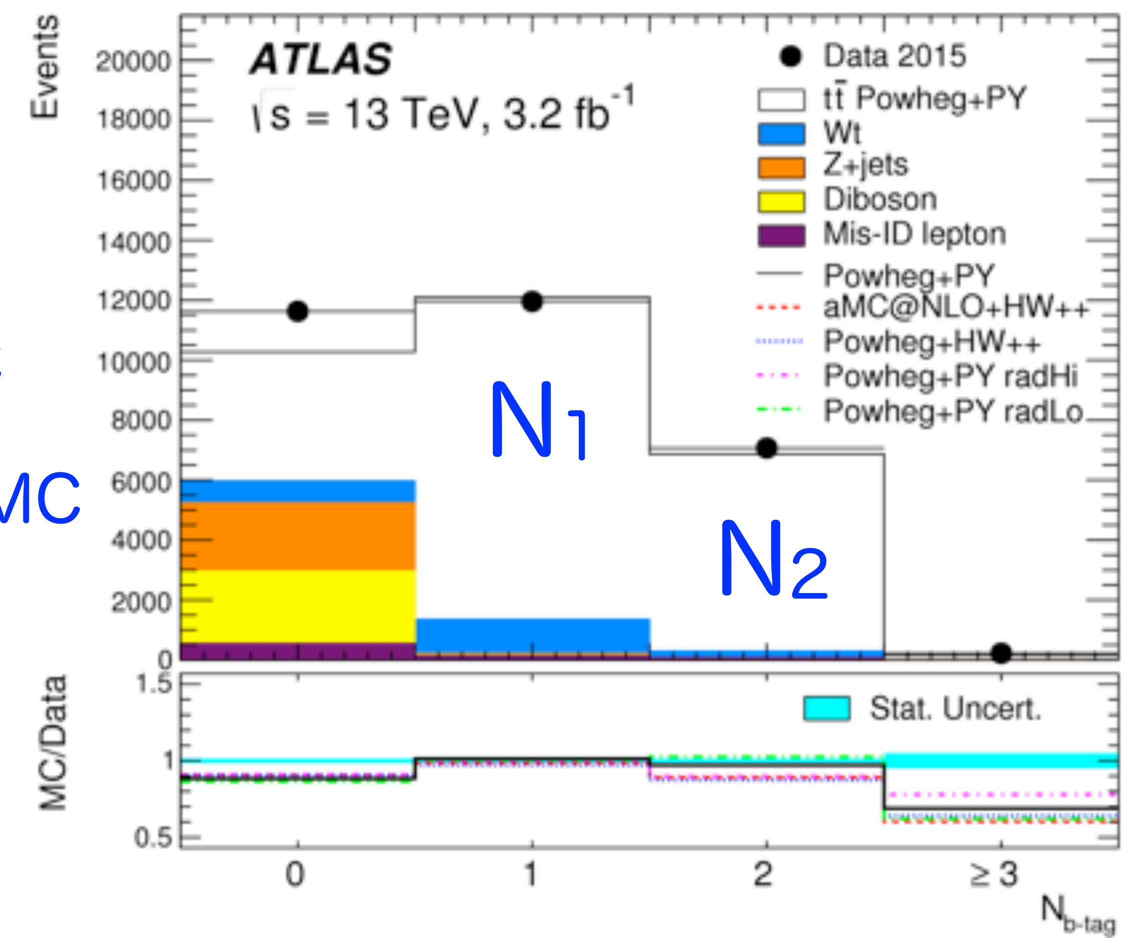
- Select exactly opposite sign 1 e and 1 μ
- Select exactly 1 and 2 b-tagged jets

Event counts	N_1	N_2
Data	11958	7069
Single top	1140 ± 100	221 ± 68
Dibosons	34 ± 11	1 ± 0
$Z(\to \tau\tau \to e\mu)$+jets	37 ± 18	2 ± 1
Misidentified leptons	164 ± 65	116 ± 55
Total background	1370 ± 120	340 ± 88

} MC (single top, dibosons, Z+jets)

data/MC (misidentified leptons)



$$N_1 = L\sigma_{t\bar{t}}\,\epsilon_{e\mu} 2\epsilon_b(1 - C_b\epsilon_b) + N_1^{\text{bkg}}$$

$$N_2 = L\sigma_{t\bar{t}}\,\epsilon_{e\mu} C_b \epsilon_b{}^2 + N_2^{\text{bkg}}$$

$\varepsilon_{e\mu}$: $e\mu$ selection efficiency

ε_b : b-tag rate

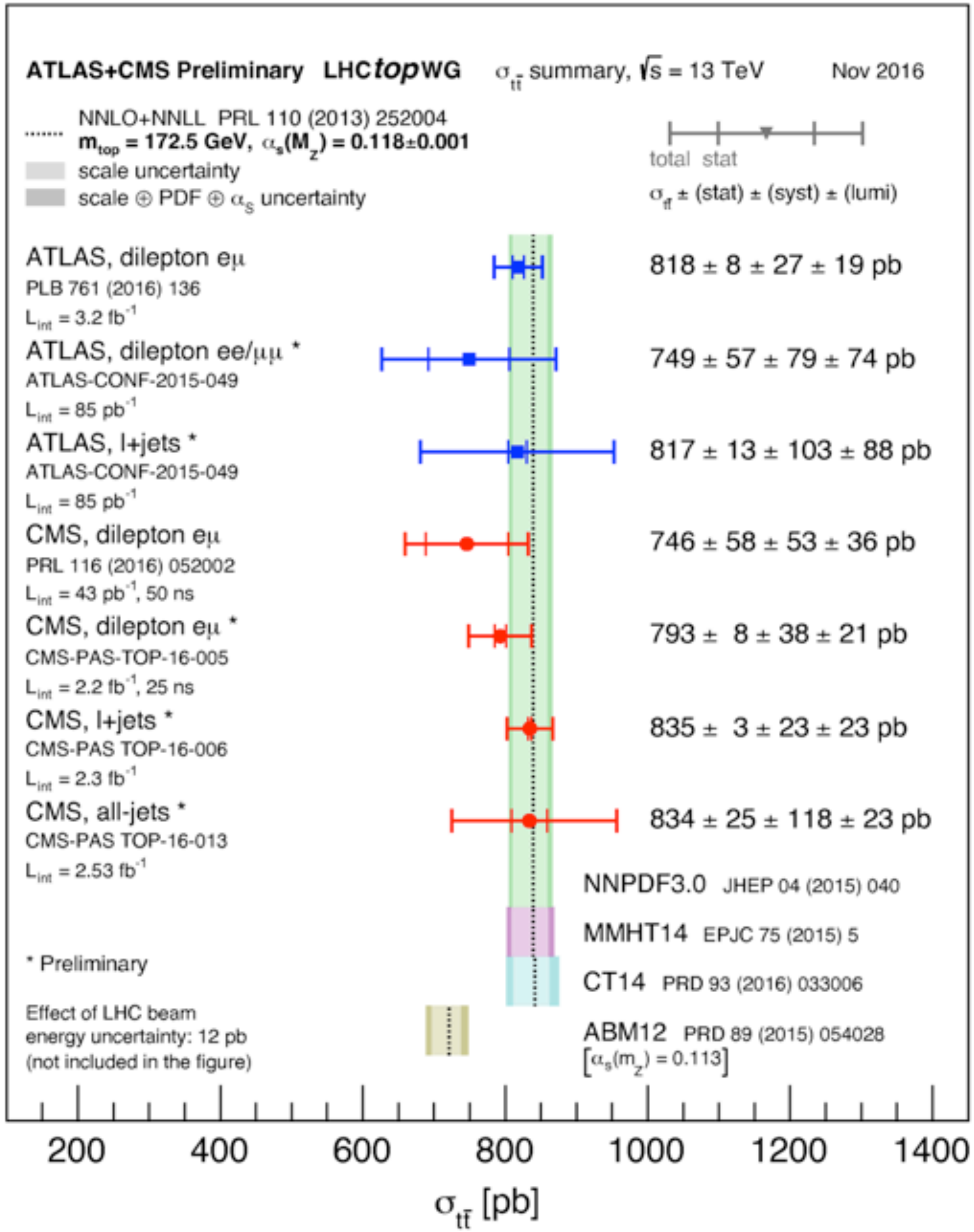
C_b : correlation constant

$$\sigma_{t\bar{t}} = 818 \pm 8\ (\text{stat}) \pm 27\ (\text{system}) \pm 19\ (\text{lump}) \pm 12\ (\text{beam})\ \text{pb}$$

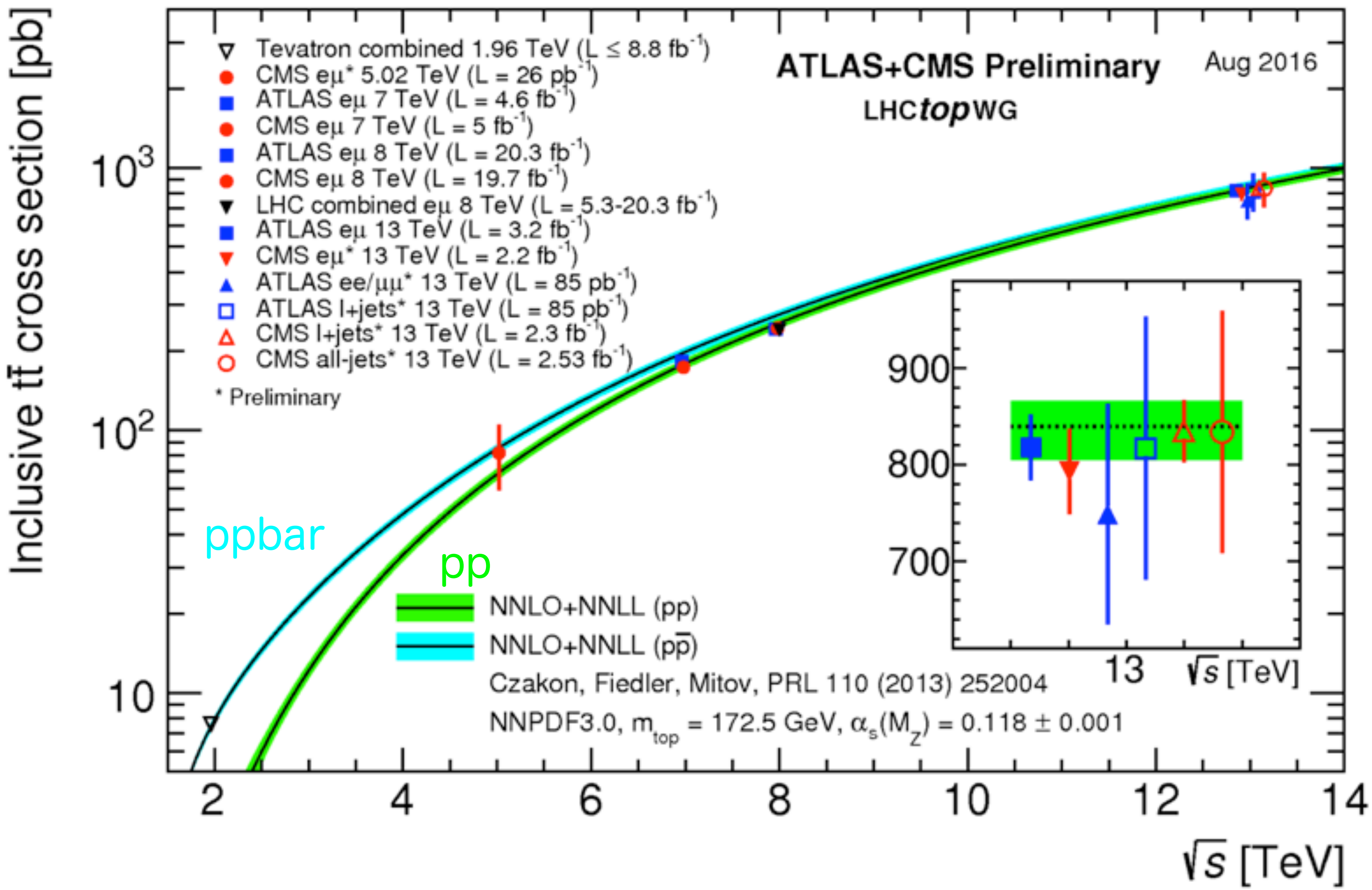
Total uncertainty: 4.4%

$$\sigma_{t\bar{t}}^{\text{NNLO+NNLL}} = 832\ {}^{+20}_{-29}\ (\text{scale})\ {}^{+35}_{-35}\ (\text{PDF} + \alpha_S)\ \text{pb}$$

Inclusive cross-section



σ_{tt} vs $\sqrt{s}$



Top++2.0
NNLO+NNLL Prediction

	7 TeV	8 TeV	13 TeV	14TeV
σ_{tt}	177 pb	253 pb	832 pb	985 pb
$\Delta\sigma/\sigma$	± 6%	± 6%	± 6%	± 5%

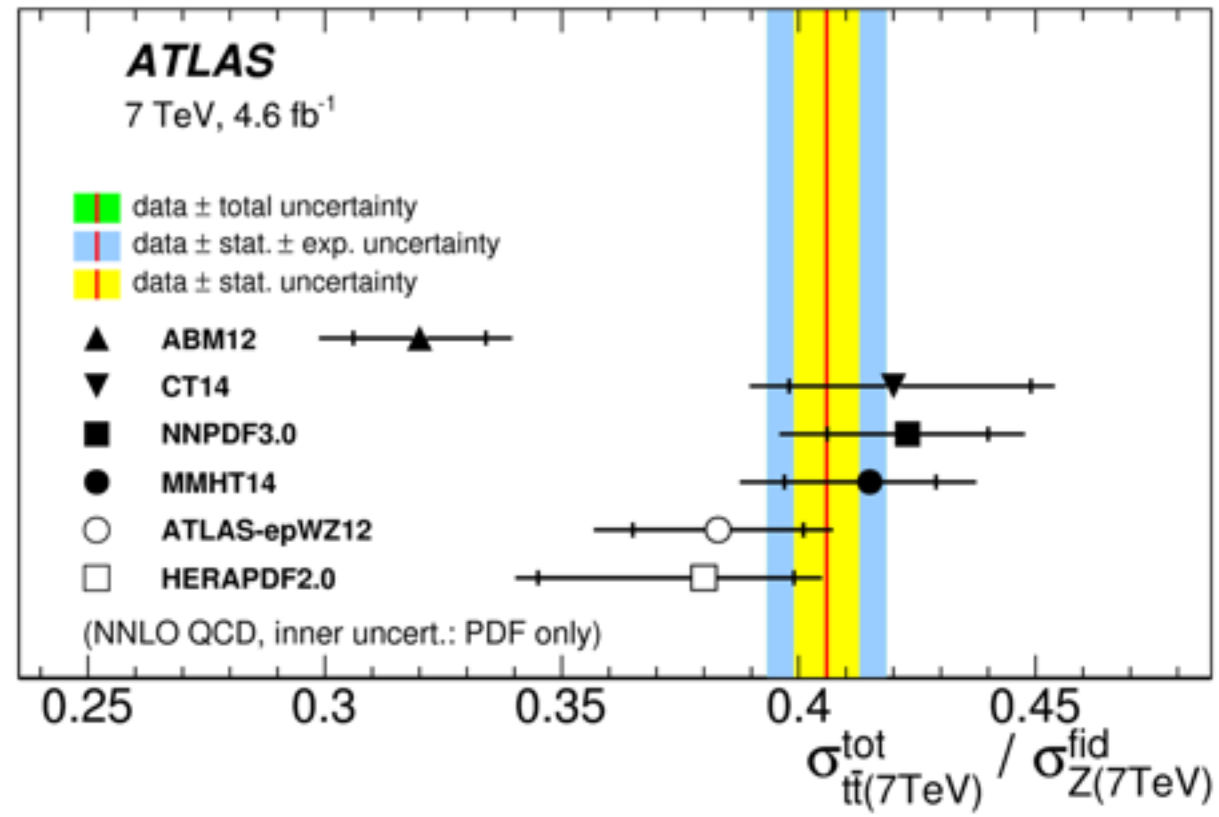
σ_{tt} / σ_Z

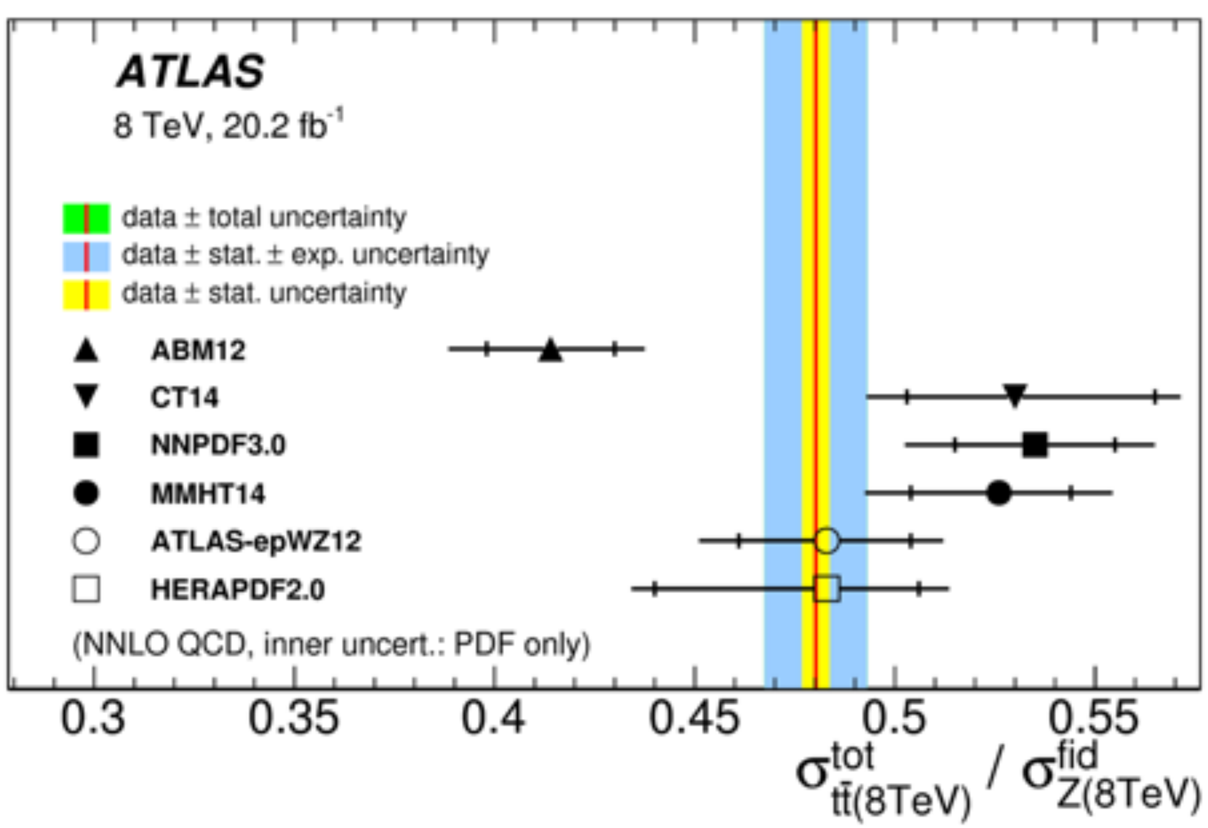
JHEP1702(2017)117

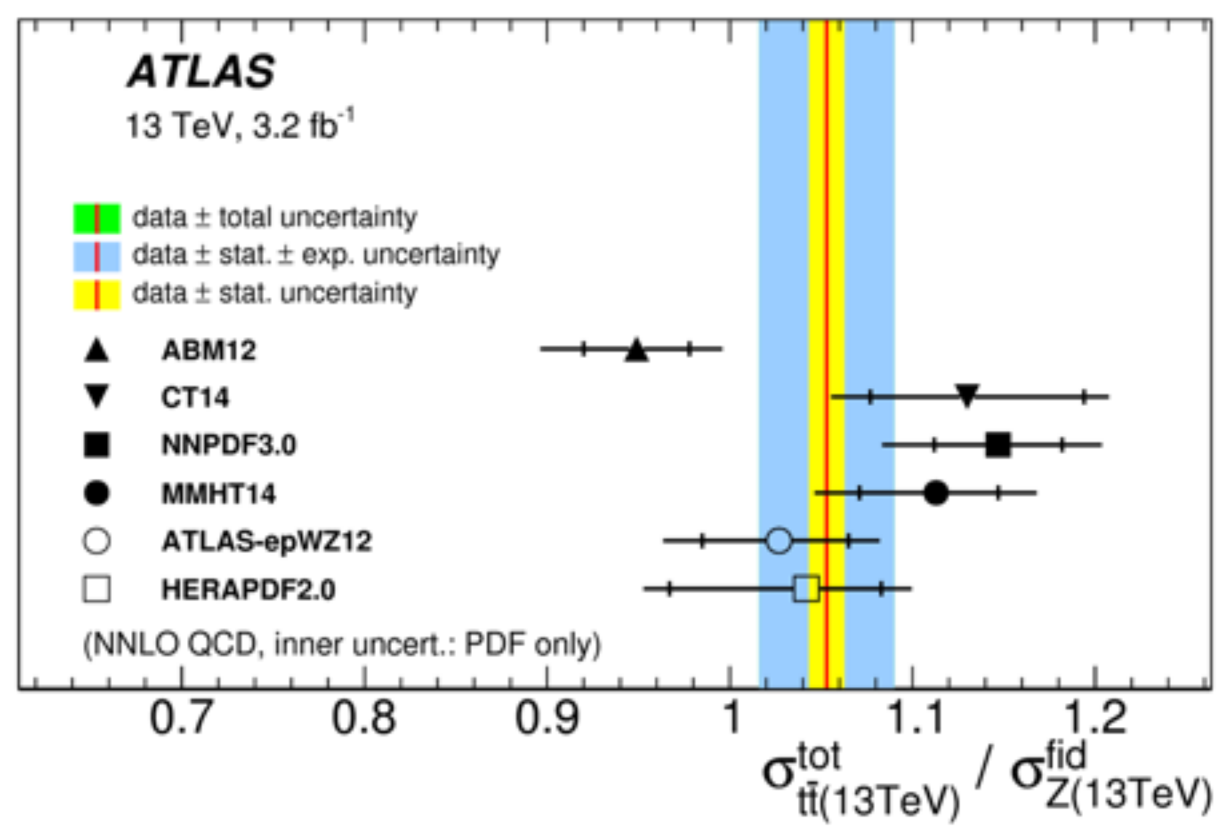
- Cross-section ratio using tt→eμ+2 bjets

$$R_{t\bar{t}/Z} = \frac{\sigma_{t\bar{t}}}{0.5\left(\sigma_{Z\to ee} + \sigma_{Z\to\mu\mu}\right)}$$

- Correct for common phase space
- Account for correlations of systematic uncertainties.
- Compare to predictions at NNLO+NNLL with 6 different PDF sets



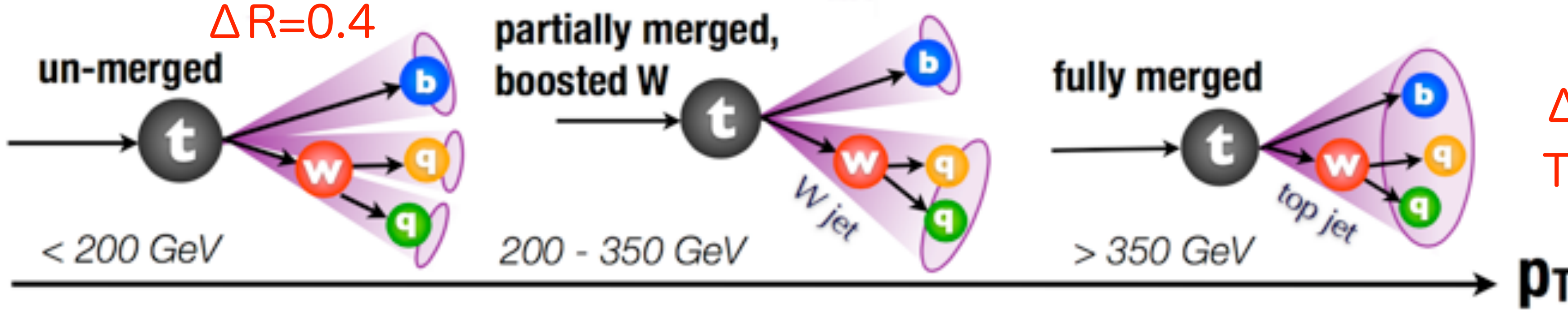




Differential cross-section

arXiv:1612.05220, ATLAS-CONF-2016-040, ATLAS-CONF-2016-100

- Resolved (for low pT top) and boosted (high pT top) topologies are used



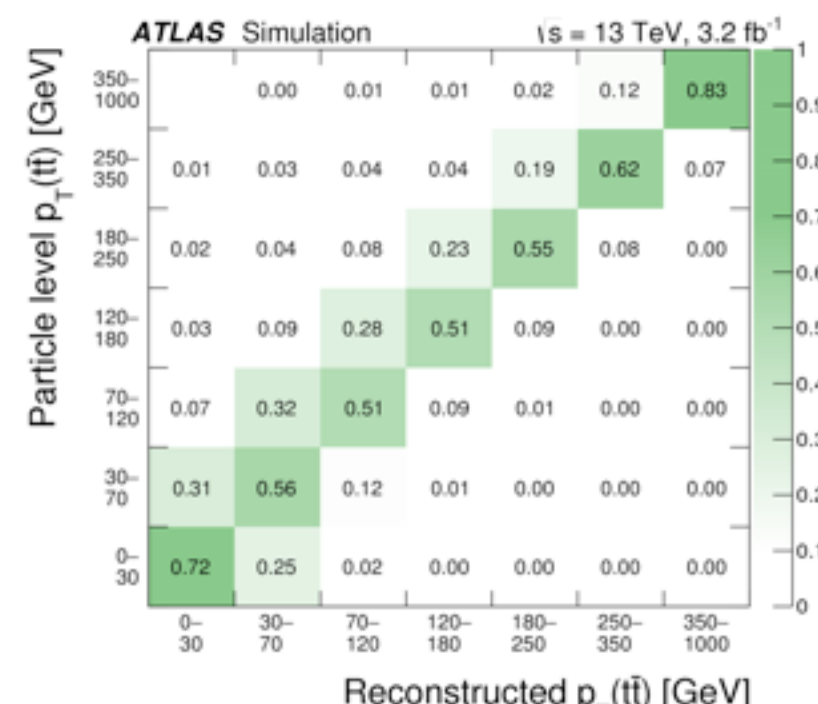
ΔR~ 2m/pT
Typically, ΔR~1.0

- Correct for the detector effects ("unfolding"), so that theoretical models can be directly probed.

$$\frac{d\sigma^{\mathrm{fid}}}{dX^i} \equiv \frac{1}{\int \mathcal{L}dt \cdot \Delta X^i} \cdot f^i_{\mathrm{off}} \cdot \sum_j \mathcal{M}^{-1}_{ij} \cdot f^j_{\mathrm{acc}} \cdot \left(N^j_{\mathrm{reco}} - N^j_{\mathrm{bg}}\right)$$

- Top quark definition
  - detector level
  - particle level
  - parton level

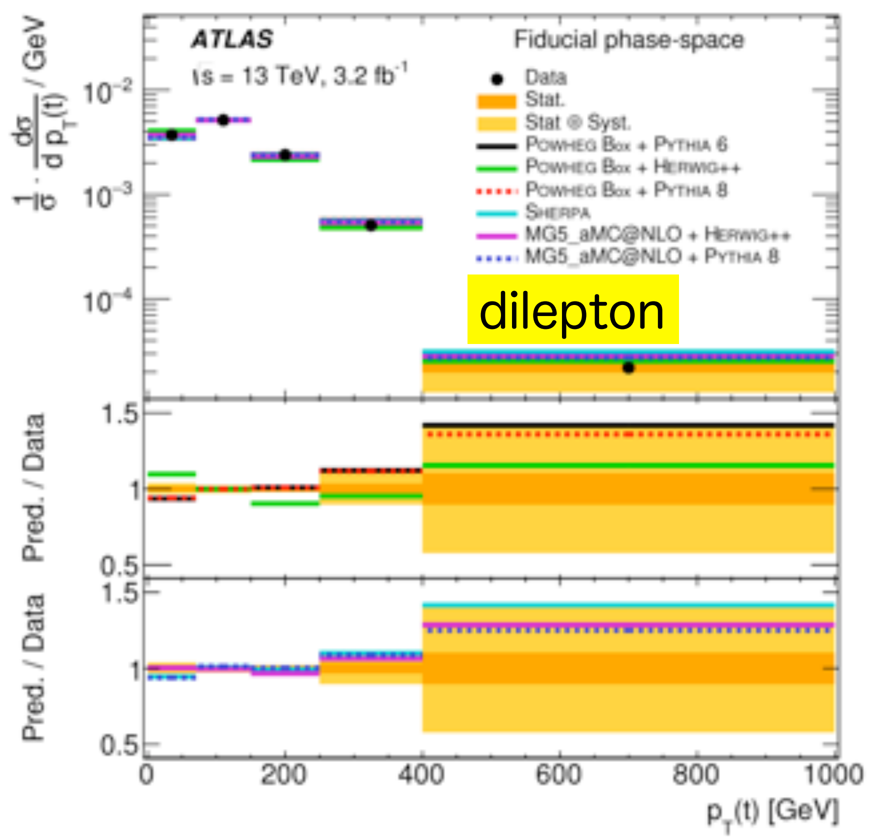
- Covered phase-space
  - detector
  - fiducial
  - full

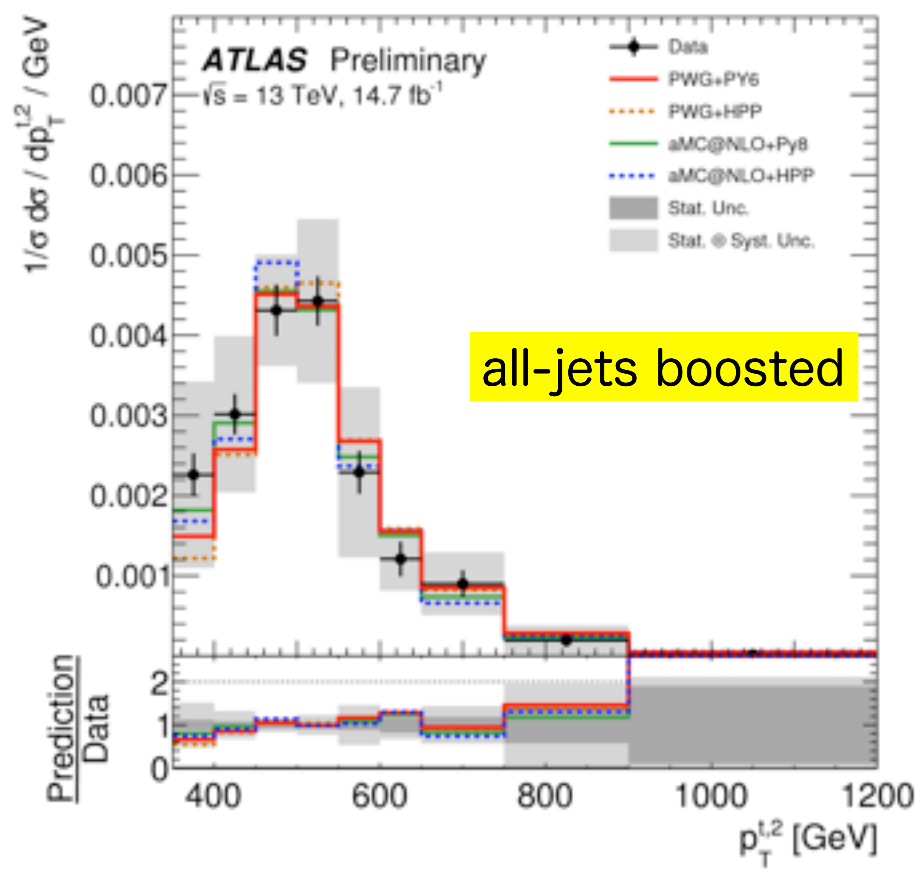


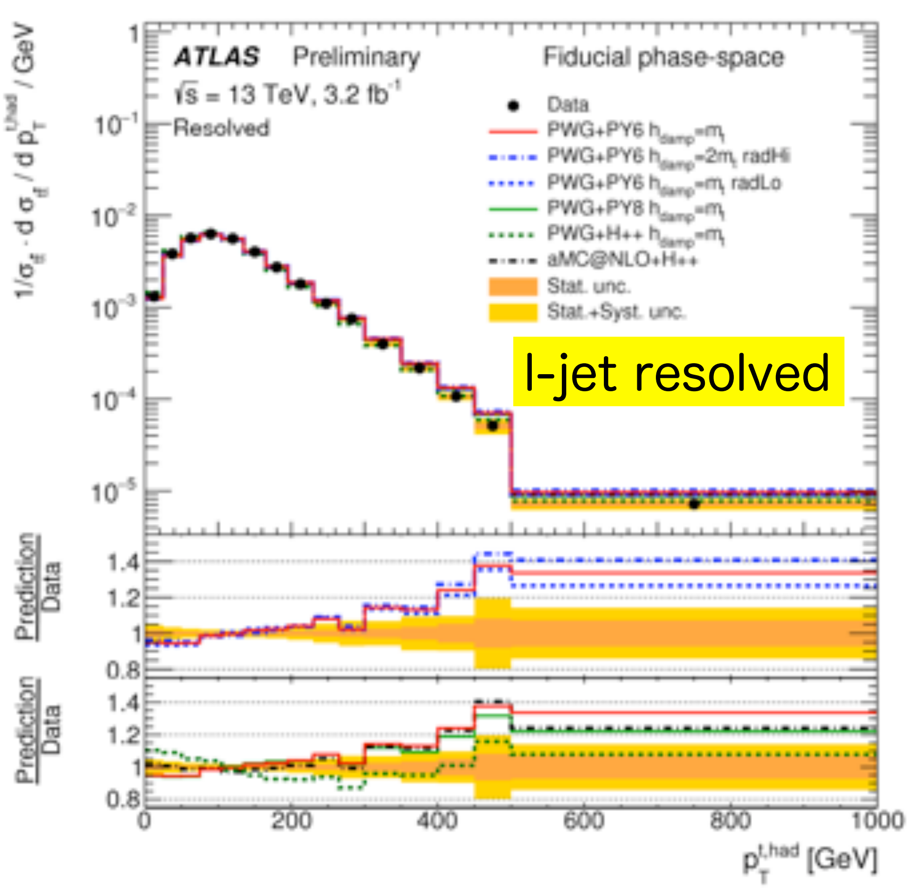
- Differential cross-section as a function of the kinematic variables, N_{jets}, etc.
  - pT(top) → Sensitive to the ISR, FSR
  - y(top), y(tt) → Sensitive to the gluon PDF $y_{t\bar{t}} = \frac{1}{2}\ln\left[(E+p_z)/(E-p_z)\right] = \frac{1}{2}\ln\left(x_1/x_2\right)$
  - m(tt)→ Sensitive to the new physics at high-Q^2

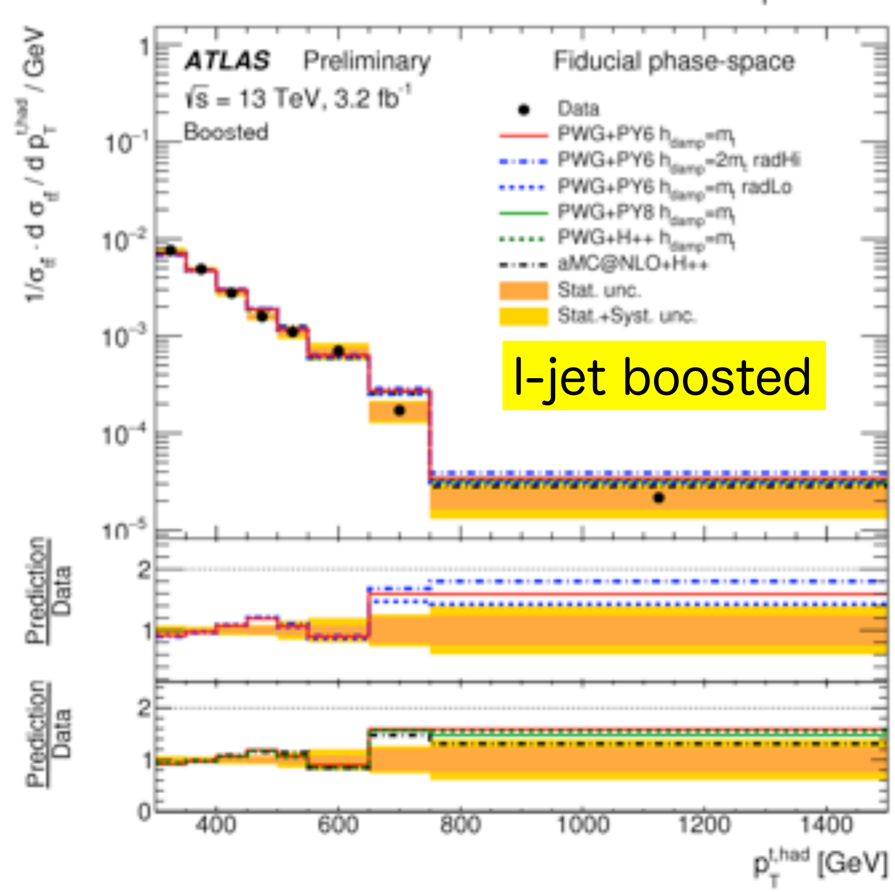
Differential cross-section : p_T(top)

arXiv:1612.05220, ATLAS-CONF-2016-040, ATLAS-CONF-2016-100



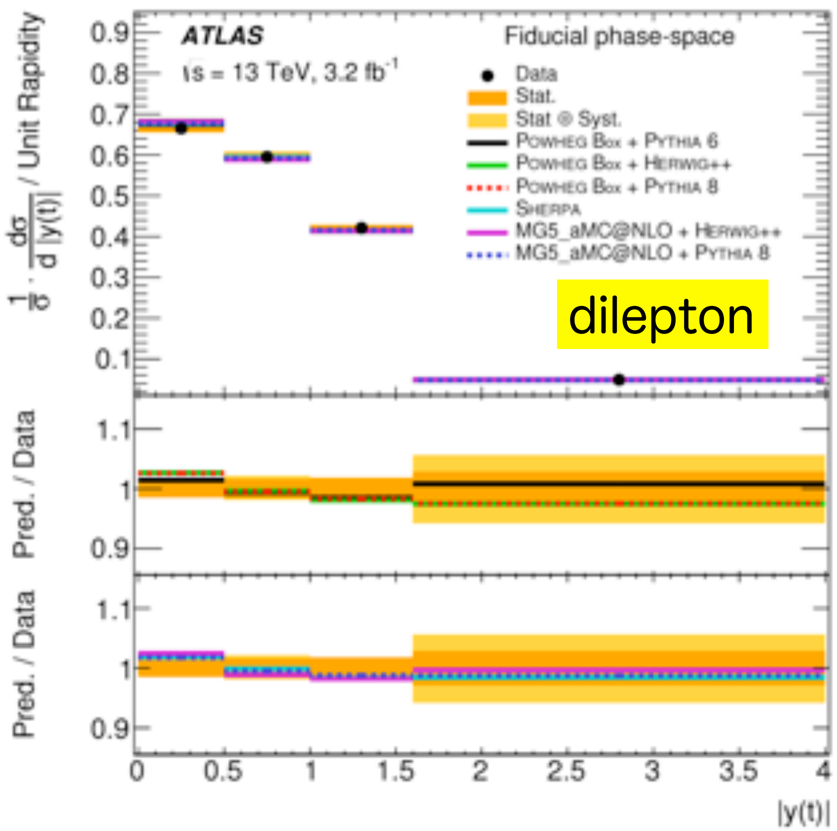


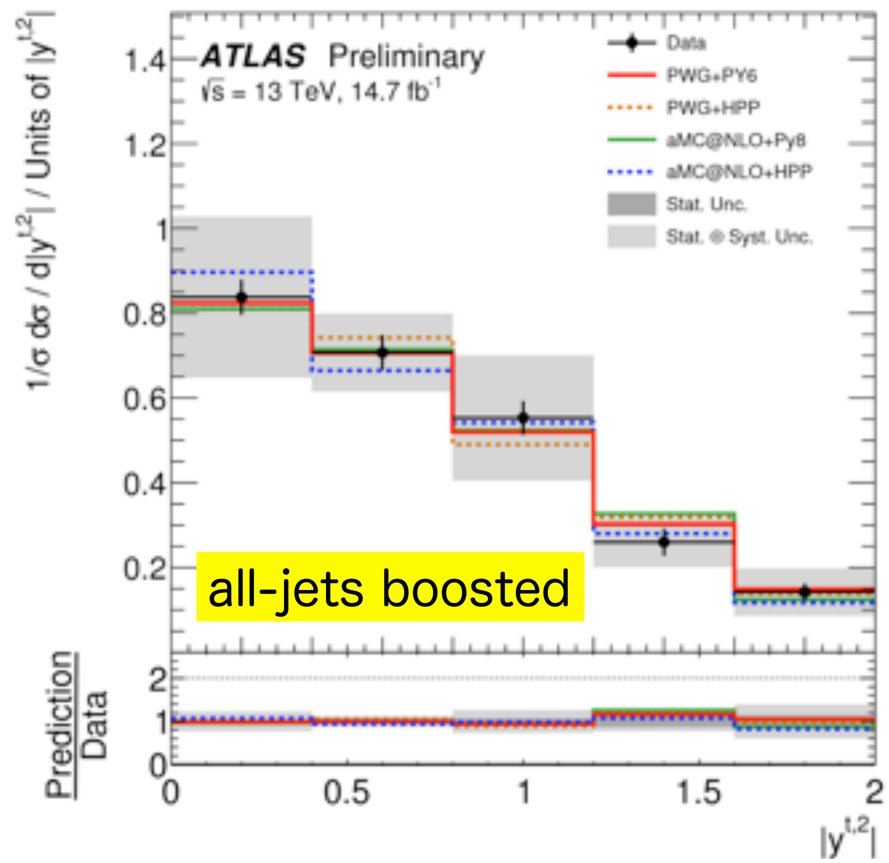


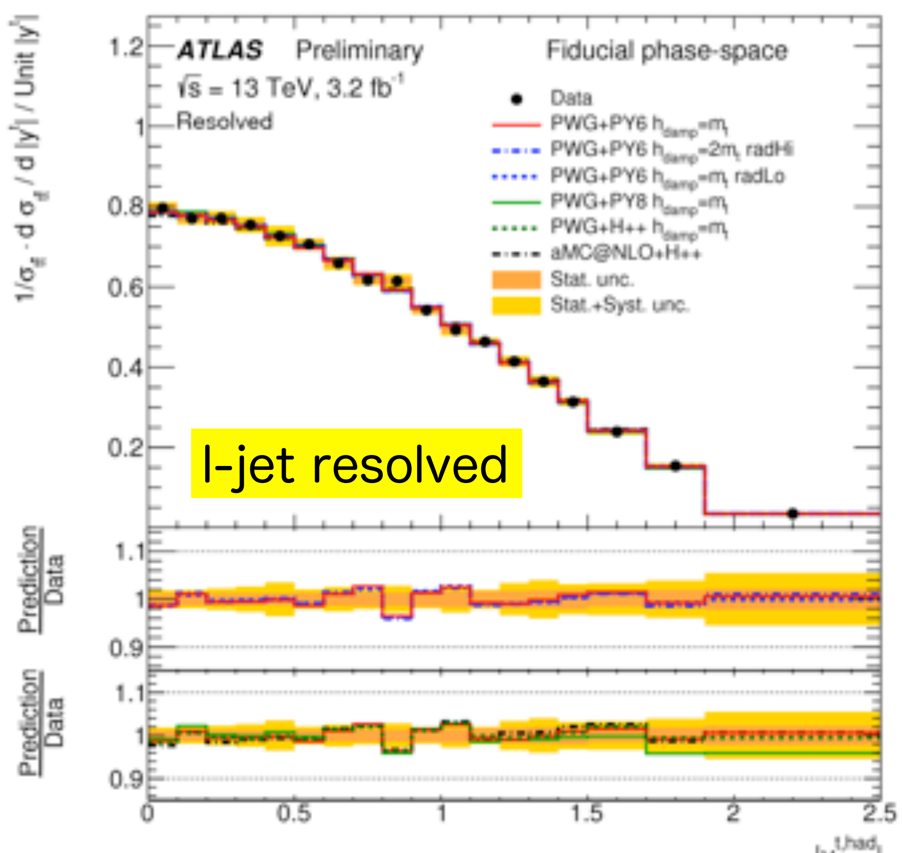


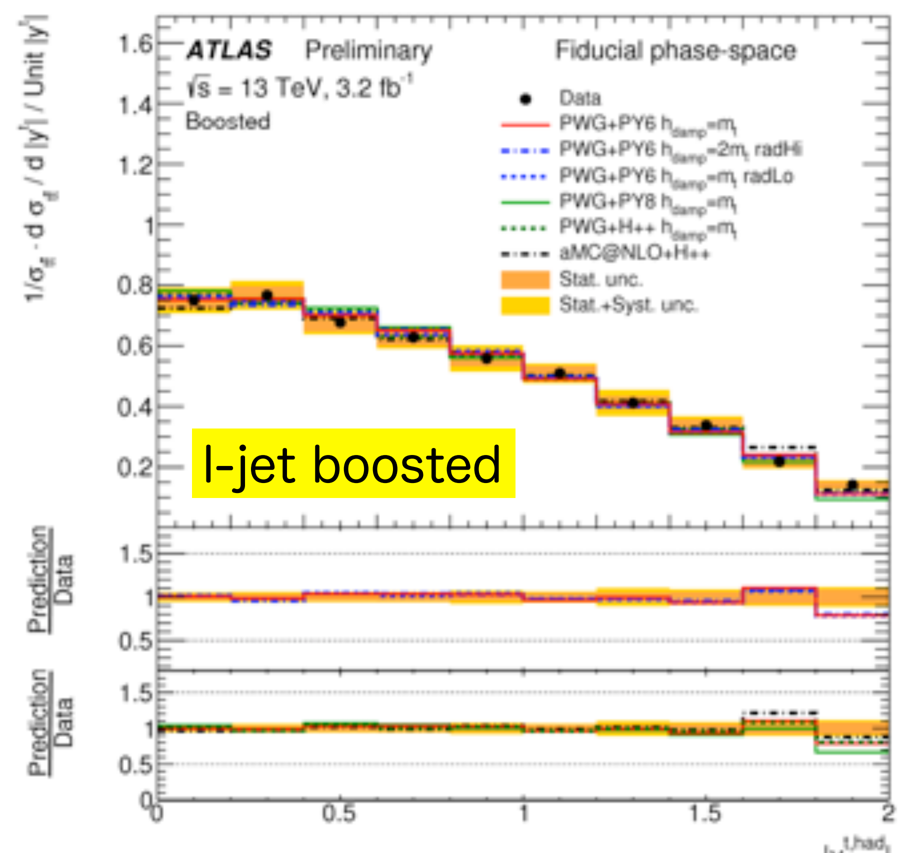
Differential cross-section : y(top)

arXiv:1612.05220, ATLAS-CONF-2016-040, ATLAS-CONF-2016-100



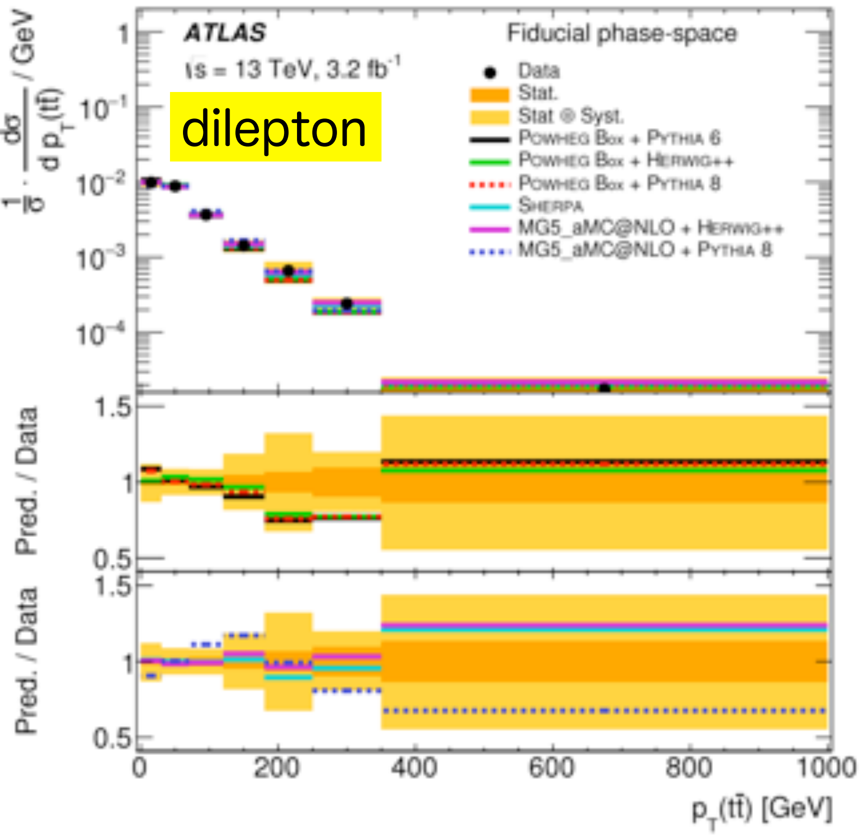


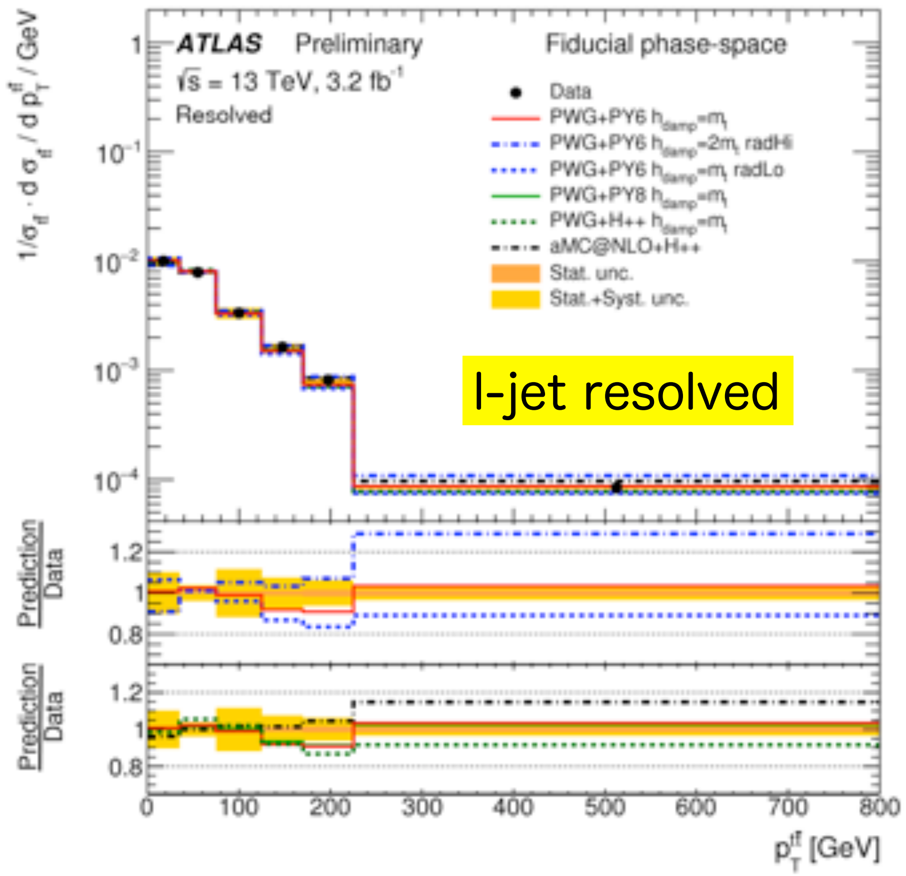


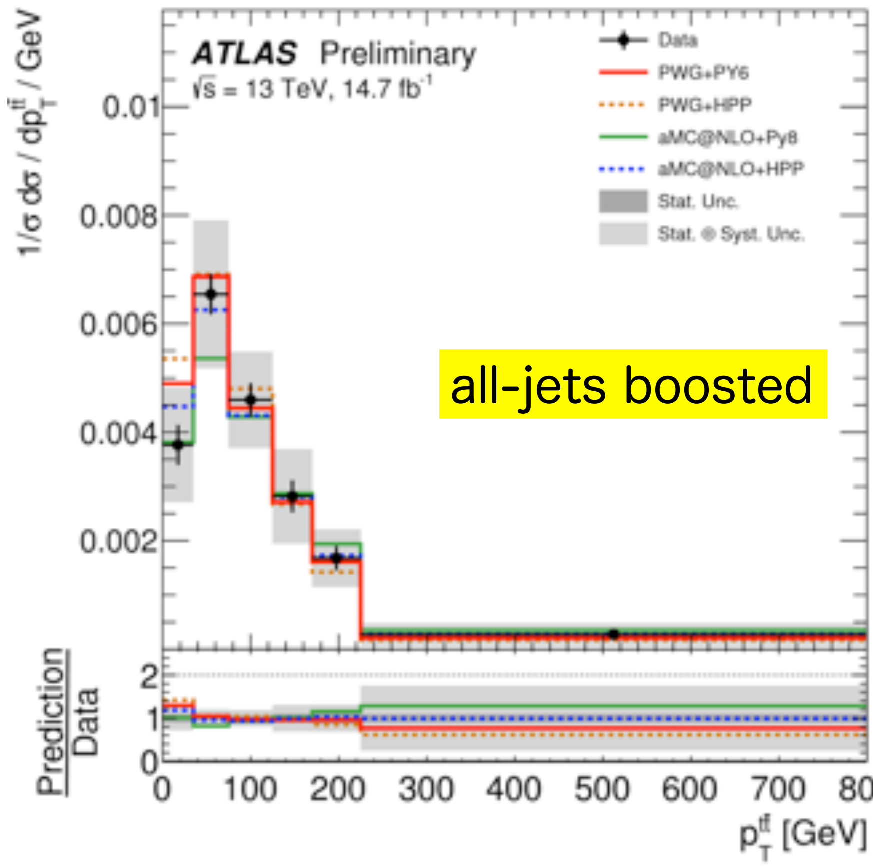


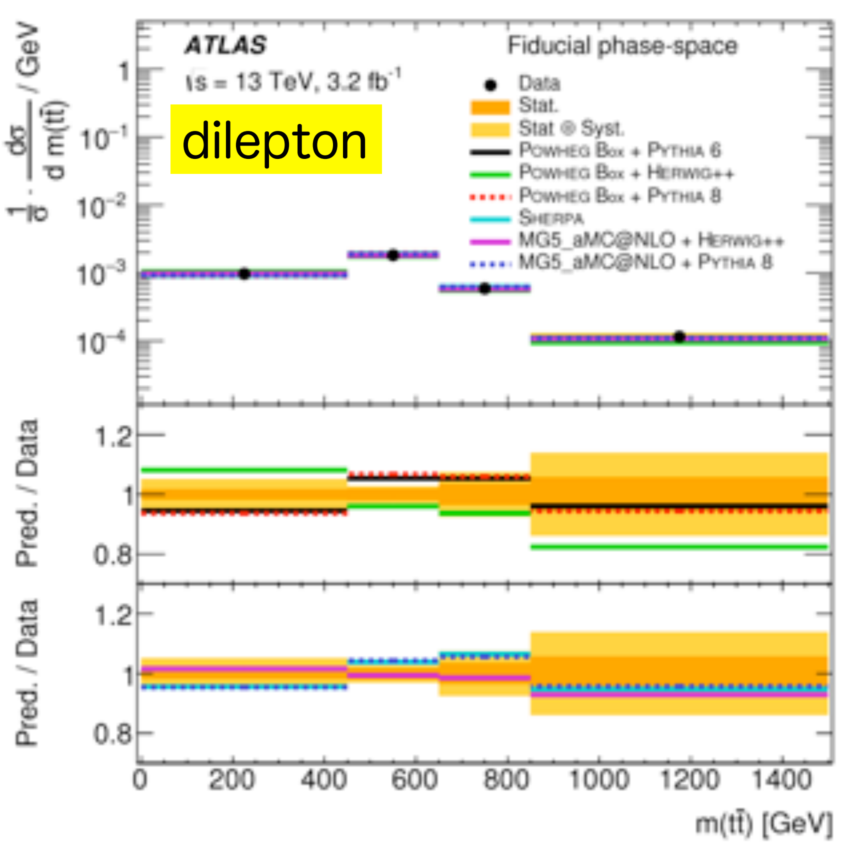
Differential cross-section : p_T^{tt}, m^{tt}

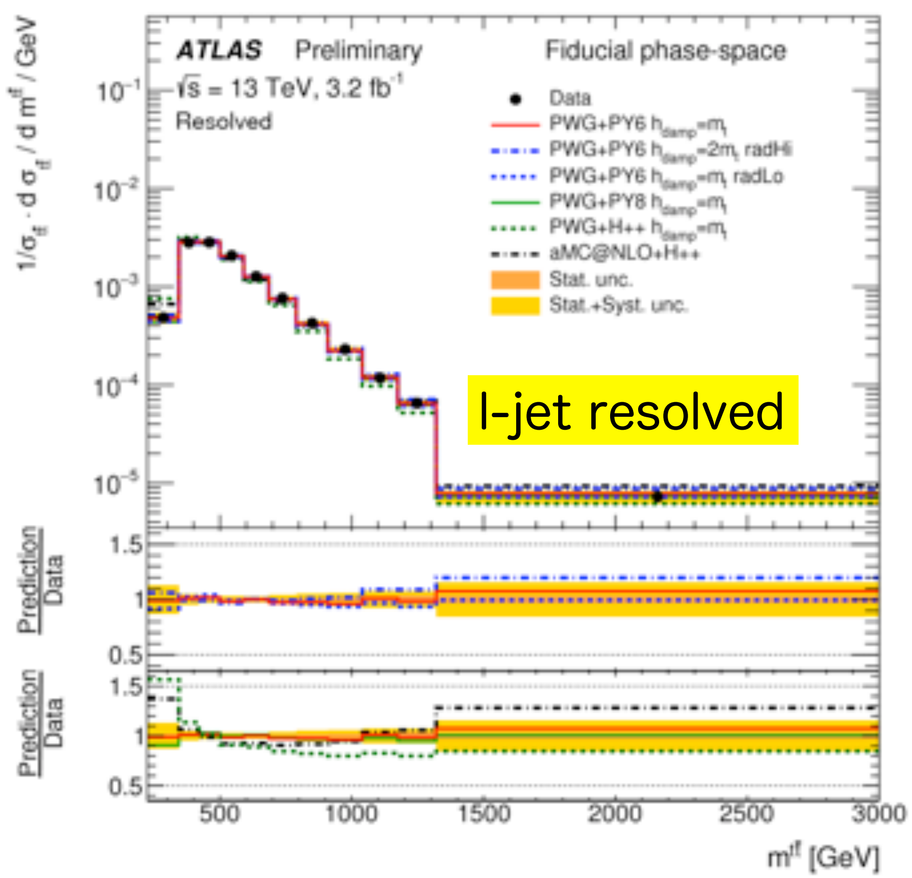
arXiv:1612.05220, ATLAS-CONF-2016-040, ATLAS-CONF-2016-100

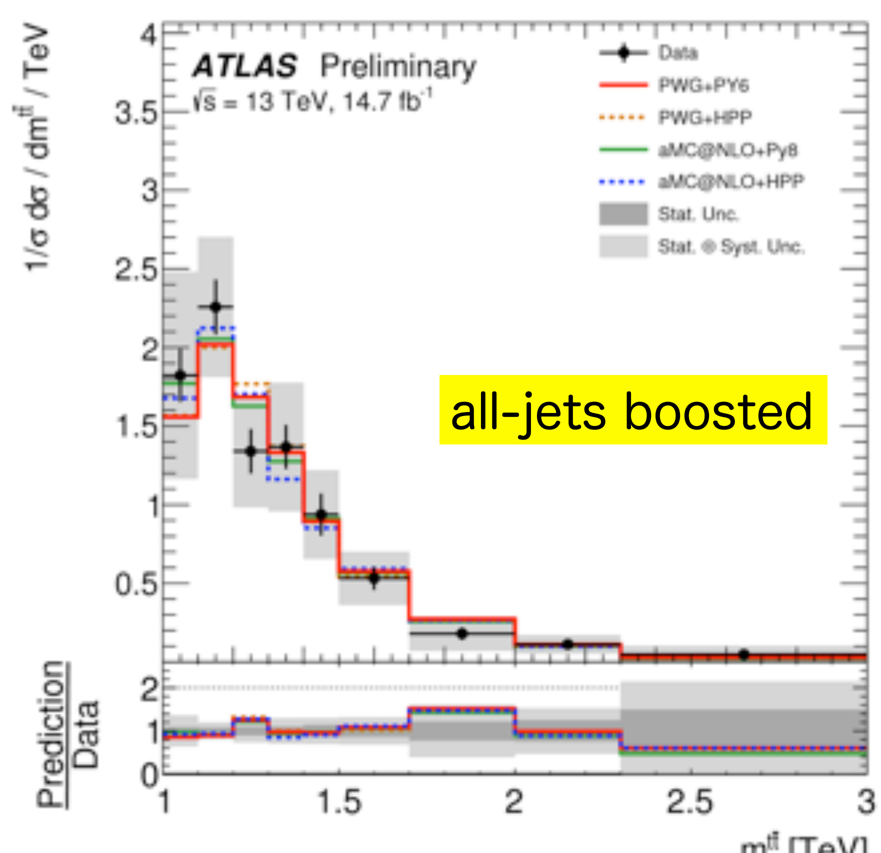








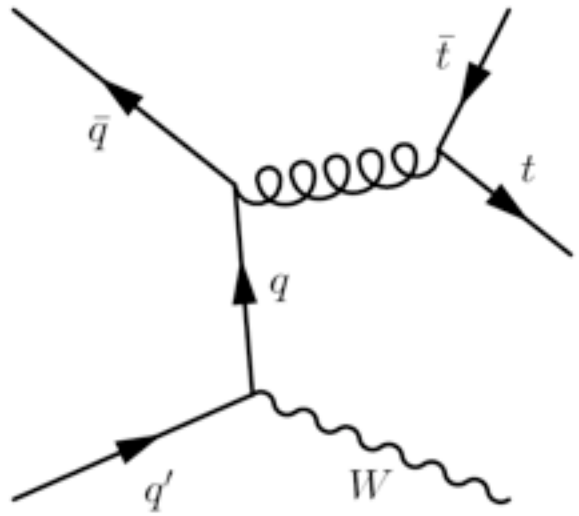


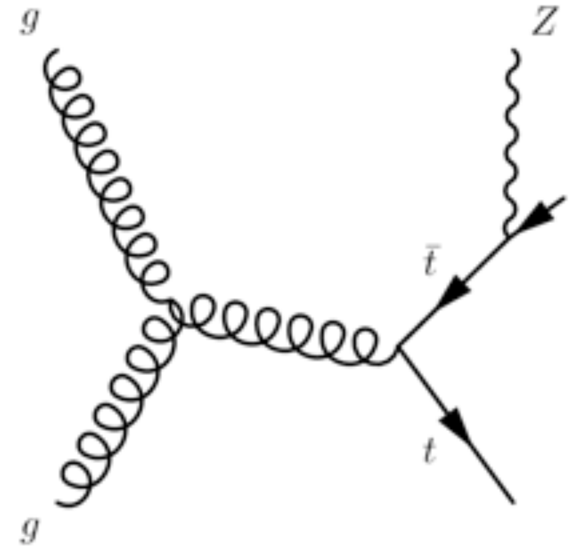


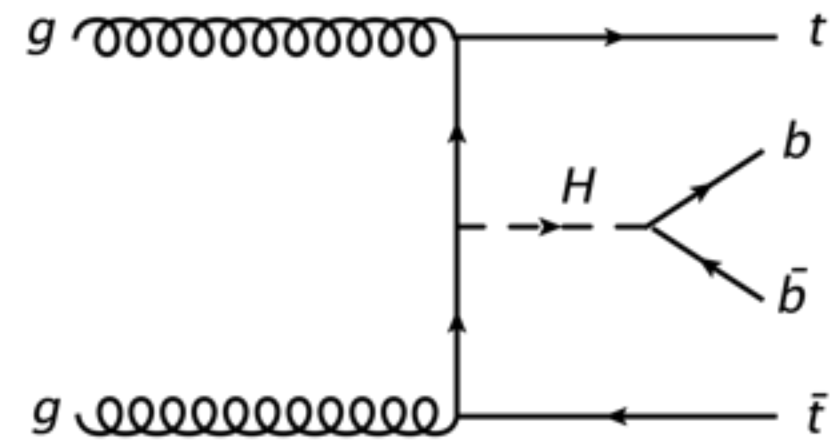
tt+X cross-section

Eur. Phys. J. C77 (2017) 40

ATLAS-CONF-2016-068



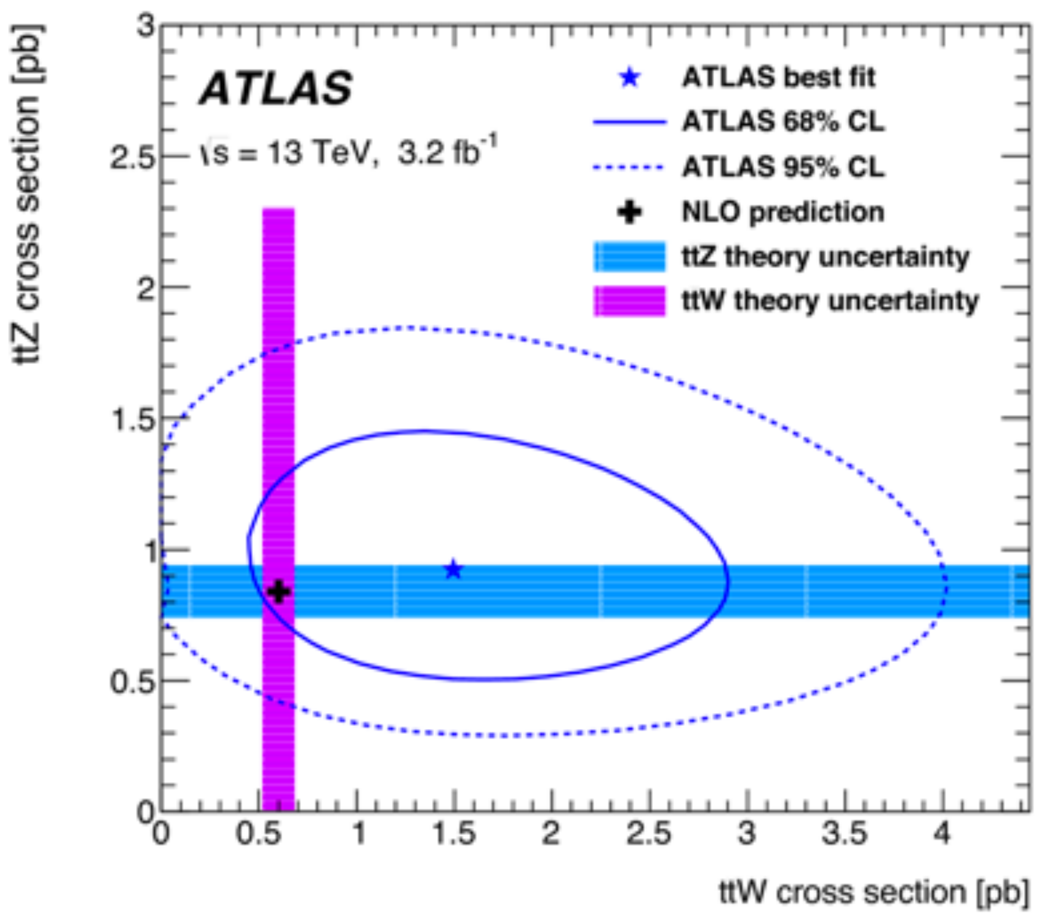




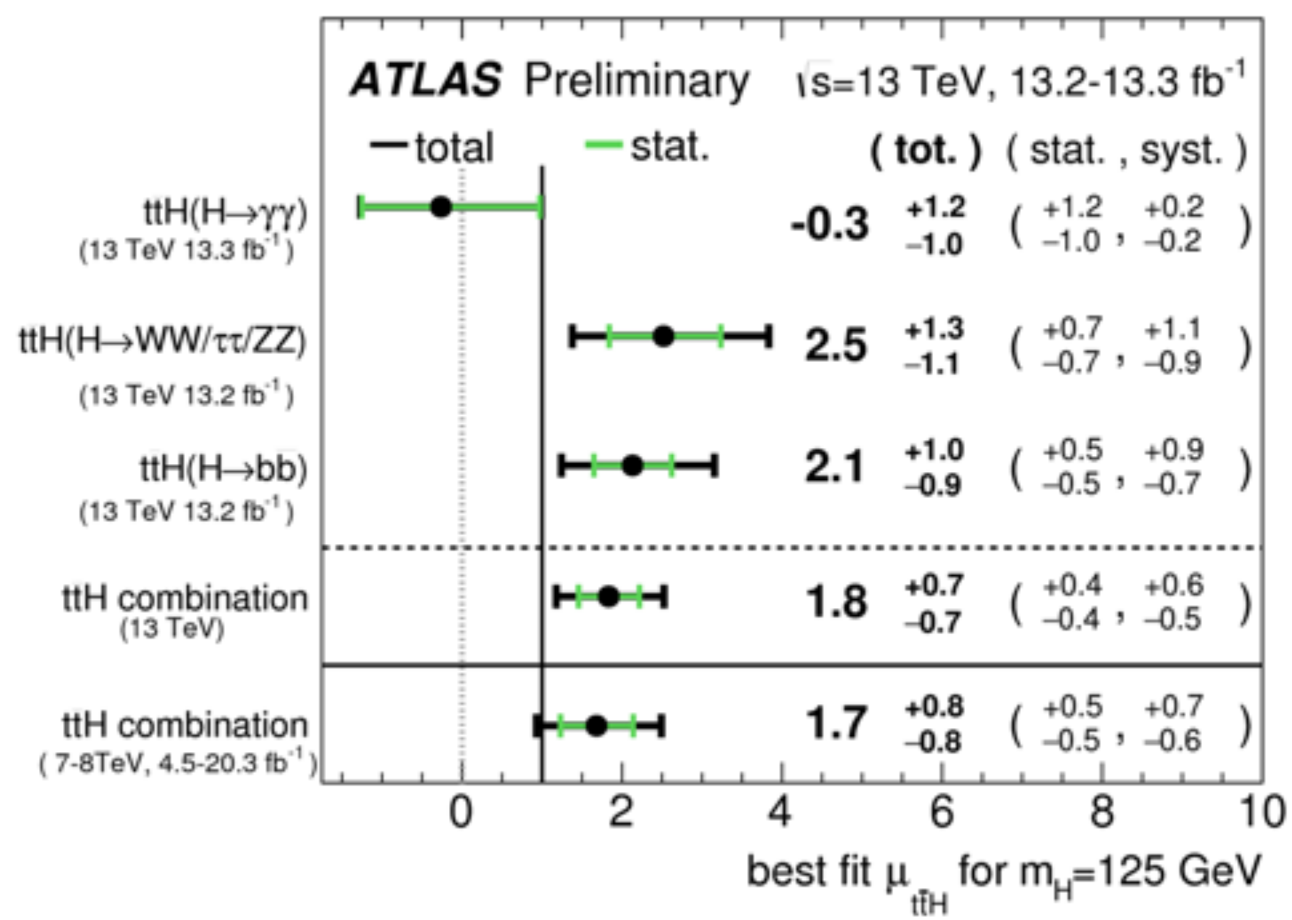
same sign 2μ or 3ℓ+2b

3ℓ or 4ℓ+1b or 2b

dilepton, l+jets,
H→$\gamma\gamma$,WW, ZZ, $\tau\tau$, bb



$$\sigma_{t\bar{t}Z} = 0.9 \pm 0.3 \text{ pb}$$
$$\sigma_{t\bar{t}W} = 1.5 \pm 0.8 \text{ pb}$$



obs. (exp.) significance= 2.8 (1.8)σ

modeling of tt+>1b is dominant syst.

Top mass : Standard method

Phys. Lett. B 761 (2016) 350, arXiv:1702.07546, etc.

Top quark mass is measured using the “template fit”

dilepton : 2 leptons, 2 b-jets→m_{lb}

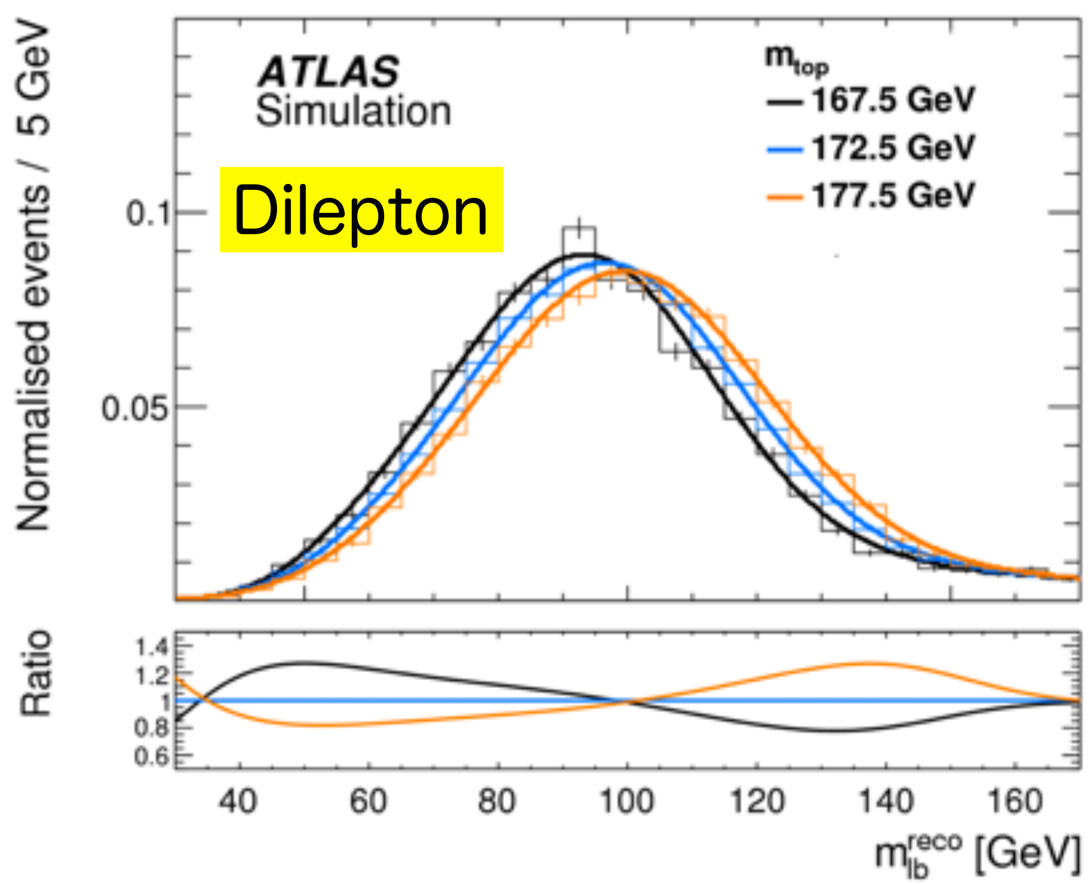
single lepton : lepton, E_T^{miss}, 2 b-jets, 2 light-jets→m_{top}^{reco}, m_W^{reco}, R_{bq}^{reco}

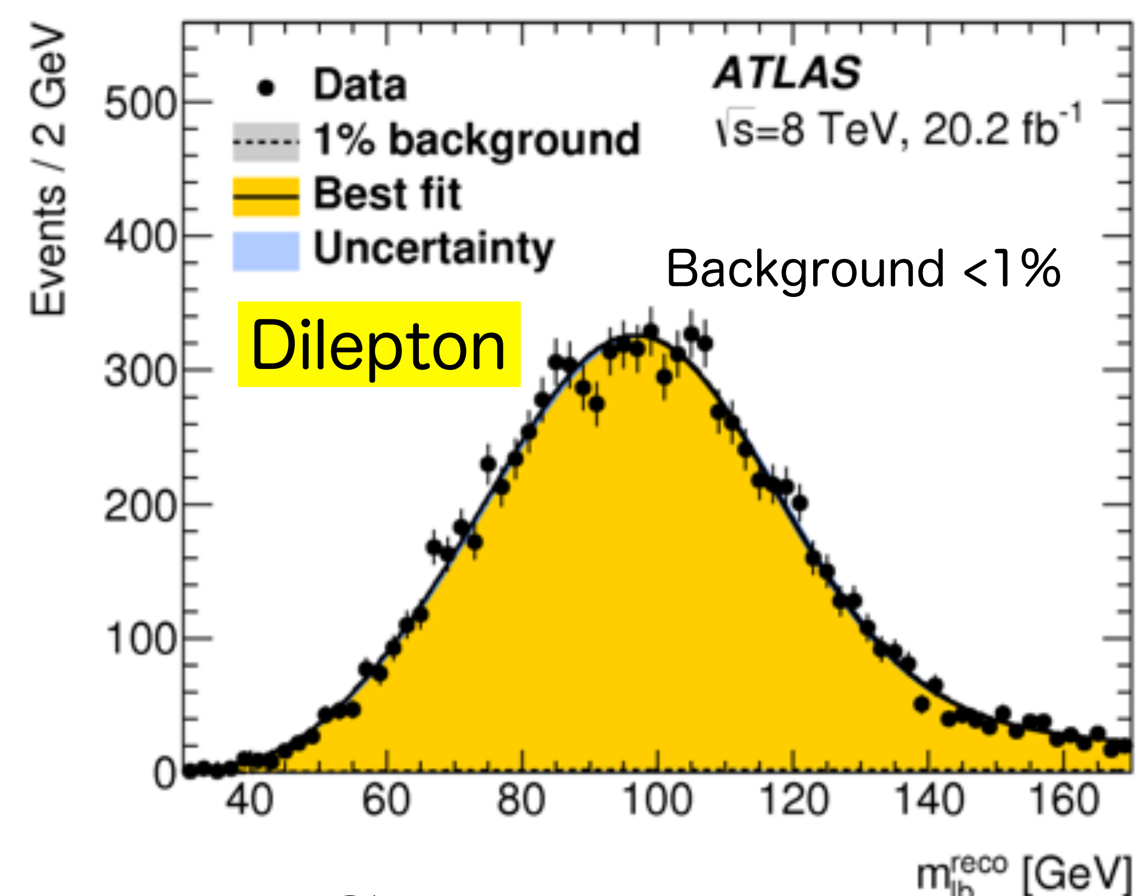
3D template fit of m_{top}^{reco}, m_W^{reco}, R_{bq} distribution

→ extract m_t, JSF, bJSF simultaneously

$$R_{bq}^{reco} = \frac{p_T^{b_{had}} + p_T^{b_{lep}}}{p_T^{W_{jet1}} + p_T^{W_{jet2}}}$$

all jets : 2 b-jets, 4 light-jets→$R_{3/2}=m_{jjj}/m_{jj}$ ← Peak at M_t/M_W〜2





$$m_t = 172.99 \pm 0.41 \pm 0.61 \text{ GeV}$$

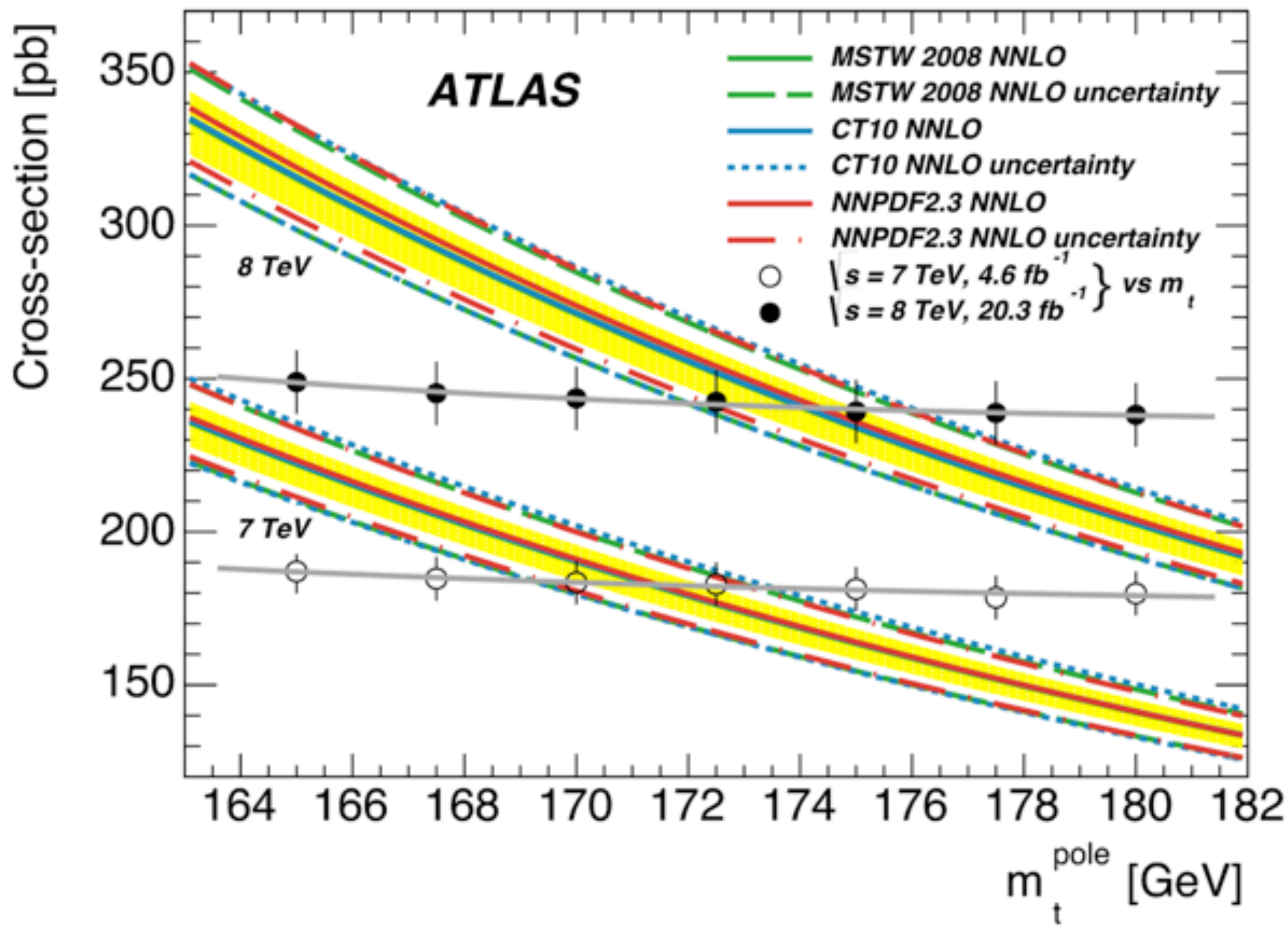
Top mass : pole mass from σ tt

EPJ C74 (2014) 3109

arXiv:1303.6254

$$\sigma(m_t) = \sigma(m_{\rm ref}) \left(\frac{m_{\rm ref}}{m_t}\right)^4 \left[1 + a_1 \left(\frac{m_t - m_{\rm ref}}{m_{\rm ref}}\right) + a_2 \left(\frac{m_t - m_{\rm ref}}{m_{\rm ref}}\right)^2\right]$$

$m_t^{\rm ref} = 172.5$ GeV



$m_t^{\rm pole} = 171.4 \pm 2.6$ GeV (7TeV)

$m_t^{\rm pole} = 174.1 \pm 2.6$ GeV (8TeV)

$m_t^{\rm pole} = 172.9^{+2.6}_{-2.6}$ GeV (combined)

Top mass : pole mass with ttbar+1 jet

arXiv:1507.01769

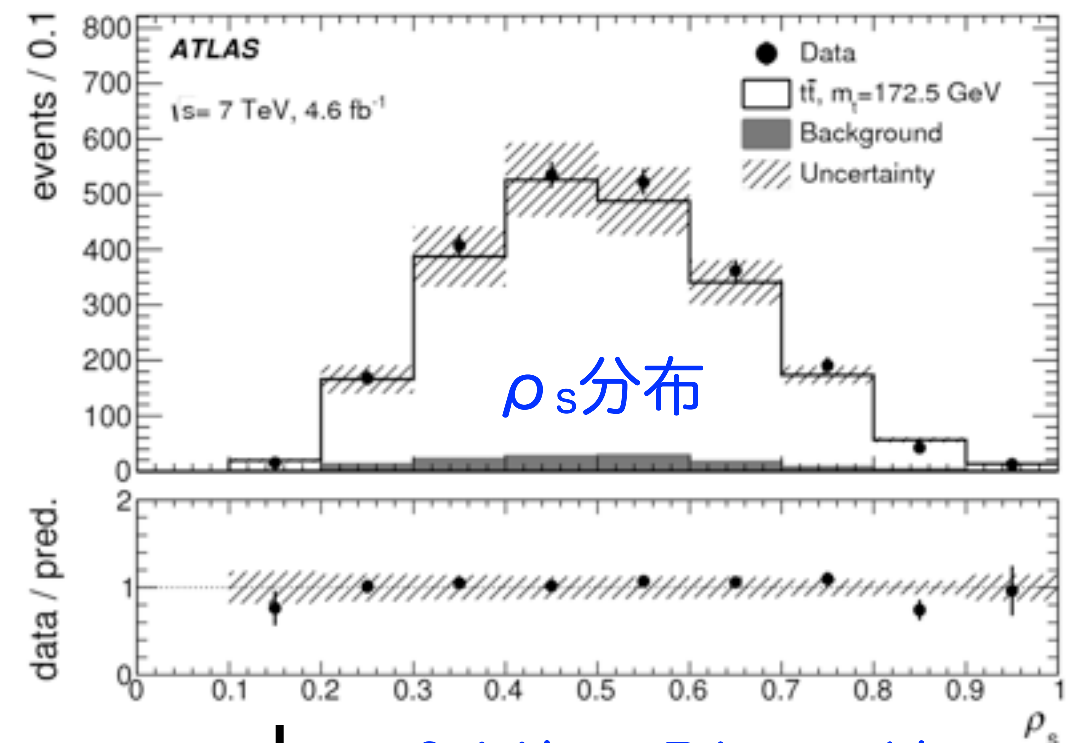
○ Indirect pole mass measurement from differential cross section

Introduced by Eur. Phys. J C73 (2013) 2438, arXiv:1303.6415

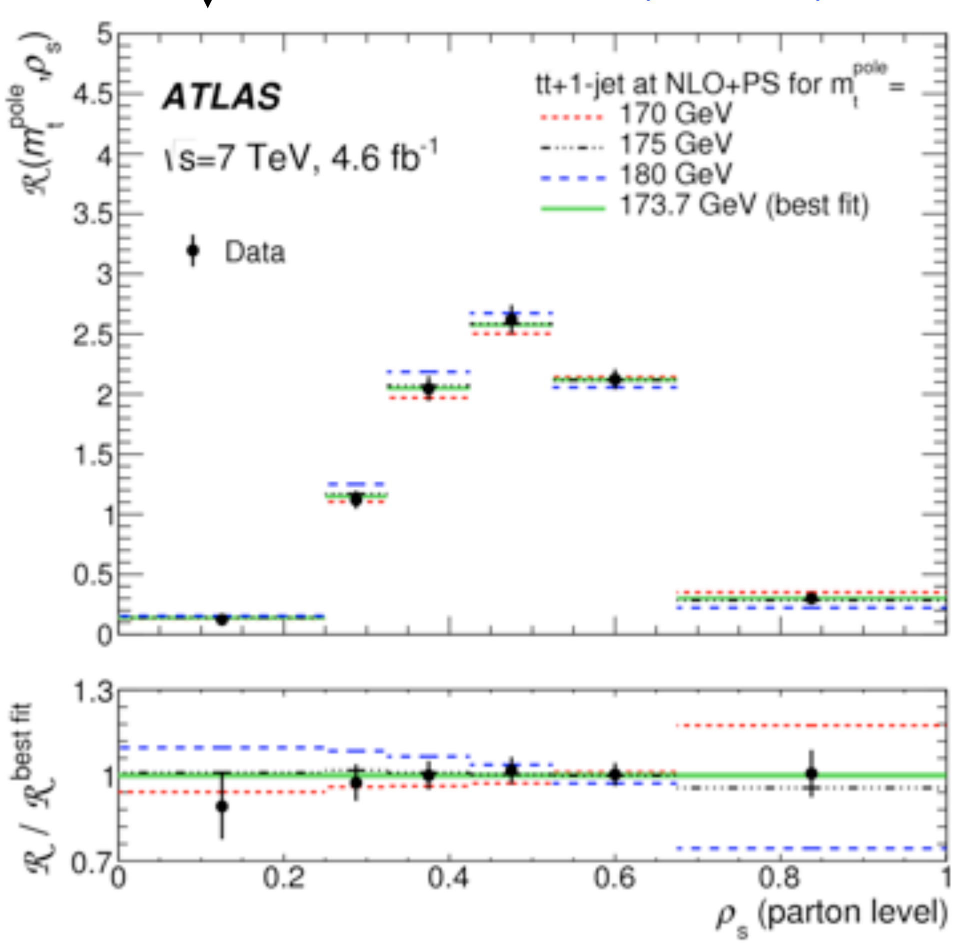
The amount of gluon radiation is sensitive to m_t

$$\mathcal{R}(m_t^{pole}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{jet}}} \frac{d\sigma_{t\bar{t}+1\text{jet}}}{d\rho_s}(m_t^{pole}, \rho_s)$$

$$\rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}j}}} \qquad m_0 = 170\ \text{GeV}$$ (Aritary of O(m_t))



↓ unfoldしてR(mt, ρ)に

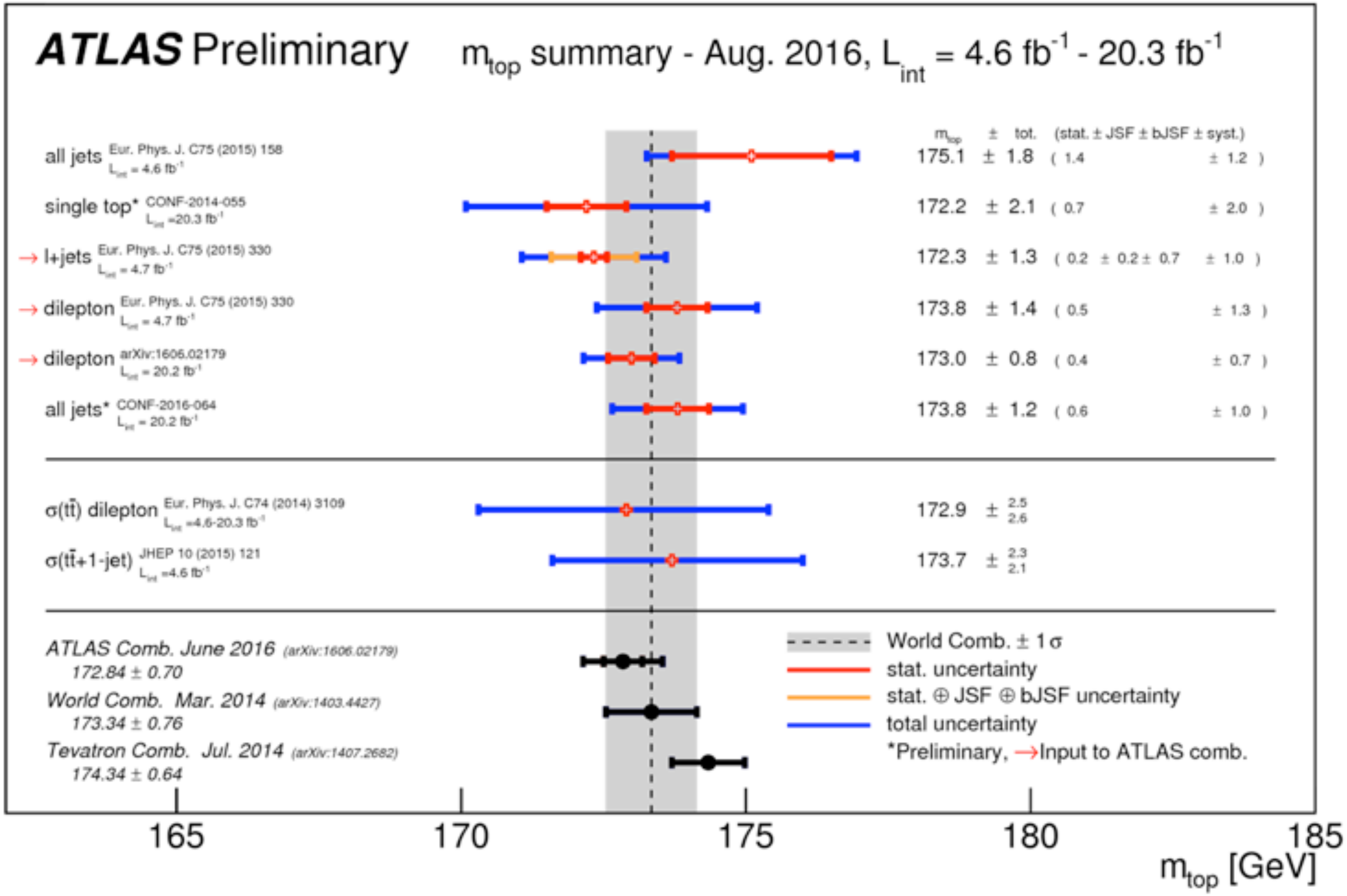


○ Analysis used single lepton final state

- Leptonic W from lepton, E_T^{miss}
- Hadronic W from kinematics reconstruction
- Combination of b-jet-W → minimize $m_t^{lep} - m_t^{had}$
- A jet from radiation satisfies pT>50GeV
- Unfold ρ_s distribution
- top mass determined by χ^2 fit

$$m_t^{pole} = 173.7 \pm 1.5(\text{stat.}) \pm 1.4(\text{syst.})\ ^{+1.0}_{-0.5}(\text{theo.})\ \text{GeV}$$

Top mass measurement summary



$$m_t = 172.82 \pm 0.70 \text{ GeV}$$ (ATLAS Comb.) 0.4%

arXiv:1606.02179

$$m_t = 173.34 \pm 0.76 \text{ GeV}$$ (World Comb.) 0.4%

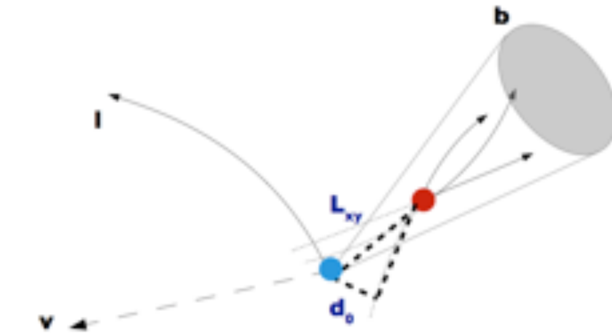
arXiv:1403.4427

$$m_t = 174.34 \pm 0.64 \text{ GeV}$$ (Tevatron Comb.) 0.4%

arXiv:1407.2662

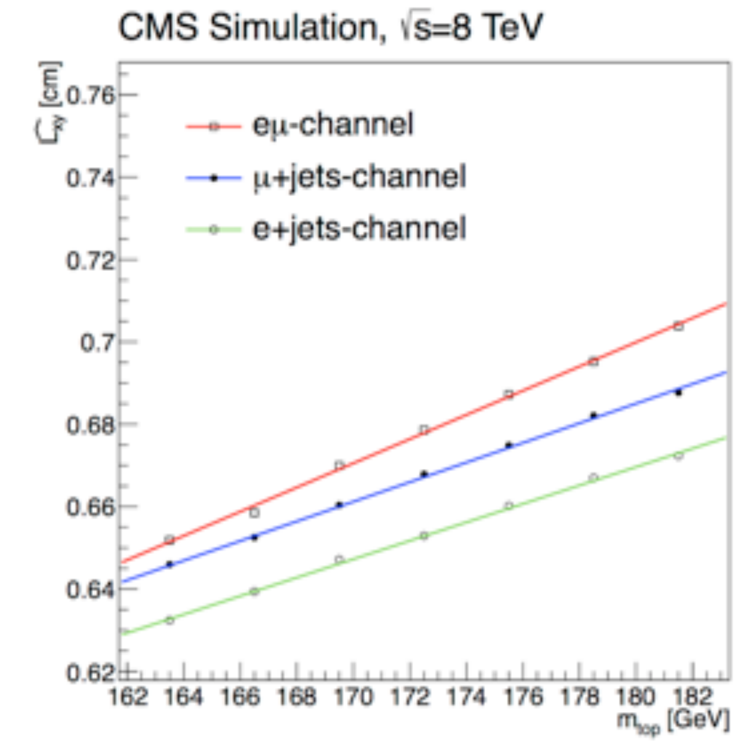
Top mass : Other methods

○ B-hadron Lifetime CMS-PAS-TOP-12-030

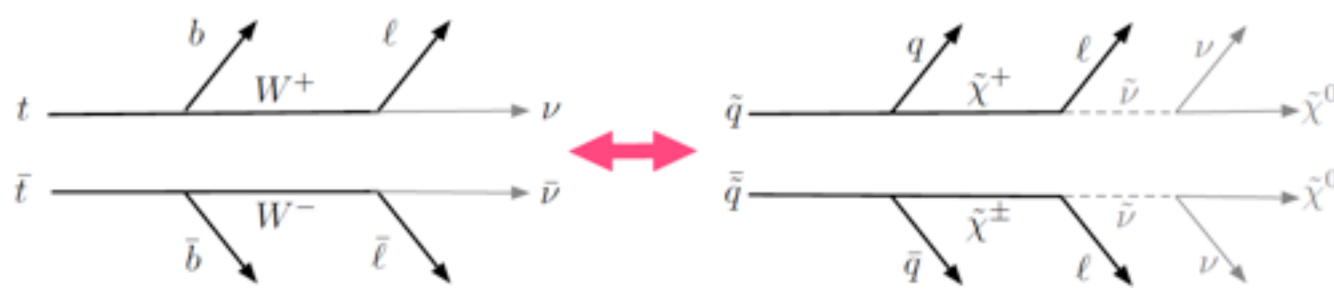


$$L_{xy} = \gamma_b \beta_B \tau_B \simeq 0.4 \cdot \frac{m_t}{m_B} \beta_B \tau_B \quad < L_{xy} > \sim 7 \text{ mm}$$

$$m_t = 173.5 \pm 1.5_{\text{stat}} \pm 1.3_{\text{syst}} \pm 2.6_{p_T(t)} \text{ GeV}$$



○ Kinematic Endpoint Eur.Phys.J.C(2013)73:2494

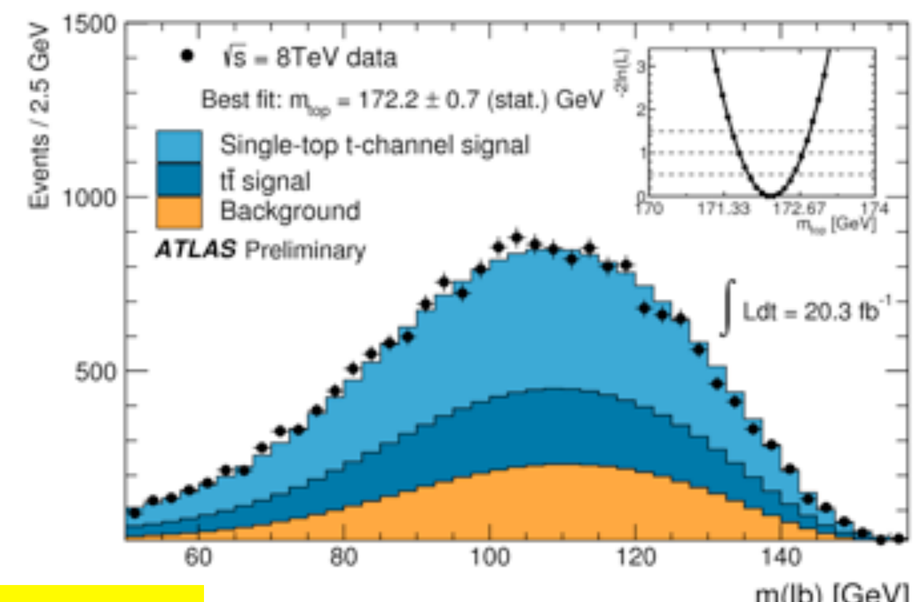


$$m_t = 173.9 \pm 0.9(\text{stat})^{+1.7}_{-2.1}(\text{syst}) \text{ GeV}$$

○ t-channel single top ATLAS-CONF-2014-055

Template fit of lepton-b-jet mass

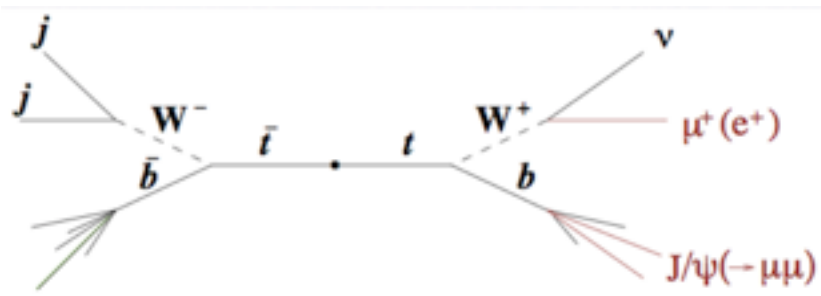
$$m_t = 172.2 \pm 0.7(\text{stat}) \pm 2.0(\text{syst}) \text{ GeV}$$



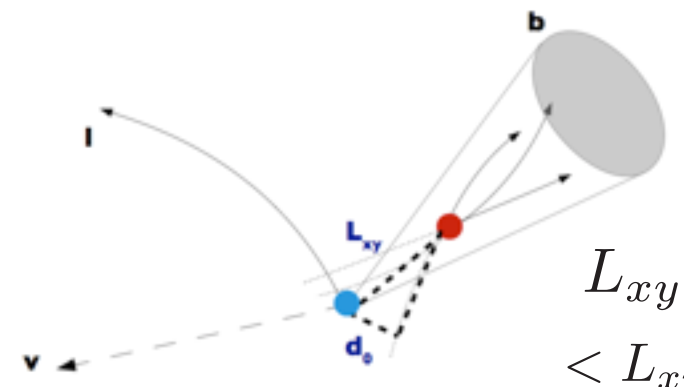
→ Standard methodと異なるSystematics

Top quark mass : prospects

- t→(W→ℓν)(b→J/ψ+X→μμ+X)



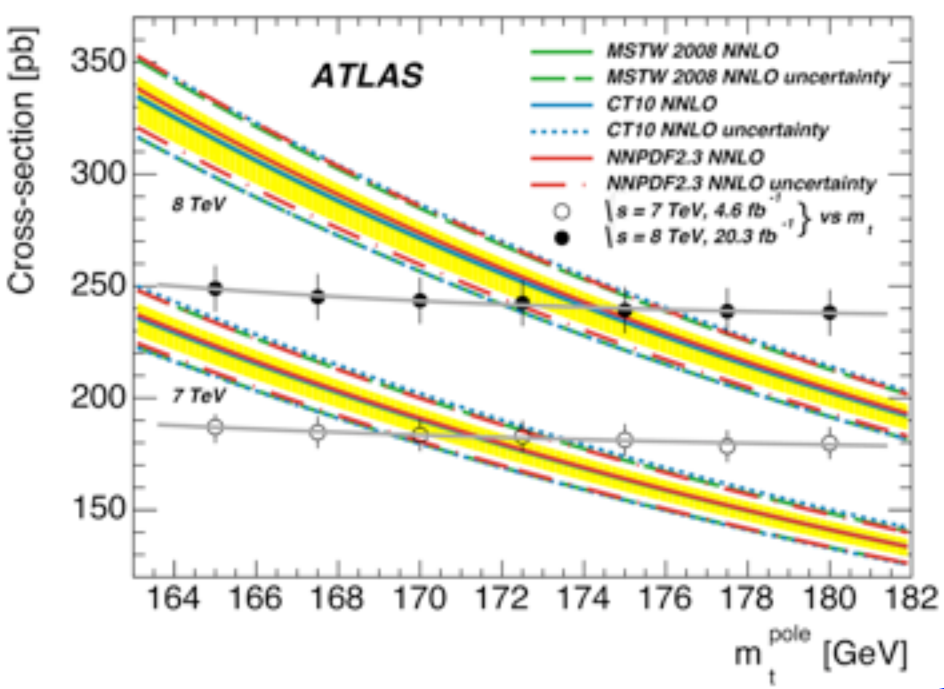
- Secondary vertex



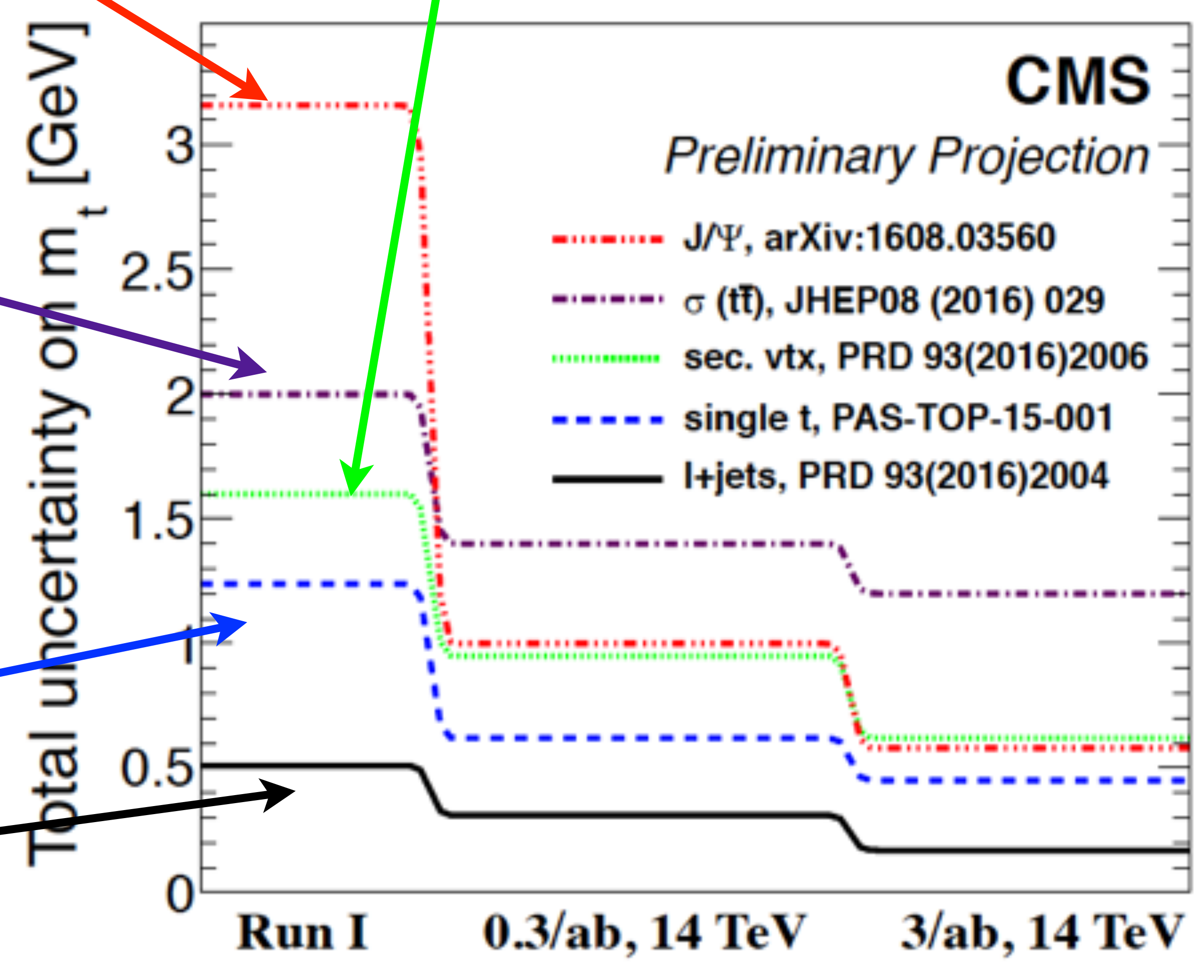
$$L_{xy} = \gamma_b \beta_B \tau_B \simeq 0.4 \cdot \frac{m_t}{m_B} \beta_B \tau_B$$

$$< L_{xy} > \sim 7 \text{ mm}$$

- cross-section v.s. m_t



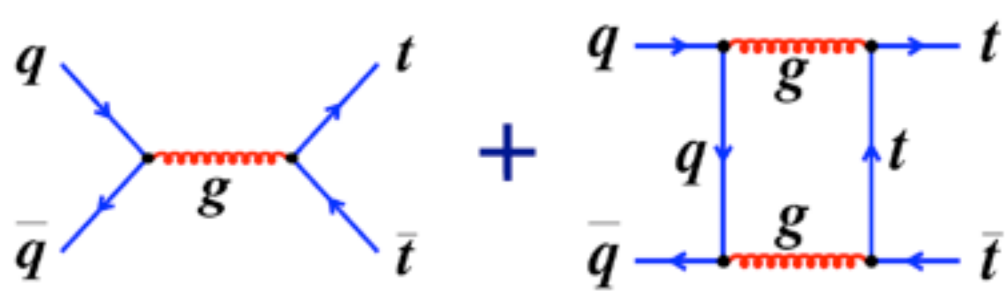
- Single top
- Classic method

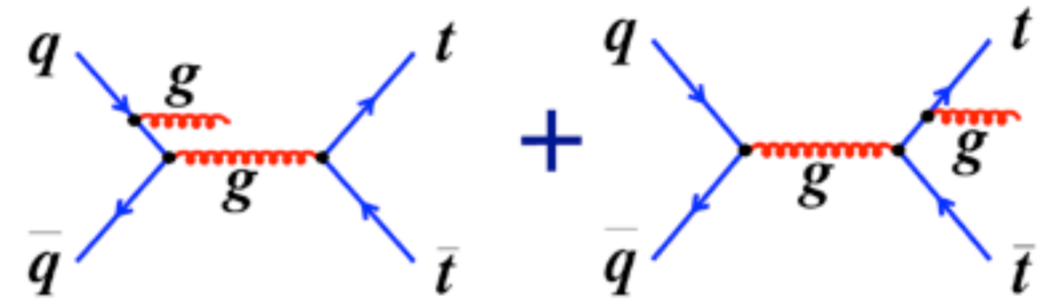


Charge asymmetry

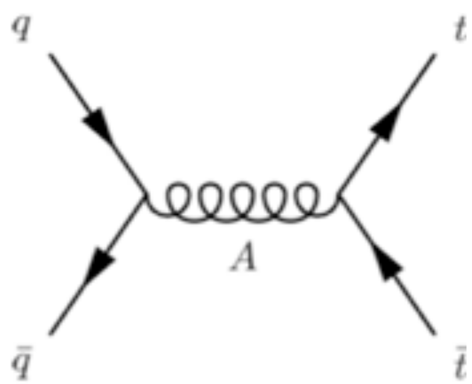
SMによるasymmetry

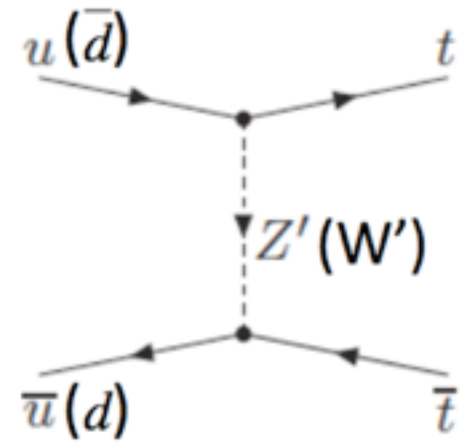
treeとboxのinterference　　　　ISRとFSRのinterference



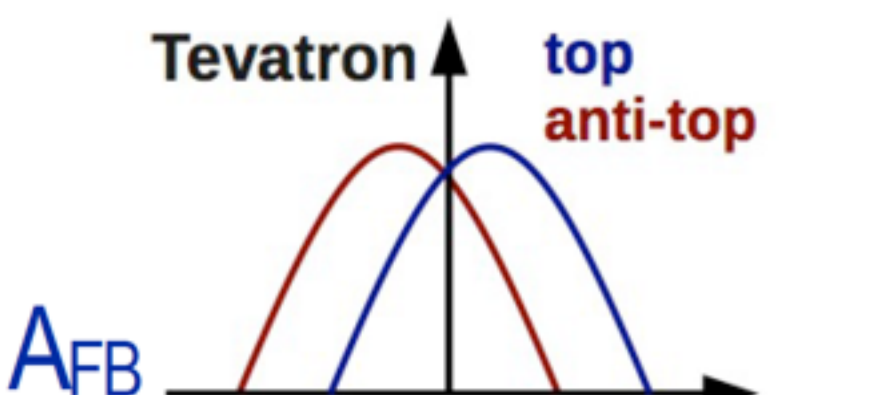


+新物理で標準模型からのズレ？



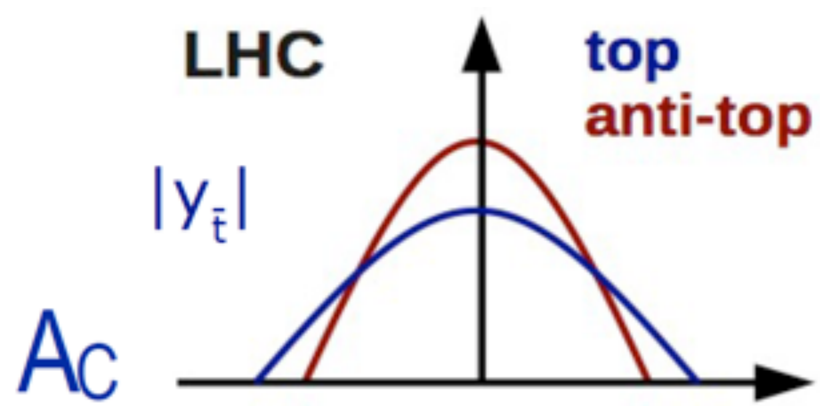


ppbarかppで見え方が異なる



$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

$$\Delta y_{t\bar{t}} = y_t - y_{\bar{t}}$$



$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

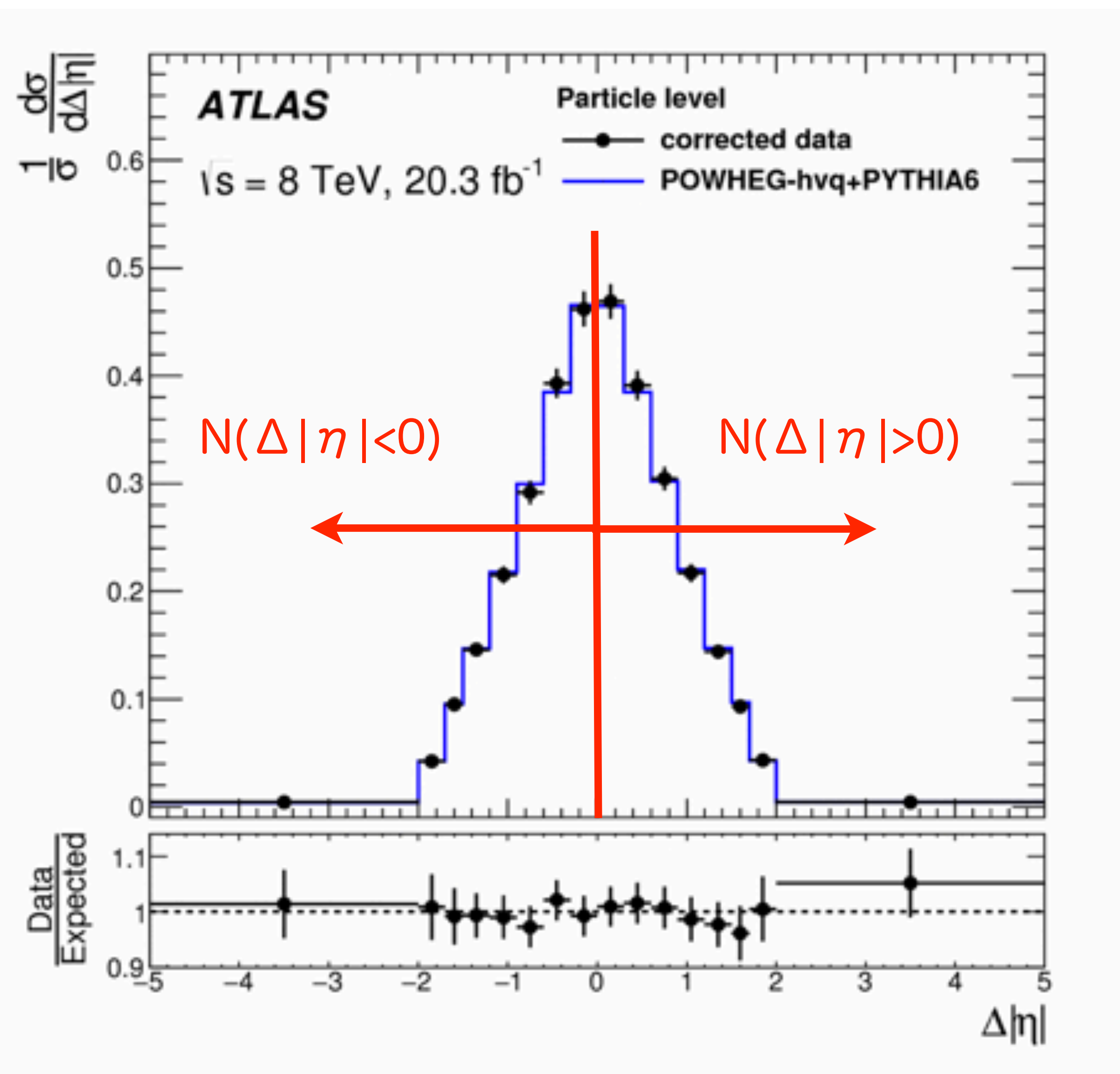
$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

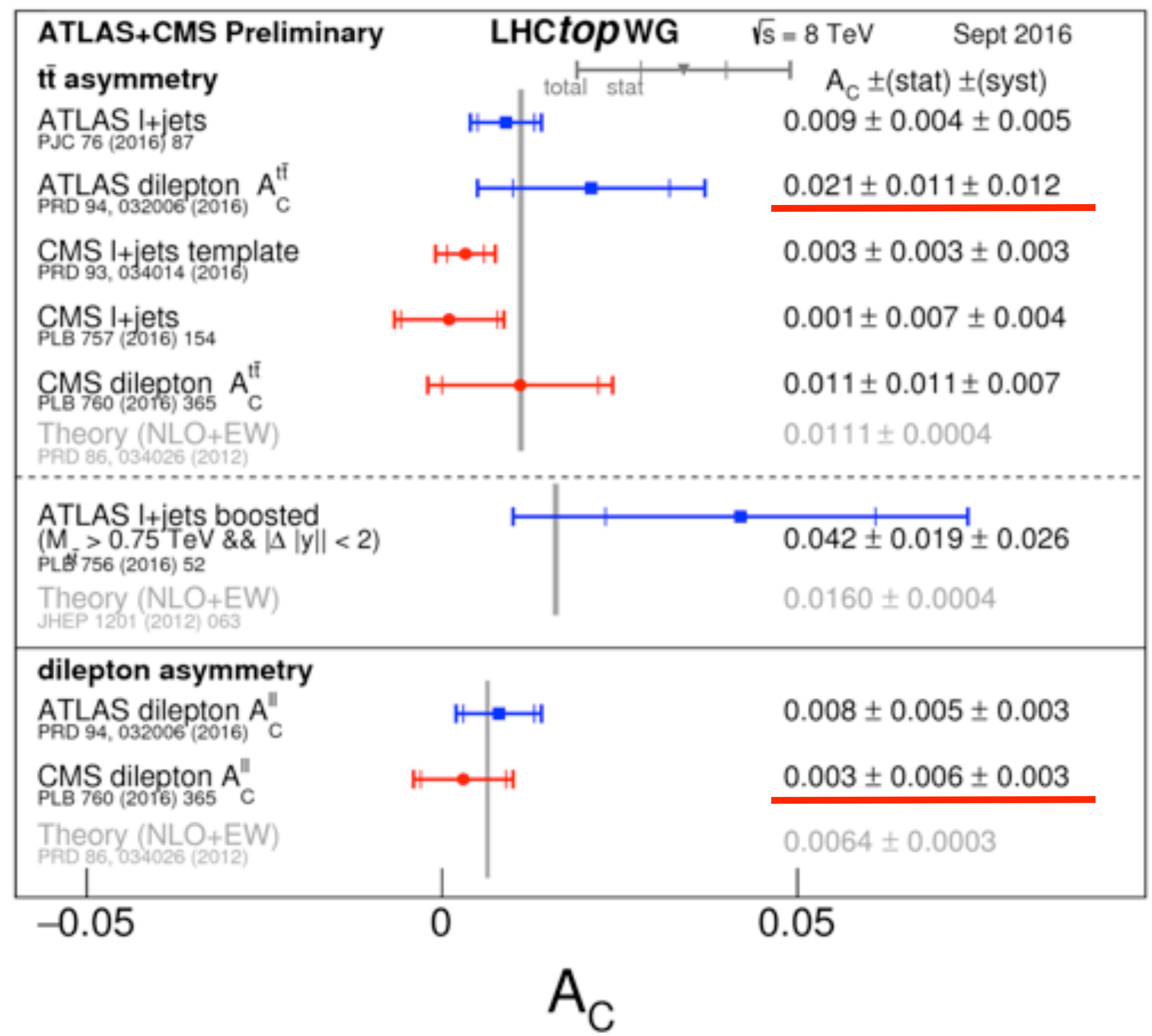
Charge Asymmetry

Phys. Rev. D 94, 032006

$$A_C^{t\bar{t}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)} \qquad \Delta|y| = |y_t| - |y_{\bar{t}}|$$

$$A_C^{\ell\ell} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| > 0) + N(\Delta|\eta| < 0)} \qquad \Delta|\eta| = |\eta_{\ell^+}| - |\eta_{\ell^-}|$$





Spin correlation

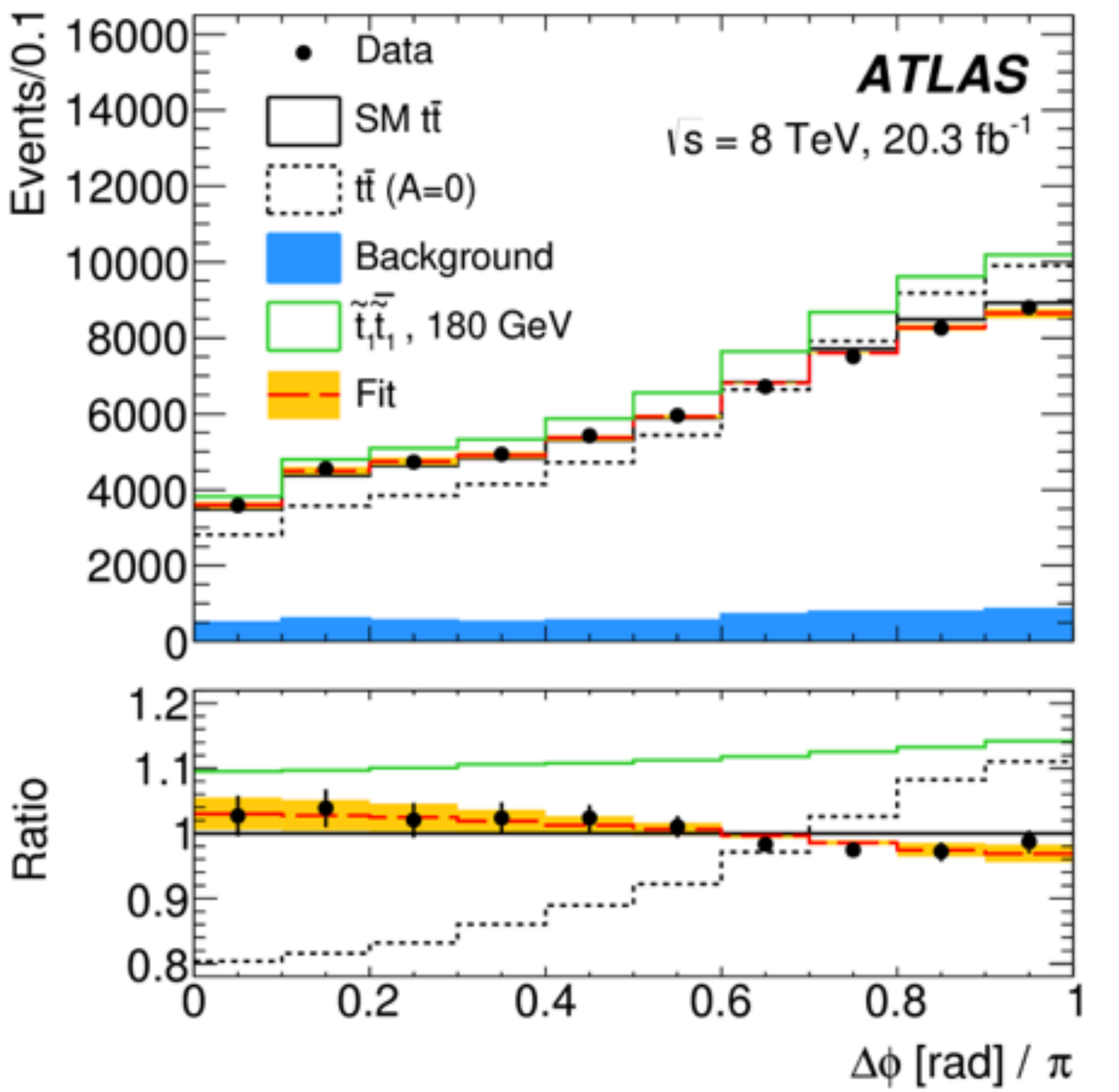
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}(1 + \alpha_1 P_1 \cos\theta_1 + \alpha_2 P_2 \cos\theta_2 - C\cos\theta_1\cos\theta_2)$$

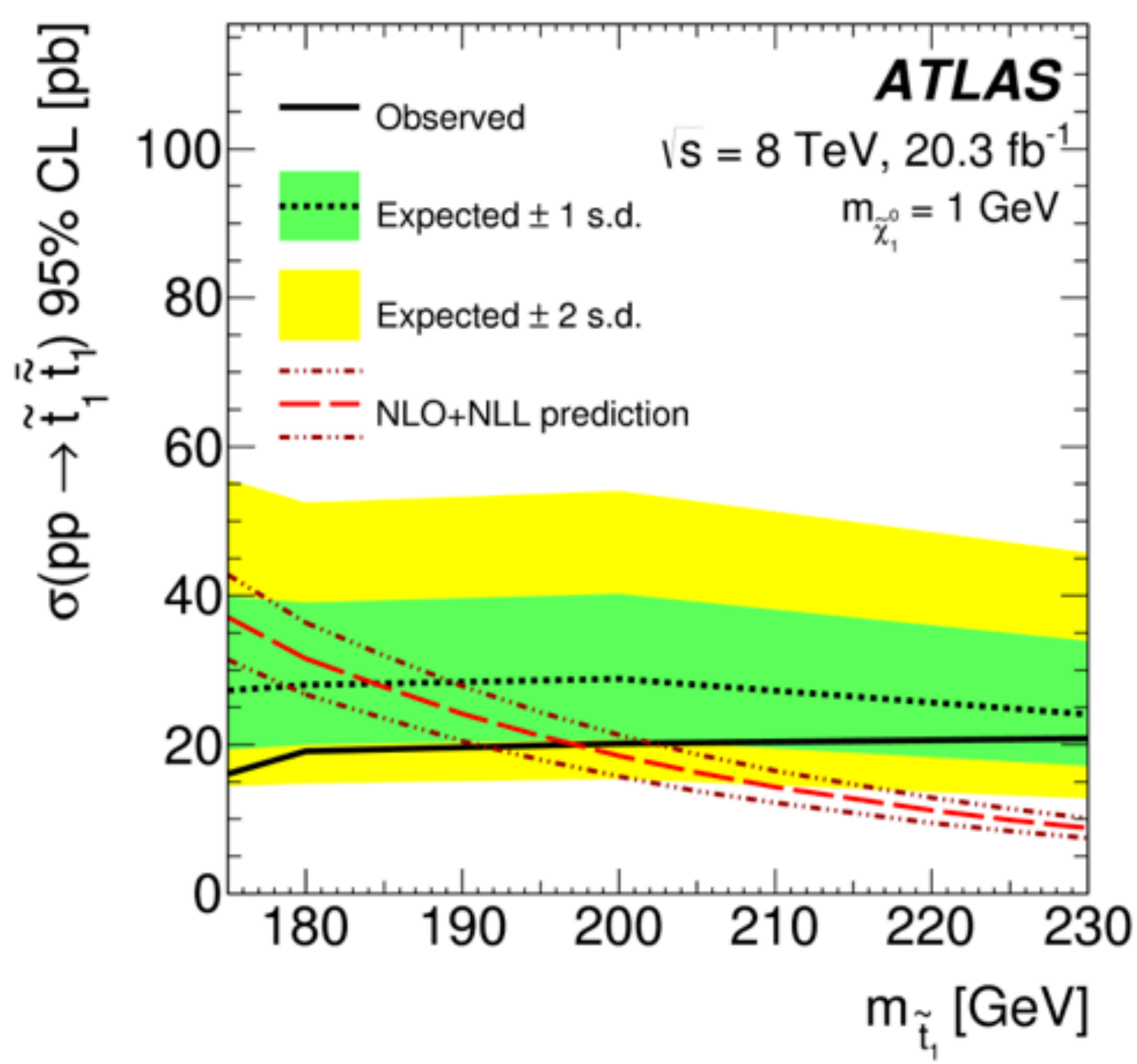
SM : unpolarized → $\alpha P\cos\theta$ are negligible

Spins of t and tbar are correlated → can be measured by $\Delta\phi_{ll}$

$$f_{SM} \times \mathrm{MC}_{t\bar{t}}^{SM} + (1. - f_{SM}) \times \mathrm{MC}_{t\bar{t}}^{\mathrm{uncorr}}$$

$$pp \to \tilde{t}_1\bar{\tilde{t}}_1 \to t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0 \quad (m_{\tilde{t}_1} > m_t + m_{\tilde{\chi}_1^0})$$





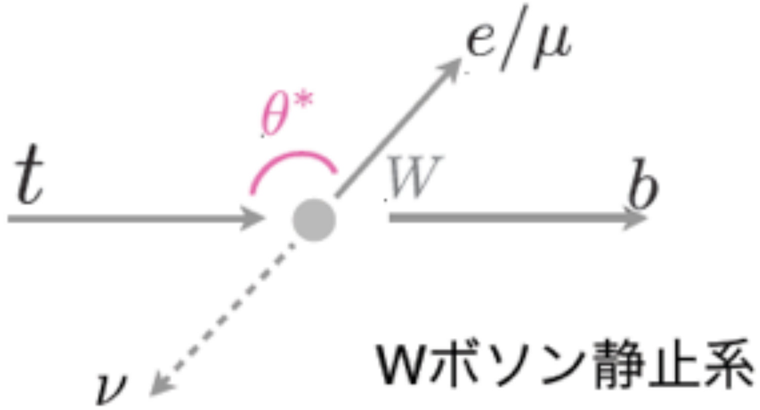
$$f_{SM} = 1.20 \pm 0.05(\mathrm{stat.}) \pm 0.13(\mathrm{syst.})$$

$$m_t < m_{\tilde{t}} < 191\mathrm{GeV}$$

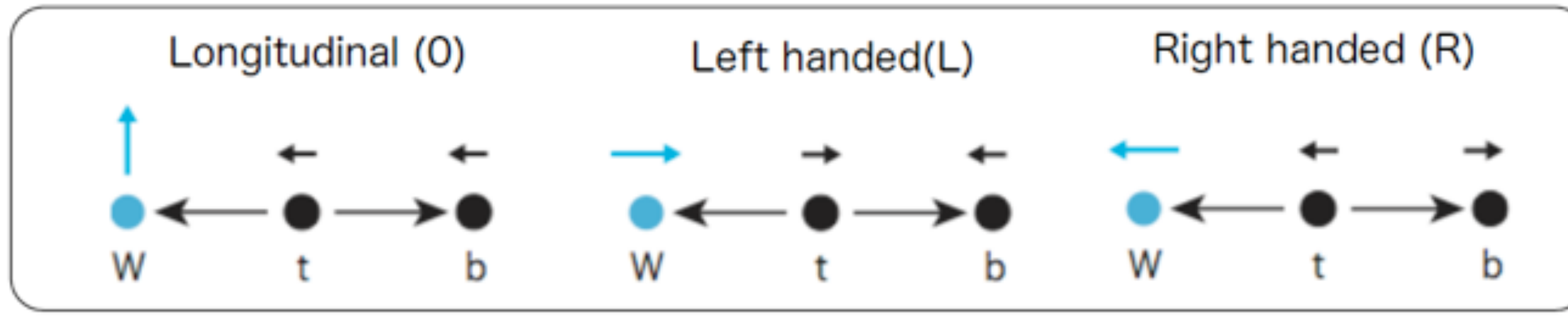
W helicity in top quark decay

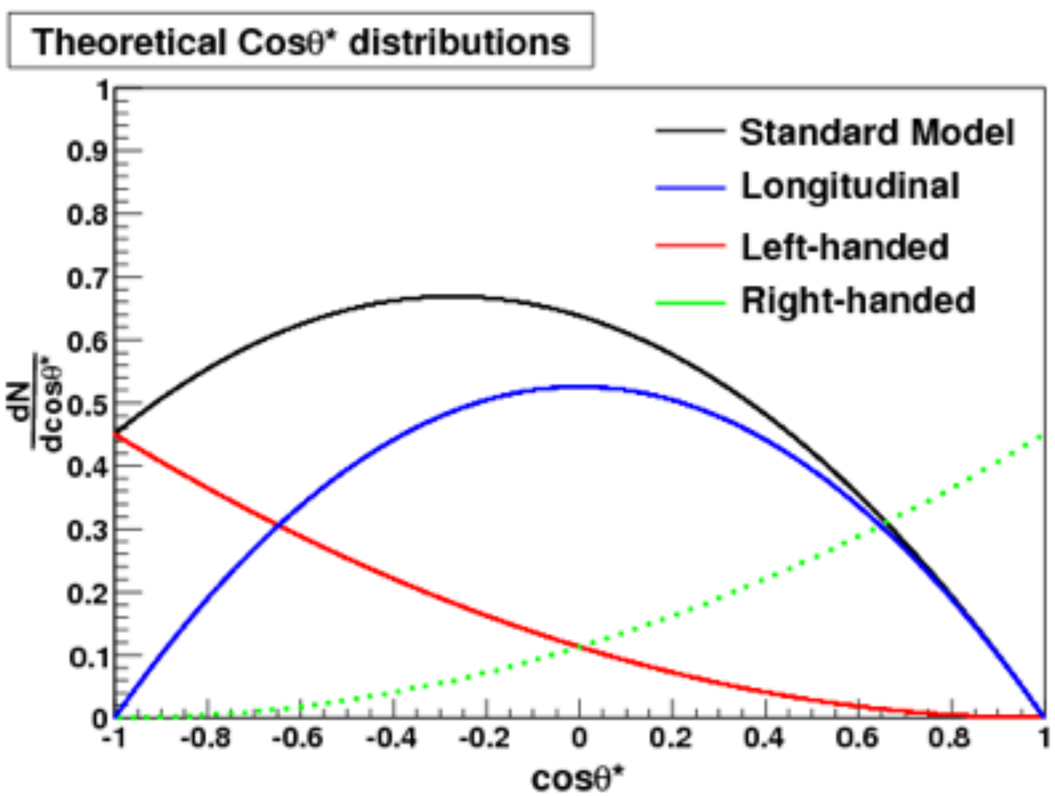
arXiv:1612.02577

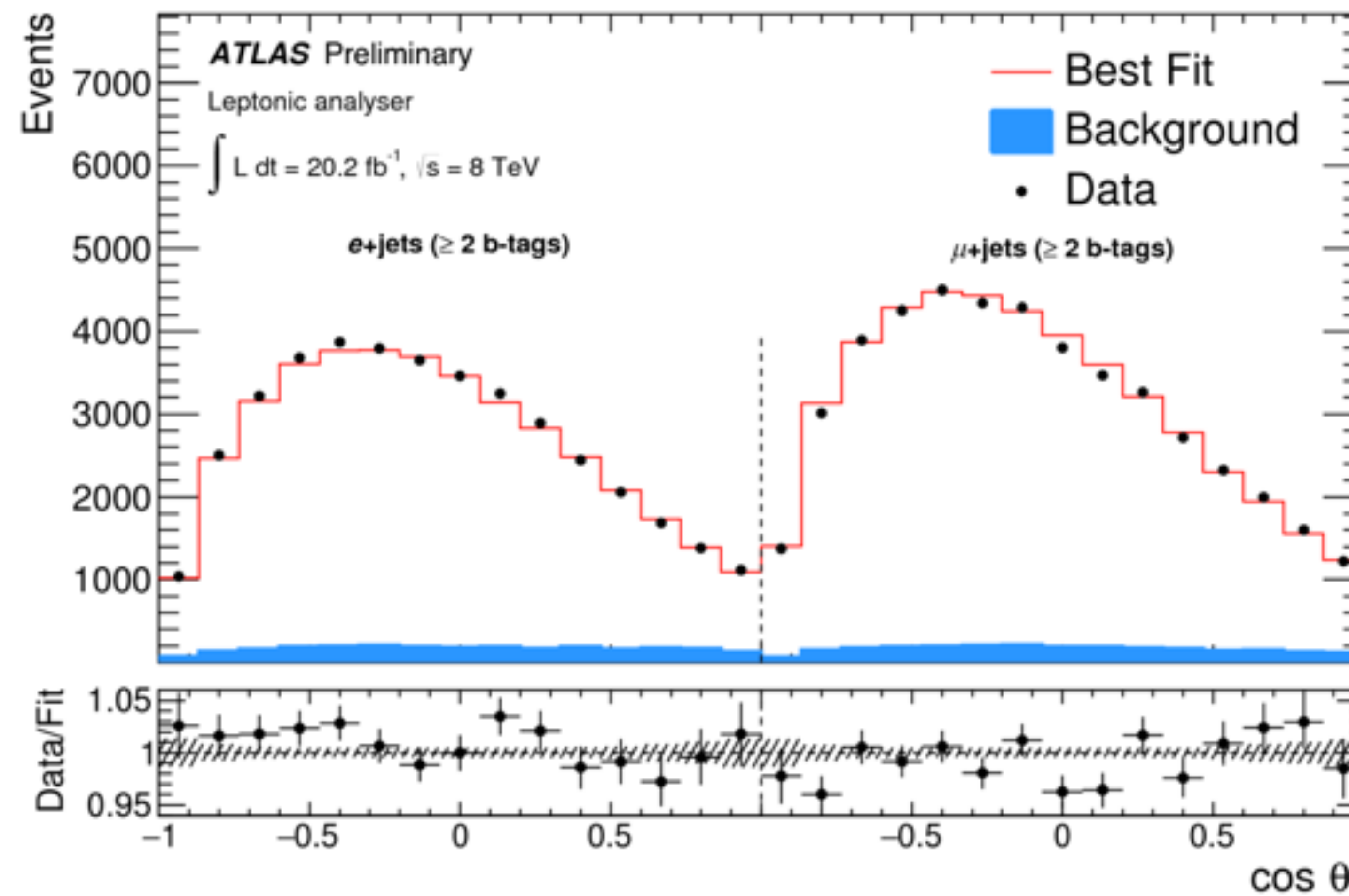
$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} = \frac{3}{4}\sin^2\theta^* F_0 + \frac{3}{8}(1-\cos\theta^*)F_L + \frac{3}{8}(1+\cos\theta^*)F_R$$



SM： F_0~0.7, F_L~0.3, F_R~0







$$F_0 = 0.709 \pm 0.019 \quad F_L = 0.299 \pm 0.015 \quad F_R = -0.008 \pm 0.014$$

Wtb anomalous couplings

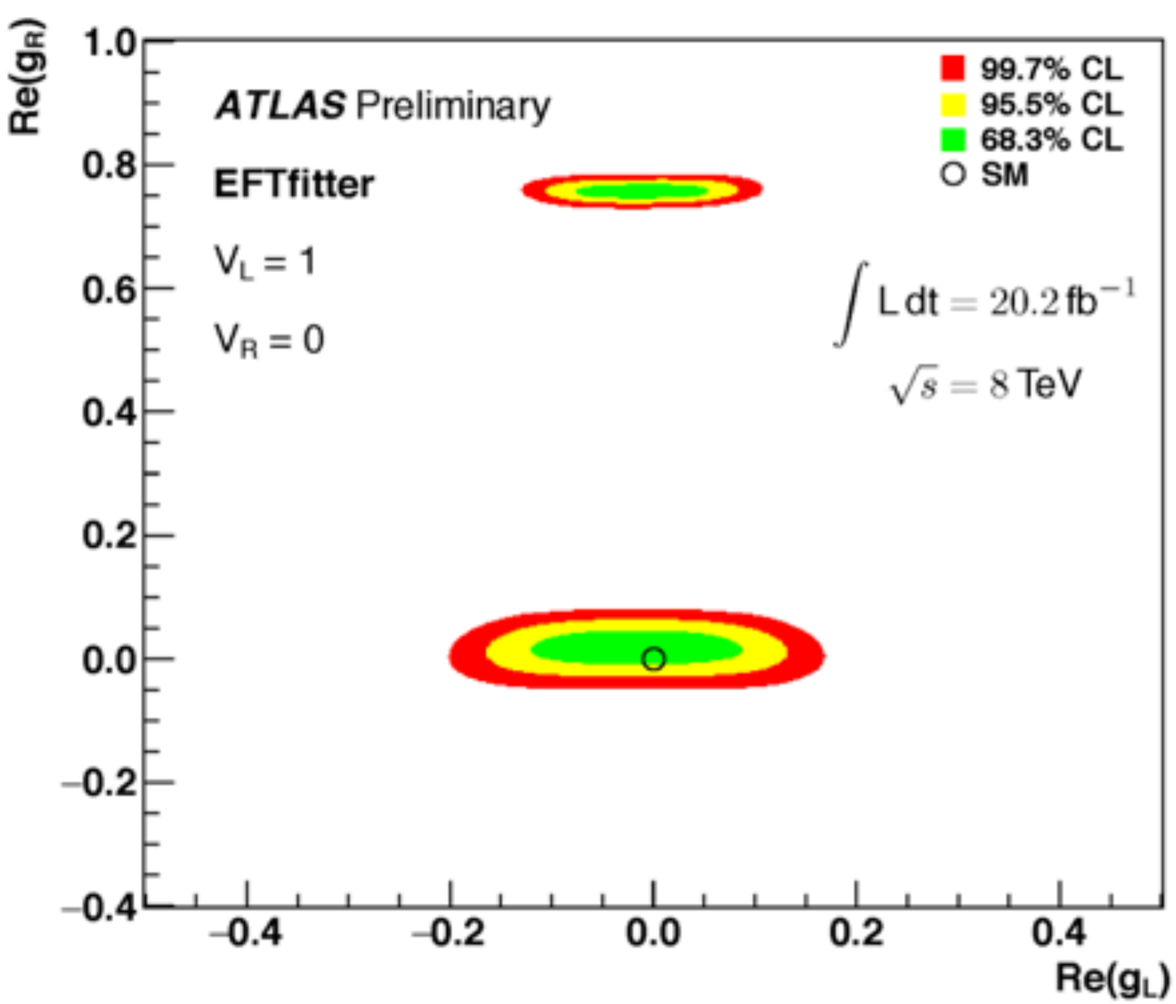
arXiv:1612.02577

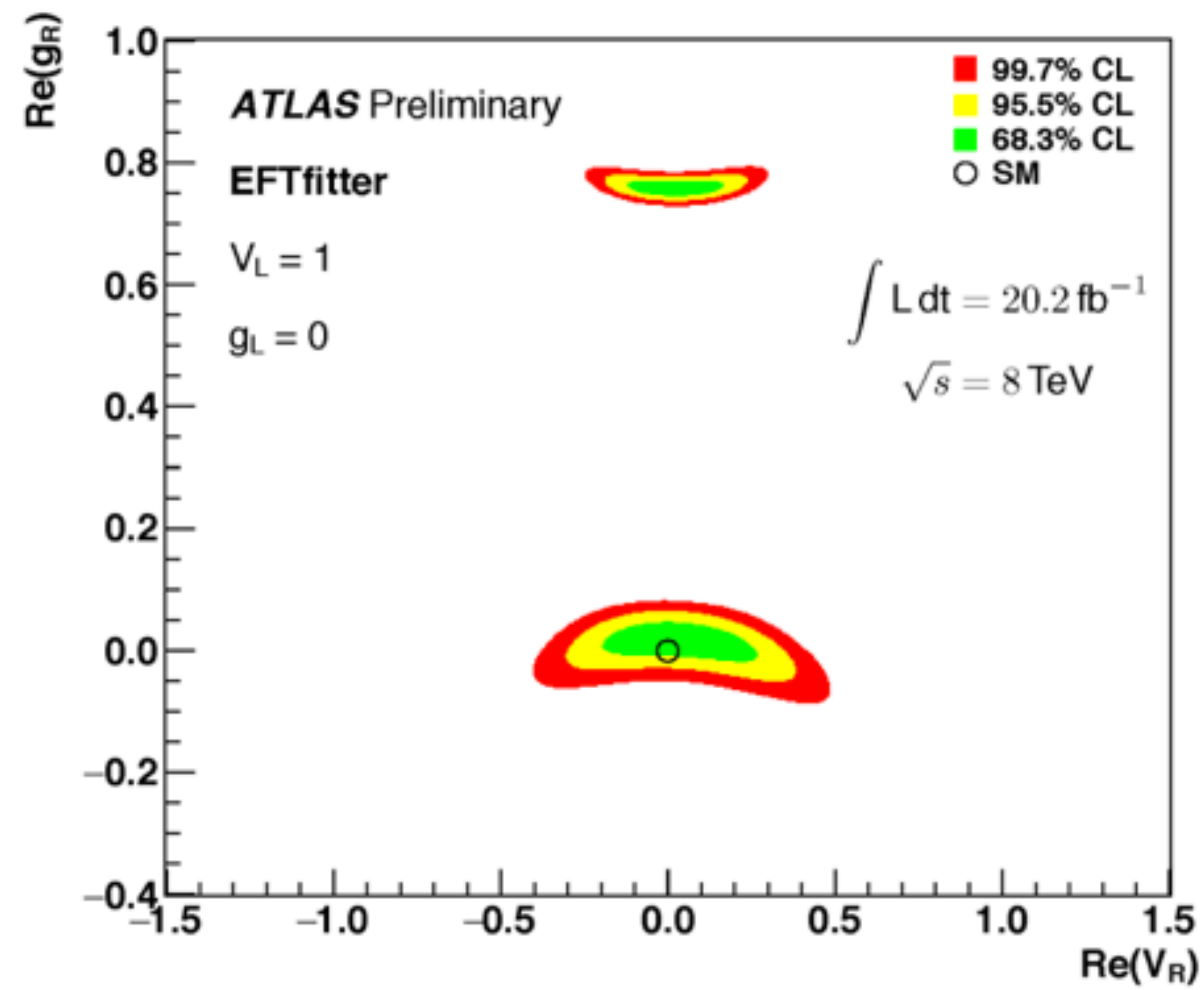
- Constraint on Wtb anomalous couplings from measurements of F_0, F_L, and F_R.

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_L P_L + V_R P_R\right) t W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}\left(g_L P_L + g_R P_R\right) t W_{\mu}^{-} + \text{h.c.}$$

SM : $V_L=1$, $V_R=g_L=g_R=0$

Coupling	95 % CL interval
V_R	$[-0.24, 0.31]$
g_L	$[-0.14, 0.11]$
g_R	$[-0.02, 0.06]$, $[0.74, 0.78]$

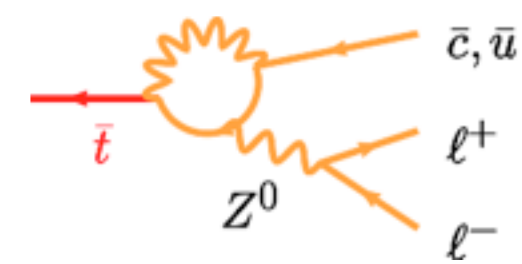




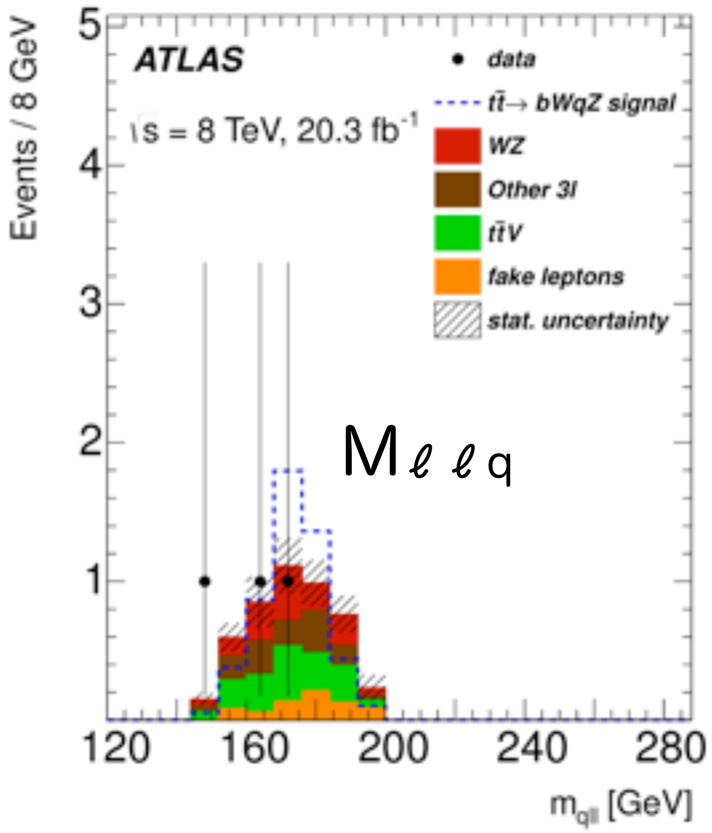
FCNC

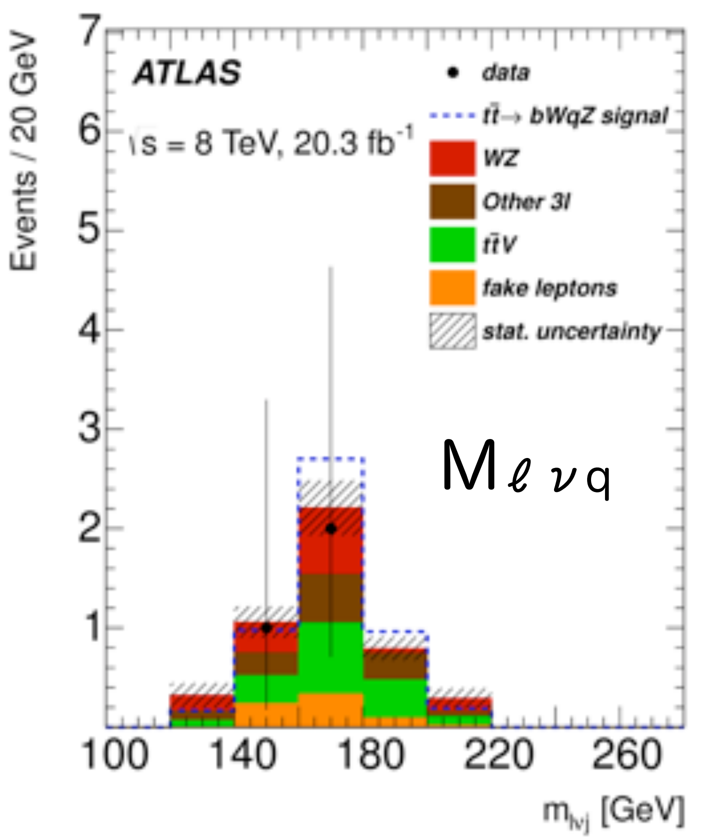
Eur. Phys. J. C (2016) 76:12

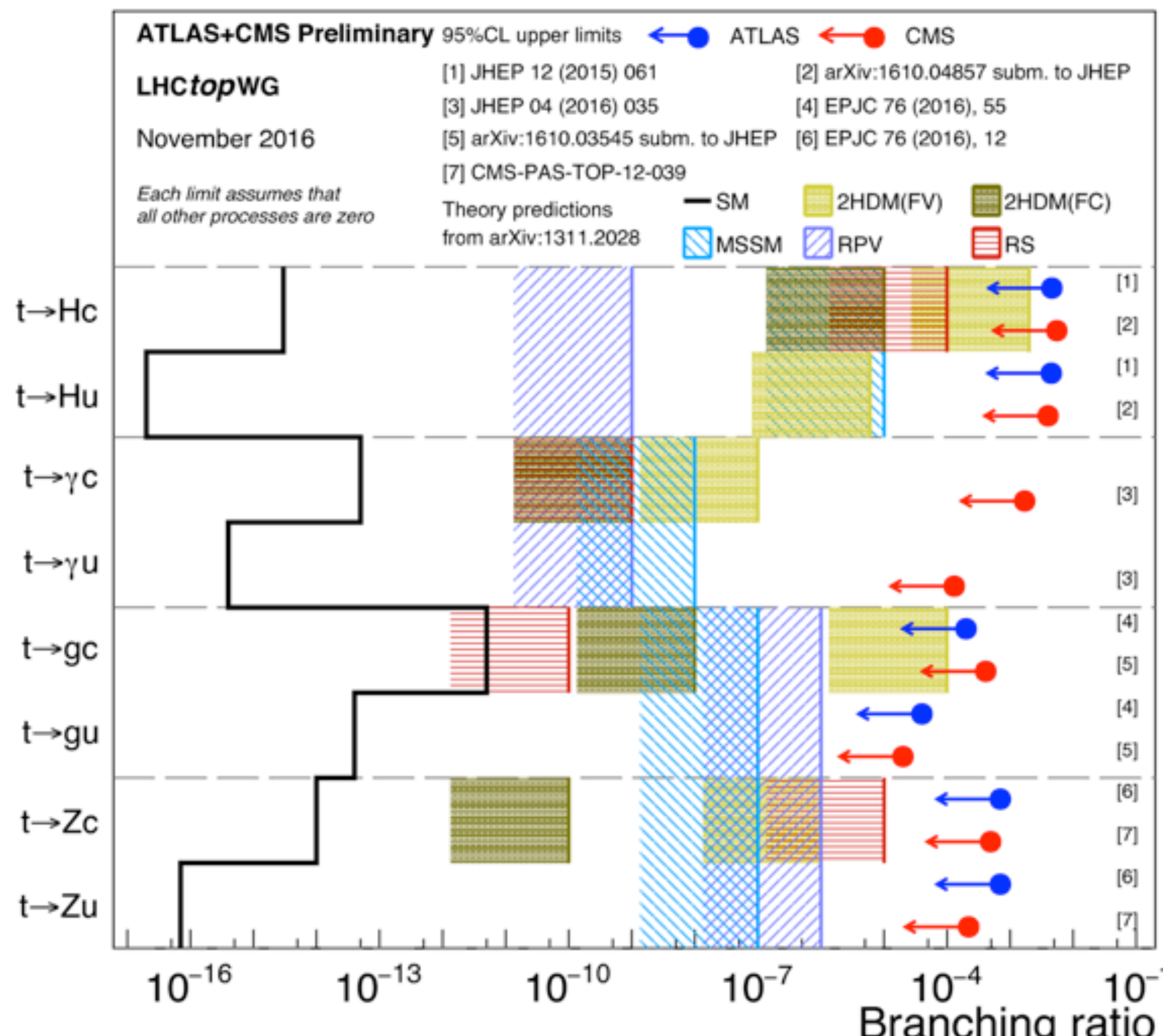
tt→ZqWb→ℓ ℓ q ℓ ν b (3 leptons, ≧2jets(≧1 b-jet), MET)



$$\mathrm{BR}(t \to Zq) < 7 \times 10^{-4}$$ @95%C.L.

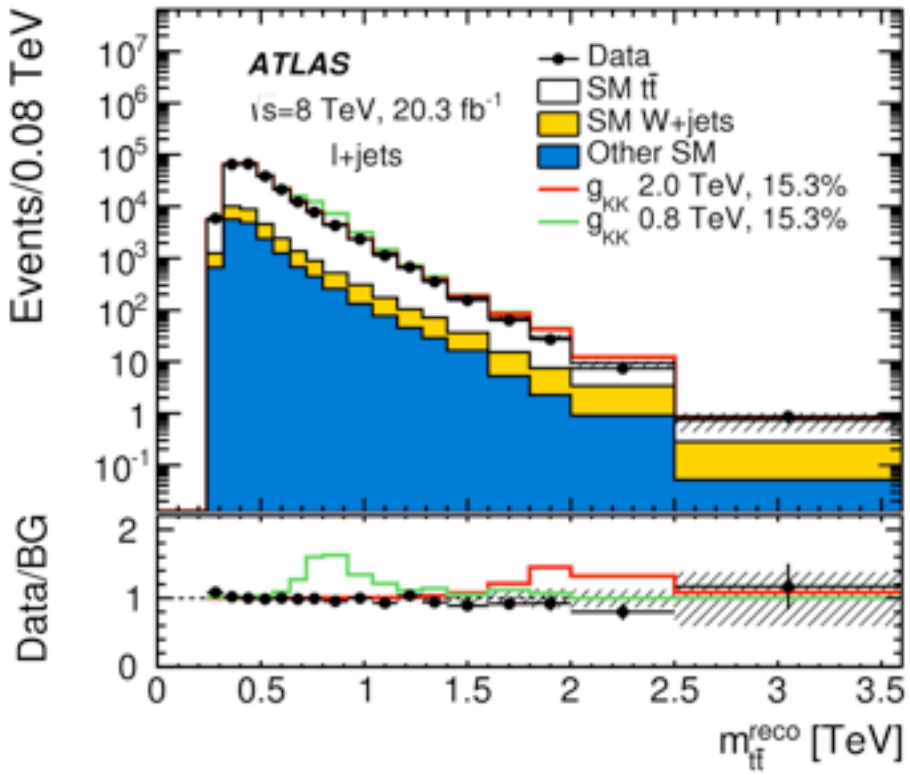


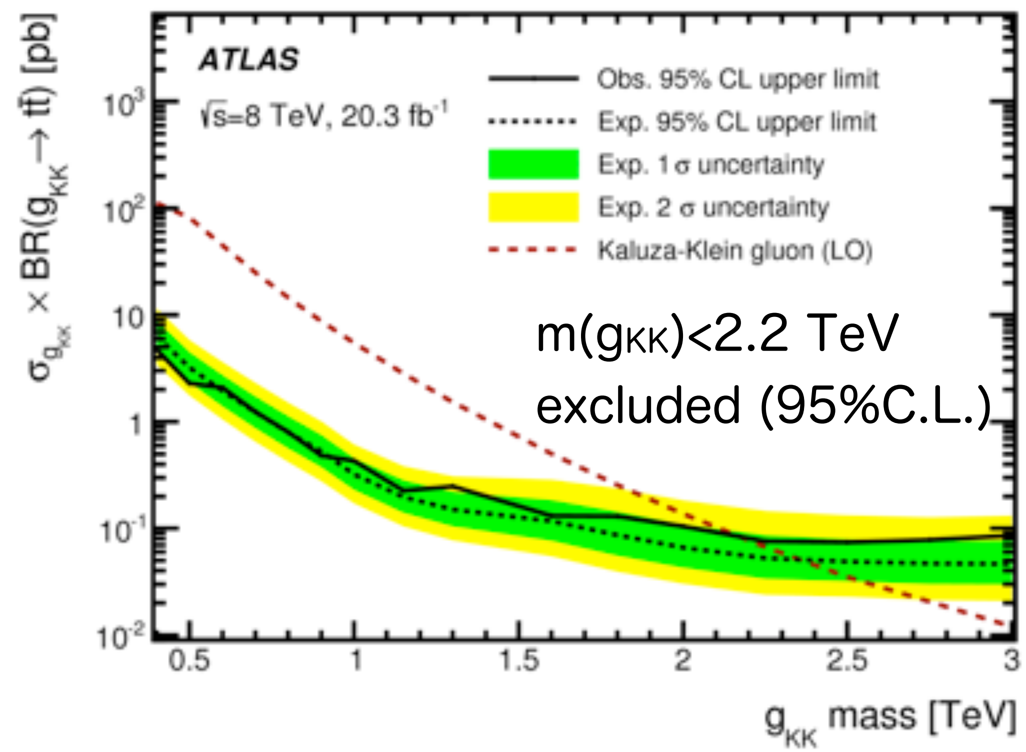




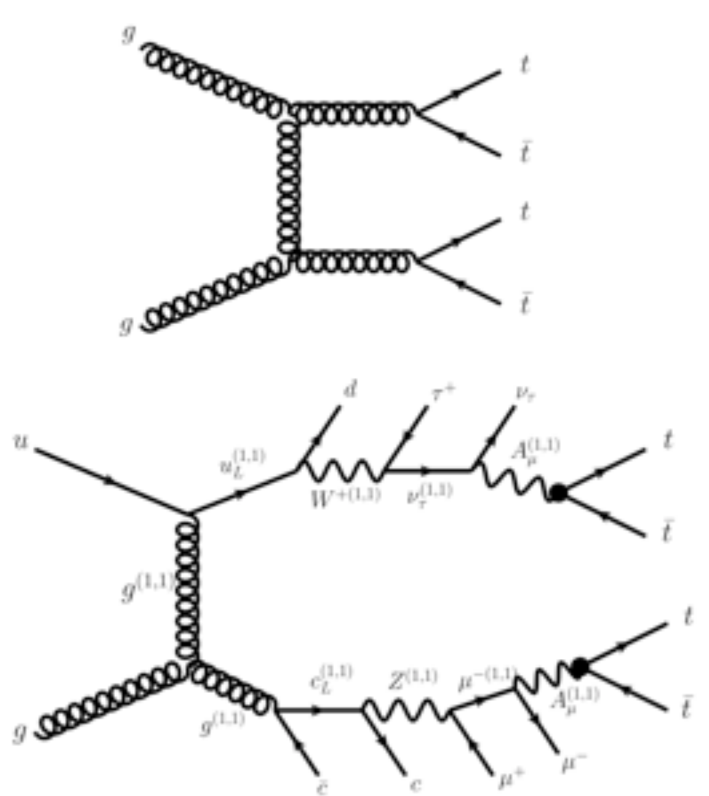
New physics searches with top quark

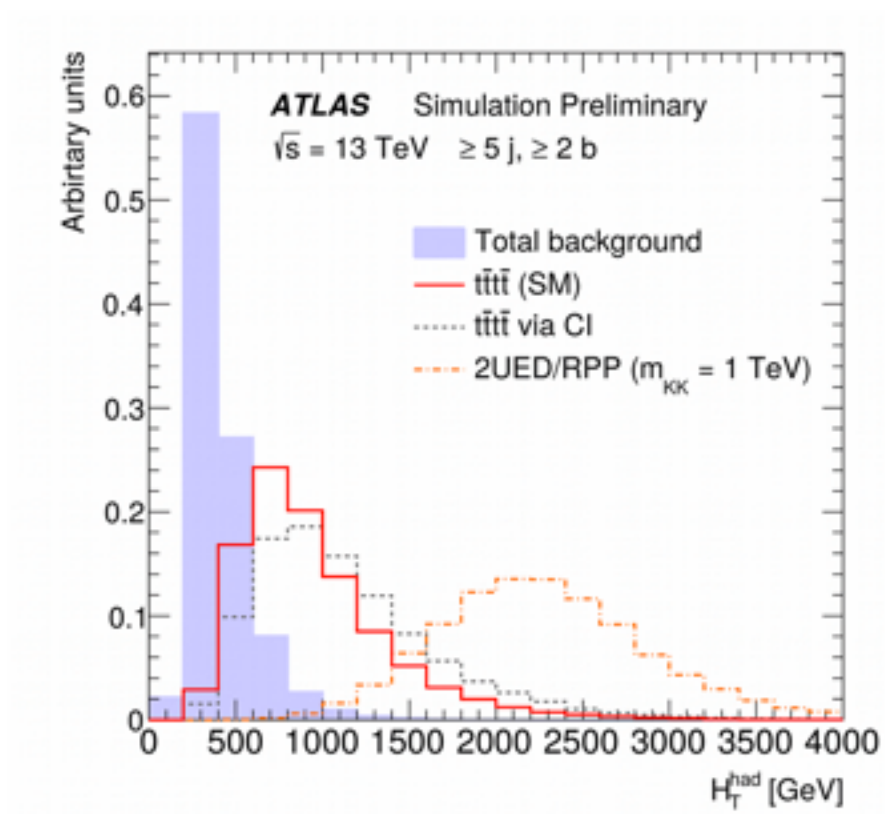
- Resonance search (Z', gKK, GKK, etc.)

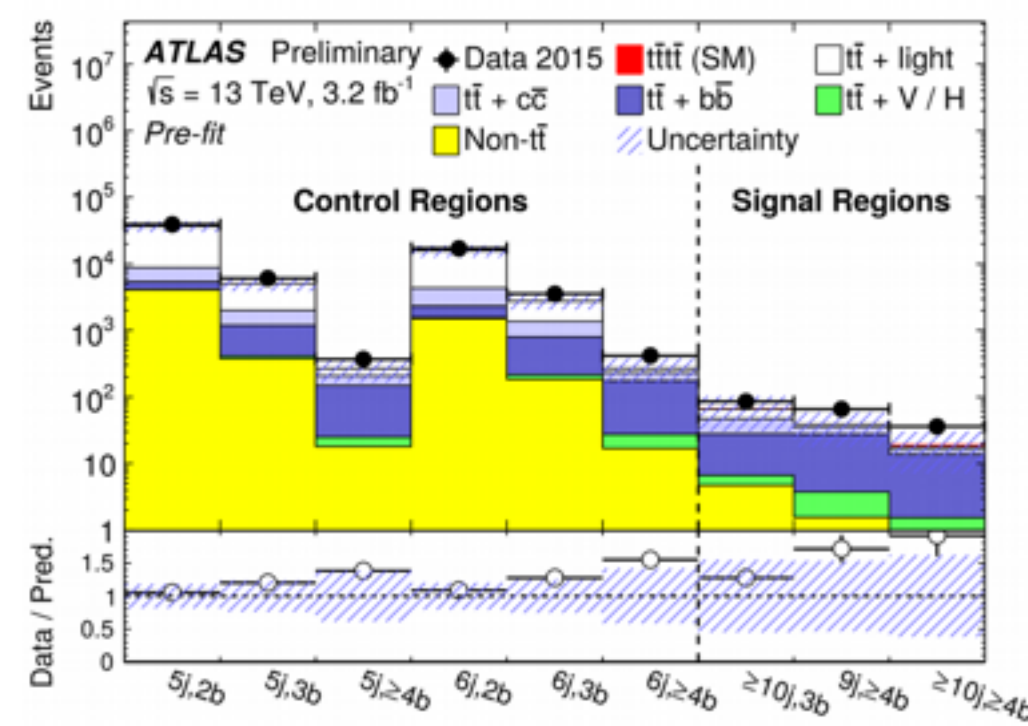




- four top quarks : small in SM, enhanced in BSM (CI, UED, etc)



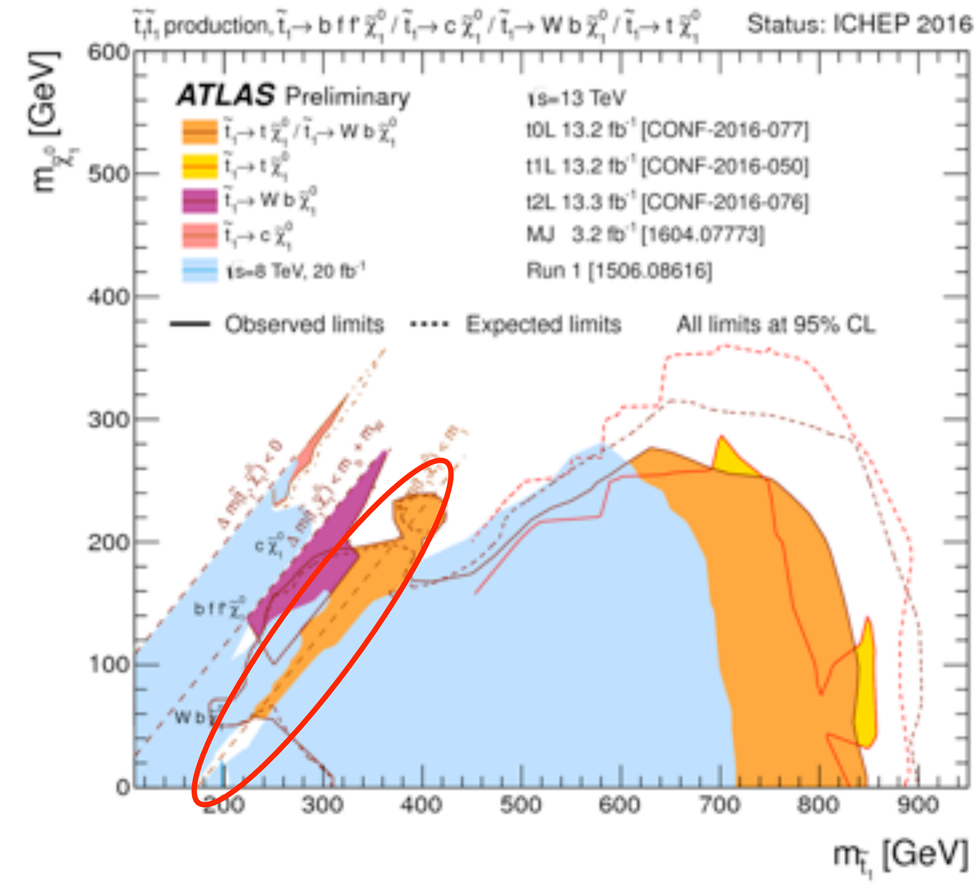


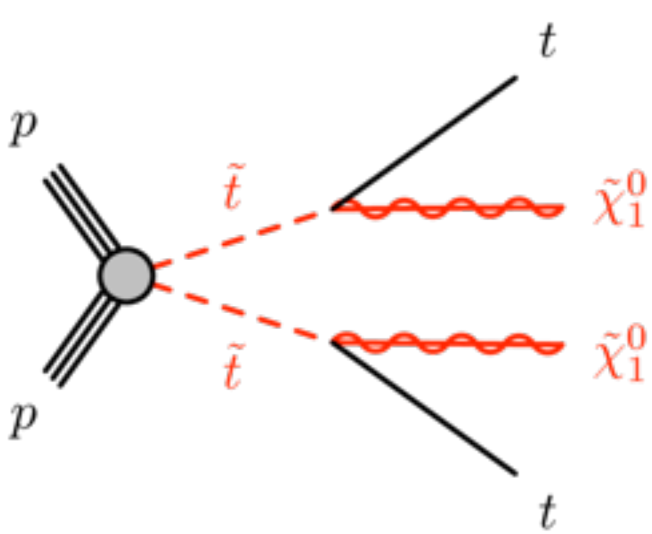


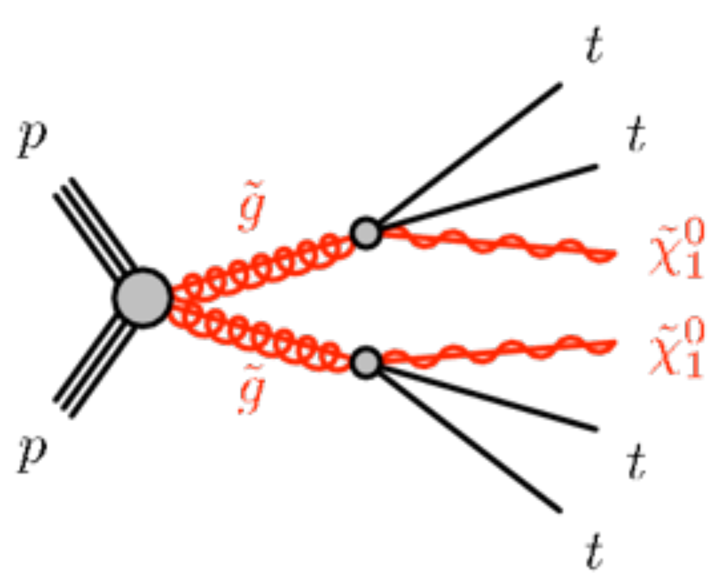
σ<21×σ(SM) at 95%C.L.

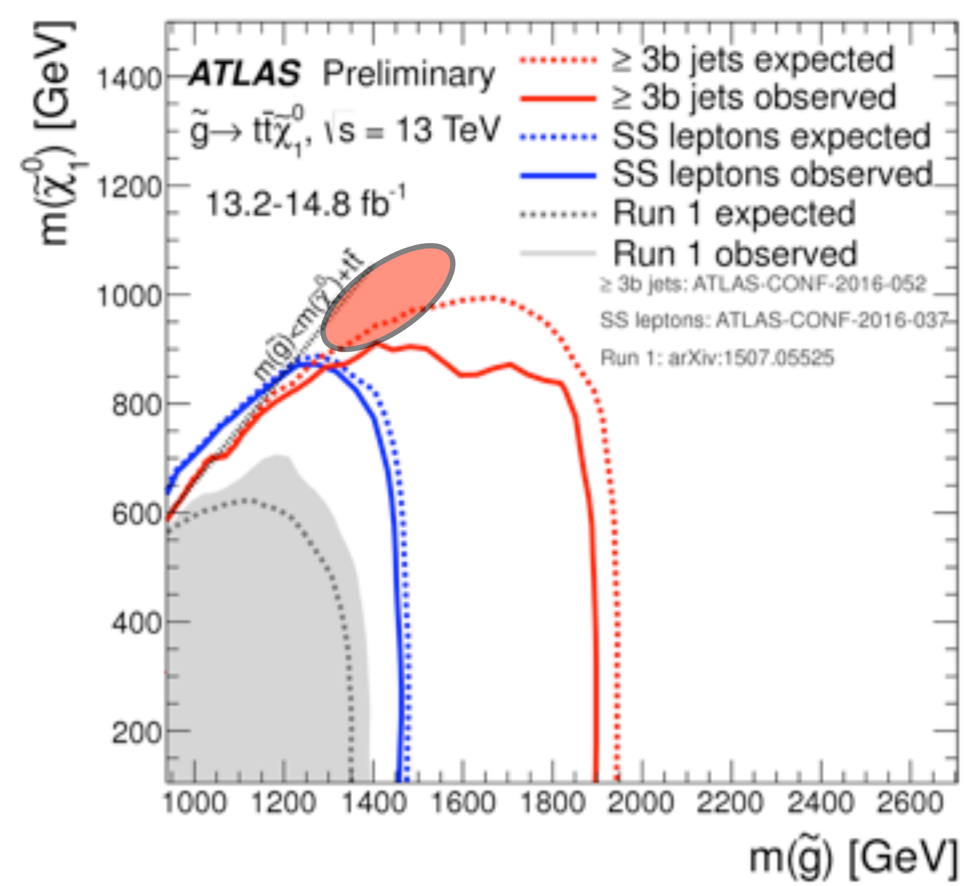
Top quark as a probe of SUSY

- In case $M_{\tilde{t}} - M_{\tilde{\chi}_1^0} \sim M_t$, stop pair production is only detectable with the precision measurement in top quark pair production cross section.
  - ttbar spin analysis correlations constrained $M_{\tilde{t}} < 190\ \mathrm{GeV}$
  - The analysis with boosted ttbar+ISR jet production constrained $230\ \mathrm{GeV} < M_{\tilde{t}} < 380\ \mathrm{GeV}$
- Same strategy can be made for gluino to ttbar decay, in case $M_{\tilde{g}} - M_{\tilde{\chi}_1^0} \sim 2M_t$
  - precision measurement in $t\bar{t}t\bar{t}$ signature









Summary

- LHC is the top quark factory experiment
  - ~10 top quark pairs are produced every second in Run 2 LHC
- We are approaching not only precision measurement of SM but also the new particle physics phenomenology using top quark as a probe.
  - Test of pQCD at high Q^2 from top quark production
  - Test of electroweak from top quark decay
  - Measurements of Higgs-top Yukawa coupling Y_t
  - Direct searches of BSM (e.g. stop, g_{KK}, etc.)
  - Rare decay and anomalous coupling searches

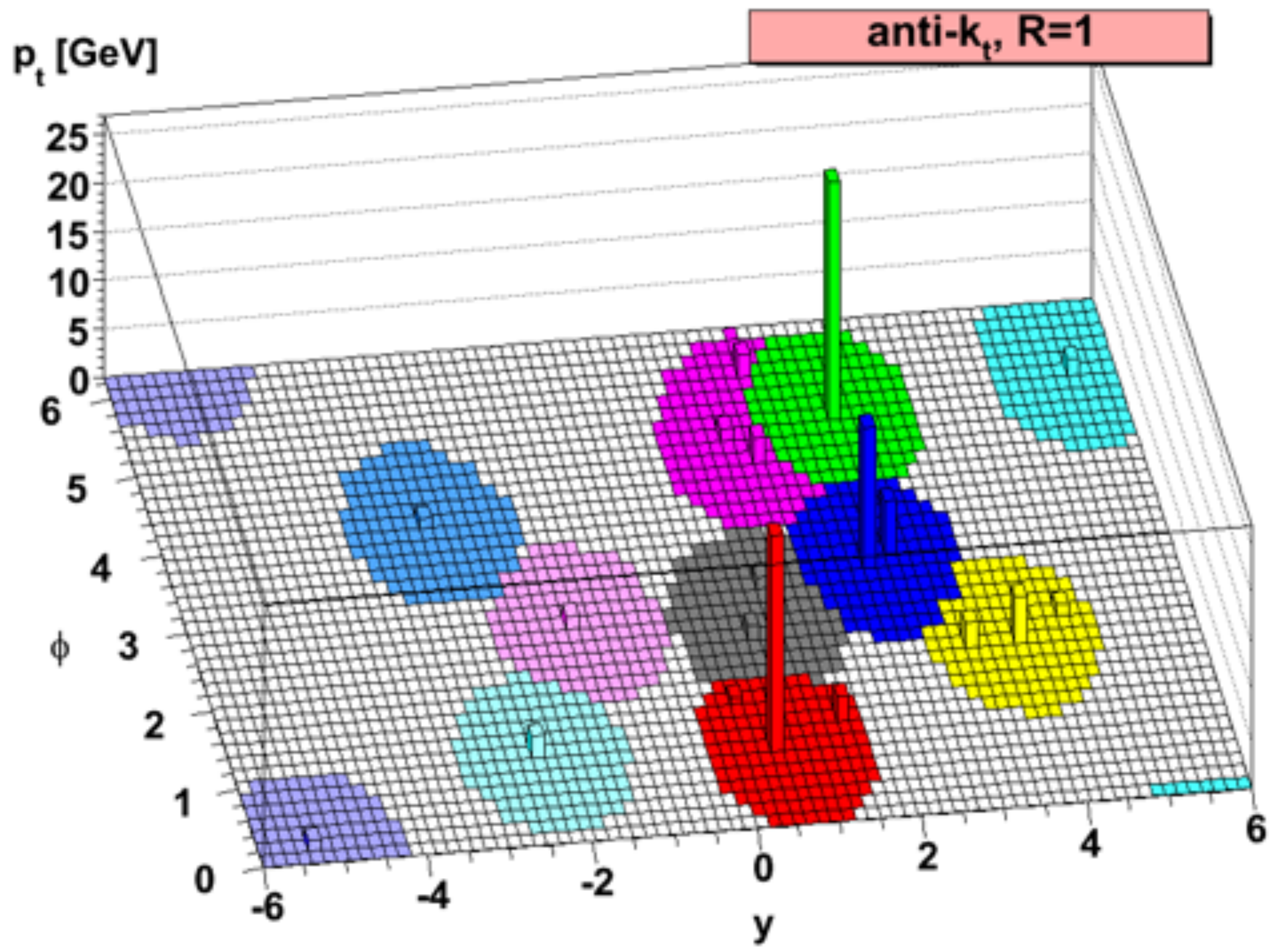
backup

Anti-k_t algorithm

$$d_{ij} = \min\left(k_{ti}^{-2} k_{tj}^{-2}\right) \frac{\Delta_{ij}^2}{R^2}$$

$$d_{iB} = k_{ti}^{-2}$$

$$\Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$



Impact on gluon PDF