Research plan of C01

Vacuum and space-time with top quark

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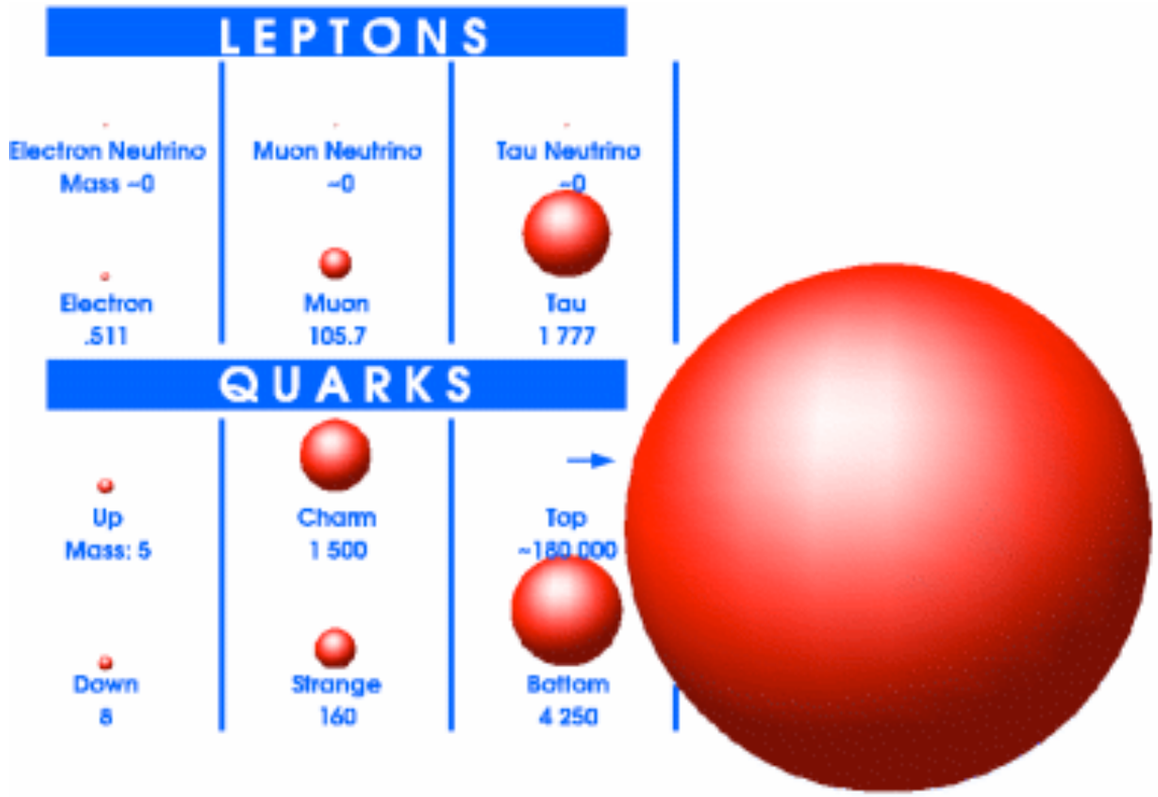
Nagoya University

Introduction

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 (Yt) ~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

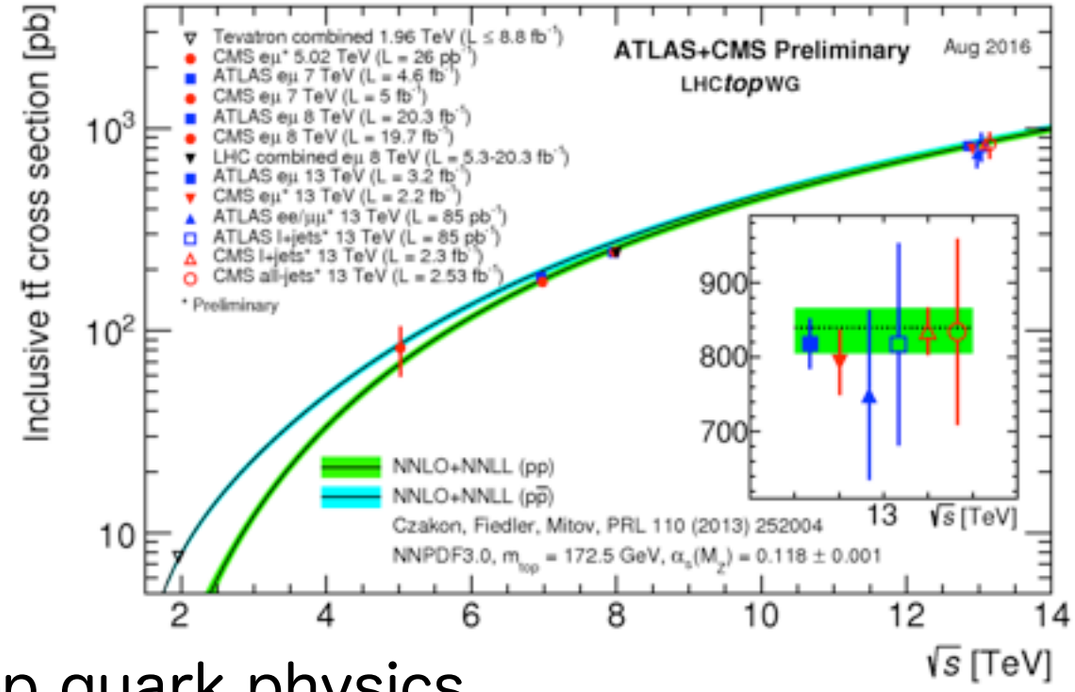
- We can approach the new particle physics phenomenology relating to vacuum and space-time, using top quark as a probe.
  - measurements of Higgs-top Yukawa coupling Y_t
  - direct searches of BSM (e.g. stop, g_{KK}, etc.)

Former JSPS grant

Scientific Research in Innovative area 2011-2015, Group A04 : “Top quark physics”

- We measured inclusive ttbar production cross-section very precisely (~4% precision is better than NNLO+NNLL prediction of ~5%)

- We found pQCD worked very well in the range from √s=2 TeV to √s=13 TeV



- Many doctor theses were released from the top quark physics,

- “The top-quark pair production cross-section measurement in the dilepton final states at proton-proton collisions with √s=7TeV”, Y Okumura (→ postdoc in U. of Chicago → Assistant prof. U of Tokyo)
- “Meapsurement of the top quark pair production cross section with SQRT(s) = 7 TeV of pp collisions at LHC with b-tagging in the dilepton final state with the ATLAS detector”, M Hirose (Osaka → postdoc in TIT→ postdoc in Freiburg)
- “Measurement of the top-quark pair production cross-section in pp collisions at √s=7TeV using final states with an electron or a muon and a hadronically decaying tau-lepton”, Y. Takahashi Nagoya (→ CERN fellow → U of Zurich)
- “Measurement of the W boson polarization in top quark decays using the di-lepton final state of the top quark pair in pp collisions with √s=7TeV”, S. Hasegawa (Nagoya → postdoc at FNAL)
- “Measurement of differential cross sections for top quark pair production in pp collisions at sqrt(s)=7 TeV with the ATLAS detector”, M. Yamada (KEK → postdoc at KEK)

- Development of the fast track trigger (FTK) of ATLAS was completed
  → Led FTK to installation/commissioning phase.

C01 group : “Vacuum and space-time with top quark”

・Research subjects

1. Top quark physics with high statistics
   (1) precise measurements of the top quark properties
   (2) direct measurements of the Higgs-top Yukawa coupling using ttH process
   (3) new physics searches via rare decays of top quark (e.g. FCNC)
   (4) new physics searches (such us SUSY and extra dimension) with top quark
2. Development of the next generation muon trigger technology for top quark physics in future experiment (e.g. HL-LHC)

・Organization

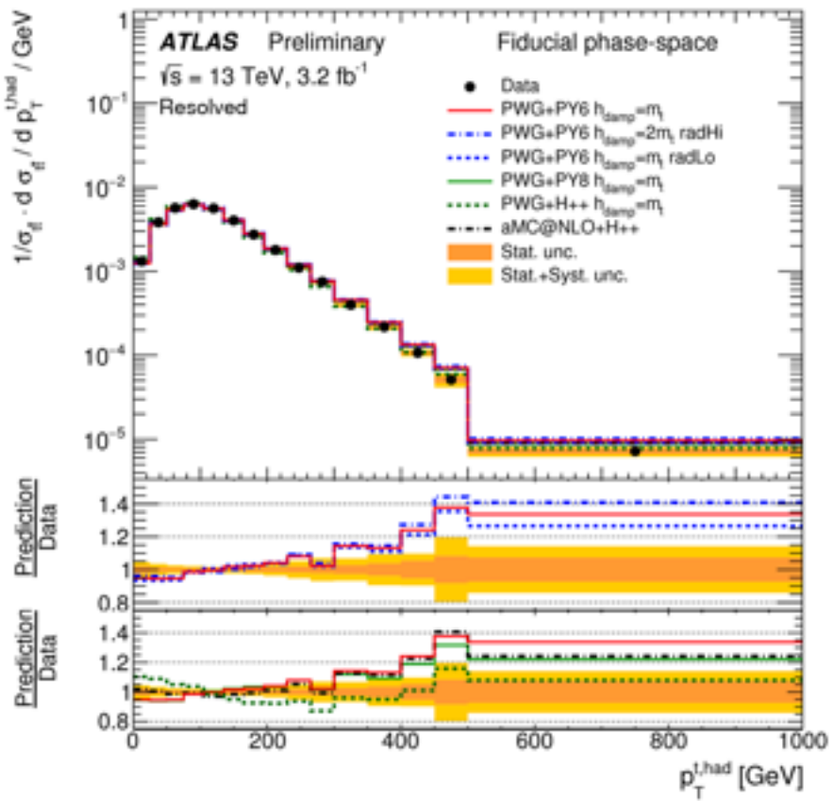
Name	Institute	Research
Makoto Tomoto	Nagoya U.	Leader, top quark, first-level muon trigger
Yuji Yamazaki	Kobe U.	top quark, high-level muon trigger
Osamu Sasaki	KEK	muon trigger electronics
Yasuyuki Horii	Nagoya U.	ttH, first-level muon trigger
Junpei Maeda	Kobe U.	ttbar resonance, first-level muon trigger
Shima Shimizu	Kobe U.	precision top quark, first-level muon trigger

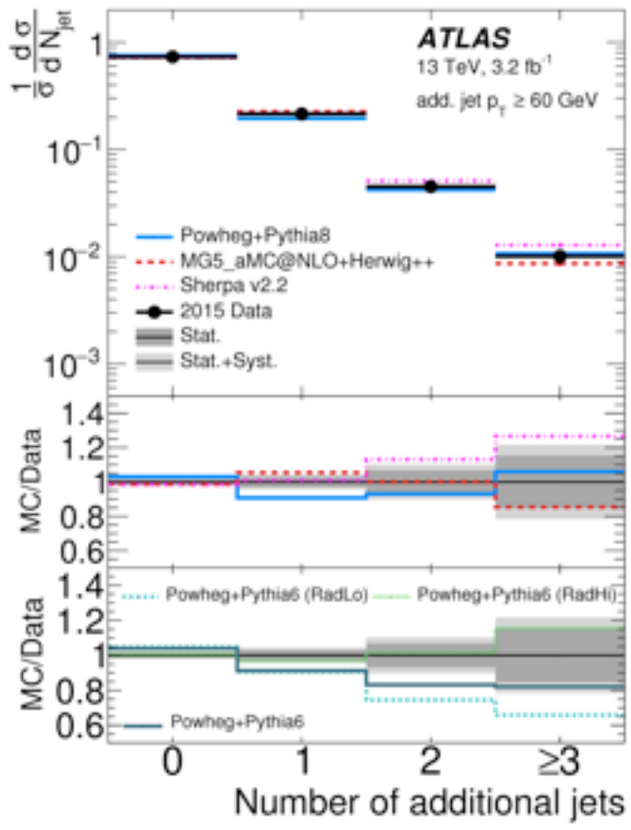
About 20 researchers in total (including about 5 doctor and about 10 master course students)

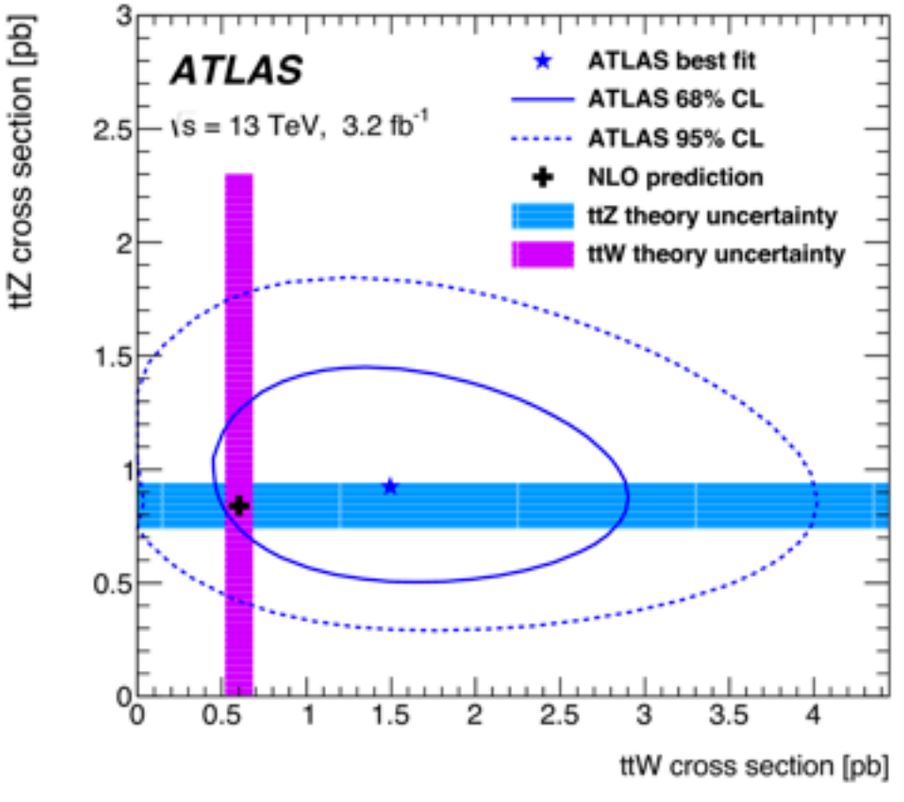
Top quark physics

Precise measurements of production

- High statistics allow us to make detailed studies
  - $d\sigma/dx$ as a function of kinematic variable $x = p_T^t$, $|y^t|$, m^{tt}, p_T^{tt}, and $|y^{tt}|$
  - differential cross-section as a function of number of additional (b) jets
  - tt+X (X=Z, W, γ etc) production cross section
- Differential distributions probe pQCD more precisely
  - constrain modeling of parton shower and hadronization
- Differential distributions are sensitive to new physics searches
  - Deviations might be detectable only in a certain phase space or final state.
  - tt+X is important backgrounds for Higgs analysis and searches
    - Reduced modeling uncertainties enhance sensitivity to new physics.





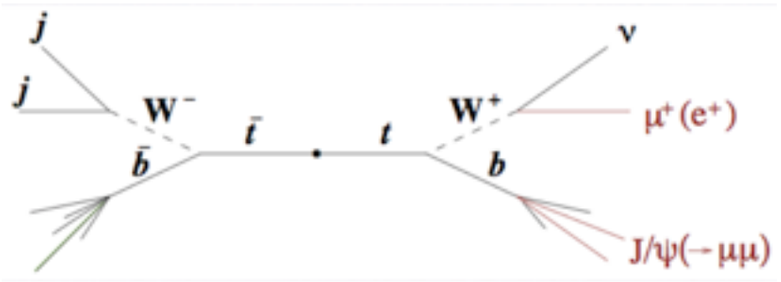


Precise measurement of top quark mass

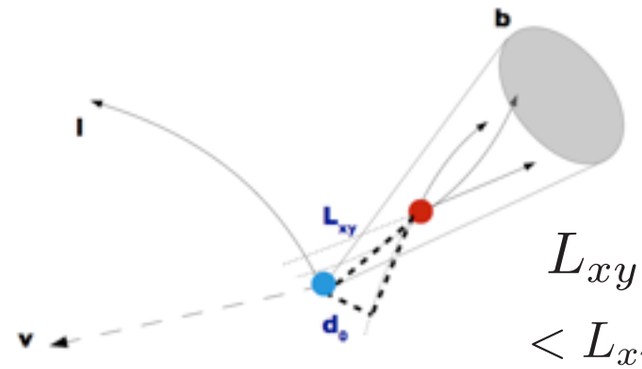
M_t is related to radiative corrections

Vacuum stability depends on exact value of M_t

- $t \to (W \to \ell\ \nu)(b \to J/\psi + X \to \mu\ \mu + X)$



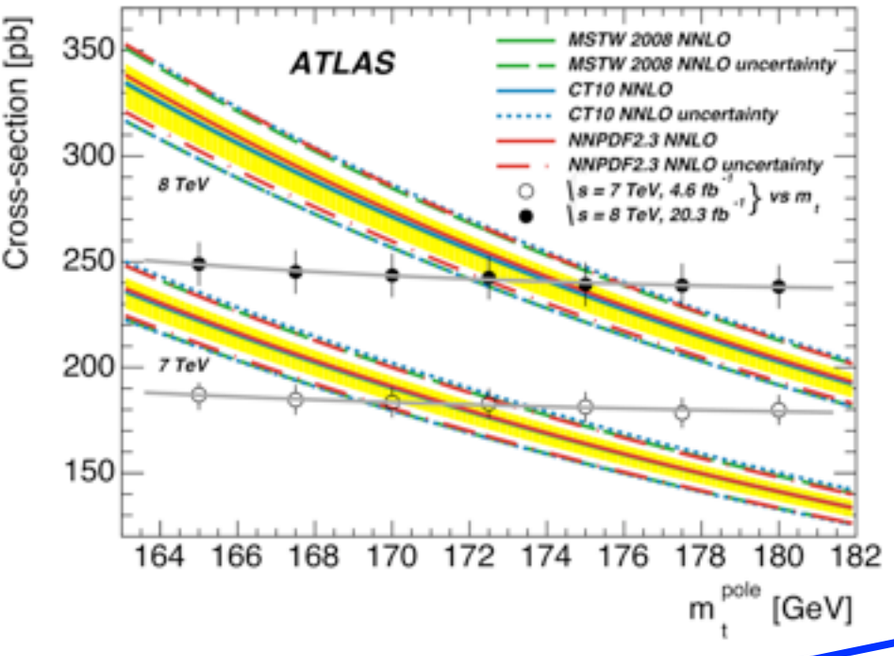
- Secondary vertex



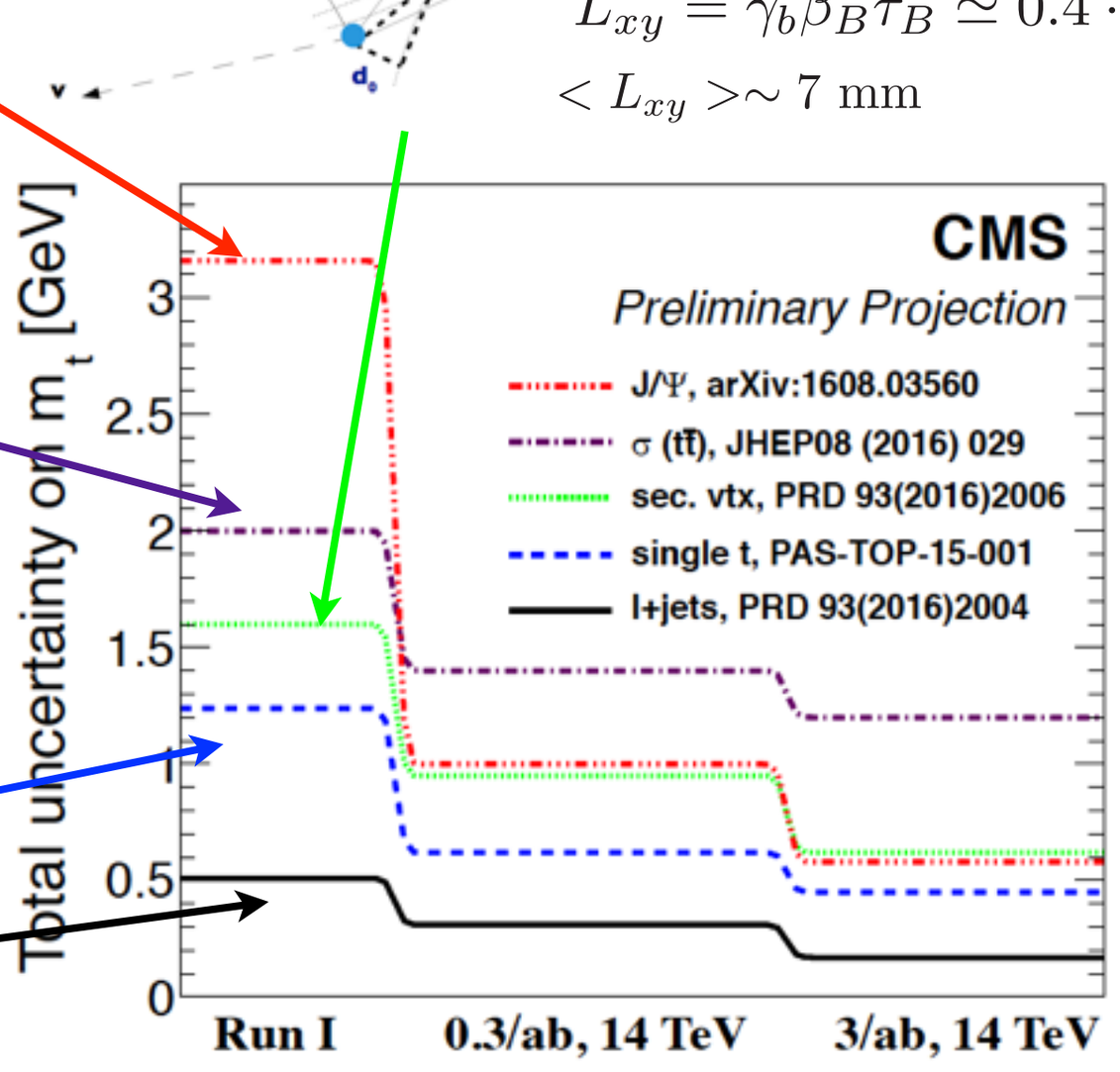
$$L_{xy} = \gamma_b \beta_B \tau_B \simeq 0.4 \cdot \frac{m_t}{m_B} \beta_B \tau_B$$

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

- cross-section v.s. m_t



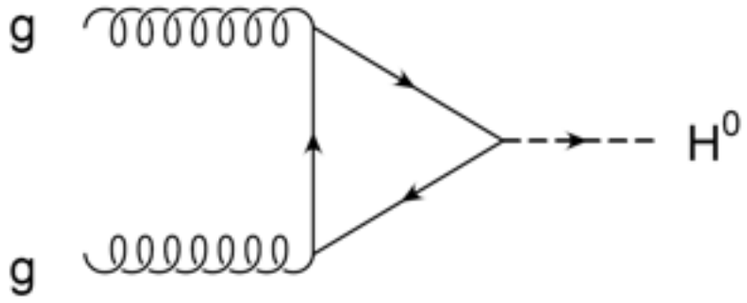
- Single top
- Classic method



Top quark mass measurement is one of the area we should contribute.

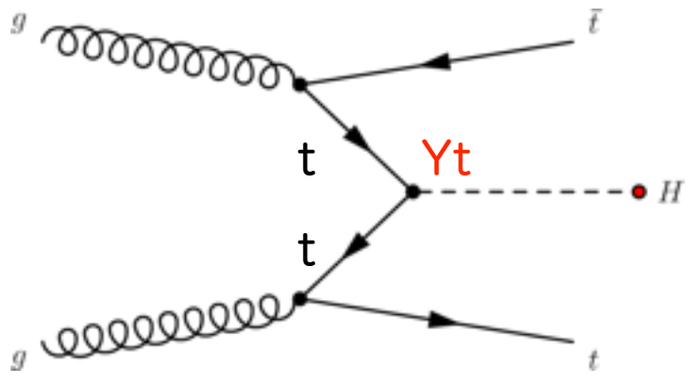
Higgs-top Yukawa coupling

- Indirect measurement from ggF

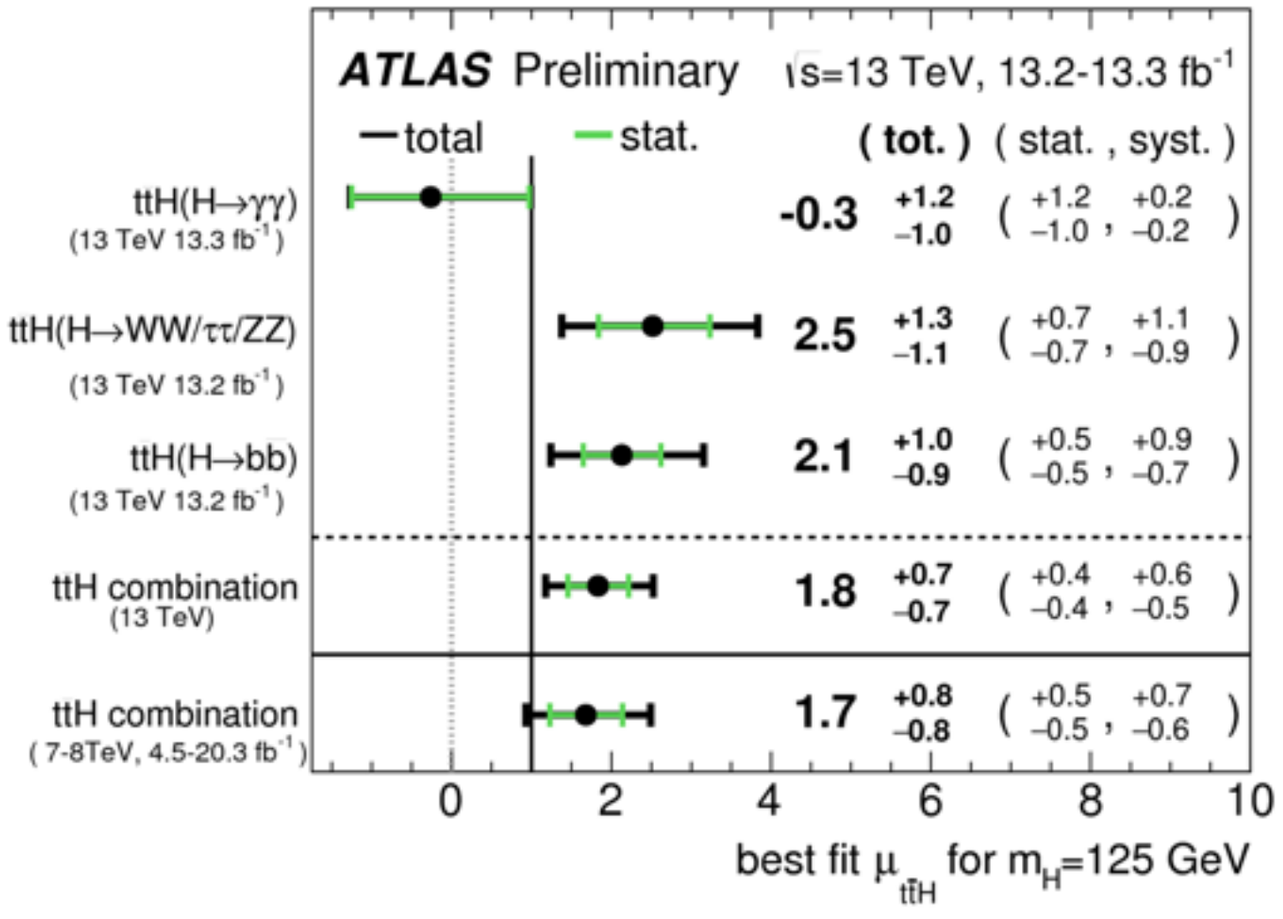


assumes the only SM particles contributing the loops.

- Direct measurement from ttH

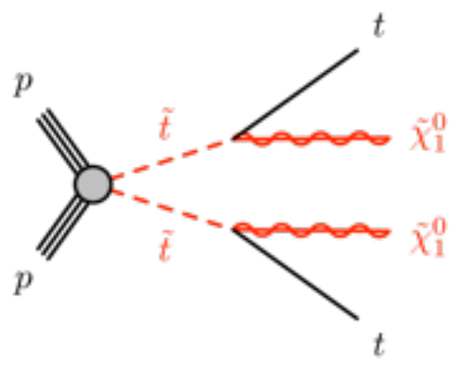


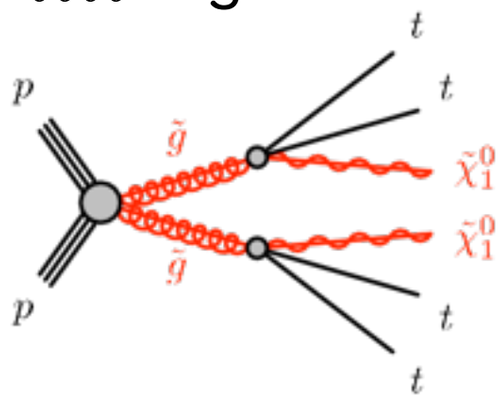
- ttH (H→$\gamma\gamma$, multilepton, bb) measured with Run 1 and Run 2 data .
  - obs. (exp.) significance= 2.8 (1.8)σ
  - modeling of tt+>1b is dominant syst.
- The discovery of ttH can be expected by the end of Run2
- ttH analysis in collaboration with group B (“Vacuum”) is the top priority in C01 group researches.



Top quark as a probe of new physics

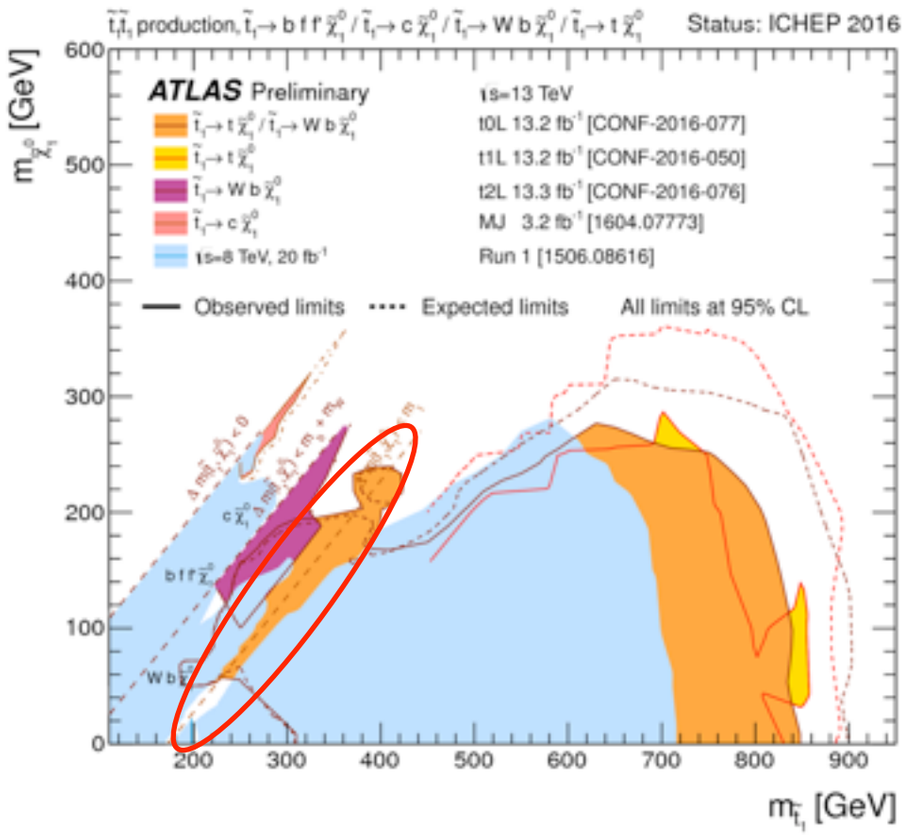
- In case $M_{\tilde{t}} - M_{\tilde{\chi}_1^0} \sim M_t$, stop pair production is only detectable with the precision measurement in top quark pair production cross section.
  - ttbar spin analysis correlations constrained $M_{\tilde{t}} < 190\ \mathrm{GeV}$
  - The analysis with boosted ttbar+ISR jet 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

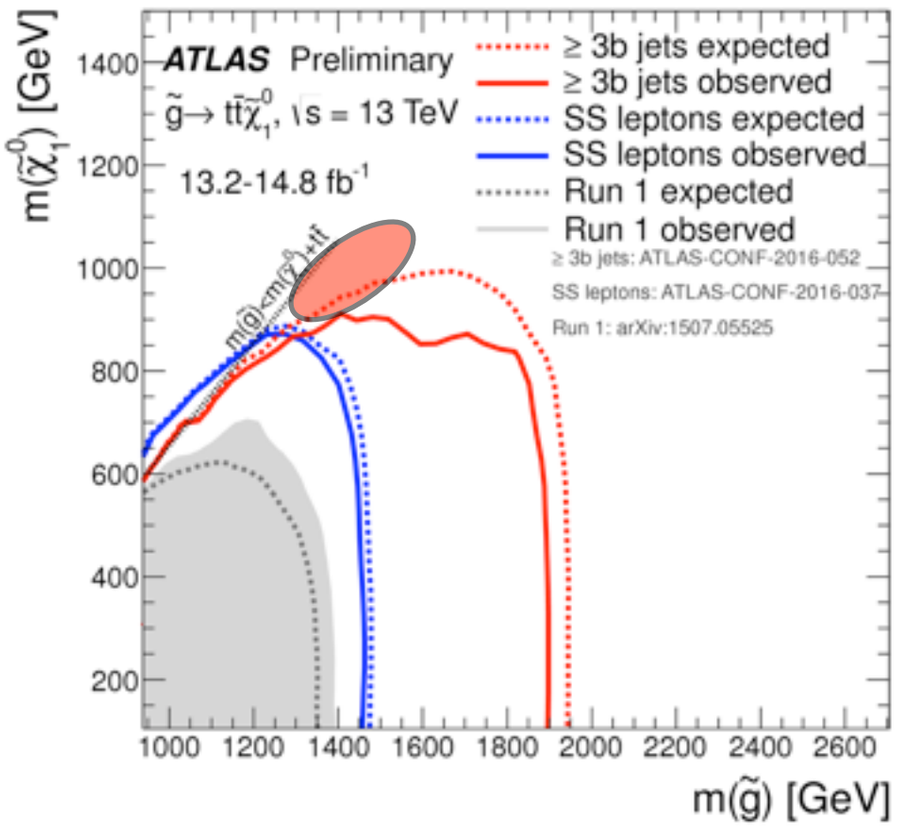




- Ditop resonance searches (current limit is m<~2TeV) are also target of C01 group research.

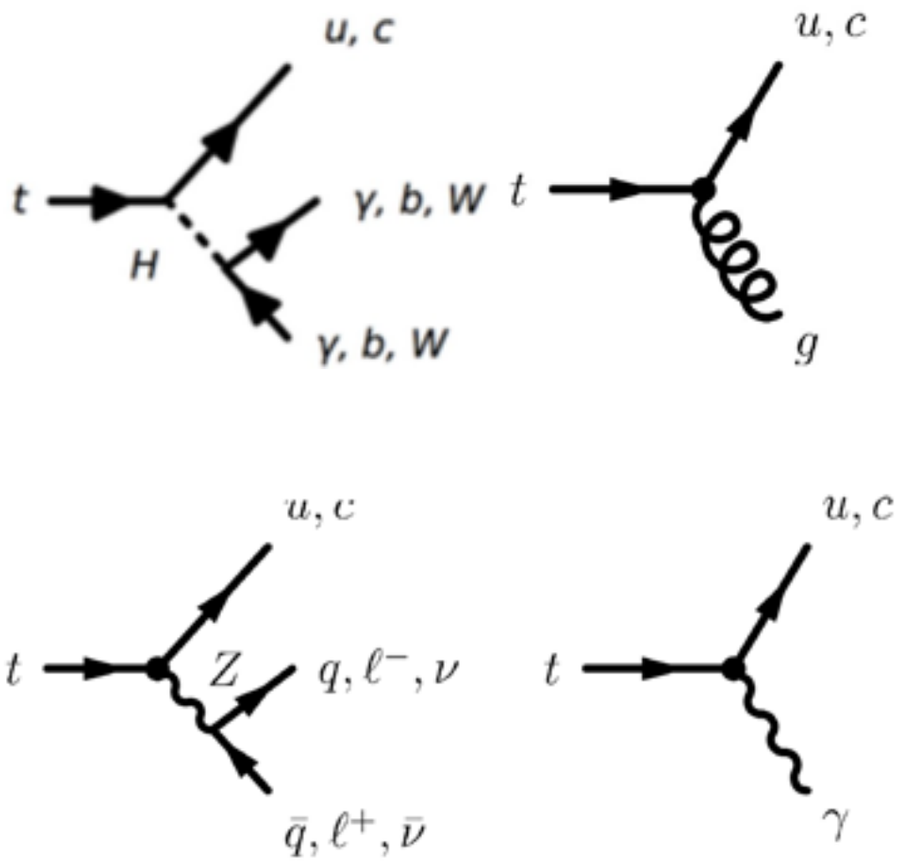
- These studies need to be done in collaboration with group A (“space-time”).

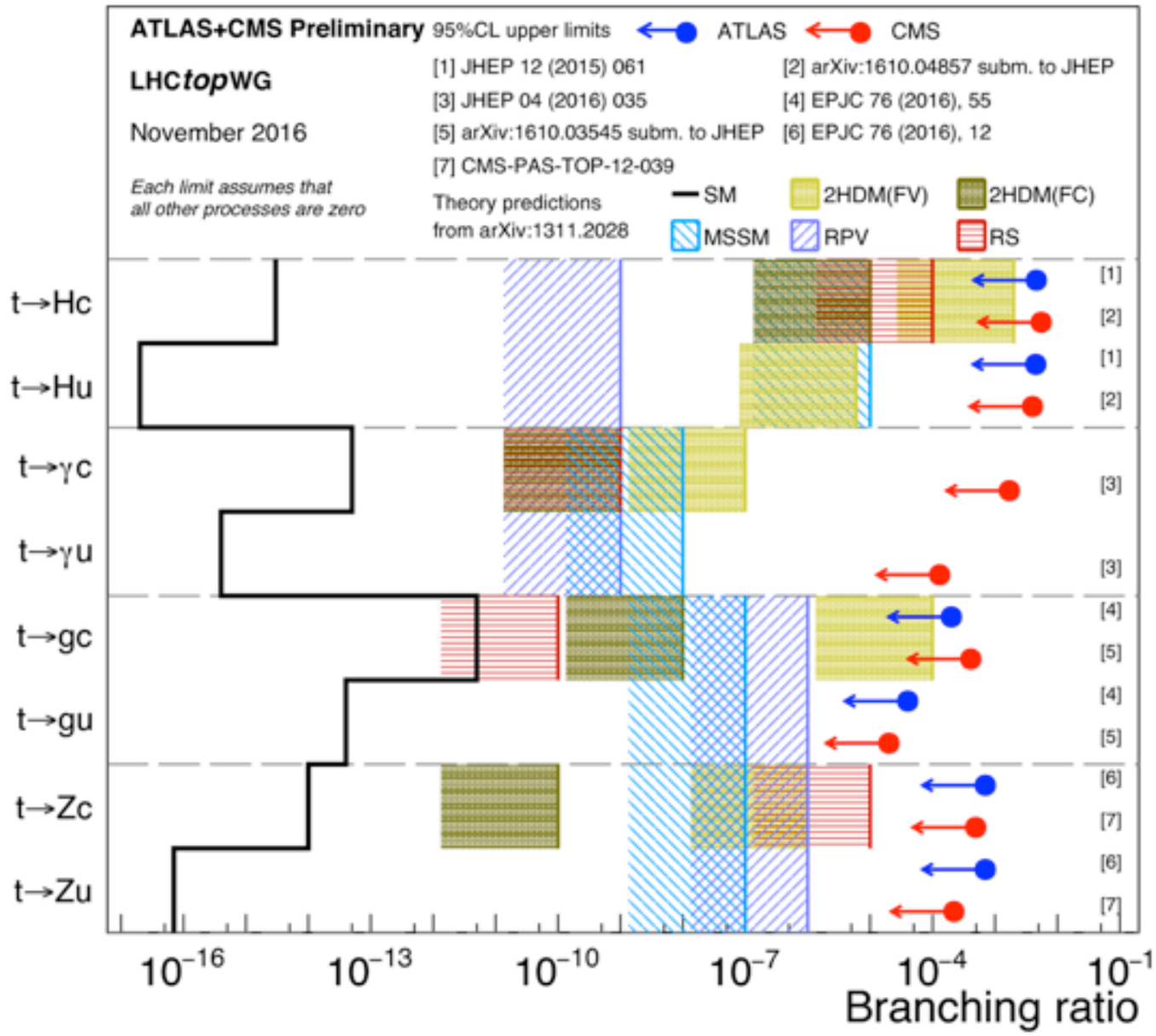




FCNC

- In SM, FCNC is forbidden at tree level
  - It is allowed only via loops but highly suppressed (Br<10^{-11})
- Existing new physics enhances the branching fraction of the FCNC process





- Some of BSM scenario (e.g. 2HDM) predicts branching fraction ~ 10^{-5}
- At the end of Run2, 95% limits for some channel will be reached the level of 10^{-5}

Next generation muon trigger for HL-LHC

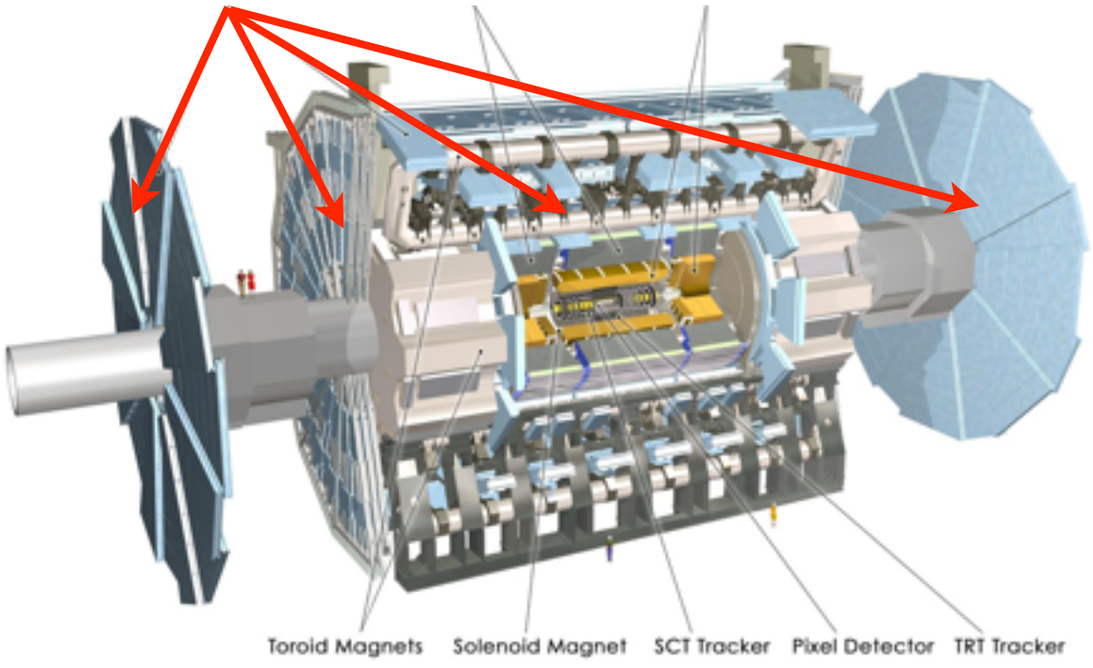
Trigger and readout scheme

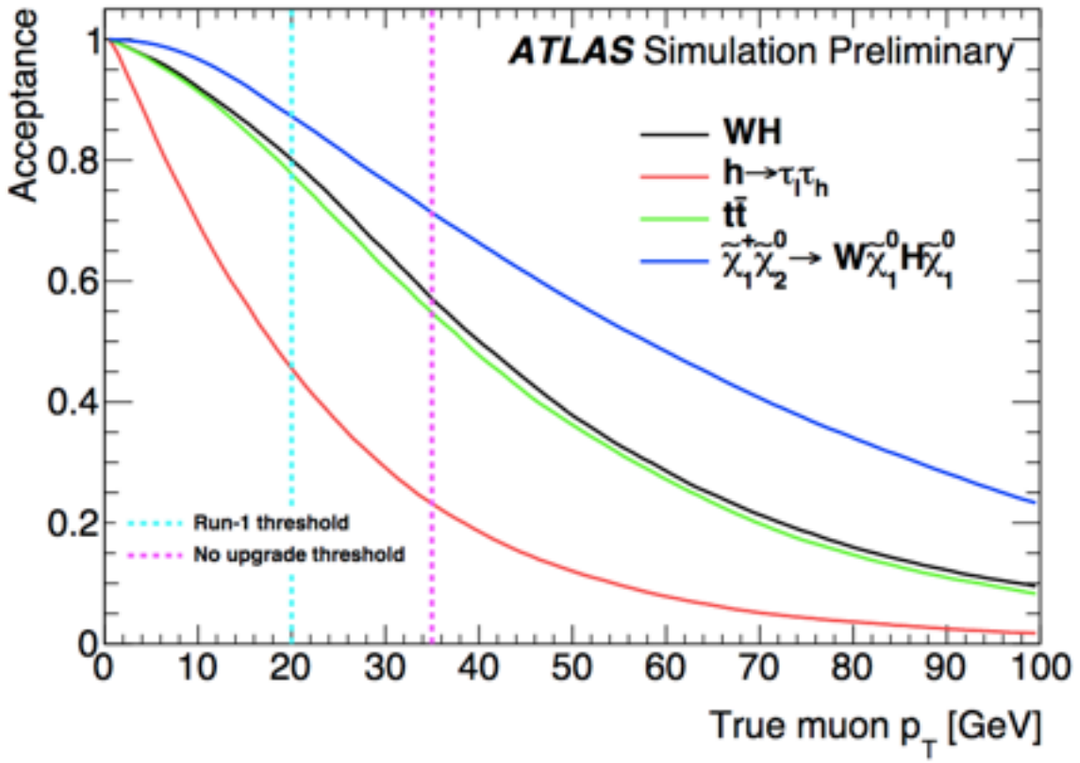
- To take full advantage of HL-LHC physics program with peak luminosity of 7×10^{34} cm^{-2} s^{-1} and integrated luminosity of 3000 fb^{-1} (300 fb^{-1}/year), a new trigger and readout scheme with longer latency and higher rate is essential.

	Latency	Rate
Current (L1)	2.5 μs	100 kHz
HL-LHC (L0)	10 μs	1 MHz

- Most of the electronics for muon system should be replaced by new ones.
- The advanced muon trigger algorithm is developed to reduce the background rate with keeping the efficiency of the top quark production high.
  - Coincidence trigger → Tracking trigger

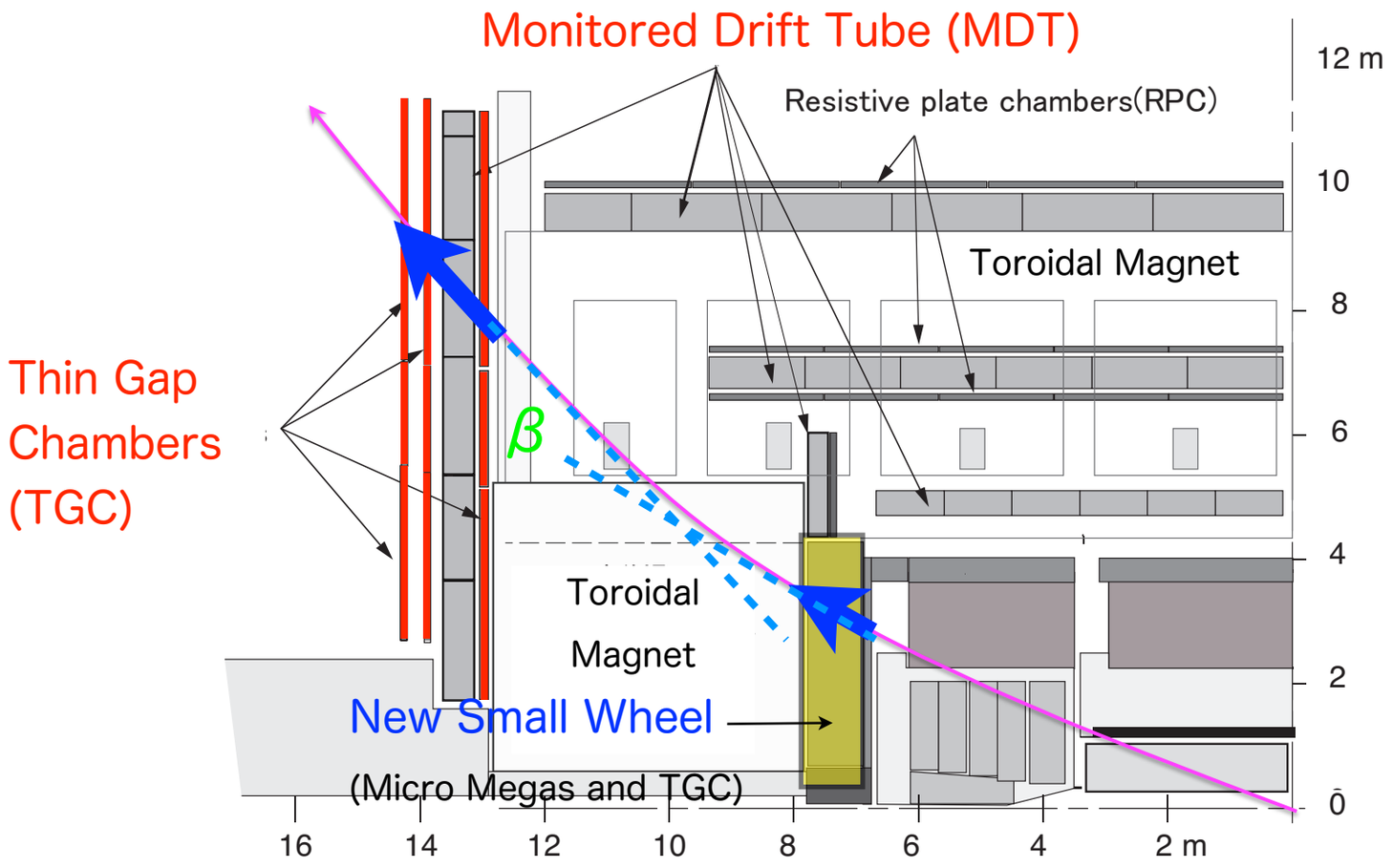
Muon detectors (MDT, TGC, RPC, CSC)





Muon trigger upgrade

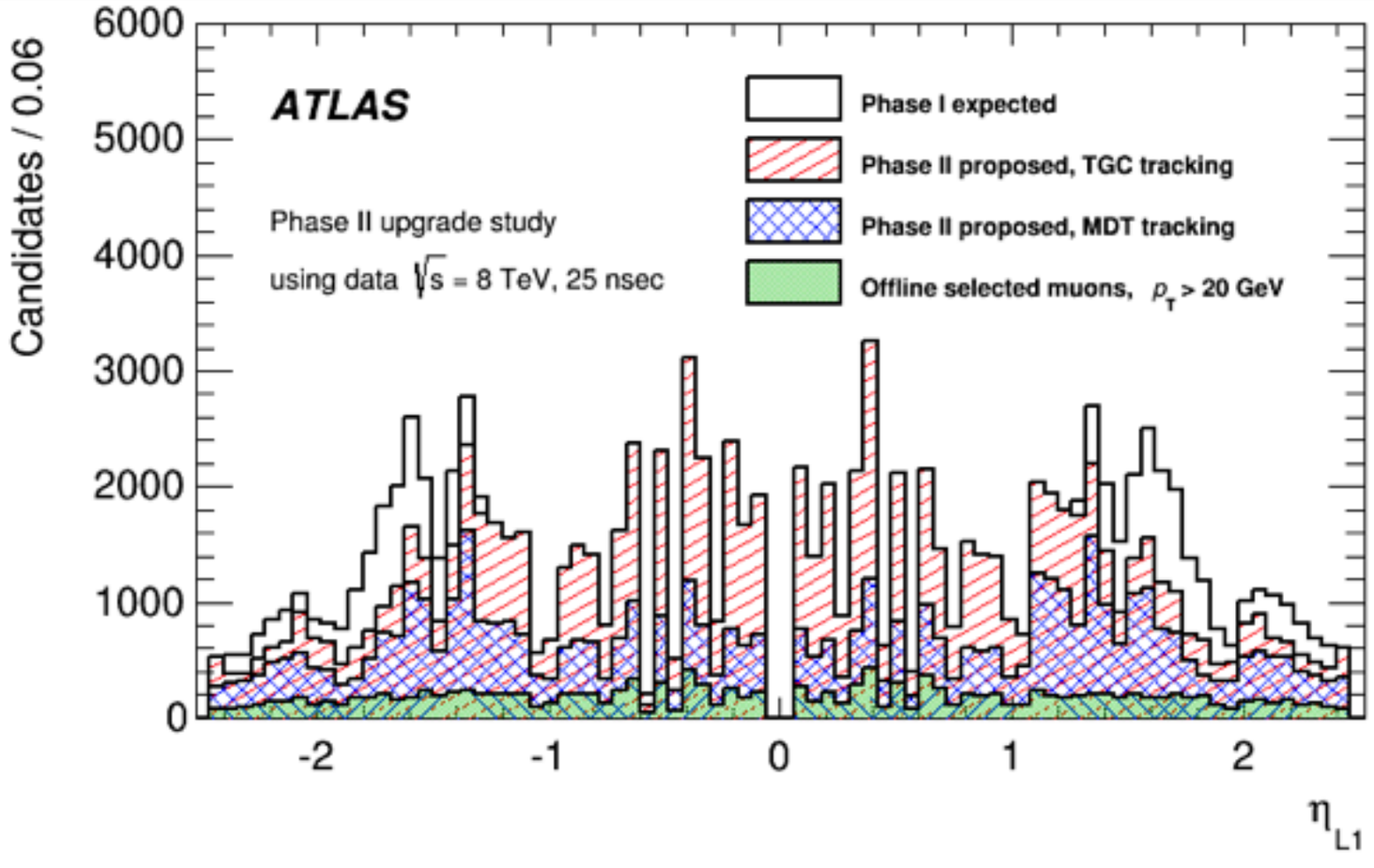
- In HL-LHC, the end-cap muon trigger makes trigger decision using the deflection angle (β) between track segments provided by the inner and outer stations
  - New small wheel (introduced before the HL-LHC upgrade) will provide the track segments with ~1 mrad resolution.
  - Upgraded TGC trigger will provide the track segments with ~3 mrad resolution.
  - MDT trigger will be newly introduced from HL-LHC upgrade and provide the track segments with ~1 mrad resolution.

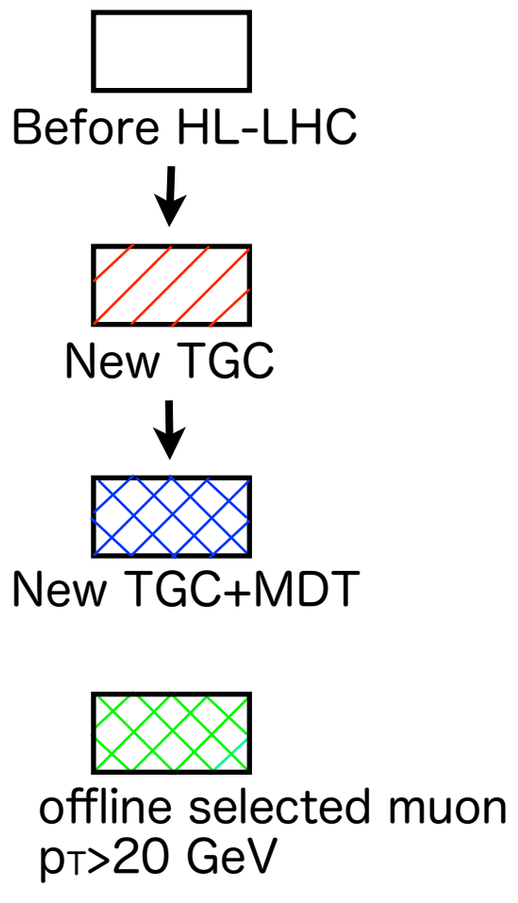


Performance of new muon trigger

- Trigger rate study for single muon trigger with 20 GeV threshold is emulated using Run1 data, $\sqrt{s}$=8 TeV, 25 ns bunch spacing
  - Rate reduction by the TGC tracking trigger is about 30% in end-cap region ($1.3 < |\eta| < 2.4$)
  - Rate reduction by the combination of the TGC tracking trigger and the MDT tracking trigger is about 50% in $|\eta| < 2.4$
  - Efficiency of muons reconstructed as p_T>20 GeV by offline is better than 95%

η distribution of the muons passed the muon trigger condition of p_T > 20 GeV

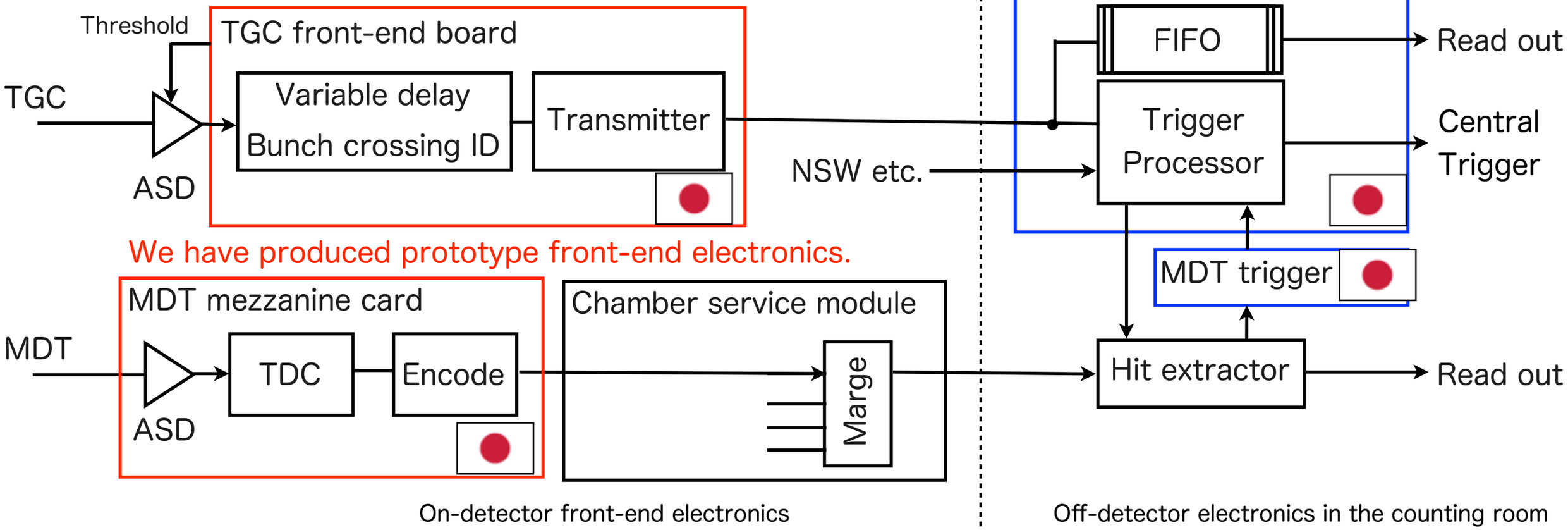




Muon track trigger electronics

ASD=amplifier-shaper-discriminator ASIC

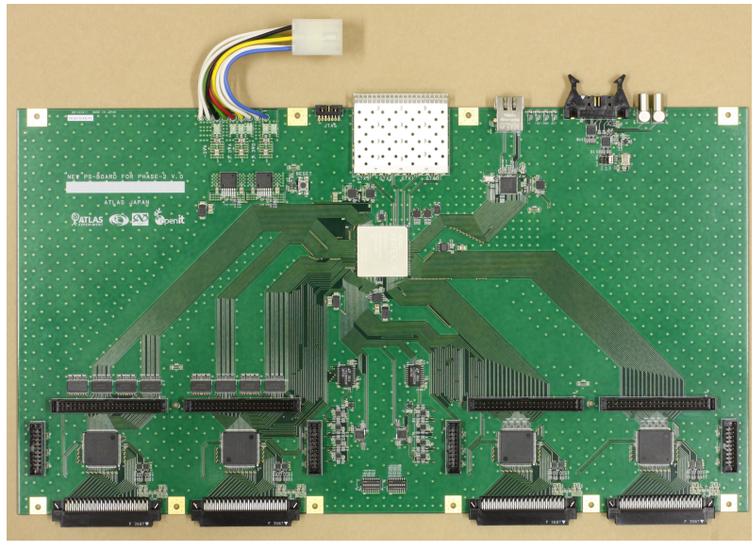
We are developing trigger algorithm.



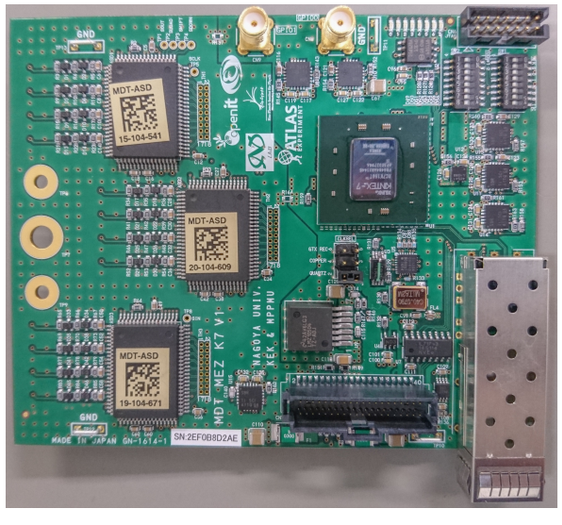
On-detector front-end electronics

Off-detector electronics in the counting room

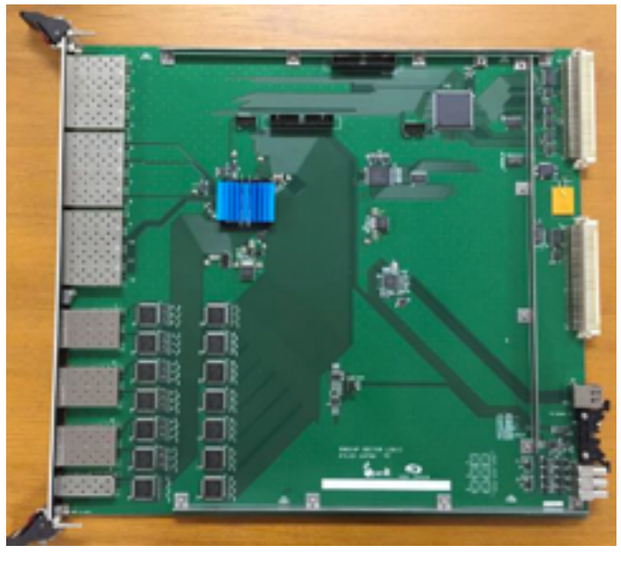
TGC front-end board
(20 Gbps hit data transmitter)



MDT mezzanine card
(TDC readout of drift tube signal)



Trigger processor board



Beam test

- Basic functionalities of the prototype-modules have been demonstrated successfully with the muon beam at CERN H8C beam line (Nov. 2016) !!

- We will finalize the design of the muon trigger algorithm and electronics
  - Technical design report will be published in 2017

Conclusion

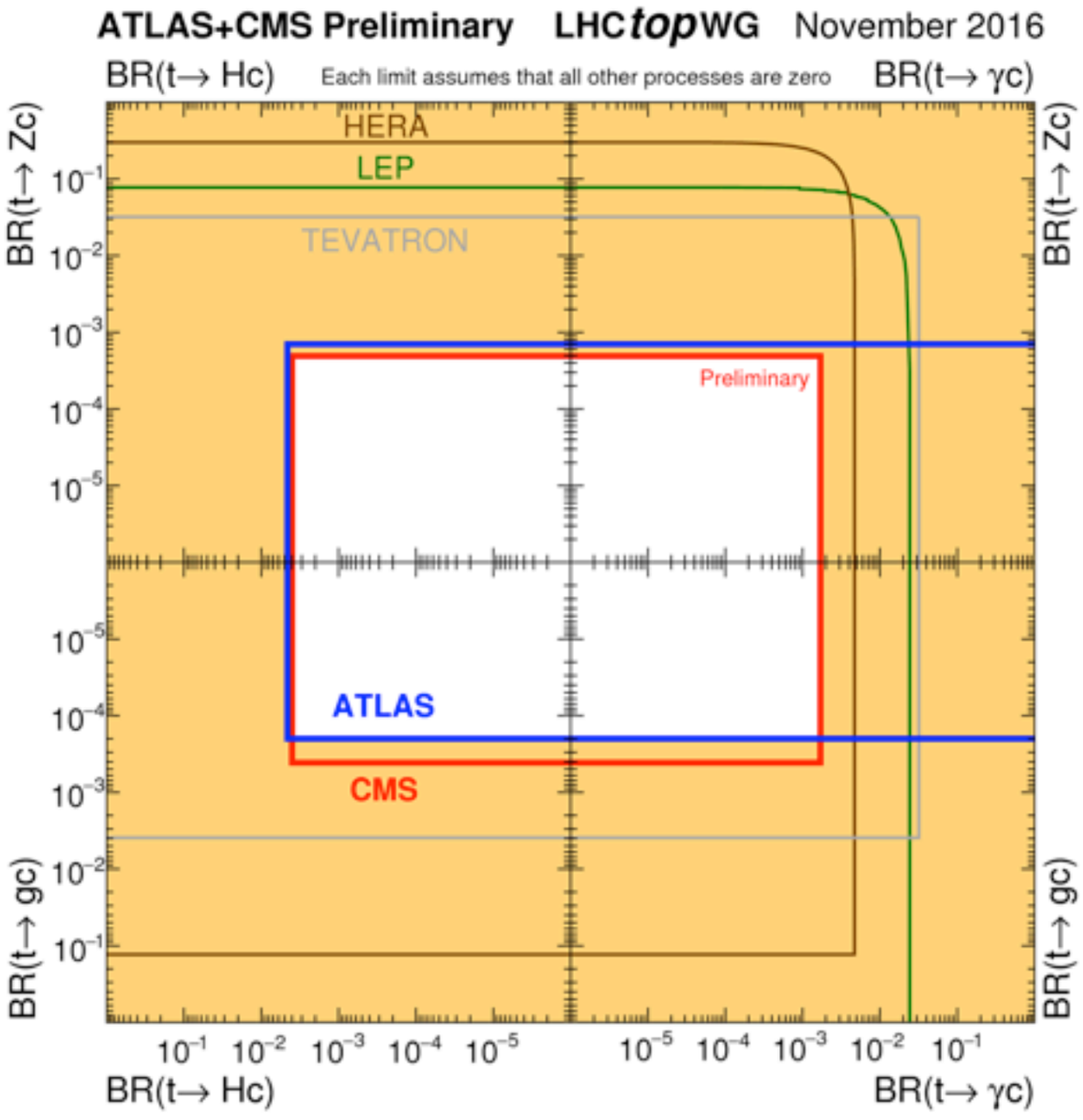
- Top quark is one of the most important particle to discover the new particle physics phenomenology relating to vacuum and space-time

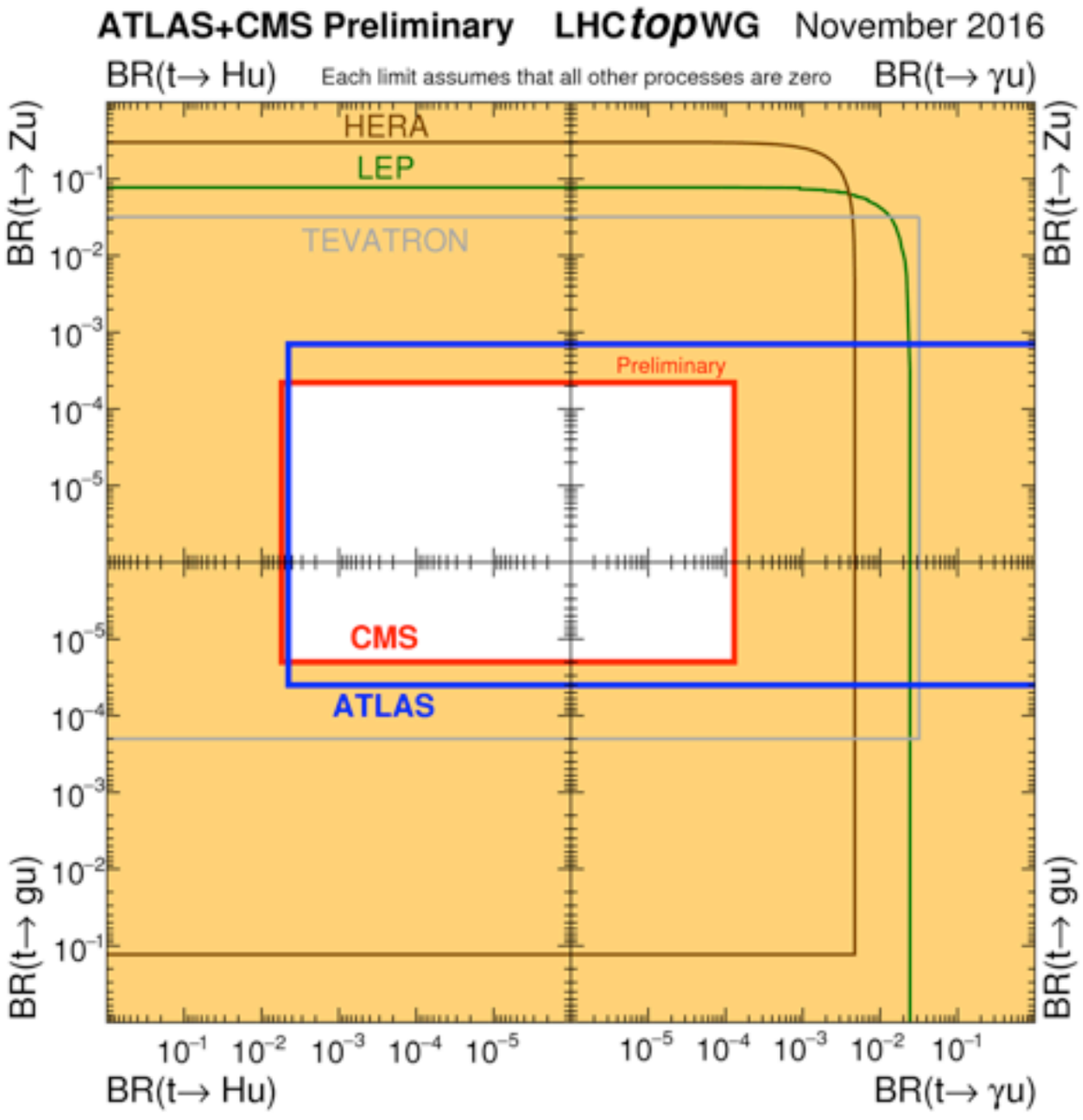
- The researches of C01 group will be focused on
  (1) precise measurements of the top quark properties
  (2) direct measurements of the Higgs-top Yukawa coupling using ttH process
  (3) new physics searches via rare decays of top quarks (e.g. FCNC)
  (4) new physics (SUSY and extra dimension) searches with top quarks

- Please let us know if you have any interesting analyses to search for new physics related to vacuum and space-time using top quark

- We also develop the next generation muon trigger technology to keep the acceptance of the top quark production high in the future experiment (HL-LHC)

backup


ATLAS+CMS Preliminary LHCtopWG November 2016
BR(t→ Hc) Each limit assumes that all other processes are zero BR(t→ γc)
HERA
LEP
TEVATRON
Preliminary
ATLAS
CMS
BR(t→ Zc)
BR(t→ gc)
BR(t→ Hc)
BR(t→ γc)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BR(t→ Hu) Each limit assumes that all other processes are zero BR(t→ γu)
HERA
LEP
TEVATRON
Preliminary
CMS
ATLAS
BR(t→ Zu)
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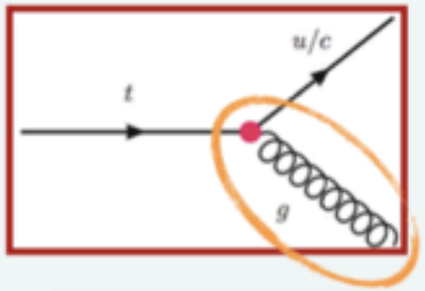
BR(t→ Hu)
BR(t→ γu)

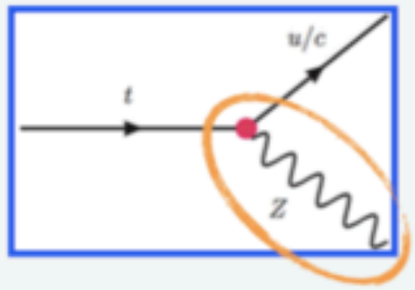
Top quark as a probe of new physics

物理過程	$g_{KK} \to tt$	$Z'_{topcolor} \to tt$
現在	2.2TeV	1.8TeV
$L=300fb^{-1}$	4.3TeV	3.3TeV
$L=3000fb^{-1}$	6.7TeV	5.5TeV

FCNC

Top + gluon

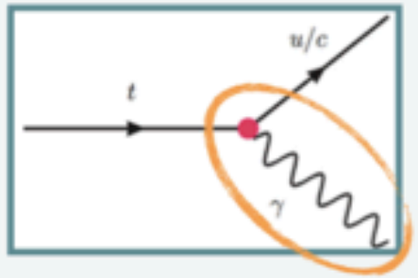


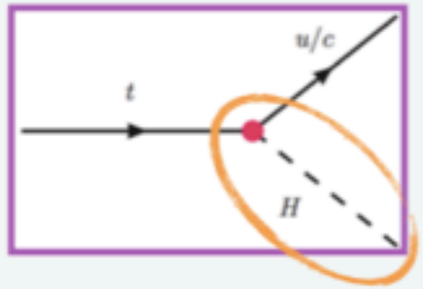


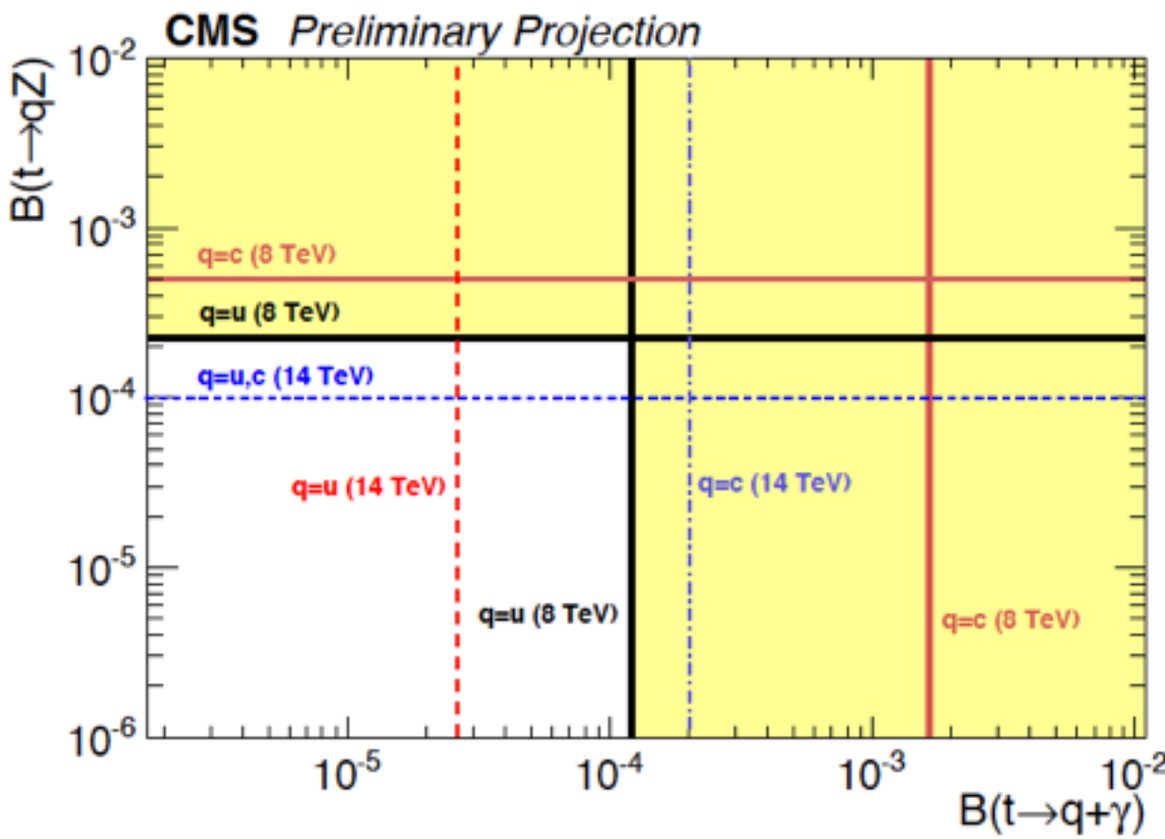
Top + Z

$$
\begin{aligned}
\mathcal{L} \;=\; & \sum_{q=u,c} \Big[\sqrt{2}\, g_s \frac{\kappa_{gqt}}{\Lambda} \bar{t}\, \sigma^{\mu\nu}\, T_a (f^L_{Gq} P_L + f^R_{Gq} P_R)\, q\, G^a_{\mu\nu} \\
& + \frac{g}{\sqrt{2} c_W} \frac{\kappa_{zqt}}{\Lambda} \bar{t} \sigma^{\mu\nu}\, (f^L_{Zq} P_L + f^R_{Zq} P_R)\, q\, Z_{\mu\nu} \\
& - e \frac{\kappa_{\gamma qt}}{\Lambda} \bar{t}\, \sigma^{\mu\nu}\, (f^L_{\gamma q} P_L + f^R_{\gamma q} P_R)\, q\, A_{\mu\nu} \\
& + \frac{g}{\sqrt{2}} \bar{t} \kappa_{Hqt} (f^L_{Hq} P_L + f^R_{Hq} P_R)\, q\, H \Big] + \text{h.c.}
\end{aligned}
$$

Top + gamma







stop pair production in scenarios with compressed mass spectra