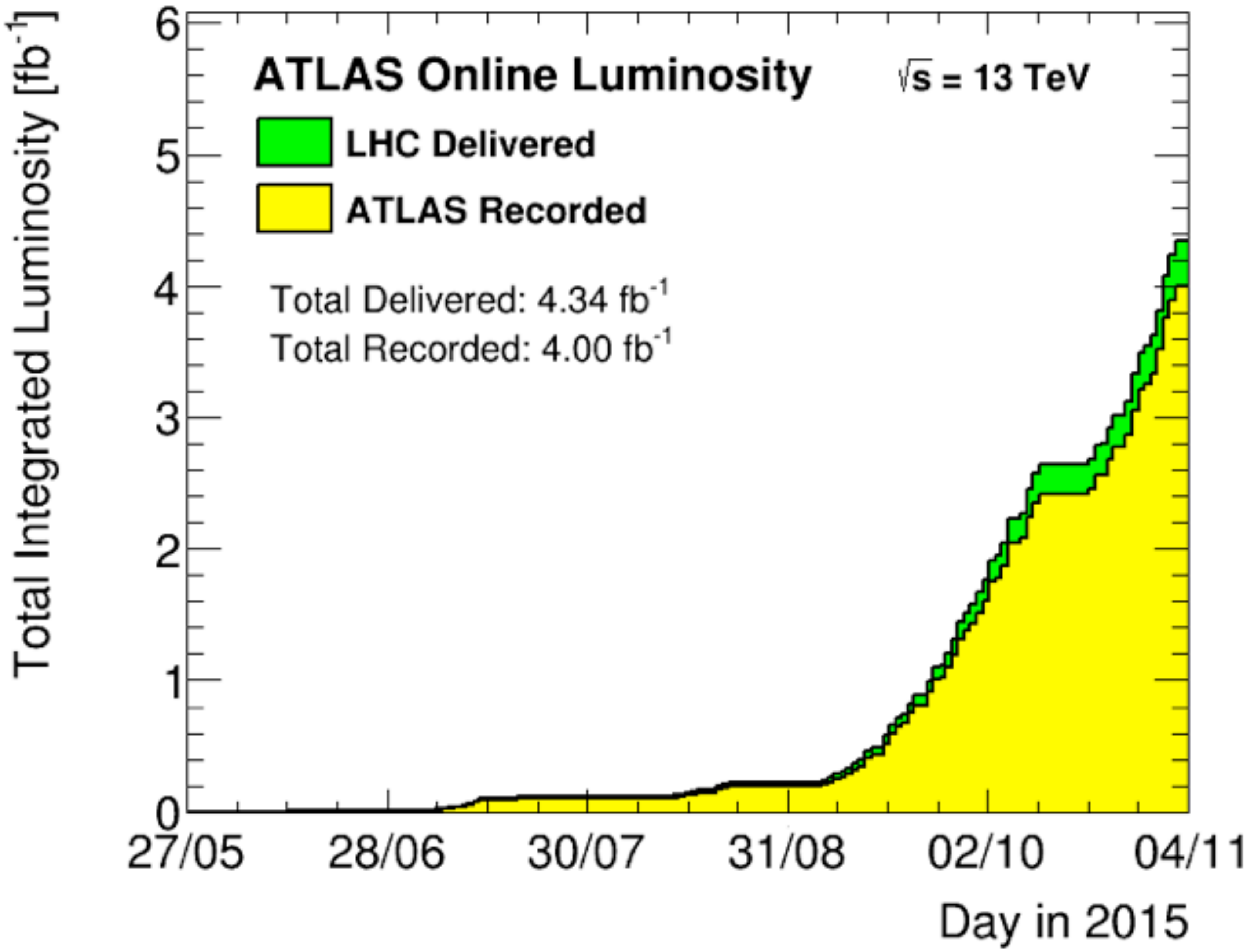
KMI-topics
“LHC-ATLAS upgrade project”

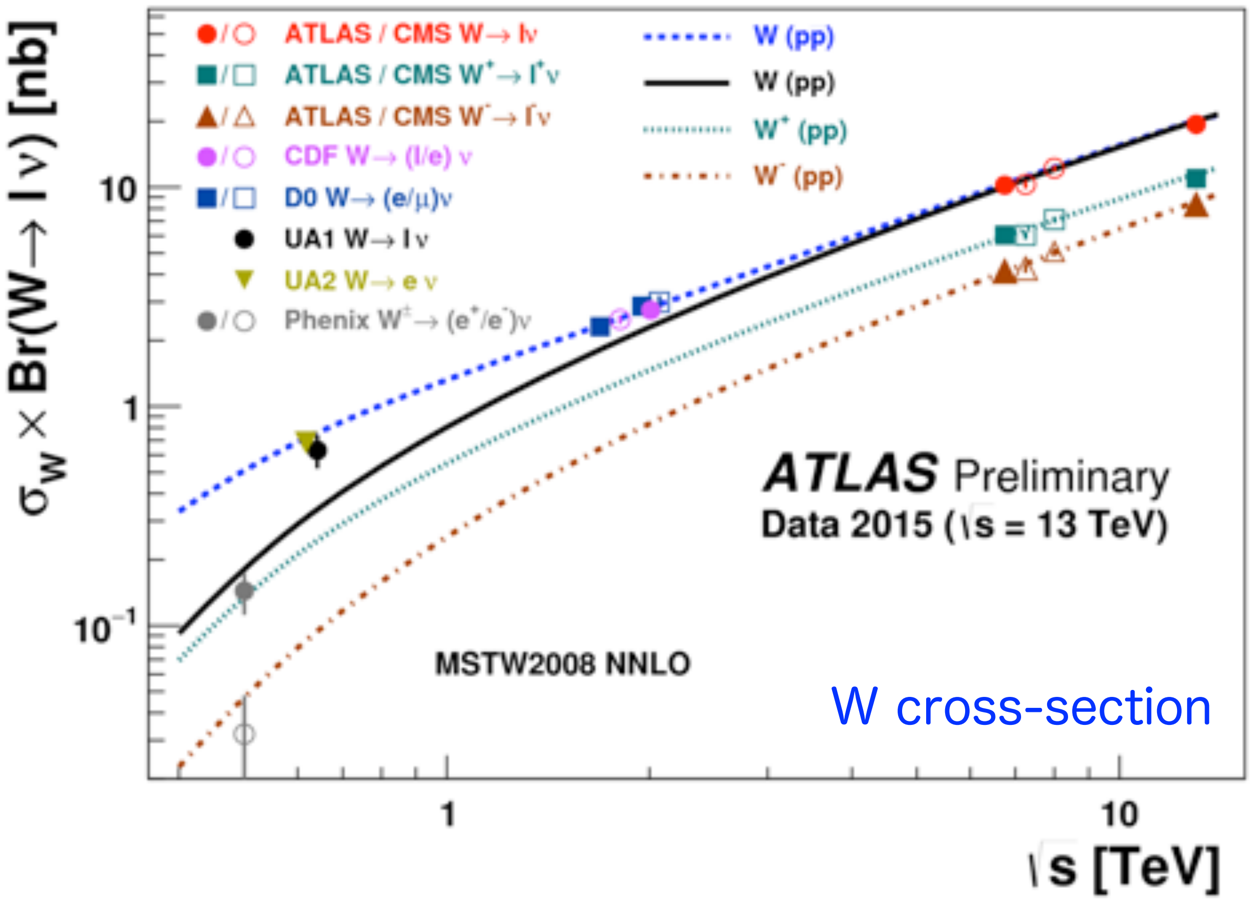
Makoto Tomoto

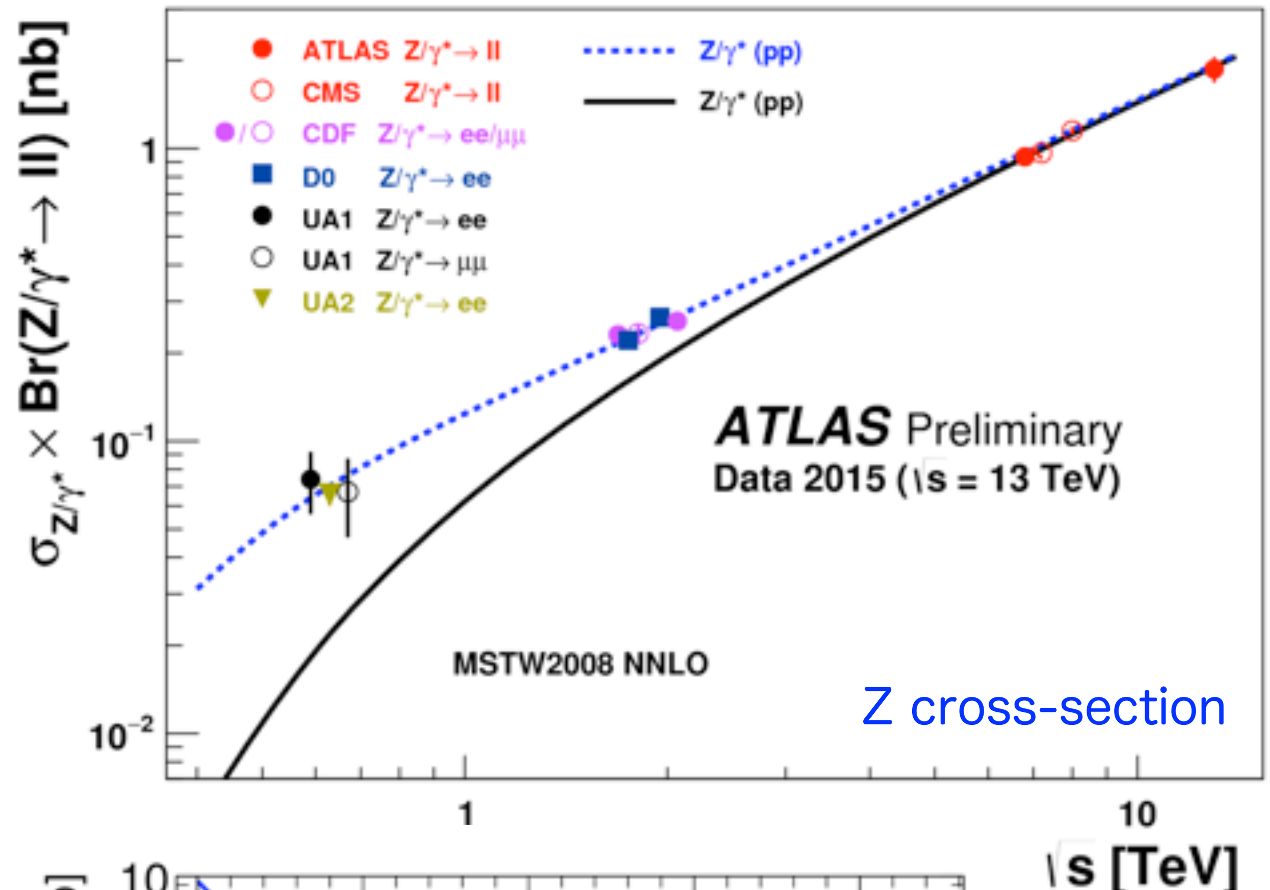
$\sqrt{s}$=13TeV LHC (Run 2) started !

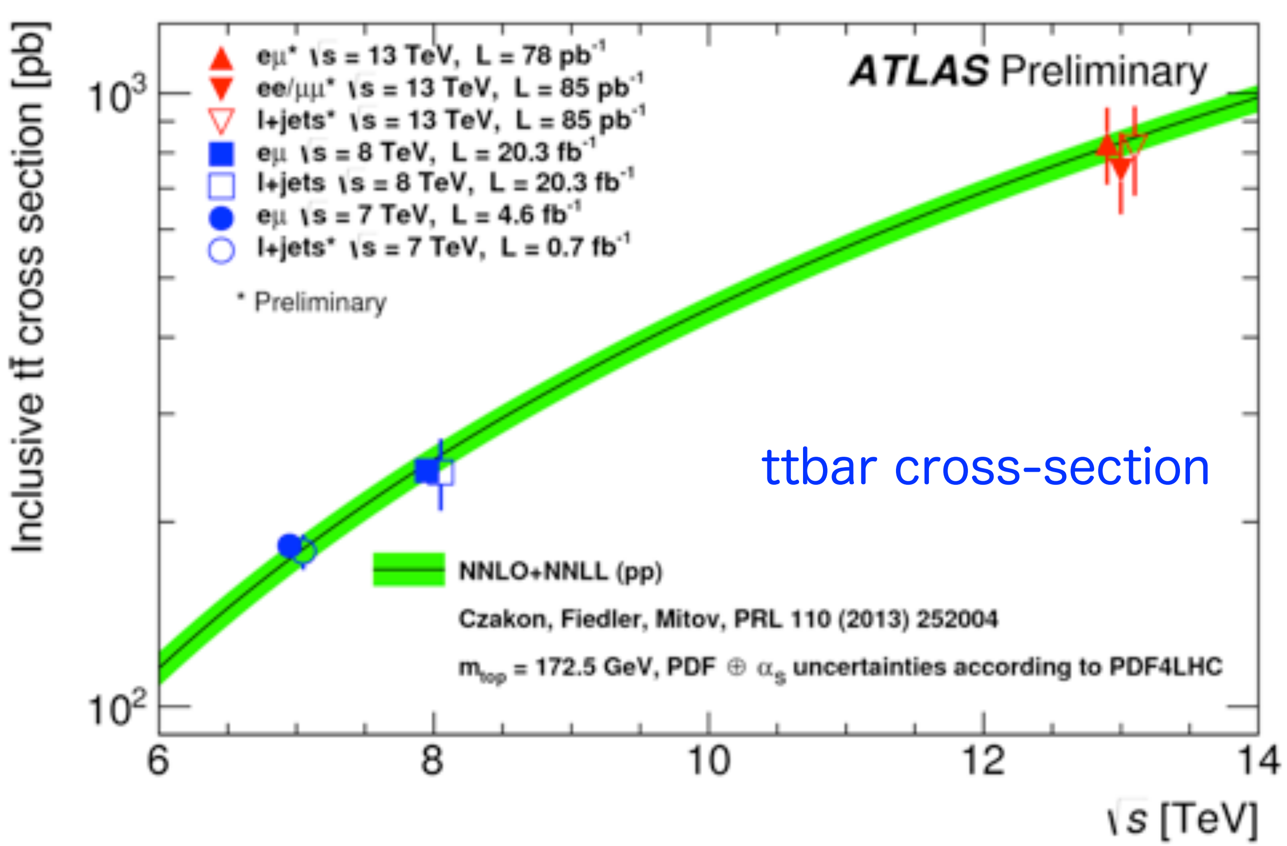


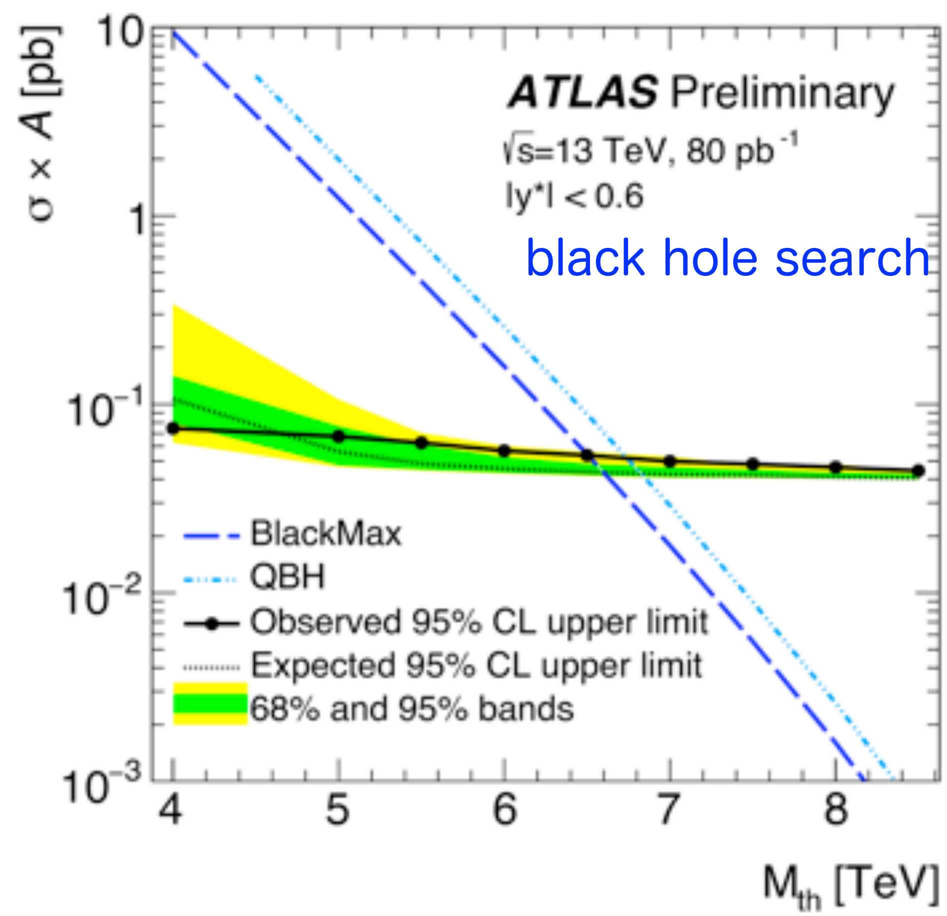
4fb^{-1} of 13TeV collision data is recorded !!

Results from Run 2



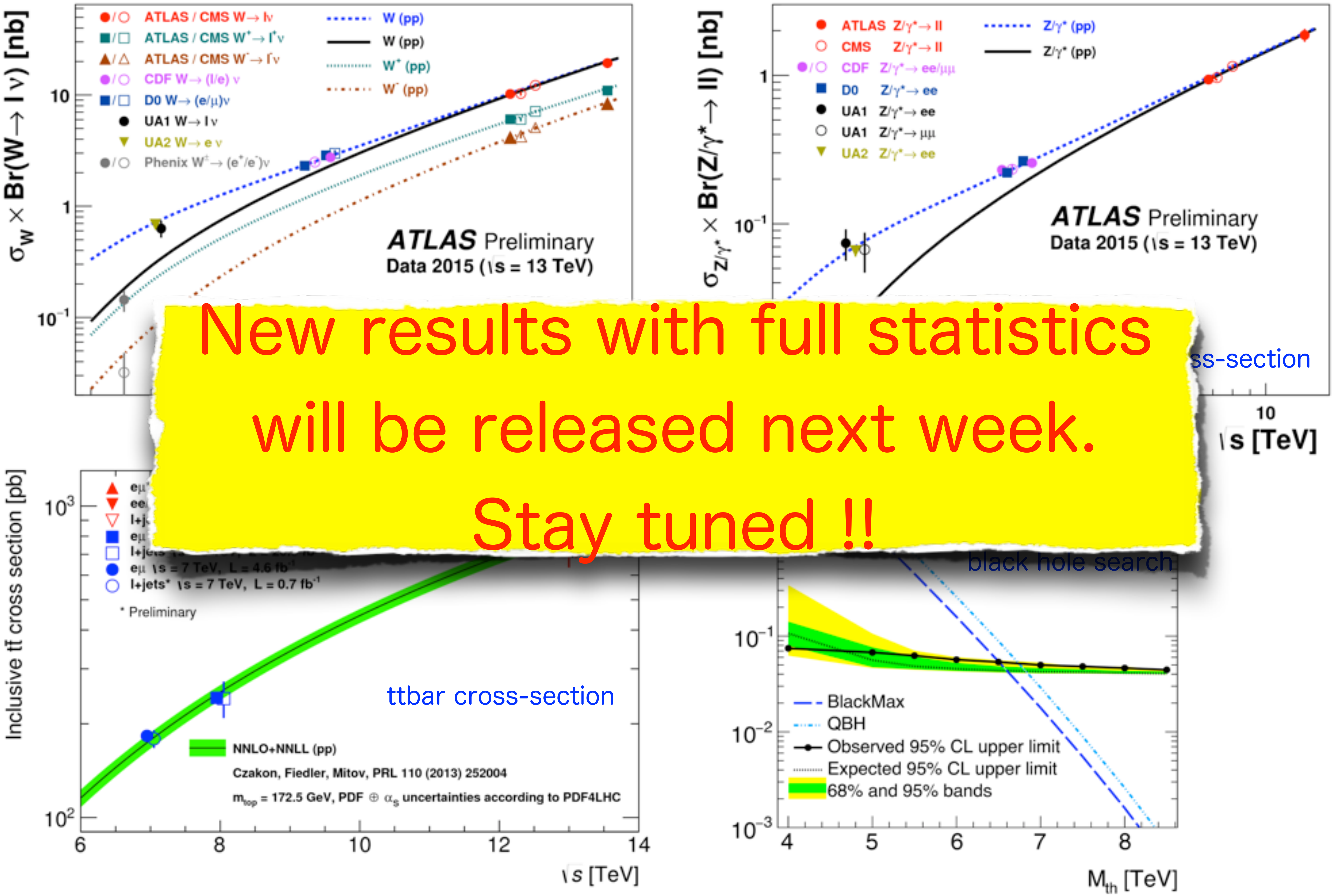






Results from Run 2

New results with full statistics will be released next week. Stay tuned !!



Today's topic

LHC upgrade

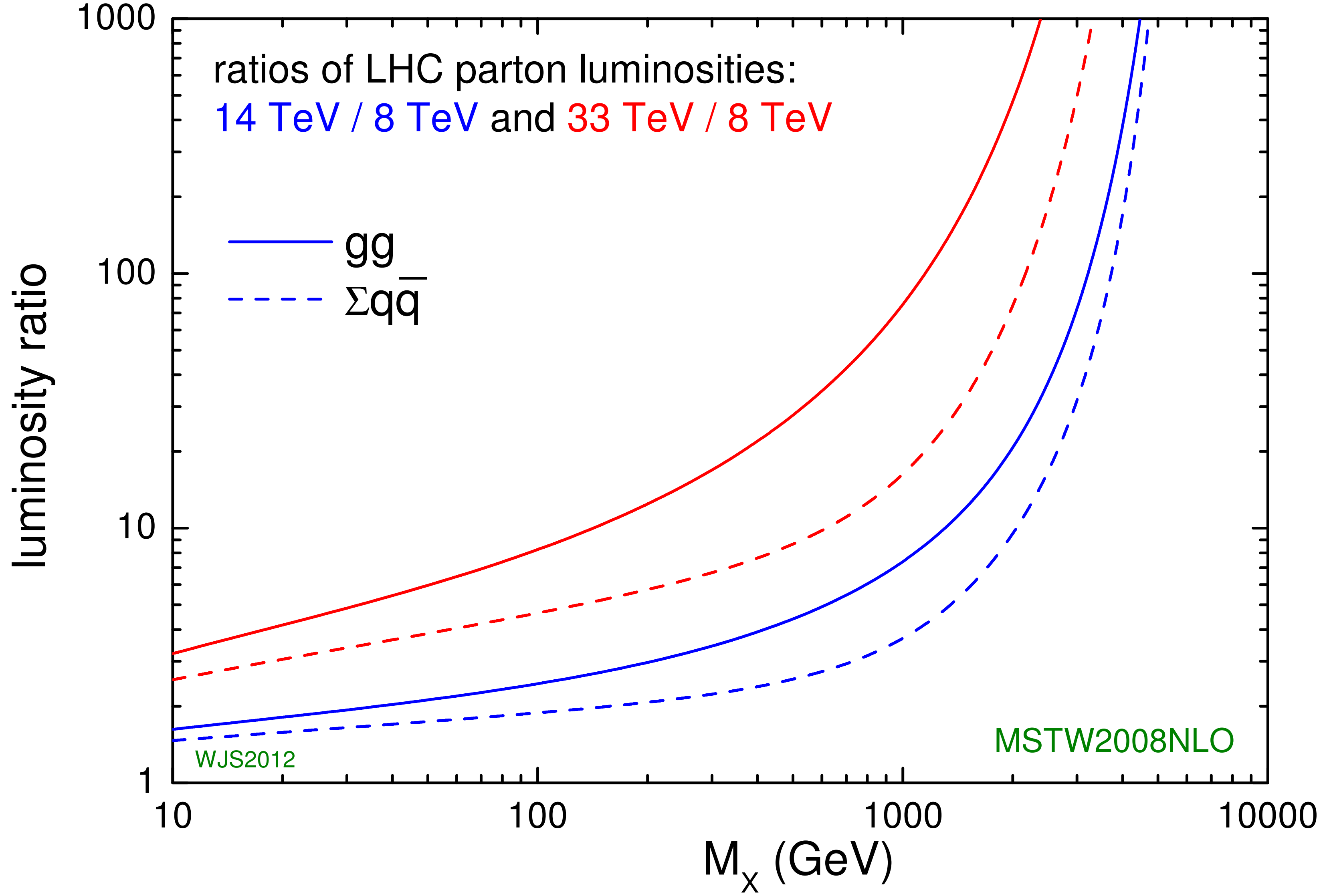
Motivation

Schedule

Our activities

Beyond the LHC Run 2

The standard model is an effective theory at low q^2
→ New physics is expected at higher q^2



Increasing the collision energy is an effective way to search for the new physics.
→ Another energy increase from 13 to 14 TeV is scheduled during Run 2.
→ 100 TeV Future Circular Collider is planed, but .... it is not so easy.

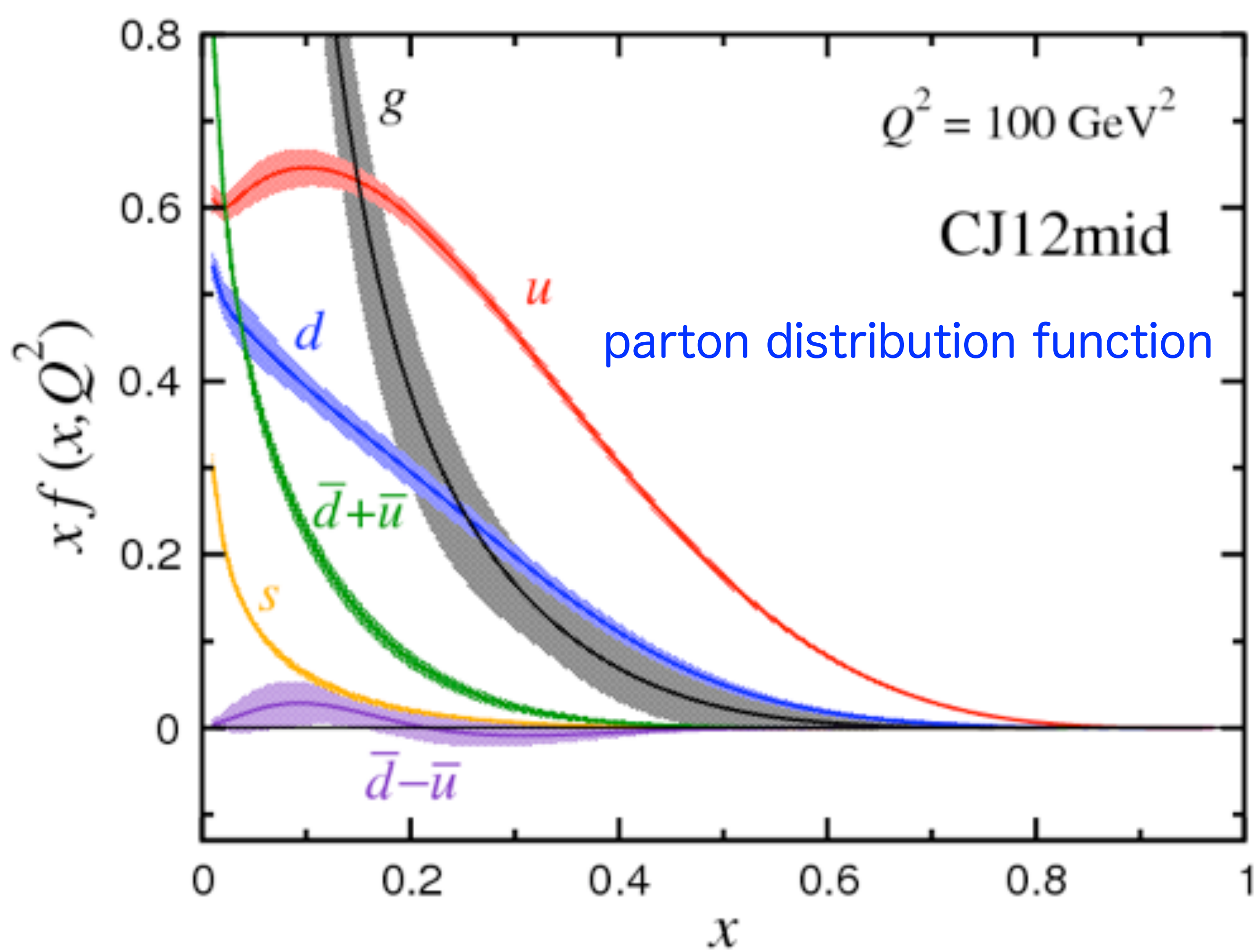
Beyond the LHC Run 2

Luminosity upgrade of LHC also increases the discovery potential for new physics.

Effective energy of parton-parton collision depends on the momentum fraction x.

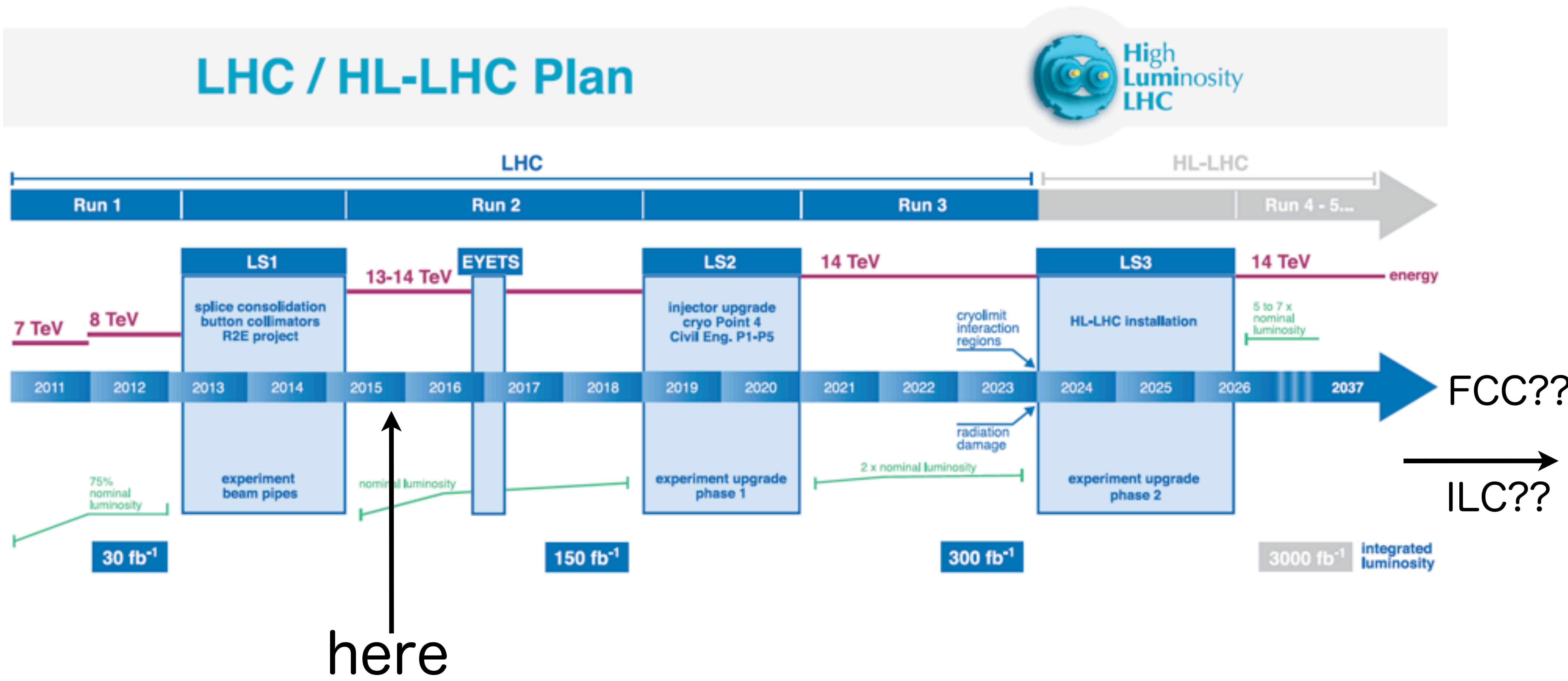
$$\underbrace{\sqrt{\hat{s}}}_{\text{effective energy}} = \sqrt{x_1 x_2}\underbrace{\sqrt{s_{pp}}}_{\text{p-p collision energy=14TeV(LHC design)}}$$

Collision with large x can produce heavier particles, but it is rare.



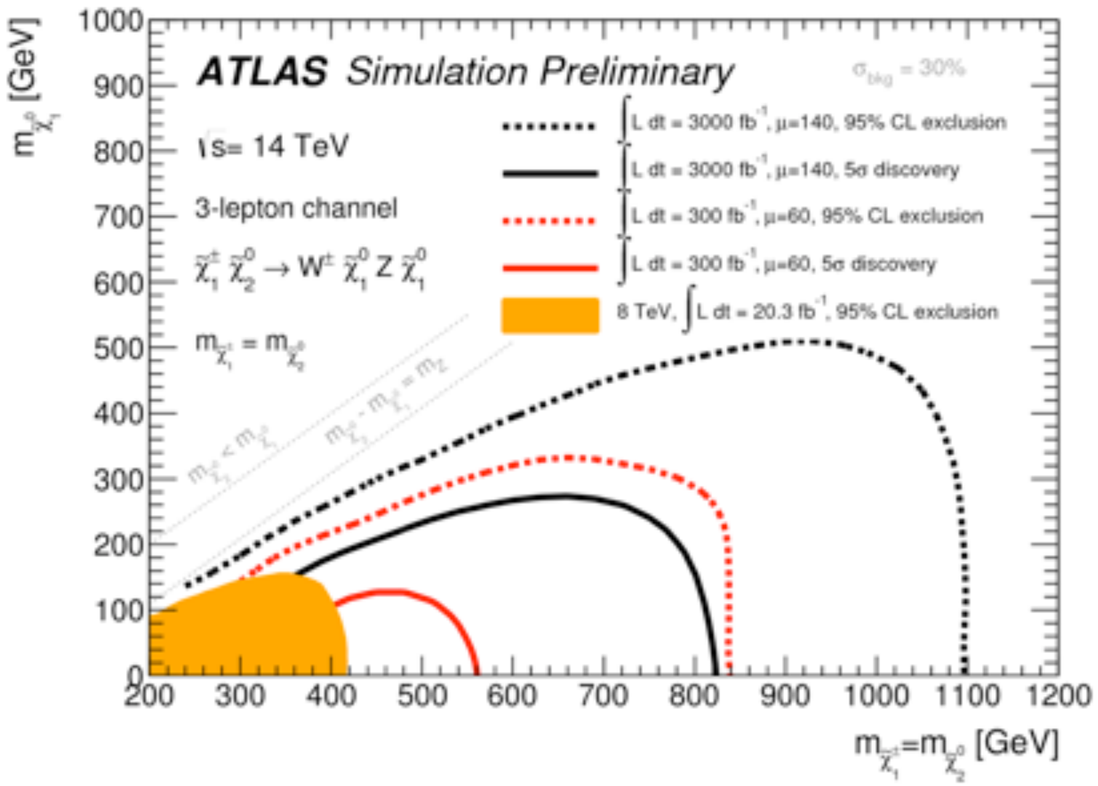
High luminosity LHC increase the potential to produce heavier particles.

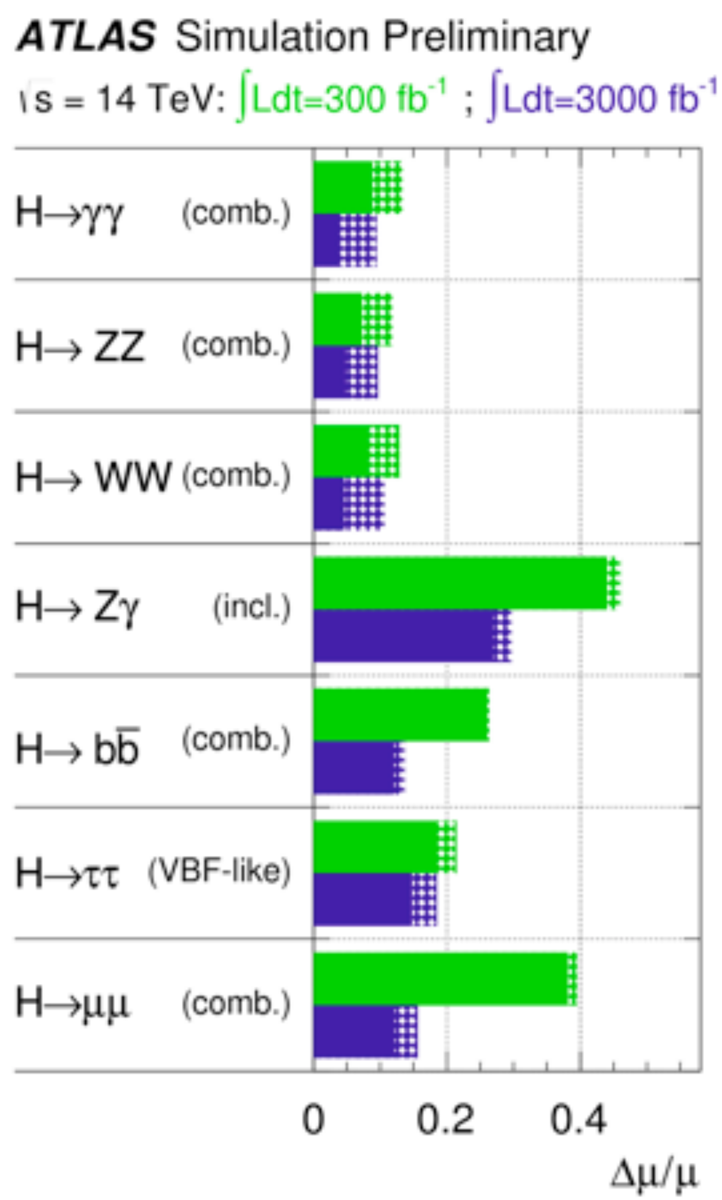
LHC upgrade projects

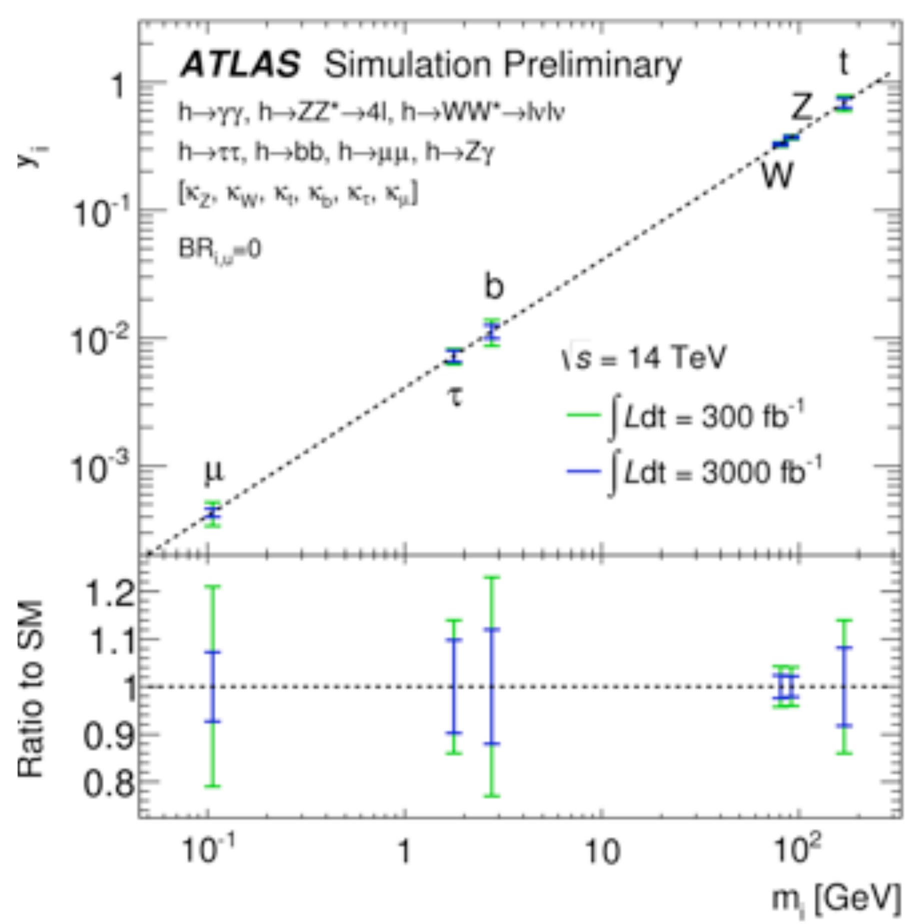


Physics motivation in HL-LHC

- Reach in new physics searches can be significantly extended.
- Higgs precision measurement can be significantly improved.
- Rare processes, such as H→$\mu\mu$ can be accessed.







Challenges

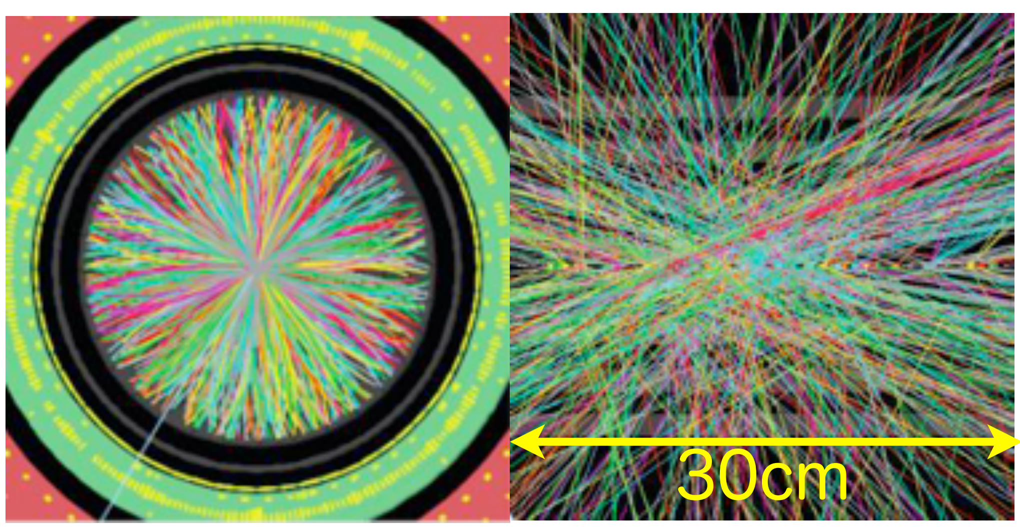
Total event rate = $\sigma_{pp} \times \mathcal{L}$

$\sigma_{pp}=10^{-1}$b >> $\sigma_{interest}=10^{-12}$b

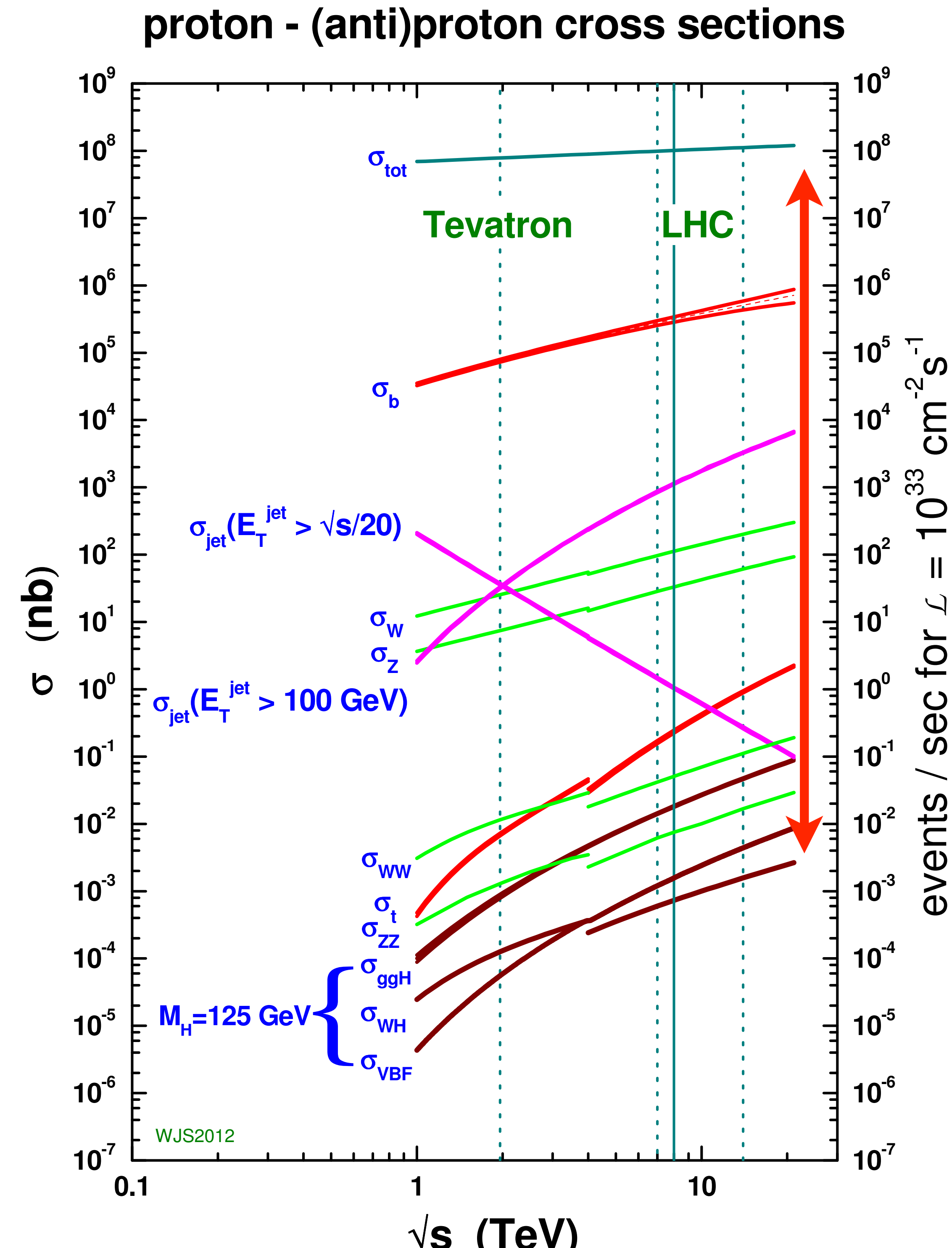
Low-q^2 QCD events need to be thrown away with keeping interesting events efficient.

$\sigma_{pp} \times \mathcal{L}$ > 40MHz of p-p collision rate

Reconstructing trajectory of the tracks of the particles in a severe environment is crucial.



pileup events $\langle\mu\rangle$ = 140~200 in HL-LHC



Detector upgrade in HL-LHC is focused on :

1. Development of the advanced trigger system — Muon trigger system

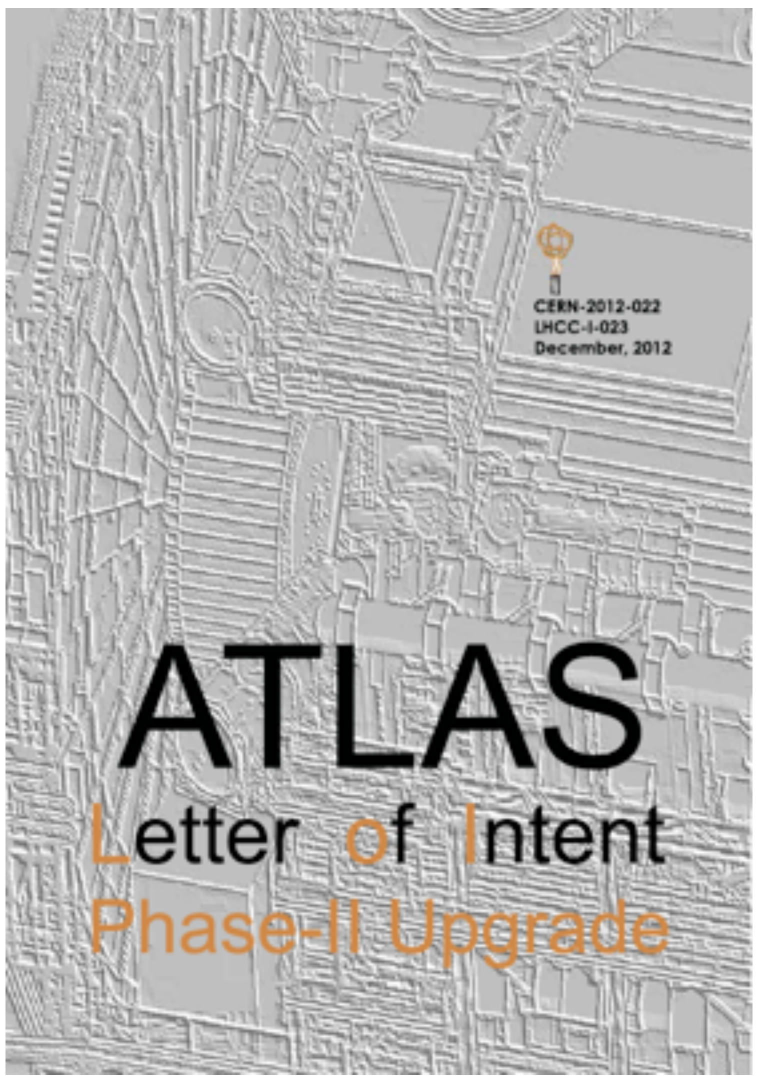
   To provide better tracking resolution in 140 pileups with rad-hard detector.

2. Replacement of the inner and forward detectors — Inner tracker

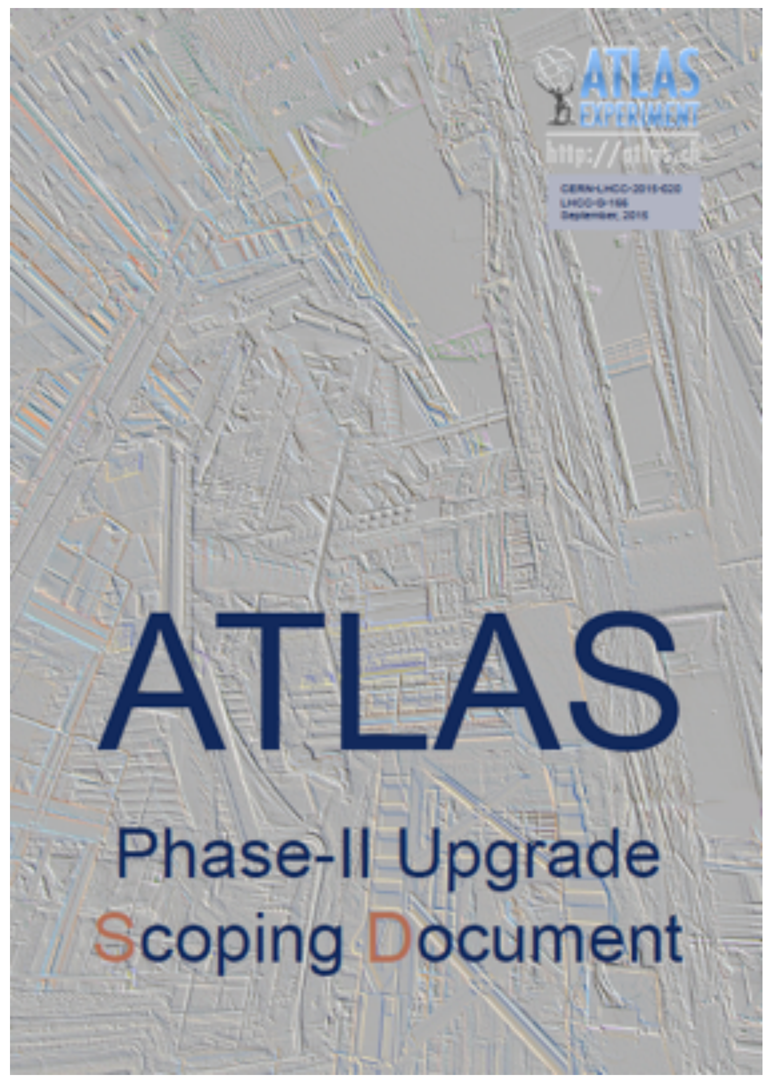
   To reduce the trigger rate without losses of the interesting events.

Milestones

Dec. 2012
Letter of Intent
148 pages



Sep. 2015
Scoping Document
239 pages



2016
Initial Design Review (IDR)

2017
Technical Design Report (TDR)

Cost estimates

200MCHF = 250億円
235MCHF = 290億円
275MCHF = 340億円

Trigger

Data acquisition

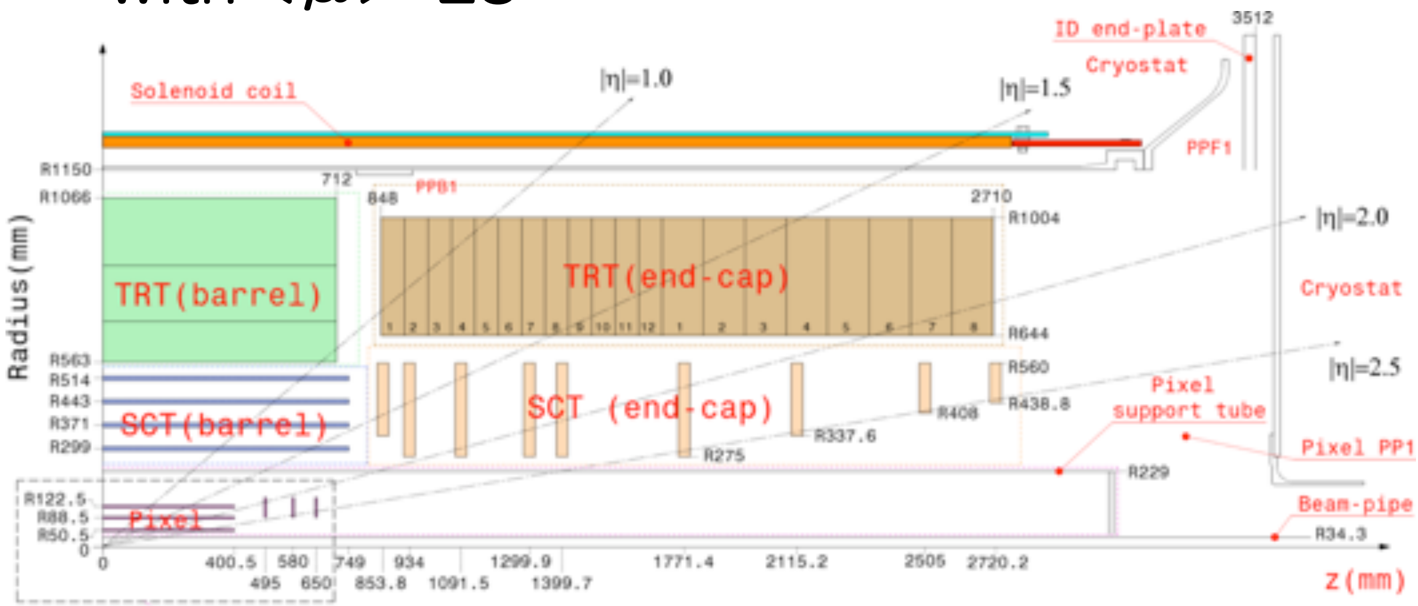
Inner Tracker

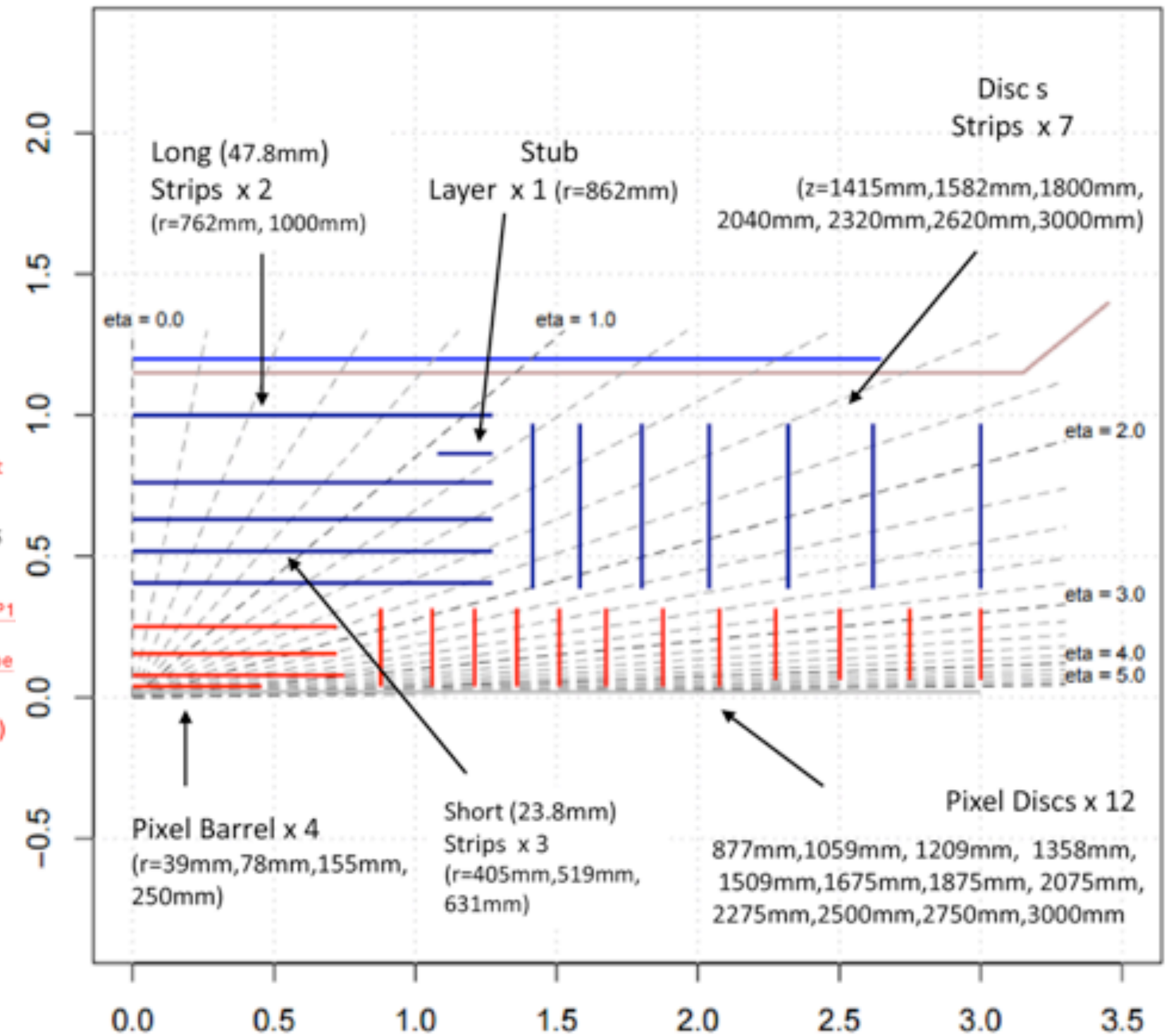
Calorimeter

Trigger and Data Acquisition	Reference (275 MCHF)	Scoping Scenarios Middle (235 MCHF)	Low (200 MCHF)
Level-0 Trigger System			
Central Trigger	✓	✓	✓
Calorimeter Trigger (e/γ)	$\lvert\eta\rvert < 4.0$	$\lvert\eta\rvert < 3.2$	$\lvert\eta\rvert < 2.5$
Muon Barrel Trigger	MDT everywhere RPC-BI Tile-μ	MDT (BM & BO only) Partial η coverage RPC-BI Tile-μ	MDT (BM & BO only) No RPC-BI Tile-μ
Muon End-cap Trigger	MDT everywhere	MDT (EE&EM only)	MDT (EE&EM only)
Level-1 Trigger System			
Output Rate [kHz]	400	200	200
Central Trigger	✓	✓	✓
Global Trigger	✓	✓	✓
Level-1 Track Trigger (*RoI based tracking*)	$p_T > 4$ GeV $\lvert\eta\rvert \leq 4.0$	$p_T > 4$ GeV $\lvert\eta\rvert \leq 3.2$	$p_T > 8$ GeV $\lvert\eta\rvert \leq 2.7$
High-Level Trigger			
FTK++ (*Full tracking*)	$p_T > 1$ GeV 100 kHz	$p_T > 1$ GeV 50 kHz	$p_T > 2$ GeV 50 kHz
Event Filter	10 kHz output	5 kHz	5 kHz
DAQ			
Detector Readout	✓ [400 kHz L1 rate]	✓ [200 kHz L1 rate]	✓ [200 kHz L1 rate]
DataFlow	✓ [400 kHz L1 rate]	✓ [200 kHz L1 rate]	✓ [200 kHz L1 rate]
Inner Tracker			
Pixel Detector	$\lvert\eta\rvert \leq 4.0$	$\lvert\eta\rvert \leq 3.2$	$\lvert\eta\rvert \leq 2.7$
Barrel Strip Detector	✓	✓ [No stub layer]	✓ [No stereo in layers #2,#4] [Remove layer #3] [No stub layer]
Endcap Strip Detector	✓	✓ [Remove 1 disk/side]	✓ [Remove 1 disk/side]
Calorimeters			
LAr Calorimeter Electronics	✓	✓	✓
Tile Calorimeter Electronics	✓	✓	✓
Forward Calorimeter	✓	✗	✗
High Granularity Precision Timing Detector	✓	✗	✗

Inner Tracker (ITK)

- Current inner detector is designed to operate for 10 years at L=$10^{34}cm^{-2}s^{-1}$ with $<\mu>=23$





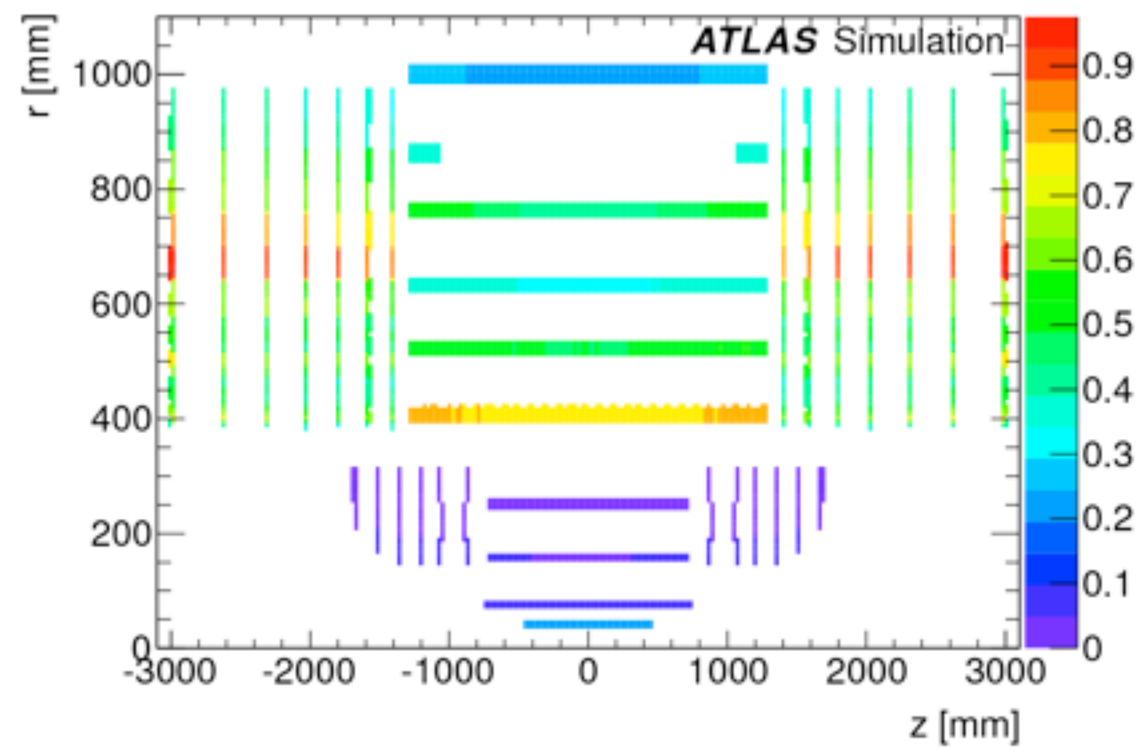
- ID will be replaced by ITK after Run 3.

- Fully silicon detector will be built extending significantly current pixel+SCT radial and forward directions and the detector performance

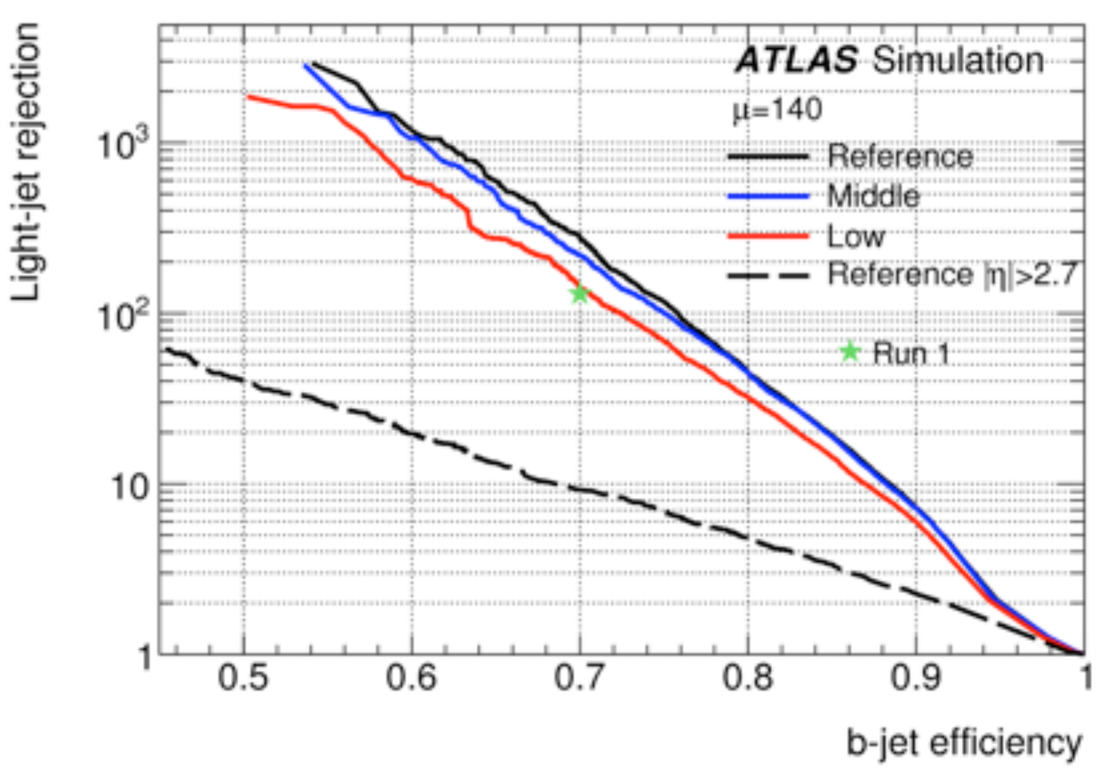
- Depending on the scenarios, the acceptance is difference
  Reference scenario : $|\eta|<4$

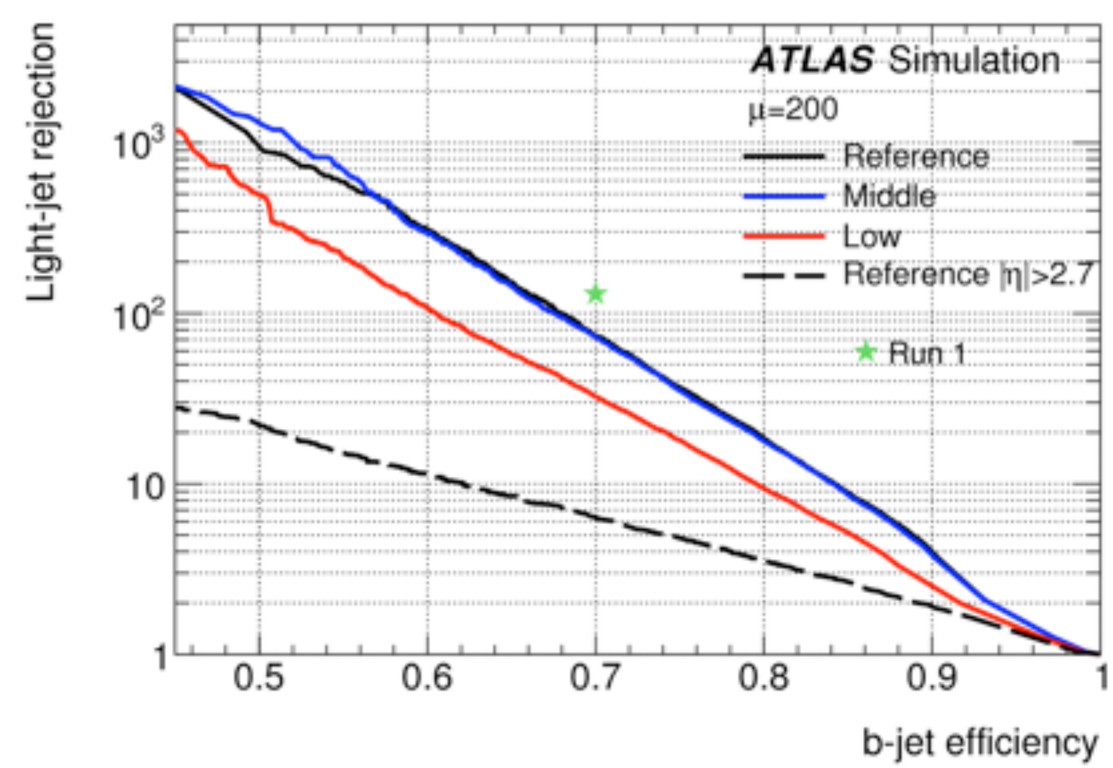
Performance of the Inner Tracker (ITK)

- Low occupancy < 1% for <μ>=200



- B-tagging efficiency will be kept to good level.
- Developing new tagging algorithm will help to recover Run 3 or better performance.

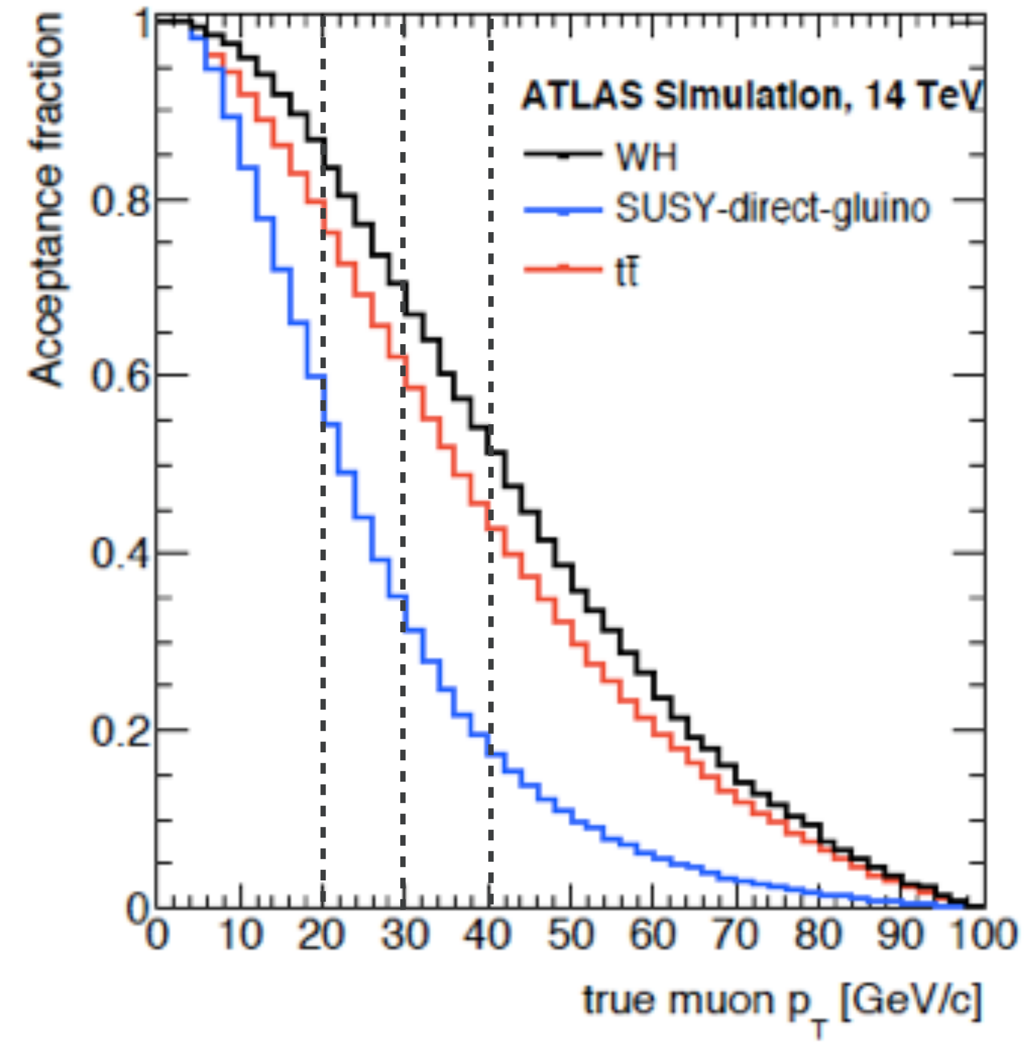




Trigger upgrade

If the current trigger is kept using in HL-LHC, the trigger rate goes up, but we cannot raise the threshold up

Trigger	Estimated L1 Rate
EM_20 GeV	200 kHz
MU_20 GeV	> 40 kHz
TAU_50 GeV	50 kHz
di-lepton	100 kHz
JET + MET	~ 100 kHz
Total	500 kHz



In HL-LHC condition, we need

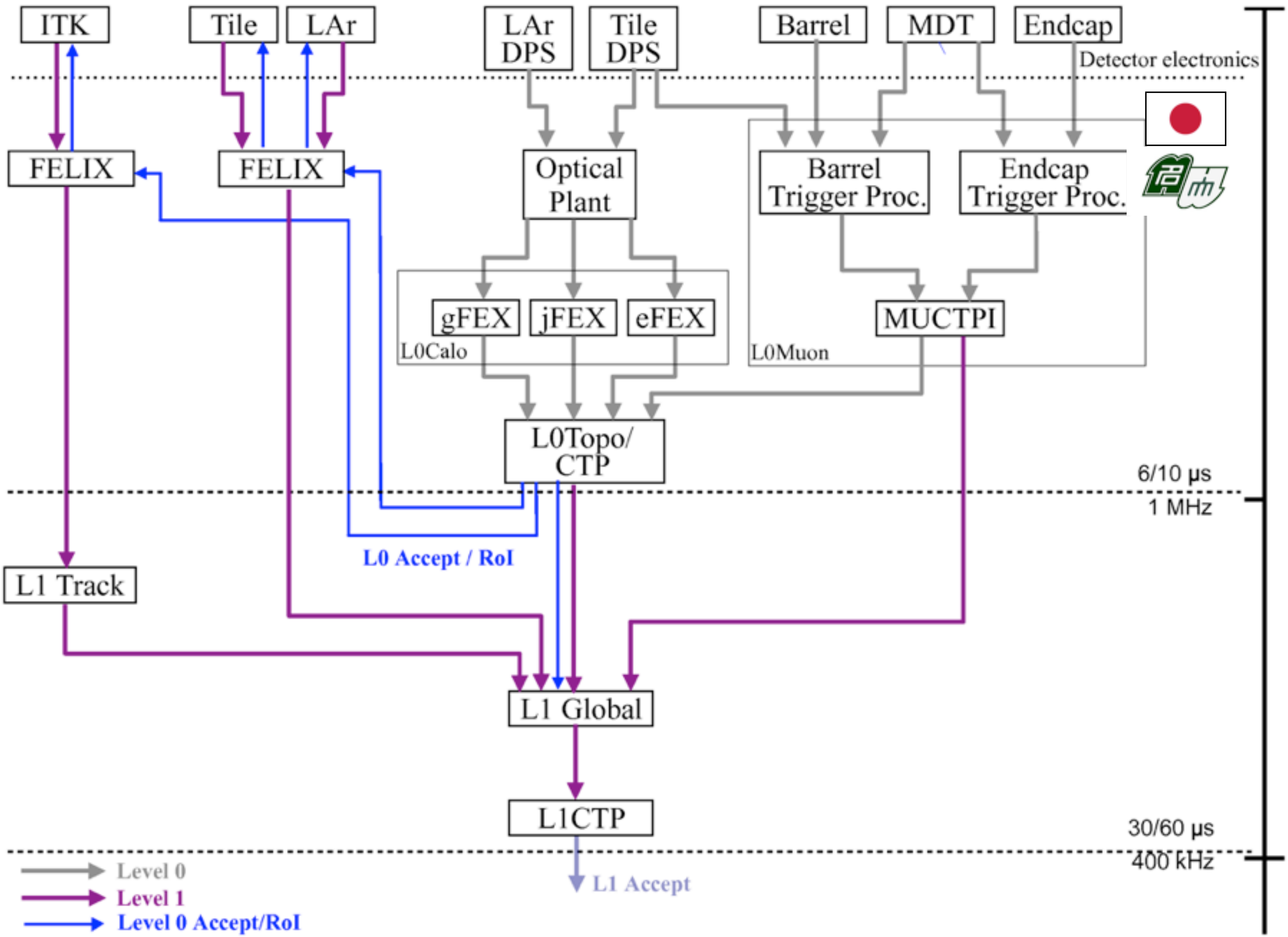
(1) Replacement of the trigger electronics to bare higher trigger rate

L0 Trigger : latency=6μs, rate=1MHz

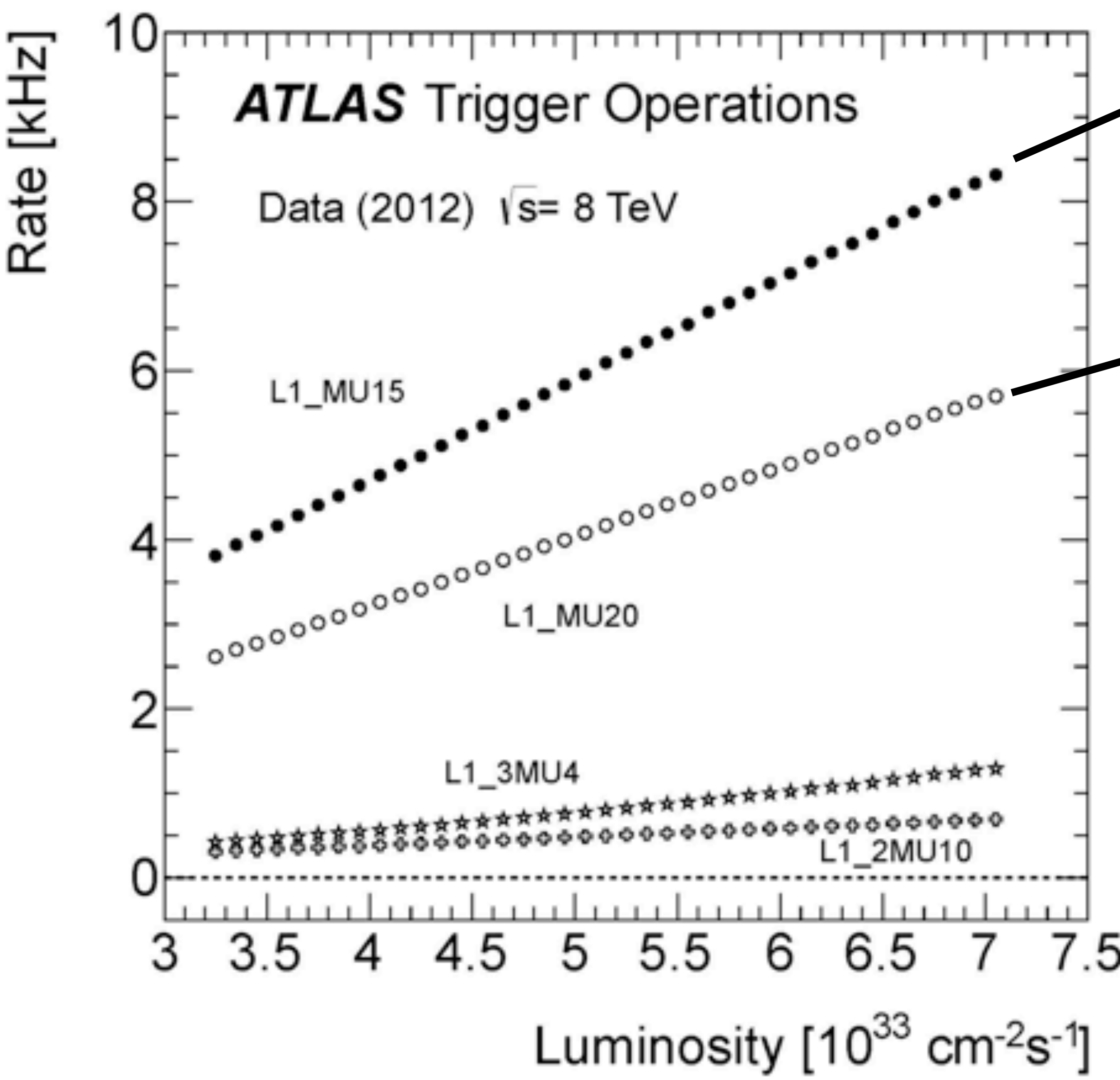
L1 Trigger : latency=30μs, rate=300~400kHz

(2) Development of the advanced trigger algorithm to reduce trigger rate with even relaxing the trigger threshold

HL-LHC Trigger system



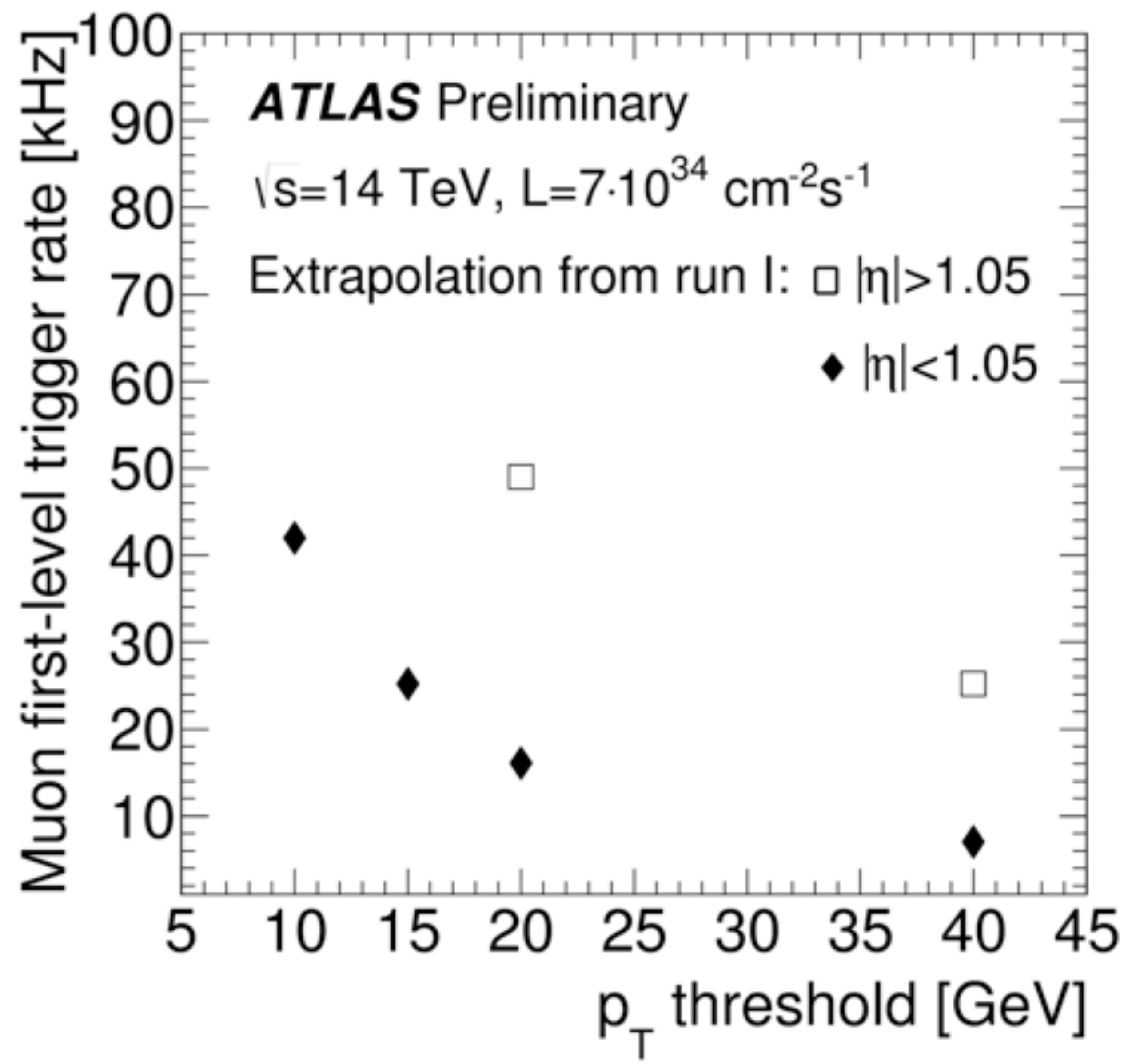
Muon trigger rate in HL-LHC



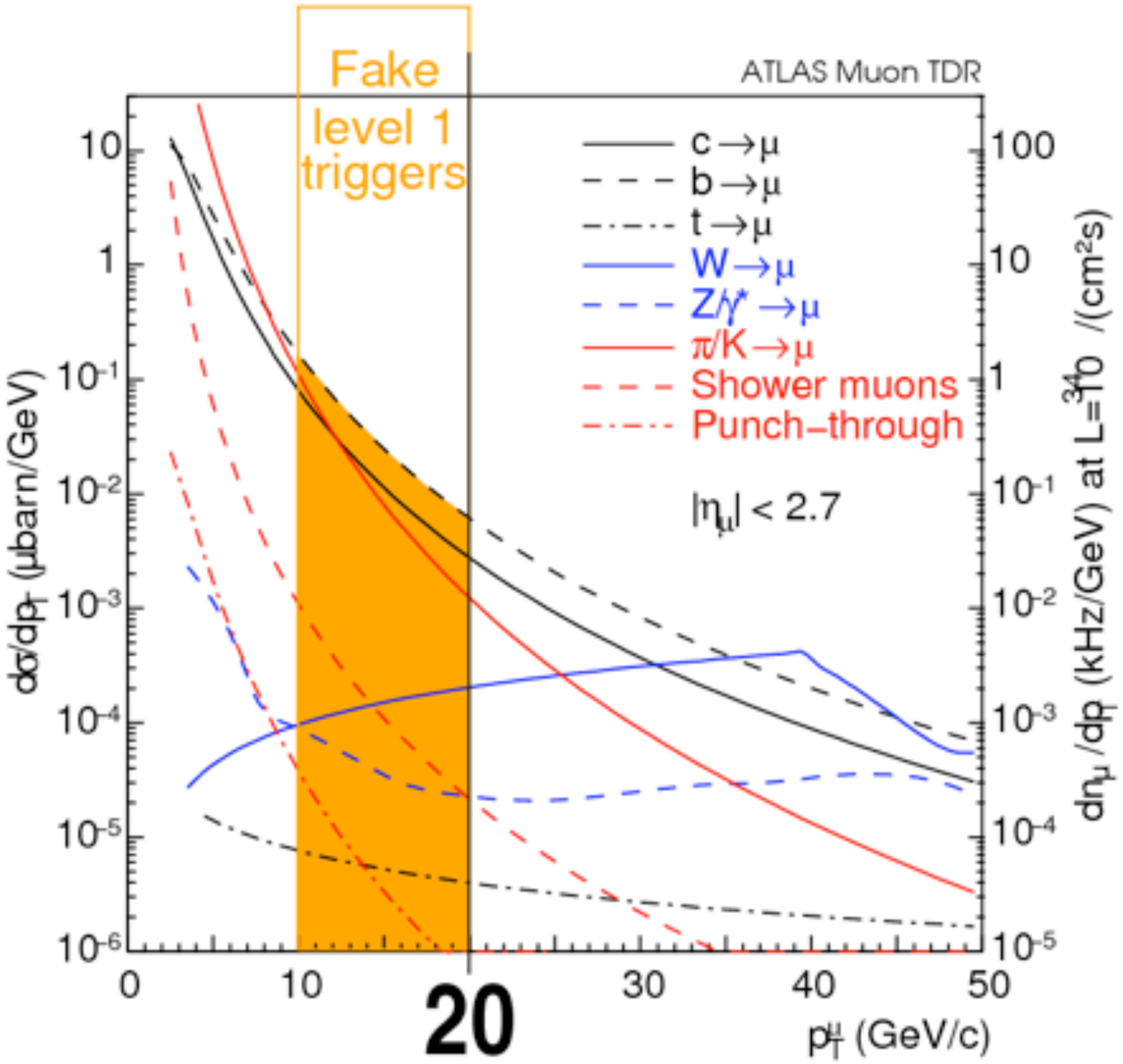
>60kHz

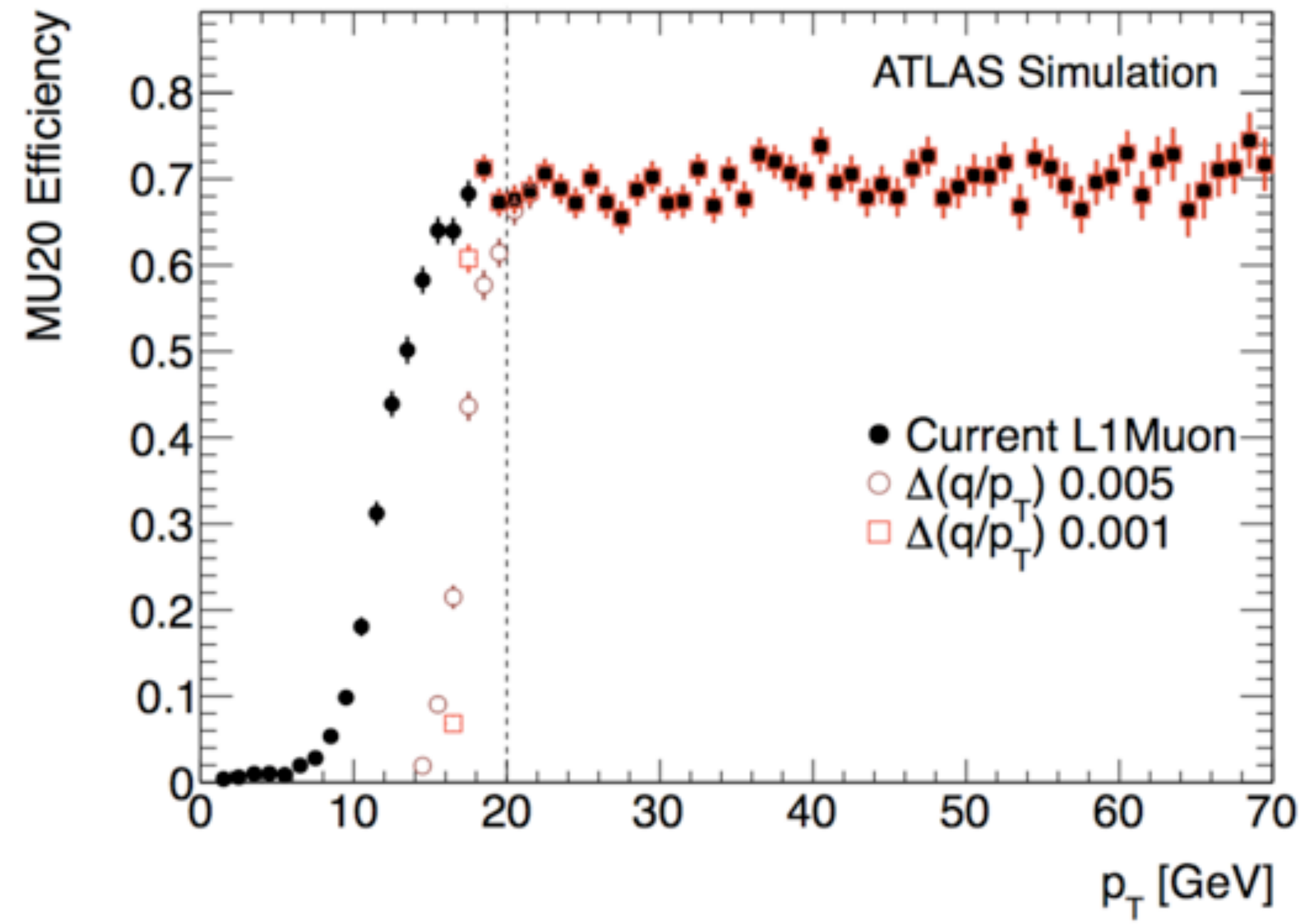
>40kHz

@ $\mathcal{L} = 5 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
8TeV →14TeV &
Run 3 upgrades
are taken into account.



Muon trigger upgrade



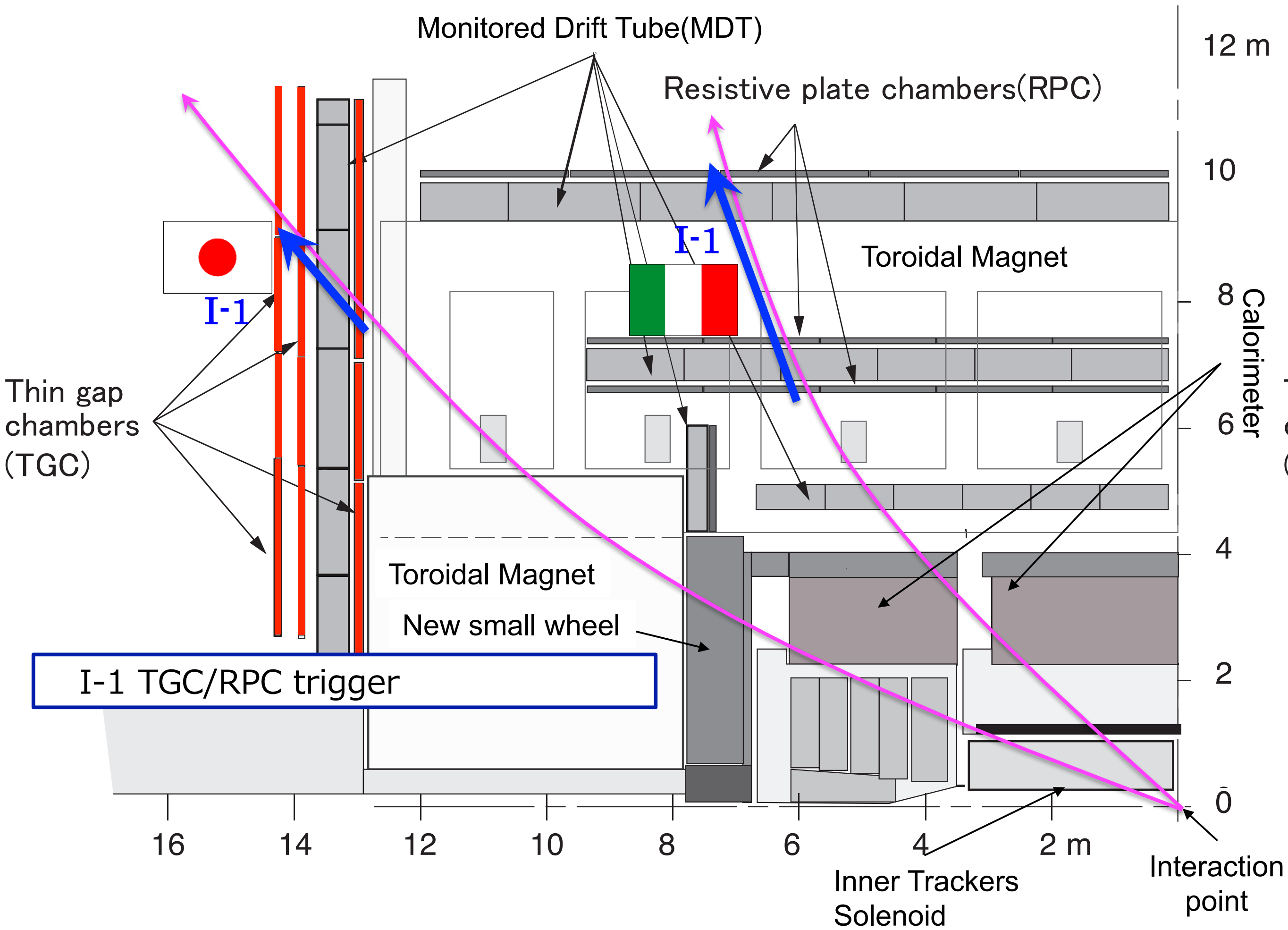


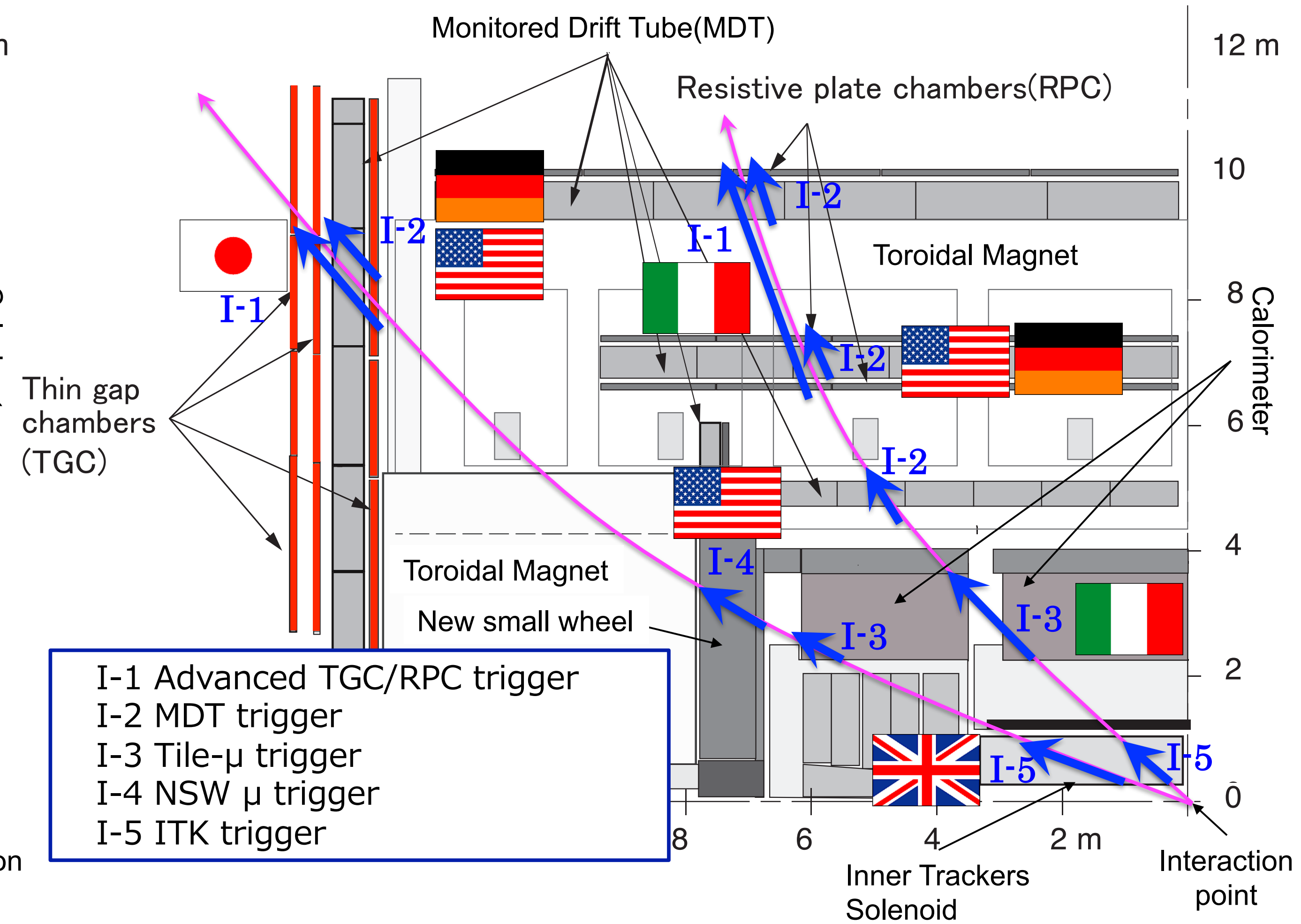
- pT threshold of muon as low as 20 GeV is desirable to be sensitive to electroweak physics processes.
- p_T distribution of muons produced by LHC is steeply falling with increasing p_T.
- Current L1 20GeV muon trigger accepts muons down to pT~10GeV.
- The muon trigger rate is dominated by the huge rate of muons with 10GeV≦pT≦20GeV.

Improving pT resolution of the muon trigger is crucial to reduce the trigger rate.

Muon trigger upgrade

Current muon trigger is based on the L1 TGC/RPC triggers.





Muon trigger upgrade for HL-LHC consists of

(1) L0 TGC/RPC muon trigger upgrade

(2) L0 Muon trigger with precision chamber (Monitored Drift Tube)

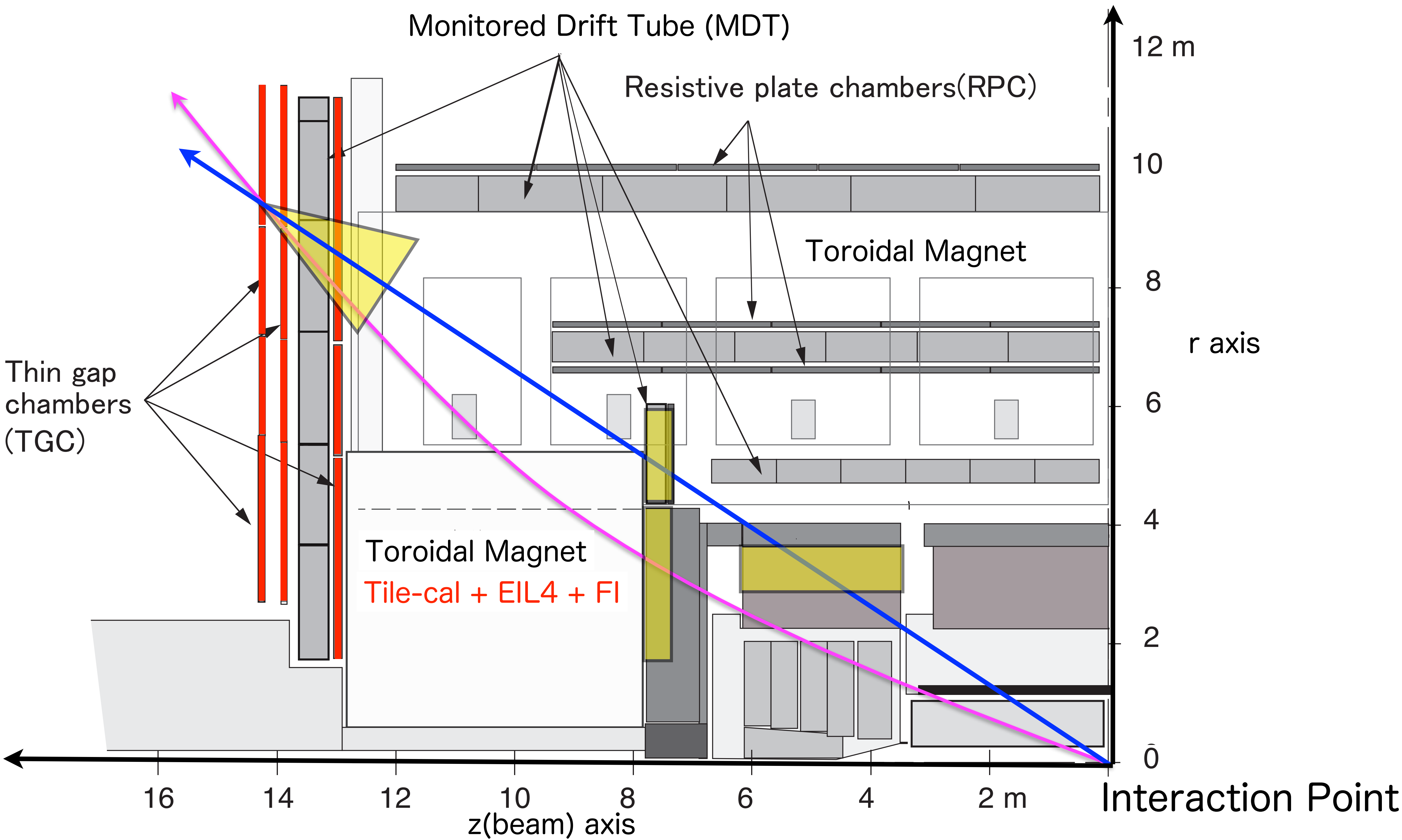
(3) L0 Muon trigger with calorimeter

(4) L0 Muon trigger with new inner muon chambers

(5) L1 Muon trigger with ITK

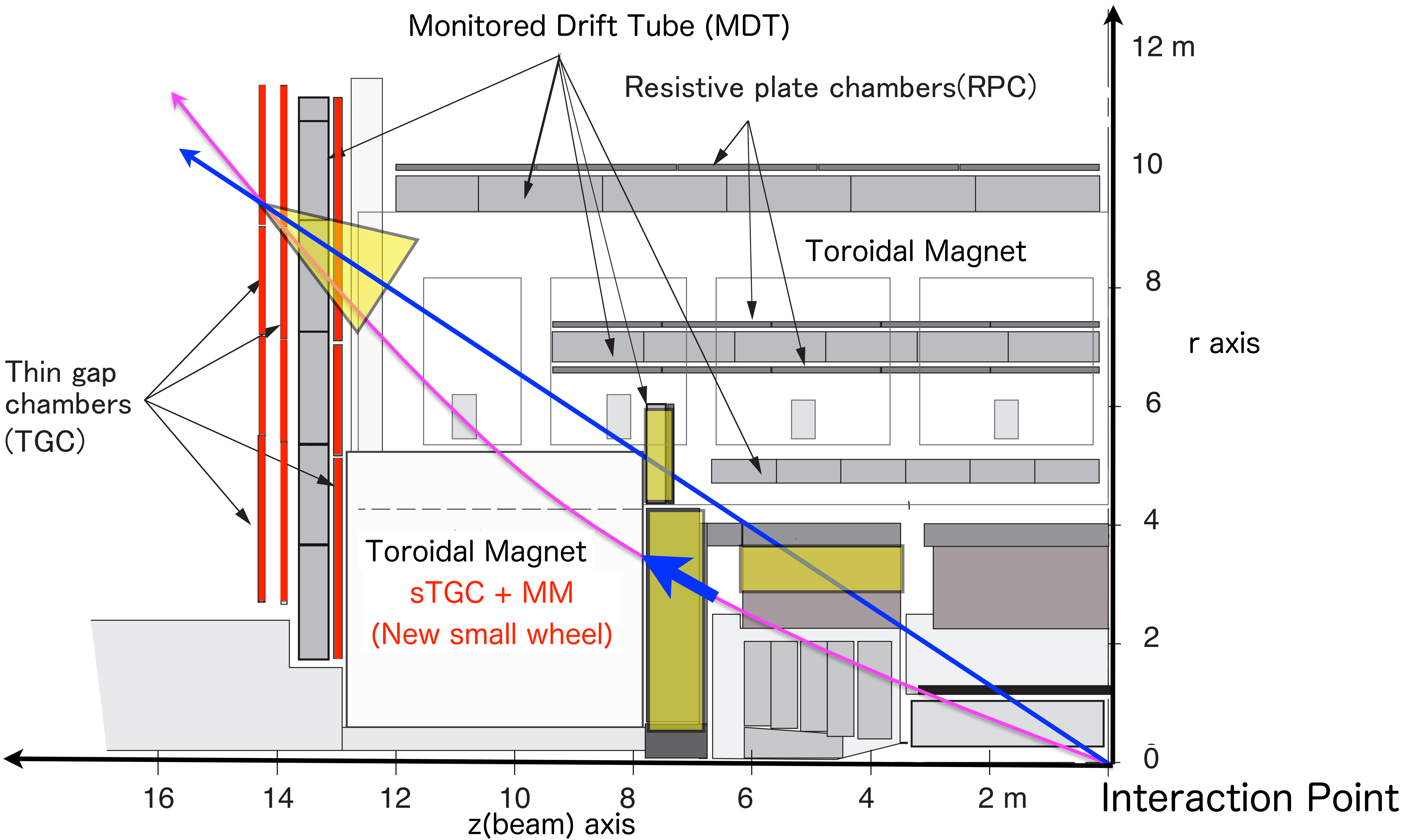
Current endcap muon trigger

Based on the coincidence between muon trigger chambers.



L1 endcap muon trigger in run 3

sTGC and Micro Megas in New Small Wheel (NSW) will provide the segment of the muon trajectory before the toroidal magnet.
Deflection angle between NSW and the direction from IP to TGC can be used.

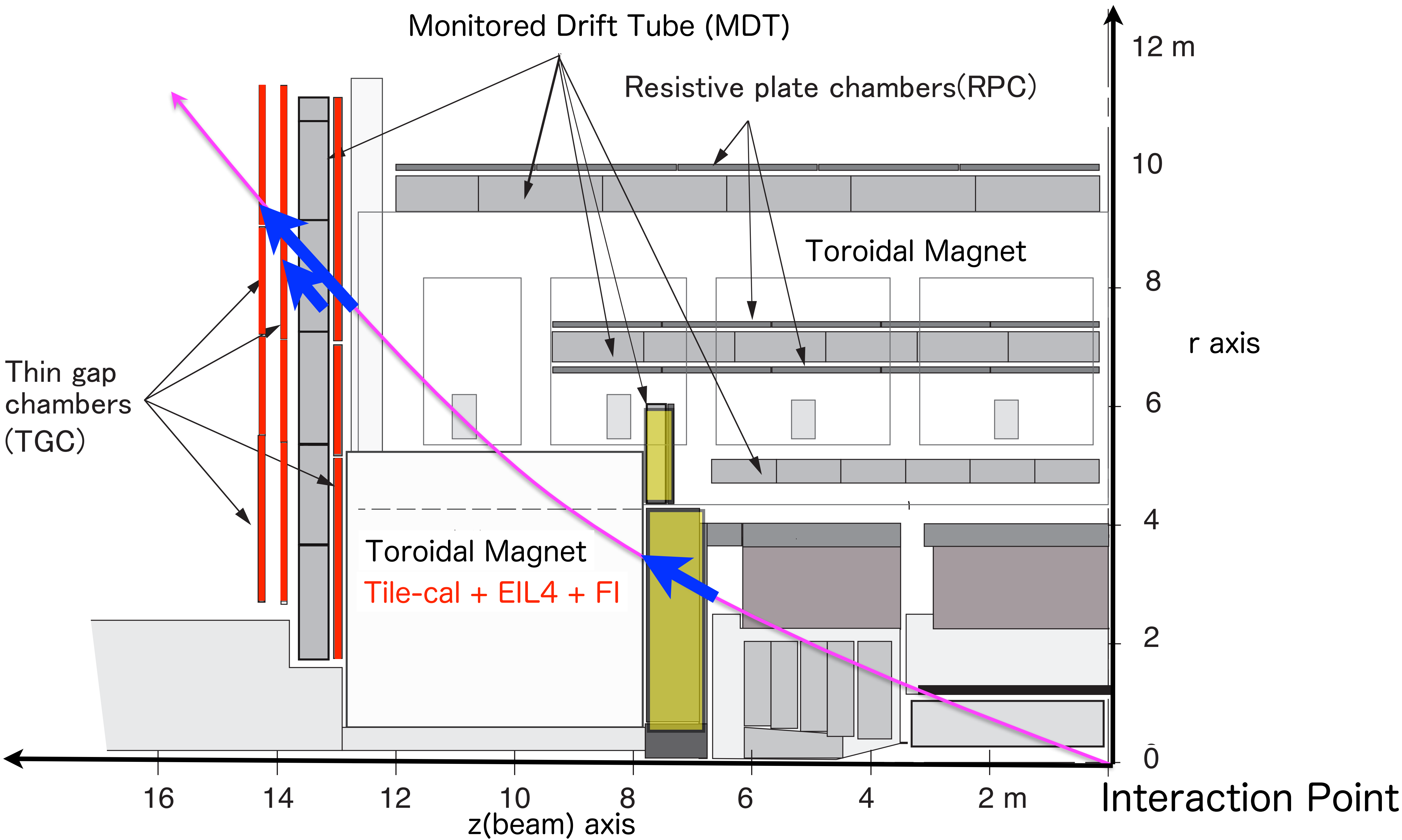


Muon Trigger in HL-LHC

In HL-LHC, the segment is reconstructed from TGC hits as well as MDT hits.

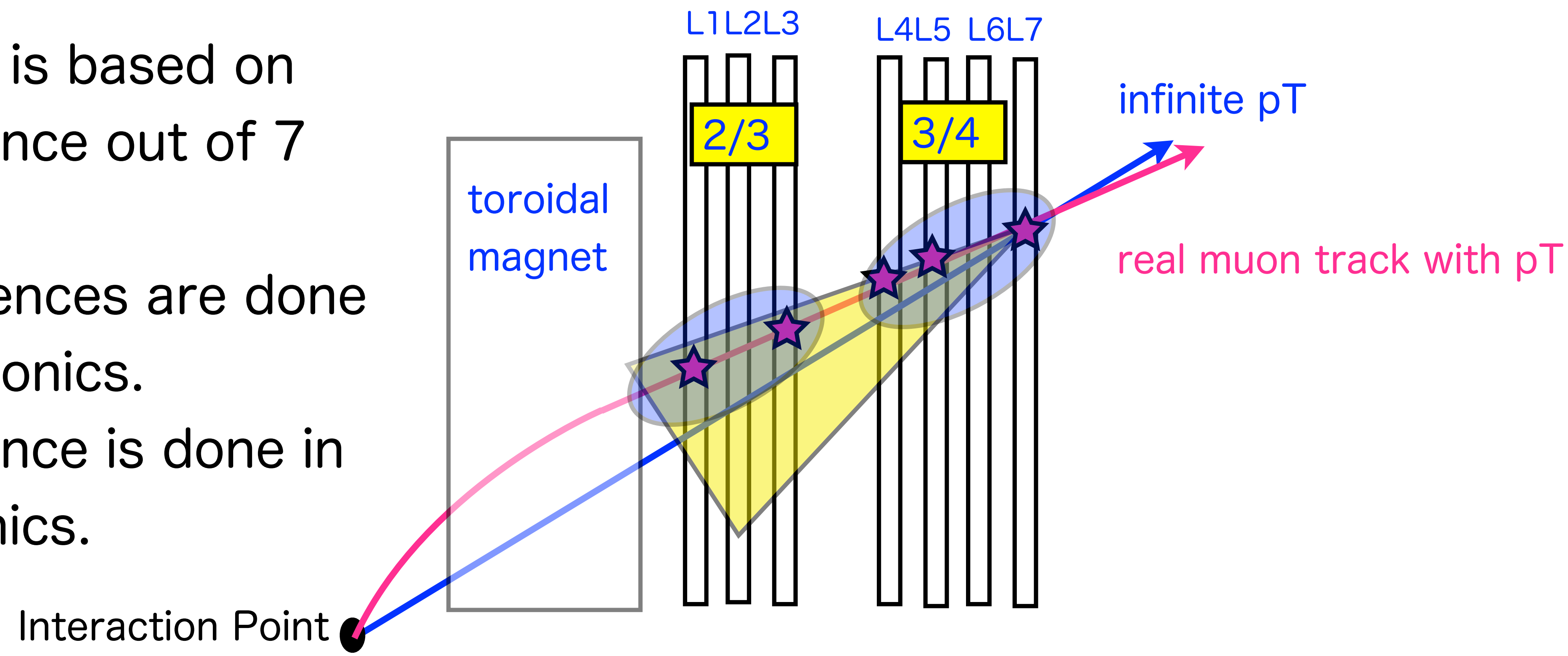
TGC tracking MDT tracking

Deflection angle between TGC/MDT and NSW can be used to improve the p_T resolution.



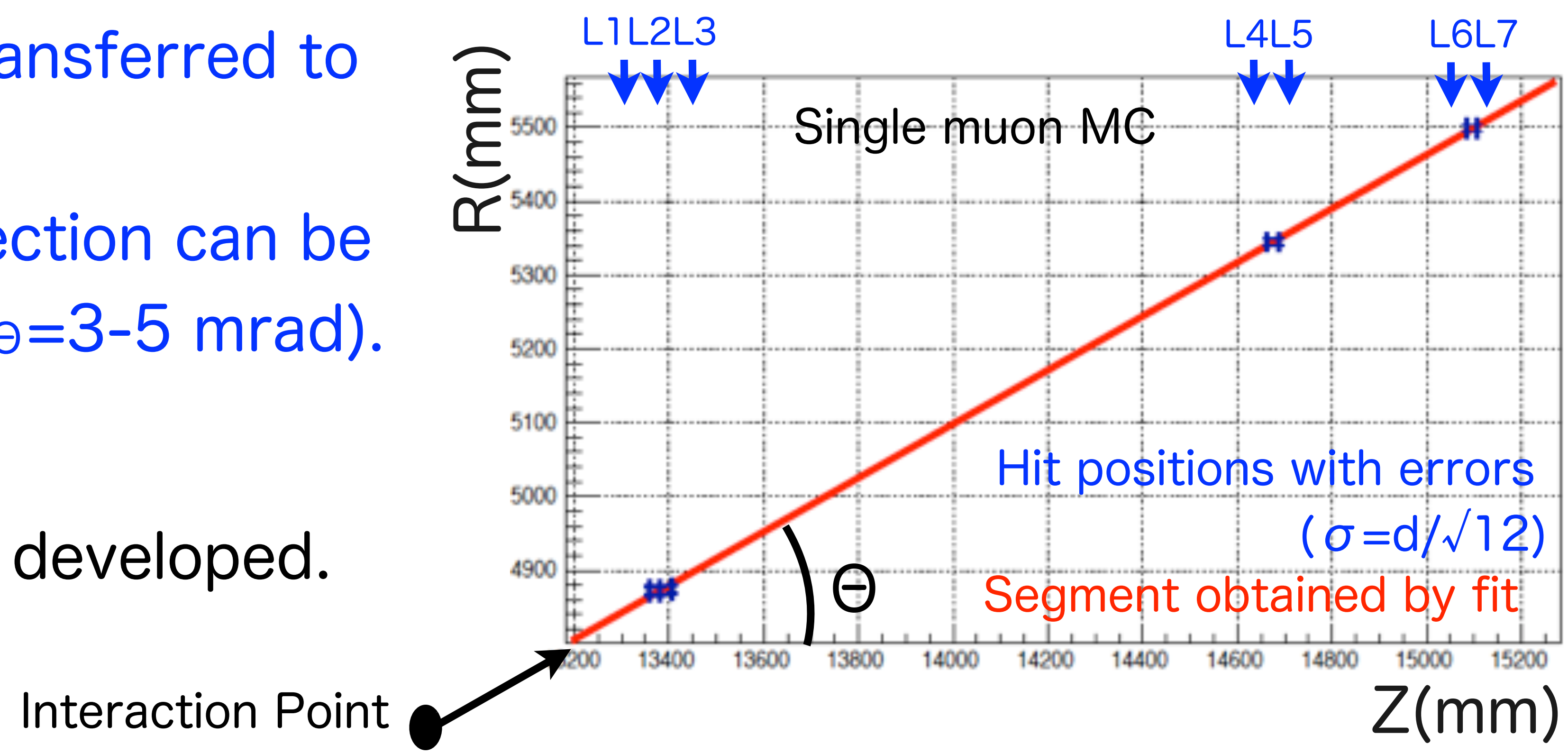
Concept of TGC tracking trigger

- Current TGC trigger is based on 2/3 && 3/4 coincidence out of 7 layer hits.
- 2/3 and 3/4 coincidences are done in on-detector electronics.
- 2/3 && 3/4 coincidence is done in off-detector electronics.



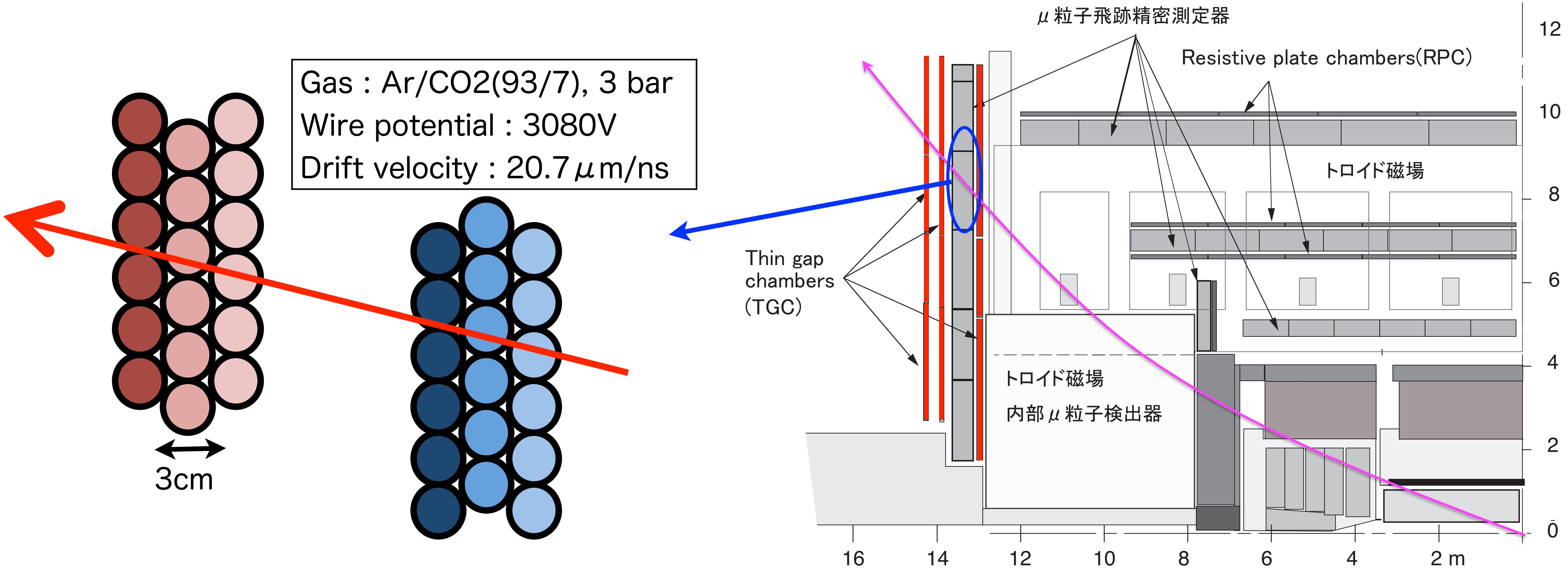
- HL-LHC upgrade will be based on 7-layer track fitting
  - All hit informations will be transferred to off-detector electronics first
  - Angle of the muon track direction can be obtained from a track fit (σ_{Θ}=3-5 mrad).

Track fit algorithm needs to be developed.



Concept of MDT tracking trigger

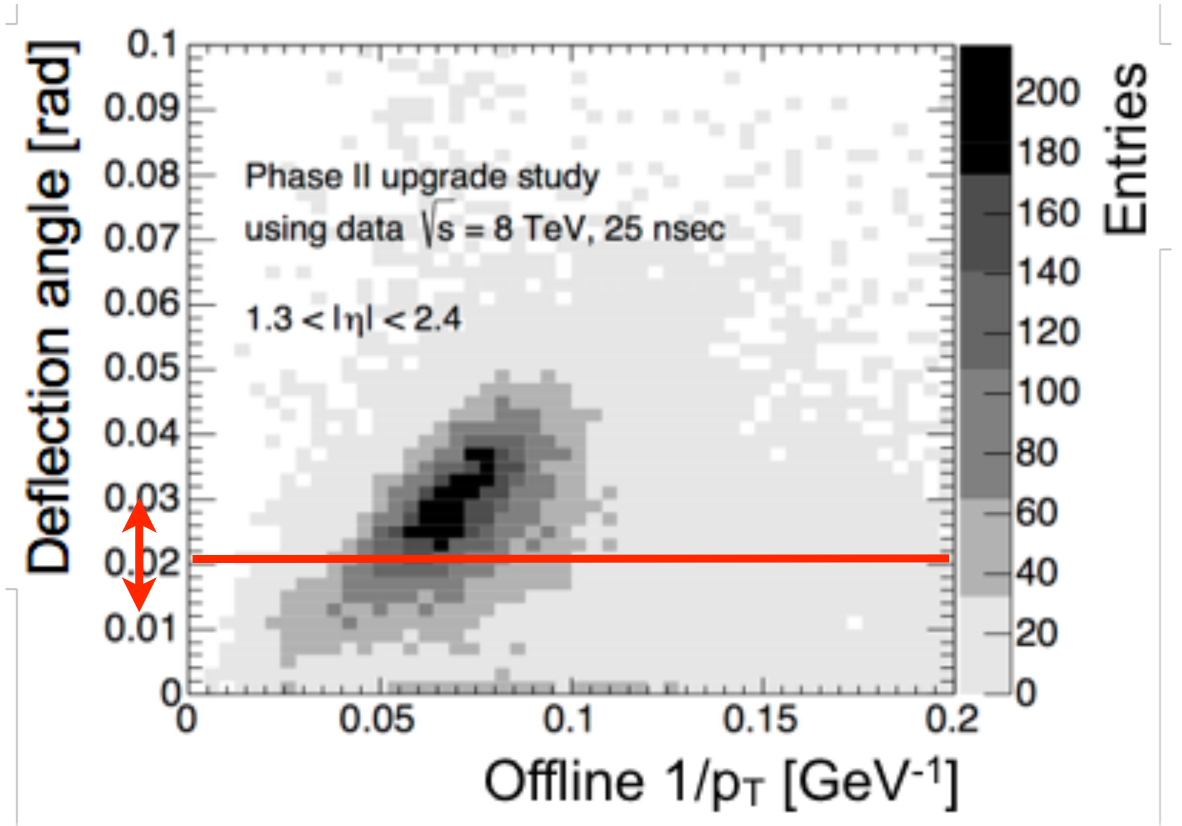
- Monitored Drift Tube (MDT) is the drift chamber which provides precise muon tracking.



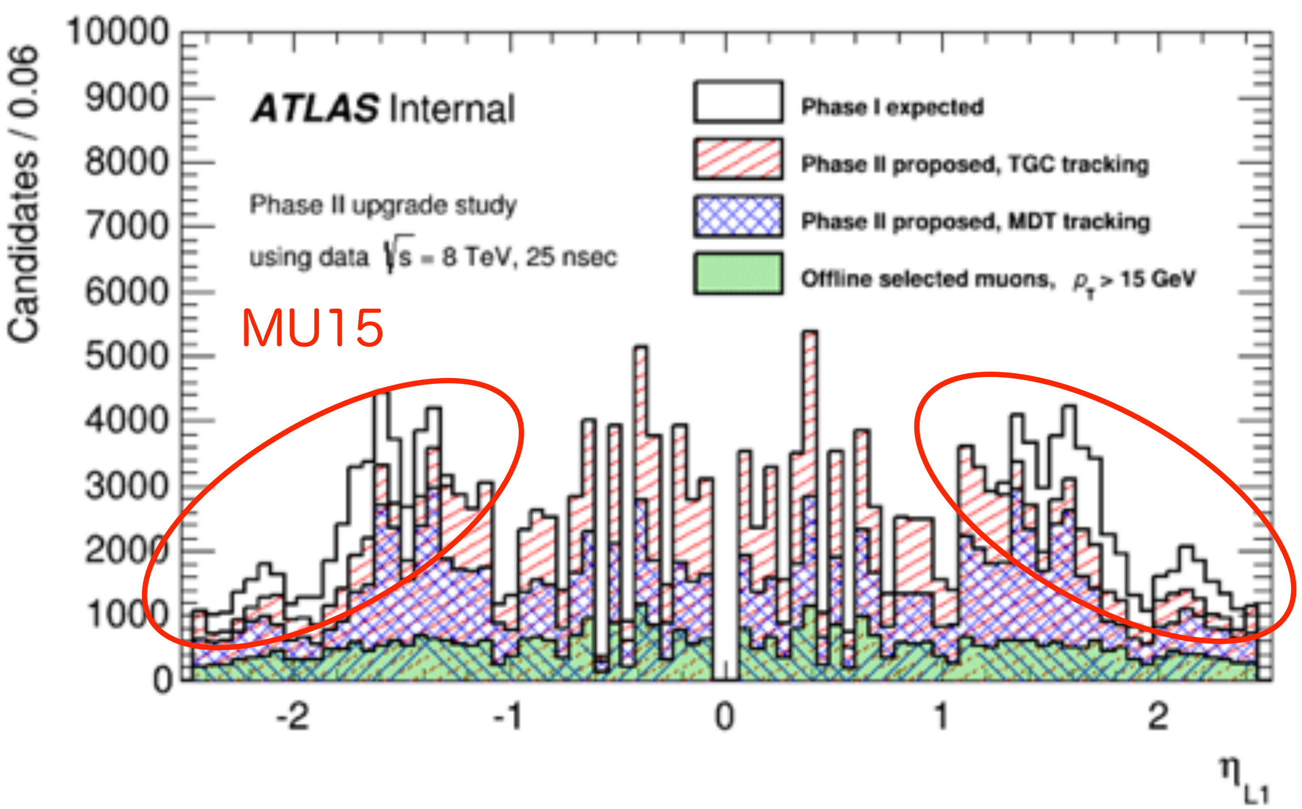
- MDT trigger is employed newly in HL-LHC upgrade.
  - TDC (Time-to-digital converter) to measure the drift time for both of the L0 trigger (binning : 12.5 ns) and the precision measurement (binning : 0.78ns) needs to be developed.
  - Track finding/fitting algorithm needs to be developed.

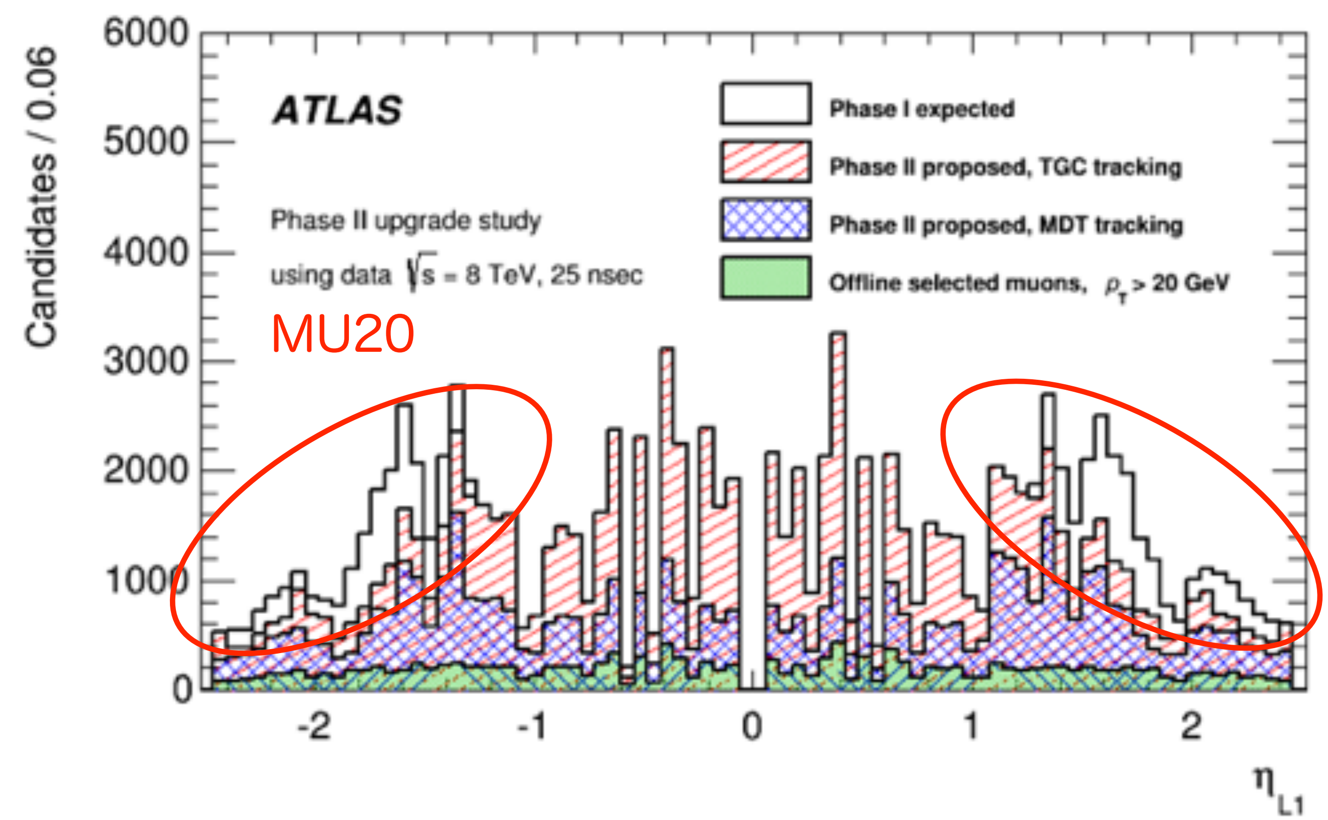
Performance study

- Done by enhanced bias trigger data in run1.
- The deflection angle between TGC/MDT and NSW is used to select muon above a certain p_T threshold.
- The selection criteria depends on the strength of the toroidal magnetic field.
- The efficiency of high pT muon is as high as one in run1.

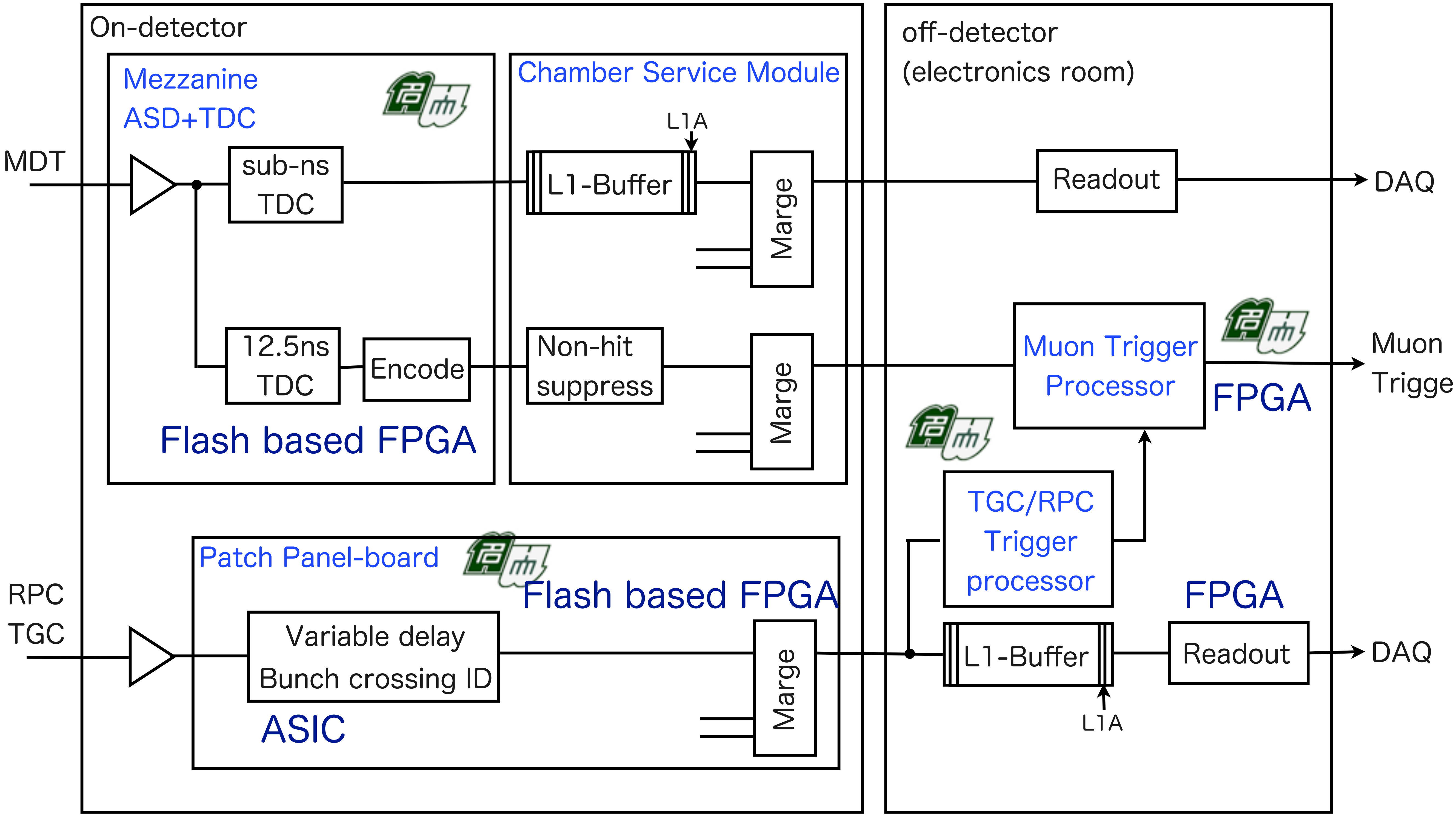


- The rate reduction by TGC track trigger is 30% for 1.3<|η|<2.4.
- The rate reduction by MDT track trigger is 50%.





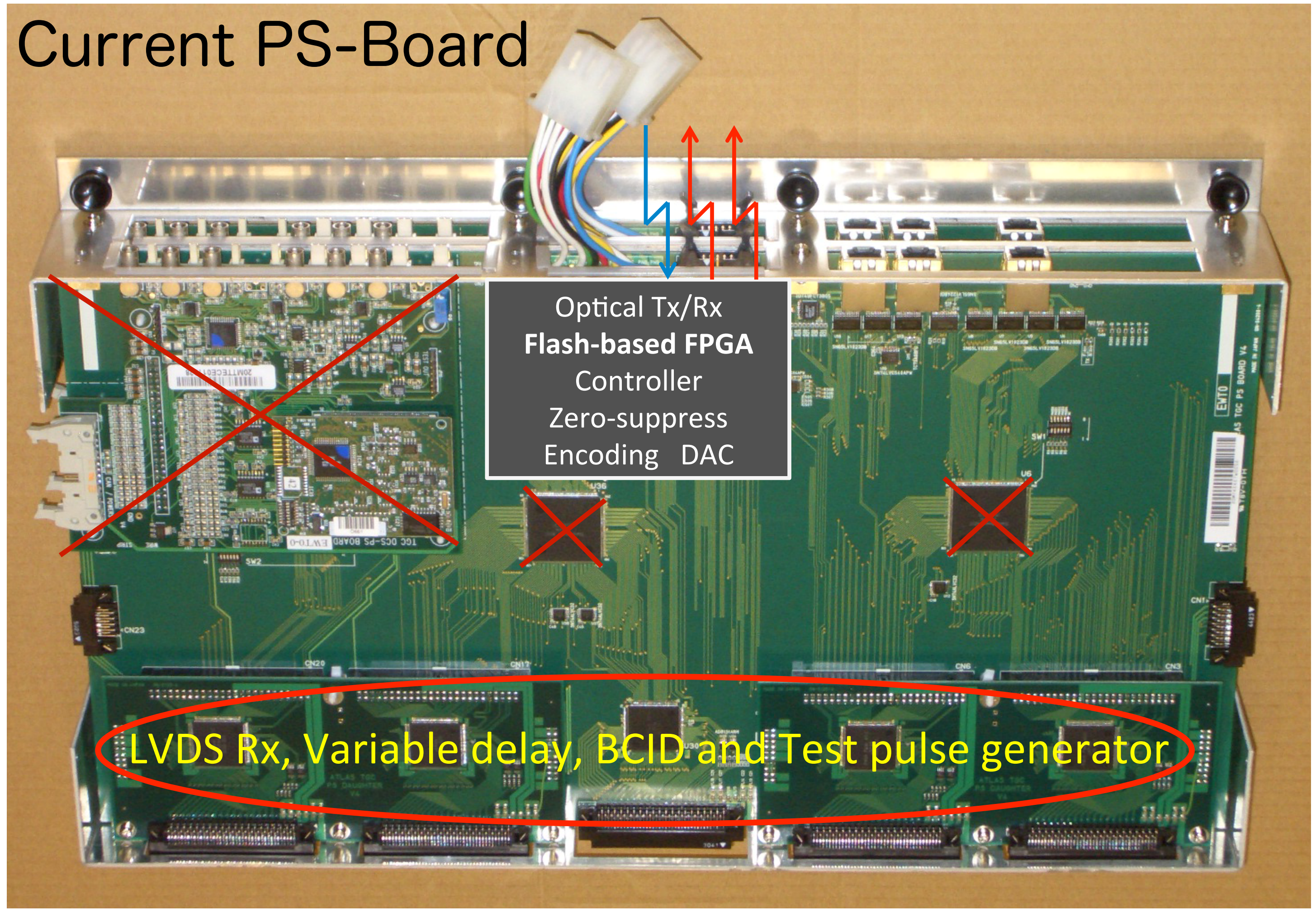
Muon trigger electronics



Most of electronics are developed by FPGA.

FPGA is flexible and easy to handle high-frequency clocks and high-speed transceiver.

Design of the Patch Panel board



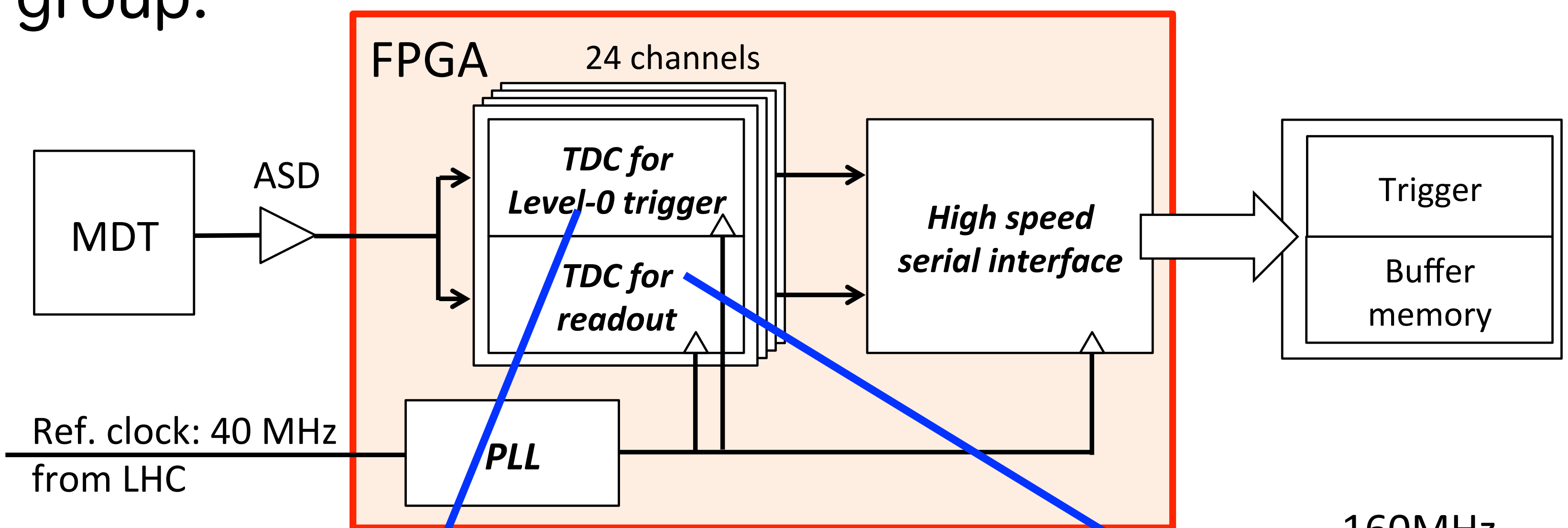
What is different from current PS-board :

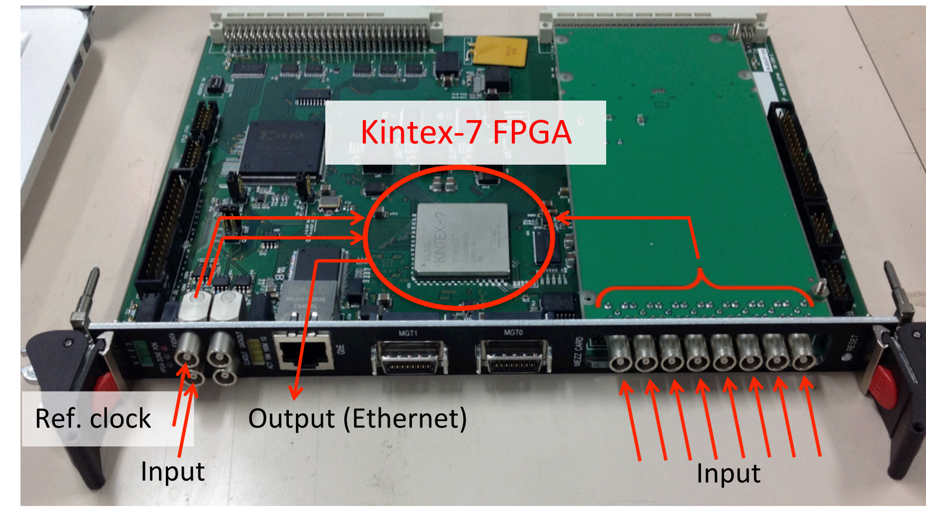
- New ASIC, which has the same functionality as the current ASIC, is developed on the rad-tolerant ASIC
  → It has already demonstrated with 0.25μm CMOS (UMC).
- (rad-tolerant) Flash-based FPGA (which is used for FPGA-TDC of MDT) is used for the controller, zero-suppression, encoder, etc.
- All hit data are transmitted to USA15 by optical links.

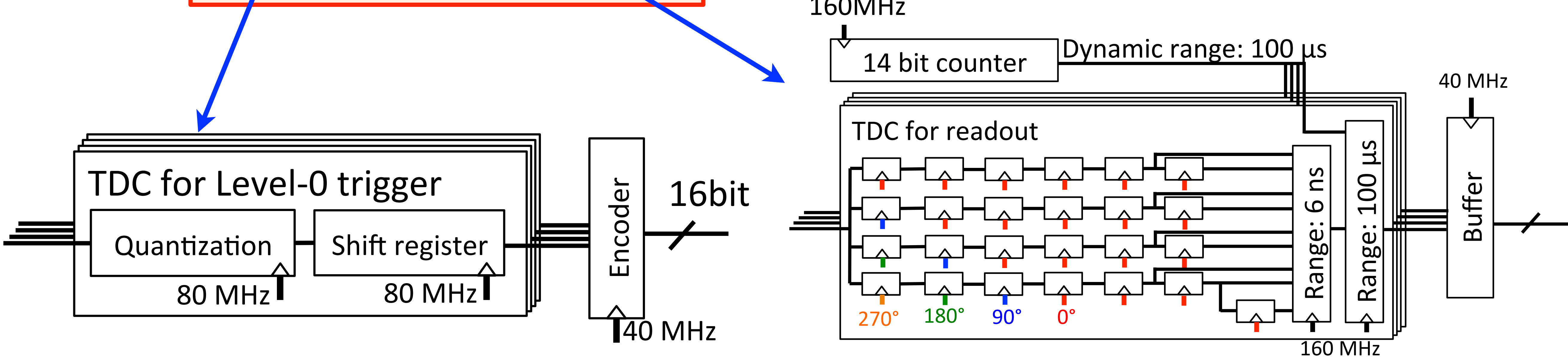
A student in our group is designing and developing the first prototype.

MDT-TDC

Design of the TDC in Xilinx Kintex-7 FPGA has been finished by a student in our group.

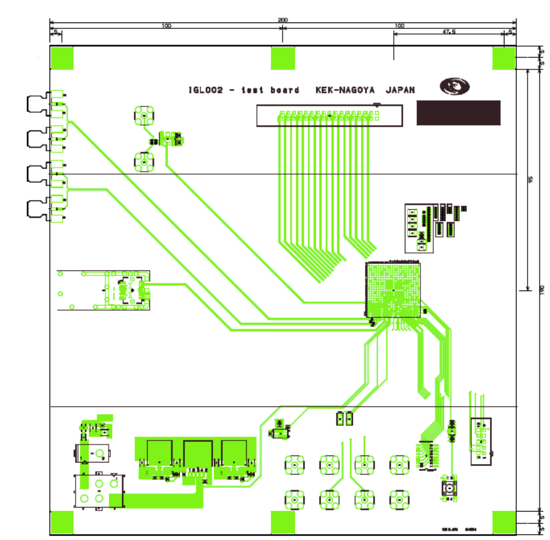






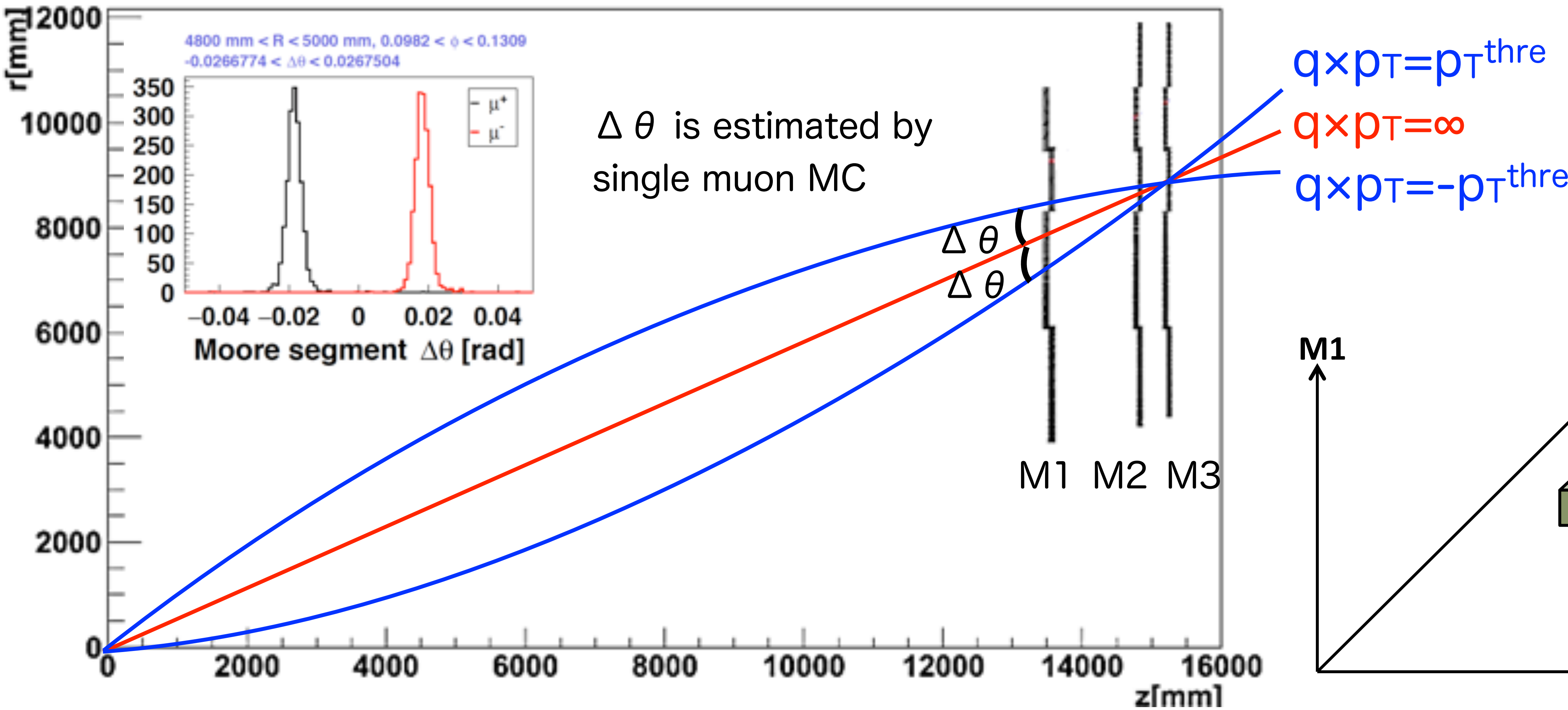
The implementation in the rad-tolerant flash based FPGA is ongoing.

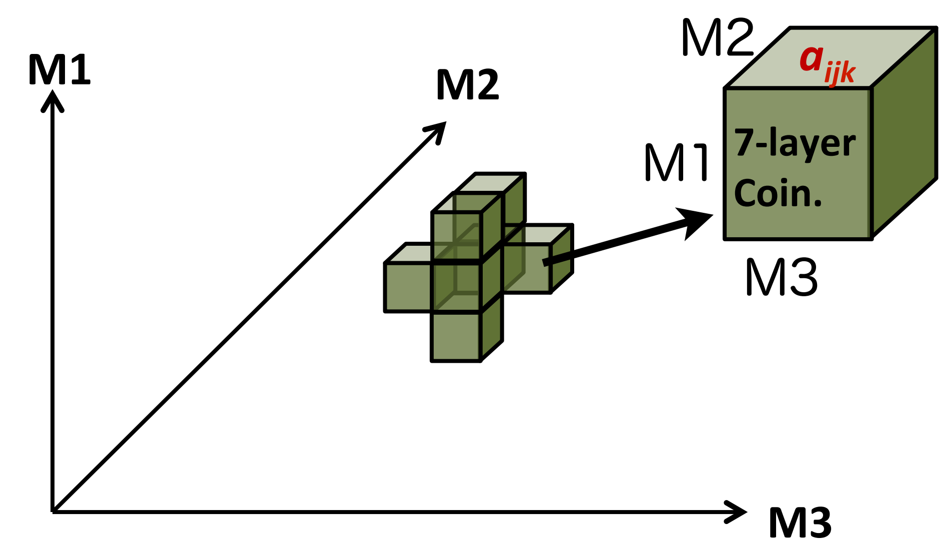
The design of the MDT-TDC for the radiation test and beam test is ongoing.



Trigger processor

- TGC track fitting is fulfilled by the three-dimensional coincidence matrix or the lookup table using "advanced" trigger processor boards with FPGAs.



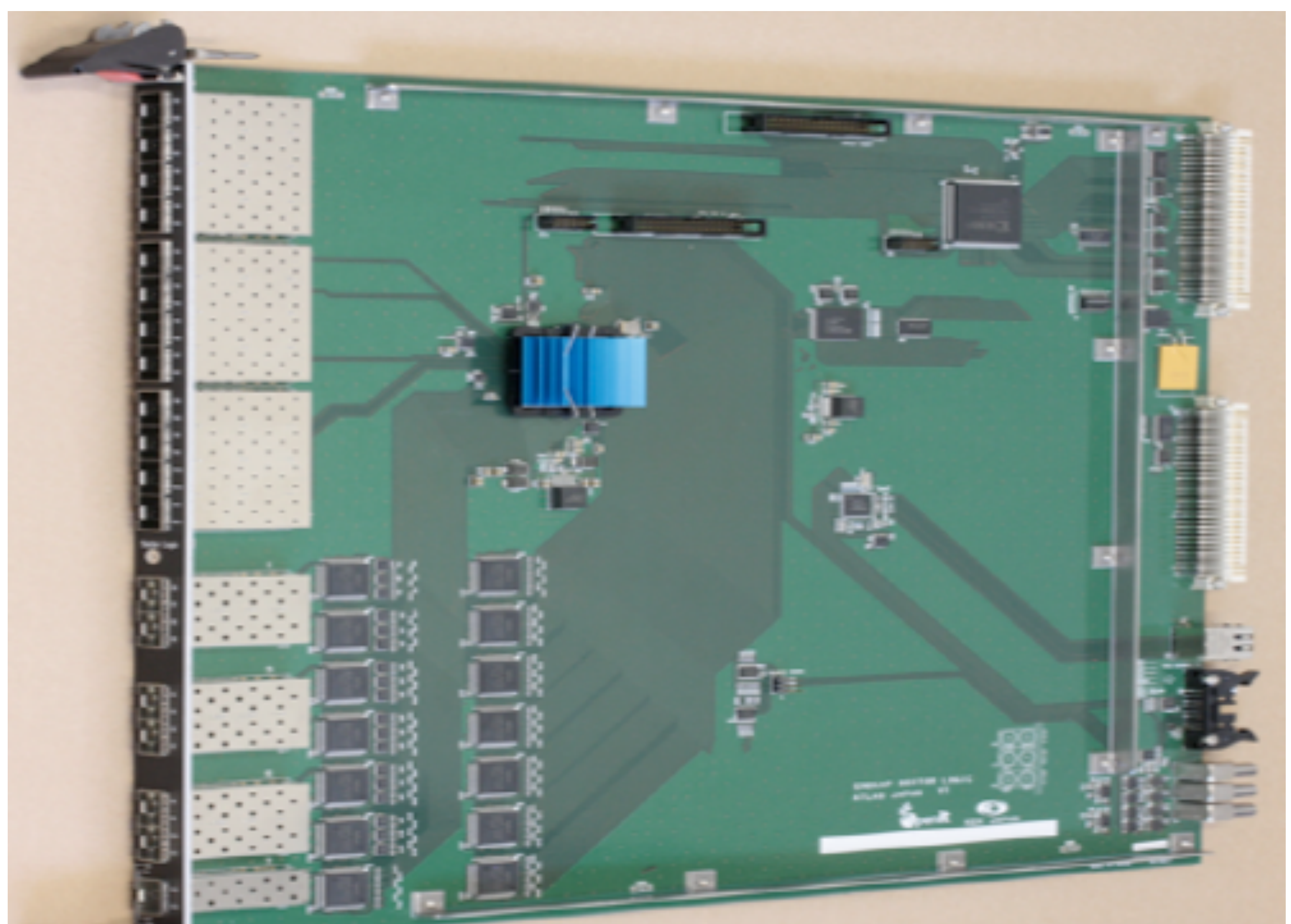


- The number of TGC hit lists for the muon tracks with $p_T \geqq p_T^{thre}$ are counted to be :
  2.6×10^5 lists / (1/12)sector (for $p_T=\infty$)
  5.2×10^6 lists / (1/12)sector (for $p_T \geqq 20$ GeV)
  1.3×10^7 lists / (1/12)sector (for $p_T \geqq 10$ GeV)
  2.6×10^7 lists / (1/12)sector (for $p_T \geqq 5$ GeV)

  in case $\geqq$ 5/7 coincidence is required.

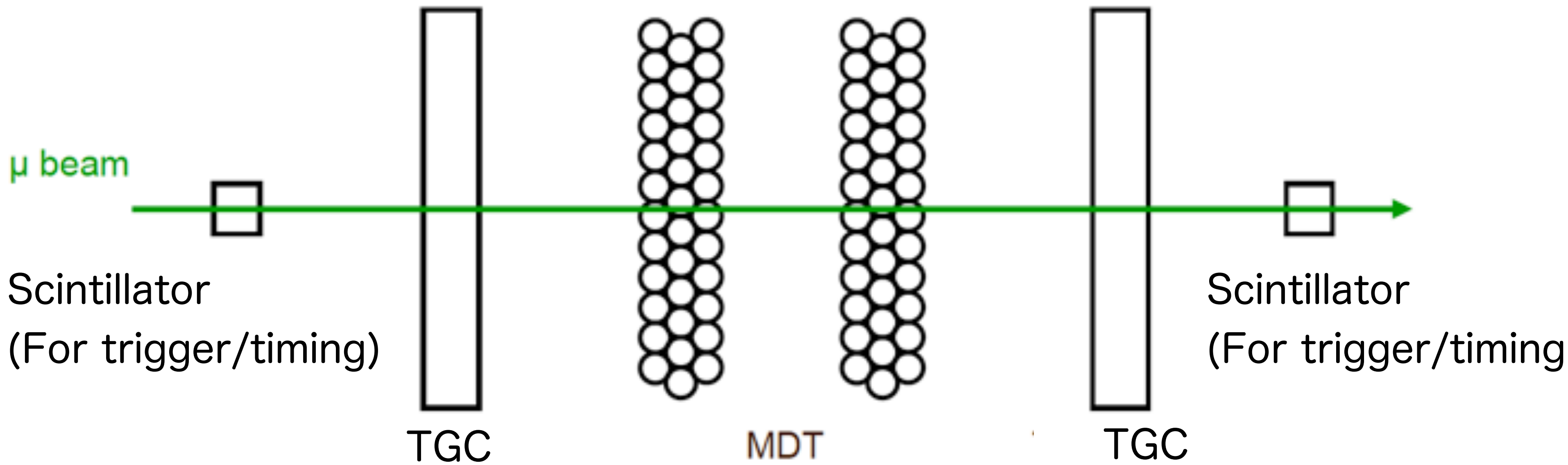
Trigger processor

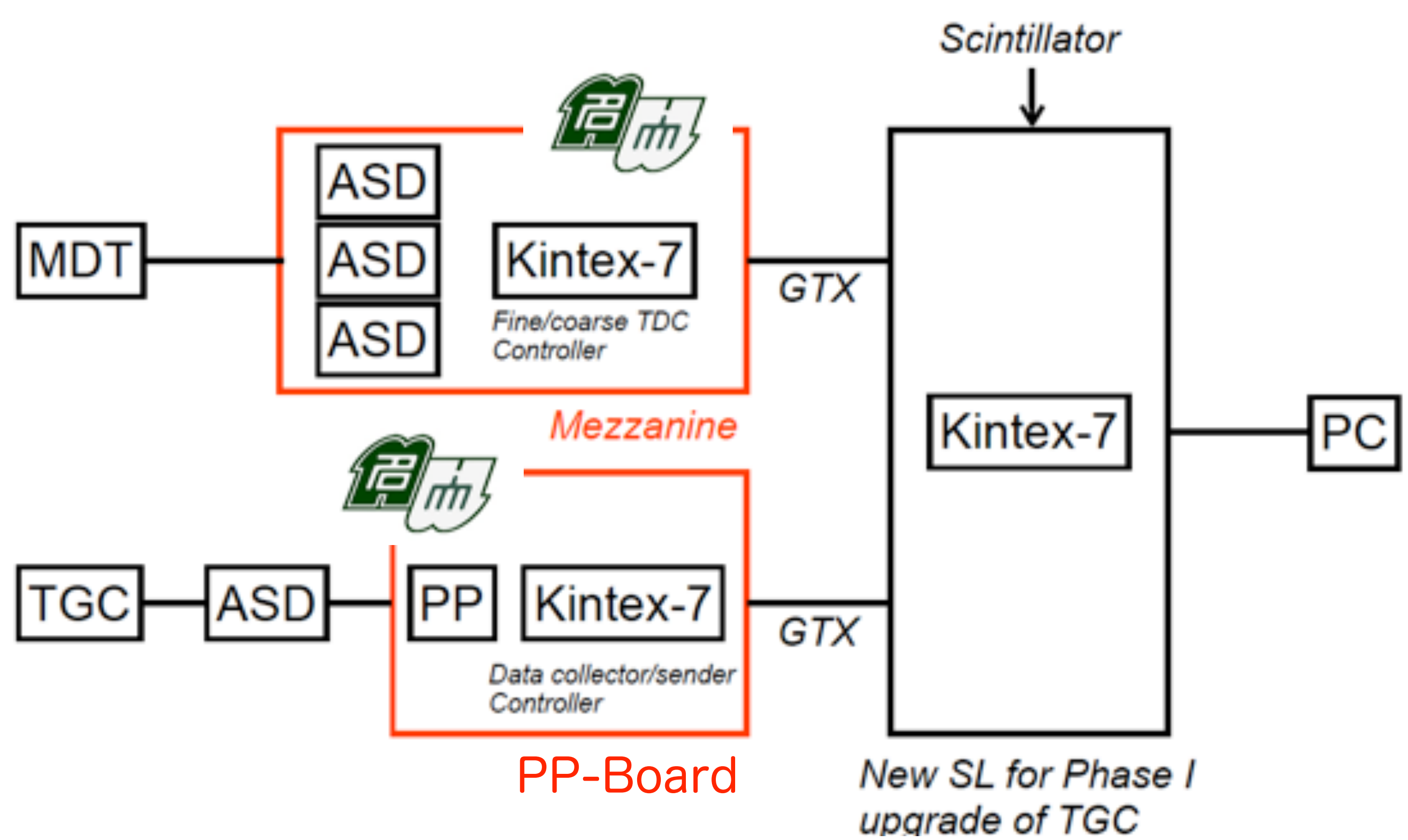
- The position and the timing of the muon track reconstructed by TGC trigger are sent to MDT Trigger processor.
- In the only region where the TGC trigger is fired, MDT trigger finds and reconstructs the muon track more precisely (σ_Θ~1mrad).
- Track finding and fitting algorithm will be fulfilled by FPGA or processor
  - In case we use processor, 6 μs trigger latency may be tight.


Trigger processor for Run3 upgrade

Beam Test in 2016

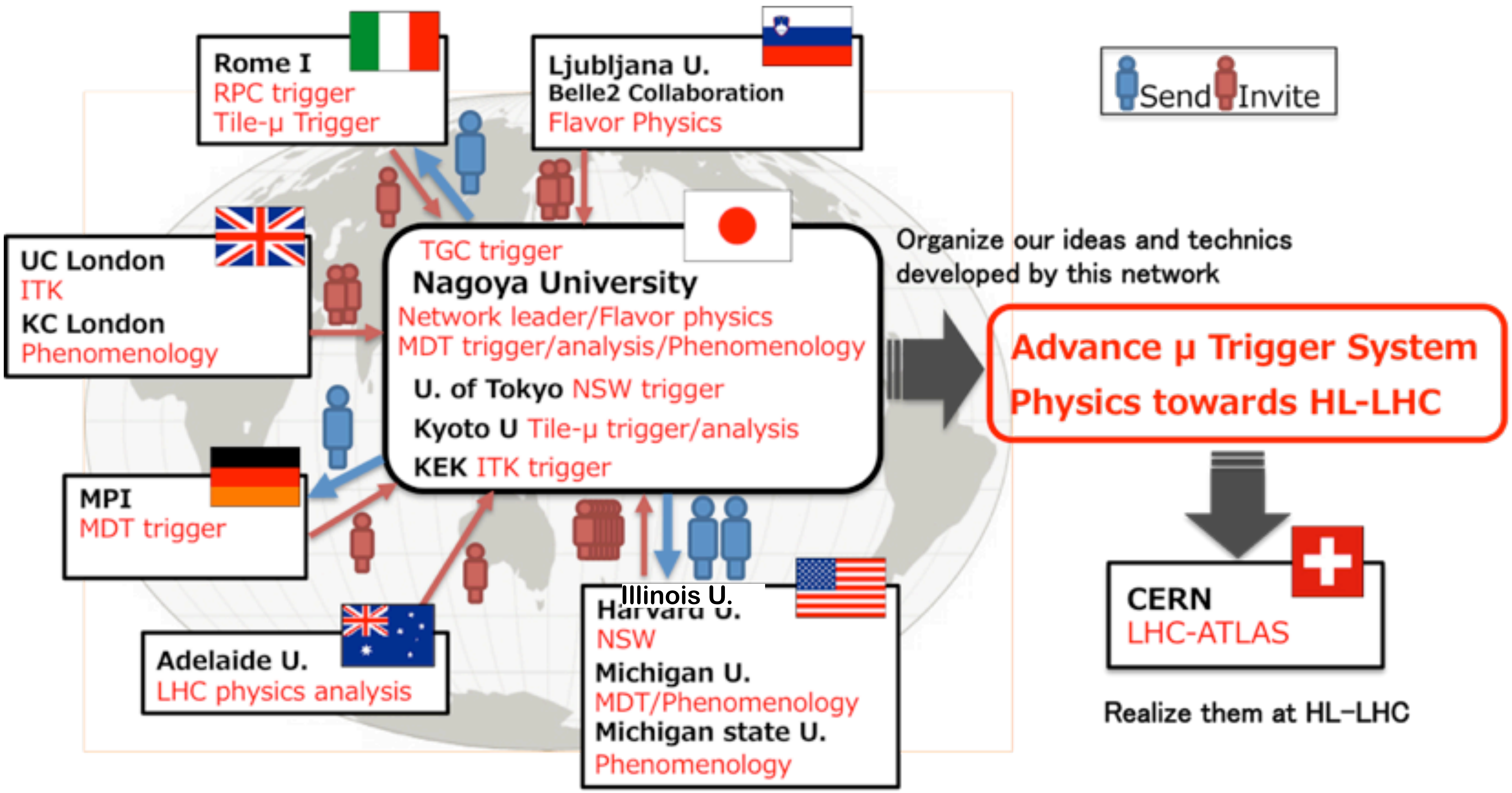
- The beam test in 2016 is scheduled at CERN with MPI, Michigan groups
  - To demonstrate FPGA-TDC for MDT trigger and sending all hit data to SL board.
  - To establish the full trigger path for the future developments.





“Zunou-junkan” program from JSPS

“Formation of the international network to challenge the discovery of the new particles from the advanced muon trigger development”



I Development of the advanced μ trigger
- I-1 Advanced TGC/RPC trigger
- I-2 MDT trigger
- I-3 Tile-μ trigger
- I-4 Inner μ detector trigger
- I-5 ITK trigger

II Physics towards HL-LHC
- II-a Data analysis using Run2 data
- II-b Flavor physics
- II-c Phenomenology

Summary

New results from Run 2 will be released next week.

150fb^{-1} of data will be accumulated in Run 2.

300fb^{-1} of data will be accumulated in Run 3.

"nominal" LHC will be finished in 2023.

High luminosity LHC will start from 2026 to extend reach in new physics searches and Higgs precision measurements.

Preparations of the detector upgrades for fulfilling stringent luminosity conditions are ongoing.

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