Physics motivations and expected performance of the Phase2-CMS muon system upgrade

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On behalf of the CMS Muon Community

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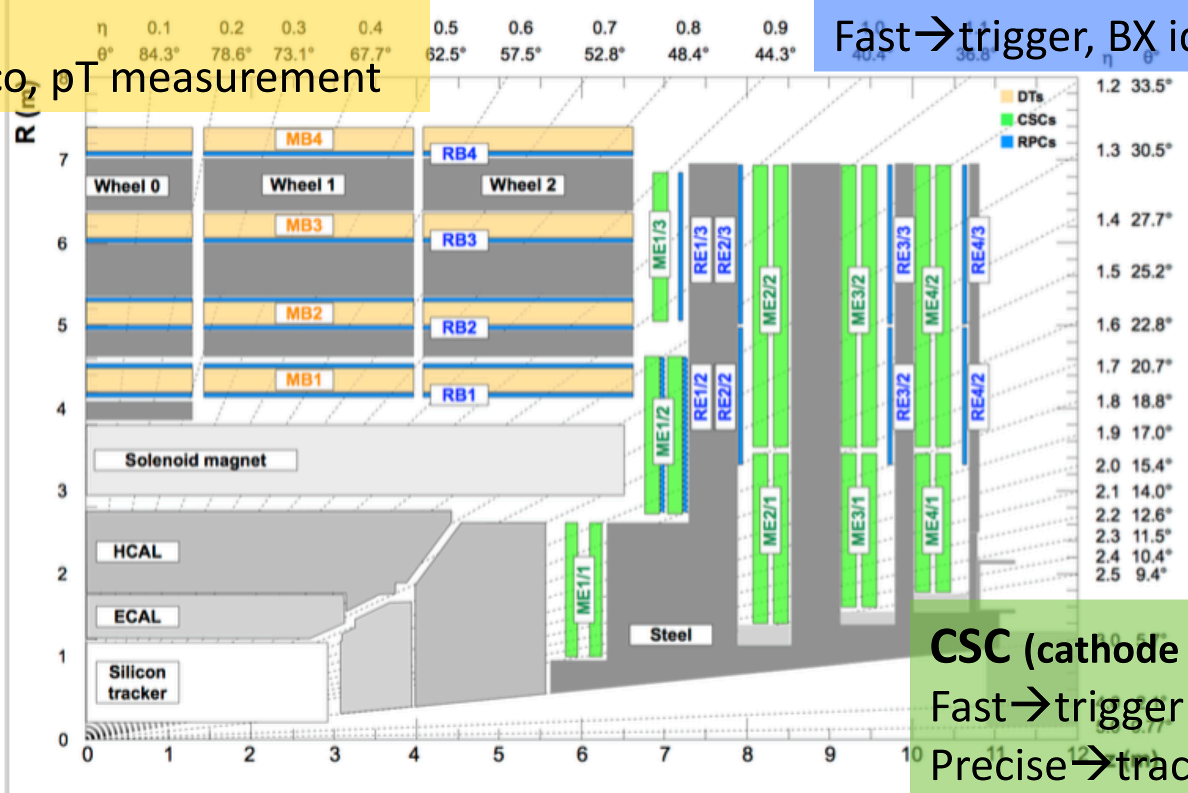
Present CMS Muon System

One system, 3 detector technologies→Redundancy
(4 stations with 2 detector technologies on the path of a muon in ≈any direction**)**
ensure robust trigger and efficient reconstruction

DT(drift tubes)
Fast→trigger
Precise→track reco, pT measurement

RPC (resisitive plate chambers)
Fast→trigger, BX identification



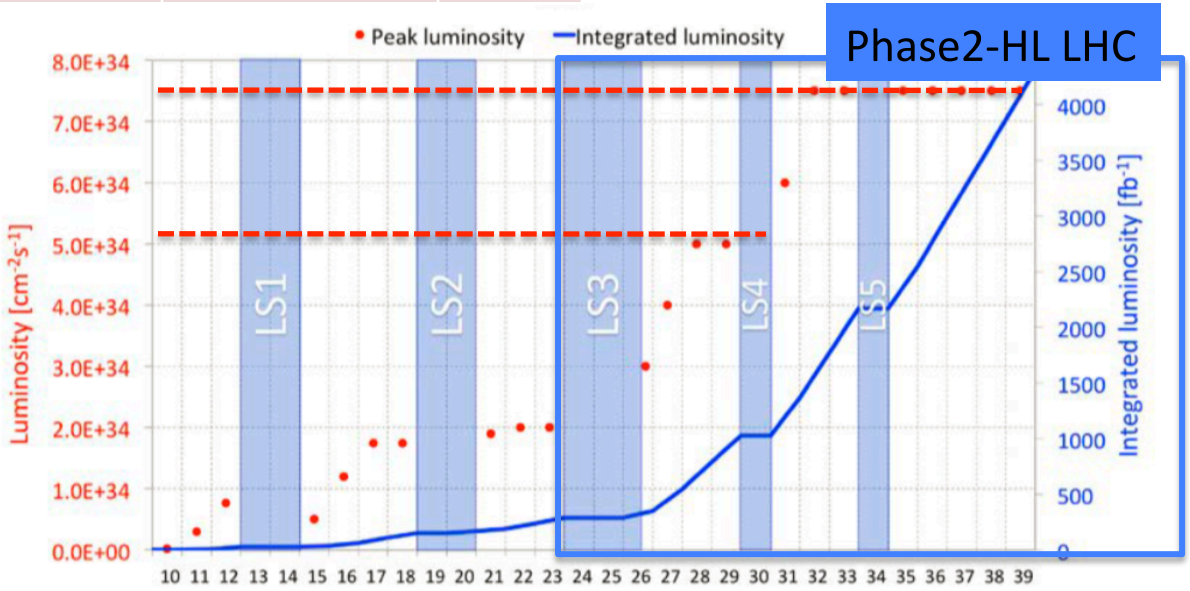
CSC (cathode strip chambers)
Fast→trigger
Precise→track reco, pT measurment
High rate capability

Acceptance: $|\eta| < 2.4$
L1 Trigger: pT > 25 GeV (μ); pT > 4 GeV (μ+μ–, ΔR<1.2)
Reconstruction: p > 3 GeV, δpT/pT ≈ 1-2% (with the Tracker)

The HL-LHC challenge

	HL-LHC	LHC
instantaneous luminosity ($cm^{-2}s^{-1}$)	5×10^{34} $(7.5)\times10^{34}$	10^{34}
Pile-up collisions	140 (200)	30
integrated luminosity (fb^{-1})	3000 (4000)	60

	CMS Ph2	CMS Ph1
L1 trigger (kHz)	750	100
L1 Latency	12.5	3.6



All LHC experiments were designed for the LHC specs →New specs require detector upgrades
Goal: keep the same performance as in Run2

HL LHC science goals and guide-lines for experiment upgrade

Precision measurement of the Standard Model

- EWK Bosons and fermions couplings
- Differential distributions

Search for new physics in SUSY and exotic scenarios

- Characterized by small cross sections and/or challenging final state signatures
- displaced tracks and HSCP are probe of new physics

Maintain sensitivity to electroweak scale

- keeping accetable rate even for low L1 pT thresholds.
- Ensure robust reconstruction/ID at L1 and offline

Add sensitivity to new physics scenarios

- Restore TrackTrigger ineff. for d_{xy} >2 mm
- Improve pT assignment for displaced tracks
- Use timing info for HSCP triggers

CMS Muon System Upgrade Concept

REPLACE electronics expected to fail at HL-LHC

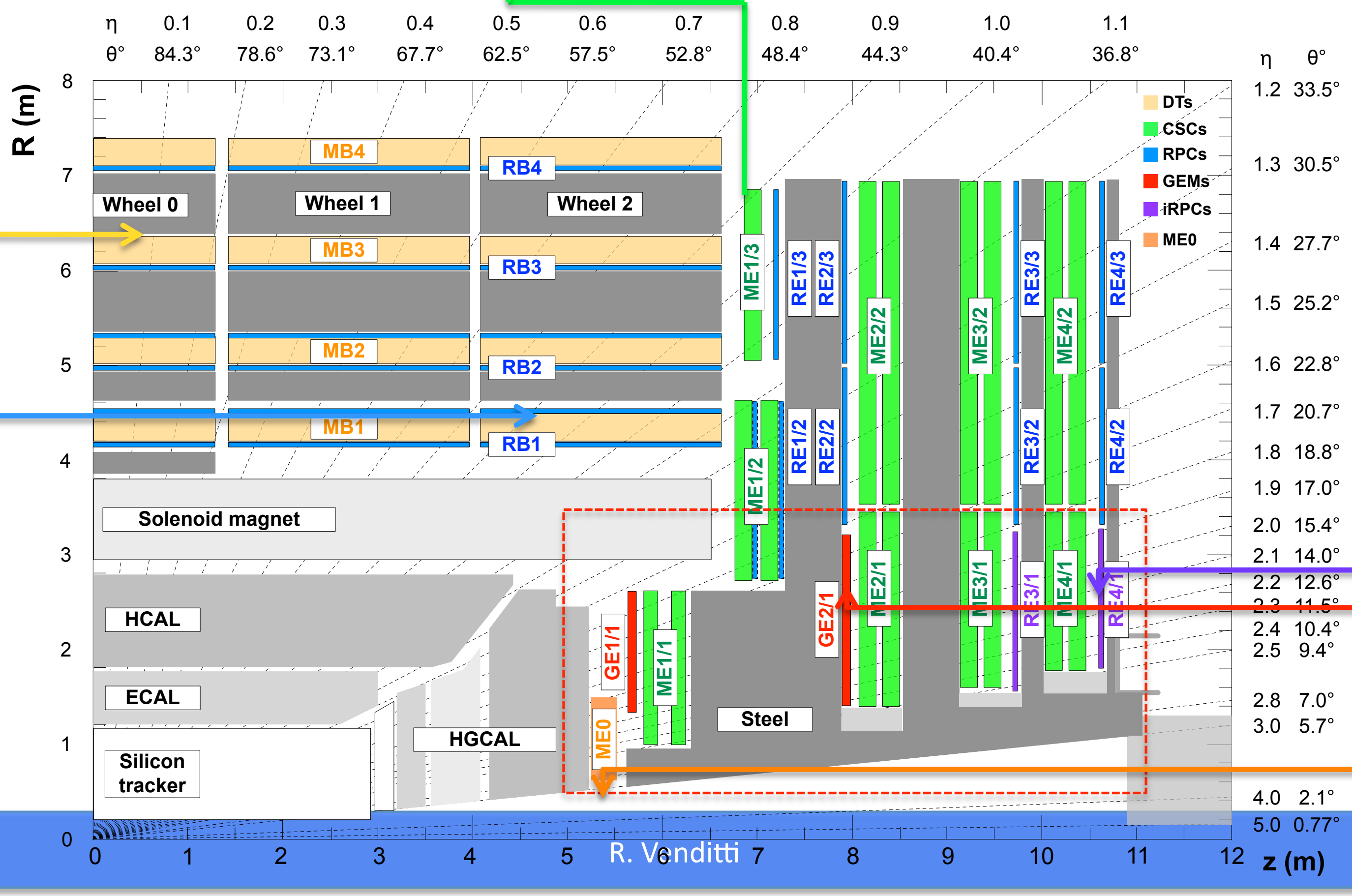
- **DT :** on-chamber minicrates and backend
- **CSC:** various on- and off-chamber boards
- **RPC :**off-chamber Link System

New detectors in the forward region

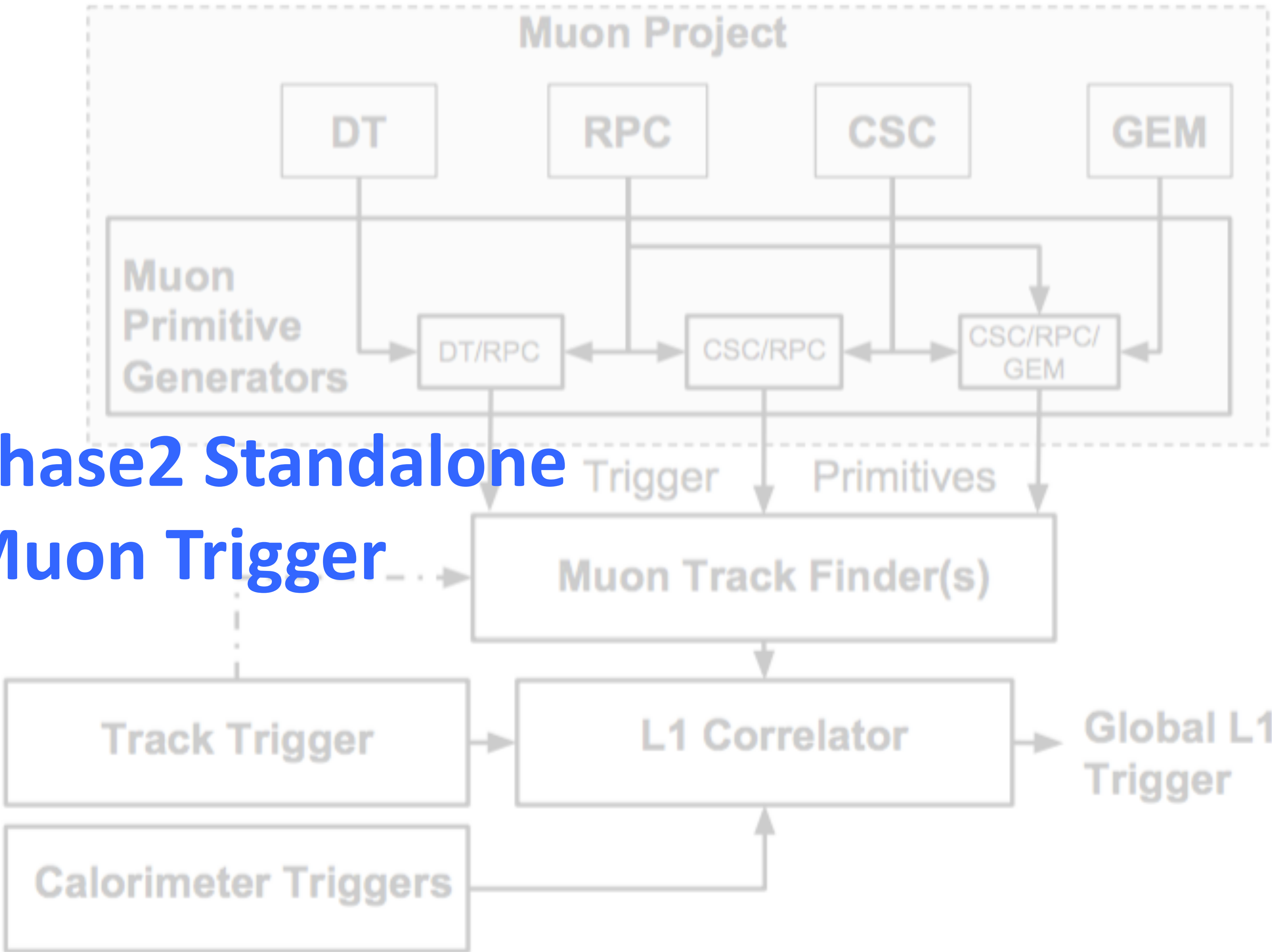
ME0: 6-layer GEM detector; ($2< \eta < 2.8$)

GE21: 2-layers GEM detector; ($1.6< \eta < 2.5$)

iRPC: improved RPCs; ($1.9< \eta < 2.4$)



Phase2 Standalone Muon Trigger

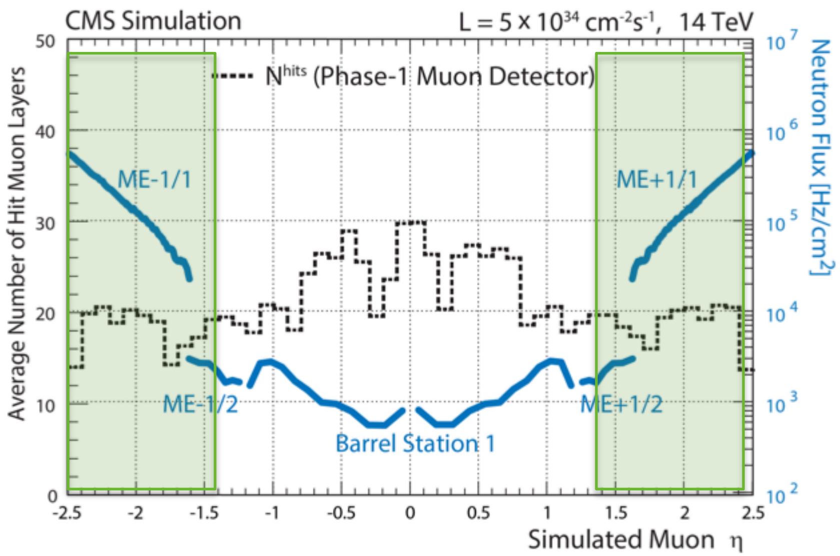


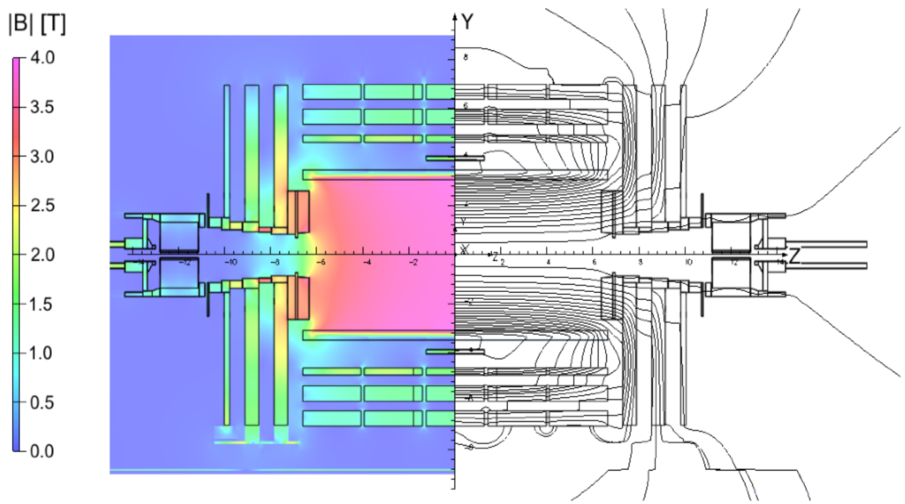
The Forward region Challenges

Main problems of the present forward muon system

1. Low B-field along the bendig direction →low bending angle of the tracks → p_T mis-measurement
   - Key role of the first and second muon station with least scattering and higher B-field.
2. High neutron background vs low hit multiplicity (lack of redundancy).

   → **trigger rate is dominated by junk muons reconstructed as high pT muons**

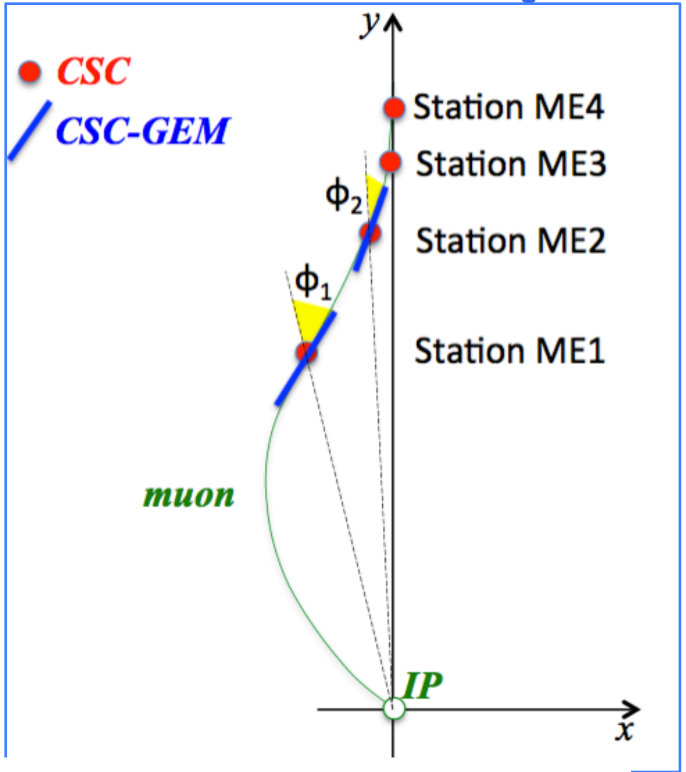




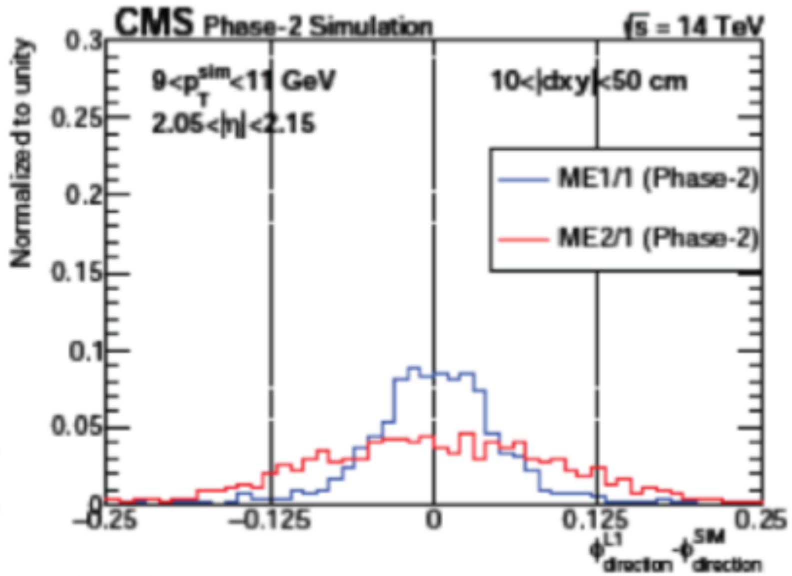
- New high-performance Muon stations are necessary tools to improve redundancy, rate capability, muon momentum resolution @ L1 and offline
- Ad-hoc choices of detector technology, segmentation, electronics have been driven by physics needs

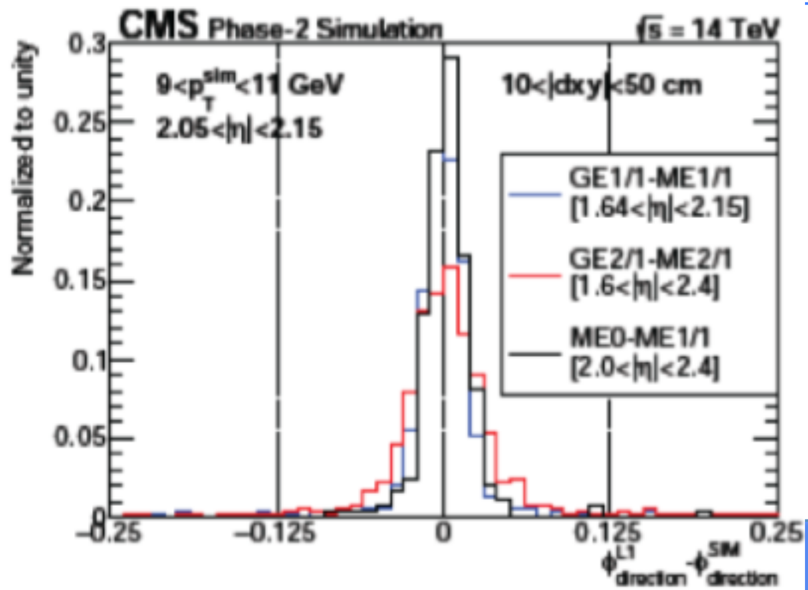
Impact of GEM stations to the Endcap Muon Trigger

Ba, Bo, Na, LNF, Pavia



- **CSC + GEM in station 1 and 2**
  - CSCs alone provide short segments with low-precision info on segment direction
  - GEM-CSC tandems in ME1 and ME2 stations give accurate measurement of muon "local" direction sensitive to muon pT
  - pT measurement improves → the L1-trigger rate drops by a factor of 10

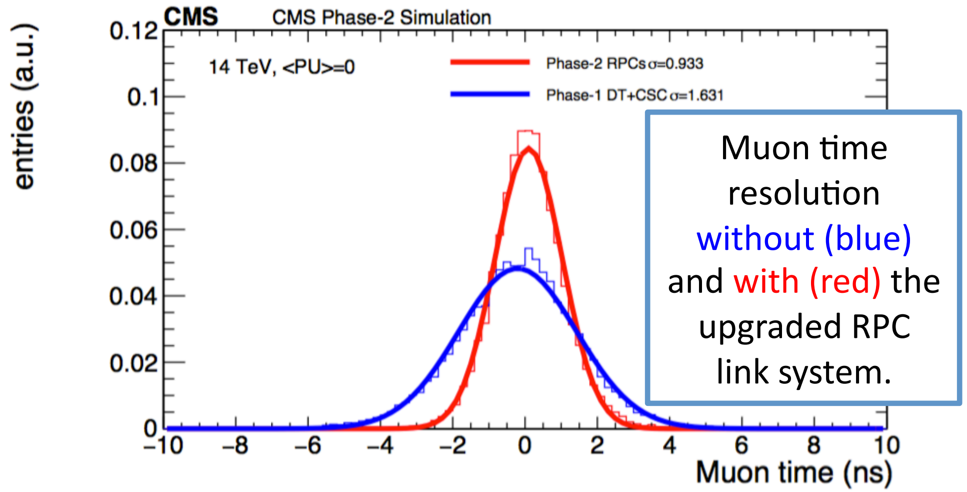


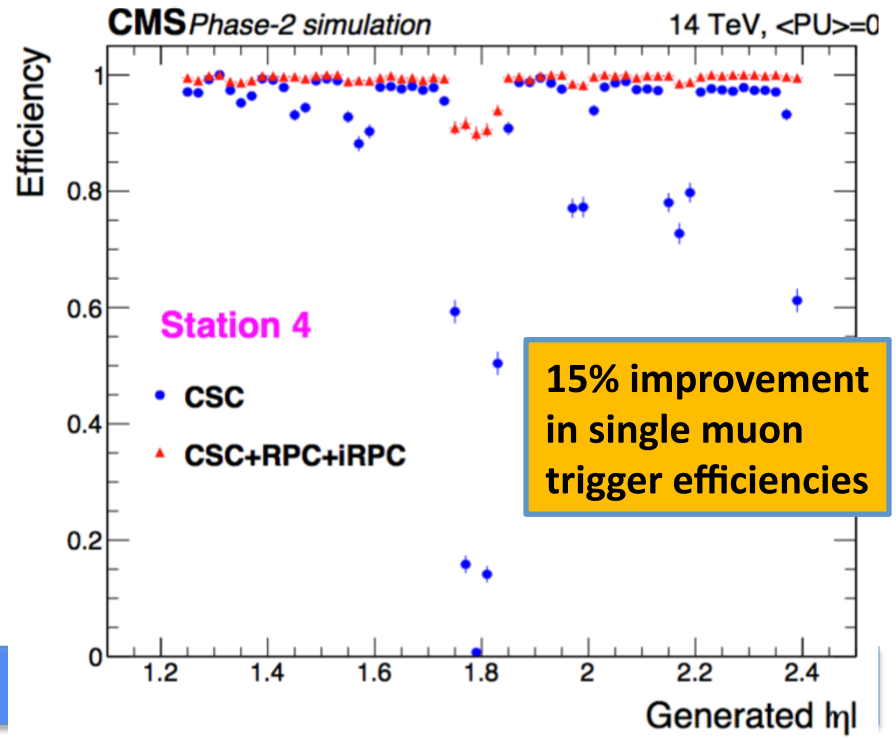


Upgraded RPC: i(mproved)-RPC and the benefit of the new linkboard

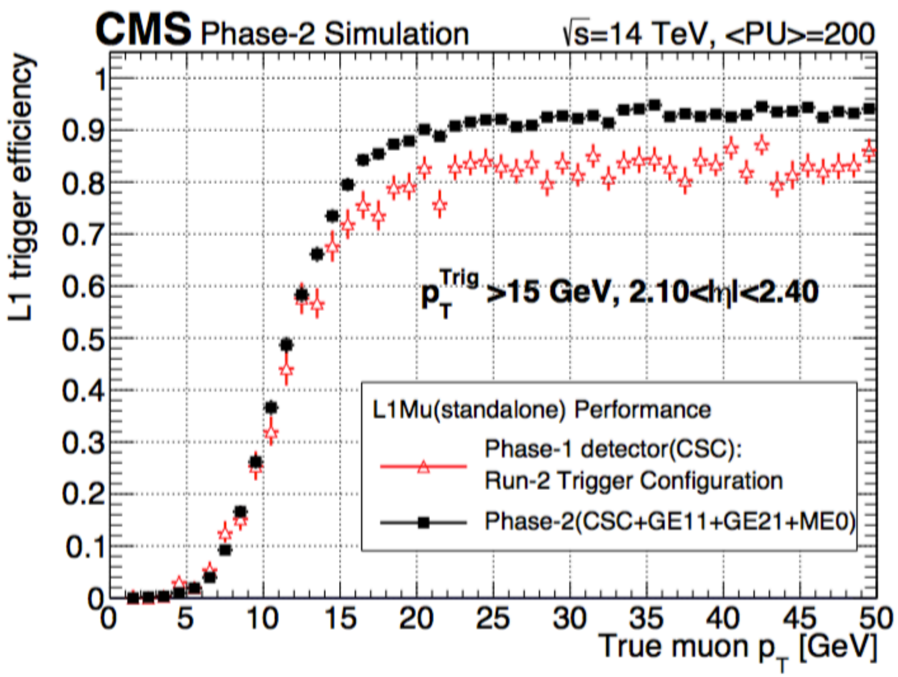
Ba, Na, LNF, Pavia

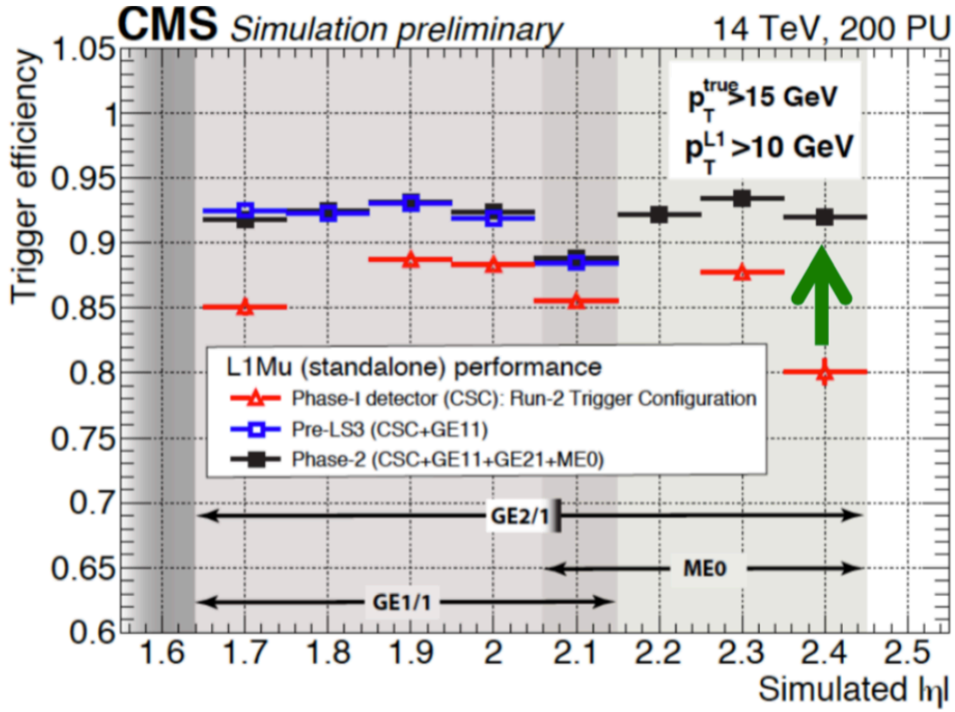
- **New Link System** redesigned for more robust performance →change from 40 MHz signal sampling to 640 MHz to exploit the excellent intrinsic RPC time resolution:
  - **25ns sampling → 1.56ns**
- **New iRPC in station 3 and 4**
  - **Reduction of "dips" in present trigger efficiency** due to the presence of high-voltage spacers inside the CSC chambers.
  - **Remove CSC ambiguities at the L1 trigger produced by "ghost tracks"**
    - 13% probability per bunch crossing.
    - in the presence of a real muon, these extra ghost LCTs can result in a high-*p*T muon





L1 standalone Muon Trigger performance: efficiency

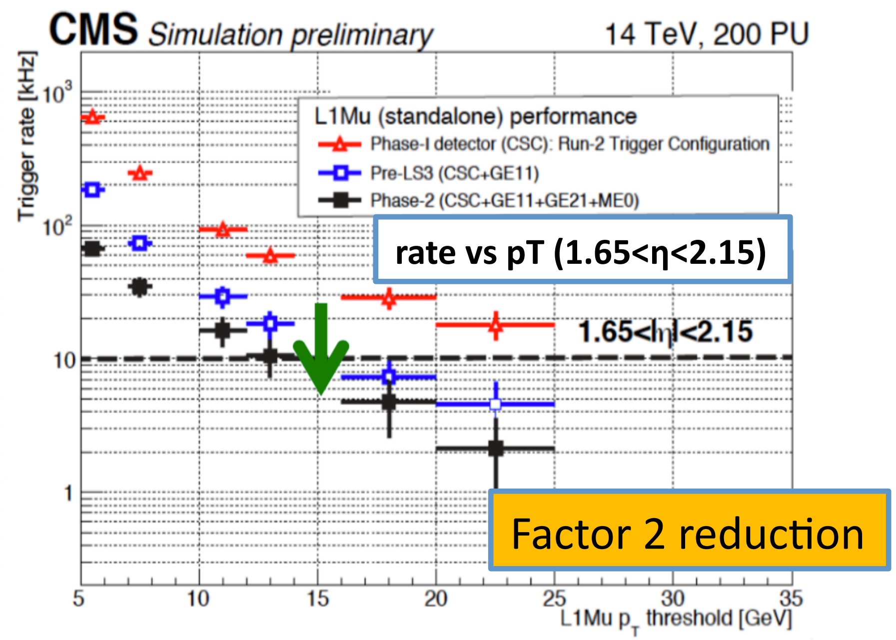


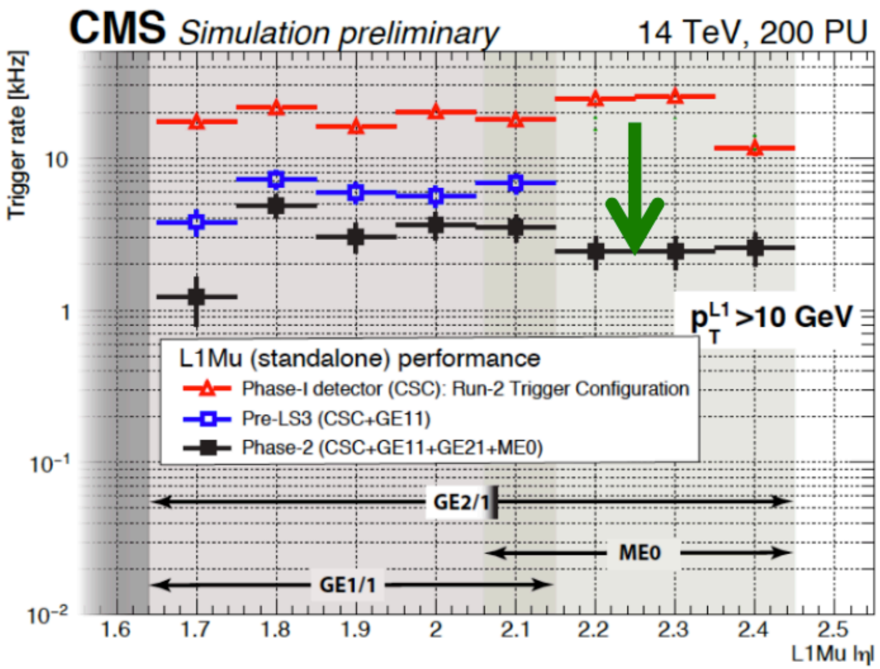


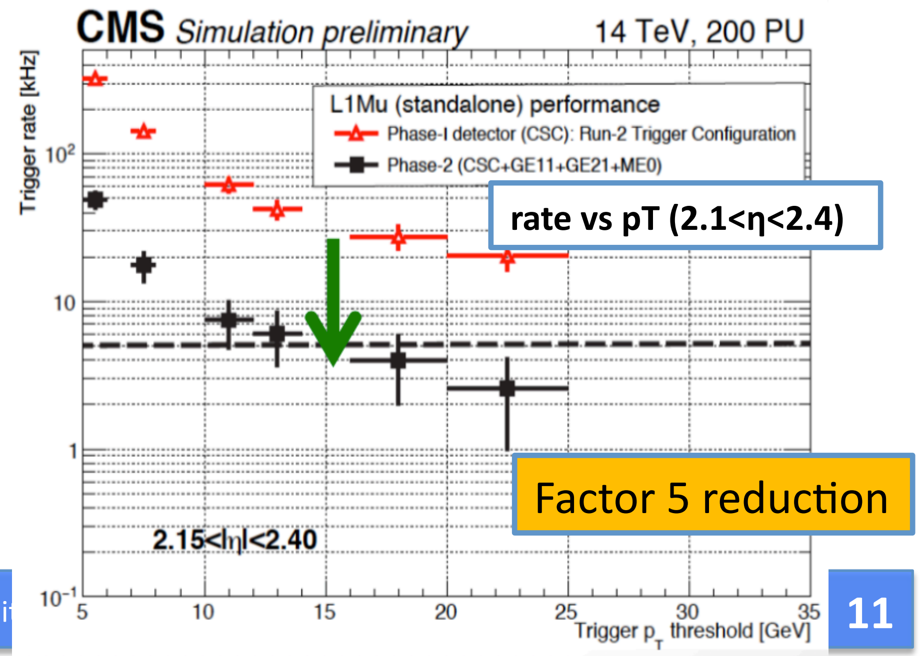
- **Super-primitives containing both GEM and CSC information** will be formed by matching GEM and CSC trigger primitives in space and time.
- **Plateau efficiency** for the standalone prompt muon trigger significantly improves from ~80% to ~90% by introducing new muon detectors.
  – This gain in efficiency will directly translate into the efficiency of the global muon trigger when L1Mu is matched to L1Tk.

L1 standalone Muon Trigger performance: rate reduction

- The installation of GE2/1 introduces the ability to correlate the GE1/1-ME1/1 and GE2/1-ME2/1 direction measurements in the region 1.65 < |η| < 2.15.
- The forward region 2.15 < |η| < 2.4 is very challenging since the magnetic field is much weaker and not instrumented with GE1/1→The inclusion of ME0 in the L1 standalone trigger will fully recover the L1 standalone muon trigger capabilities

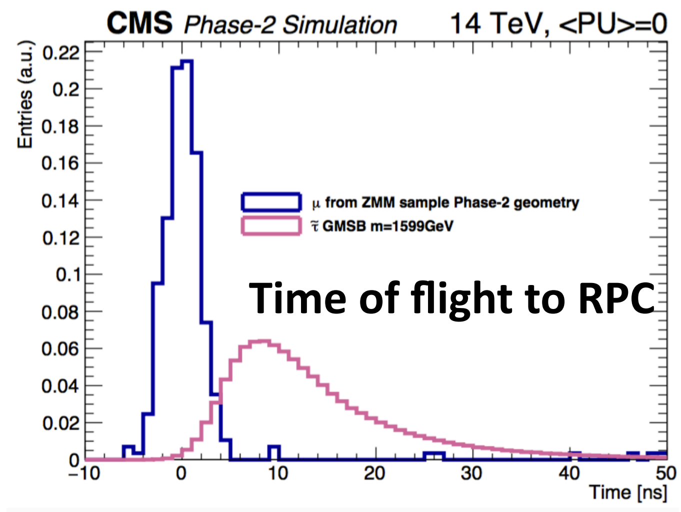


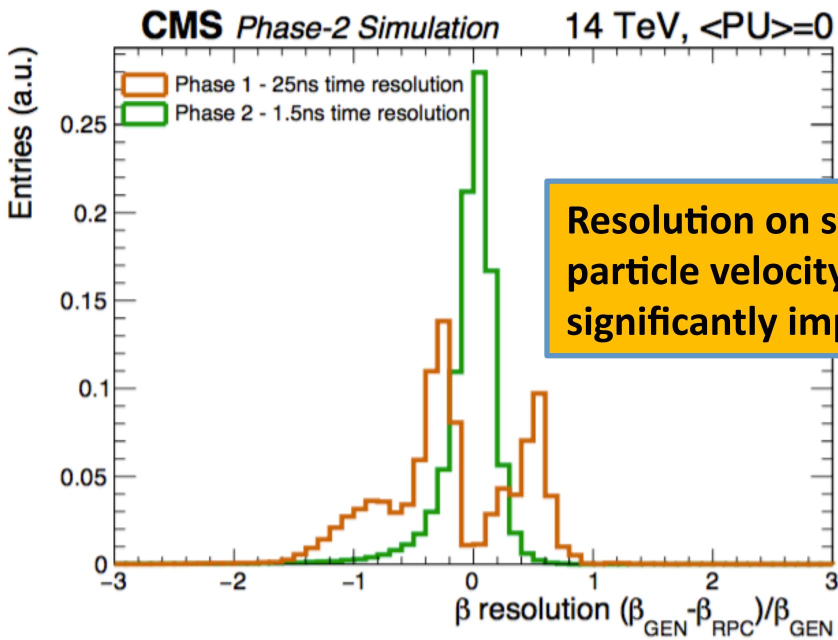




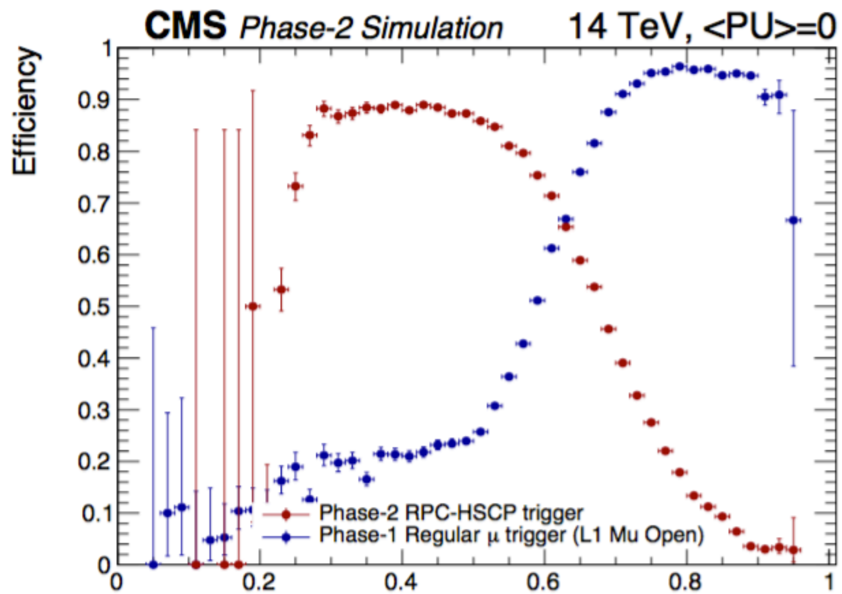
BSM triggers: HSCP

- **New RPC Link System** timing: 25 ns→1.56 ns
- **New physics opportunity**: muon-like HSCP L1 trigger based on TOF to the RPC
  - Much more direct and efficient than a MET trigger currently used for HSCP searches
- **Trigger rate is not a problem**
  - slow muons do not have penetrating power
  - accidental rates for an “HSCP pattern” is the same as for a “fast muon pattern”, and the latter is very small.





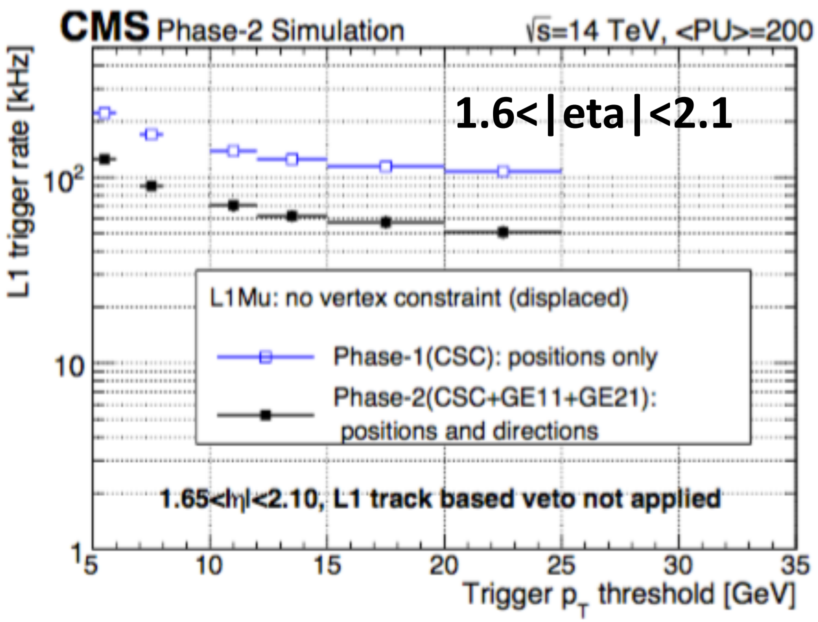
Resolution on slow particle velocity significantly improved

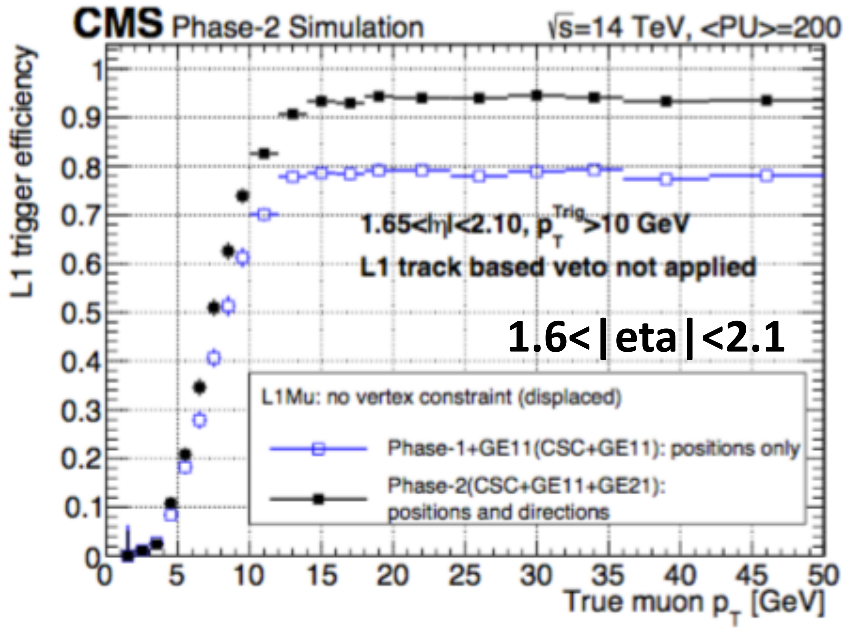


Trigger efficiency enhancement for small β

BSM triggers: displaced muons

- **Trigger with tracker cannot menage higly dispaced signature → dispalced trigger rely completely on the muon system**
  - pT fit can no longer use the beam constraint →Rate control is the main challenge
- **"Hybrid" algorithm:**
  - Measure pT by comparing direction measurements in at least two stations
  - check compatibility with position measurements
- **Apply L1 Track trigger veto (background suppression)**
  - Still under optimization for the endcap, factor 6 reduction in the barrel



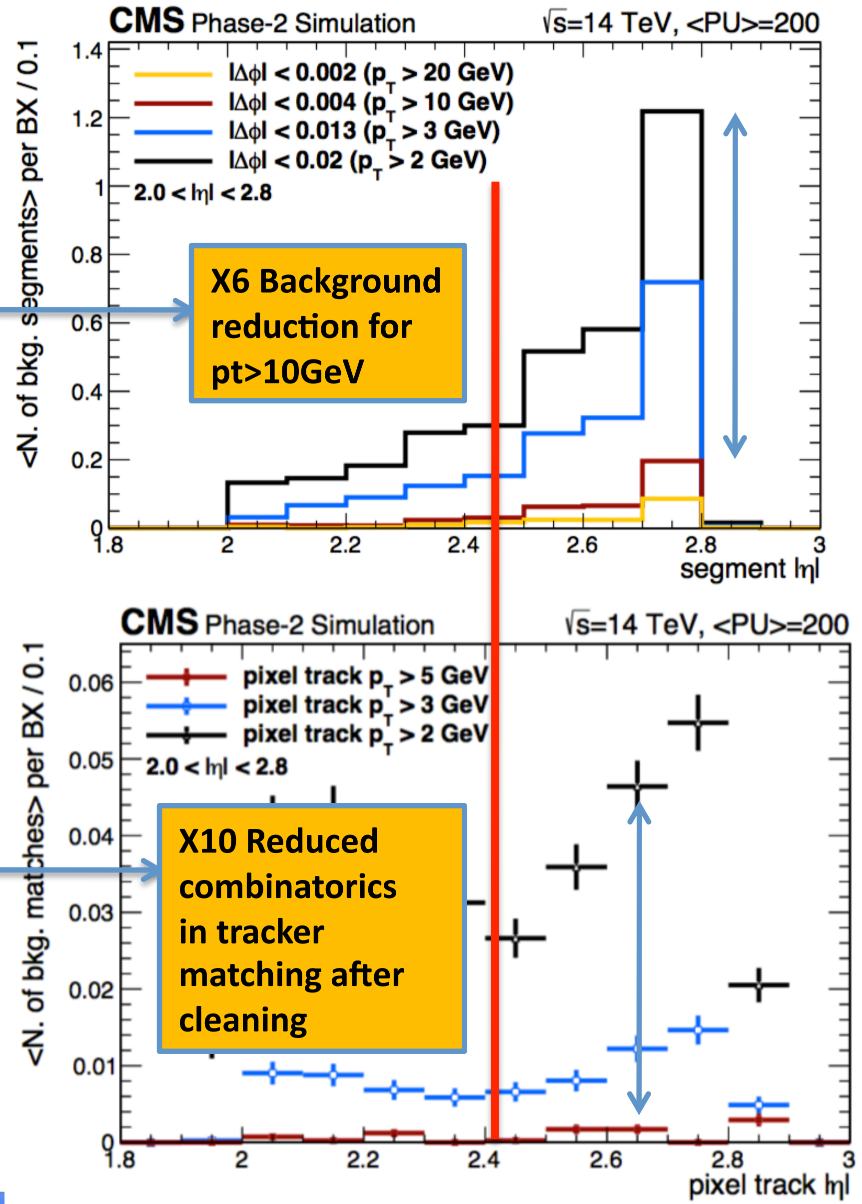


Result: efficiency improves, trigger rate is reduced by a factor of 2-10
Plots for 2.1<|eta|<2.4 in backup

Feasibility of a Very Forward Muon Trigger

- **ME0 capabilities allow to extend muon triggering beyond η=2.4:**
- **Level-1: ME0 object**
  - ME0 stub with quality and direction measurement
  - Apply pT thresholds based on the bending angle
- **Level-2: additional rate reduction using finer granularity**
  - ME0 stub with improved directionality measurement (better segmentation at full granularity) - sharper pT thresholds!
  - Level 2.5: a powerful rate drop using regional tracking & isolation:
  - Regional pixel tracking validating track match, a superior pT measurement, global kinematic selections (invariant masses etc.)
  - Road search seeded by an ME0 stub can be extremely fast
- **Level 3: tracking isolation, global reconstruction**

  Regional pixel tracking isolation, global pixel tracking
- **Promising preliminary results, work ongoing**



Muon reconstruction and identification performance

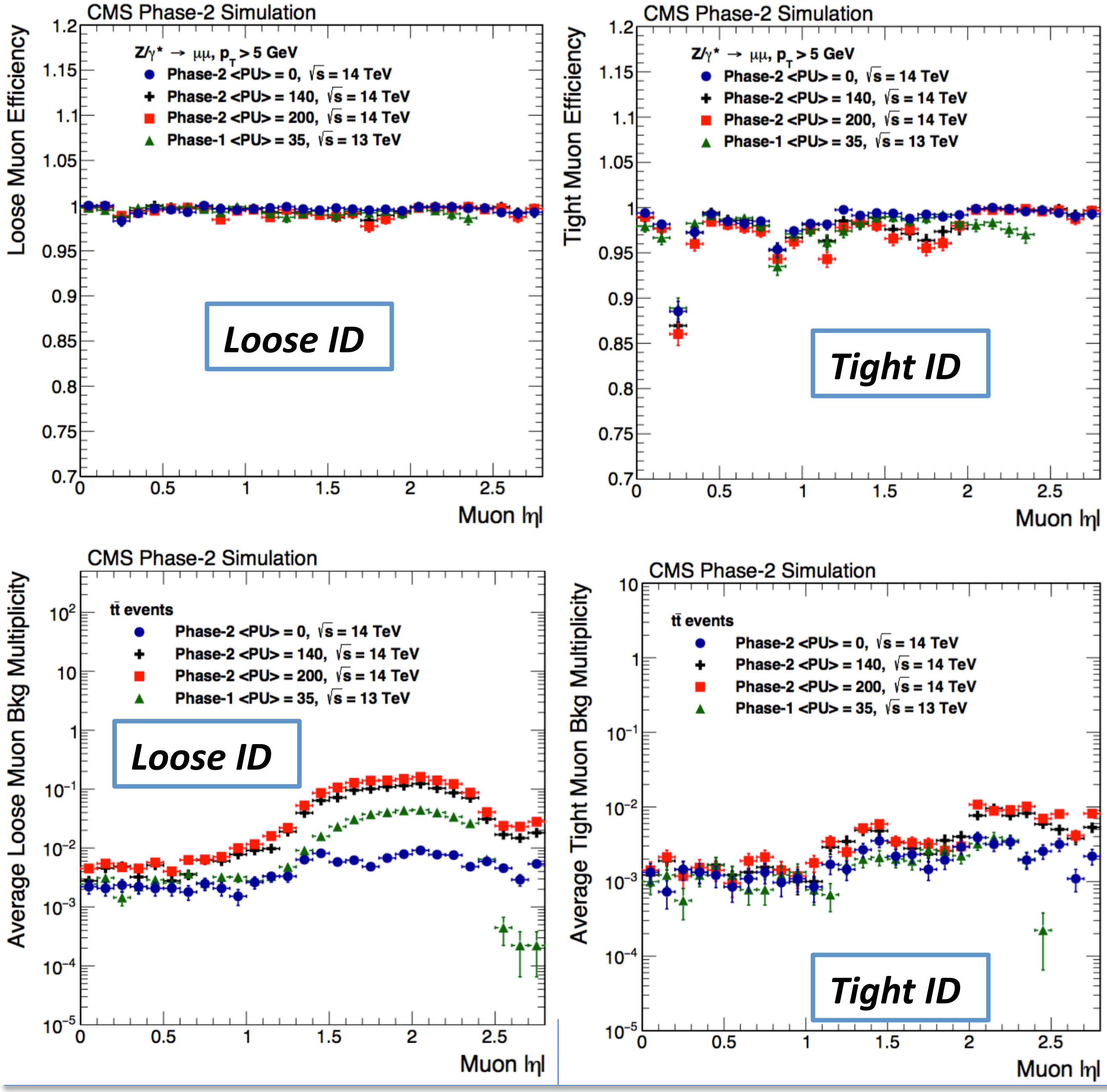
Optimization of muon reconstruction for Phase2

- Big effort to include the new detectors and electronics in the simulation
  - updated software for geometry simulation, digitization, local and global muon reconstruction
- Checking muon performance in following scenarios
  - **Reference: Run2, <PU>=35**
  - **Phase2, ideal: PU=0**
  - **Phase2, semi-realistic: <PU>=140**
  - **Phase2, pessimistic: <PU>=200**
- Performance given in terms of muon reconstruction efficiency and background multiplicity for Loose and Tight ID
  - Muon ID definition as in Run2 in the whole acceptance
    - Ad-hoc ID developed to cope high bkg while keeping high efficiency fully exploiting the new muon detectors
  - New Phase2 Loose ID: (Run2 Loose muon) OR (Loose ME0 muon + IP cuts)
  - New Phase2 Tight ID: (Run2 Tight muon) OR (Tight ME0 muon)

- **Goal is to keep the same performance as in Run2 in the HL-LHC conditions exploiting the new detectors and electronics**

Prompt Muon performance

Bari

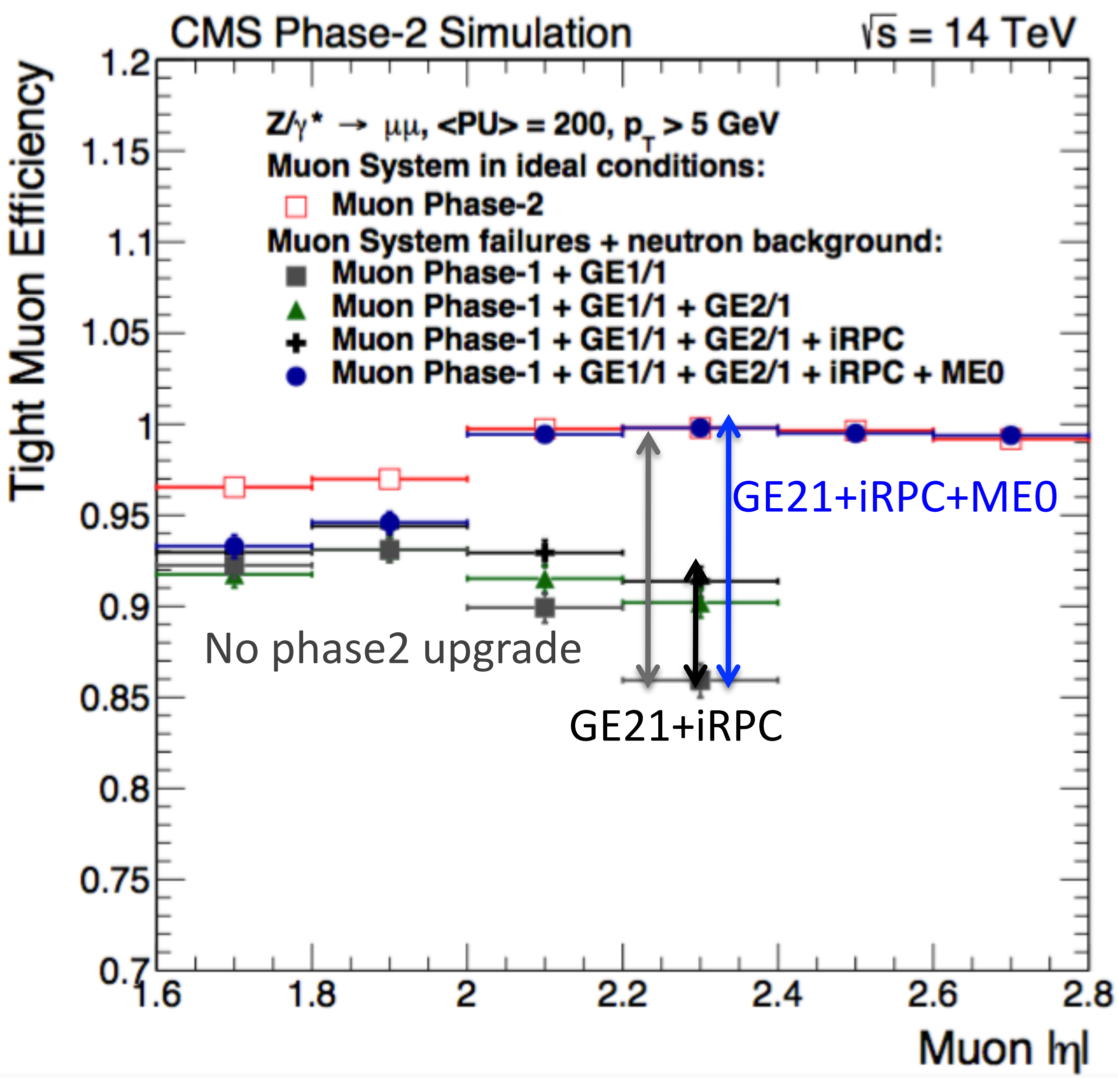


- Increased acceptance in muon reconstruction thanks to ME0
- Upgraded muon system guarantees the same performance of muon reconstruction at PU200 as in present (run2) scenario
- Very high efficiency in the whole eta range [0, 2.8] at any pileup
- The level of background muons is comparable with Run2
- There is room for further improvements (in the case of Loose ID) using the timing information of tracker+muon detectors

Muon ID performance compatible with Run2

Neutron bkg and muon system aging impact

Bologna,Bari,Pavia

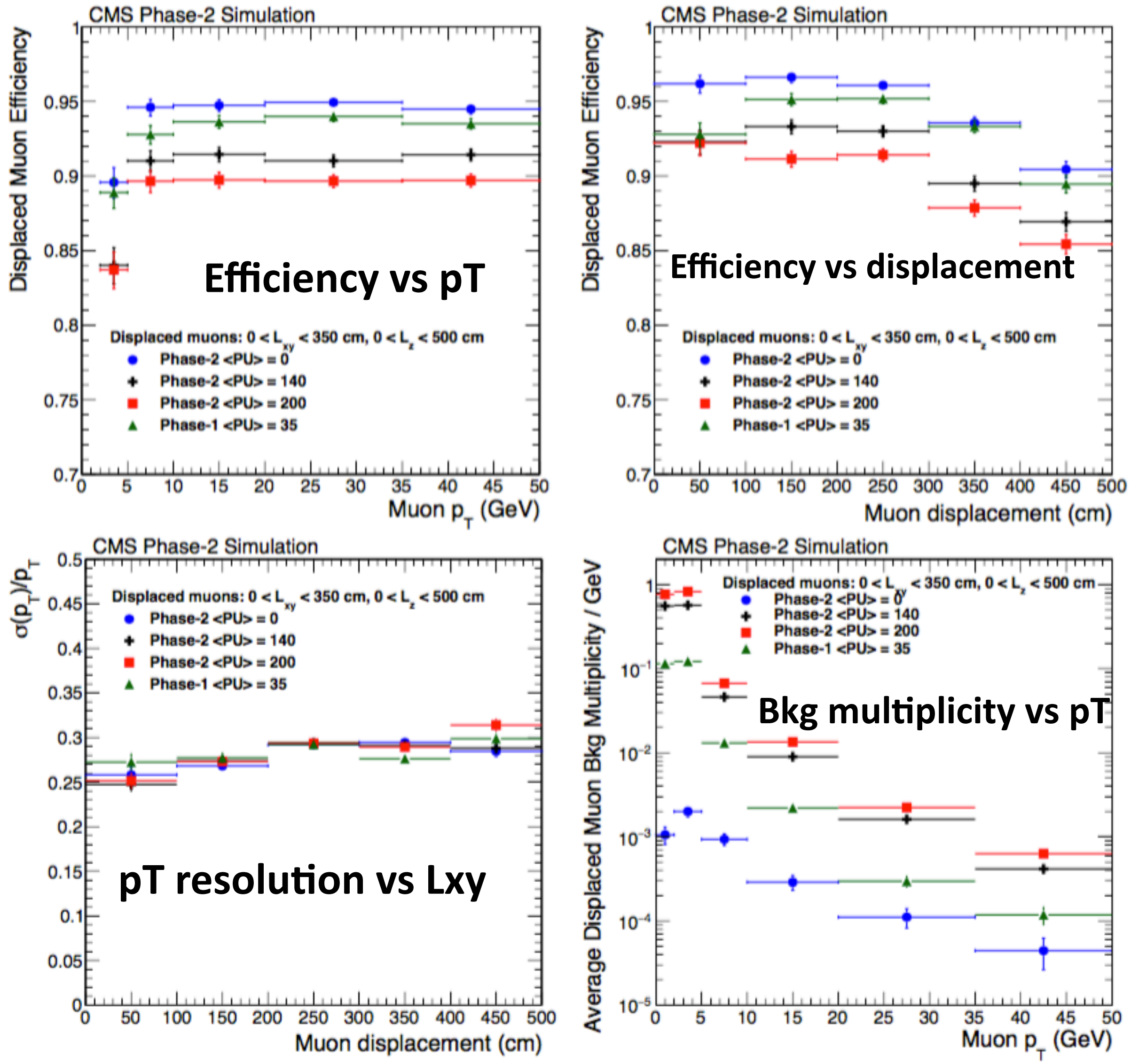


- Realistic description of the neutron induced cavern background included in the simulation
- Aging of muon detectors also simulated, according to the experimental measurement
- The upgraded detector allows for the identification of muons at PU200 with the same efficiency as the Phase-1 detector
- **The aged detector shows a drop in efficiency of approximately from 5 to 15%.**
- The impact of the new muon detectors in the forward region is clearly visible, up to the $|\eta|$ coverage provided by ME0.
- **No significant increase in the level of background muons**

New Muon stations allow to keep the same performance as in Run2

Displaced Muon performance

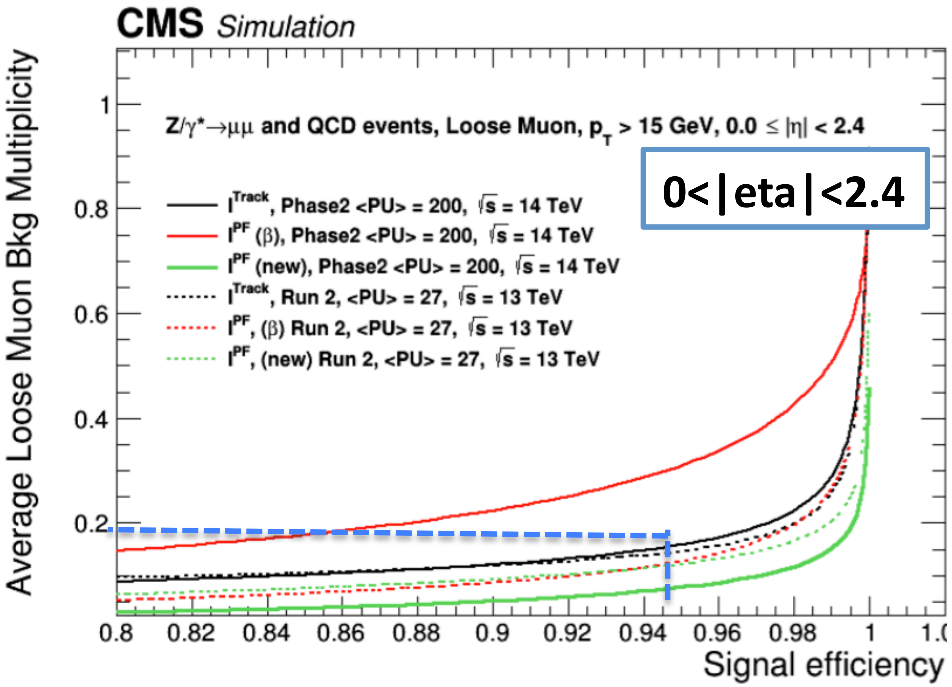
- A special standalone muon reconstruction algorithm (DSA) is available for the reconstruction of displaced muons decaying out of the tracker volume
  - The displaced tracks are reconstructed using only hits in the muon chambers
  - The reconstructed segments are not required to point towards the event vertex, and have no constraints to the beam spot
- The efficiency is decreased of ~5% by the pileup conditions
- Reconstruction remains efficient also for big displacements, not covered by the tracker
- The background multiplicity increases with pileup as expected, but it is kept under control up to PU 200
- pT resolution preserved in the PU200 condition

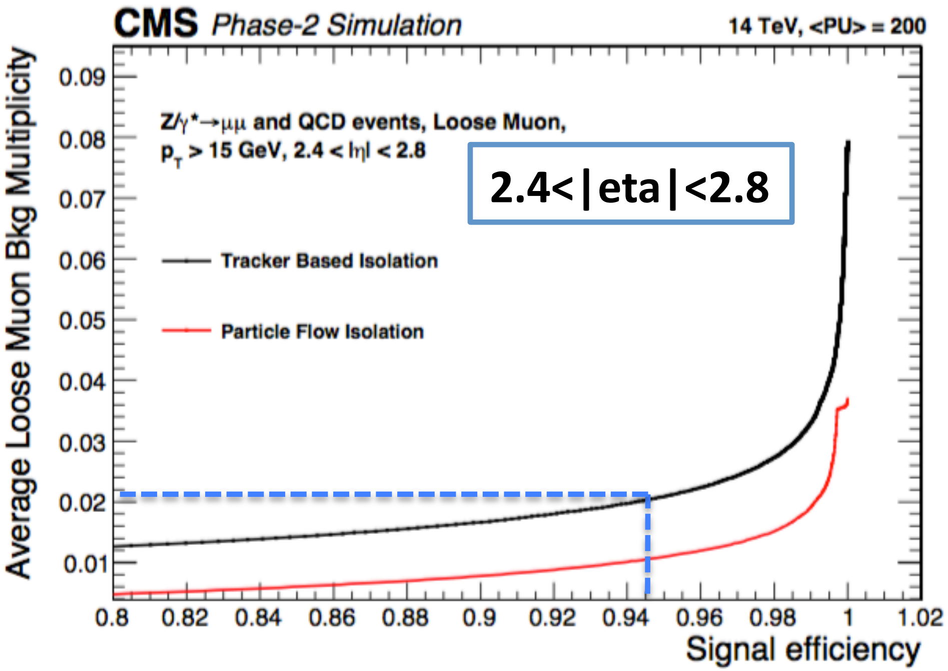


Muon Isolation

Two isolation methods (already used in Run2) have been studied

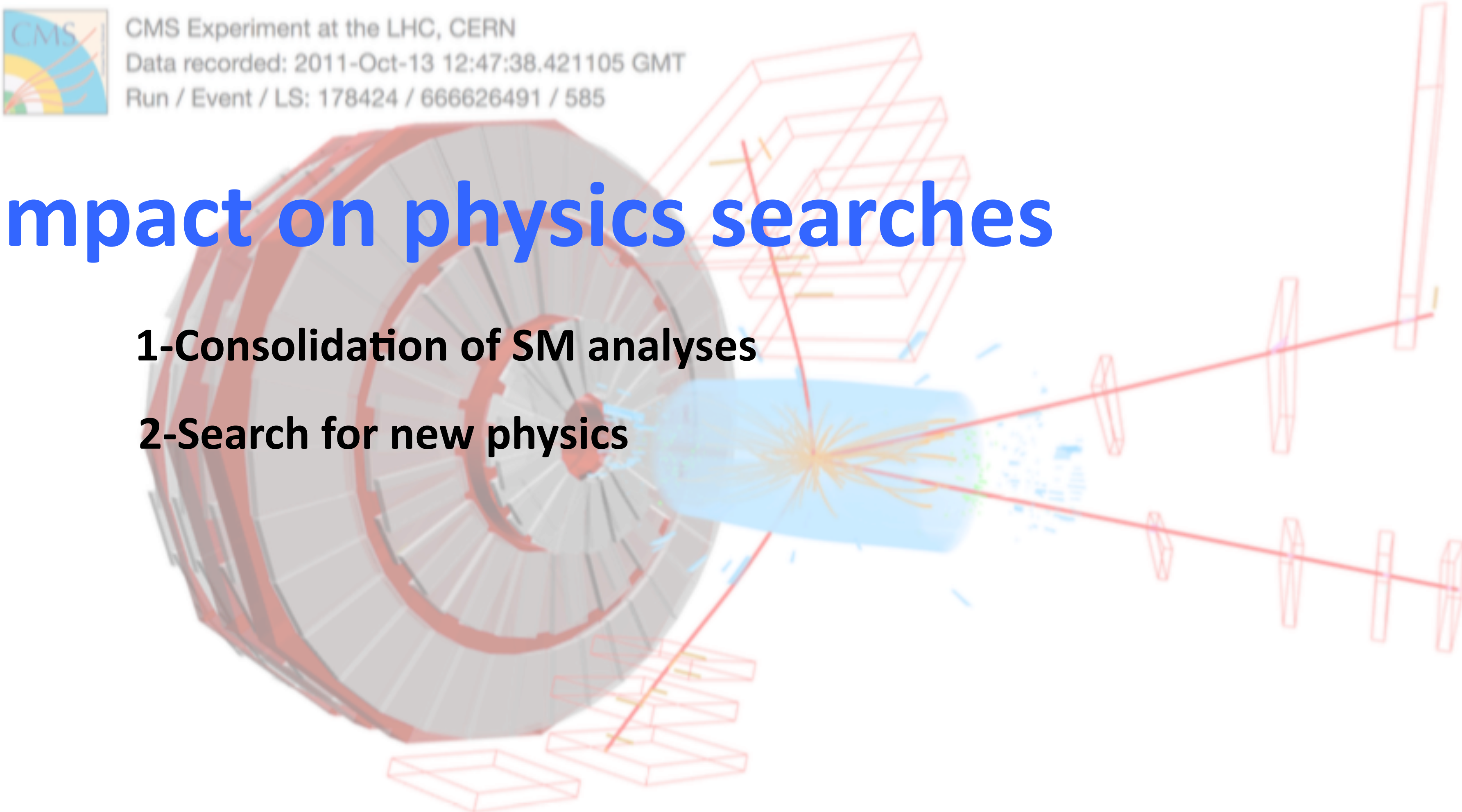
- Tracker based isolation used as a reference. Not very sensitive to PU.
- Particle Flow based isolation with PU subtraction. Better performance once optimized
- A re-optimization of the PF isolation algorithm in the barrel region shows the large potential of this approach also for Phase2 to reduce the background due to jets faking muons even at the highest PU values expected
- Track-based isolation used in physics analyses is a powerful tool to remove background





Same performance as in run2

Small background and high efficiency



Impact on physics searches

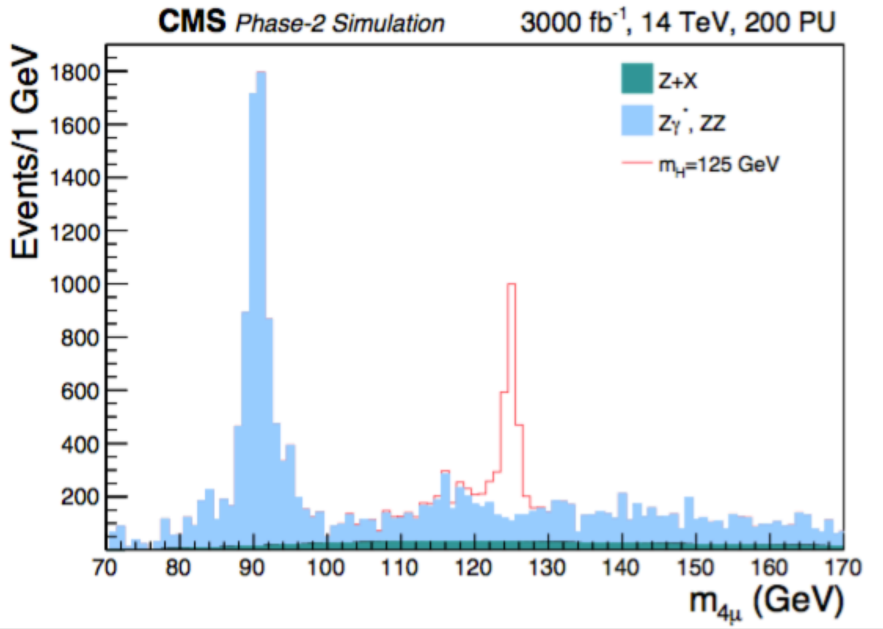
1-Consolidation of SM analyses

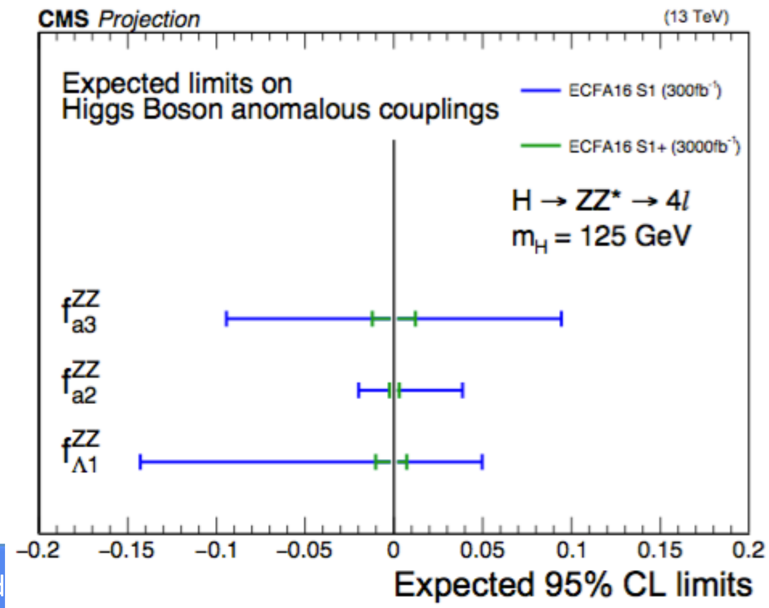
2-Search for new physics

Higgs → ZZ* → 4μ

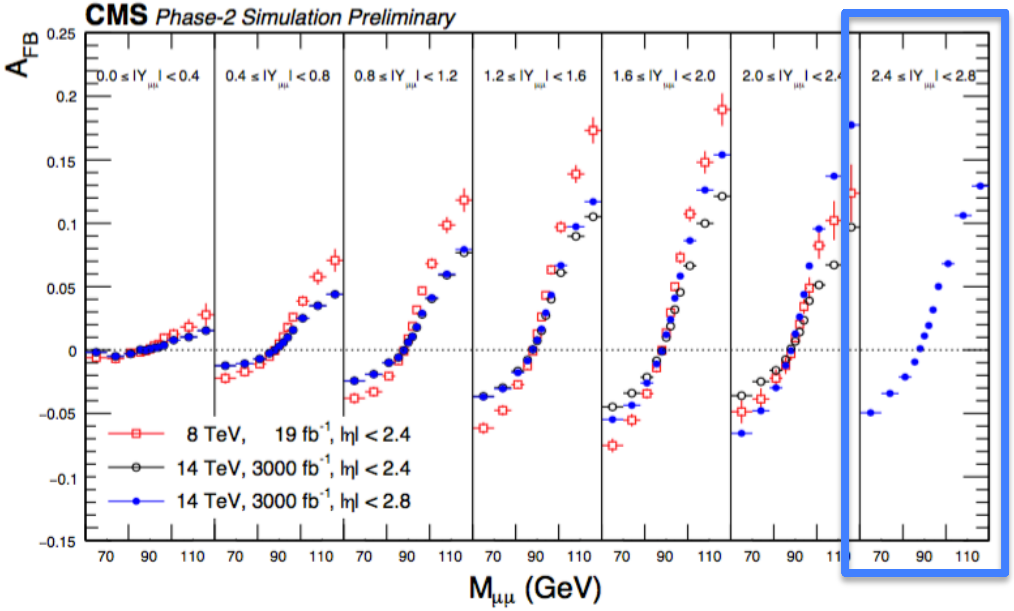
Bologna,Bari

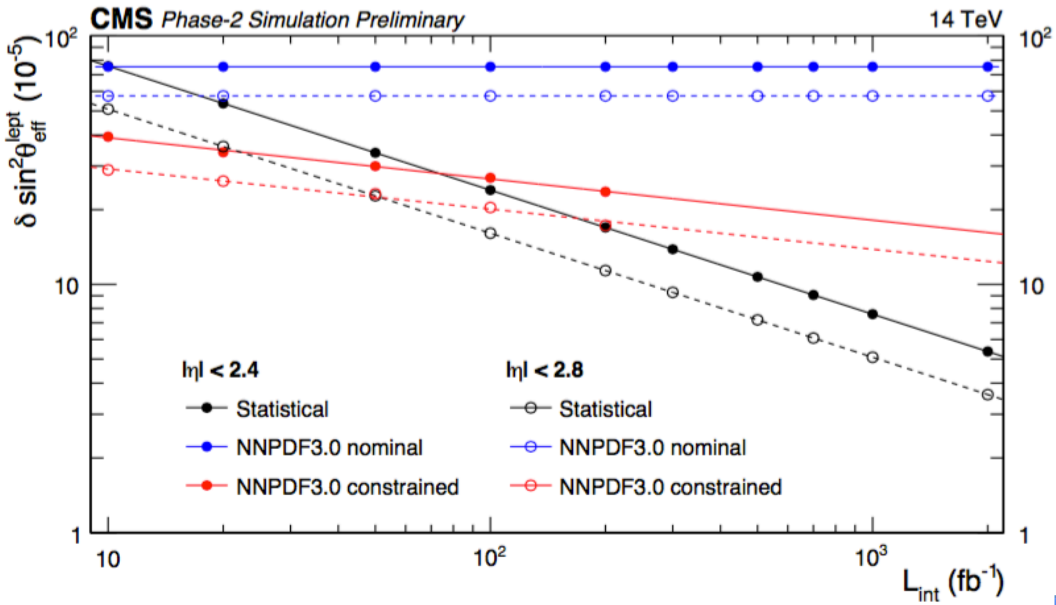
- Golden channel that allows complete reconstruction of Higgs boson decays with small background.
  - 4 loose identified isolated muons → Test bench for muon ID algos usage in phase 2
- **Signal acceptance <u>fairly immune to PU conditions (as well as S/N)</u>**
- **<u>Extra benefit:</u> 17% increase in acceptance (after analysis selection) due to high eta coverage by tracker and ME0.**
  - **This can be translated to 8% improvement in signal cross section measurement (or 500fb-1 of equivalent luminosity)**
- Can study differential distributions: ex. probe the high pT Higgs distribution (>100 GeV) and improve sensitivity to anomalous couplings





Effective weak mixing angle measurement





- Measurement of the effective weak mixing angle using the forward-backward asymmetry in Drell-Yan events
  - Generator level study with detector effect smearing
- Significant improvement brought by the extended eta coverage→

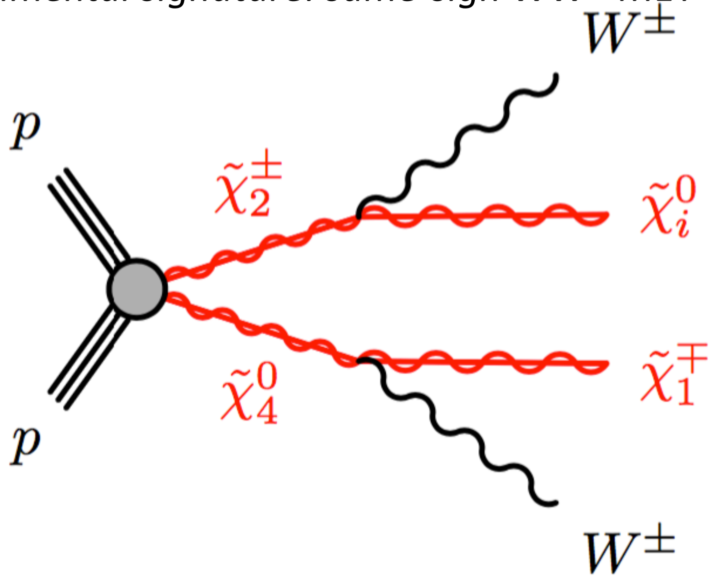
significantly increase of the coverage for larger *x*-values of colliding partons→

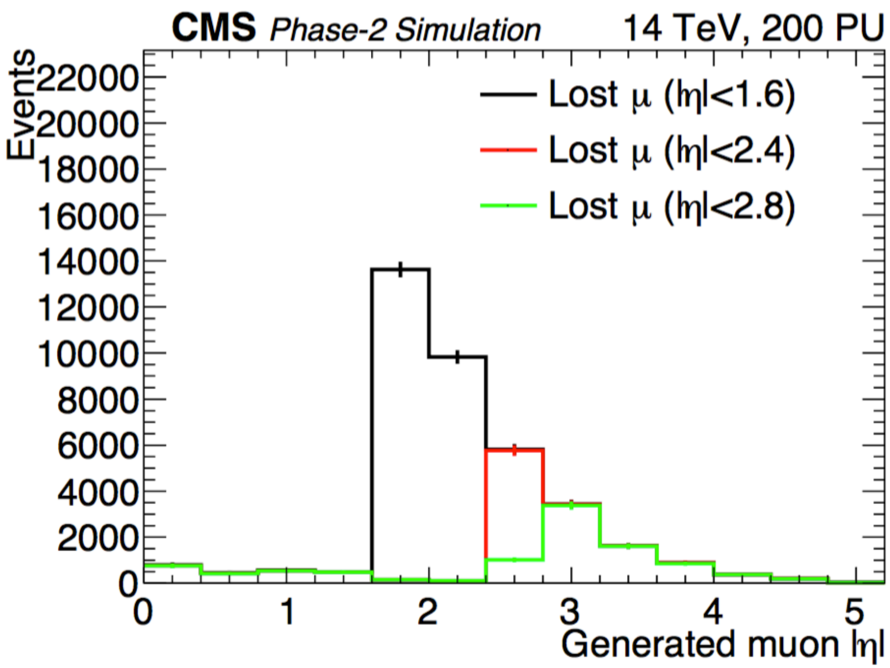
- **30% reduction of the statistical uncertainties**
- **20% reduction of the pdf uncertainties**

EWK Background suppression in SUSY searches

- Many new particle search signatures at the HL-LHC can be characterized by the presence of low momentum and forward leptons
- Example: search for wino pair production characterized by two same-sign leptons and large MET in the final state
- Extended coverage up to 2.8 in η allows a more efficient veto of WZ→ μμμ decays
  - Same sign leptons mimic signal + one muons missing since it is out of the acceptance
- **With extended coverage from 2.4<|η|<2.8: the WZ background decreases by a factor ~1.5 →this translates to a S/B improvement by 22%**

Wino-pair production
Experimental signature: same-sign WW +MET

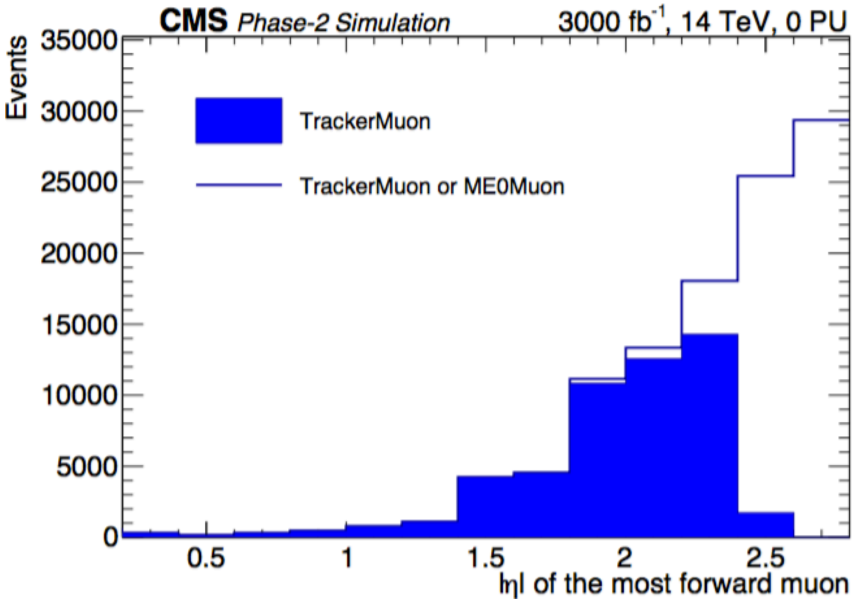


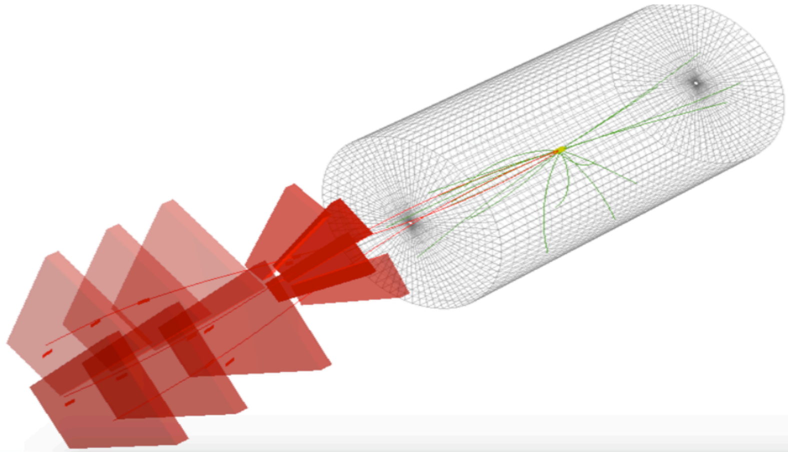


LFV Tau→3μ: a test of the SM

Bologna,Bari

- Extremely low cross-section also in BSM models→ accessible at HL-LHC
- The main source of τ leptons in pp collisions is $Ds \rightarrow \tau\nu$ decays.
  - Muons with very low momenta and boosted in the forward direction.
- The ME0 chambers increases the signal fiducial acceptance by a factor of 2 but
  - worse trimuon mass resolution at high $|\eta|$ →event categorization
  - Momentum measurement with GEM-CSC tandems not yet implemented
- MVA-based analysis
- Ad-hoc trigger and muon-ID
- Projected exclusion limit for 3000 fb^{-1}
  - **B(τ→3μ) is 4.3×10^{-9} at 90% without ME0**
  - **B(τ→3μ) is 3.7×10^{-9} at 90% CL with ME0**

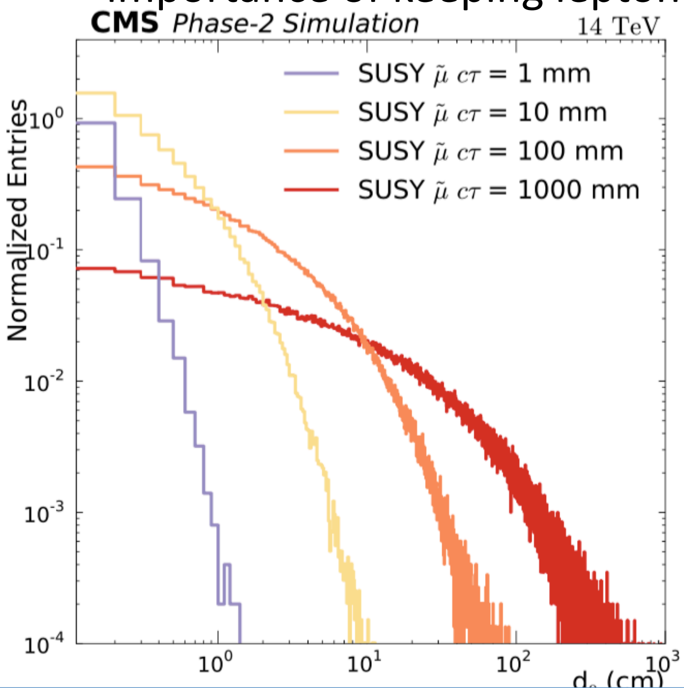


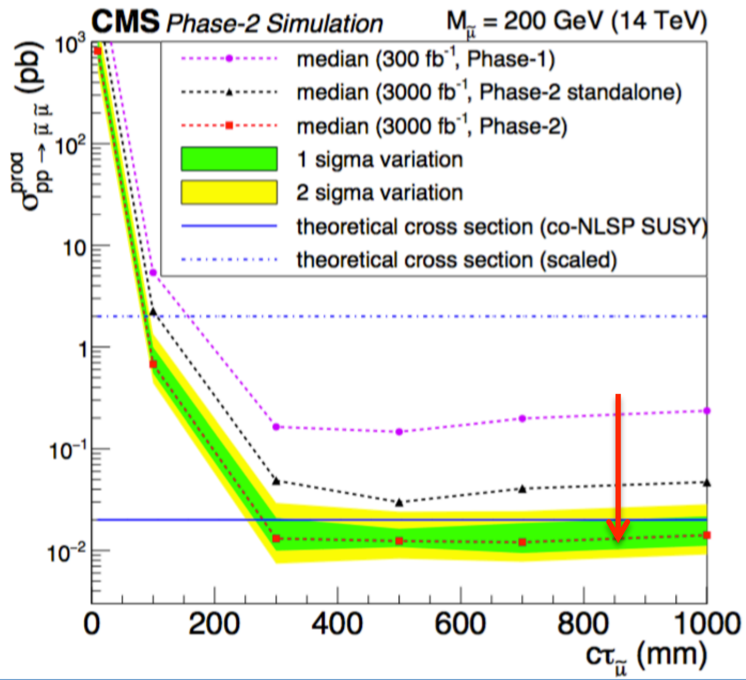


The difference can be re-interpreted as an effective gain in integrated luminosity ~1.35 →from 3000 to ~ 4000 fb^{-1} due to the muon extension

BSM searches: Displaced muons

- **Searches for the direct production of heavy sparticles with long lifetimes are difficult in the present LHC runs**
  - small cross sections (~10^{-2} fb for 1 TeV smuon)→become possible at the HL-LHC.
- **The sensitivity depends on *cτ* because shorter decay lengths shift the signal closer to SM background**
- Discovery sensitivity of 3*σ* significance can be reached with 3000fb^{-1} of data with the trigger/reconstruction/analysis efficiency assumed in this study
  - importance of keeping lepton trigger thresholds at a few times 10 GeV, even at PU200





Large displacements not covered by the tracker→key role of the Muon system

Analysis is sensitive only at HL-LHC, assuming full efficiency on trigger&offline

Summary and Conclusions

- **Upgrade concept**:
  - REPLACE electronics expected to fail at HL-LHC
  - ENHANCE forward system robustness: add GEM and iRPC detectors
- **System enhancements translate into new physics opportunities, provided highly performant muon trigger and muon reconstruction in HL-LHC conditions**
- **Trigger:**
  - Single Muon efficiency slighltly improves, trigger rates under control in the track trigger coverage
  - Dedicated trigger for the BSM searches
  - Very forward muon trigger with ME0 feasibility looks promising
- **Muon reconstruction**
  - Big effort to optimize the local reconstruction including new detectors in the simulation
  - Reco, identification, isolation algorithm optimized and deployed for various muon phase-space
  - Performance comparable with Run2 in HL-LHC conditions
- **Impact on physics searches**
  - Re-discovery SM channels absolutely feasible even at PU200, thanks to the upgraded detectors
  - New physics with small cross-section became accessible thanks to HL & higly performant muon trigger and reconstruction
  - Sensitivity improvement thanks to the additional statistics from ME0

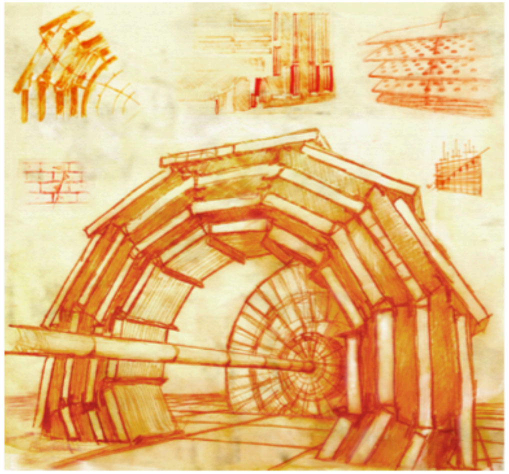
The Phase 2 Muon TDR

- TDR submitted on 12 September, first iteration with LHCC succesfully concluded
- *Summarize the last 4 year work of many people and several institutions involved.*
- ***Significant contribution in the editorship from INFN people***

CERN European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

CERN-LHCC-2017-012
CMS-TDR-17-003
12 September 2017

CMS



The Phase-2 Upgrade of the CMS Muon Detectors

TECHNICAL DESIGN REPORT

Main editors: Thomas Hebbeker, Andrey Korytov
chapter 2 = longevity: Andrey Korytov
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chapter 10 = summary: Thomas Hebbeker, Andrey Korytov

Next steps

- Nov 28 - LHCC review
- Nov. 29 - kick-off UCG
- Jan 9 – UCG iteration meeting
- Jan 24 – final UCG review

Backup

ME0 spatial resolution

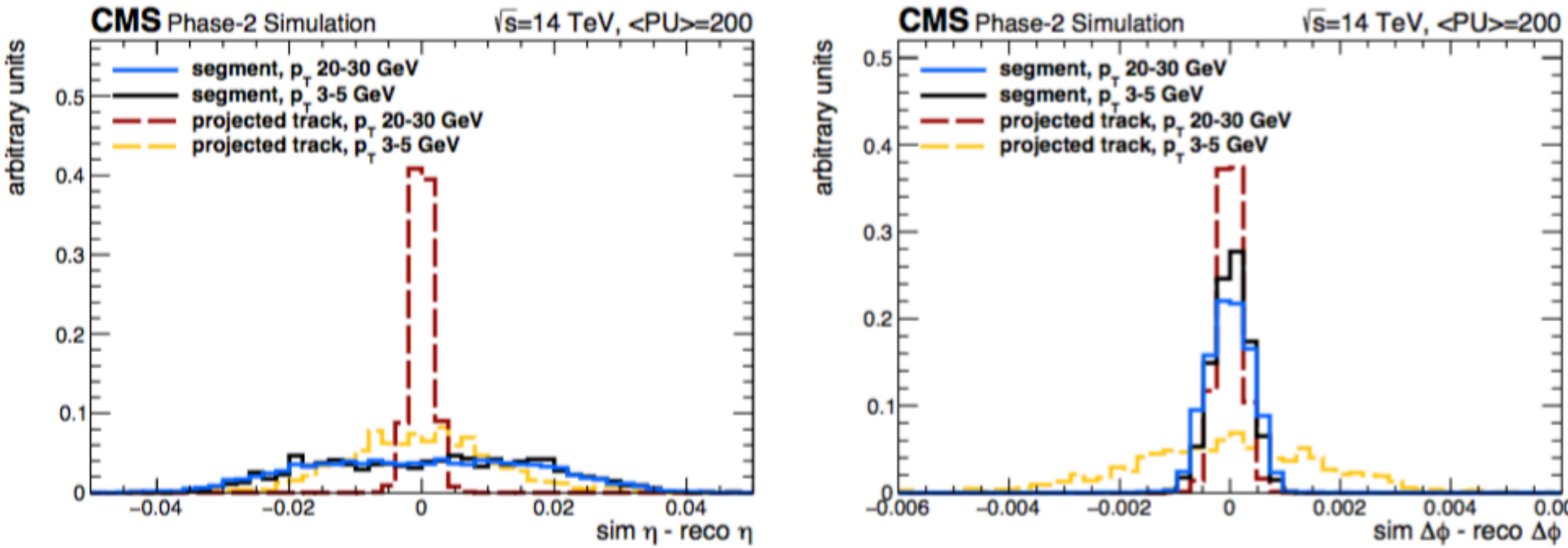
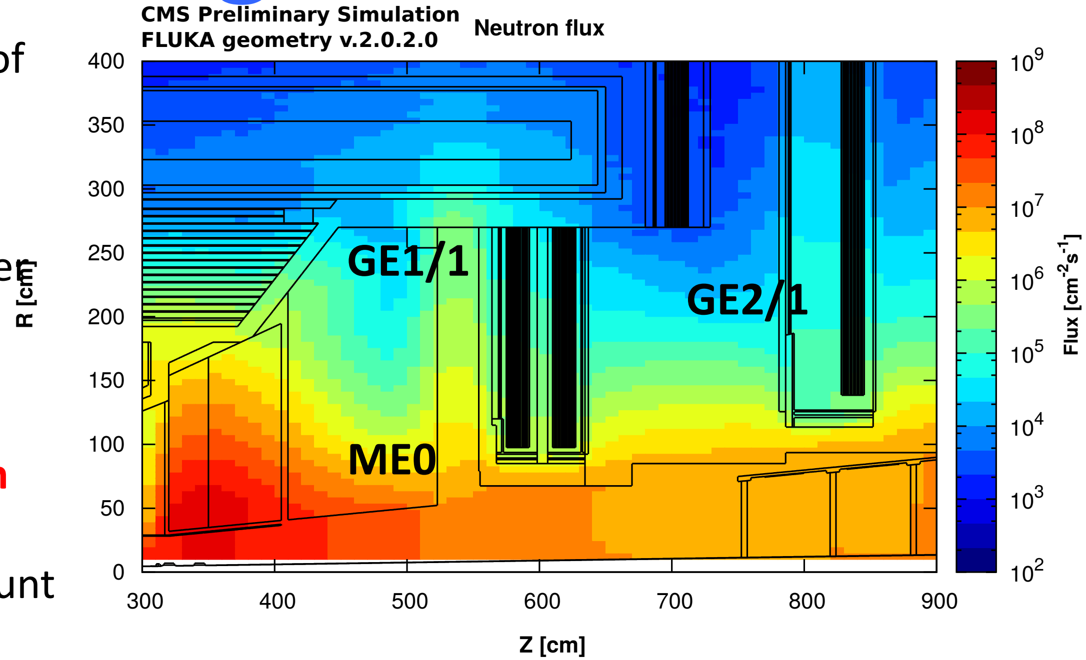
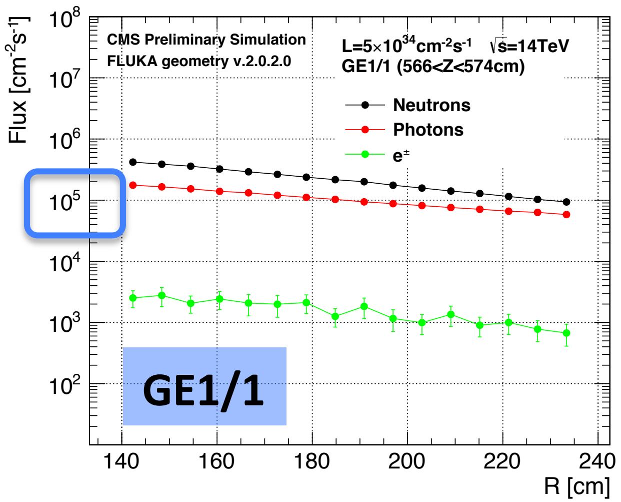


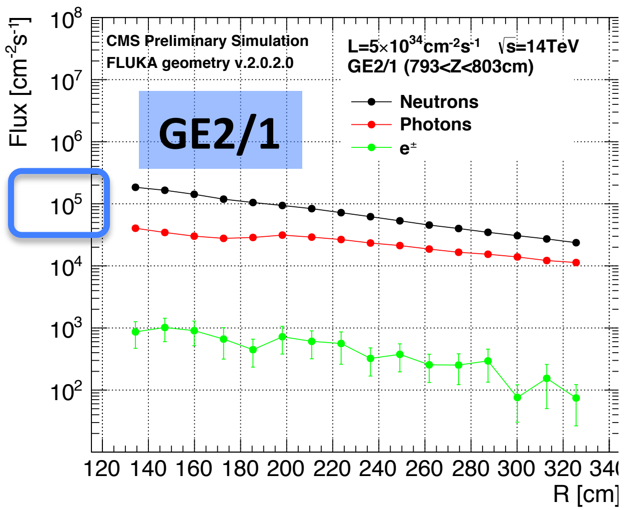
Figure 6.6: Reconstructed quantities, η of the particle at the center of ME0 on the left and $\Delta\phi$ on the right, compared to their generated values for different muon transverse momentum ranges. The quantities obtained by projecting the pixel track onto the ME0 surface are denoted "projected track" and those obtained from reconstructed ME0 segments are labeled "segment". The generated quantities are obtained from the simulated hits on the ME0 detector layers and include the effect of multiple scattering. For "projected track" the primary source of difference from the generated values is multiple scattering through the calorimeter while for "segment" it is the ME0 granularity.

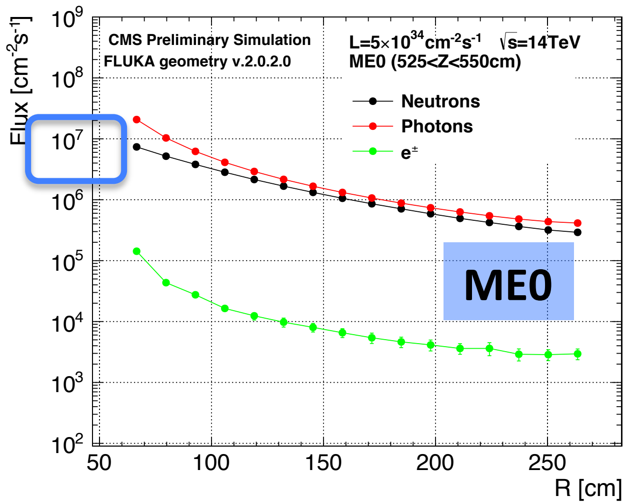
The Background @ high eta

- Hadronic interactions lead to activation of materials and give rise to neutron backgrounds.
- Long living neutrons can interact with nuclei and produce photons which further decay to electrons/positrons with some possibility to generate fake signals.
- **Expected hit rate 250 Hz – 1.5 kHz/cm^2 well within the margin of safe operation for GEM technology**
- Effect of the background taken into account in the simulation.





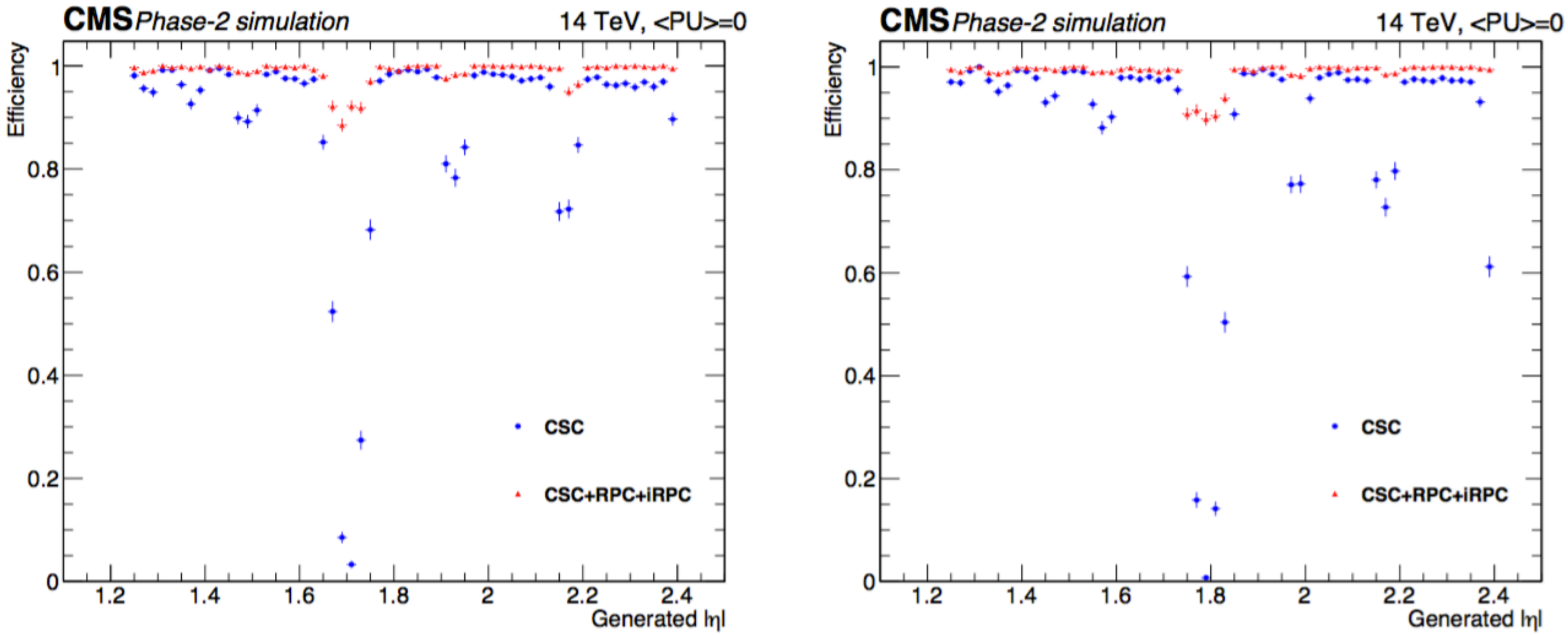




L1 standalone Muon Trigger performance: impact of RPC

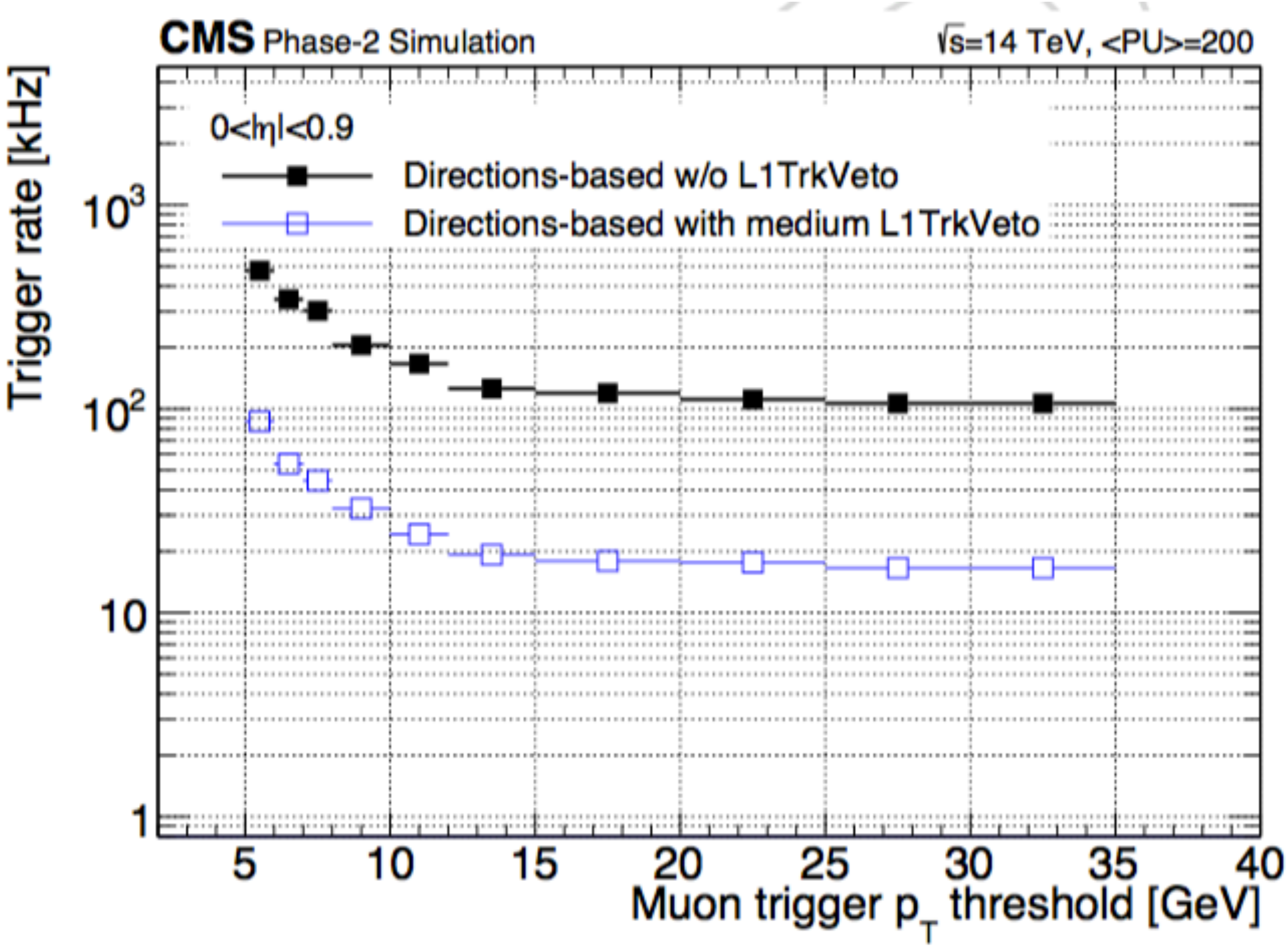
RE3/1 and RE4/1 were meant to be built, but were descoped

- CSCs paired with RPCs make segment-finding probability much more robust
- iRPCs will provide unambiguous 2D-hits, thanks to two-sided strip readout with new fast Link System, to help resolve combinatorial ambiguities in CSCs



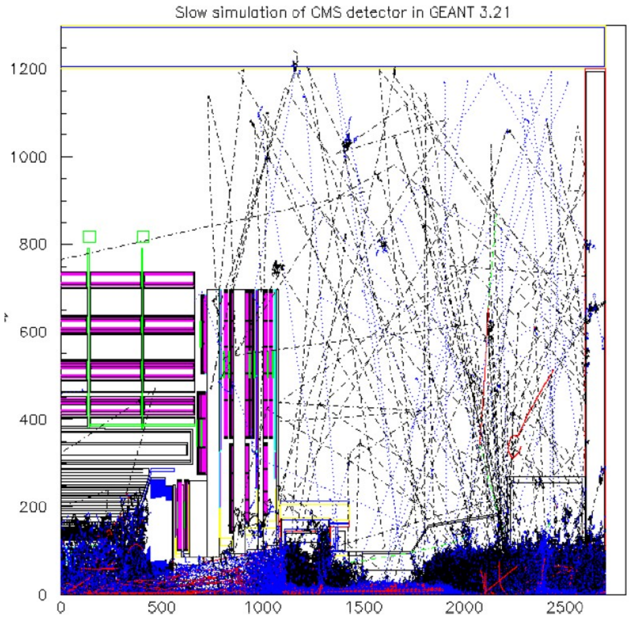
Efficiency of identifying muon segments/hits in muon stations 3 (left) and 4 (right)by the EMTF with and without RPC/iRPC detectors.

Standalone Displaced muon trigger



Defining the detector requirements: neutron background rejection

Neutron



- *pp*-collisions create long-lived neutrons ⇒ CMS in *neutron gas:*
- neutrons get captured in nuclei, emitting a photon (γ)
- γ produces $e^{\pm}$ of O(MeV) through Compton scattering or photoelectric effect

hits in muon chambers due to elastic (n, p) collisions in muon chambers or from γ produced outside muon chambers

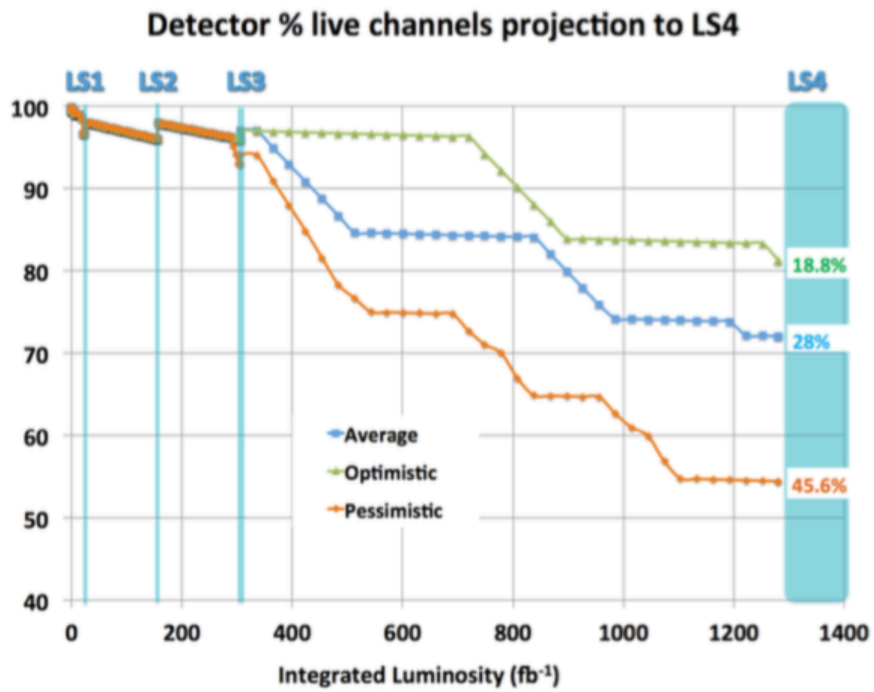
- **neutron** induced interactions result in 1–2 hits, not enough to form a segment, but at high rate might confuse segment building overlap of neutron hits from millions of BX
- **muons** travelling through a multi-layered structure leave (ideally) hits in each layer **⇒ Segment**
  - ⇒ **Multilayered structure** will allow to discriminate against ^{1}n background, but different layers should be decoupled
  - ⇒ **timing** can in principle mitigate part of the neutron background: if detection location is known precisely, only small time window is compatible with genuine muon hits from the interaction point.

The detector longevity problem

- **Very harsh conditions expected at HL-LHC with integral radiation dose parameters and hit rates**
- **High radiation affects both the detectors and electronics**:
  - can decrease the gas gain and increase hit-efficiency losses
  - radiation damage of the silicon substrate in electronic chips can lead to noisier electronics performance and even fatal failures of entire electronic boards.
- Accelerated tests (indicative only) are on-going by exposing detectors and electronics to irradiation source:
  - At least a factor of 3 larger than what we expect to see over the HL-LHC (3000 fb-1) lifetime is considered.

$\|\eta\|$ range	DT 0-1.2	CSC 0.9-2.4	RPC 0-1.9	iRPC 1.8-2.4	GE1/1 1.6-2.15	GE2/1 1.6-2.4	ME0 2.0-2.8
neutron fluence (10^{12} n/cm^2)	0.4	40	1	7	20	12	200
total ionization dose (kRad)	0.12	10	2	3	3	7	490
hit rate (Hz/cm^2)	50	4500	200	700	1500	700	48000
charge per wire (mC/cm)	20	200	-	-	-	-	-
charge per area (mC/cm^2)	-	-	280	700	6	3	280

Muon system Ageing Model



DT

Muon ID Definitions

SIGNAL:

Reconstructed and identified muons associated to muons produced by the generator in the Z/ $\gamma^* \rightarrow \mu\mu$ event generation

FAKES/BACKGROUND:

1. Out of time muons associated to (uncorrelated) in-time tracker track
2. In-time muons from pileup matched to an uncorrelated tracker track
3. Punch-through's Muons from decays in flight of the main interaction
4. All the real muons coming from pileup interactions
5. Duplicated muons

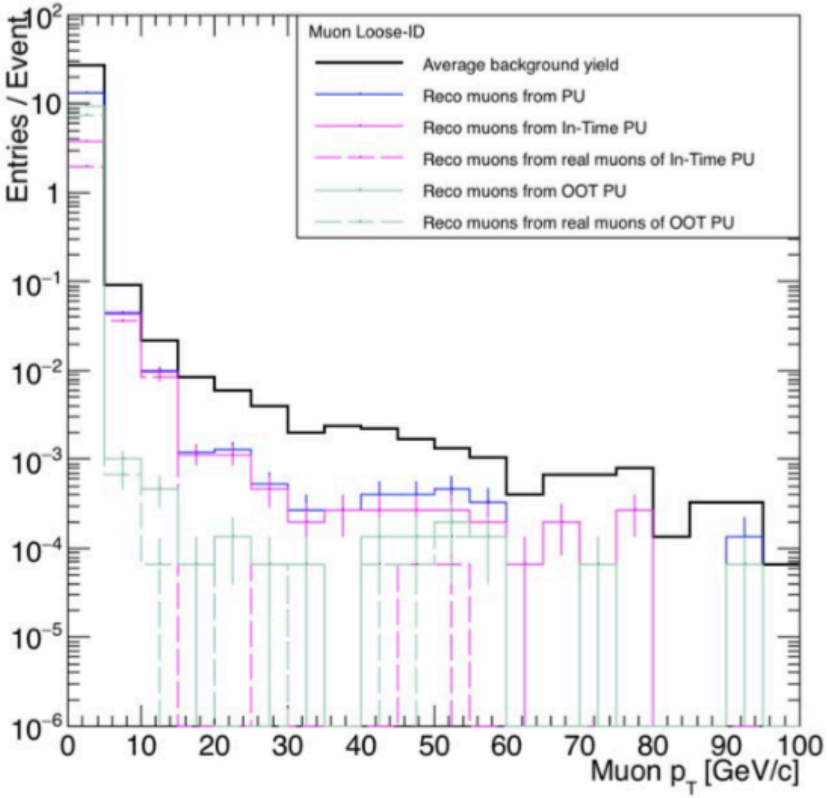
Efficiency=# of simulated muons associated to the recoMuons that pass id criteria/# of simulated muons from signla

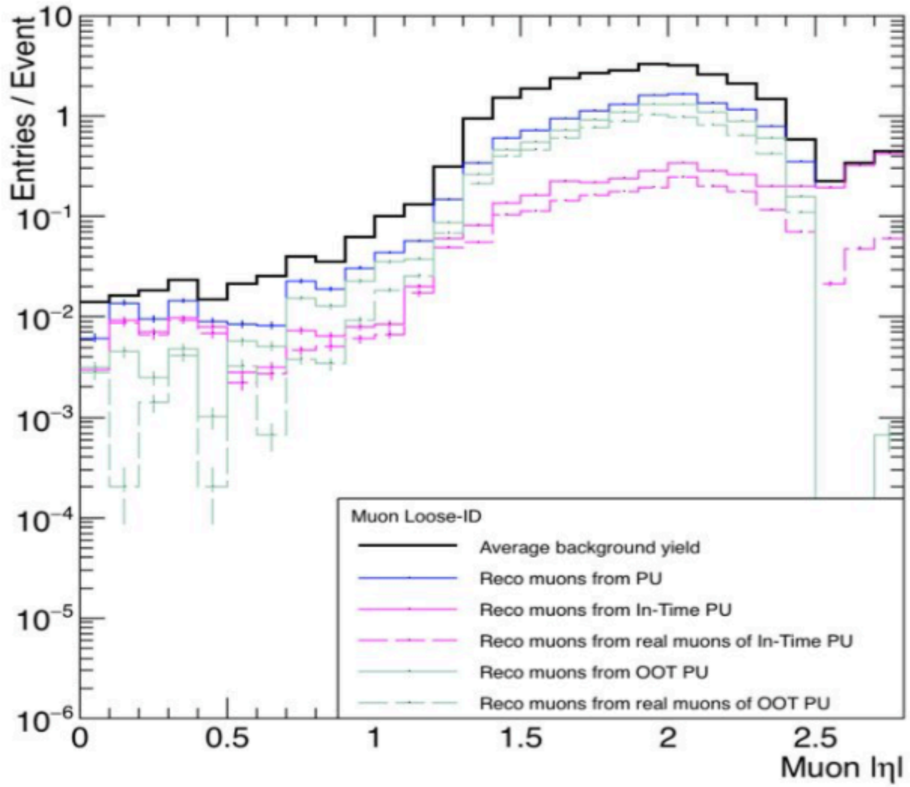
Background yield= number of muons NOT associated to generated muon from signal/ total numer of processed events

Background muon composition

A selection is applied on the timing of the standalone muons exploiting the high time resolution of the muon detector→this reduced the background of the standalone muons

This can apply also for the global muons (even if is not yet implemented)
Many background muons are from OOT pile-up→ can be suppressed by requiring a selection on the timing of the tracker track





Run II Muon ID Selections

- **Loose ID**
  - Particle identified as a muon by the Particle-Flow (PF) event reconstruction
  - Discard muon candidates which are reconstructed only on the muon detectors, without hits reconstructed on the inner tracking system
- **Tight ID**
  - Particle identified as a muon by the PF event reconstruction
  - Global muon track, including hits in the inner tracking system and in the muon detectors
  - At least one muon chamber hit used in the global track fit
  - Global track fit chi2/ndf < 10
  - Muon Inner track extrapolation matched to segments in at least two muon stations (by the Tracker Muon algorithm)
  - Hits on more than 5 layers of the inner tracking system
  - At least one pixel hit in the silicon tracker layers
  - Cuts on the impact parameters in the transverse and longitudinal planes w.r.t. the primary vertex of the event: $|dxy| < 0.2$ cm, $|dz| < 0.5$ cm

NB: Largest summed squared pT is no more able to identify the correct primary vertex (PV) at high PU even if with the new PV sorting.

The impact parameter calculation is done w.r.t. the PV closest in global z to the simulated vertex

ME0 MUON ID SELECTIONS: DETAILS

- **Tagging tracker tracks using the ME0 segments**
  - All possible combinations are taken into account
  - Arbitration implemented as for the classic tracker muons
- **Further selecting the ME0 identified muons by requiring:**
  - a matching (tracker track-ME0 segment) in global eta
  - a matching (tracker track-ME0 segment) in global phi (shrinking cut with muon p)
  - a matching (tracker track-ME0 segment) in the bending angle (shrinking cut with muon p)
  - the tagged track is a high purity tracker track
  - the tagged tracker track has at least one pixel hit in the silicon tracker layers
  - a cut on the transverse and longitudinal impact parameters w.r.t. the primary vertex of the event: $|dxy| < 0.2$ cm, $|dz| < 0.5$ cm
- **Playing with the matching criteria we define:**
  - a Loose ME0 muon ID targeting 95% efficiency for 2-4 GeV muons
  - a Tight ME0 muon ID targeting 95% efficiency for 3-5 GeV muons

To do list for Phase 2 Muon reconstruction

Reconstruction Task List
Check and improve the GEM segment algorithm
Study the GEM segment quality
Check the GEMMuon ID: tuning and performance
global track fit of ME0Muons
GEM-CSC super segment with RU algorithm. Then add in STA and Tracker Muon algo + performance
Complete the development of the ME0 simulation on top of the realistic digitizer: recHit, segment, validation
Use of GEM/ME0 BX information for OOT pile-up rejection

Complete the packer/unpacker development for the new detectors (GEM, ME0)
Background composition study for ME0 (this is of general interest for the Muon POG)
GEM alignment
Study the neutron background rates and comparison with FLUKA

DT Upgrade

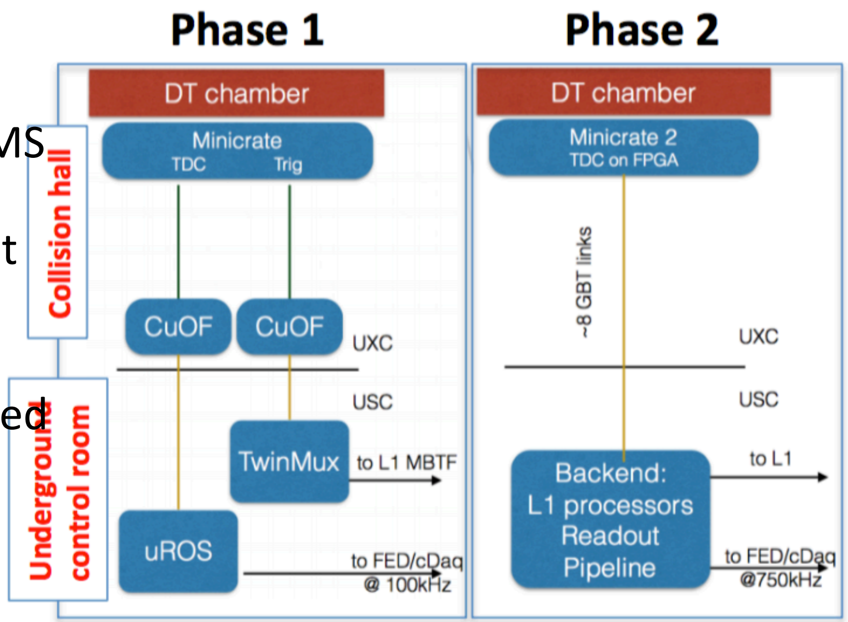
Bo, PD, To

PROBLEM:

- The readout system cannot work with the new CMS L1 specs
- The aging of the detector will reduce the single hit efficiency.

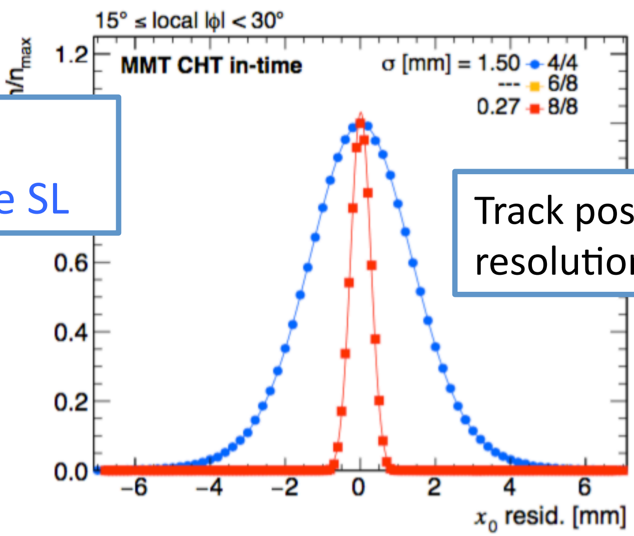
SOLUTION:

- New minicrates (simpler and rad-hard), FPGA-based TDCs , no segment-building logic
- New backend electronics
  - unified trigger and DAQ data stream handling
  - much more flexibility in building TP
  - RPC hits are used for unified RPC-DT segment
- New algorithm for BX identification and track fitting (MMT-CHT) developed to fully exploit hardware resources

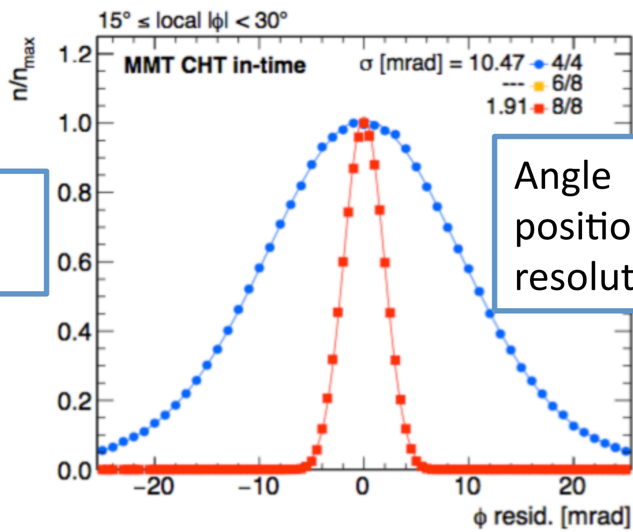


•8 aligned hits in 2 SL

•4 aligned hits in only one SL



Track position resolution



Angle position resolution

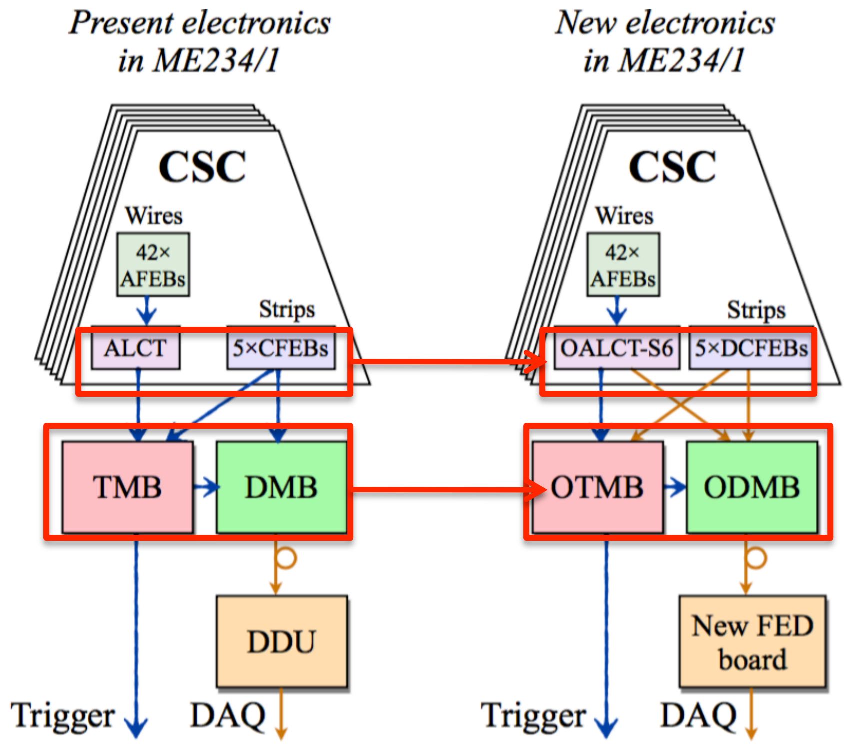
CSC Upgrade

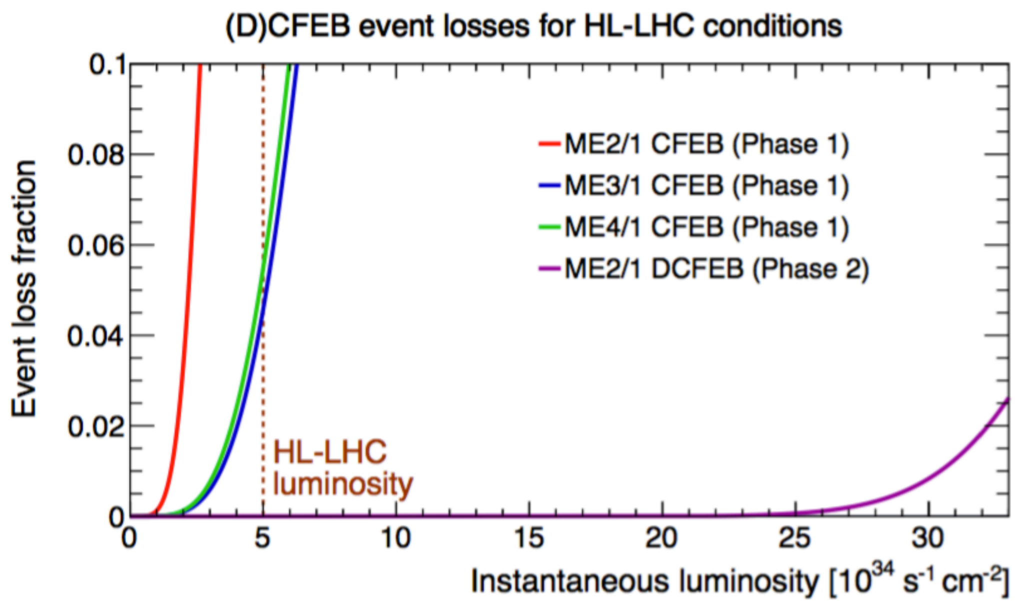
PROBLEM:

- DCFEBs on ME1/1:
  - EPROMs not rad-hard enough
- CFEBs on ME2/1, 3/1, 4/1
  - fail new L1/DAQ specs
- ALCT boards cannot handle the new L1 latency
- HV system: needs more current; ME1/1 HV noisy

SOLUTION:

- New DCFEBv2 boards for ME1/1
- Present ME1/1 DCEBs → move to ME2/1, 3/1, 4/1
- ALCT: new mezzanine boards (larger FPGA)
- New frontend board imply upgrades in corresponding on-CSC LV boards, and off-CSC Trigger and DAQ boards
- HV: new master boards; new distr. boards for ME1/1





RPC Upgrade

Ba, Na, LNF, Pavia

Chamber performance decrease slightly with rate, from about 97% at low rates to 95% at 600 Hz/cm2

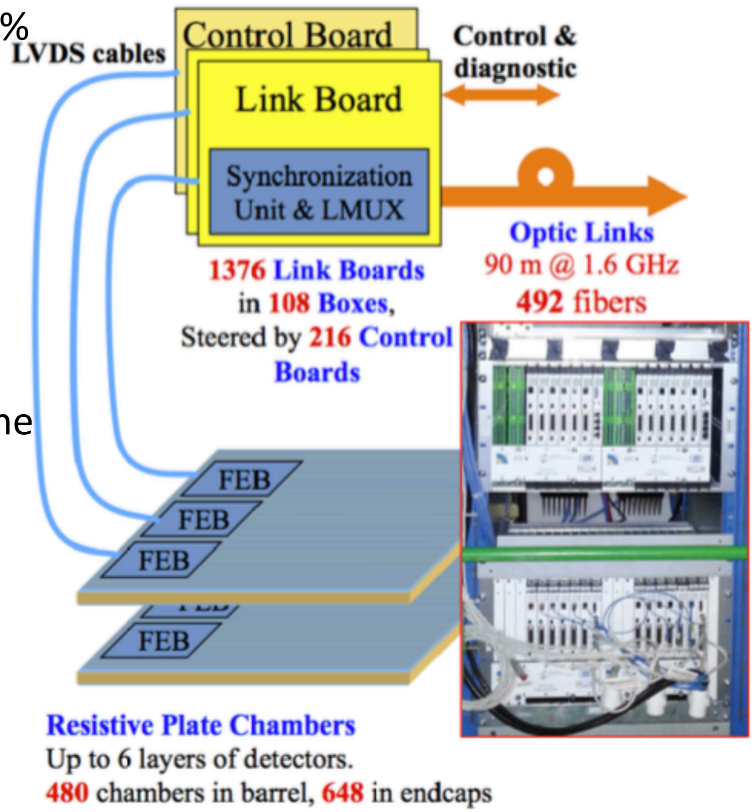
PROBLEM:

- System is prone to losing communication with the configuration system
- Link board failure rate is not sustainable in long run

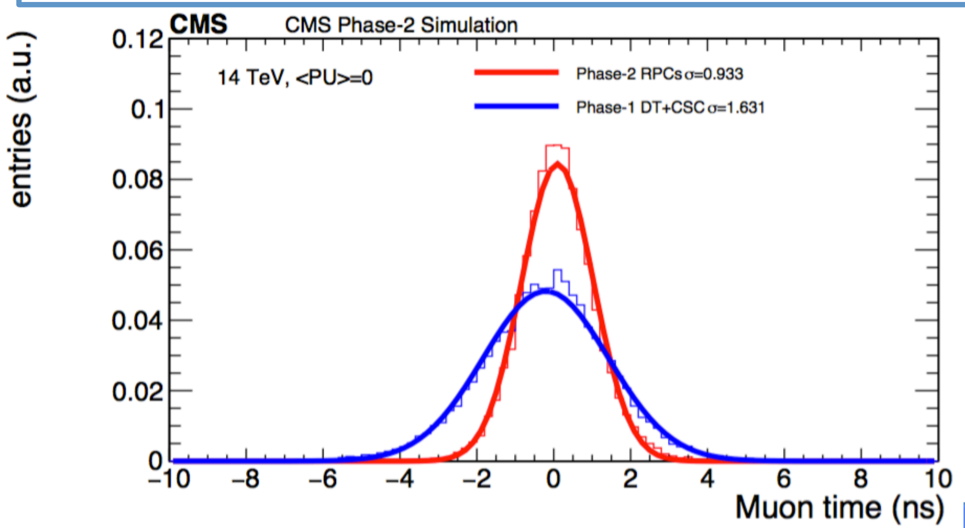
SOLUTION:

- New Link System redesigned for more robust performance
- change from 40 MHz signal sampling to 640 MHz to exploit the excellent intrinsic RPC time resolution (25ns sampling → 1.56ns sampling)

Link system



Muon time resolution without (blue) and with (red) the upgraded RPC link system.



Advantages:

- background hits arriving out of time can be identified and removed
- triggering on slow heavy stable charged particles becomes possible
- the synchronization of the RPC system is facilitated.

Triggering at HL-LHC

The goals:

- Maintain sensitivity to electroweak scale physics keeping acceptable rate even for low L1 pT thresholds.
- Add sensitivity to new physics scenarios, i.e. acceptance to displaced muons and HSCPs from long-lived particle decays

The HL-LHC challenges (induced pile-up and electronics):

- worse muon pT resolution
- increase of the trigger rate
- lack of redundancy in the forward region

CMS will have new handle to cope these conditions

- New detectors in the forward region (ME0, GE21, RE31,RE41) → Additional bending angle measurement and improved time resolution
- L1 Track Trigger → require clever segmentation for the new detectors
- Increased latency and bandwidth → new on-detector electronic
- Add triggering capabilities in the forward region $2.4<|\eta|<2.8$

This implies a completly new design for phase 2 Muon trigger

HL-LHC Barrel Muon Trigger

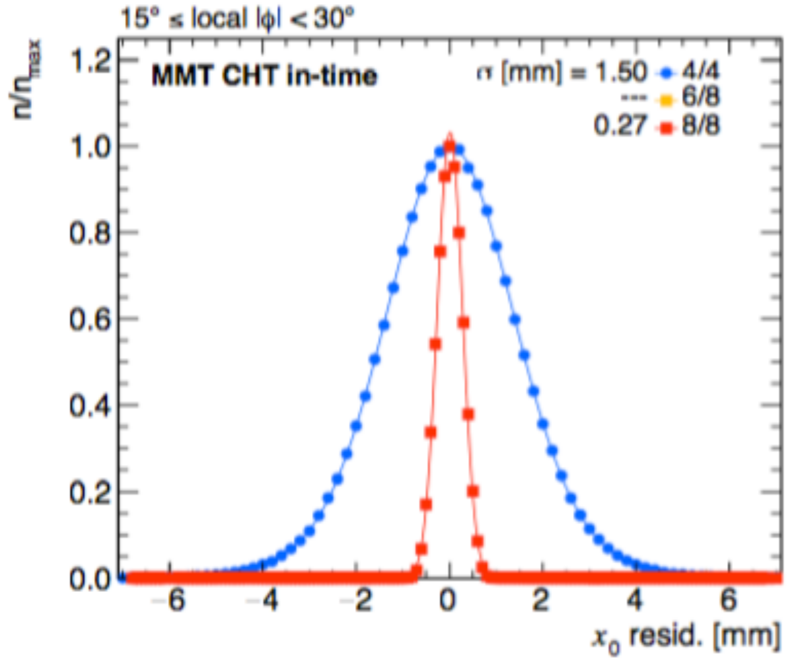
Major upgrade in the DT system

- Stubs computed in USC55 with full access to information from multiple stations
  - Not anymore limited to small regions in a given SL
- Better TDC resolution thanks to the upgraded electronics
- New algorithm for BX identification and track fitting (MMT-CHT) developed to fully exploit hardware resources

RPC hits with improved timing (25 ns→1.56 ns) used in the TP generation

- Entire set of muon hits available for muon track identification:
  - more resilient to losses of hits in comparison to the present logic of having to build and use per station segments
  - Phase-2 L1 trigger will have as much (and even more) information as the present HLT L2, which has ~1/5 rate of L1
- **Result:**
  - Higher efficiency
  - Trigger rate is reduced by a factor of 5

Track position resolution with improved DT electronics and algo

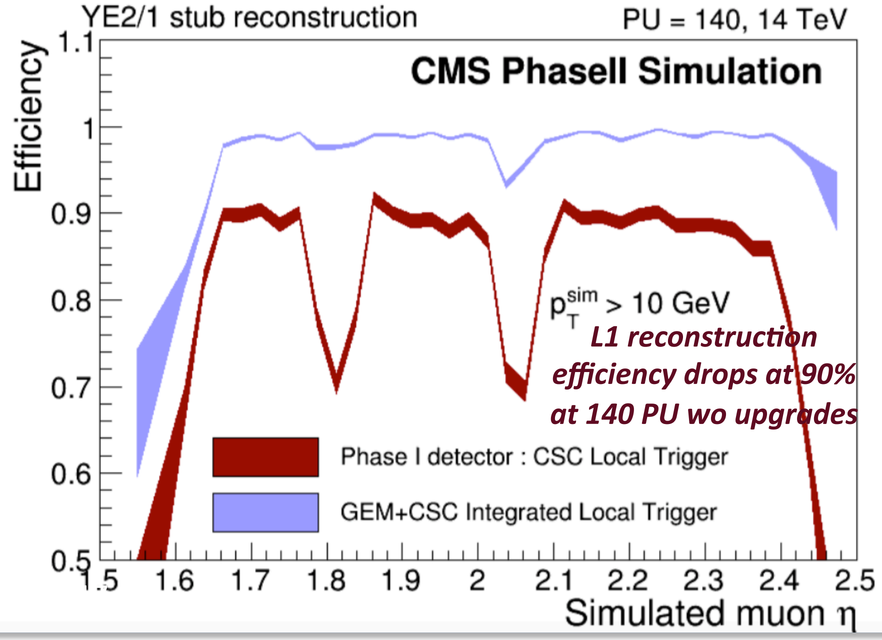


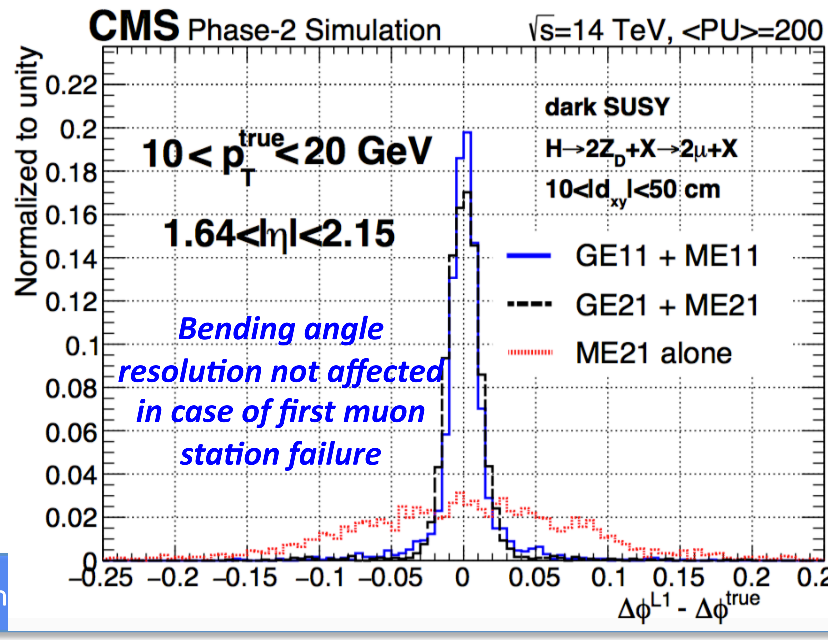
- 8 aligned hits in 2 SL
- 4 aligned hits in only one SL

GE2/1: a new tool for triggering

- 20-degree triple-GEM chambers arranged in two layers
  - High-rate capability and time resolution
  - Readout optimized to cope HL-LHC conditions
  - Big size detector→ each chamber is segmented into 4 modules
- Second muon direction measurement by the GE21-ME21
  - improves trigger efficiency, stability, rate reduction
  - even in scenarios with a severe degradation of the ME1/1
- Allow precise pT-measurement of displaced tracks

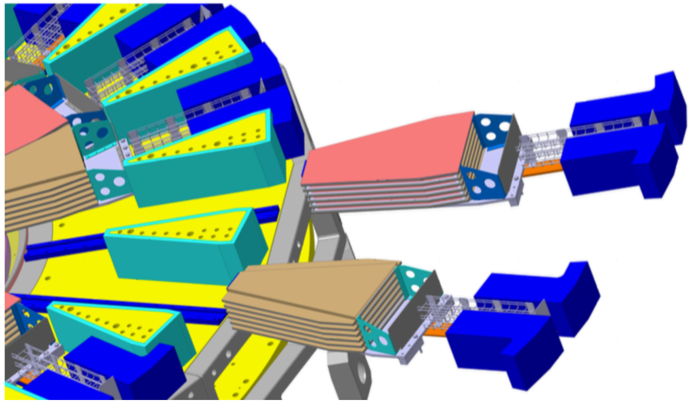
Ba, Bo, Na, LNF, Pavia



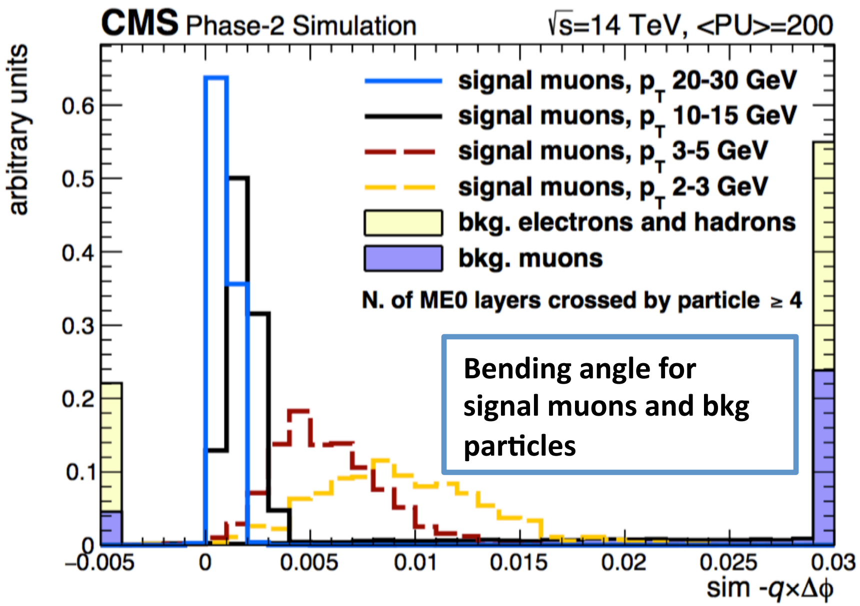


ME0: the first muon station in the very forward region (2.0 < |η| < 2.8)

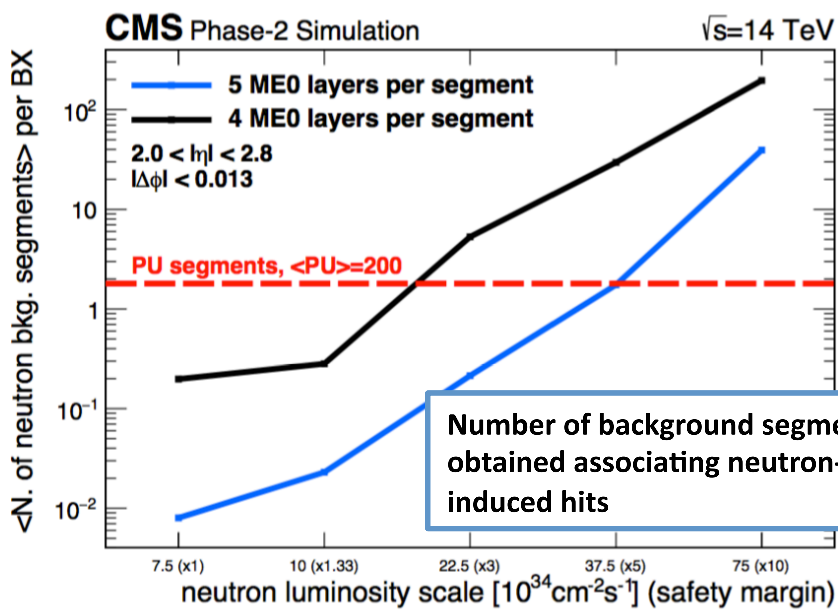
- 6 layers of triple GEM detectors
- Identify muons with low pT but large p and provide coarse momentum estimation at L1
- High background rates from:
  - charged particles produced in PU interaction → ~ 1000 pixel tracks/BX at PU200 → granularity of the ME0 design to allow precise bending angle measurement
  - long lived neutrons and theirby products → 1000 ME0 hits per BX → reduced by requiring hits in at least 4 layers
- Extend the range of muon triggering to the 2.4 < |η| < 2.8 region
  - for cross-triggers
  - pixel tracks are matched to ME0 segments at HLT → x10 bkg reduction



Ba, Bo, Na, LNF, Pavia



Bending angle for signal muons and bkg particles

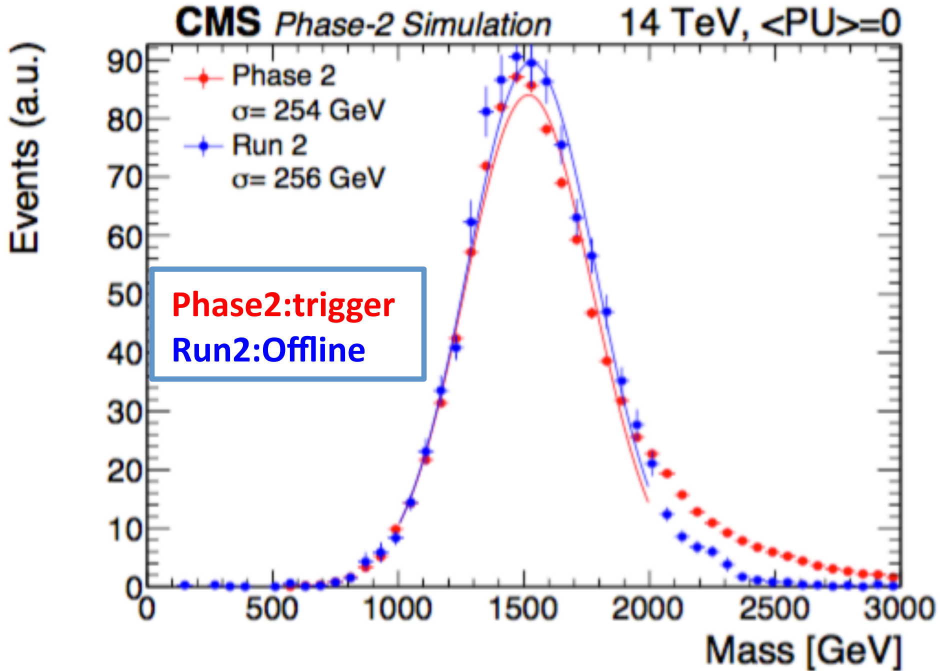


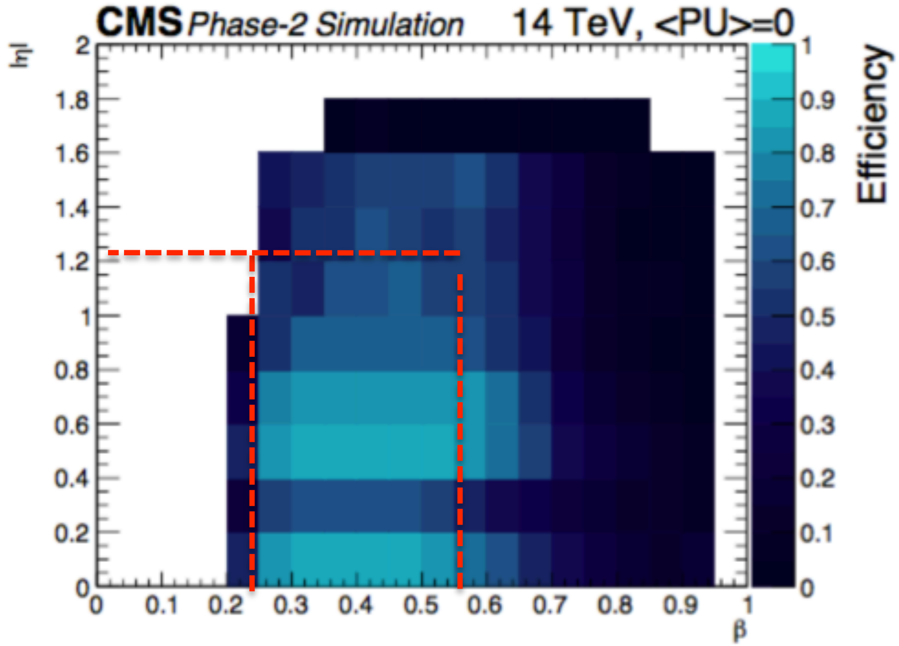
Number of background segments obtained associating neutron-induced hits

BSM searches: HSCP

LNF,Napoli

- Split SUSY predict the existence of new heavy particles with long lifetimes
  - it can travel through the majority of the detector before decaying and therefore appear as stable
- HSCPs can move much more slowly than muons→identified using **time-of-flight (TOF)** from the center o CMS to the muon systems.
- Particles moving slowly through the muon systems leave hits with a linear pattern in hit-position versus time. The **hits can be spread across several bunch crossings.**
  - **muon detectors with precise timing can provide important information for the HSCP signal searches→exploit RPC time resolution with the upgraded linkboard**





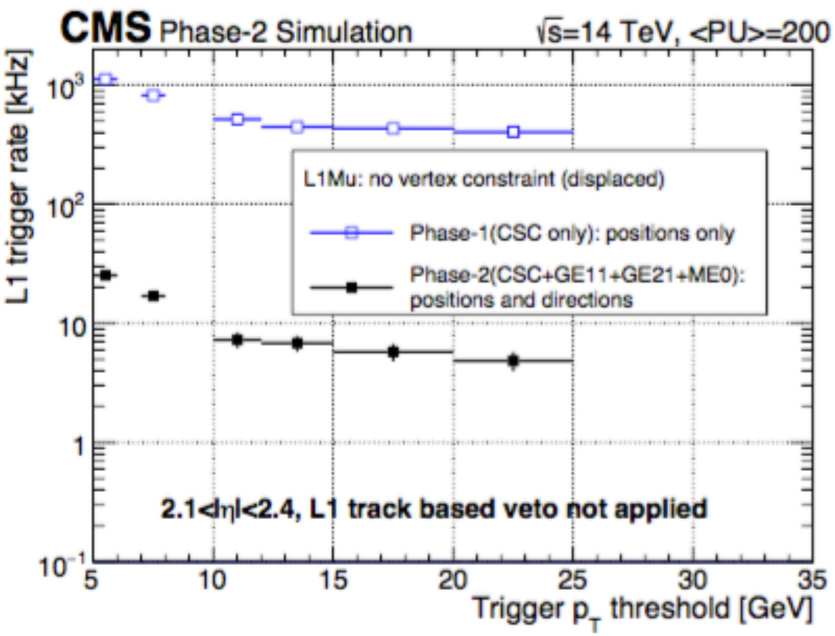
Phase2 trigger allows to reach same mass resolution at trigger level as in run2 offline analysis

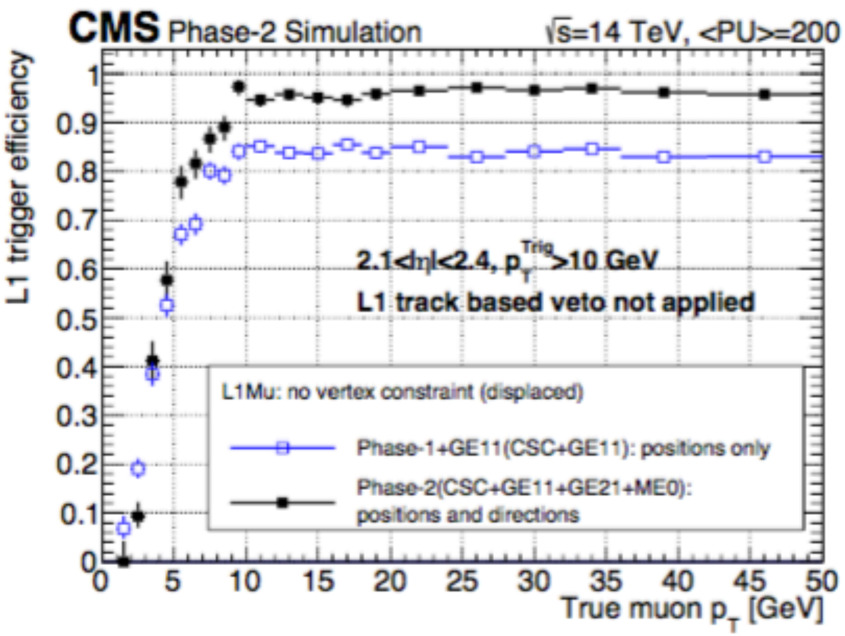
ditti

With the Phase-2 upgrade events with $\beta < 0.5$ can be triggered with nearly 90% efficiency for $\eta < 1.2$

Displaced Muon trigger performance

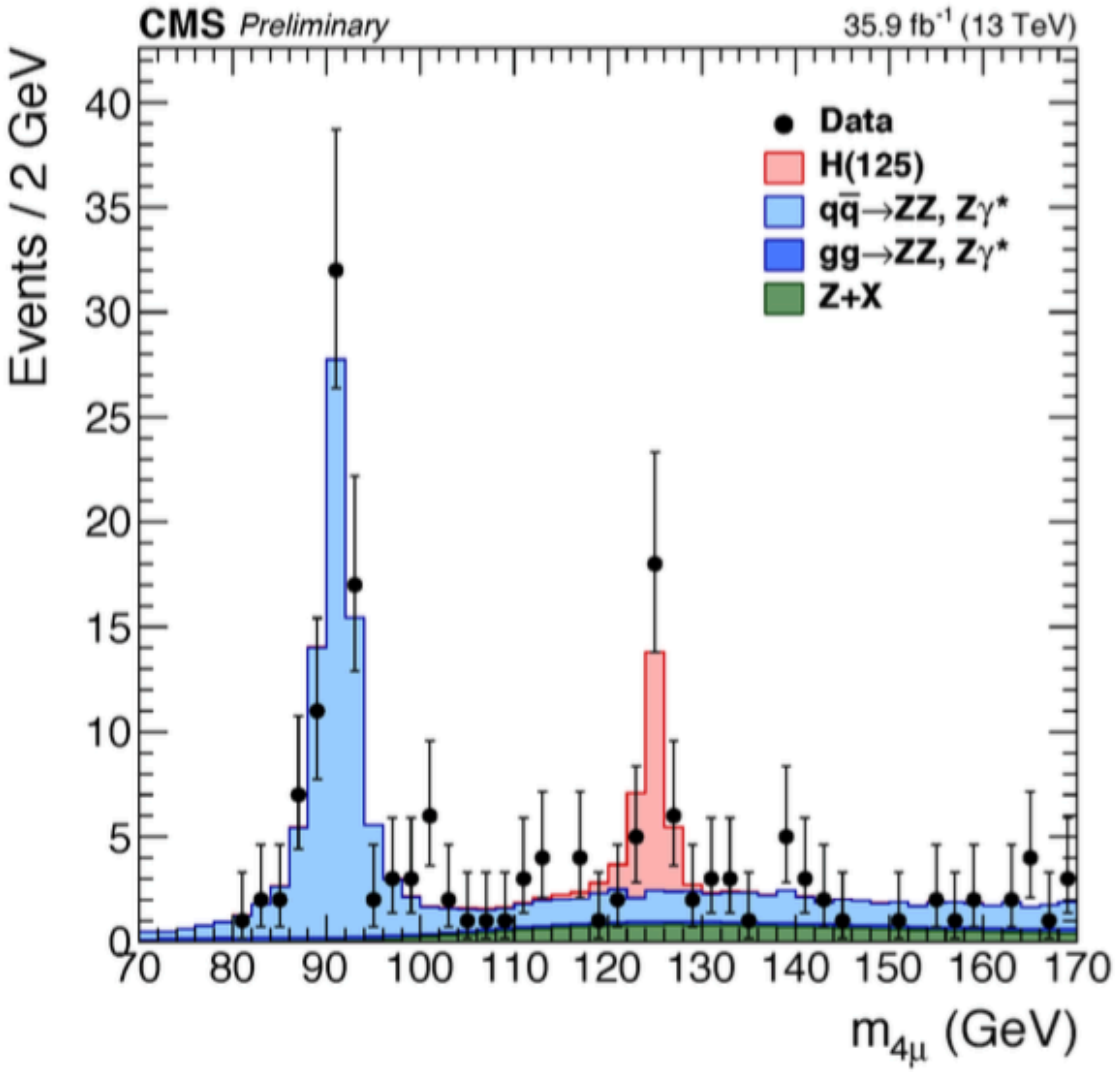
Very fwd region





L1 muon trigger rate vs trigger pT threshold (left) and trigger efficiency vs true muon pT (right) for the endcap displaced muon algorithm in the region and 2.1 < |η| < 2.4. The track veto is not applied here yet.

H→ZZ*→4μ run2



CMS Preliminary
35.9 fb-1 (13 TeV)
Events / 2 GeV
Data
H(125)
qq̄→ZZ, Zγ*
gg→ZZ, Zγ*
Z+X
0
5
10
15
20
25
30
35
40
70
80
90
100
110
120
130
140
150
160
170
m4μ (GeV)