CMS Upgrade and Future Plans

LISHEP 2015
Manaus Amazonas, August 5th , 2015

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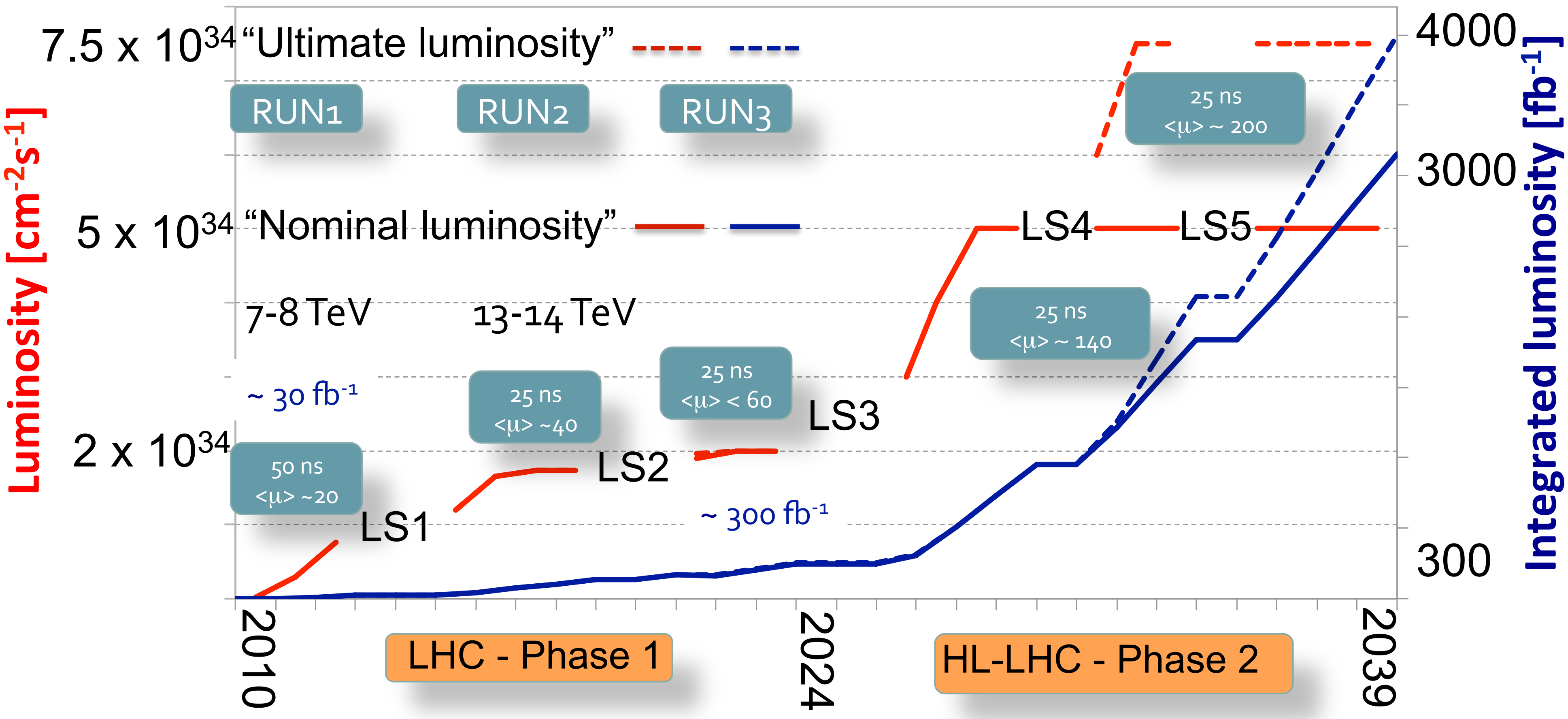
On behalf of the CMS Collaboration

The Past- Present-Future of LHC

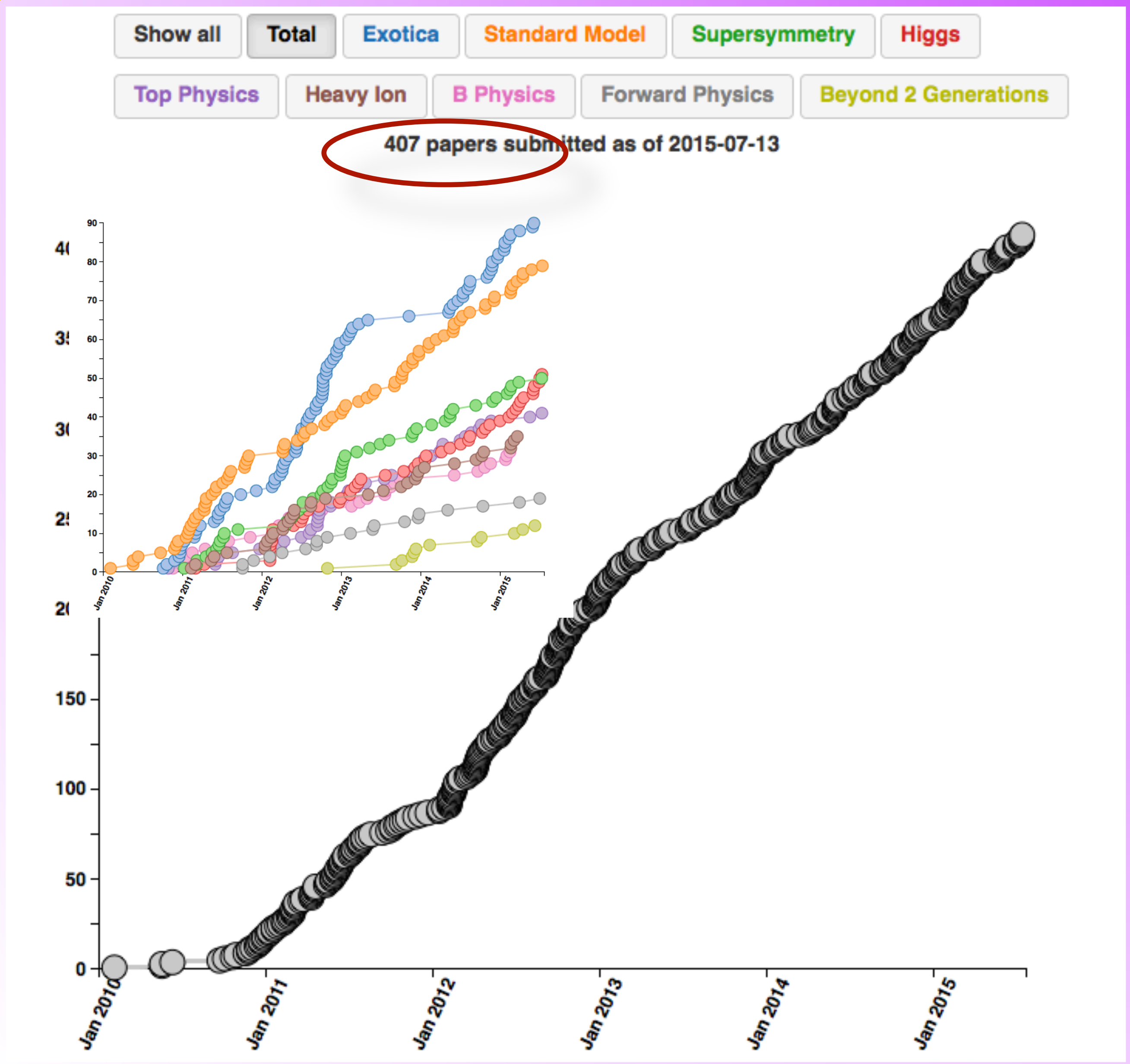
New schedule proposed for long shutdowns and accelerator perspective for luminosity

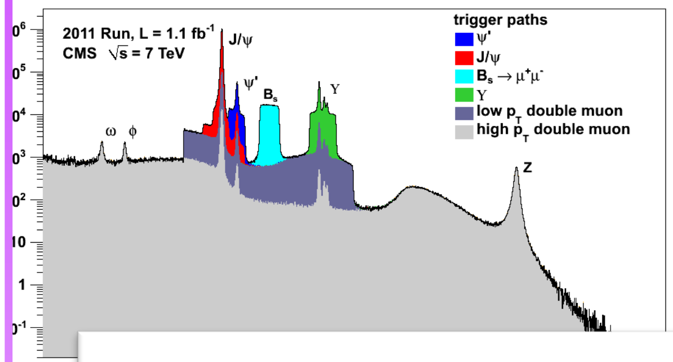


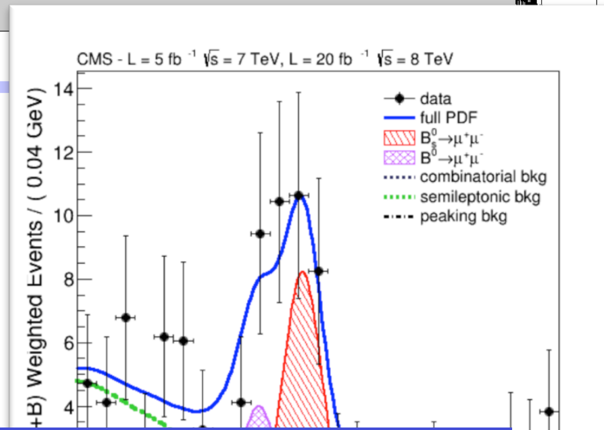
Upgrade injection to increase beam brightness

Upgrade interaction region to increase beam overlaps

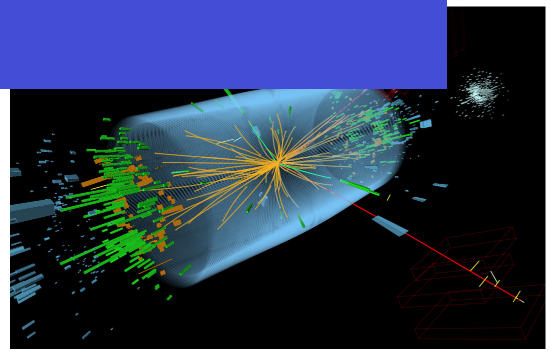
Lot of Physics Results @ RUN1







ecision studies and ..
st around the corner..



CMS Phase I Upgrade

- Goals are to provide strong physics performance for luminosities up to twice the original design (2×10^{34}) and manage radiation-damage effects up to 500 fb^{-1}

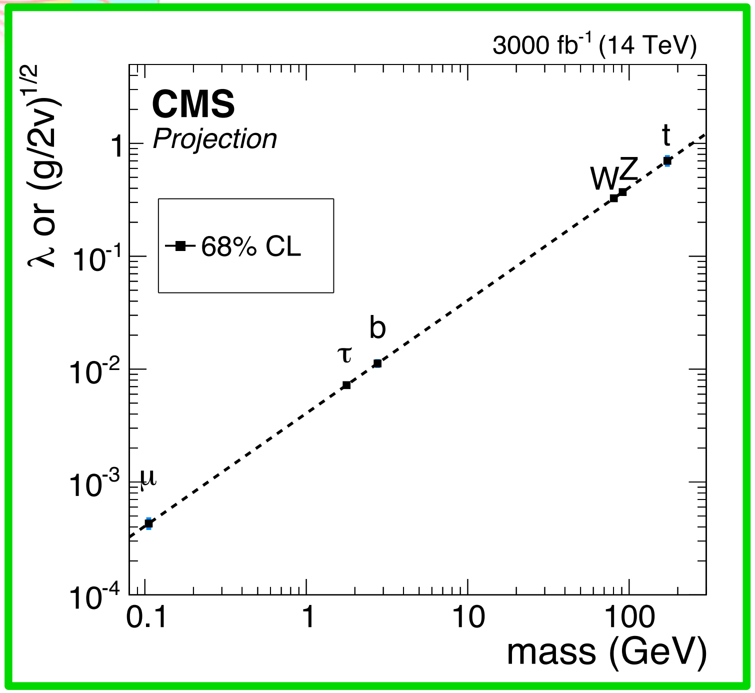
- Upgrades planned to three subsystems of CMS

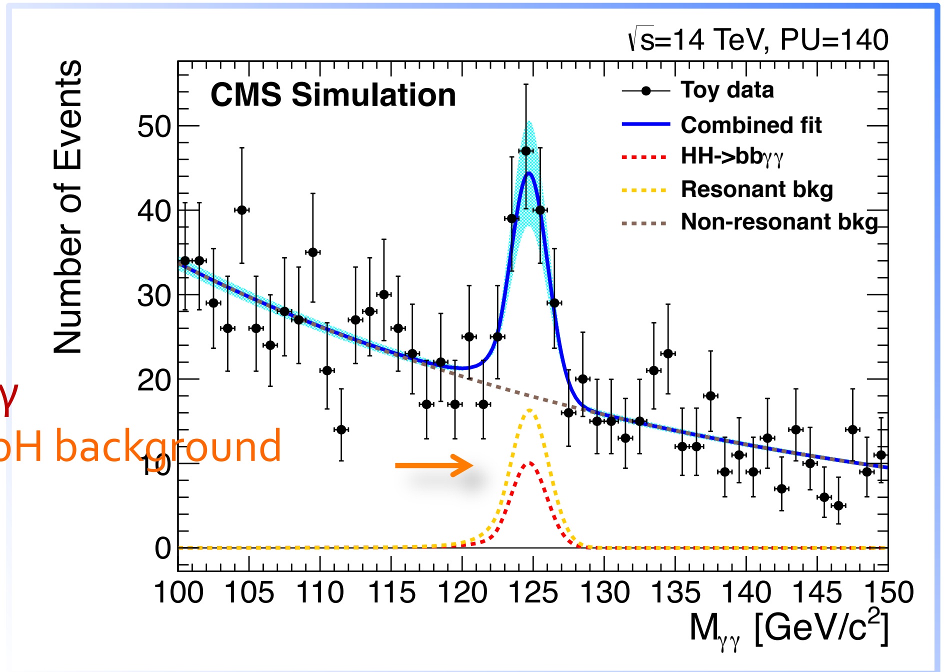
  - Pixel tracker : four-layer barrel and 3 forward-disk pixel tracker with new readout chip (ROC) capable of higher hit rate

  - Hadron calorimeter : Installation of SiPM devices into barrel/ endcap calorimeters and new electronics in the forward calorimeter allowing timing-based background rejection

  - Trigger : upgrade to the muon and calorimeter Level-1 trigger systems and global trigger processor to handle higher luminosities without loss of efficiency for key physics channels

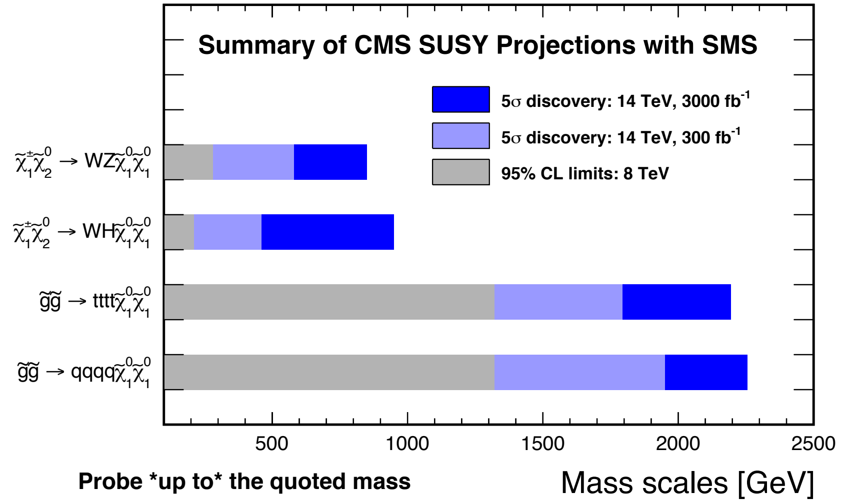
Exciting Prospects at the HL-LHC





HH → bbγγ

ZH, ttH, bbH background



- Few % precision on Higgs couplings
- Evidence of di-Higgs production
- Access to small cross section SUSY processes
- Several other SM rare processes

and BSM physics predictions

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HL-LHC Physics Drivers

Requirements:

- Precision measurements of
  - Leptons (e, μ, τ), γ, Jets, b (c) quarks, MET
- Reconstruction of complex event topologies to identify
  - W/Z, top, VBF, etc.
- Over the full range from low to high p_T
  - In a very high rate and high pile-up environment

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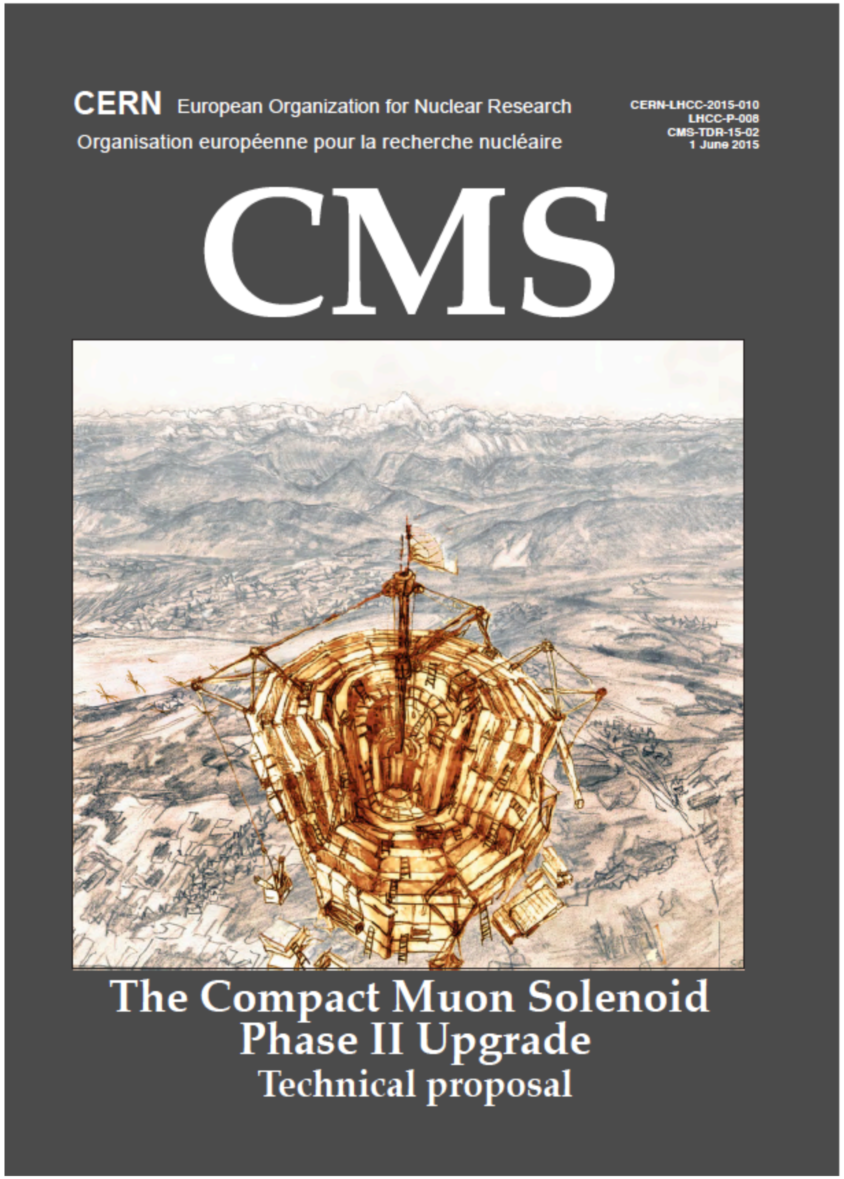
https://cds.cern.ch/record/2020886

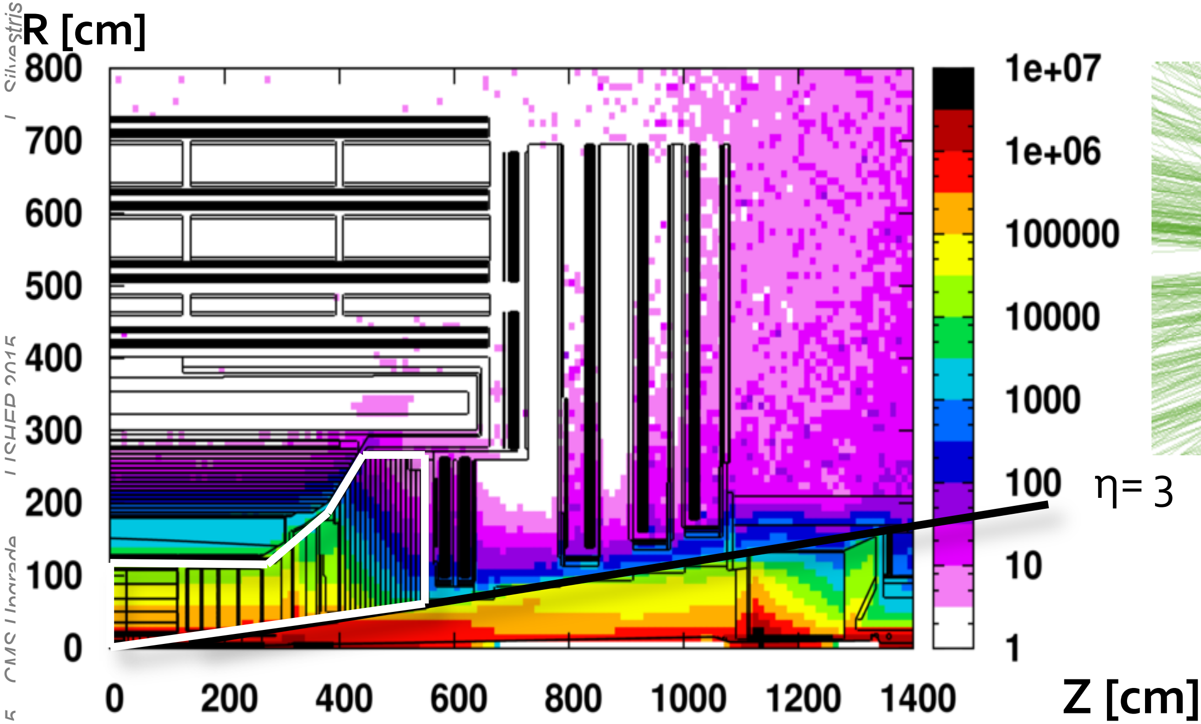
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFP



HL-LHC Challenges

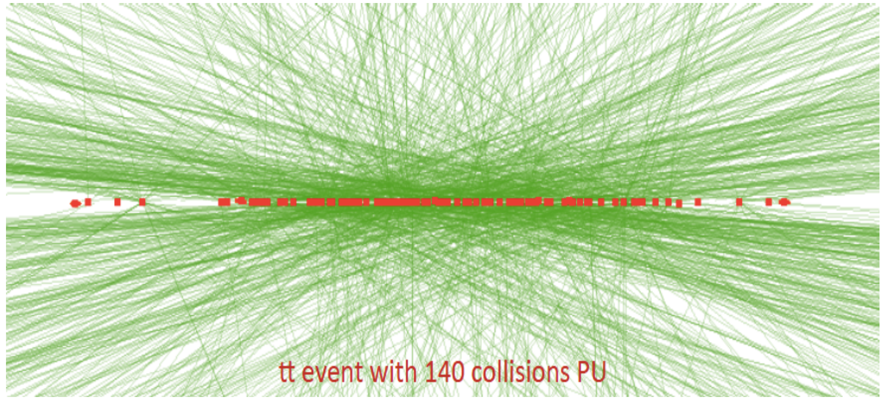
High radiation level

- 3000 fb^{-1} Dose map in [Gy] simulated with MARS and FLUKA
- Aging studies show that Tracker & End cap Calorimeters need replacement



High Pile-Up

tT events with 140 PU collisions



HL-LHC presents increased challenges for Triggering, Tracking and Calorimetry, in particular for low to medium P_T objects

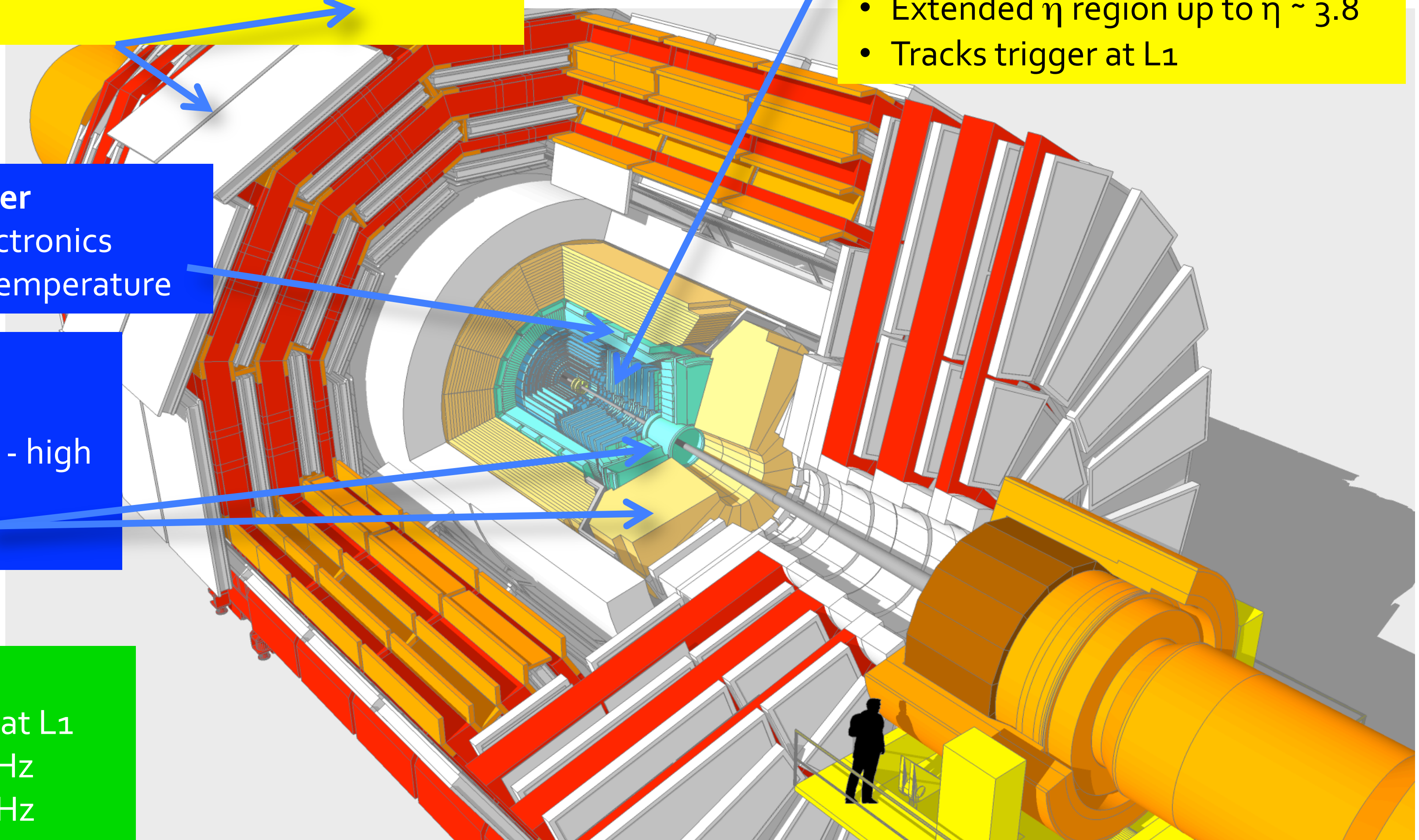
Phase 2 Upgrades

Muon System
- Replace DT & CSC FE/BE electronics
- Complete RPC coverage in region $1.5 < \eta < 2.4$ (new GEM/RPC technology)
- Muon-tagging $2.4 < \eta < 3$

Replace Tracker
- Radiation tolerant - higher granularity - less material -better p_T resolution
- Extended η region up to $\eta \sim 3.8$
- Tracks trigger at L1

Barrel EM calorimeter
- Replace FE/BE electronics
- Lower operating temperature

Replace endcap Calorimeters
- Radiation tolerant - high granularity
- 3D capability



Trigger/HLT/DAQ
- Track information at L1
- L1-Trigger ~ 750 kHz
- HLT output ~7.5 kHz

Tracking system
b-tagging – τ-ID – μ-ID

Phase II Tracker Design

Total Outer Tracker 220 m² area - 15500 modules

- 50M strips - 220M macro-pixels
- 90/100 μm pitch (2S/PS modules)
- 2.5/5 cm strips (2S/PS) - 1.5 mm macro-pixels in PS modules
- 200 μm active or physical thickness

Total pixel area ~ 4.0 m²

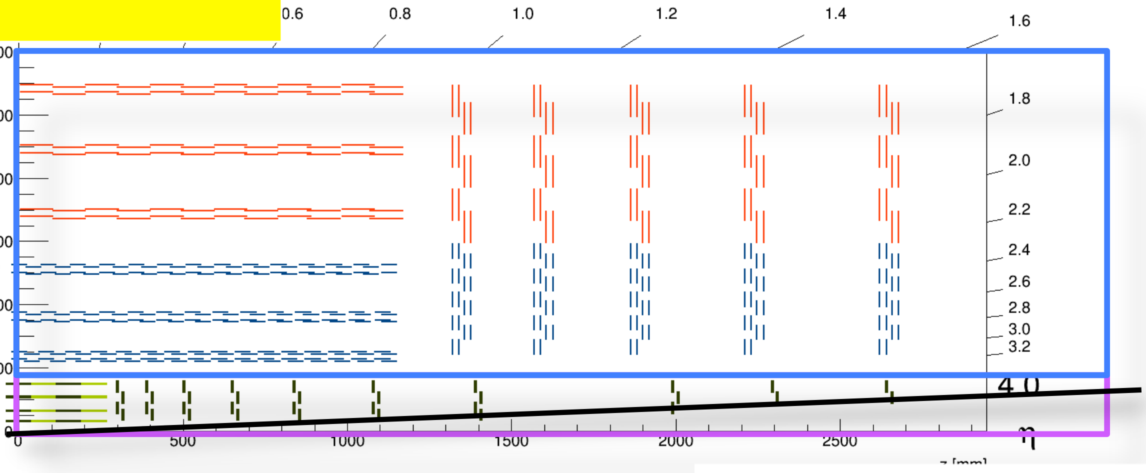
- 50x50 - 25x100μm² pixels
- ≤ 150 μm sensor physical thickness

Strip/Strip modules 2S

Macro Pixel/Strip modules PS
Z measurement

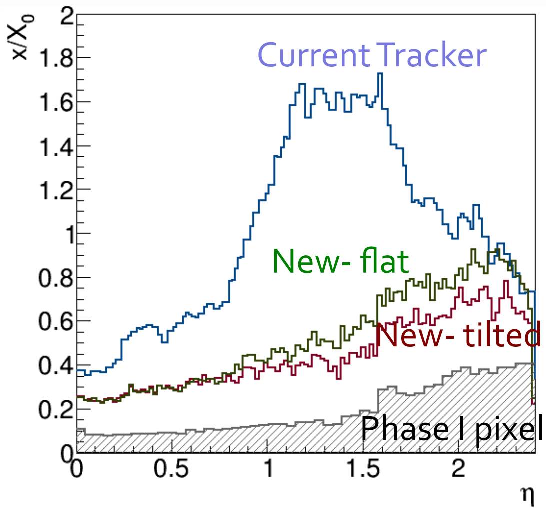
Inner Tracker,
new Disks to η=3.8

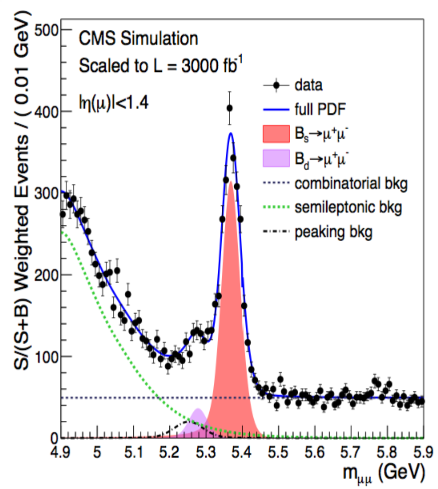
Pixel modules



Material (lighten up!)

- Tracker weight ½ of current
- Improved track p_T resolution & reduce rate of γ conversion (factor 2 to 3 depending on η)
- ex. HH -> bbγγ; ttH -> γγ ; H -> μμ - $B_{s,d}$ -> μμ ..





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Track Trigger Performance

High B-field allows to measure bending of tracks in few mm spacing between two sensors of a module

- Selective readout "stubs" of $P_T \geq 2$ GeV reduce bandwidth for readout at 40 MHZ

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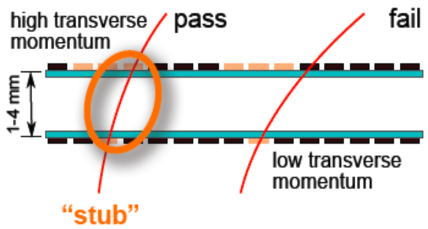
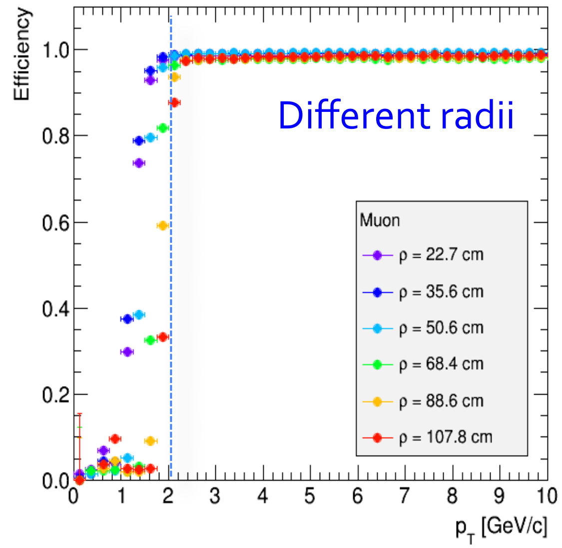
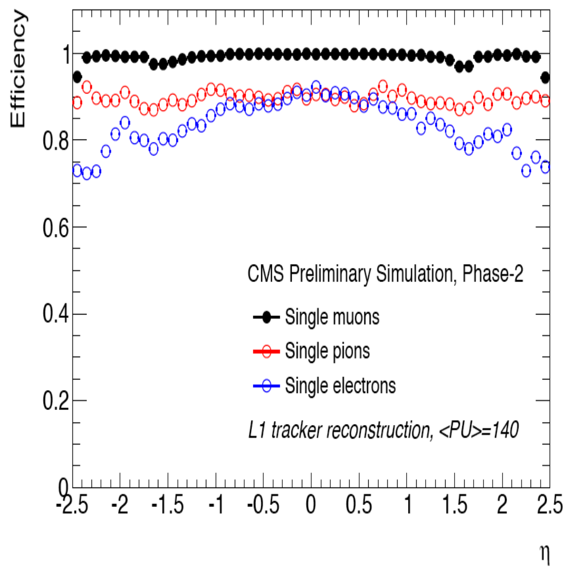
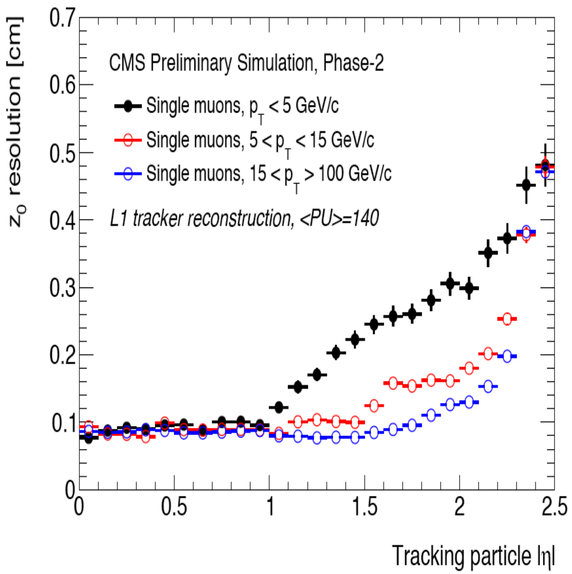
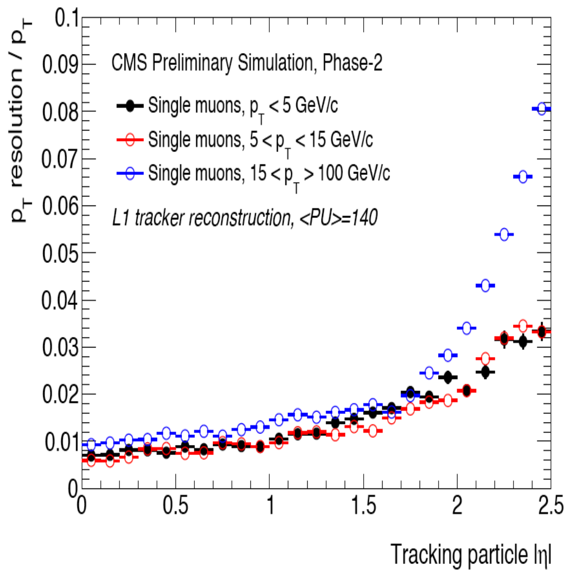




L1 Track Trigger reconstruction performance



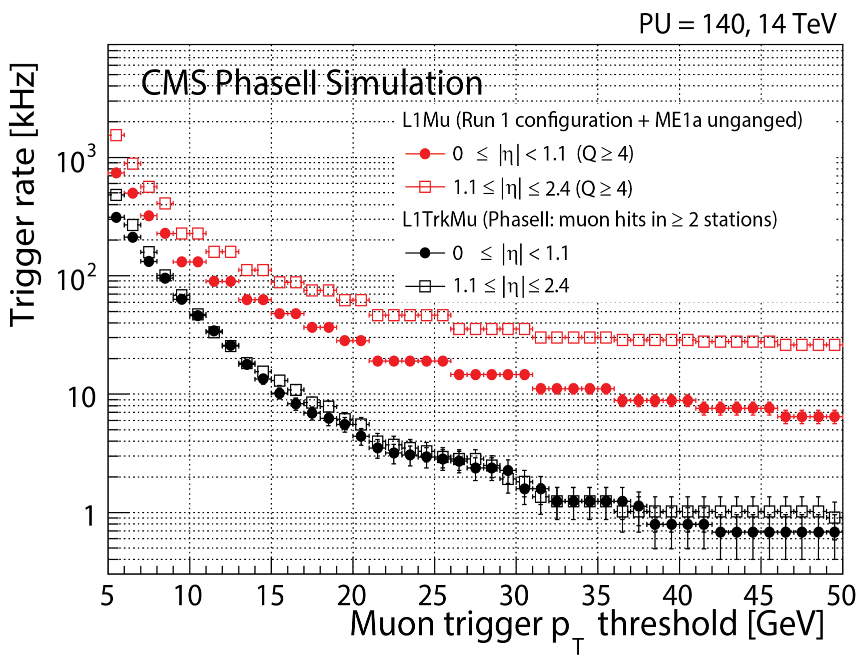


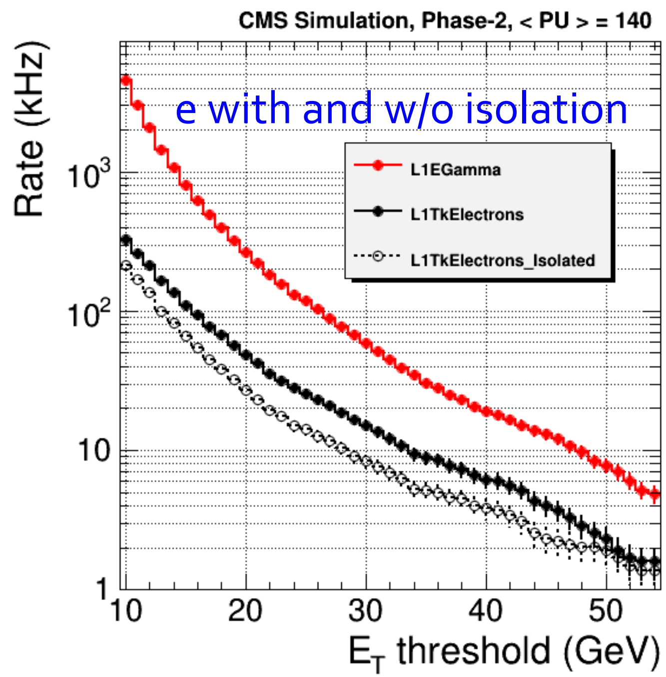


L1 Trigger performance with Track-Trigger

Powerful scheme to control all inclusive trigger rates at first 40 MHz stage

- Single μ rate divided by 10
- Single e rate divided by 5(10) w/o (with) isolation
- γγ rate/5 from isolation
- τ efficiency x 2 at same rate
- Vertex ≃ 1 mm resolution → HT & MET rates divided by 10 to 100





L1-Trigger studies with Phase-I menu thresholds including Track-Trigger:

- Requires ≃ 500/750 kHz rate at 140/200 PU (with 1.5 safety margin)

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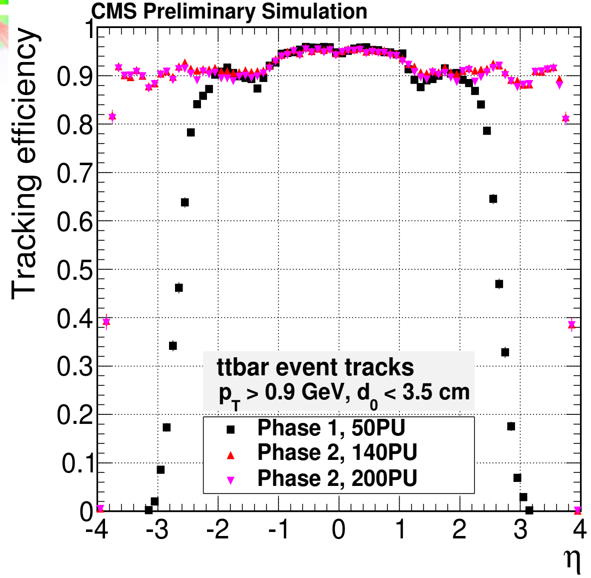
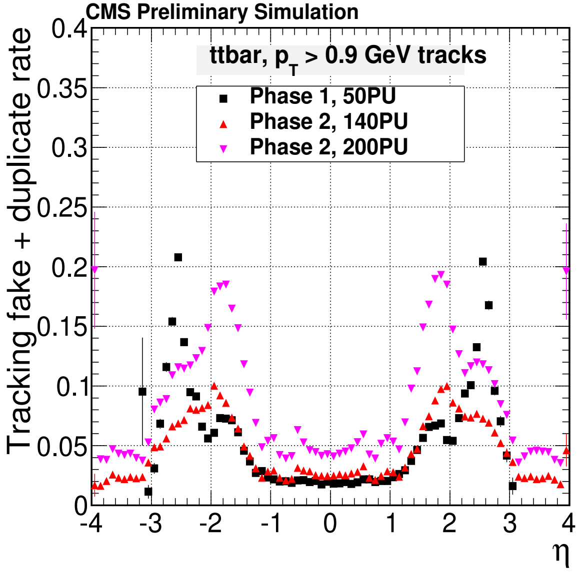
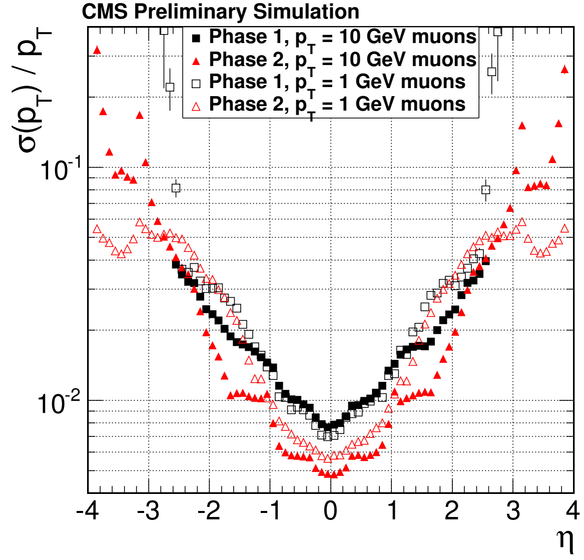
Track and Vertex Reconstruction Performances







- Track efficiency and fake rates for Phase-II 200 PU similar to Phase-I 50
  - tolerable fake increase at 200 PU
- Momentum resolution substantially improved (lower pitch & material)

Signal primary vertex efficiency ≥ 95% with 20 μm resolution at 200 PU

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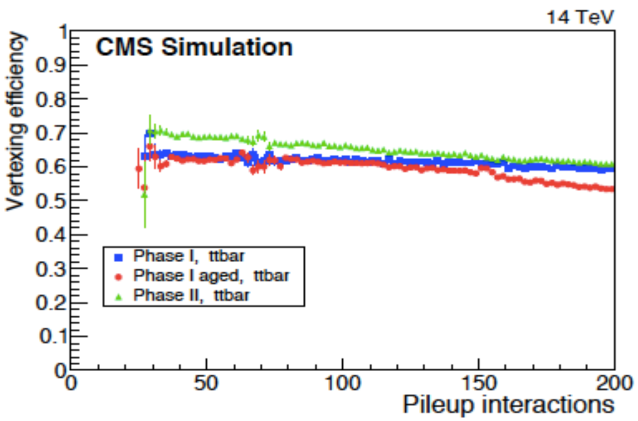
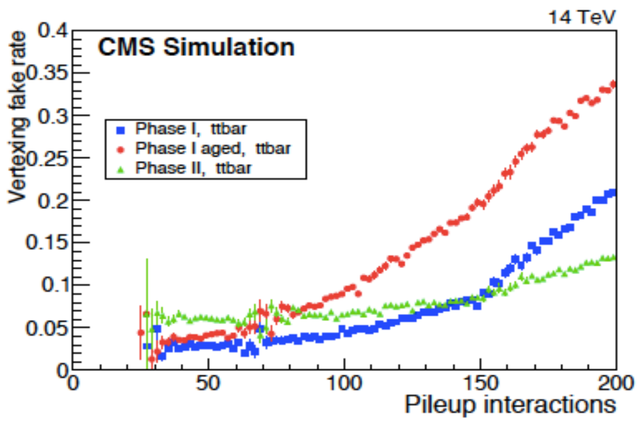
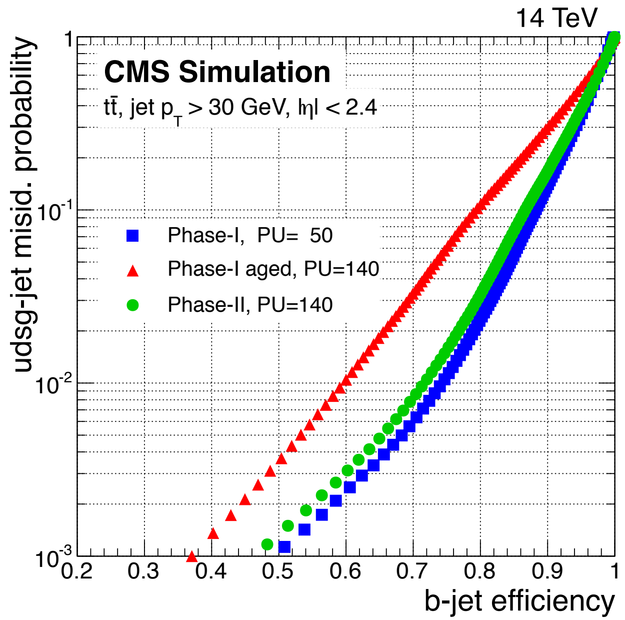
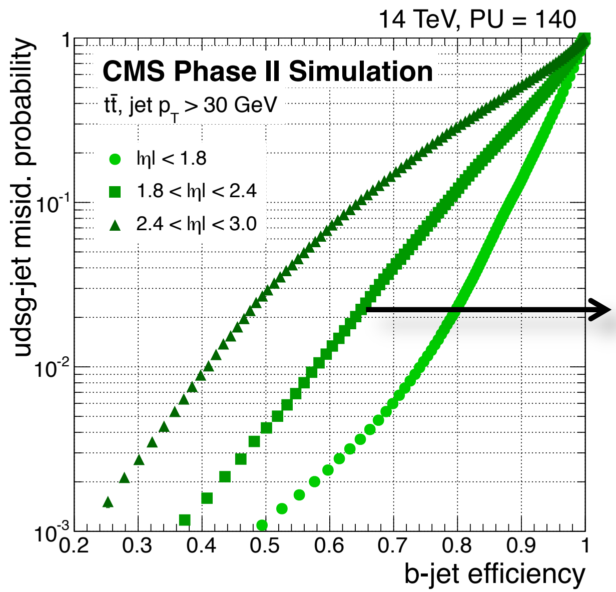




b-tagging Phase-II recovers Phase-I performance

- Expected further improvements with new pixel design (smaller pitch & material)





Coverage to η = 3.8

τ-ID - based on track isolation (robust to PU) same efficiency working point below

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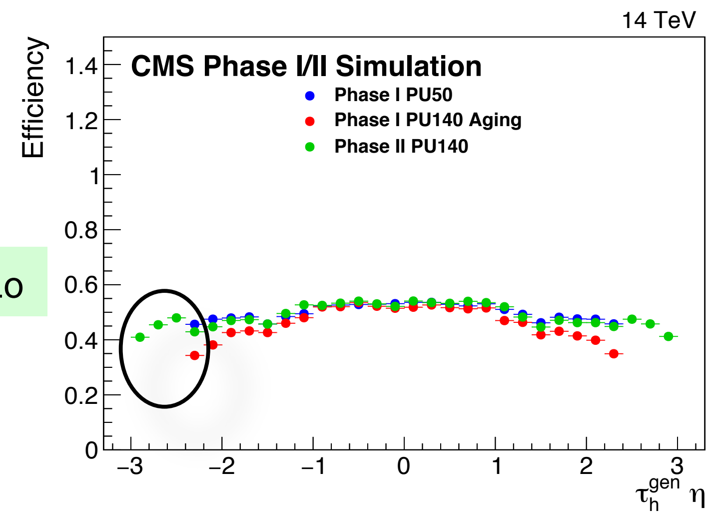
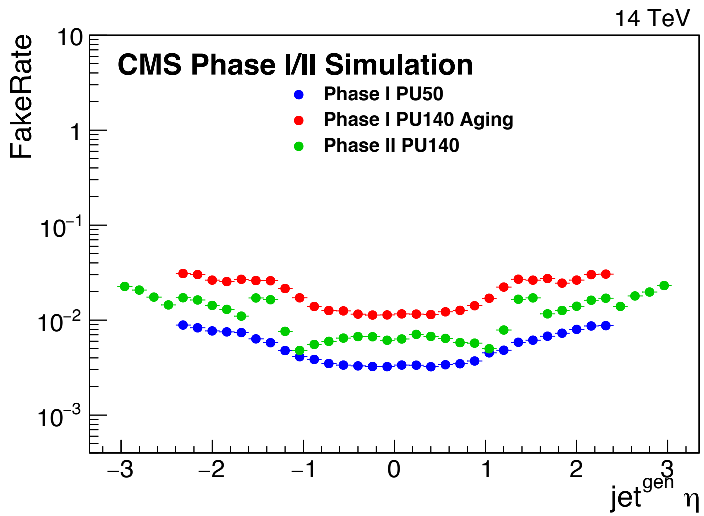
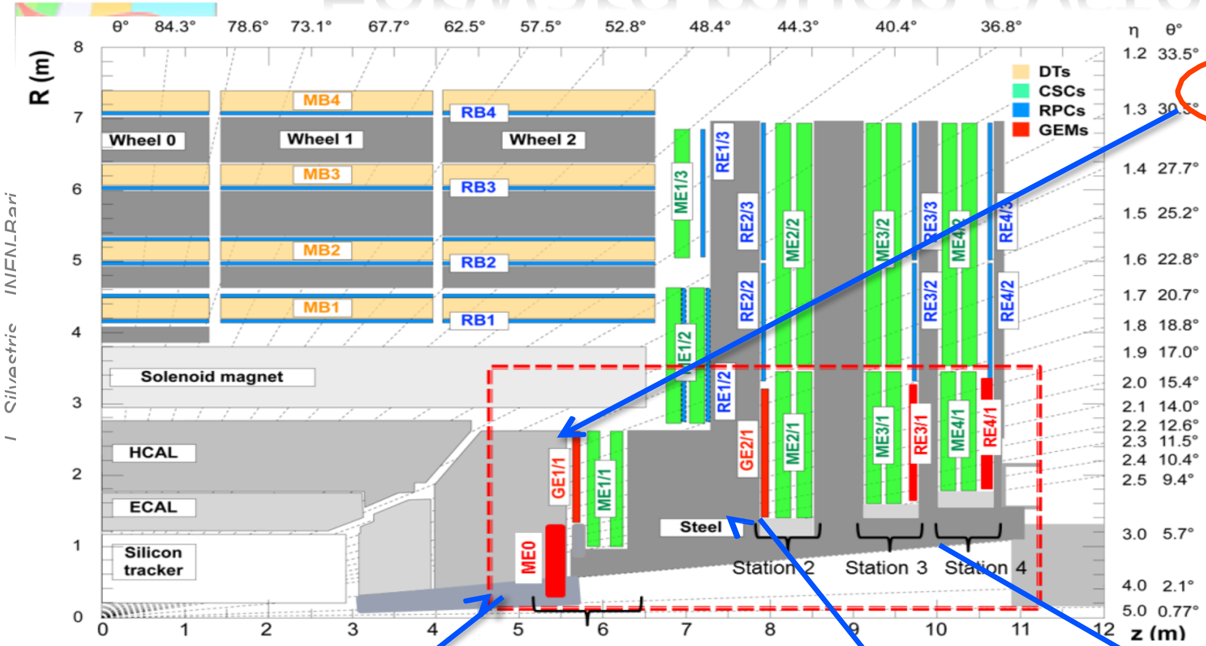




Forward muon system enhancement



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GE1/1

Trigger and reconstruction

- 1.55 < |η| < 2.18
- **baseline detector for GEM project**
- 36 staggered super-chambers (SC) per endcap, each super-chamber spans 10°
- One super-chamber is made of 2 back-to-back triple-GEM detectors
- Installation: LS2

ME0

- **Muon tagger** at highest η
- **6 layers of Triple-GEM**
- each chamber spans 20°
- Installation: LS3

GE2/1

Trigger and reconstruction

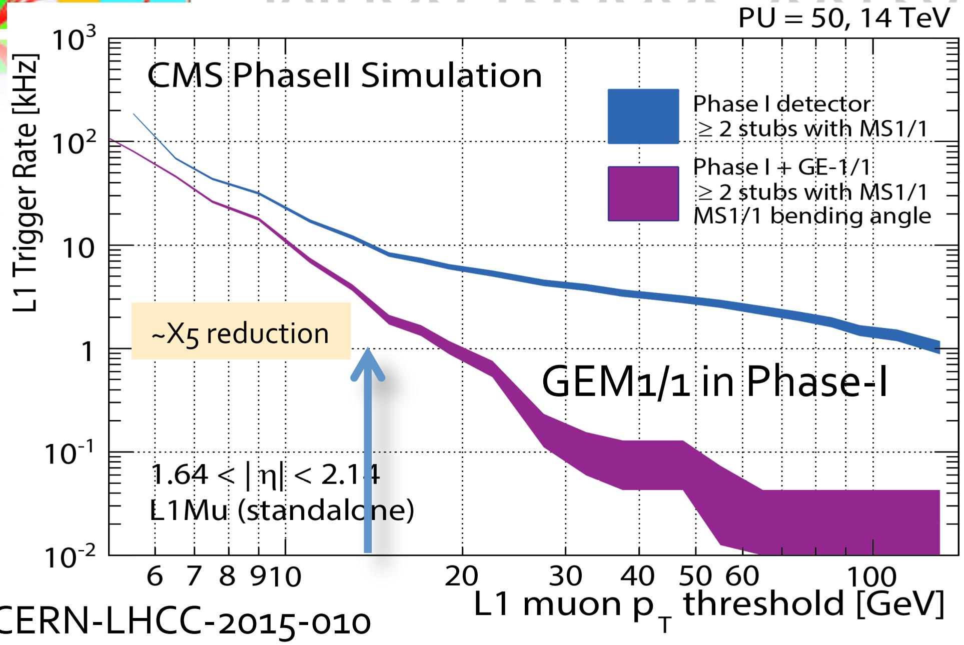
- 1.55 < |η| < 2.45
- 18 staggered SC per endcap, each chamber covers 20°, **3.5 x GE1/1 area**
- Installation: LS3

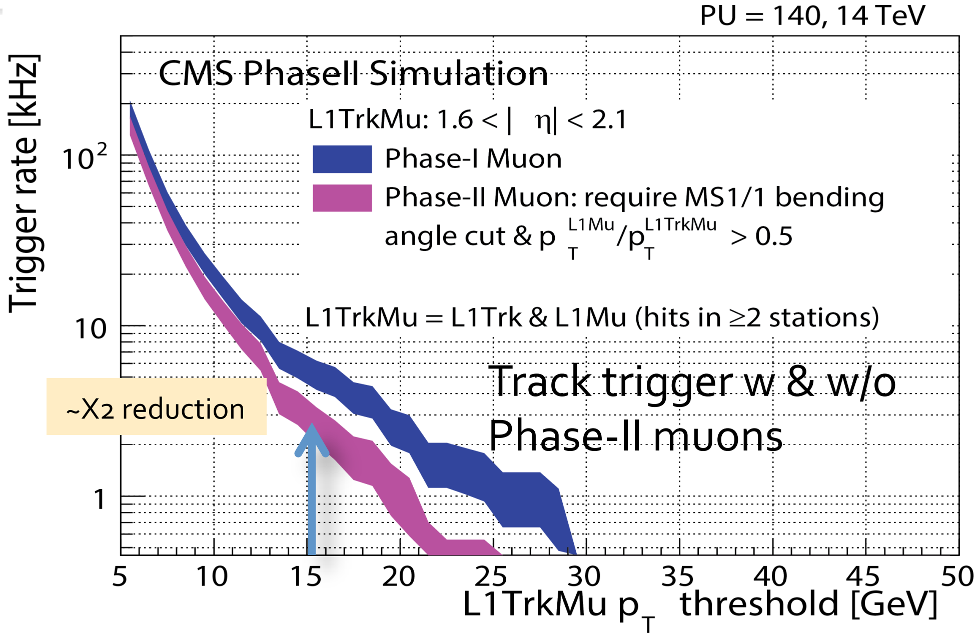
RE 3/1 –RE4/1

Trigger and reconstruction

- 1.8 < |η| < 2.4
- **Improved RPC (iRPC), finer pitch**
- 18 chambers per endcap, each chamber spans 20°
- Installation: LS3

Muon Trigger and reconstruction performance





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- Good standalone L1-Trigger capability - GEM1 important already after LS2
- Improved rate reduction combined with Track-Trigger
- Trigger on displace vertices
- Better offline reconstruction resolution - sign assignment

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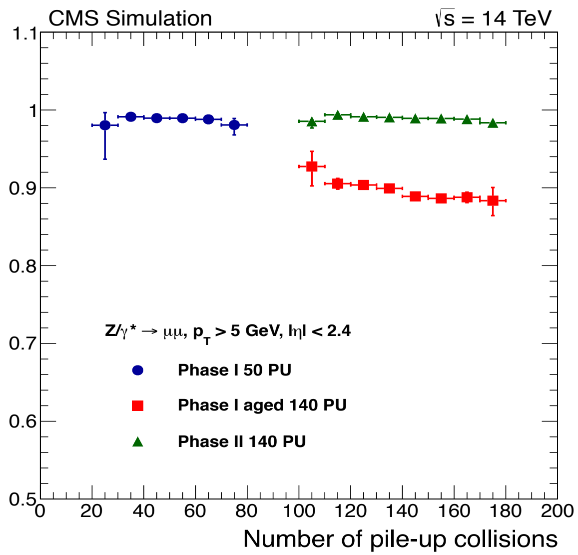
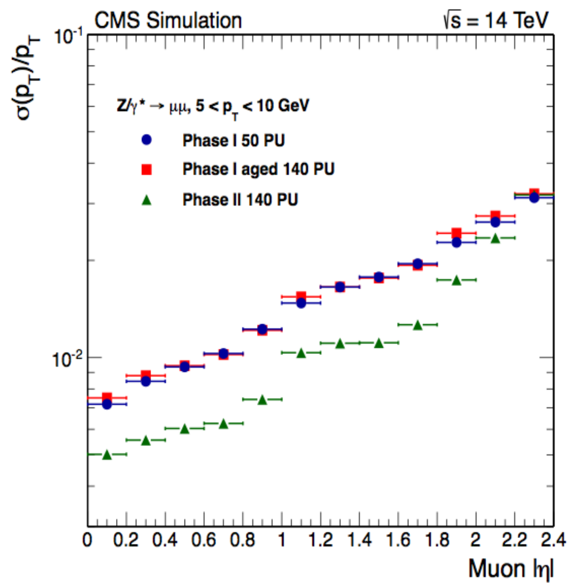
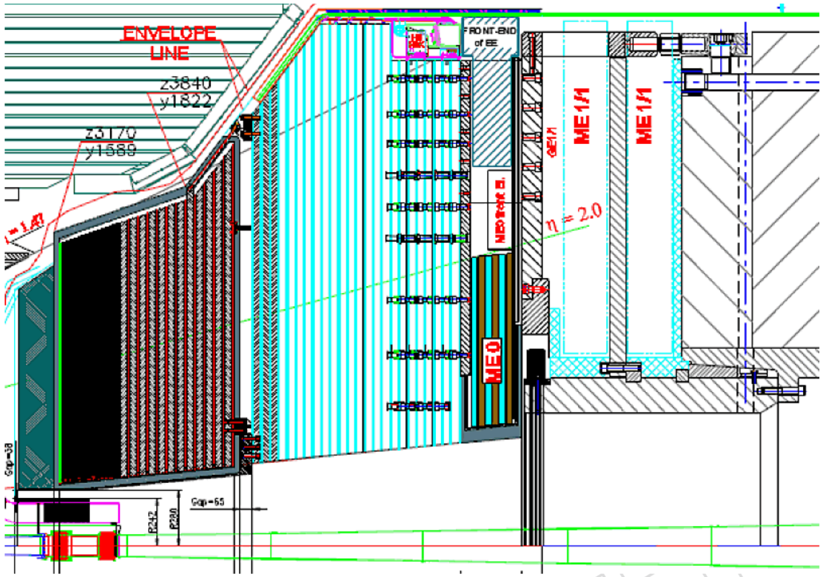
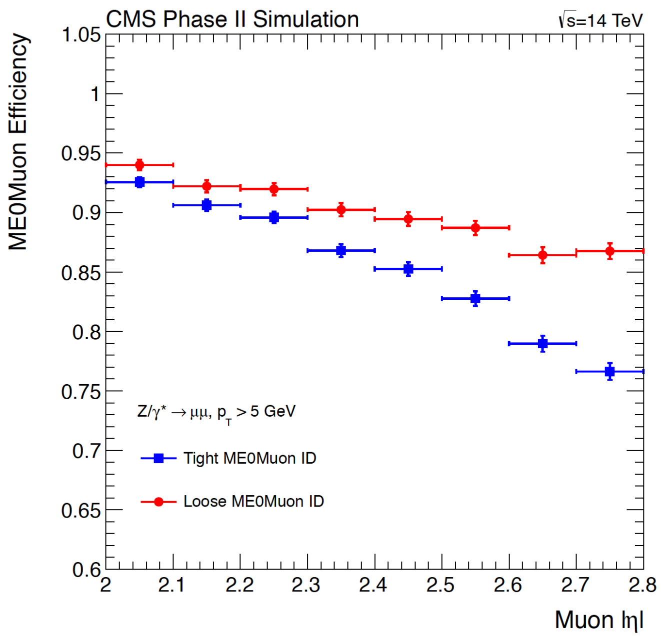


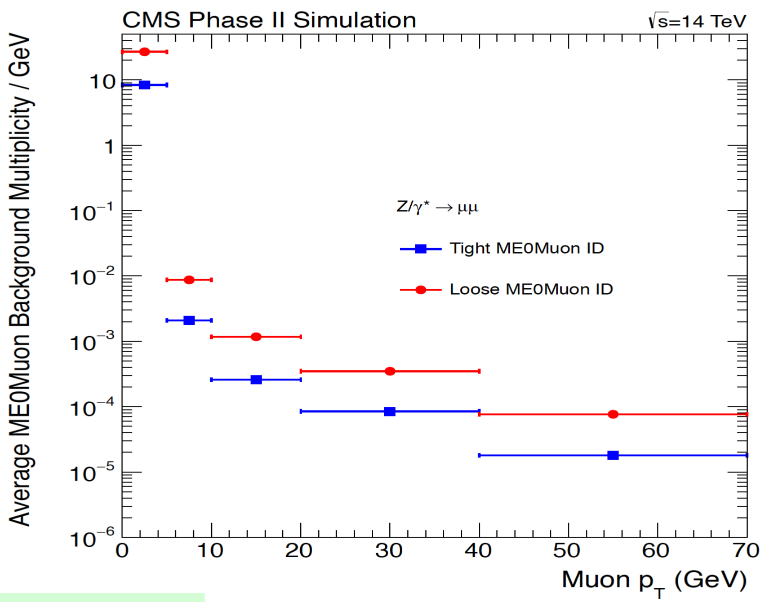


Muon tagger



- new muon detectors MEo (6-layer GEM detector) cover 2.0 < |η| < 2.8
- segments matched with tracker tracks
- MEo provides efficient muon identification with reasonable background rates





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Calorimeters
e/γ – Jet/Met

Phase Endcap Calorimeters

- 3D shower measurement in High Granularity Calorimeter (HGC)
  - Electromagnetic EE (Σ_{depth}~26 X_o, 1.5λ): 28 layers of Silicon-W absorber
  - Front Hadronic FH (Σ_{depth}~3.5 λ): 12 layers of Silicon/Brass
- Back Hadronic Calorimeter (BH) (Σ_{depth}~5 λ): 12 layers of Scintillator/Brass

Total Depth >10λ

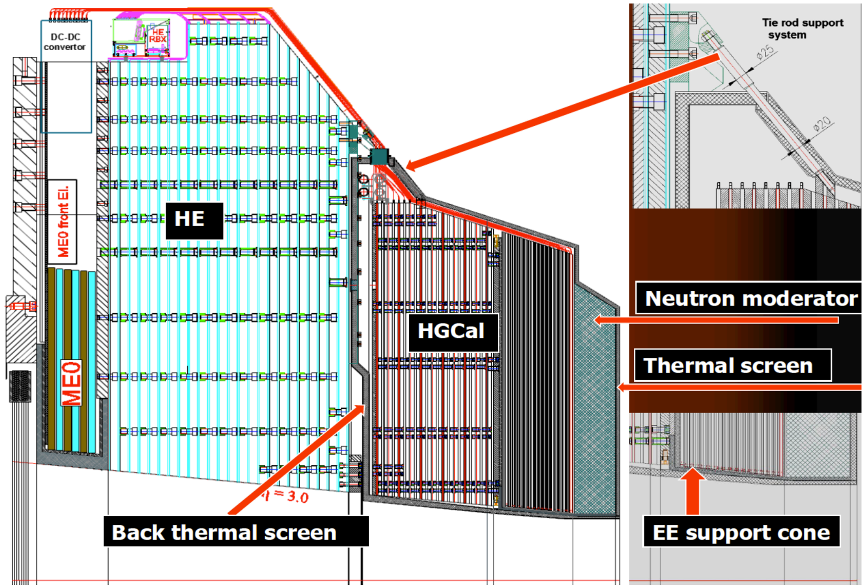
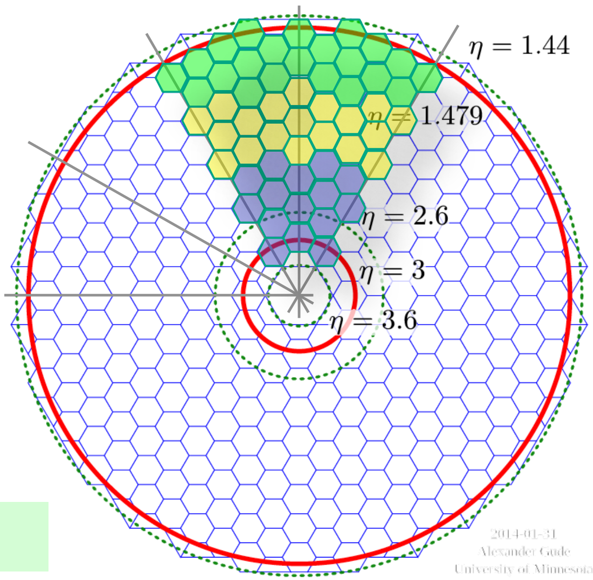


Table 3.2: Parameters of the EE and FH.

	EE	FH	Total
Area of silicon (m^2)	380	209	589
Channels	4.3M	1.8M	6.1M
Detector modules	13.9k	7.6k	21.5k
Weight (one endcap) (tonnes)	16.2	36.5	52.7
Number of Si planes	28	12	40



3 sensor active thicknesses 100-200-300 µm
0.5(1) cm² pads for 100(200/300) µm

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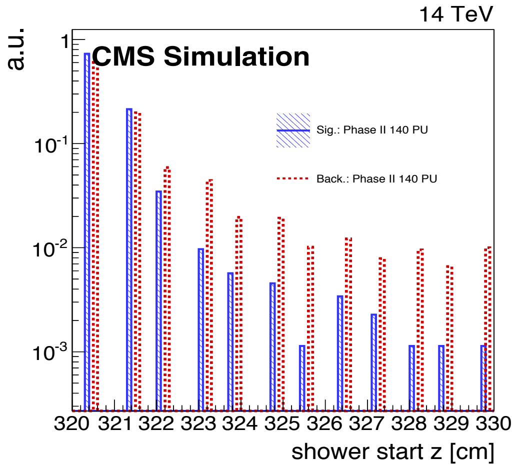
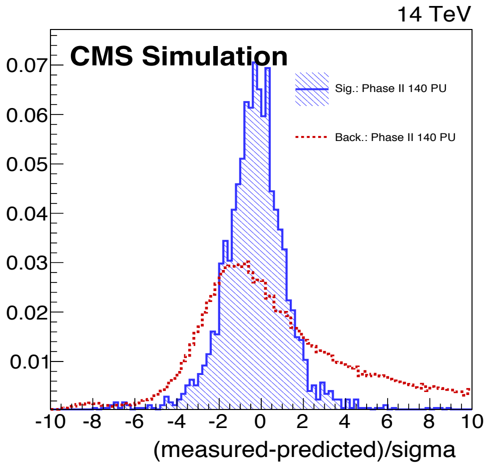
HCG e/γ new ID variables

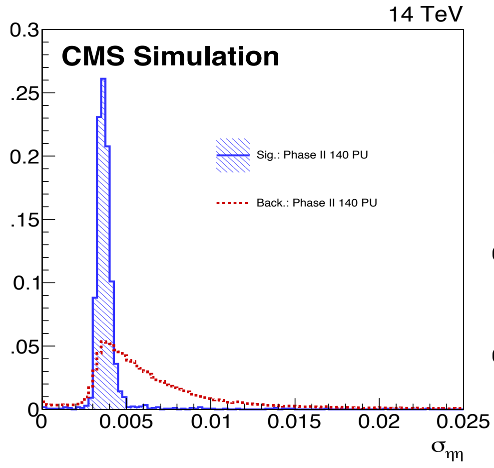
Shower start



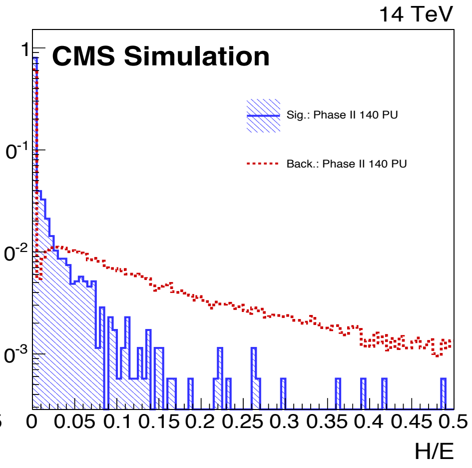
Length compatibility



η width



H/E



Signal (blue) - background (red)

- And to mitigate PU use trans. granularity - cells in ≤ 1.5R_M - H/E in tight cone 0.05

Variables used to perform the electron identification using BDT trained algorithm.

Electron efficiency recovered with smooth decrease up to 200 PU

DY→ ee

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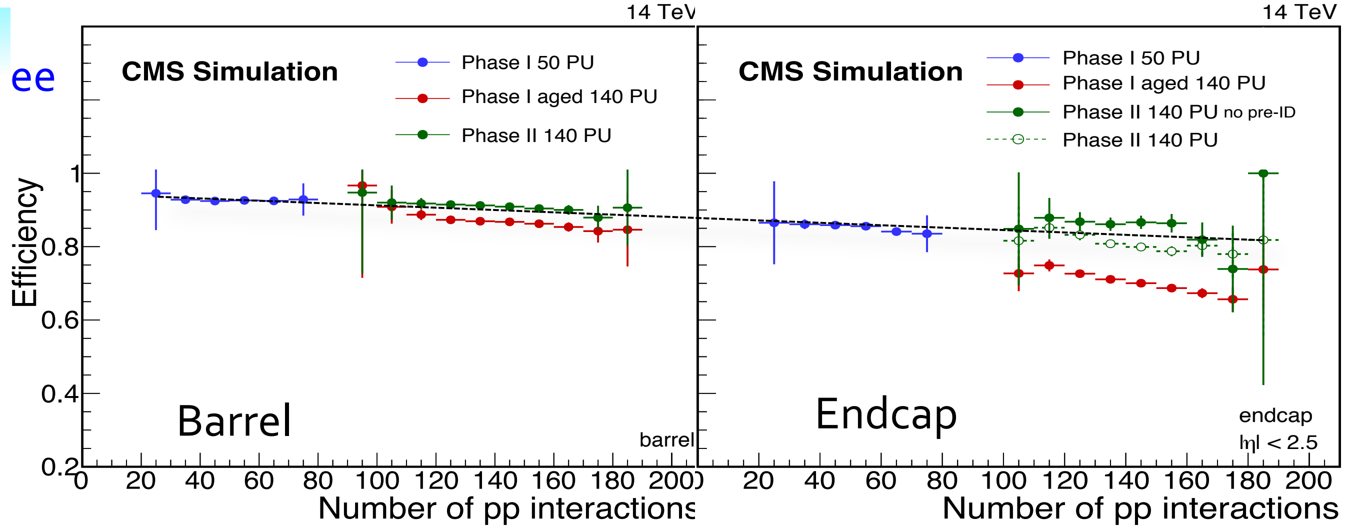
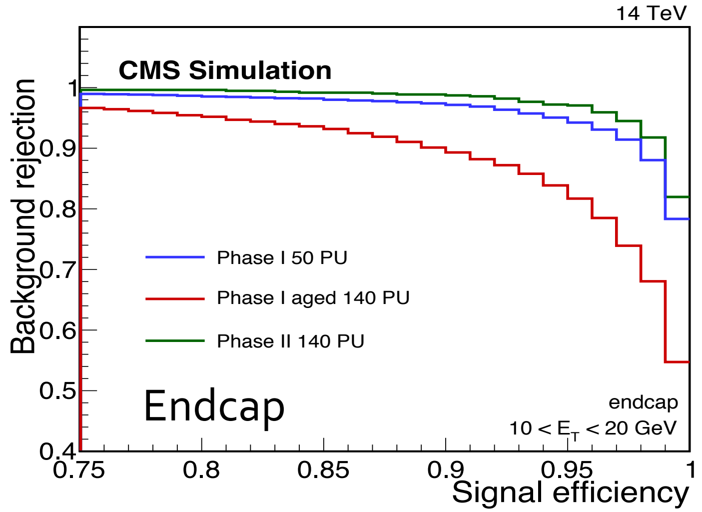
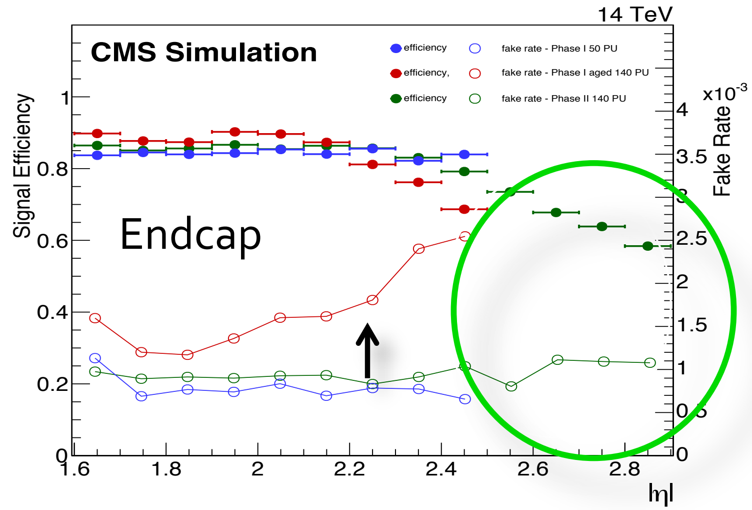


BDT efficiency for DY electrons vs bck rejection for Jets (left) and BDT efficiency for γ and Jet fake rate for a WP at ≃ 85% efficiency (right)

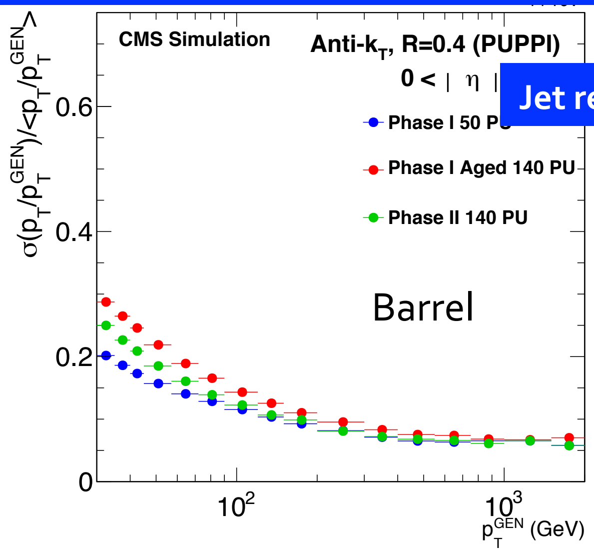


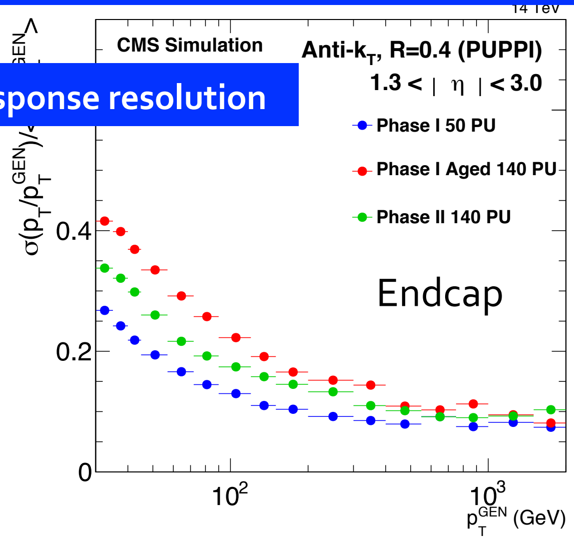


Jet and MET performance

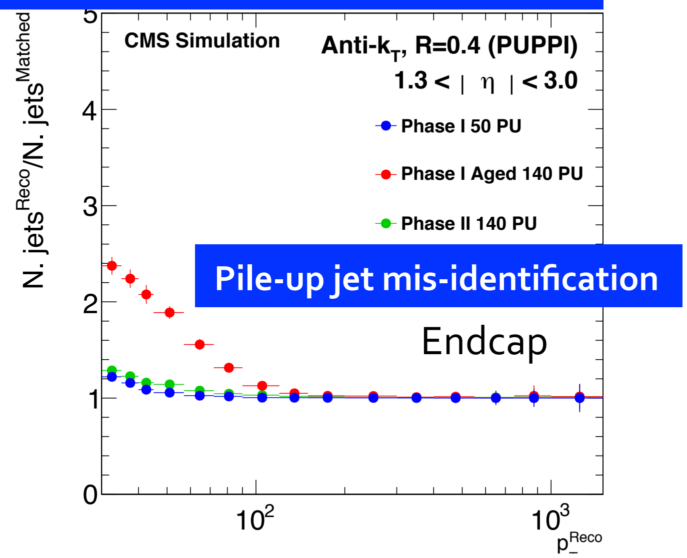
Combined effect of new EC and Tracker extension allows Phase-II to mostly recover energy resolution & fake rate of Phase-I detector at 50 PU

Jet response resolution



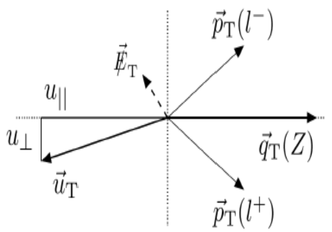


Pile-up jet mis-identification

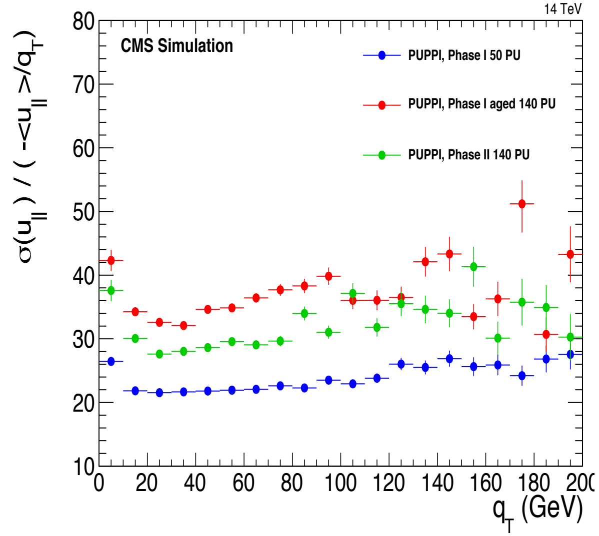


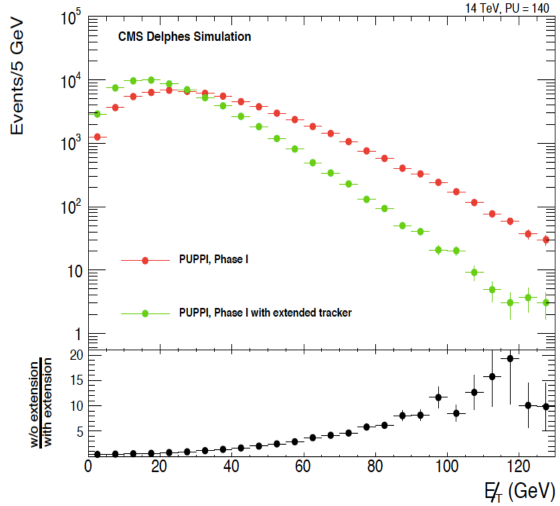
Phase-II detector recovers MET resolution partially

MET tails significantly reduced by tracking extension



MET energy resolution from hadronic recoil in Z → μμ





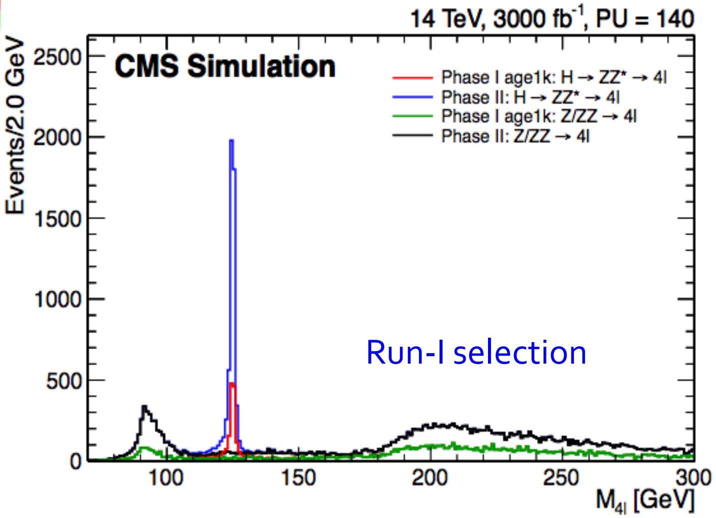
Object Performance Summary

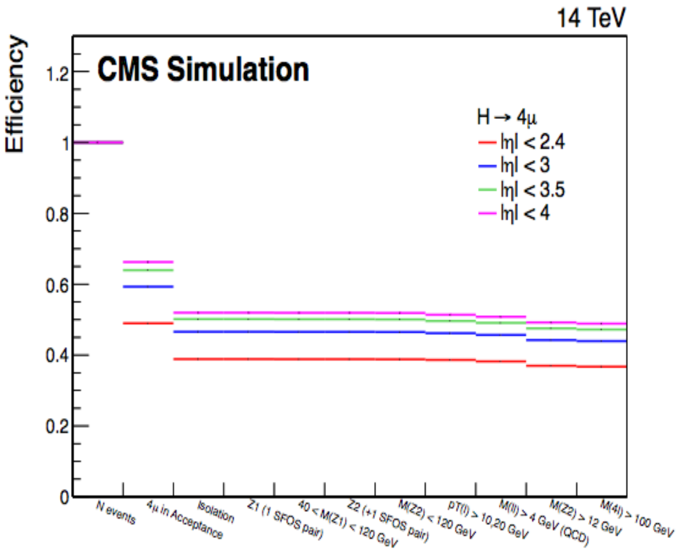
- Demonstrated that reconstruction of Physics Object is possible in HL-LHC environment
  - High efficiency
  - Low background
  - Good resolution
- Matching Phase 1 performance with PU=50 in most cases
- Phase 2 detector will allow CMS to fully benefit from the data delivered by the HL-LHC

Enhancement of the Physics Reach with CMS Upgrades

HL-LHC is an Higgs factory !

H → ZZ* → 4l: precision measurements



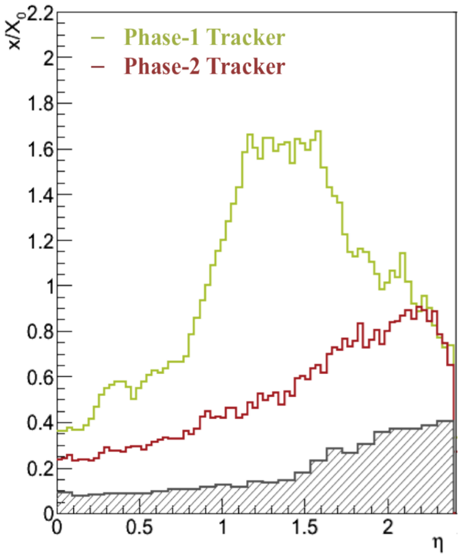


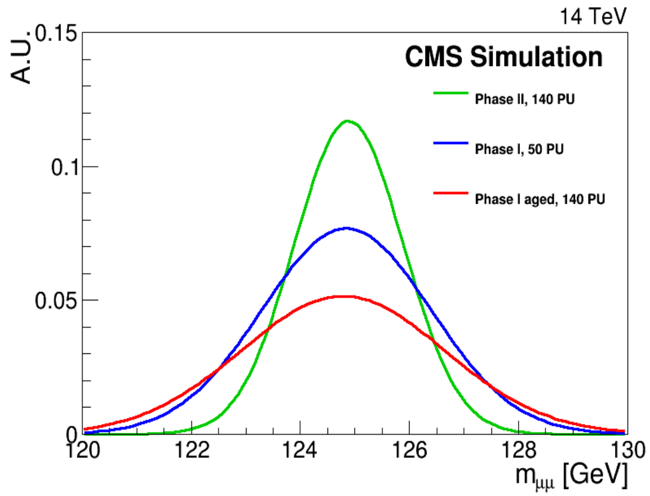
Improvements: lepton reconstruction efficiency at low-pT & ~20% acceptance

H → μμ (rare decay): probes the 2nd generation couplings

Search of narrow resonance with huge DY background

L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	$\kappa_{\mu\mu}$	BR_{SM}
300	[5, 7]	[4, 6]	[4, 6]	[6, 8]	[10, 13]	[14, 15]	[6, 8]	[41, 41]	[23, 23]	[14, 18]
3000	[2, 5]	[2, 5]	[2, 4]	[3, 5]	[4, 7]	[7, 10]	[2, 5]	[10, 12]	[8, 8]	[7, 11]





Improvements: 20% efficiency & 45% mass resolution

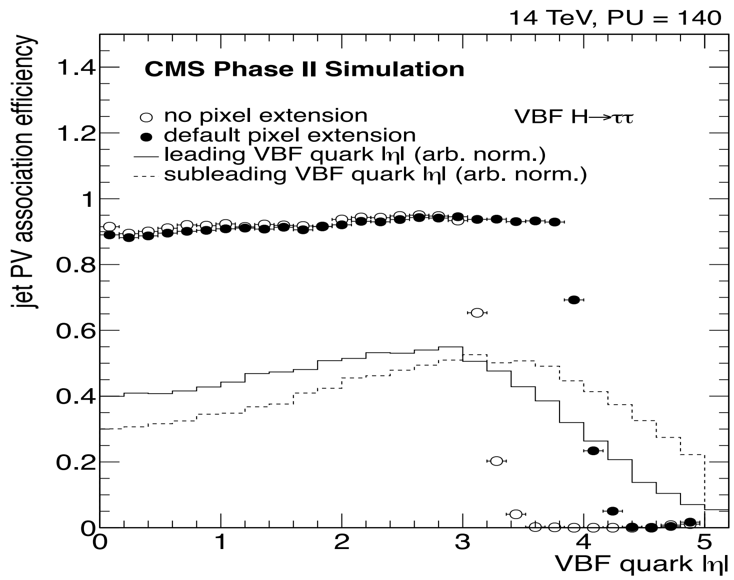
→ expect ~5% uncertainty on κ_μ

CERN-LHCC-2015-010

VBF H → ττ and di-H: Excellent probes for BSM physics

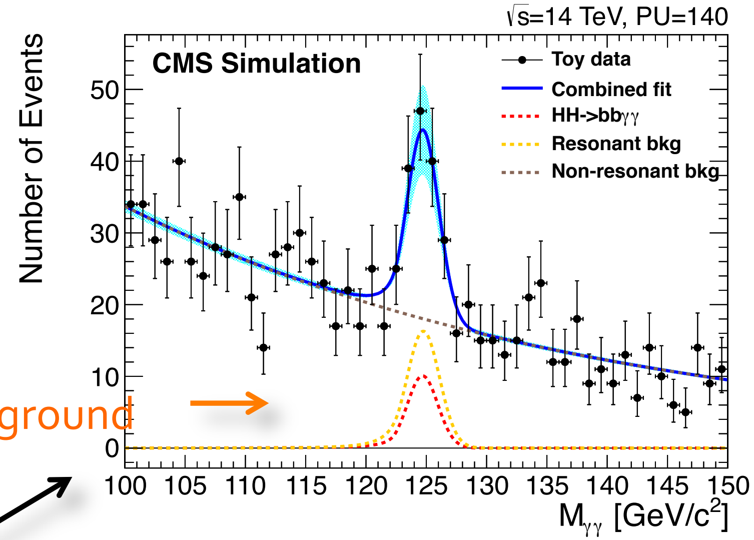
VBF H → ττ: enable by VBF jet tagging, τ-ID, MET resolution

L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	$\kappa_{\mu\mu}$	BR_{SM}
300	[5, 7]	[4, 6]	[4, 6]	[6, 8]	[10, 13]	[14, 15	[6, 8]	1, 41]	[23, 23]	[14, 18]
3000	[2, 5]	[2, 5]	[2, 4]	[3, 5]	[4, 7]	[7, 10]	[2, 5]	0, 12]	[8, 8]	[7, 11]

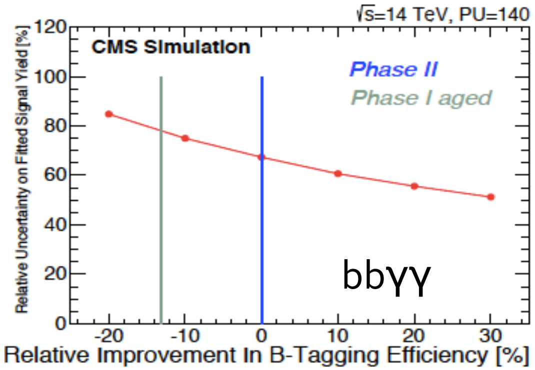


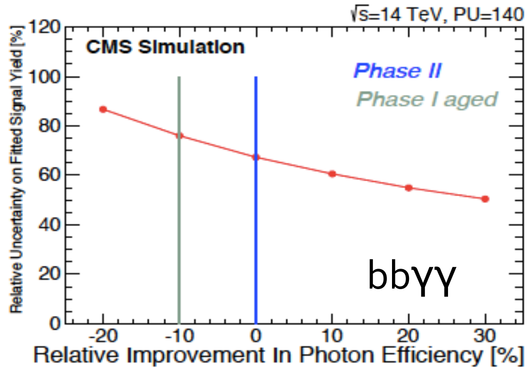
Phase II detector
- ✓ x 5.5 acceptance with Track-Trigger
- ✓ Tracker extension help in rejecting fake jets
- ✓ 90% efficiency for Jet-ID with tracks
- ✓ 15 % gain expected from improved mass resolution (MET)

HH → bbγγ
ZH, ttH, bbH background



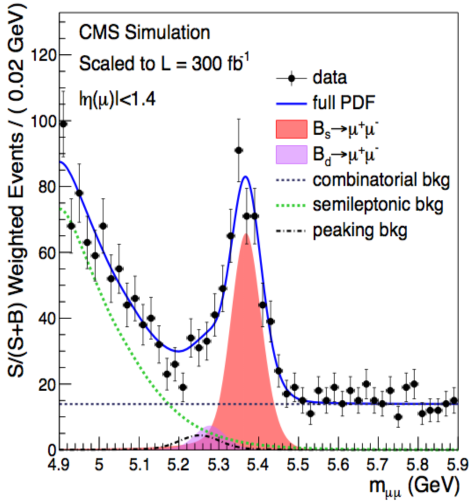
HH→ bbγγ – 60% cross section uncertainty
enabled by Tracker b-tagging, EC γ-ID performance

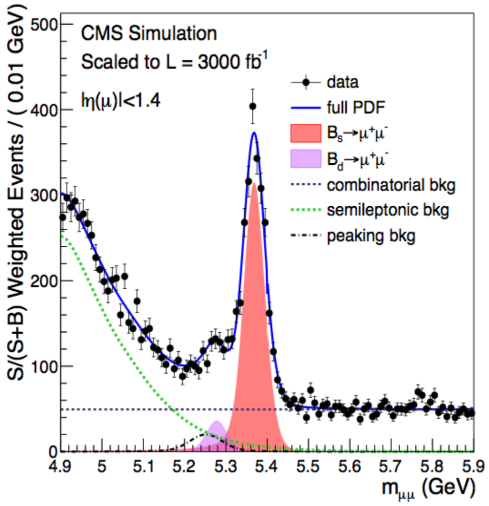




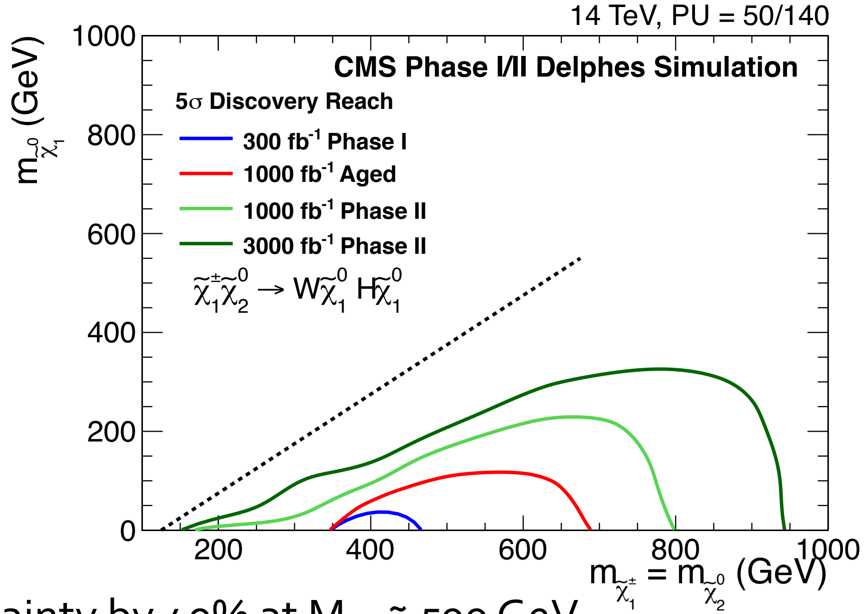
HH → bbττ- 100 % cross section uncertainty
enabled by Tracker-Trigger (x2 acc) and b-tagging, τ-ID performance

$B_d/B_s \rightarrow \mu\mu$ resolved two decay peaks measure also enabled by Track-Trigger

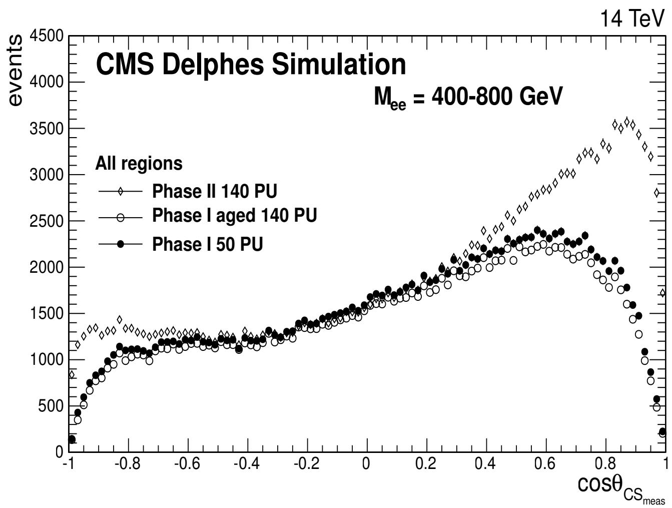


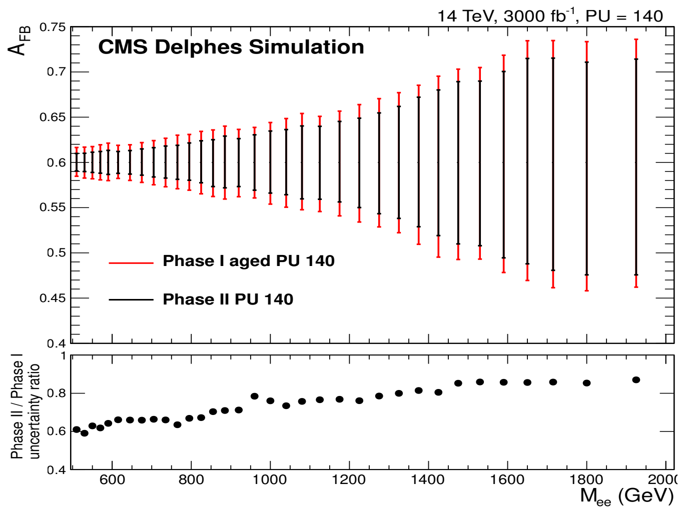


Neutralino mass range increase - enabled by Tracker b-tagging, extension (MET)



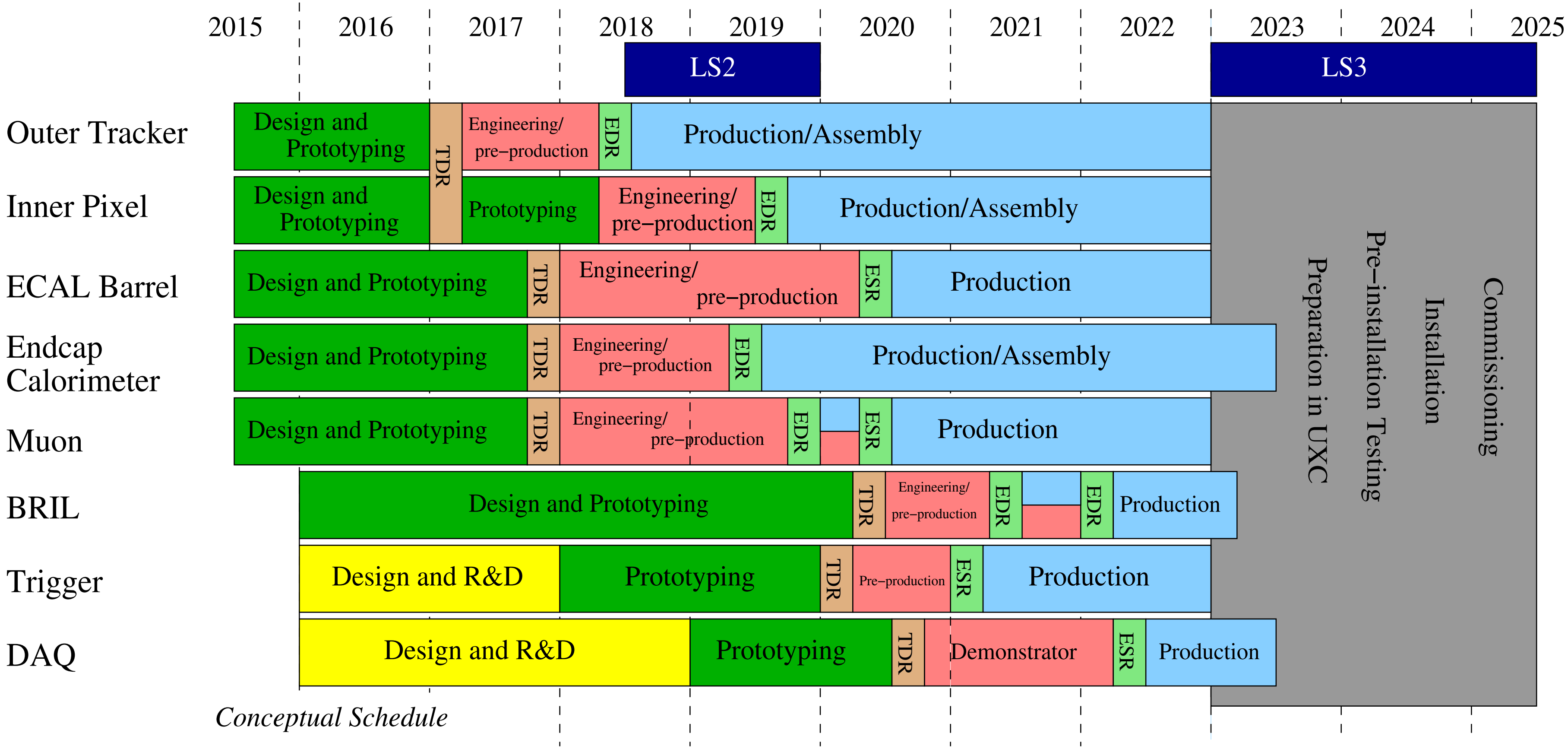
New physics search in A_{FB} of DY ee – improved uncertainty by 40% at M_{ee} ≃ 500 GeV
Resolution (charge assignment) new EC and coverage up to η = 3





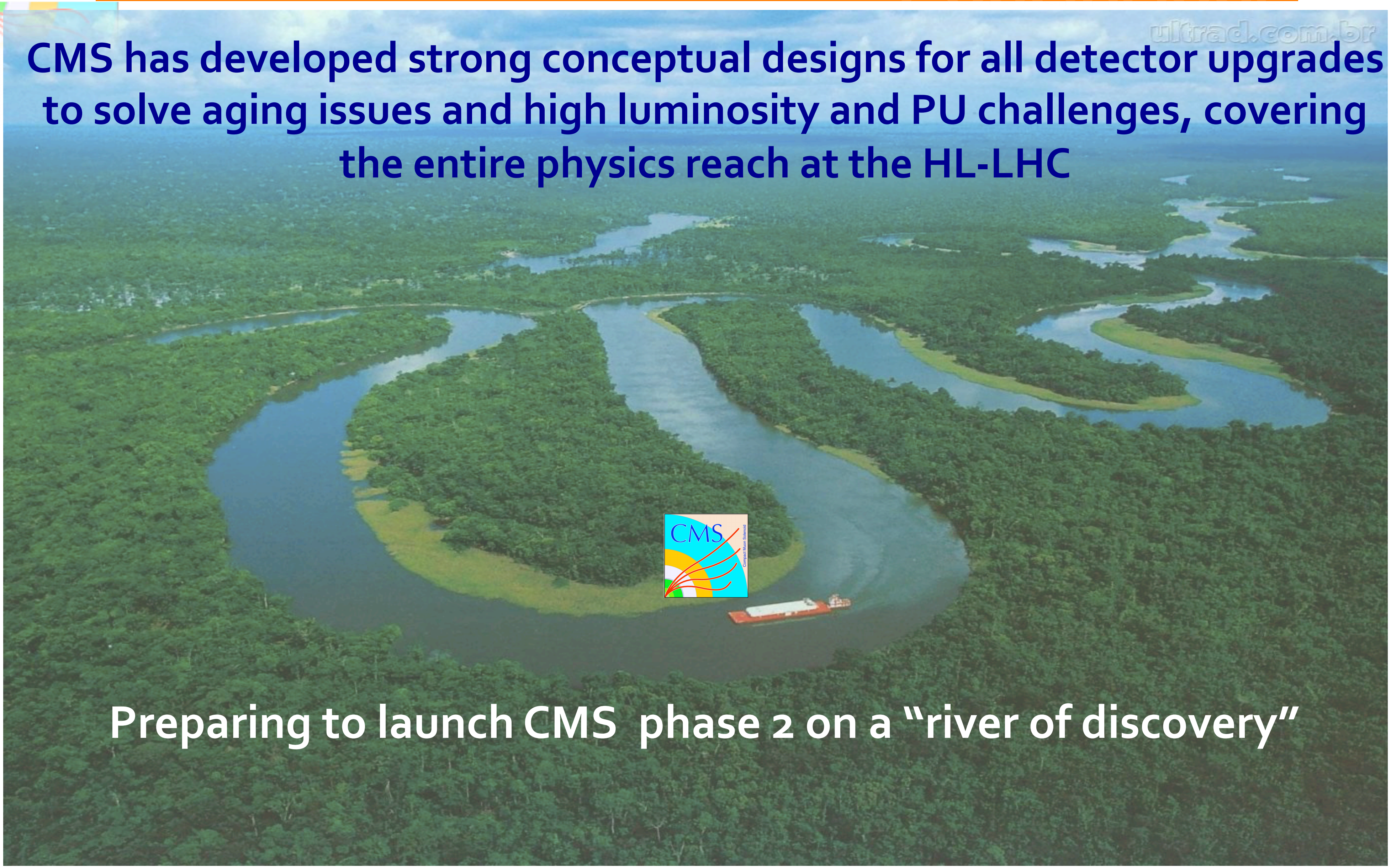
CMS Phase II Future Plans

R&D program well established for all upgrades
TDRs foreseen in 2016-2017 will include design optimization and main technical choices



Conclusions

CMS has developed strong conceptual designs for all detector upgrades to solve aging issues and high luminosity and PU challenges, covering the entire physics reach at the HL-LHC



Preparing to launch CMS phase 2 on a "river of discovery"

Many more public results:

CERN-LHCC-2015-010 (Phase II technical Proposal)

- https://cds.cern.ch/record/2020886

and

- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFP

Back-up slides

Enhancement of the Physics Reach with CMS Upgrades

Performance/ Physics	Higgs VBF $H\to\tau\tau$	Higgs $H\to\mu\mu$	Higgs $H\to ZZ\to 4l$	Higgs $HH\to bb\gamma\gamma$	Higgs $HH\to bb\tau\tau$	SMP VBS	SUSY VH(bb) +MET	EXO A_{fb} (Z')	EXO Dark Matter	EXO HCP	BPH $B_{s,d}\to\mu\mu$
Tracker											
Performance		*mass resolution*	mass resolution	*b-tagging*	*b-tagging*						*mass resolution*
Extensions	*forward jets / MET*		*acceptance*		*MET resolution*	*forward jets*	*MET resolution*	*acceptance*	*acceptance*		
Trigger											
Bandwidth	*acceptance*				*acceptance*						
Track Trigger	*background rejection*				*background rejection*						*background rejection*
Calorimeter											
ECAL	*forward jets / MET*		*acceptance*	*acceptance*	*MET resolution*	*forward jets*	*MET resolution*	*acceptance*	*acceptance*		
HCAL	*forward jets / MET*				*MET resolution*	*forward jets*	*MET resolution*				
Muons											
Extension			*acceptance*					*acceptance*	*acceptance*		

Summary & Conclusions

- The discovery of the Higgs boson at LHC-RUN 1 has opened the door towards a deeper understanding of particle physics
- With the start of RUN 2 we are now entering in the era of precisions Higgs studies and even more motivated searches for new physics
- The HL-LHC with a ten times more luminosity will allow thorough exploration of the TeV scale with a two-pronged approach
  - Precision SM, EWSB & Higgs physics, rare processes
  - Direct searches for new physics, including low cross-section
- It is time to prepare for HL-LHC operation in ≥ 2026.
- Ageing and radiation damage will require to rebuild the inner tracker and forward detectors.
  - New detectors designed to cope with high rates, high pile-up and radiation.
- New trigger concepts implemented. Larger bandwidth require upgrade of electronics.