CMS Upgrades
(w/ an emphasis on post-LS2 heavy flavor measurements)

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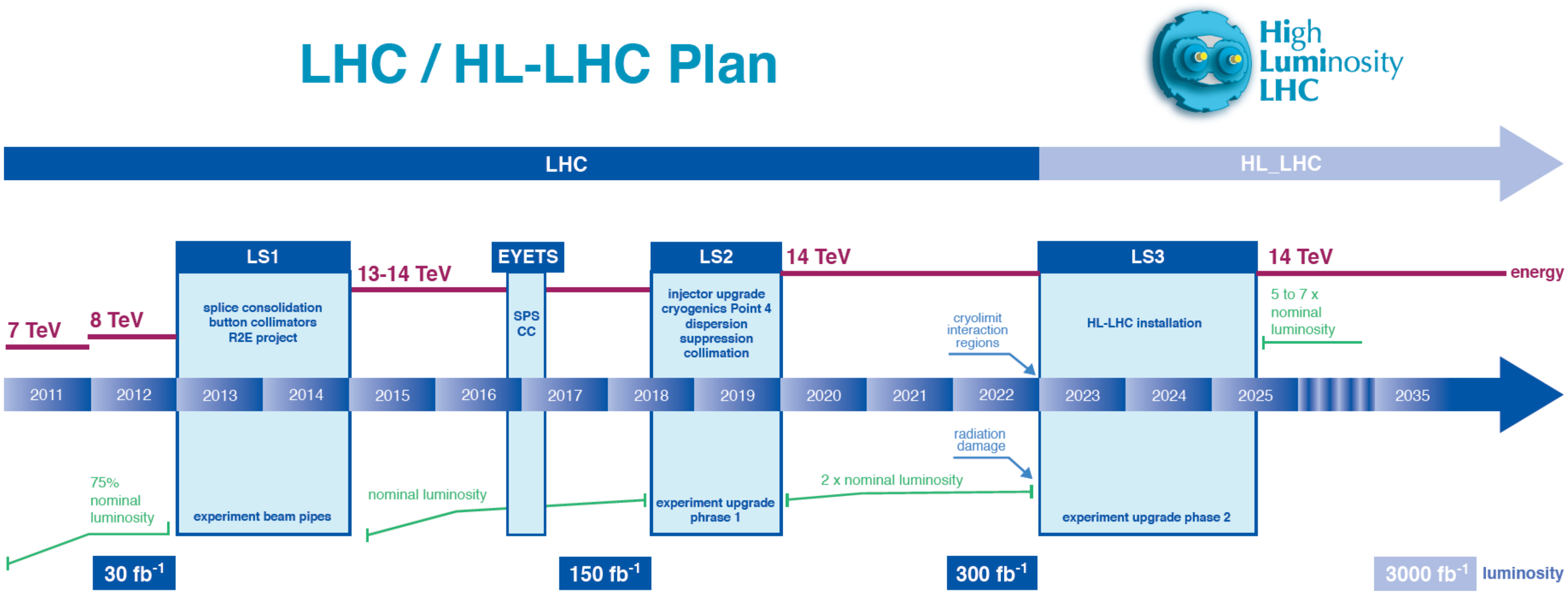
Sapore Gravis

December 11th, 2014

LHC Luminosity Evolution



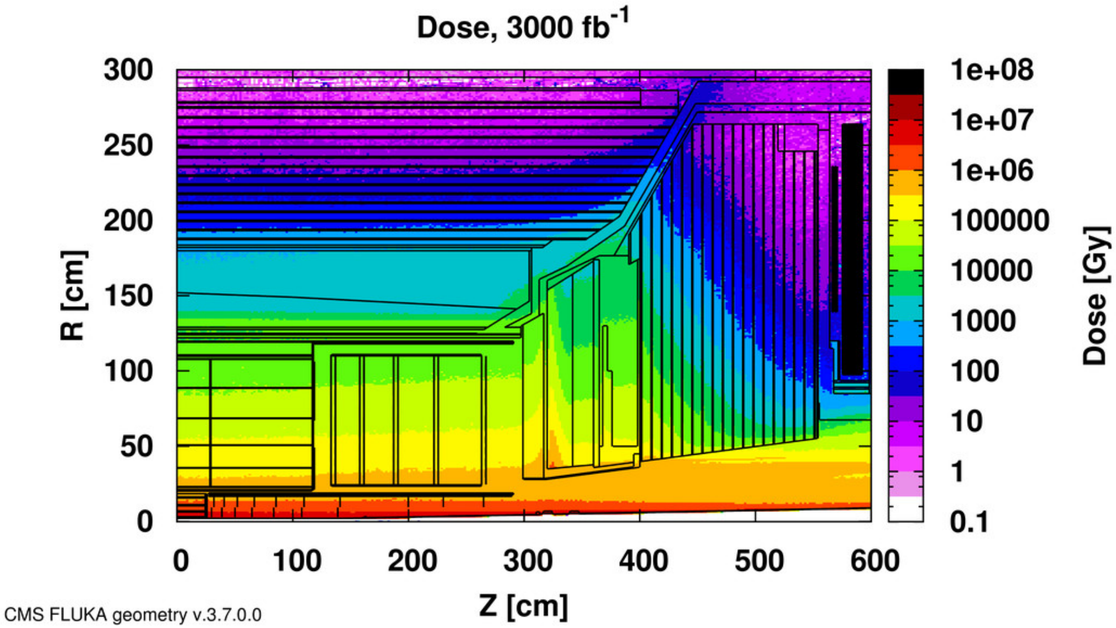
Whereas ambitious upgrades are planned for ALICE and LHCb during LS2 ….

For ATLAS and CMS, this is a period of *consolidation*: Phase 1 upgrades

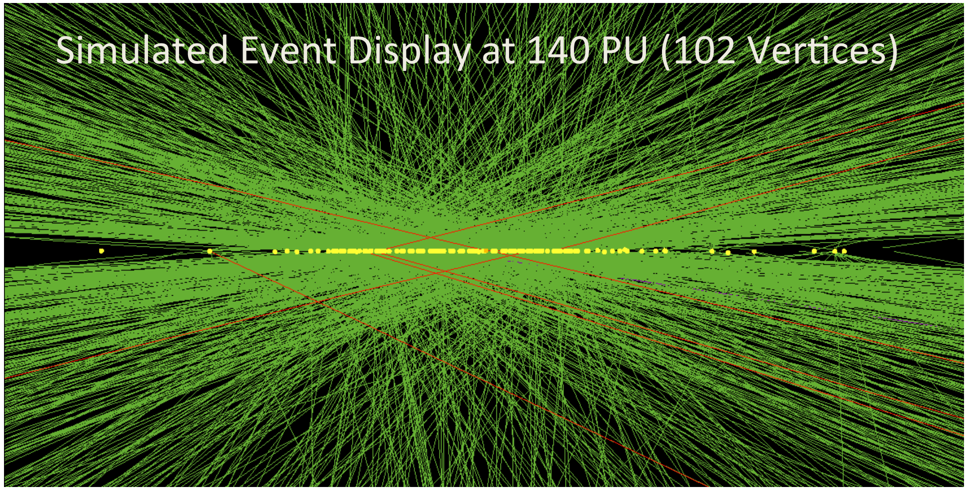
Ambitious upgrades are currently being planned for the HL-LHC era: Phase 2

http://hilumilhc.web.cern.ch/about/hl-lhc-project

A bright light on new physics …



- Radiation
  - Neutron fluences up to 2×10^{16} n/cm^2 in pixels
- Pileup
  - 140 average simultaneous interactions (many events with > 180)



“Mainstream” CMS physics goals

In addition to all the great SM precision measurements with Z, W and the top quarks, HI Physics, flavour physics etc. …

Driven by the new physics (i.e. the scalar sector) Discovered during run I

- Complete precision measurements of the Higgs boson
- Observe Di-Higgs production and access the self-coupling
- Measure trilinear and quartic couplings of weak bosons
- Measure rare decays and search for forbidden H decays
- Search for an extended scalar sector
- Search for extra-structure, supersymmetric matter, Exotica, …

From Yves Sirois (LLR), Split ‘14

Given the scope of the CMS upgrade program based on these goals, what are the prospects for the physics relevant this workshop?

Run 3 PbPb Projections

CMS-PAS-FTR-13-025

Table 3: Quarkonia yield estimates for $L_{\text{int}} = 10\ \text{nb}^{-1}$ at $\sqrt{s_{NN}} = 5.5$ TeV. Bottomonia are inclusive in p_T, charmonia have $p_T > 6.5\ \text{GeV}/c$.

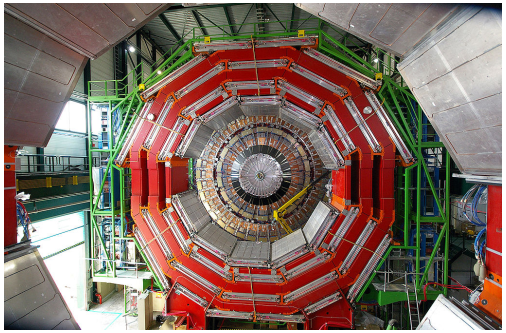
$\sqrt{s_{NN}}$	2.76 TeV	5.5 TeV						
L_{int}	$150\ \mu\text{b}^{-1}$	$10\ \text{nb}^{-1}$						
Centrality(%)	0-100	0-100	50-100	60-100	70-100	80-100	90-100	0-100
Signal	p_T-inclusive raw yields							($p_T > 30$ GeV)
$B \to J/\psi$	2 250	300 000	12 400	6 150	2 350	810	215	5500
Prompt J/ψ	9 000	1 200 000	49 500	24 500	9 420	3 240	860	4400
$\psi(2S)$	200	26 600	1 100	547	210	70	20	100
$\Upsilon(1S)$	2 000	266 000	11 000	5 460	2 090	720	191	267
$\Upsilon(2S)$	300	40 000	1650	820	314	108	29	80
$\Upsilon(3S)$	50	6 700	275	137	52	18	5	20

In terms of delivered yield, precise heavy flavor measurements are possible
But, need corresponding detector upgrades and trigger strategy

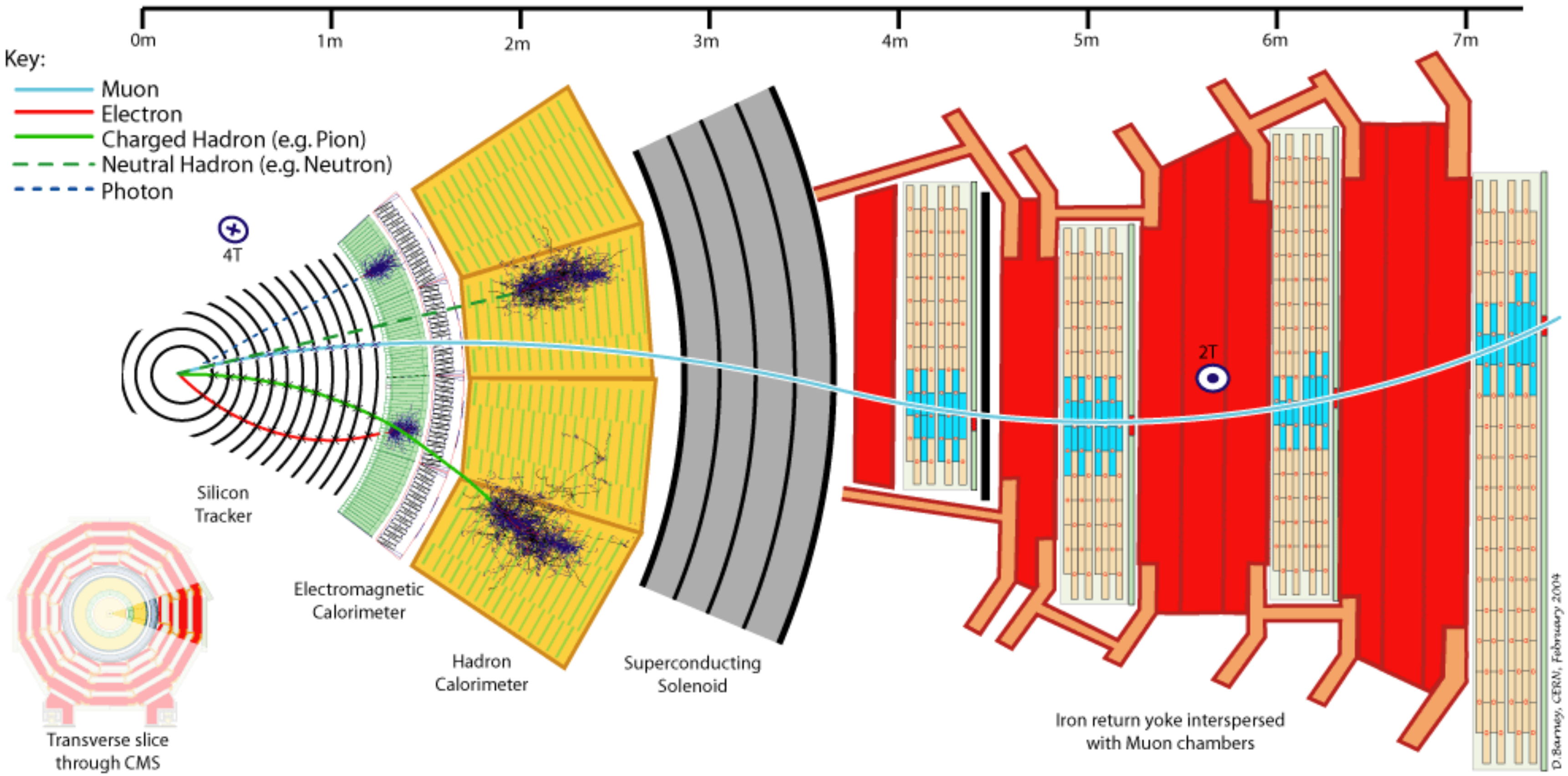
CMS

4 main subsystems:

Tracker
ECAL
HCAL
Muon



Barrel-endcap (solenoid) geometry

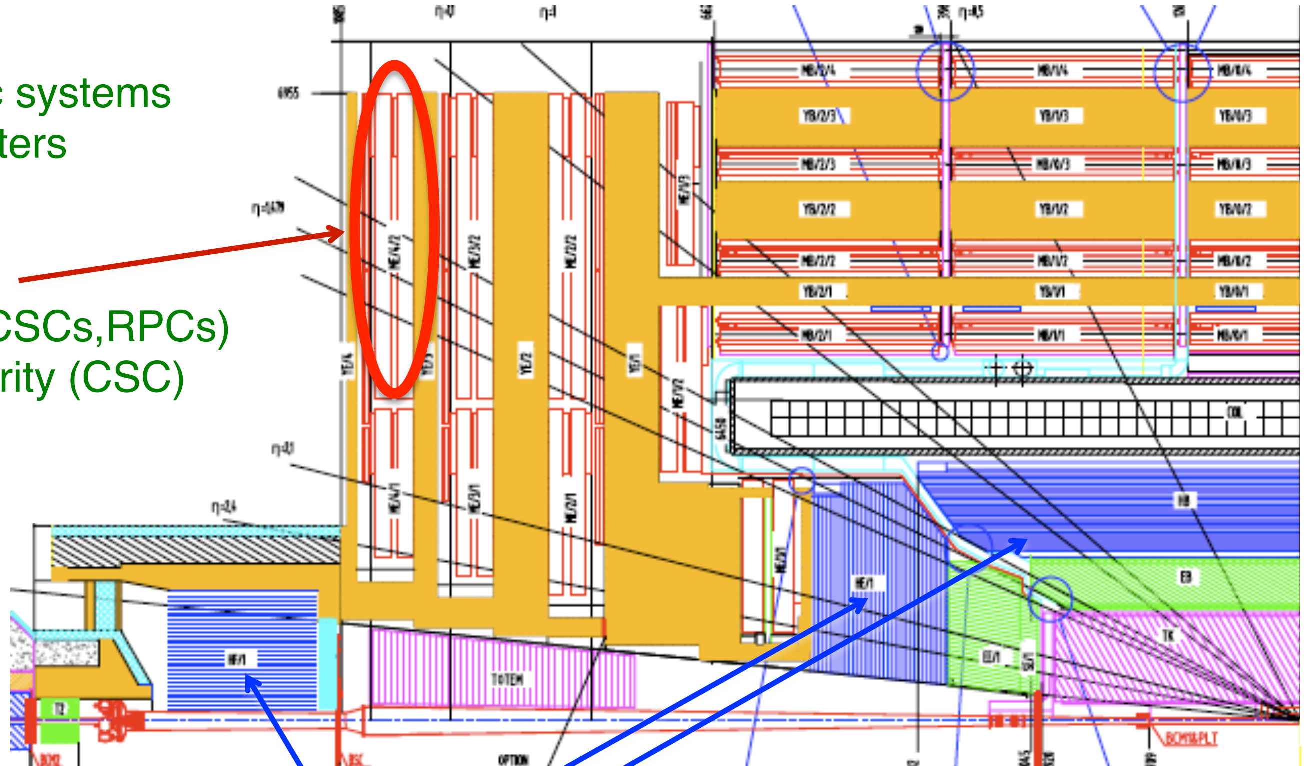


+ sophisticated hardware (L1) and software (HLT) triggers

Overview of Phase 1 upgrades

L1 trigger
New backend electronic systems for muons and calorimeters

Muon systems
Complete μ coverage (CSCs,RPCs)
Higher read-out granularity (CSC)



Hadron calorimeters
Replace photo-detectors and read-out (in LS2) → longitudinal segmentation

Pixel detector
Full replacement during extended YETS 2016/17
+ New beam pipe

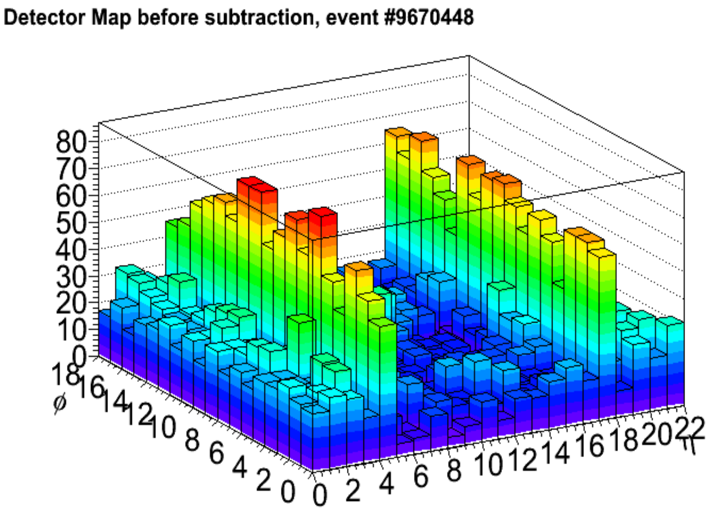
TDRs:
Pixel: http://cds.cern.ch/record/1481838?ln=en
L1 Trigger: http://cds.cern.ch/record/1556311?ln=en
HCAL: http://cds.cern.ch/record/1481837?ln=en

Phase 1 L1 Calo trigger upgrade

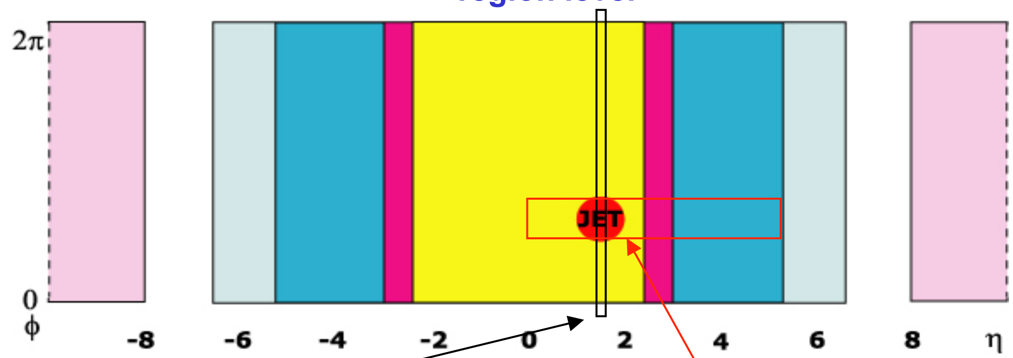
- CMS L1 accept rate limited by pixel readout to 3 kHz for HI collisions
- In 2011 the collision rate was of 4.5 kHz, only modest rejection required at L1
- Expect 20-30 kHz in 2015 → require a factor of 10 in L1 rejection
- Upgrade motivated primarily by heavy ions! Funded by the DOE

UE subtraction at L1

Region Energy Distributions
One Central Event



Stage-1 HI L1 algorithm: phi ring background subtraction in region level

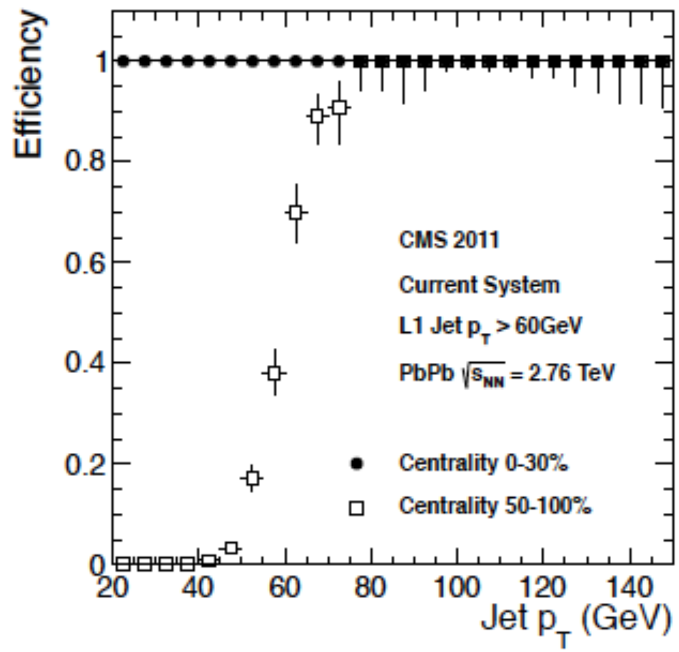


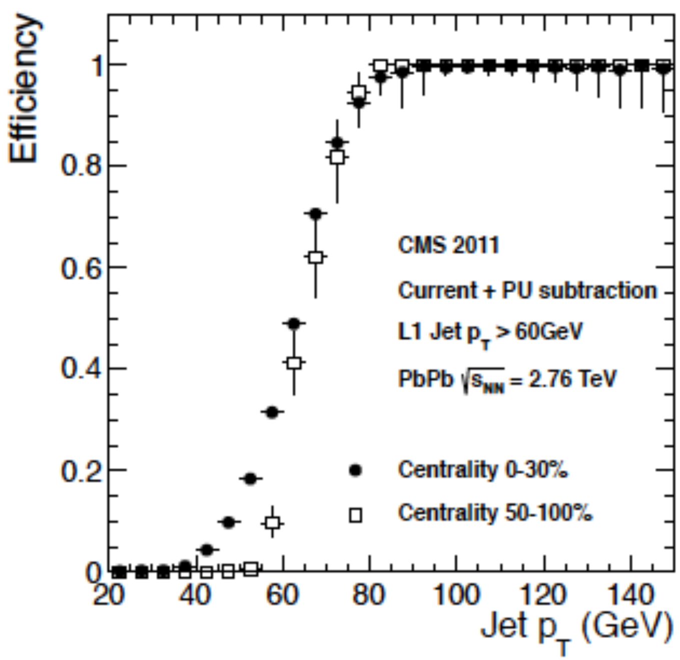
HLT/Offline background subtraction:
- Process phi rings at const. eta
- Calculate average and subtract
- Jet finder runs after BG subtraction

Current L1 Jet Finder:
- Processes eta strips at const. phi
- Sliding window jet finder

- Variation of HI UE w/ η of does not permit a useful BG subtraction within a single 2x11 sector
- Access to the full eta-phi map at L1: efficient underlying event subtraction (phi-rings)

Jet triggers for Run 2

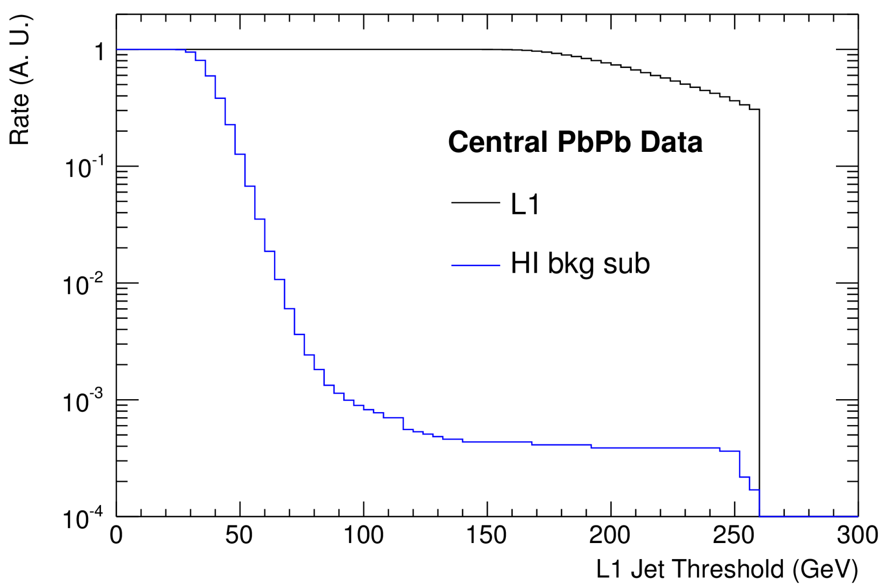




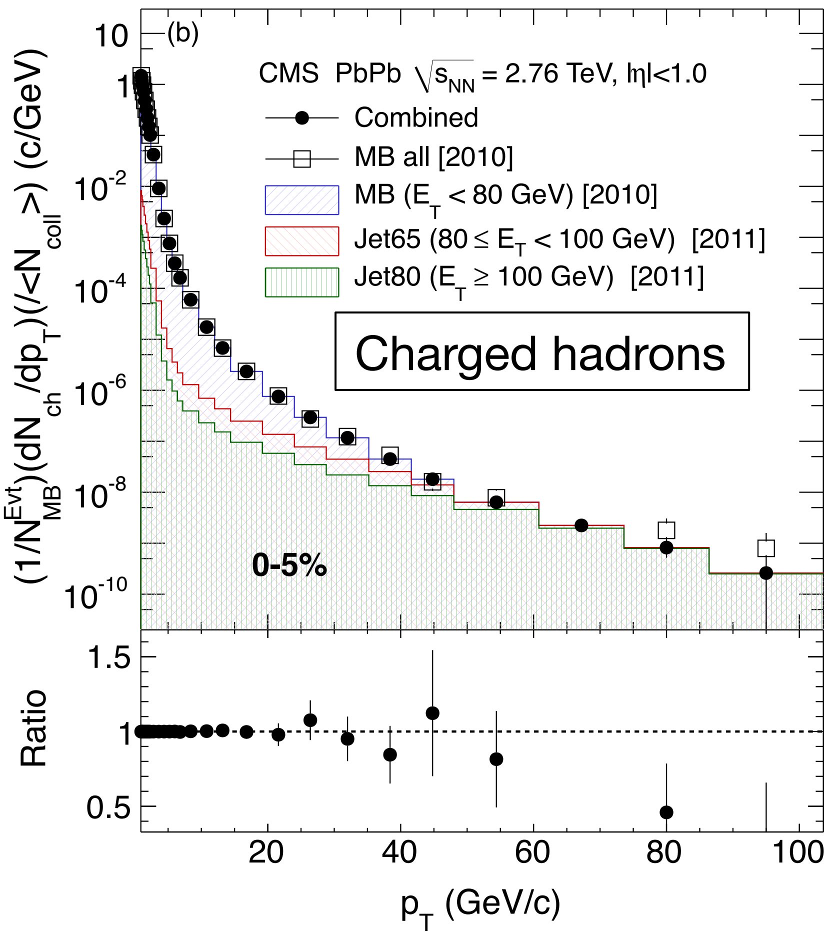
Before upgrade:
L1 jet trigger fires on every central event!

After upgrade:
Sharp turn-on even in central

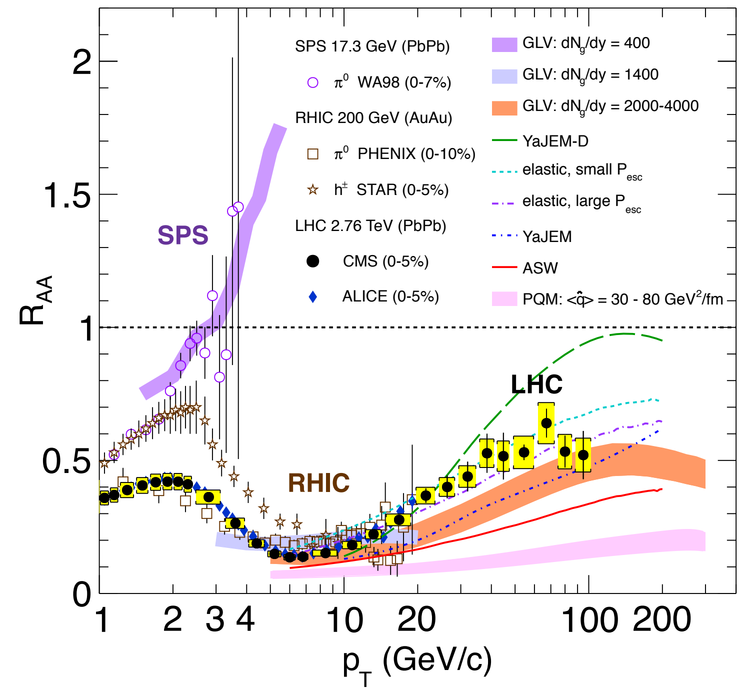
~ 100x L1 rejection for L1 jets > 60 GeV



Measuring spectra w/ jet triggers



p_T reach of spectra is extended w/ jet triggers

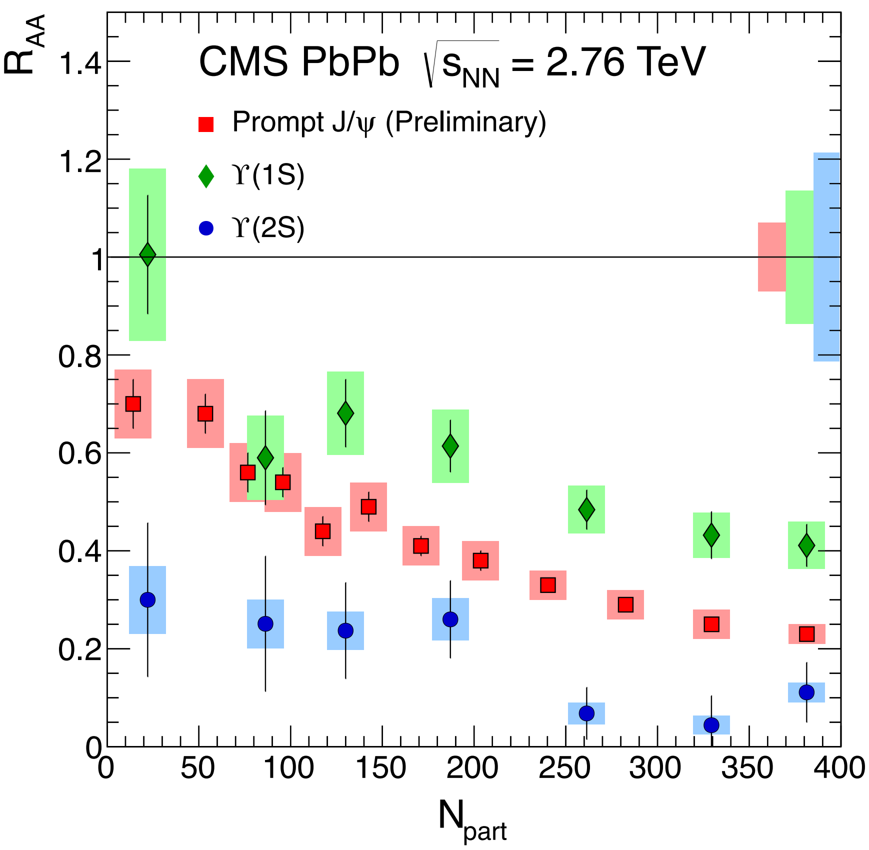


Rarer probes require lower p_T threshold jet/track triggers

L1 calo upgrade should permit, e.g., D meson spectra to high p_T

Centrality trigger

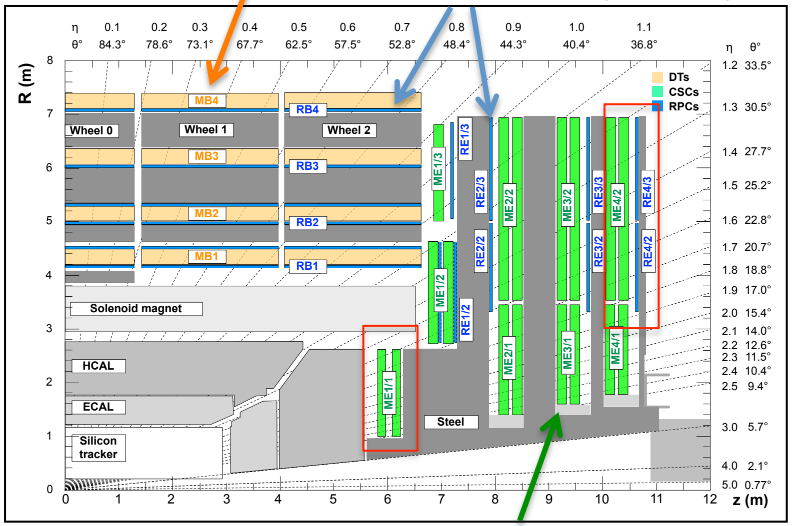
- For many probes, we do not see full turn off of nuclear effects, i.e., $R_{AA} \rightarrow 1$
- However, typically restricted to 60-100%
- Can sample full luminosity of low threshold di-muon triggers in peripheral events
- Already possible for Run 1, but not needed



Muon LS1 Upgrades

Drift Tubes (barrel)

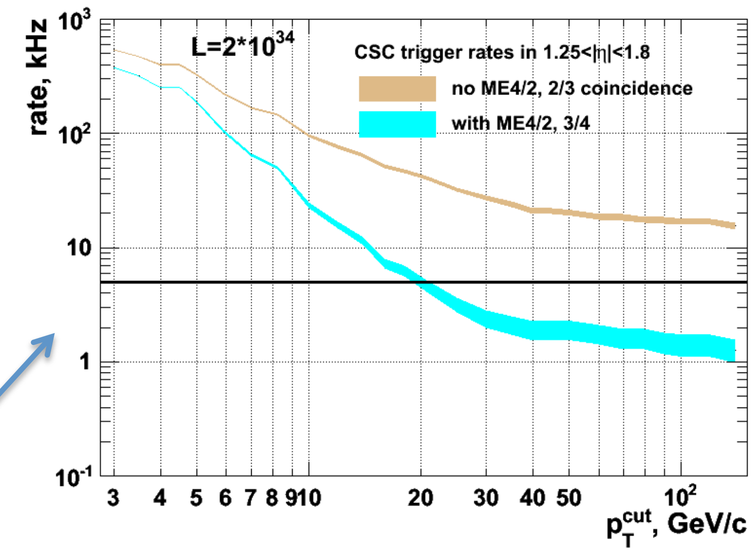
Resistive Plate Chambers (|η|<1.6)

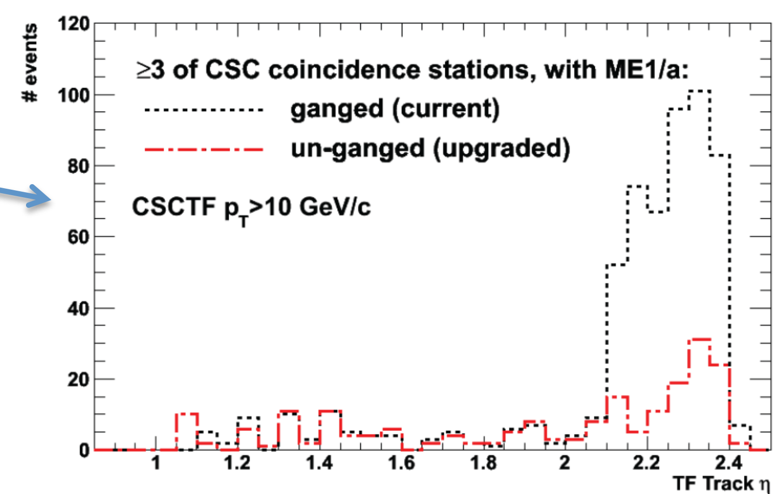


Cathode Strip Chambers (endcap)

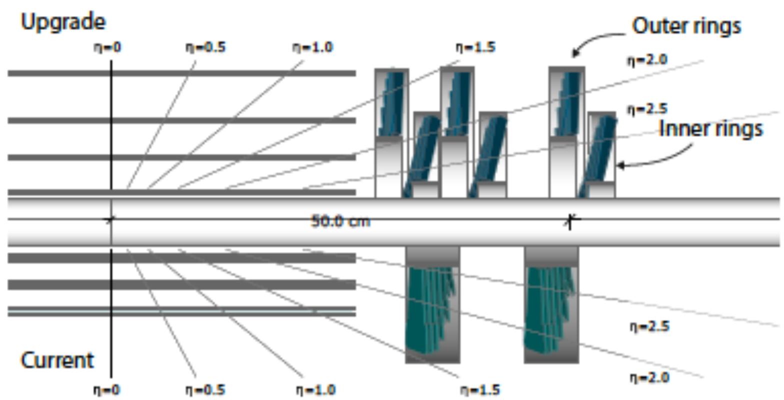
- For Run 2:
  - 4^{th} endcap layer for 1.2<|η|<1.8 (CSC + RPC)
  - Improved read-out granularity of forward CSC (|η|>1.6)
  - complete rewrite of muon track finding at L1

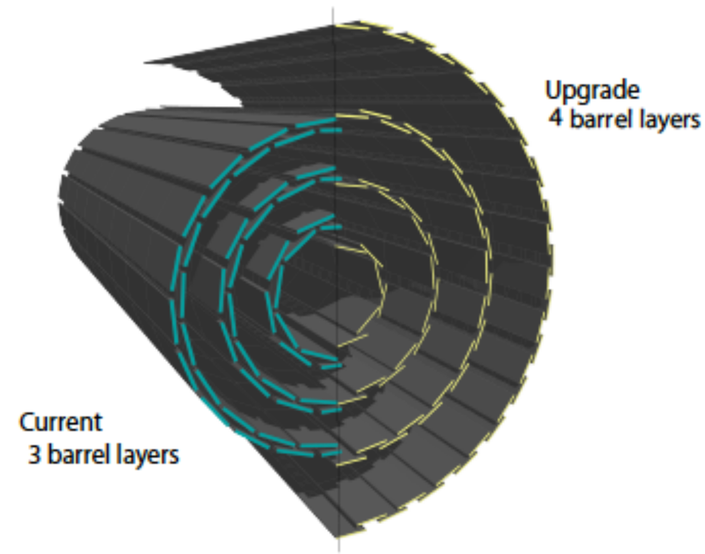
→ Improved muon trigger selectivity





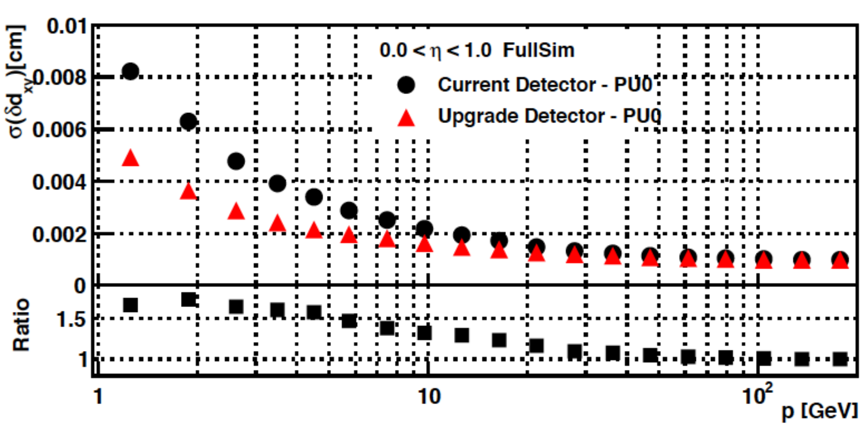
Pixel Upgrade

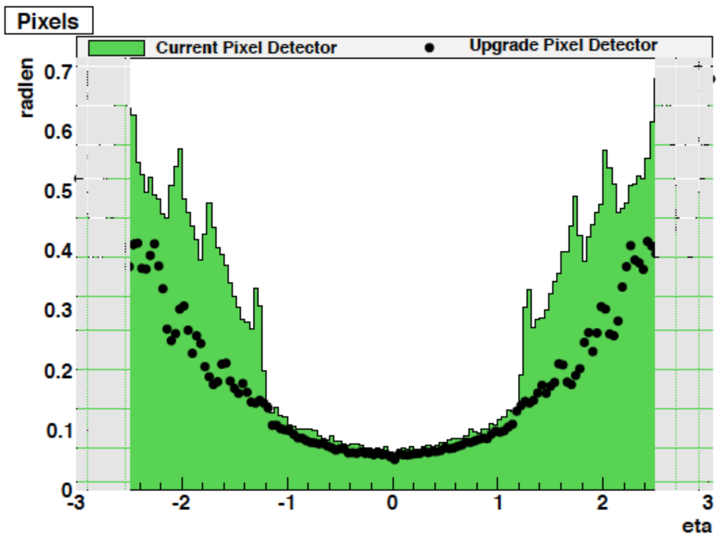




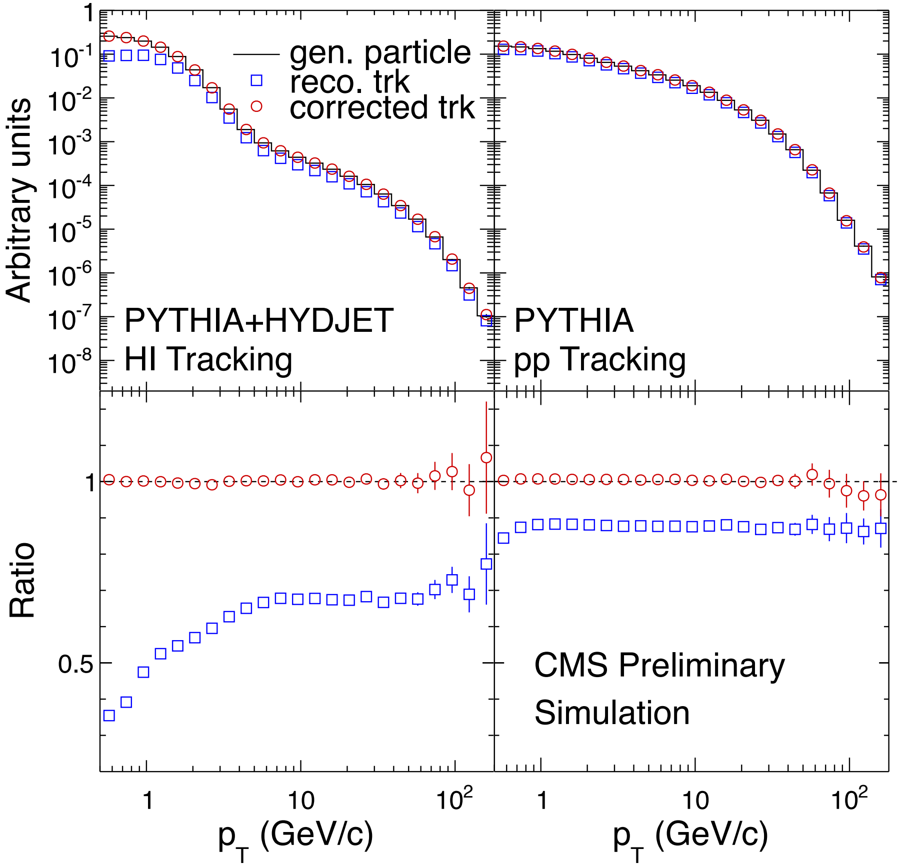
- Added redundancy → fake rejection
- Faster readout cards
- Reduced material budget
- Improved IP resolution

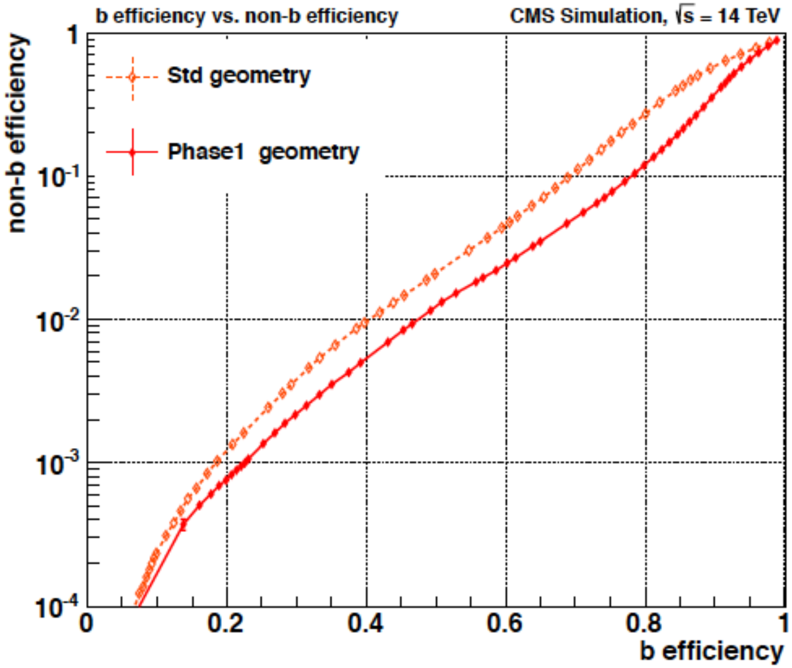
To be installed during 2016 YETS





Impact of pixel upgrade on HI



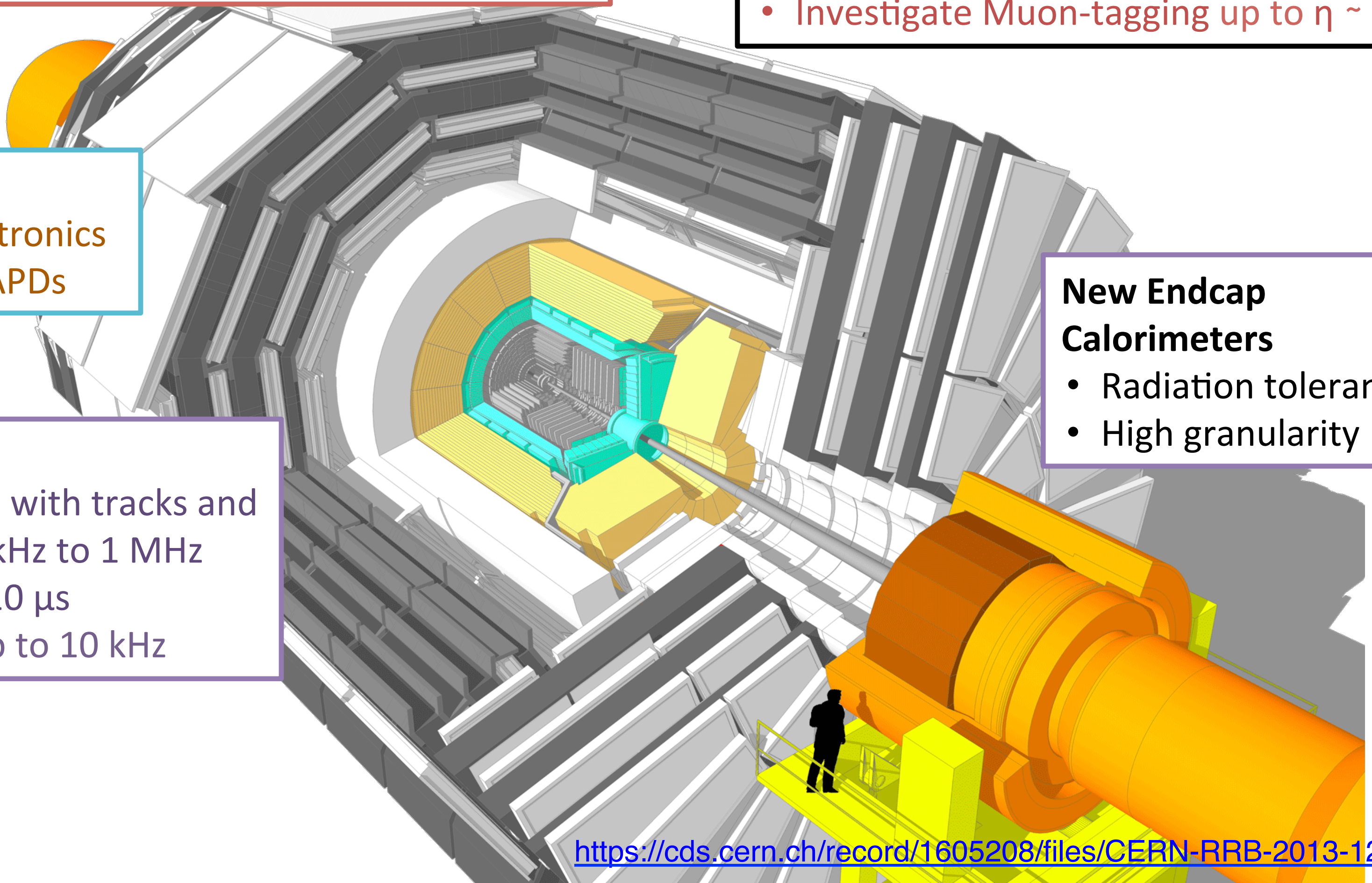


Tracking efficiency currently limited by track quality requirements for fake rejection → after upgrade should be much closer to pp-like tracking efficiency

Also:

- Improved b-tagging, non-prompt J/ψ
- Improved onia mass resolution
- Photon conversions? V0s?

CMS Phase 2 Upgrades



New Tracker
- Radiation tolerant - high granularity - less material
- Tracks in hardware trigger (L1)
- Coverage up to η ~ 4

Muons
- Replace DT FE electronics
- Complete RPC coverage in forward region (new GEM/RPC technology)
- Investigate Muon-tagging up to η ~ 4

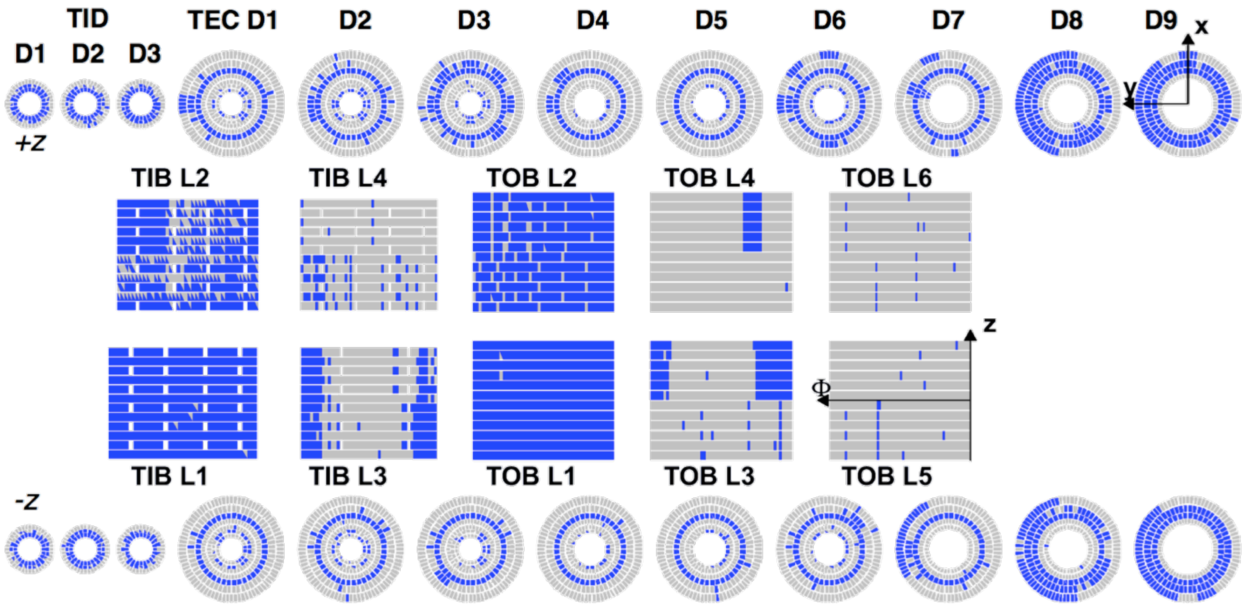
Barrel ECAL
- Replace FE electronics
- Cool detector/APDs

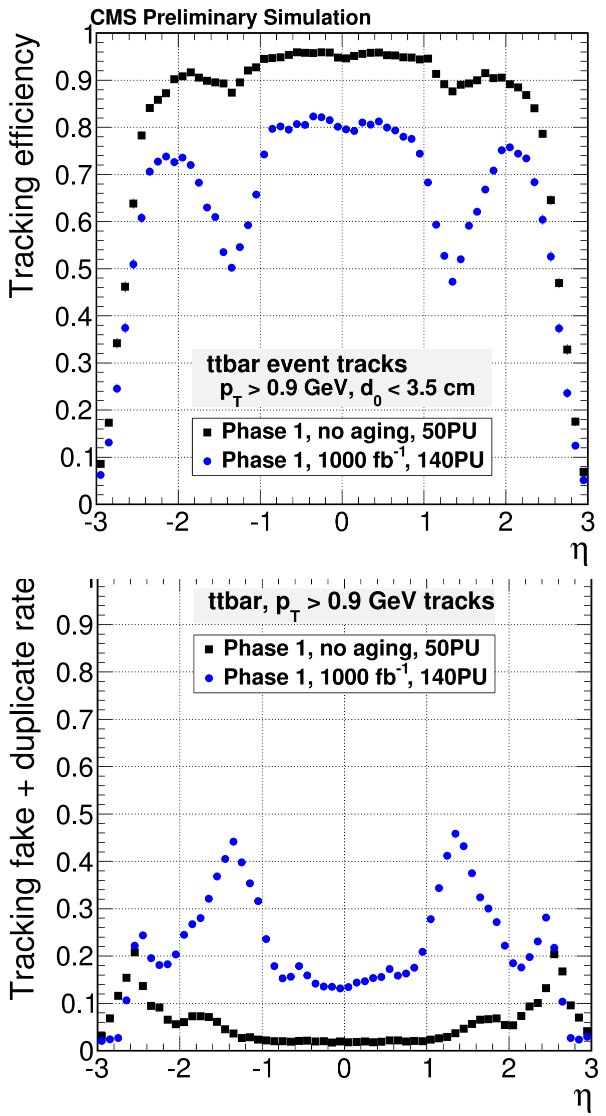
New Endcap Calorimeters
- Radiation tolerant
- High granularity

Trigger/DAQ
- L1 (hardware) with tracks and rate up ~ 500 kHz to 1 MHz
- L1 Latency > 10 μs
- HLT output up to 10 kHz

https://cds.cern.ch/record/1605208/files/CERN-RRB-2013-124.pdf

Tracker Radiation Damage



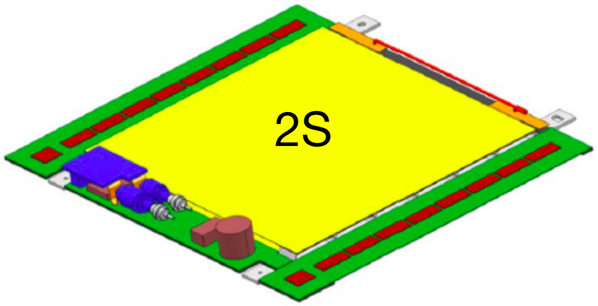


Blue tracker modules are inactive after 1000 fb^{-1} due to very high leakage currents induced by neutron fluence.

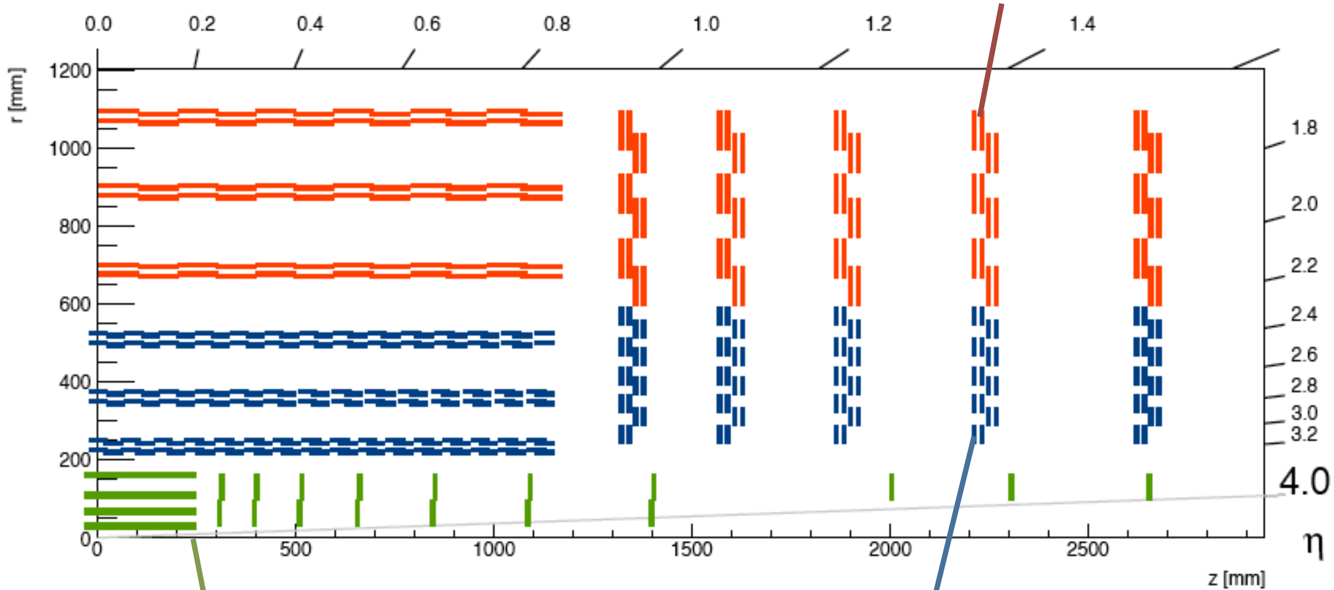
Strip and pixel tracker are seriously degraded after Phase 1

⇔ need rad-hard replacement

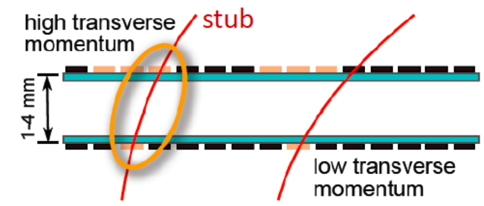
Phase 2 Tracker



Strip/Strip Modules
90 µm pitch/5 cm length

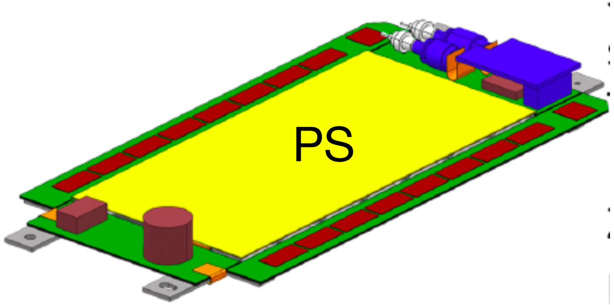


Also, L1 track trigger:



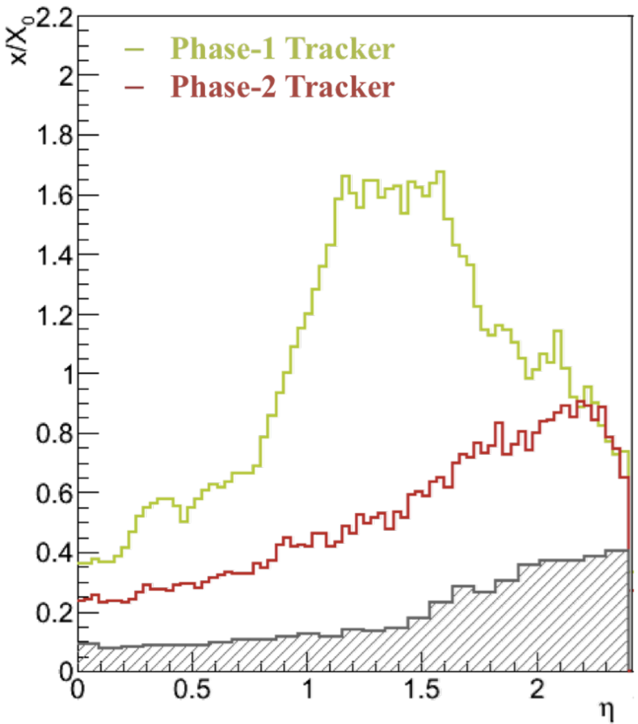
Inner Pixel
Covers up to η=4.0

Strip/Pixel Modules
100 µm pitch/2.5 cm length
100 µm x 1.5 mm "macropixels"

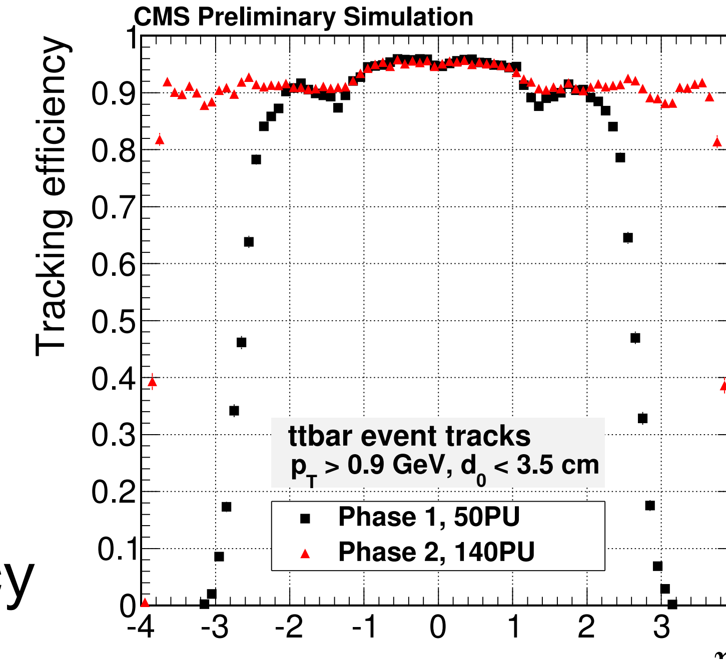


Phase 2 tracker performance

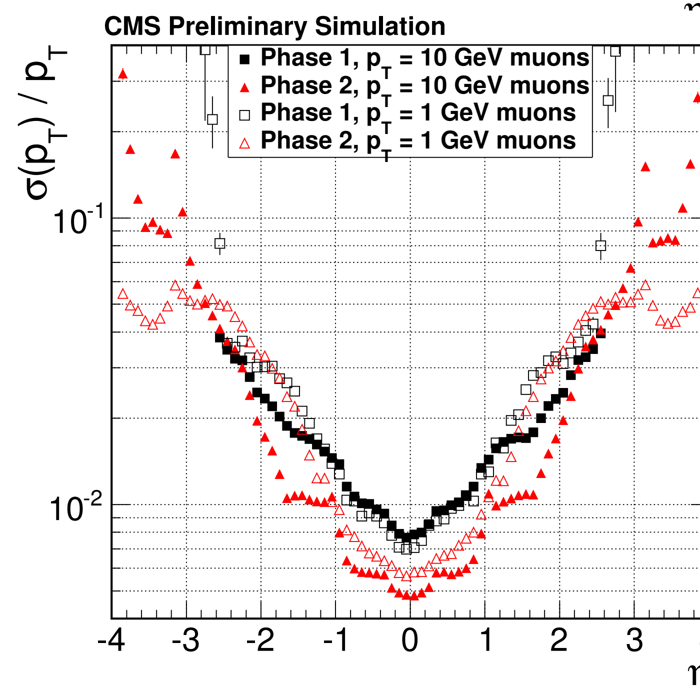
Dramatically reduced material budget



High efficiency out to |η| < 4



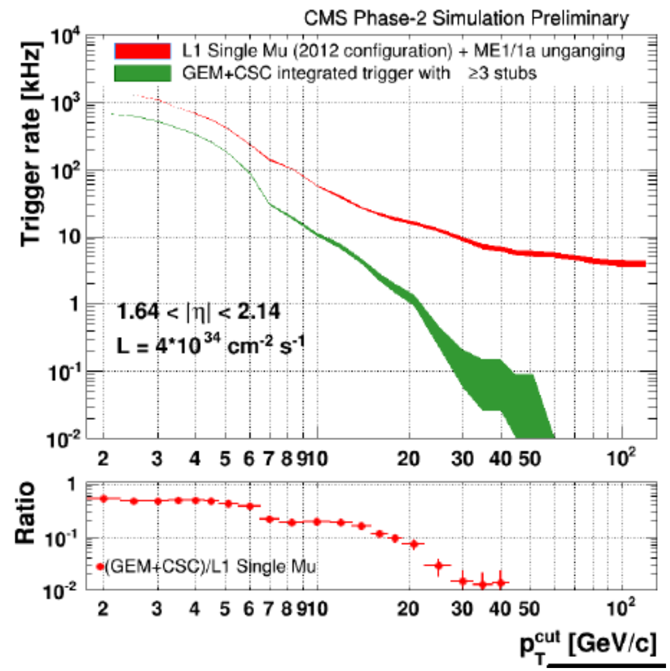
Improved p_T resolution

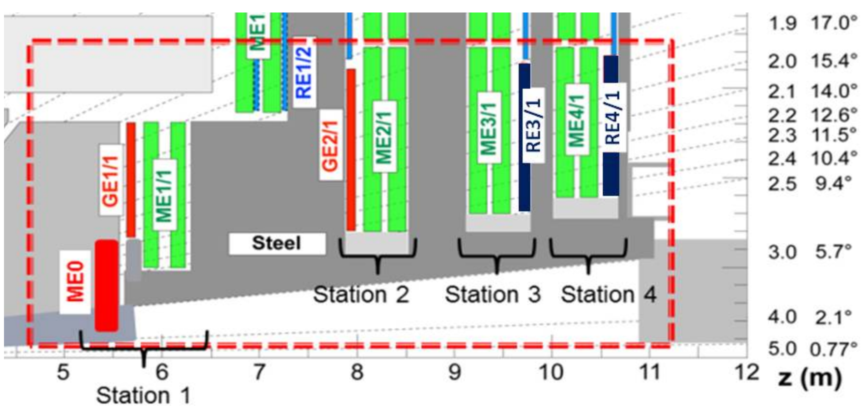


Phase 2 Muon Detector

- Improvements of existing detector electronics
- Forward 1.6<|η|<2.4 upgrades
  - Double-layered triple GEMs
    - GE1/1 for LS2, GE2/1 for LS3
  - Glass RPCs

  → Reduced trigger rate, improved redundancy
- Very forward extension
  - 6-layered triple GEMs
  - At least |η|<3, possibly |η|<4





Dimuon projections

- Gain of x1.5 (1.2) resolution in the barrel (encaps)
- Improved track resolution
- Muon triggering keeping pace with rate

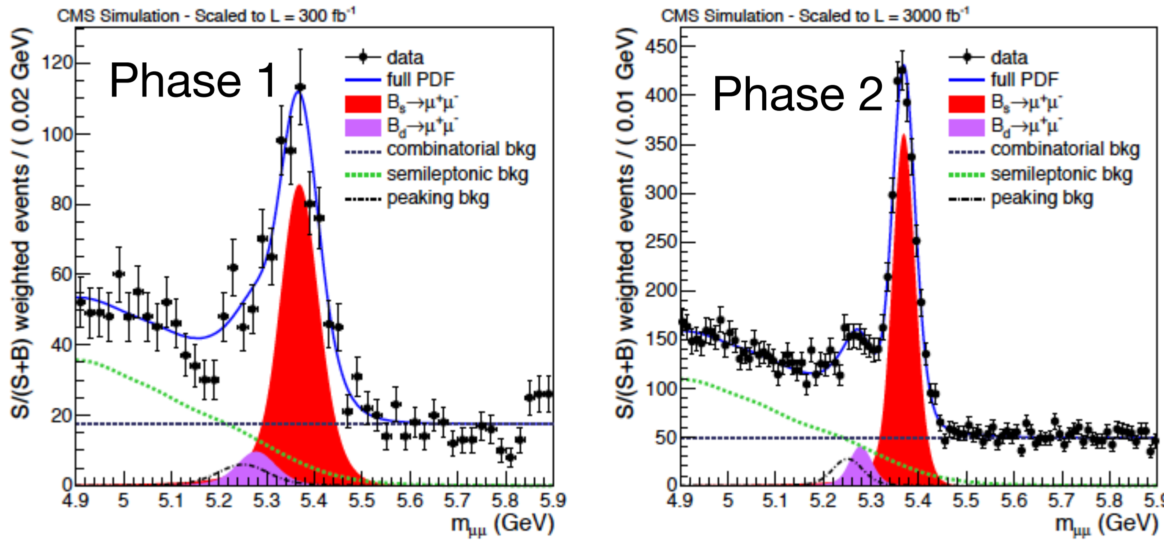
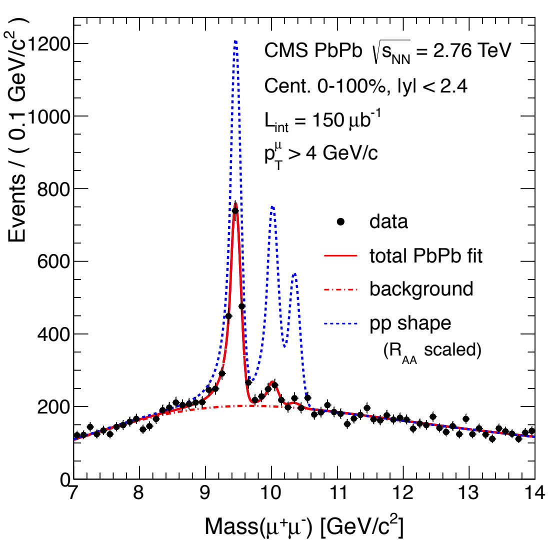


Figure 1: Fit results of the invariant mass distribution for 300 fb^{-1} and 3000 fb^{-1}. The improvement in the mass resolution for the 3000 fb^{-1} projection is expected from an improved inner tracker system and removing endcap candidates.

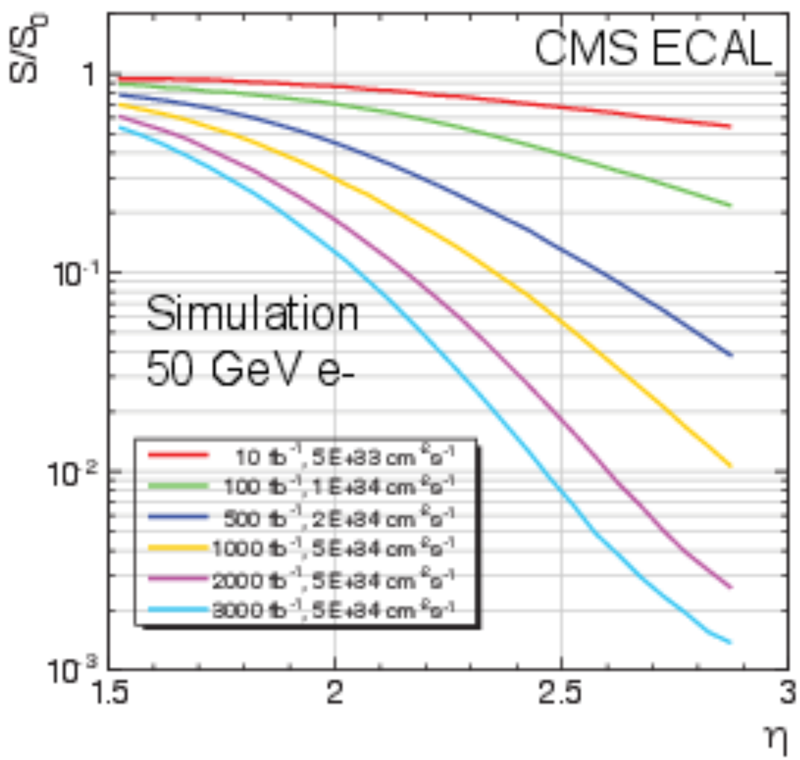


?

Expect similar gains, e.g., for Upsilon in PbPb

Phase 2 calorimeters

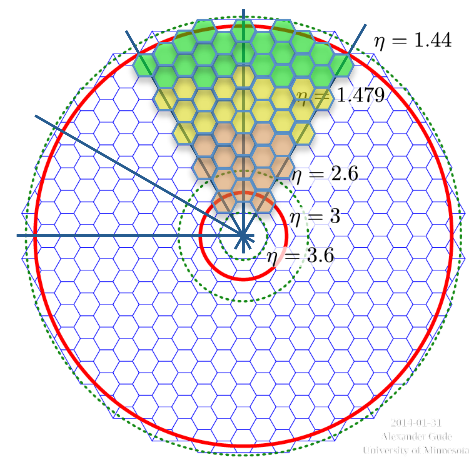
At high |η|, the $PbW0_4$ crystals of ECAL endcap progressively lose transparency



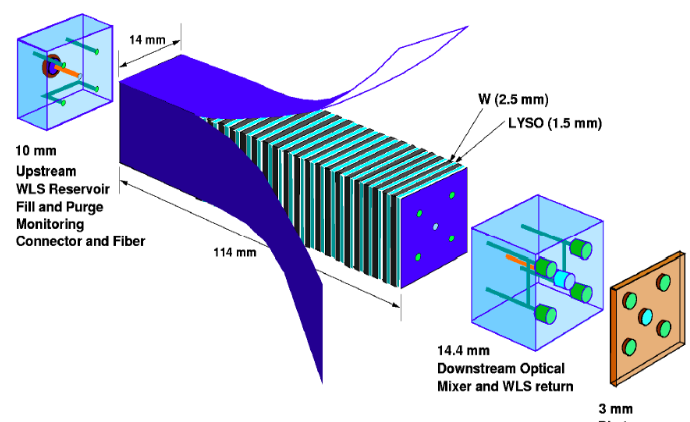
2 possible calorimetry options (decision in 2015)

High Granularity (HGCAL)

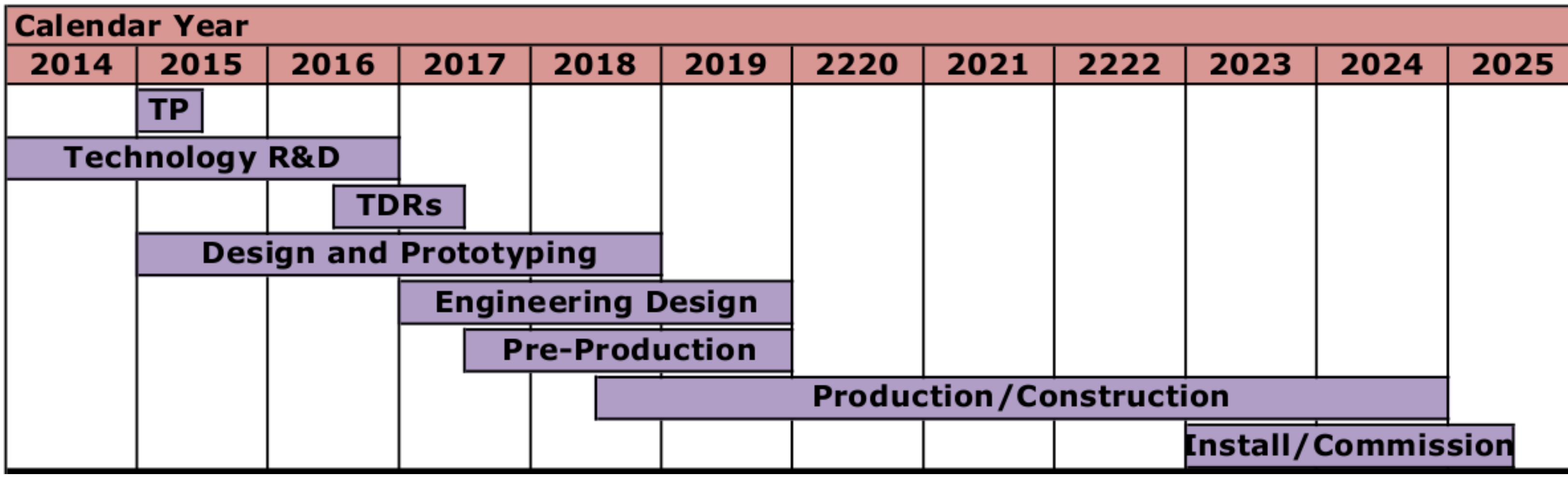
Highly Segmented for particle flow



Shashlik – "Conventional dense":



Phase 2 timeline



- CMS HL-LHC Technical Proposal is being completed now with full-simulation physics studies
    - Decision on endcap calorimeter technology planned for early 2015
- CMS will complete Technical Design Reports on the key upgrades in 2016/17
    - Next two years are very important for final R&D leading up to the TDRs

Conclusions

- Phase 1: Consolidation of current detector
  - L1 Calo upgrade: Essential for HI program
  - Completion of muon detectors
  - New pixel detector for end of 2016
- Phase 2: New detector for HL-LHC era
  - Tracker out to $|\eta| < 4$, including triggering
  - Add'l muon redundancy, possibly ext. to $|\eta| < 4$
  - New calo endcaps, possibly high granularity
- Implications for heavy flavor in heavy ions:
  - Improved tracking, jet triggers for open HF & b jets
  - Improved onia triggering, mass resolution


Upgrade my CMS?
http://www.wsol.com/why-waiting-to-upgrade-your-cms-is-planning-to-fail/
I'll think about that tomorrow