Forward Detector Performance at the HL-LHC

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on behalf of the ATLAS and CMS Collaborations

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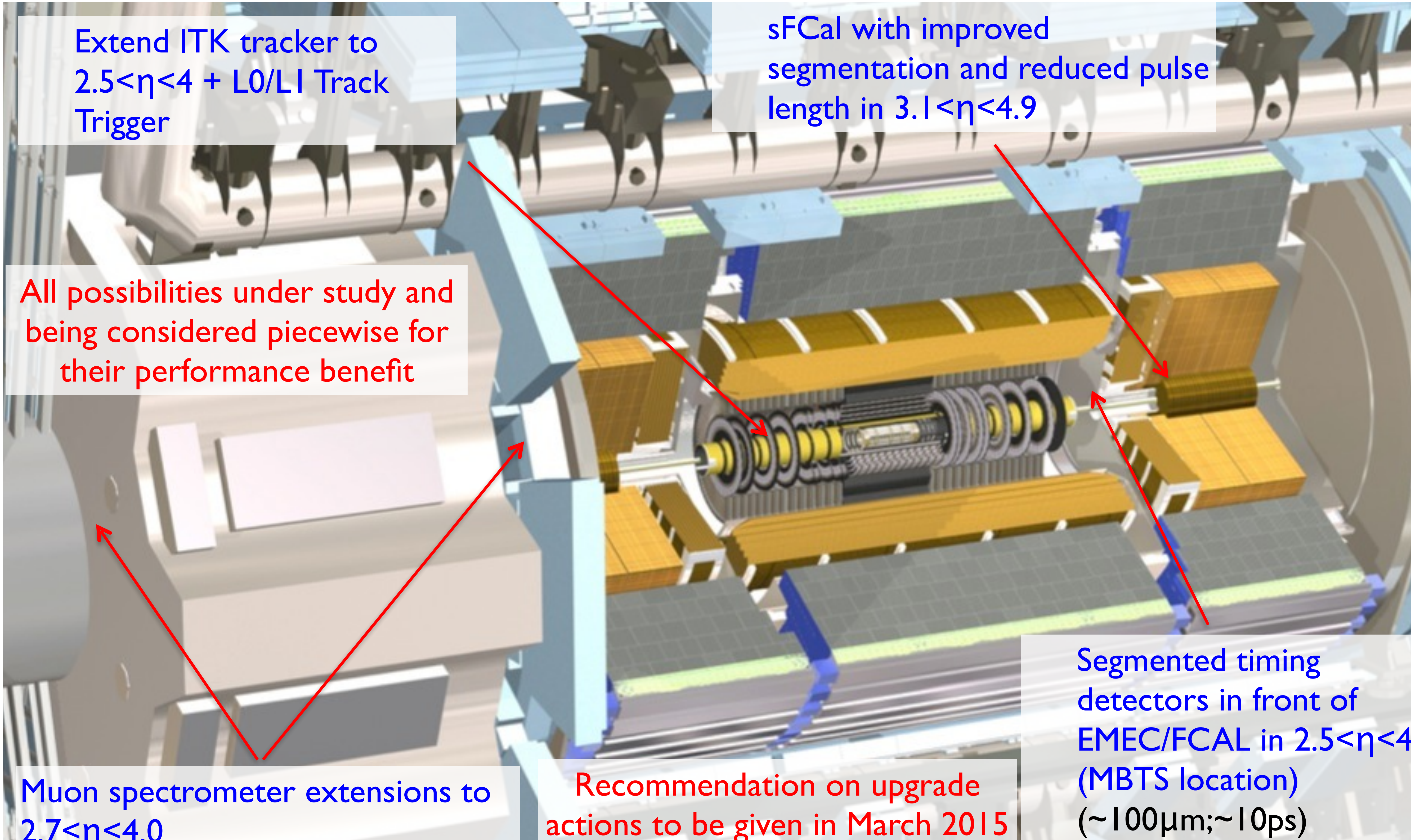
ECFA High Luminosity LHC Experiments Workshop

ATLAS Phase 2 Possibilities at Large η

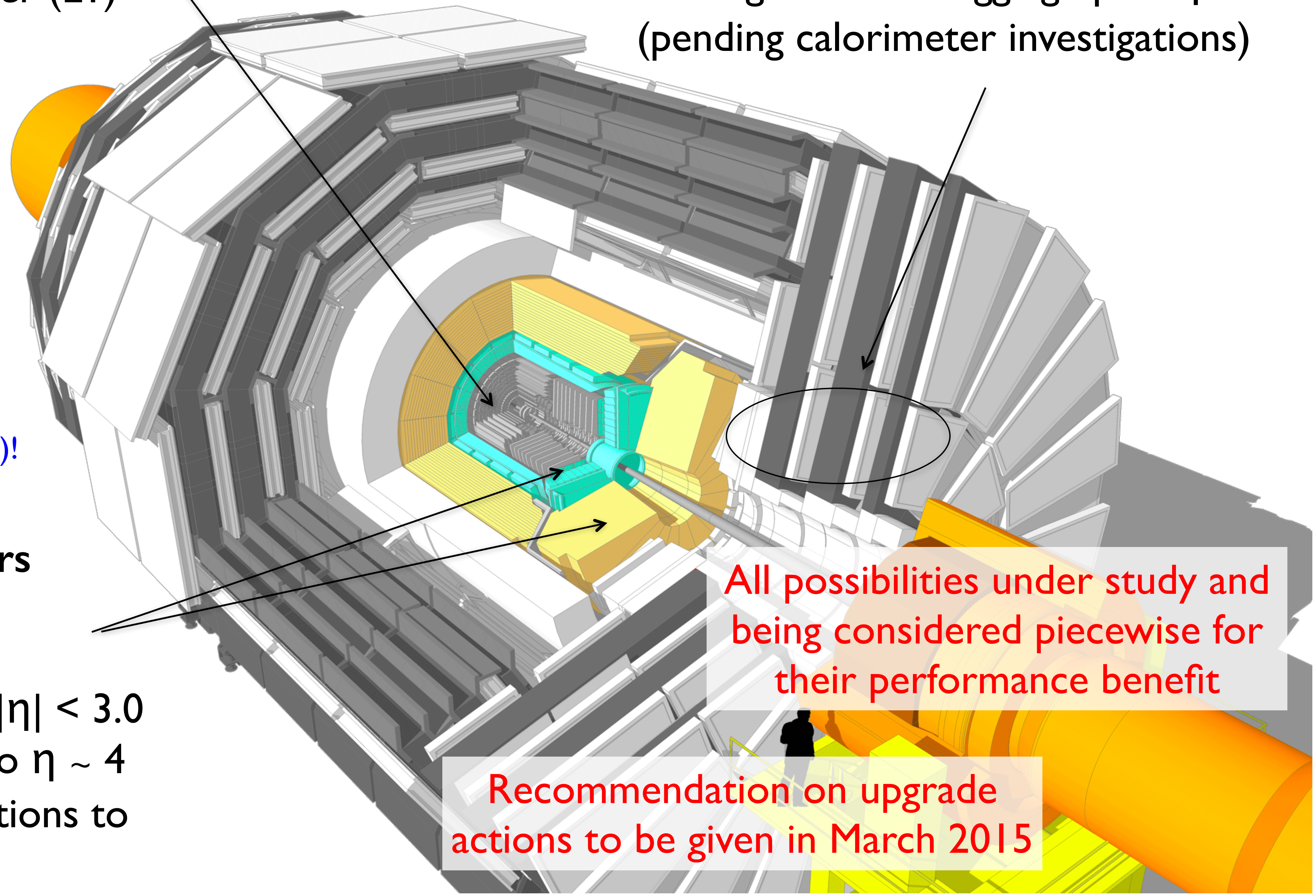


See Tommaso Tabarelli's talk for more information on fast timing!

CMS Phase 2 Possibilities at Large η

Muons
- Complete RPC coverage in forward region (new GEM/RPC technology)
- Nominal coverage to η ~ 2.4
- Investigate Muon-tagging up to η ~ 4 (pending calorimeter investigations)

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



See talks by:
Roger Rusack (Si HGCal),
David Petyt (Shashlik + HE Rebuild)!

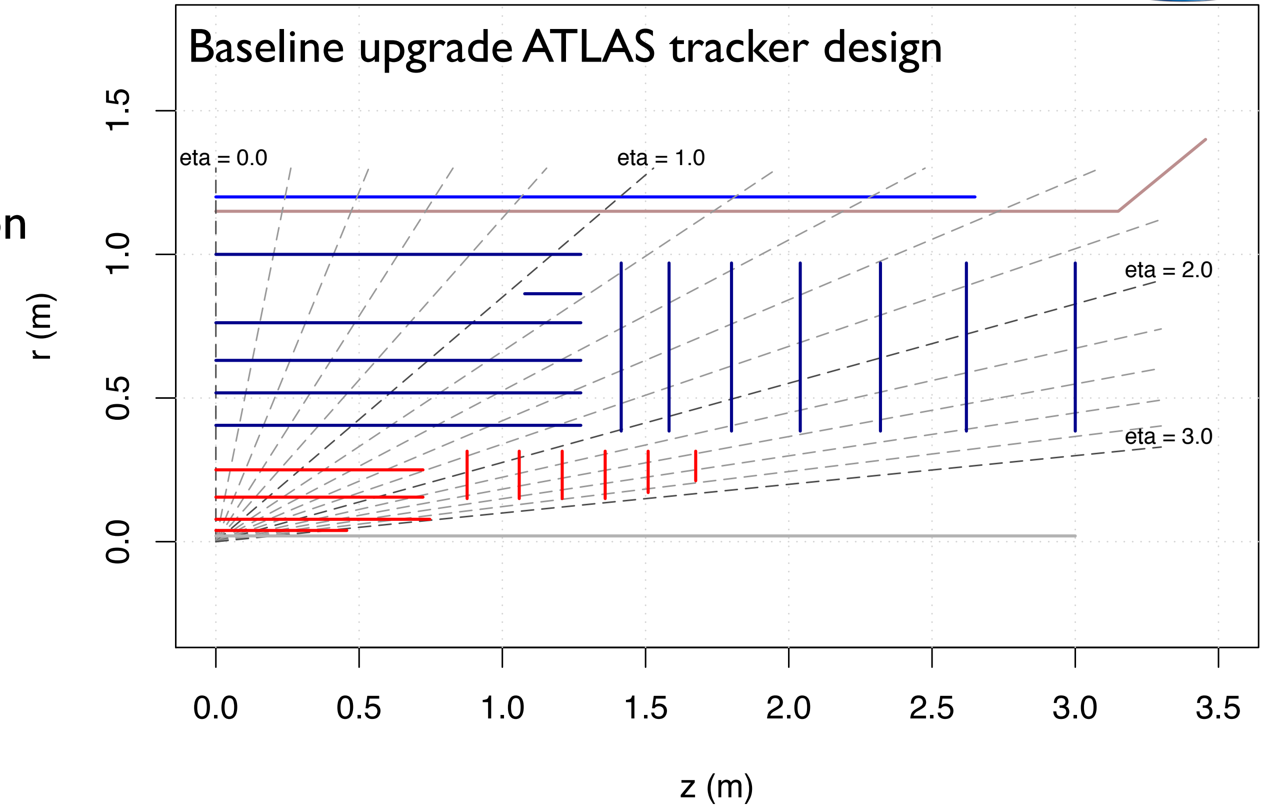
New Endcap Calorimeters
- Radiation tolerant - high granularity
- Nominal coverage 1.5 < |η| < 3.0
- Investigate coverage up to η ~ 4
- Investigate fast timing options to augment Endcap

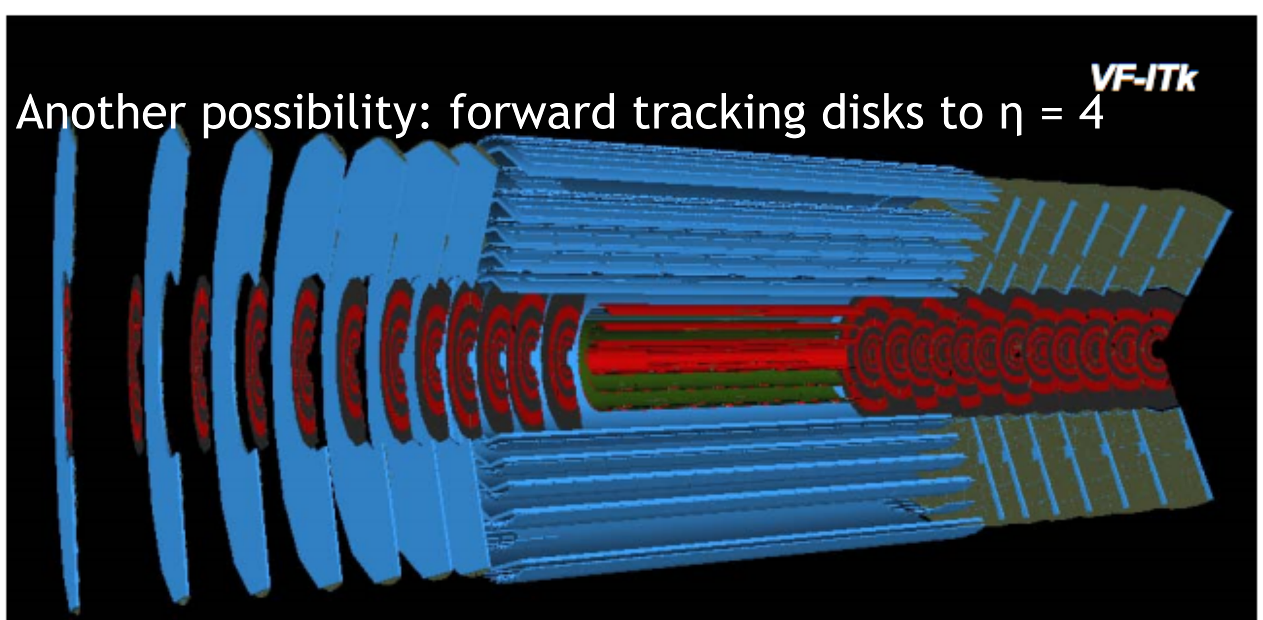
All possibilities under study and being considered piecewise for their performance benefit

Recommendation on upgrade actions to be given in March 2015

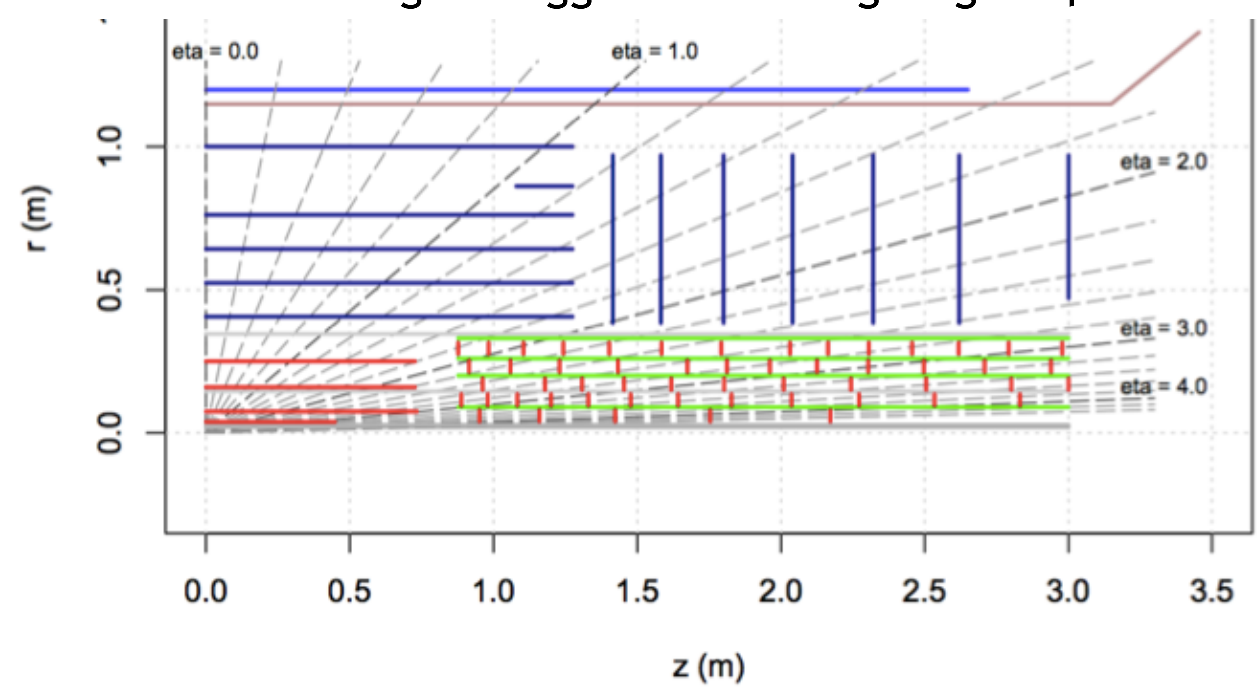
ATLAS Tracking Extension Possibilities

- Improve tracking acceptance to:
  - Reconstruct low p_T tracks and improve Missing E_T resolution
  - Improve pileup jet rejection up to large pseudorapidity
    - Important for VBF tagging and drives Higgs measurements at large rapidity
- Consider each proposal and separate improvement piecewise to evaluate individual physics impact
  - A number of tracking geometries are being investigated
  - Likewise, the spatial granularity of the tracker is being studied



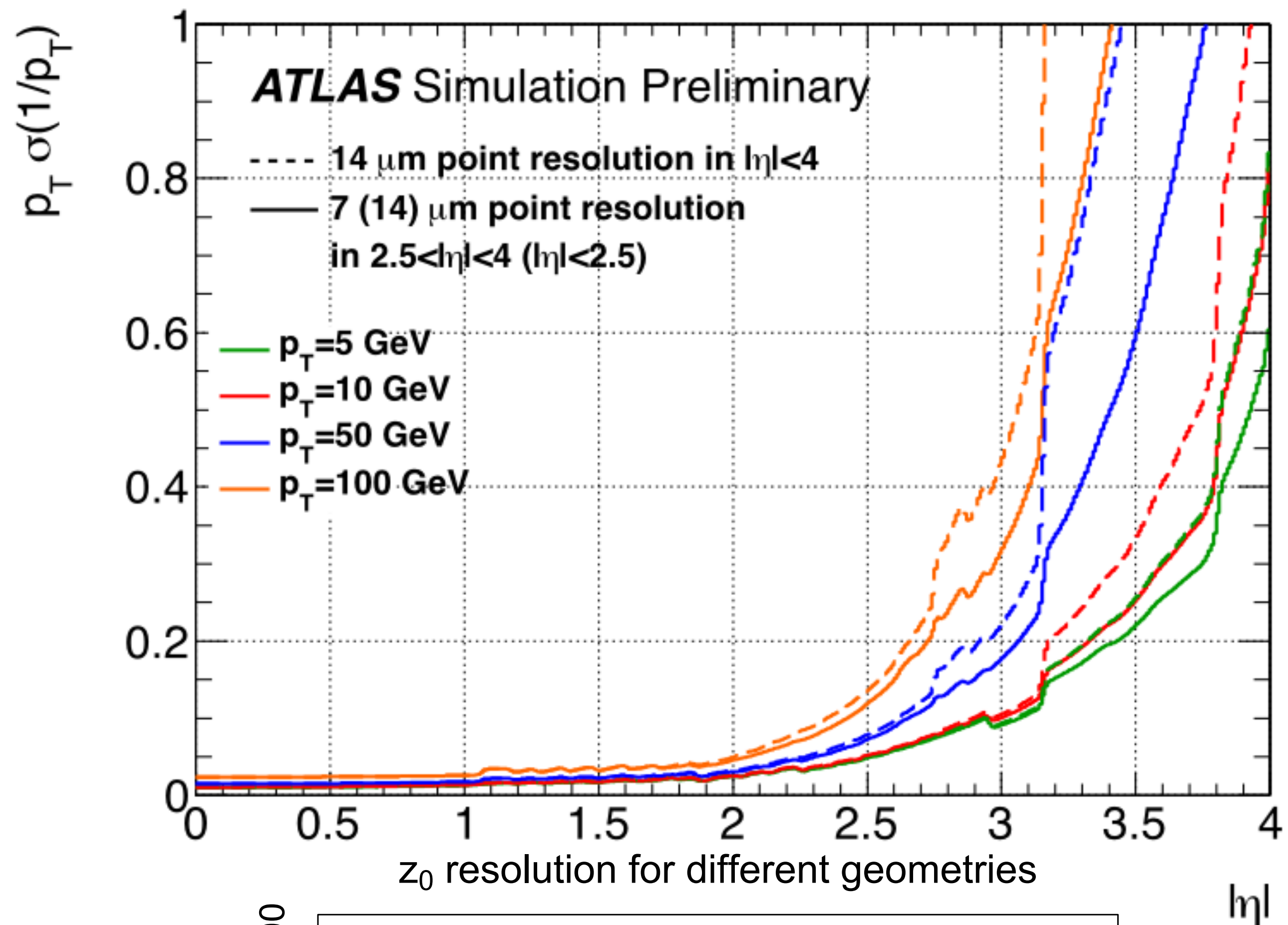


Possible design: staggered tracking ring to η = 4

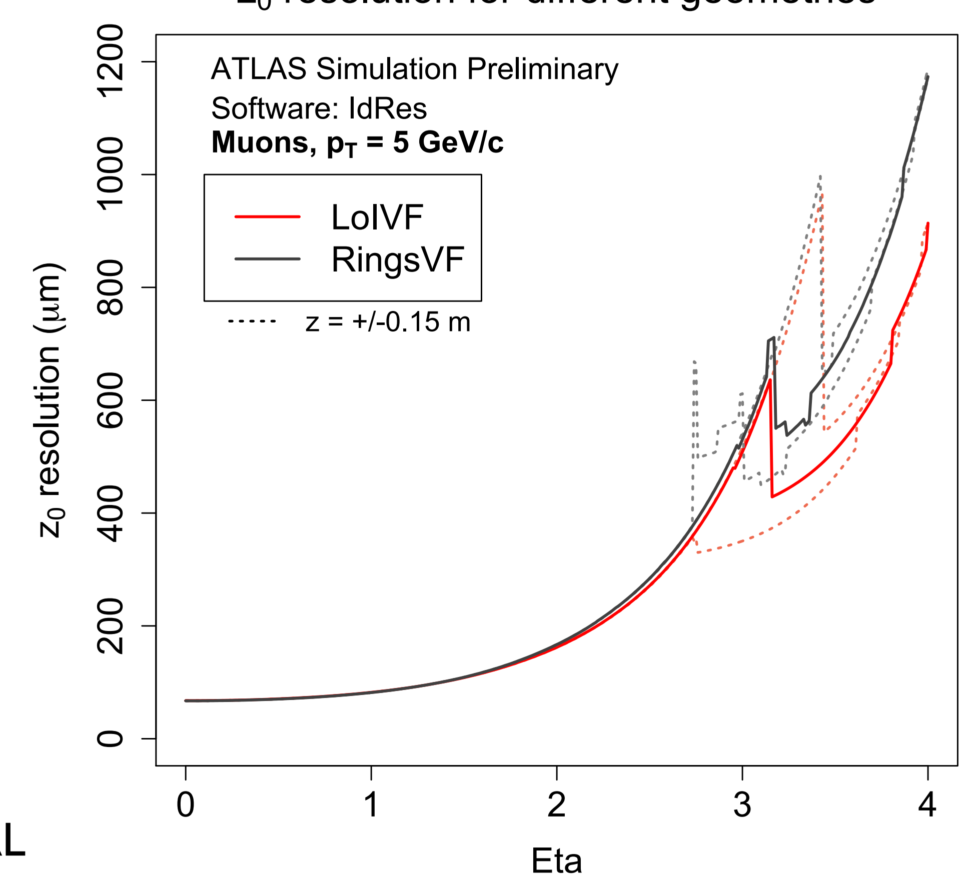


ATLAS Extended Tracking Performance

- Forward tracker in ATLAS operates in ~1T magnetic field
  - Position resolution becomes an important driver for momentum resolution
  - Investigating impact of finer position resolution and detector configuration on
    - p_T resolution
    - initial z position (z_0) of track
- Finer granularity brings improvement to p_T resolution at large η
  - Improvement clear where where point resolution upgrade is considered
- Geometrical configuration impacts z_0 resolution
  - Optimized z_0 resolution important for efficiently discriminating origin vertex of tracks

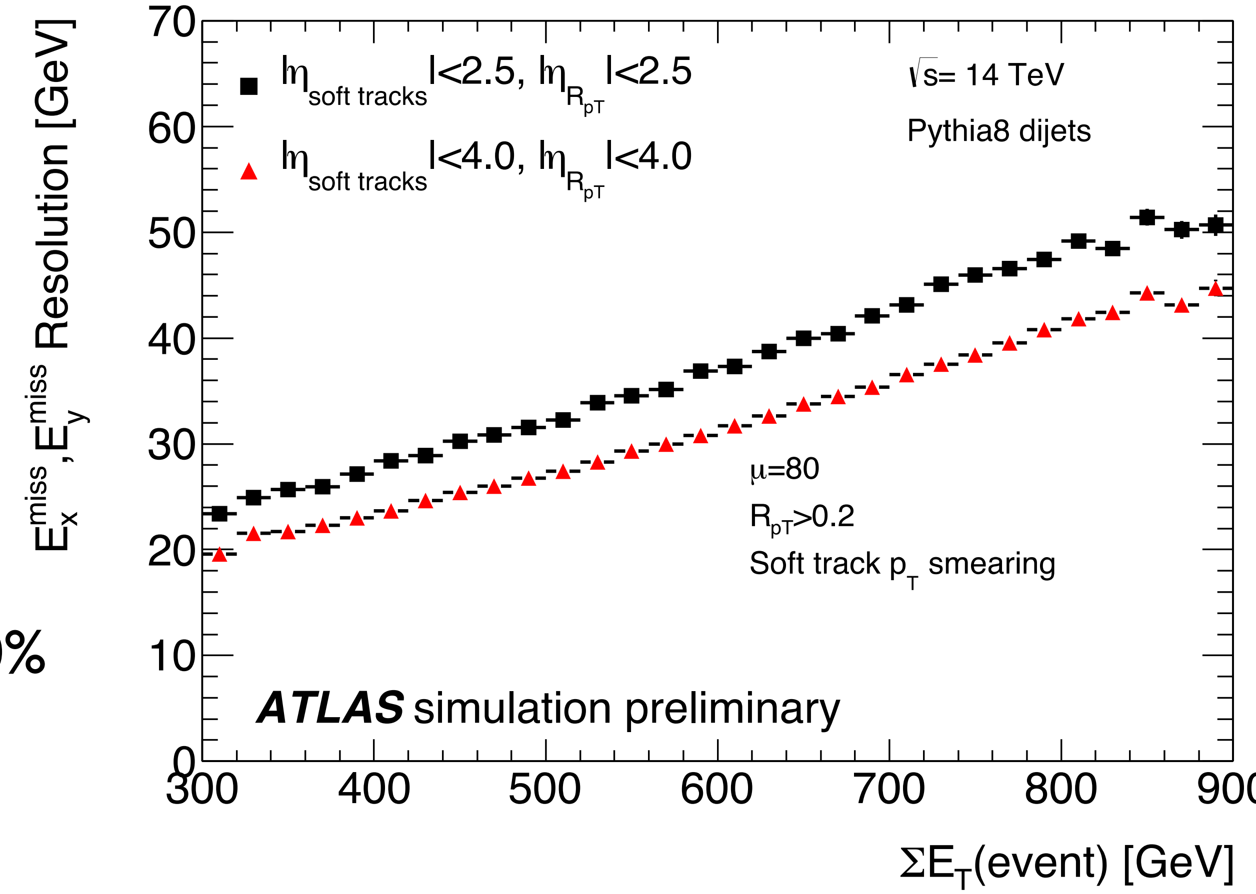


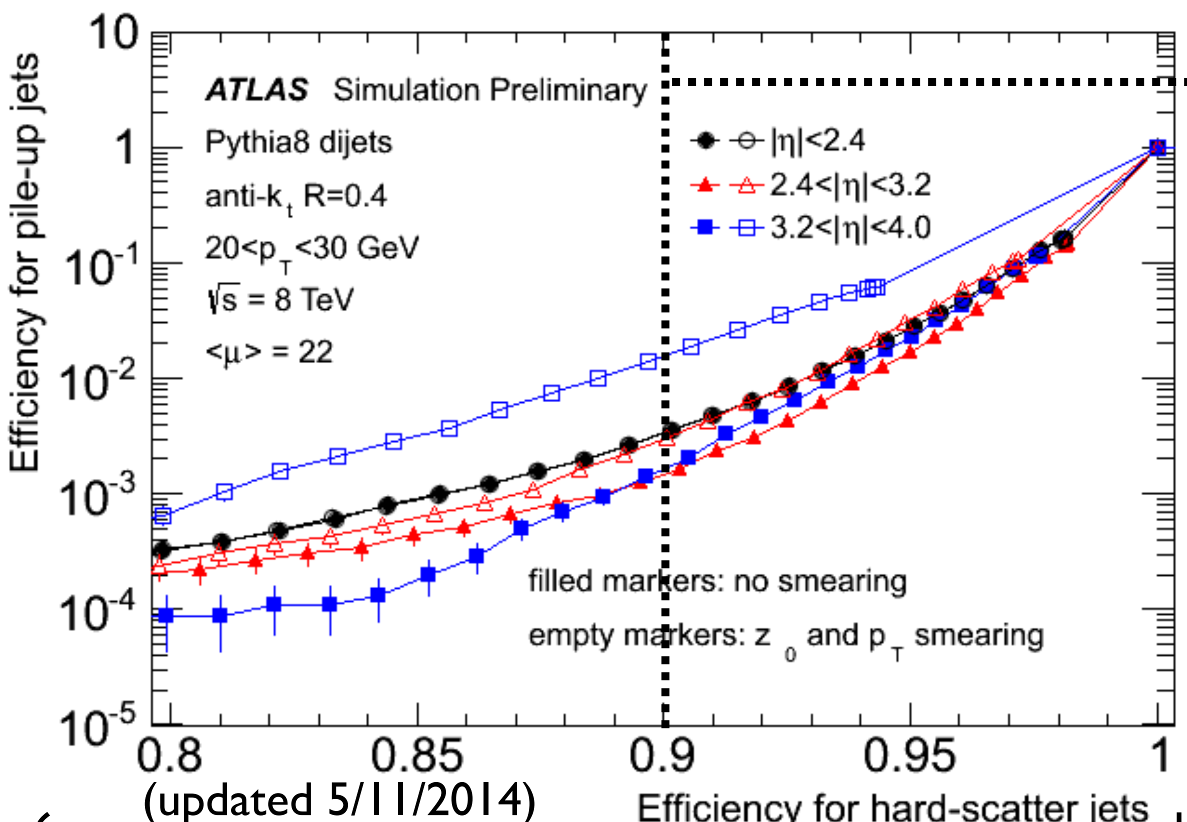
z_0 resolution for different geometries

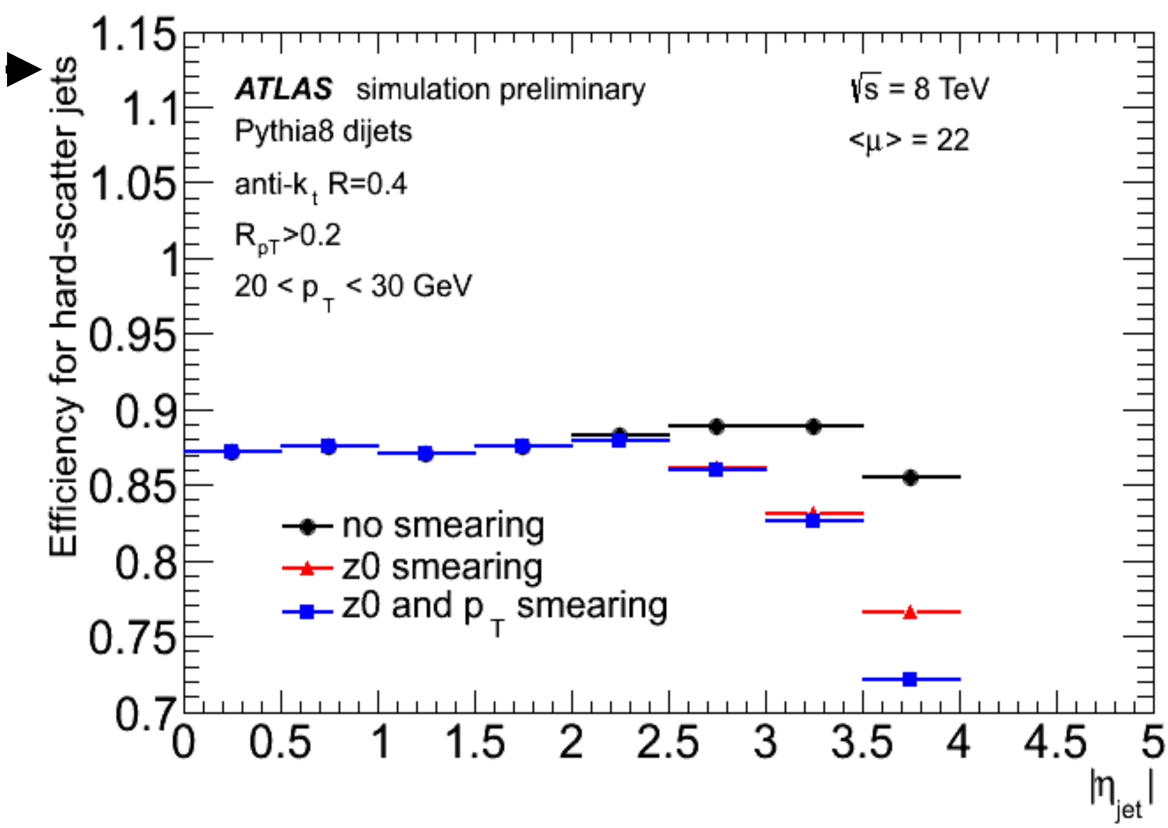


ATLAS Jet/MET Performance

- Study Jet/MET performance with realistic forward ITK
  - Use p_T and z_0 smearing + truth-level tracking information
- 20% MET resolution for average pileup of 80
  - Mainly from pileup jet suppression requiring more than 20% of the charged jet energy from primary vertex
- Pileup jets suppressed by 100x with jet efficiency of 90%
  - Large improvement remains when introducing realistic p_T and z_0 smearing







(updated 5/11/2014)

Higgs Studies & Improved PU Rejection

- ATLAS Jet/MET performance has large impact on VBF $H\tau_l\tau_{had}$ signal strength uncertainty
  - 2.25x improvement in expected signal strength error using 90 % jet selection working point
  - Largely driven by vastly improved pileup tagging

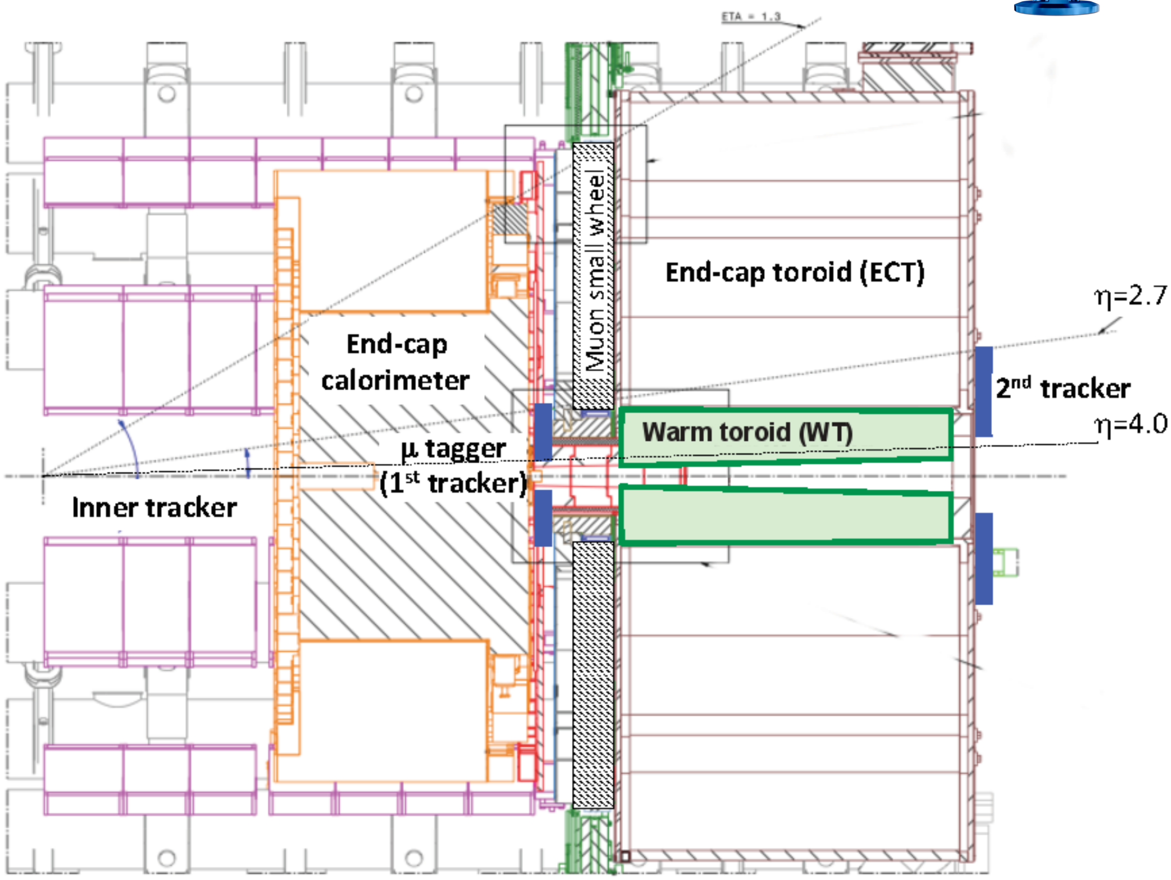
ATL-PHYS-PUB-2014-018

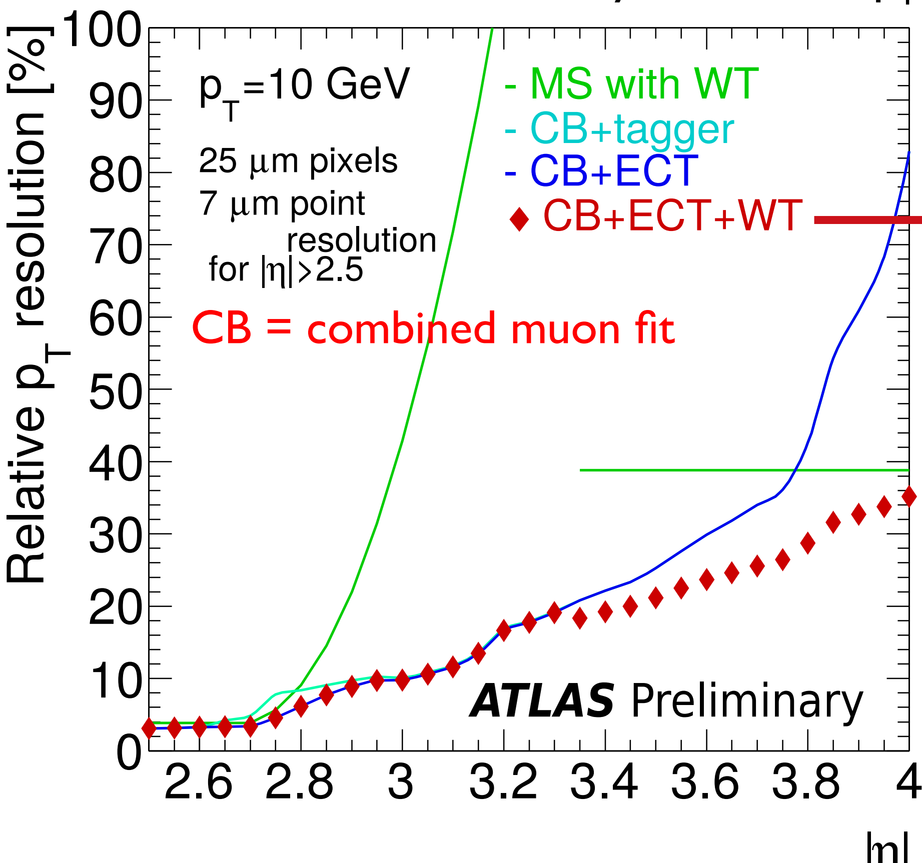
forward pile-up jet rejection	50%	75%	90%
forward tracker coverage		$\Delta\mu$	
Run-I tracking volume		0.24	
$\|\eta\| < 3.0$	0.18	0.15	0.14
$\|\eta\| < 3.5$	0.18	0.13	0.11
$\|\eta\| < 4.0$	0.16	0.12	0.08

Table 5: Uncertainty on the signal strength ($\Delta\mu$) for different scenarios of forward tracking. Negligible loss of HS jets to forward pile-up jet rejection is assumed. A 10% systematic uncertainty is assumed for backgrounds, a 5% experimental systematic uncertainty is assumed for signals, and theoretical uncertainties on signals are ignored.

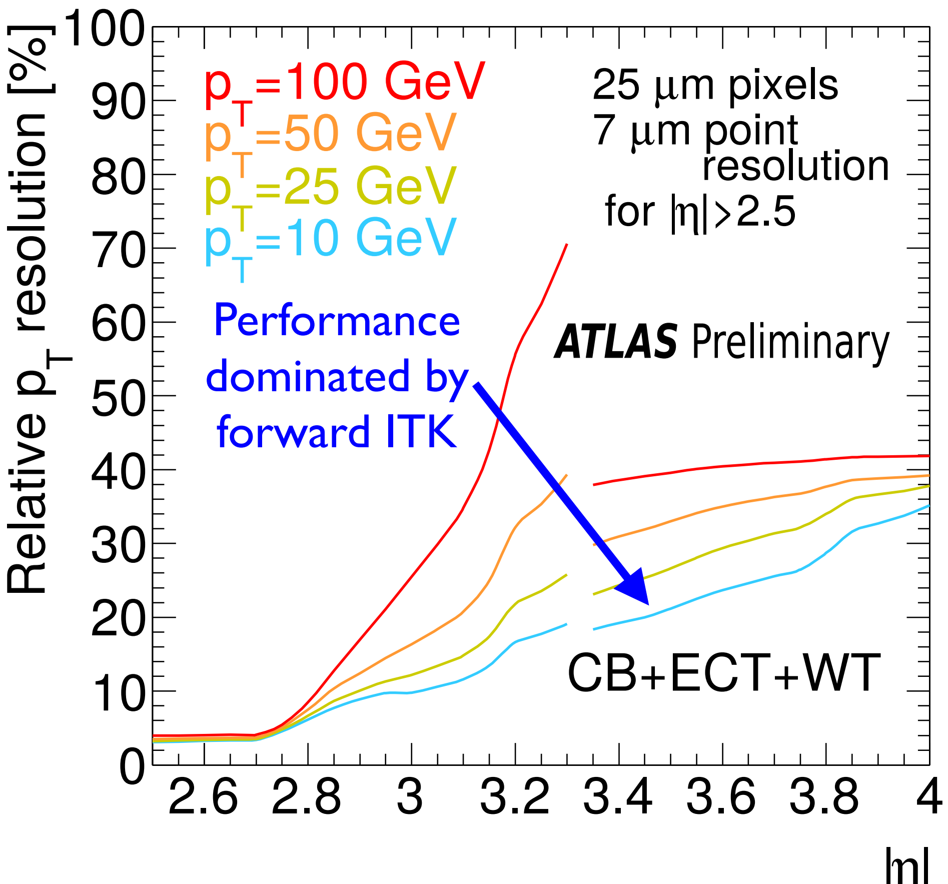
ATLAS Extended Muon Performance

- Muon spectrometer acceptance has a direct impact on channels with large muon multiplicity, especially ZZ to 4μ
- ATLAS Muon Spectrometer options:
  - Pixelated tag chamber before end cap (EC) toroids
  - Pair of chambers before/after EC toroids
  - Additional warm toroid: 8 Tm bending power (1.5 T max field)
- Including all possible upgrade options maintains resolution of better than 35% to η= 4
  - Performance dominated by ITK at low p_T



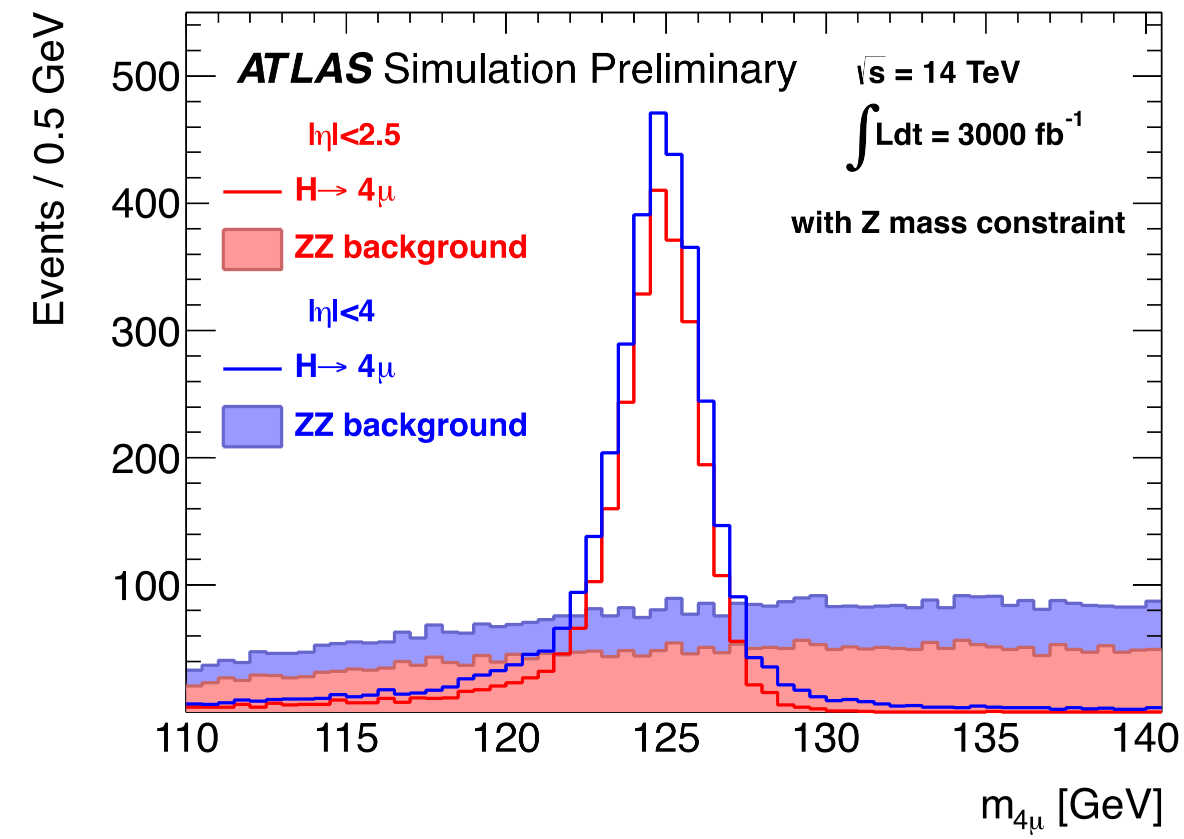


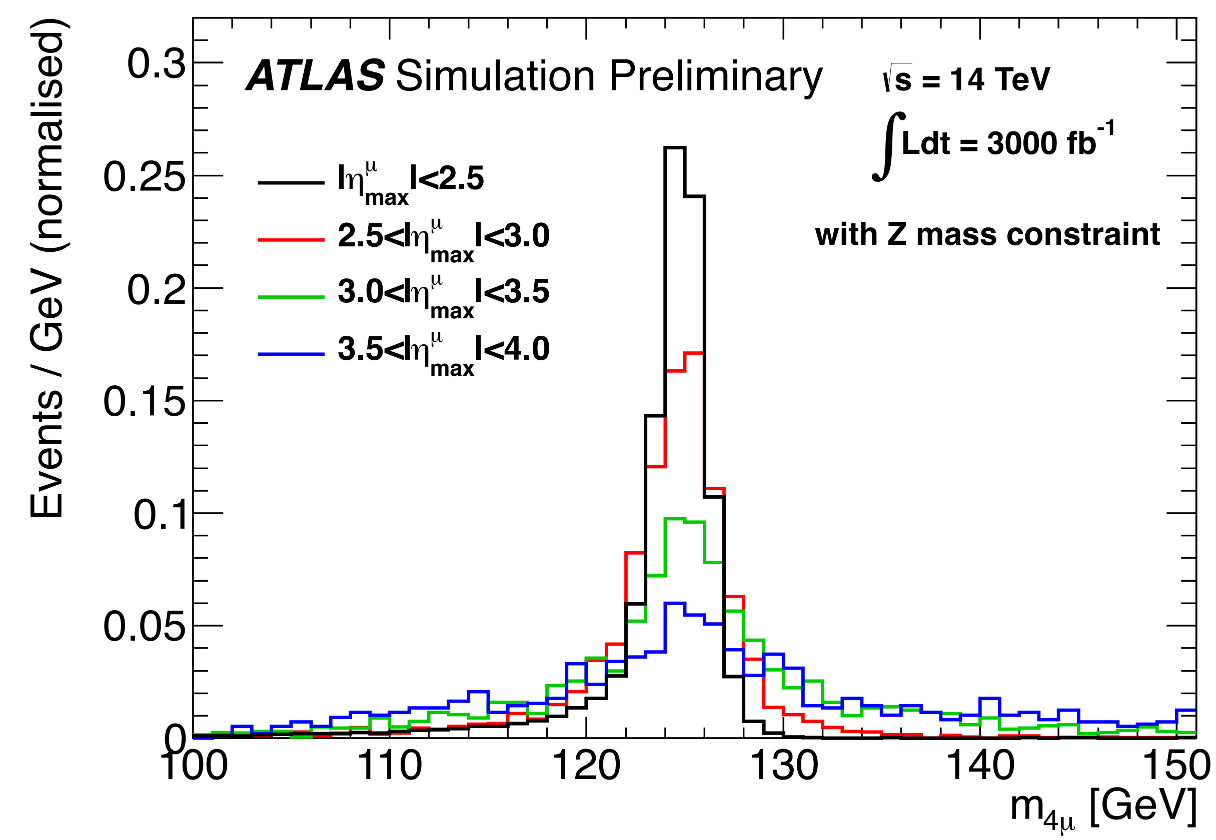
Each option considered combinatorially.



Higgs Studies & ATLAS Extended ITK

- Study impact of various ITK and MS p_T resolution and trigger acceptance scenarios
- Lepton requirements
  - p_T μ > 20,15,10,6 GeV
  - ΔR, m12, m34 as in Run1 analysis
- Using the best setup:
  - 7μm pixel reso., full muon upgrade
  - 35% Acceptance gain from nearly 100% efficient muon reconstruction
  - Mass resolution degrades quickly with η





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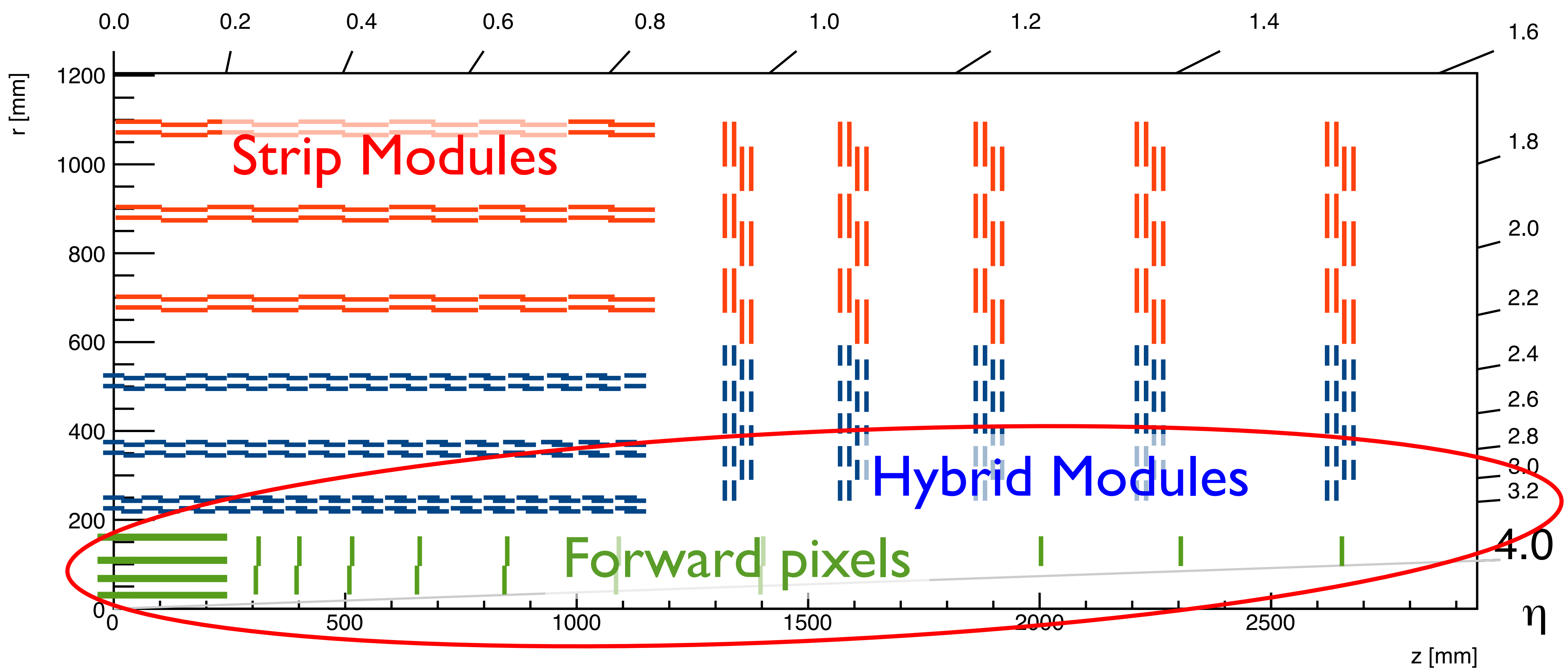
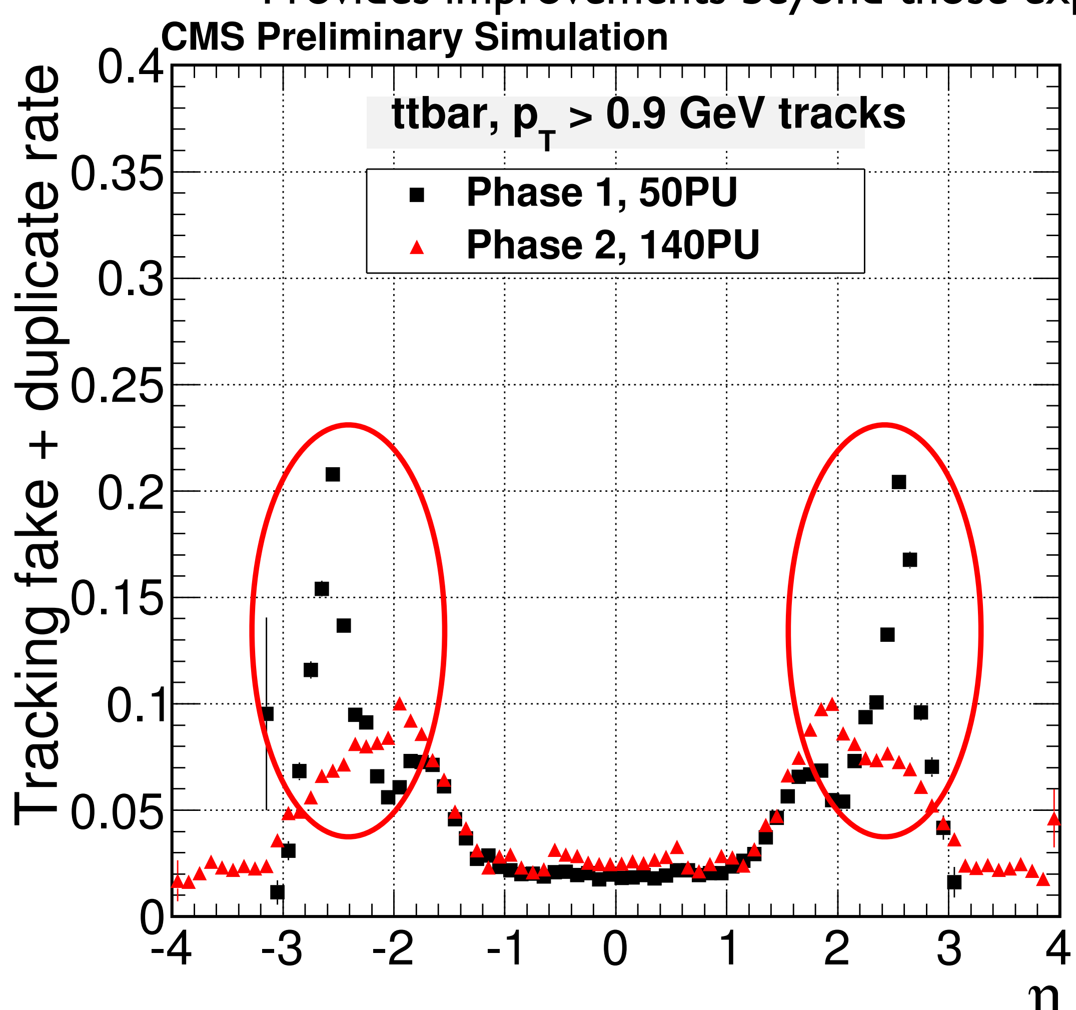
CMS Phase 2 Tracker Replacement

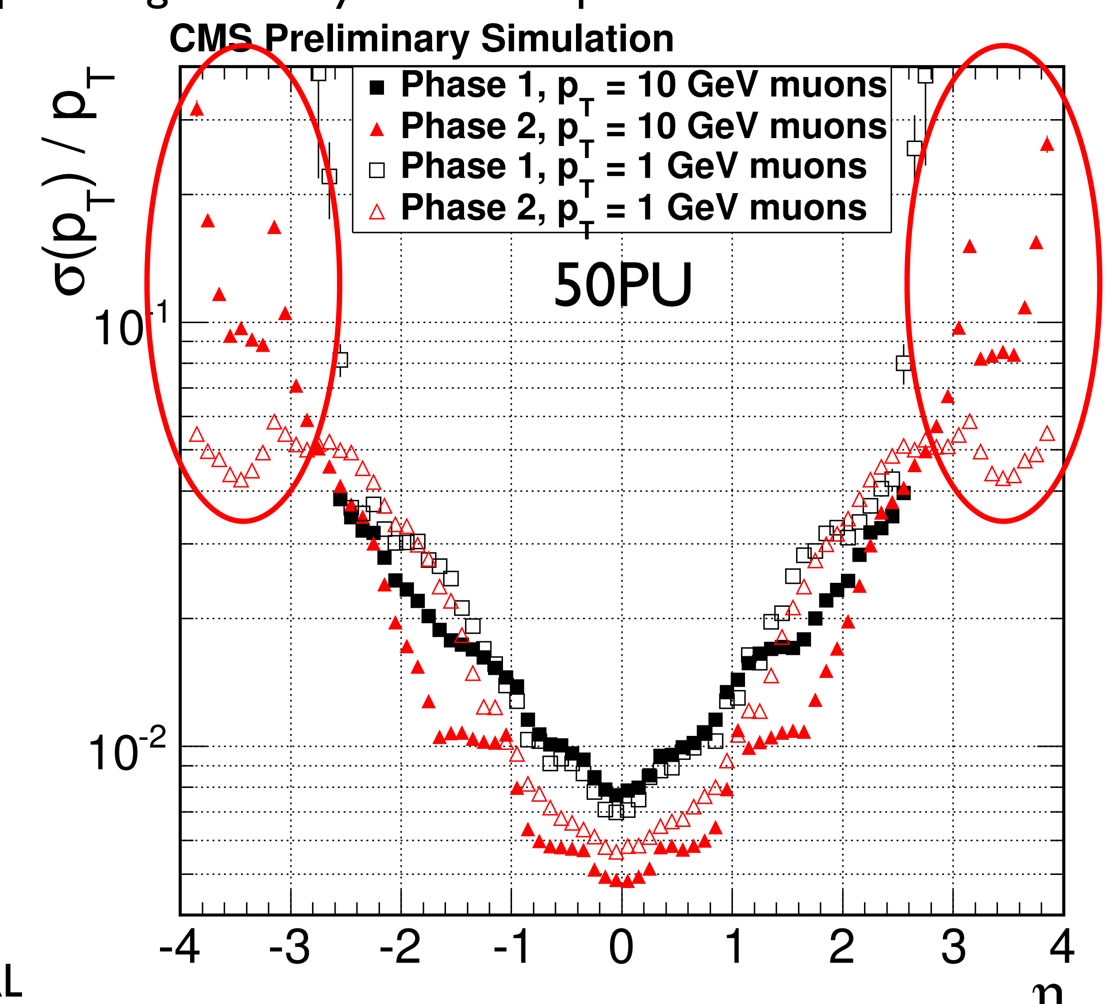


- Tracker design detailed in Jeremy's talk this afternoon
  - Repeated here to emphasize physics goals and specific impact on forward physics
- Aim is largely the same as the ATLAS Tracker Extension
  - Improved material layout yields fewer nuclear interactions and showering EM objects
  - Forward pixels discs, efficient tracking until $|\eta| = 3.8$
  - Improved tracker granularity at large η, hybrid strip/pixel modules and forward pixels provide greatly reduced fake rate

Performance of Extended CMS Tracker

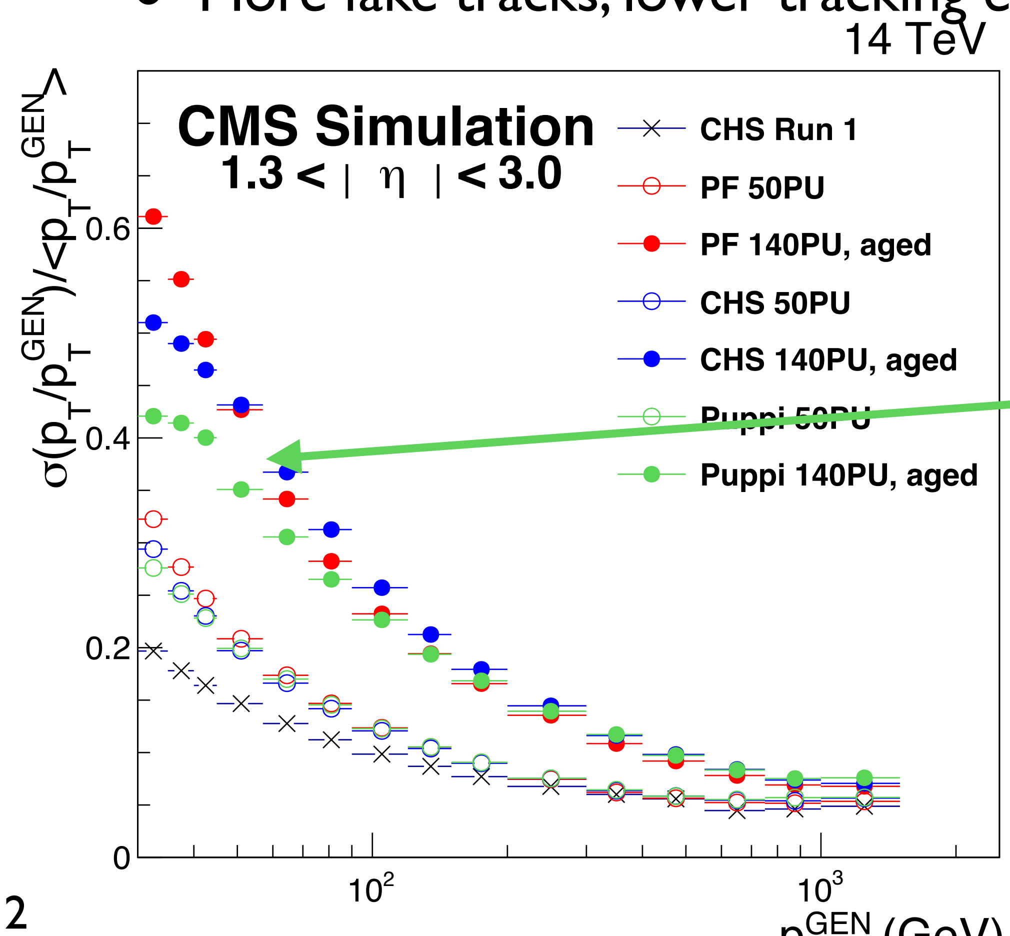
- Phase 2 tracker upgrade (with extension) recovers run one efficiency in barrel region and *significantly improves* endcap fake rate above η = 2.3
  - More layers due to extended coverage
- Fake rate directly determines the efficacy of particle flow, especially at large η where resolution degrades
  - Incorrect association of tracks to clusters yields incorrect energy flow determination
  - Exceptionally important for correctly identifying low p_T charged hadrons, and hence Jet/MET resolution
- Good tracking resolution to very large η will allow for effective leveraging energy balance between tracker and new endcap calorimeter choice
  - Provides improvements beyond those expected from the improved granularity of chosen phase 2 calorimeter





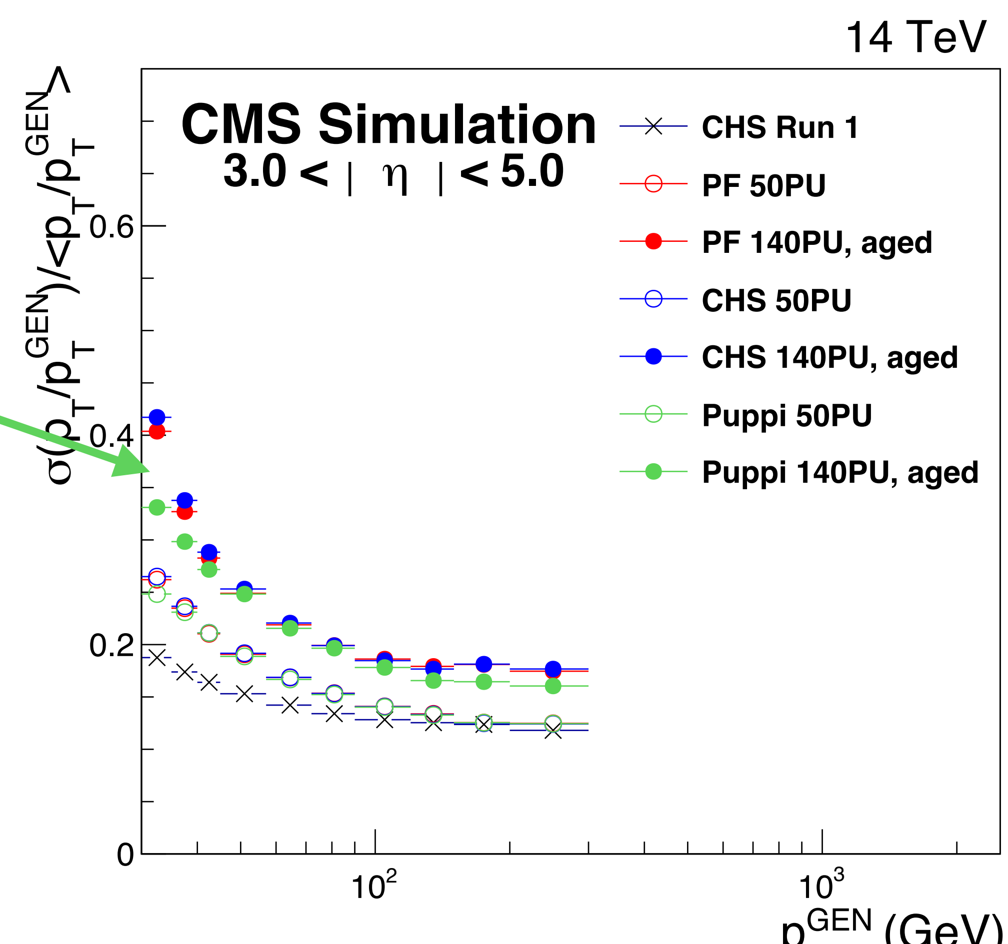
Making A Case: CMS Phase 1 Jet Performance

- Jet resolution significantly degraded by pileup and using Phase 1 detector
  - Missing layers in tracker significantly effect Particle Flow reconstruction performance
- Very large effect on Charged Hadron Subtracted (CHS) Jets
  - Due to age, acceptance, and fake rate
  - More fake tracks, lower tracking efficiency
- Expect Phase 2 tracker and calorimeter upgrades to recover or improve jet resolution specifically in this region
- CHS or PUPPI?
  - Improvement at low p_T in both cases
  - PUPPI gives the largest improvements, covered previously in Pippa's talk



PUPPI brings significantly improved performance at low p_T even to very large values of pseudorapidity

Note, there is presently **no** tracker forward of η = 2.5! Only an aged calorimeter



Conclusions

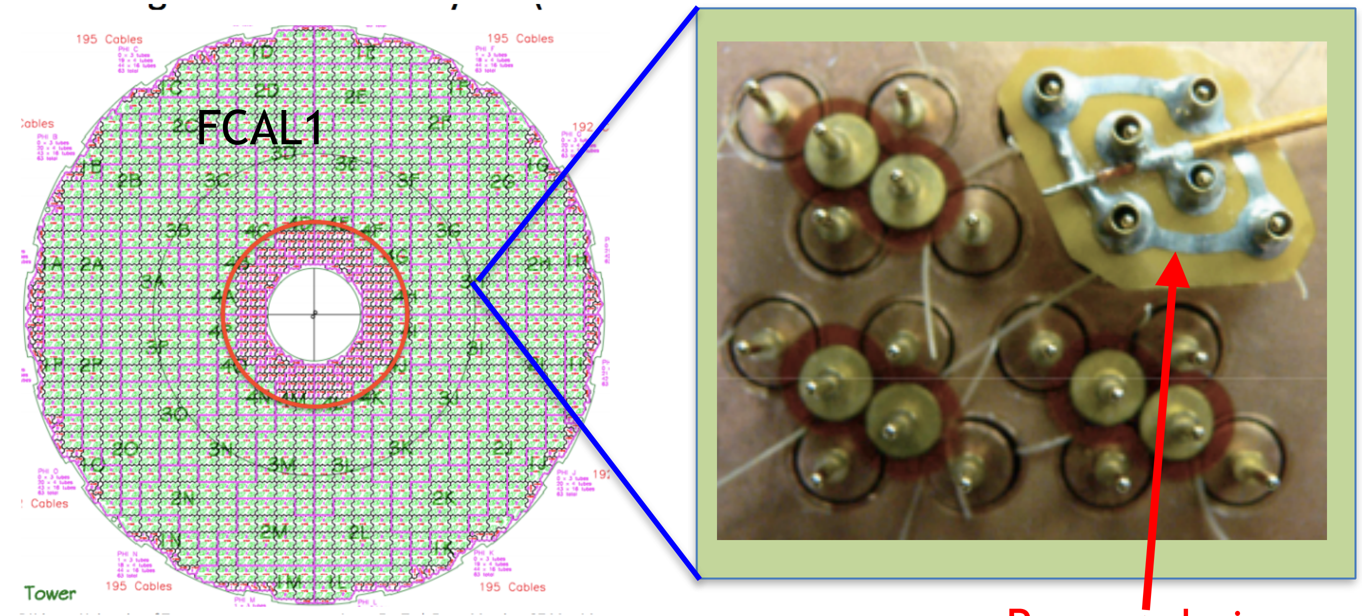
- An active program of forward detector research is in progress at both ATLAS and CMS
  - Results analyzing both the depth of need and impact on physics performance of upgrades are arriving
    - Each subdetector upgrade is being considered individually to arrive at optimized sets of upgrades for each detector
- Forward tracking upgrades in both detectors play a prominent role in driving the physics motivation for these upgrades, as shown in Higgs physics
  - ATLAS demonstrates significantly improved Jet/MET performance using forward tracking to mitigate the effects of large pileup
    - Significant gain in sensitivity to VBF production of Higgs
  - CMS upgraded tracker η coverage and granularity similar to ATLAS
    - Excited to see full physics impact of the upgraded tracker combined with the higher granularity endcap calorimeter upgrade options
- ATLAS extended tracker + muon system increases ZZ to 4μ acceptance by up to 35%
- Stay tuned, exciting times are ahead of us!
  - Both ATLAS and CMS plan to finalize studies by March 2015

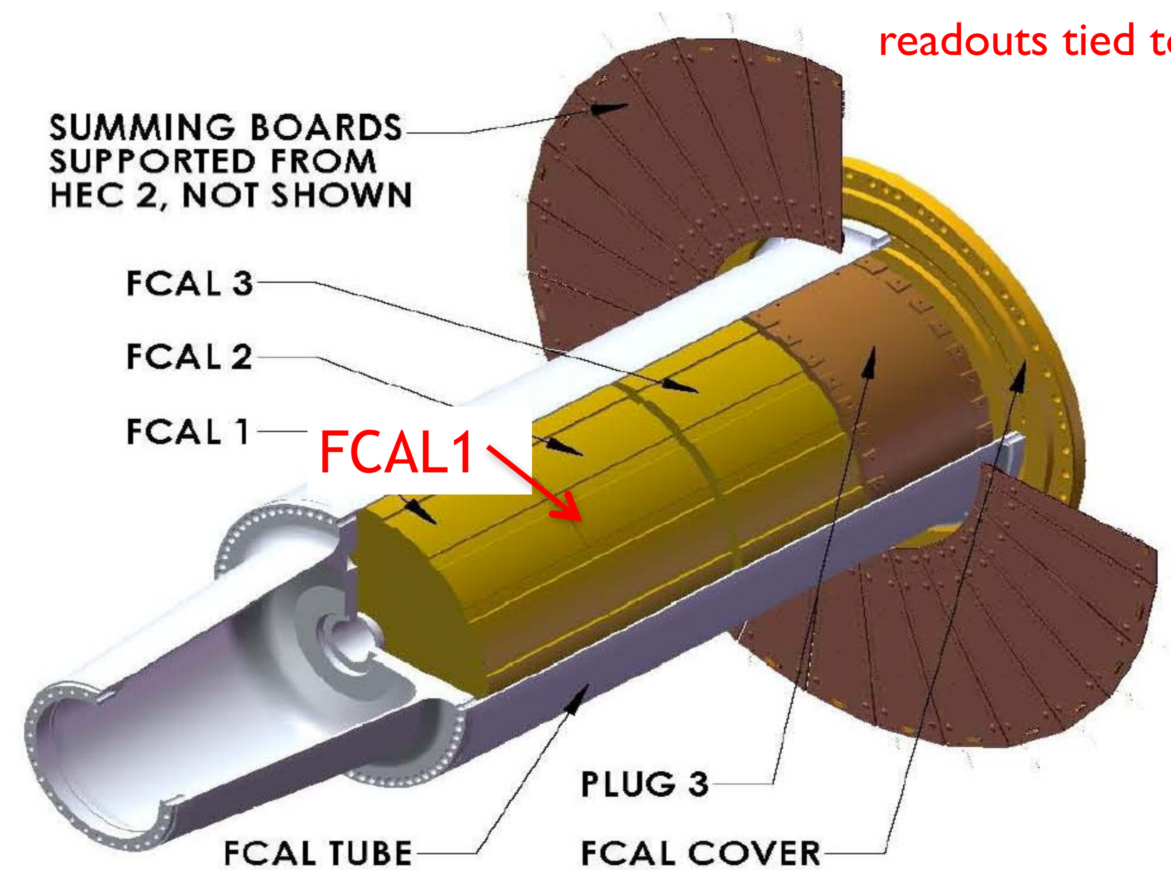
Backup

ATLAS sFCAL Upgrade

- Must understand the physics impact of all proposed detector upgrades
  - Understand how FCAL must be adapted to cope with HL-LHC conditions
  - Which adaptations have highest impact?
- Evaluate the impact of a finer granularity innermost depth
- Increase the calorimeter granularity
  - 16x more channels for 85% of FCAL1
- Reduce size of gap for LAr
  - Reduces space-charge effects, fewer ions
  - Improves timing, shorter pulse due to smaller gap
- Design decisions to be made in early March

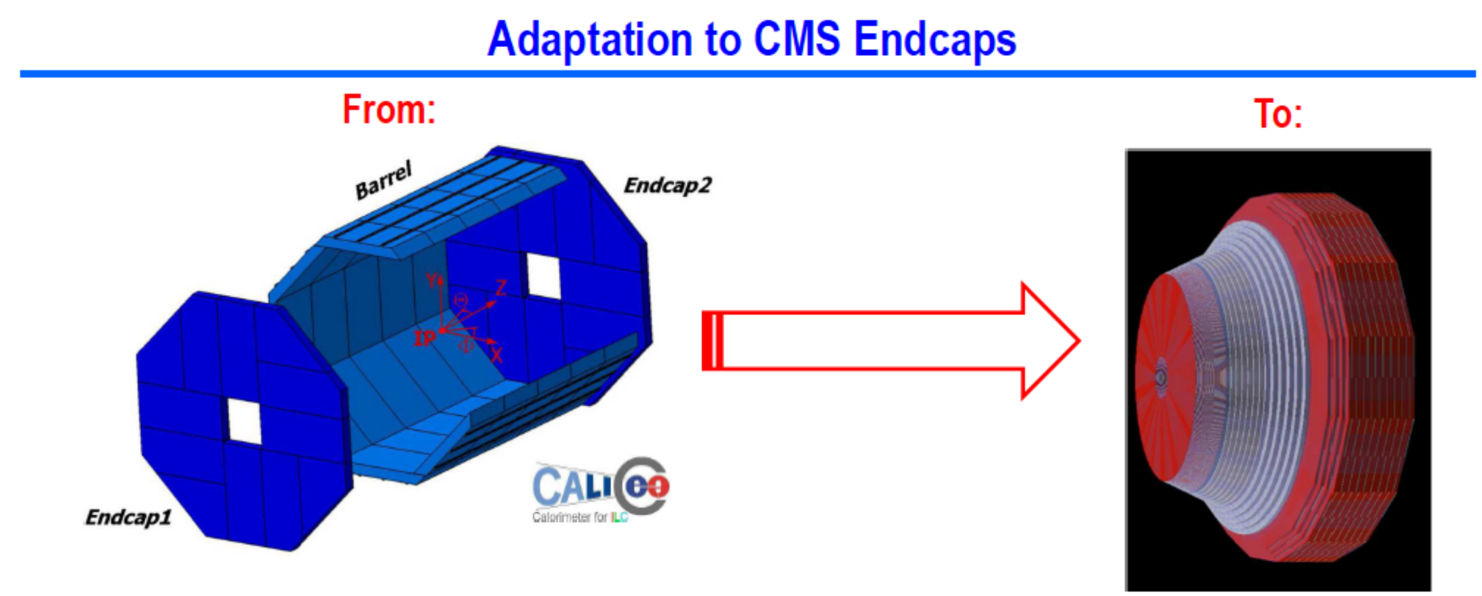
Present detector, upgraded inner depth





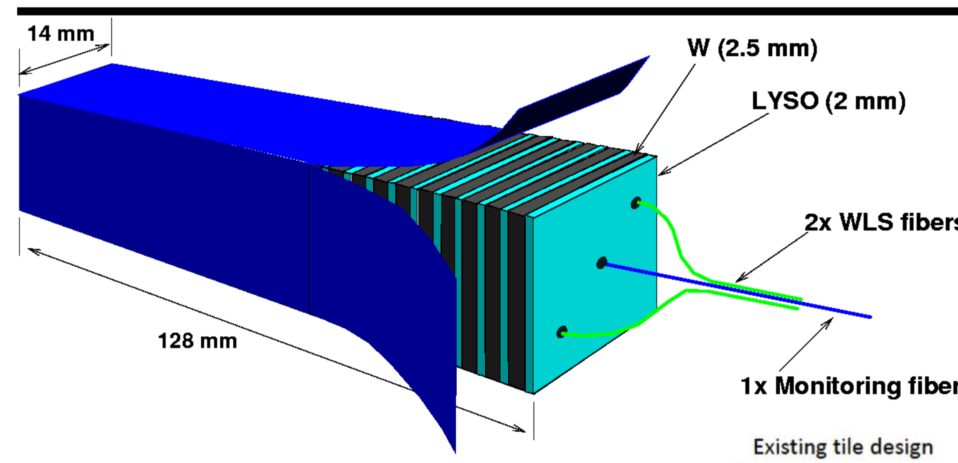
CMS End Cap Upgrade Options

- Present CMS end cap ECAL and HCAL will severely degrade by the end of phase one
  - Plan to replace with:
    - High granularity imaging calorimeter … or …
    - Radiation tolerant Shashlik ECAL + full rebuild of present HE
- Decision to be made in February
  - Carefully analyzing physics impact of detectors
  - Determine what physics performance is enabled by calorimeter design choice



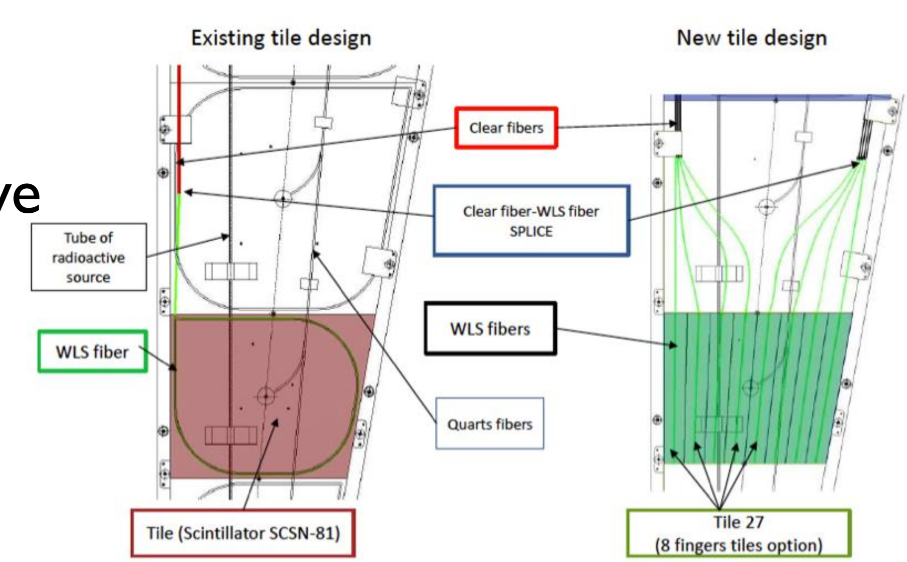
Inspired by Calice W/Si imaging calorimeter

1cm² cell size
9M channels



Replace ECAL with radiation tolerant Shashlik device

Simultaneously improve φ/z granularity and light output through rebuild of HCAL



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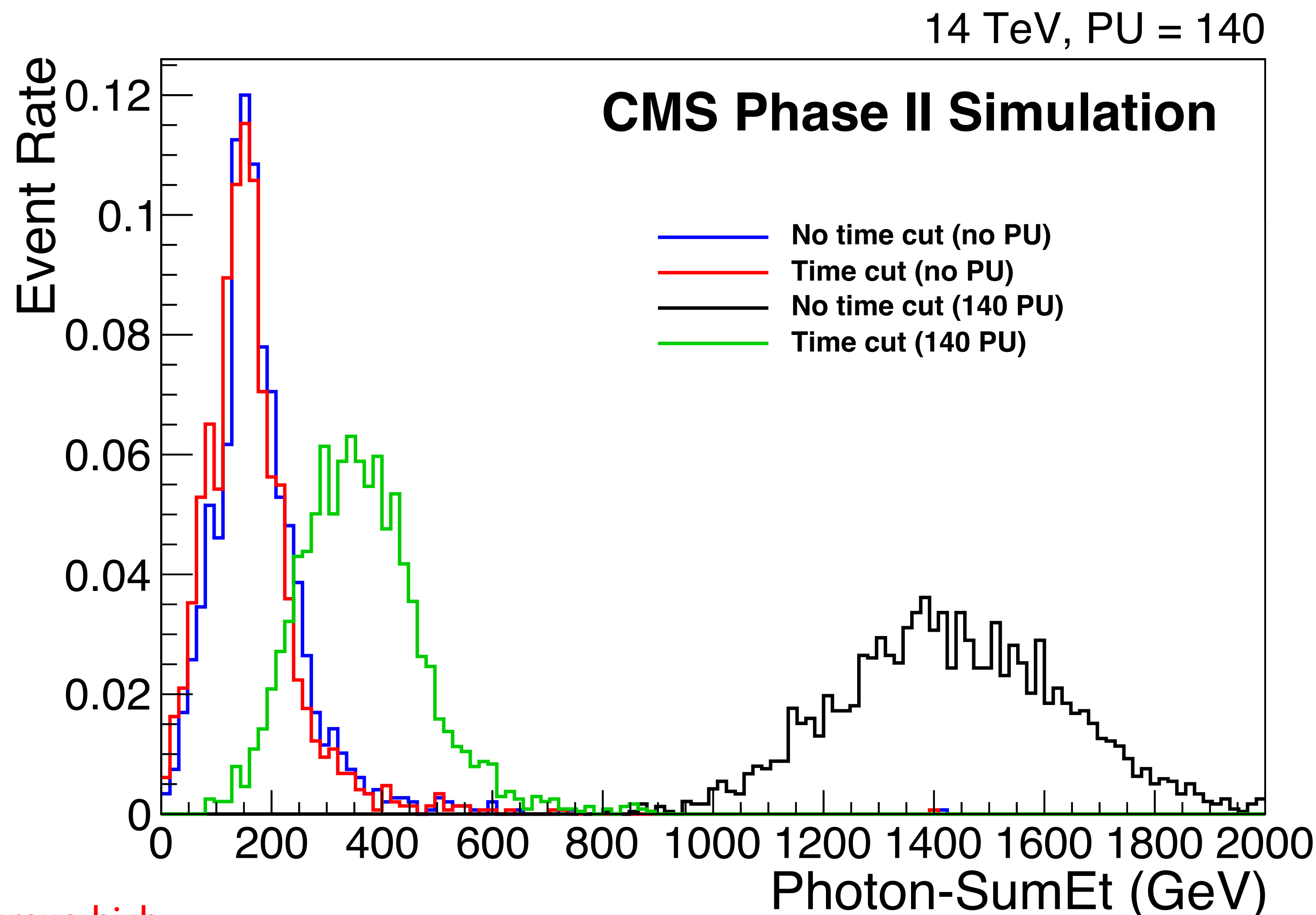
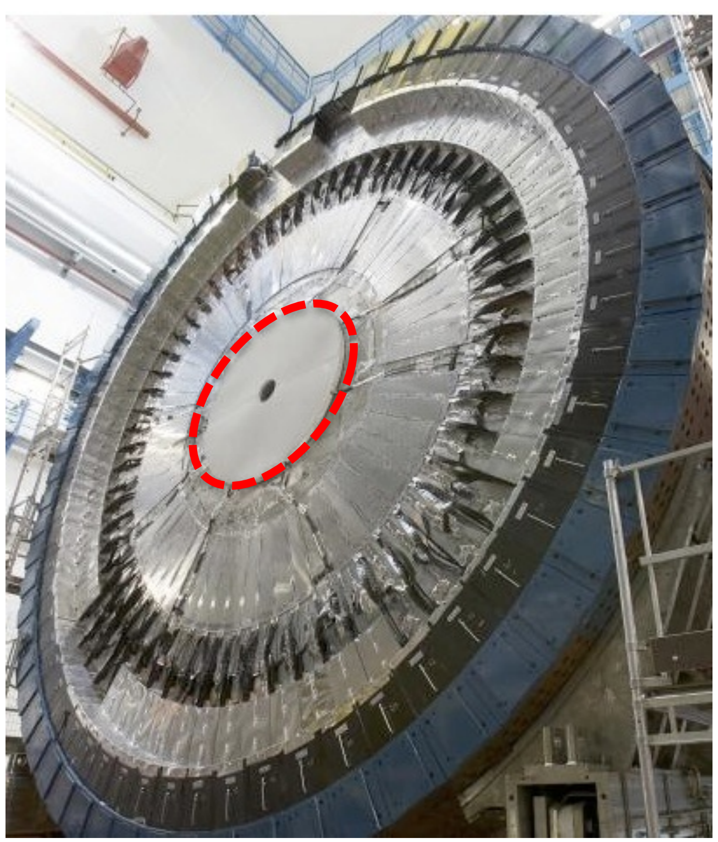
Fast Timing Options on CMS and ATLAS

- Multiple fast timing options are under study by both CMS and ATLAS
  - CMS pursuing either calorimeter embedded or preshower-like option
  - ATLAS pursuing high-precision tracking or pre shower options





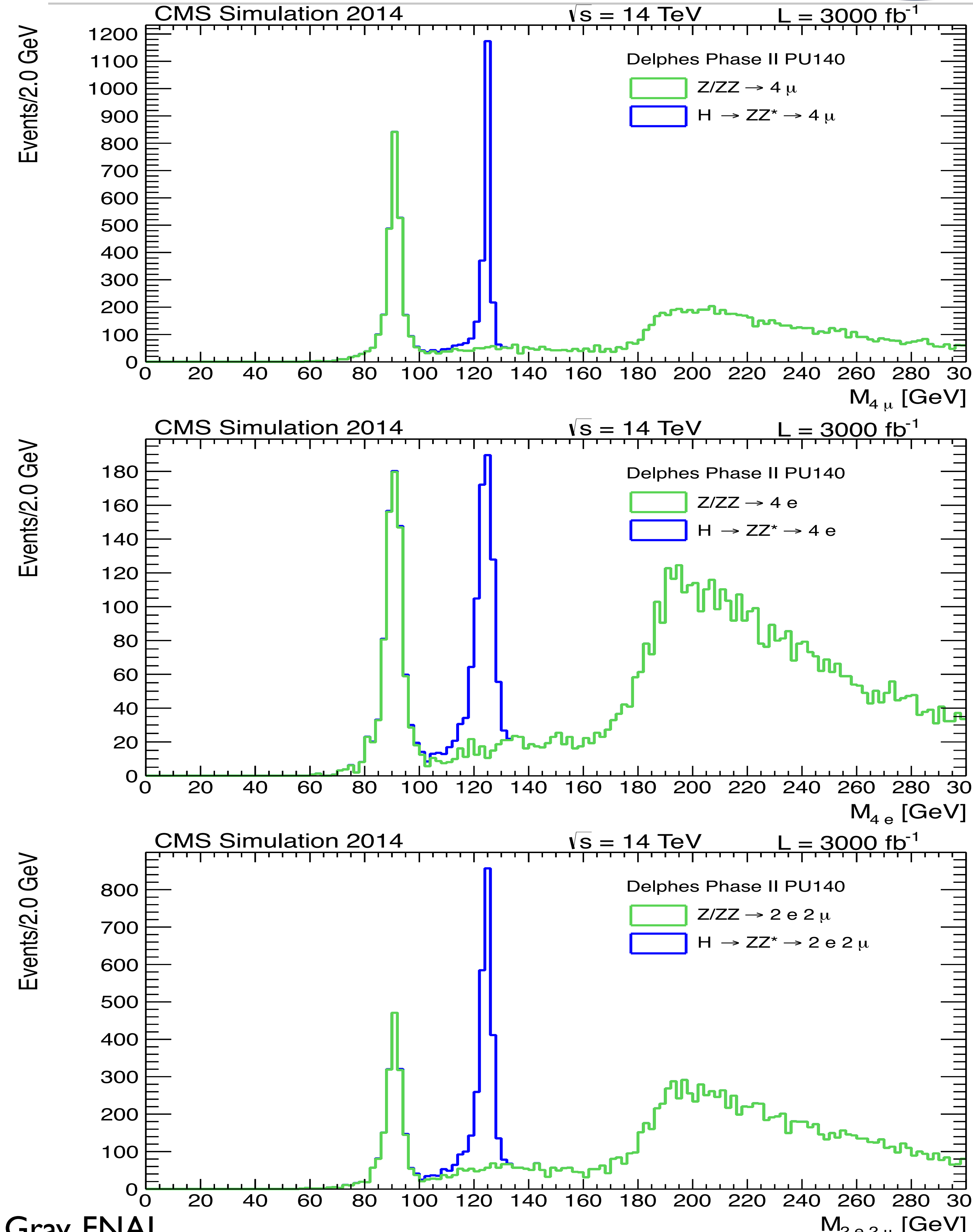
ATLAS may also pursue high granularity pre sampler instead of fast timing.

Recommendation by March 2015

- Physics impact and detector design considerations being studied for all options
- Considerable resolving power demonstrated for electromagnetic showers in CMS
  - Direct impact on Jet/MET resolution

CMS Higgs Studies Using Phase 2 Tracker

- Study to η = 3.0 using DELPHES simulation of CMS detector
  - Emulates extended acceptance using parameterization
- Study muon and electron channels
  - Analysis similar to Run I analysis accounting for lepton acceptance
  - Demonstrates power of raw acceptance gain
    - Similar to η = 4.0 studies shown at last ECFA workshop
  - Z+X background not considered
  - First exploration of electrons past η = 2.5



ATLAS Links

- ITK Performance:
  - http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/UPGRADE/PLOT-UPGRADE-2014-001/index.html
- Jet/MET Performance:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LargeEtaECFA2014
- Higgs Studies:
  - http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/UPGRADE/PLOT-UPGRADE-2014-002/
- General:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/UpgradePhysicsStudies#Studies_for_the_ECFA_HL_LHC_work

CMS Links

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