XI ATLAS Italia Workshop

Cosenza 4-6 Novembre 2015

Physics Studies for Upgrade Plans

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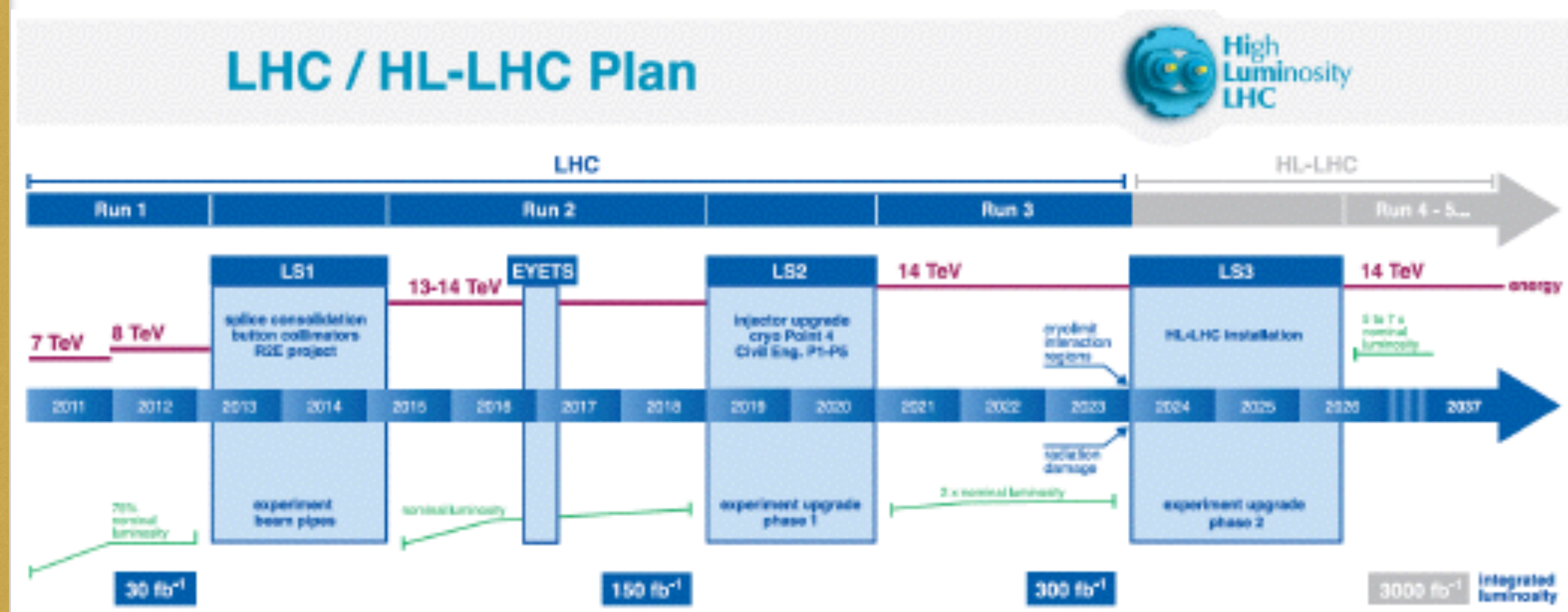
UpGrade: Phase II Scenarios

The target integrated luminosity for the HL-LHC program, during an operating period of roughly 10 years is intended to provide about 3000 fb^{-1}. In order to achieve this extraordinary goal, an ultimate performance of the accelerator complex, based on achieving an instantaneous levelled luminosity of **$L = 7.5\ 10^{34} cm^{2} s^{-1}$** and delivering more than **300 fb^{-1} per year**, is required.



- During the LS2 and LS3 will take place the detector upgrades.
  - **Three possible scenarios are considered**, corresponding to three different instantaneous luminosities and different detector layouts.
- Need to understand the challenging operation, mitigating the pileup effects. **The Detector Performance and Physics results** have been investigated for different upgrade's scenarios.

Motivations

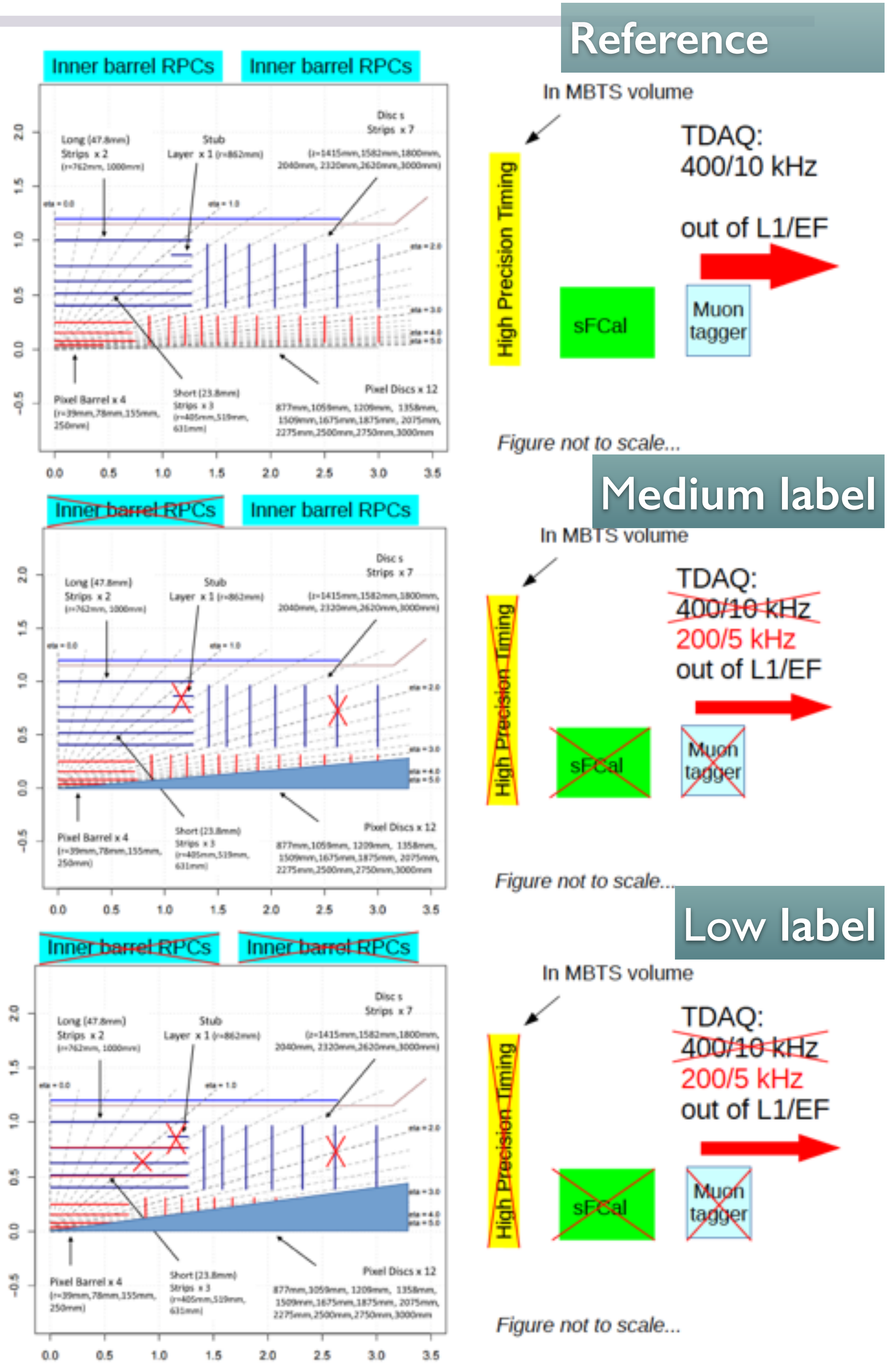
Several physics studies have been carried out to assess the impact of the object performance in the scoping scenarios. The aim is to pick some representative channels which illustrate the impact of the scenario-dependent performance of specific objects on a particular physics result.

- On 2012 the "**Letter of Intent for the Phase-II Upgrade of the ATLAS Experiment**" was published with preliminary results on same analyses.
  - In particular, precision measurements of the Higgs production and decays modes along with its properties.
- on 2015 latest results published in the **"Upgrade Scoping Document":** *https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/UPGRADE/CERN-LHCC-2015-020/index.html*
  - Six reference analysis have been investigated.
    - VBF production -> sensitive forward jet identification
    - VBS and ggH -> sensitive to lepton identification
    - BSM models -> sensitive to missing transverse energy, b-tagging and lepton identification

Technically: Trigger and identification efficiencies, and the resolution for reconstructed object properties are then parametrised as simple functions which can be applied to the truth level particles in generated events of interest. In addition, jets from pile-up events are overlaid on the hard-scatter events.

Three Possible Scenarios

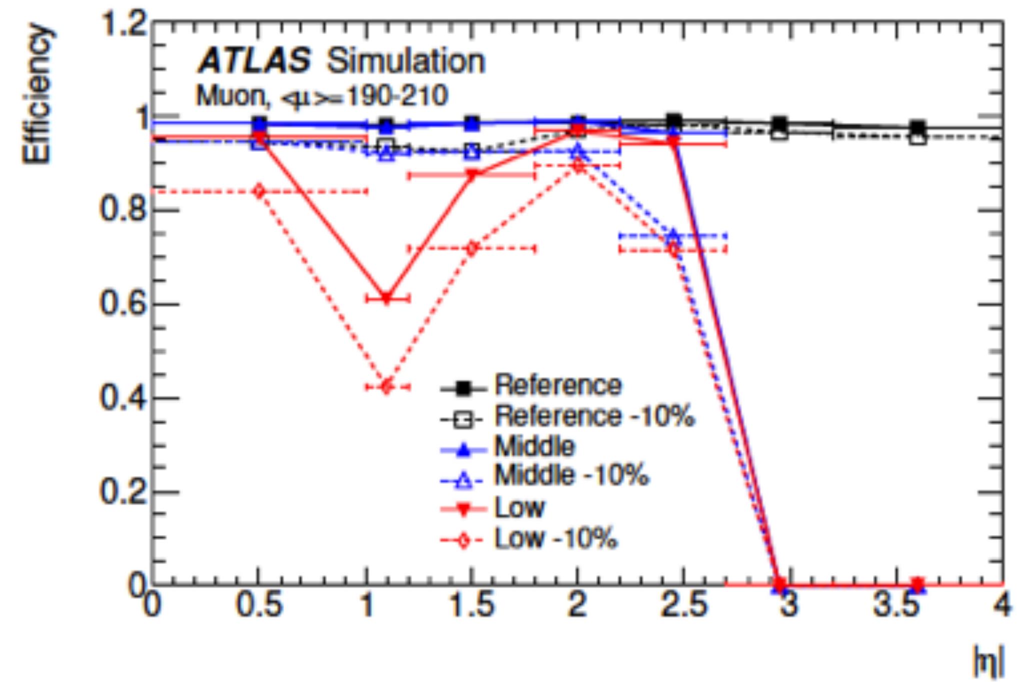
- **Target μ = 200**
  - in order to assure integrated luminosity of 3000 fb^{-1} in 10 years 2025-2035 (8 running years)
- **Three scenarios are considered:**
  - **Reference label (270M CHF):** - contains all possible upgrade projects, including sFCAL (not in simulation at the moment). Finely-segmented precision timing detector, trigger chambers (RPCs) in inner Muon barrel layer and best possible inner tracker and Forward Tracker up to |η| = 4.0. More powerful L1Track and FTK++.
  - **Medium label (235M CHF):** - contains some upgrade projects as trigger chambers (RPCs) in half of inner Muon barrel layer and slightly degraded inner tracker and Forward Tracker up to |η| = 3.2. Powerful L1Track and FTK++.
  - **Low label (200M CHF):** - contains mostly current detector with degraded inner tracker only (|η| < 2.7). More powerful L1Track and FTK++ with higher pT threshold.

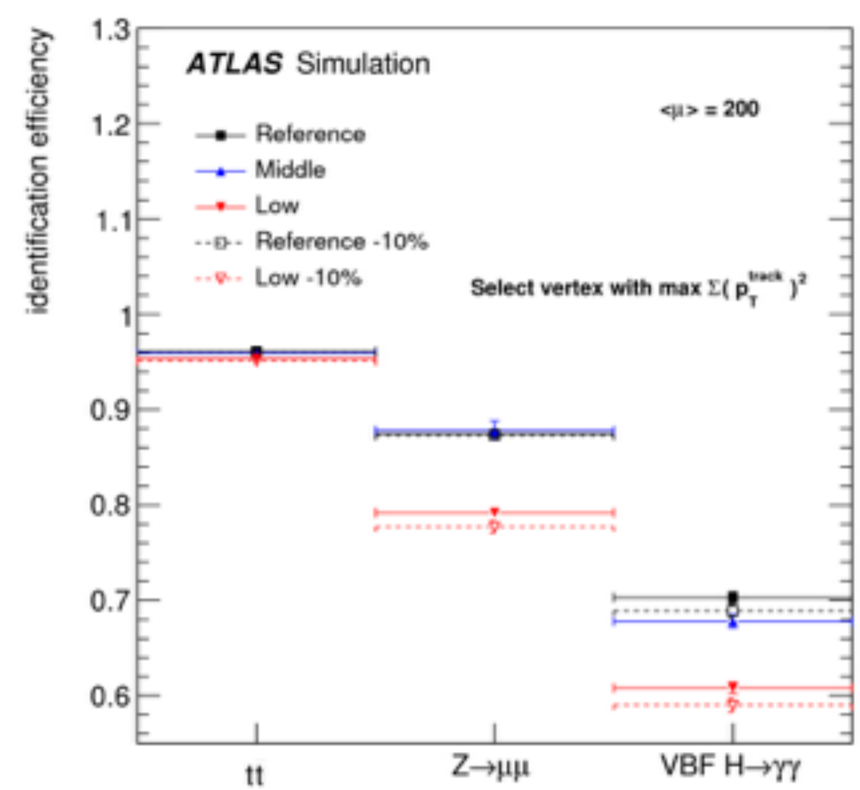


Detector Performance

Tracking Studies

- **Tracking Performance:**
  A. Tracking performance studied with muons and pions. Use three main scenarios and with 10% dead modules for robustness tests
    - Reference: >99% efficiency to |η|~4, ~5% drop from dead modules
    - Middle: similar nominal performance, ~10% drop from dead modules
    - Low: poor tracking performance, especially in barrel/endcap transition, ~15% drop from dead modules
    - For pions: ~10% lower efficiency, but similar conclusions
- **Vertexing Perfomance**
  A. Studied efficiency and resolution of primary vertexing
    - Little impact on reconstruction efficiency, but forward tracking (Middle/Reference) improves identifying the correct primary vertex by 8-10%
    - Vertex resolution not much affected by scenarios
- **b-tagging Perfomance**
  A. Studied with MV1 algorithm
    - Reference and Middle similar, Low is x2-3 worse
    - Can do b-tagging with forward tracker at degraded performance
    - -10% scenario degrades rejection by x1.5-2



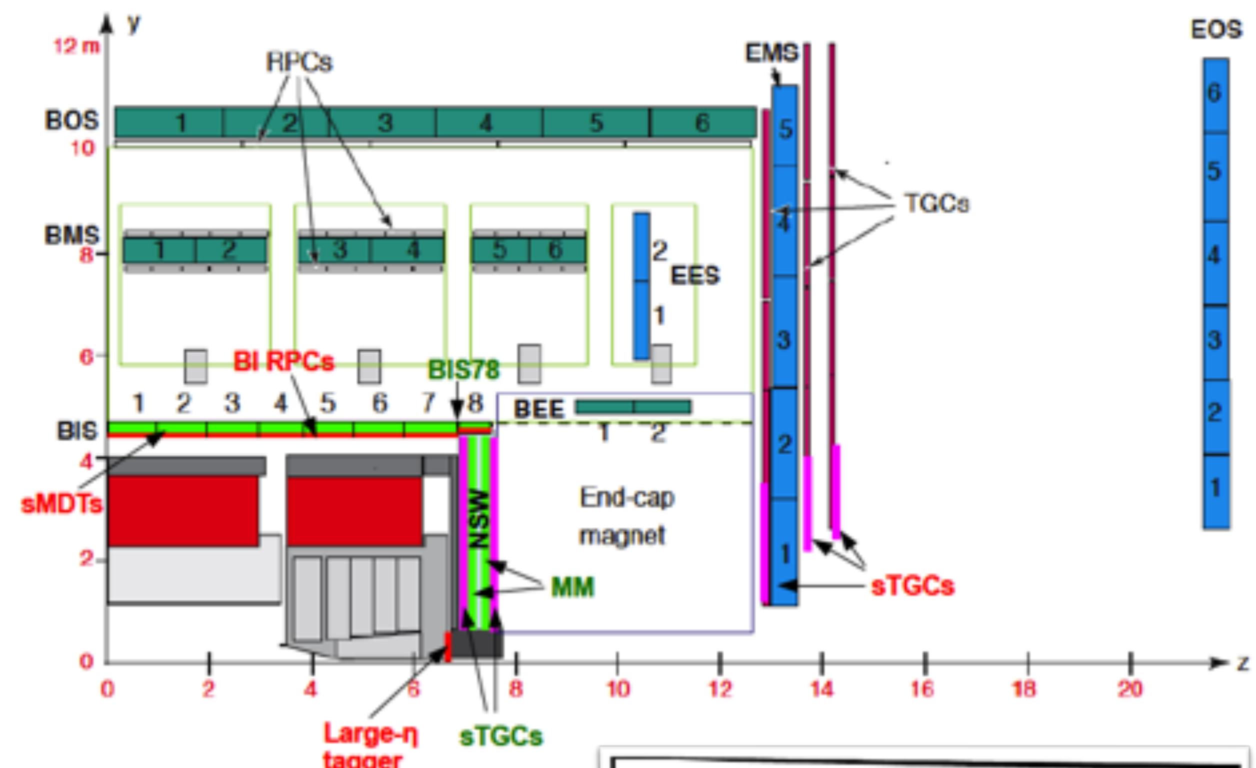


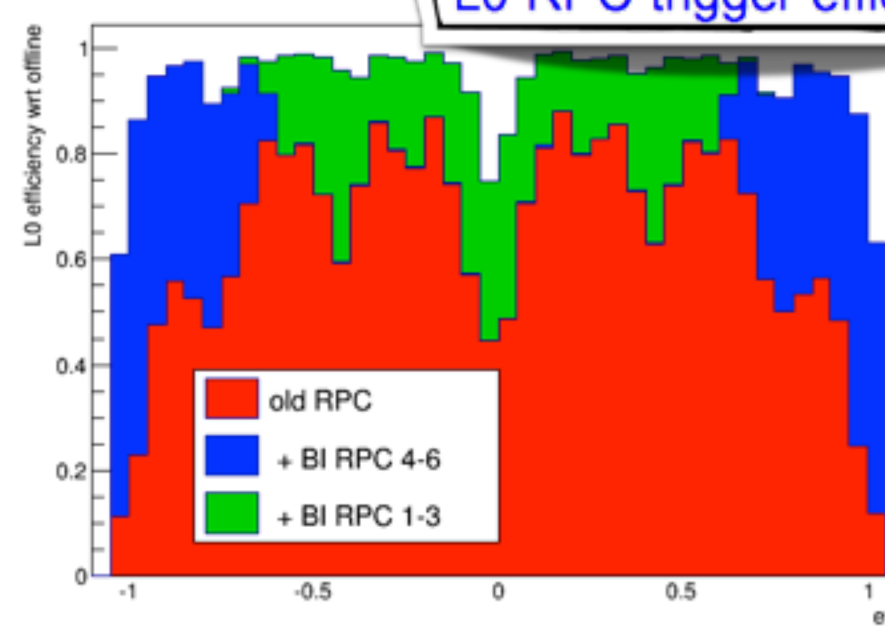
Muon System Upgrade

- **Trigger System**
  - Large part of the muon upgrade consists in the replacement of MDT/TGC/RPC electronics to cope with new trigger scheme.
  - **MDT trigger**: improved sharpness of pT thresholds. Basically same as present L2 but at L0.
  - Allows to keep single muons triggers with pt>20 GeV
  - **RPC on BI layer:**
    - increase present L1 geometrical acceptance from 78% to 95%
    - robustness against reduced efficiency of the old RPC system

- **Tracking System**
  - **ID->ITK**: better p_T resolution for tagged and combined muons
  - **BI RPC/sMDT**: part of the MDT in BI will be substituted by sMDT
  - **Large Eta Tagger**: extend muid to eta~4 (with p_T from ITK)

Muon system Phase-2 upgrade: Reference scenario





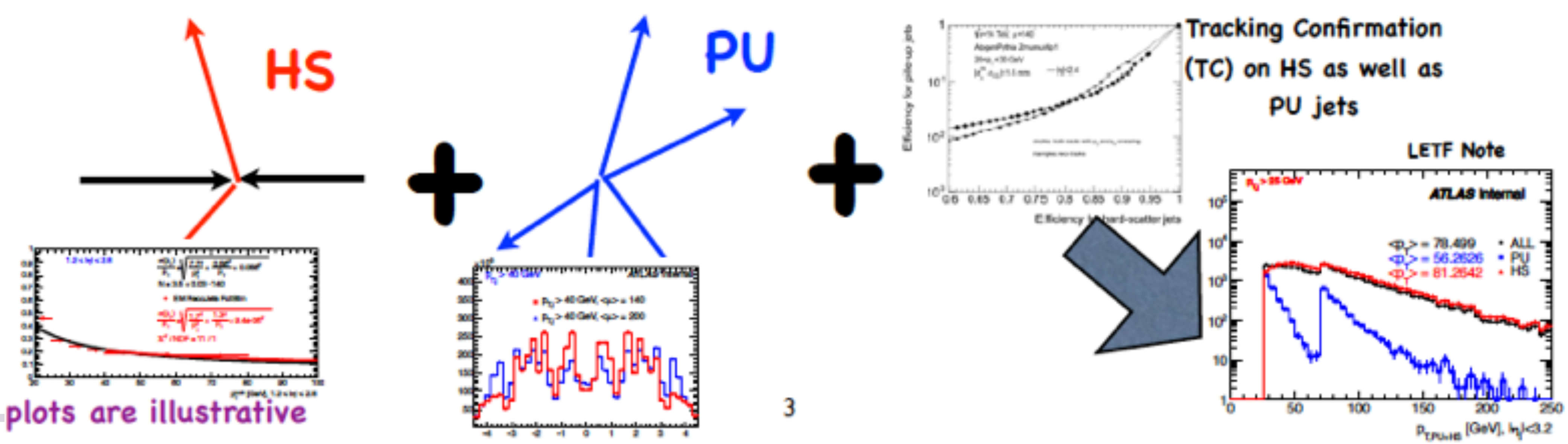
Scenario with reduced HV setting on old RPCs to cope with phase-2 rates

Jets Performance

(Phase2) Upgrade physics community is small and deals with future scenarios --> it is not possible to request FullSim samples for all analyses (1 ttbar events FullSim = 10.6 mins @ μ=200!).

Technically:

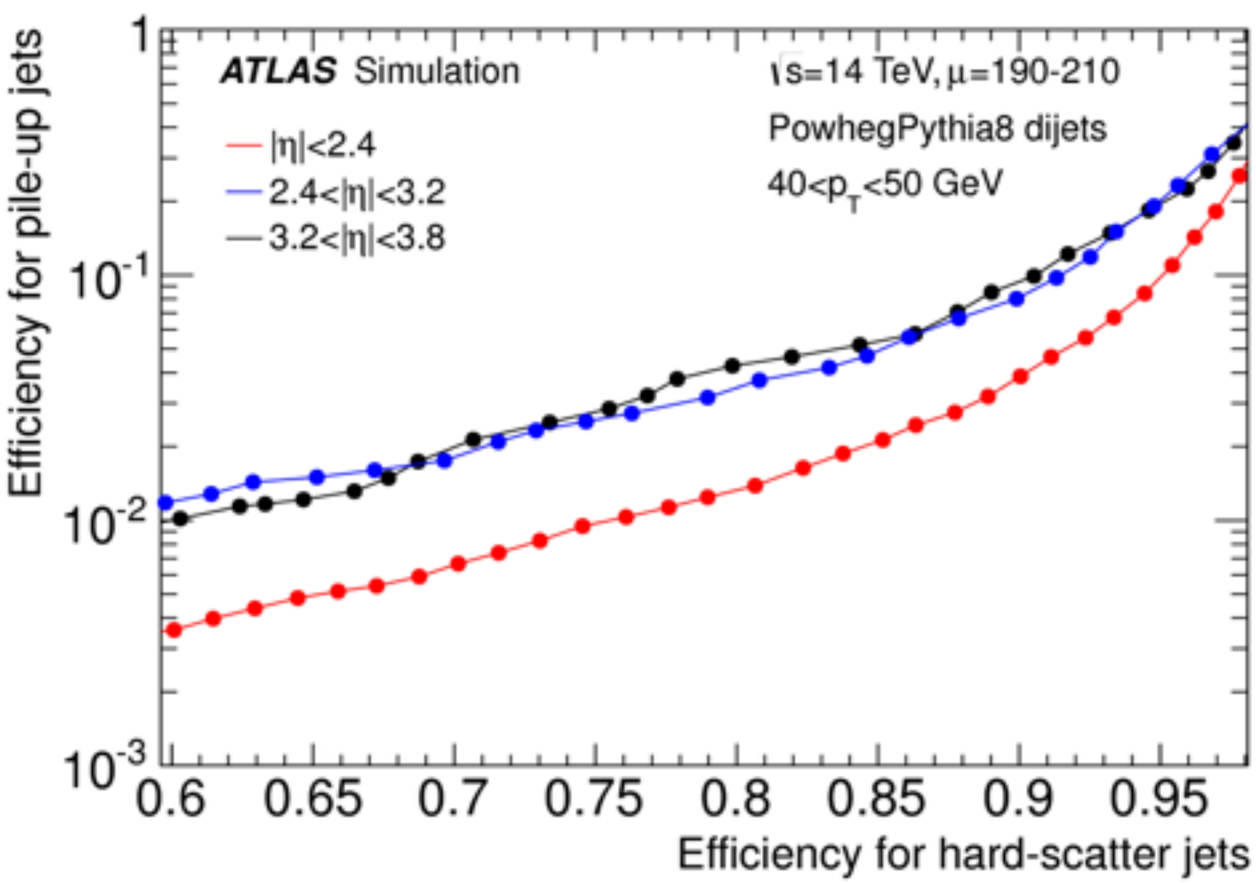
- concept of work based on NTUP_TRUTH (i.e. Hard Scattering HS only) and applying Smearing Functions(parametrisation, mostly pT/E)
  - those are derived (once) from FullSim samples by CP groups
- this approach does not take into account additional PileUp PU jet activity (recently added in form of overlay with jets from a PU Library)
  - PU Library: Event collection with FullSim PU jets only, for few jet p_T thresholds (user input)
- future capability of tracking to suppress pile up (Tracking Confirmation, JVF, JVT) is taken into account through HS/PU rates obtained from ROC curves (connecting probability for a HS as well as PU jet to survive the tracking selection).

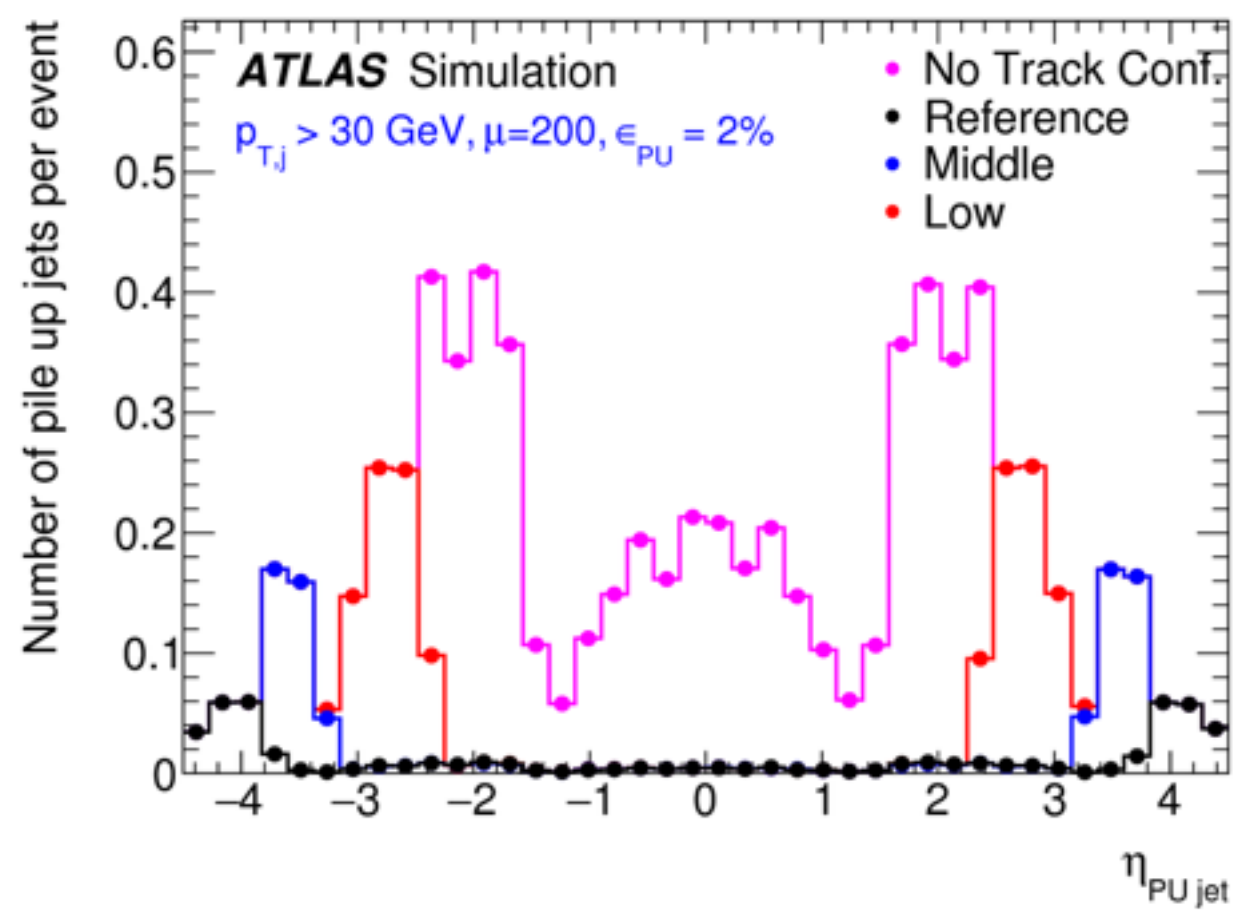


Pile Up Jets Suppression

- **Very large rate of pileup jets at μ=200**
- Use track confirmation (R_{pT}) to suppress
  - Needed up to p_T~100 GeV
  - Not as efficient for |η|>2.4, but still provides strong argument for forward tracking extension
- In forward region, also early studies of timing detector and sFCal for pileup suppression

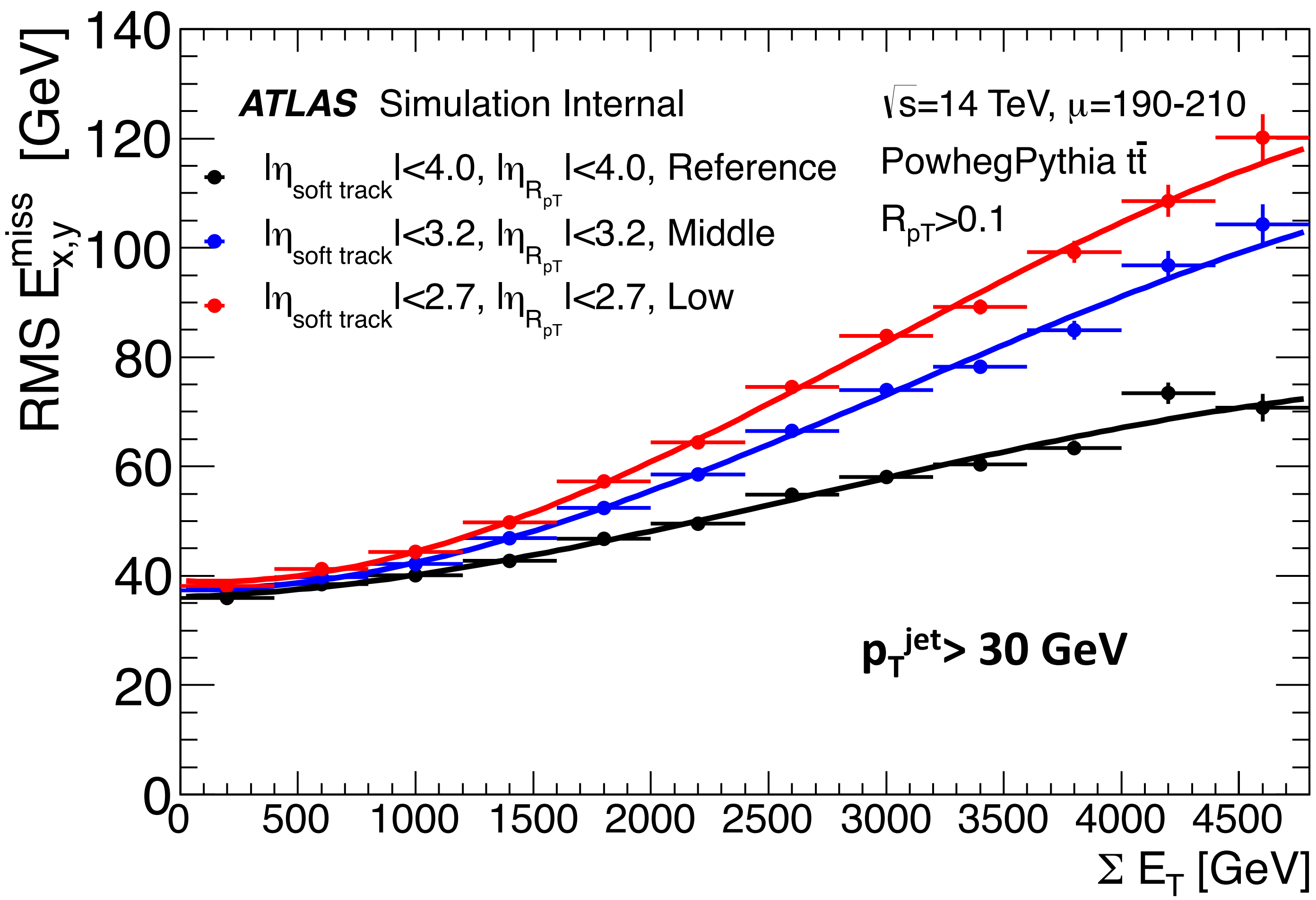
$$R_{pT} = \frac{\Sigma_i(p_{\mathrm{T}}^{\mathrm{track},i})}{p_{\mathrm{T}}^{\mathrm{jet}}}$$





Missing Energy Resolution

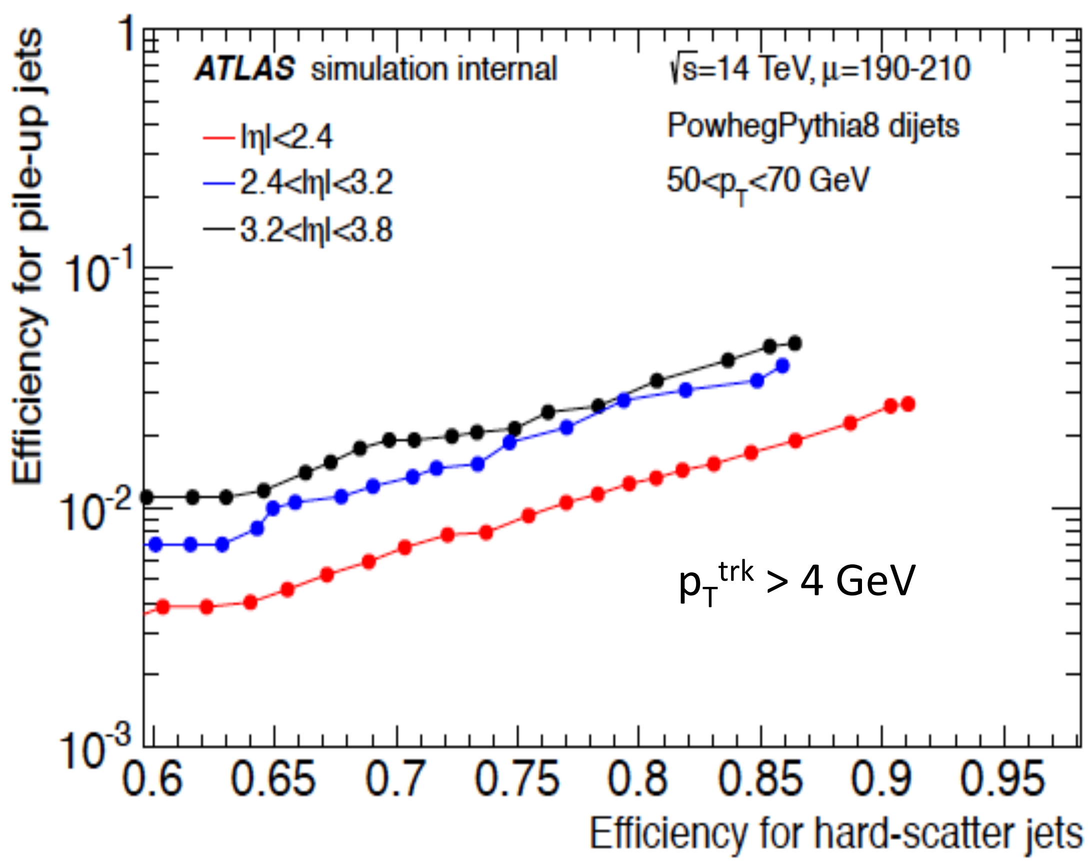
- **Use Track SoftTerm (TST) variant**
- Apply η cut for:
  - soft tracks acceptances
  - R_{pT} cut for jets with pT>30 GeV
  - **Large improvement in the Reference scenario**, wrt to Middle and Low scenarios,also using jets with pT>40 GeV

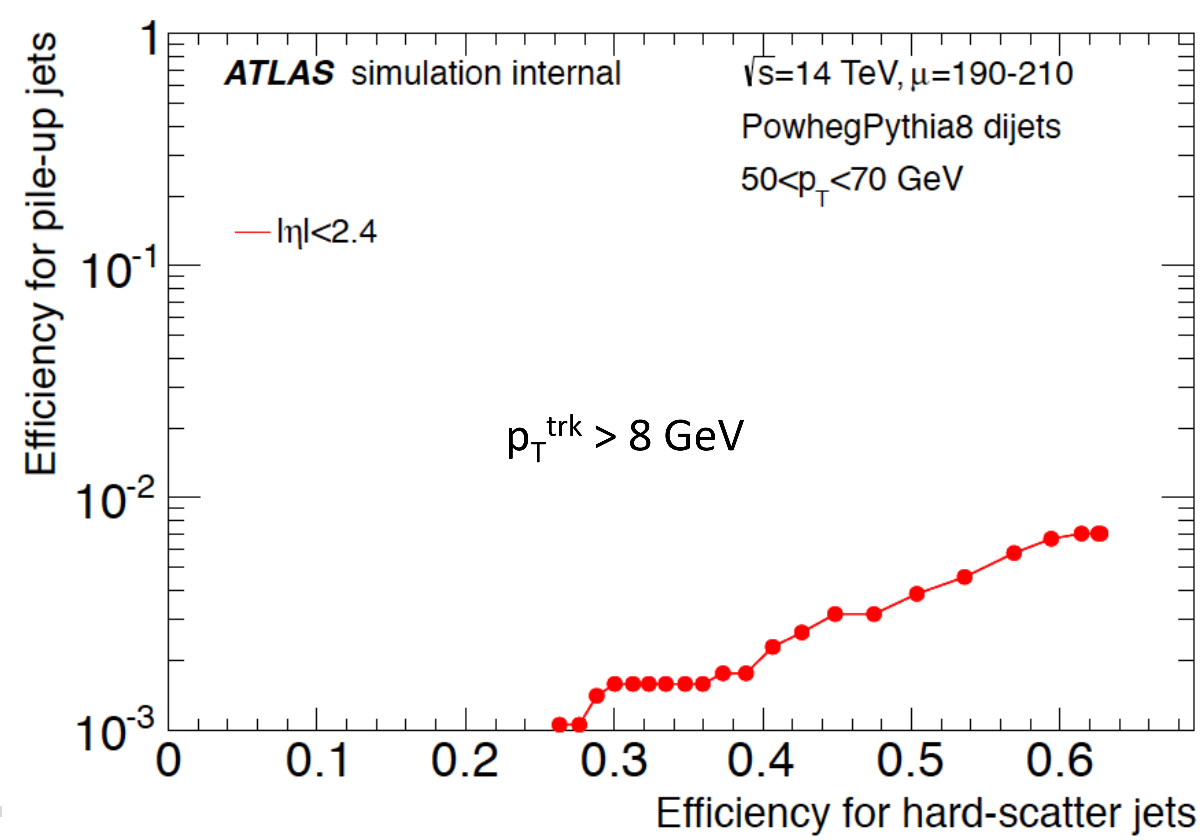


Use RpT > 0.1,
corresponding to:
eff. on HS jets: 90%,86%,88%
eff. on PU jets: 4%,6%,7%
for |η|<2.4, 2.4<|η|<3.2, 3.2<|η|<3.8

Pileup suppression for Trigger Jet

- Online tracks available from L1Track and FTK++
- Use RpT discriminant
- **Reference**: p_T>4(1) GeV, |η| < 4.0 for L1Track (FTK++)
- **Middle**: p_T>4 GeV(1), |η| < 3.2 for L1Track (FTK++)
- **Low**: p_T>8(2) GeV , |η| < 2.4 for L1Track (FTK++)
- For L1Track Low scenario, significant loss of efficiency on HS jets, due to high p_T threshold on tracks





Physics Performance

Physics Analyses (published)

- **Six results made it into the scoping document**
  - Partly due to no significant differences seen
  - Partly due to not converging in time (was very tight schedule!)
  - Partly due to lack of people

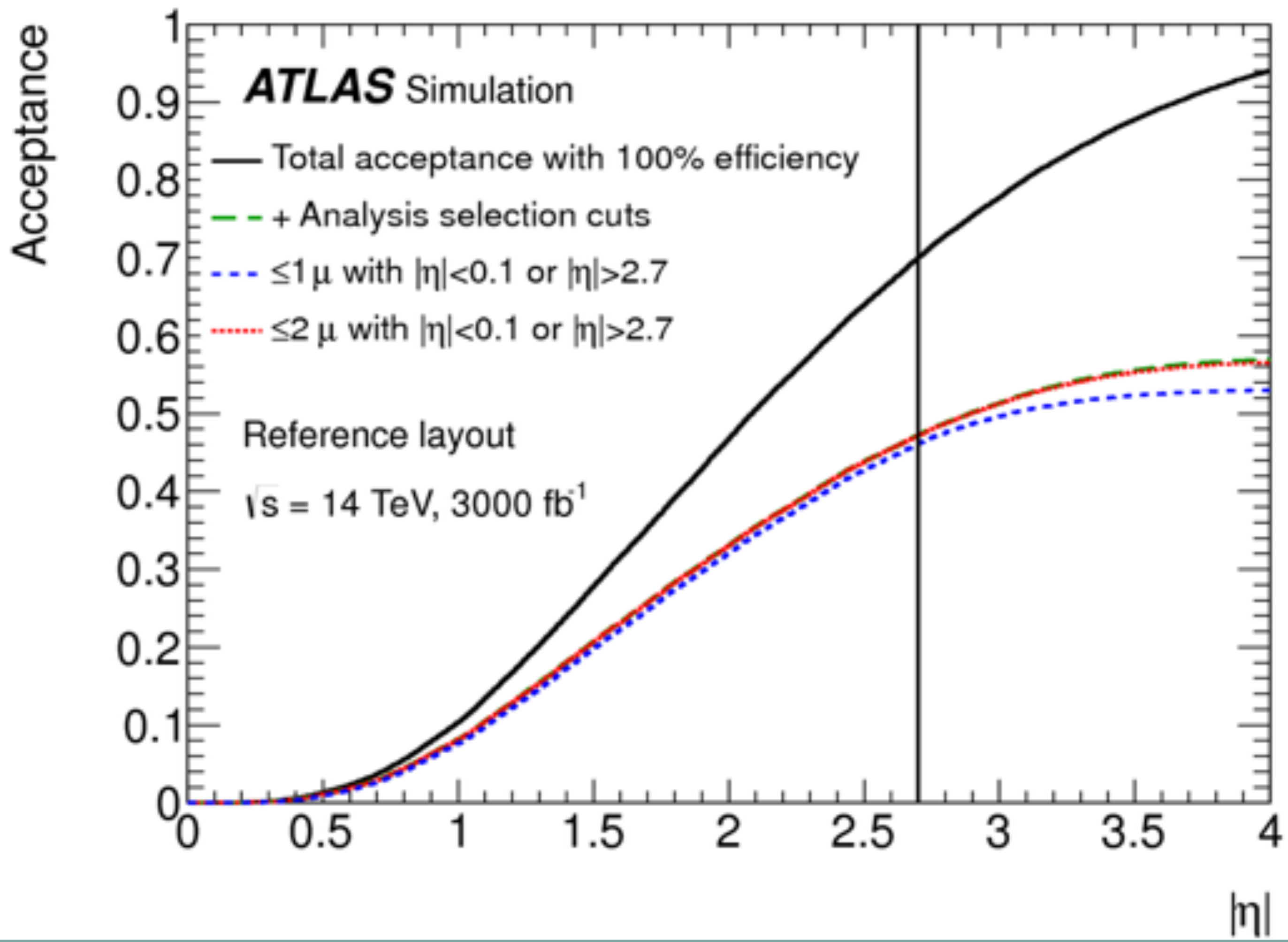
Detector system	Trigger–DAQ		Inner Tracker	Inner Tracker + Muon Spectrometer	Inner Tracker + Calorimeter		
Object Performance / Physics Process	Efficiency/ Thresholds $\mu^{\pm}$	Efficiency/ Thresholds $e^{\pm}$	b-tagging	$\mu^{\pm}$ Identification/ Resolution	Pile-up rejection	Jets	$E_{\mathrm{T}}^{\mathrm{miss}}$
$H \longrightarrow 4\mu$	✓			✓			
VBF $H \rightarrow ZZ^{(*)} \rightarrow \ell\ell\ell\ell$	✓	✓		✓	✓	✓	
VBF $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$	✓	✓	✓	✓	✓	✓	✓
SM VBS ssWW	✓	✓		✓	✓	✓	✓
SUSY, $\chi_1^{\pm}\chi_2^{o} \rightarrow \ell b\bar{b} + X$	✓	✓	✓	✓	✓	✓	✓
BSM $HH \rightarrow b\bar{b}b\bar{b}$			✓			✓	

Inclusive $H \to ZZ \to \mu\mu\mu\mu$

Acceptance increases by 21% with larger tracker acceptance:
From 47% to 57%
Almost no gain in sensitivity due to worse resolution

Scenario	$H \to 4\mu$	$ZZ^{(*)} \to 4\mu$	$\Delta\mu/\mu$
Reference	2551 ± 51	741 ± 27	0.022
Middle	2104 ± 46	351 ± 19	0.024
Low	2014 ± 45	336 ± 18	0.024

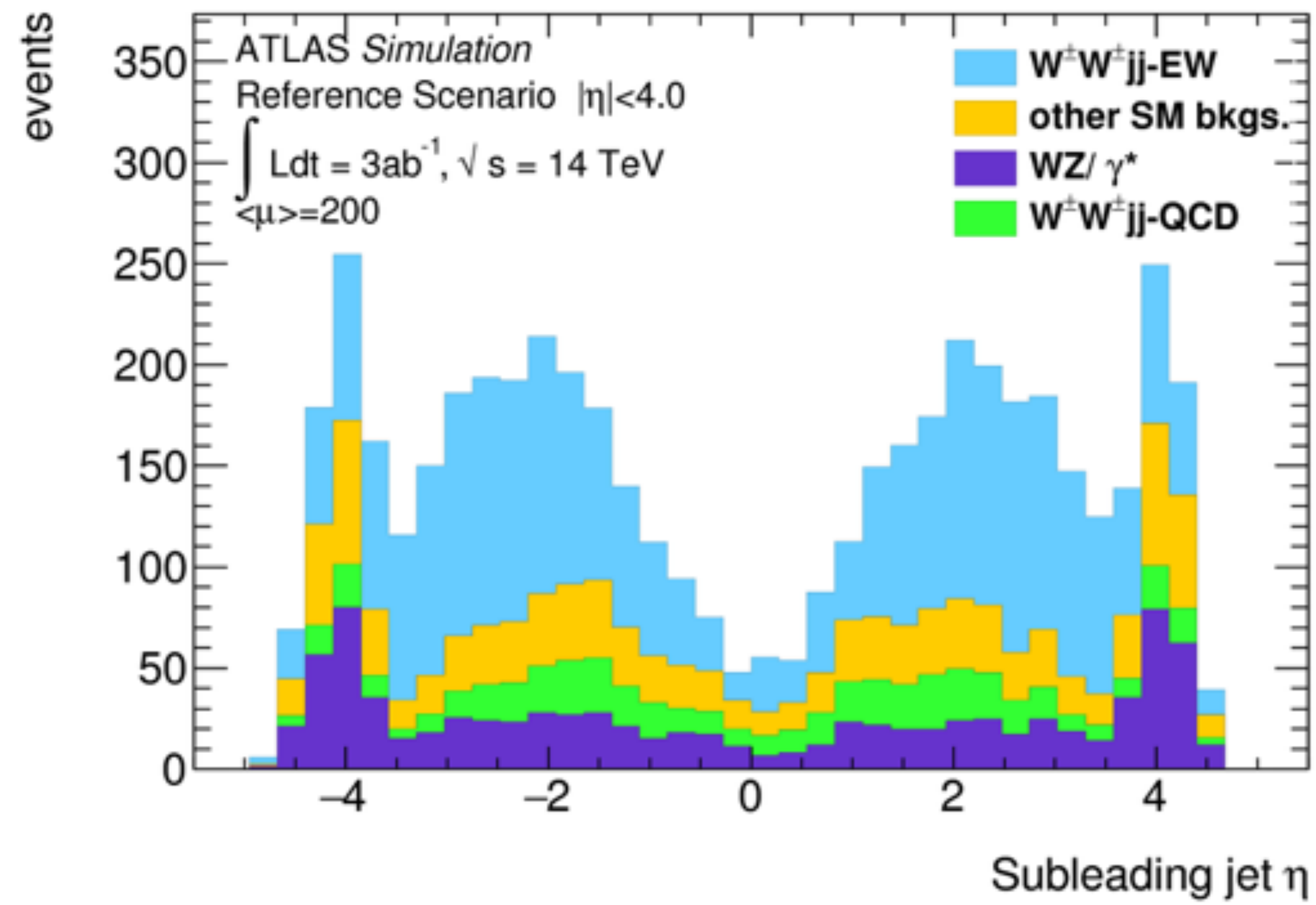
Coverage	Mass ()	Width ()
$\lvert{}^{\mu}_{\max}\rvert < 2.7$	124.95 ± 0.01	1.11 ± 0.01
$2.7 < \lvert{}^{\mu}_{\max}\rvert < 3.2$	125.31 ± 0.07	2.53 ± 0.08
$3.2 < \lvert{}^{\mu}_{\max}\rvert < 4.0$	125.89 ± 0.17	4.61 ± 0.23



$H \to \mu\mu$ also studied
10% gain in acceptance from forward tagger
8% gain in acceptance from improved muon trigger
PUB note is under review

Vector Boson Scattering

- Same-sign WW measurement
- Signal requires exactly 2-leptons
  - η range depends on scenario
- Two jets with large mass
  - $\Delta\eta$ >2.4, m_{jj}>500 GeV
- Main background is WZ(+jets)
  - Gain factor 2 in sensitivity from larger coverage for 3rd lepton veto
  - Fraction of events with pileup jets reduced from 27% (Low) to 17% in reference

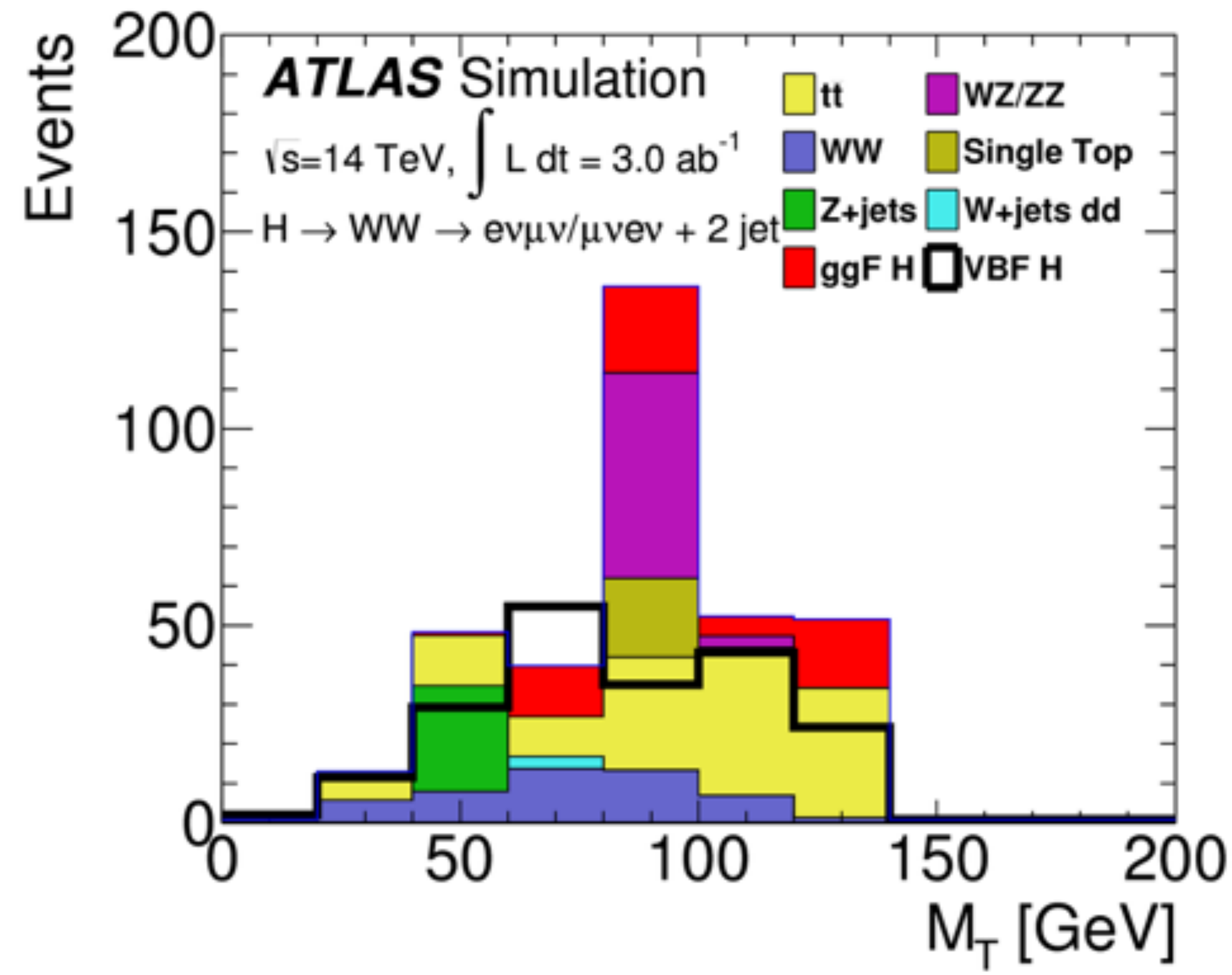


Very large improvement seen from Reference scenario

Scenario	Z_{σ_B}	$\Delta\sigma/\sigma$
Reference scenario	11.3 ± 0.6	5.9%
Middle scenario	6.06 ± 0.3	11%
Low scenario	5.02 ± 0.2	13%

VBF H→WW→$e\nu\mu\nu$

- Run-1 VBF H→WW extended to 3 ab^{-1}
- Complex analysis with many background components
  - Use VBF jet selection: $|\eta_{jet}|>2$, $m_{jj}>1200$ GeV, bjet veto and central jet-veto to suppress backgrounds
  - Benefits strongly from improved pileup jet rejection and better b-tagging in Reference scenario

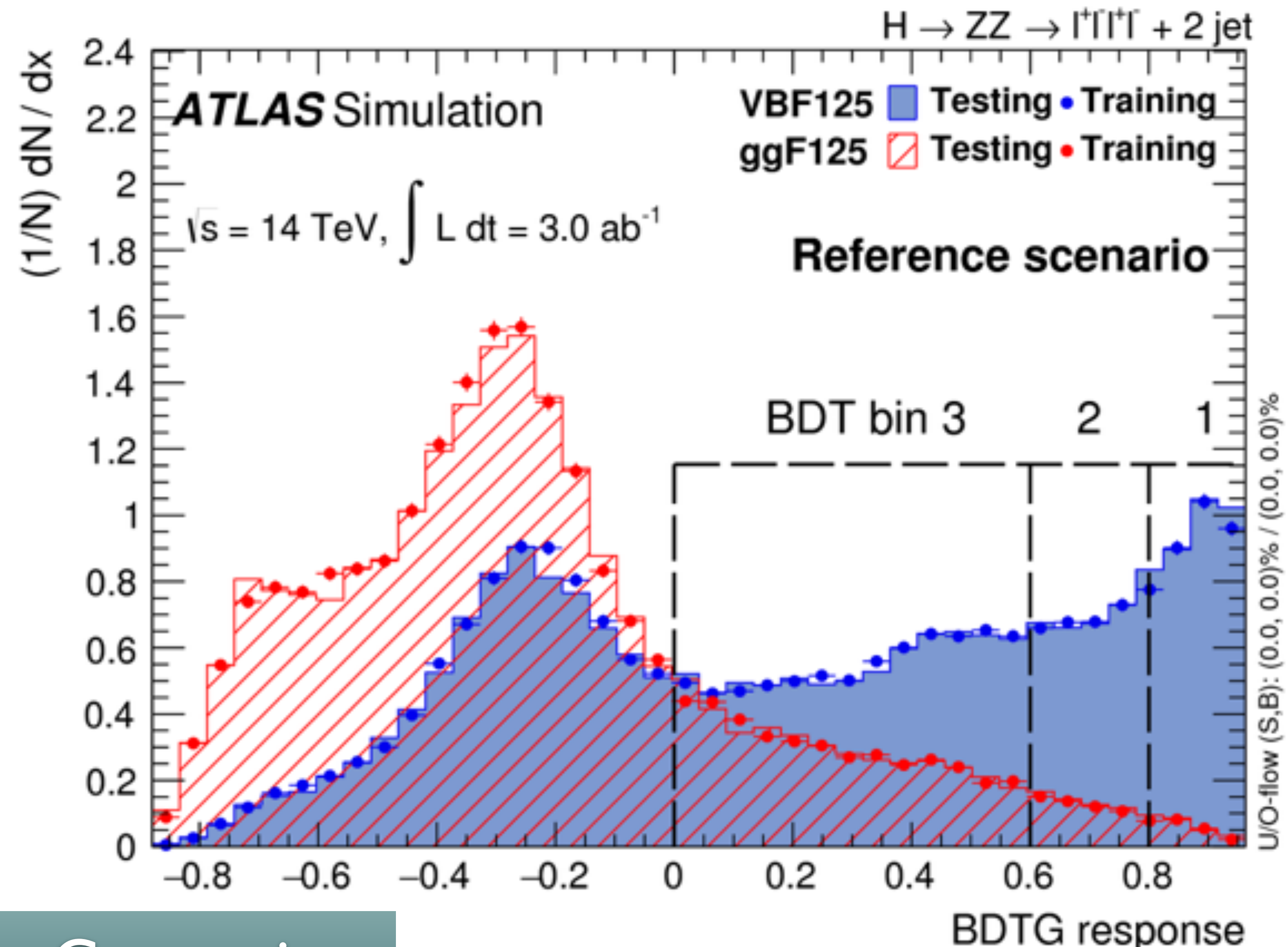


Significant theory uncertainties
Also benefit from reduced backgrounds

Scoping Scenario	without theo. unc.		with theo. unc.	
	$\Delta\mu/\mu$	Z_0-value (σ)	$\Delta\mu/\mu$	Z_0-value (σ)
Reference	0.14	8.0	0.20	5.7
Middle	0.20	5.4	0.25	4.4
Low	0.30	3.5	0.39	2.7

VBF H→ZZ→ℓℓℓℓ

- Background dominated by gluon-fusion H production.
- Use BDT to discriminate VBF and ggF states.
  - Separate tuning for each scenario
- Some benefit from better pileup suppression, gain 6% over Low in signal sensitivity

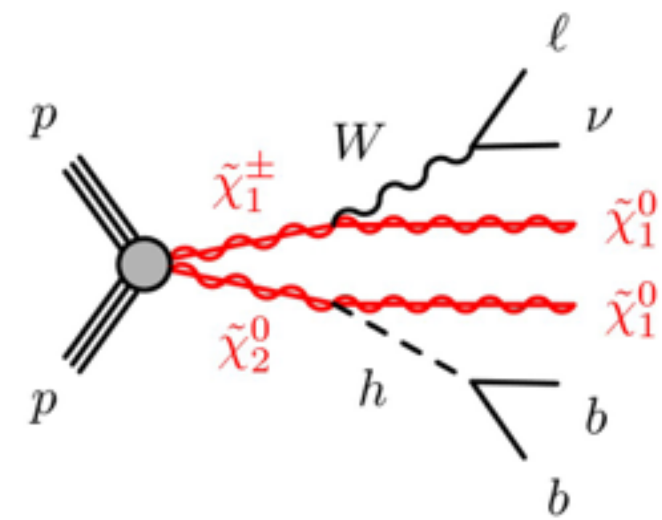


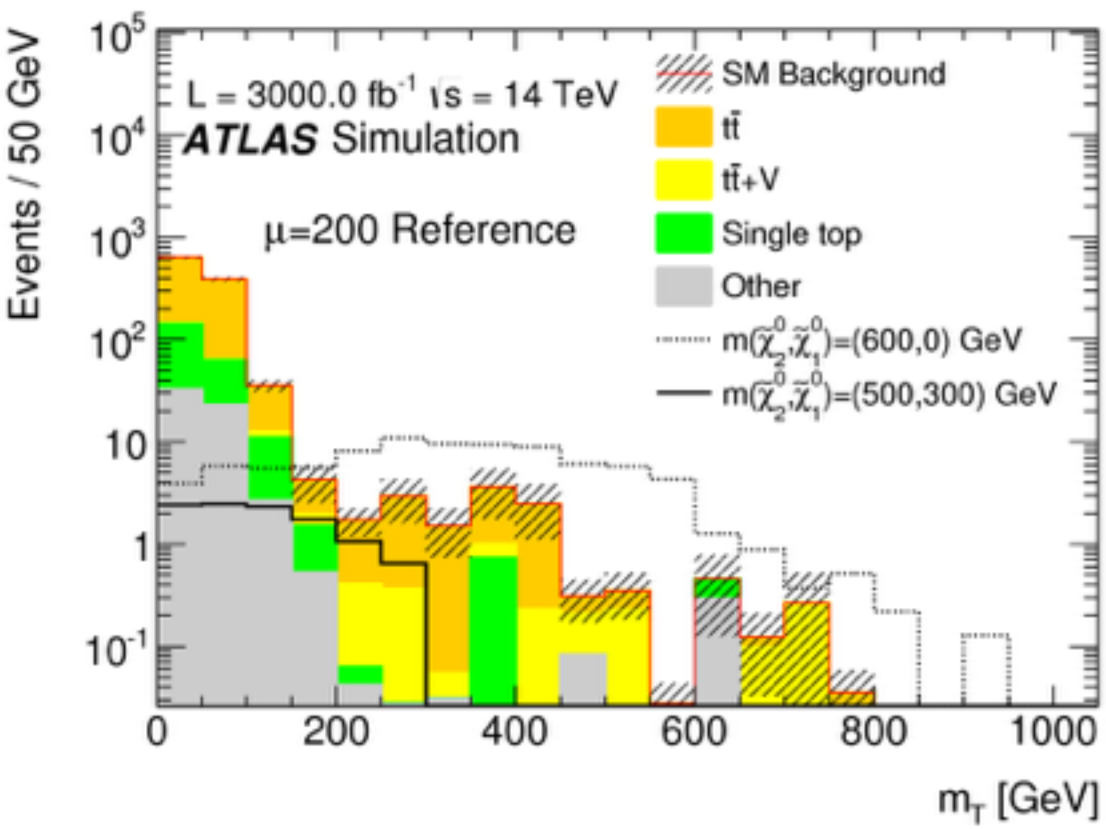
VBF/VBS Summary of $\Delta\mu/\mu$ Comparison

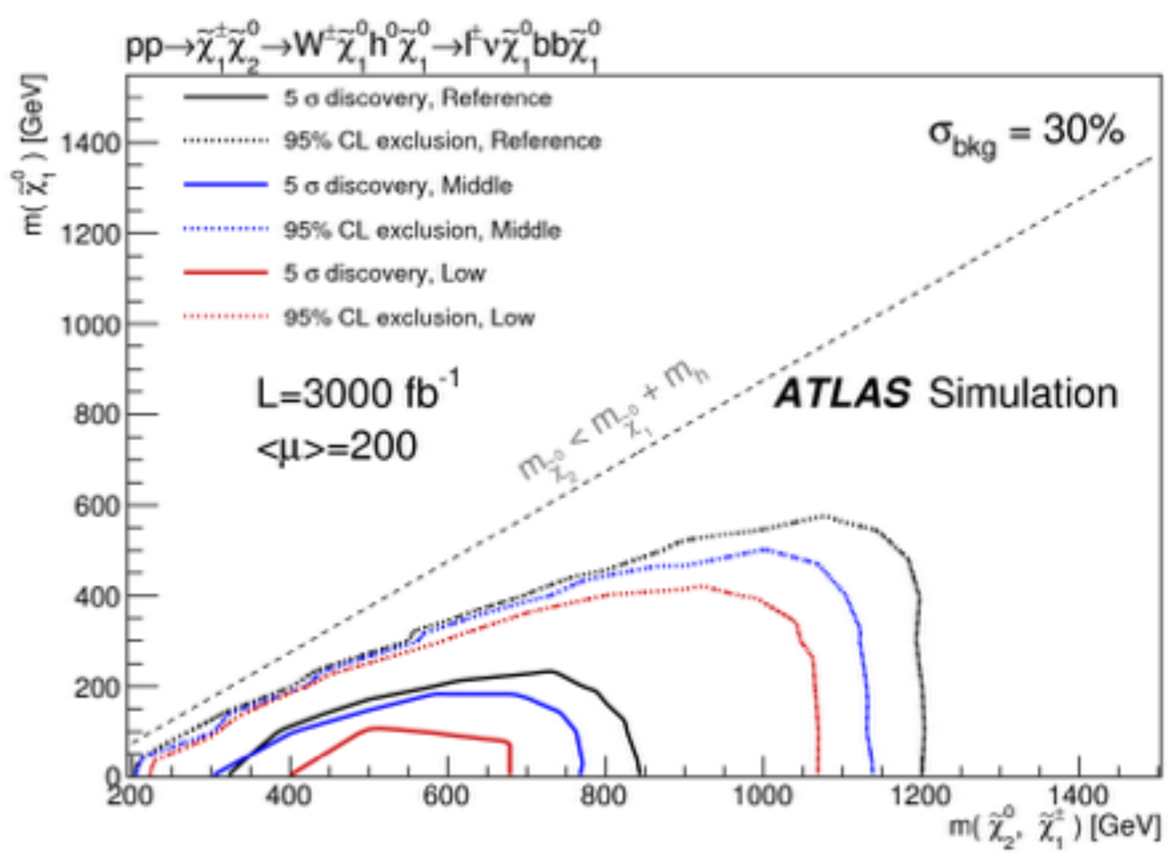
Scenario	VBF $H \to WW^{(*)}$	VBF $H \to ZZ^{(*)}$	VBS ss$W^{\pm}W^{\pm}$
Reference	0.14	0.134	0.059
Middle	0.20	0.137	0.11
Low	0.30	0.142	0.13

$\tilde{\chi}_1\tilde{\chi}_2^0 \to \ell\nu b\bar{b}\tilde{\chi}_1^0\tilde{\chi}_1^0$

- Lepton and 2 b-jets with |η|<2.5, E_{Tmiss} > 400 GeV
  - Main backgrounds ttbar, single top, W+jets, ttW, ttZ
  - Single lepton trigger, b-tagging affect signal and background
  - **Worse E_{Tmiss} resolution in lower scenarios increases background**



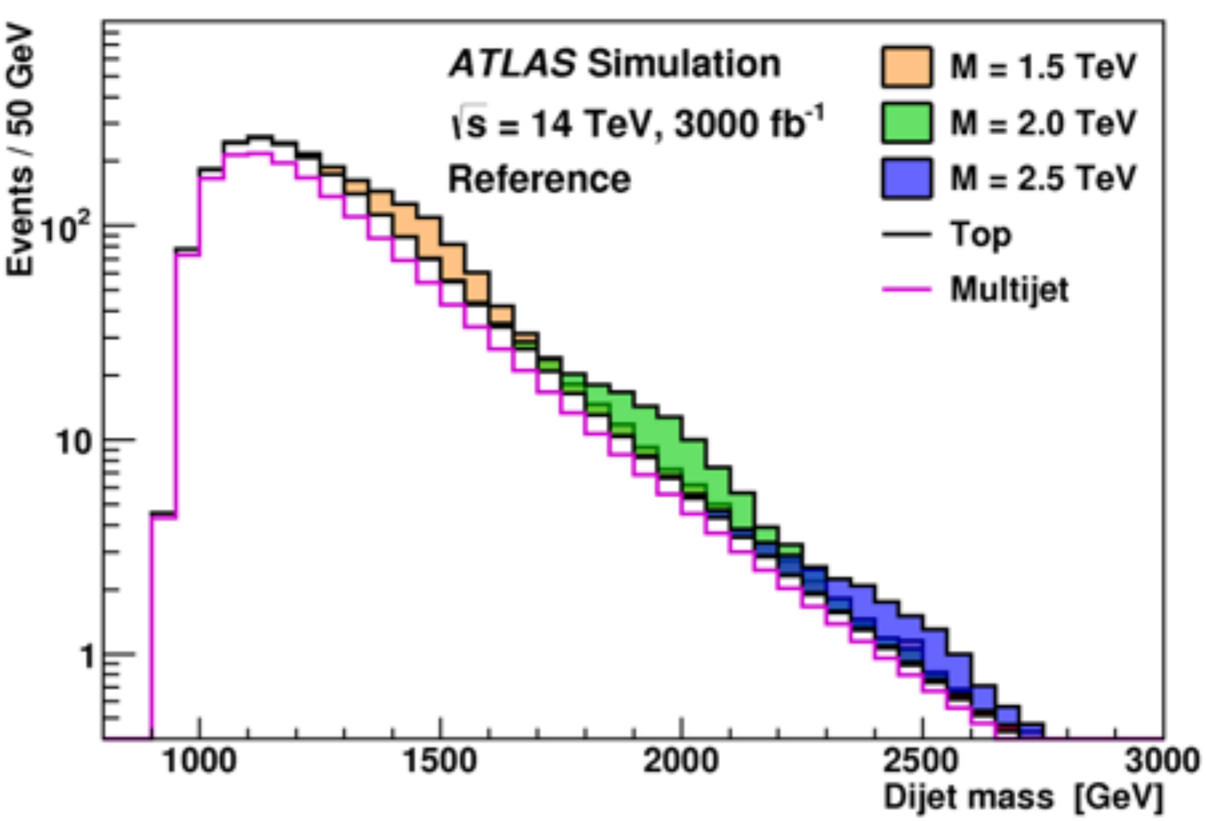




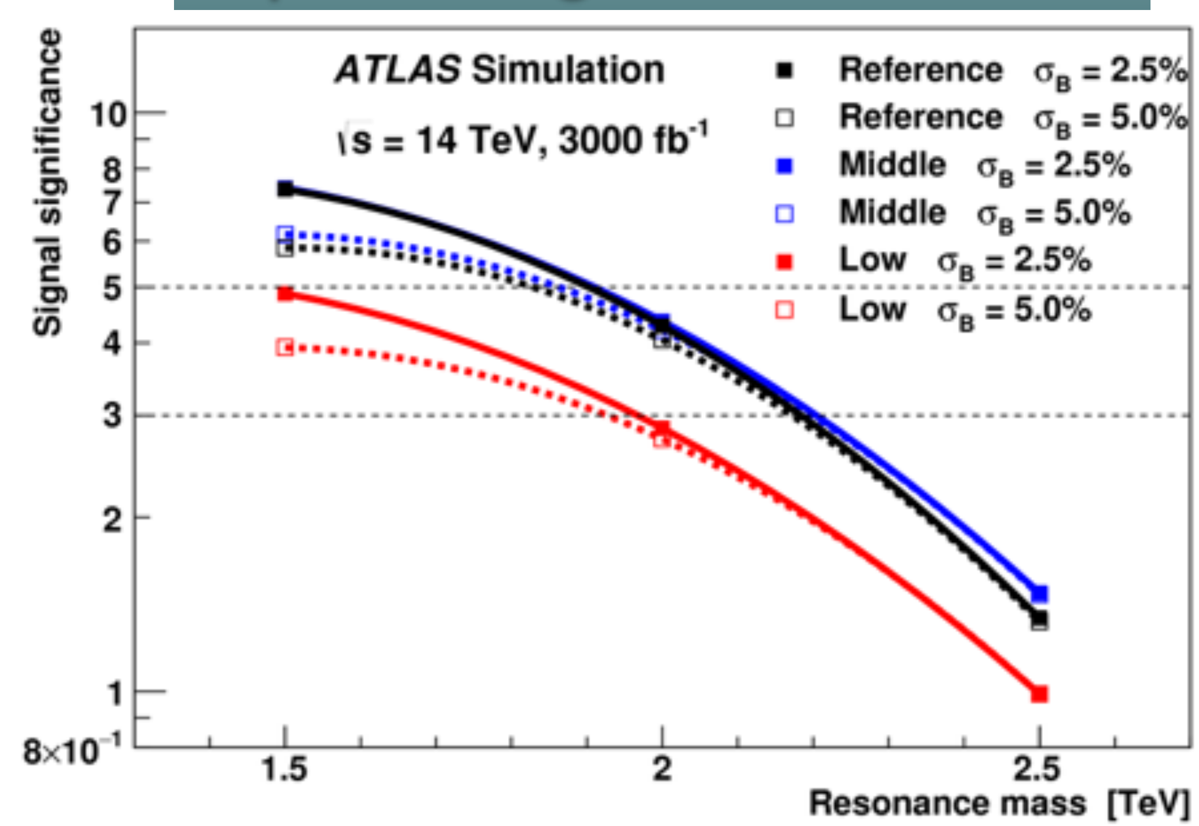
Mass reach in GeV: 850 (R), 770 (M), 675 (L)
Need 6000 (12000)/fb in M (L) to equal reach of Reference

BSM Resonance HH→$b\bar{b}b\bar{b}$

- **Search for heavy resonance, such as KK graviton, decaying into two Higgs bosons**
- Each H reconstructed with large-R jet with two b-tagged sub-jets
  - High-pT jets – used approximate b-tagging performance
- **No gain from forward tracking, but poor b-tagging in Low scenario gives worse significance**



Expected significance vs mass



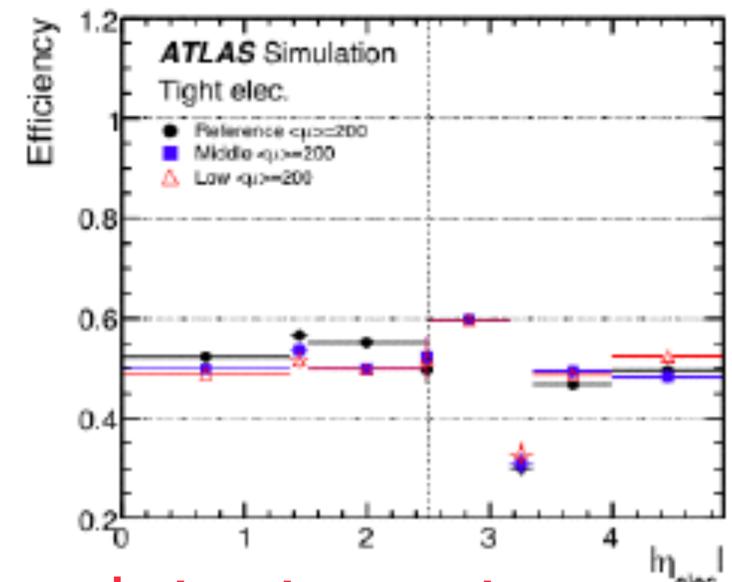
Scoping Document Wrap-up

- **Six physics analyses made it into scoping document**
  - These are only briefly described and focused on differences between the three scenarios
- Would like to better document some of these in form of supporting PUB notes where feasible and desirable
  - Would be same analysis procedure as approved for scoping document with no changes in results and minimal extra results.
  - Results help build public case for forward extension of tracker
- Candidate analyses for PUB notes:
  - VBF $H \to WW$
  - VBF $H \to ZZ$
  - SM $W^{\pm}W^{\pm}$
- Additional results that didn't make scoping document:
  - $H \to \mu\mu$
  - FCNC top decays

Aim to wrap these up in the next 1-2 months

Transition to Release 20.X (xAODs)

- Upgrade studies done so far have used release 17.3 and NTUP_COMMON with a few exceptions
- Need to move to release 19/20 and xAODs
  - Should make it easier for new people to contribute
- **First release 20 samples with ITK (LoI layout) are now available!**
- Highest priority studies:
  - Re-establish performance from scoping document and understand any differences
  - Develop pileup-robust algorithms and object definitions for elections, photons, taus, b-jets etc.



- Slightly longer term: Implement and study more detector setups
  - Run-3 detector with NSW and LAr/L1Calo supercells
  - Run-4 detector with ITK layout, sFCAL/miniFCAL and Run-3 detectors

Support of IDR/TDRs

- 4 Phase-II IDRs and 6 TDRs planned for the next two years
  - Expect that Upgrade Physics will provide supporting studies for most of these

	Q1	Q2	Q3	Q4
2016	ITK Layout TDAQ IDR	sFCAL dec. Muon IDR	LAr IDR Tile IDR	Strip TDR
2017		Muon TDR	LAr TDR Tile TDR	Pixel TDR TDAQ TDR

- At least the TDRs will need some set of performance studies
- Need to understand which physics case studies are required
  - To what extend do we propagate performance through to final physics results (mostly with smearing approach)
  - Aim to provide central effort in support of all TDRs rather than having effort split between TDR teams
- Simulation samples coordinated through Upgrade Physics

Upgrade Physics Studies

- **Possible ECFA HL-LHC workshop in fall of 2016**
  - Provides a natural target for the next physics studies
- Would like to update some old results
  - Take advantage of the better understanding of the future detector performance including the possible forward tracking
  - Example of channels desired to be updated: di-Higgs production (multiple channels) h→ $\tau\tau$
- **New channels also possible**
  - **To some extent driven by analyser interests**
- Studies to be based on updated performance functions
  - Hope to have updated Run-3/4 function ready in 4-6 months
  - Can use current smearing functions until then
- **Ideally the channels studied has some overlap with what is desired for TDRs**

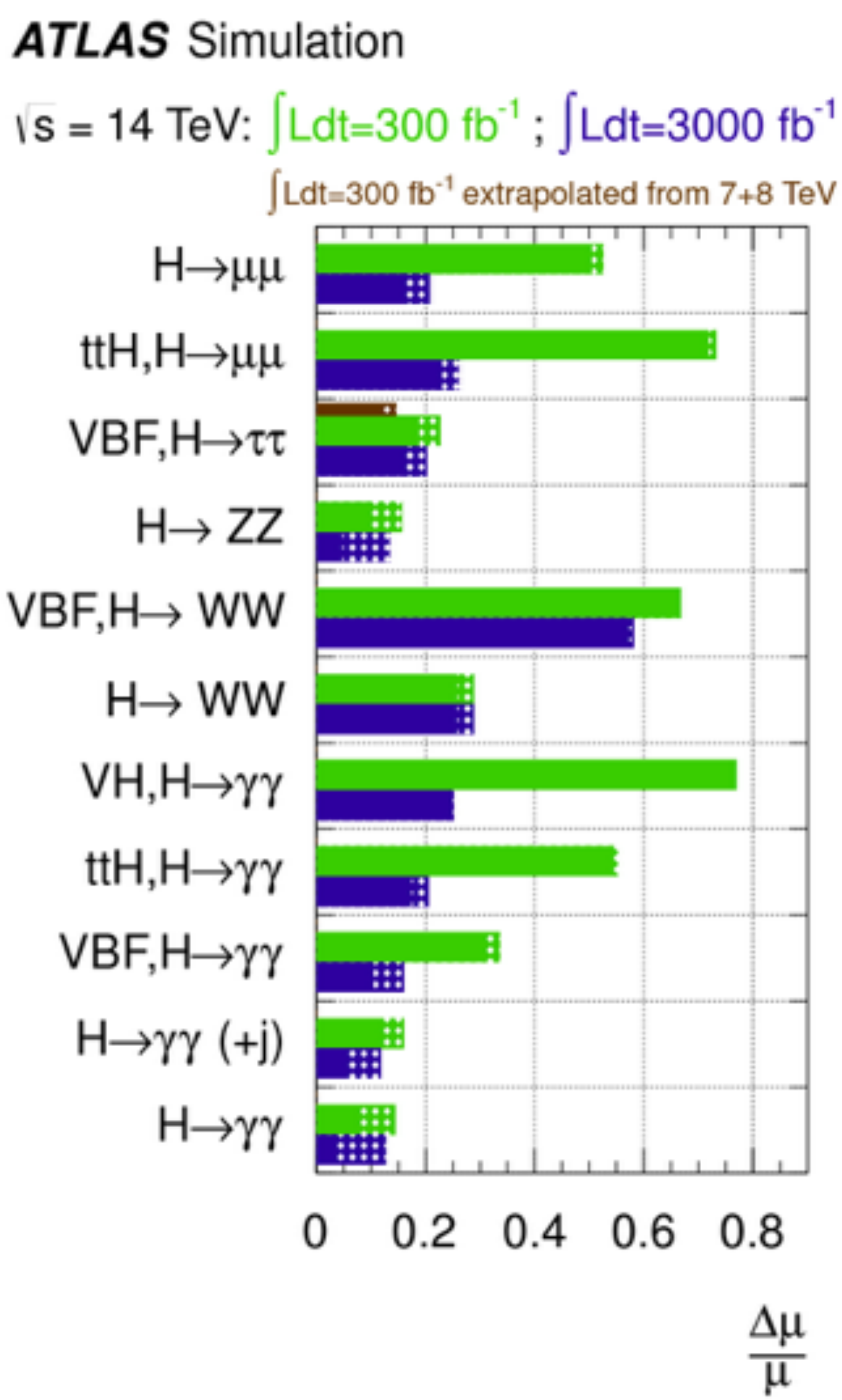
Summary

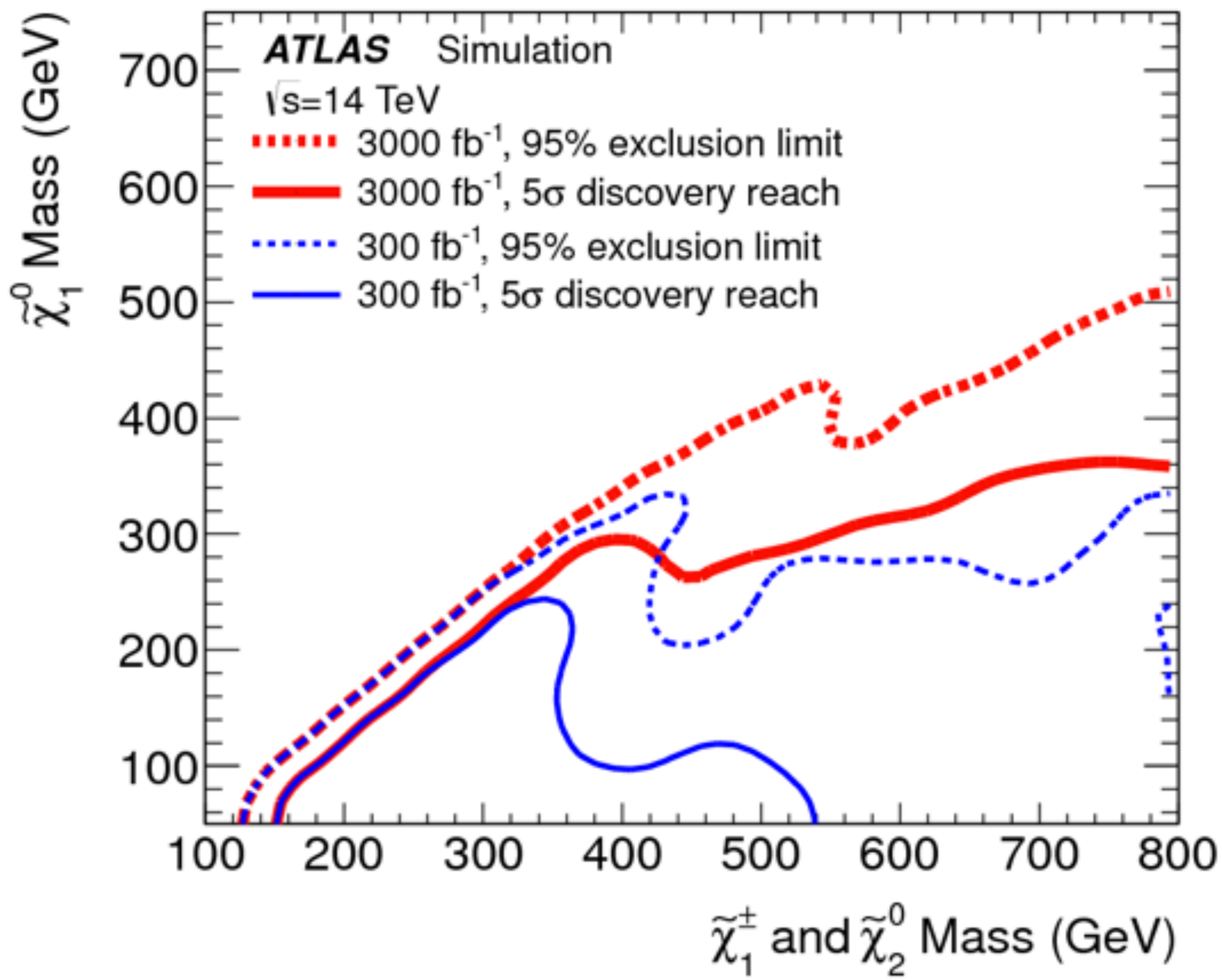
- **Large effort for scoping document completed**
  - Comprehensive snapshot of Phase-II performance
  - Propagated through analyses to quantify physics gains
  - Strong case against Low scenario and clear gains of Reference scenario with improved forward reconstruction
- Now preparing for Phase-II design decisions and TDRs
  - Migrating to release 20.x and xAOD
  - Aim to simulate possible full phase-II detector setups
  - Want to measure and retune performance for high pileup
- **New physics results to also target ECFA in Fall 2016**
- Continue to support Phase-I effort, particular simulation
- **Few Italians groups are involved in these studies!**
  - Italians have some responsibilities on key aspects but it is a very small community….
  - Great possibility to contribute immediately in physics analyses and get large visibility in the ATLAS Collaboration.

Back up

LoI Predictions

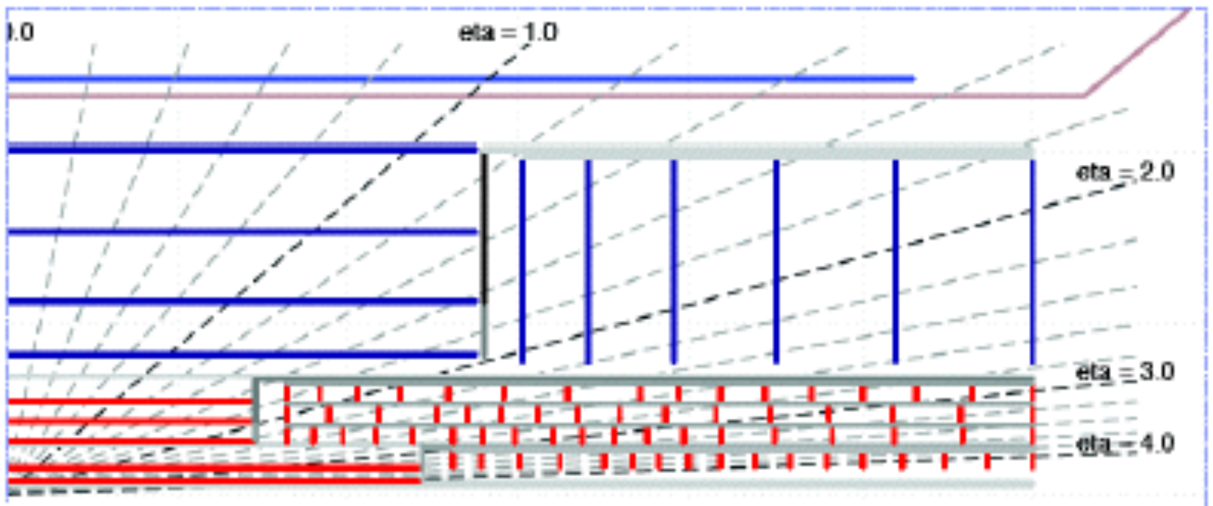
The High Luminosity LHC (HL-LHC) prediction from LoF



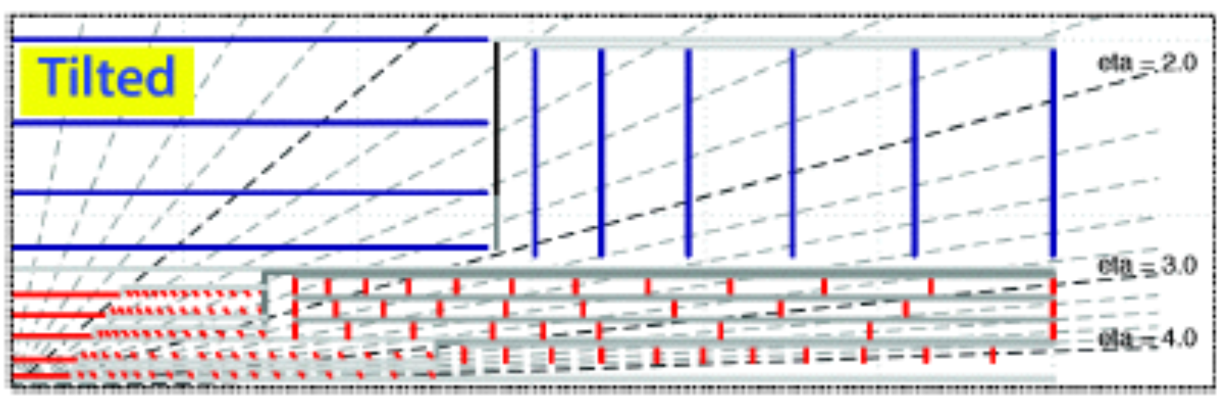


New ITK Layouts

Extended barrel layout



Tilted layout



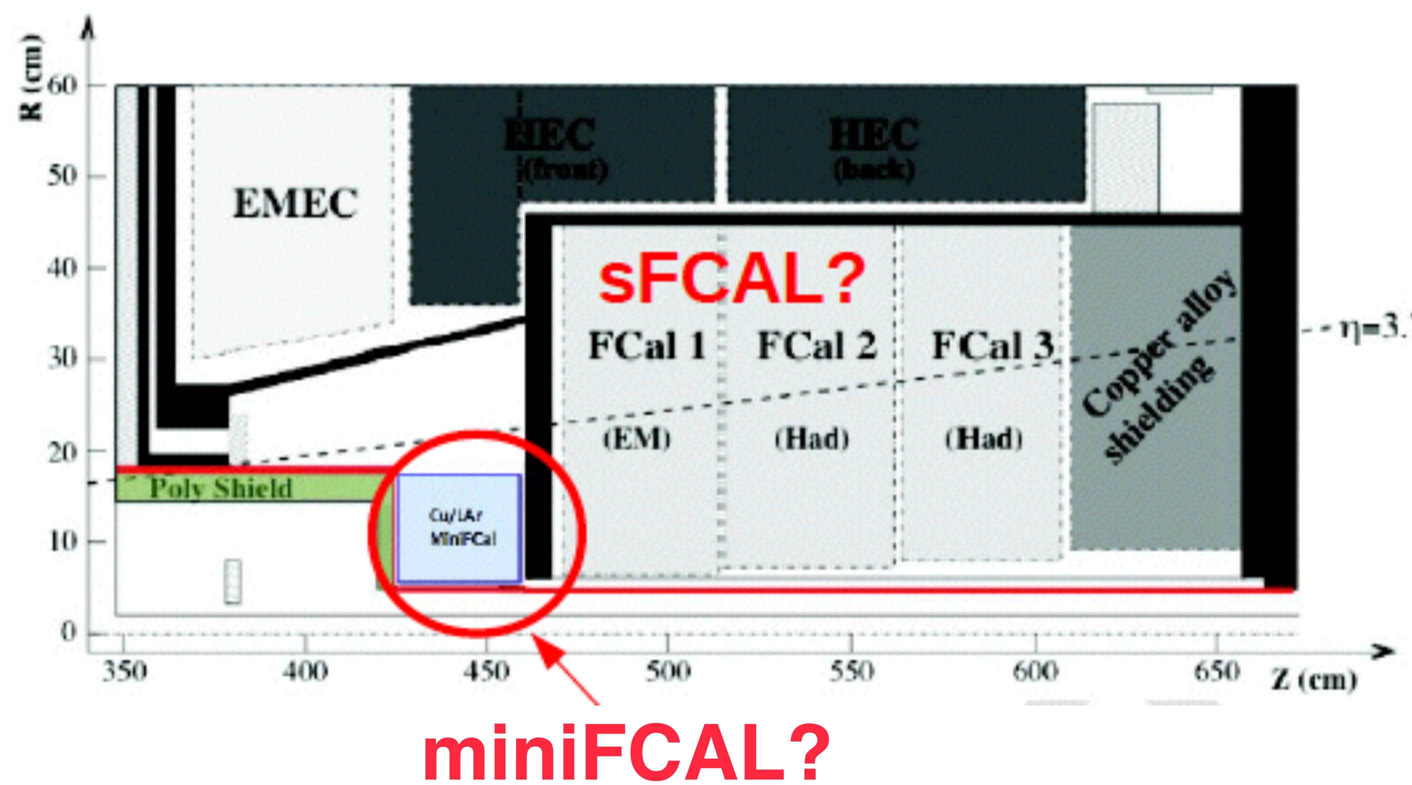
Exact studies needed still to be discussed

- ITK Layout task force working since December 2014 on defining a final detector layout
- Expect the task force to narrow it down to a few options over the next months
- These will ideally need to be evaluated with a full suite of performance studies beyond tracking-only results
  - Measure b-tagging performance
  - Pileup jet suppression
  - Ensure that photon conversion reconstruction is efficient

Switch to release 20 needs to be done before these studies can start in earnest

sFCal, miniFCal or FCal?

- Upgrade of FCal to sFCal is major and potentially risky intervention
- Need detailed performance studies to justify the upgrade
- First studies already on-going
  - Currently using ITK LoI layout for material simulation and truth info for “forward tracking”
  - Will need to be updated to more realistic material model

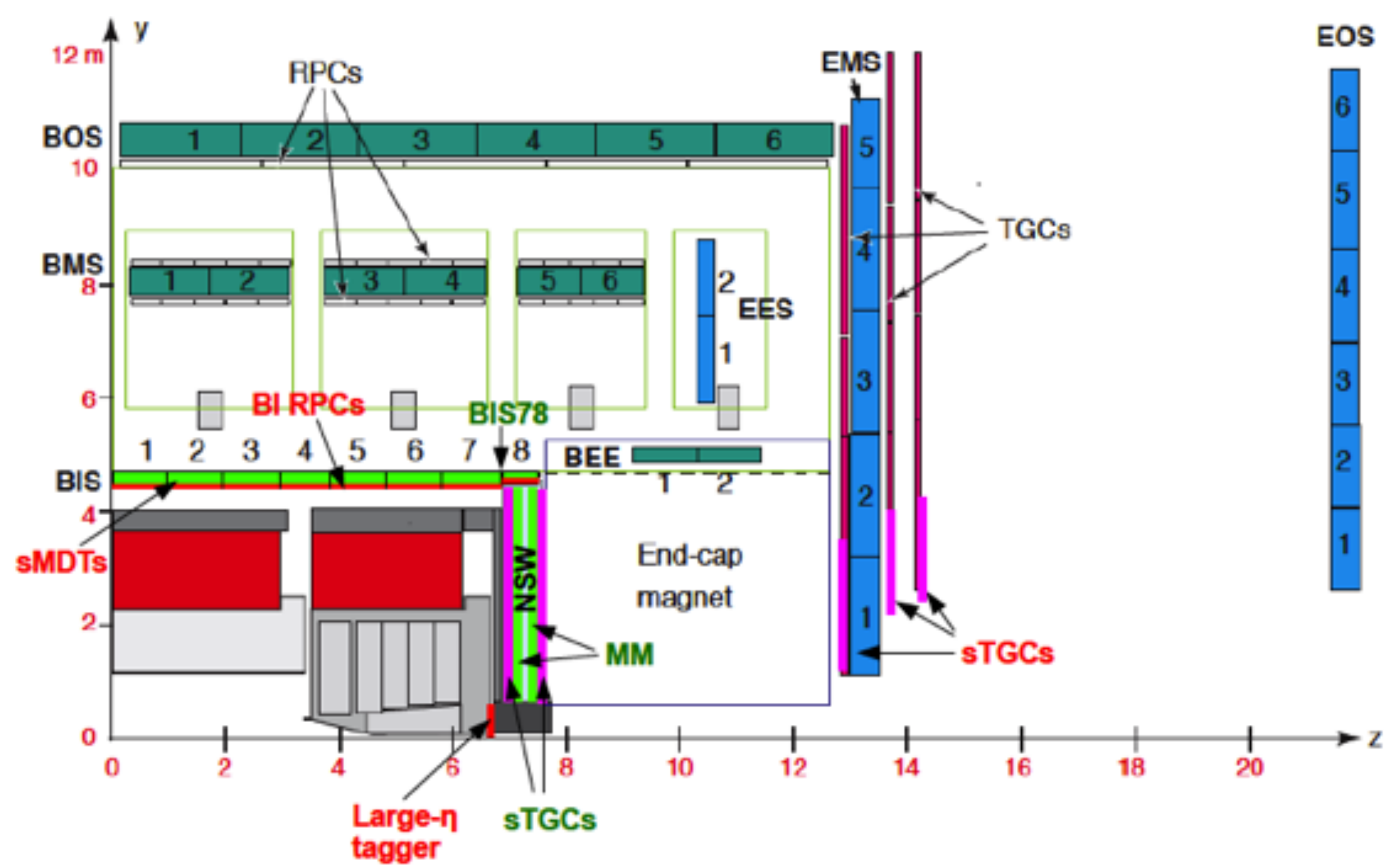


- Also want to be prepared to study impact of a possible miniFCal if sFCal is not feasible or desirable.

Tracking Perfomance

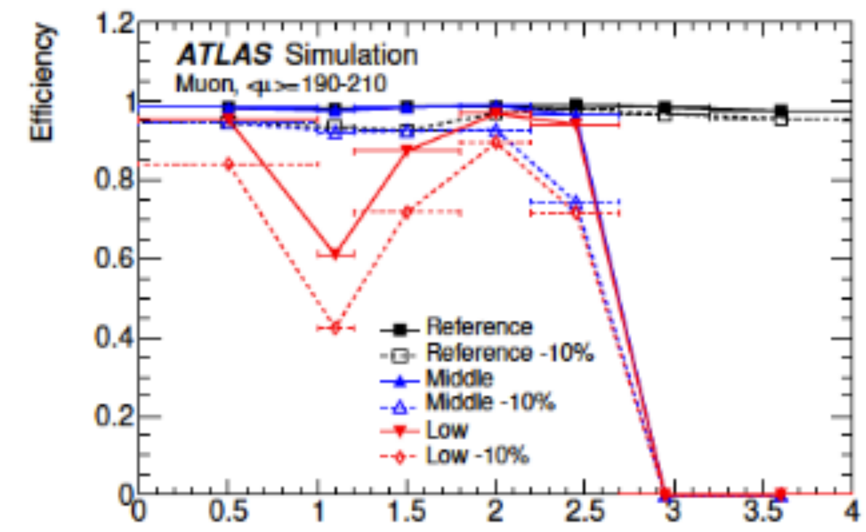
- ID -> ITK: better p_T resolution for tagged/combined muons
- BI RPC/sMDT: extend L1 barrel acceptance + allow to maintain high trigger efficiency
- Large eta tagger extend muon ID to eta=4 (with p_T from ITK)
- MDT trigger + sTGC on Big Wheel allow to maintain single mu triggers with pT>~20 GeV at high luminosity

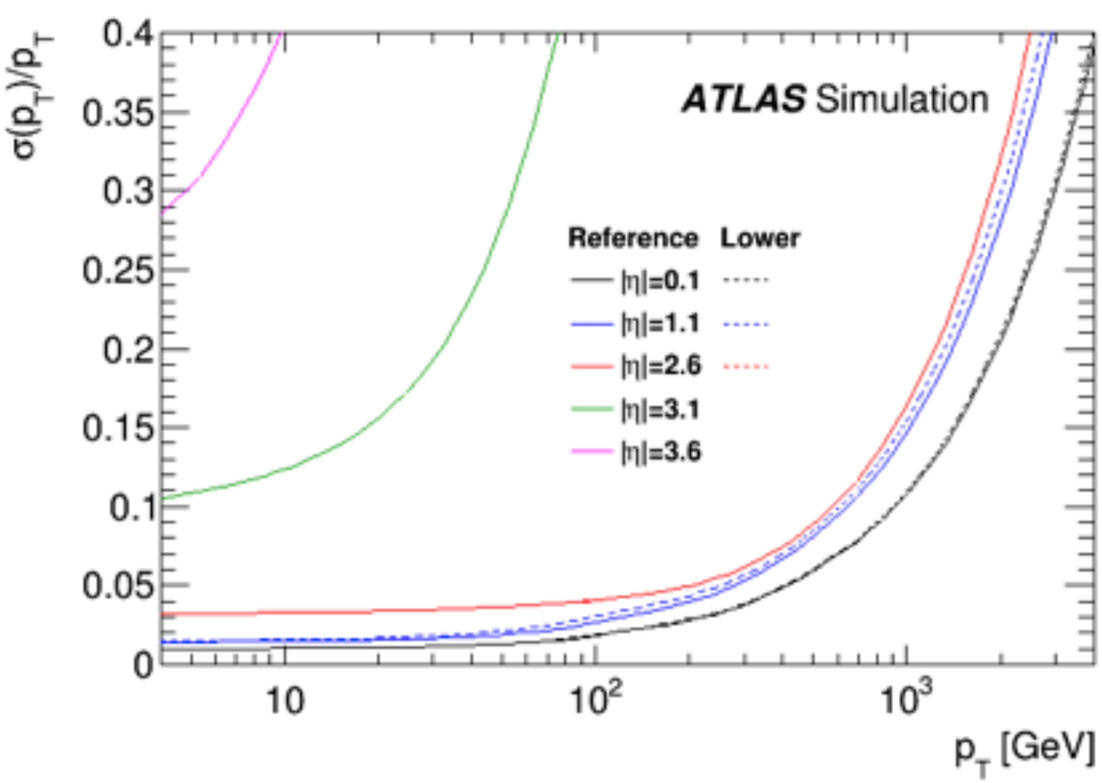
Muon system Phase-2 upgrade: Reference scenario

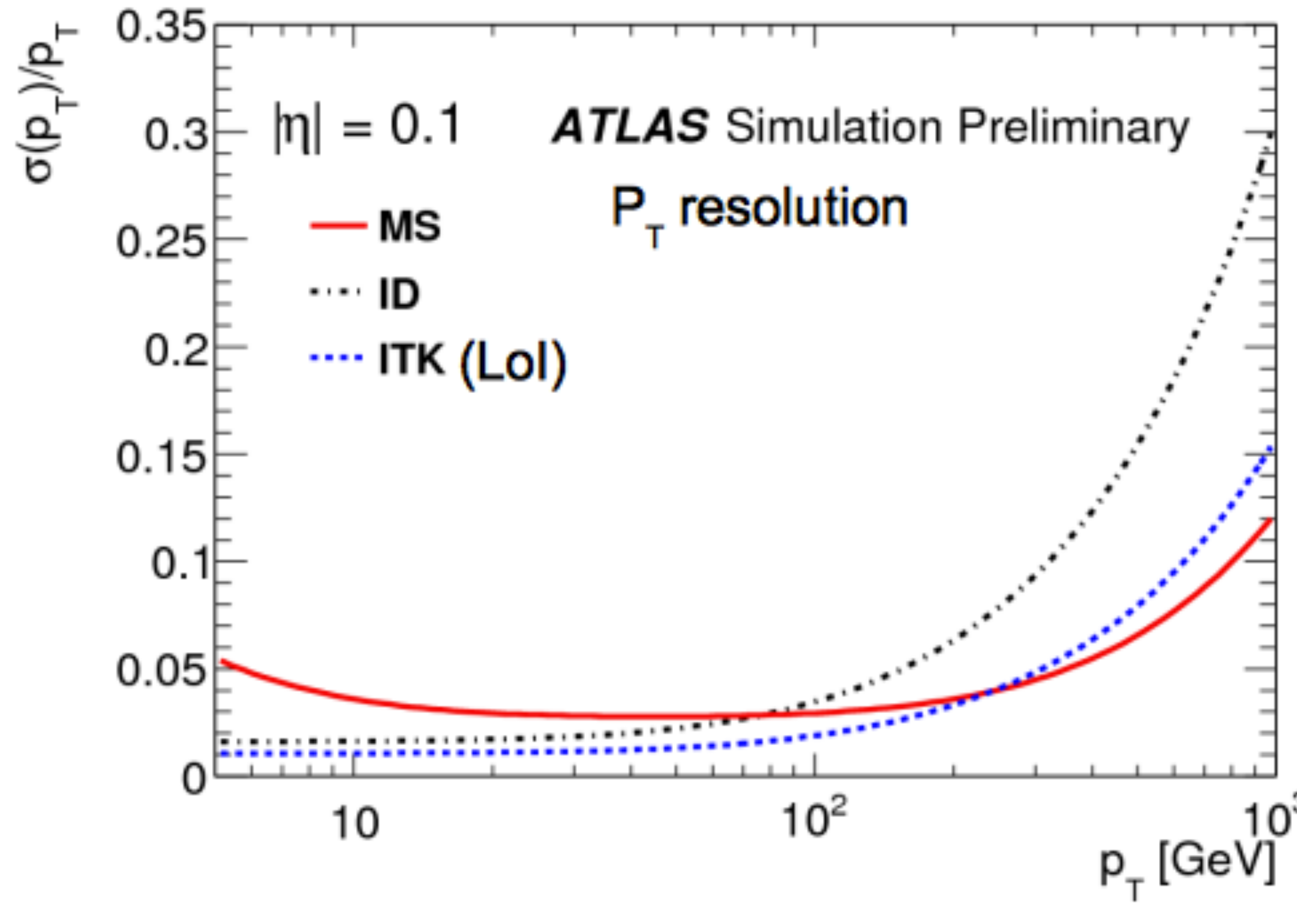


Muons: reconstruction performances

- Efficiency, good for reference ITK (worse for down-scoped versions)
- Combined Muons upt to |eta|=3
- 3<|eta|<4 : large eta tagger
  - poor resolution / fake rate ~1%
- p_T resolution:
  ITK much better at low-p_T wrt ID
  Muon Spectrometer unchanged







pT resolution: improves at low-pT (ITK dominates)
similar at high-pT (MS dominates)

Trigger

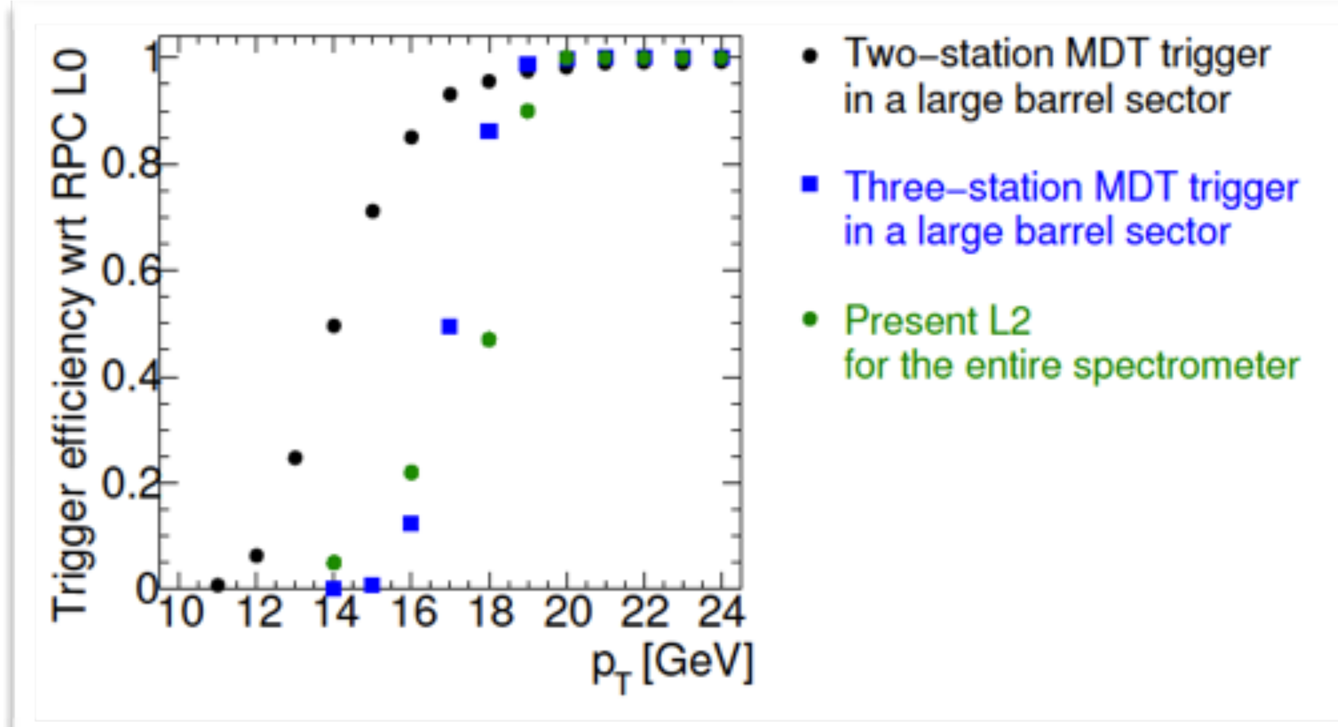
- Large part of the muon upgrade consists in the replacement of MDT/TGC/RPC electronics to cope with new trigger scheme.

- MDT trigger: improved sharpness of pT thresholds. Basically same as present L2 but at L0.
  Allows to keep single muons triggers with pt>20 GeV

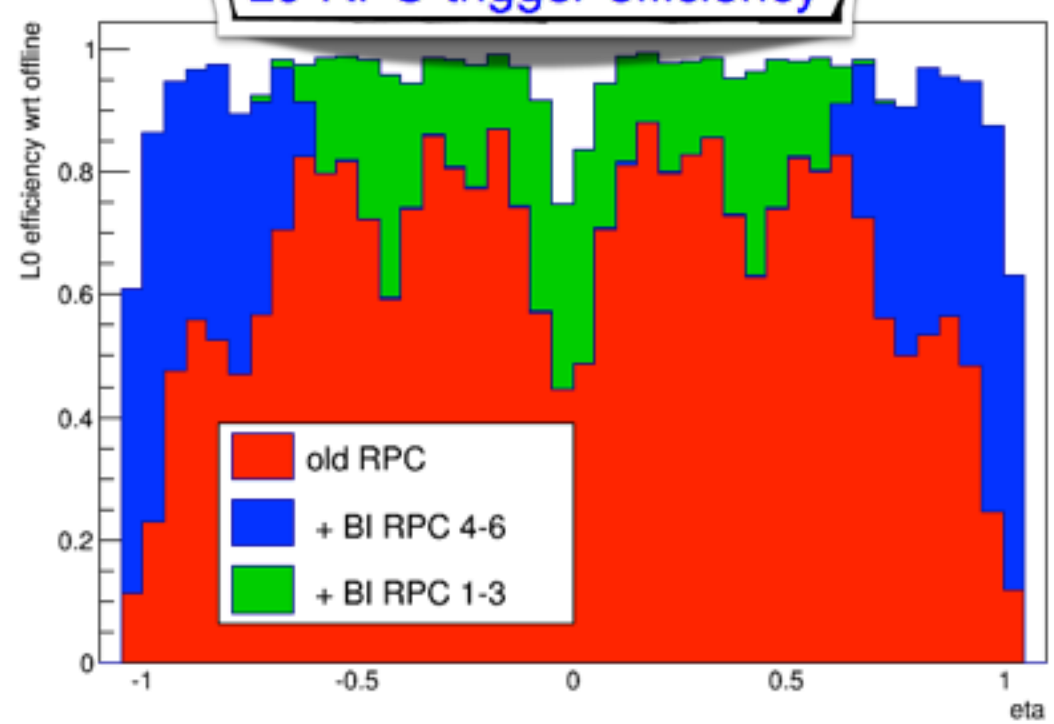
- RPC on BI layer:
  - increase present L1 geometrical acceptance from 78% to 95%
  - robustness against reduced efficiency of the old RPC system

So far studies using MDT BI hits to minic RPCs

Detailed simulation studies of trigger acceptance and rates are needed.



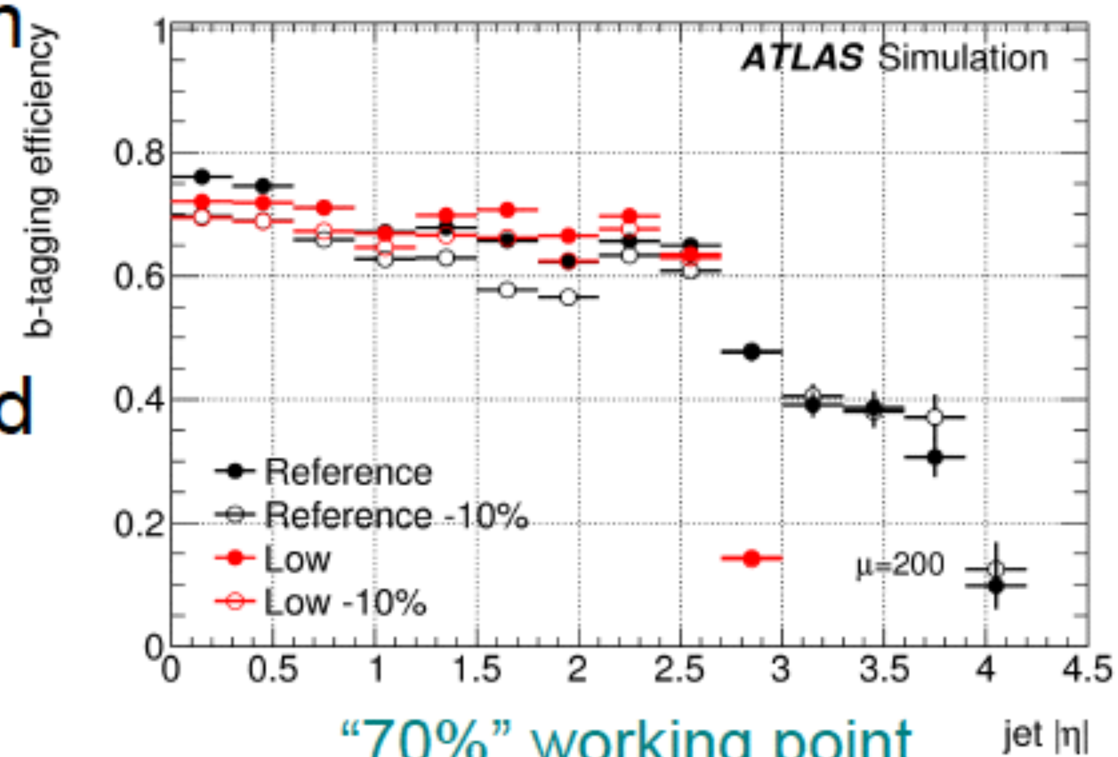
L0 RPC trigger efficiency



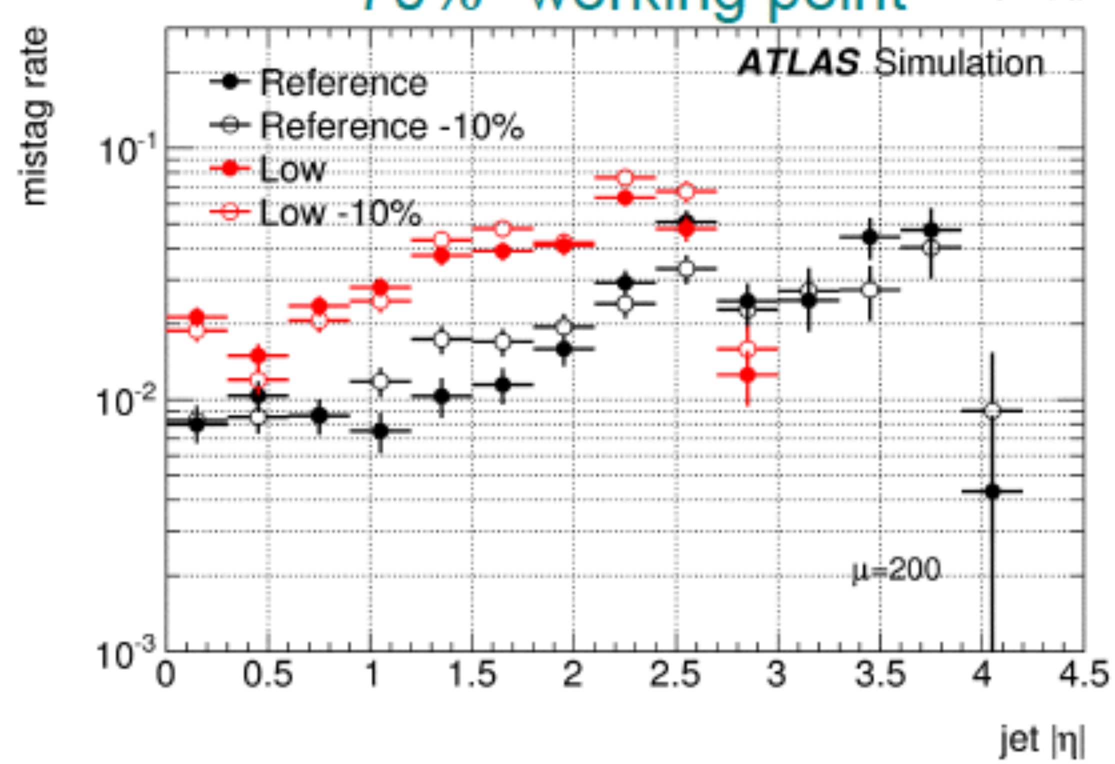
Scenario with reduced HV setting on old RPCs to cope with phase-2 rates

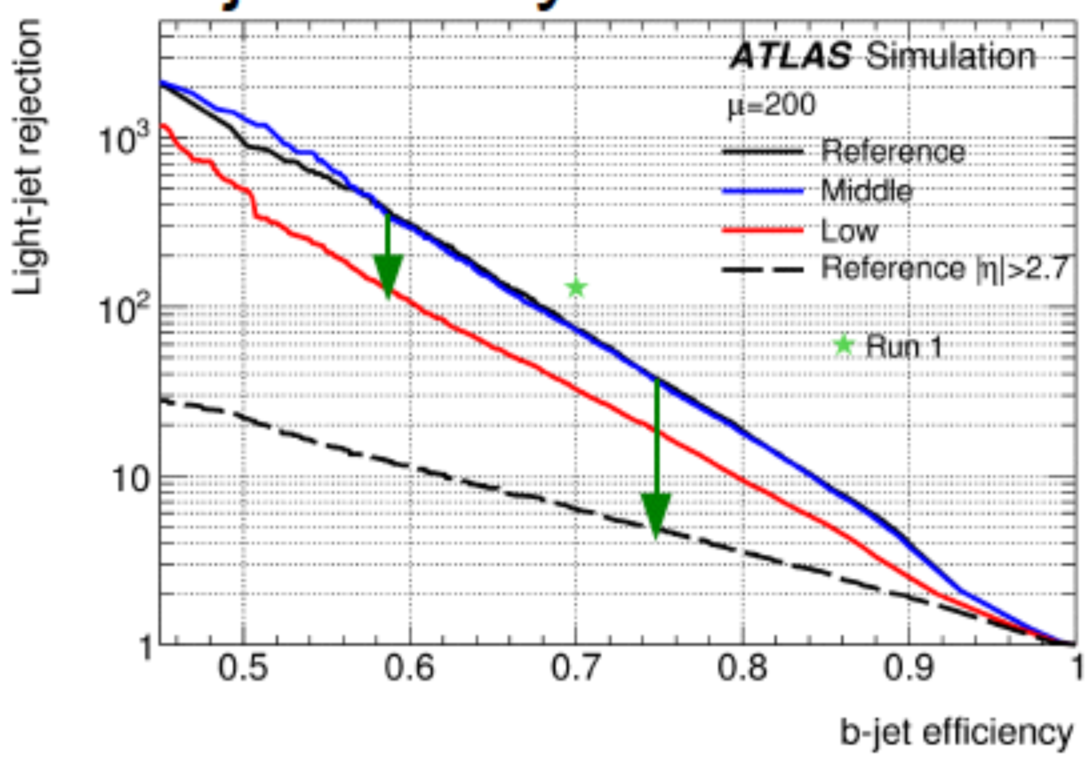
B-Tagging

- Studied with MV1 algorithm
- Reference and Middle similar, Low is x2-3 worse
- Can do b-tagging with forward tracker at degraded performance
- -10% scenario degrades rejection by x1.5-2



"70%" working point

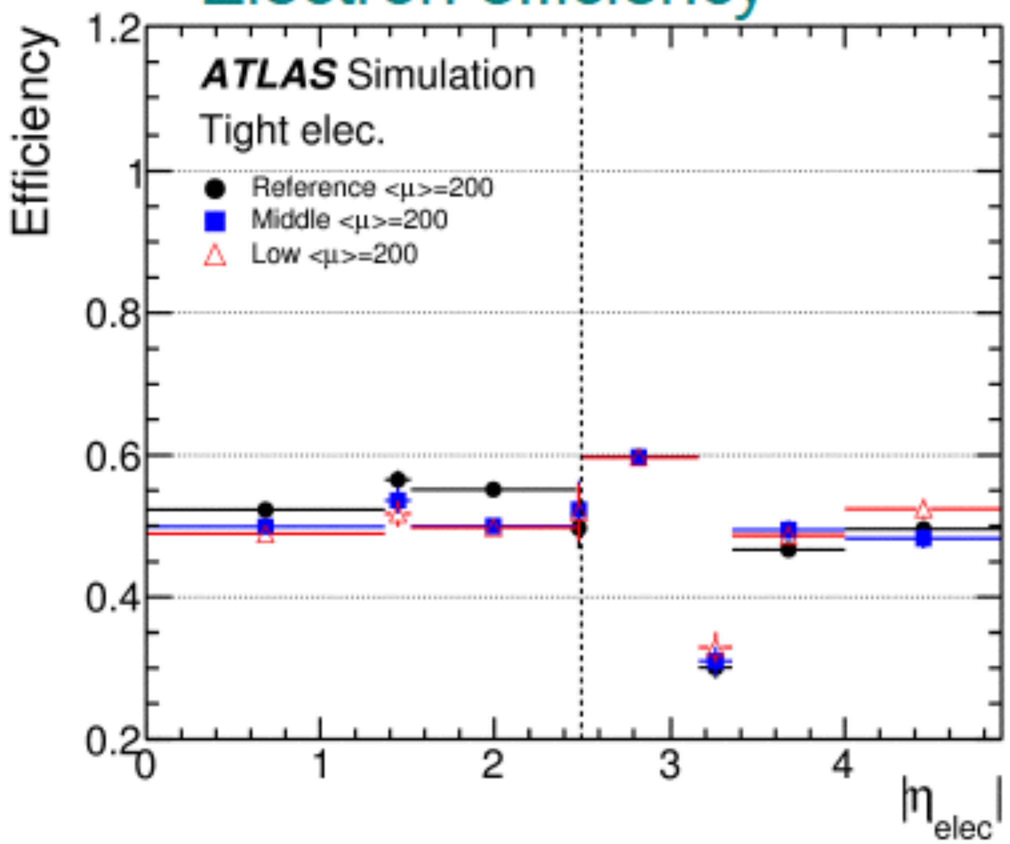




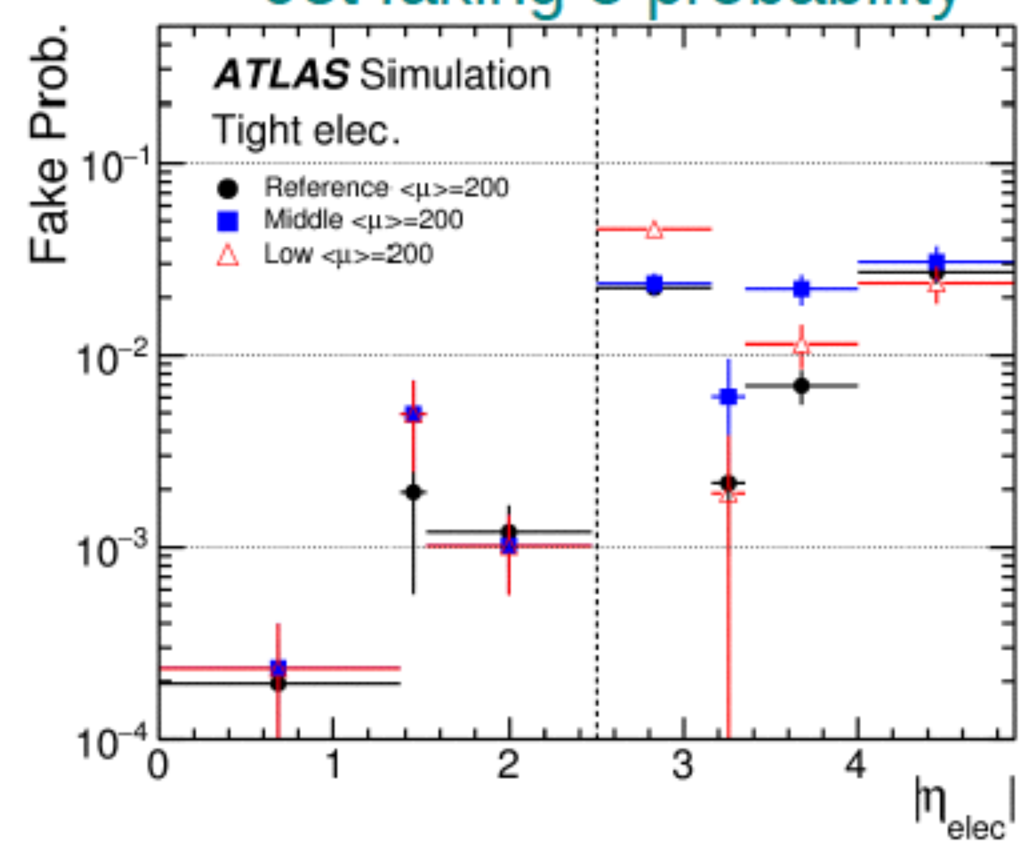
Electron performance

- Run-2 cut based electron algorithm used
  - No retuning for high pileup or loss of TRT information
- Results in rather poor efficiency
  - Few % improvement in reference scenario
- Factor 2 extra fake rejection at high η with forward tracker

Electron efficiency



Jet faking e probability

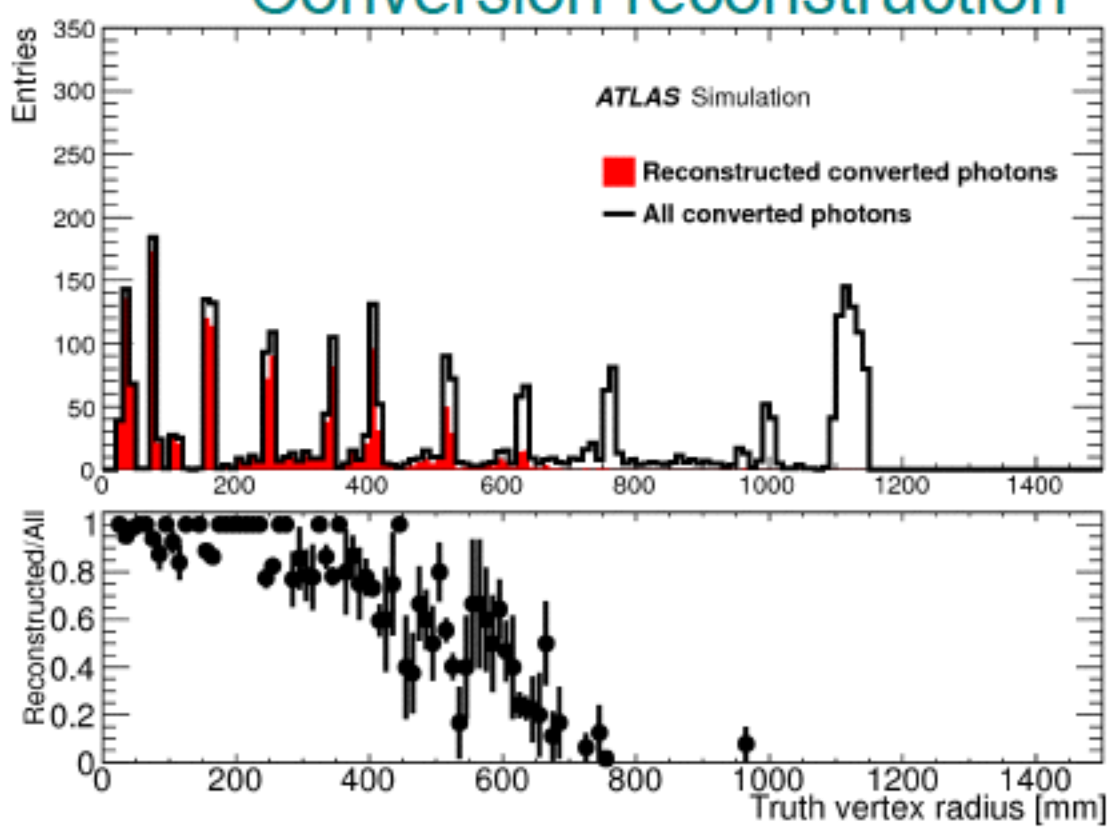


Photon Performance

- New conversion finder optimized for ITk layout
  - Runs after standard tracking
  - Loosen selection on $n_{hits,}$ impact parameters, large radius seeding
- Still need to study general photon ID at μ>80 with ITk

Less material in ITk
→ less conversions

Conversion reconstruction



Conversion probability