ATLAS Upgrades

Mostly to preserve current performance at higher instantaneous and integrated luminosity

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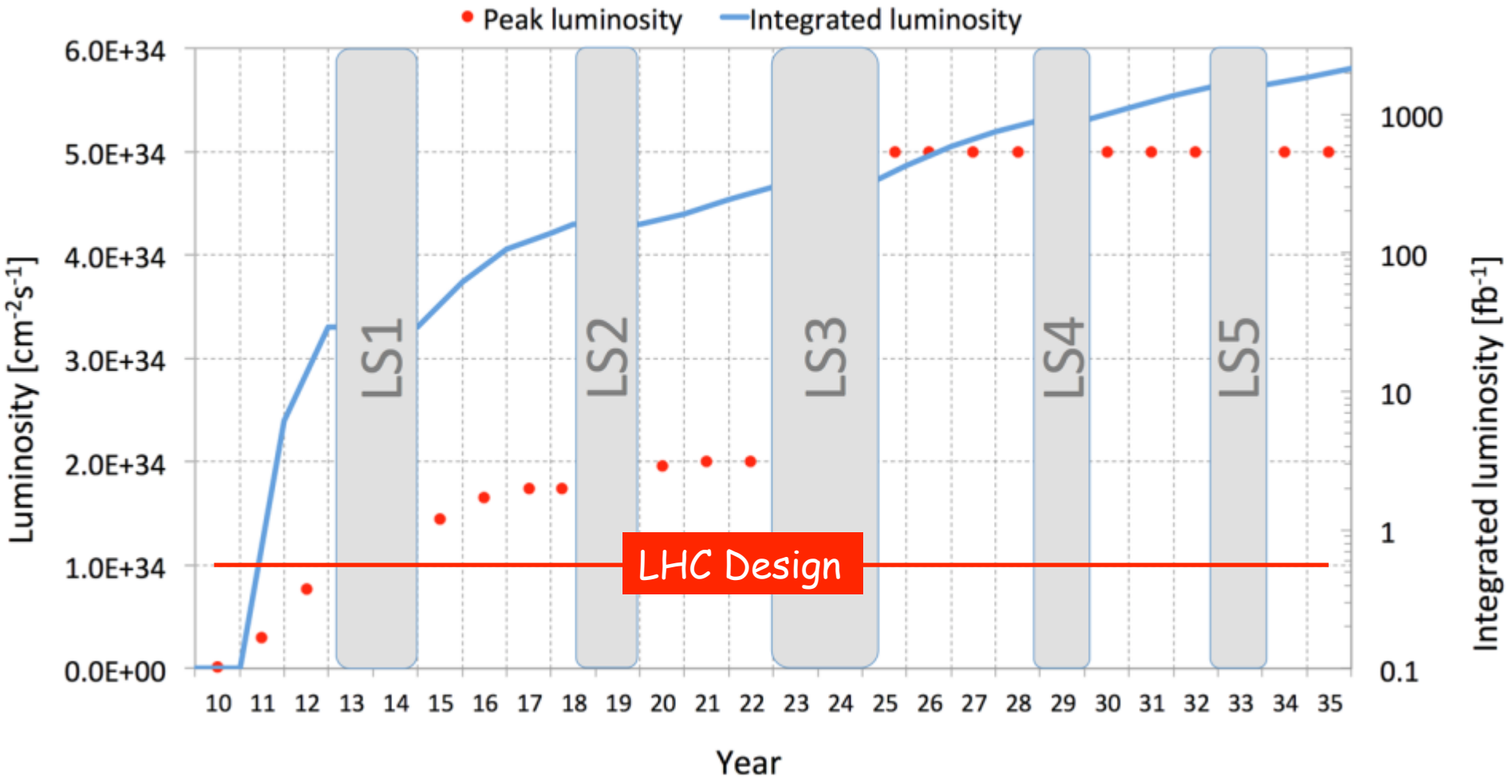
ATLAS Upgrades

- Requirements and schedule driven by LHC luminosity and shutdown plans
  - Detector performance sensitive to instantaneous luminosity
  - Radiation damage and detector aging related to integrated luminosity
  - Detector upgrades typically require long shutdown (LS) for installation
  - Some Trigger and DAQ (TDAQ) upgrades and computing upgrades can be installed at other time
- Biased selection of topics

LHC Schedule

LHC Luminosity Goal

from ECFA High luminosity LHC Experiments Workshop 2014, Aix-les-Bain



LHC Luminosity Goal

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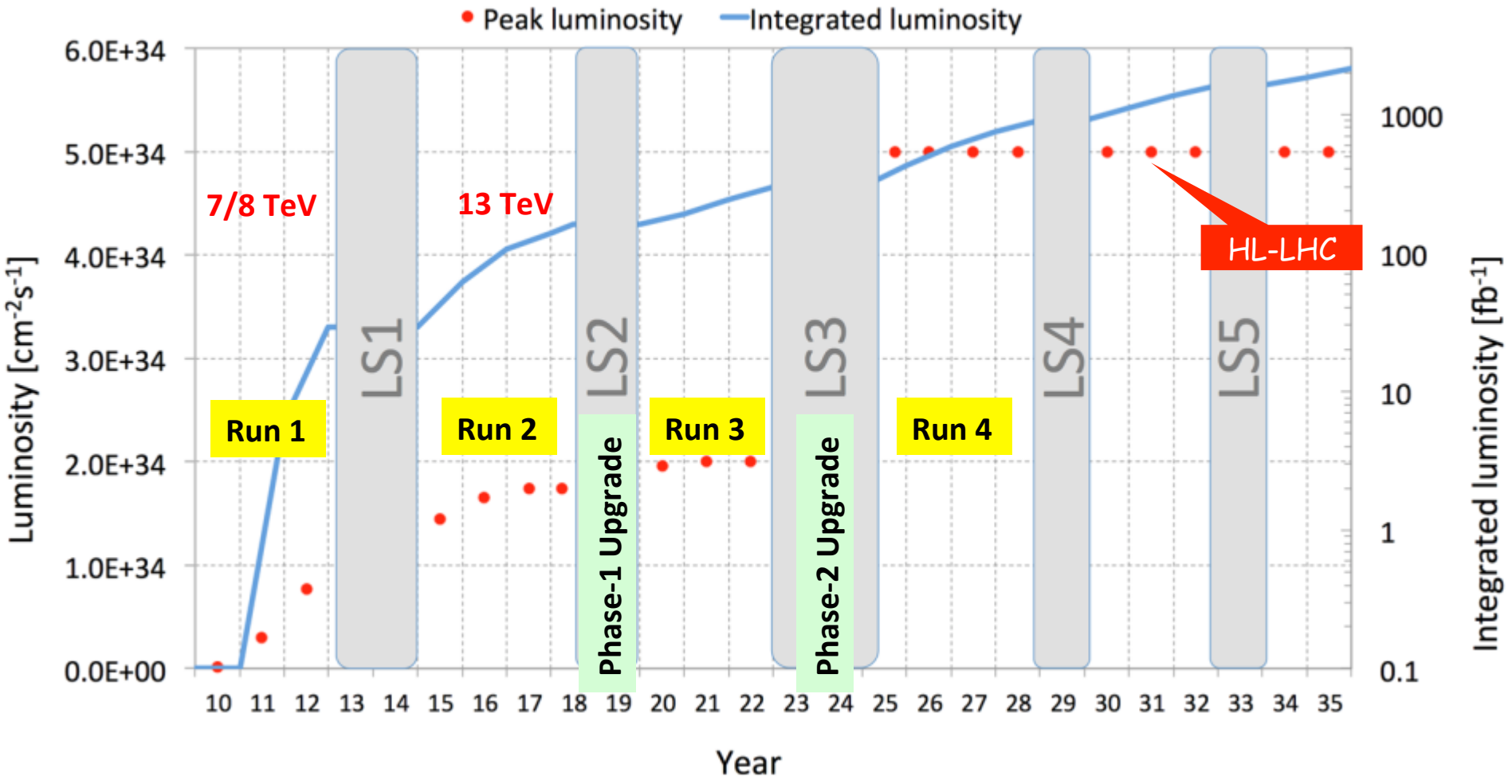


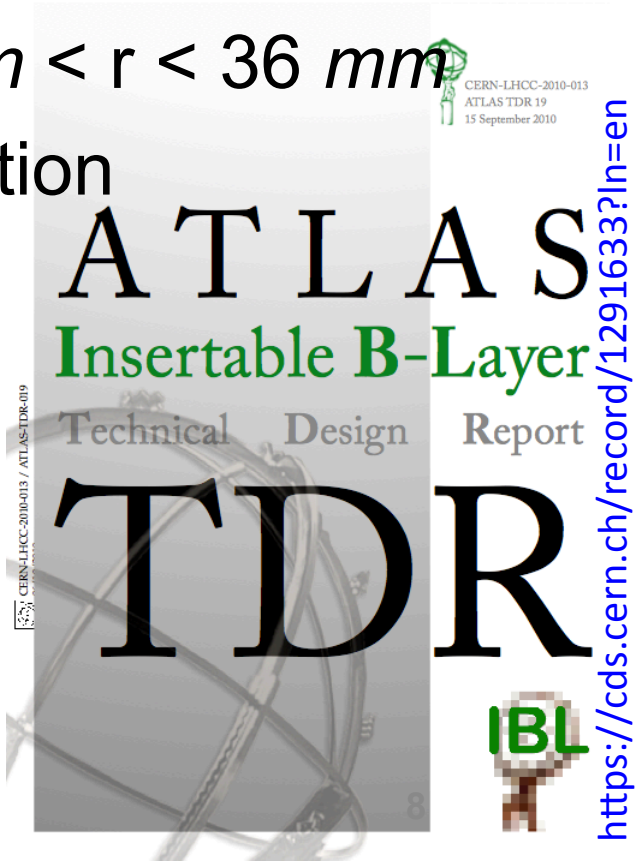
LS1

LS1 Upgrades

- Pixel Insertable B-Layer (IBL)
- Level-1 Muon trigger (L1Muon)
- Fast Tracker (FTK)

Insertable B-Layer (IBL)

- Inside current pixel detector and closer to IP
  - R ~ 35 *mm* vs 50 *mm*
- Smaller and thinner beam pipe
  - 25 *mm* < R < 29 *mm* vs 29 *mm* < r < 36 *mm*
- Improved track parameter resolution
  - Especially impact parameter
  - Primarily for low p_T tracks
- *b*-tagging



IBL Layout

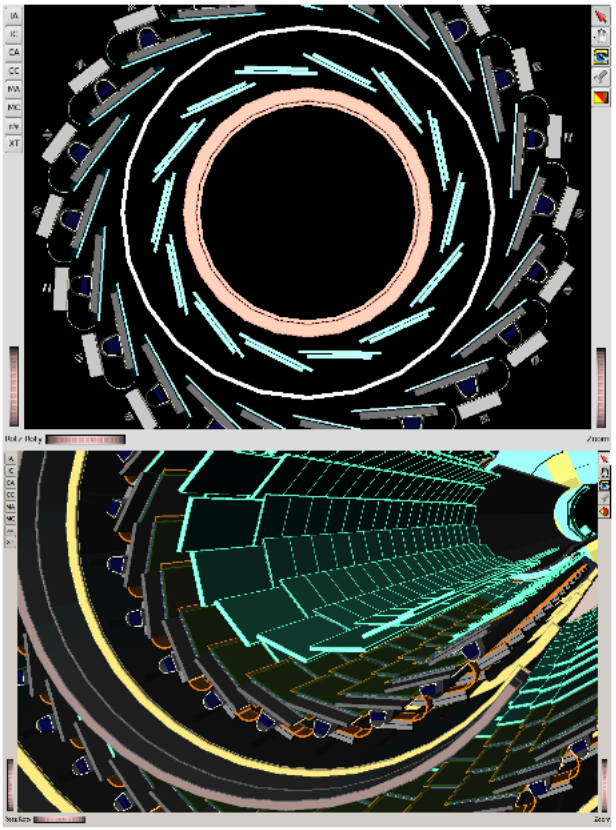


Figure 12. (top) XY view showing the new (smaller) beam pipe, the IBL with modules, staves and s tube and the Pixel *B*-layer all implemented in the ATLAS geometry model; (bottom) 3D view of tl inside the Pixel detector illustrating the geometrical arrangement.

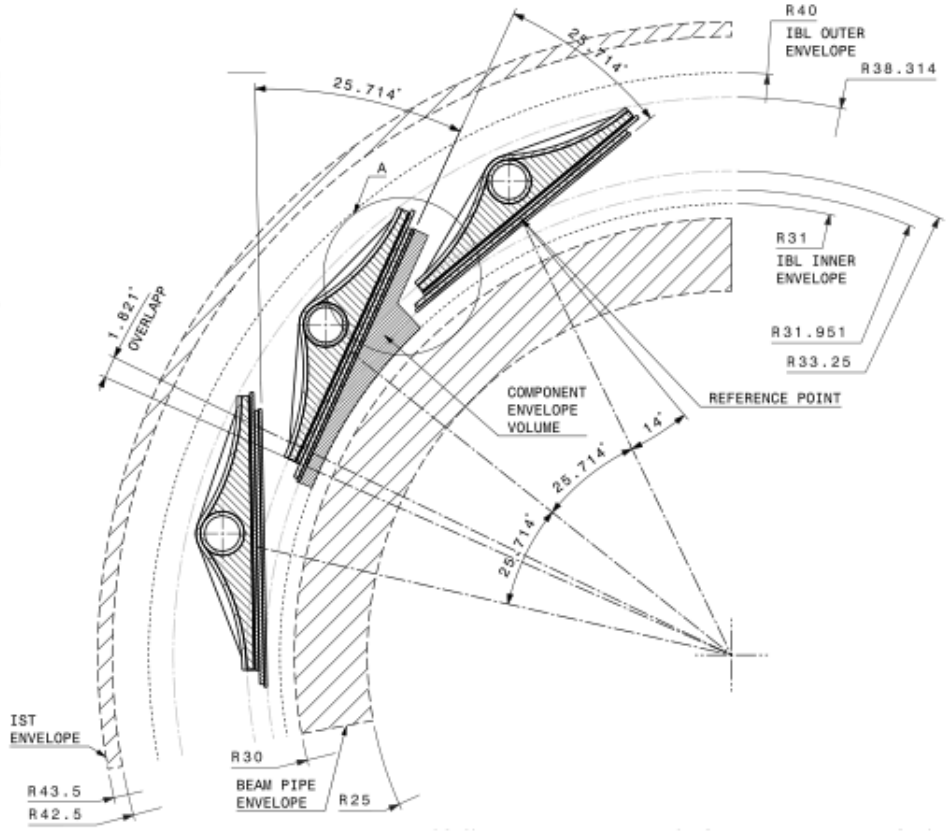
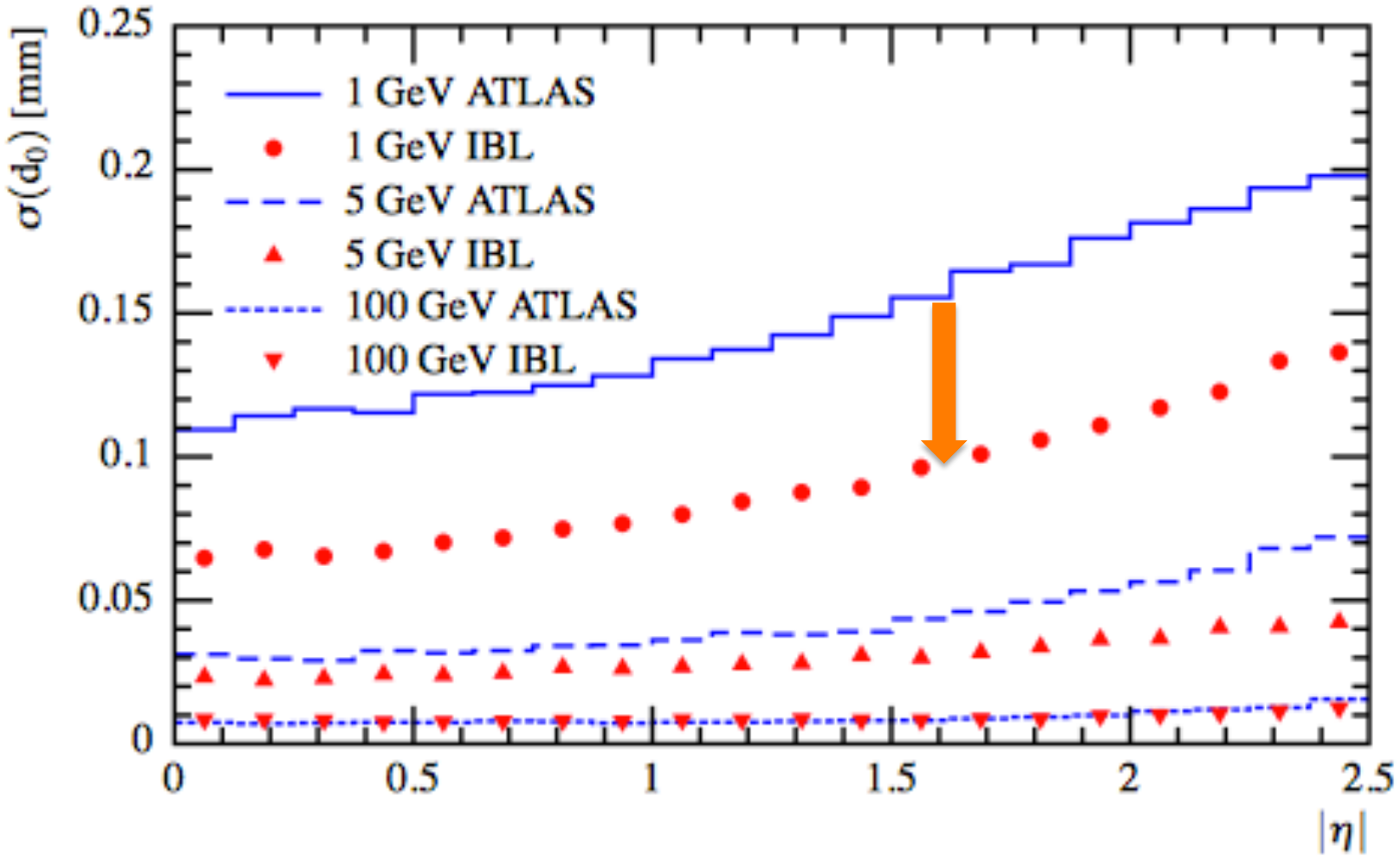
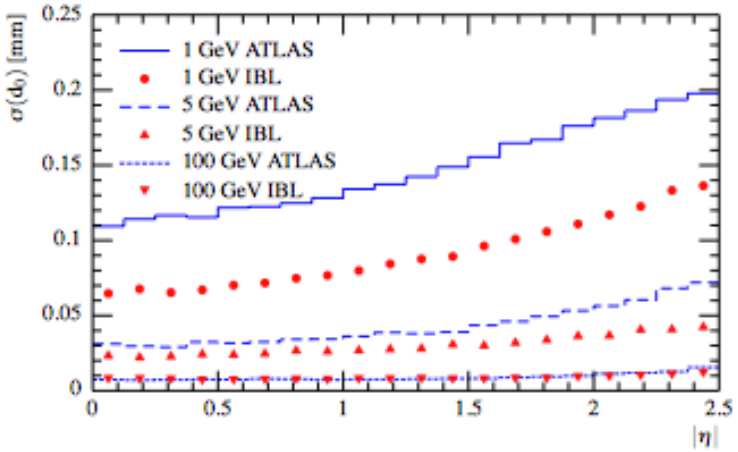
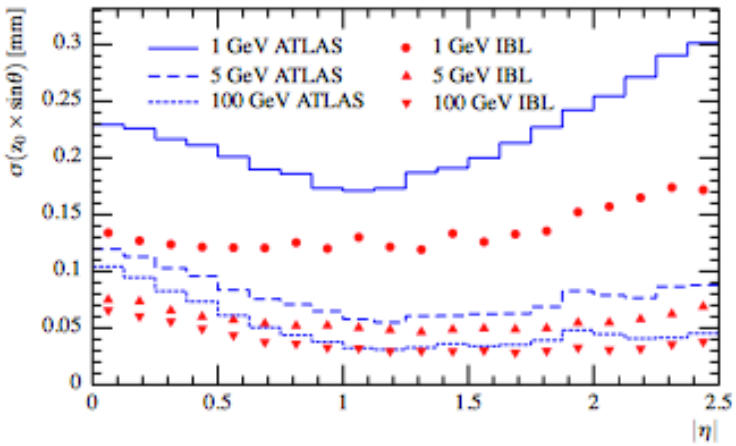


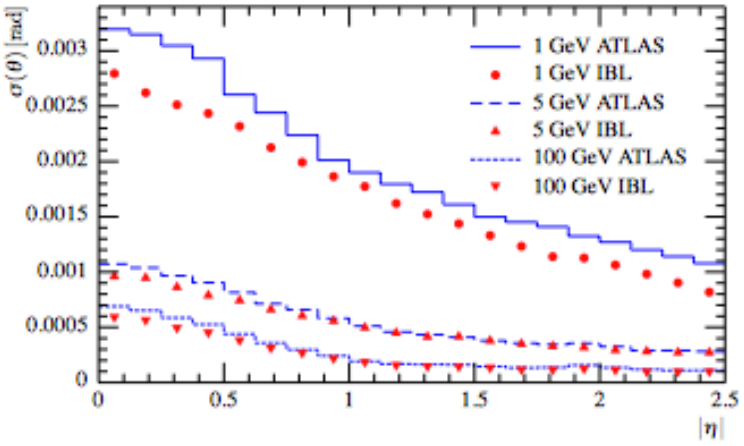
Figure 5. IBL layout: $r\phi$ view.

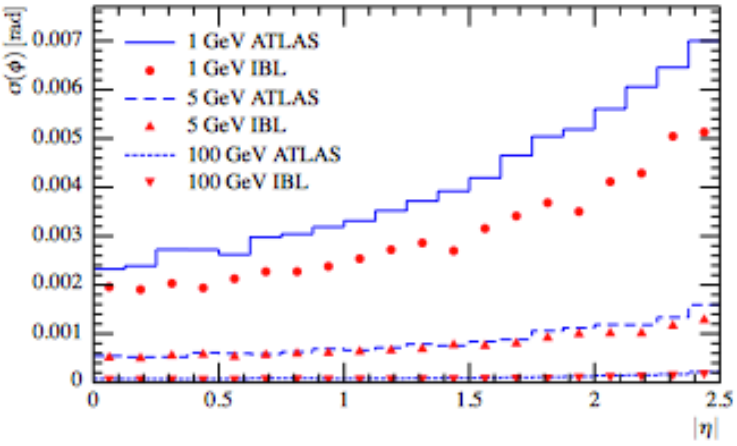
Transverse Impact Parameter

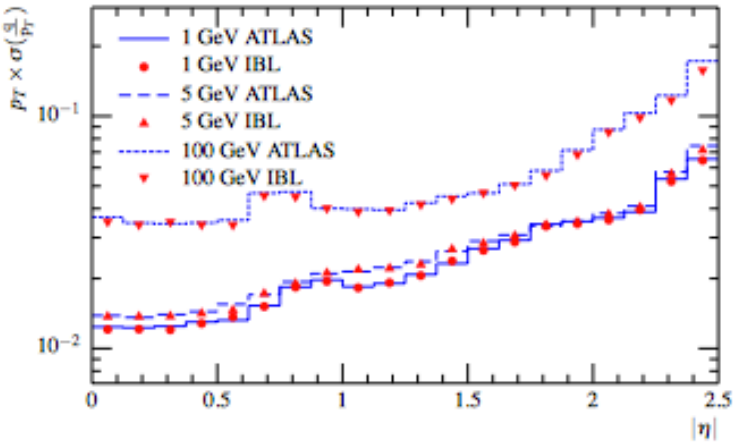



$\sigma(d_0)$ [mm]
1 GeV ATLAS
1 GeV IBL
5 GeV ATLAS
5 GeV IBL
100 GeV ATLAS
100 GeV IBL
$|\eta|$

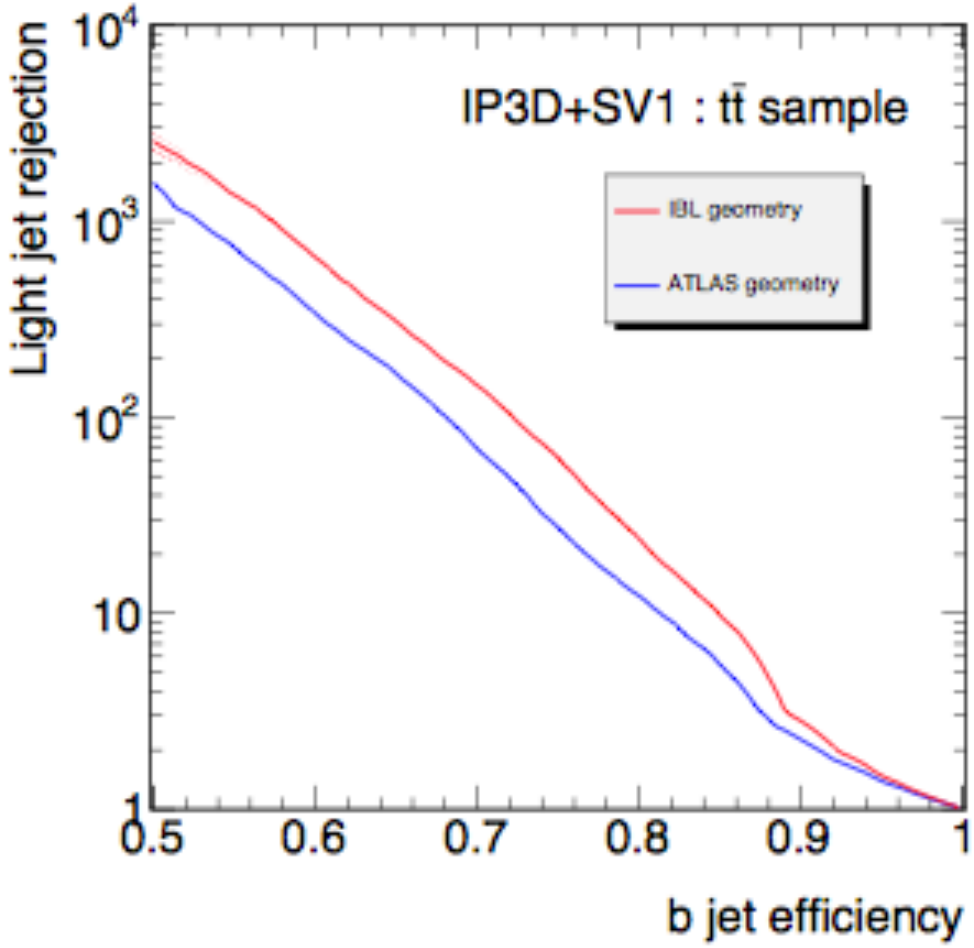

$\sigma(z_0 \times \sin\theta)$ [mm]
1 GeV ATLAS
5 GeV ATLAS
100 GeV ATLAS
1 GeV IBL
5 GeV IBL
100 GeV IBL
$|\eta|$


$\sigma(\theta)$ [rad]
1 GeV ATLAS
1 GeV IBL
5 GeV ATLAS
5 GeV IBL
100 GeV ATLAS
100 GeV IBL
$|\eta|$


$\sigma(\phi)$ [rad]
1 GeV ATLAS
1 GeV IBL
5 GeV ATLAS
5 GeV IBL
100 GeV ATLAS
100 GeV IBL
$|\eta|$

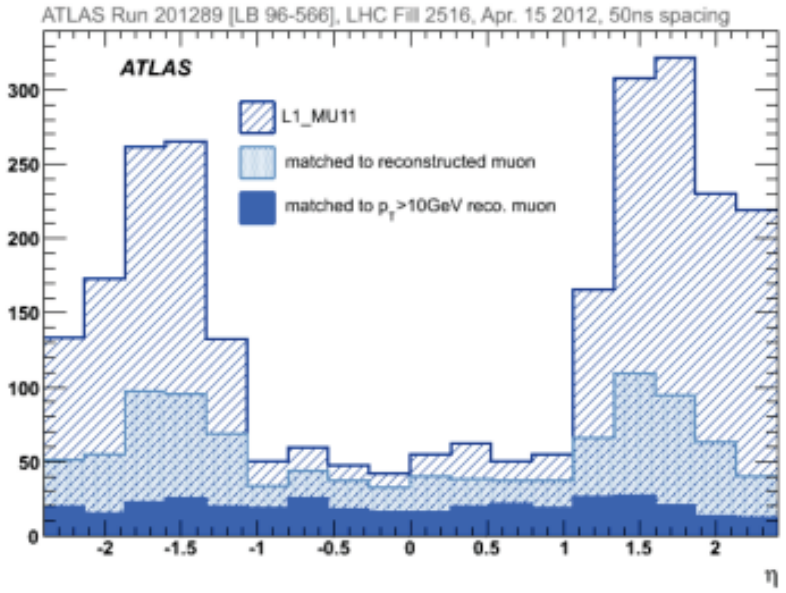

$p_T \times \sigma(\frac{q}{p_T})$
1 GeV ATLAS
1 GeV IBL
5 GeV ATLAS
5 GeV IBL
100 GeV ATLAS
100 GeV IBL
$|\eta|$

b-tagging Efficiency



L1Muon

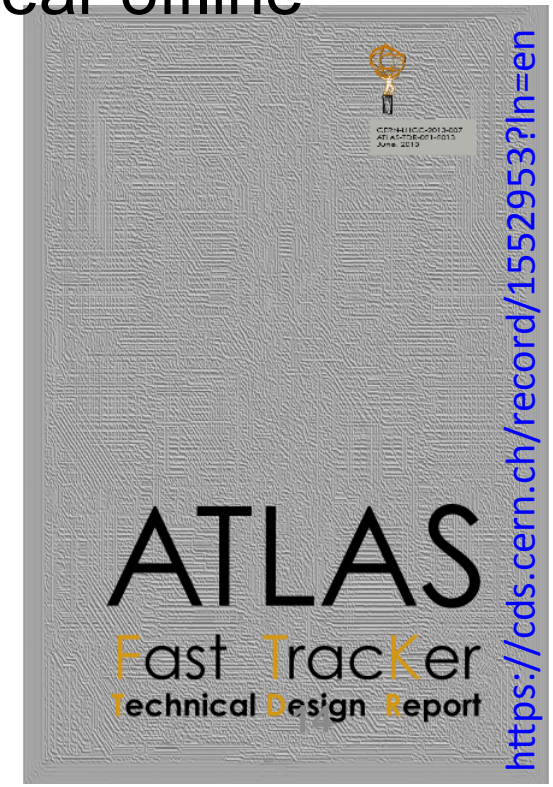
- Endcap L1Muon rate during Run 1 ~90% fakes
- Level-1 trigger bandwidth constraint
- Remediation during LS1
  - Incorporate chambers in front of endcap toroids into L1Muon logic
  - Improve shielding to reduce background



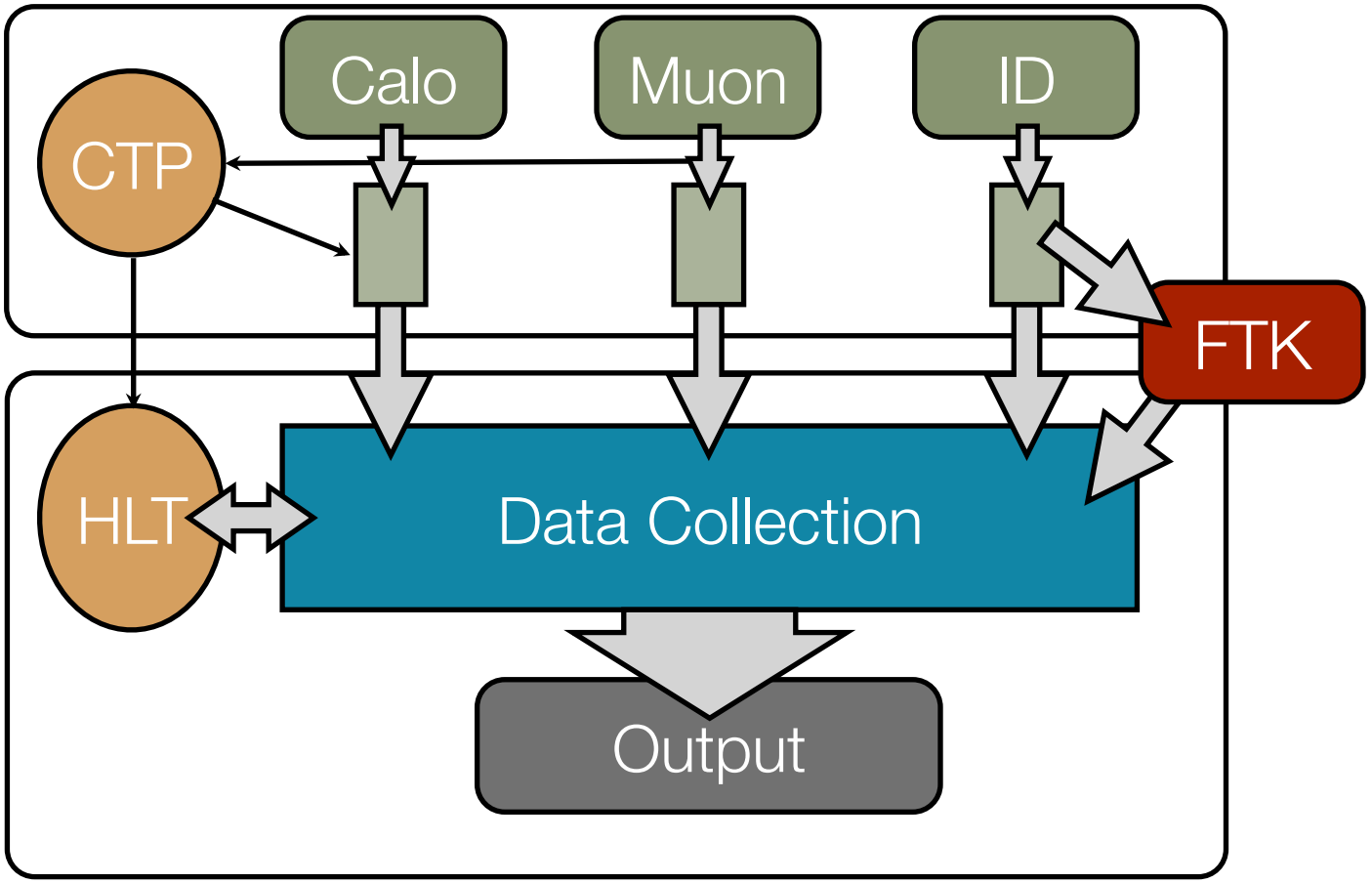
Addressed more thoroughly in Phase-1 New Small Wheel upgrade

Fast Tracker (FTK)

- Track information important for triggering
- Pure software-based track reconstruction prohibitively expensive at high luminosity
  - Except for specific regions of interest (ROI)
- Full track reconstruction by FTK with near offline resolution in under 100 μsec
- Global information (rather than ROI) useful for certain trigger decisions
- Novel uses:
  - Unseeded *b* and τ finding
  - Trackless jets

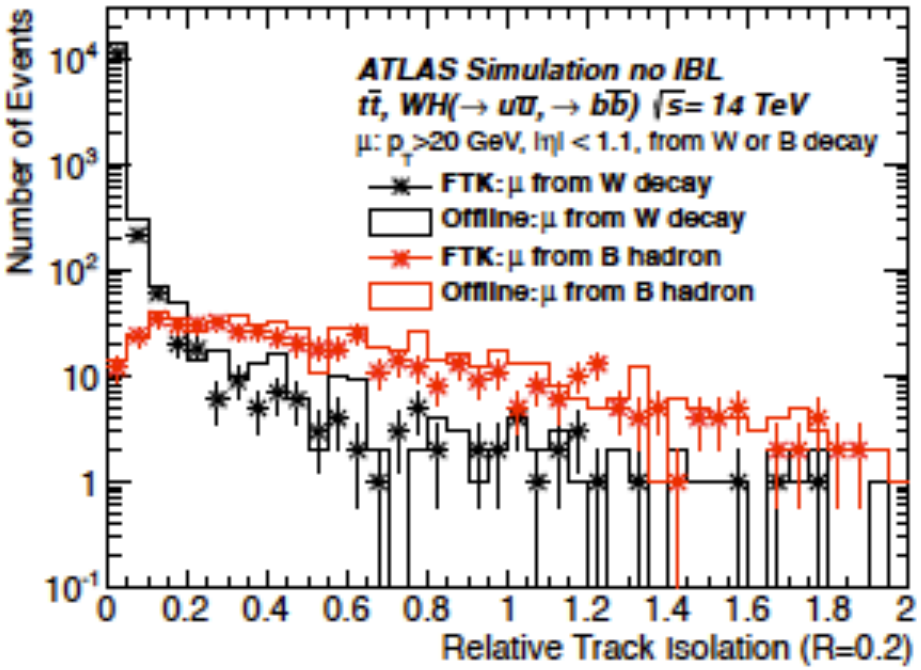


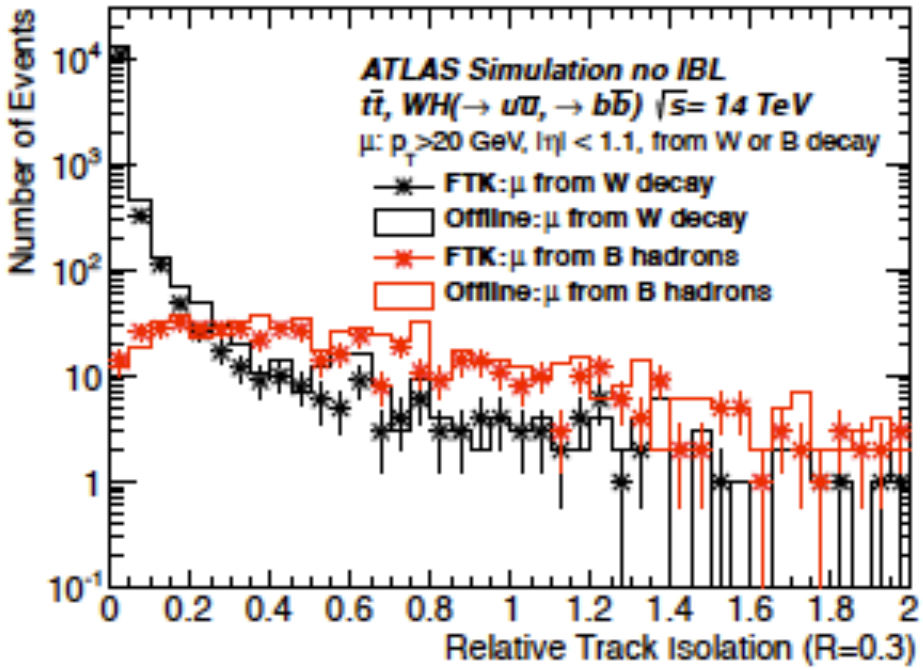
FTK in ATLAS Trigger System



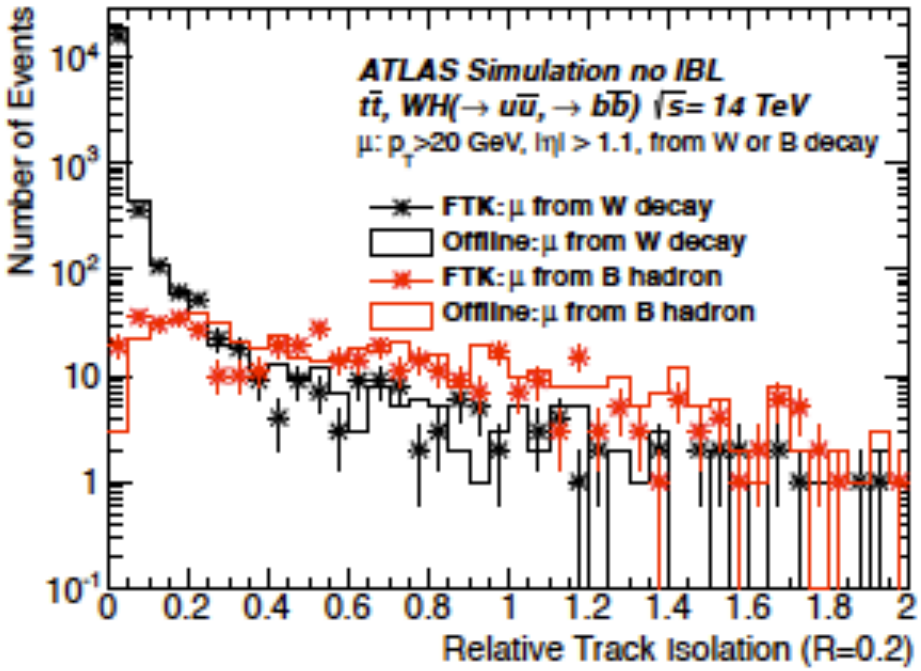
Full detector tracking @ 100kHz through pattern matching in custom **Associative Memories** Latency: O(100μs)

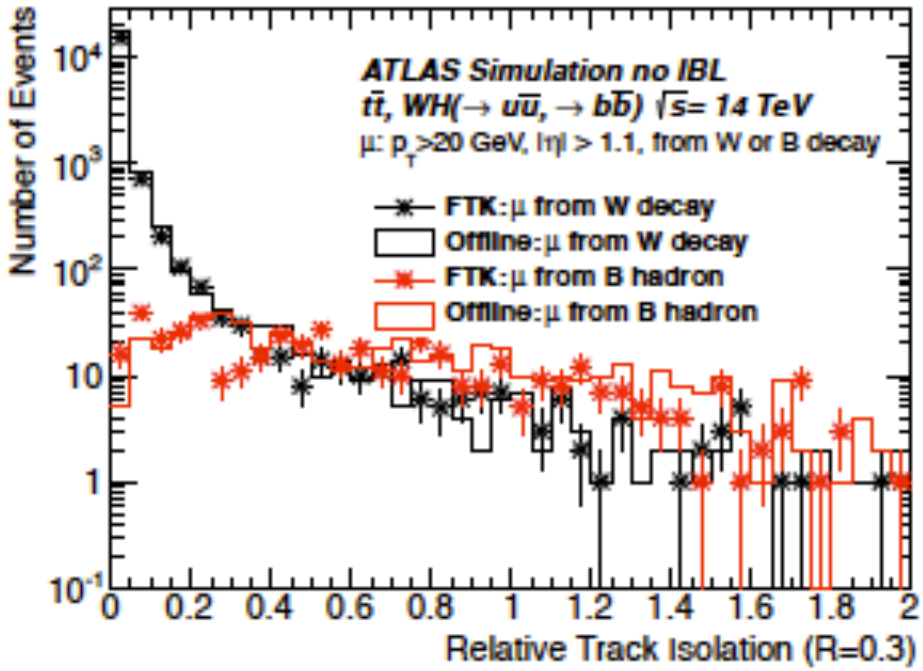
Lepton Isolation Performance





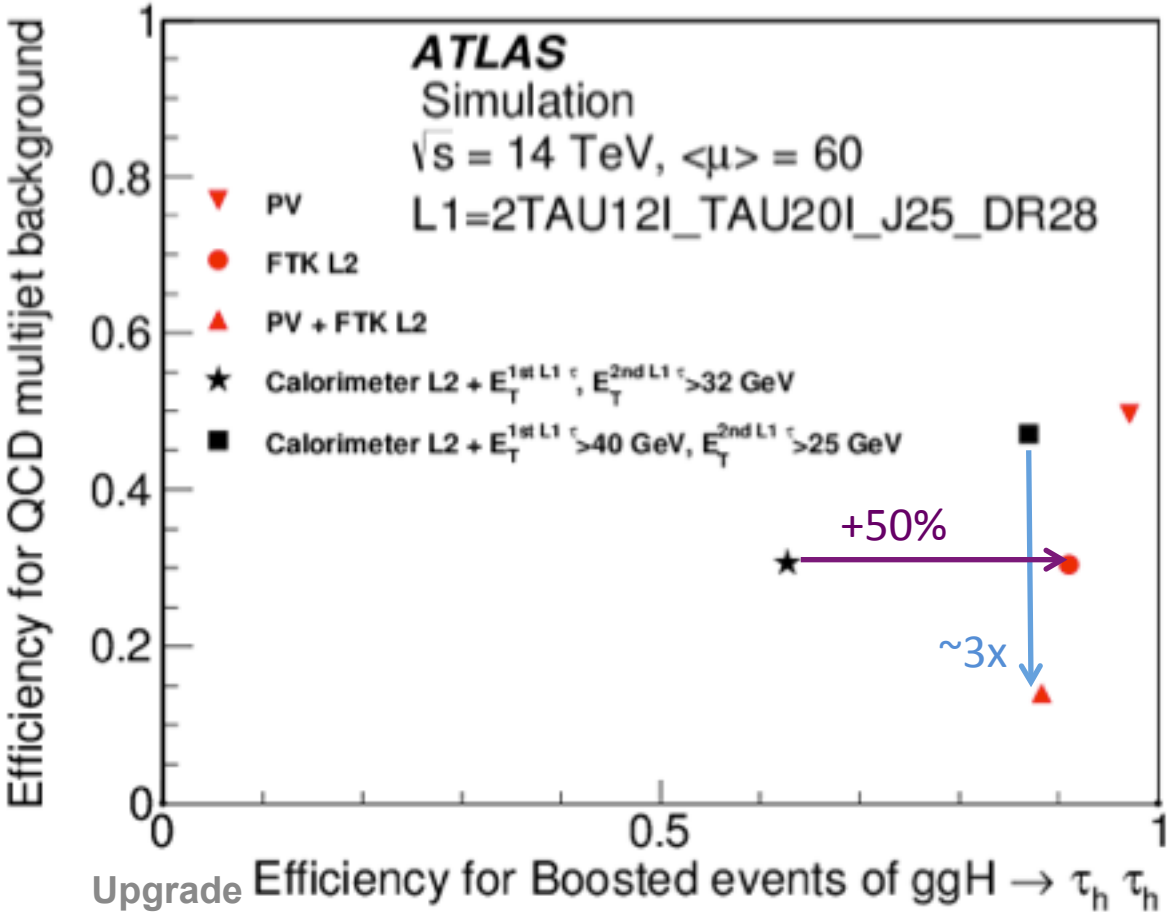
b-tagging Performance



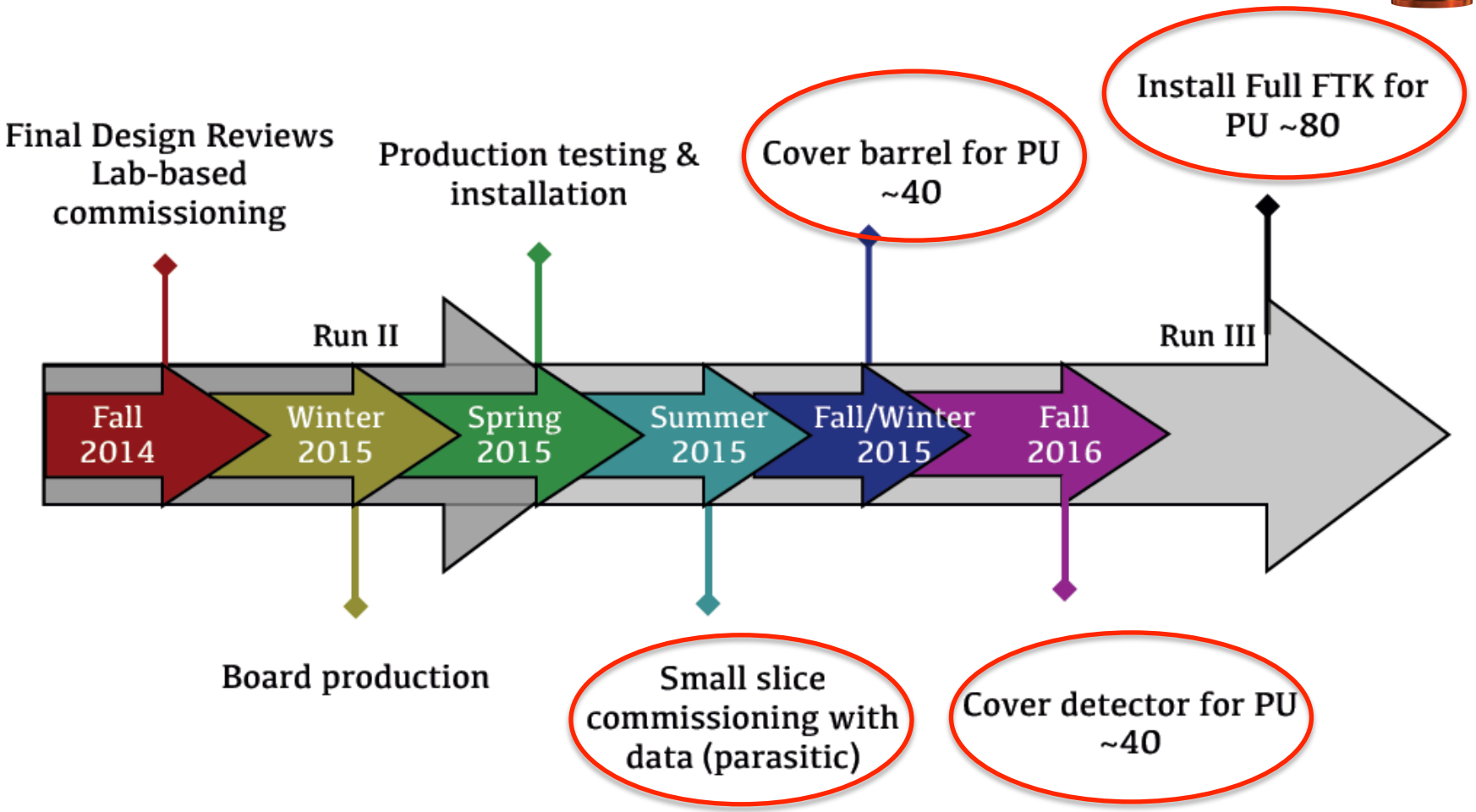


τ Selection Performance

- 3x greater background rejection for fixed ε
- 50% higher ε for fixed background rate



FTK Timeline



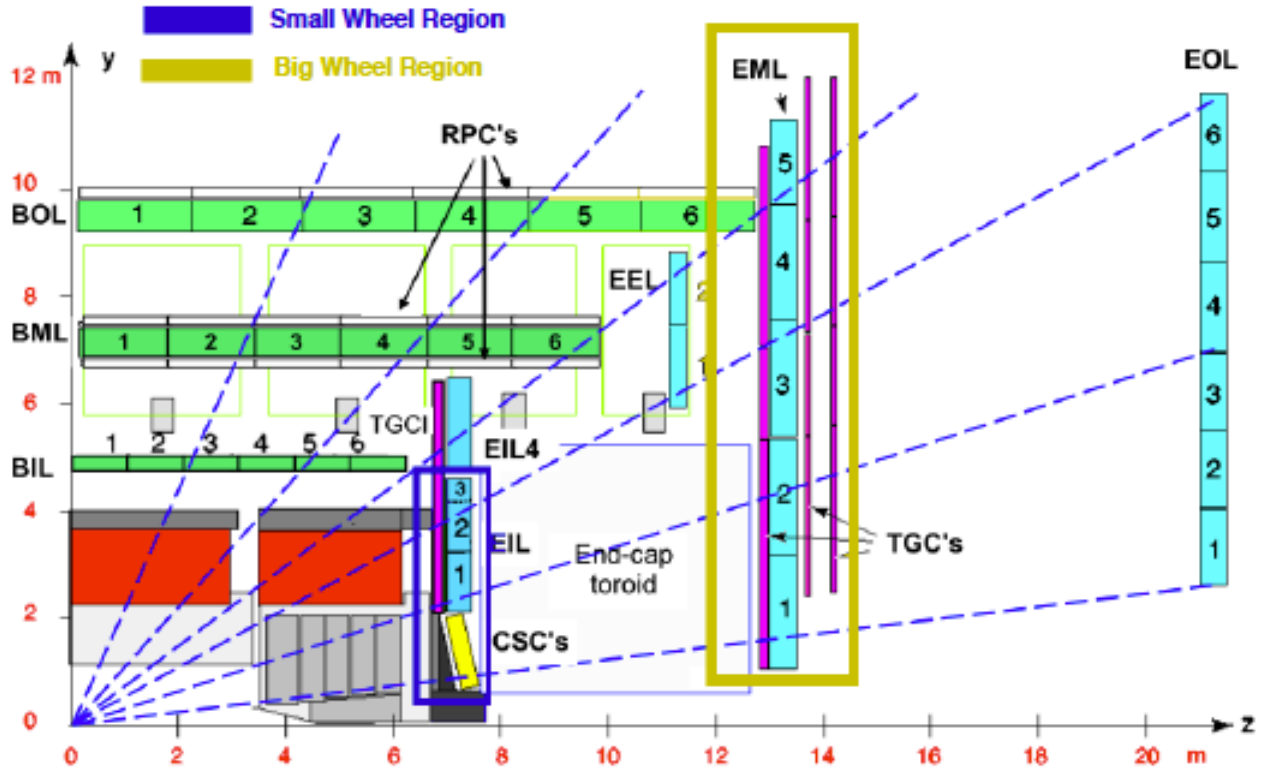
LS2 – PHASE-1

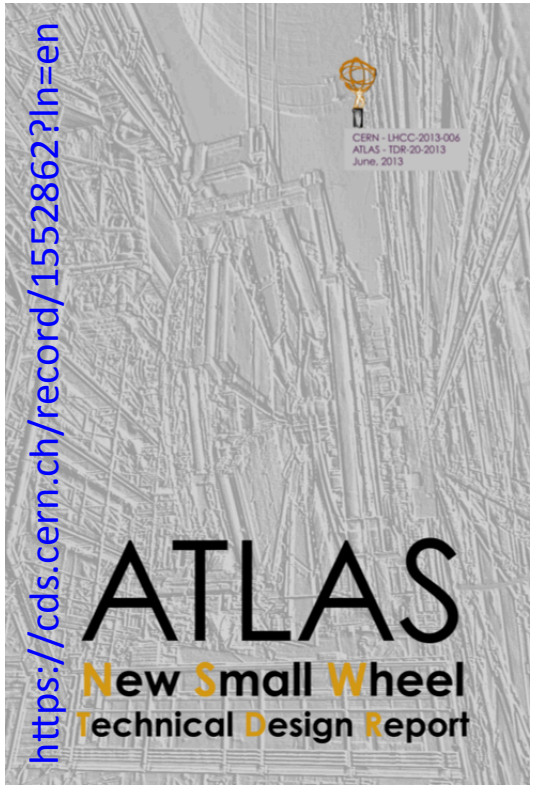
LS2 (Phase-1) Upgrades

- FTK fully deployed and ready for high pile-up
- New Small Wheel (NSW)
- L1 Calorimeter trigger

New Small Wheel (NSW)

- Small Wheel = closest of three endcap muon stations





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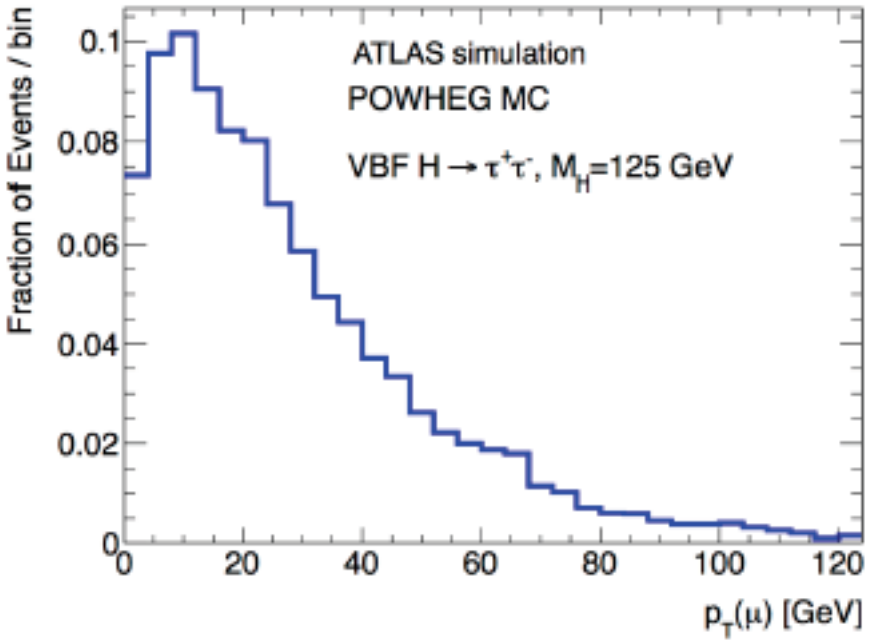
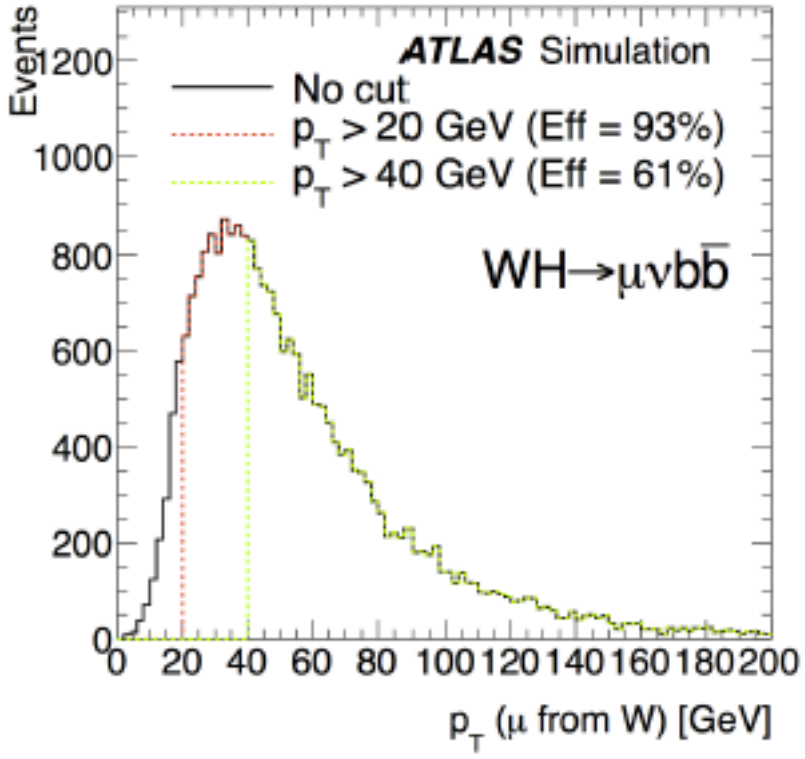
Upgrade

Goals

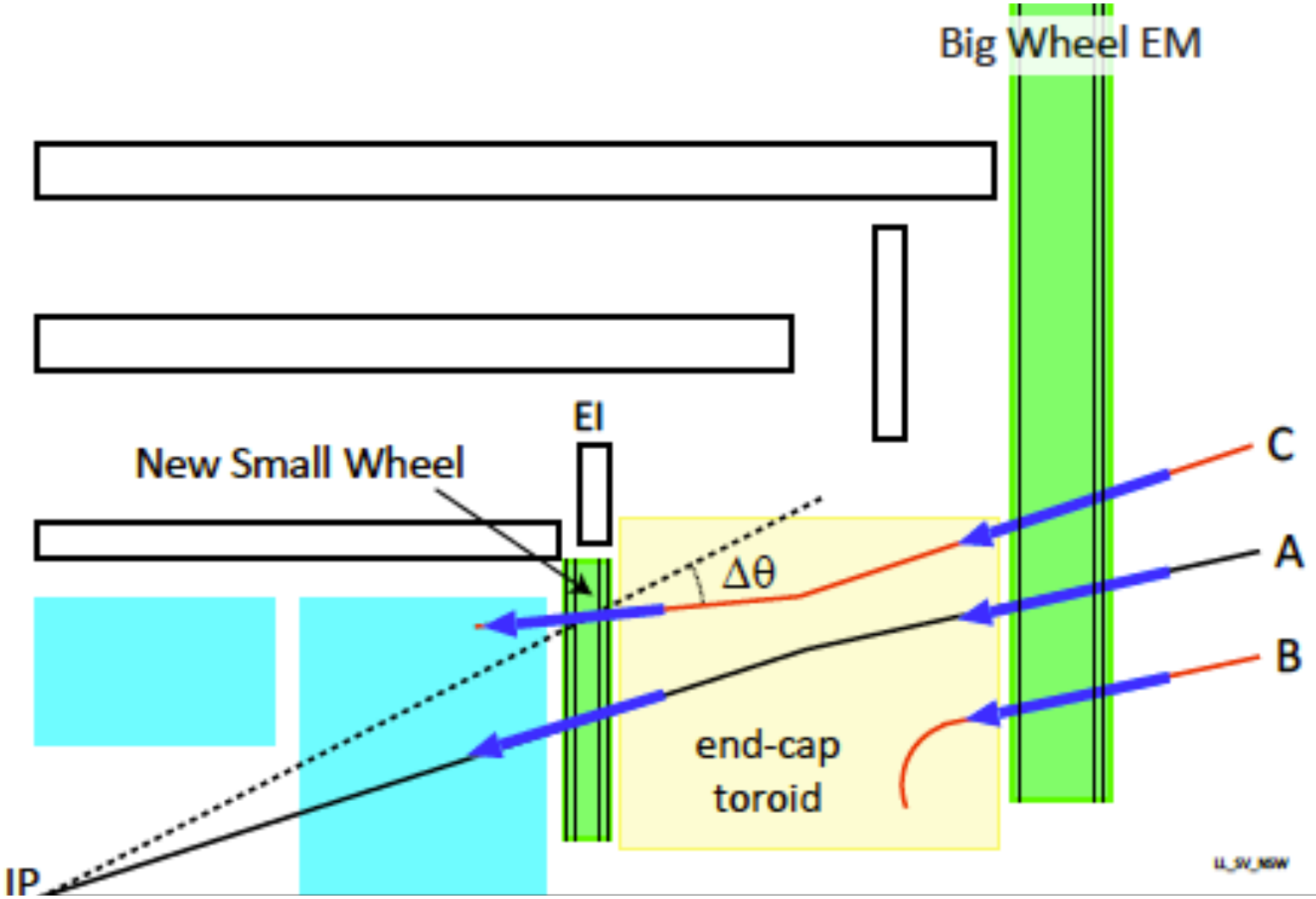
- Low p_T threshold for signal efficiency
- Rejection of fake triggers
- Good p_T resolution to control L1Muon trigger rate from background
- Improved signal resolution

p_T Threshold and Signal Efficiency

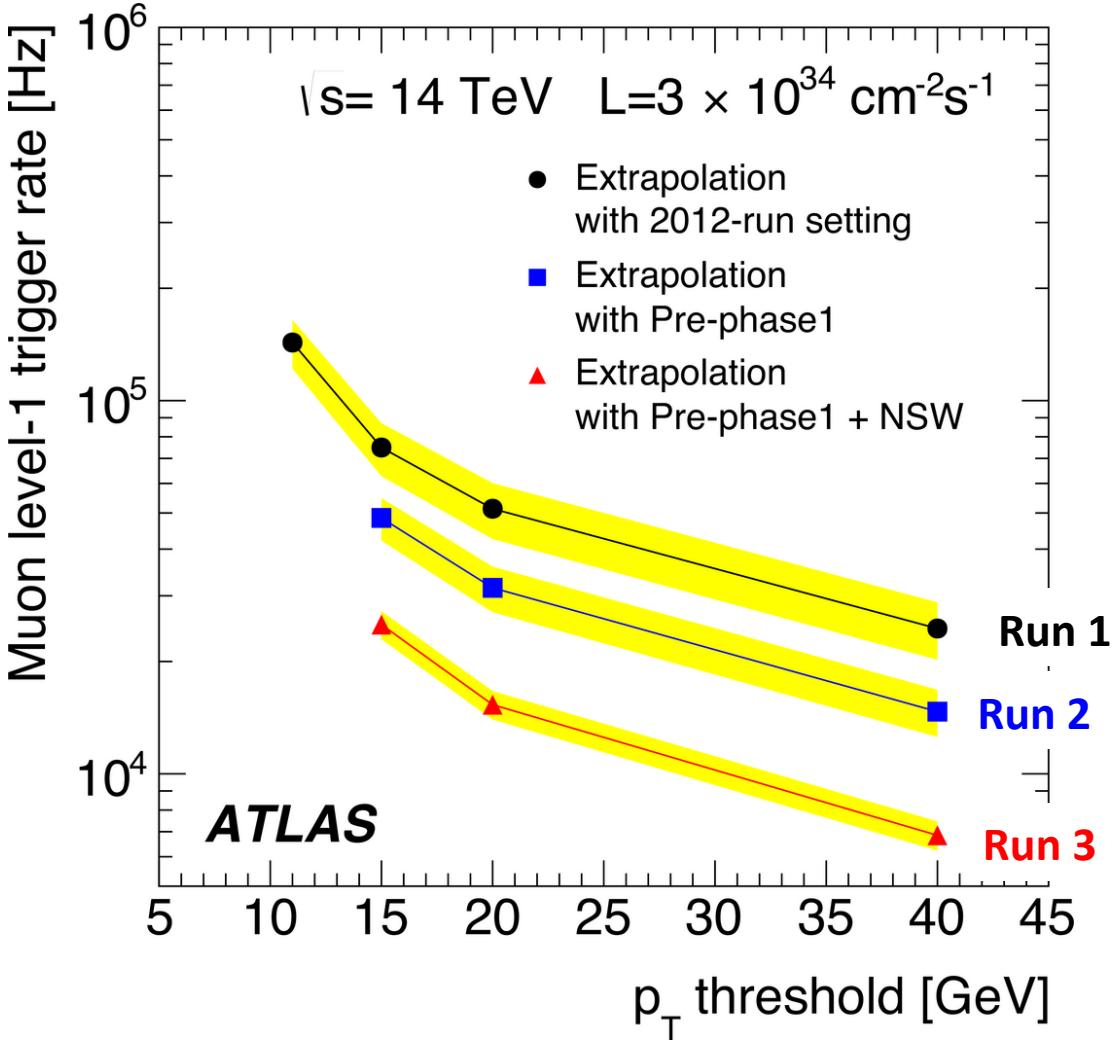




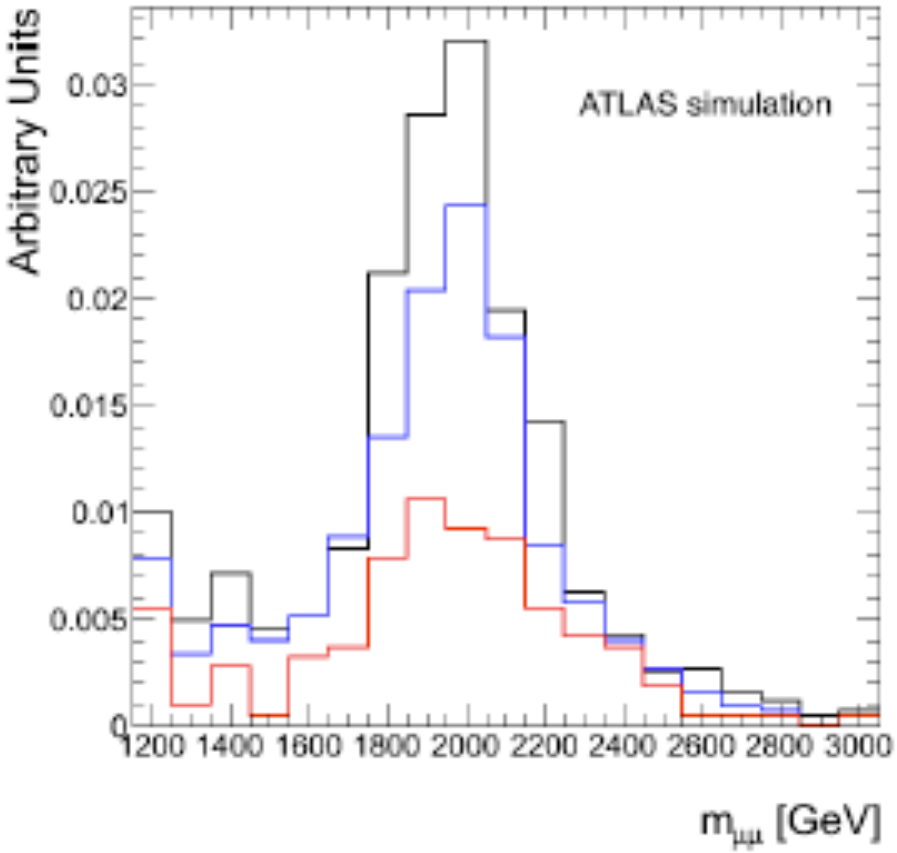
Fake Triggers



L1Muon Trigger Rate



Impact of Background on Resolution



Mass resolution of $Z' \Rightarrow \mu\mu$ in present ATLAS detector for three luminosity assumptions:

black $0.3\ 10^{34}\ cm^{-2}\ sec^{-1}$

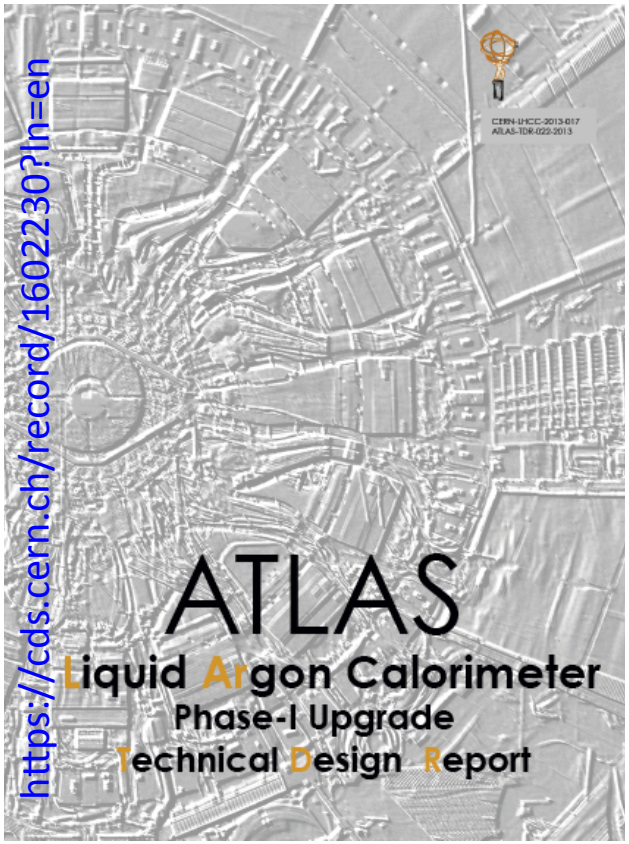
blue $3\ 10^{34}\ cm^{-2}\ sec^{-1}$

red $5\ 10^{34}\ cm^{-2}\ sec^{-1}$

Performance impact due to inefficiencies in present Small Wheel recovered by NSW

Liquid Argon Calorimeter

- Greater granularity for trigger
- Sharper trigger efficiency curves possible
  - Especially for high pile-up
- Reduced L1 trigger rates



L1 Calorimeter Trigger

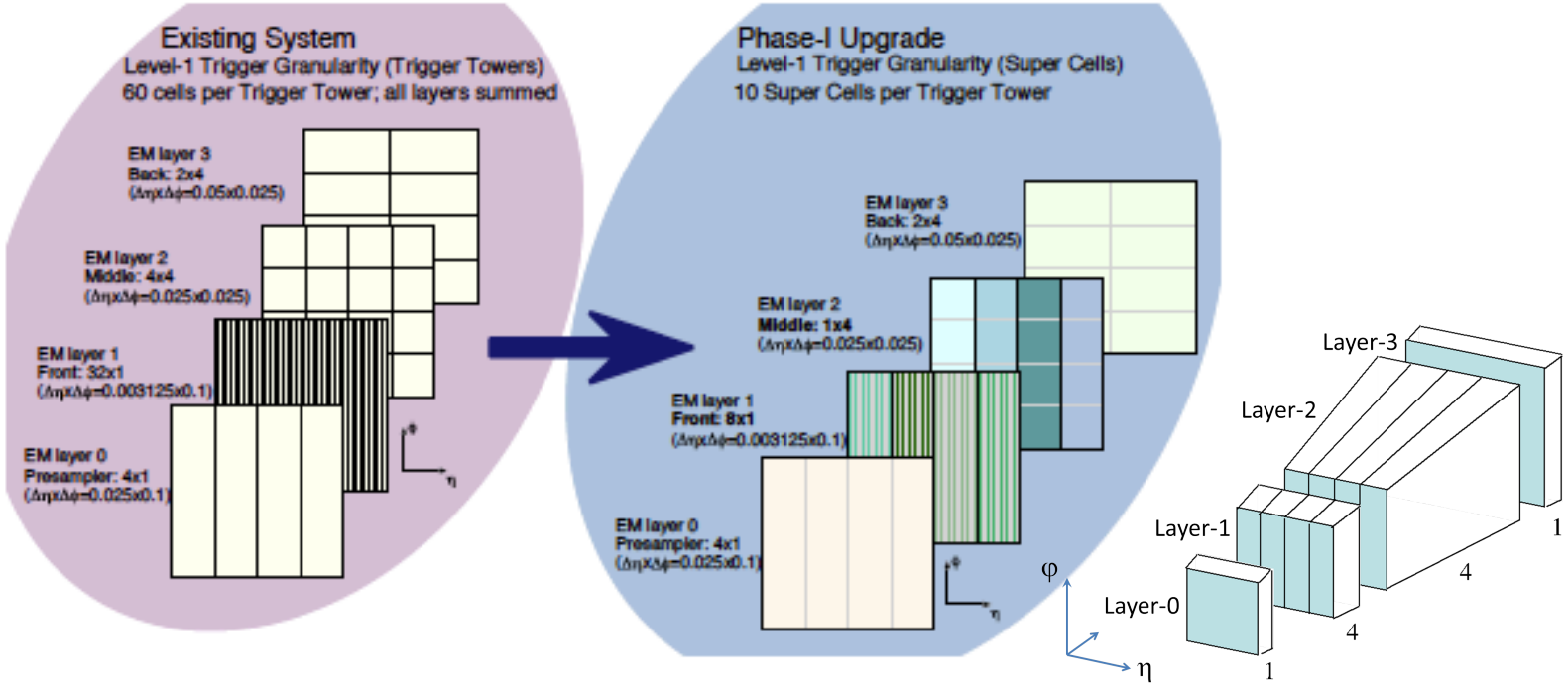


Figure 3. Geometrical representation in η,ϕ space of an EM Trigger Tower in the current system, where the transverse energy in all four layers are summed (left) and of the Super Cells proposed for the Phase-I upgrade, where the transverse energy in each layer is retained in addition to the finer granularity in the front and middle layers (right). Each square represents an area of size $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$.

Trigger Efficiency

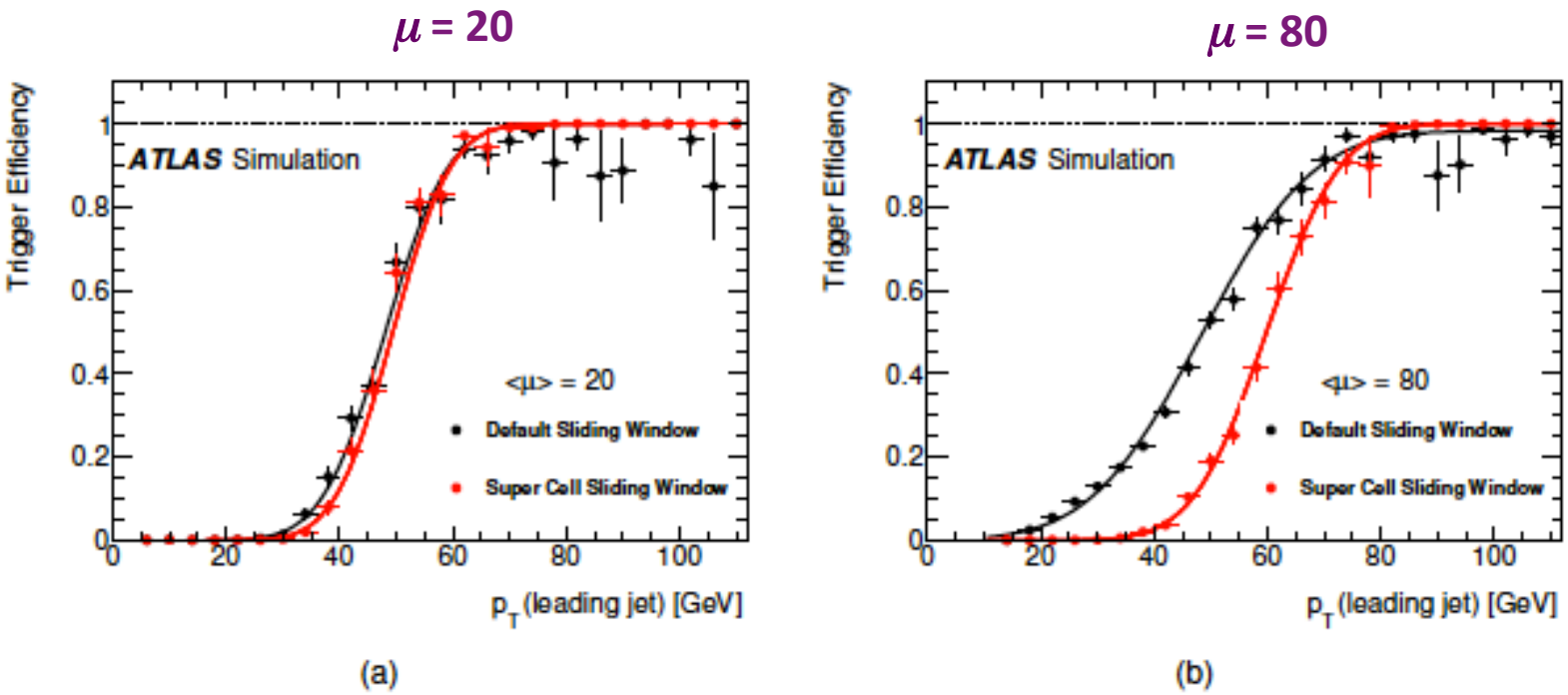
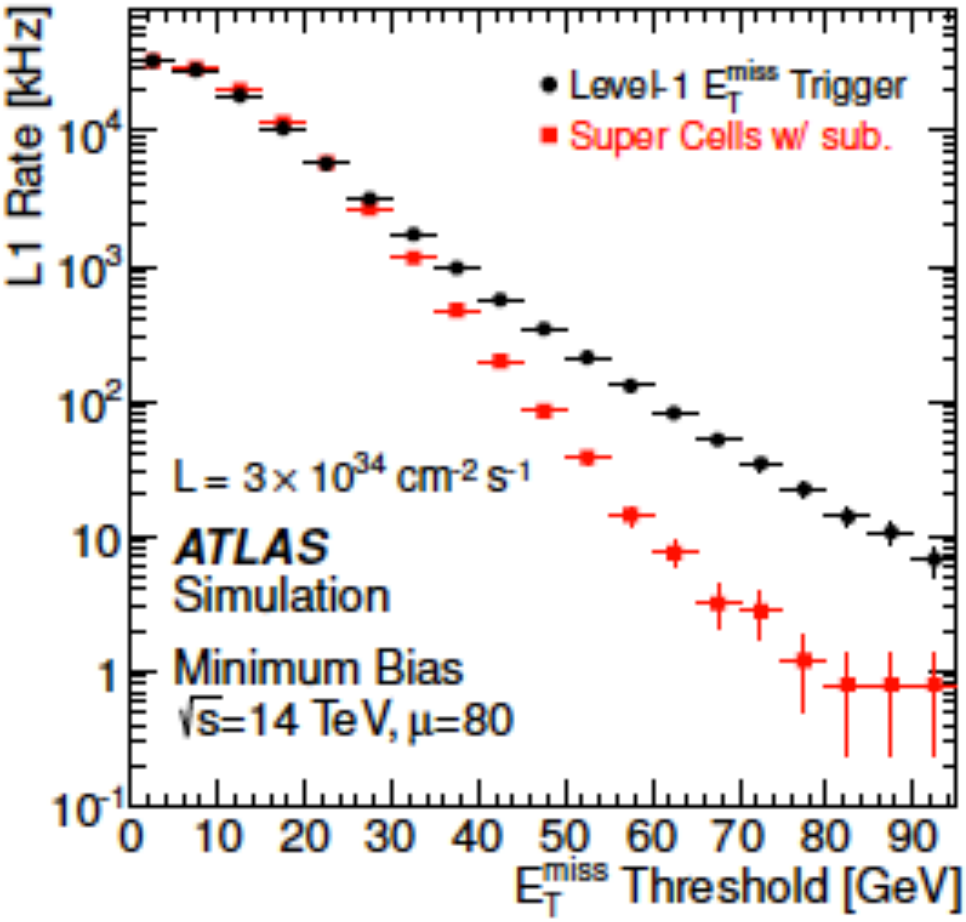
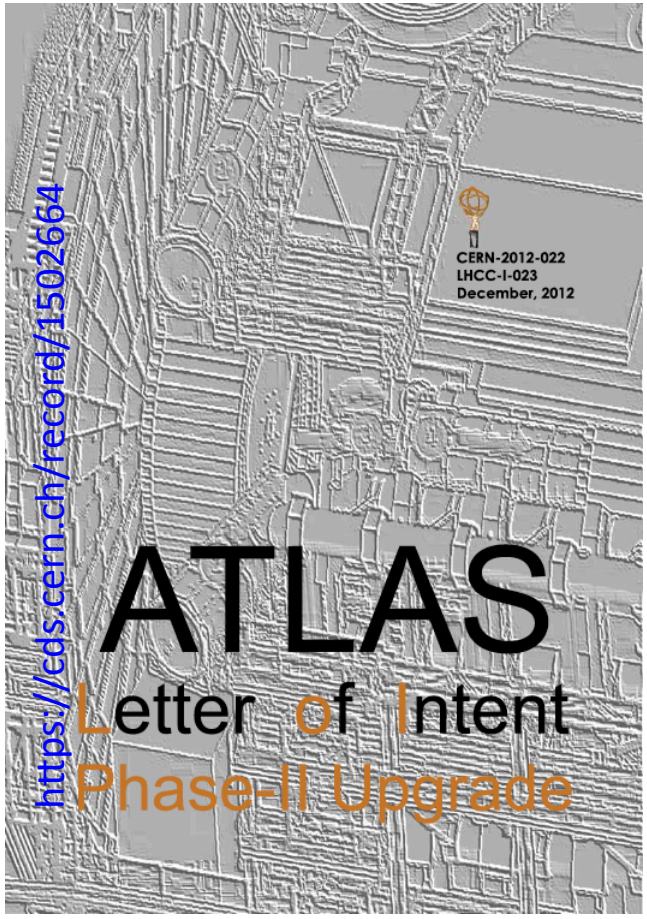


Figure 14. The trigger efficiency as a function of the highest p_T offline jet for $\langle\mu\rangle = 20$ (a) and $\langle\mu\rangle = 80$ (b) in simulated QCD dijet events. The performance of the default sliding window algorithm (black points) is compared to that of the sliding window algorithm based on Super Cells (red points) for jets within $|\eta| < 2.5$.

L1 ETmiss Trigger Rate



LS3 – PHASE-2



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Upgrade

Current ATLAS Tracker

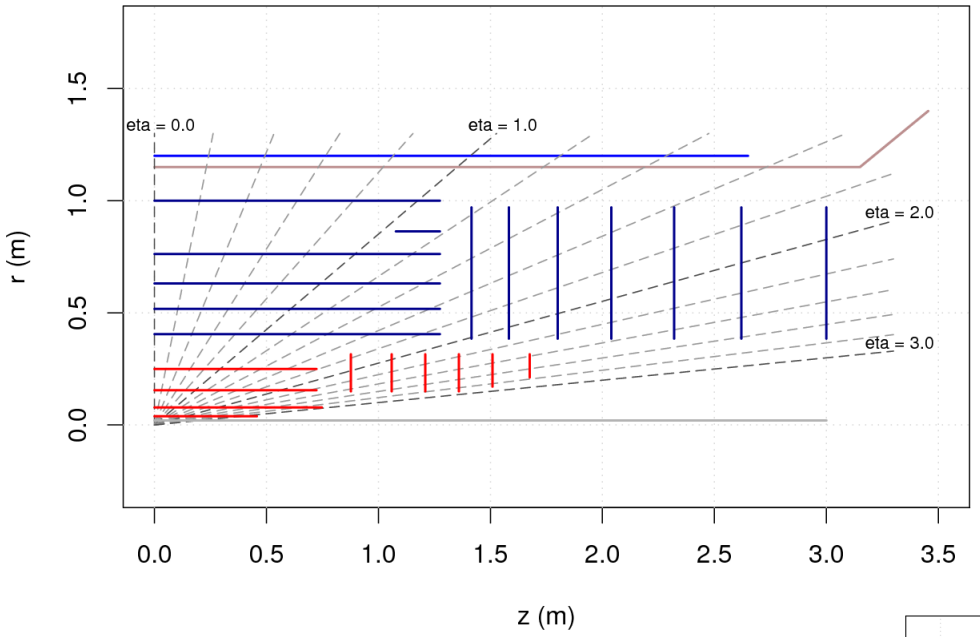
- Three components
  - Pixel
  - Silicon strip (SCT)
  - Transition radiation tracker (TRT)
- TRT already very high occupancy during Run 1
- Pixel and SCT incompatible with data rates of HL-LHC and anticipated higher L1 trigger rate
- End of life from radiation damage

Must be replaced for HL-LHC

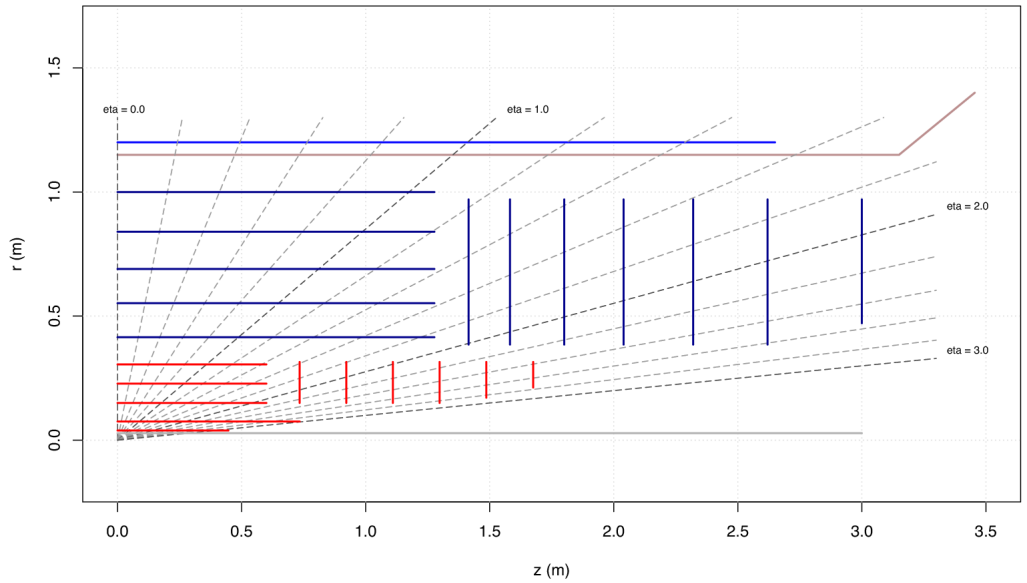
Inner Tracker (ITK) Plans

- All silicon tracker
  - Loss of electron ID capability by TRT ☹
- η coverage at least same as current tracker
  - May be extended from ~2.5 to ~4
- Comparable or better performance
- Level-1 track trigger capability

Baseline Layout and One Alternative



Several additional layouts under study



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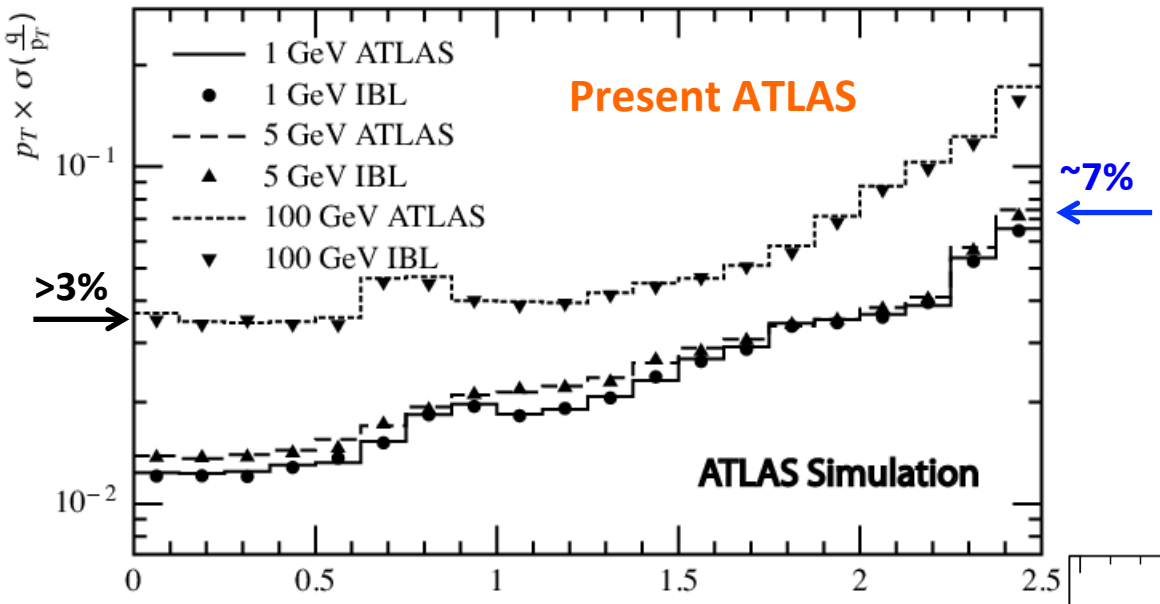
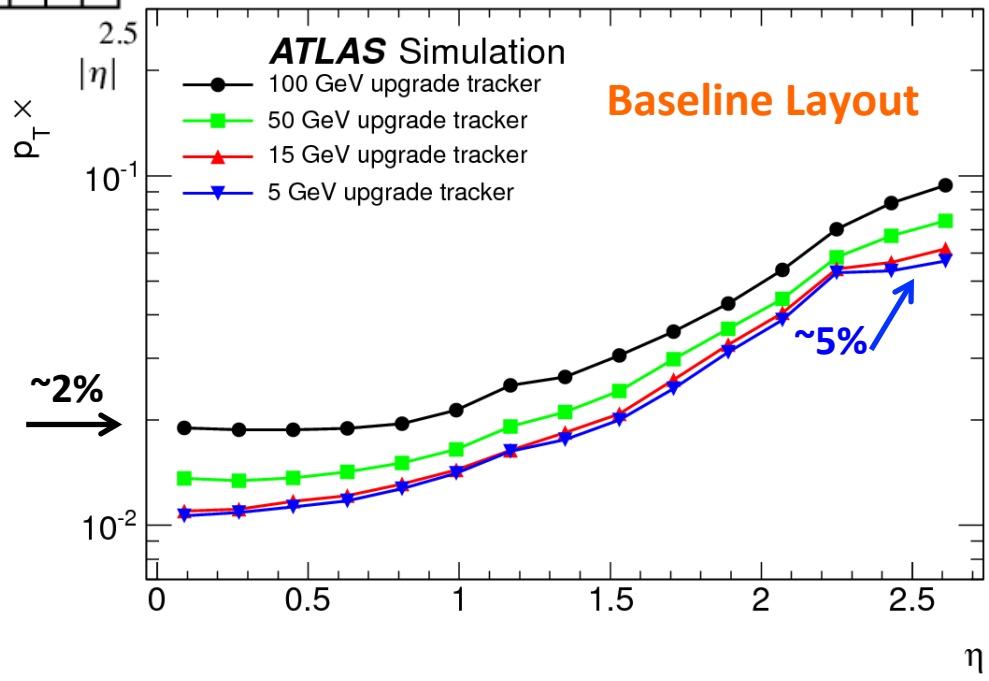
Upgrade

p_T Resolution





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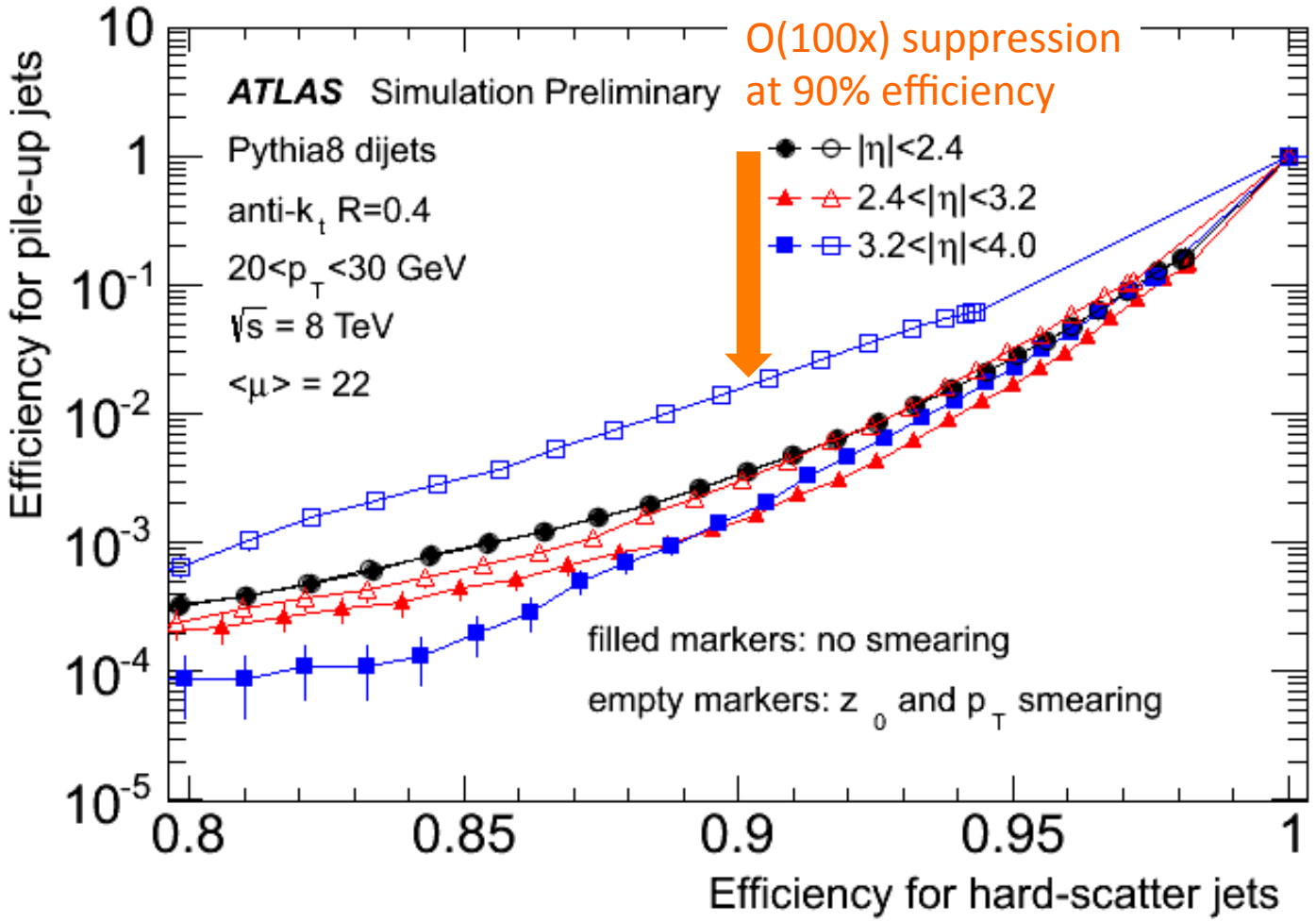
Upgrade

Extended η Coverage

- Benefits
  - Charged tracking coverage
  - Necessary for potential extended μ coverage
  - Pileup suppression in forward calorimeter
  - What are the critical physics improvements?
- Challenges
  - Layout (including services)
  - p_T resolution due to shorter track length and greater multiple scattering
  - Vertex resolution due to multiple scattering and extrapolation distance

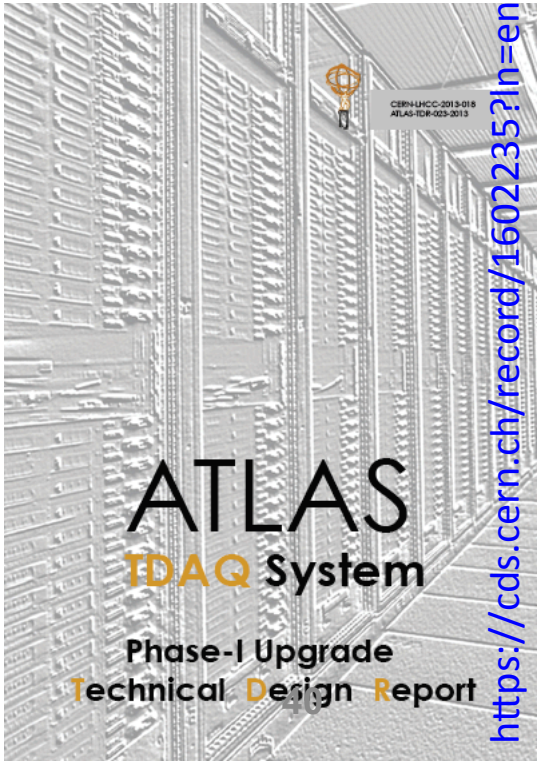
Pileup Suppression with Tracks



OTHER UPGRADES

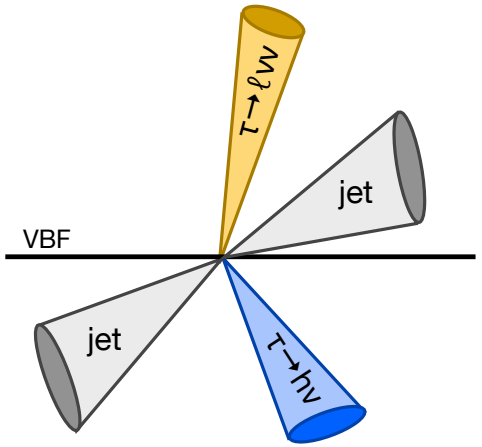
Trigger and DAQ Upgrades

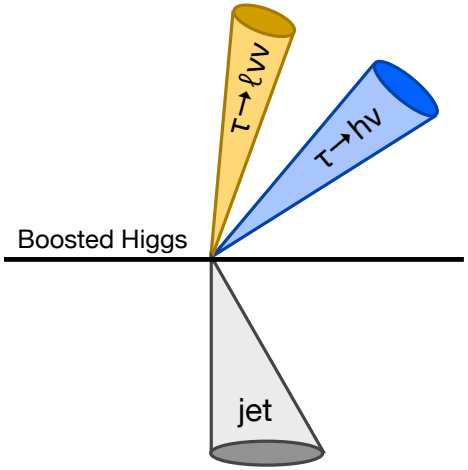
- Continuous upgrades not necessarily tied to LHC schedule, e.g. rolling replacement of high-level trigger (HLT) hardware
- Detector upgrades mostly related to trigger
- LS1
  - Multi-object and topological trigger
  - Higher logging rate
- Phase-1 upgrades
  - New HLT more like current offline
  - New L1 more like current HLT
- Phase-2
  - L1Track using ITK

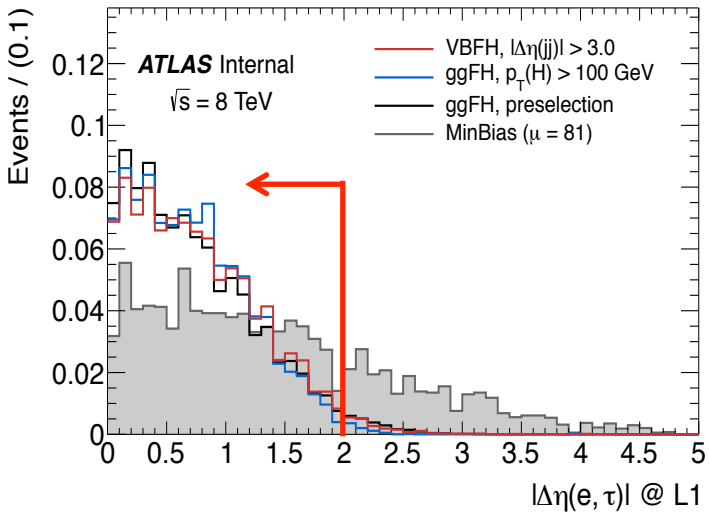


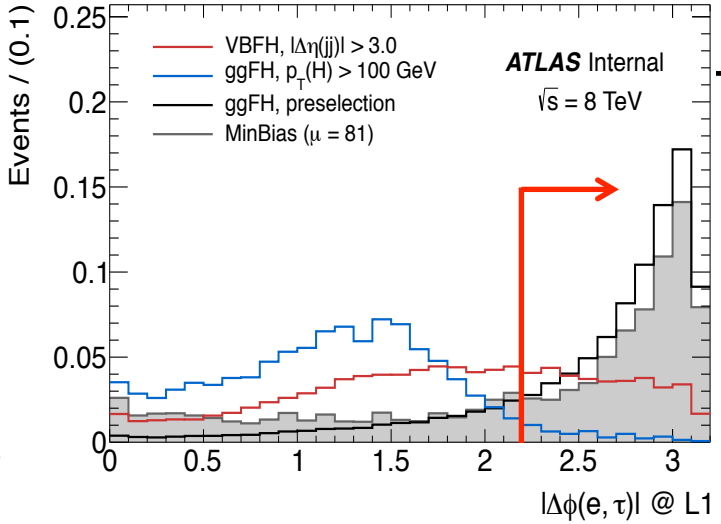
Topological Trigger Example

- VBF $H \Rightarrow \tau\tau$ and $\tau \Rightarrow l\nu\nu$, $\tau \Rightarrow h\nu$
- $\Delta\eta(l,\tau_h) < 2.0$ reject ~25% QCD
- $\Delta\phi(,\tau_h) > 2.2$ rejects ~80% ggF









Summary

- Increasing LHC luminosity leads to degradation in detector performance
  - Lower efficiencies and higher trigger rates
  - Detector aging
  - Higher physics rate vs logging rate
- ATLAS detector will be upgraded to restore physics performance
  - Sharper trigger turn-on curves
  - More capable triggers
  - Increased capacity
- Practically every component of ATLAS will be upgraded

Reminder: the other general purpose detector at the LHC…