Performance of the CMS Pixel detector for the Phase I upgrade at HL-LHC

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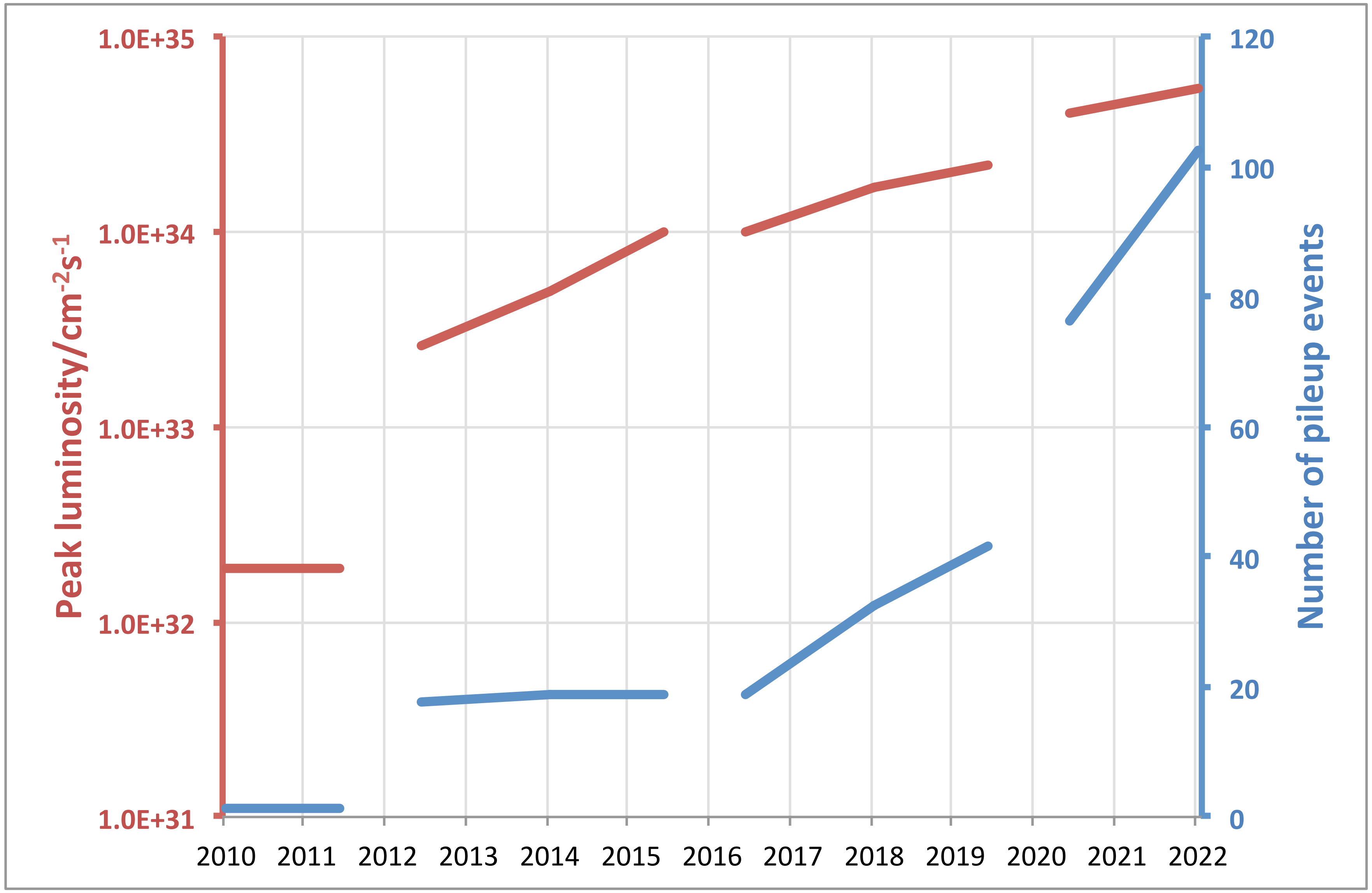
University of BRISTOL

Expected luminosity

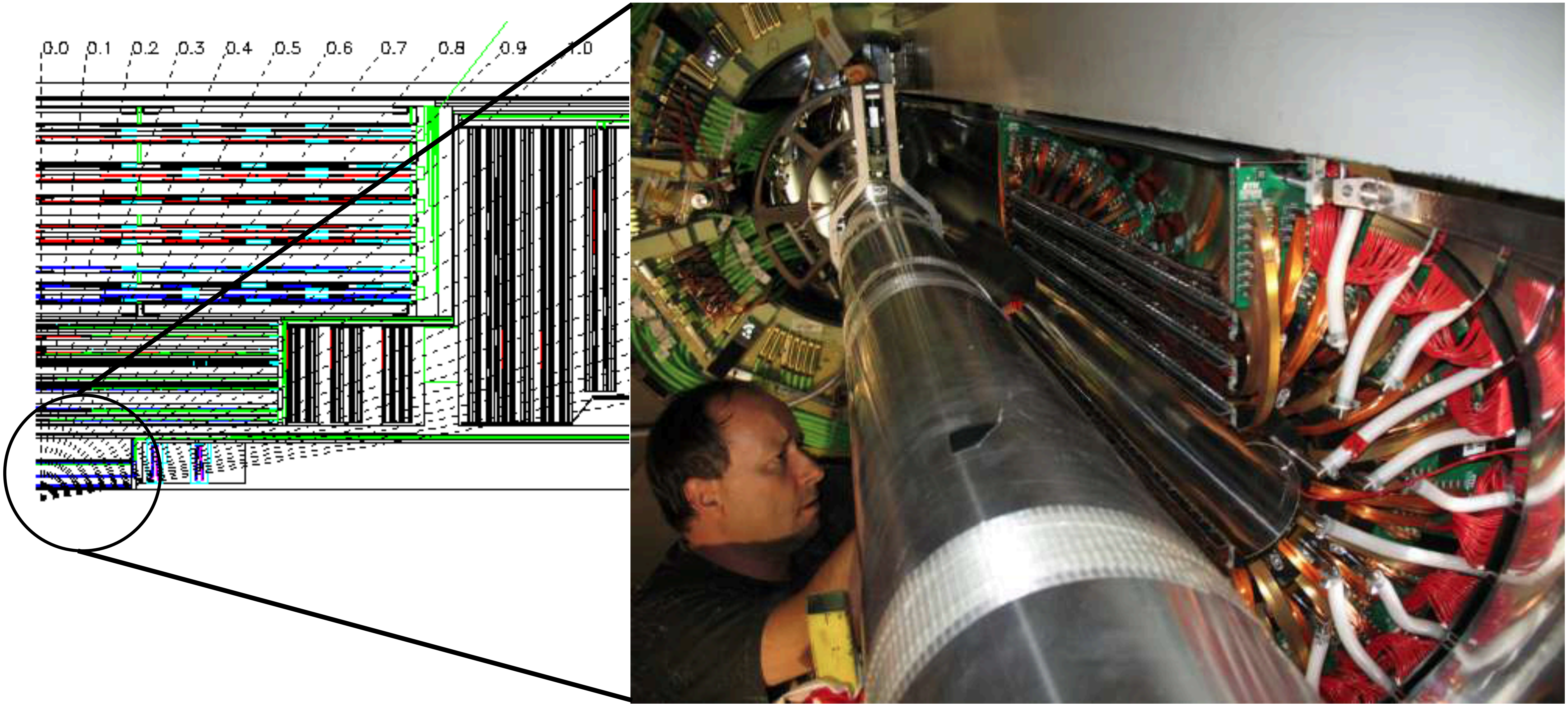
The expected luminosity for each year of LHC operations between 2010 and 2022



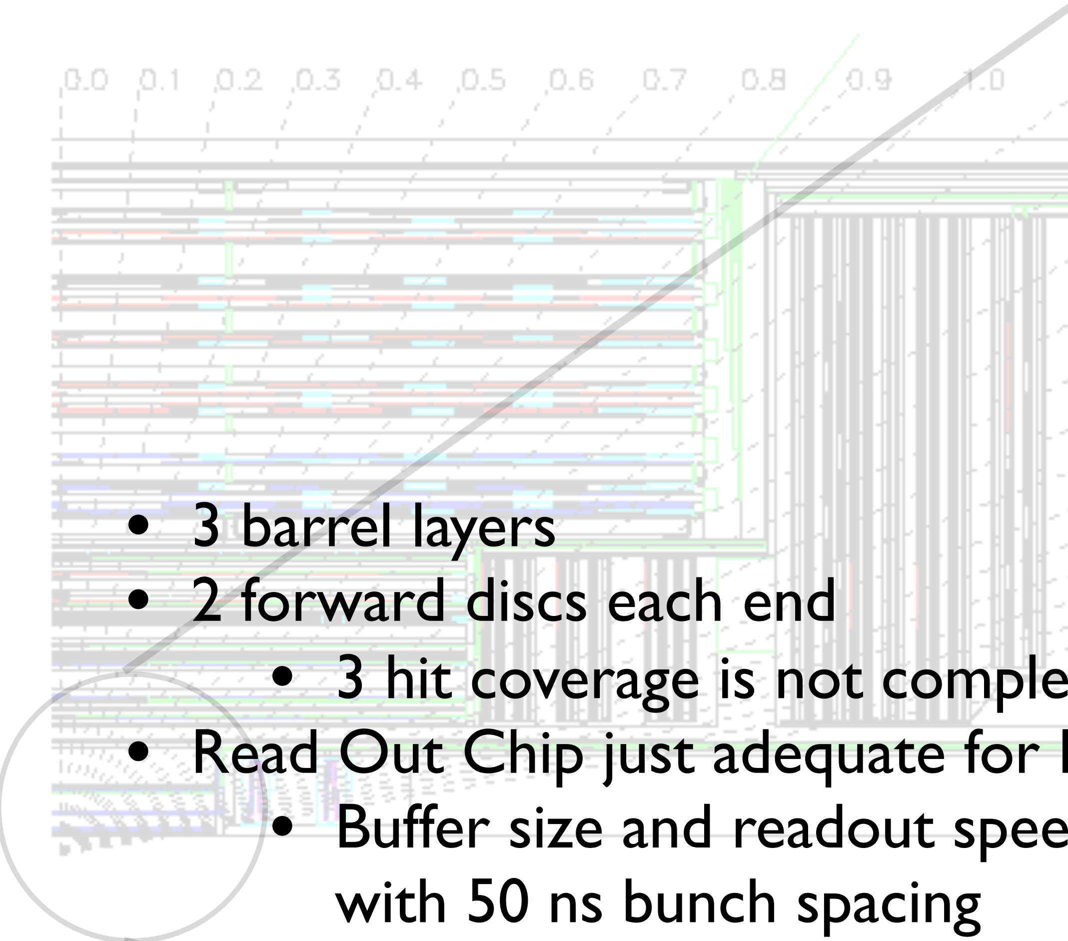
Assuming 25ns bunch spacing, already slightly out of date.

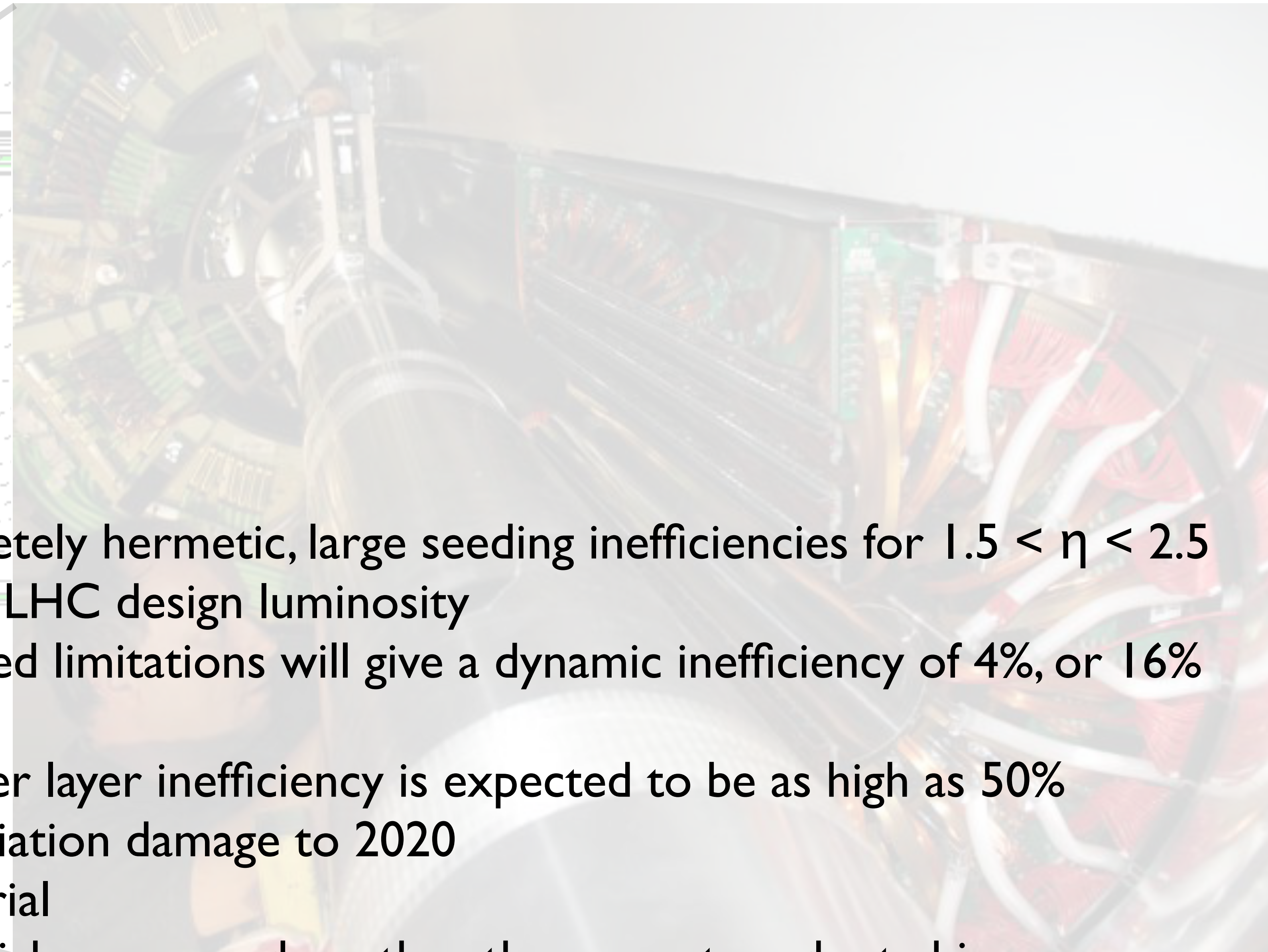
CMS was originally designed to run at $1\times10^{34}cm^{-2}s^{-1}$. We will soon exceed that.

Current pixel detector



Current pixel detector





- 3 barrel layers
- 2 forward discs each end
  - 3 hit coverage is not completely hermetic, large seeding inefficiencies for $1.5 < \eta < 2.5$
- Read Out Chip just adequate for LHC design luminosity
  - Buffer size and readout speed limitations will give a dynamic inefficiency of 4%, or 16% with 50 ns bunch spacing
  - At 2×10^{34} $cm^{-2}s^{-1}$, 50 ns inner layer inefficiency is expected to be as high as 50%
- Detector will not survive the radiation damage to 2020
- Contains significant passive material
  - e.g. cooling designed for a higher power draw than the current readout chip
- **Designed to be easily removed or installed in a few days**

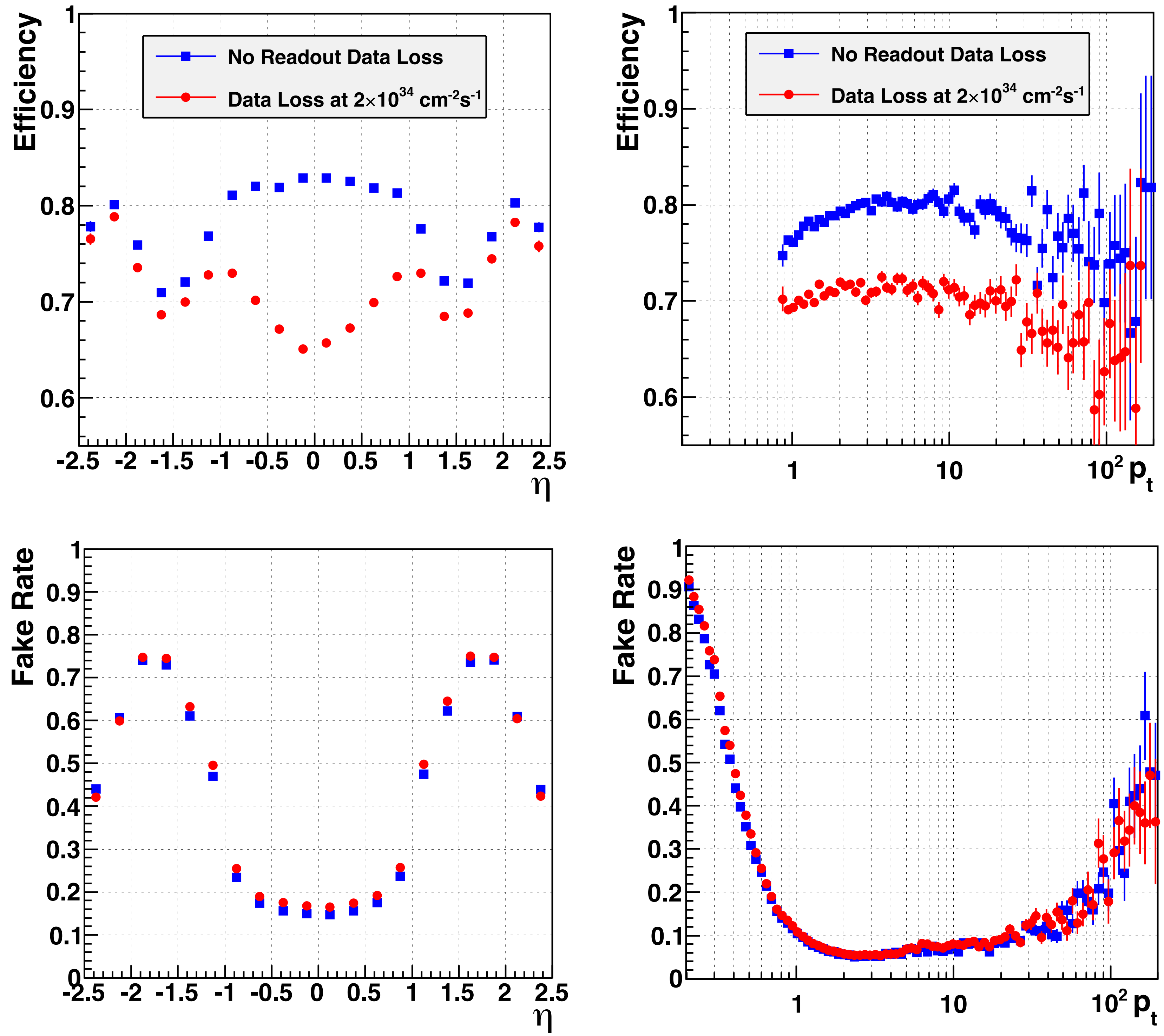
Simulation results

Detailed Geant4 based full simulations have been undertaken to assess the performance of the current geometry and the upgraded pixel detector (described later) at high pileup.

A fast Monte Carlo 4 vector based physics study has also been undertaken to assess the physics performance. More detailed studies are being worked on.

High luminosity problems

Tracking performance for $t\bar{t}$ events in the current geometry with and without estimated data loss for the current pixel readout electronics.



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All tracks

The current detector will have significant problems even at 50 pileup ($2x10^{34}cm^{-2}s^{-1}$@25ns).

A technical proposal has just been released for detector upgrades to mitigate these problems.

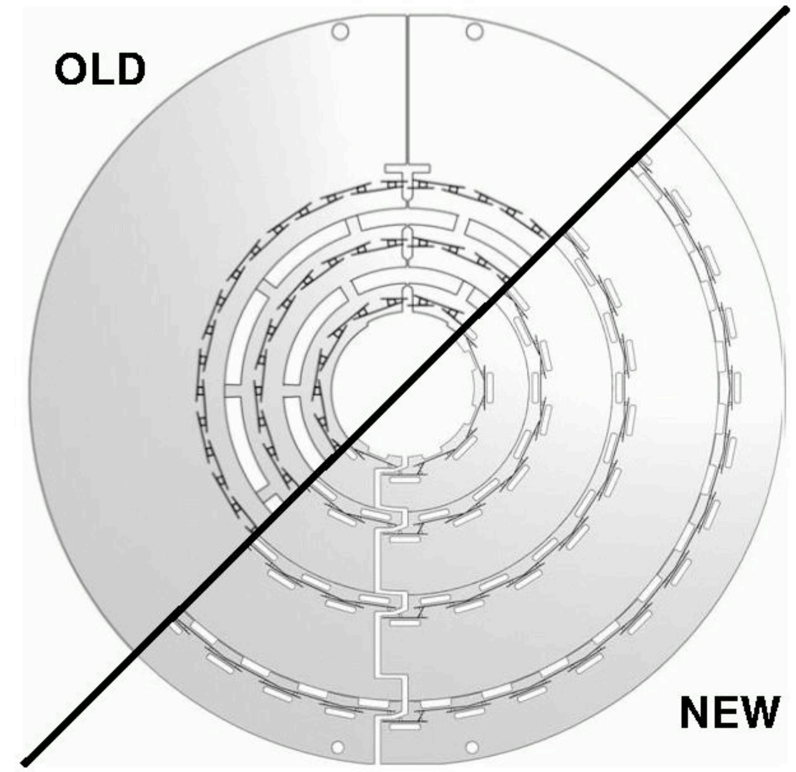
Erratum 27/Sep/2011:
The lower right plot originally had the plot from slide 8 incorrectly substituted.

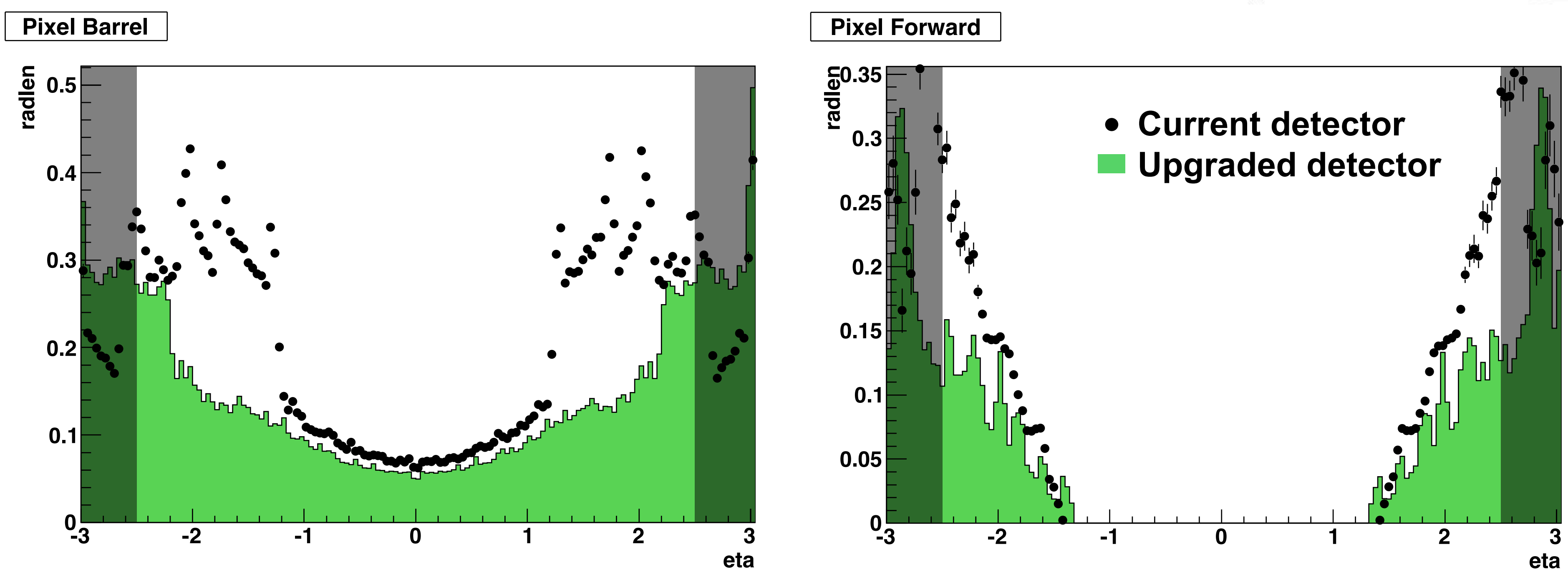
N.B. Tracking reconstruction has not been fully tuned for high pileup.

Proposed Phase 1 tracker upgrade

Phase1 tracker upgrade:

- Replaces the pixel detector.
- Moves the inner barrel layer closer to the beam line to improve impact parameter resolution and b tagging.
- Adds a fourth barrel layer and a third forward disk to help with pattern recognition and improve standalone tracking efficiency.
- Barrel has 80 M pixels (current geometry 48 M), forward disks 45 M pixels (current geometry 18 M).
- Reduced mass by moving connectors and electronics further out, and by changing to CO_2 cooling.

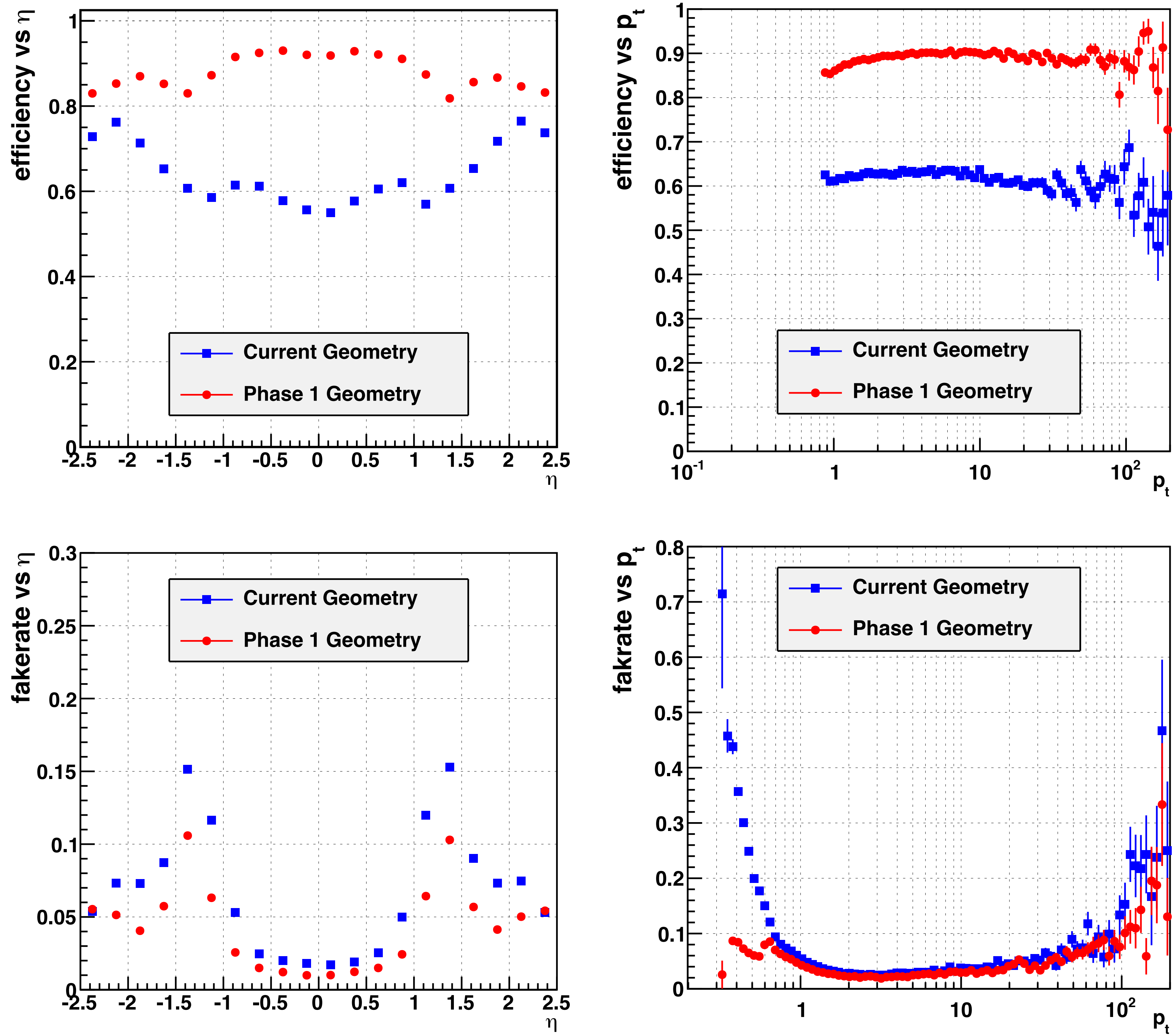




At η~2.5 photon conversion drops from 22% to 11%

Pixel upgrade performance

Tracking performance with 50 pile up for $t\bar{t}$ events in the current geometry and the Phase1 pixel upgrade.



High purity tracks

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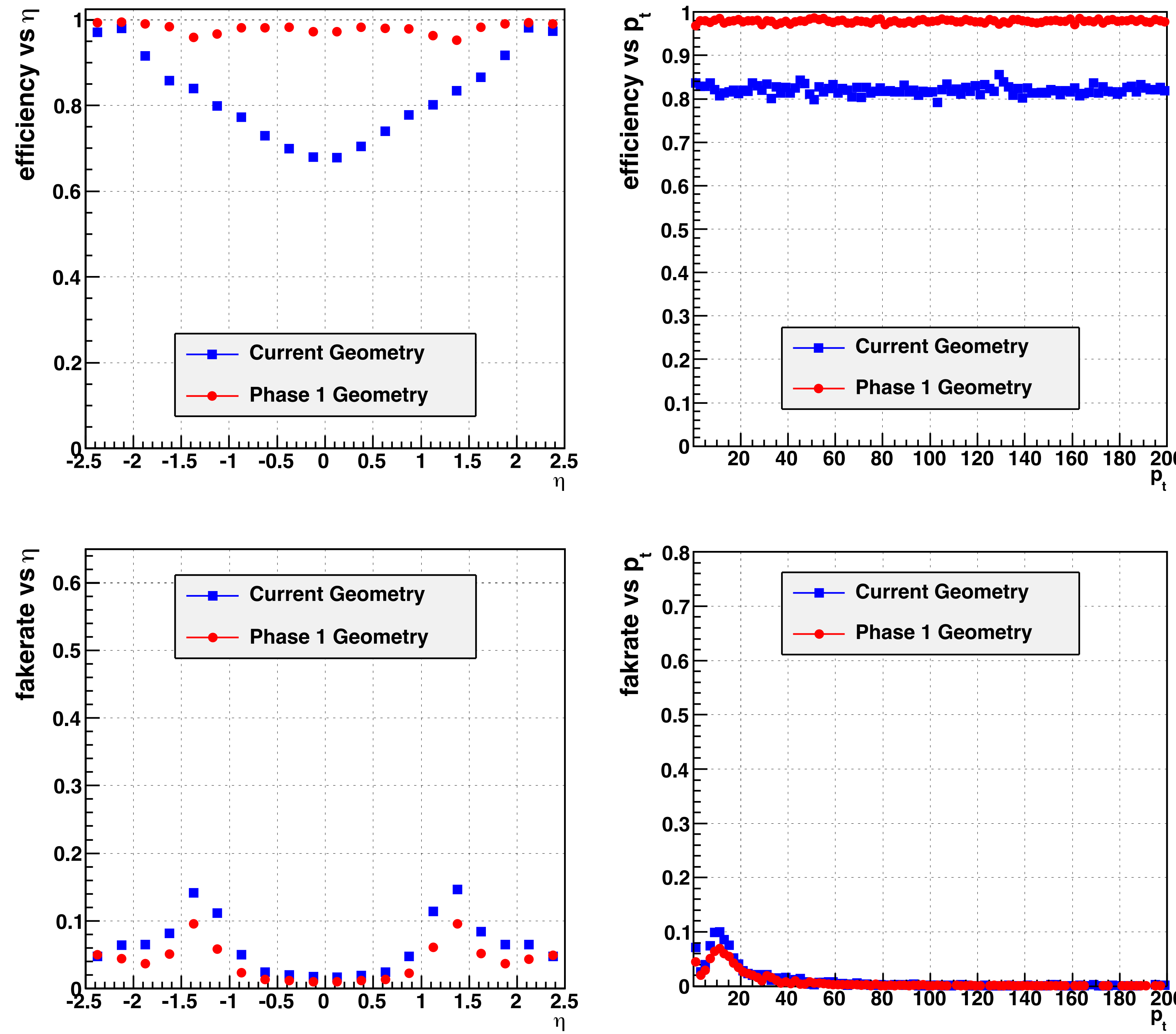
Simulations of the Phase1 tracker upgrade show significant improvement in tracking efficiency and reduced fakerates.

Pixel upgrade performance

Tracking performance with 50 pile up for single μ events in the current geometry and the Phase1 pixel upgrade.



Muon efficiency is ~15% better across the momentum range. Analyses requiring two well identified muons would suffer with 0.85^2 relative efficiency.

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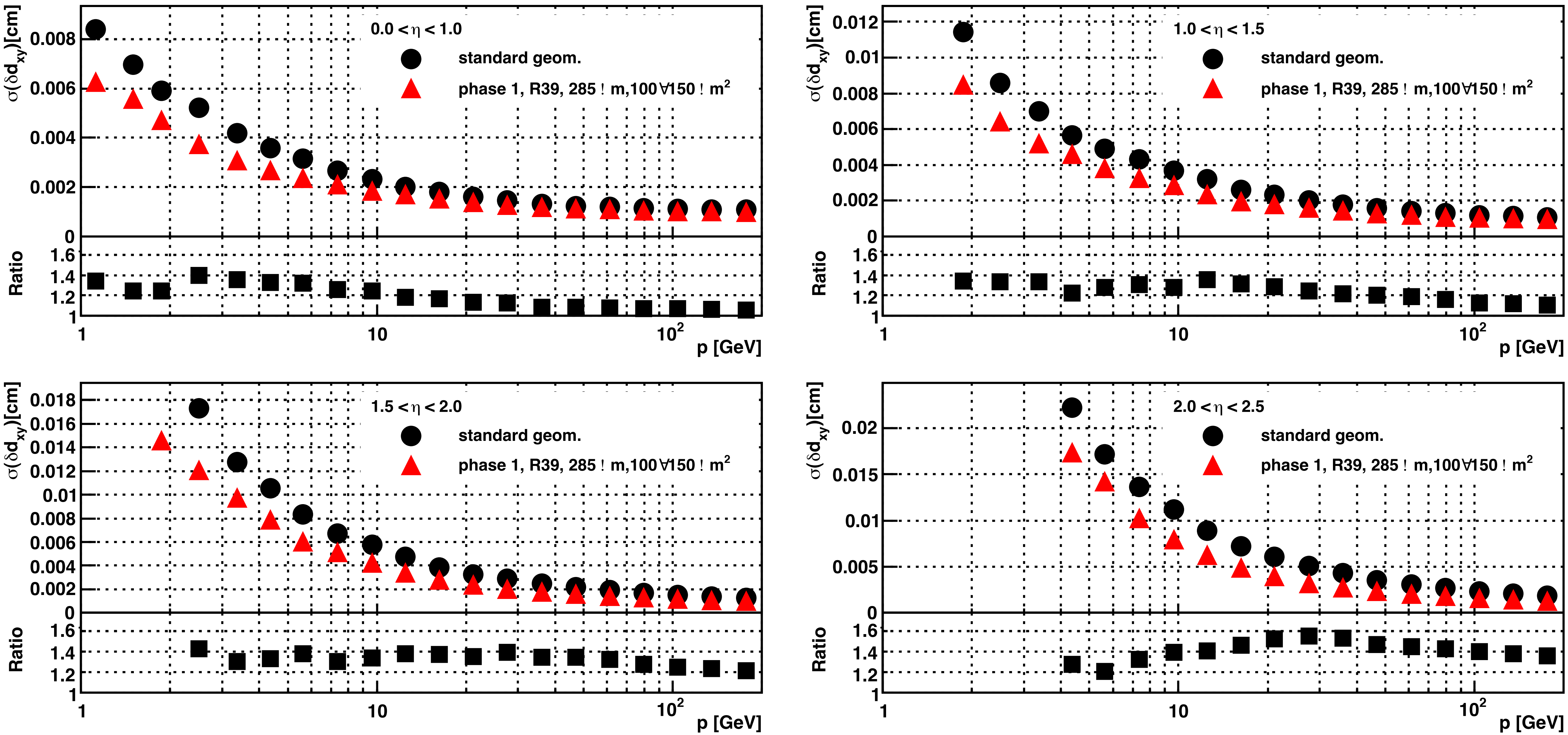
Impact parameter resolution

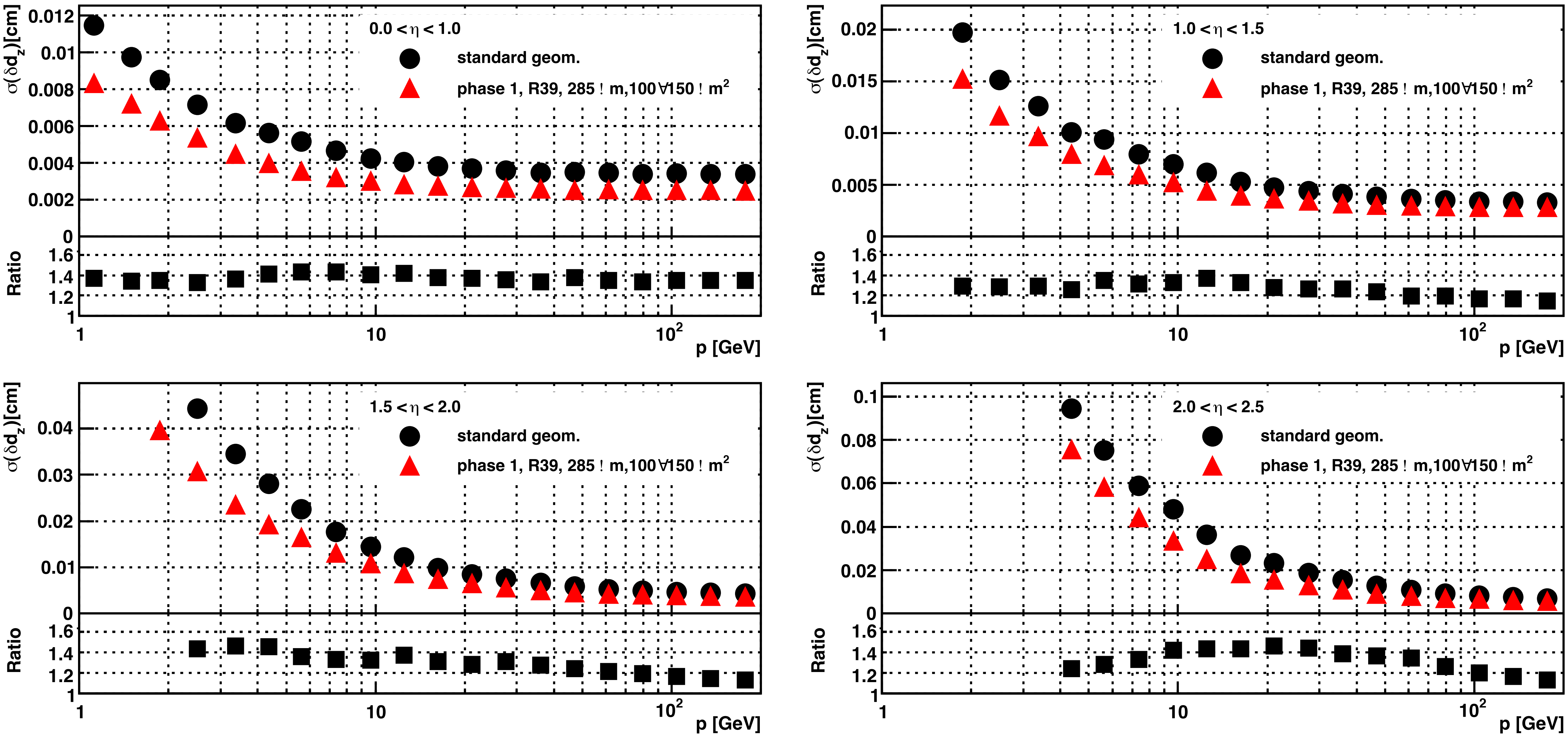
Transverse impact parameter resolution for different η regions.



M. Luk

Impact parameter resolution

Longitudinal impact parameter resolution for different η regions.

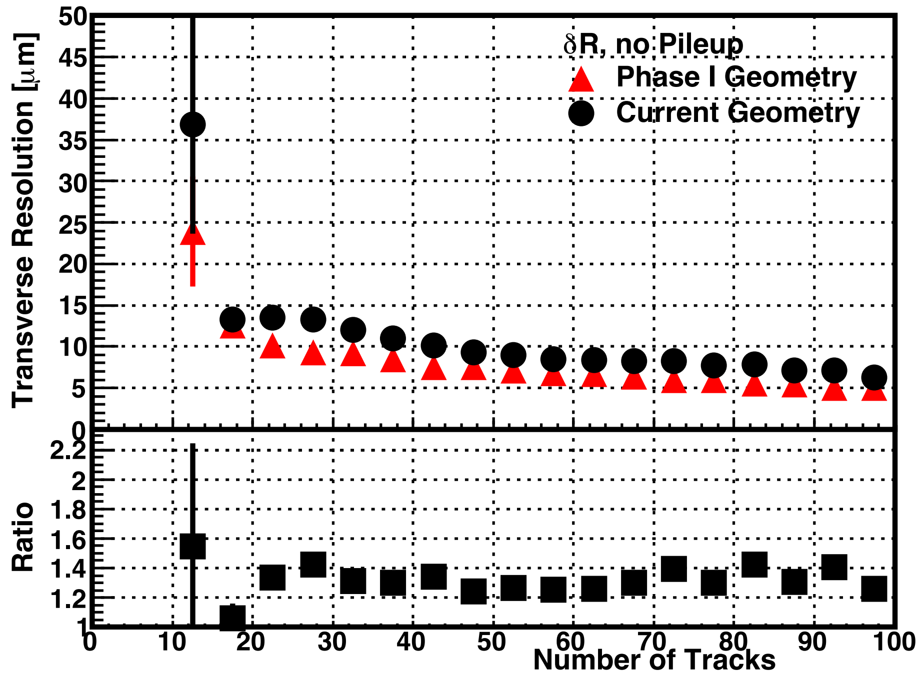


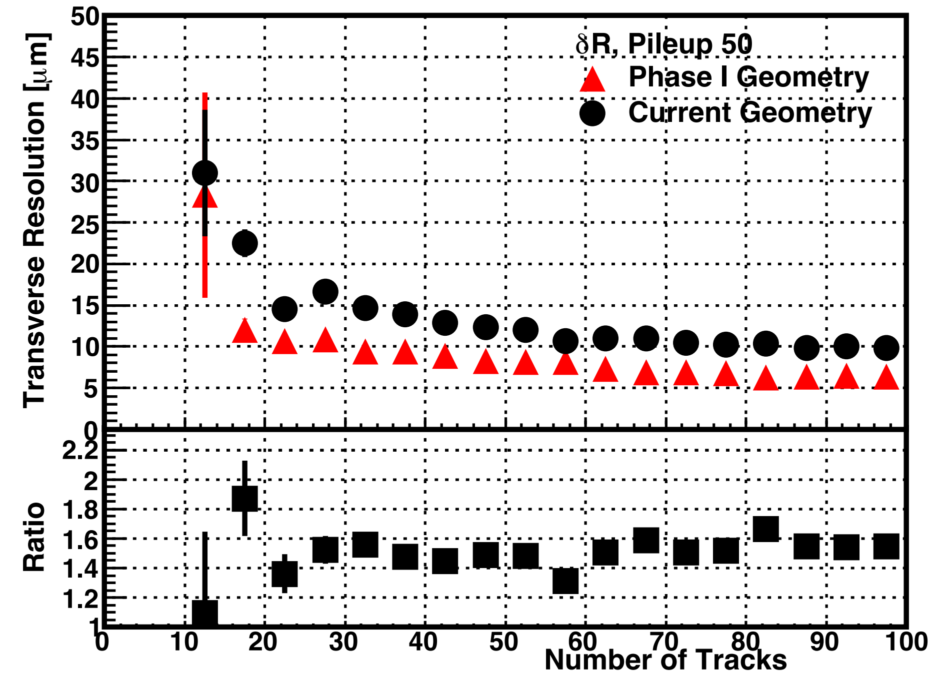
M. Luk

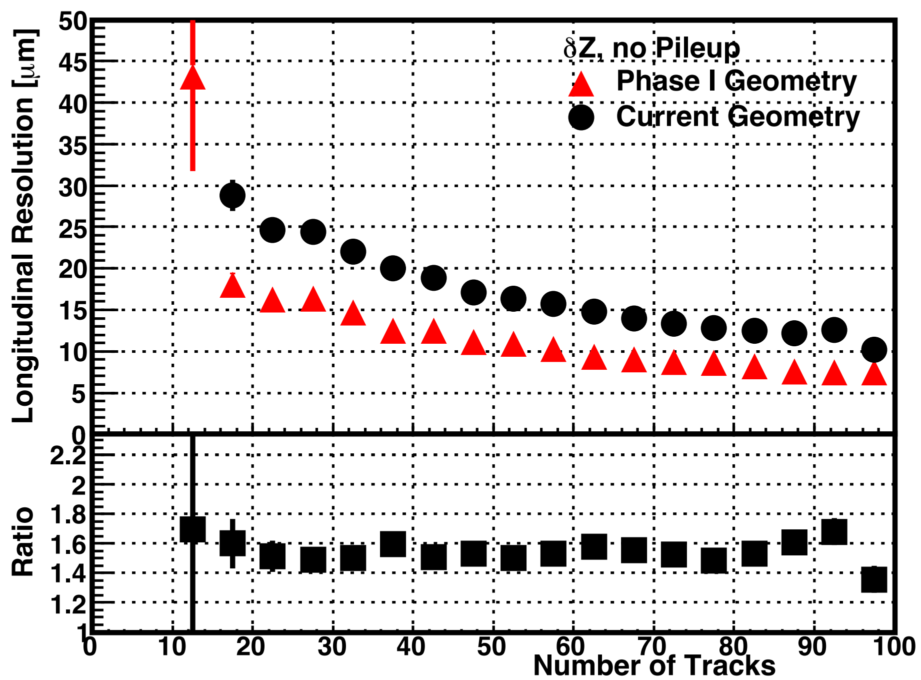
Vertex resolution

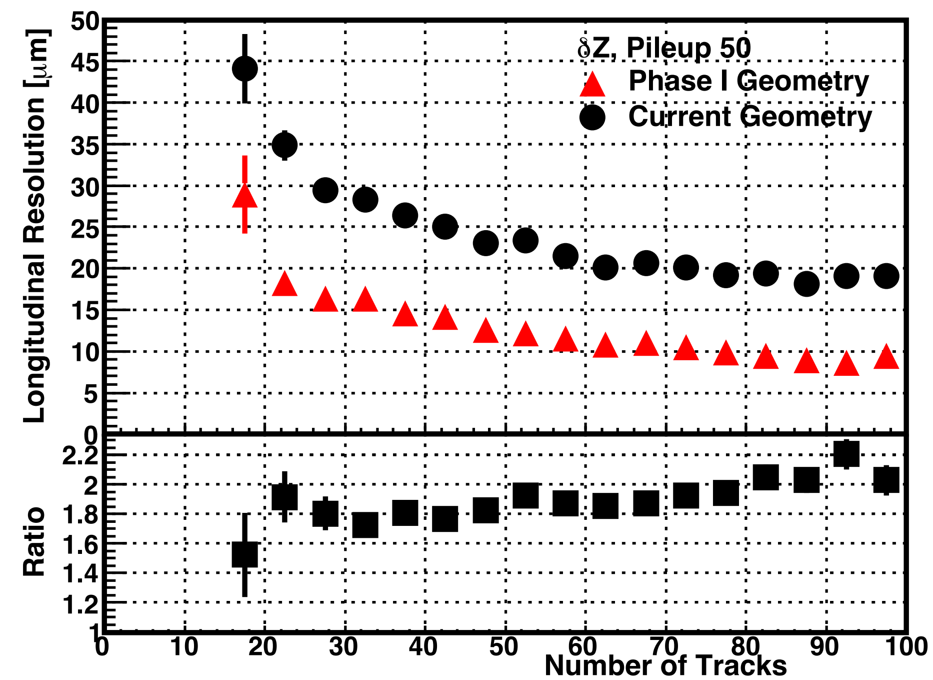
Transverse and longitudinal primary vertex resolutions

No pileup | **50 pileup events**









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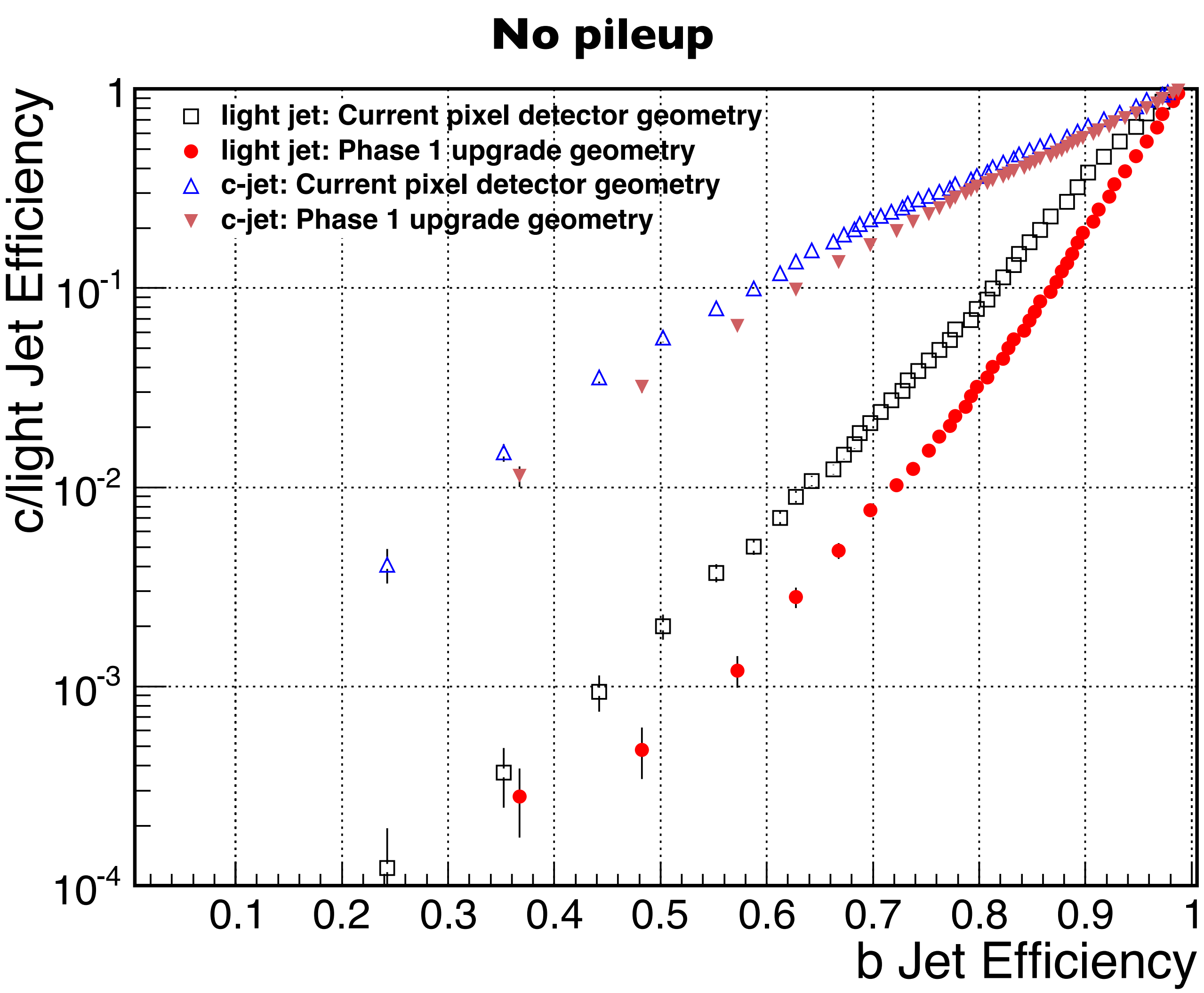
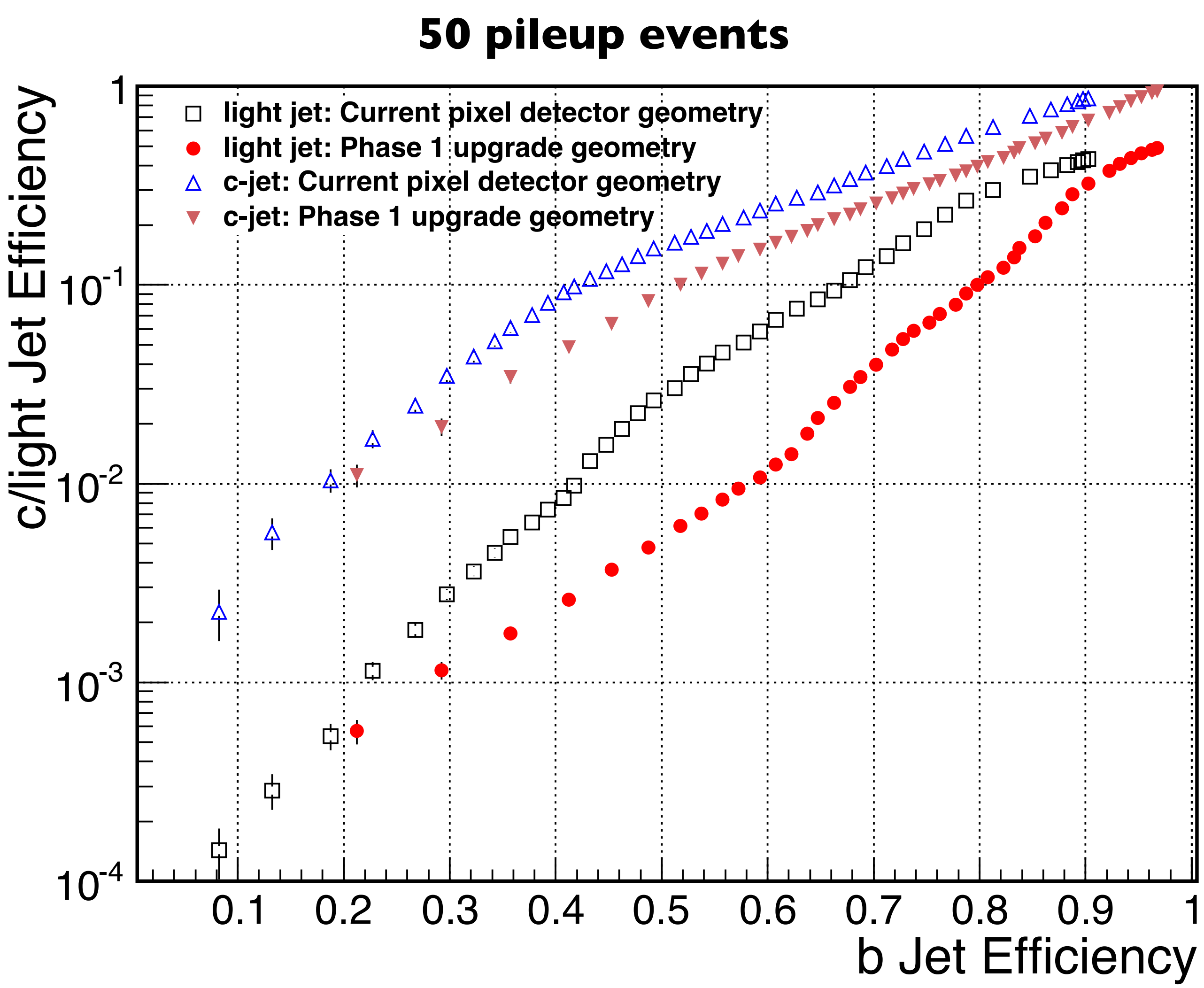
b tagging performance

b tagging performance





H. Cheung

UltraFast physics study

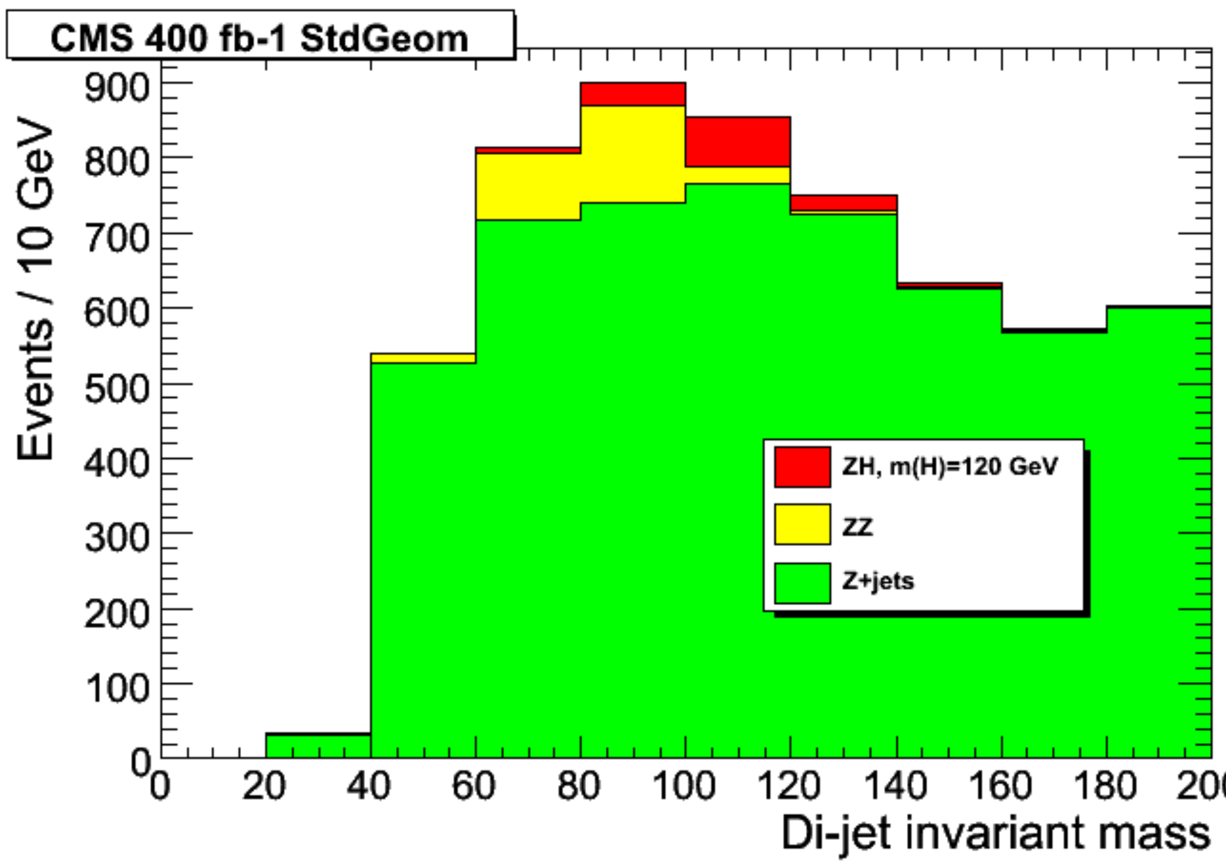
The LHCC asked for an upgrade physics case for their last meeting. In the time available a parameterised fast simulation was undertaken:

- Chose ZH with Z decaying to muons and H(120GeV) to b jets.
  - Requires a lot of data, more appropriate for when the upgrade will be running.
  - Note that the low luminosity, 7 TeV analysis is still being optimised.
- Included the two largest expected backgrounds, ZZ and Z+jets.
- Events generated in Pythia8.
- Average of 50 minimum bias events overlaid.
- Four vectors smeared with expected detector performance.
- 15% of muons lost in the current geometry at 50 pileup.
- Jets "tagged" using the tagging performance on the previous slide, with a 60% b tag efficiency operating point.

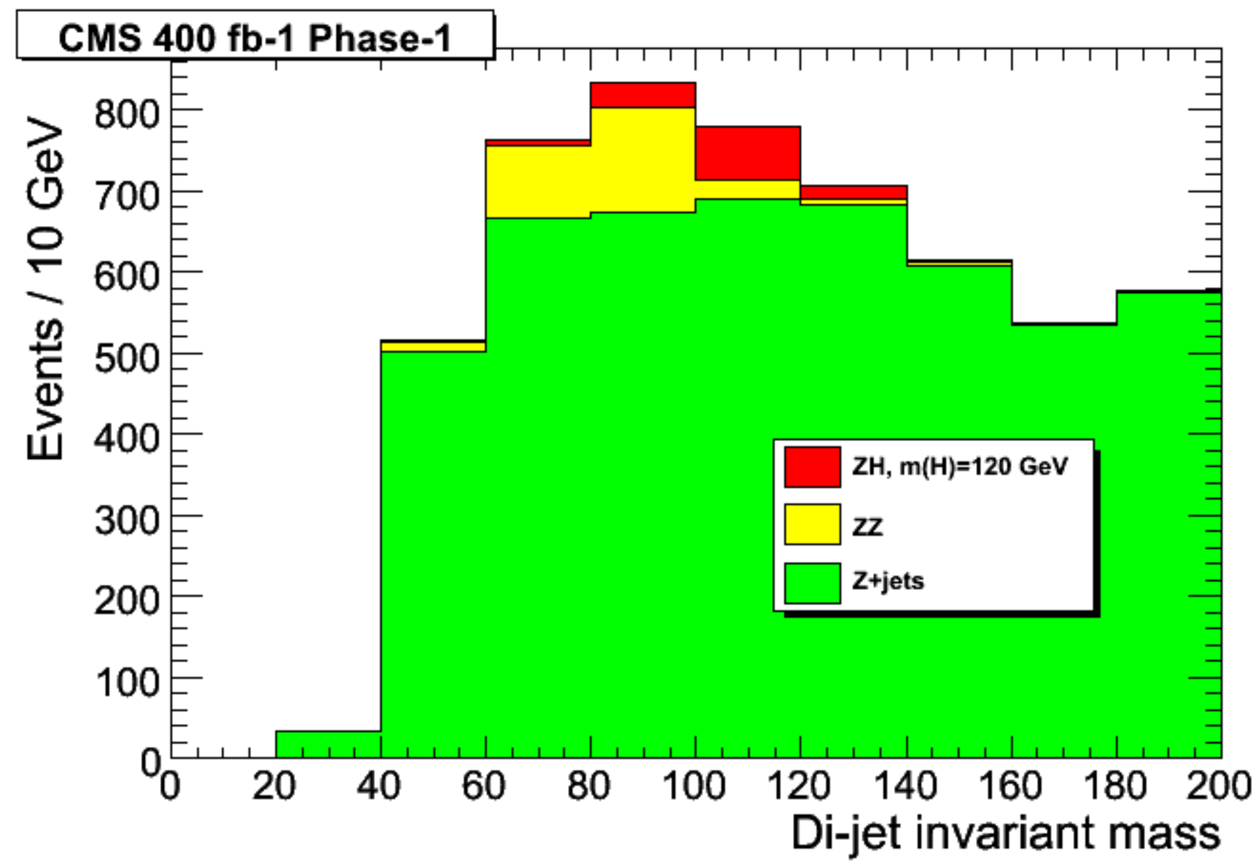
Not the most detailed of analyses, but it makes a good starting point for further studies.

UltraFast physics study

No pileup



$$\frac{s}{\sqrt{s+b}}=2.26$$



$$\frac{s}{\sqrt{s+b}}=2.33$$

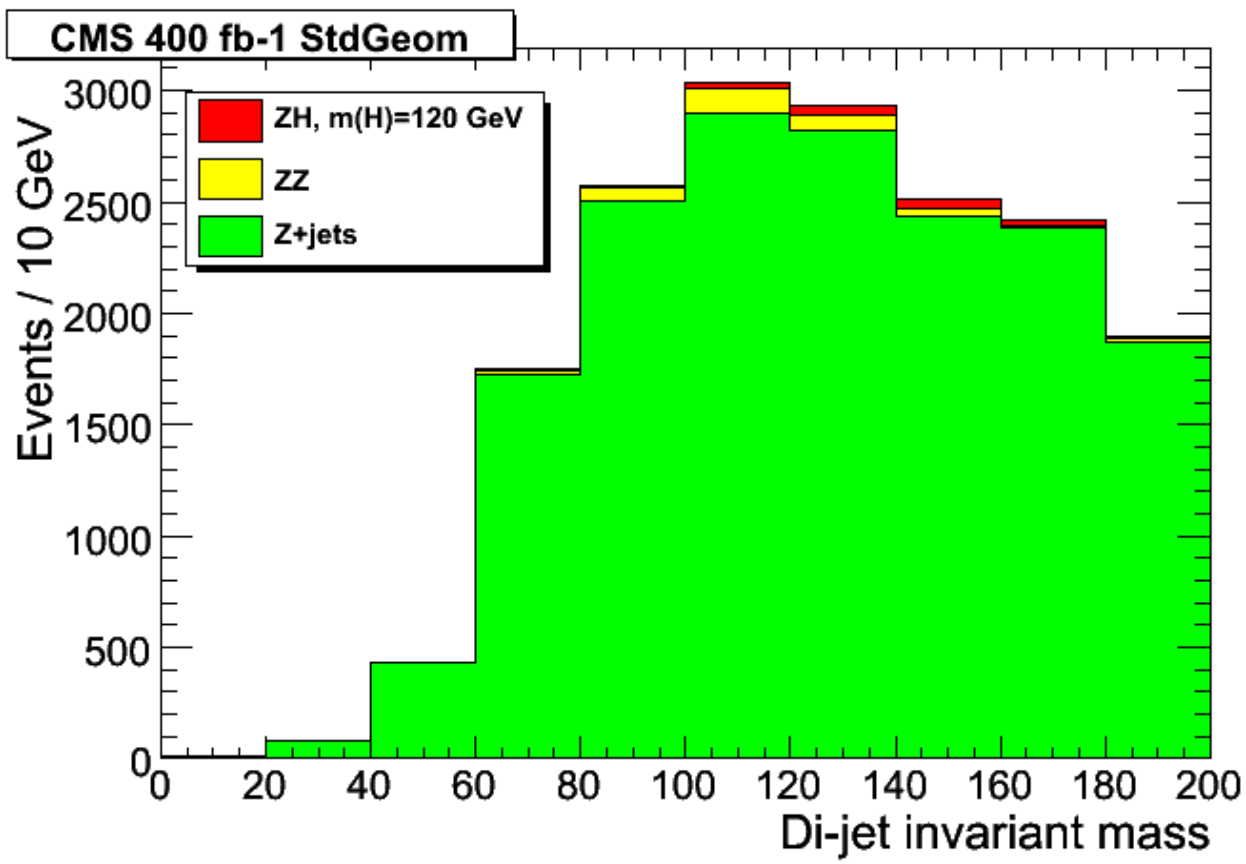
Brown, Fermilab, Iran, Nebraska, Princeton, Purdue-Calumet, Vanderbilt, Wisconsin

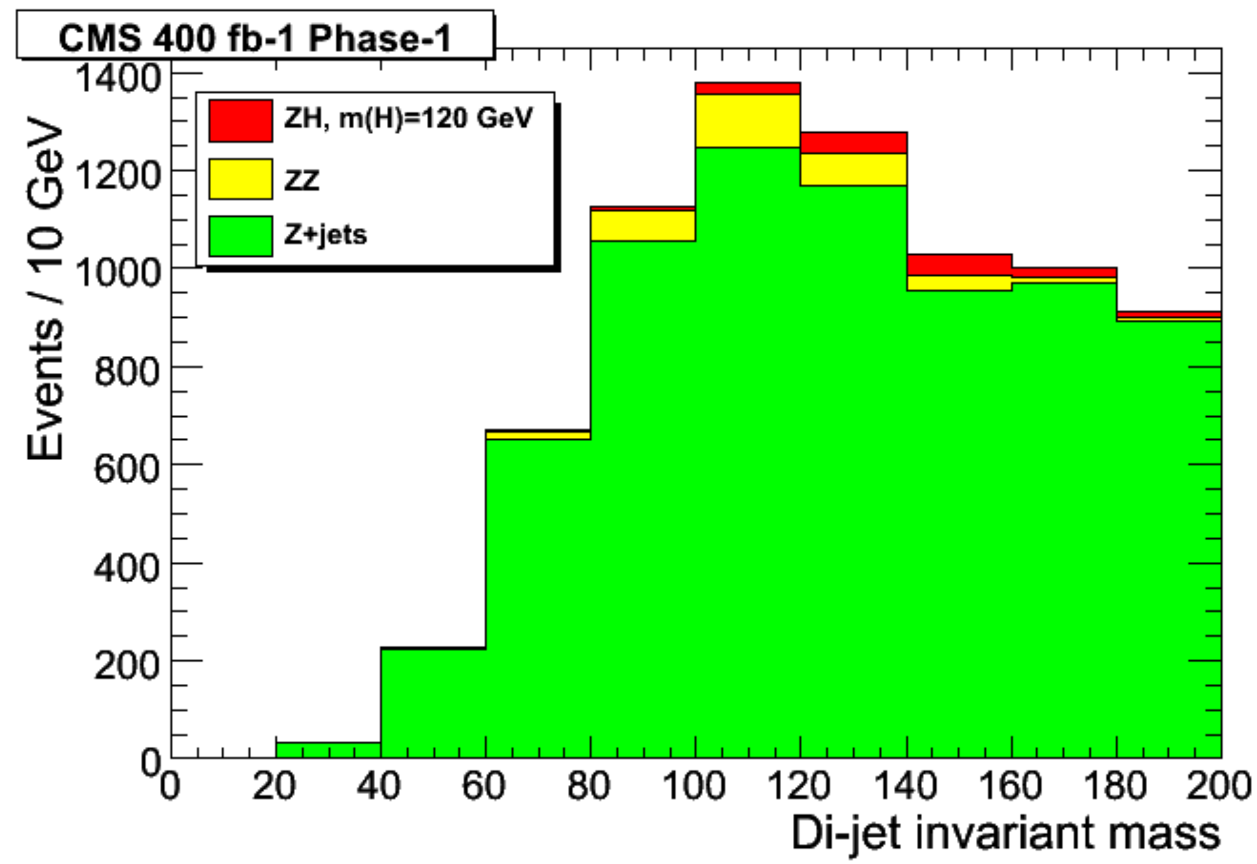
N.B. ZH peak shifted lower by ~5GeV due to uncalibrated jet energy scale.

UltraFast physics study

Brown, Fermilab, Iran, Nebraska, Princeton, Purdue-Calumet, Vanderbilt, Wisconsin

50 pileup events





$\frac{s}{\sqrt{s+b}} = 1.1$ $\frac{s}{\sqrt{s+b}} = 2$

Signal significance will change with analysis optimisation. However, relative differences can be used to estimate upgrade improvements.

N.B. ZH peak broadened and shifted higher by ~10GeV due to uncalibrated jet energy scale.

Summary

- The current pixel detector will not have sufficient performance as we move into high luminosity running.
- A credible replacement has been designed, technical proposal just released.
- Detailed simulations show that the detector performance will increase even at high luminosity.
- Initial fast simulations of the physics reach show performance can be maintained. Work is ongoing for detailed studies.