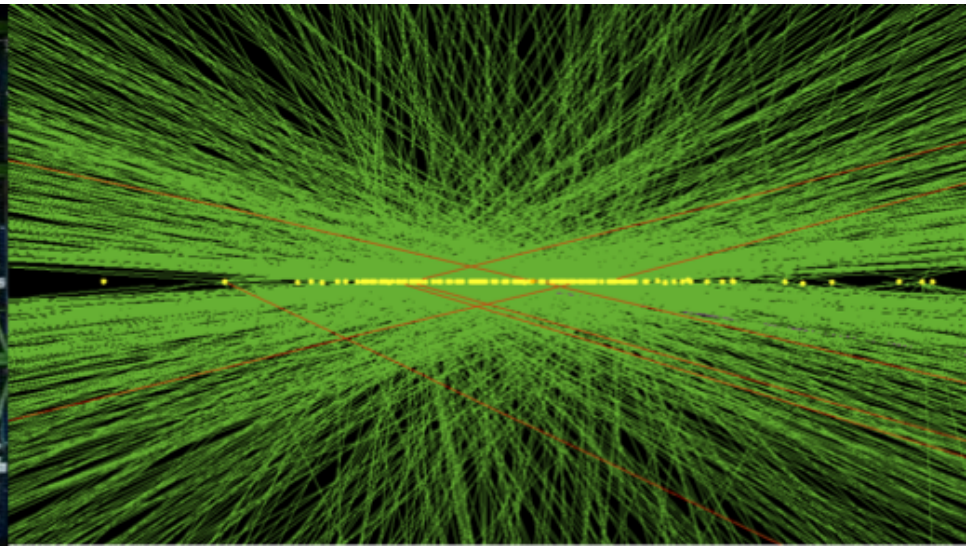
Motivation for time resolution targets

David Stuart
Univ. of California, Santa Barbara

Director's review
20 March 2019



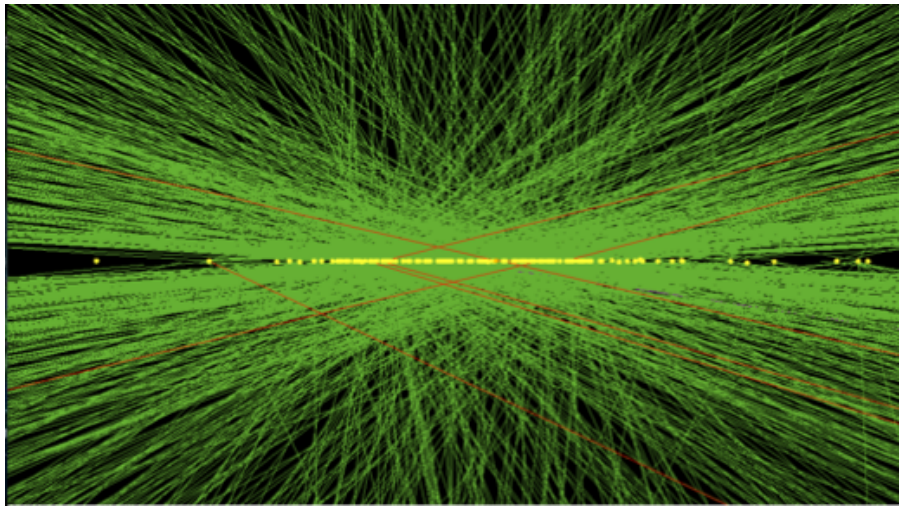
The motivation for the <40 and <60 resolution targets

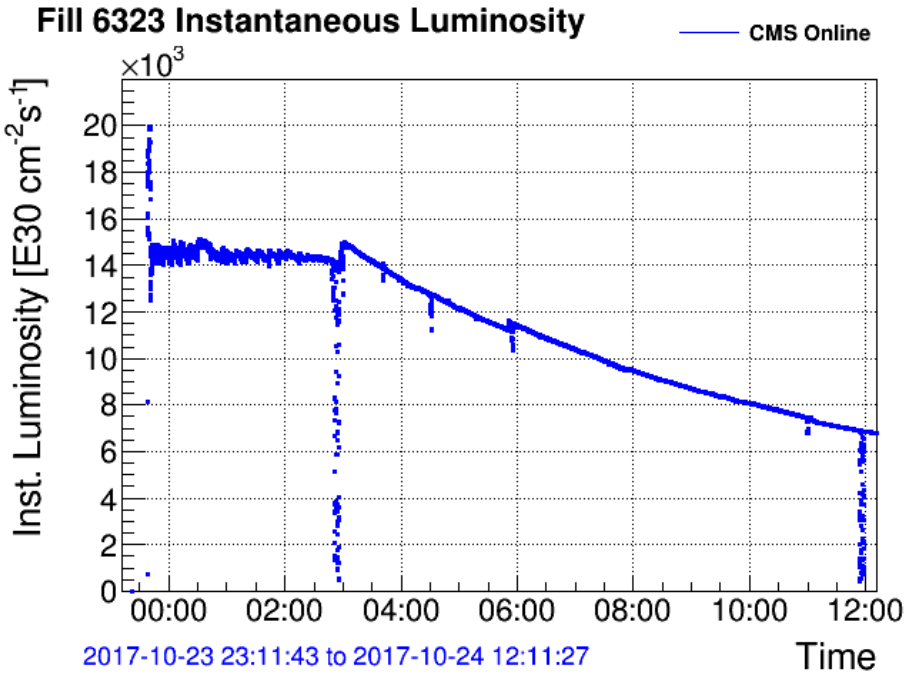
- The 40 and 60 ps resolution targets stems from the physics motivation and the reasonably achievable beginning and end of life resolution.

- I will explain both of these, and show the physics impact.

The pile-up limitation

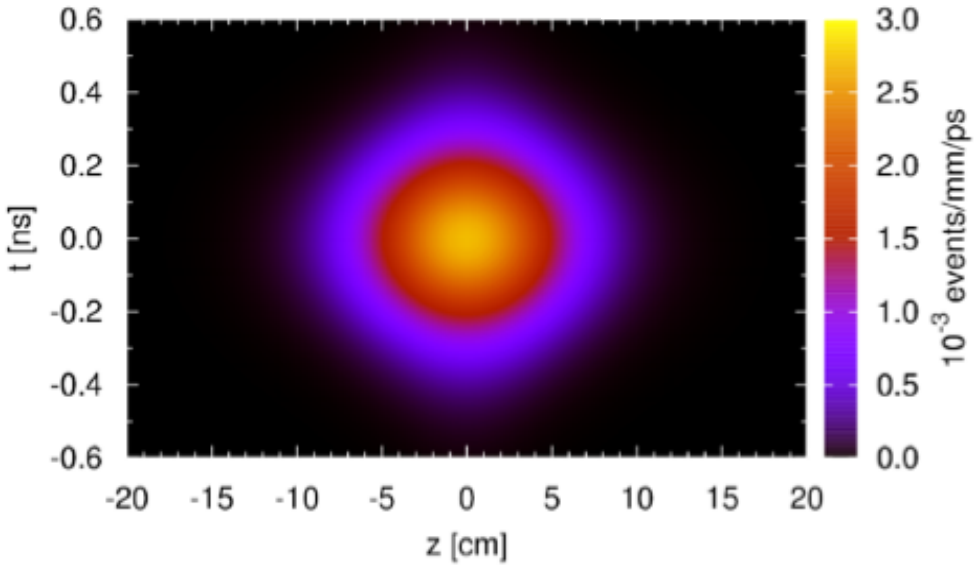
- The CMS HL-LHC upgrade targeted a baseline lumi of $5x10^{34}$ $cm^{-2}s^{-1}$ accumulating 3 ab^{-1}, limited by PU induced confusion above 140 PU.
- However, the upgrade's rad-damage requirements were set by the expected $7.5x10^{34}$ $cm^{-2}s^{-1}$ ultimate LHC performance, which yields 4 ab^{-1}, but 200 PU.





Pile-up suppression

- The MTD's precise measurements of particle production times reduces the confusion from PU by separating vertices in time as well as position.
- This is a new version of an old trick, reducing bunch spacing from 396 → 132 and 50 → 25 → 0.1 ns.



A simple view of the effect of time resolution effect:

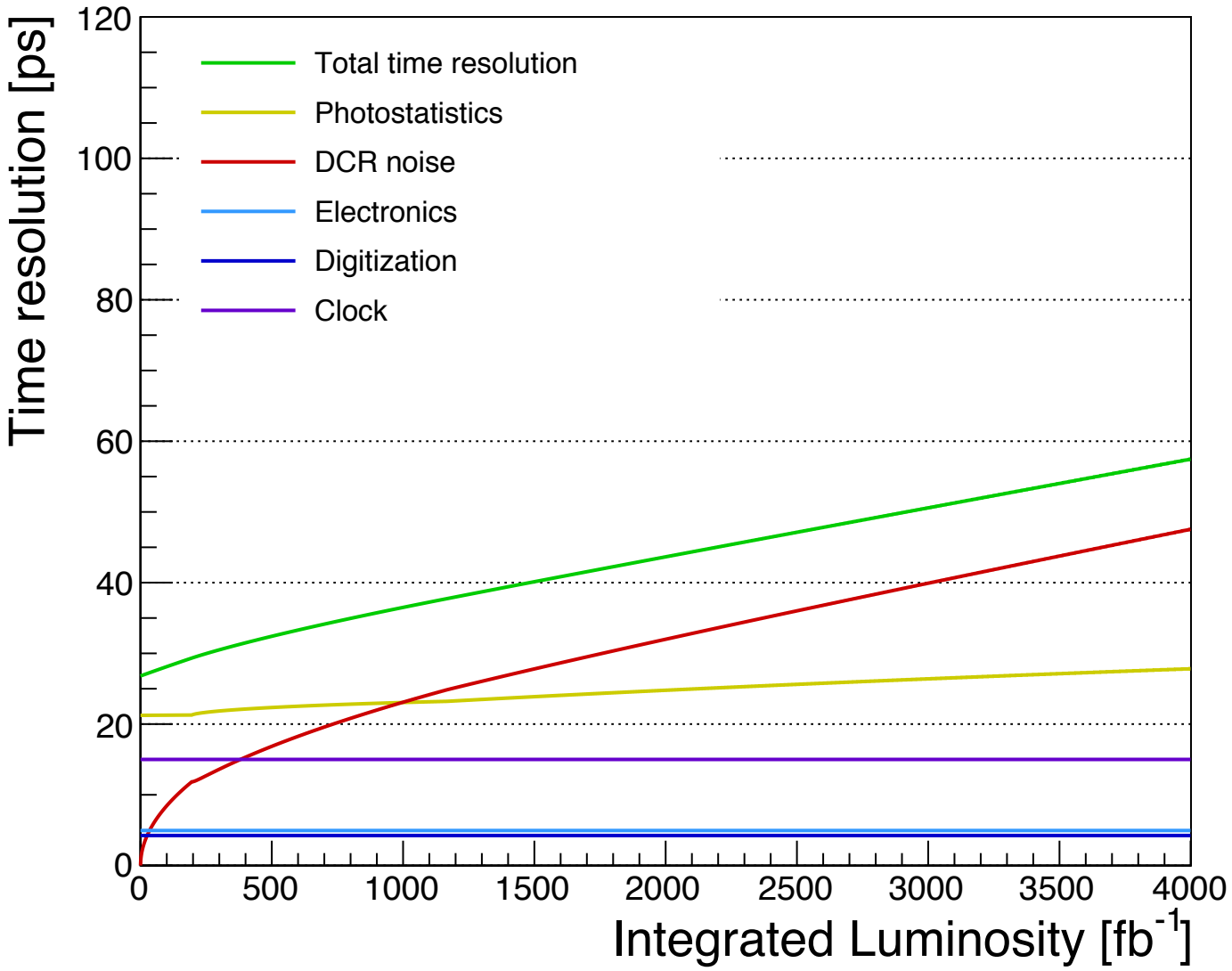
$RMS_t \approx$ 180-200 ps

40 ps res. is about 5σ RMS

60 ps res. is about 3σ RMS

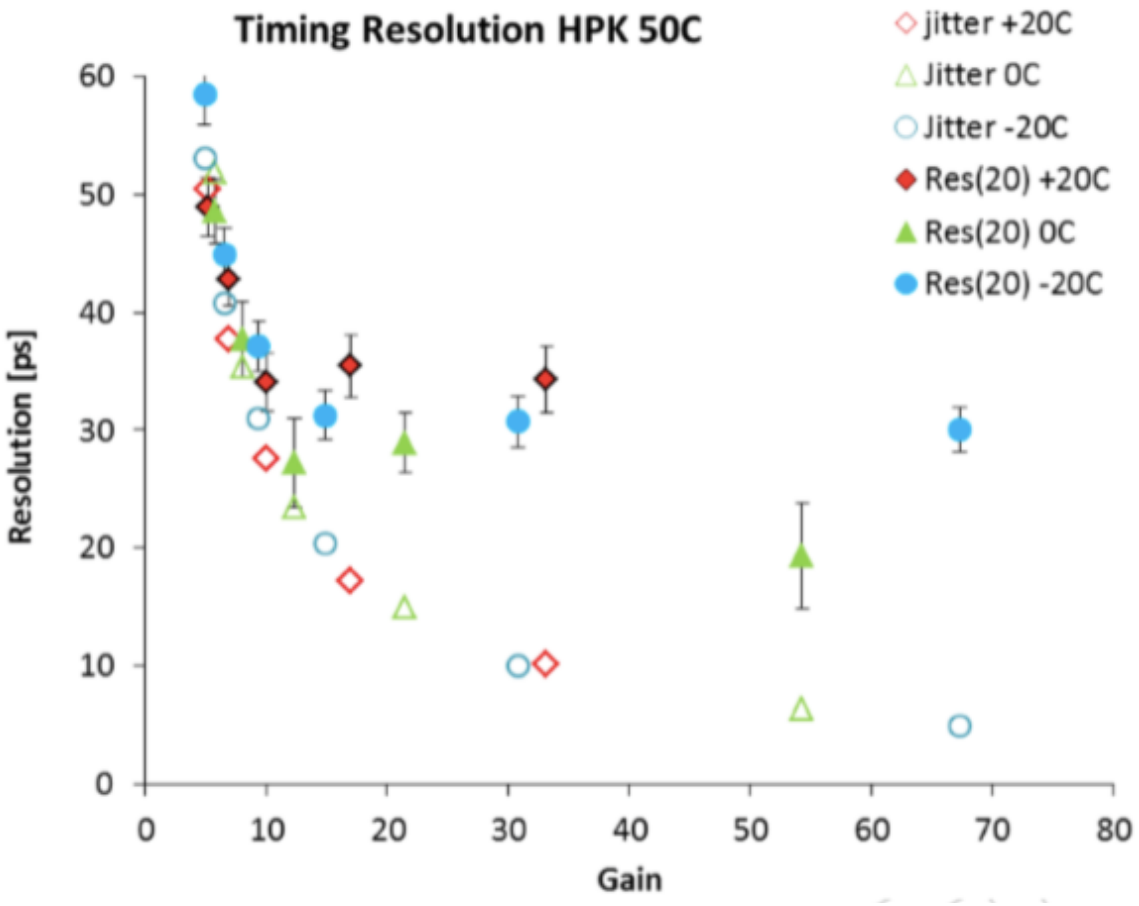
The full story is more nuanced, but this simple picture helps see the benefit intuitively.

BTL achievable resolution range



ETL achievable resolution range

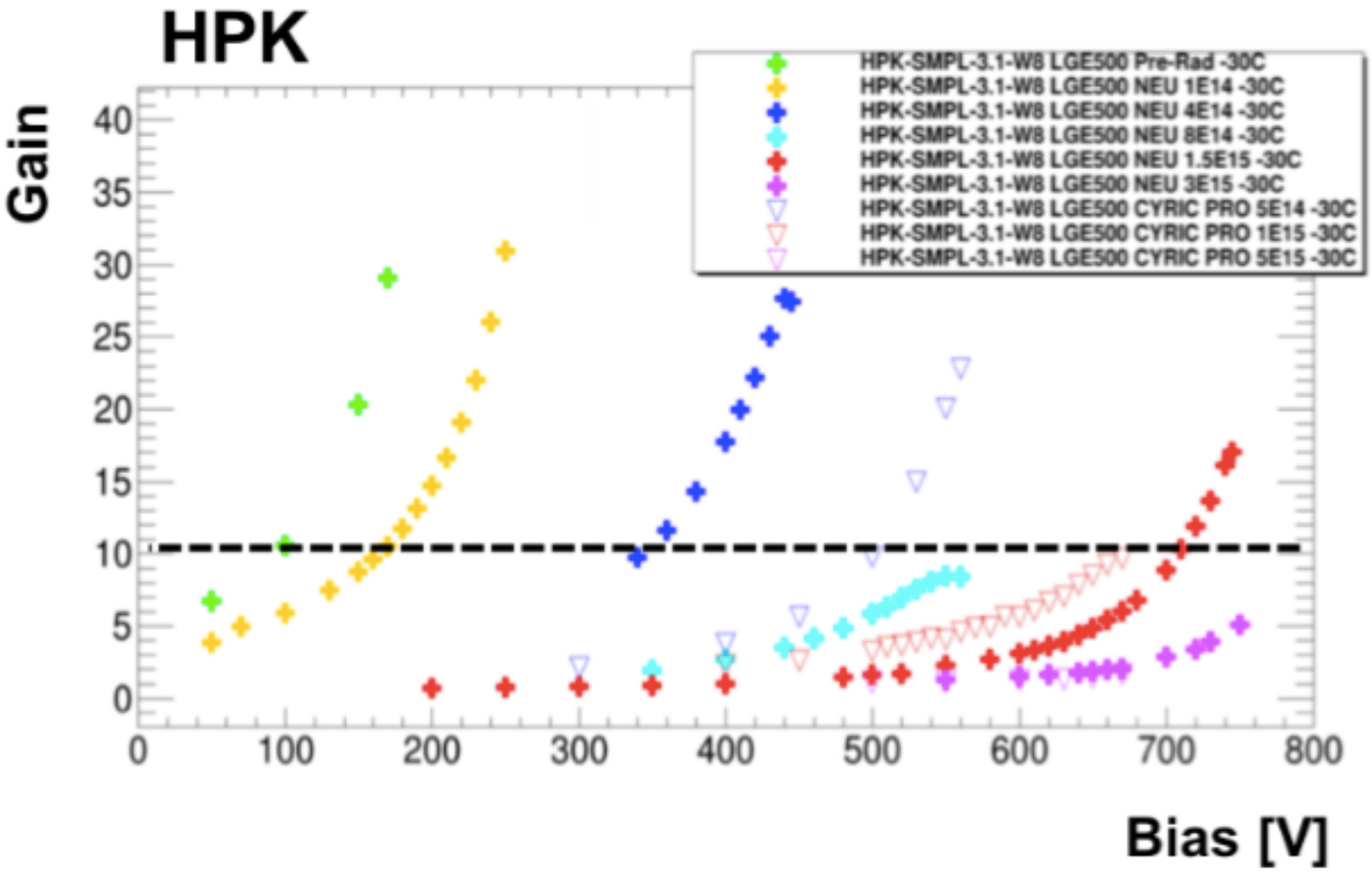
ETL resolution is LGAD+ASIC+system
System contribution is expected to be negligible
LGAD & ASIC contribs. scale with gain
ASIC contrib scales with power



ETL achievable resolution range

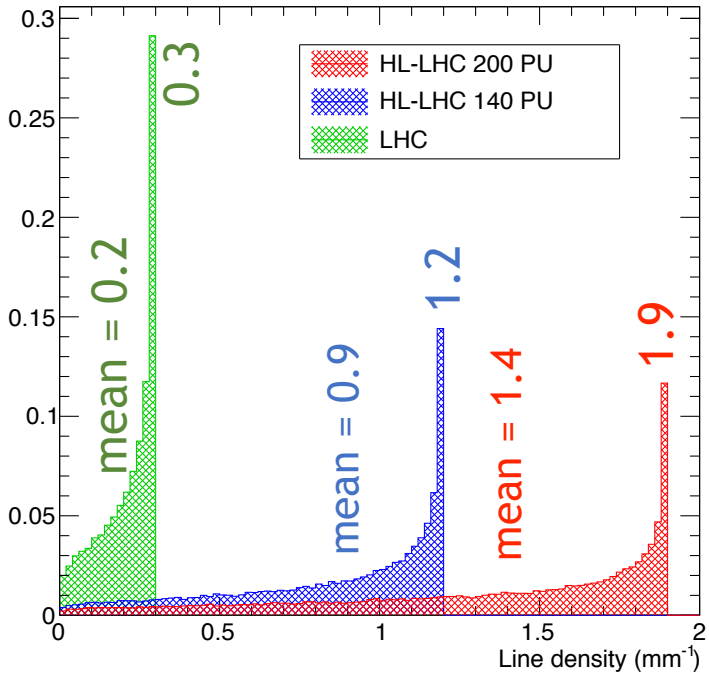
ETL resolution is LGAD+ASIC+system
System contribution is expected to be negligible
LGAD & ASIC contribs. scale with gain
ASIC contrib scales with power

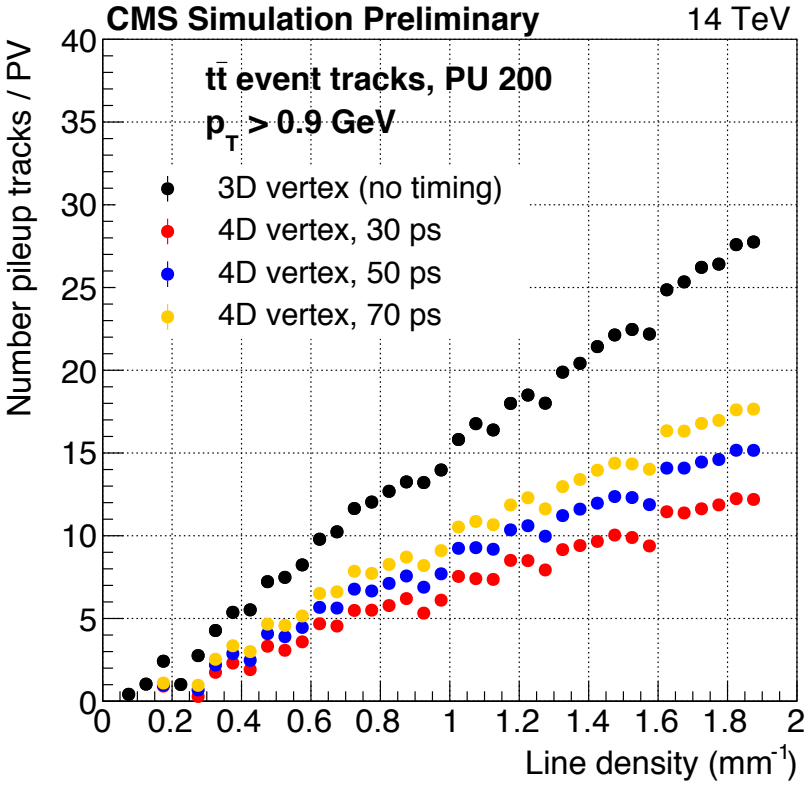
Gain is limited
at highest fluence
by max bias voltage



Pile-up suppression

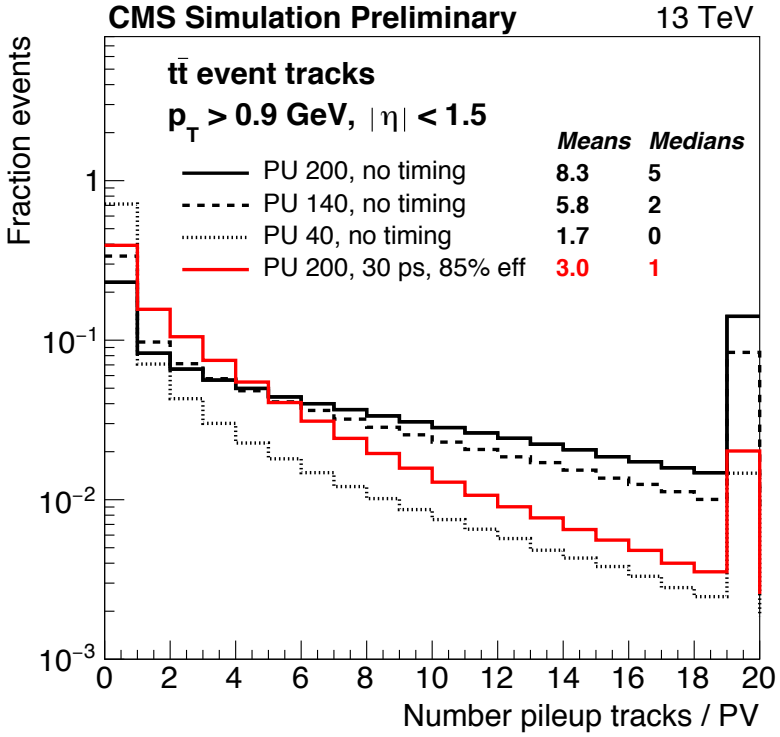
- The figure of merit for PU confusion is line density, i.e., collisions per mm, and number of PU tracks overlapping a primary vertex.
- Resolutions of 30-40 ps push the PU200 average to below the level of PU140, closer to current PU.

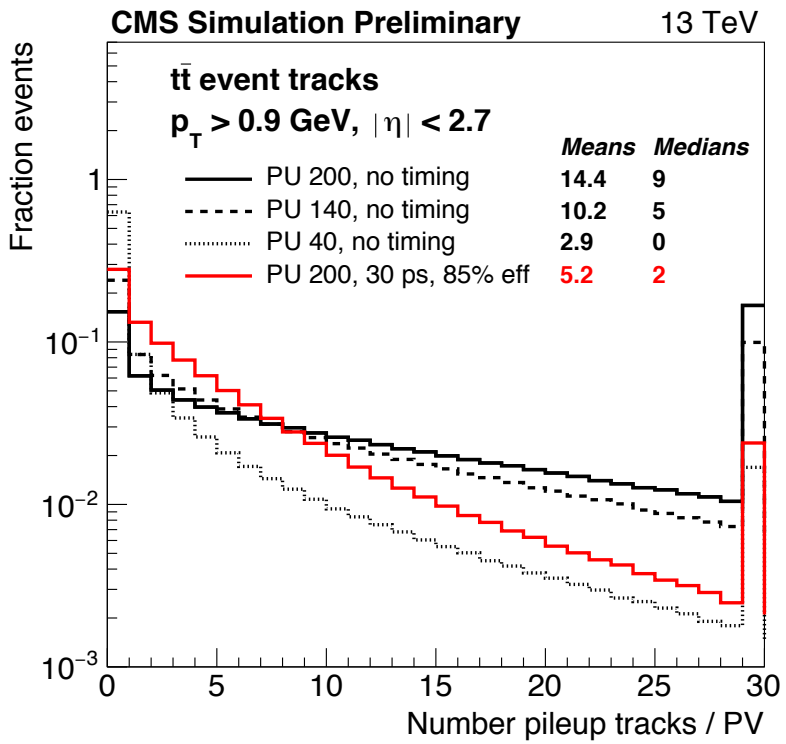




Pile-up suppression

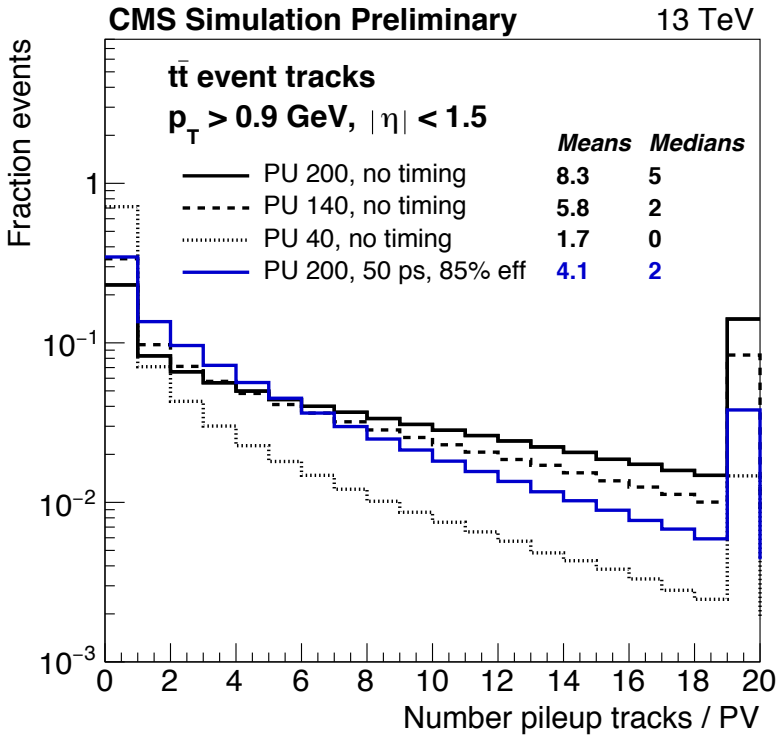
- The figure of merit for PU confusion is line density, i.e., collisions per mm, and number of PU tracks overlapping a primary vertex.
- Resolutions of 30-40 ps push the PU200 average to below the level of PU140, closer to current PU.

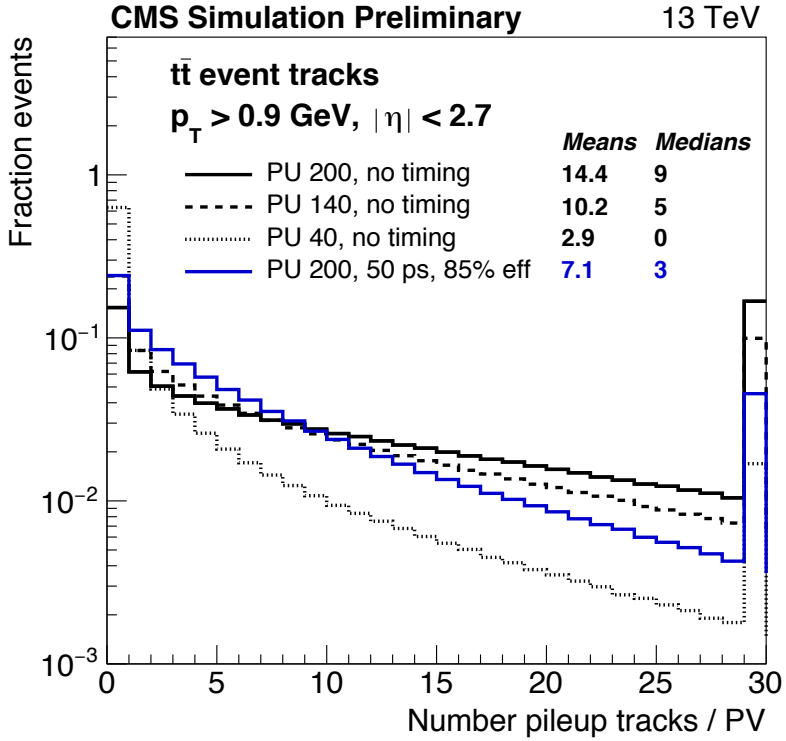




Pile-up suppression

- The figure of merit for PU confusion is line density, i.e., collisions per mm, and number of PU tracks overlapping a primary vertex.
- Resolutions of 30-40 ps push the PU200 average to below the level of PU140, closer to current PU.





Maintain improvement wrt PU140 even at end-of-life resolution of ≈ 50 ps.

MTD Physics motivation

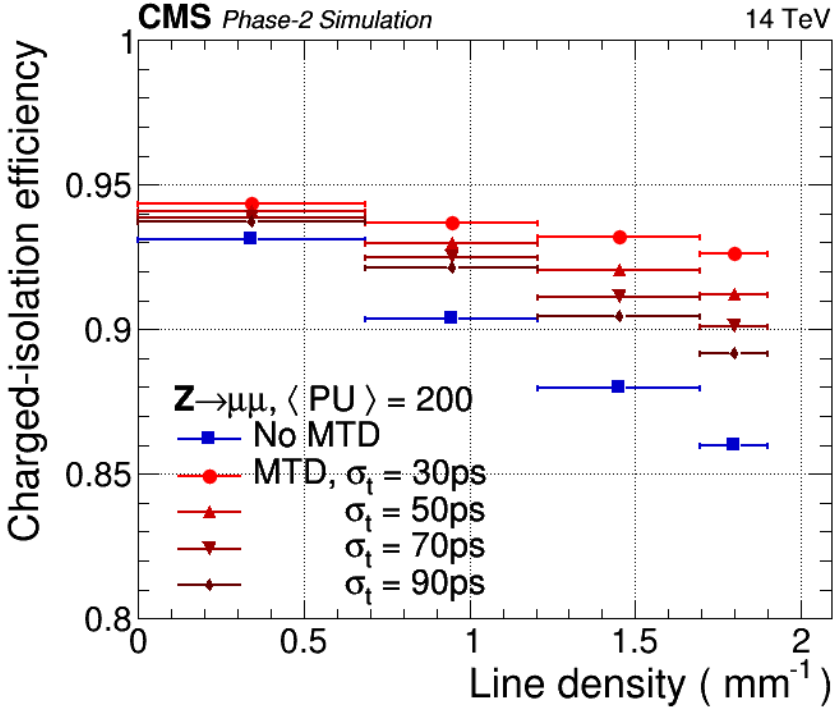
- The MTD's timing information reduces the PU confusion present at the LHC's highest luminosity to well below that of the baseline upper limit (140 PU).

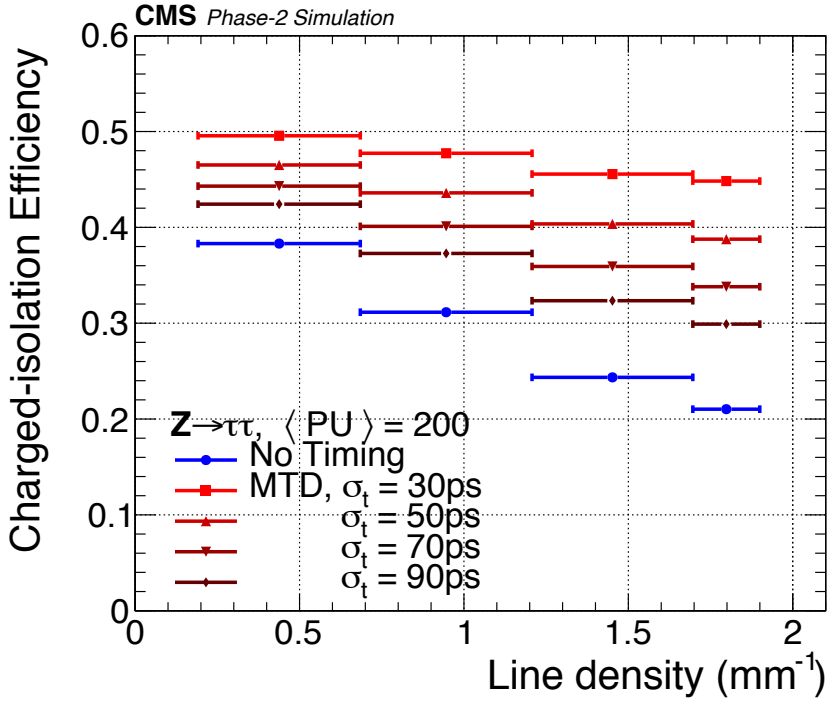
- This will allow CMS to exploit the full potential of the accelerator, increasing the accumulated luminosity from 3 ab^{-1} to 4 ab^{-1}. HL-LHC → HrL-LHC.

- It will also improve the performance of most physics objects beyond that of the baseline detector design, as illustrated on the following slides.

Lepton isolation

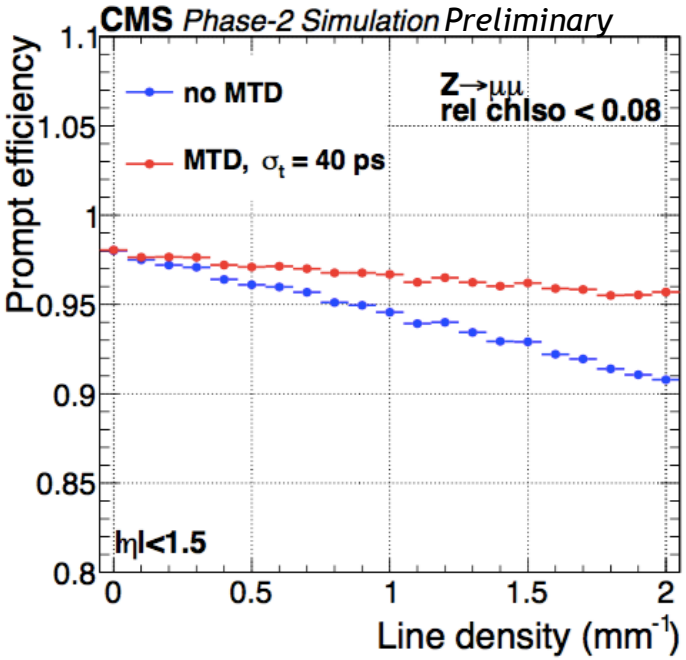
- Leptons are important for many physics results, including the high priority Higgs coupling measurements and new physics searches, e.g., HH with Z or τ final states.
- Improvement is robust vs resolution aging & lower $\mathcal{L}$.

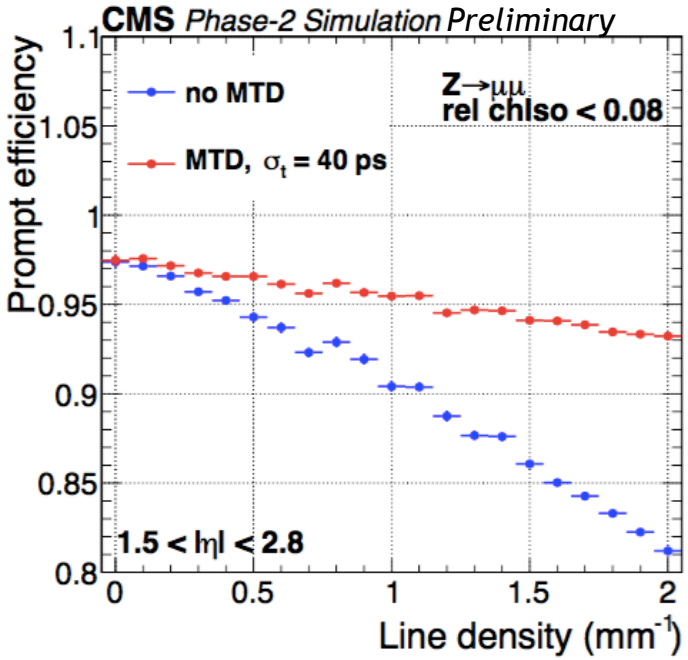




Lepton isolation

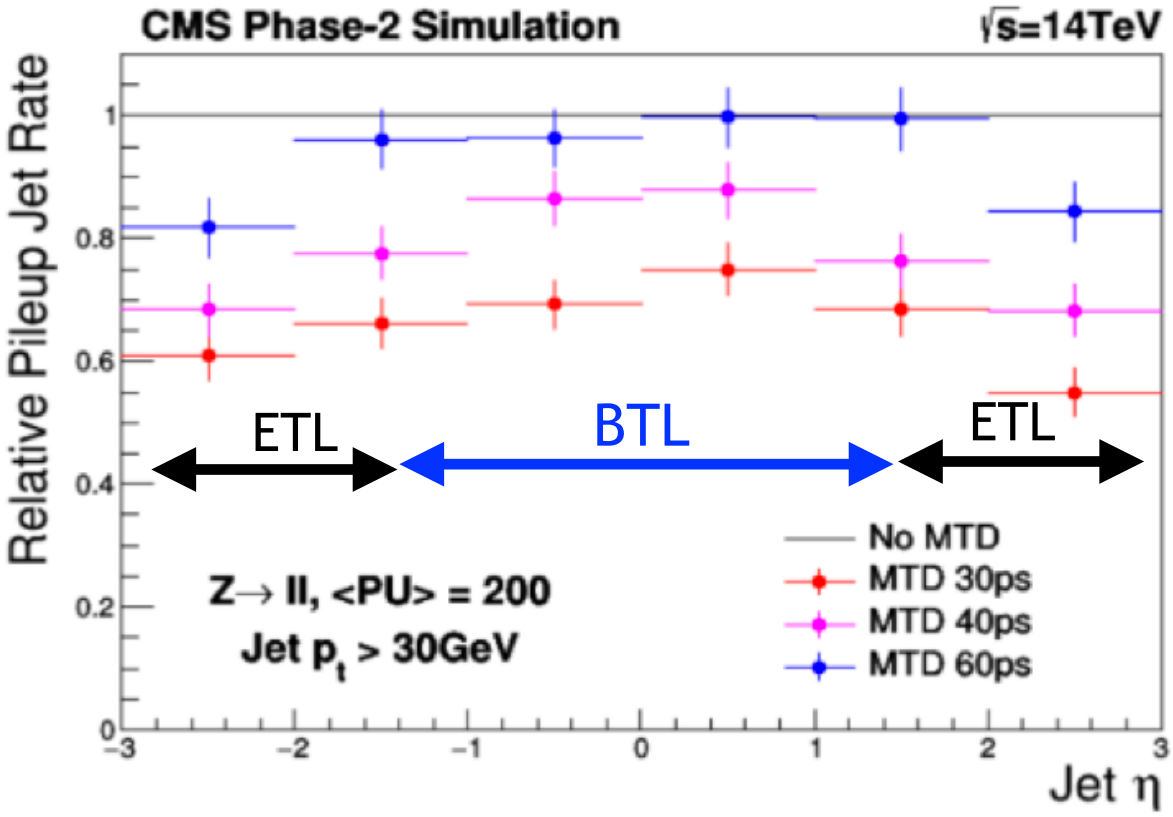
- Leptons are important for many physics results, including the high priority Higgs coupling measurements and new physics searches, e.g., HH with Z or τ final states.
- Improvement is robust vs resolution aging & lower $\mathcal{L}$.





Jet & MET reconstruction

- Jet and Missing Energy reconstruction also benefit.
- Overlapping PU jets can fake signal jets
- Suppressed by 10-40% with 4D vertex matching

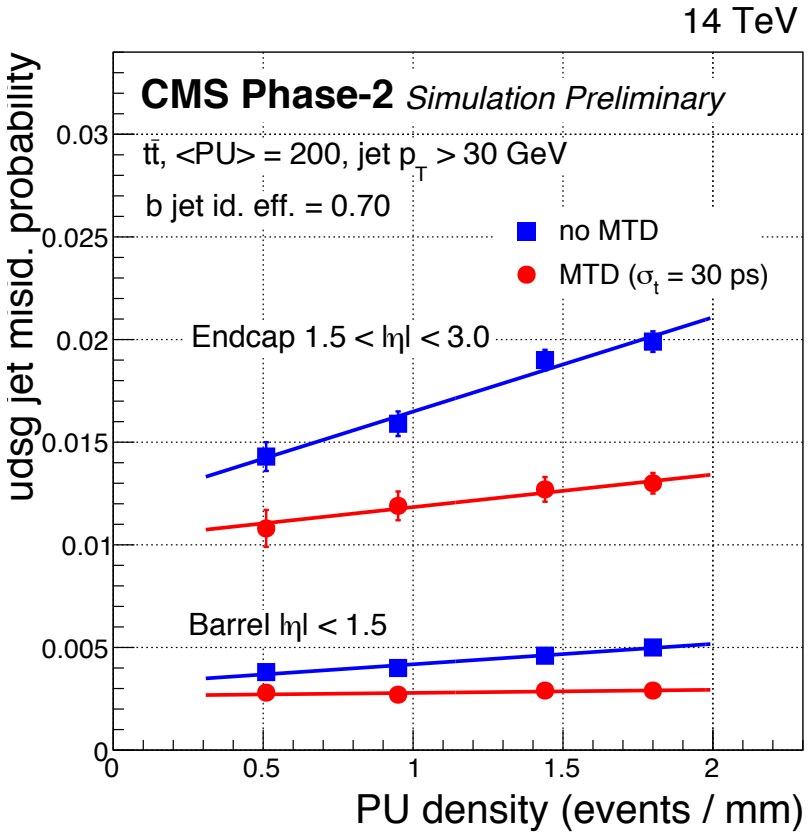


Significant improvement, particularly in ETL region, were PU jet rate is a larger issue.

b-quark tagging

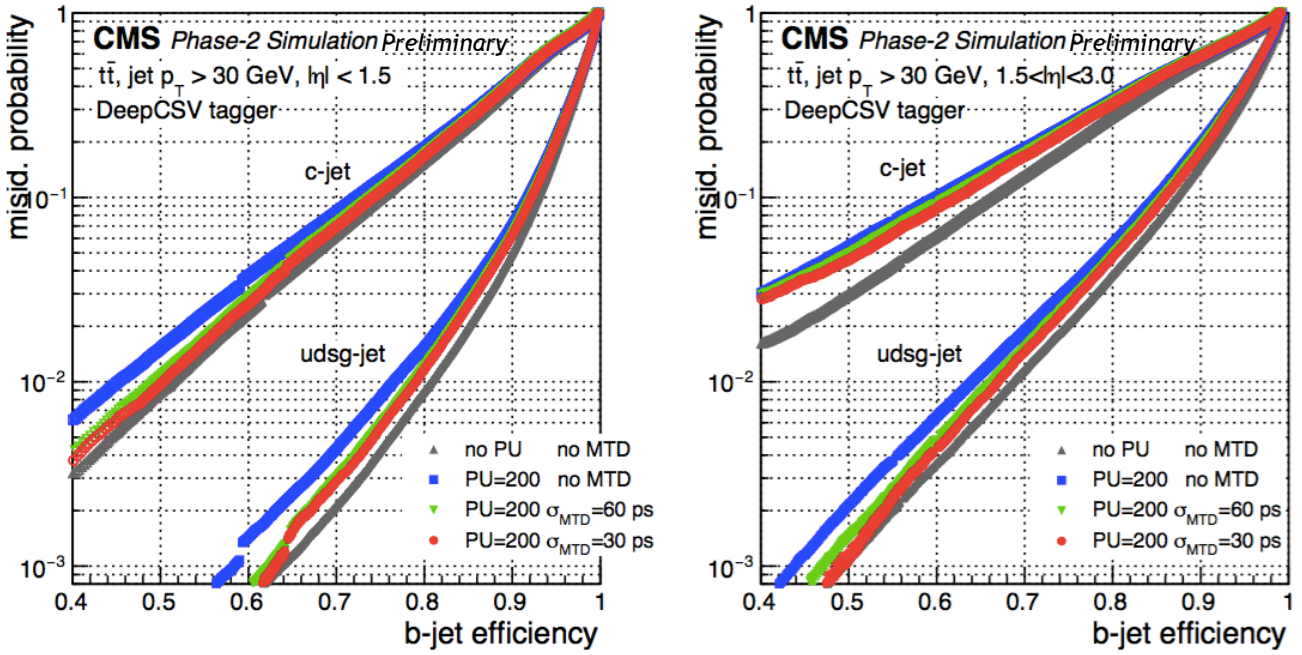
- The 4D tracking reduces fake contributions to secondary vertices and improves b-tagging.
- Time aware algorithm improves efficiency by ≈ 5%, or reduces bkgd by ≈ half at constant efficiency.

The improvement in background suppression is particularly large in the endcap, which is important for hermeticity in high multiplicity final states like HH → bbbb



b-quark tagging

- The 4D tracking reduces fake contributions to secondary vertices and improves b-tagging.
- Time aware algorithm improves efficiency by ≈ 5%, or reduces bkgd by ≈ half at constant efficiency.



Impact on physics program

- The improvement in the core physics objects provides a breadth of gains in sensitivity across the physics program.
- This has been studied [1] for several of the high priority science goals. Find improvement of 10-20% with BTL and 20-25% with hermetic BTL+ETL.
- The physics case has been endorsed as very strong by the LHCC.

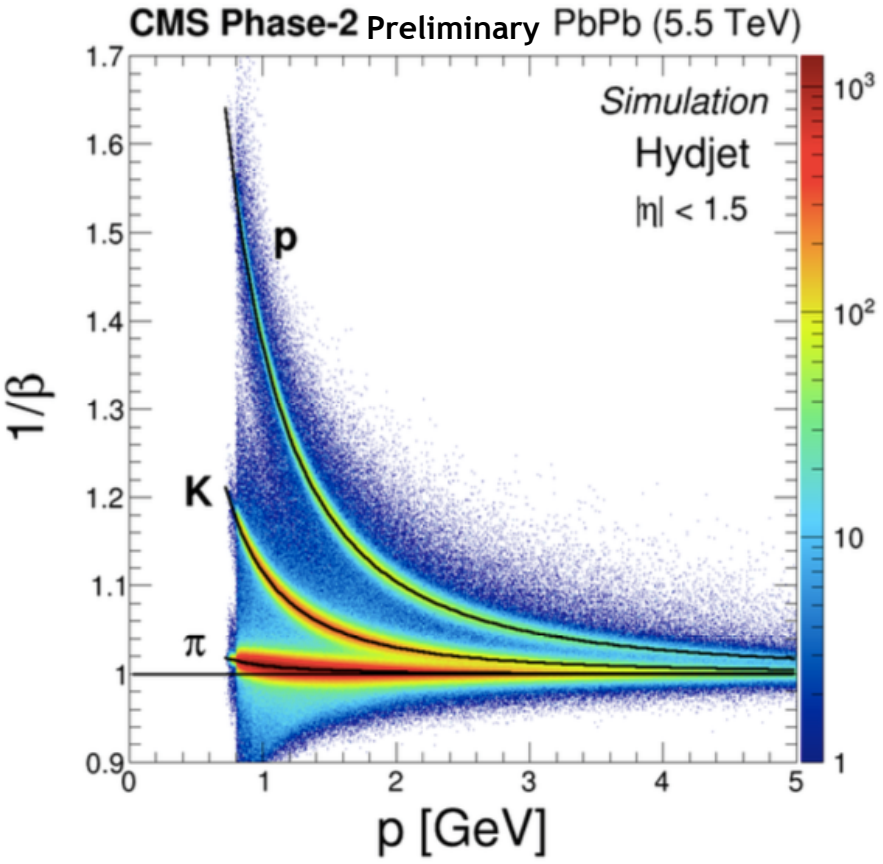
Table 1.1: Expected scientific impact of the MIP Timing Detector, taken from Ref. [8].

Signal	Physics measurement	MTD impact
$H \to \gamma\gamma$ $H \to 4$ leptons	+15–25% (statistical) precision on the cross section $\to$ Couplings	Isolation Vertex identification
VBF$\to$H$\to \tau\tau$	+30% (statistical) precision on cross section $\to$ Couplings	Isolation VBF tagging, p_T^{miss}
HH	+20% gain in signal yield $\to$ Consolidate searches	Isolation b-tagging
EWK SUSY	+40% reducible background reduction $\to$ 150 GeV increase in mass reach	MET b-tagging
Long Lived Particles (LLP)	Peaking mass reconstruction $\to$ unique discovery potential	β_{LLP} from timing of displaced vertices

[1] https://cds.cern.ch/record/2296612

Particle identification

- The time-of-flight determination allows kaon and proton ID for momentum up to about 2 or 4 GeV.



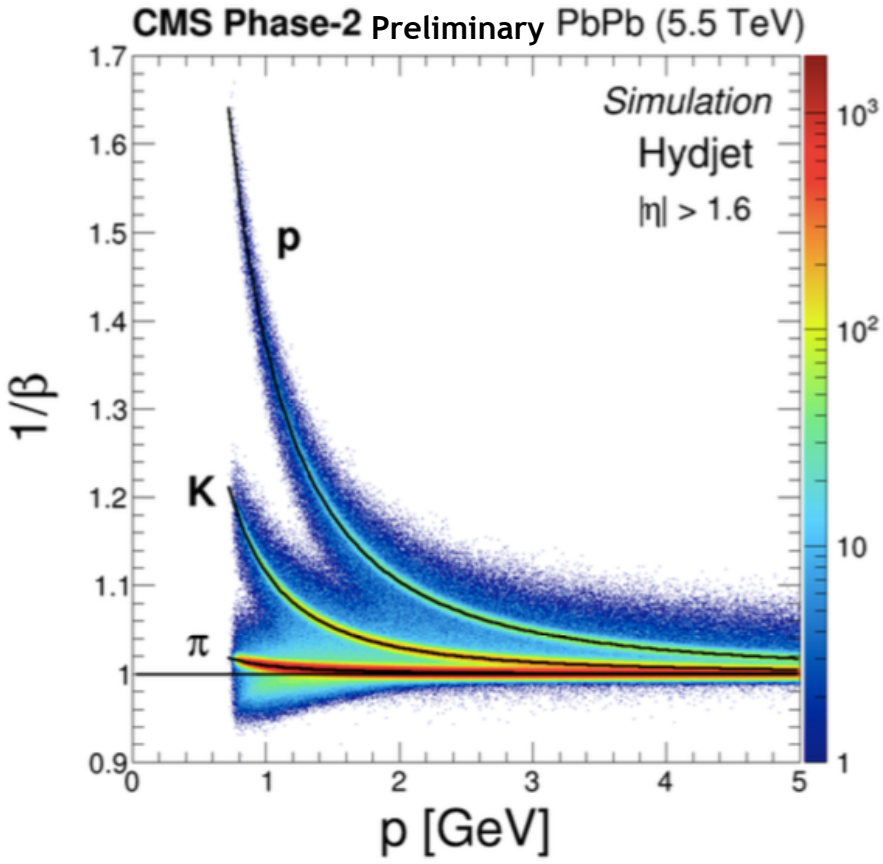
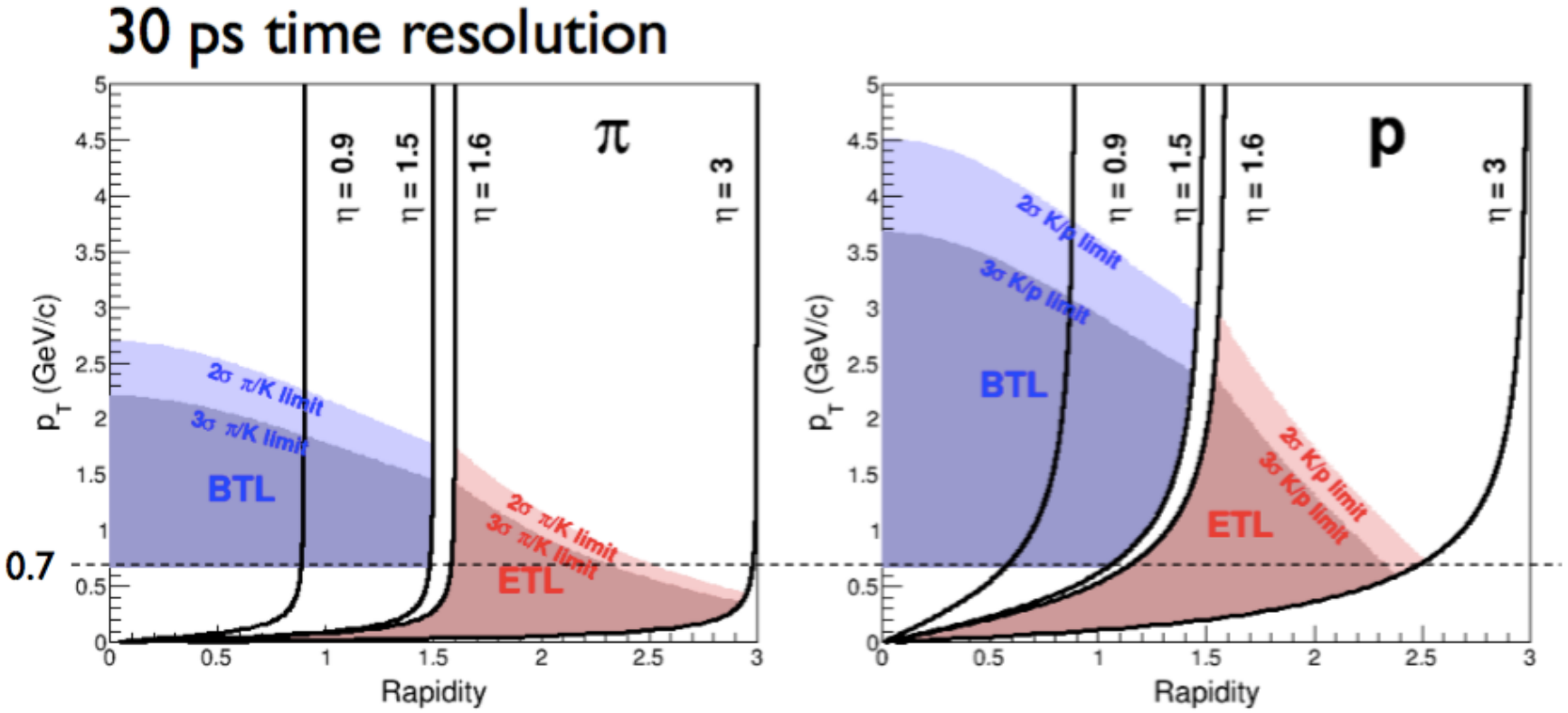


Figure 5.24: The inverse velocity ($1/\beta$) as a function of the particle momentum, p, for BTL ($|\eta| < 1.5$) and ETL ($|\eta| > 1.6$) in HYDJET PbPb simulation at 5 TeV.

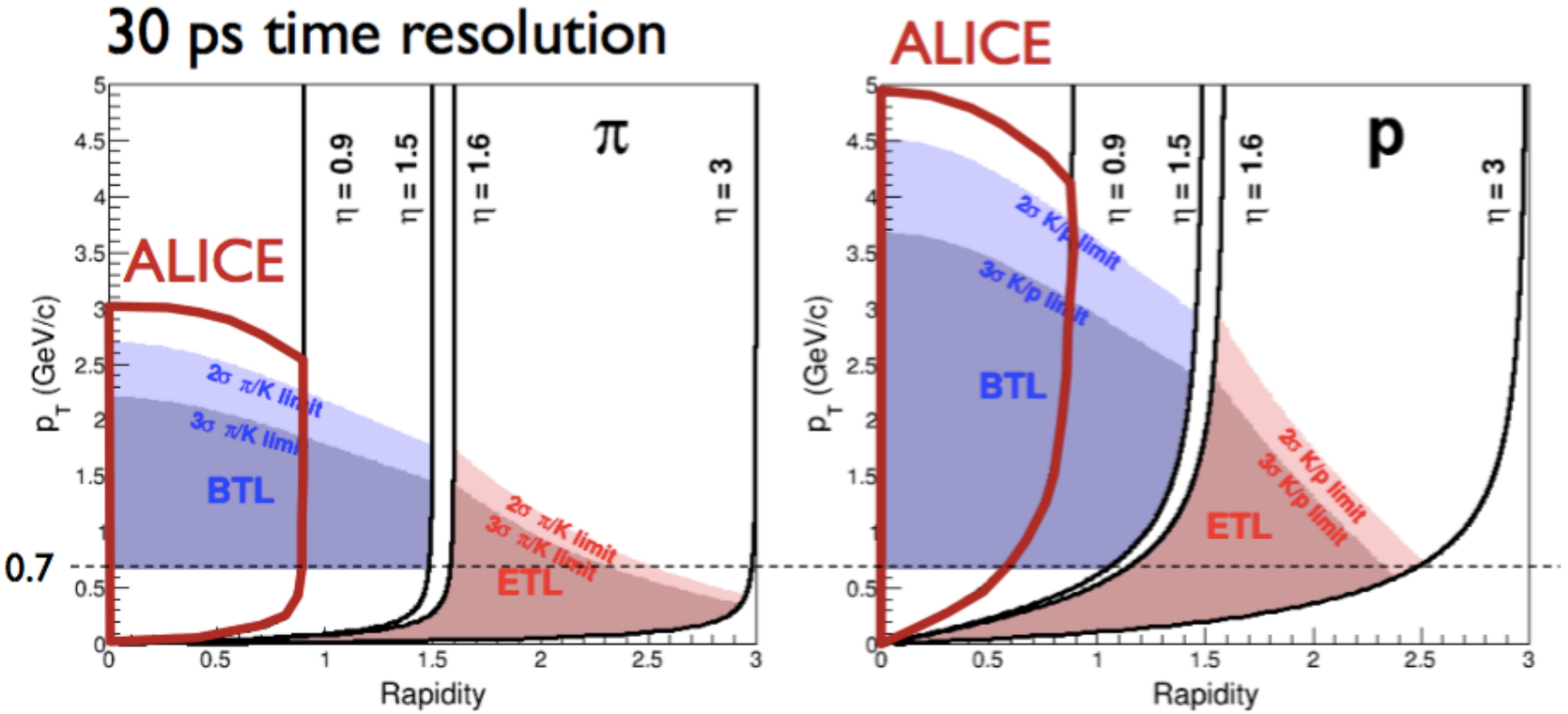
Particle identification

- The time-of-flight determination allows kaon and proton ID for momentum up to about 2 GeV.



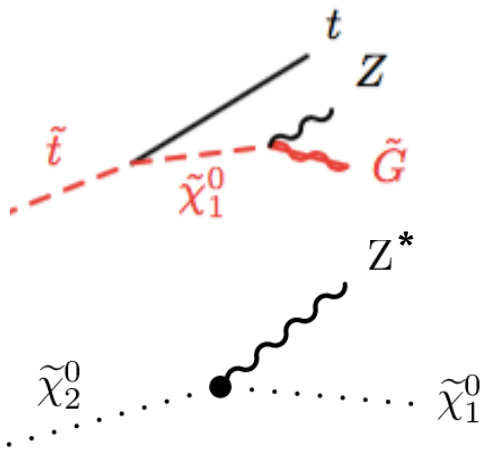
Particle identification

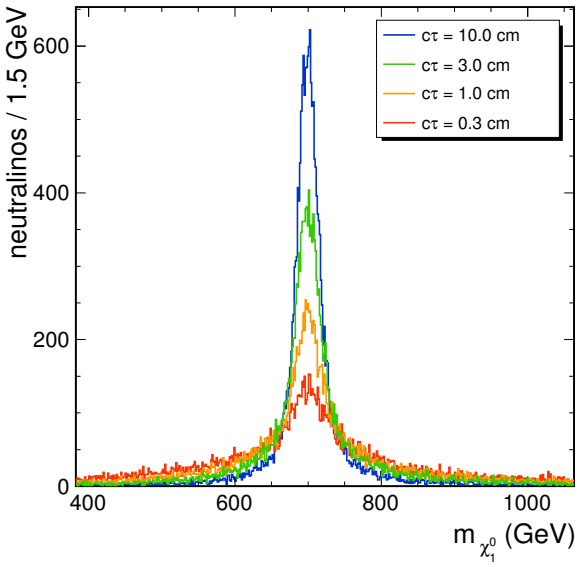
- The time-of-flight determination allows kaon and proton ID for momentum up to about 2 GeV.
- This is significant for heavy-ion studies, and the $|\eta|>1$ region is uncovered by other experiments.

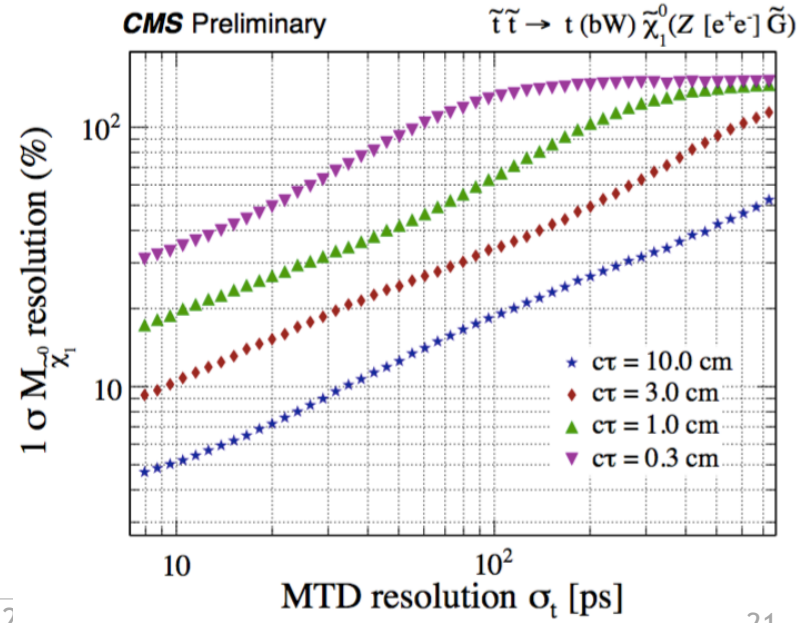


Particle identification

- The time-of-flight also provides a new handle on long-lived particles (LLPs). These are motivated in many NP models, e.g., GMSB and compressed SUSY.
- With 4D secondary-primary vertexing, can measure the LLP's β and reconstruct its mass, if mass of the invisible system is known. Gives powerful background suppression and signal characterization.







Summary

- The MTD's pile-up suppression allows accumulation of up to 30% more data; 3 ab^{-1} → 4 ab^{-1}.

- MTD also improves the performance of most physics objects by 10-20%, which extends the sensitivity of priority analyses by 15-25%.

- MTD maintains its HrL-LHC benefit for resolutions ranging from the initial 30-40 ps to ≈60 ps, which correspond to the achievable start and end of life.