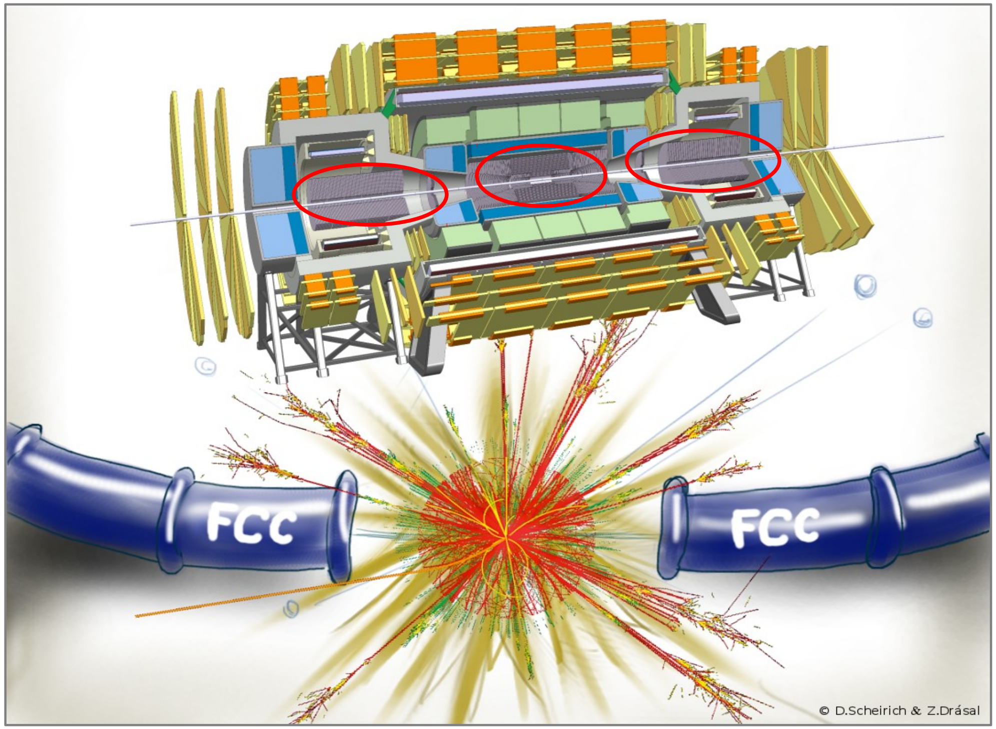
FCC-hh: Pile-up & PU Mitigation Studies



Zbyněk Drásal
CERN

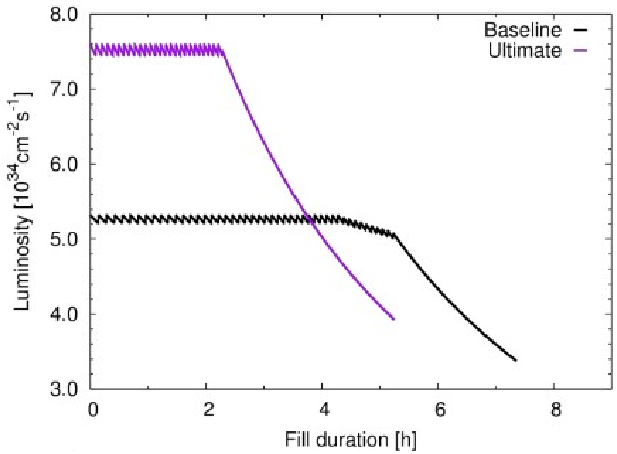
Overview

- Pile-up numbers: HL-LHC versus FCC-hh
- Effective pile-up rate & primary vertexing
  - Comparison CMS versus FCC v4.01
  - Effect of luminous region size
- Summary & Plans

Pile-up Numbers: HL-LHC

- How to estimate pile-up limits for FCC-hh?

  → numbers from G.Arduini's ECFA talk on HL-LHC luminous region



$$\langle\mu\rangle = \frac{\sigma_{inel}.L}{n_B.f_r}$$

- σ_{inel} ~ 85mb @ 14TeV HL-LHC
- **Tunnel length** = 26.659 km
- n_B **= 2748** → N bunches (2808 for LHC)
- **Bunches fill-up factor** f_{up} = 2748/3554 ~ 77.3%
- f_r **= 11.245kHz** → revolution frequency (nominal LHC)
- **Baseline Luminosity** (levelled) **= 5.3 x 10^{34}** cm^{-2}s^{-1}
- **Ultimate Luminosity** (levelled) **= 7.6 x 10^{34}** cm^{-2}s^{-1}

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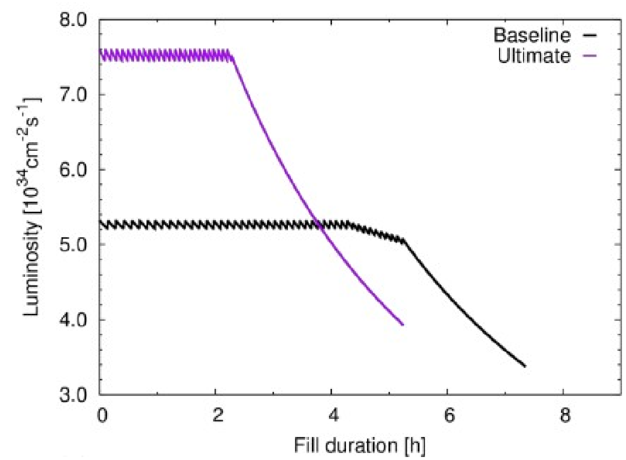

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– **Luminosity variations** between bunches ± 8% (see e.g. ATL-PHYS-PUB-2013-014)

– **Pile-up: μ is Poisson distributed** → quantify **limits** by 95% confidence interval (σ~1.96√N)

→ **HL-LHC Baseline: <μ> = (146 ± 12) ± 25**

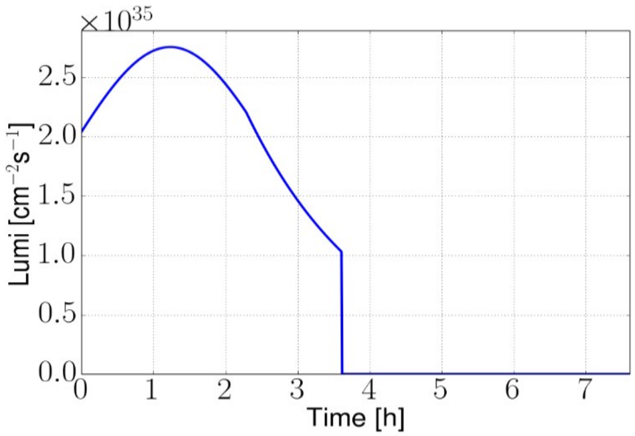
with σ_{inel}~81mb (TOTEM), n_b~2808, L~5x10^{34} cm^{-2}s^{-1} → <μ> = [(128 ± 10) ± 23]

→ **HL-LHC Ultimate: <μ> = (209 ± 17) ± 29** (with σ_{inel}~81mb etc. → <μ> = [(184 ± 15) ± 28])

Pile-up Numbers: FCC-hh

- How to estimate pile-up limits for FCC-hh?

→ numbers extrapolated (plot from D.Schulte's talk at FCC Week)



$$\langle\mu\rangle = \frac{\sigma_{inel} . L}{n_B . f_r}$$

- σ_{inel} ~ 108mb @ 100TeV FCC-hh
- **Tunnel length** = 97.500 km
- n_B **= 10050** (using f_{up} factor)
- f_r **= 3.075kHz** (assuming FCC tunnel)
- **Ultimate Luminosity** ~ **30 x 10^{34}** $cm^{-2}s^{-1}$
- **Levelled luminosity (assuming loss in int. L ~20%) = 15 x 10^{34}** $cm^{-2}s^{-1}$

– Assume the same luminosity variations between bunches ± 8%

– **Pile-up Poisson distr.:** quantify **limits** by 95% confidence interval (σ~1.96√N)

→ **FCC-hh Ultimate: <μ> = [(1048 ± 84) ± 66] → Max O(1200), Avg ~ O(1000)**

→ **FCC-hh Levelled: <μ> = [(524 ± 42) ± 47] → Max O(600)**

Vertexing @ PU=1000 & Timing Information

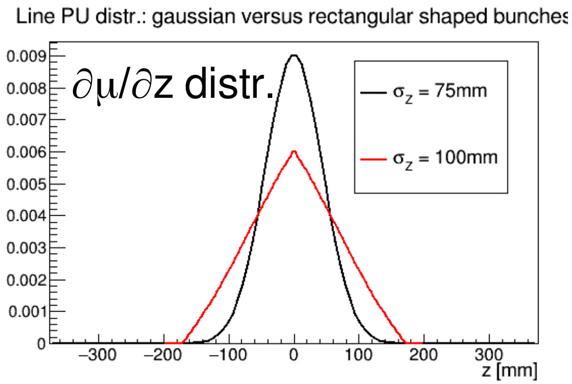
- How the pile-up (PU)~1000 degrades primary vertexing? Does the timing info help?

→ Dependent on scenario for luminous region (Gauss, “rectangular”,...) → simulate **1000 PU** vertices according to Gaussian (HL-LHC) Line & Time PU densities (c.f.: PhysRevSTAB.17.111001)

- **Gauss.** bunch: $\frac{1}{\sqrt{2\pi}\sigma_z} e^{-\frac{1}{2}\left(\frac{z}{\sigma_z}\right)^2}$

Line PU: $\frac{\sqrt{1+\phi^2}}{\sqrt{\pi}\sigma_z} e^{-(1+\phi^2)\left(\frac{z}{\sigma_z}\right)^2}$

Time PU: $\frac{\sqrt{1+\psi^2}}{\sqrt{\pi}\sigma_z} e^{-(1+\psi^2)\left(\frac{ct}{\sigma_z}\right)^2}$



Piwinsky angle Φ ~ 0.67
Time Piw. angle Ψ ~ 0.40
Luminous reg. ~ 44mm

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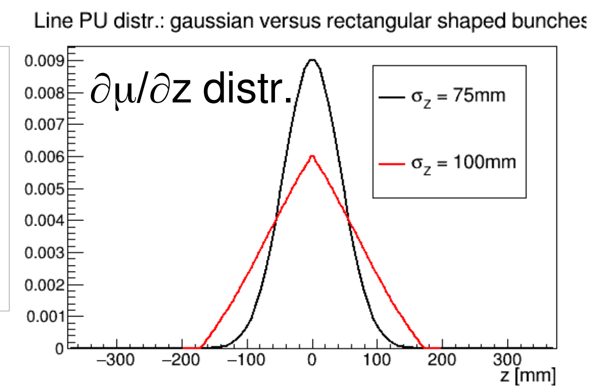

Piwinsky angle Φ ~ 0.67
Time Piw. angle Ψ ~ 0.40
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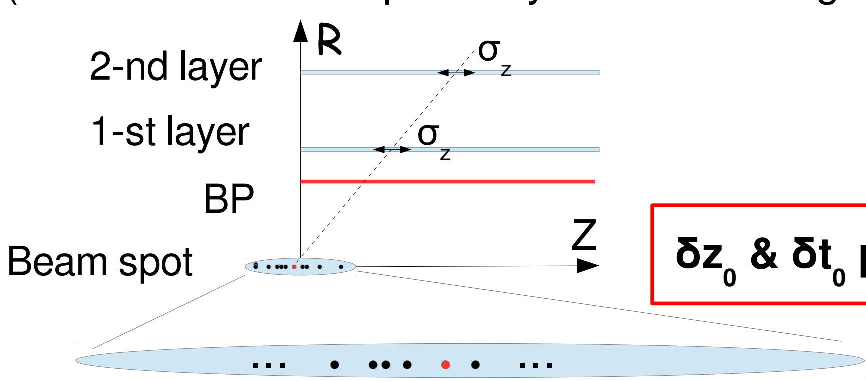
→ Study **what fraction of tracks may be unambiguously assigned to the primary vertex @ 95% CL? Use 2D info** (PV assumed to be "precisely" found from e.g. high p_T tracks)

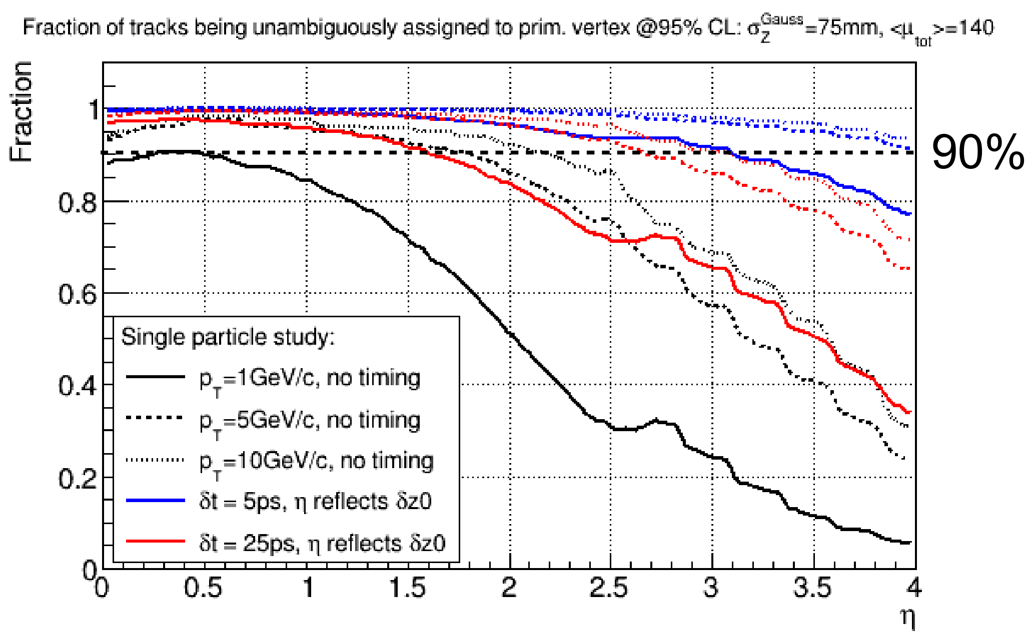


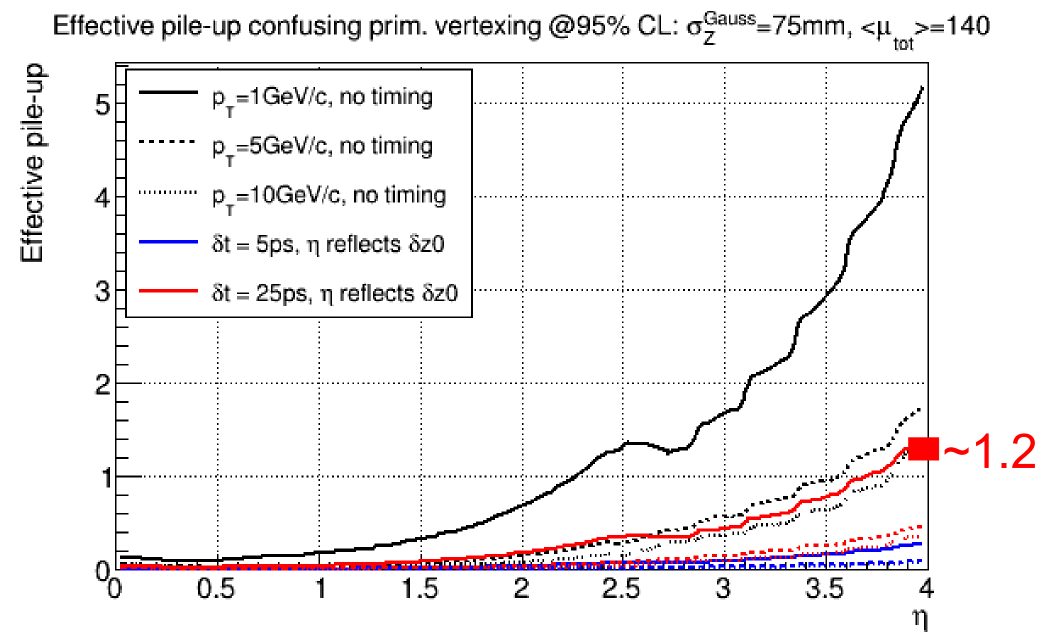
δz_0 & δt_0 play the crucial role!

CMS Ph2: Effective PU Rate @ PU=140

- Compare FCC-hh to HL-LHC conditions (PU~140), using e.g. CMS Ph2 upgrade layout

HL-LHC scenario @ PU=140
CMS Ph2 Upgr. tracker





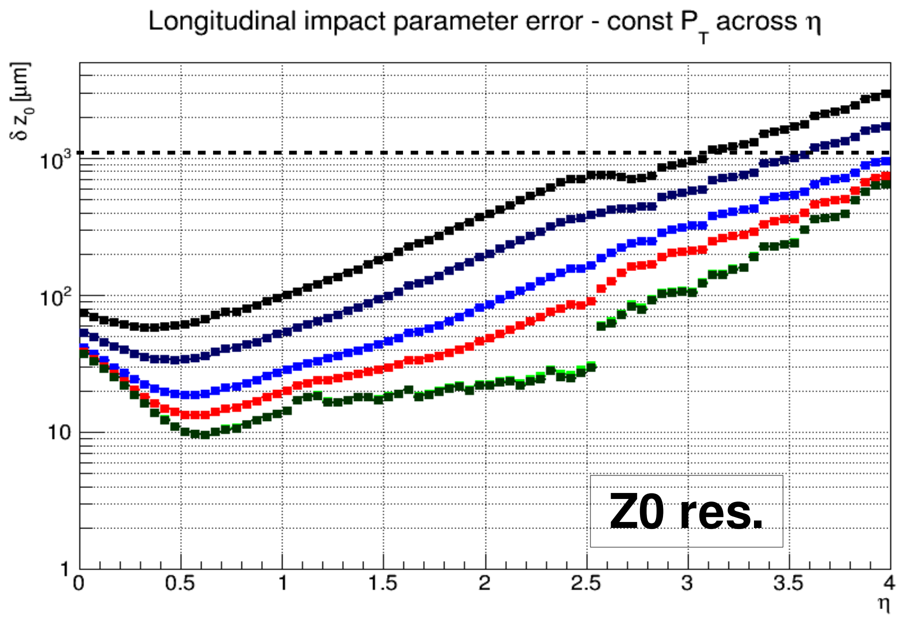
Comment:

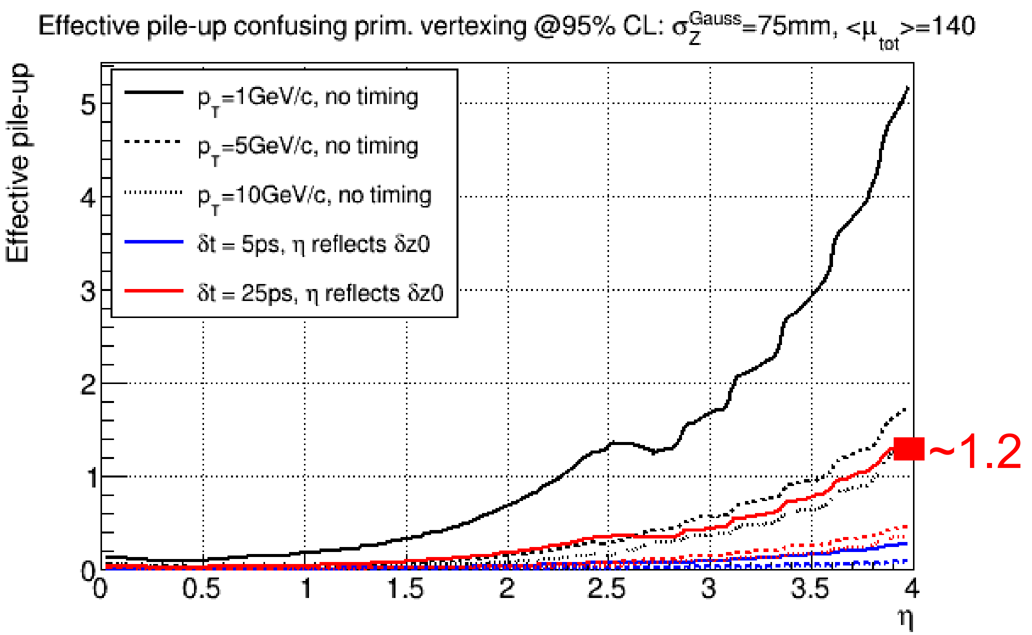
- Error on TOF ~ 1.5 – 3ps (η dependent) → negligible wrt 25ps (hence, not included into calculations)

CMS Ph2: Effective PU Rate @ PU=140

- Why such a shape of effective PU rate? Mostly driven by **z0 res.**

HL-LHC scenario @ PU=140
CMS Ph2 Upgr. tracker

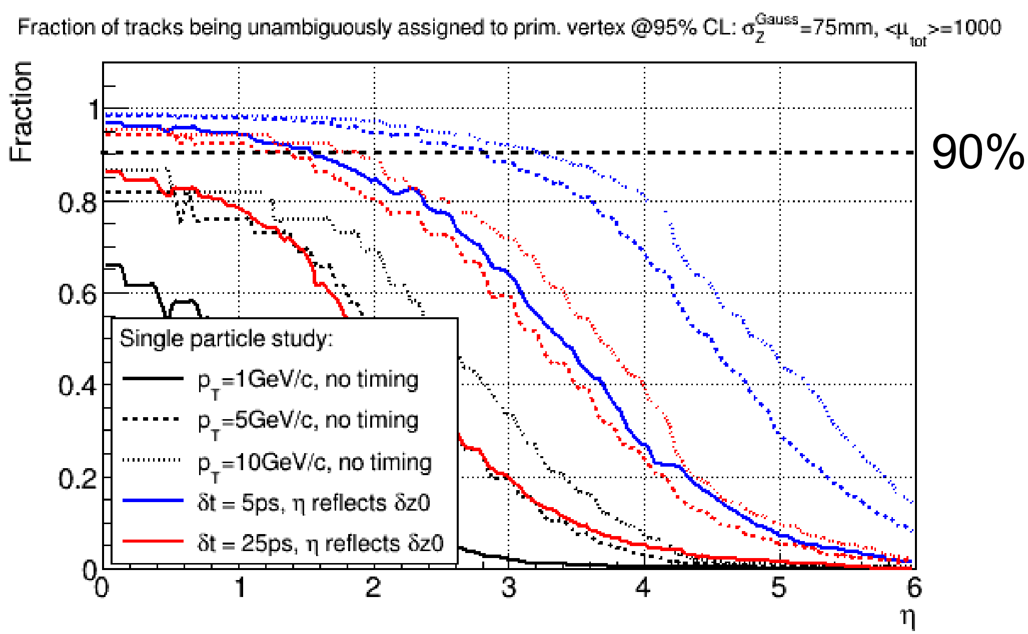


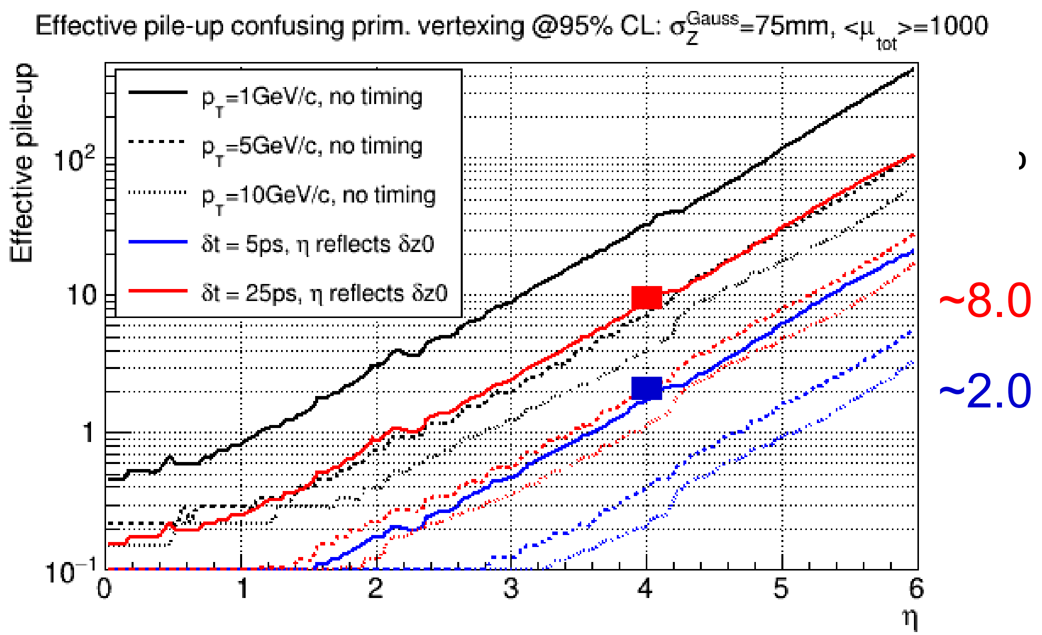


FCC v4.01: Effective PU Rate @ PU=1000

- Compared to FCC-hh (PU~1000)?

FCC-hh scenario @ PU=1000
Tilted layout





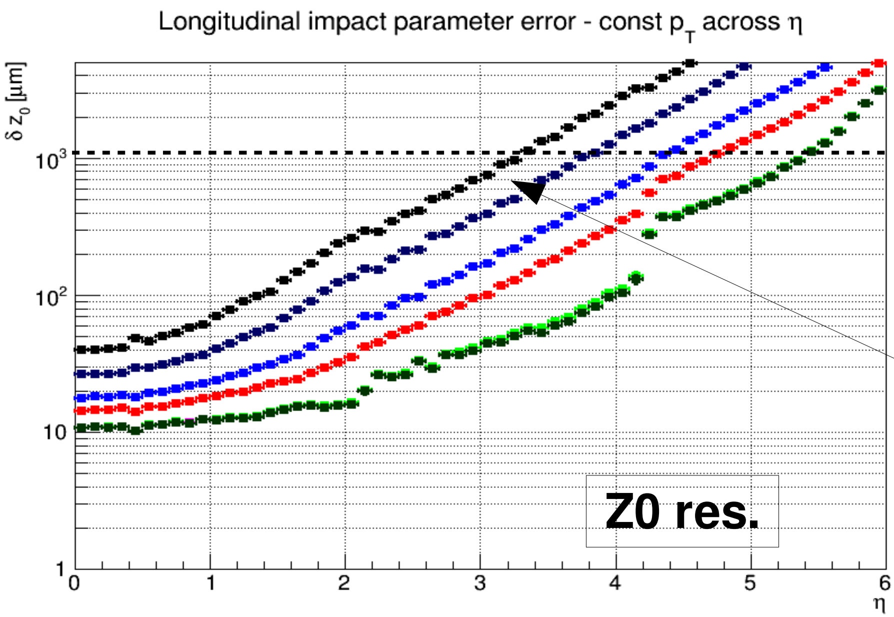
Comment: Not taken into account non-negligible error on time of flight correction (see other slide)

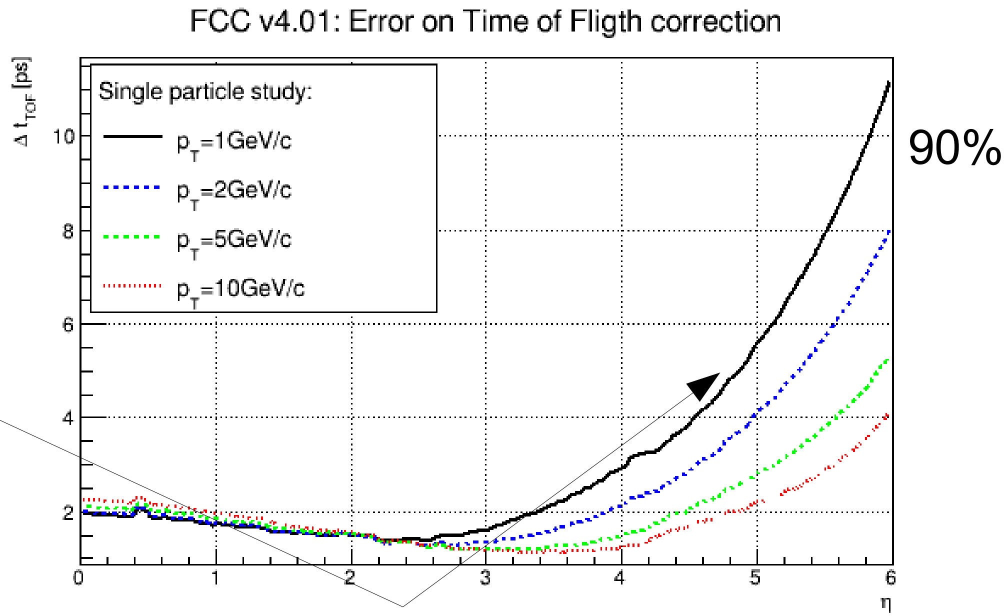
Conclusion: 2D vertexing (time & z) essential, but may not be sufficient to mitigate PU effect (even up-to η=4.0, unless δt_0~5ps assumed)!

FCC v4.01: Effective PU Rate @ PU=1000

- What is the effect of TOF correction?

FCC-hh scenario @ PU=1000
Tilted layout





Error on TOF correction mostly due to z0 res.

→ Non-negligible effect if one aims for t0 res. ~ 10ps (Remember: time must be propagated along track to vertex position) → **Several timing layers necessary to mitigate the error on TOF!**

Pile-Up Mitigation

- How one can possibly mitigate the PU?
  - **Improve vertexing performance:**
    - **t0 res.** → hard, at the technology limits
    - **z0 res.** → hard, limited by beam-pipe material, namely at high eta → crossing @ shallow angle

Pile-Up Mitigation

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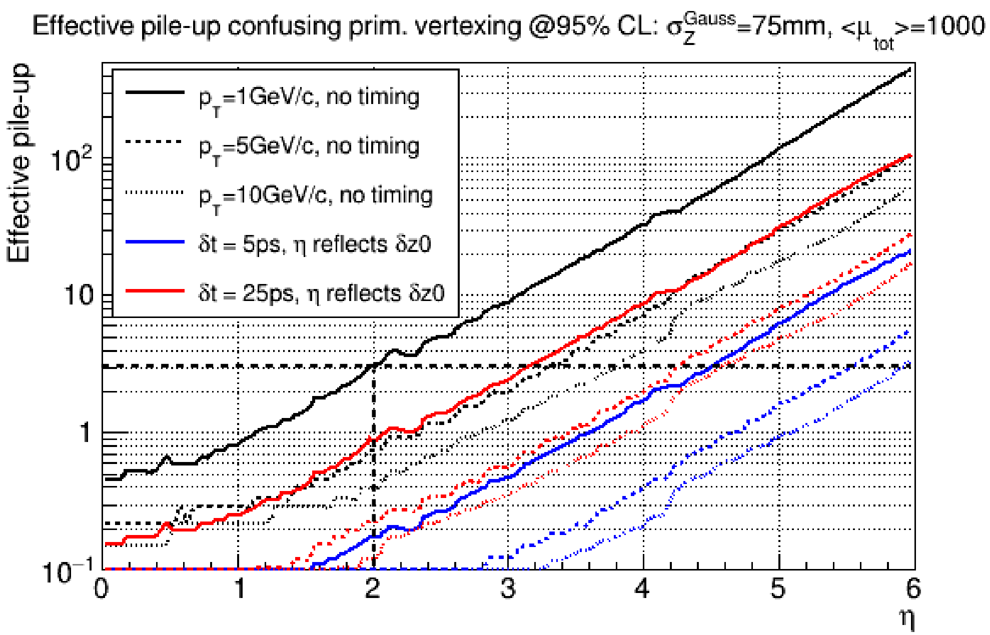
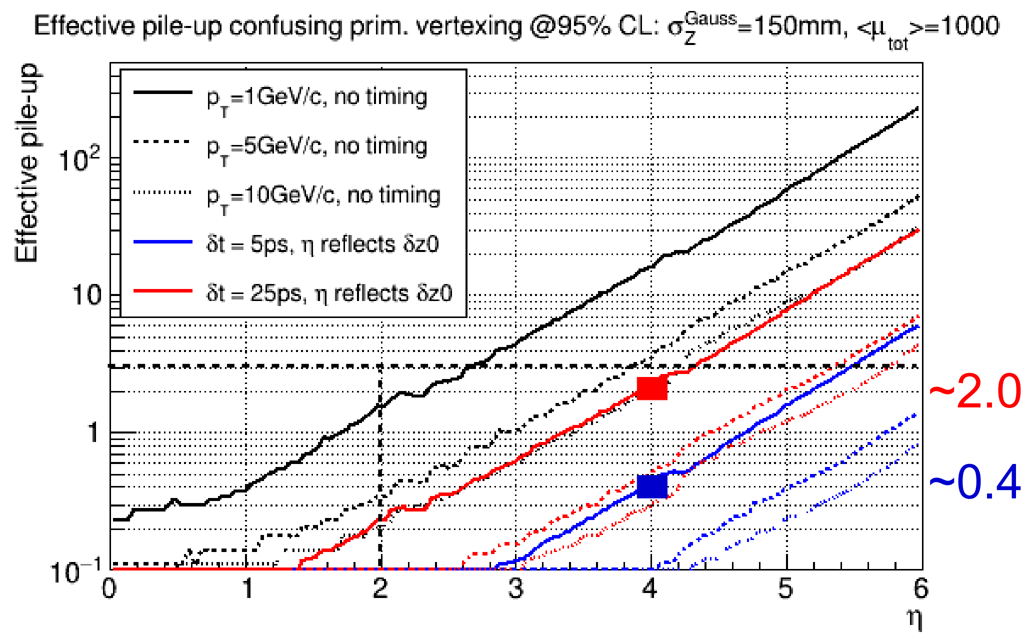
  - **Extend luminous region** → PU vertices better separated in space & time, does it help? How much?

Effect of Luminous Region Size on Effective PU

- Studied Gaussian distributed PU densities with bunch σ_z=75mm versus 150mm
  - Does extension of luminous region decreases effective PU rate? **By how much?**
  - Lum. region size: $\sigma_{lum.region\ z} \sim \sigma_z/\sqrt{2}$





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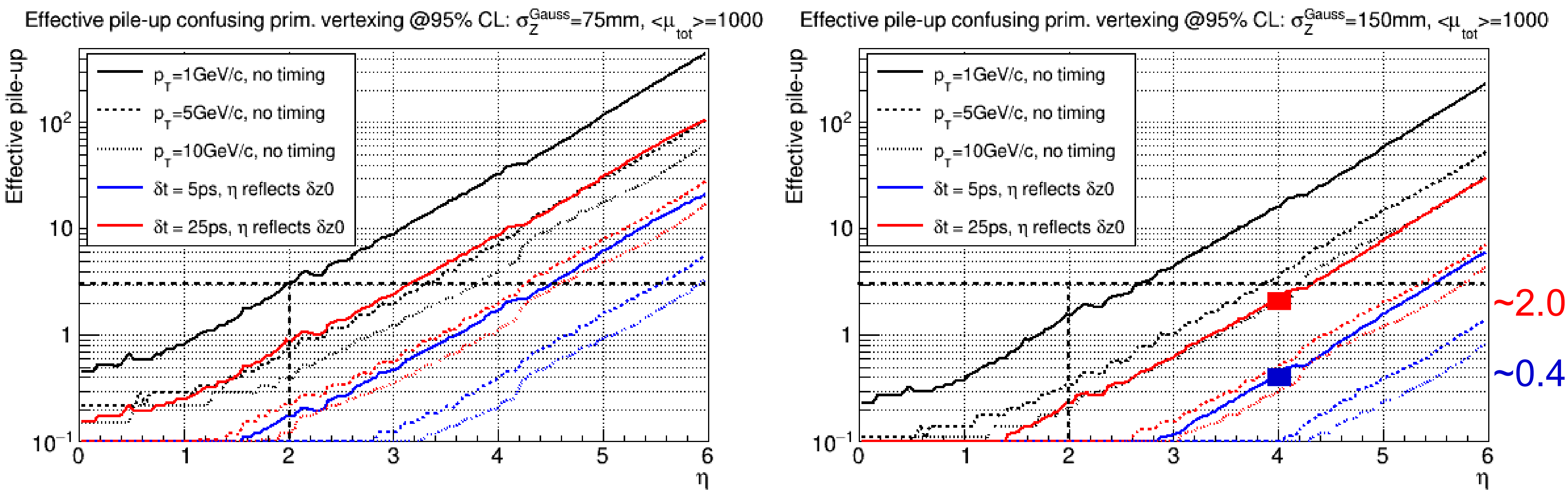

→ Effective PU rate decreases by the same factor **f** as one increases **σ_z if z0 information used only**, **by f^2 if both t0 & z0 used** (unless time & line PU correlated)**!**

Summary & Plans

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→ **Effective PU may be significantly decreased by increasing size of luminous region,** increase in size by factor **f** results in **a quadratic decrease ($1/f^2$) in effective PU, if both timing & spatial information is being used**

Summary & Plans

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  - → **Effective PU may be significantly decreased by increasing size of luminous region,** increase in size by factor **f** results in **a quadratic decrease ($1/f^2$) in effective PU, if both timing & spatial information is being used**
- **Plans:**
  - → Study different PU scenarios (ultimate versus levelled)
  - → To get more realistic estimates on effective PU & comparable plots to full simulations, convolve pT curves with min bias dpt/dη distr. & study 1 real physics case (e.g. Z'->μμ, $t\bar{t}$)
  - → To understand the effect of size of luminous region on effective PU, several scenarios need to be modelled:
    - Gaussian versus rectangular shape of bunches
    - Different bunch sizes (75mm as a reference, 120mm as a current limit & 200mm as an ultimate limit)