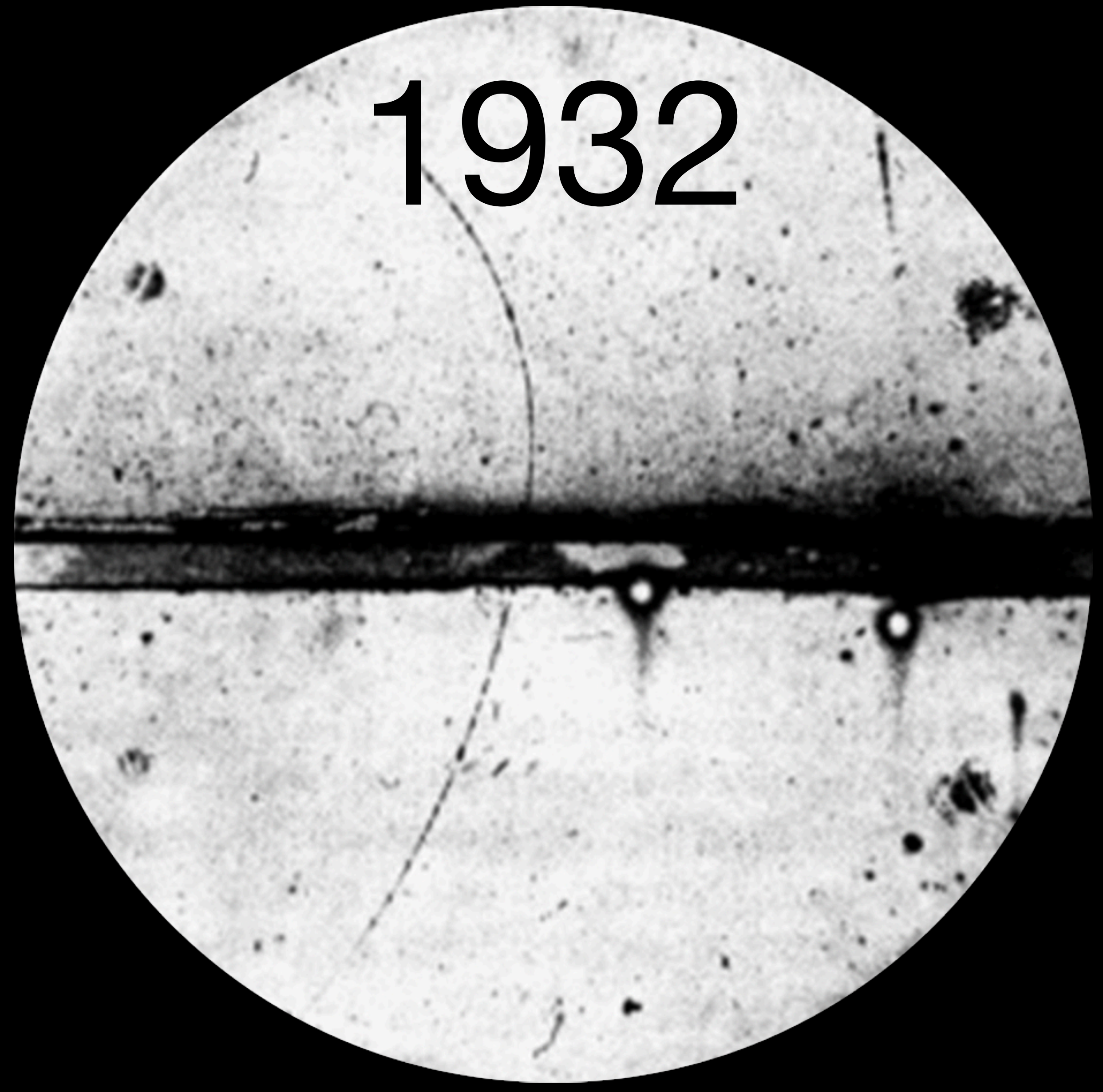
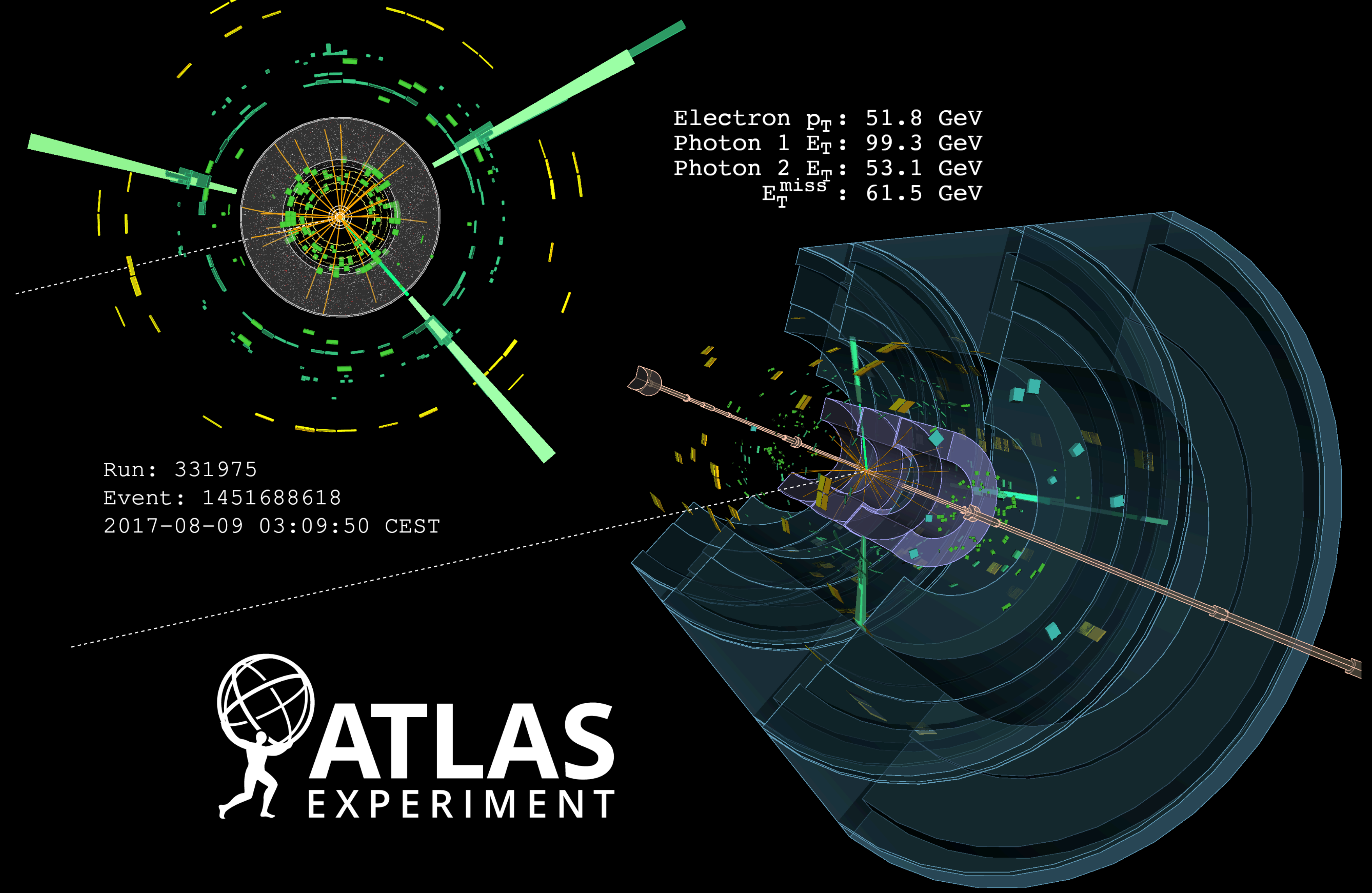
PHYS 7363 - Experimental Particle Detection and Detectors I



2017



Particle detectors are the workhorses of experimental physics. In this course, we'll dive deep into their physics, exploring the incredible evolution of our experimental techniques over the past nine decades. You'll gain a solid understanding of *particle detection* and *identification*, examine the intricate designs of modern detectors, and learn how machine learning is being harnessed to push the boundaries of detector design. If you're intrigued by how we "see" subatomic particles, this course is for you!

Detect   Identify   Measure

To discuss prerequisites (and any questions on the content of the course), please contact me: saptaparnab@smu.edu

Schedule

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
August	18	19	20	21	22	23	24
	25 ✅	26	27	28	29 ✅	30	31
September	1	2	3 ✅	4	5 ✅	6	7
	8 ✅ 1.5 hours	9	10	11	12	13	14
	15 ✅ 1.5 hours	16	17 ✅ 1.5 hours	18	19 1.5 hours	20	21
	22 1.5 hours	23	24 1.5 hours	25	26 1.5 hours	27	28
October	29 1.5 hours	30	1 1.5 hours	2	3 1.5 hours	4	5

Schedule

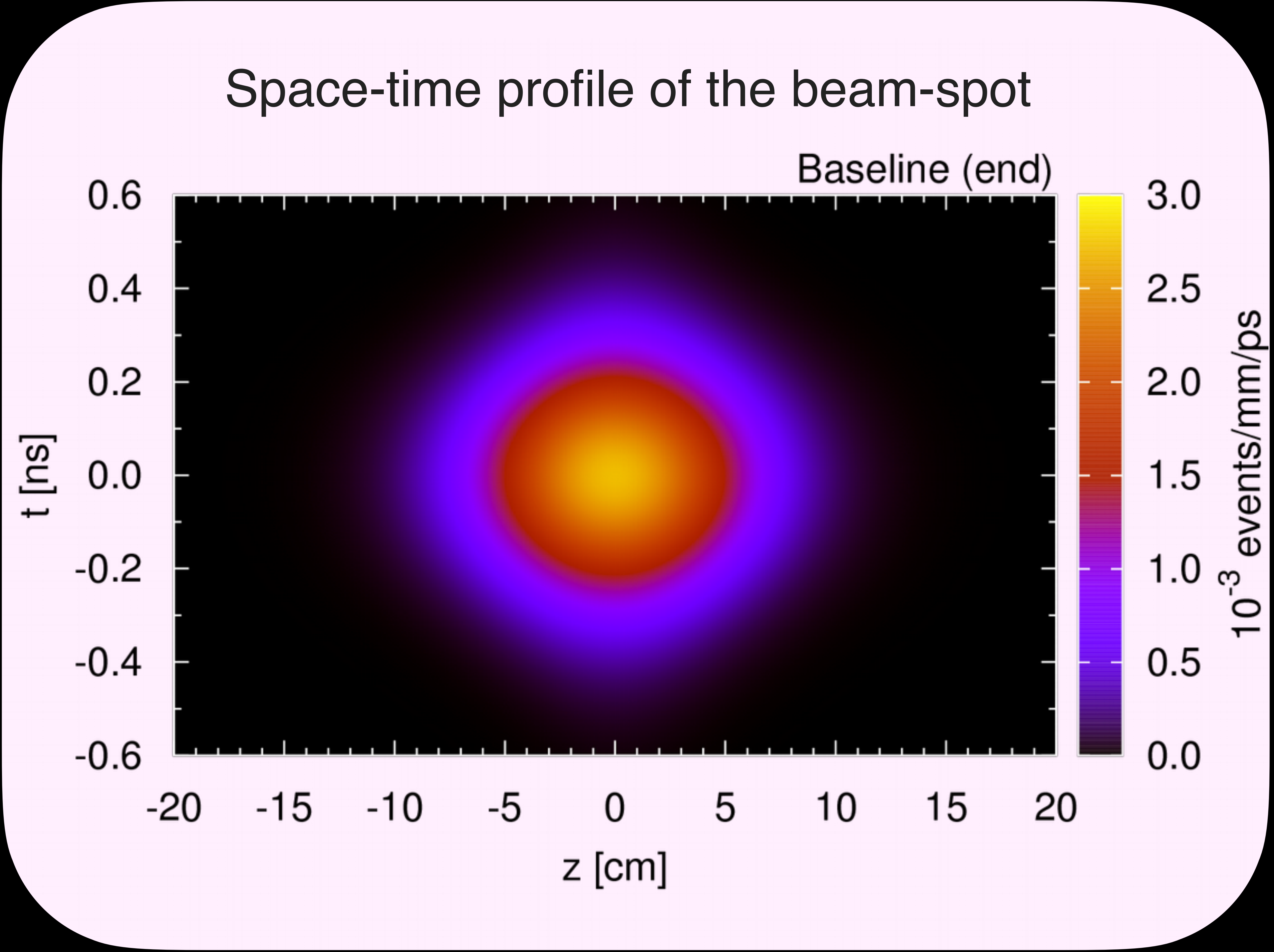
Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
October	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
	27	28	29	30	31	1	2
November	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30
December	1	2	3	4	5	6	7
	8	9	10	11	12	13	14

Setting up the code

- FCC-ee: https://indico.fnal.gov/event/67484/contributions/314057/attachments
187076/257915/US%20FCC%20Tutorial_FullSim.pdf
- Muon collider: https://mcd-wiki.web.cern.ch/software/tutorials/fermilab2024/

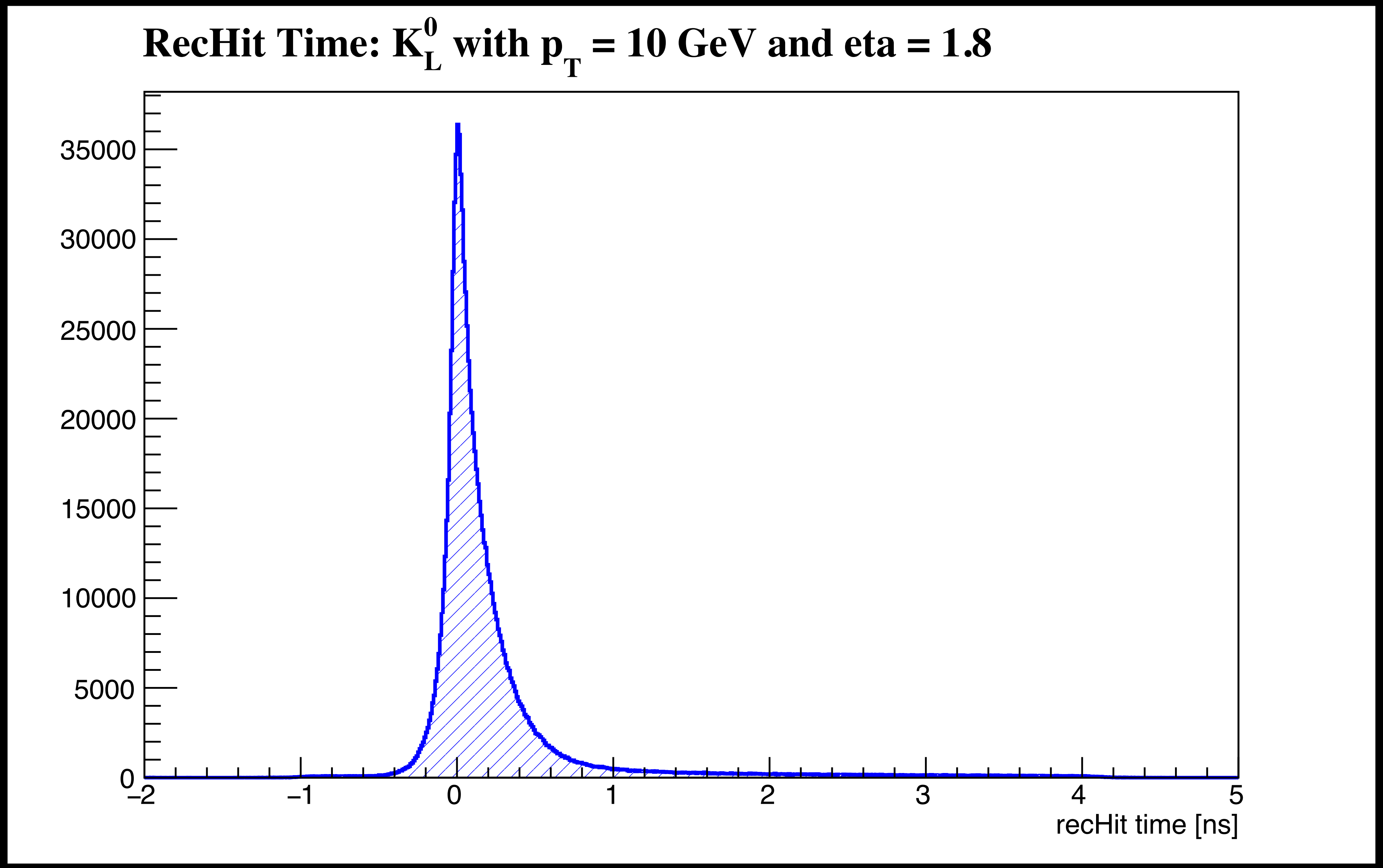
Timing properties

- Interactions at the LHC are spread over 100-200 ps in time
- HGCAL is capable of providing timing information associated with each recHit
- Time information can be used to distinguish between overlapping showers in space (from pile-up)
- Start with computing shower timing
- Hadronic showers pose big challenges as they are more diffused than EM showers
- Study neutral hadrons (K_0^L) first --> straight trajectories

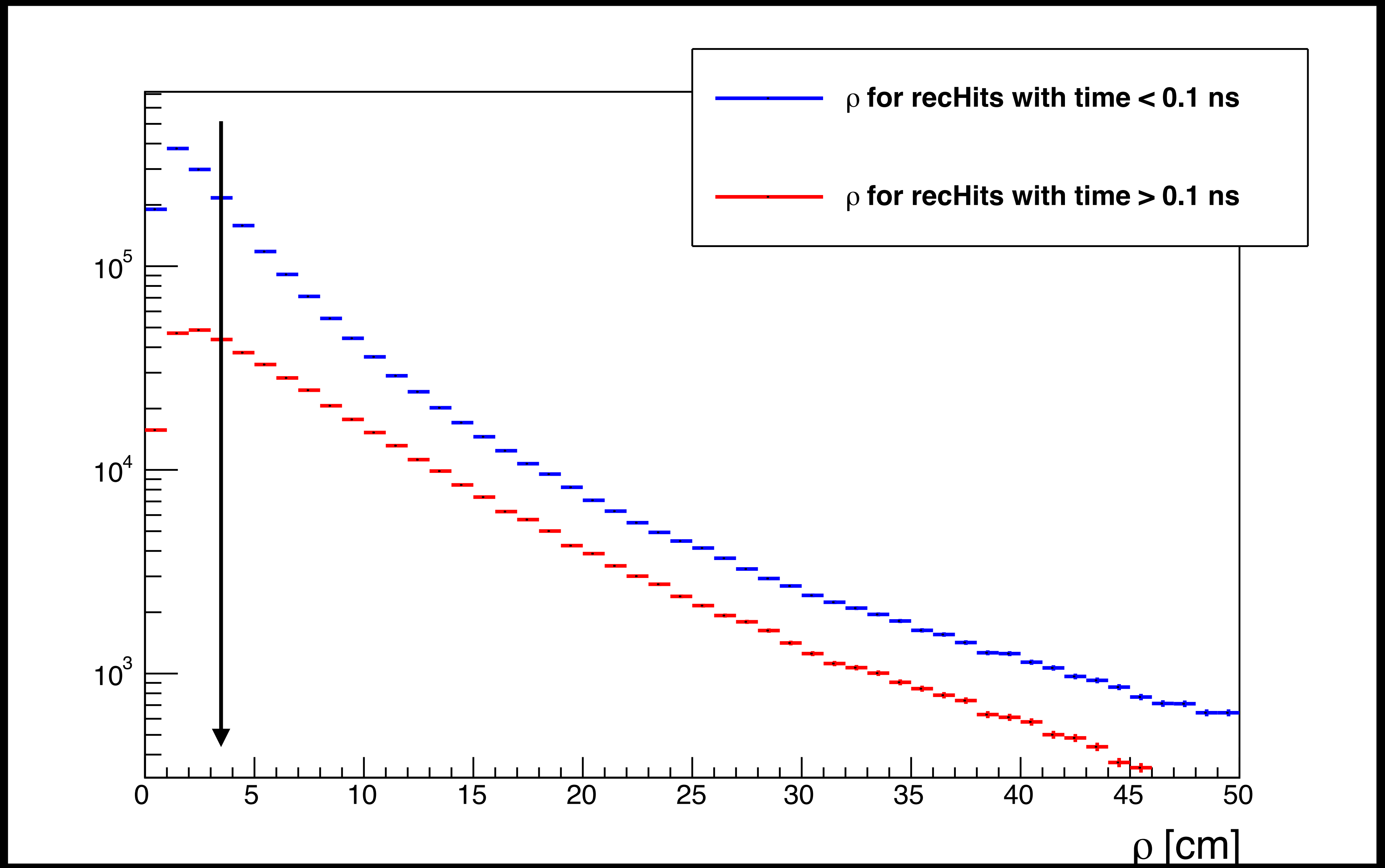


Timing properties

- Hadronic shower times have long tails
- These tails contribute toward the average time per event, worsening the timing resolution
- Need to mitigate the impact of tails by designing algorithms that minimize their contribution



Hits with large times tend to be found at the periphery, while hits with small times come more from the core.

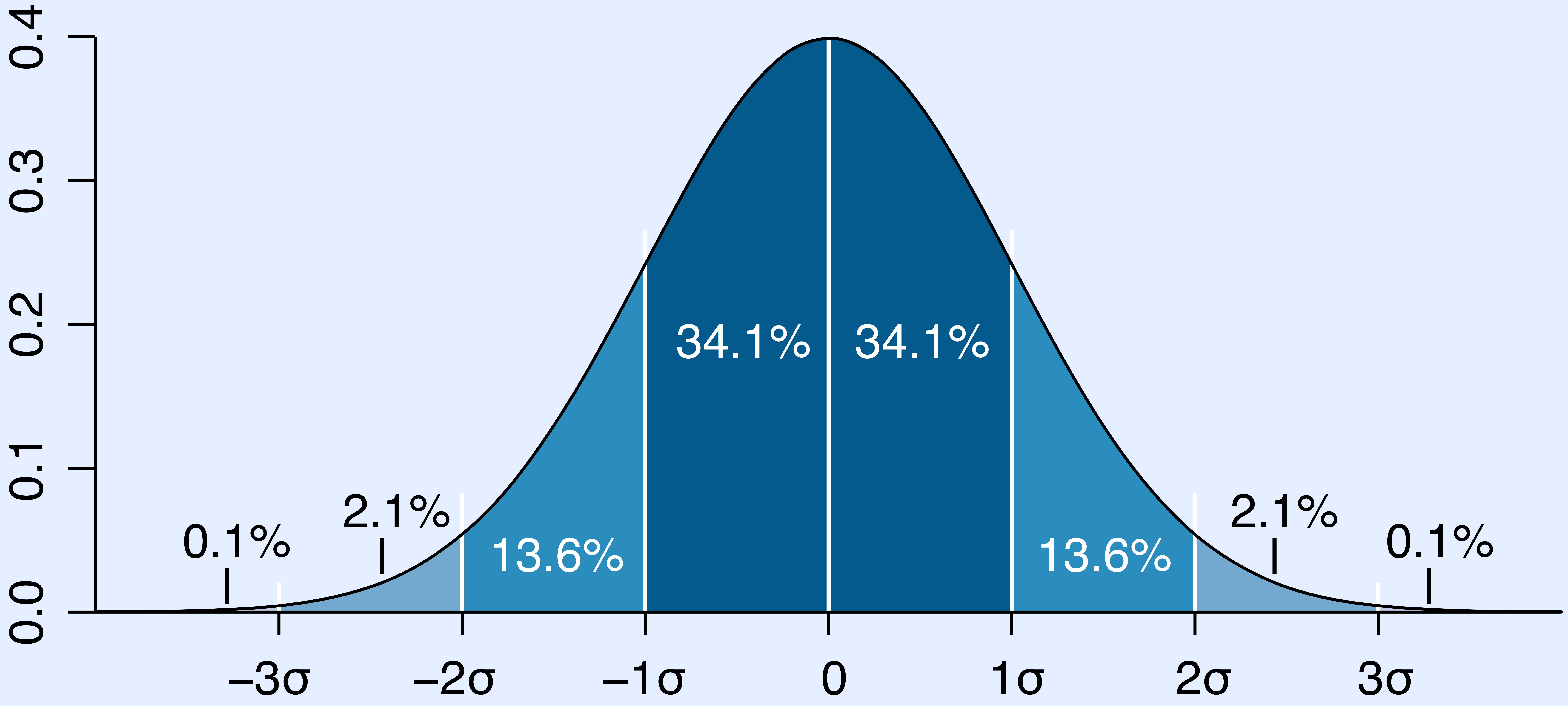


Transverse distance from the shower axis (ρ) [cm]

Procedure for truncation

- Implement double sided truncation by independently varying fixed fraction of hits to be removed from both the lower and the higher end of the recHit time distribution
- Retain at least 3 hits (important for low energy showers)
- Optimize bias vs. variance study with a k-long of pT 10 GeV
- Figure of merit is the central one-half of the 68% CI of the distribution (better way to handle skewness)
- Performed for $\rho < 2$ cm

Gaussian Distribution



Bias-Variance Study

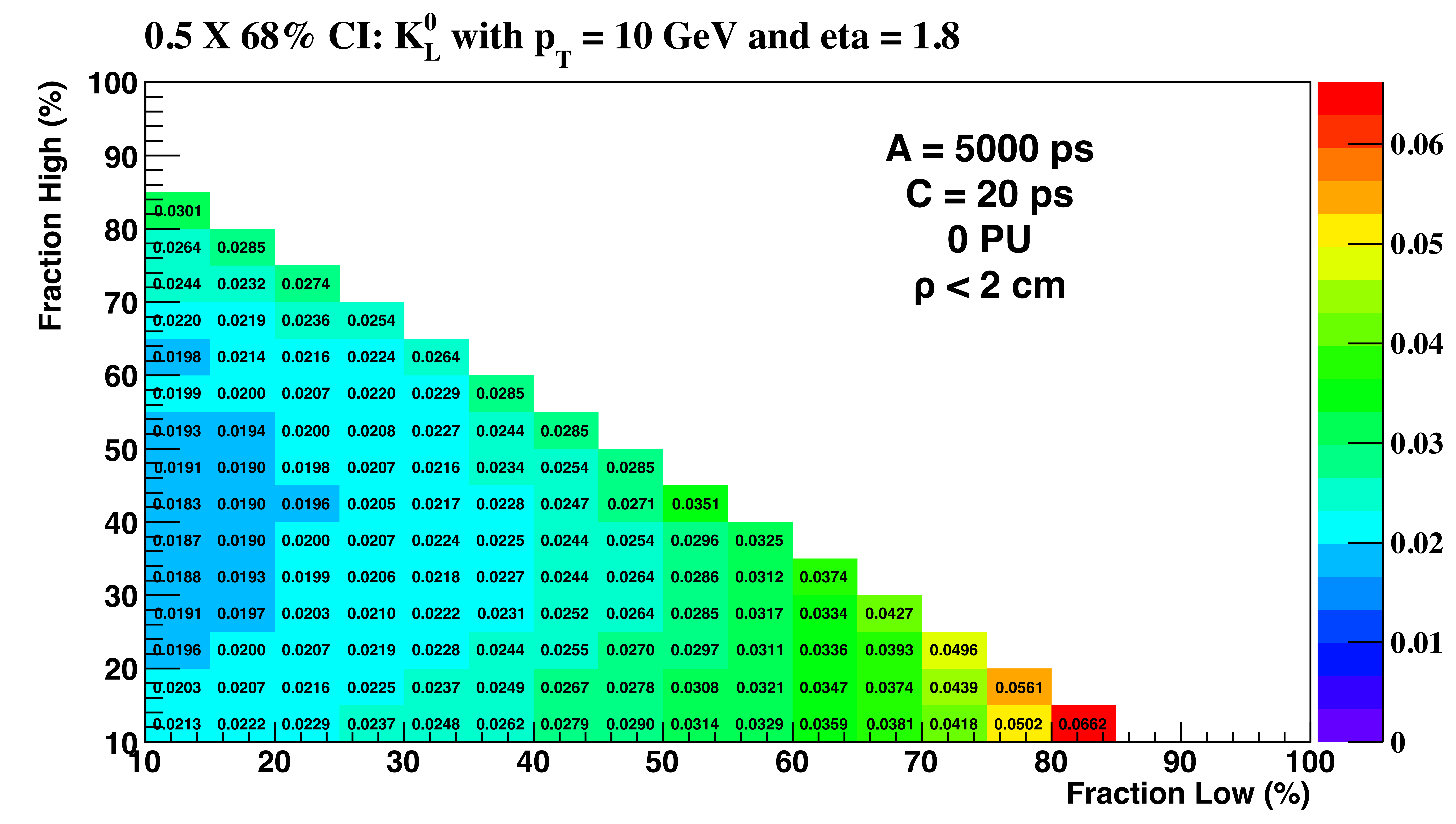
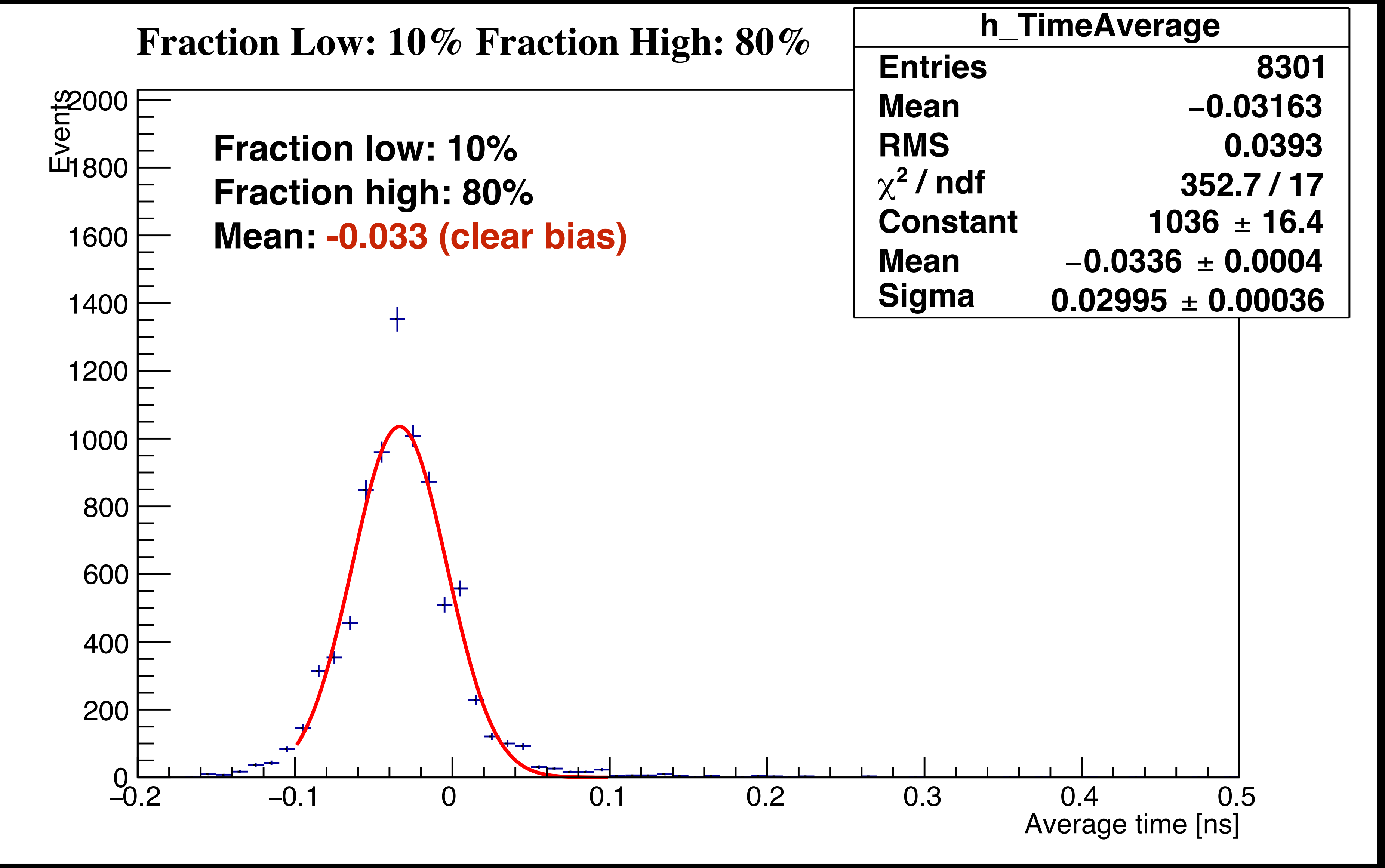
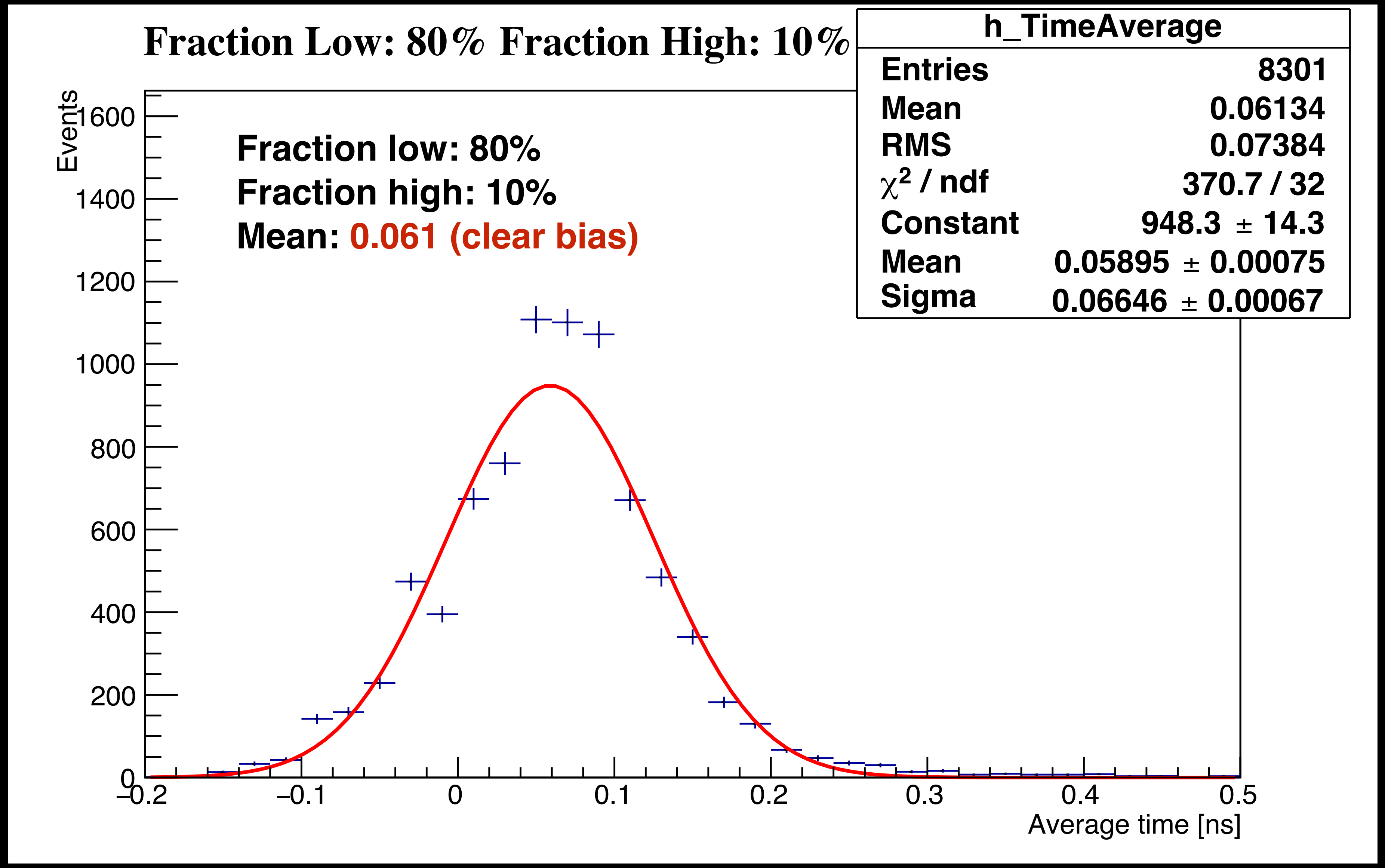


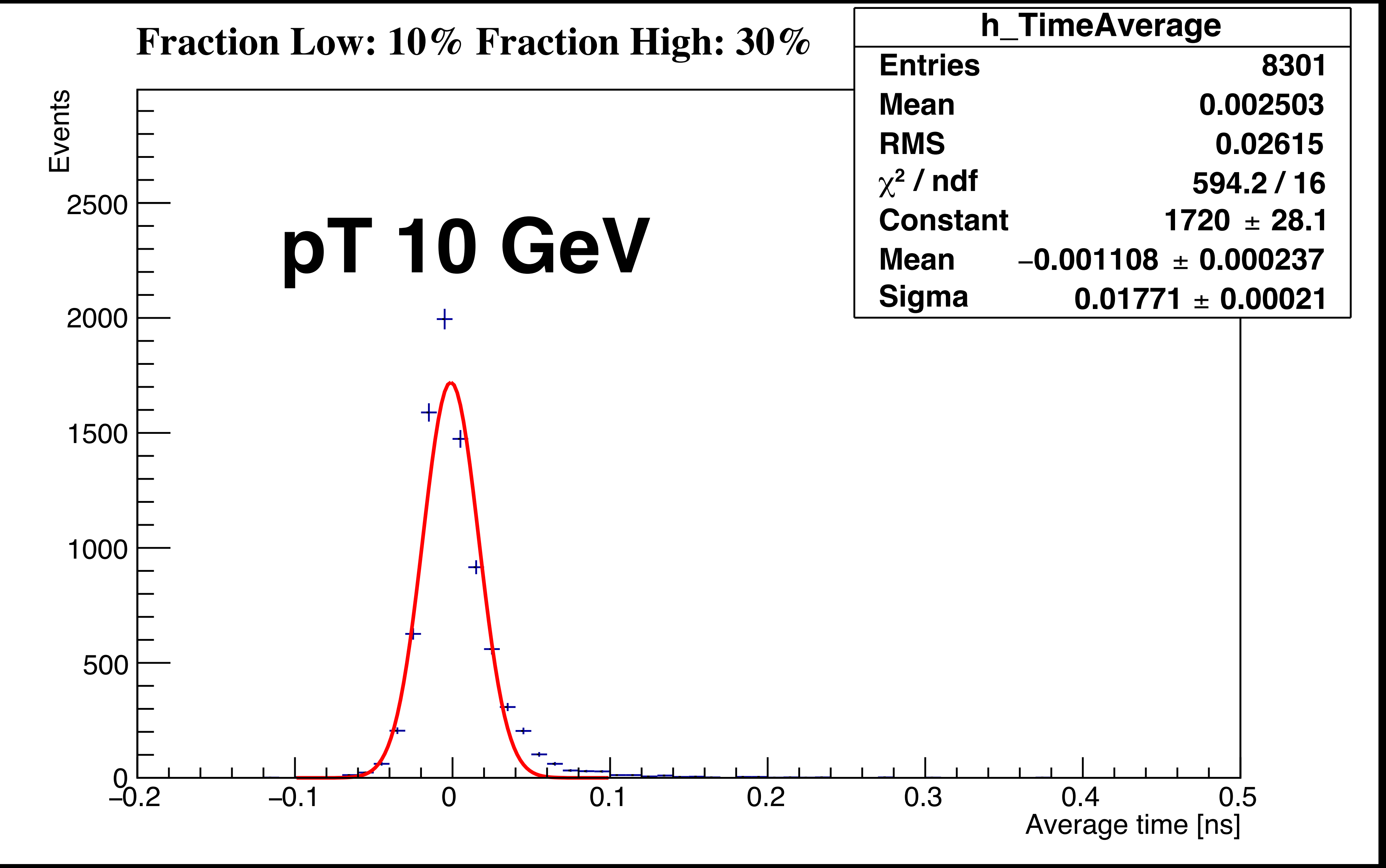
Illustration of the extreme cases





- Optimize to :
- **minimize central 68% CI**, and
- **reduce bias** (and not incur additional bias during the process of truncation)

Optimized Double Sided Truncation

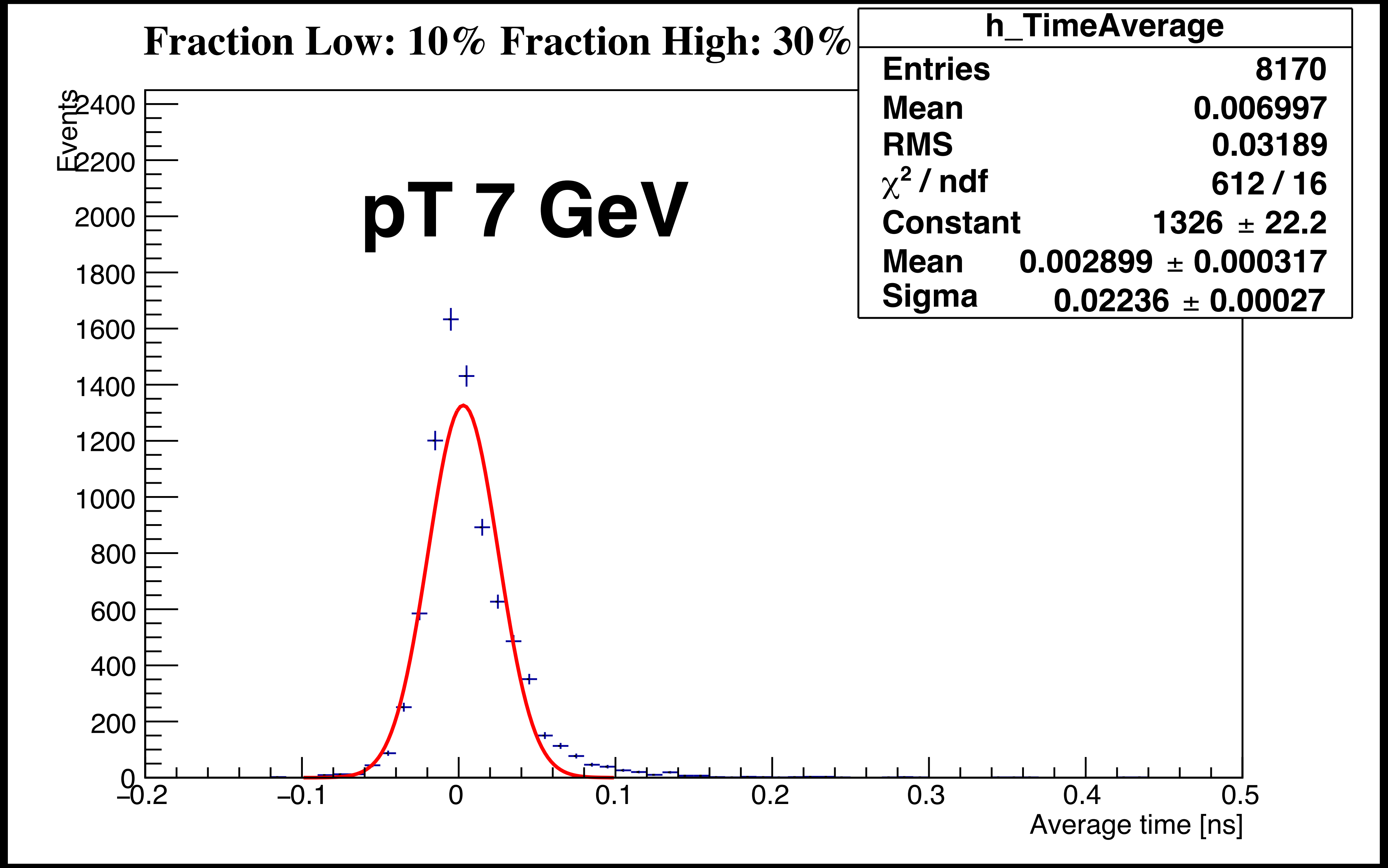


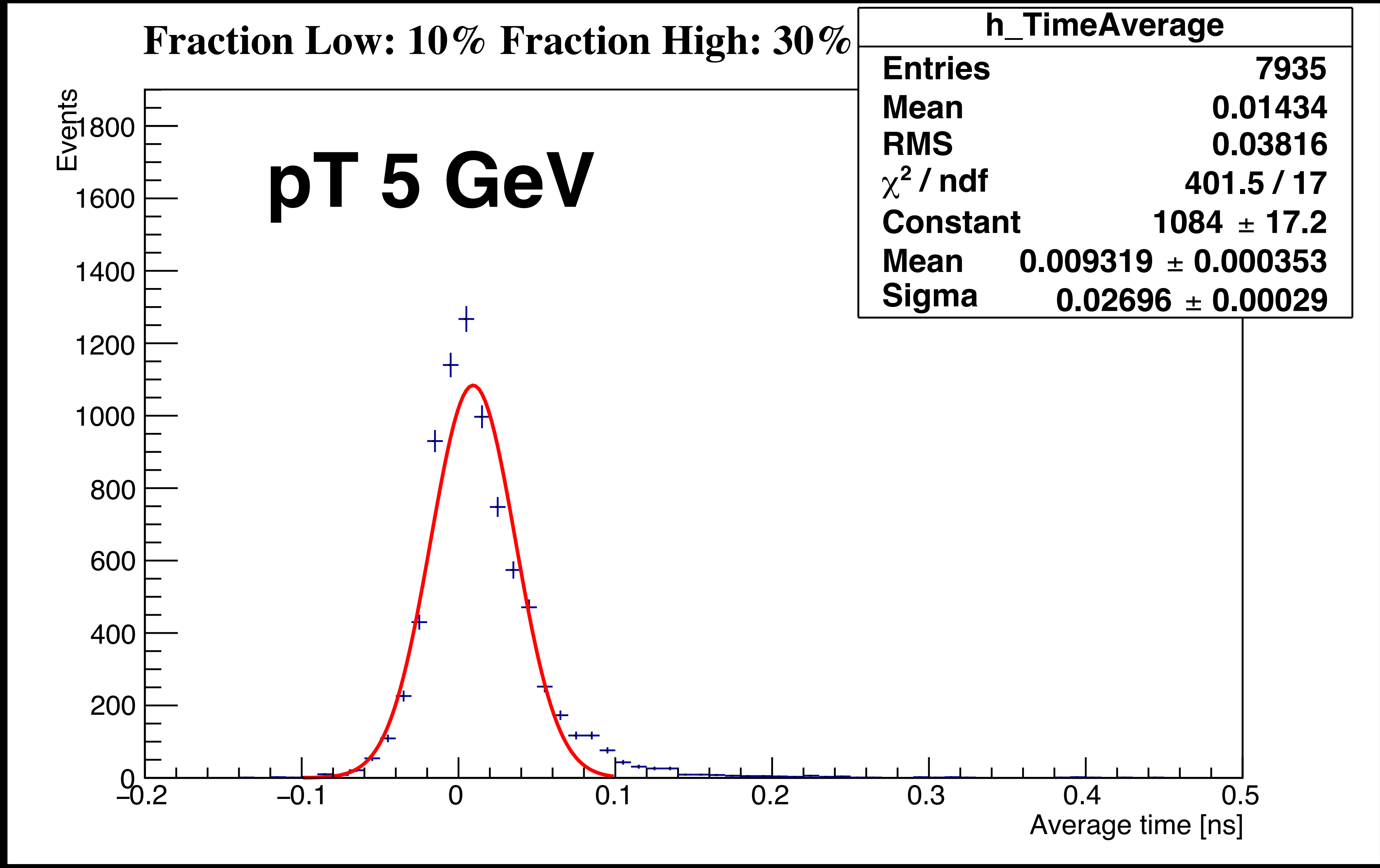
K^0_L

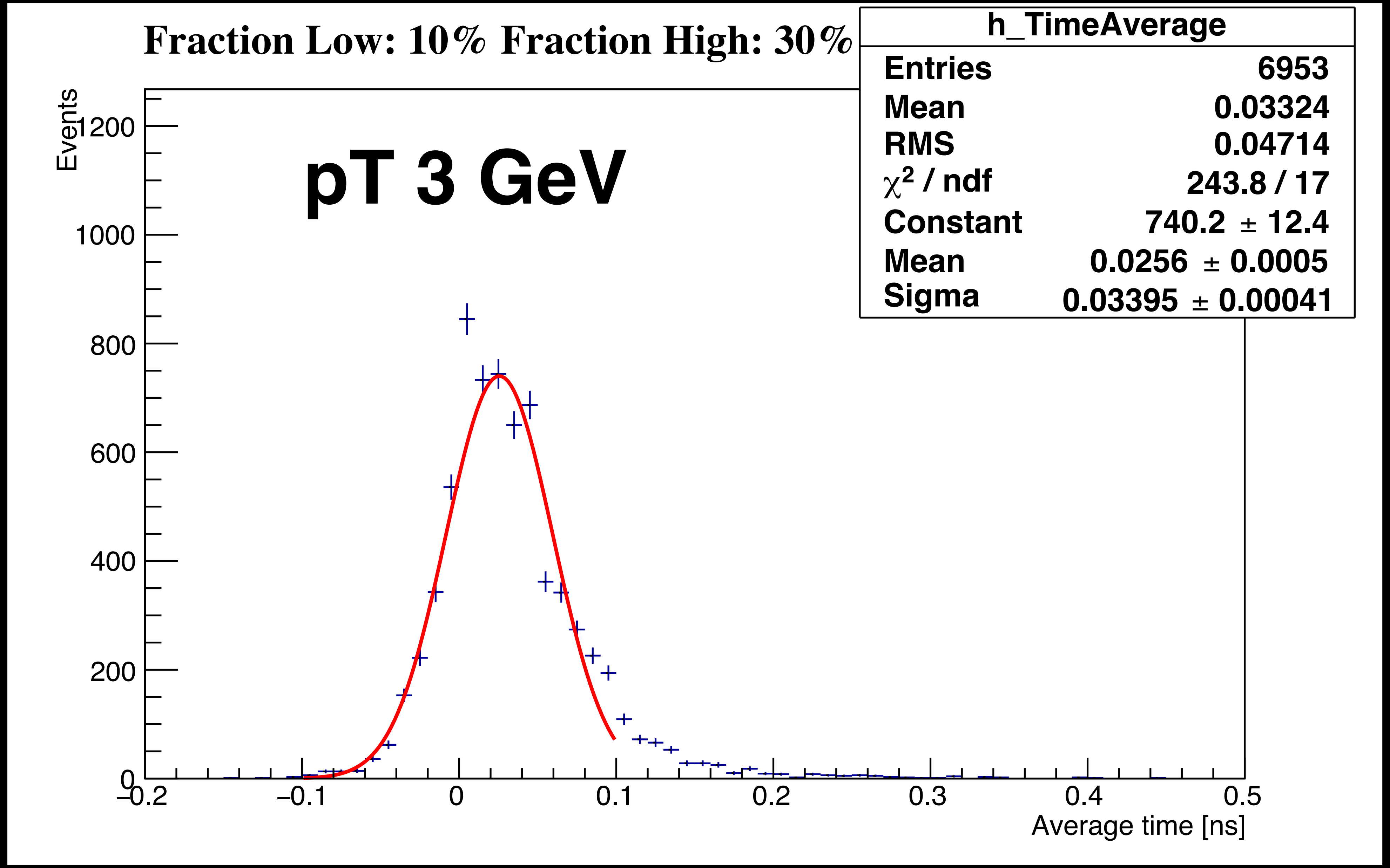
$\eta = 1.8$

0 PU

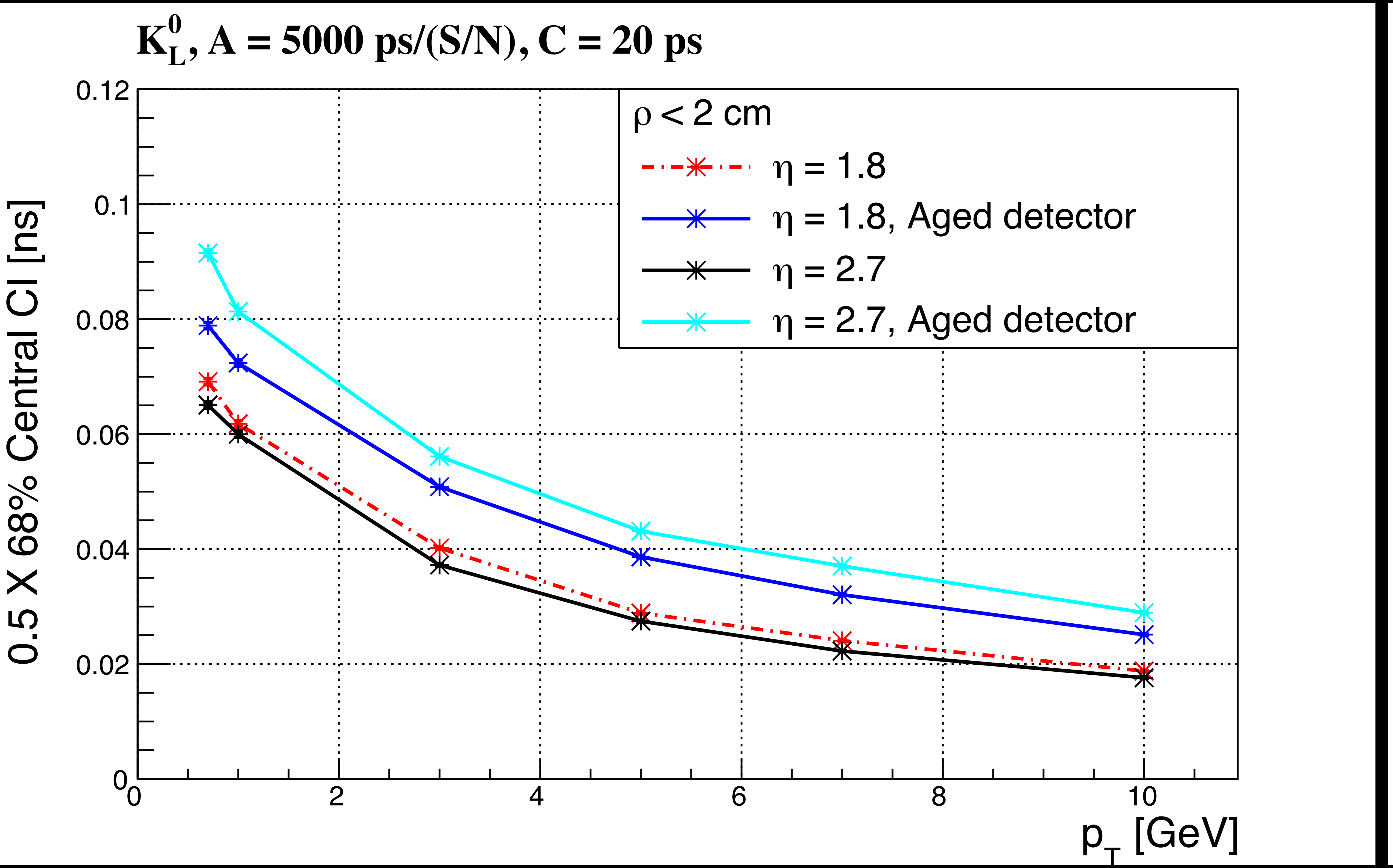
$\rho < 2$ cm

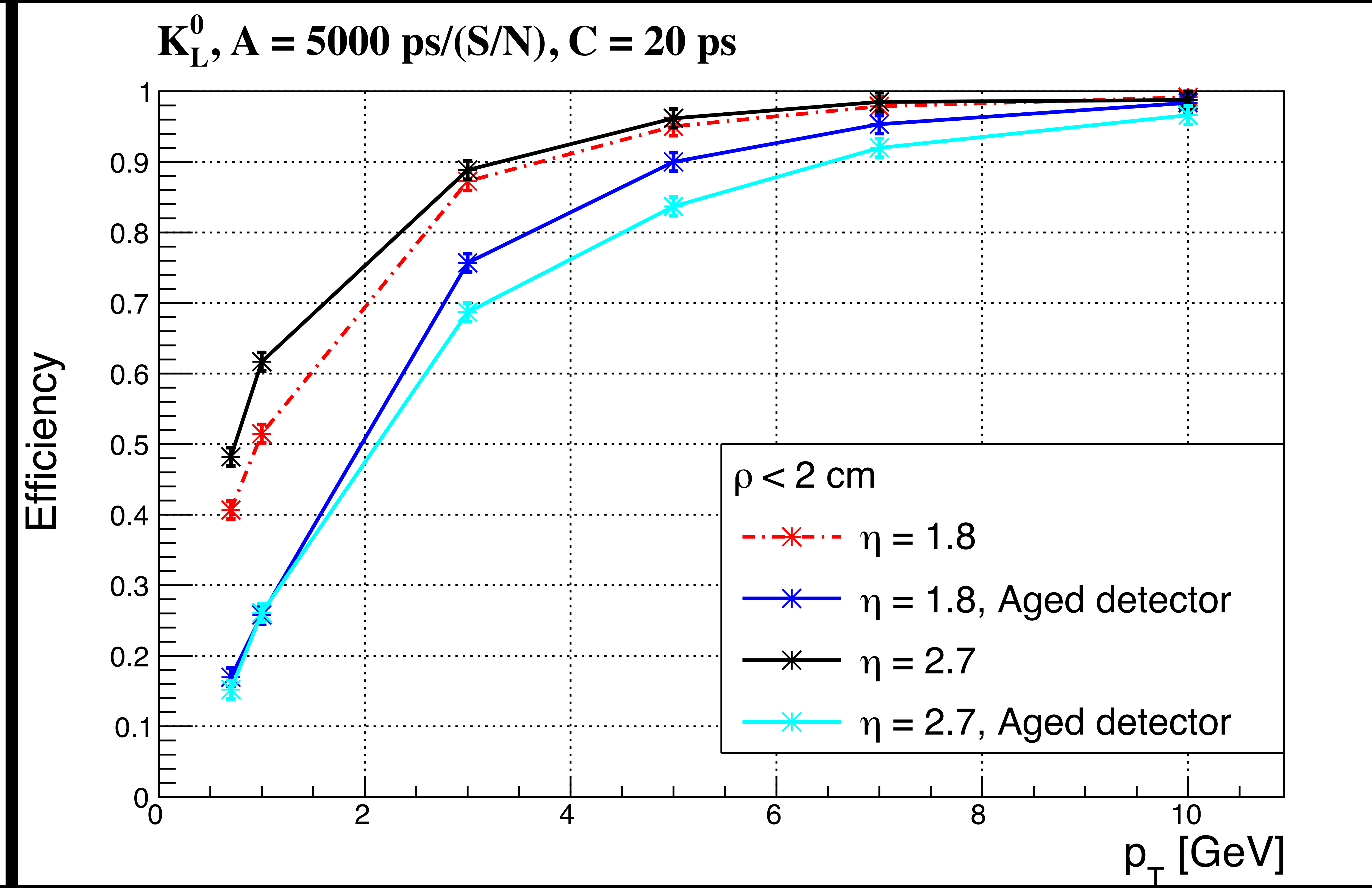






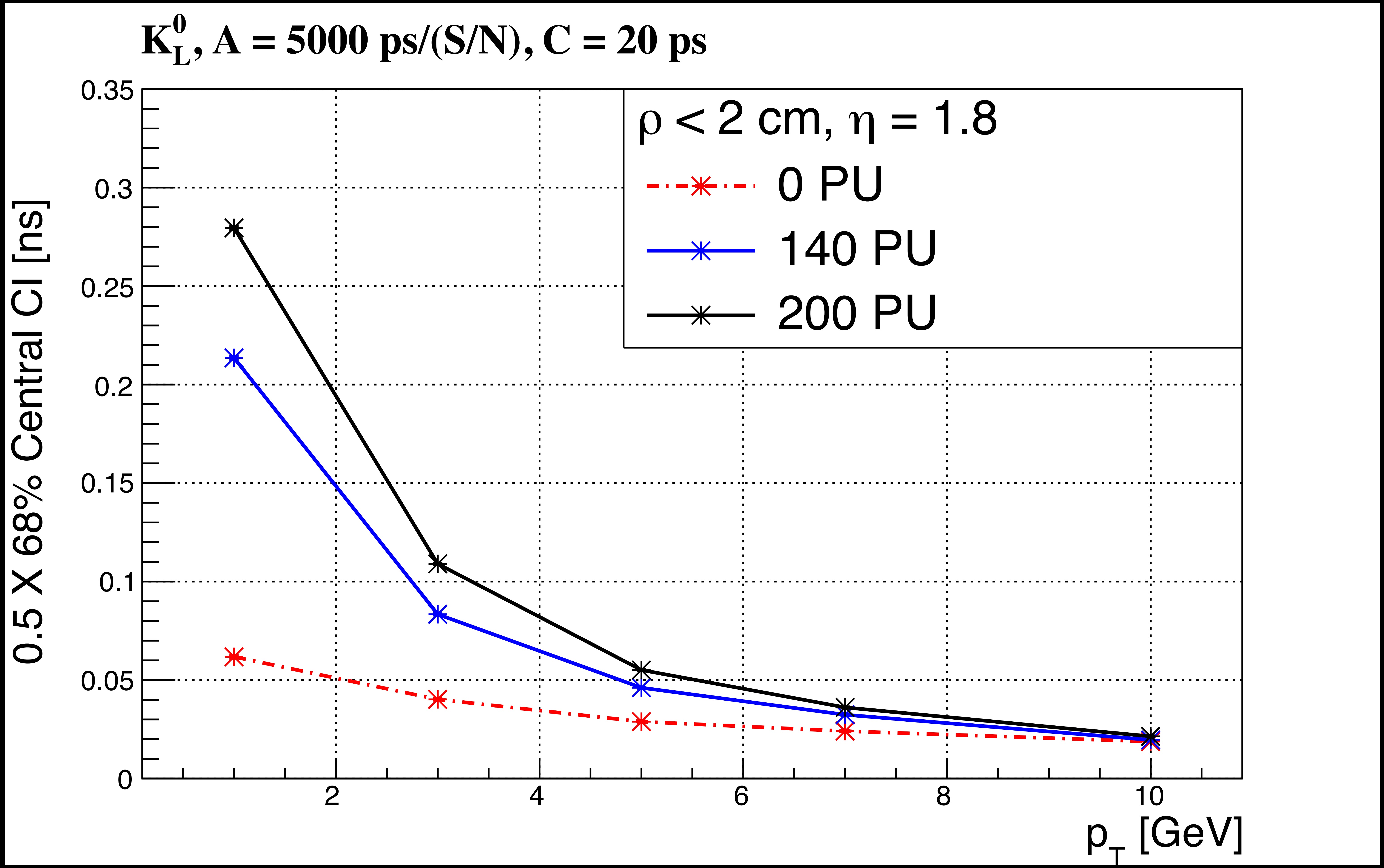
Summary plot with several scenarios





- **Aging simulated by lowering total charge collected by 50% (100 μm, 200 μm) and 70% (300 μm) and appropriately scaling noise**

Summary plot with pileup



Using hits within 2 cm of the shower axis is effective against pile-up

Efficiency of finding 3 hits is 100% for the 140 and 200 PU cases (even for the low energy showers)

Semiconductor detectors

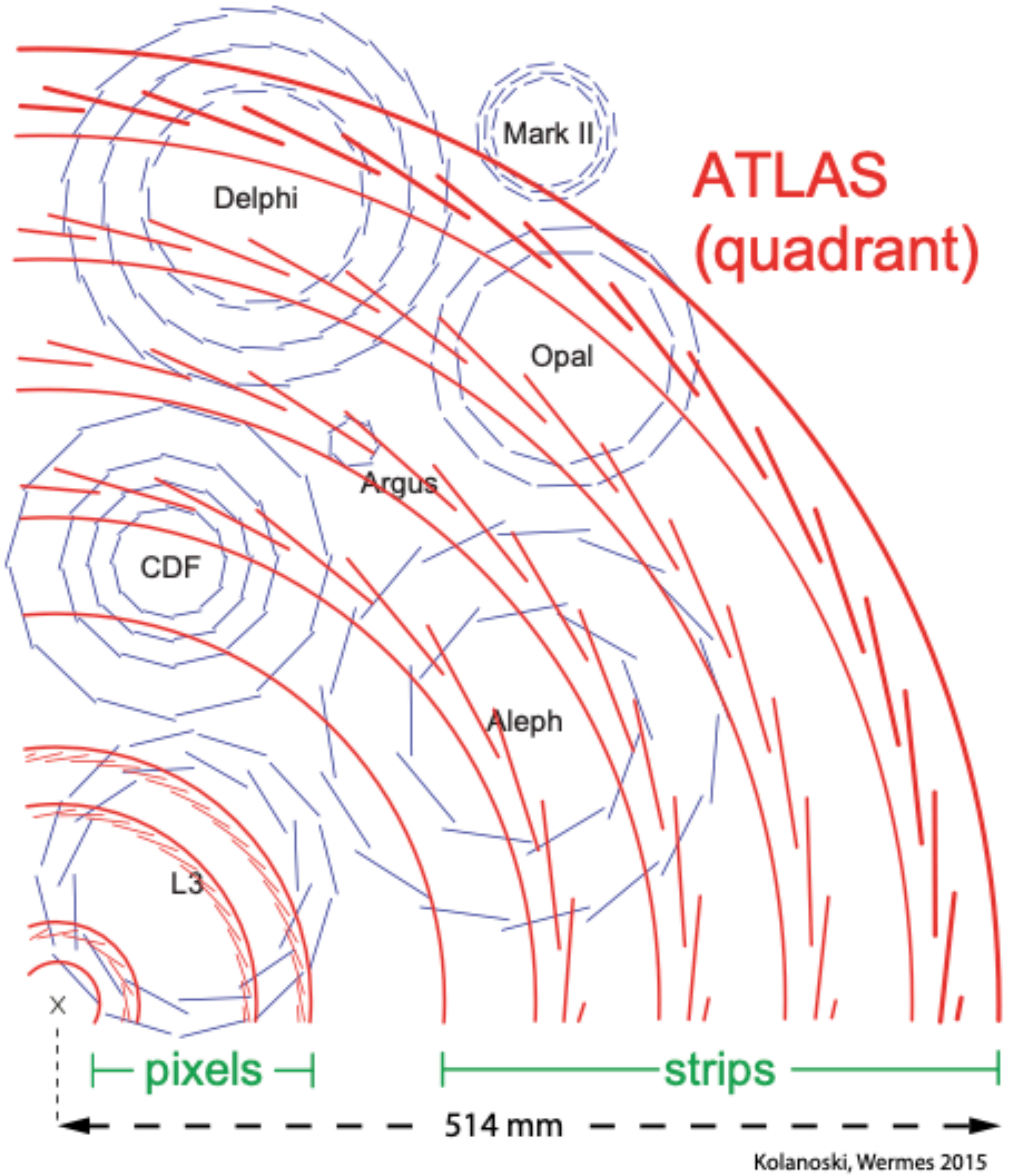
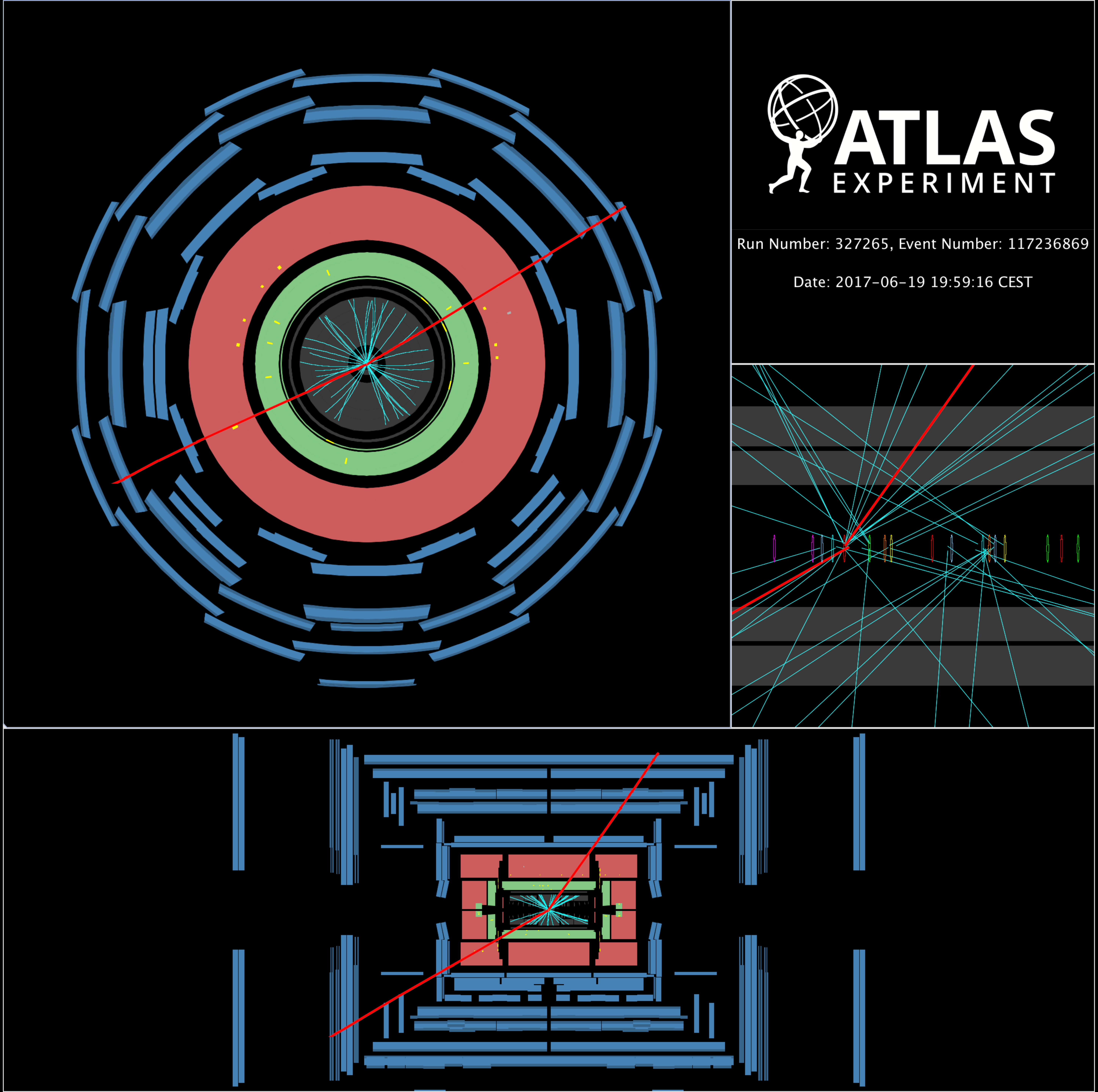
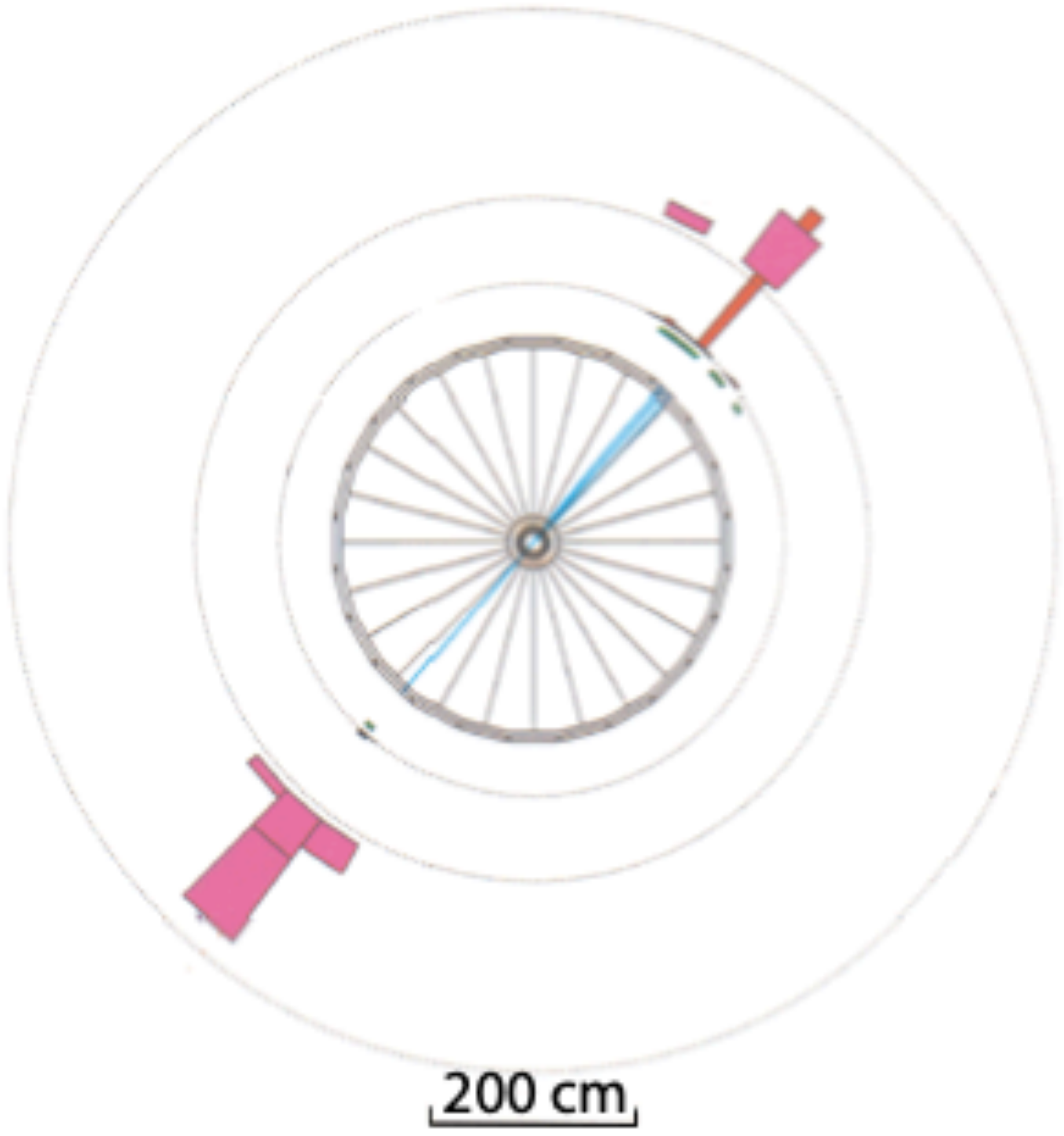


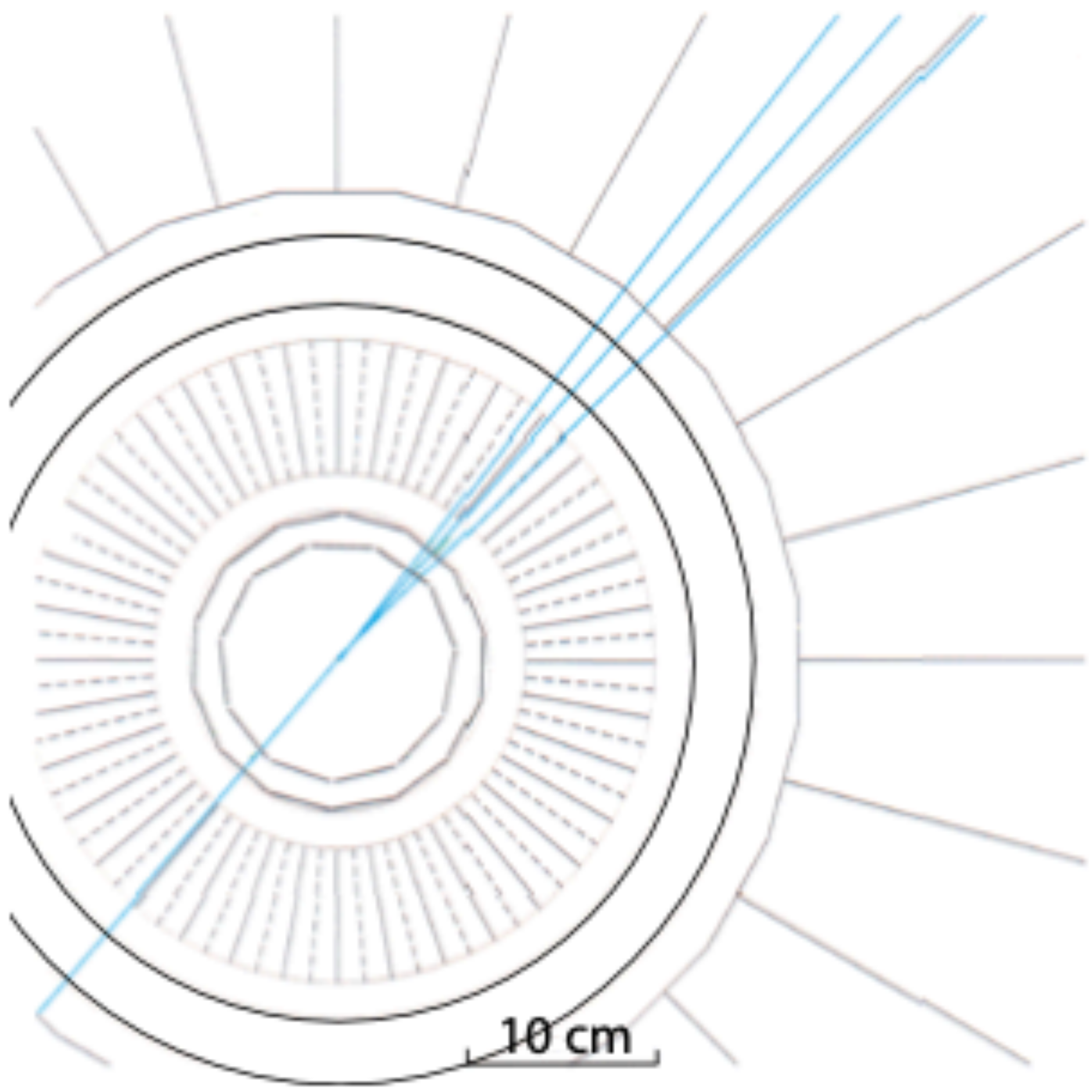
Fig. 8.52 Size comparison of various silicon detectors that have been installed in present and past collider experiments. The various smaller (vertex) detectors (all strip detectors) are compared with the size of one quarter of the ATLAS tracker (in red) consisting of pixels and strips. Not shown here is the semiconductor tracker of the CMS experiment [754,298] consisting of silicon microstrip and pixel detectors with an outer radius of 1.25 m.


ATLAS
EXPERIMENT
Run Number: 327265, Event Number: 117236869
Date: 2017-06-19 19:59:16 CEST

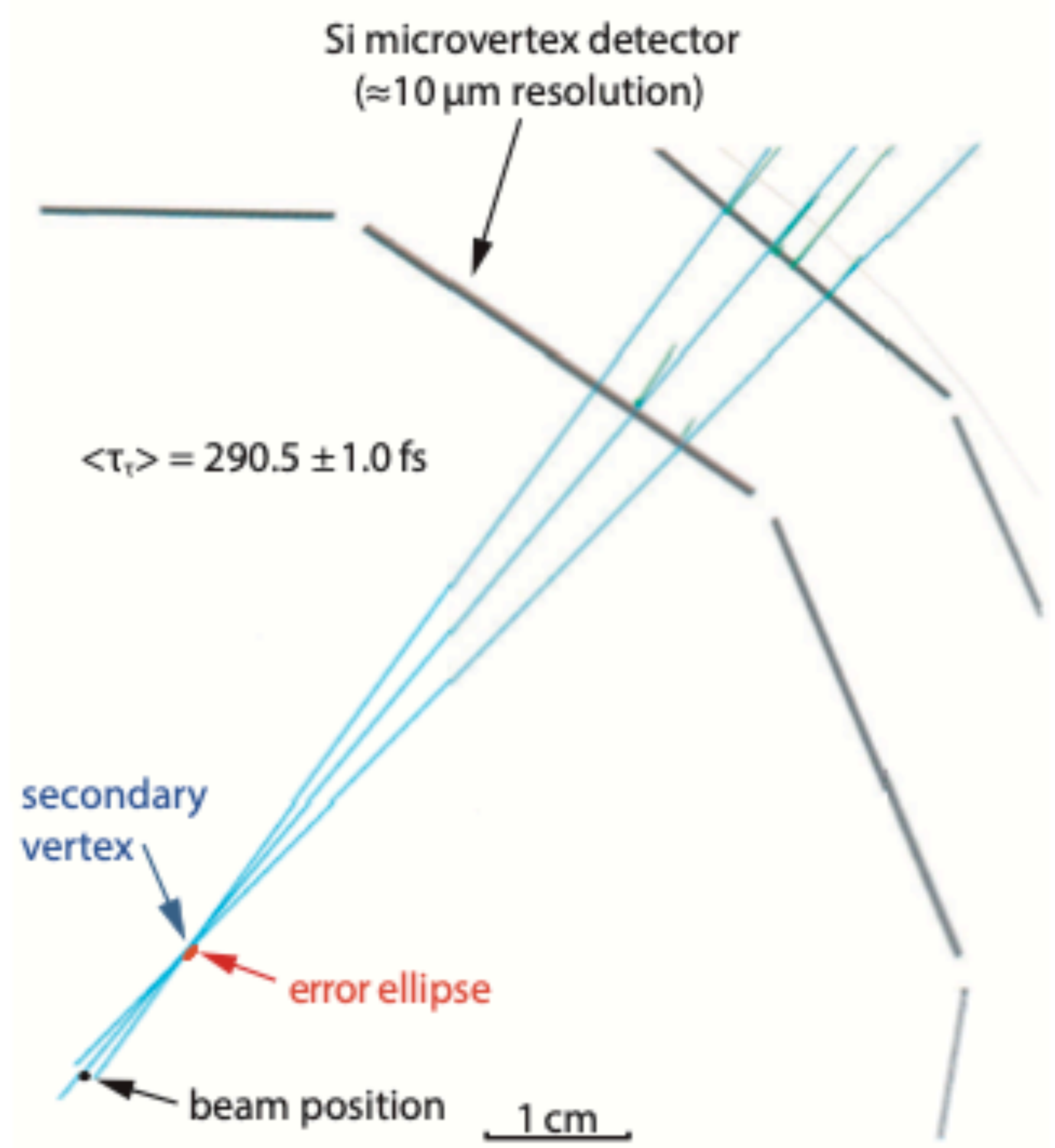
A display of a Z->μμ candidate event from proton-proton collisions recorded by ATLAS with LHC stable beams at a collision energy of 13 TeV on 19th June 2017 (Run 327265, Event 117236869). The Z candidate is reconstructed in a beam crossing with 16 additionally reconstructed vertices from minimum bias interactions. The two muons have p_T=31.7 GeV and 28.5 GeV. The invariant mass of the two muons is 91.8 GeV. The left display presents a transverse view of the event (X-Y plane) where the red lines show the two muons' paths. The right display zooms into the interaction region and shows a fraction of the 17 reconstructed vertices. The hard interaction vertex is represented by a red ellipse (on the left of the insert) from which the two muons (red tracks) are emerging. The bottom display presents the event in longitudinal view (Z-Y plane).



(a) Reconstruction of a τ-pair event.



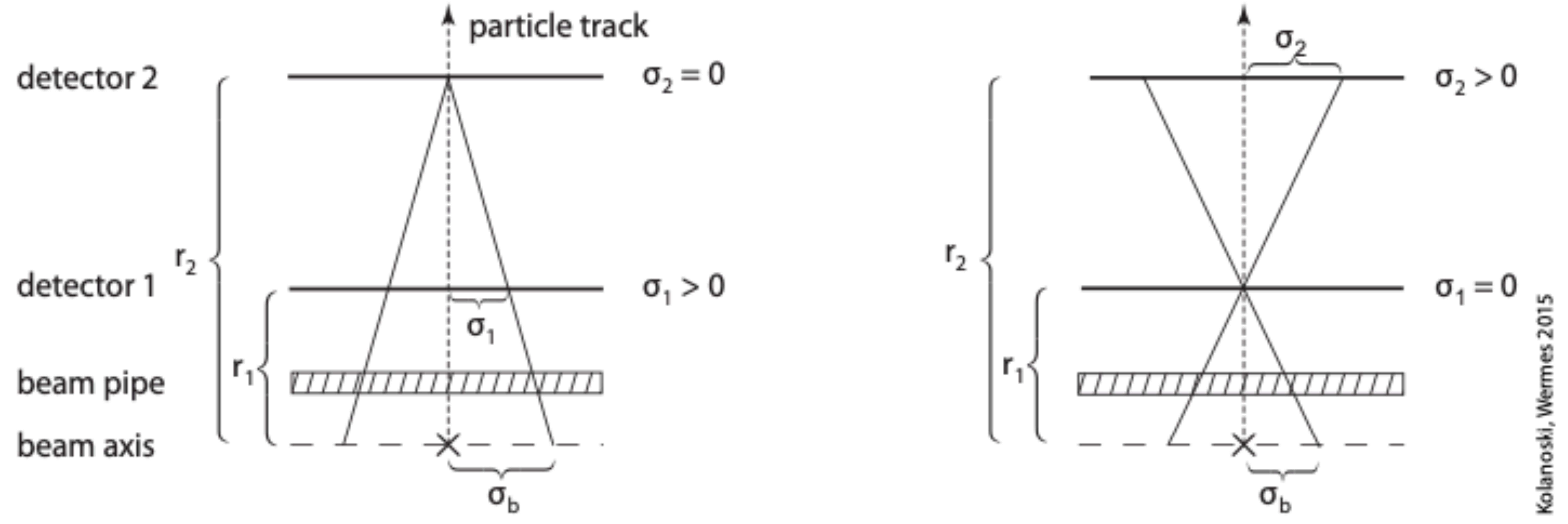
(b) Enlarged detail (20:1).



Simplified silicon detector

- Simple two-layer microstrip detector
- Layers cylindrically arranged around the beam direction at distances r_1 and r_2 and have position resolutions σ_1 and σ_2 in the plane perpendicular to the beam
- Perfect detector: $\sigma = 0$
- Planar detector modules
- Straight tracks passing the layers perpendicularly

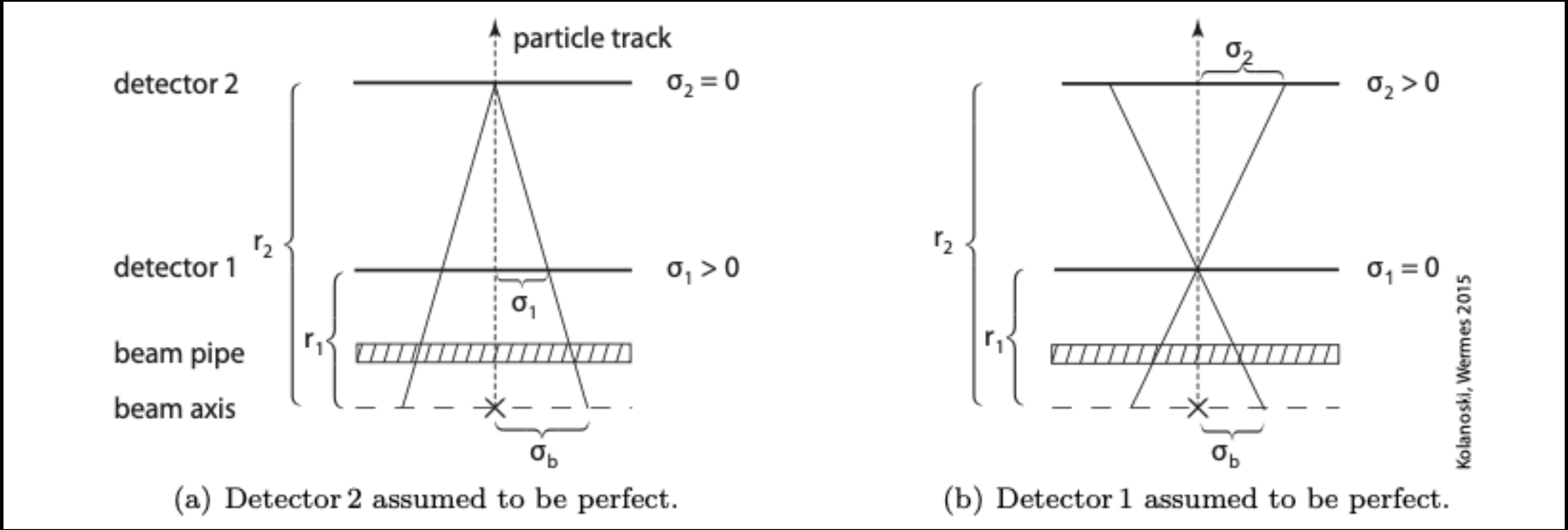
Simplified silicon detector



(a) Detector 2 assumed to be perfect.
(b) Detector 1 assumed to be perfect.

- Assume detector 2 is perfect ($\sigma_2 = 0$) and detector 1 has resolution $\sigma_1 > 0$
- $\dfrac{\sigma_b}{\sigma_1} = \dfrac{r_2}{r_2 - r_1}$

Simplified silicon detector



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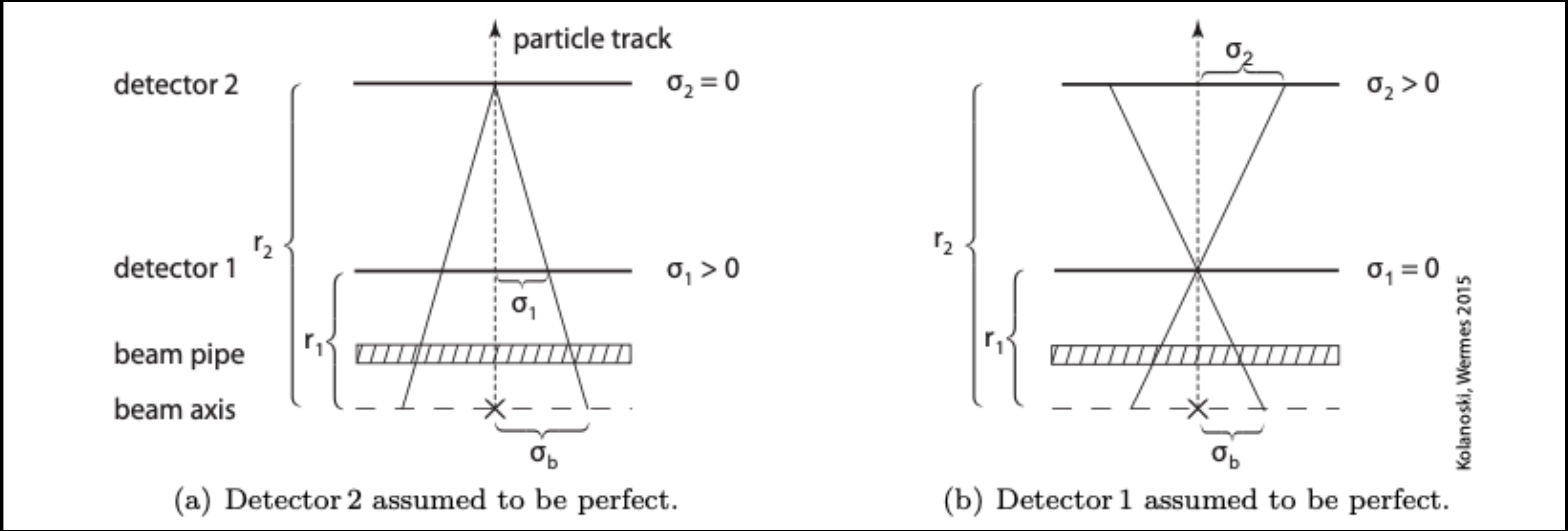
Simplified silicon detector



- Quadratically summing the two respective resolutions and adding a term σ_{ms} due to multiple scattering
- Total resolution:
- $\sigma_b^2 = \left(\frac{r_2}{r_2 - r_1}\sigma_1\right)^2 + \left(\frac{r_1}{r_2 - r_1}\sigma_2\right)^2 + \sigma_{ms}^2$: of the order of a few micrometers