STARTERKIT

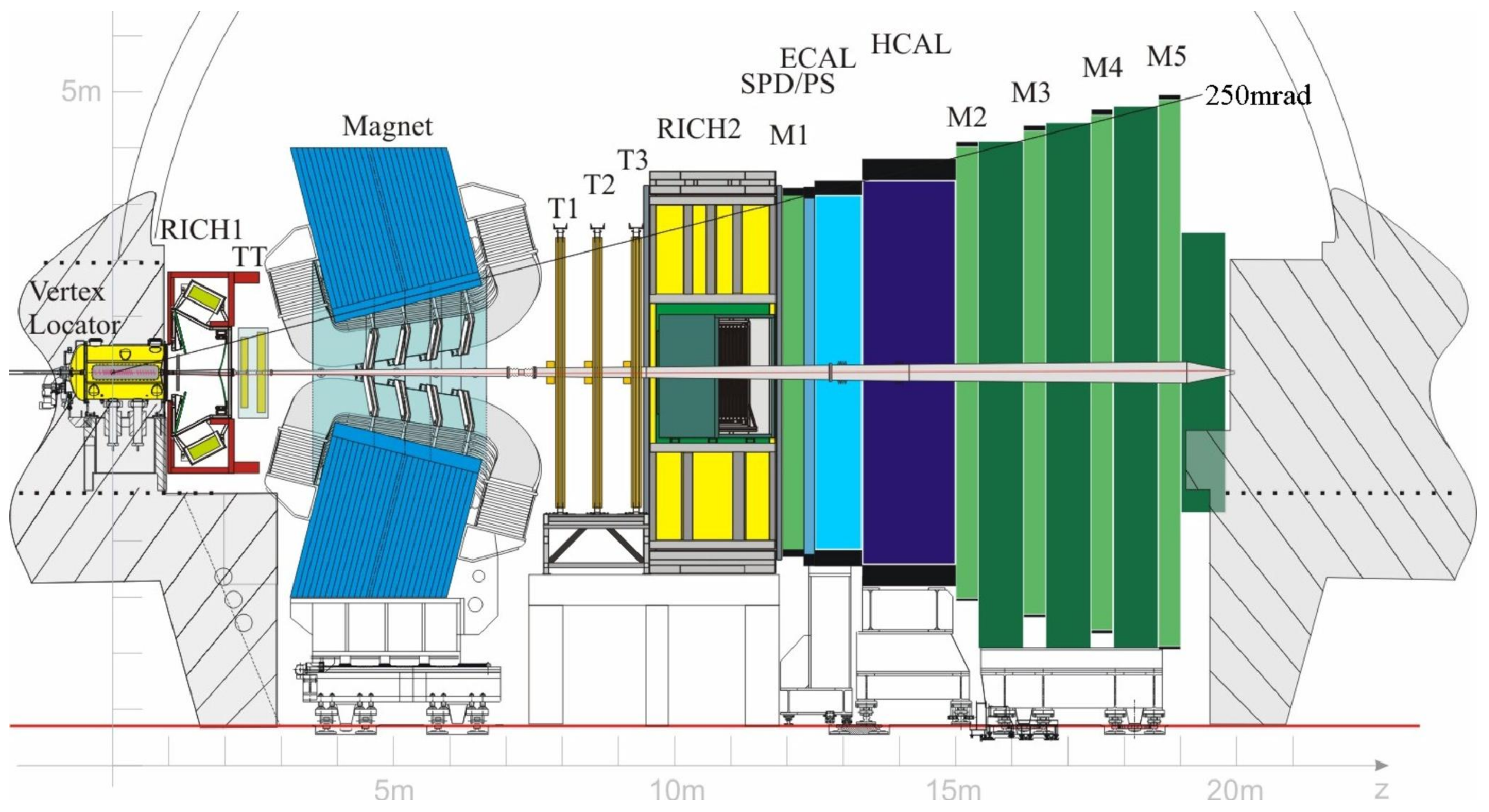
LHCb

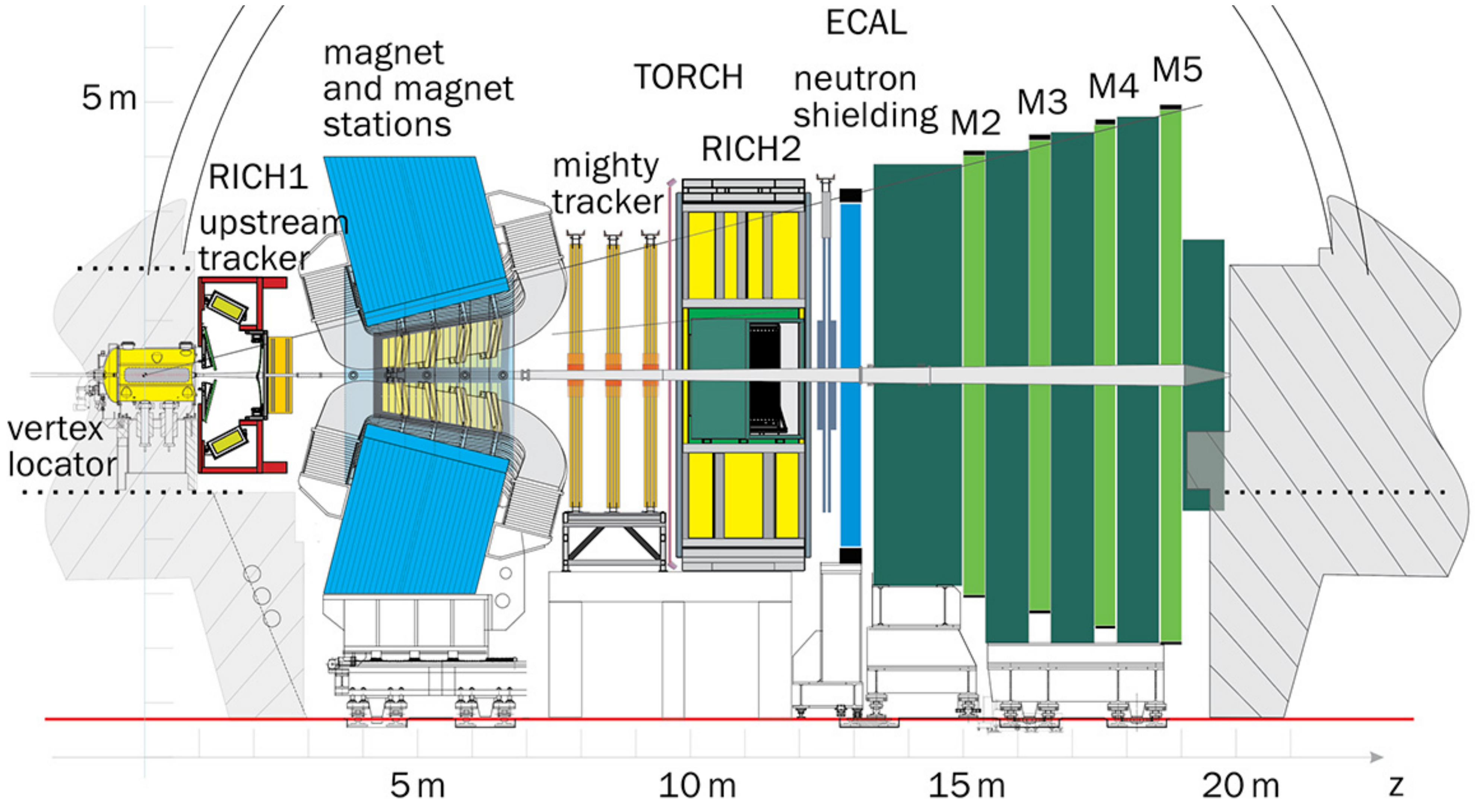
Estd. 2015

LHCb Upgrade II
What we want to do and why?

Janina Nicolini

16.02.2024





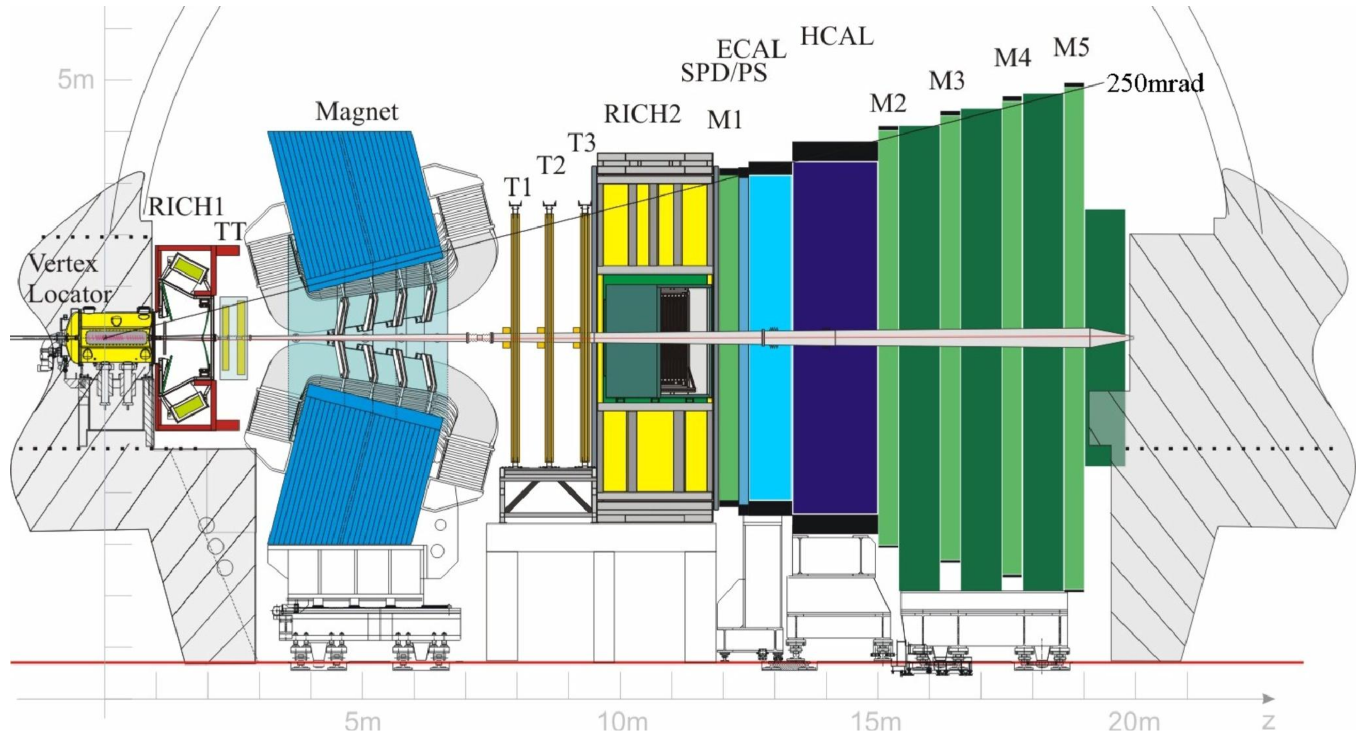
UPGRADES IN A NUTSHELL

- Single-arm forward spectrometer
- LHCb acceptance $2 < \eta < 5$
- Essentially the same spectrometer detector

$\rightarrow$ needs **fast readout, high granularity, fast timing, extreme radiation hardness**

Original

Run 1+2



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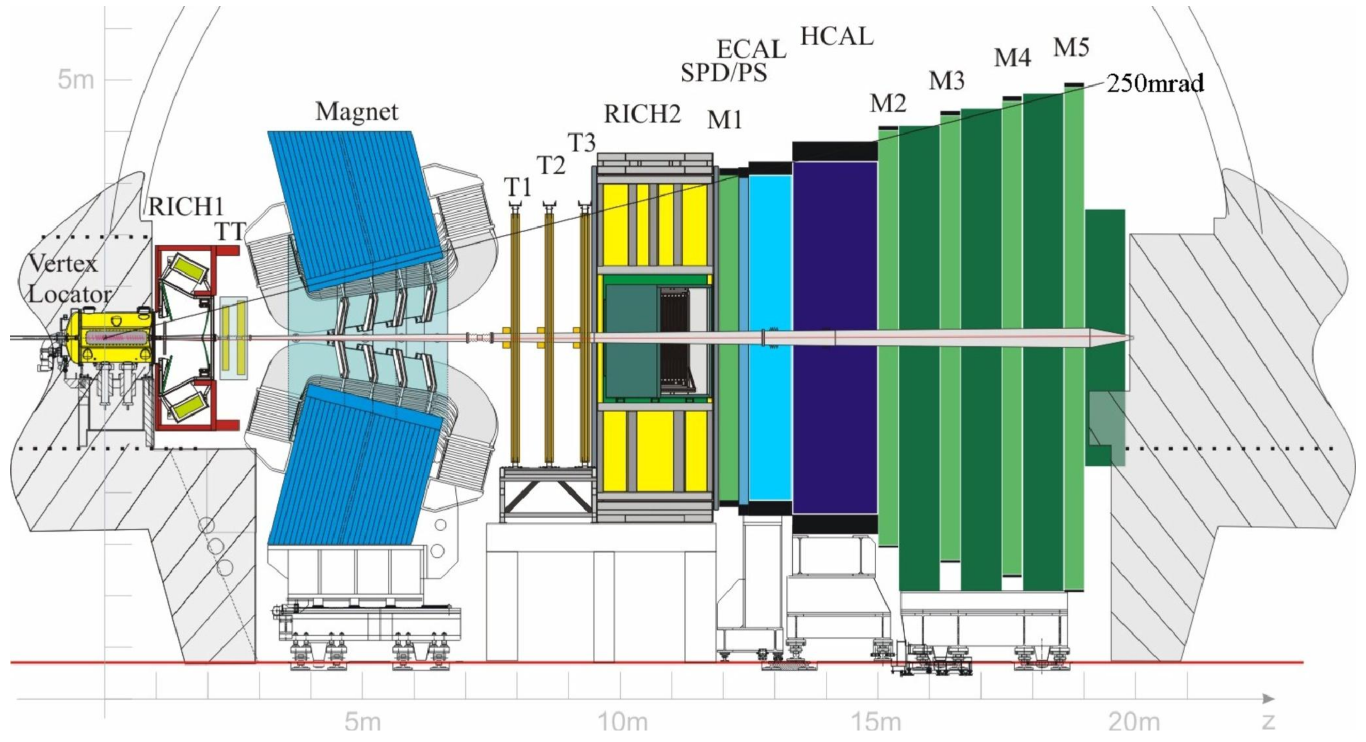
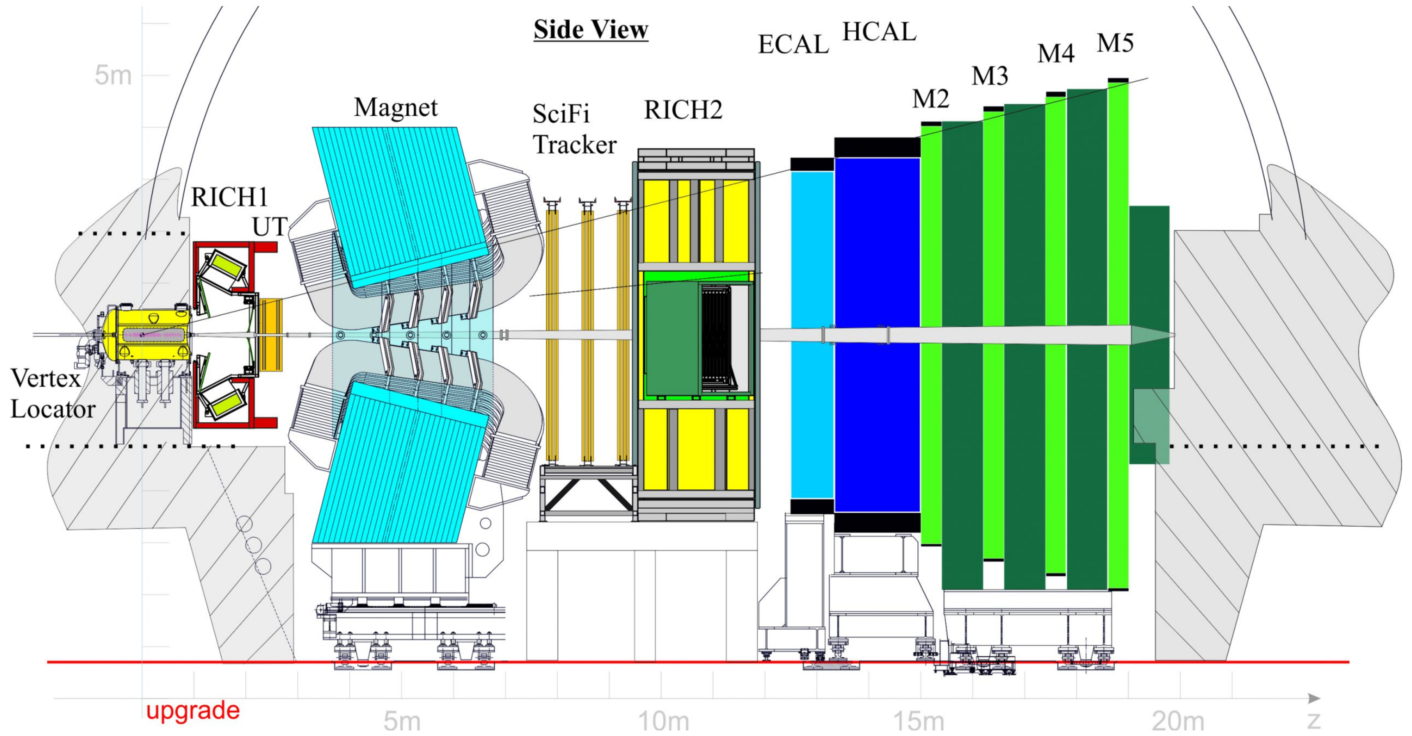


Upgrade I
Run 3+4



Fast readout + higher granularity
+improved radiation hardness

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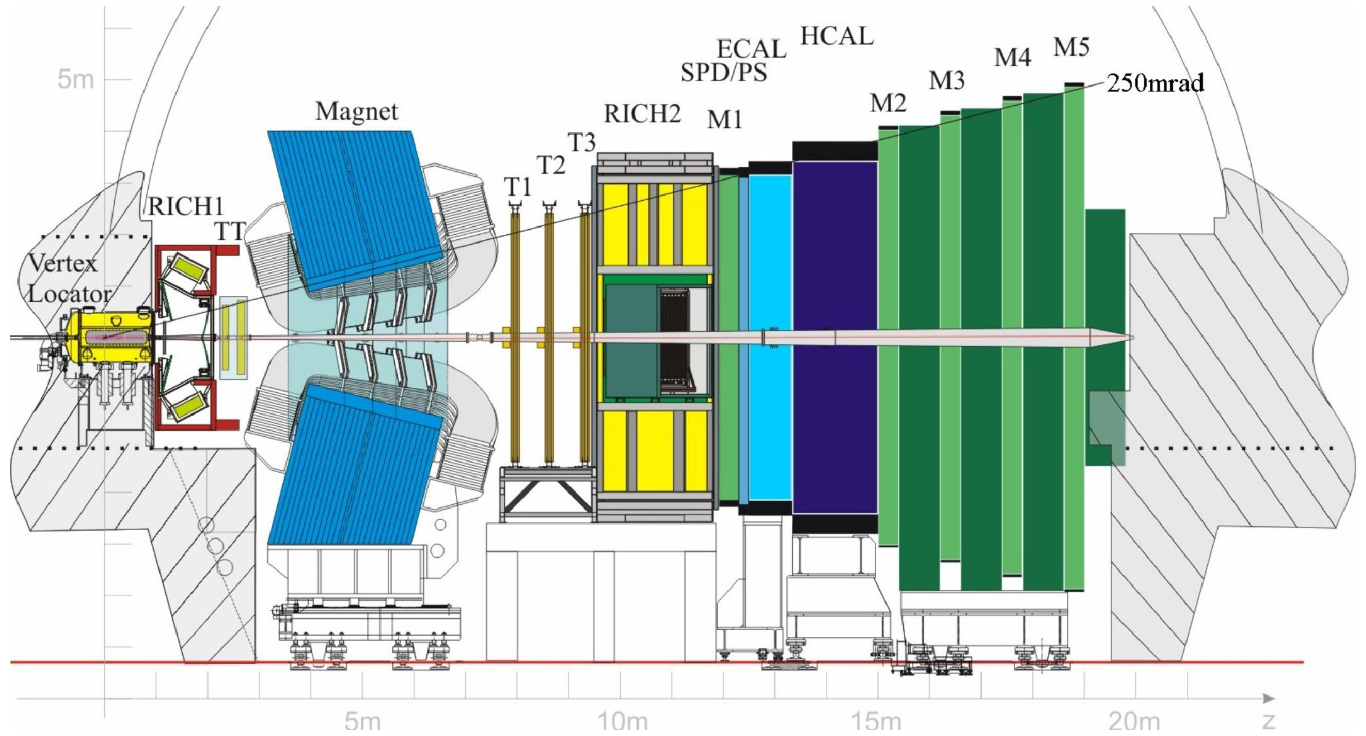

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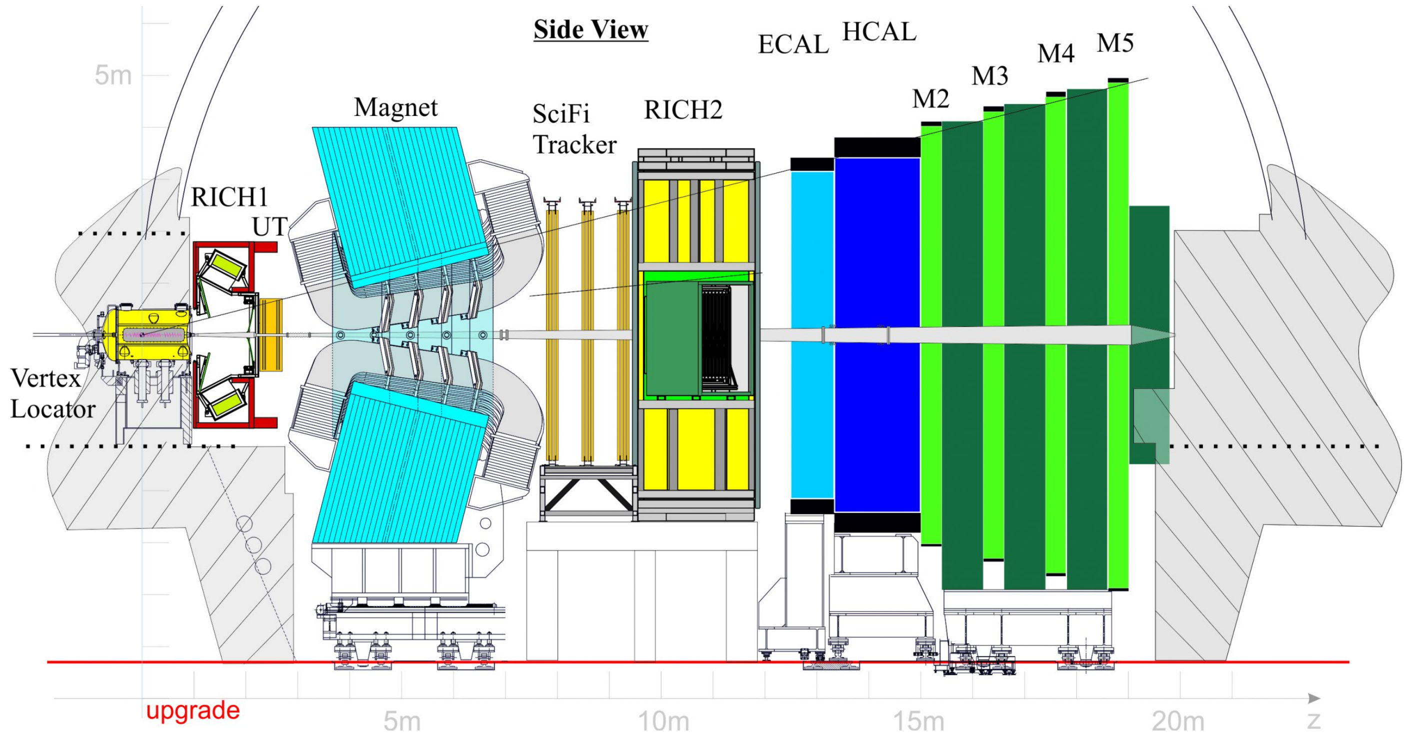
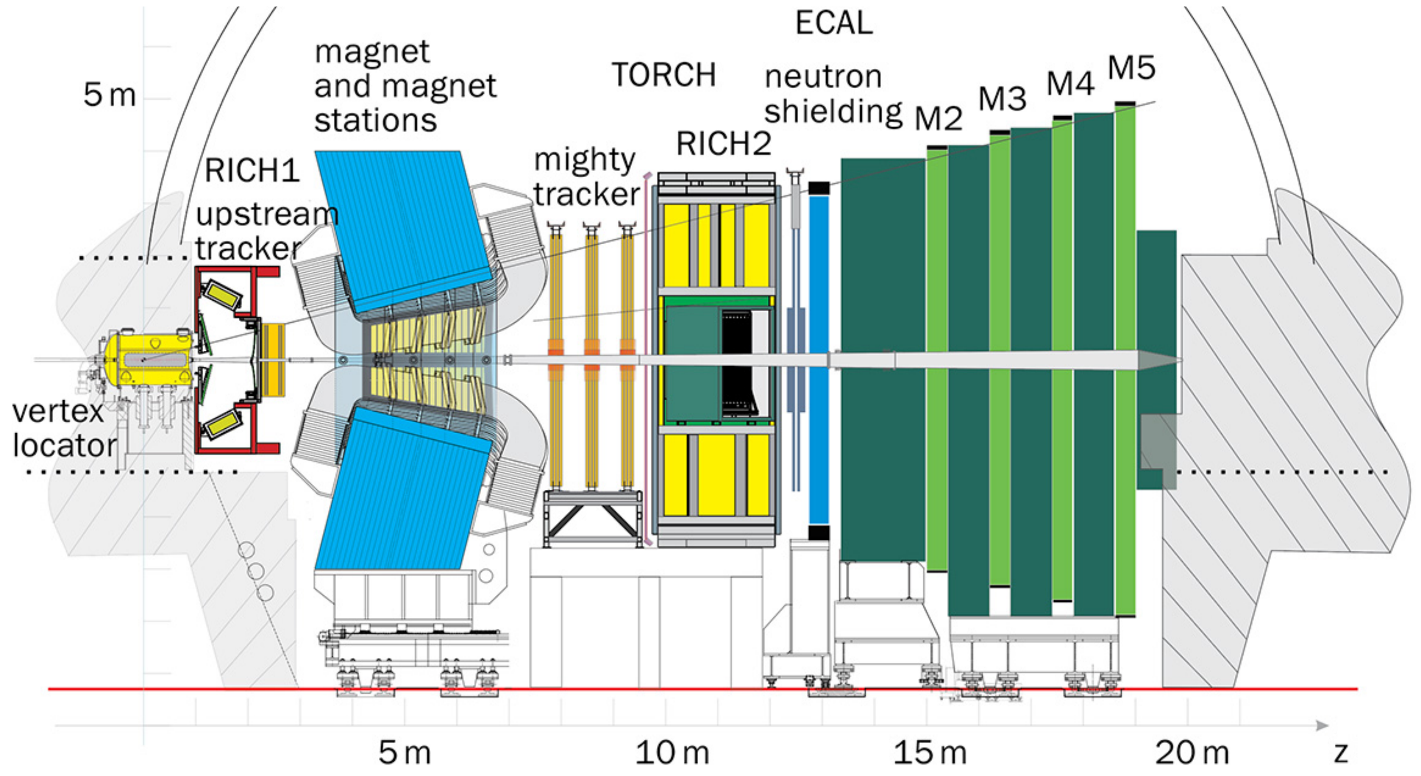


Upgrade II
Run 5+6



All of the above

UPGRADES IN A NUTSHELL

- Single-arm forward spectrometer
- LHCb acceptance $2 < \eta < 5$
- Essentially the same spectrometer detector

$\rightarrow$ needs **fast readout, high granularity, fast timing, extreme radiation hardness**

Currently limited by the experiment, not LHC

What does that mean?

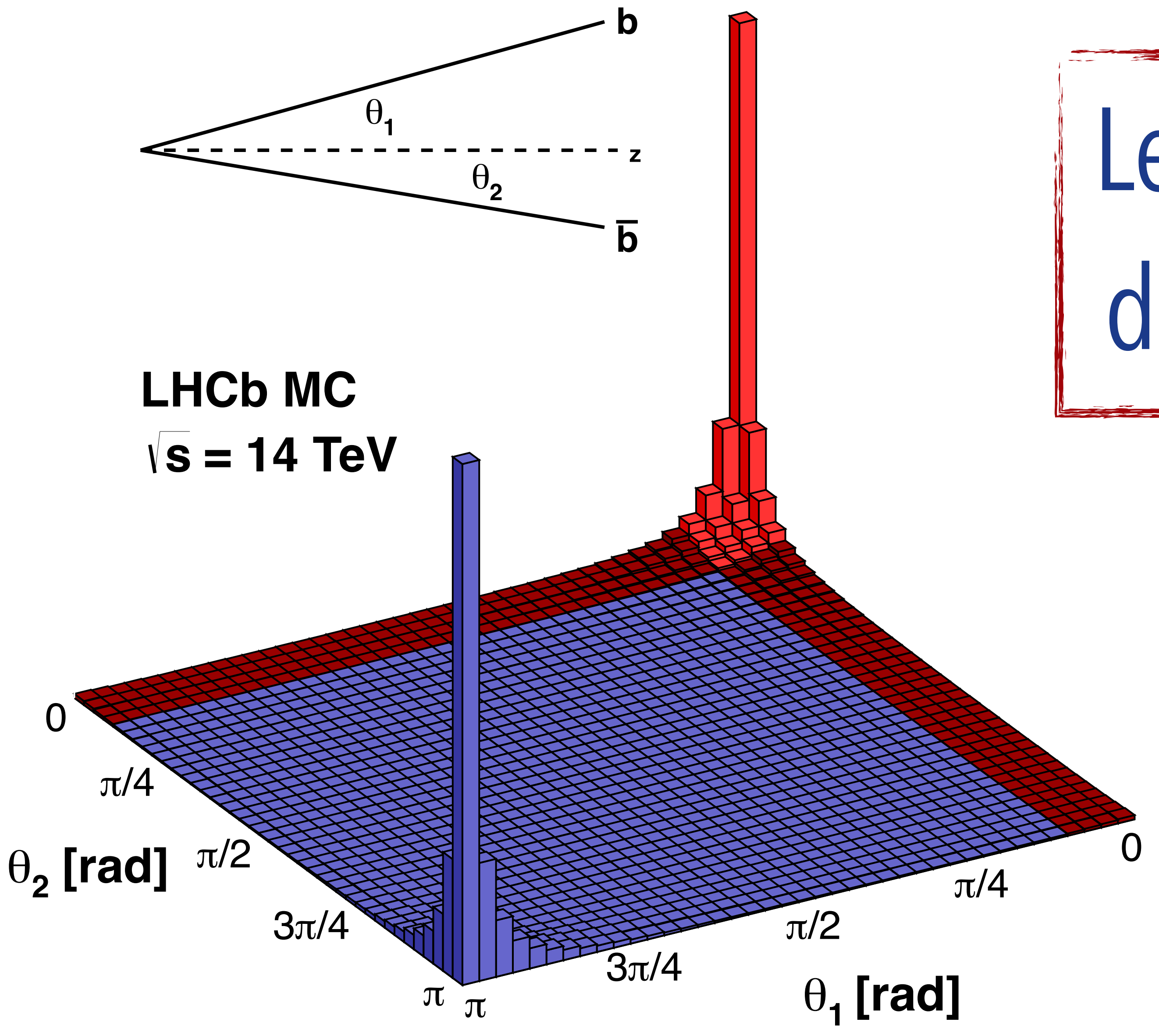
Original
Run 1+2

Upgrade II
Run 5+6

All of the above

REMINDER: $b\bar{b}$ PAIRS @ LHC

Gluon-gluon fusion



Let's translate this in detector acceptance

REMINDER: $b\bar{b}$ PAIRS @ LHC

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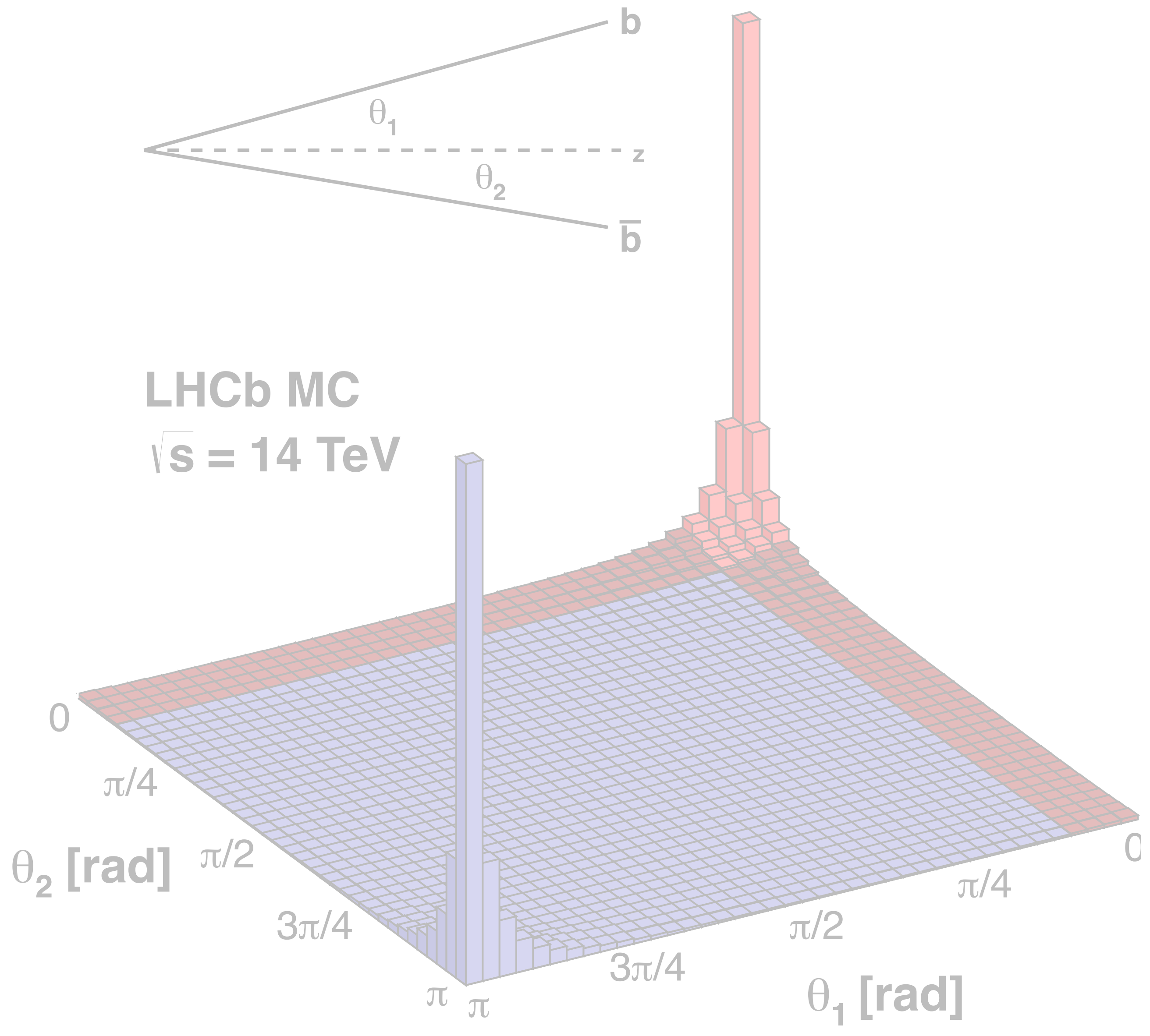
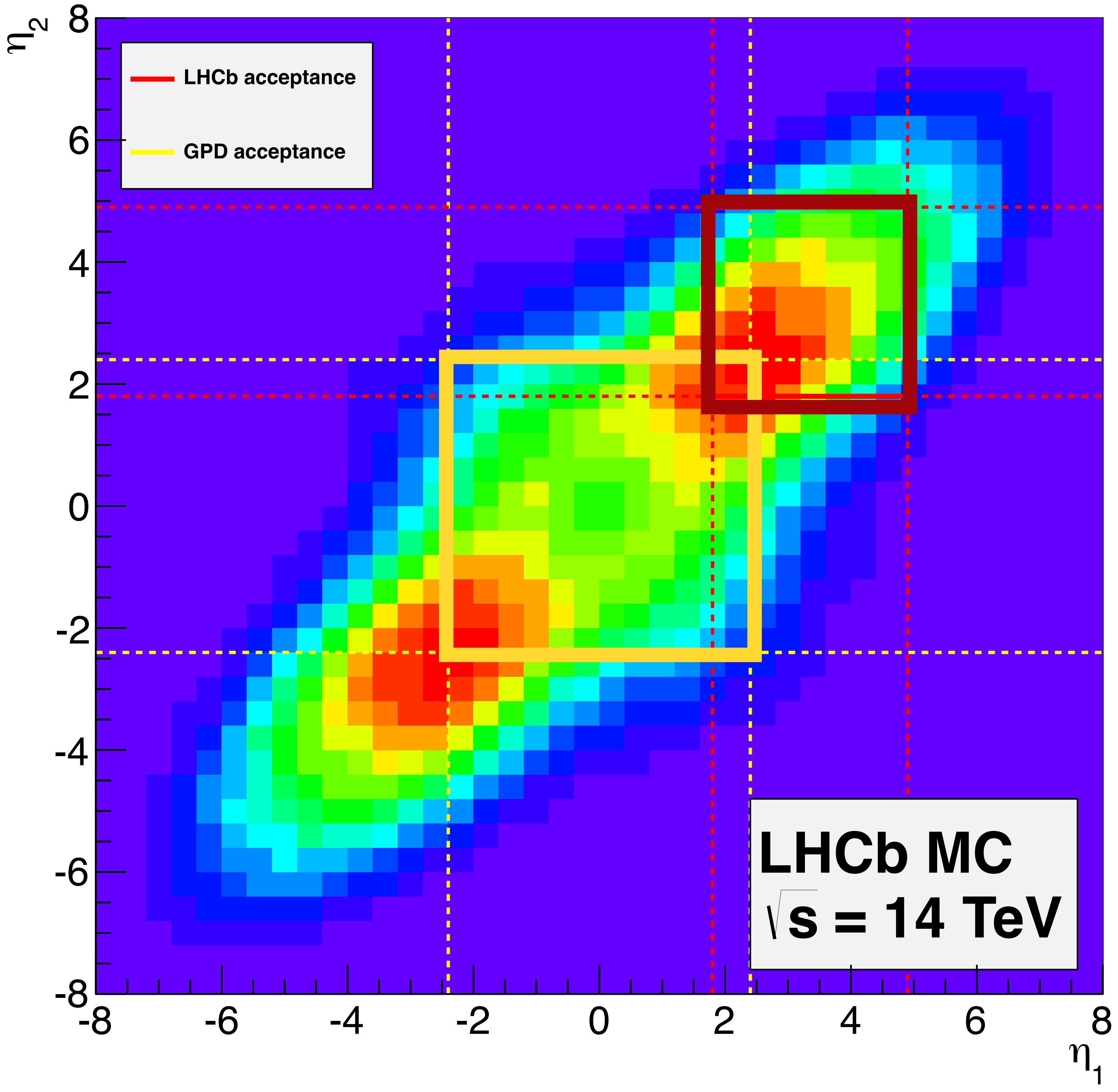




- LHCb Detector

  $2 < \eta < 5$

  27% b or $\bar{b}$ and 24% of $b\bar{b}$ pairs *

- General Purpose Detector (GPD)

  $|\eta| < 2.5$

  49% b or $\bar{b}$ and 41% of $b\bar{b}$ pairs *

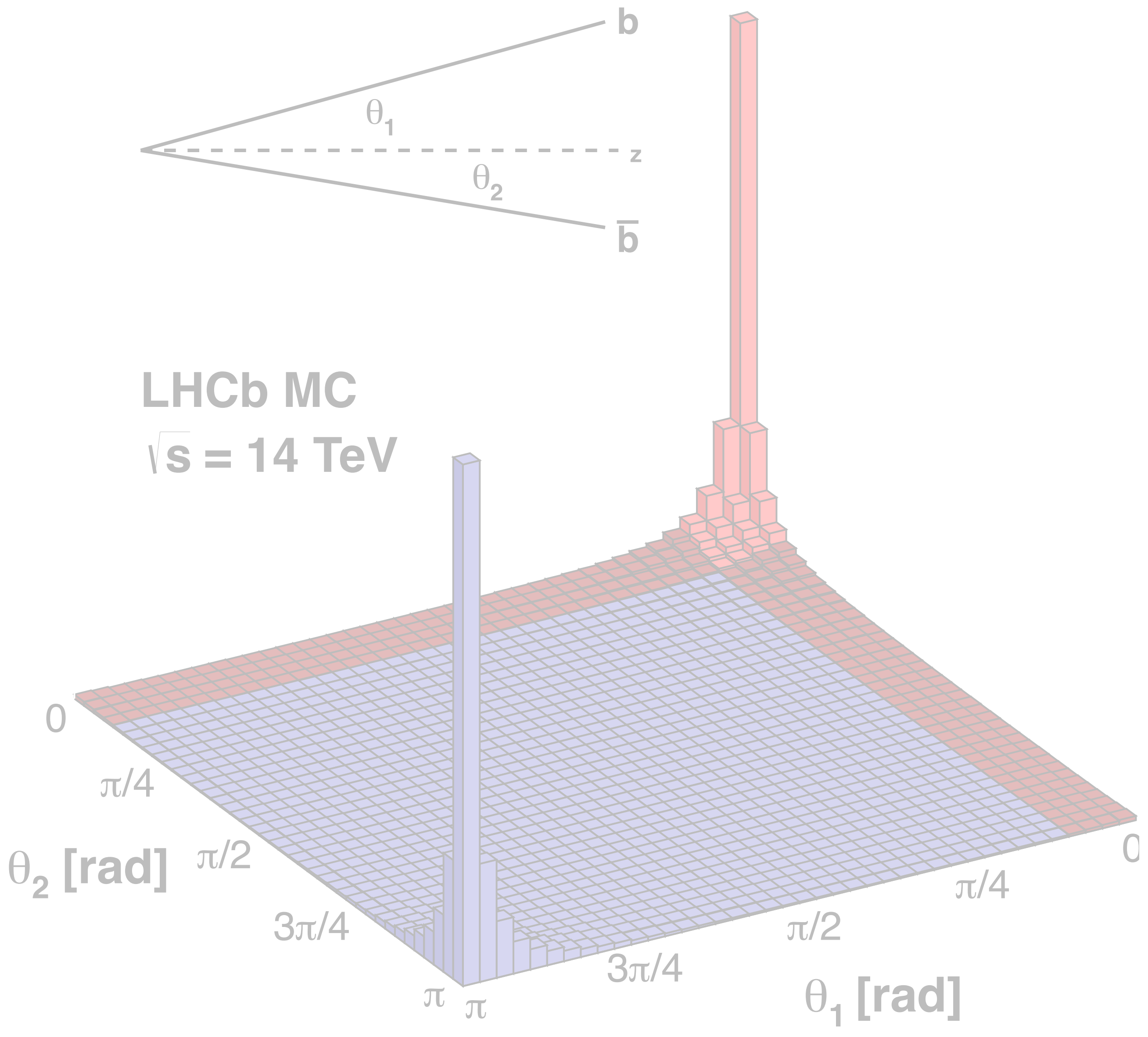
*in acceptance

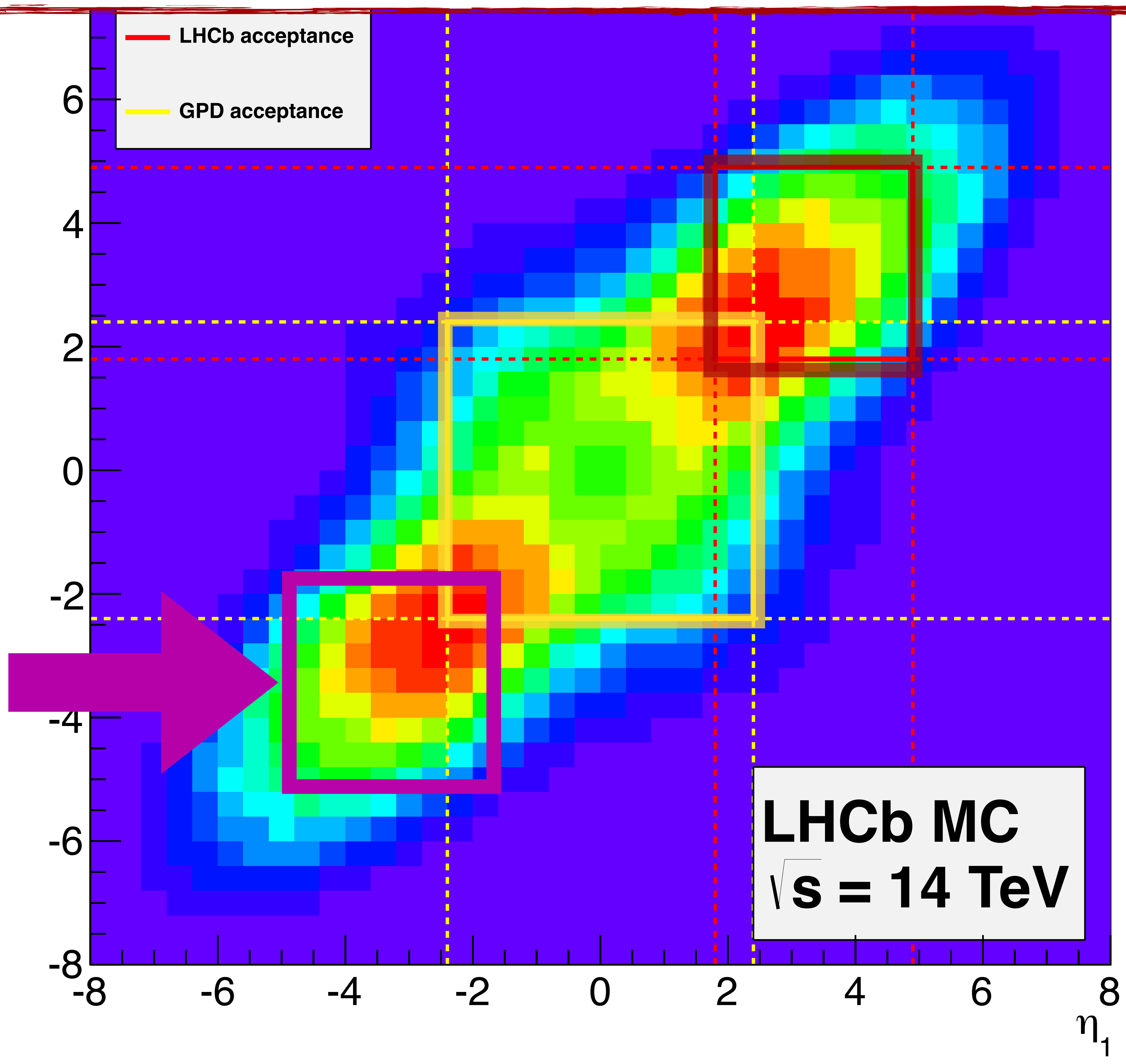
REMINDER: $b\bar{b}$ PAIRS @ LHC

So GPD catches more?

Yes and no, with a mirrored second LHCb we would have a better acceptance

Gluon





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- General Purpose Detector (GPD)

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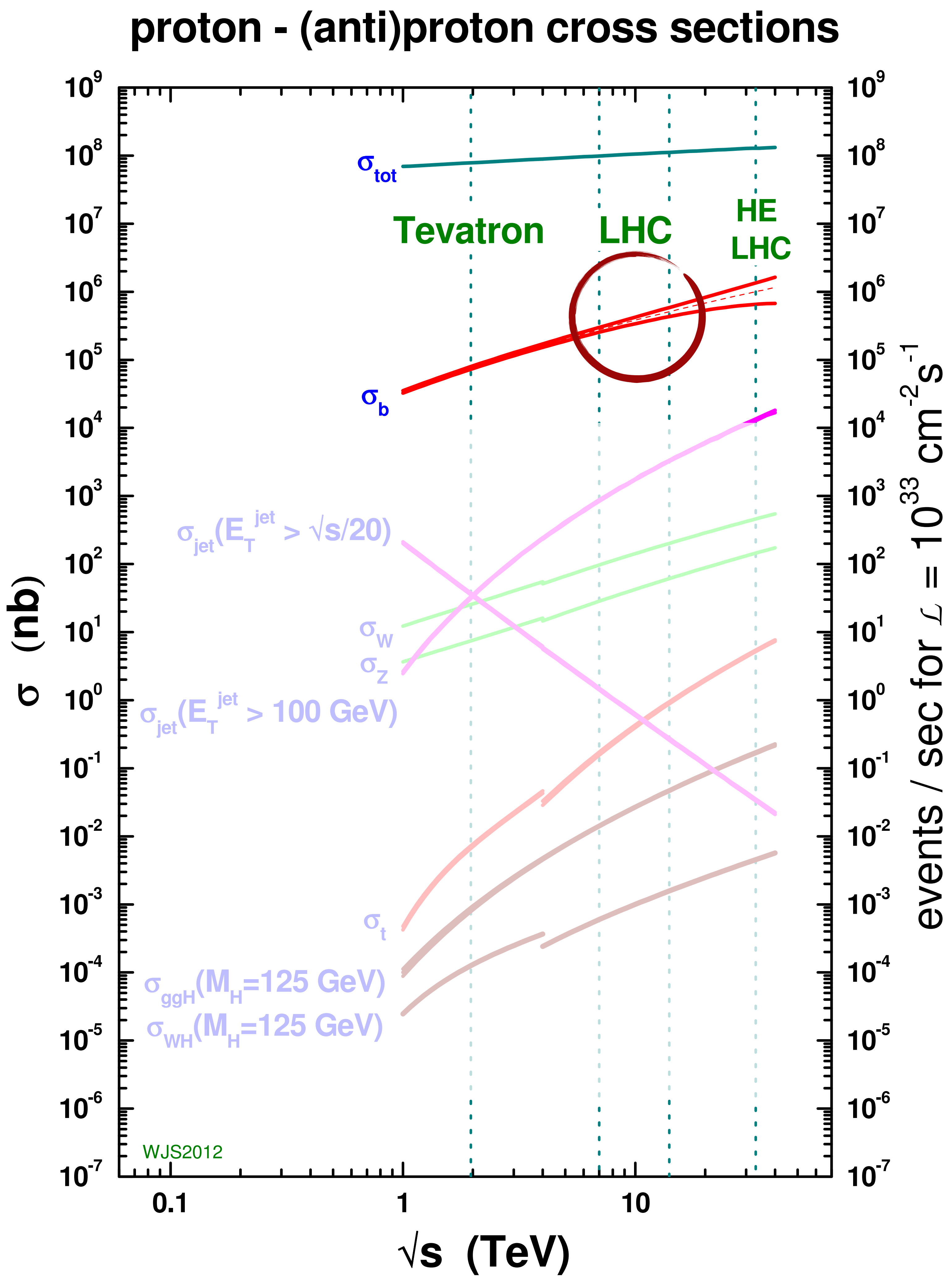
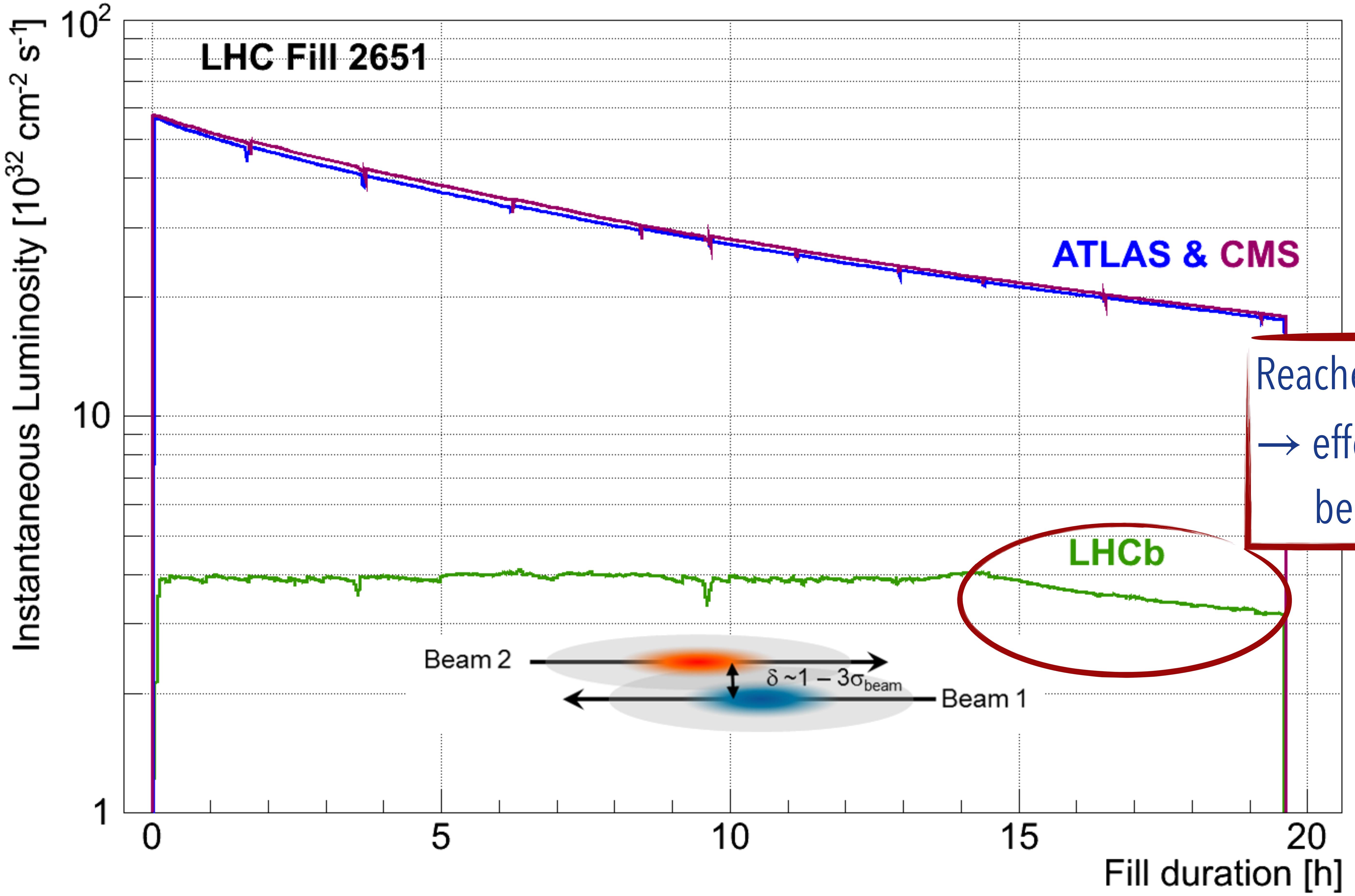
Our detector is optimised for b physics, we still do better.

REMINDER LUMINOSITY LEVELLING

Luminosity levelling: lead beams collide with offset and reduce it till head-on collision

→ stable luminosity = stable readout rates





Reached head-on collision
→ effected by decreasing beam quality

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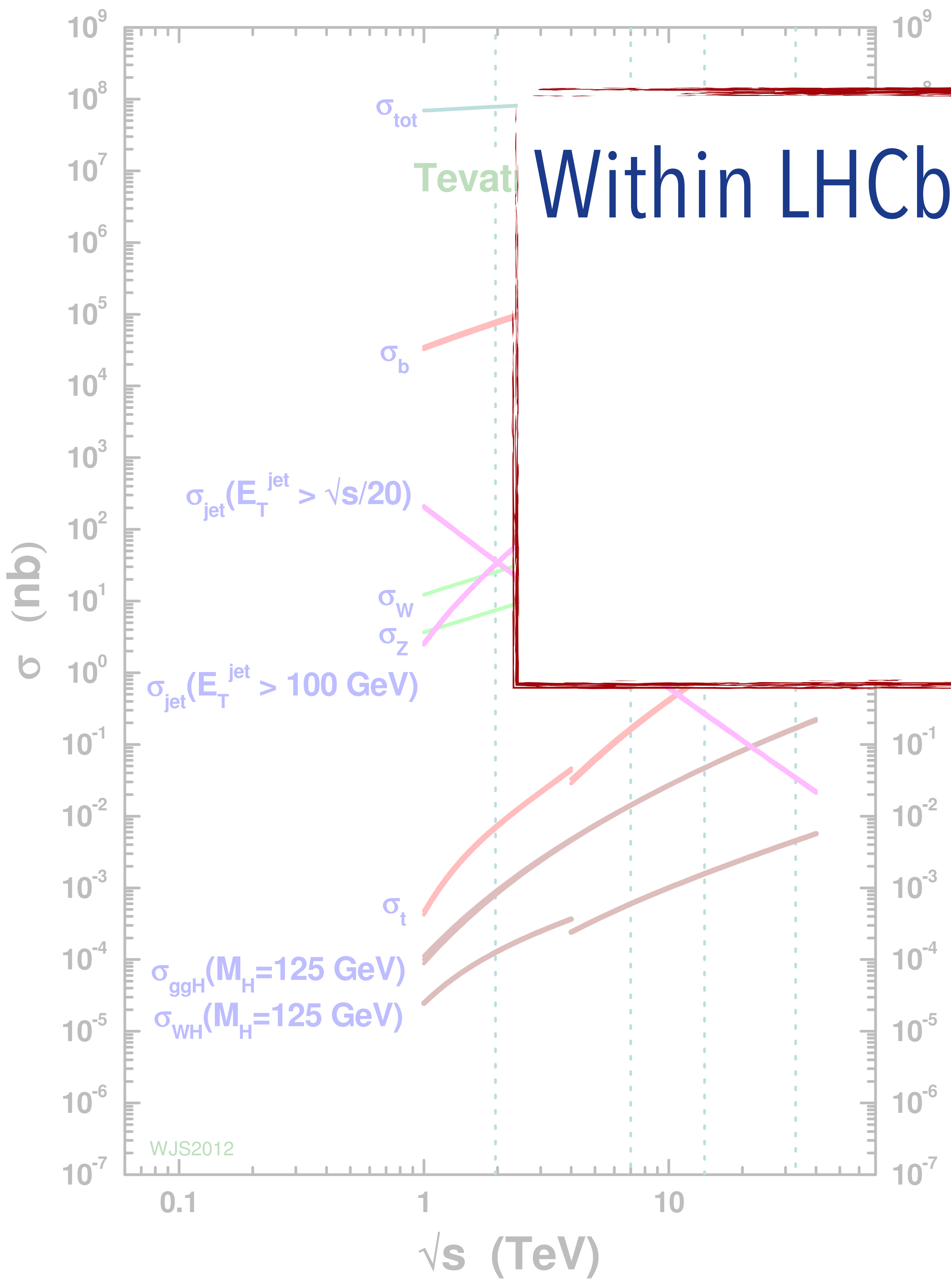

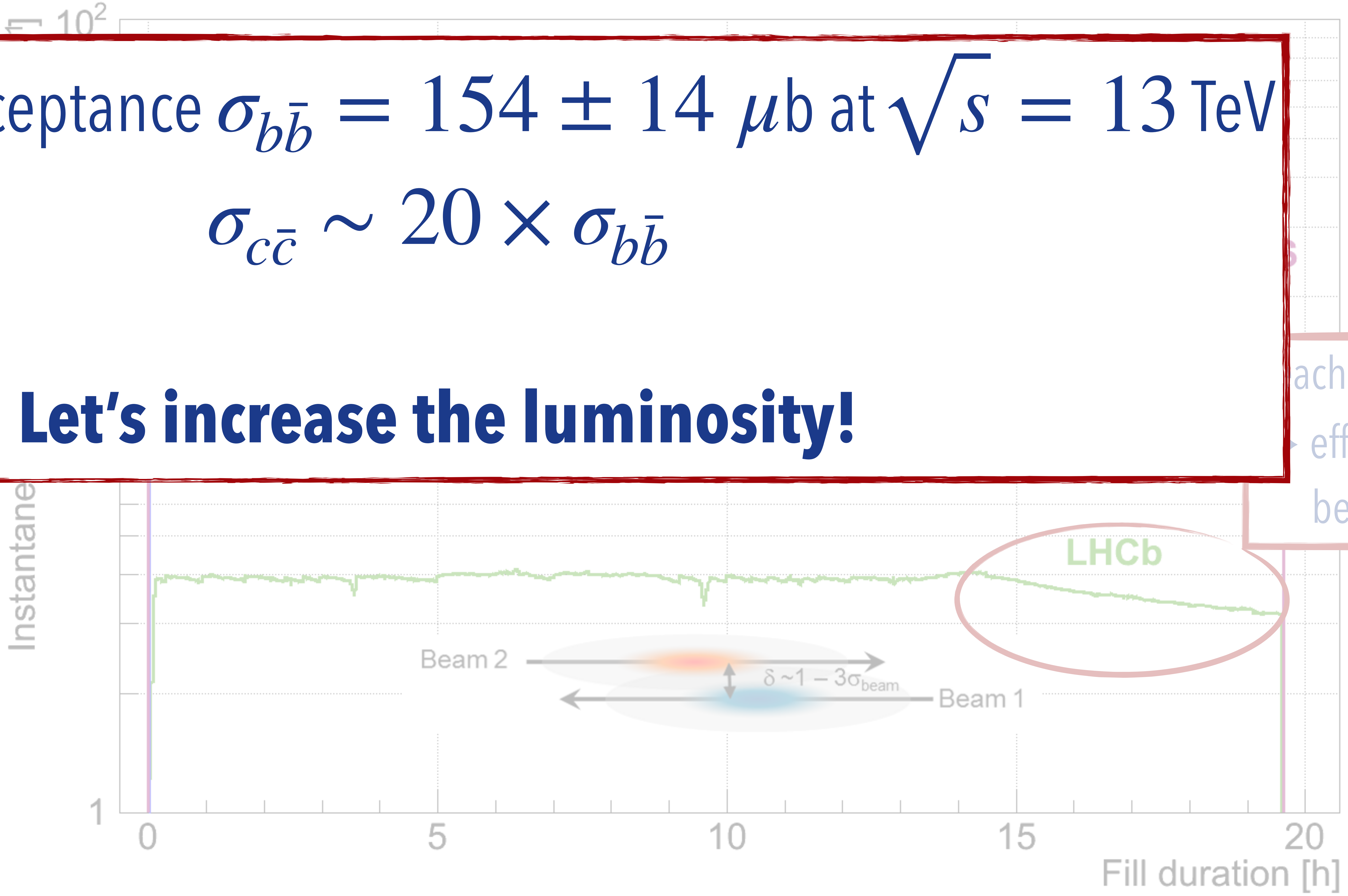

ached head-on collision
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Within LHCb acceptance $\sigma_{b\bar{b}} = 154 \pm 14\ \mu$b at $\sqrt{s} = 13$ TeV

$$\sigma_{c\bar{c}} \sim 20 \times \sigma_{b\bar{b}}$$

Let's increase the luminosity!

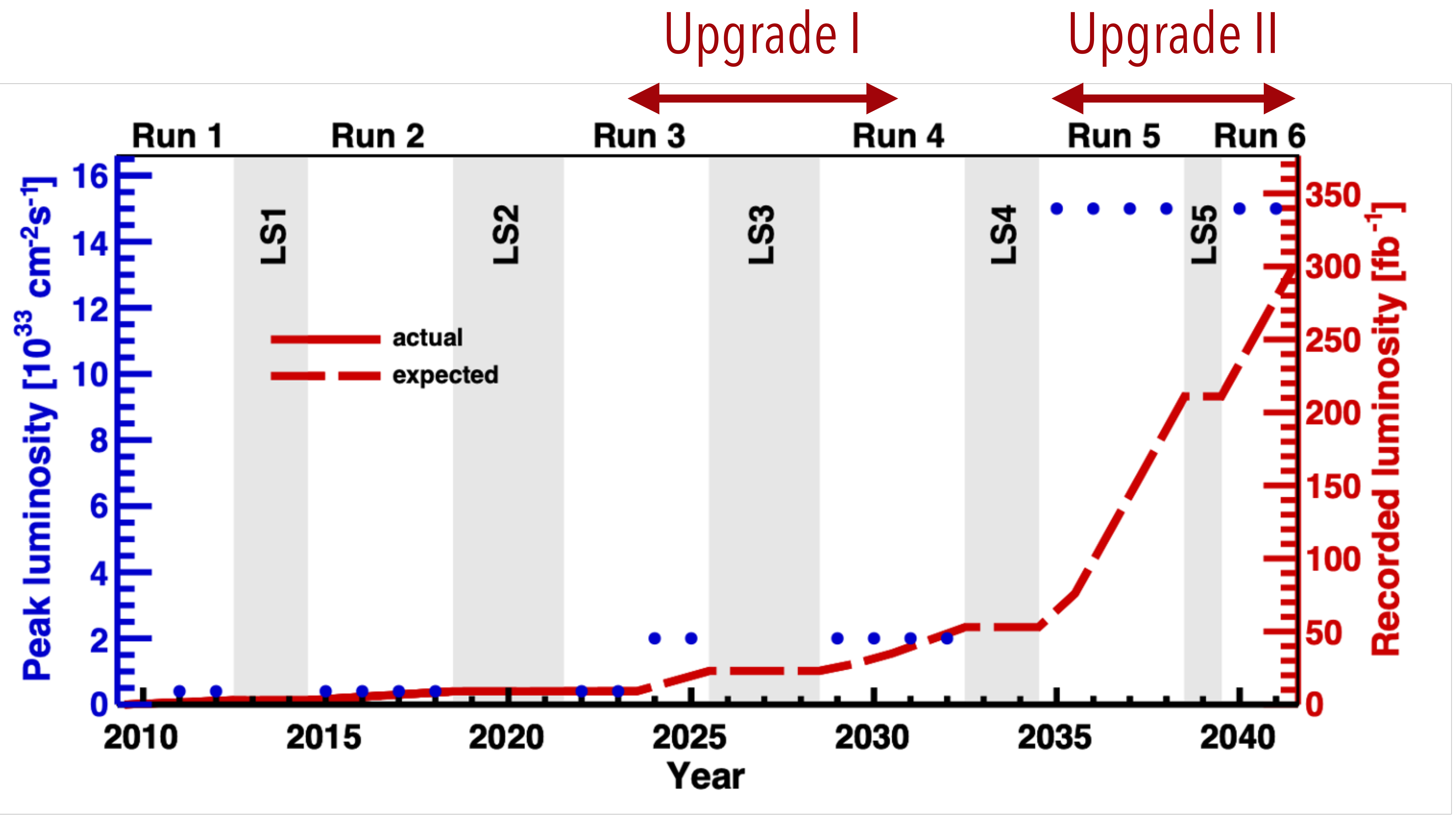
NEED FOR UPGRADES

- Hardware trigger limited at frontend to 1.1MHz rate
- With lumi increase from 1 to $2-4\cdot 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$:

  p_T and E_T cuts saturate for hadronic channel
- Pile-up significantly increases

  $\rightarrow$ higher track/PV multiplicity
- Not processable in online farm
- Limit of radiation hardness will be hit

LUMINOSITY TARGETS



Enabling high precision flavour physics + BSM

(see Vincenzos talk on Monday)

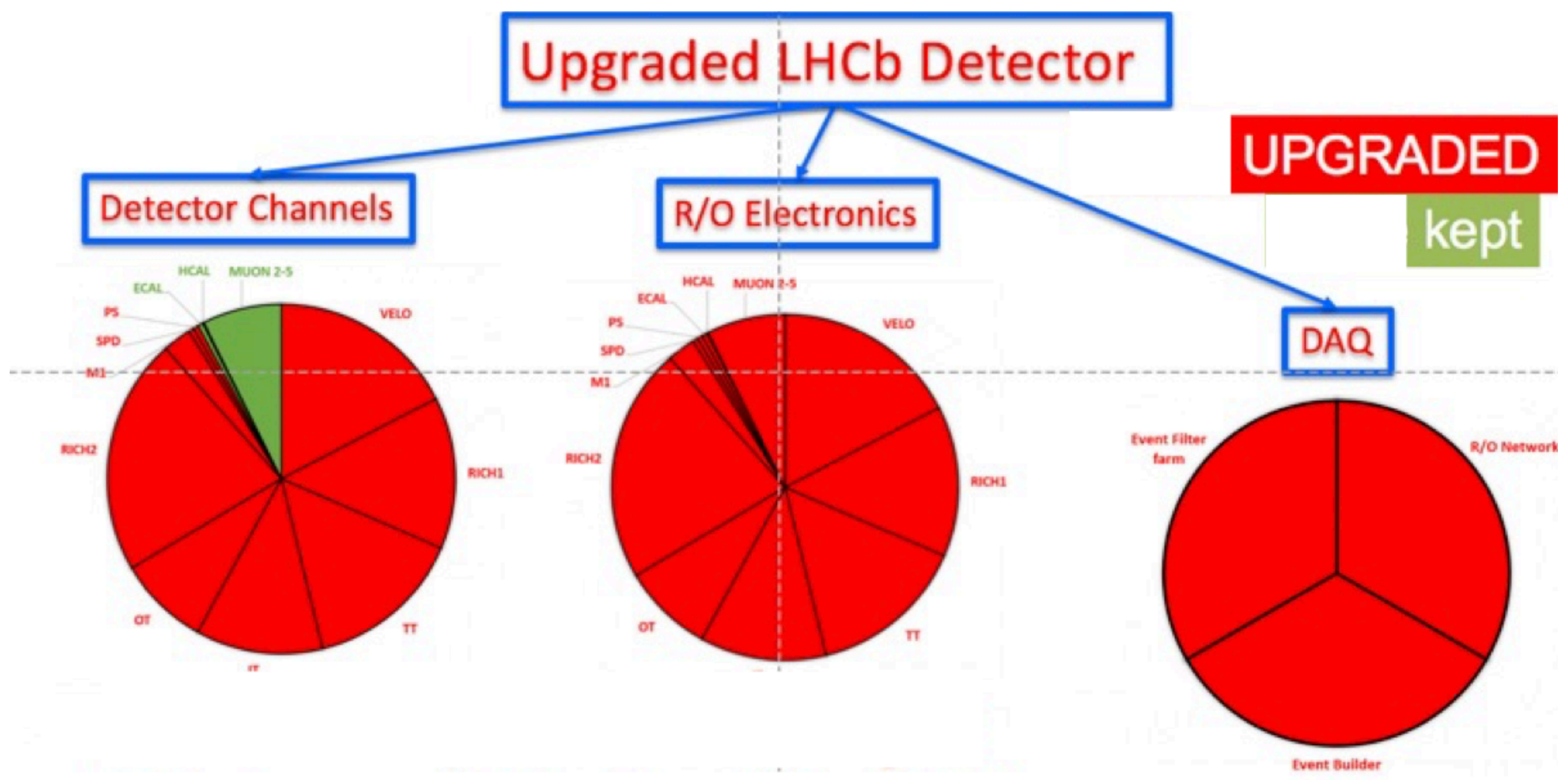
- Upgrade I till end if Run 4: 50 fb^{-1}
- Upgrade II accumulate maximum possible integrated luminosity but at least: 50 $\mathrm{fb}^{-1}/\mathrm{y}$

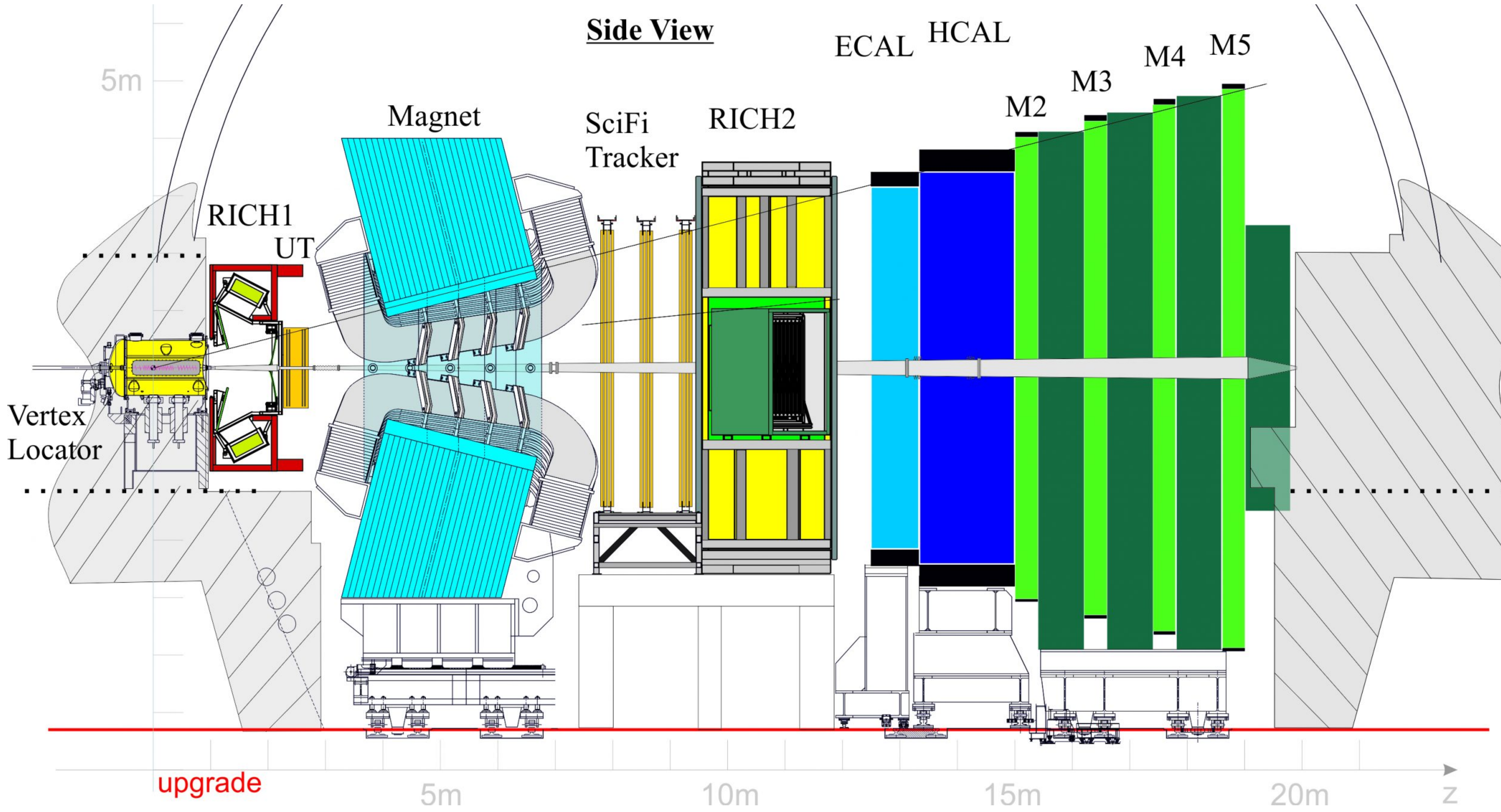
OVERVIEW UPGRADE I

- Tracking detector exchanged due to radiation damage
  - Upgrade to finer granularity
    - Pixel VELO getting as close as 5mm to beam
    - New silicon based Upstream detector (UT)
    - SciFi tracker 11.000km of scintillating fibre
- New RICH mechanics, optics and photodetectors

  → better granularity
- New electronics for all systems

Basically brand new detector





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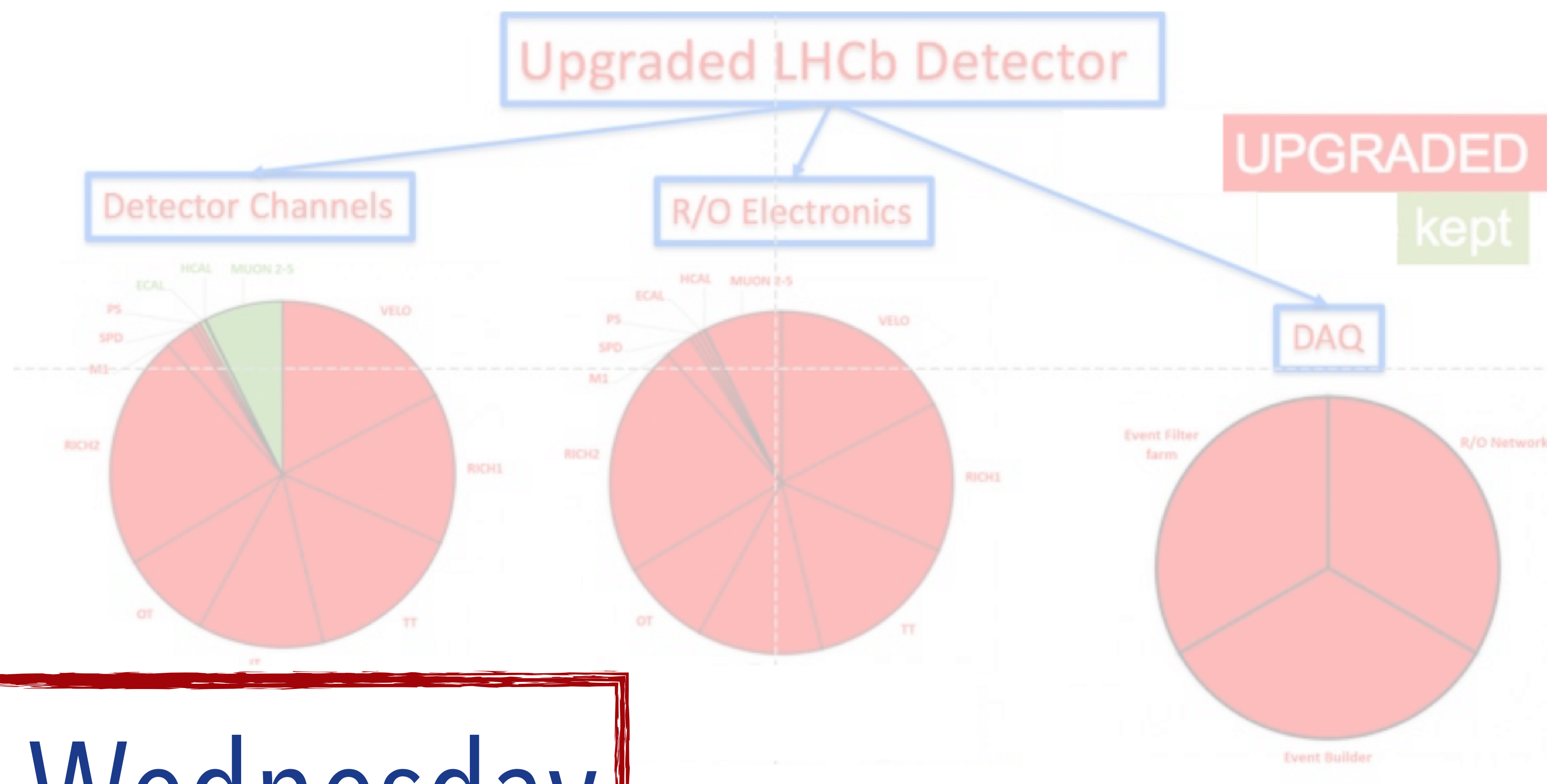
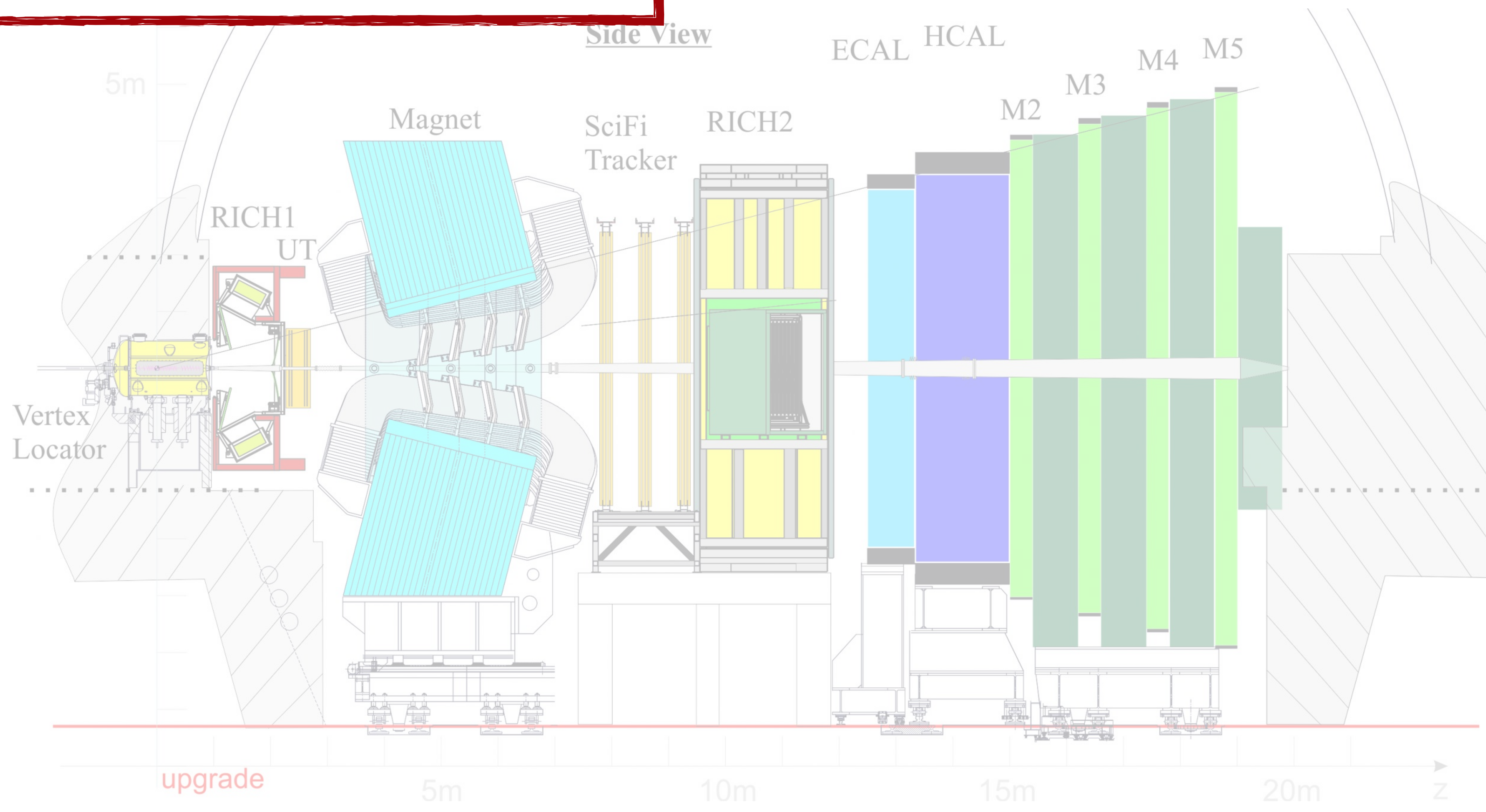
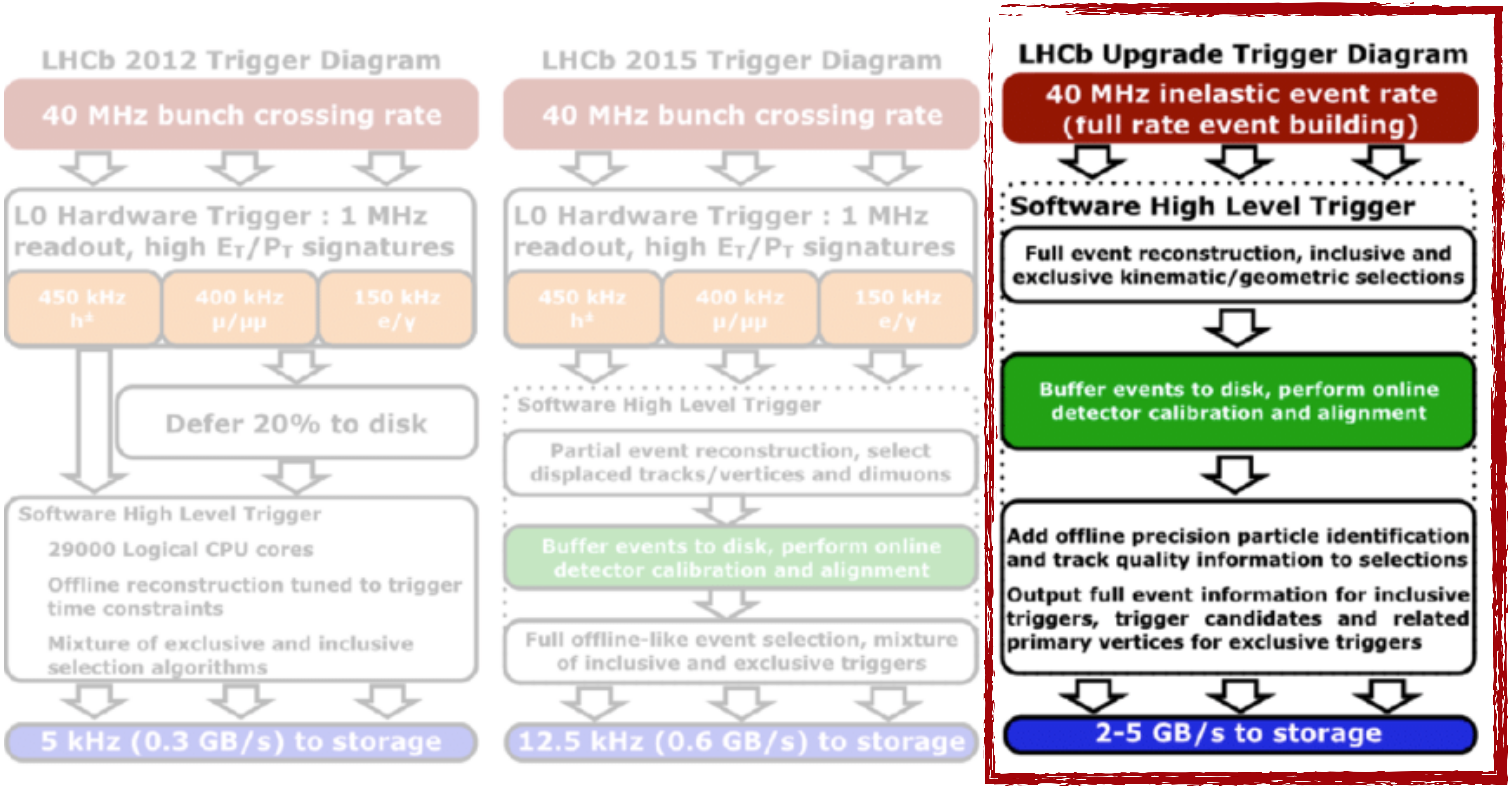


More details see talk on Upgrade I on Wednesday



MILESTONE 1 - RTA

- Fast readout: Upgrade of computing resources to GPU + FPGAs for readout electronics



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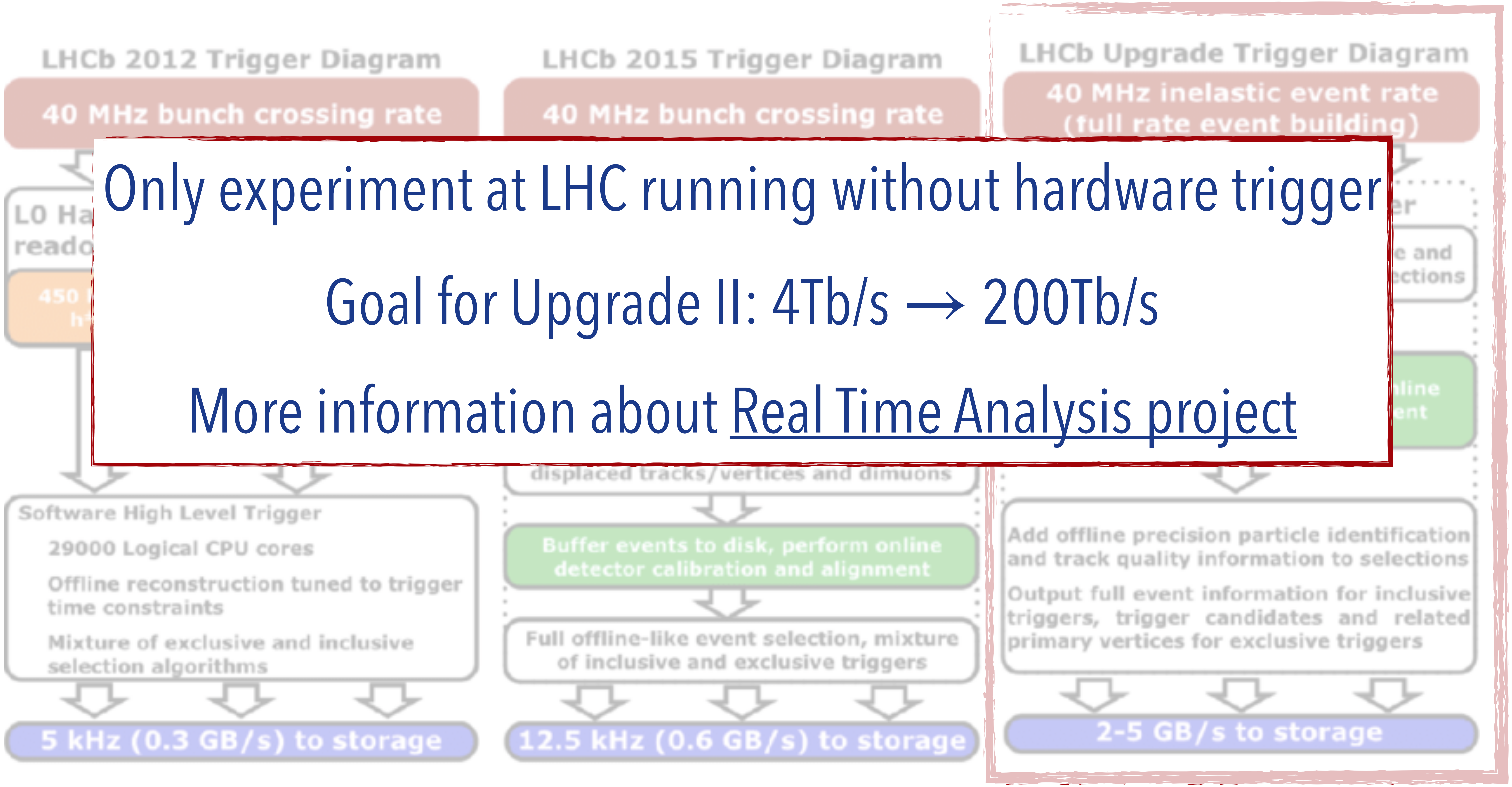


Only experiment at LHC running without hardware trigger

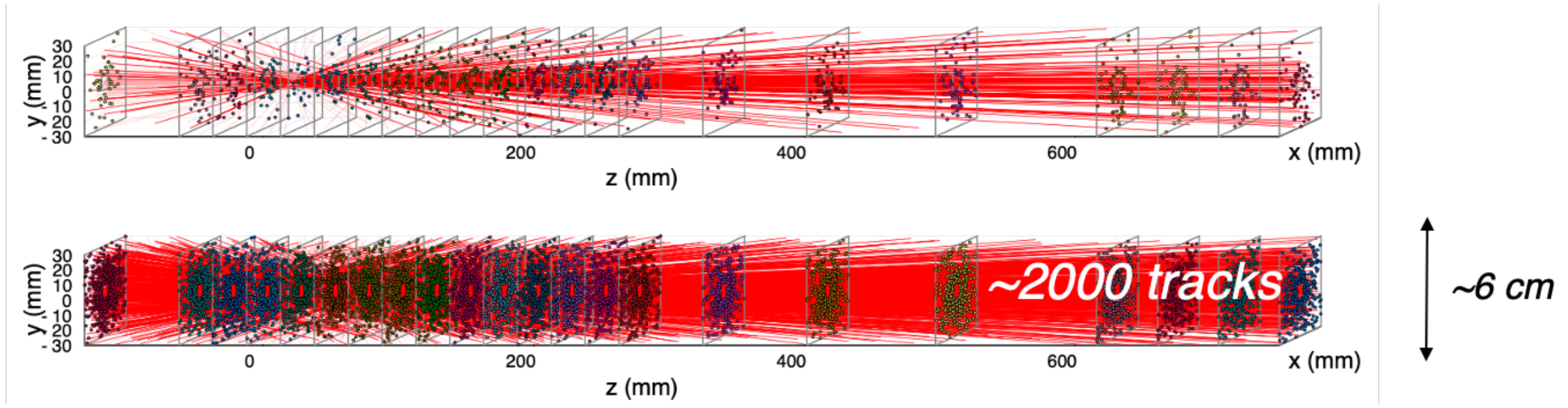
Goal for Upgrade II: 4Tb/s → 200Tb/s

More information about Real Time Analysis project

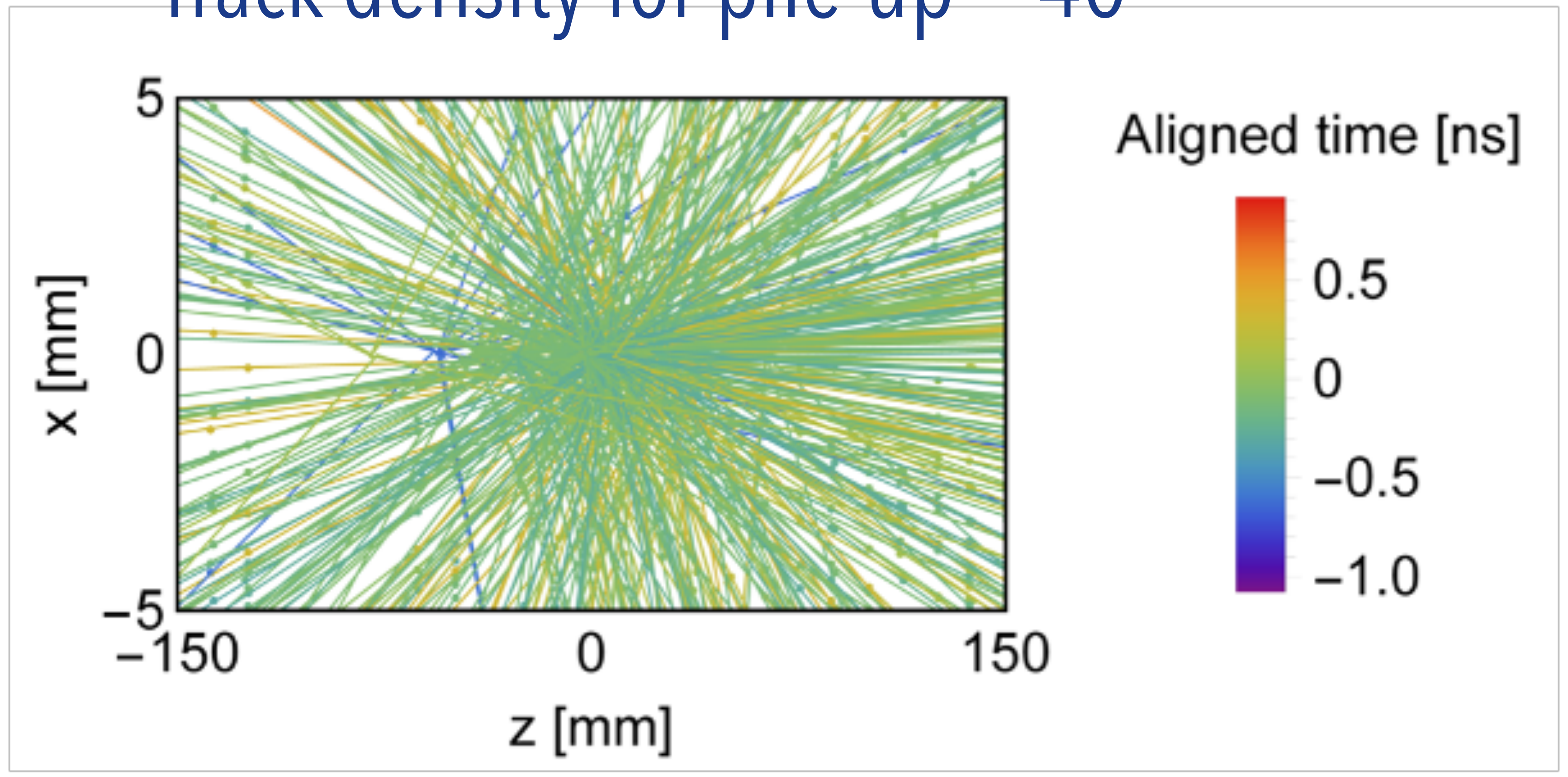
UPGRADE SCHEDULE

NEED FOR TIMING

- Let's have a look at VELO
- Run 3: pile-up ~6
- Upgrade II: pile-up ~42
- Closer look at PV region



Track density for pile-up ~40



Distinguishing PV ⚡

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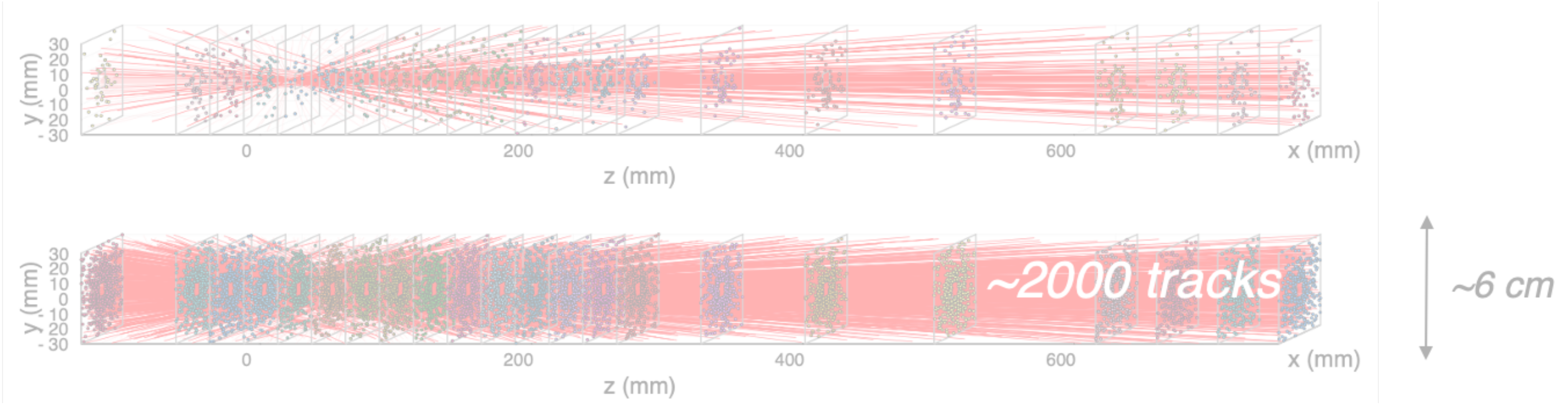

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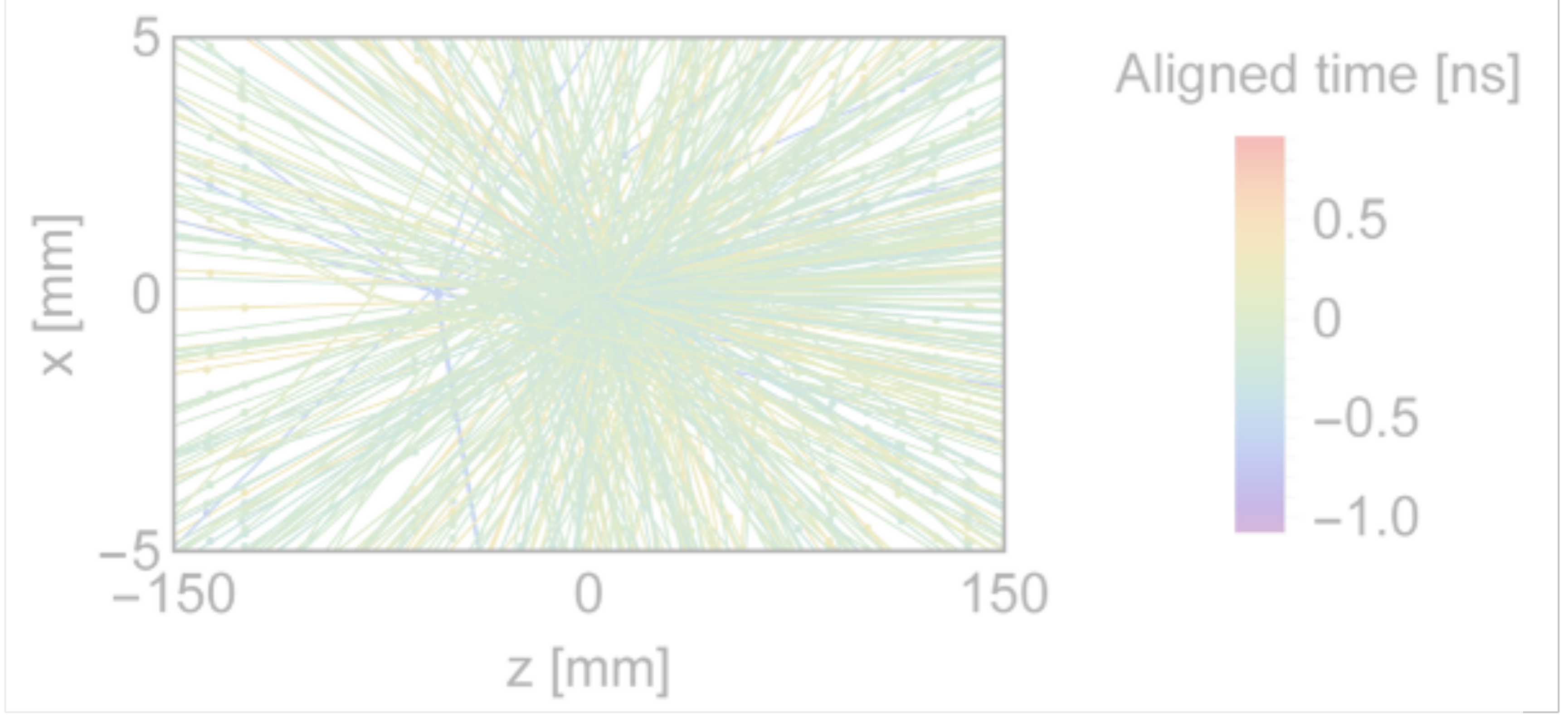
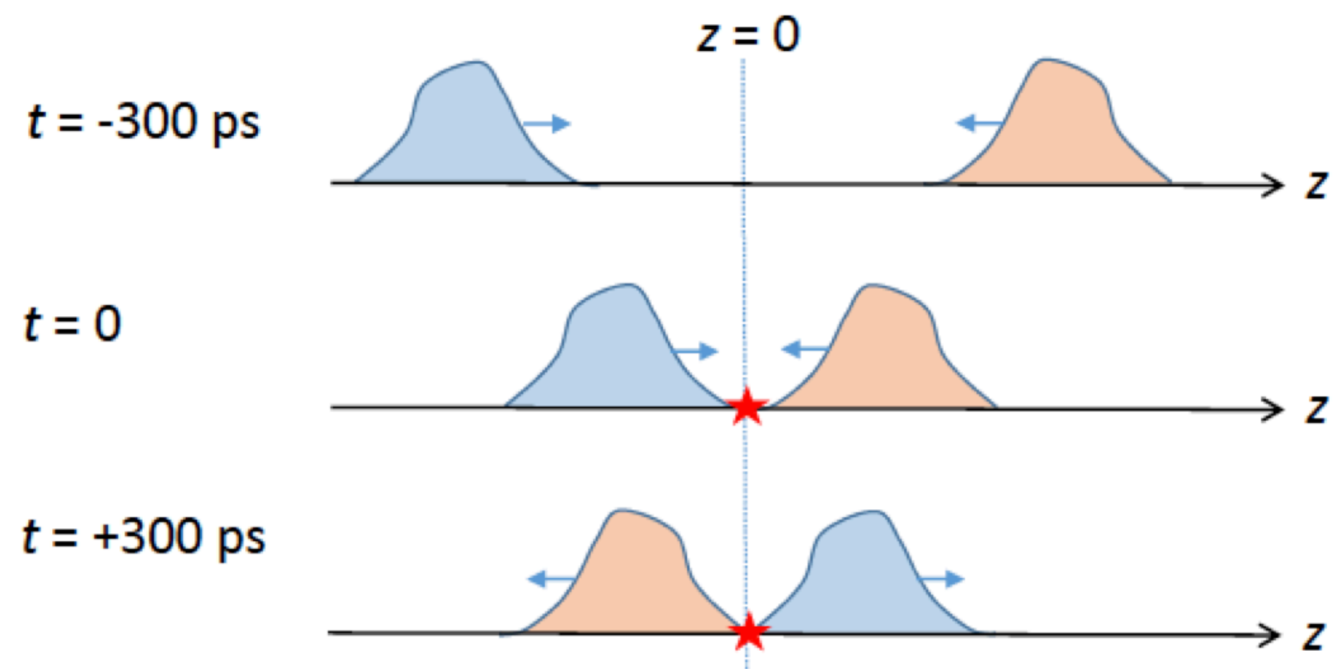


Distinguishing PV ⚡

PV happen to many different times



Example: interactions happening are at same *z* but separated by 300 ps in time

Make timing available

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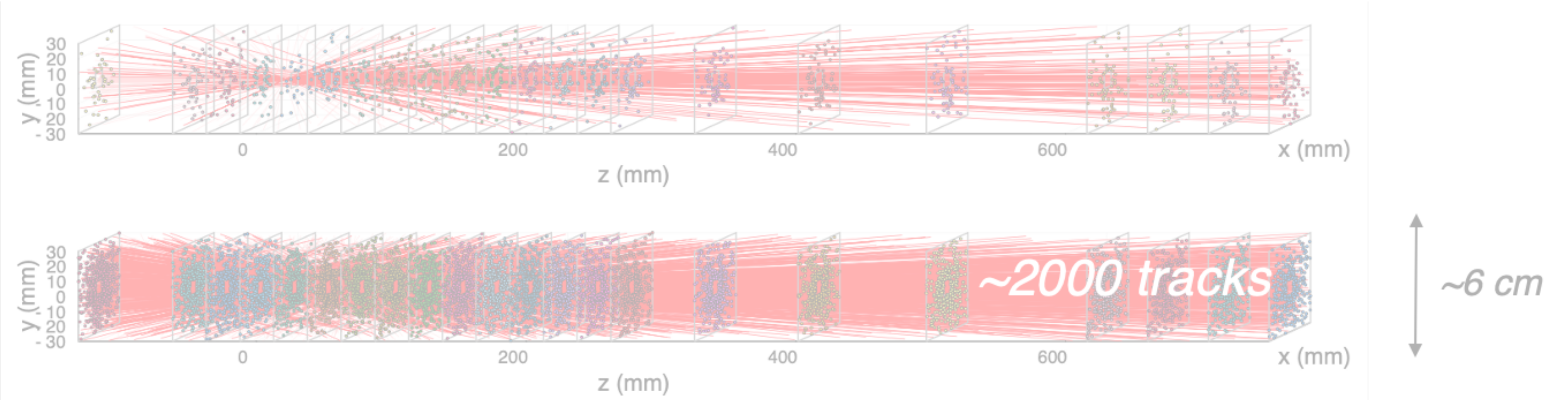

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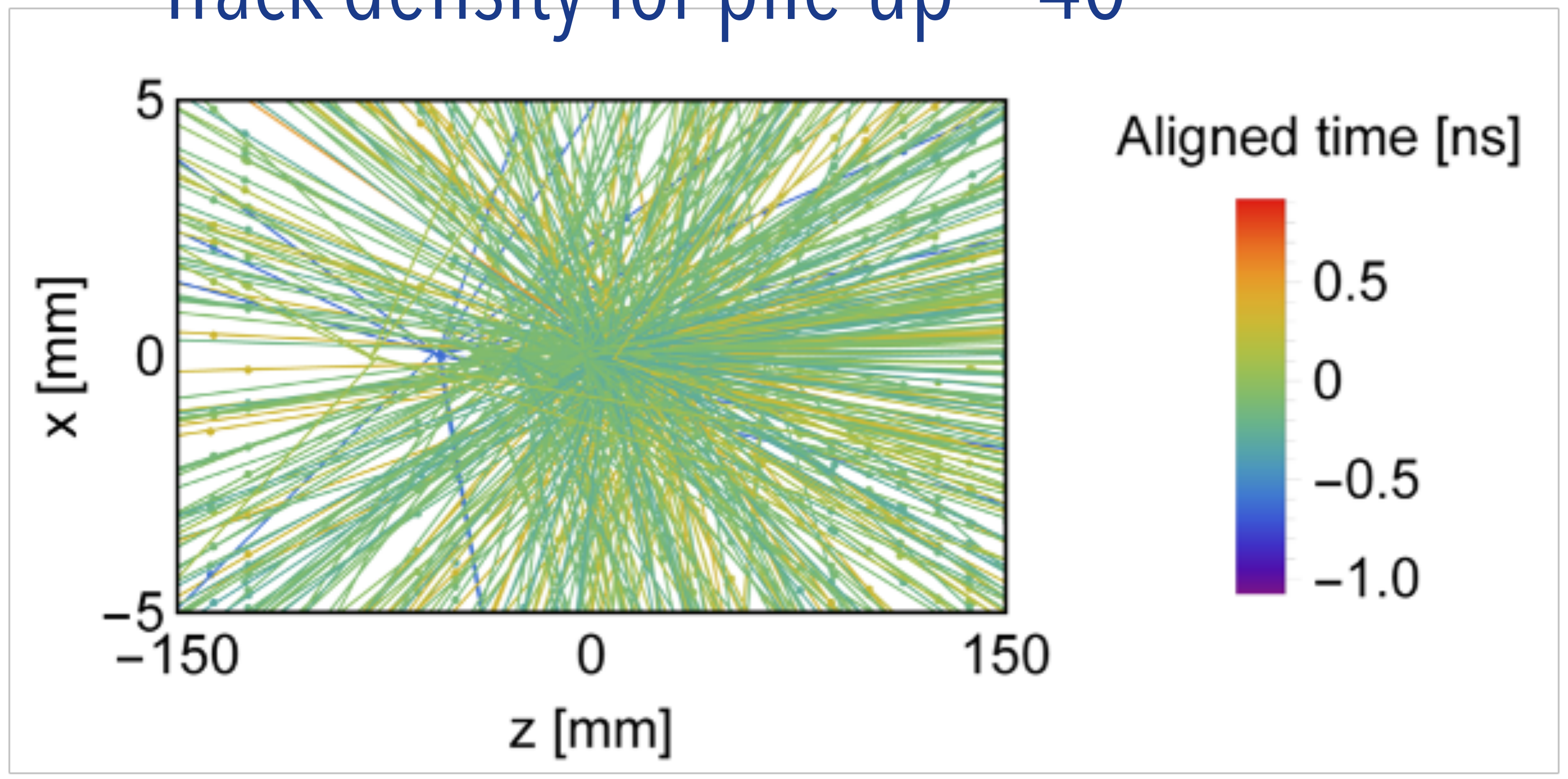
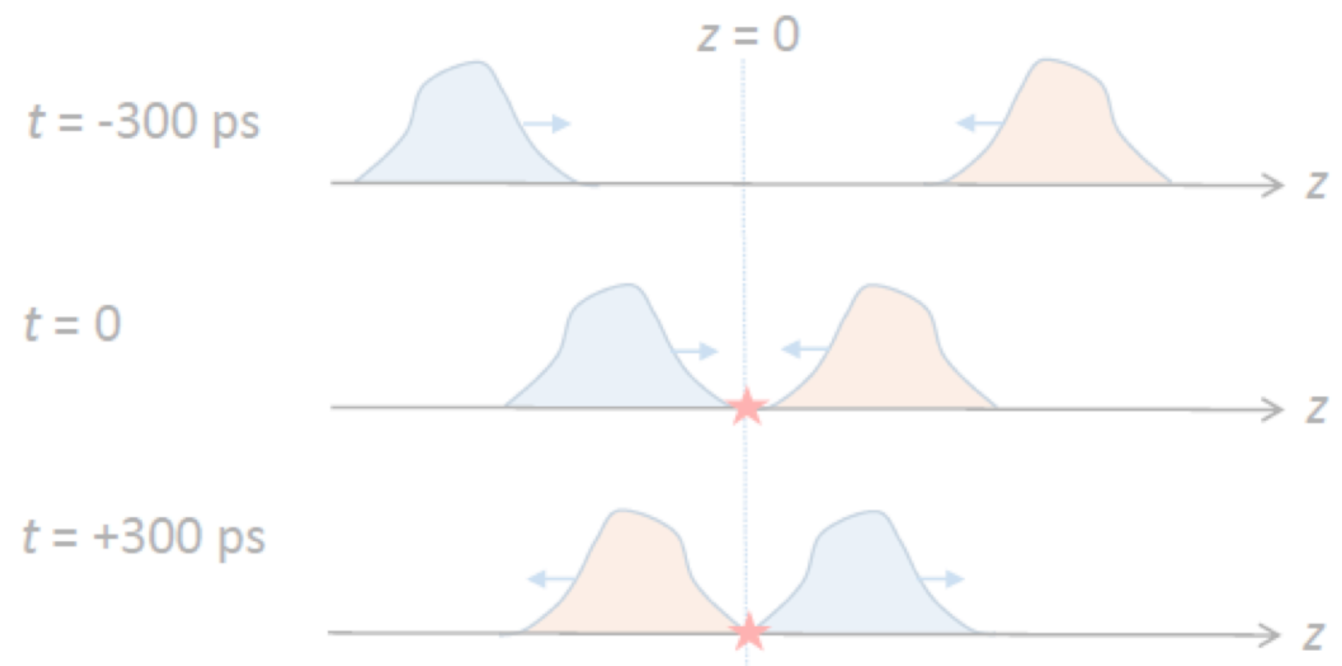


Distinguishing PV



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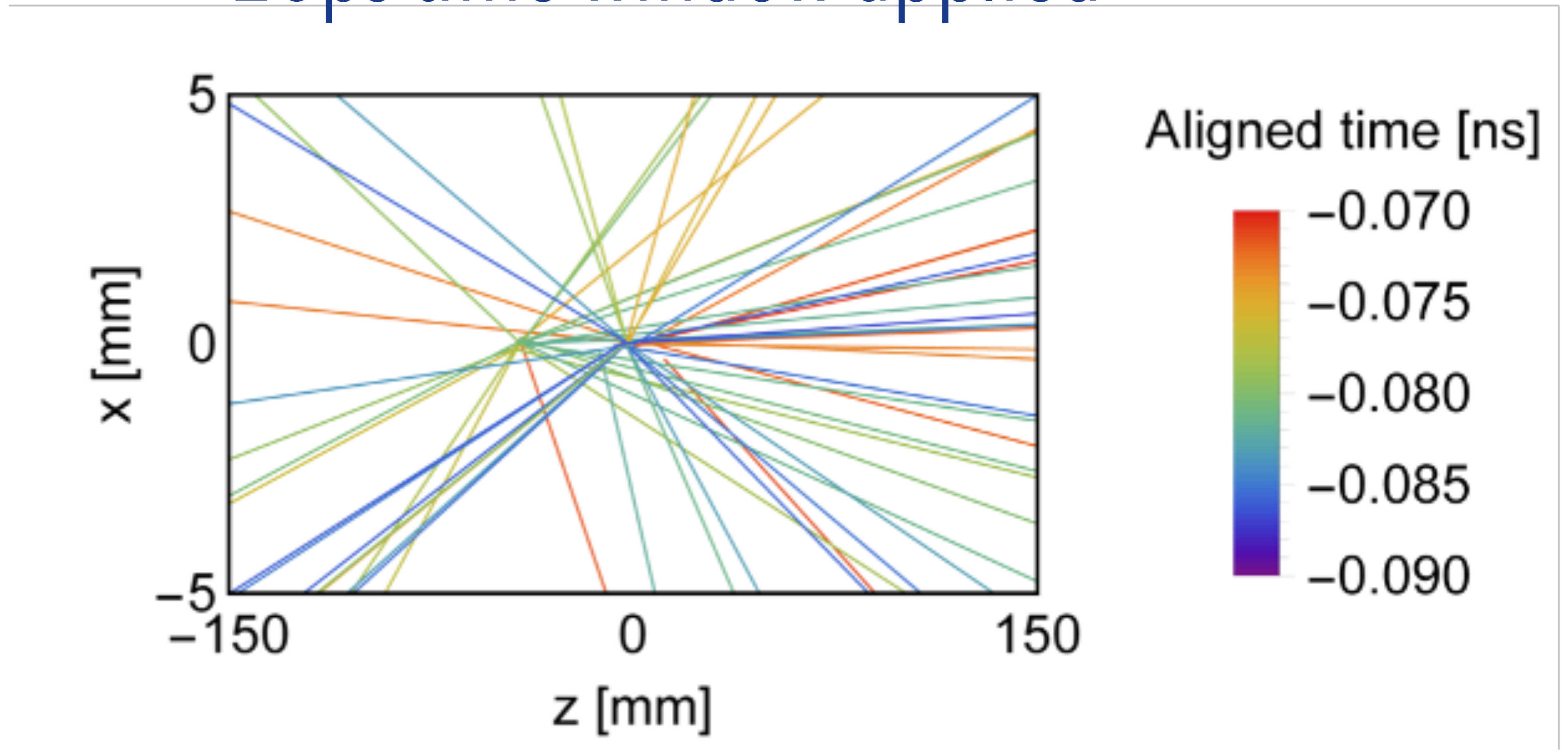
20ps time window applied



Distinguishing PV

NEED FOR TIMING

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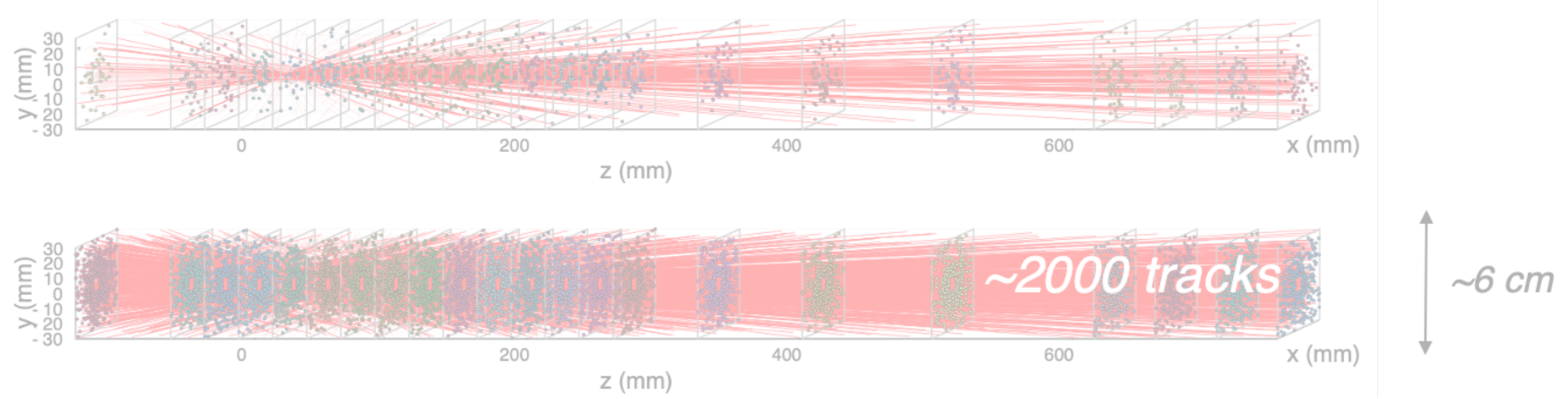
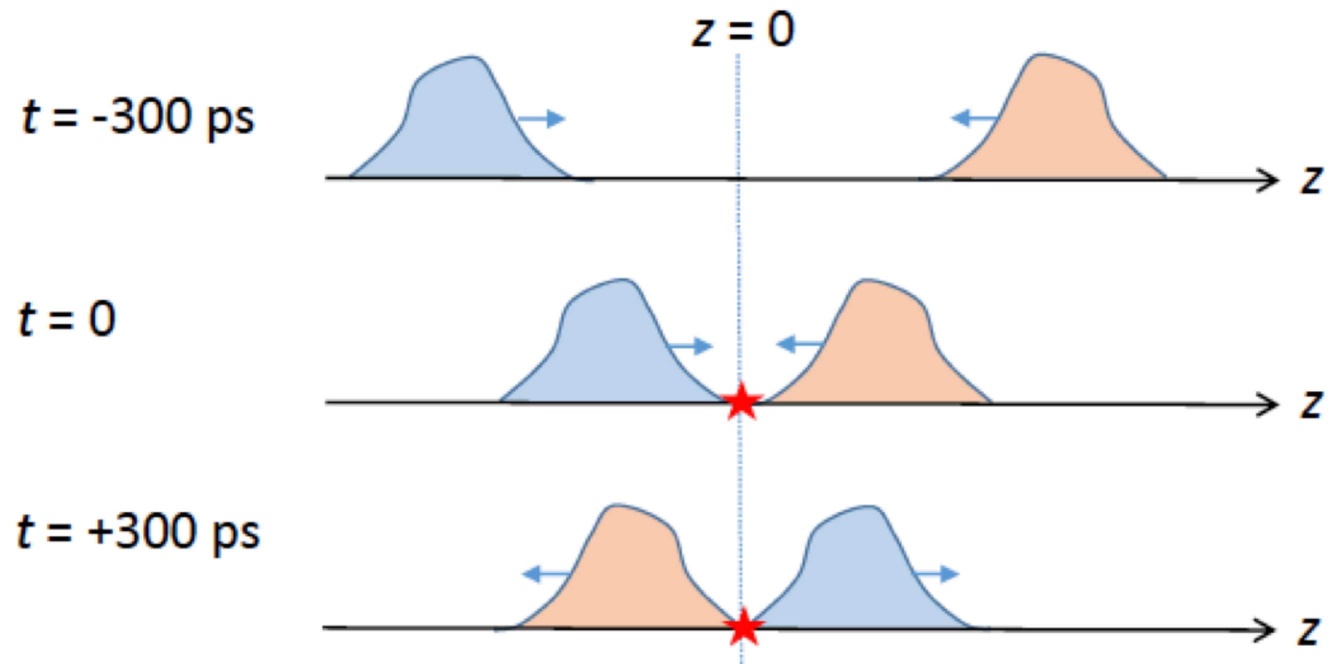
- Closer look at Calorimeter



→ overlapping CALO cluster due to pile-up

PV happen to many different times



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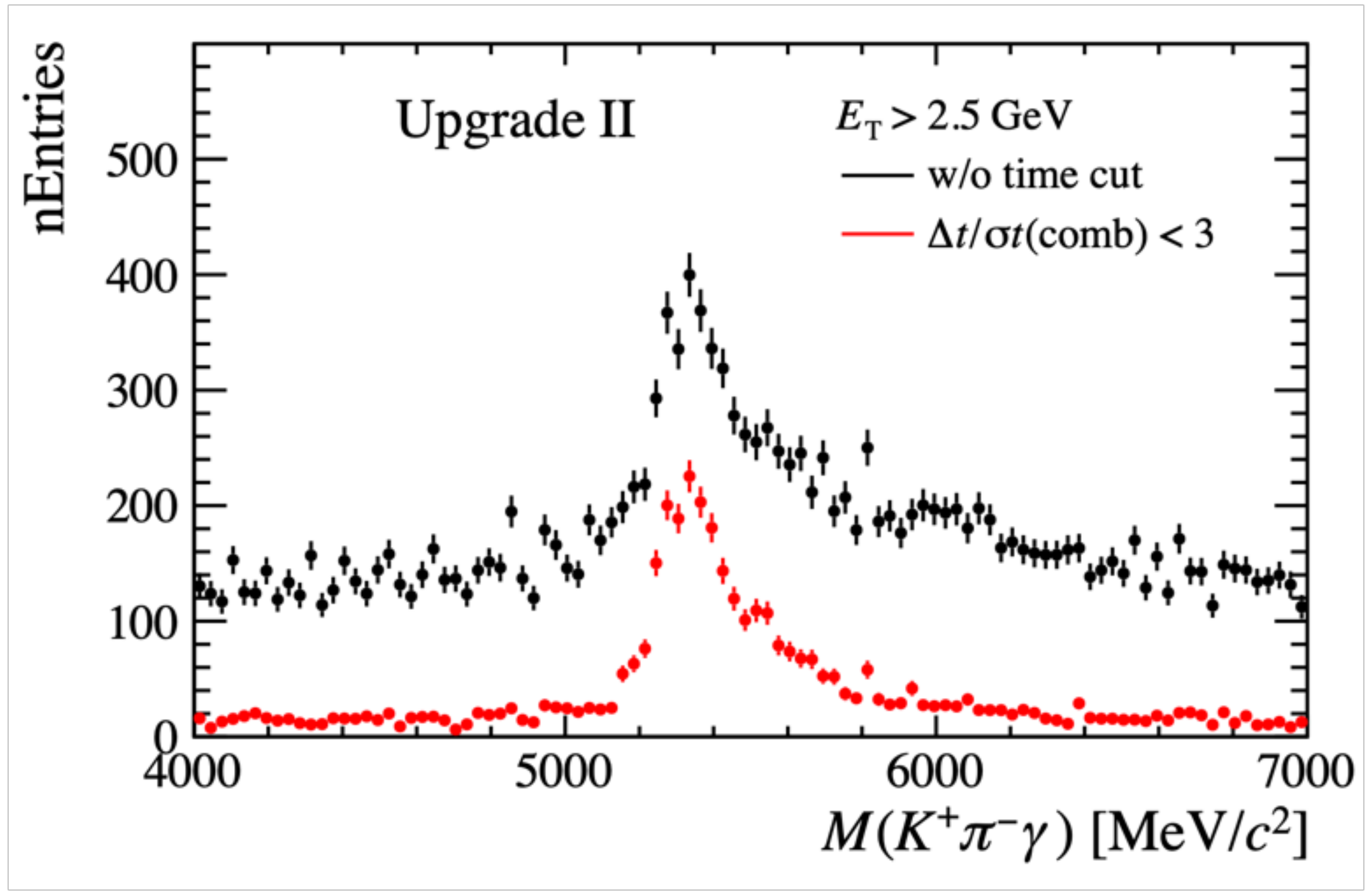
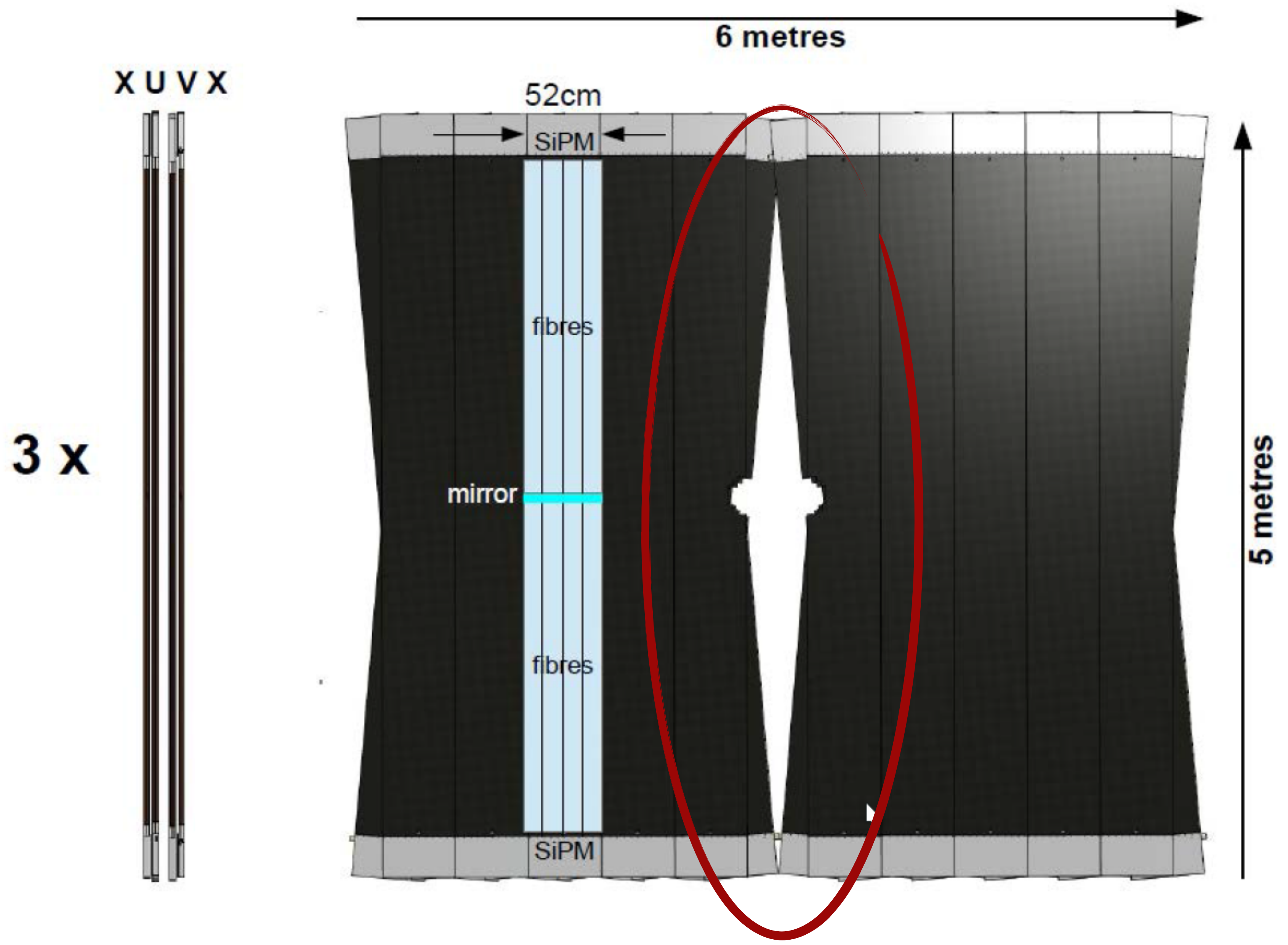


Precision timing in CALO
→ significant reducing of BKG

UPGRADE Ib

- Motivation: opportunity to test Upgrade II technology under real conditions
- Reuse of designs and part of Upgrade II budget, but independent of approval
- Some exchange needed due to radiation damage



SciFi replacement of the inner modules

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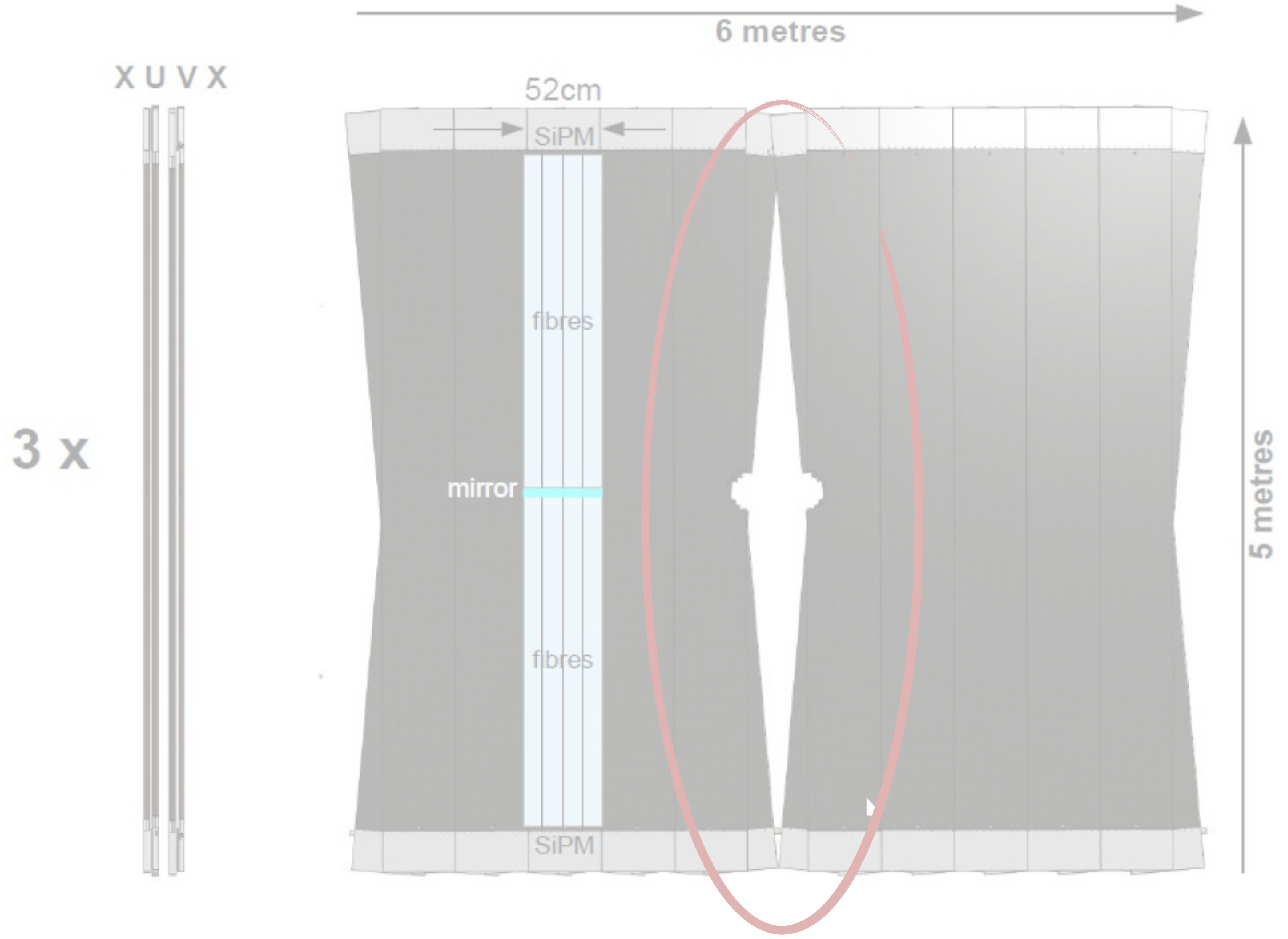

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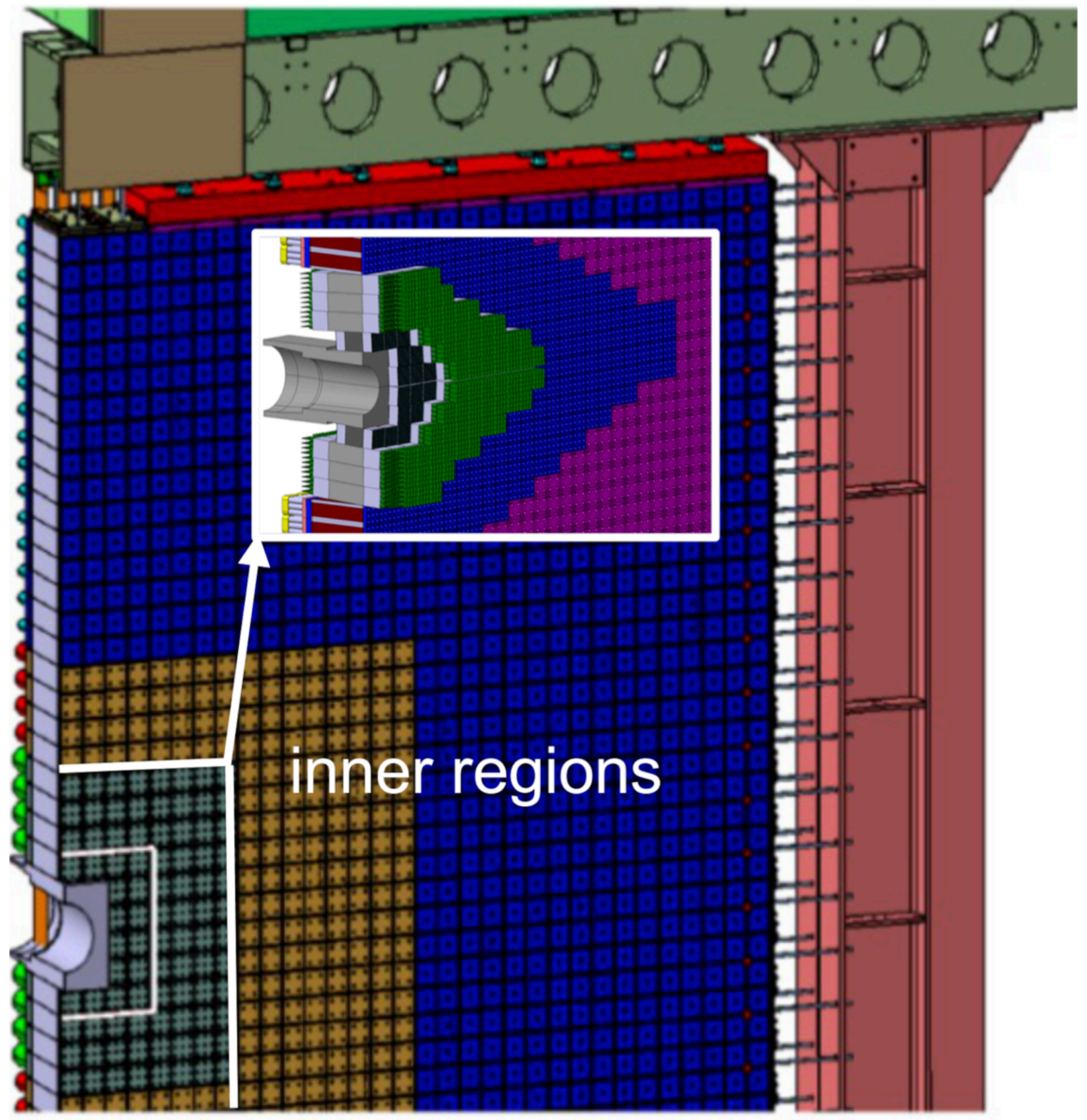
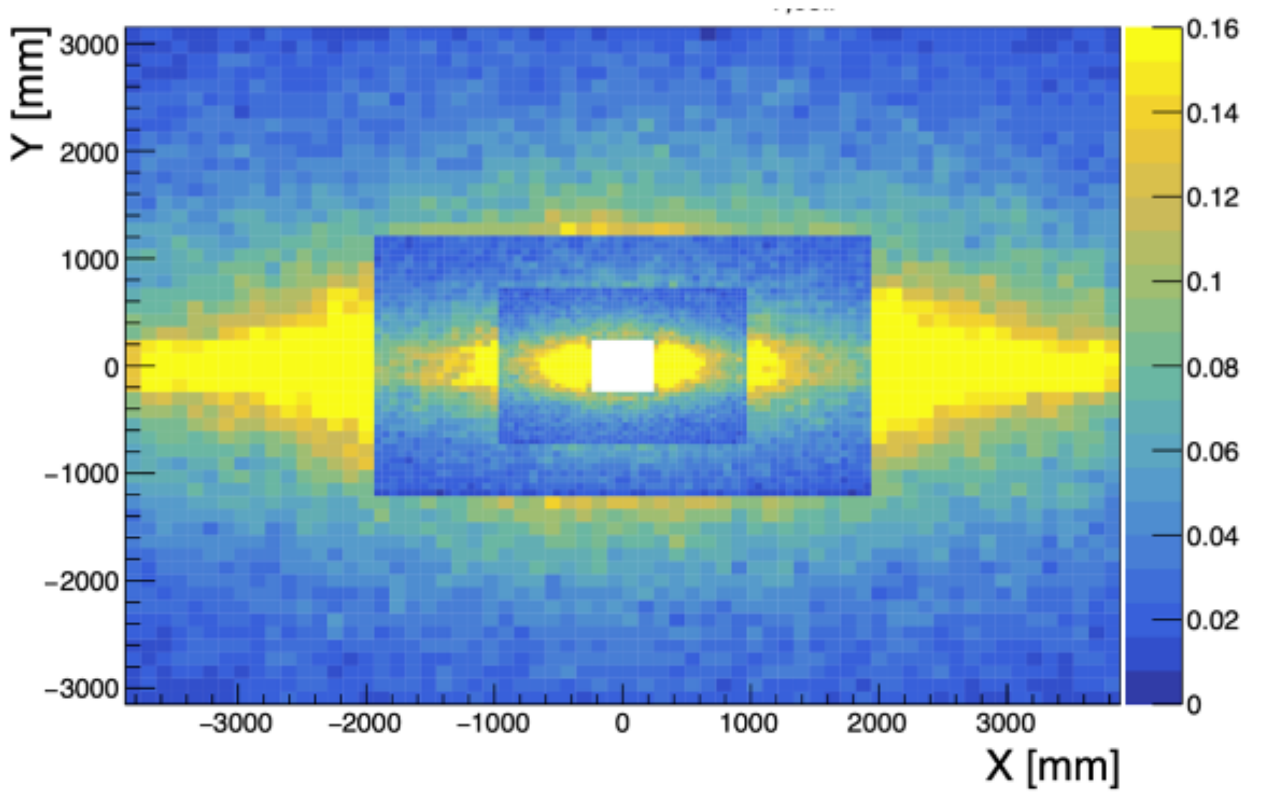
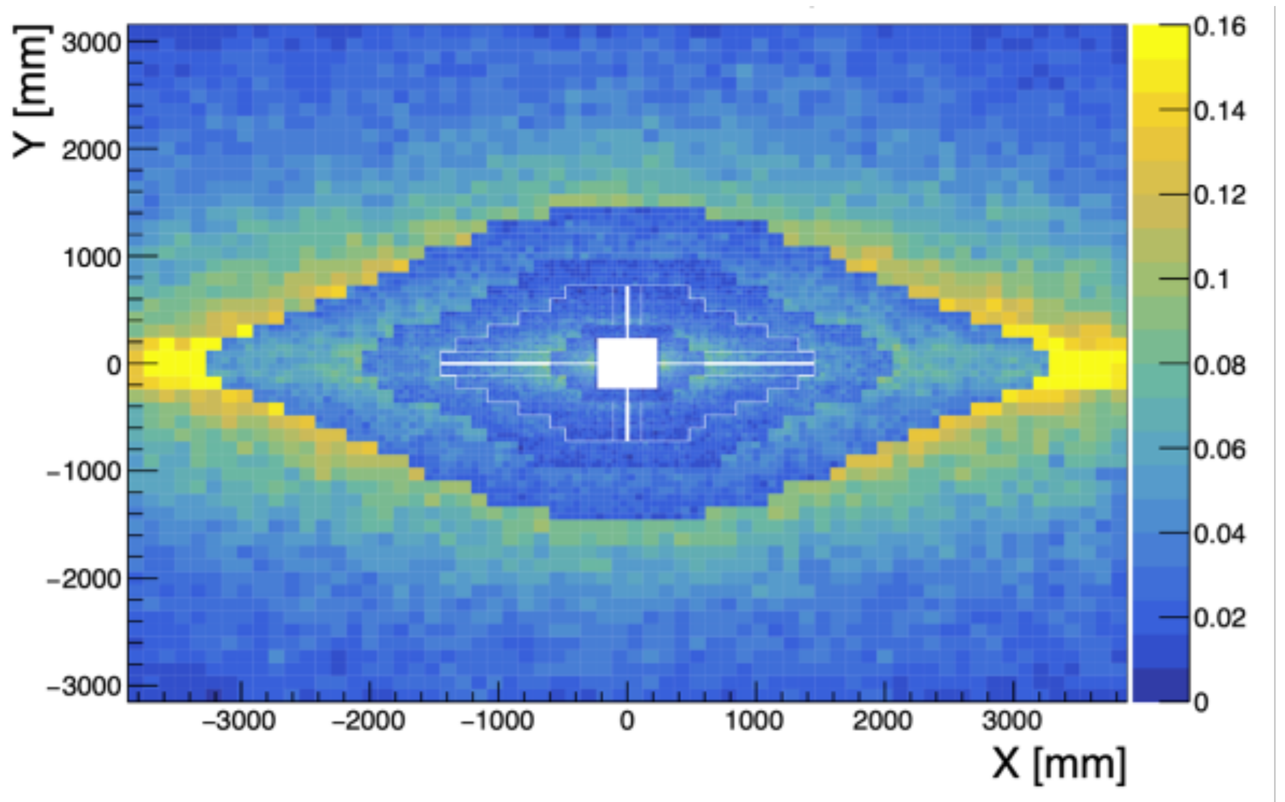


ECAL exchange inner region with new SpaCal technology



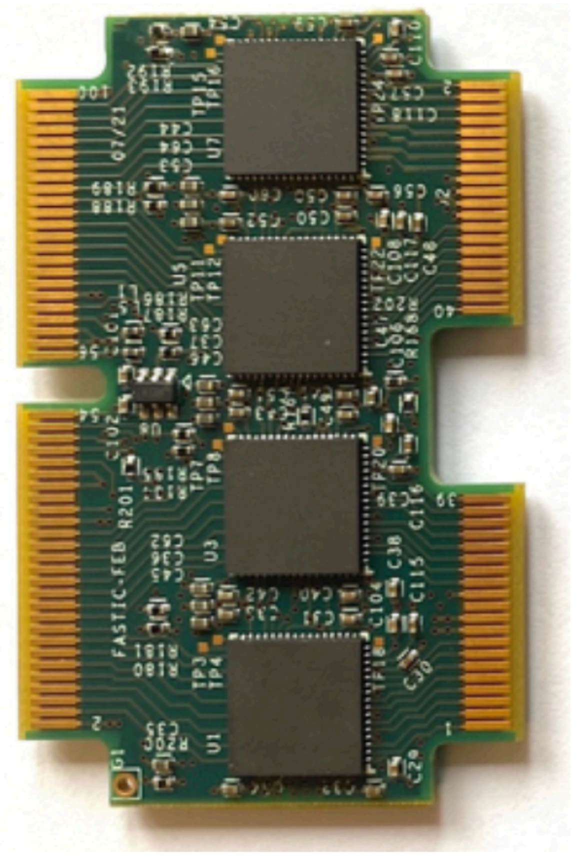
Run 3



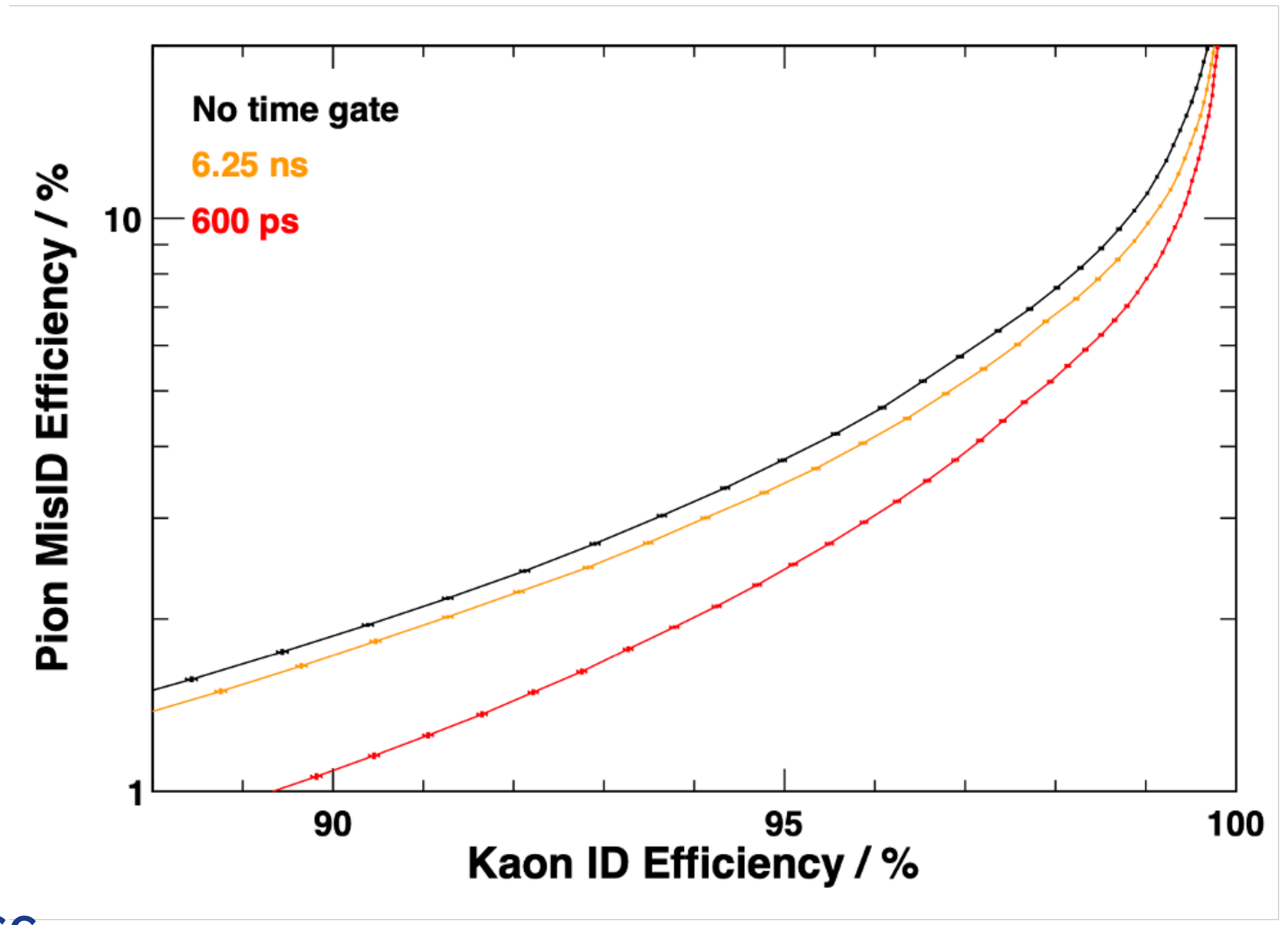
Run 4

UPGRADE Ib - TECHNOLOGY

- Same overlap problem for Cherenkov rings
  - → fastRICH ASCI ~25ps resolution
  - → apply time window gate



RICH electronics with timing



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- Same overlap problem for Cherenkov rings
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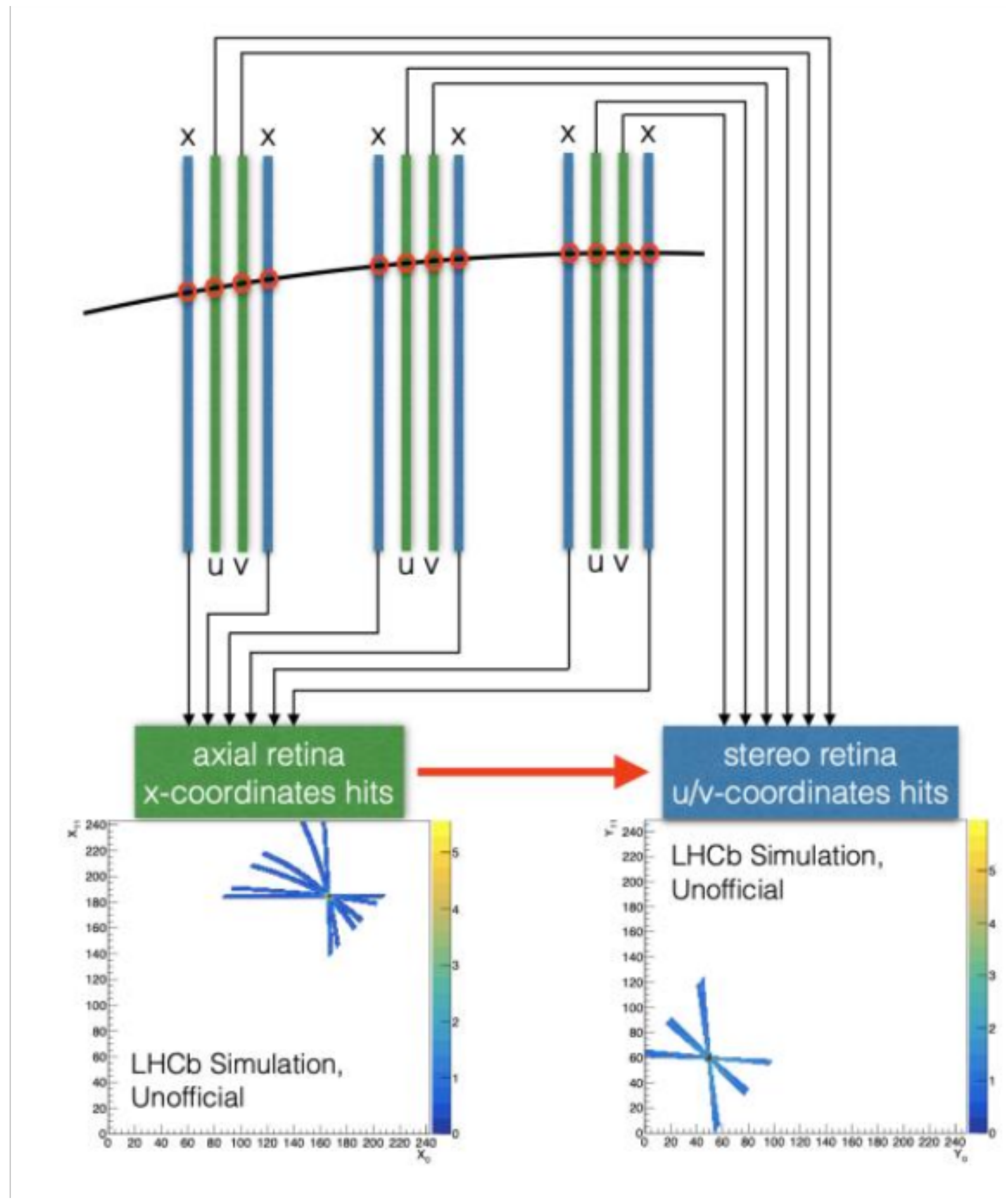
- Run for downstream cluster & track reconstruction on FPGA
  - → done for Run3 VELO clusters
  - → downstream tracking at 30MHz
  - → frees resources

Downstream tracking with RETINA



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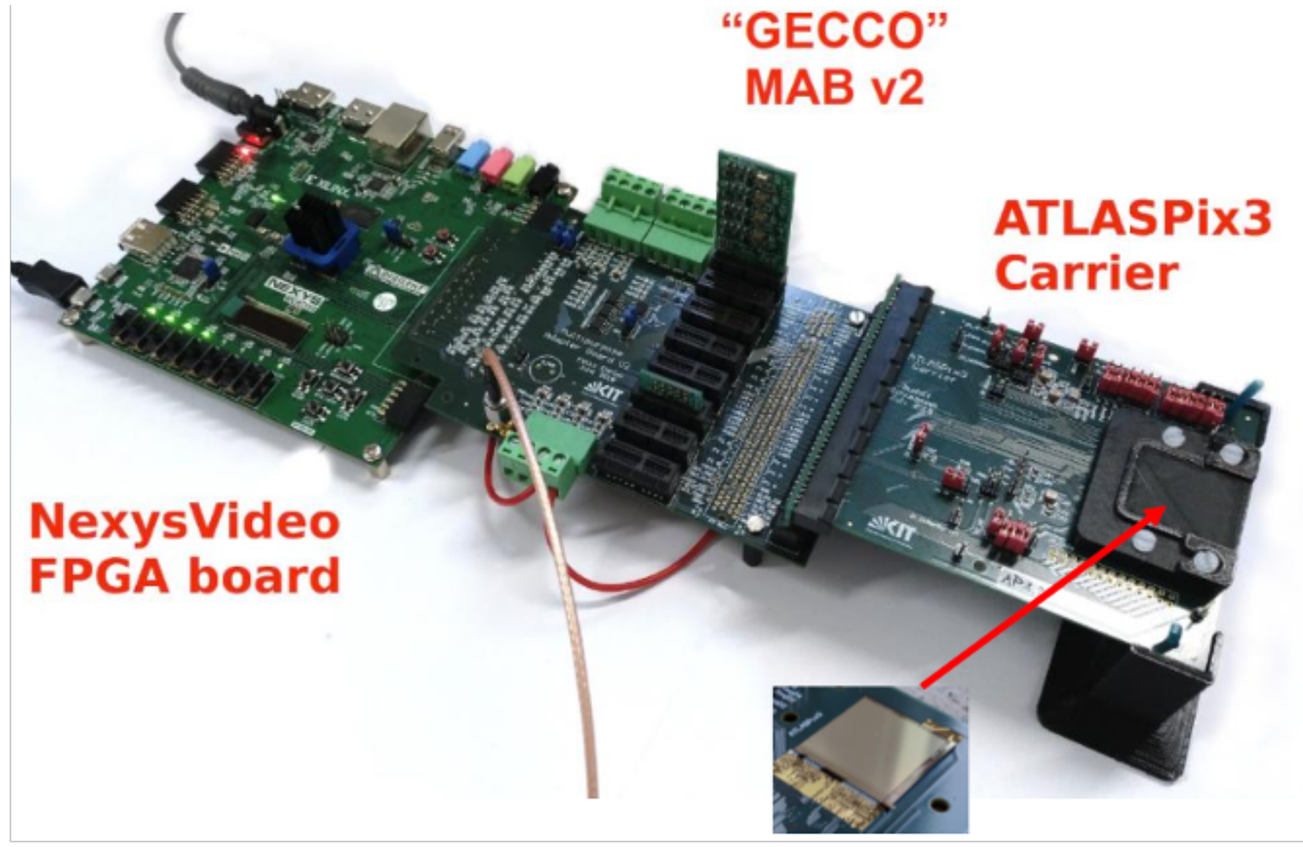
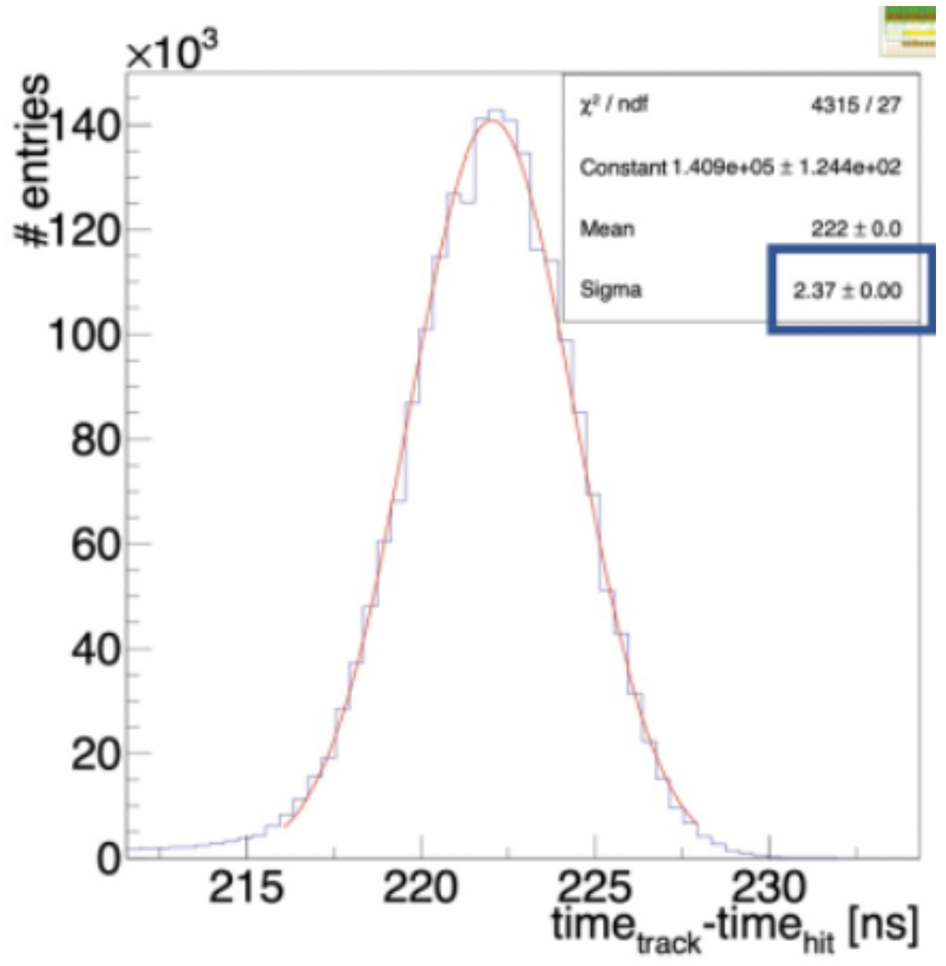
- Monolithic Active Pixel sensors (MAPS)
  - → needed radiation hardness and granularity
  - → include 2 first layers with 1m^2 surface



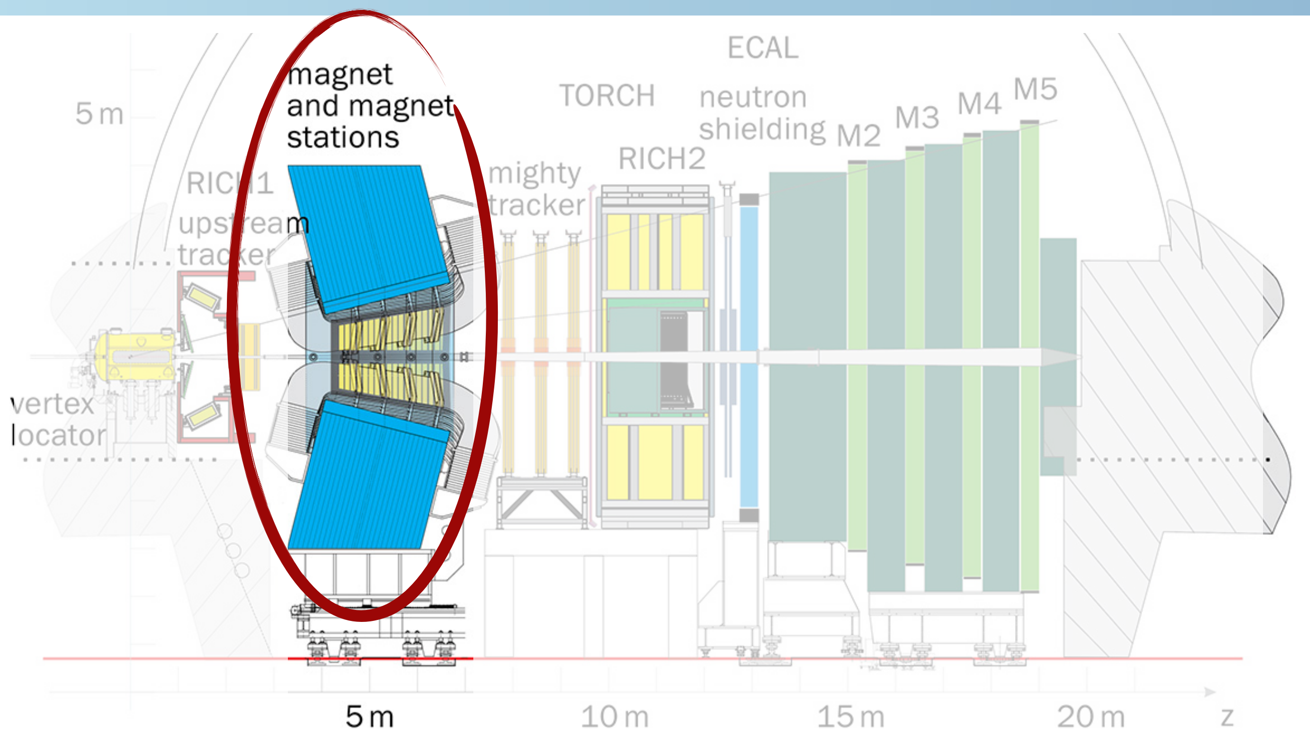
ATLASPix3

→ MightyPix1

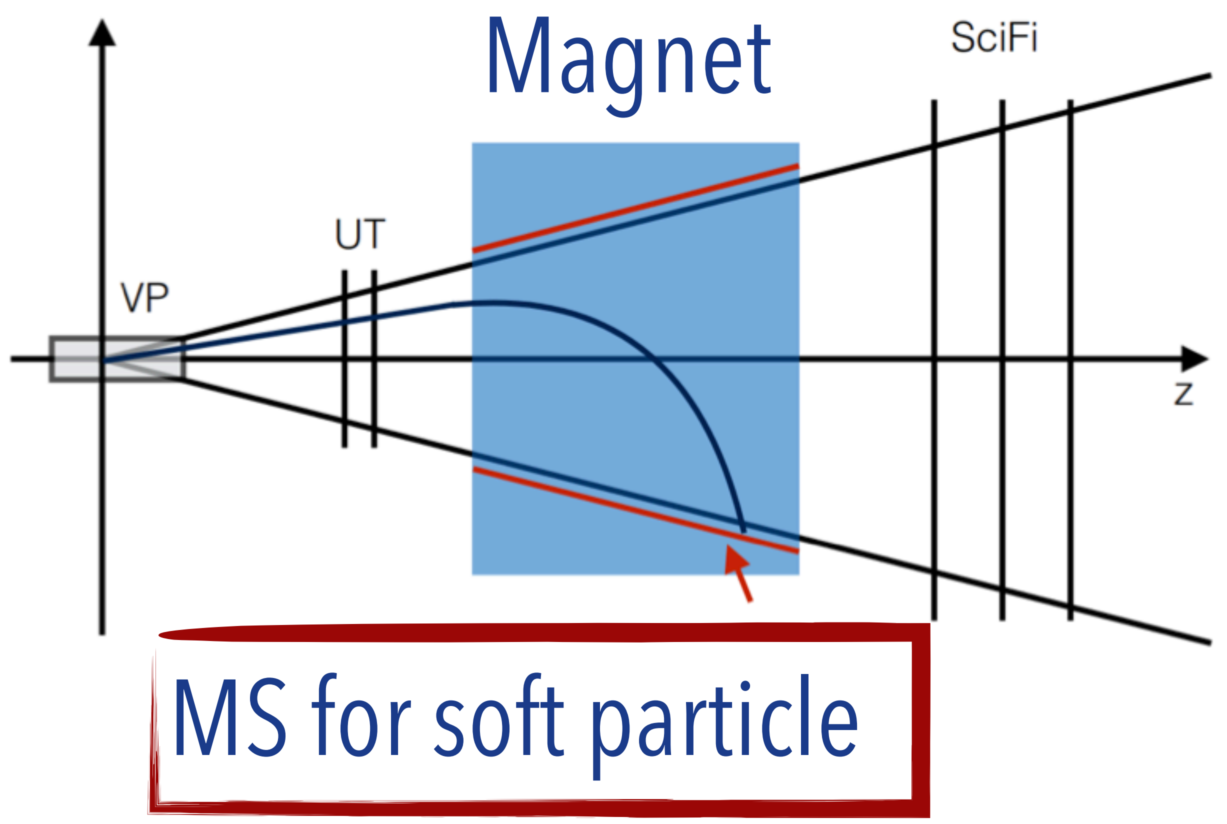


Great resolution 2.37+/– 0.00

UPGRADE Ib - MAGNET STATIONS



- Soft particles bend out of acceptance
- Example soft π^- from $\Lambda_b^0 \to J/\psi\Lambda(\to p\pi^-)$
- Magnet stations as solution



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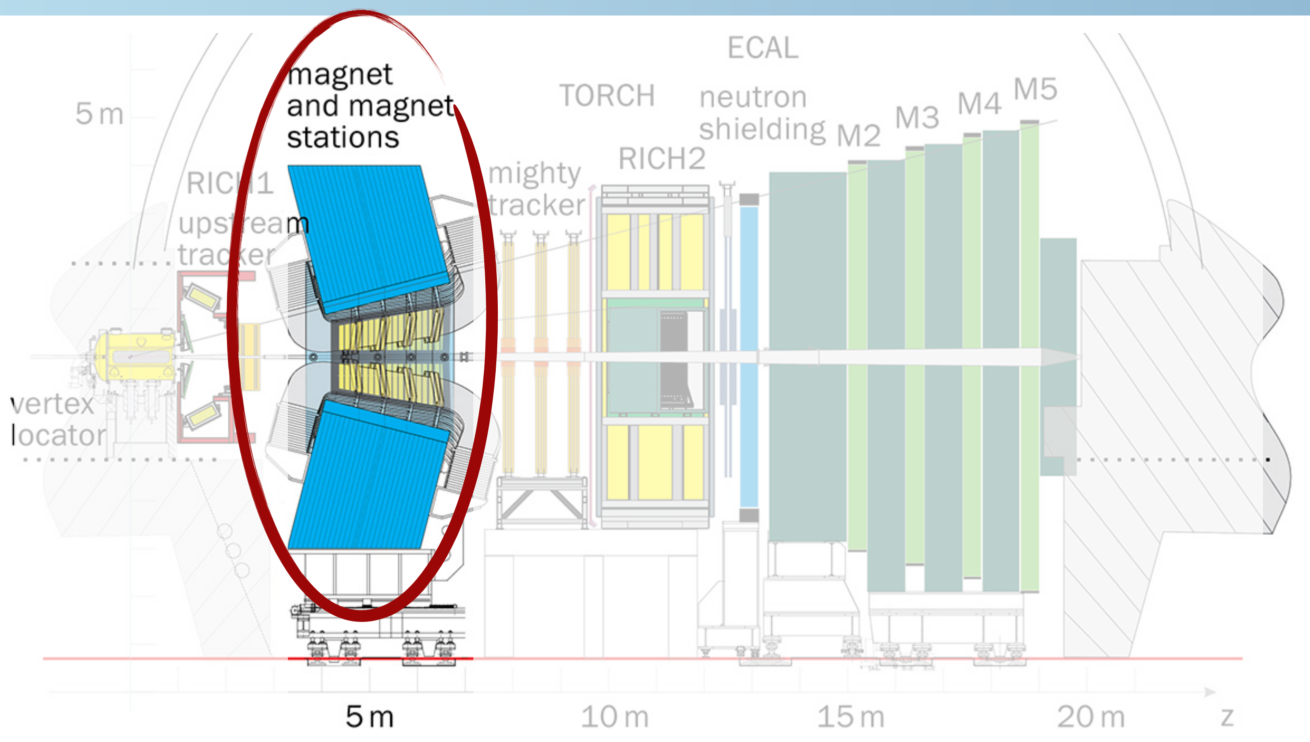

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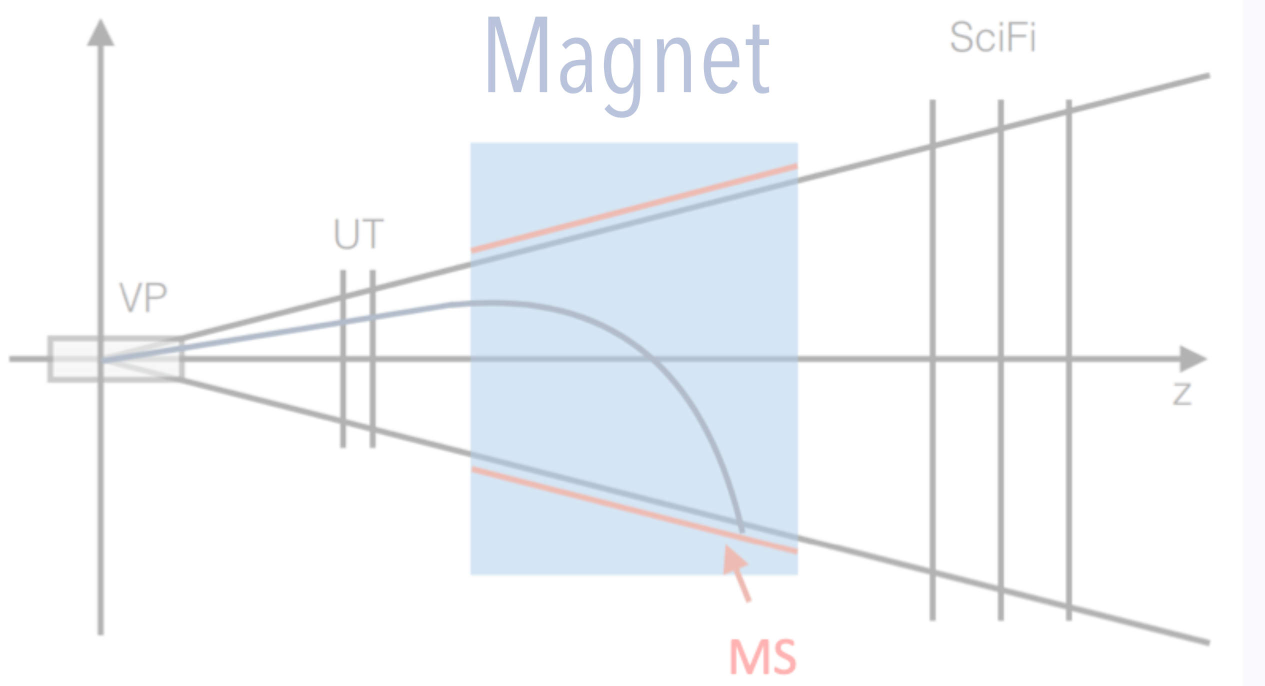

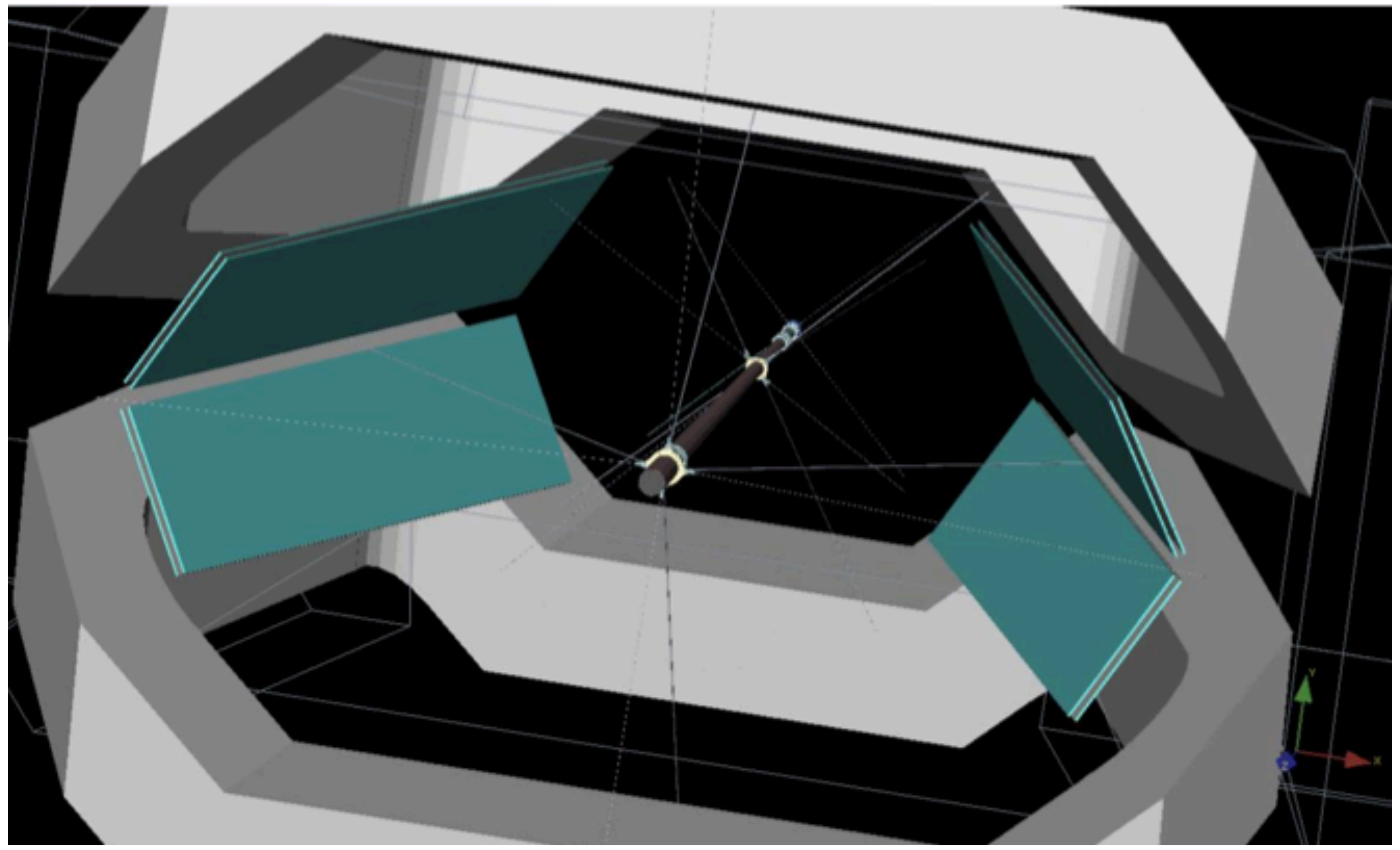

- Scintillators inside magnet (4layers each)
- Photomultiplier outside
- Horizontal ~O(1mm) vertical ~O(10cm)

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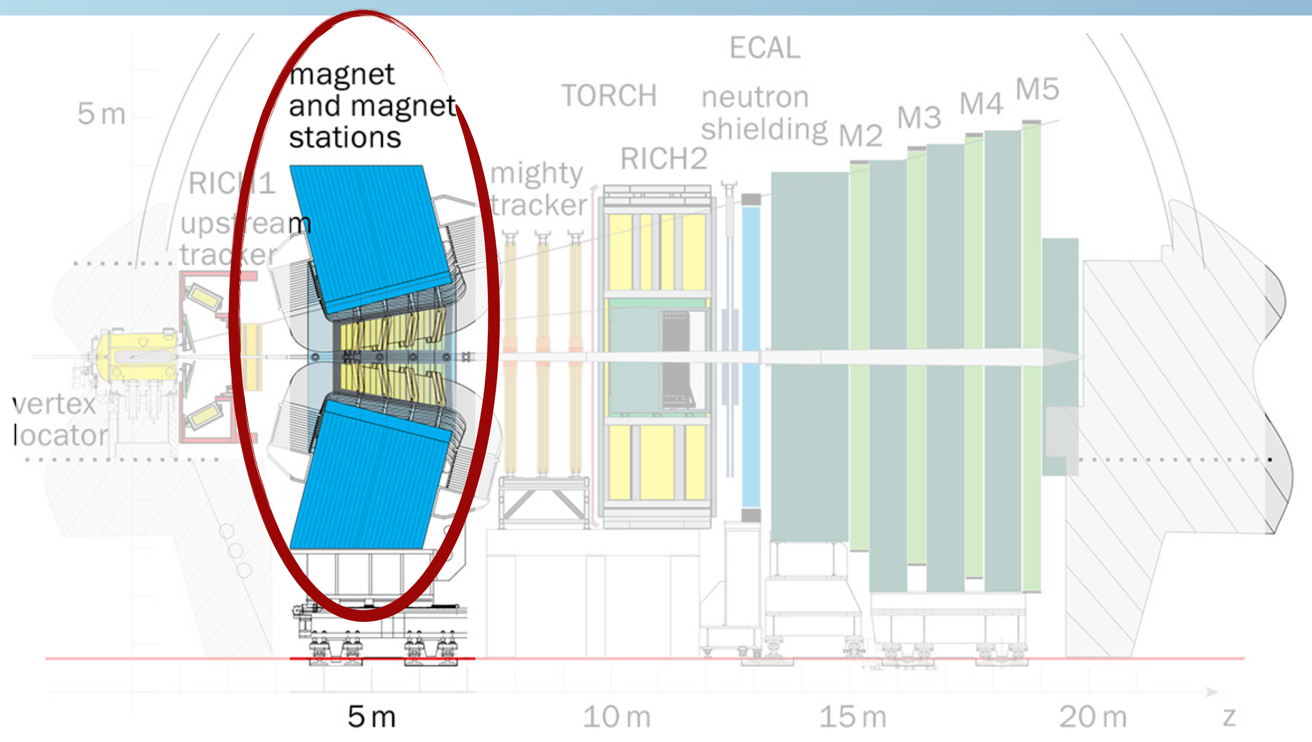

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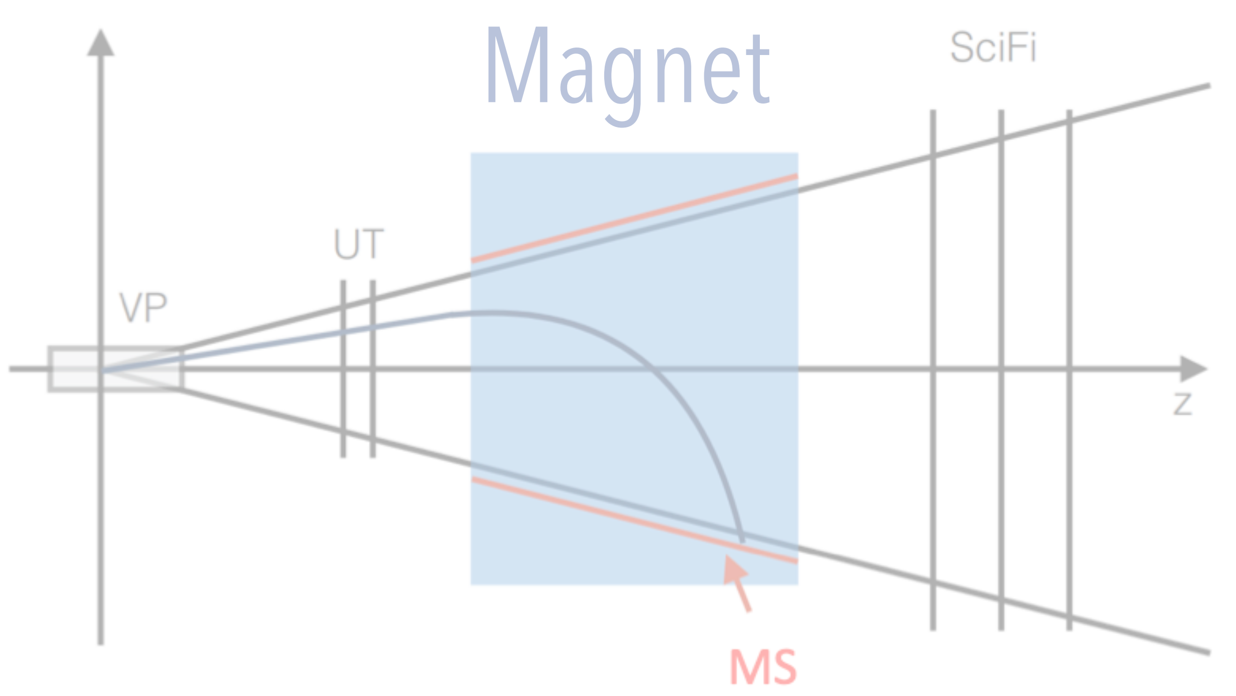

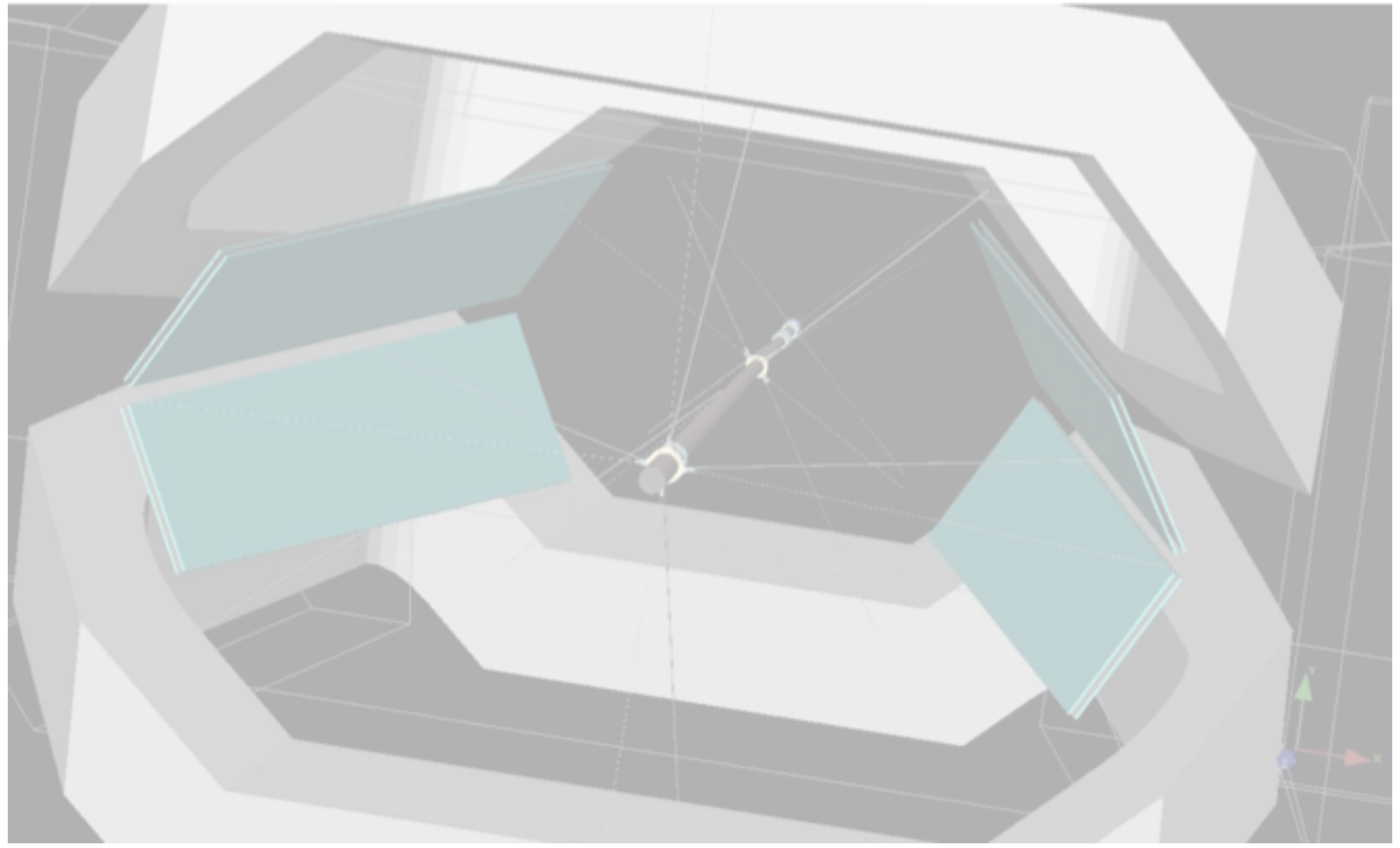

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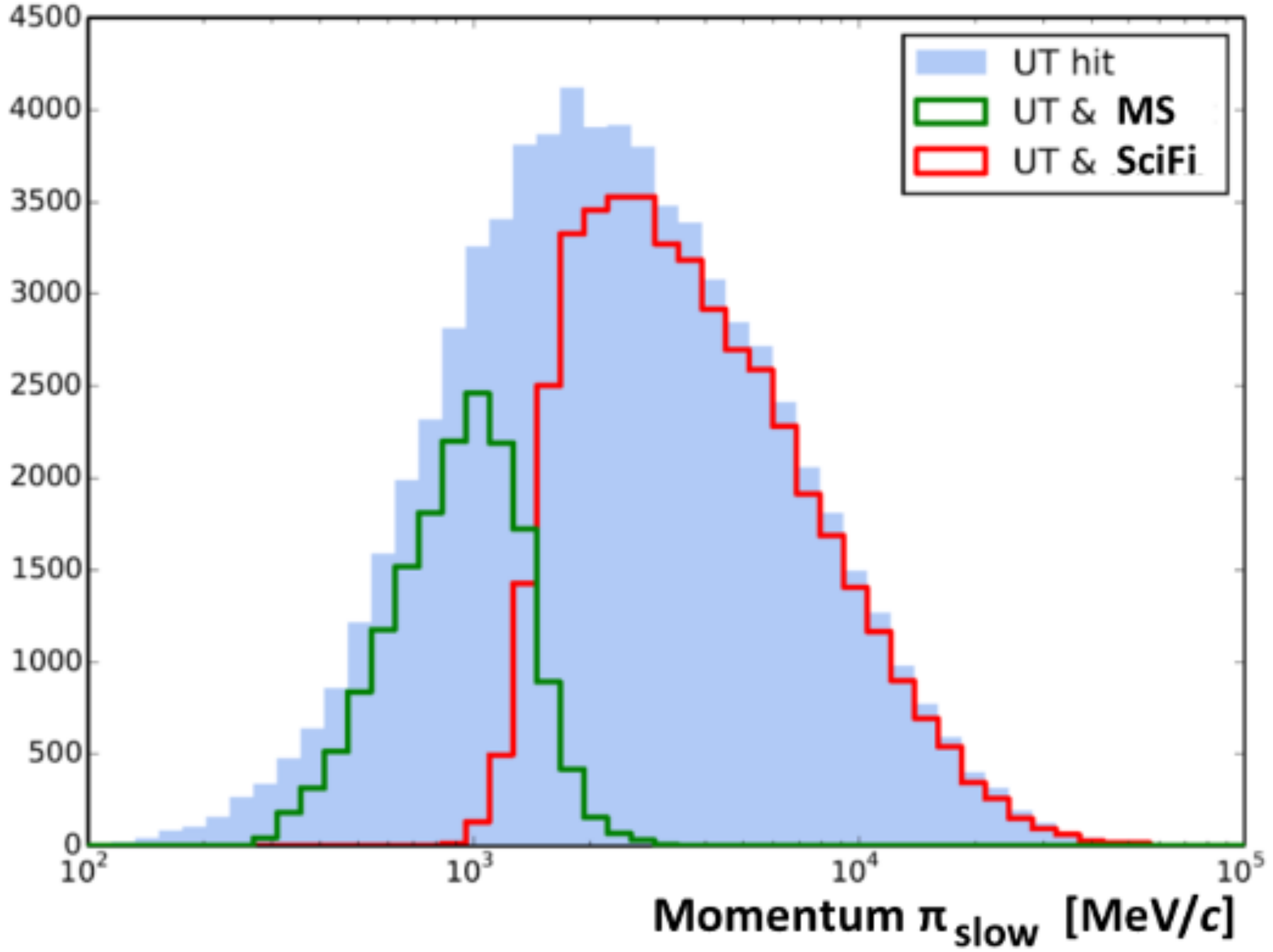
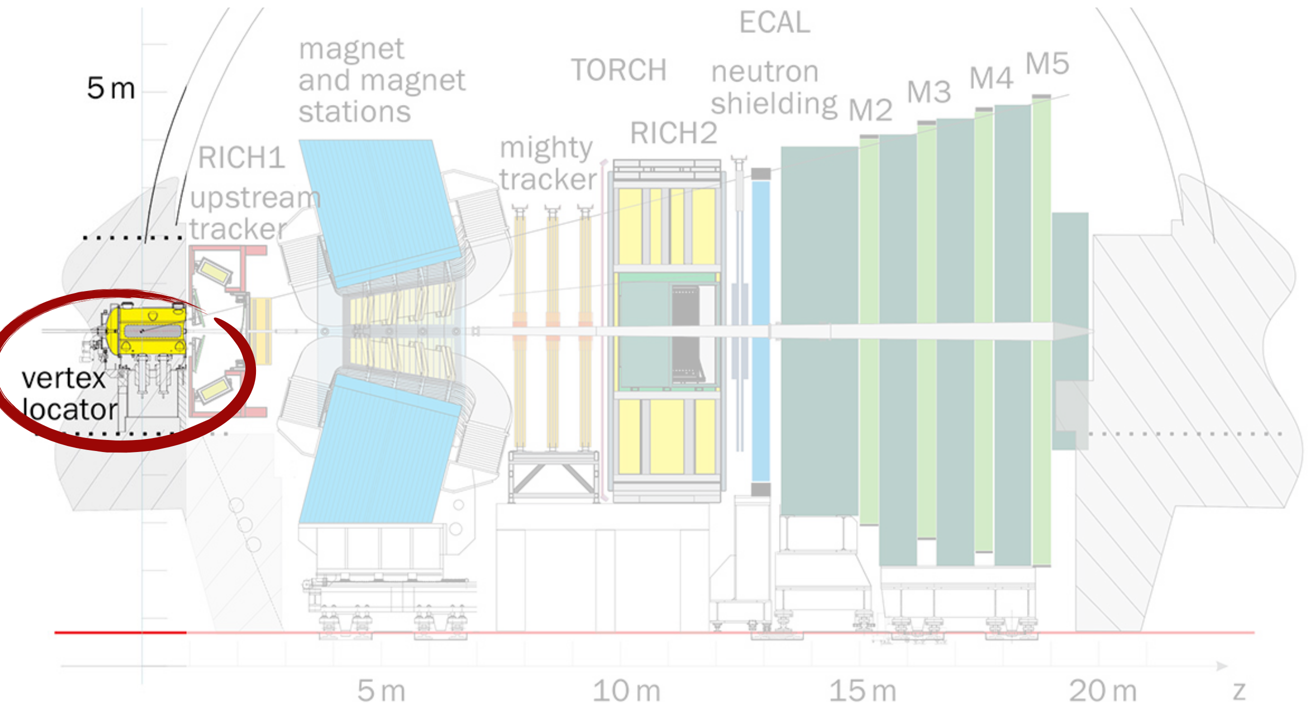
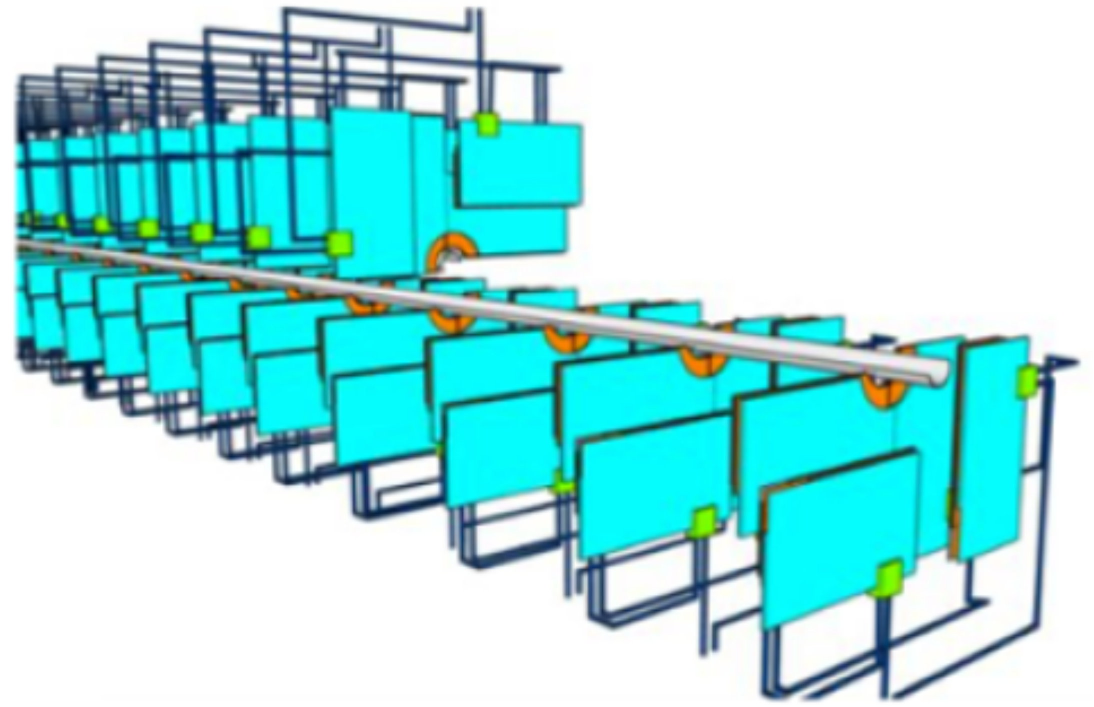
- Horizontal ~O(1mm) vertical ~O(10cm)

Significant improved p resolution



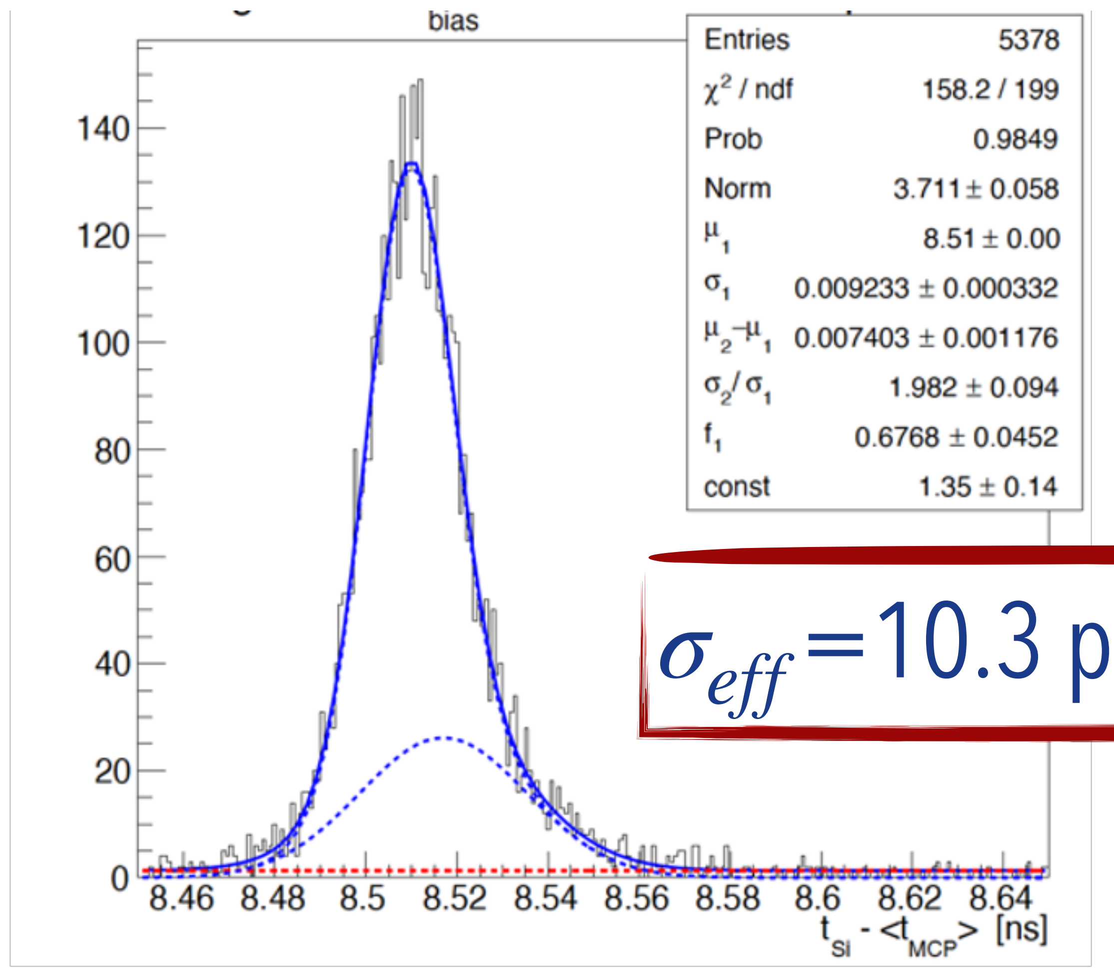
VELO





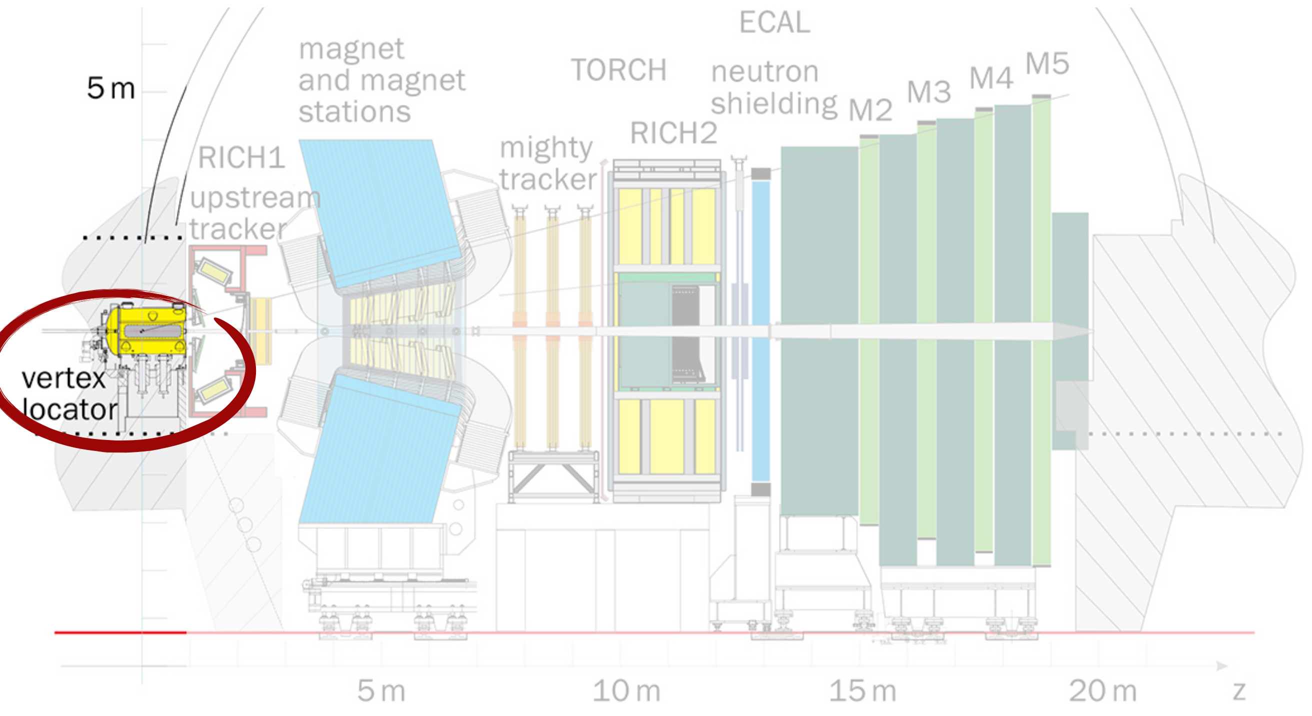
- VELO based on pixel for high granularity : 3D sensor with 28nm thickness
- New RF foil
- Add timing

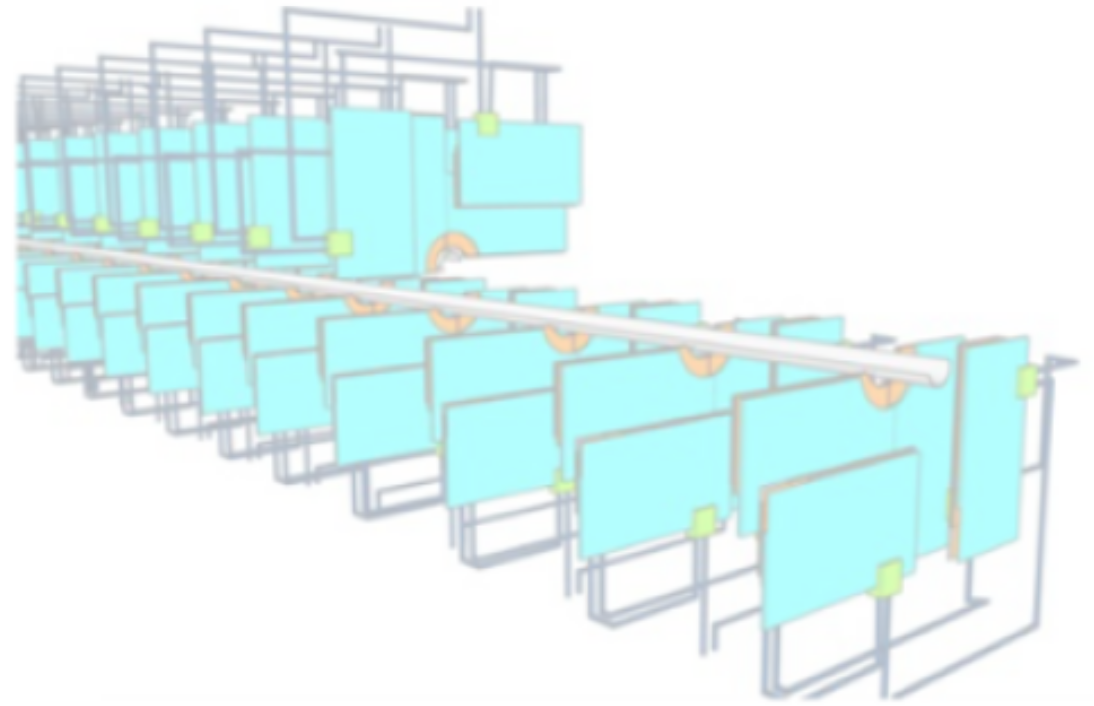
After irradiation with $2.5 \times 10^{16} n_{eq} cm^{-2}$



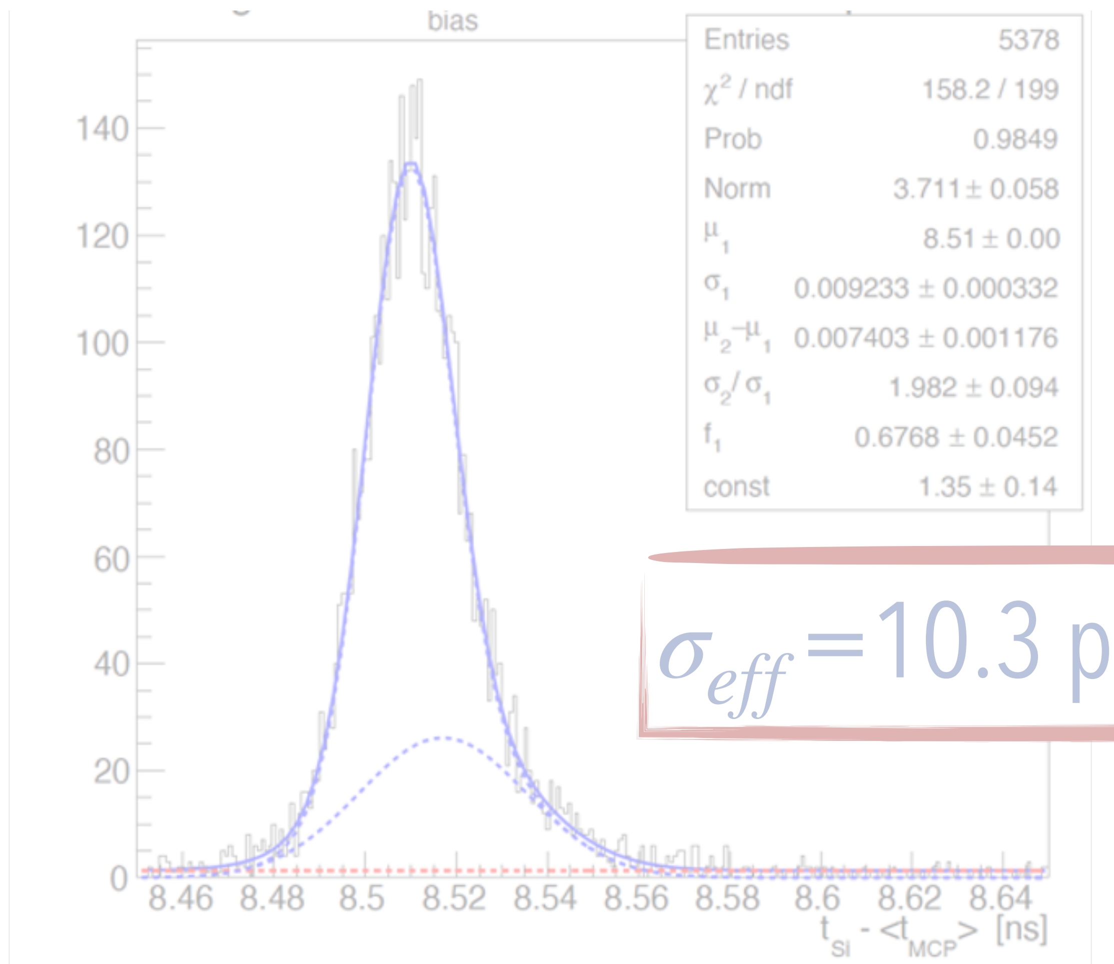
σ_{eff}=10.3 ps @. 150V

VELO





After irradiation with $2.5 \times 10^{16} n_{eq} cm^{-2}$



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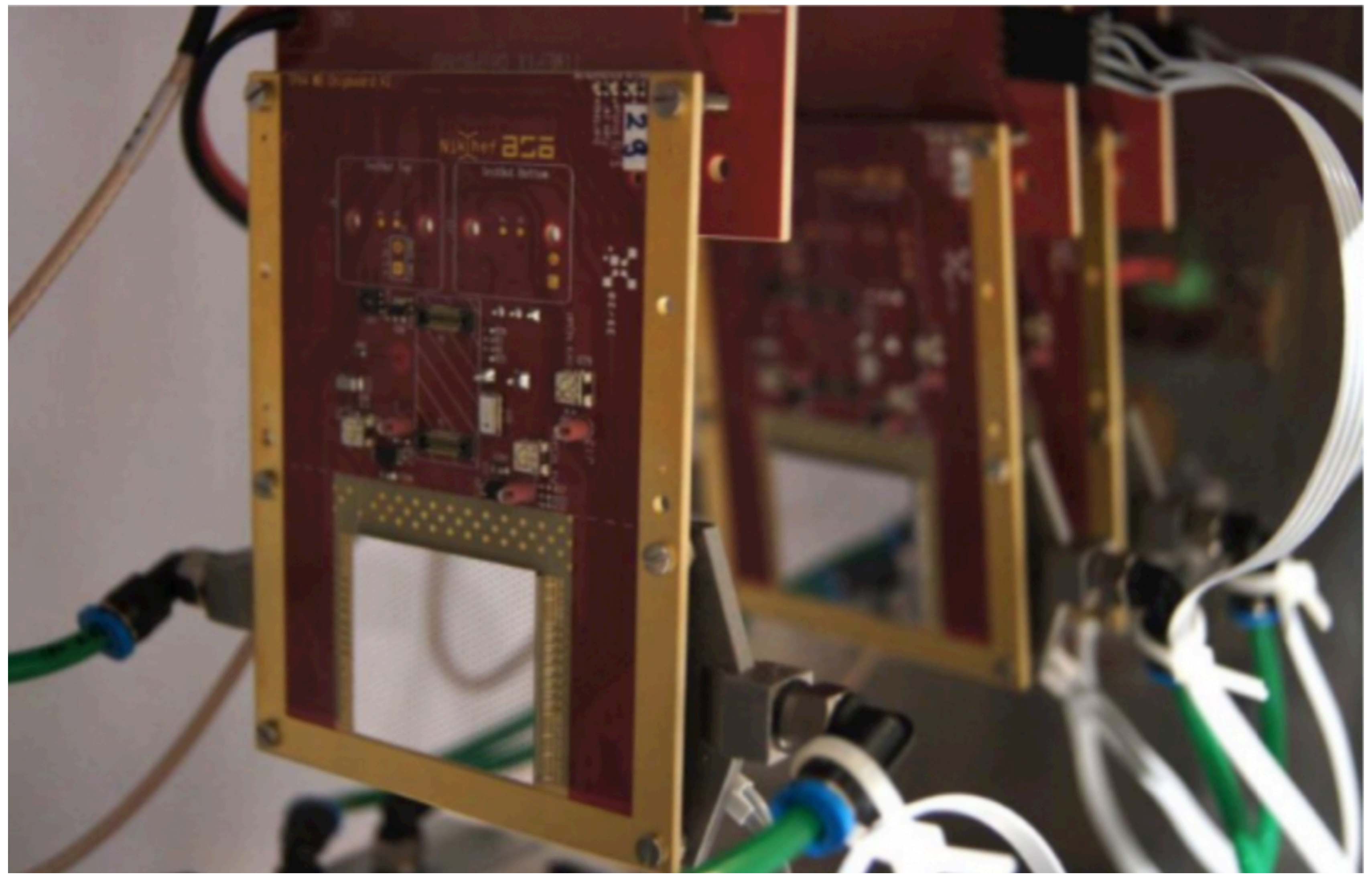
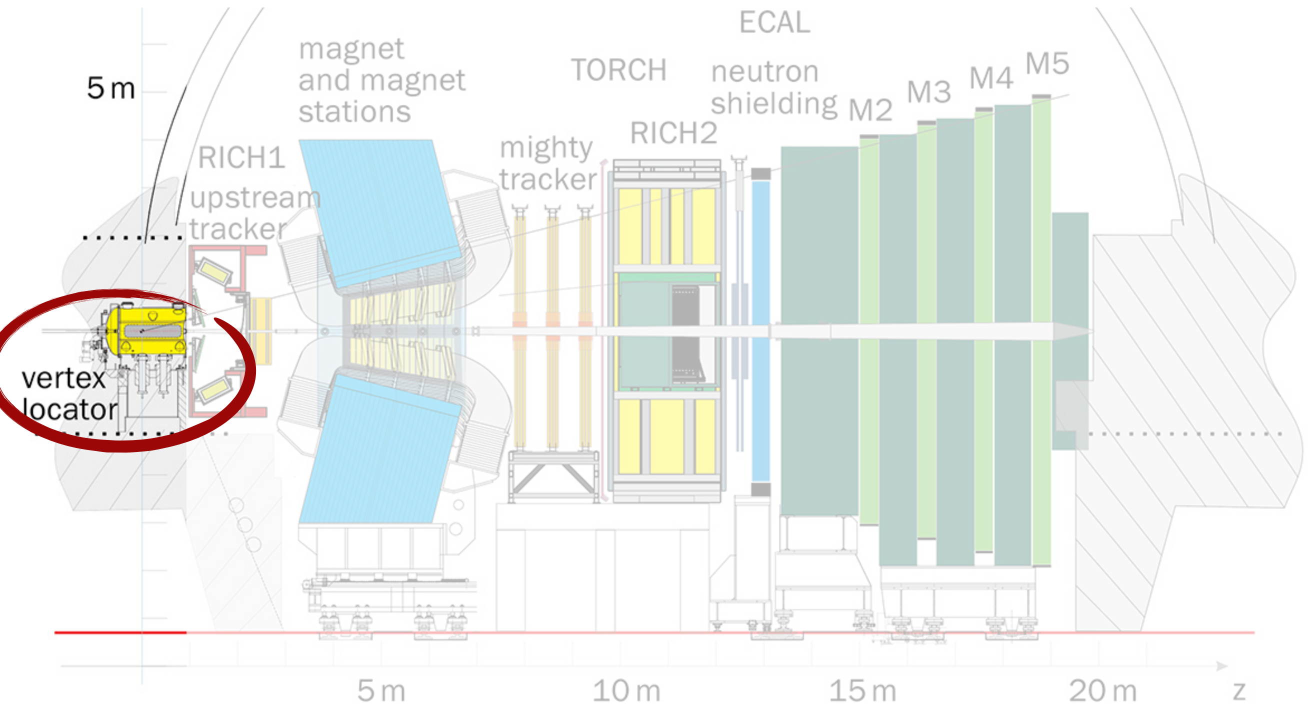


- Timepix4 ASIC most advanced
- Planned to be used in Timepix Telescope for new lumimeter

VELO



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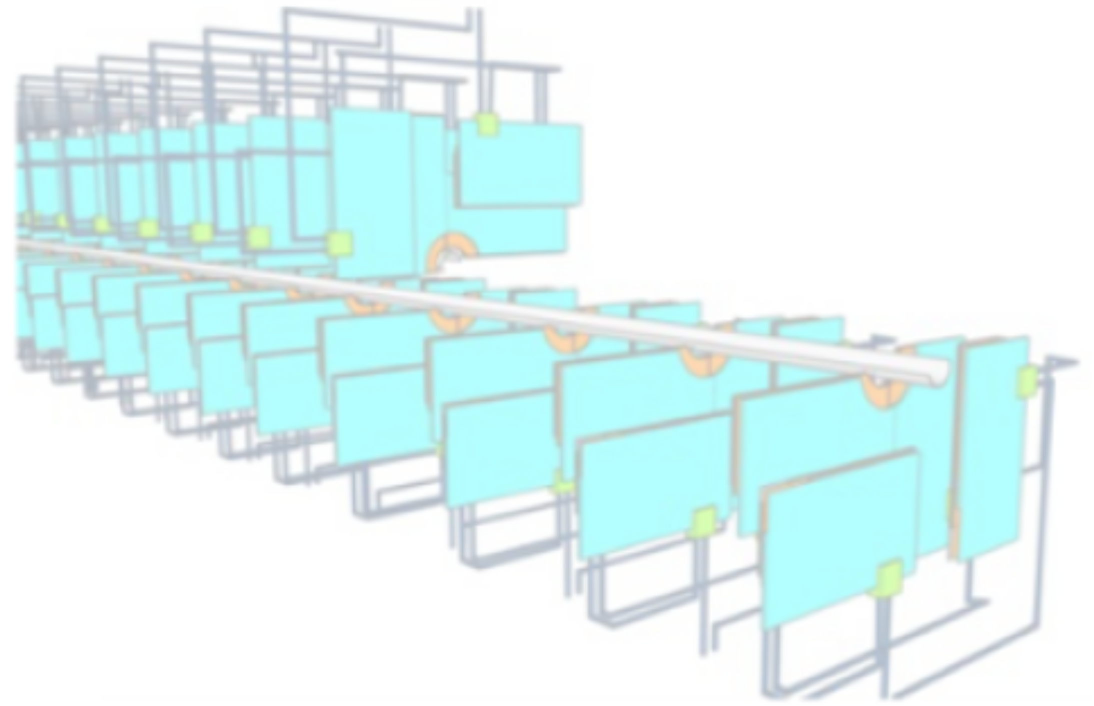
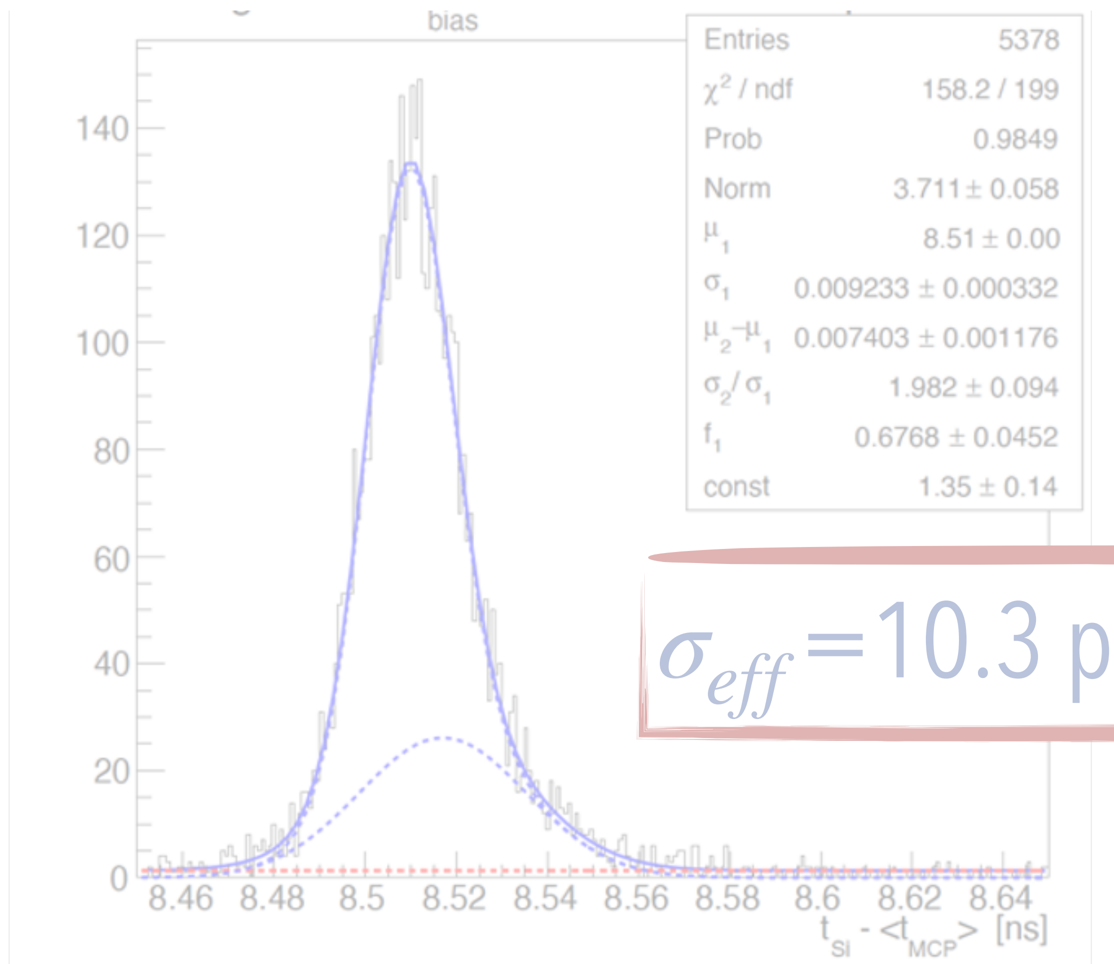


After irradiation with $2.5 \times 10^{16} n_e$



σ_{eff} =10.3 ps @. 150V

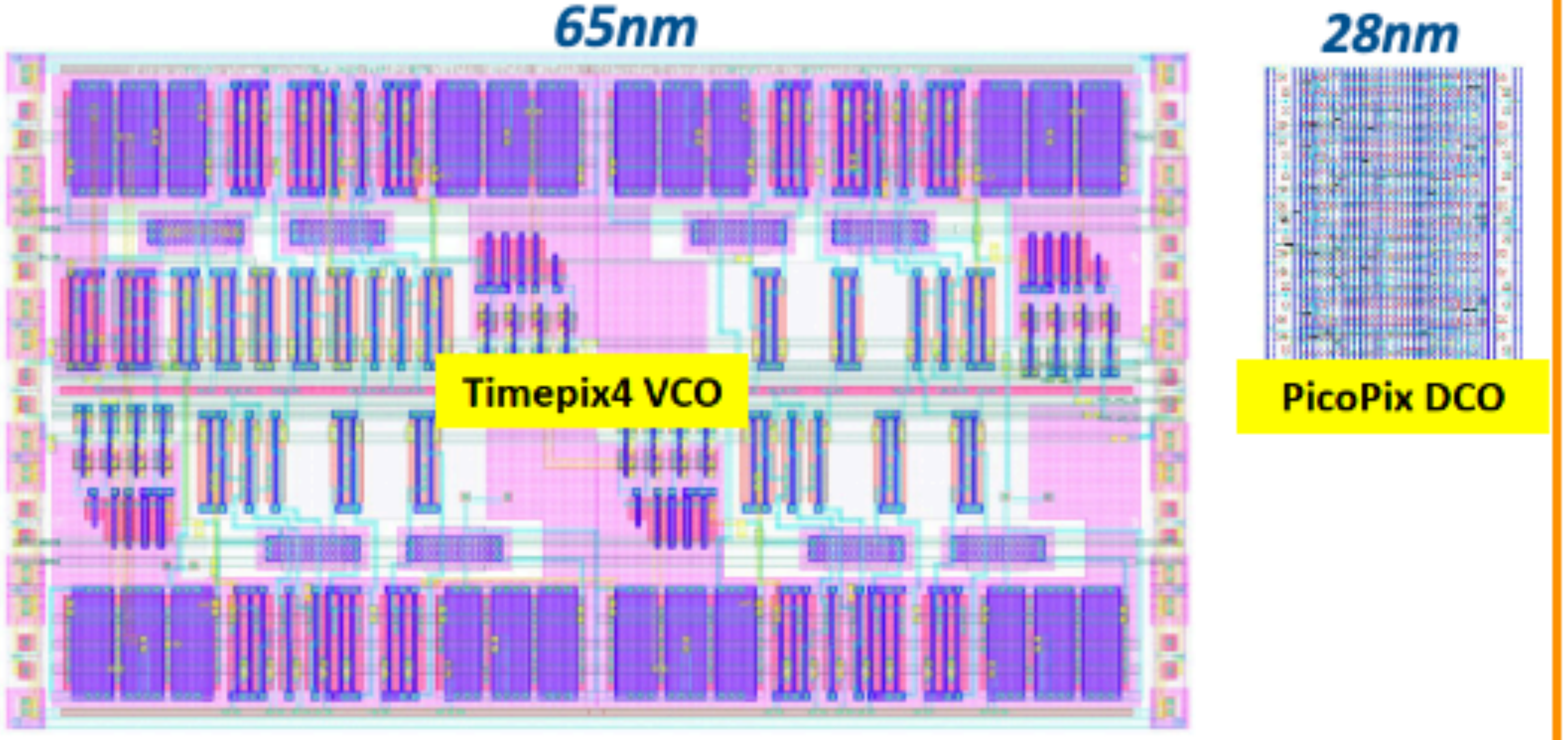
PicoPix ASIC alternative with ~factor 4 improvement in timing

PicoPix ASIC design advancing

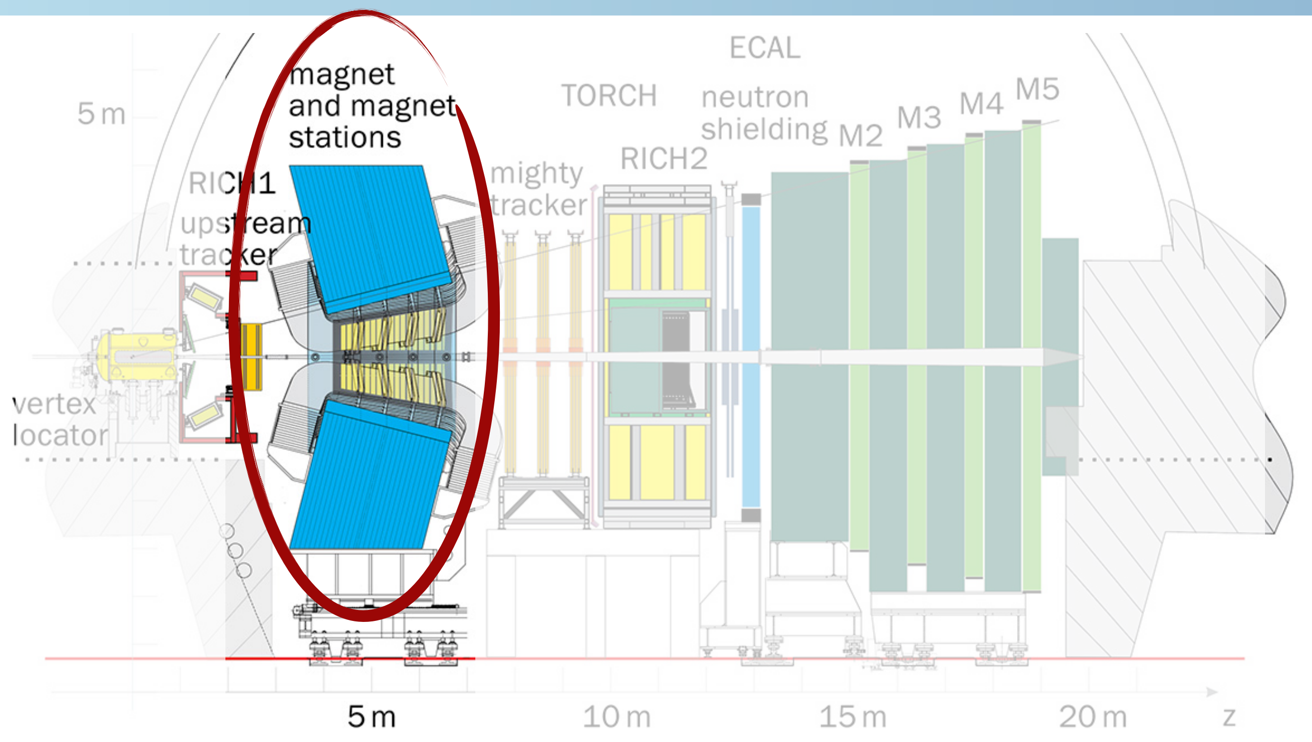
	freq	Phases	Phase mismatch [max-min]	LSB	Area	power
Timepix4 VCO	640 MHz	8	~25%	195ps	~350µm²	~500µW
PicoPix DCO	2-3 GHz	10	< 5%	50-33ps	~38µm²	~150µW

CERN-EP-ESE

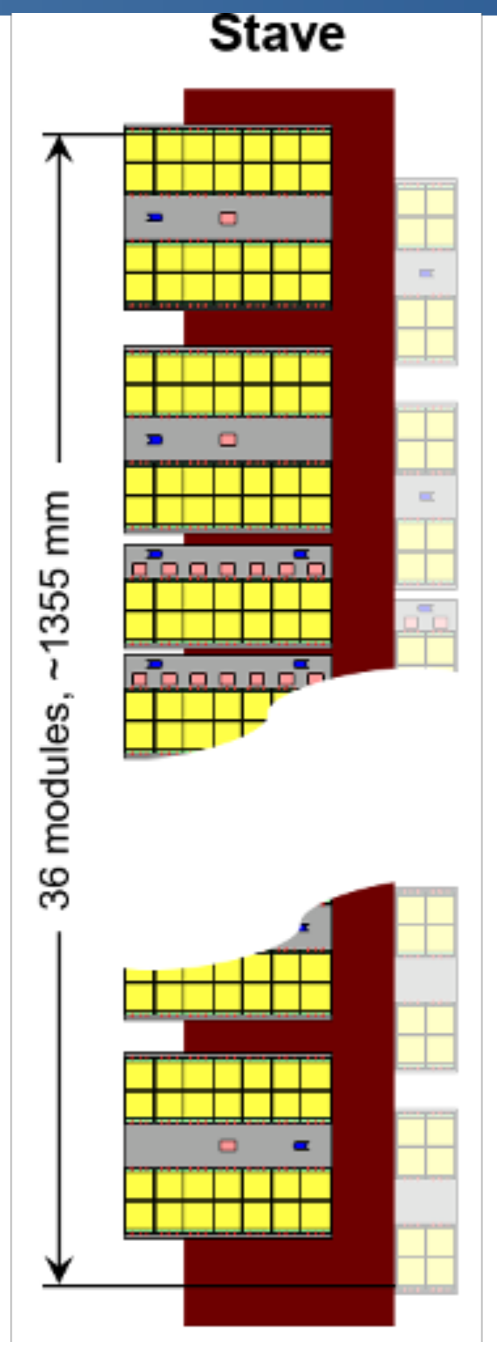
Layout below is the oscillator-core of in-pixel TDC, with comparison to previous generation (Timepix4), massive size reduction in 28nm → pixel size feasible



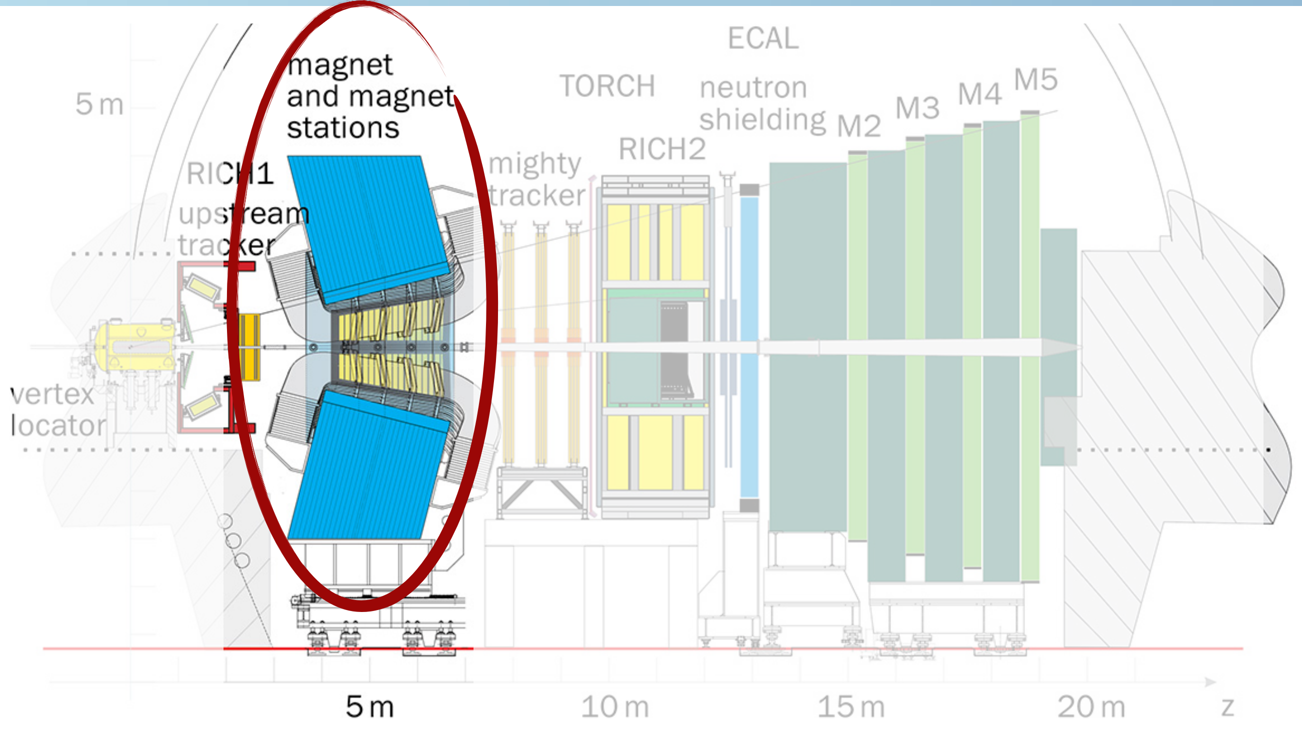
UT + MIGHTYTRACKER



- Pixel for UT using MAPS (50x150μm^2)
  - Low-cost commercial production + low material budget
  - Radiation requirement $3 \times 10^{15} n_{eq} cm^{-2}$



UT + MIGHTYTRACKER



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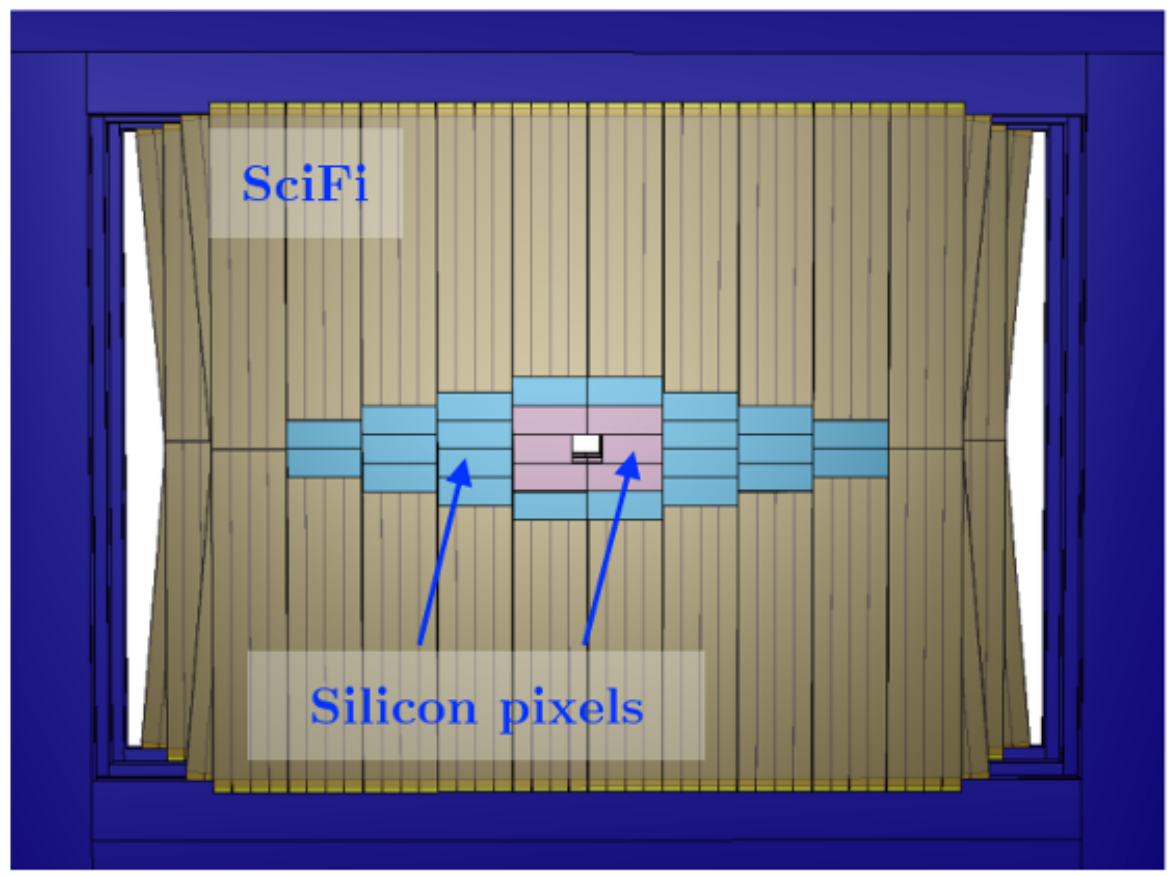
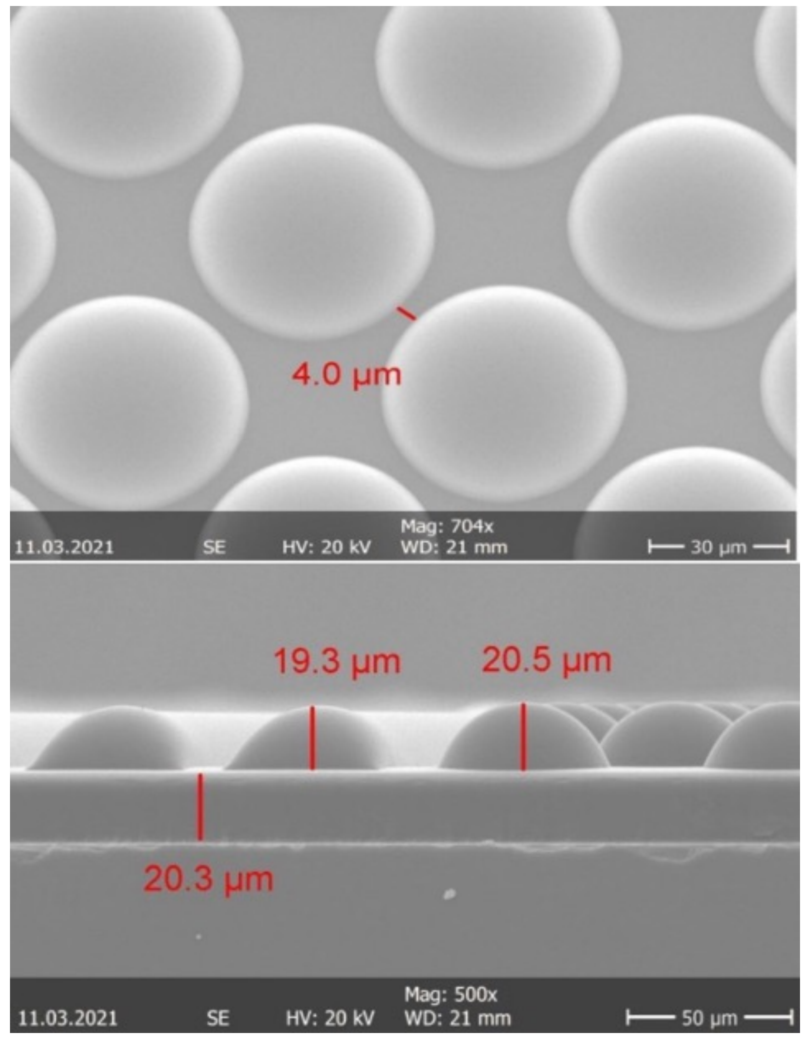
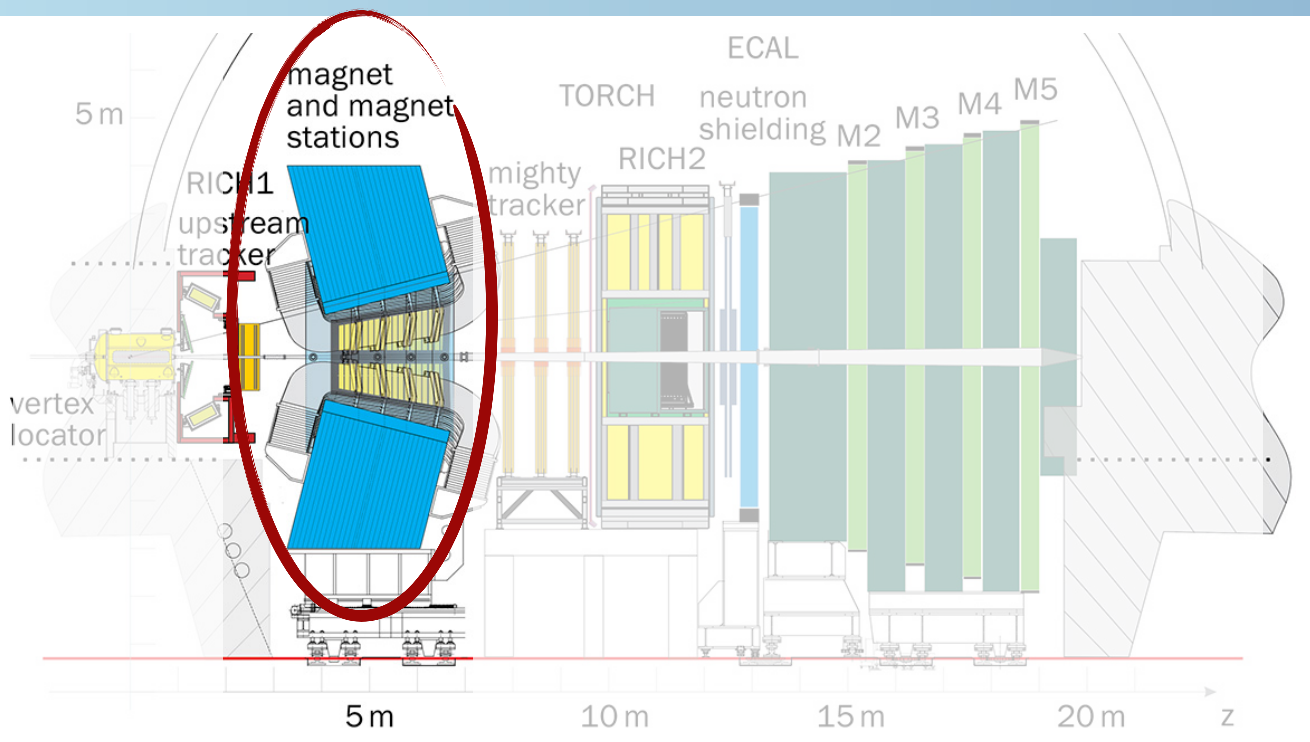


- MightyTracker: MAPS pixel inner, scintillating fibres outer
  - Radiation hard fibres, cryogenic cooling
  - Photo detection efficiency enhancement with micro-lenses for SiPMs



µ-Lens characterisation

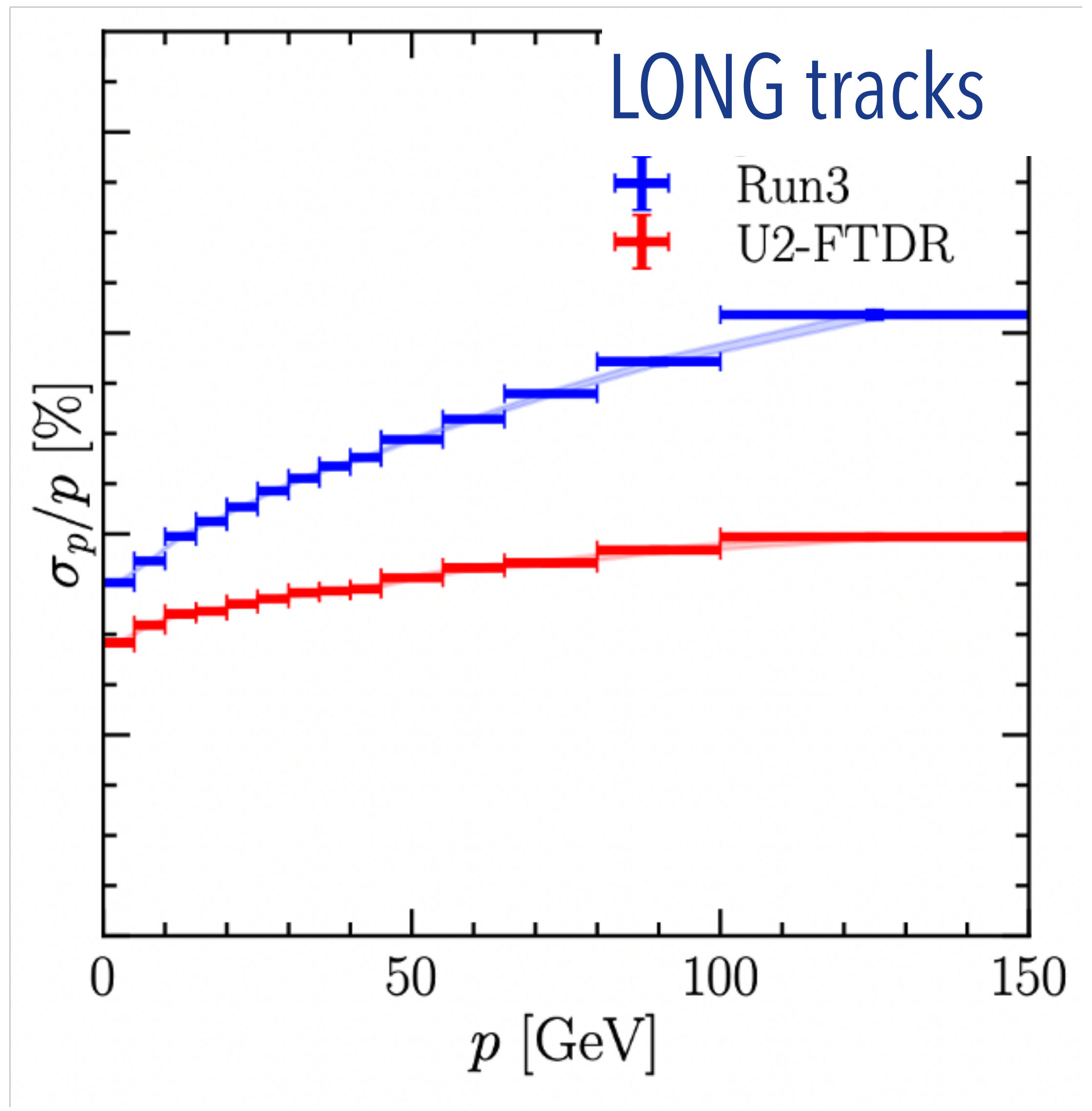
UT + MIGHTYTRACKER

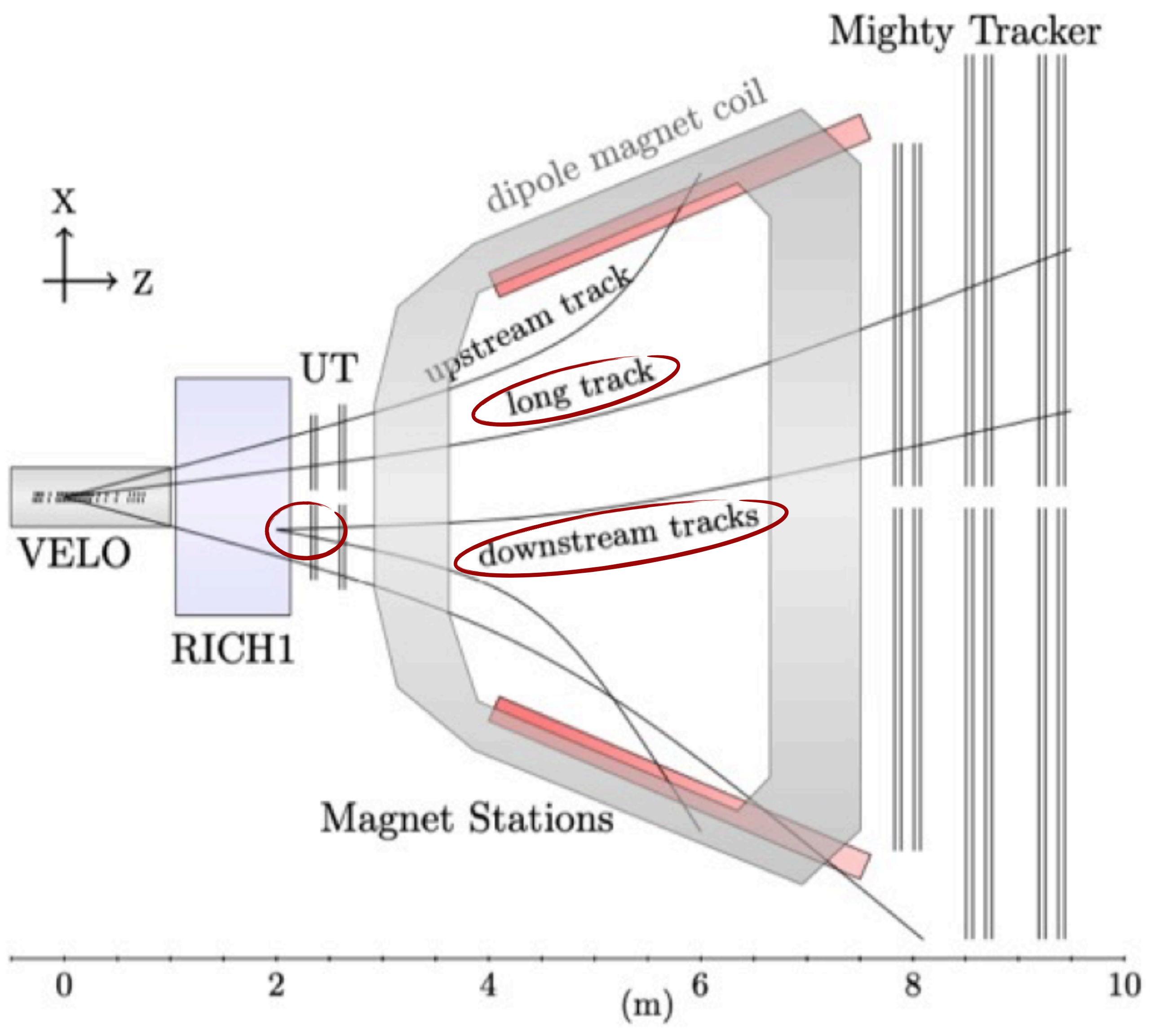


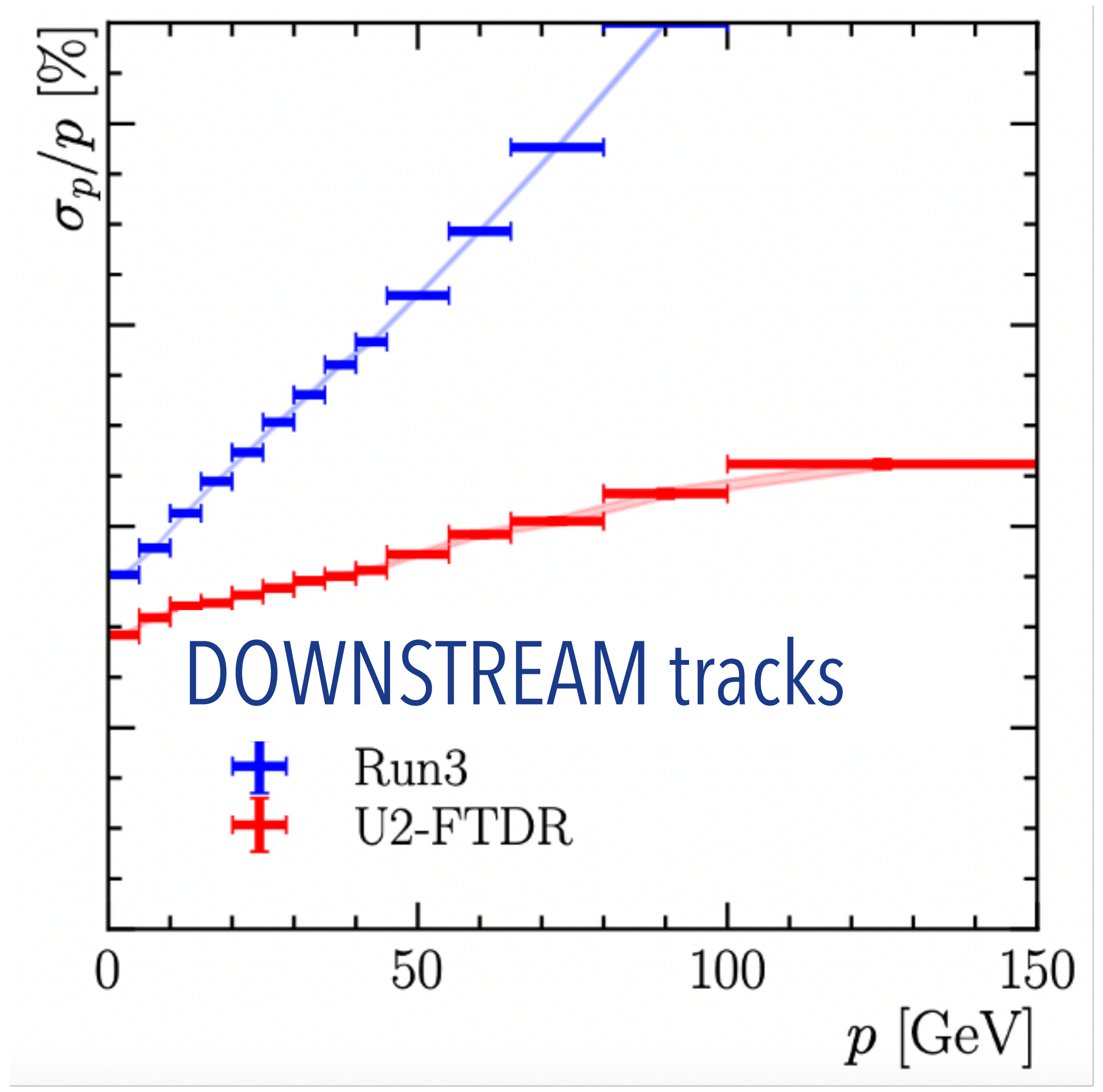
- Pixel for UT using MAPS ($50x150\mu m^2$)
  - Low-cost commercial production + low material budget
  - Radiation requirement $3 \times 10^{15} n_{eq} cm^{-2}$
- MightyTracker: MAPS pix
  - Radiation hard fibres,
  - Photo detection efficiency enhancement with micro-lenses for SiPMs

Largely improved momentum resolution

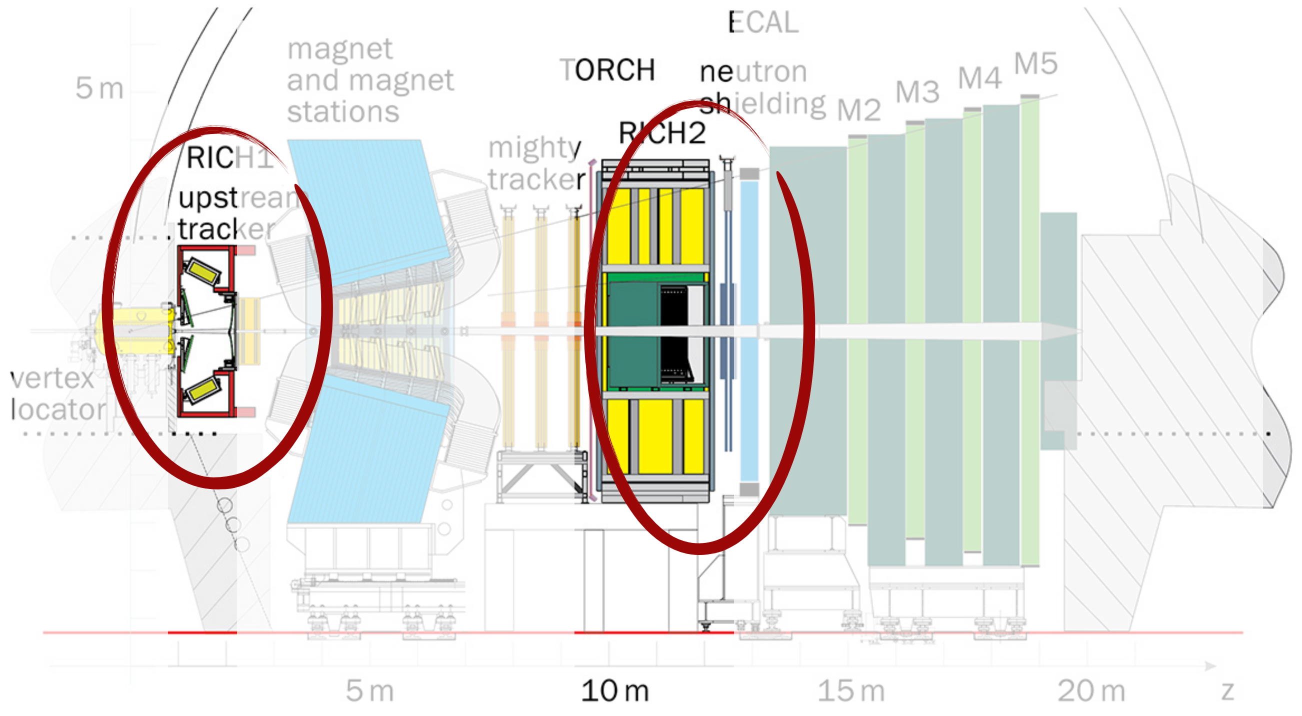
→ especially for downstream tracks (no VELO info)





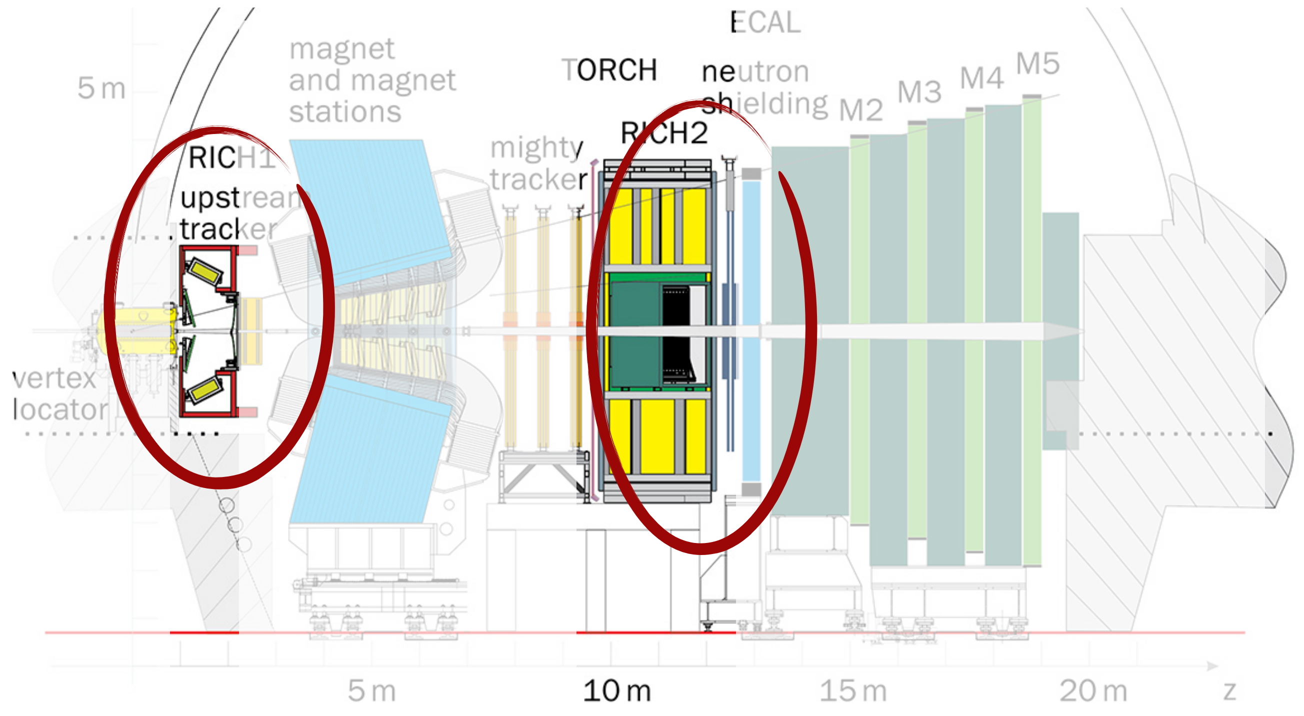


PID - RICH & TORCH



- RICH1 and RICH2: reduced pixel size and adding timing fastRICH ASIC
- SiPM and microchannel plates (MCP) limit timing to $\sigma \sim 150$ps

PID - RICH & TORCH



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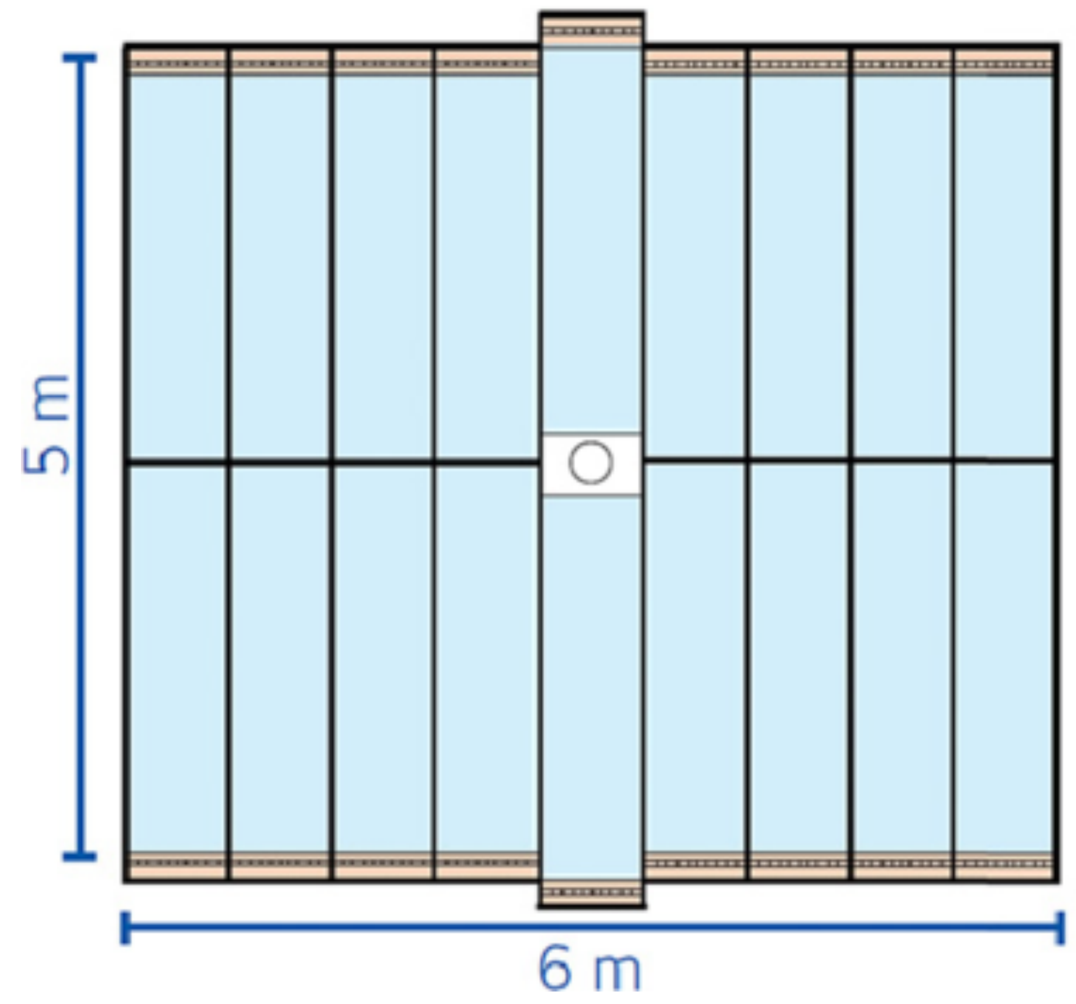
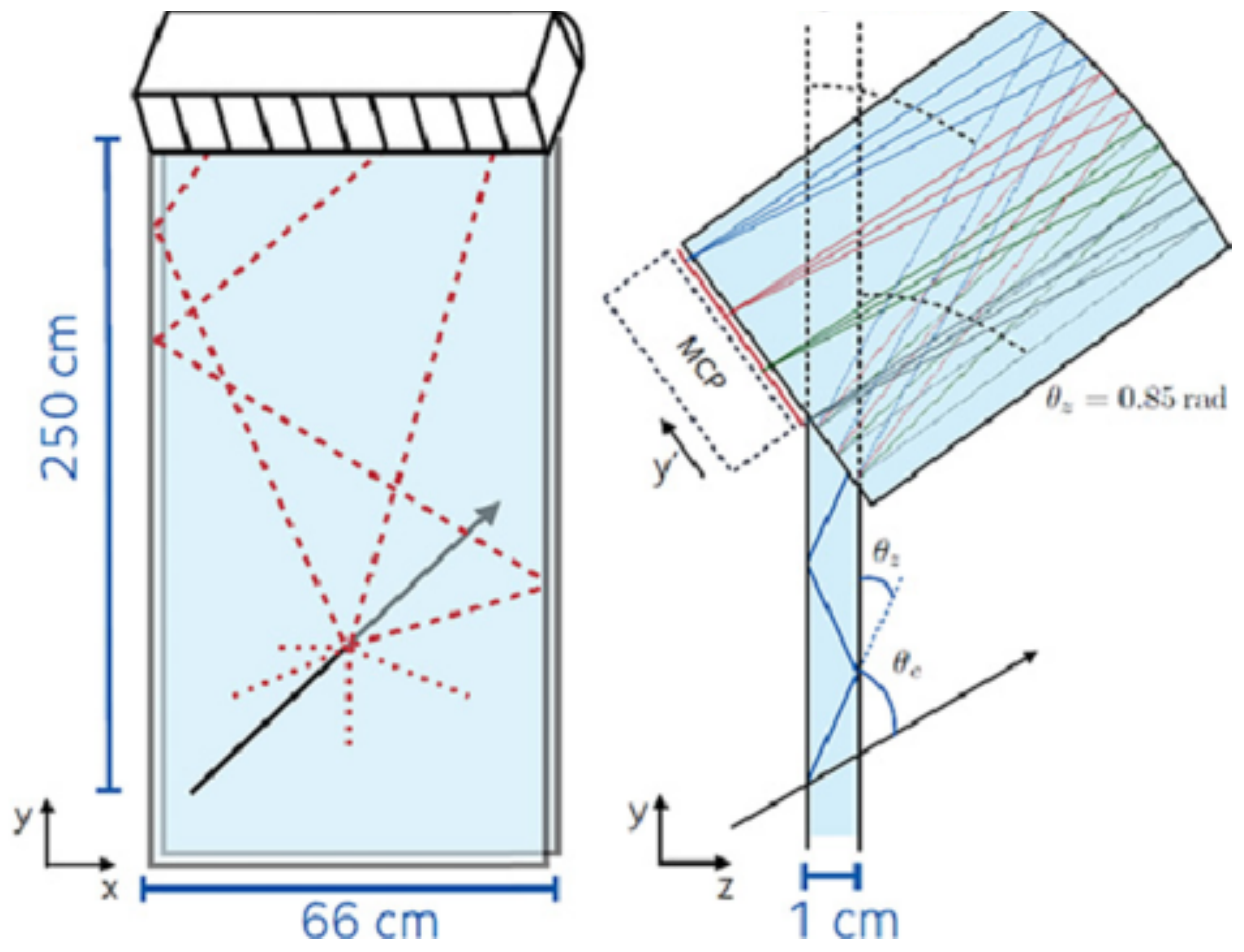
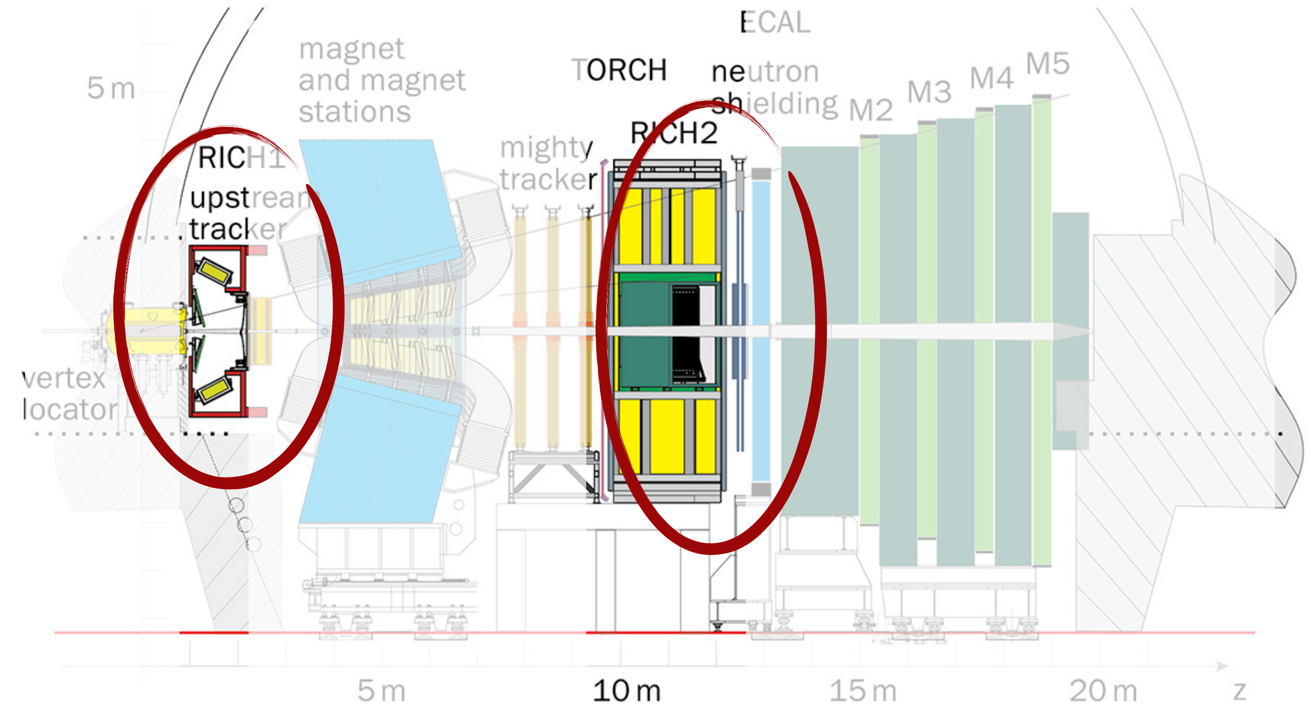


In front of RICH2

- TORCH: Timing Of internally Reflected CHerenkov photons
  $\longrightarrow$ new detector with Time-of-flight quartz
- Photon readout with SiPM + MCP
- Enables hadron separation inaccessible by RICH



PID - RICH & TORCH



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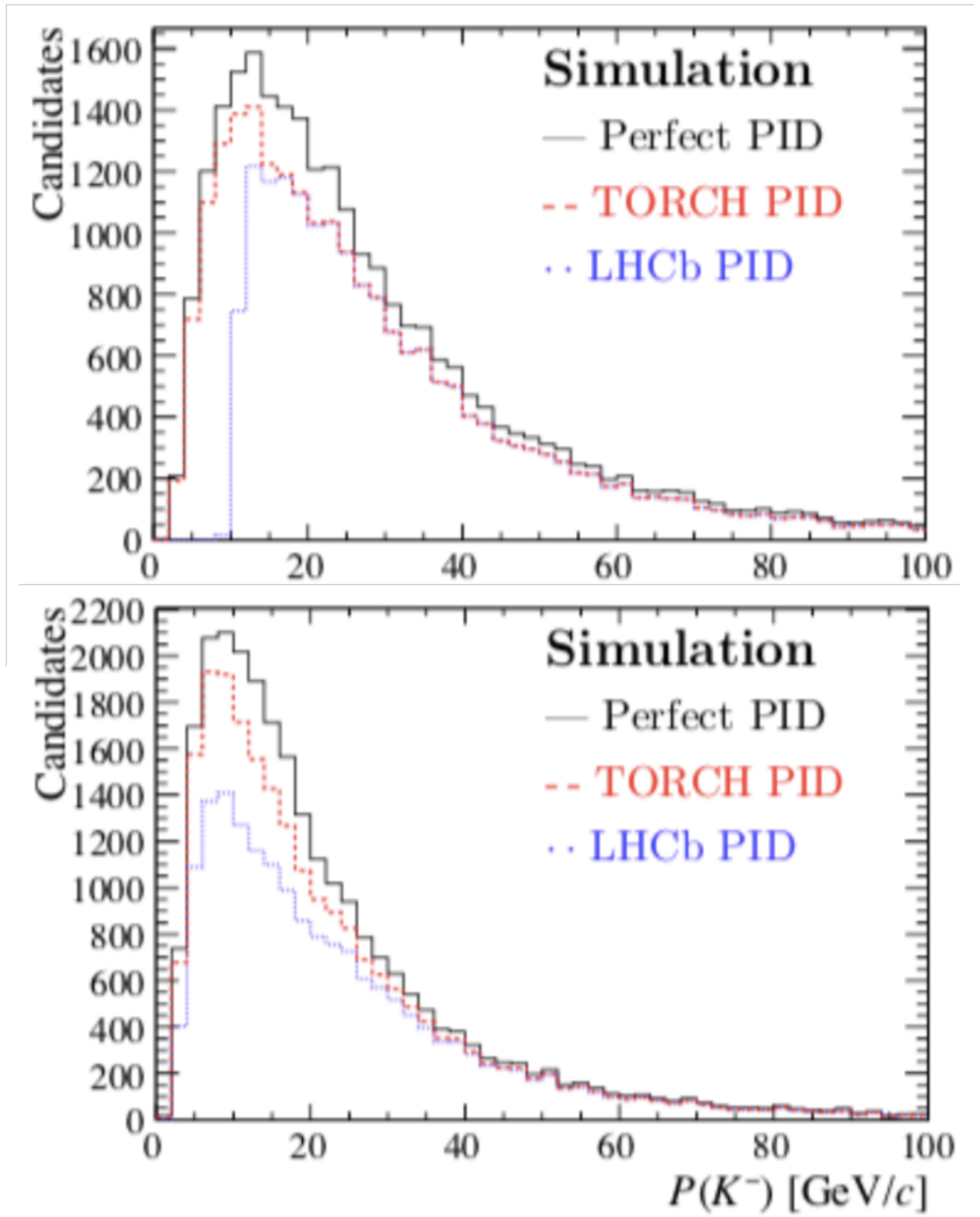
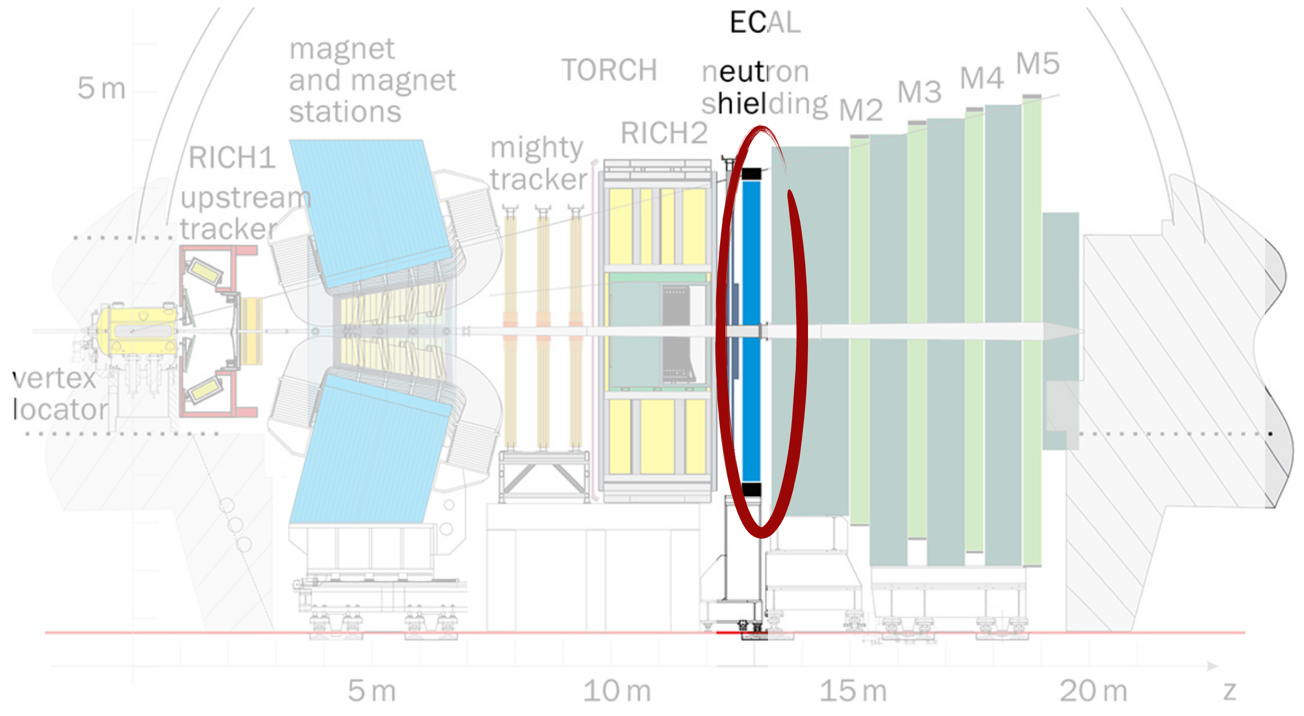


Studies of PID for p and K from $\Lambda_b^0 \to pK^-J/\psi$

significant PID improvement

ECAL



- ECAL combination of old Shashlik ECAL and SpaCal

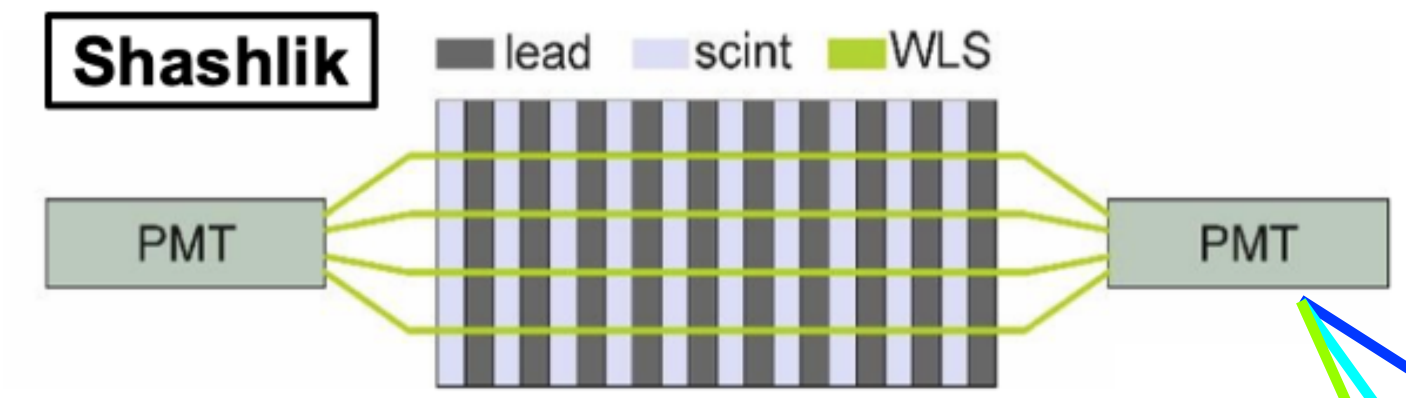
  → 5D reconstruction: Space + Time + longitudinal separation

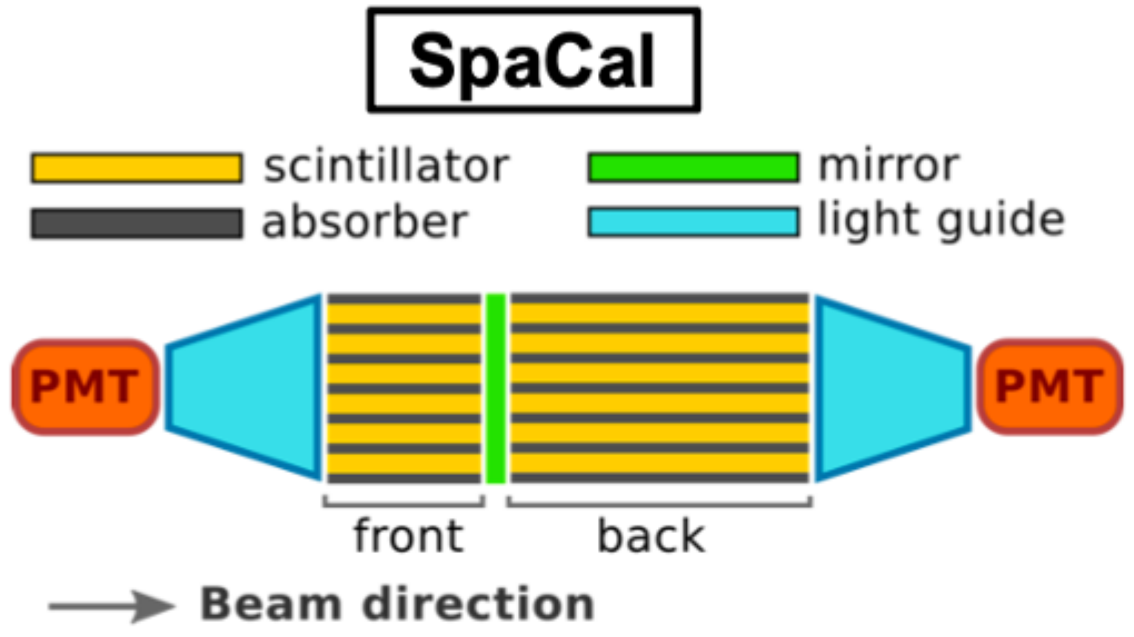
- Goal : same energy resolution and reconstruction efficiency as Run 1+2

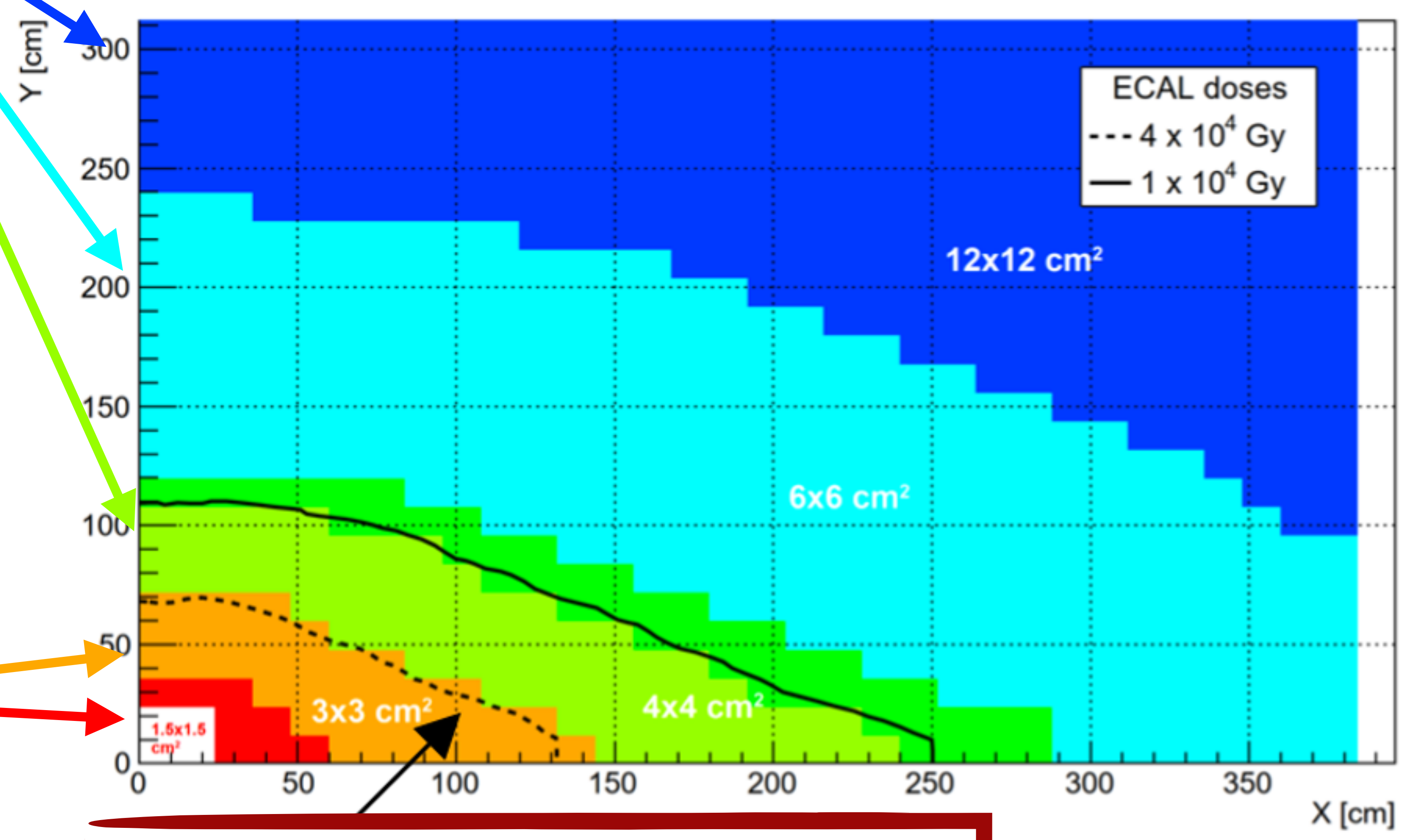
  → suffer from pile-up and radiation up to 1MGy

- Need granularity and precision timing

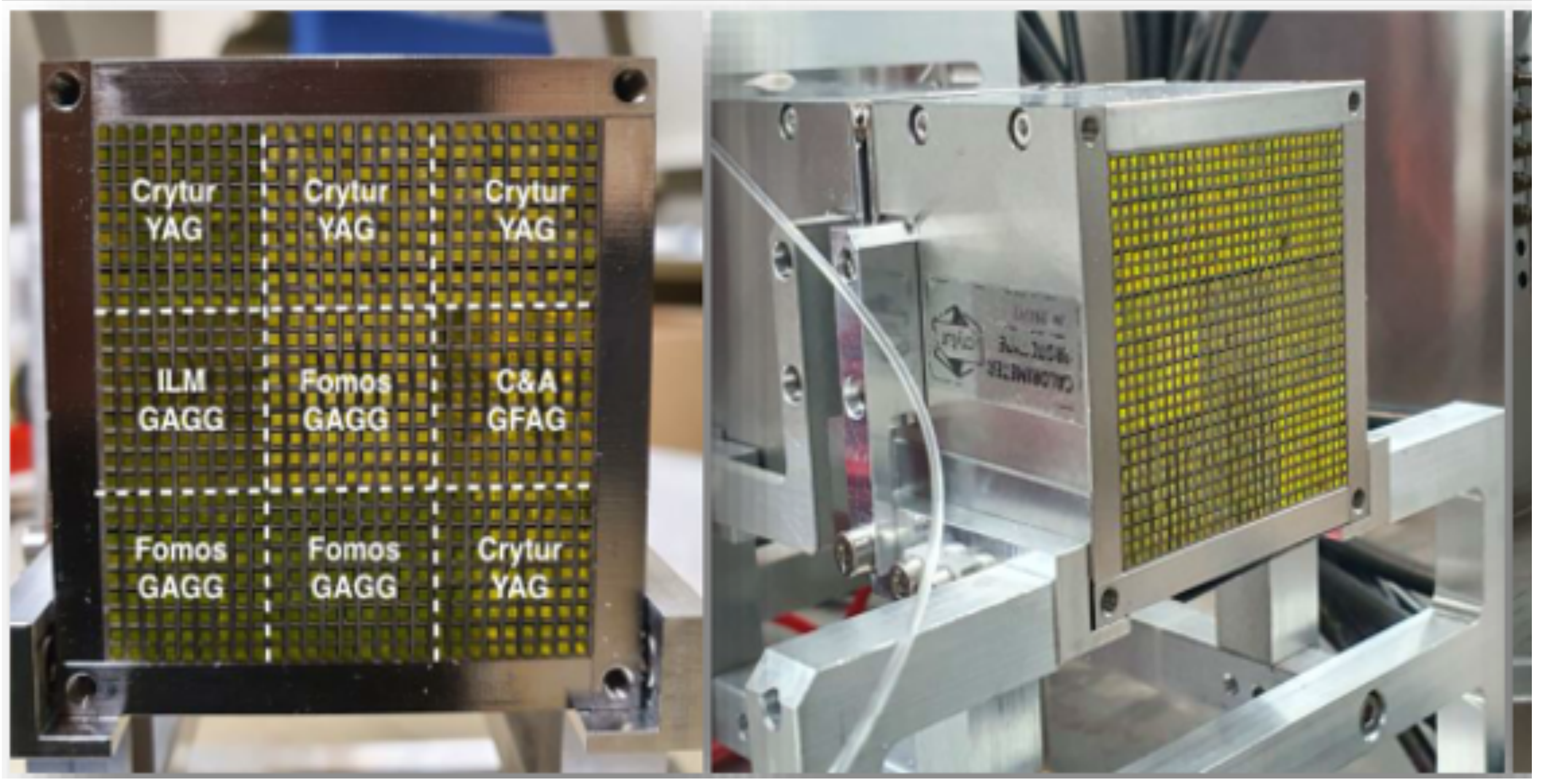
  → SpaCal with crystal fibres





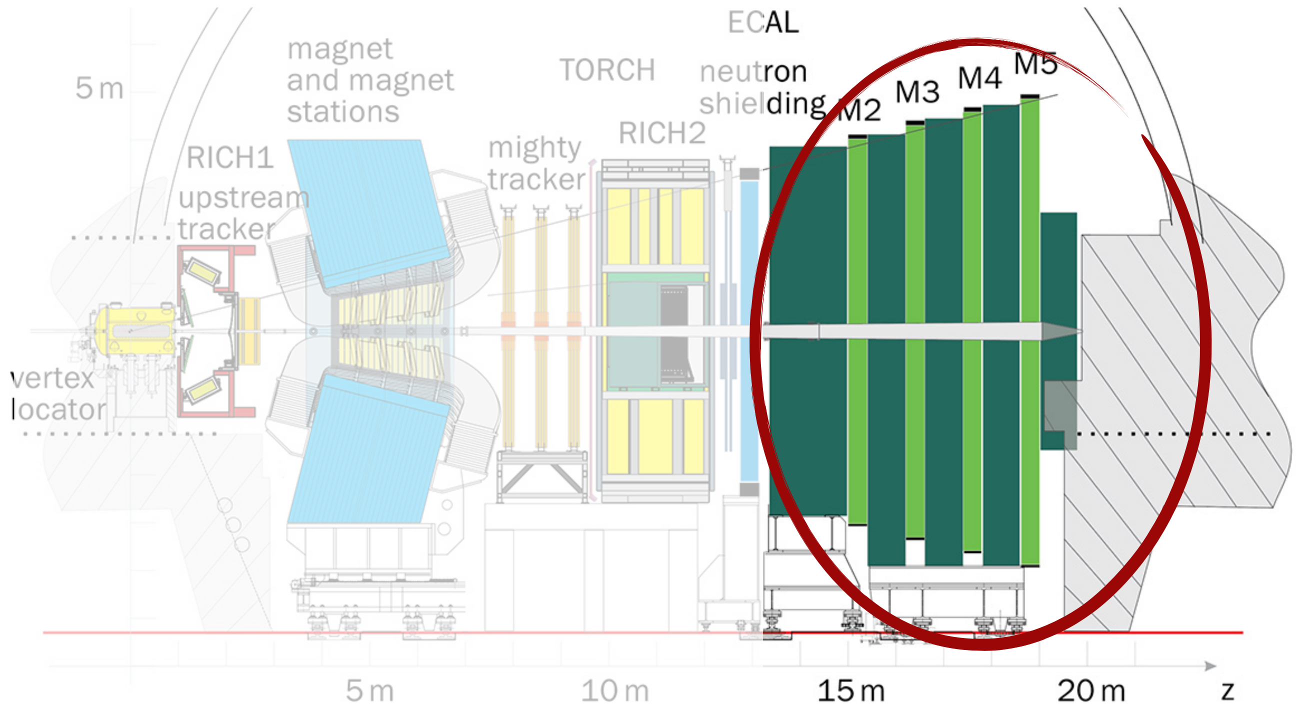


Radiation limit of Shashlik

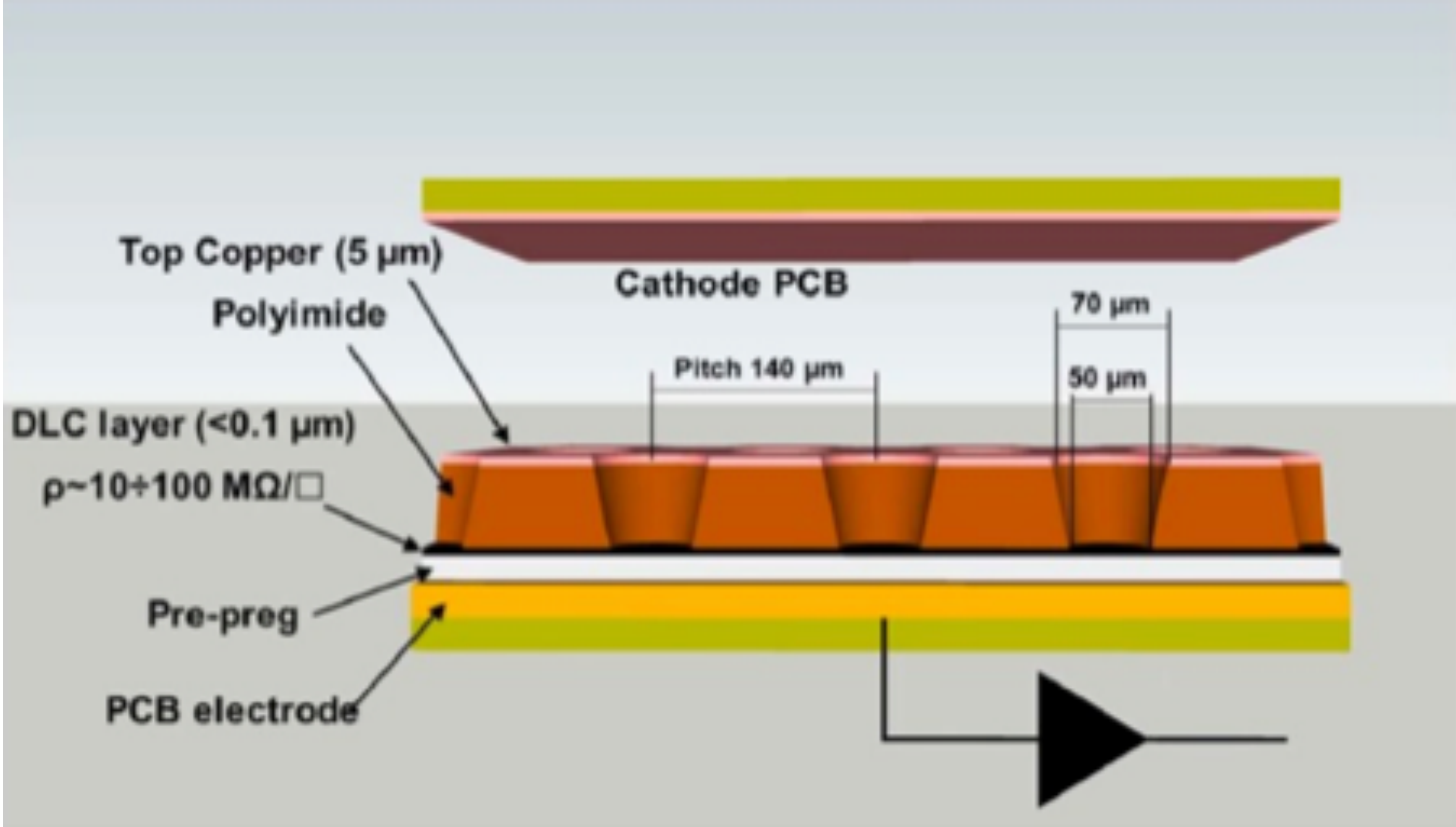


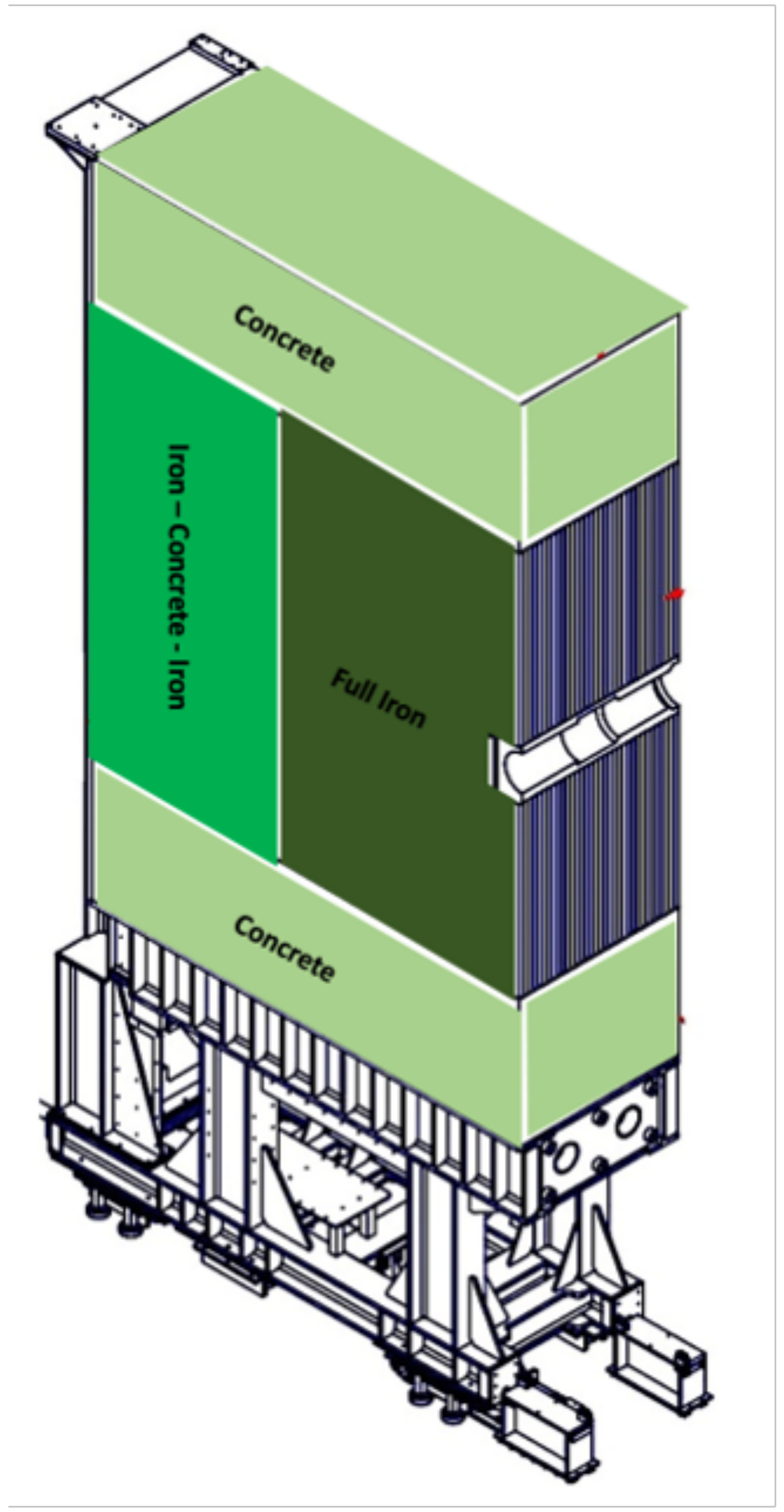
Prototyping, now towards production

MUON CHAMBERS



- Novel micro-pattern gas detectors μRWELL
- Used in innermost region
- Reuse multi-wire chambers otherwise

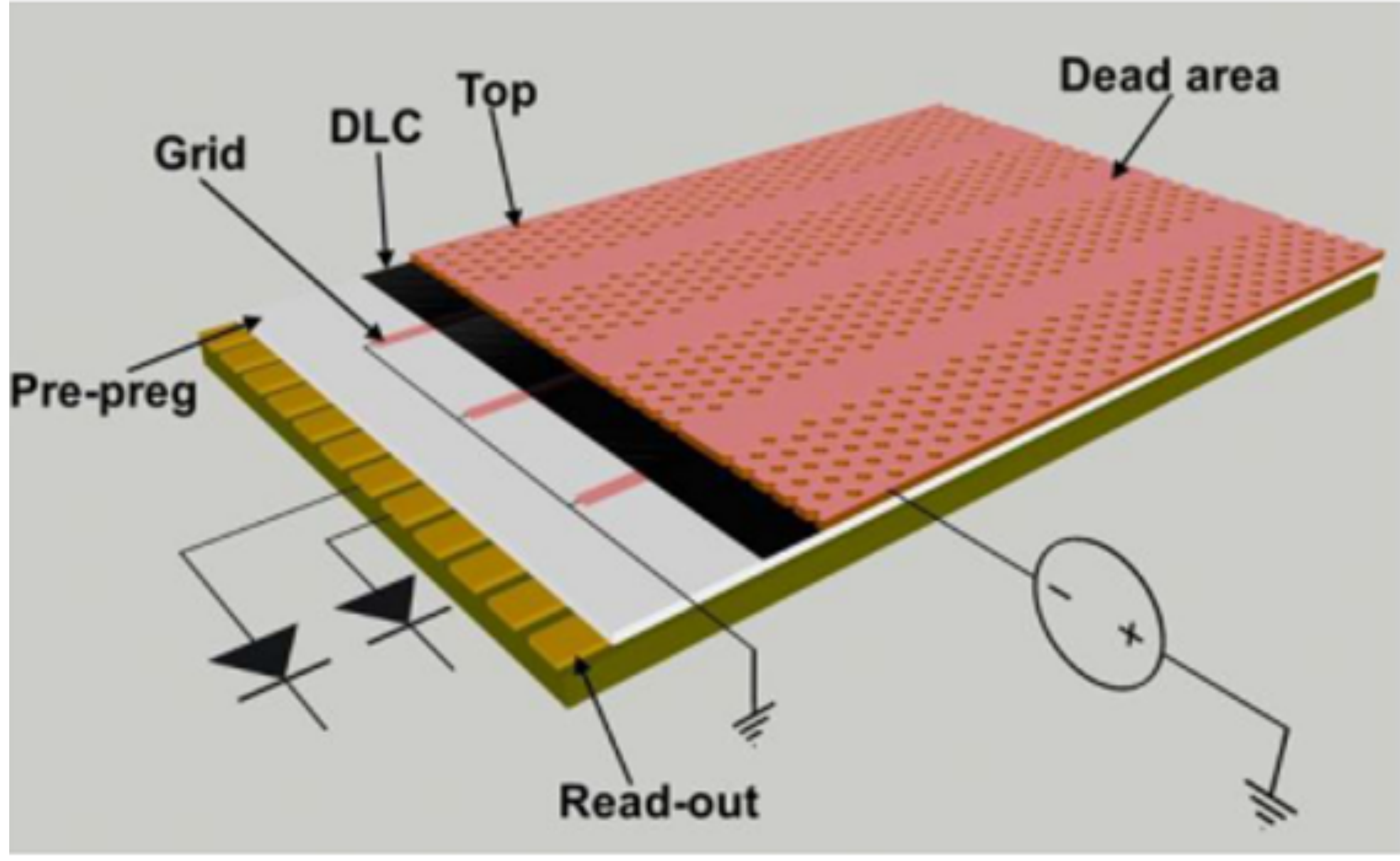




- HCAL replaced with iron-concrete shielding

  → shielding against neutrons

- Shielding in front of ECAL also remains for RICH



CONCLUSION

- Framework TDR published in February 2022
- This year finish scoping document

  → evaluating different technology and cost options
- With approval final TDR will follow
- Various stages of testing and already production
- Full production planned for LS3 to ensure installation in LS4
- More details on physics next week in Upgrade II Session of LHCb week

Check Twiki on Upgrade 2