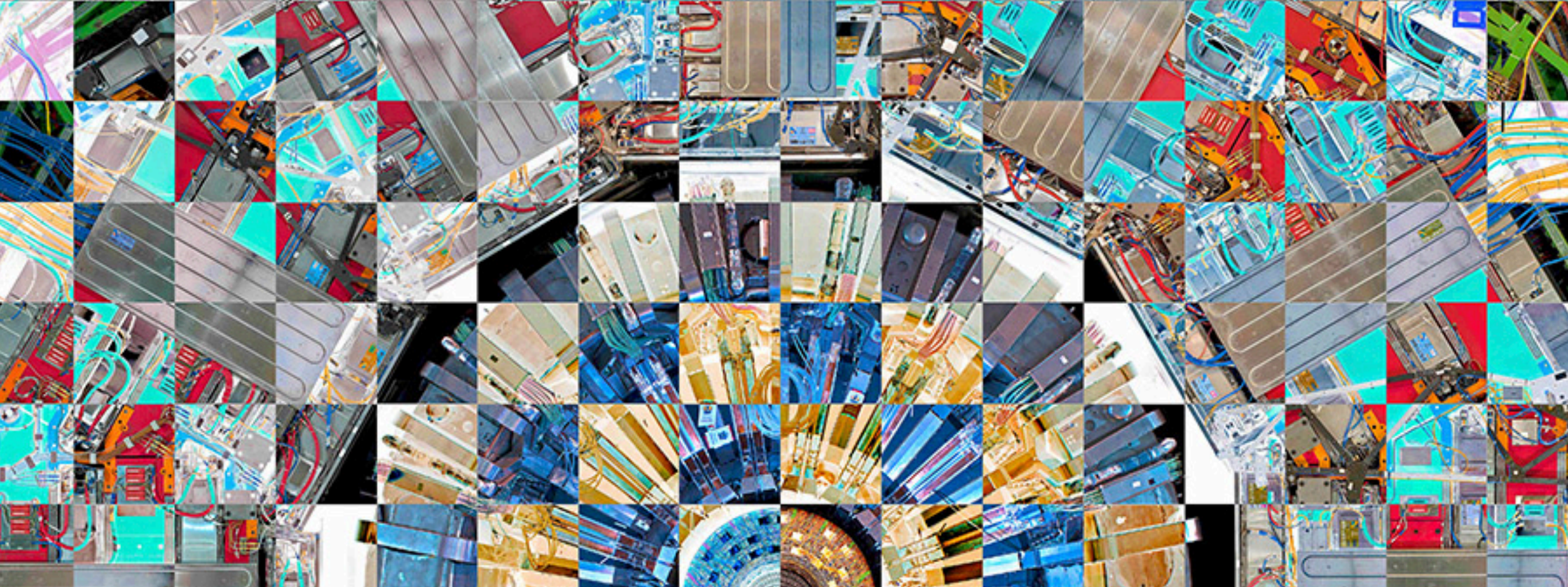
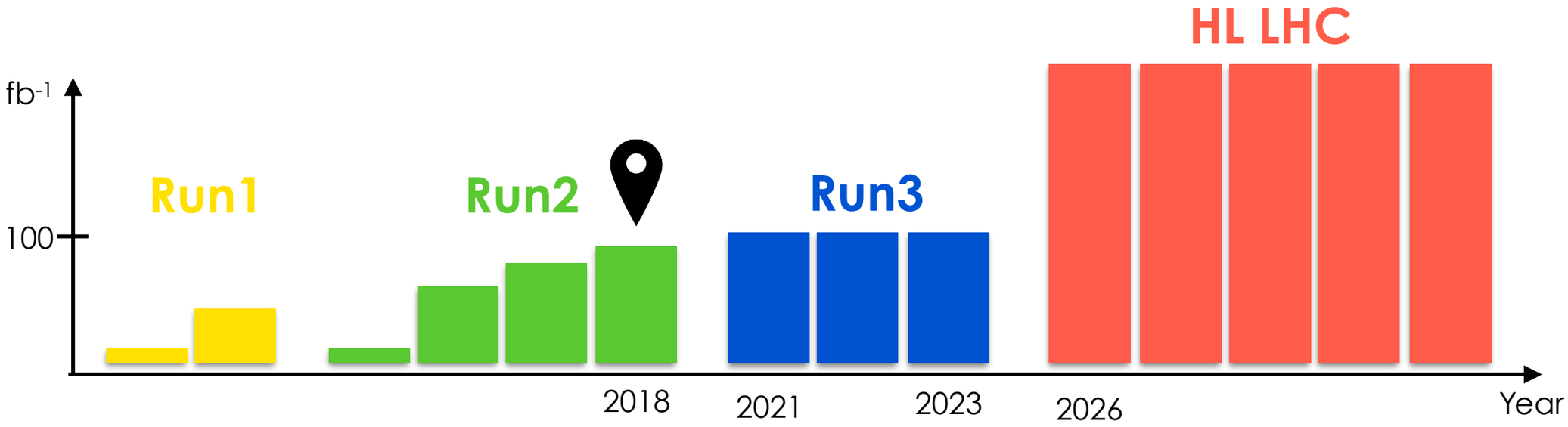


CMS Phase-2 MIP timing detector

Livia Soffi

on behalf of the CMS Collaboration

Heading to the future at LHC



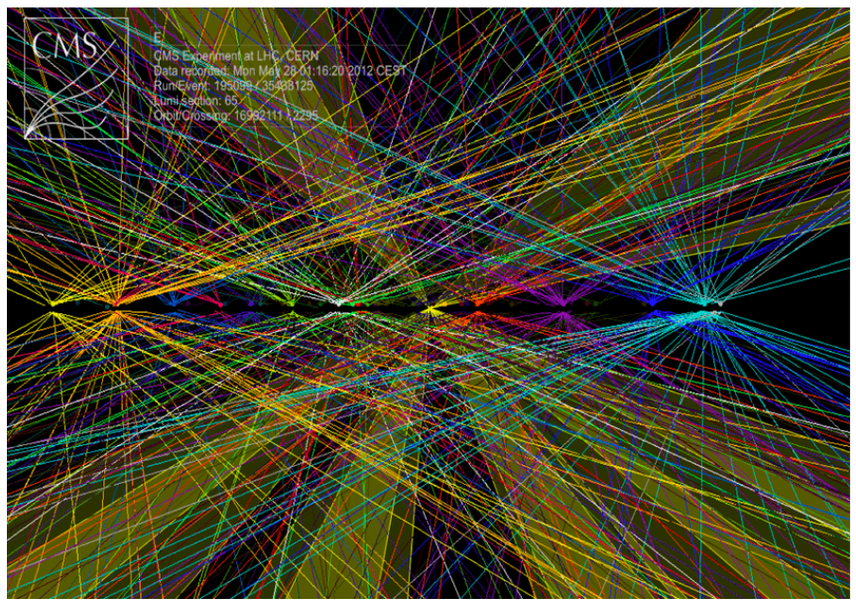
- Reach set of physics results at the **end of Run2** (Inst. Lumi 2×10^{34} $cm^{-2}s^{-1)}$ of LHC .. but .. no sign for BSM physics

- **Run3** (2x Run2 Luminosity ~ 300fb^{-1}) very last opportunity to look for new physics at "low pileup"

- **HL LHC** (Inst. Lumi 5-7.5$\times10^{34}$ $cm^{-2}s^{-1}$)

More p-p interaction per bunch crossing

Need **performant and flexible detector** to allow a deep **exploration of corners of phase space**



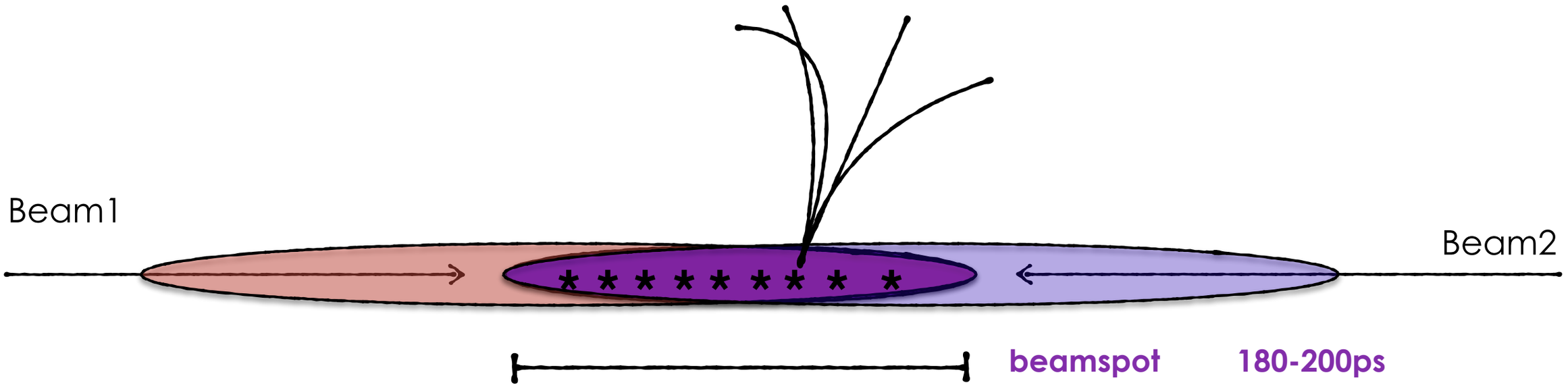
Motivation for a MIP Timing Detector

- High Luminosity-LHC:

$$L_{inst}(start) = 5 \cdot 10^{34} cm^{-2} s^{-1} (140 PU)$$

$$L_{inst}(goal) = 7.5 \cdot 10^{34} cm^{-2} s^{-1} (200 PU)$$

- **Increase vertex density by a factor 4-5**

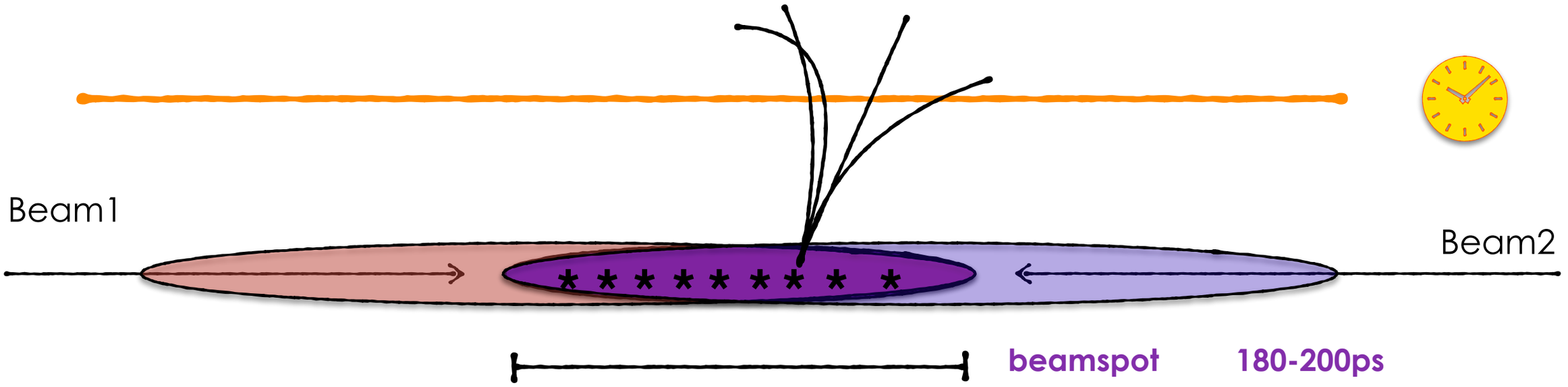


Motivation for a MIP Timing Detector

- High Luminosity-LHC:

$$L_{inst}(start) = 5 \cdot 10^{34} cm^{-2} s^{-1} (140 PU)$$
$$L_{inst}(goal) = 7.5 \cdot 10^{34} cm^{-2} s^{-1} (200 PU)$$

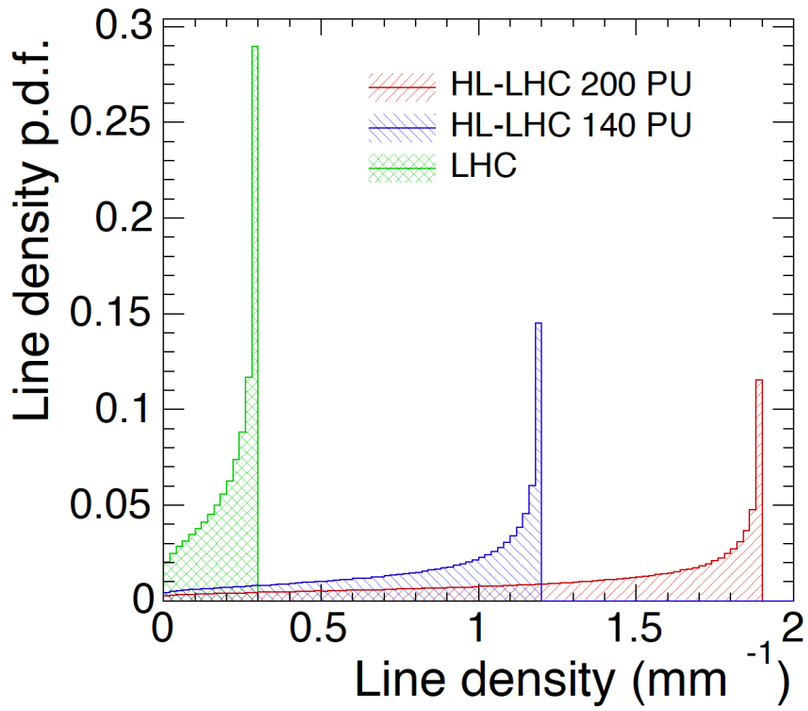
- **Increase vertex density by a factor 4-5**



- Significant **PU contamination** and whole **event reconstruction degradation**

- Challenge: **keep current performance** @ HL-LHC (30-40 collisisons in 4.5cm)

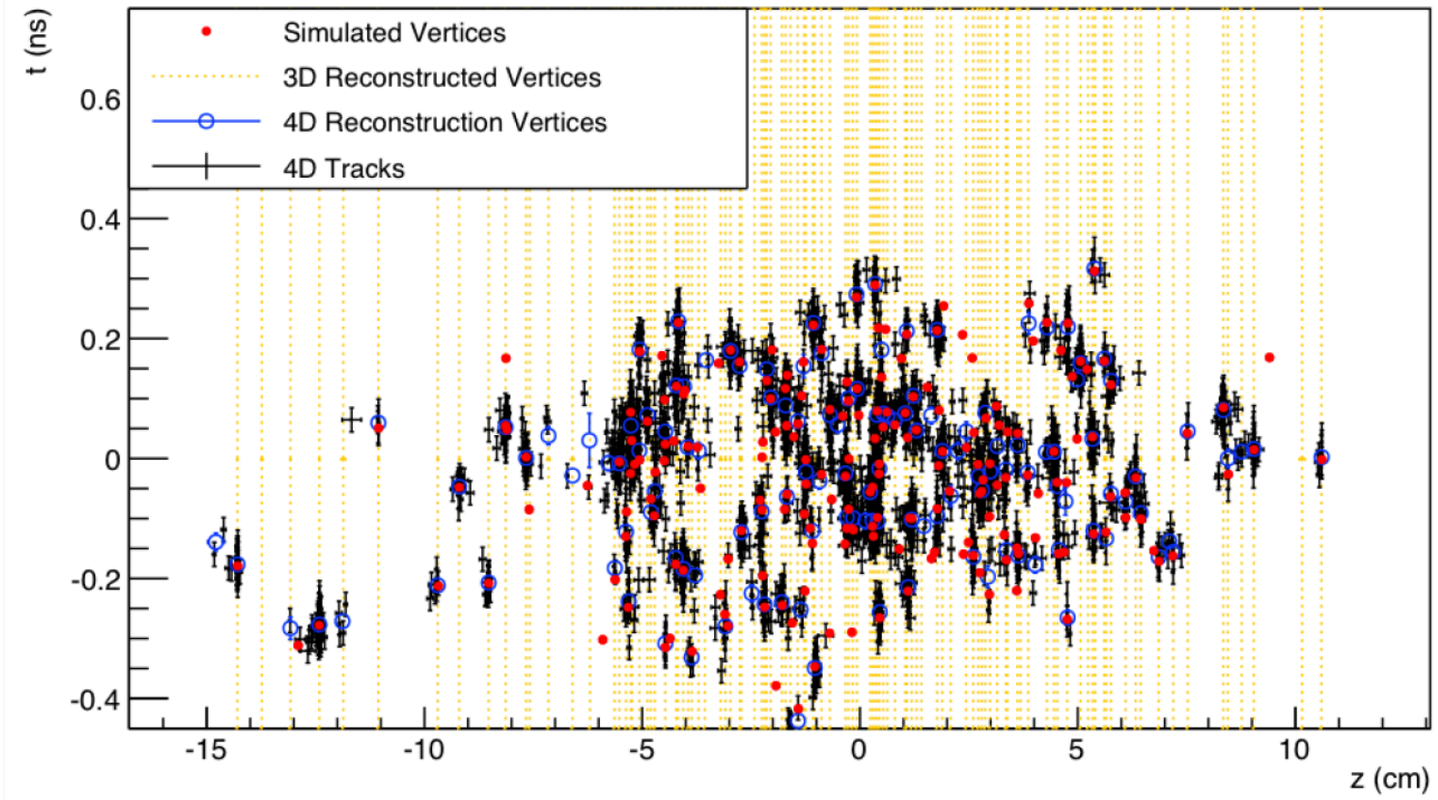
- **Basic Idea: Use track timing for a 4D vetex reconstruction**

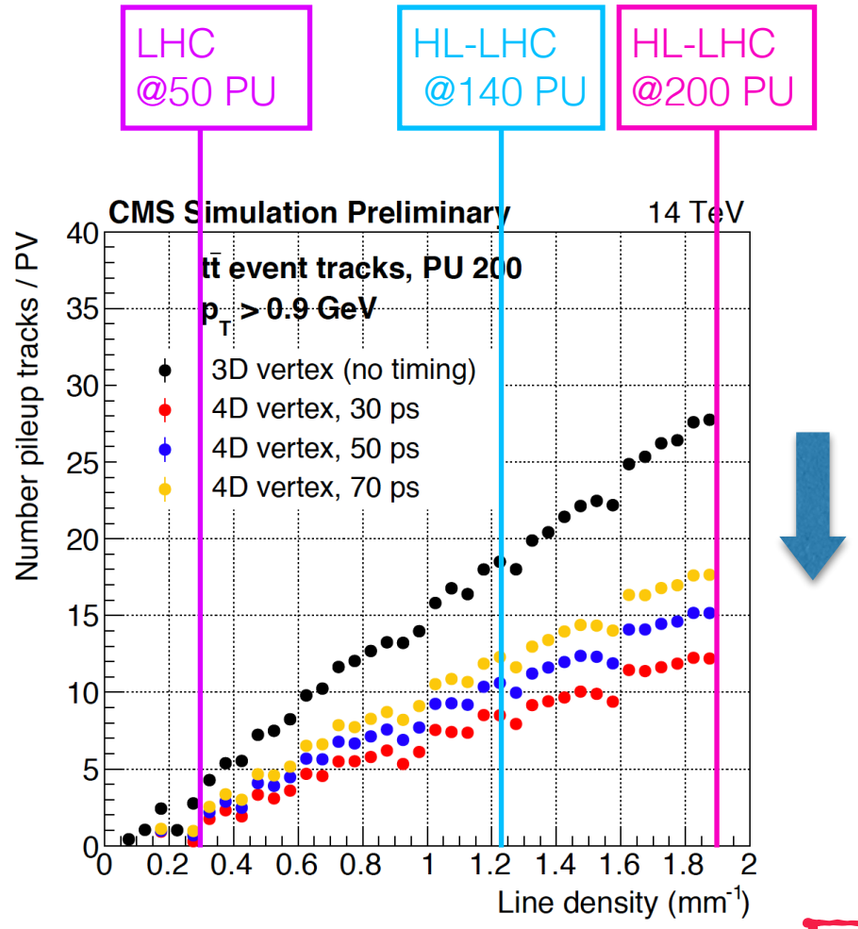


A MIP Timing Detector agaisnt Pileup

- 4D Vertexing: **vertex overlapping in z might not overlap in time**
- Require time compatibility within O(30ps) for **track vertex association**
- Better time resolution better separation

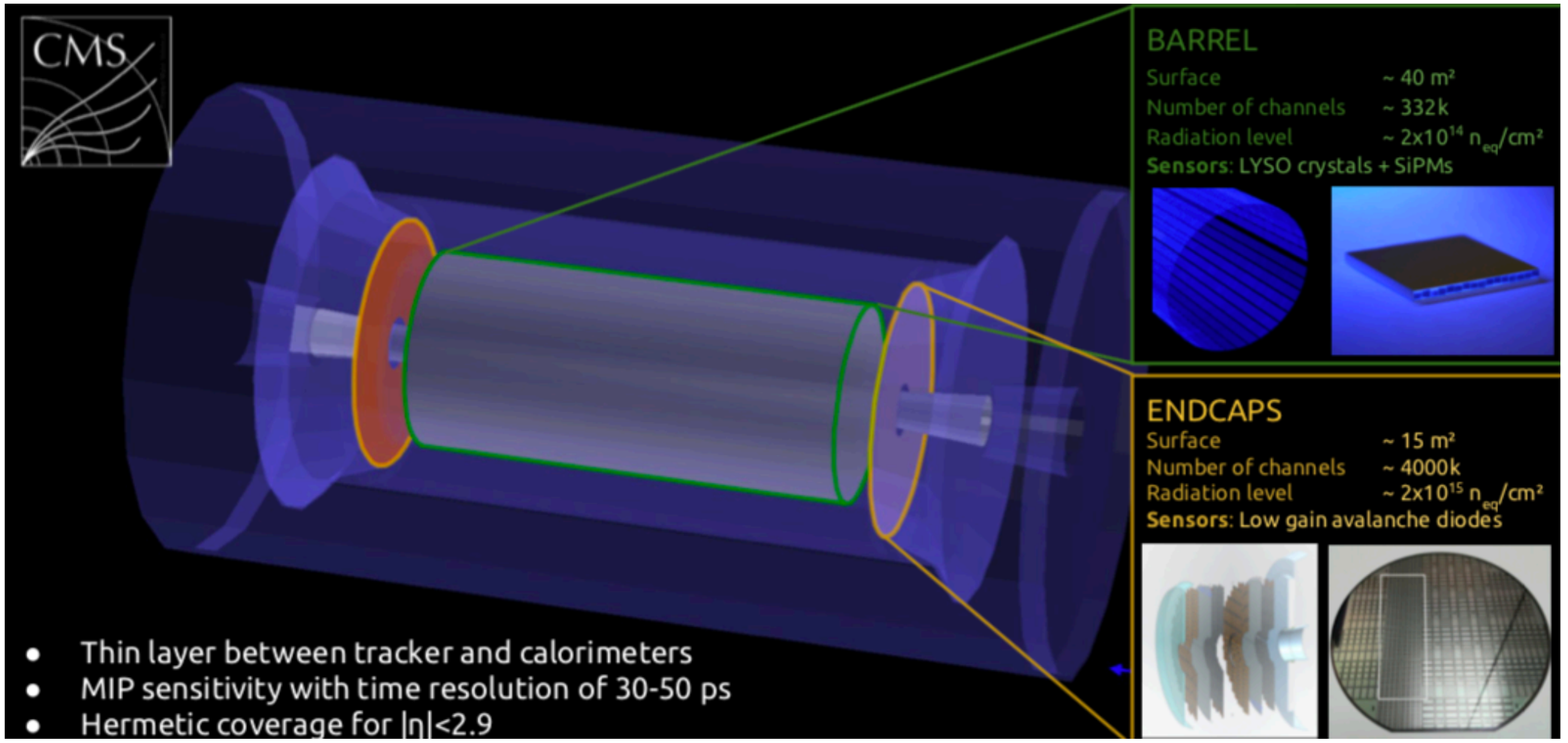
  - Effectively **reduce actual pileup** to level of the current LHC well handled by CMS detector *(by slicing the beam spot in consevutive time exposures)*





Detector Layout

- **Hermetic detector** with different technologies optimized for different radiation levels



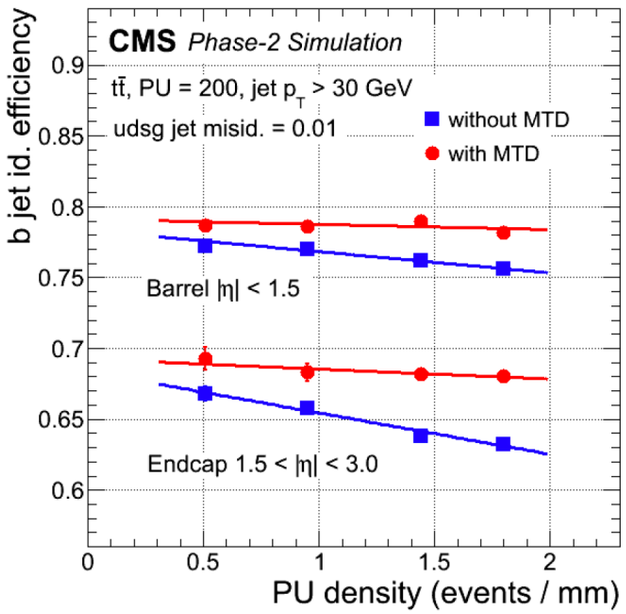
- **BTL: LYSO:Ce crystal bars** with double readout **SiPMs**
- **High and Fast signal**: Dense (>7.1 g/cm3), bright (40k ph/MeV)
- Rise time O(100ps) and decay time O(40ns)

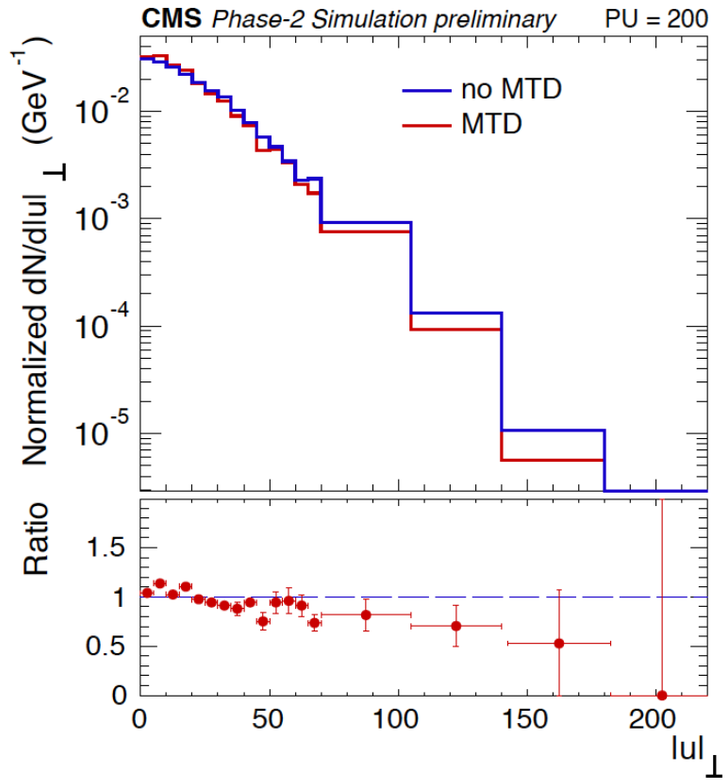
- **ETL: Low Gain Avalanche Diodes**
- Radiation tolerance sufficient for endcal fluences

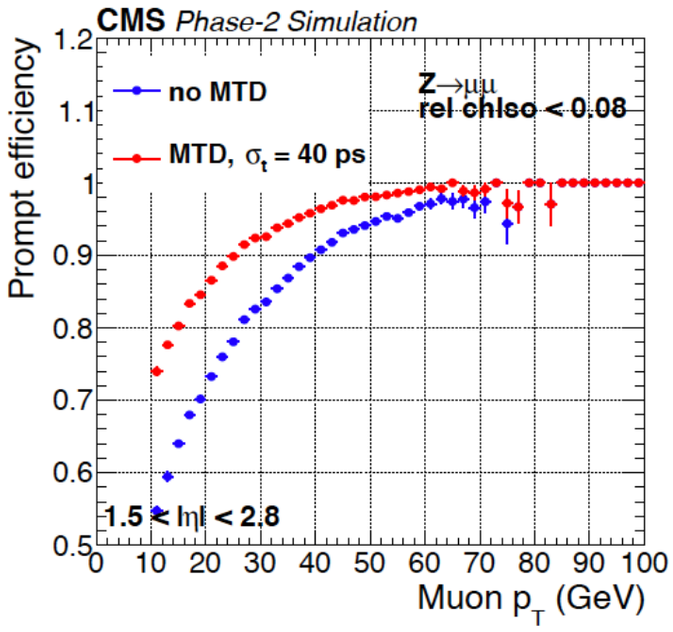
Impact on Performance

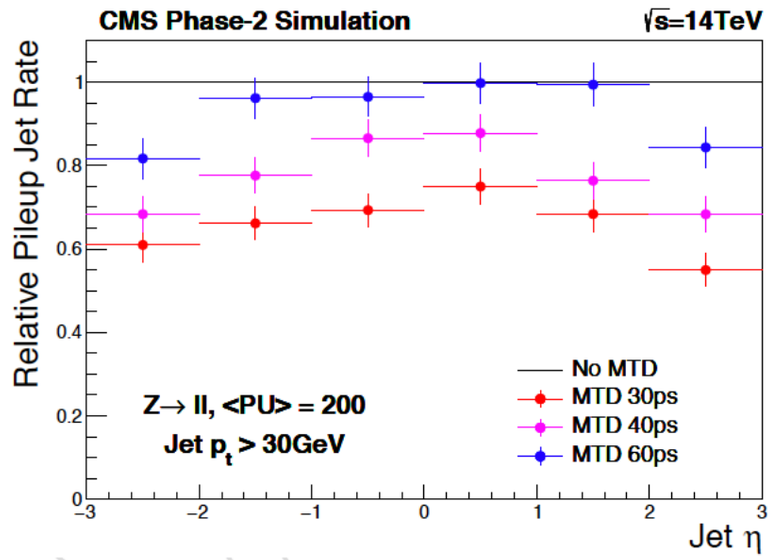
- **Tracks are associated with the primary vertex** with: $|\Delta z(trk, vtx)| < 1mm \quad |\Delta t(trk, vtx)| < 3\sigma_t$
- Reduction of pileup enhances the **quality of CMS particle reconstruction at HL-LHC**

- Increase of **b-tagging efficiency +6-10%**
- Increase photon and lepton identification efficiency and **isolation +6-8%**
- Improve **missing transverse resolution -5-10%**
- Reduction of fake jets reconstruction due to **pileup -25-40%**







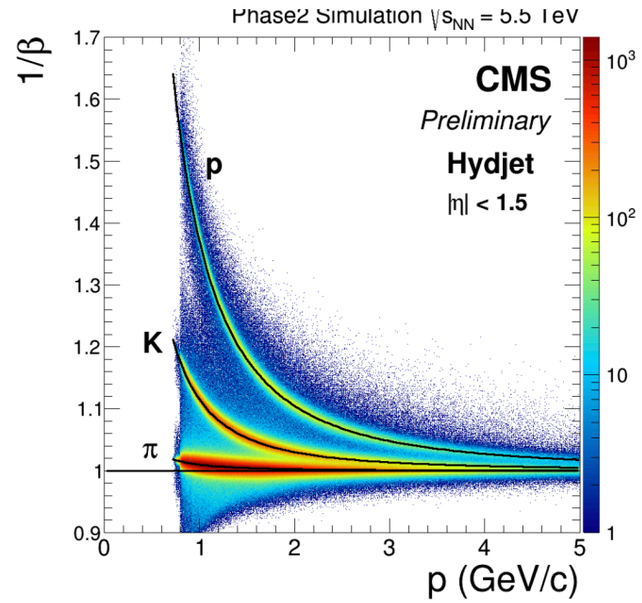


Enabling new physics studies

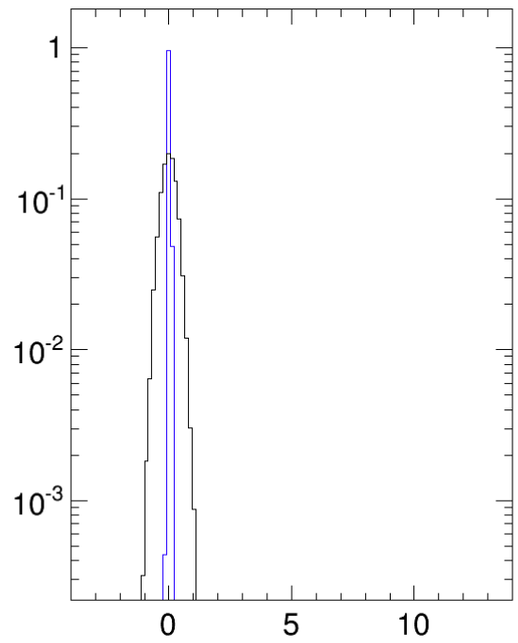
- **Particle ID**: MTD offers unique opportunity for discrimination mechanisms using **TOF information**

$$\frac{1}{\beta} = \frac{c(t_f - t_o)}{L}$$

t_f: time at MTD hit
t_0: time from 4D PV
L: track path length



- **Direct measurement of time of arrival** of displaced objects (photons, leptons,jets)
    - Significant reduction of SM background processes



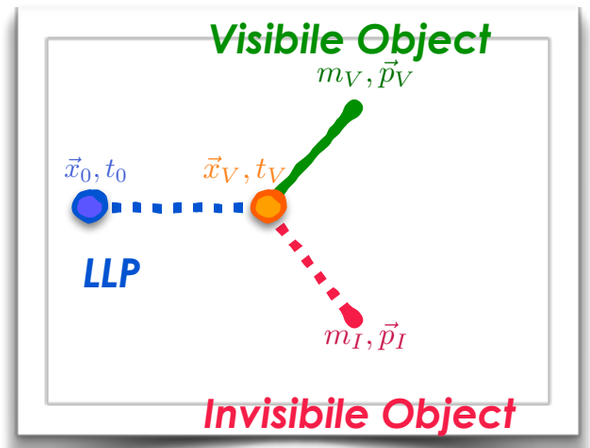
- Direct measurement of the **Long Lived Particles` mass**

Boost visible system to LLP rest frame:

$$E_V^P = \gamma_P \left(E_V^{LAB} - \vec{P}_V^{LAB} \cdot \vec{\beta}_P^{LAB} \right)$$

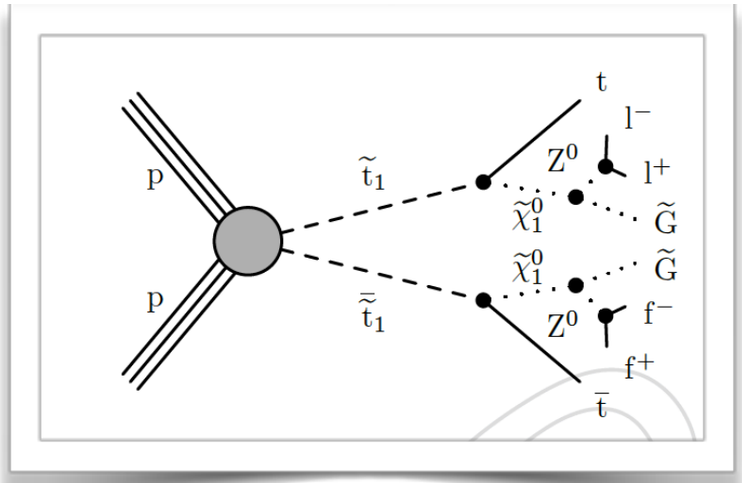
Beta being known, calculate LLP mass:

$$m_P = E_V^P + \sqrt{E_V^{P^2} + m_I^2 - m_V^2}$$

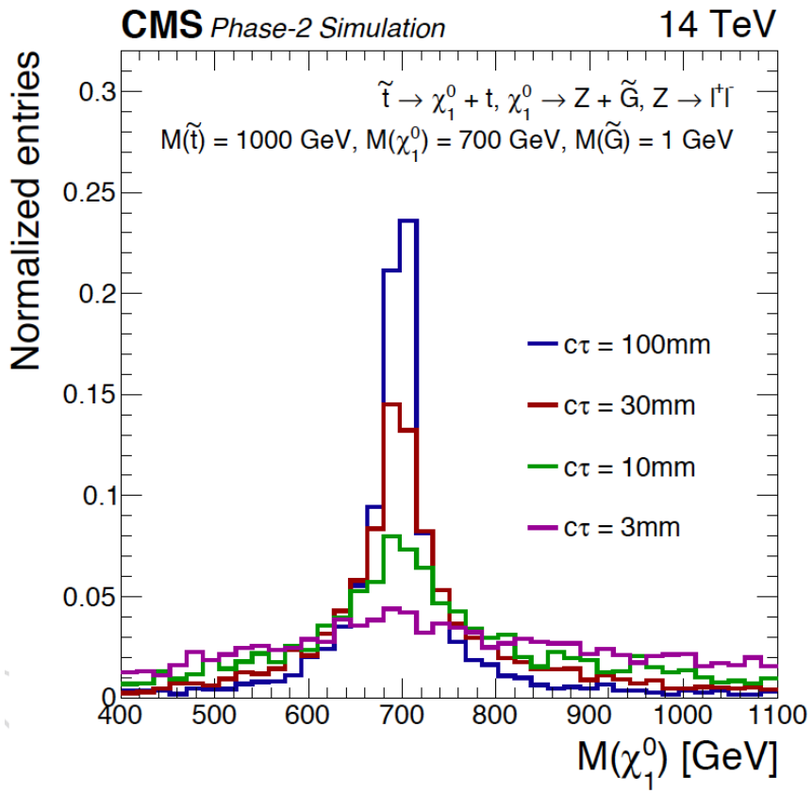


Displaced Leptons

- Stop production with LL neutralino decaying into Z (dileptons) and Gravitino
- Basic selection: 2 OS leptons pT > 20 GeV and |eta|<2.8 + mZ constraint
- Discrimination power: cut on **time difference between the production and the decay vertex**

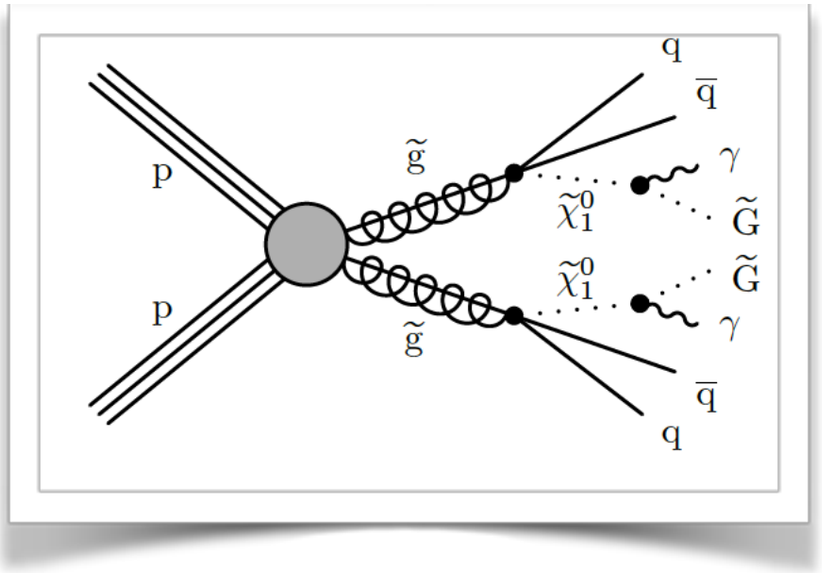


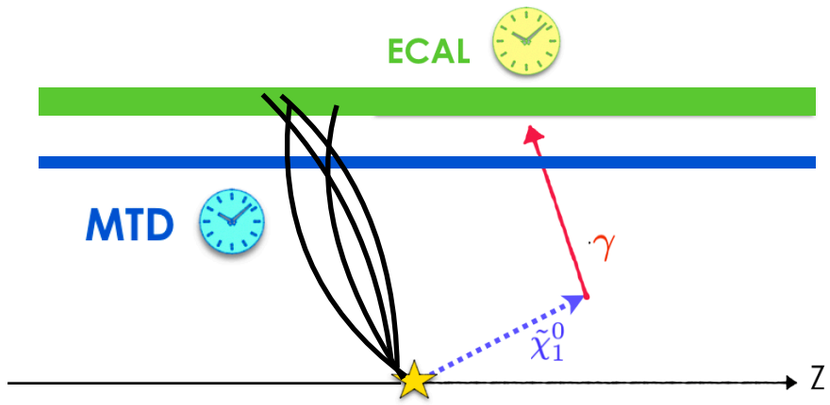
- Measure the v**elocity of the neutralino** and kinematics properties of the visible decay products
- Infer the **neutralino mass** under the assumption of a massless gravitino



Displaced Photons

- Gluino production with a LL neutralino decaying into photon and Gravitino.

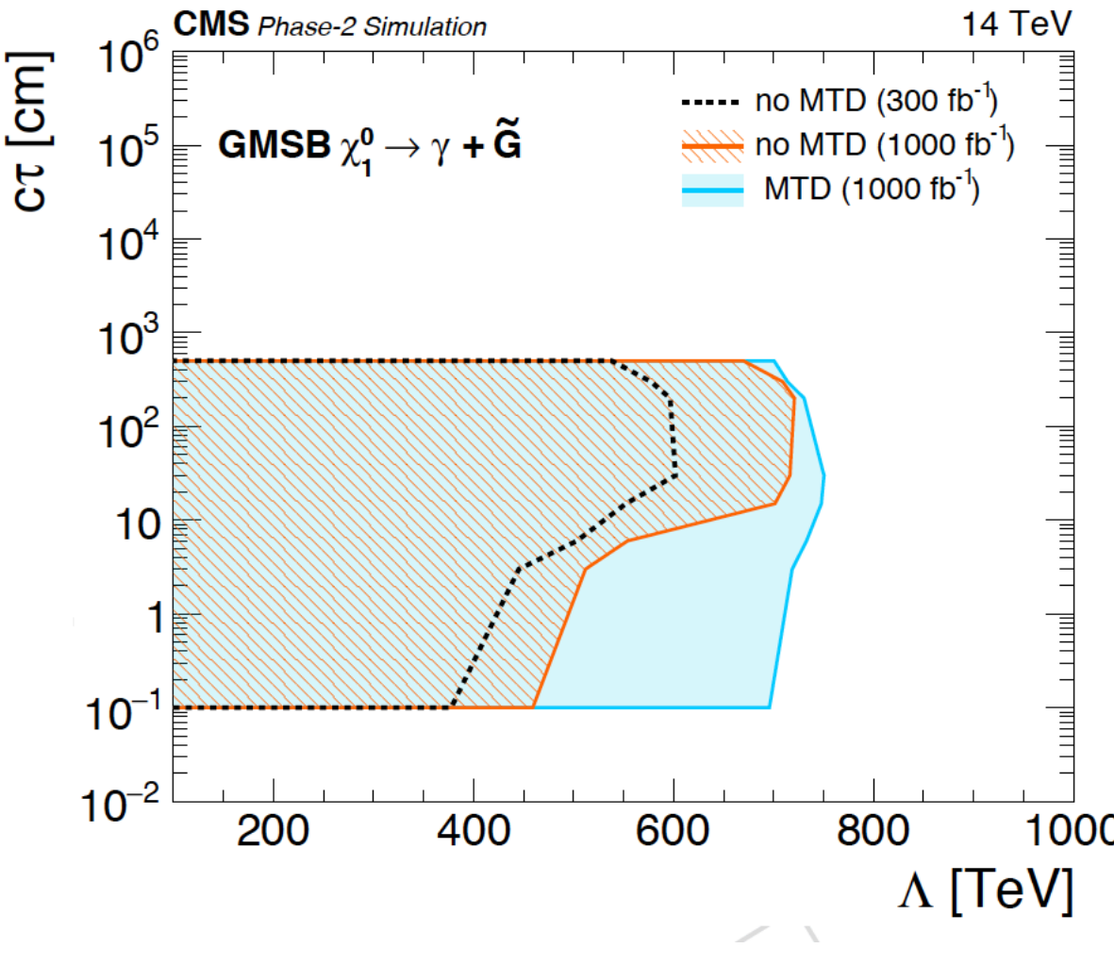




- The **time difference** between the photons and the PV is used to discriminate signal events.

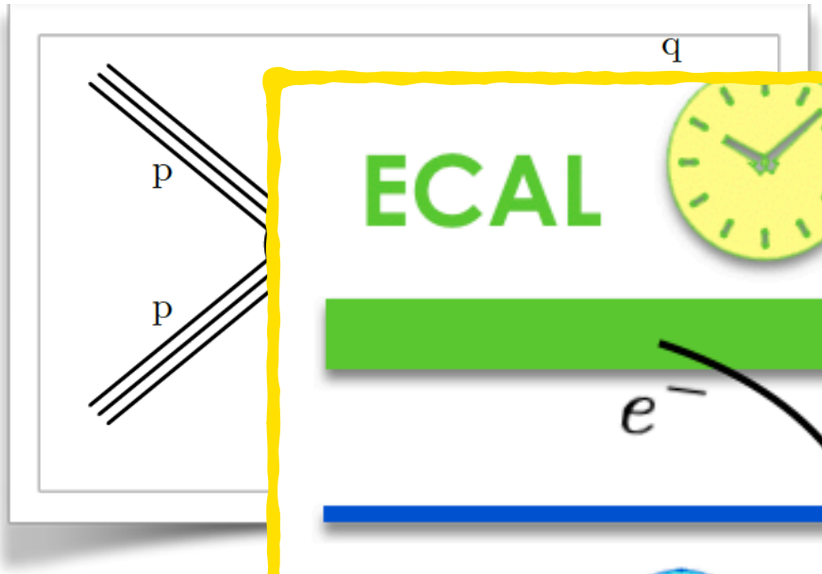
- Exploit **MTD to reduce BS timing information** crucial to **evaluate photons TOF w/ ECAL**

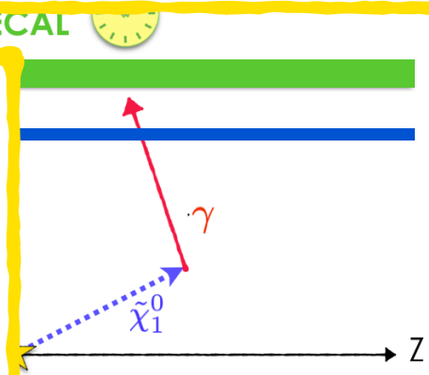
- Sensitivity of the analysis is explored requiring at least one displaced photon and making a 0 background assumption.

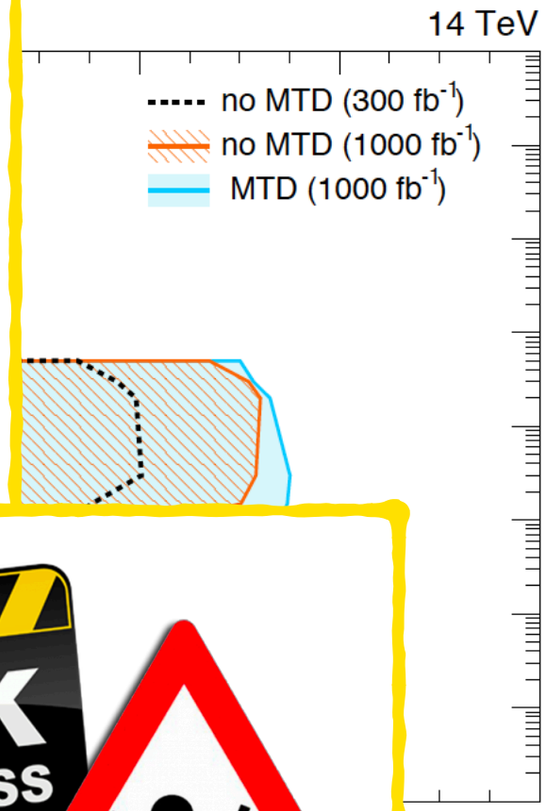


Displaced Photons with conversions

- Gluino production with a LL neutralino dec







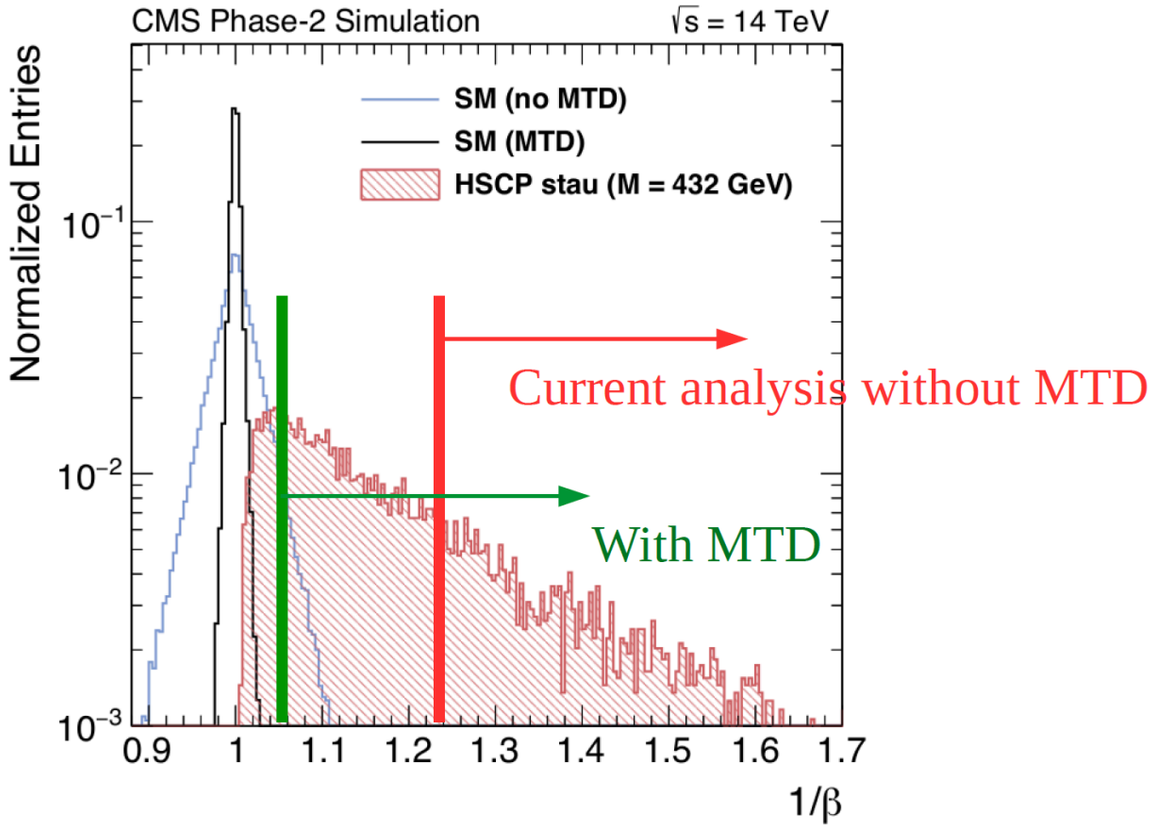
- The **time differe** and the PV is us events.

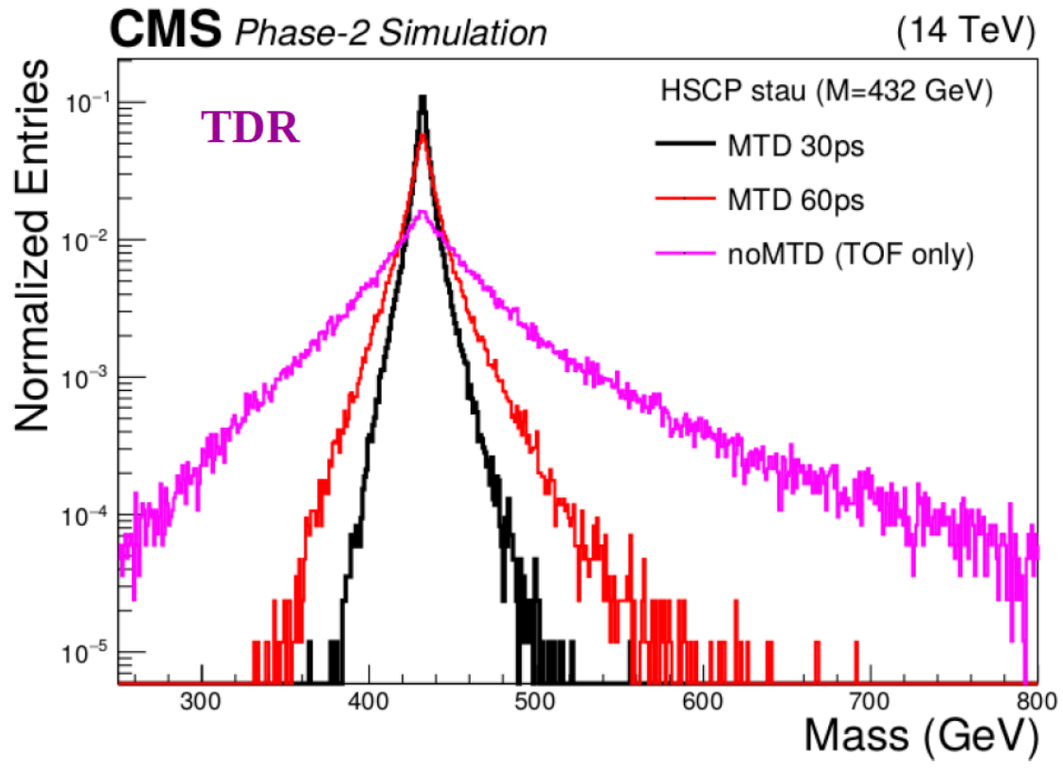
- Exploit **MTD to red** crucial to **evaluat**

- Sensitivity of the a at least one displaced photon and making a 0 background assumption.

HSCP

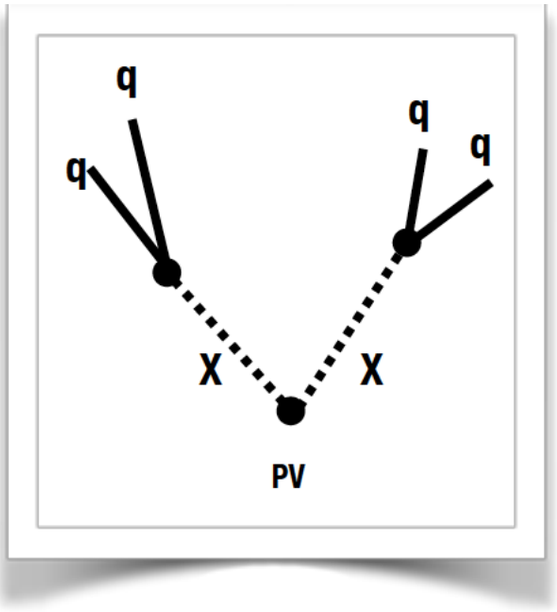
- Long-lived staus in a GMSB model **moving slowly through the detector.**
- Energy loss dE/dx used w/ **TOF** (HSCP masses > 100 GeV → $\beta < 0.9$)
- MTD allows to reduce the uncertainty in $1/\beta$ to improve the **discrimination power**.





- For the same background level a **factor 4 gain in signal**
- **Higher acceptance** since HSCP time can be measured just after tracker.
- **Mass of the HSCP** can also be reconstructed using β and the 4-momentum

Displaced Jets



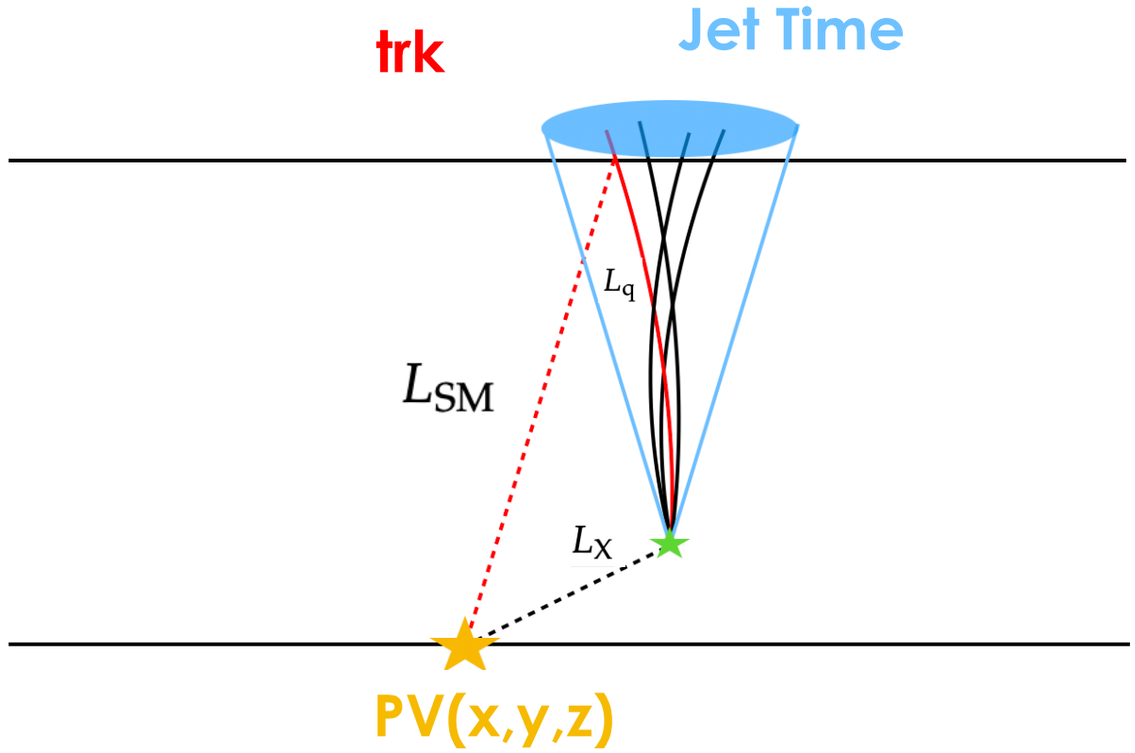
- Higgs decays in two LLP each decaying hadronically into two jets

- Madgraph model from theorists (thanks Zhen!!!)
  - **h → XX → qqqq**
  - mX = 50 GeV
  - **Various lifetimes of X**:
  - cτ = 1mm, 10mm, 100mm, 1000mm, 10000mm, ..

Generator-level study

- Cluster particles within ΔR < 0.3 of a quark or a jet
- Calculate Δt of arrival to MTD
- Smear time to match MTD resolution (30ps)
- Jet time = average of constituents' time

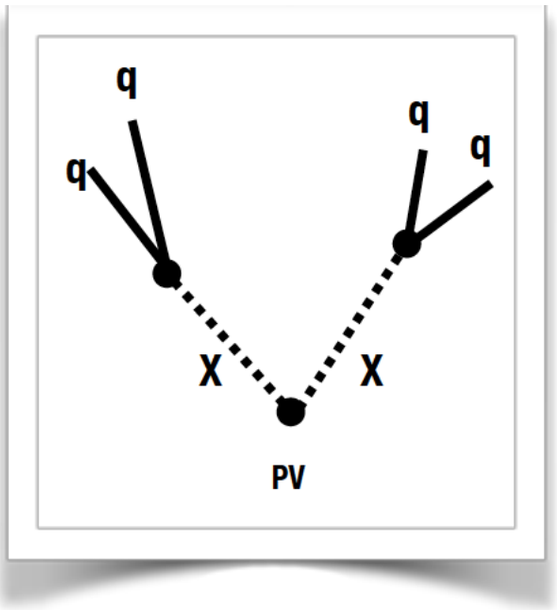
$$\Delta t = \frac{L_X}{\beta_X} + \frac{L_q}{\beta_q} - \frac{L_{SM}}{\beta_{SM}}$$



- Large **interest from both experiments and theorists** communities:

arXiv:1805.05957
arXiv:1806.07396
arXiv:1905.07772

Displaced Jets



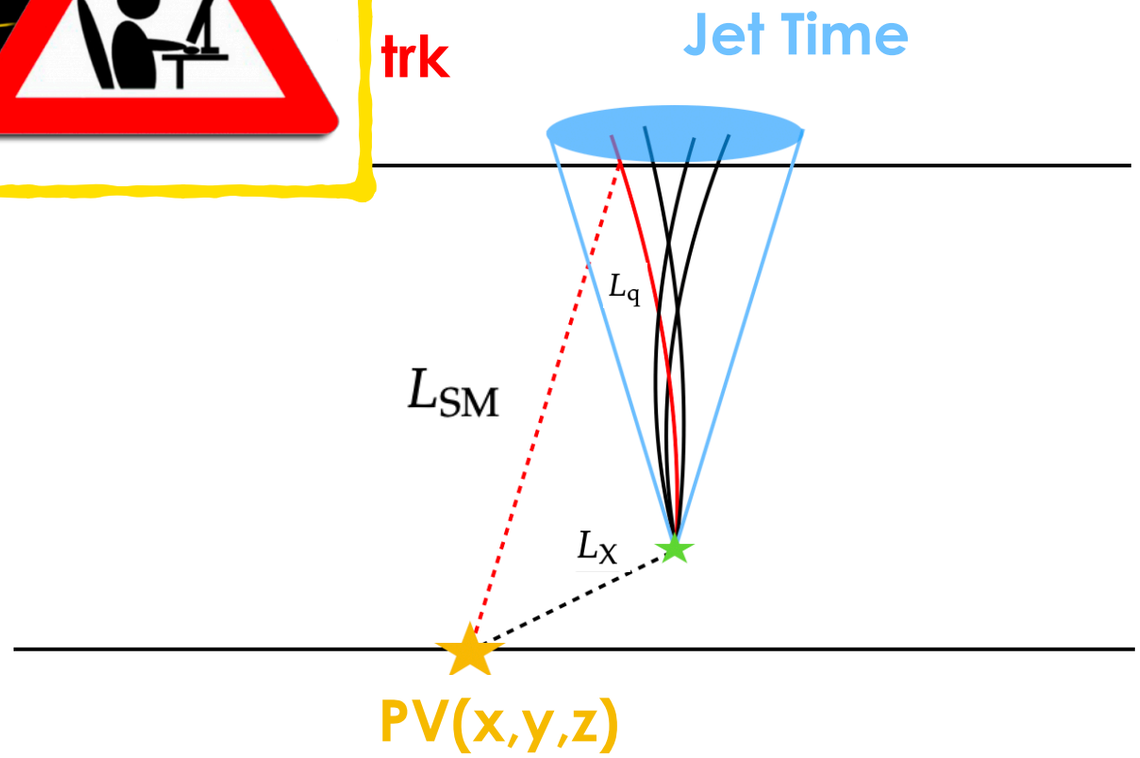
- Higgs decays in two LLP each decaying hadronically into two jets

- Madgraph model from theorists (thanks Zhen!!!)
  - **h → XX → qqqq**
  - mX = 50 GeV
  - **Various lifetimes of X**:
  - cτ = 1mm, 10mm, 100mm, 1000mm, 10000mm, ..

Generator-level study

- Cluster particles within ΔR <
  or a jet
- Calculate Δt of arrival to M
- Smear time to match MTD
- Jet time = average of cons

$$\Delta t = \frac{L_X}{\beta_X} + \frac{L_q}{\beta_q} - \frac{L_{SM}}{\beta_{SM}}$$



- Large **interest from both experiments and theorists** communities:

arXiv:1805.05957
arXiv:1806.07396
arXiv:1905.07772

Conclusions

- **CMS upgrade for HL-LHC**: adding a timing detector for charged particles
- Target: **30-40 ps time resolution**, hermetic coverage
- Full CMS physics program would benefit
- Dramatically **improvement discovery potential for new searches**

LLP are a clear physics cases for the MTD *in two ways:*

It offers **new discrimination mechanisms** (time difference to PV)

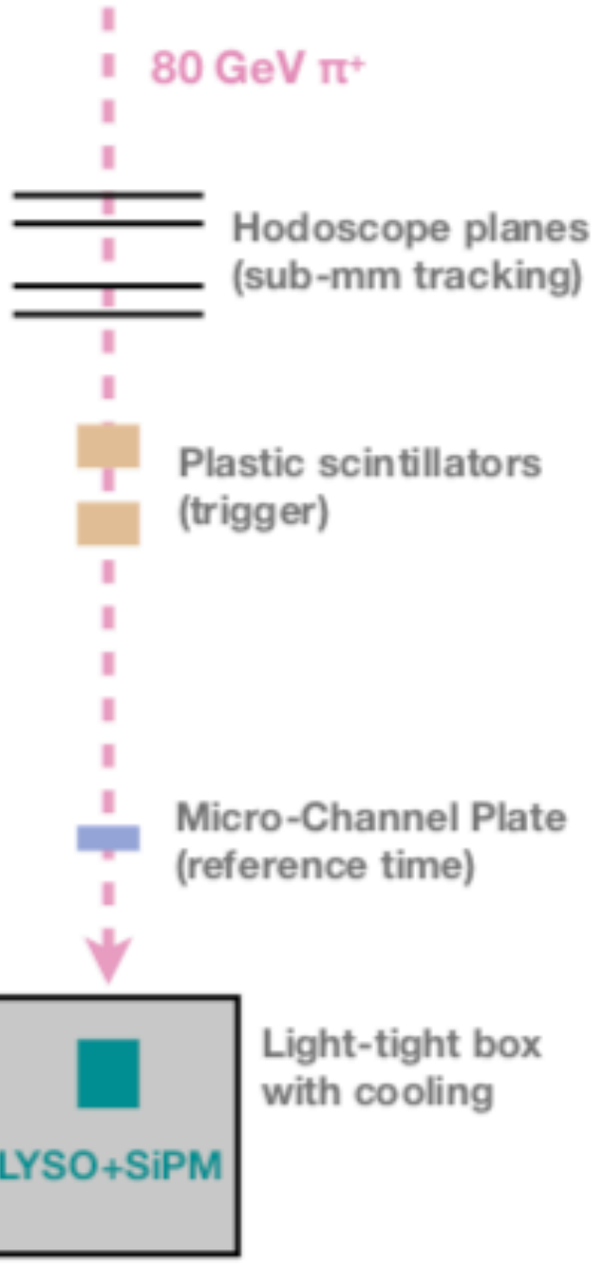
It also offers the possibility of **measuring properties of the LLP** like the mass.

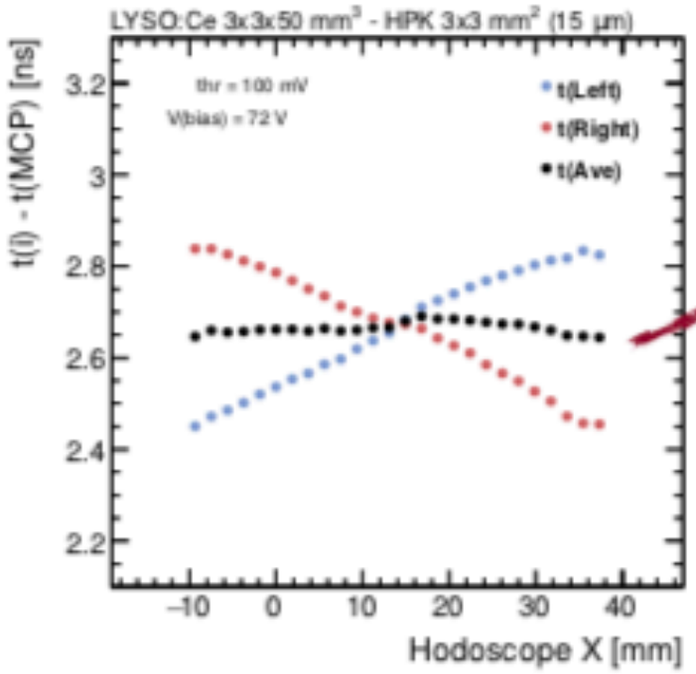
We are exploring new territories and we look forward to walk side by side with our theorists friends!

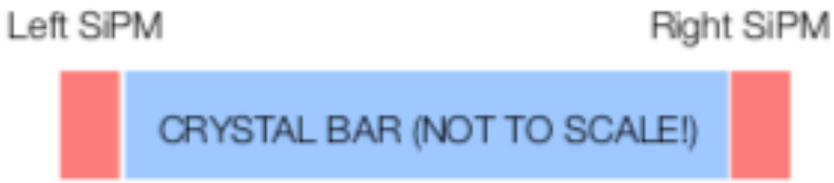
Backup

Region	$\lvert\eta\rvert$	R (cm)	z (cm)	n_{eq}/cm^2	Dose (kGy)
Barrel	0.0	117	0	1.7×10^{14}	16
Barrel	1.15	117	170	1.9×10^{14}	21
Barrel	1.45	117	240	2.0×10^{14}	25
Endcap	1.6	127	304	1.1×10^{14}	25
Endcap	2.0	84	304	2.4×10^{14}	75
Endcap	2.5	50	304	6.6×10^{14}	260
Endcap	3.0	30	304	1.7×10^{15}	690

Beam Tests: 30 ps Resolution Achieved!

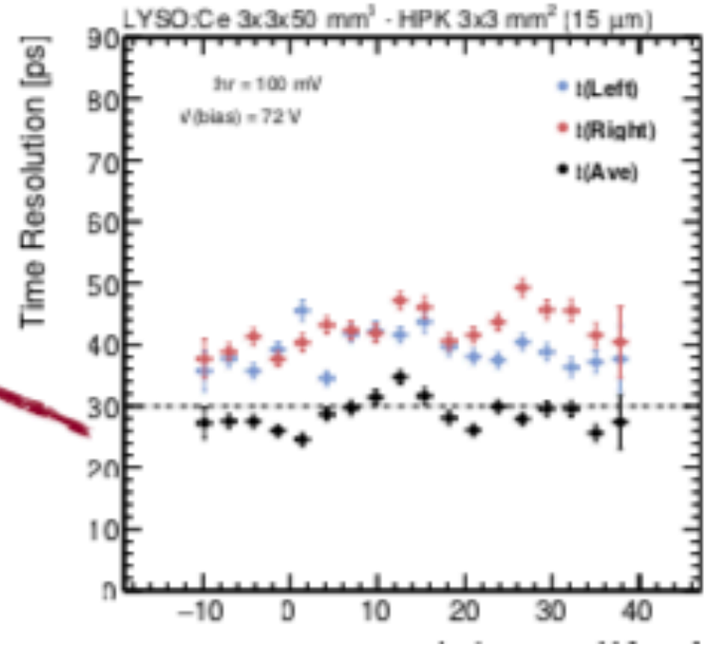




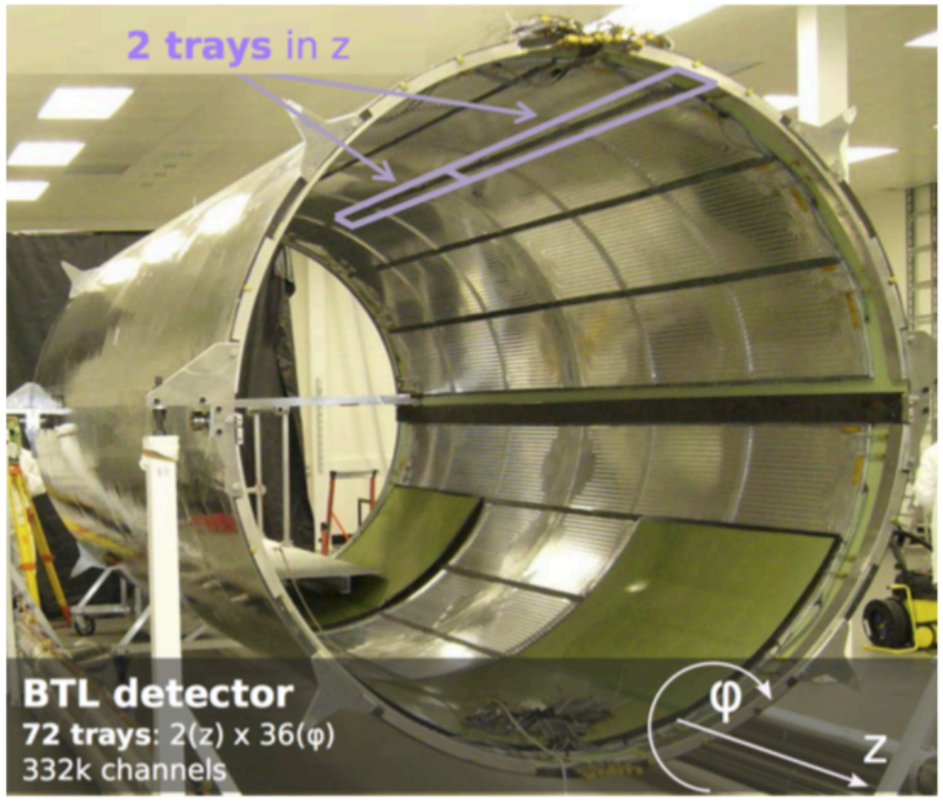


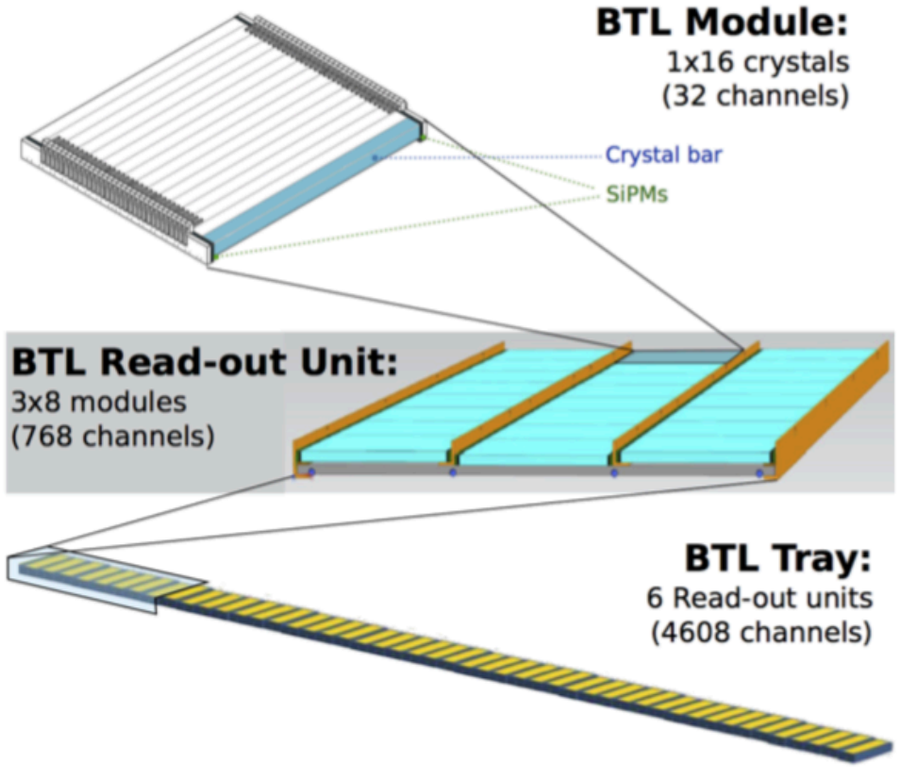
Arrival time on SiPM proportional to distance

Achieved 30 ps resolution
Uniform across bar length



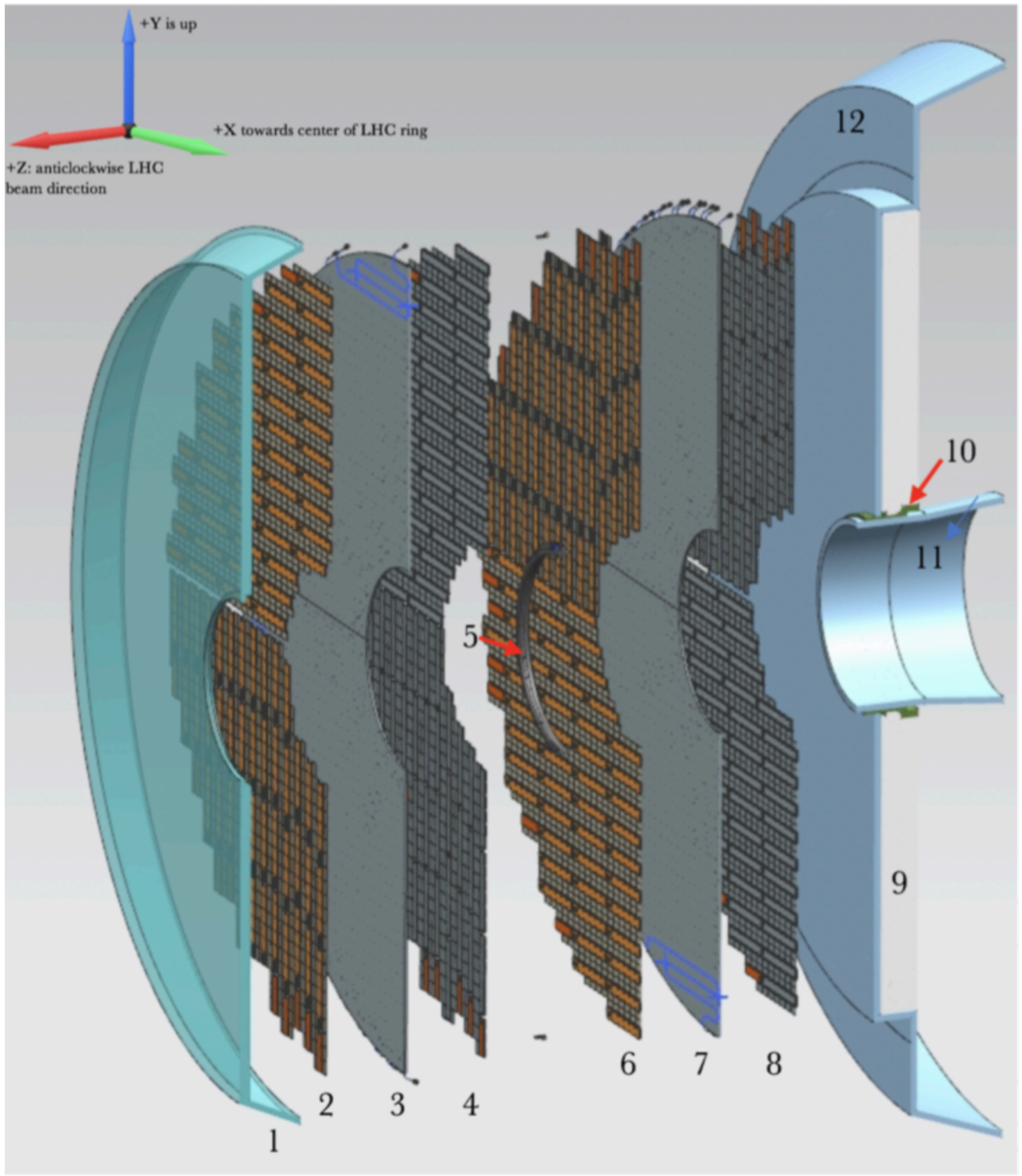
BTL Integration and Geometry





- Integrated with **tracker**
  - Will share services (cooling) with tracker
- Arrays of LYSO crystal bars (50×3 mm²)
  - Aligned in z direction
  - Read out by 2 SiPMs (one per side)

Endcap Timing Layer Layout and Geometry



- Two disks of LGADs
  - Two hits needed to achieve target 30-40ps timing resolution
- Each disk has LGADs on both faces
  - 90% acceptance per disk
- Currently evaluating LGADs from three producers:
  - CNM (Spain)
  - FBK (Italy)
  - Hamamatsu (Japan)

Endcap Timing Layer: the Radiation Challenge

- ETL will cover $1.6 < |\eta| < 3.0$
  - Higher radiation dose
  - Highly non-uniform in $|\eta|$
- SiPMs not radiation hard enough
  - Will use silicon LGADs (Low Gain Avalanche Detectors)
  - Internal gain: 10-30

AFTER 4000 fb^{-1}

	$\lvert\eta\rvert$	Hadron Fluence (n_{eq}/cm^2)	Dose (kGy)
BARREL	0	$1.7 \cdot 10^{14}$	16
	1.15	$1.9 \cdot 10^{14}$	21
	1.45	$2.0 \cdot 10^{14}$	25
ENDCAP	1.6	$1.1 \cdot 10^{14}$	25
	2	$2.4 \cdot 10^{14}$	75
	2.5	$6.6 \cdot 10^{14}$	260
	3	$1.7 \cdot 10^{15}$	690

×30