Timing the Pulses of BSM physics

Zhen Liu (Fermilab)

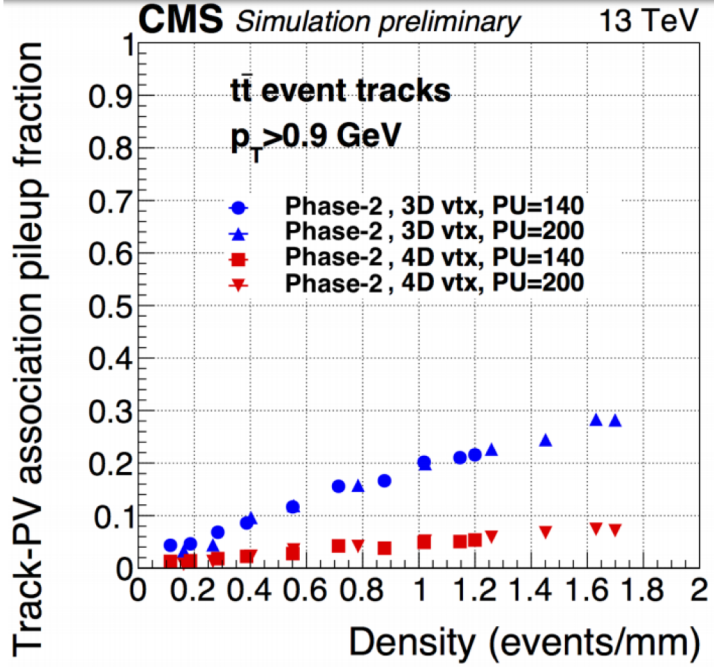
Pheno 2018

May. 7th , 2018

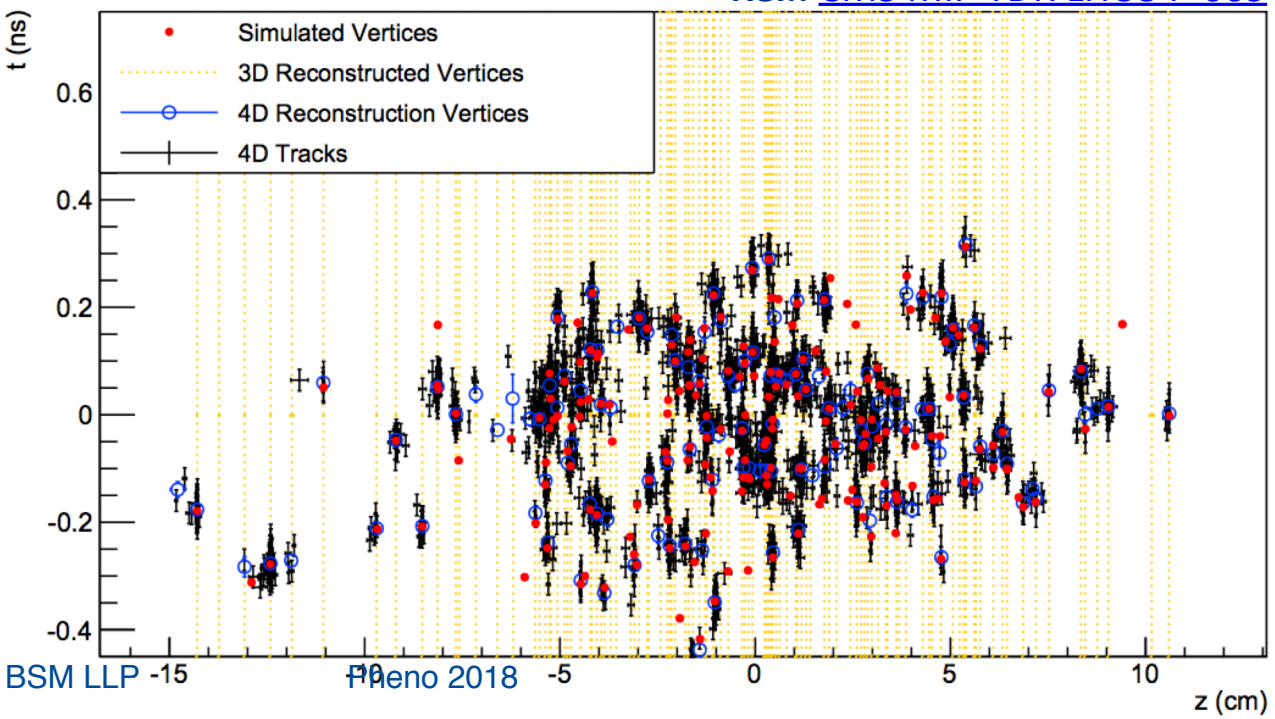
Based on work with Jia Liu and Lian-Tao Wang, to appear

Precision timing

- 30 picosecond timing resolution at CMS after phase2 upgrade (in front of ECal, 1.2 m from beam);
- Proposed to enable 4d construction of vertices:
  - Reducing pile-up track mis-association in to the primary interaction;
  - reducing the pileup level;



Ref.: CMS MIP TDR LHCC-P-009



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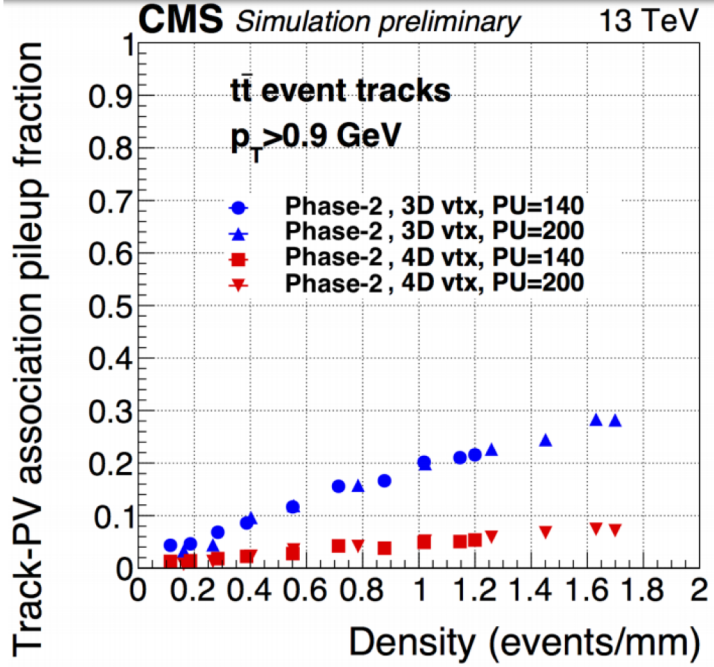

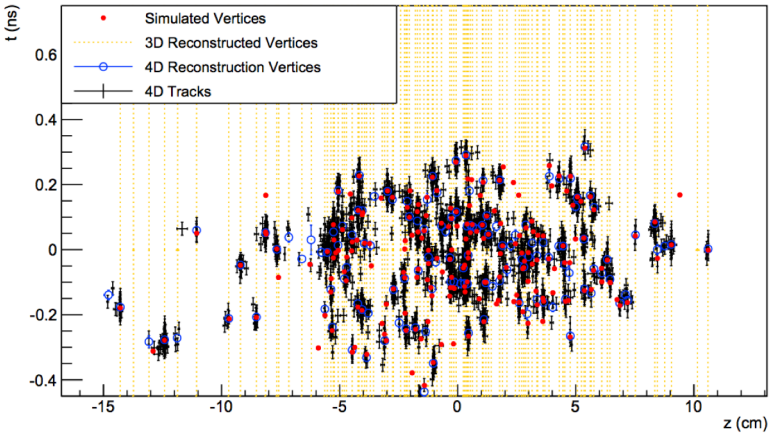

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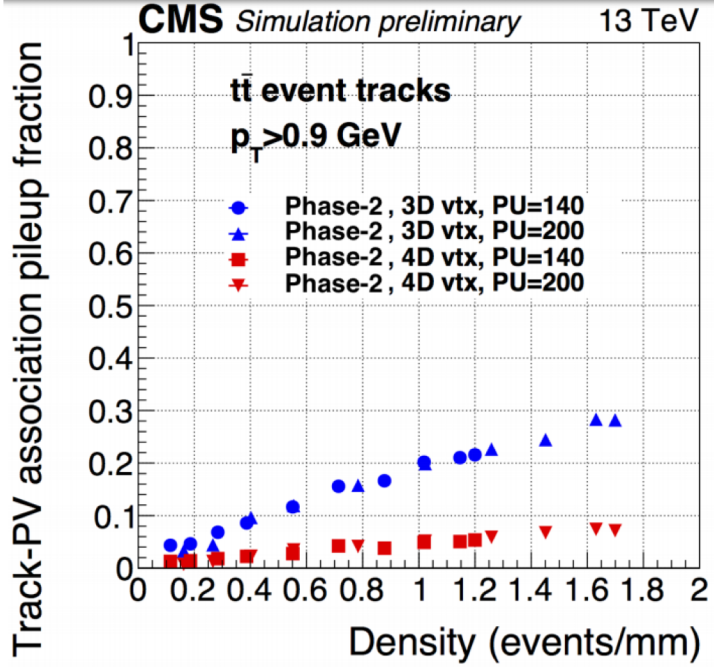

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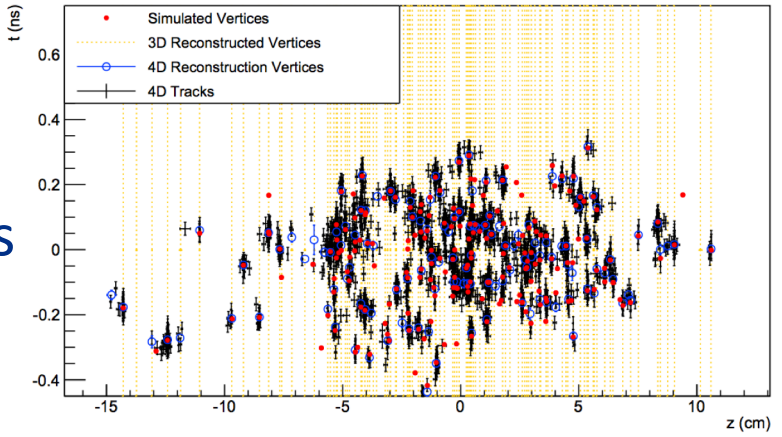
- Time hasn't been used or thought of much as traditional BSM physics signals do *not* behave differently from SM particle background in its time profile.



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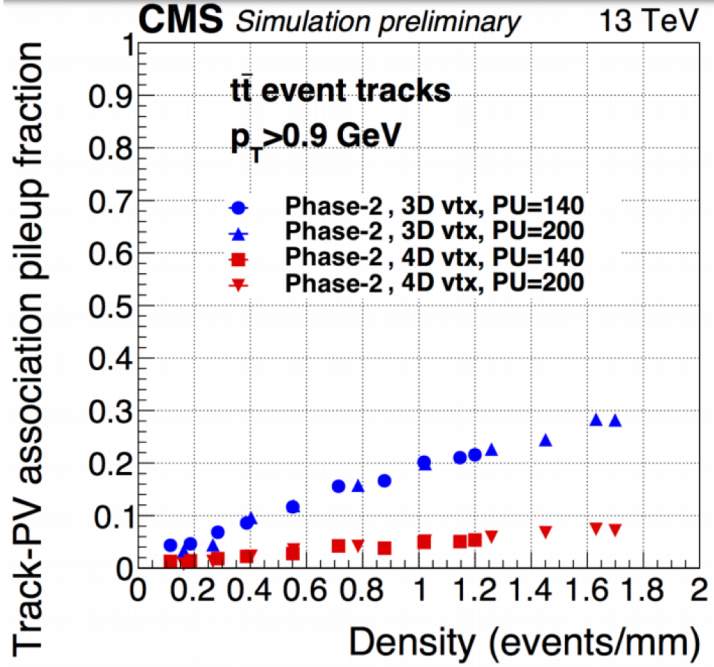

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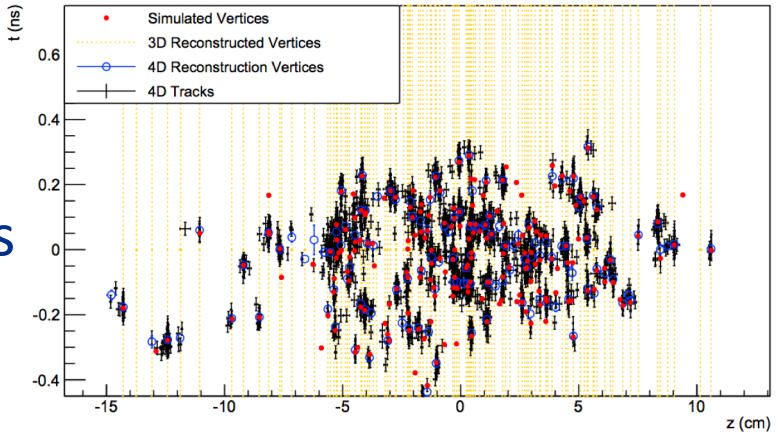


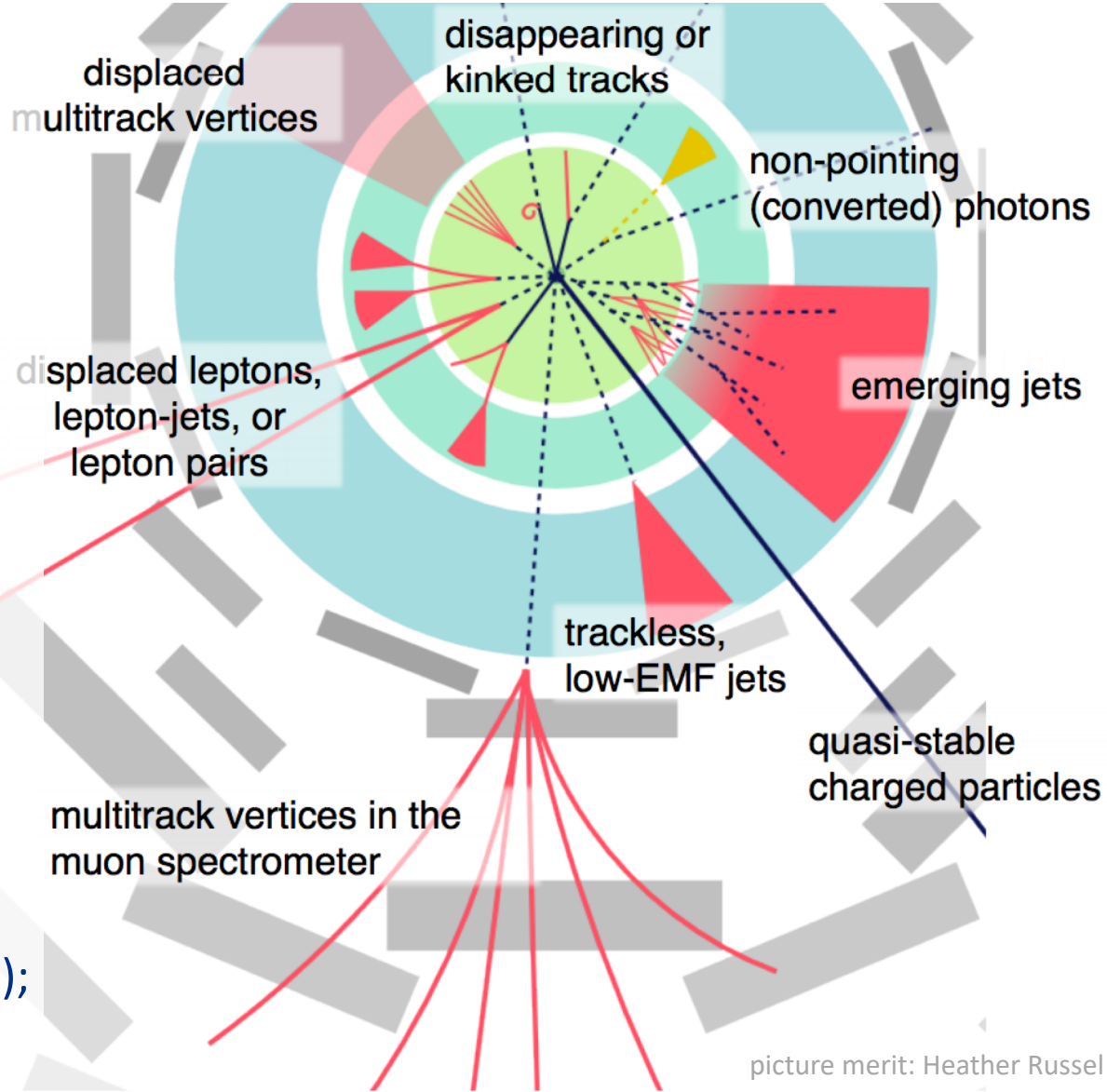
- However, for long-lived particles (whose lifetime is macroscopic >~ mm), they generically move slower and their long-lived nature substantiates their slowness in motion at colliders.

Long-lived particles

current status and challenges also mentioned in *Robin Erbacher's* plenary talk Monday

These nonconventional and rich BSM signatures receives a lot of attention as:

- Theoretically well motivated: SUSY (RPV, GMSB, Split, compressed, etc.), neutral naturalness, hidden valley, dark shower… etc;
- Experimentally challenging but bearing great potential for discovery:
  - New signatures could have been missed by conventional searches;
  - Low (zero) background analysis once carried out);



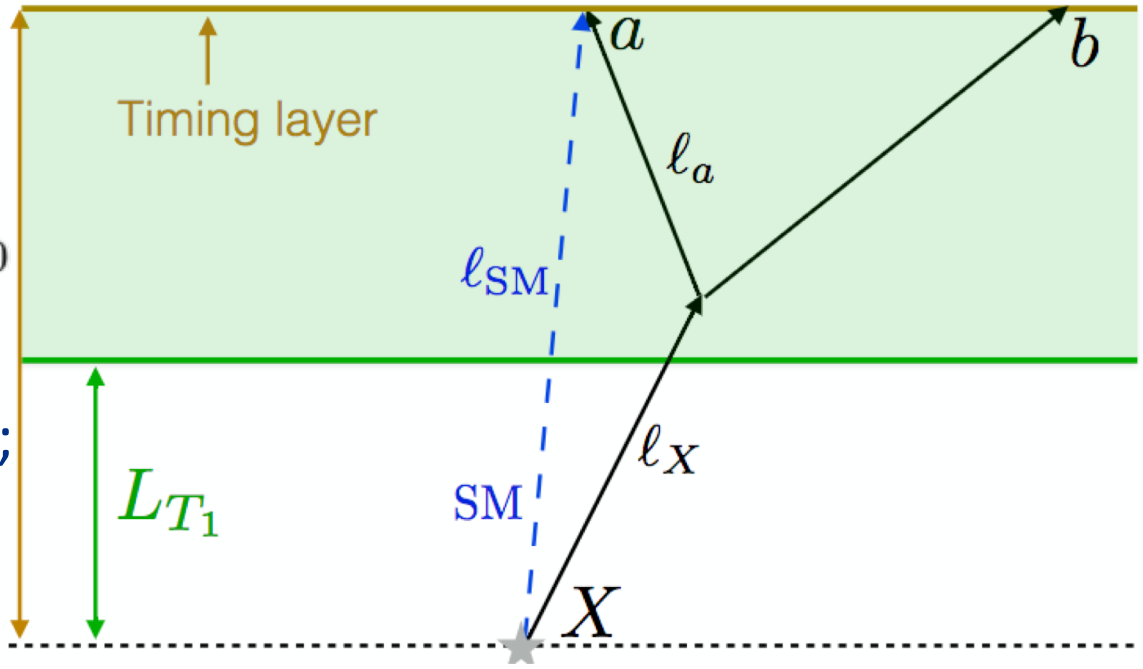
picture merit: Heather Russel

Timing BSM

$$t = \frac{\ell_X}{\beta_X} + \frac{\ell_a}{\beta_a} - \frac{\ell_{\rm SM}}{\beta_{\rm SM}} + t_0$$

t: signal arrival time;

t0: SM particles arrival time;



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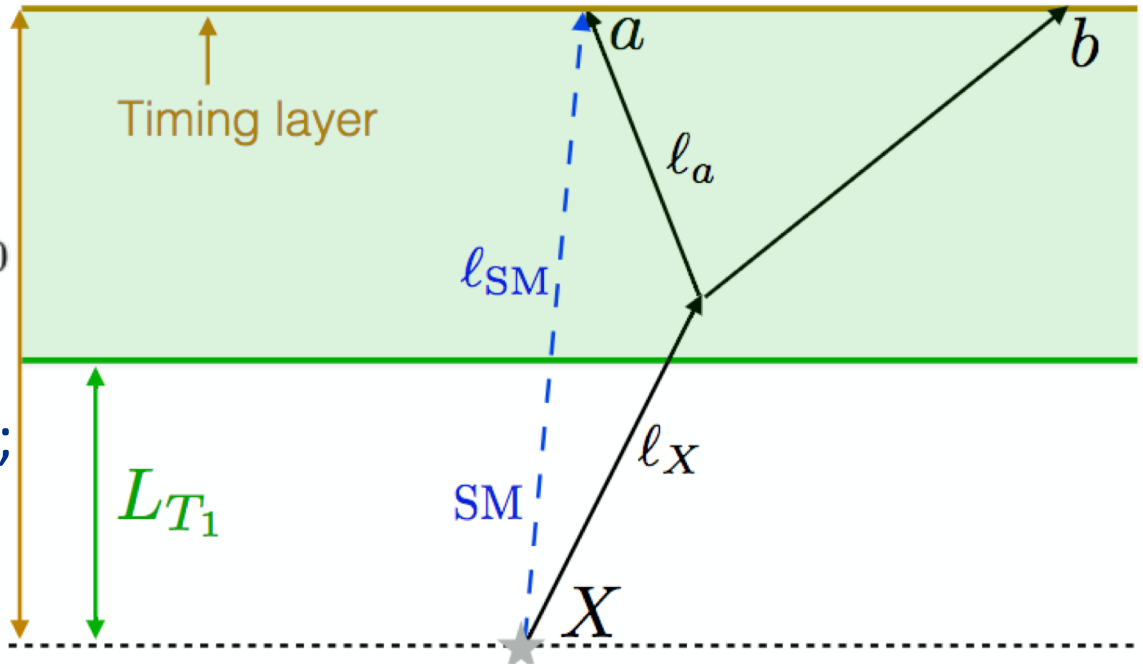


For CMS timing layer (1.2 m, t0=4 nanoseconds)*, 30 picosecond timing resolution indicates sensitivity to BSM signal having 1% velocity (path) difference w.r.t. SM particles!

LLP (with mass > 10s of GeV) typically all have much slower motion!

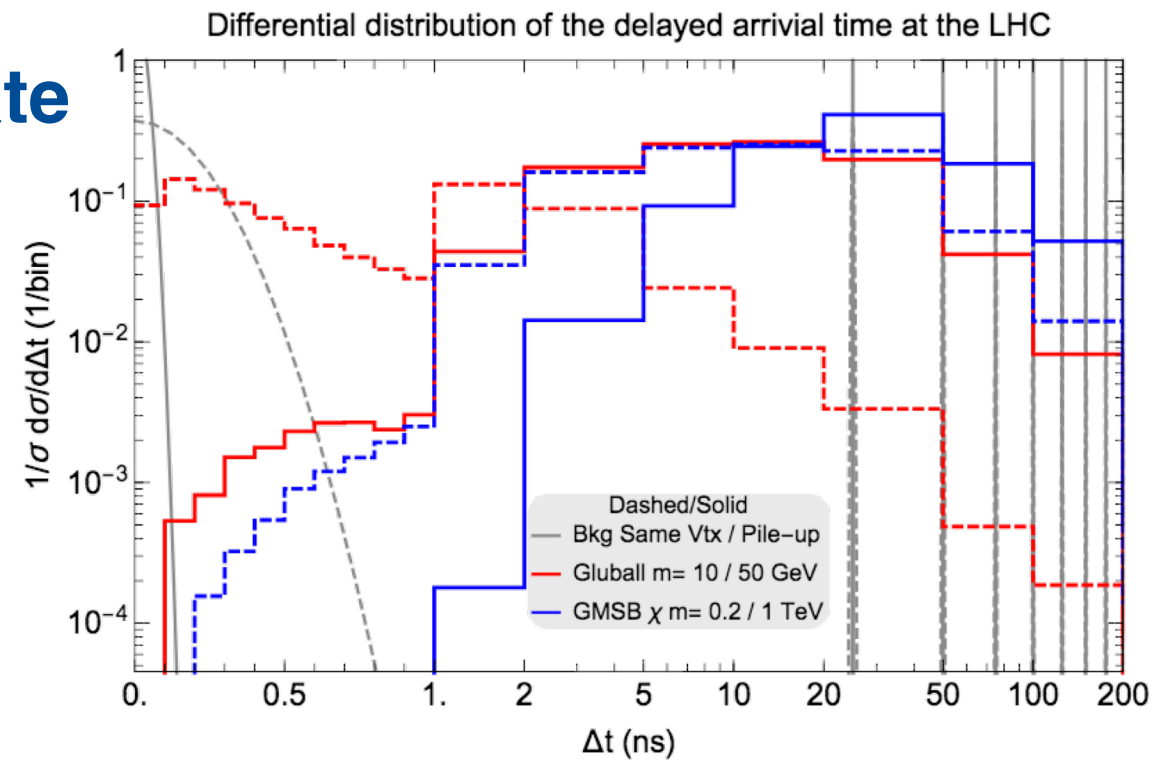
*for pseudorapidity 0; higher rapidity enlarges the timing difference;

*SM particles essentially all travel at speed of light;

LLPs arrive (very) late

$$t = \frac{\ell_X}{\beta_X} + \frac{\ell_a}{\beta_a} - \frac{\ell_{\rm SM}}{\beta_{\rm SM}} + t_0$$

We also consider a possible timing layer outside Muon spectrometer, making use of the large LHC detector volume.



Signals:

- Red: Higgs decaying into gluballs (neutral naturalness)
  Representative as particles produced with typical pT;
- Blue: Higgsinos (GMSB SUSY)
  Representative as particles pair produced at the LHC;

ctau=10 m, assuming timing layer at 10.6 m (ATLAS MS)

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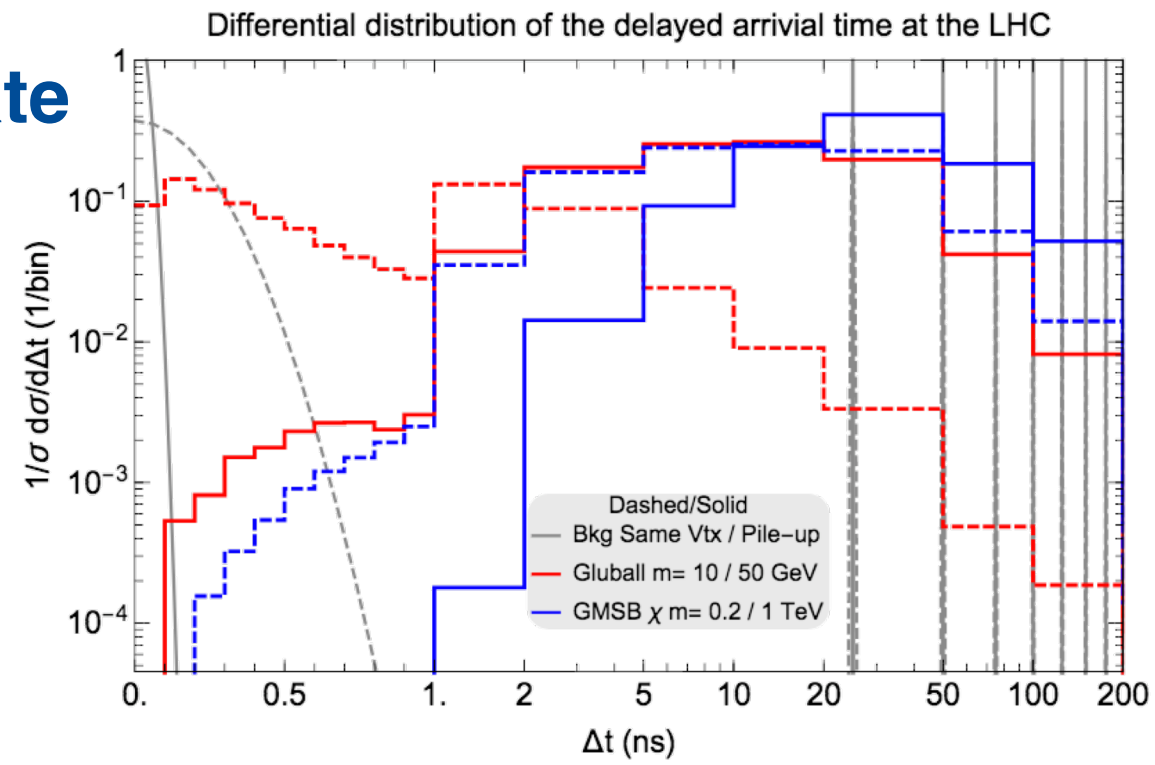

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Backgrounds:

- Gray (Dashed): Pile-up with natural spread of 190 ps (beam property)
- Gray (Solid): Hard collision spread due to uncertainties in timing

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Late comers will be spotted easily:

	L_{T_2}	L_{T_1}	Trigger	ϵ_{trig}	ϵ_{sig}	$\epsilon^{j}_{\text{fake}}$	Ref.
EC	1.17 m	0 m	DelayJet	0.5	0.5	10^{-3}	[6]
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CMS timing module

ATLAS MS LLP search (without timing)

Designed 2 generic search: no restriction on the signal, as long as they can deposit energy (25 GeV pT min);

Huge dijet and pile-up background can be rejected use timing alone;

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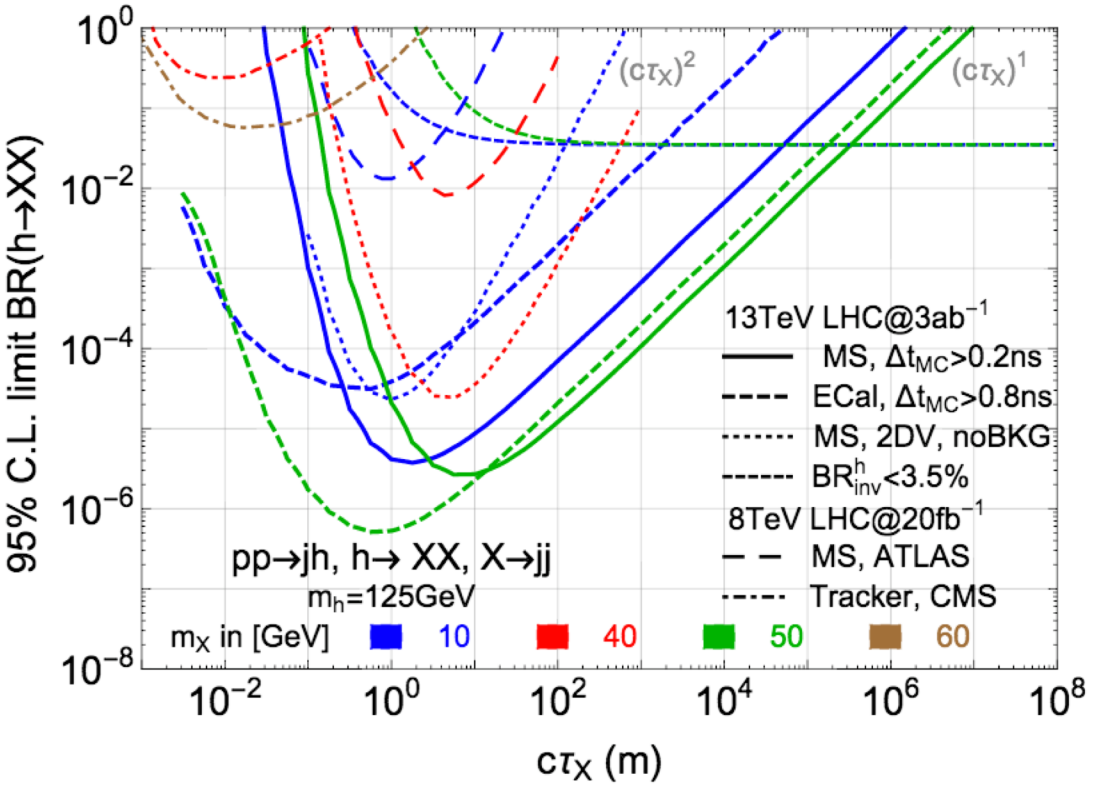

8 TeV results from C. Csaki, E. Kuflik, S. Lombardo, O. Slone, 1508.01522

13 TeV MS search projection (w.o. timing), C. Coccaro, D. Curtin, H. Lubatti, H. Russell, J. Shelton 1605.02742

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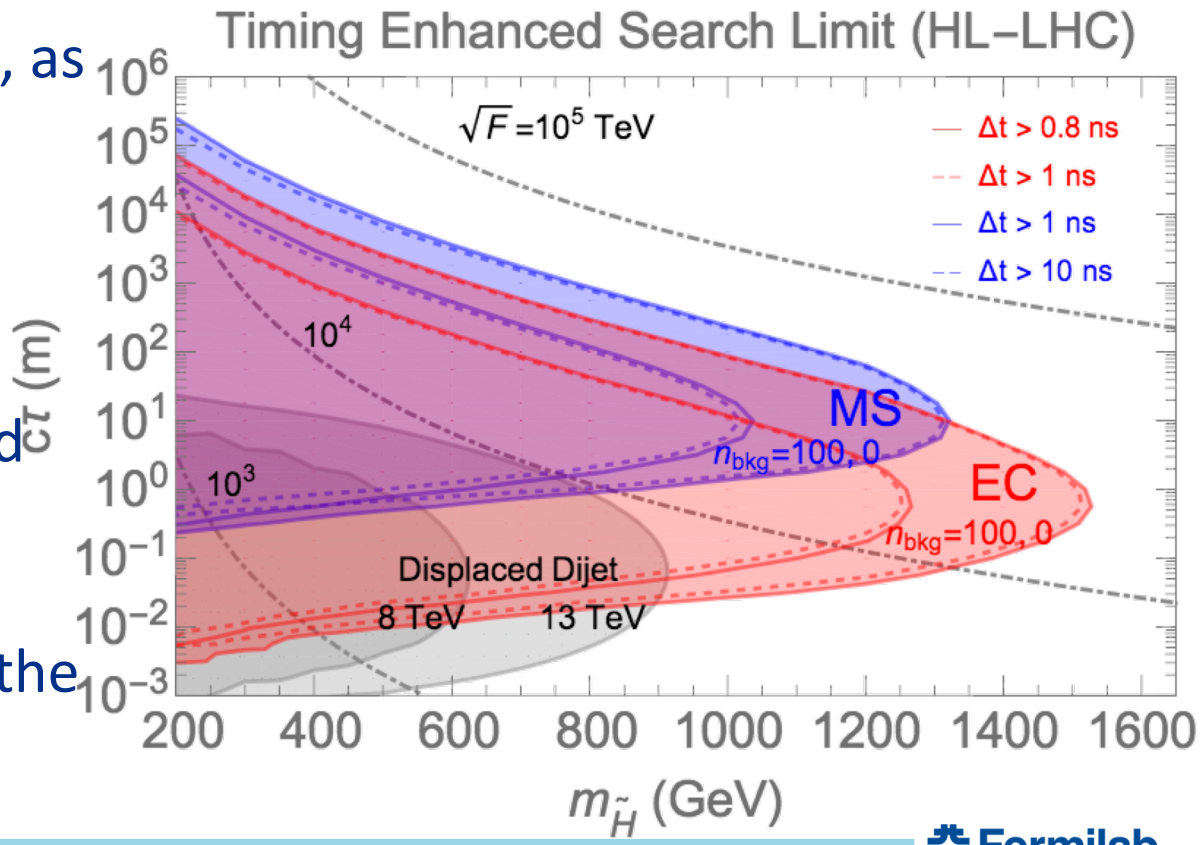

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For comprehensive 8 TeV analysis, see **ZL**, B. Tweedie **1503.05923**

Summary and outlook

- LHC great detector for LLP searches, a rich program is still under development;

- All traditional LLP searches should be augmented by the timing information;
- We proposed two new searches: one is ECal based with delayed jet trigger, one is MS based with new timing layer;
- New searches can capture general features of the LLP in a very robust way by exploiting their delayed feature;

- Fun to think more about precision timing as a new piece of particle physics information (to become) available;

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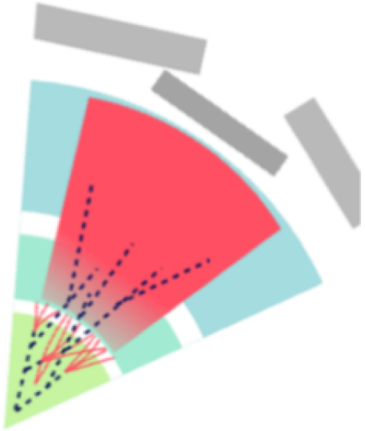
Thank you!

Backup

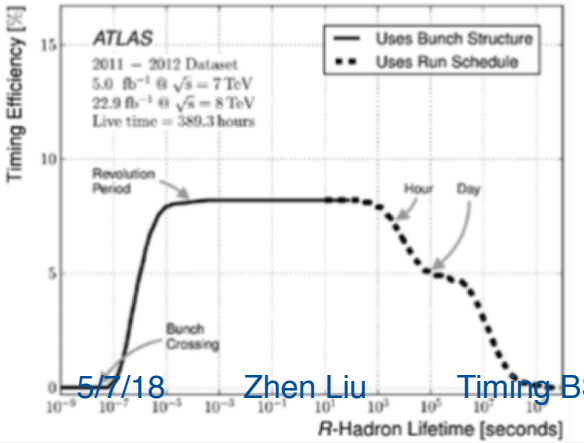
LLPs decaying to hadrons:

- signature could be displaced multi-track vertex
  + resolved jets (CMS, LHCb), or single boosted jet (ATLAS)
- a jet with no tracks & low EMF
  - ATLAS can trigger on this signature
- multi-track vertex in the muon system



Emerging jets

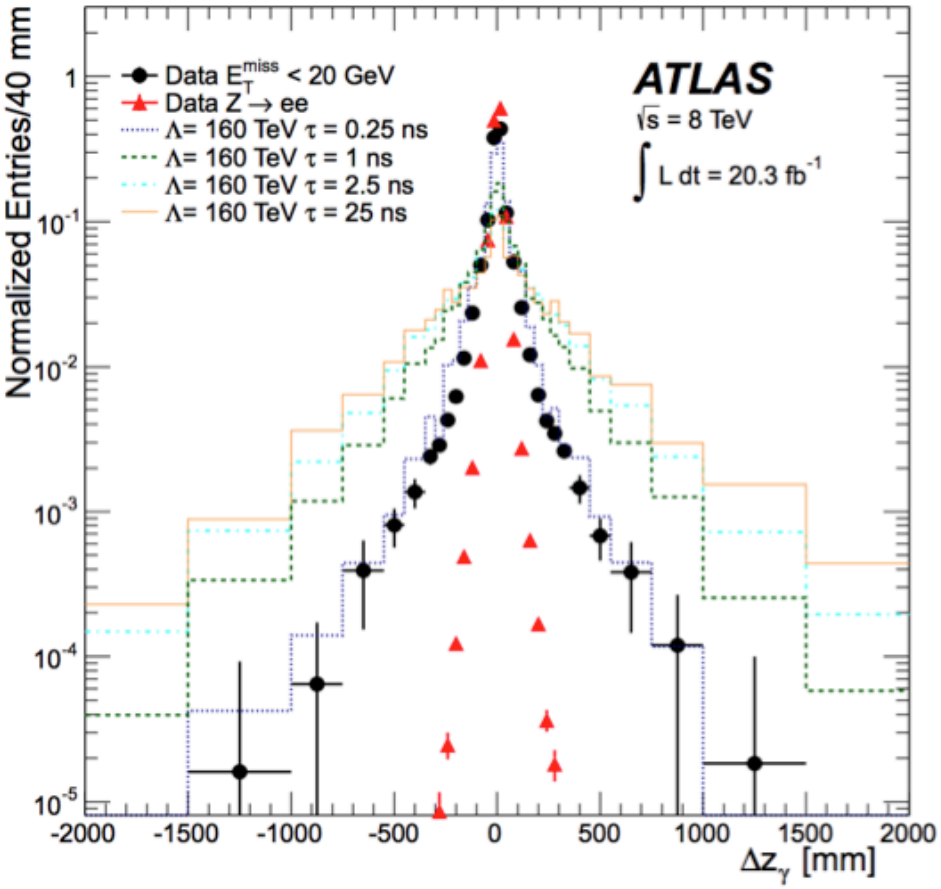
- multiple displaced vertices

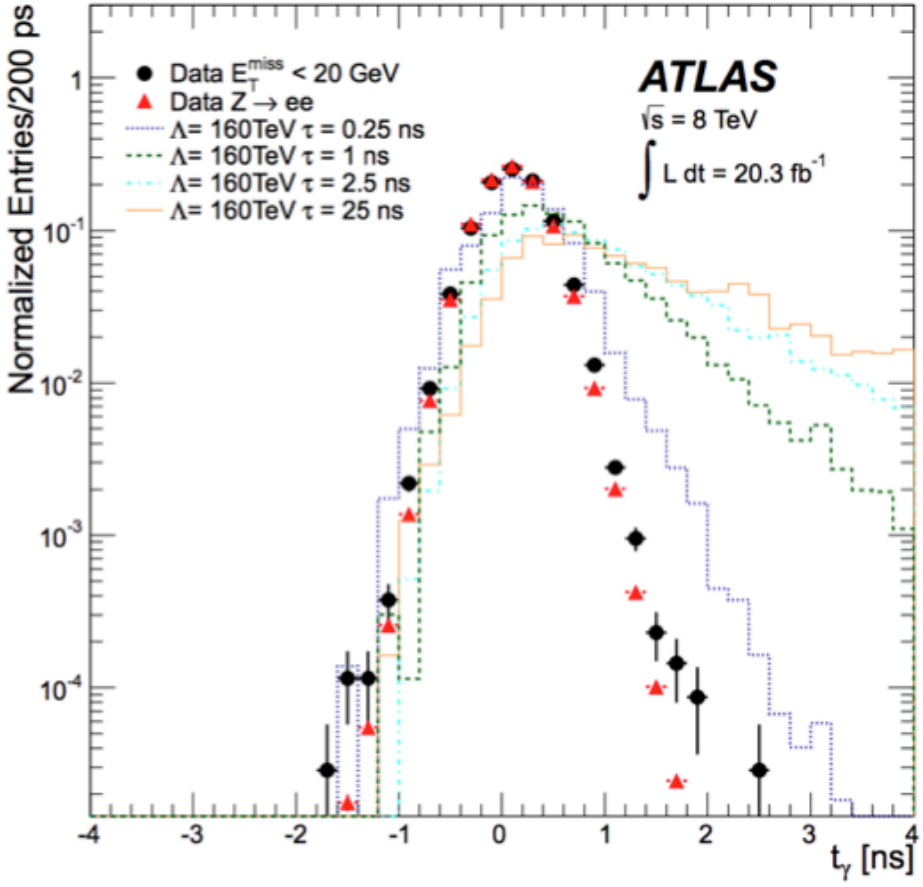


(very) late decays in the calorimeter

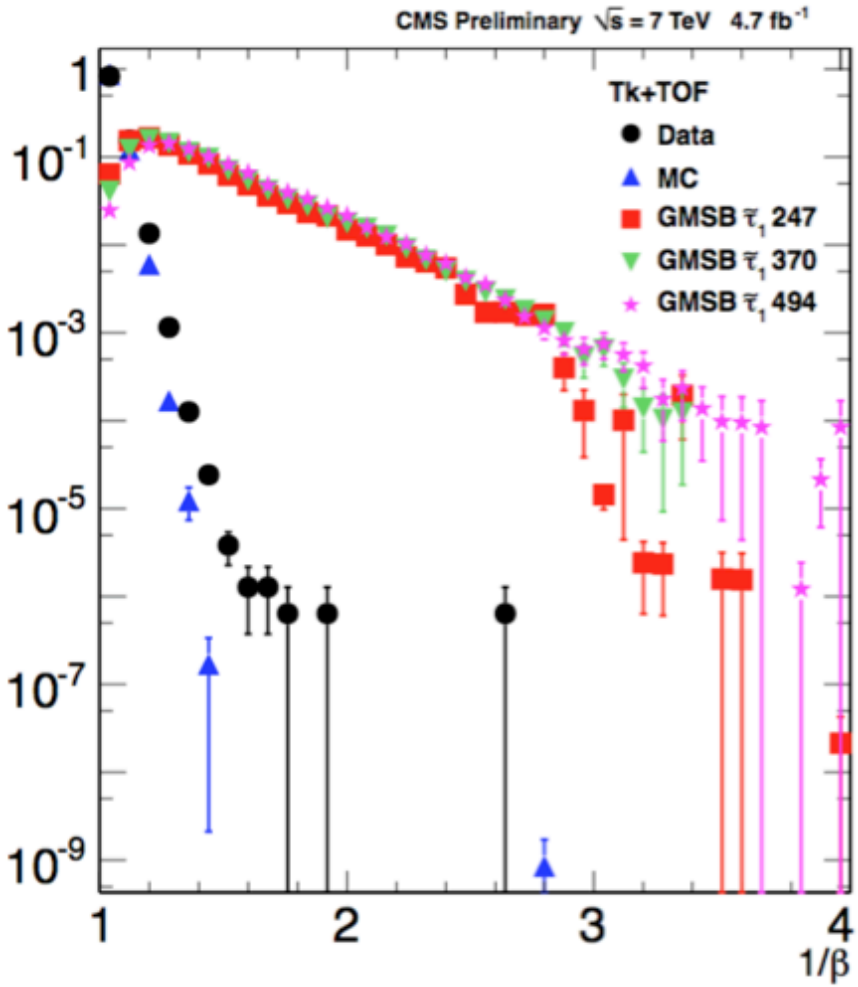
- ATLAS and CMS look for jets in empty bunch crossings (neither beam in the detector)

ATLAS non-pointing photon





CMS Heavy stable charged particle (HSCP) track+ToF



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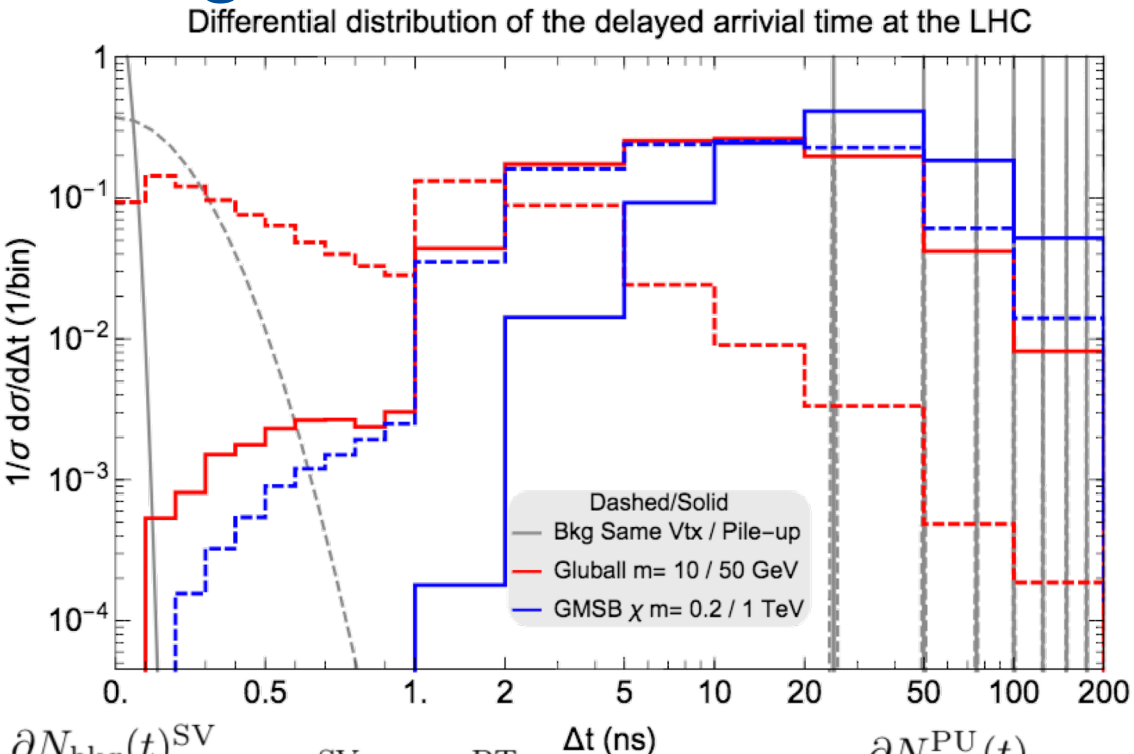
Background consideration



$$\frac{\partial N_{\rm bkg}(t)^{\rm SV}}{\partial t} = N_{\rm bkg}^{\rm SV}\mathcal{P}(t;\delta_t^{\rm PT}).$$

$$\frac{\partial N_{\rm bkg}^{\rm PU}(t)}{\partial t \partial z} \simeq N_{\rm bkg}^{\rm PU}\mathcal{P}(t;\delta_t^{\rm PU})$$

$$\text{EC}: \quad N_{\rm bkg}^{\rm SV} = \sigma_{\rm j}^{\rm multi}\mathcal{L}_{\rm int}\epsilon_{\rm trig}\epsilon_{\rm fake}^{j} \approx 5.6\times 10^{9}$$

$$\text{MS}: \quad N_{\rm bkg}^{\rm SV} = \sigma_{\rm j}^{\rm multi}\mathcal{L}_{\rm int}\epsilon_{\rm trig}\epsilon_{\rm fake}^{j} \approx 2.8\times 10^{5}$$

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$$\text{MS}: \quad N_{\rm bkg}^{\rm PU} = \sigma_{\rm j}\mathcal{L}_{\rm int}\epsilon_{\rm trig}\left(\bar{n}_{\rm PU}\frac{\sigma_{\rm j}}{\sigma_{\rm inc}}\epsilon_{\rm fake}f_{\rm nt}^{j}\right) \approx 1.3, \qquad (4)$$