Long-lived particles (LLP) with Delphes and MadAnalysis 5

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(Re)interpreting the results of new physics searches at the LHC & Long-Lived Particles Workshop
14-16 May 2018

Outlines

1. Review of Delphes v3.4.1 & Long-lived particles
2. The MadAnalysis 5 v1.6 tune for Delphes
3. Recast analysis benchmark: CMS-EXO-16-022
4. Perspectives

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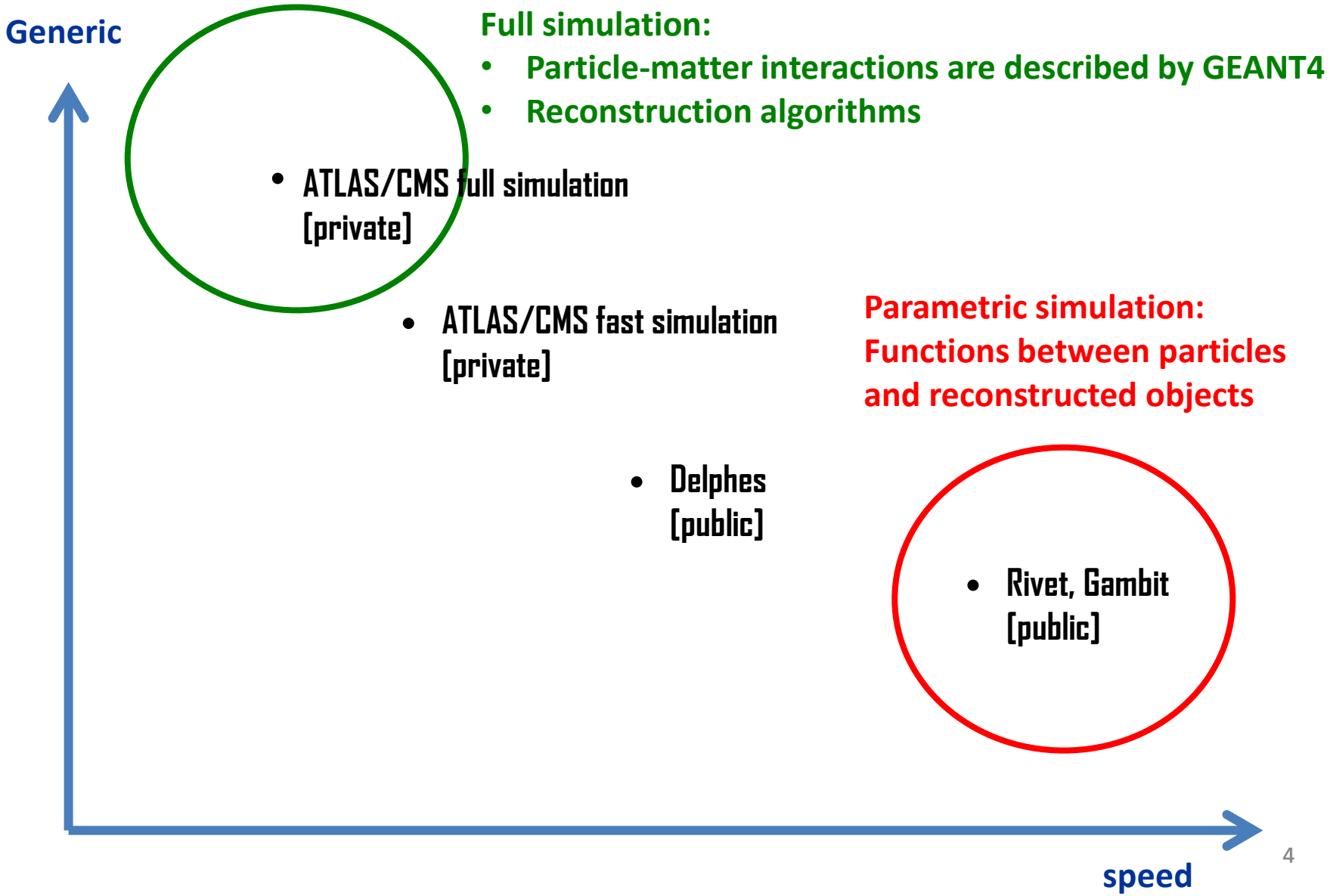
Motivations for Delphes



Overview of Delphes

- **DELPHES** is a very-fast-simulation for generic detector:
  - ATLAS & CMS detectors
  - Upgrade of ATLAS & CMS
  - LHCb
  - Future detectors: ILC, FCC, CEPC

DELPHES
fast simulation

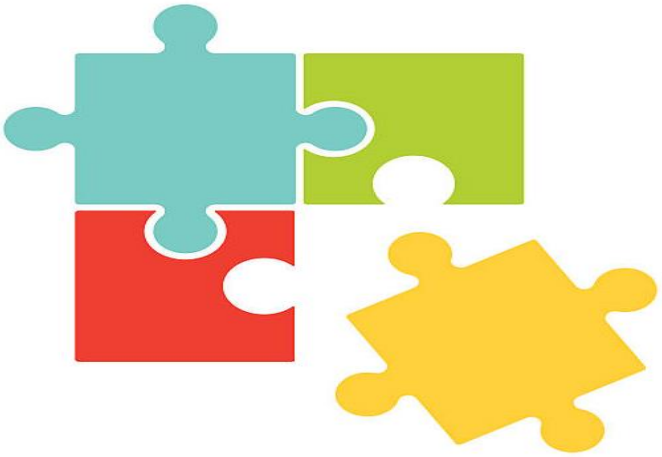
- **Output in ROOT format**

- **The simulation is split into generic modules.**

→ Each module is devoted to a function.

- **JHEP 02 (2014) 057**
- **J.Phys.Conf.Ser. 523 (2014) 012033**
- **J.Phys.Conf.Ser. 608 (2015) 1, 012045**

- **The detector simulation is totally described by a card** (text file in TCL language), containing:
  - *The sequence of the modules that are needed*
  - *How they interact between themselves*
  - *The setting of this module.*



- **The Delphes development model is community-based.**

Overview of Delphes

Requirements:

Package	Utility
ROOT 6	Main framework & data format
TCL	Language of detector card
FastJet	Jet-clustering algorithm, pile-up

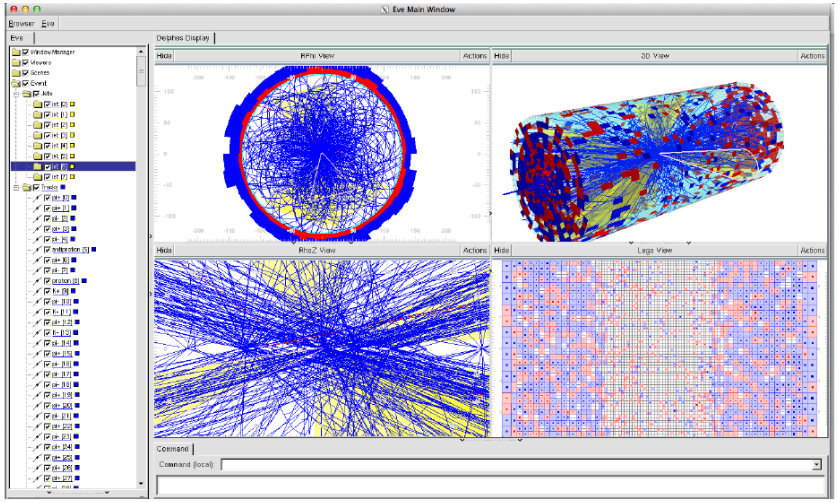
→ To be installed

→ To be installed

→ Encapsulated in the delphes package

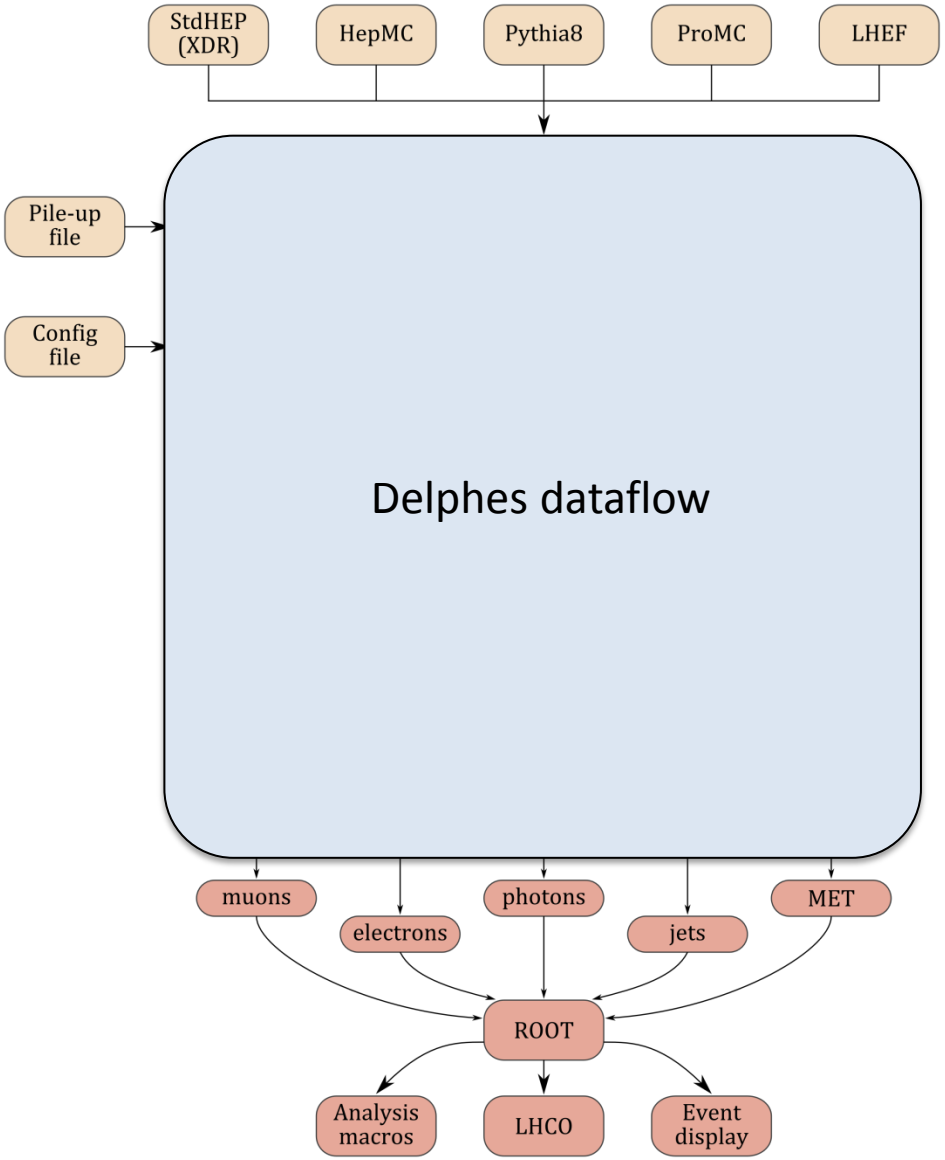
Extra programs:

- **EVE** (former FROG): program of event vizualisation
- **DelphesAnalysis**: reading Delphes ROOT file with Python



Site web: https://cp3.irmp.ucl.ac.be/projects/delphes

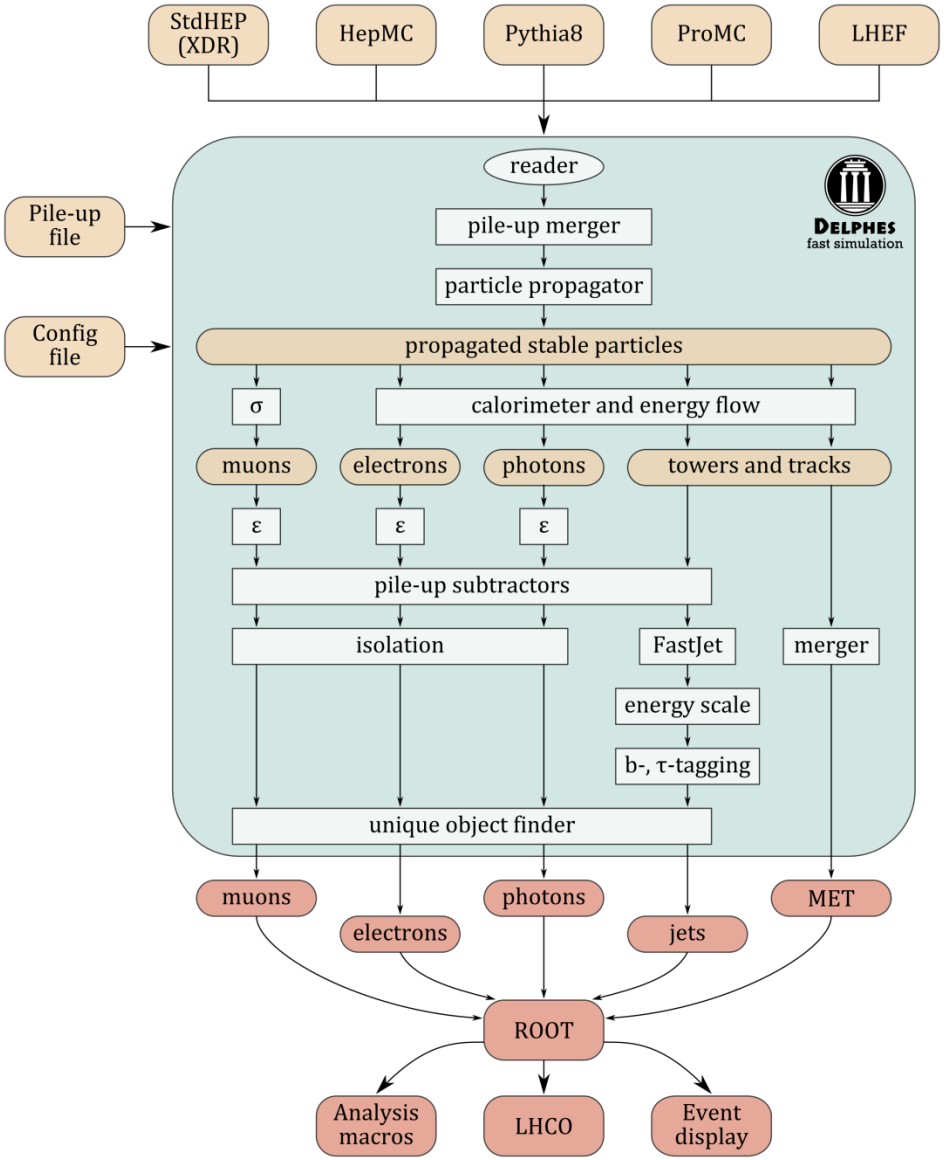
Delphes Dataflow



Example of dataflow diagram:

https://cp3.irmp.ucl.ac.be/projects/delphes/wiki/WorkBook/DataFlowDiagram

Delphes Dataflow



Example of dataflow diagram:

https://cp3.irmp.ucl.ac.be/projects/delphes/wiki/WorkBook/DataFlowDiagram

Main features for CMS/ATLAS detector

Tracking

- no genuine tracker simulation
- charged particles are propagated until the ECAL calorimeter
- efficiency + resolution functions

Calorimetry

- segmentation of the ECAL & HCAL calorimetry into cells
- determining the energy fraction absorbed by the calorimeter
- smearing of the cell energy

Particle-flow algorithm

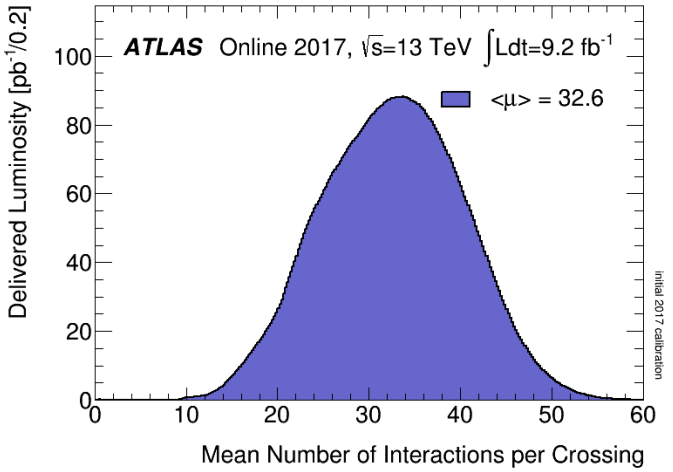
- get a better estimation of the momenta for charged particle
- determine if a energy deposit is more compatible with a charged + neutral hypothesis

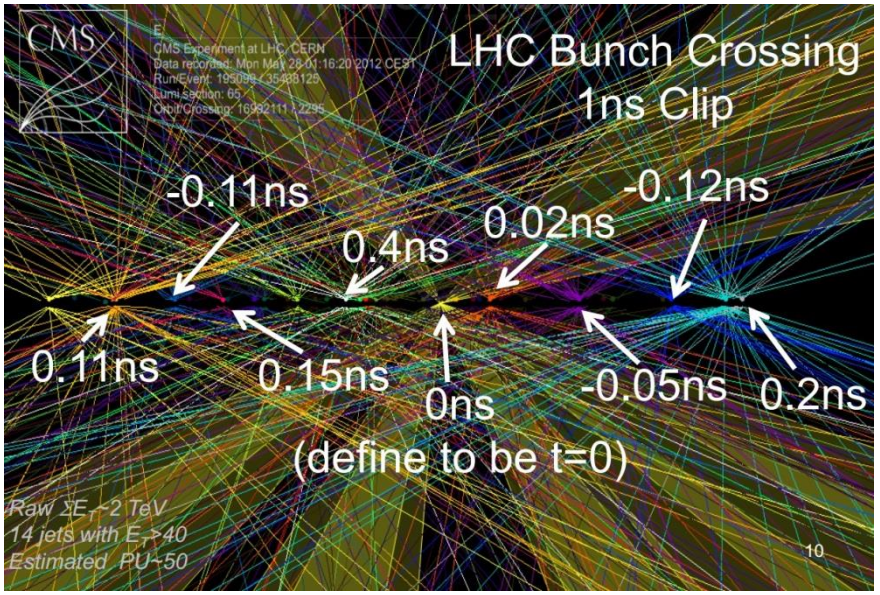
Jet reconstruction

- jet-clustering algorithm of FastJet
- jet energy scale
- b and tau tagging
- jet substructure can be probed via FastJet/contrib

Main features for CMS/ATLAS detector

- **Pile-up simulation**:





The consequences on the reconstruction:

– reduced efficiency
– worsened resolution (jets, MET)
– degraded isolation
– fake tracks, jets

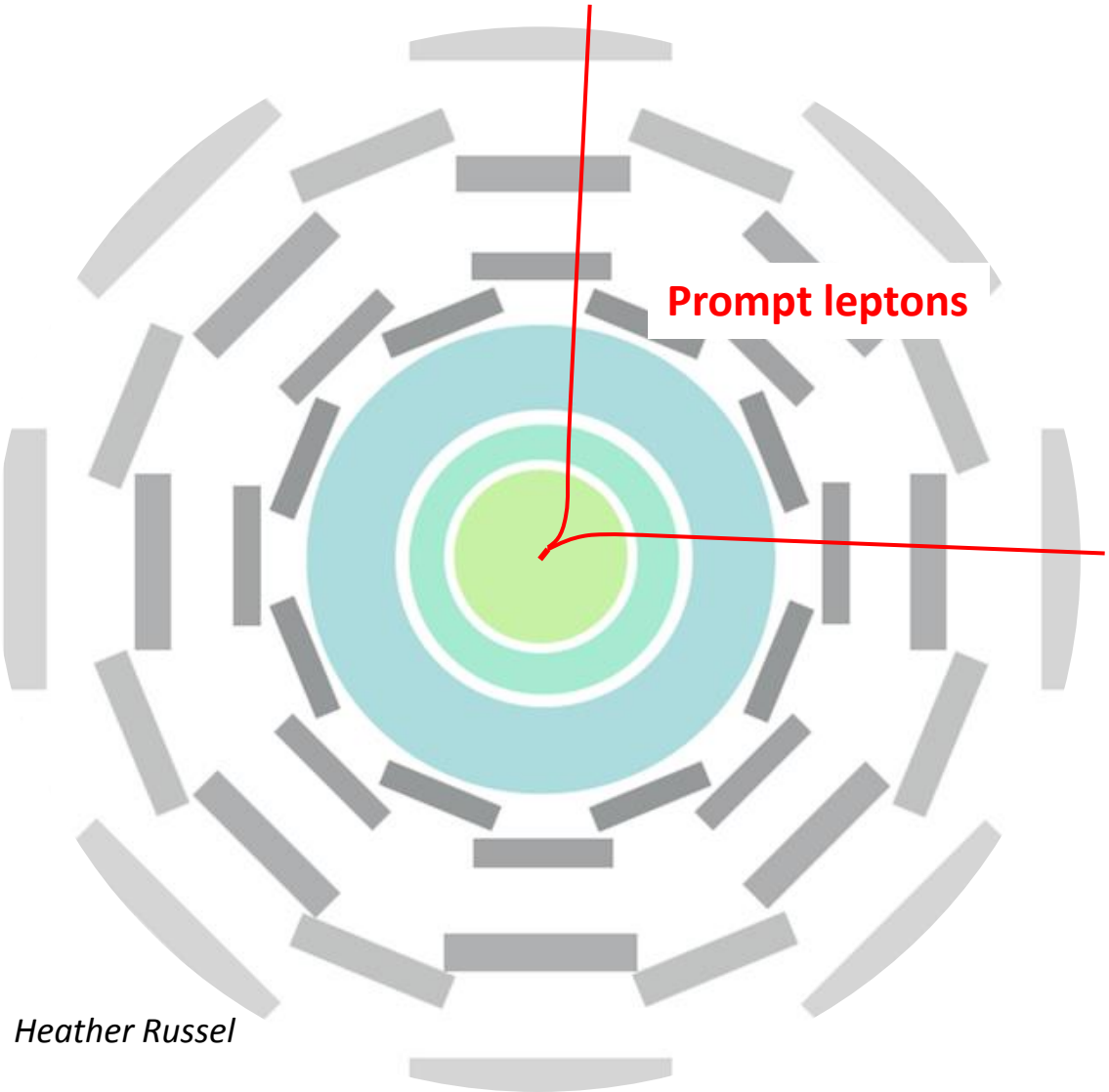
Delphes simulation of this effect:

- injecting several interactions (required an extra MinBias events sample)
- computing the pile-up density ρ with the GridMEdianBackgroundEstimator approach of FastJet
- computing jet area during jet-clustering process
- (neutral and charged) pile-up subtraction @ reconstruction level
- degrading isolation of leptons & photons

Or using the PUPPI method (Pileup Per Particle Identification)

LLP in Delphes

Official ATLAS and CMS TCL-descriptions are not designed for LLP exotic signatures.
Let's take the example of a LL neutralino decaying into ll'v



Case where the neutralino decays before the first layer of the tracker

→ Prompt leptons
→ **The simulation is correct**.

LLP in Delphes

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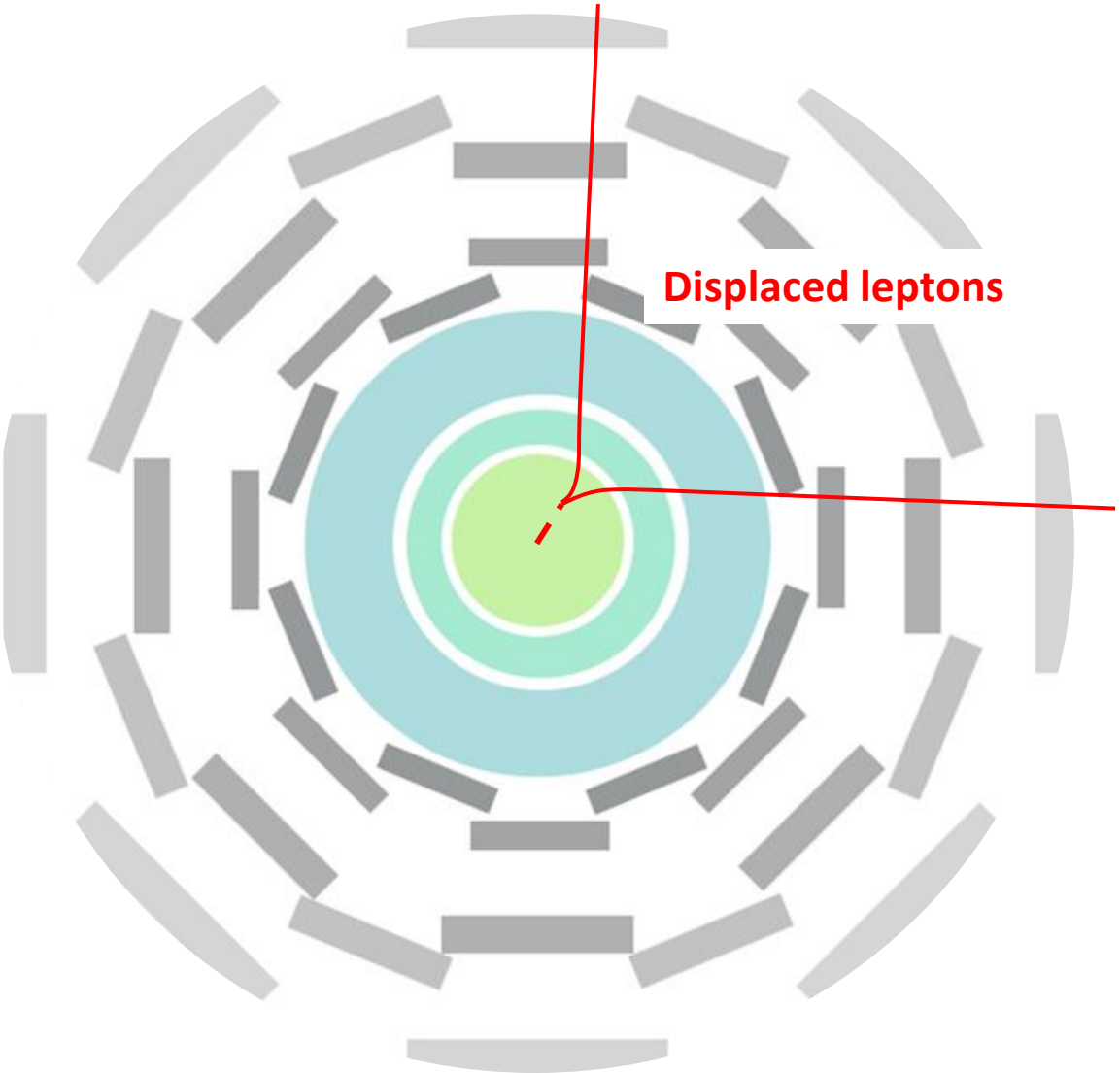

Case where the neutralino decays inside the tracker volume

→ Leptons are considered as prompt leptons.
→ Tracking efficiencies are not correct.
→ The card needs to be modified.

LLP in Delphes

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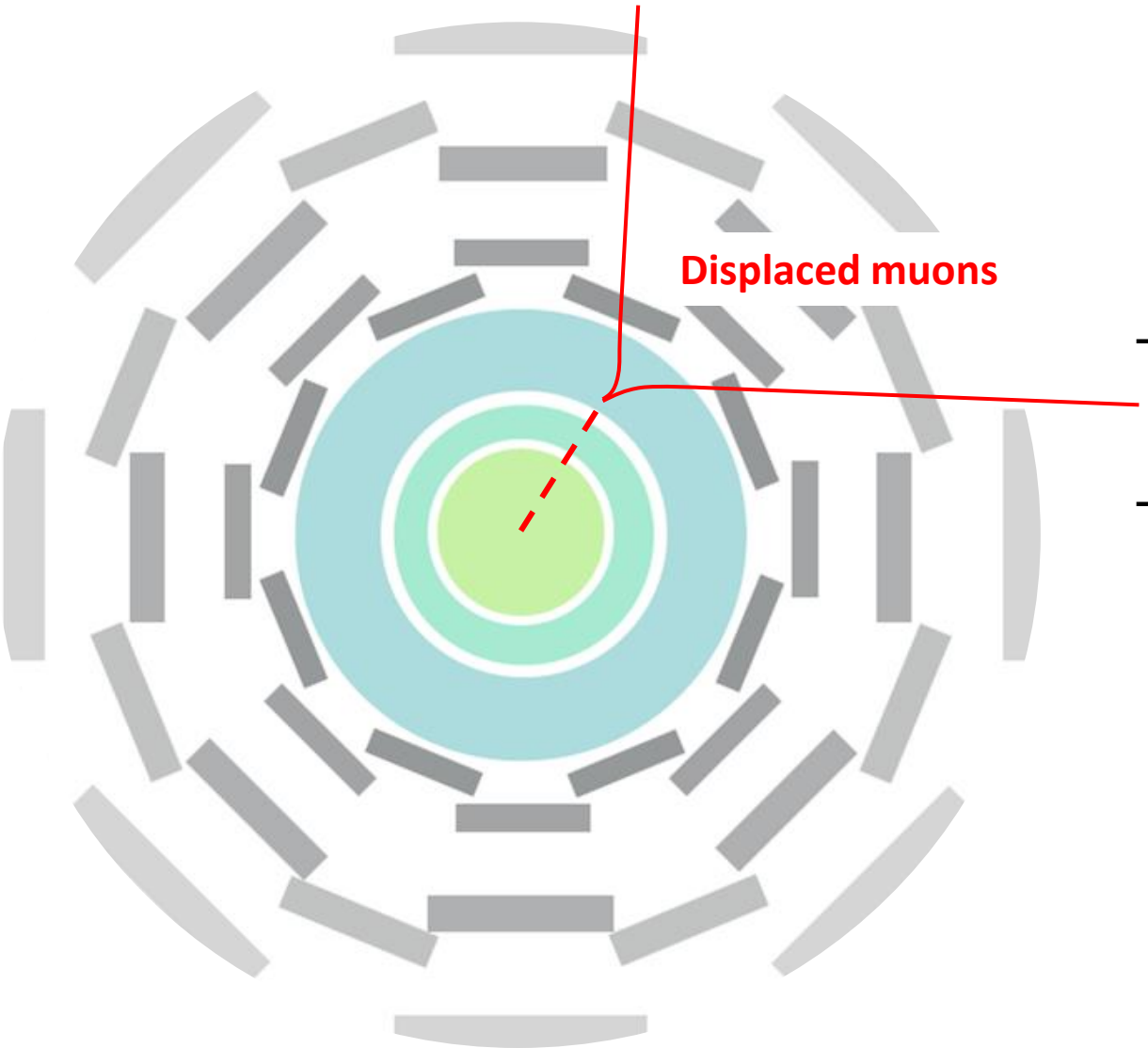
Let's take the example of a LL neutralino decaying into ll'v



Case where the neutralino decays outside the tracker volume

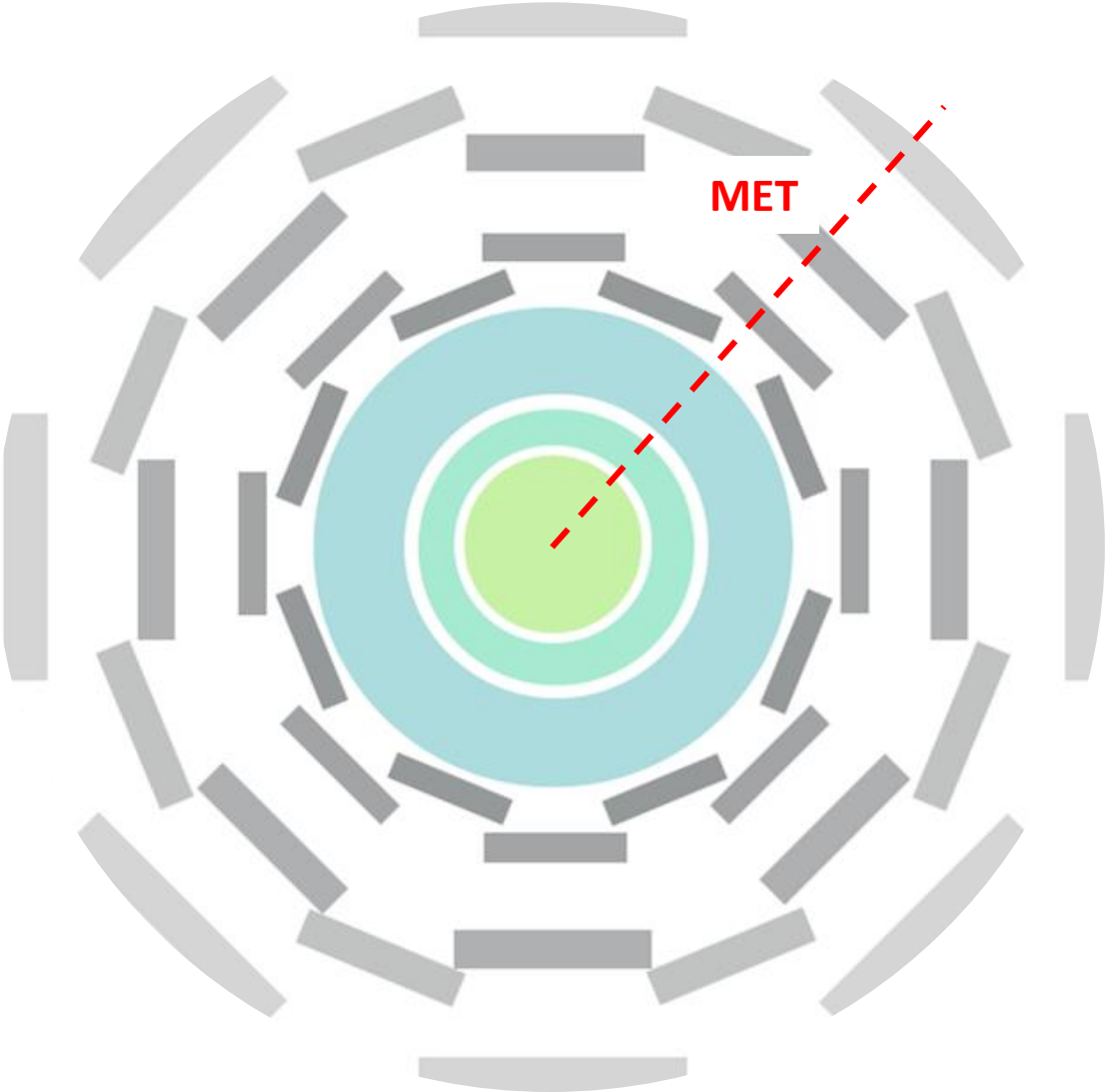
→ Initially, the neutralino is considered as invisible.

→ The parameter RadiusMax of ParticlePropagator module must be changed for getting the muons.

+ adding specific efficiencies (at the reco level or at the analysis level)

LLP in Delphes

Official ATLAS and CMS TCL-descriptions are not designed for LLP exotic signatures.
Let's take the example of a LL neutralino decaying into ll'v



Case where the neutralino decays outside the tracker volume

→ The neutralino is considered as MET.
→ **The simulation is correct.**

Other modules can be relevant for LLP

Two complementary Delphes modules could be interesting for LLP analyses:

- TRACKSMEARING: smearing the track momentum according to the d0 and dz parameters

- VERTEXFINDERDA4D: determine the vertices from tracks using deterministic annealing and timing information

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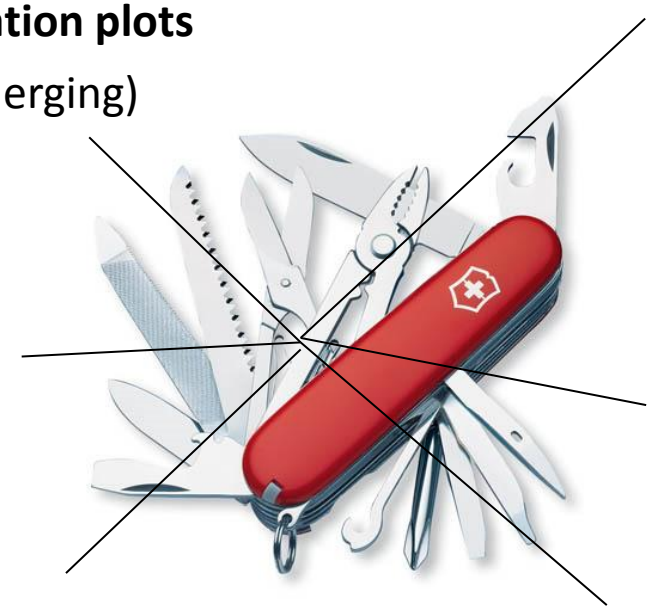
What is MadAnalysis 5?

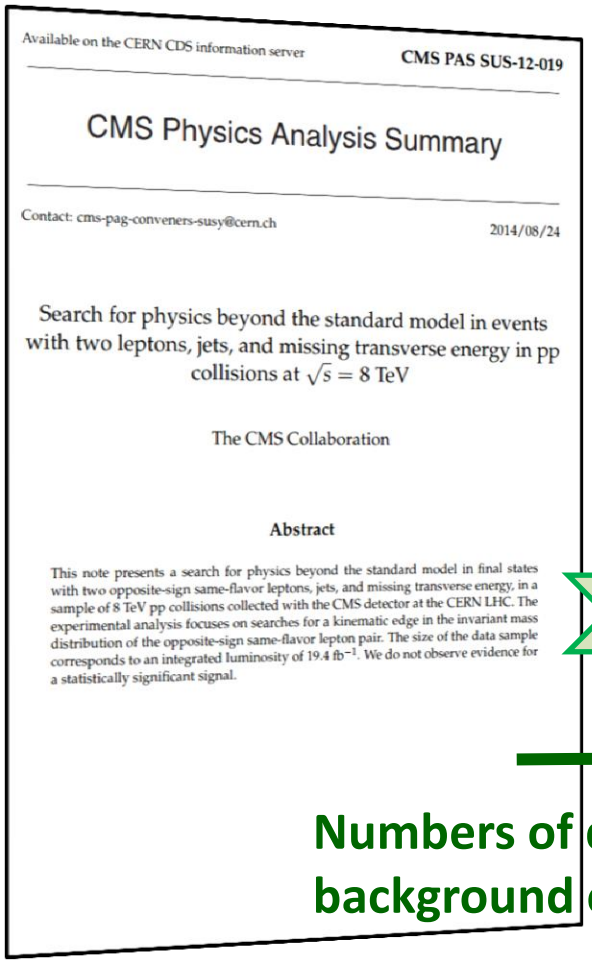
- Producing special plots such as **ME/PS merging validation plots** (see talk devoted to merging)
- **Writing** the events in another data format.



- Applying **a jet-clustering algorithm** to your hadronic events
- Designing a sophisticated analysis in the **expert mode**
- Applying a **fast-simulation detector (Delphes)** to your hadronic events
- **Recasting an existed analysis** and **computing a limit** to a BSM signal

More details can be found on G. Chalons' talk
Last version: v1.6 (finally) released on May 2018

Recasting strategy with MadAnalysis 5


Available on the CERN CDS information server CMS PAS SUS-12-019

CMS Physics Analysis Summary

Contact: cms-pag-conveners-susy@cern.ch 2014/08/24

Search for physics beyond the standard model in events with two leptons, jets, and missing transverse energy in pp collisions at $\sqrt{s} = 8$ TeV

The CMS Collaboration

Abstract

This note presents a search for physics beyond the standard model in final states with two opposite-sign same-flavor leptons, jets, and missing transverse energy, in a sample of 8 TeV pp collisions collected with the CMS detector at the CERN LHC. The experimental analysis focuses on searches for a kinematic edge in the invariant mass distribution of the opposite-sign same-flavor lepton pair. The size of the data sample corresponds to an integrated luminosity of 19.4 fb^{-1}. We do not observe evidence for a statistically significant signal.

Signal events

(STDHEP or HEPMC format)

DELPHES / DELPHESMA5TUNE

Recast selection
(Expert Mode)

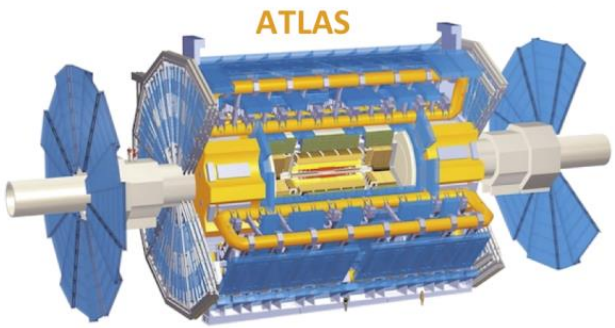
Limit computation

Numbers of data and background events

Physics Analysis Database

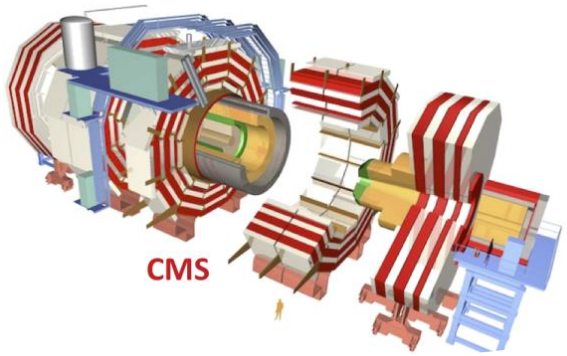
Eur.Phys.J. C74 (2014) 3103

Embedded Delphes tune



Detector

very-fast-simulation



old way

Delphes MA5-Tune

Special tuning of the Delphes 3.0 package provided by MadAnalysis 5

- Reducing the ROOT size.
- Lepton & photon isolation done @ analysis level.
- More realistic parametrization of the b-tagging(mis-)efficiency @ analysis level.
- More info on generated particles.

new way

from MA5 v1.2

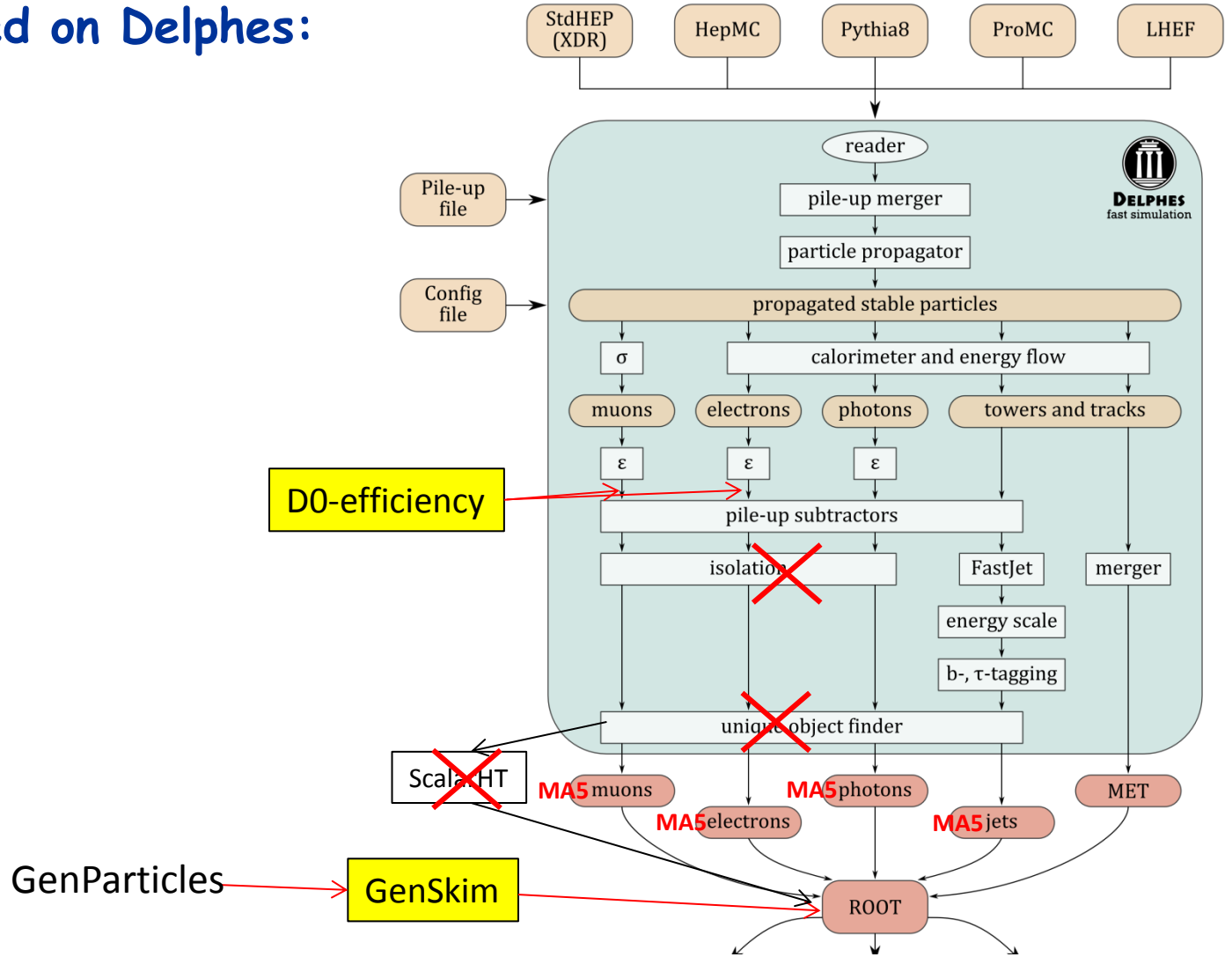
Delphes + MA5 card

Official Delphes release using special CMS/ATLAS detector cards provided by MadAnalysis 5

- Most of the features implemented in the official Delphes release.
- Other features are encapsulated into external Delphes modules.
- Lepton & photon isolation always done @ analysis level **+ improvement**.

Embedded Delphes tune

Detector simulation based on Delphes:



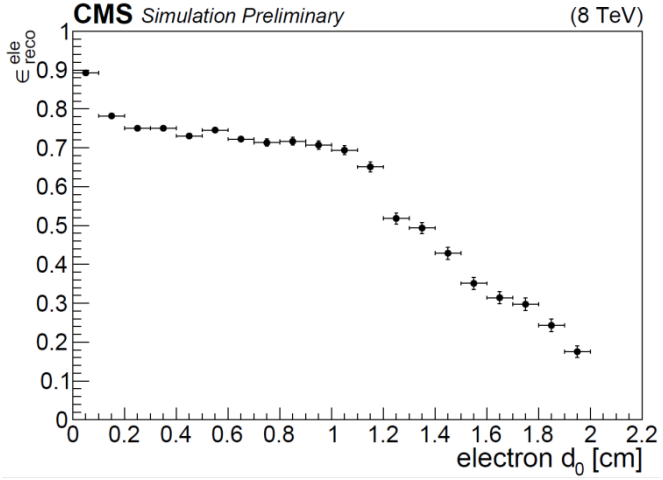
Embedded Delphes tune

Special tune devoted to displaced leptons in MA5:

→ Special package devoted to LLP decaying in leptons
https://madanalysis.irmp.ucl.ac.be/wiki/MA5LongLivedParticle

- If the LLP decays in the tracker volume, the proper efficiency is applied to displaced tracks by a new module MA5EFFICIENCYD0 (using parametrization of the CMS detector)

https://twiki.cern.ch/twiki/bin/view/CMSPublic/DisplacedSusyParametrisationStudyForUser




```
set EfficiencyFormula {
(d0<=20) * (-5.06107e-7 * d0**6 +
0.0000272756 * d0**5 - 0.00049321 *
d0**4 + 0.00287189 * d0**3 + 0.00522007
* d0**2 -0.0917957 * d0 + 0.924921) +
(d0>20) * (0.00) }
```

- If the LLP decays outside the tracker volume, the LLP is ignored by the simulation.

- **Suits for neutralino-like LLP decaying into leptons**
- **Suits for squark-like / gluino-like LLP decaying into leptons (if the B-field effects can be neglected on the LLP)**

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CMS-EXO-16-022

- Energy in the center of mass of the collision: **13 TeV**
- Integrated luminosity: **2.6 fb-1**
- Inspire link: http://inspirehep.net/record/1479633/

- Signal: **p p →** $p\,p \rightarrow \tilde{t}_1\,\tilde{t}_1$ with $\tilde{t}_1 \rightarrow b\,l$ in RPV-SUSY framework
  samples are generated with top squark masses between 200 and 1200 GeV and lifetimes over a range of 0.1 to 100 cm/c.

- Experimental signatures: **a displaced vertex e-μ**

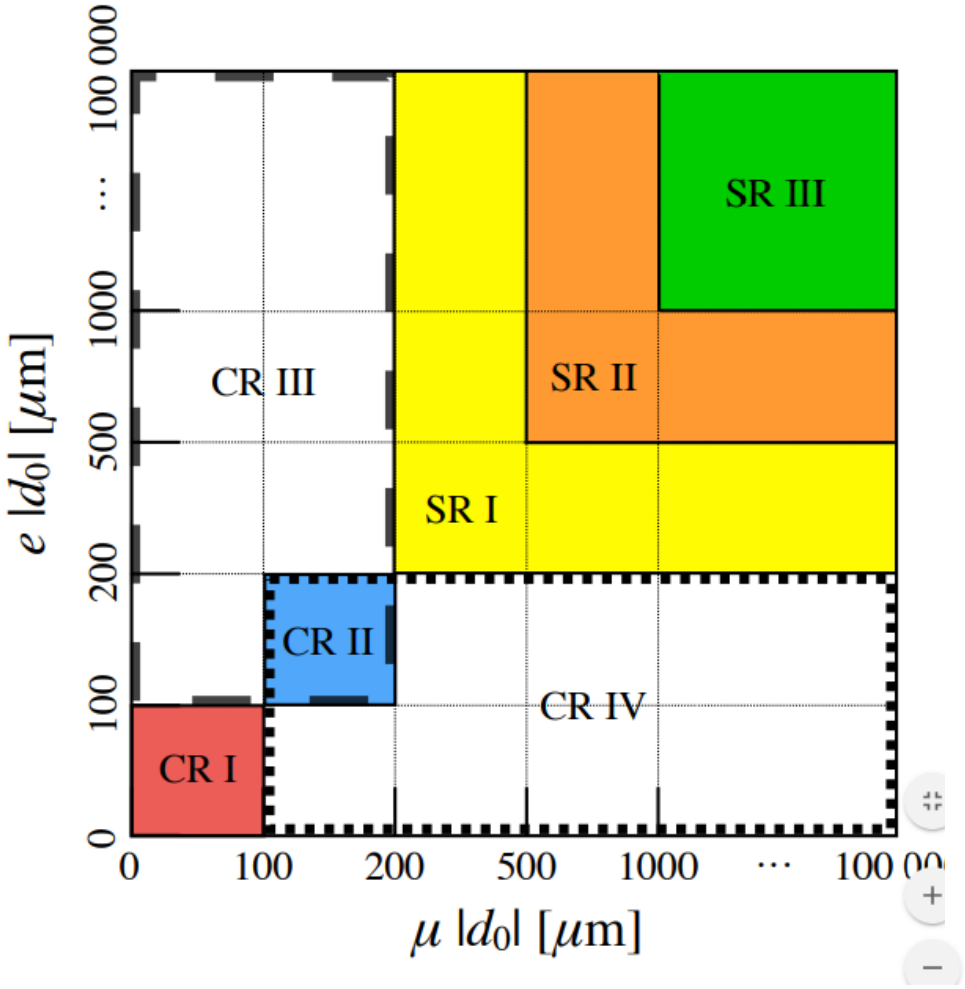
- Online Selection: **specific trigger e-μ displaced with pT> 38 GeV**

- Offline Selection:

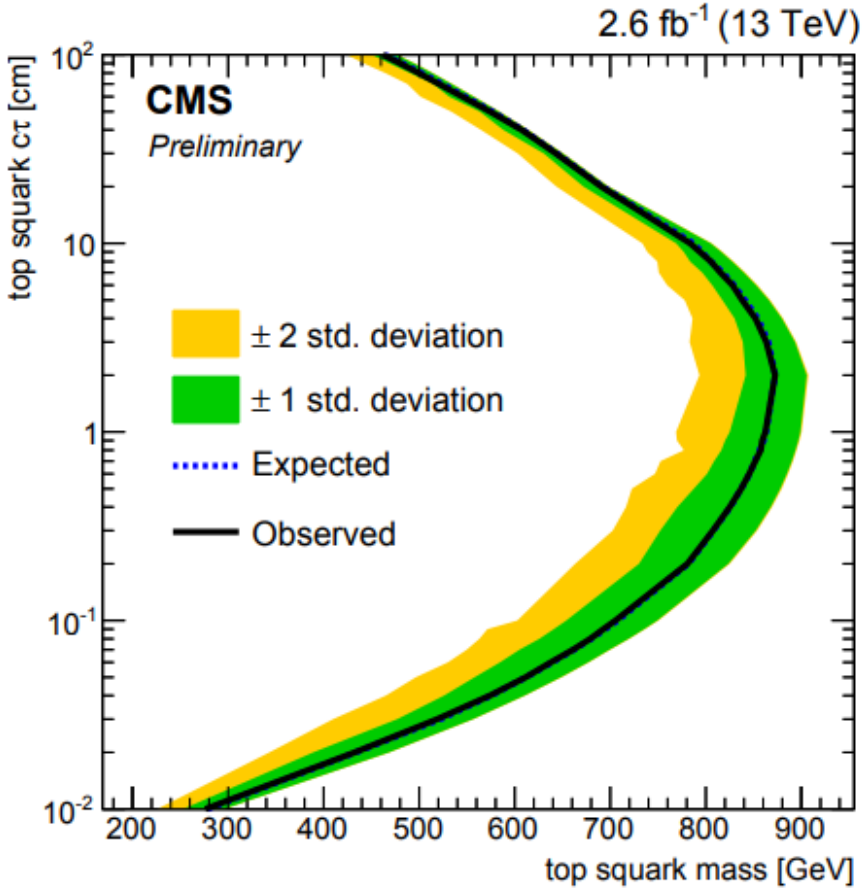
Criterion	Threshold for e	Threshold for μ
|η| <	2.4	
pT >	42 GeV	40 GeV
Isolation between e-μ: DR(e,μ)>0.5		
Relation isolation with DR=0.4 size cone >	0.065 for 1.57 < |η|< 2.4 0.035 for |η|< 1.4	0.015
d0 <	10 cm	

CMS-EXO-16-022

3 signals regions are defined



Limit plot



Recasting implementation of the analysis

- **Recasting done in the framework of the first MA5 school organised in Korea**
  Authors: Jung Chang under the supervision of Jory Sonneveld and Sam Bein
  Both recast analysis & validation note are available on the PAD.

- **Software: MA5 v1.6 + Delphes 3.4.1_Tracks with 8 TeV CMS tracking performance**

Region	$c\tau_{\tilde{t}}$ [cm]	MA5	CMS	Difference [%]
SR-I	0.1	3.89	3.8	2.30
	1	4.44	5.2	14.51
	10	0.697	0.8	12.84
	100	0.0610	0.009	$> 100\%$
SR-II	0.1	0.924	0.94	1.71
	1	3.87	4.1	5.61
	10	0.854	1.0	14.58
	100	0.0662	0.03	$\sim 100\%$
SR-III	0.1	0.139	0.16	12.84
	1	6.19	7.0	11.59
	10	4.45	5.8	23.56
	100	0.497	0.27	$\sim 100\%$

Critical review of this implementation

- **Agreement between MA – CMS:**
  - Agreement for $c\tau < 10$ cm
  - Discrepancy for $c\tau = 100$ cm: CMS efficiency parametrization not available for large d0 values

- **Limits of Delphes simulation (+ tune):**
  - No trigger definition but offline selection must have included the online selection.
  - No pile-up simulation in the validation note but satisfaying agreement.
  - No simulation of B-field on the stops particle but effects should be negligle. [coming soon]
  - Efficiency and resolution map for leptons with large d0 values
  - Stops decay outside the tracker-volume? R-hadrons interaction with matter?

- **Advantages of the Delphes simulation vs a parametric simulation?**
  - Selection based only on lepton tracks

  → Parametric simulation should give similar results

  → Need to find a new benchmark analysis using calorimetry information (MET, b-tagging, …)

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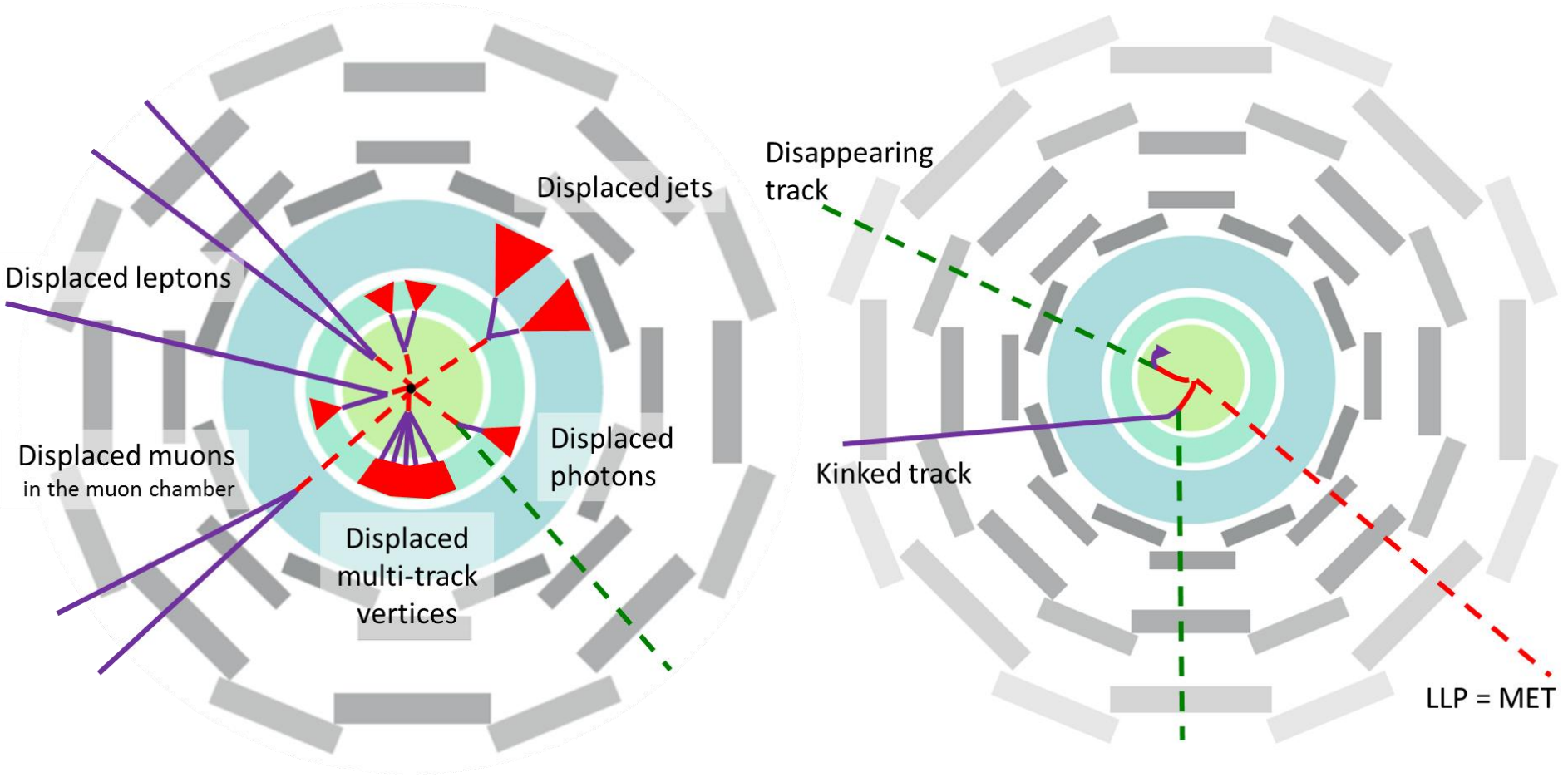
A plethora of LLP signatures



Future developments?

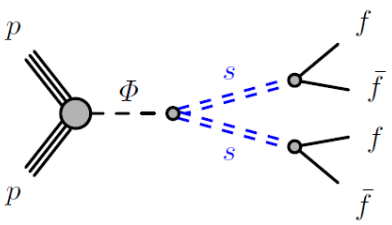
Other implementations are possible in Delphes+MA5:

- **Displaced objects can be achieved and are expected**
  - Displaced jets:
    Delphes must provided more information on jet shape.
    A new module must be created for clustering secondary vertices based on the displaced tracks matched to jets.
    Next analysis to recast: **CMS-EXO-16-003**
  - Displaced vertices:
    To addition to the new module devoted to Displaced jets, a simple vertexing algorithm must be implemented. It can be done by relaxing the z-axis constraint on the existing VertexFinder module.
- **Other signatures are more delicate**
  - Disappearing tracks and kink require a genuine tracker simulation
  - HSCP (Heavy Stable Charged Particle) with dE/dx detection way
  - Stopped particles where MC events are not independent between themselves

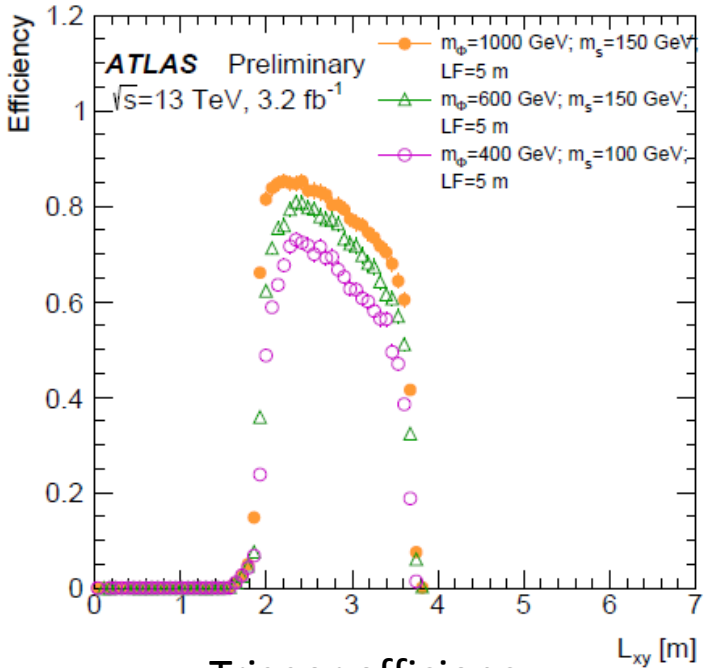
Back-up

Example of analysis to recast

Example: ATLAS-CONF-2016-103 – displaced jets



- **Models tested:** hidden sector benchmark model
- **Trigger:** a dedicated trigger called *CalRatio-trigger :* trackless jet + properties of the jet
- **Reconstruction:** classical jet-clustering + BDT to select displaced jets
- **Background:** cosmics+beam induced backgrounds (a broad timing distribution), multijets processes (data-driven method estimation)



Trigger efficiency