



40 MHz Level-1 Scouting @ CMS

Physics Scenarios for Run 3 and beyond

CERN Openlab
Technical Workshop

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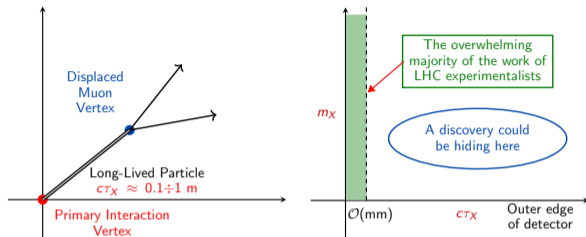
³CERN, Geneva, Switzerland

March 22, 2022

Introduction

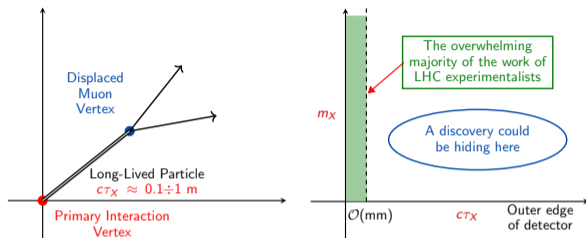
CMS Run 1 + Run 2 summary:

- ✓ Higgs boson discovery
- ✓ Standard Model (SM) precision measurements
- ✗ Limited CMS current triggering system
- ✗ Keep only know SM objects interacting with detector
- ✗ Bias induced by Trigger
- ✗ Limit feasibility of Beyond SM (BSM) searches



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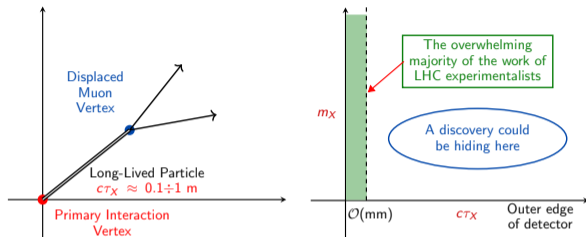


LHC Run 3, Upgrades for Phase-2 HL-LHC:

- New “displaced triggers”
- New algorithms on hw at Level-1 Trigger (DNNs, Kalman Filters, CNNs, ...)
- Still limited and biased by Trigger

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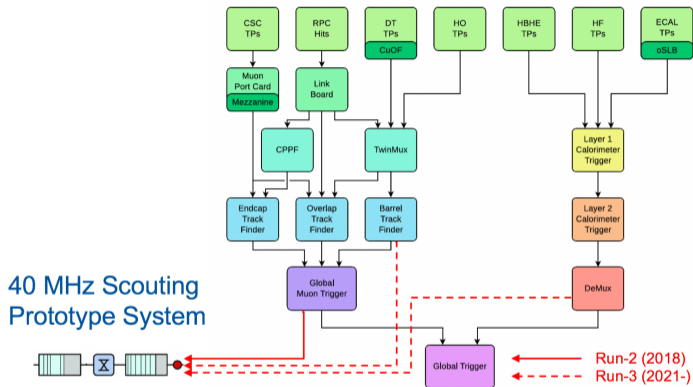
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Level-1 Scouting at 40 MHz:

- Complementary to standard CMS double Trigger system
- At the cost of having Level-1 (low) resolution...
- ...remove trigger bias and perform semi-real time analysis

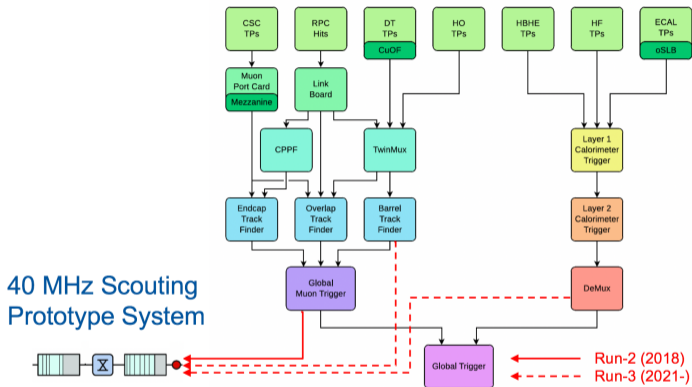
Objects available for a physics search and analysis



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Global Muon Trigger (μ GMT):

- GMT muons (Up to 8)
- 64 bits per object



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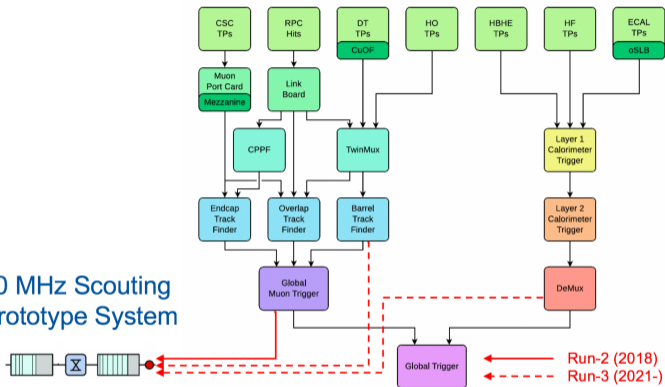
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Calo Layer 2:

- Jets (Up to 12)
- Electrons/Photons (Up to 12)
- Taus (Up to 12)
- Missing transverse Energy, Energy sums
- 32 bits per object

40 MHz Scouting
Prototype System



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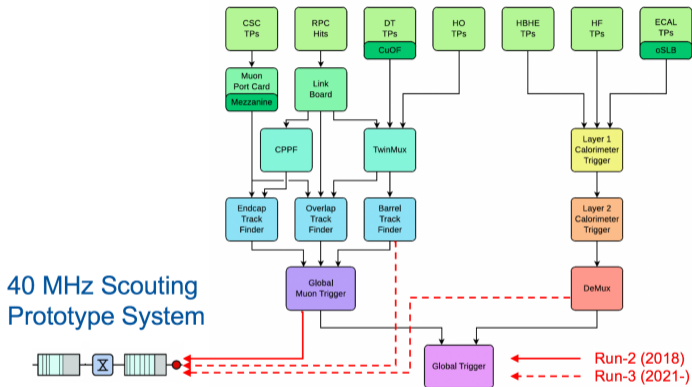
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Barrel Muon Track Finder (BMTF):

- **BMTF muons** (Up to 36, 64 bits each)
- Improved resolution w.r.t. GMT muons



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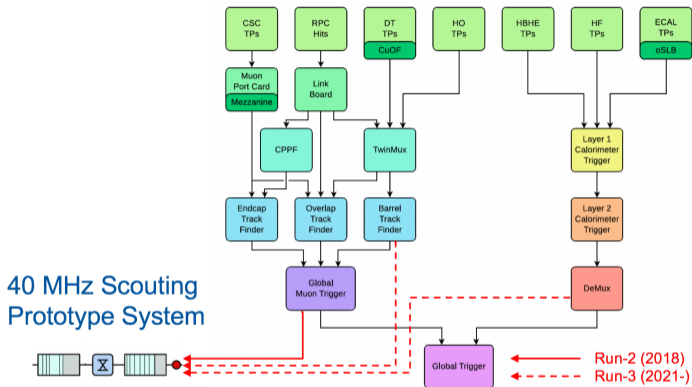
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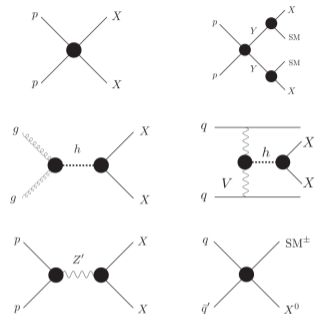
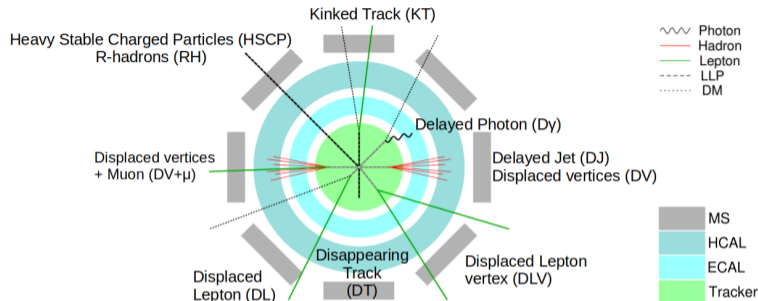
- **BMTF muons** (Up to 36, 64 bits each)
- Improved resolution w.r.t. GMT muons

Possibility to **combine the information from all the sources**, e.g.:

- Correlate GMT/BMTF muons in barrel and hadronic activity in Calo
- Correlate missing energy with other charged objects
- ML inference on hw to reconstruct Level-1 objects



Overview of exotic signatures



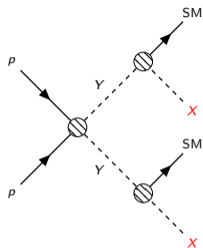
Very Active community working on exotic signatures:

- Numerous physically motivated models available
 - Dark Matter (DM)
 - Super SYmmetry (SUSY)
 - Heavy Neutrino (RH ν)
 - Higgs-portal
- **Long-Lived Particles** (LLP) most promising

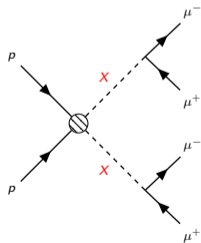
Promising signatures:

- Direct LLP Pair Production
- LLP production from Heavy Parent
- LLP production from Higgs
- LLPs from heavy resonance

Physics signatures: Muons with high impact parameter



(a) Heavy Parent Production

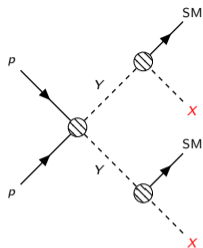


(b) Direct Pair Production

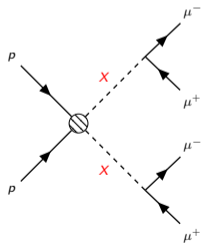
Produced when LLP has lifetimes of order $c\tau_X \approx 0.1 \div 1$ m:

- Consequence of **feeble coupling of the LLP to the SM particles**
- Predicted in Dark Matter and SUSY
- Free parameters of model: $M_Y, M_X, c\tau_X$

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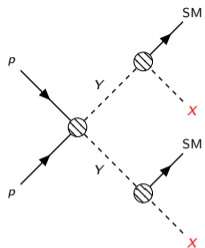
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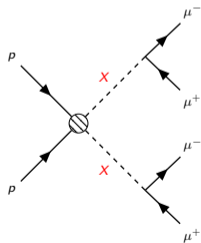
Why triggering this signature is so difficult?

- LLP can have a very compressed spectrum, namely $\Delta = M_X - M_{SM} \ll M_X$
- \Rightarrow Spectrum Compression
- \Rightarrow **Low p_T products from LLP decay**

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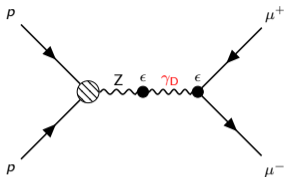
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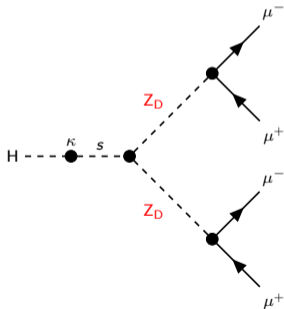
Level-1 trigger cannot cope with high rate coming from muons with low p_T :

- **Very low trigger efficiency**
- Alternative: implement complex triggers on other known objects of the process
- **Level-1 Scouting: scout the exotic signature among all collisions**
- Exploit information from GMT and BMTF muon objects and missing energy from Calo

Physics signatures: Muons with high impact parameter



(a) Gauge Sector

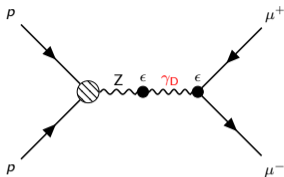


(b) Higgs Sector

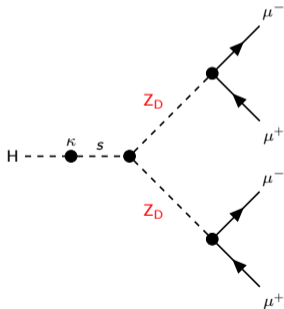
Dark Photon (from Dark Matter theory):

- Vector portal: coupling with Vector bosons (Z, \dots)
- Higgs portal: coupling with Higgs boson
- Features (mass, interactions, ...) depending on Dark sector properties
- Compressed spectrum
- \Rightarrow Low p_T products from dark γ decay
- Displaced muons

Physics signatures: Muons with high impact parameter



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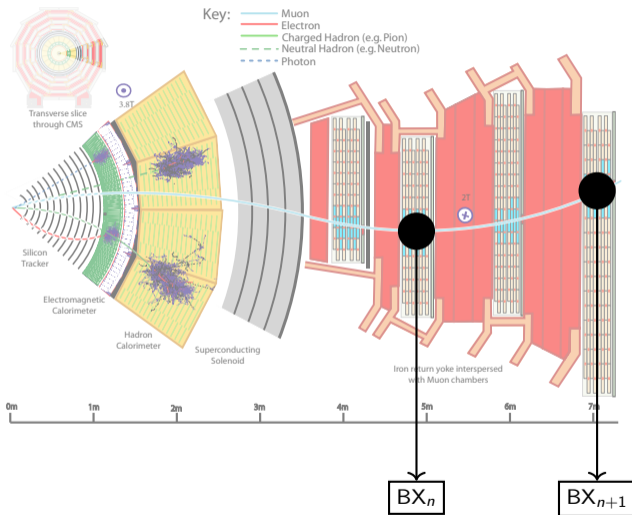
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Level-1 trigger cannot cope with high rate coming from muons with low p_T :

- A range of possible topologies, depending on dark sector properties
- Need (very) creative trigger or...
- ...scout muons from GMT/BMTF

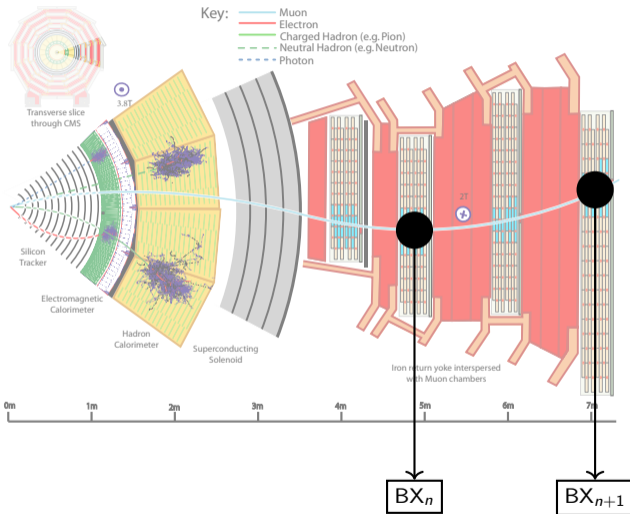
Physics signatures: Heavy Stable Charged Particles



HSCP are charged, heavy, slow, stable particles:

- β (\sim velocity) is significantly lower than 1
- $\Rightarrow > 1$ Bunch Crossings (BXs) to reach muon chambers
 - $\beta \sim 0.5$: 2 BXs
 - $\beta \sim 0.3$: 3 BXs
 - $\beta \sim 0.2$: 4 BXs
 - $\beta \sim 0.1$: 5 BXs
- **Exotic timing**
- Slow moving, appearing, disappearing

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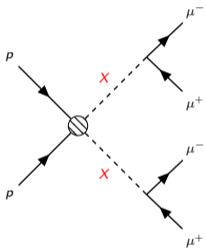
Physics search:

- Trigger currently cannot look into more than 1 BX
- \Rightarrow Signature not recognized
- L1 Scouting: multiple BXs information available
- \Rightarrow Correlate Missing Energy with muon signatures

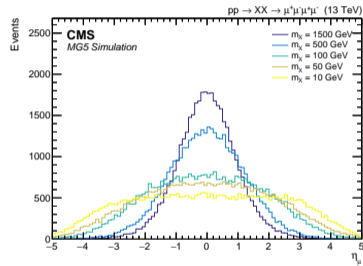
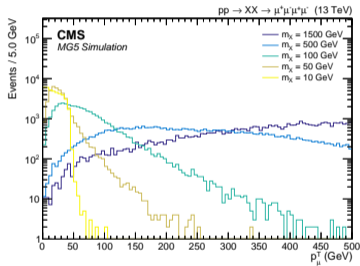
Setting-up a physics analysis

Start from theory and use Monte Carlo generators to explore signature:

- Simulate proton-proton collision + Hadronisation + Detector response
- Scan features along the free parameters of the model (e.g., M_X)



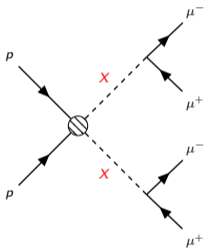
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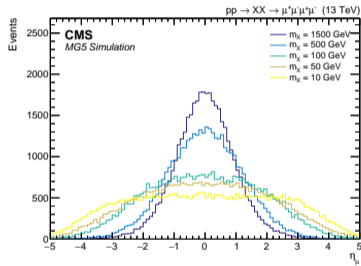
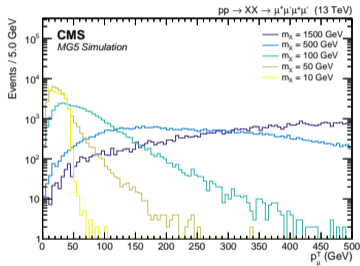
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Simulation + M_X Scan



After identification of a possible promising signature and phase space region:

- Perform standard analysis with data from double Trigger system
- Perform analysis with L1 scouting data
- Comparison of results \Rightarrow Understand what can be improved

Summary

- Standard Model
 - Extremely precise measurements...
 - ...but lots of questions not answered
- Very active studies on exotic signatures going on
- Explore with L1 Scouting regions not covered by Trigger
- Long-Lived-Particles most promising signatures
 - Leading to displaced (soft) muons
 - Heavy Stable Charged Particles covering > 1 BXs
- Studies on-going to set-up a physics analysis
- Studies on how to exploit and correlate information from:
 - μ GMT: muons (up to 8)
 - BMTF: muons (up to 36)
 - Calo: jets, e/γ , τ (up to 12 each), missing energy
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Special thanks to

