Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Trigger Studies for Self-Interacting Dark Matter at CMS

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CMS Compact Muon Solenoid

ROMA TRE UNIVERSITÀ DEGLI STUDI

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Outline

- **Introduction:**
  - Self-Interacting Dark Matter
  - CMS and trigger systems
- **Purpose and analysis overview**
- **Analysis and results**
  - Per-object efficiency: tag and probe method
  - Per-event efficiency
- **Conclusions**

Self-Interacting Dark Matter

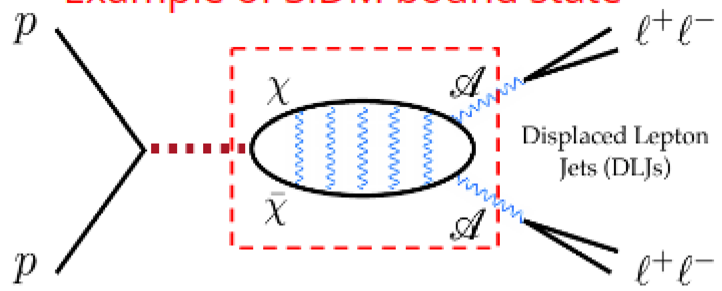
- **Dark Matter** (DM) is 'weakly' interacting matter that is **postulated** to exist to explain several **astrophysical observations.**

- **Self-Interaction Dark Matter** (SIDM) models assume dark matter has self-interactions (ie, **bounds states** exist)

- The **SIDM group** at Fermilab is considering the following SIDM model:

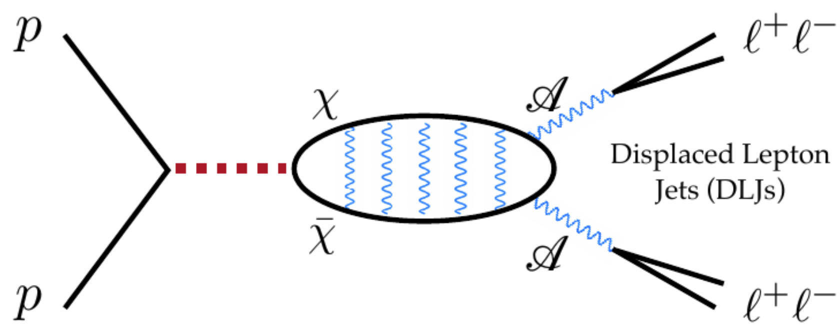
$$\mathcal{L}_{\mathrm{SIDM}} = \bar{\chi}(i\partial\!\!\!/ + g_\chi \mathcal{A}\!\!\!/ - m_\chi)\chi + \frac{1}{2}m^2_{\mathcal{A}}\mathcal{A}_\mu\mathcal{A}^\mu + \frac{1}{2}\epsilon_{\mathcal{A}}\mathcal{F}_{\mu\nu}\mathcal{F}^{\mu\nu}$$

- Fermionic dark matter particles χ couples to a dark photon A with mass m_A



[Displaced Lepton Jet Signatures from Self-Interacting Dark Matter Bound States - Tsai, Yuhsin et al. JHEP 1908 (2019) 131 arXiv:1811.05999 [hep-ph]]

Production and decay



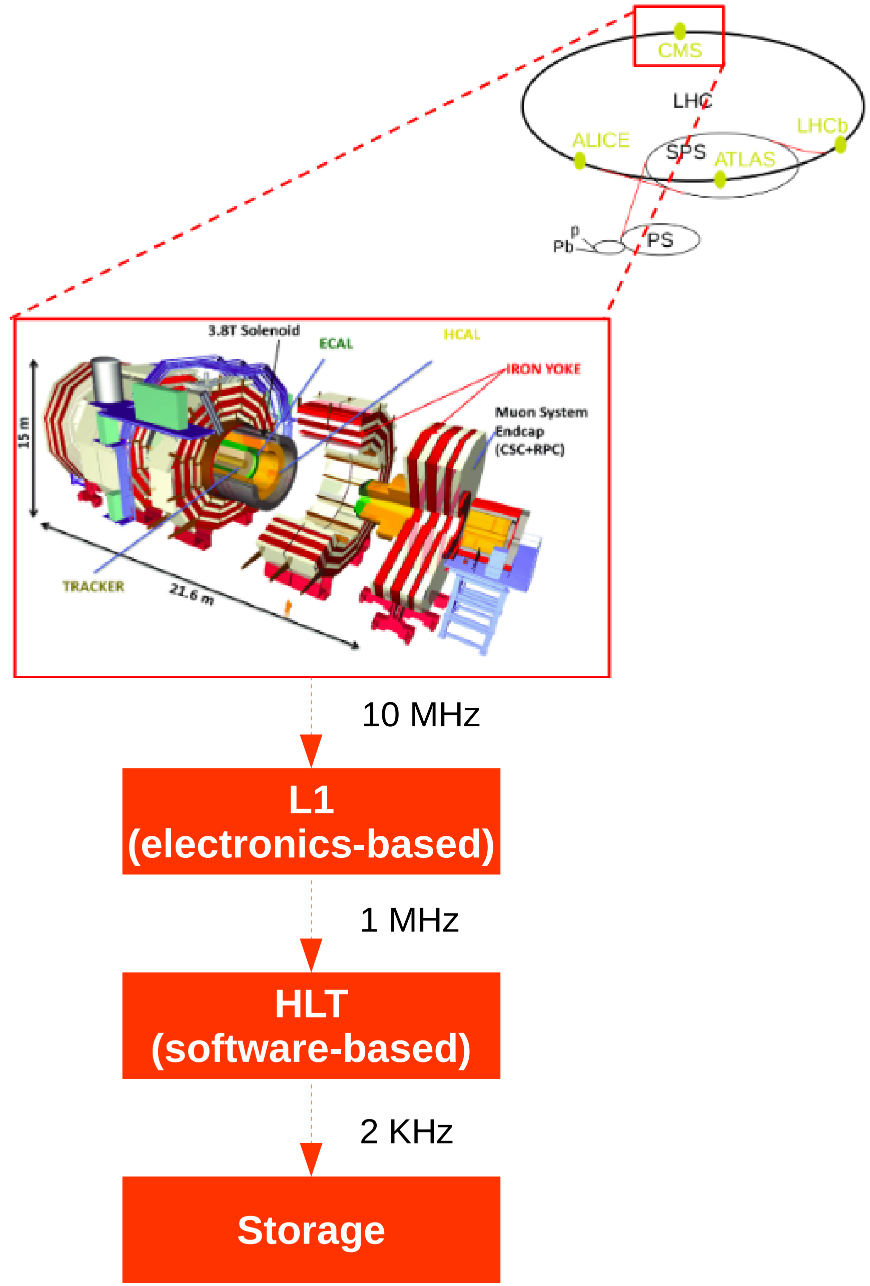
- The SIDM bound state decays in two dark photons
- A dark photon is a **long-lived particle** (LLP), decaying outside the inner tracker
- Dark photons decay in lepton jets (LJ), i.e. **groupsof SM leptons collimated in a tight cone**
- LJs can be **mu**, **electron** or **mixed-type** (electron-type are difficult to study)
- **Signal:** two or more displaced LJ back-to-back in the detector ($\Delta\eta > 2.5$)
- **Backgrounds:** QCD and Drell-Yan processes

CMS and trigger systems

- What is CMS?
- What is a trigger and why we need it?
- What is trigger efficiency?

$$\varepsilon = \frac{\#\text{interesting events triggered}}{\#\text{interesting events produced}}$$

- How do we use trigger efficiency?
- What is a trigger object (TO)



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Purpose and Analysis Overview

Compute the efficiency of a trigger system that selects events with 2 muon-type LJs

- We do not have 2 LJ triggers → we use double Mu triggers (TOs are muons)

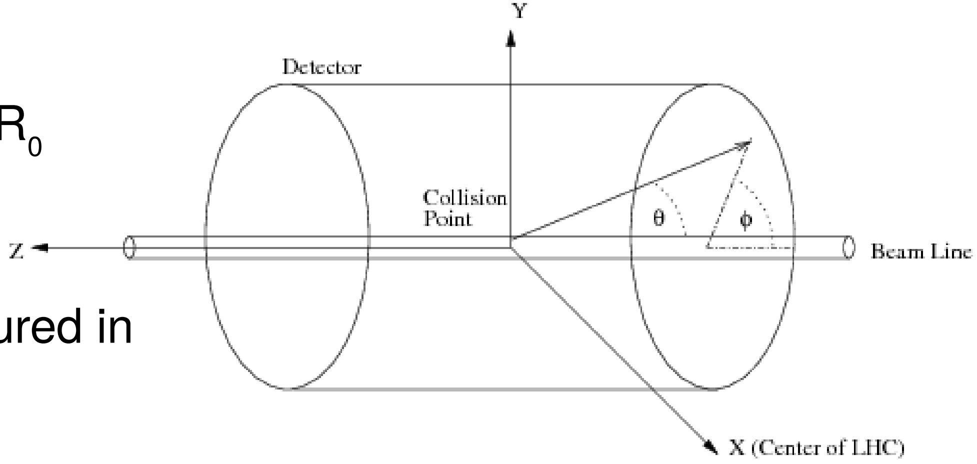
- The analysis is divided into 2 parts:
  1. Compute probability for a LJ to contain 1 or 2+ TOs (per-object eff. ε_o)
  2. Compute probability for 2 LJs to contain 2+ TOs (per-event eff. ε_e)

Per-object efficiency: tag and probe method

- We select all possible pairs of Mu-type LJs (same event)
- We consider all the pairs with at least a LJ (**tag**) containing at least a TO
- The other LJ (**probe**) can either contain a TO or not.
- Per-object efficiency is: $\varepsilon_o = \frac{\#\text{good probes}}{\#\text{tags}}$
- That is the probability for a LJ to contain at least 1 TO
- **Note:** each LJ can be both tag and probe → roles must be inverted
- **Reference trigger:** we want to be sure tag would be saved regardless of the 2Mu triggers
- A TO is contained in a LJ if: $\Delta R < \Delta R_0$

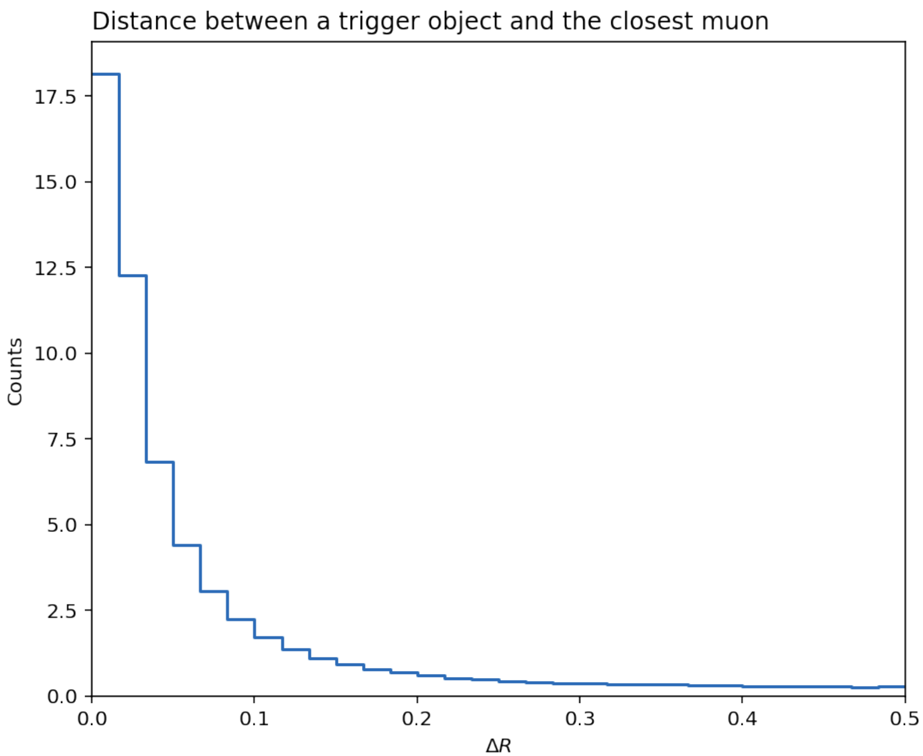
$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$

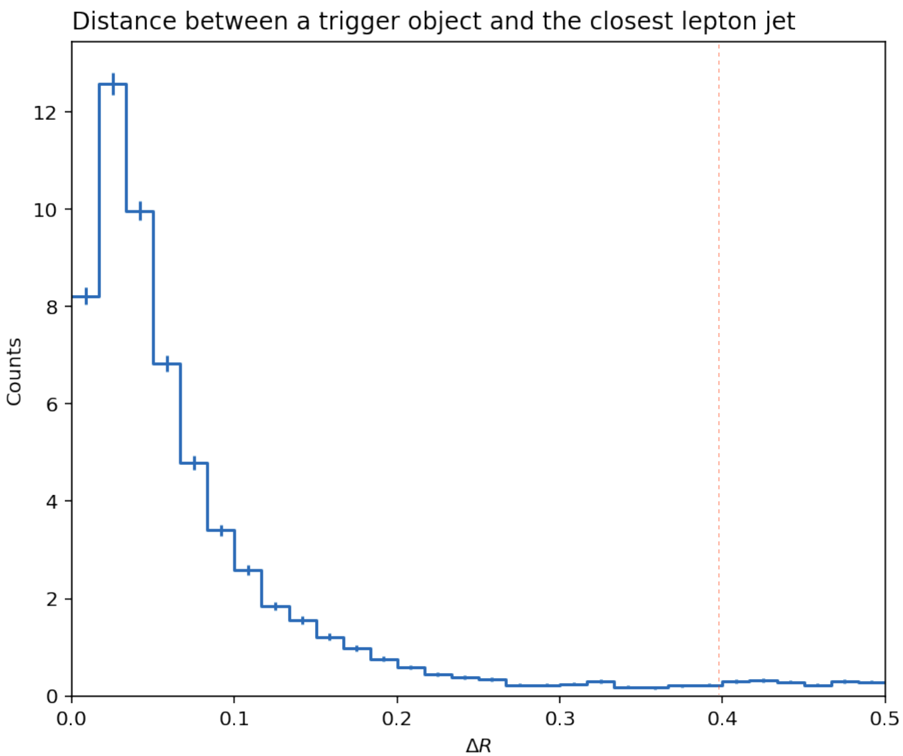
Where φ and η are meant as measured in the innermost part of the detector



Preliminary study of ΔR

- In the SIDM model, LJs have size of ΔR ~ 0.5
- Distance between a given TO and the closest LJ is well below 0.5

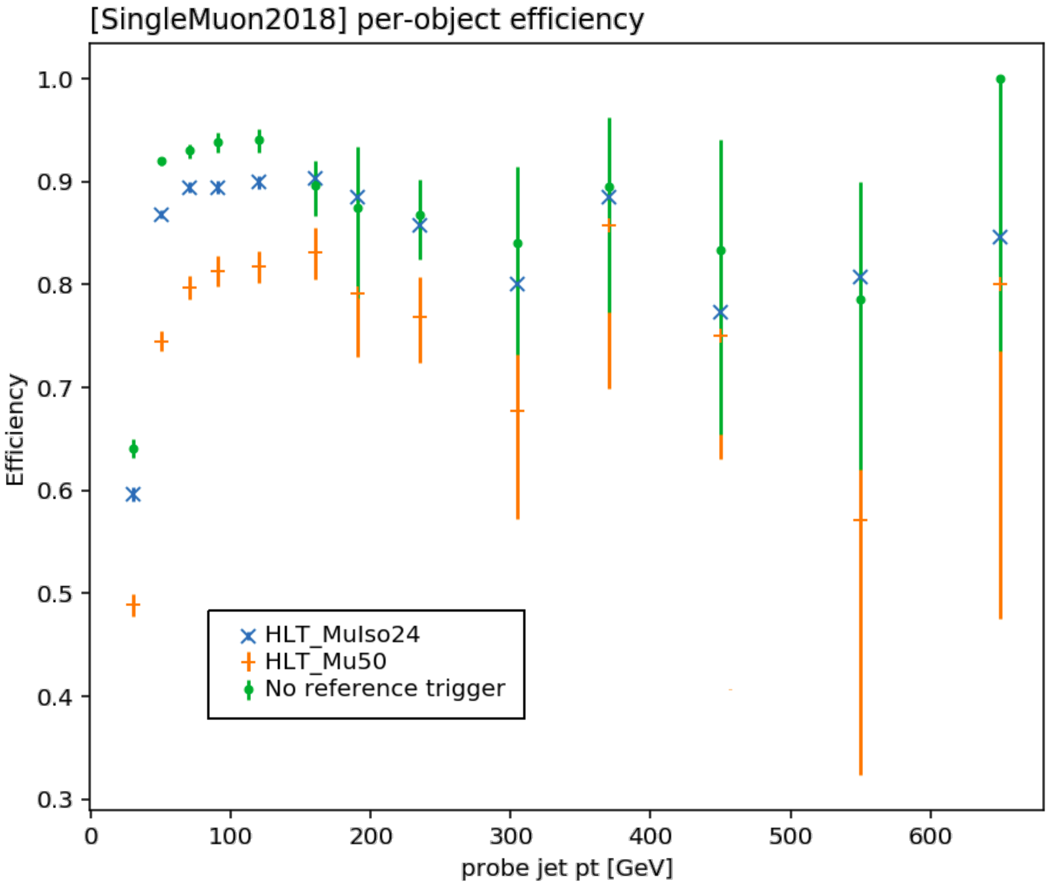




- We decide that a LJ is matched by a TO if $\Delta R < \Delta R_0 = 0.4$
- Condition for tag and probe: ΔR > 0.8 (otherwise, pair rejected)

With reference trigger vs without

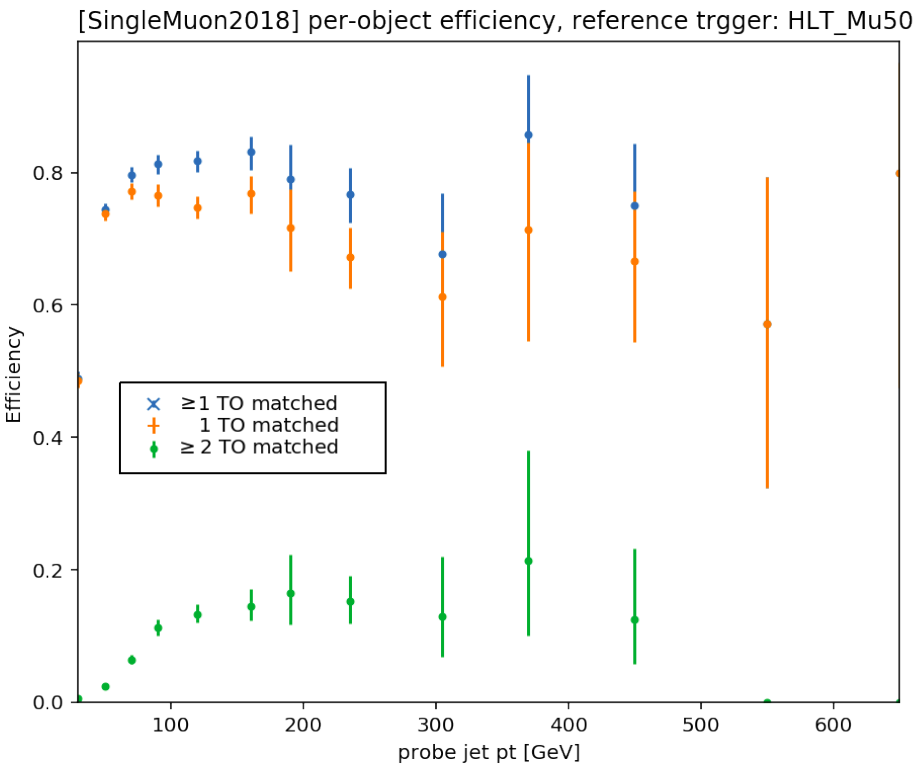
- We used two different reference triggers (**HLT_Mu50** and **HLT_MuIso24**)

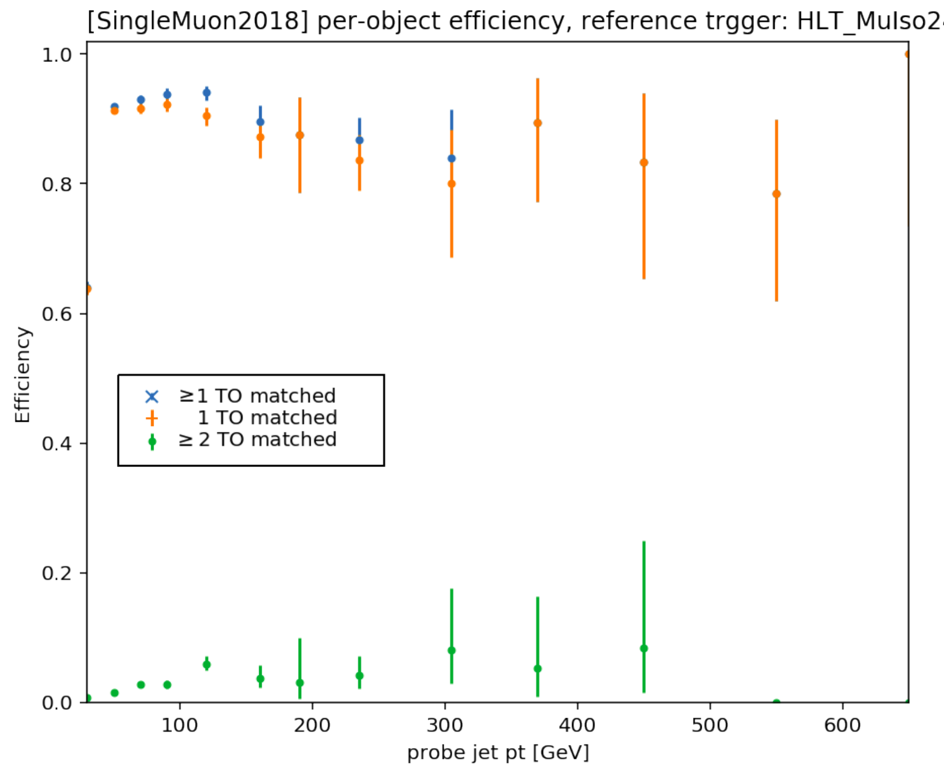


- Discrepancy between HLT_Mu50 and HLT_MuIso24 may be due to the different L1 seeds (L1 trigger outcome)

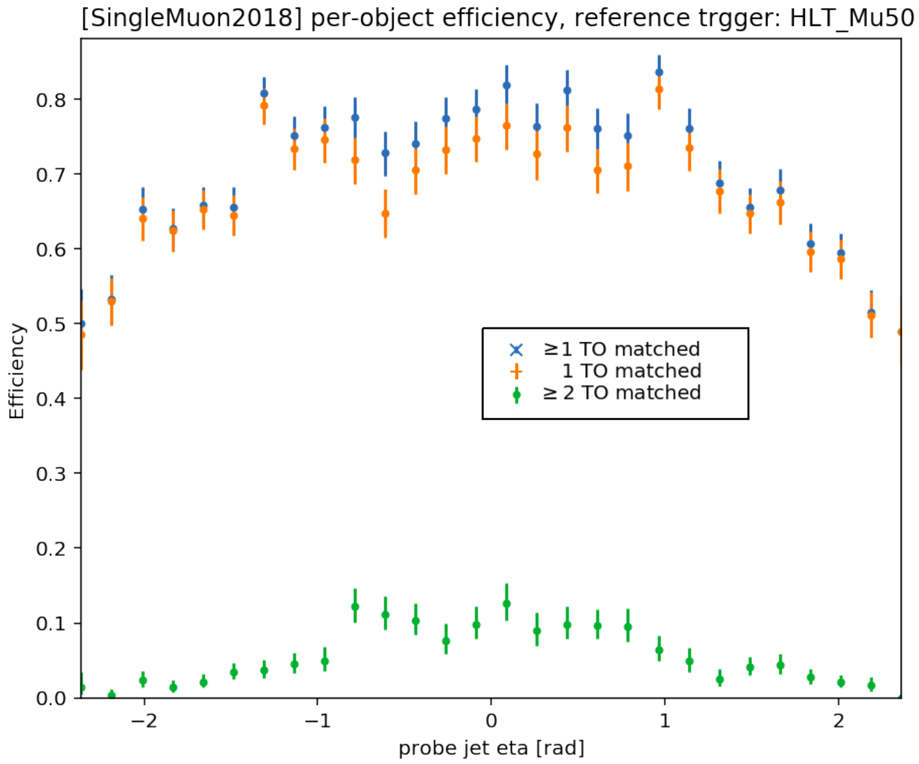
How many TOs in a LJ?

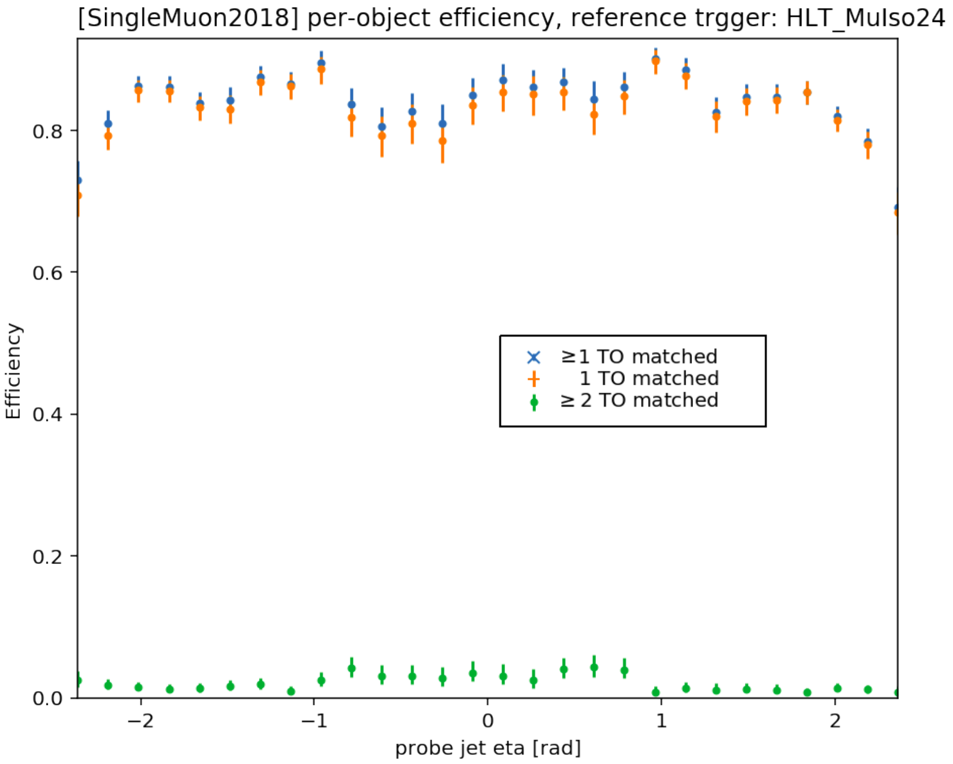
- Each LJ can be matched by more than one TO
- To compute per-event efficiency, we need to know what fraction of LJ is matched be 1 TO or 2+ TOs





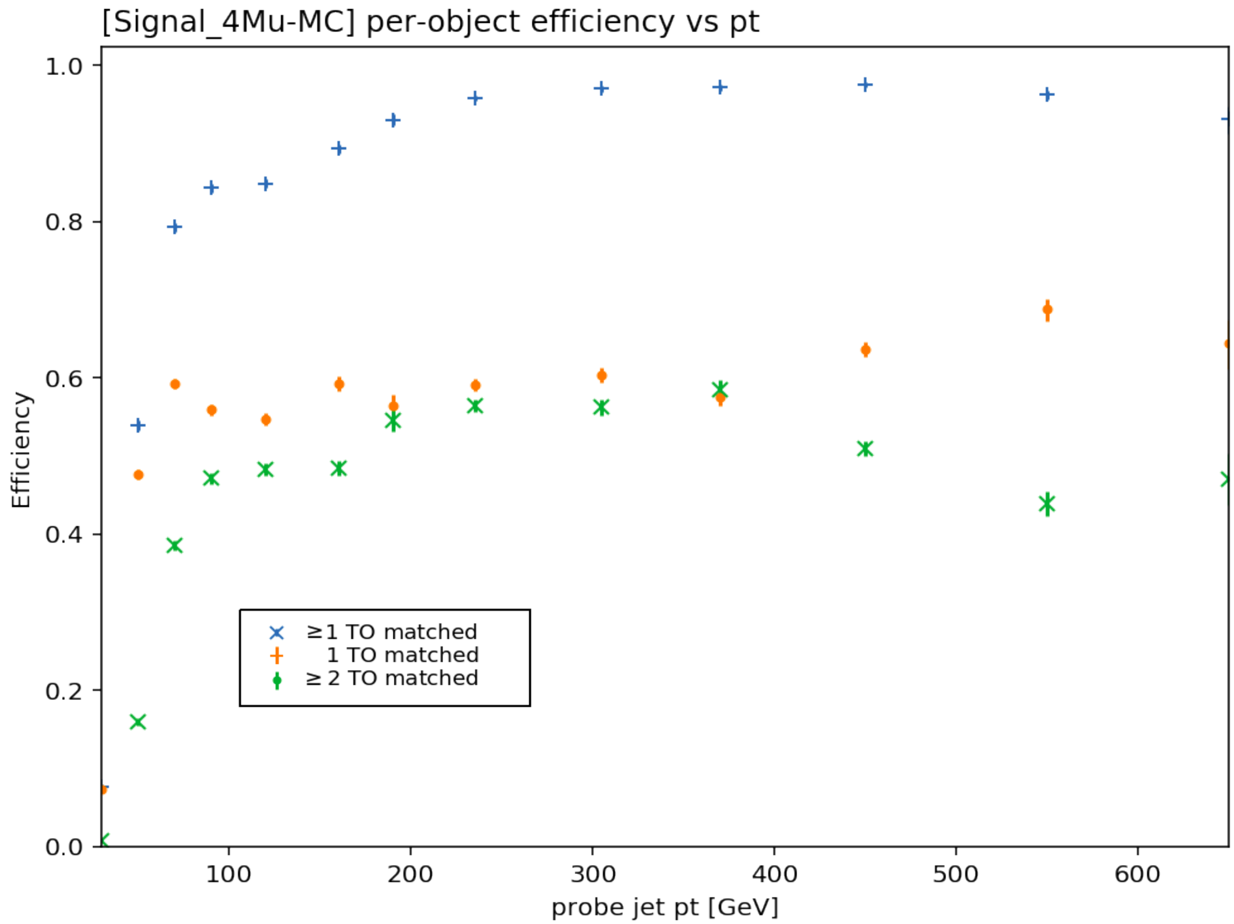
Control Region Data (Eta)





MC Signal Region (Pt)

- For MC we do not need reference a trigger
- In the signal events, more lepton jets will have two real muons (higher fraction of 2+ TO)



Plateau values

- The plateau values for Pt efficiencies were computed after applying a Pt cut to the efficiency curves and averaging over the plateau points
- The values are:

TOs	Control Region (Mu50)	Control Region (MuIso24)	MC Signal
≥ 1	0.78 ± 0.09	0.84 ± 0.07	0.99 ± 0.01
1	0.69 ± 0.10	0.83 ± 0.09	0.58 ± 0.05
≥ 2	0.15 ± 0.04	0.11 ± 0.02	0.56 ± 0.06

- We will use these values to compute per-event efficiency
- **Note:** for more accurate computation, binned histogram values should be used

Per-event efficiency: two methods

We want to compute the probability for 2 LJs to contain 2+ TOs

1. Montecarlo: combining per-object probabilities with a simulation

(applicable for events with more than 2 LJs too)

2. Analytical Method:

Assuming per-object probabilities are independent:

$$P_{2LJs}(TOs \geq 2) = P(1)^2 + P(\geq 2)^2 + 2P(0)P(\geq 2) +$$
$$+ 2P(1)P(\geq 2)$$

$\mathbf{LJ_A}$	$\mathbf{LJ_B}$
1	1
1	≥ 2
≥ 2	1
0	≥ 2
≥ 2	0
≥ 2	≥ 2
1	0
0	0

Per-event efficiency: final results

- Probability for a 2 LJs to contain at least 2 TOs
- The two methods produce consistent results within the errors
- Montecarlo result is systematically smaller

Method	Control Region (Mu50)	Control Region (MuIso24)	MC Signal
Analytical	0.81 ± 0.04	0.86 ± 0.05	1.00 ± 0.01
Motecarlo	0.76 ± 0.07	0.81 ± 0.09	0.98 ± 0.02

Conclusions

The results are good, but there are further steps to take:

- Understand the dependence on the reference trigger
- Combine per-object efficiency as probability distribution, not only plateau val
- Compare efficiencies between MC and Data

What I learned:

- Dark matter phenomenology (SIDM and LJs)
- CMS data analysis: crab and condor utilities
- Array programming and Coffea library: a possible ROOT's successor

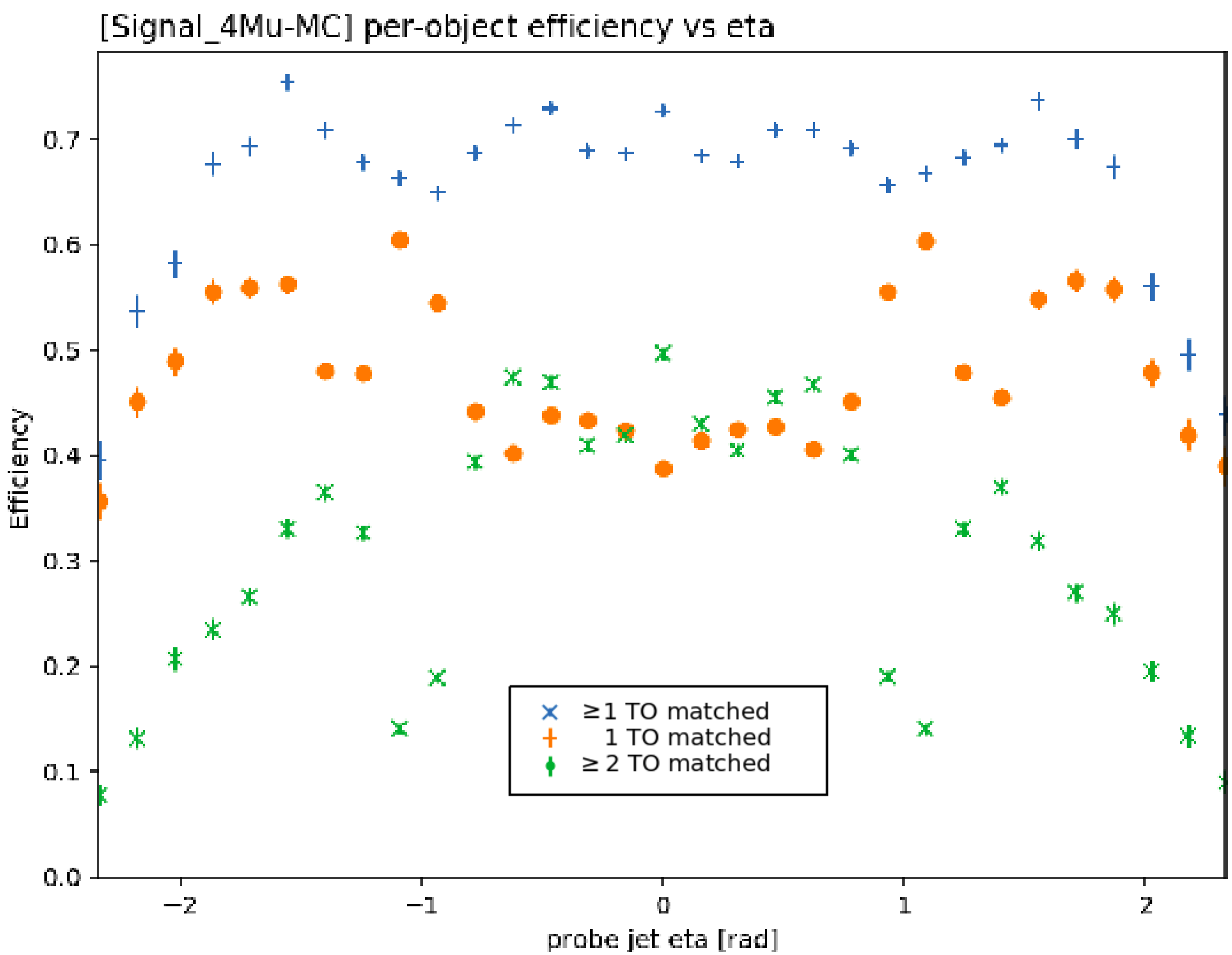
How my work will help the SIDM group:

- I produced useful code that will be used to conclude trigger analysis

Thanks for your attention

Backup

MC signal samples: efficiency vs Eta



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Signal parameters

Bound state mass: [100, 150, 200, 500, 800, 1000] GeV

c*tau (mean Lxy): [0.3, 3, 30, 150, 300] cm

Dark photons mass: [0.25, 1.2, 5] GeV

Trigger paths

Logical OR of:

- HLT_DoubleL2Mu23NoVtx_2Cha
- HLT_DoubleL2Mu23NoVtx_2Cha_NoL2Matched
- HLT_DoubleL2Mu23NoVtx_2Cha_CosmicSeed
- HLT_DoubleL2Mu23NoVtx_2Cha_CosmicSeed_NoL2Matched
- HLT_DoubleL2Mu25NoVtx_2Cha_Eta2p4
- HLT_DoubleL2Mu25NoVtx_2Cha_CosmicSeed_Eta2p4

≥2 L2 muons; **pT>23GeV**; **|eta|<2.0**; **≥2 muon chambers**

NoVtx: L2 muons are reconstructed with "**NoVtx**" algorithm

NoL2Matched: add **SingleMu22** L1 seed in addi9on to original DoubleMu_15_7; mitigates rapid efficiency

loss with d0 at L1.