# Search for Groups of Nearby Muons at CMS ("Muon Jets")

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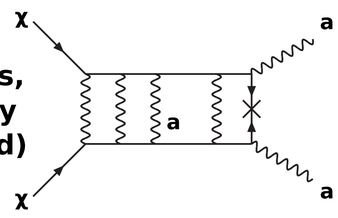
(for other lepton-jet related work at CMS, see Princeton, Florida State, Rice, and Rutgers)

## MOTIVATION

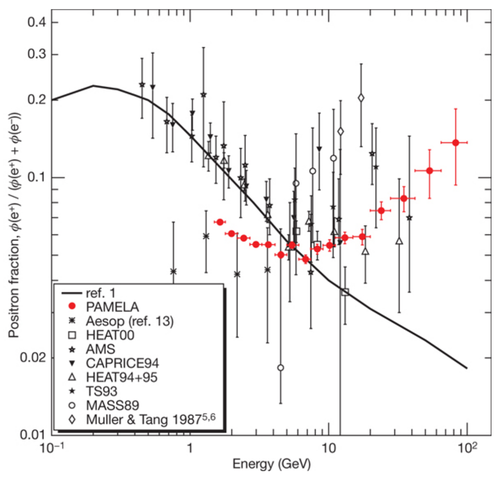
**1. PAMELA positron excess might be due to dark matter, but only if WIMP annihilation rate is much higher than expected**

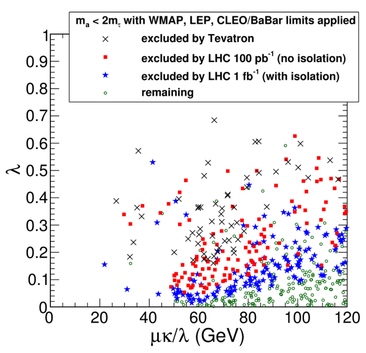
**→ adding an O(1 GeV/$c^2$) boson to the dark sector would enhance present-day WIMP annihilation without upsetting freeze-out constraints, and also kinematically forbid an (unobserved) antiproton excess**

**(see e.g. PRD 79, 015014)**

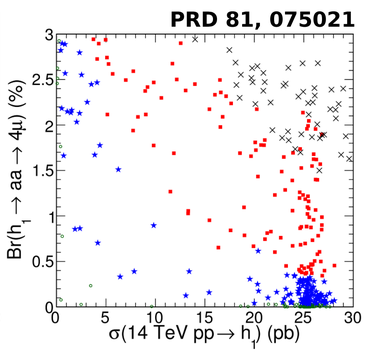



Nature 458, 607




PRD 81, 075021




**2. NMSSM could hide Higgs in Higgs-to-Higgs decays such as h → aa → 4μ if CP-odd "a" is O(few GeV)**

**→ regions of parameter space survive current experimental constraints**

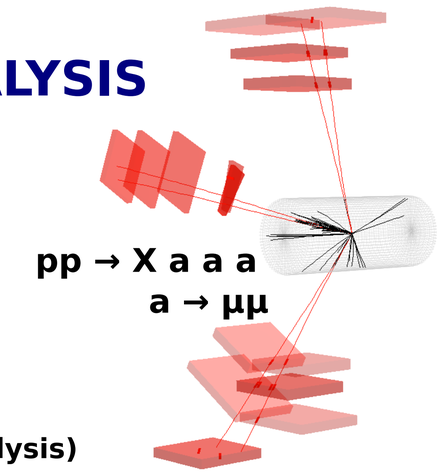
**3. General "hidden valley" phenomenon predicts new low-mass particles produced at high energies, kinematically forced to decay to light fermions**

## GENERAL SIGNATURE

- **low-mass, high-momentum neutral resonances from top-down decays**
- **unknown number of fermion pairs at the end of the cascade**

## RESTRICTION FOR THIS ANALYSIS

- **muon-only final states**
- **≥ 2 groups ("muon jets")**




**Similarity to jets:** **we don't know how many particles to expect**

**Similarity to tau-jets:** **we want to accept a well-defined mass range (like "shrinking cone" analysis)**

**Similarity to dimuons:** **we can fully reconstruct the final state, hunt for mass-peaks**

## MUON-JET DEFINITION

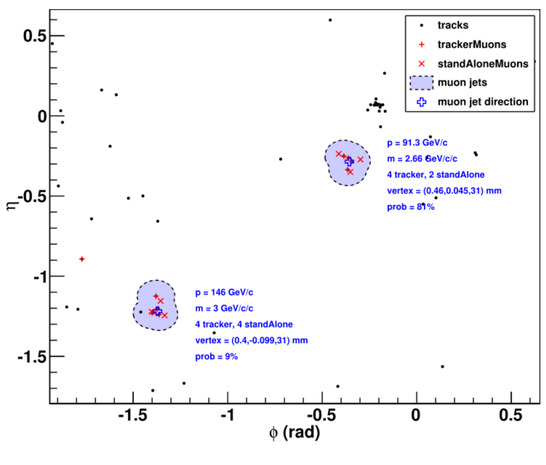
**→ Recursively group pairs of "nearby" muons**

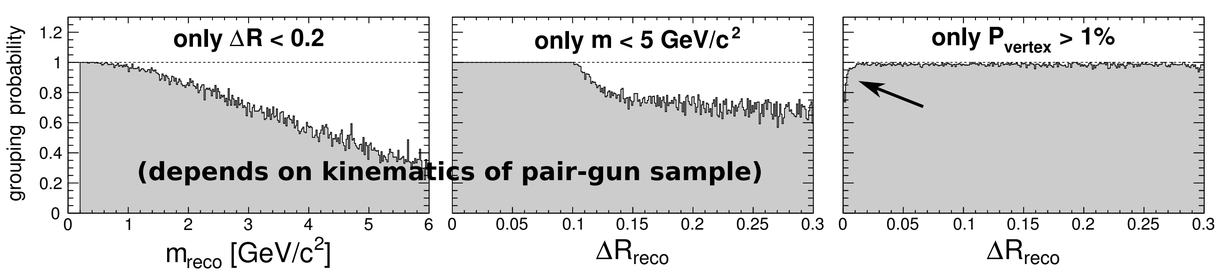
**→ "Nearby" means:**

$(m_{\text{inv}} < 5\ \text{GeV}/c^2$ **and** $P_{\text{vertex}} > 1\%)$

**or** $\Delta R < 0.1$

for oppositely charged muons



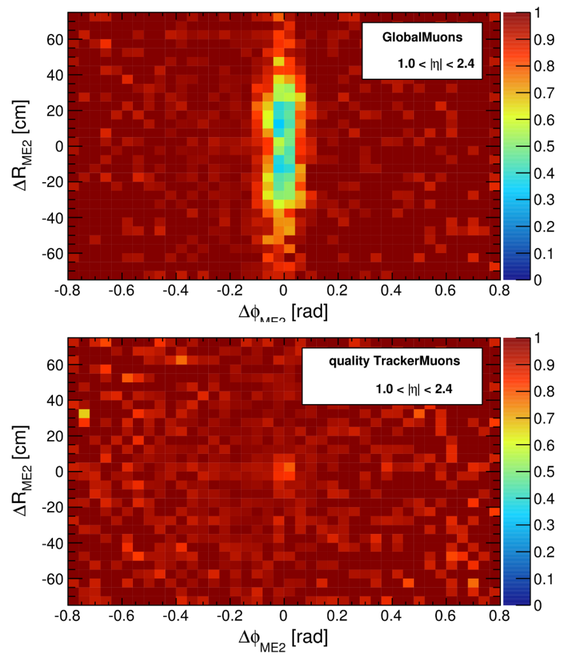

## ANALYSIS STRATEGY

1. **Optimize detector sensitivity and define selections from MC (done)**
2. **Identify single muon-jet background (a.k.a. the SM dimuon spectrum)**
3. **Estimate two-or-more muon-jet backgrounds from data**
4. **Understand trigger efficiency for nearby muons**
5. **Search for events with at least two clean muon-jets (a) by counting above background estimate and (b) with a double-mass peak fit**

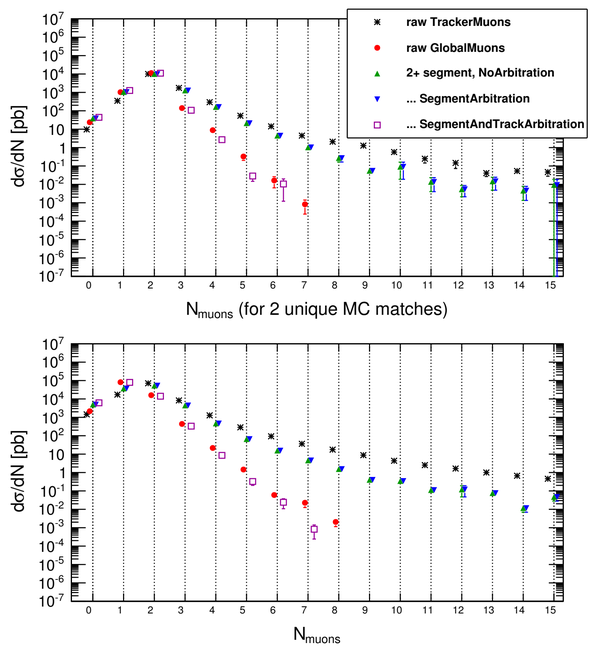
## DETECTOR AND RECONSTRUCTION

- **GlobalMuons: low fake rate, but StandAloneMuon reconstruction (a prerequisite) is inefficient *when muons cross in the muon system***
- **TrackerMuons: efficiency is independent of crossing but fake rates are high in jets, where many tracks point to the same muon segments**
- **TrackerMuons with number of arbitrated segments ≥ 2: provides both high, well-understood efficiency and a fake rate as low as GlobalMuons**

**efficiency (color scale) vs. difference in track positions evaluated at ME2 plane**



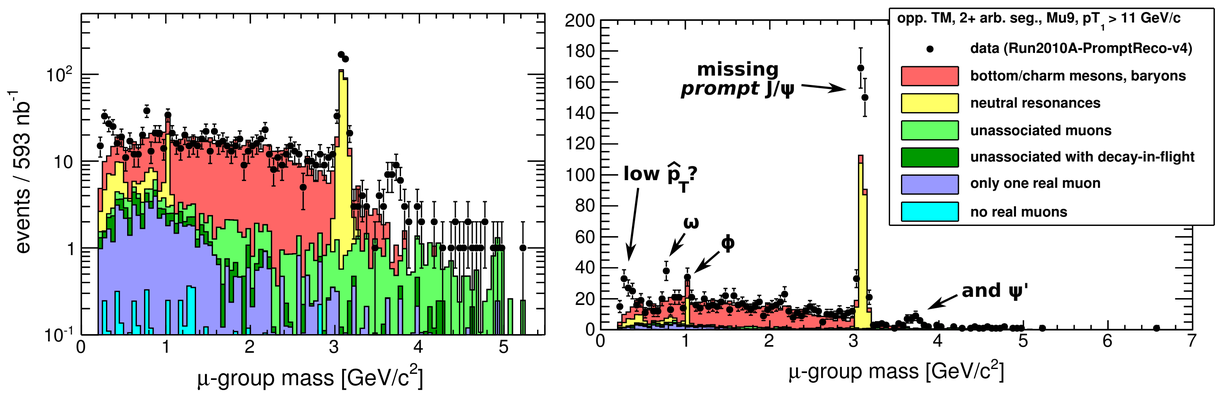

**number of reconstructed tracks for a given number of generator-level muons**




***Note: StandAlone inefficiency still an issue for the trigger!***

## BACKGROUNDS

**Overlay of single muon-jets from $\hat{p}_T > 30$ GeV/c QCD Monte Carlo and 0.6 pb$^{-1}$ of data shown below (more complete MC and data in progress)**



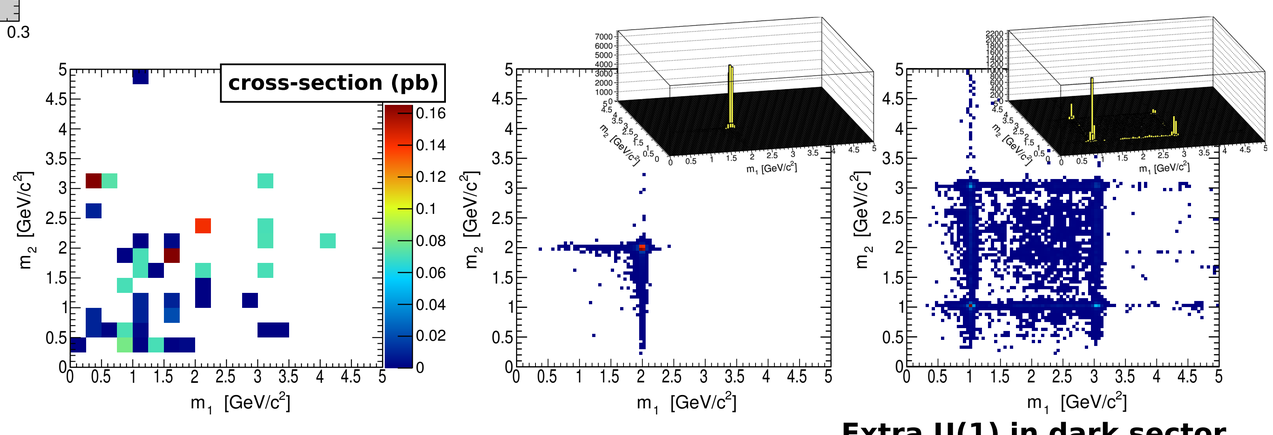

## ESTIMATING BACKGROUNDS FROM DATA

- **Decay method: assume decay chain for each jet is independent; measure P(≥2 muons | 1 muon) in single muon/muon-jet, apply it to ≥2 jet events**
- **Isolation method: assume kinematics and isolation are independent; extrapolate from anti-cut**
- **Fitting method: assume background shape, fit for 2-D peaks plus background in $m_1$, $m_2$ plane**

**Each method will need to be tested in Monte Carlo (fitting method was demonstrated for a simplified detector in PRD 81, 075021)**

## DOUBLE-MASS PEAKS

**In signal events with at least two muon-jets, the muon-jet masses are correlated; backgrounds are not**




**QCD backgrounds**

**NMSSM point ($m_a$ = 2 GeV/$c^2$)**

**Extra U(1) in dark sector ($m_a$ = 1 GeV/$c^2$, $m_h$ = 3 GeV/$c^2$, both a → 2μ and h → aa → 4μ)**