Reconstructing Groups of Nearby Muons

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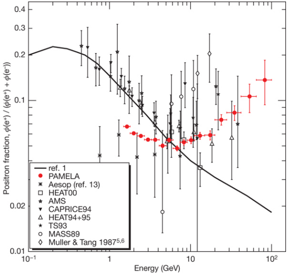
29 July, 2010

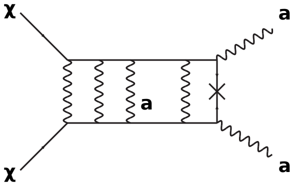
Very quick motivation (1/2)

For full details, see *Lepton Jets as a Signature for Dark Matter* by Chaouki Boulahouache, Exotica, March 16: http://indico.cern.ch/materialDisplay.py?contribId=2&materialId=slides&confId=87421



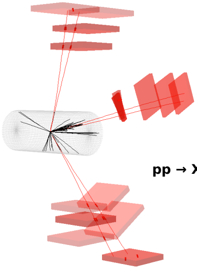
- Pamela discovered a source of high-energy positrons in primary cosmic rays (2008)
  - could be undiscovered nearby pulsars
  - could be WIMP-WIMP annihilation
- If it's WIMP-WIMP annihilation, the observed cross-section is too large for the "WIMP miracle" scenario

- Introducing a long-range force in the dark matter sector, mediated by "a" (new boson; $m_a \sim 1$ GeV$/c^2$), enhances annihilation cross-section in the present universe (when WIMPs have low velocity)
- $m_a \sim 1$ GeV$/c^2$ also explains lack of excess in antiprotons: kinematically forbidden



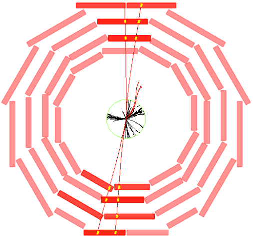
hep-ph/0810.0713

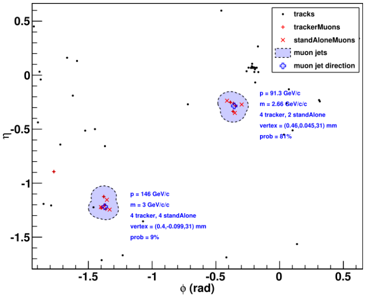
Very quick motivation (2/2)



pp → X a a a
a → μμ

- Not a specific model, but a general theoretical idea ("Lepton Jets")
  - many different scenarios proposed
  - other properties of a are not restricted
  - there may be several a_i with different masses, leading to cascades
- Need to be able to reconstruct the general signature of "collimated leptons," or low-mass, high-$\vec{p}$ groups of leptons (muons)





https://twiki.cern.ch/twiki//bin/viewauth/CMS/ExoticaMuonJets

TWiki > CMS Web > EXOTICA > ExoticaMuons > ExoticaMuonJets (25-Jul-2010, JimPivarski)

Complete:

- Lepton Jets Analysis
  - Group
  - Organization/Task list
    - Task list
  - Resources
    - Physics Results
      - Benchmark results plots
      - Presentations and notes/papers
    - Event samples
      - Monte Carlo: muon jet guns
        - Alternating jet-gun sample
      - Monte Carlo: sample models
      - Monte Carlo: background skims
      - Real Data
    - Known bugs in samples
    - Analysis Software
      - Installation and compiling
        - Compiling everything in the full framework
        - Compiling only pat::MultiMuonCandidates in strict FWLite
      - Skimming datasets with CRAB
      - Generating samples on LPC Condor
      - Analysis: constructing muon jets (LeptonJetEquivalenceClassProducer documentation)
      - Analysis: making plots (MultiMuonCandidate documentation)
        - With FWLite
        - Without FWLite

Groups working on "Lepton Jets"

Princeton
- **Nadia Adam**
- **Valerie Halyo**
- **Adam Hunt**

Rice
- **Chaouki Boulahouache**

Texas A&M
- **Jim Pivarski**
- **Aysen Tatarinov**
- **Alexei Safonov**

Florida State
- **Sergei Gleyzer**

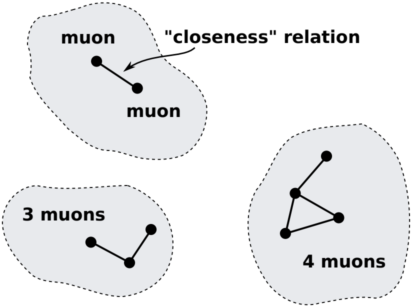
But this talk will only be on the A&M work; more later. . .

Method and infrastructure

- Develop a "μ-group" object, like any other object in CMS
  - study its performance
  - use it in searches
- Software model:

  - pat::MultiMuonCandidate is a persistent group of N muons with methods to perform vertexing and specialized isolation (neighboring muons must not cancel each other out!)
  - LeptonJetsEquivalenceClassProducer groups muons according to their "closeness" (next page)
  - MultiParticleByMassGunProducer simulates pairs and quadruplets of muons uniformly in mass-momentum space
- SVN repository: https//svnweb.cern.ch/cern/wsvn/LeJOG/trunk/

Merging muons into groups



Muons are grouped if

- they are "close" to each other
- they're close to another muon which is close to another, etc.

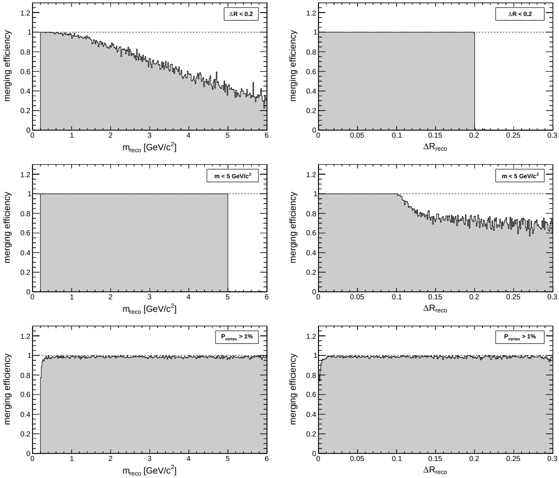
No dependence on the order of the grouping process, easy to analyze

- Definition of "closeness" is tunable, with these ingredients:
  - ΔR: geometrically close in a metric with uniform background
  - m_{inv}: guarantees that low-mass objects will be found, regardless of boost
  - P_{vertex}: requires a consistent track vertex
  - opposite charge: avoids connecting groups that can't be from the same neutral resonance

Merging muons into groups

Grouping efficiency vs. reconstructed mass and ΔR

(denominator: reconstructed two muons; numerator: grouped them)



$\Delta R < 0.2$

$m_{\text{inv}} < 5$ GeV$/c$

$P_{\text{vertex}} > 1\%$

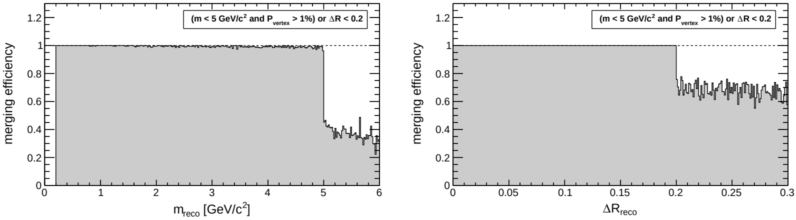
(Note low efficiency due to vertexing failures for collinear muons)

Merging muons into groups

Optimization: group by

$$(m_{\text{inv}} < 5\ \text{GeV}/c\ \textbf{and}\ P_{\text{vertex}} > 1\%)\ \textbf{or}\ \Delta R < 0.1$$

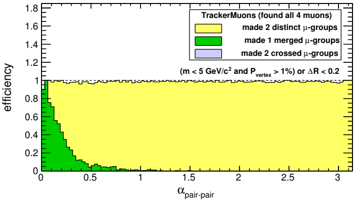
- We guarantee that we get low-mass objects
- Usually require them to vertex well
- Except when they're very close together

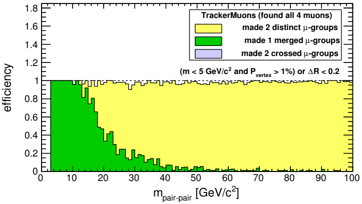


Leave the opposite-sign requirement for later

Merging muons into groups

- If we have two low-mass ($m < 5$ GeV$/c^2$) dimuons in an event, what is the probability that they will be merged into two groups or one group? (denominator: reco'ed four muons; numerator: grouped them)
  - $\alpha_{\text{pair-pair}}$ is the 3D angle between dimuons
  - $m_{\text{pair-pair}}$ is the parent particle mass
  - "crossed" means 1-2, 3-4 gets reconstructed as 1-3, 2-4



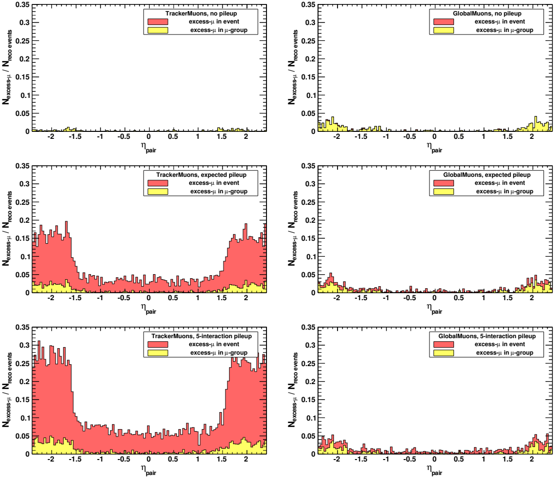


- Can be tuned with grouping criteria: loose "closeness" criteria yield higher efficiency for pairs and higher probability of pair-merging
- The plots above came from a flat-generated pair-pair gun; should try with realistic cascades because it could depend on kinematics

Extra muons in group

- μ-groups can absorb an extra muon from unrelated tracks in the event
- Below: simulations with increasing amounts of pile-up ($\frac{N_{\text{extra}}}{N_{\text{total}}}$ vs. η)

  left: TrackerMuon-groups, right: GlobalMuon-groups

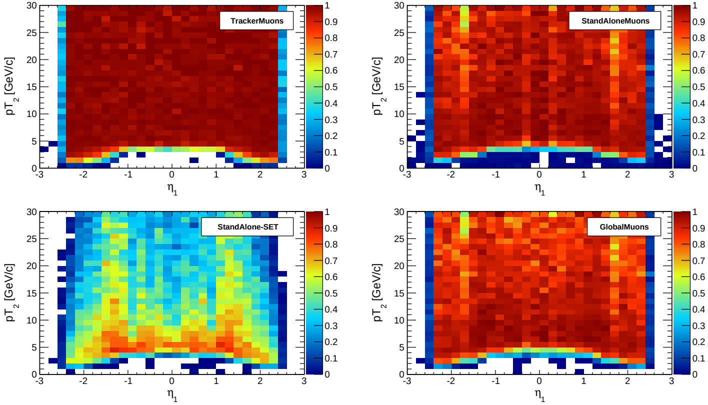


Despite extra tracks identified as muons (red), the extra-muons-in-group (yellow) is controlled by $P_{\text{vertex}} > 1\%$

We'll also soon see that fake TrackerMuons can be controlled with quality cuts

Acceptance and efficiency

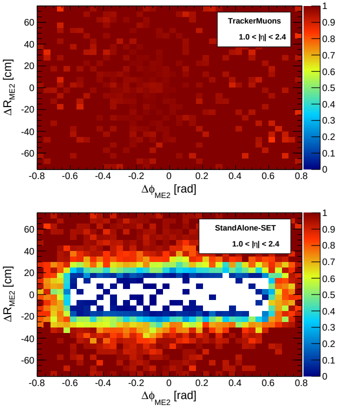
- Acceptance region of a dimuon defined by $pT_2 > 5$ GeV/c and $|\eta_1| < 2.4$ where pT_2 is the second-highest p_T muon and η_1 is the highest-$|\eta|$ muon in the event (denominator: all; numerator: reco'ed two muons)
- Try reconstructing muons in four separate collections: TrackerMuons, StandAloneMuons, StandAlone-SET algorithm, and GlobalMuons



- TrackerMuons have high efficiency everywhere, but they also have (curably) high backgrounds
- StandAloneMuon efficiency depends on how close the muons approach each other in the muon system (next slide)
- GlobalMuon efficiency $\leq$ StandAloneMuon efficiency
  - probability of crossing in the muon system depends on kinematics of the decay
  - this would make it more complicated to quote limits on Lepton Jets derived from GlobalMuons
- I tried StandAlone-SET because I knew that it is an alternative to the standard StandAloneMuons
  - it wasn't designed for nearby-muon efficiency
  - we won't be using it

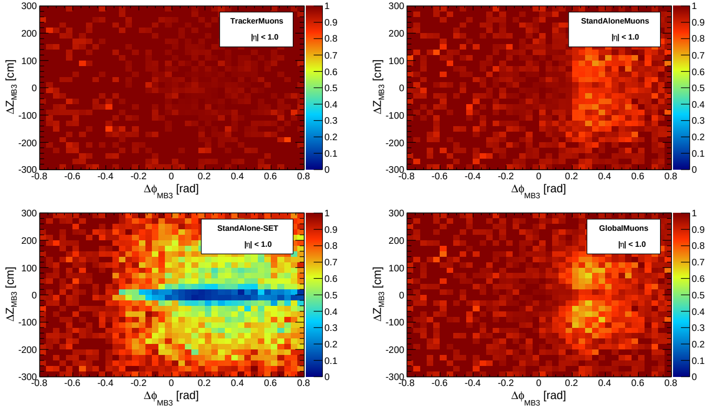
Efficiency vs. crossing

- StandAloneMuon inefficiencies are driven by reconstruction issues for muons that overlap in the muon system
- Test: propagate generator-level muons to planes of constant-z in the endcap and cylinders around the beamline in the barrel
- Plot efficiency as a function of trajectory intersections: $\Delta\phi_{\mathrm{ME2}}$ is $\phi_{\mu^+} - \phi_{\mu^-}$ at $z = 828.561$ cm, ΔRME2 is radial difference

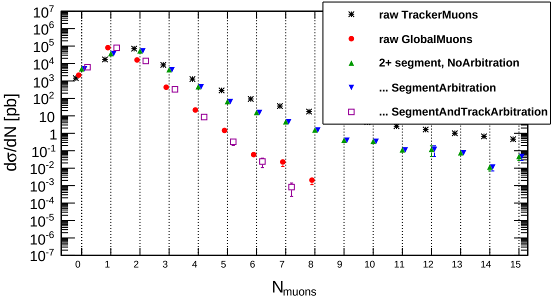


Efficiency vs. crossing

- Same thing in the barrel: $\Delta\phi_{MB3}$ and ΔZ_{MB3} on a cylinder of radius 618.269 cm
- Not completely understood: inefficiencies are off-centered from zero
- Suggests that this plot is "out of focus"— the intersection that drives inefficiency is perhaps at smaller radius than barrel?



- Before moving on, we should address backgrounds with TrackerMuons
- Number of reconstructed muons N_{muons} in the InclusiveMu5_Pt* samples (all QCD backgrounds, including decay-in-flight):



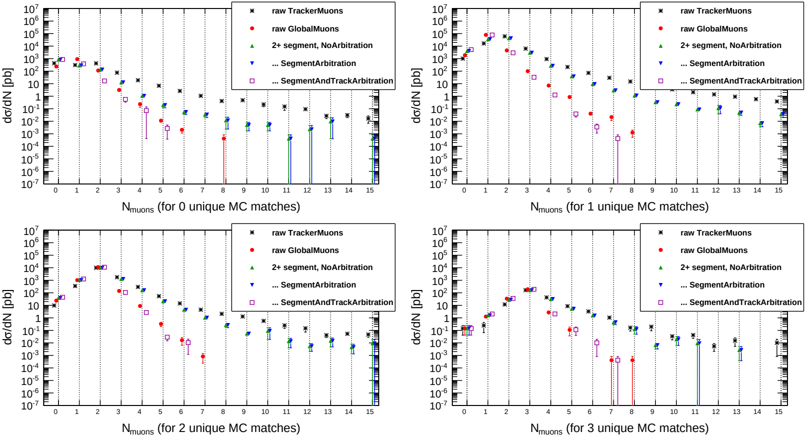
All sets of track cuts include $p_T > 5$ GeV/c

GlobalMuon distributions are nearly independent of sensible cuts

- The *one cut* that makes TrackerMuons as pure as GlobalMuons is $N_{\mathrm{segments}} \geq 2$ for segment-and-track arbitrated segments

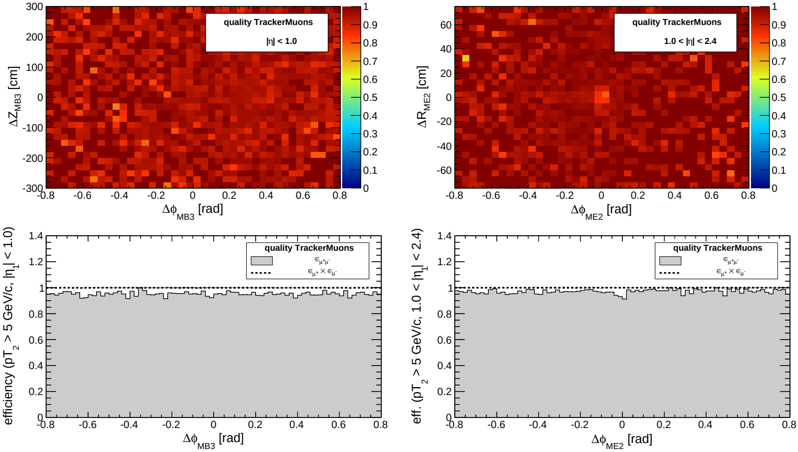
TrackerMuon Backgrounds

- Same plot, split up by the number of real muons in the event
  - defining “real muons” by number of *unique* GenParticle muons matched to all reconstructed muons
- As you can see, TrackerMuons with $N_{\text{segments}} \geq 2$ (open purple boxes) are narrowly distributed around the true number of muons



Quality-cut efficiency

- TrackerMuon efficiency with $N_{\text{segments}} \geq 2$ (and other quality cuts) is still $\sim$95% without a hard-to-model dip when pairs cross each other in the muon system

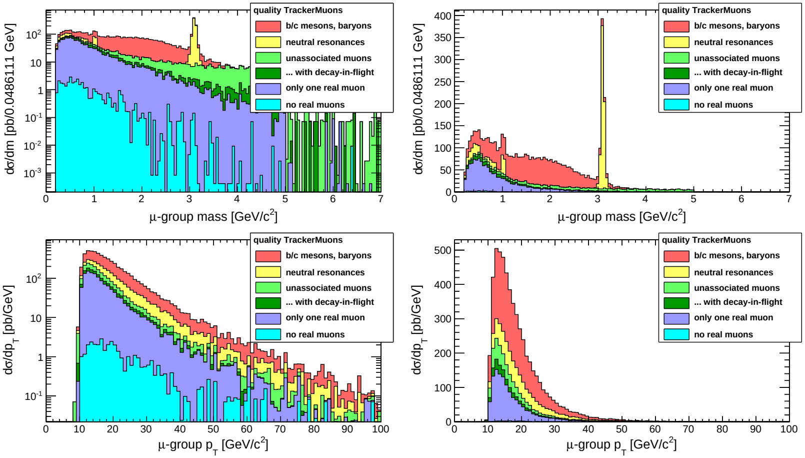


Trigger efficiency

- It may be a challenge to quantify our trigger efficiency
- Issues in L1:
  - when multiple muons pass through the same chamber, only one may be read out
  - if an L1 muon is constructed from some μ^+ segments and some μ^- segments, they may fail to be reconstructed as a single high-p_T muon
  - this is not fully modeled in the L1 emulator! (not for the CMSSW_3_6_3 version that I'm using, anyway...)
- Issues in HLT:
  - uses StandAloneMuon reconstruction, with the inefficiencies already presented
  - only need to reconstruct one StandAloneMuon at HLT, not two, but reconstruction can still be confused by overlaps
- Also, time-dependence as trigger conditions change

QCD backgrounds: one μ-group

- The Standard Model has two clear signals in the one μ-group channel: J/ψ and $\phi(1020)$ (yellow)
- $b \to c \to s$ with two semi-leptonic decays also correlates muons (red)



QCD backgrounds: one μ-group

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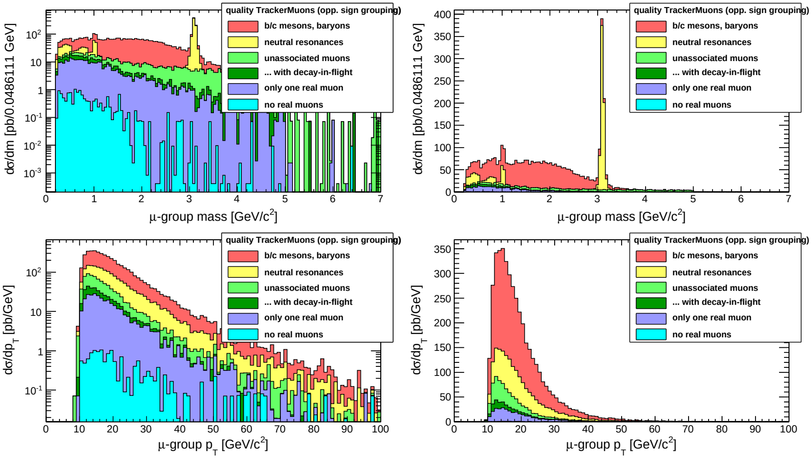
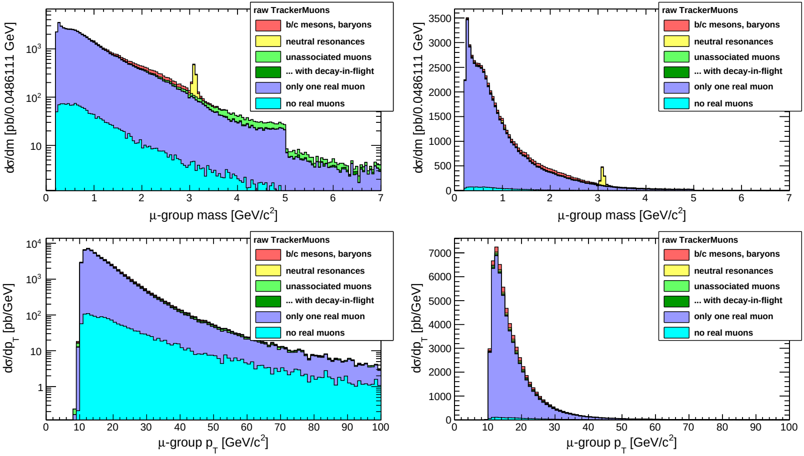
- $b \to c \to s$ with two semi-leptonic decays also correlates muons (red)
- Only-one-muon (grey/blue) suppressed with opposite-sign grouping



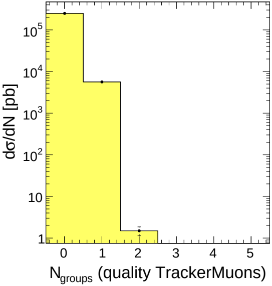
QCD backgrounds: one μ-group

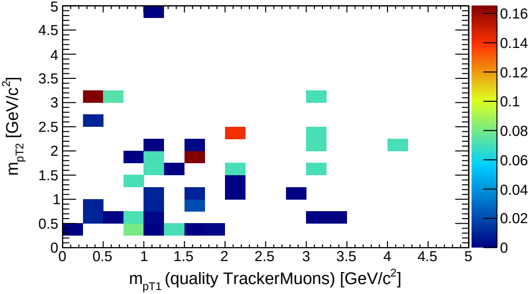
- Just for fun: what it would look like without $N_{\text{segments}} \geq 2$ cut



Multiple μ-groups

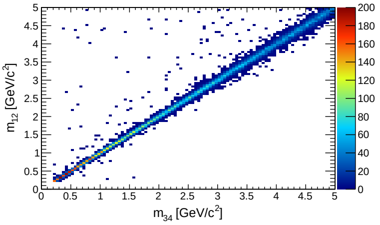
- Asking for a second μ-group reduces the QCD backgrounds to 1 pb
- Many of the models we've looked at have $\sim$pb cross-sections or at least limits can be set with 1–100 pb^{-1}
- Since we're looking for new resonances, we get more sensitivity by searching for peaks: the QCD backgrounds are roughly flat in mass



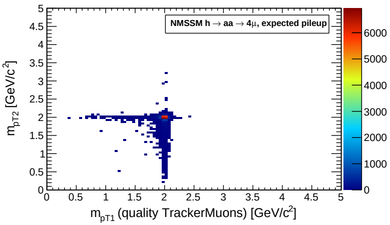


Signals: mass peaks

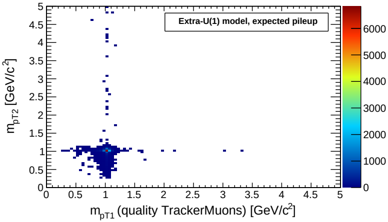
Pair-pair μ gun with both pairs having the same mass



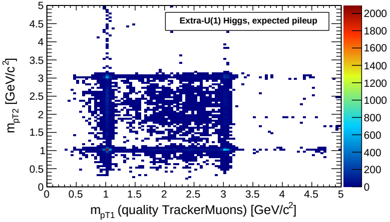
NMSSM Higgs with $h \to aa \to 4\mu$ ($m_h = 100$, $m_a = 2$ GeV/c^2)



Extra-$\mathcal{U}(1)$ dark matter model with $\gamma_{\text{dark}} \to \mu^+\mu^-$, $m_\gamma = 1$ GeV/c^2



Same with $h_{\text{dark}} \to \gamma_{\text{dark}}\gamma_{\text{dark}}$, $m_h = 3$ GeV/c^2 and $m_\gamma = 1$ GeV/c^2



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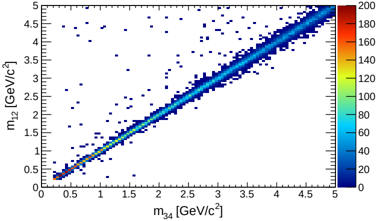
Pair-pair μ gun with both pairs having the same mass



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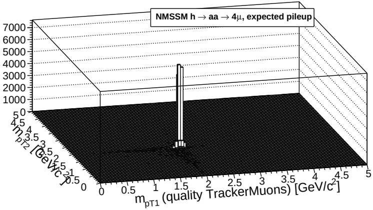

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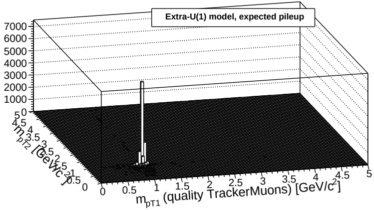

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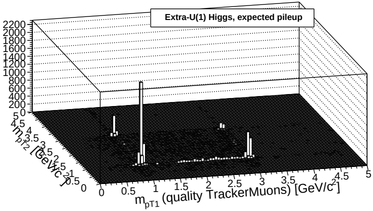
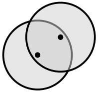
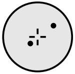


Isolation variables

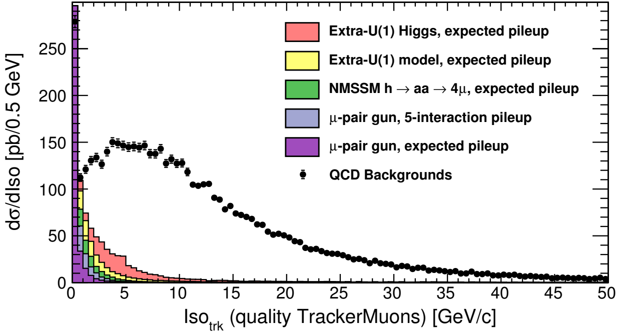
Normal muon isolation: in each other's cones and double-counting



μ-group isolation: one cone around group momentum axis

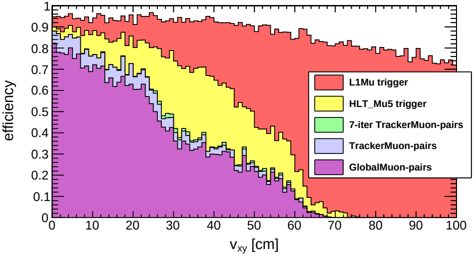


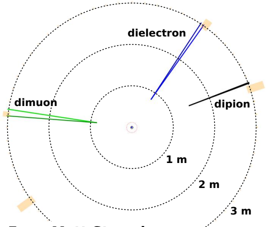
- $\sum |p_T|$ in a cone of $\Delta R < 0.3$
- Vertical axis only applies to backgrounds (the rest are arbitrarily normalized)



Displaced vertices

- To have avoided detection so far, dark-sector boson must be weakly coupled to Standard Model
- In an extreme case, it could decay far from beamline
- Displaced-dimuon efficiency (denominator: all $pT_2 > 5$ GeV/c, $|\eta_1| < 2.4$, mass < 5 GeV/c^2; numerator: found trigger or muon-groups, respectively)
  - HLT muon trigger depends on StandAloneMuon with beamline-constraint
  - special 7-iteration tracking (for γ conversions; light green) doesn't help much in its out-of-the-box configuration





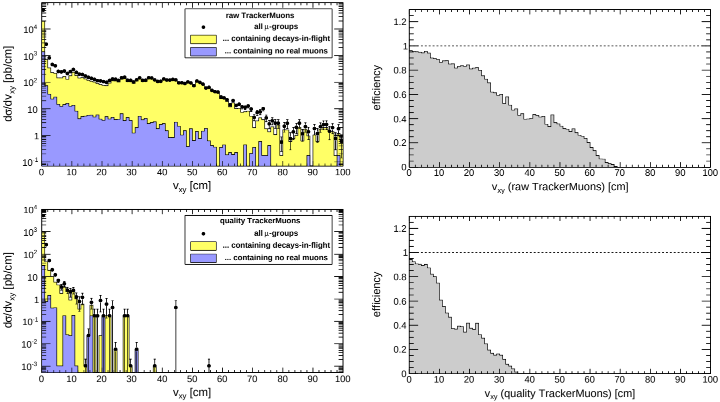
From Matt Strassler

Higgs → 2 vpions → U-bosons → lepton pairs

see http://silicon.phys.washington.edu/LongLivedWorkshop/

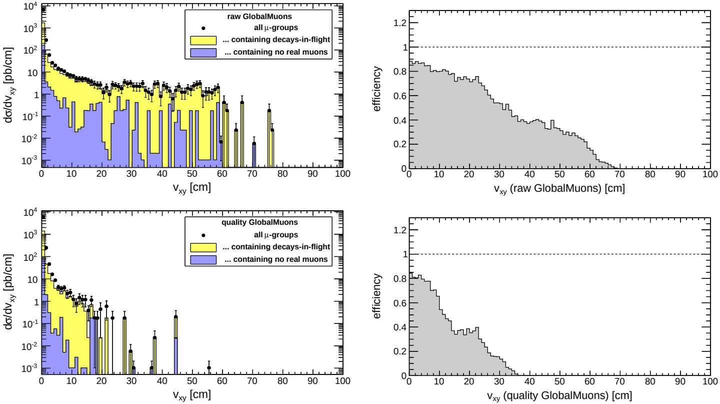
Displaced vertices

- Quality cuts seem to be cutting both signal and background: something should possibly be loosened for the displaced-vertex case
- Left: QCD background effective cross-section; right: signal efficiency
- Top: no quality cuts; bottom: with quality cuts



Displaced vertices

- Quality cuts seem to be cutting both signal and background: something should possibly be loosened for the displaced-vertex case
- Left: QCD background effective cross-section; right: signal efficiency
- Top: no quality cuts; bottom: with quality cuts
- Same for GlobalMuons (uncut GlobalMuon backgrounds are 1 pb/cm)



Conclusions

- Muon-grouping algorithm designed to find low-mass resonances, no matter how boosted or how many are in the event
- StandAlone/GlobalMuon inefficiencies traced to overlapping trajectories in the endcap, still not clear in the barrel
- TrackerMuons have high, uniform efficiency, and large backgrounds can be suppressed by requiring $N_{\text{segments}} \geq 2$ with track-and-segment arbitration
- Understanding the exact trigger efficiency will be challenging
- Two μ-group QCD backgrounds are 1 pb and $\sim$flat in mass
- Displaced vertex case has not been fully optimized