Search for Resonant Production of Muon Jets in the CMS experiment at LHC

Aysen Tatarinov

Texas A&M University

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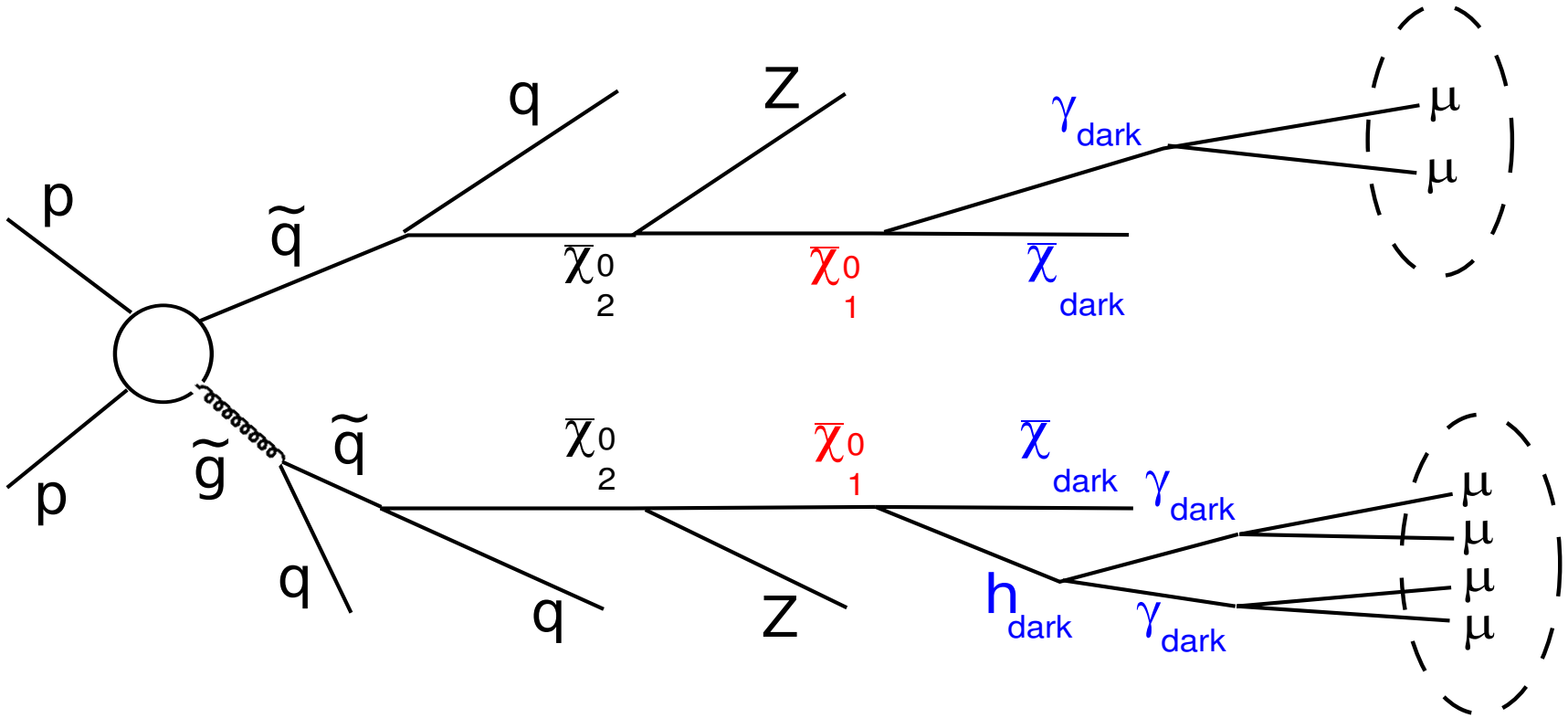
Introduction

- Wide class of scenarios beyond Standard Model predicts new light bosons, which may decay to muon pairs (muon jets with two muons)
  - In case of production in complex cascade decays we may observe muon jets with more than two muons
- Analysis is designed to remain model independent
  - Minimize dependence on the details of specific models
- Two specific benchmark scenarios:
  - SUSY + hidden dark sector (Dark SUSY)
    - Dark matter candidate
    - Several satellite experiments observe rise of positron fraction in high energy cosmic rays: annihilation of dark matter particles?
  - Next-to-Minimal Sypersymmetric Model (NMSSM)
    - Well motivated extension of MSSM: for example, solves μ-problem

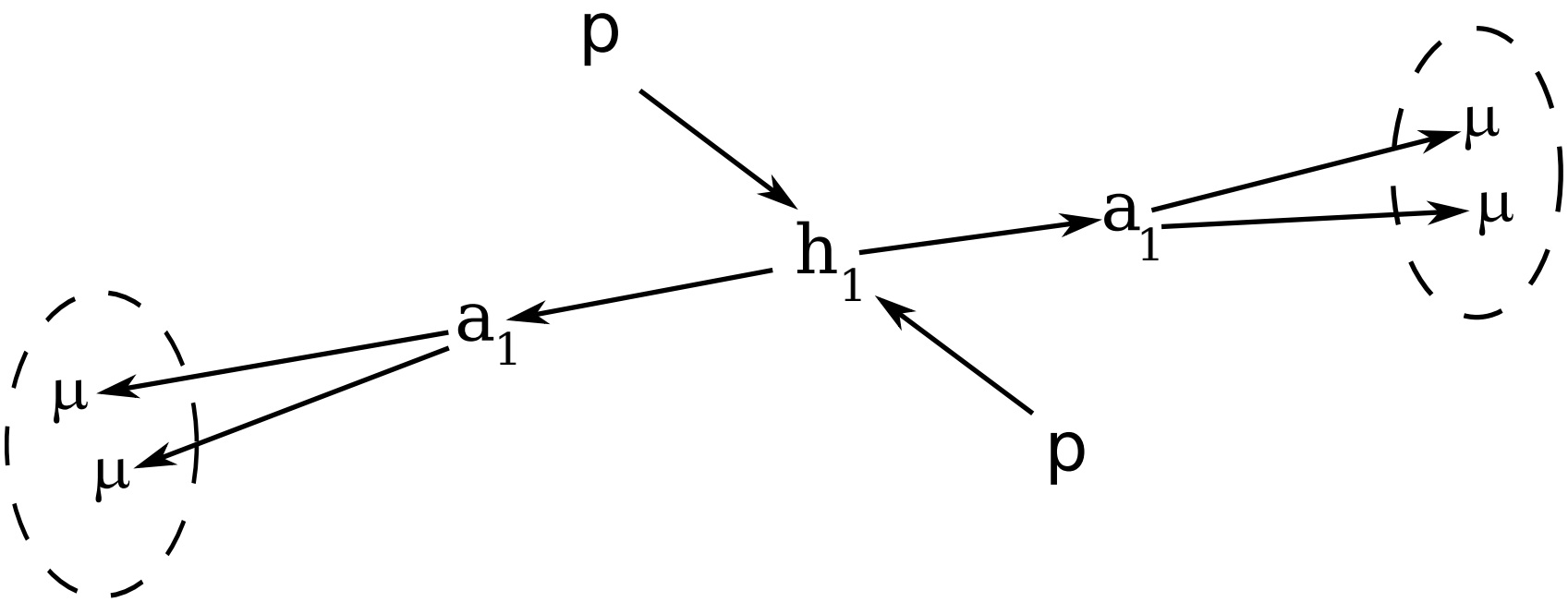
Benchmark Scenario I: Dark SUSY

- SUSY + hidden dark sector
  - dark neutralino $\tilde{\chi}_{dark}$ (new LSP)
  - dark Higgs h_{dark}
  - dark photon γ_{dark} — new light boson which may decay to pair of muons
- Decay of MSSM LSP $\tilde{\chi}_1^0$ to $\tilde{\chi}_{dark}$ in combination with γ_{dark} or h_{dark}



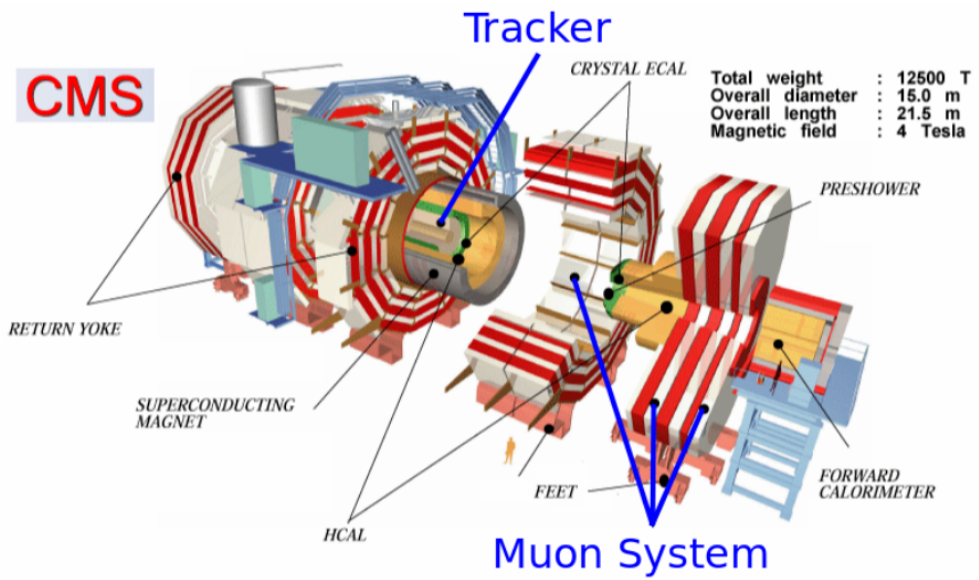
Benchmark Scenario II: NMSSM

- NMSSM — well motivated extension of MSSM
  - CP-even Higgs boson h_1 ($m_{h_1} \sim 100$ GeV)
  - CP-odd Higgs boson a_1 ($m_{a_1} \sim 2$ GeV)
  - $Br(a_1 \to \mu\mu)$ up to 17%
- Decay of $h_1 \to a_1 a_1 \to 2\mu 2\mu$



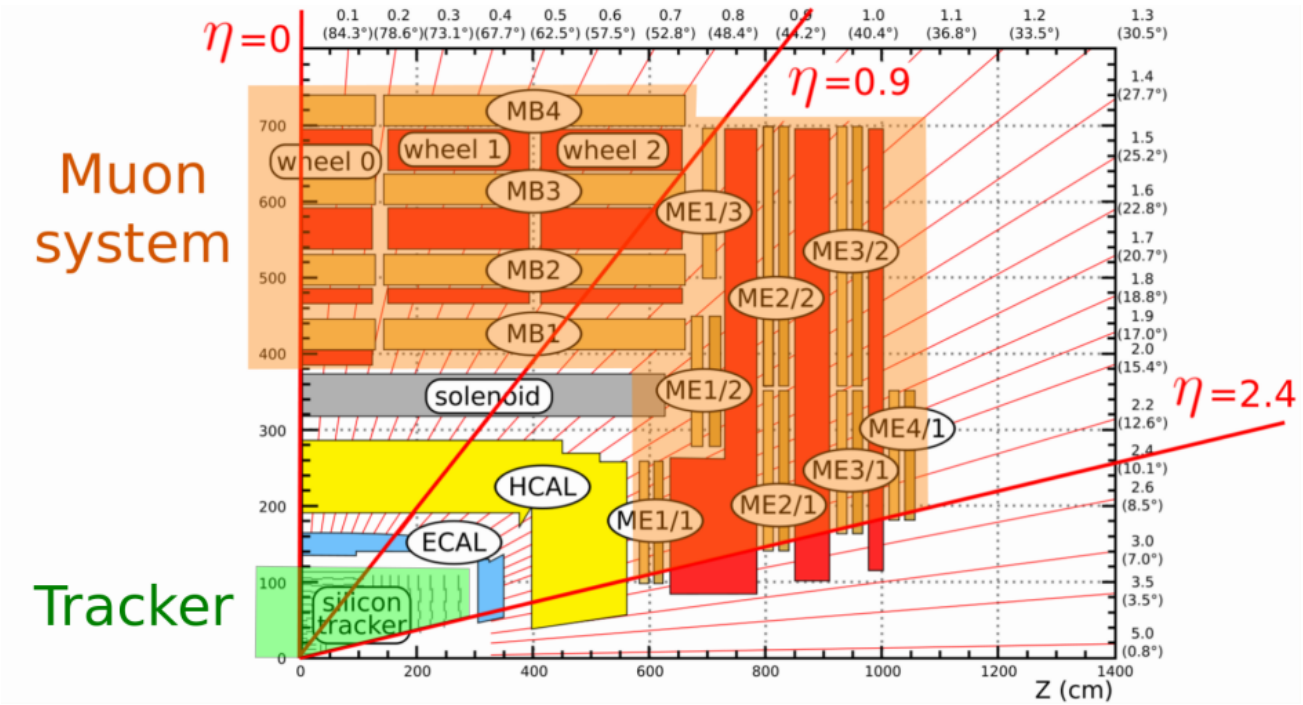
Experimental Apparatus

- CMS experiment at the LHC
  - Excellent ability of CMS detector to reconstruct muons
  - Efficient and well understood muon trigger
- Analysis Datasets @ 7 TeV:
  - 2010 year with $\int L \sim 35$ pb^{-1} (published)
  - 2011 year with $\int L \sim 5.3$ fb^{-1} (in collaboration review)



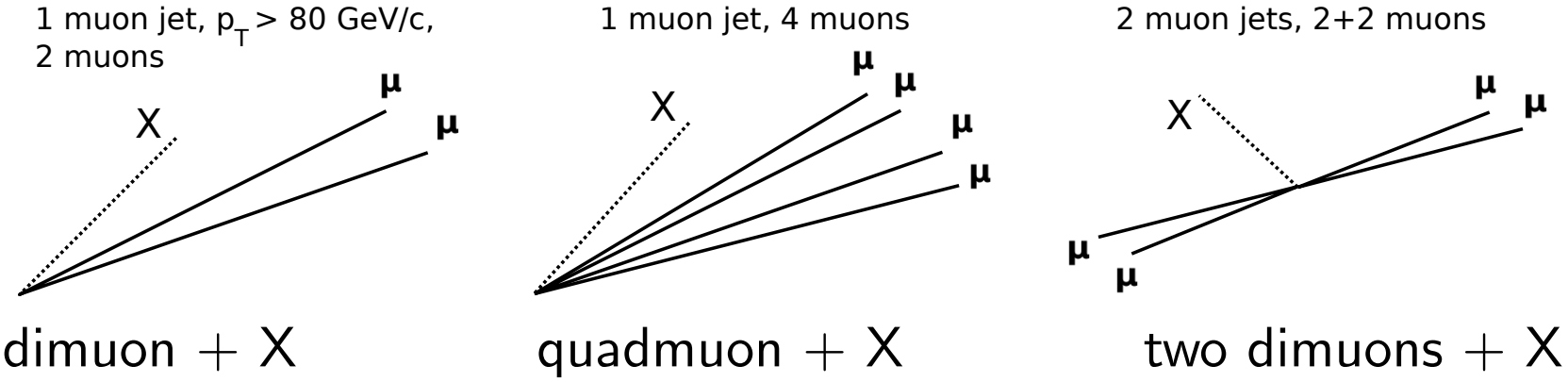
Analysis Selection

- At least four muons: $p_T > 5$ GeV/c, $|\eta| < 2.4$, good track quality
- To ensure flat plateu in trigger efficiency
  - At least one good quality muon with $p_T > 15$ GeV/c, $|\eta| < 0.9$
- Assign two opposite-sign muons to a muon jet
  - $m_{\mu\mu} < 9$ GeV/c^2 **and** (good common vertex **or** $\Delta R_{\mu\mu} < 0.01$)

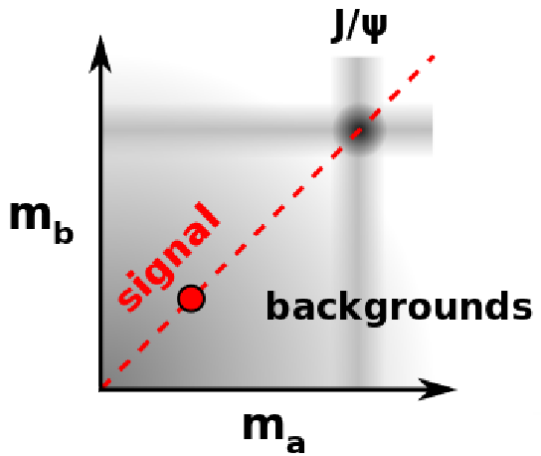


Event Topologies

- Define non-overlapping event topologies by number of muon jets and number of muons in them:
  - After we opened the signal box, only three of them had data events

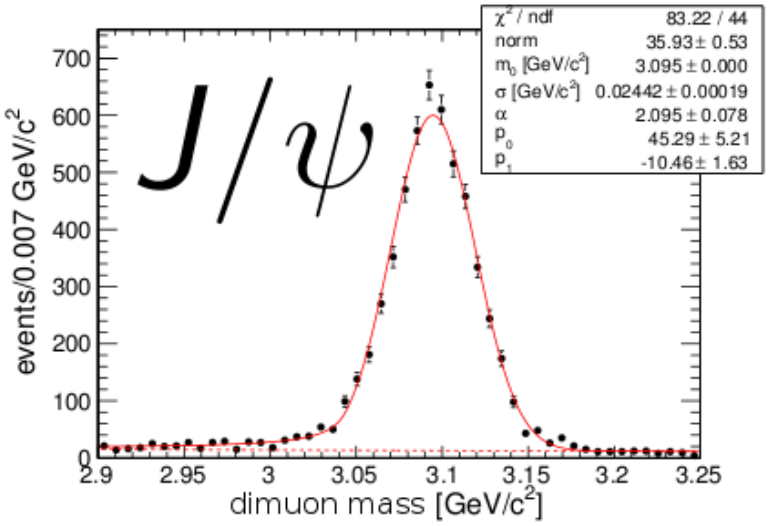


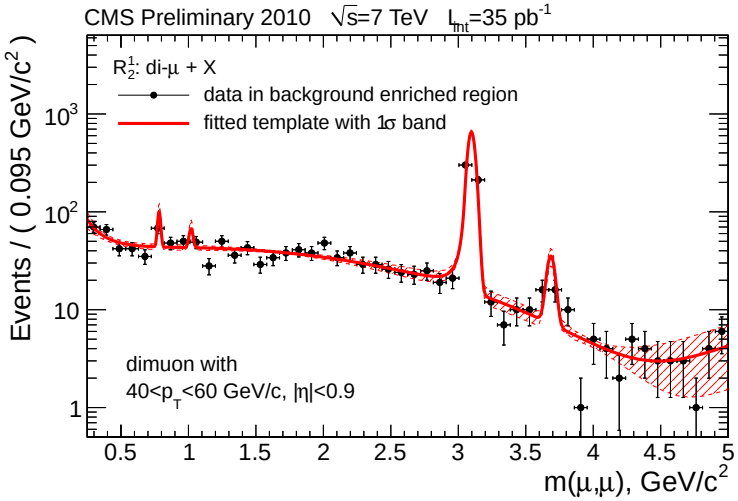
- 1 dimuon: search for enhancement in dimuon mass distribution
- 2 dimuons: search for enhancement on diagonal in 2D dimuon mass space



Modeling Signal and Background Shapes

- Width of signal shape is determined by detector resolution
  - Use narrow SM resonances in data: ω, ϕ, J/ψ, ψ'
- Model signal with a Crystal Ball function
- Data driven background shape estimation
  - Performed in "background-enriched" samples
  - Tested in control samples and used in final fit

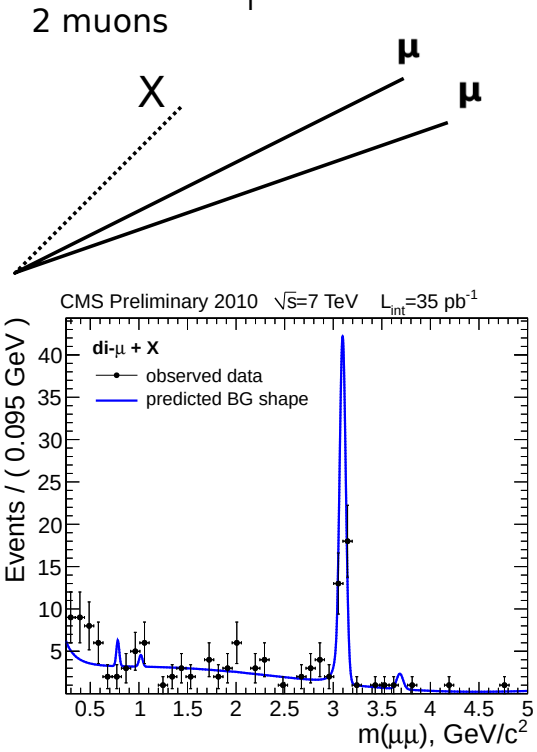




Open the Signal Box (2010 data)

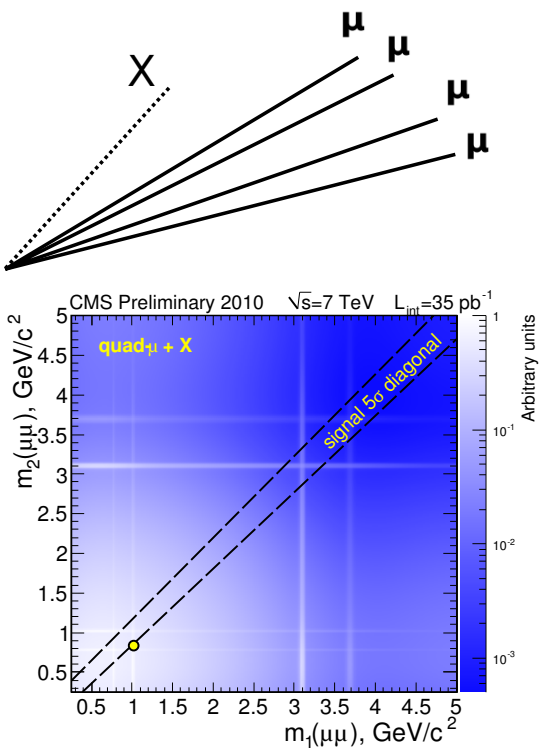
- Only three event topologies had data events

1 muon jet, $p_T > 80$ GeV/c, 2 muons



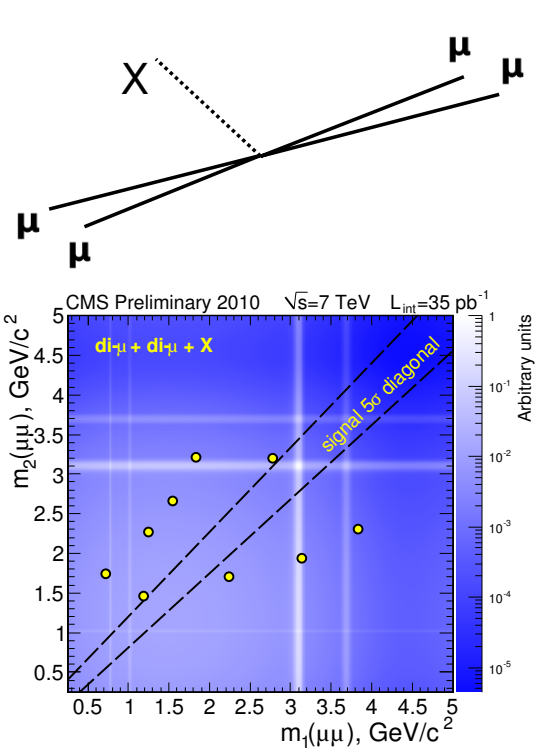
145 events

1 muon jet, 4 muons



1 off-diagonal event

2 muon jets, 2+2 muons

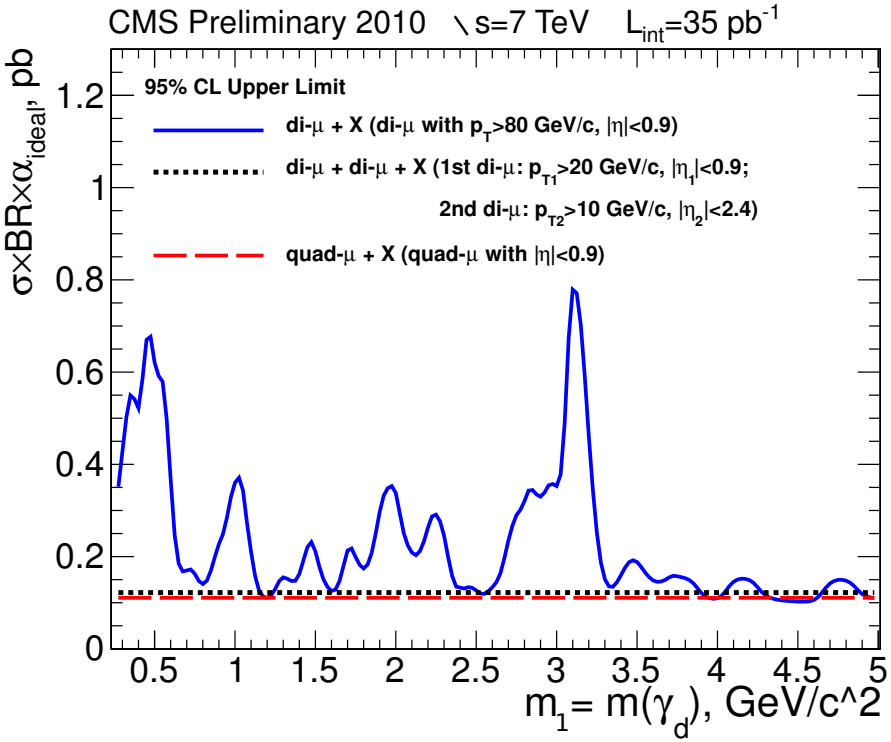


9 off-diagonal events

- No observation of excess over Standard Model backgrounds

Model-independent limits with 2010 data

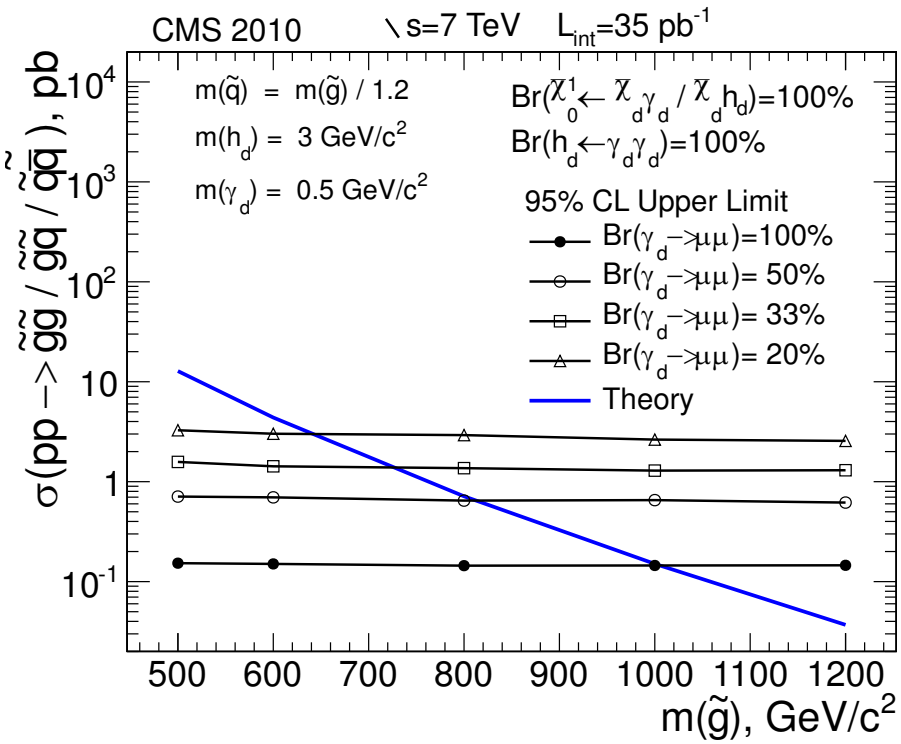
- Set 95% C.L. upper limit on the signal rate: σ x Br x α_{ideal}
  - 0.1–0.7 pb limit for topology with one dimuon
  - 0.1 pb limit for topologies with more than one dimuon



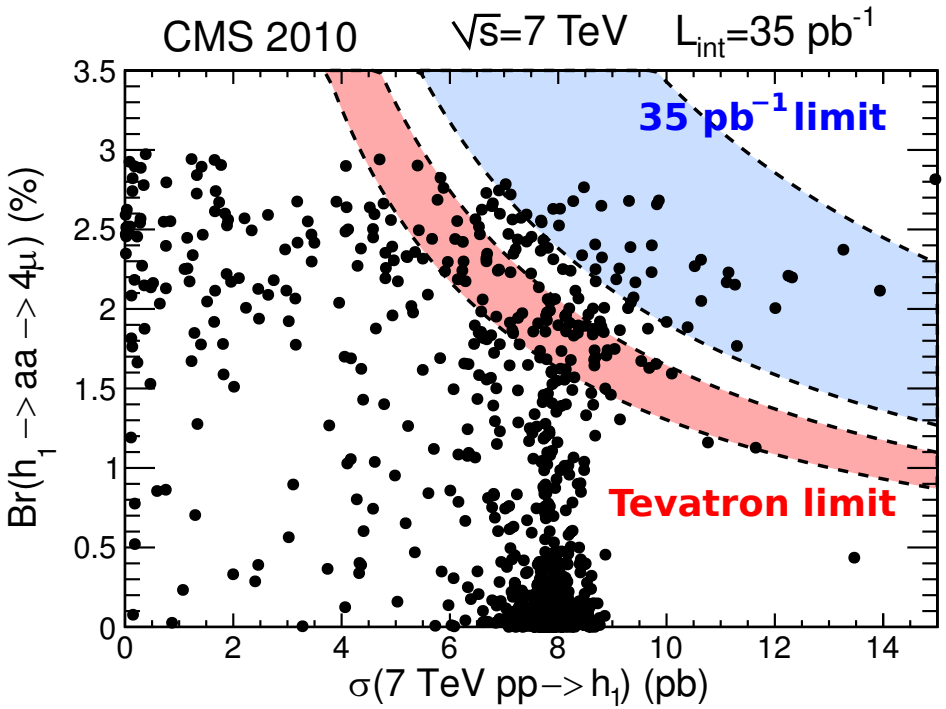
- σ — m_1 production cross section, Br — branching ratio of $m_1 \rightarrow \mu\mu$
- α_{ideal} — acceptance for particular signal topology assuming ideal detector

Model-dependent limits with 2010 data

- Dark SUSY



- NMSSM



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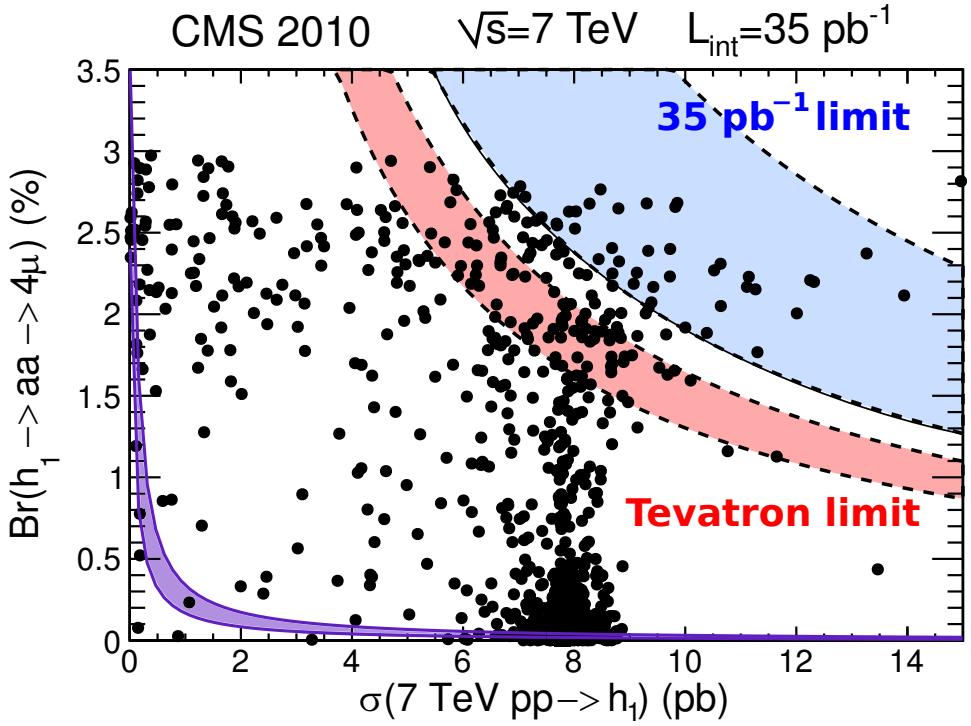
Model-dependent limits with 2011 data

- In case of zero data events in the signal regions with 2011 data, projected limits are expected to be improved by a factor of ~ 100
  - For example, NMSSM parameter space expected to be severely restricted



5.3 fb^{-1} expected limit

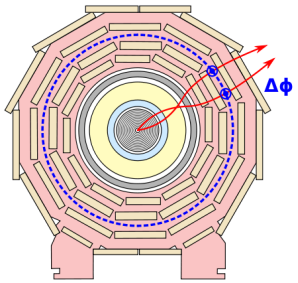
Conclusions

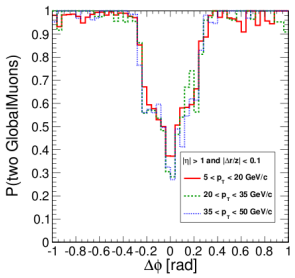
- Search for new light bosons decaying to muon jets presented with 35 pb^{-1} of data collected at CMS during 2010 year
  - No excess over SM background is observed
  - Model independent limit on the production of new light bosons set
  - Results interpreted in the context of NMSSM and Dark SUSY
- In case of zero data events in the signal regions with 2011 data, projected limits are expected to be improved by a factor of ~ 100
  - Currently the analysis in collaboration review
- Stay tuned!

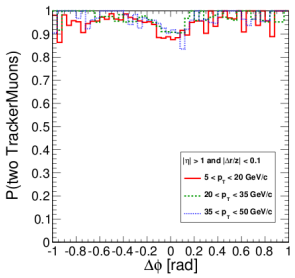
BACKUP SLIDES

Analysis Selection

- All signal events should have:
  - at least one $p_T > 15$ GeV/c, $|\eta| < 0.9$ muon
  - HLT_Mu15 or equivalent
  - at least one muon jet
- Muon cuts:
  - TrackerMuon $p_T > 5$ GeV/c, $|\eta| < 2.4$, arbitrated segments ≥ 2, tracker hits ≥ 8, $\chi^2/N_{dof} < 4$
- TrackerMuons (high reconstruction efficiency):

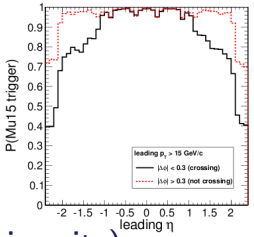




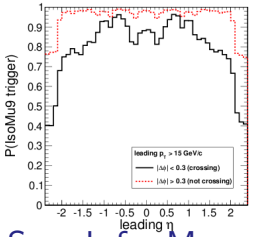


- $p_T > 15$ GeV/c, $|\eta| < 0.9$, and HLT_Mu15 (flat trigger efficiency):

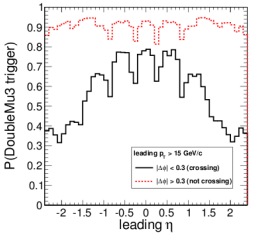
single-muon (HLT_Mu15)



single-muon isolated (HLT_IsoMu9)



double-muon (HLT_DoubleMu3)

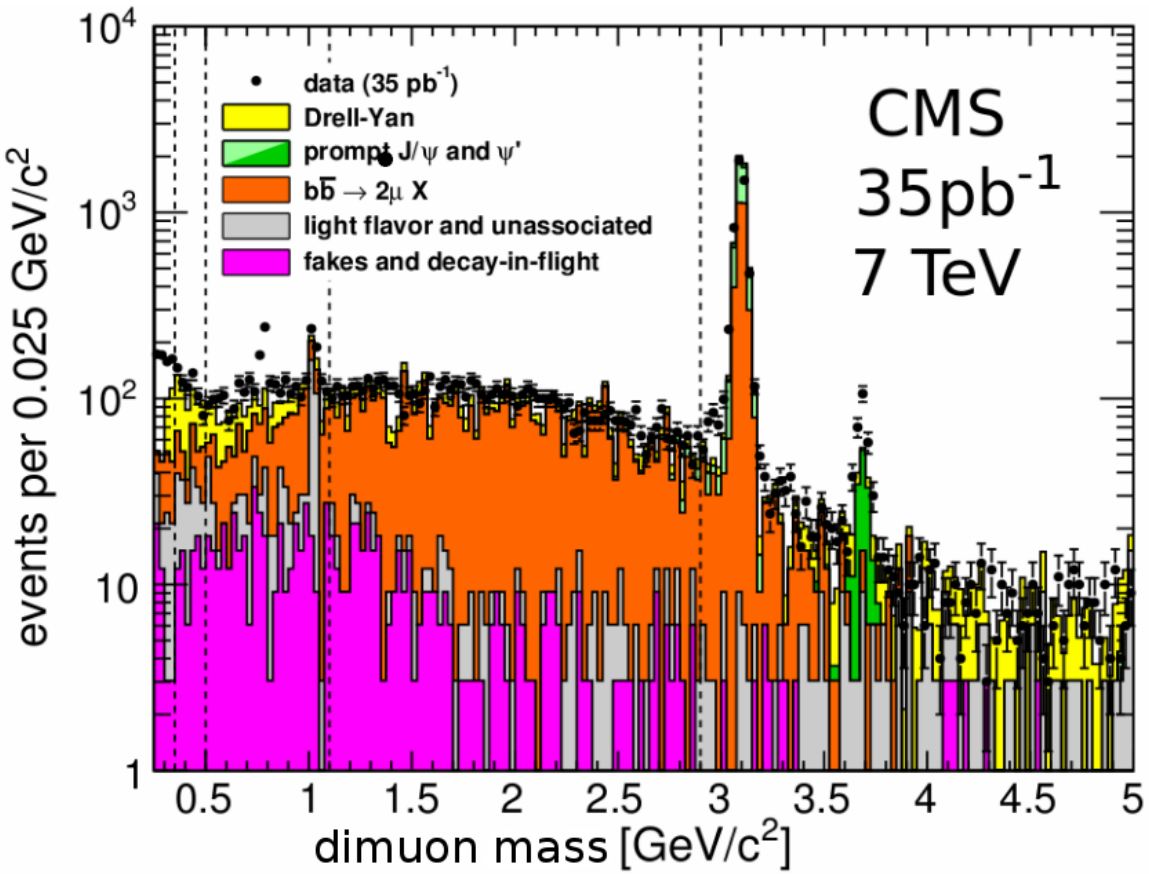


black: crossing in muon system

red: not crossing

Data and Monte Carlo Comparison

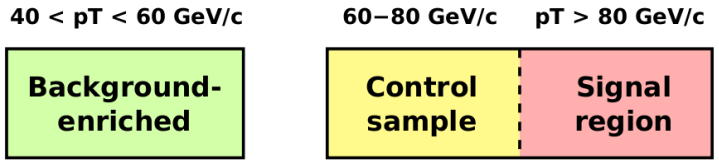
- Main backgrounds for collimated muon pairs
  - $b\bar{b}$, Drell-Yan, resonances (J/ψ, ψ')
- Good agreement between data and Monte Carlo



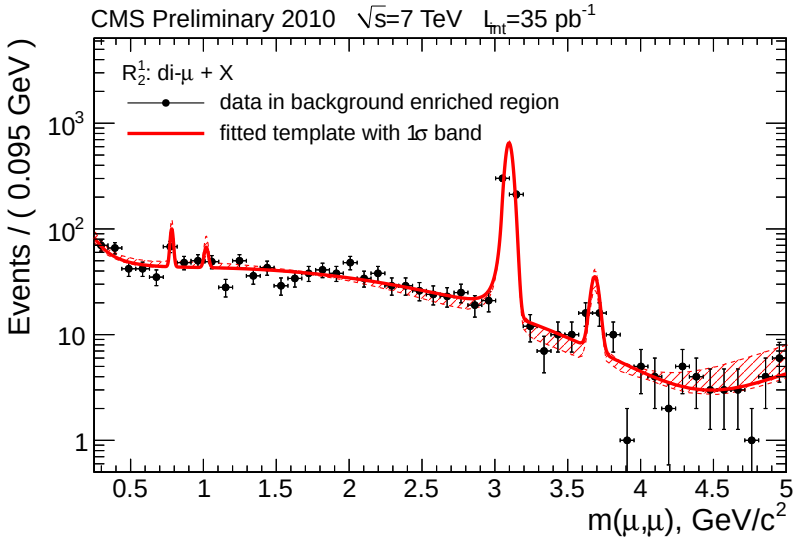
Background Shapes (1/3)

Each signal region has different background sources, and, thus, individual background shape templates

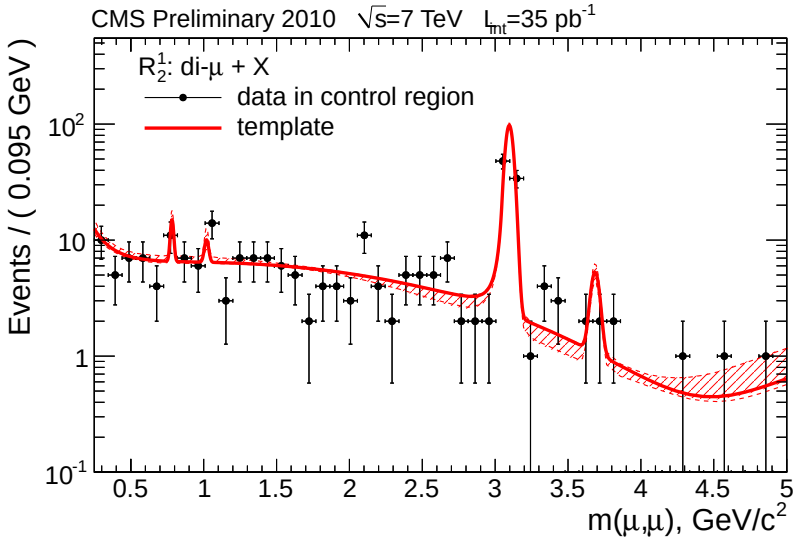
- R_2^1 signal region:



background-enriched

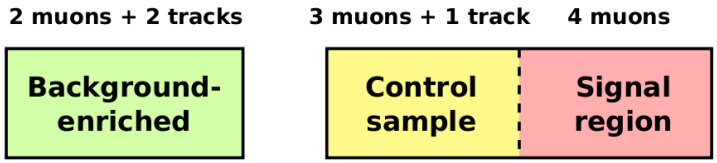


control

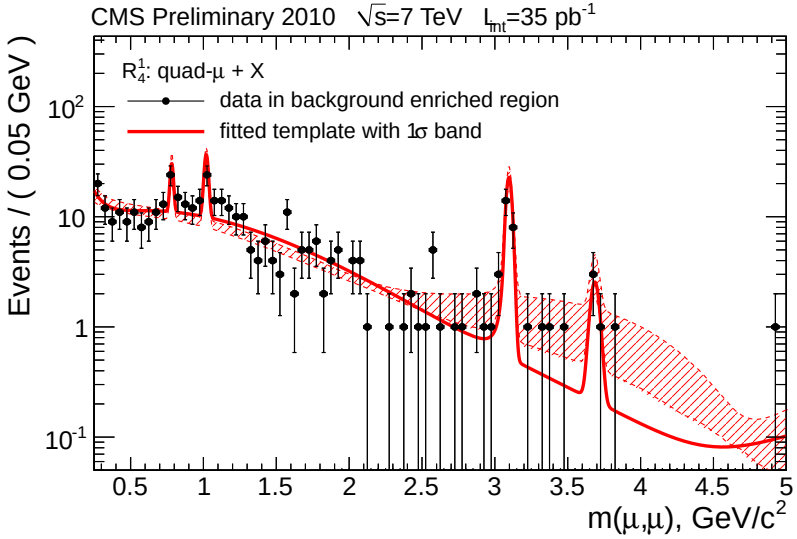


Background Shapes (2/3)

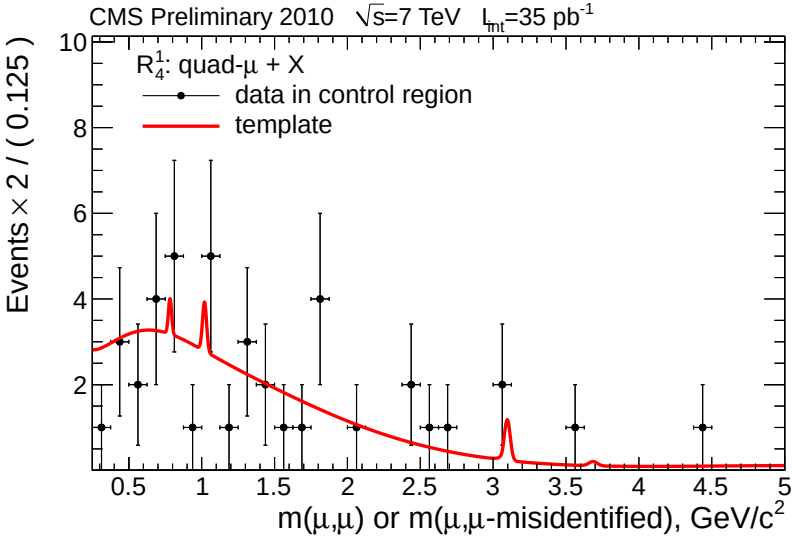
- R_4^1 signal region:



background-enriched

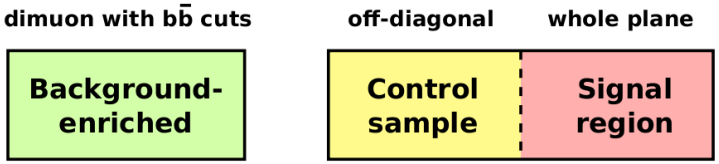


control



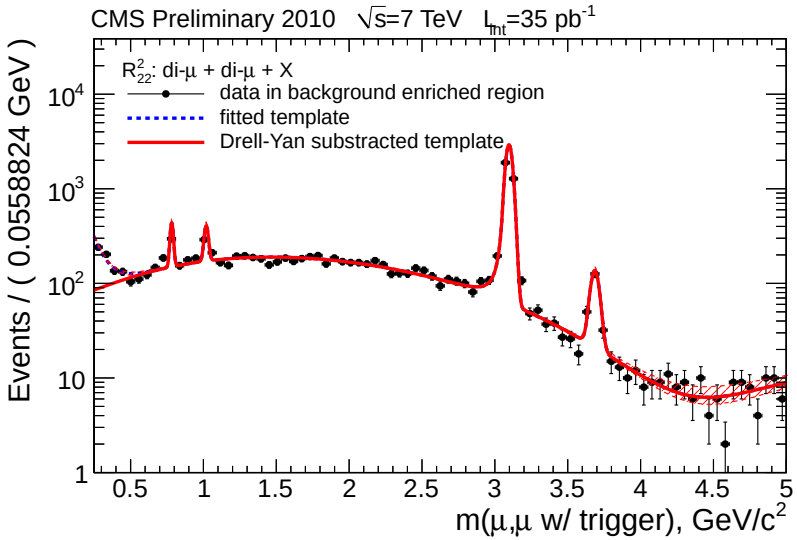
Background Shapes (3/3)

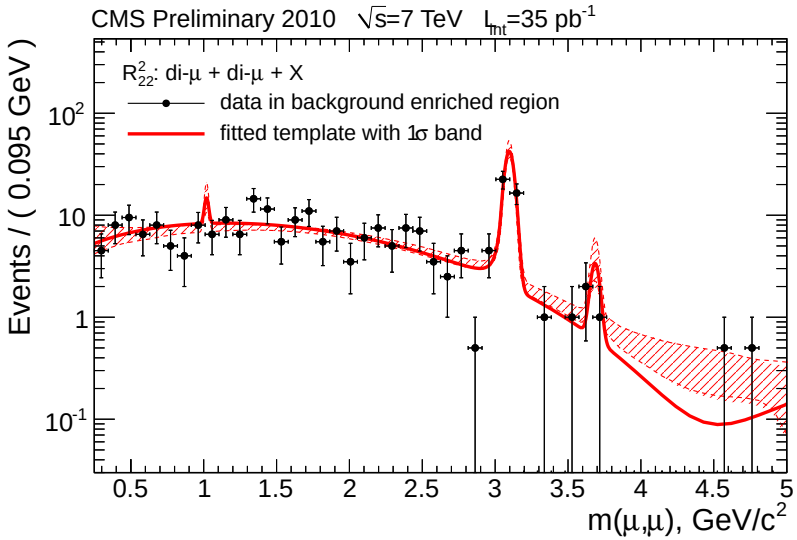
- R^2_{22} signal region:



- requiring a $p_T > 15$ GeV/c trigger muon changes the distribution
- templates for each case:

background-enriched (triggered) background-enriched (not triggered)

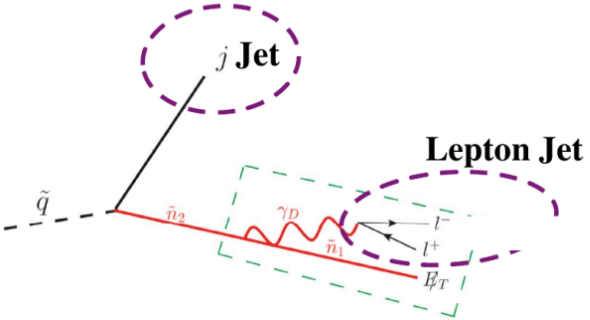




Model-dependent limits

- SUSY with dark fermion cascades
- Dark sector consists of an hierarchy of the new dark bosons and fermions
- Dark photons are produced in cascade decays of dark fermions

$$\tilde{n}_2 \to \tilde{n}_1 \gamma_{\text{dark}} \to 2\mu$$



$$\tilde{n}_2 \to \tilde{n}_1 h_{\text{dark}} \to \gamma_{\text{dark}} \gamma_{\text{dark}} \to 4\mu$$