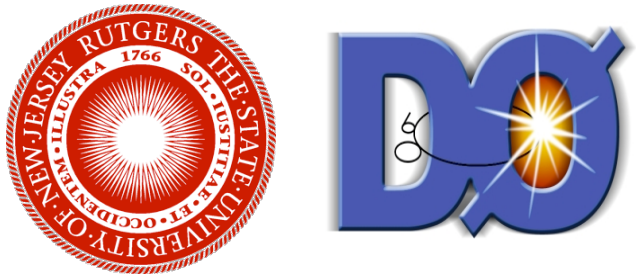
Search for Hidden Valleys with Photons

Yuri Gershtein



Outline

- Hidden Valley Models
- DØ detector
- Long-lived heavy resonance search
  - novel search technique for previously unexplored final state
- Search for a light short-lived boson (aka "dark photon") decaying into lepton pairs
  - leptons are spatially close – therefore not isolated. New final state that could have been missed

Hidden Valley Models

- New sector which is very weakly coupled to the Standard Model (SM)
- very phenomenologically rich class of models with a few common features
  - Strassler, Zurek et al, PLB 651 (2007), JHEP 0807(2008);
  - very small cross-section of direct production
  - two ways to produce at colliders:
    - over the ridge: i.e. through heavy Z' that couples comparably to both sectors
    - in SUSY decays: since LSP is otherwise stable
  - hidden states can decay back into SM, sometimes with macroscopic decay lengths

Tevatron Collider

1992-95

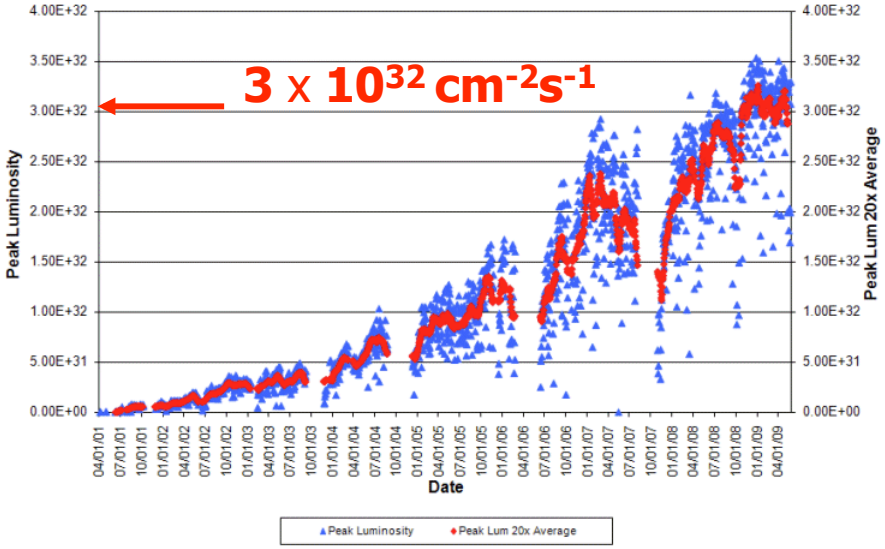
Run 1: 100 pb^{-1}, 1.8TeV

2001-2009 Run 2: major upgrades

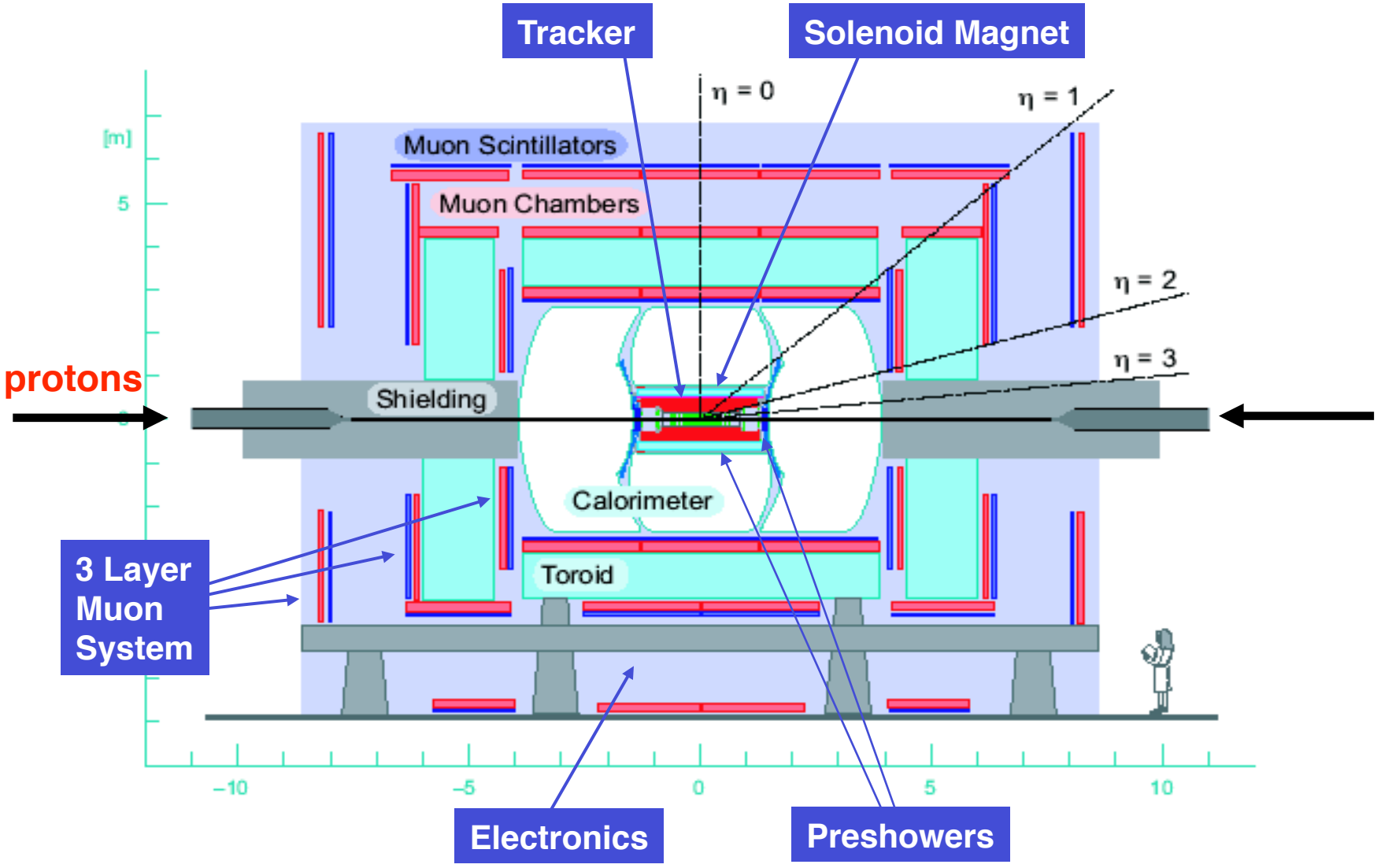
higher E_{CM} = 1.96 TeV

~6 fb^{-1} recorded

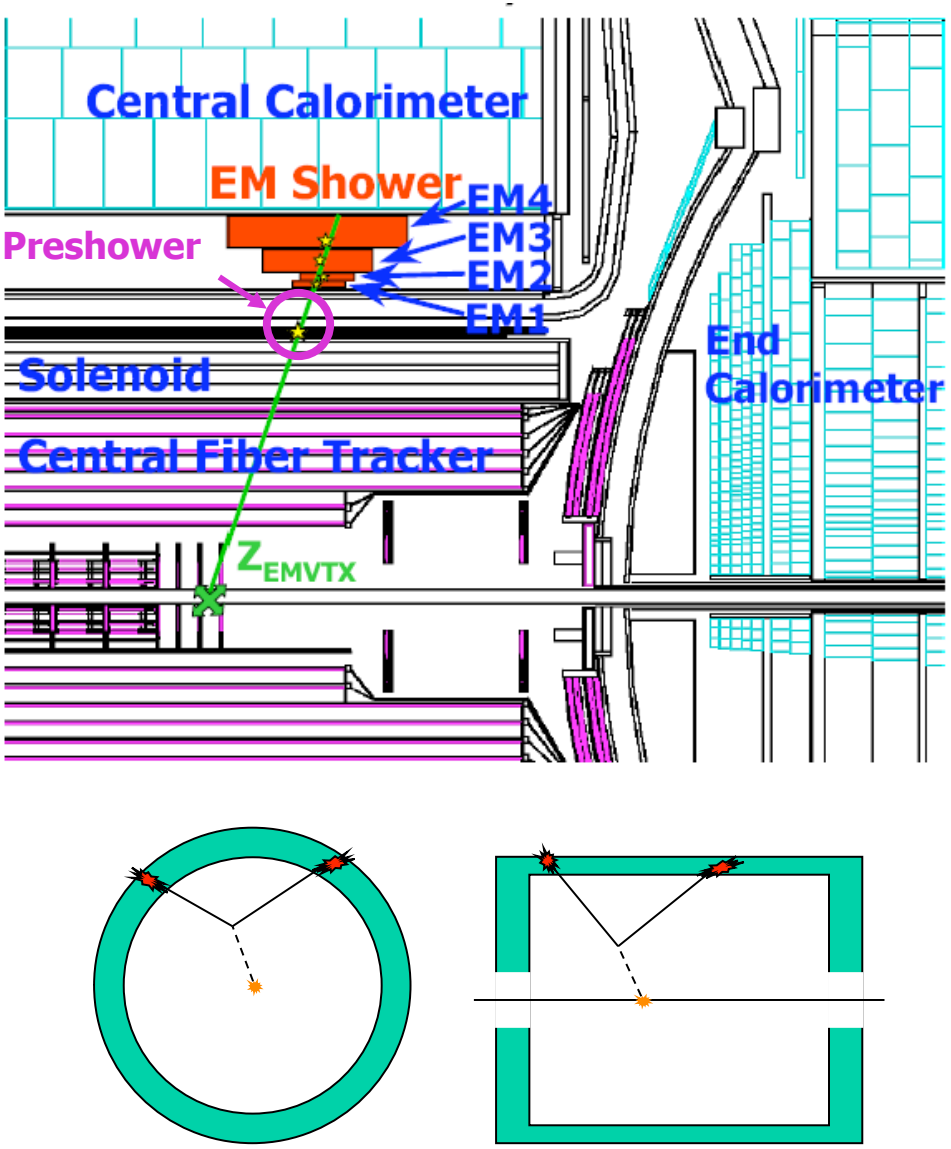
Collider Peak Luminosity



DØ Detector

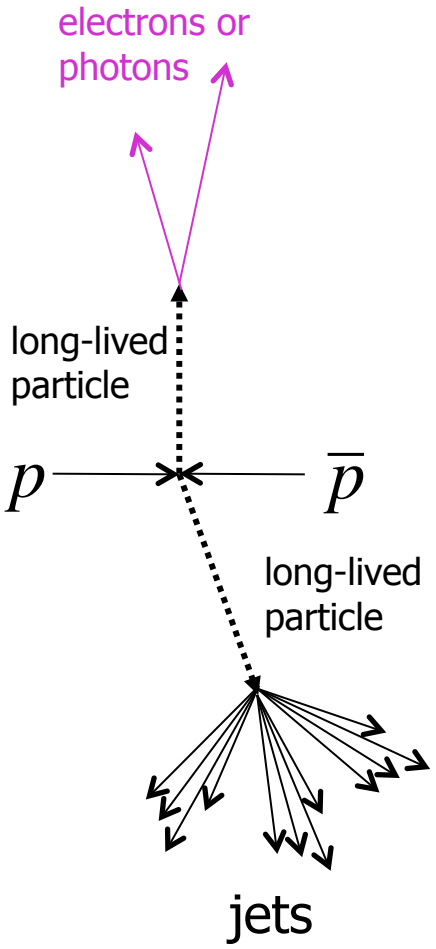

Tracker
Solenoid Magnet
η = 0
η = 1
η = 2
η = 3
[m]
5
Muon Scintillators
Muon Chambers
protons
Shielding
Calorimeter
Toroid
3 Layer Muon System
Electronics
Preshowers
−10
−5
0
5
10

Pointing EM showers

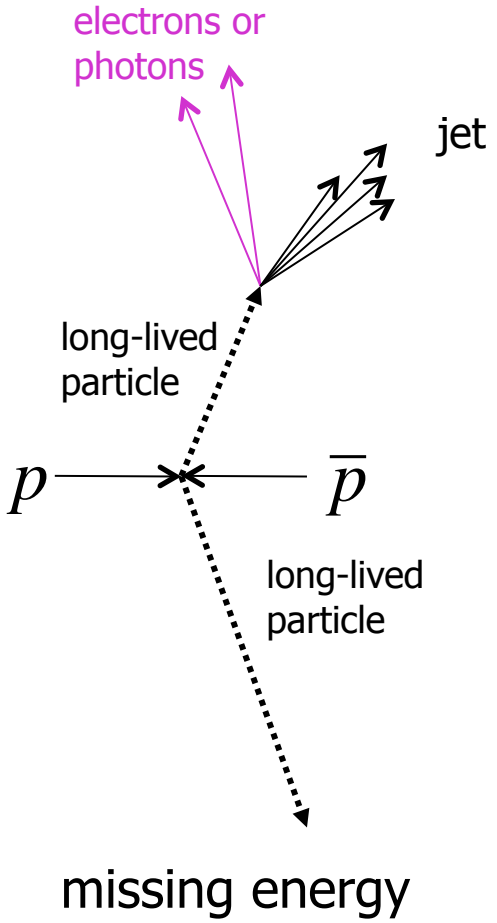


- Excellent granularity of the calorimeter and preshower allows reconstruction of EM shower direction
  - i.e. EM cluster becomes a vector instead of a scalar
- Can measure / identify production vertex
- Very far away from the primary vertex – where tracking is inefficient

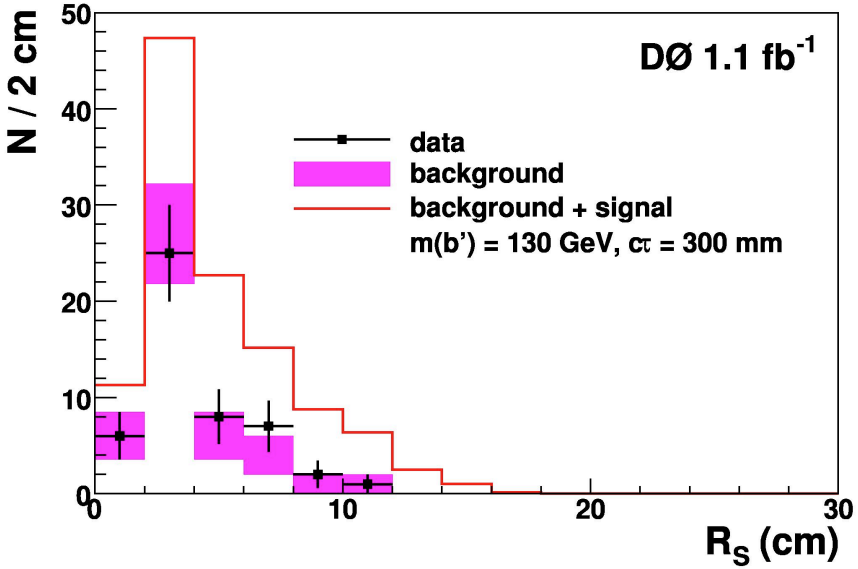
Long-Lived Particles



- Wide variety of possible scenarios
  - Decays directly into e^+e^- / $\gamma\gamma$
  - Cascades
  - Three-body decays
- Events are prone to having large missing transverse energy (MET)
- Select event with two photons above 25 GeV (at high impact parameters electrons are reconstructed as photons)
- look for excess of di-EM vertices with positive R
  - for different di-EM masses
  - or for significant MET

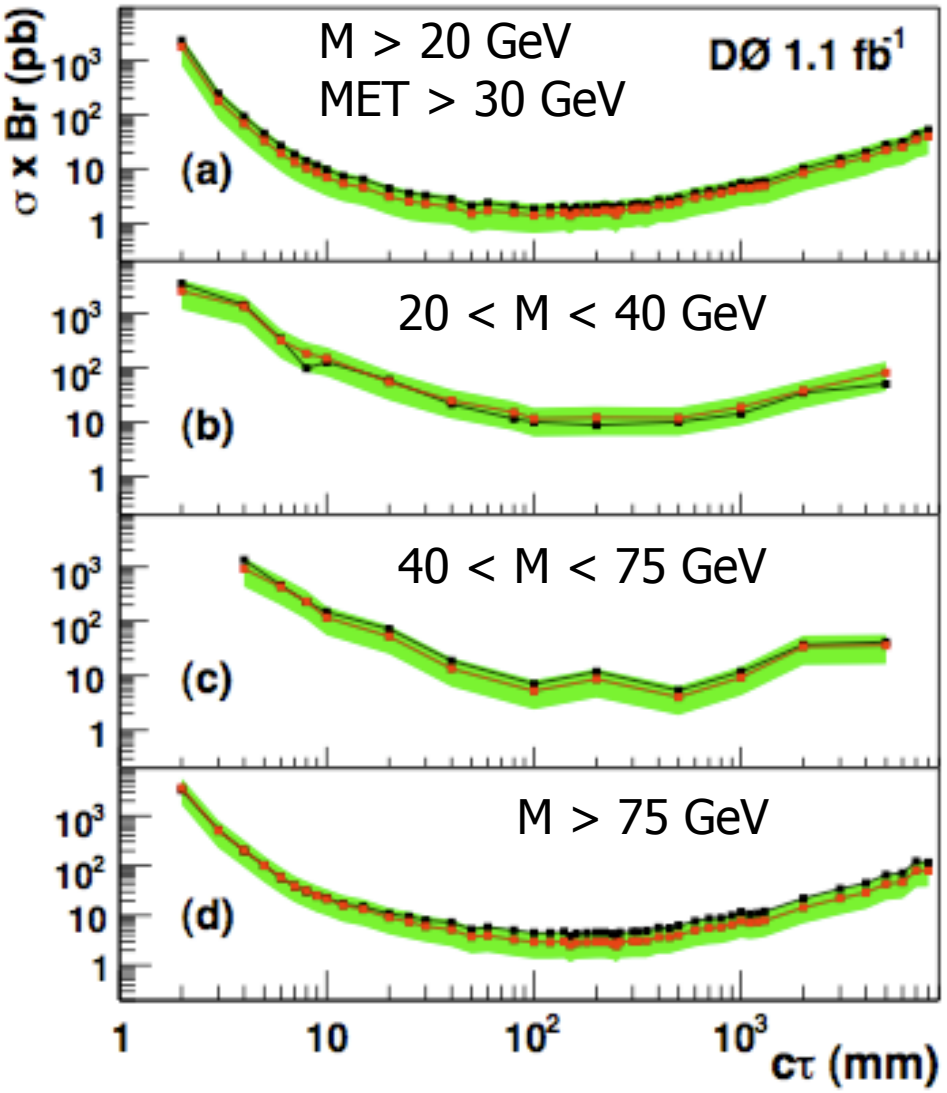


Long-Lived Particles



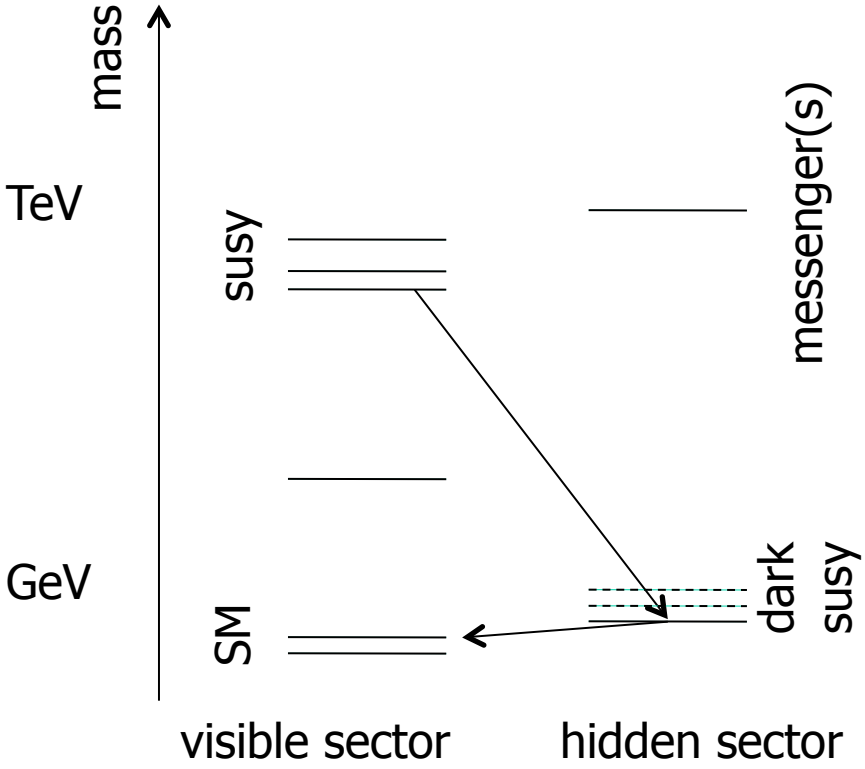
- See no excess – set quasi model-independent limits on production of particles decaying into e/γ

Phys. Rev. Lett. 101 , 111802 (2008)



Hidden Valley + SUSY

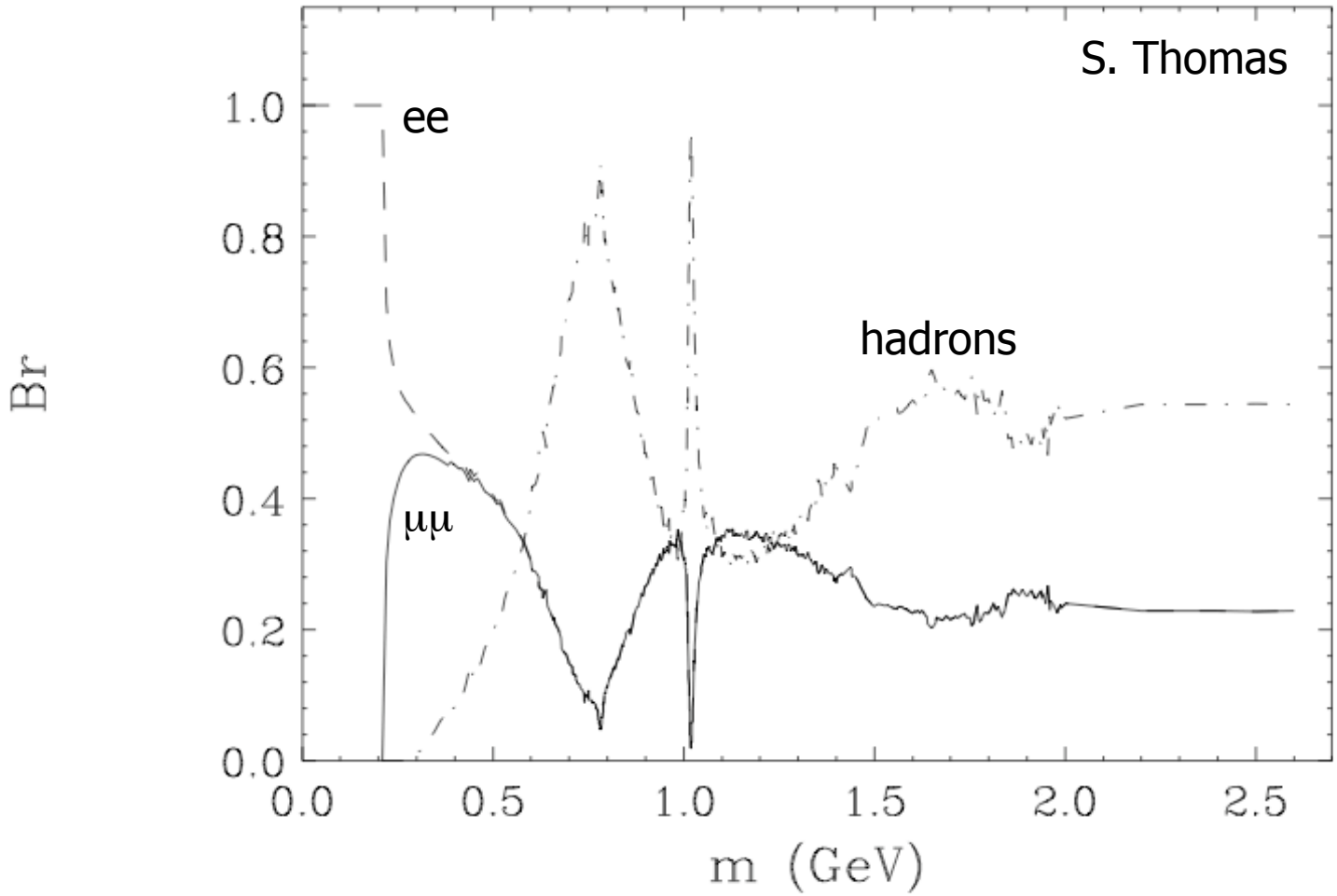
- Introduced by Strassler & Zurek PLB 651 (2007)
- Recently, called upon by Arkani-Hamed and Wiener to explain PAMELA signal (plus ATIC, DAMA, …) PRD 79 (2009), JHEP 12 (2008)



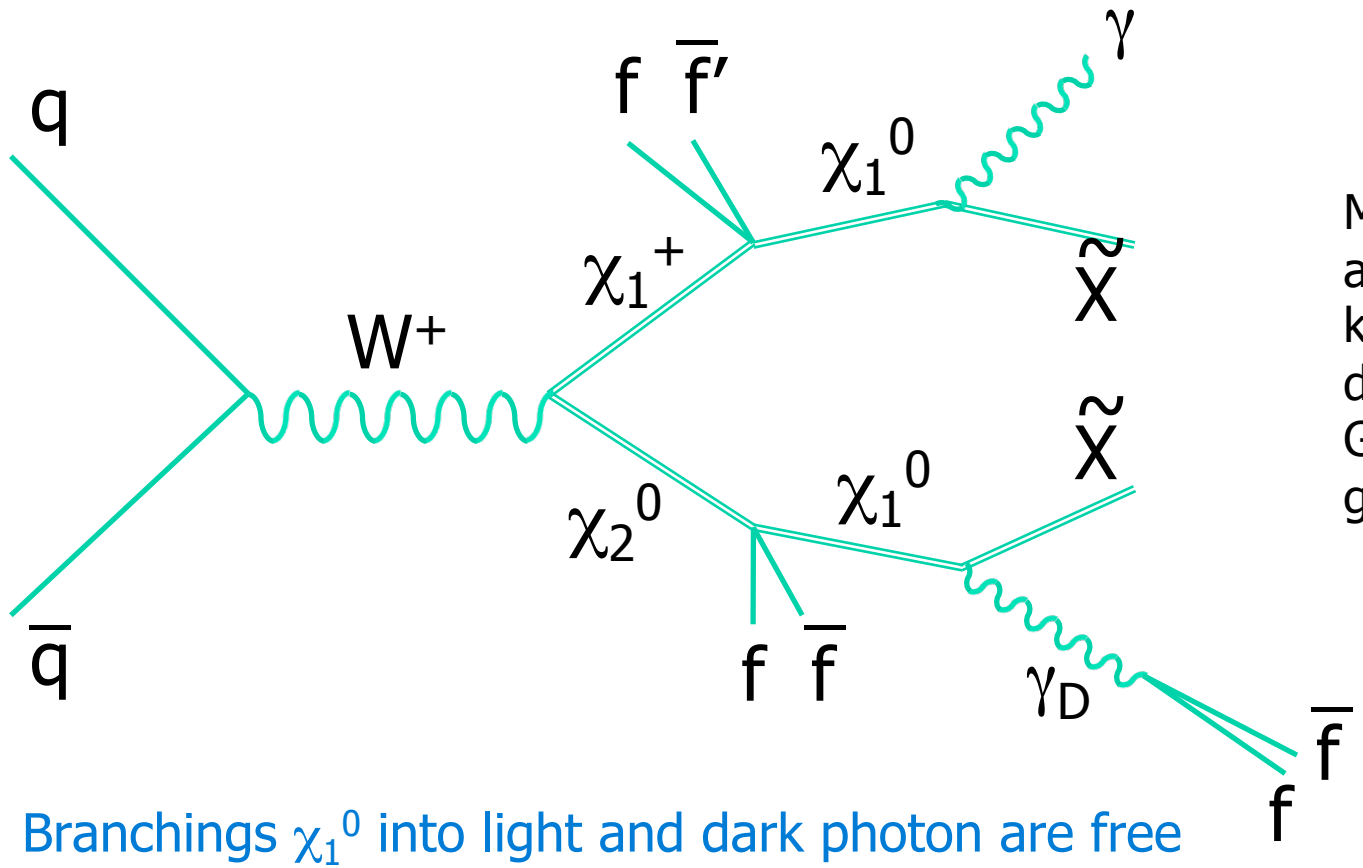
- Many phenomenological scenarios possible. One is very similar to GMSB
- being developed by S. Thomas and D. Shih
- Visible sector SUSY is produced
- Cascades to visible LSP
- LSP decays into hidden sector:
  - photon + Dark LSP
  - dark photon + Dark LSP
- Dark LSP => MET
- Dark photon (~GeV) – decays into SM fermions through mixing with photon

Dark Photon Decays

- Dark photon decays through its mixing with light photon, so its branchings can be calculated from measurement of R



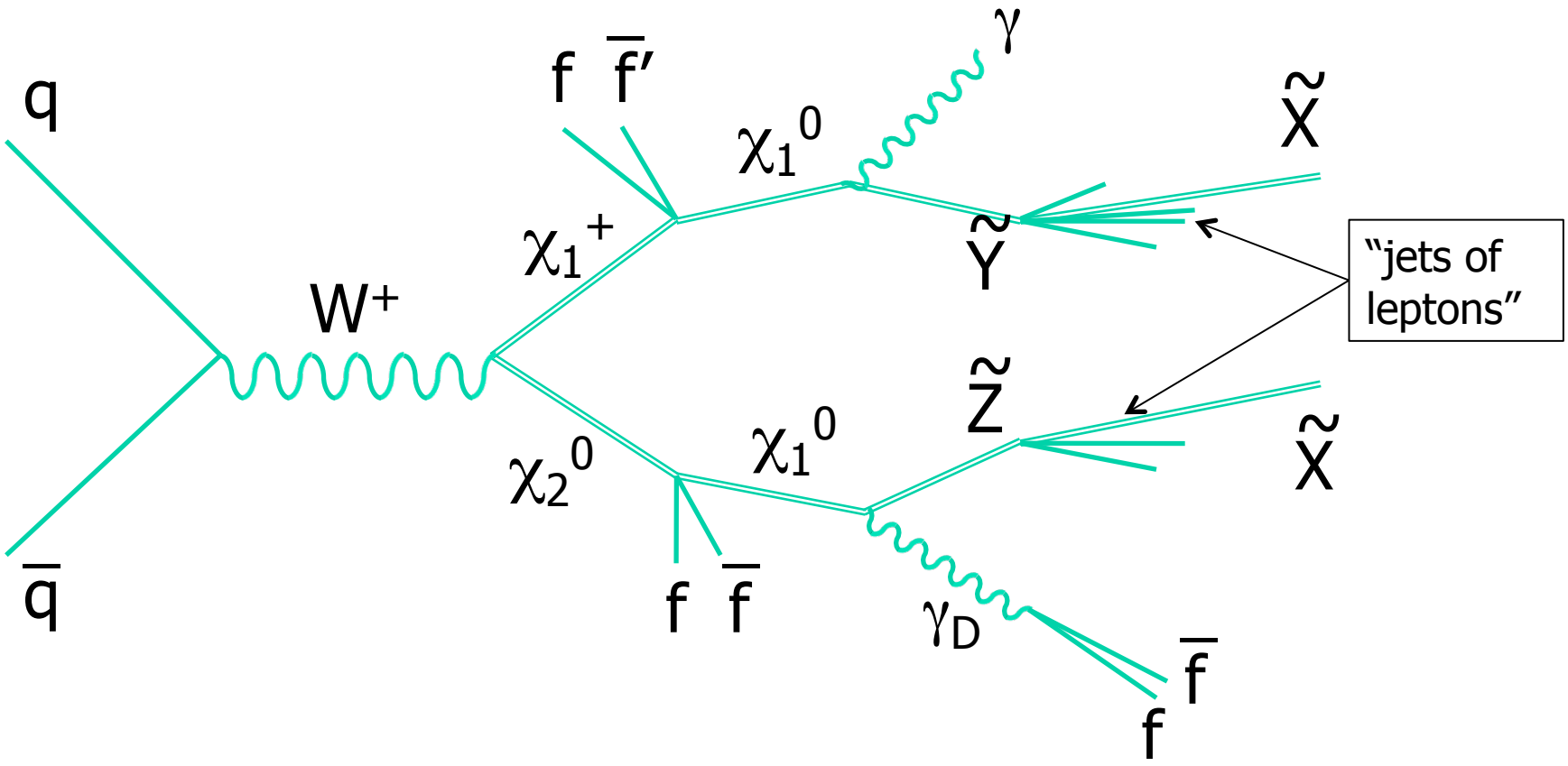
SUSY with a Hidden Valley



M(X) = O(GeV) assume kinematics of the decay identical to GMSB decays into gravitino

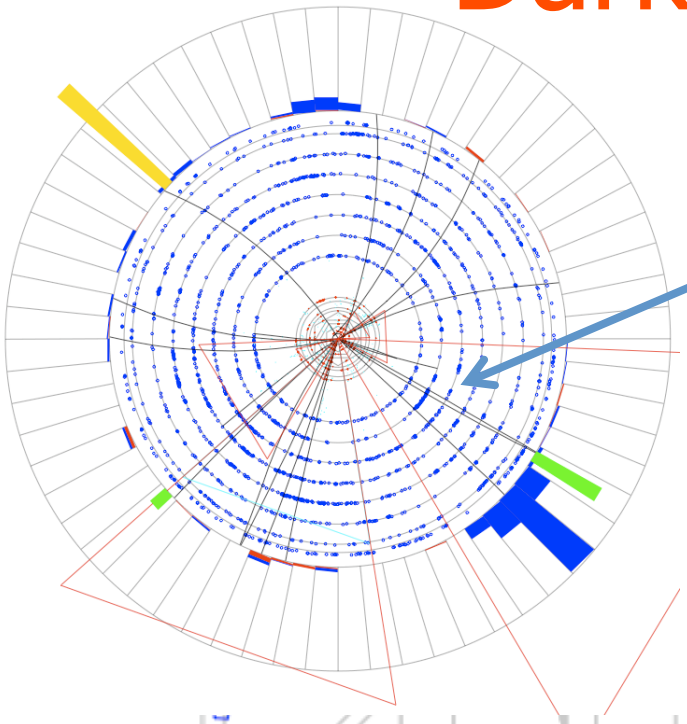
- Branchings χ_1^0 into light and dark photon are free (depend on how large is α_{dark} compared to our α.
- These two decays dominate in large fraction of parameter space
- For large Br into light photon -> identical to GMSB

SUSY with a Hidden Valley

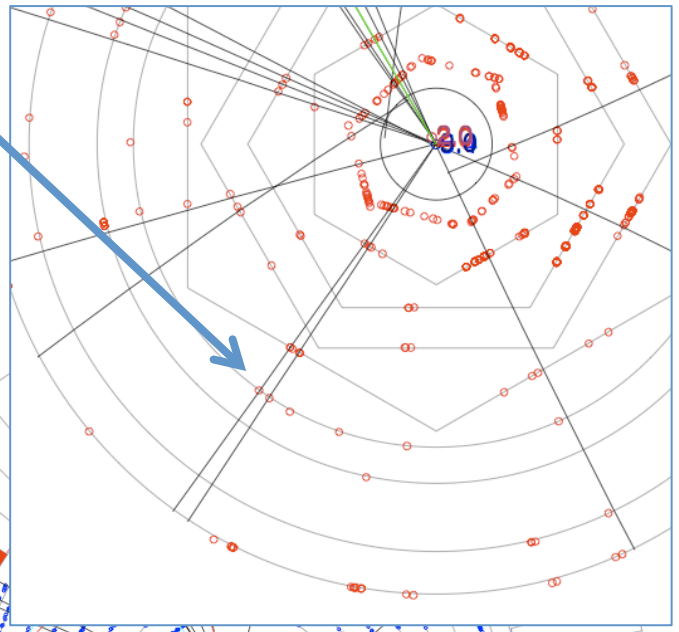


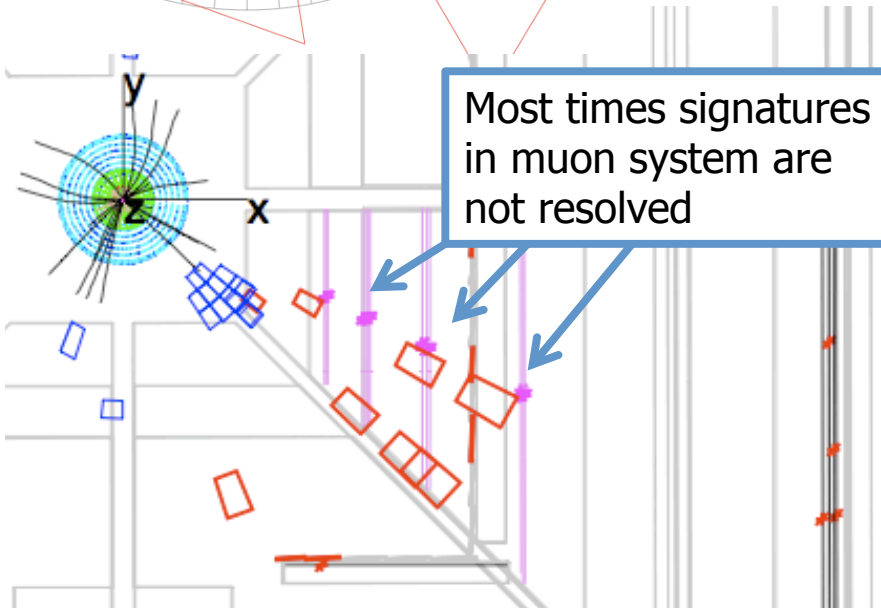
smaller MET, but not by much:
splitting between dark states ~O(MeV), leptons/hadrons from transition are relatively soft (and may be delayed). Have not tried to simulate – no model yet.

Dark Photon Reconstruction

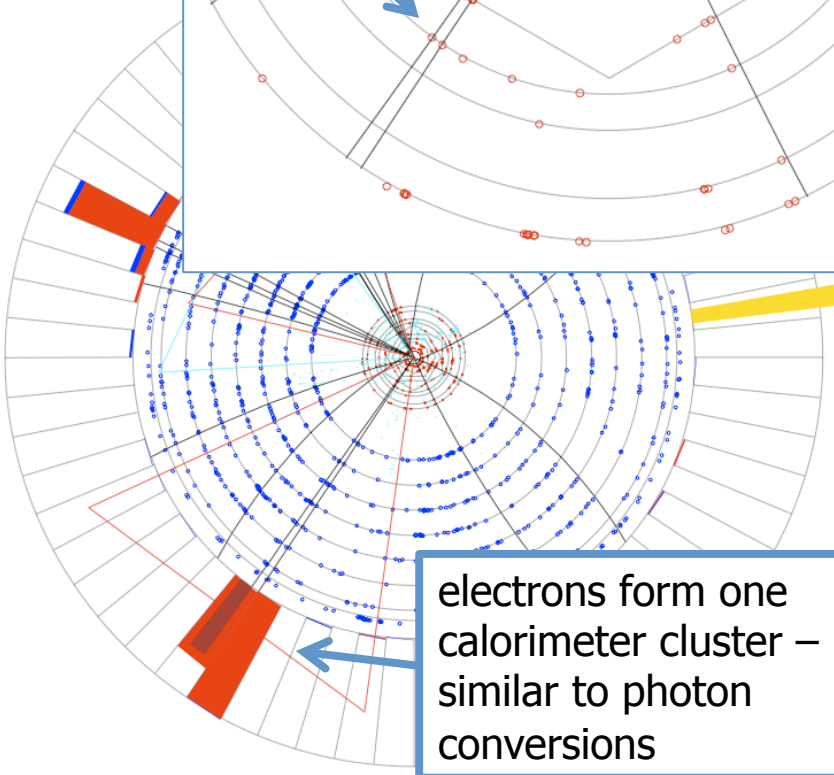


Two spatially close tracks can be reliably resolved in the central tracker





Most times signatures in muon system are not resolved



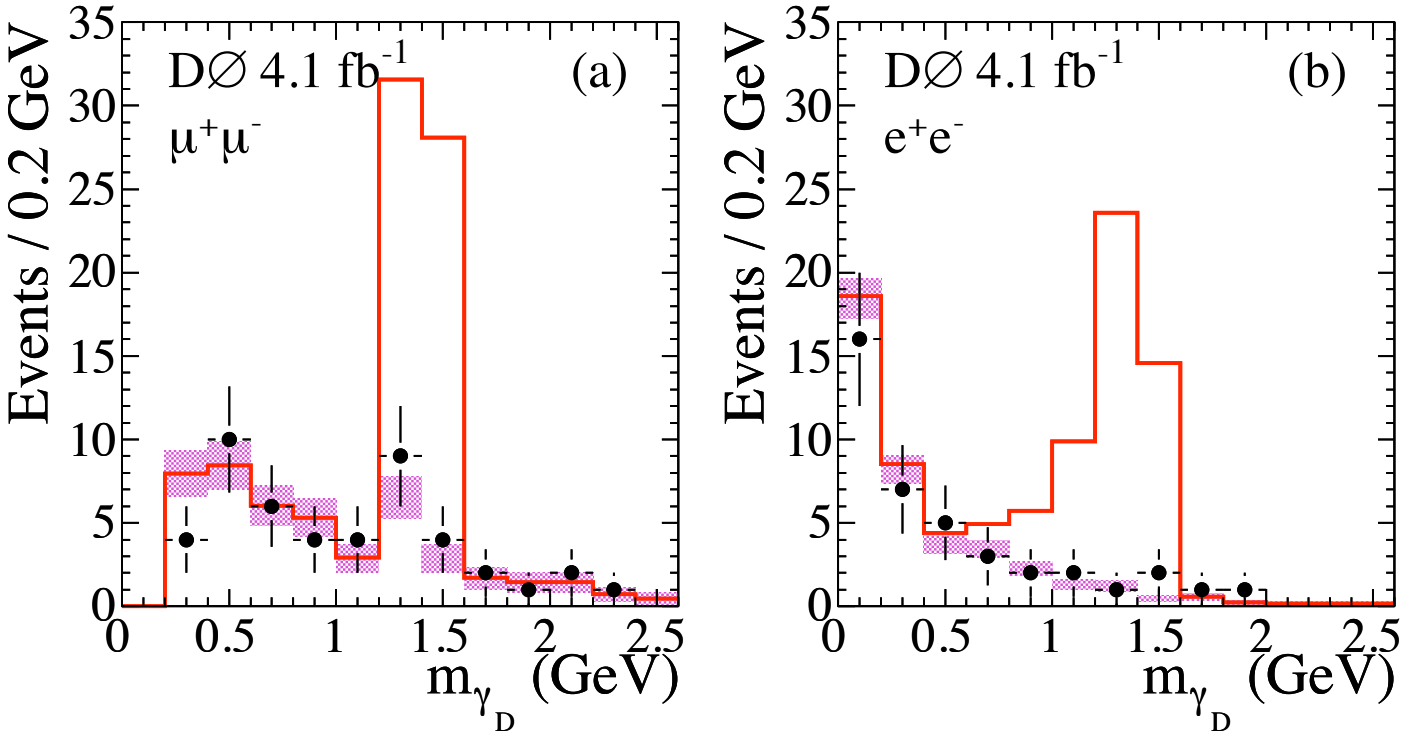
electrons form one calorimeter cluster – similar to photon conversions

Dataset, Skim & Selection

- at least one photon with E_T>30 GeV
- dark photon candidates: all combinations of oppositely charged tracks with p_T>10/5 GeV within 0.2 from each other from the same vertex, not back-to-back with the photon (suppresses QCD direct photons / dijets)
- select the leading isolated dark photon candidate:
  - sum of tracks in 0.4 cone around the candidate is less then 2 GeV
  - if more then one, select candidate with the highest trailing track p_T
- match dark photon candidates with either
  - a loose muon - only require one (overlaps in the muon system)
  - with an EM object with E_T>10 GeV
- Close tracks – main source of systematic error (20%)
  - our MC describes tau decays very well
  - checks with photon conversions from $Z \to \mu\mu\gamma$

Candidate Mass Spectrum

- Black points are data from the signal region
- purple band is combined distribution from control regions
  - background is dominated by jets, plus direct photon conversions in ee channel
- red is MC signal with dark photon mass of 1.4 GeV

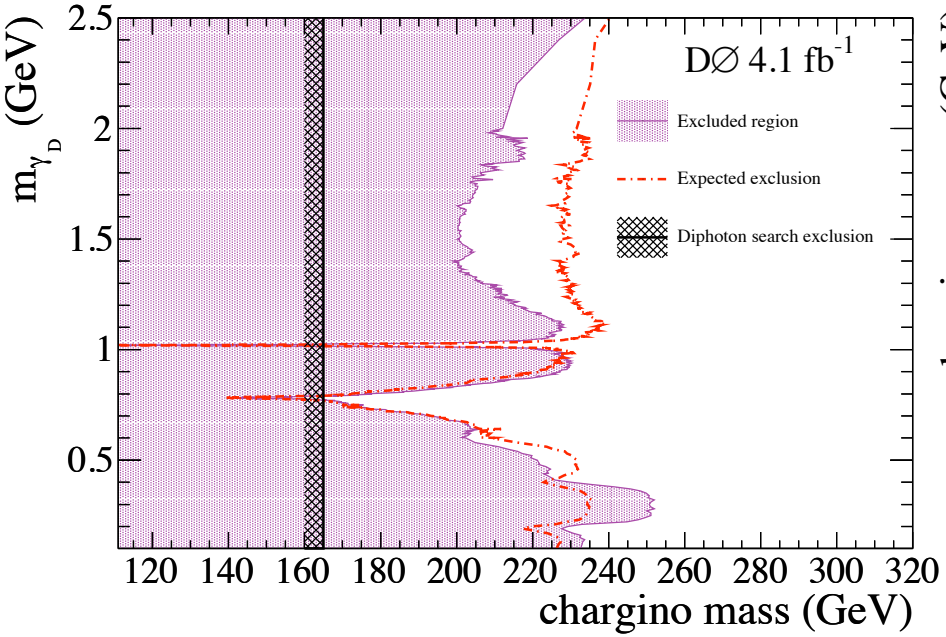


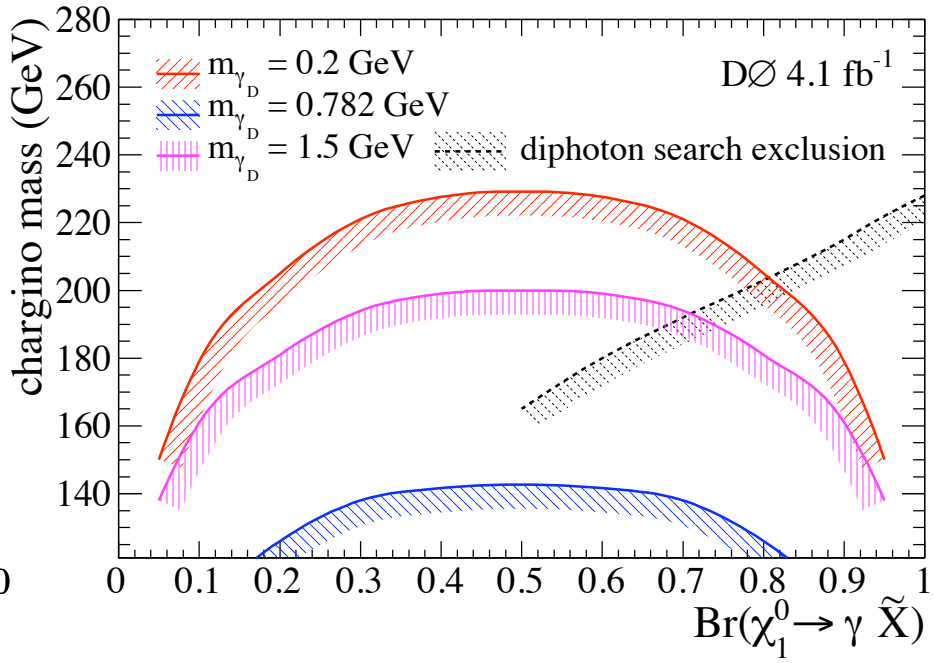
- No signal - feed electrons and muons simultaneously into limit setter

Model Limits

- Use mGMSB model line that was a benchmark for SUSY searches in CDF and DØ – Snowmass Slope SPS8
  - make neutralino decay into a dark photon and a massless invisible particle
- Snowmass slope parameters
  - Λ – varies
  - $M_m = 2 \cdot \Lambda$
  - $N_5 = 1$
  - $\tan\beta = 15$
  - sign $\mu = +1$

Br(χ_1^0 → dark photon) = 0.5

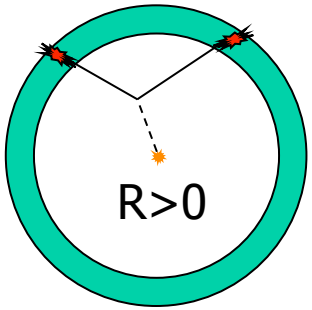


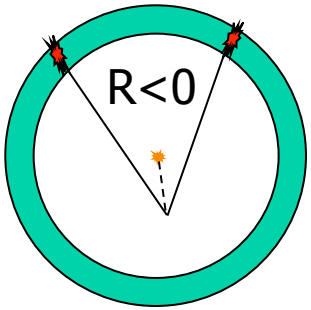


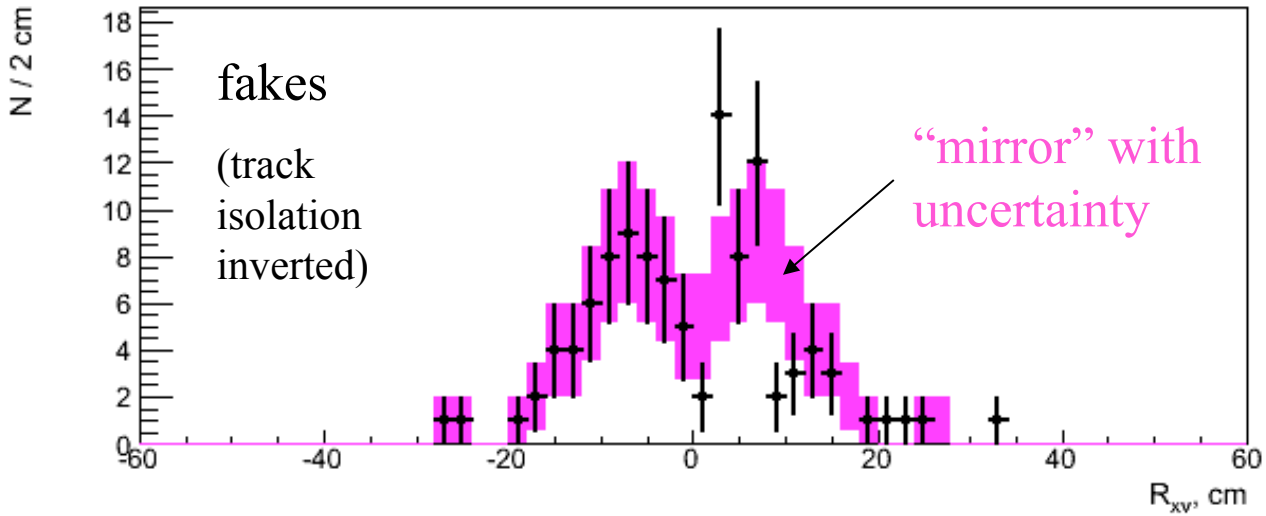
Summary

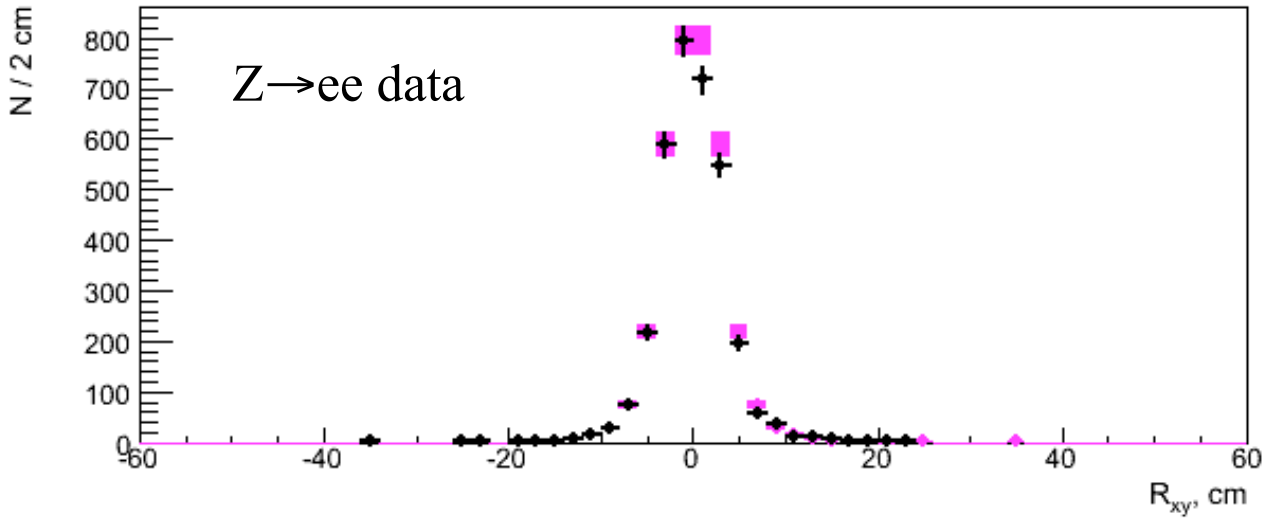
- Hidden Valley models are a constant reminder that we should keep looking for new physics in unusual places
  - some models can explain observed anomalies in astrophysics and direct dark matter searches – and predict striking collider signatures
- DØ examined two previously unexplored final states
  - long-lived particles decaying into electrons/photons
  - photon + two spatially close leptons + MET
- No signals, but the developed strategies will be useful for the LHC

Vertexing for Z→ee and fakes



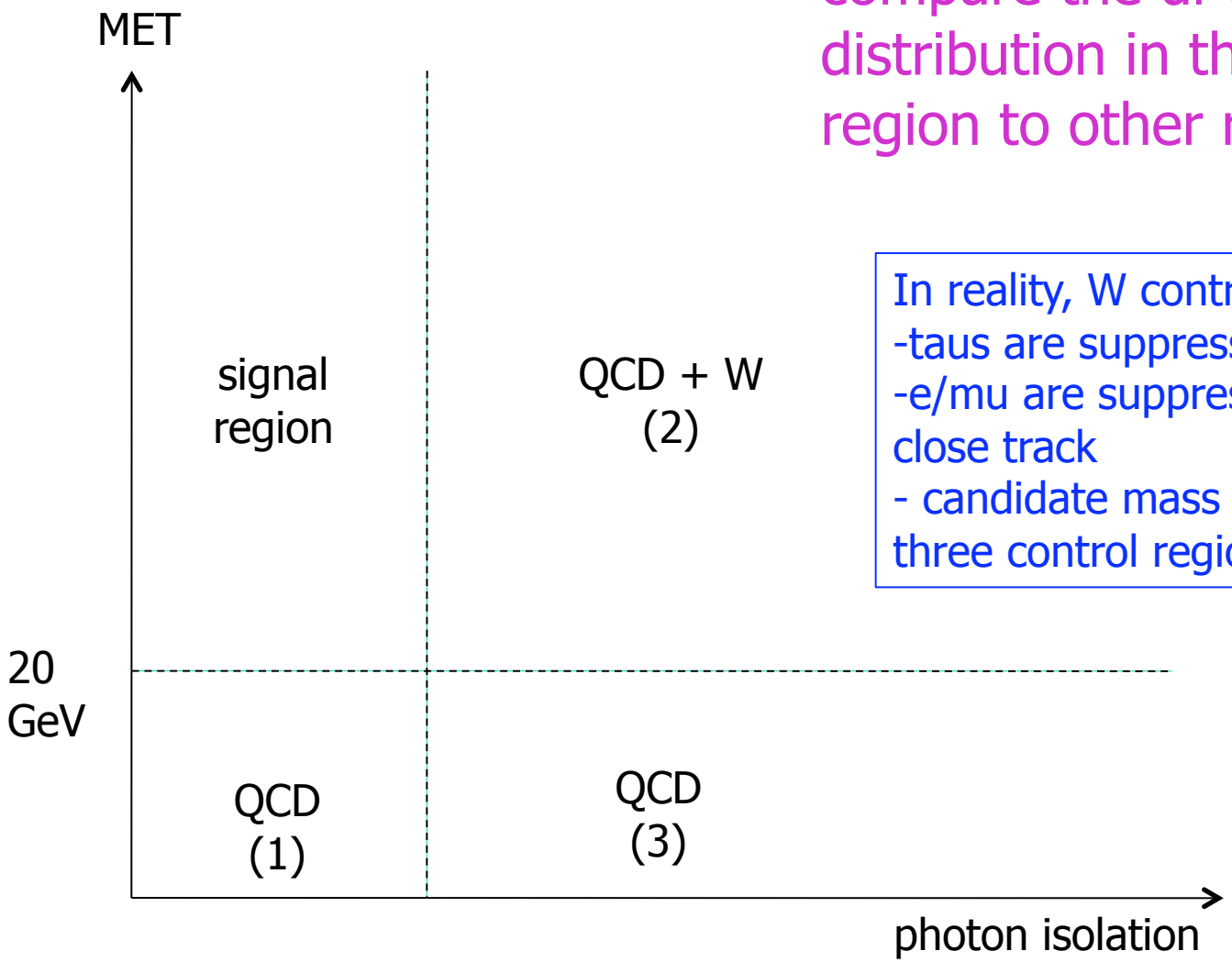






Signal and Control Regions

compare the di-track mass distribution in the signal region to other regions



In reality, W contribution is negligible
-taus are suppressed by high track p_T
-e/mu are suppressed by the second close track
- candidate mass distributions in all three control regions are identical