Searches for Dark Photons

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with great help from A. Haas, M. Narain and S. Thomas

Outline

- DØ detector
- 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
- Search for $h \rightarrow aa \rightarrow 4\mu$
  - not a hidden valley search , but sensitive
- Future efforts

Tevatron Collider

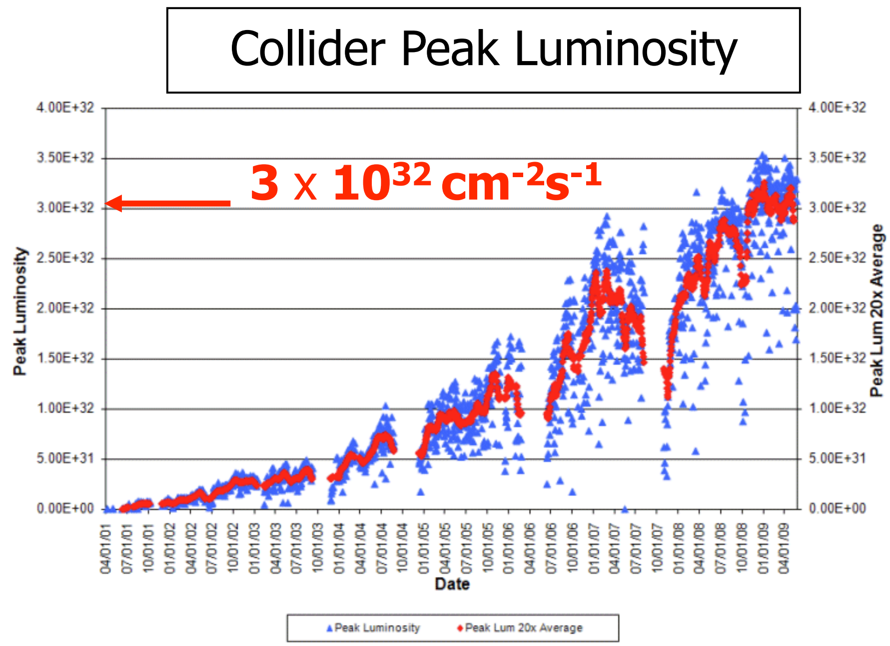
1992-95

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

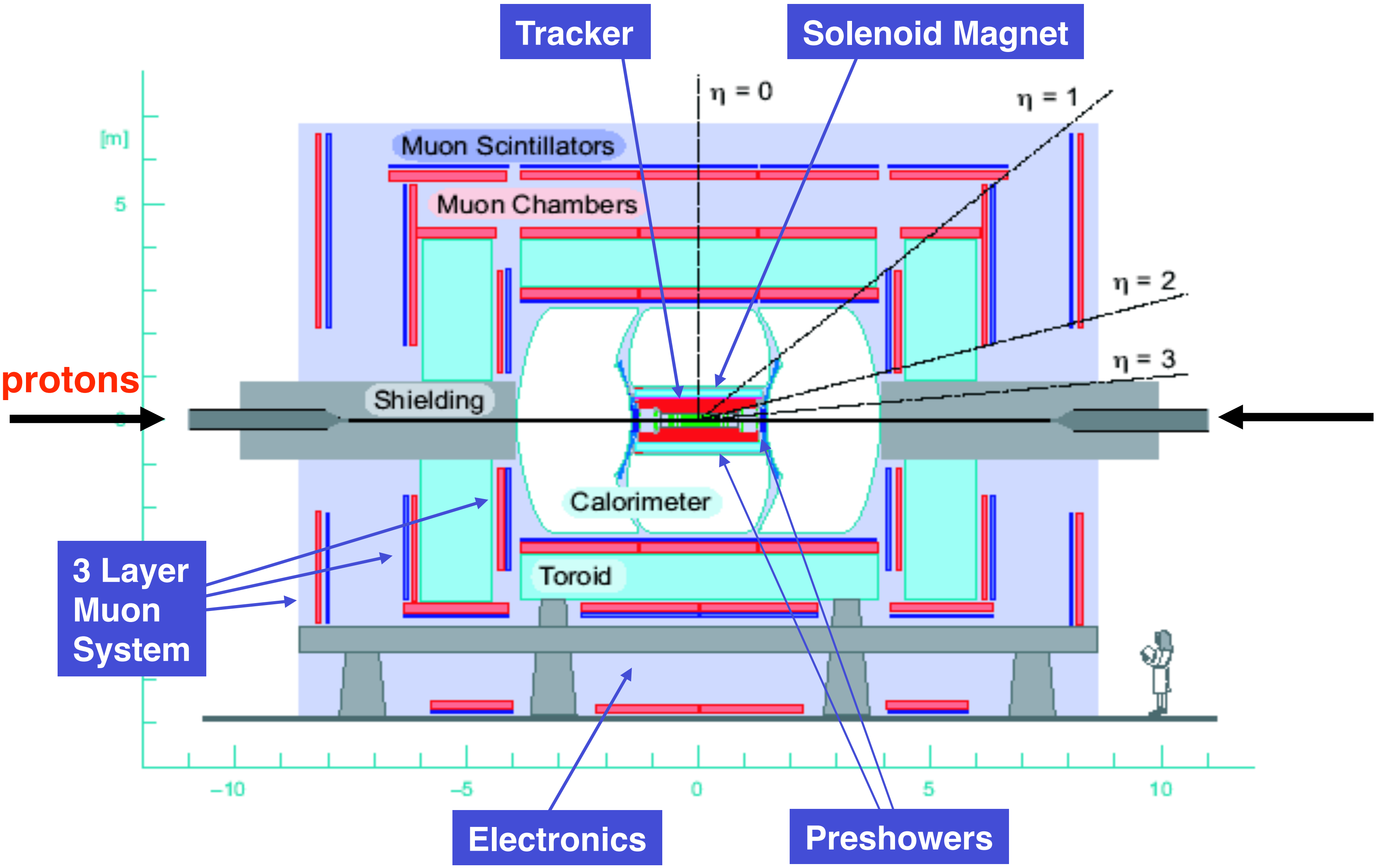
2001-2009 Run 2: major upgrades

higher E_{CM} = 1.96 TeV

~6 fb^{-1} recorded



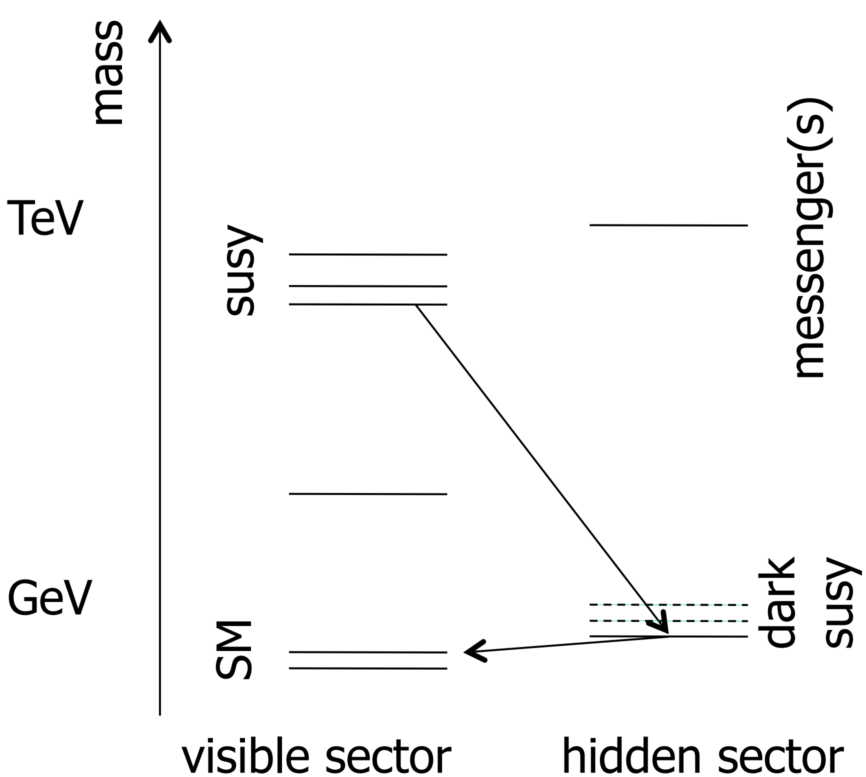
DØ Detector



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
–10
–5
0
5
10
Electronics
Preshowers

Hidden Valley + SUSY

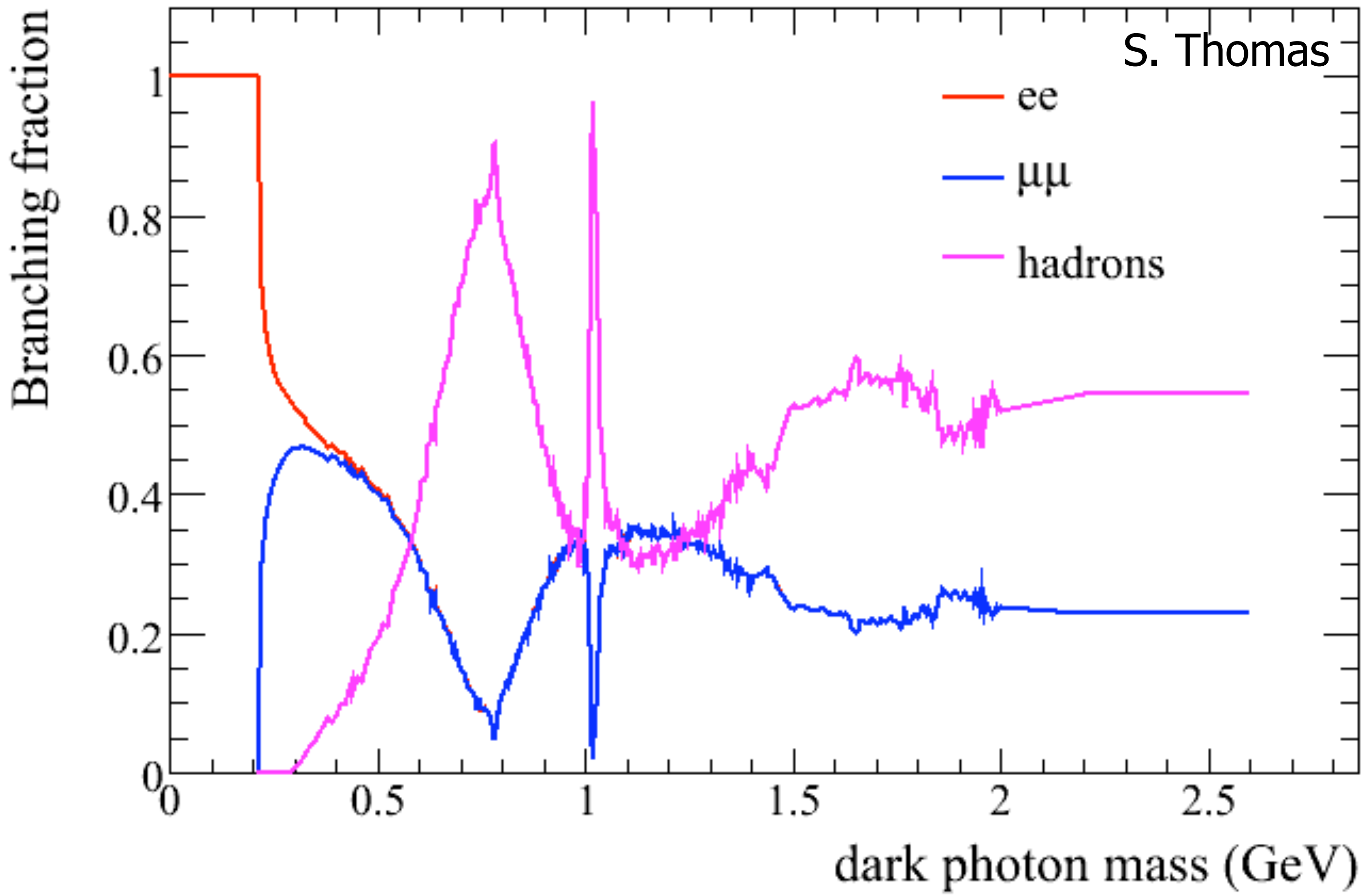
- Introduced by Strassler & Zurek PLB 651 (2007)
- Recently, called upon by Arkani-Hamed and Wiener to explain PAMELA signal (plus ATIC, DAMA, …) PRD 79 (2009), JHEP 12 (2008)



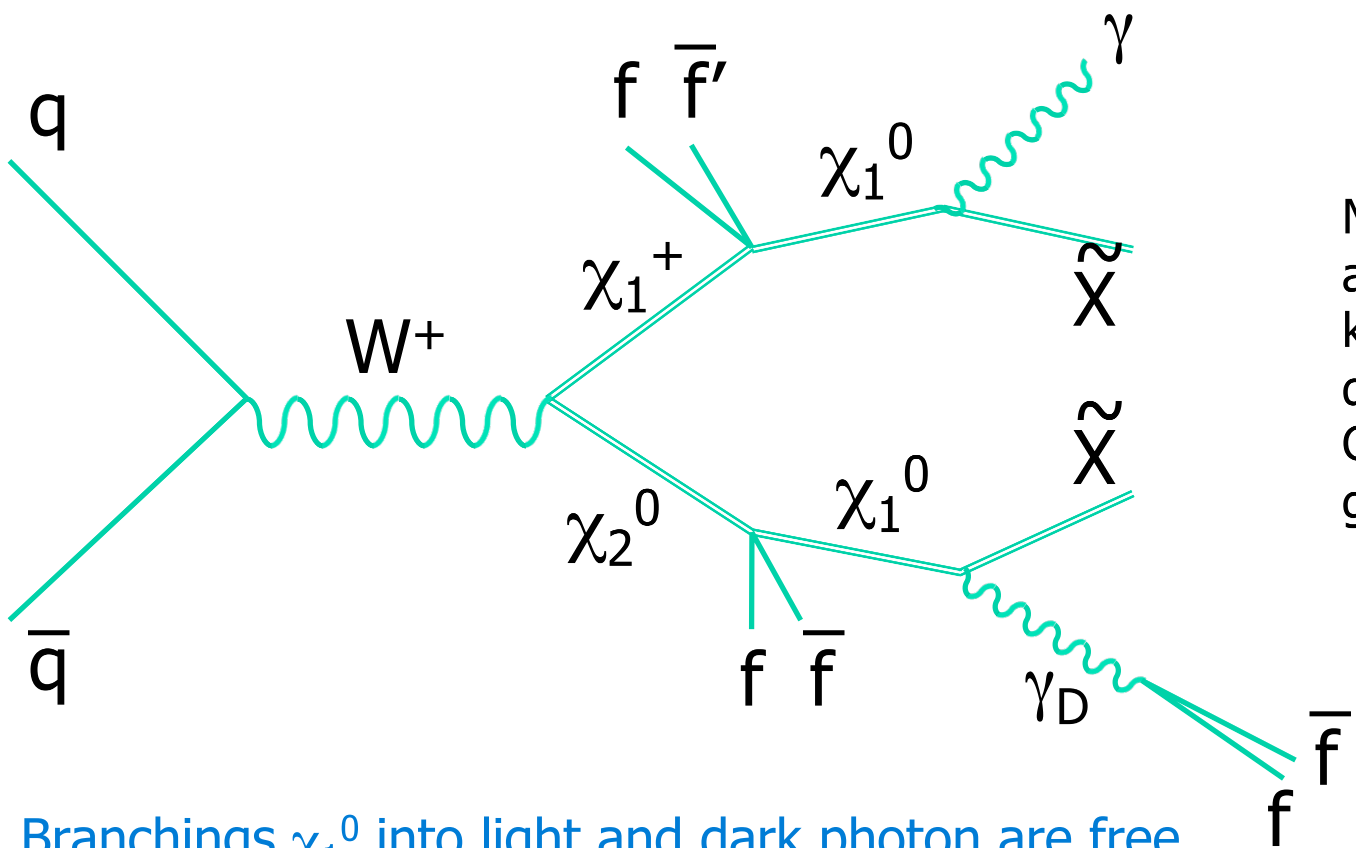
- Many phenomenological scenarios possible. One is very similar to GMSB
- being developed by S. Thomas and D. Shih
- Visible sector SUSY is produced
- Cascades to visible LSP
- LSP decays into hidden sector:
  - photon + Dark LSP
  - dark photon + Dark LSP
- Dark LSP => MET
- Dark photon (~GeV) – decays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



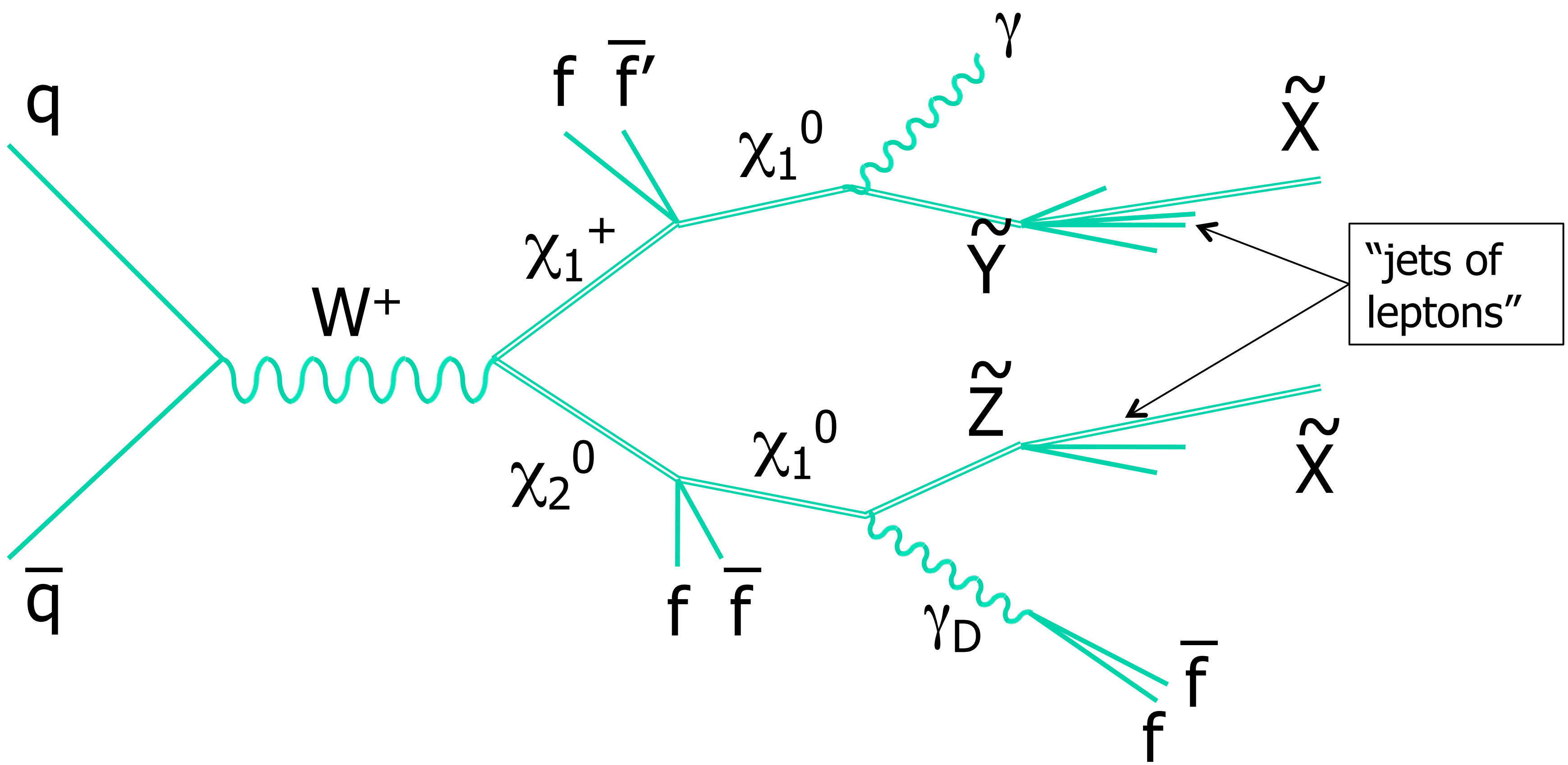
SUSY with a Hidden Valley



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

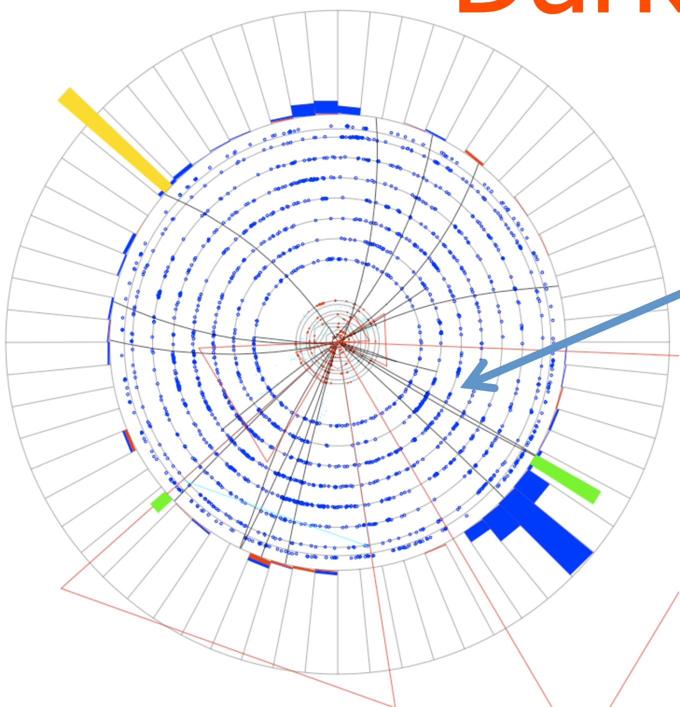
- Branchings χ_1^0 into light and dark photon are free (depend on how large is α_{dark} compared to our α.
- These two decays dominate in large fraction of parameter space
- For large Br into light photon -> identical to GMSB

SUSY with a Hidden Valley

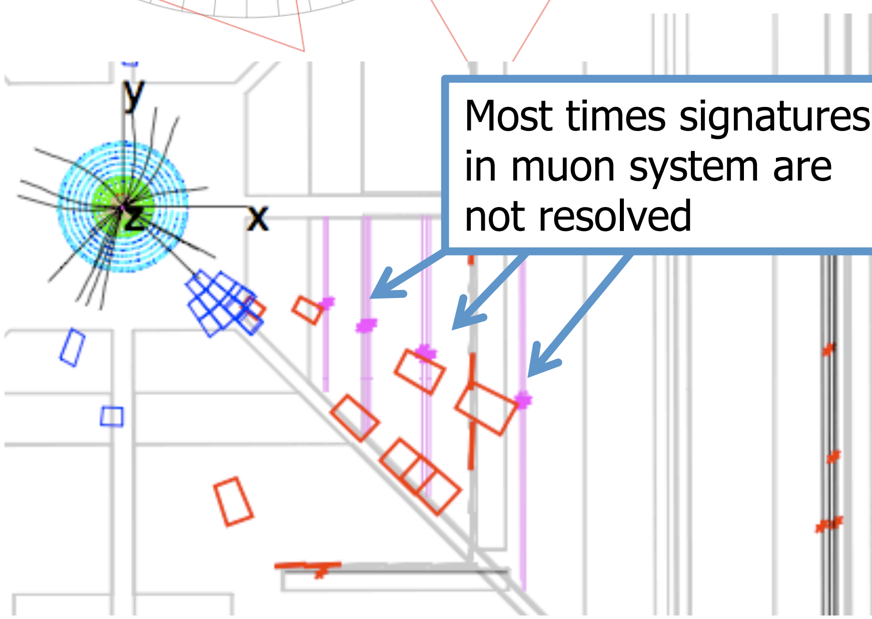


smaller MET, but not by much:
splitting between dark states ~O(MeV), leptons/hadrons from transition are relatively soft (and may be delayed). Have not tried to simulate

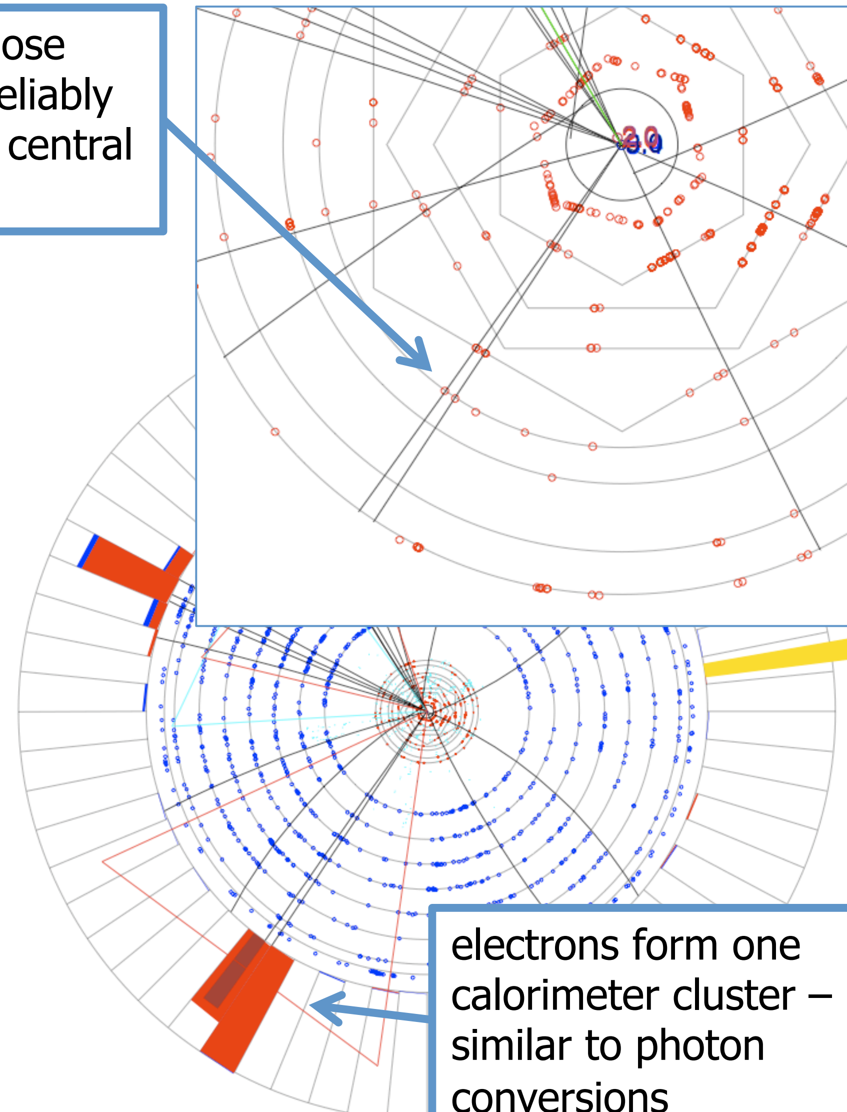
Dark Photon Reconstruction



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



Most times signatures in muon system are not resolved

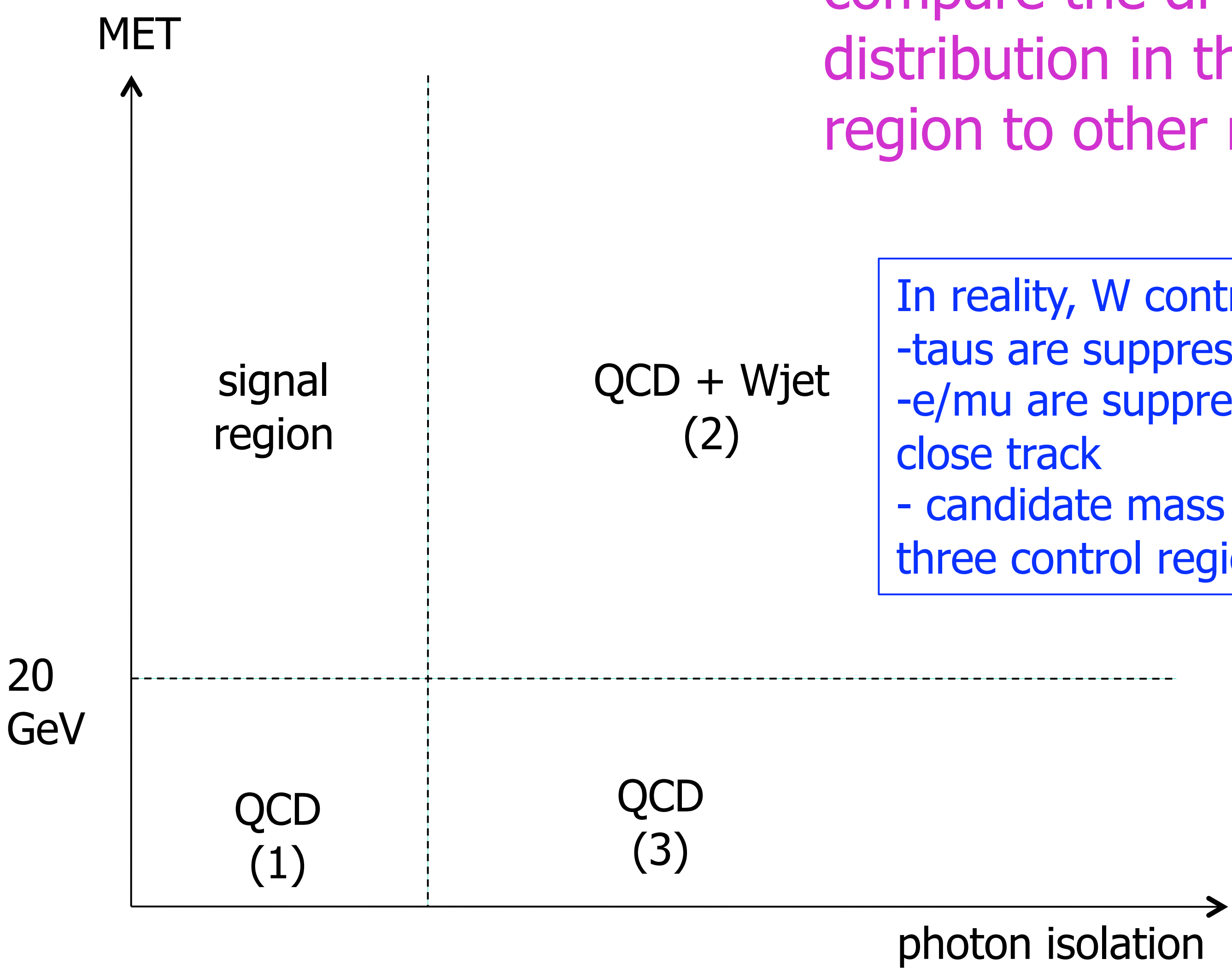


electrons form one calorimeter cluster – similar to photon conversions

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 $Z \to \mu\mu\gamma$

Signal and Control Regions

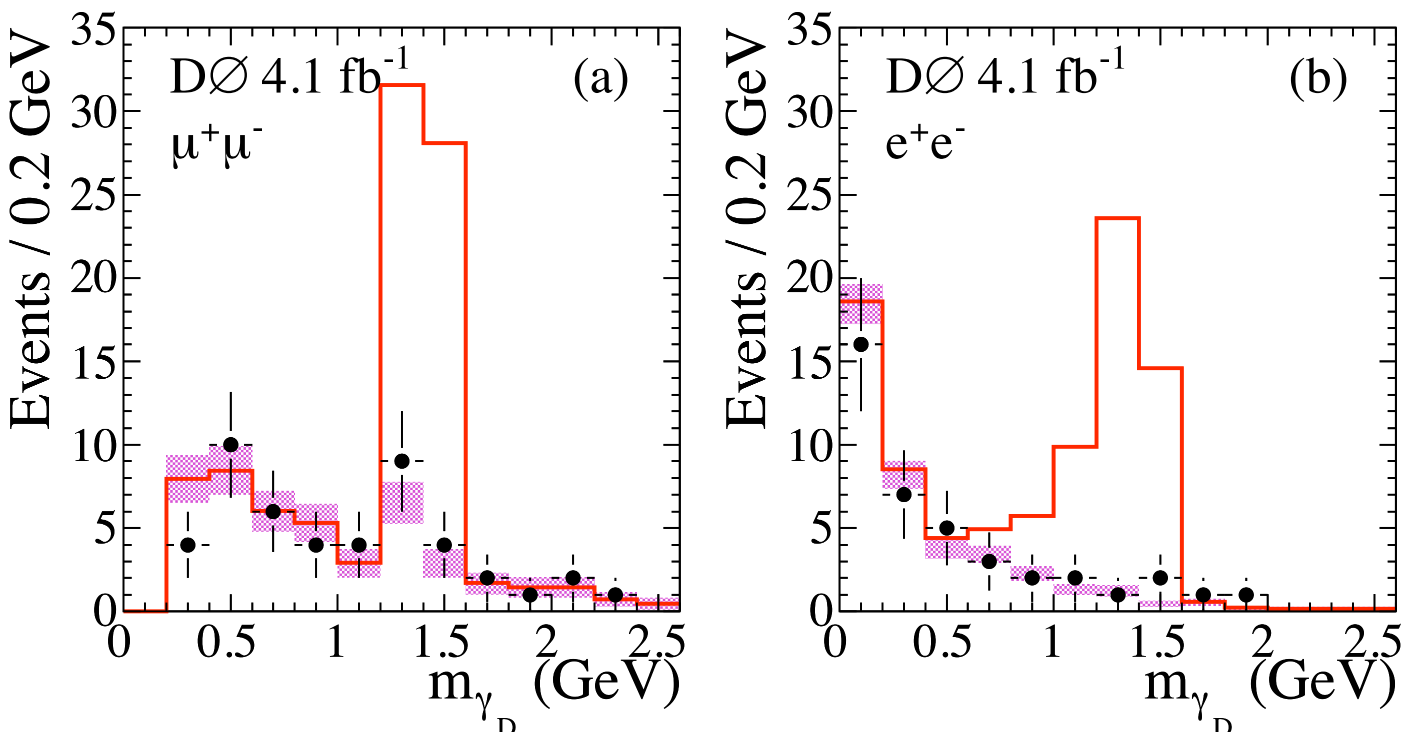


compare the di-track mass distribution in the signal region to other regions

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

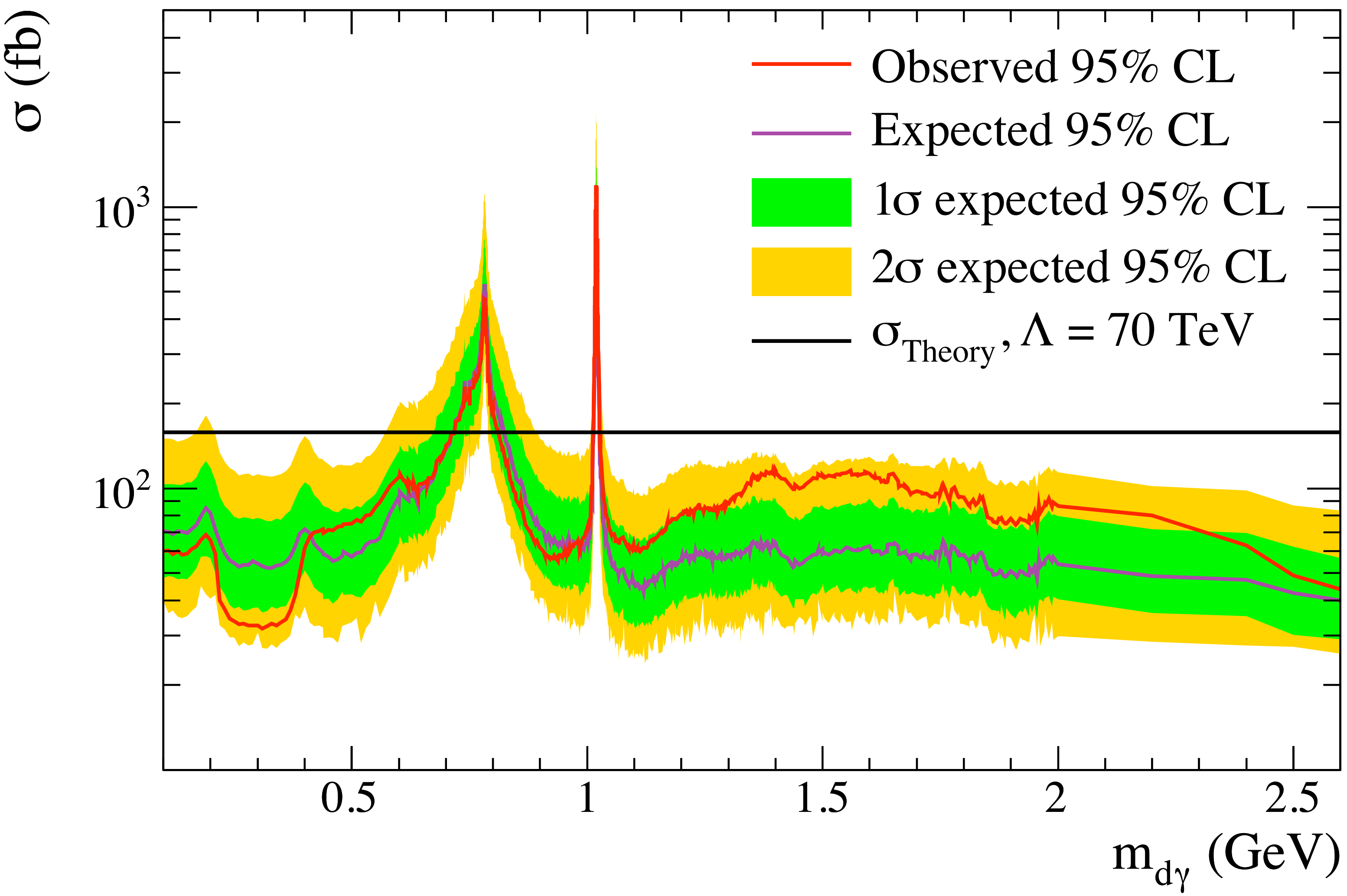
Candidate Mass Spectrum

- 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
  - normalized outside of the tested mass region
- red is MC signal with dark photon mass of 1.4 GeV



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

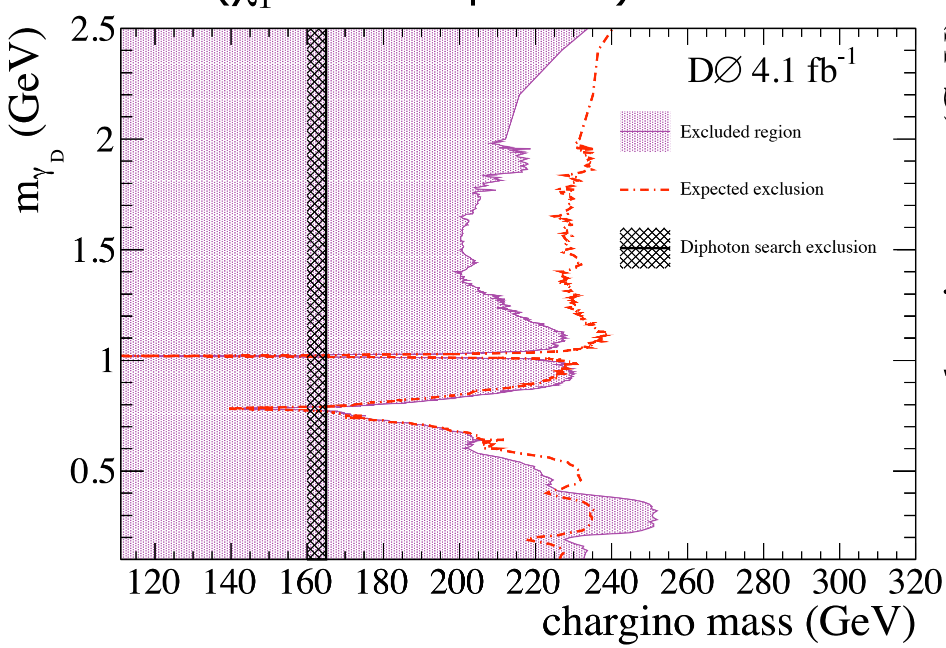
Typical Limit Plot

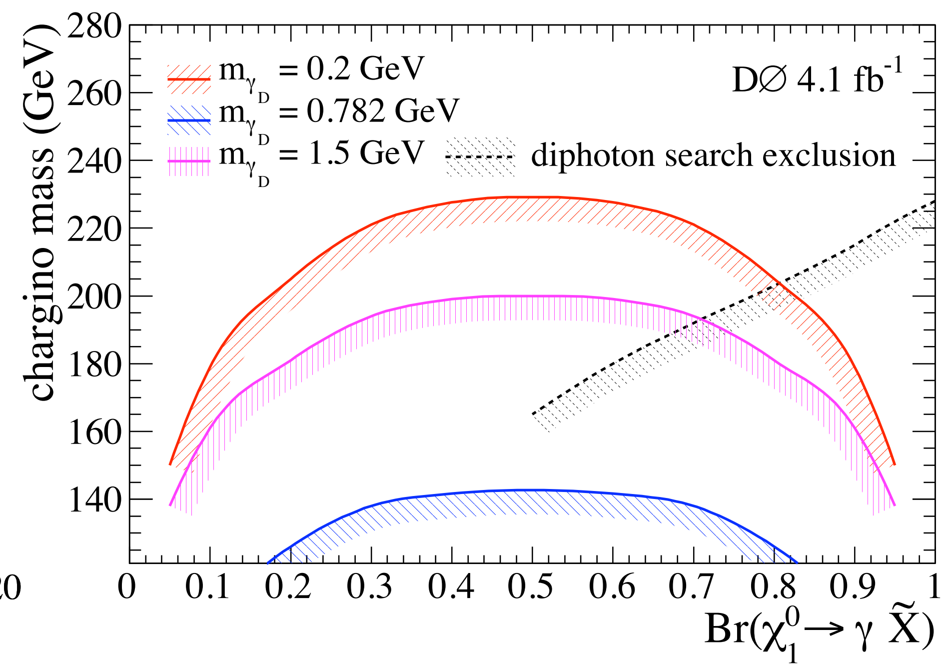


Model Limits

- 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
  - $M_m = 2 \cdot \Lambda$
  - $N_5 = 1$
  - $\tan\beta = 15$
  - $\text{sign}\ \mu = +1$

Br(χ_1^0 → dark photon) = 0.5





Phys. Rev. Lett. 103, 081802 (2009)

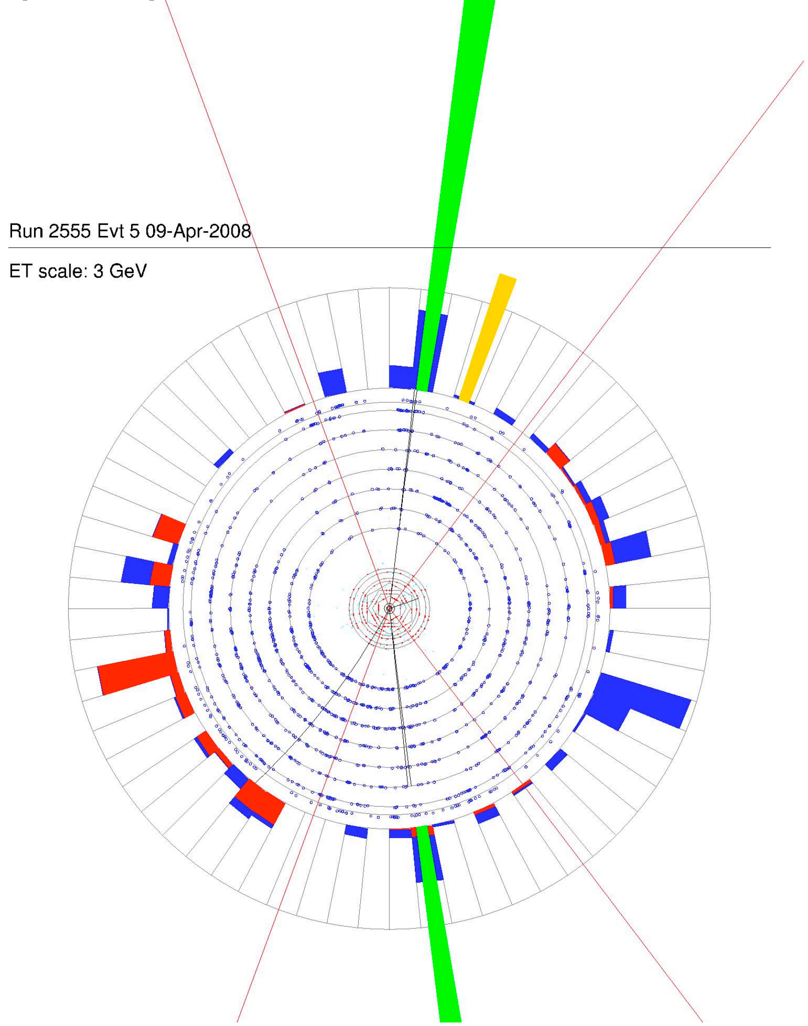
Two Dark Photons per event?

- No dedicated search yet, but one can re-interpret the $h \rightarrow aa \rightarrow \mu\mu\mu\mu$ and $h \rightarrow aa \rightarrow \mu\mu\tau\tau$ searches

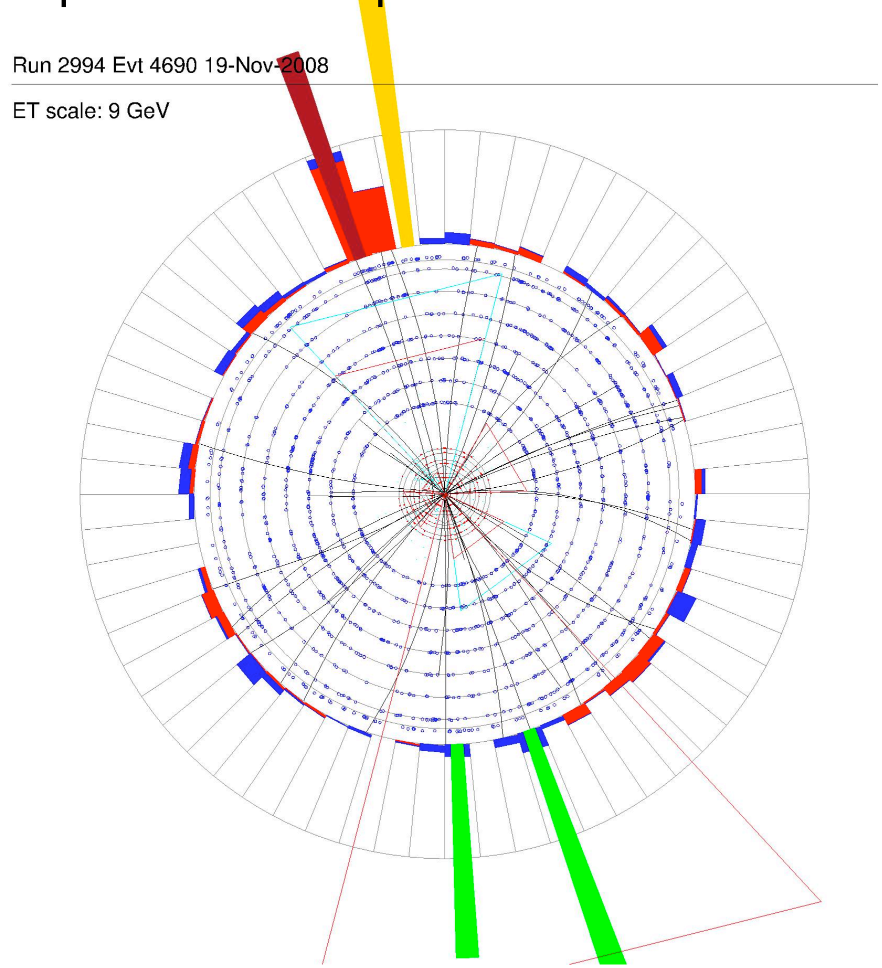
Phys. Rev. Lett. 103, 061801 (2009)

Topology of the h→aa search

low m_a – two pairs of spatially close muons

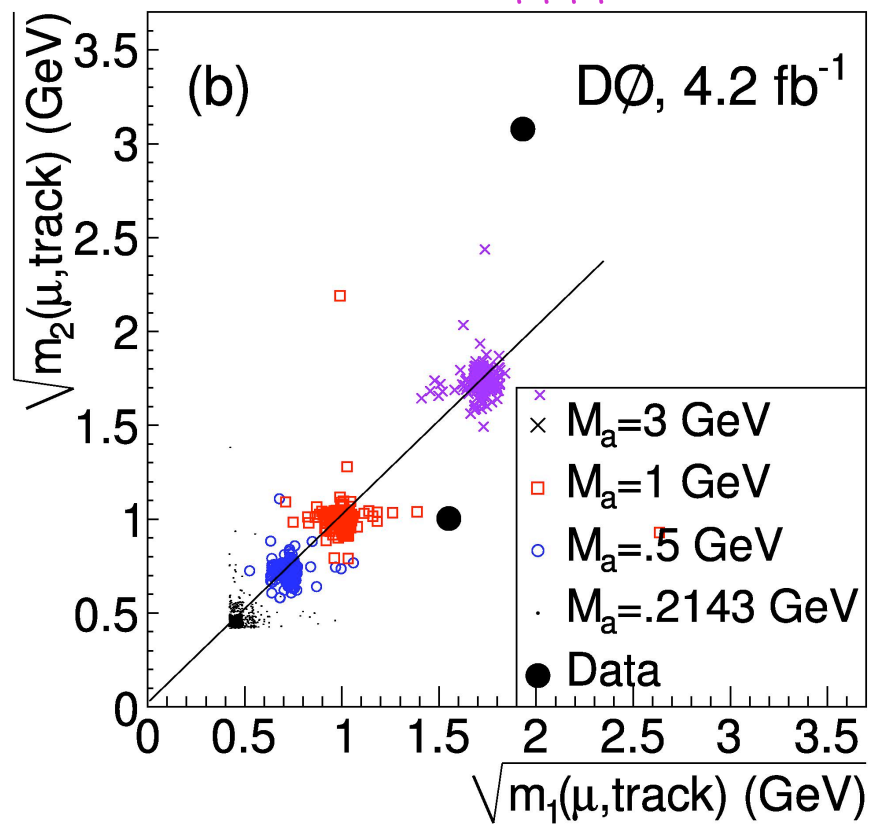


higher m_a – decays mostly into taus, but require one to decay into muons to preserve mass peak

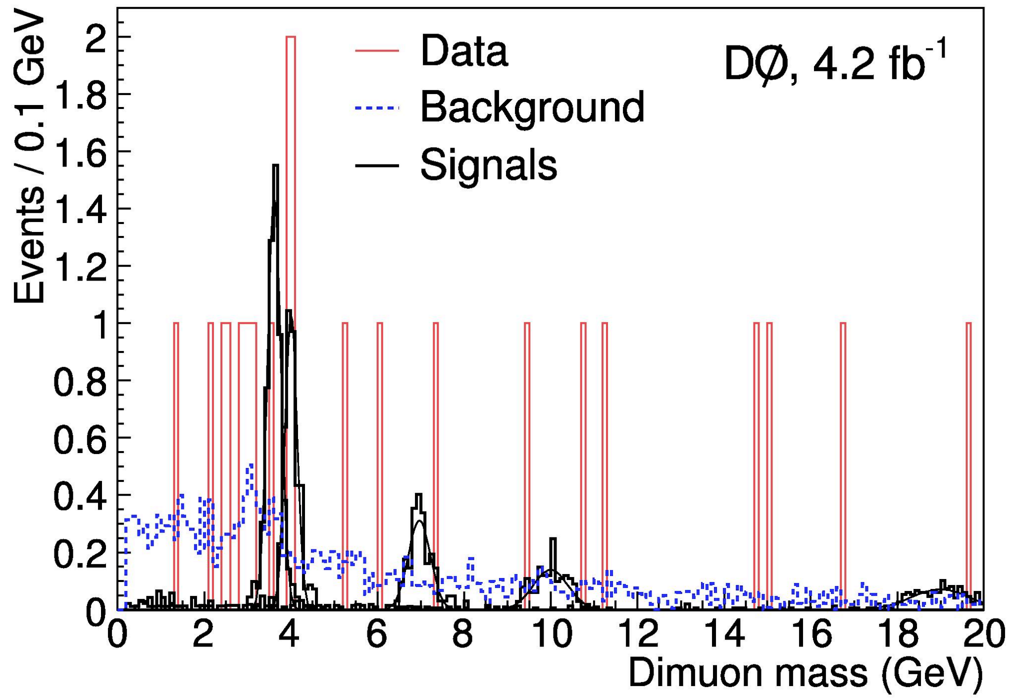


M_a

h→aa→μμμμ



h→aa→μμττ

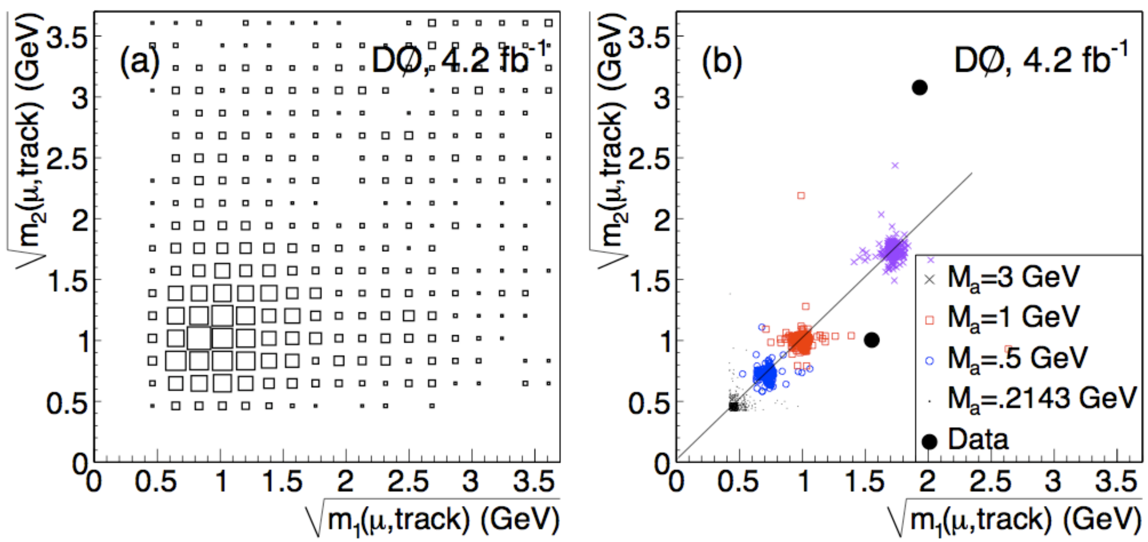


muon p_T>10 GeV,
companion track p_T> 4 GeV
no other significant cuts

2 muons with p_T>10 GeV,
non-iso muon or loose electron on τ side
Selections on MET
very model dependent and probably with small acceptance for SUSY-like events

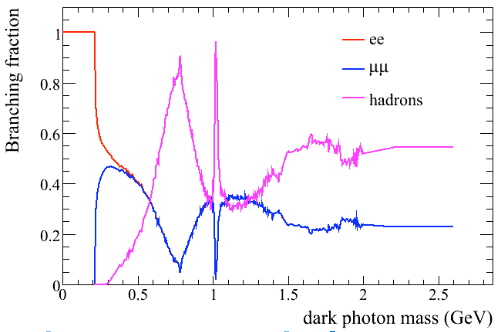
Background Normalization

- Trying to predict absolute value of the background is hard
- The usual trick for fake rates is to flip isolation cut and determine fake rate $\mathcal{P}$(b-jet → isolated μ+trk) by counting pairs (not-isolated, not-isolated) and (isolated, not-isolated)
  - fake rate is a strong function of jet p_T – requiring one isolated μ+trk changes the spectrum and therefore probability of the second pair to be isolated. For this analysis fake rate changes by more then a factor of two depending on cuts on other μ+trk.
  - the correlation was explored and in the end predicted number of events is 1.9±0.4 events – and two observed.



Future Searches

- want to accommodate scenarios like $\chi_1^0 \to \tilde{\chi}\tilde{h} \to \tilde{\chi}\gamma_D\gamma_D^{(*)}$
  - two dark photons close together
  - if on-shell: can have all-leptonic mode, ee$\mu\mu$ is promising
  - if off-shell: $\gamma_D{}^*$ will be mostly dominated by hadronic resonances (ρ)
  - need to somewhat relax isolation



- Handles:
  - two objects per event
  - missing E_T
  - invariant mass – although combinatorics makes it much less useful; one can also imagine models with several resonances
    - looks like a simple counting experiment may work
    - still may be possible to do ee$\mu\mu$ or eeee channel with all four tracks reconstructed and properly paired and achieve enough of background rejection to do a single-object search
      - hh$\mu\mu$ is much more challenging, hhee is hopeless.
- Work is only starting, stay tuned!!