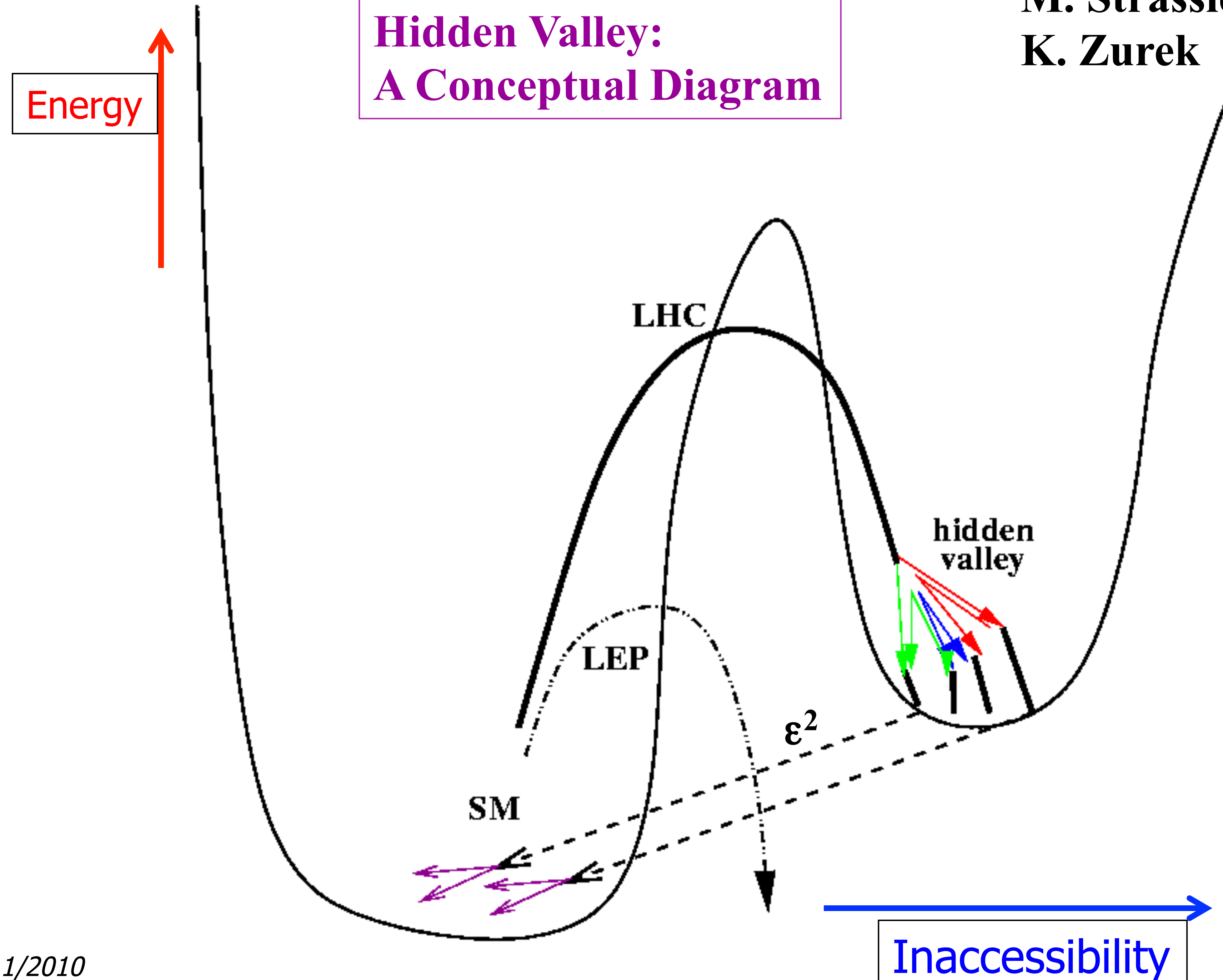
Search for Hidden Valleys with DØ detector

Yuri Gershtein

Hidden Valley: A Conceptual Diagram

M. Strassler, K. Zurek



Motivation for Hidden Sectors

- From the point of view of superstrings & GUT theories, extra sectors are quite natural
  - usually model builders have to work hard to eliminate them
- It is possible to hide these sectors without violating any precision EWK data
  - phenomenology can be very different from the "usual" new phenomena
  - some natural scenarios give signatures that are very hard to detect with current experiment hardware, trigger, and software design

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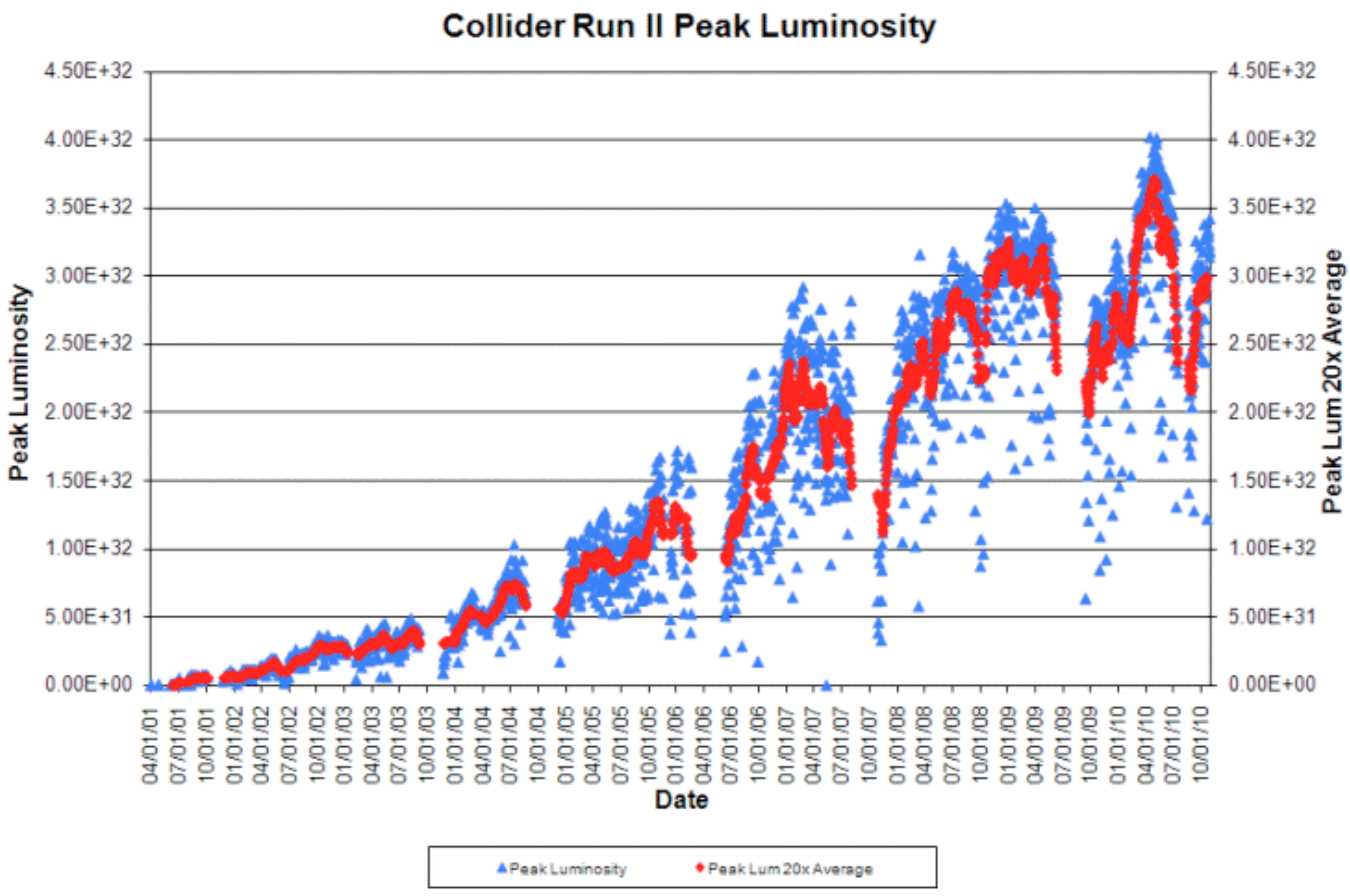
Like looking for non-magnetic needle in a haystack!

In this talk

- Two new results from DØ:
  - search for quirks
    - new fermions with new QCD
  - search for leptonic jets
    - recall N. Weiner’s talk on Tuesday
      - Dark Matter from a hidden sector
      - New force carrier, dark photon

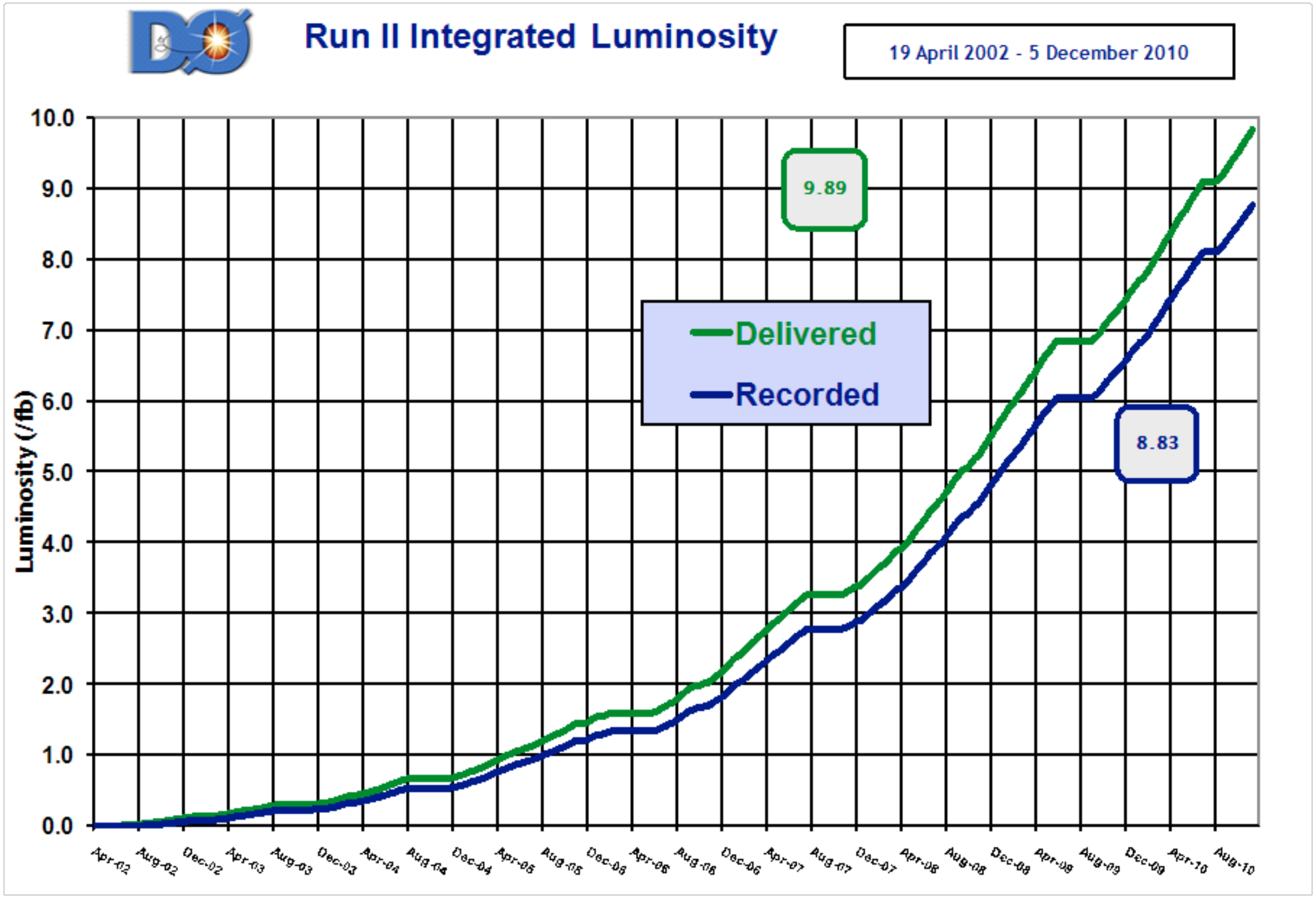
Tevatron Performance

- Accelerator works beautifully



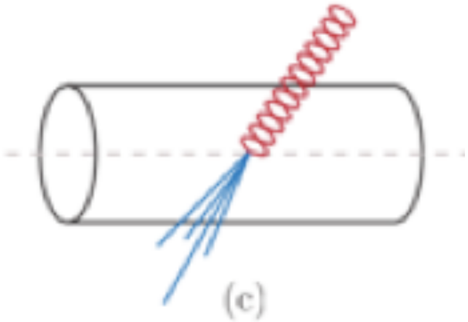
DØ Performance

- high data taking efficiency
- Radiation damage seems to be under control



Quirks

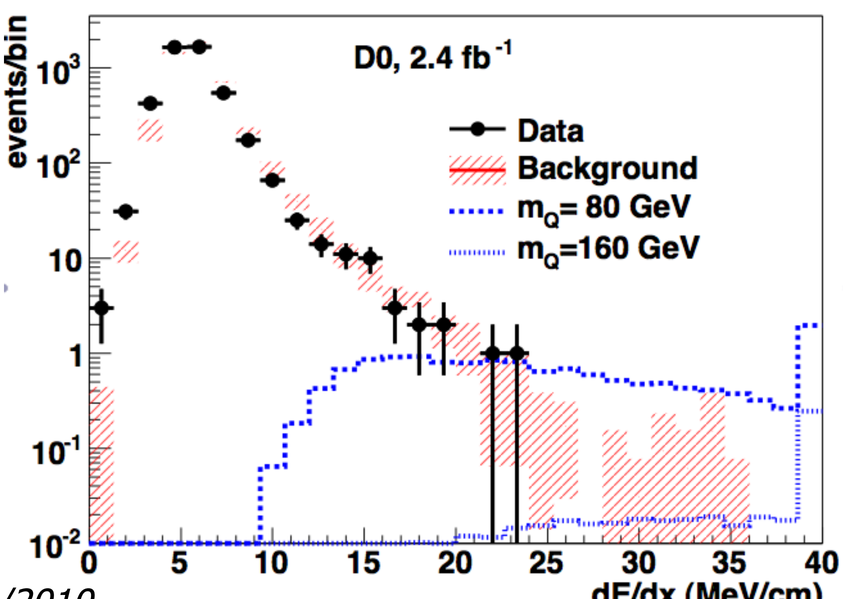
- Extra SU(3): new fermions ("quirks") and new "QCD" with some scale Λ. Phenomenology depends on Λ/m_Q **J. Kang, M. Luty, JHEP 0911:065 (2009)**
- If Quirks have SM charges – can be produced at colliders
- If $\Lambda << M_Q$ the string can become macroscopic
- This search considers string sizes of up to ~50 microns
- Quirk pairs like this most times do not even enter the tracker – they fly slowly along the beam pipe and annihilate some time later
- Way to find them is to trigger on ISR jet
- The two quirks then would appear as a single straight highly ionizing track

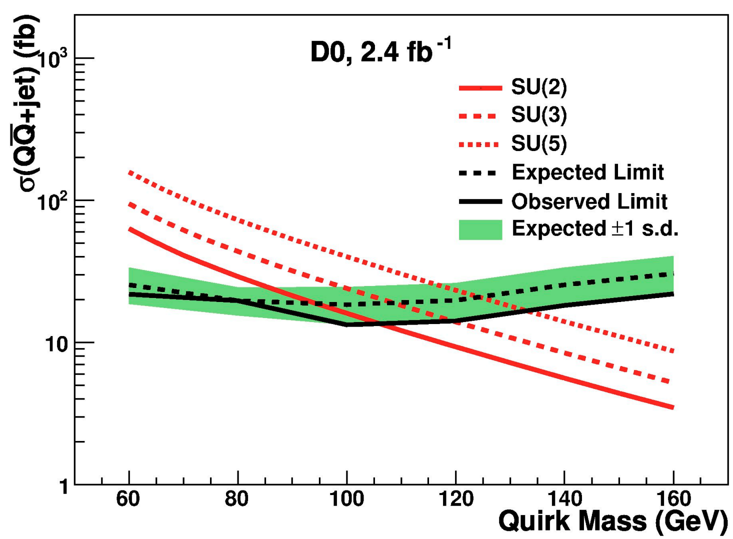


- **Requiring ISR jet cuts down the statistics, but this is often the only way to find particles that are register mostly as strange-looking tracks**

Quirks

- Select events with high E_T jet, high E_T isolated high quality track back-to-back with it and significant MET
  - SM background: W(→μν)+jet and QCD
- Quirk pair ionization is larger because of double charge and slowness
  - somewhat reduced due to relative movement of the quirks
- Use non-isolated tracks and high E_T leptons from W/Z to extract dE/dx for particles with v≈c
- Scale the measured dE/dx by theoretical boost distribution and make a cut on dE/dx optimized for each Quirk mass





Extra U(1) sector with force carrier ~O(GeV) and weak coupling to SM ($\varepsilon^2 < 10^{-5}$)

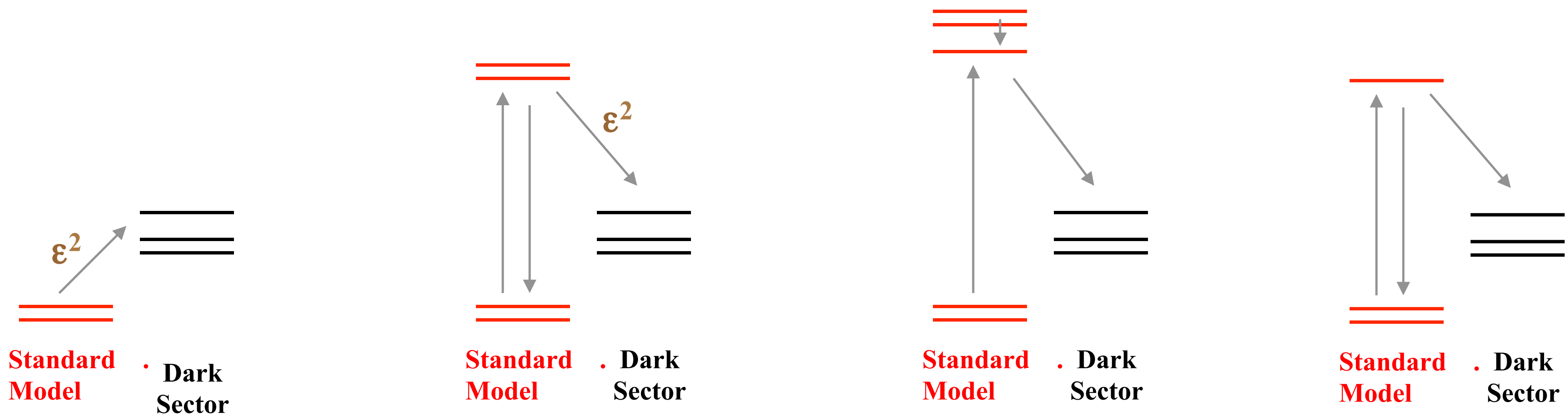
- Motivated by non-collider observations
- Direct Dark Matter detection
  - DAMA/LIBRA – anomaly?
- Cosmological anomalies
  - low energy positrons from galactic center: INTEGRAL and 511 keV line
  - new sources of high energy electrons/positrons in cosmic rays: PAMELA, FERMI/LAT, ATIC, WMAP

D.P. Finkbeiner and N. Weiner, Phys. Rev. D 76 083519 (2007)

N. Arkani-Hamed, N. Weiner et al., Phys. Rev. D 79 015014 (2009)

Weakly coupled Hidden Sector Production at Colliders

Direct Production	Indirect Production	Indirect Production with Shared Conserved Quantum Number	Direct communicator production
Resonant Dark DY	Higgs, Z Decay	SUSY + R-Parity	Z' Decay

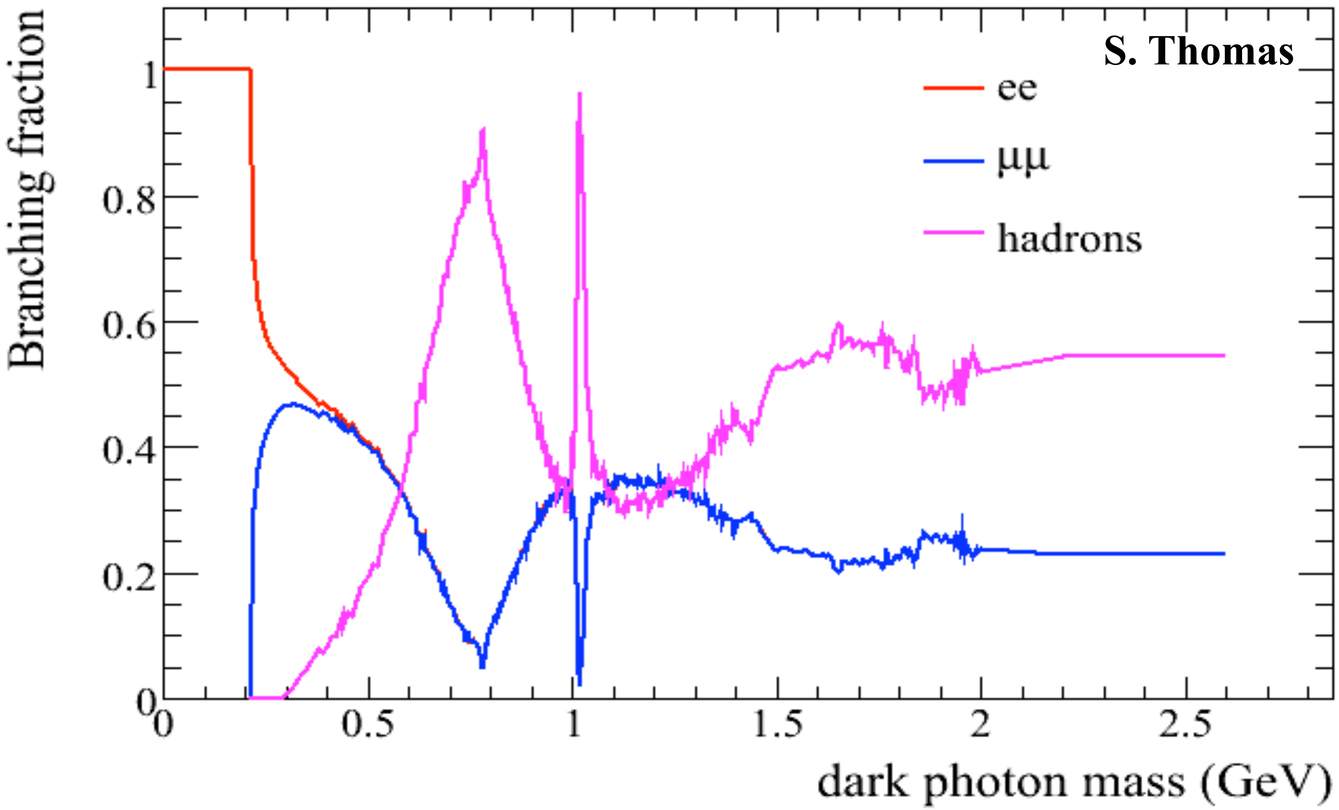


$\sigma \sim O(\varepsilon^2)$	$Br \sim O(\varepsilon^2)$	σ & $Br \sim O(\varepsilon^0)$	σ & $Br \sim O(\varepsilon^0)$

dark photons are produced in transitions to and within the dark sector

Dark Photon Decays

- Dark photon decays through its mixing with light photon, so its branchings can be calculated from measurement of R
- for $\varepsilon > 10^{-4}$ decays are prompt

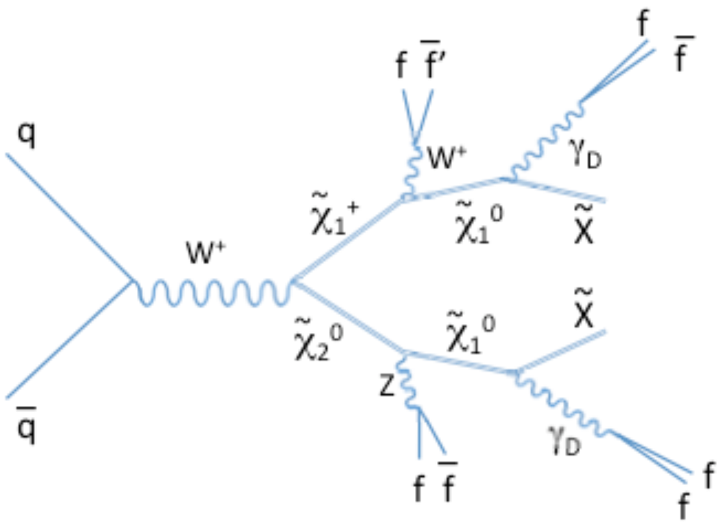


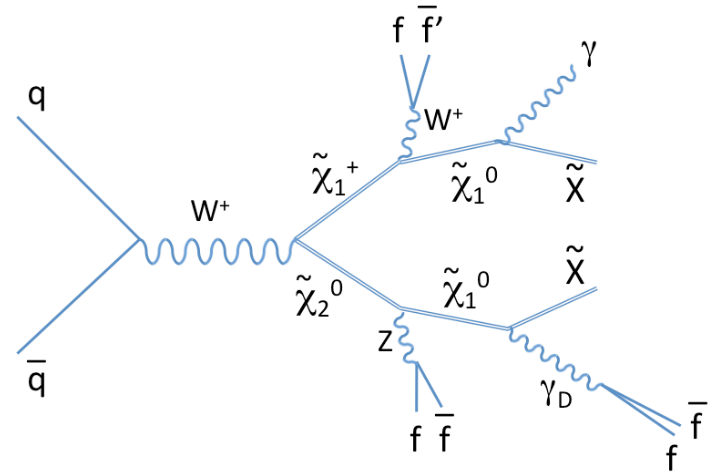
- **Experimental signature: two very close leptons or hadrons**

Dark Photons at Tevatron

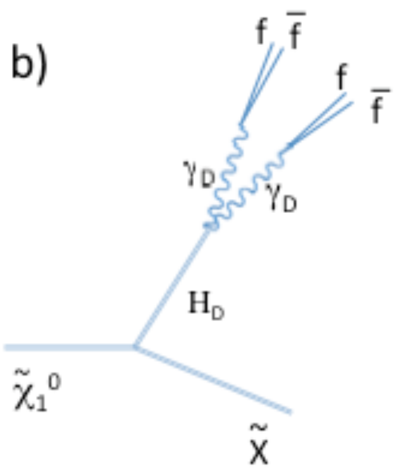
- Leads to final states that could have been missed – non-isolated leptons!

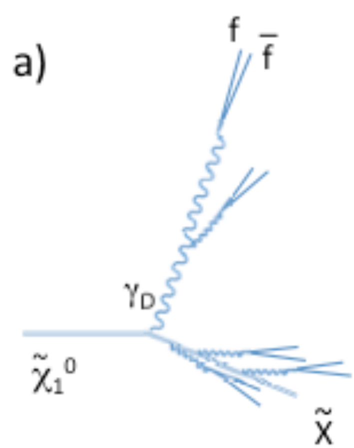
DØ, PRL 103, 081802 (2009)





- could also lead to "jets" of dark photons, either through cascades or showering



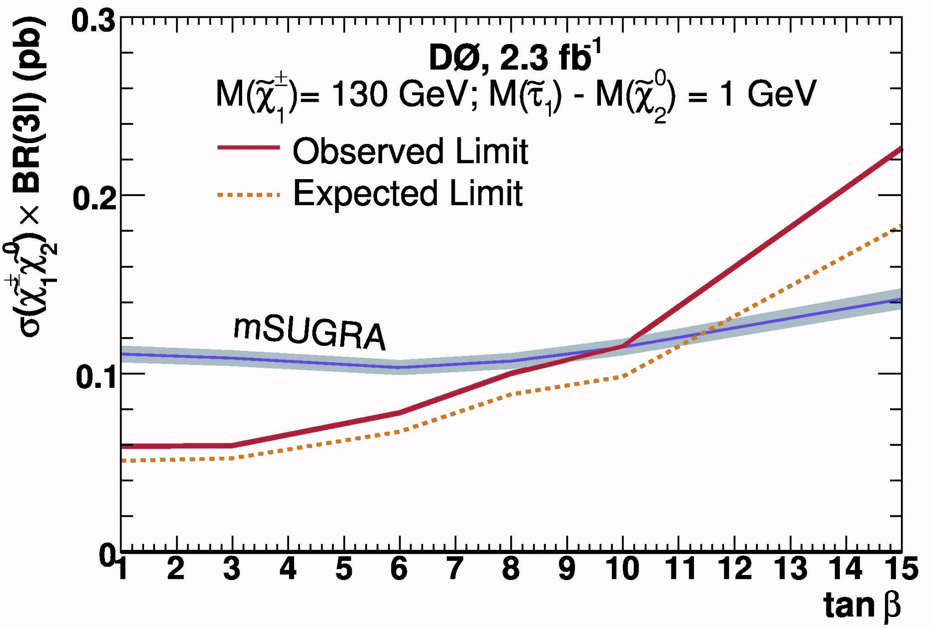


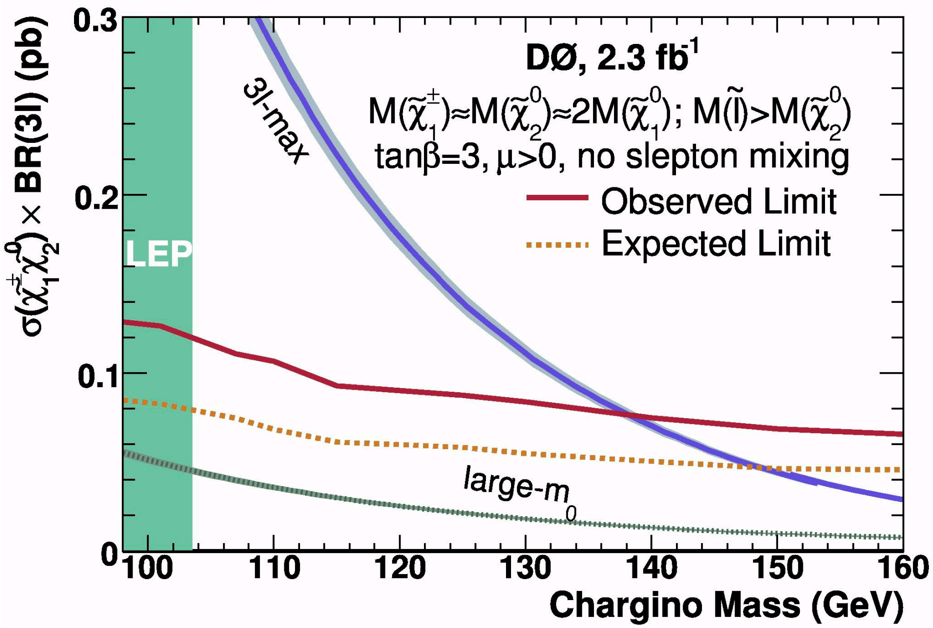
Dark radiation is modeled following M. Baumgart, C. Cheung, J. T. Ruderman, L. T. Wang and I. Yavin

0901.0283 [hep-ph]
0909.0290[hep-ph]

Limits from trilepton searches

cross-section for SUSY signals with dark photons can be as high as 200 fb even for chargino mass as high as 130 GeV…

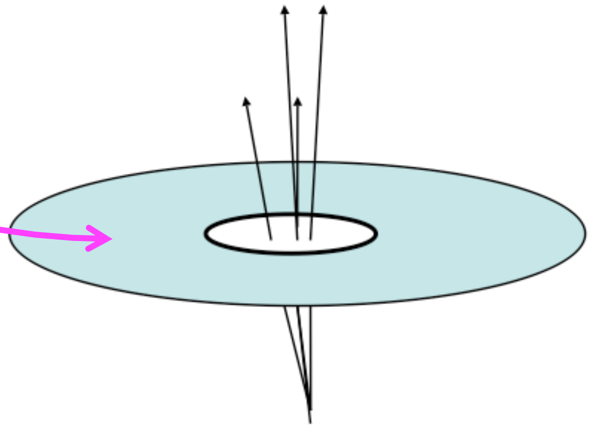




… and can be even higher for lower chargino masses (model independent limit is 105 GeV) or if sleptons are only slightly lighter then charginos

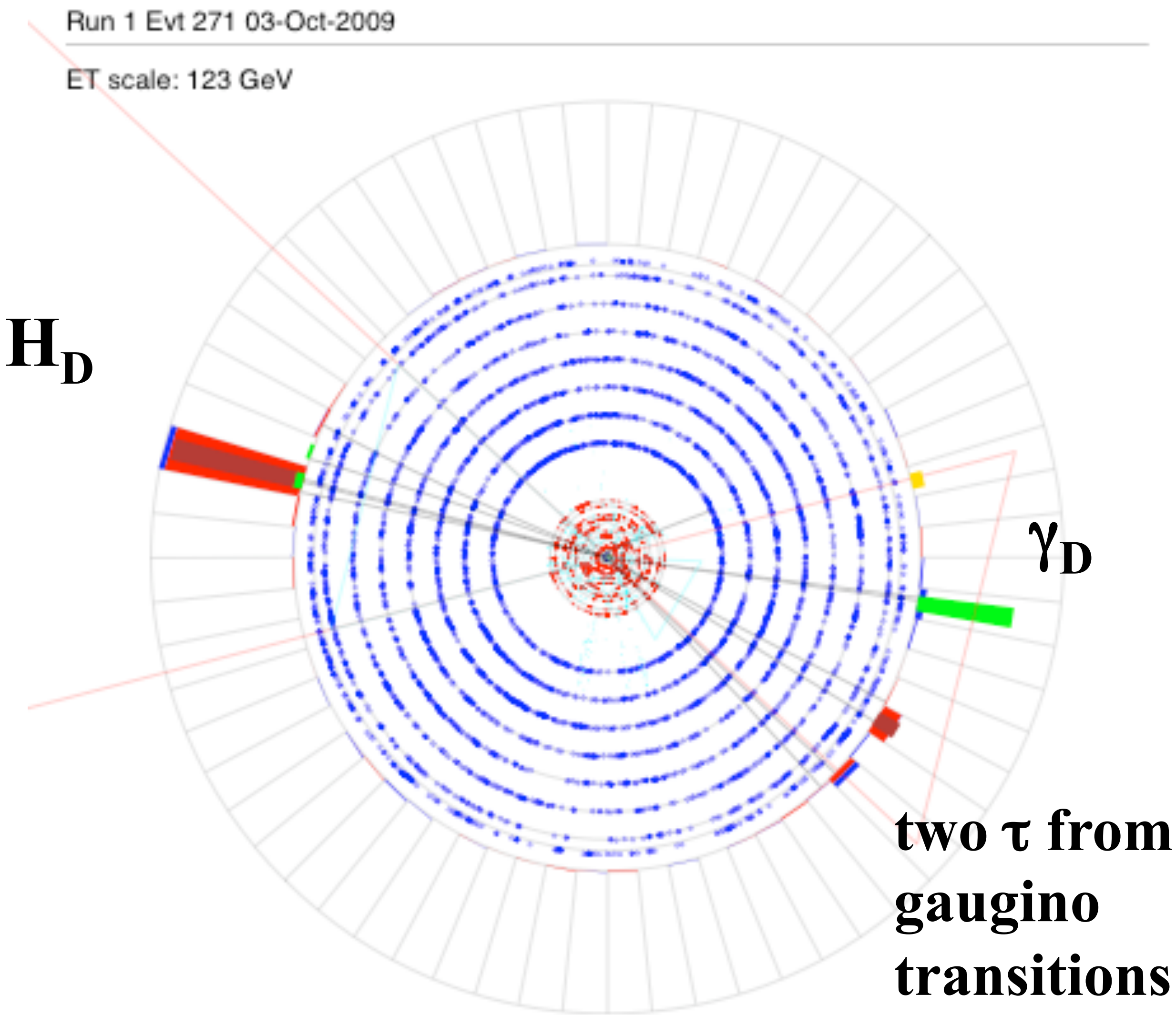
Leptonic Jet Definition

- Pair of oppositely charged tracks with $\Delta R<0.2$
  - $p_T>10$, 4 GeV
  - match to muon or cluster of EM energy
- main handle for identification: isolation
  - do not restrict activity in the core
  - require track and calorimeter isolation in the annulus



- Efficiency to reconstruct spatially close tracks is the main source of systematic uncertainty

Leptonic Jet Definition

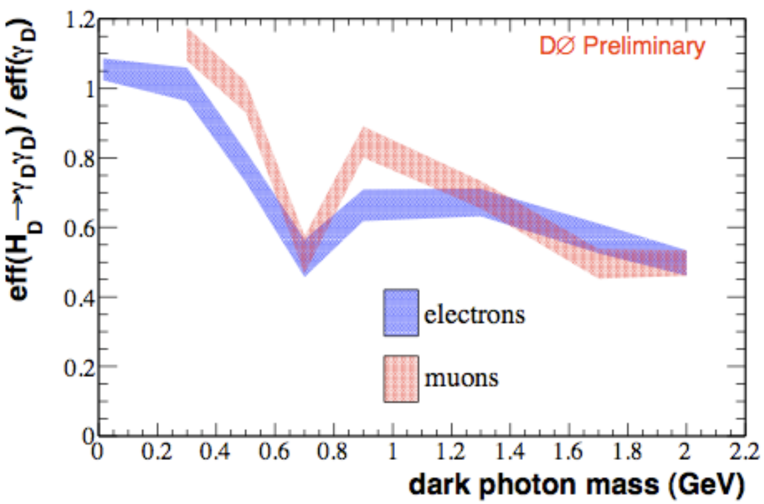


Two leptonic jets + MET

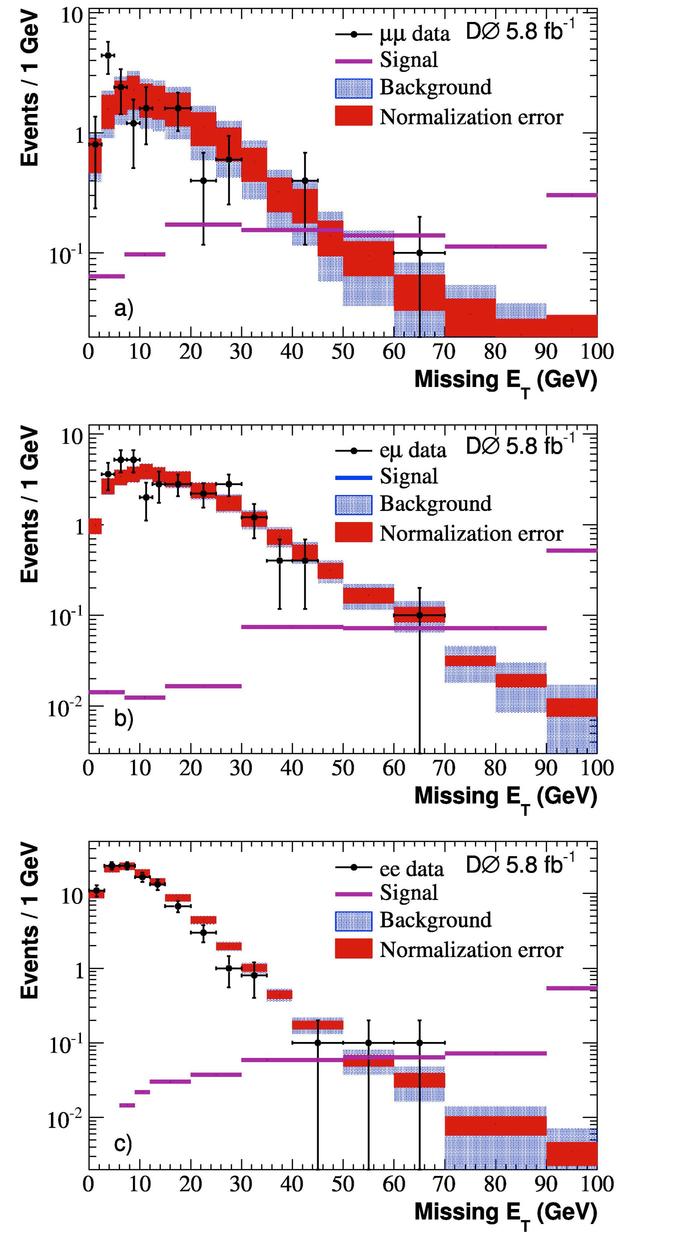
- Background is dominated by heavy flavor and direct photon production (for electron l-jets)
- Background shape is extracted from data

Channel	Data	Background	SPS8 Acc.	Reco. eff.	Total eff.
ee	7	10.2 ± 1.7	0.45	0.20	8.9 %
$e\mu$	11	17.5 ± 4.2	0.53	0.15	7.8 %
$\mu\mu$	3	8.6 ± 4.5	0.50	0.12	5.8 %

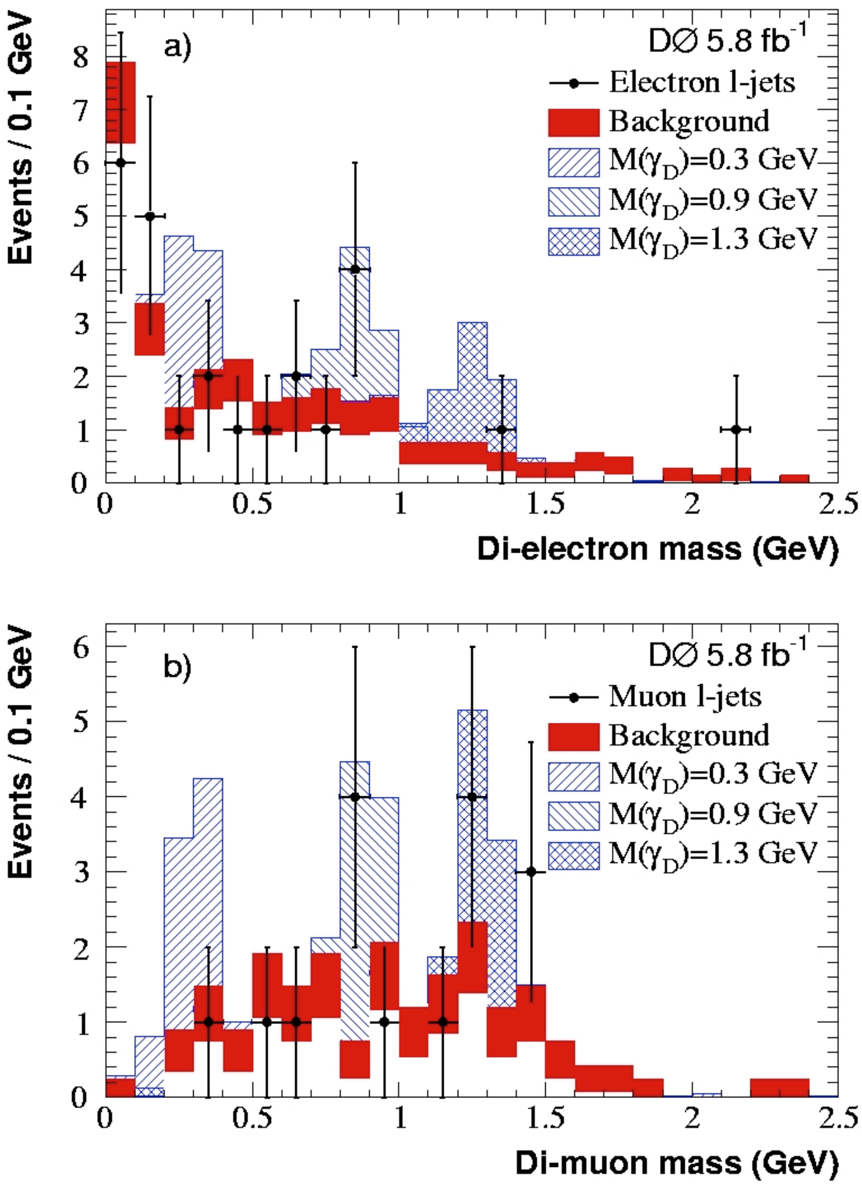
- Efficiency depends on the l-jet composition



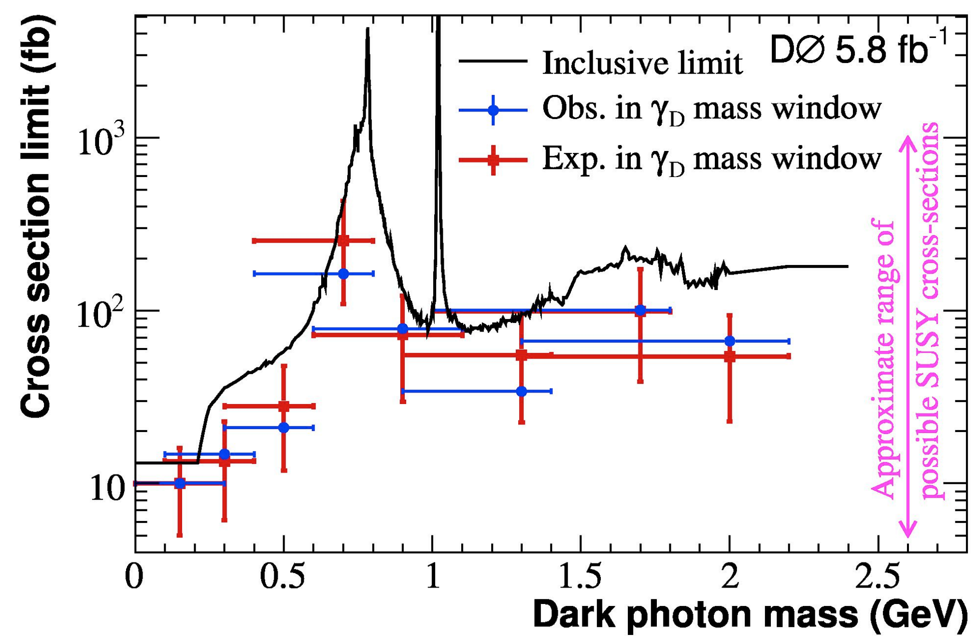
efficiency decreases by ~20% for α_D=0.3 compared to no dark radiation



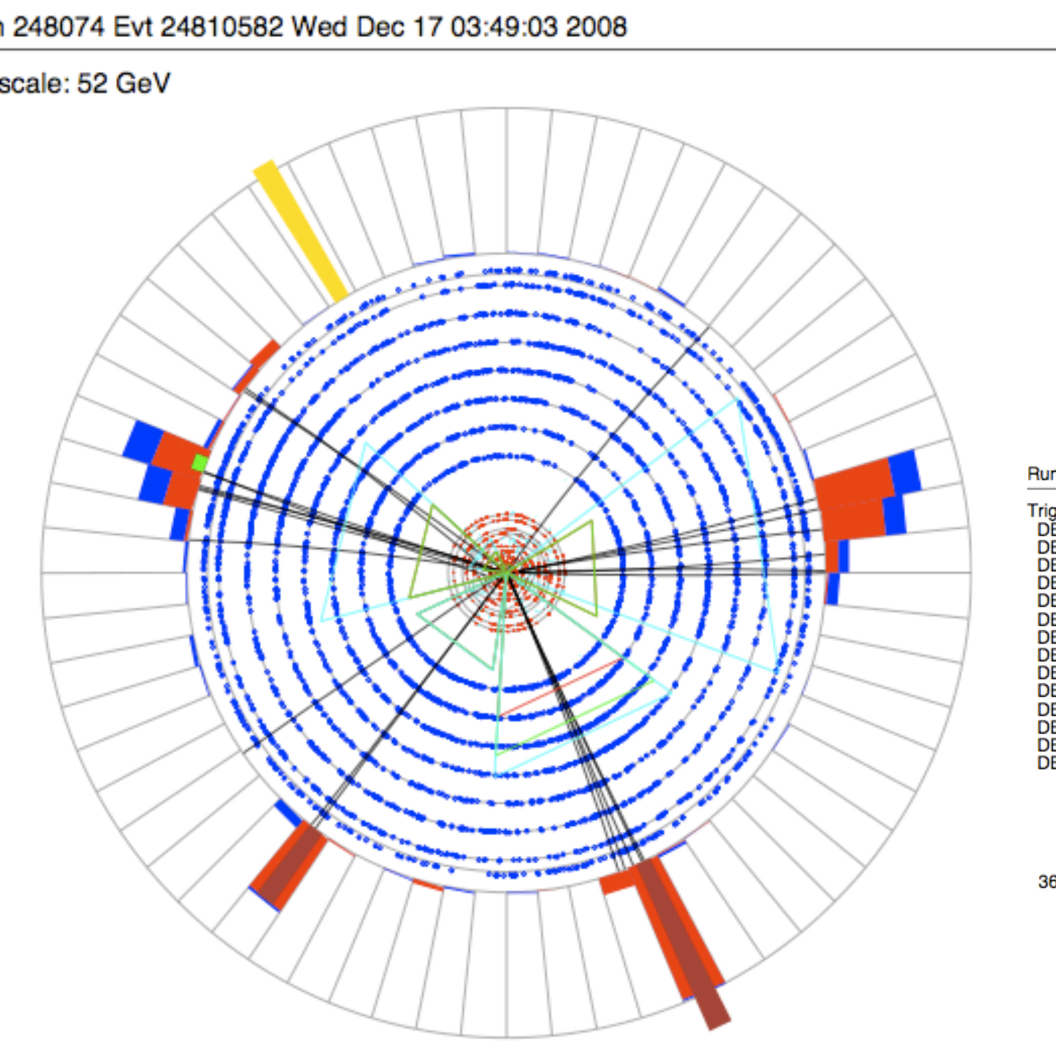
Dark photon mass in high MET Events

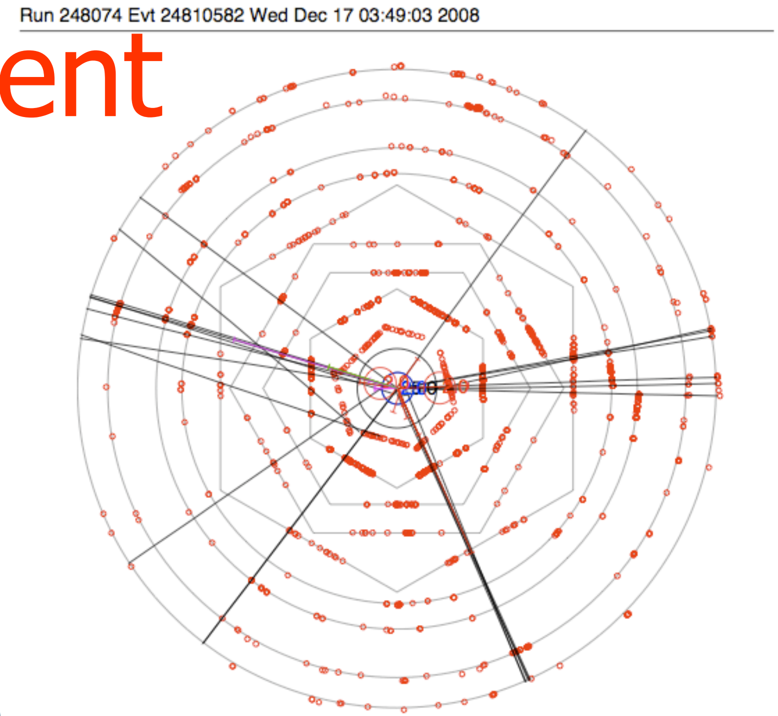


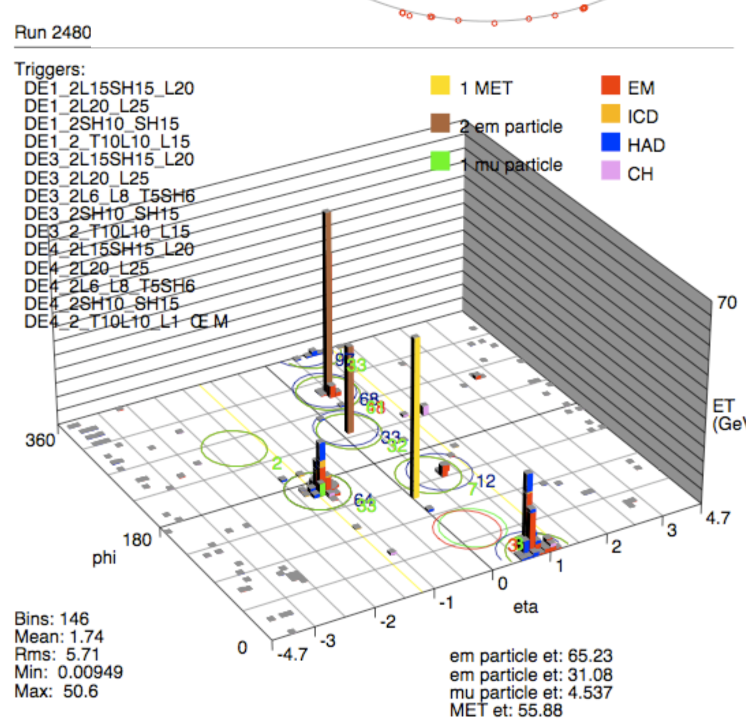
- Extra information: invariant mass of the track pair in l-jet
- allows to improve limits by a factor of ~4



Highest MET Event







Summary

- DØ continues the program of searches for Hidden Valleys
  - Long-lived resonances decaying into electrons or photons **Phys. Rev. Lett. 101, 111802 (2008)**
  - Search for Resonant Pair Production of Neutral Long-Lived Particles Decaying to bb= **Phys. Rev. Lett. 103, 071801 (2009)**
  - Non-standard Higgs decays (h->aa->μμμμ, μμττ) **Phys. Rev. Lett. 103, 061801 (2009)**
  - First search for dark photon at hadron colliders (events with dark photon, photon and missing transverse energy) **Phys. Rev. Lett. 103, 081802 (2009)**
- Two new analyses
  - Quirks **Phys. Rev. Lett. 105, 211803 (2010)**
  - First search for pairs of leptonic jets with large missing E_T **Phys. Rev. Lett. 105, 211802 (2010)**

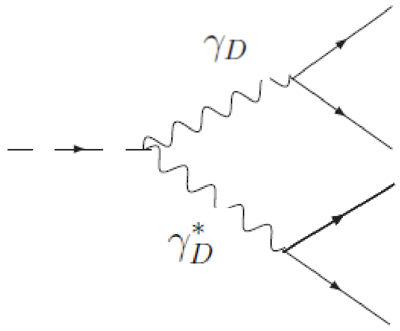
  Unfortunately – no evidence of signal. But rule out scenarios with light SUSY decaying into l-jets

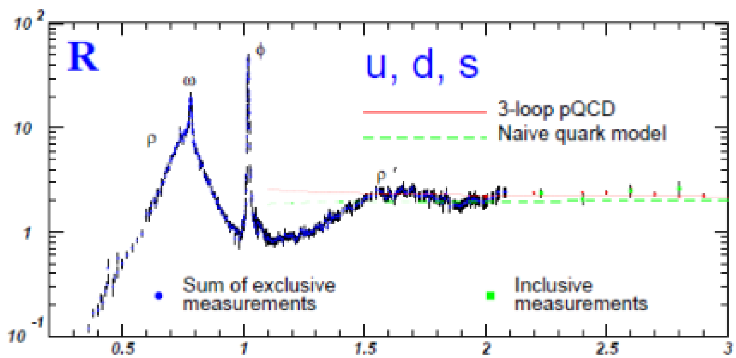
- Ball is now in the LHC's court
  - But – can be scooped by APEX / Meintz / other low energy experiments

backups

Dark Higgs Decays

- Dark Higgs should be at same scale O(GeV)
- can decay in the dark sector similarly to ours Higgs
  - if $m_h > 2m_{\gamma d}$ decay into two dark photons open
  - if $m_{\gamma d} < m_h < 2m_{\gamma d}$ decays through γ_D^* - mostly through hadronic resonances
  - if $m_h < m_{\gamma d}$ then can decay into SM fermion pairs (possibly with very long lifetime) or stays in the dark sector

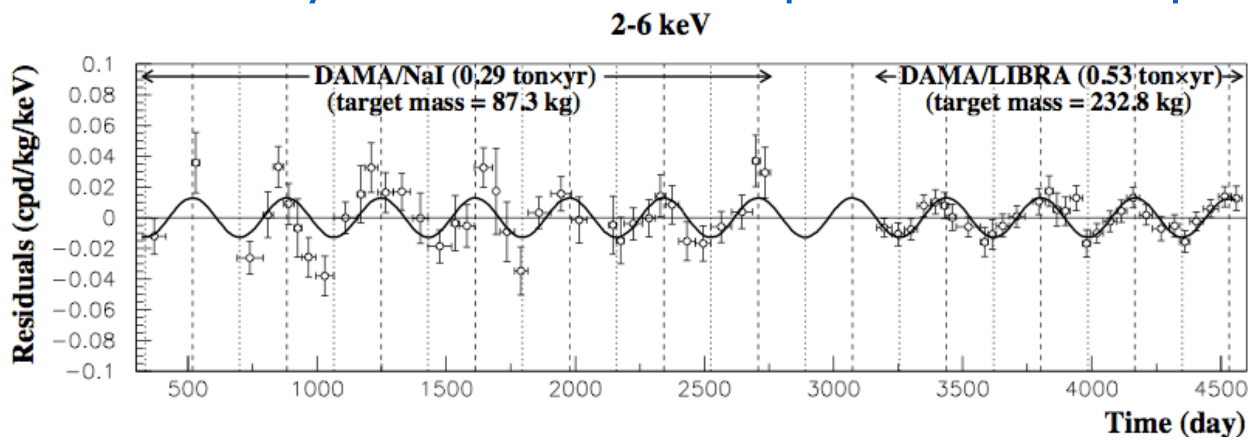




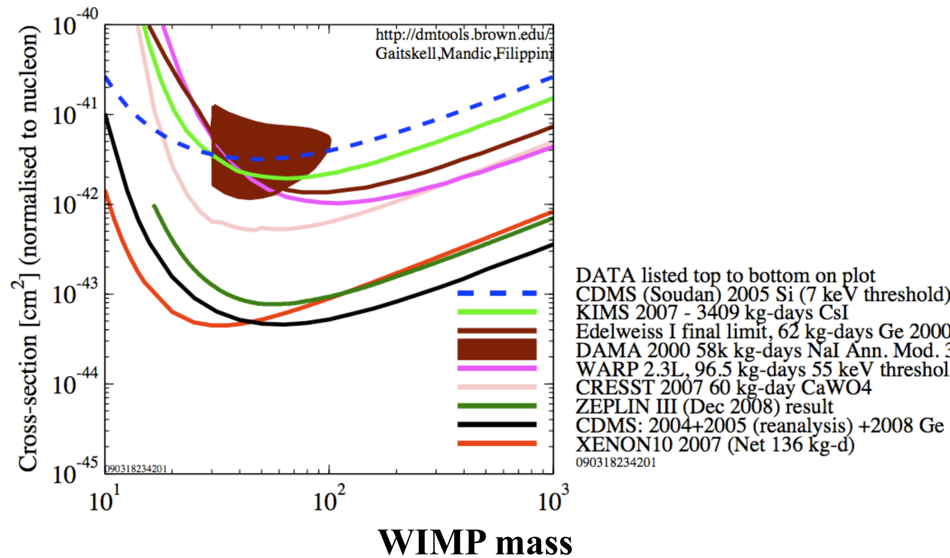
- **experimental issues with non-isolated spatially close lepton pairs, especially with hadronic dark photon decays**

DAMA/LIBRA

- DAMA/Libra sees annual modulation (changes in relative speed of Earth w.r.t. DM halo in the Milky Way)
  - the only direct detection experiment to see positive signal

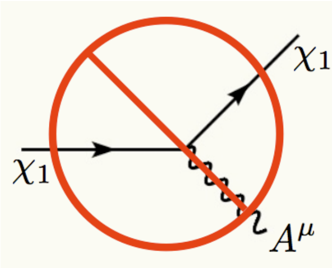


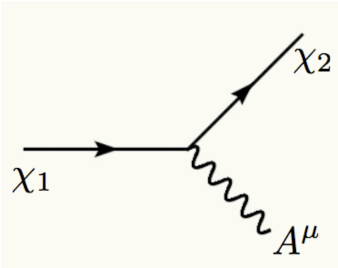
  - But it turns out it's easy to hide DM signal if we drop assumption that DM is a single particle!



Inelastic Dark Matter

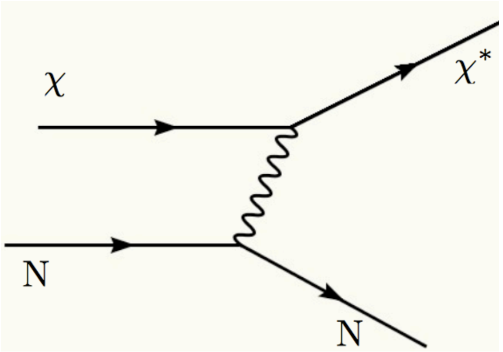
- Suppose that there is at least one excited DM state that is only heavier by O(MeV)
- It's easy to arrange that elastic scattering is suppressed, and the DM has to go into excited state after the scatter





I.e. turns out that for vector interaction if $M_{DM} >> M_{force\ carrier}$ interactions are off-diagonal

- this leads to dramatic reduction of nuclear recoil
  - hard (but possible) to probe in Xe experiments, almost impossible with CDMS



Finkbeiner and Weiner, Phys Rev D76 083519

Inelastic Dark Matter

- Turns out that this also can explain 511 keV line seen by INTEGRAL from galactic center (original motivation for Weiner and Finkbeiner): higher DM state decays into e^+e^- pair and DM, and the line is the positron annihilation signal

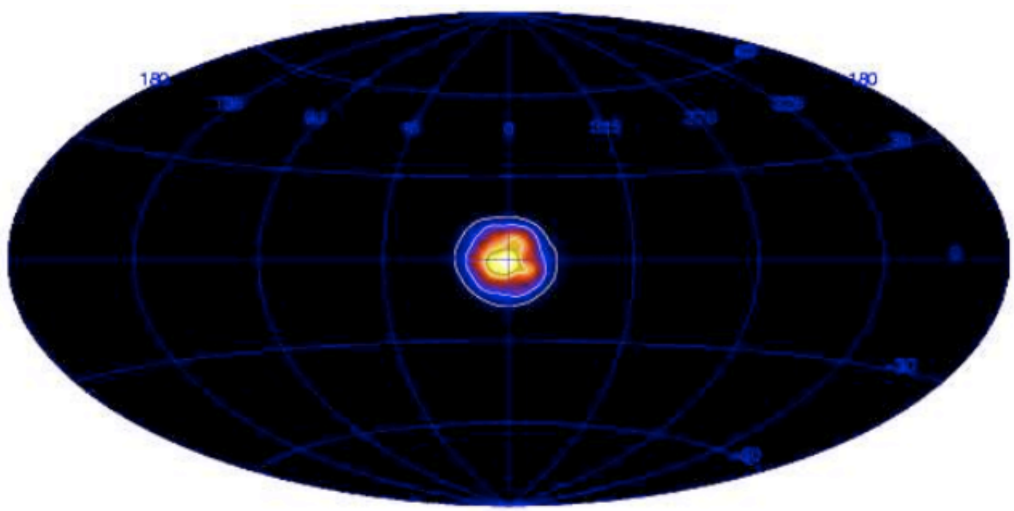


Fig. 1. A Richardson-Lucy sky map of extended emission in the summed Ps analysis intervals (the combination of the intervals 410–430, 447-465, and 490–500 keV). The contour levels indicate intensity levels of 10^{-2}, 10^{-3}, and 10^{-4} ph cm^{-2} s^{-1} sr^{-1}. Details are given in the text.

arXiv:astro-ph/0601673v1

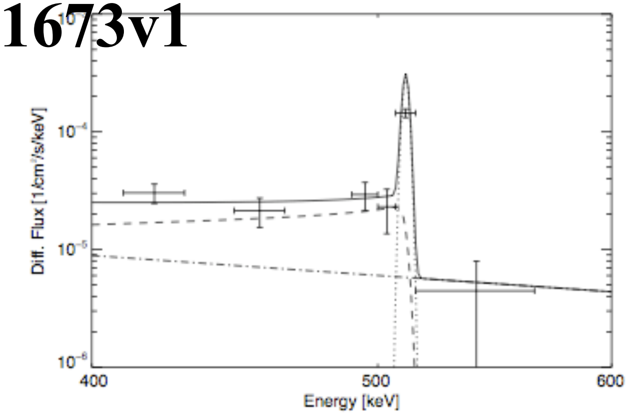


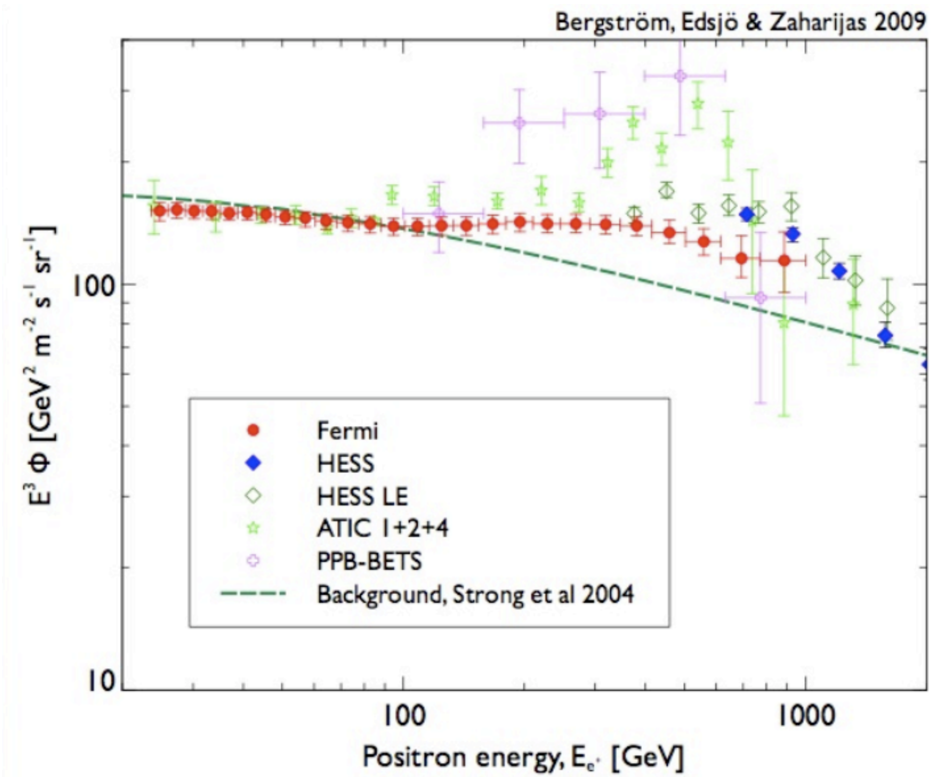
Fig. 2. A fit of the SPI result for the diffuse emission from the GC region ($|l|, |b| \leq 16°$) obtained with a spatial model consisting of an 8° FWHM Gaussian bulge and a CO disk. In the fit a diagonal response was assumed. The spectral components are: 511 keV line (dotted), Ps continuum (dashes), and power-law continuum (dash-dots). The summed models are indicated by the solid line. Details of the fitting procedure are given in the text.

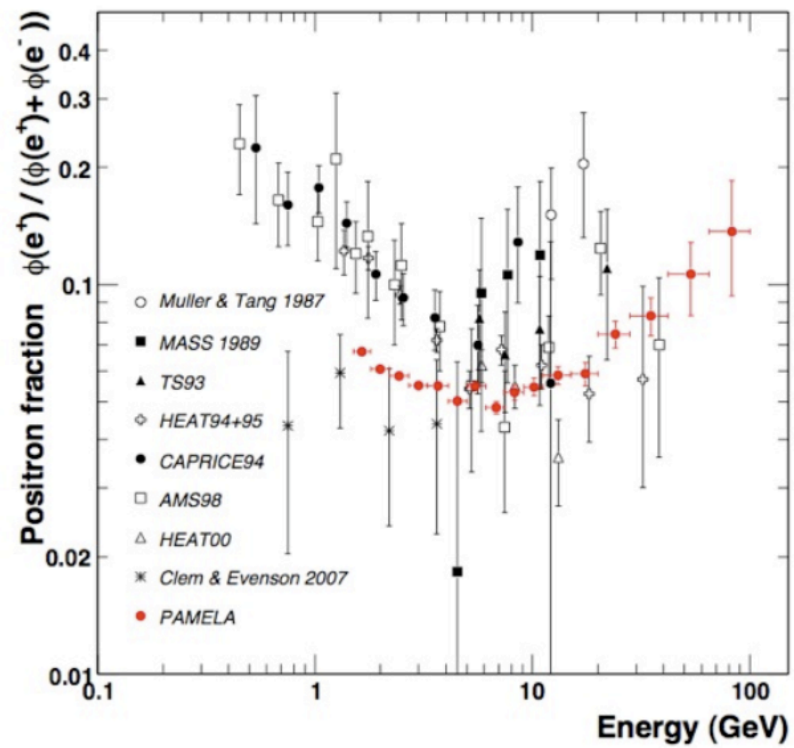
Cosmic Rays

Three key observations

- excess in positrons
- no excess in anti-protons
- large annihilation cross-section

- **WMAP data also shows what could be bremsstrahlung photons from such electrons coming from GC (no disk component)**





Dark Matter Annihilation

- since no anti-protons and huge cross-section for suggested WIMP mass O(TeV) – this can not be a garden variety WIMP annihilation
- Enter a new theory of Dark Matter by Arkani-Hamed, Finkbeiner, Slayter, and Weiner **Phys Rev D79 015014 (2009)**
  - and many other models that followed with different assumptions but same features
- New vector force carrier “dark photon” with mass O(GeV) is postulated
  - provides Sommerfeld enhancement of annihilation cross-section
  - Dark Matter annihilate into these “dark photons” – no anti-protons
  - GeV mass scale is “natural” after one makes mild assumptions about SUSY breaking
  - has to kinetically mix with regular photon with $\varepsilon \sim O(10^{-3})$ strength