Lepton-Jet Searches at D0

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Outline

- Where to find L-jets

- Tevatron and D0 experiment

- Decays to the Dark Side and Dark Photon Decays

- L-jet identification and isolation

- Data Sample

- Resonance Search

- Results

- Summary

Where to find L-jets
(Hidden Valley + SUSY)

- Introduced by Strassler & Zurek PLB 651 (2007)
- Many phenomenological scenarios possible.

- Visible sector SUSY is produced
- SUSY SMLP -> L-jet
  - At least 2 L-jets per event
  - Also get large MET
  - But need low-mass SUSY to be real
  - Dark photon (~GeV) –> decays into SM fermions through mixing with photon
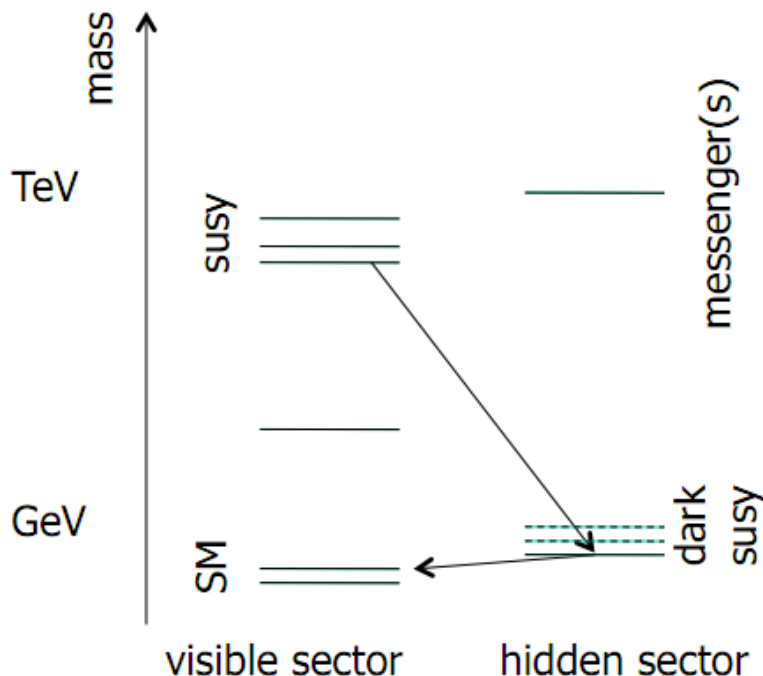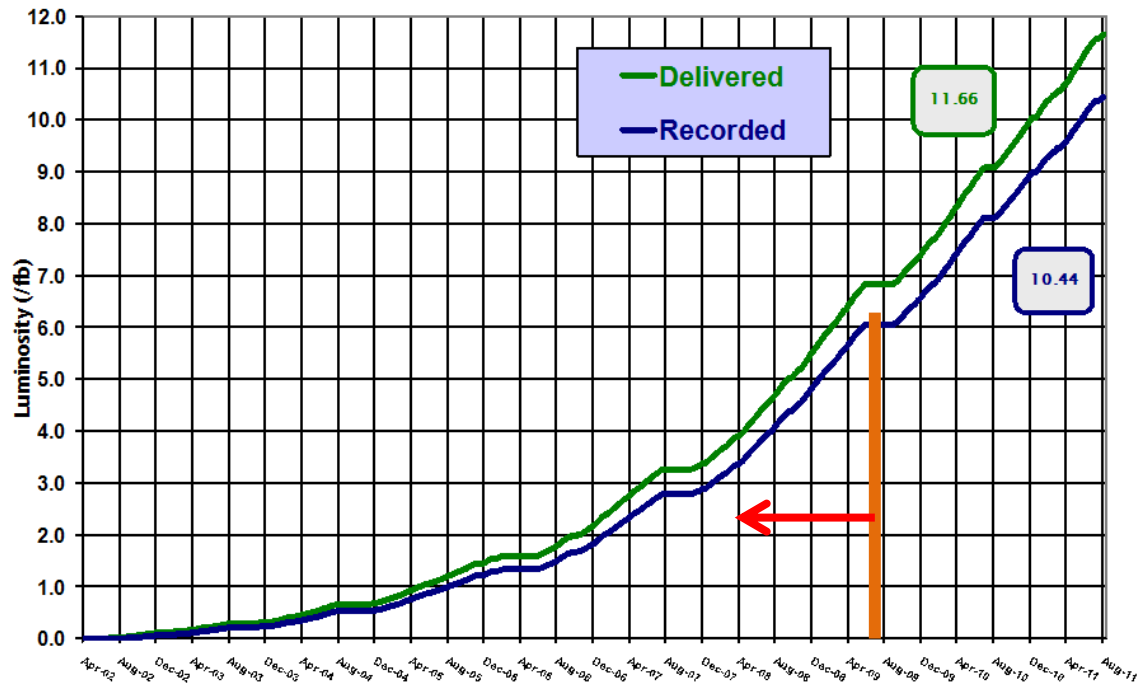
Tevatron Performance
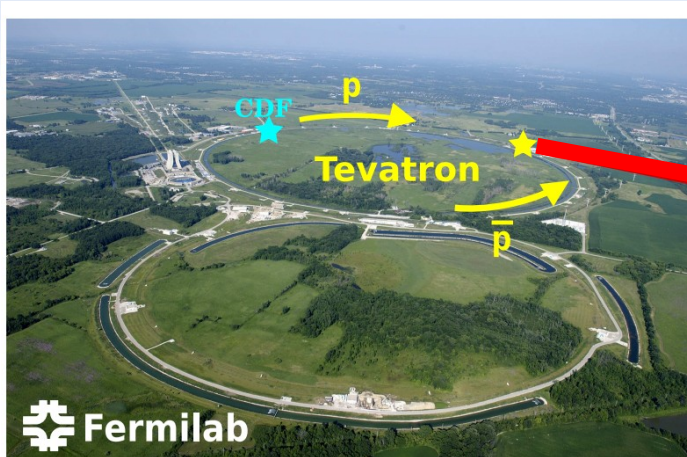
Tevatron
pp collision at 1.96TeV
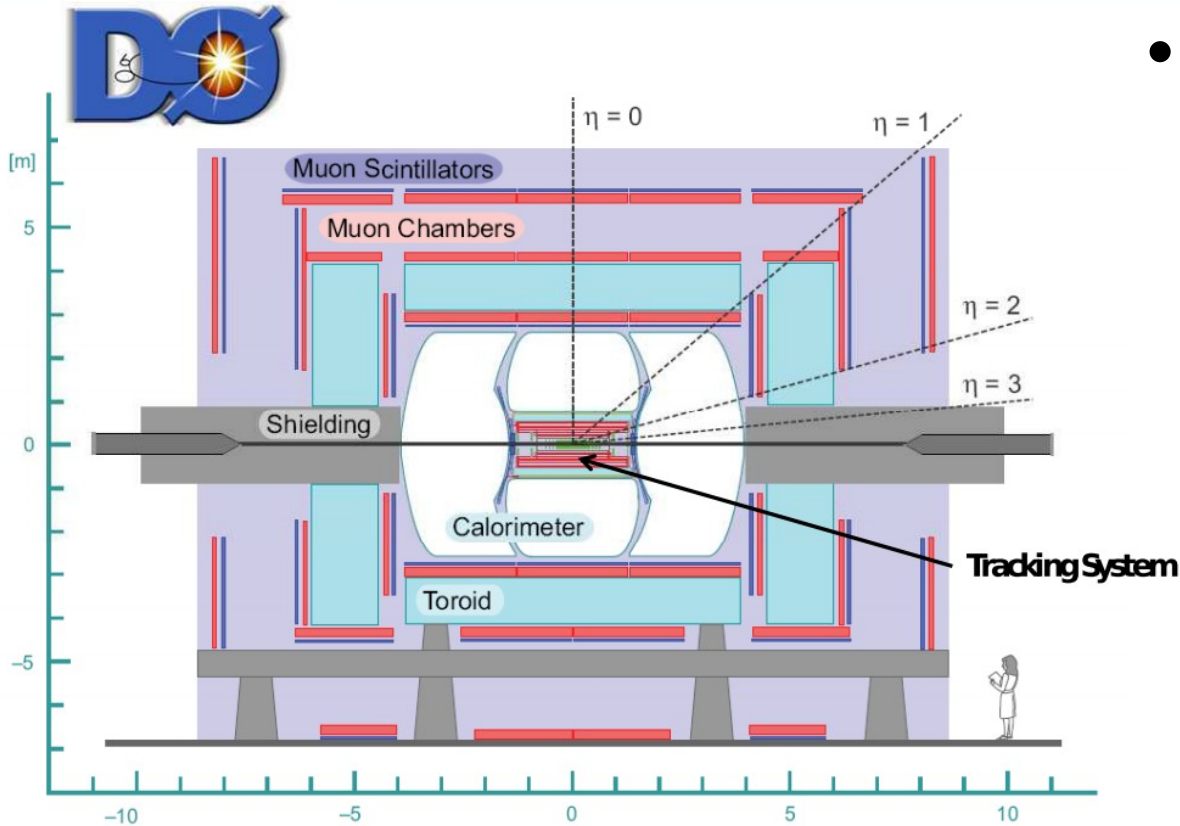Delivered ~ 11 /fb
Recorded ~10 /fb
For this analysis 5.8 /fb

Thanks to Tevatron for its incredible performance along all these years!!!

Experimental Setup

- **Central Tracking**
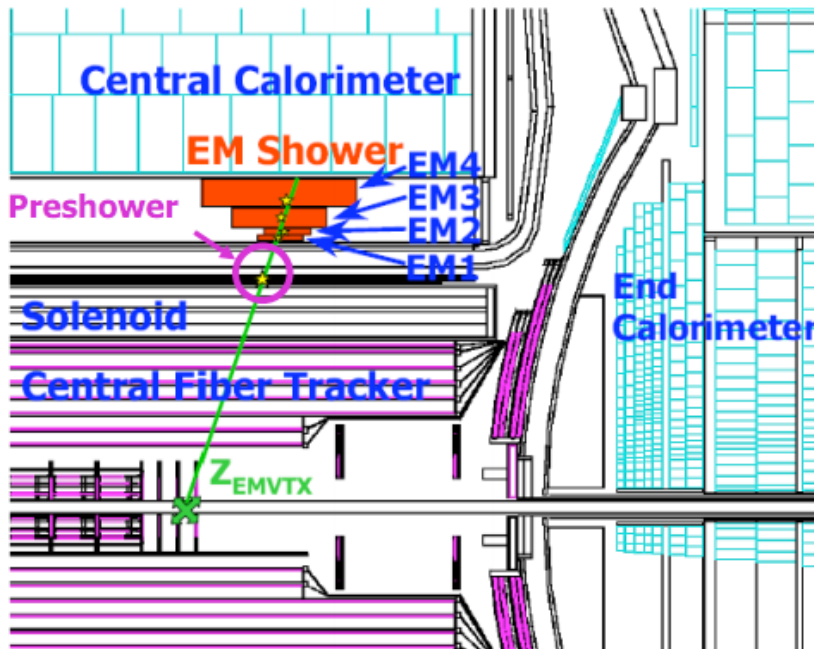 - Silicon Vertex Detector
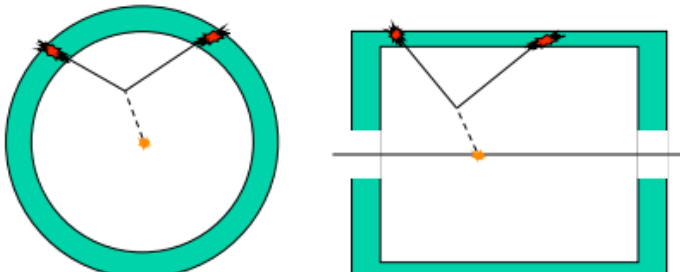 - Fiber Tracker

Calorimeter
  - $|\eta| < 3$

Muon System
 - Good Coverage $|\eta| < 2$

Pointing EM showers

- Excellent granularity of the calorimeter and preshower allows reconstruction of EM shower direction.

- Able to measure / identify production vertex

- Far away from the primary vertex – where tracking is inefficient

Decays to the dark side

- If the lightest SUSY particle (LSP) of the hidden sector (X) is lighter than the lightest SM SUSY partner (SM-LSP), the SM-LSP can decay promptly into particles of the hidden sector

- All SM LSPs decay to L-jet
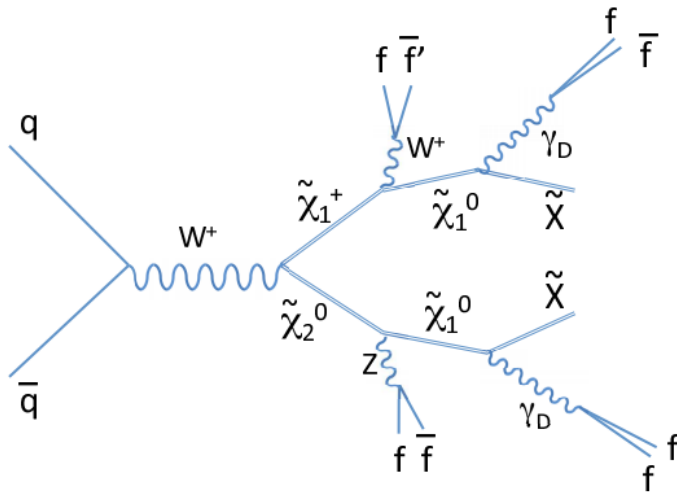
i.e. chargino+neutralino production, with decays into SMLSPs, which then decay into dark sector SUSY particles (X) and dark photons.
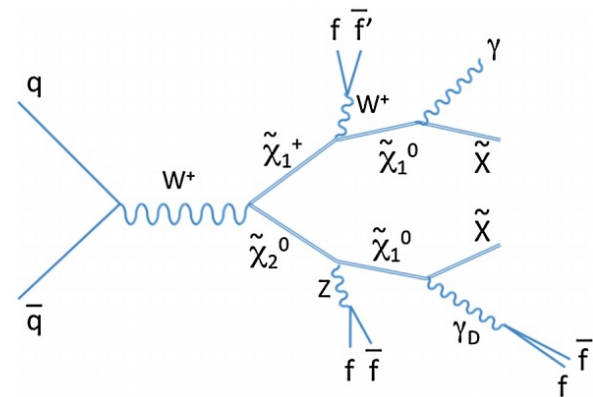
One of the diagrams giving rise to the events with a photon, dark photon (γD), and large missing energy due to escaping dark neutralinos (X)
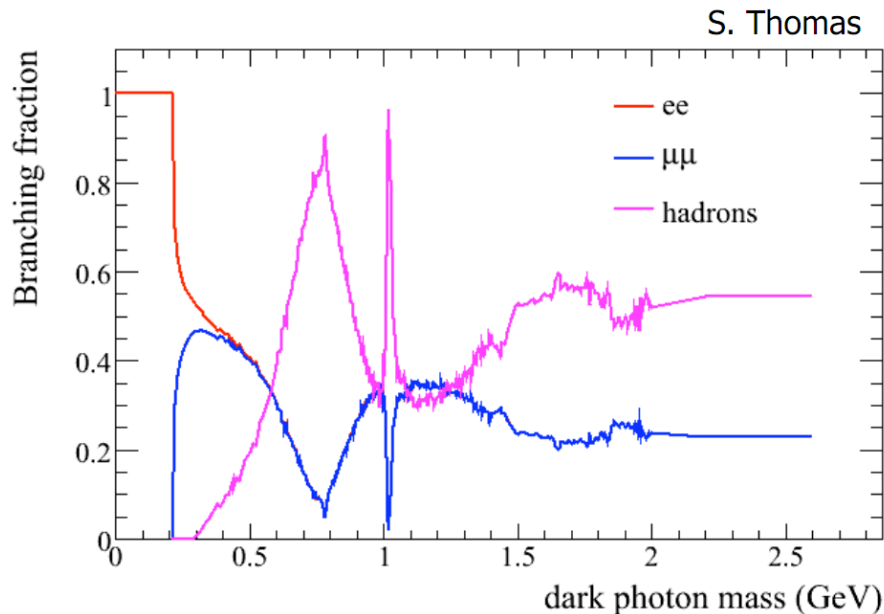**PRL 103, 081802 (2009)**

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Dark Photon Decays

- Dark photons decay through mixing with photons into SM fermions with branching fractions that can be calculated from the measurements of

$$R = \frac{\sigma(e^+ e^- \rightarrow hadrons)}{\sigma(e^+ e^- \rightarrow \mu^+ \mu^-)}$$

and strongly depend on the dark photon mass.

- We study a range of dark photon masses from 0.15 to 2.0 GeV.
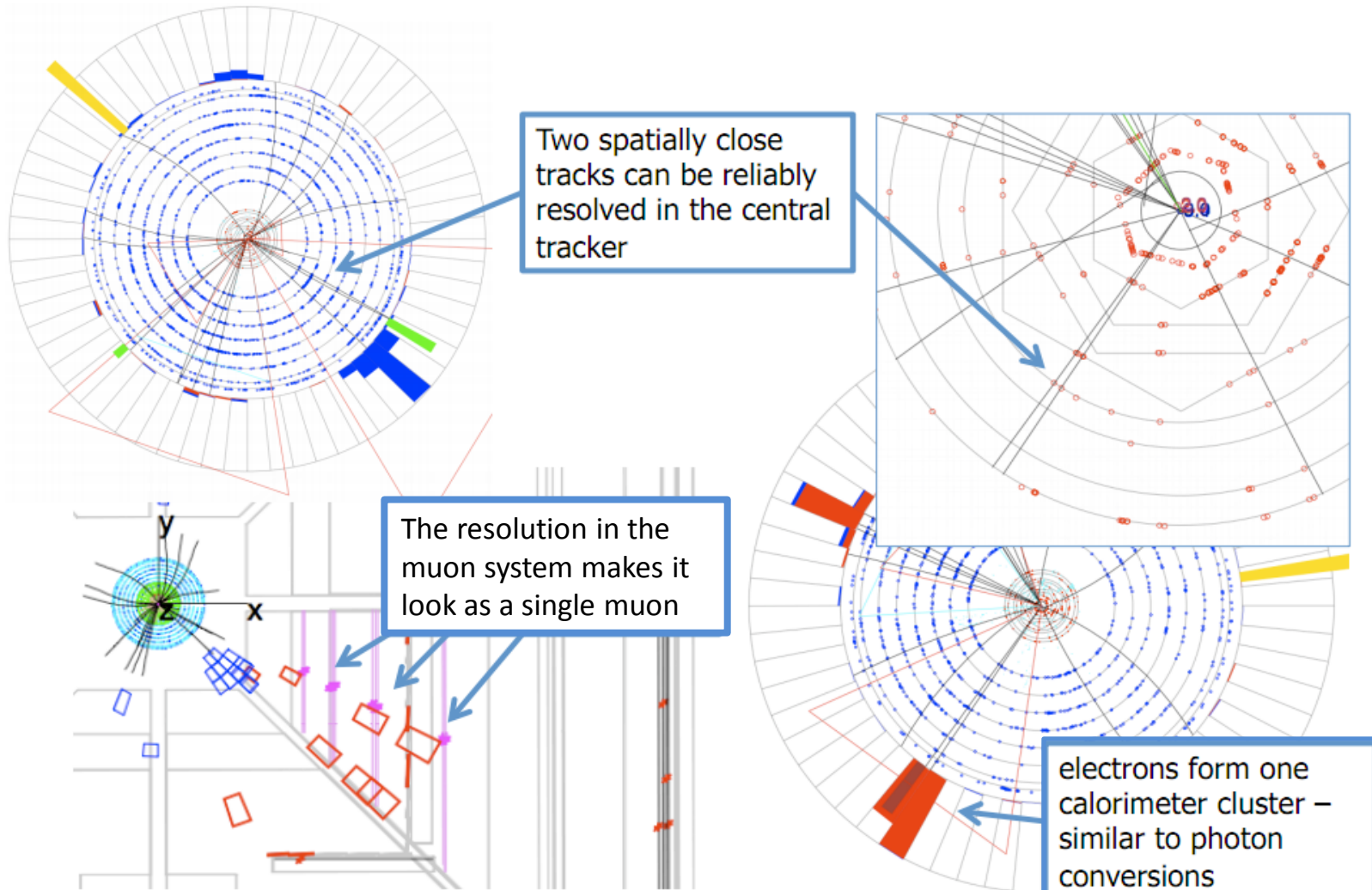
S. Thomas

Branching ratio of the dark photon into electrons (red line), muons (blue line) and hadrons (magenta line)

Experimental signature: two very close leptons

Dark Photon Reconstruction

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

The resolution in the muon system makes it look as a single muon

electrons form one calorimeter cluster – similar to photon conversions
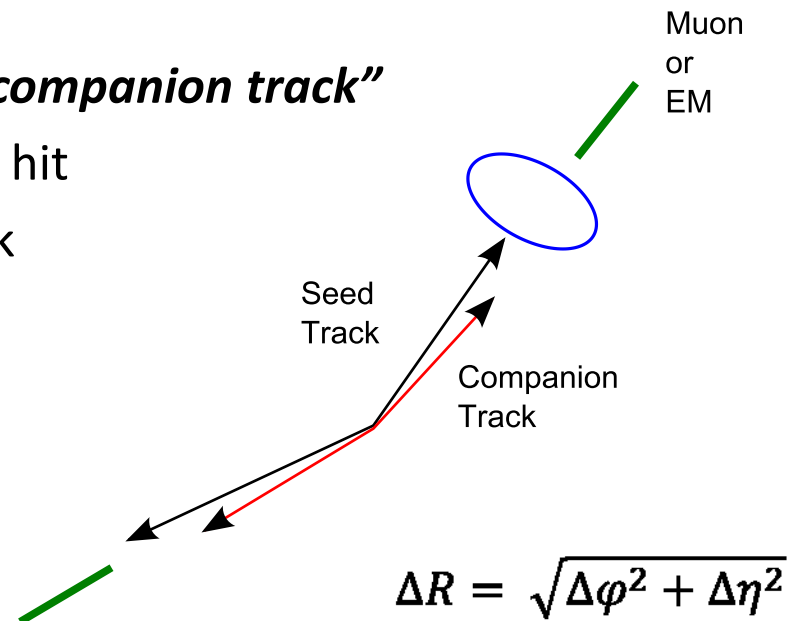
L-jet Identification

"Electron L-jet"
EM cluster, pt > 15 GeV
Matched to pt> 10 GeV track

"Muon L-jet"
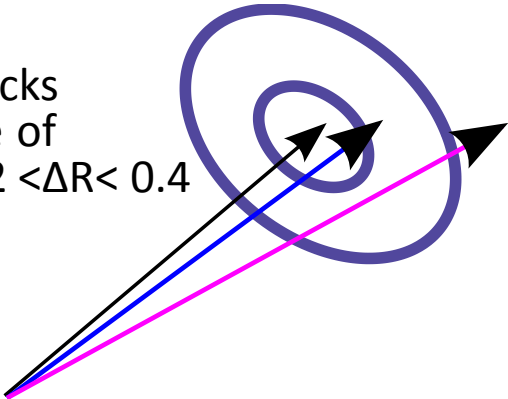3 hit tracks in muon system
Matched to pt> 10 GeV track

- The two tracks must be ΔR>0.8 apart
- ***Each of the two tracks must have a "companion track"***
  - pt > 4GeV, and at least one silicon hit
  - ΔR<0.2, |dz|<1cm from seed track
  - Opposite charge from seed track

Muon
or
EM

Seed
Track

Companion
Track

$$\Delta R = \sqrt{\Delta \varphi^2 + \Delta \eta^2}$$

L-jet Isolation

- Need isolation to separate from multi-jet background
- But keep isolation loose enough not to kill possible signals!

- The ''track isolation'' is defined by a scalar sum over pT of tracks with pT > 0.5 GeV, z < 1 cm from the seed track at its distance of closest approach to the beam line, and within an annulus 0.2 <ΔR< 0.4 relative to the seed track

- Muon isolation in calorimeter I_μ < .066*pT+2.35 GeV, 0.1<ΔR<0.4 of either muon or companion track
  - Remove 94% of Background

- Electron isolation in calorimeter I_{EM}< .085*pT-.53 GeV 0.2<ΔR<0.4 in EM layers and ΔR<0.4 in hadronic layers (corrected for underlying event and pileup at high luminosity)
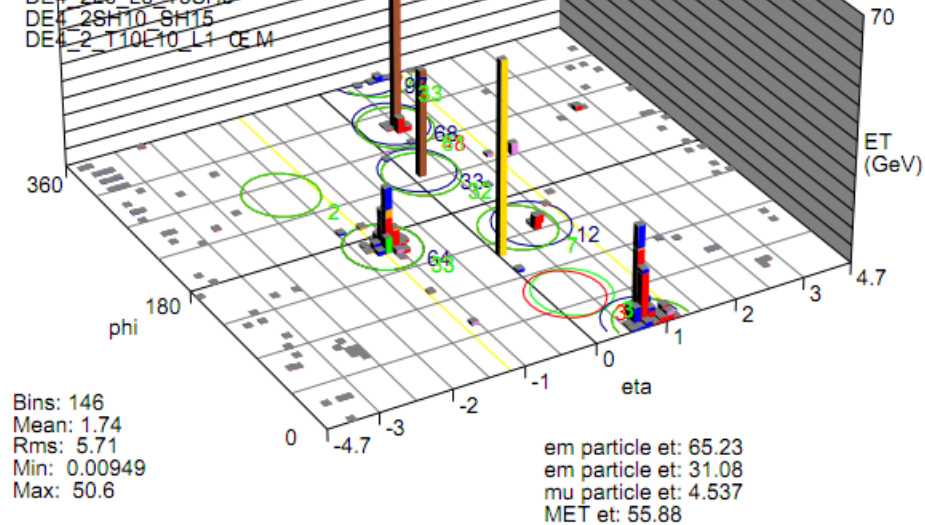 - Remove 90% of Background

Isolation cuts are functions of L-jet pT so not to bias MET measurement

Two candidates electron l-jets, two jets, large MET
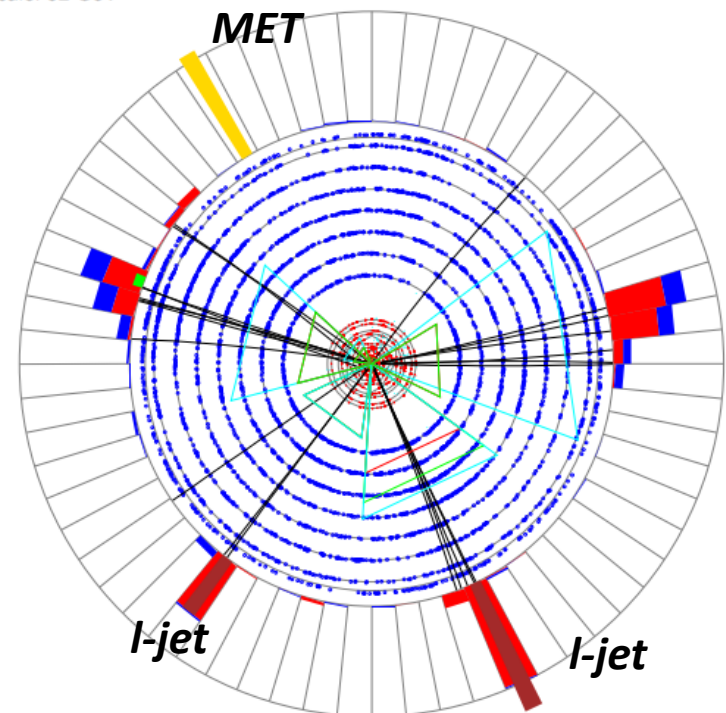
Two L-jet Data Sample

- To model the background we use the MET distribution in data without isolation requirements.

- No excess observed at high MET

- Signal MC has large MET.

- For the MC-Signal the highest bin contains all events with MET > 90 GeV.

- Systematics on the background shape are determined from changes in the MET shape when just one or the other L-jet is non-isolated.
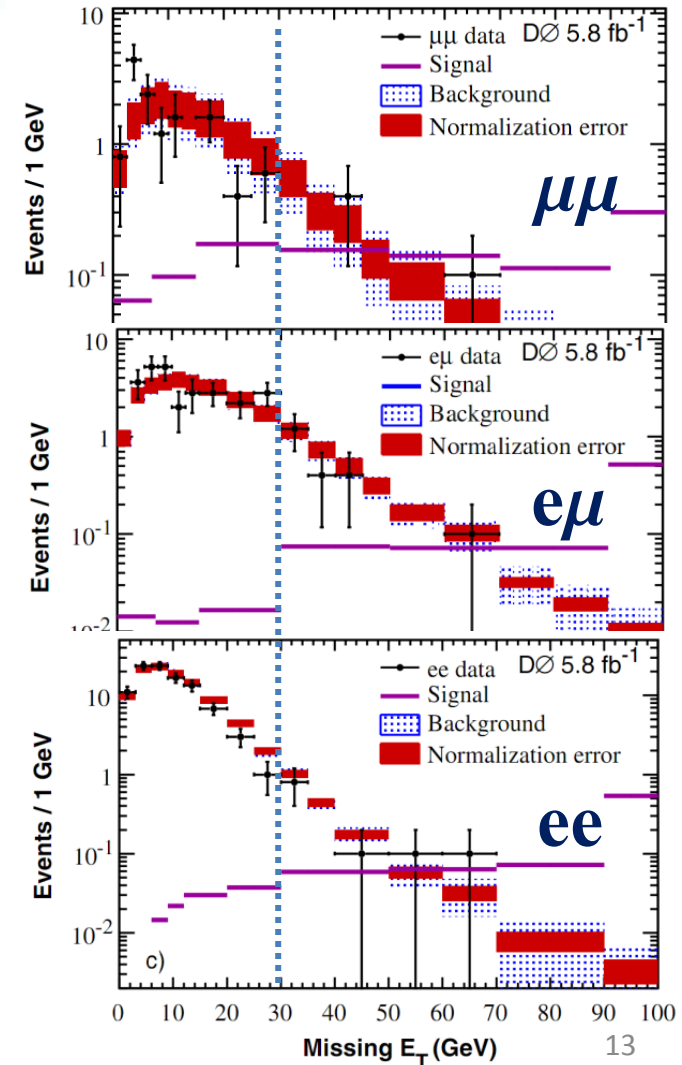
Resonance Search

- For events with 2 isolated L- jets and MET>30 GeV, look for resonance in track/companion track mass

- Background estimated from isolated di-L-jet sample with MET<20 GeV
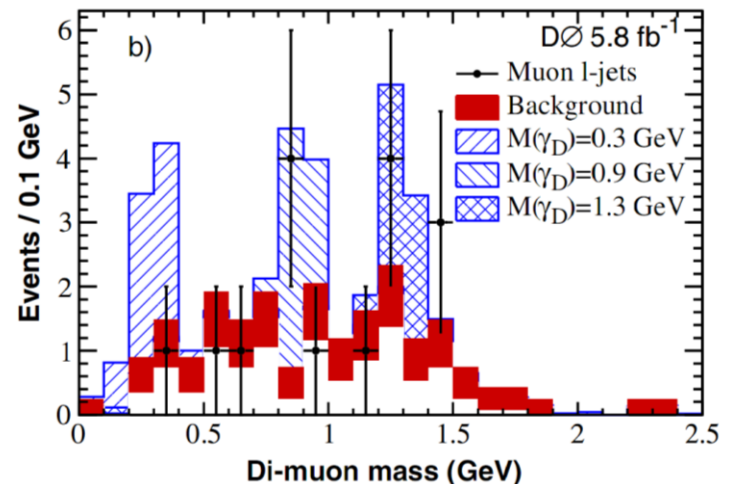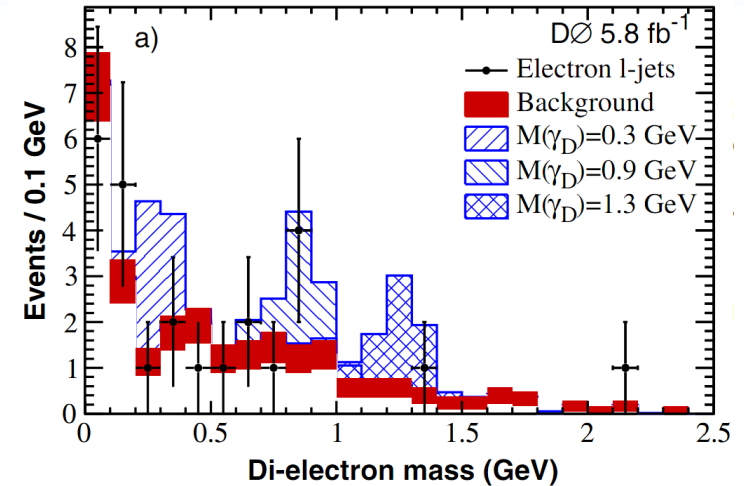
$M(\gamma_D)$(GeV)	$\mathcal{B}_e, \mathcal{B}_\mu$	$\Delta M(\ell\text{-jet})$(GeV)	Eff. $ee, \mu\mu$(%)
0.15	1.00, 0.00	0.0–0.3	81, −
0.3	0.53, 0.47	0.1–0.4	82, 88
0.5	0.40, 0.40	0.3–0.6	81, 89
0.7	0.15, 0.15	0.4–0.8	85, 89
0.9	0.27, 0.27	0.6–1.1	82, 91
1.3	0.31, 0.31	0.9–1.4	72, 79
1.7	0.22, 0.22	1.0–1.8	73, 76
2.0	0.24, 0.24	1.3–2.2	73, 83

Results

- Limits with CLs method
- Systematics
  - Signal efficiency, 20%
  - Background normalization, 20-50%
  - Luminosity, 6.1%
- Limits are weaker when the dark photon branching ratio to hadrons is larger, particularly near the ρ and φ resonances.
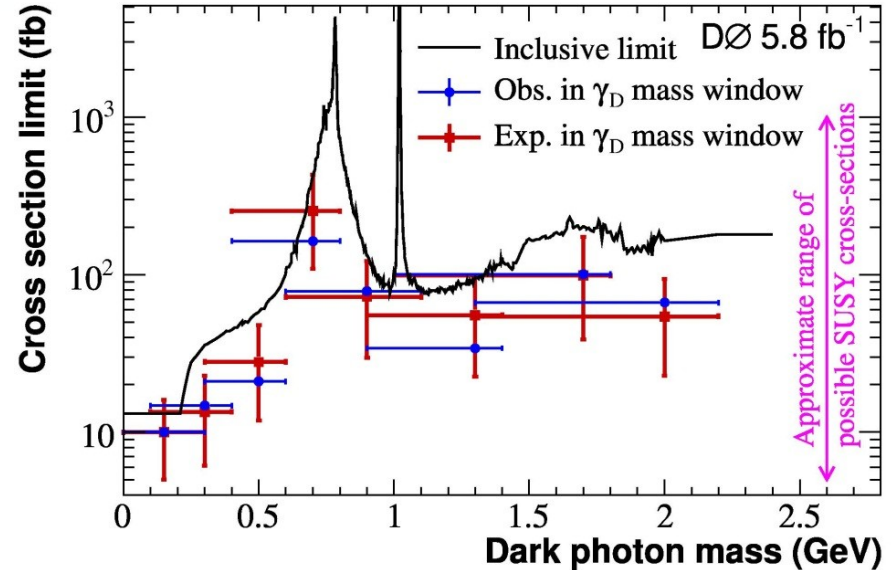
Chan.	$\mathcal{R}_f$	N_{obs}	N_{pred}	$\mathcal{A}(\%)$	$\epsilon(\%)$	$\mathcal{B}$	$\sigma_{95\%} \times \mathcal{B}$, (fb) Observed	$\sigma_{95\%} \times \mathcal{B}$, (fb) Predicted
$\mu\mu$	0.33	3	8.6 ± 4.5	50	12	$\mathcal{B}_\mu^2$	20	35^{+26}_{-21}
$e\mu$	0.37	11	17.5 ± 4.2	53	15	$2\mathcal{B}_e\mathcal{B}_\mu$	19	30^{+19}_{-15}
ee	0.04	7	10.2 ± 1.7	45	20	$\mathcal{B}_e^2$	13	19^{+11}_{-9}

Summary

- We have performed a search for events with two tightly collimated jets consisting mainly of charged leptons and large MET in 5.8 /fb of integrated luminosity.

- The invariant mass of the L-jets, formed by a seed track and a companion track was also examined for a resonant signal.

- No evidence was observed for such signals, and upper limits were set, as a function of M(γ_D), on the production cross section for SUSY particles decaying to two jets and large MET.

- **This work has been published, PRL 105, 211802 (2010)**