Lepton-jet searches at hadron colliders

Andy Haas
SLAC

Heavy Photon Search group meeting
August 2, 2011 – *debt ceiling day!*

SLAC NATIONAL ACCELERATOR LABORATORY

Dark photon + Super-symmetry

- Nature doesn't have to be just SU(3)xSU(2)xU(1)

- String theory naturally has additional gauge groups, weakly-coupled to the SM

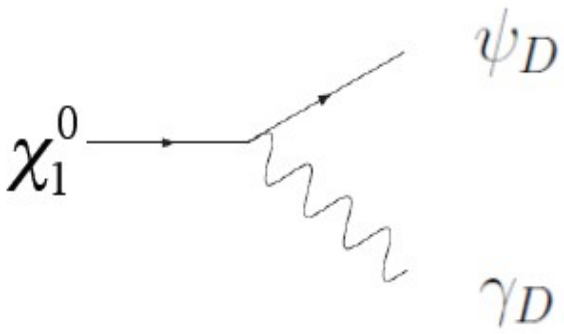
New, kinetically coupled U(1)

$$\mathcal{L}_{\text{gauge mix}} = -\frac{1}{2}\epsilon_1 b_{\mu\nu} A^{\mu\nu} - \frac{1}{2}\epsilon_2 b_{\mu\nu} Z^{\mu\nu}$$

- Old dark matter WIMP now decays into hidden sector ! (and creates a dark photon)

Lightest SUSY particle in hidden sector

"darkino" = MET

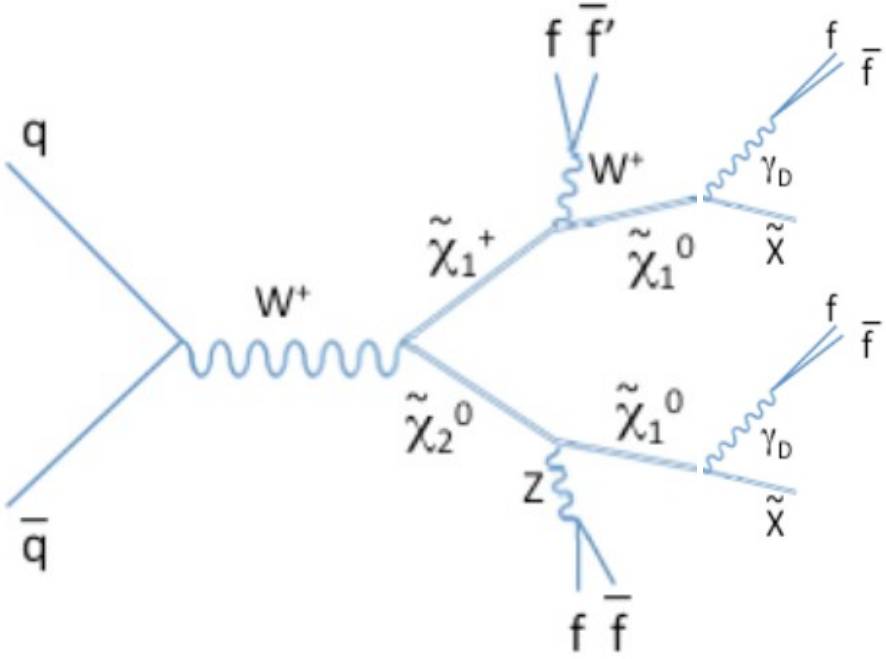


"dark photon"
Force carrier in hidden sector

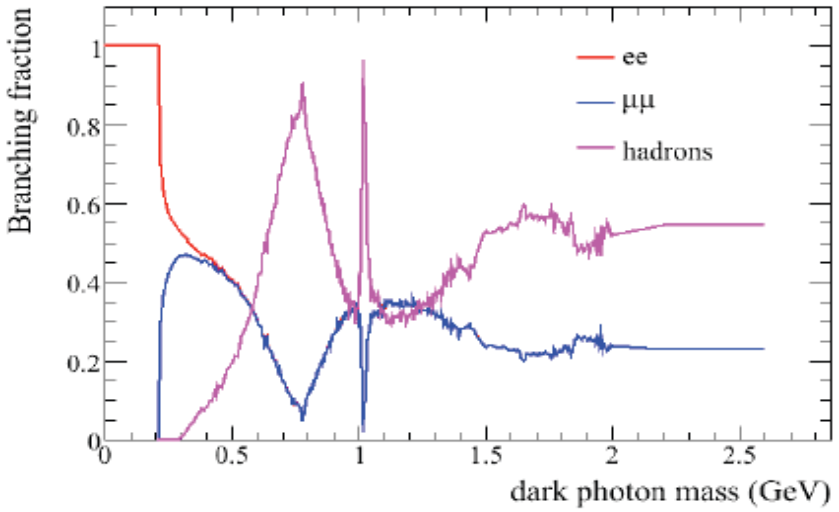
Arkani-Hamed, Finkbeiner, Slatyer, Weiner Phys.Rev.D79:015014,2009.

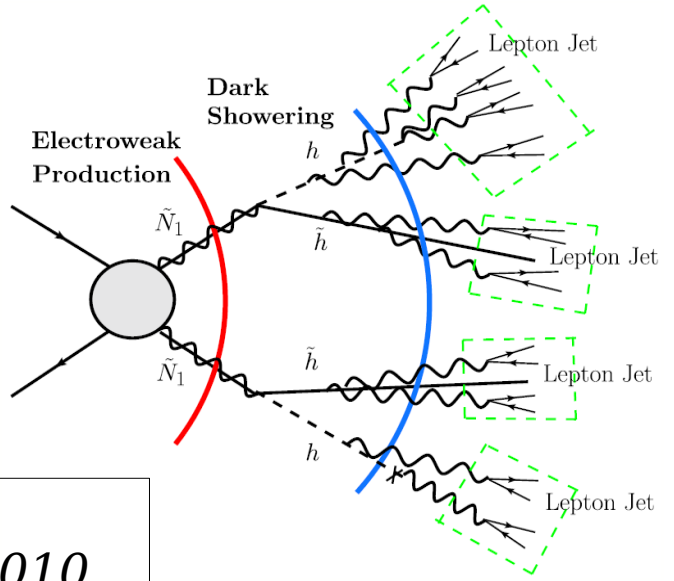
SUSY Lepton Jets

- Changes the signature of SUSY dark matter
  - Less MET
  - Two dark photons



- Dark photons are boosted
  - Create “lepton jets”: pair of collinear electrons or muons





Cheung et al. JHEP 1004:116,2010.

SUSY Lepton Jets at D0

MET distribution for 2 isolated l-jets
(not μ corrected – calorimeter only)

Background determined from *non-isolated data scaled to data for MET<15 GeV*

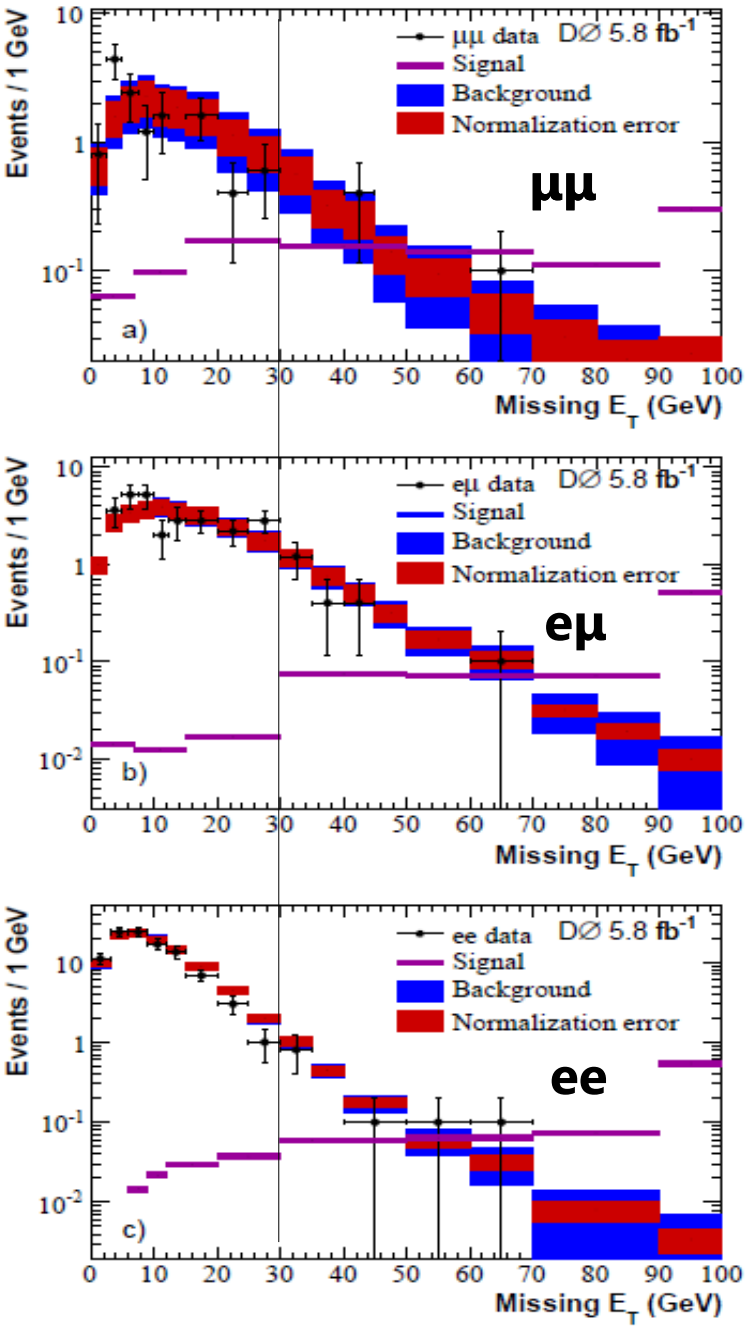
- Normalization uncertainty from statistics

Systematics on background shape

- change in the MET shape when just one l-jet is non-isolated

Require MET > 30 GeV

No excess observed at high MET



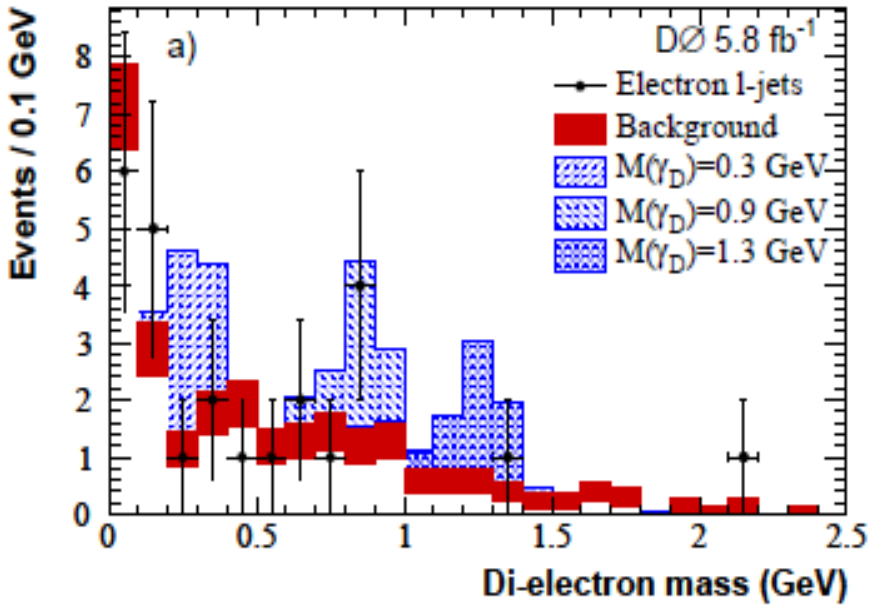
SUSY Lepton Jets at D0

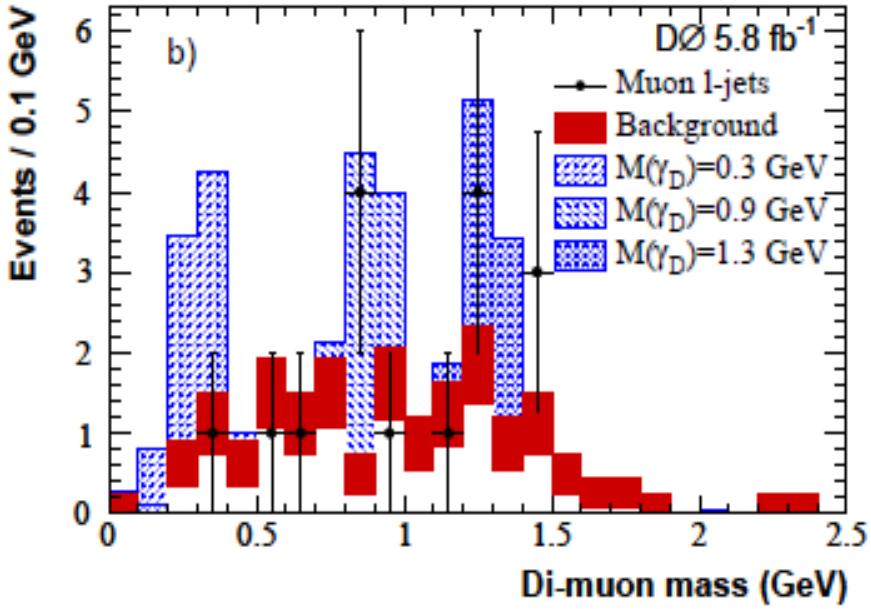
For events with 2 isolated l-jets and MET>30 GeV, look for resonance in track / companion track mass

Background estimated from isolated 2 l-jet sample with MET<20 GeV

No significant peak observed

$M(\gamma_D)$ (GeV)	$\mathcal{B}_e/\mathcal{B}_\mu$	$\Delta M(l\text{-jet})$(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



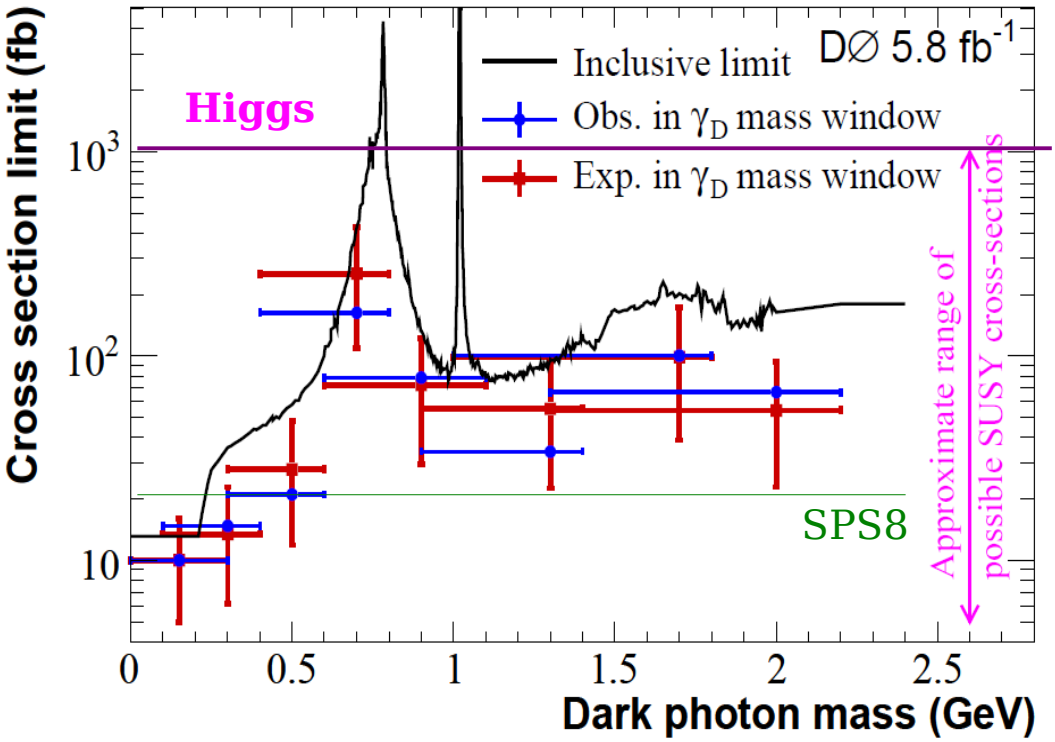


SUSY Lepton Jets at D0

Limits with CL_s method

Rules out "SPS8" for decays to jets for low γ_D masses

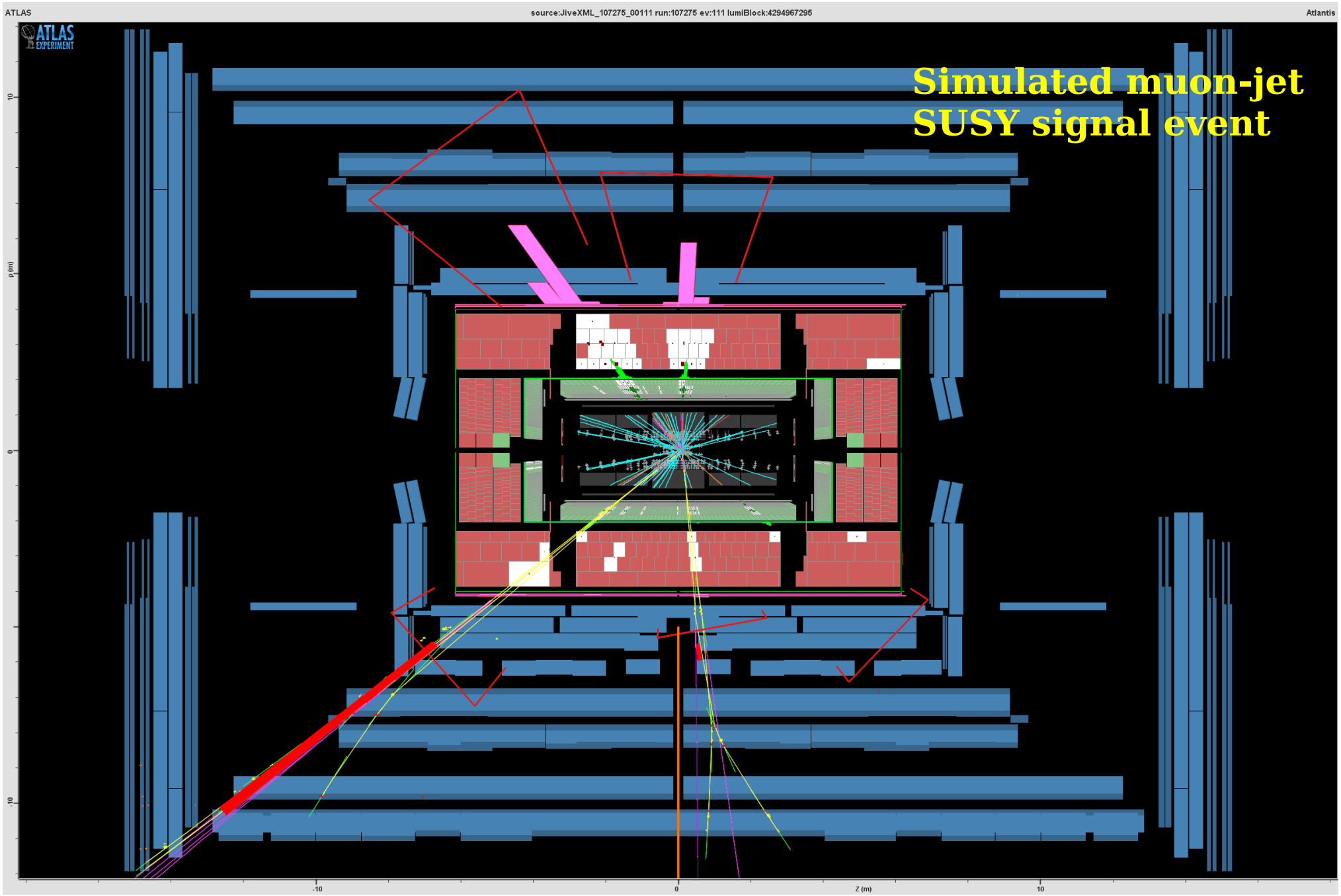
Would rule out other SUSY points with lighter chargino / neutralino, or strong production



Chan.	$\mathcal{R}_f$	$N_{\rm obs}$	$N_{\rm pred}$	$\mathcal{A}(\%)$	$\epsilon(\%)$	$\mathcal{B}$	$\sigma_{95\%} \times \mathcal{B}$, fb	
							obs.	pred.
$\mu\mu$	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}

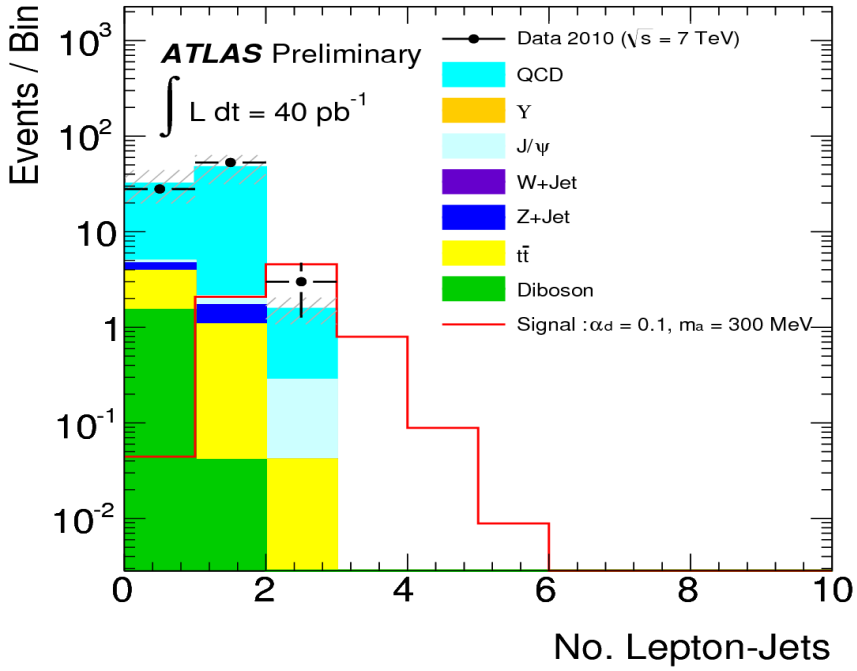
arXiv:1008.3356
Phys.Rev.Lett.105:211802,2010

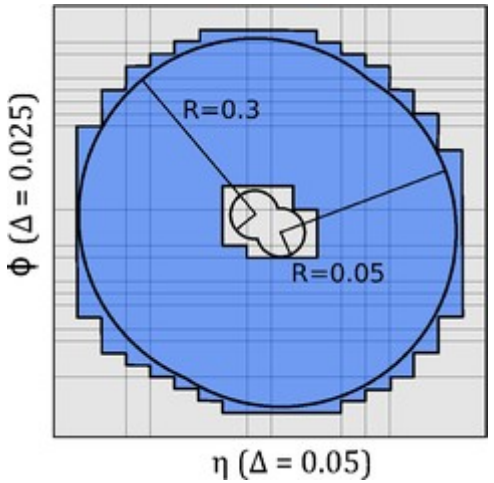
SUSY Lepton Jets at ATLAS

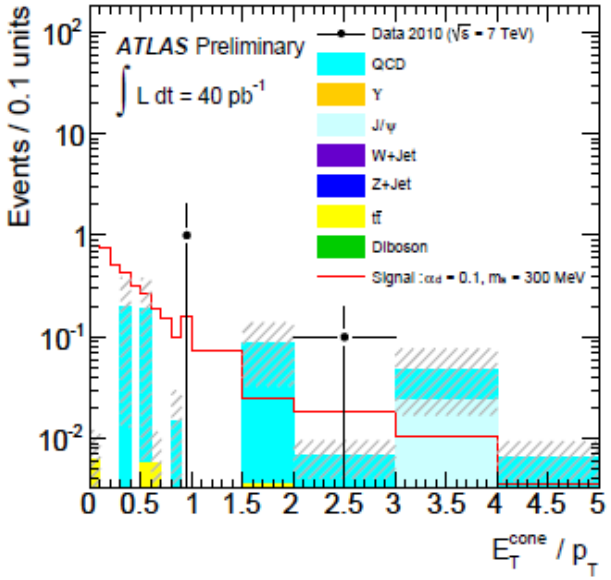


SUSY Lepton Jets at ATLAS

- ATLAS search for 2 muon-jets with 2010 data
- Custom multi-muon calorimeter isolation calculated, to reject QCD jets
- No events seen with 2 *isolated* muon-jets





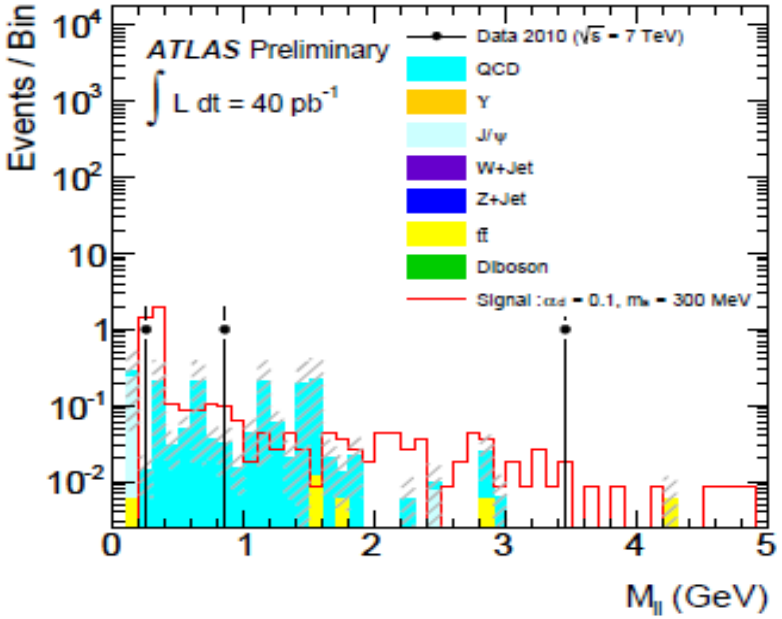


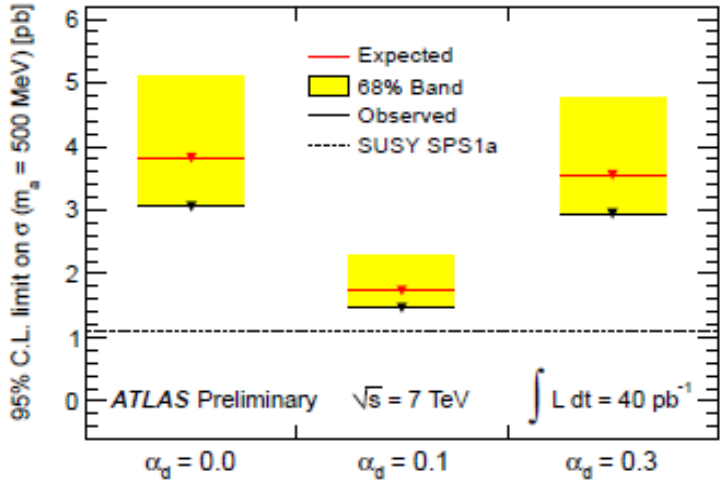
SUSY Lepton Jets at ATLAS

- Dark photon → $\mu^+\mu^-$ would give peak at dark photon mass

- Limits set on SUSY production with dark photon decays up to m(squark) ~500 GeV
  - **Comparable to D0 result, but *no MET required***

- 2011 analysis underway
  - Muons *and electrons*
  - 50x more data !



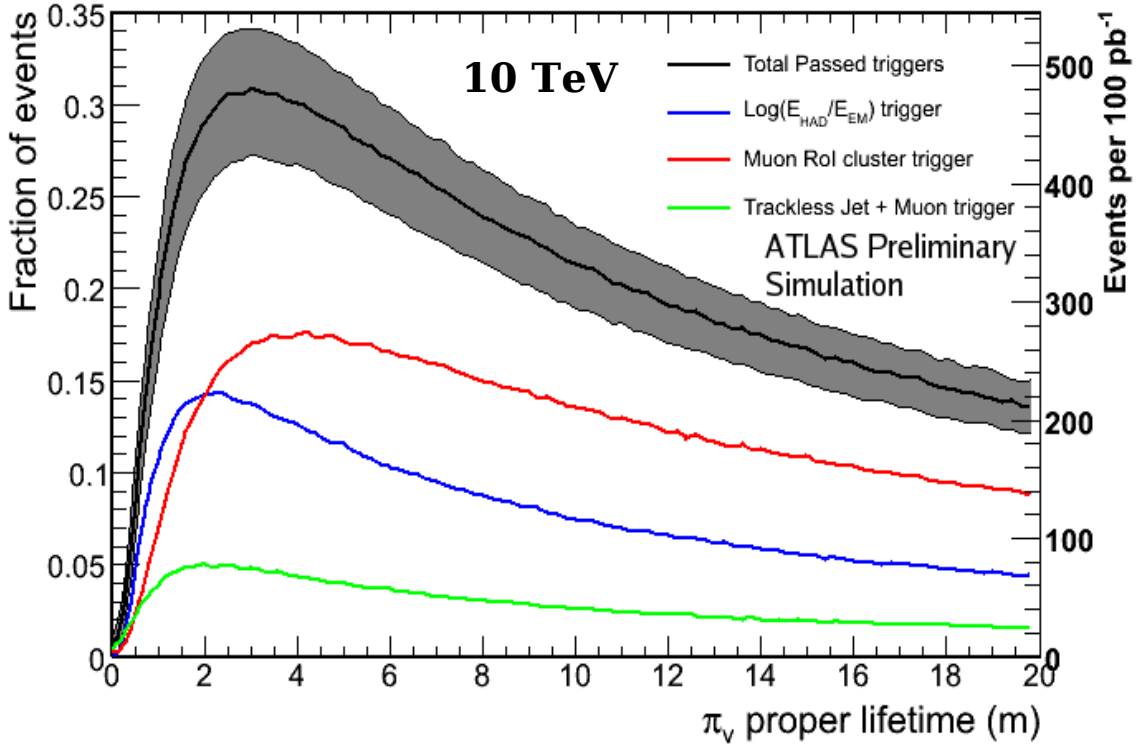


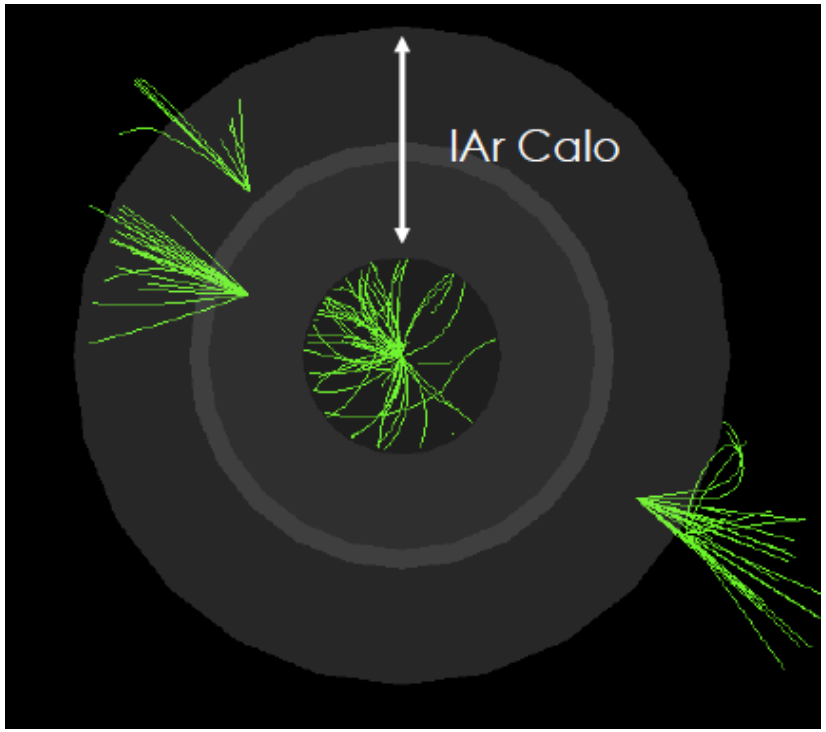
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-076/
ATLAS-CONF-2011-076, 22 May 2011.

Long-lived lepton-jets at ATLAS

- Look for vertices in inner-detector matching muons or EM clusters
- Special triggers for decays farther out in the detector
- Possible to do (2D) vertexing in muon chambers...
  (These plots are for decays to jets, but the idea is similar...)

ATL-PHYS-PUB-2009-082



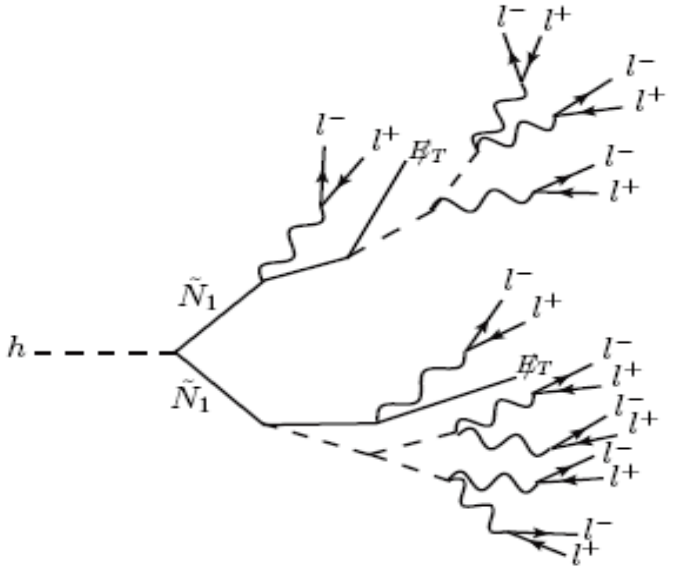


Other Lepton-jet sources

- Jet + lepton-jet
  - Very difficult to reduce backgrounds

- **Z decays to lepton jets**
  - ATLAS now has more Z's than LEP II

- **Higgs decays to lepton jets**
  - Tevatron xs is ~1pb
  - LHC (7 TeV) is ~50pb



Could also hide the Higgs at LEP

Likely less MET than SUSY decays

Adam Falkowski, Joshua T. Ruderman, Tomer Volansky, Jure Zupan
arXiv:1002.2952

CDF Search

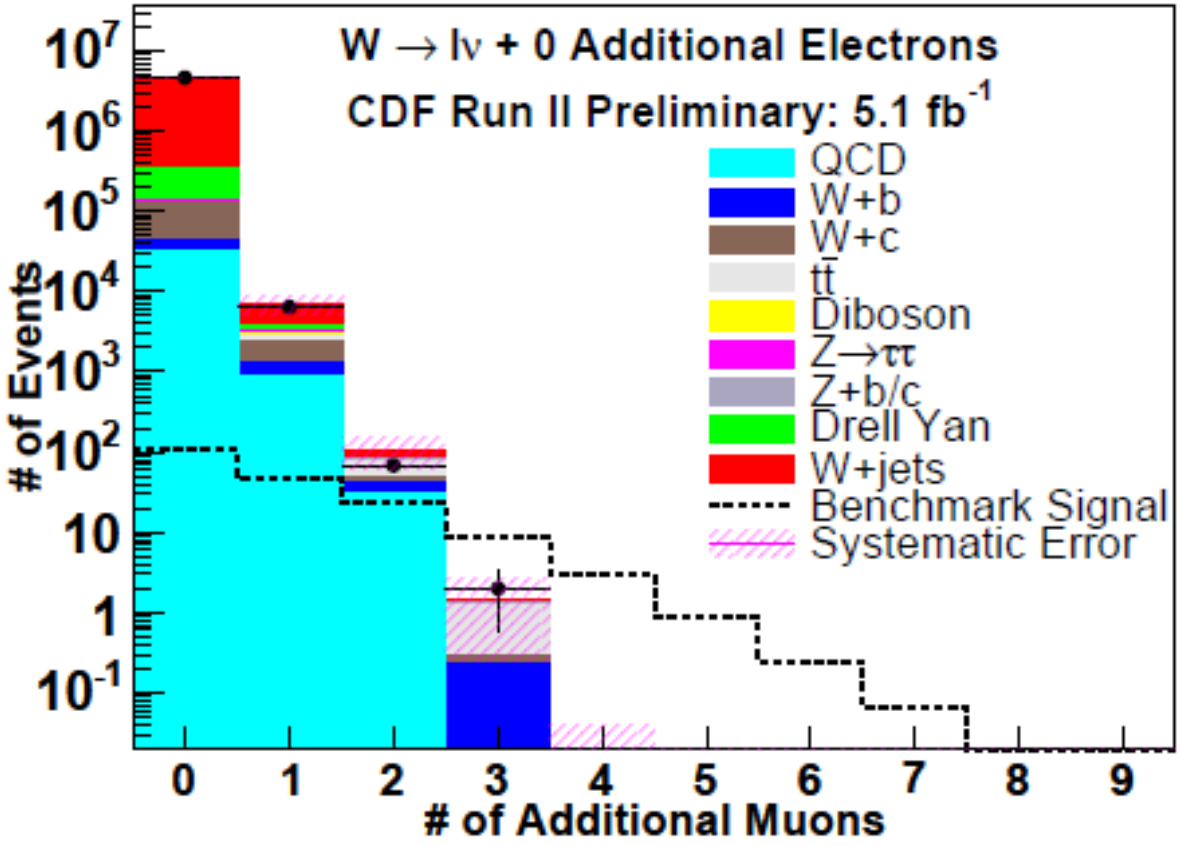
- We use 5.1 fb^{-1} of CDF data, collected from Dec. 2004 to Jan. 2010
- Trigger on leptonic W or Z with standard CDF high-p_T electron and muon cuts, validate W and Z
- Develop soft lepton identification - p_T down to 1 GeV for electrons, 3 GeV for muons
- Parameterize response of soft lepton ID to calculate expected additional leptons in SM
- Normalize predictions to W/Z + exactly one lepton bin
- Count events with multiple additional leptons
- Set limit (or observe excess) based on the number of events with multiple additional electrons and muons

Scott Wilbur
University of Chicago
On behalf of the CDF Collaboration

BOOST 2011, Princeton, May 24th

CDF Search

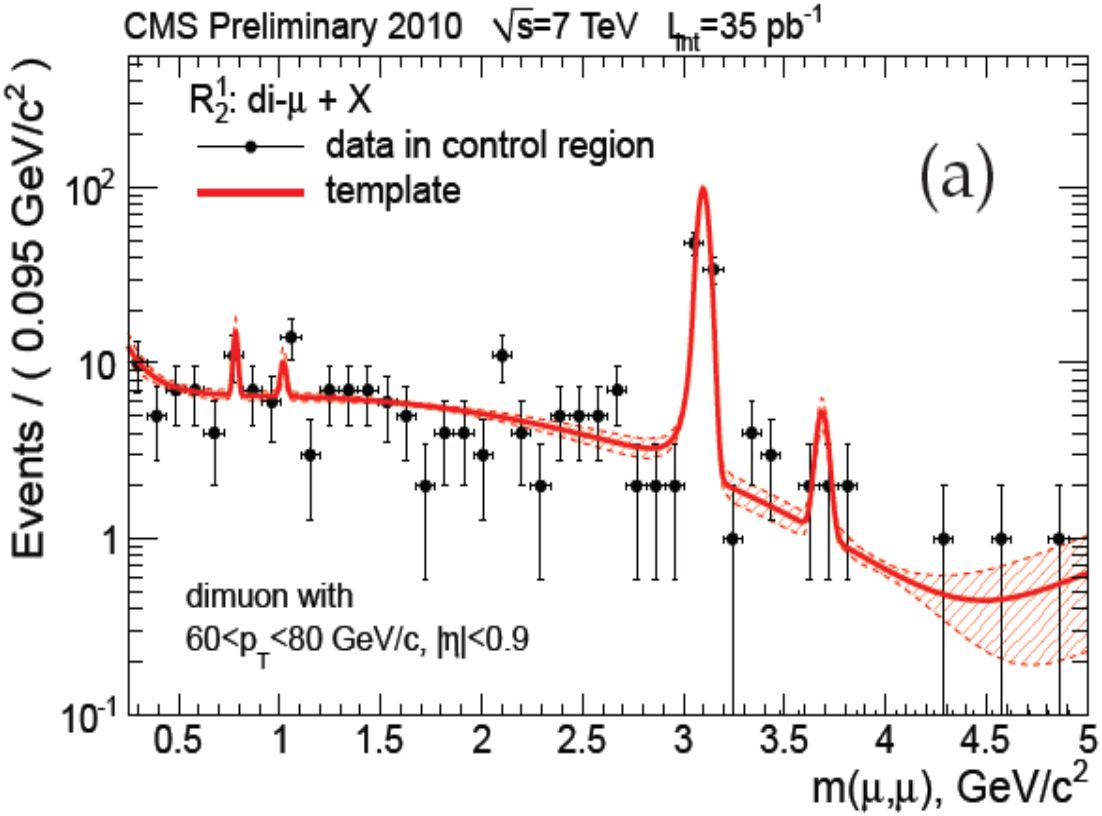
No excess events seen with >2 isolated leptons



- We rule out the benchmark model at 99.7% confidence.
- We set a 95% confidence level limit on this model of 6.9% of the cross section, or 27 fb for a leptonic W or Z plus a Higgs.

CMS Search

- Just look at the di-muon invariant mass for a bump
  - CMS: great momentum resolution for muons
  - Require large $pT_{\mu\mu}$ to reduce backgrounds
- Various muon-jet signatures searched for ...



name	description	Lead μ-Jet p_T	Backgrounds
R^1_2	Single dimuon+X	>80 GeV/c	2μ's from a b-jet, Drell Yan
R^1_4	Single quadmuon+X	no explicit cut	2μ's from a b-jet + 2 fakes
R^2_{22}	Two dimuons+X	no explicit cut	bb-bar+X, 2μ's from each b
R^N_{5+}	All other categories	no explicit cut	Rare, from bb-bar+X/fakes

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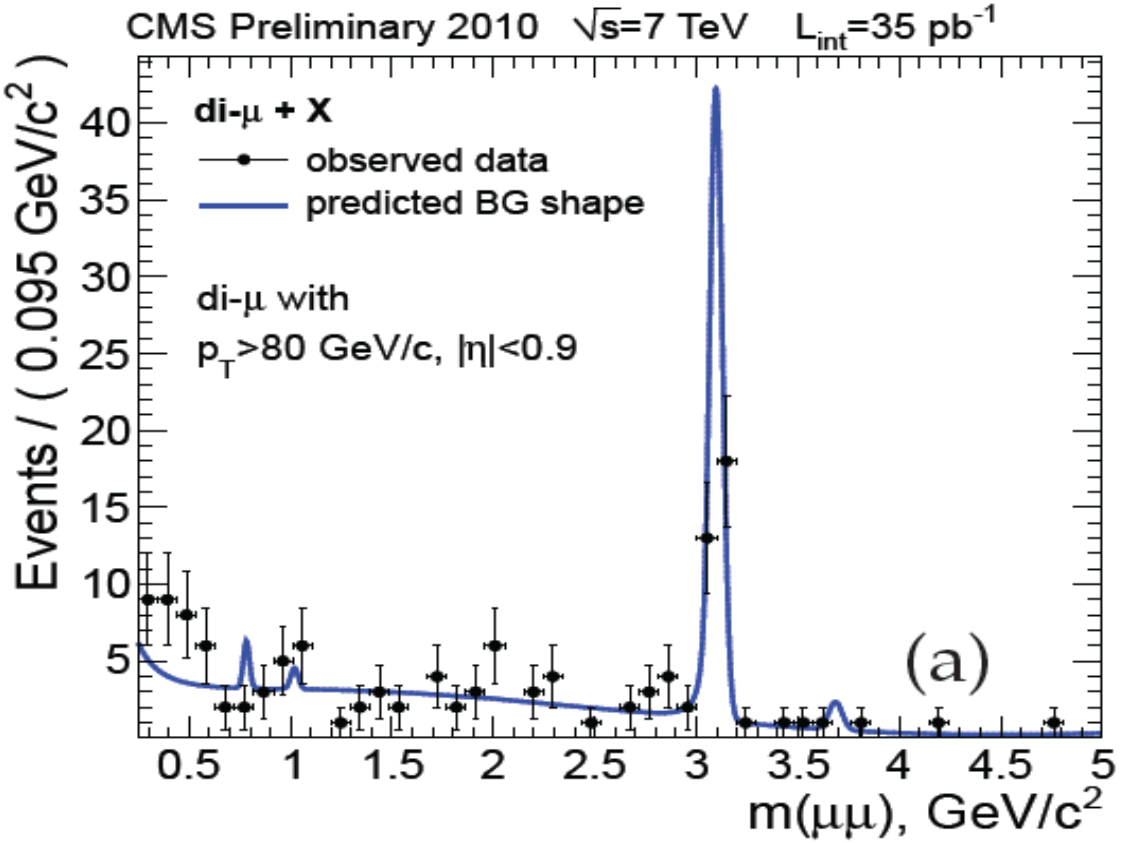

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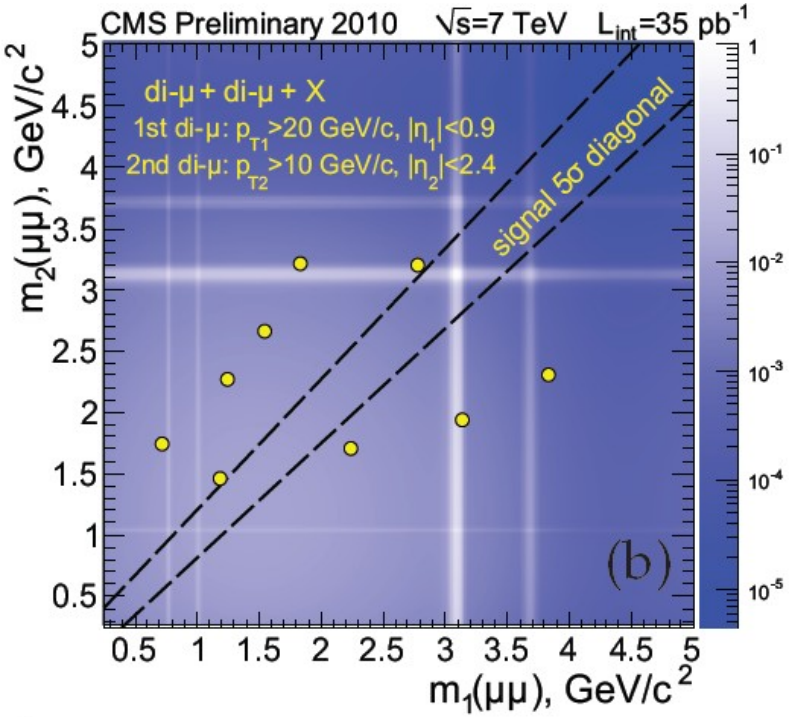
R^N_{5+}	All other categories	no explicit cut	Rare, from bb-bar+X/fakes

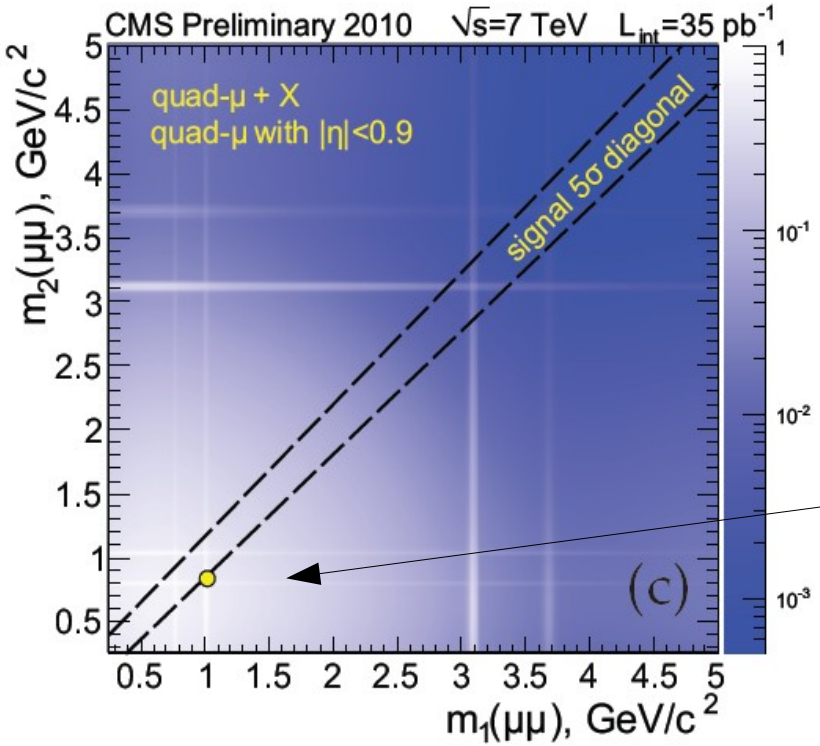
CMS search

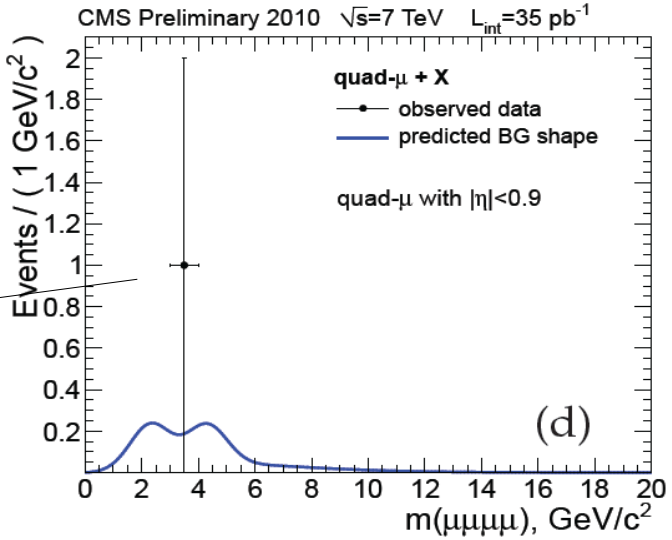
- When there are 4 muons, form two mu+ mu- pairs
- Look for the two pairs to have the same mass

2 lepton jets with 2 muons



1 lepton jet with 4 muons

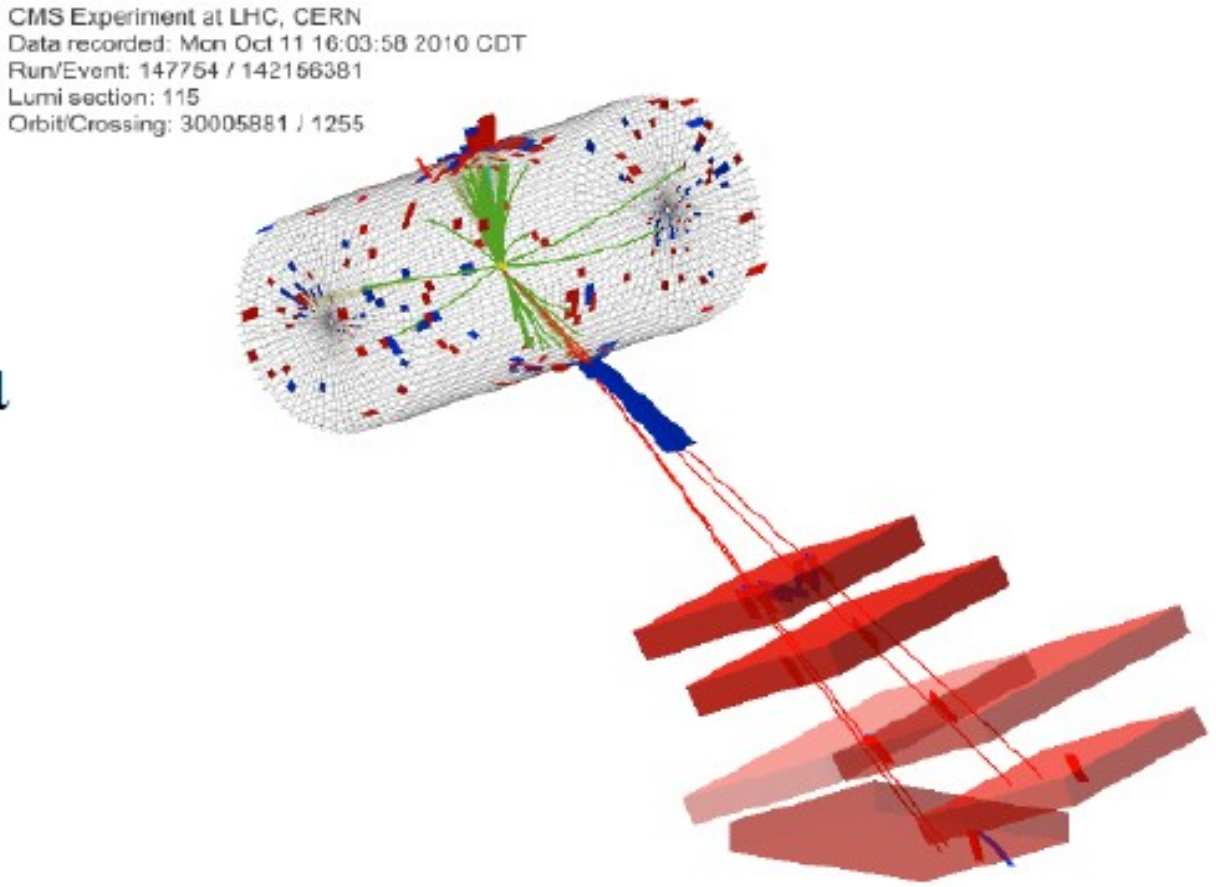




The Quadmuon Event

- Consistent with two true muons and two tracks misidentified as muons
- Likely a bb-bar event with $\phi \rightarrow \mu\mu$ in one of the b-jets

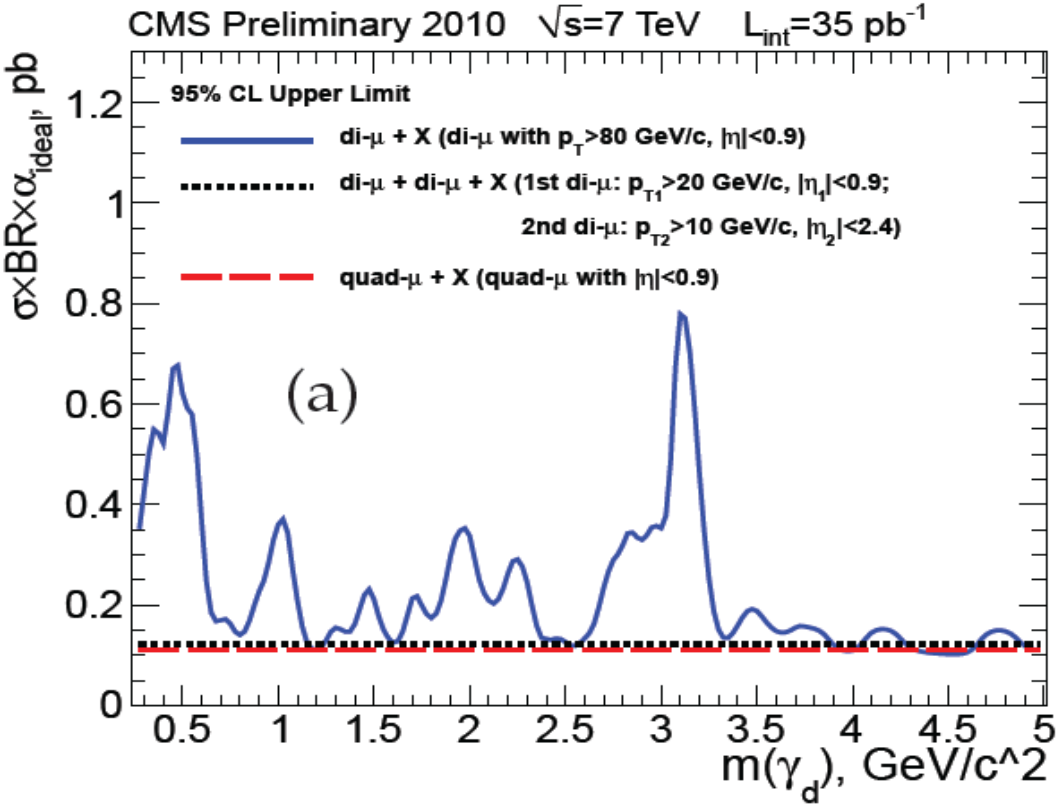
R_4^1: four nearby muons (only event)

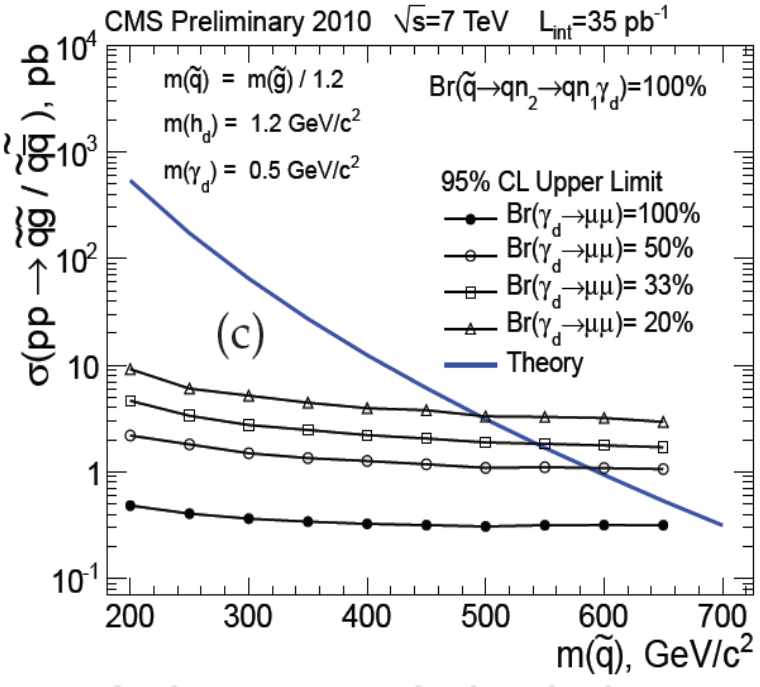


CMS search

- Comparable limits to ATLAS search
- ~1 pb or m(squark)<500 GeV excluded

- No isolation or MET required !!
- Strong requirements on invariant mass





Conclusions

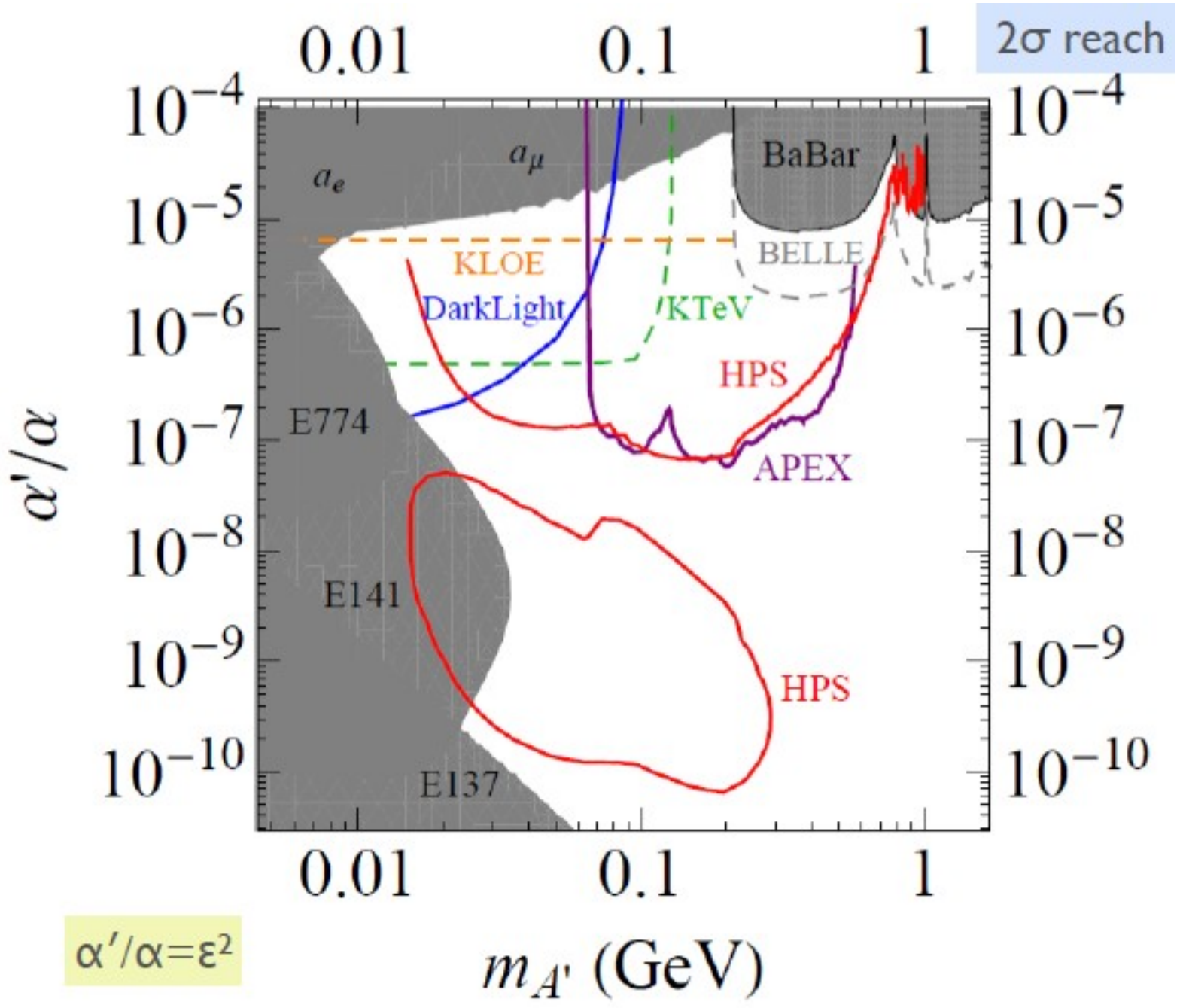
- Lepton-jet searches now from all 4 hadron-collider experiments
- Each search method is a bit unique – a good thing!
  - D0 : 2 isolated lepton jets + MET
  - CDF : W/Z + extra isolated leptons
  - ATLAS : 2 isolated muon lepton jets
  - CMS : 1 or 2 muon lepton jets with mass bump

- Many searches focus on SUSY production (best for hadron machines!)
- Also looked for Higgs decays or rare Z decays

- ATLAS and CMS will continue to search, in much larger datasets
- Also include electron lepton-jets and long-lived decays

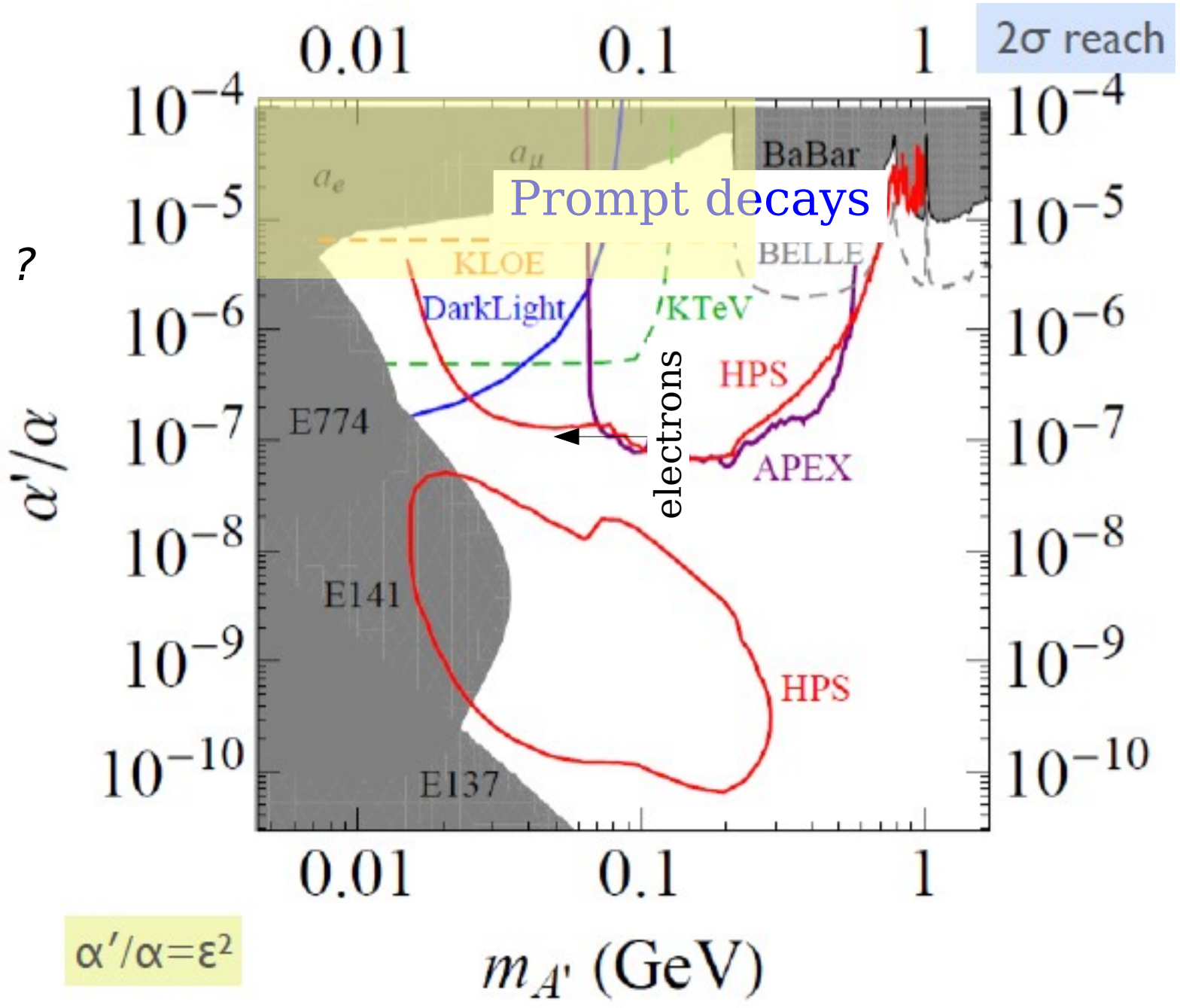
Lepton-jets at ATLAS

Large program of dark photon searches



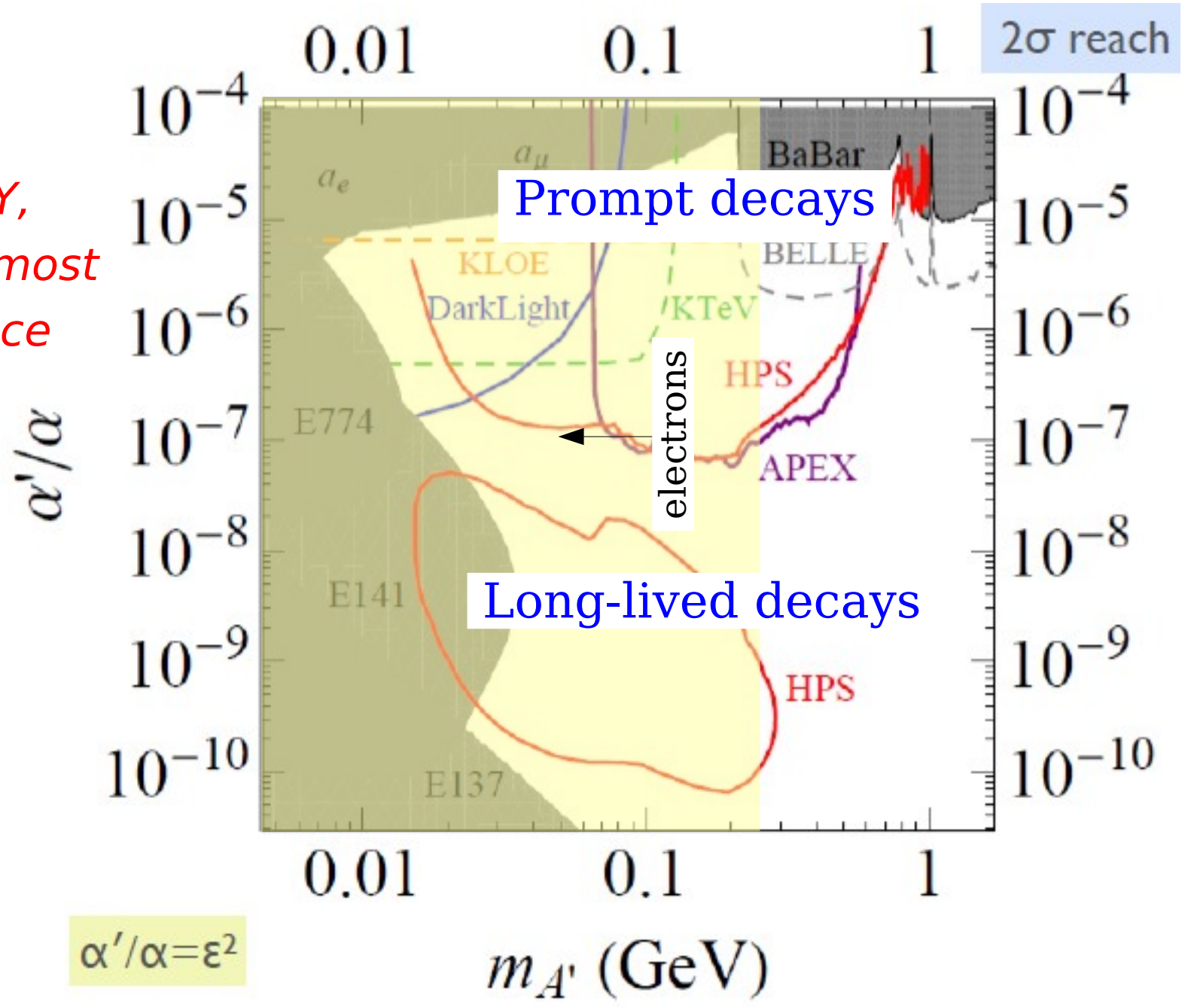
Lepton-jets at ATLAS

Sensitive to
10^{-6} BR of
$Z \rightarrow$ lepton jets ?



Lepton-jets at ATLAS

With light SUSY, ATLAS covers most parameter space



Backup