

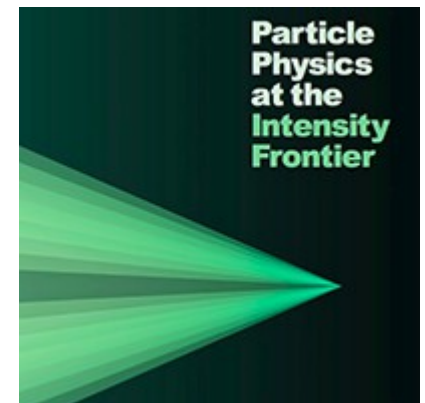
Hidden Sector Particles at the LHC

Andy Haas
New York University

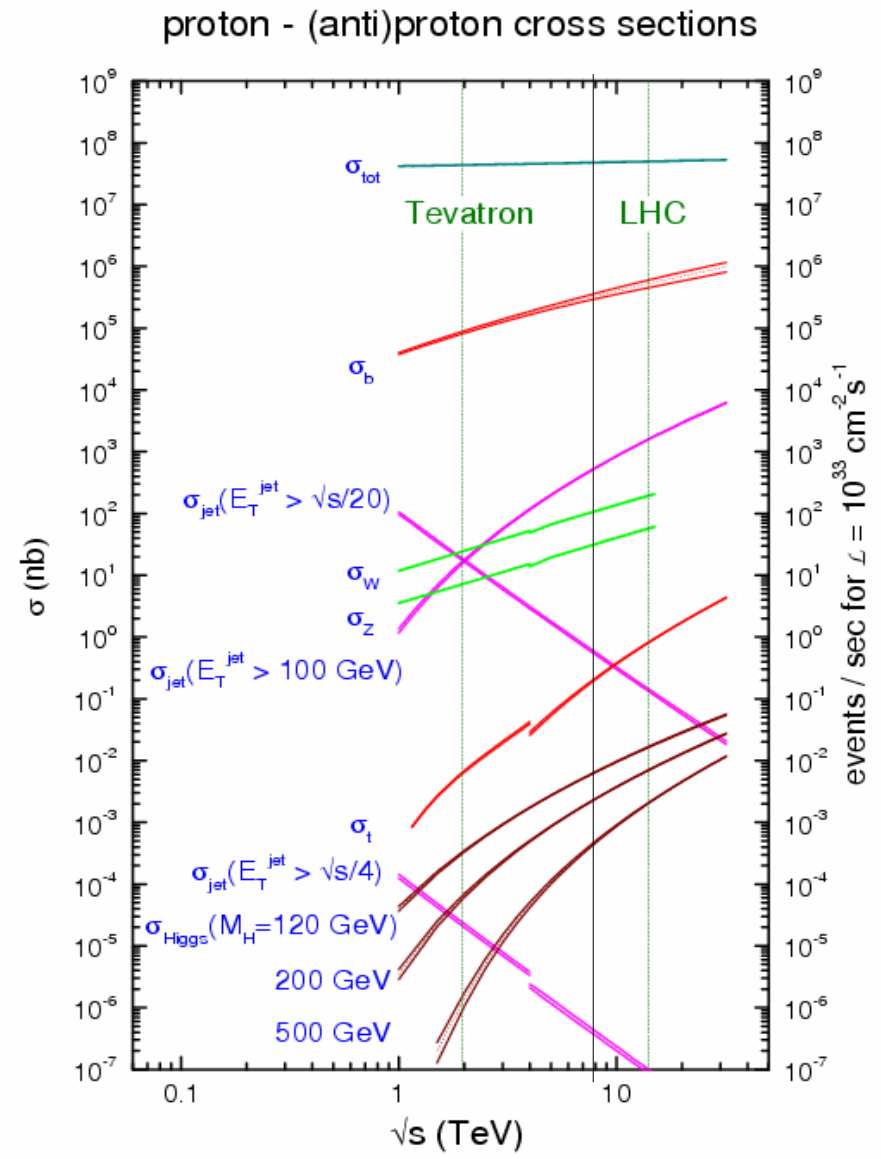
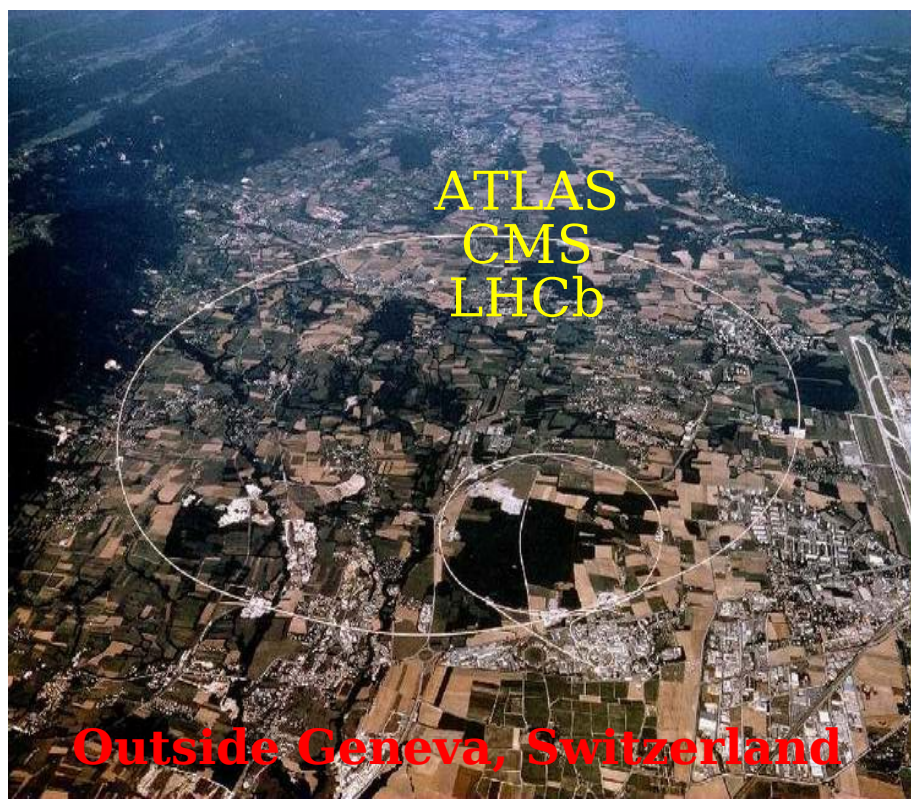
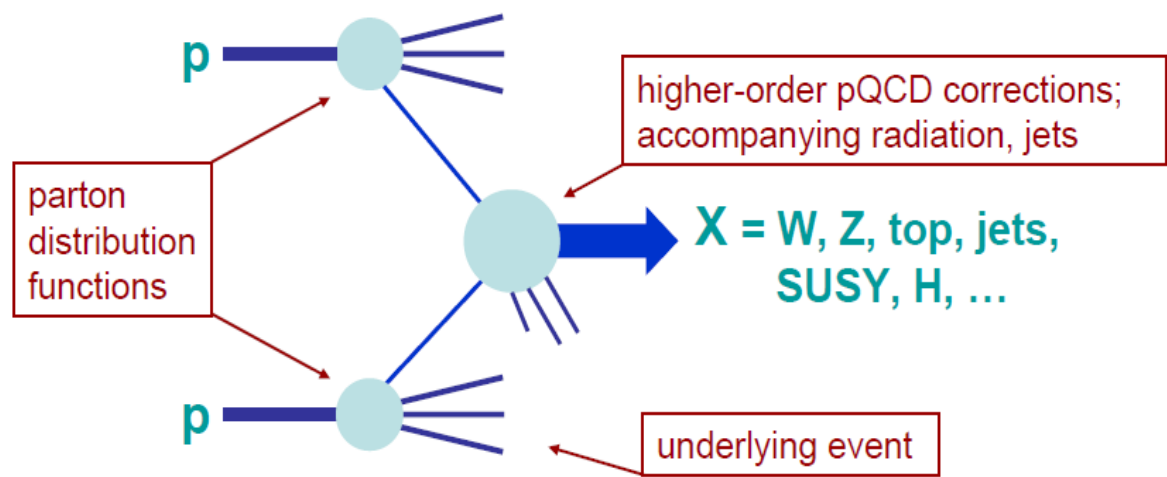
Intensity Frontier Workshop
Argonne

April 26, 2013

<https://indico.fnal.gov/conferenceTimeTable.py?confId=6248>



The (intense) energy frontier

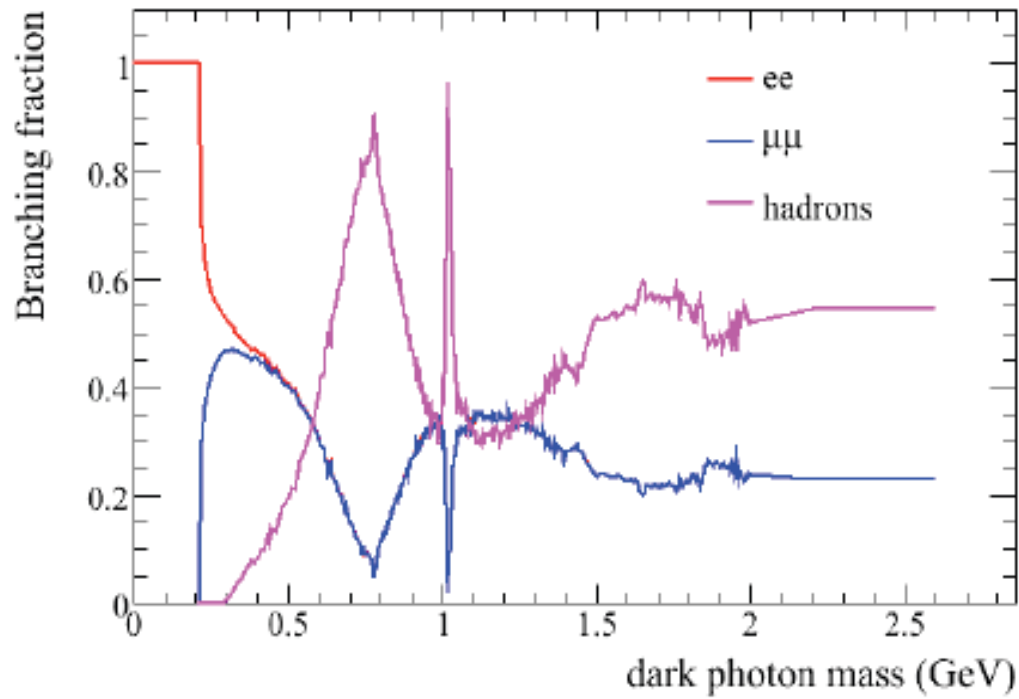
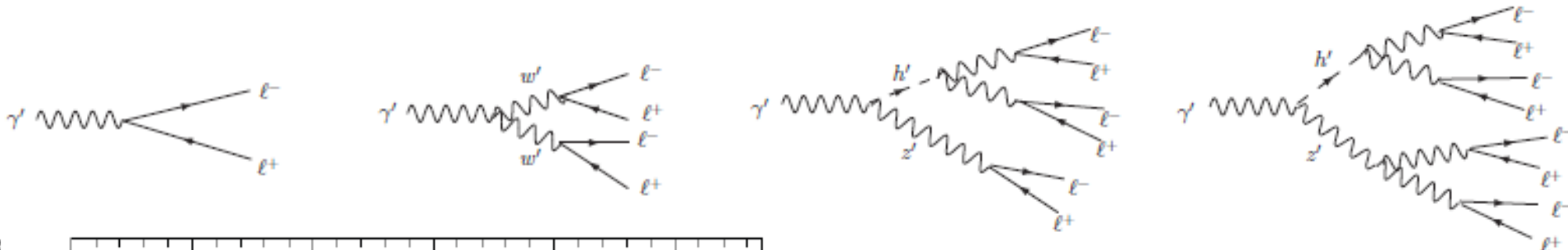


~150 Hz of Z's
 ~0.03 Hz of H's

Lepton jets

- **Dark photons are *boosted***

Create “lepton jets”:
pairs of collinear electrons or muons



Probably prompt decays,
but maybe not...

$$c\tau_{2\text{-body}}^{\gamma' \rightarrow n\ell} \sim \frac{1}{\alpha\epsilon^2 m_{\gamma'}} = 2.7 \times 10^{-6} \text{ cm} \left(\frac{\text{GeV}}{m_{\gamma'}} \right) \left(\frac{10^{-3}}{\epsilon} \right)^2$$

SUSY lepton jets

- **Changes signature of SUSY dark matter**

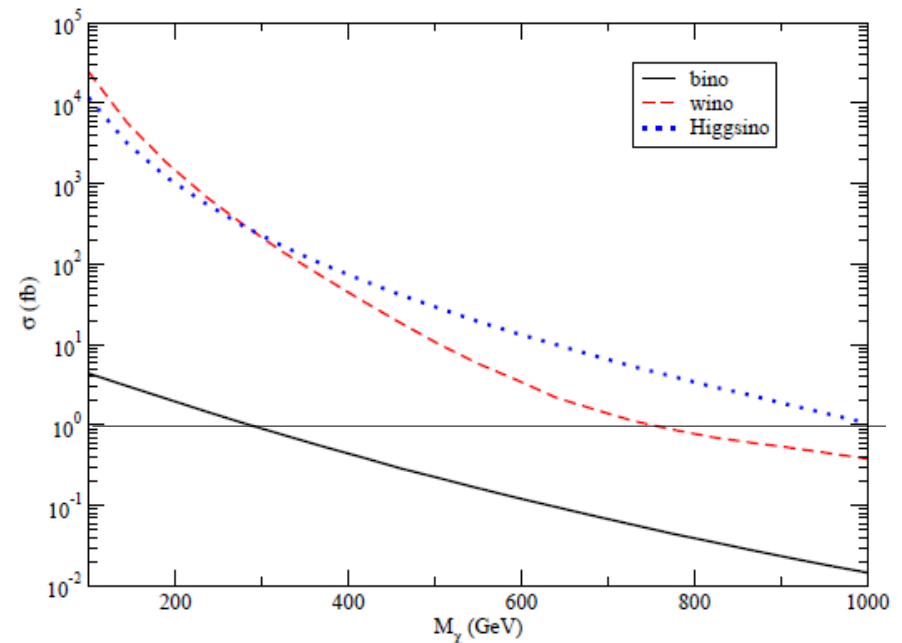
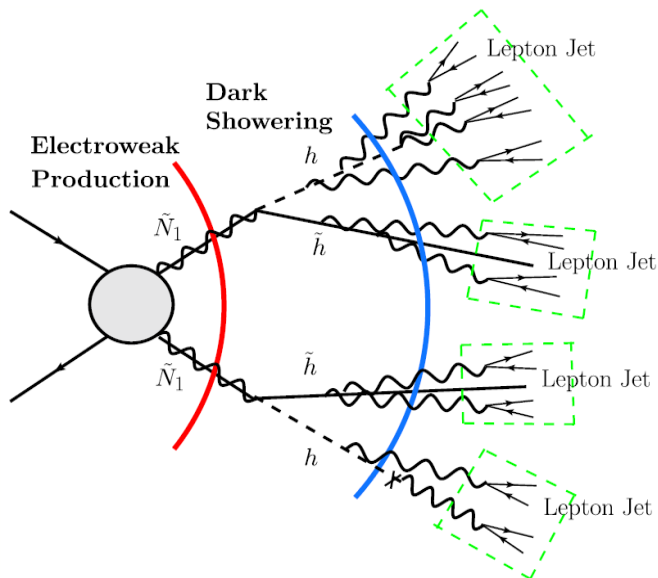
- Less MET
- Two *dark* photons

BR = 1!

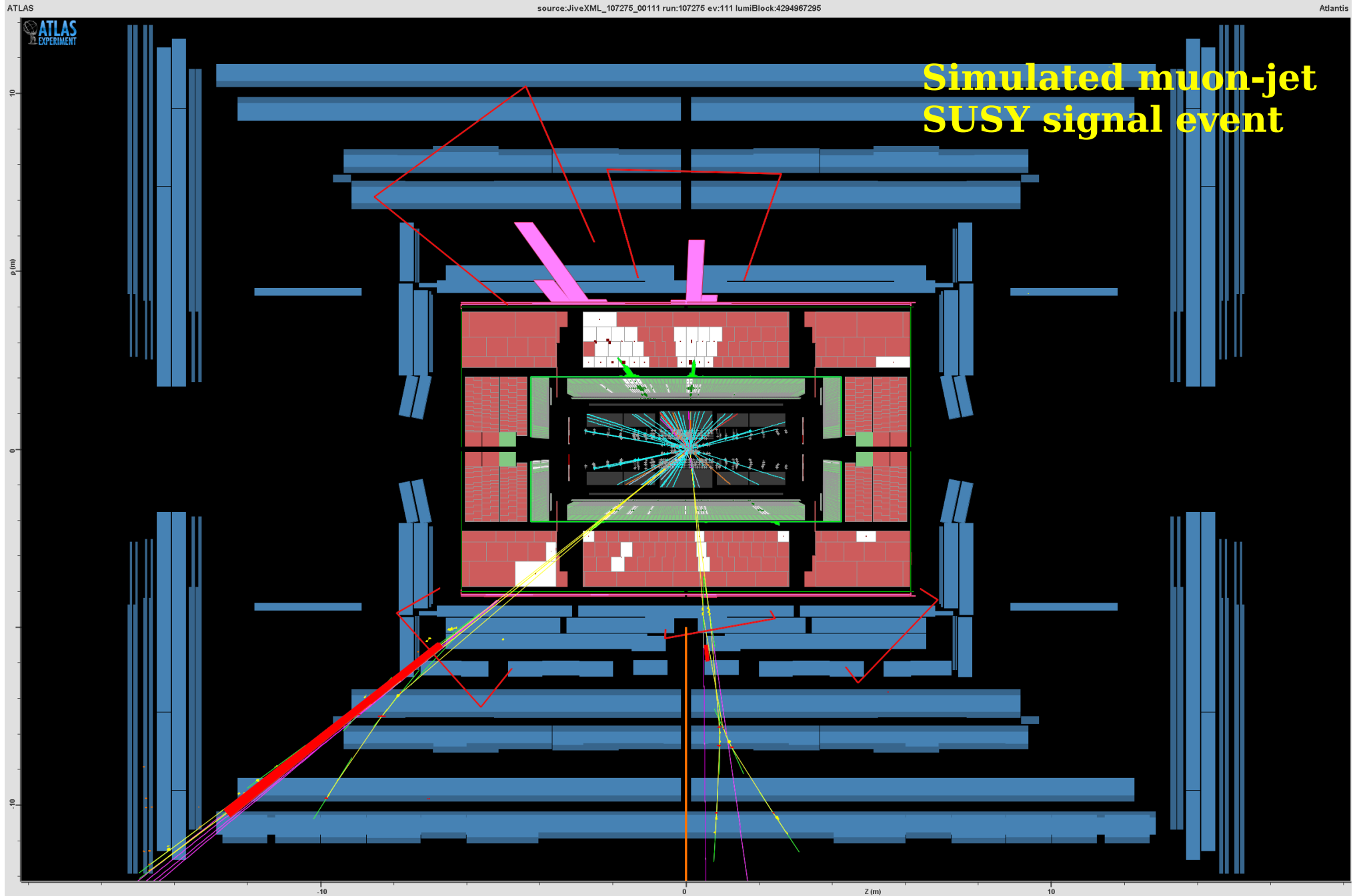
Prompt:

$$\begin{aligned} \tau_{\text{LSP} \rightarrow h + \tilde{h}} &\sim \left(\alpha_y^{\text{dark}} f_{\tilde{B}}^2 \epsilon^2 M_{\text{LSP}} \right)^{-1} \\ &= 7 \times 10^{-19} \text{ s} \left(\frac{100 \text{ GeV}}{M_{\text{LSP}}} \right)^2 \left(\frac{0.01}{\alpha_y^{\text{dark}}} \right) \left(\frac{1.0}{f_{\tilde{B}}} \right)^2 \left(\frac{10^{-3}}{\epsilon} \right)^2 \end{aligned}$$

Possibly large production rate for colored SUSY particles

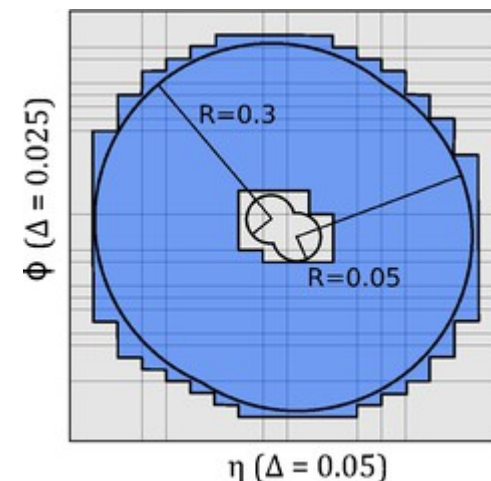


SUSY lepton jets at ATLAS



SUSY lepton jets at ATLAS

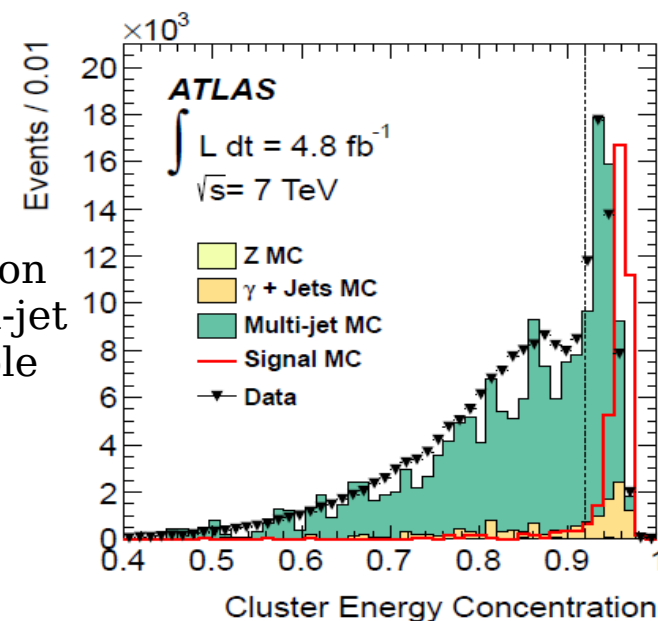
- Search for events with:
 - 2 prompt muon lepton-jets
 - 2 prompt electron lepton-jets
 - 1 prompt 4-muon lepton-jet
- Custom lepton-jet identification to separate from QCD jets
- Backgrounds measured in control regions
- No excess observed



	Electron LJ	1 Muon LJ	2 Muon LJ
Data	15	7	3
All background	15.2 ± 2.7	3.0 ± 1.0	0.5 ± 0.3

Jet prob bkgd method: $14.55^{+0.23}_{-0.04}$ 2.2 ± 0.9 events

Electron lepton-jet variable



SUSY lepton jets at ATLAS

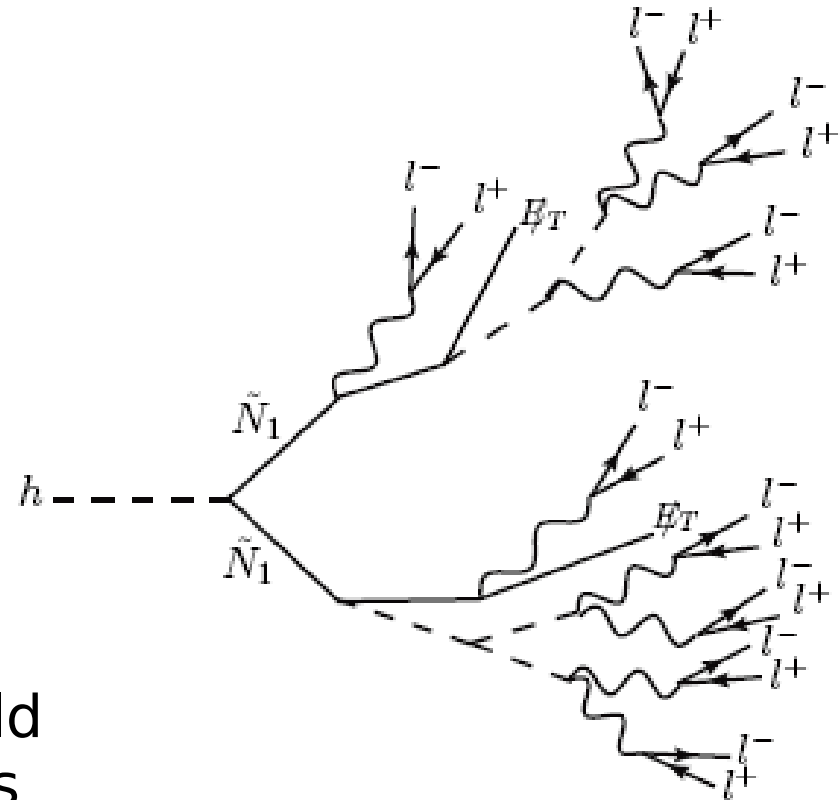
- Dark photon also would give peak at dark photon mass
- Cross-sections excluded for various dark-photon masses and radiation parameters $< \sim 0.02 - 0.1$ pb
- Constrains strong-production up to \sim TeV and even weak-production up to \sim 400 GeV (assuming LSP \rightarrow lepton-jet)
- Working on update to 2012 data and also a study of long-lived decays to electron lepton-jets in the tracker

Signal Parameters		Electron LJ	1 Muon LJ	2 Muon LJ
α_d	m_{γ_D} [MeV]	Obs (Exp) pb	Obs (Exp) pb	Obs (Exp) pb
0.0	150	0.082 (0.082)	-	-
0.0	300	0.11 (0.11)	0.060 (0.035)	0.017 (0.011)
0.0	500	0.20 (0.21)	0.15 (0.090)	0.019 (0.012)
0.10	150	0.096 (0.10)	-	-
0.10	300	0.37 (0.37)	0.064 (0.036)	0.018 (0.011)
0.10	500	0.39 (0.39)	0.053 (0.035)	0.018 (0.011)
0.30	150	0.11 (0.11)	-	-
0.30	300	0.40 (0.40)	0.099 (0.055)	0.020 (0.012)
0.30	500	1.2 (1.2)	0.066 (0.043)	0.022 (0.015)

<http://arxiv.org/abs/1212.5409>

Higgs decays

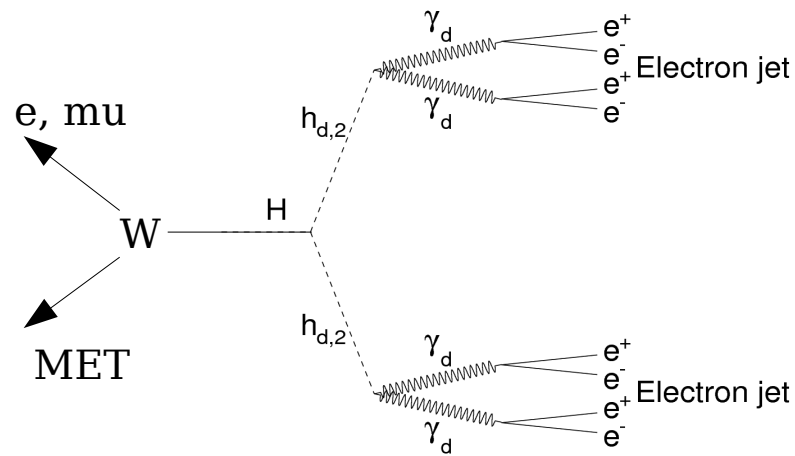
- The Higgs exists!
- **Higgs decays to lepton jets**



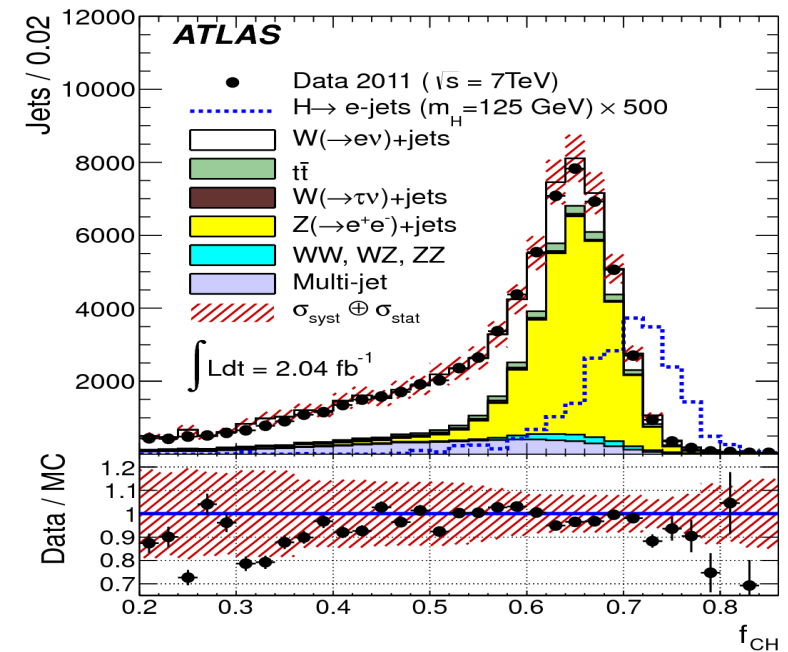
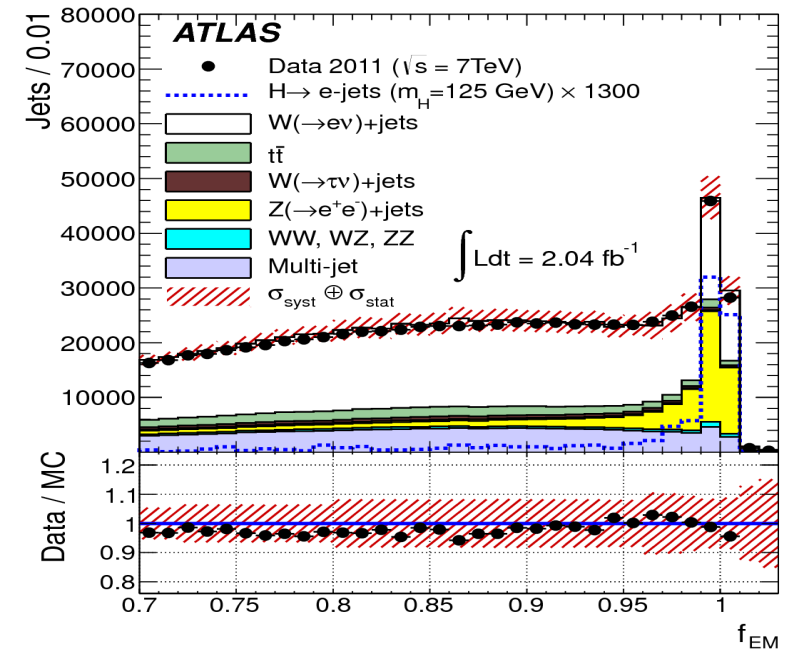
- Since it has a small width, it could have a large BR to non-SM states

Branching ratio could be $O(10\%)$!

ATLAS Search for $W+H \rightarrow$ prompt electron-jets

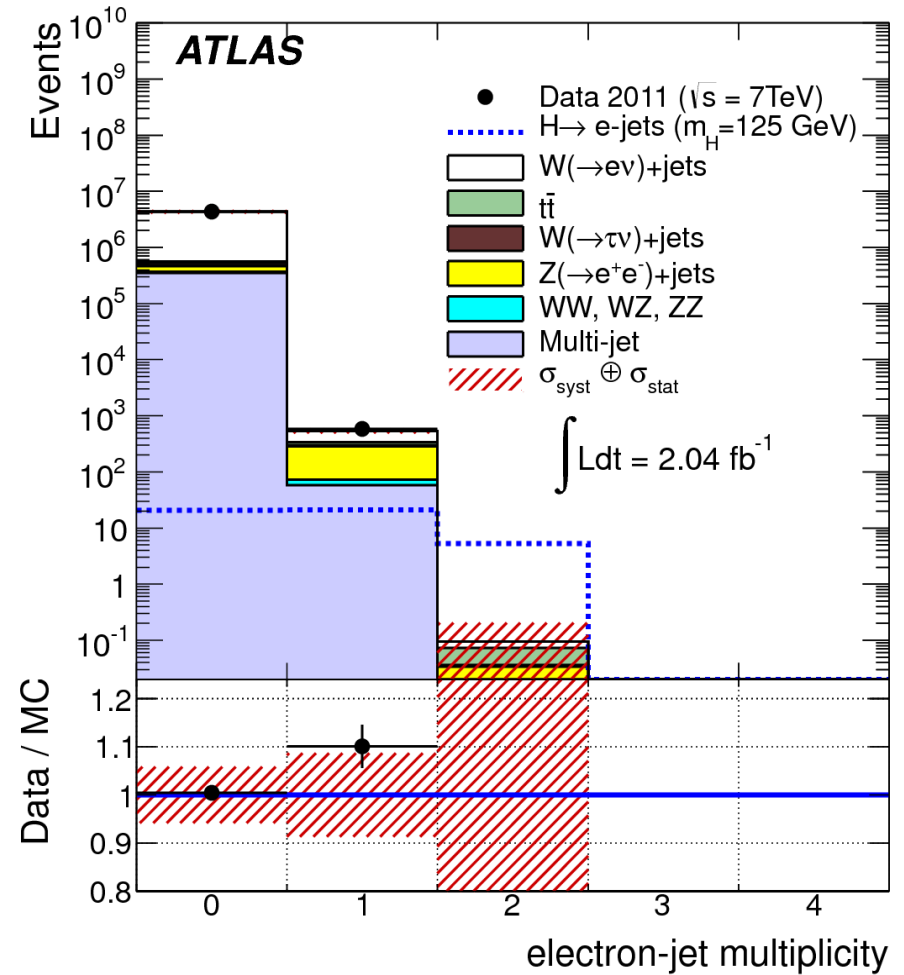
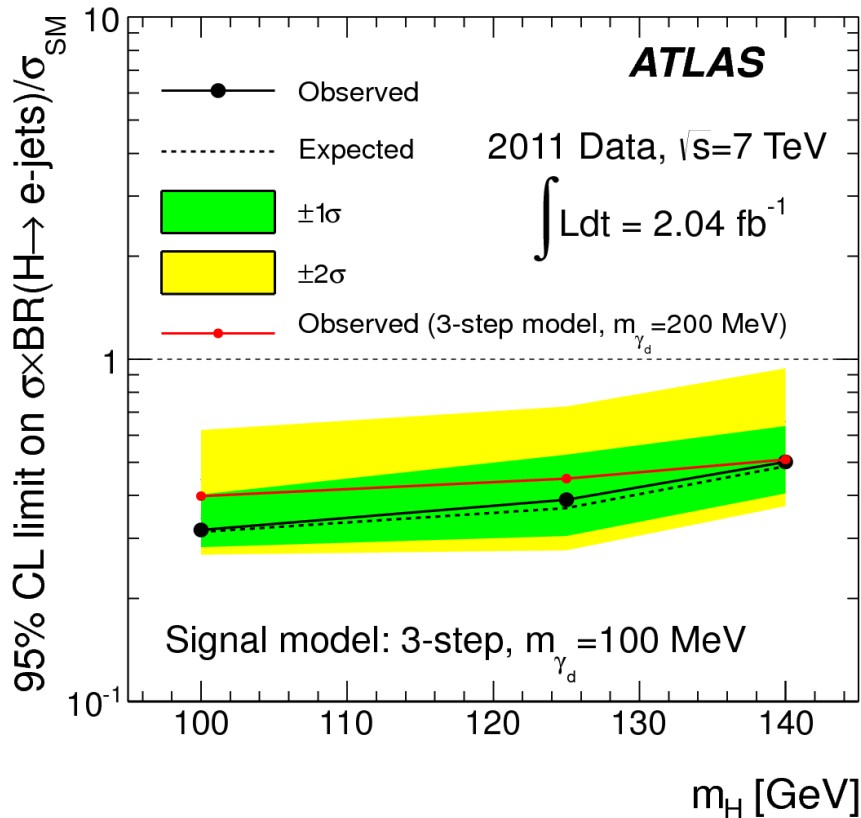


- Electron lepton-jets would have:
 - Large EM energy fraction
 - Large charged particle p_T fraction
 - Large number of tracks
- Separate signal from other backgrounds with QCD jets



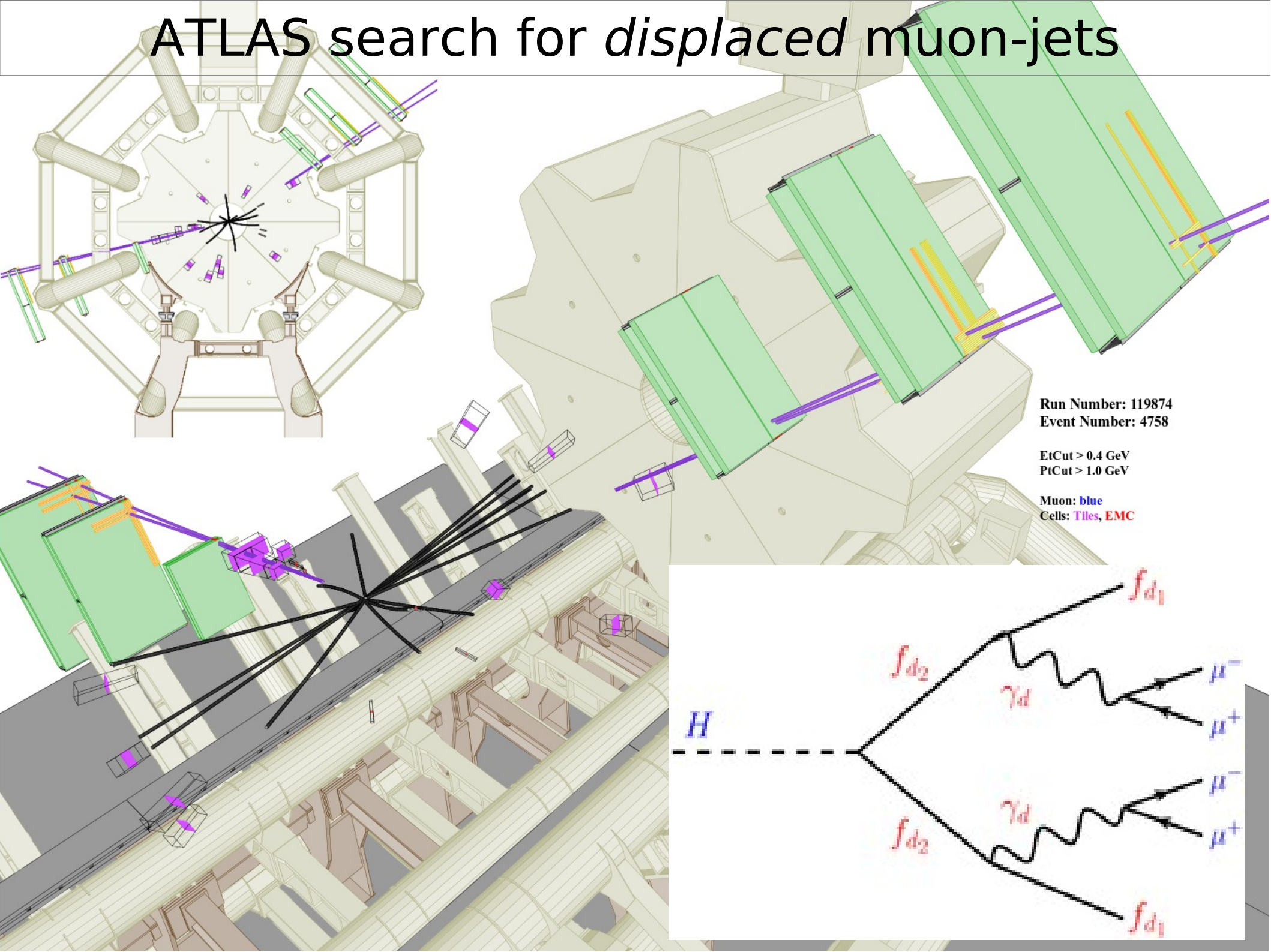
ATLAS Search for $W+H \rightarrow$ prompt electron-jets

- No excess observed with 2 electron-jets
- $BR(h \rightarrow \text{electron-jets}) < \sim 50\%$**



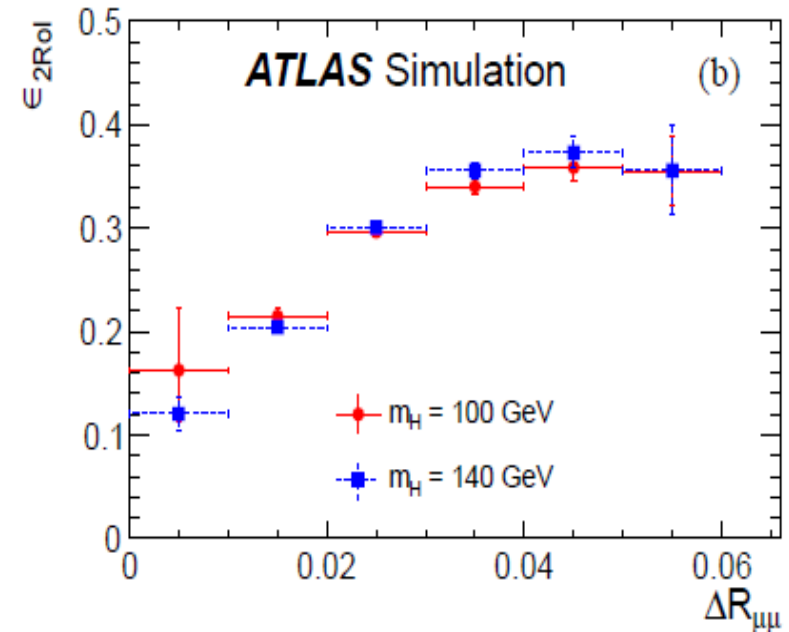
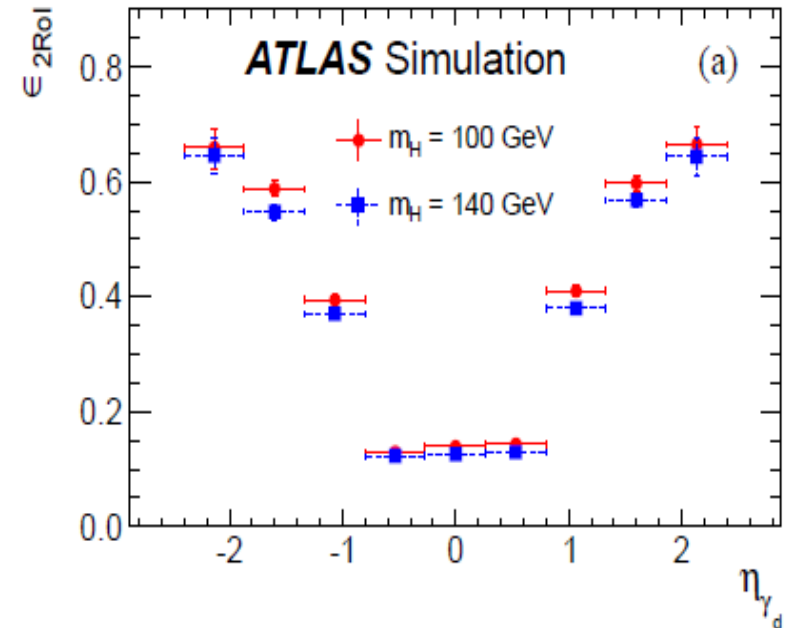
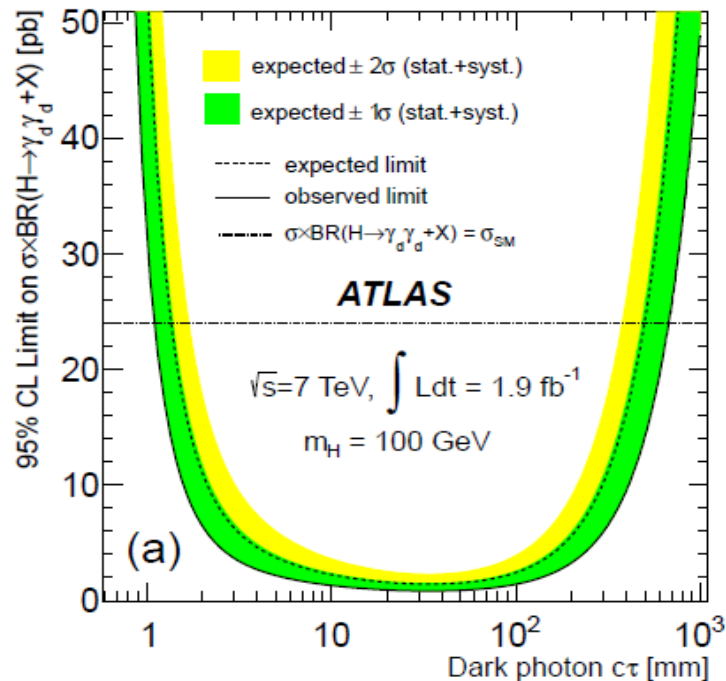
<http://arxiv.org/abs/1302.4403>

ATLAS search for *displaced* muon-jets



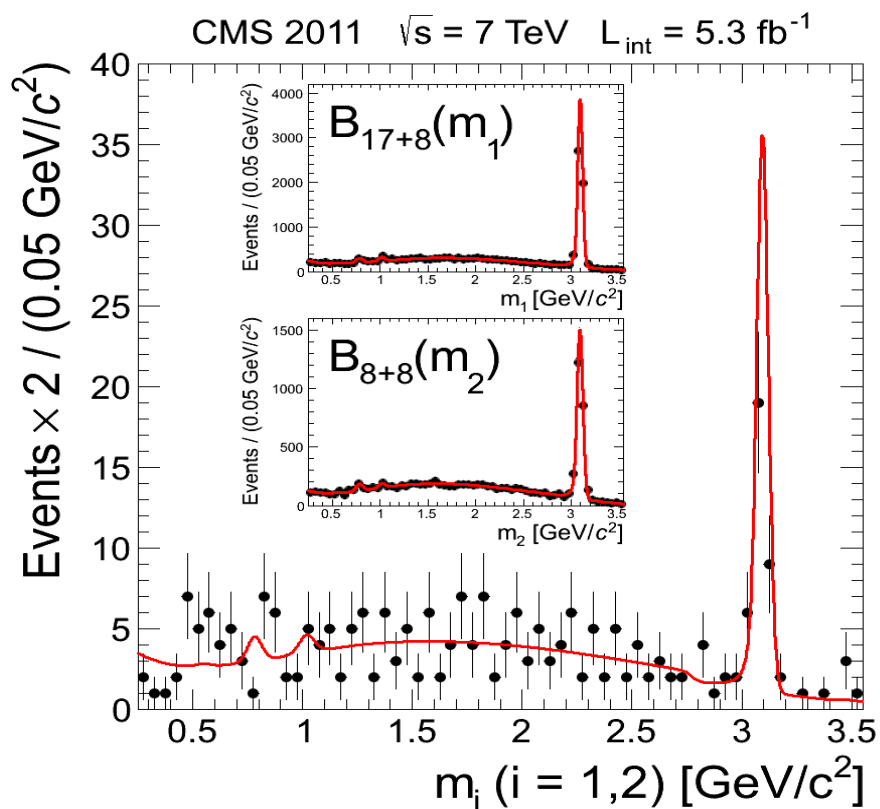
ATLAS search for *displaced* muon-jets

- Specially designed trigger for multi-muon objects in the *muon system*
- No events observed with 2 isolated muon-jets
 - ~ 0.5 cosmic event expected

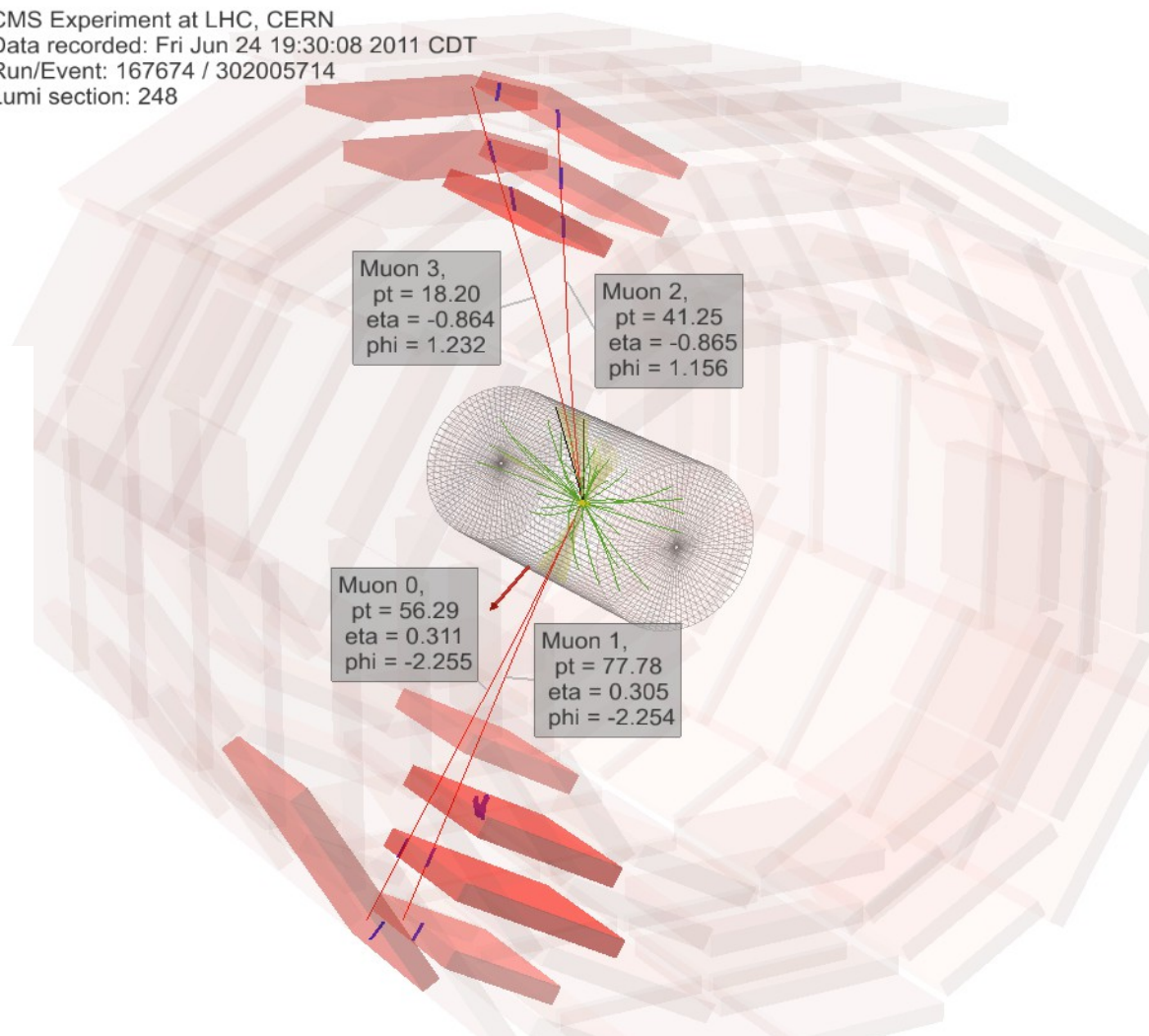


CMS search for $H \rightarrow \text{muon-jets}$

- Select 4-muon events
- Look for di-muon invariant mass bump at low mass in *isolated* muon pairs



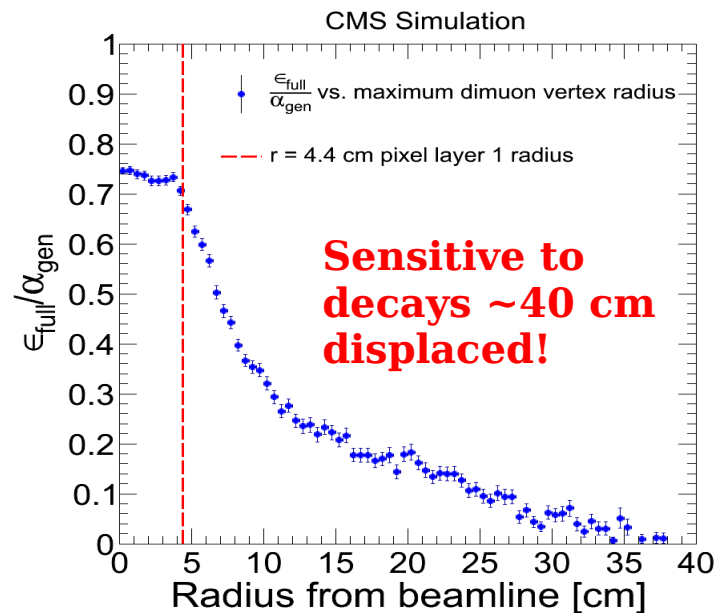
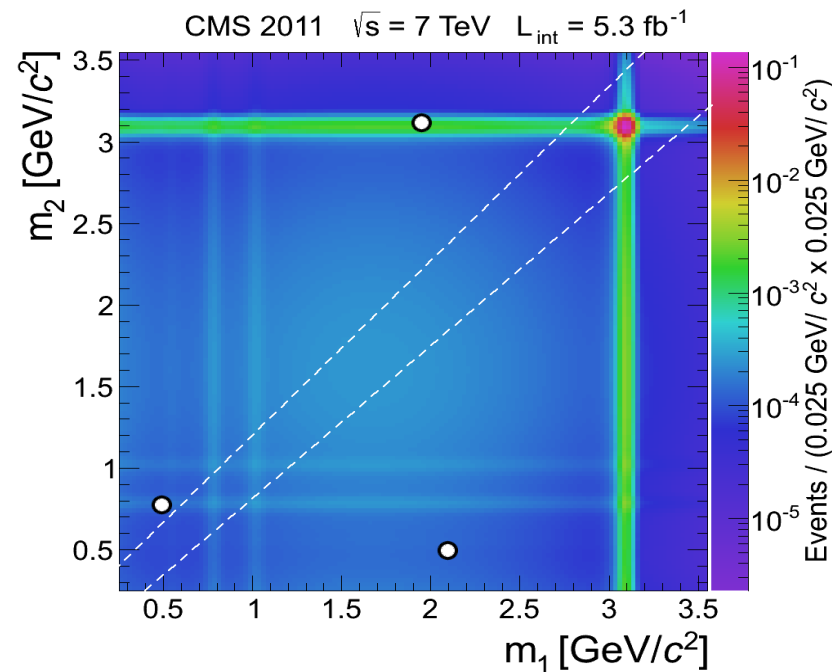
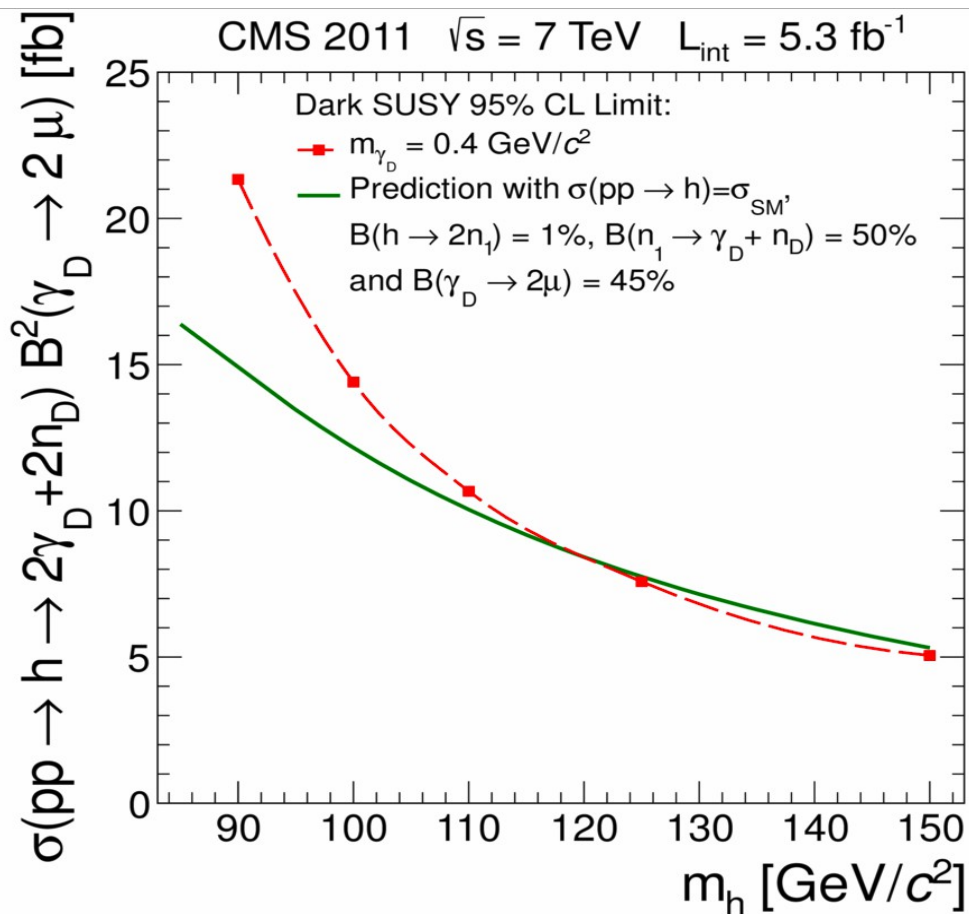
CMS Experiment at LHC, CERN
Data recorded: Fri Jun 24 19:30:08 2011 CDT
Run/Event: 167674 / 302005714
Lumi section: 248



<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO12012>

CMS search for $H \rightarrow \text{muon-jets}$

- Look for two $\mu^+ \mu^-$ pairs to have the same mass
- Exclude SM H decays with $\sim 1\%$ BR to muon-jets



Conclusions

- LHC could produce boosted dark photons → **lepton jets**
 - Decays of SUSY LSP or Higgs are nice candidates
- Several searches complete for lepton jets
 - SUSY prompt electron or muon
 - Higgs prompt electron
 - Higgs (very) displaced muon
 - Higgs prompt (or a little displaced) muon
 - *Working on (SUSY / Higgs) displaced electron search*
- **ATLAS and CMS will continue to search, in much larger datasets and at 13 TeV, starting in 2015**

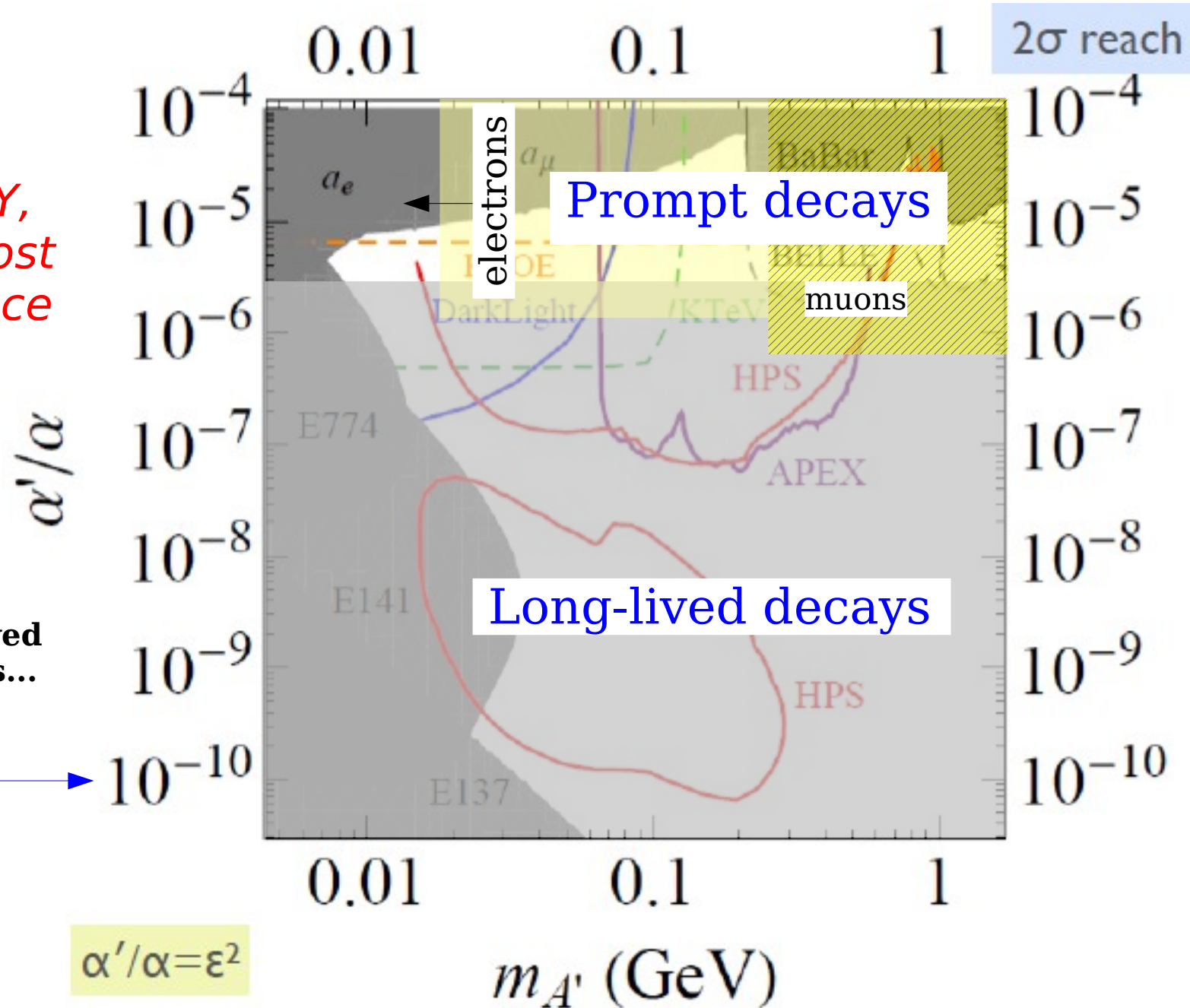
Backup

Constraints from the energy frontier

With light SUSY, sensitive to most parameter space

Must study long-lived dark photon decays...

$c\tau \sim 30 \text{ cm}$ →

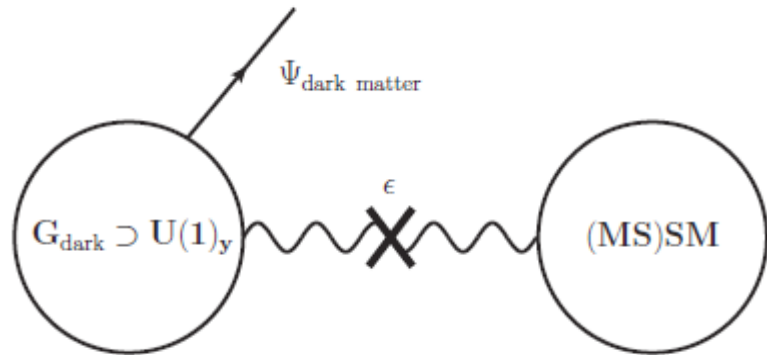


Dark-photon production

- Jet + dark-photon**

New, kinetically coupled U(1)

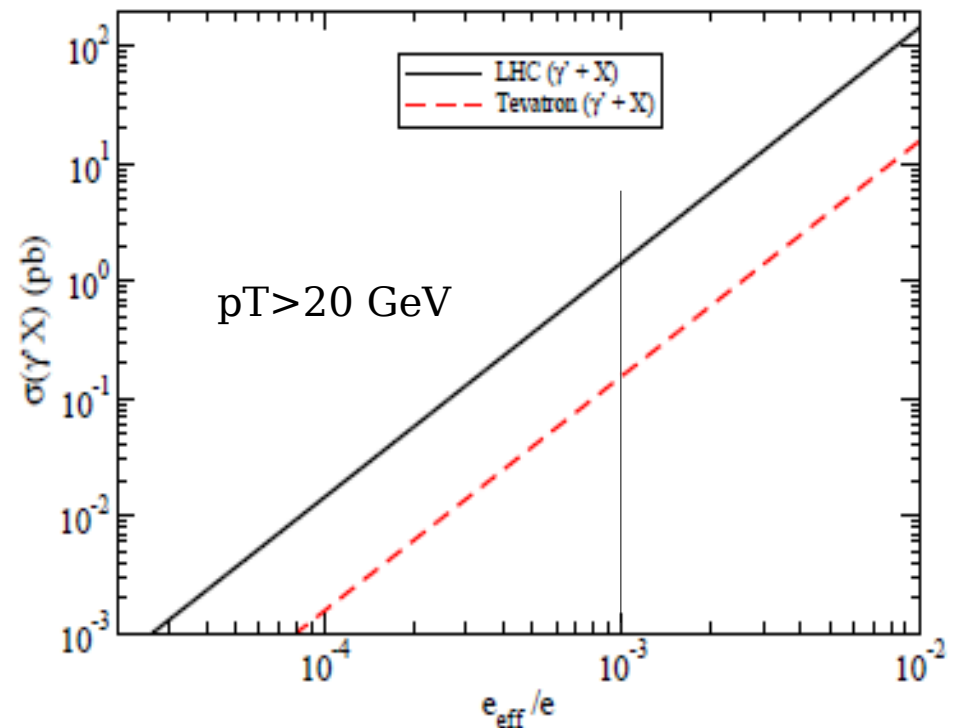
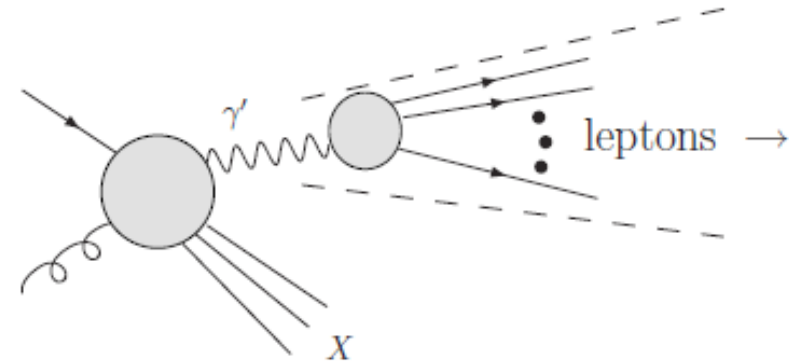
$$\mathcal{L}_{\text{gauge mix}} = -\frac{1}{2}\epsilon_1 b_{\mu\nu} A^{\mu\nu} - \frac{1}{2}\epsilon_2 b_{\mu\nu} Z^{\mu\nu}$$



$$\sigma \approx (\alpha_{\text{EM}} \epsilon)^2$$

Large jet background

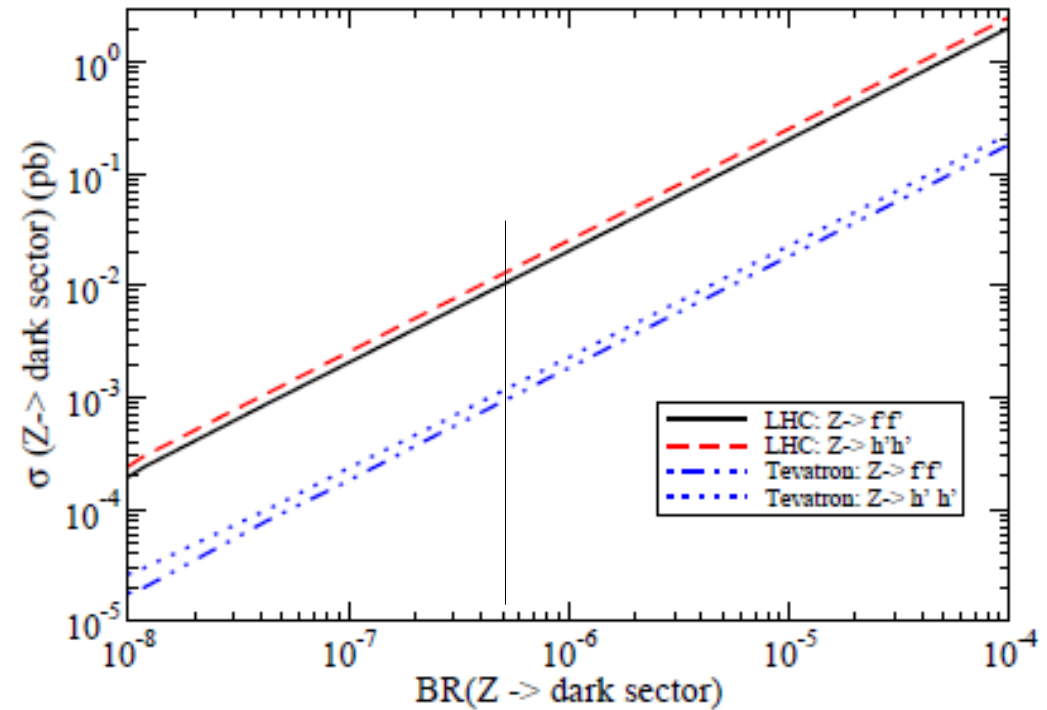
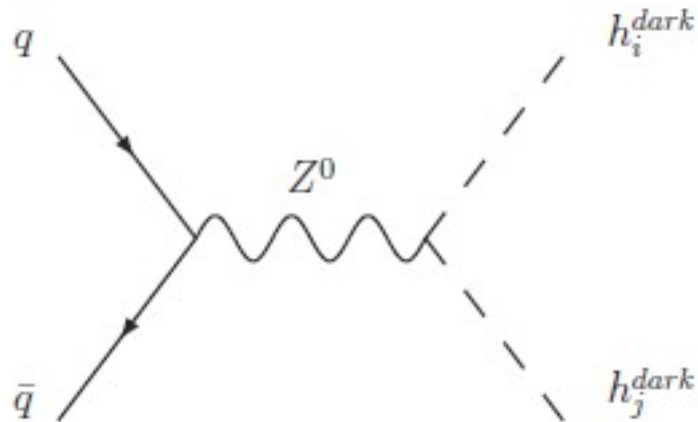
$$\sigma \approx (\alpha_s)^2$$



Rare Z decays

- Z decays to dark sector**

$$\text{BR}(Z^0 \rightarrow d_i d_i) = \frac{c_{d_i} \epsilon^2 g_y^2 y_{d_i}^2 \sin^2 \theta_W}{\Gamma_Z^0 48\pi} M_{Z^0}$$



Factor ~200 smaller cross-section
But *two* dark-things in each event

Much less background from jets