ATLAS searches with non hadronic jets

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ATLAS EXPERIMENT http://atlas.ch

Summary

- Introduction
- The ATLAS detector
- Signature for non hadronic jets
- Recent searches:
  - Prompt muon jets
  - Non-prompt muon jets
- Conclusions

Introduction

Final states consisting of non hadronic jets with and without macroscopic decay lengths are predicted by a large class of theory models:

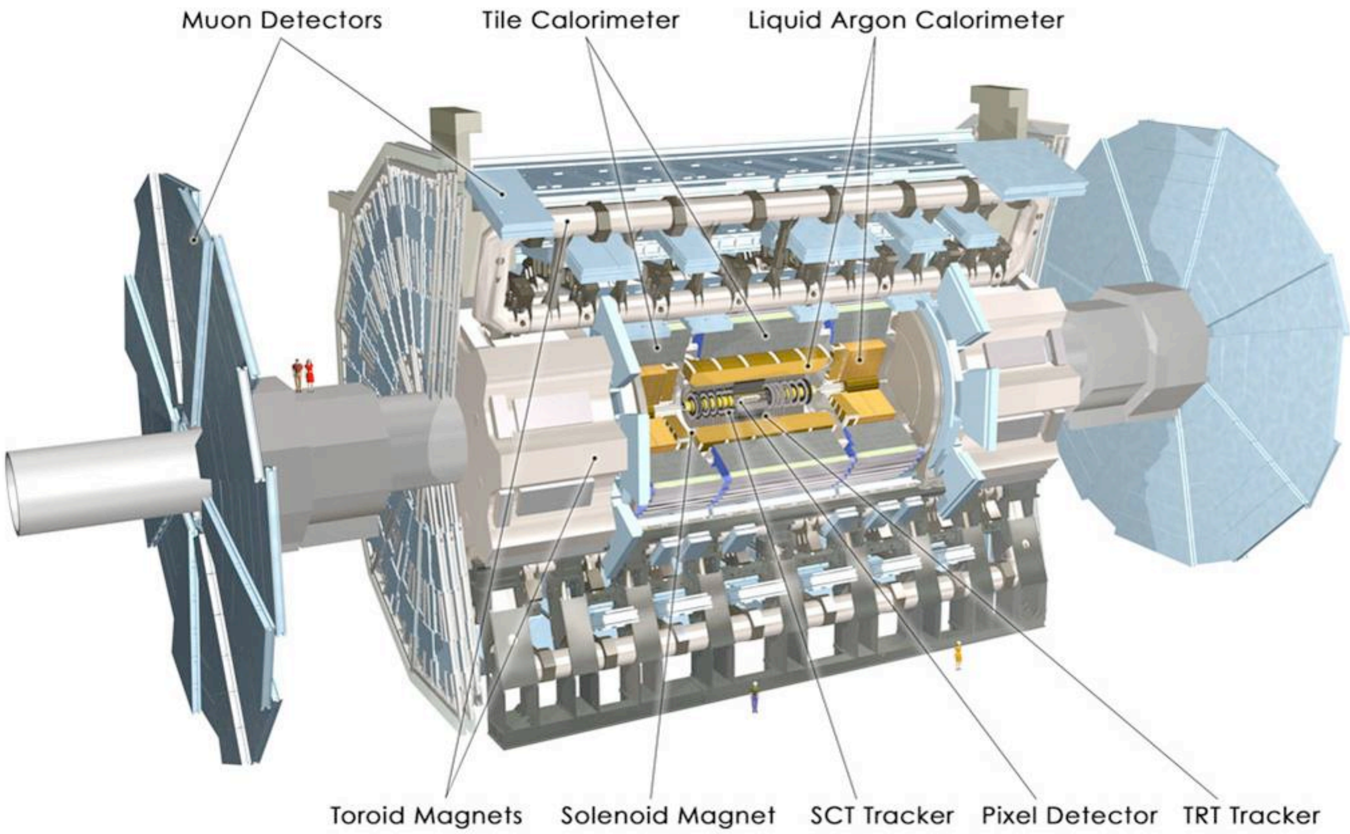
MSSM with R-parity violation, gauge-mediated SUSY, inelastic dark matter, Hidden Valley (HV) Scenarios, Split-SUSY, GMBS, mSUGRA, 4th generation fermions, ...

The leptonic jets provide unique signature, large cross section not excluded: potential for early discovery

Here focussing on Hidden Valley decays of Neutral Particles to leptonjets

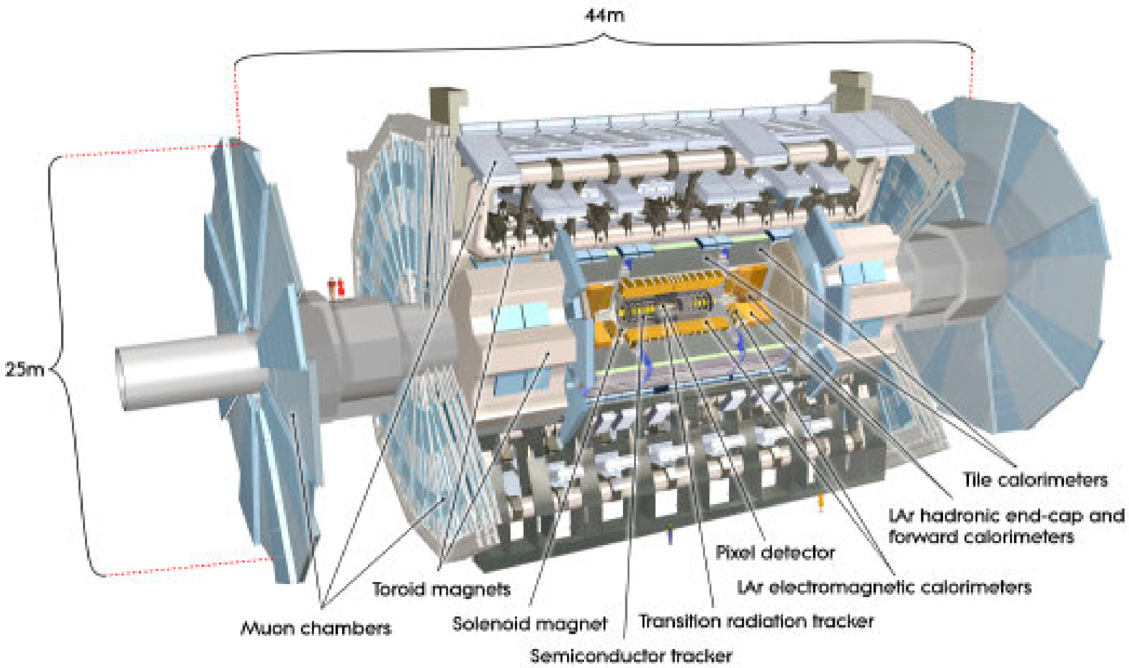
- exploring the challenges to the trigger posed by peculiar decay topologies
- designing new analysis strategies to maximize the discovery potential

The ATLAS apparatus



Discovers head-on collisions of protons of extraordinarily high energy

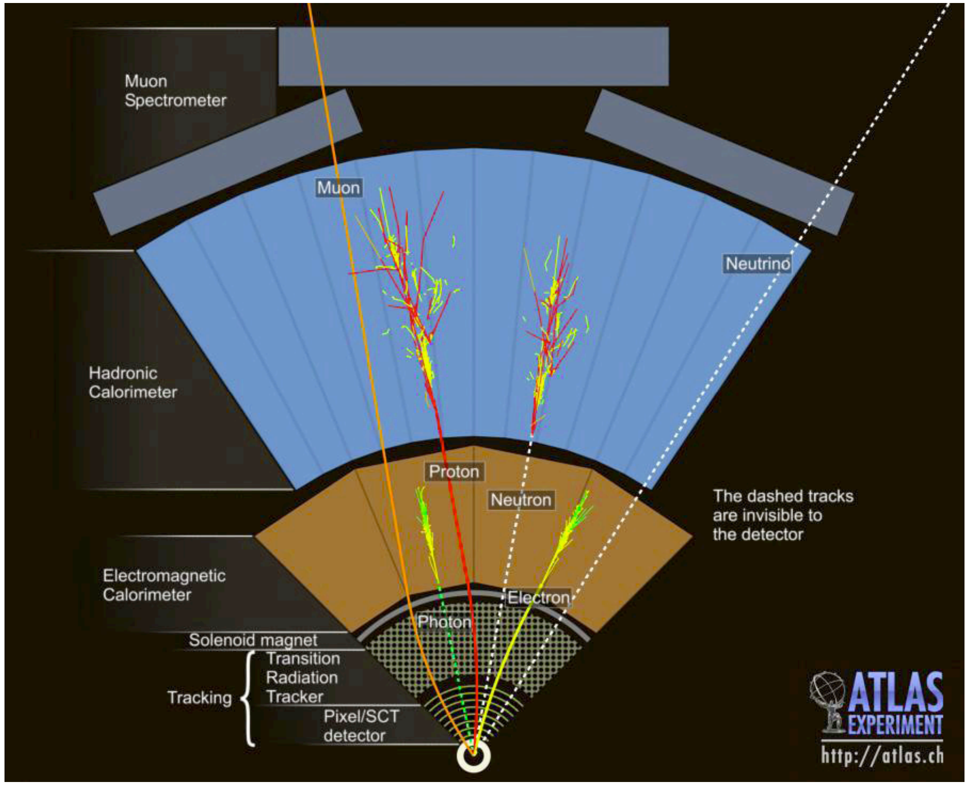
ATLAS detector



- ~44 m length, ~25 m diameter, ~7000 tons weight, ~10^8 electronic channels
- Inner Detector ($|\eta|<2.7$, B=2T): Si Pixel, Si strip, TRT. Precise tracking and vertexing; momentum resolution $\sigma/p_T \sim 3.8\ 10^{-4}\ p_T(\text{GeV}) \oplus 0.015$
- EM calorimetry: Pb-Lar accordion; e/γ trigger, identification and measurement; E_{res}: $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.007$; granularity: 0.025 x 0.025
- HAD calorimetry ($|\eta|<4.9$): Fe/scintillator Tile (central), Cu/W-Lar (fwd); E_{res}(Tile): $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$; E_{res}(fwd): $\sigma/E \sim 90\%/\sqrt{E} \oplus 0.07$; granularity 0.1 x 0.1;
- Muon Spectrometer ($|\eta|<2.7$): air core toroids with gas-based muon chambers. Momentum resolution ~10% up to 1TeV.
- 3-level trigger: reduce the rate to ~200 Hz

Signature for non hadronic jets

- Electrons: EM cluster in calorimeters with or without matching track
- Muons: matching track in ID and MS trackers or MS standalone reconstruction extrapolated to the IP



Non prompt objects require dedicated triggers and reconstruction algorithms

Recent searches at ATLAS

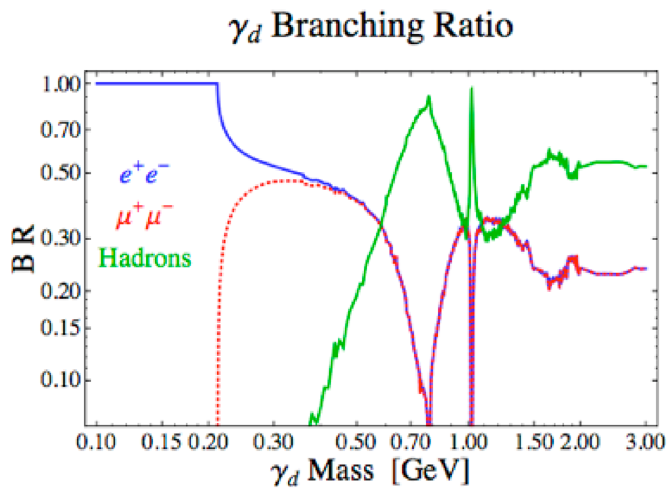
- Displaced muon jets **_ATLAS-CONF-2012-089_**

- Prompt lepton jets with muons **_ATLAS-CONF-2011-076_**

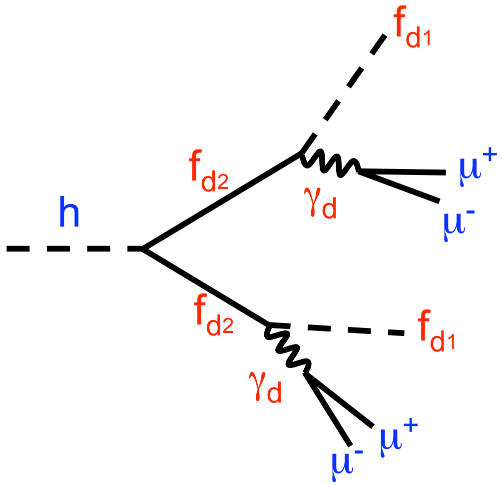
Displaced muon jets: model

"Hidden Valley" scenarios predicts

- Higgs boson decays in light particles of the hidden sector (γ_d dark matter candidate) that can decay back in the standard sector via collimated jets of leptons or light hadrons
- The BR of Higgs in hidden sector (HV) maximum for m_h<150 GeV
- Long lived hidden particles: displaced decays
- Possible missing energy
- Large BR($\gamma_d \rightarrow \mu\mu$) for $m_\gamma \in (0.2,0.7)$ GeV



Displaced muon jets: benchmark



- simplest topology

- hardest case: low visible energy and low particles multiplicity

Higgs mass (GeV)	f_{d2} mass (GeV)	f_{d1}mass (GeV)	γ_d mass (GeV)	$c\tau$ (mm)
100	5.0	2.0	0.4	47
140	5.0	2.0	0.4	36

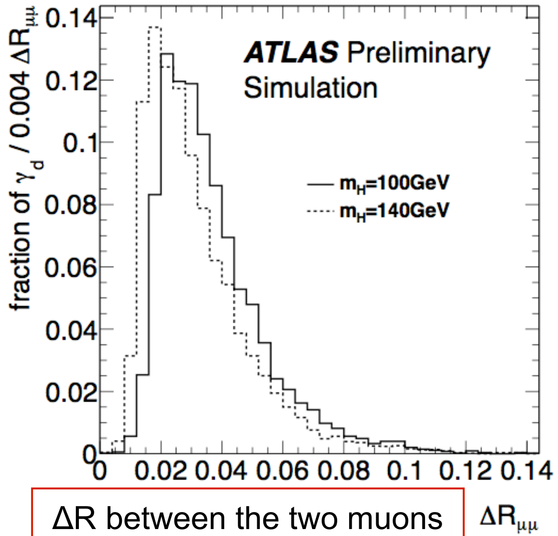
Lifetime chosen to get enough decays in each detector region (dark photon boost ~40)

For the dark photon mass chosen the decay BRs are expected to be:

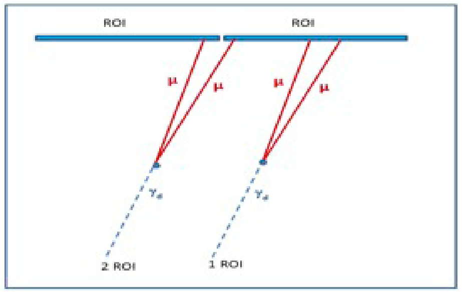
- BR($\gamma_d \rightarrow \mu^+\mu^-$ = 45 %)
- BR($\gamma_d \rightarrow e^+e^-$ = 45 %)
- BR($\gamma_d \rightarrow \pi^+\pi^-$ = 10 %)

Displaced muon jets: trigger

The signature is a pair of back to back $\gamma_d \rightarrow \mu^+\mu^-$. The muons have $\Delta R<0.1$ and quite low p_T (spectrum peak @ 7GeV). The trigger requires 3 muons in MS with p_T(@IP)>6 GeV and $|\eta|<2.4$ each

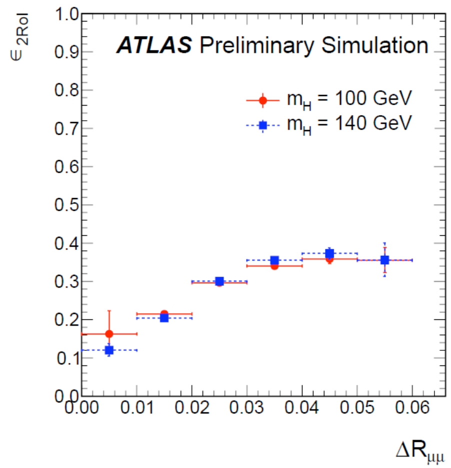


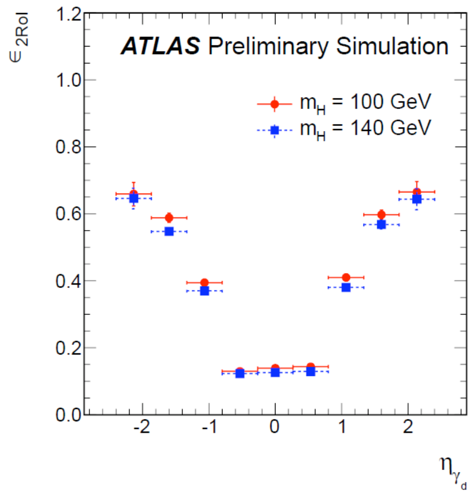
ΔR between the two muons



The trigger efficiency results quite low (~ 30% relative to offline). The reasons: $\Delta R_{\mu\mu}$ typically smaller then L1 granularity (0.2x0.2 for B and 0.1x0.1 for EC)

MC trigger efficiency validated with J/ψ data (T&P method on sub-sample $\Delta R_{T\&P}<0.1$ signal-like); relative difference between 2 estimates taken as systematic uncertainty on trigger efficiency: 10%

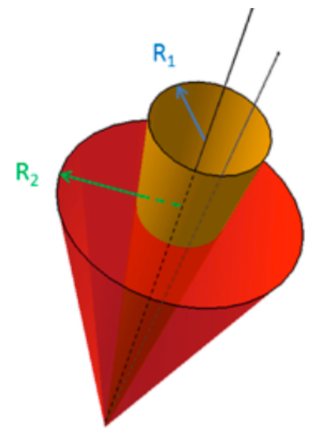




Displaced muon jets: reconstruction

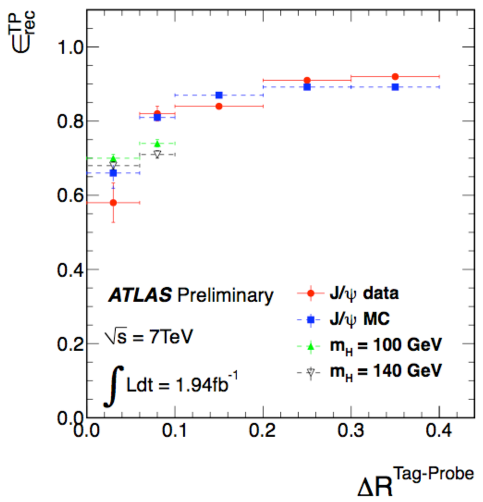
Displaced decays → use only muons reconstructed into the MS

- Muon jet contains
  - ✓ two collimated muons ($\Delta R<0.2$), $p_T>6$GeV and $|\eta|<2.4$ each
  - ✓ zero total charge
  - ✓ calorimeter isolation in hollow cone $0.2<\Delta R<0.4$ around each muon ($E_T<5$GeV)
  - ✓ scalar sum p_T of tracks in $\Delta R<0.4$ cone around each muon-jet < 3 GeV



- Single $\gamma_d \rightarrow \mu^+\mu^-$ reconstruction efficiency from signal MC after the offline selection
  - ✓ T&P method (tag is the leading muon of the pair)
  - ✓ Efficiency is the ratio between the number of the reconstructed γ_d after the offline selection and the number of γ_d with both muons with $p_T>6$GeV and $|\eta|<2.4$

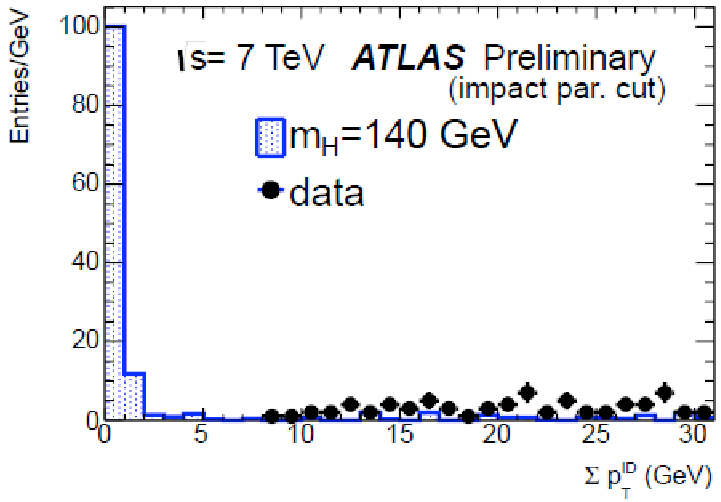
- Reconstruction efficiency validation using J/Ψ →μμ data and MC samples (T&P method)
  - ✓ Total difference between J/Ψ data and signal MC estimates for $\Delta R<0.1$ taken as systematic uncertainty: 13%



Displaced muon jets: selection

Data were collected in 2011 and represent an integrated lumi of 1.9/fb. The events have

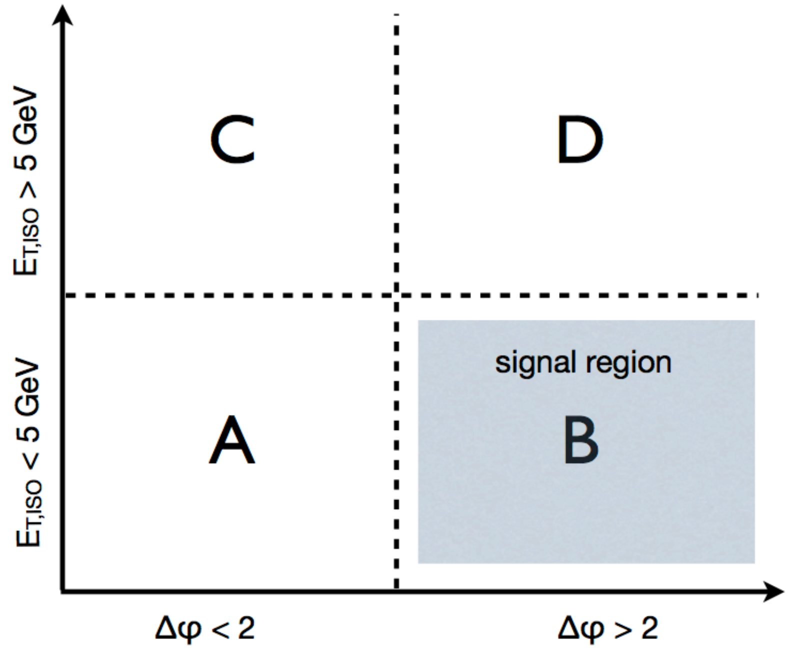
- 2 muon jets
- $\Delta\varphi > 2$ between the 2 muon jets
- Invariant mass of the 4 muons in the interval (20÷120) GeV
- d_0<200mm and $|z_0|$<270mm w.r.t. PV (remove cosmic background)



sample	2MJ	Final Selection
Cosmics	3.0±2.1	$0^{+1.64}_{-0}$
multi − jet		$0.059\pm0.015^{+0.66}_{-0.059}$
Total background		$0.059^{+1.64}_{-0.015}{}^{+0.66}_{-0.059}$
m_{Higgs} =100 GeV	$135\pm11^{+29}_{-21}$	$75\pm9^{+16}_{-12}$
m_{Higgs} =140 GeV	$90\pm9^{+17}_{-13}$	$48\pm7^{+9}_{-7}$
DATA	871	0

Displaced muon jets: bkg estimation

- Electroweak and ttbar
  - ✓ From simulation
  - ✓ Completely negligible after selection
- Cosmics
  - ✓ Evaluation from cosmic stream selecting the trigger in the empty bunch trigger
- QCD
  - ✓ Data driven estimation: ABCD method; use muon jet cal isolation and $\Delta\varphi$ as uncorrelated variables



isolation: both MJs in the event are isolated
anti-isolation: at least one not isolated MJ (bkg)

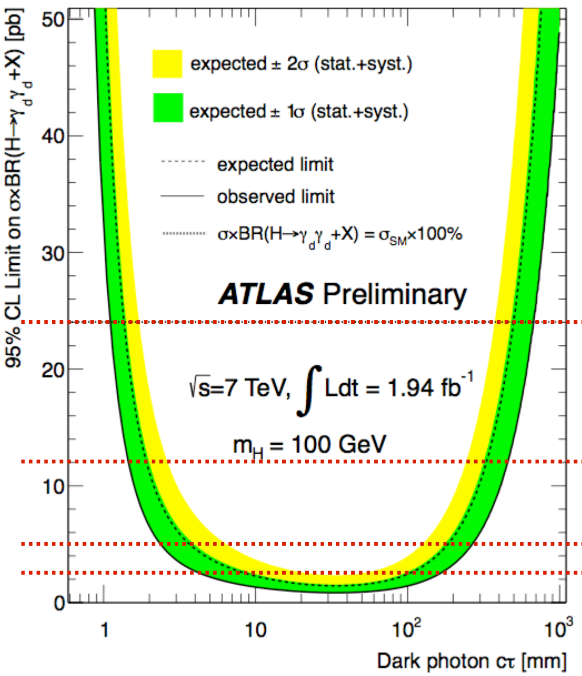
Number of bkg events in signal region: $N_B = N_D \cdot N_A / N_C$
where N_A, N_C and N_D are extracted by modelling Σp_T distributions with bifurcated gaussian templates with parameters fitted from the data in the corresponding regions and integrating the fitted function in the range $0 < \Sigma p_T < 3$GeV

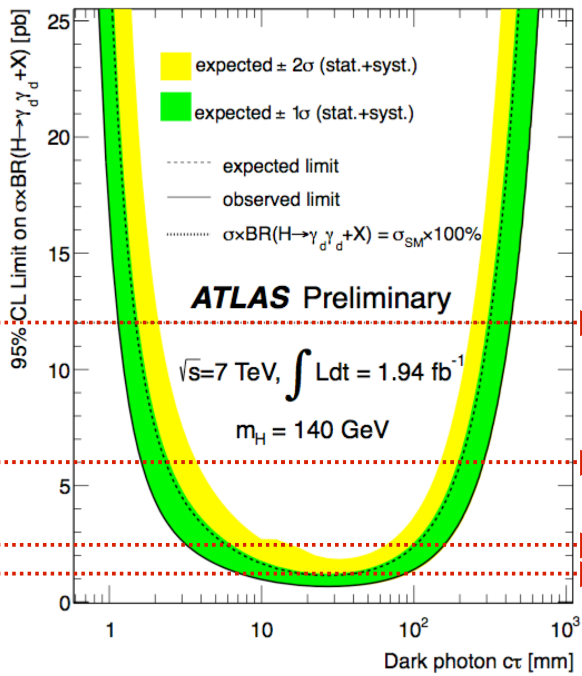
Displaced muon jets: limits

sample	$\Sigma\, p_T^{ID}$
Cosmics	$0^{+1.84}_{-0}$
multi-jet	$0.059 \pm 0.015 \pm 0.66$
sig(H_{100})	$75 \pm 9^{+16}_{-12}$
sig(H_{140})	$48 \pm 7^{+9}_{-7}$
DATA	0

MC events numbers normalized to 1.94 fb-1 integrated luminosity

Limits as a function of the proper decay length of the γ_d





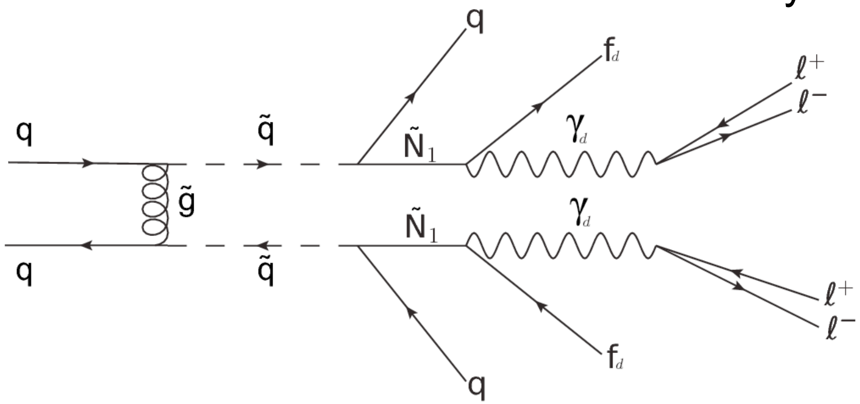
Ranges of γ_d proper decay lengths excluded at 95% CL for both Higgs masses

BR (%)	cτ (mm) m_H=100GeV	cτ (mm) m_H=140GeV
100	1.1÷674	1.2÷431
50	1.5÷455	1.6÷286
20	2.4÷260	3.3÷156
10	4.5÷159	7.3÷87

Lepton jets with muons: model

Several observations of abundances of cosmic e^- and e^+ reports unexpected large rates. Some dark matter experiments also show unexpected excesses over bkg. A “Hidden Valley” could explain these anomalies.

- ✓ Pair production of strongly interacting squark-gluinos, each cascade decay in LSP plus a jet. LSP is stable in MSSM instead it is allowed to decay into the dark sector



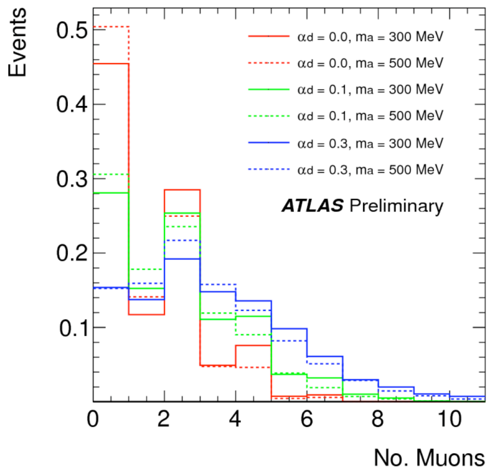
- ✓ Neutralino decays to a γ_d and a dark fermion (carrying SUSY R-parity), both of which have GeV-scale mass

- ✓ SPS1a SUSY parameters

- ✓ HV scenarios predicts $\gamma_d \to \mu^+\mu^-$, e^+e^- or $\pi^+\pi^-$. The γ_d is boosted and decay back to the SM particles in collimated jets of >= 2 leptons

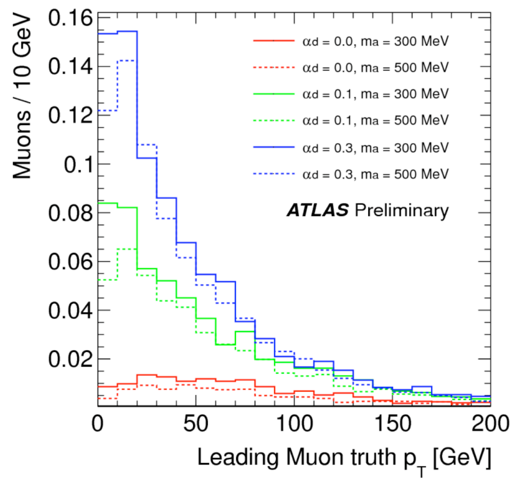
Lepton jets with muons: kinematics

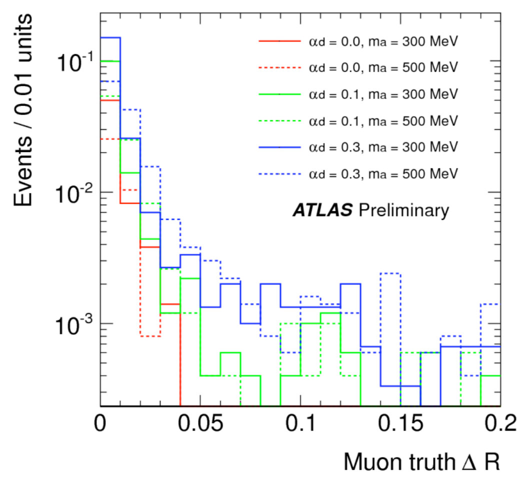
The dark fermion f_d can radiate other γ_d, thus increasing the the lepton multiplicity.



- The amount of radiation is determined by α_d (coupling with dark sector): small value produces simply jet of two leptons; larger values produce jets with additional prompt lepton pairs
- p_T and ΔR distributions varies with the number of γ_d into the event
- The γ_d mass determines the branching fractions and modifies p_T spectrum and the angular separation between the γ_d decay muons

Benchmark values of
α_d: 0.0, 0.1 and 0.3
and
γ_d mass: 300 and 500 MeV





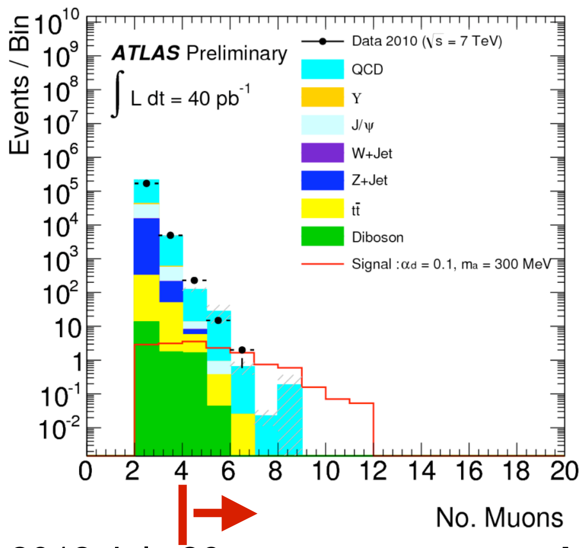
Lepton jets with muons: selection

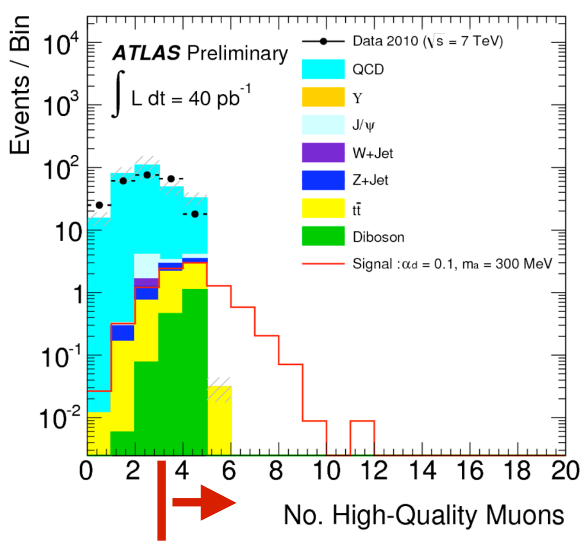
Data were collected in 2010 and represent an integrated lumi of 40/pb. The events have to

- pass a trigger that requires at least 2 separated muons with p_T(@IP)>6 GeV and $|\eta|<2.4$ each. (During the entire data taking the trigger was un-prescaled and the one with the greatest acceptance.)

- contain at least 4 reconstructed muons in the MS, each of them with a matched ID track, with p_T>7 GeV and within the ID tracking coverage, $|\eta|<2.5$, of which at least 3 must have χ^2/ndof < 5 (high quality muons)

- include the two muons satisfy the trigger





Cosmic muons bkg is negligible after requirements

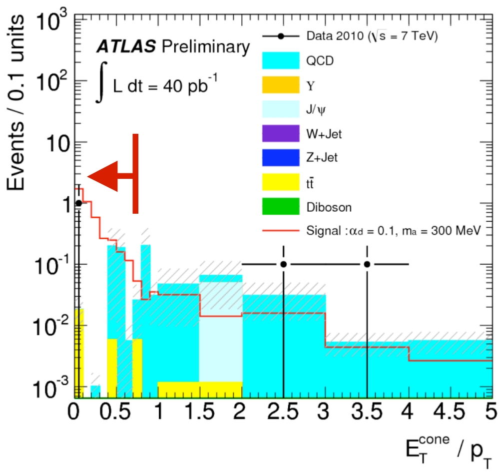
No. HQ mu plot is after 4 reconstructed muons cut

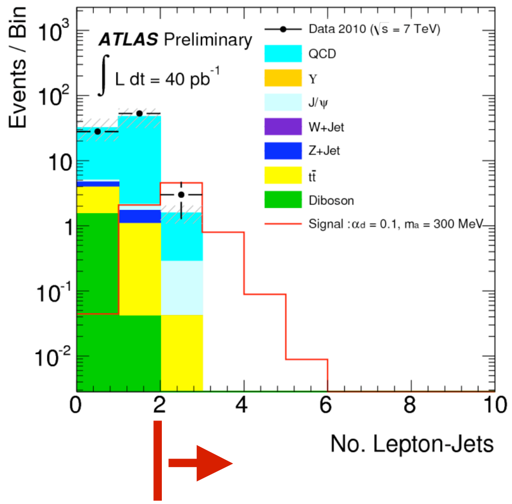
Lepton jets with muons: LJ reco.

LJ are reconstructed using an iterative cone algorithm around the leading muon

- Vector sum of muons momentum within $\Delta R<0.1$
- Center re-calculated after each addition
- LJ isolation calculated as the difference between the sum of E_T of the muons in a cone 0.3 and that in a cone 0.05

two such lepton-jets must have scaled isolation $E_T^{cone}/p_T < 0.7$





Distribution of the number of lepton-jets after requiring >= 4 muons in the event, of which >= 3 must satisfy the high-quality requirements.

Lepton jets with muons: QCD bkg

Main residual bkg after selection is QCD, which is accompanied by a large systematic uncertainty. Use the weight method to predict the background:

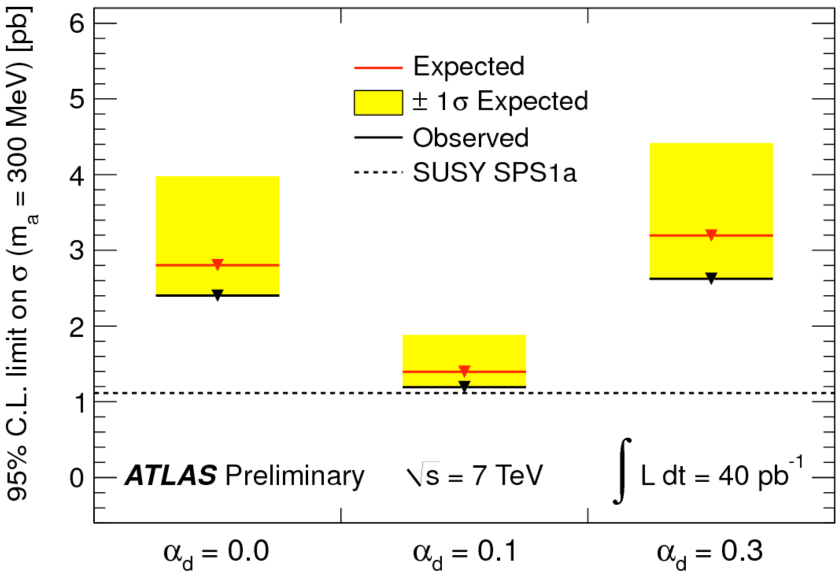
- Measure the probability of reconstructing a LJ made of at least 2 fake muons of which at least one is HQ muon in a DR<0.1 cone, using bkg-dominated data sample and a T&P method.
- Compute the probability *p* to have ≥ 4 fake muons of which ≥ 3 are HQ
- Replace the HQ cut with the weight equal to *p* and compute the number of QCD event in the signal reagion: 0.19±0.19 QCD events after all cuts.
- The ABCD method is used to cross-check the above predictions

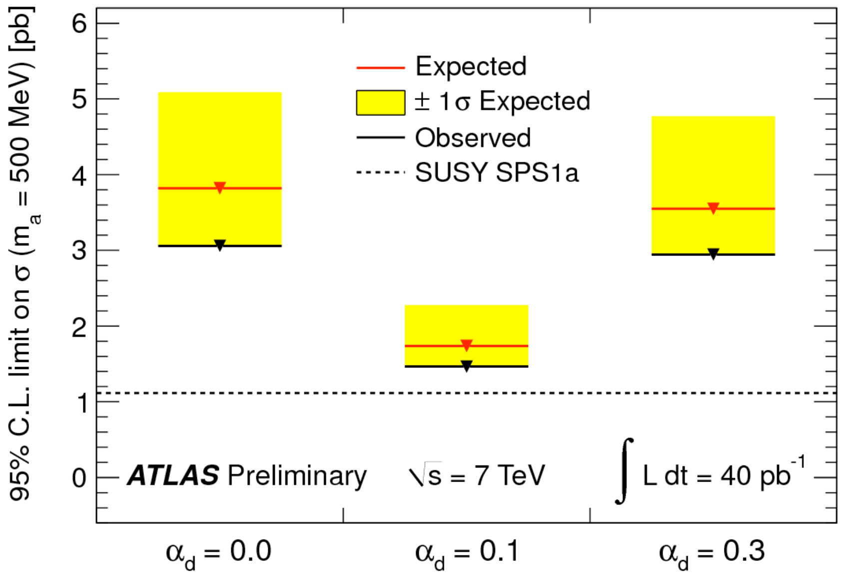
(A) Signal region: ≥4 muons, ≥ 3 HQ muons, 2 LJ with scaled iso <0.7 and muons with p_T≥7 GeV	**(B) Anti p_T region:** third and following muons with 4<p_T<7 GeV
(C) Anti isolation region: one or more LJ fails the isolation cuts	**(D) Anti both region:** third and following muons with 4<p_T<7 GeV and one or more LJ fail the isolation cuts

The ABCD method predict 0.11±0.11 bkg events into the signal region

Lepton jets with muons: limits

- Acceptance varies between 8 and 30% depending on the dark-sector showering parameter α_d
- No events seen, so set 95% CL limits on signal cross section
- CLs method with a Log-Likelihood-Ratio test statistic considering stat and sys uncertainties on each sample





Muon channel provides a unique and almost background-free signal

Conclusions

- Search in 1.94/fb 2011 data for no prompt pairs of back-to-back particles decaying to collimated muon pairs:
  - weak dependence of the γ_d proper decay length on m_H
  - exclude γ_d proper decay lengths ~1÷500 mm for 100% BR($H \rightarrow \gamma_d \gamma_d + X$)
- Search in 40/pb 2010 data for prompt highly-collimated pairs of muons
  - zero signal candidates were found after cuts
  - more stringent limits are set on α_d=0.0 and γ_d mass of 500MeV

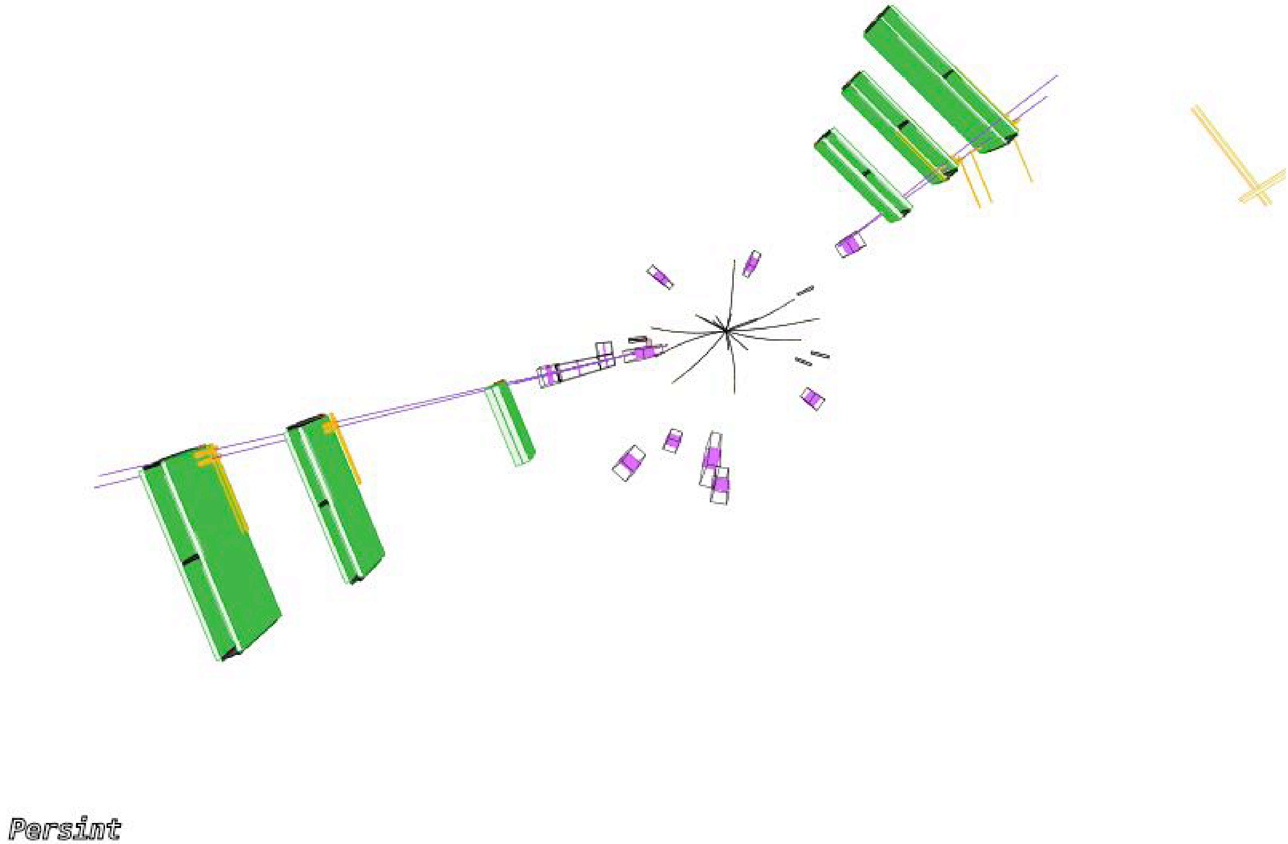
No hints for signal yet...
We'll continue to look at new signatures
and with more data in the years to come!

Next….

- ATLAS experiment plans to study other possible dark-matter signals, along with any associated production, like
  - Prompt electron jets
  - No prompt electron jets

Spares

Event display: $2(\gamma_d \rightarrow \mu^+\mu^-)$



(x,y) view of the Higgs decay into two $\gamma_d \rightarrow \mu^+\mu^-$. The muon energy loss in the calorimeters and the RPC hits in the muon spectrometer are clearly visible.