Search for non-prompt LeptonJets

X ATLAS ITALIA WORKSHOP ON PHYSICS AND UPGRADE
MILANO - FEB. 10/12 2015

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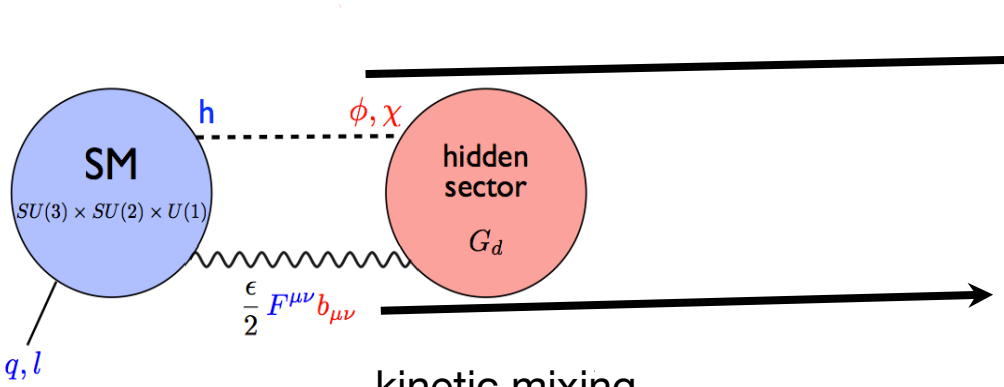
Outline

- Why look for LeptonJets?
- Non-prompt LeptonJets
- LeptonJet definitions and limitations
- "LeptonJet Gun" MC tool
- Triggers
- Major backgrounds
- Final products
  - Model dependence
  - Limits on Higgs→ LJ branching fractions
  - Efficiency tables
  - (m, ε) dark matter exclusion plot
- Run 2
  - Extending analysis coverage
  - Harmonization and Joint Efforts

Why look for LeptonJets?

Several BSM models predict the existence of a new (hidden) sector weekly coupled to SM



Portal to hidden sector: e.g. higgs or supersymmetric particles

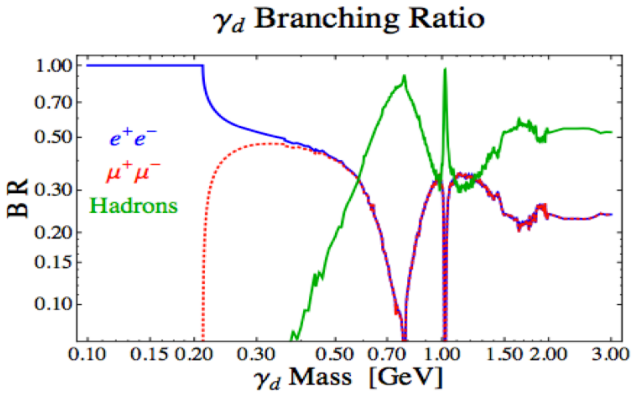
Lightest hidden particles (**dark-photons** (γ_d)) decay back, via kinetic mixing with standard photon, to collimated pairs of leptons or light hadrons.

LeptonJets (LJs): collimated jet-like structure from γ_d decays

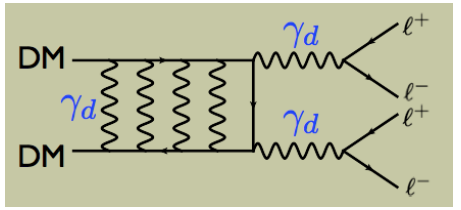
kinetic mixing

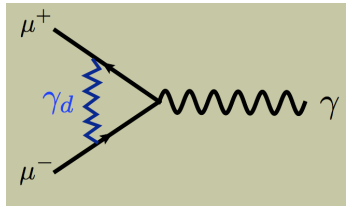
$$\mathcal{L} \supset \frac{\epsilon}{2} F^{\mu\nu} b_{\mu\nu} + m_{\gamma_d}^2 b^2$$

Dark photon lifetime depends on the size of kinetic mixing (ε)
small ε → displaced decays
LeptonJets can be prompt or **displaced**



- (Some) motivations
  - Excess of positron flux in cosmic rays (not anti-proton) → if DM annihilates to a hidden sector it would produce leptons
  - $(g_s\text{-}2)_\mu$ anomaly: comparing theory to experiment there is a 3.2σ discrepancy → anomaly can be explained including corrections from an hidden photon





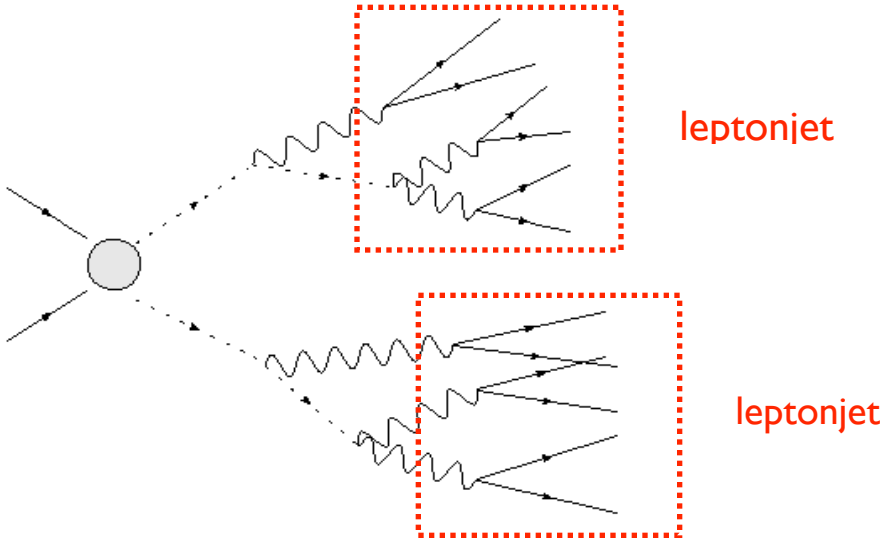
Non-prompt LeptonJets

When studying LJs, it is better to avoid focusing on one specific model (that can be more or less motivated), and try instead to use as much as possible an experimental definition that reproduces a set of signatures.

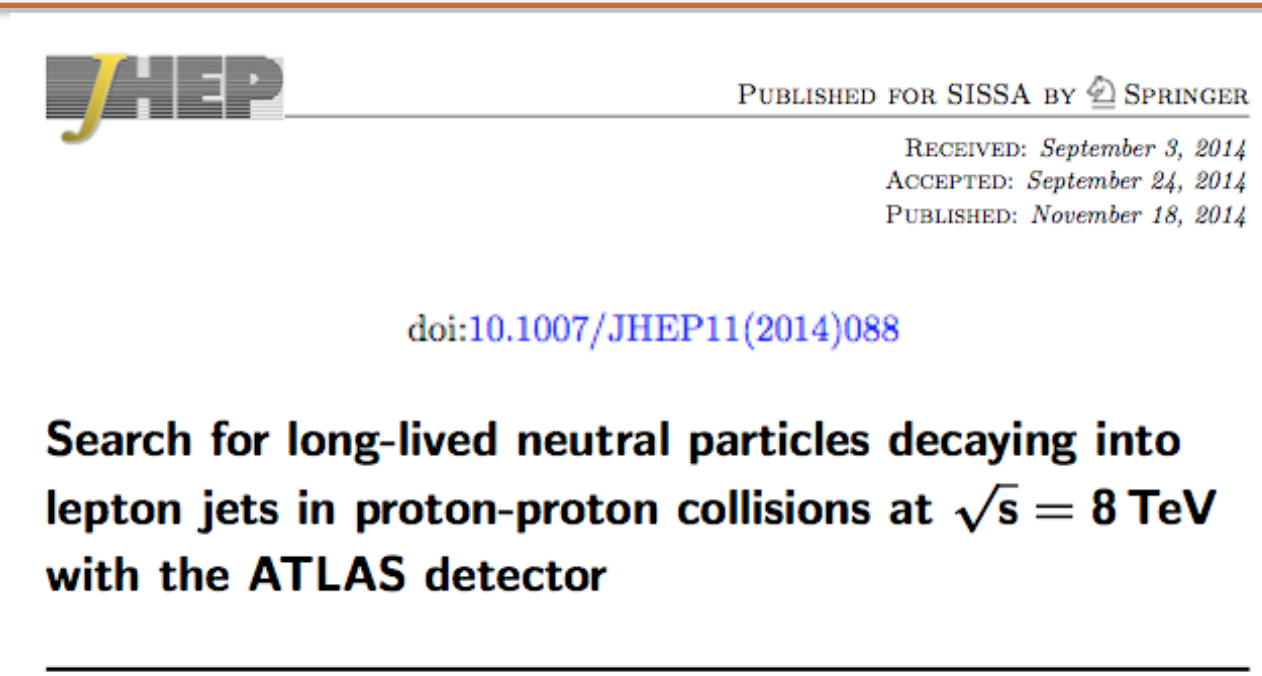
Model independent search strategy for non-prompt LJs: start from a general non-prompt LJ definition

LeptonJets: **N** neutral light dark photons in a narrow cone (ΔR) decaying to pairs of electrons/muons/pions → **lepton/hadron pairs in a narrow cone ΔR**

Non-prompt LeptonJets: LeptonJets with long-lived γ_d's (small ε) → **displaced decays highly isolated in ID**



Run1 search



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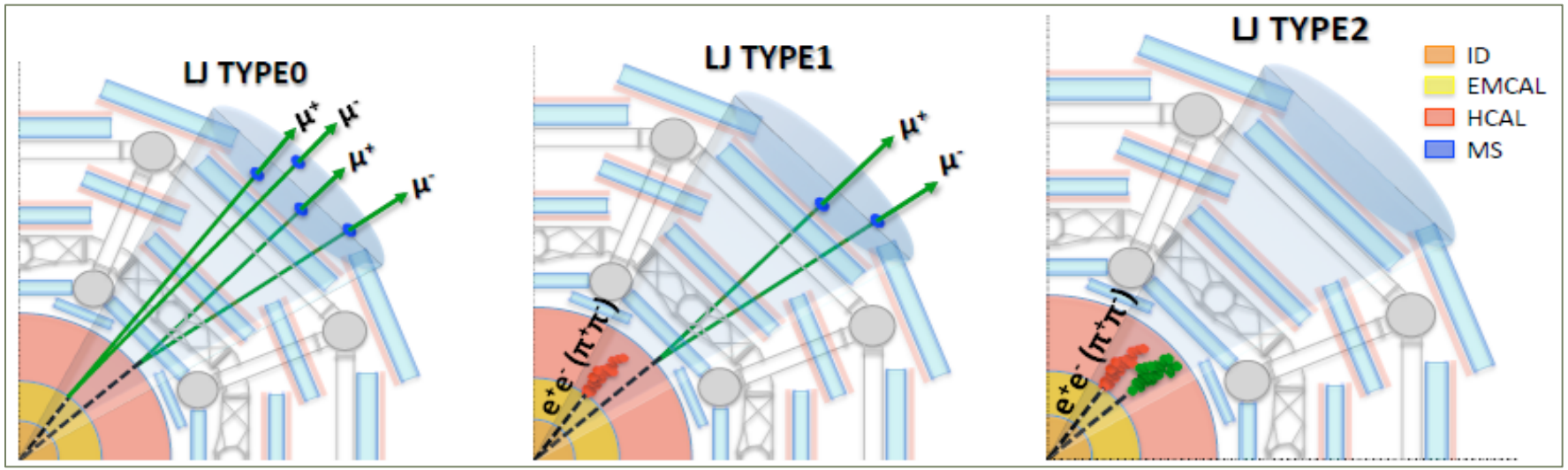
Search for long-lived neutral particles decaying into lepton jets in proton-proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector

- Analysis team
  - G. Ciapetti, S. Giagu - Sapienza & INFN ROMA1
  - A. Policicchio, M. Schioppa - U. Calabria & INFN LNF/CS
  - J. Ruderman and T. Volansky (STA)

LeptonJet Definitions...



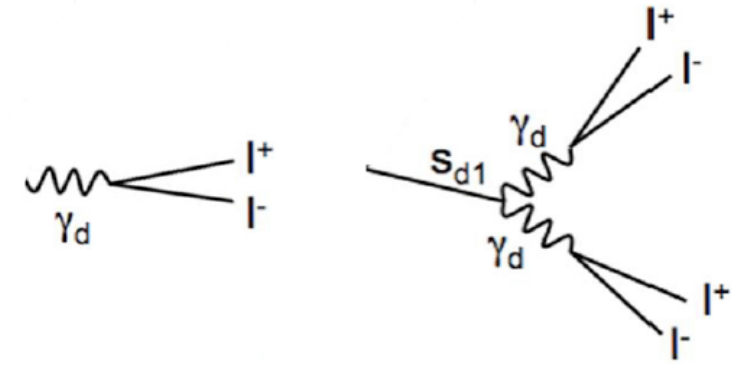
- Classify LJs into different types
- Most important kinematics variable: angular aperture of γ_d decay products
- Basic clustering algorithm with a cone of a given ΔR
- LJs with only muons:
  - Use MSonly muons, veto on combined muons (decay point beyond outermost pixel layer up to first trigger layer of the MS)
- LJs with only electrons/pions:
  - Use jets with low EM fraction (decays in HCAL)
- LJs with electrons/pions and muons
  - Use jets and MSonly muons (decays from IP up to the end of HCAL)

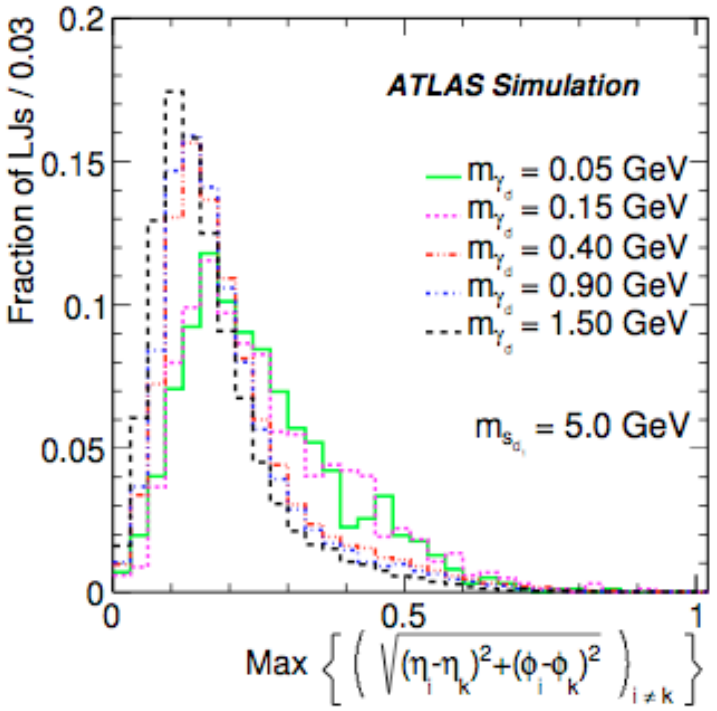
....and Limitations

- LJs with muon content:
  - Very close muon tracks → low reconstruction efficiency due to ambiguity-solving cuts for tracks sharing hits
    - ✦ In touch with MCP to test a new ambiguity-solving algorithm, work in progress
  - Investigate the possibility of implement a vertexing algorithm
    - ✦ would help to reduce QCD and cosmic backgrounds and to reconstruct the γ_d mass
  - Add a muons+EM cluster LJ definition (muon+electron LJs)
- LJs with only electrons/pions:
  - jets with low EM fraction → decays in ID/ECAL lost
  - investigate use of gamma-like EM cluster to extend search

“LeptonJet Gun” MC Tool

- Very useful tool to study the LJ signatures in the detector
- Simulates LJs with one or two γ_d’s
- Allows us to determine detector response
  - As a function of various LJ observables (composition, lifetime, opening angle, p_T)
  - For different models that produce LJs
- LJ gun MC samples valuable for finding suitable set of LJ selection cuts, estimating the corresponding detection efficiency, and defining the parameter space we can access
- Used for production of efficiency tables as a function of decay distance and transverse momentum
  - Constrain theoretical models predicting LJs
- In Run2 continue to use LJ gun extending the range of the LJ parameters





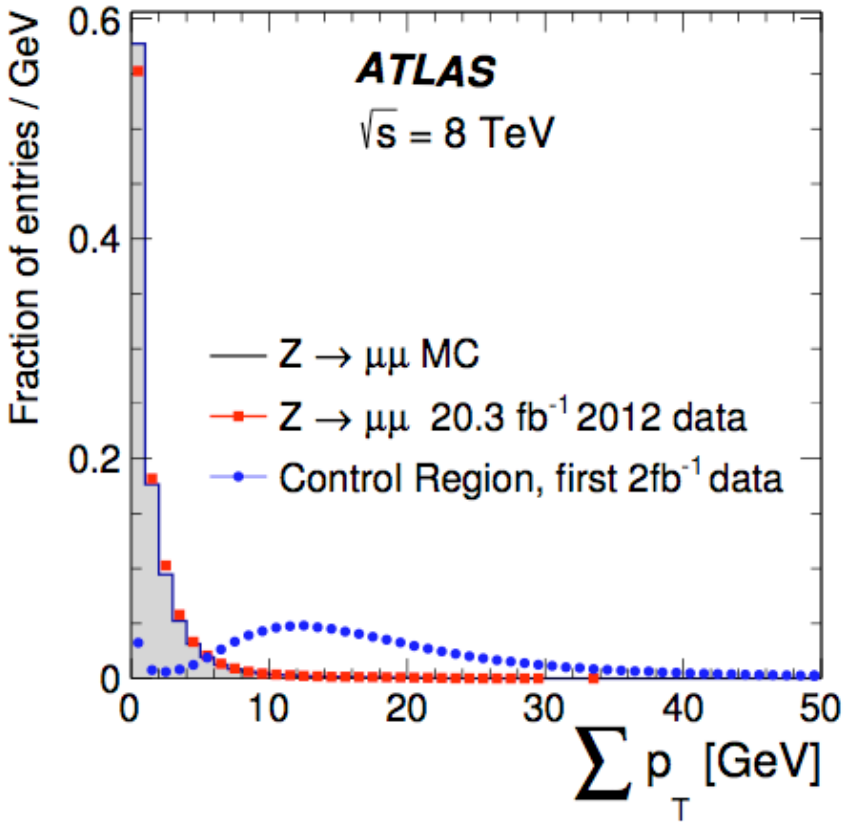
Triggers

- Triggers used in Run 1:
  - For LJs involving muons, 3mu6_MSonly
    - Does not require MS-ID muon tracks
    - Has fairly low p_T threshold
  - For LJs involving electrons/pions
    - High-threshold jet triggers too inefficient
    - Use “Calorimeter Ratio” trigger (a 35 GeV jet with very low EM fraction) – loses decays in ID / ECAL
- For Run 2, add
  - g35_medium1_g25_medium1 (for LJs with electrons)
  - mu20_MSonly_mu6noL1_MSonly_NS05 (for LJs with muons)
  - g12/15_loose1_2mu10_MSonly (for muon-electron LJs)

Major Backgrounds (I)

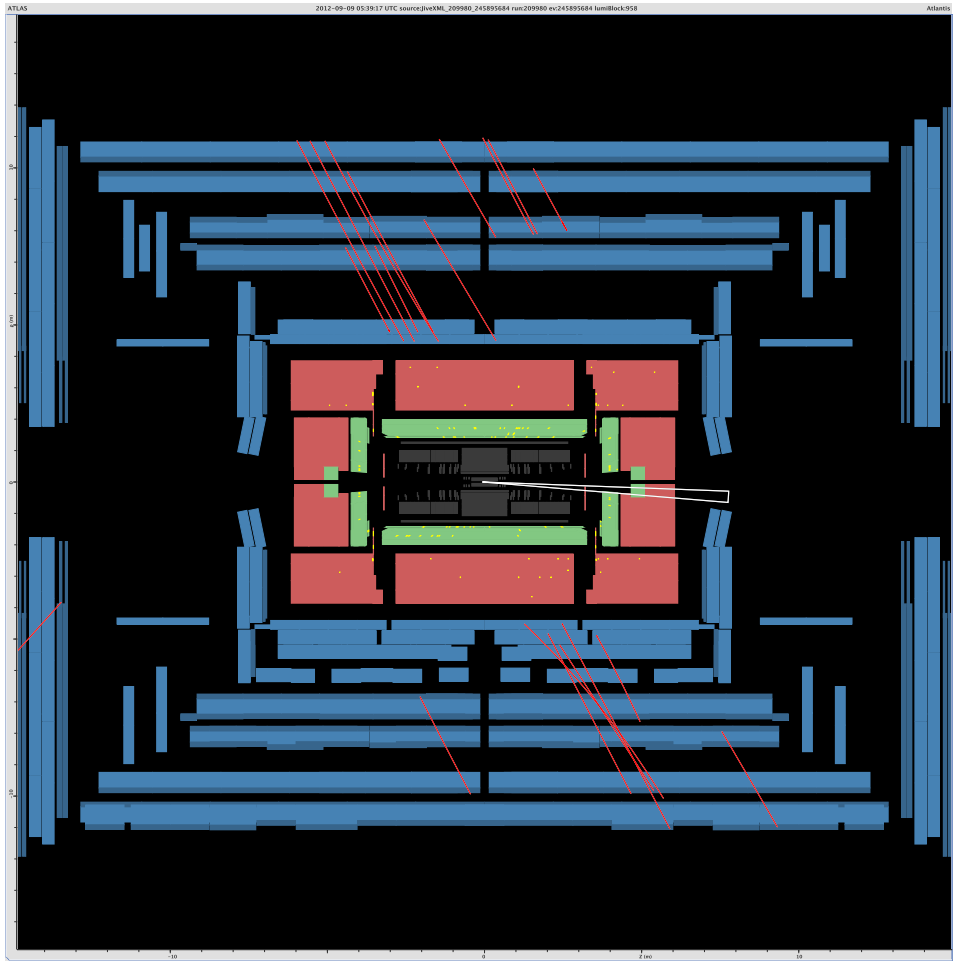
- QCD multi-jets
  - Cuts:
    - Small EM fraction
    - Narrow jet width
    - Track isolation around LJ direction in ID
  - Dijet background estimation: data-driven method, ABCD
  - Investigate use of BDT multivariate technique for Run 2
  - Also investigate use of jet substructure, possibly using particle-algorithms

Isolation in ID



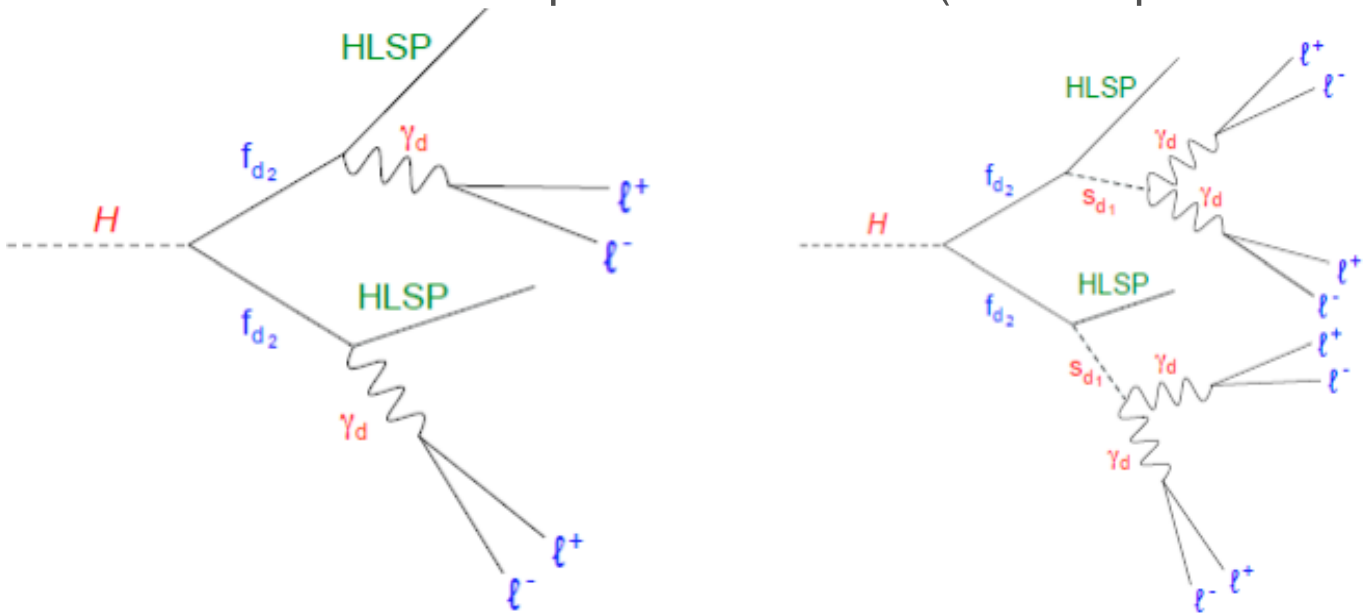
Major Backgrounds (II)

- Cosmic ray muons
  - Cuts:
    - Perigee parameters of muon tracks
    - Jet timing
  - Background estimation: data-driven, using empty bunch crossings
  - For Run 2, investigate cosmic muon bundle removal
- Beam-induced
  - Some cuts available at the trigger level
  - For Run 2, investigate removal using muon segments in EndCap to further reduce BIB



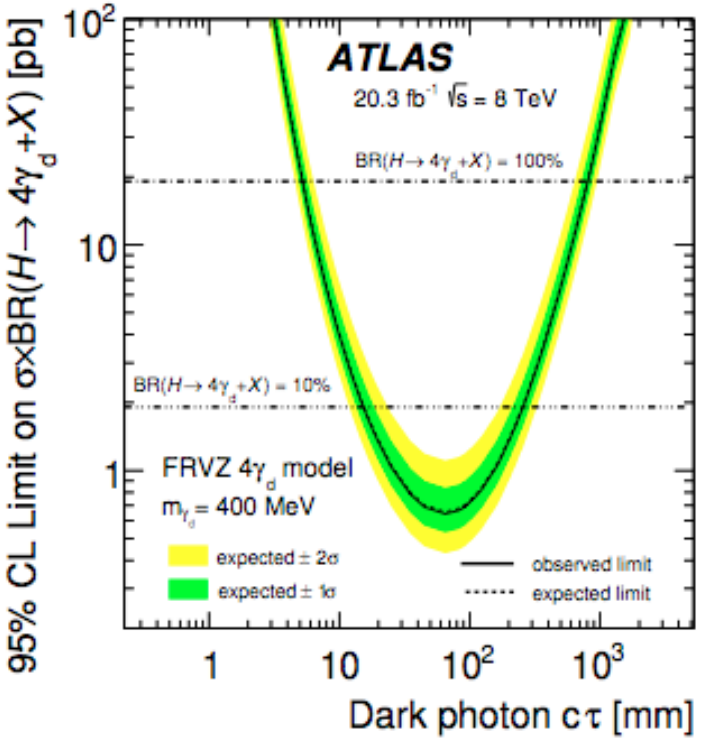
Final Products

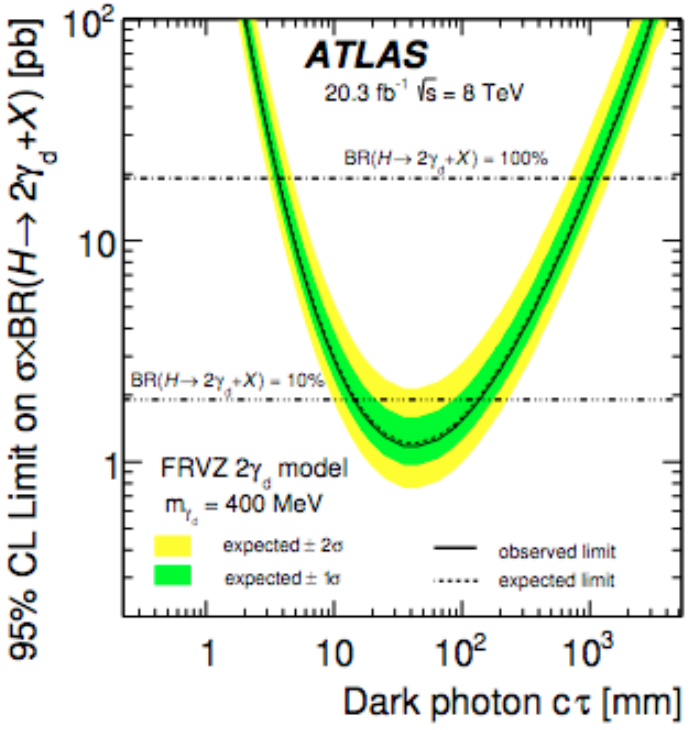
- No excess of events observed over the estimated background to the LJ signal
- Need to choose a specific model for limit-setting, even though the rest of the analysis is model-independent
  - Used two FRVZ models (kinetic mixing portal) as benchmarks
  - Assumed Higgs production via gg fusion
  - Custom MC (MadGraph5 + BRIDGE + PYTHIA8) used
    - ✦changed over to standard ATLAS production chain (MadGraph5 + PYTHIA8) for Run 2



Final Products

- Exclusion limits on Higgs [σ x branching fraction to LJs] in benchmark models, as function of γ_d lifetime
  - Likelihood-based simultaneous CLs ABCD method
  - RooFit workspace takes into account all background contaminations, signal leakages into control regions, systematics, etc.

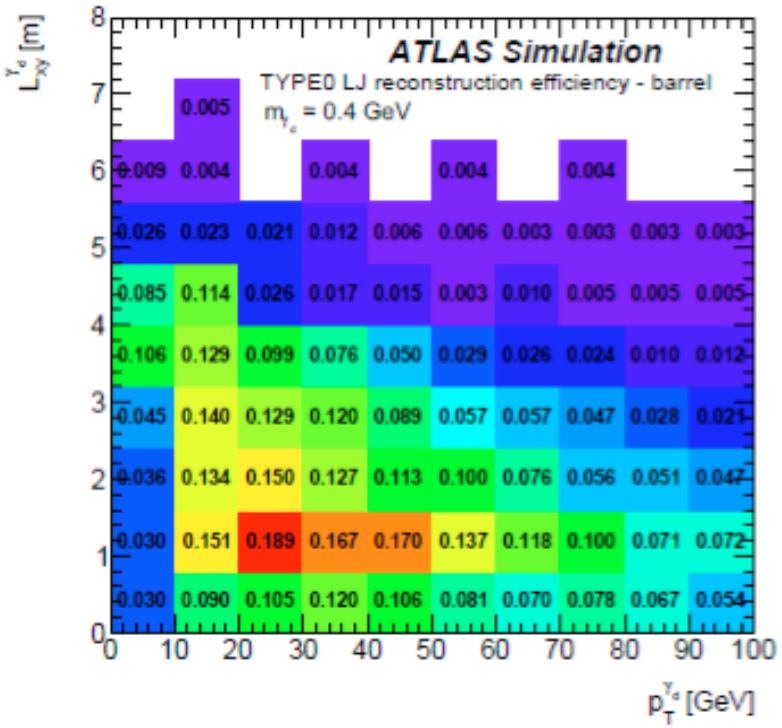


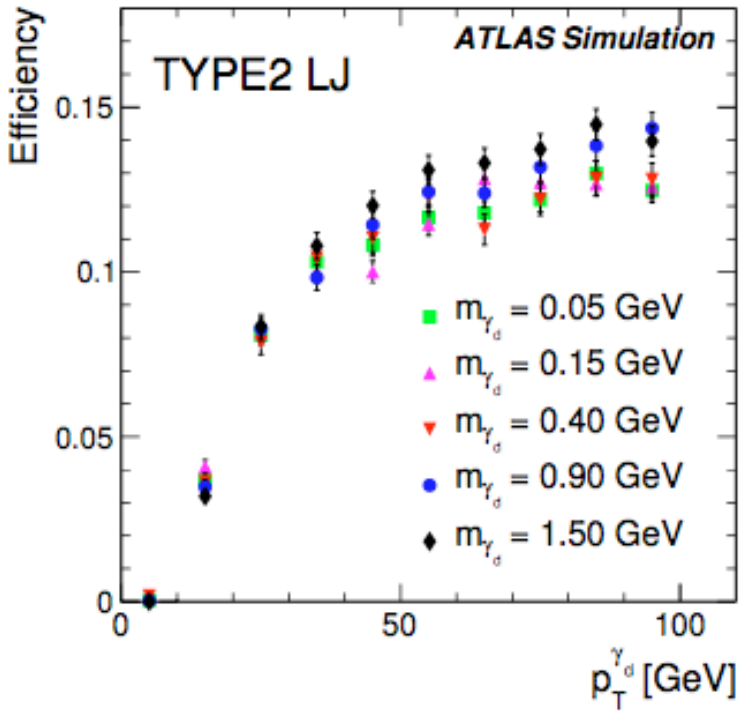


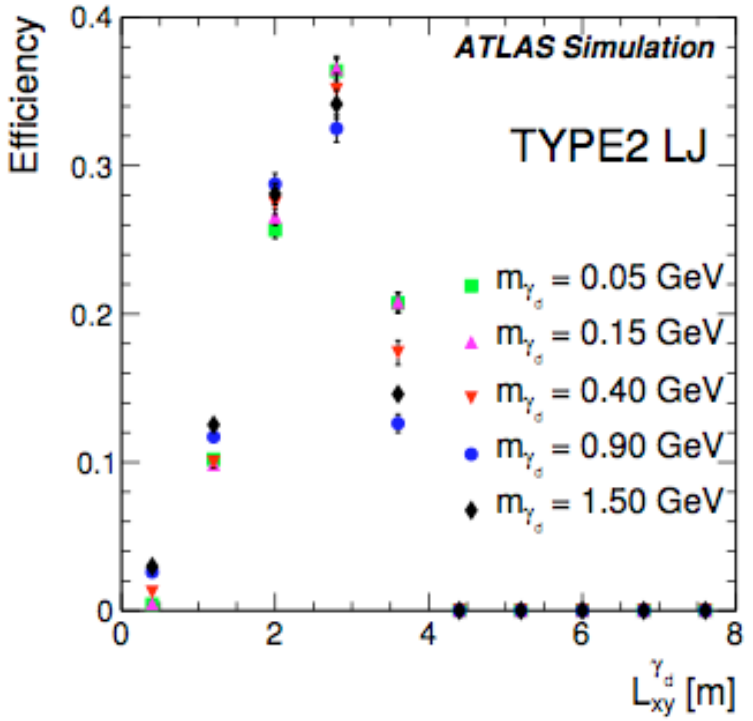
FRVZ model	Excluded $c\tau$ [mm] BR(10%)
$H \to 2\gamma_d + X$	$14 \leq c\tau \leq 140$
$H \to 4\gamma_d + X$	$15 \leq c\tau \leq 260$

Final Products

- Detection efficiency tables obtained with the LJ gun MC tool
- Useful for “recasting” analysis using somewhat different model assumptions

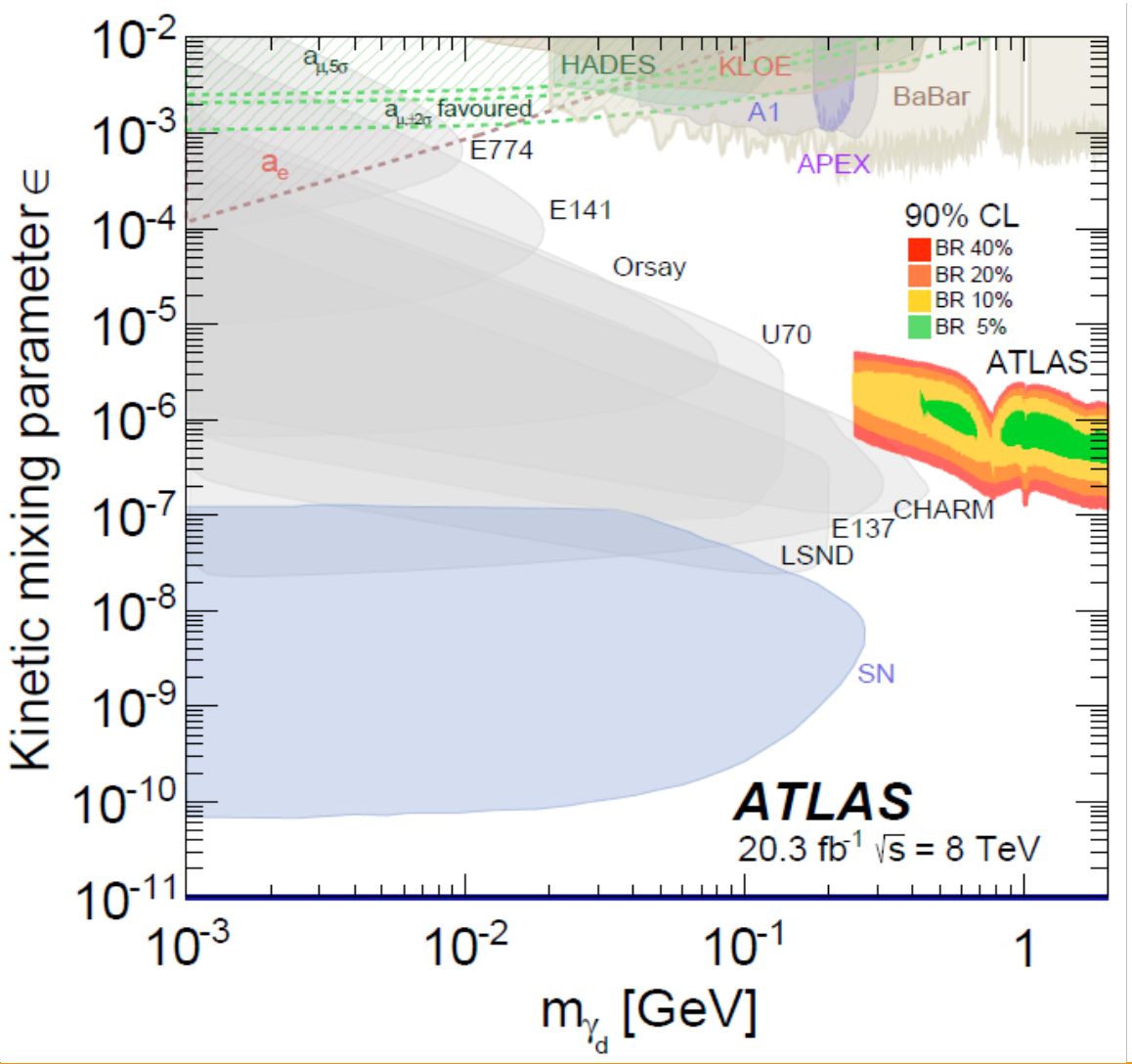






Final Products

- Interpretation in Vector Portal model, as exclusion contours in [γ_d mass, ε] plane
  - "Standard" dark matter exclusion plot that allows comparisons with wide variety of other experiments
  - Our limits have an extra parameter (BR for H → hidden sector)
  - An extended version will be released for Moriond including prompt LJ and H→2z_d, H→zz_d (high dark photon masses) results



Extending Coverage

- Higher Higgs masses
  - In case of extended Higgs sector, could have heavier Higgs decaying to LJs
  - Can implement in new MC (MadGraph5 + PYTHIA8) framework
- Higher γ_d masses
  - Run 1 limits in [γ_d mass, ε] plane abruptly cut off at 2GeV
- New final states with electrons produced in interval [few cm from IP, HCAL]
  - LJ reconstructed as EM cluster (photons)
- Other LJ production models
  - Higgs Portal
  - W/Z associated
    - Use of high p_T single (isolated) muon and electron triggers
  - SUSY

Harmonization & Joint Efforts for Run 2

- Joint effort with $H \rightarrow 2z_d$ group
  - $H \rightarrow 2z_d$ used Higgs portal model, while we used kinetic mixing portal model… but can have Hidden Abelian Higgs models incorporating both
  - $H \rightarrow 2z_d$ looked only at *distinct* leptons as LJ products
  - If we use HAH model and harmonize parameters for MC signal production, can put limits on same [γ_d mass, ε] plot: LJ covers lower z_d mass range, distinct leptons covers higher
- Harmonization with Prompt LJ search
  - Complementary results in [γ_d mass, ε] plane
- Dual-use LJ tool that can be used by other groups to easily incorporate LJs into their analyses
  - Will run over DxAODs produced with EXOT13 derivation
  - Will find LJs, create container of LJ objects, and facilitate basic analysis of the LJs

Manpower

- More manpower wrt Run1
- Analysis team for Run2
  - G. Ciapetti, S. Giagu - Sapienza & INFN ROMA1
  - A. Policicchio, M. Schioppa, M. Del Gaudio - U. Calabria & INFN LNF/CS
  - M. Diamond - U. Toronto
  - J. Saler - Tokyo IT
  - J. Ruderman and T. Volansky (STA)
- Ambitious analysis program → room for other LJ enthusiasts

Summary

- Models predicting LeptonJets are theoretically and experimentally well motivated
- Clear signature in the detector even if displaced decays are challenging from the reconstruction and trigger point of view
- Fruitful analysis program carried out in Run1
  - PLB 721 (2013) 32 - 2fb^{-1} @ 7 TeV
  - JHEP 11 (2014) 088 - 20.3fb^{-1} @ 8 TeV
- Ambitious analysis program for Run2
  - preparation has started
- Increasing interest on this topic
  - LPCC Collider cross-talk on February 26th

Backup

Major Systematics

Cosmic-ray bg estimation	22%
Multi-jet bg estimation	15%
p_T resolution for γ_d	10%
Higgs production σ	8%
Trigger	5.8% (multi-muon), >11% (CalRatio)
Muon reco efficiency	5.4%
Pile-up effect on isolation	4.1%
Luminosity	2.8%
JES	0.9% - 1.7%

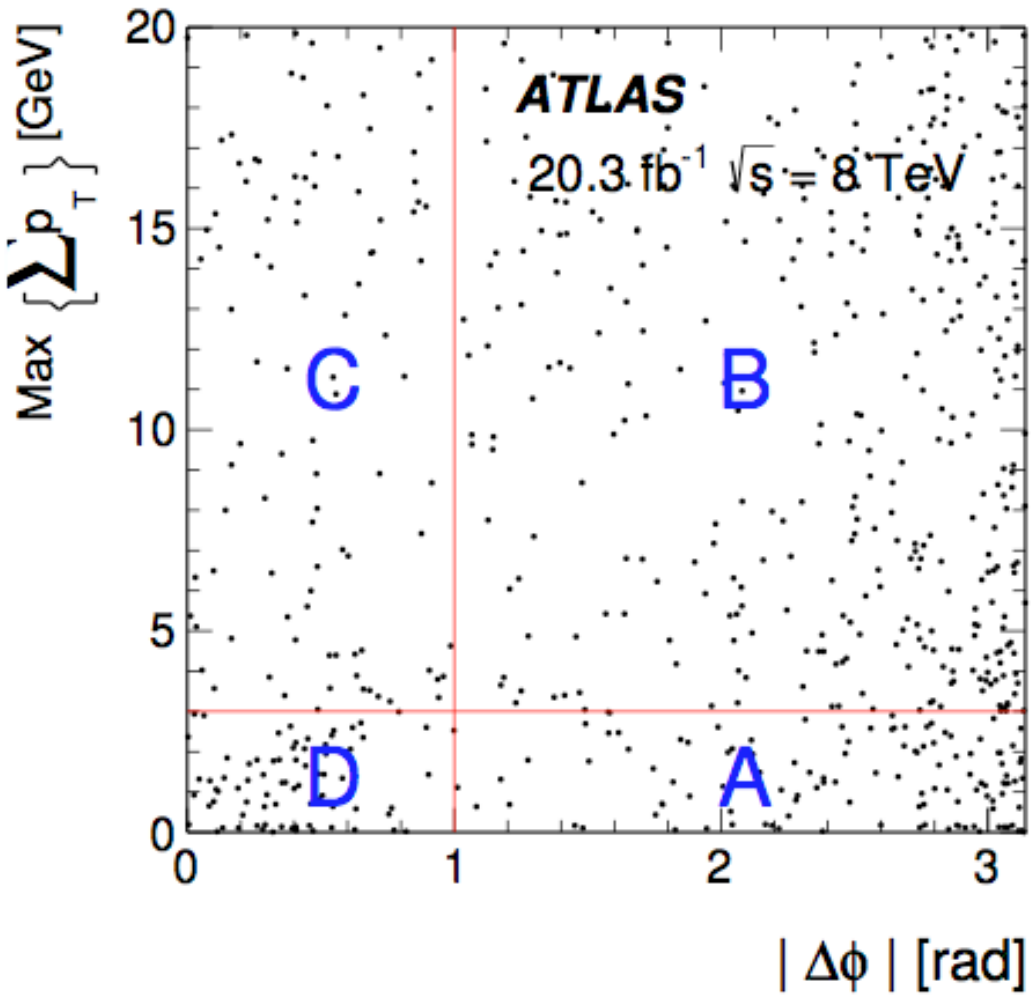
Cut-flow

Requirement	Description
Two reconstructed LJs	select events with at least two reconstructed LJs
η range (TYPE1)	remove jets with $\lvert\eta\rvert > 2.5$
η range (TYPE2)	remove jets with $\lvert\eta\rvert > 2.5$ and $1.0 < \lvert\eta\rvert < 1.4$
EM fraction (TYPE2)	require EM fraction of the jet < 0.1
Jet width W (TYPE2)	require width of the jet < 0.1
Jet timing (TYPE1/TYPE2)	require jets with timing -1 ns $< t < 5$ ns
NC muons (TYPE0/TYPE1)	require muons without ID track match
ID isolation	require $\max\{\Sigma p_{\mathrm{T}}\} \leq 3\,\mathrm{GeV}$
$\Delta\phi$	require $\lvert\Delta\phi\rvert \geq 1$ rad between the two LJs

Cut-flow on data

LJ pair types	0-0	0-1	0-2	1-1	1-2	2-2	All
Trigger selection	9.226×10^6						
Good primary vertex	9.212×10^6						
Two reconstructed LJs	946	1771	16676	1382	19629	82653	123057
η range (TYPE1/TYPE2)	946	1269	5063	701	3838	25885	37702
EM fraction (TYPE2)	946	1269	393	701	172	4713	8194
Jet width W (TYPE2)	946	1269	350	701	148	3740	7154
Jet timing (TYPE1/TYPE2)	946	1054	216	547	92	578	3433
NC muons (TYPE0/TYPE1)	27	3	42	5	5	578	660
ID isolation	12	0	19	4	3	160	198
$\lvert\Delta\phi\rvert$	11	0	11	4	3	90	119

Background estimation



ALL LJ PAIR TYPES

Data Type	Events in B	Events in C	Events in D	Expected Events in A
Cosmic-ray data	0	0	60 ± 13	40 ± 10
Data (cosmic rays subtracted)	362 ± 19	99 ± 10	19 ± 16	70 ± 58

TYPE 2-2 EXCLUDED

Data Type	Events in B	Events in C	Events in D	Expected events in A
Cosmic-ray data	0	0	3 ± 3	29 ± 9
Data (cosmic rays subtracted)	29 ± 5	15 ± 4	6 ± 4	12 ± 9