New Physics Searches Using Novel Topologies

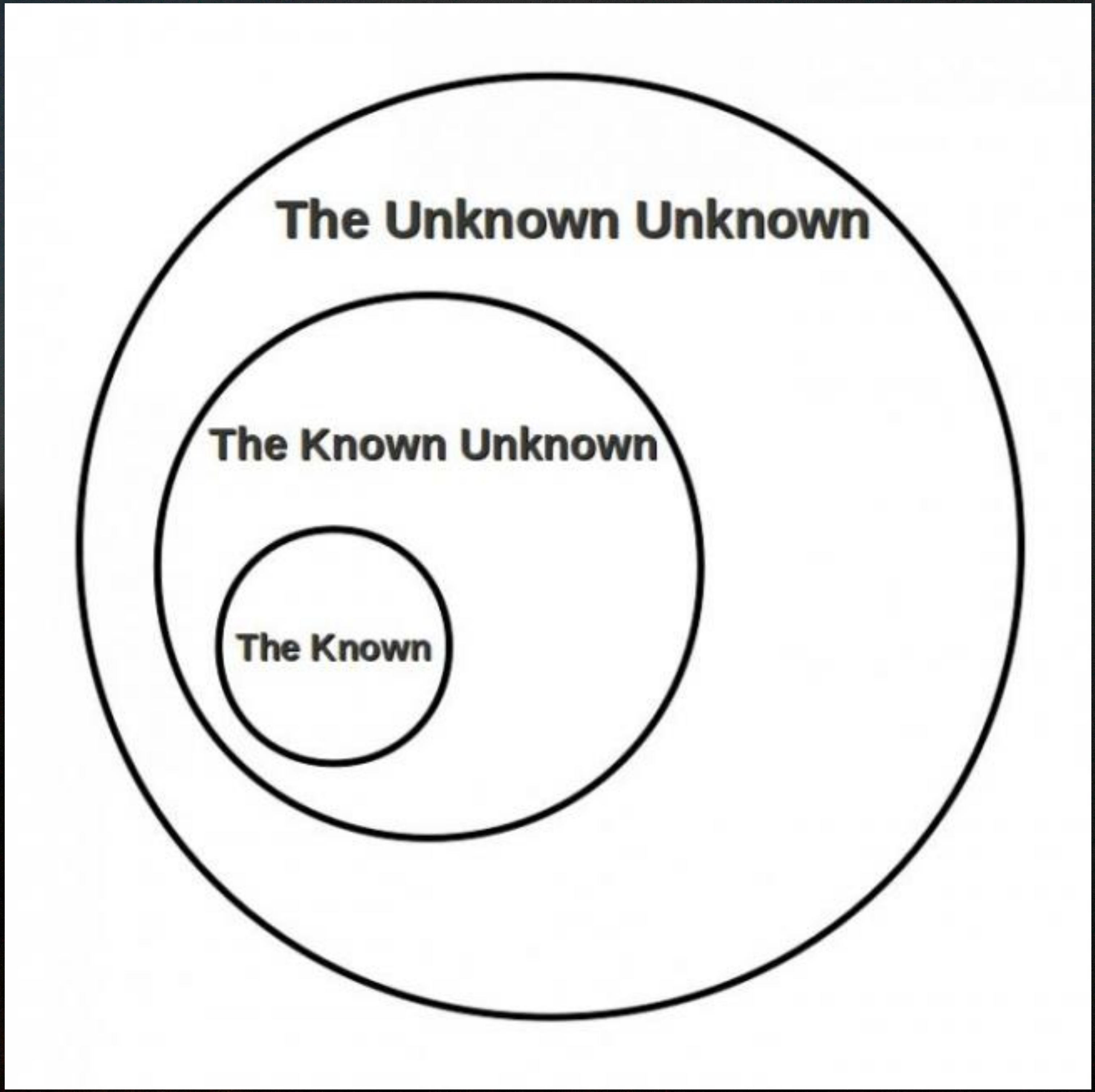
Deepak Kar
University of Witwatersrand (South Africa)

ICHEPAP, 2023, SINP

What do we do at the LHC?


Search for signatures of new physics

Search for signatures of new physics



However ...

Novel?

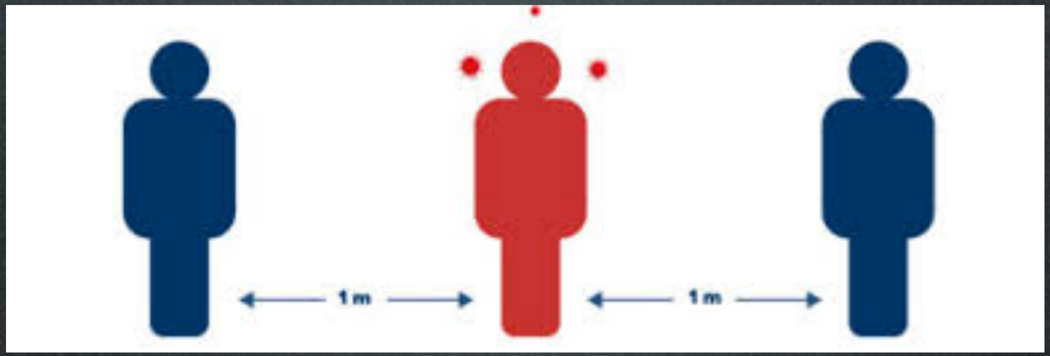
Unexplored signatures ignored so far ...

Novel?

Unexplored signatures ignored so far ...

Events we typically do not look at!

Principle of (social) distancing in object reconstruction!

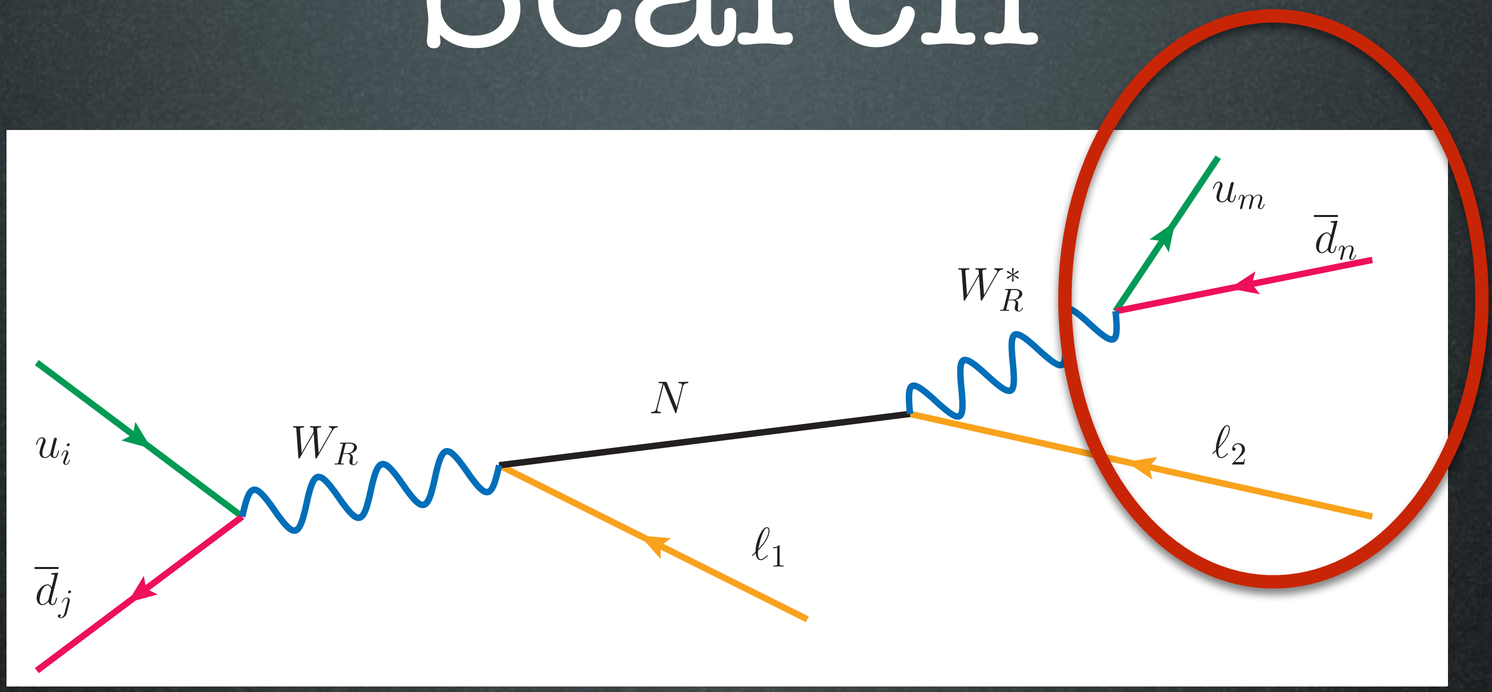


we followed it before it was cool …

Principle of (social) distancing in object reconstruction!

- Object reconstruction algorithms run independent of one another
- Same detector signature can result in multiple objects being reconstructed, results in fakes!
- Electrons as jets, and vice versa (jets contain neutral pions!)
- Overlap removal to address the double counting

Boosted Heavy Neutrino Search

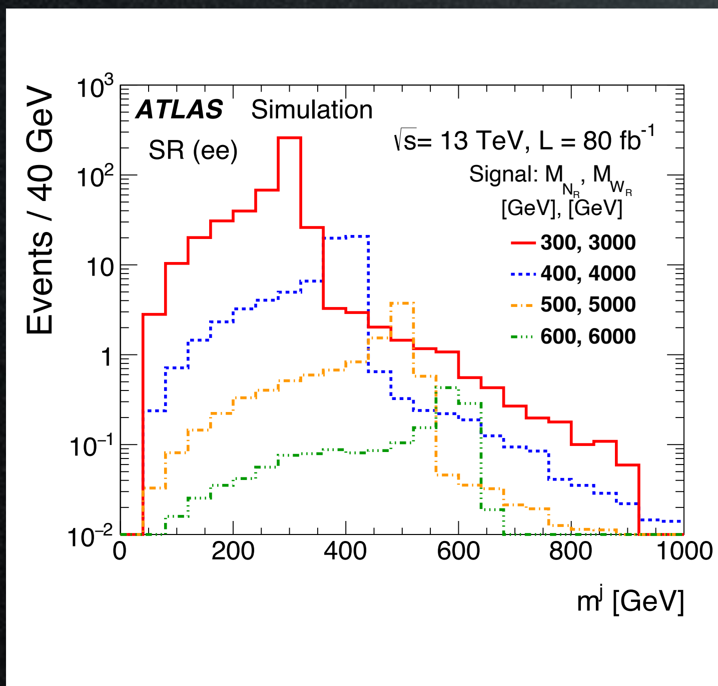


Boosted heavy neutrino search:
electron in a large-radius jet

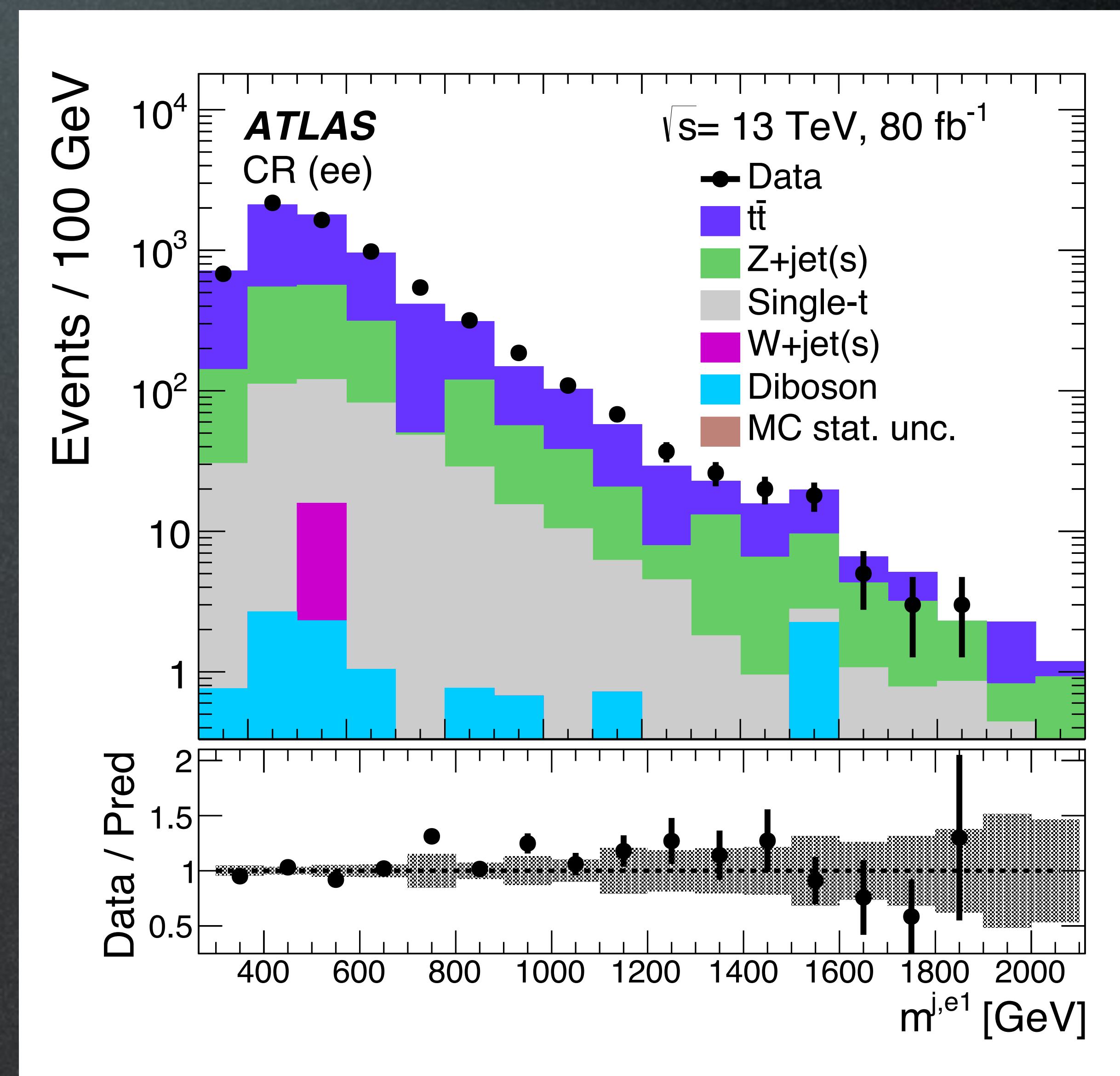
In ATLAS electron reconstruction assumed no nearby real jet, and applies implicit isolation requirement. That reduces signal efficiency, and the presence of such a jet affects the electron performance numbers

Boosted Heavy Neutrino Search

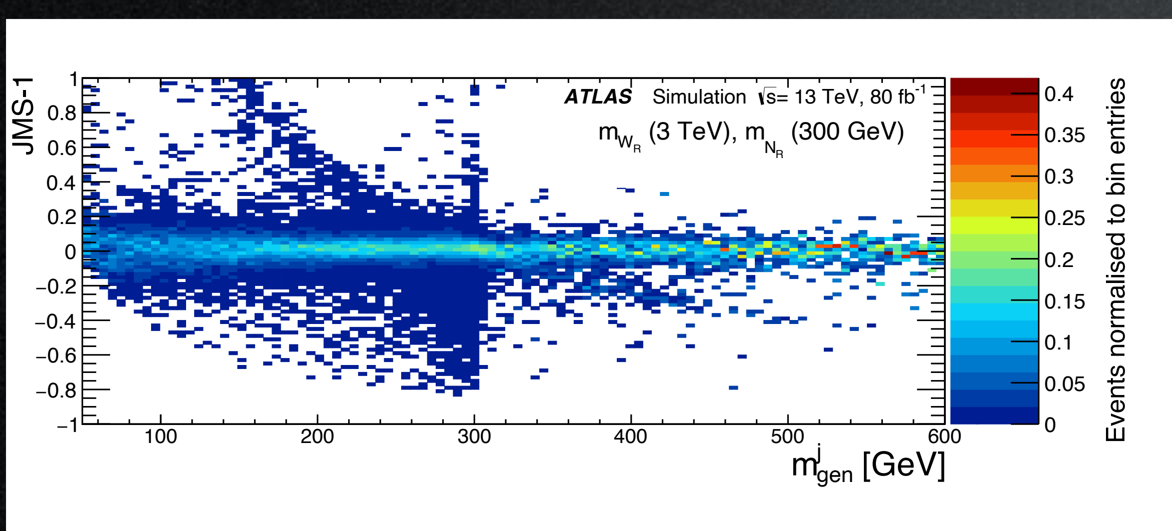
Debarati Roy: former postdoc



Good neutrino mass reconstruction



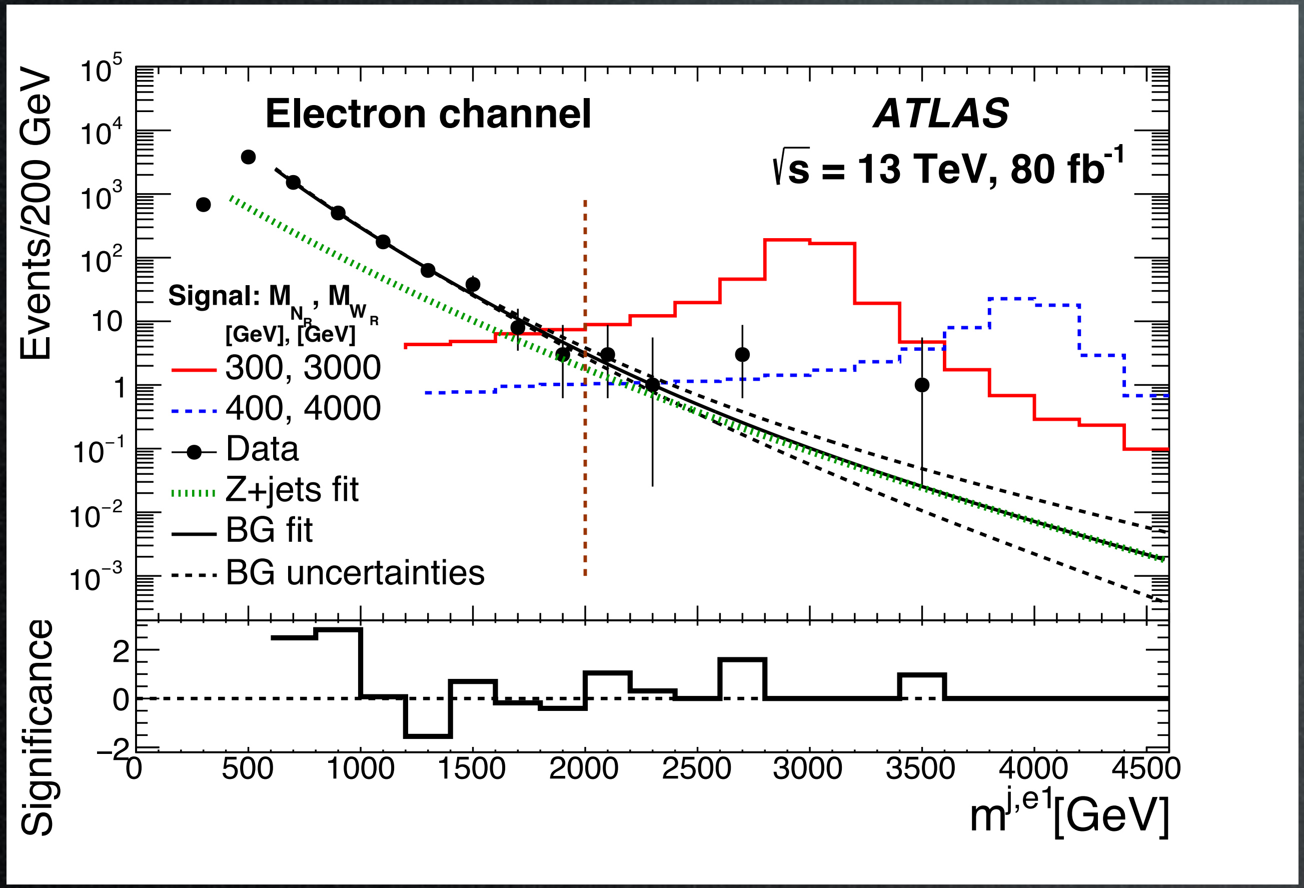
JMS well modelled



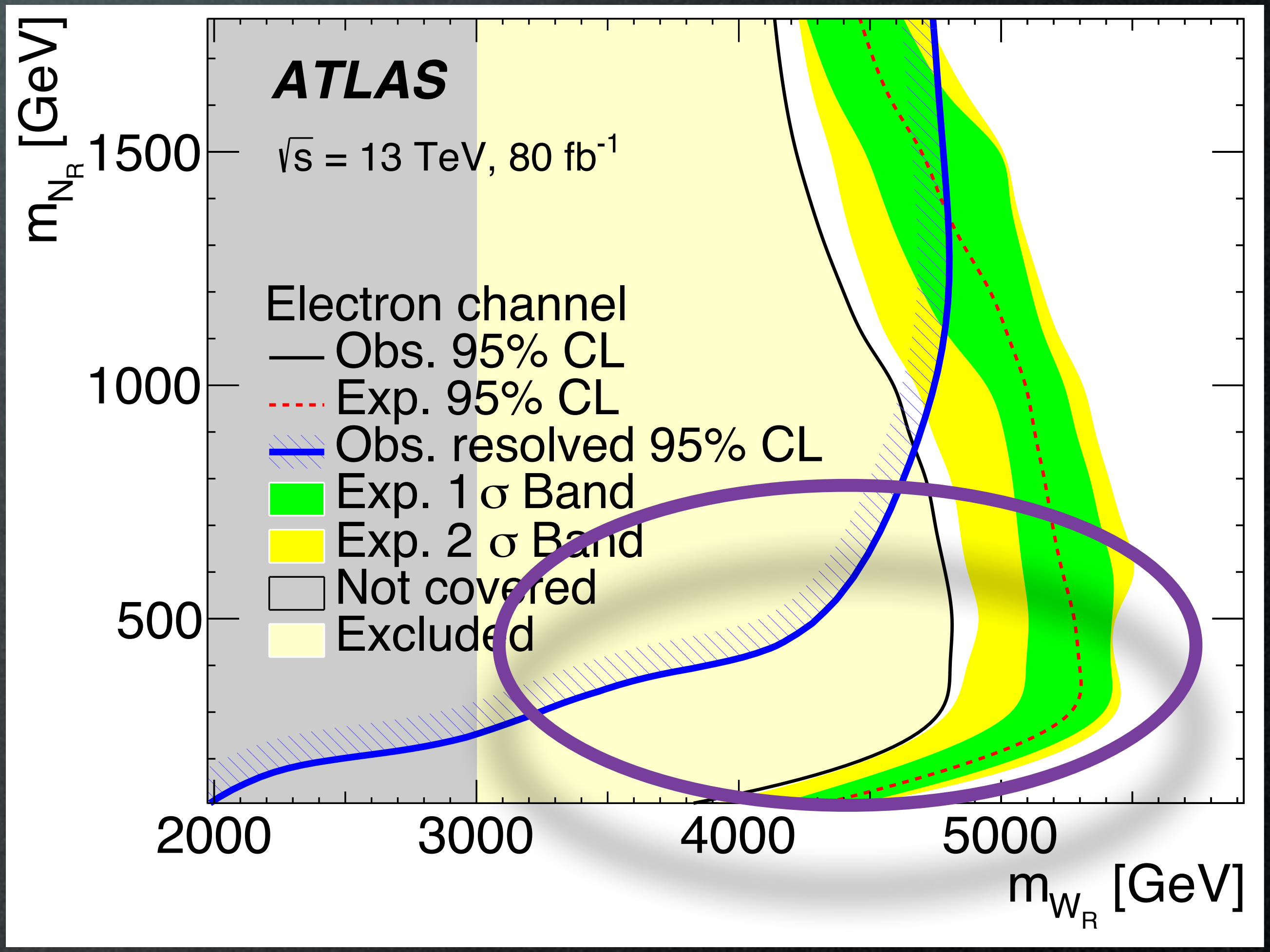
CR well modelled

Phys. Lett. B 798 (2019) 134942

Boosted Heavy Neutrino Search



Very small background
due to the extreme topology



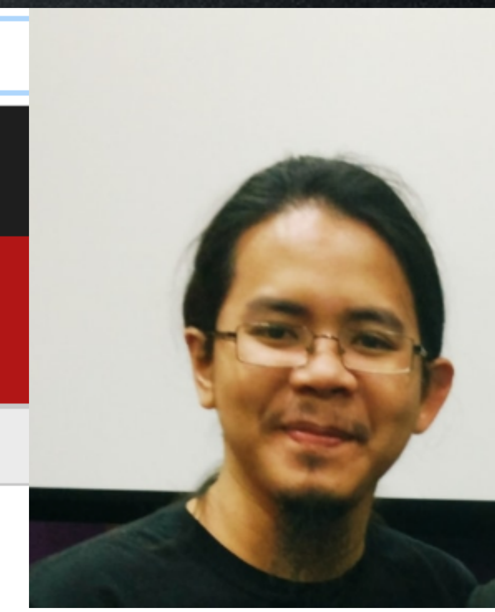
Complementary strength
from resolved analysis

Why stop at electrons?

Phys. Lett. B 798 (2018) 134942

Why stop at electrons?

Marvin Flores
Former postdoc



https://arxiv.org/abs/1905.08026

Cornell University

arXiv.org > hep-ph > arXiv:1905.08026

High Energy Physics – Phenomenology

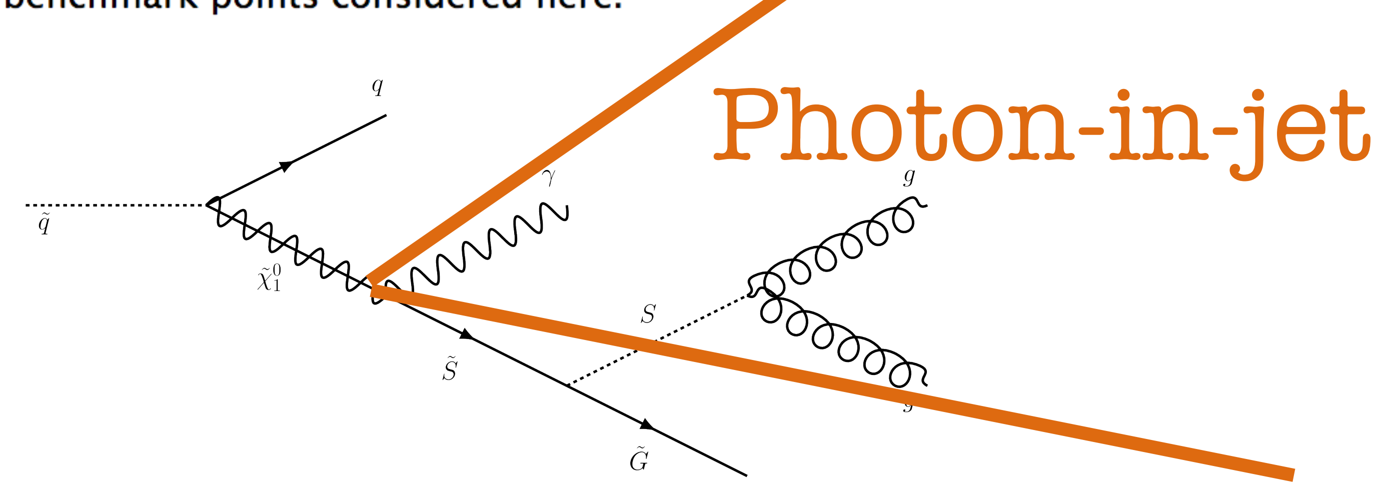
Constraining Stealth SUSY with illuminated fat jets at the LHC

Marvin Flores, Deepak Kar, Jong Soo Kim

(Submitted on 20 May 2019)

We investigate the discovery potential of a Stealth SUSY scenario involving squark decays by reconstructing the lightest neutralino decay products using a large-radius jet containing a high transverse momentum photon. Requirements on the event topology, such as photon and large-radius jet multiplicity result in less background than signal. We also estimated the sensitivity of our analysis and found that it has a better exclusion potential compared to the strongest existing search for the specific benchmark points considered here.

Comments: 6 pages, 5 figures
Subjects: **High Energy Physics – Phenomenology (hep-ph)**
Cite as: **arXiv:1905.08026 [hep-ph]**
(or **arXiv:1905.08026v1 [hep-ph]** for this version)

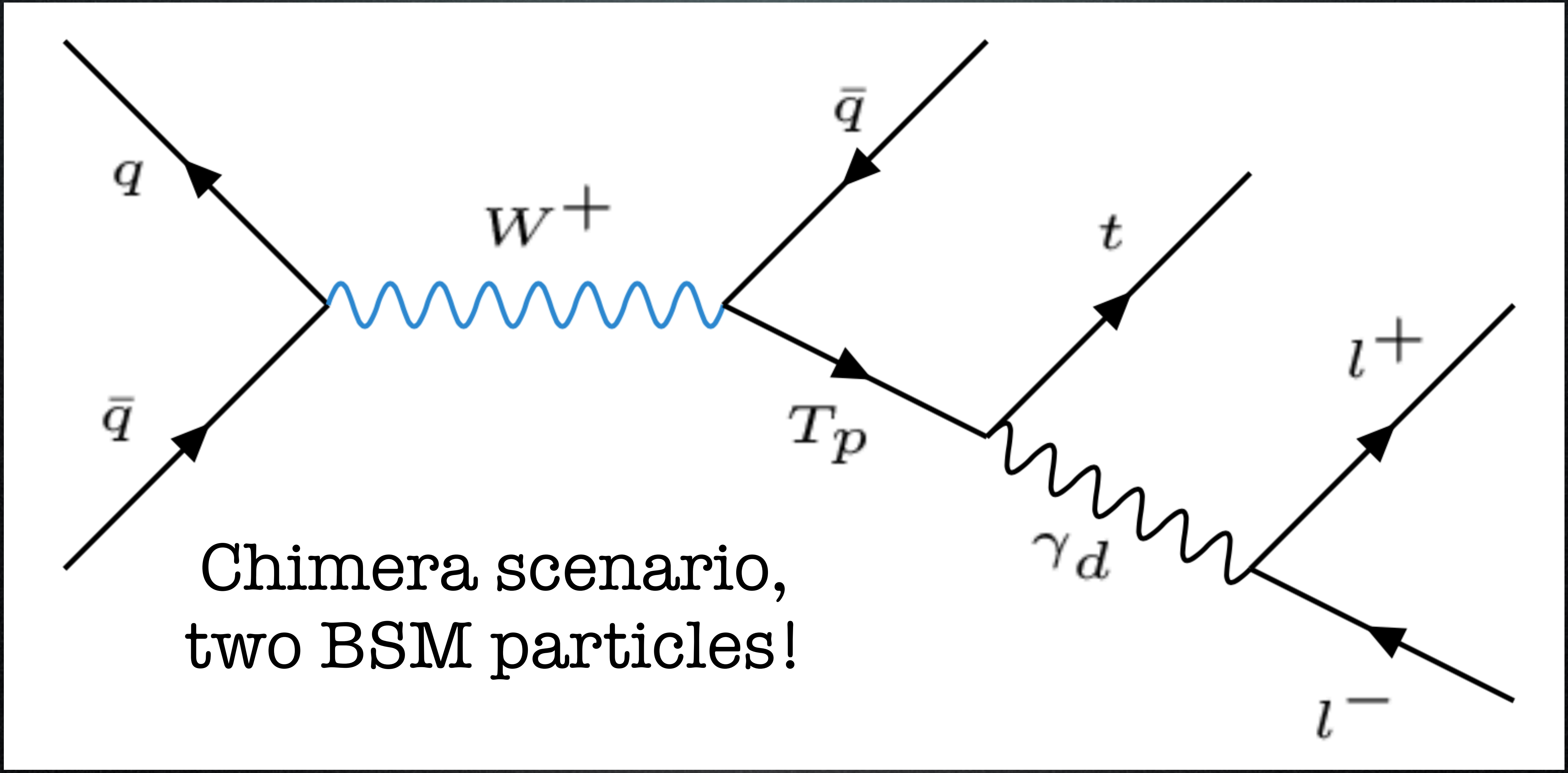


Submission history

From: Marvin Flores [view email]
[v1] Mon, 20 May 2019 12:19:37 UTC (251 KB)

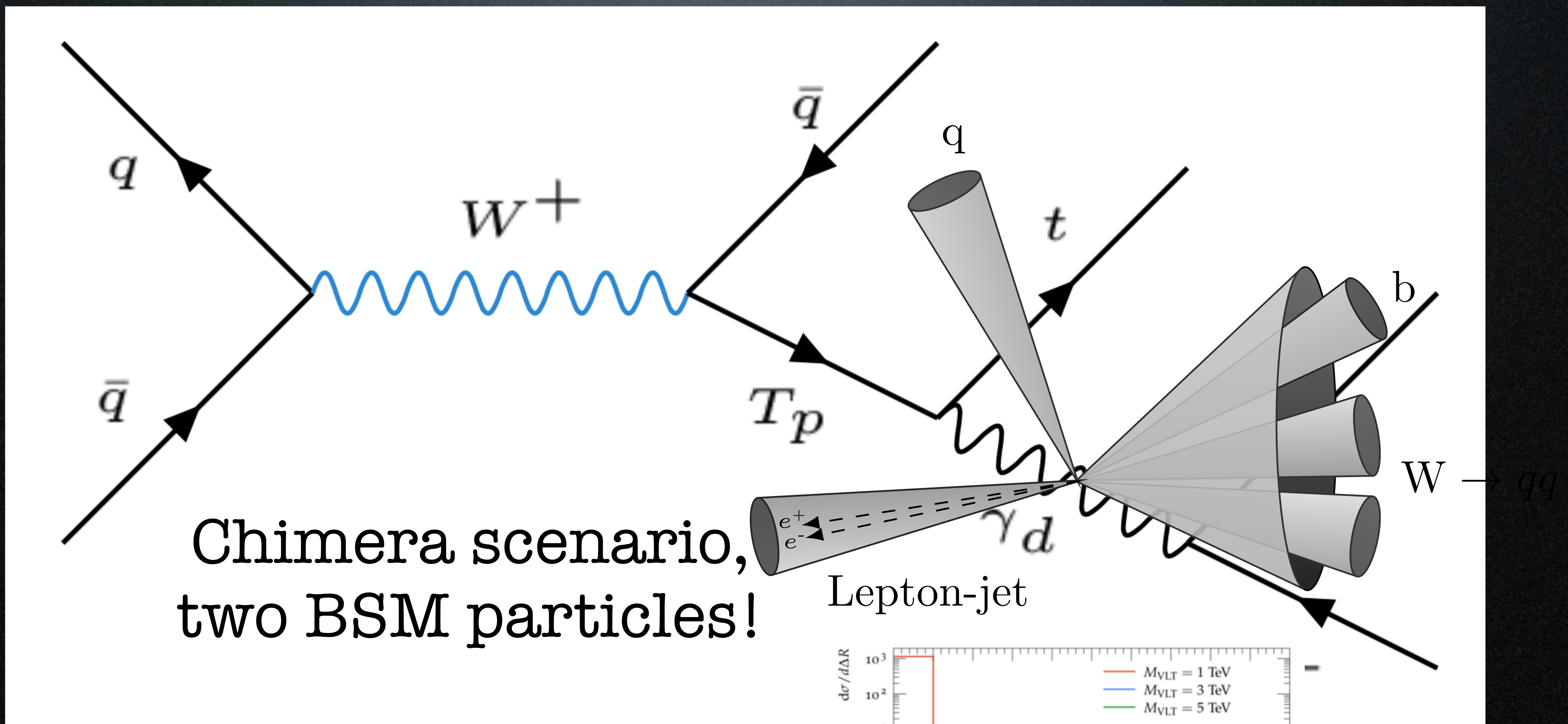
Lepton jet from dark photon

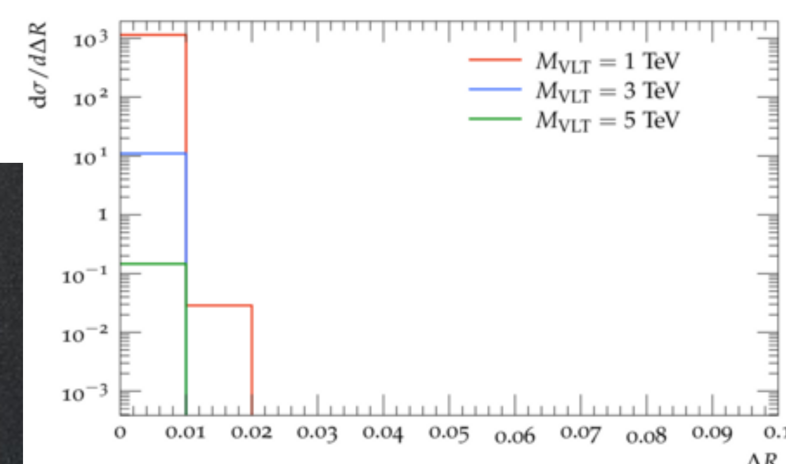
... with Karien du Plessis, M. Flores, S. Sinha, and H. van der Schyf, SciPost Phys. 13, 018 (2022)



SciPost Phys. 13, 018 (2022)

Lepton jet from dark photon

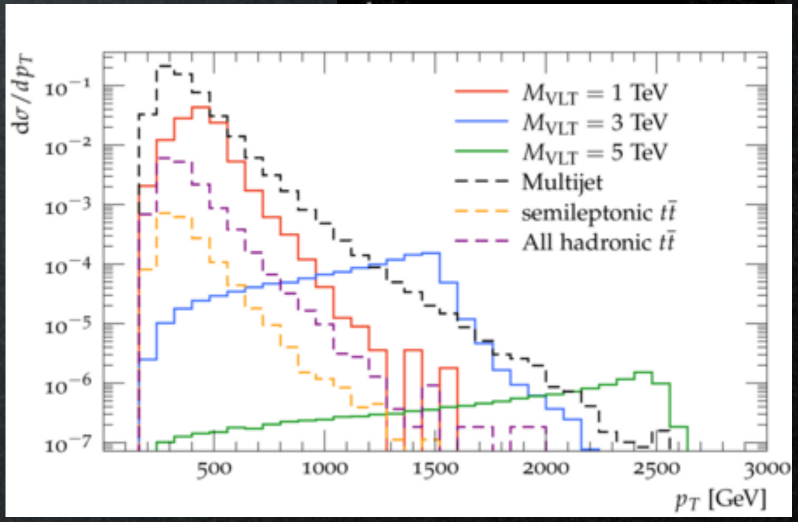


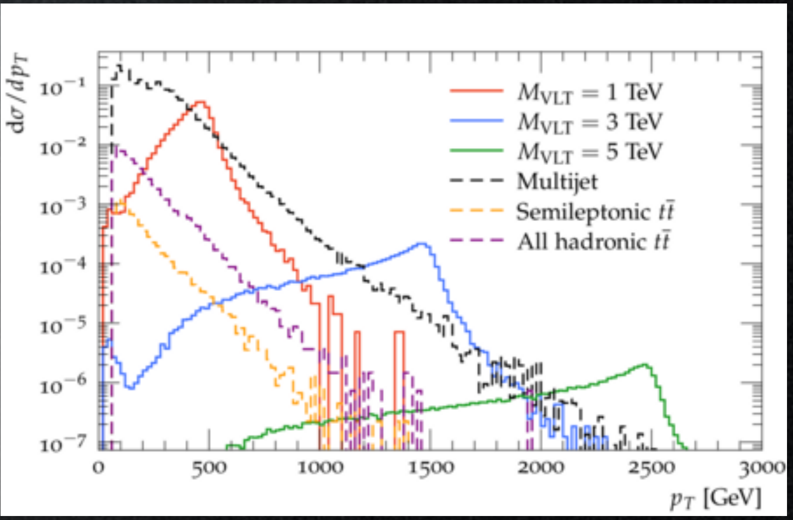


For dark photon masses < 200 MeV

SciPost Phys. 13, 018 (2022)

Search Strategy (hadronic channel)



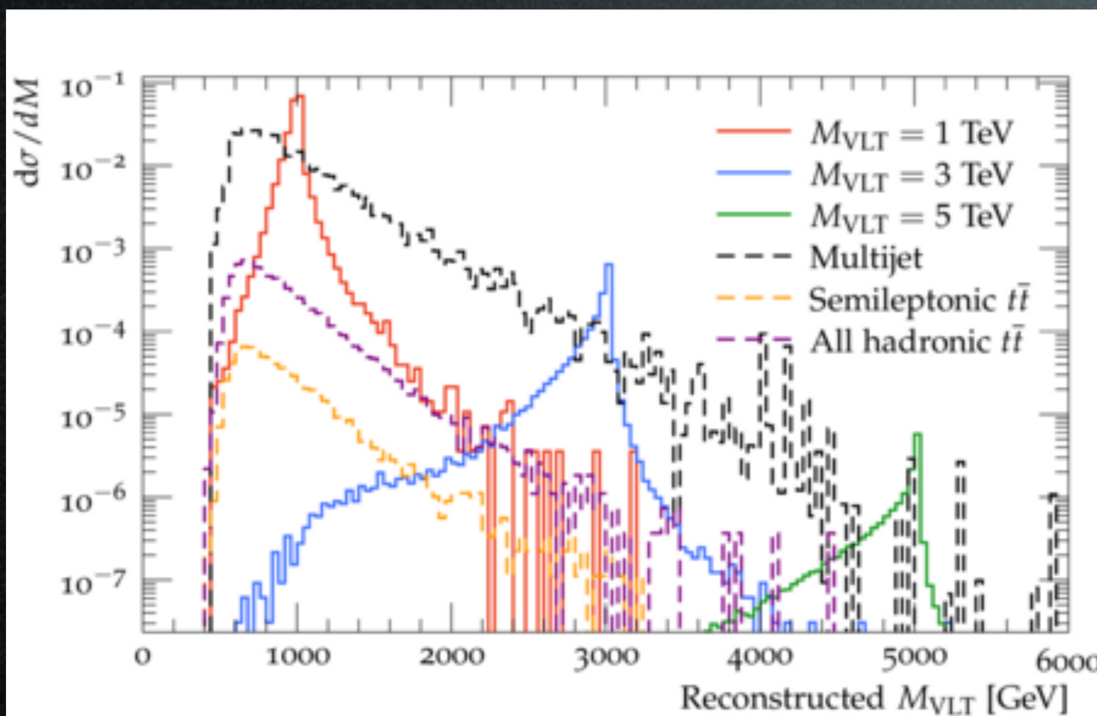


- Light lepton jet and heavy top jet, both boosted!
- Electron multiplicity -> misleading
- Cannot reconstruct the lepton jet mass
- Largest background: multijet

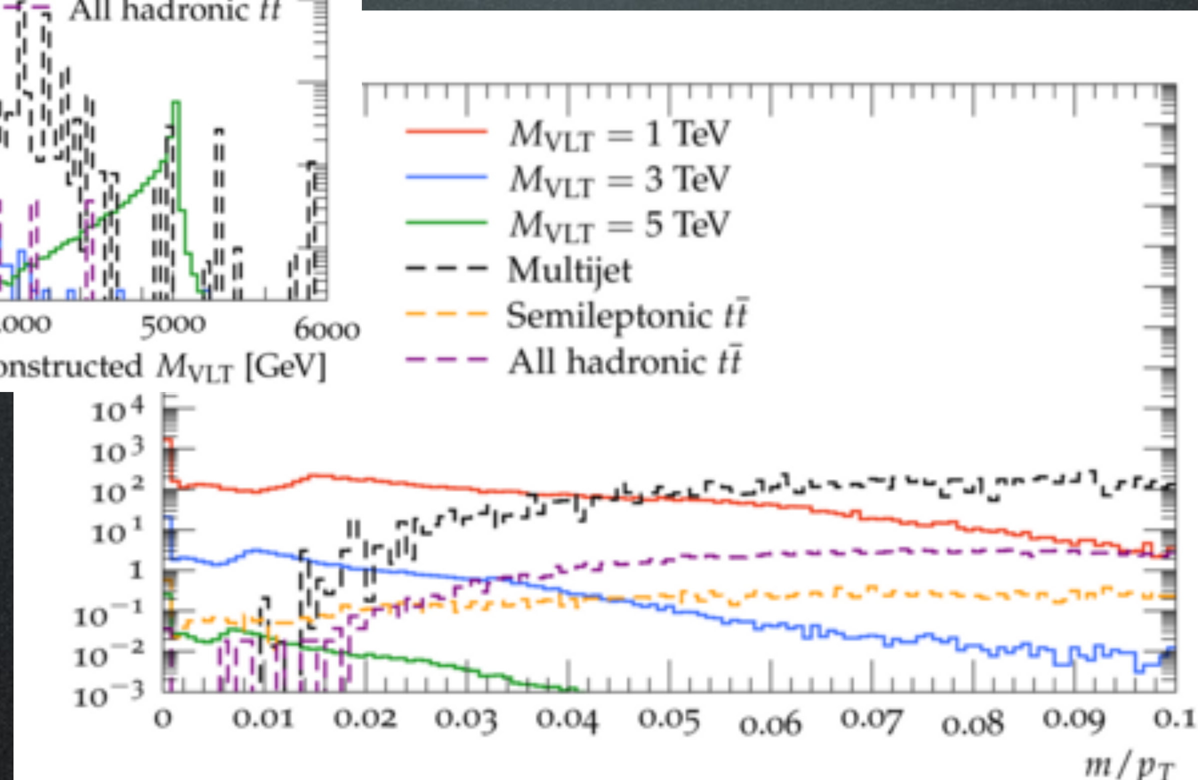
Not covering the lepton channel result, but mostly same considerations apply

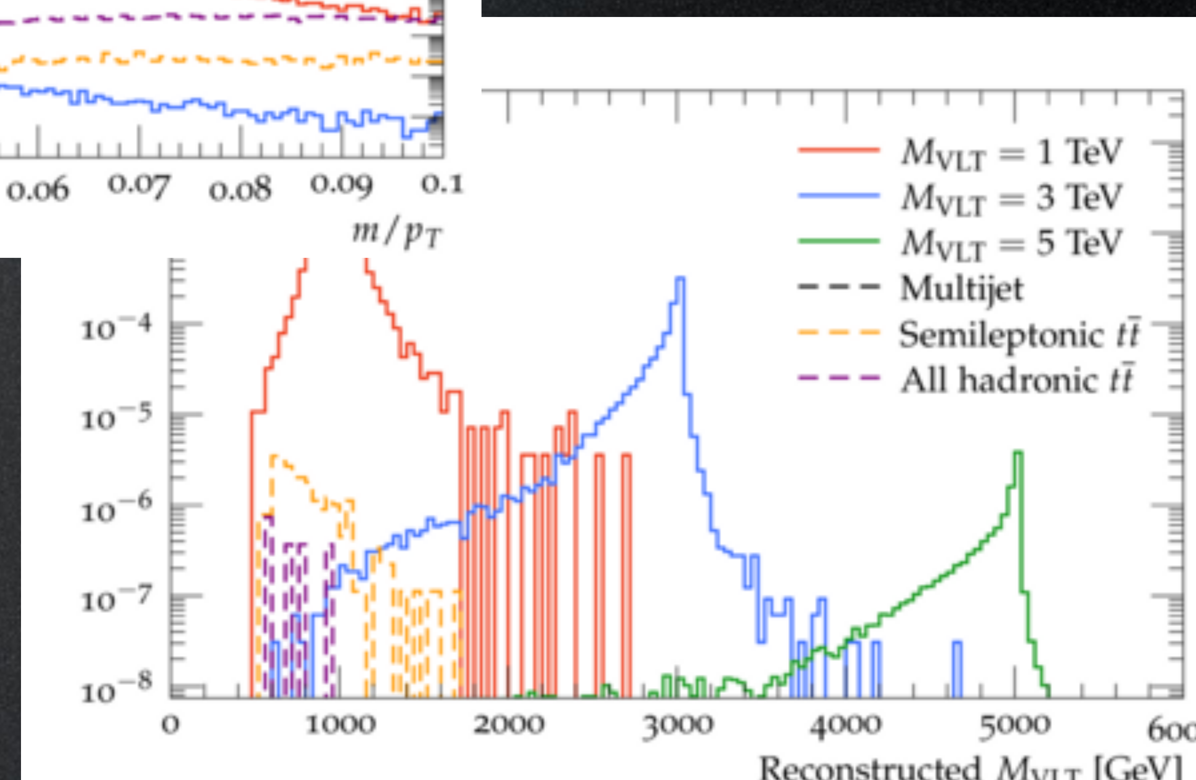
SciPost Phys. 13, 018 (2022)

Then what?



Lepton jet m/p_T ratio is a strong discriminant



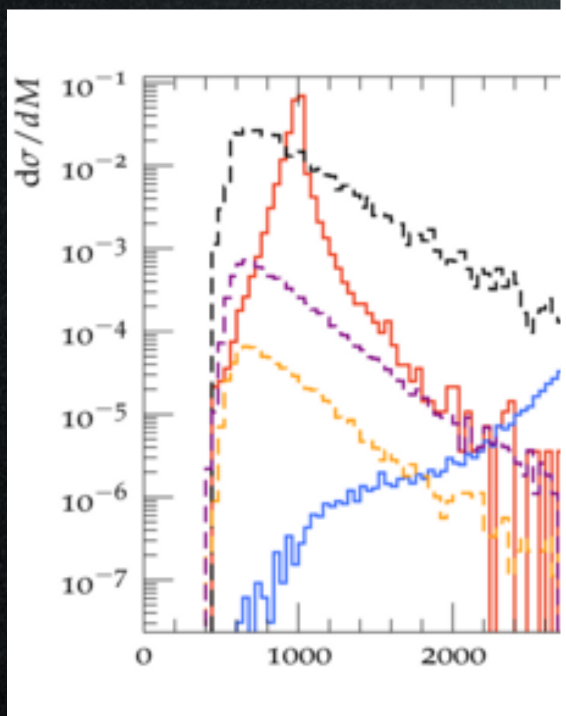


Hannah Van Der Schyf: current PhD student

Results in an almost zero background search!

SciPost Phys. 13, 018 (2022)

Then what?



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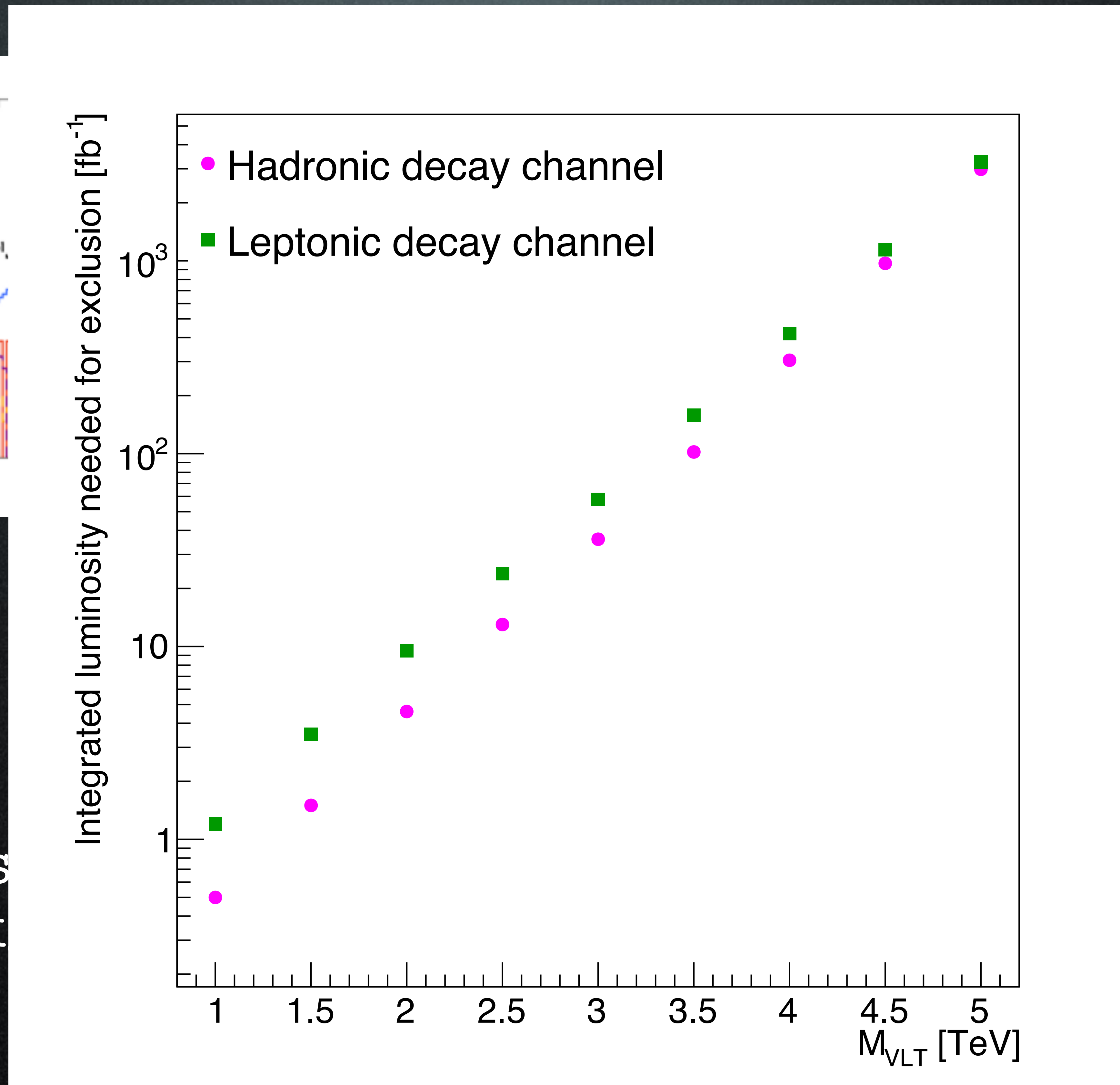
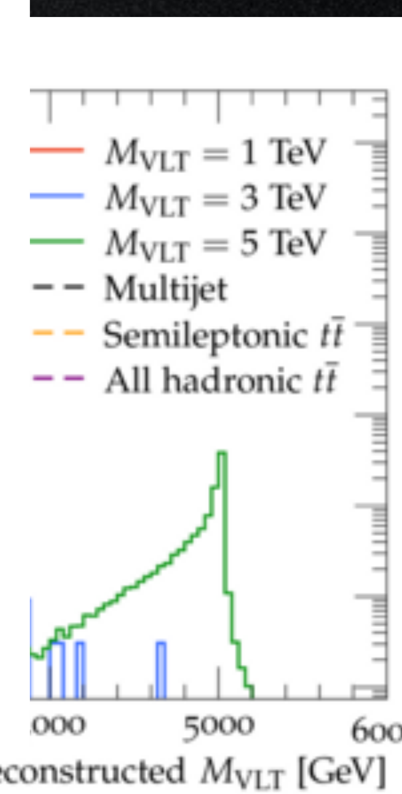
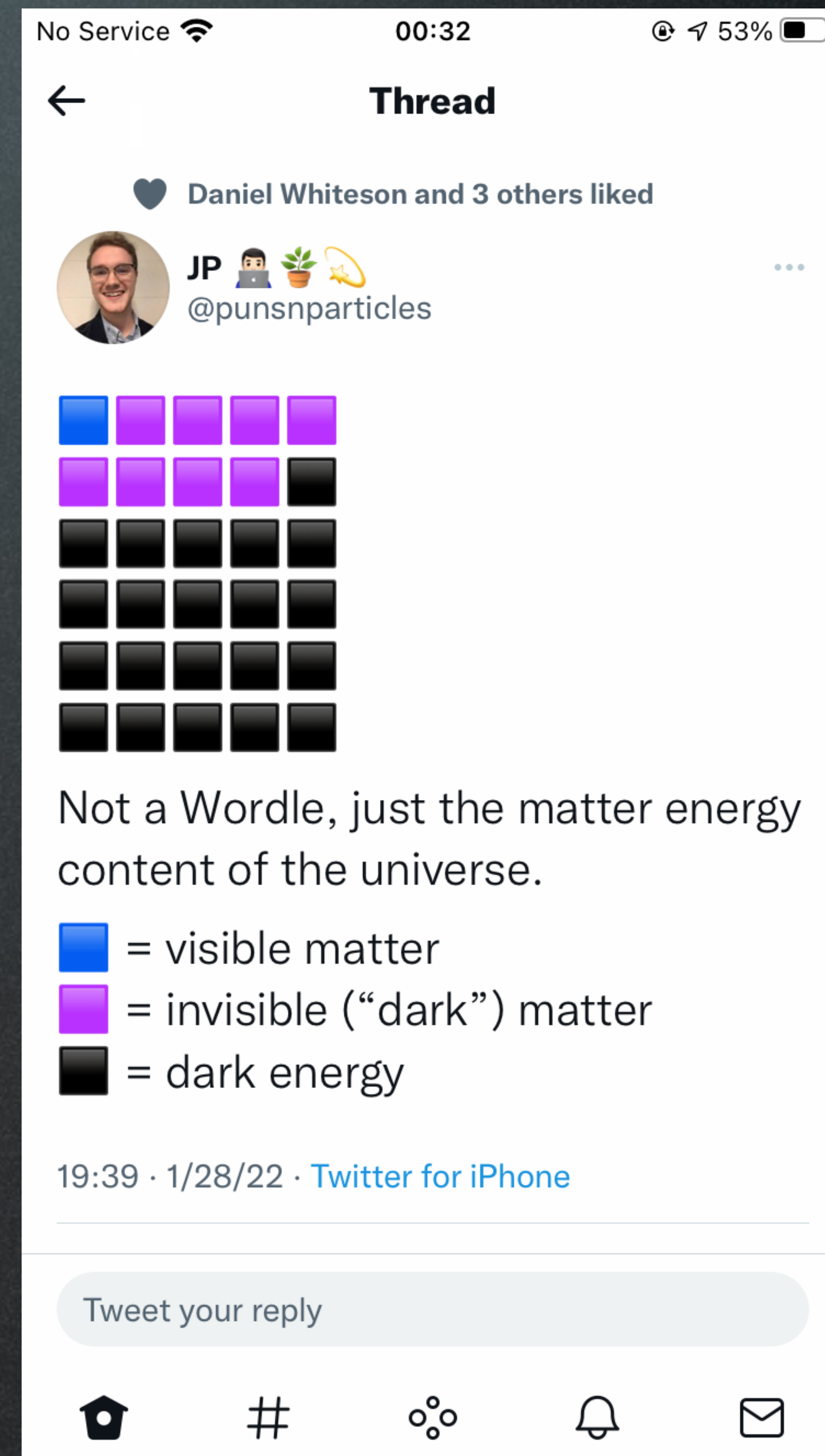




Results
back

Dark Matter

Gravitational lensing seen in JWST image

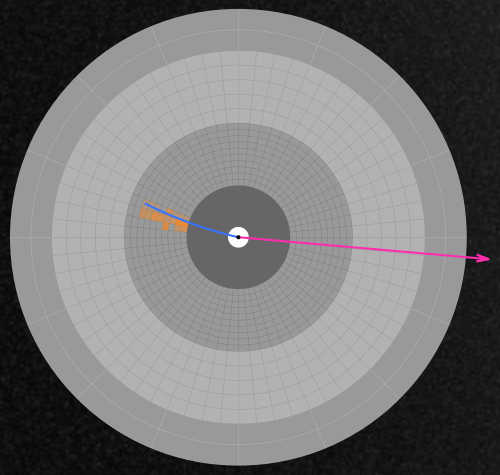


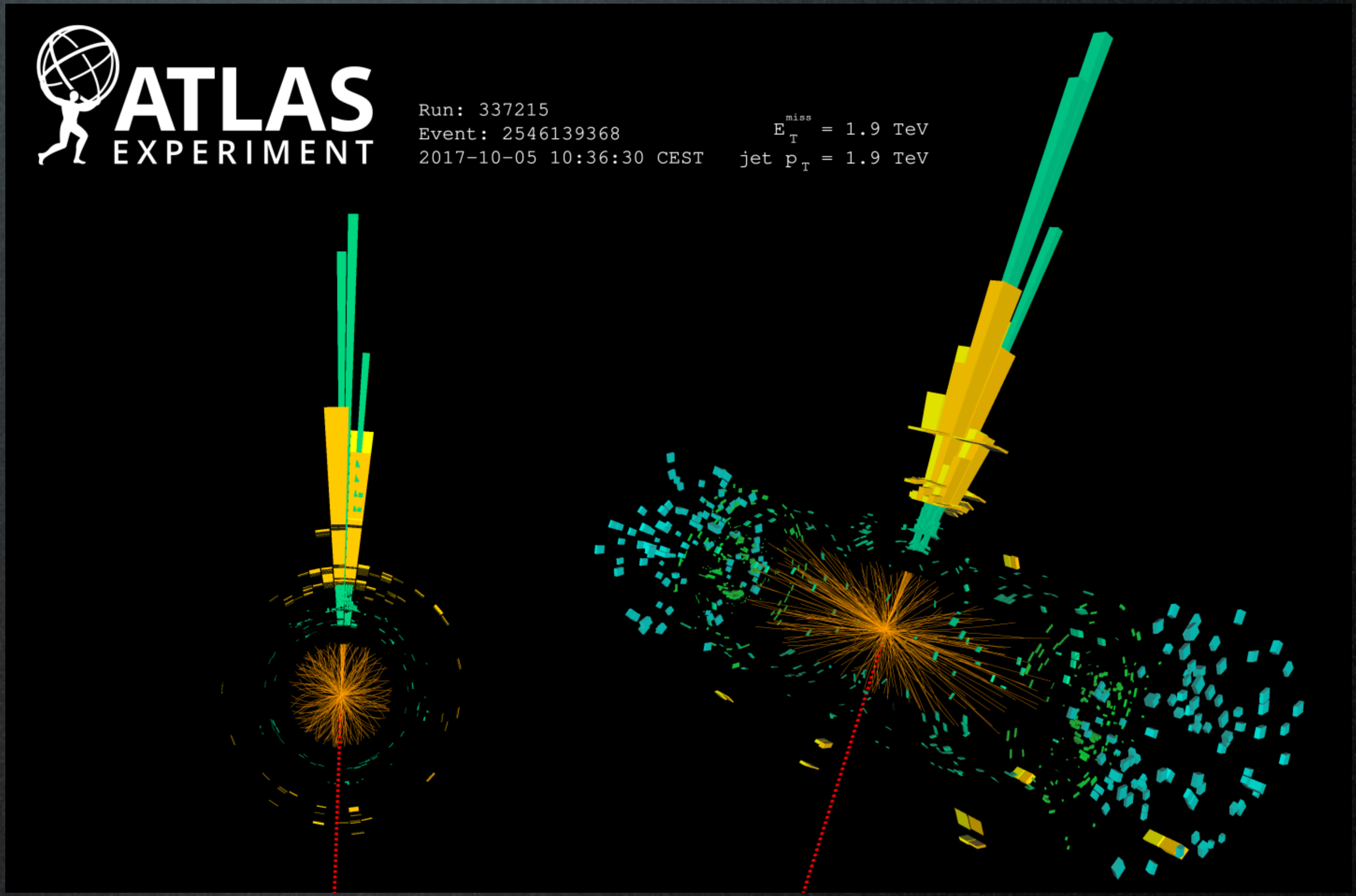
Dark Matter Searches at the LHC

So far, almost all dark matter searches in colliders are for WIMPs

So called mono-X signatures, X being any SM particle(s) or object(s).

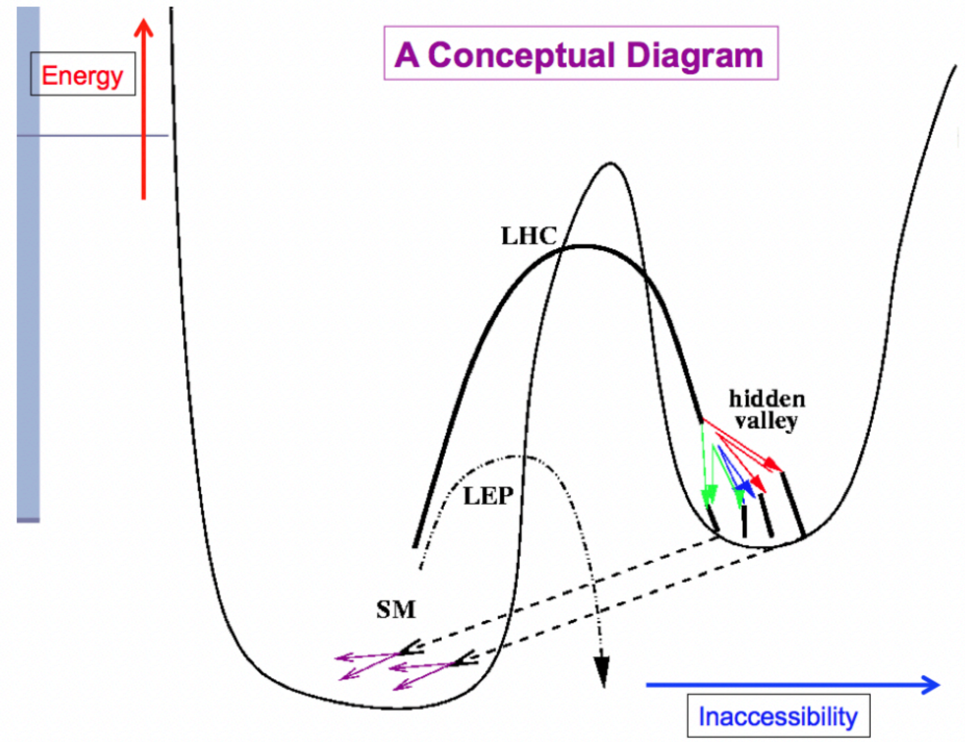
Large MET on one side!





However so far ...

Into the Hidden valley:



Courtesy
M. Strassler

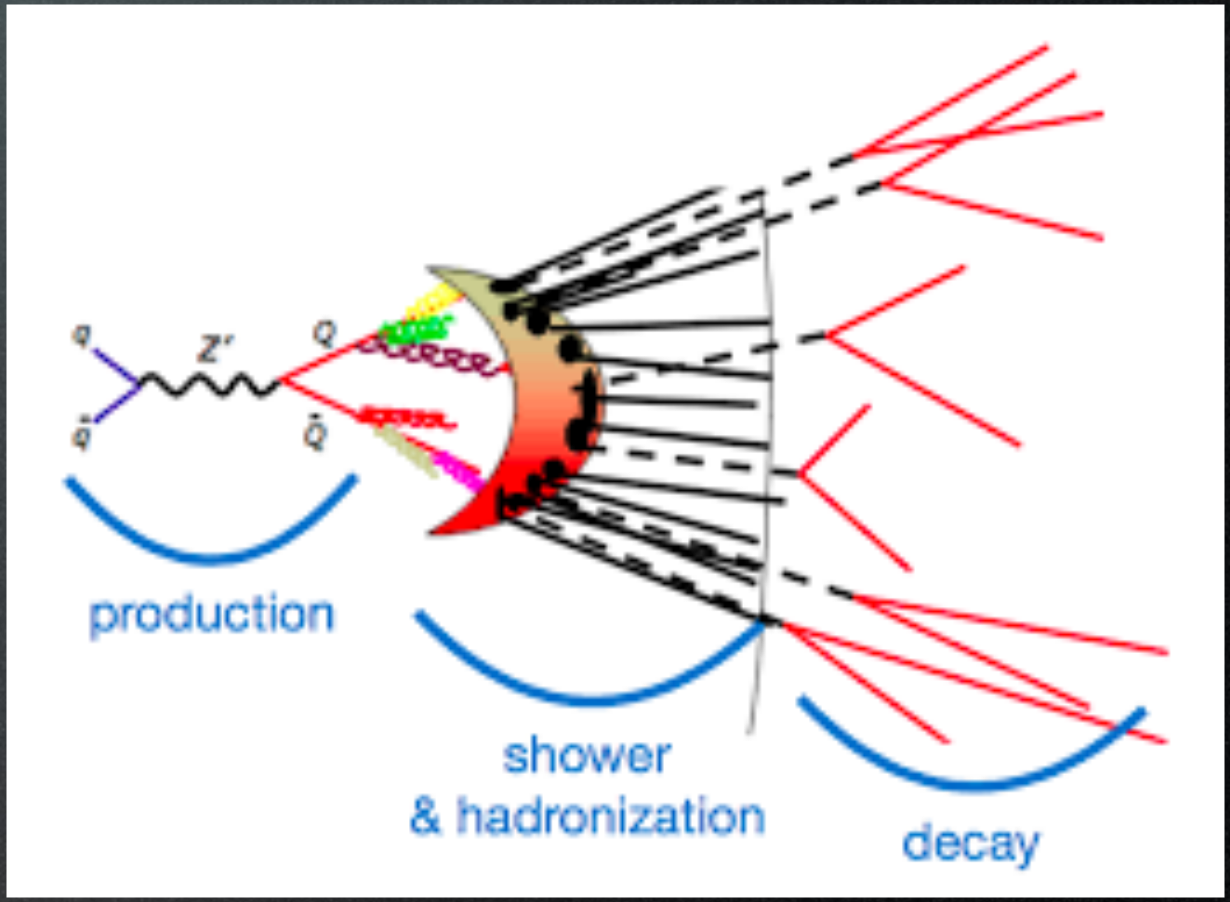
Secluded dark sector!

Not a model, more like a framework

Not too weakly coupled to SM, particle masses must be accessible at the LHC!

Dark QCD/SIMP

- A simple replica of standard QCD!
- Can give rise to rich phenomenology
- Hadronisation in hidden sector, off-diagonal dark hadrons, invisible and stable while diagonal ones can decay back to SM quarks.



Sabine Hossenfelder @skdh

That's basically what it is. The "dark sector" or "hidden sector" is a name for increasingly contrived and complex collections of particles (and their interactions) which physicists have invented and that no one has ever seen.

> **Benjamin Titus** @Benny_Switch · Feb 14
> Replying to @WKCosmo
> Please tell me what "Dark Sector" means. I thought I was well read enough, but I've been seeing this phrase thrown around and all I get from it is "additional Dark things that may or may not be there"

… into the hidden valley!

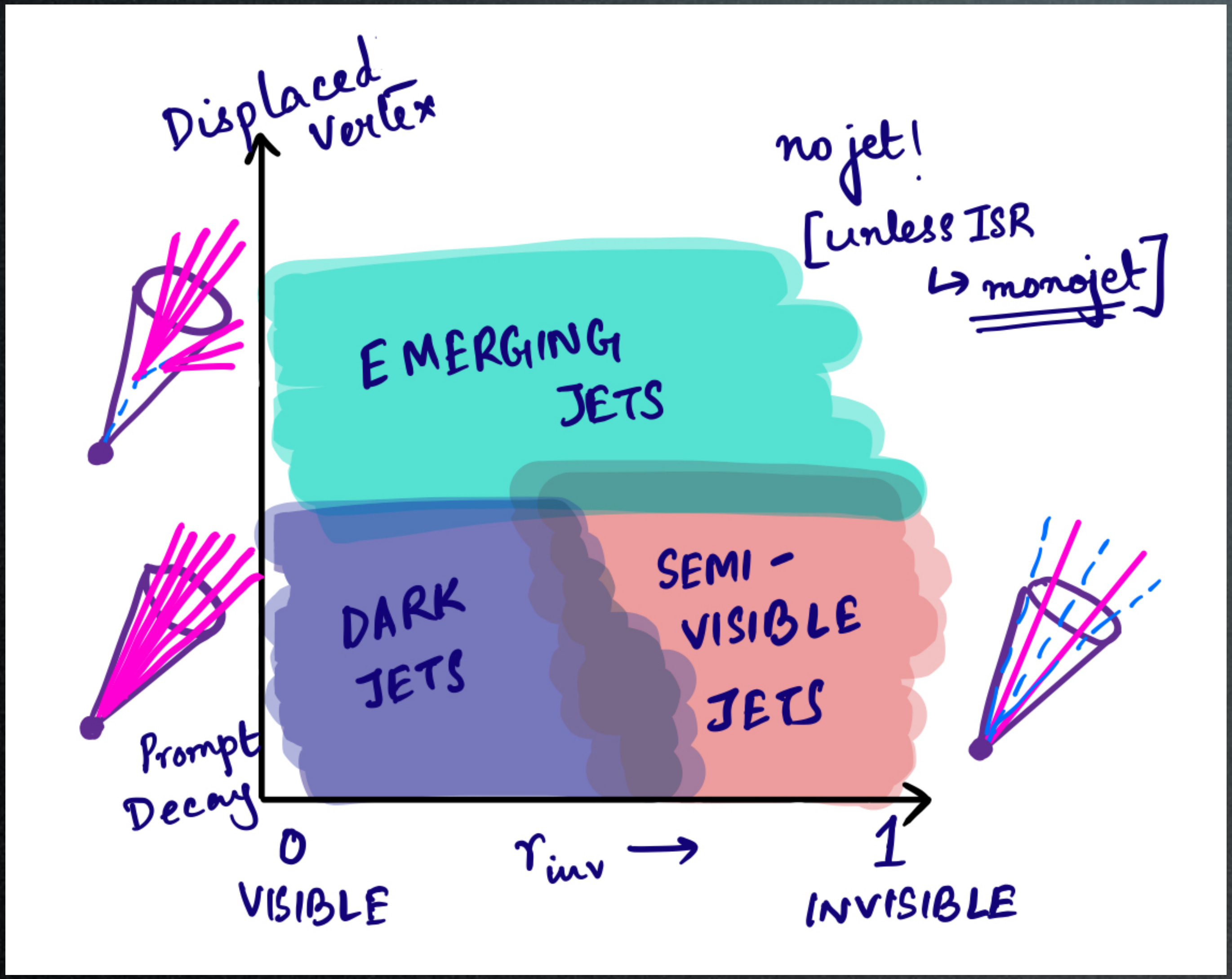
Will Kinney @WKCosmo

There's a very good reason why the default assumption is that dark matter consists of a single type of particle: Dark matter must be stable, and only the lightest particle in a mass hierarchy is stable. For example, the only stable baryon in the Standard Model is the proton.

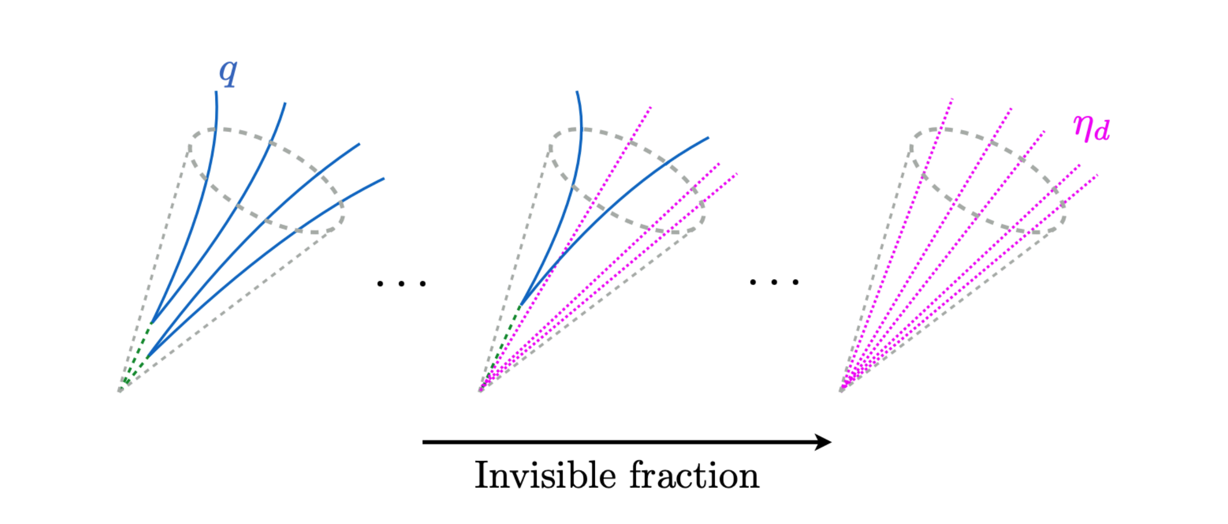
2:36 AM · Feb 15, 2023 · **72.4K** Views

33 Retweets **17** Quote Tweets **411** Likes

Semi-visible jets!

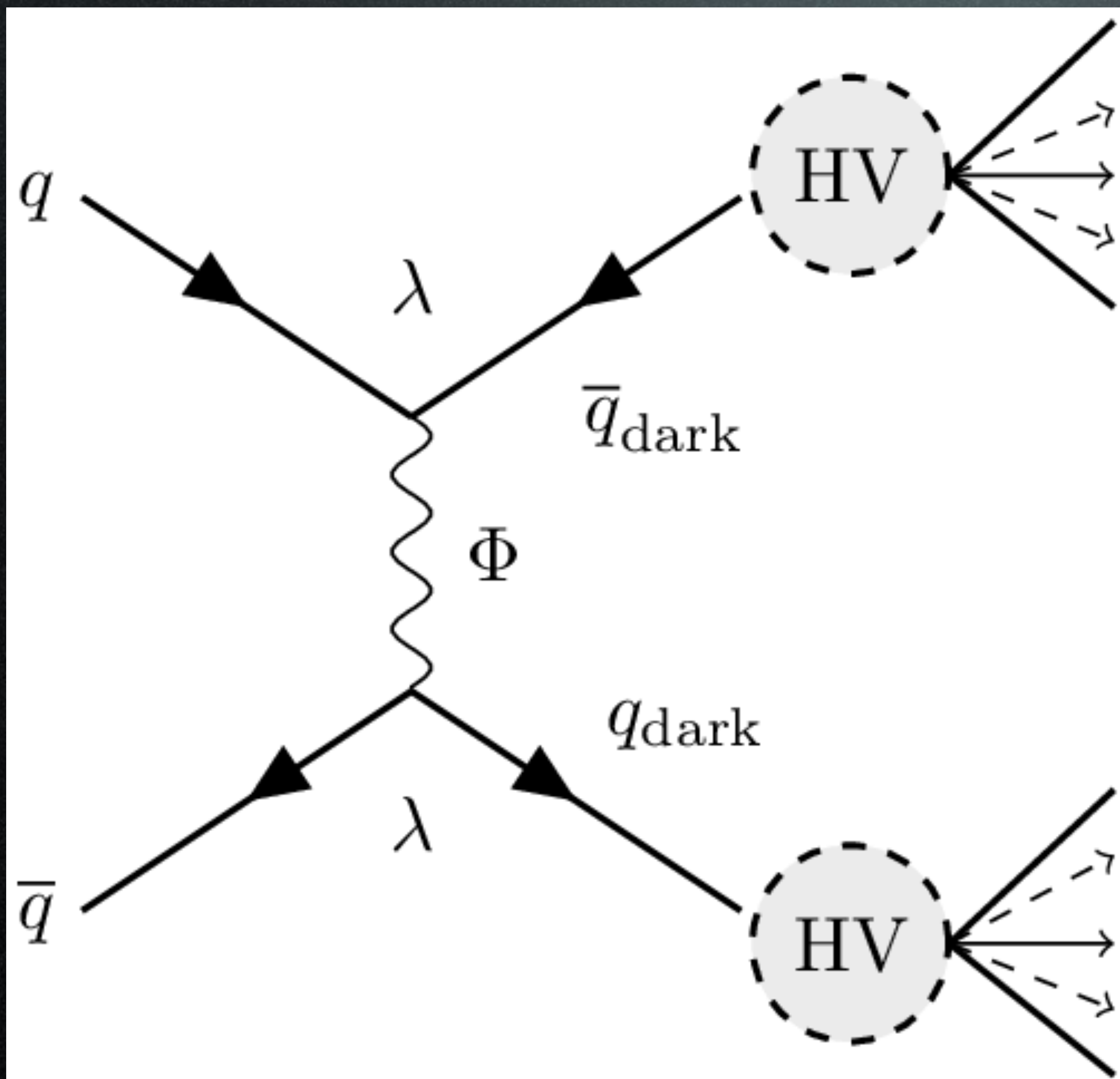


Dark hadrons decaying in a QCD-like fashion, fully (dark jets) or partially back to visible sector (semi-visible jets, based on Cohen et al)



R_{inv} = Ratio of stable dark hadrons over number of hadrons

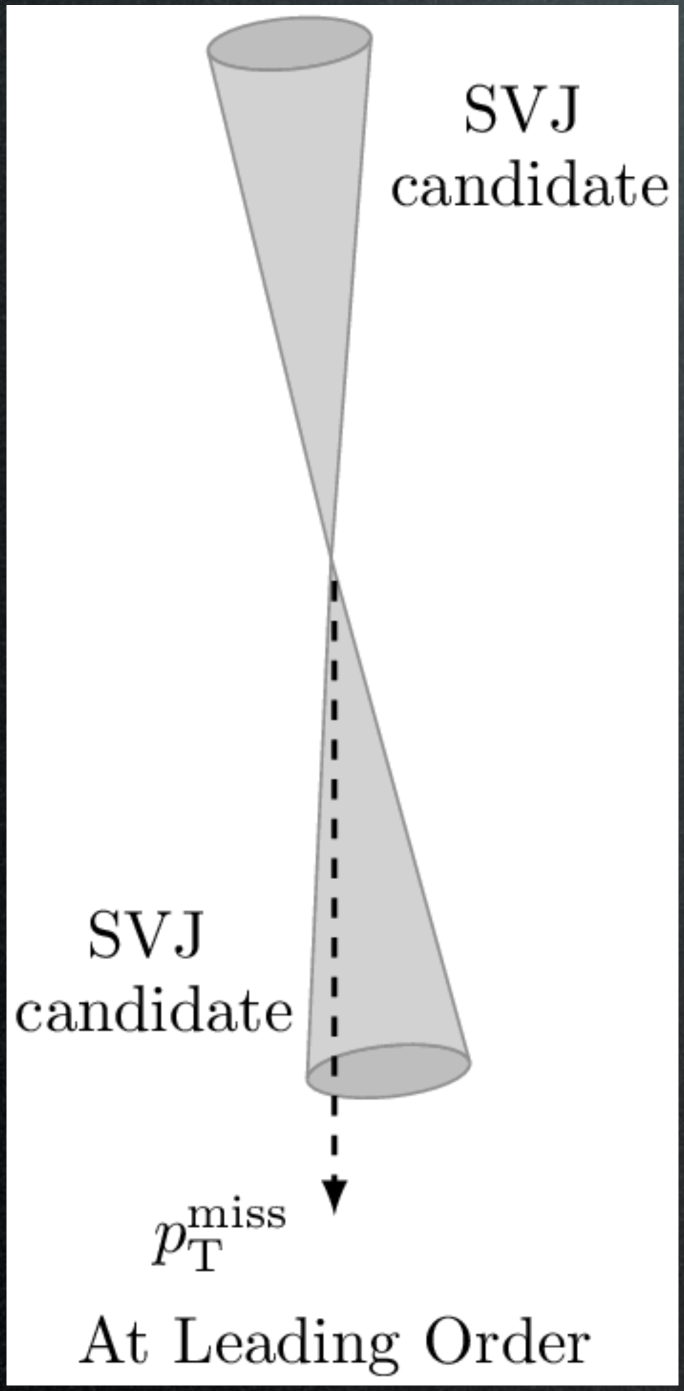
What We Searched for?



SVJ in
t-channel
production
mode

Signal simulation
Making use of
Pythia8 HV
module

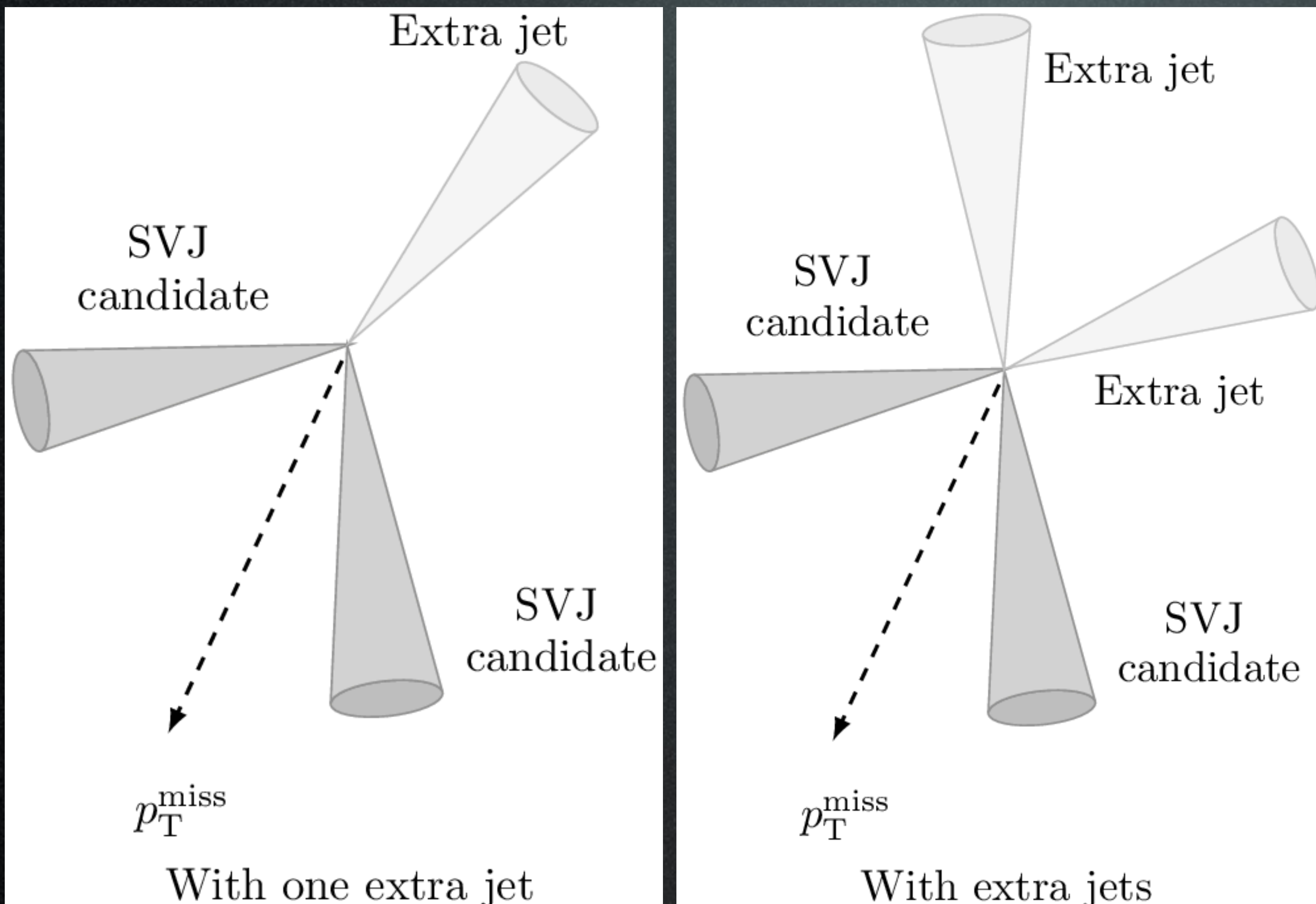
The topology and the challenges for SVJ



Same fraction
of dark hadrons
In each jet

Why any MET?

The topology and the challenges



A real event will look like this!

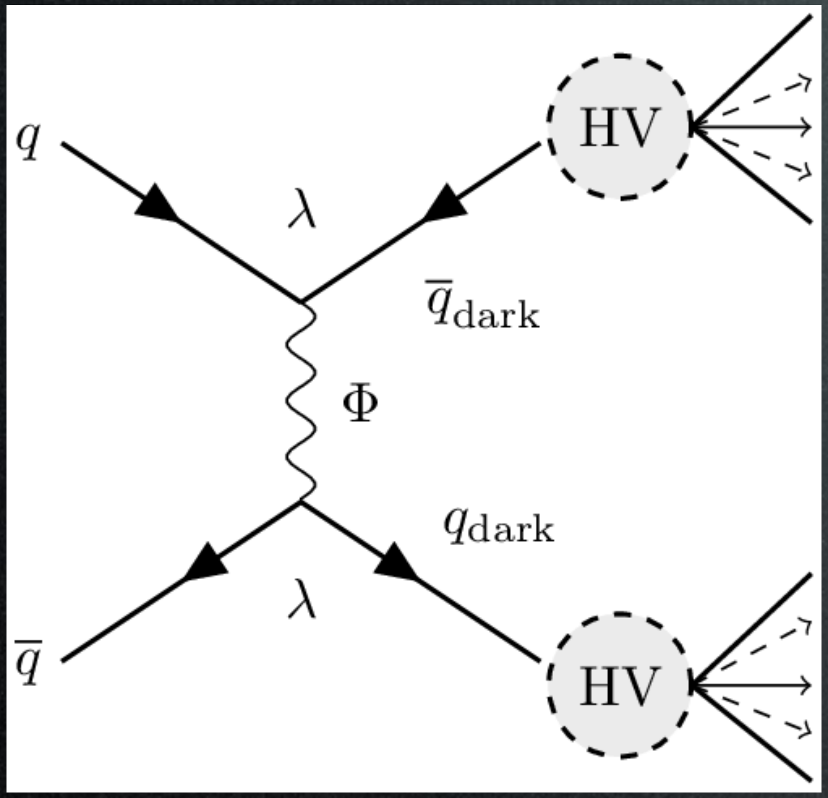
Quantum fluctuations, and boost by extra jets

Therefore MET


ATLAS
EXPERIMENT
Run Number: 299184, Event Number: 439826223
Date: 2016-05-15 01:13:16 CEST

Phys. Lett. B 848 (2024) 138324

SVJ Search



Results in jets interpersed with dark hadrons, with missing transverse momentum direction aligned with one of the SVJs in leading order. Not so for events with extra jets and large boost.

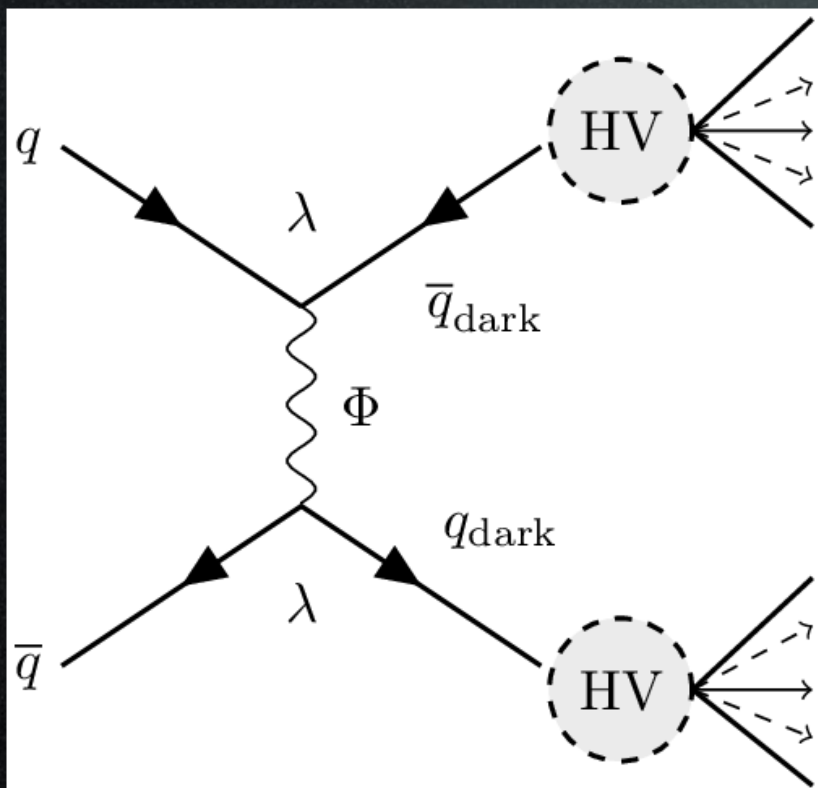
Events with two central jets, MET trigger, leading jet $p_T > 250$ GeV, $H_T > 600$ GeV, MET 600 > GeV, jet closest to MET with $\Delta\Phi<2$

Define: SR (muon veto), and three CRs, 1L, 1L1B, 2L (with muons and b-tagged jets)

Usually signs of detector noise, so discarded in analyses

Phys. Lett. B 848 (2024) 138324

SVJ Search



Results in jets interspersed with dar... hadrons, with missing transve... momentum direction alig... with one of the SVJs in leading ... Not so for events with ext... and large boost.

Unique collider topology - mostly overlooked in searches!

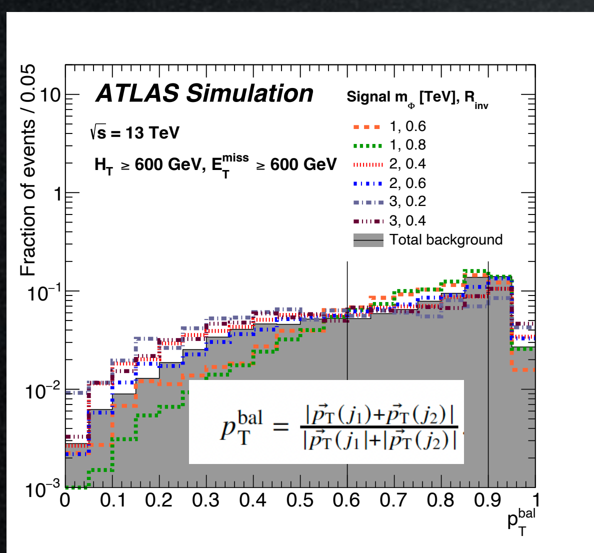
Events with two central j... MET trigger, leading jet p_T > 250 GeV, H_T > 600 GeV, MET 600 > G... closest to MET with $\Delta\Phi$<2

Define: S... muon veto), and three CRs, 1L, 1L1B, 2L (with muons and b-tagg... jets)

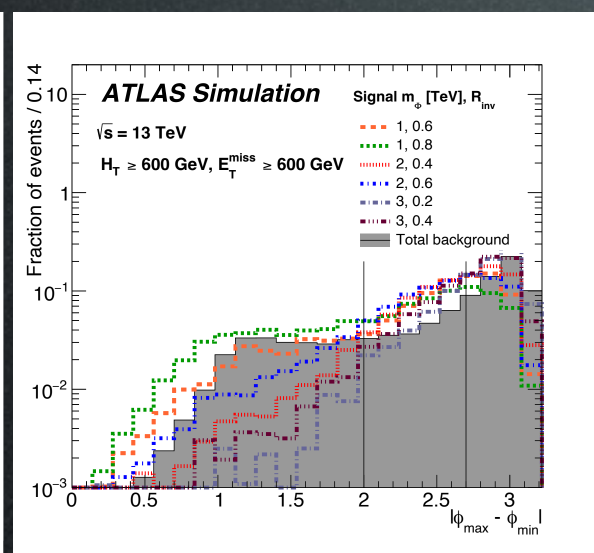
Usually signs of detector noise, so discarded in analyses

Background Estimate

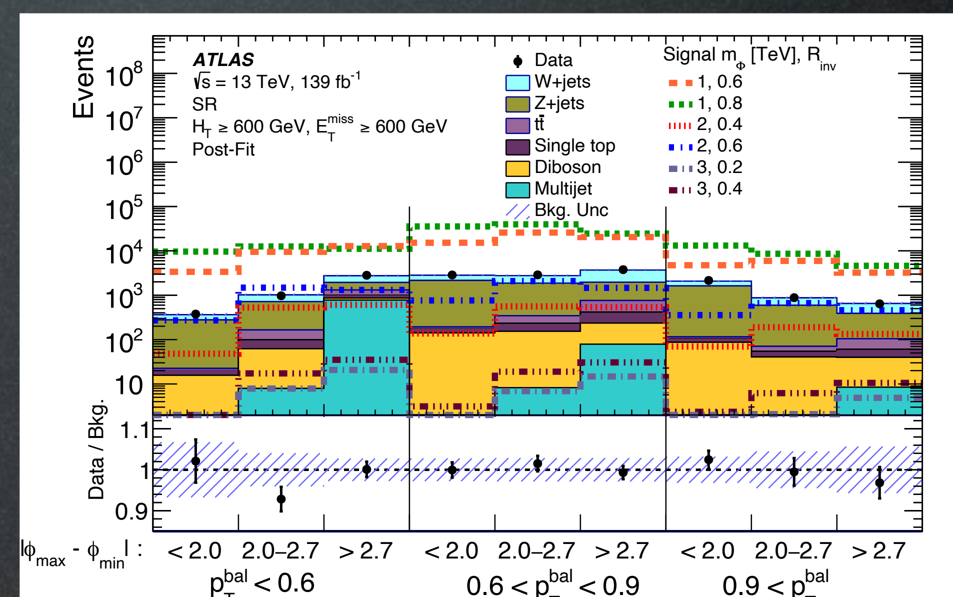
Two sensitive observables:



$$p_{\mathrm{T}}^{\mathrm{bal}} = \frac{|\vec{p}_{\mathrm{T}}(j_1)+\vec{p}_{\mathrm{T}}(j_2)|}{|\vec{p}_{\mathrm{T}}(j_1)|+|\vec{p}_{\mathrm{T}}(j_2)|}$$

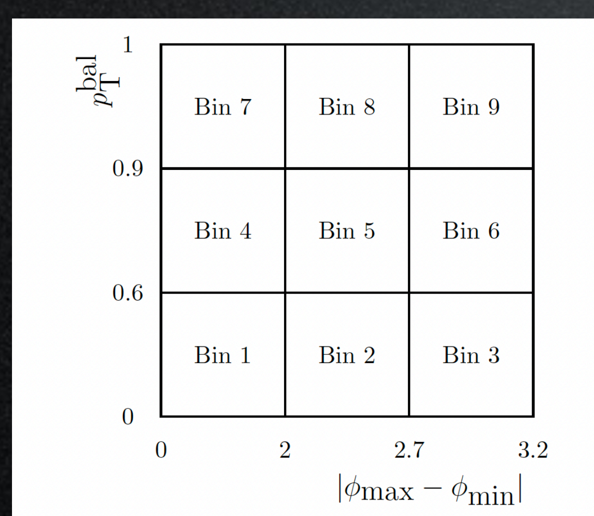


Partially data-driven method, simultaneously fit SR and three CRs to obtain scale factors for each bg process:



Process	k^{SF}
Z+jets	1.18 ± 0.05
W+jets	1.09 ± 0.04
Top processes	0.64 ± 0.04
Multijet	1.10 ± 0.04

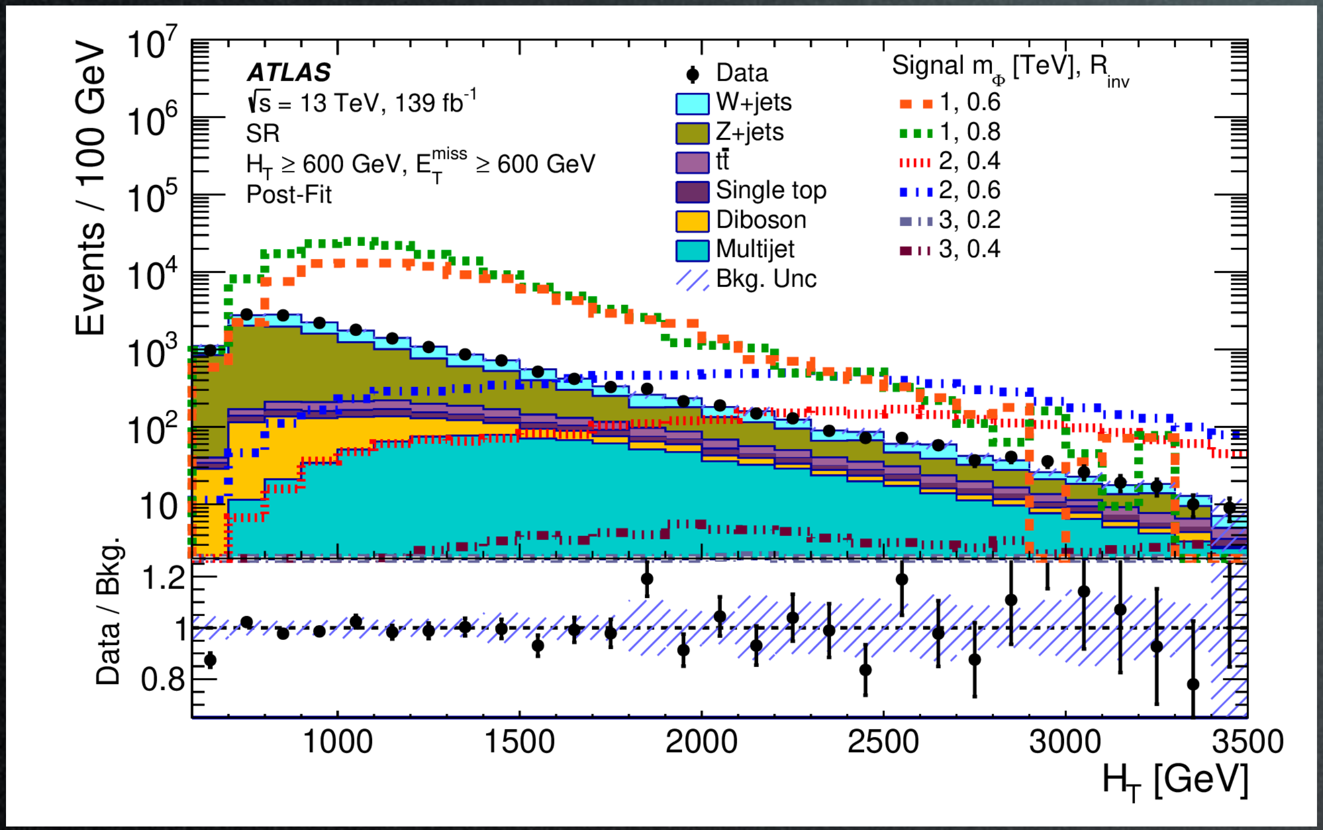
Used to Form a 9-bin grid, with yields in each bin treated as observables:

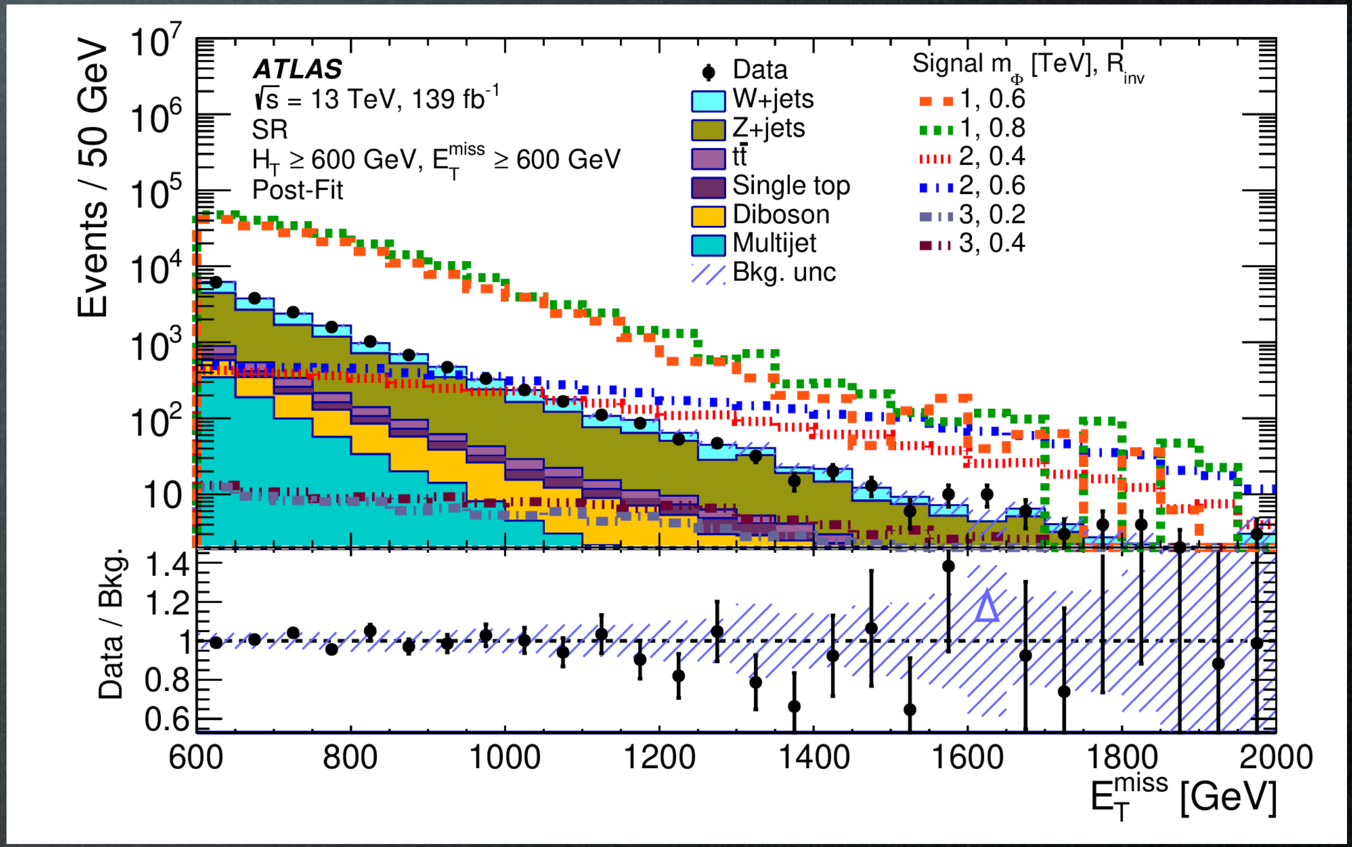


Absence of signal, good postfit agreement :(

Multijet reweighed in using a dedicated VR given by MET within 250 to 300 GeV, then fitted

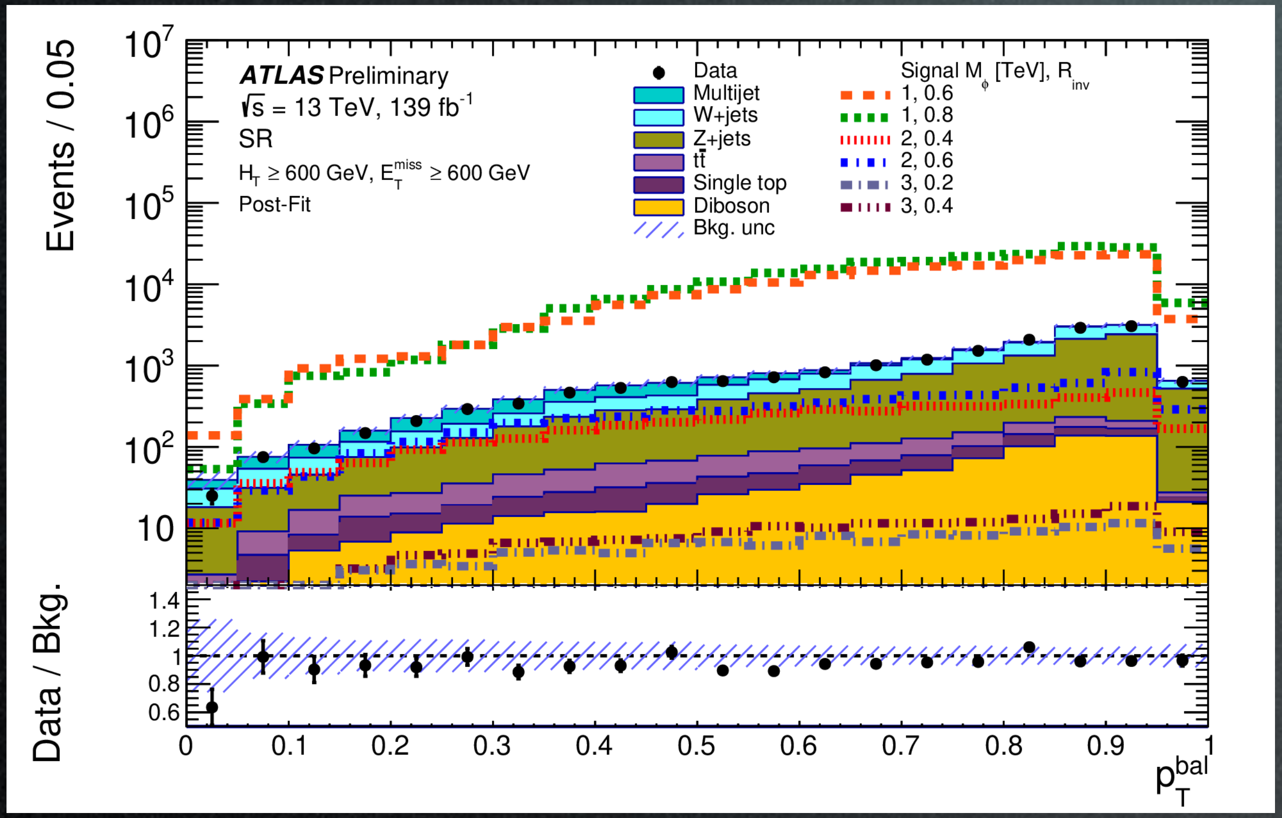
Results

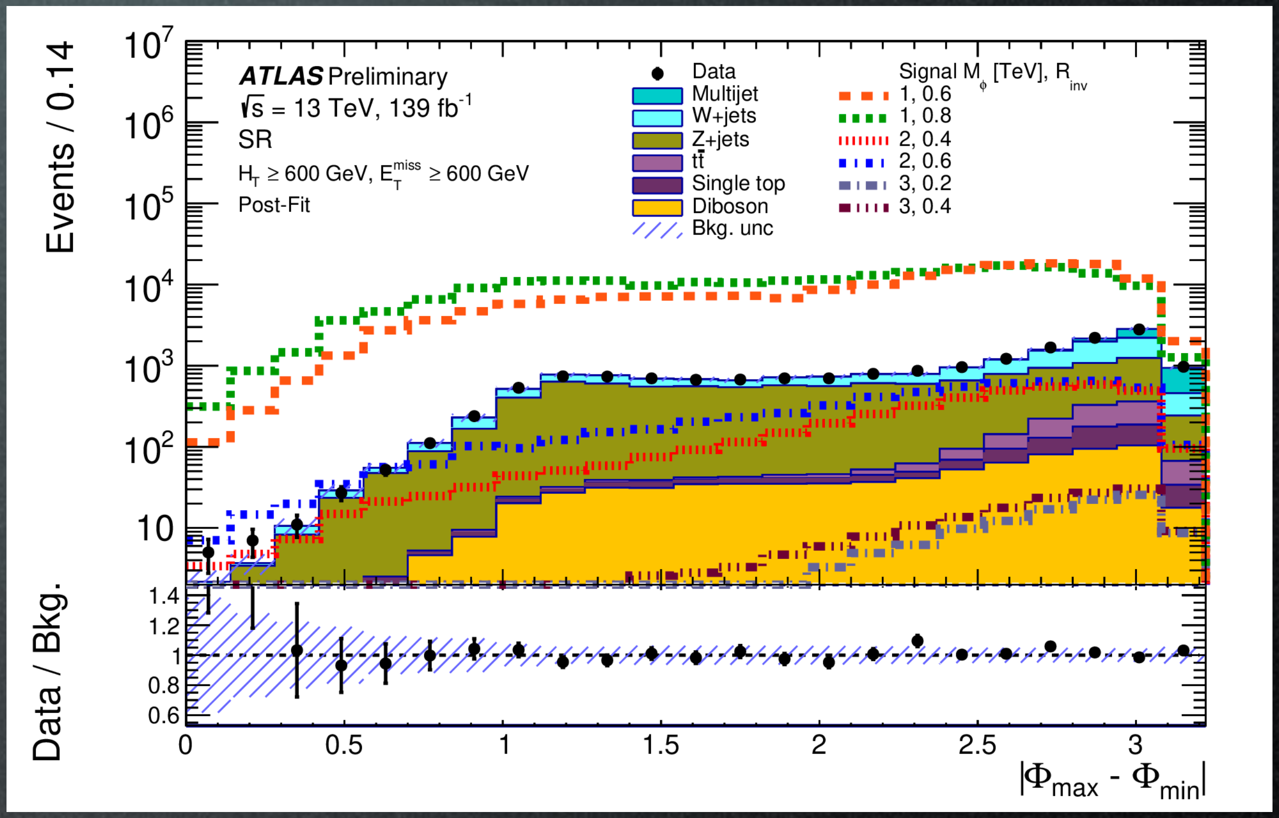




Excellent agreement between data and background prediction: H_T and MET

Results





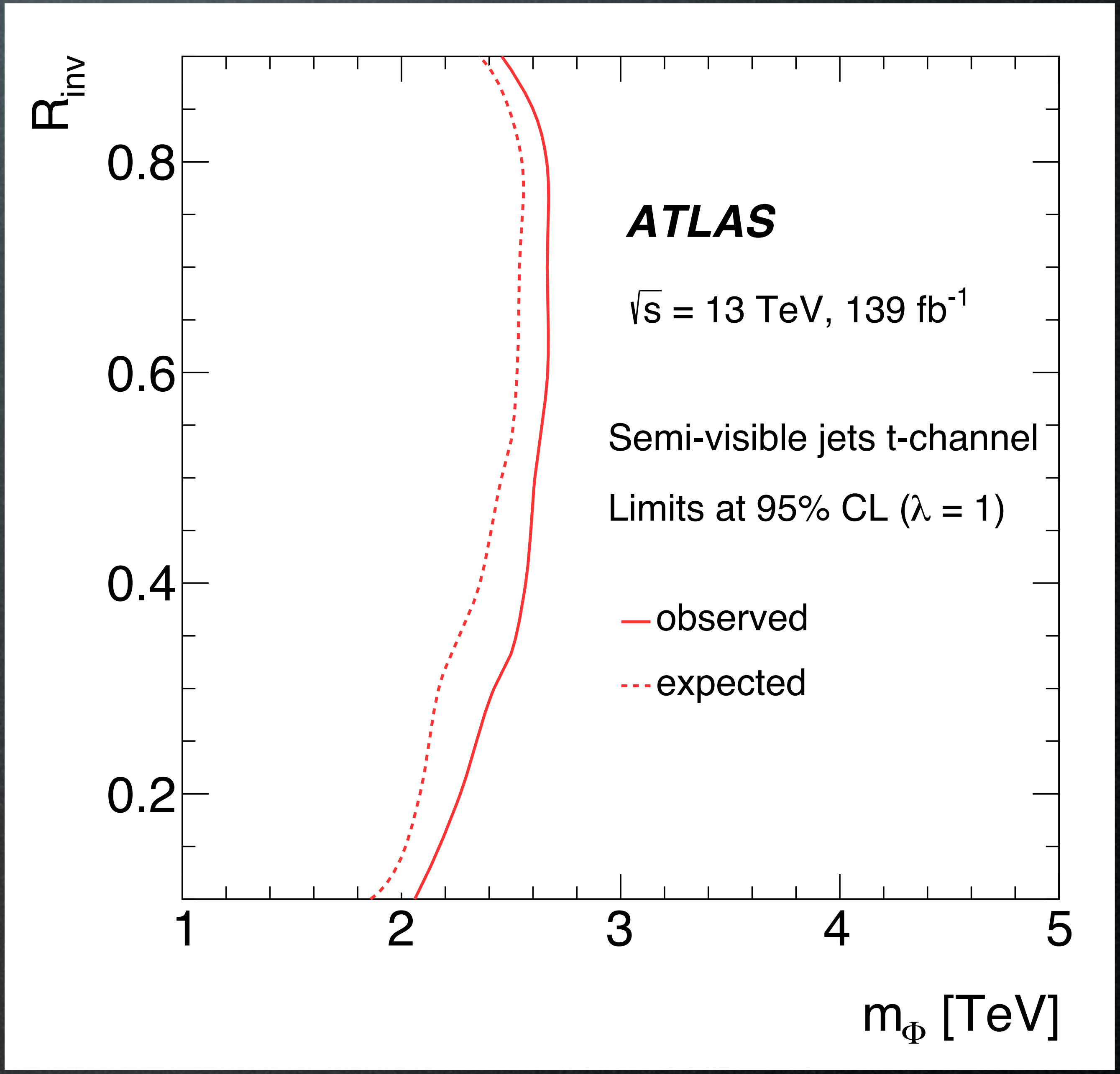
Excellent agreement between data and background prediction: $P_T^{balance}$ and max-min ϕ

Phys. Lett. B 848 (2024) 138324

Results

Sukanya Sinha: former PhD student, now in UofM

- Excellent agreement between data and background prediction.
- Limits on mediator mass separately for each Rinv
- Data yield in SR, proxy for model independent limit with this SR selections



An Aside: Why Limits?

We all want to find new physics.

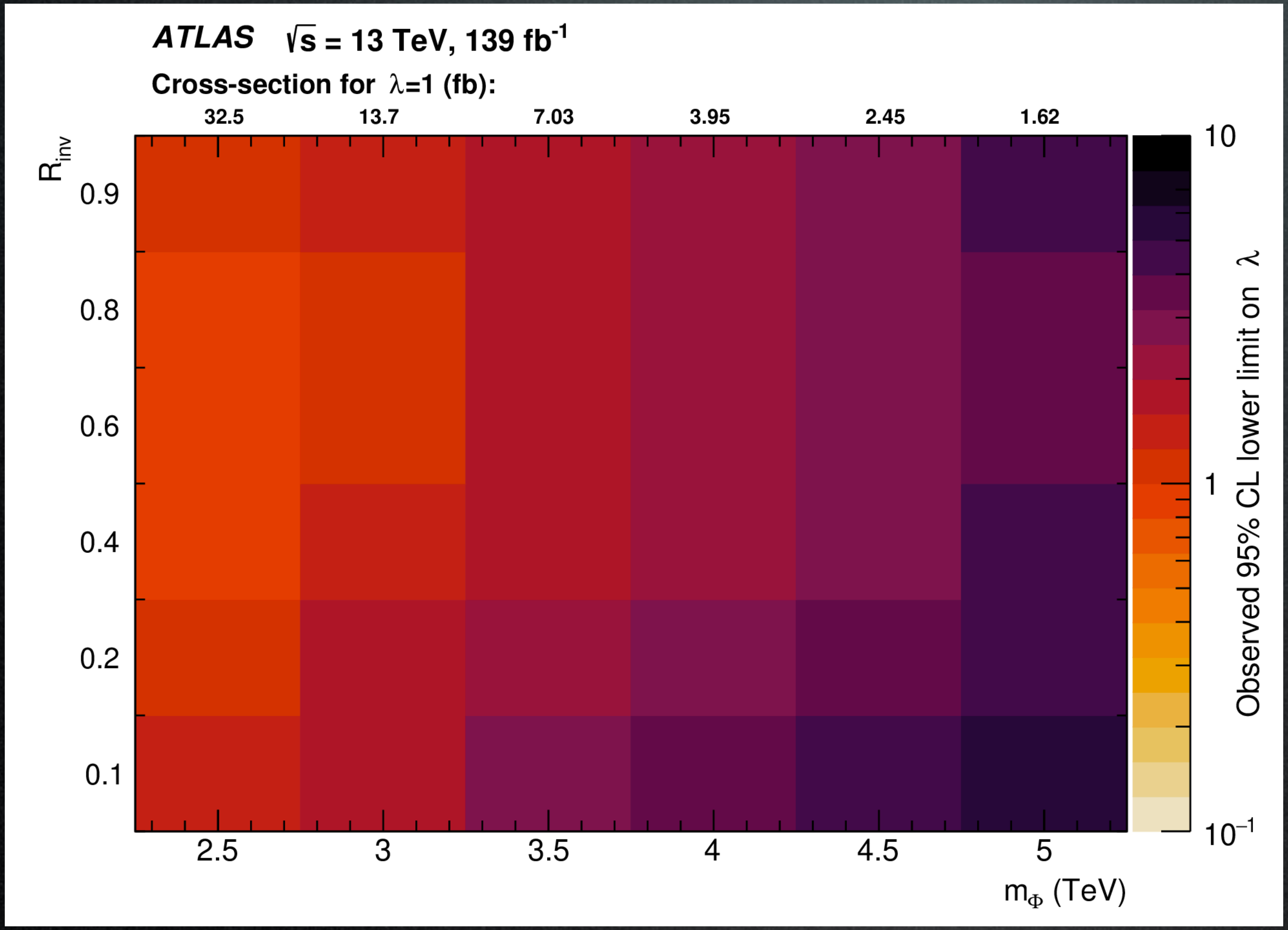
But out of 100 new physics models, at least 99 are wrong, possibly all 100 are!

So null results also tell us a lot.

And techniques/methods developed can help in a future discovery!

Phys. Lett. B 848 (2024) 138324

Results



For mediator mass of 2.5 TeV or higher can also express the limits in terms of the q-q_d-ϕ vertex coupling strength λ, with the XS scaling as λ^4

https://atlas.cern/Updates/Briefing/Semi-Visible-Jets

ATLAS briefing!

ATLAS EXPERIMENT

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Physics Briefing

Tags:
LHCP 2023,
new physics,
dark matter,
physics results

Not a jet all the way: is dark matter hiding in plain sight?

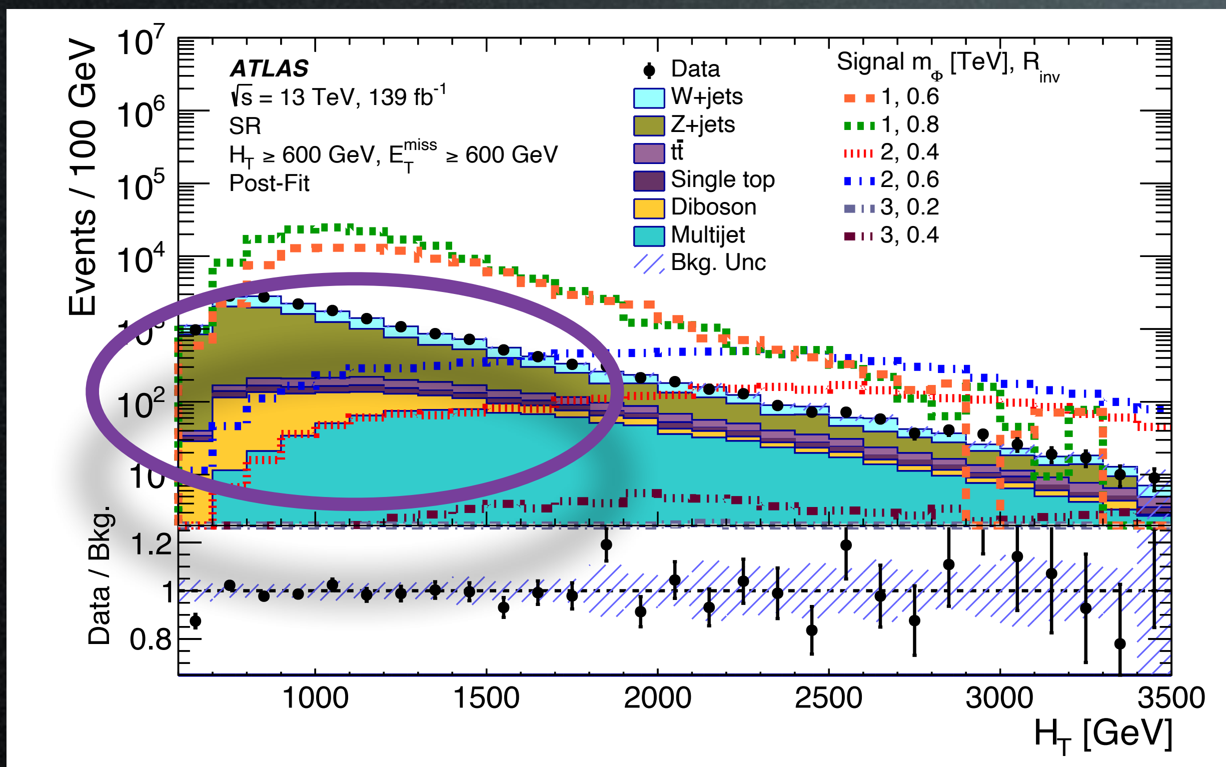
26 May 2023 | By ATLAS Collaboration

What happens if dark-matter particles are produced inside a jet of Standard-Model particles? This leads to a novel detector signature known as semi-visible jets! The ATLAS Collaboration has come up with the first search for semi-visible jets, looking for them in a general production mode where two protons interact by exchanging an intermediate particle, which is then converted into two jets.

The elusive nature of dark matter remains one of the biggest mysteries in particle physics. Most of the searches have so far looked for events where a "weakly interacting" dark-matter particle is produced alongside a known Standard-Model particle. Since the dark-matter particle cannot be seen by the ATLAS detector, researchers look for an imbalance of transverse momentum (or "missing energy"). However, some theoretical models predict a "strongly interacting" dark sector, with dark quarks and gluons as replicas of Standard-Model quarks and gluons. Semi-visible jets would arise when dark quarks decay partially to Standard-Model quarks and partially to stable dark hadrons (the "invisible fraction"). Since they are produced in pairs, typically along with additional Standard-Model jets, the missing energy arises when all the jets are not fully balanced. The direction of the missing energy is often aligned with one of the semi-visible jets, as can be seen in the event display above.

https://arxiv.org/abs/2207.01885

SVJ with Heavy Flavour

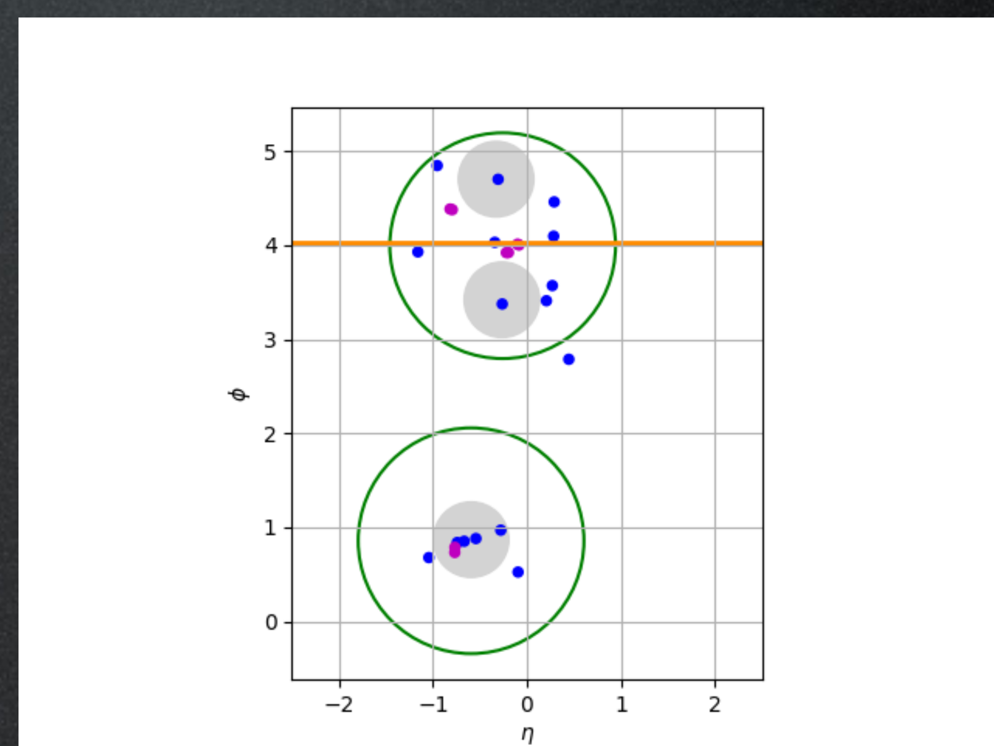


Wandile Nzuza:
current masters student

Better handle on identifying/ reconstructing the SVJ!

Can we reduce non dominant backgrounds?

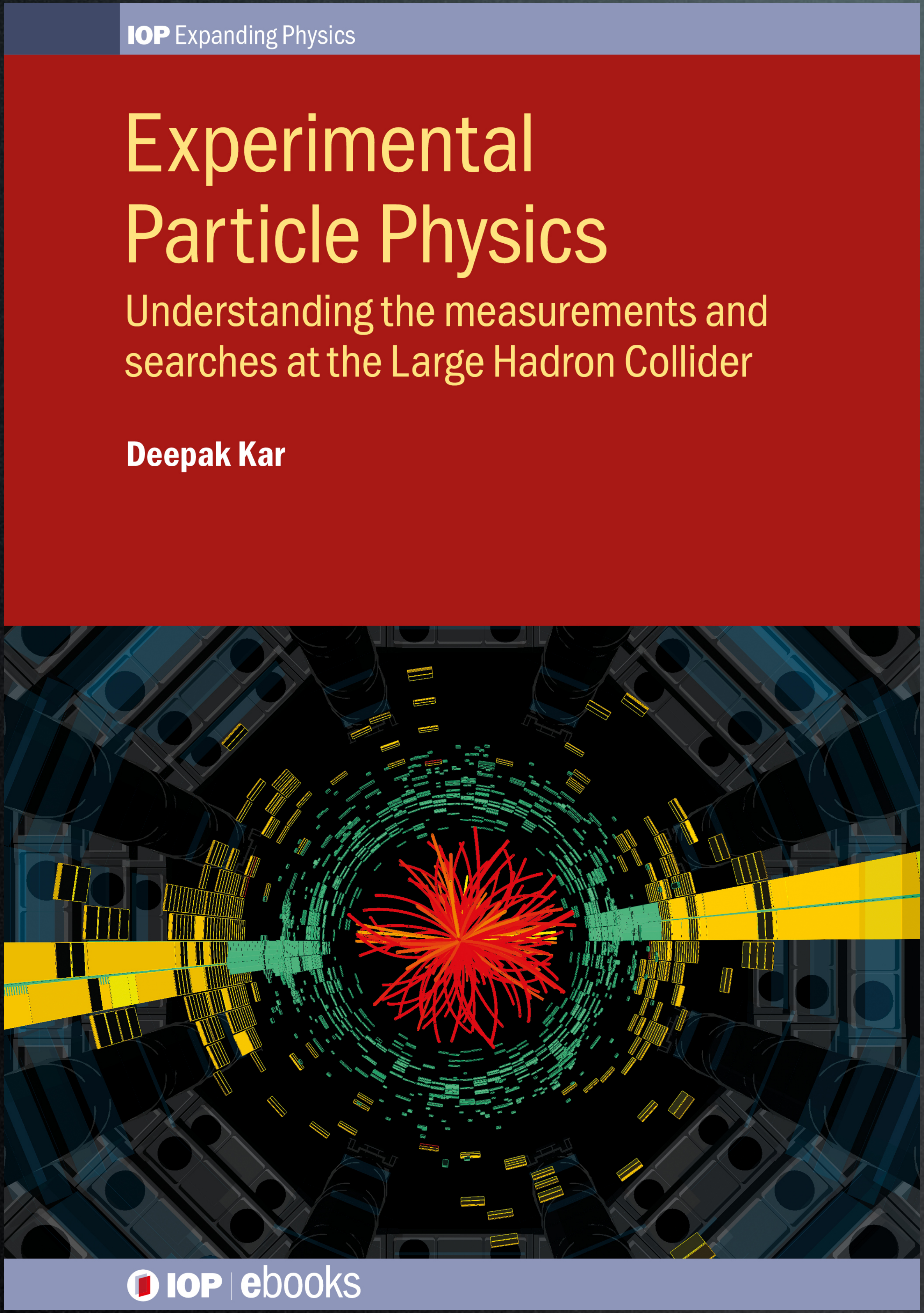
What if SVJ is produced exclusively with b-jets? Turns out it is a theoretically well motivated scenario!



-> Better reconstruction with Variable Radius jets

Summary

- Novel signatures are fun!
- Perhaps we need more a bottom up/ signature driven approach than a top down/model driven approach?
- Unless we search for them, can't really rule them out, can we?



If you can’t access online, ask me ;-)

Backups

Signal Samples: into the Hidden Valley

- Simplest possible implementation to give a search-able experimental signature.

- Single dark QCD flavour, one loop running of dark QCD coupling, confinement scale of 6.5 GeV, coupling between dark and SM sector taken to be unity.

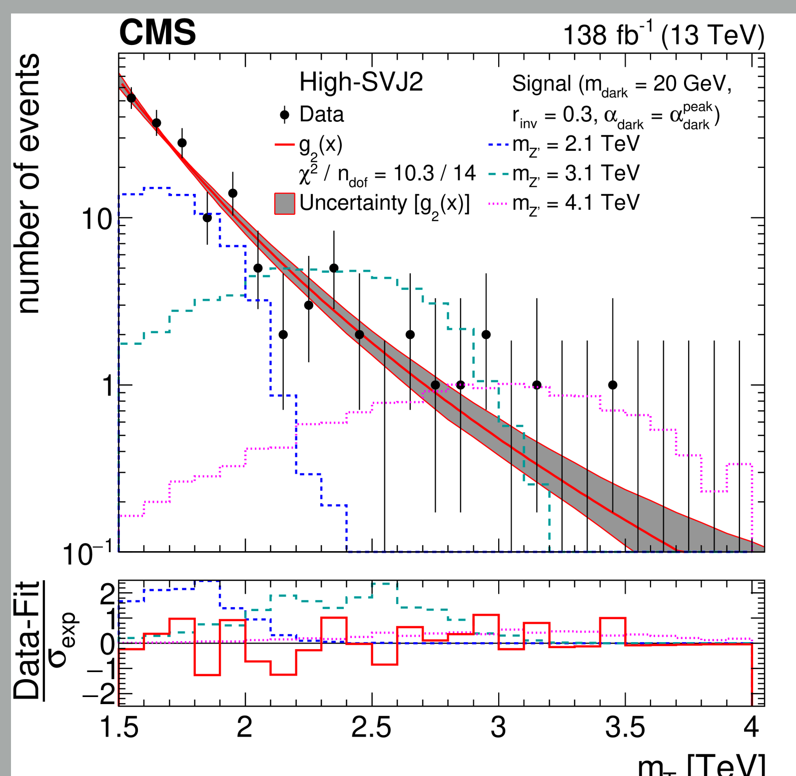
arXiv:2305.18037

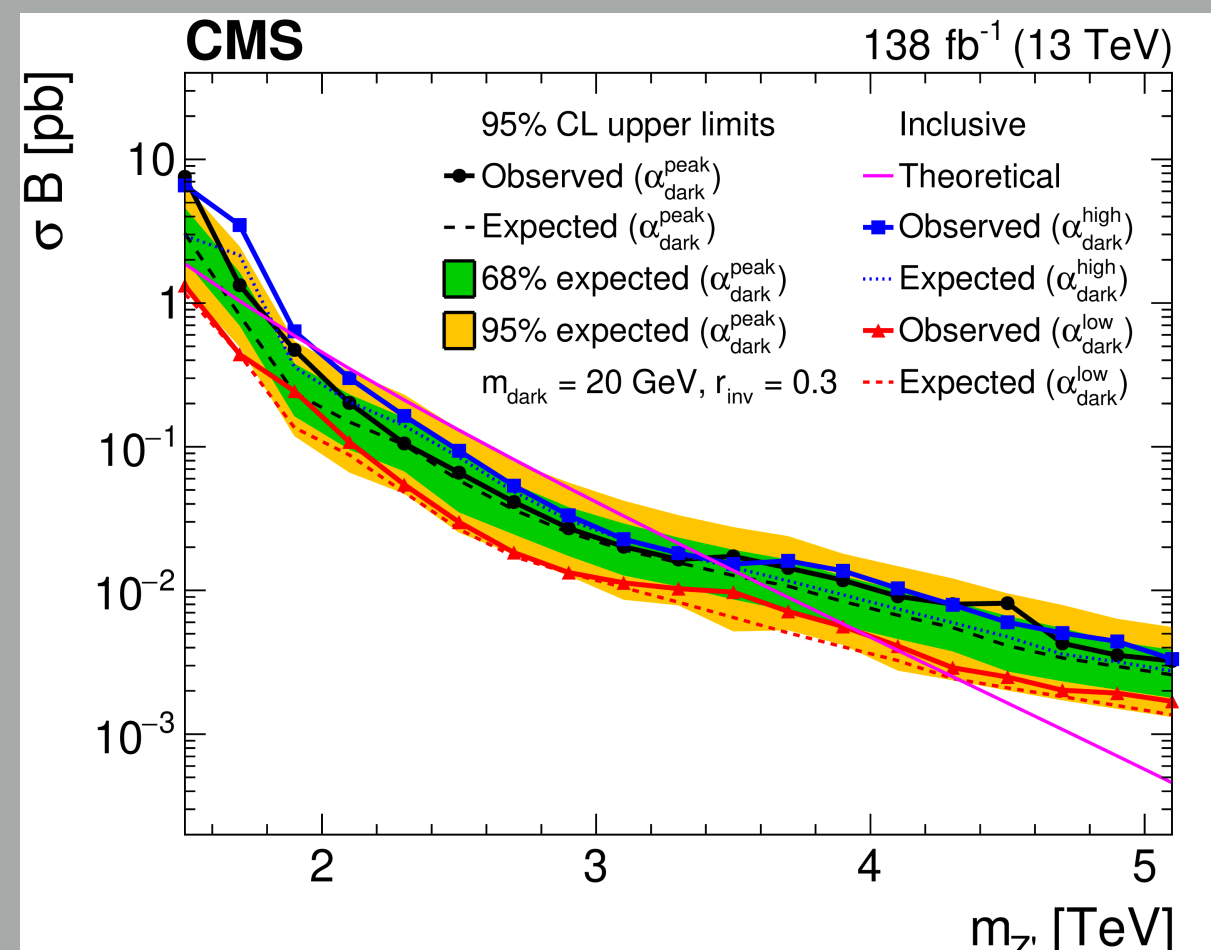
Results

Sukanya Sinha:
former PhD student, now
in UofM

BONUS

Resonant search:





JHEP 06 (2022) 156

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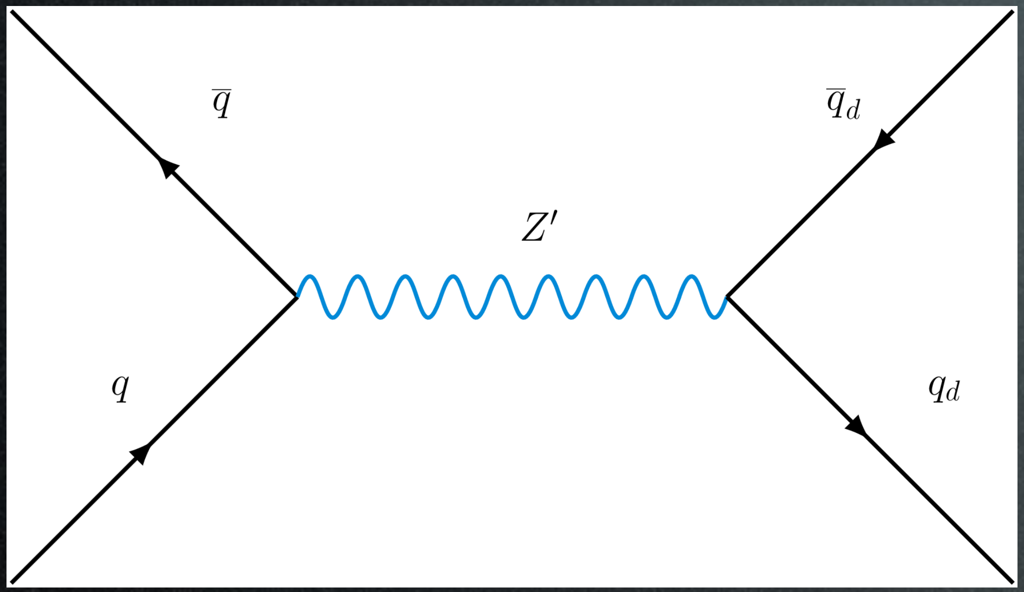
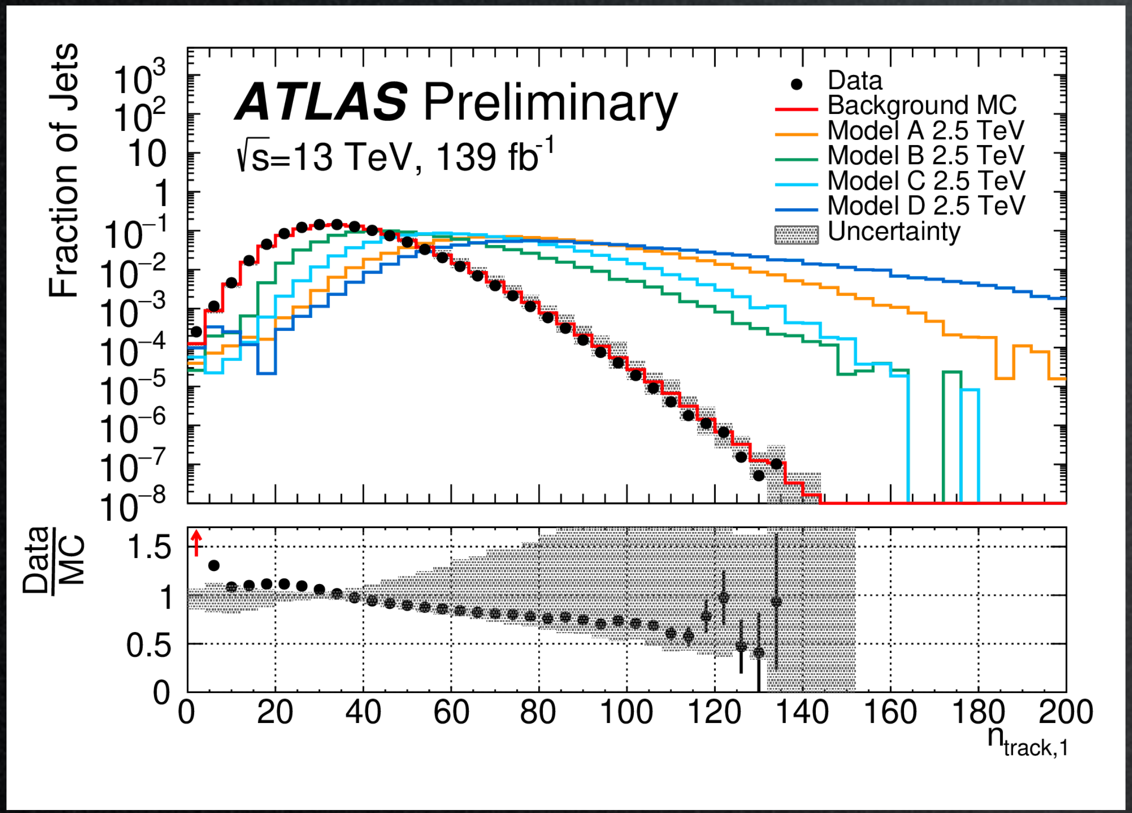
selections

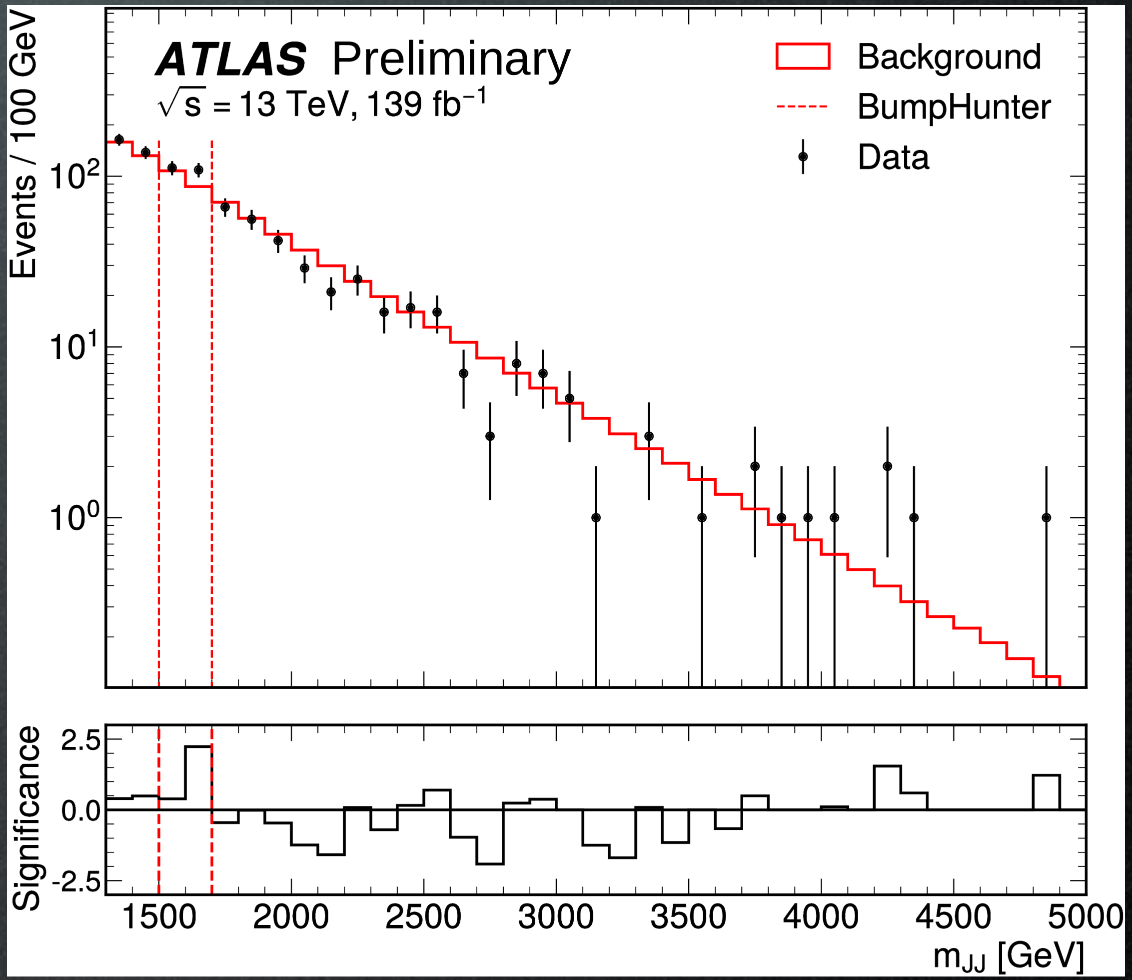
m_Φ [TeV]

ATLAS DarkJets



Dark quarks decay fully back to SM, but results in jets with higher track multiplicity





No bumps found … limits set …