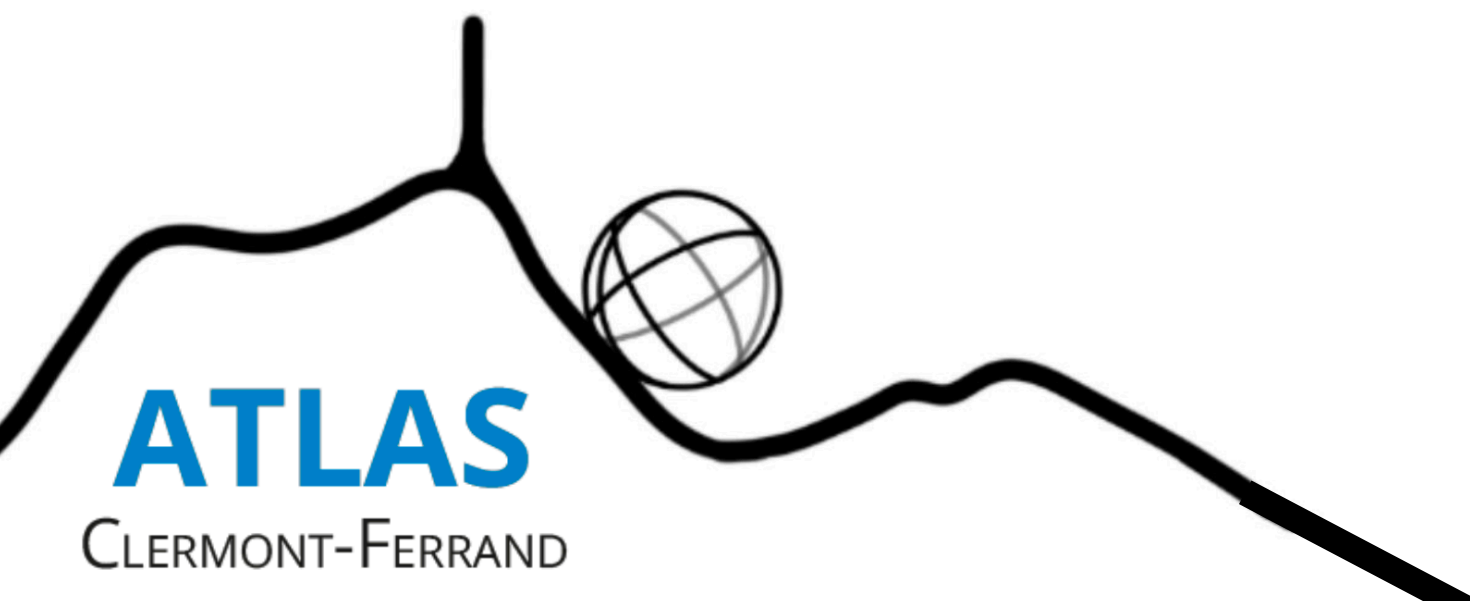


Imperial College Seminar, 27 Feb 2026

The ATLAS Exotics programme

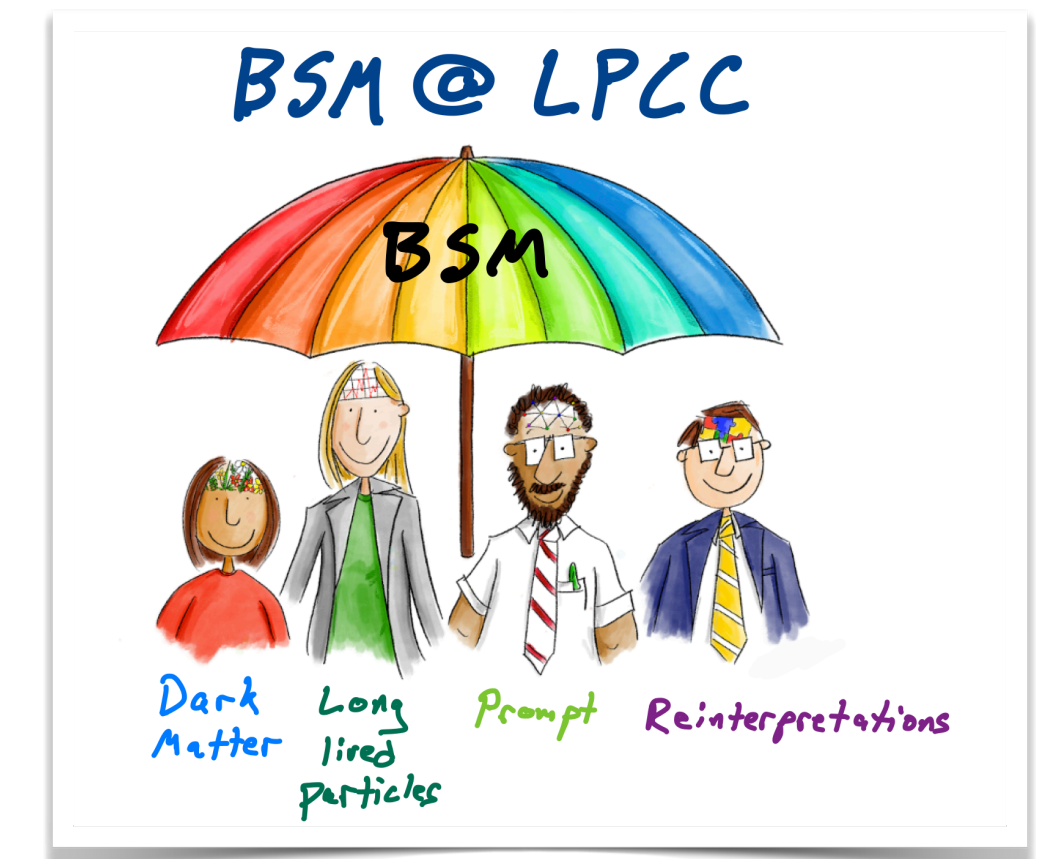
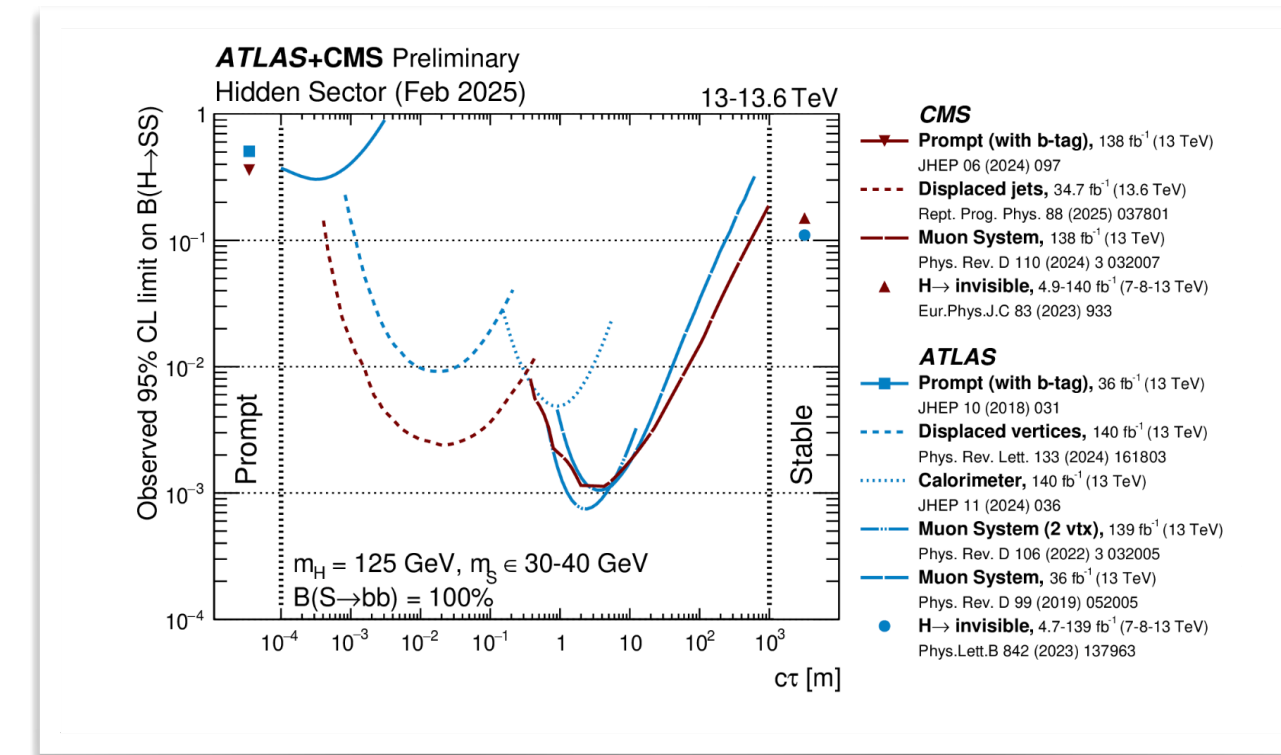
How we are organising the search for new physics for Run 3 and beyond

Louie Corpe (Clermont-Ferrand), on behalf of ATLAS Exotics



About me

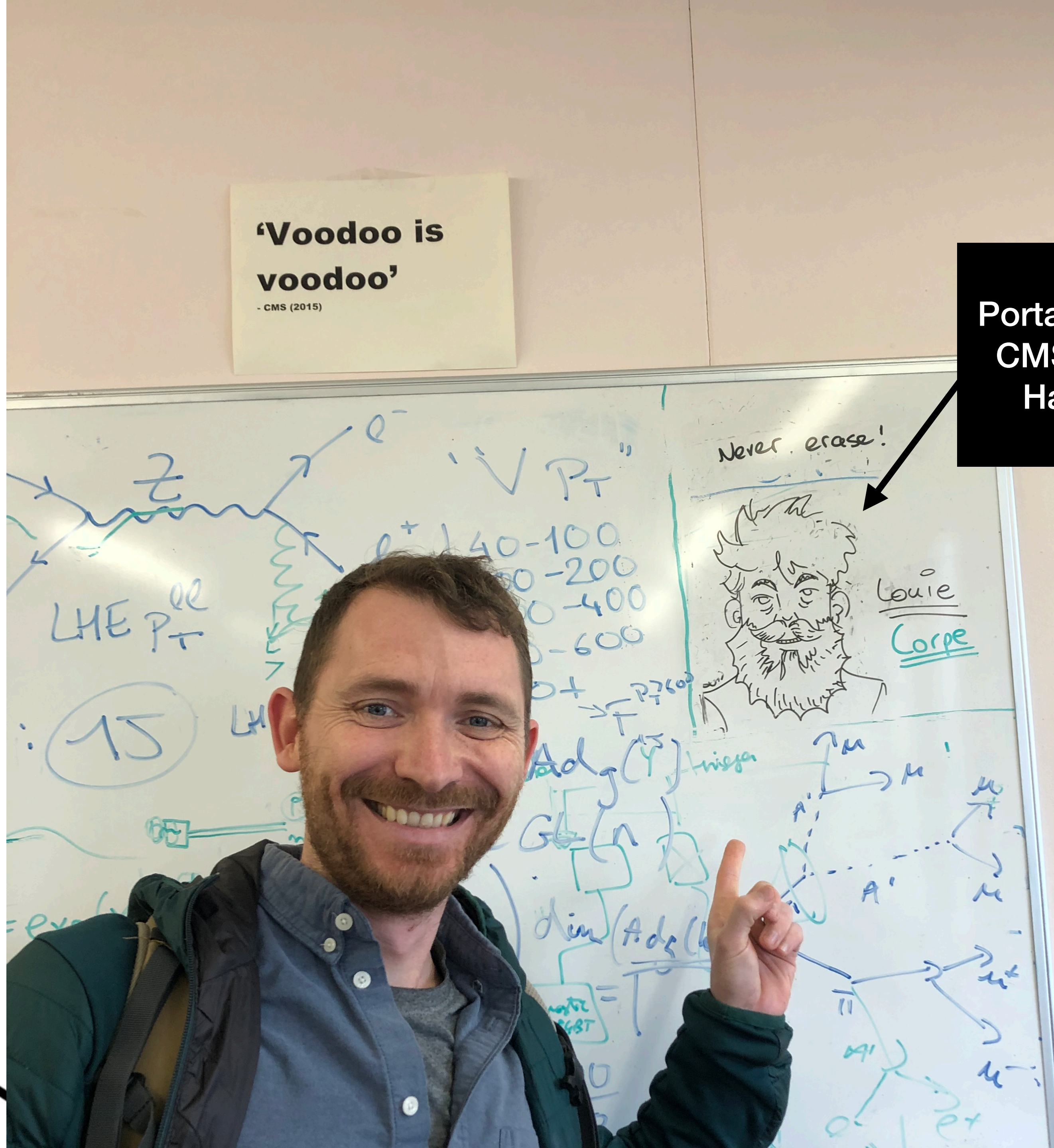
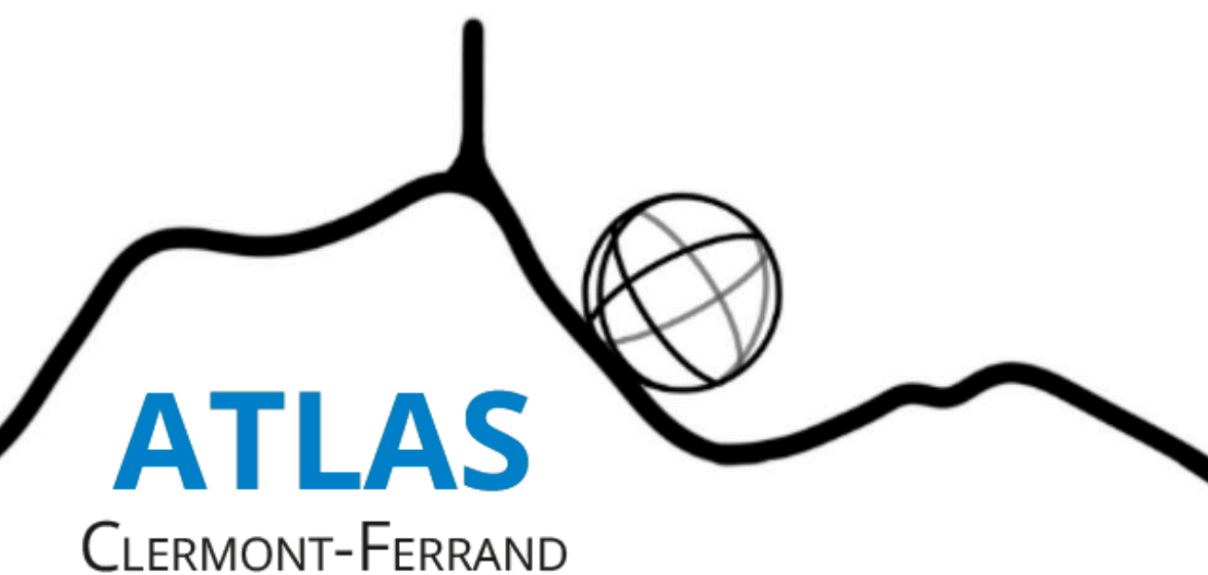
- ATLAS Exotics convener
- Former ATLAS LHC LLP WG convener
- Long ago, PhD student on CMS at IC



A long time ago (2015)
in a galaxy far, far away (Cessy)...

About me

The Imperial College
CMS office at CERN
last December



**'Voodoo is
voodoo'**

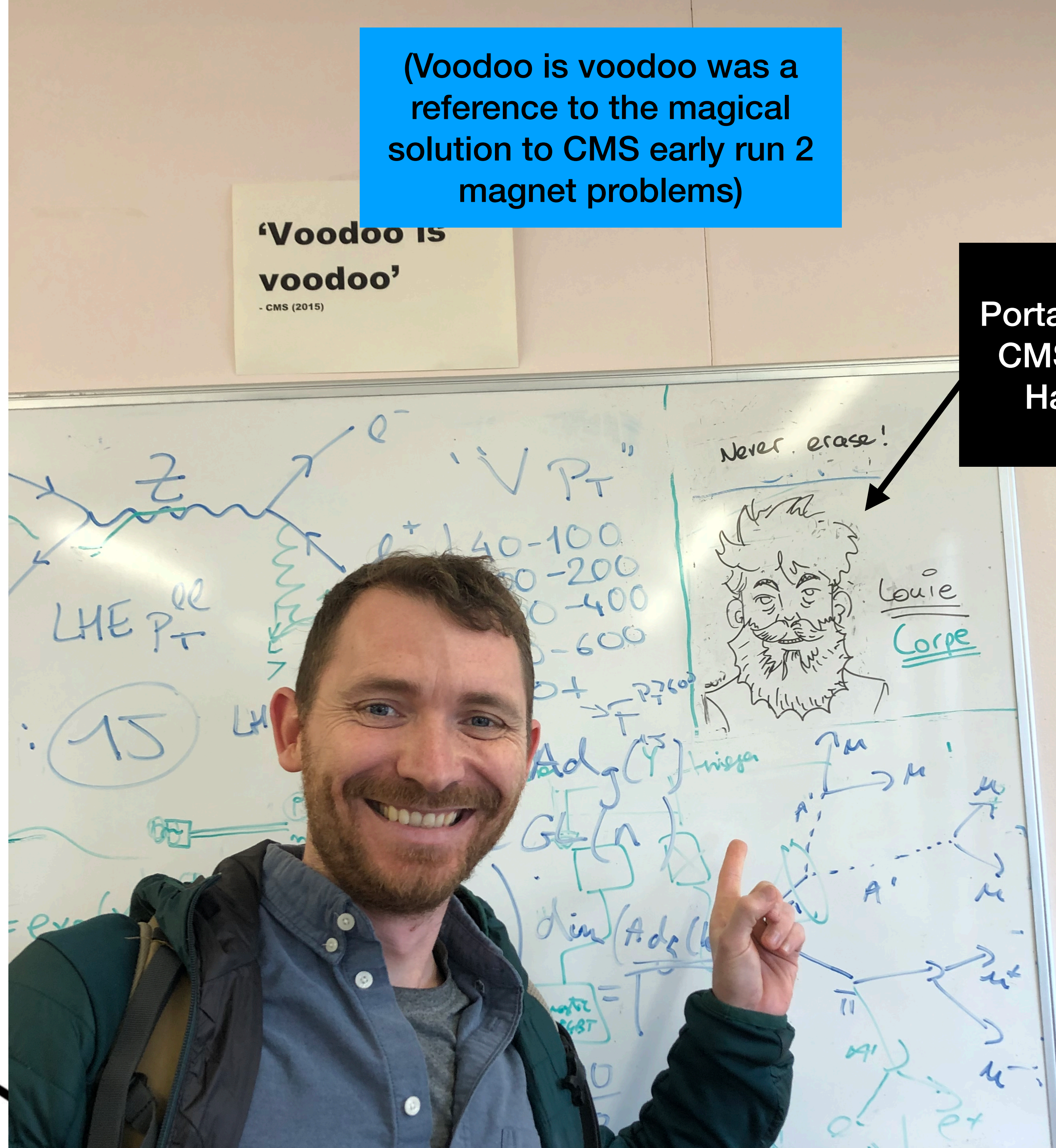
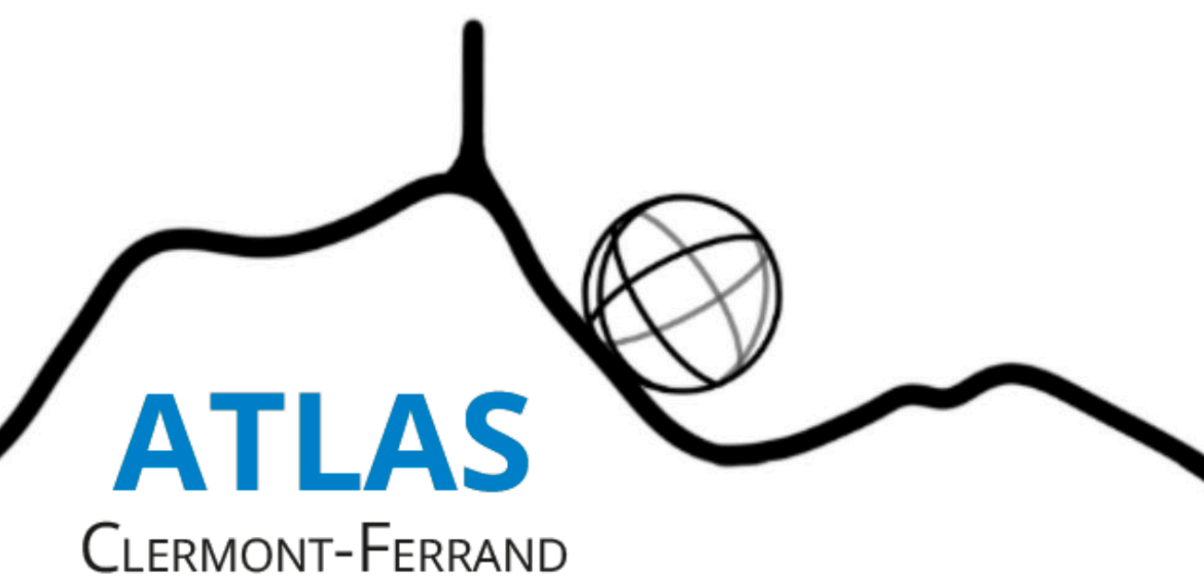
- CMS (2015)

Portrait drawn by Imperial
CMS post-doc Yassine
Haddad, circa 2015

I am glad that
despite a decade
passing, I am still
leaving some kind
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Imperial College !

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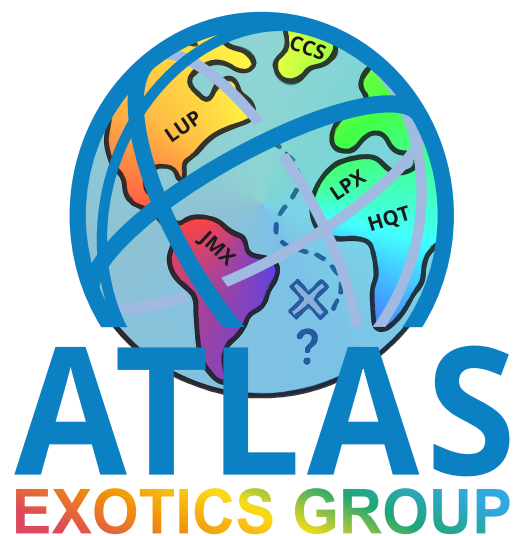
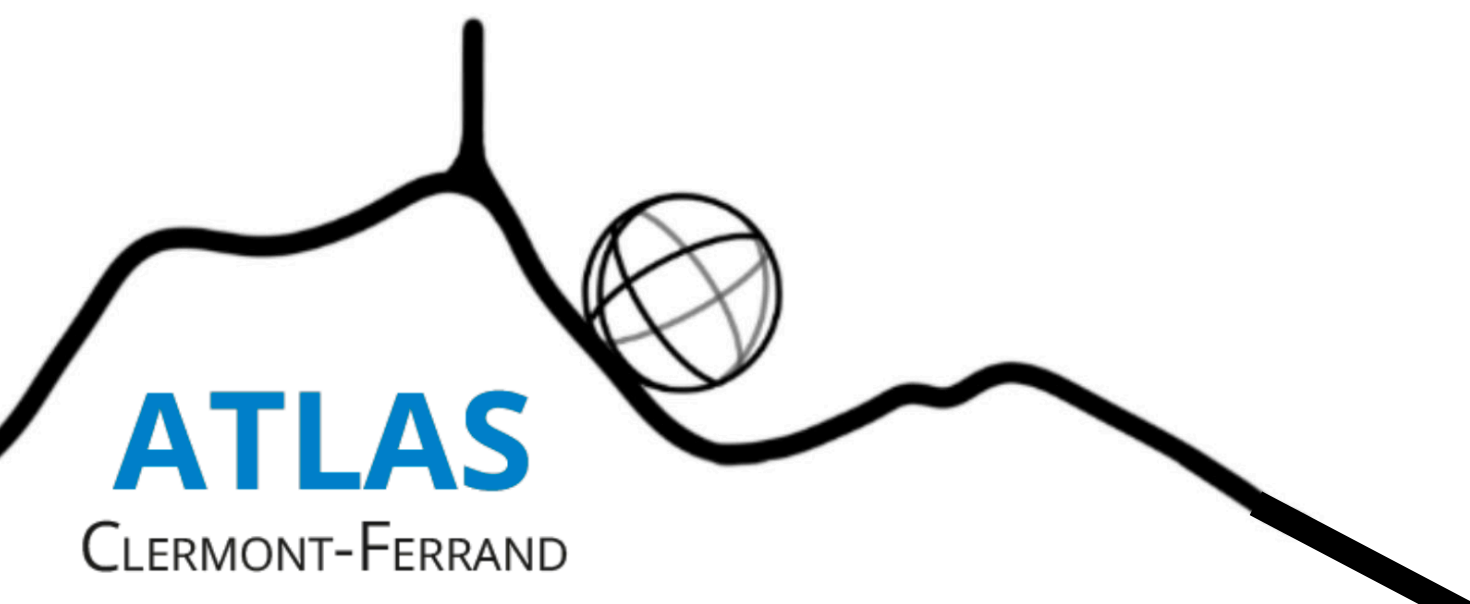
(Voodoo is voodoo was a reference to the magical solution to CMS early run 2 magnet problems)

Portrait drawn by Imperial CMS post-doc Yassine Haddad, circa 2015

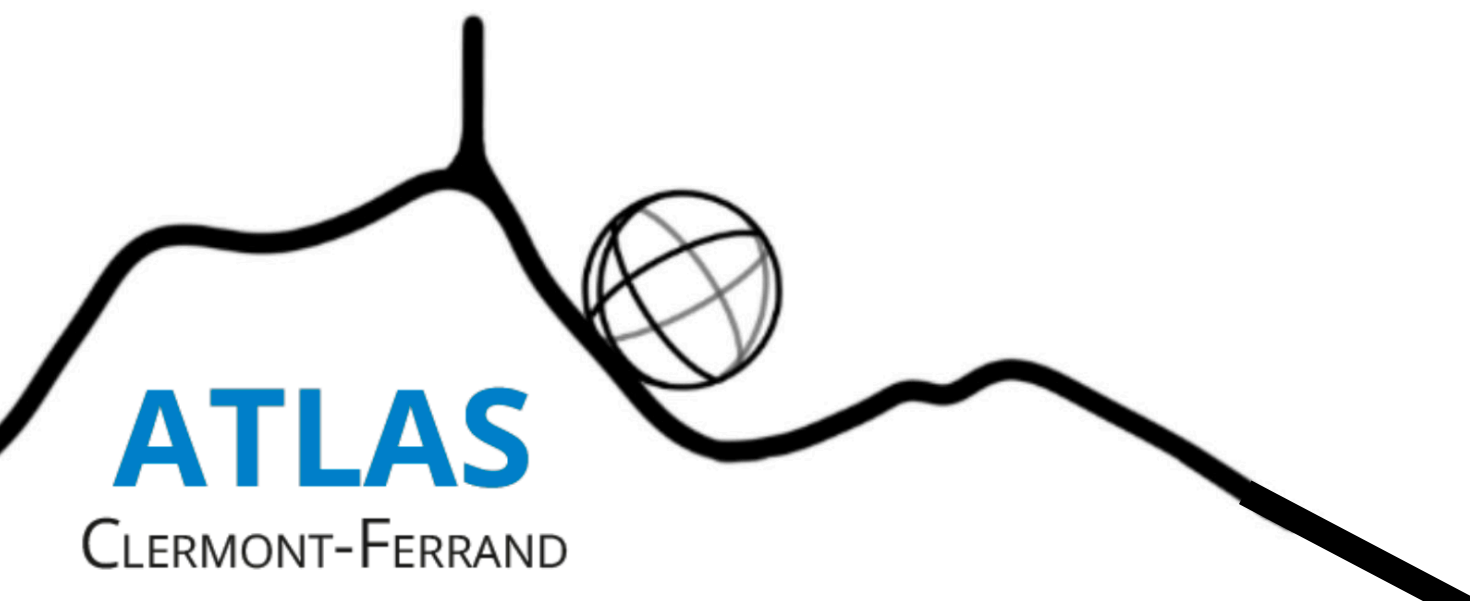
I am glad that despite a decade passing, I am still leaving some kind of mark on Imperial College !

About this talk

- I will **not use this time to make a laundry list** of our recent results.
 - You can see great summaries from EPS, Lepton-Photon and SEARCH 2025
 - (I will however show a couple of recent examples of our searches)
- I thought I would instead try to make this talk different from what you usually get at conferences...
-instead give you a **flavour of our thinking in ATLAS** as we organise our Run-3 (and beyond) search programme.



What is the ATLAS plan for searches for the rest of the LHC lifetime?



Louie Dartmoor Corpe (Clermont-Ferrand)

6





Breaking new ground in the search for dark matter

By: Ana Lopes

7 AUGUST, 2020 · Voir en français

“We will leave no stone unturned, no matter how big or small and how long it will take us,” says Pani.



Leave no stone unturned

- ▶ Run-2 searches starting to converge, early analyses with full data:
 - ▶ dijets, dileptons, lepton+MET, di-bosons, di-Higgs, multileptons...
- ▶ Many others will follow soon

What is the ATLAS plan for searches for the rest of the LHC lifetime?

No Stone Unturned: A Comprehensive Approach to New Physics Searches at Colliders

What can we do with the LHC data?

probe the Standard Model - and search for new phenomena beyond it!

- Why should we search for new physics beyond the Standard Model?
 - we *must* leave no stone unturned in data
 - ... and we have good motivations to think that new physics exists
 - mass hierarchy of the fermions
 - matter/anti-matter asymmetry
 - dark matter
 - ...



High Energy Physics – Phenomenology

[Submitted on 13 Jun 2013 (v1), last revised 27 Sep 2013 (this version, v2)]

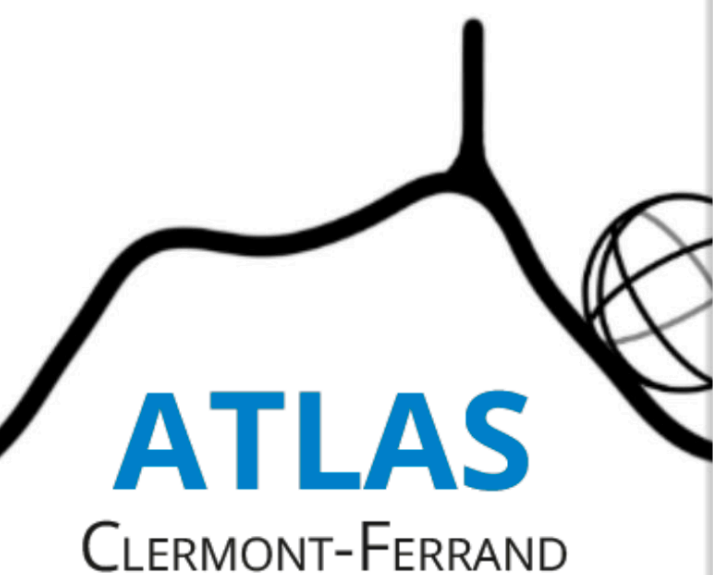
Leaving no stone unturned in the hunt for SUSY naturalness: A Snowmass whitepaper

Howard Baer, Vernon Barger, Peisi Huang, Dan Mickelson, Azar

Why Search for Long-Lived Exotica?

Why not?

- No sign of new physics yet! → We should leave no stone unturned
- A new massive, long-lived particle would be a clear sign of new physics
- **But challenging (exciting)!** We need to push our detectors, triggers, reconstruction, and analysis techniques to the limit





Breaking new ground in the search for dark matter

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- ▶ Run-2 searches starting to converge, early analyses with full data:
 - ▶ dijets, dileptons, lepton+MET, di-bosons, di-Higgs, multileptons...
- ▶ Many others will follow soon

What is the ATLAS plan for searches for the rest of the LHC lifetime?

- Just saying "Leave no stone unturned" is **not good enough**
 - Intellectually light-weight
 - Impossible: ~infinitely many models and final states
- What we need is a **planned**, and well thought-out **strategy**
- It's a focus of the current BSM search convenership in ATLAS to make this strategy a concrete reality more than just vague ideas.

What can we do with the LHC data?

probe the Standard Model - and search for new phenomena beyond it!

Why should we search for new physics beyond the Standard Model?

no stone unturned in data

motivations to think that new physics exists

of the fermions
matter asymmetry

Help | Ad

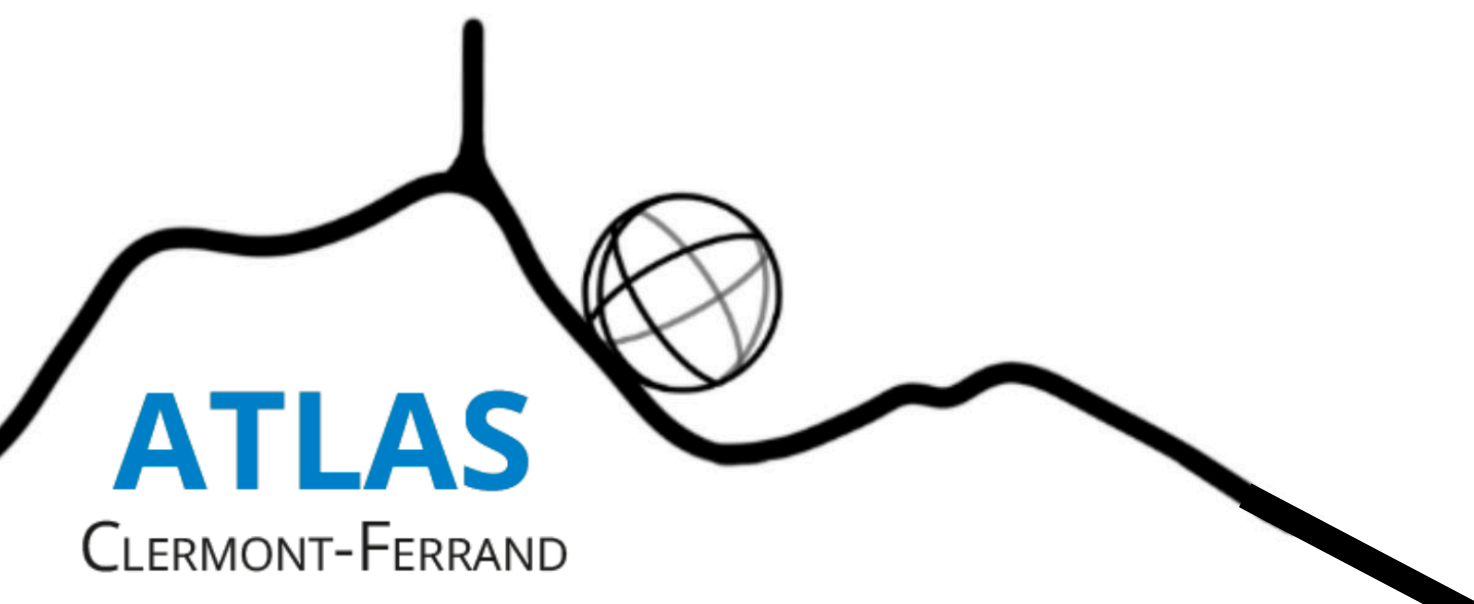
(version, v2)]

the hunt for
mass whitepape

– But challenging (exciting)! We need to push our detectors, triggers, reconstruction, and analysis techniques to the limit

Howard Baer, Vernon Barger, Peisi Huang, Dan Mickelson, Azar

What is the ATLAS plan for searches for the rest of the LHC lifetime?



It's time to plan the Endgame of the LHC

In chess, the **endgame** refers to the **final phase** of the game, when most of the pieces have been used up (**limited resources and time** remaining), and one player must eventually win.

Having a **clear endgame strategy** is essential.

So let's take stock of the state of the board



Let's take stock of the board



Louie Dartmoor Corpe (Clermont-Ferrand)

11

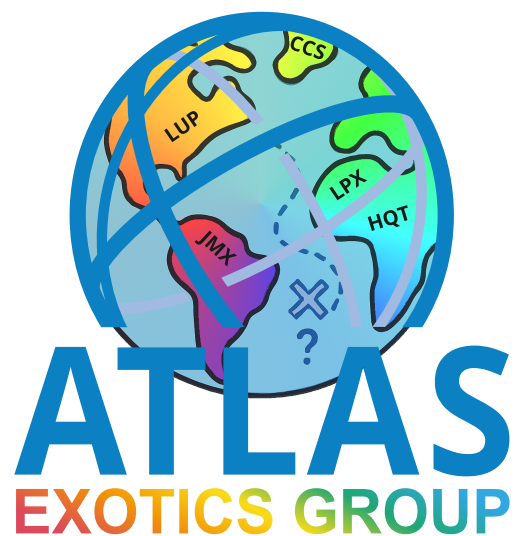
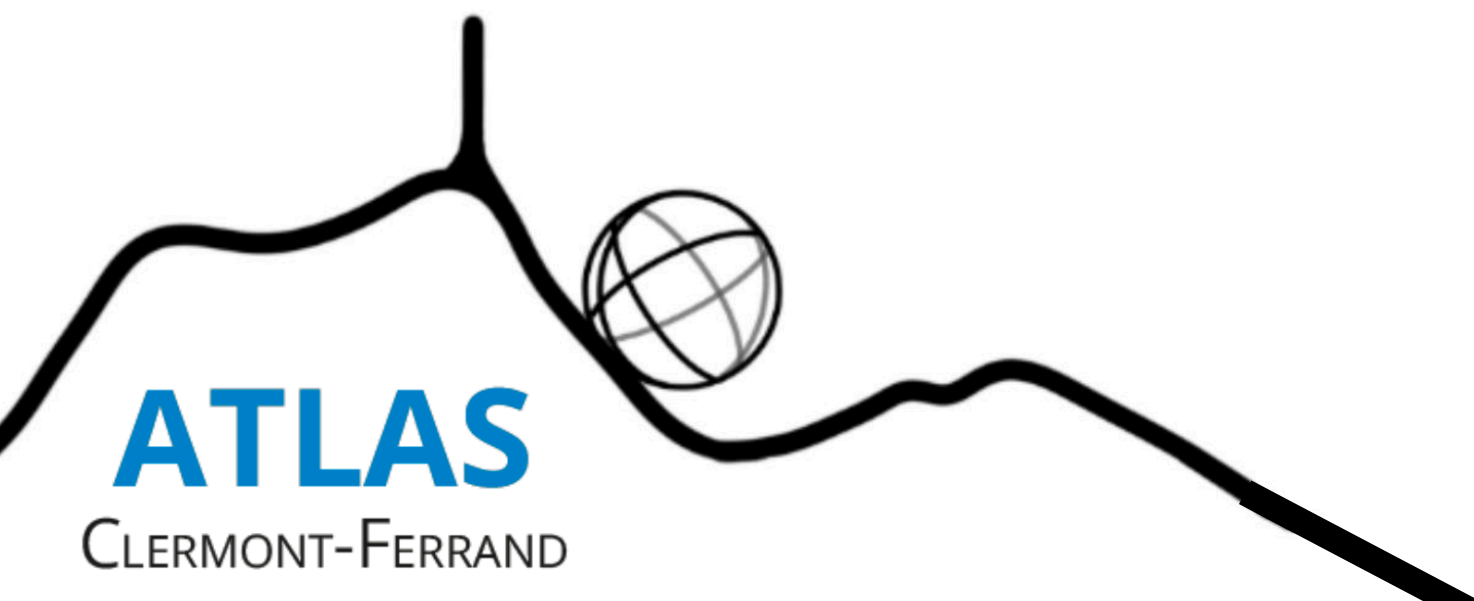


Boundary conditions for a search programme

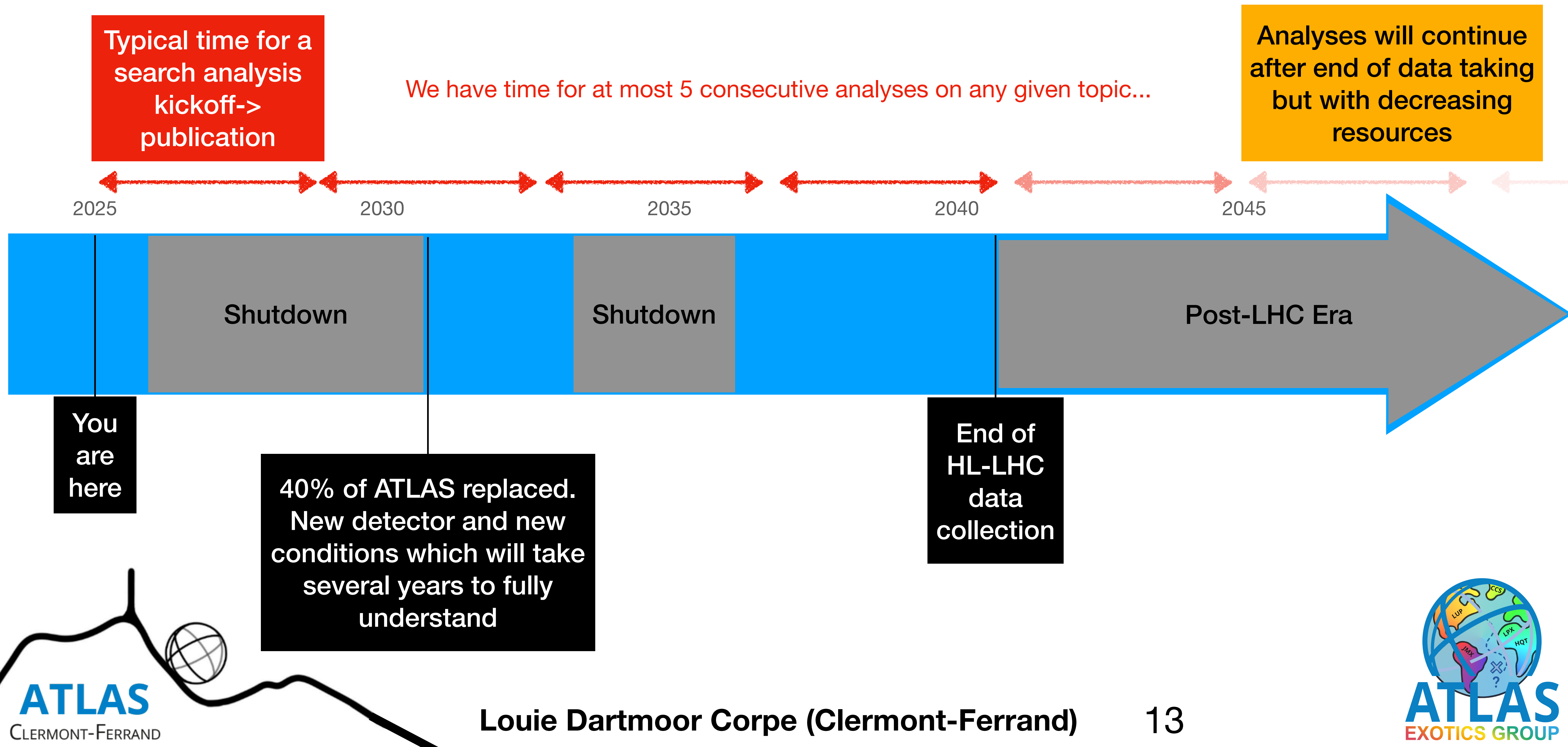
Time

Resources

Objectives



Time: the LHC will not last forever



Boundary conditions for a search programme

Time: the LHC will not last forever

- 15 years til end of LHC data-taking
- 1/3 of time during shutdowns periods
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- Searches will continue after shutdown, but no possibility to collect new data

We need to plan the endgame of the LHC today!

Resources: People and Tools

Objectives:

Resources: People

Population:
550 + 450 - overlap ~ O(900) active analysts

Capacity:
70+60 = O(130) active analyses

Throughput:
2x ~18 = O(35) search papers / year

Inter-operability:
last year:
35% of analysts participated in upgrade
1/3 of operations tasks by Search analysts



HMBS
Higgs, Multi-Boson and SUSY searches

HLRS
Higgs & Light Resonances

EWK SUSY
Electroweak SUSY production

HBSM
Beyond the SM Higgs

Strong SUSY
Strong SUSY production

MBL
Multi-Boson Lab

CMBF
Central Methods & Background Forum

*previously
HDBS*

*previously
SUSY*



EXOTICS
New Physics Beyond the SM signature-based searches

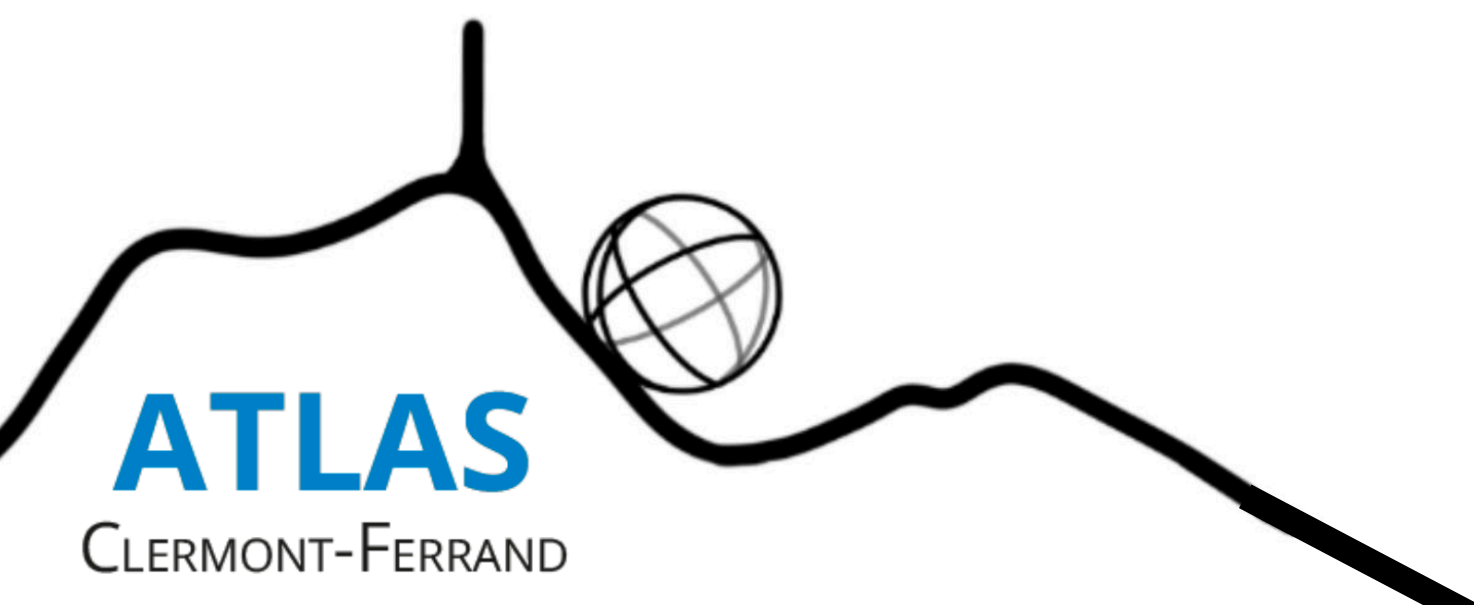
LPX
Leptons + X

JMX
Jets & MET + X

LUP
Long-Lived & Unconventional

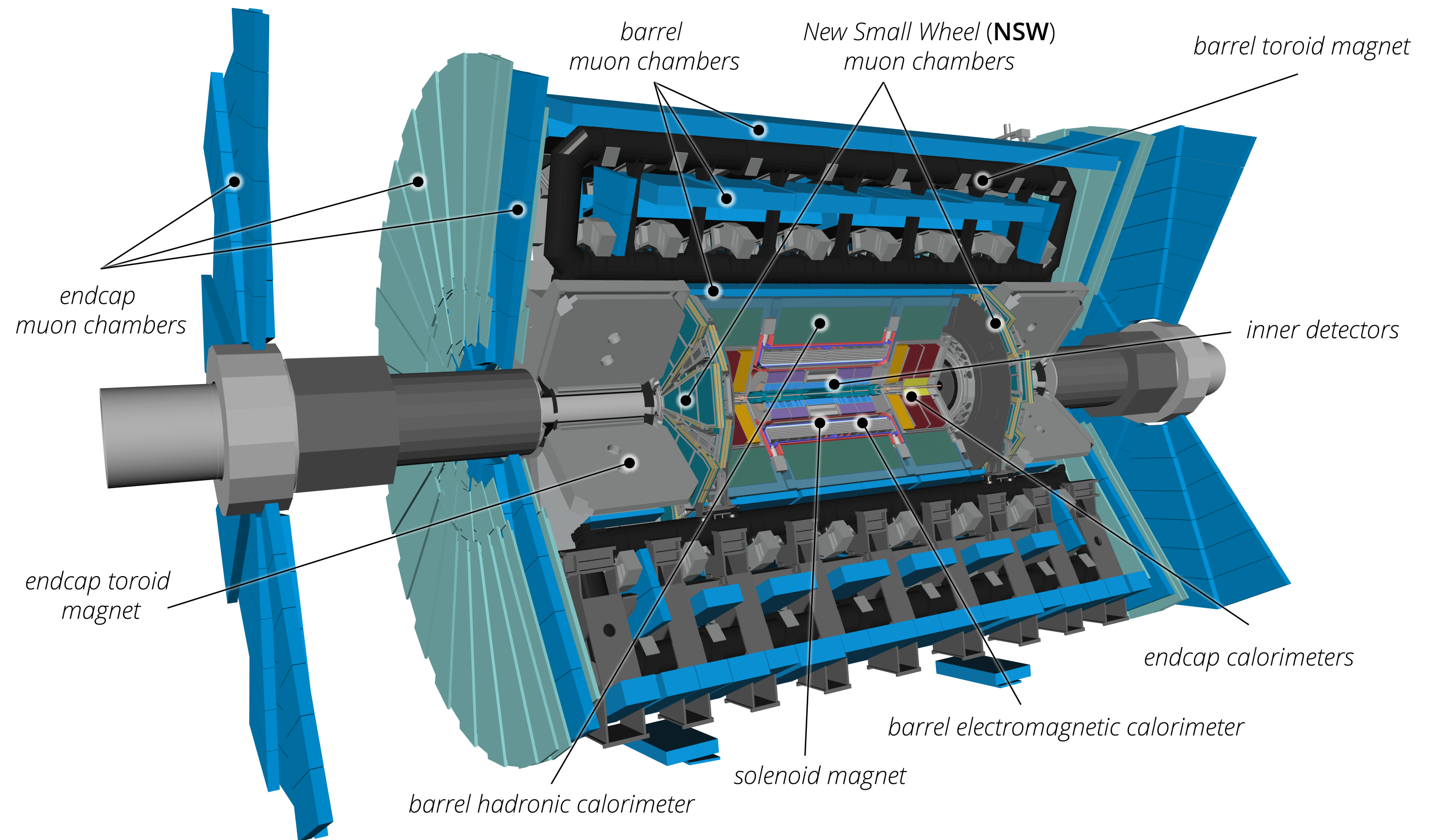
HQT
Heavy Quarks & Top

CCS
Combinations, Cross-talk & Summaries



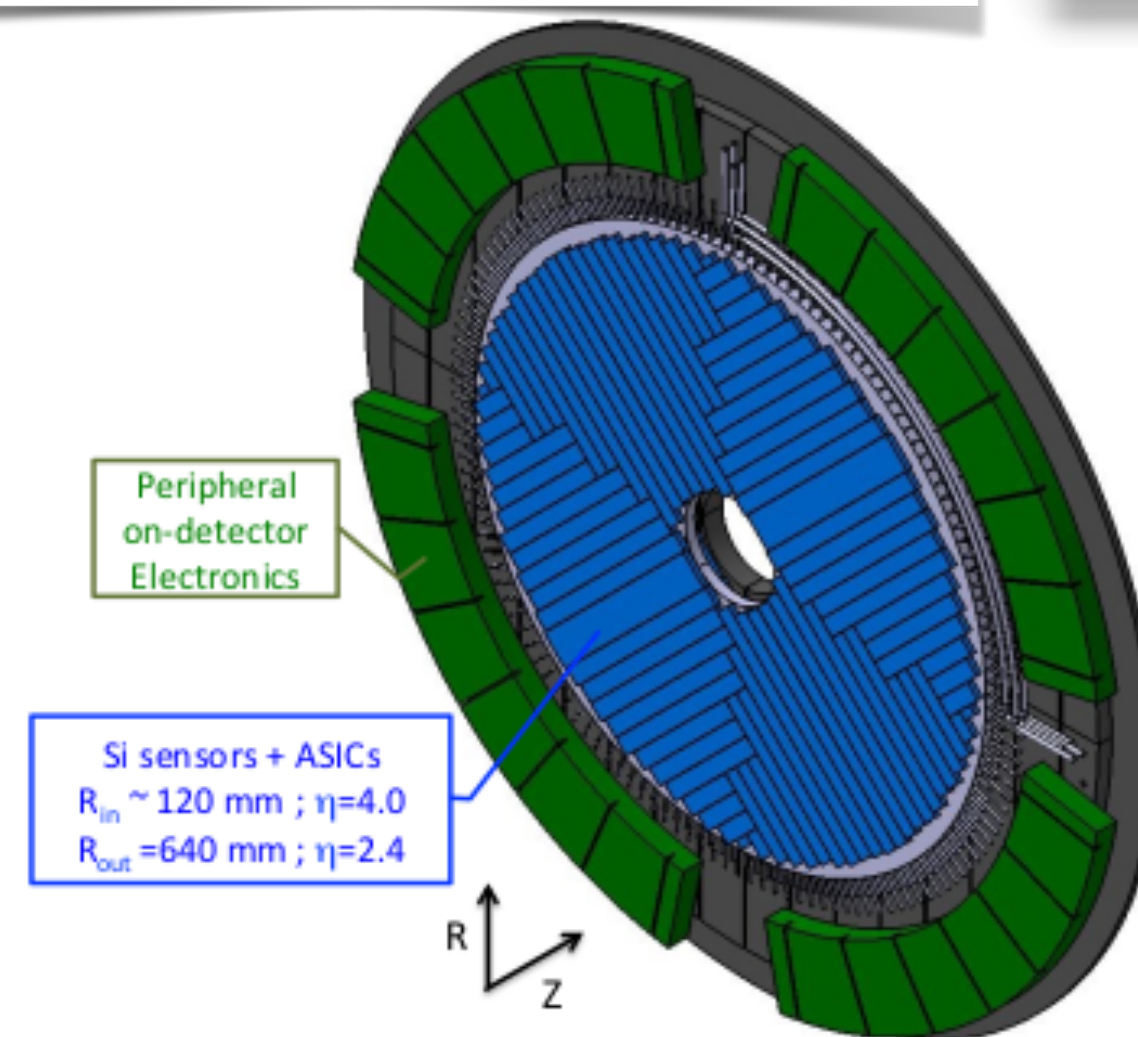
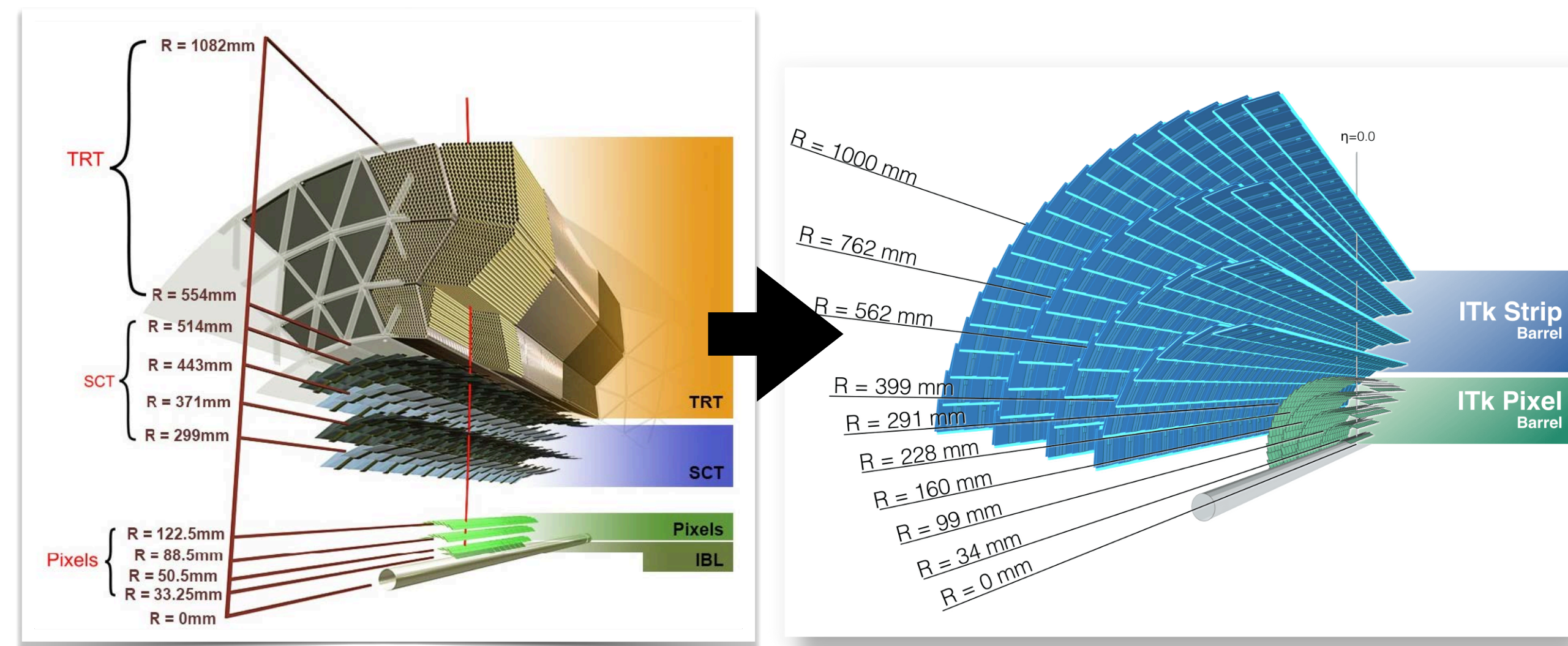
Resources: Phase 1 Detector

- Will have nearly **0.5/ab** of data collected by Run2+3 detector
- Likely the **best-understood dataset** until mid 2030s!
- Half an attobarn is a **lot** of data, (more than we were expecting due to 2026 running extension)
- **Revisit out priors** in terms of analyses are scientifically interesting with Phase 1 data

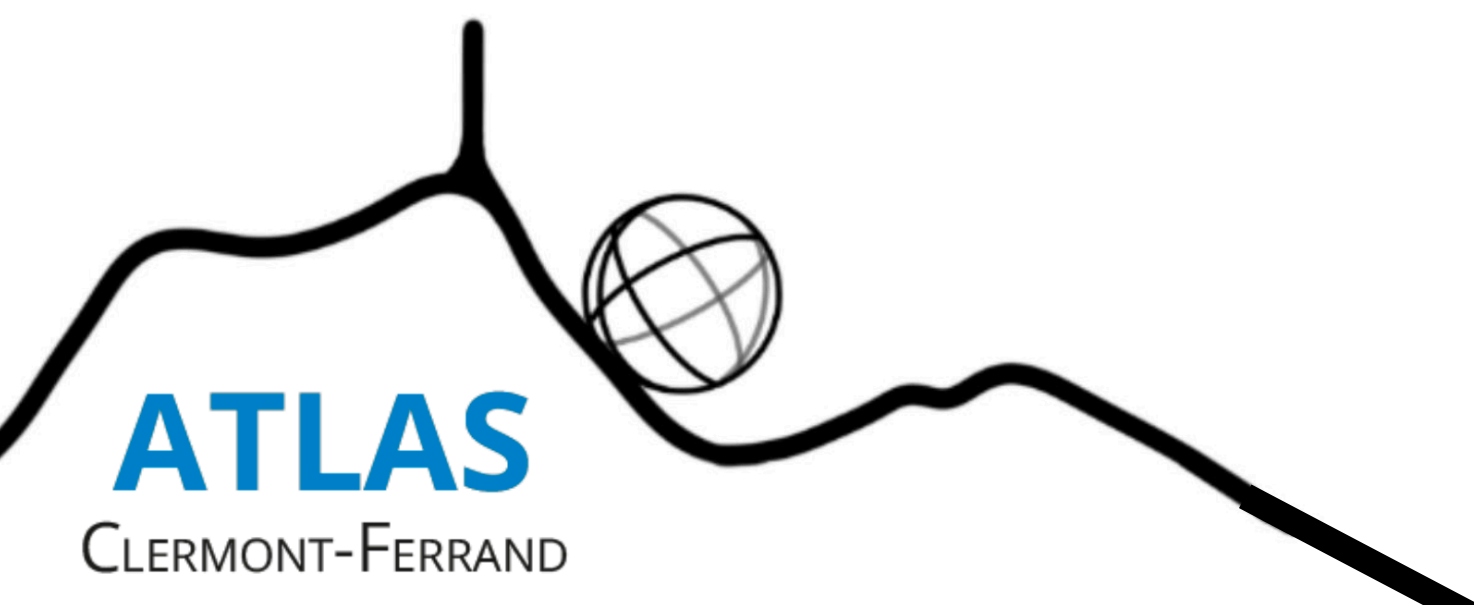


Resources: Phase 2 Detector

- ITk + HGTD: **existential challenge** for ATLAS community.
- Challenge = opportunity:
 - Silicon tracking to radii of 1m
 - Tracking + timing from $2.5 < |\eta| < 4$
 - Exciting possibilities for searches !!!
- To exploit upgrades, search analysts must **be at forefront** of assembly, installation + commissioning

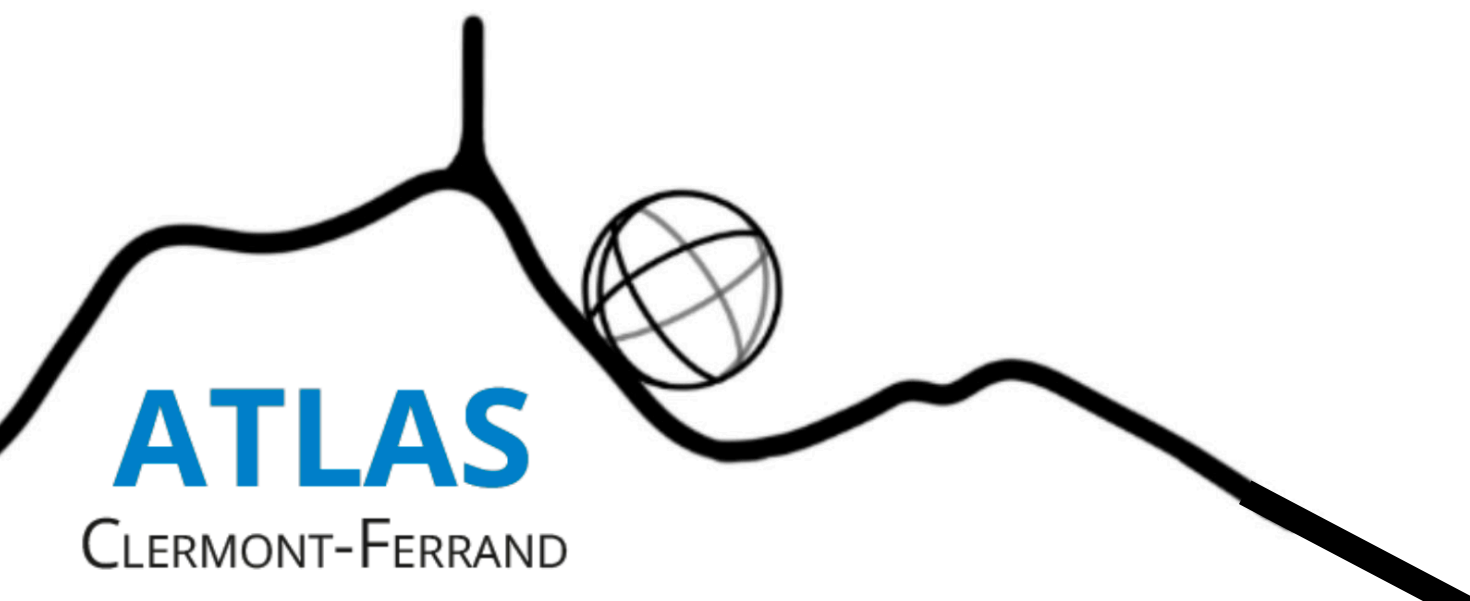


- Distinguish beam induced backgrounds
- Large Radius Tracking
- Unprecedented resolution



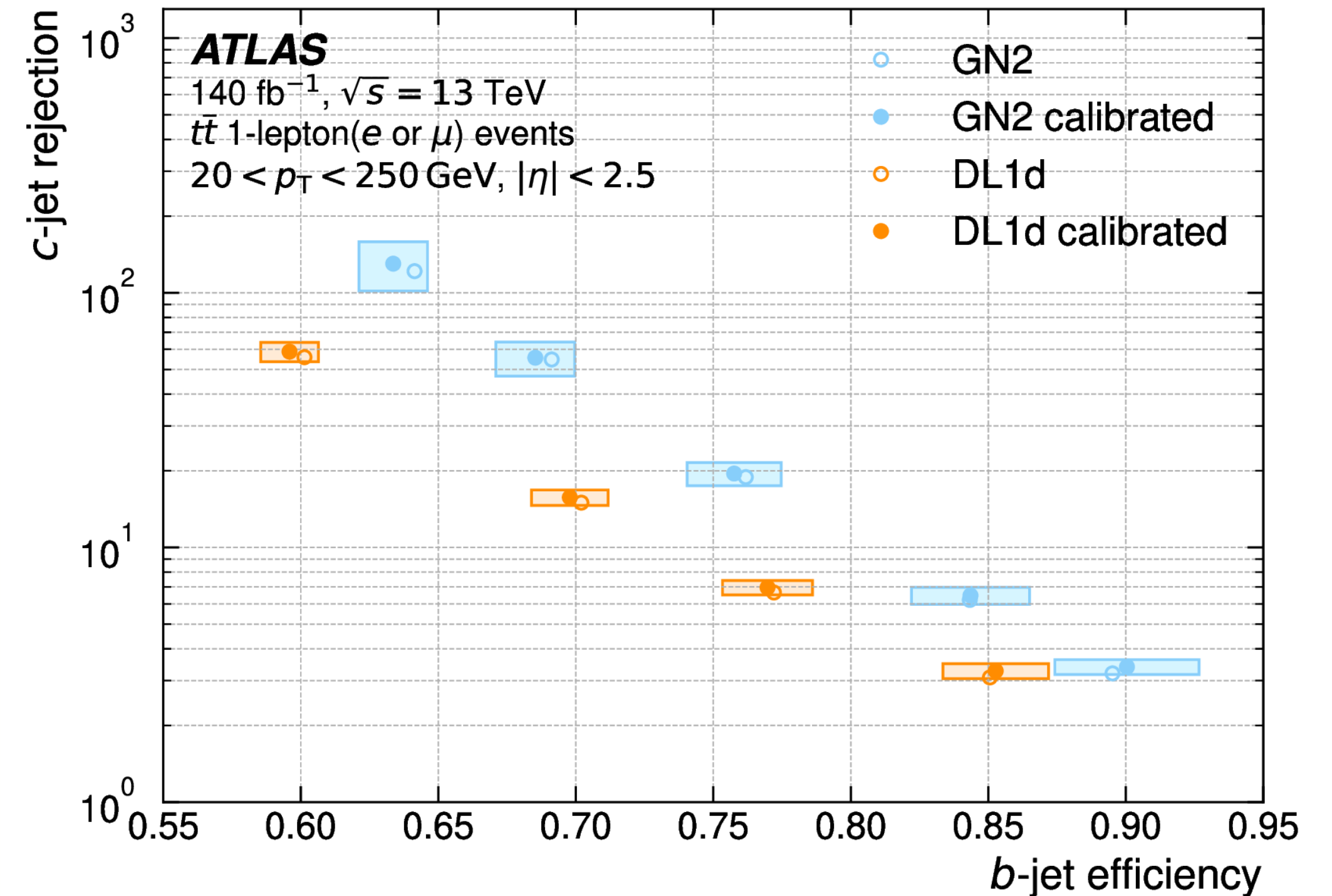
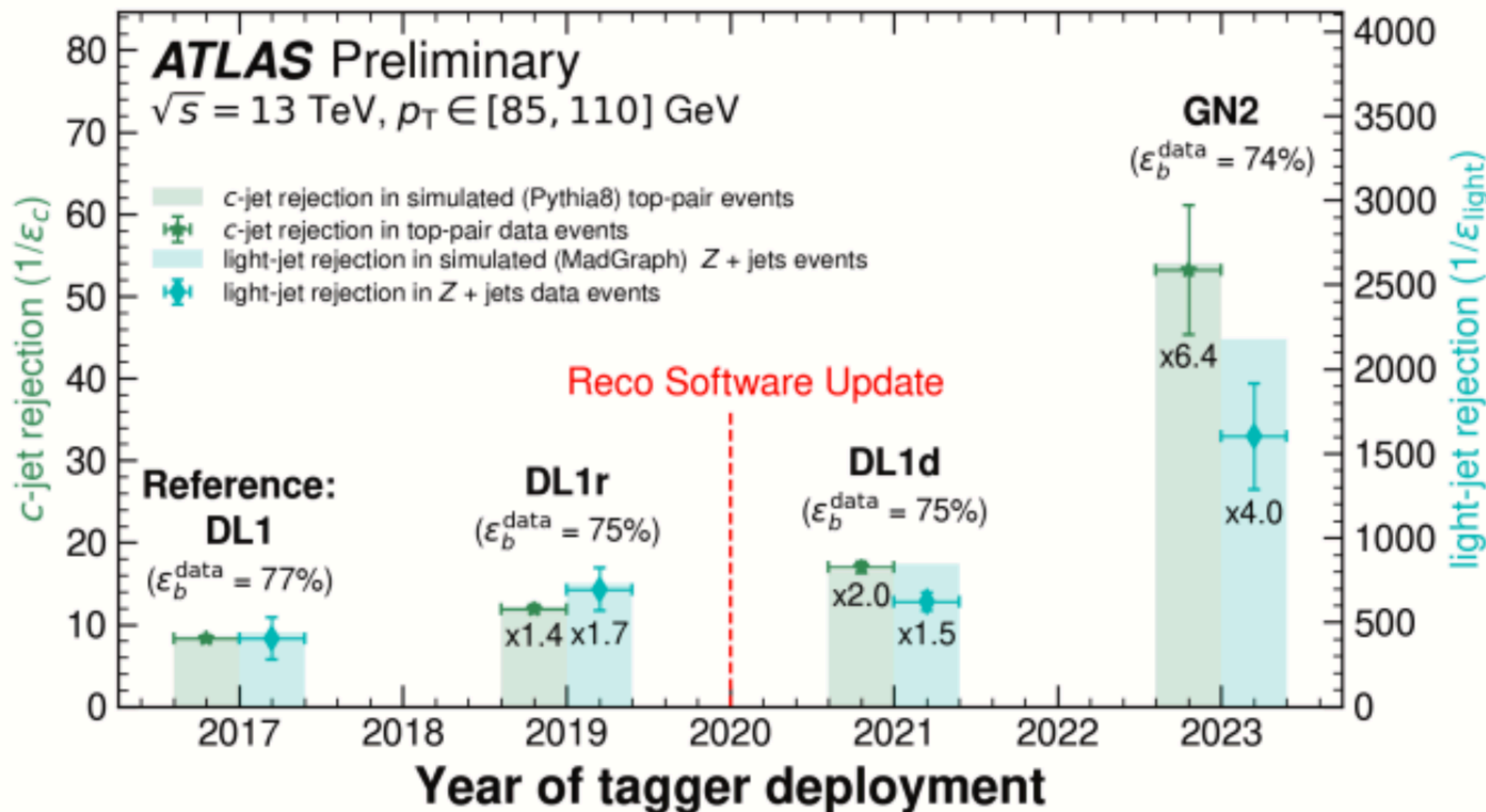
Resources: Tools

- **New technologies** can change the way we do searches. Examples:



Resources: Tools

- **New technologies** can change the way we do searches. Examples:
 - **Machine learning:** eg Graph Neural Networks unlocked c-tagging, and access to new parameter space



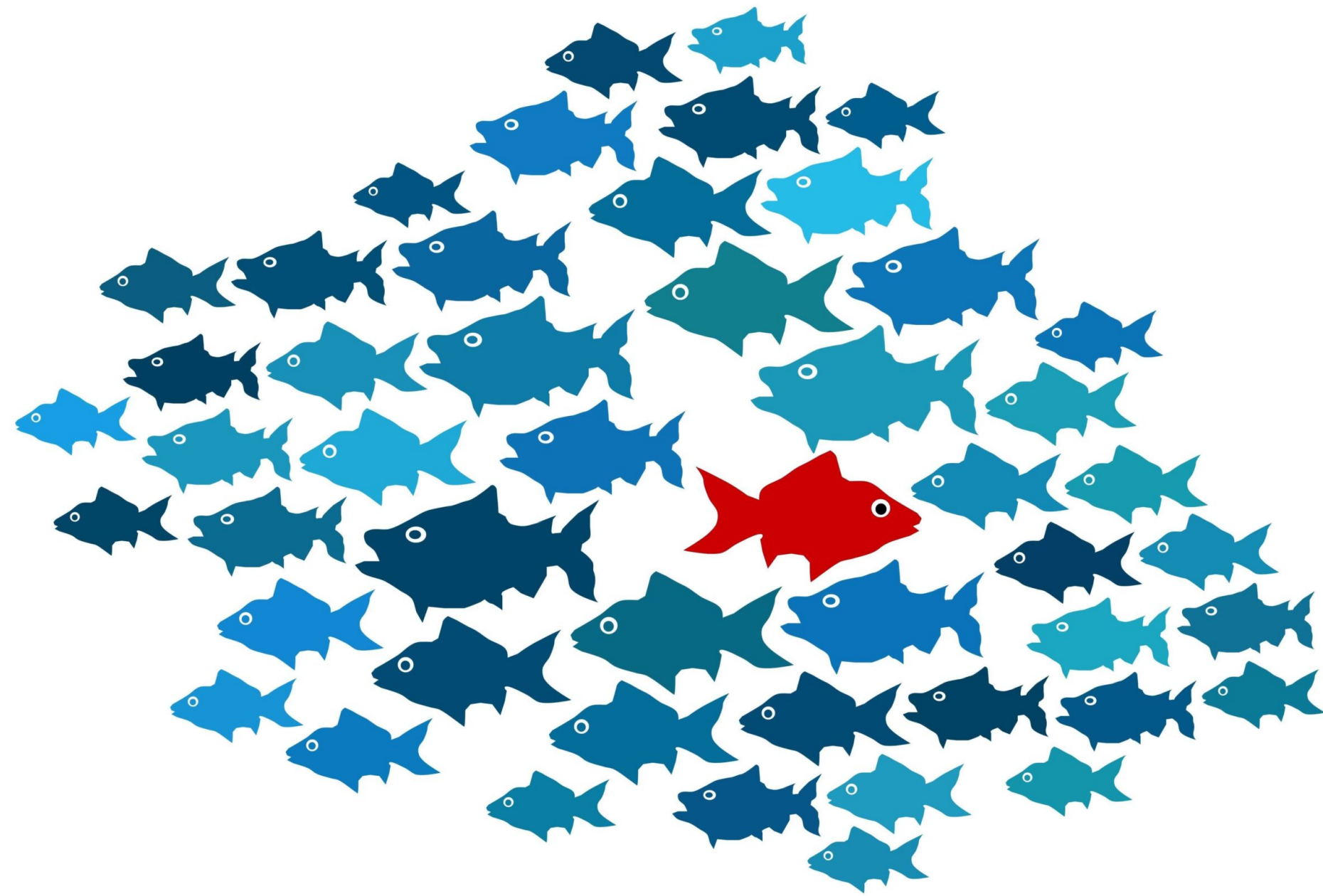
Nature Commun. 17 (2026) 541

<https://arxiv.org/abs/2505.19689>

<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/FTAG-2023-07/>

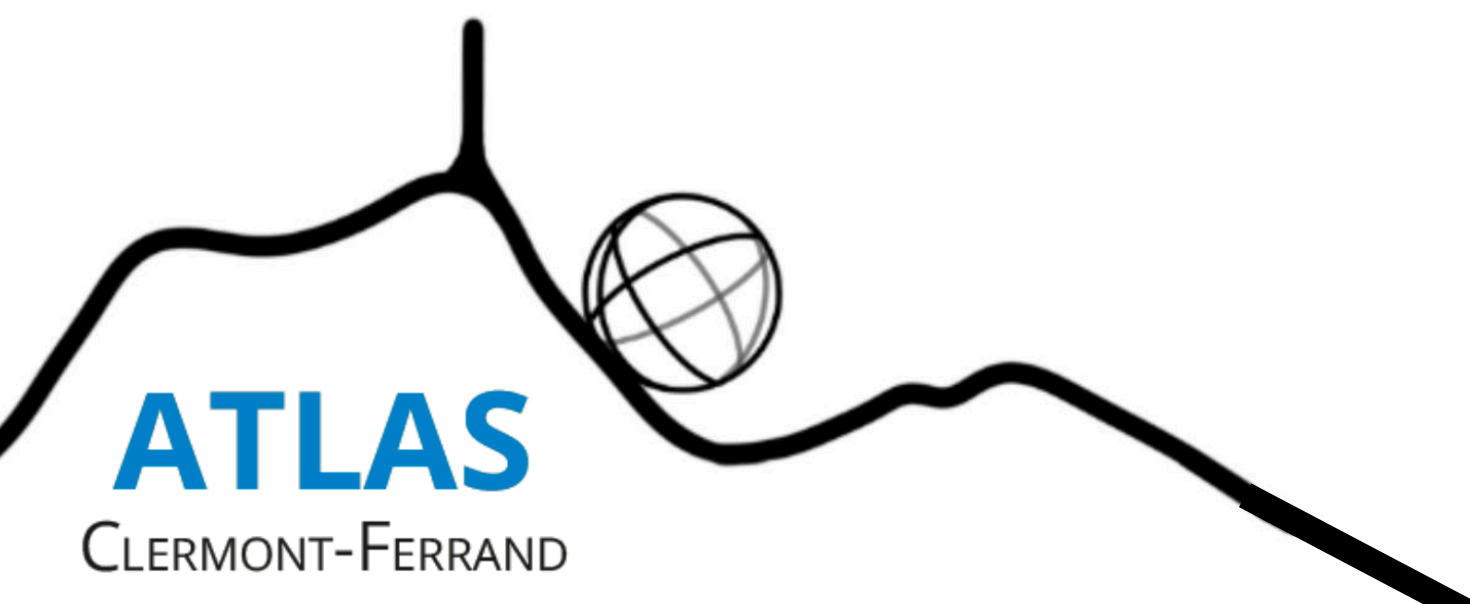
Resources: Tools

- **New technologies** can change the way we do searches. Examples:
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 - **Anomaly detection:** cover large parts of model space quickly but with reduced sensitivity
 - **More about this later!**



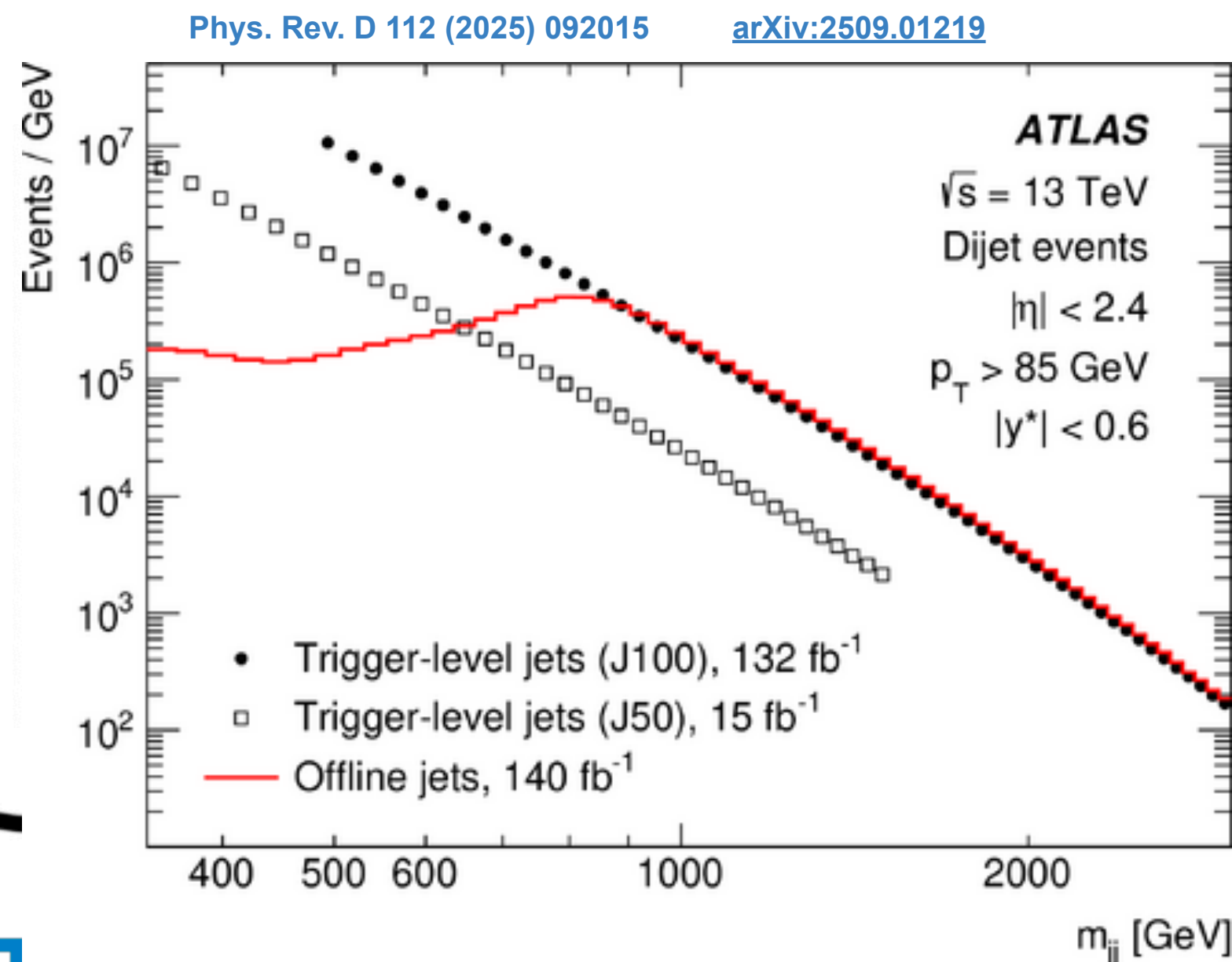
Resources: Tools

- **New technologies** can change the way we do searches. Examples:
 - **Machine learning:** eg Graph Neural Networks unlocked c-tagging, and access to new parameter space
 - **Anomaly detection:** cover large parts of model space quickly but with reduced sensitivity
 - **Event picking:** Add extra information in Signal Regions. Typical gain in sensitivity: factor 1.2 to 3
 - Define a SR as usual, containing about 1M events in data.
 - For those 1M events, initiate a new reprocessing from RAW data, in which we can add much more information -- custom format, with low-level variables.
 - Use these extra variables to add extracting cuts which can remove even more background. Cannot gain signal, but can improve S/\sqrt{B} !

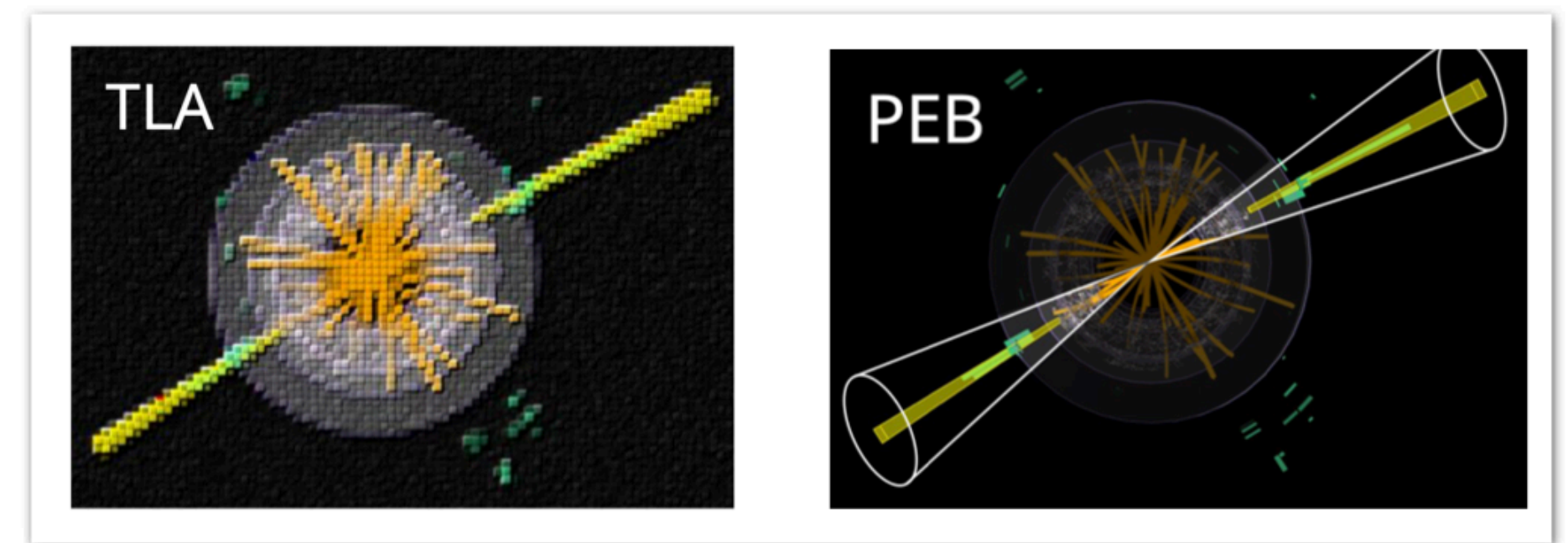


Resources: Tools

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 - **Anomaly detection:** cover large parts of model space quickly but with reduced sensitivity
 - **Event picking:** Add extra information in Signal Regions. Typical gain in sensitivity: factor 1.2 to 3
 - Extensive **Trigger-level Analysis/Partial Event Building** programme to explore trigger-limited regions



- ▶ Single and Multi-Jets
- ▶ Flavour Tagging
- ▶ Photons
- ▶ Partial-Event Building



A. Salvador

Bandwidth = Rate x Event Size

$$\approx = \uparrow\uparrow \times \downarrow\downarrow$$

Boundary conditions for a search programme

Time: the LHC will not last forever

- 15 years til end of LHC data-taking
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We need to plan the endgame of the LHC today!

Resources: people and tools

- Two search groups, O(1000) people capable of producing 35 papers / year
- Search community heavily invested in Upgrade and Operations
- 0.5/ab with our best-understood detector, exploitable for next decade.
- Then unprecedented dataset w/ new detector, opening new opportunities.
- Harness detector expertise, new techniques+ideas to support and drive our programme

We have plenty of people, need to make sure to organise efforts efficiently

Objectives:

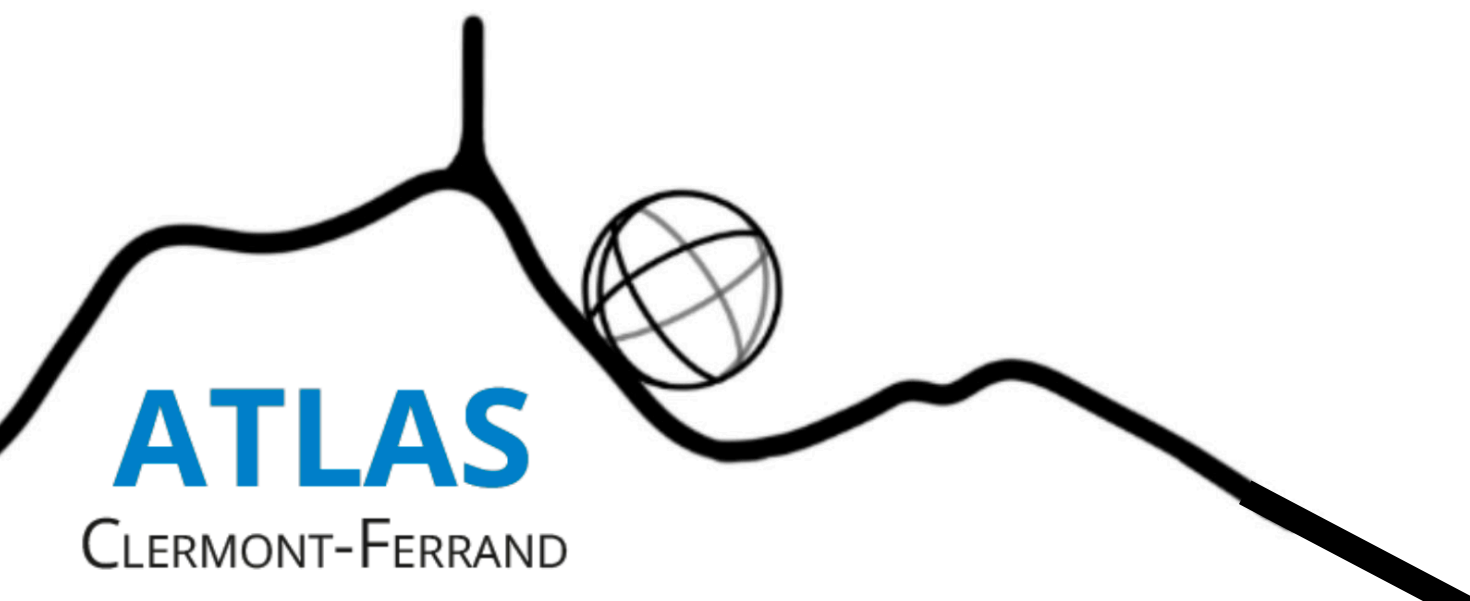
Objective: What do we want to achieve with the LHC?

- Primary objective, by the end of the LHC programme:

Discover a new particle or interactions

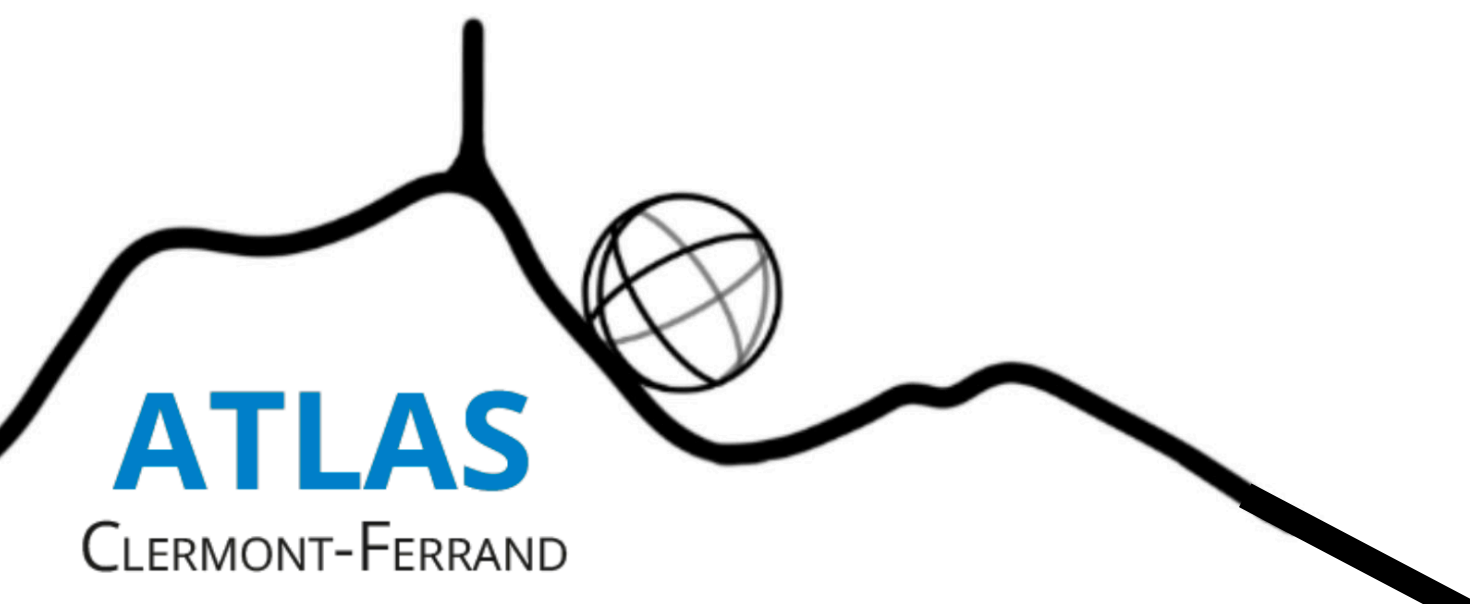
OR

**Be 95% confident there was no discovery to make
(at accessible energy and coupling scales)**



Objective: What do we want to achieve with the LHC?

- **Game theory:** what is the most efficient way to achieve this objective with the constraint of limited resources.
- **Not the answer:** randomly sampling model space with no plan.
- **Also not the answer:** Blindly turning handle on same analyses with more data.
- **DEFINITELY NOT THE ANSWER:** forcing people to work on things they don't want to work on.

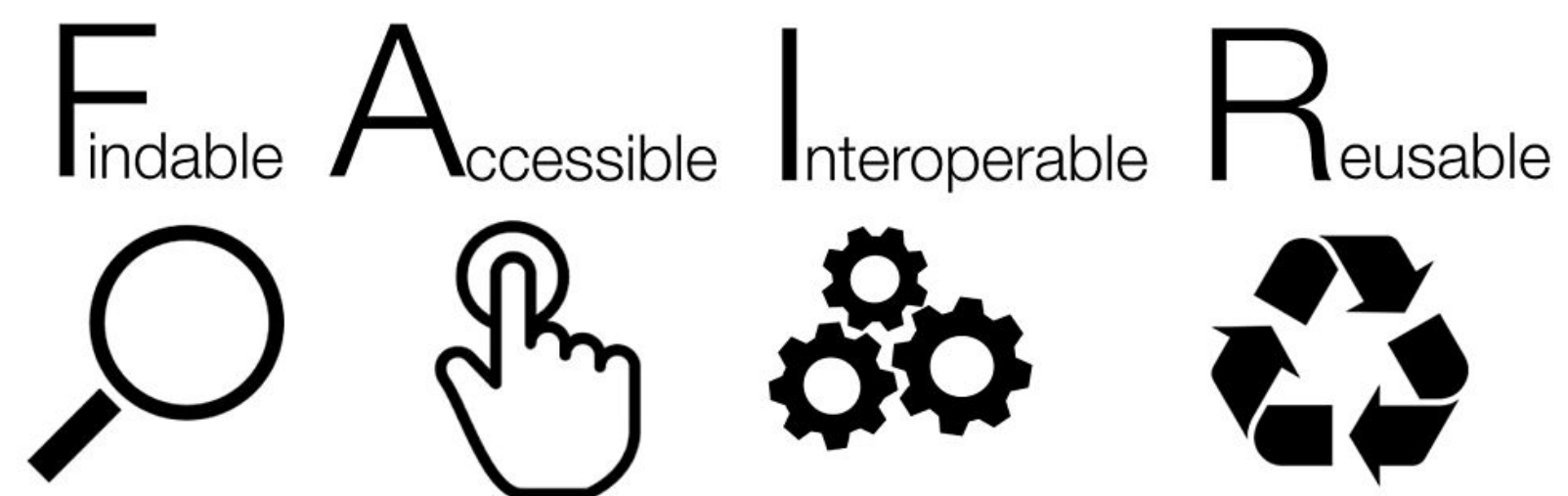
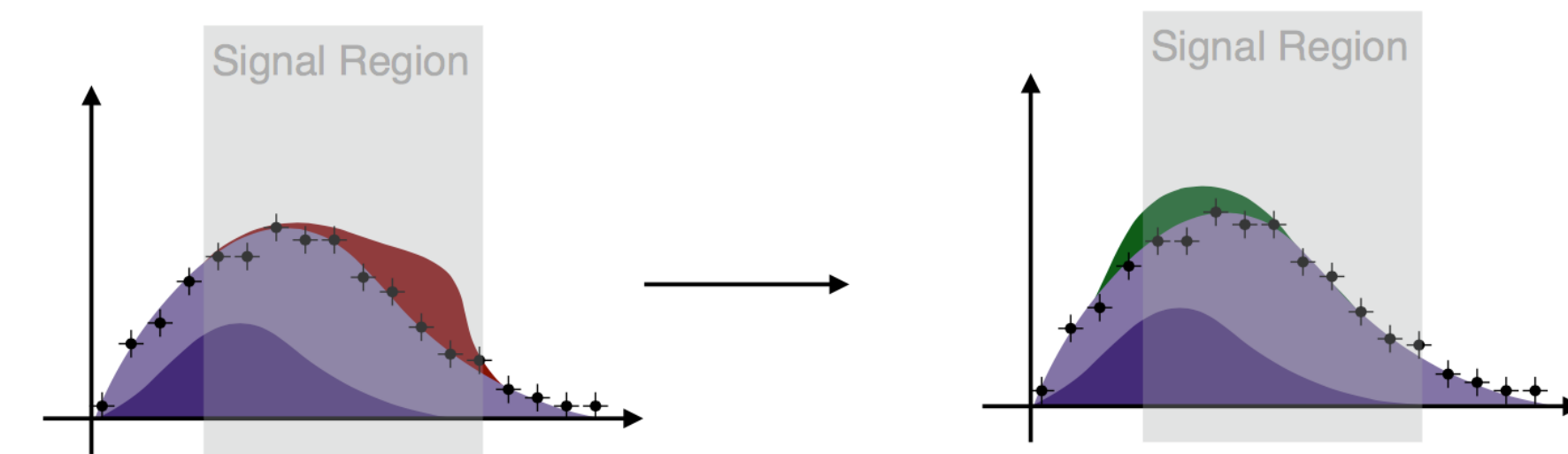


Objective: What do we want to achieve with the LHC?

- **Maybe the answer:**
 - Exploiting the **strengths** of our **people** to
 - ensure **deep but focused** coverage of **well-motivated models**,
 - and also **broad but shallow** coverage for more **speculative models**,
 - **scheduled in time** according to **potential gains** and with **critical mass** to converge,
 - from **extra data** and **instrumental/tools/method** developments,
 - and designed for **long-term impact** and **avoiding repetition** of work

Objective: Multi-use results and a long-lasting legacy

- All searches should be **re-exploitable**:
 - Able to constrain another model in a similar signature.
Repeating searches because we didn't correctly preserve/present past results **is inefficient and unacceptable**.
- Serious focus on **analysis preservation** and **re-interpretability**. Results should still **be re-useable** until next hadron collider comes online in **half a century**.
- On some topics, the Run2+3 searches will be the last word. We need to get this right **NOW**.
- On a human level, knowing one is working on a long-impact publication is more motivating



As of this week, ATLAS Exotics has 100% HEPData coverage for its 2025 papers

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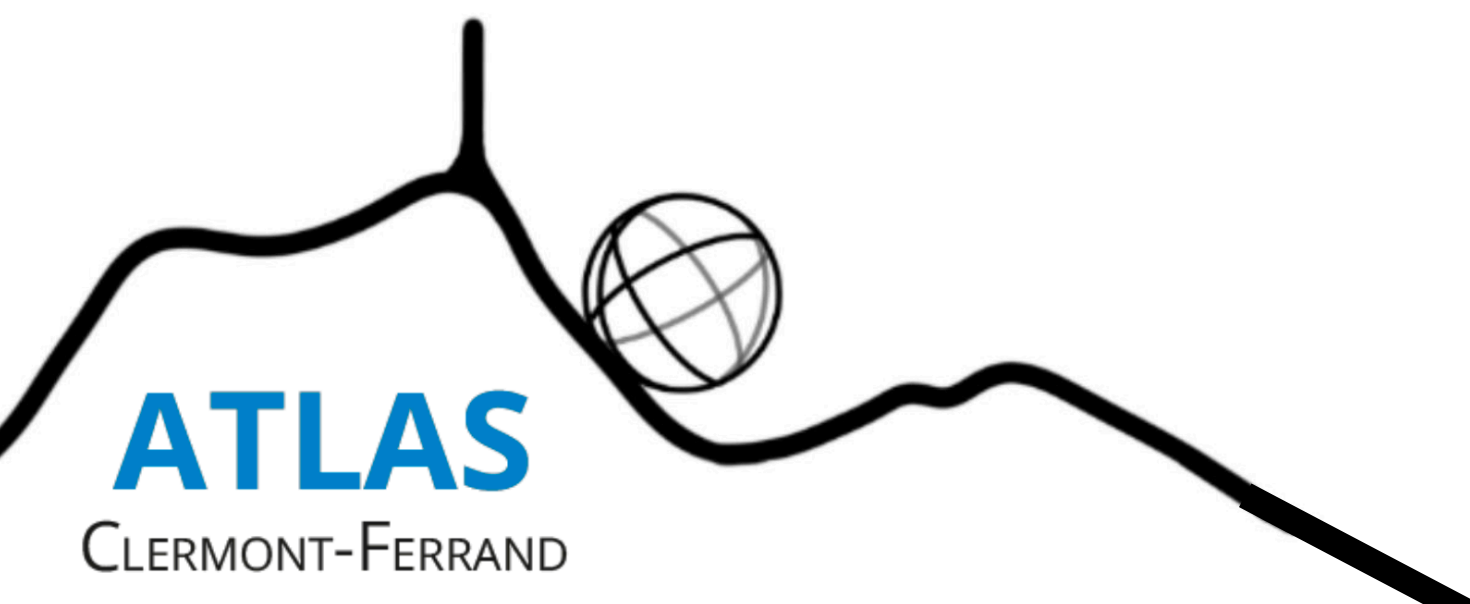
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- Then unprecedented dataset w/ new detector, opening new opportunities.
- Harness detector expertise, new techniques+ideas to support and drive our programme

We have plenty of people, need to make sure to organise efforts efficiently

Objectives:

- Discover new particles or interactions
- Or be certain that there was nothing there to find in all reasonably-accessible parts of model space.
- Analyses with long scientific legacy
- Game theory:
 - How to achieve one of these outcomes in the most efficiently, given time+resource constraints ?

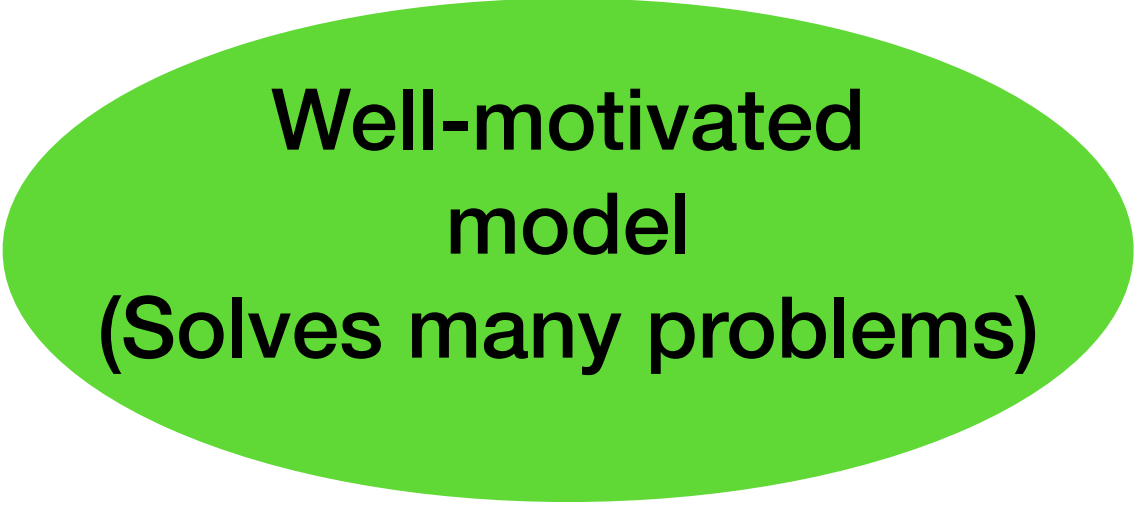
We need to plan the endgame of the LHC today!



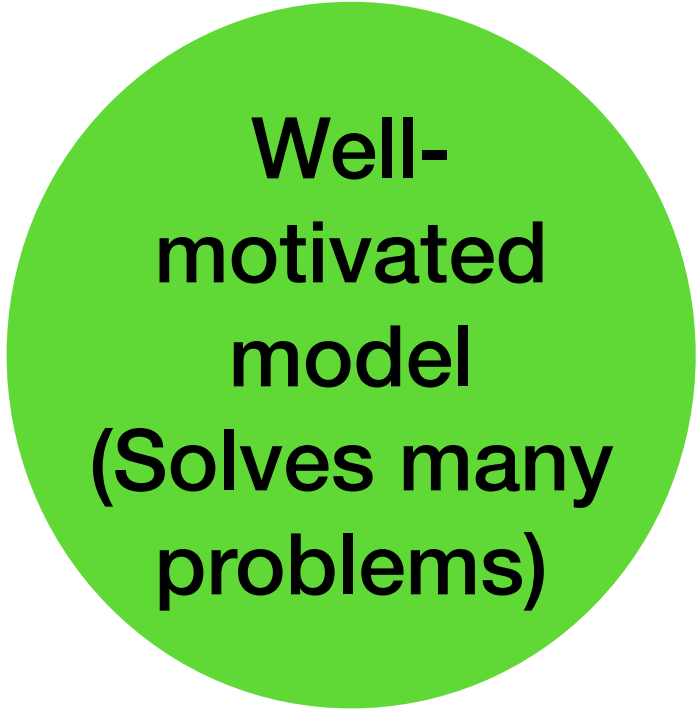
Now that we know
The **time** available
What **resources** are at our disposal
And what we want to **achieve..**

Let's make a plan

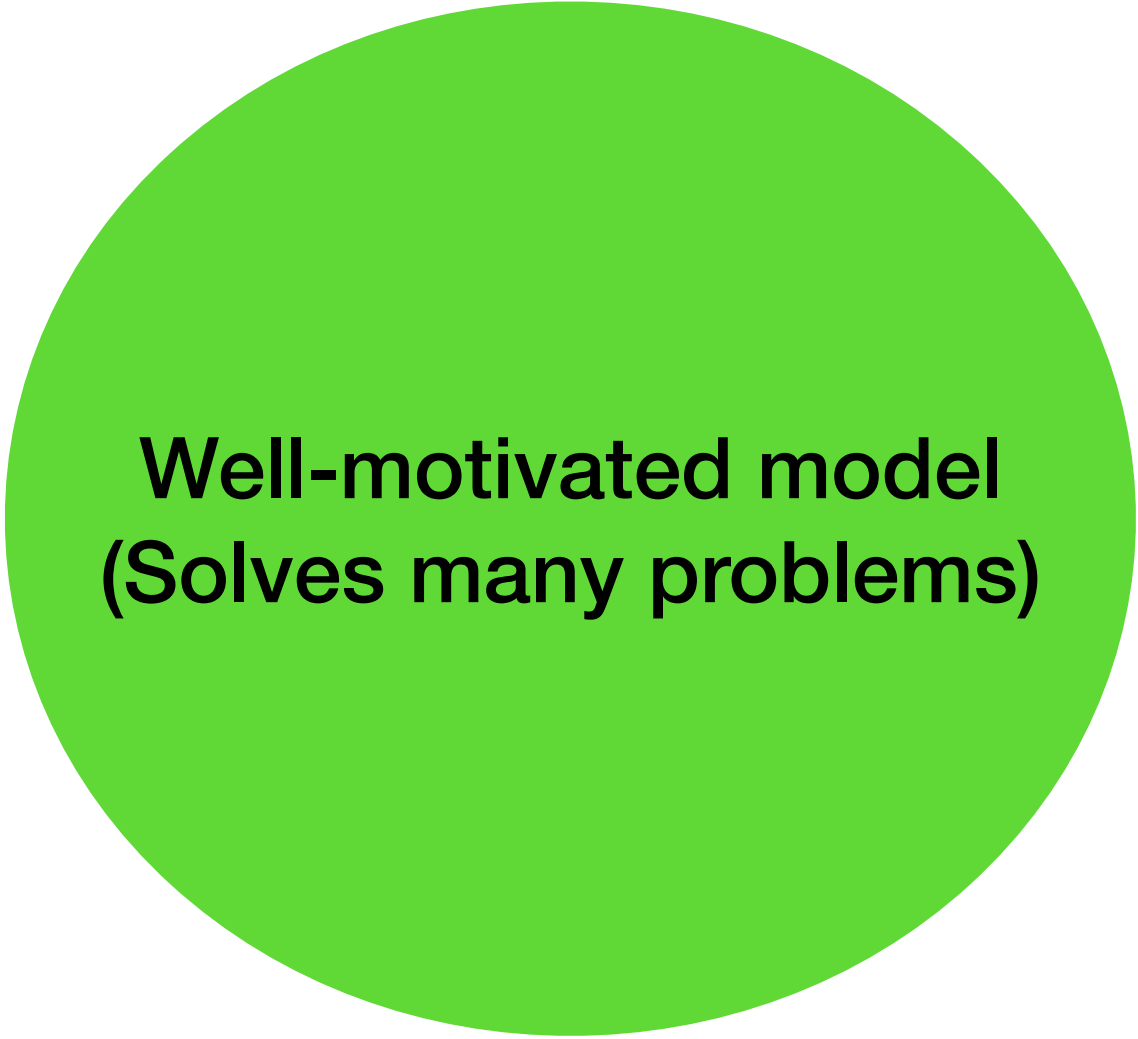
Many models



Well-motivated
model
(Solves many problems)

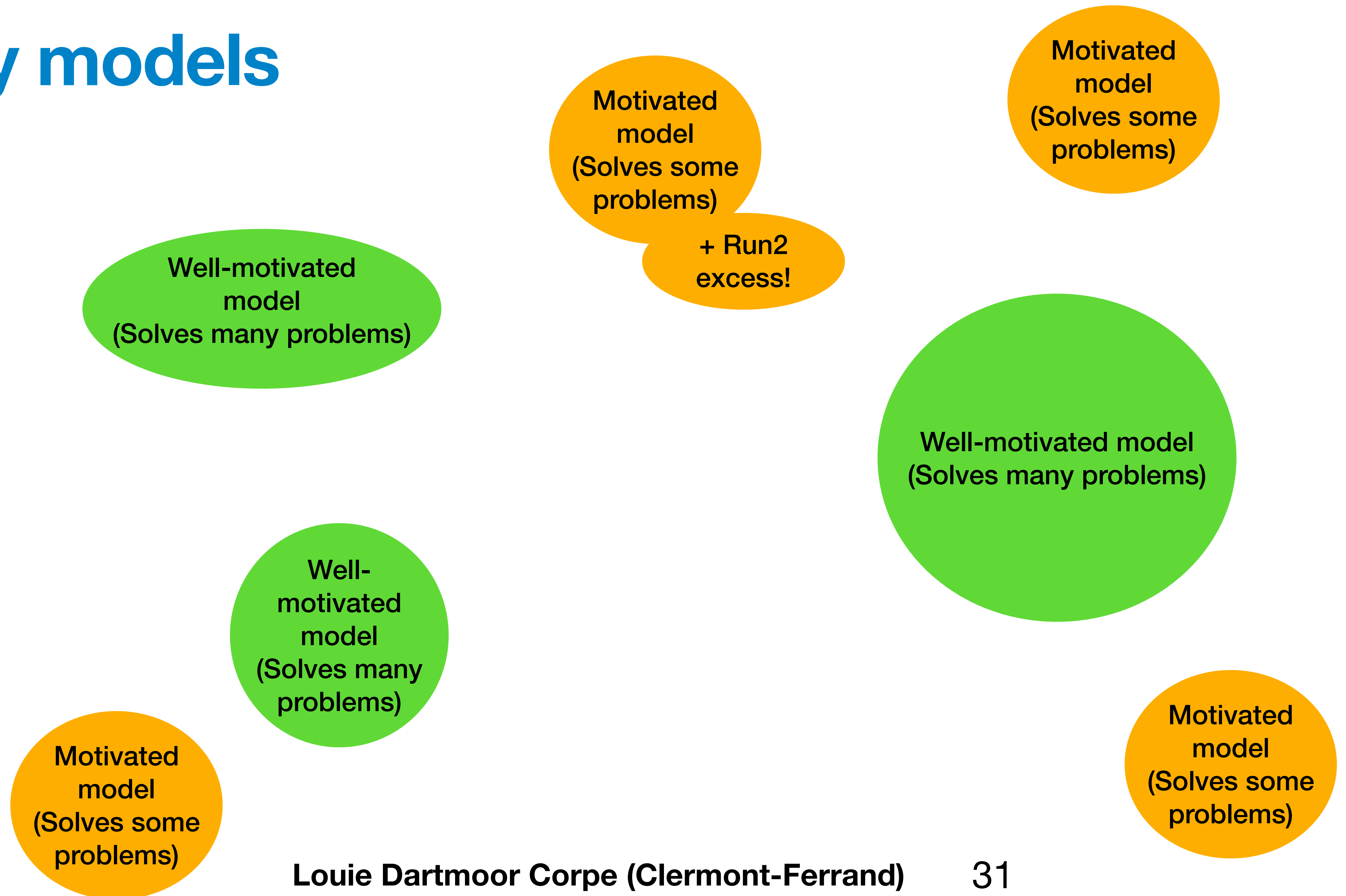


Well-
motivated
model
(Solves many
problems)



Well-motivated model
(Solves many problems)

Many models



Many models

Speculative model
(Solves one problem)

Well-motivated model
(Solves many problems)

Speculative model
(Solves one problem)

Well-motivated model
(Solves many problems)

Motivated model
(Solves some problems)

Motivated model
(Solves some problems)

Speculative model
(Solves one problem)

+ Run2
excess!

Speculative model
(Solves one problem)

Motivated model
(Solves some problems)

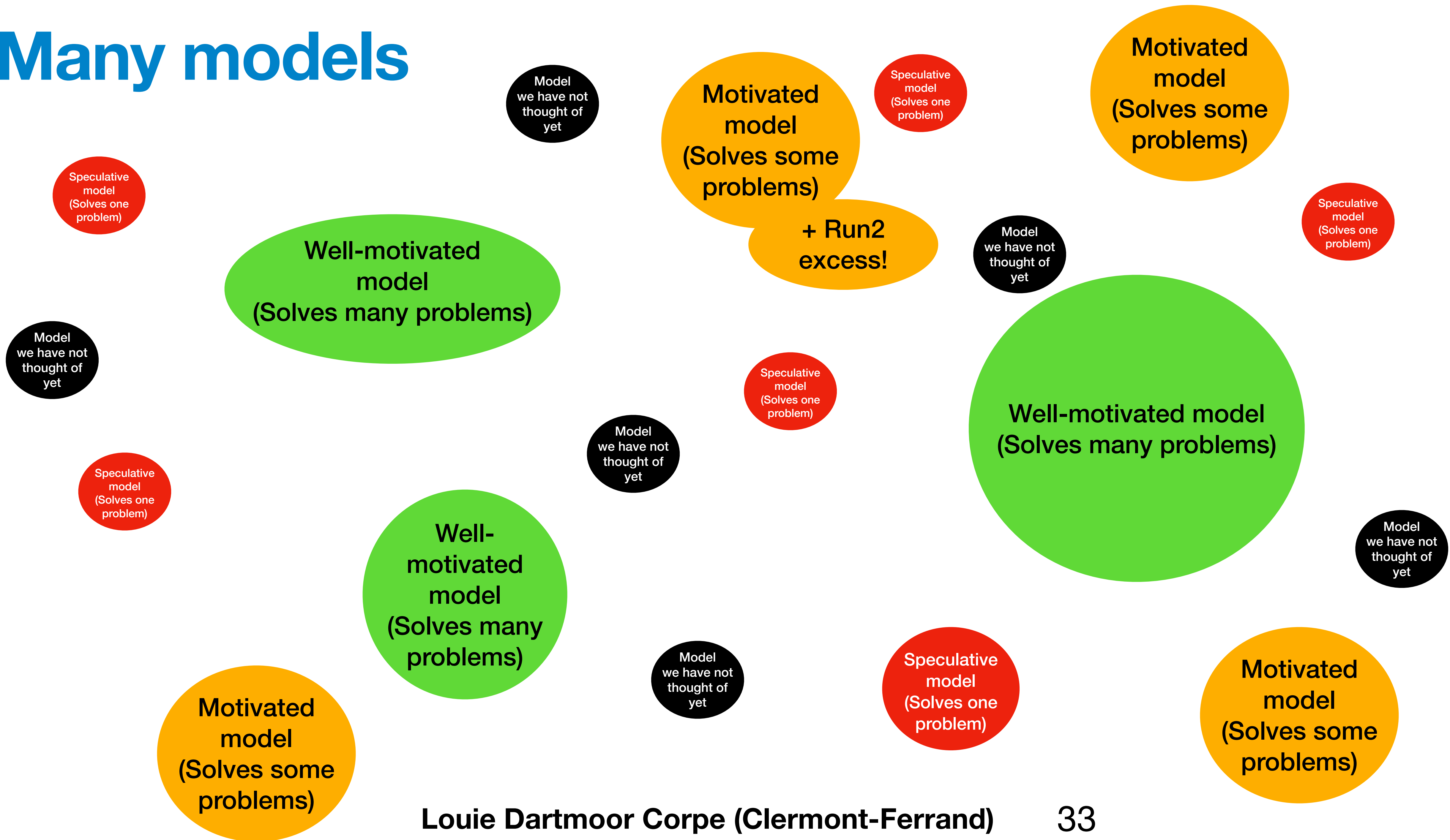
Speculative model
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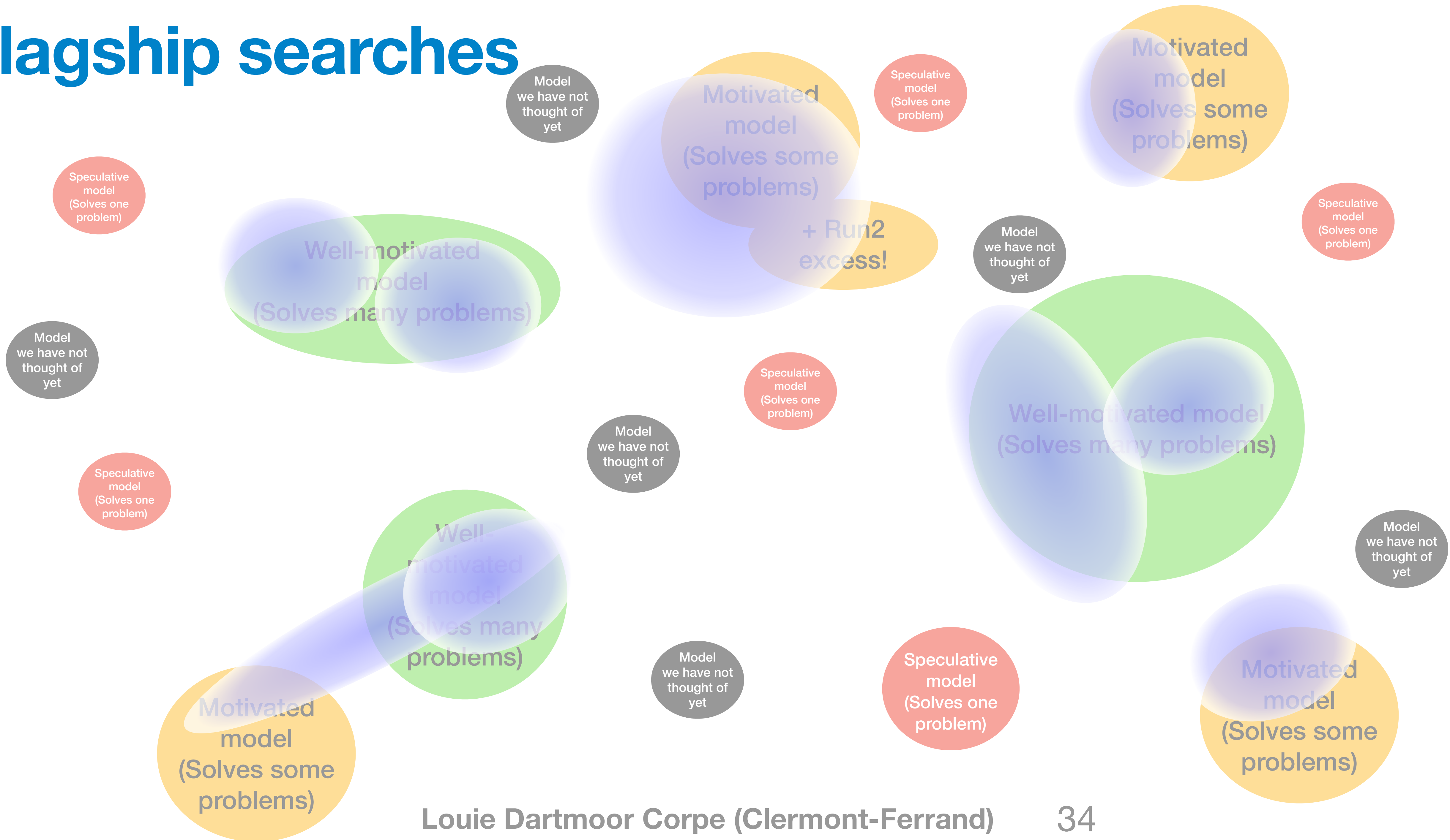
Speculative model
(Solves one problem)

Motivated model
(Solves some problems)

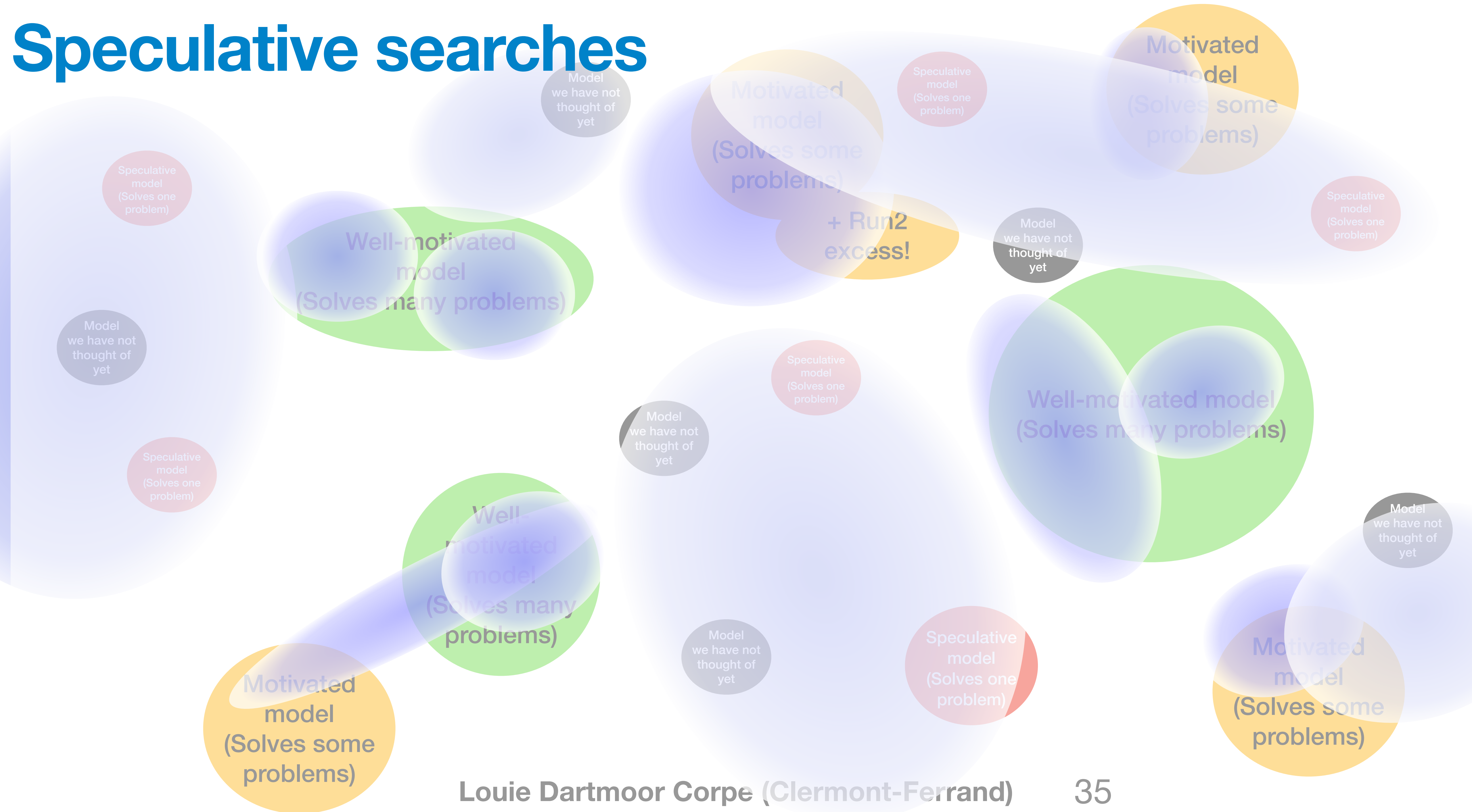
Many models



Flagship searches



Speculative searches



The Flagship programme

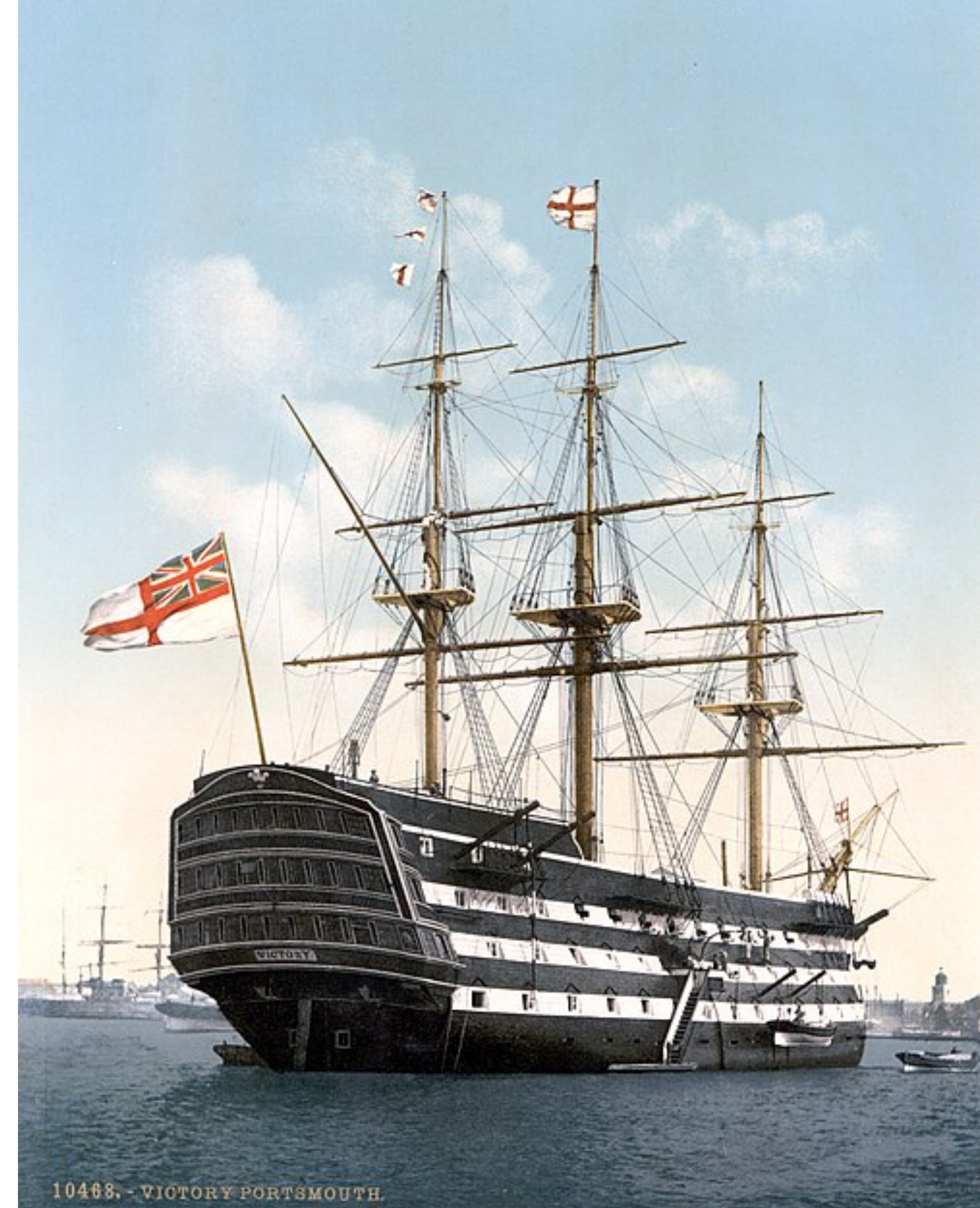
flagship noun

flag·ship ('flag-, ship)

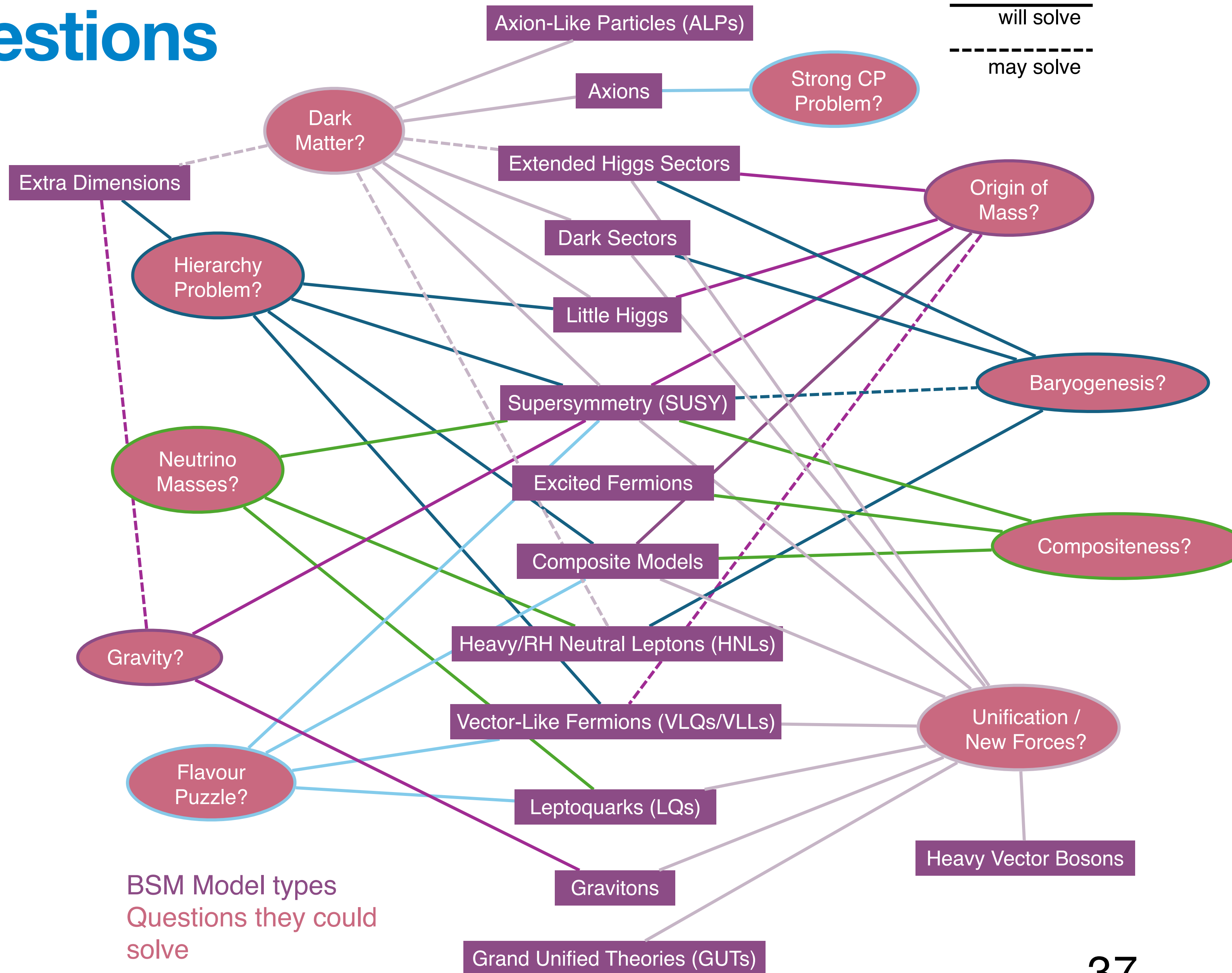
Synonyms of *flagship* >

- 1 : the ship that carries the commander of a fleet or subdivision of a fleet and flies the commander's flag
- 2 : the finest, largest, or most important one of a group of things (such as products, stores, etc.) → often used before another noun

The mantra is:
"Narrow but deep sensitivity"



Tentative answers to big questions

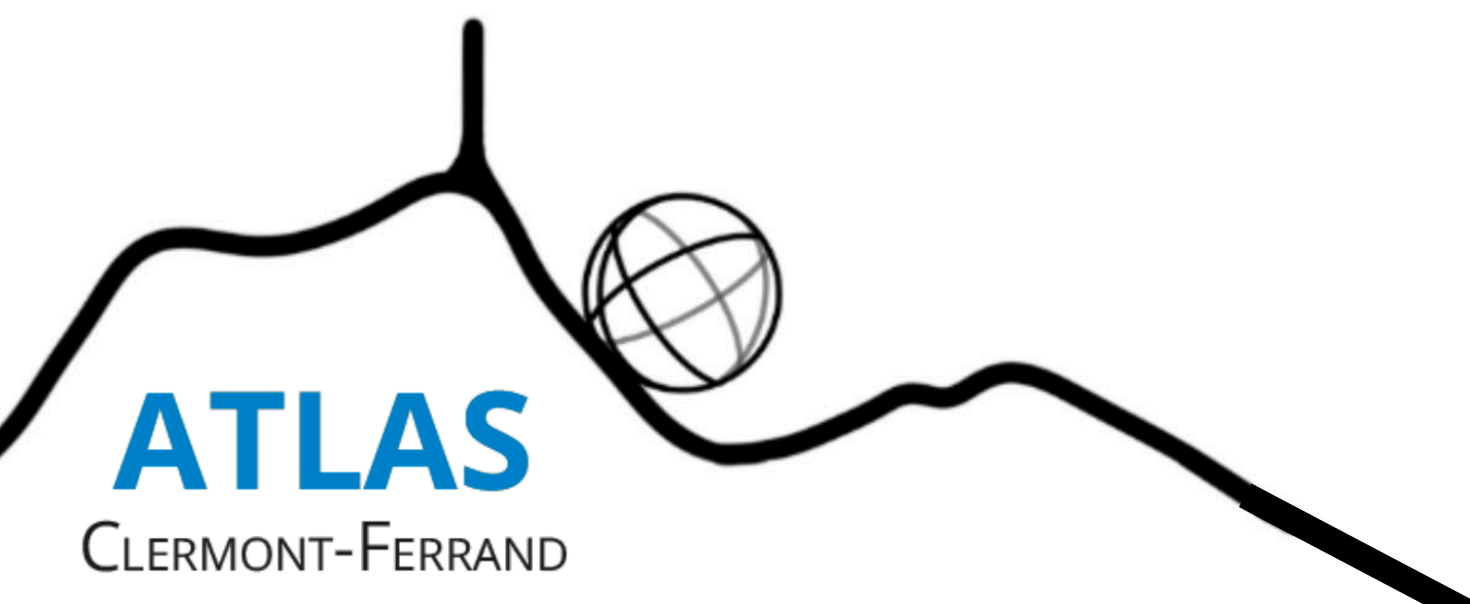
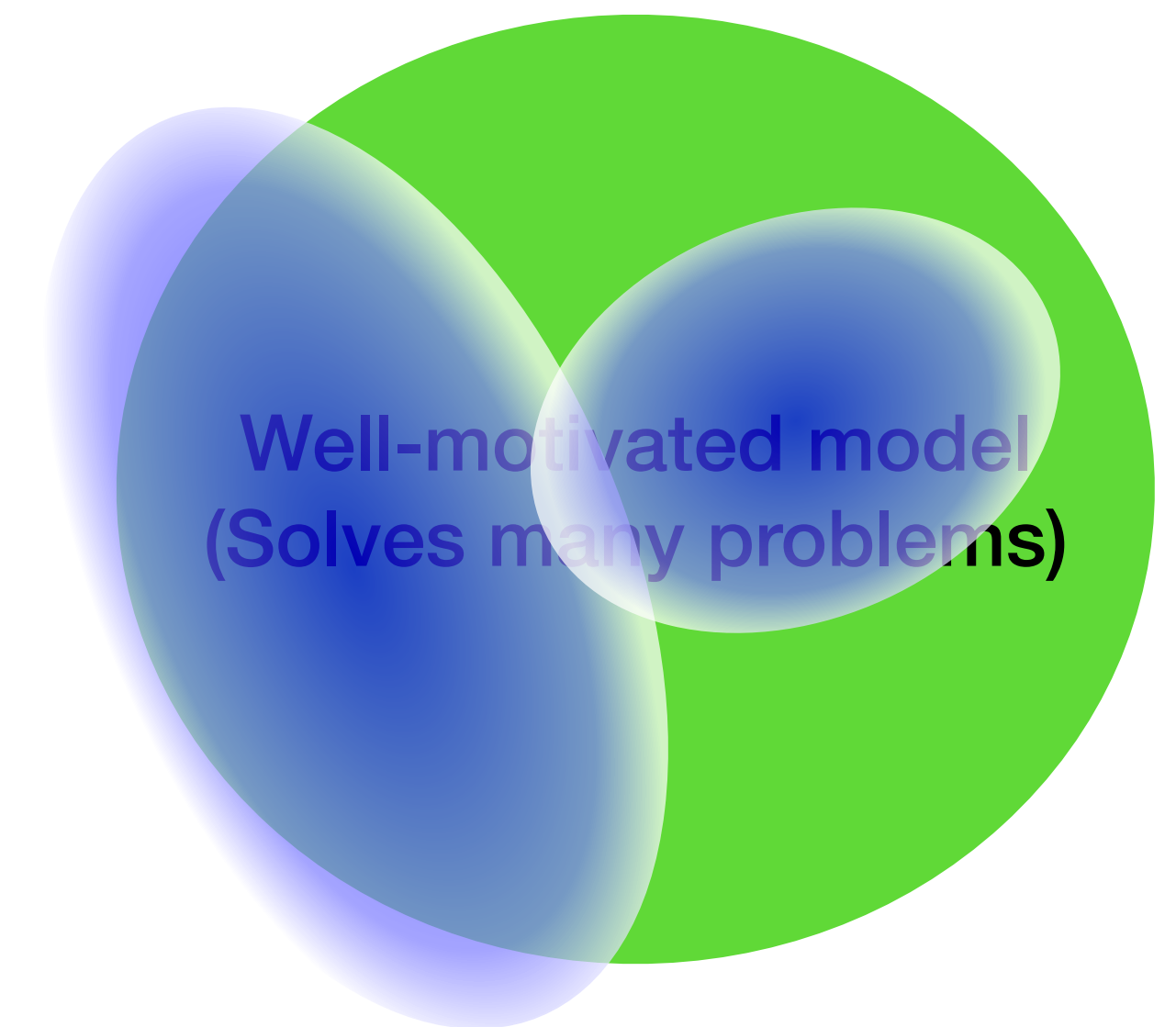


BSM Model types
 Questions they could solve

By Holly Pacey

The ATLAS search flagship programme

- Probe most **promising models** with **focused sensitivity**.
- Dedicated searches and techniques, **optimised for target model(s)**
- **Summary plots to gauge our progress** against each other + the rest of the field.
 - Important to use **comparable benchmarks** with CMS and non-collider
- **Timing of searches** will depend on **data collection**:
 - Each new wave only when **enough data** to make **significant impact**
 - Calls for a **5-year plan** / timeline
 - Set objectives for HL-LHC programme for each model family



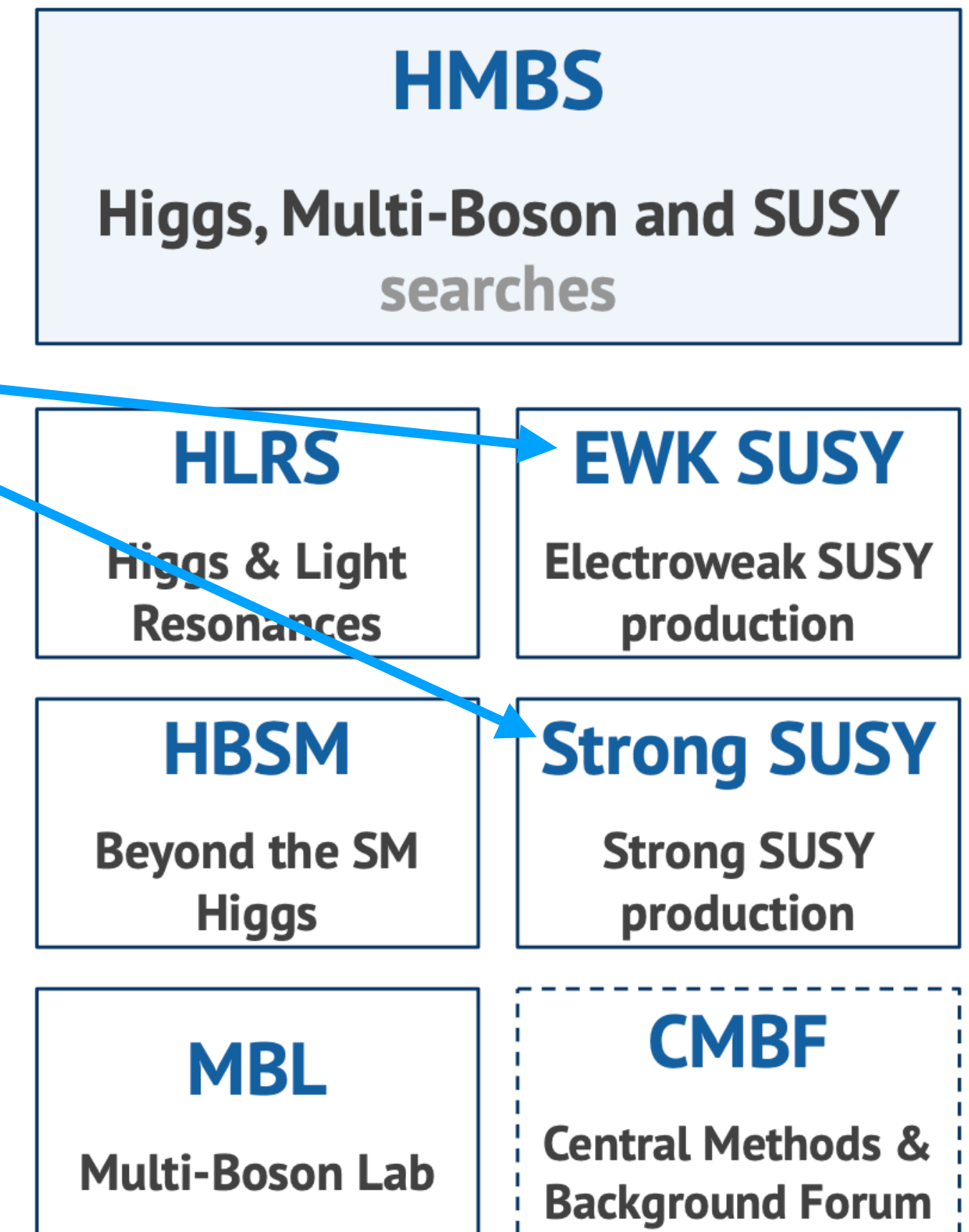
Subgroups organised around the flagships

- What are the best-motivated parts of model/signature space?
- Still the *same models as the start of the LHC*:
 - SUSY
 - Exotic Higgs
 - Leptoquarks
 - Axions and Axion-like particles
 - Vector-like quarks and vector-like leptons
 - Direct DM production
 - Heavy Neutral Leptons
 - Unusual signatures and LLPs
 - GUT/Extra Dimensions (Z' / W')

Subgroups organised around the flagships



- What are the best-motivated parts of model/signature space?
- Still the *same models as the start of the LHC*:
 - **SUSY**
 - **Exotic Higgs**
 - Leptoquarks
 - **Axions and Axion-like particles**
 - Vector-like quarks and vector-like leptons
 - Direct DM production
 - Heavy Neutral Leptons
 - Unusual signatures and LLPs
 - **GUT/Extra Dimensions (Z' / W')**



previously
HDBS

previously
SUSY

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EXOTICS
New Physics Beyond the SM
signature-based searches

LPX
Leptons + X

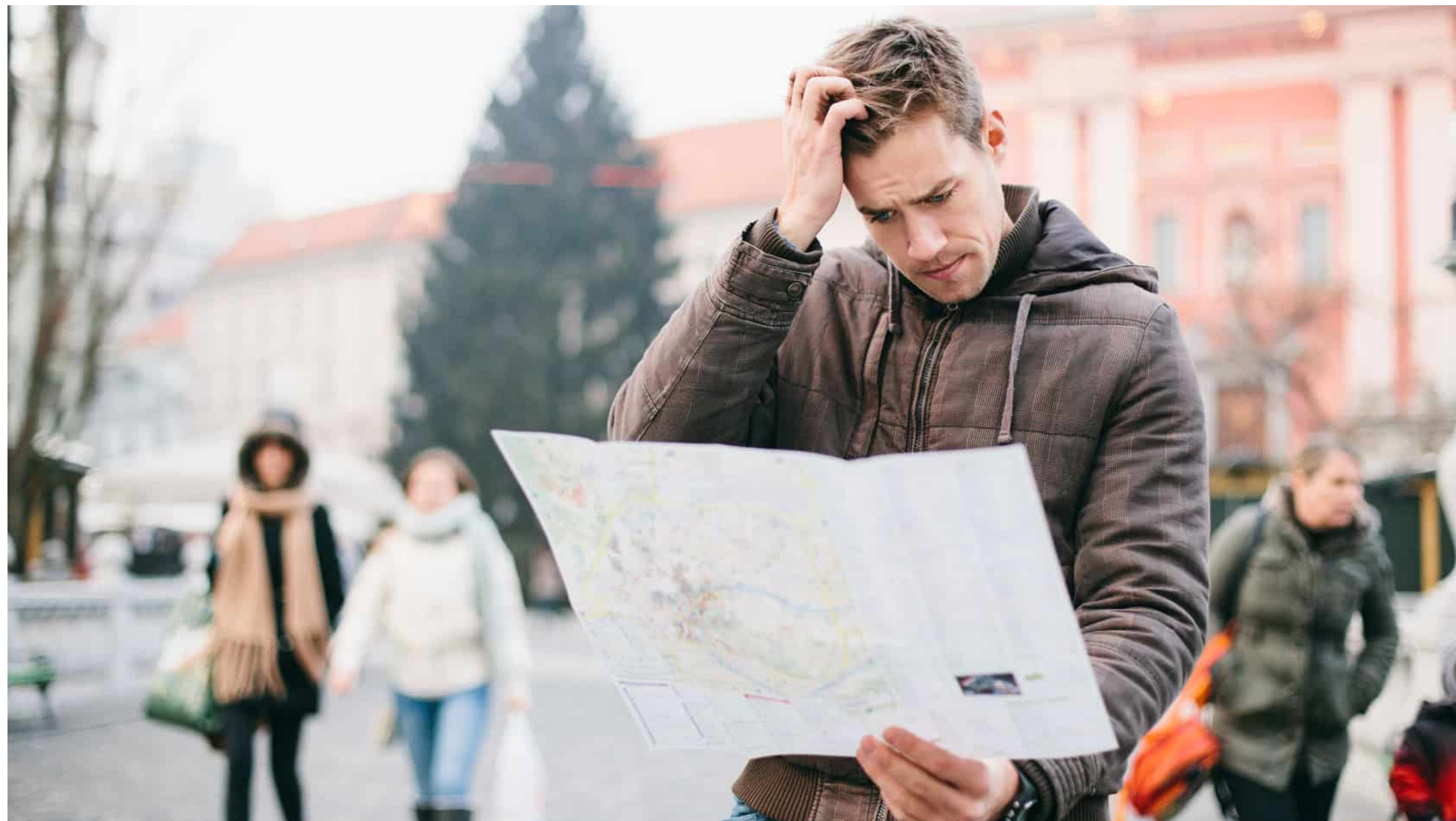
JMX
Jets & MET + X

LUP
Long-Lived & Unconventional

HQT
Heavy Quarks & Top

CCS
Combinations,
Cross-talk &
Summaries

Check your map regularly



HMBS
Higgs, Multi-Boson and SUSY searches

HLRS
Higgs & Light Resonances

EWK SUSY
Electroweak SUSY production

HBSM
Beyond the SM Higgs

Strong SUSY
Strong SUSY production

MBL
Multi-Boson Lab

CMBF
Central Methods & Background Forum

previously HDBS

previously SUSY



EXOTICS
New Physics Beyond the SM signature-based searches

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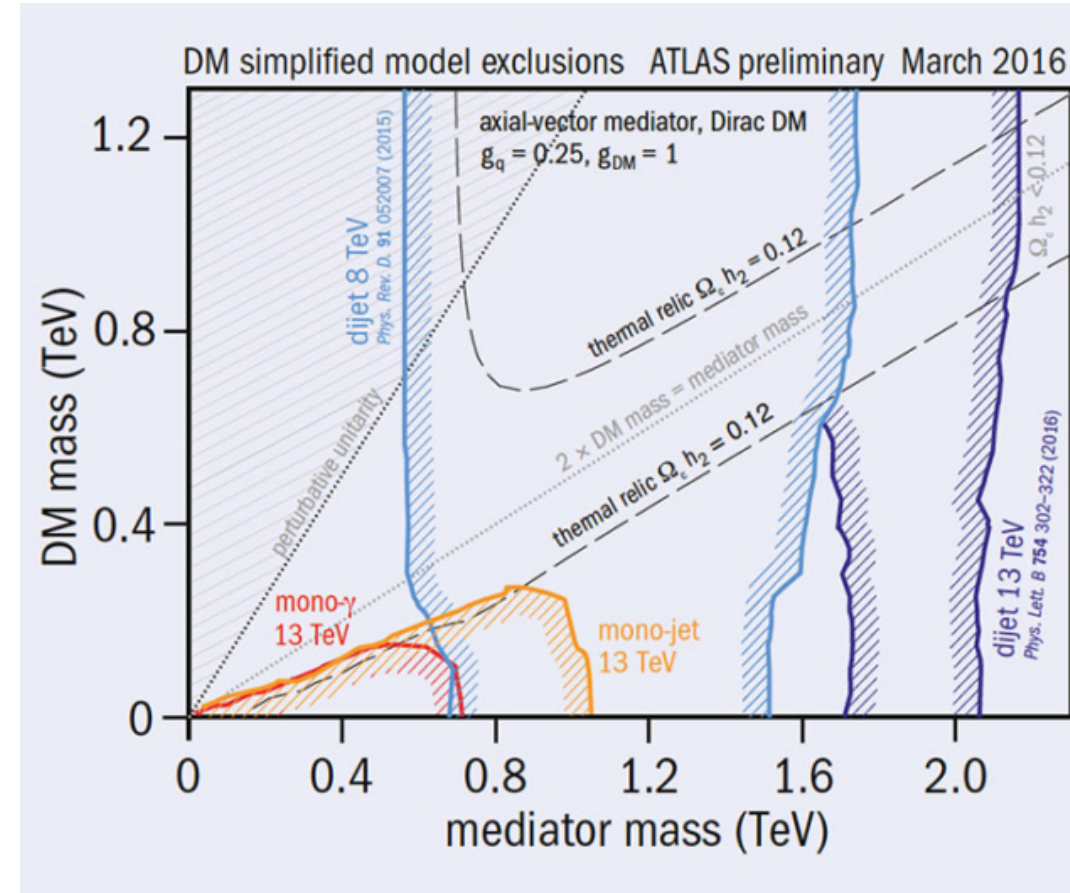
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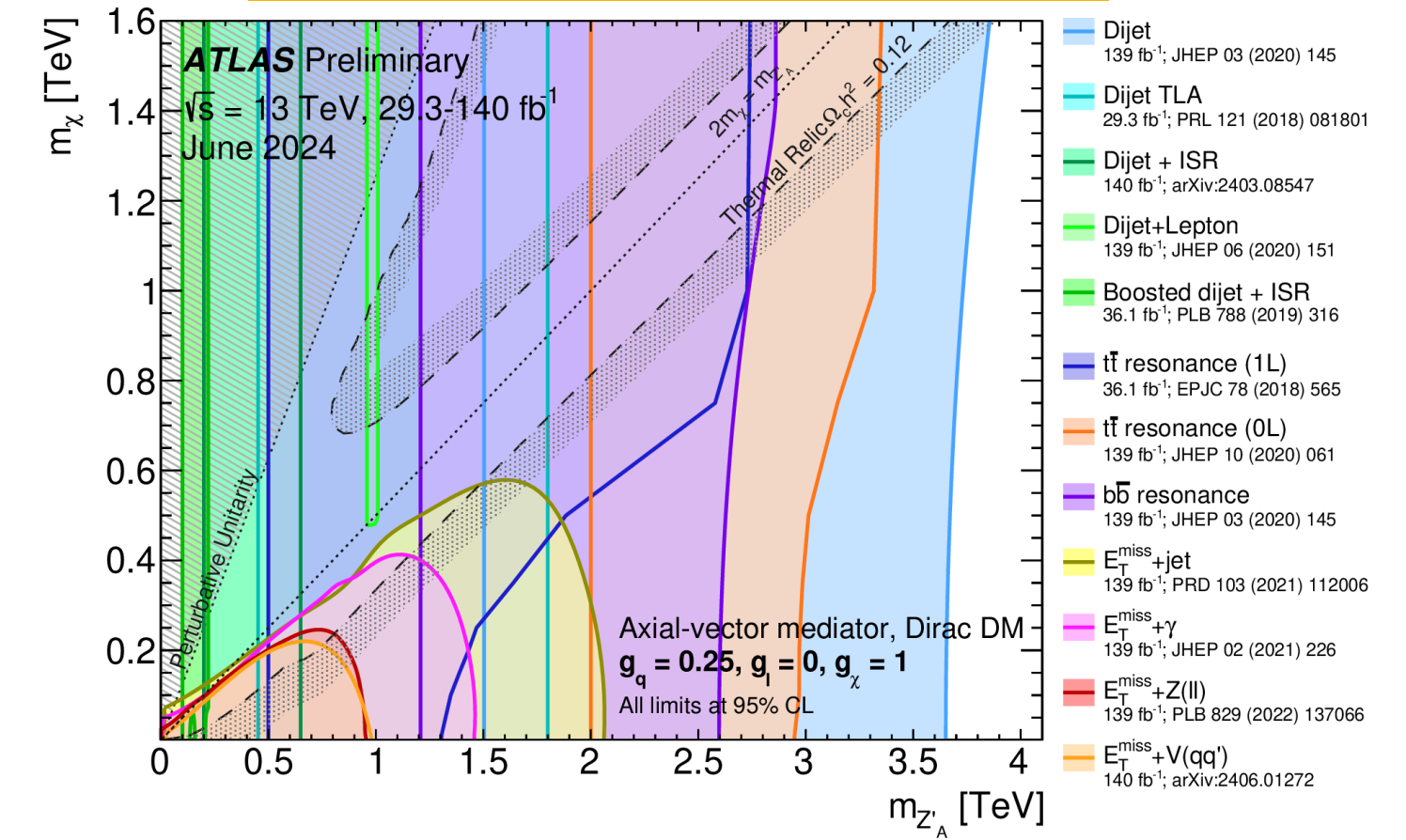


Summaries as signposts (2 examples)

<https://cerncourier.com/a/atlas-explores-the-dark-side-of-matter/>

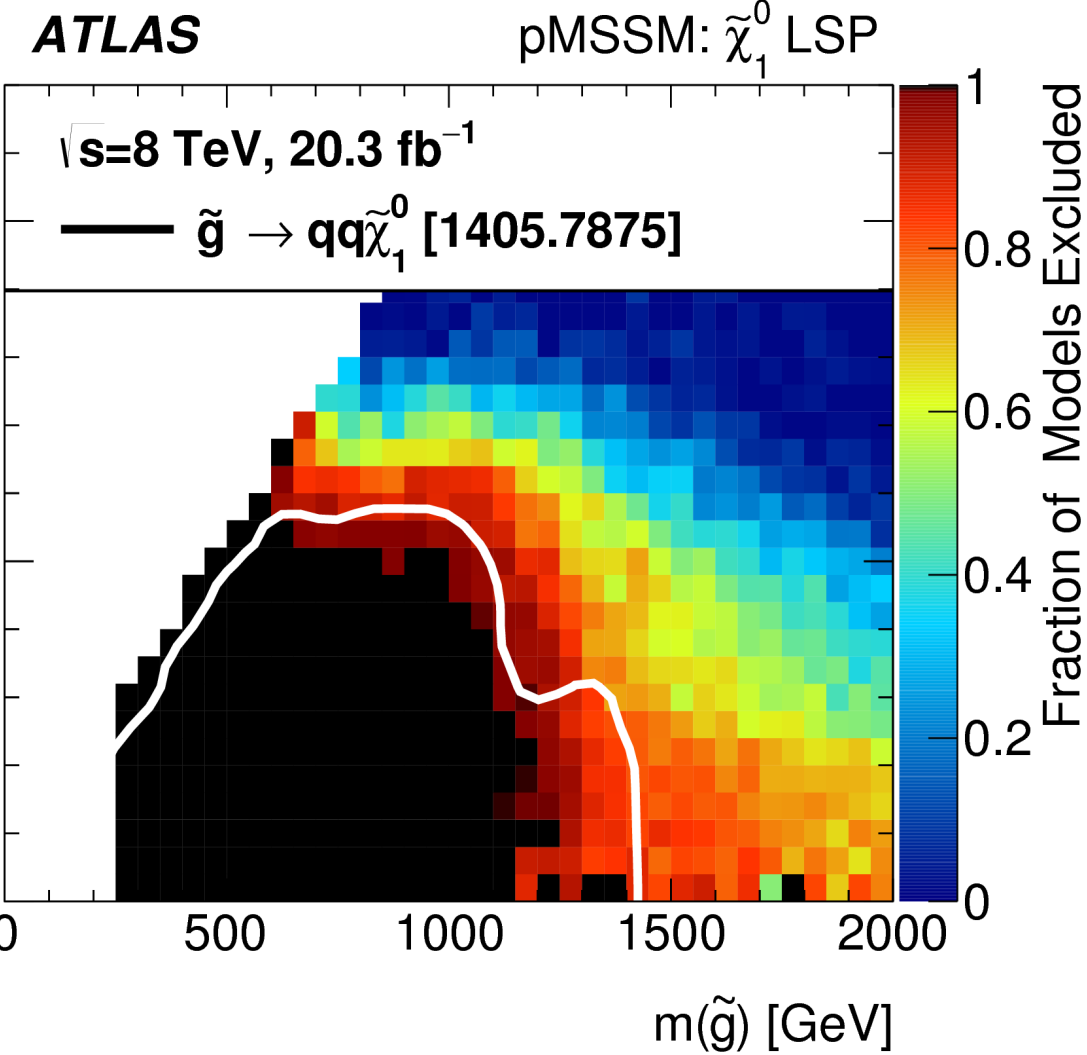


ATL-PHYS-PUB-2024-010,
<https://cds.cern.ch/record/2901527/>

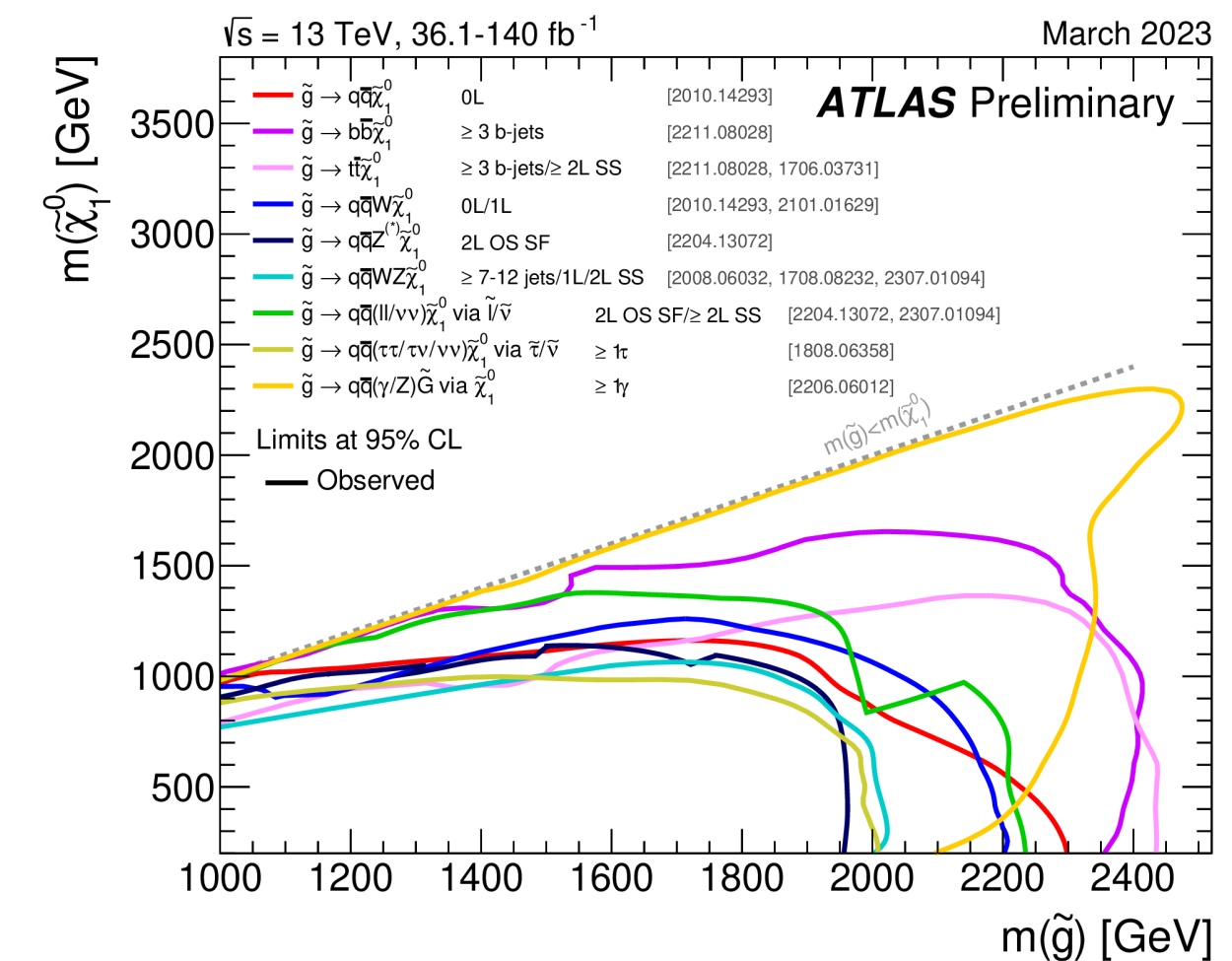


A decade of searches

<https://arxiv.org/abs/1508.06608>

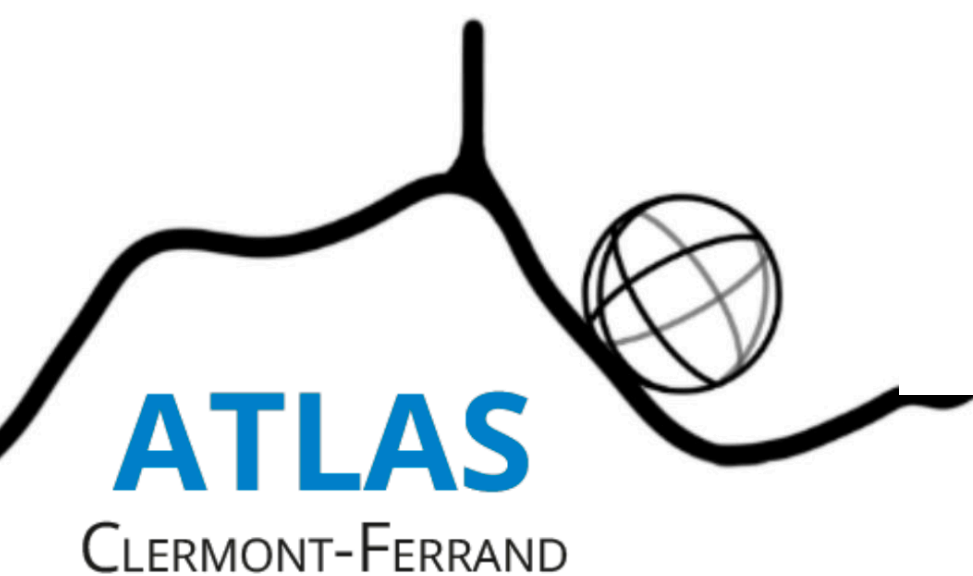


<https://arxiv.org/abs/2403.02455>



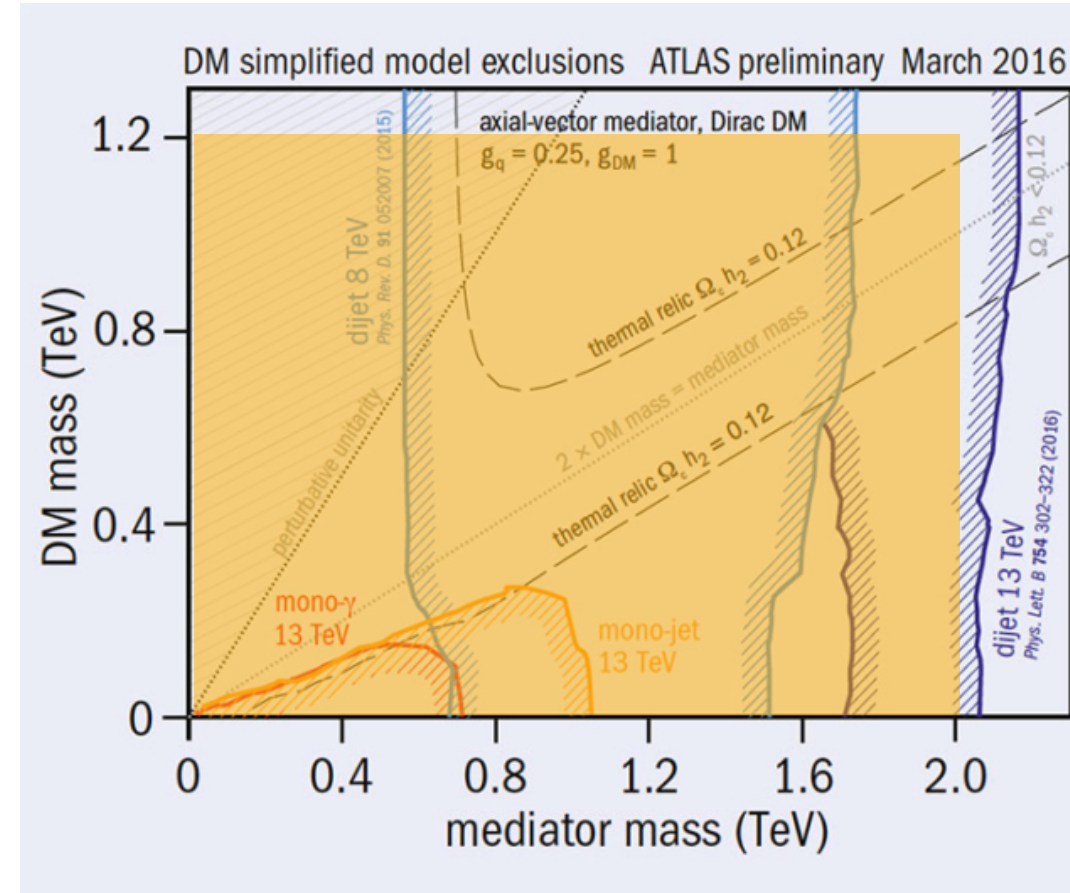
Dark Matter
Simplified model

Phenomenological
Minimal
Supersymmetric
Standard Model

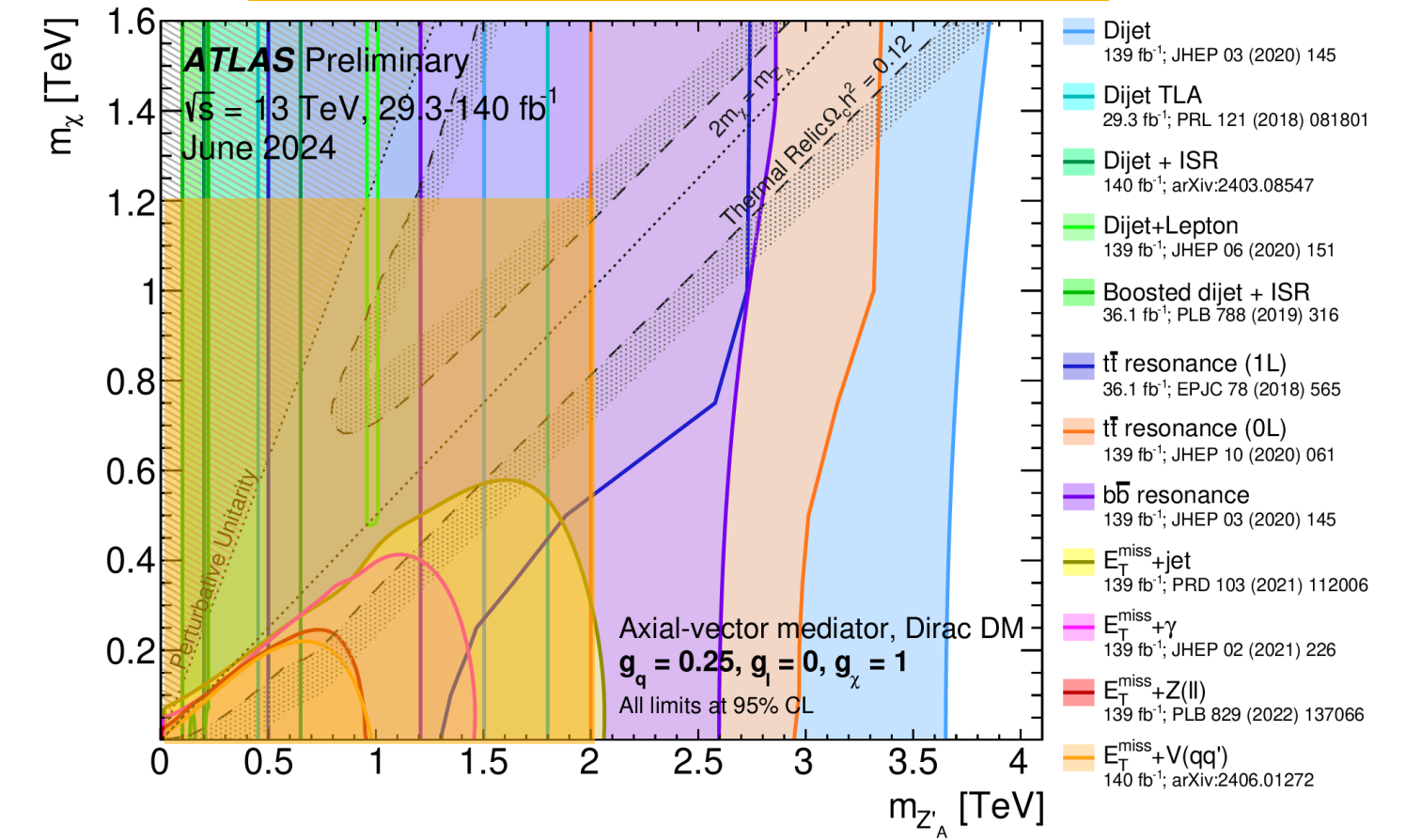


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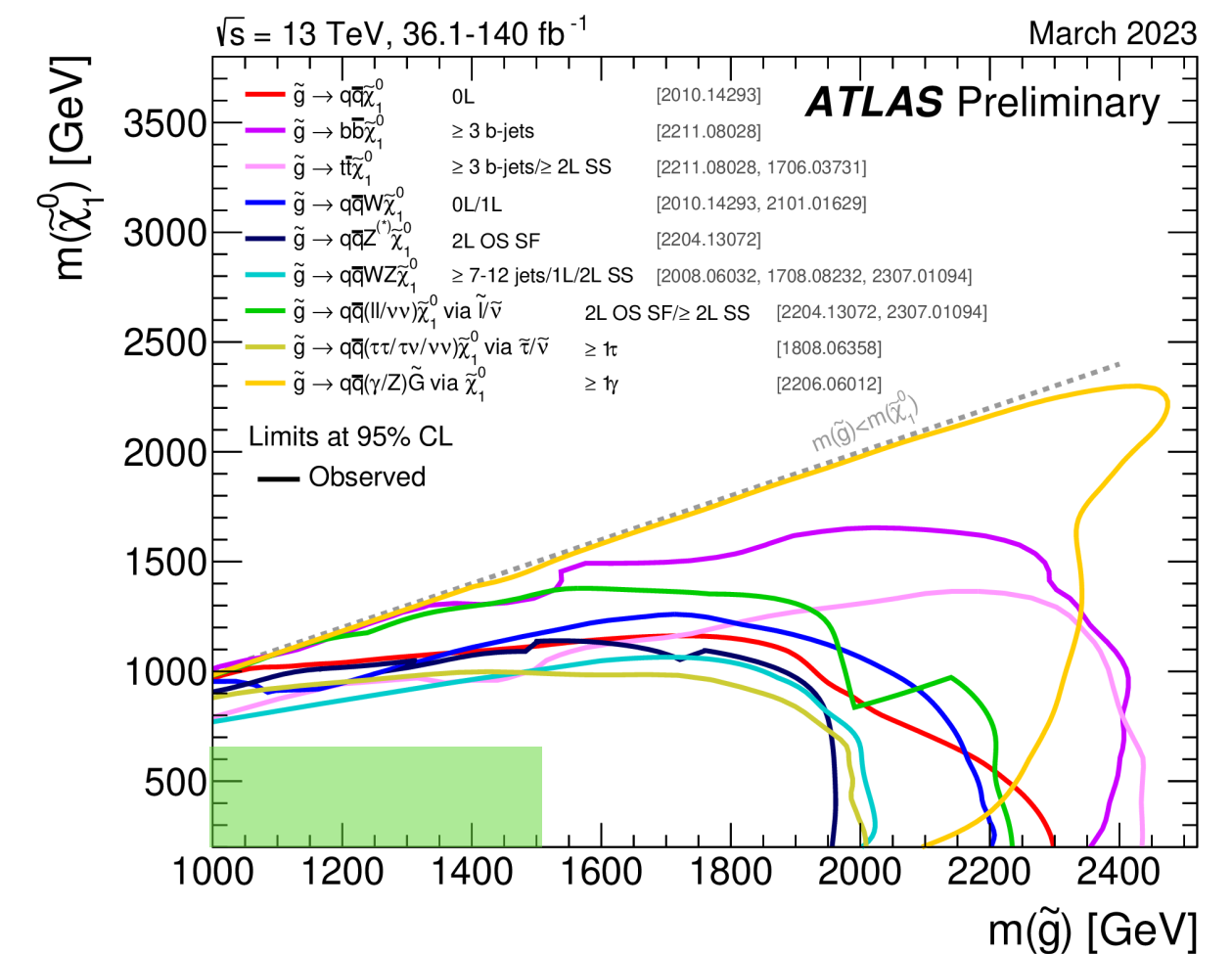


LHC-accessible parameter space almost totally ruled out

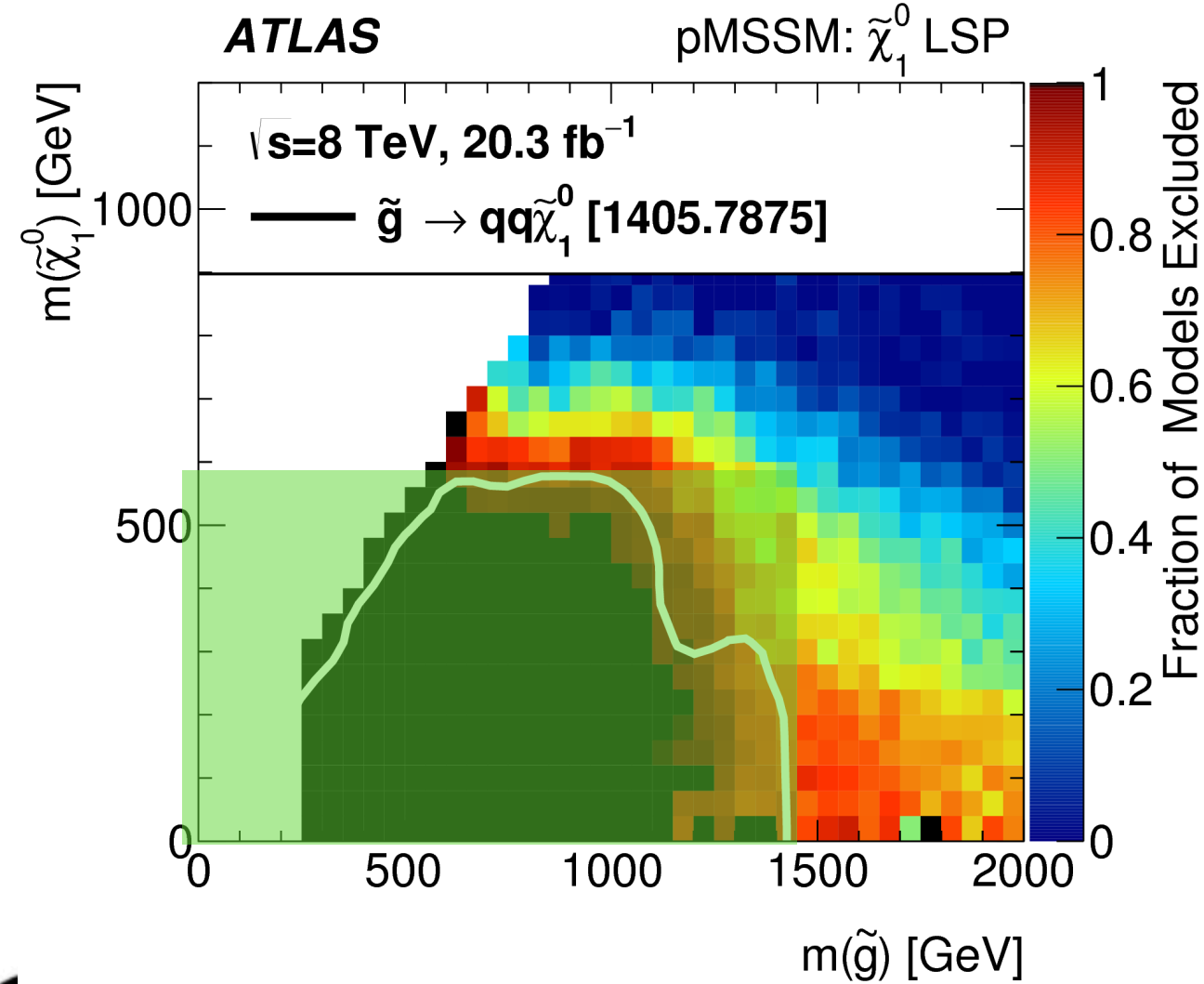
A decade of searches

TeV-scale improvements in all allowed directions!

<https://arxiv.org/abs/2403.02455>



<https://arxiv.org/abs/1508.06608>

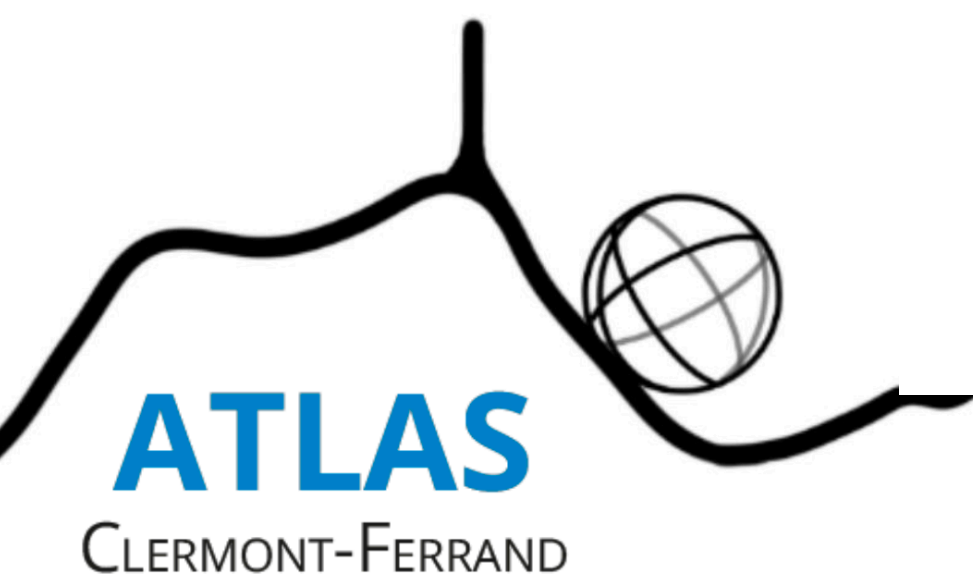


Louie Dartmoor Corpe (Clermont-Ferrand)

44

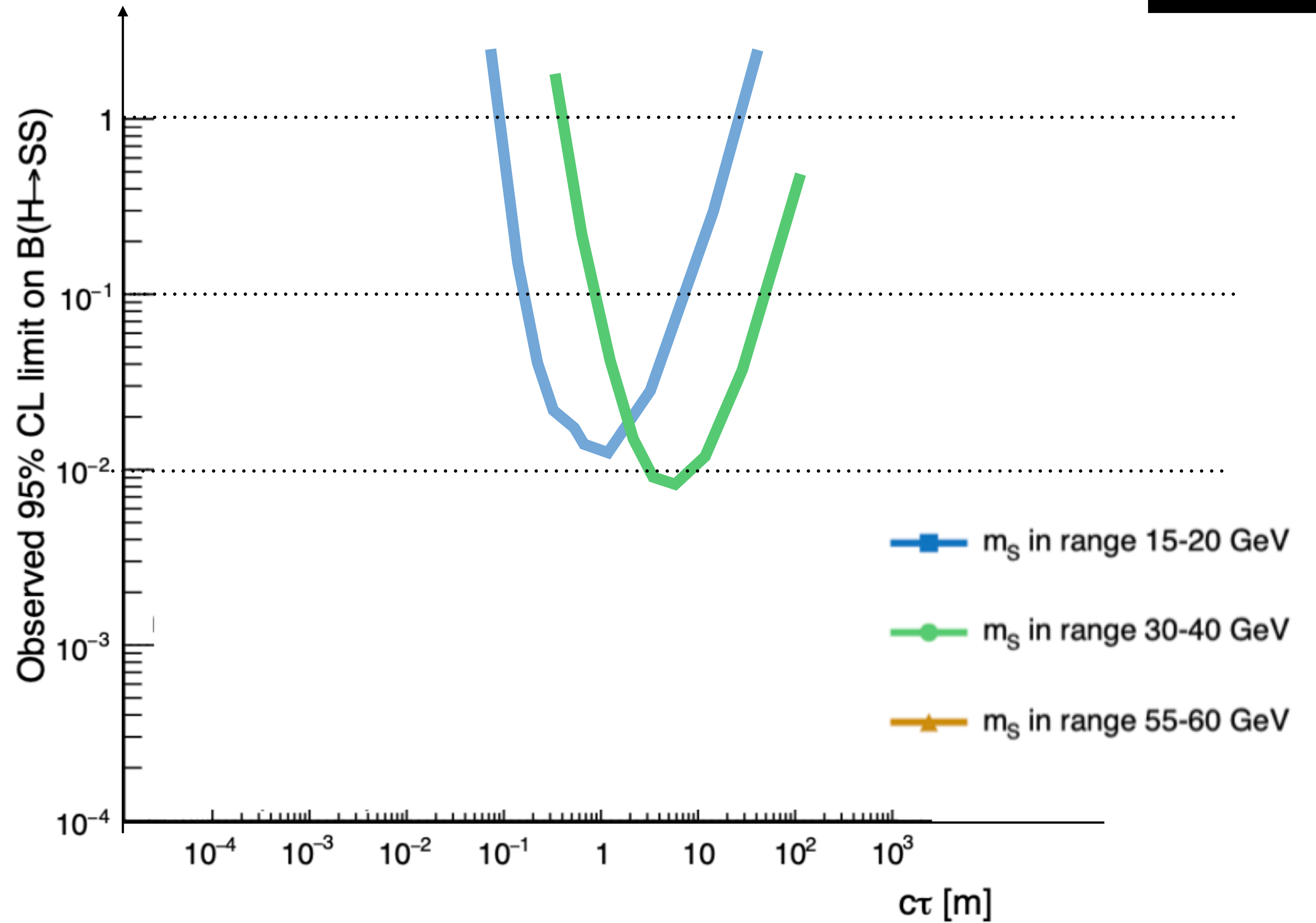
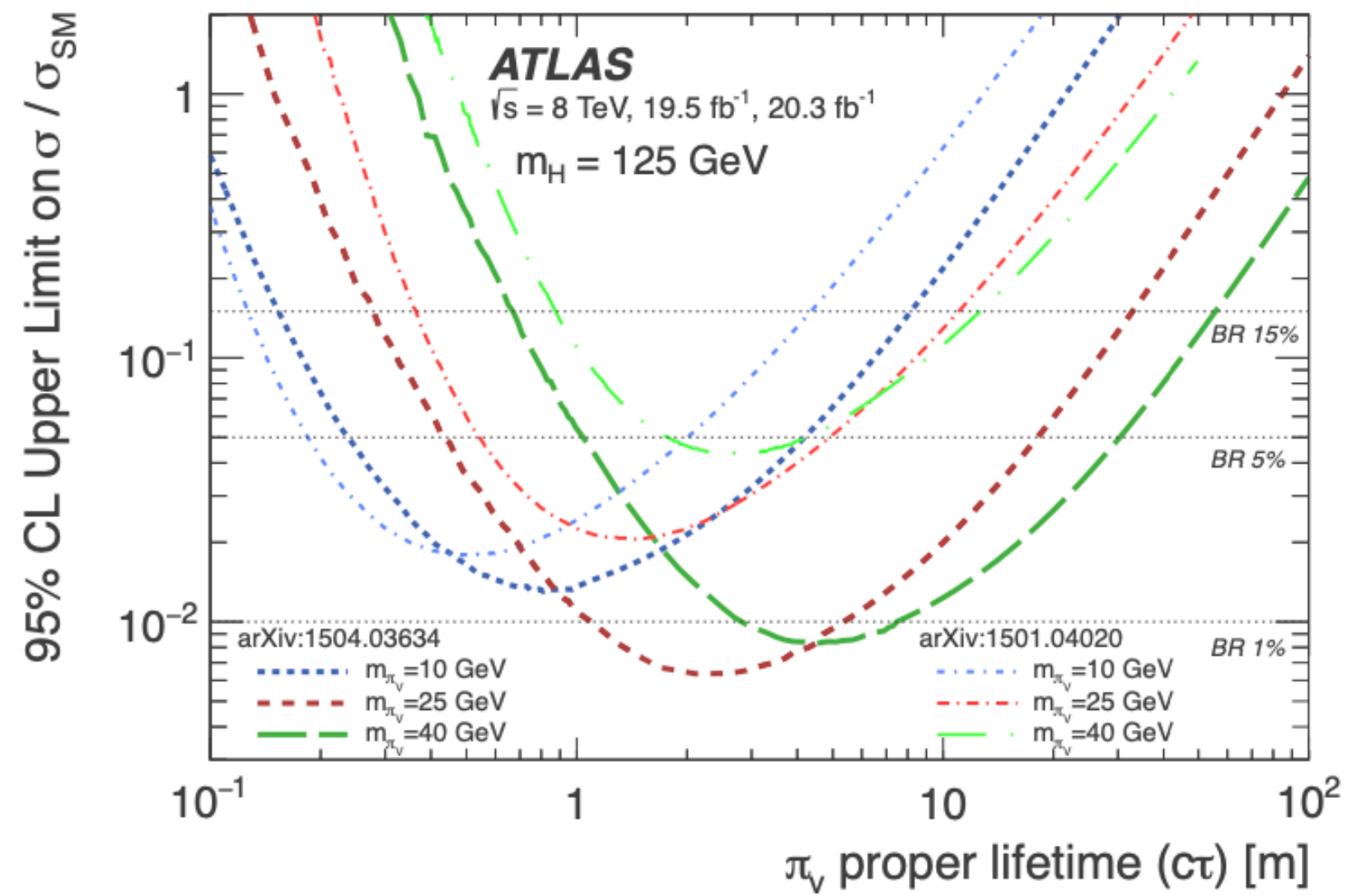
Dark Matter Simplified model

Phenomenological Minimal Supersymmetric Standard Model



The difference a decade makes (Hidden Sector LLPs)

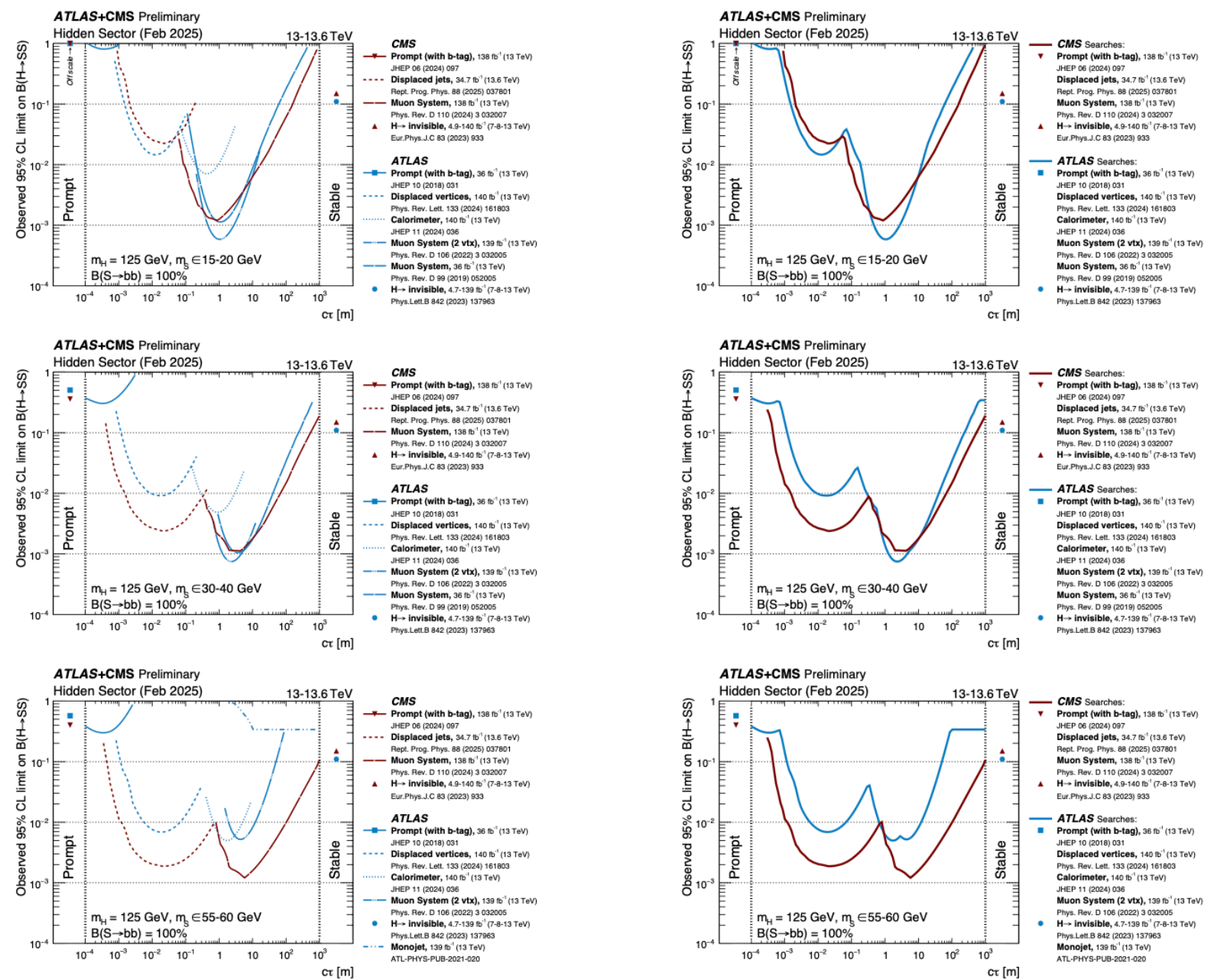
2015



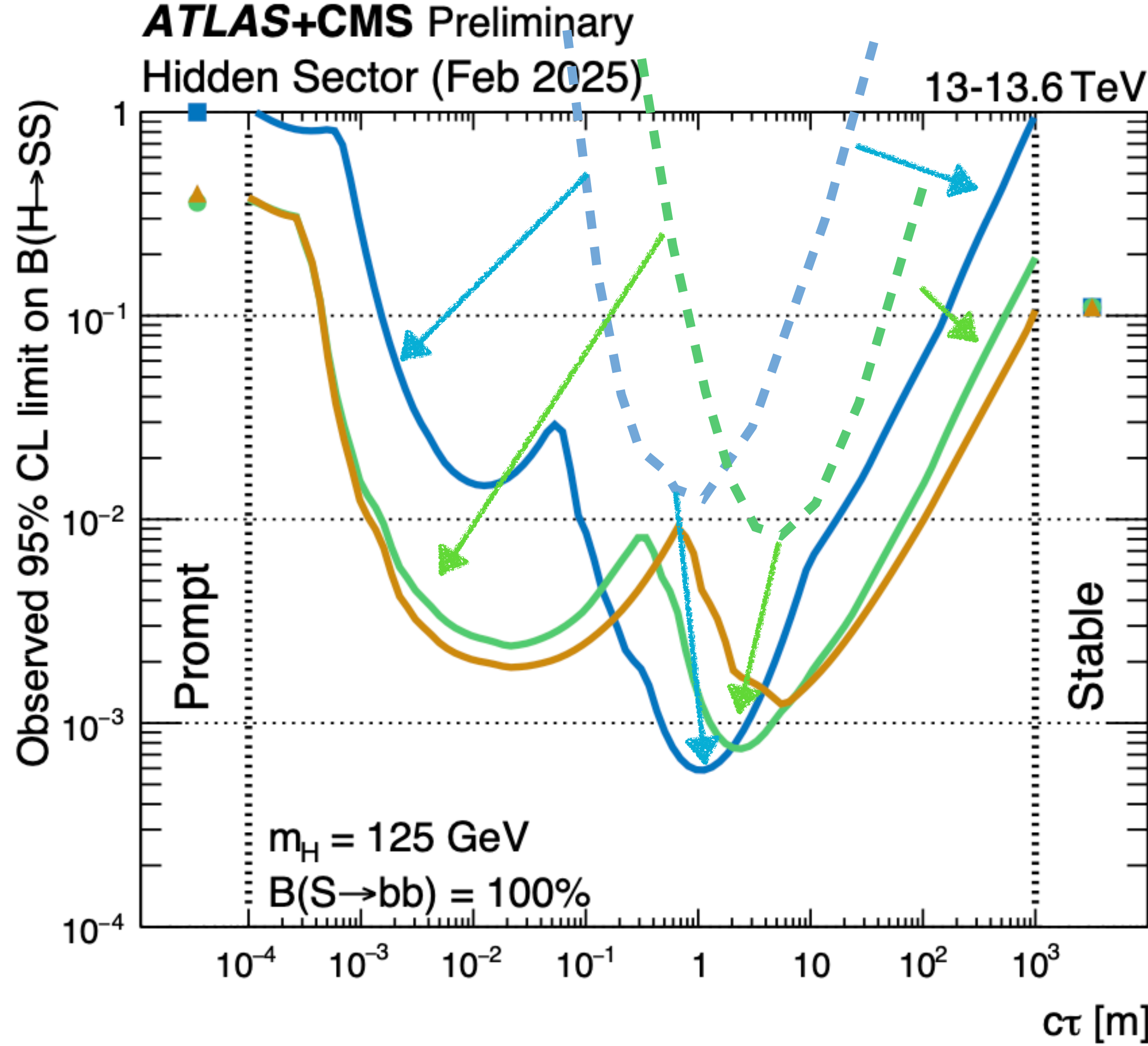
Phys. Rev. D 92 (2015) 012010,
arXiv: 1504.03634 [hep-ex]

The difference a decade makes (Hidden Sector LLPs)

2025

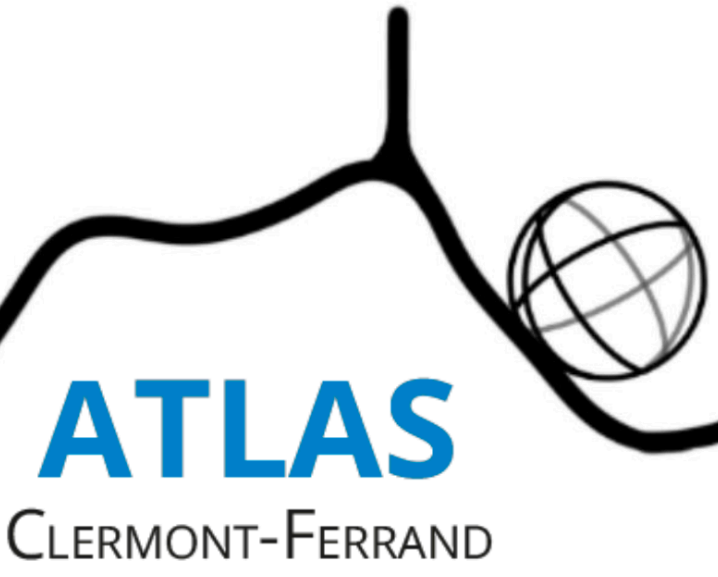


ATL-PHYS-PUB-2025-002
<https://cds.cern.ch/record/2924617>



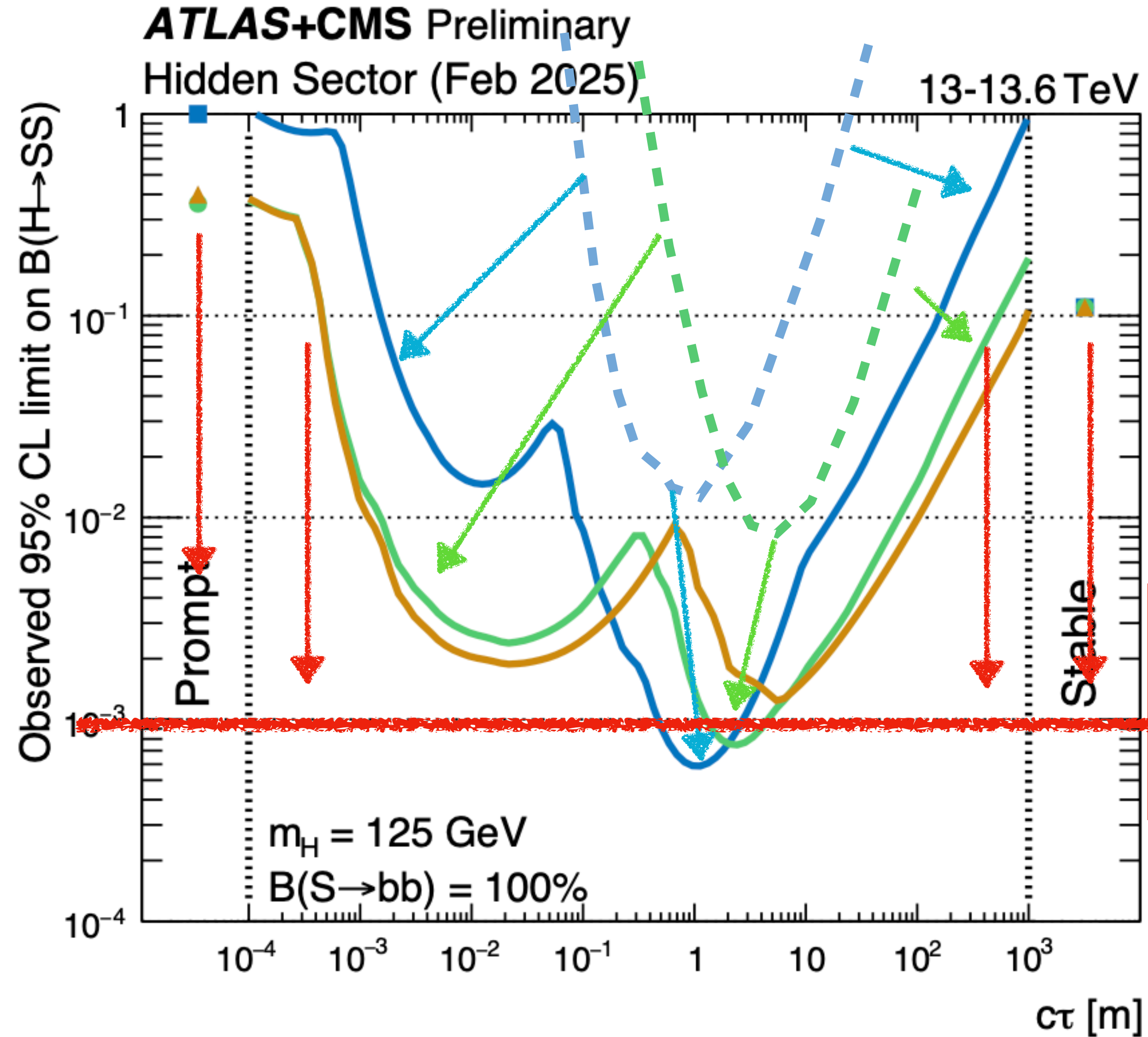
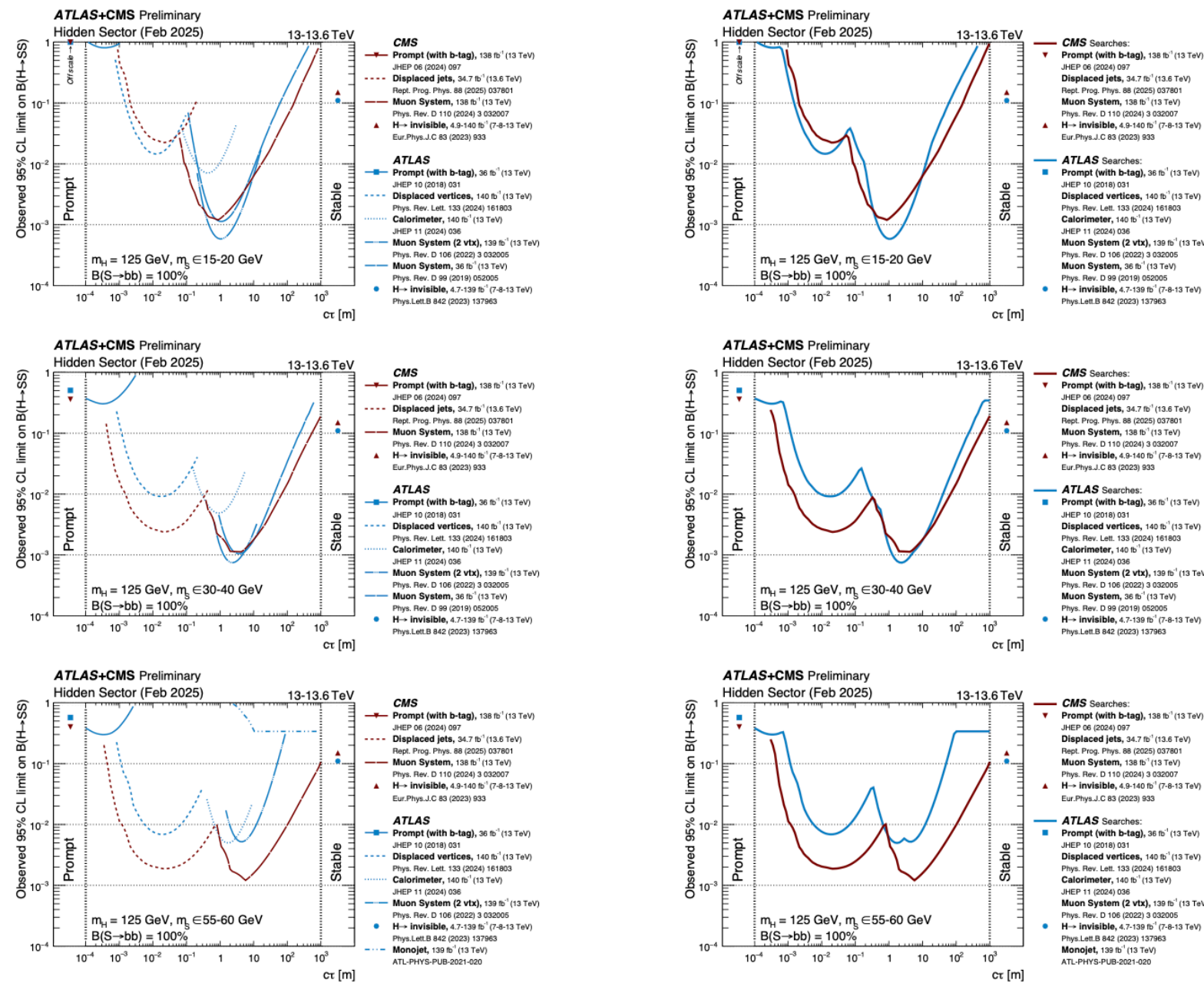
LHC Best:

- m_S in range 15-20 GeV
- m_S in range 30-40 GeV
- m_S in range 55-60 GeV



What is a reasonable target for HL-LHC?

2025

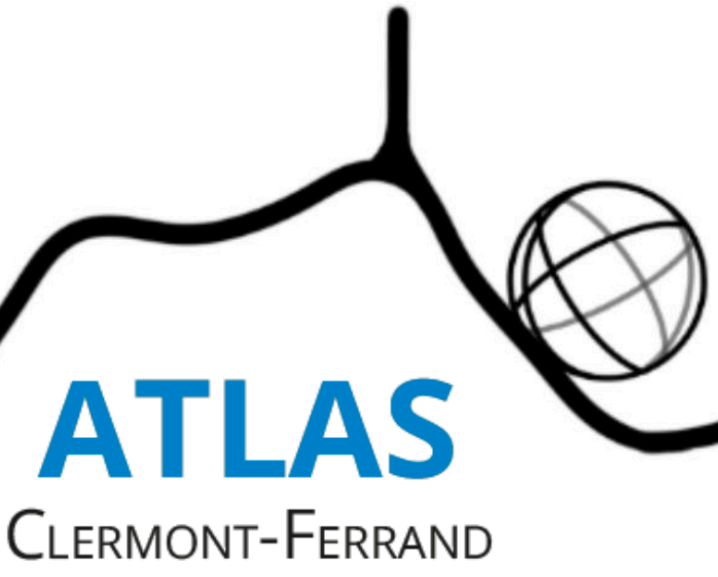


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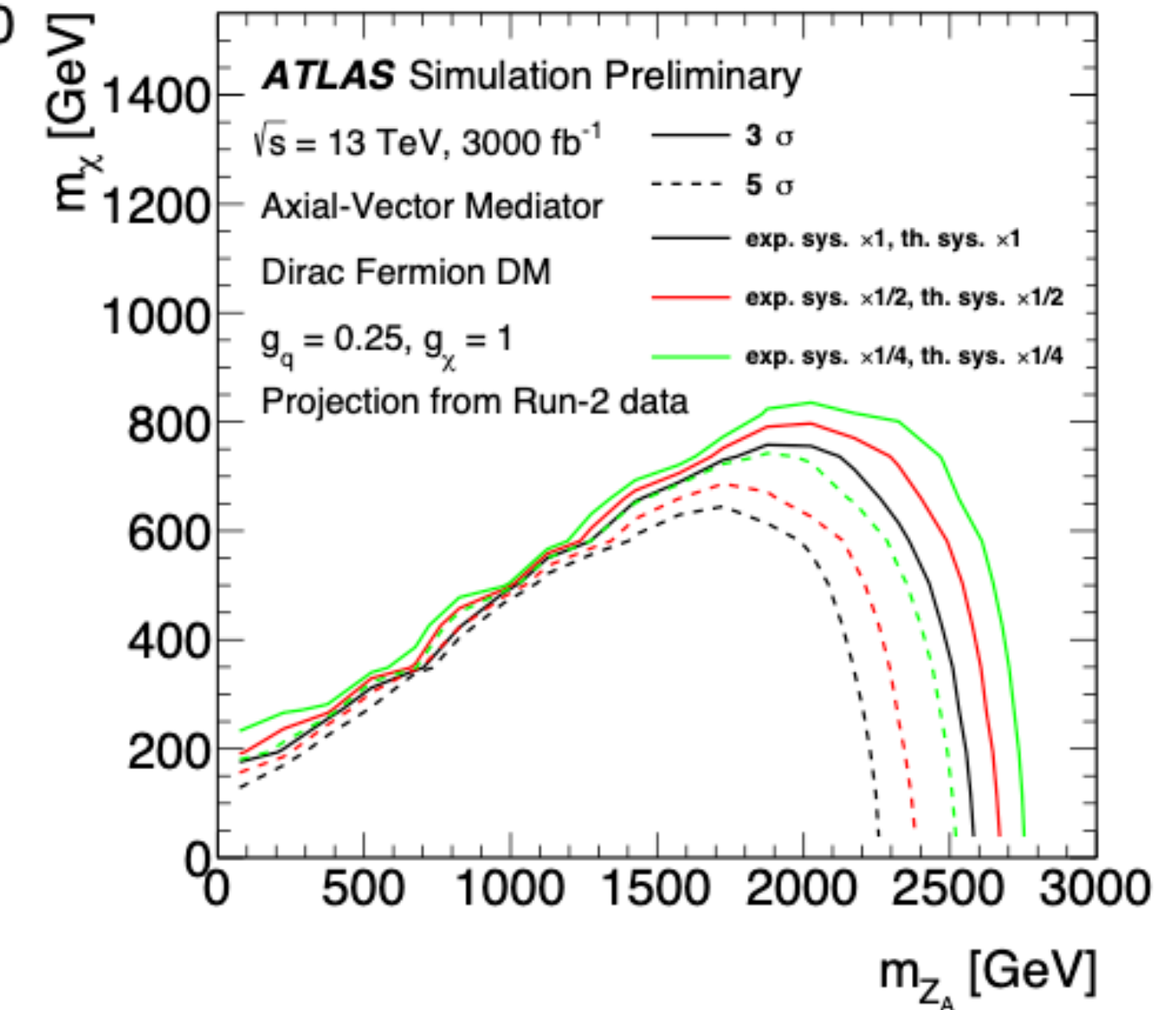
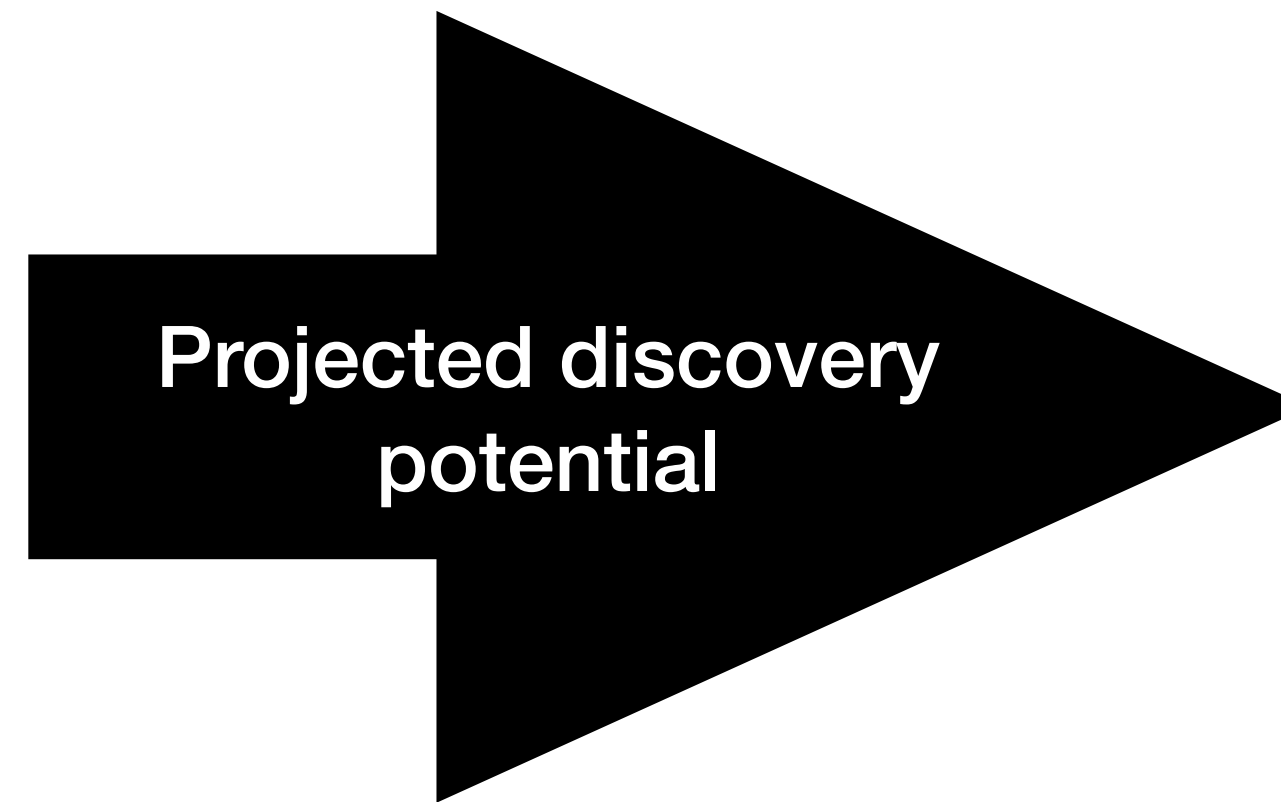
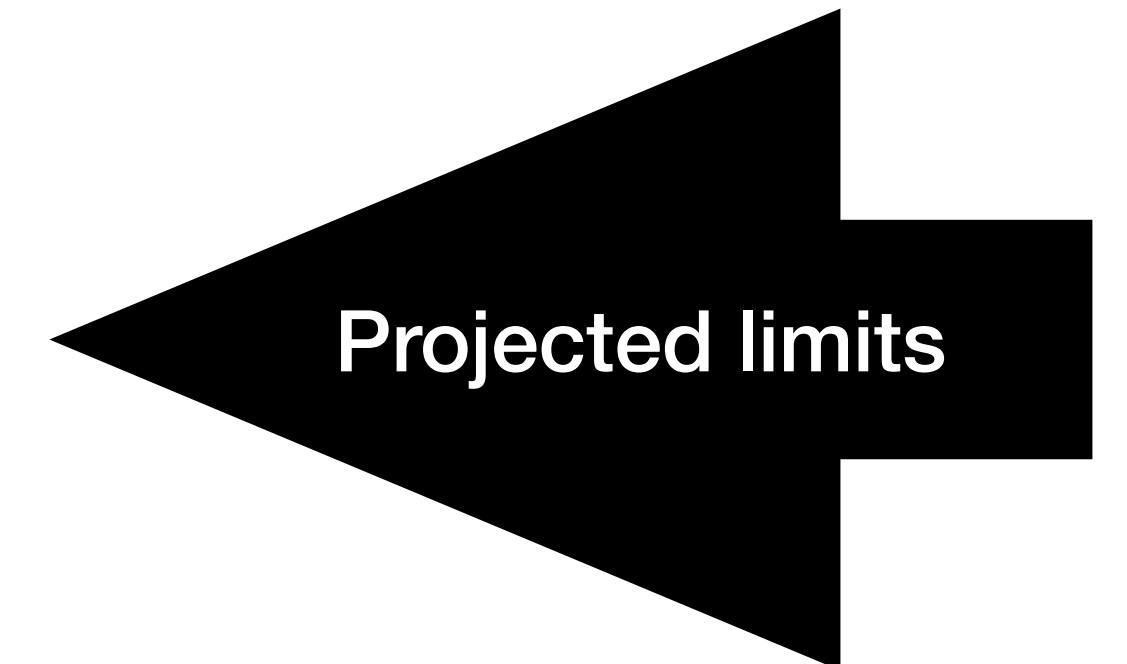
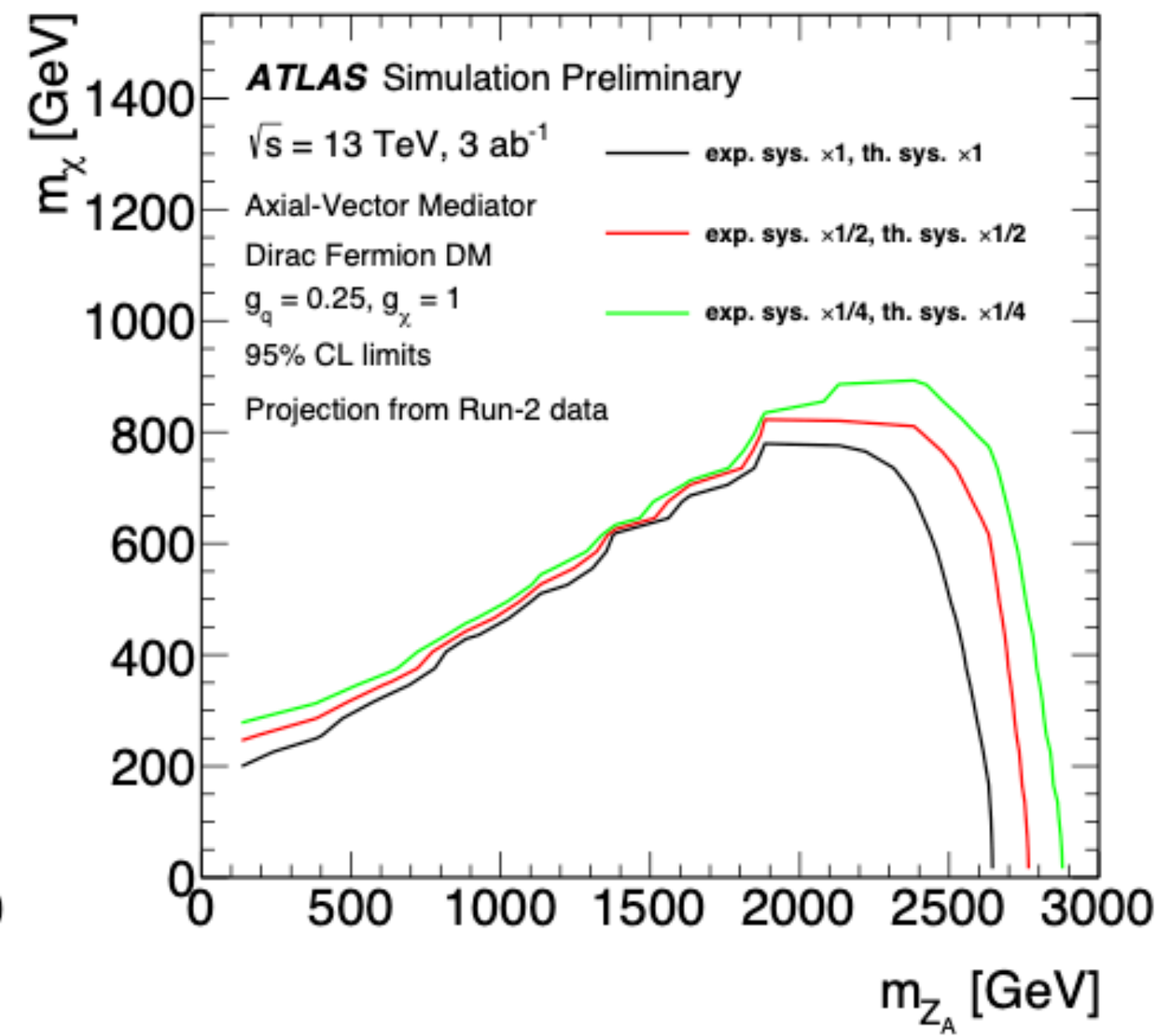
Approx $H \rightarrow ZZ^* \rightarrow \nu\nu\nu$
BR
Our own "neutrino floor" ?

ATL-PHYS-PUB-2025-002
<https://cds.cern.ch/record/2924617>



Project to plan

- Systematically project our flagship results to understand when it's time to repeat them
- do need more data ? Wait for theory improvements ? Work on systematics ?
- When can we make a big impact on limits ? When could we make a discovery ?
- Use this to inform our 5-year plan

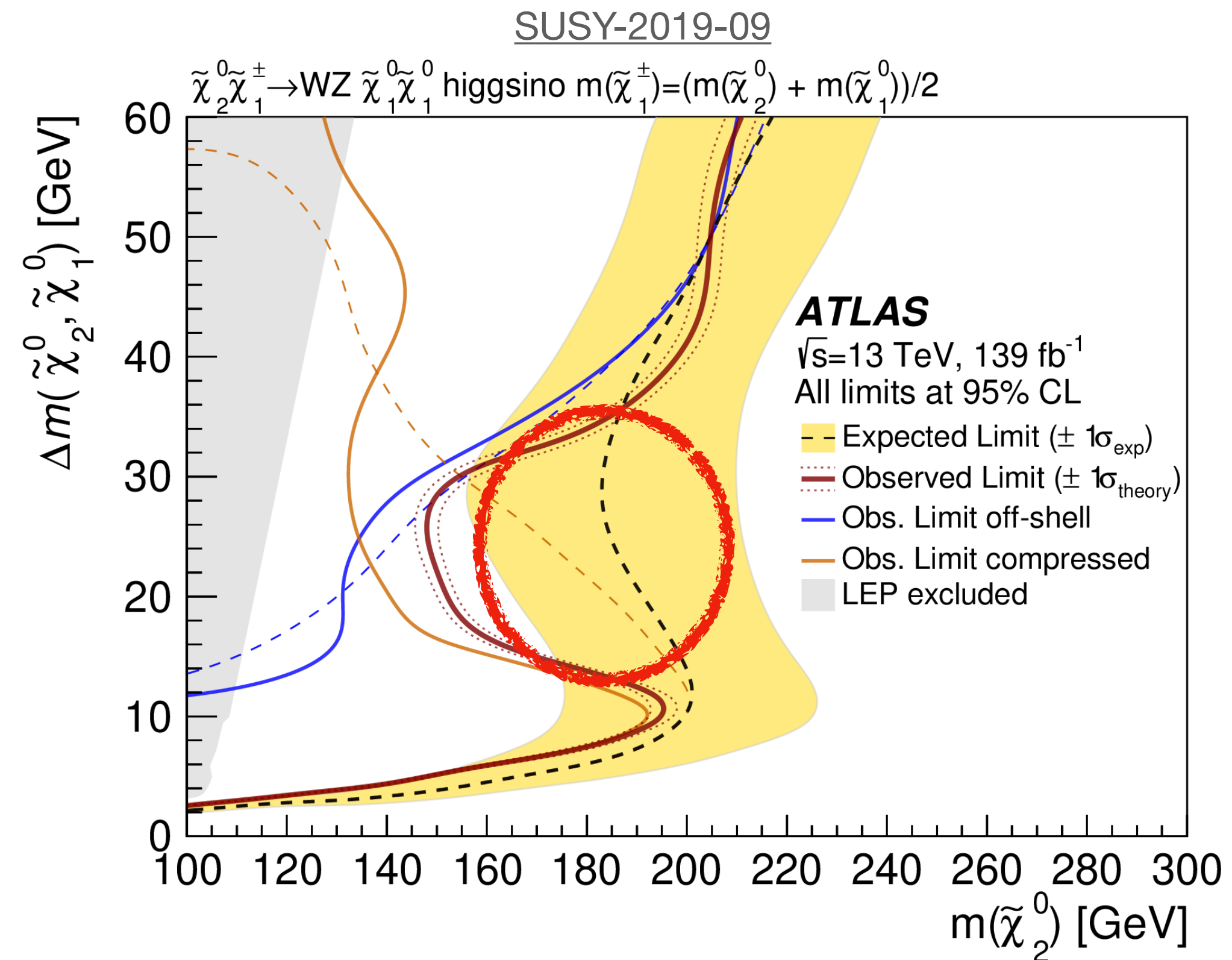
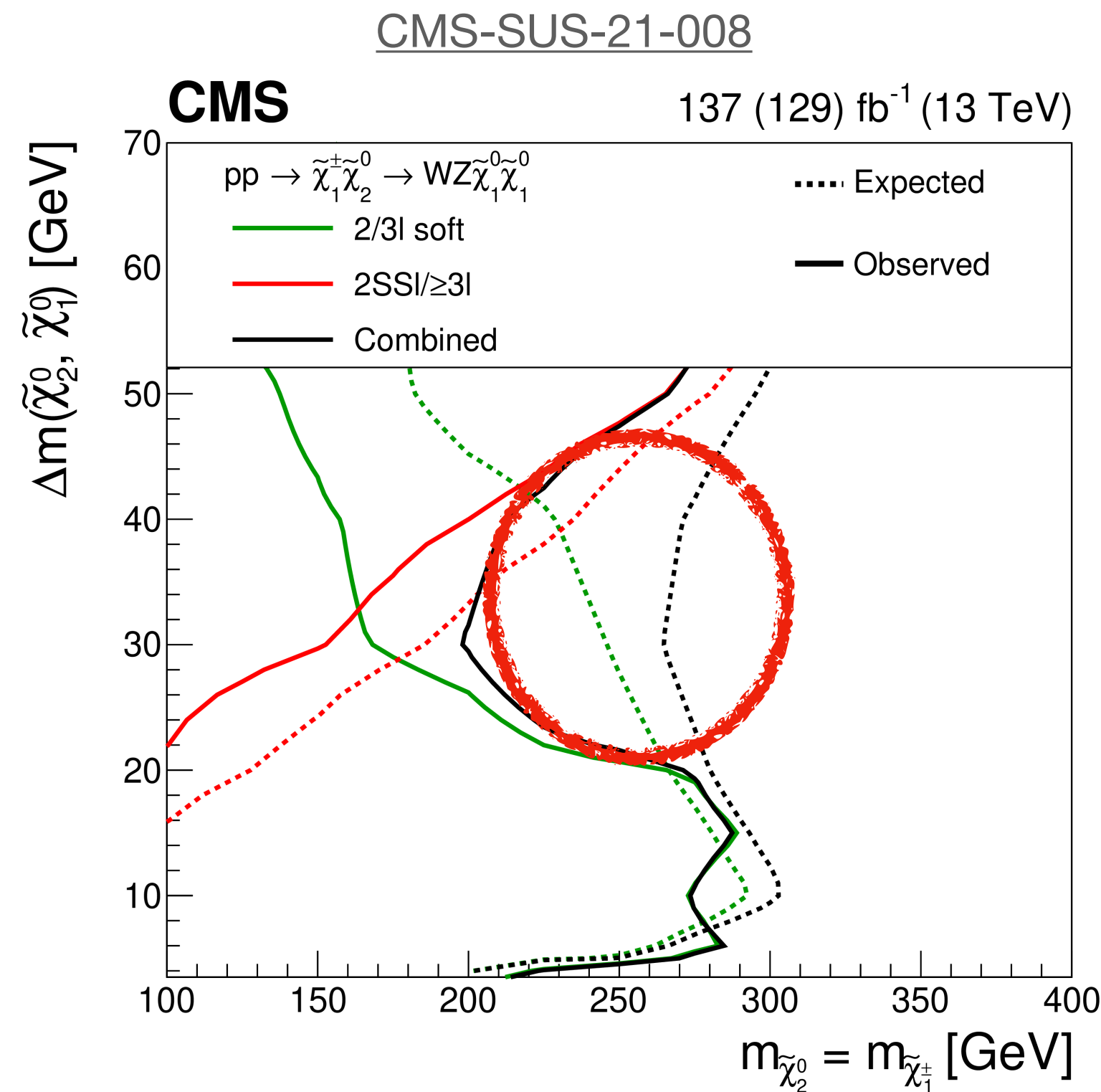


ATL-PHYS-PUB-2018-043,
<https://cds.cern.ch/record/2650050/>



Follow up on excesses

- Don't forget our main objective : a discovery could still be in store for us!
- Should invest huge resources in following up excesses, eg: compressed SUSY



ATLAS Excesses:

[[Soft 2L](#)], [[3L](#)],

[[Sleptons 2L](#)],

[[SBH 3L](#)]

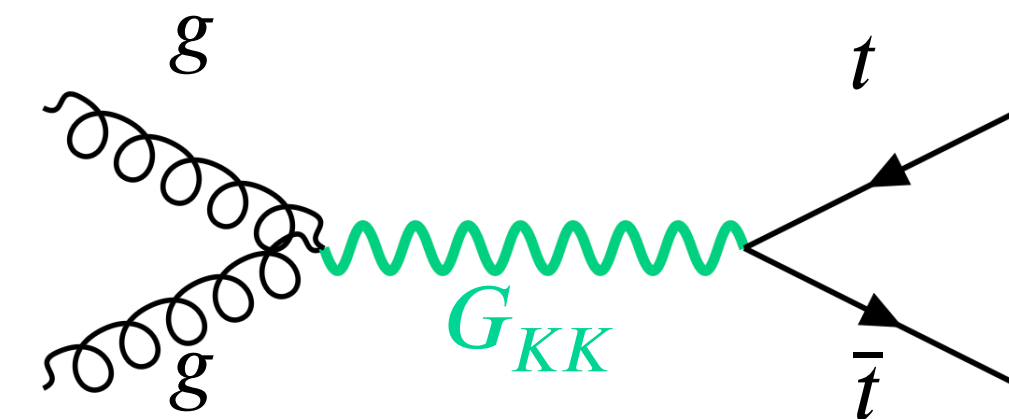
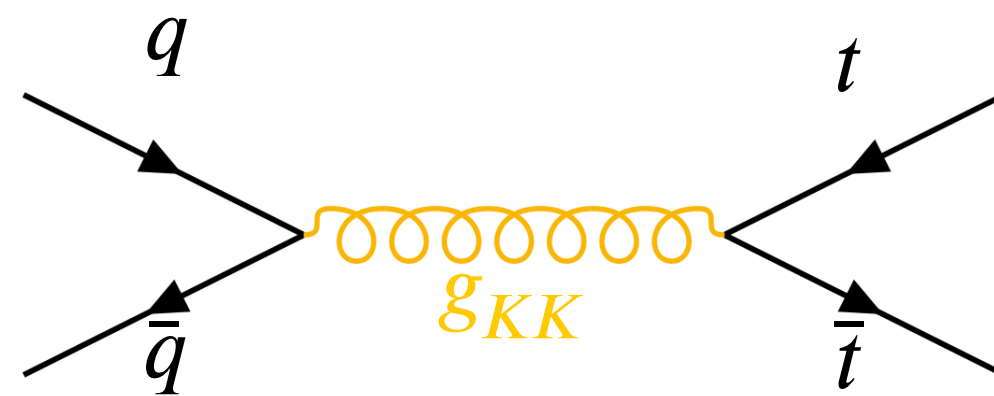
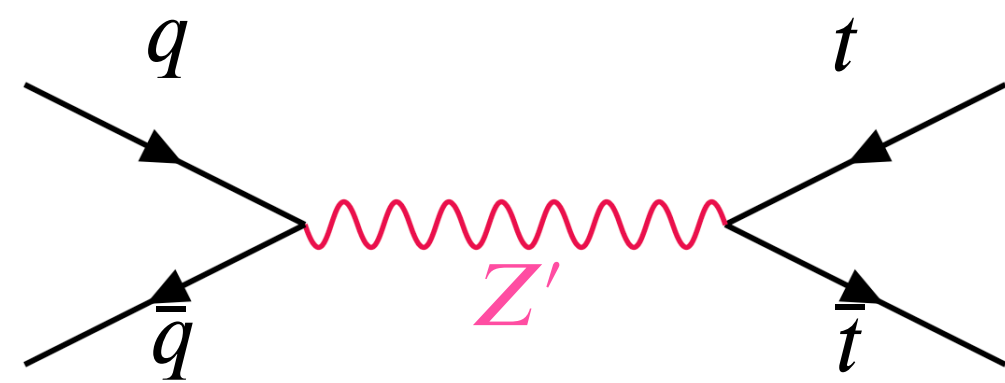
CMS Excesses:

[[Soft 2/3L](#)]

Example of a recent 'flagship' result: $t\bar{t}$ resonances

- Search for $t\bar{t}$ resonances in the 1L and 2L decay channels
 - Results presented from the combination of the channels
- Target signals (all with negligible interference):
 - Spin-1 leptophobic boson, Z'
 - Spin-1 Kaluza-Klein excitations of the gluon, g_{KK}
 - Spin 2 Kaluza-Klein excitations of the graviton, G_{KK}
- Target mass range:
 - $400 \leq m_{t\bar{t}} \leq 5000$ GeV

All signals generated with MadGraph-Pythia8 (spin correlations correctly propagated)



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)



Submitted to: JHEP



CERN-EP-2025-281
22nd December 2025

Search for $t\bar{t}$ resonances in final states with exactly one or two leptons using 140 fb^{-1} of pp collision data at $\sqrt{s} = 13$ TeV with the ATLAS experiment

The ATLAS Collaboration

Example of a recent 'flagship' result: $t\bar{t}$ resonances

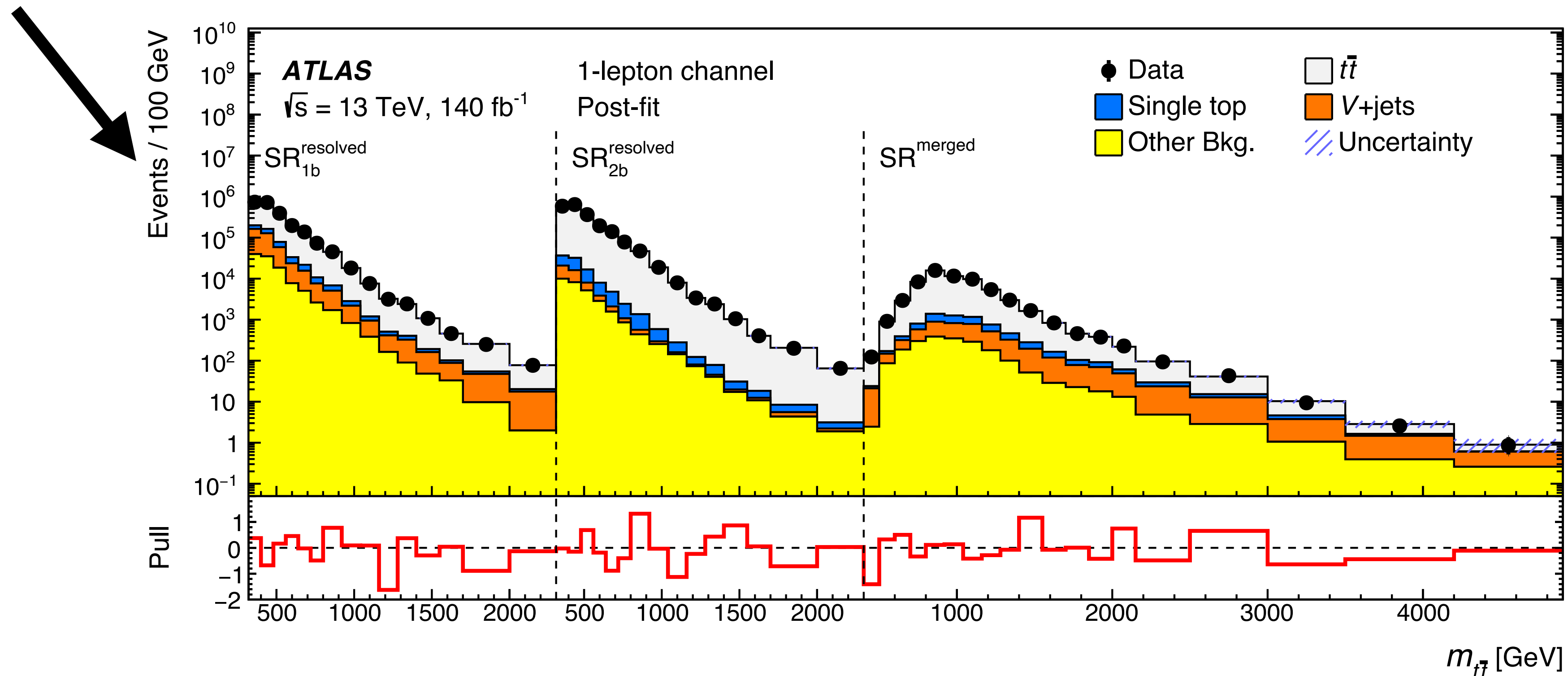
Two orthogonal channels considered: **lepton+jets** and **dilepton**. Statistical combination performed

1L

- Invariant mass spectrum of the $t\bar{t}$ pair
- $\Delta\eta(t^{had}, \ell)$ used to define signal and validation regions

2L

- Invariant mass spectrum of di- b -plus-dilepton system, $m_{\ell\ell bb}$
- $\Delta\eta(\ell, \ell)$ used to define signal and validation regions
- Additionally binned in $\Delta\phi(\ell, \ell)$



Example of a recent 'flagship' result: $t\bar{t}$ resonances

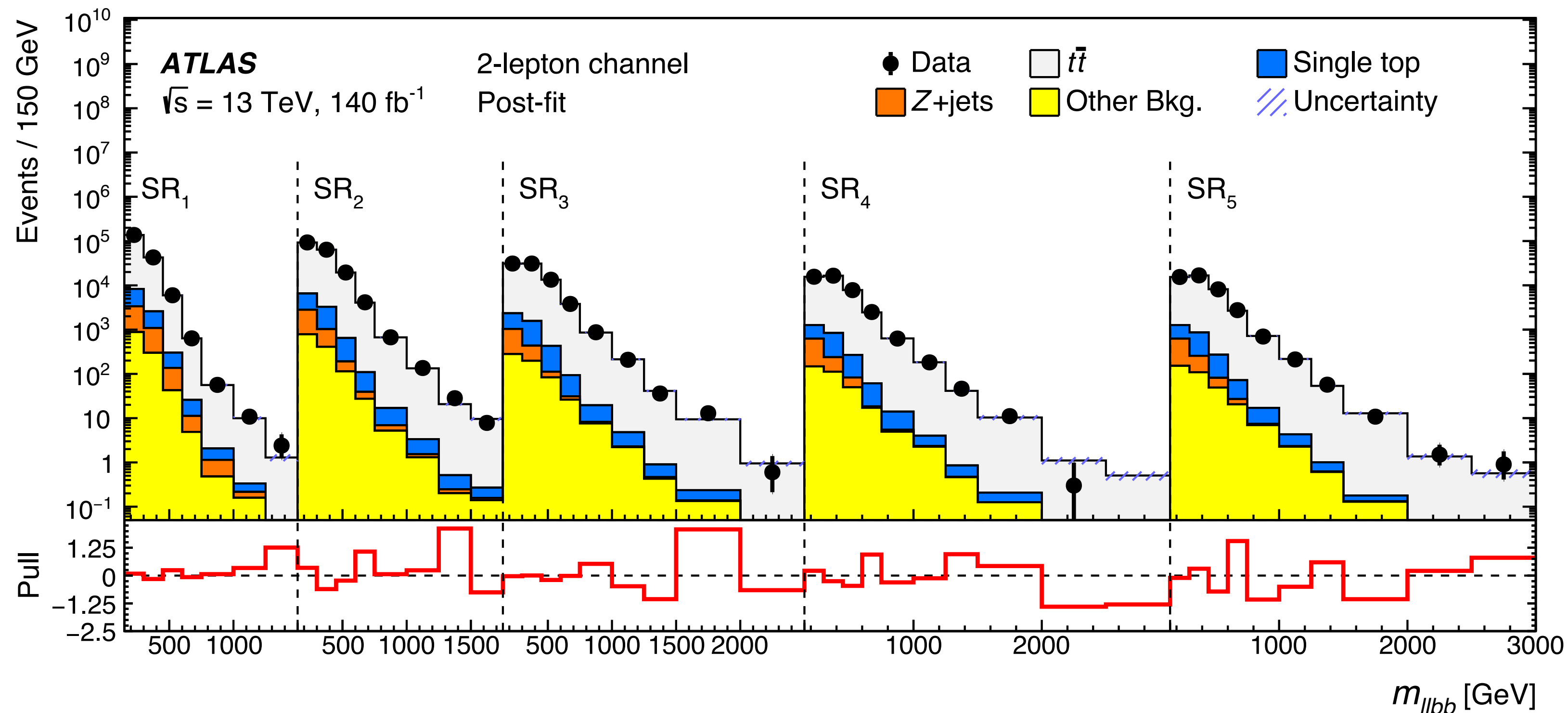
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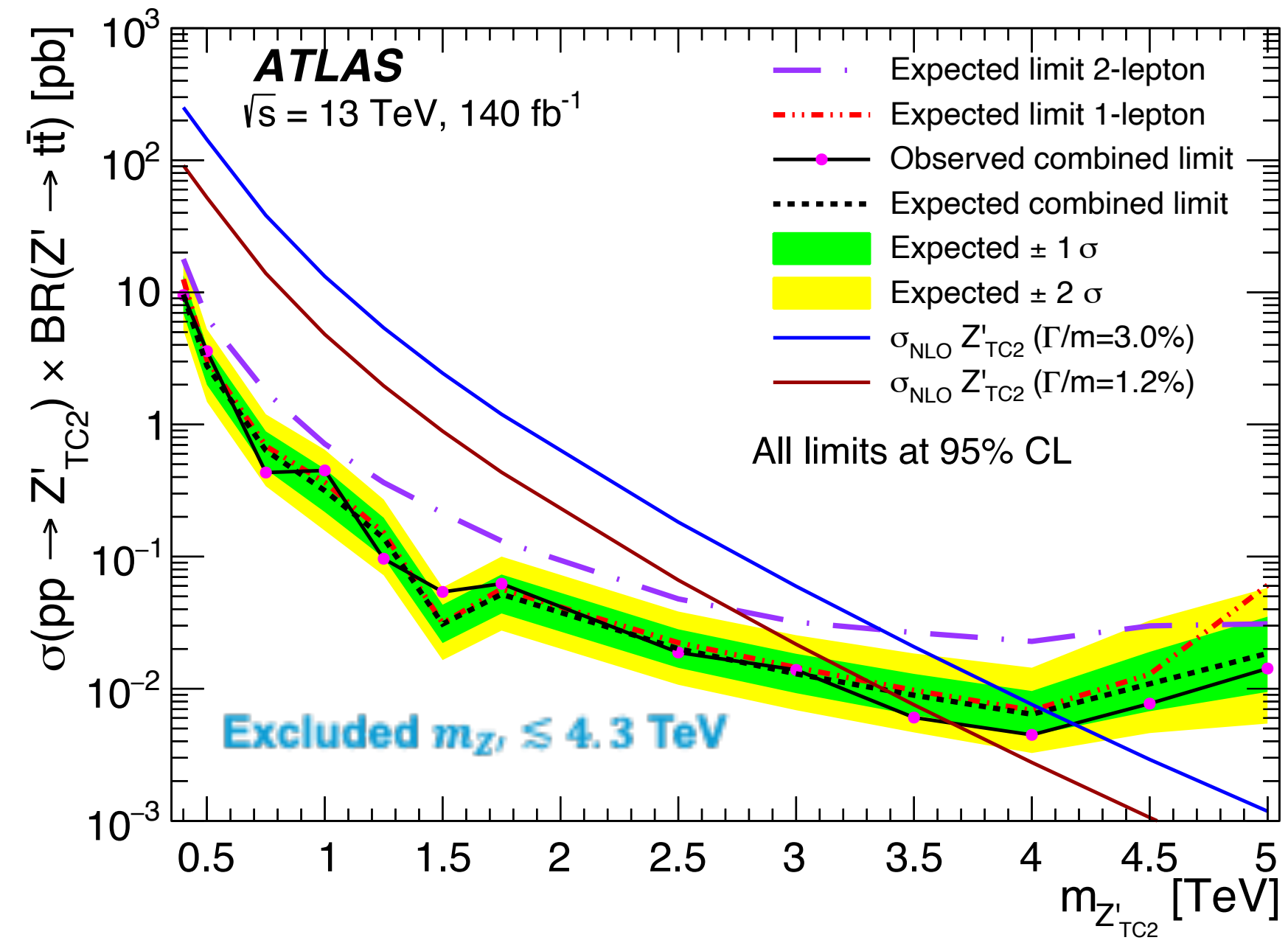
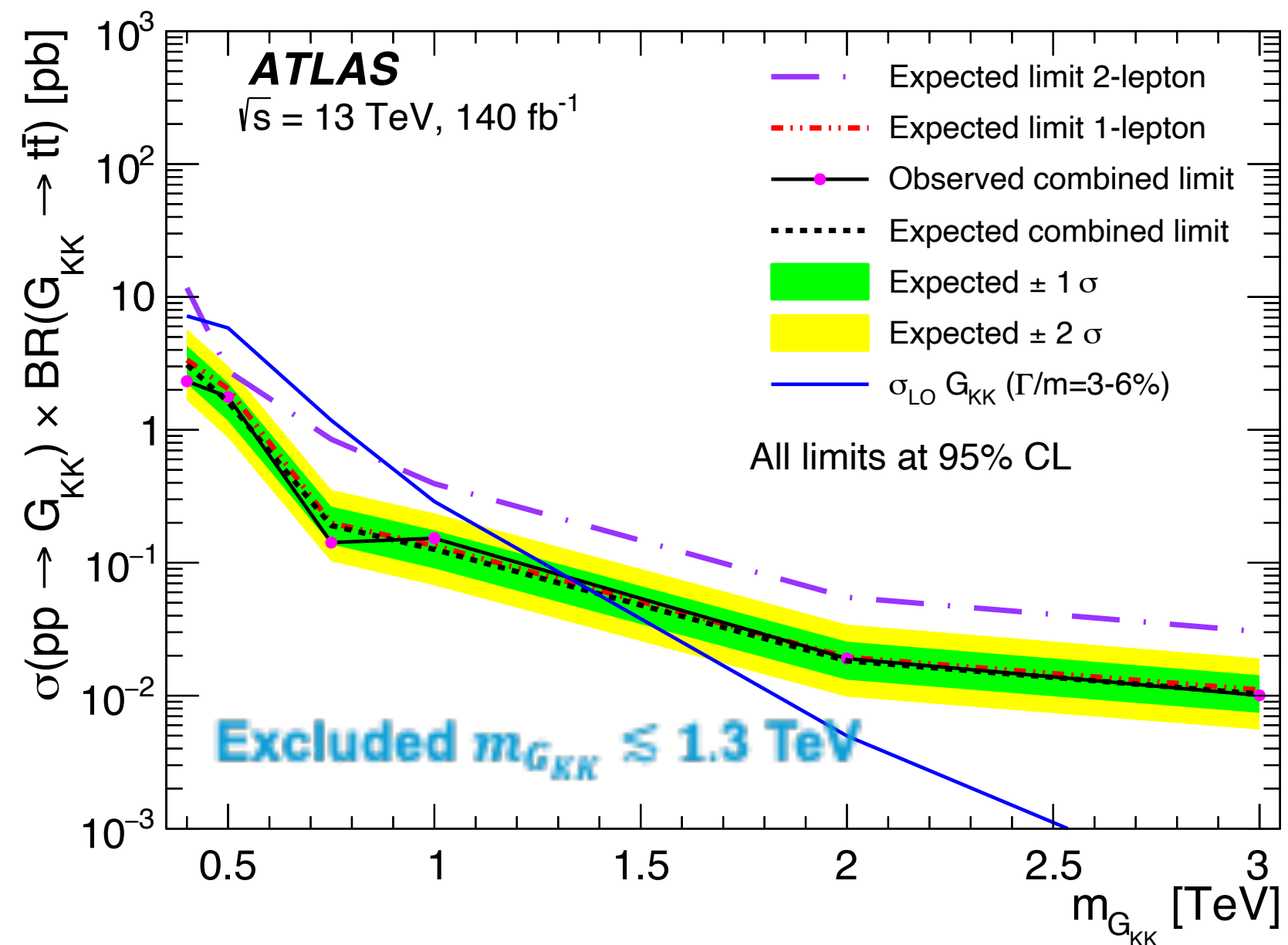
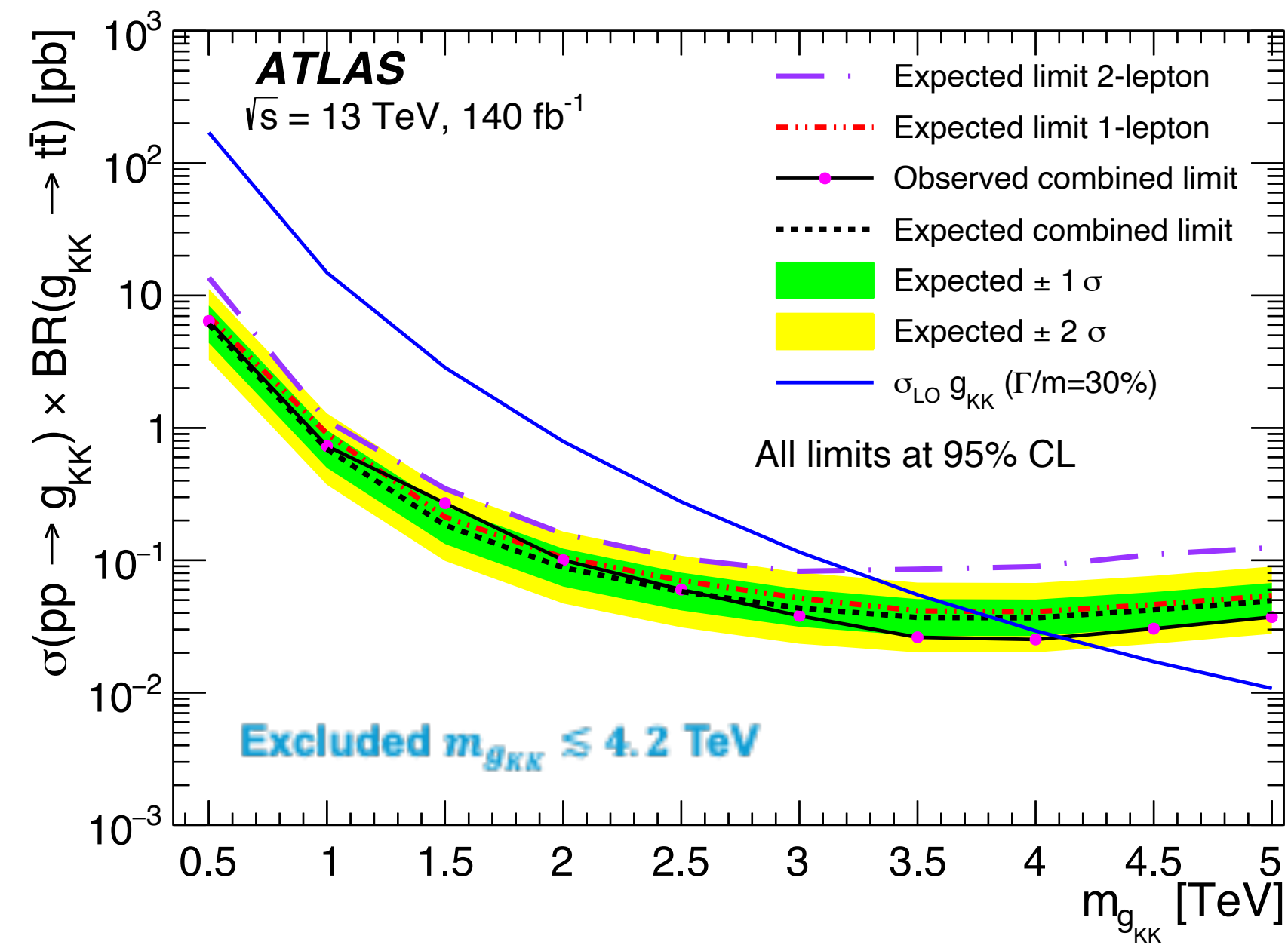
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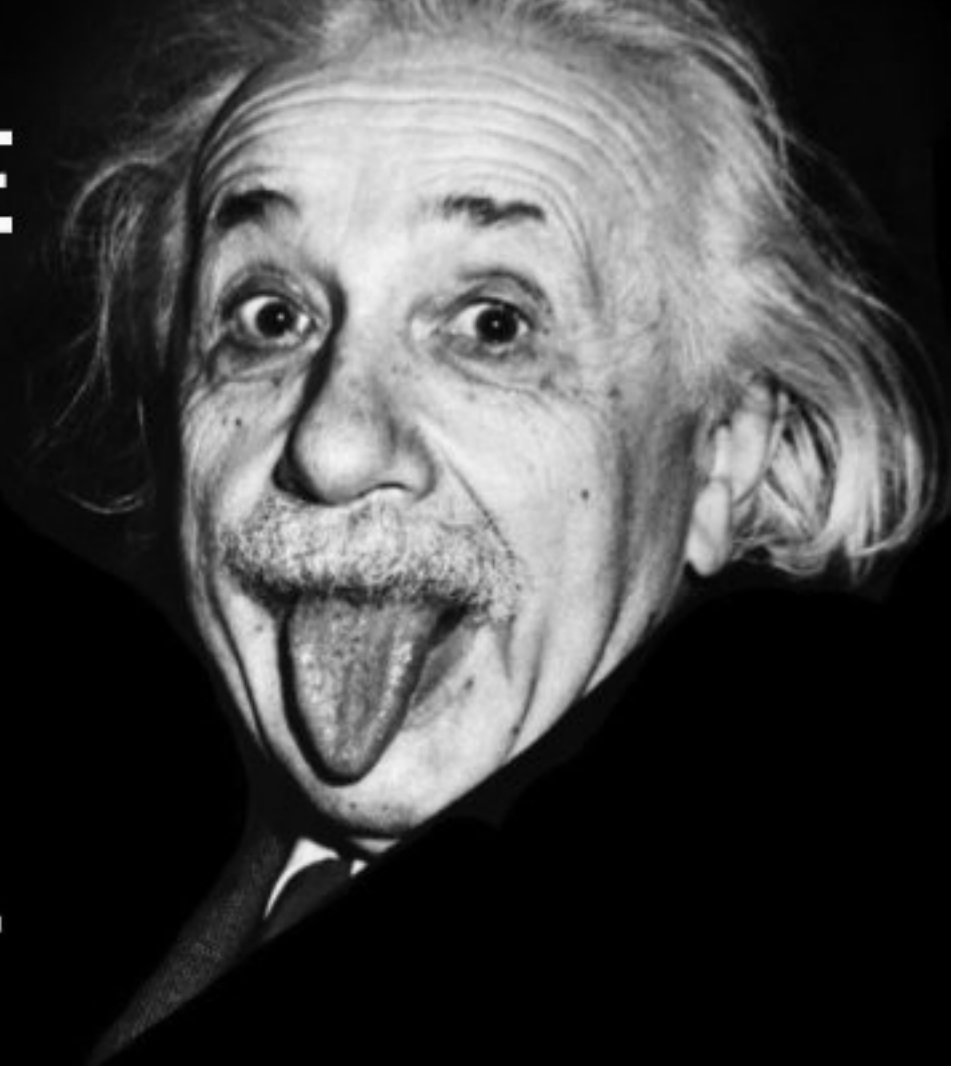


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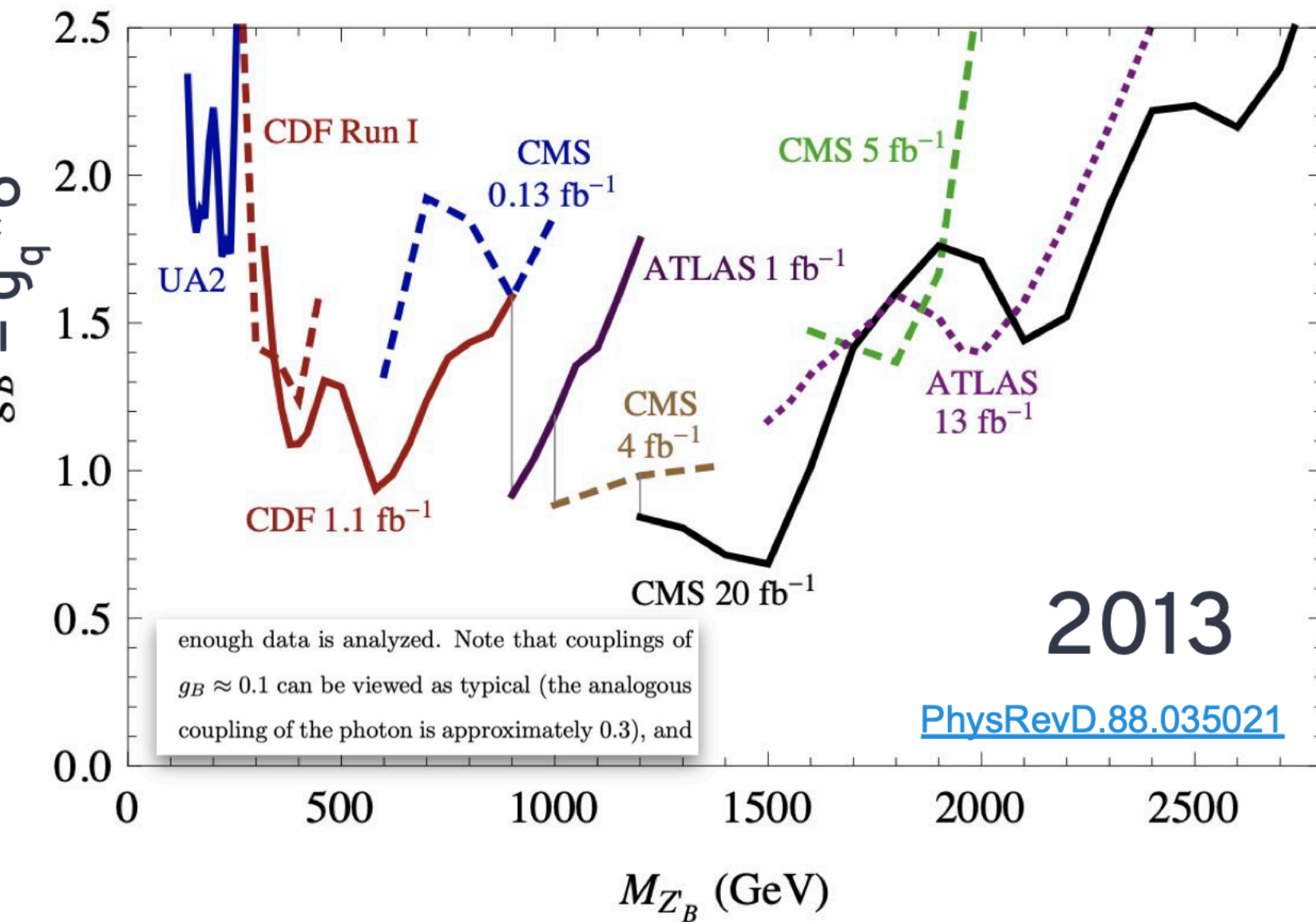
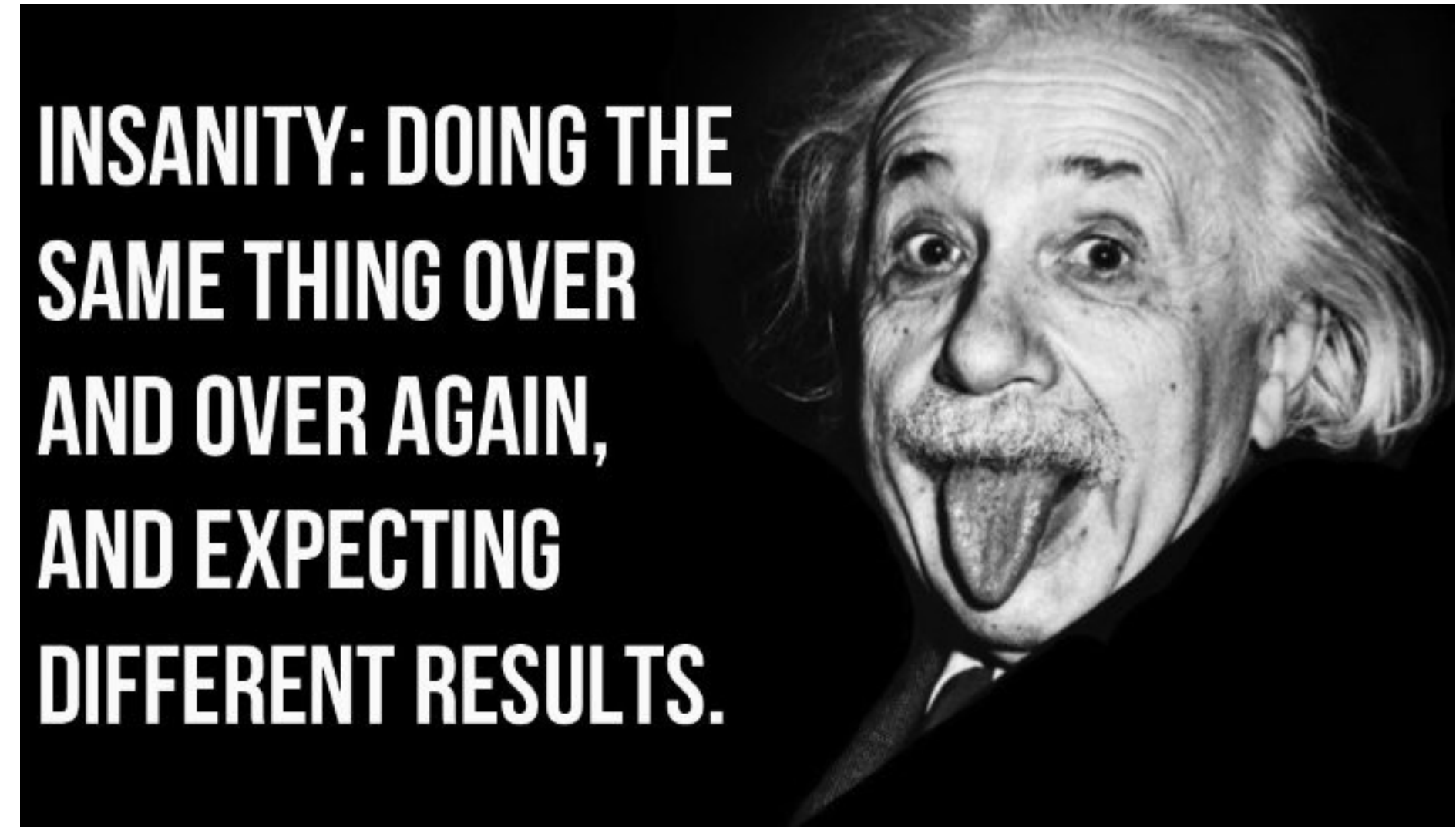
Why keep digging ?

**INSANITY: DOING THE
SAME THING OVER
AND OVER AGAIN,
AND EXPECTING
DIFFERENT RESULTS.**



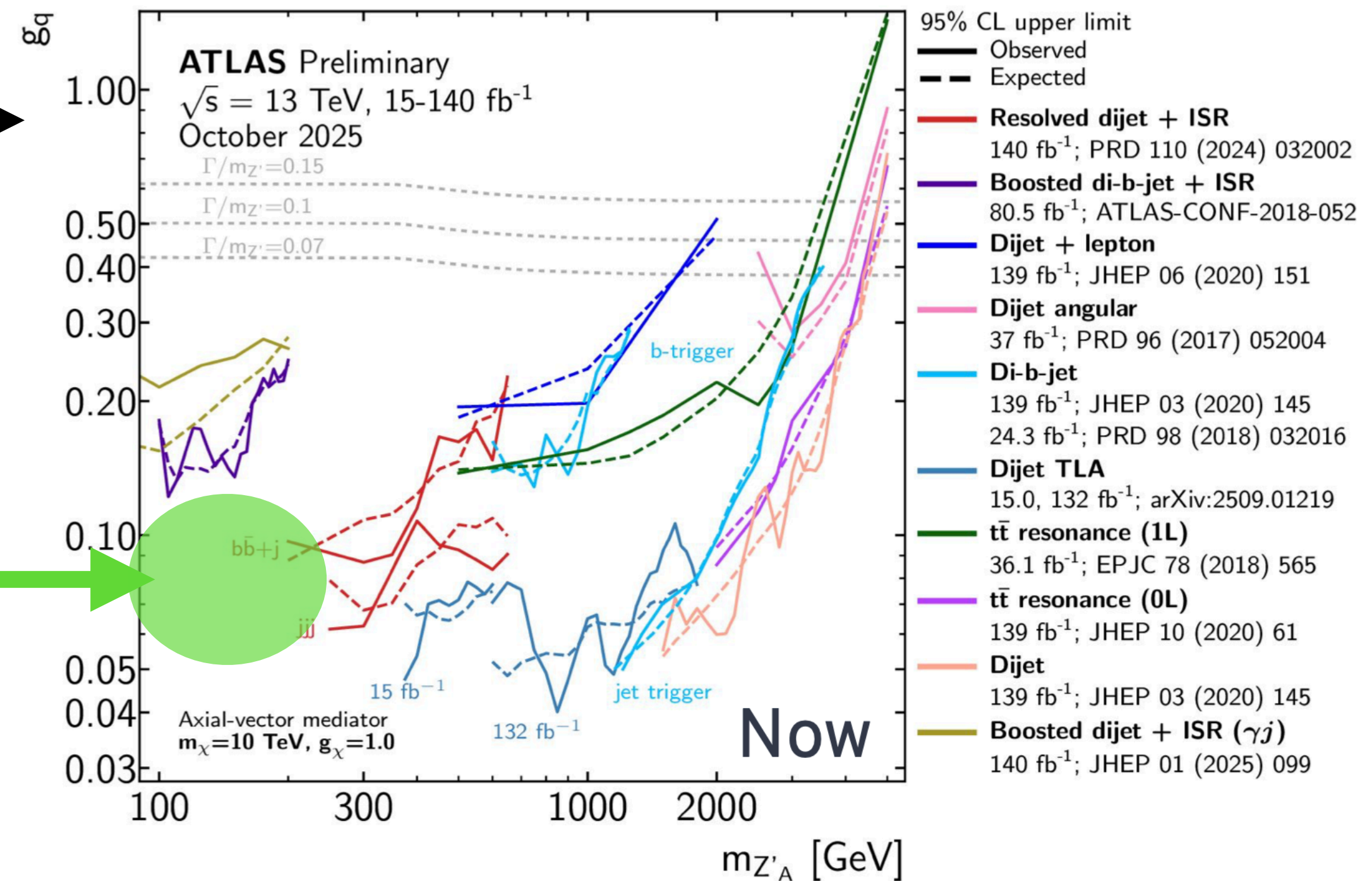
Why keep digging ?

BUT... we are only now beginning to probe some areas which are *actually* well motivated...
(Eg dijet resonances!)



13 years

enough data is analyzed. Note that couplings of $g_B \approx 0.1$ can be viewed as typical (the analogous coupling of the photon is approximately 0.3), and



Speculative searches

noun

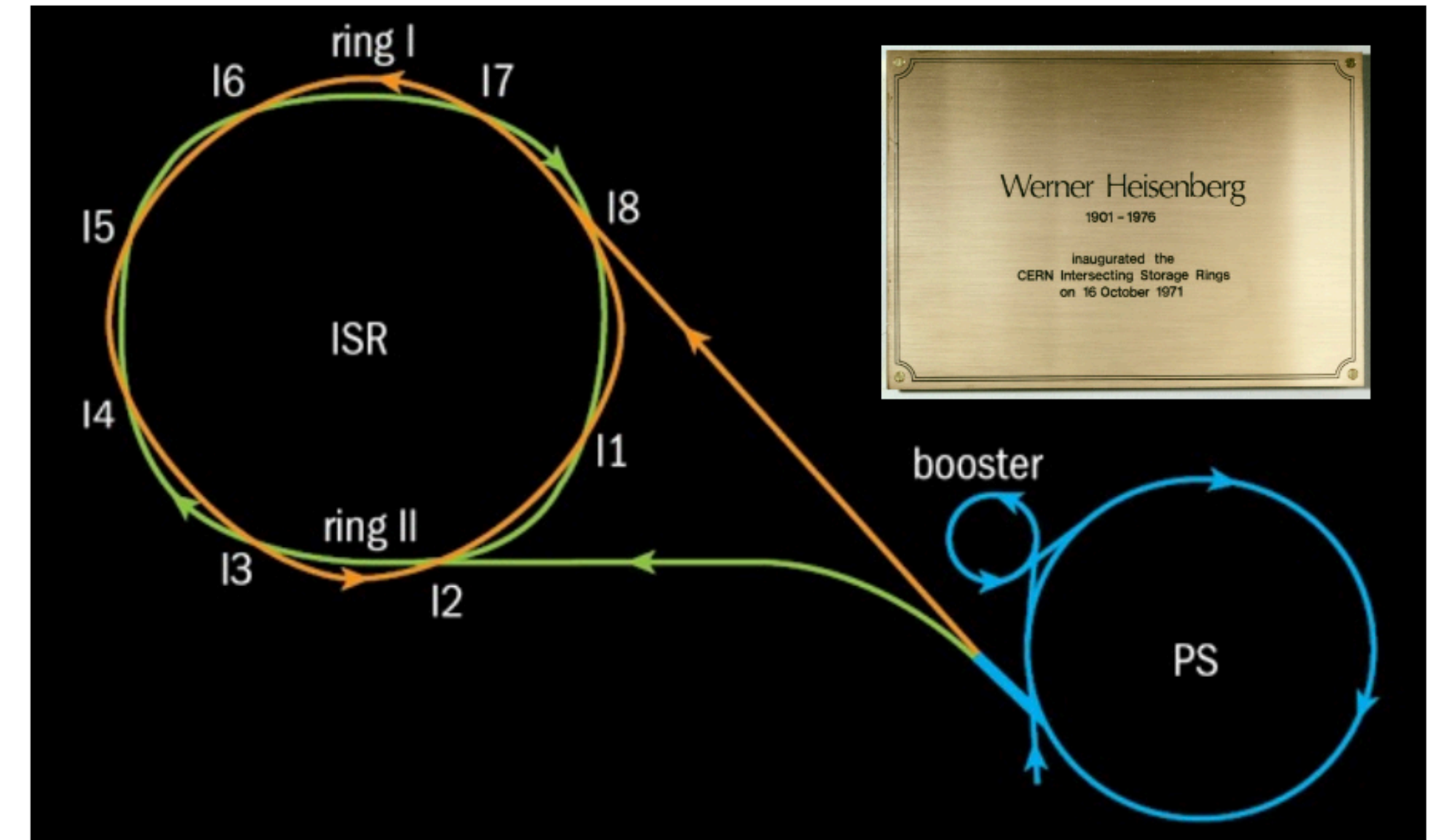
Definition : Investment in stocks, property, or other ventures in the hope of gain but with the risk of loss.

The mantra is:
"Broad but shallow sensitivity"



First ... a warning from history

- 1971: **Intersecting Storage Rings (ISR)** at CERN marked **birth of hadron colliders**
- $\sqrt{s} = 30 \text{ GeV}$: enough for bound states of ***c-* and *b*-quarks (at time undiscovered!!)**
- ...but theoretical bias suggested "new physics" to manifest in forward direction
Transverse direction not instrumented !!
- **ISR could have discovered J/ψ and Υ ...** but **did not** : instrumentation in wrong place.
CERN/Europe left as a bystander during November revolution in US.



2026: similar situation, with **theoretical bias for new physics to be prompt** preventing a discovery?

Disaster scenario: fundamental physics **breakthrough possible at LHC, but missed.**

Question for the audience

- Consider this list of basic ATLAS objects: e^+ , e^- , μ^+ , μ^- , light jets, b-jets, ETMiss

What fraction of 3-body invariant mass spectra involving any of these objects have *ever* been probed for resonances by ATLAS ?

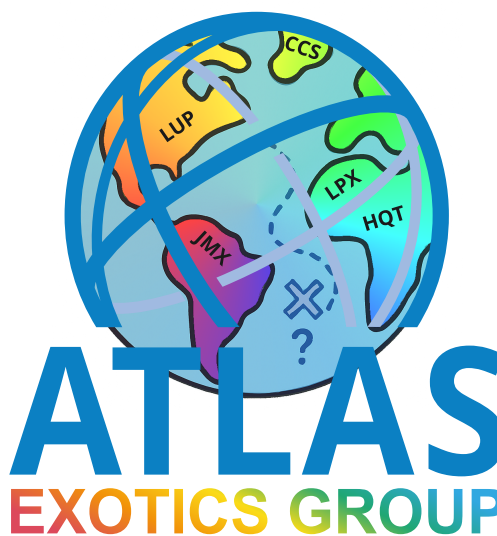
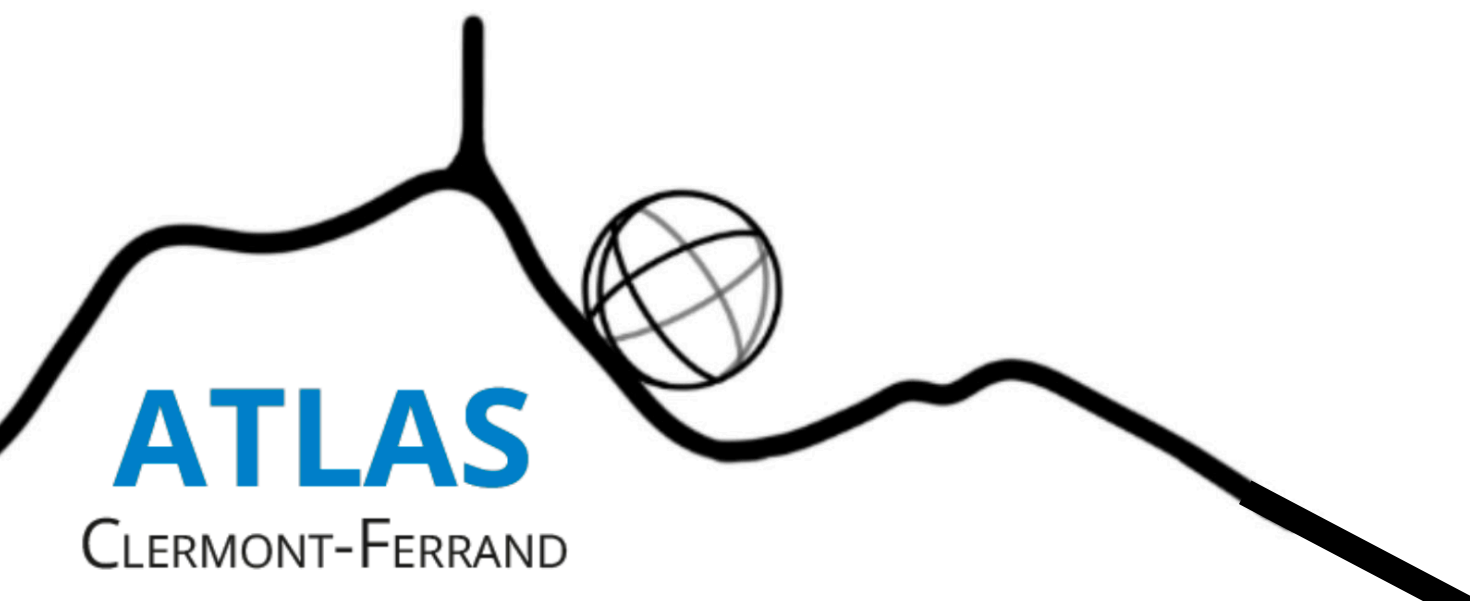
85%?

70%?

50%?

30%?

15%?



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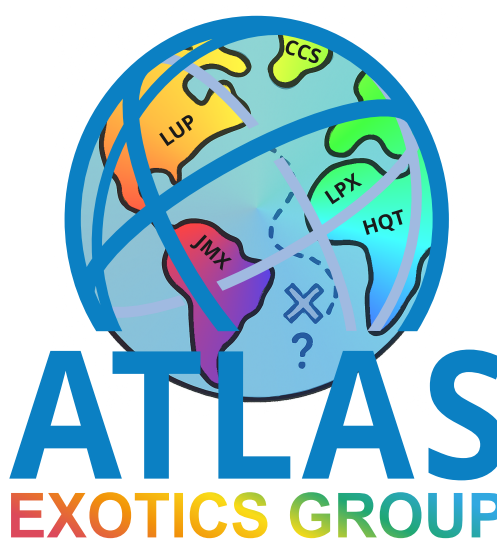
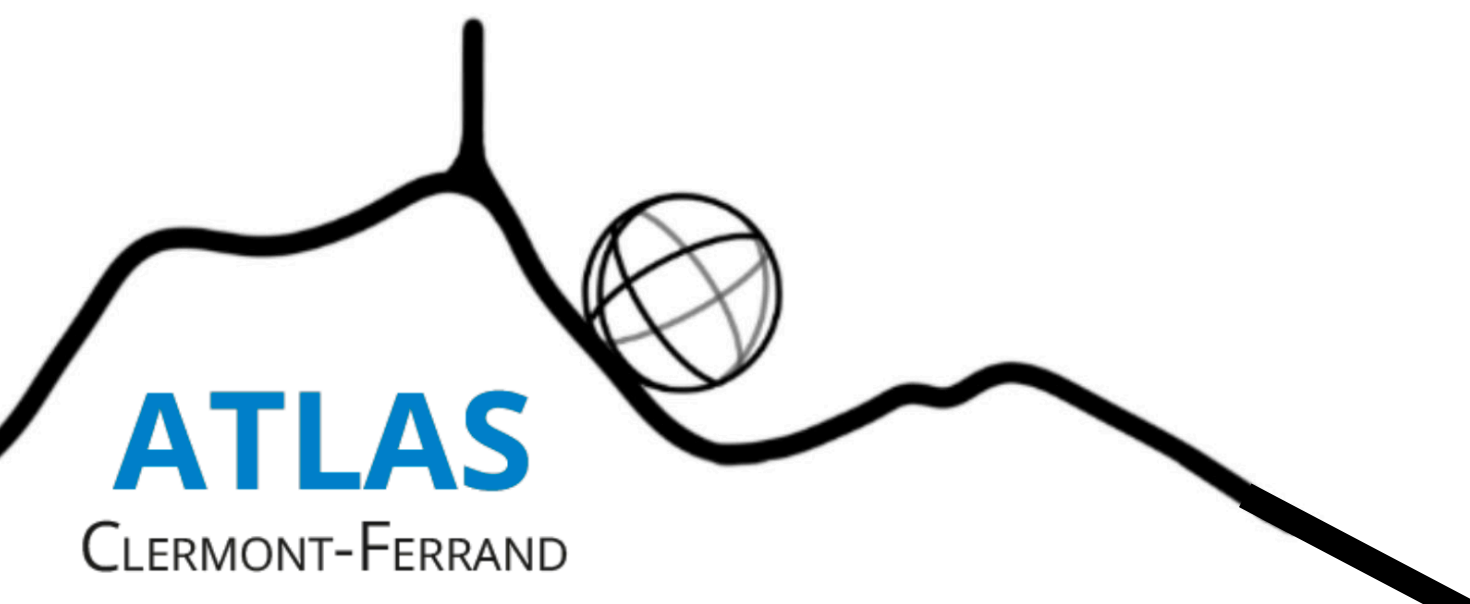
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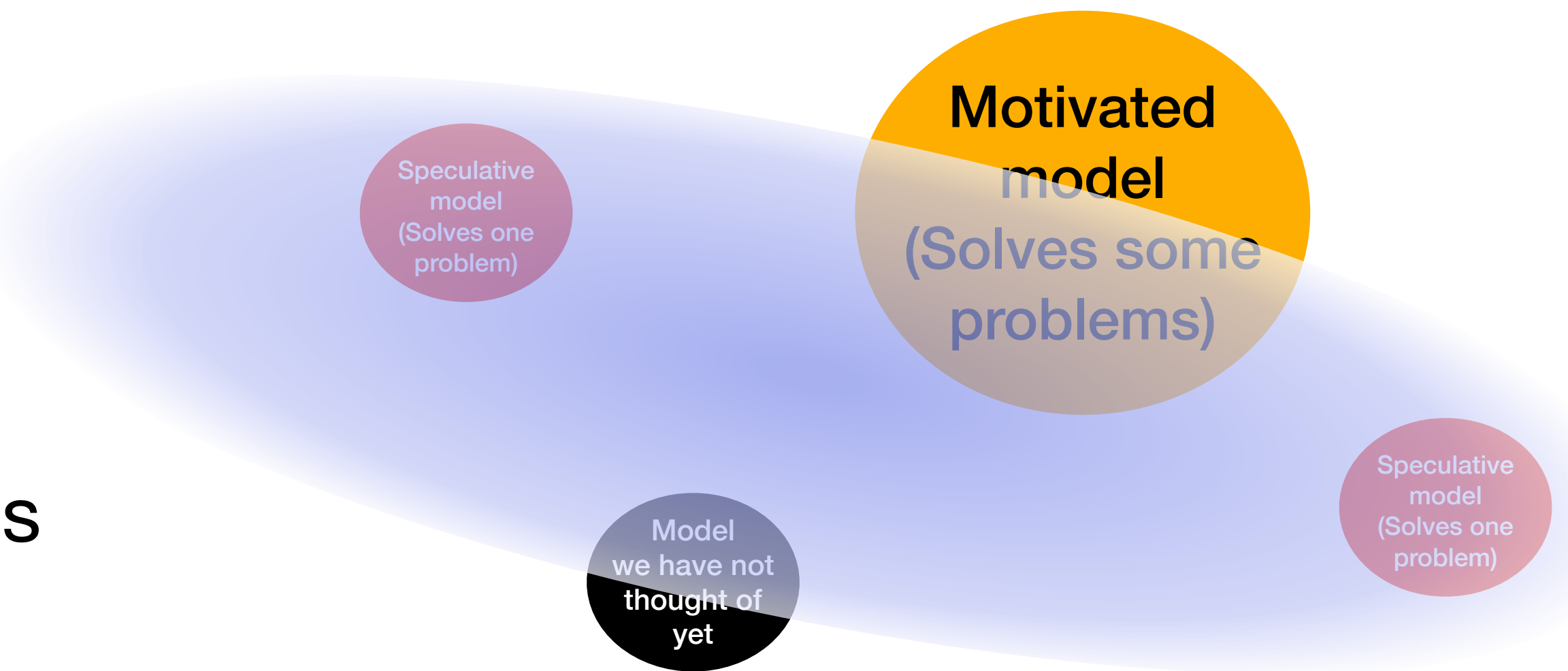
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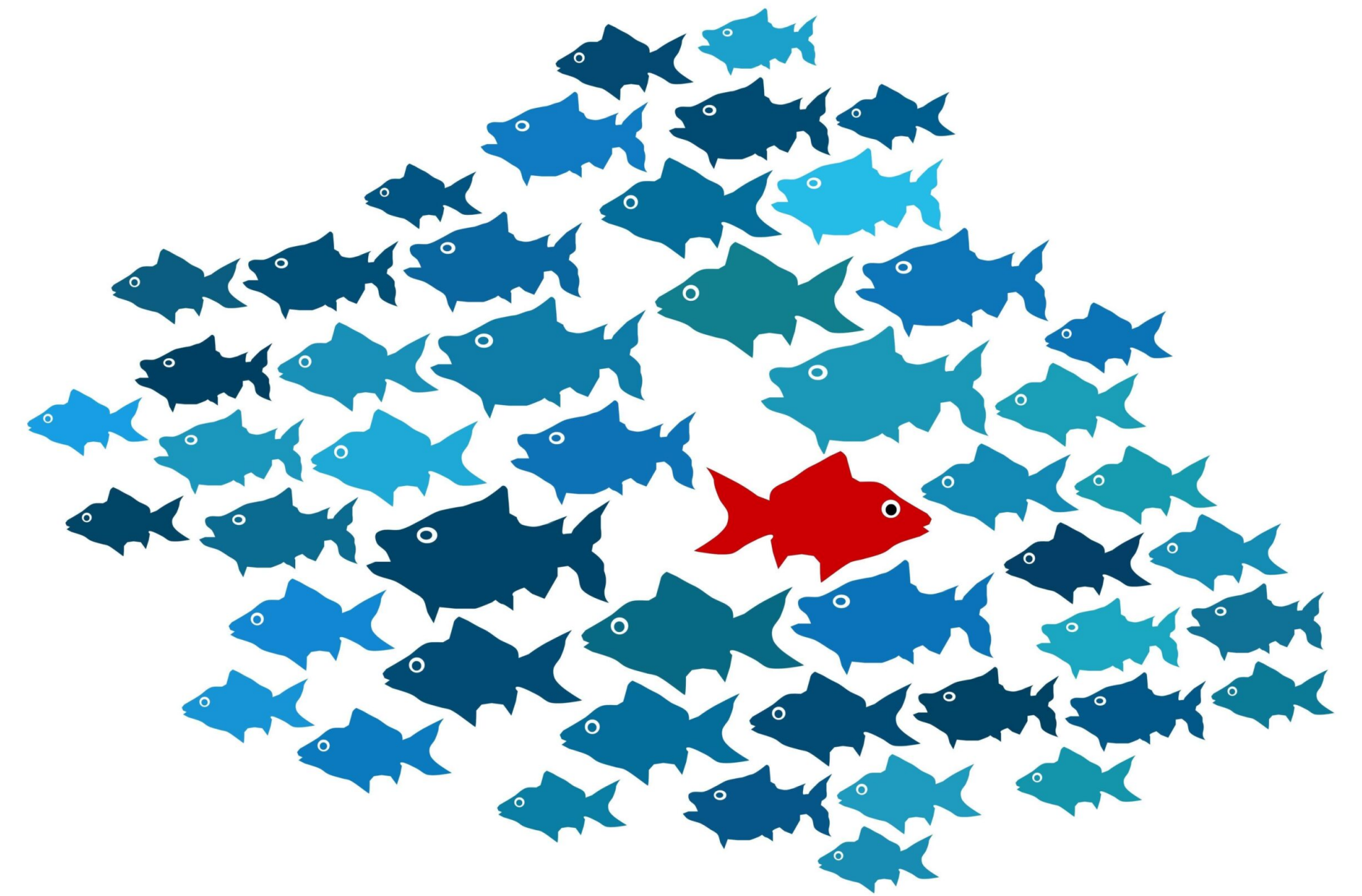
Shallow but broad coverage: the speculative programme

- Flagship models don't cover whole signature space
- Cannot accept to miss discovery by theory bias
- Hence: need to think outside the box. Can't afford to look only in well-motivated places!
- New paradigm, next techniques:
 - Dedicated searches for speculative models where discovery potential is proven
- General searches and anomaly detection: allow us to cover a very large part of parameter space. One paper instead of 10 : more efficient use of resources.



Anomaly detection

- Guidelines to show how we plan to use AD safely and effectively as part of the wider programme
- One AD analysis of a final state could save us 10 papers on each permutation
- But, just **like any other ATLAS search**:
 - Have an null and alternative hypothesis / p-values
 - Validated background estimation
 - Clear scope and physics message
 - Teach us something new about nature
 - Decide in advance what to do if we see an excess (also true in standard search program!)



CMS and ATLAS can work together on this, via the LHC BSM Working Group :)

Analysis recycling

- What if we could check if signals are already excluded on-the-fly, as they come out of the MC Production pipeline?

ATLAS Exotics AutoContur Table

Campaign	DSID	Shortname	Nominal XS [pb]	CLs Exl (Obs)	CLs Exl (Exp)	Rivet Plots	Dominant Pool	Dominant Analysis	Projected 95%CL OBS excl [pb]	Projected 95%CL EXP excl [pb]	Projected 95%CL EXP excl at HL-LHC [pb]
mc23_13p6TeV	604209	PhH7EG_NLO_LQ_S43_DYSP_lam32_3000_0p5_600SL14000	1	0.06	0.18	Plots	ATLAS_13_LMETJET	/ATLAS_2019_11750330:TYPE=BOTH/d851-x01-y01 Inspire HEPData	16 (mu=16) CLs_extrap	11 (mu=11) CLs_extrap	0.35 (mu=0.35) CLs_extrap
mc23_13p6TeV	604208	PhH7EG_NLO_LQ_S43_DYSP_lam32_3000_0p5_100SL600	1	0.79	0.91	Plots	ATLAS_13_LLJET	/ATLAS_2017_11627873/d02-x01-y01 Inspire HEPData	1.9 (mu=1.9) CLs_extrap	1.3 (mu=1.3) CLs_extrap	0.1 (mu=0.1) CLs_extrap
mc23_13p6TeV	604207	PhH7EG_NLO_LQ_S43_DYSP_lam32_2500_3p5_600SL14000	0.0025	0.00	0.00	Plots	ATLAS_13_LMETJET	/ATLAS_2019_11750330:TYPE=BOTH/d36-x01-y01 Inspire HEPData	0.25 (mu=1e+02) CLs_extrap	0.25 (mu=1e+02) CLs_extrap	0.25 (mu=1e+02) CLs_extrap
mc23_13p6TeV	604177	PhH7EG_NLO_LQ_S43_DYSP_lam32_1000_0p5_600SL14000	1	0.06	0.05	Plots	ATLAS_13_LMETJET	/ATLAS_2019_11750330:TYPE=BOTH/d36-x01-y01 Inspire HEPData	35 (mu=35) CLs_extrap	36 (mu=36) CLs_extrap	2.2 (mu=2.2) CLs_extrap
mc23_13p6TeV	604168	PhH7EG_NLO_LQ_S43_DYSP_lam31_3500_0p5_100SL600	1	0.98	1.00	Plots	ATLAS_13_LLJET	/ATLAS_2017_11627873/d02-x01-y01 Inspire HEPData	0.8 (mu=0.8) CLs_extrap	0.65 (mu=0.65) CLs_extrap	0.1 (mu=0.1) CLs_extrap
mc23_13p6TeV	604161	PhH7EG_NLO_LQ_S43_DYSP_lam31_3000_0p5_600SL14000	4.7e-06	0.00	0.00	Plots	ATLAS_13_LMETJET	/ATLAS_2019_11750330:TYPE=BOTH/d12-x01-y01 Inspire HEPData	0.00047 (mu=1e+02) CLs_extrap	0.00047 (mu=1e+02) CLs_extrap	0.00047 (mu=1e+02) CLs_extrap
mc23_13p6TeV	604160	PhH7EG_NLO_LQ_S43_DYSP_lam31_3000_0p5_100SL600	1	0.93	0.98	Plots	ATLAS_13_LLJET	/ATLAS_2017_11627873/d02-x01-y01 Inspire HEPData	1.2 (mu=1.2) CLs_extrap	0.77 (mu=0.77) CLs_extrap	0.1 (mu=0.1) CLs_extrap
mc23_13p6TeV	604124	PhH7EG_NLO_LQ_S43_DYSP_lam22_5000_2p5_100SL600	1	0.76	0.89	Plots	ATLAS_13_LLJET	/ATLAS_2017_11627873/d02-x01-y01 Inspire HEPData	1.9 (mu=1.9) CLs_extrap	1.4 (mu=1.4) CLs_extrap	0.1 (mu=0.1) CLs_extrap
mc23_13p6TeV	604117	PhH7EG_NLO_LQ_S43_DYSP_lam22_3000_3p5_600SL14000	1	0.12	0.24	Plots	ATLAS_13_JETS	/ATLAS_2018_11634970/d01-x01-y01,/ATLAS_2018_11634970/d02-x01-y01,/ATLAS_2018_11634970/d03-x01-y01,/ATLAS_2018_11634970/d04-x01-y01,/ATLAS_2018_11634970/d05-x01-y01,/ATLAS_2018_11634970/d06-x01-y01 Inspire HEPData	13 (mu=13) CLs_extrap	7.2 (mu=7.2) CLs_extrap	0.23 (mu=0.23) CLs_extrap

Avoid work where a signal is already covered by measurements

TODO: preserve our searches such that they can be included in this system



Example of a recent 'speculative' result: multi-lepton AD

Latest stage of general searches within ATLAS, focusing on ≥ 4 light leptons.

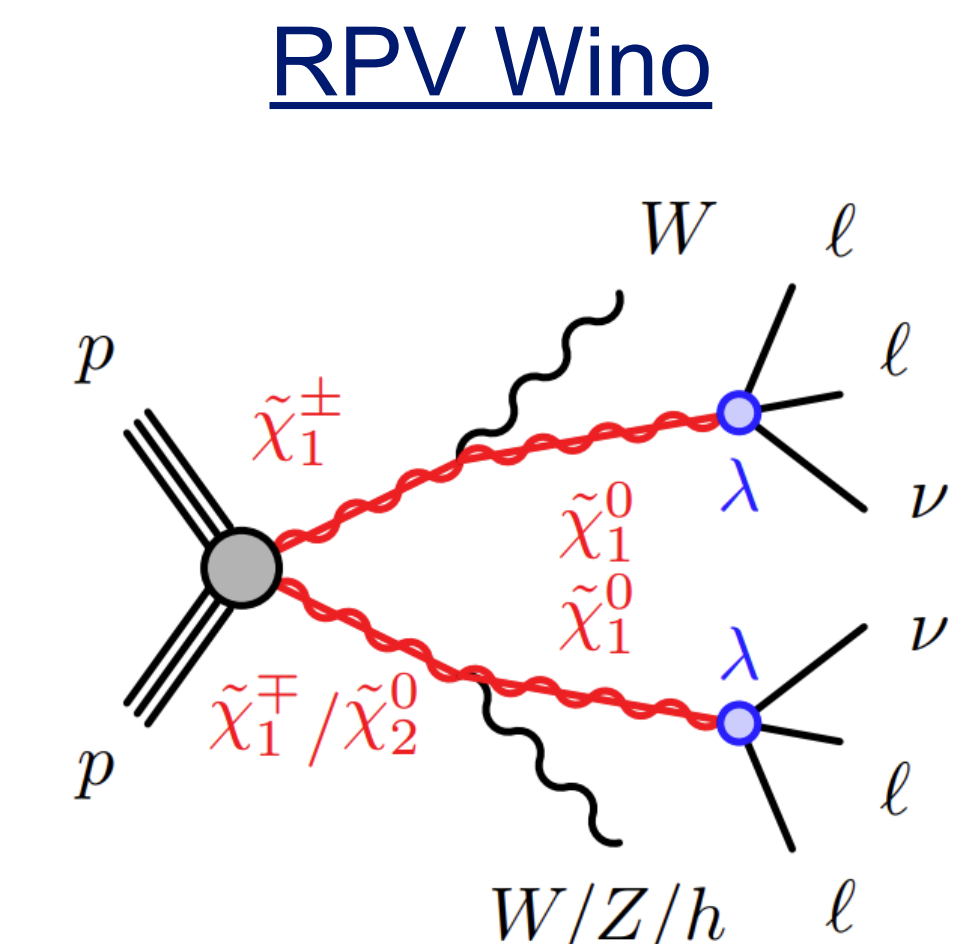
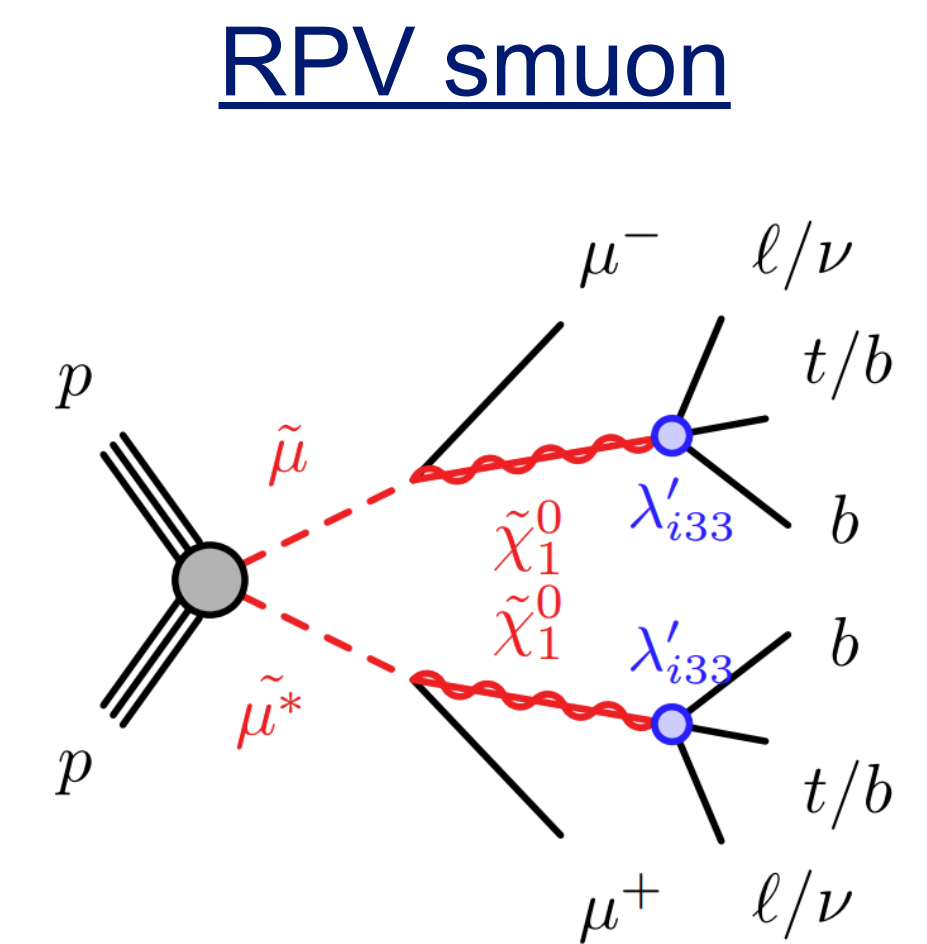
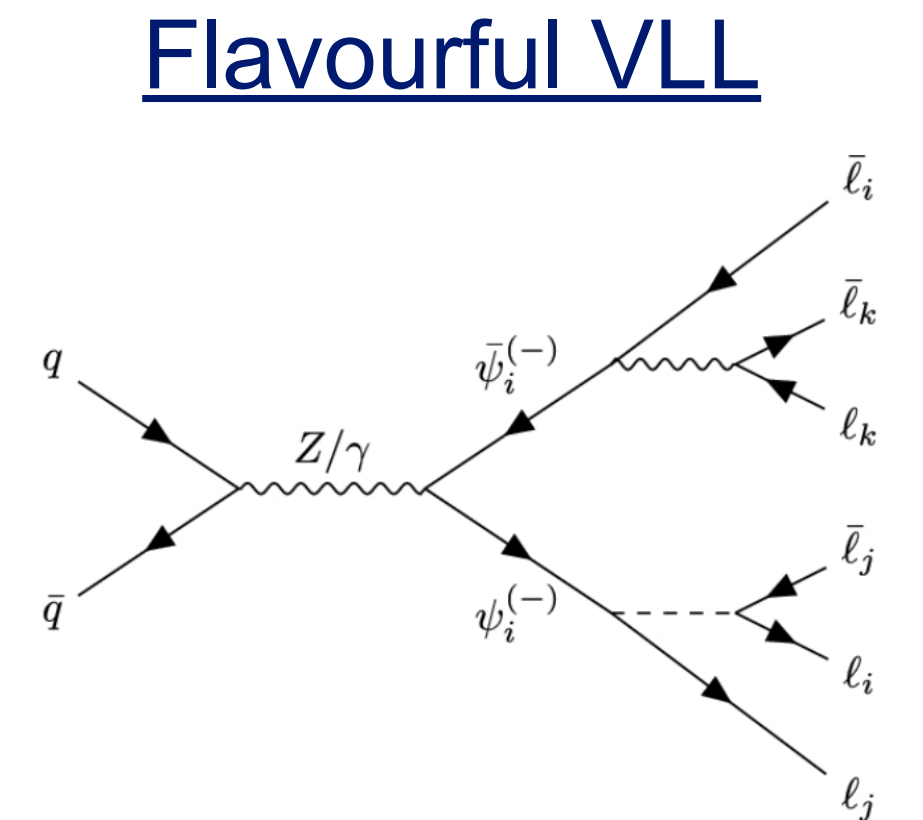
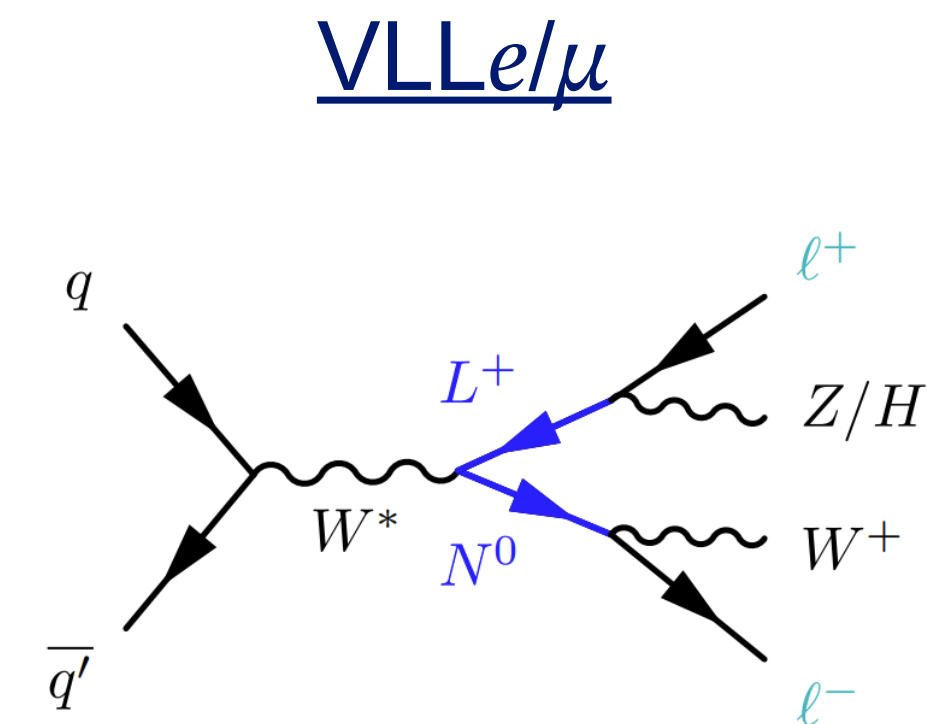
Anomaly detection (AD) is used to improve the sensitivity in a model agnostic way.

First ATLAS search to exploit AD in high lepton multiplicity.

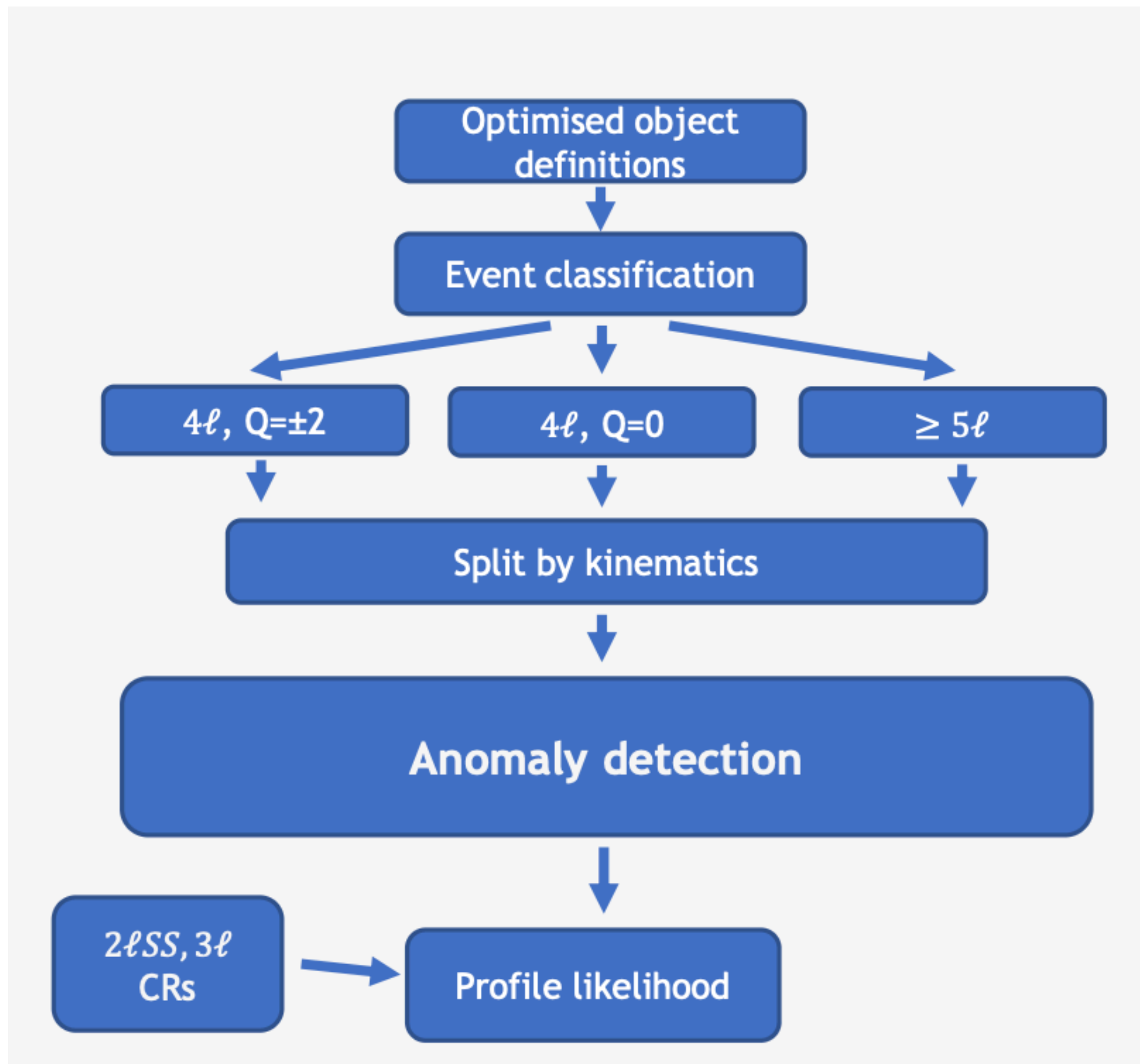
Exploit both charge and flavour to probe interesting regions of phase space that have until recently been unexplored. (e.g. $e^+e^+\mu^-\mu^-$, $\mu^+\mu^-e^+\mu^-$)

Use several BSM models to compare the sensitivity with dedicated analyses, along with an ATLAS first result for a VLL model decaying through a flavourful scalar S.

Benchmark models

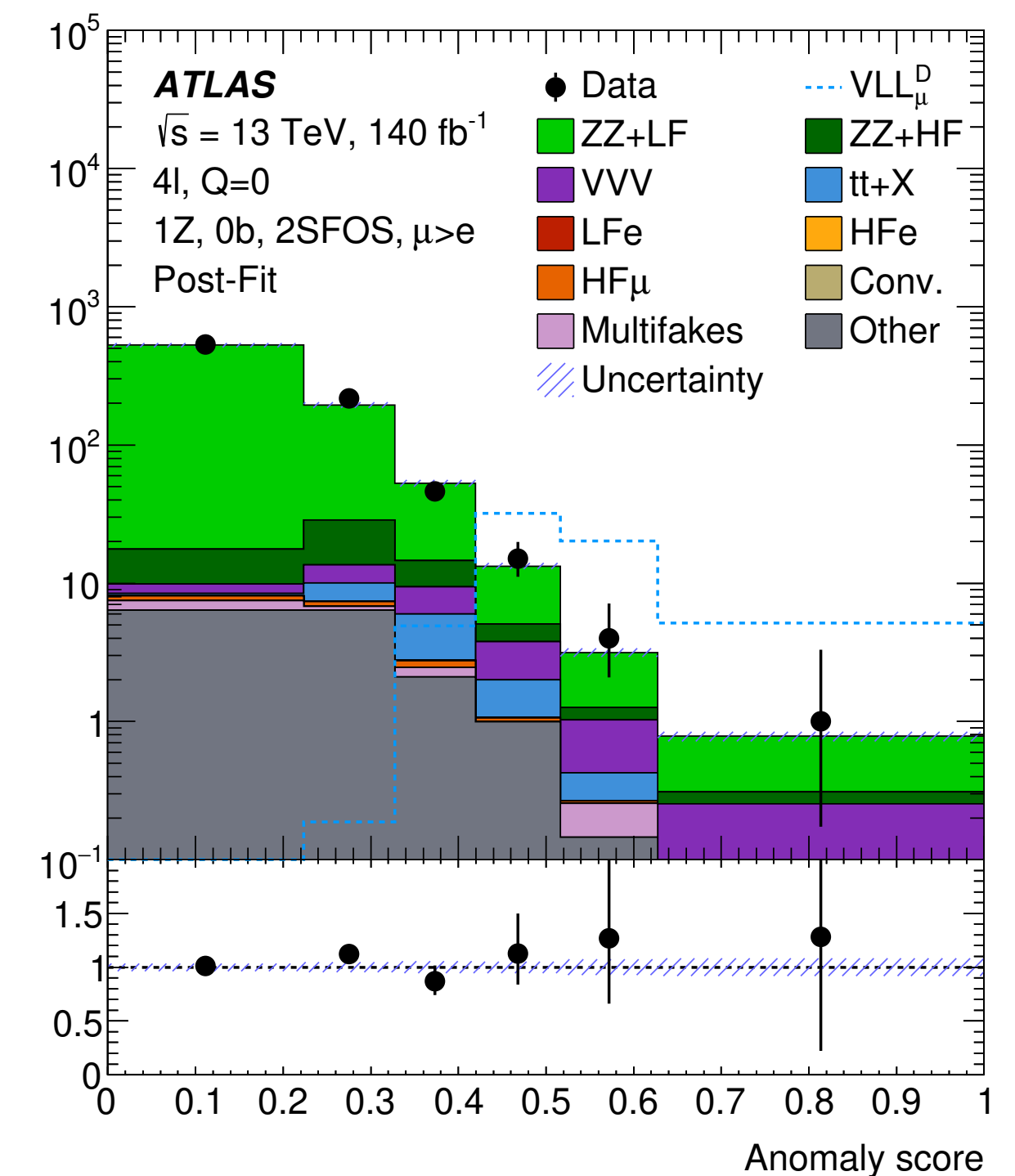
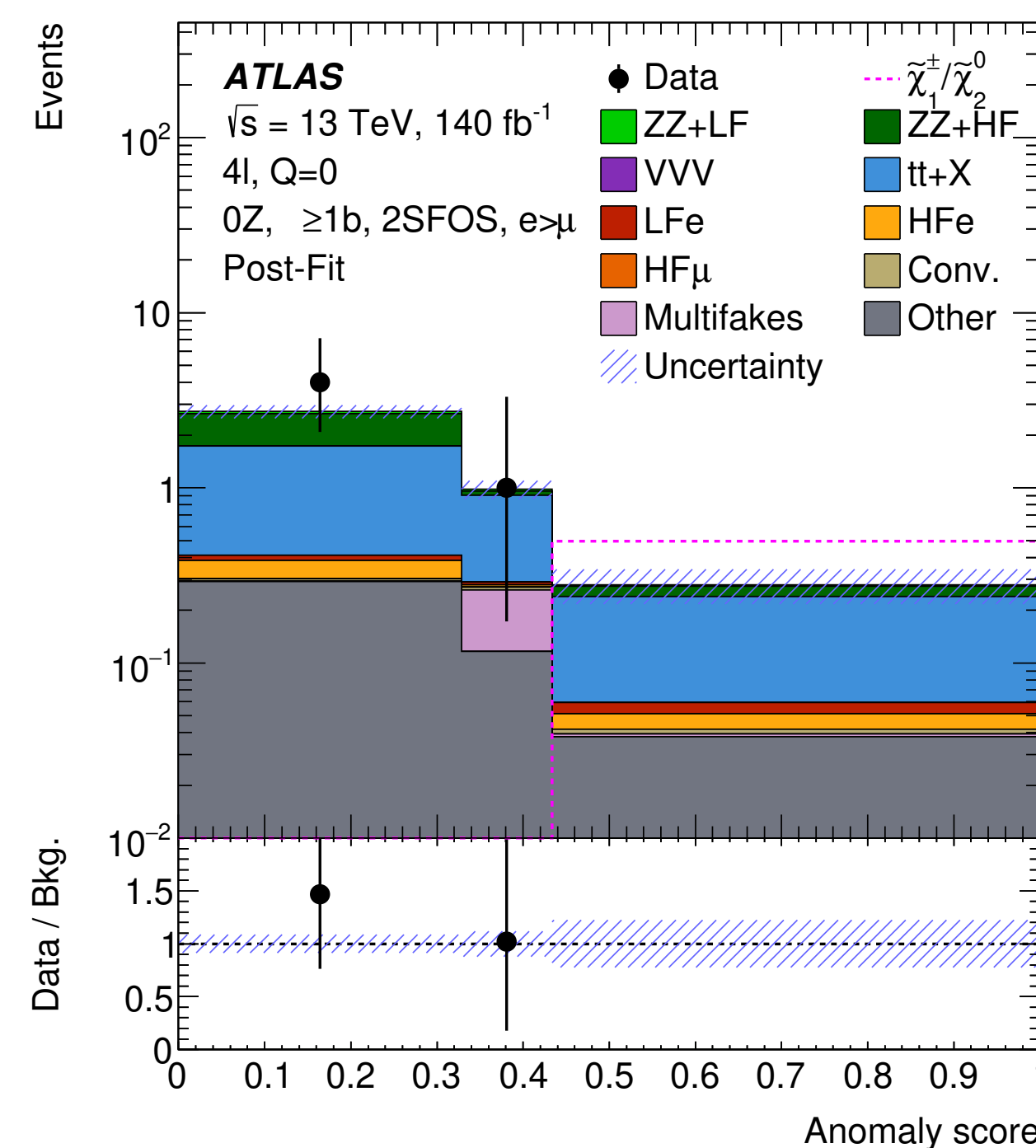


Example of a recent 'speculative' result: multi-lepton AD



AD technique: normalising flows

- Train on MC to learn p_{bkg} and build event-level anomaly score.
- Further include background modelling such as data-driven charge mis-ID, VV Njet reweighting...

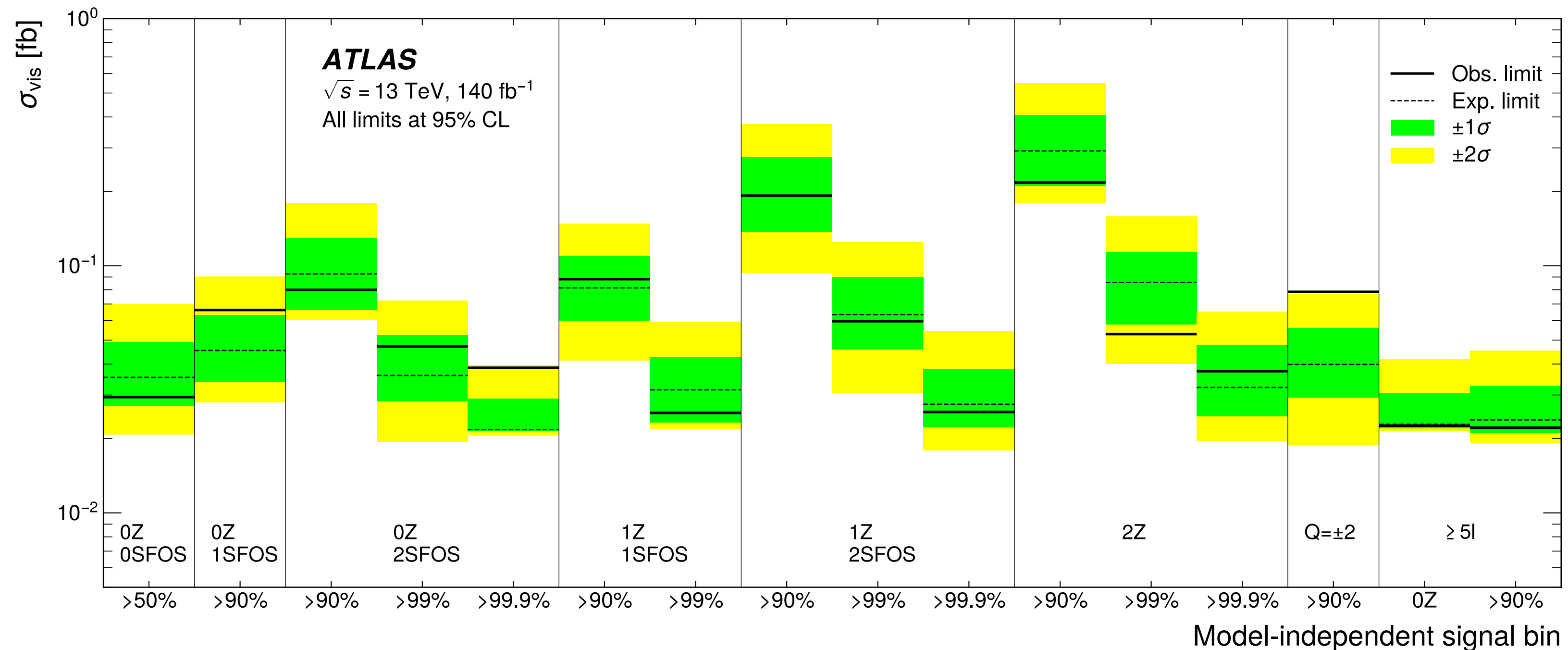


Example of a recent 'speculative' result: multi-lepton AD

Model-independent

- Small number of regions split by number of Z's+SFOS
- Define signal bins at background rejections of 90%, 99%, 99.9%
- Fit individually with CRs

No significant excess seen across the discovery regions. Largest excess of $\sim 2\sigma$ in $Q = \pm 2$ and 0Z 2SFOS highest score bins. Model-independent limits set on σ_{vis} :

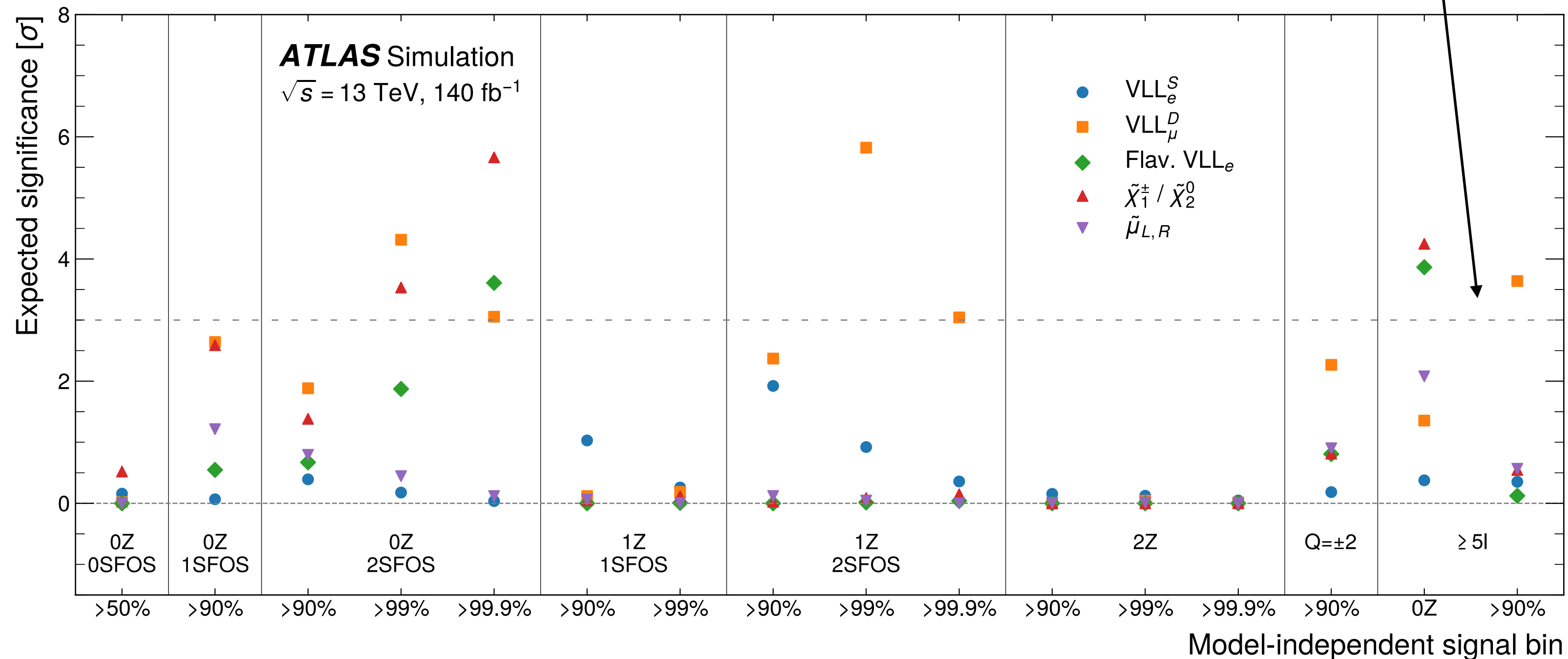


Example of a recent 'speculative' result: multi-lepton AD

Model-independent

- Small number of regions split by number of Z's+SFOS
- Define signal bins at background rejections of 90%, 99%, 99.9%
- Fit individually with CRs

But we COULD have seen some >3 sigma excesses in some models if nature had realised some of the benchmarks

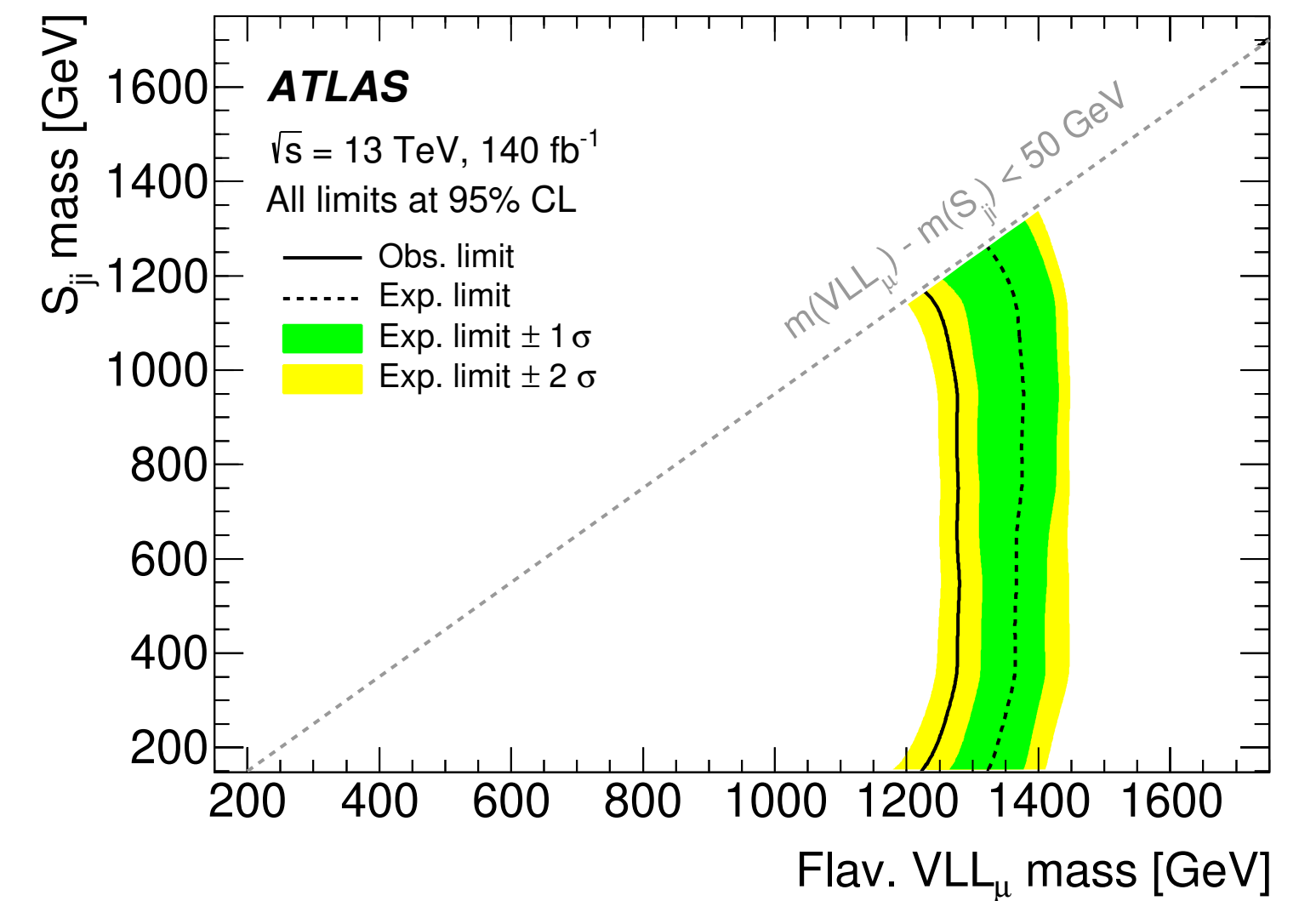
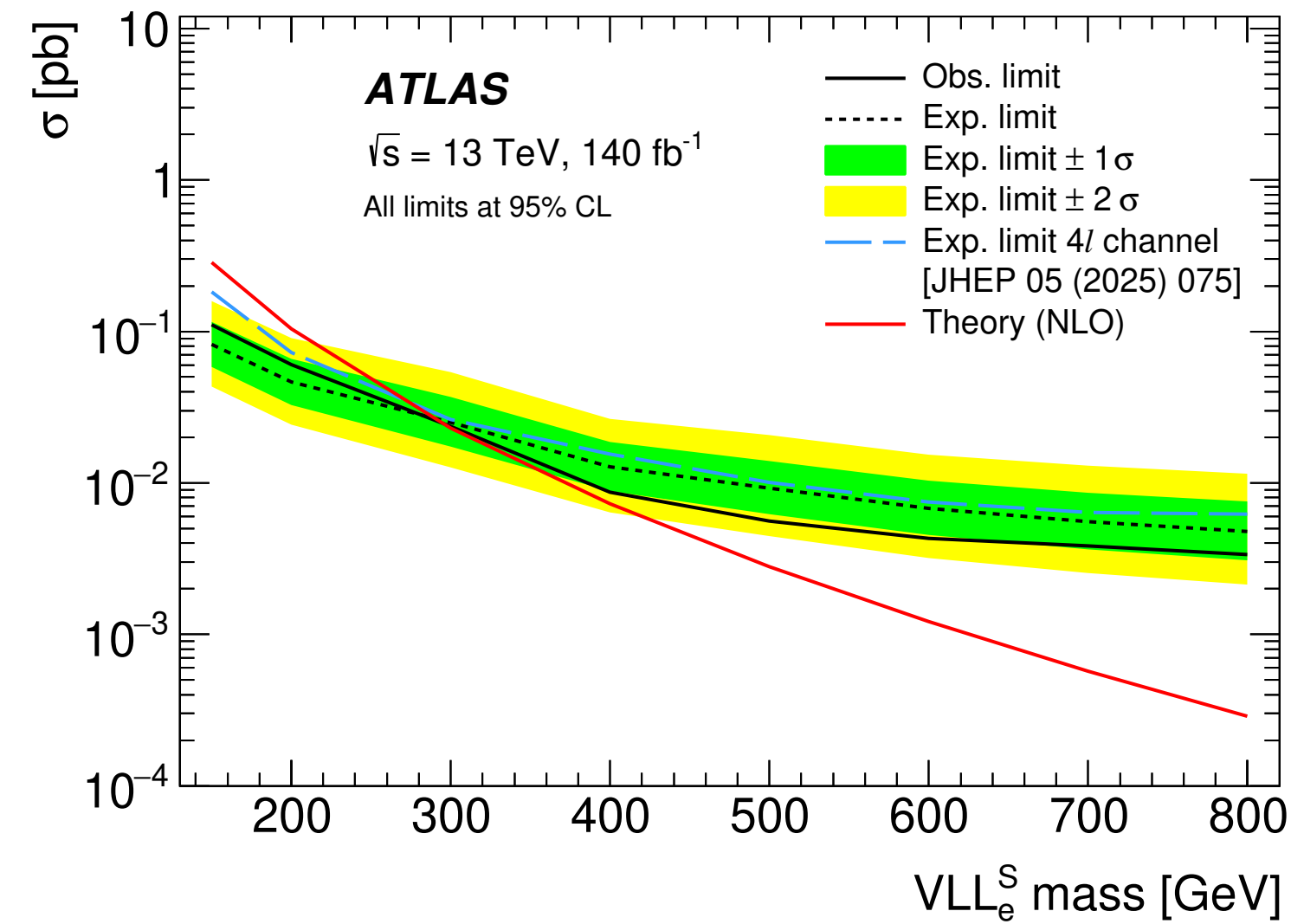
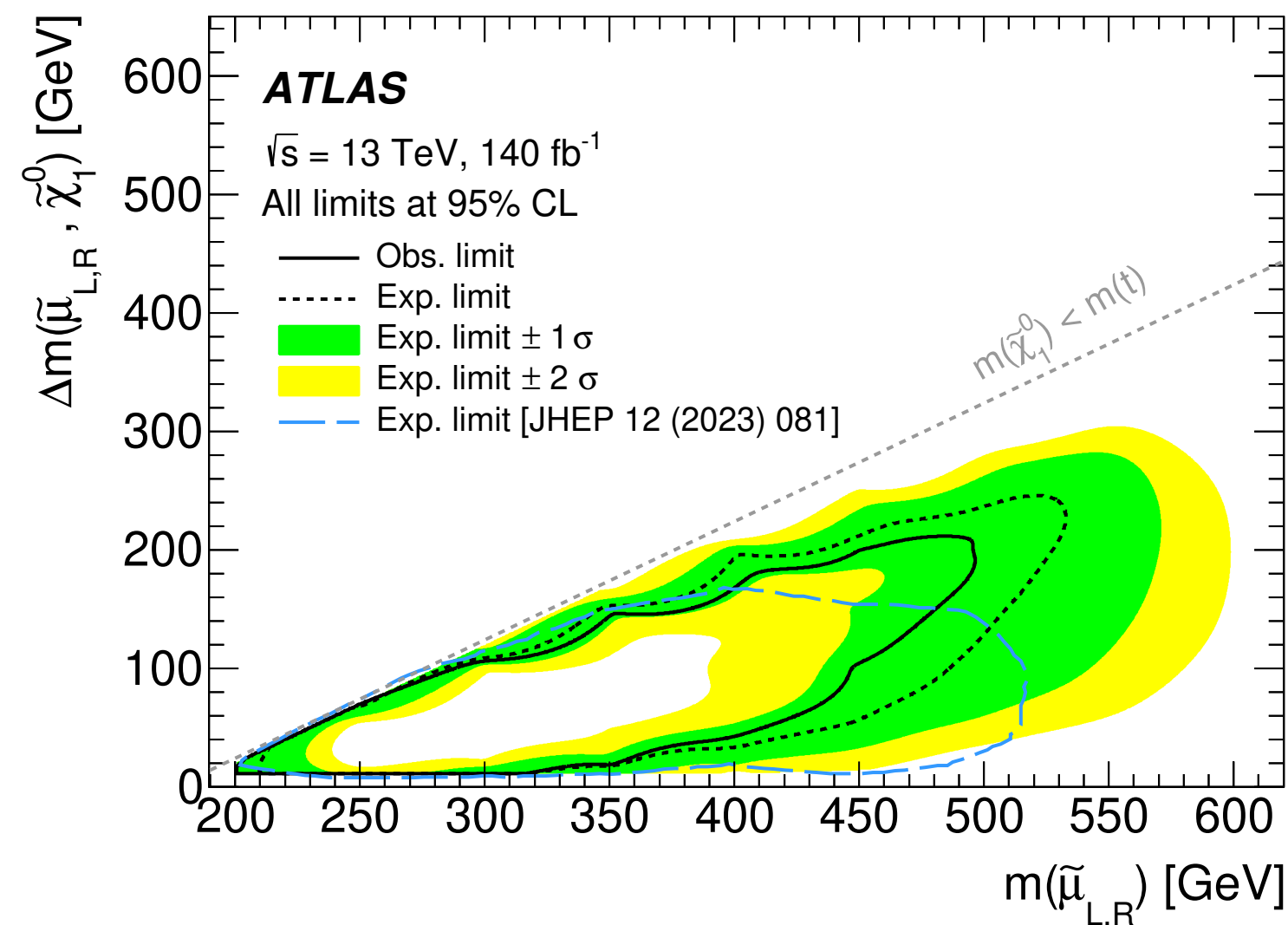


Example of a recent 'speculative' result: multi-lepton AD

Model-dependent

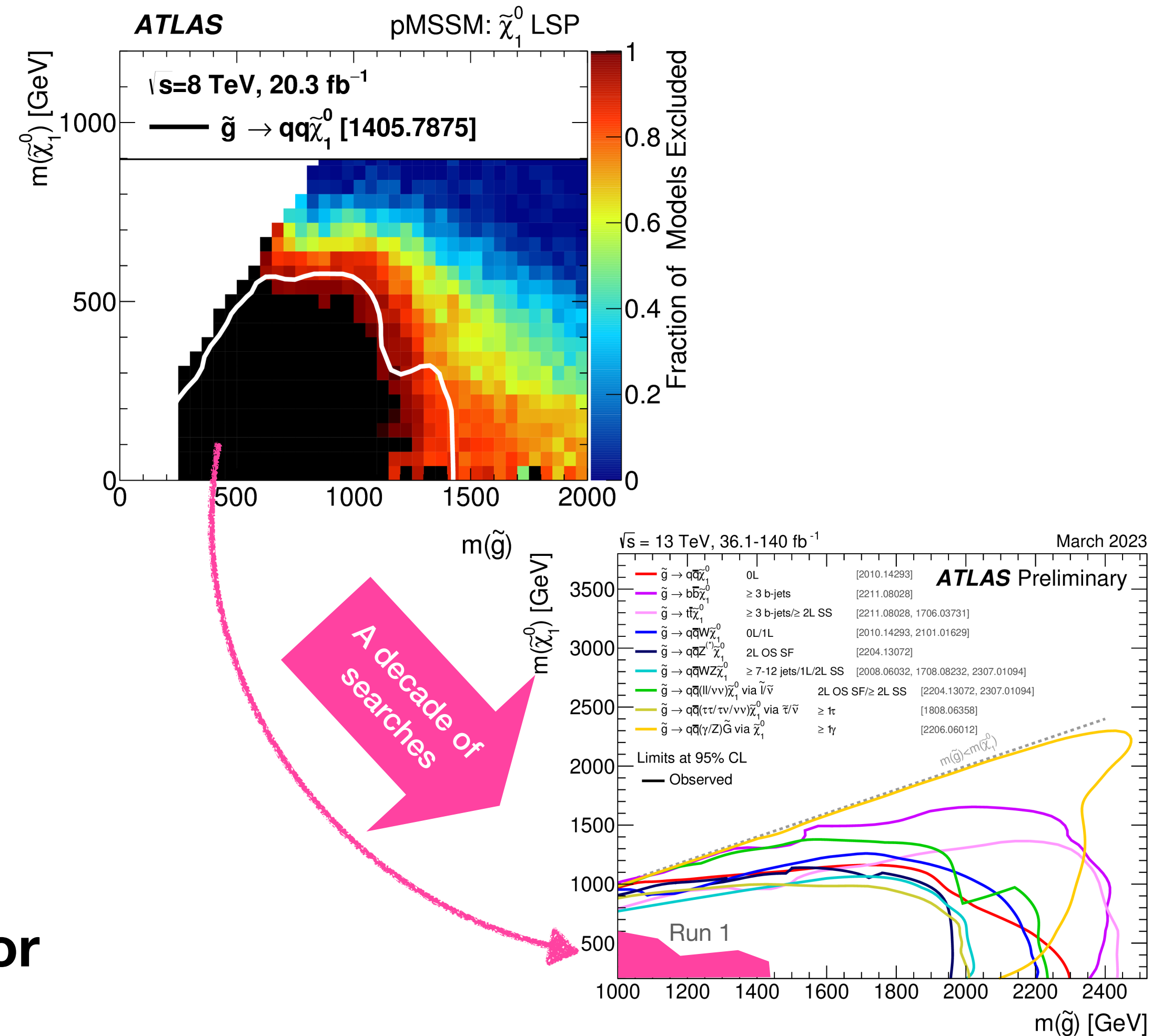
- Further split by flavour and presence of b-jets.
- Use the entire anomaly score distributions.
- Fit all simultaneously with CRs.

Model-dependent benchmarks show strong sensitivity. Flavourful VLLe (μ) model excluded up to 1.35 (1.3) TeV.



To finish: what have we achieved with Run 1+2 ?

- After 13 years of LHC operation... **we have not discovered any BSM particles or processes.**
- ...but **lack of discovery \neq null result.**
- Before LHC turned on, theory community convinced SUSY was "just around the corner".
 - Today, SUSY at EW scale **pushed back** to more **remote corners** of parameter space.
 - Still a great candidate for BSM, but not in its most obvious realisations (compressed spectra?)
- **The LHC has already revolutionised our best guess for the underlying nature of fundamental physics.**
- Similarly, simple DM models are also largely excluded at TeV scale. These are **big achievements!**



Working together across the ring



Louie Dartmoor Corpe (Clermont-Ferrand)

What to expect from us for Run 3

- I am not here to make promises...
- But there are some things to look out for from ATLAS Exotics in Run 3
 - More LLP analyses exploiting improved **Large Radius Tracking** (secondary vertexing) both at **trigger and offline**. (No surprise our first Run 3 searches were for unusual signatures!)
 - More **anomaly detection**, as we hone our techniques and presentation of results (please bear with us while we try to get it right)
 - **100% HEPData coverage**, with improve focus on **quality re-interpretation materials** (eg Surrogate Models and likelihoods)
 - Some cool **new techniques / alternative workflows** (event picking, pileup in physics, trigger-level analysis, forward proton detector searches), and **maybe some c-tagging searches**
 - The **usual big ticket (flagship) searches**, scheduled in time to benefit from gains in data, and **regular publication of summary plots**.
 - ... some surprises :)
- And we plan to **wrap up our Run 2 campaign** by the end of the year !

Final thought :

Surprises can still happen !

Surprises can still happen

<https://arxiv.org/pdf/2503.22382>

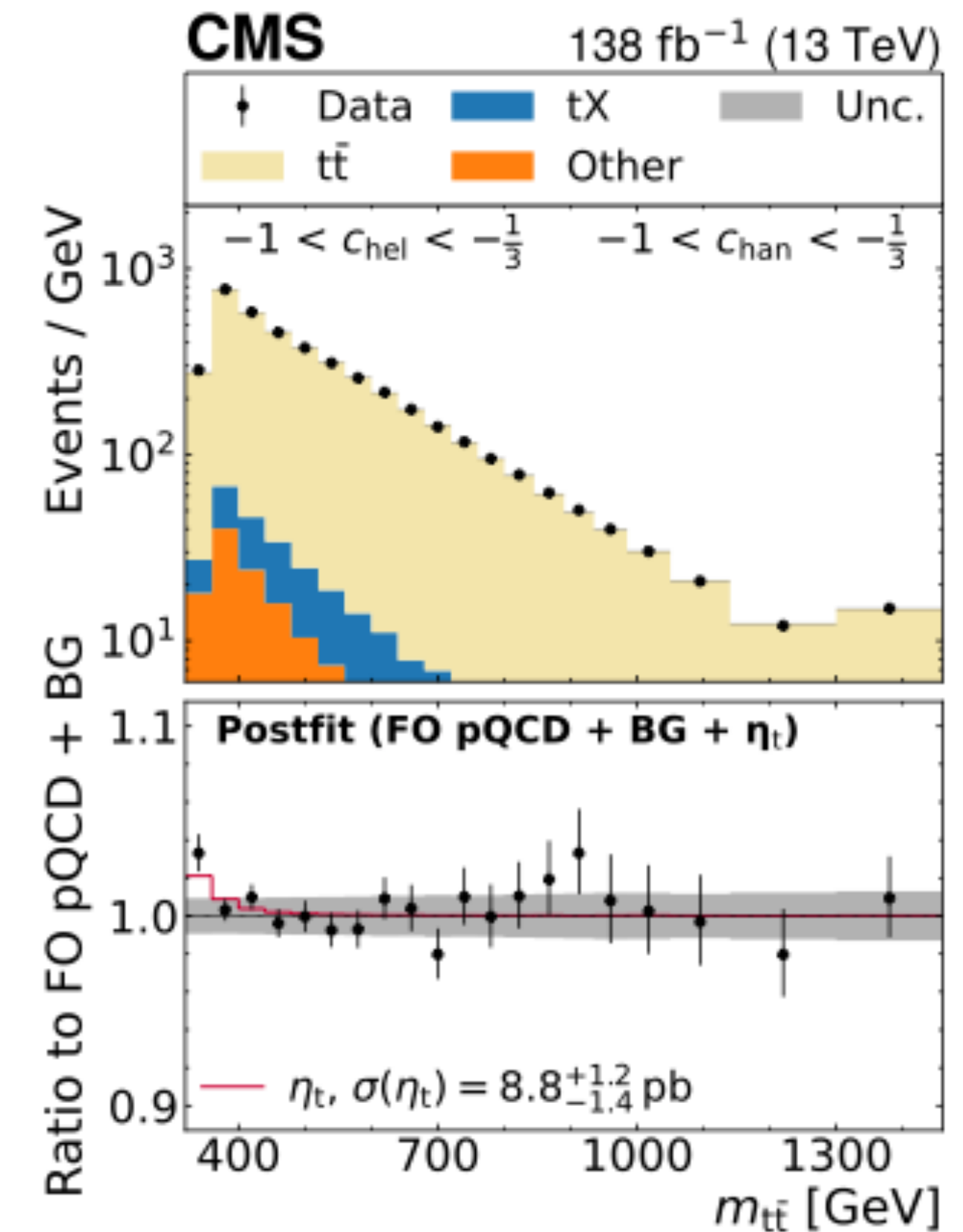
Observation of a pseudoscalar excess at the top quark pair production threshold

The CMS Collaboration*

<https://cds.cern.ch/record/2937636>

Observation of a cross-section enhancement near the $t\bar{t}$ production threshold in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector

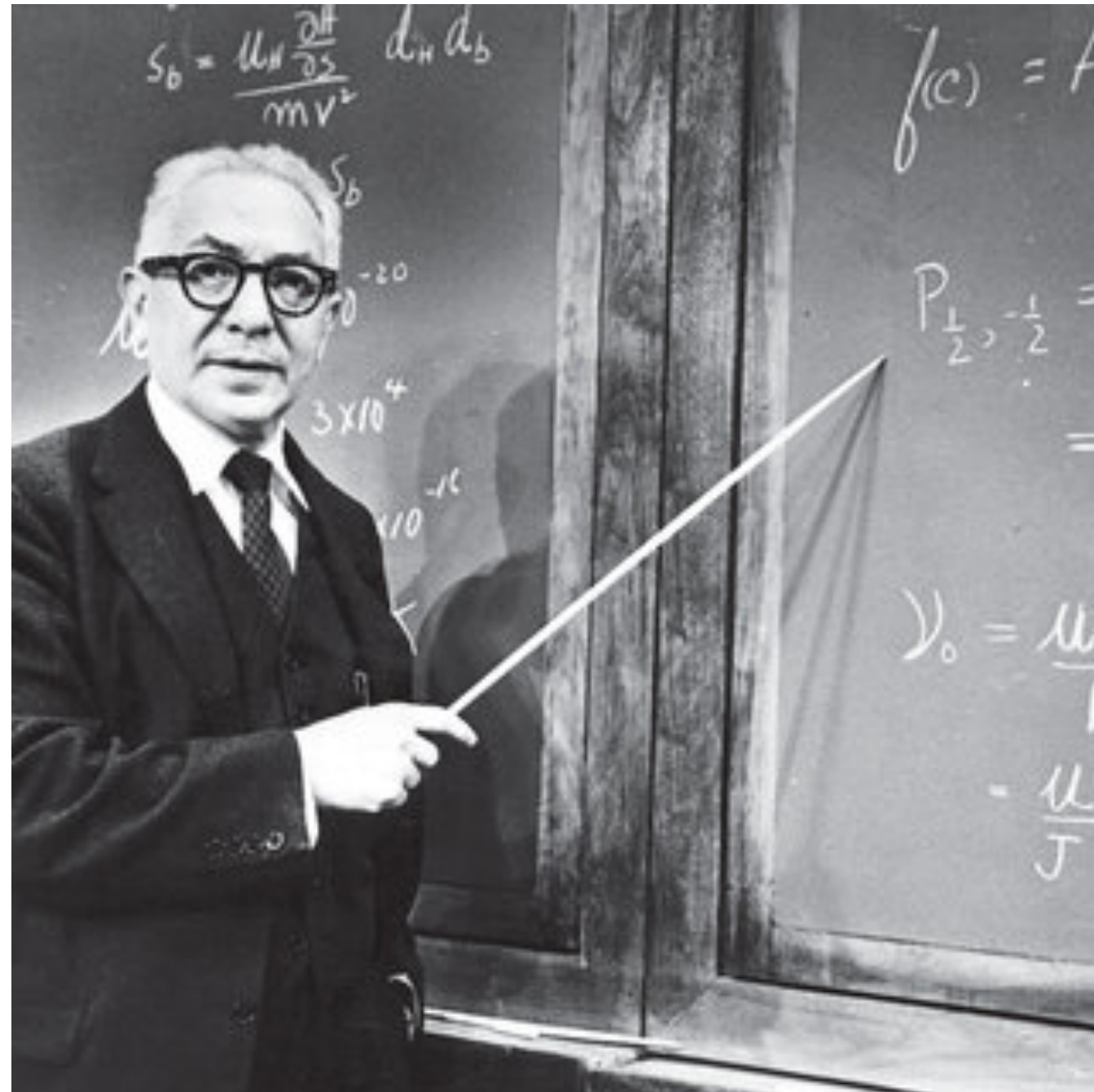
The ATLAS Collaboration



A deviation from the background prediction, modeled only using pQCD, is observed. It is located close to the $t\bar{t}$ production threshold, similar to the moderate deviation observed in a previous CMS search based on a data sample corresponding to an integrated luminosity of 35.9 fb^{-1} [24]. This deviation significantly favors the pseudoscalar signal hypothesis over the scalar hypothesis. It is compatible with the production of a $^1S_0^{[1]}$ $t\bar{t}$ bound state η_t , as predicted by a simplified model of nonrelativistic QCD. The cross section of this contribution is found to be $\sigma(\eta_t) = 7.1 \text{ pb}$, with an uncertainty of 11%. The excess has a significance of above five standard deviations. Further investigations by both the experimental and theoretical communities are necessary to elucidate the nature of this excess.

Could have been a BSM resonance ... dress rehearsal for unexpected discovery ?

Surprises can still happen

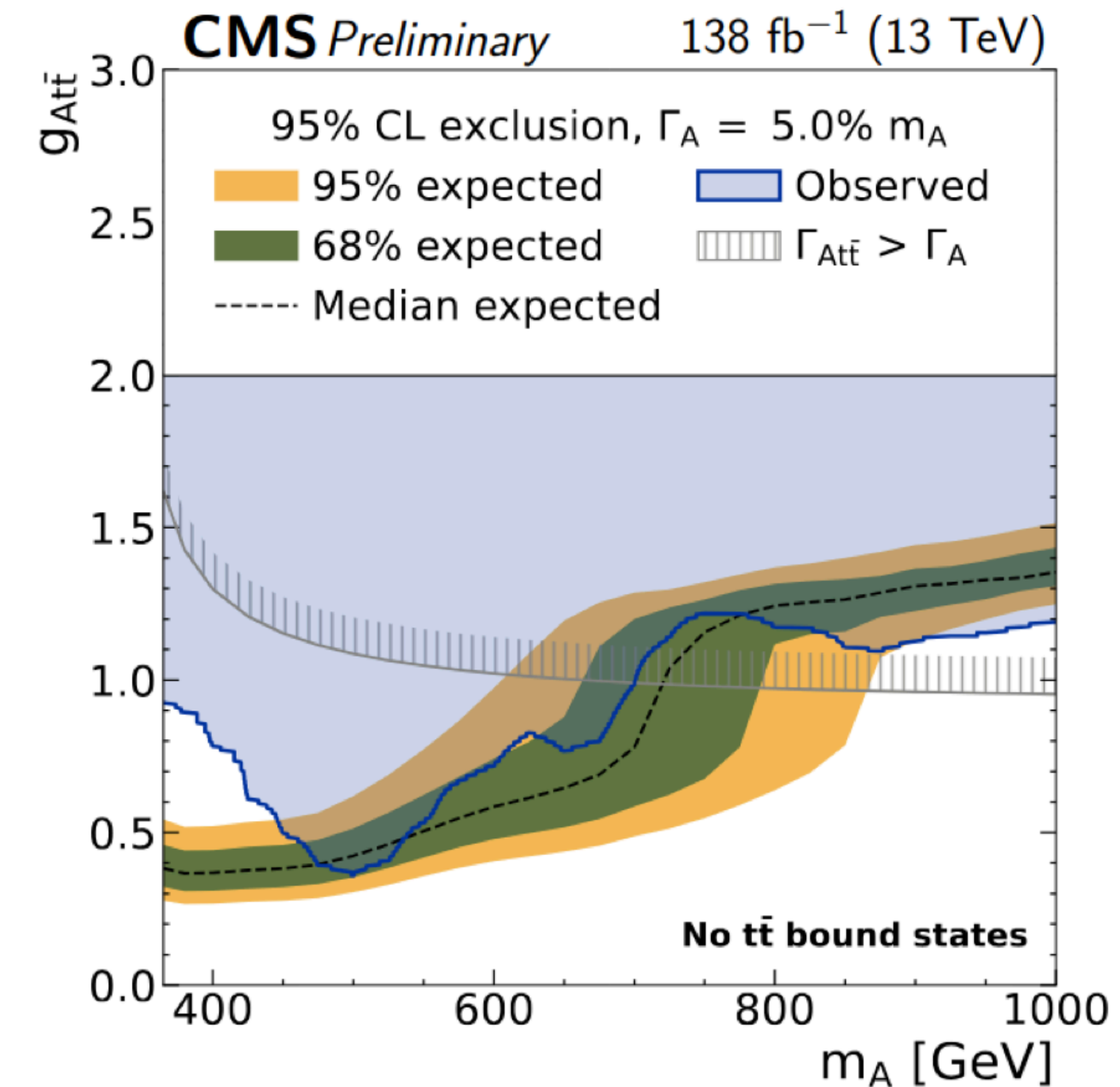
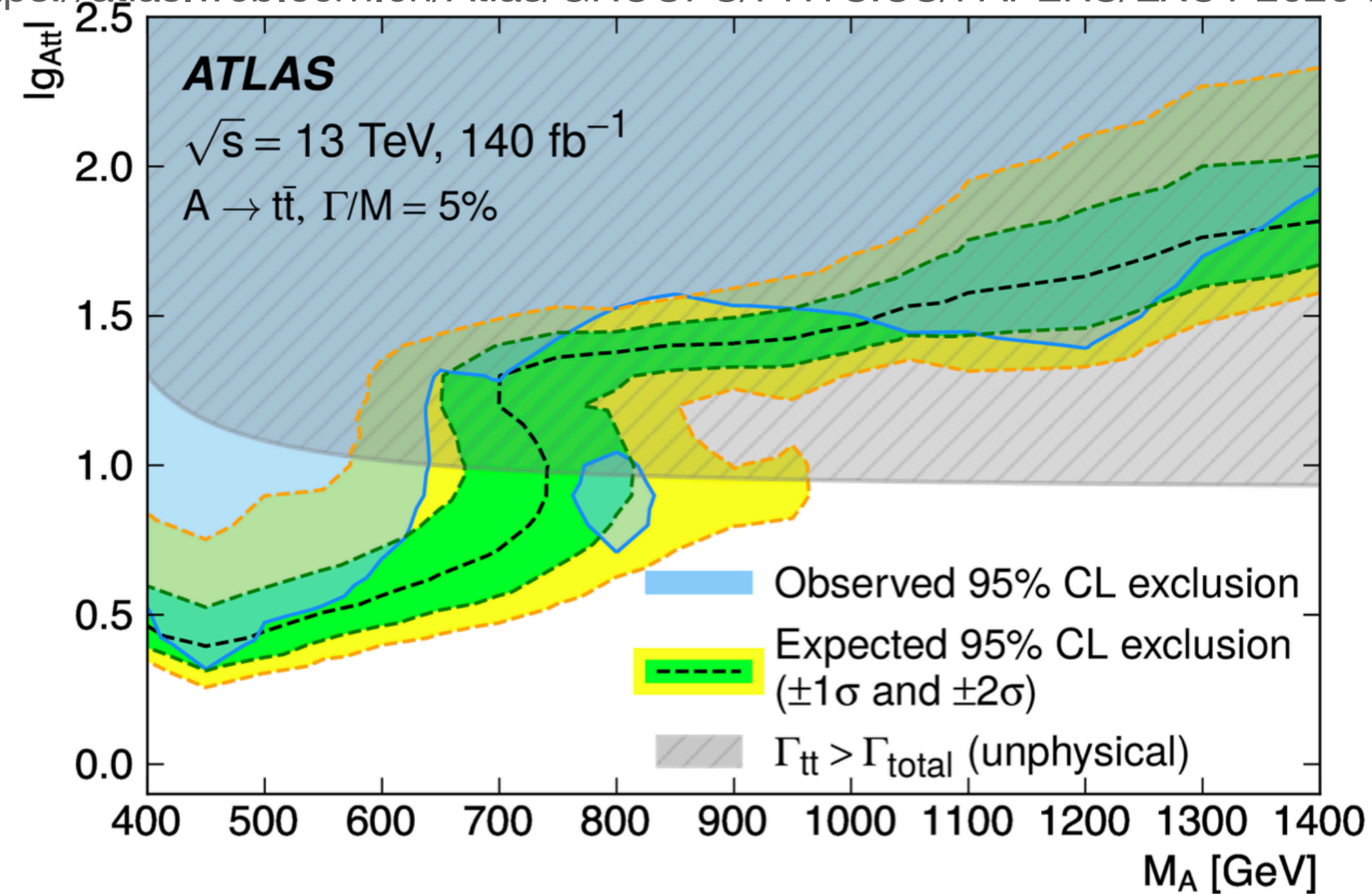


“
Who ordered that?
”

I. Rabi on the discovery of the muon.... Also applies to "toponium"

But a few months earlier...

<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2020-25>



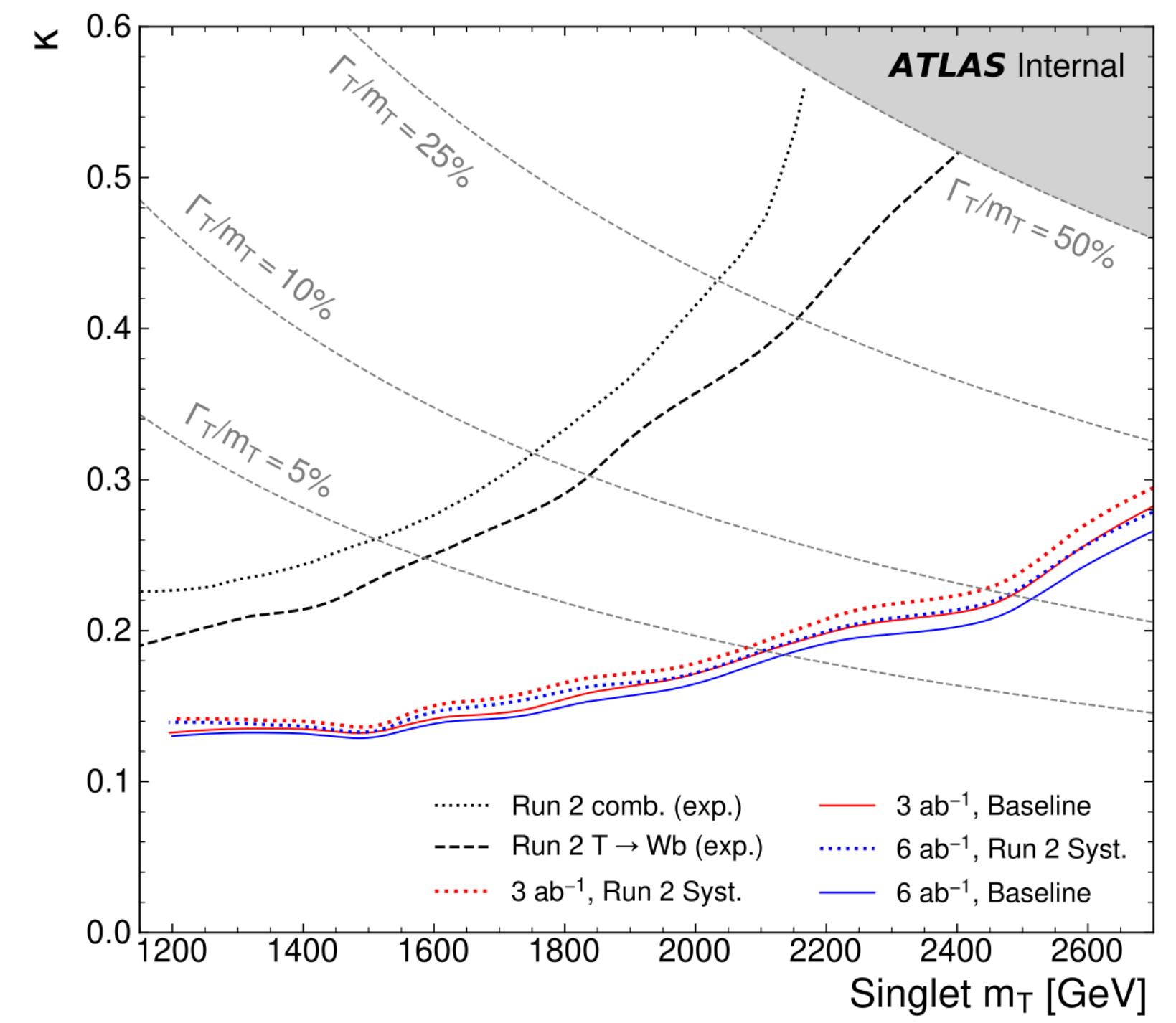
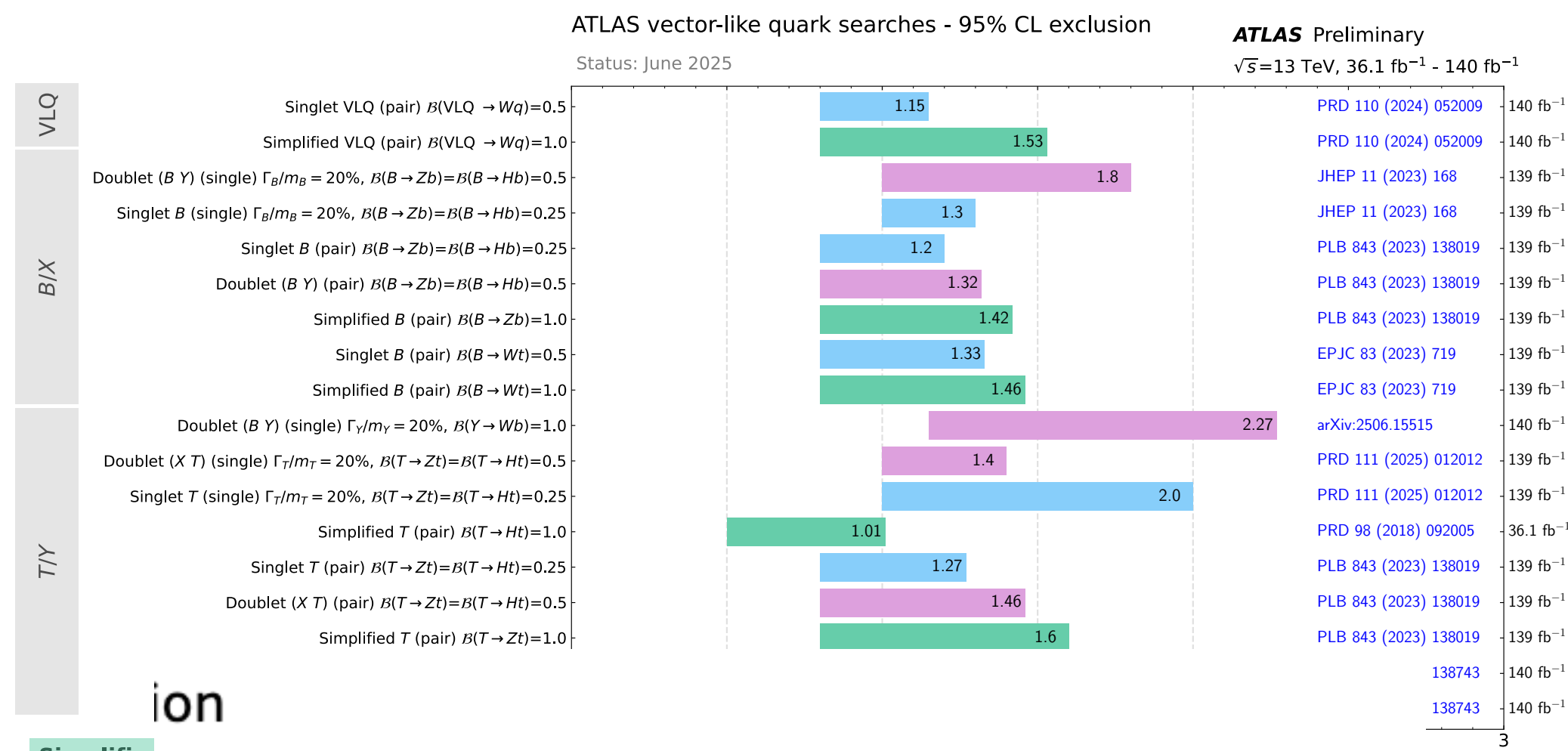
- ATLAS seemingly excluded (at 95%CL) the same discovery they confirmed a few months later... We need to be careful about this!
- Treatment of theory systematics, different signal model... and plain old confirmation bias ?
- Is there a risk that a BSM discovery could similarly be disregarded ?

In conclusion

- I have tried to use this talk to give you an idea of the thinking on the ATLAS side of the Ring for Exotics
- The **search for new particles** or interactions is one of the **key deliverables of the LHC** programme (there is more to life than Higgs self-coupling)
- Task is not easy to define, but with some thought can create a **strategy which maximises our chances** to reach our objective
- In short: **dig deep for well motivated "flagship" models**, **dig widely for things we don't expect**.
 - **Plan our papers** such that we get maximum impact from extra data and developments, and plan for long-term legacy
 - **Every single search should be exciting**.
 - Every single unblinding **teaches something new** about nature.
- We are pulling our weight: the **search community is heavily invested in the detector** operation and upgrade.
- We're in the **endgame** of the LHC. **We have a plan**.

VLQs

Run 2 comb beaten but this single quark - better to invest resources in sensitivity channels than combinations?

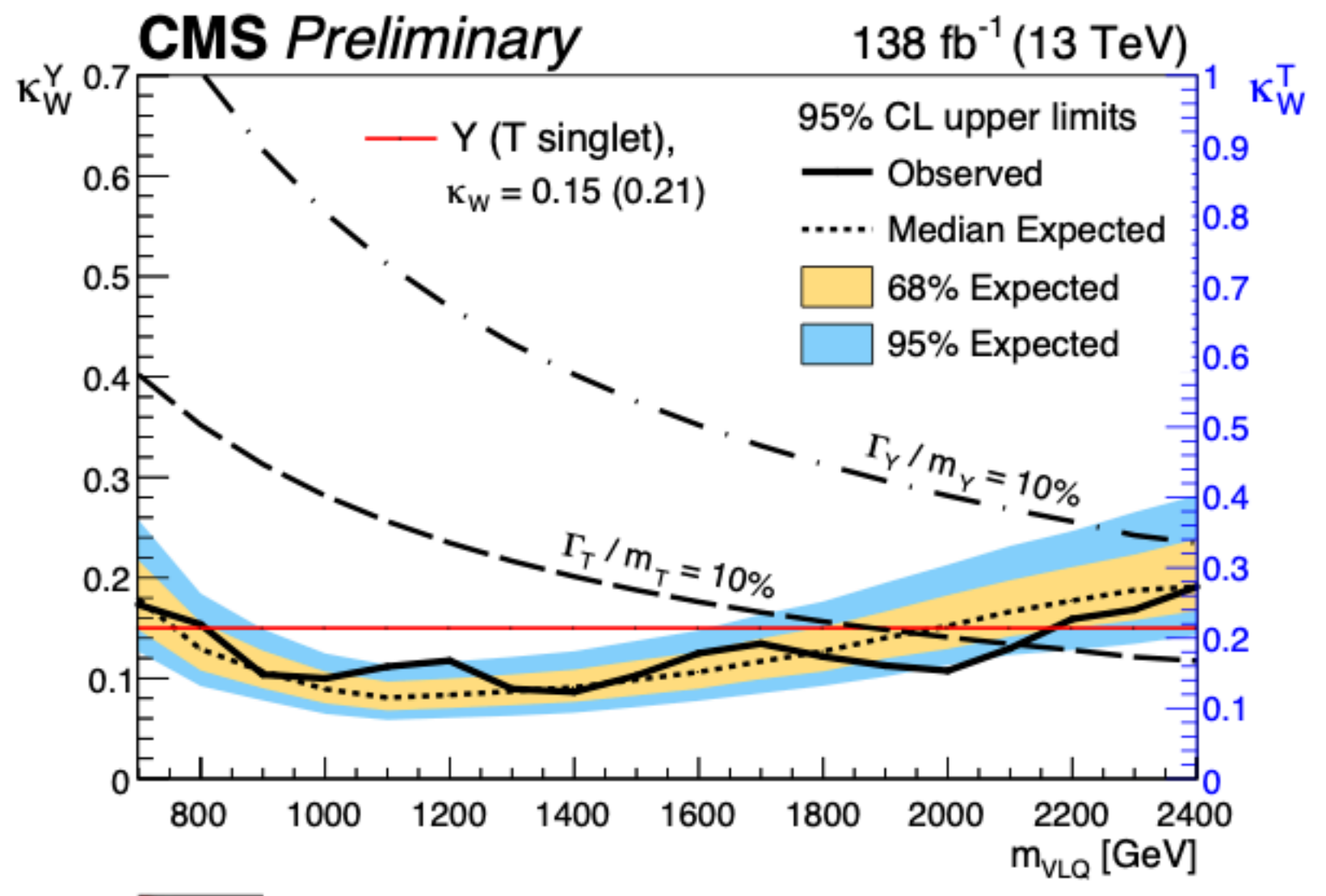


At some stage we become syst limited and not stat limited

ion
Simplified model
result

CMS-PAS-B2G-22-004, May '25

https://at



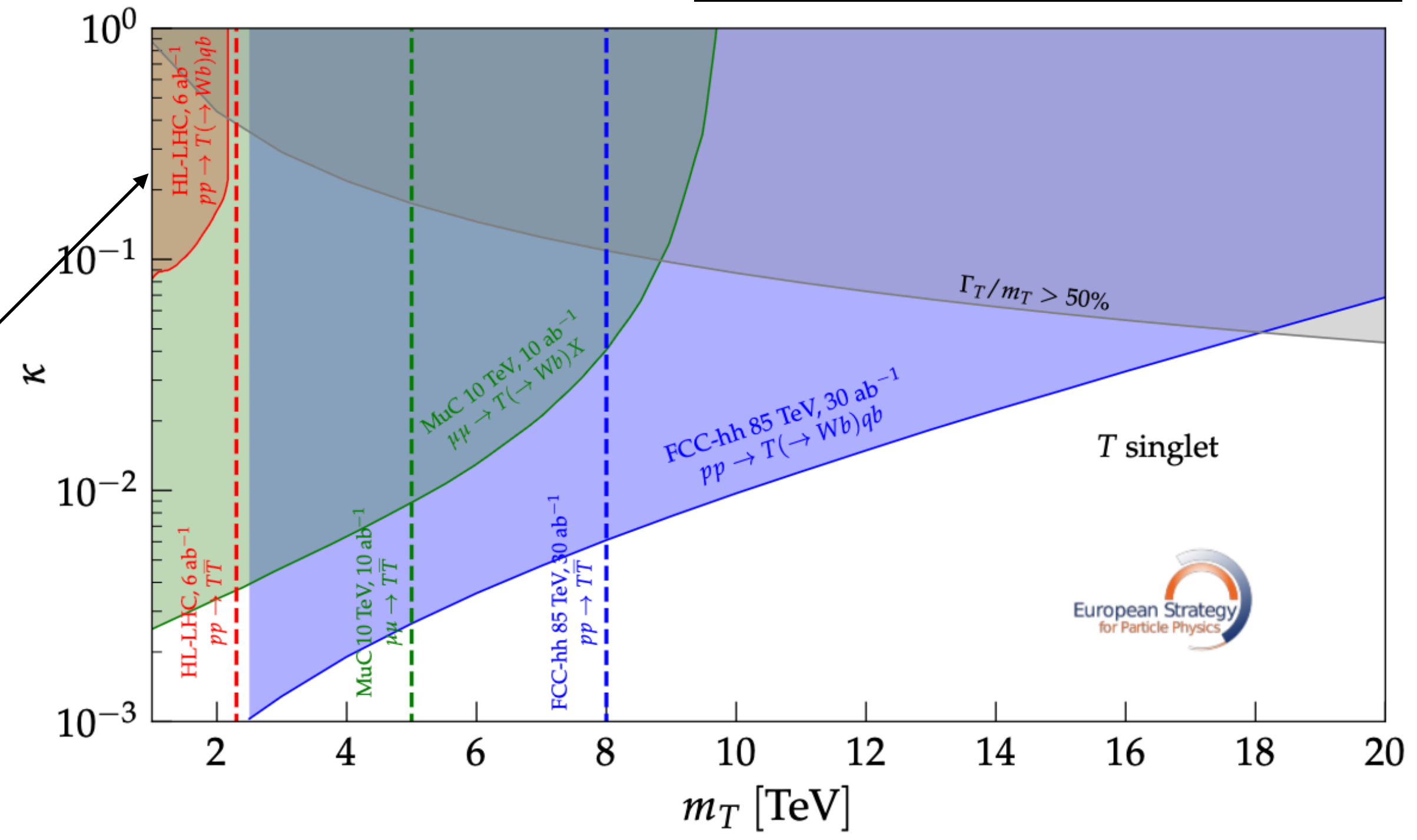
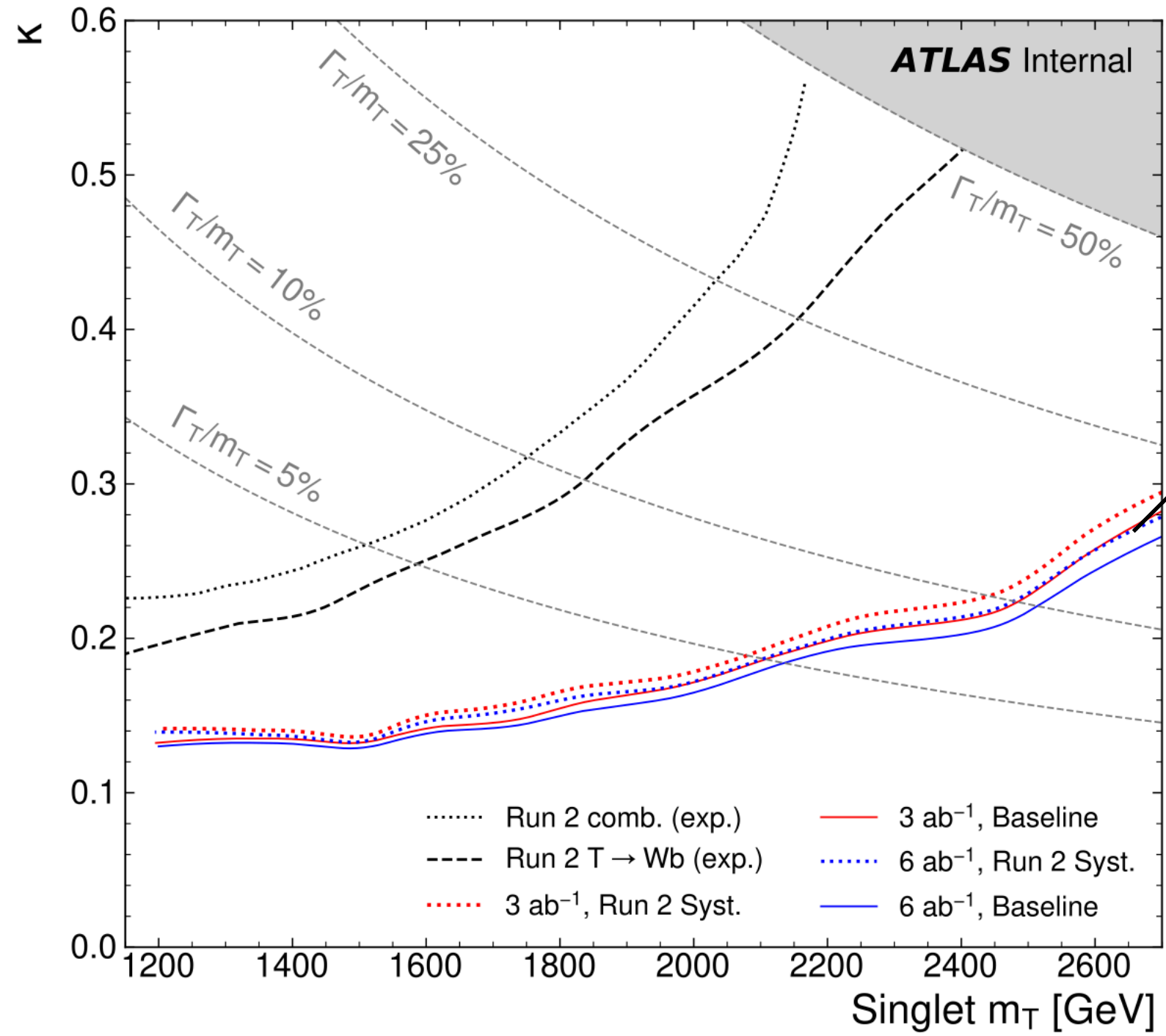
-PHYS-PUB-2025-030/



VLQs - the long view

Run 2 comb beaten but this single quark - better to invest

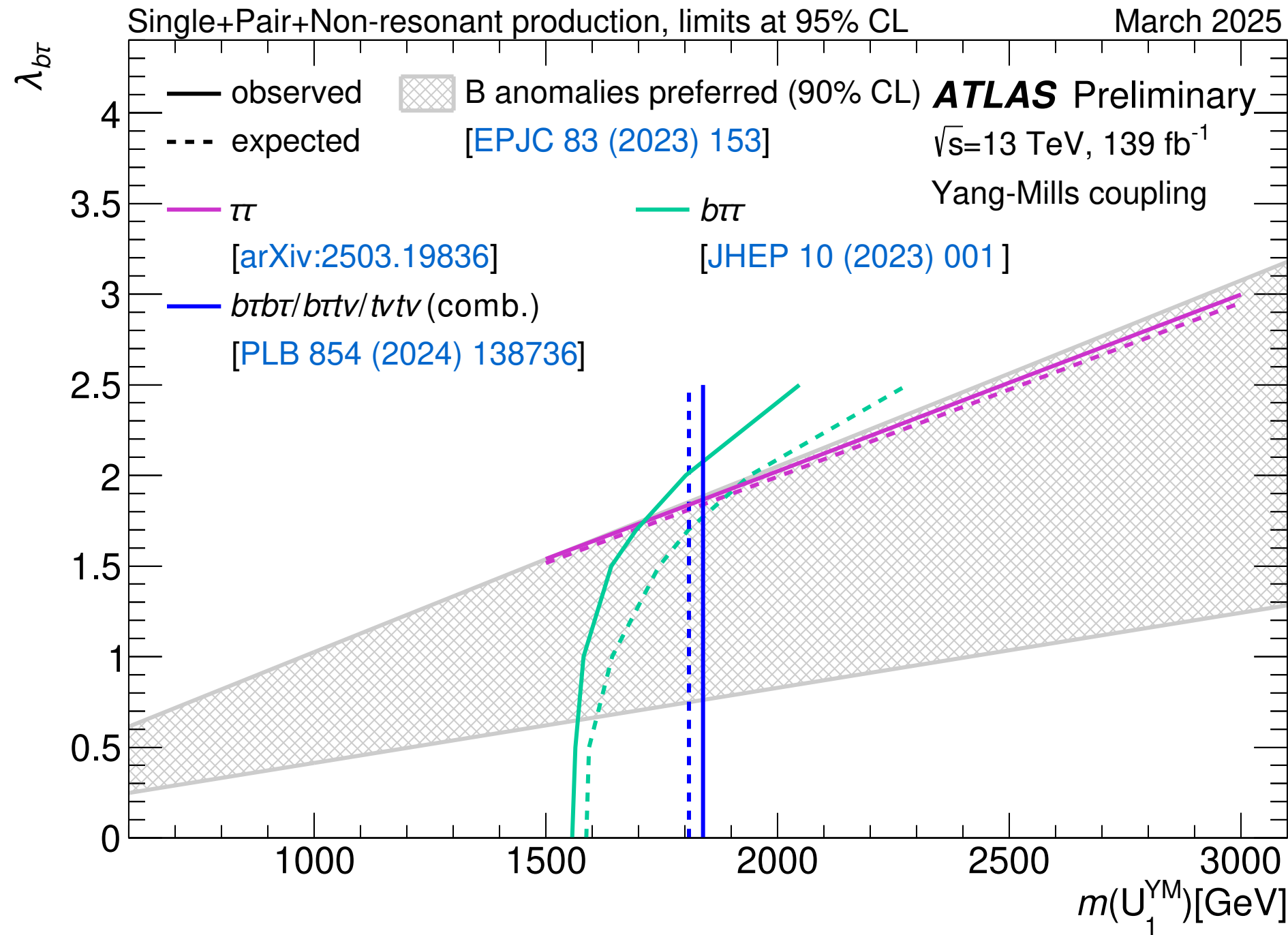
EPPSU briefing book



at some stage we become syst limited and not stat limited

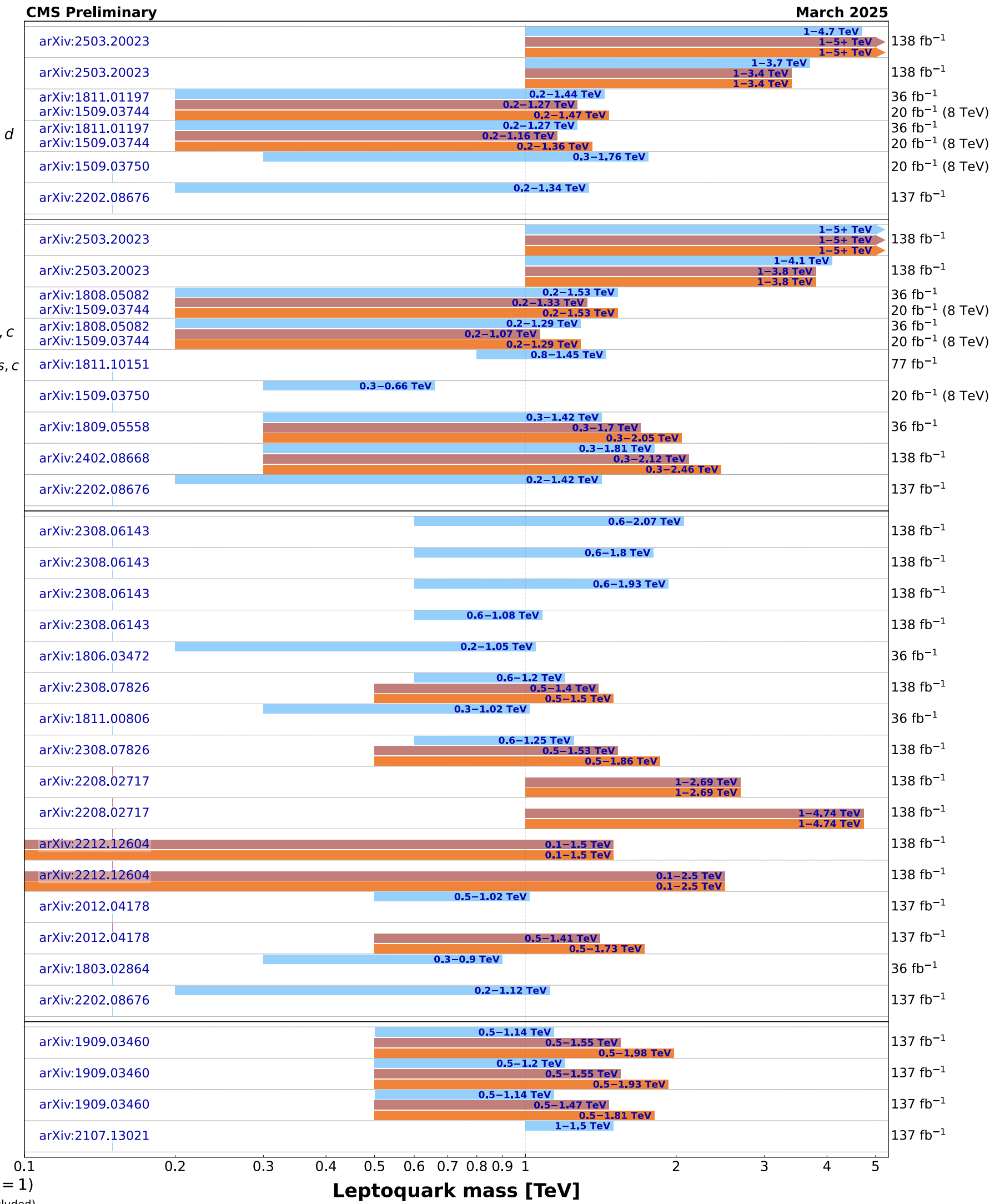


LQs



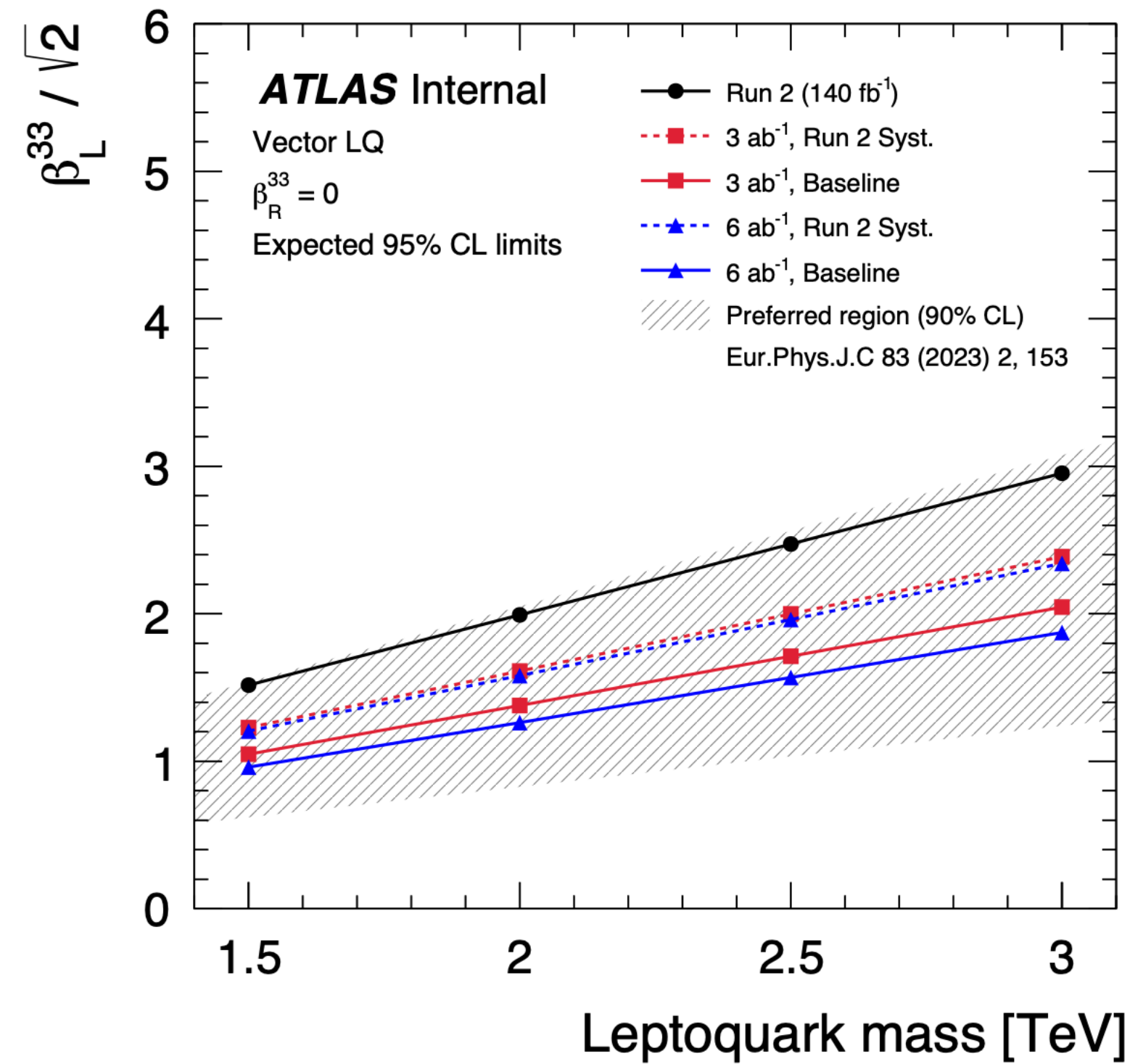
- LQ → qe**
 - Nonres. ee , $B(LQ \rightarrow ue) = 1$, $\lambda = 1$
 - Nonres. ee , $B(LQ \rightarrow de) = 1$, $\lambda = 1$
 - $LQ(qe)LQ(qe)$, $B(LQ \rightarrow qe) = 1$, $q = u, d$
 - $LQ(qe)LQ(qe) + LQ(qe)LQ(q\nu_e)$, $B(LQ \rightarrow qe, q\nu_e) = 0.5$, $q = u, d$
 - $eLQ(qe)$, $B(LQ \rightarrow qe) = 1$, $\lambda = 1$, $q = u, d$
 - $LQ(te)LQ(te)$, $B(LQ \rightarrow te) = 1$
- LQ → qμ**
 - Nonres. $\mu\mu$, $B(LQ \rightarrow u\mu) = 1$, $\lambda = 1$
 - Nonres. $\mu\mu$, $B(LQ \rightarrow d\mu) = 1$, $\lambda = 1$
 - $LQ(q\mu)LQ(q\mu)$, $B(LQ \rightarrow q\mu) = 1$, $q = u, d, s, c$
 - $LQ(q\mu)LQ(q\mu) + LQ(q\mu)LQ(q\nu_\mu)$, $B(LQ \rightarrow q\mu) = 0.5$, $q = u, d, s, c$
 - $LQ(q\mu)LQ(XDM)$, $B(LQ \rightarrow q\mu) = 0.5$, $\lambda \approx \frac{\sqrt{2}}{10}$, $m_{DM} \leq 0.45$ TeV, $q = s, c$
 - $\mu LQ(q\mu)$, $B(LQ \rightarrow q\mu) = 1$, $q = u, d$, $\lambda = 1$
 - $LQ(t\mu)LQ(t\mu)$, $B(LQ \rightarrow t\mu) = 1$
 - $LQ(b\mu)LQ(b\mu)$, $B(LQ \rightarrow b\mu) = 1$
 - $LQ(t\mu)LQ(t\mu)$, $B(LQ \rightarrow t\mu) = 1$
- LQ → qτ**
 - $\tau LQ(u\tau)$, $B(LQ \rightarrow u\tau) = 1$, $\lambda = 1$
 - $\tau LQ(d\tau)$, $B(LQ \rightarrow d\tau) = 1$, $\lambda = 1$
 - $\tau LQ(s\tau)$, $B(LQ \rightarrow s\tau) = 1$, $\lambda = 3$
 - $\tau LQ(b\tau)$, $B(LQ \rightarrow b\tau) = 1$, $\lambda = 3$
 - $\tau LQ(b\tau)$, $B(LQ \rightarrow b\tau) = 1$, $\lambda = 2.5$
 - $\tau LQ(b\tau)$, $B(LQ \rightarrow b\tau) = 1$, $\lambda = 2.5$
 - $LQ(b\tau)LQ(b\tau)$, $B(LQ \rightarrow b\tau) = 1$
 - $LQ(b\tau)LQ(b\tau)$, $B(LQ \rightarrow b\tau) = 1$
 - Nonres. $\tau\tau$, $\lambda_L(b\tau) = 2.5$, $\lambda_R(b\tau) = 0$, $\lambda_L(s\tau) = 0.48$ ($\lambda = \frac{g_u}{\sqrt{2}}$)
 - Nonres. $\tau\tau$, $\lambda_L(b\tau) = \lambda_R(b\tau) = 2.5$, $\lambda_L(s\tau) = 0.53$ ($\lambda = \frac{g_u}{\sqrt{2}}$)
 - Nonres. $\tau\nu$, $\lambda_L(b\tau) = 2.5$, $\lambda_R(b\tau) = 0$, $\lambda_L(s\tau) = 0.48$
 - Nonres. $\tau\nu$, $\lambda_L(b\tau) = \lambda_R(b\tau) = 2.5$, $\lambda_L(s\tau) = 0.53$
 - $LQ(t\tau)LQ(b\nu_\tau) + \nu_\tau LQ(t\tau)$, $\lambda(t\tau) = \lambda(b\nu_\tau) = 2.5$
 - $LQ(b\tau)LQ(t\nu_\tau) + \tau LQ(t\nu_\tau)$, $\lambda(t\tau) = \lambda(b\nu_\tau) = 2.5$
 - $LQ(t\tau)LQ(t\tau)$, $B(LQ \rightarrow t\tau) = 1$, $\lambda = 1$
 - $LQ(t\tau)LQ(t\tau)$, $B(LQ \rightarrow t\tau) = 1$
- LQ → qν**
 - $LQ(q\nu_{e(\mu)})LQ(q\nu_{e(\mu)})$, $B(LQ \rightarrow q\nu_{e(\mu)}) = 1$, $q = u, d, s, c$
 - $LQ(b\nu_\tau)LQ(b\nu_\tau)$, $B(LQ \rightarrow b\nu_\tau) = 1$
 - $LQ(t\nu_\tau)LQ(t\nu_\tau)$, $B(LQ \rightarrow t\nu_\tau) = 1$
 - $LQ(u\nu_e)LQ(u\nu_e) + \nu_e LQ(u\nu_e)$, $B(LQ \rightarrow u\nu_e) = 1$, $\lambda = 1$

Legend: █ Scalar █ Vector ($\kappa = 0$) █ Vector ($\kappa = 1$)
 Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

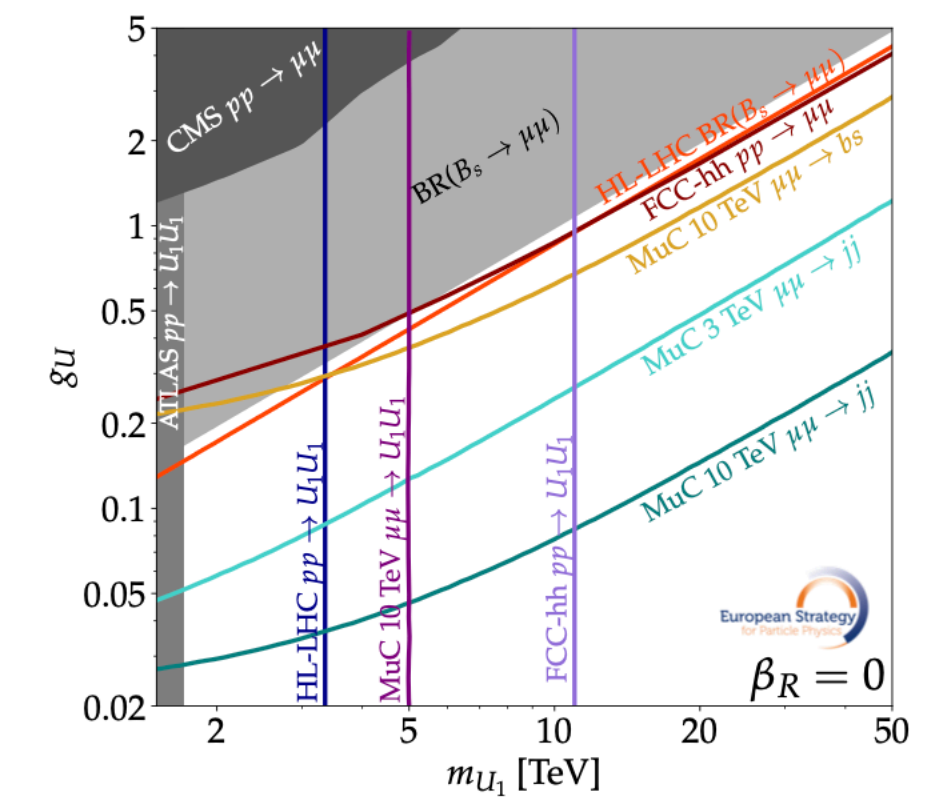
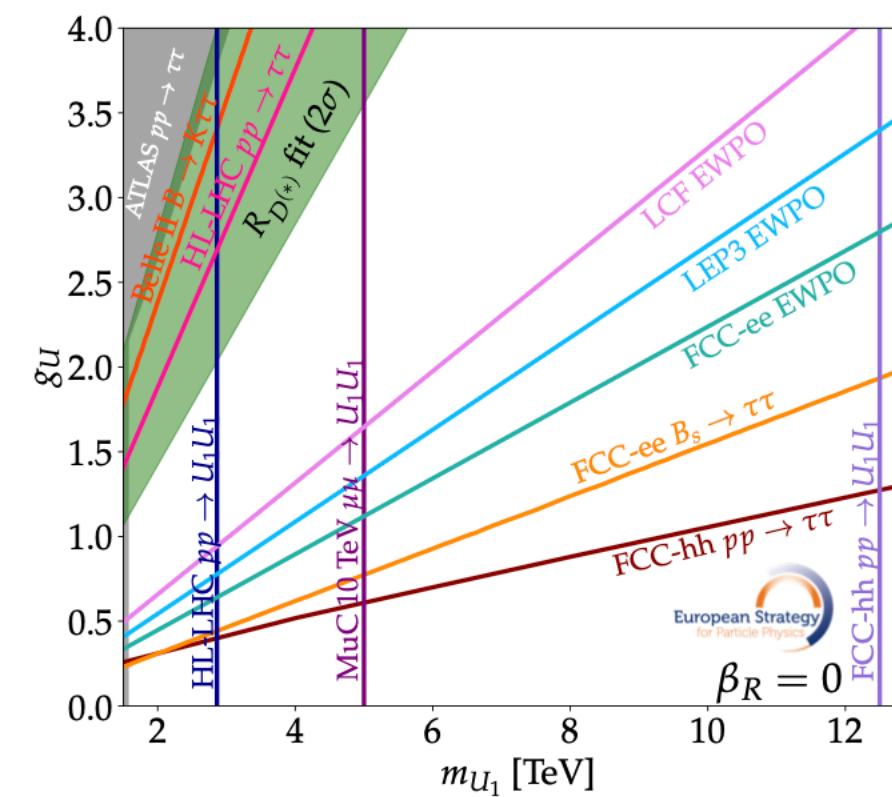


• Leptoquark mass constraints consistently above 1 TeV, but to 5+ TeV depending on the configuration. Starting to seriously probe the b-anomaly preferred region!





<https://cds.cern.ch/record/2942985/files/ATL-COM-PHYS-2025-799.pdf>



- Together, We (CMS+ATLAS) can seriously probe the b-anomaly preferred region. What other developments (beyond lumi scaling) are needed to **completely** probe the region by the end of LHC lifetime?

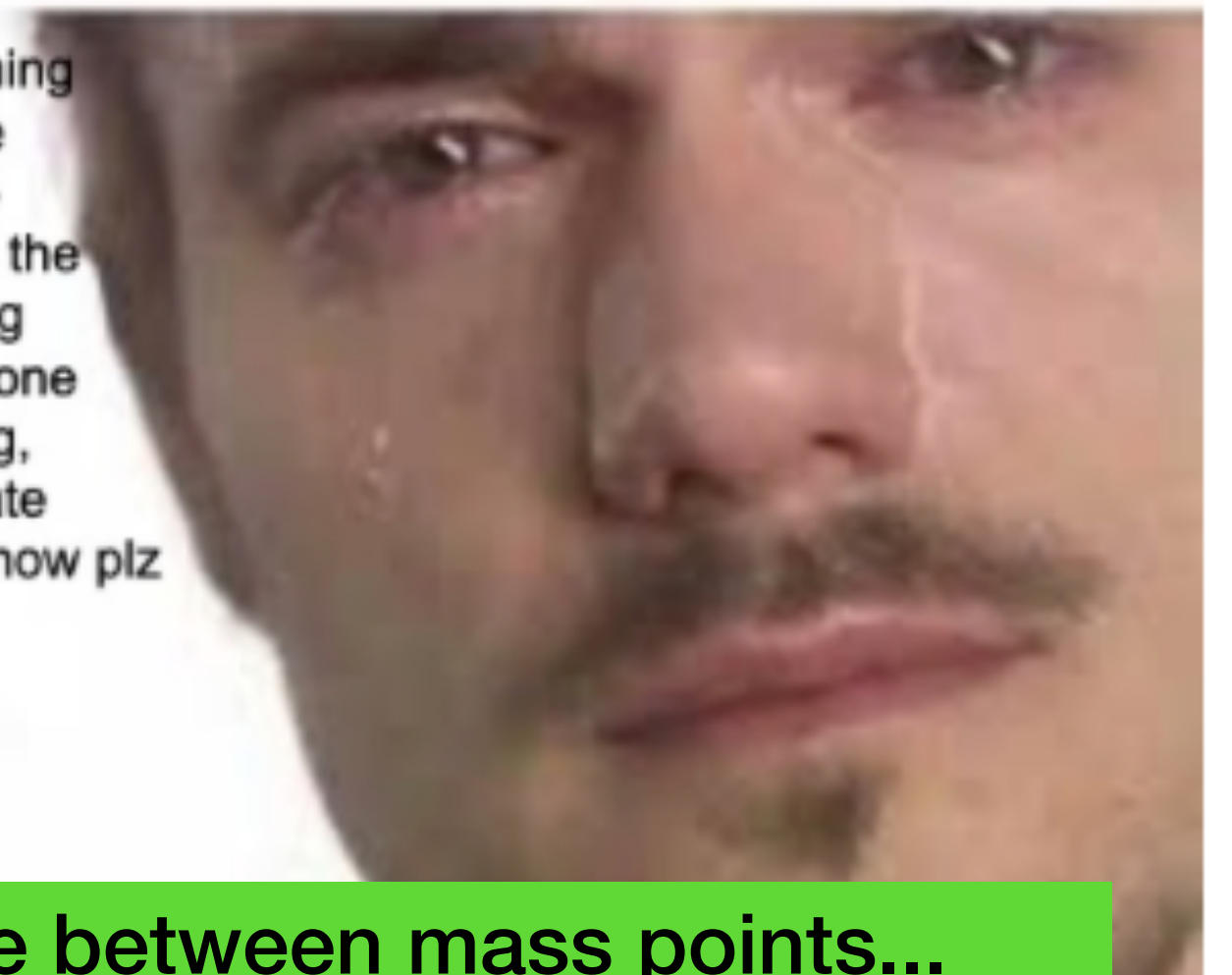
Surrogate models?

- LLP re-interpretation problem is also the "any analysis which uses ML" re-interpretation problem...
- Could the solution be **MORE** ML ?

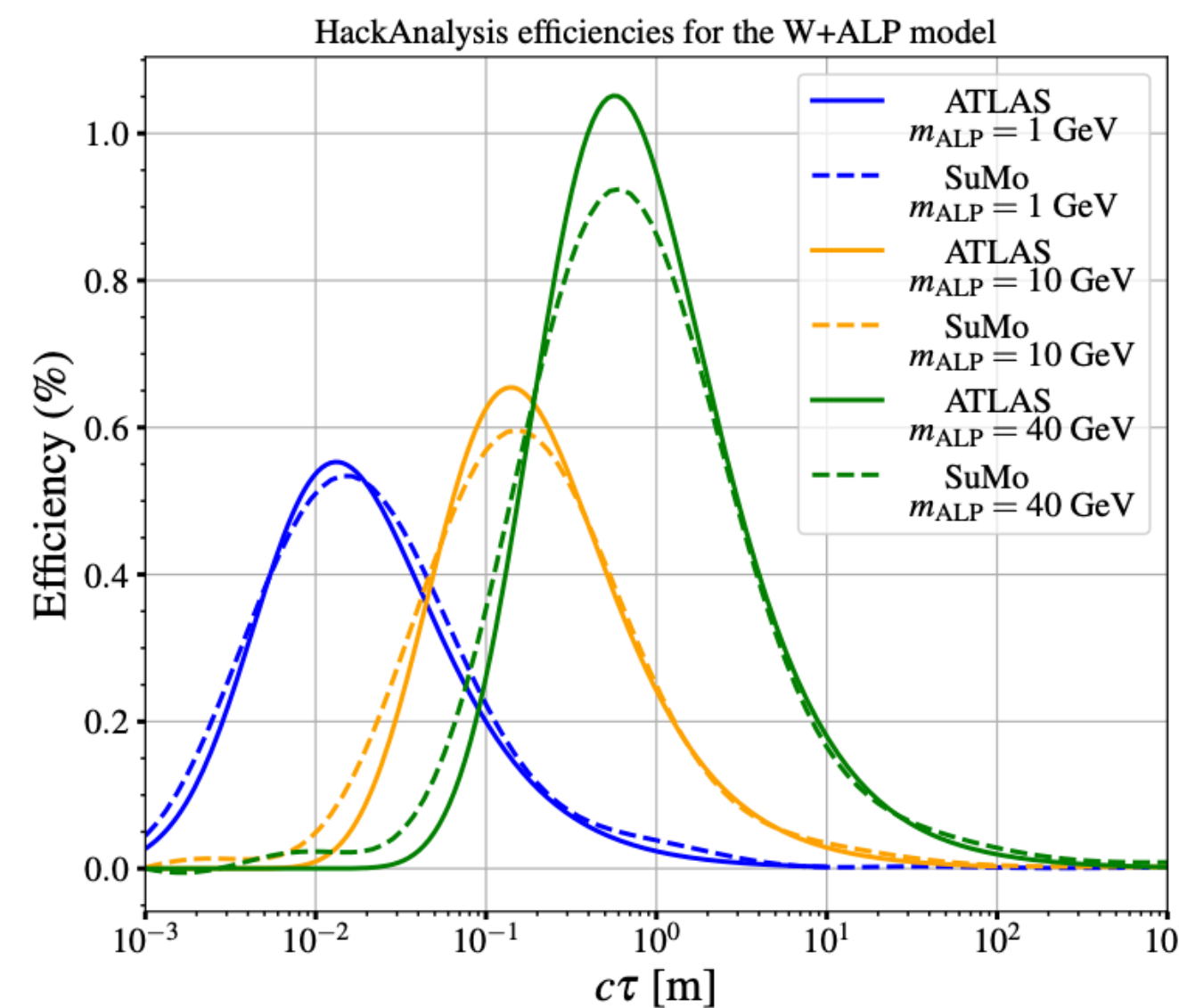
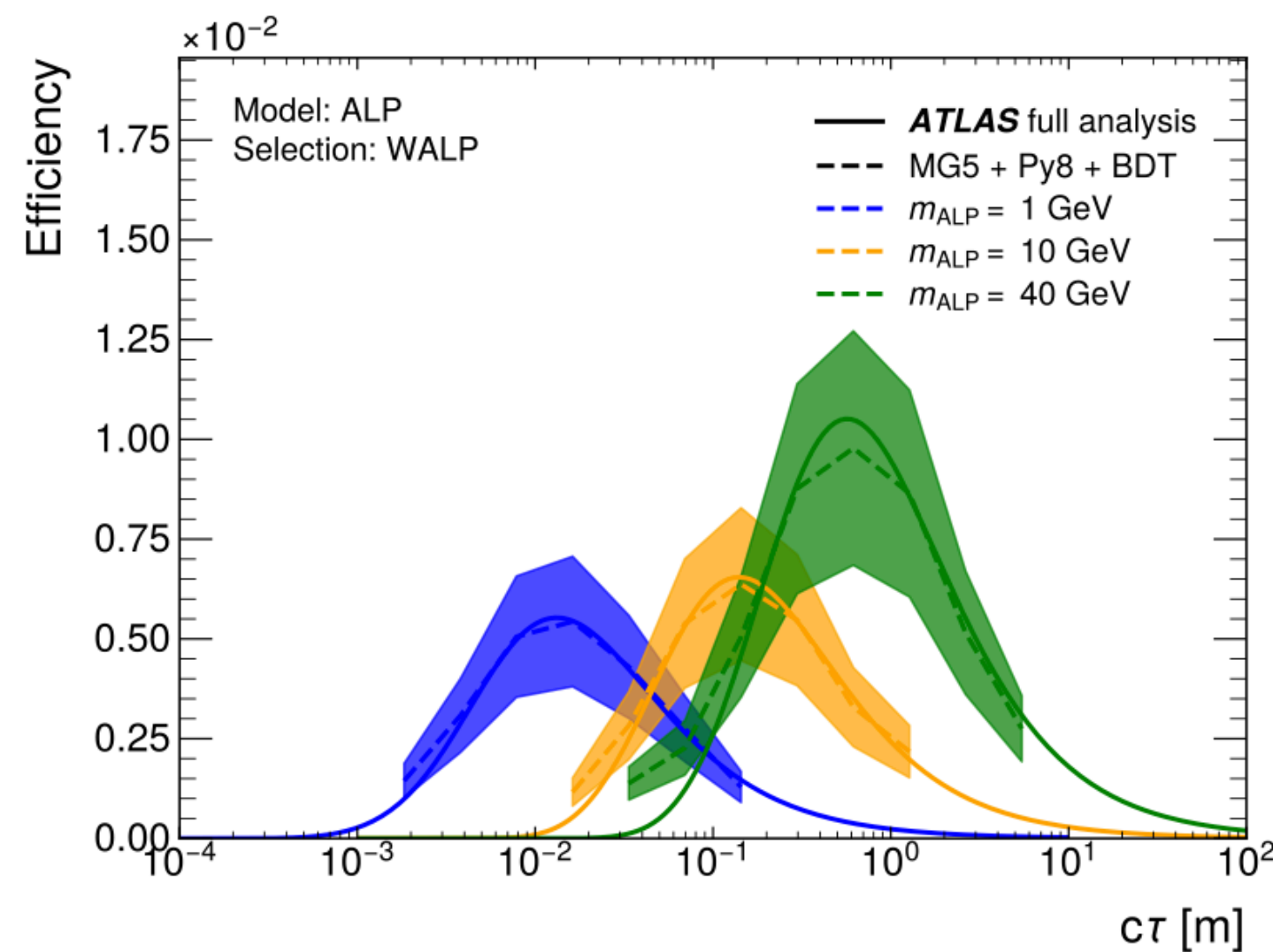
Reproduce published results with high accuracy...

Easily port ONNX files to new frameworks (eg HackAnalysis)

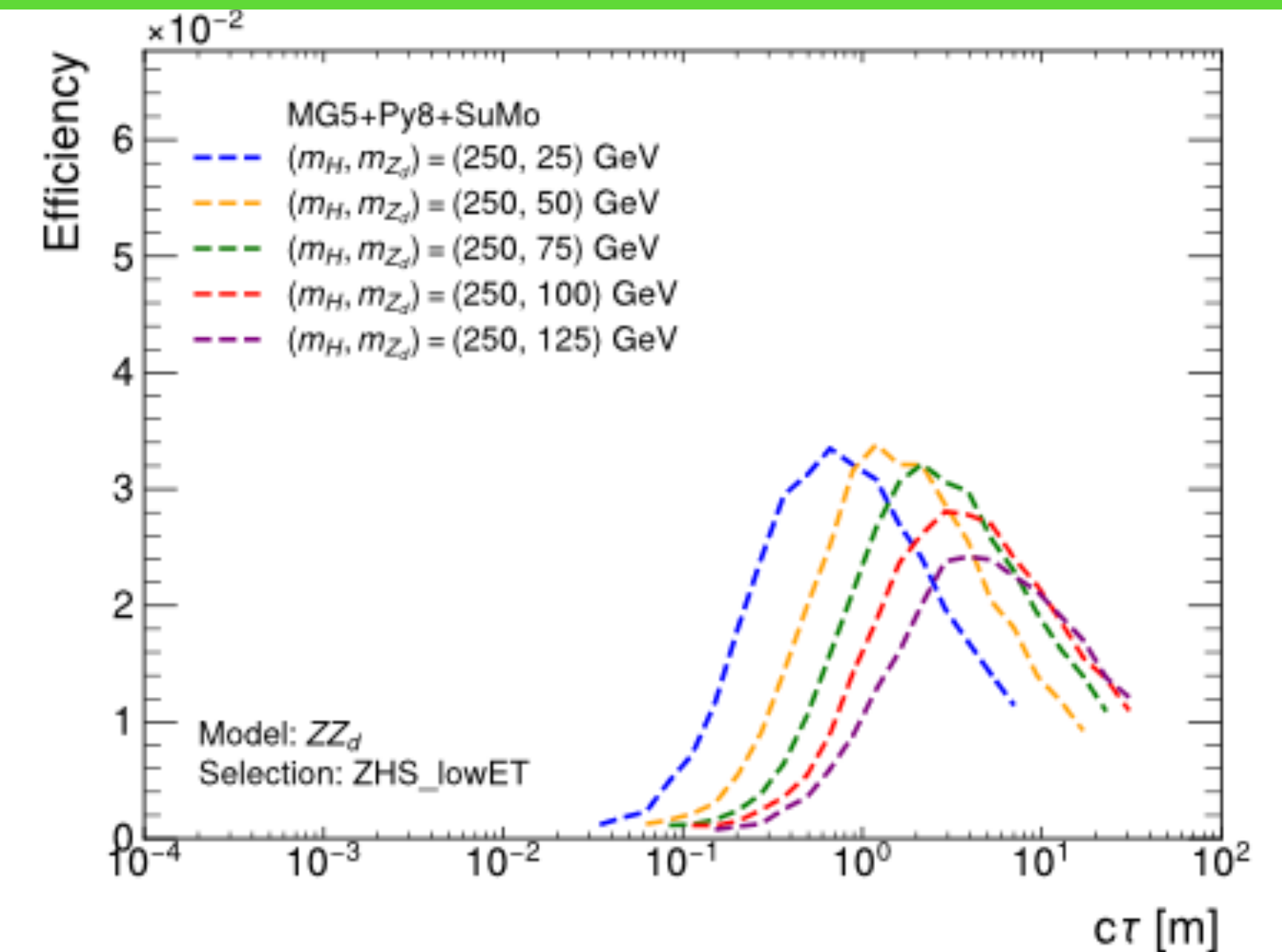
please bro just one more machine learning model its the last one I promise, it can help everyone understand all the other machine learning models, bro please just one more machine learning, we can call it a surrogate model no one will have to know plz



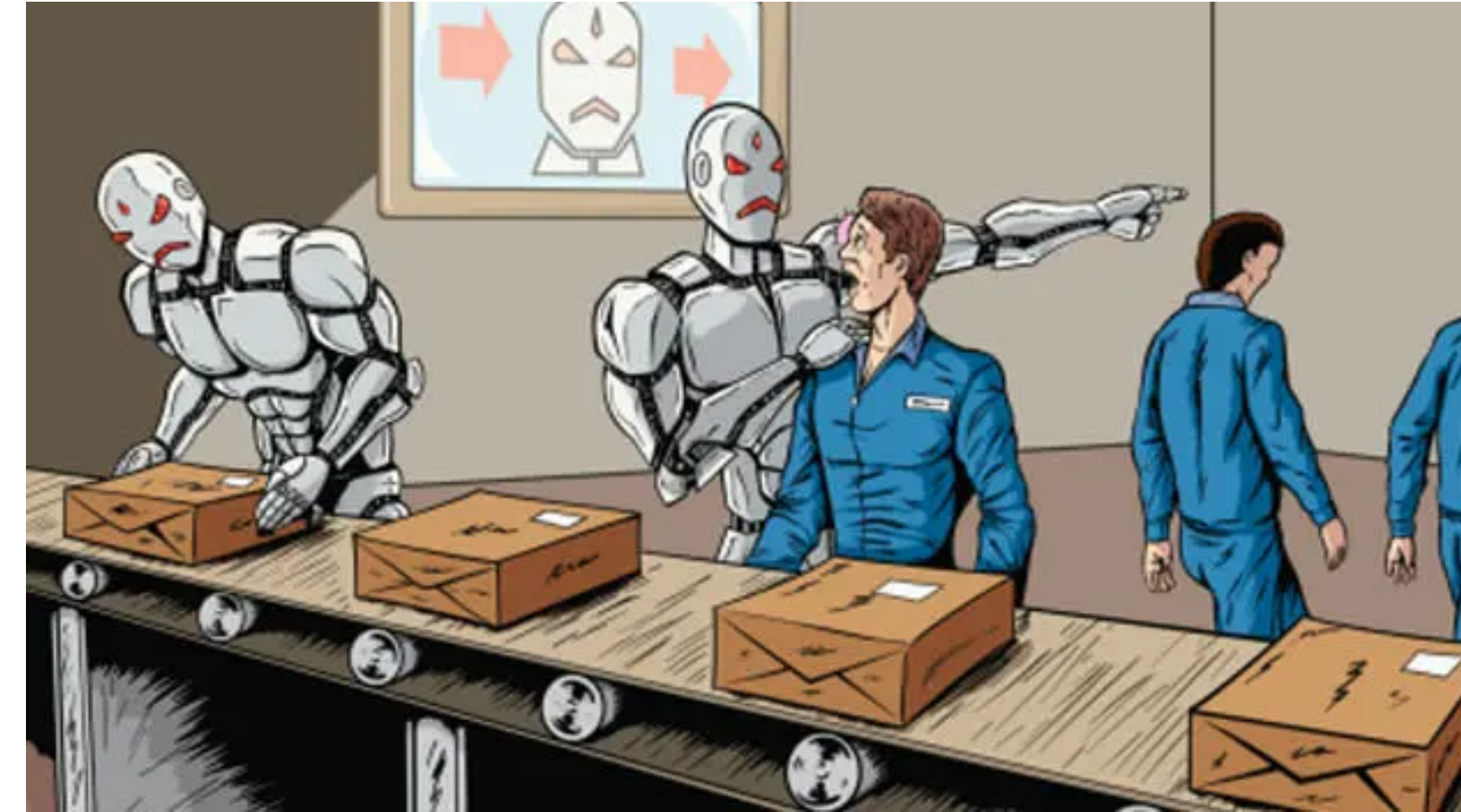
Interpolate between mass points... Or new models with different kinematics !



<https://arxiv.org/abs/2502.10231>

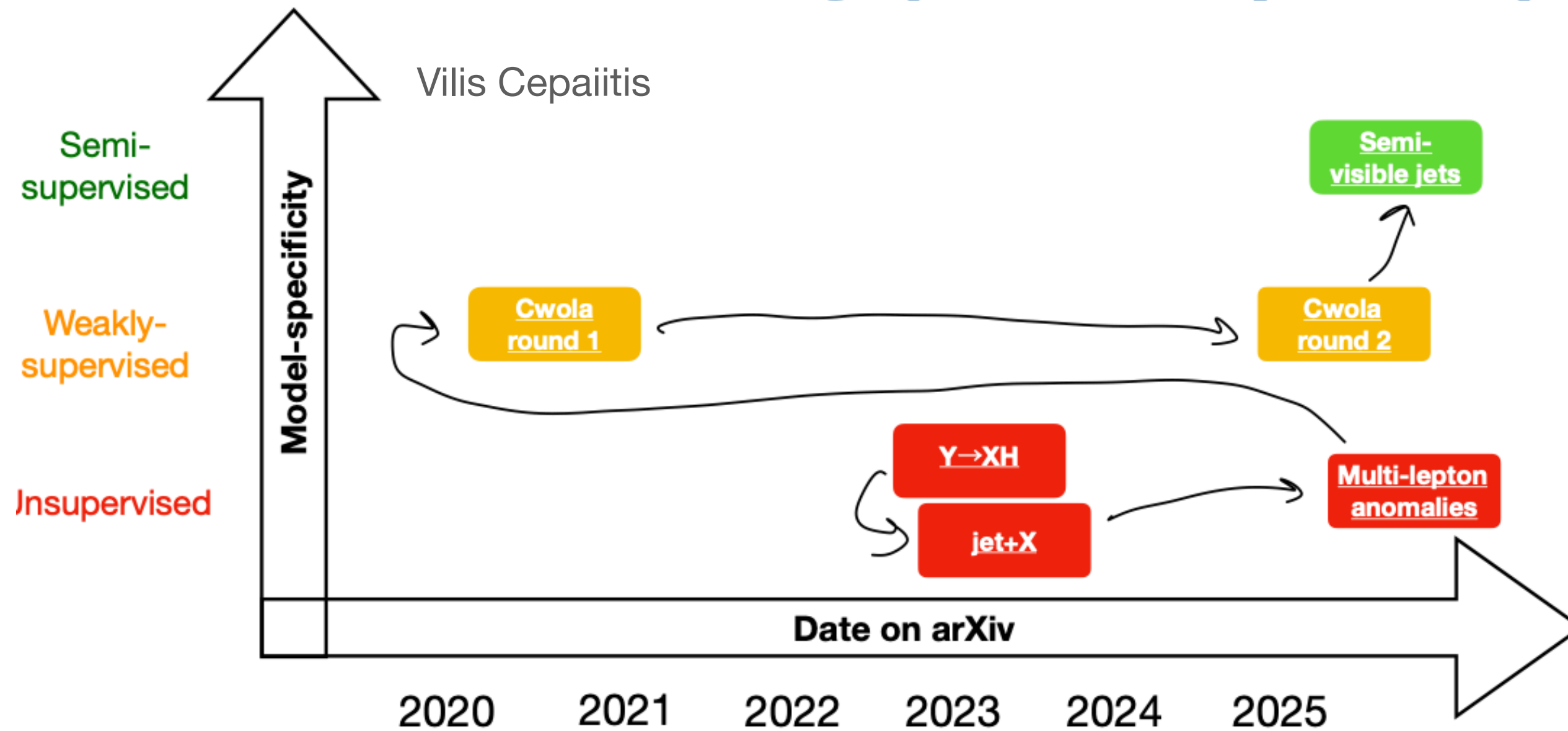


**The machines are coming to steal out jobs
(kidding, but let's use them properly)**



The ATLAS and CMS Anomaly Detection Papers

ATLAS AD summary (as of Sep 2025)



<https://indico.cern.ch/event/1578072/contributions/6648740/attachments/3136423/5565386/ADTopicalMeetingATLAS.pdf>

Overview

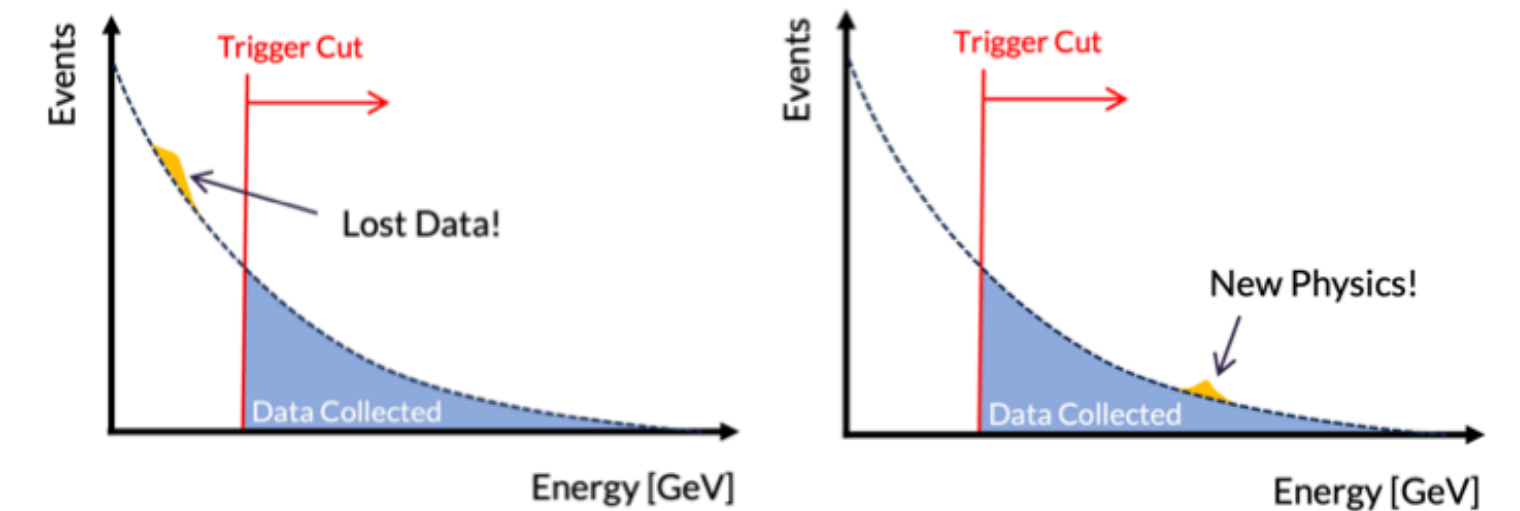
Louis Moureaux

Data quality monitoring

- ECAL [2309.10157]

Triggers

- AXOL1TL [CDS]
- CICADA [CDS]



Offline

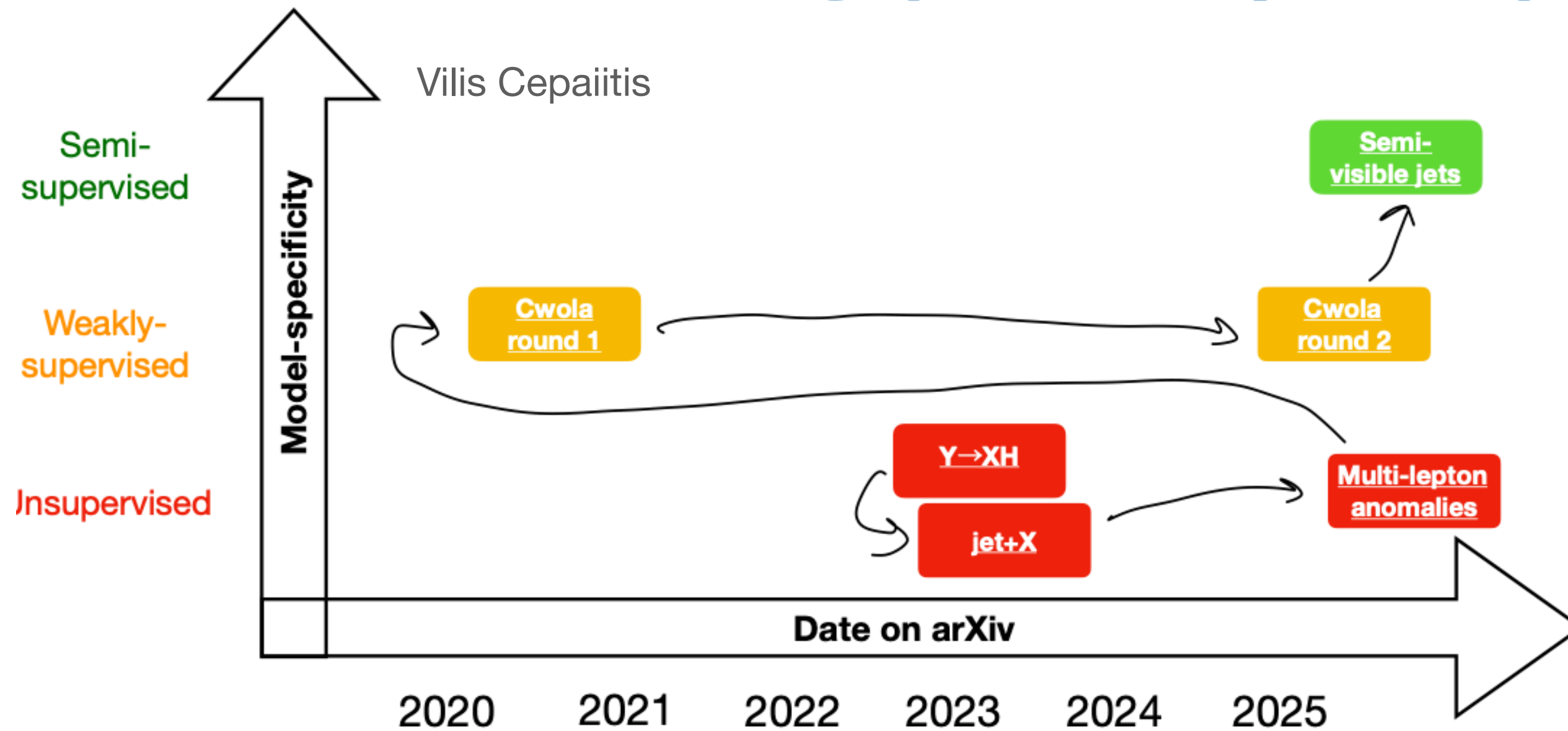
- Dijet resonances [2412.03747]
- Study of the methods [CDS link]
- H(bb) + anomalous [CDS link]

https://indico.cern.ch/event/1578072/contributions/6648741/attachments/3136689/5565917/CMS_Anomalies.pdf

- CMS and ATLAS have together published only a handful of AD searches, mostly on hadronic final states...
- But now we are breaking into leptonic final states!

The ATLAS and CMS Anomaly Detection Papers

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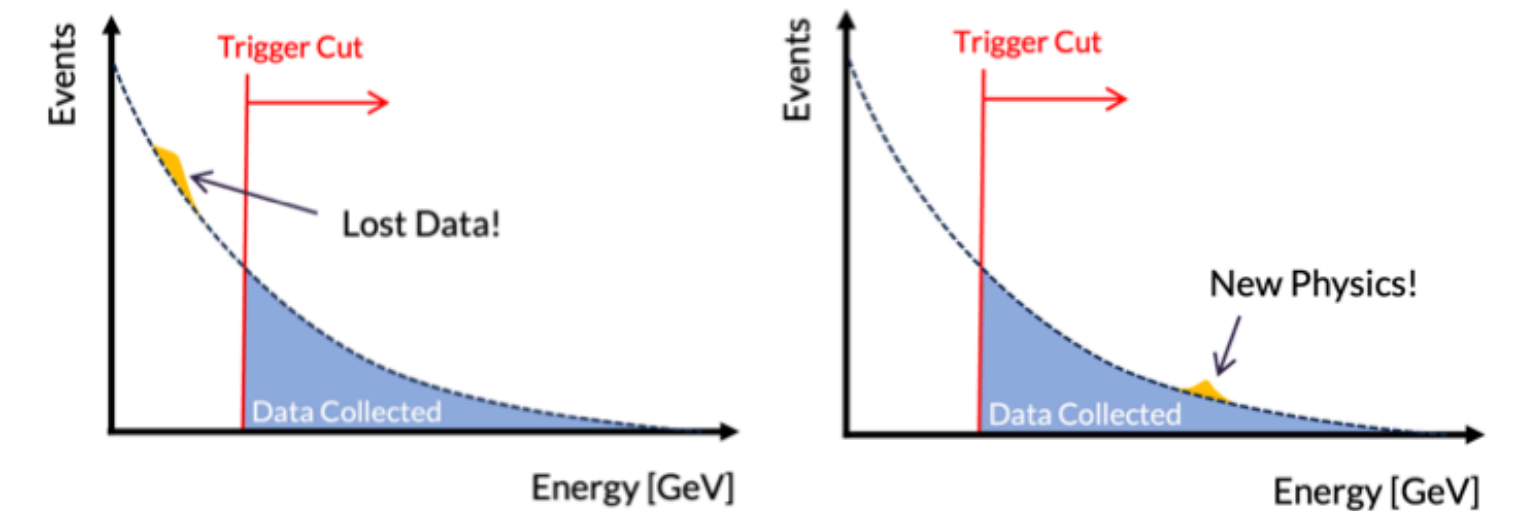
Louis Moureaux

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