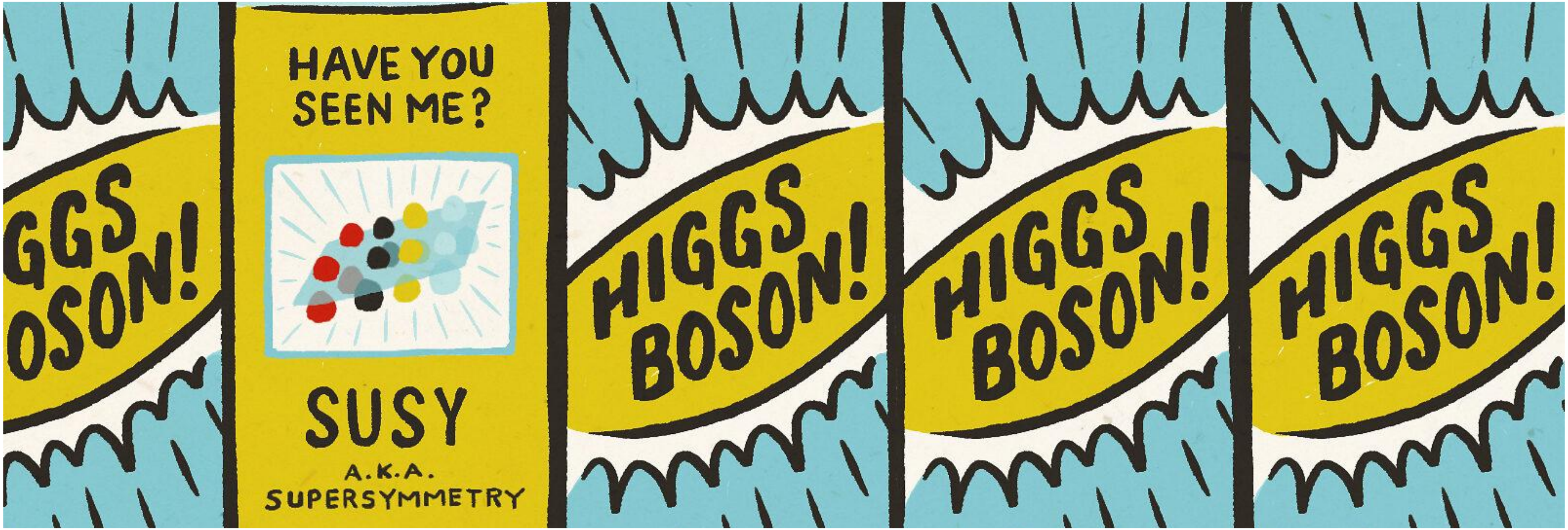
Illustration by Sandbox Studio, Chicago with Steve Shanabruch



SUS Long Exercise:
Searching for stau pair production in Run 3

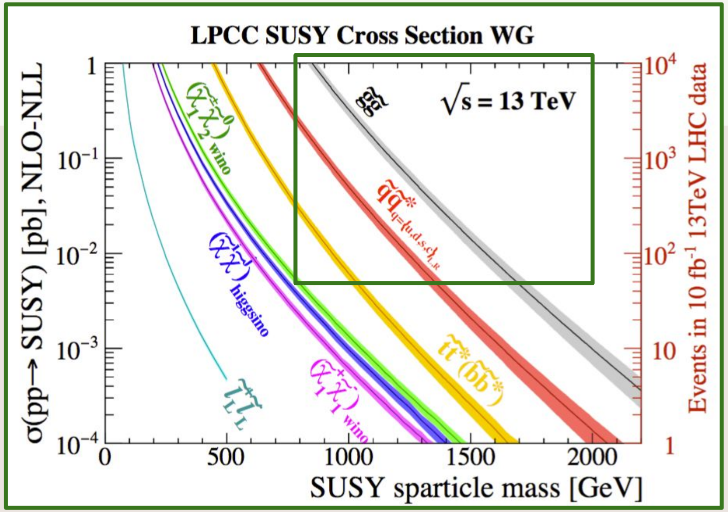
Cécile Caillol (CERN), Jaana Heikkilä (CERN), Mario Masciovecchio (UCSD)

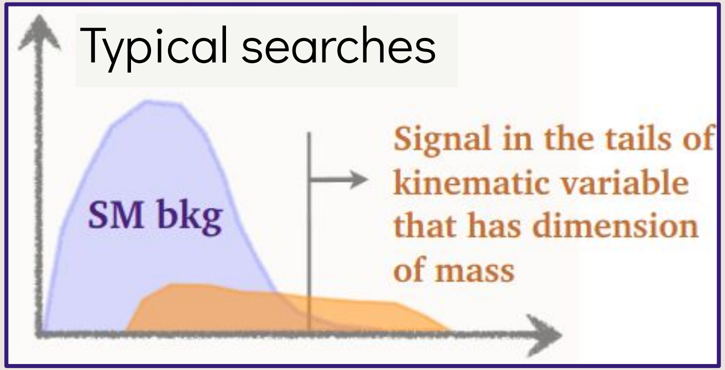
CMSDAS 2024 - CERN

Expanding the SUSY search program

Targeting challenging and rare SUSY signatures

First statements on SUSY using full Run-2 data focused on the strong sector
→ Rely on "typical" SUSY searches: target final states with multiple SM objects, and large missing energy from undetected SUSY states





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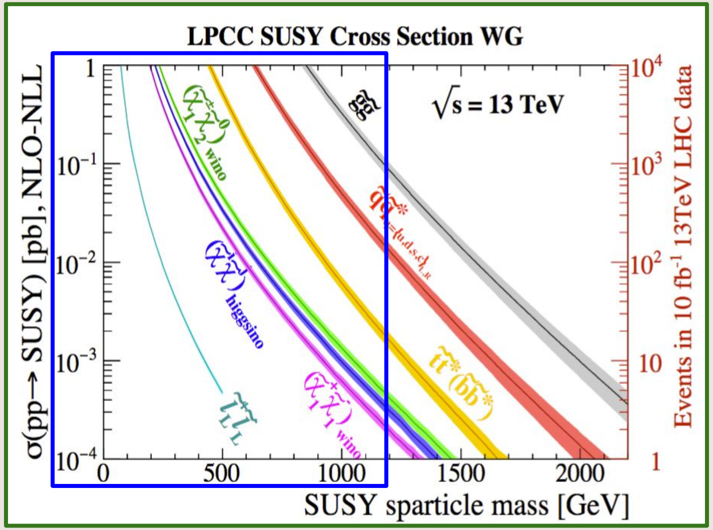


Full Run 2 data helped us to expand the SUSY search program further

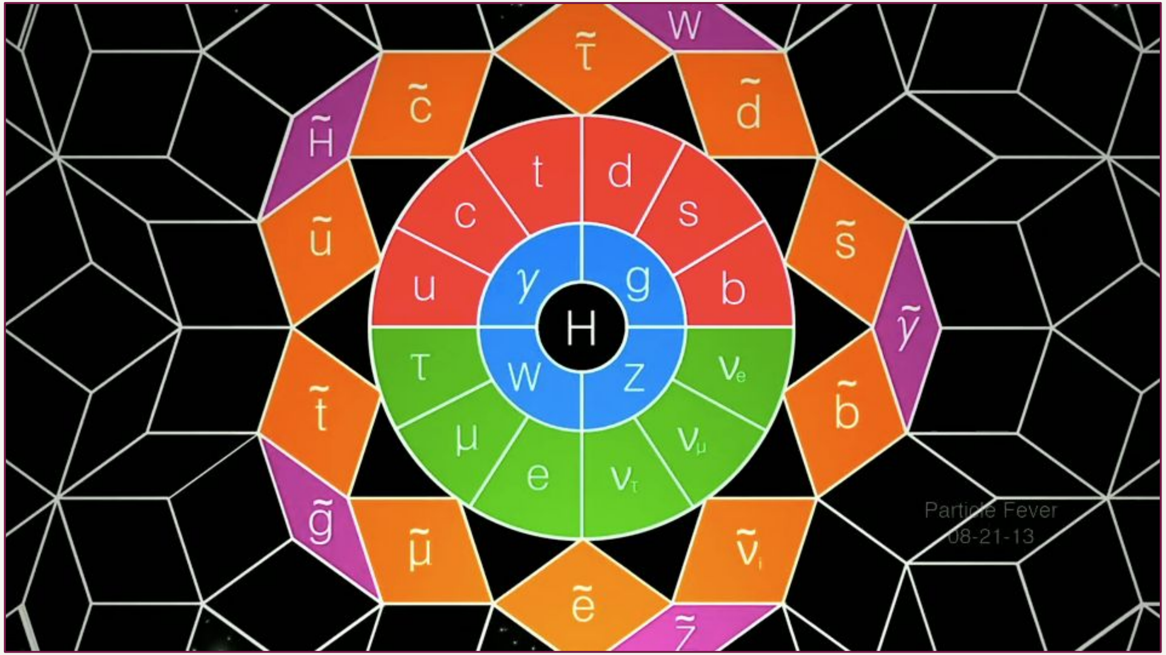
- Target specific, challenging signatures (e.g. stealth SUSY sector)
- Exploit novel analysis techniques
- Explore previously uncovered corners
  - Compressed scenarios (small amount of visible energy)
  - Sleptons (extremely low cross sections)

→ *As of today, there are no significant excesses - where do we go from here?* (Spoiler alert: back to work!)

Cropping the SUSY landscape to perform a search…

Supersymmetry: each boson (fermion) of the SM is accompanied by a fermionic (bosonic) superpartner [R-parity: $R=(-1)^{3(B-L)+2S}$]

Minimal Supersymmetric extension of the Standard Model (MSSM):
O(100) parameters after supersymmetry breaking
→ Phenomenology defined by the underlying (unknown) mechanism of SUSY breaking



Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	−1	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$	(same)
			$\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$	(same)
			$\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$	$\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$
sleptons	0	−1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$	(same)
			$\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$	(same)
			$\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	$\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$
neutralinos	1/2	−1	$\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$	$\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$
charginos	1/2	−1	$\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$	$\tilde{C}_1^\pm\ \tilde{C}_2^\pm$
gluino	1/2	−1	$\tilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	−1	$\tilde{G}$	(same)

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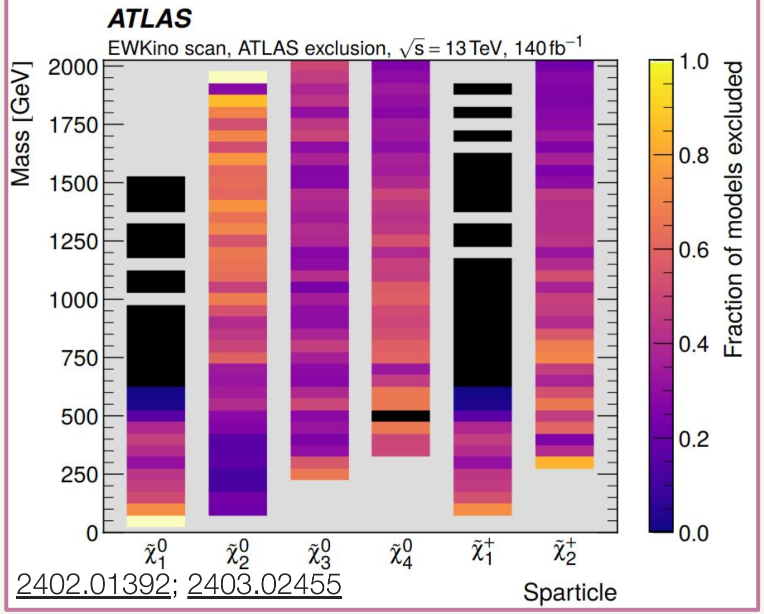
Absence of new sources of CP violation beyond that present in the CKM matrix
No flavour-changing neutral currents
First and second sfermion generation universality at low energy

Phenomenological MSSM (pMSSM): *O(20) free-parameters*
→ Tens of thousands of models - cannot be targeted by a usual search
→ Investigated in detail both by the ATLAS and CMS Collaborations

$\tan\beta$: the ratio of the vevs of the two–Higgs doublet fields.
$m^2_{H_u}, m^2_{H_d}$: the Higgs mass parameters squared.
M_1, M_2, M_3: the bino, wino and gluino mass parameters.
$m_{\tilde{q}}, m_{\tilde{u}_R}, m_{\tilde{d}_R}, m_{\tilde{l}}, m_{\tilde{e}_R}$: the first/second generation sfermion mass parameters.
$m_{\tilde{Q}}, m_{\tilde{t}_R}, m_{\tilde{b}_R}, m_{\tilde{L}}, m_{\tilde{\tau}_R}$: the third generation sfermion mass parameters.
A_u, A_d, A_e: the first/second generation trilinear couplings.
A_t, A_b, A_τ: the third generation trilinear couplings.



2402.01392; 2403.02455

Very few models are excluded - a similar CMS analysis is in progress!

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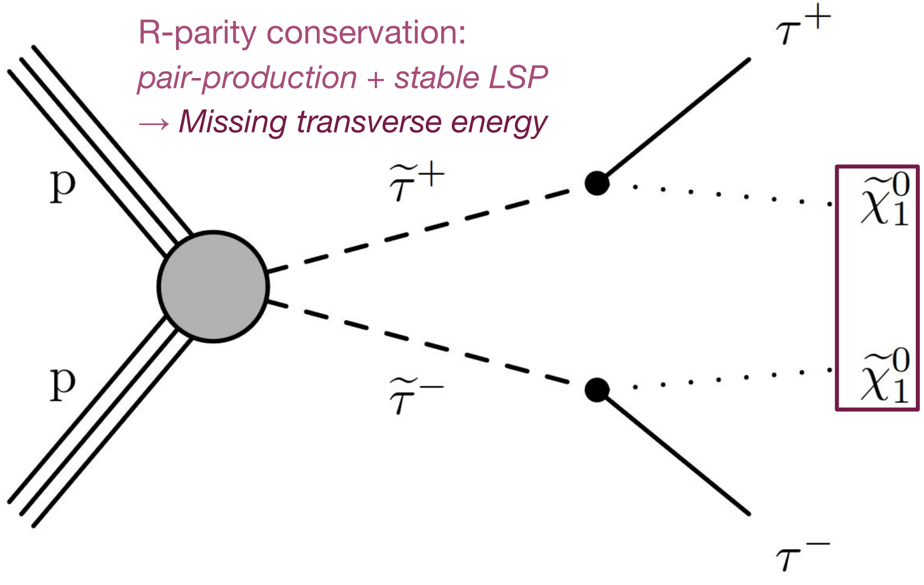
Target only the "relevant" particles; other sparticles decoupled
Pure-state sparticles (EWKinos with minimal mixing)
Given production mode and decay channel of a sparticle

Simplified model spectra (SMS): a handful of parameters
→ R-parity (non-)conservation drives the phenomenology
→ Lightest sparticle (LSP) potential dark matter candidate

→ *A suitable handle for searches at LHC that can be used as an input for pMSSM interpretations!*

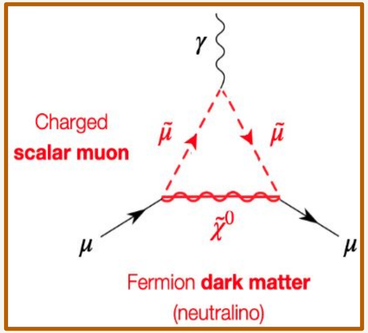
R-parity conservation:
pair-production + stable LSP
→ *Missing transverse energy*

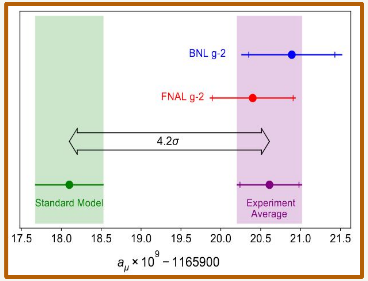


Stau pair production in a nutshell

Well-motivated scenario answering to some of the open questions of particle physics

- Observed relic density can be interpreted as LSP co-annihilation with light stau
- The sleptons could explain the results on the muon g-2 anomaly*, measured by the Fermilab and BNL experiments





*Pending last word on the prediction from the theory community!)

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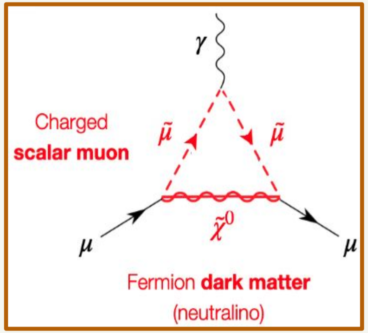
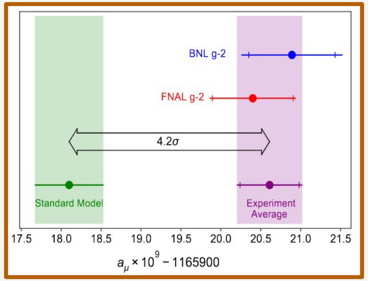
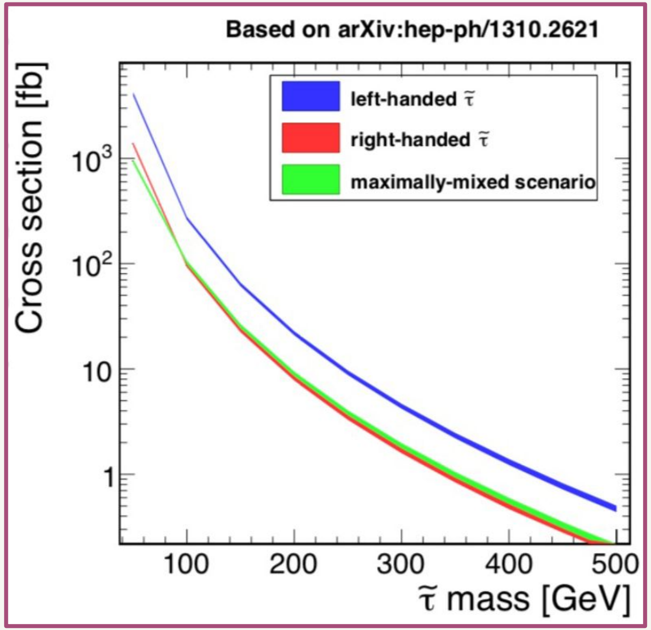
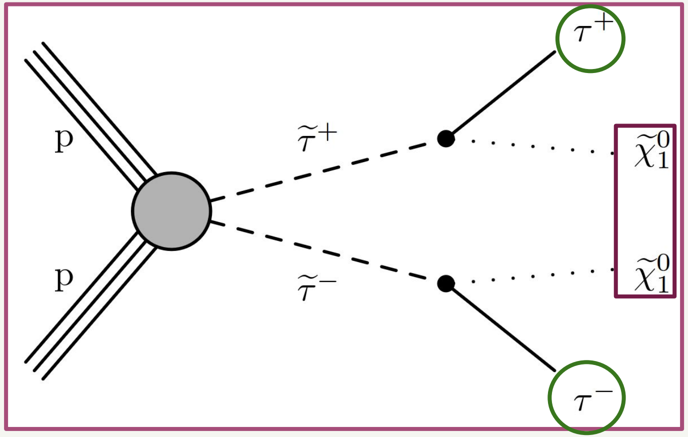
→ The cross section is extremely small, and the signature is hidden under overwhelming background!









The final state consists of two tau leptons and MET
→ The analysis strategy depends on the tau decay channel
→ None of the existing searches have found a strong evidence of the process (yet) (SUS-18-006, SUS-21-001)

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Stau pair production in a nutshell

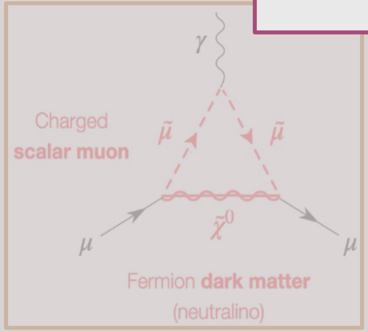
Despite this, there is no need to discard SUSY!

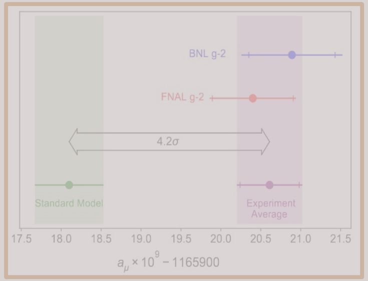
→ We have gathered only a small part of data expected to be delivered by LHC

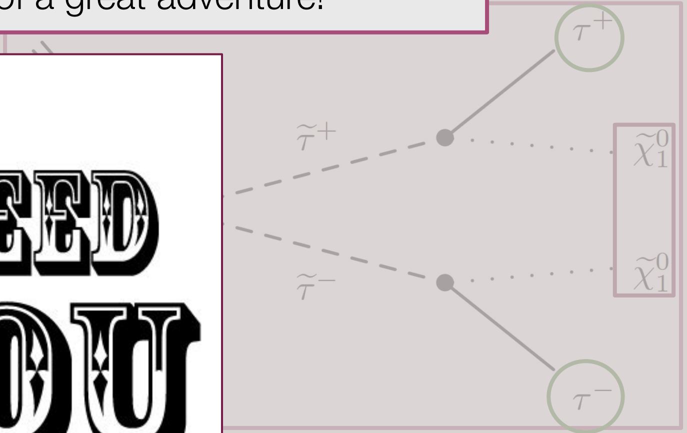
→ HL-LHC will help us to understand if SUSY truly exists…

*Our collaboration relies on **you** to provide the final word on SUSY*

→ Today is (hopefully) just a beginning of a great adventure!







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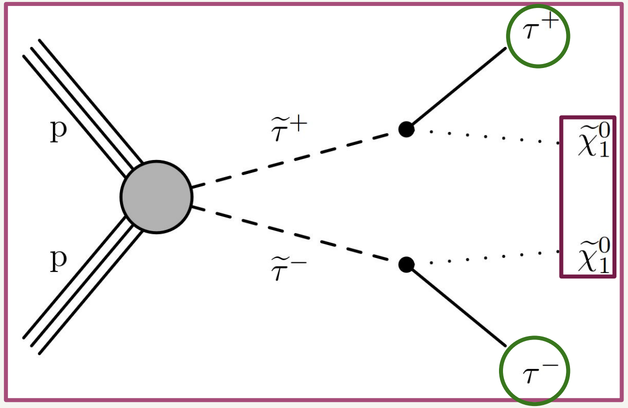
CMSDAS: how to kickstart an analysis in three days?

You will be the first people to look at this process with Run 3 data (2022)!

- You will concentrate on the semi-hadronic final state: $\tau_h\tau_l \rightarrow \tau_h\mu$
- The background contributions will be defined using MC and data
- Your first results will consists of an asymptotic limit for one signal scenario (and possibly a re-analysis with the other)



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Crucial pieces of the analysis code are available at the gitlab of this exercise - we will proceed one step at a time

- Wednesday: Prepare the input (make flat trees from NanoAOD)
- Thursday: Analyze the data, provide datacards (input for Friday)
- Friday: Use Combine to extract the expected limits, use ReAna to ensure a feasible reinterpretation
- Saturday: Present your results to the review committee and other school attendees!

→ The timeline is tight, so let's divide the tasks and start searching for SUSY!

Any questions?