Experimental overview of BSM searches

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Livia Soffi

on behalf of ATLAS and CMS collaborations

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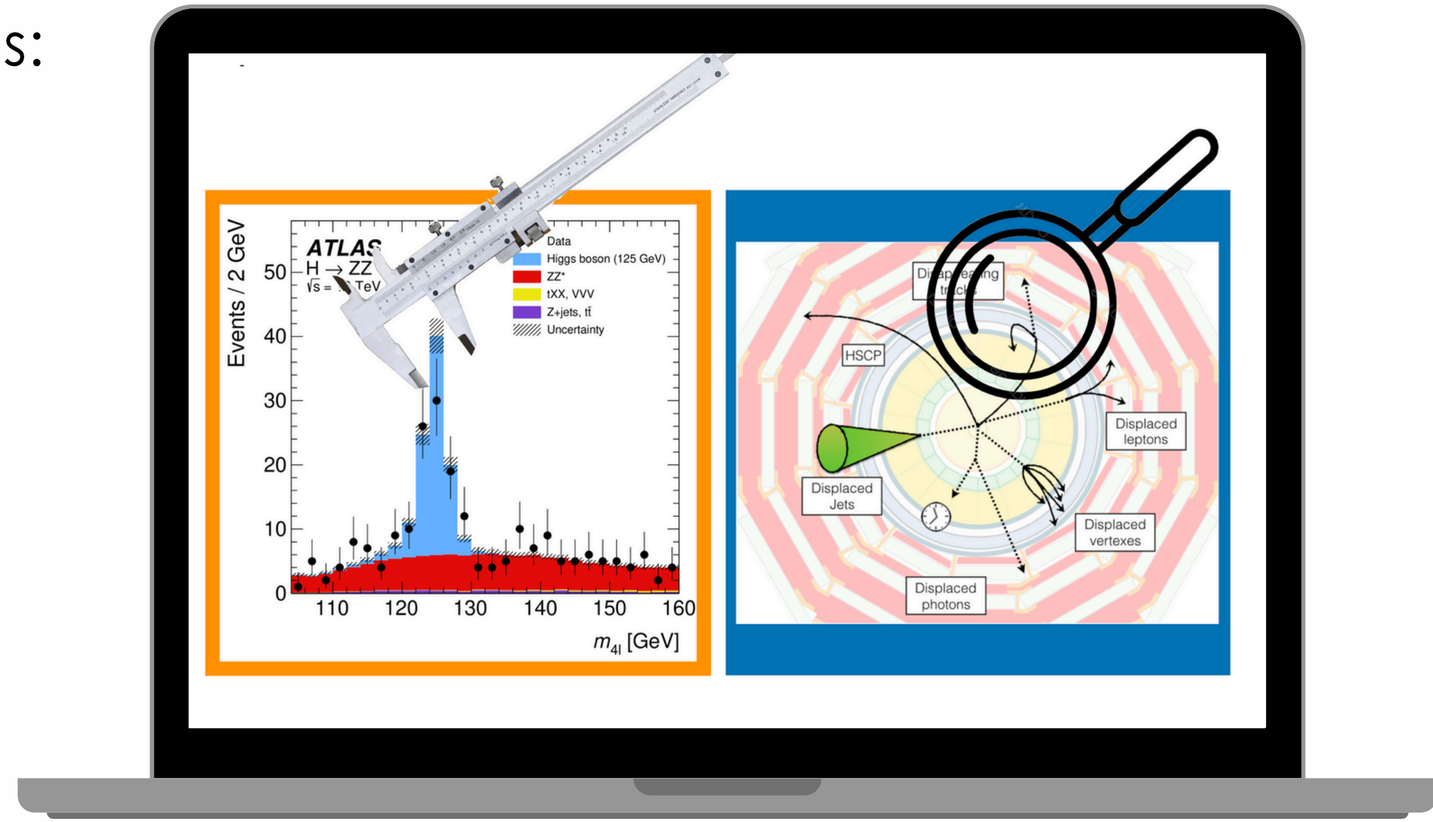
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Beyond the Standard Model (BSM) searches at the LHC

LHC experiments searches strategies:

Precision measurements &
searches for rare process and
unconventional final states



Beyond the Standard Model (BSM) searches at the LHC

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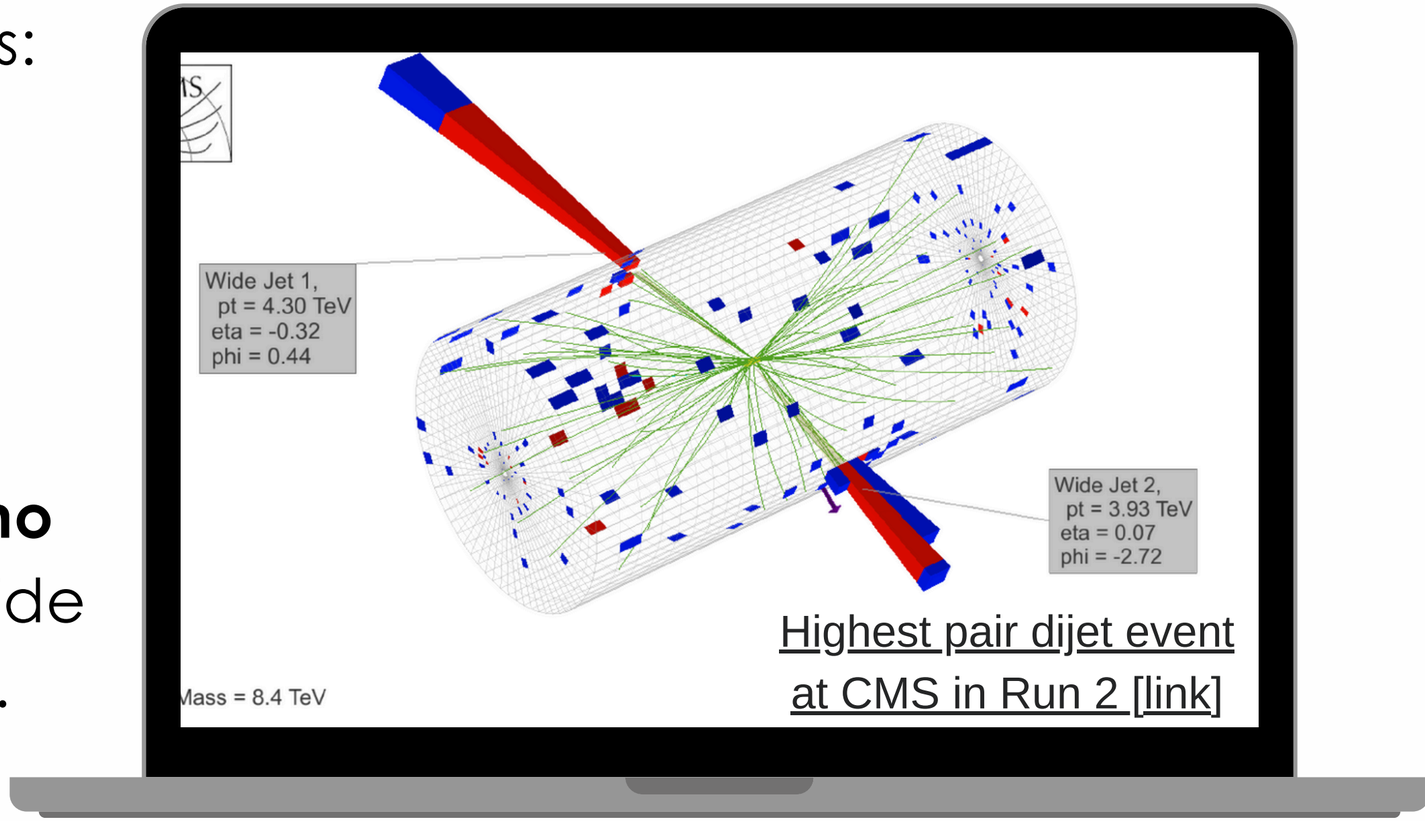
Promising **hints at high energy but no BSM evidence yet**: sensitivity on a wide range of phase space established.



Highest pair dijet event at CMS in Run 2 [link]

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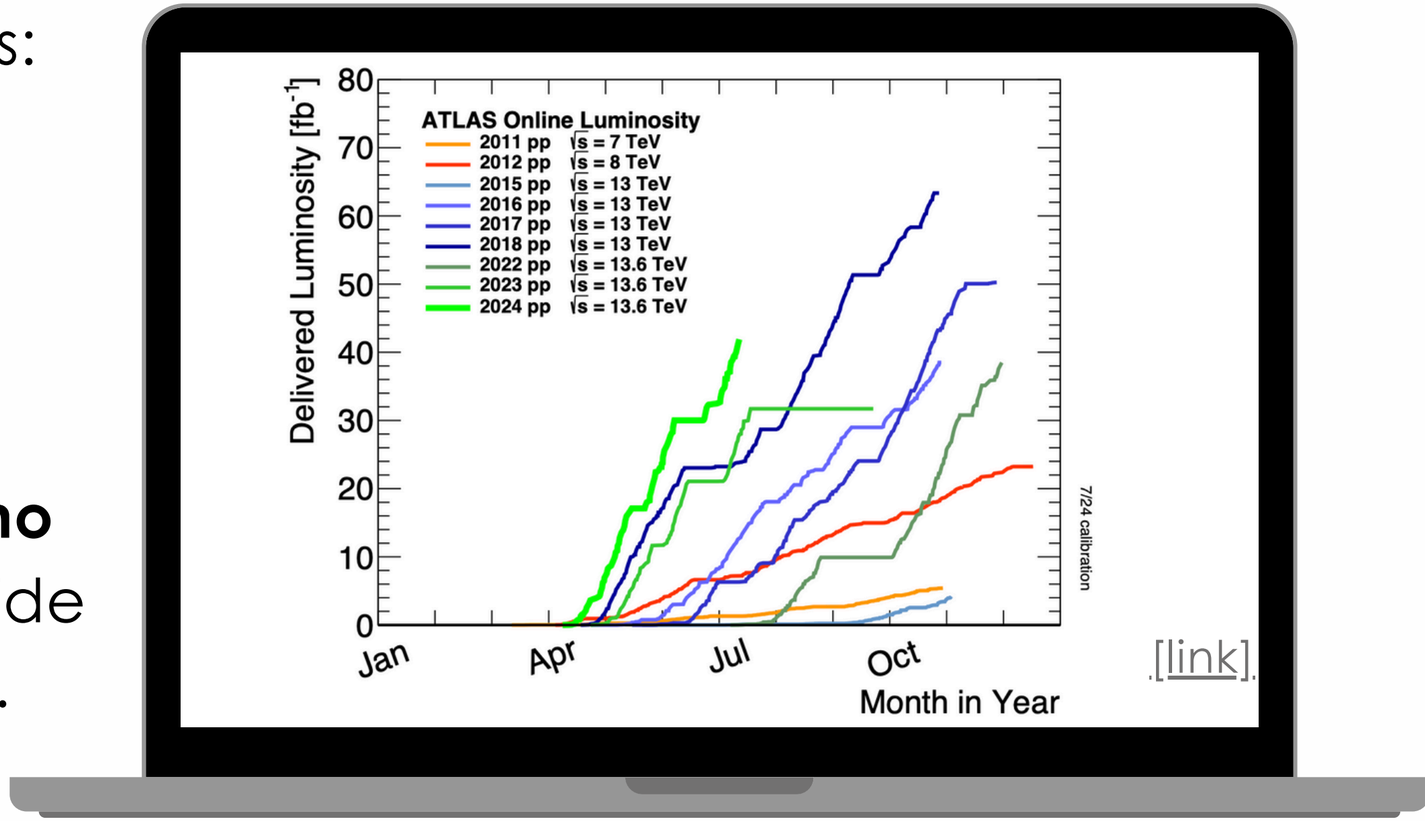

[link]

Gain in luminosity and improvements in detector technology **enhance potential for discoveries in new physics during**

NEW

New BSM searches for

ICHEP 2024 PRAGUE ichep2024.org

Reference	Topic	Experiment	Model	Explored energy range
HDBS-2021-07	$H \to aa \to bb\tau\tau$	ATLAS	Extended Higgs Sector	
HDBS-2020-11	$H^{\pm} \to cs$	ATLAS		
HDBS-2023-19	Combination of charged Higgs	ATLAS		
HIG-24-002	$H \to ZZ \to 4l$	CMS		
HIG-22-004	$A \to Zh(\tau\tau)$	CMS		
SUS-24-001	$\phi \to b\bar{b}$	CMS		
EXOT-2018-55	Prompt Lepton-Jets	ATLAS	Dark Sector	
EXOT-2022-04	Long Lived Particles in the hadronic calorim.	ATLAS		- displaced
SUS-23-004	$\text{mono}-t$	CMS		dark matter
SUS-23-012	$\text{mono}-h(\tau\tau)$	CMS		dark matter
SUS-23-018	$H \to Za \to ll\chi\chi$	CMS		
SUS-24-004	pMSSM	CMS	Supersymmetry	
SUS-23-003	Compressed Supersymmetry	CMS		Δm
ATLAS-CONF-2024-011	Run3 displaced leptons	ATLAS		- displaced
SUS-23-002	Supersymmetry w/ charged leptons and missing energy	CMS		
ATLAS-CONF-2024-008	Vector Like Leptons (VLL) 4321 model (tau hadronic)	ATLAS	Heavy Fermions	
EXO-23-015	$\text{VLL} \to \tau a(\gamma\gamma)$	CMS		- displaced
B2G-22-005	$t^* \to tg$	CMS		
EXO-23-010	$ll + \text{b} - \text{jets}, \text{non} - \text{resonant}$	CMS	EFT	
EXO-24-007	Low mass dijet+ISR	CMS	New Mediators	
EXO-22-006	$Z' \to \mu\mu + \text{b} - \text{jets}, \text{resonant}$	CMS		
EXO-22-013	t-channel scalar and vector	CMS	Leptoquarks	up t 5 TeV

Explored energy range: 0 300 600 900 1200 1500 1800 2100 2400 2700 3000 [GeV]

Shown today

NEW

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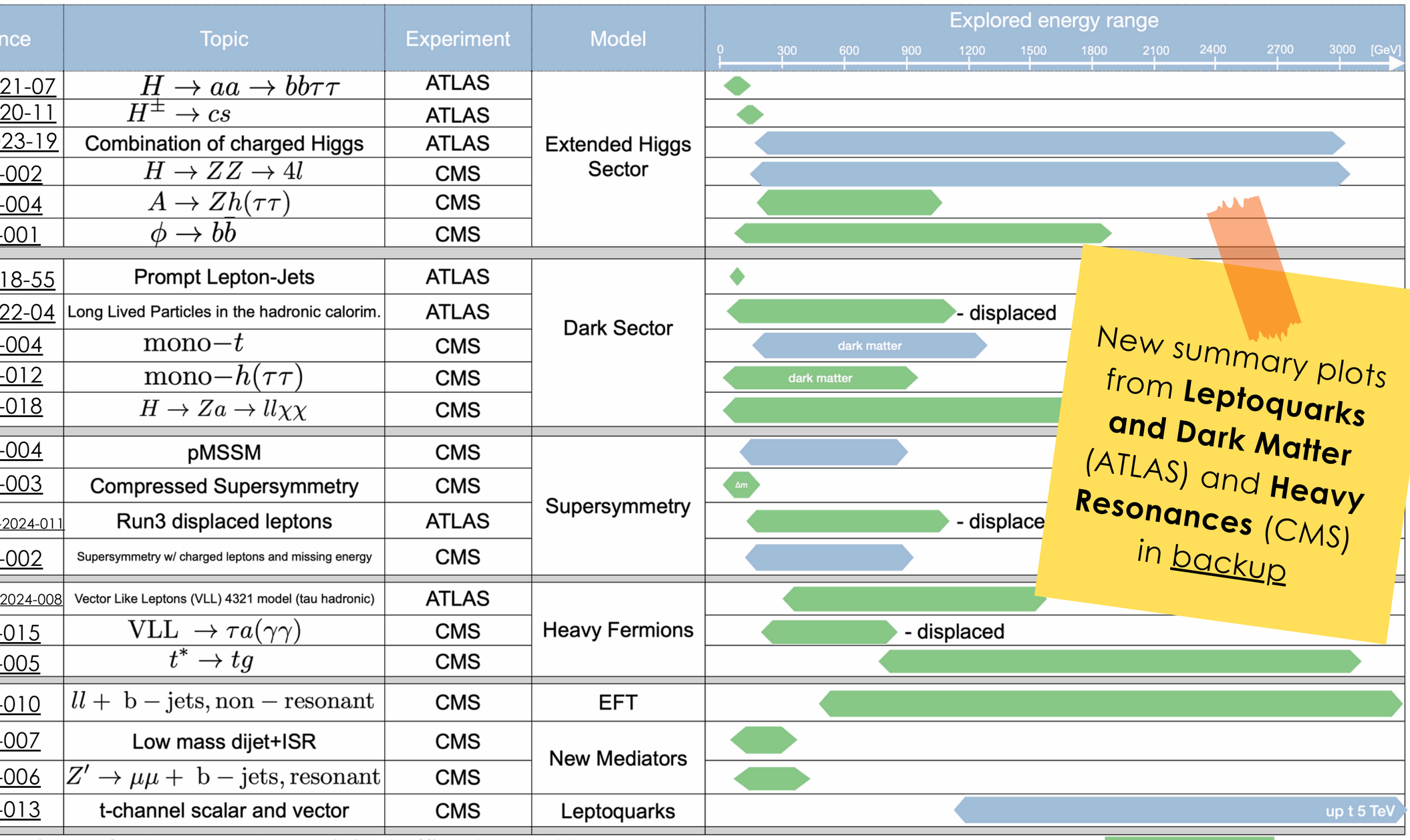


New summary plots from **Leptoquarks and Dark Matter** (ATLAS) and **Heavy Resonances** (CMS) in backup

Shown today

Beyond **S**tandard

Model

Strategies

Signatures

Tools

Beyond Standard

Model

- *Extended Higgs Sector(2HDM)*
- *Supersymmetry (SUSY)*
- *Heavy fermions*

Strategies

Signatures

Tools

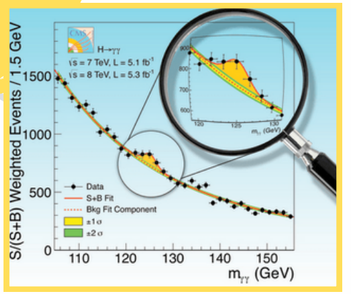
Extended Higgs Sector: Two Higgs doublet model (2HDM).

$H^{\pm}$

A

H

h



[link]

Already observed Higgs Boson

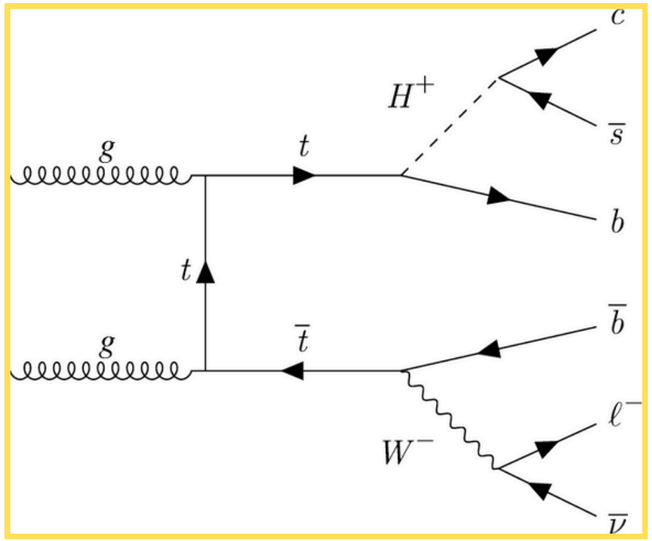
arXiv:2203.07244

NEW

Two Higgs doublet model (2HDM): $H^{\pm}$, A, H, h

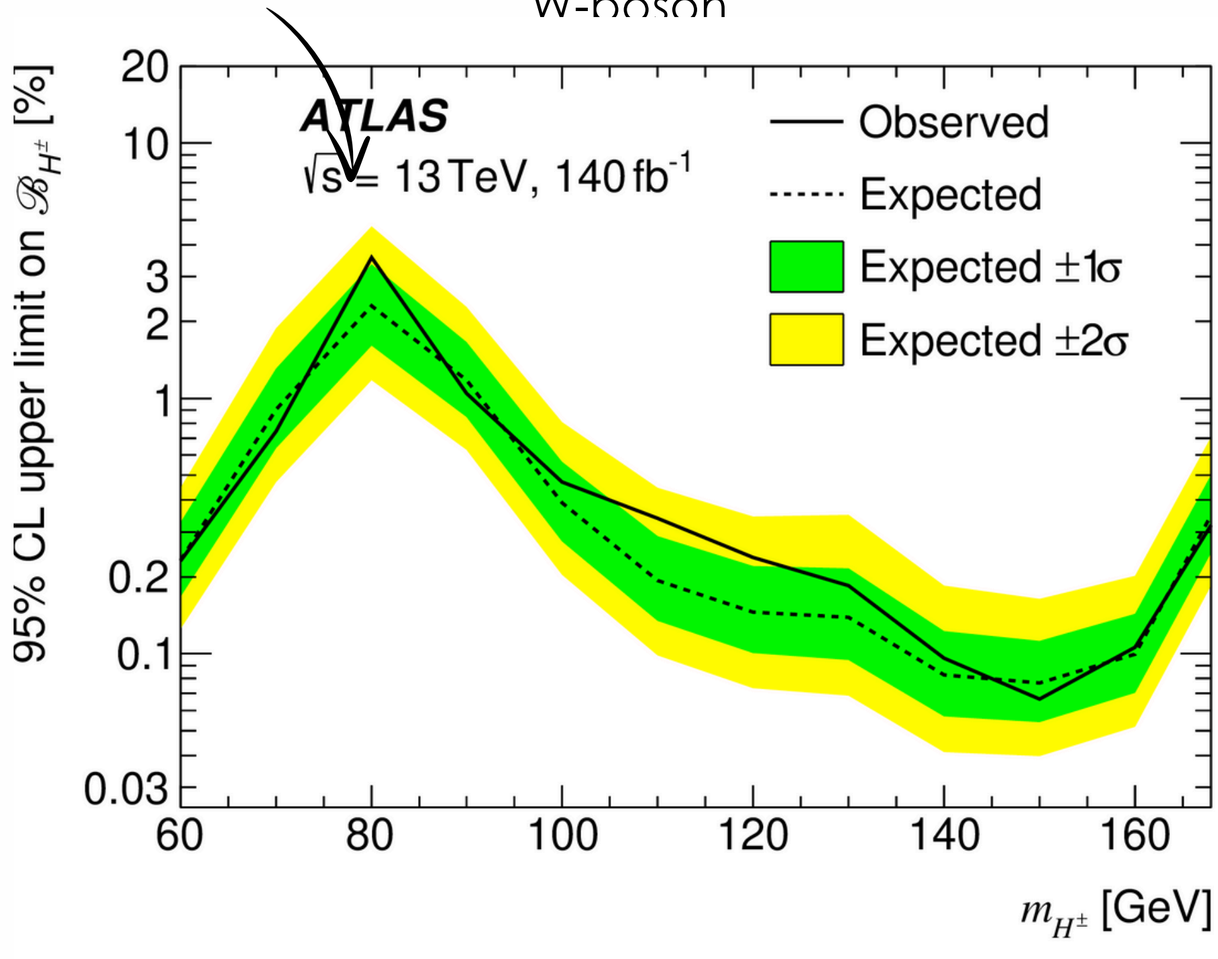
Search for $t \to H^{\pm} b$ *with* $H^{\pm} \to cs$

$H^{\pm} \to cb$ moderate **excess around 130 GeV from ATLAS**, with global significance of 2.5 σ [link]



Dedicated flavour-tagging scheme: **simultaneous tagging of b- and c-jets.**

Least stringent at ~80 GeV about 2.3%, as signal mass closest to W-boson



Limits worsen as the acceptance decreases

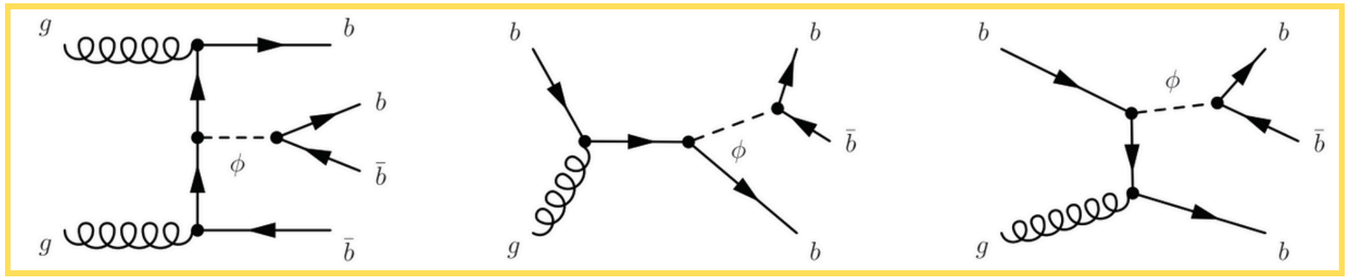
arXiv:2407.10096

Backup

NEW

Two Higgs doublet model (2HDM): $H^{\pm}$, A, H, h

Search for bosons of an extended Higgs sector in b quark final states

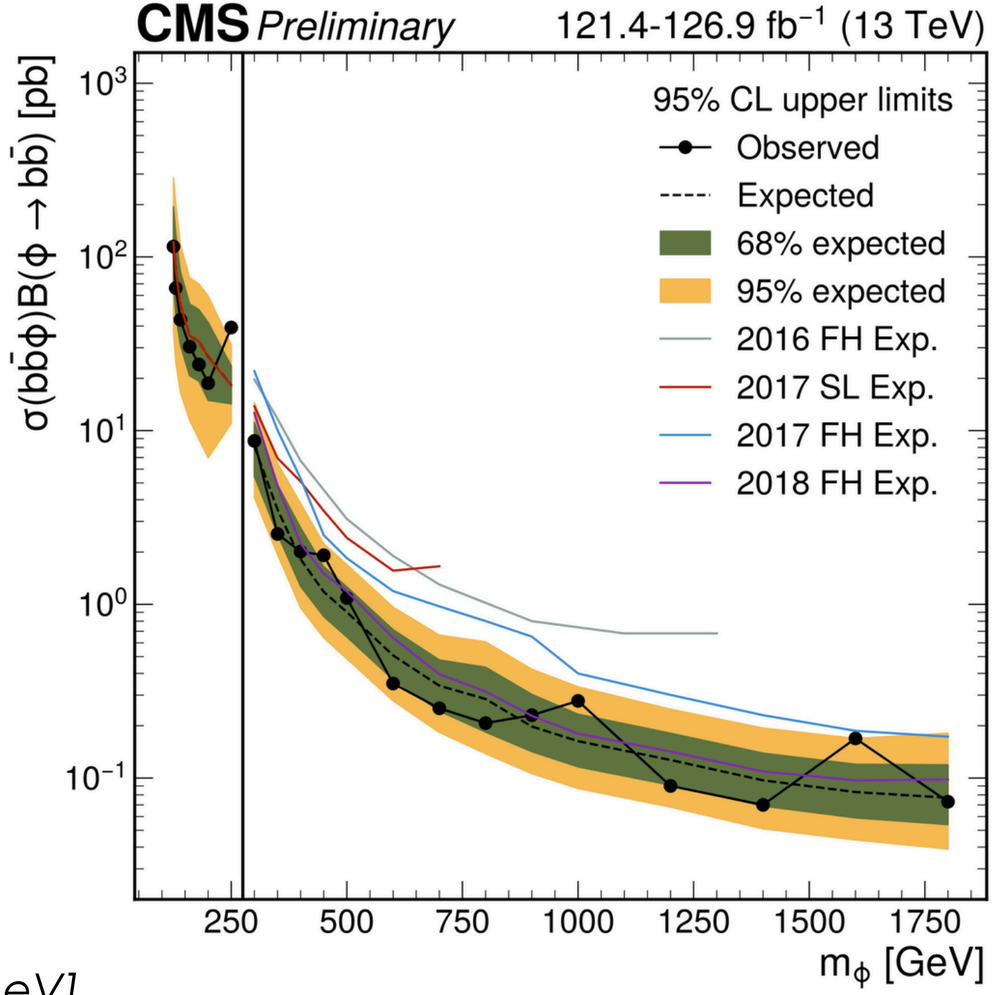


Searching for a **peak in the invariant mass distribution**,of the two b jets with the highest p_T values

Two different signatures explored to maximize sensitivity over a wide mass range

Semi Leptonic (SL) **Fully Hadronic (FH)**

125 700 1800 m [GeV]



CMS-PAS-SUS-24-001

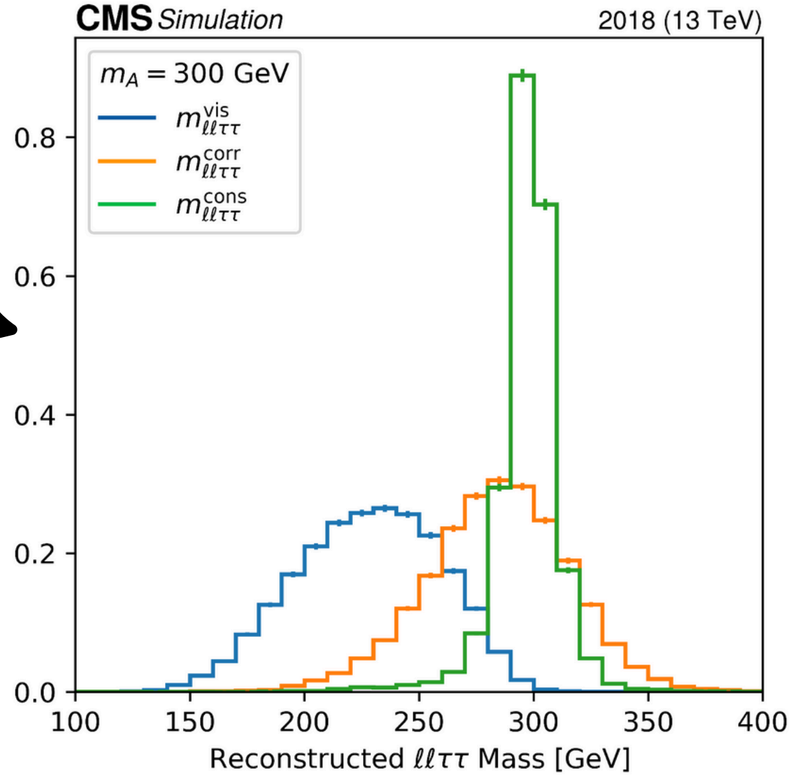
Backup

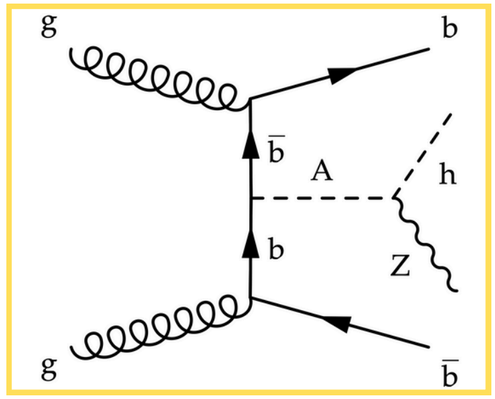
NEW

Two Higgs doublet model (2HDM): $H^{\pm}$, A, H, h

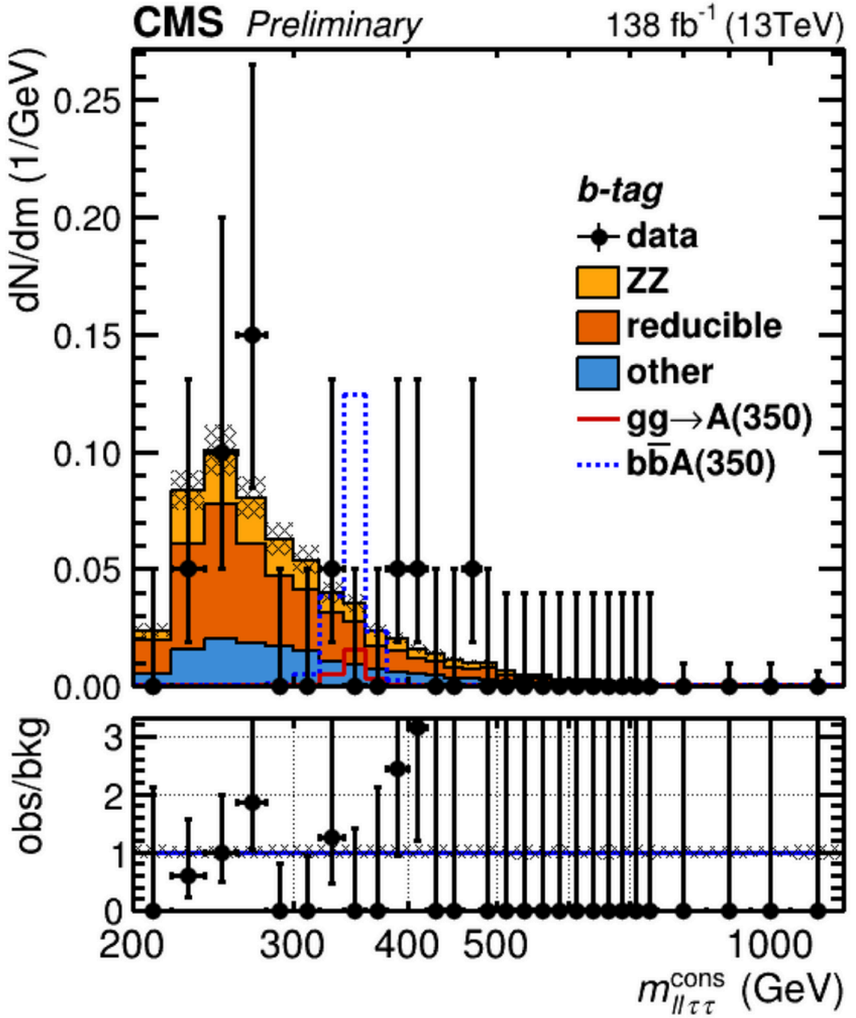
Search for $A \to Zh(h \to \tau\tau)$

Dedicated mass estimator corrects for missing momentum from neutrinos while constraining h mass to 125 GeV: **best mass resolution of 5-7%**





Category w/ b-jets designed to bbF production mode



CMS-PAS-HIG-22-004

Backup

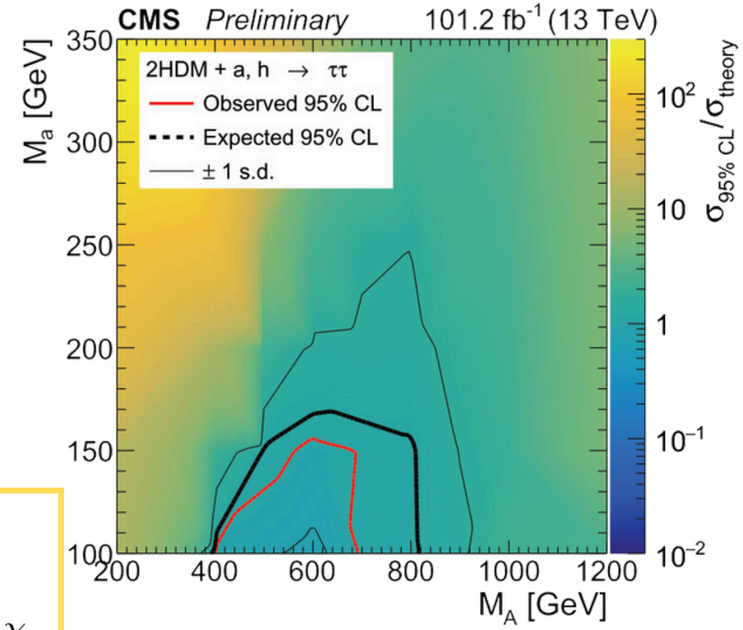
NEW

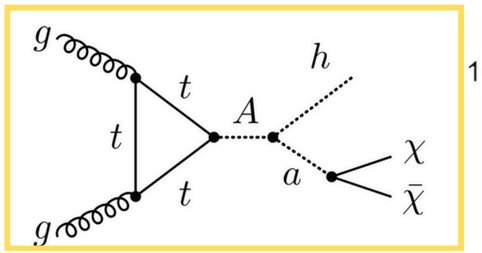
Two Higgs doublet model (2HDM+a): $H^{\pm}$, A, H, h,a

2HDM+a: extension of the Standard Model that includes two Higgs doublets and **an additional pseudoscalar particle (a)**

*Search for **dark matter produced with a Higgs boson** decaying to $\tau\tau$*

CMS-PAS-SUS-23-012





*Search for **dark matter with b-quarks and lepton pairs***

Impacts the masses and couplings of the Higgs bosons

b-quark fusion

tan β

CMS-PAS-SUS-23-018

first time at the LHC

Backup

NEW

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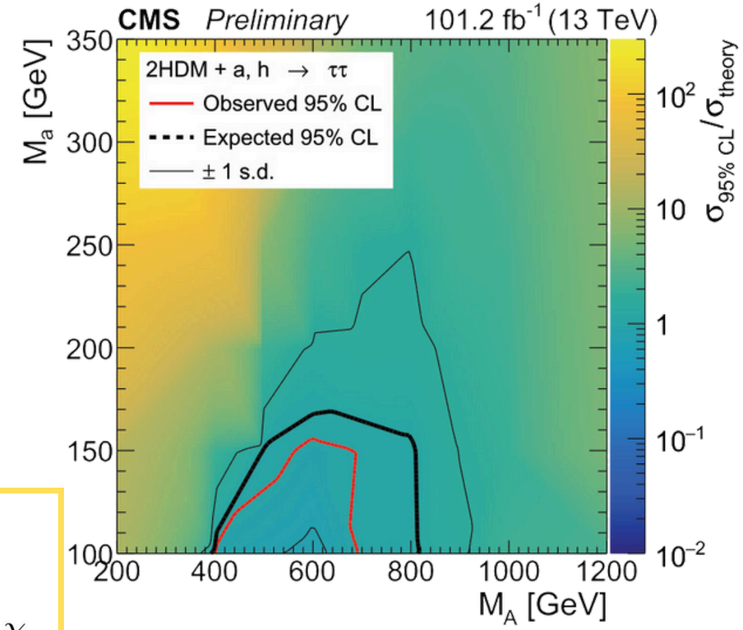
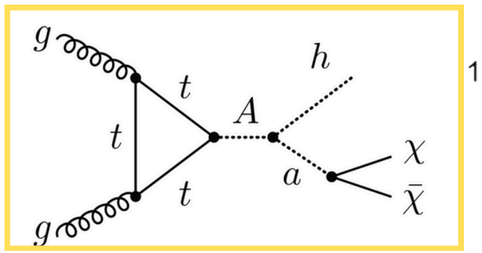
CMS-PAS-SUS-23-012





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CMS-PAS-SUS-23-018

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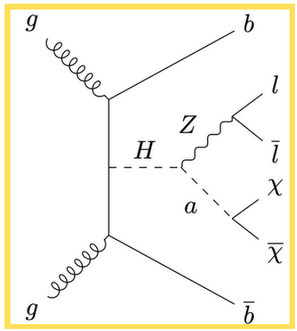
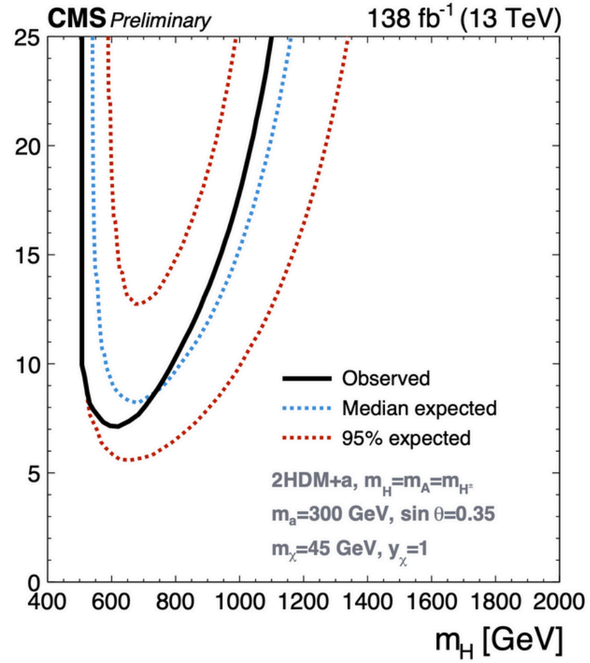


b-quark fusion

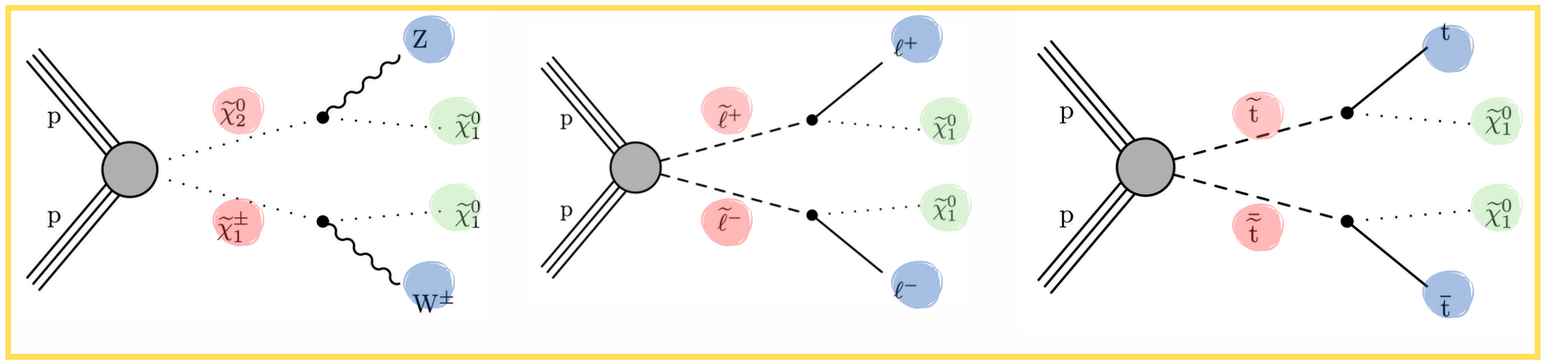


first time at the LHC

Backup

Supersymmetry (SUSY).

Compressed supersymmetry scenarios



Events categorized based on lepton or (b)jets multiplicity and **kinematic variables sensitive to mass splittings**

$3\text{GeV} < \Delta m(\tilde{\chi}_2^0 - \tilde{\chi}_1^0) < 200\text{GeV}$ → low-p_T visible objects; very little missing energy

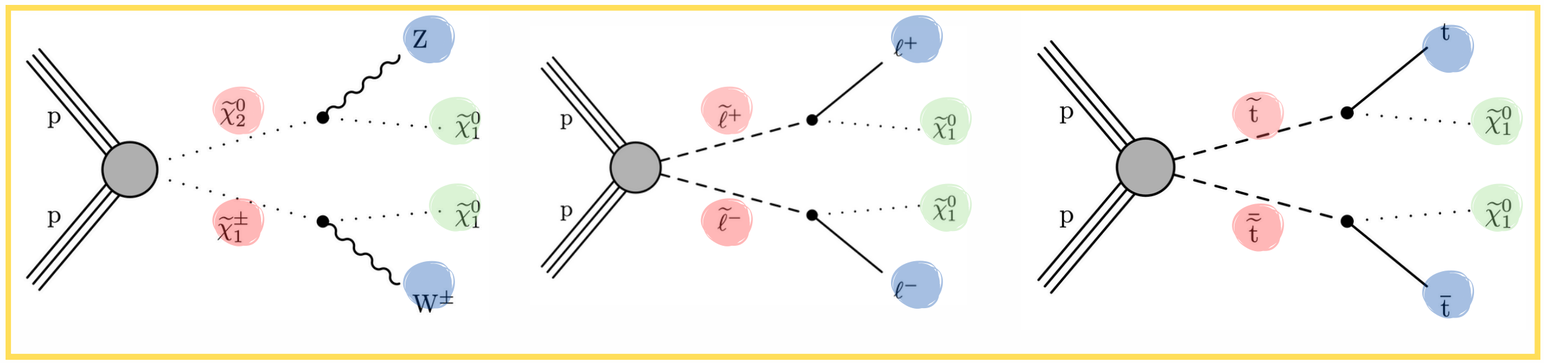
$R_{ISR} \sim m_{invisible\ system}$

CMS-PAS-SUS-23-003

Backup

NEW

Compressed supersymmetry scenarios



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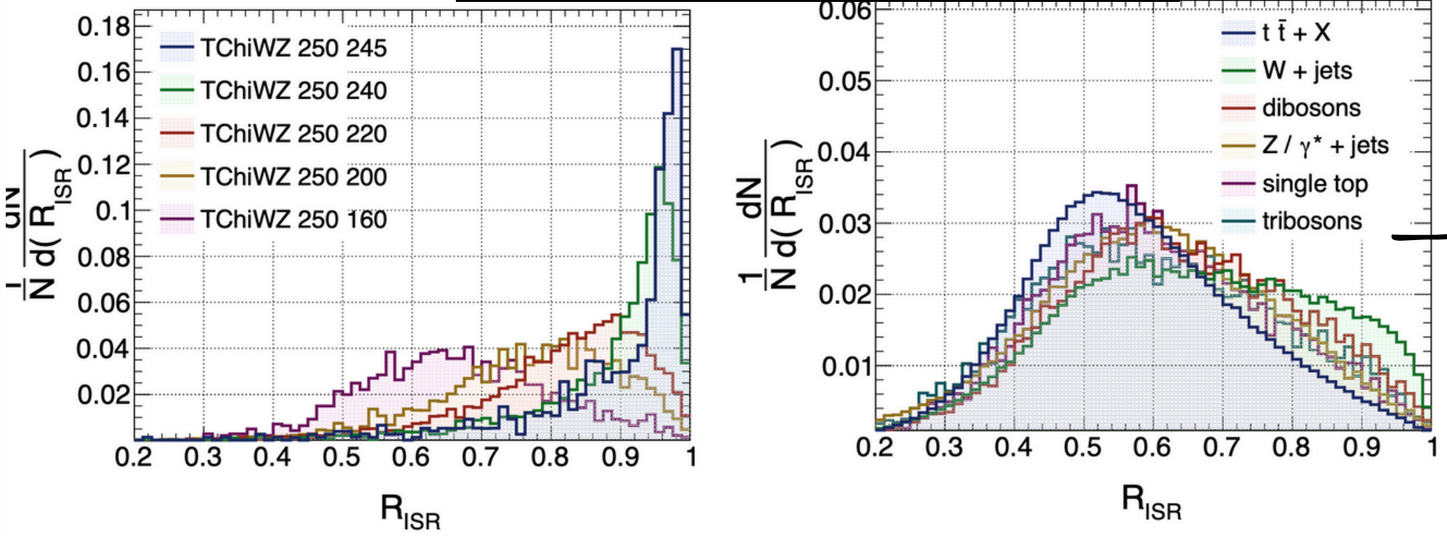
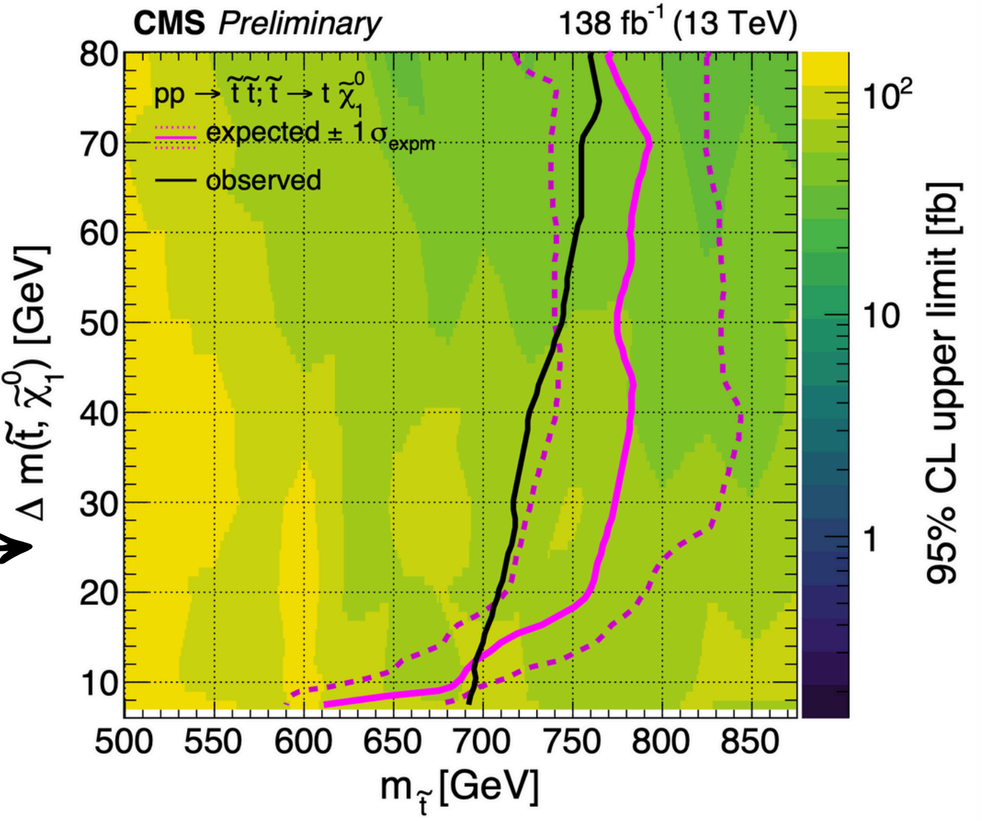




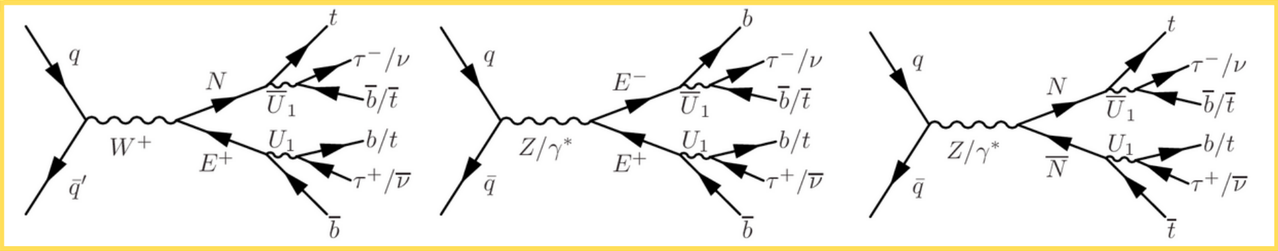
CMS-PAS-SUS-23-003

Backup

Heavy Fermions

NEW

Vector Like Leptons (VLLs)

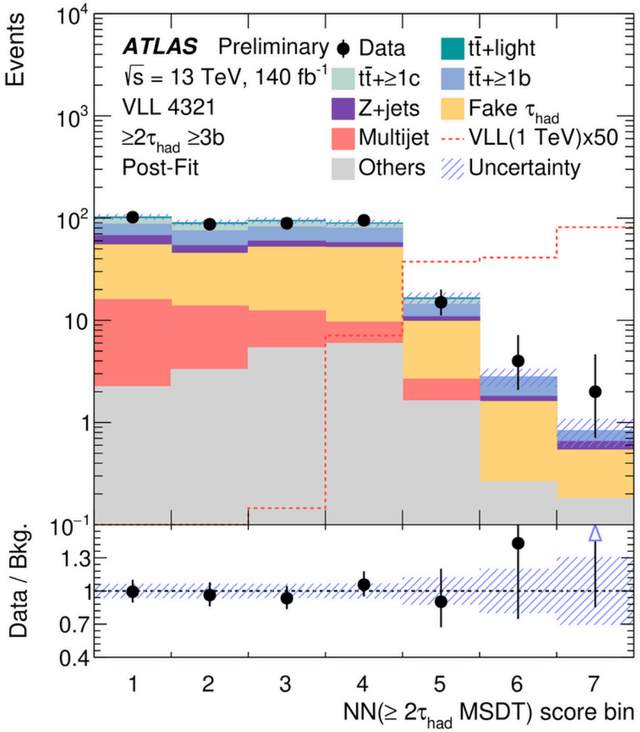


<u>Existing result from CMS</u> w/ local 2.8σ **excess at mass of 600 GeV** disfavoured

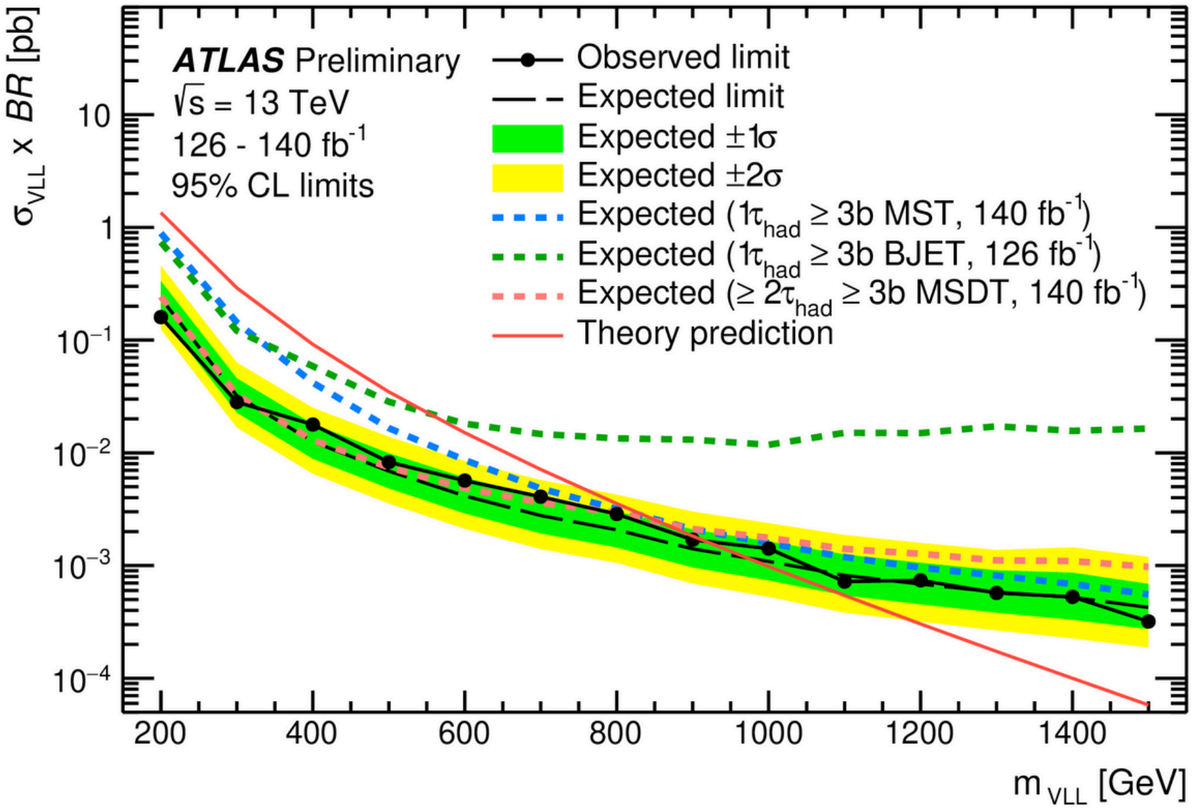
<u>"4321 model" explored</u>

Signature: large # jets, b-jets, and multiple τ_h

Neural network exploits the complex kinematic of the final state to discriminate the signal



Observed (expected) limit on the VLL mass at 910 GeV (970 GeV)

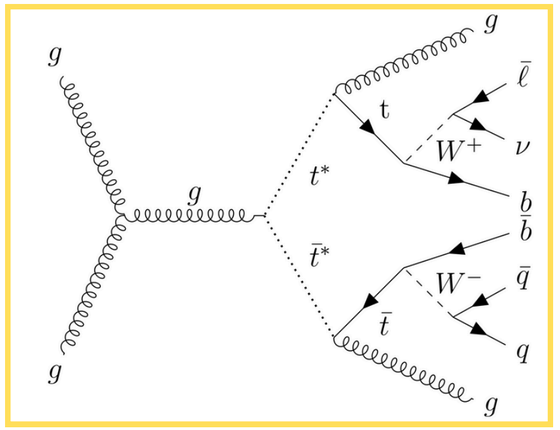


ATLAS-CONF-2024-008

Backup

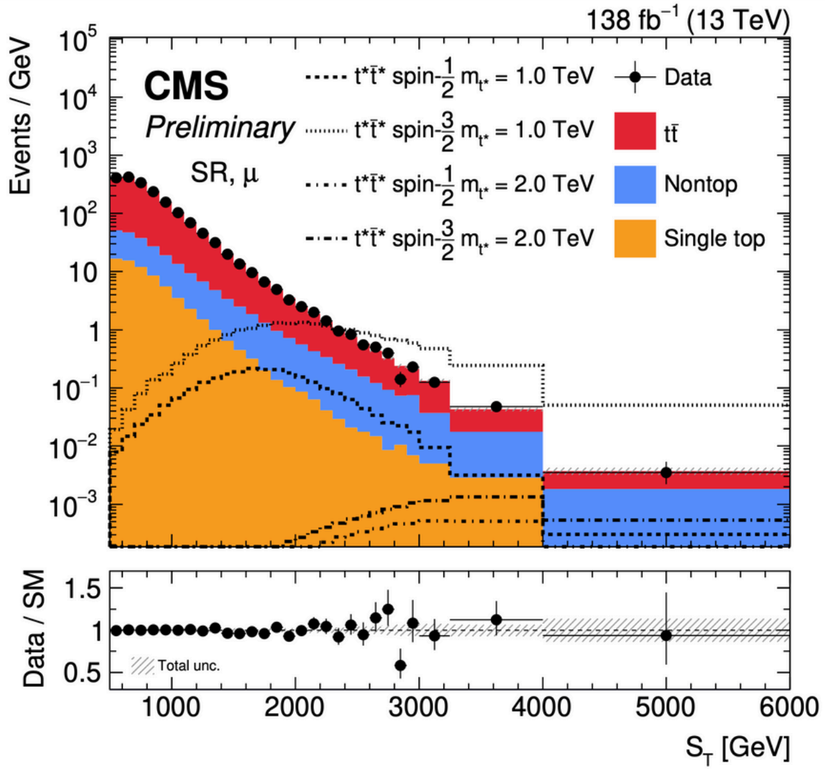
NEW

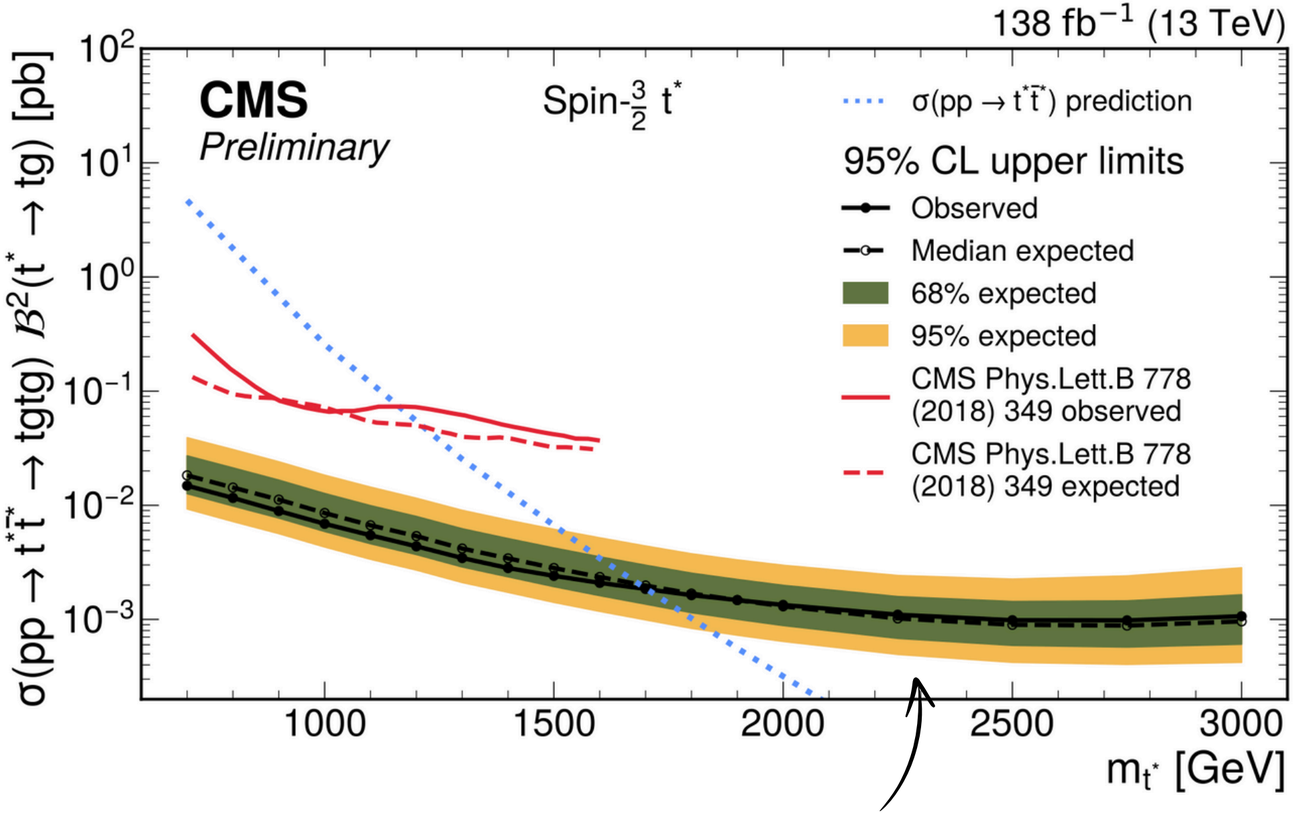
Pair production of excited top (t*).



$$S_{\mathrm{T}} = p_{\mathrm{T}}{}^{\ell} + p_{\mathrm{T}}^{\mathrm{miss}} + \sum_i p_{\mathrm{T},i}{}^{\mathrm{jet}}$$

Quarks as non fundamental particles can have substructure and can exist in excited states





Improved reach w/ full Run 2 data and doubled mass range explored

CMS-PAS-B2G-22-005

Backup

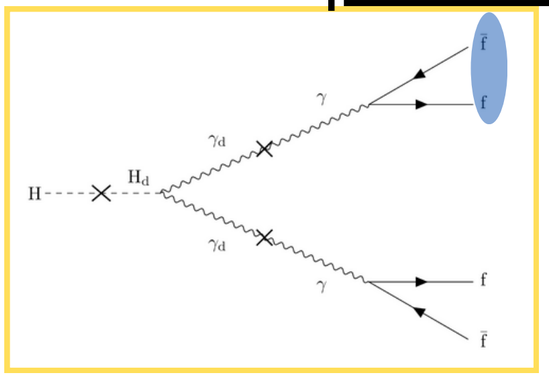
Beyond Standard

Strategies

- *Identifying merged objects*
- *Accessing low energies*

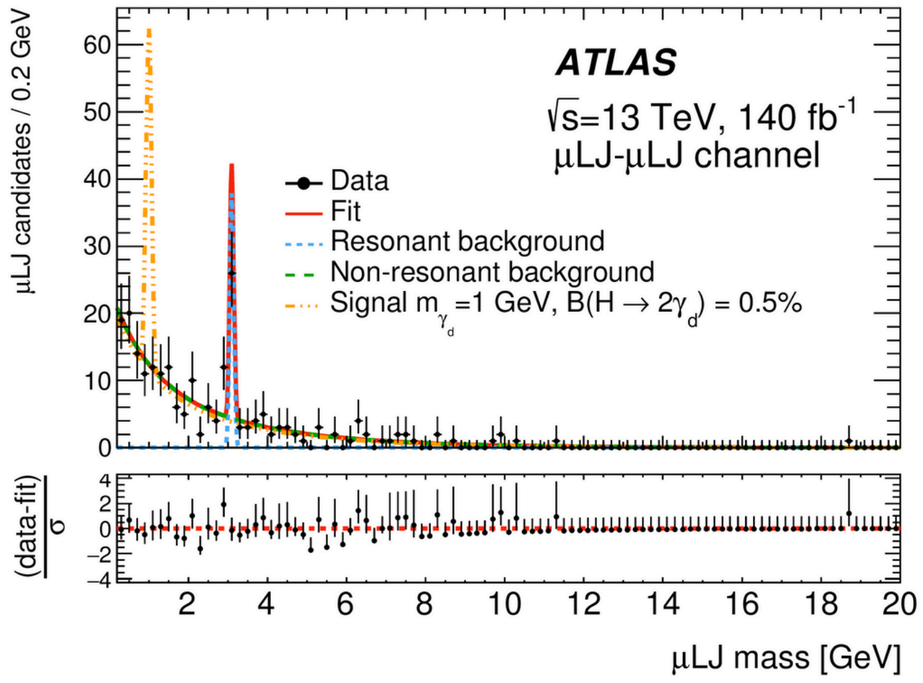
NEW

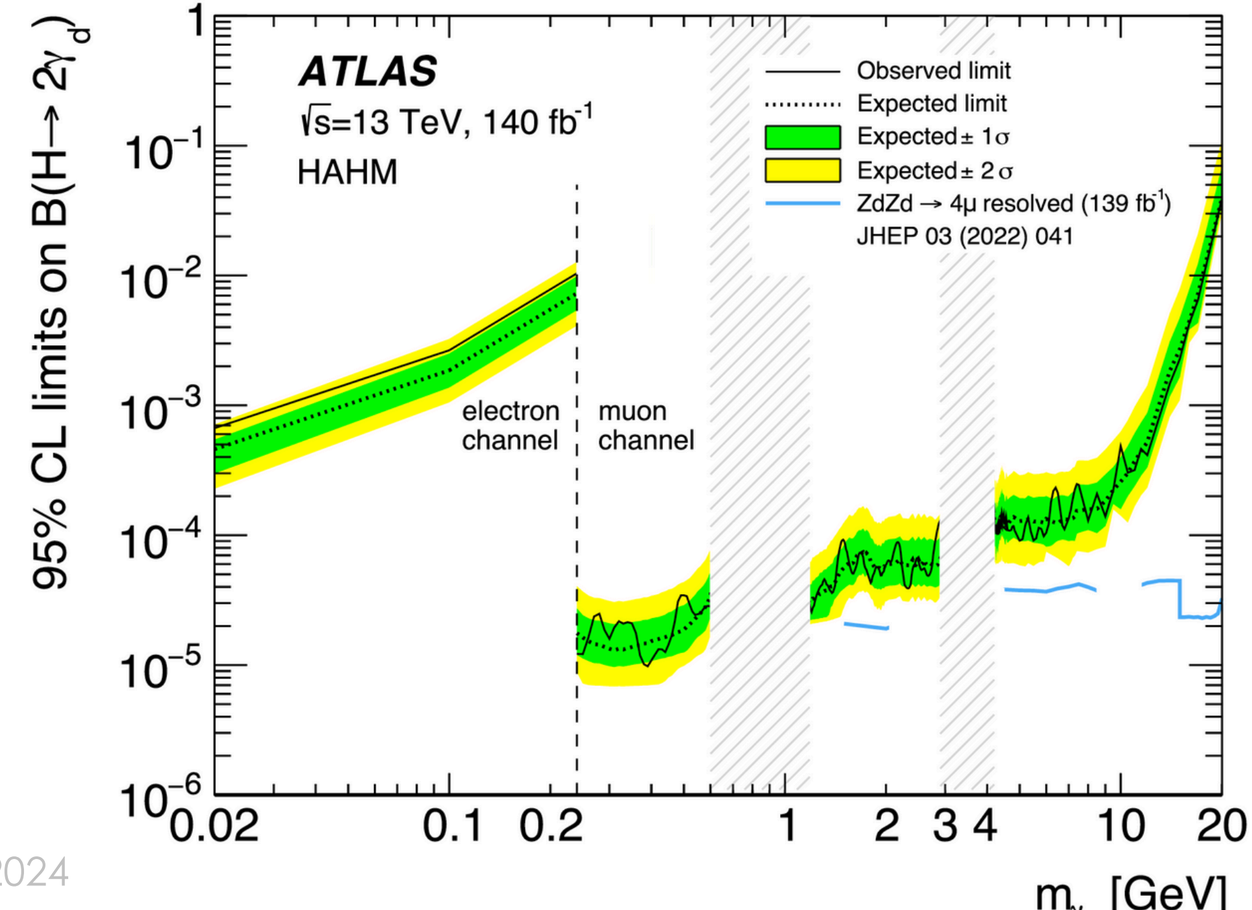
Search for neutral particles decaying promptly to collimated pairs of leptons



LeptonJets (LJs): highly collimated pairs of electrons or muons from light neutral particles decay

Dedicated reconstruction and ID of merged dilepton pairs





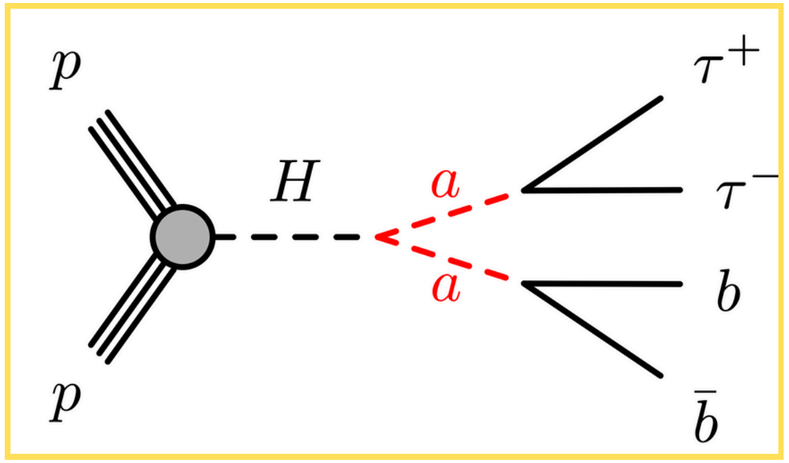
arXiv:2407.09168

Backup

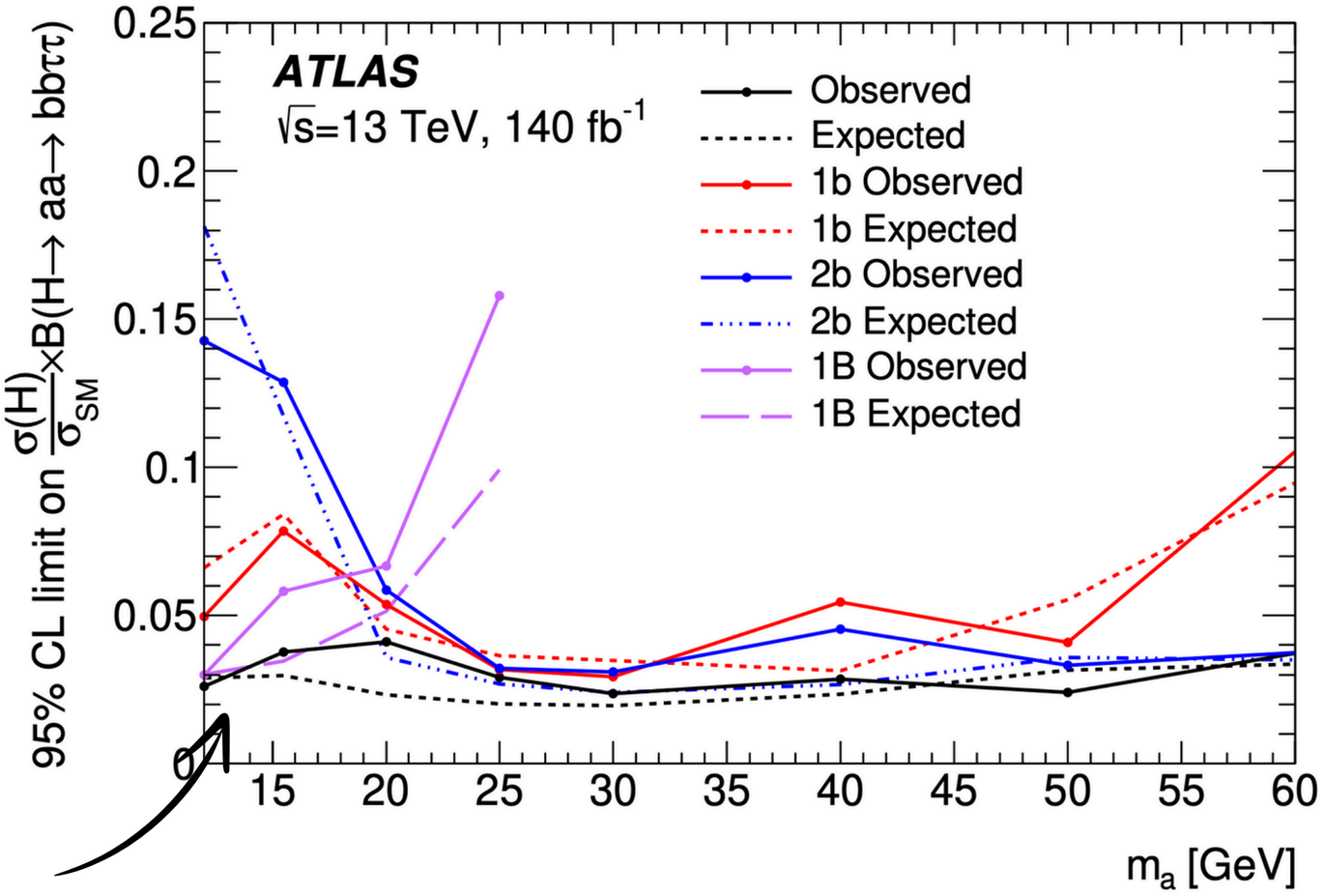
NEW

Exotic decays of the SM Higgs boson

Search for decays of the Higgs boson into a pair of pseudoscalar particles decaying into $b\bar{b}\tau\tau$



Novel, **dedicated algorithm** to identify low mass merged, **"double b-quark" jets (B)** from $a \to b\bar{b}$



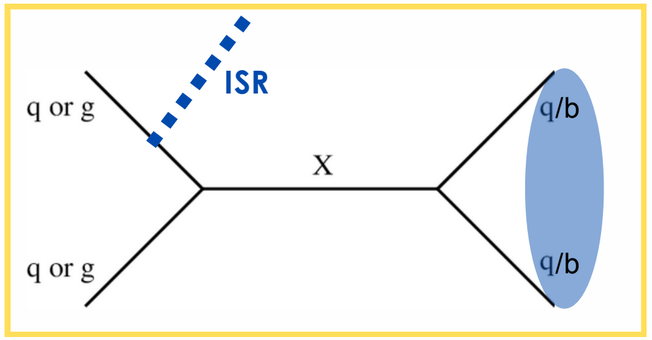
B categories sensitive at low-mass

arXiv:2407.01335

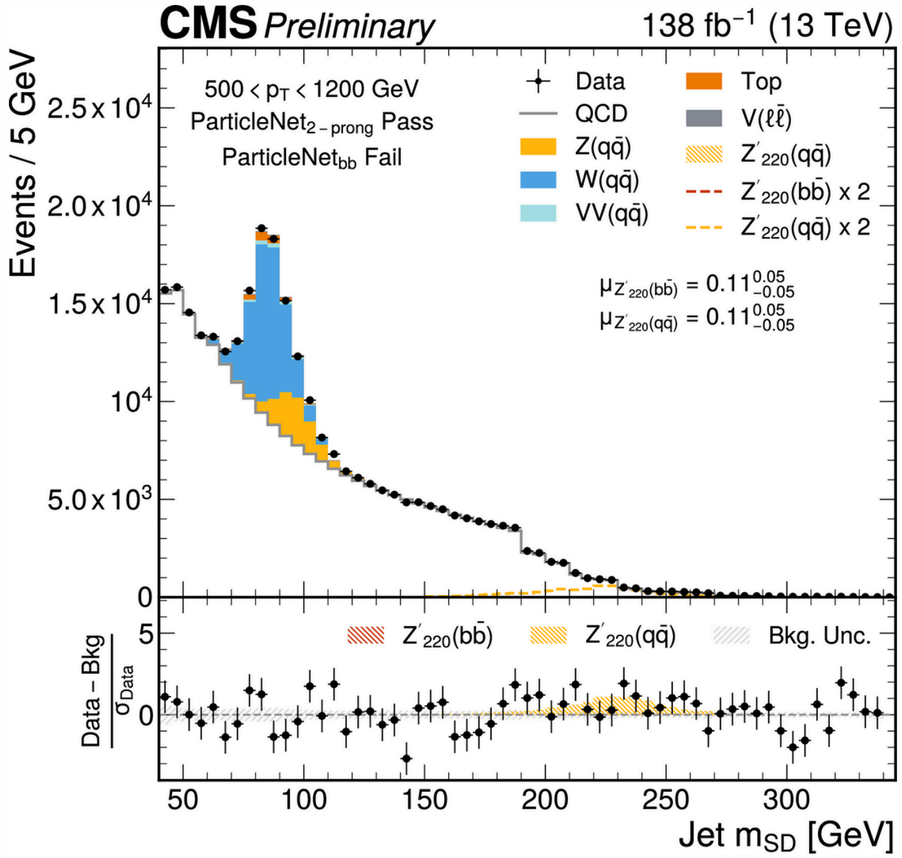
Backup

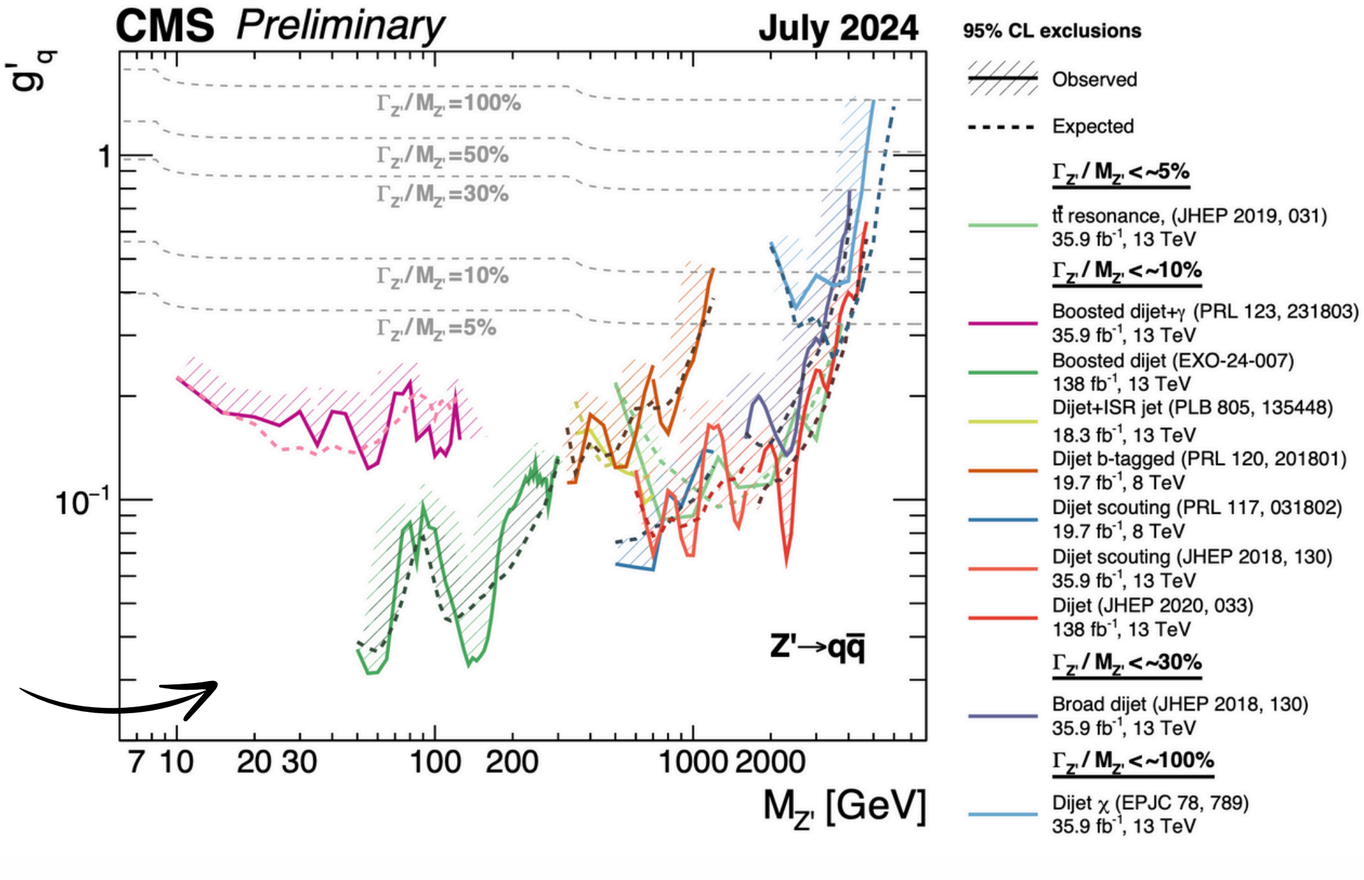
NEW

Search for low-mass resonances into hadrons + ISR



ParticleNet algorithm reconstructs **Large Radius Jet w/ 2 pronged substructure**





CMS-PAS-EXO-24-007

CMS-EXO-Summary-Plots

Backup

Beyond Standard

Model

Strategies

Tools

Signatures

- *Probing the multi-TeV scale*
- *Long-lived particles*
- *Innovative usage of the detector*

NEW

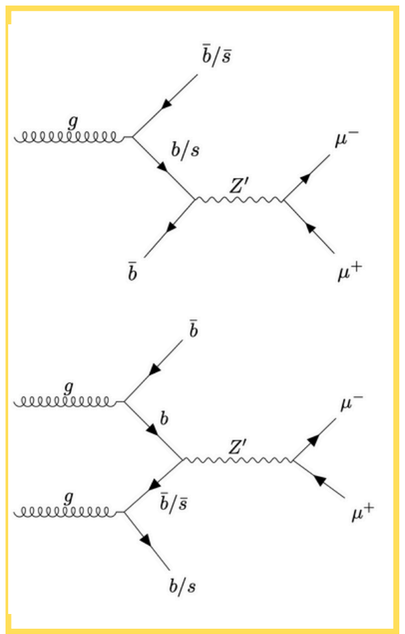
Searches for energetic dileptons w/ b-jets

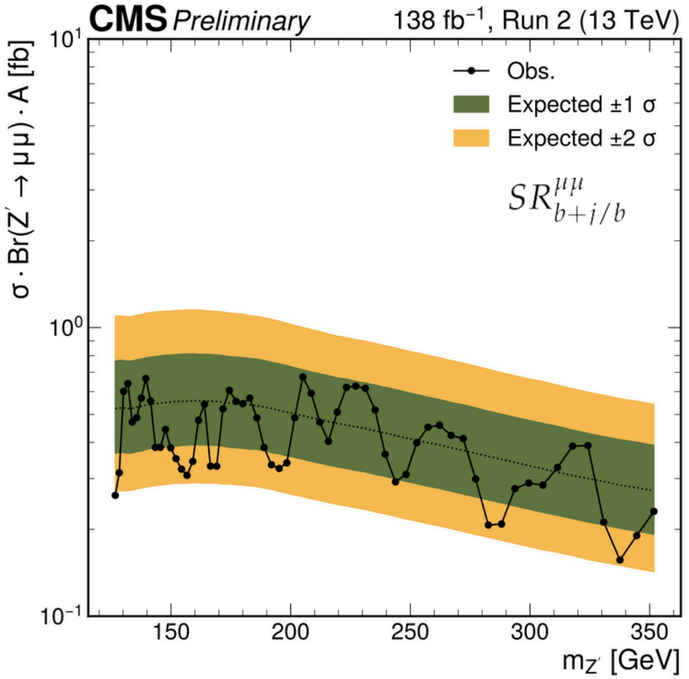
Less conventional dilepton searches beyond inclusiveness in number of jets

Resonant Z' *in dimuon decay + b-jets*

Complementary **result at high mass**
(up to 2 TeV) already published

CMS-PAS-EXO-22-006





Backup

Non-resonant dilepton *+ b-jets*

Lepton flavor universality tested by comparing dimuon and dielectron mass vs # b-jets.

CMS-PAS-EXO-23-010

Backup

NEW

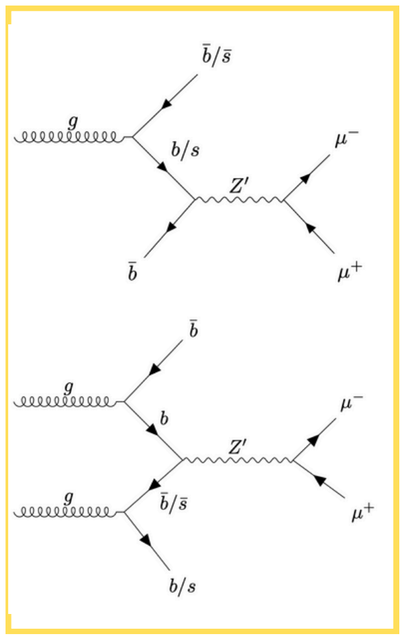
Searches for energetic dileptons w/ b-jets

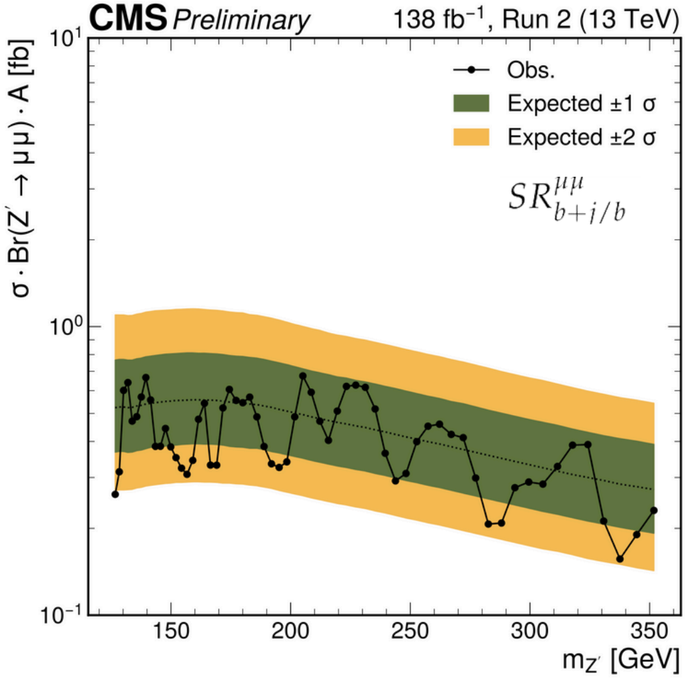
Less conventional dilepton searches beyond inclusiveness in number of jets

Resonant Z' *in dimuon decay + b-jets*

Complementary **result at high mass** (up to 2 TeV) already published

CMS-PAS-EXO-22-006

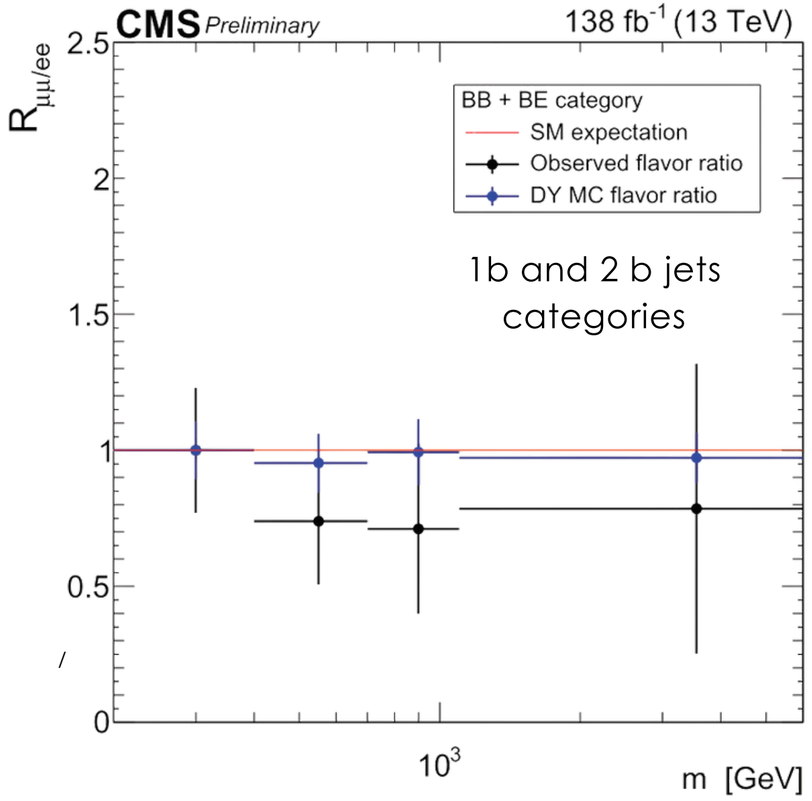




Backup

Non-resonant dilepton *+ b-jets*

Lepton flavor universality tested by comparing dimuon and dielectron mass vs # b-jets.

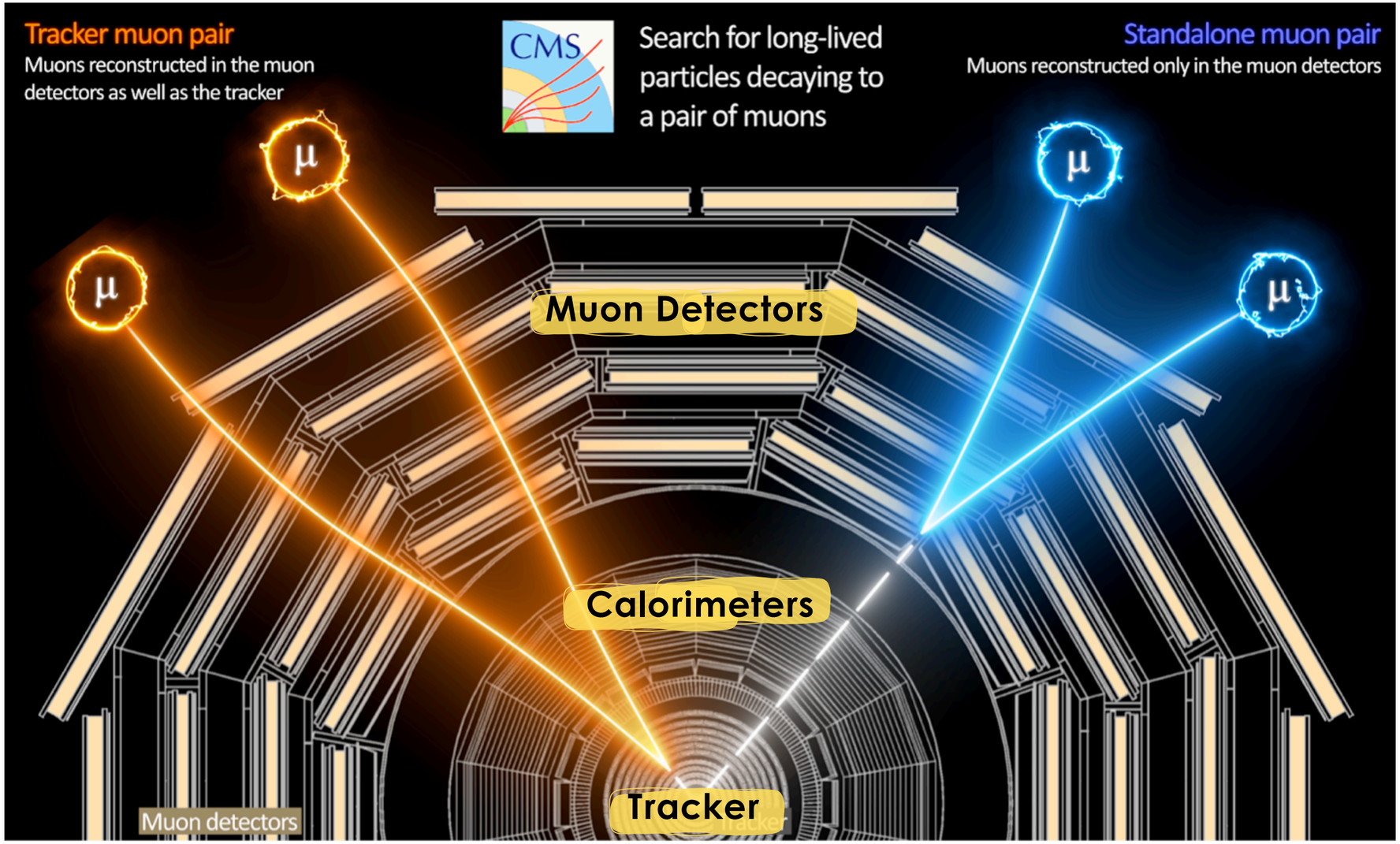


Backup

CMS-PAS-EXO-23-010

NEW

Searches for Long Lived Particles: Decays in Tracker, Calorimeters and Muon Detectors



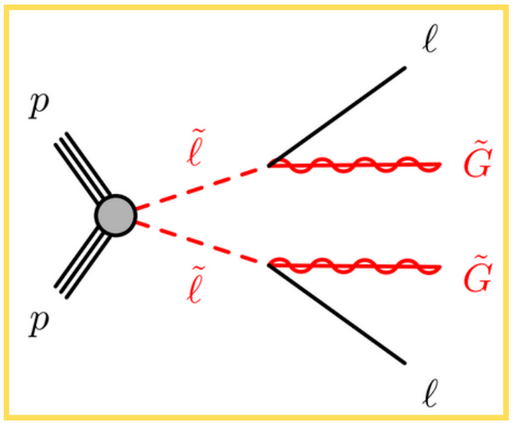
[link]

Searches for Long Lived Particles: Decays in Tracker, Calorimeters and Muon Detectors

Search for displaced leptons in 13 TeV and 13.6 TeV

Large Radius Tracking: designed to increase efficiency for decay products of LLPs.

LRT run in the HLT for the first time at Run 3



Enhanced discovery reach beyond prior searches through several

← **novel additions.**

95% CL exclusion contours for **long-lived selectrons (smuons** and **staus,** see backup)

ATLAS-CONF-2024-011

Backup

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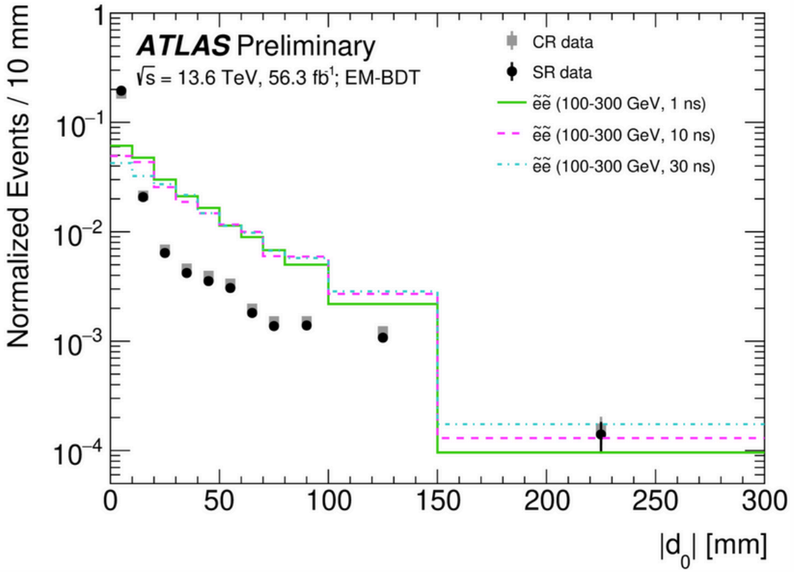

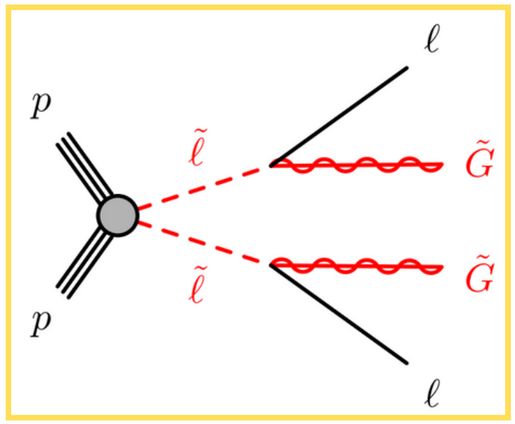

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ATLAS-CONF-2024-011

Backup

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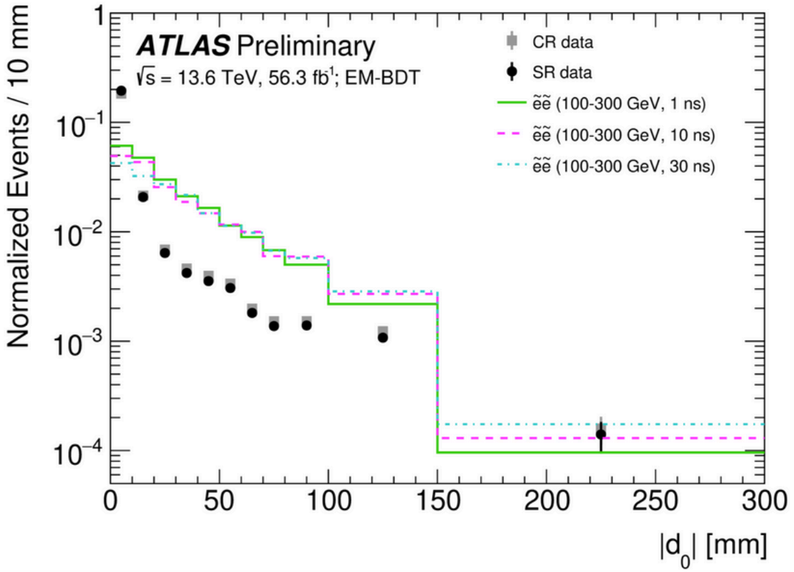

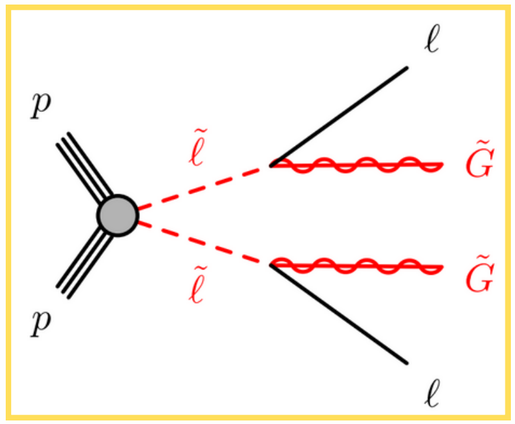

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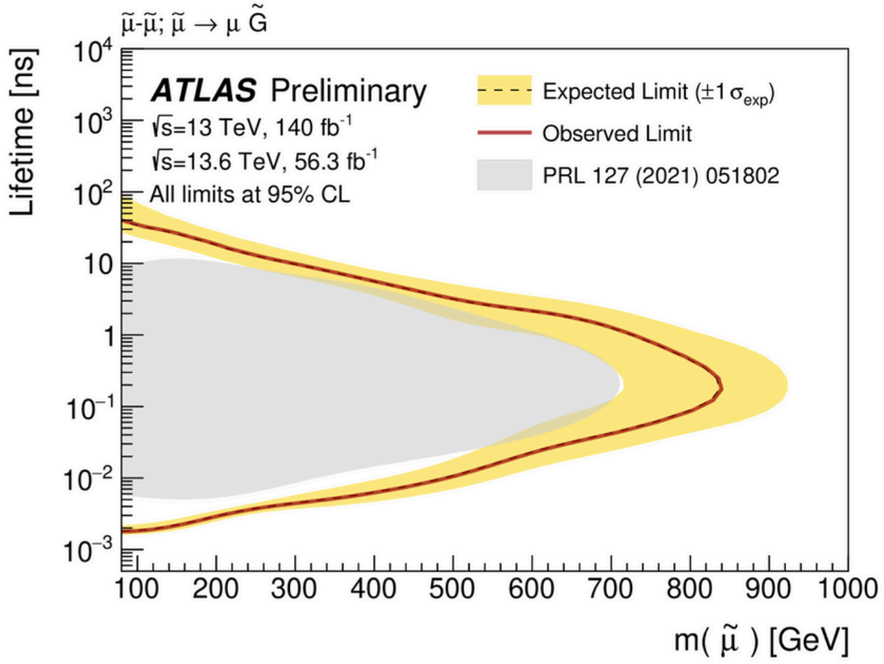


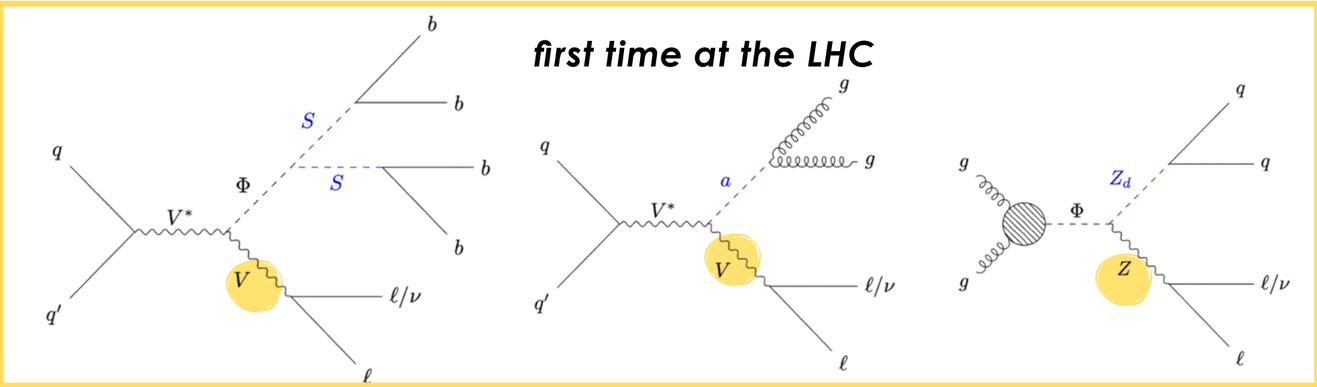
ATLAS-CONF-2024-011

Backup

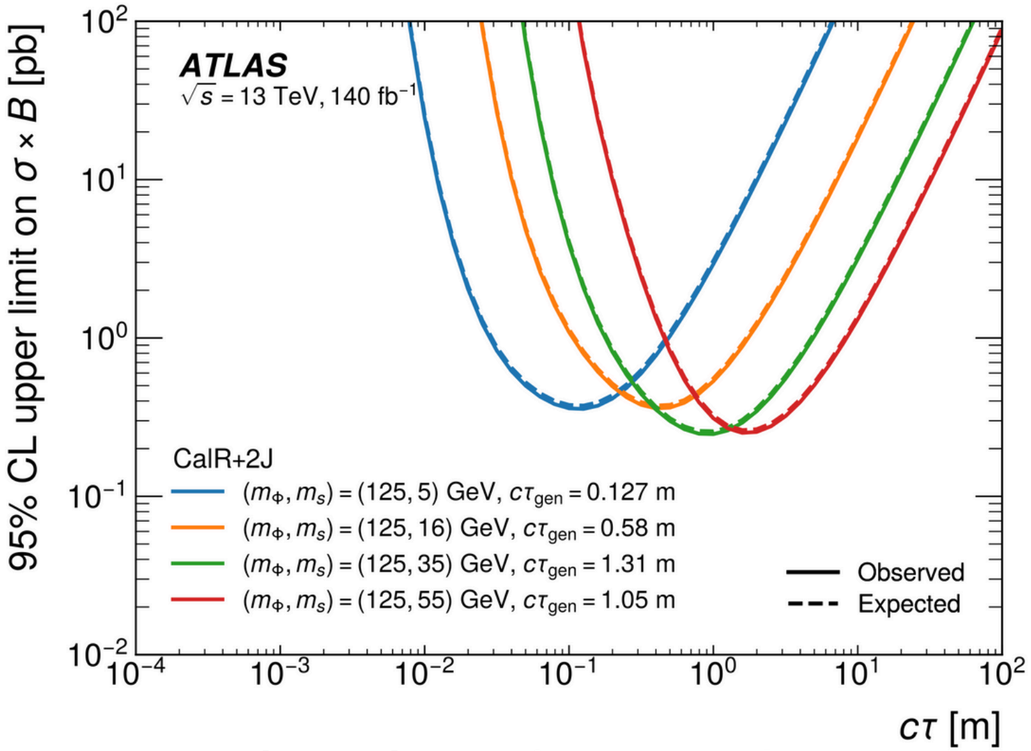
NEW

Searches for Long Lived Particles: Decays in Tracker, Calorimeters and Muon Detectors

Search for neutral long-lived particles that decay into displaced jets in the calorimeter w/ leptons or jets



few cm -- tens of m



arXiv:2407.09183

Backup

== **additional object to trigger** the event + access low-mass/boost regions (enhance sensitivity)

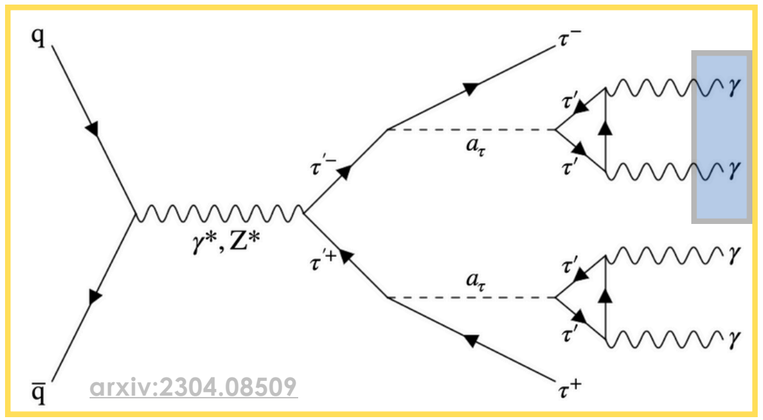
CalRatio: LLPs that decay after the electromagnetic calorimeter have very low electromagnetic component

x3 improvements w.r.t. previous searches

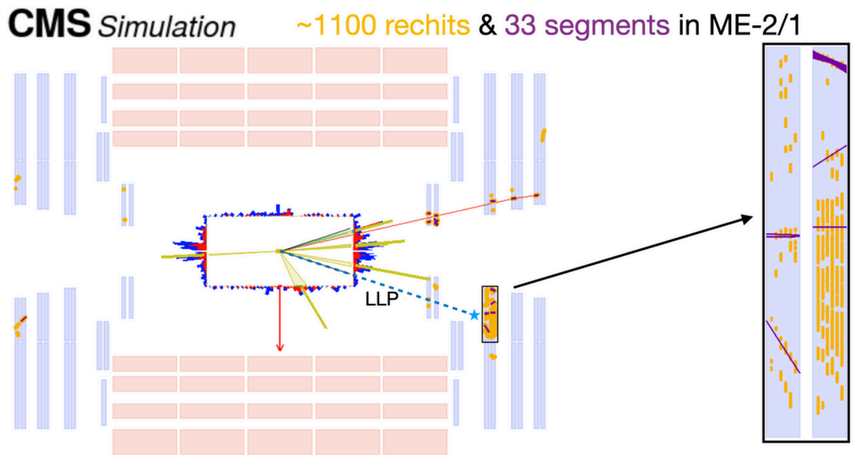
NEW

Searches for Long Lived Particles: Decays in Tracker, Calorimeters and Muon Detectors

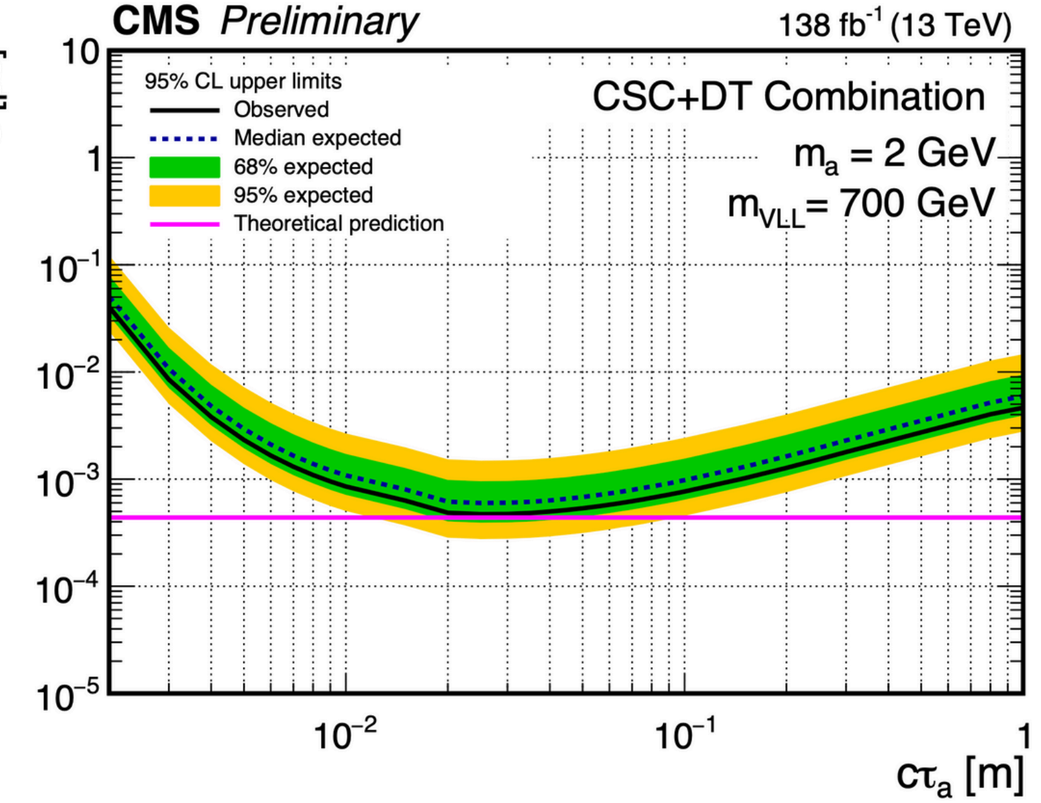
Vector Like Leptons via LLP decays in the muon system



Muon Detector Shower (MDS): cascade of secondary particles produced by high energy particles crossing muon detectors



high-multiplicity MDS



CMS-DPS-2022-062

CMS-PAS-EXO-23-015

Backup

Beyond Standard

Model

Strategies

Signatures

Tools

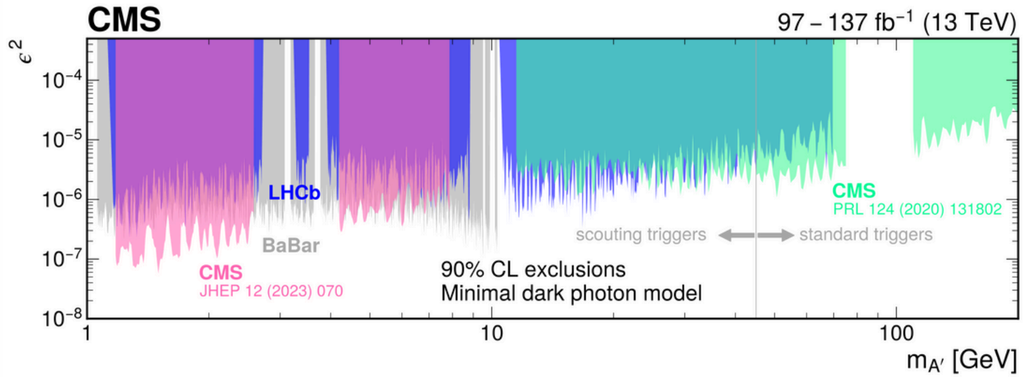
- *Machine Learning (see Javier's talk)*
- *Dedicated data streams*
- *Ad-hoc triggers for LLPs at Run 3*

Scouting opportunities at Run 2 & 3

Size standard event O(1MB) vs scouting O(10kB)

Size ↘ Rate ↗

Scouting in Run 2 explored **simple objects**: low-mass **dimuon** spectra



arXiv:2403.16134

NEW

Scouting Run 3: more elaborated objects, tau leptons reconstruction from all info stored in scouting dataset

Dynamical tau cone definition vs p_T

first time in Scouting data

CMS-NOTE-2024/006

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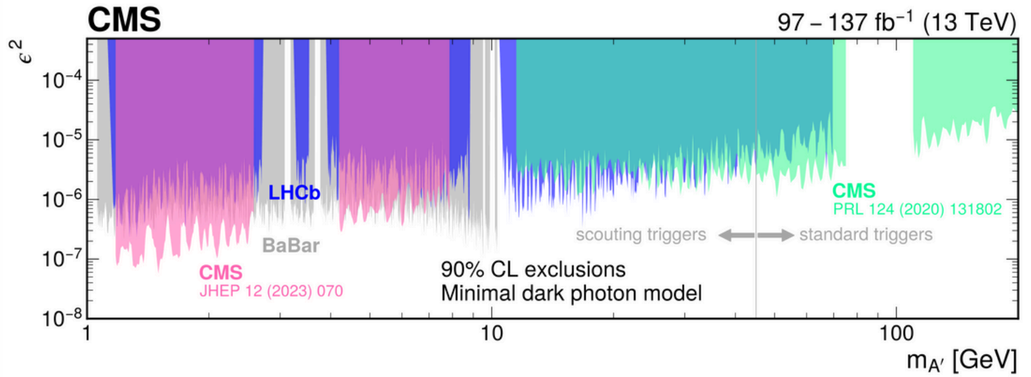

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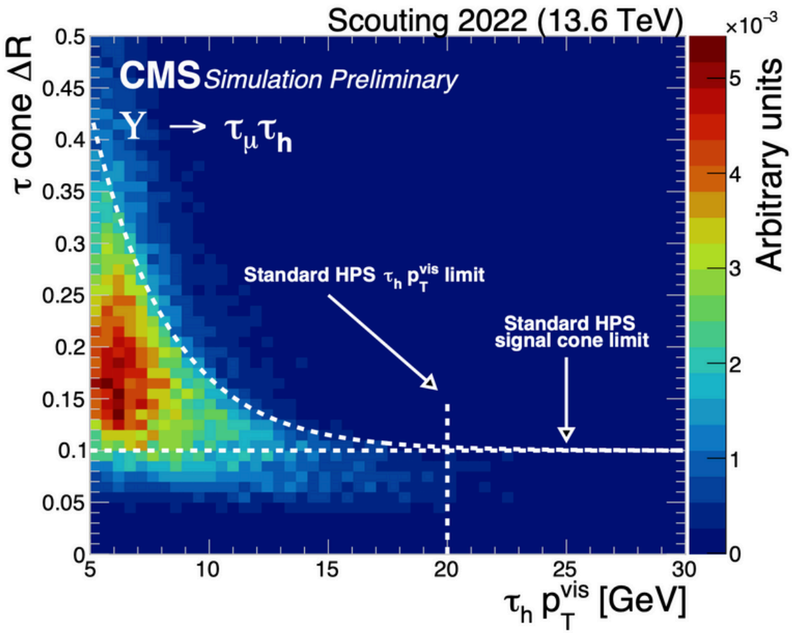
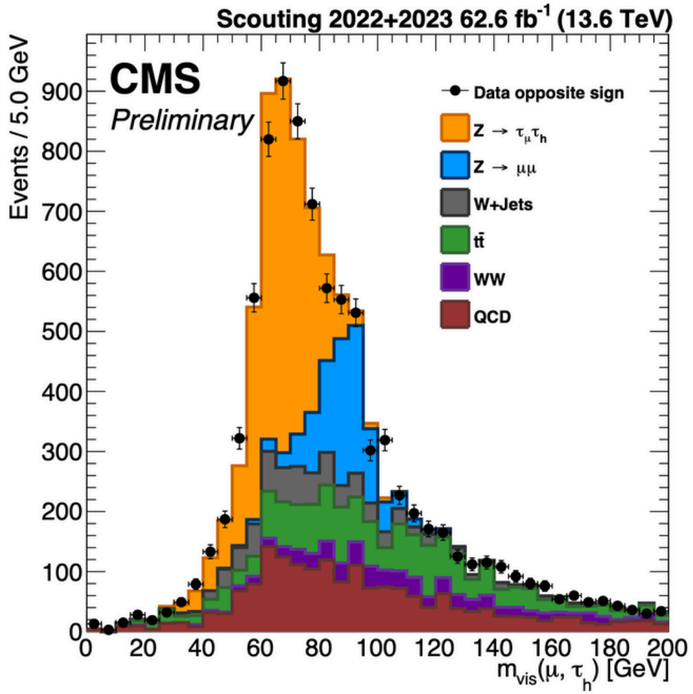


dynamical tau cone definition vs p_T



first time in Scouting data

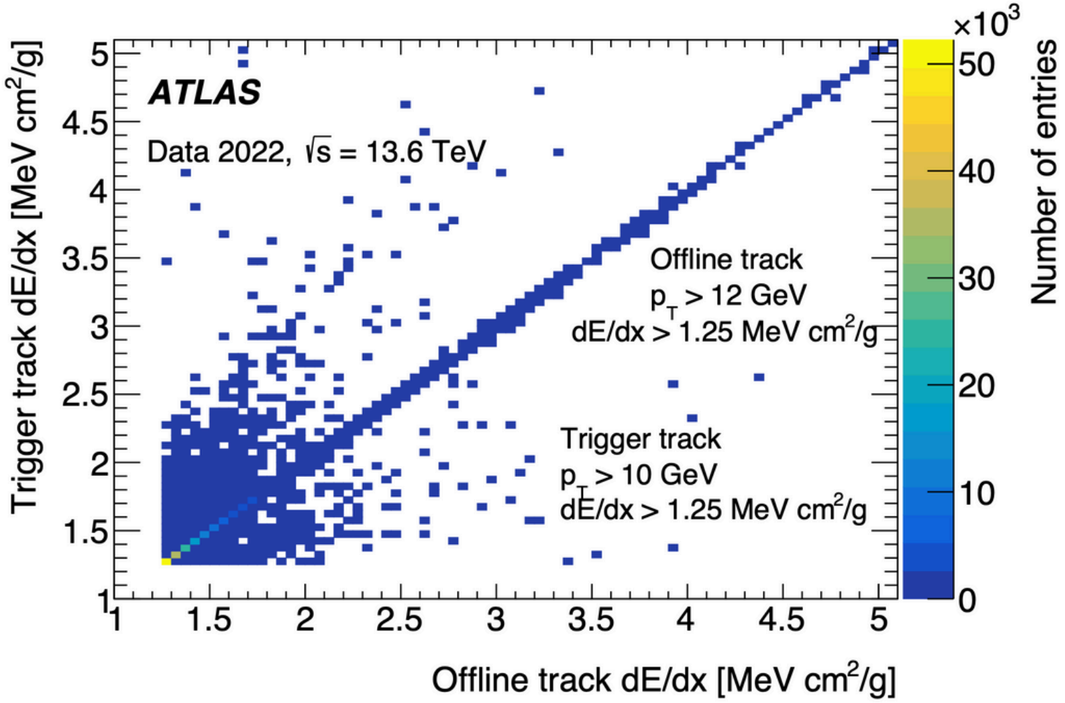
CMS NOTE-2024/006

Backup

Innovative trigger strategies at Run 3

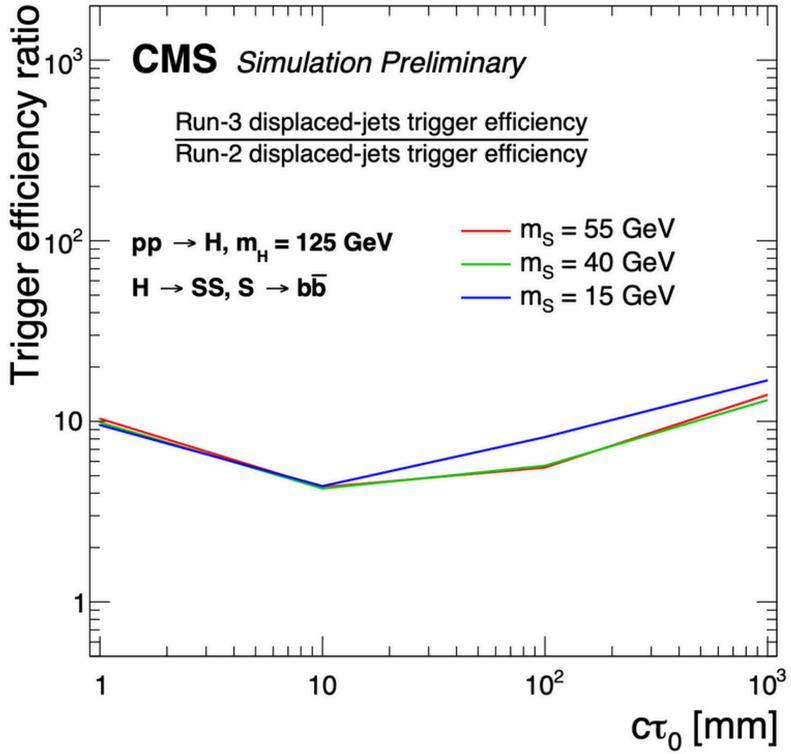
Run 3 physics program **expands the scope of searches for BSM** with addition of dedicated LLPs triggers

dE/dx handle to **identify new heavy charged particles**



arXiv:2401.06630

Displaced-jets tagging in Run 3 search brings up to x10 improvements w.r.t. Run 2.



CMS-DPS-2023-043

BSM searches in ICHEP2024 light-cone

Run 3 provides a powerful platform to explore new physics through combination of **higher energy, increased luminosity, and improved experimental techniques**

Low-mass $X \to \gamma\gamma$

arXiv:2405.18149

High-mass $Y \to XX \to 4j$

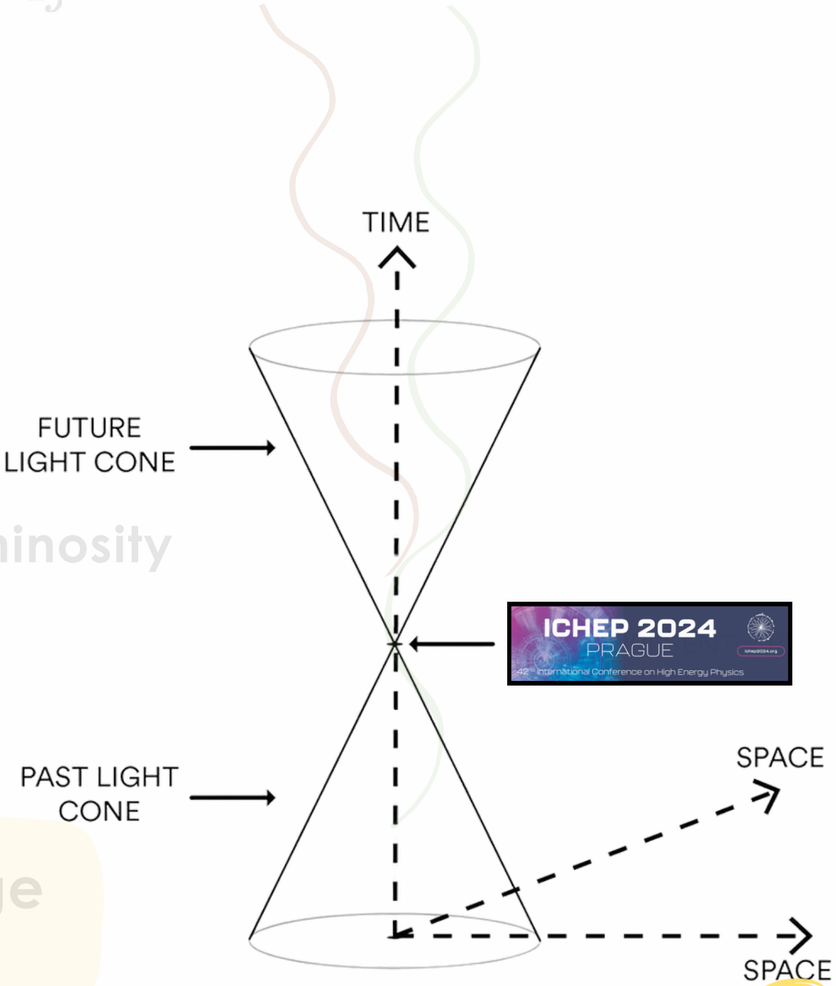
arXiv:2307.14944

Some excesses around to chase..e.g.:

HL-LHC Run 3

HL-LHC will significantly increase physics reachs: gains from **high luminosity and new detector capabilities**

e.g. Long Lived Particles searches and Particle ID with timing detectors



Next years will provide massive amount of new knowledge and we are expecting to exceed expectations!

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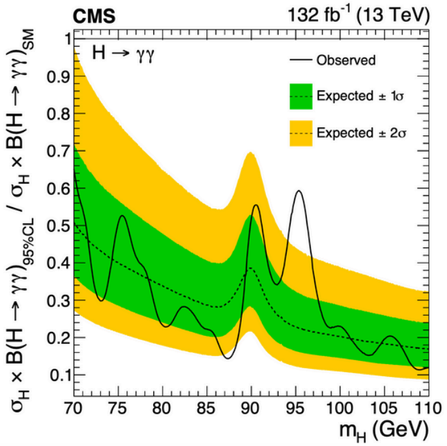

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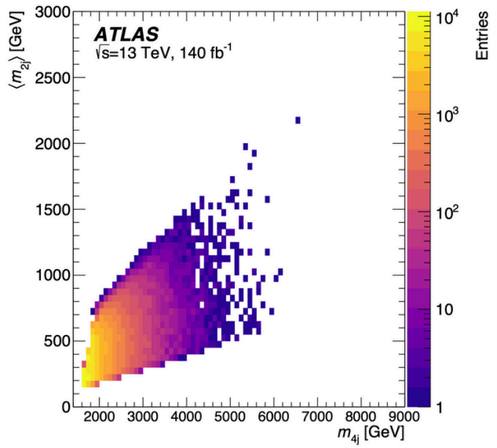

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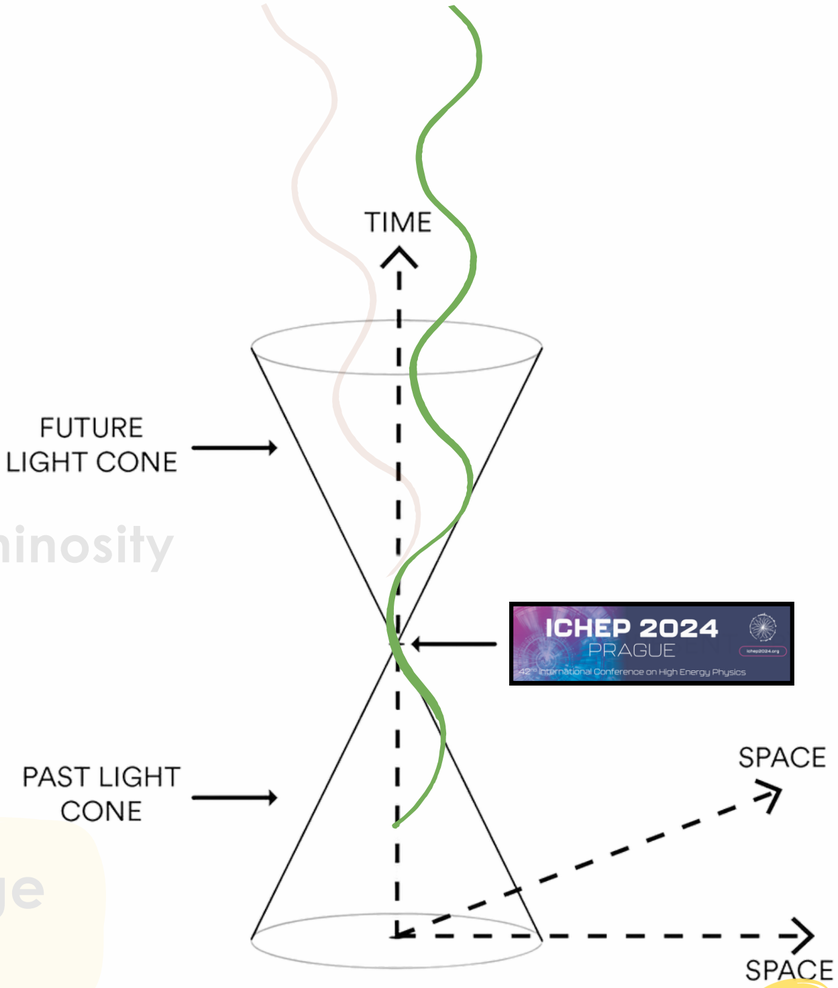

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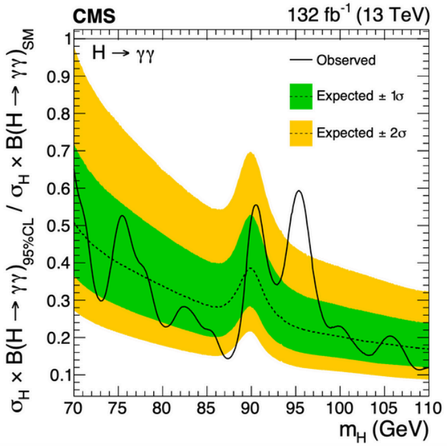

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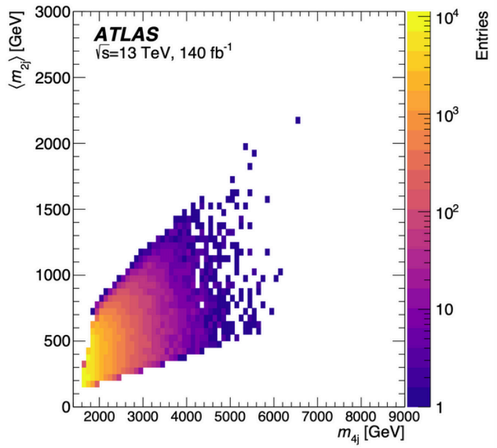

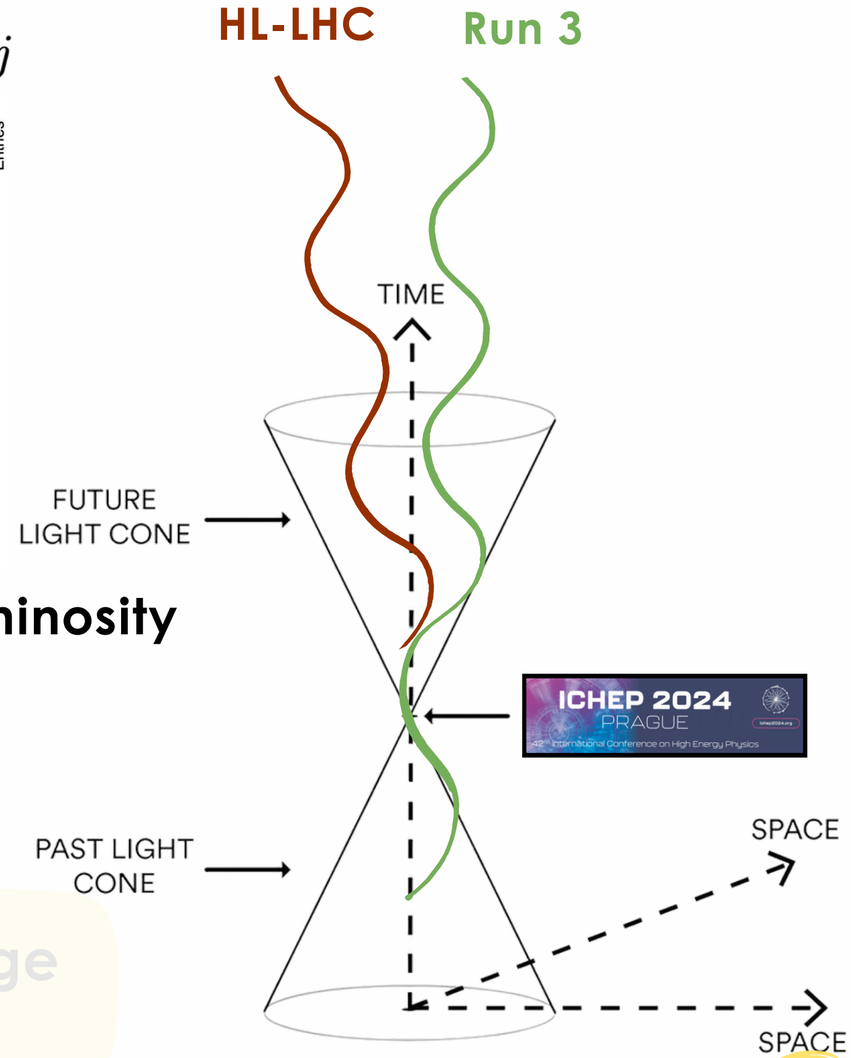

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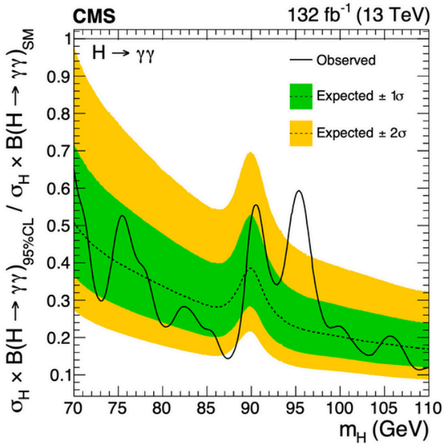

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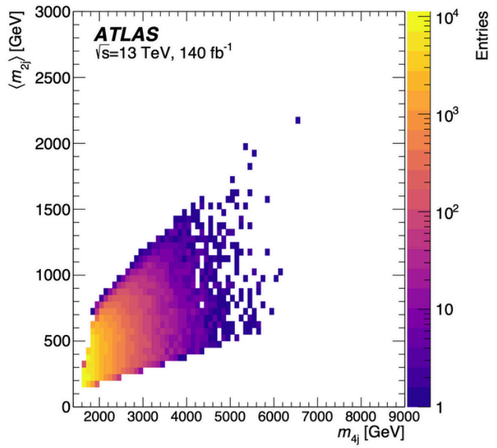

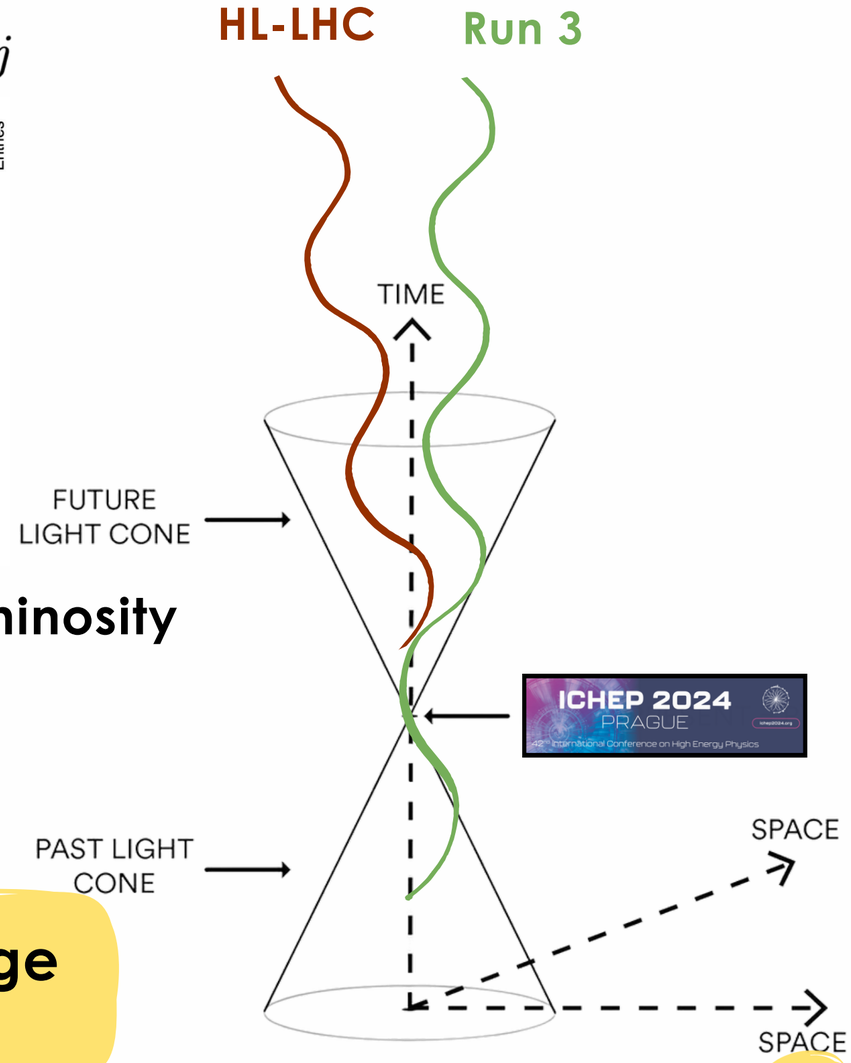

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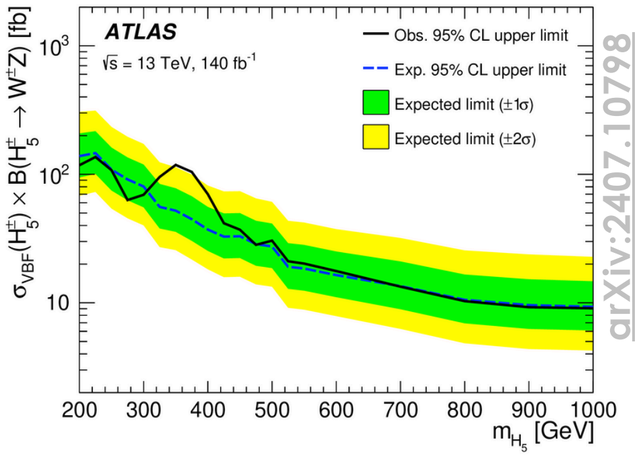
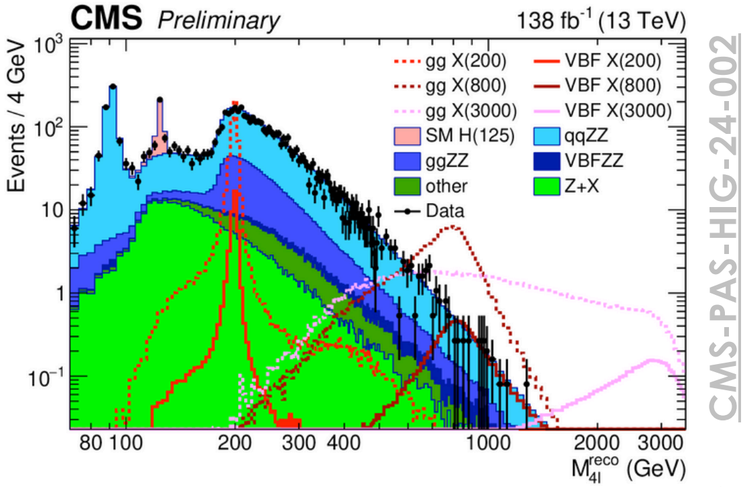
Thank you for listening!

New results uncovered today

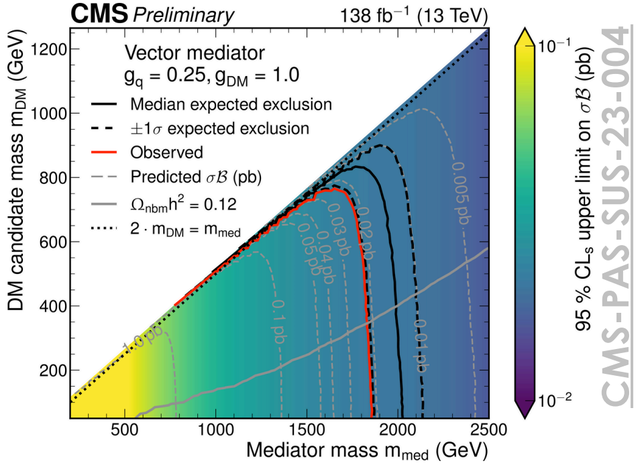
NEW



arXiv:2407.10798



CMS-PAS-HIG-24-002



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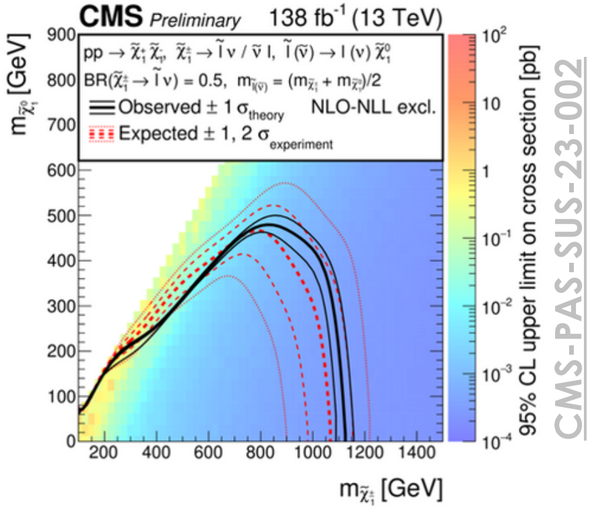
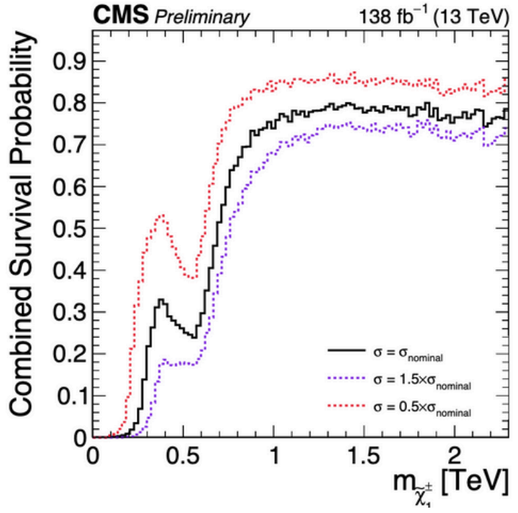


CMS-PAS-SUS-23-002



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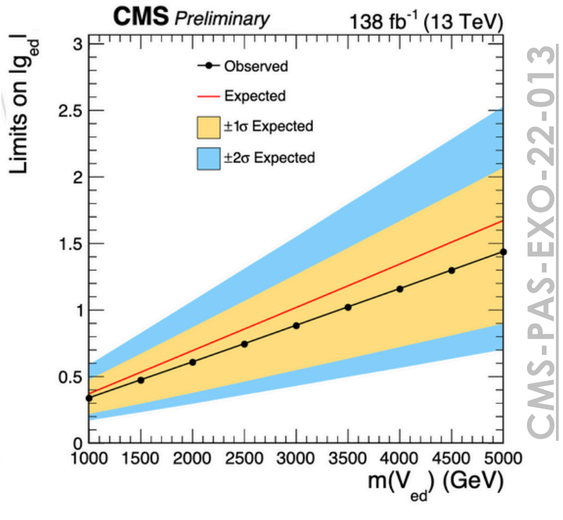
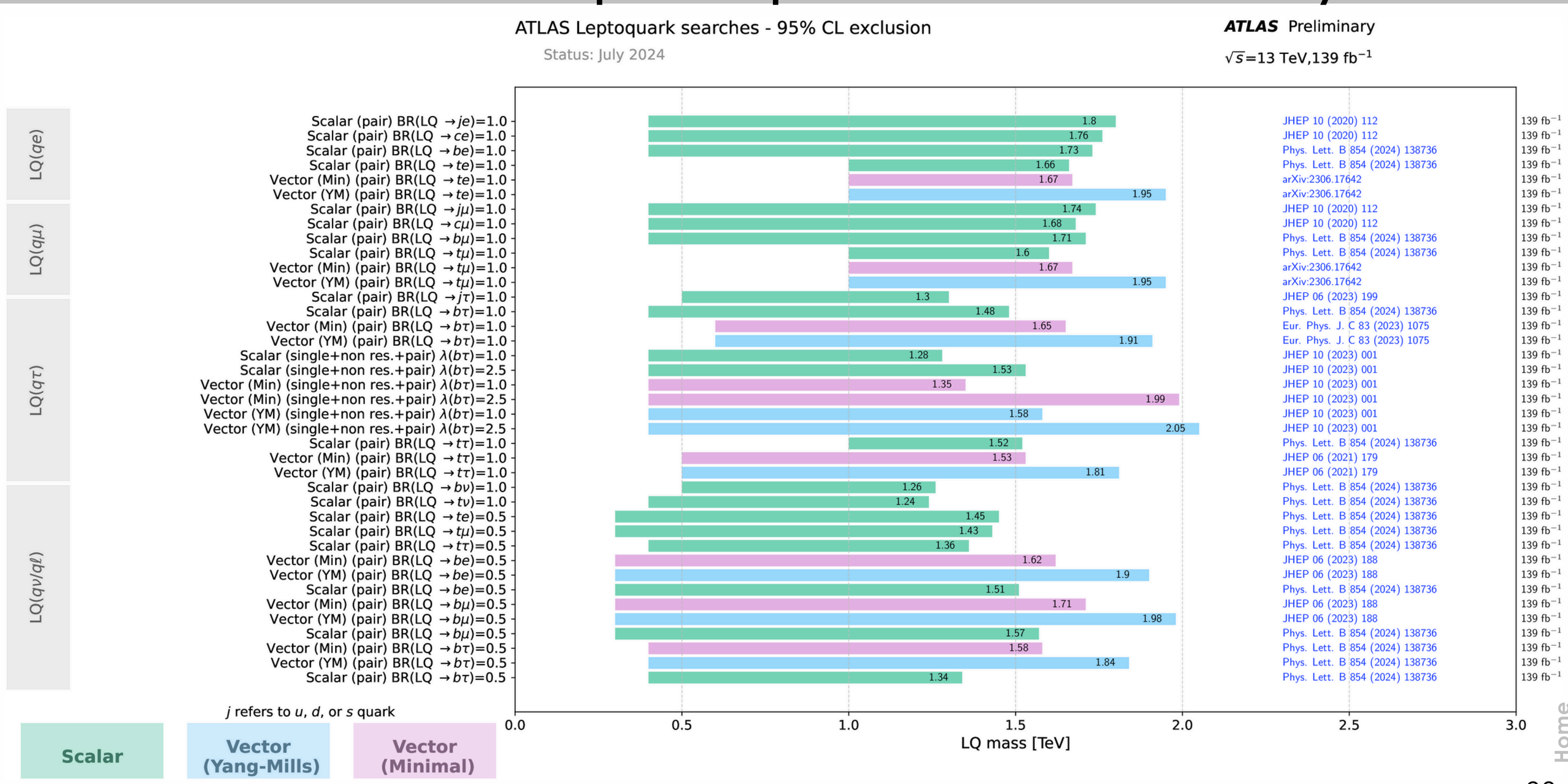


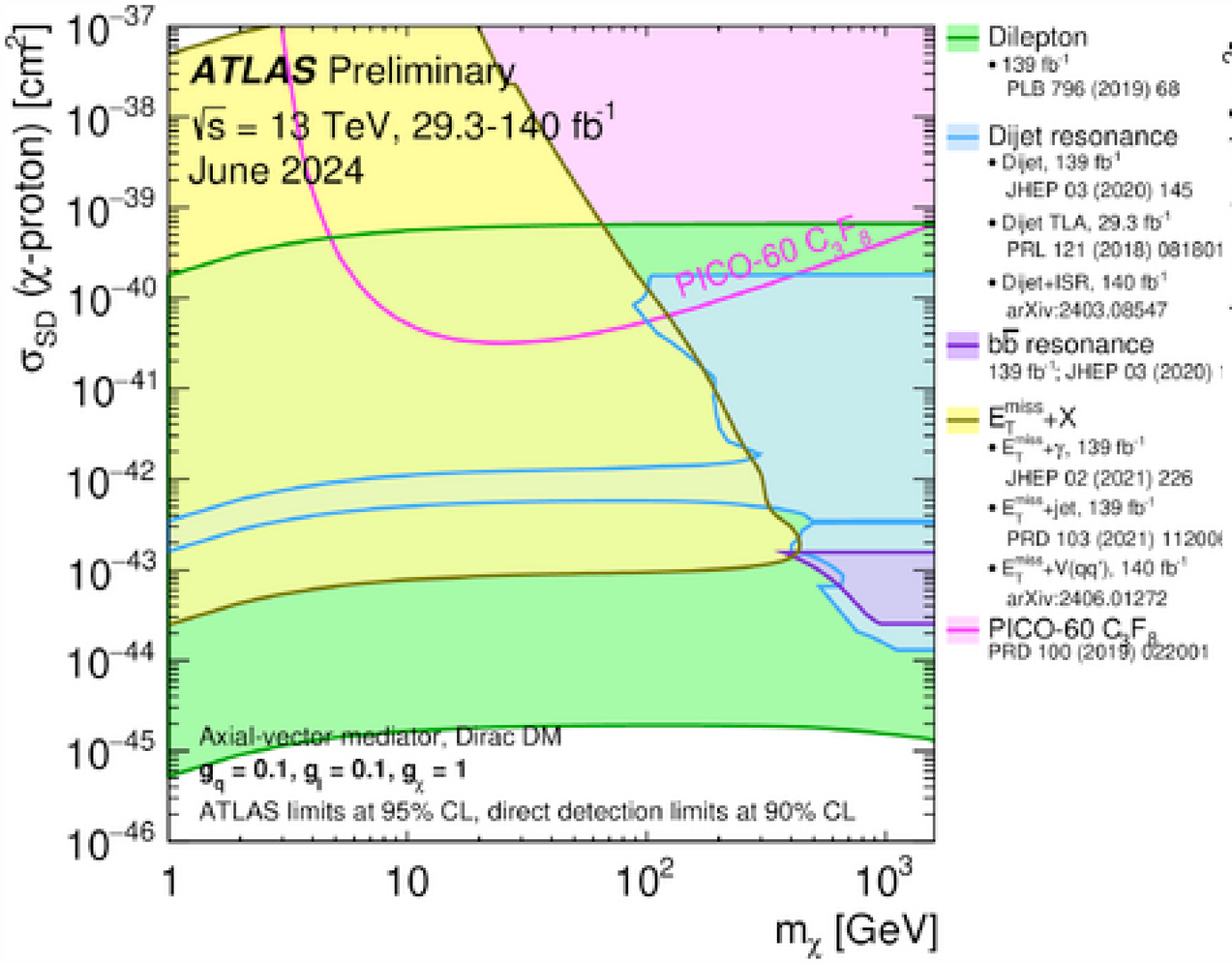
CMS-PAS-EXO-22-013

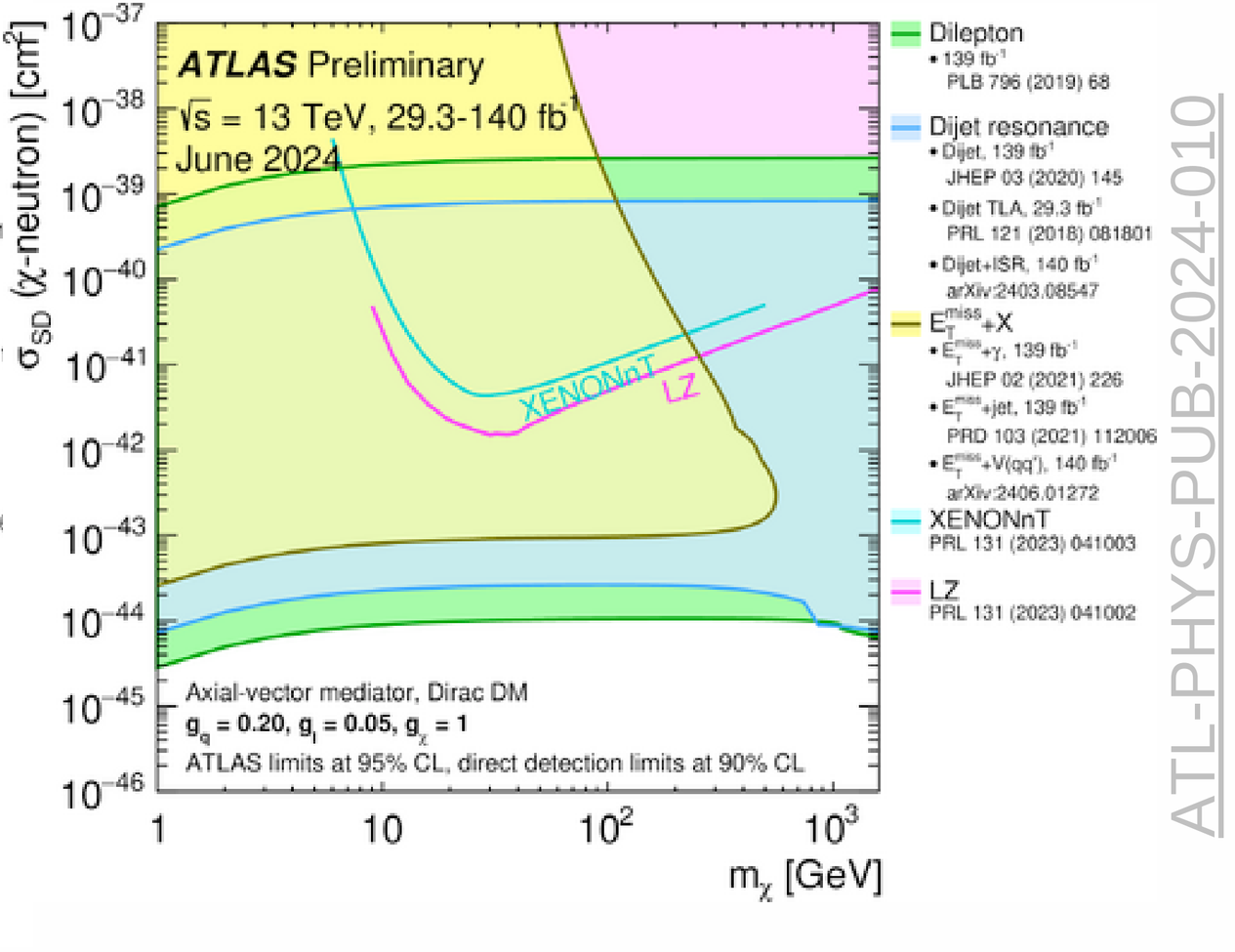
Backup

ATLAS Leptoquark summary



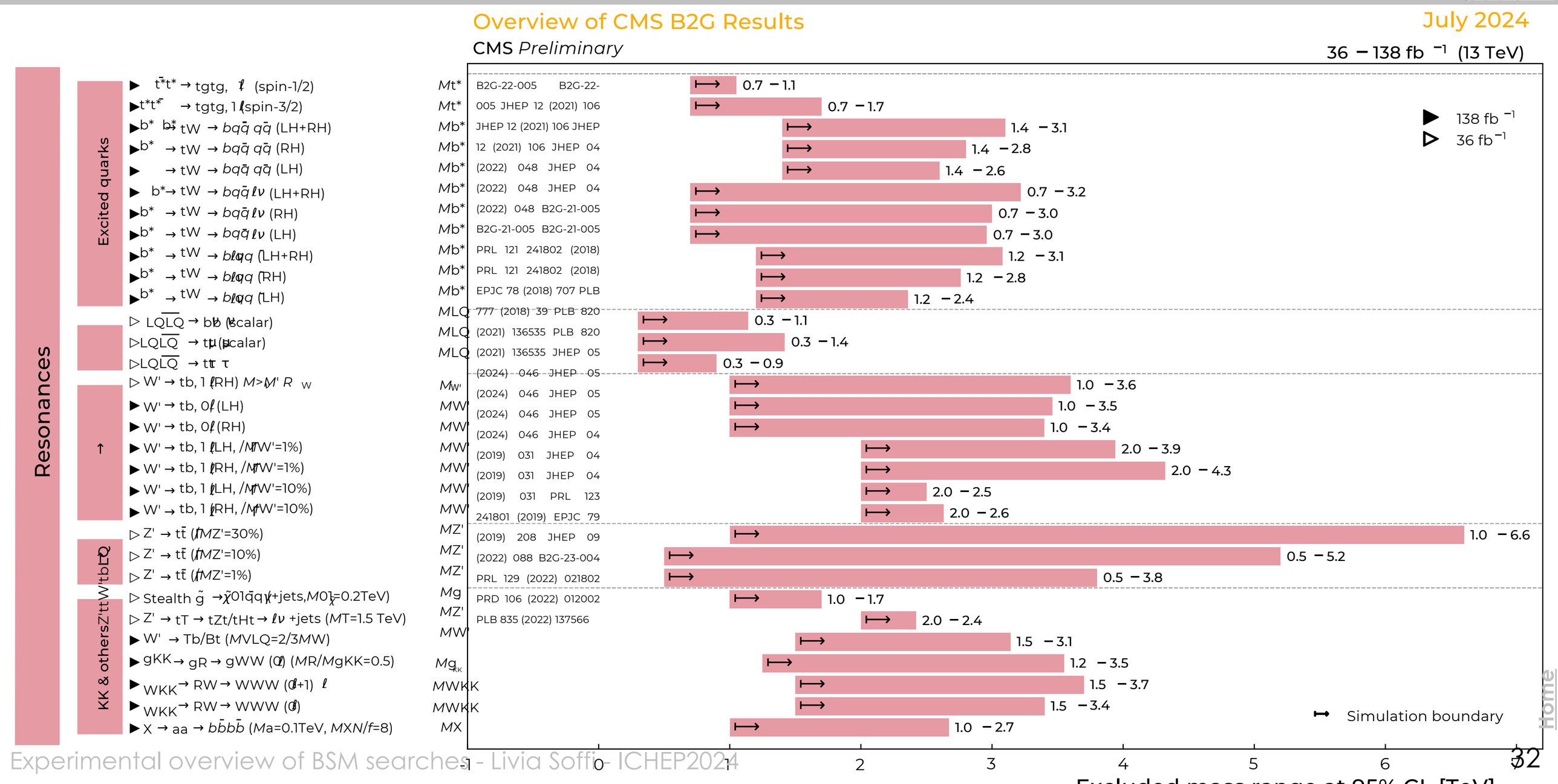
ATLAS Dark Matter summary





ATL-PHYS-PUB-2024-010

CMS Heavy Resonances summary

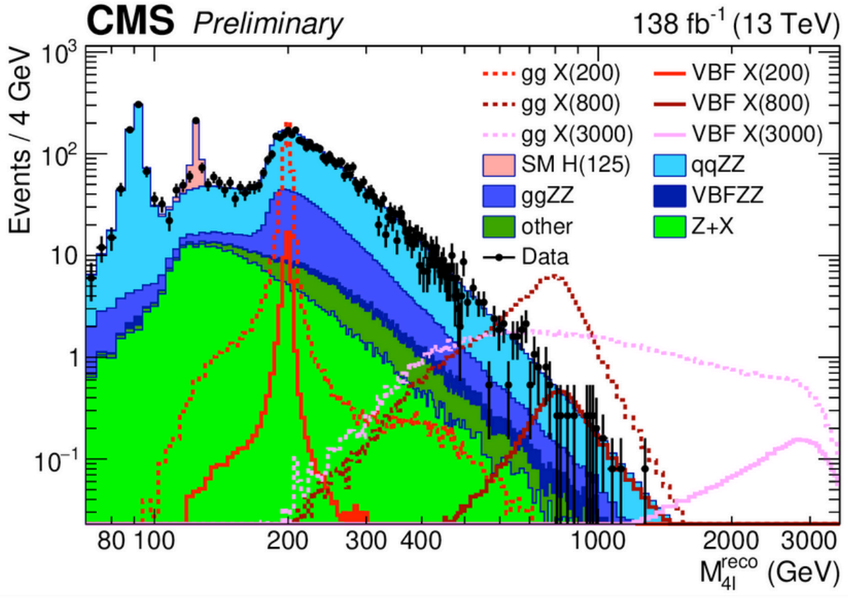


Search for high mass H⟶ZZ⟶4leptons

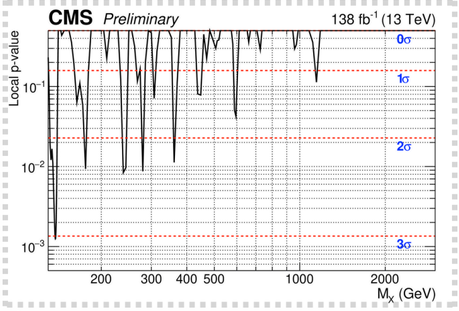
NEW

$$130\text{GeV} < M_X < 3\text{TeV} \qquad 0 < \Gamma_X/M_X < 0.3$$

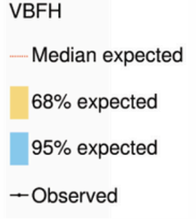
fVBF, fraction of VBF production considered as a parameter in the model together with mass and width

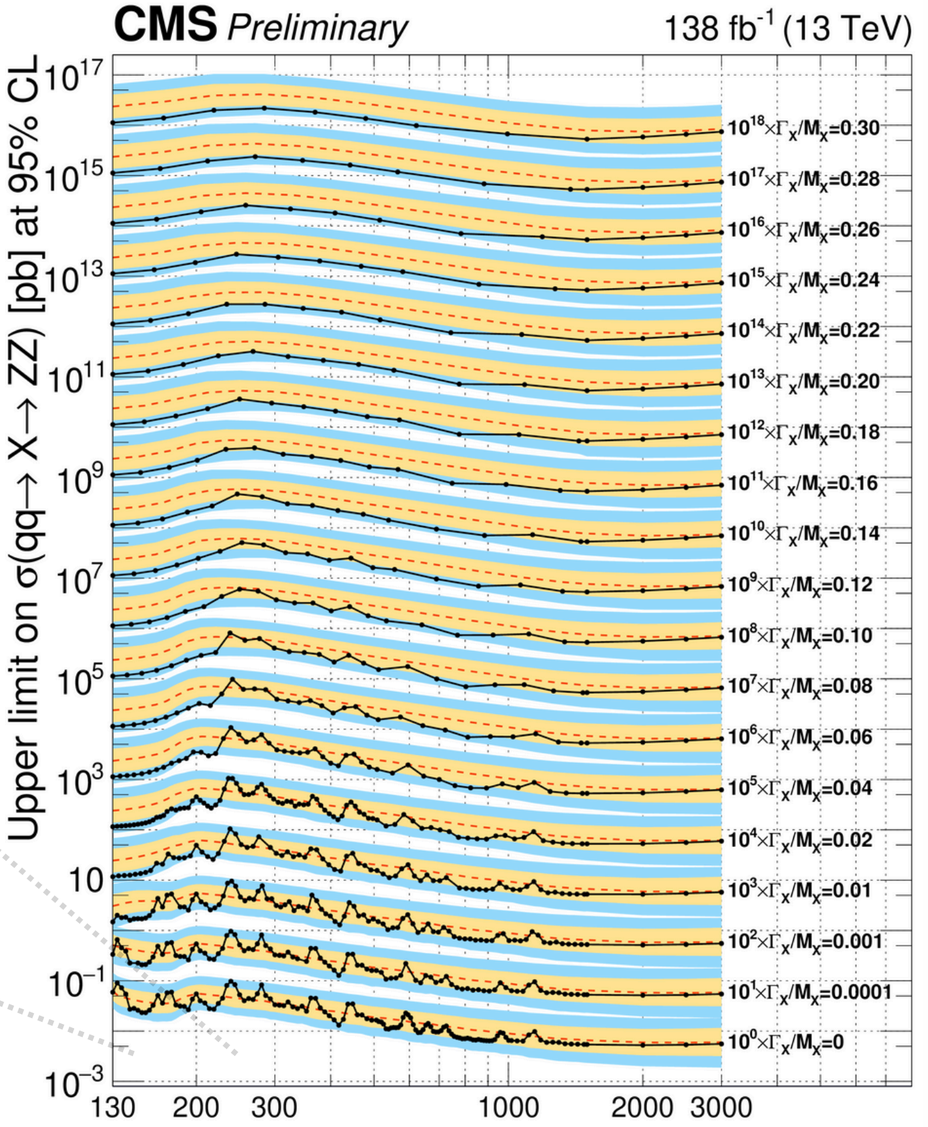


- largest excess at 138.1 GeV: 3 sigma local 1.9 global



- large X width leads to sizable interference: considered for ggF and VBF: 9.5% to 18% of syst. unc.

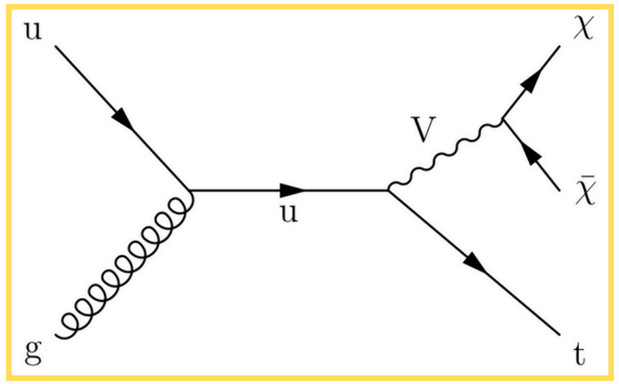




CMS-PAS-HIG-24-002

NEW

Search for new physics with a mono-top signature

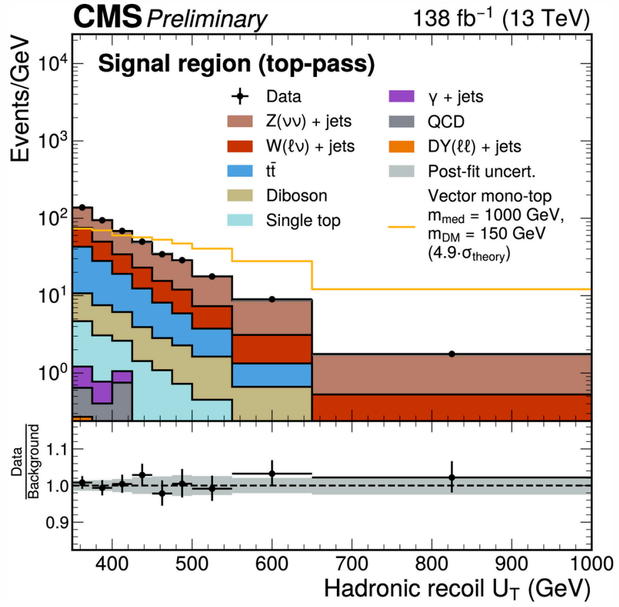


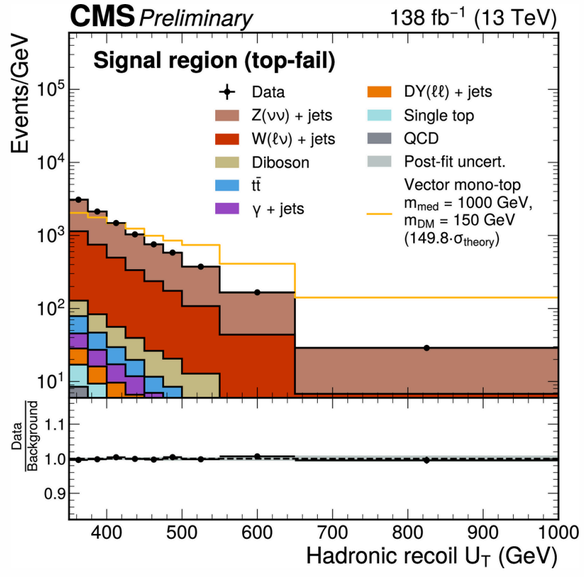
ParticleNet: Graph neural network distinguishes AK15 jets from hadronic decay of top quark from QCD radiation.

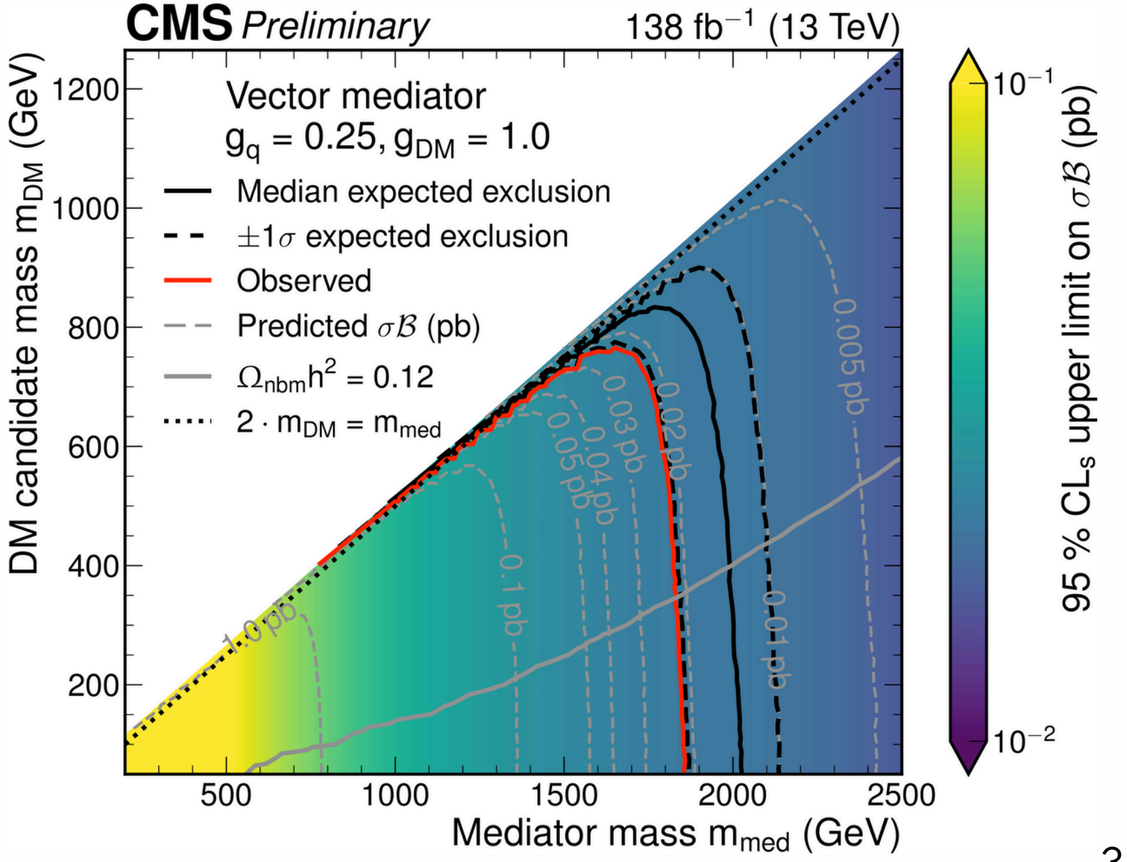
PASS

FAIL

7 CRs defined to estimate major background processes in the pass and fail SRs from data in the CRs.





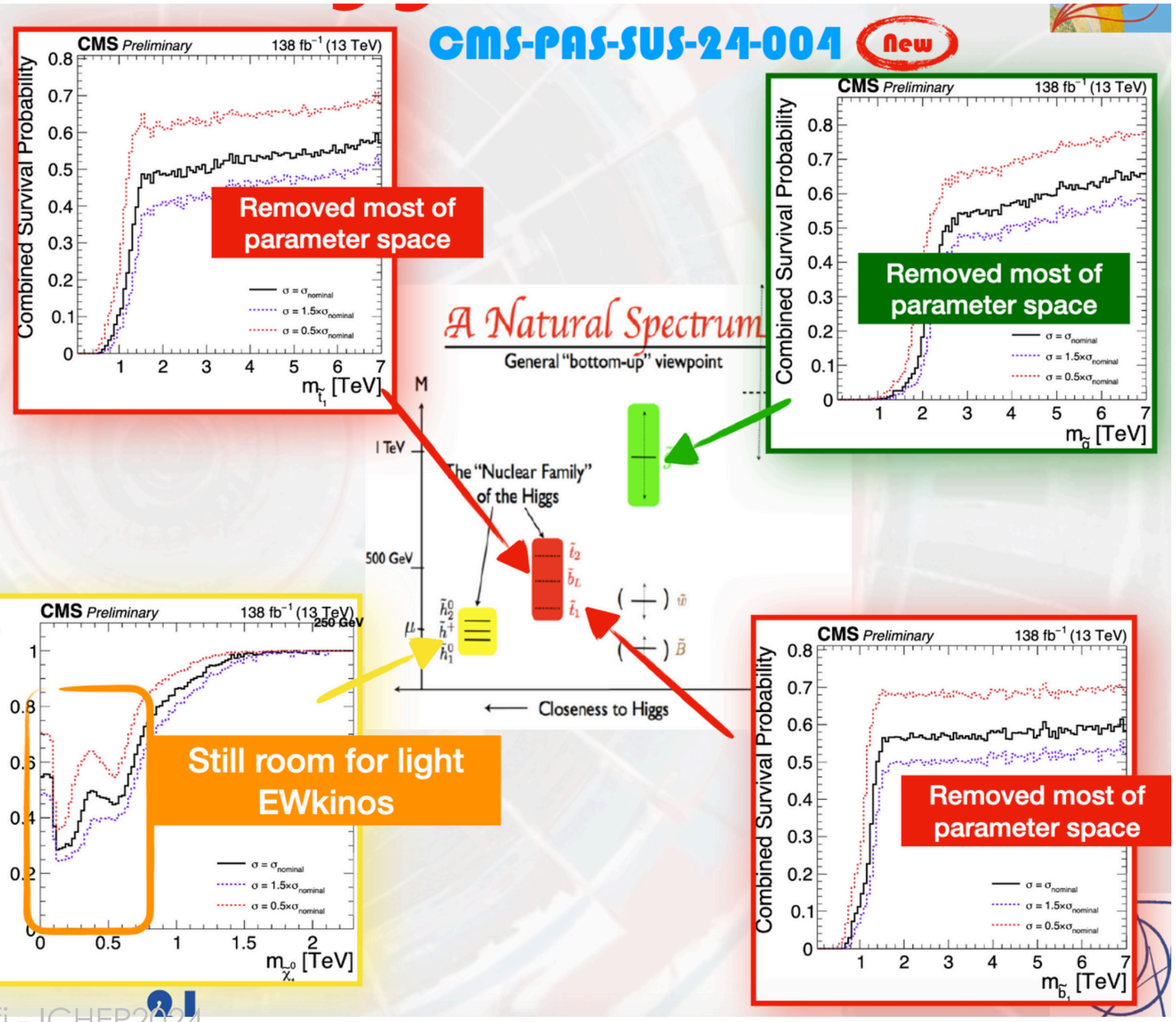


CMS-PAS-SUS-23-004

Home

pMSSM interpretation of Run 2 SUSY results

- Performed first statistical combination of SUSY searches with full Run2 luminosity
  - In the framework of phenomenological MSSM (pMSSM): 19 free parameters
  - Useful tool to identify weak spots in our program
  - Gives us a big picture under realistic assumptions (e.g., on relative branching ratios)
    - quantified as fraction of tested models that survive the exclusion



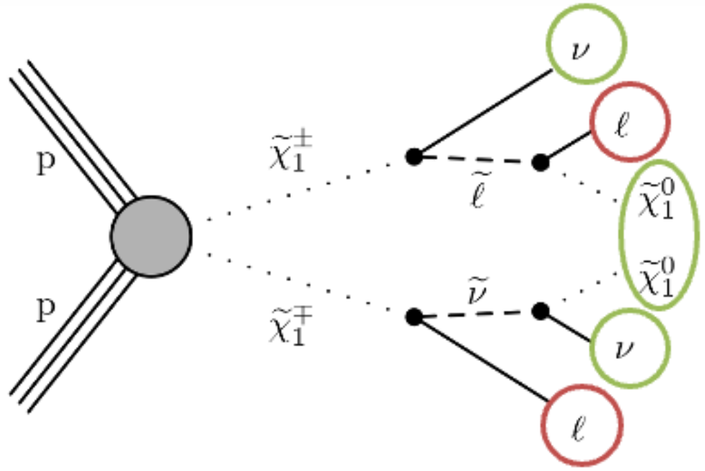
M.Pierini's talk @ICHEP2024

CMS-PAS-SUS-24-004

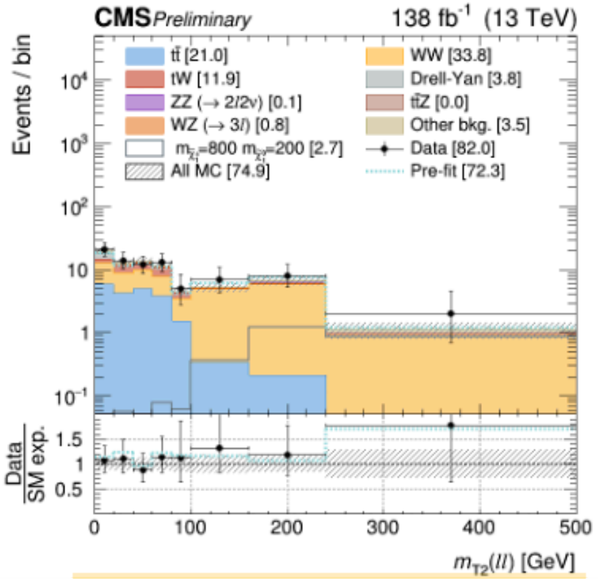
NEW

Search for charginos and stops in 2LOS final state

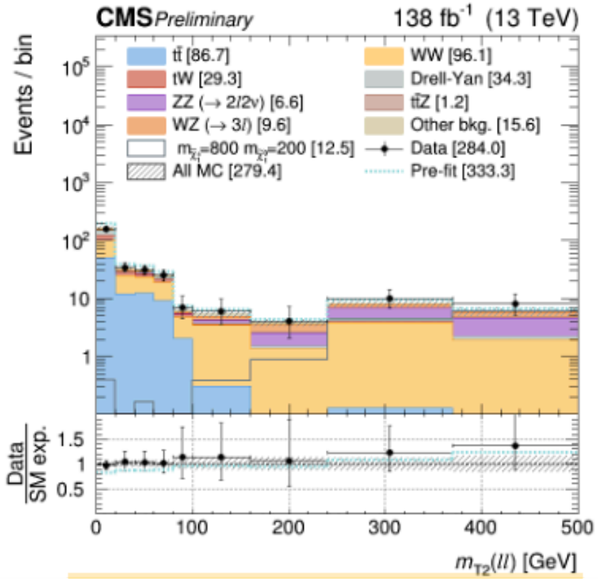
- Novel analysis probing for **direct chargino pair production** in final states with two oppositely charged leptons and **large MET** (>160 GeV):
- SRs are defined in terms of MET bins, jet content, and lepton flavour



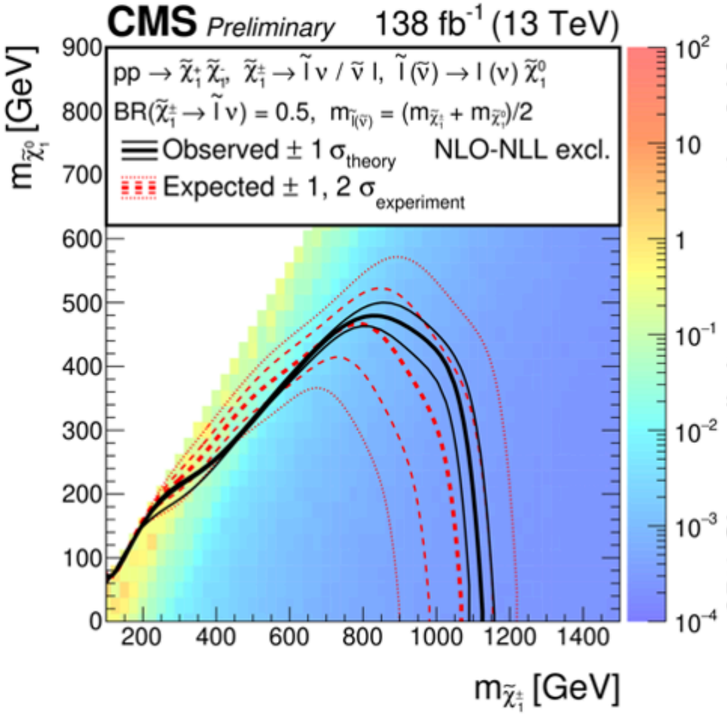
- Main backgrounds coming from ttbar and WW production, which are normalized at low mT2
- The signal is extracted via a **Simultaneous fit to observed mT2 distribution in all the SRs.**



220< p_T^{miss} < 280 GeV
n_{jets}=0, DF



p_T^{miss} > 380 GeV
$n_{B\text{-}jets}$=0, SF



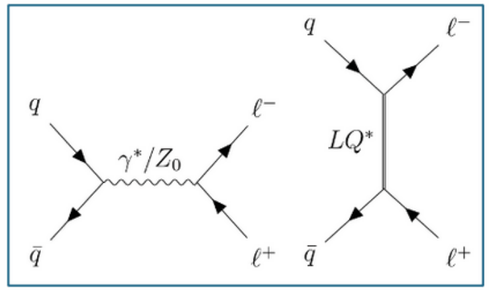
CMS-PAS-SUS-23-002

Home

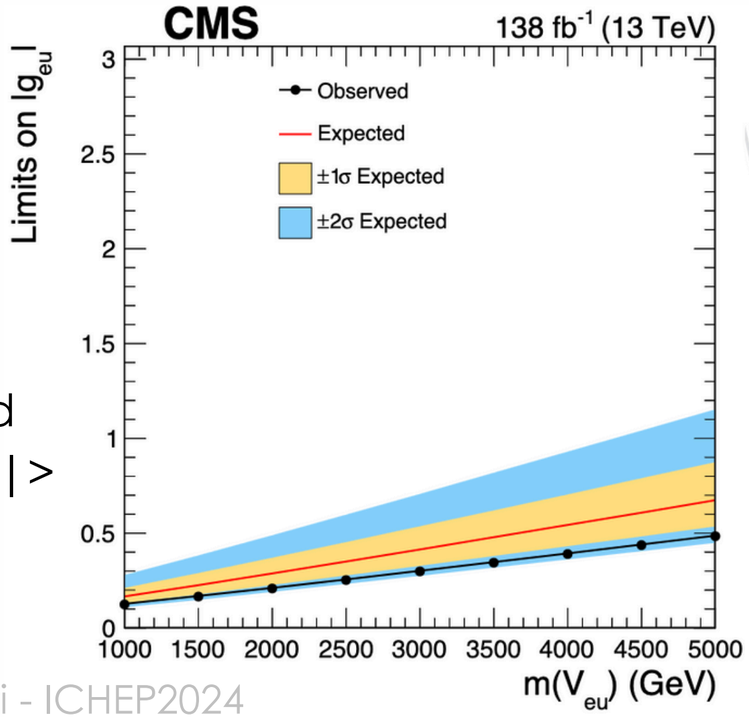
NEW

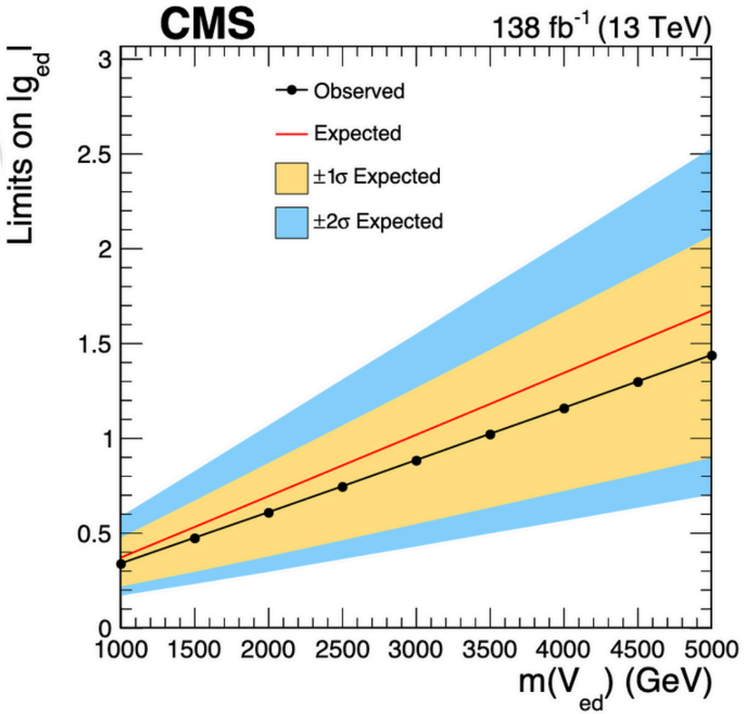
t-channel scalar and vector leptoquark in the high mass dimuon and dielectron

- First search for 8 nonresonant leptoquarks coupling up and down quarks to electrons and muons in dilepton masses $m\_\ell\ell$>500 GeV using the full Run-2 dataset
  - S_eu, S_ed - scalar LQs coupling u/d quarks to electrons (R_2 family, RL couplings)
  - $S\_\mu u$,$S\_\mu d$ - scalar LQs coupling u/d quarks to muons ($\tilde{R}$_2 family, RL couplings)
  - V_eu, V_ed - vector LQs coupling u/d quarks to electrons (U_3 family, LL couplings)
  - $V\_\mu u$,$V\_\mu d$ - vector LQs coupling u/d quarks to muons (U_3 family, LL couplings)



- t-channel LQ effects sensitive to LQ-fermion coupling y_LQ^4 (pure LQ exchange) and y_LQ^2 (interference with the SM Drell-Yan process which proceeds via γ^*/Z^0)
- 95% CL upper limits exclude scalar LQ masses upto 5 TeV for |y_LQ |> 1.2, and vector LQ masses upto 5 TeV for |y_LQ |> 1.5. Best limits so far on first and second generation scalar and vector LQs.





CMS-PAS-EXO-22-013