Search for long-lived charged particles using the CMS detector in Run 2

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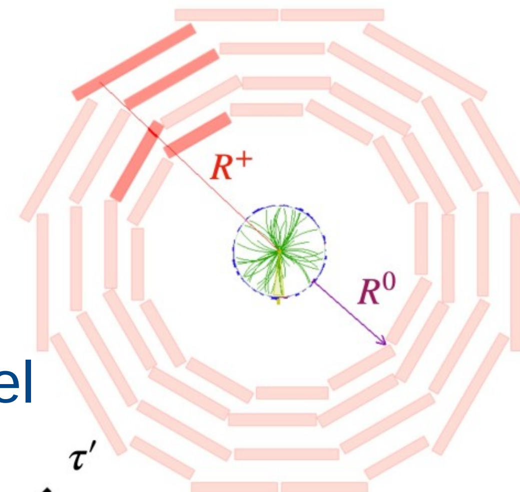
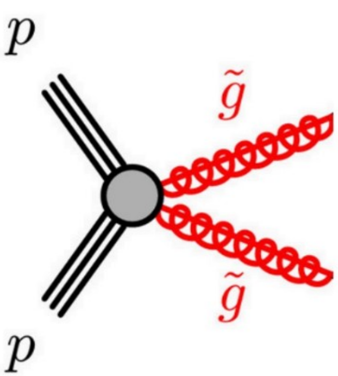
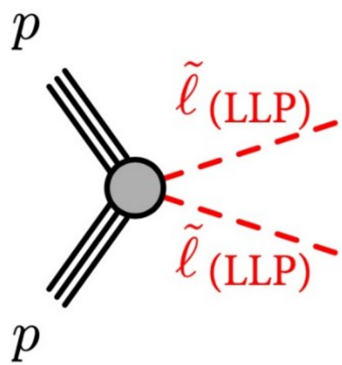
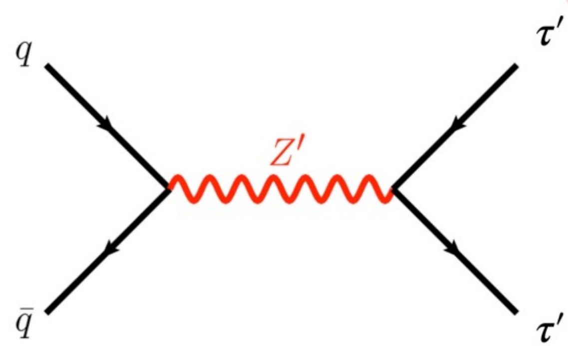
Motivation

- Many models predict Heavy Stable Charged Particles (HSCP):
  - split-SUSY (R-hadrons with gluinos, stops)
  - GMSB/GGM SUSY (staus)
  - extra dimensions and fourth-generation BSM models (τ' with Q=1e and 2e)
  - ATLAS excess motivated Z' to τ'(2e) model









- Isolated track of high p_T with large $\frac{dE}{dx}$ in the tracker

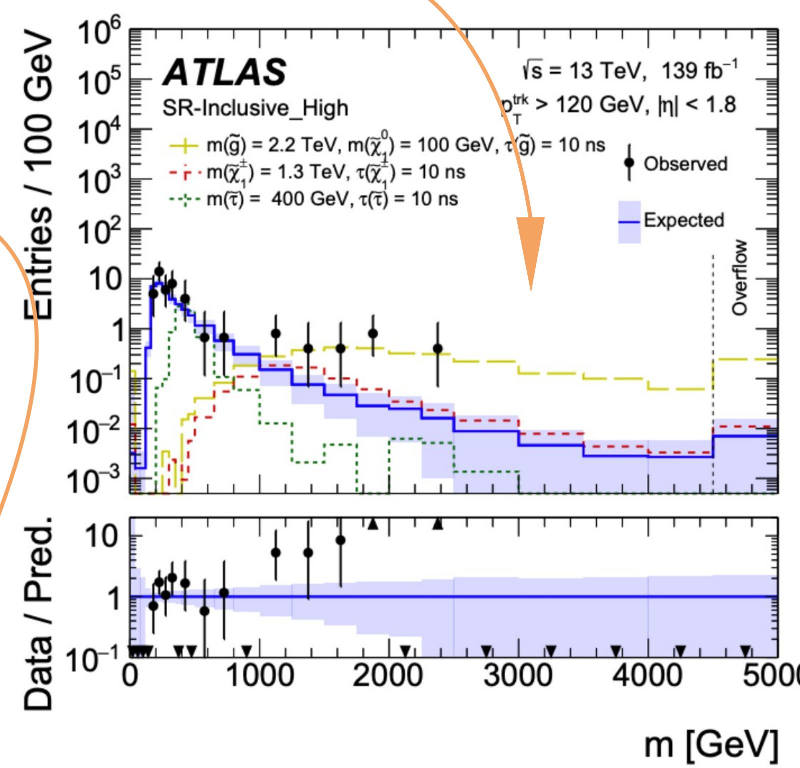
$\Rightarrow$ Signature-driven, model-independent search with many possible interpretations

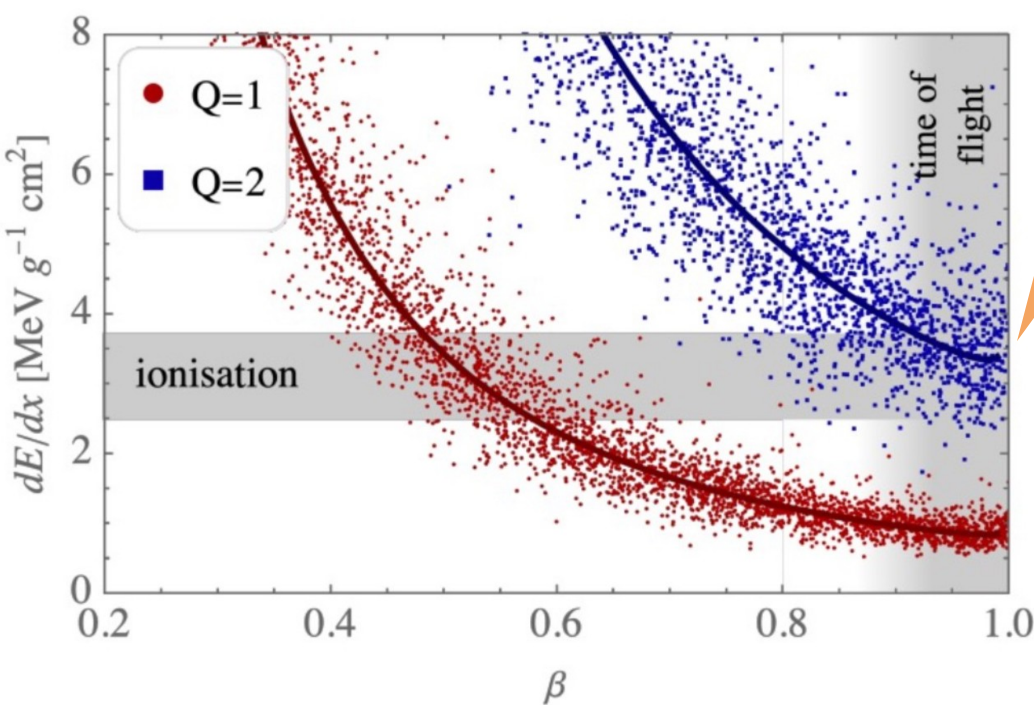
ATLAS excess

- 3σ excess (exp 0.7, obs 7), reconstructed as muons
  - However, $\beta \sim 1$, compatible with SM ("not slow")

2205.06013

- proposed explanation:
  Z' decaying into 4th gen leptons (τ') with Q=2e



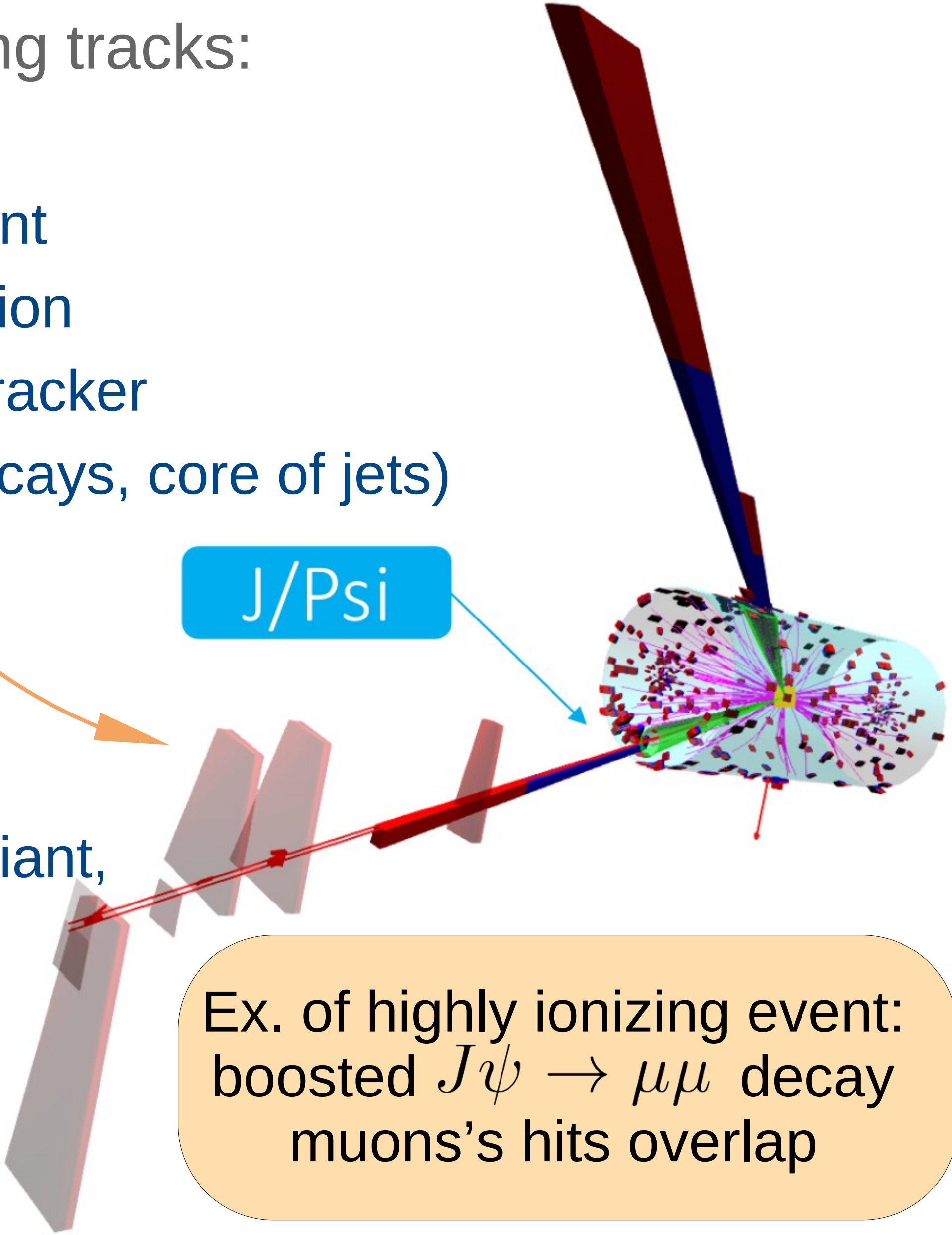


2205.04473

Selection of HSCP candidates

- SM sources of highly ionizing tracks:
  - Fake tracks
  - Bad ionization measurement
  - Tail of the Landau distribution
  - Overlapping tracks in the tracker (pileup, boosted meson decays, core of jets)

- Preselection:
  - $p_T > 55\ \mathrm{GeV}$
  - Track isolation
  - `Mini' isolation (boost invariant, includes calorimeter info)
  - general track/hit clean-up
  - no 2016 data



Ex. of highly ionizing event: boosted $J\psi \rightarrow \mu\mu$ decay muons's hits overlap

Ionizaton observables

EXO-18-002

- Pixels: $$F_{\mathrm{i}}^{\mathrm{Pixels}} = 1 - \prod_{j=1}^{n} P_j' \sum_{m=0}^{n-1} \frac{[-\ln(\prod_{j=1}^{n} P_j')]^m}{m!}$$
- Strips: $$G_{\mathrm{i}}^{\mathrm{Strips}} = \frac{3}{N}\left(\frac{1}{12N} + \sum_{j=1}^{N}\left[P_j\left(P_j - \frac{2j-1}{2N}\right)^2\right]\right)$$

Using info from different detector sub-systems $\Leftrightarrow$ Uncorrelated by construction!

Ionizaton observables

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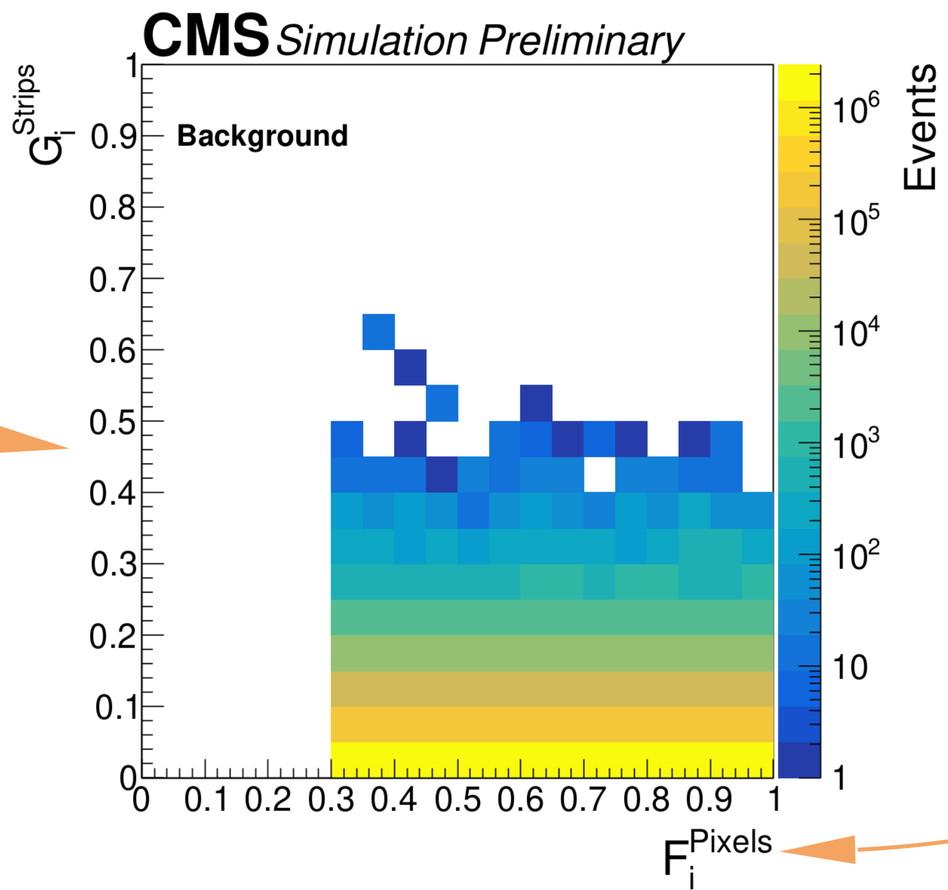
Flat for bkg!



Bkg steeply falling.

Ionizaton observables

EXO-18-002

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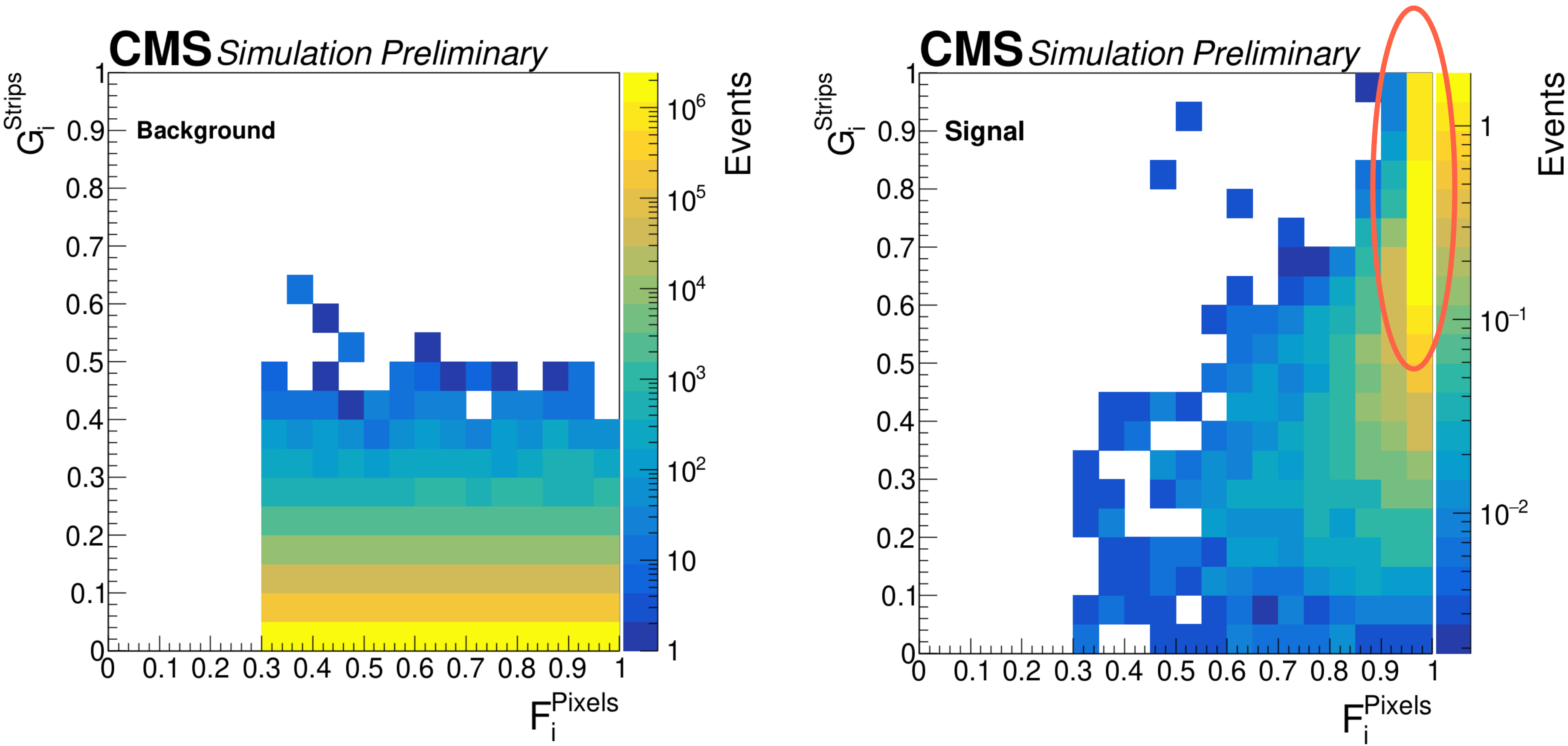
Signal region



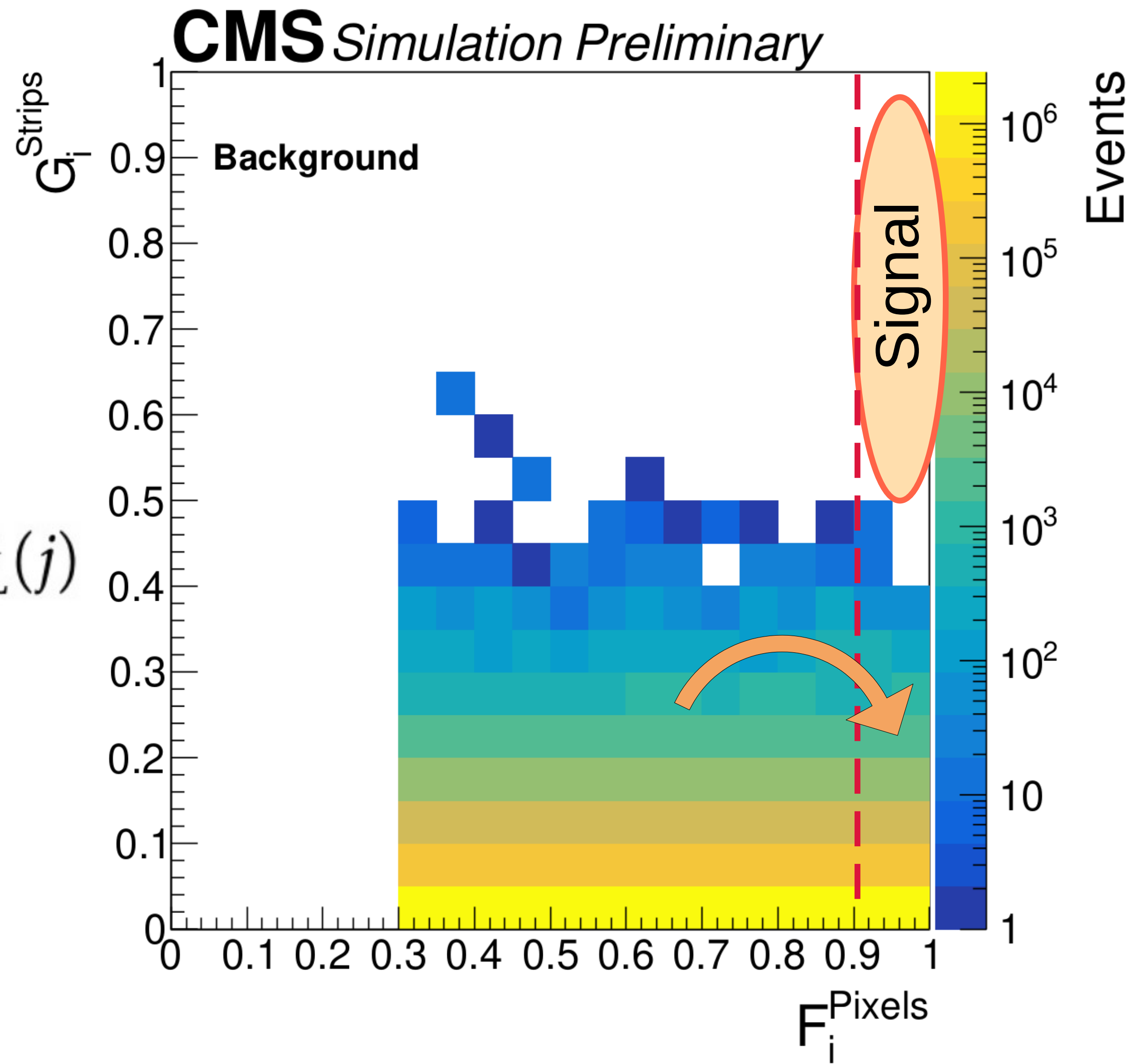
Bkg estimation #1: ‘Ionization method’

EXO-18-002

- F and G and uncorrelated, and F is flat for bkg...

- Use sideband of F to predict shape of G in signal region

$$N^{\mathrm{bkg}}_{\mathrm{PASS}}(j) = R_{\mathrm{P/F}}(j)\, N^{\mathrm{data}}_{\mathrm{FAIL}}(j)$$



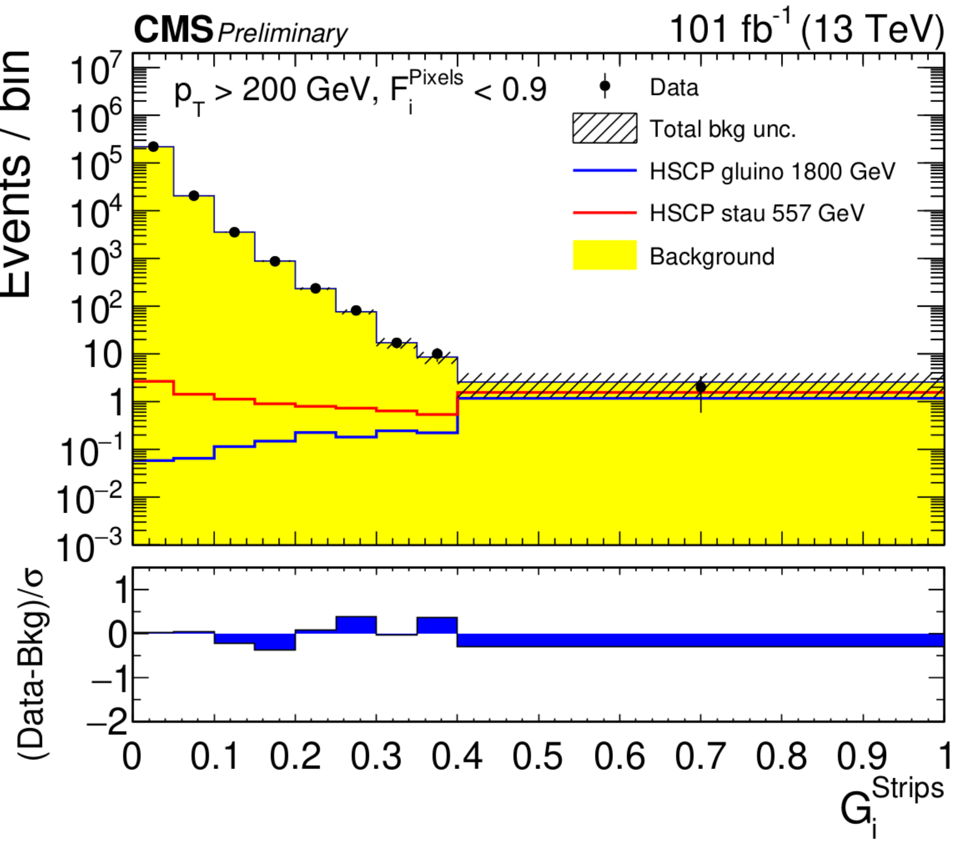
Results: 'Ionization method'

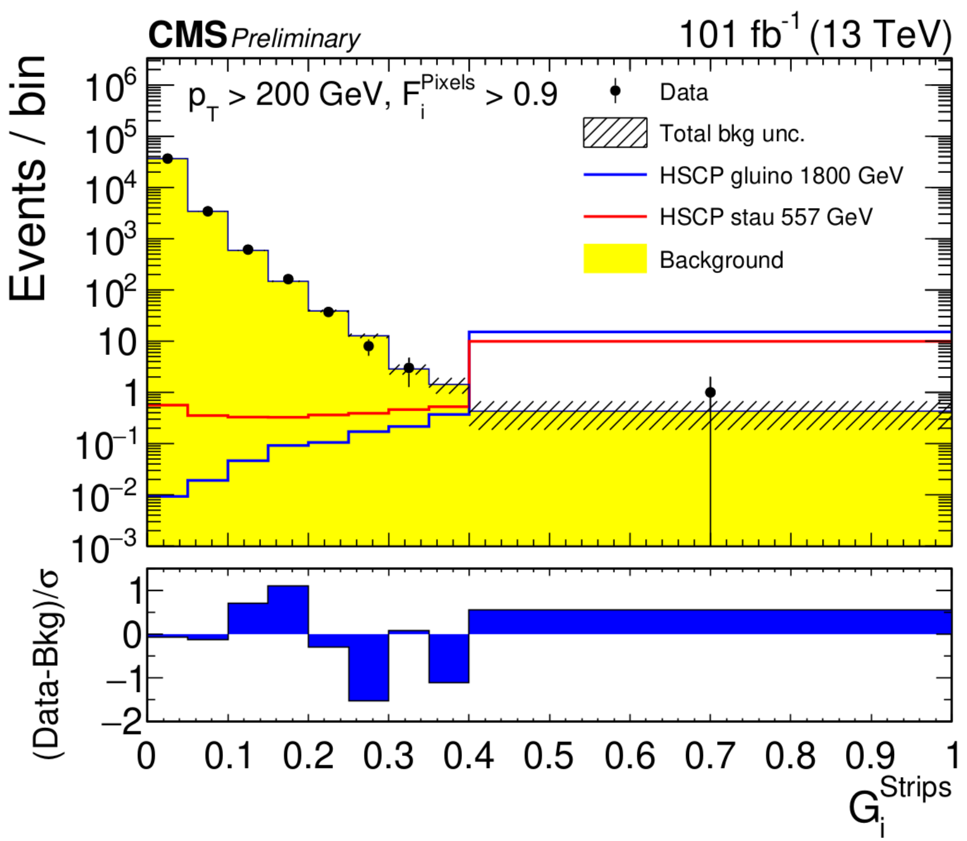
EXO-18-002

- $F_i^{\text{Pixels}} > 0.9$; use the full shape of G_i^{Strips} + $p_T > 200$ GeV

Fail = F sideband

Pass = F signal region





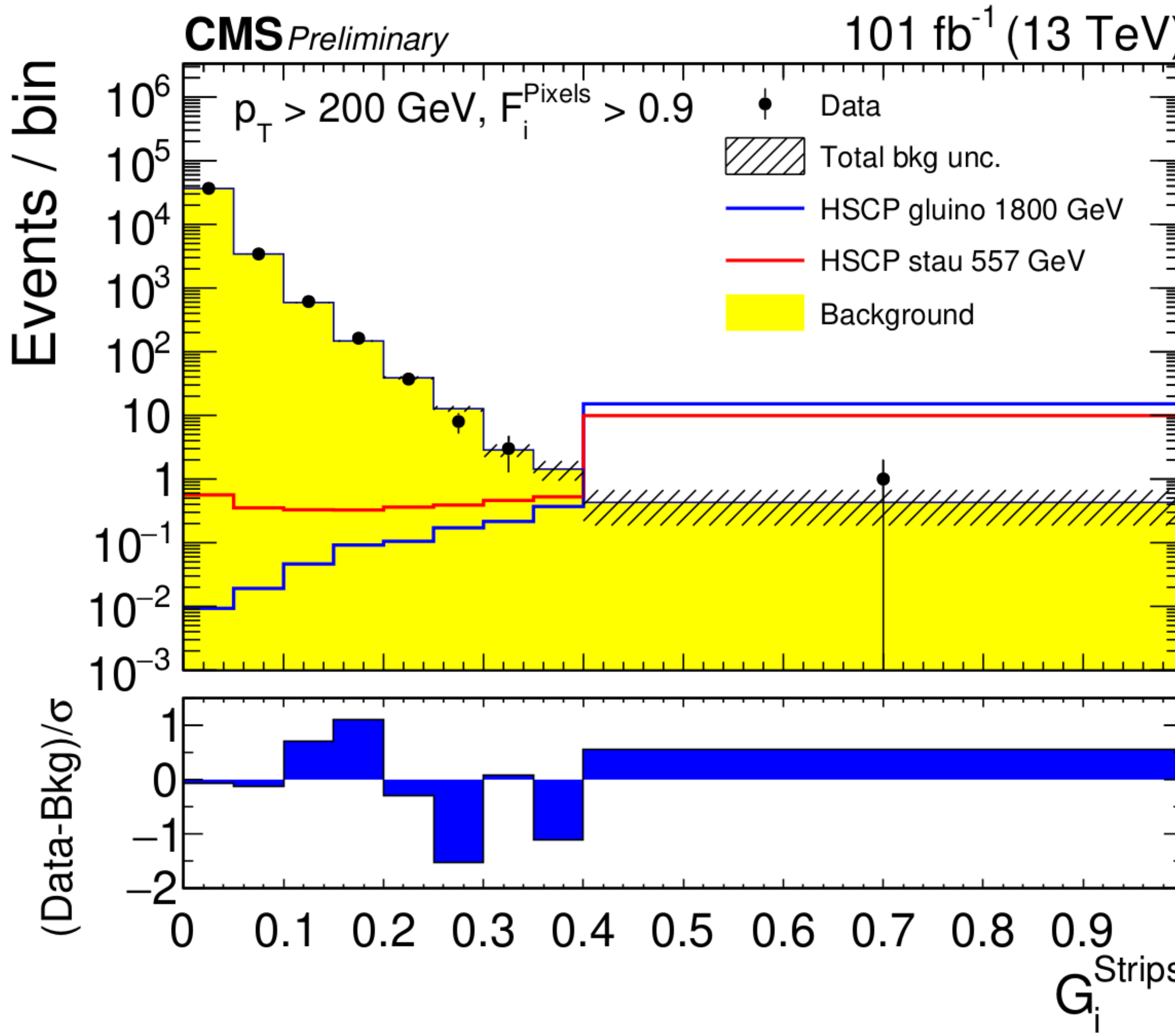
Results: ‘Ionization method’

EXO-18-002

- $F_i^{Pixels} > 0.9$; use the full shape of G_i^{Strips} + $p_T > 200$ GeV

No significant excess above SM

Last G bin: expected 0.4, observed 1

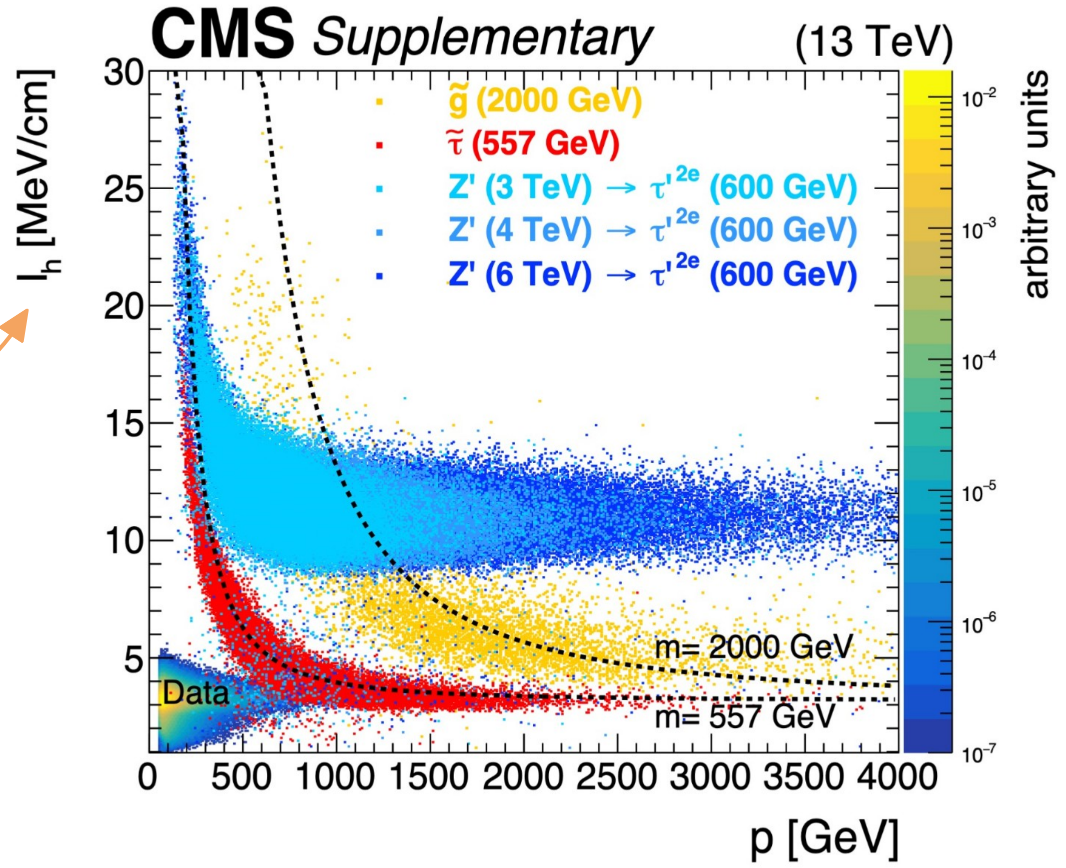


Bkg estimation #2: `Mass method'

EXO-18-002

- If excess, need to know mass; F vs G not very sensitive to it
  - Improved method used in previous HSCP searches by CMS.
  - Harmonic mean of dE/dx (suppresses Landau tails)

$$I_h = \left(\frac{1}{N}\sum_j^N (dE/dx_j)^{-2}\right)^{-1/2}$$



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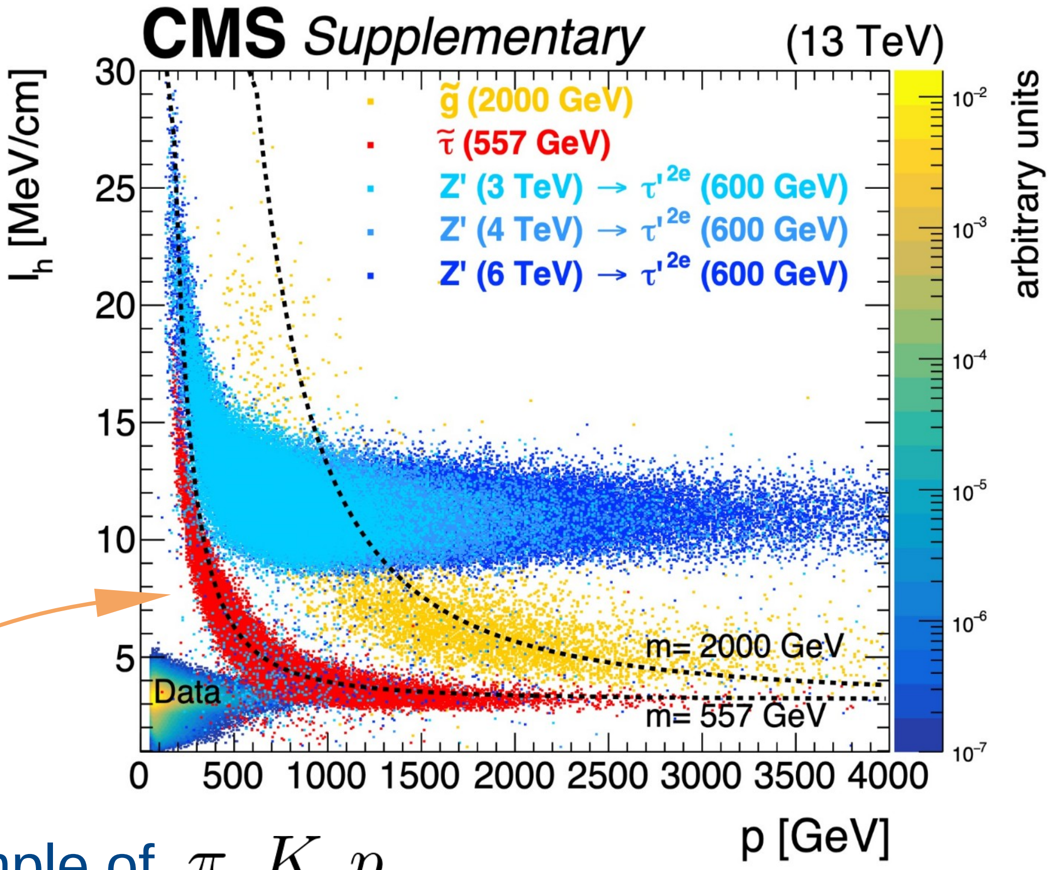
$$I_h = \left(\frac{1}{N}\sum_j^N (dE/dx_j)^{-2}\right)^{-1/2}$$

  - Approximation of Bethe-Bloch:

$$I_h = K\frac{m^2}{p^2} + C$$



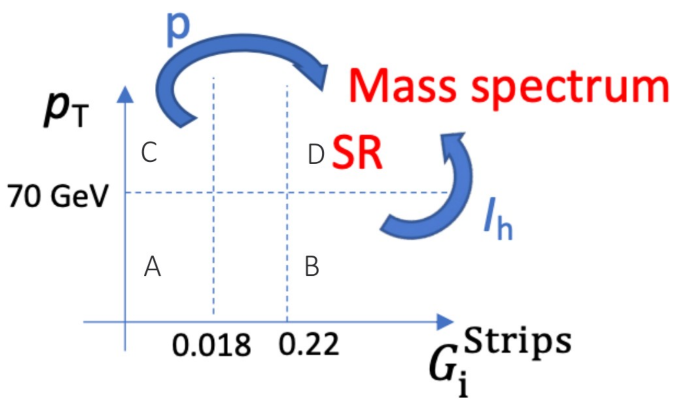
  - K, C from a low-p_T sample of π, K, p
  - Solve for m, plot

Bkg estimation #2: `Mass method'

EXO-18-002

- Data-driven: assume independence of I_h and p, and of p_T and G_i^{Strips}. Note lower $p_T > 70\ GeV$

  - ABCD method to determine every bin in mass spectrum



  - Fit I_h shape in B and p in C, in bins of η, use to predict m in SR.

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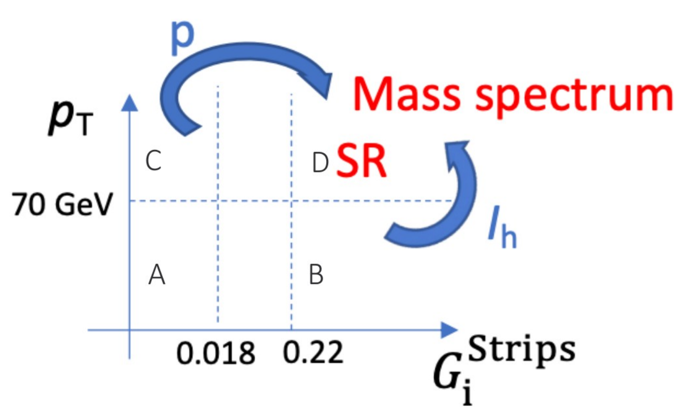
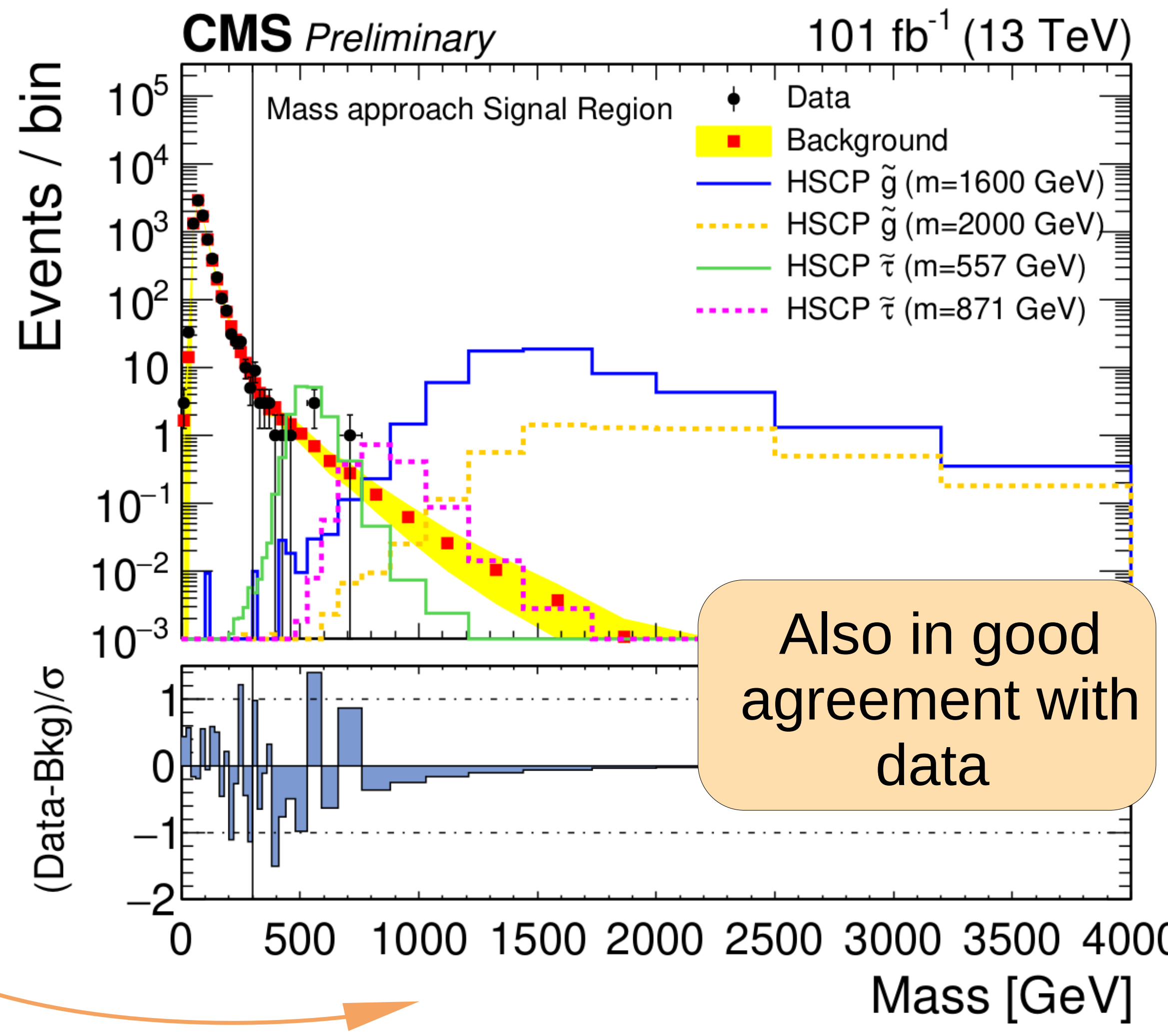


  - Counting experiment in dedicated mass windows

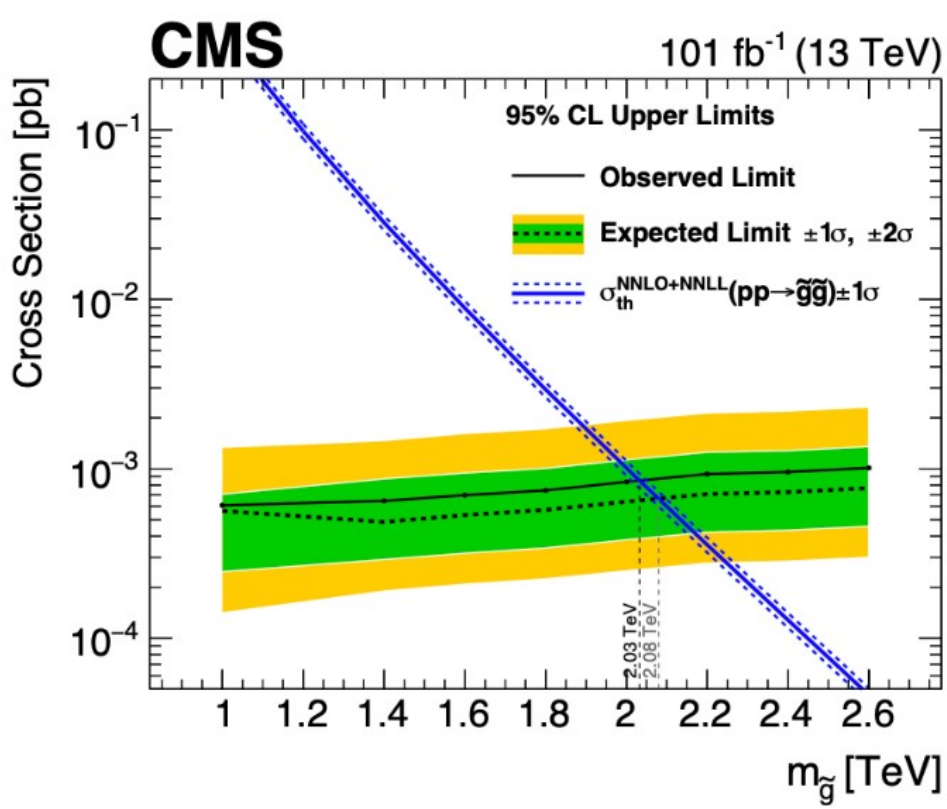


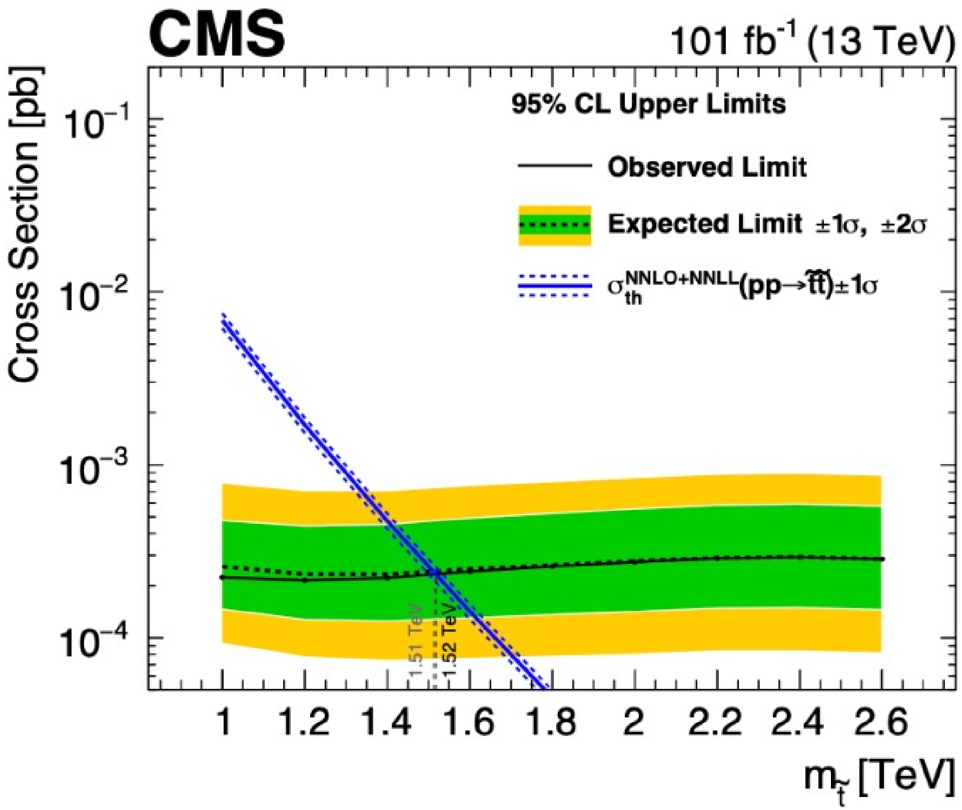
Also in good agreement with data

Interpretations (1)

EXO-18-002

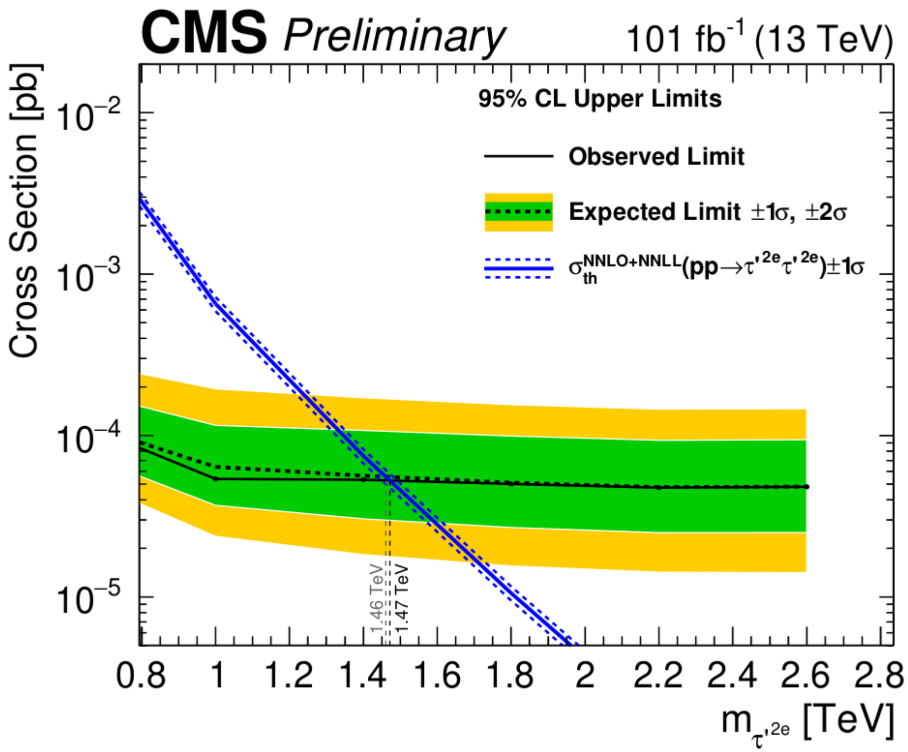
- Use the more suitable measurement for each model
- Gluino
  - mass > 2.03 TeV
  - (ionization method)
- Stop
  - mass > 1.52 TeV
  - (mass method)





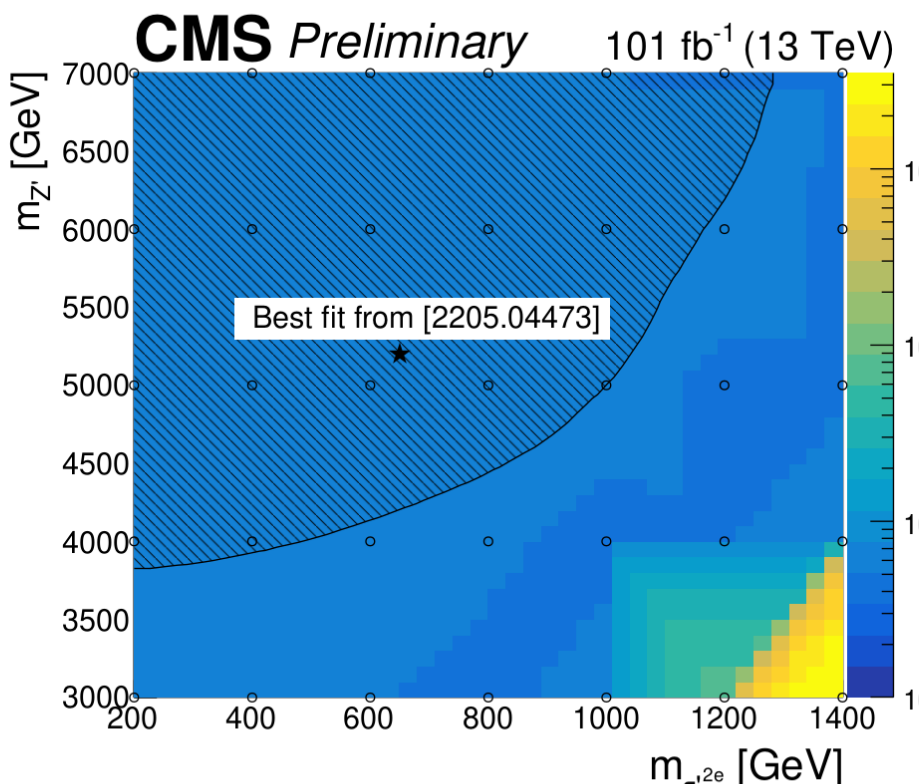
Interpretations (2)

EXO-18-002



- DY produced $Z' \to \tau'\tau'$ (doubly-charged τ') mass > 1.47 TeV
- (mass method)

- Model (2205.04473) created as an explanation of ATLAS excess: provides a highly ionizing track with $\beta \sim 1$
- (ionization method)



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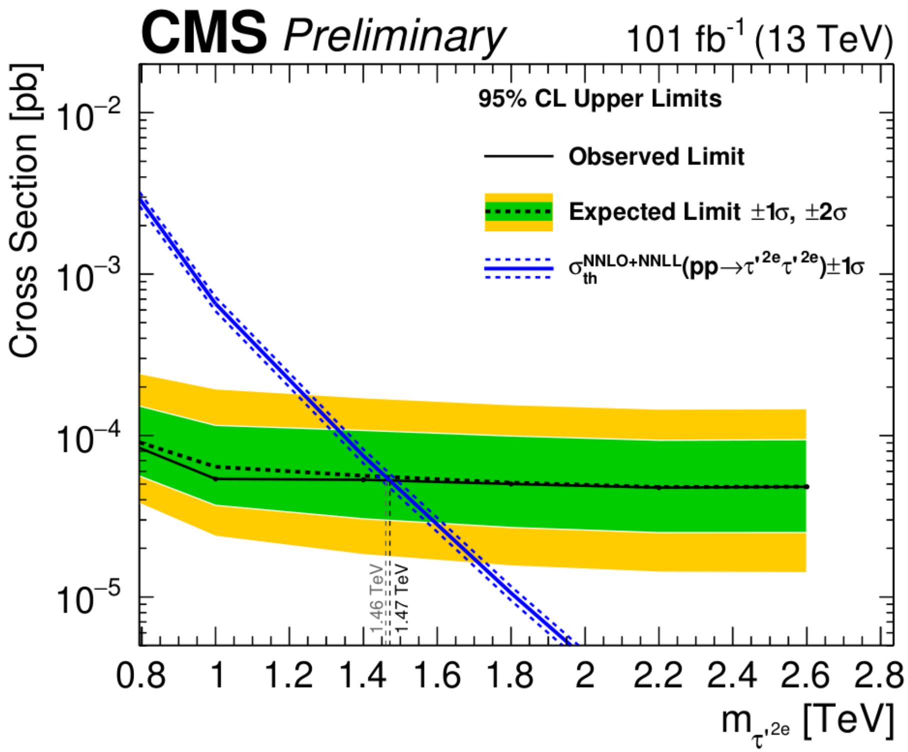

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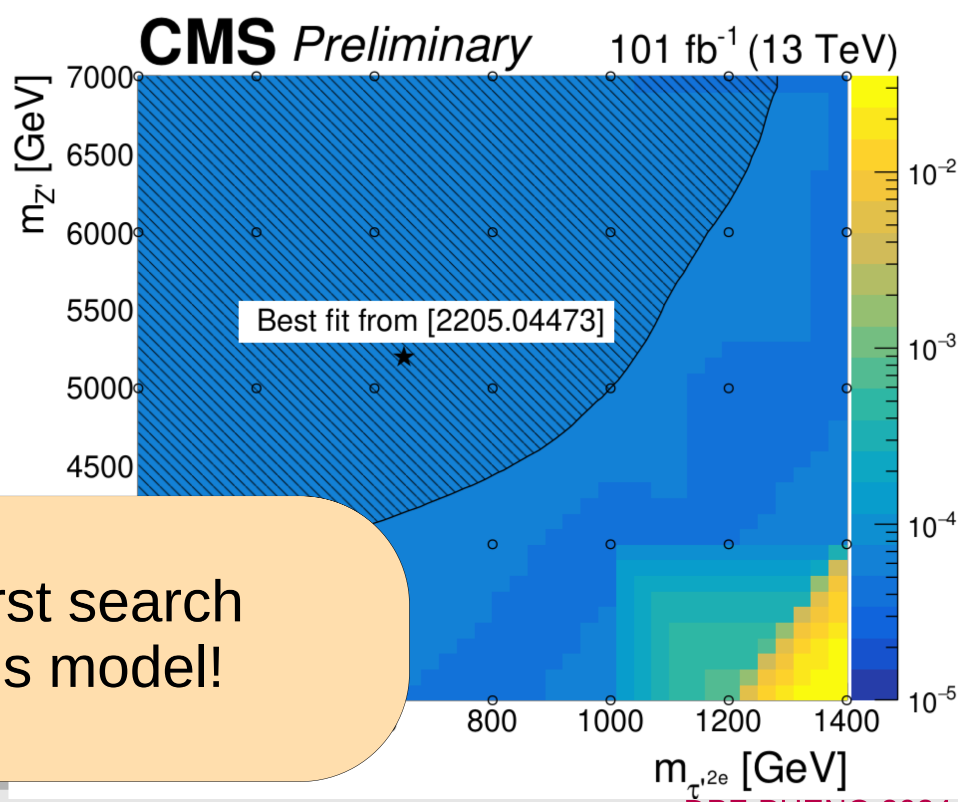

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The first search of this model!

Interpretations (3)

EXO-18-002

- X-sec limits: ionization method better limits at low signal masses
- While the mass methods is more efficient at large masses

Model	Ionization method Exp. (TeV)	Ionization method Obs. (TeV)	Mass method Exp. (TeV)	Mass method Obs. (TeV)
$\widetilde{g}$	2.08 ± 0.09	2.03	2.13 ± 0.11	2.13
$\widetilde{t}$	1.45 ± 0.08	1.40	1.51 ± 0.10	1.52
GMSB $\widetilde{\tau}$	0.88 ± 0.07	0.84	0.87 ± 0.09	0.85
pair-prod. $\widetilde{\tau}_R$	0.55 ± 0.07	0.52	0.52 ± 0.07	0.51
pair-prod. $\widetilde{\tau}_L$	0.68 ± 0.08	0.64	0.68 ± 0.10	0.61
pair-prod. $\widetilde{\tau}_{L/R}$	0.73 ± 0.08	0.69	0.75 ± 0.10	0.64
τ' $(Q = 1e)$ from DY prod.	1.06 ± 0.10	1.02	1.18 ± 0.12	1.20
τ' $(Q = 2e)$ from DY prod.	1.44 ± 0.17	1.37	1.46 ± 0.13	1.47
$Z'_{\psi} \to \tau' \tau'$	4.01 ± 0.27	3.88	4.20 ± 0.29	4.22
$Z'_{SSM} \to \tau' \tau'$	4.56 ± 0.28	4.41	4.75 ± 0.28	4.76

Conclusions

- A signature based, model independent search for HSCPs
- Two data-driven background predictions:
  - a novel approach relying on the independence of the ionization in the tracking detectors
  - an improved version of the historical mass method
- No significant excess over the SM :(
- Interpreted in 10 different models

  (one of them a direct response to ATLAS excess)
- HSCP mass exclusions significantly increased compared with previous CMS previous search