Searches for exotic physics with unconventional signatures at ATLAS and CMS

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Exotic among exotics?

Search for new BSM physics at LHC with exotic signatures:

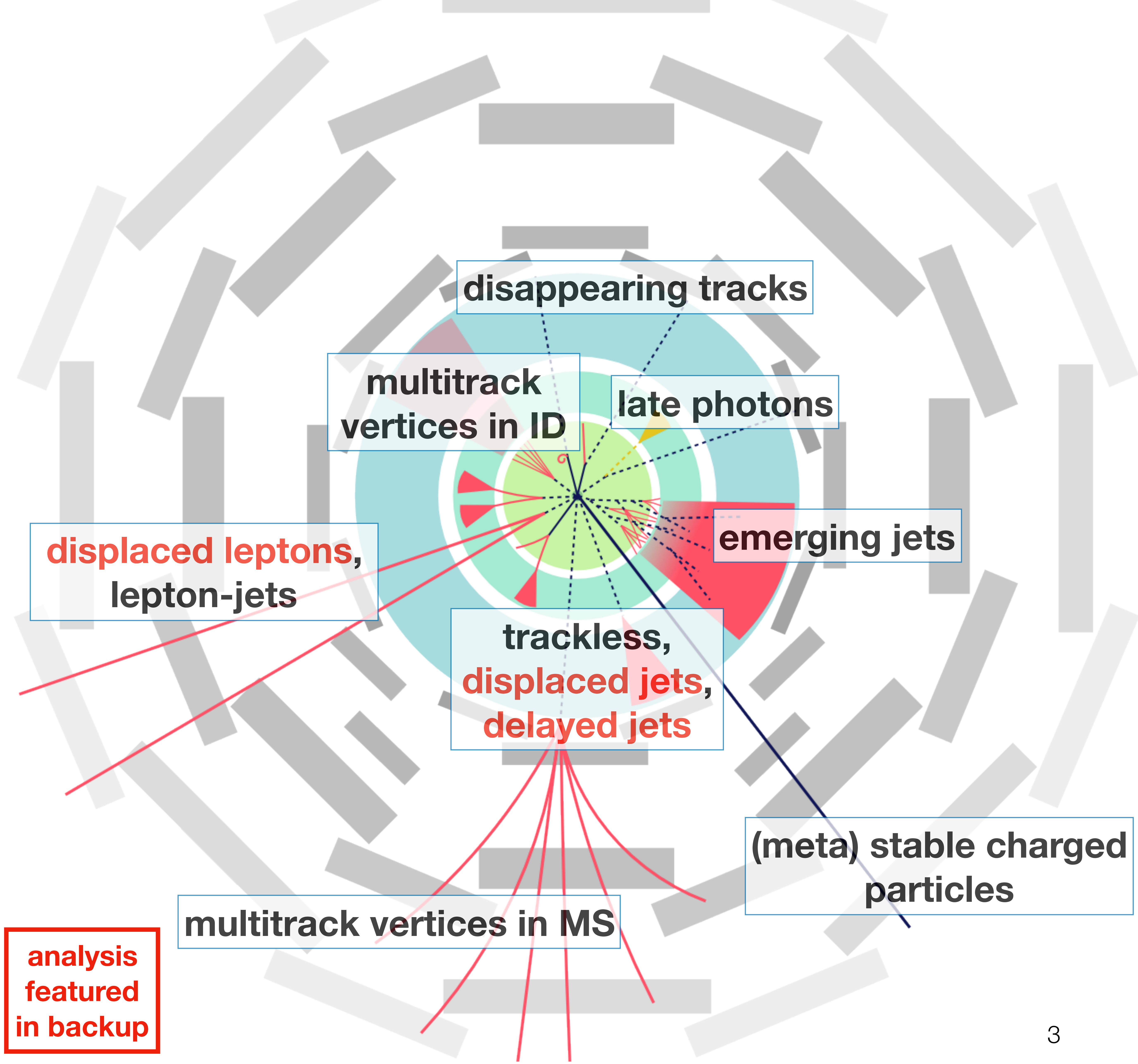
- Standard decays
- **Unconventional signatures**: long time-of-flight, anomalous energy deposits, displaced secondary vertices…
- Detector-stable particles

ATLAS and CMS are not optimised for this kind of signals

Unusual and unique signatures are extremely challenging to probe:

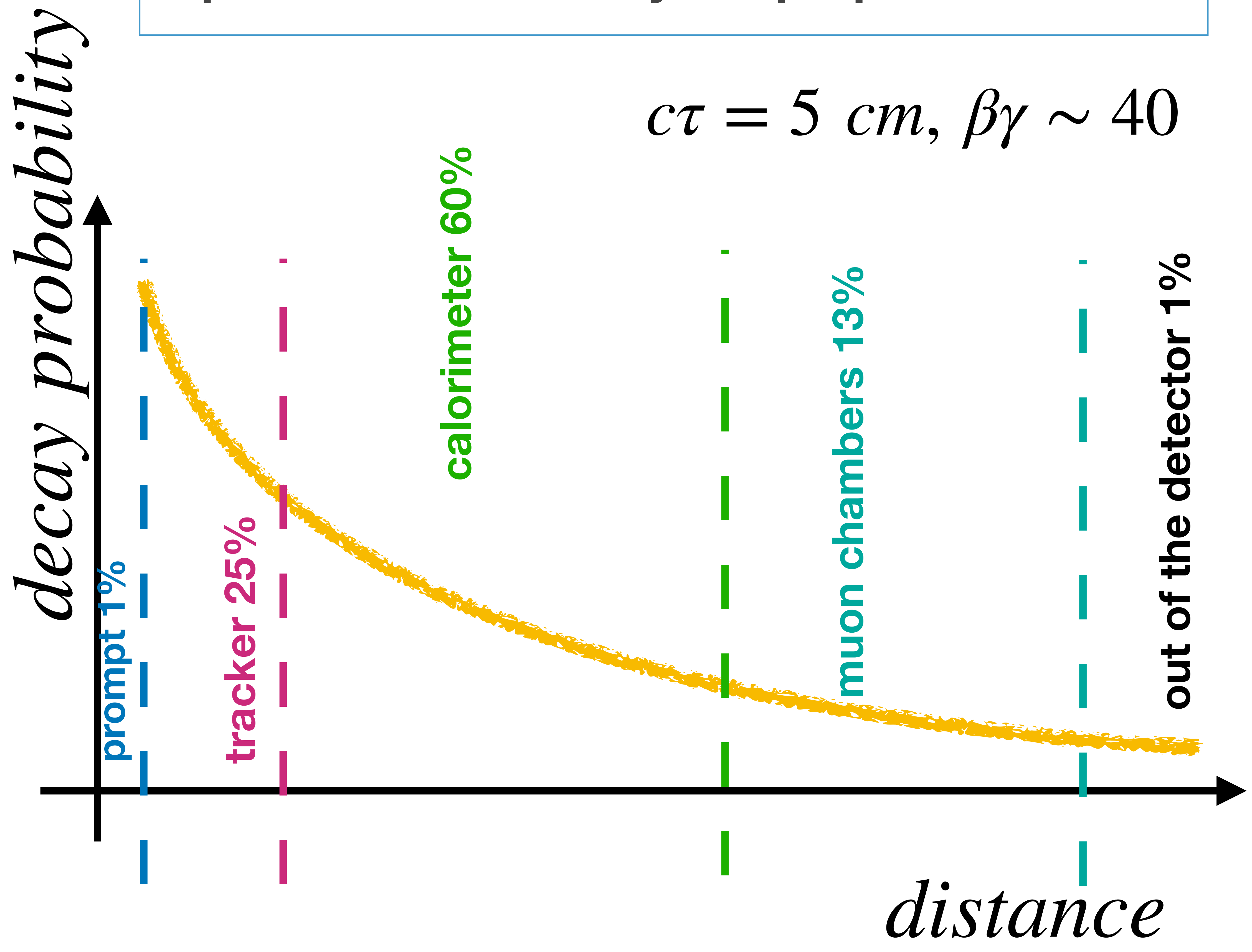
TRIGGER	RECONSTRUCTION	NON-COLLISION BACKGROUND
Anomalous signatures not associated with standard activity in the detector require the development of dedicated triggers!	Object identification and reconstruction algorithms are to be updated to include non-standard tracks and energy deposits	Unconventional signatures have unconventional backgrounds, from detector noise to non-collision physics events

Unconventional signatures



analysis featured in backup

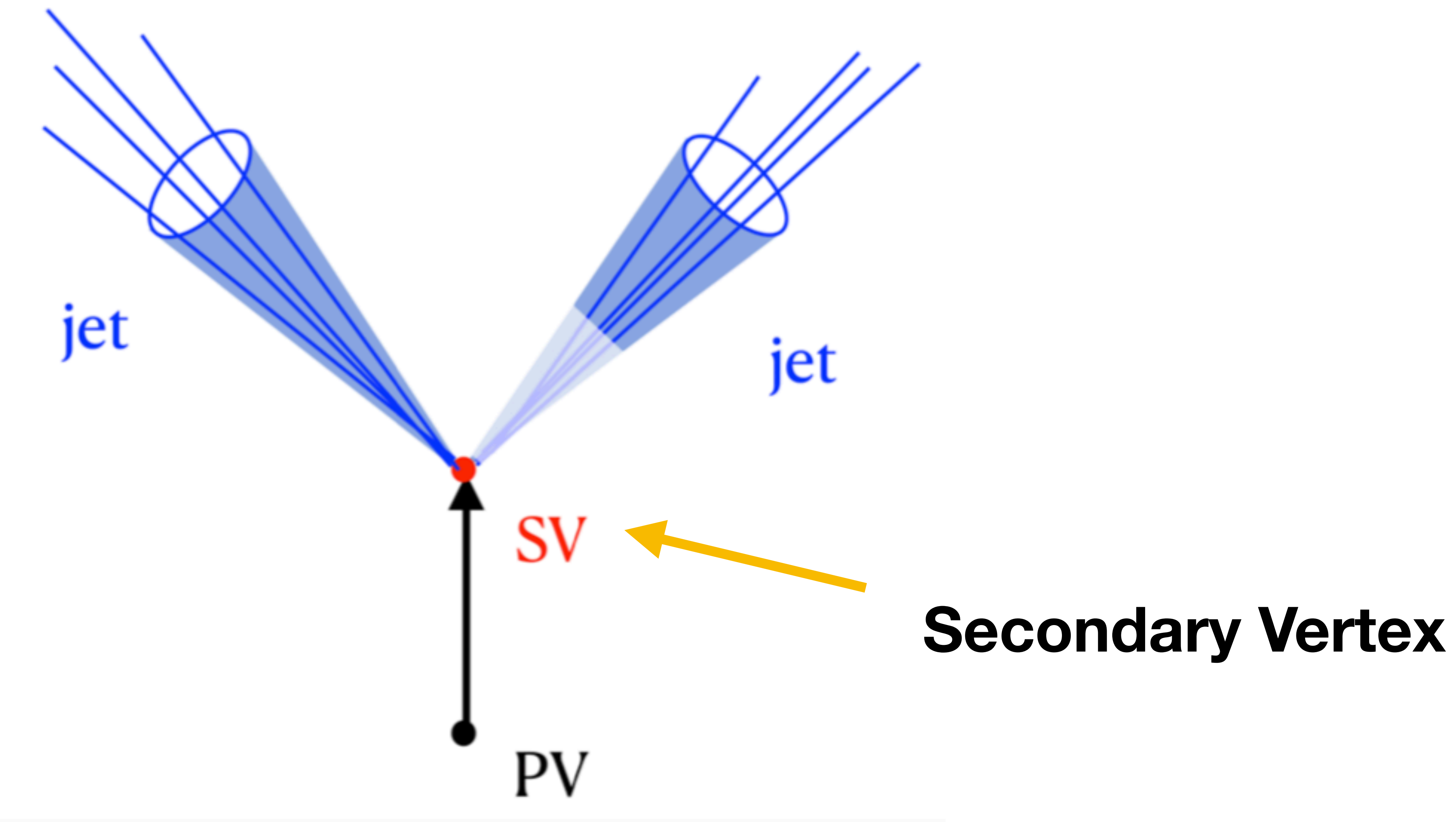
New particles can be long-lived: observed lifetime is governed by an exponential defined by the proper lifetime cτ



CMS-PAS-EXO-19-021

Displaced jet

Inclusive search for long-lived particles decaying into jets (covering lifetime between ~1 mm to ~1 m)

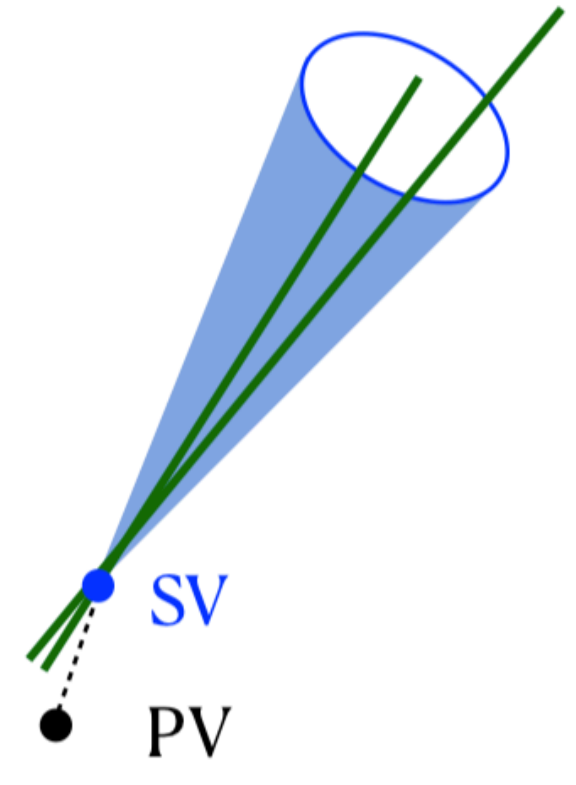


- Dedicated di-jet trigger to lower HT threshold from ~1 TeV to 0.4 TeV
- Select 1 displaced secondary vertex (SV) within tracker and 2 displaced jets
- MVA selection to discriminate signal from huge QCD background:
- Minor backgrounds from nuclear interactions, heavy flavour decays, randomly crossing tracks

HT: scalar sum of jet pT for jets with pT > 40 GeV and |η| < 2.5

CMS high-level trigger

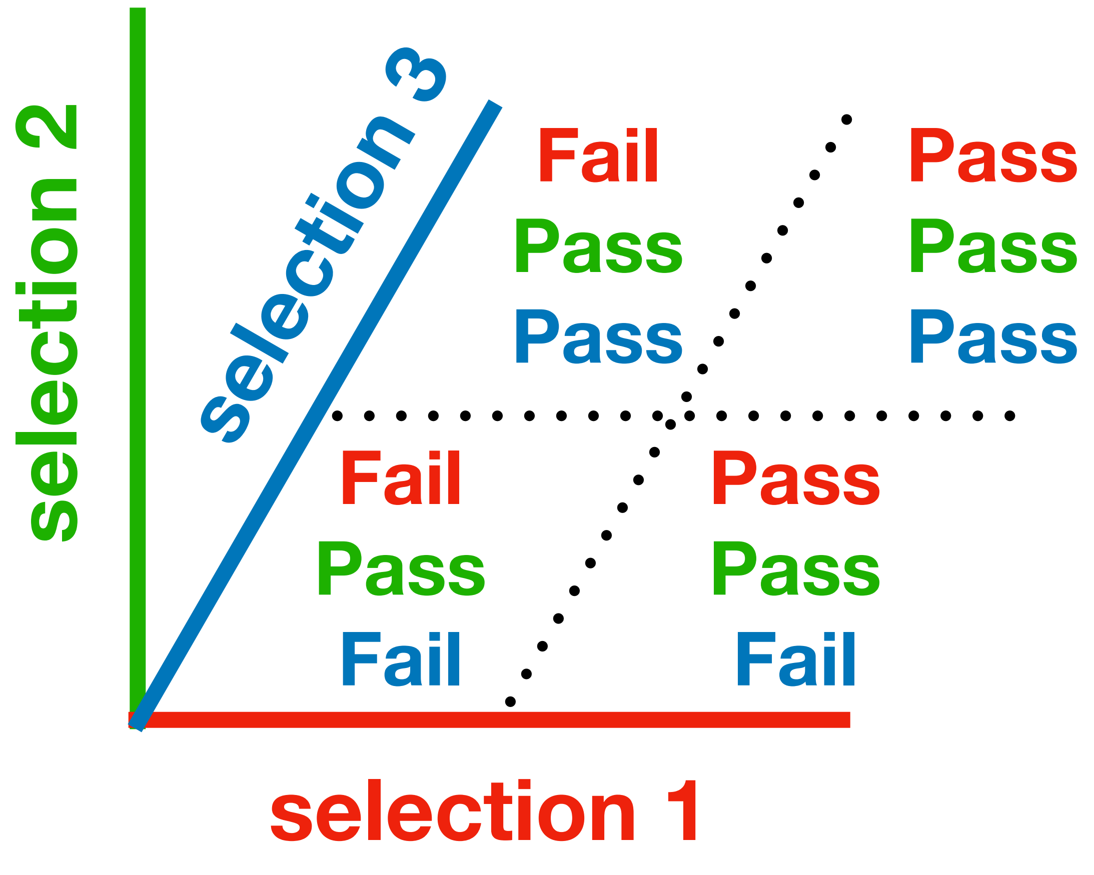
select displaced tracks online and tag displaced-jets with the HLT system by counting the number of prompt/displaced tracks associated with the jets



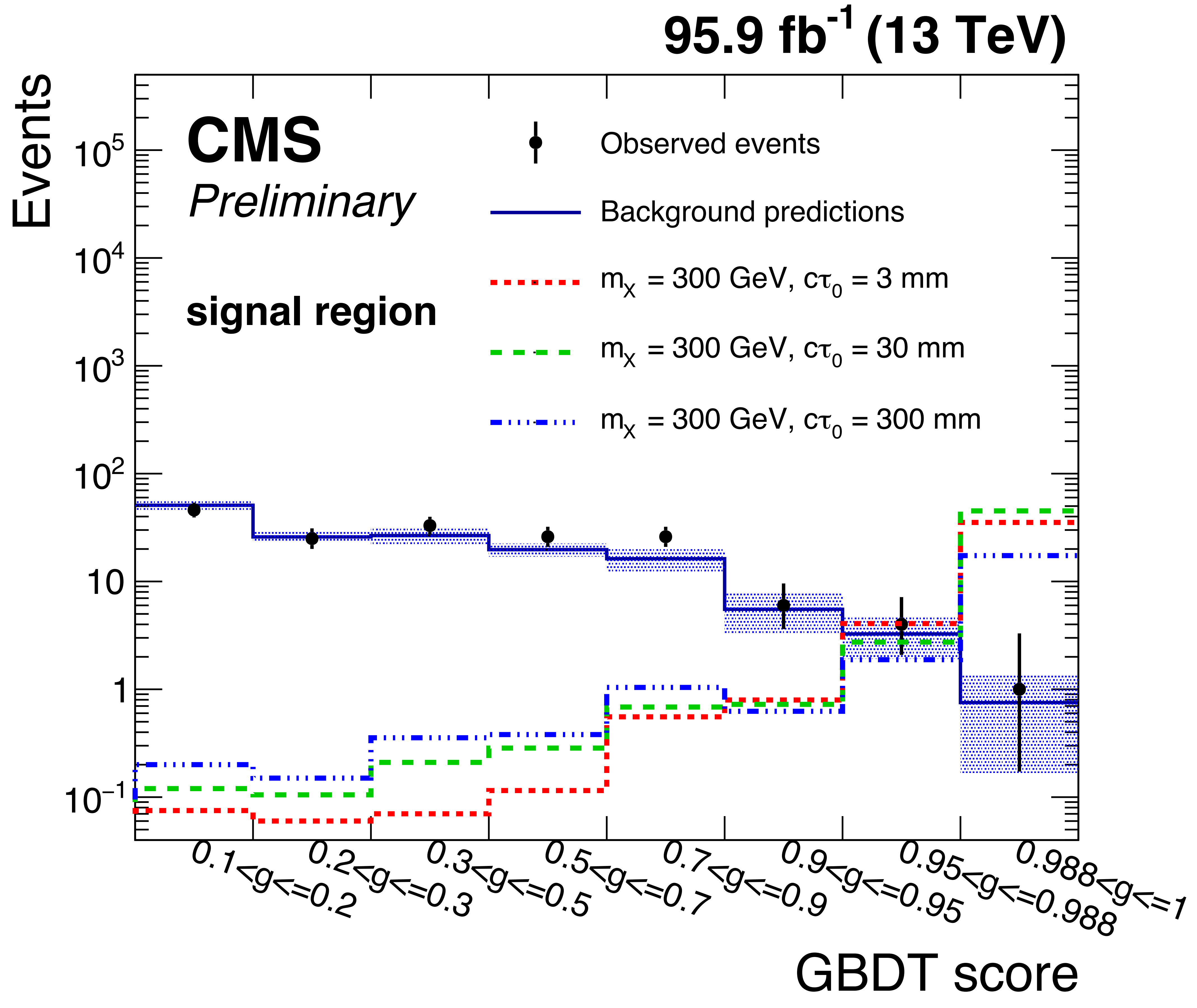
Displaced jet

Data-driven background estimate based on 3 dimensional ABCD method:

selection 1: # prompt tracks of first jet <= 2
selection 2: # prompt tracks of second jet <= 2
selection 3: Gradient BDT score



$$N_{ppp} \simeq N_{ppf} \frac{N_{ffp} + N_{fpp} + N_{pfp}}{N_{fff} + N_{pff} + N_{fpf}}$$



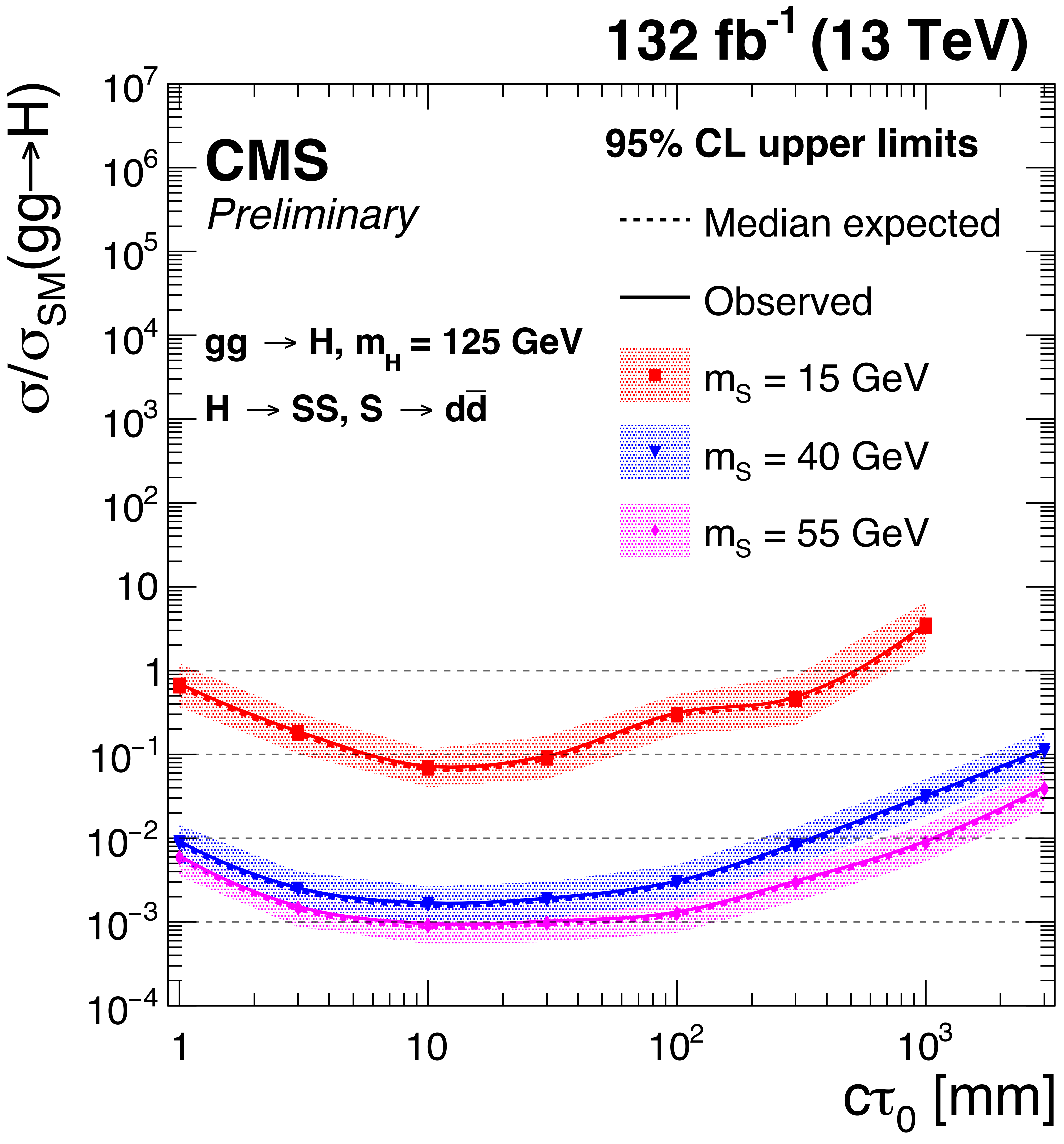
Background uncorrelated in sel 3 vs sel 1/2

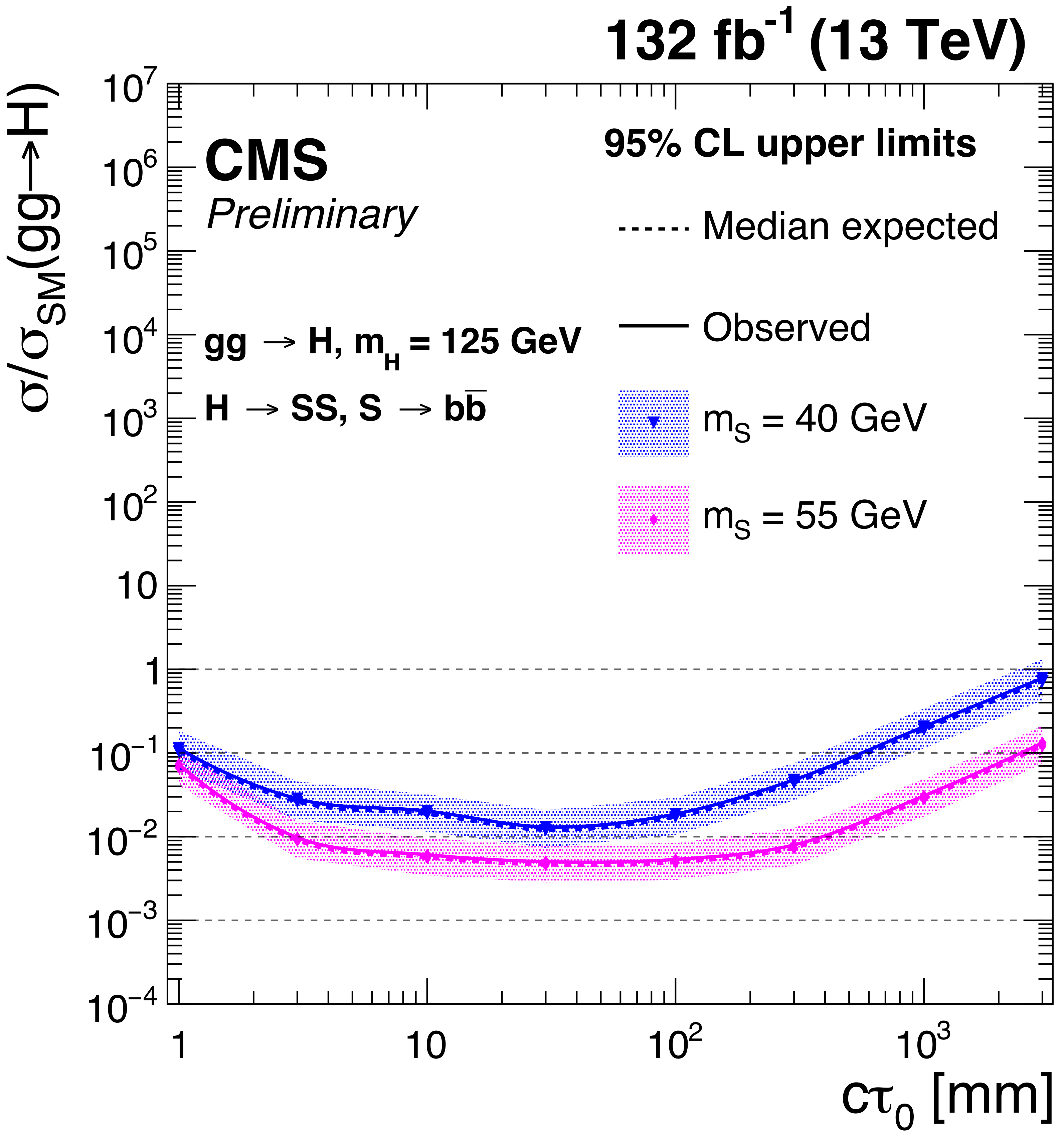
Signal highly correlated in sel 3 vs sel 1/2

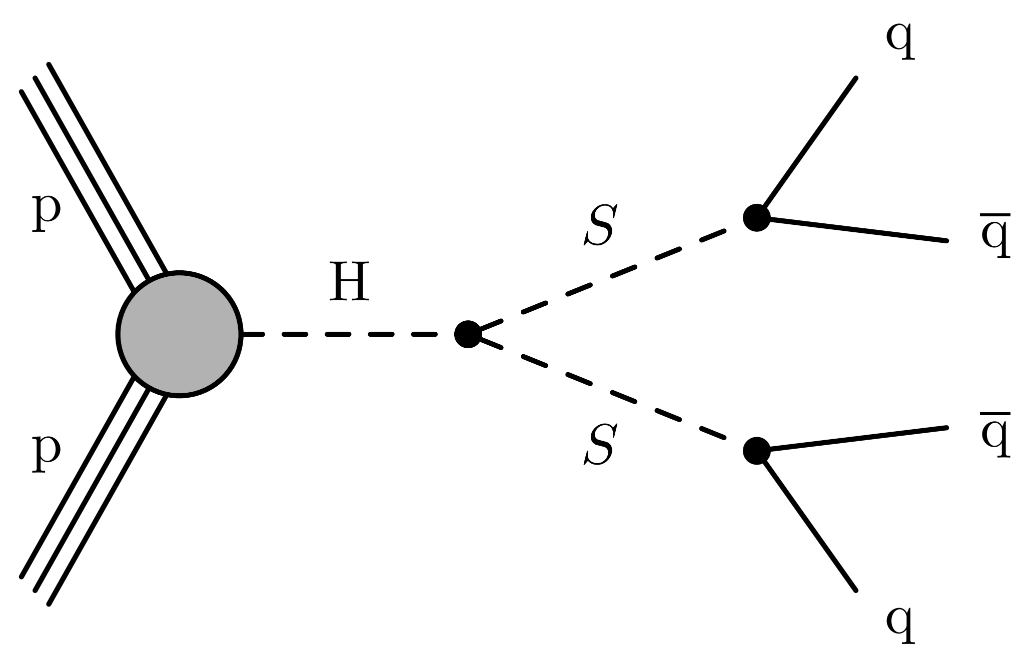
CMS-PAS-EXO-19-021

Displaced jet

Exclusion limits at 95% CL: for a Higgs portal model with two long-lived scalars, each decaying to a quark-antiquark pair, Higgs branching fractions larger than 1% can be excluded for mean proper decay lengths between 1mm and 1m







ATLAS-CONF-2021-005

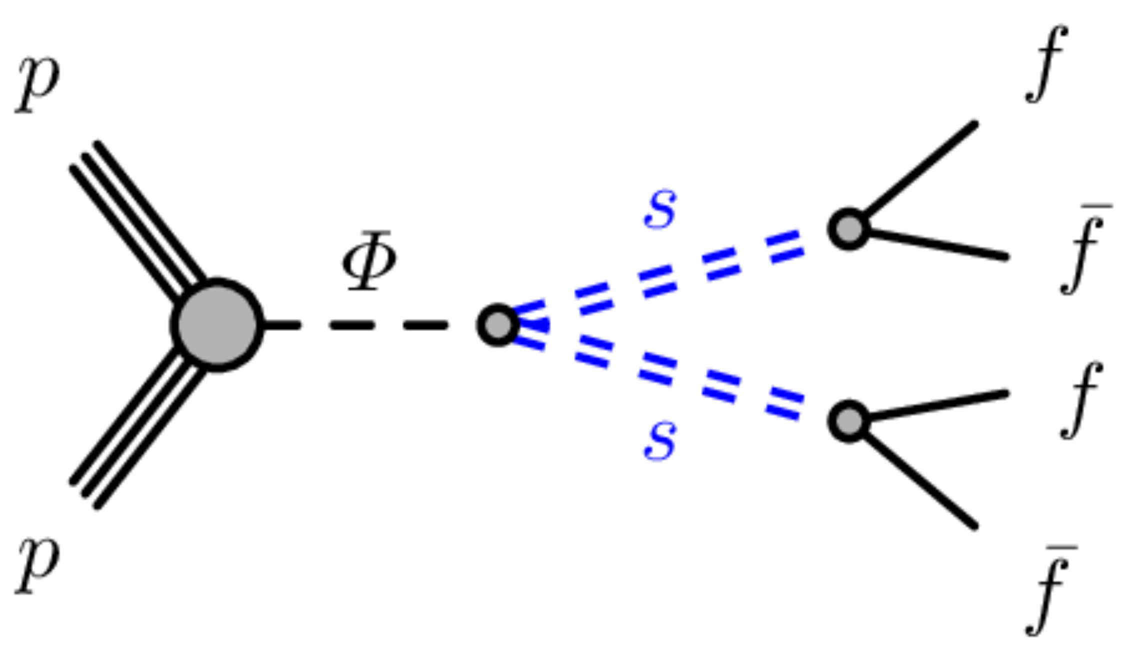
Displaced Vh 4b

Search for exotic decays of the Higgs boson to pairs of long-lived neutral particles, each decaying to a bottom quark pair:

- Trigger on ZH production: target lower masses and be sensitive in this unprobed phase space
- Dedicated LLP reconstruction in tracker region with custom Large Radius Tracking algorithm

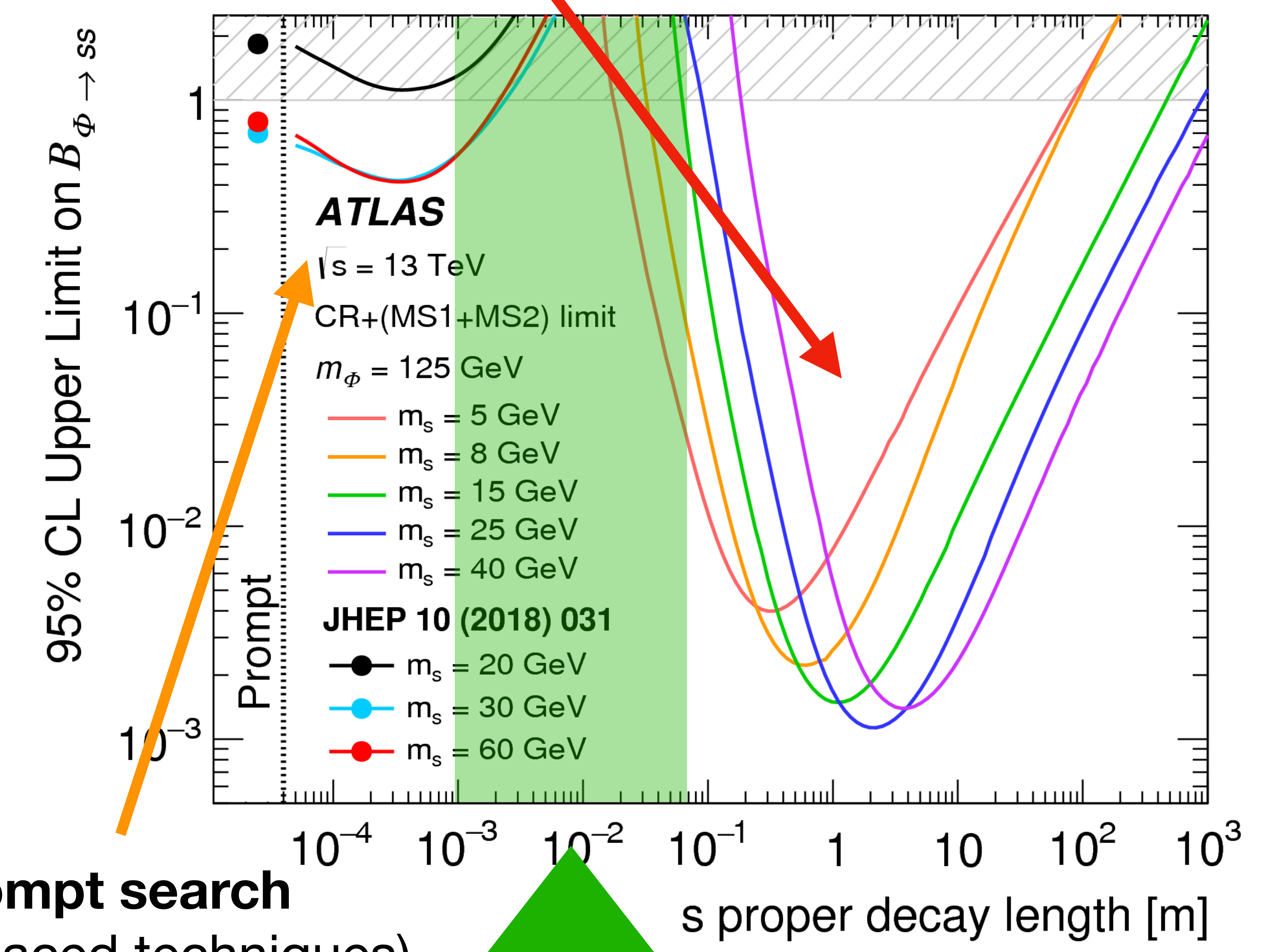
$$\kappa H^2 S^2 + \mu H^2 S$$

Higgs portal and mixing with ‘dark’ scalars



For scalar masses above 10 GeV —> bb decay mode favoured

Dedicated searches:
in calorimeter: $0.1 \leq c\tau \leq 10\ m$
in muon system: $c\tau \leq 100\ m$
EPJC 79 (2019) 481



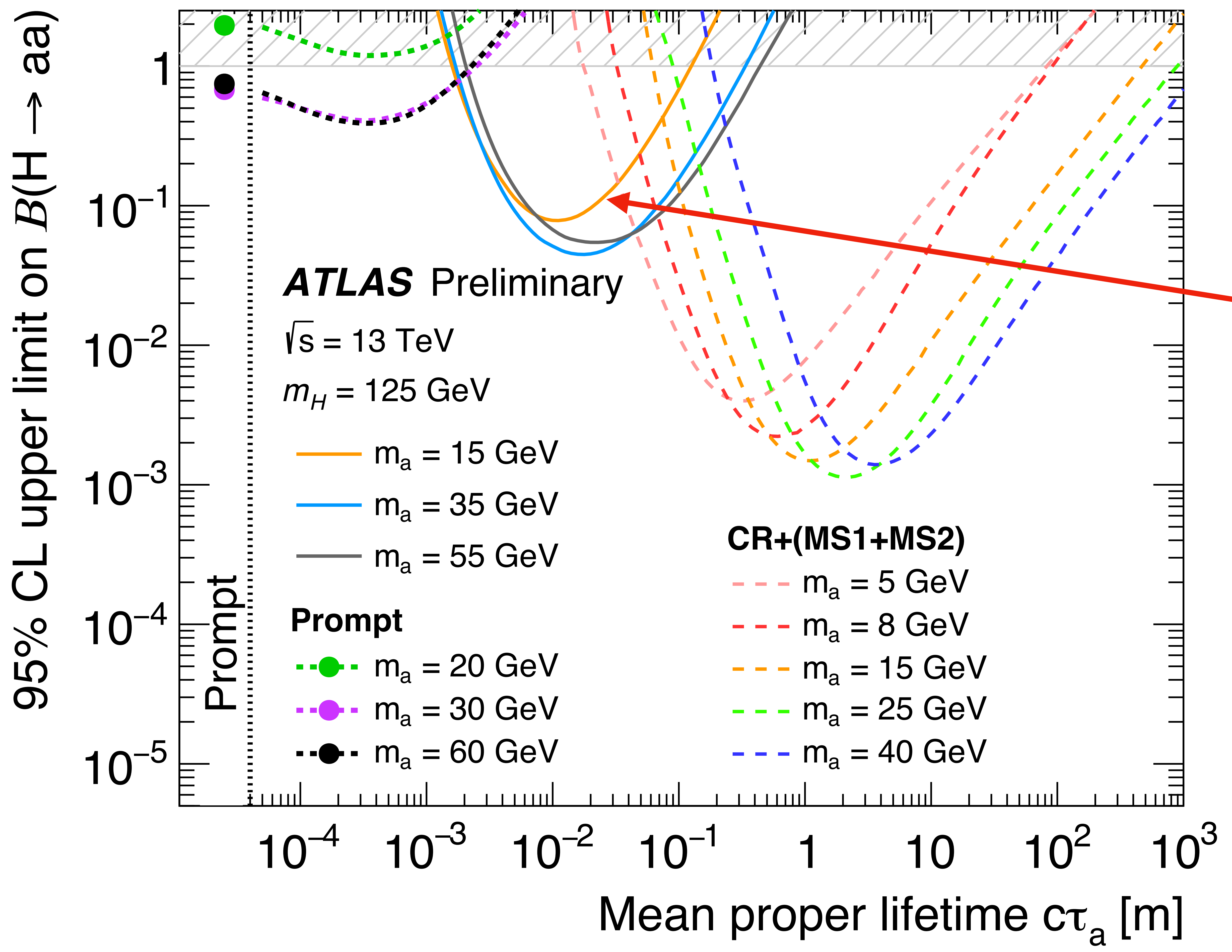
Prompt search
(no displaced techniques)
$50\ \mu m \leq c\tau \leq 2\ mm$
JHEP 10 (2018) 031

Uncovered spot:
LLP decays inside inner detector

ATLAS-CONF-2021-005

Displaced Vh 4b

Zero events observed in signal region and consistent with background estimate



This analysis complements ATLAS prompt and dedicated searches

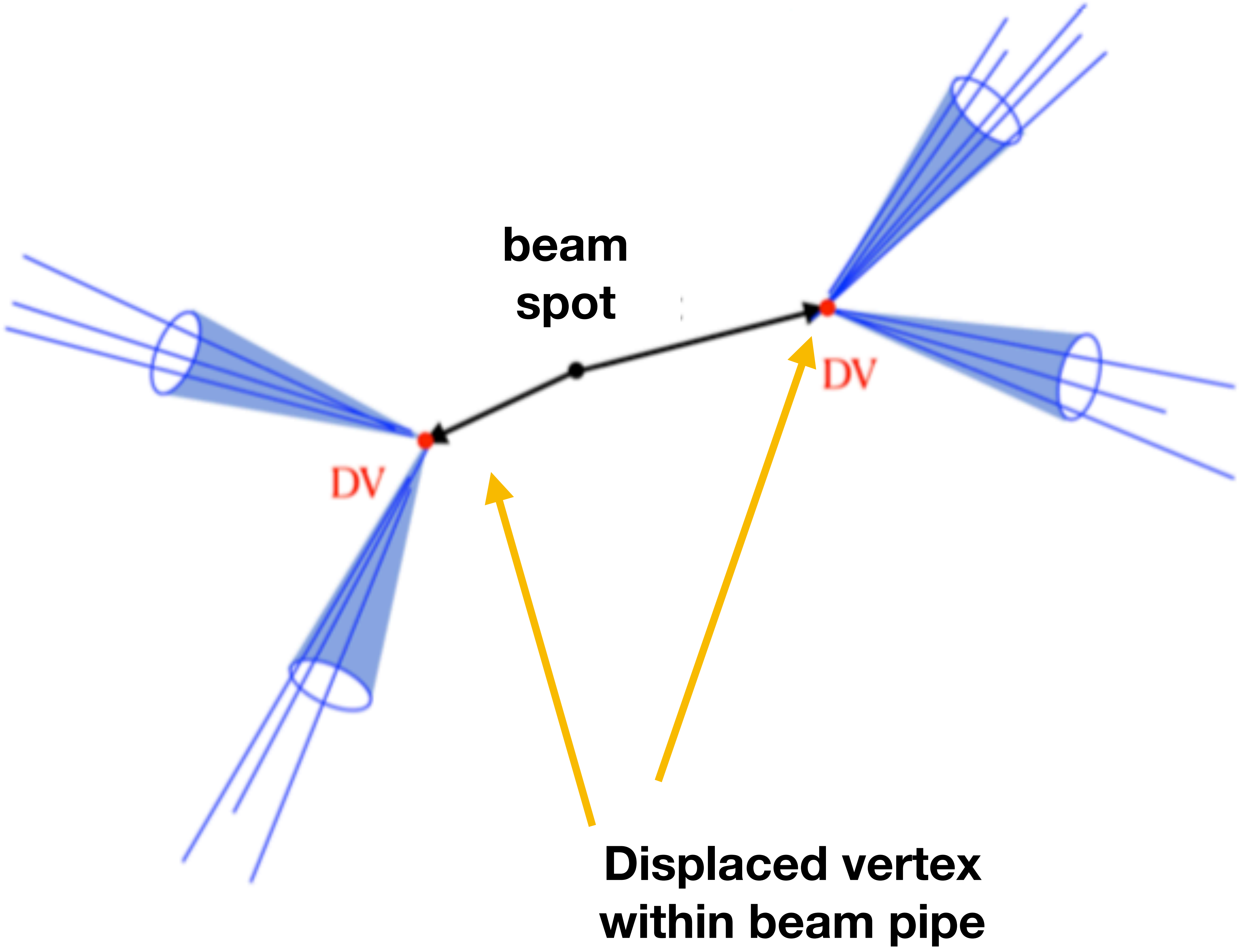
Most stringent 95% CL upper limits on BR(H->ss) for masses below 40 GeV

CMS-PAS-EXO-19-013

Displaced vertices

Search for long-lived particles decaying into jets (covering lifetime between ~0.1 mm to ~100 mm)

- Jet trigger with HT 1050 GeV
- Select 2 displaced vertices events with more than 4 jets
- Customised track and vertex reconstruction for LLPs decaying inside the beam pipe (no association with jets)
- Target pairs of LLP: distance between the two DV as main discriminating variable
- Target tiny lifetimes: displacement of the vertex within the beam pipe (<~21 mm)

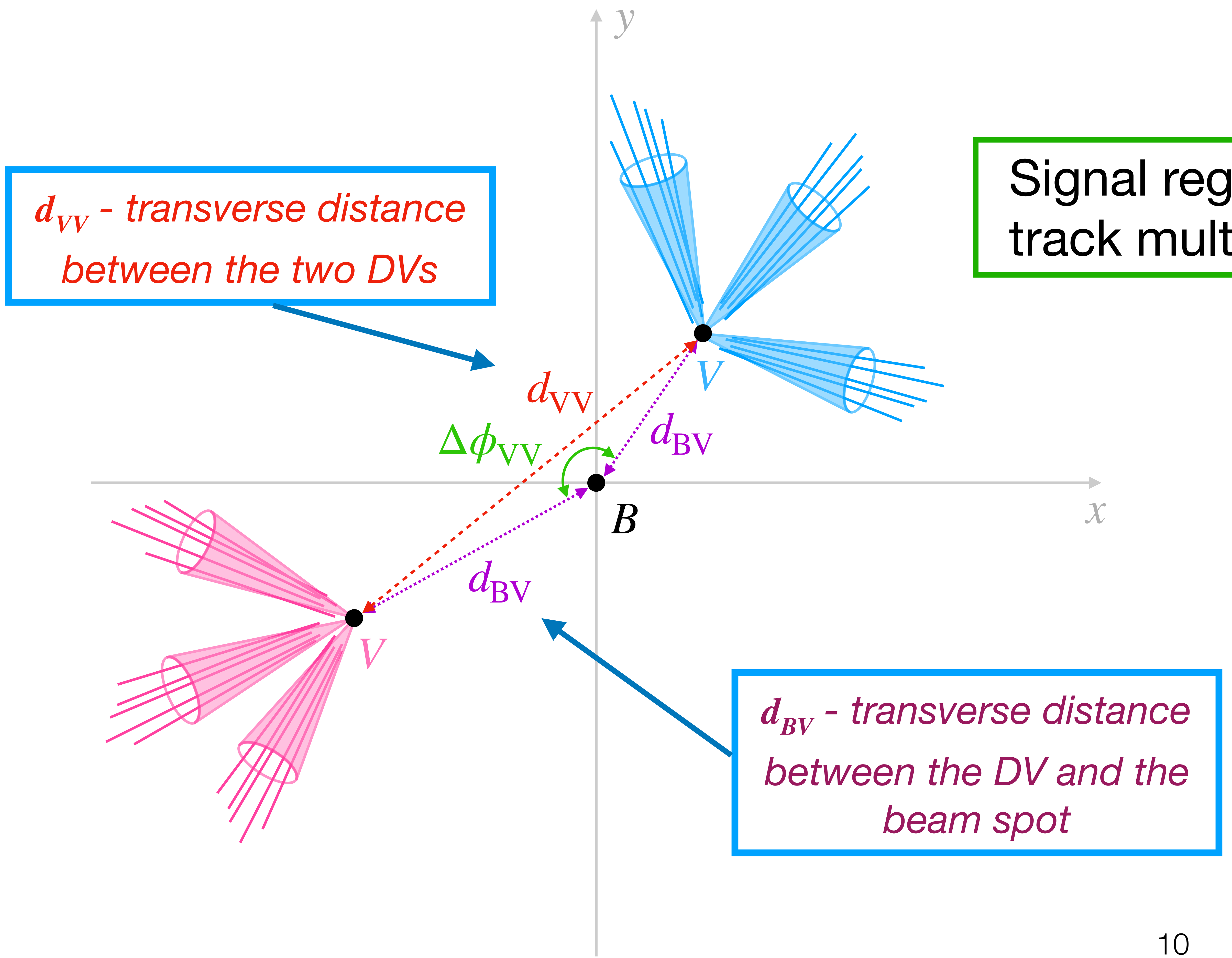


HT: scalar sum of jet pT for jets with pT > 40 GeV and |η| < 2.5

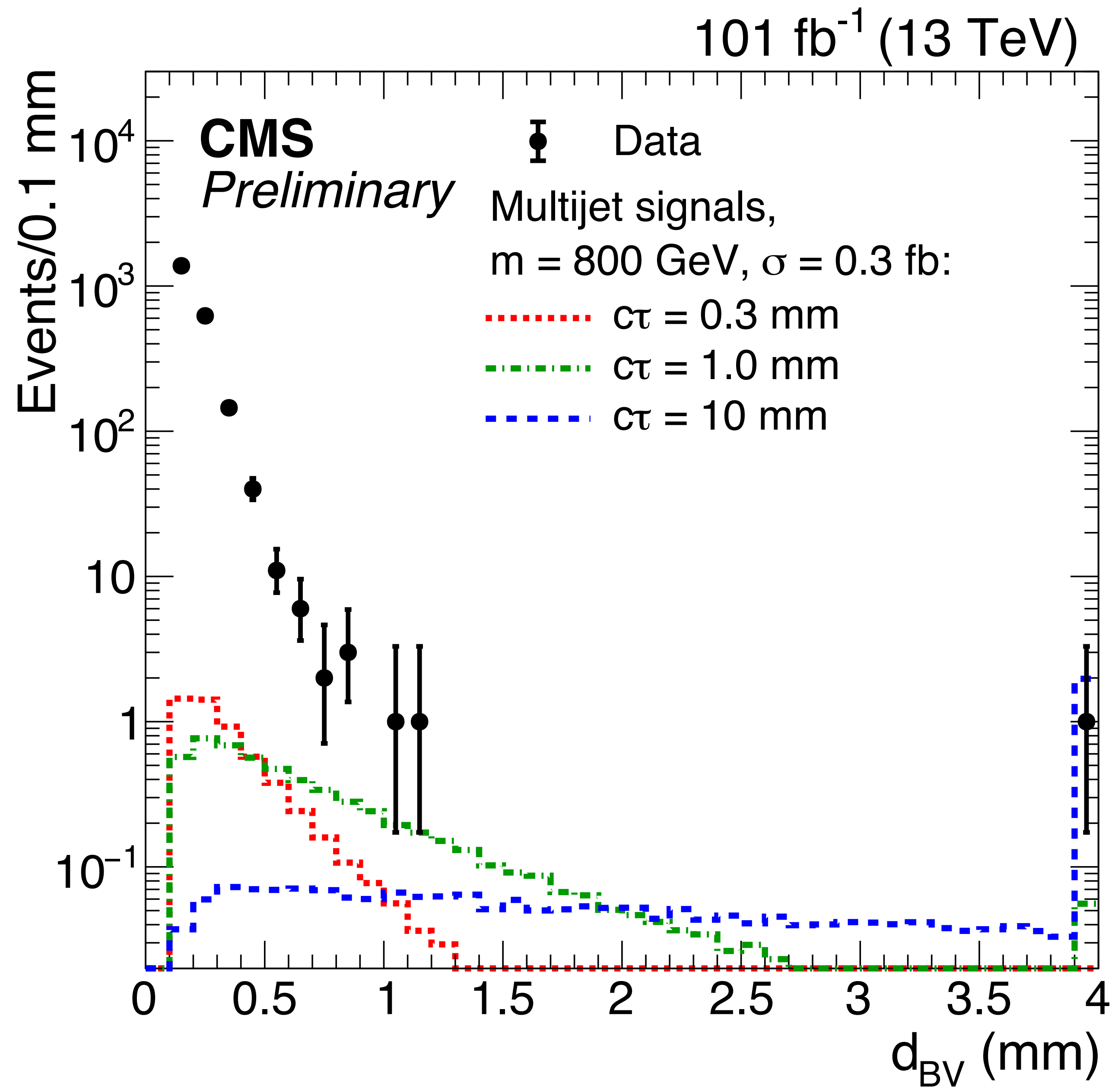
CMS-PAS-EXO-19-013

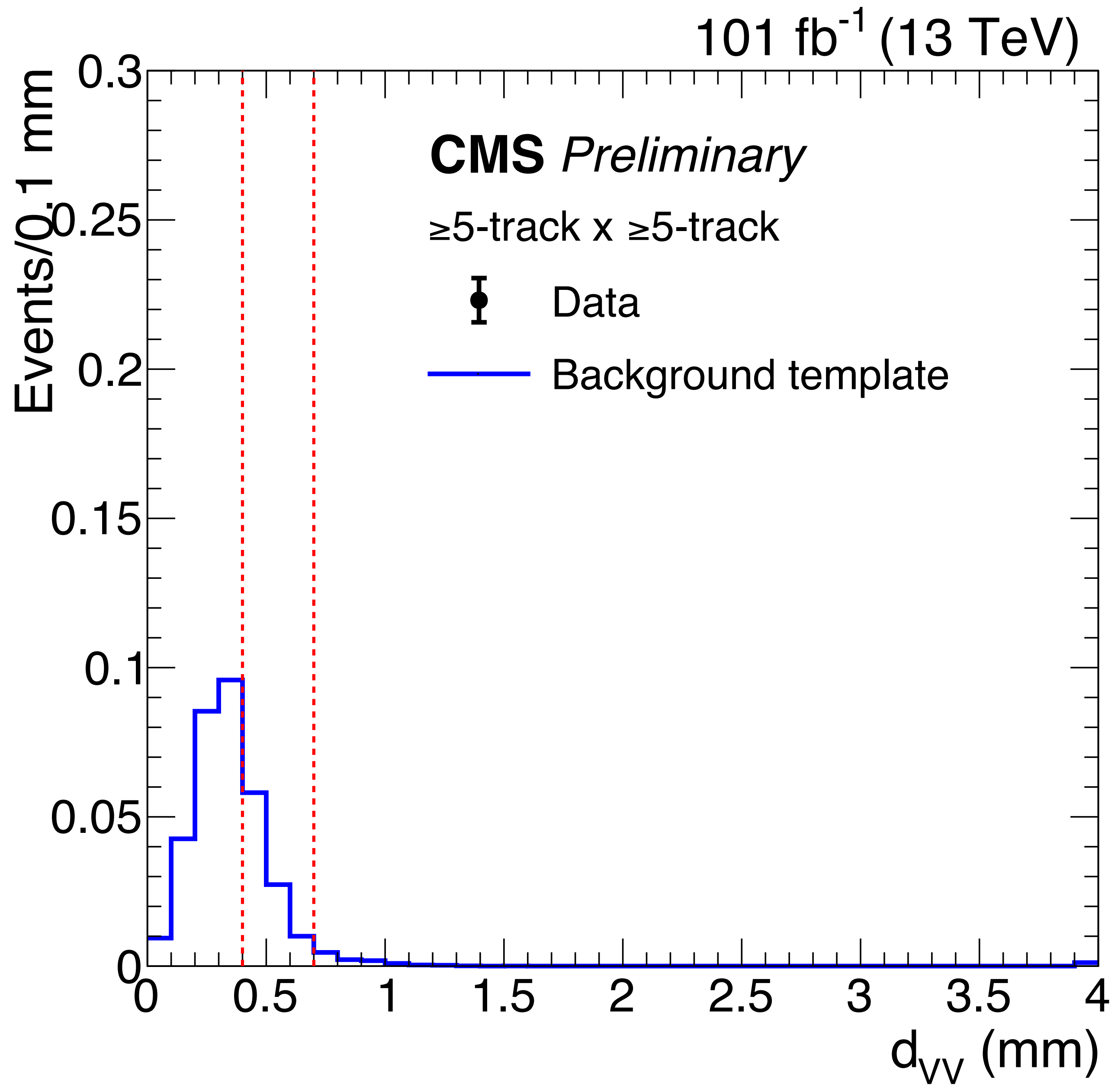
Displaced vertices

Background prediction purely data-driven: build background template for d_{VV} distribution in 2DVs events from d_{BV} distribution in 1DV events



Signal region: 2DVs with track multiplicity >=5



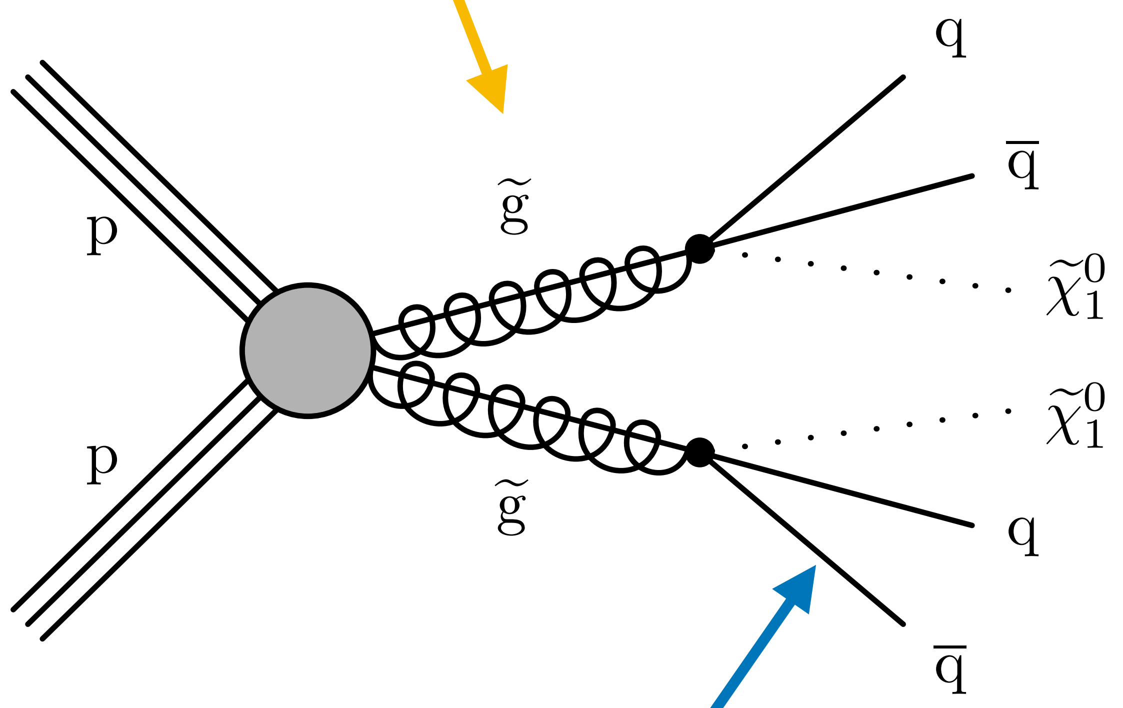


CMS-PAS-EXO-19-013

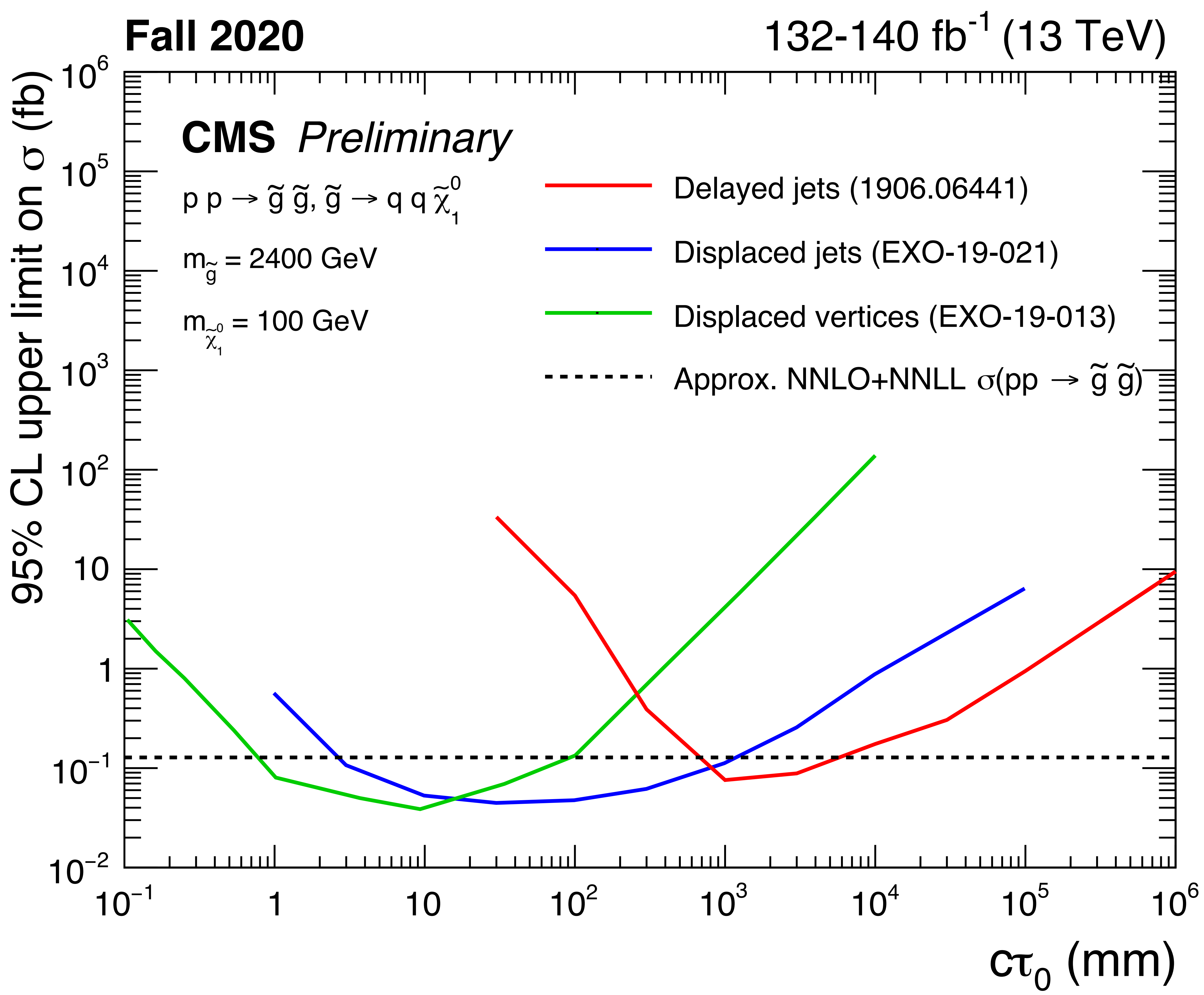
Displaced vertices

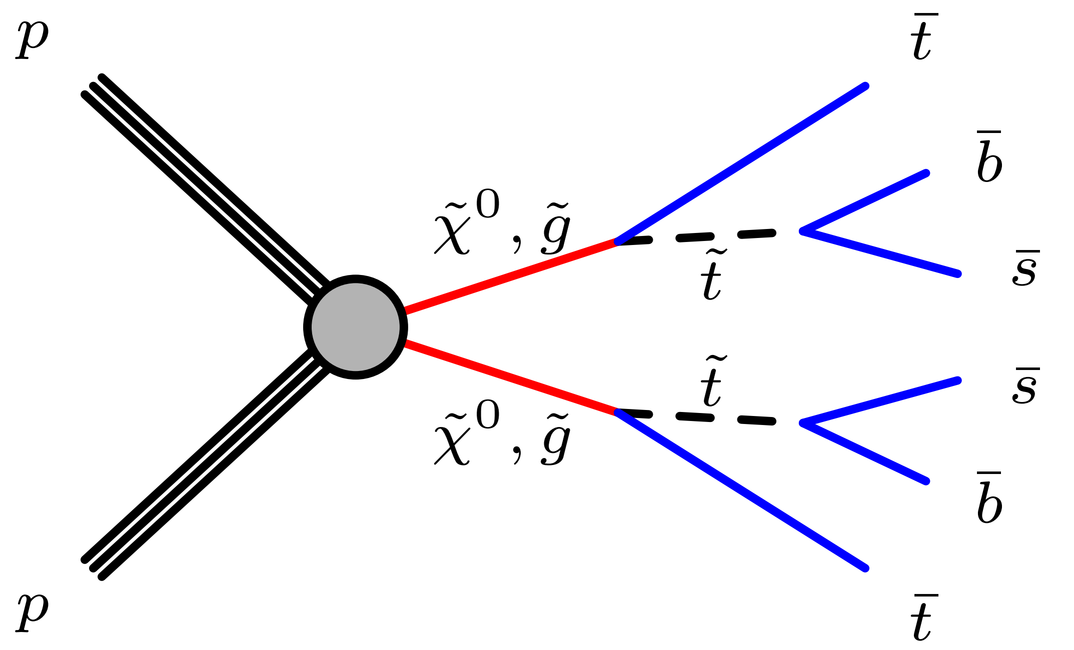
The search is sensitive to various models with pair produced LLP decays into two or more jets in the final state. Zero events observes, results are interpreted in RPV SUSY models.

gluino is long-lived

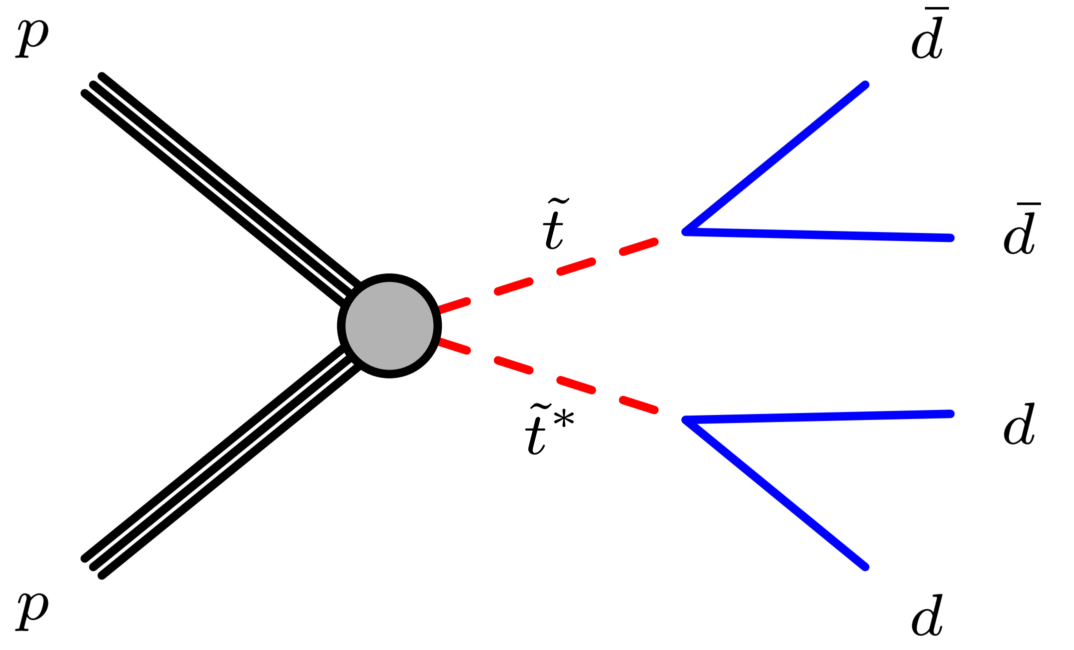


large jet activity





more interpretations shown in backup



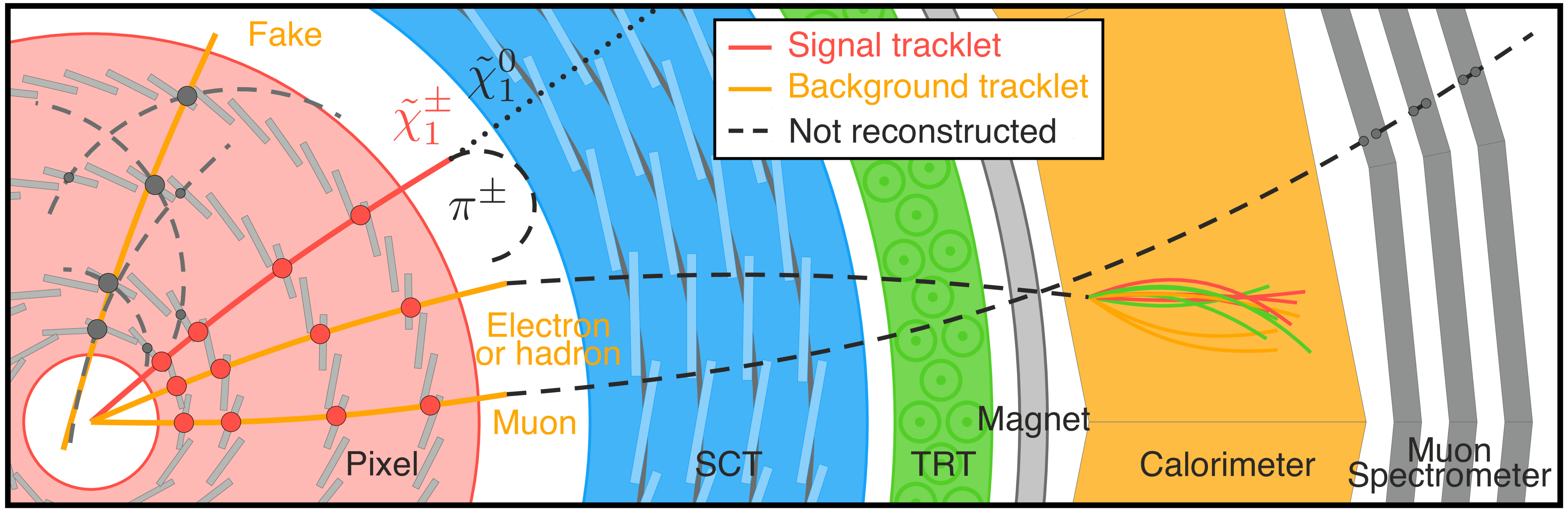
Exclusion limits complementary to the displaced-jets and delayed-jet (j.physletb.2019.134876) searches

Disappearing tracks

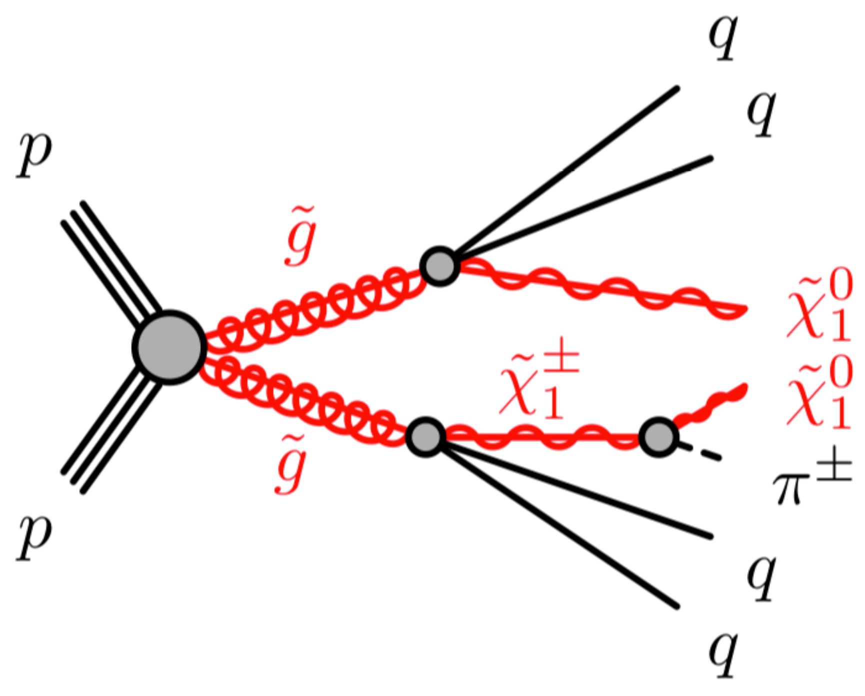
ATLAS EXPERIMENT

Search for long-lived particle decaying within the inner tracker

- MET trigger to select events with jets and ‘disappearing tracks’ (due to suppressed interaction or low-pT)
- ‘Disappearing track’: 4-hit pixel tracks with no hits in the silicon traker (SCT) and < 5 GeV of energy deposits in calo dR < 0.2
- Rare SM backgrounds from charged lepton scattering and combinatorial fakes

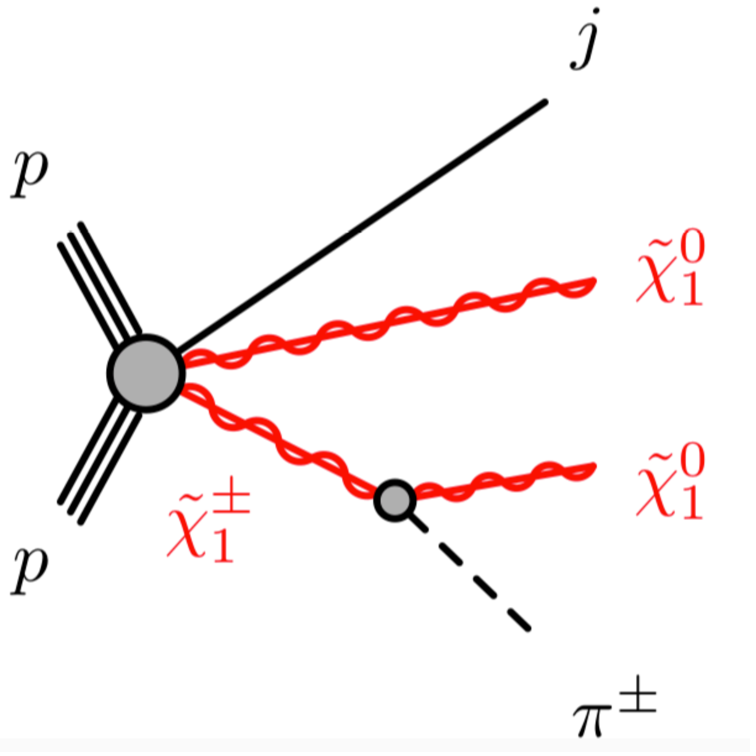


Targets very compressed SUSY scenarios (…and various DM models)



Electroweak (EWK) production

$$\underbrace{\tilde{\chi}^\pm}_{\text{leaves hits}} \to \overbrace{\pi^\pm}^{\text{undetectable}} \underbrace{\chi^0}_{\text{MET}}$$

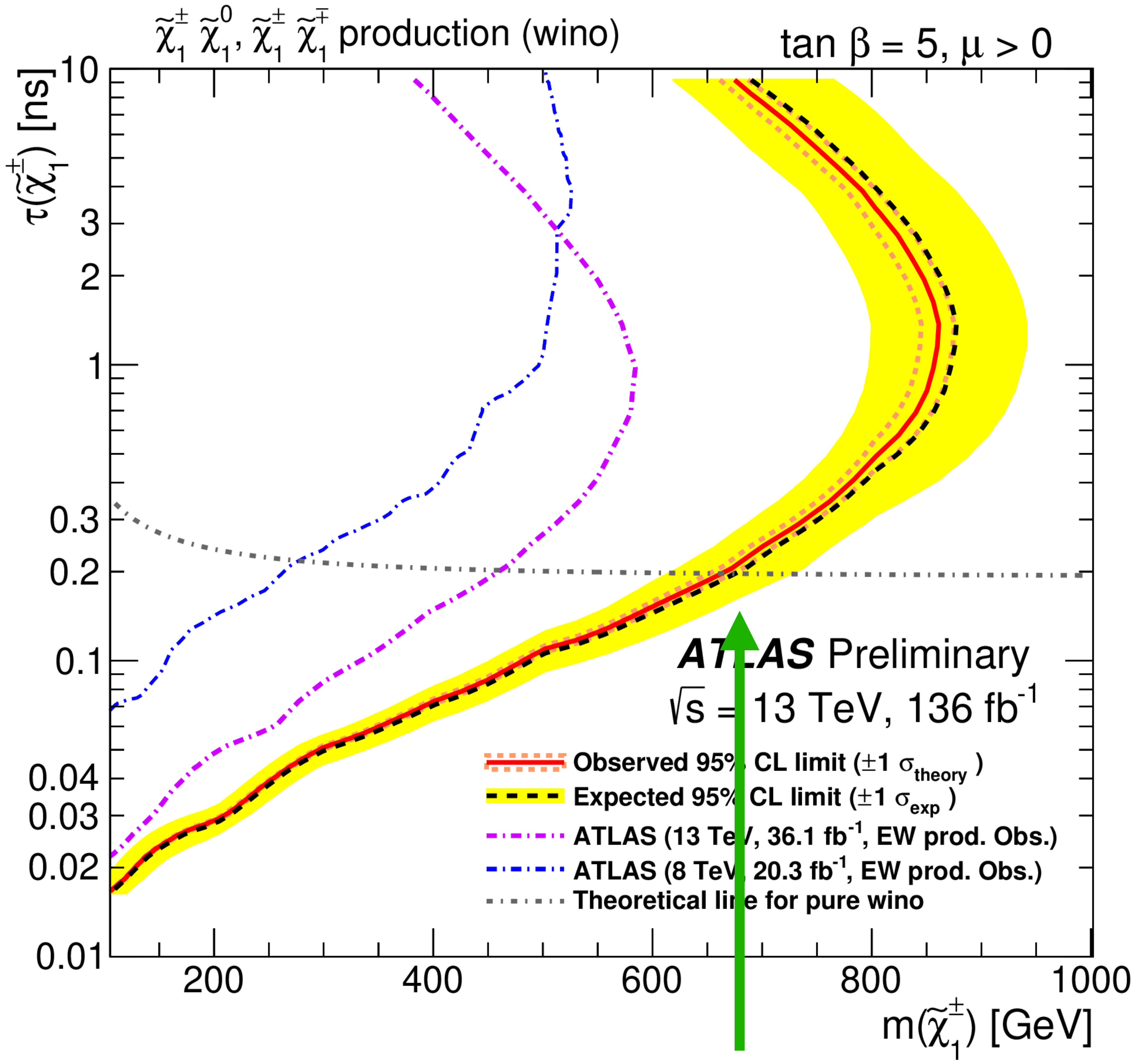


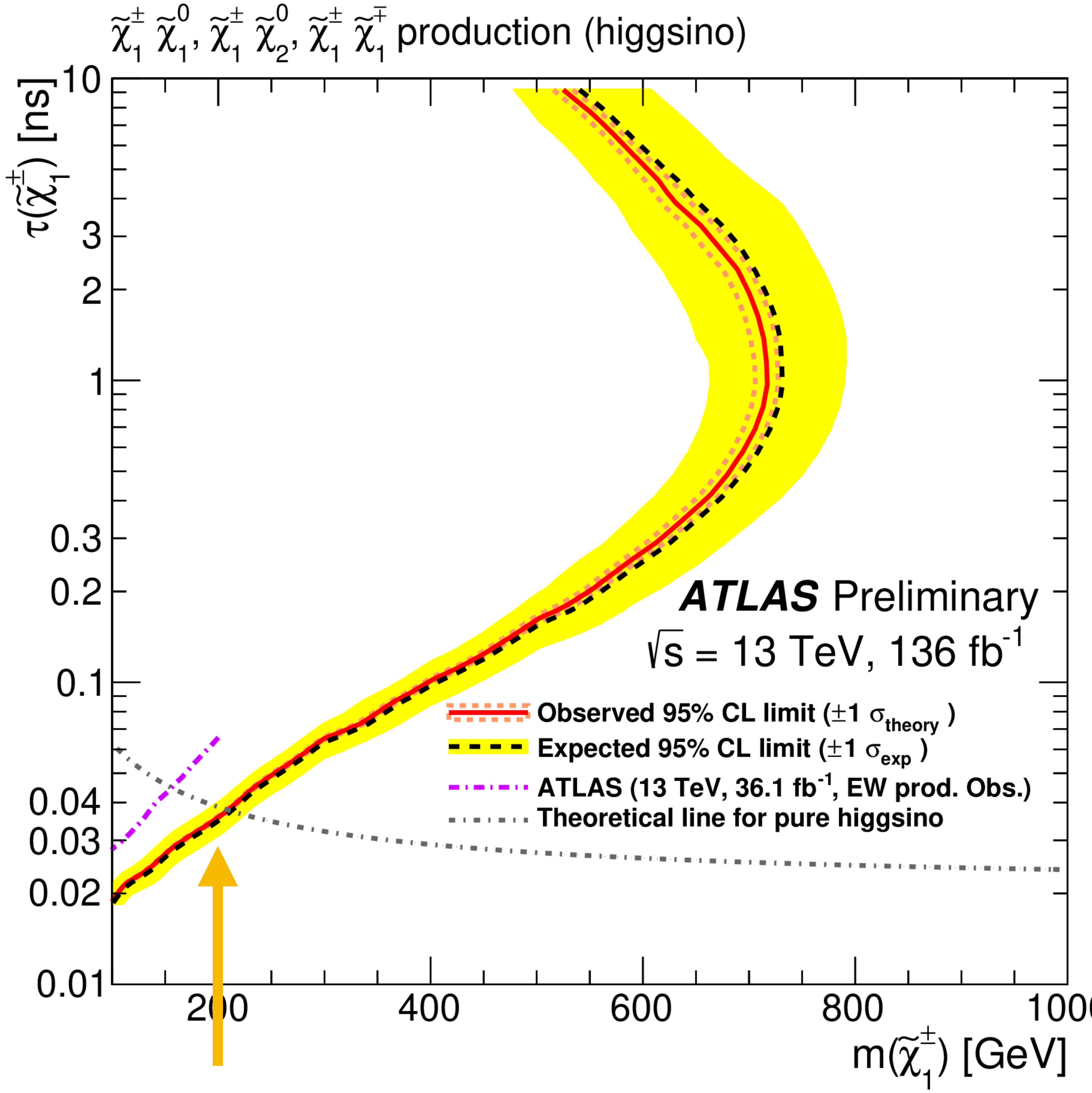
Strong production

ATLAS-CONF-2021-015 Disappearing tracks

ATLAS EXPERIMENT

Exclusion limits at 95% CL for the EWK channel fo the AMSB model, neutralino mass vs lifetime





Exclusion for 660 GeV wino, best limit for wino-like neutralino (460 GeV in early Run2)

Exclusion for 210 GeV Higgsino, best limit for higgsino-like neutralino (155 GeV in early Run2)

CERN-EP-2021-041

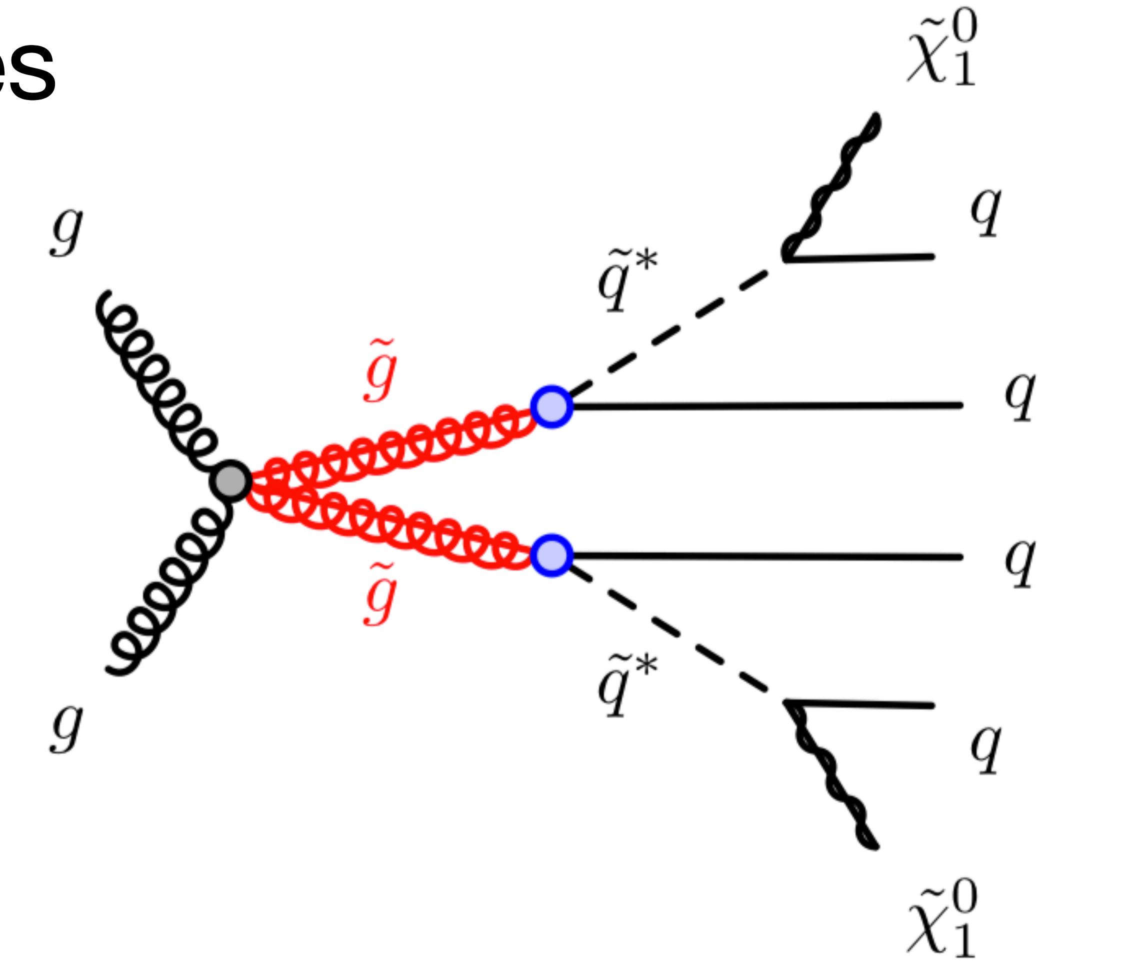
Stopped particles

Search for late decays to hadronic jets from long-lived particles

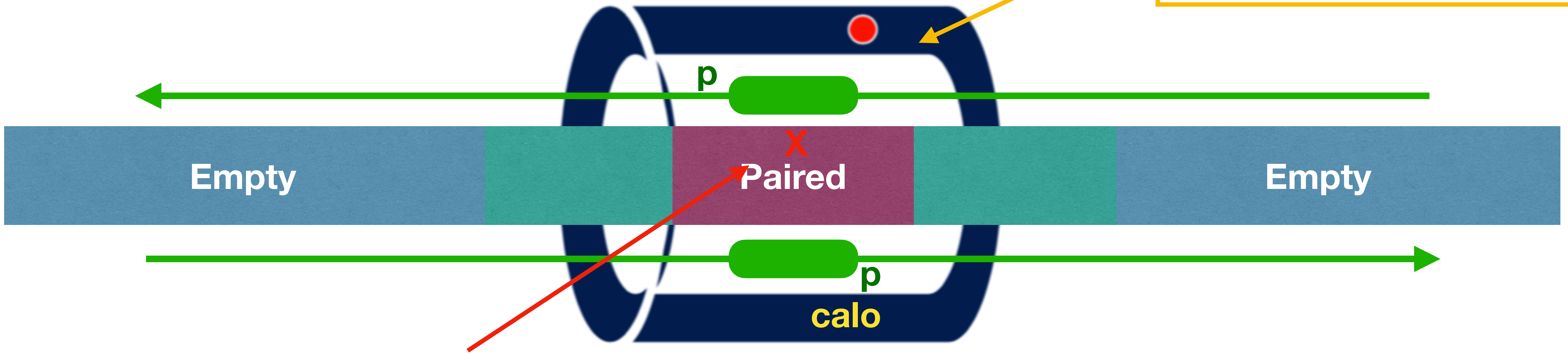
- dedicated jet+MET trigger, recorded in <u>empty bunches</u> to reduce background

- Non collision background that can produce energetic jets in out-of-time bunch crossings: cosmic-ray muons, beam induced background (BIB), cavern background and calorimeter noise

SUSY gluino R-hadrons as benchmark (gluino as LLP)



if LLP long-lived enough, some will stop inside the detector before decaying



LLP produced here

CERN-EP-2021-041

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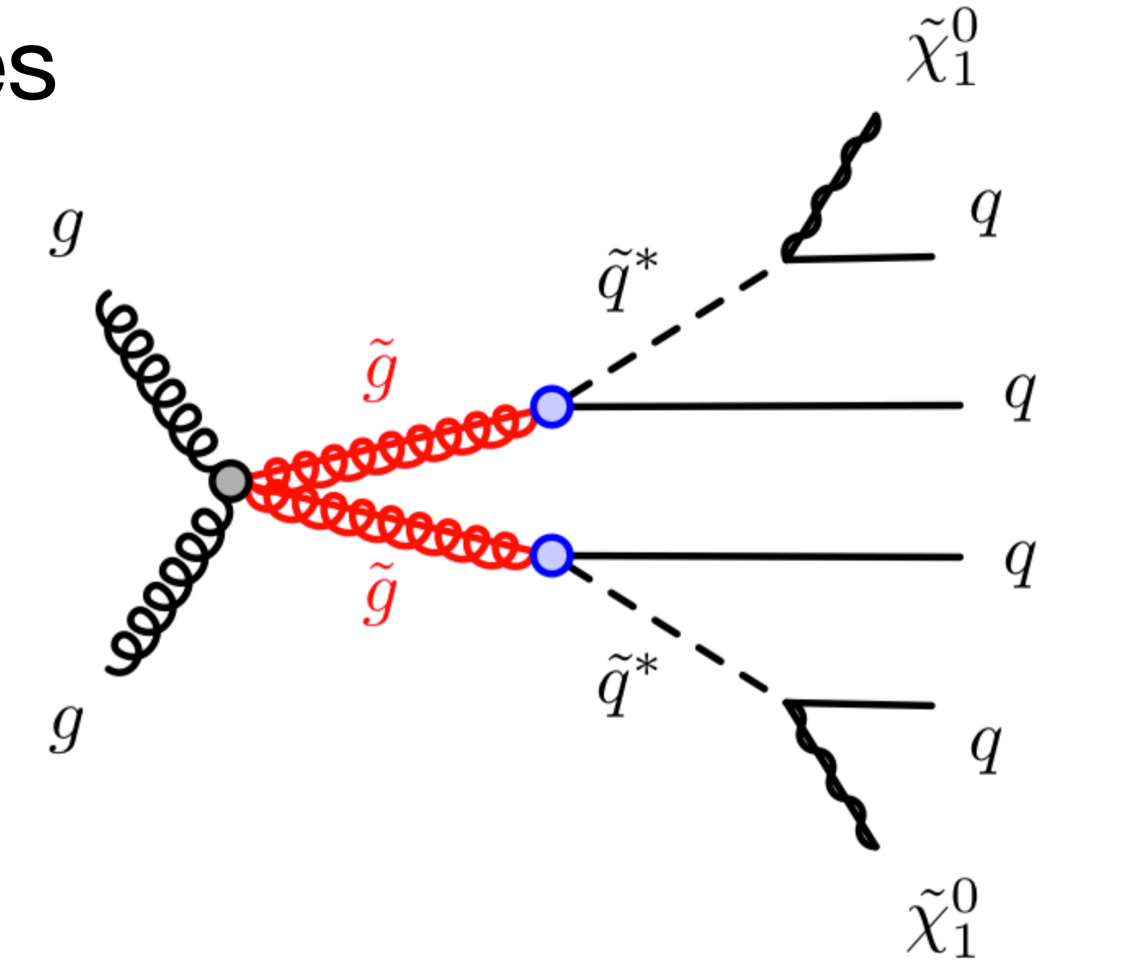

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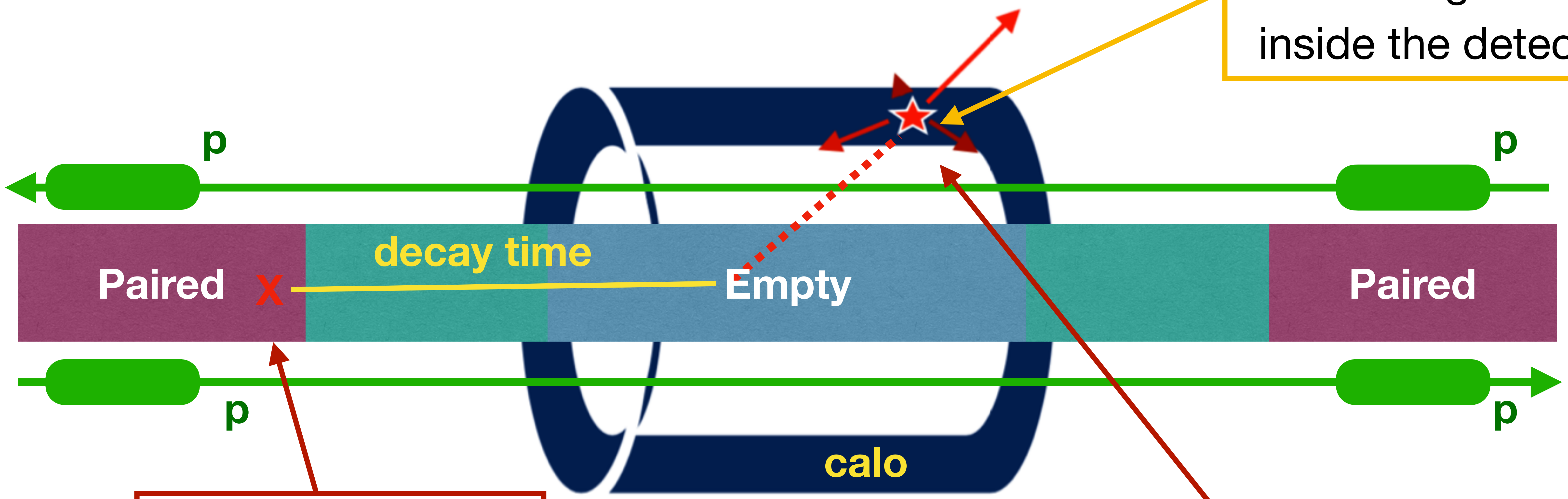


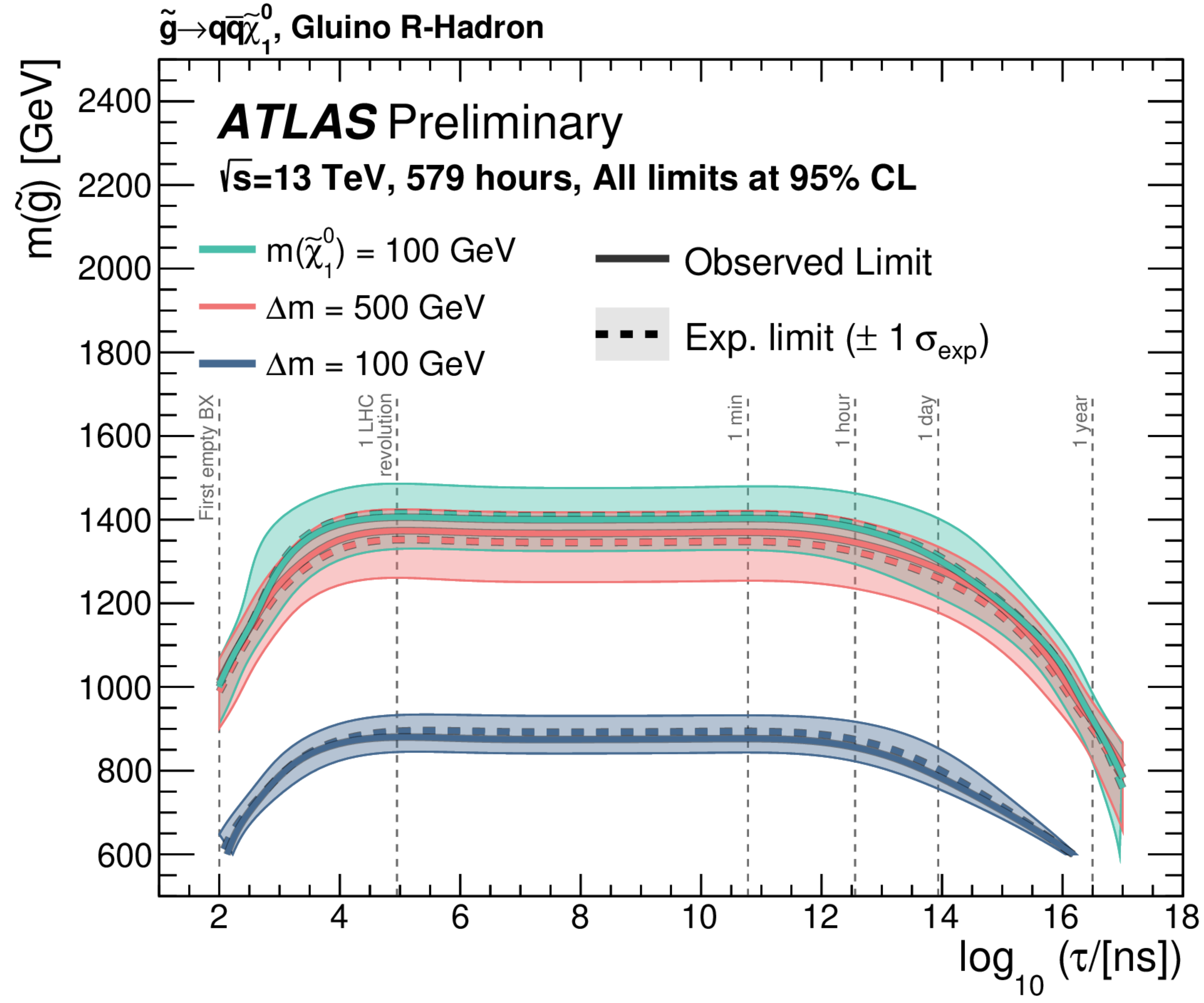
LLP produced here

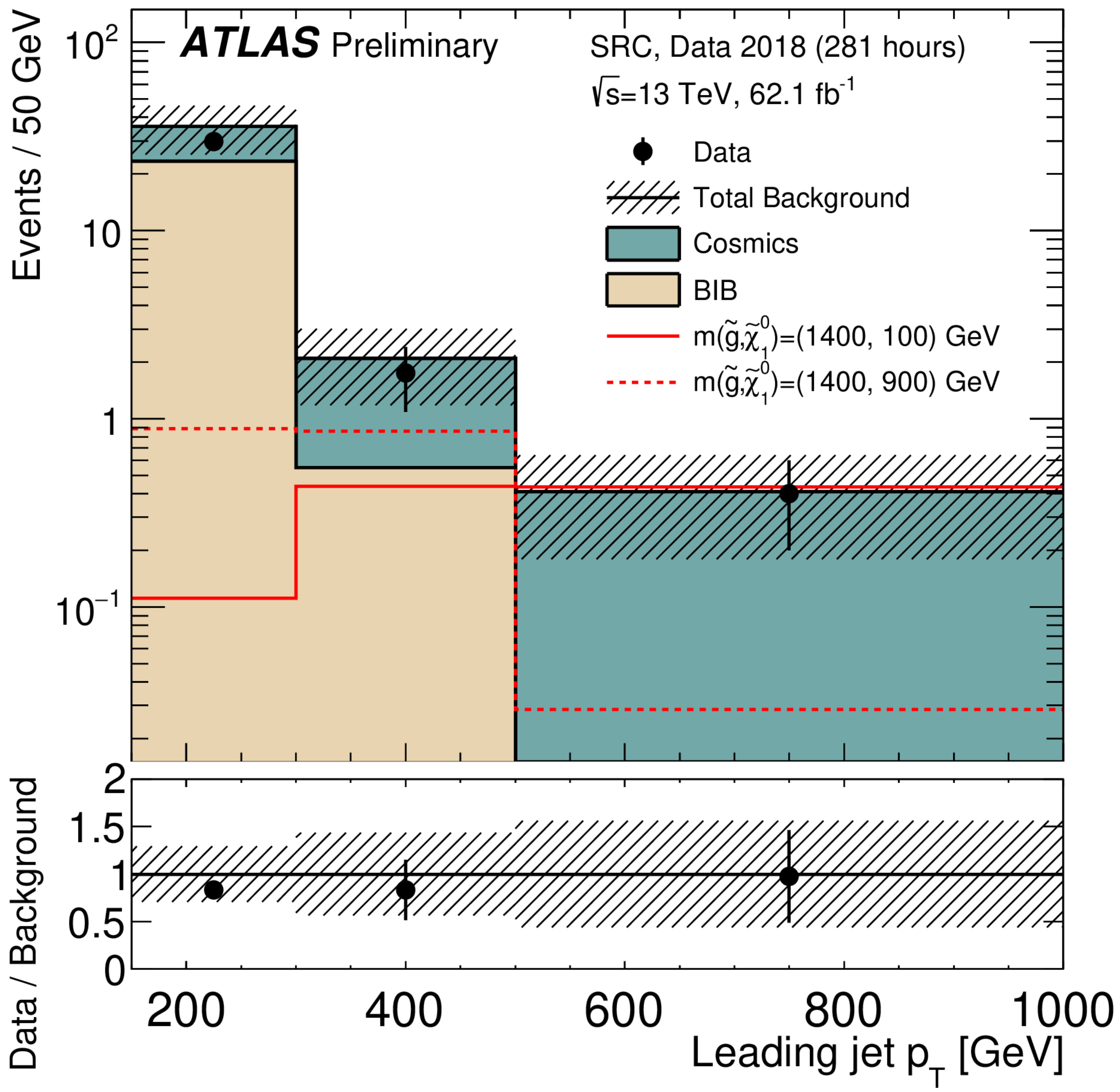
LLP decays here

CERN-EP-2021-041

Stopped particles

Fully data-driven background estimate with inputs from the background enriched control regions for cosmic-ray muons and BIB background. No excess found and 95%CL limits are presented.





signal region, 2018 data $|\eta|<0.8$

Conclusions

- New searches for long-lived particles in events with jets at ATLAS and CMS using full Run-2 dataset have been presented, mainly focusing on decays inside the inner tracking system and calorimeters

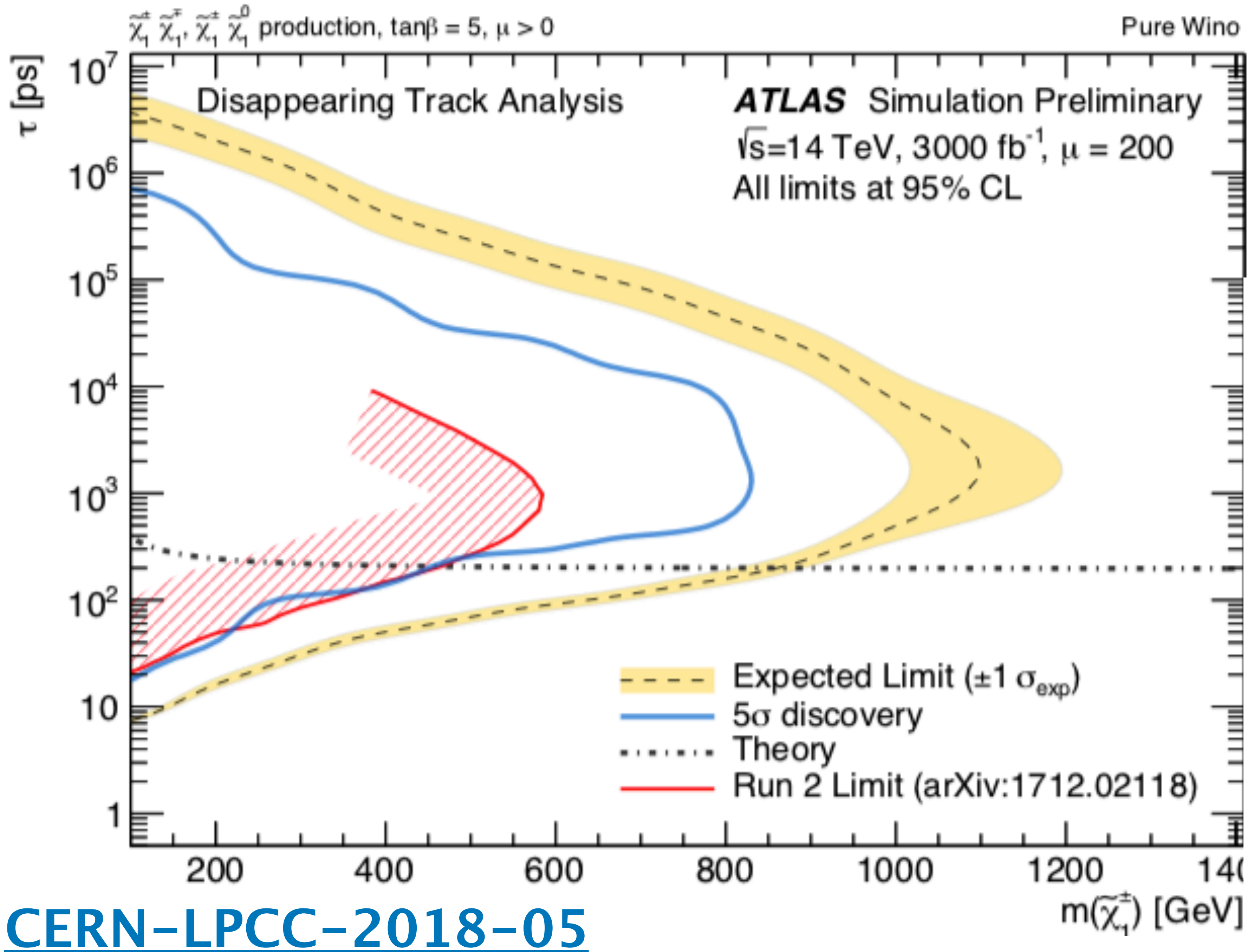
- Several New Physics models imply the presence of unconventional signatures at colliders, which can be very challenging and require new ideas and techniques

- Experiments increasingly focus on unconventional signals and long-lived particles with ambitious research programs… but there is still much to be done

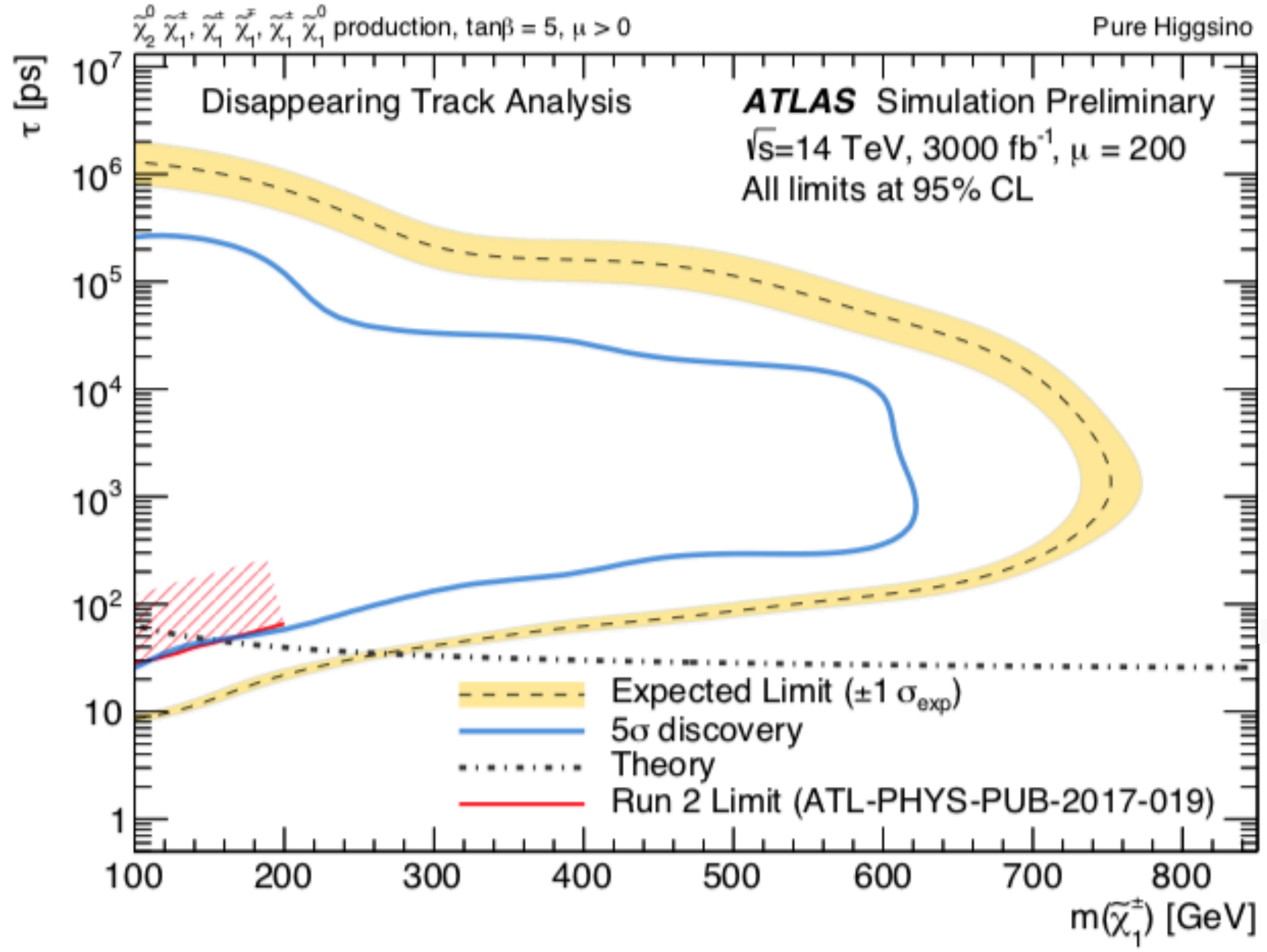
- Great effort in developing new tools and strategies to improve identification and reconstruction of long-lived particles pushing the detectors beyond their limits

- Run-3 and HL-LHC programmes offer a unique opportunity to plan, innovate and create new unconventional searches yet to be explored

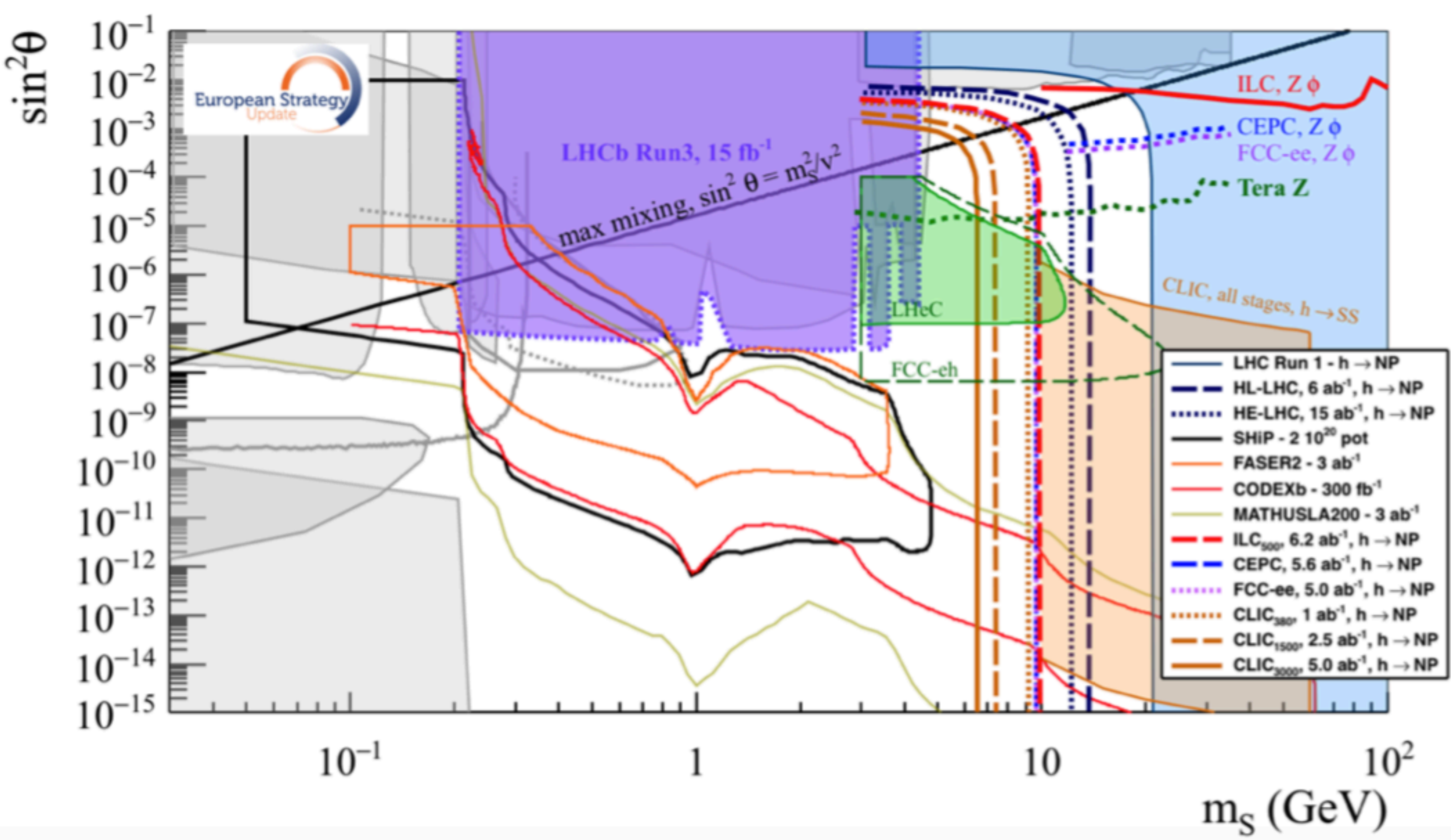
Prospects



CERN-LPCC-2018-05



CERN-ESU-004



$$\kappa H^2 S^2 + \mu H^2 S$$

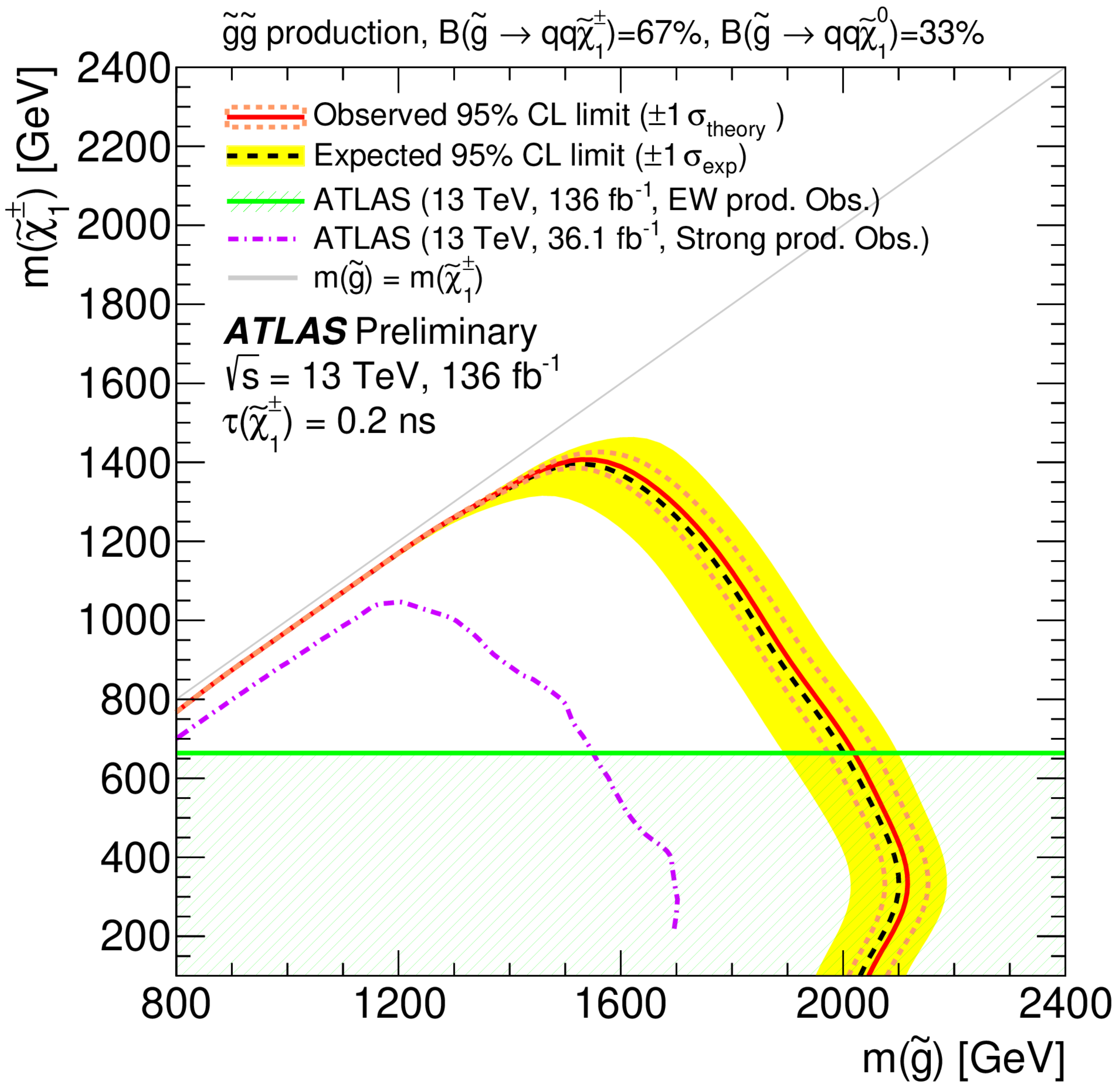
Higgs portal and mixing with ‘dark’ scalars

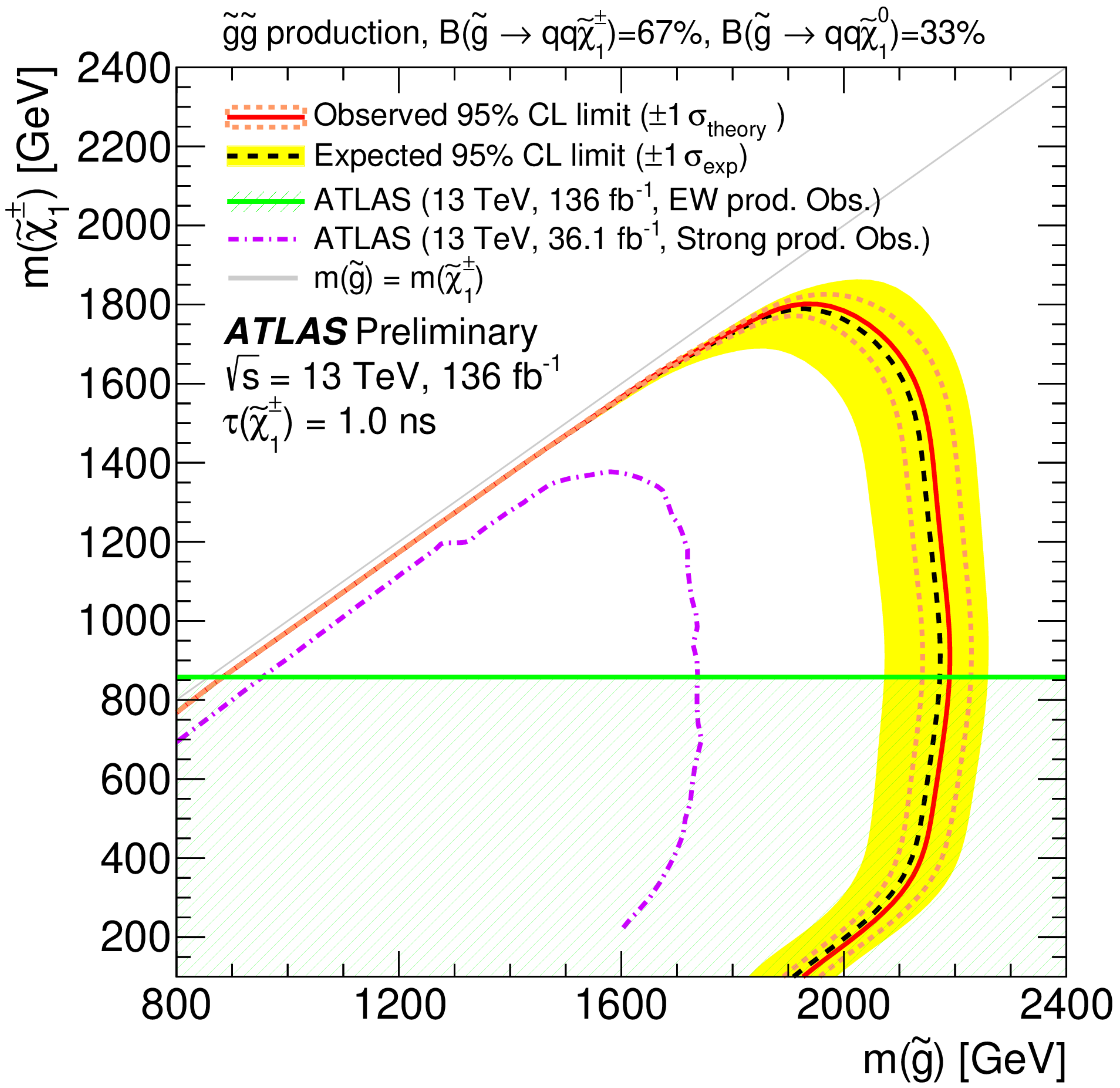
Backup

ATLAS-CONF-2021-015

Disappearing tracks

Exclusion limits at 95% CL for the strong channel fo the AMSB model, neutralino mass vs lifetime

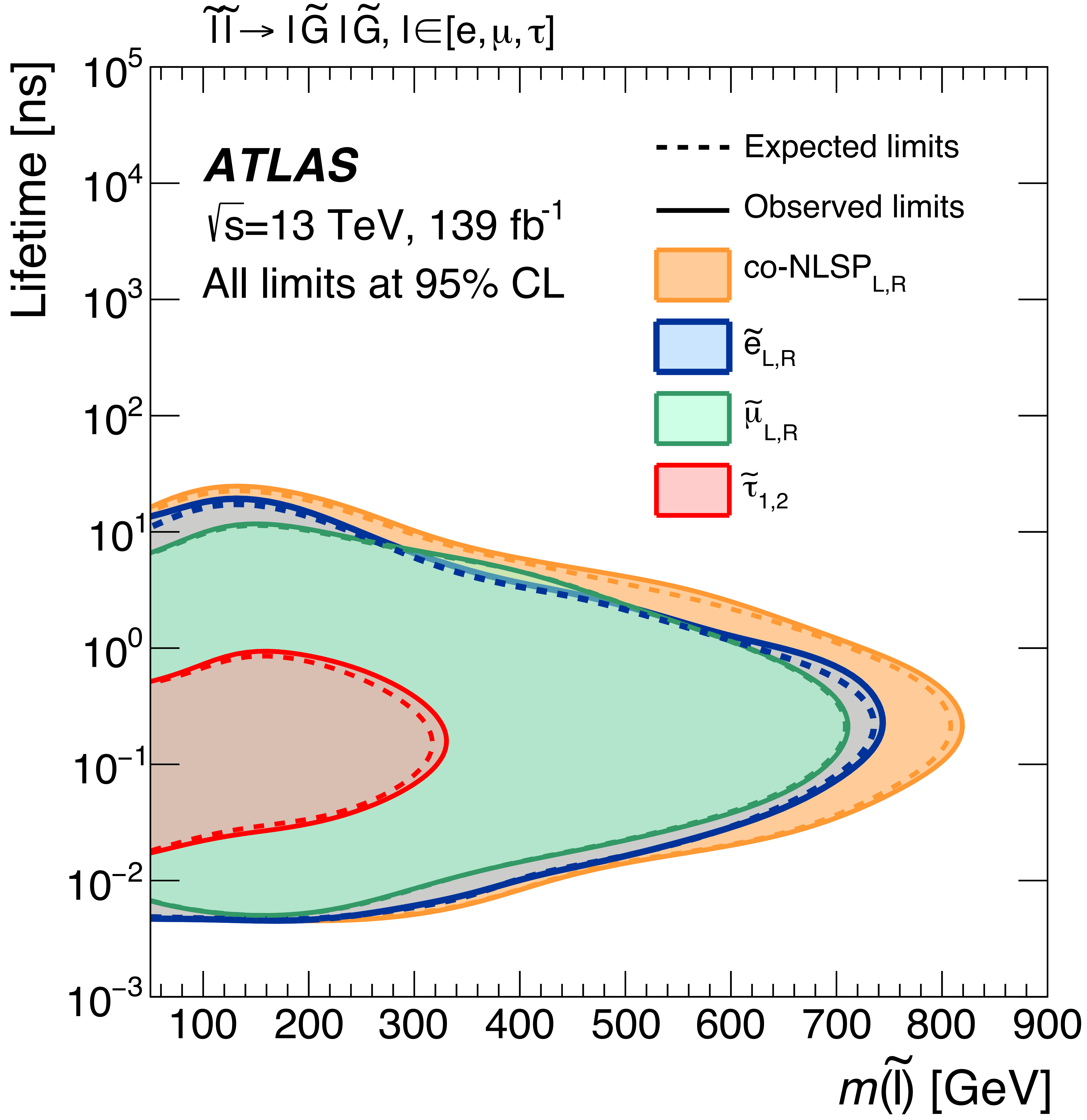


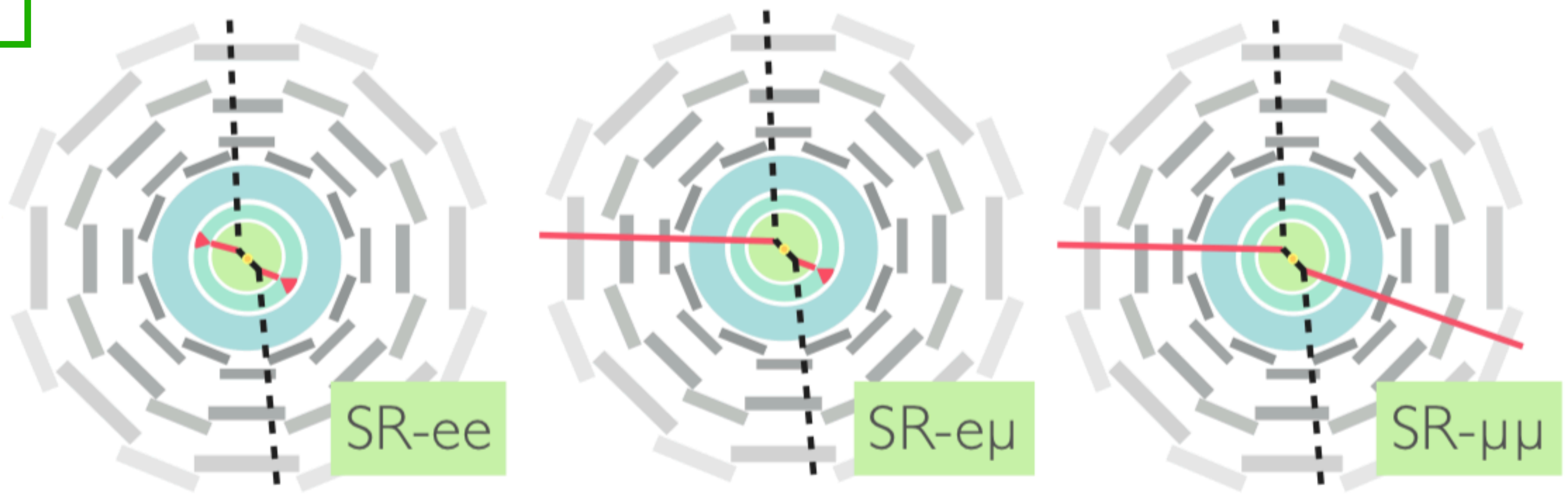


CERN-EP-2020-205

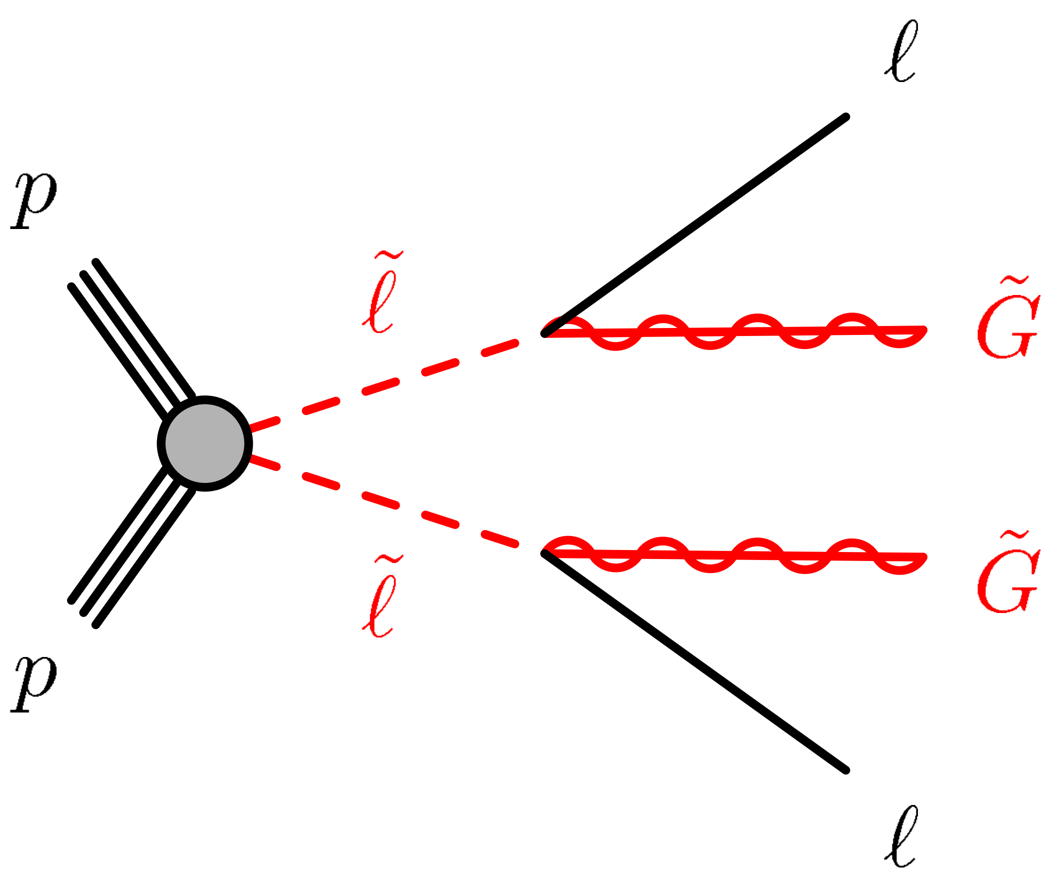
Displaced leptons

Search for two leptons with high impact parameter





Exclusion up to 830 GeV for 0.1 ns, up to 200 GeV for 10 ns lifetime (previous limits at 90 GeV)

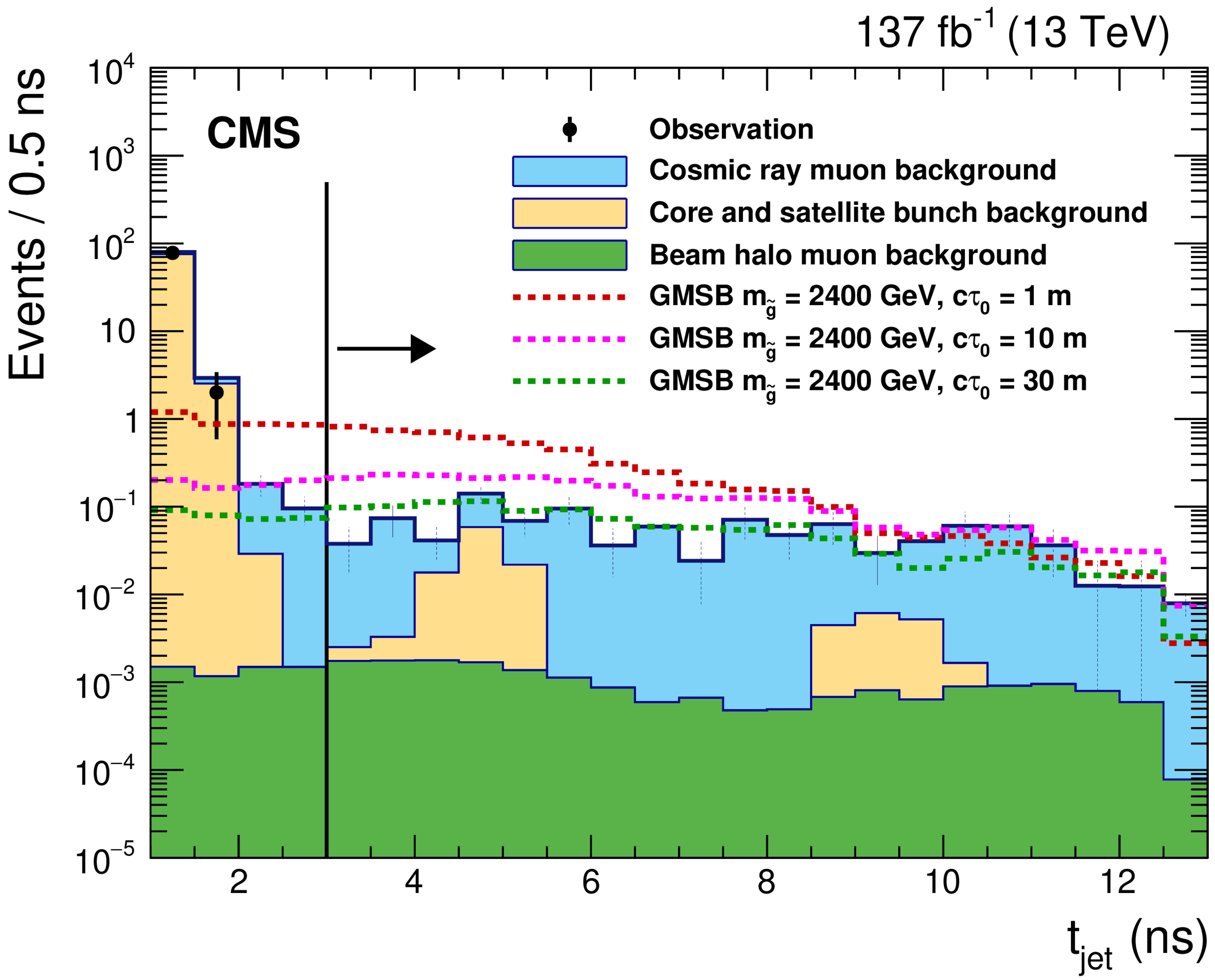


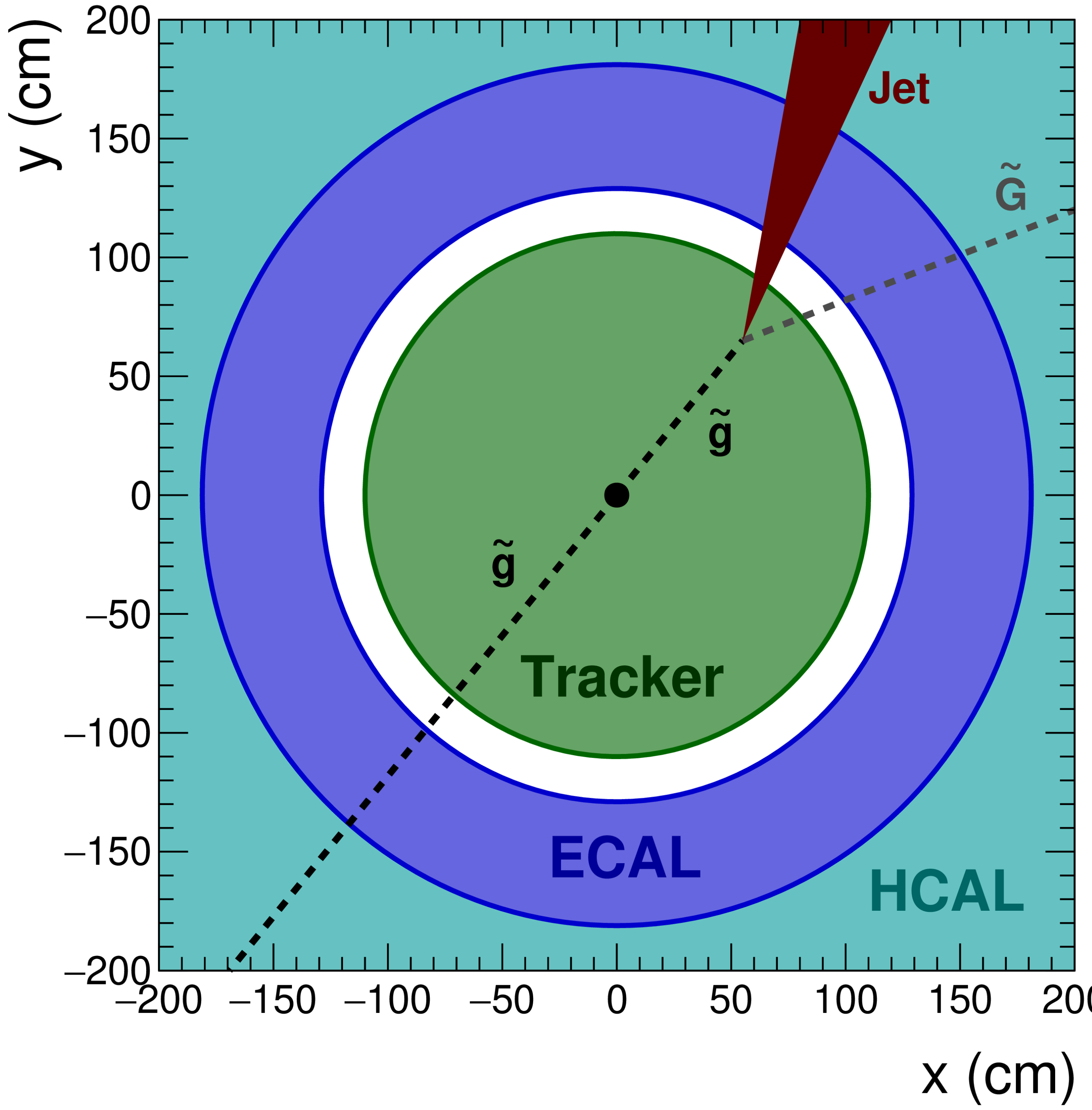
j.physletb.2019.134876

Delayed jet + MET

Search for delayed decays to hadronic jets of long-lived particles and missing transverse momentum

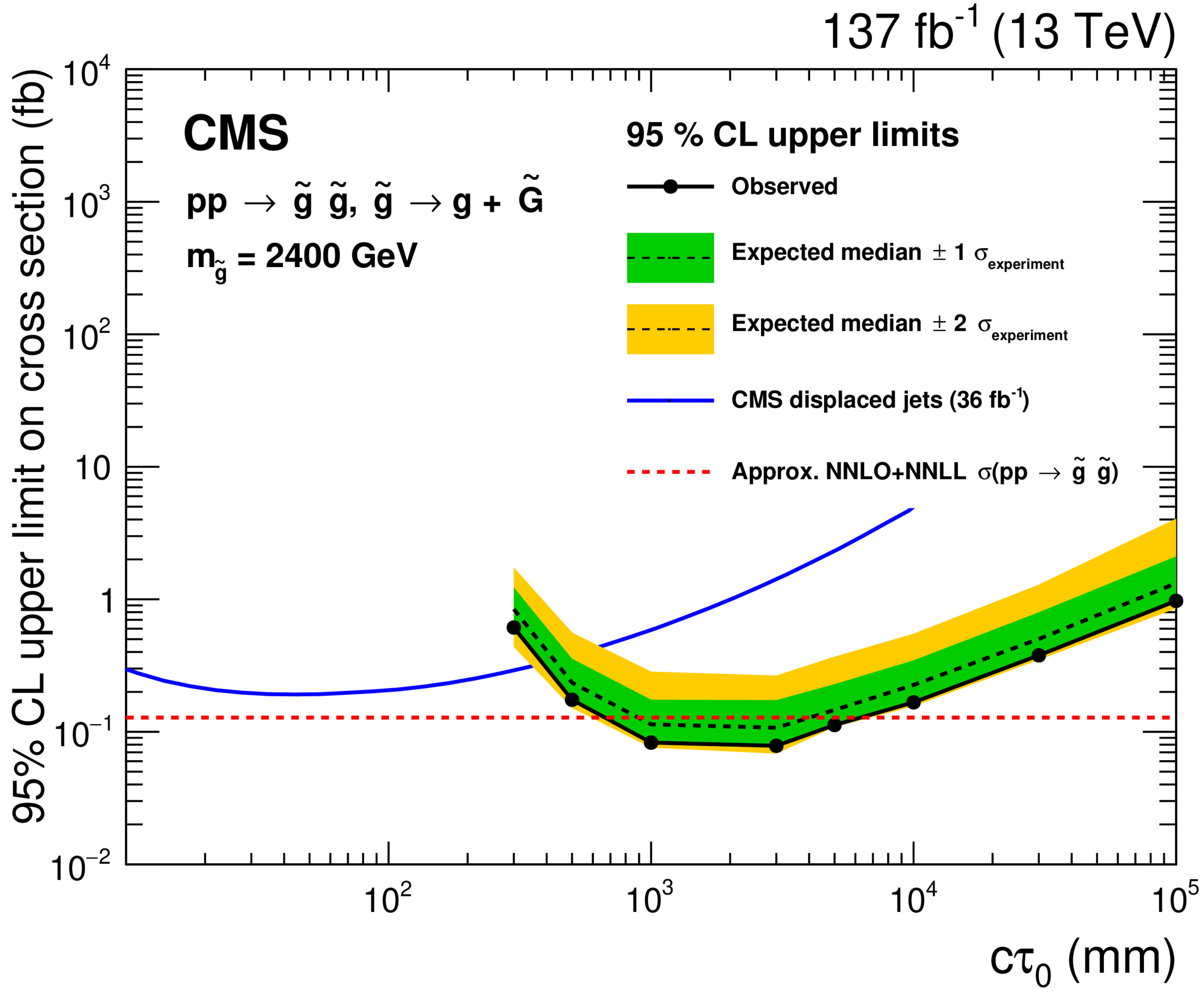
- exploits ECAL energy deposits timestamp to define t_{jet}
- Main QCD background highly suppressed by out-of-time (within same bunch crossing) jet cuts
- ~0 expected background in SR; high signal efficiency of out-of-time decays events

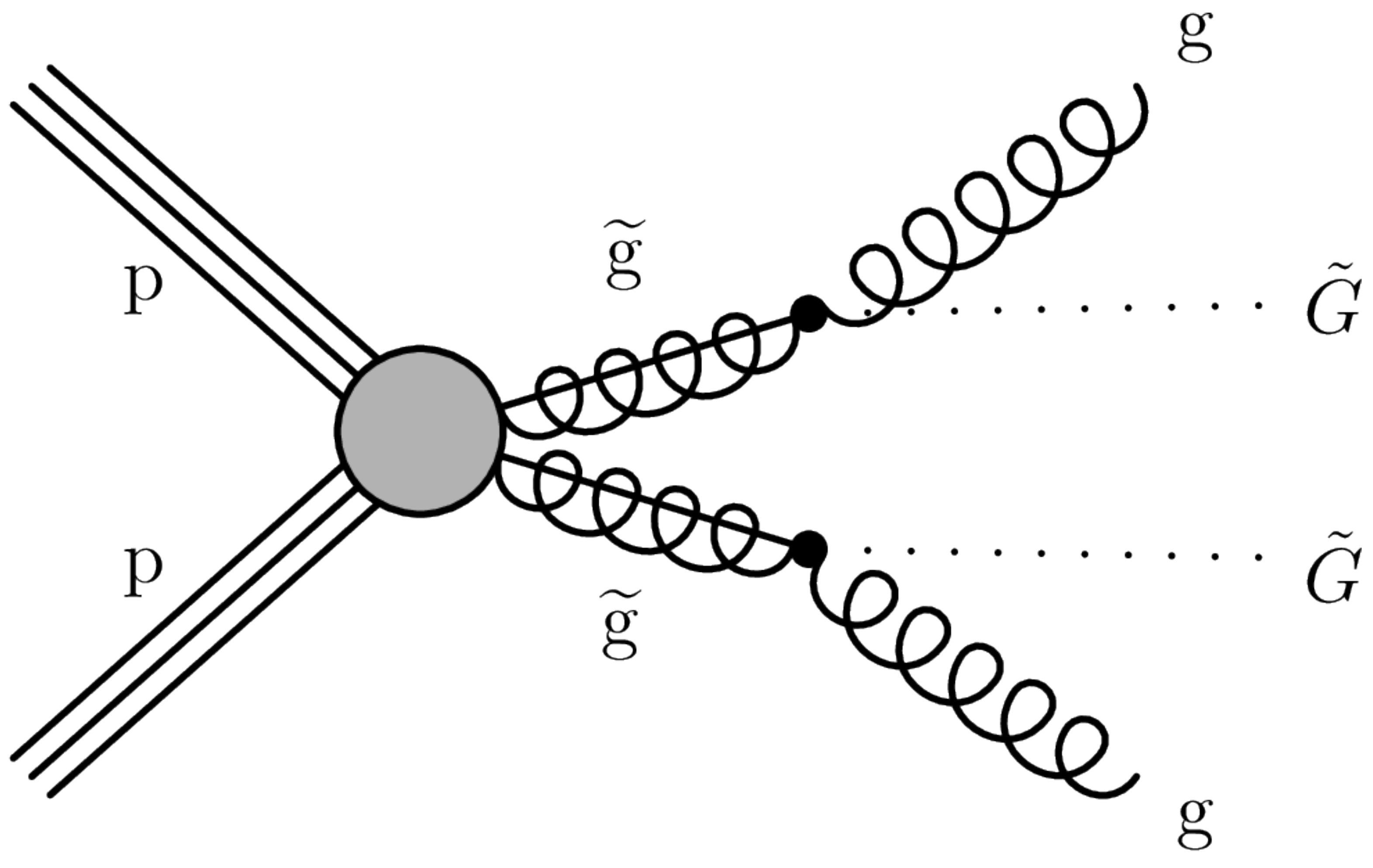




j.physletb.2019.134876

Delayed jet + MET

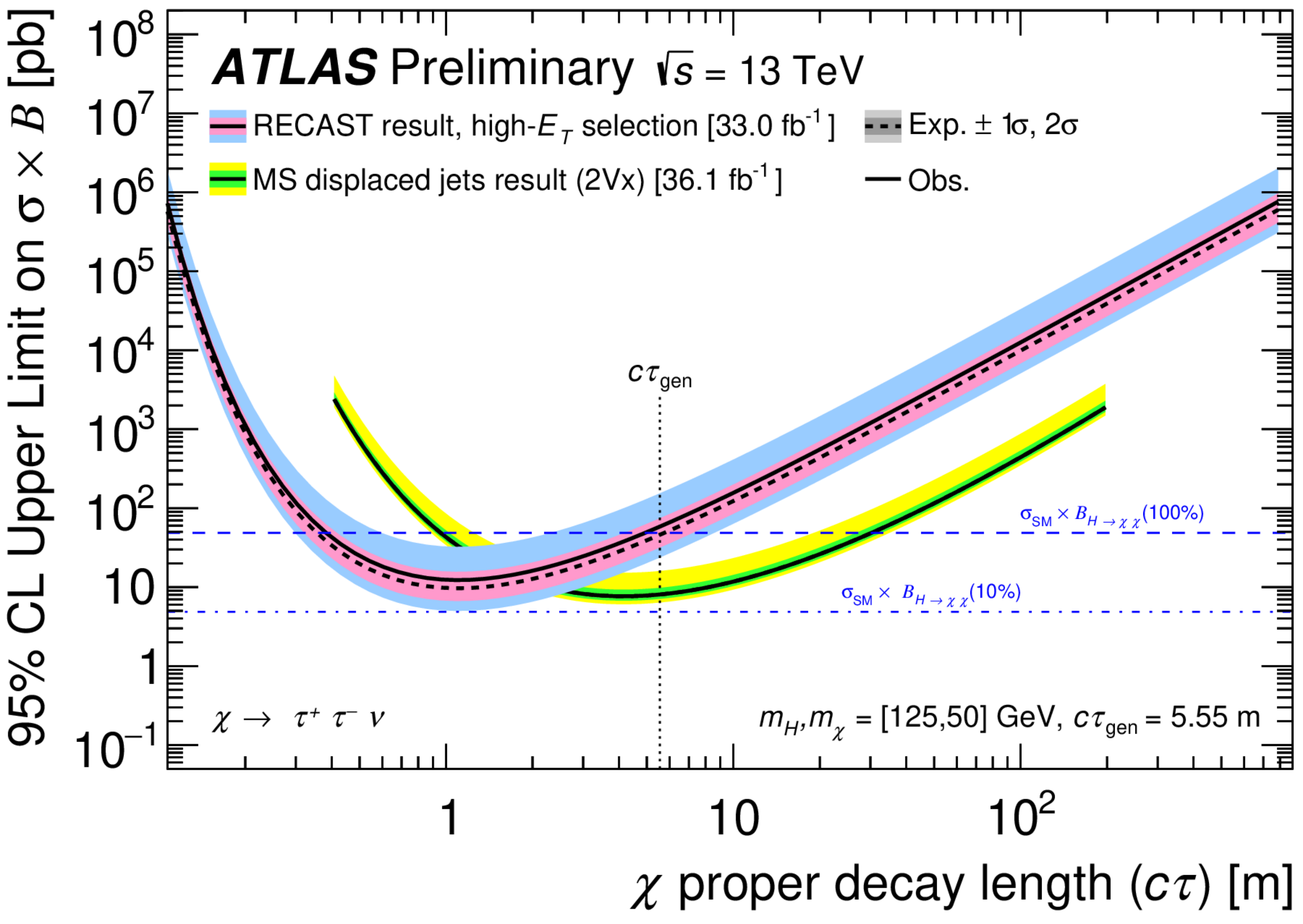


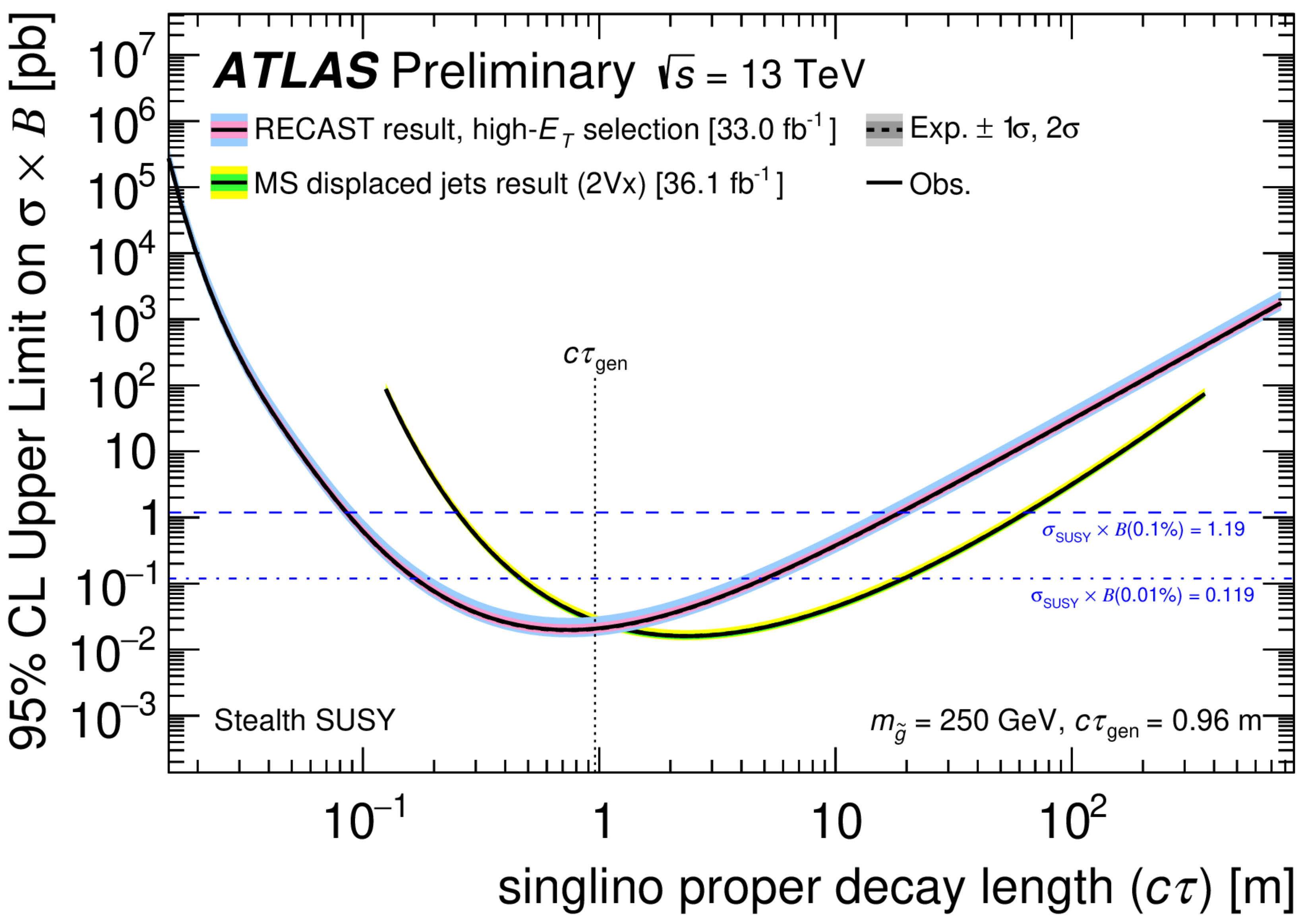


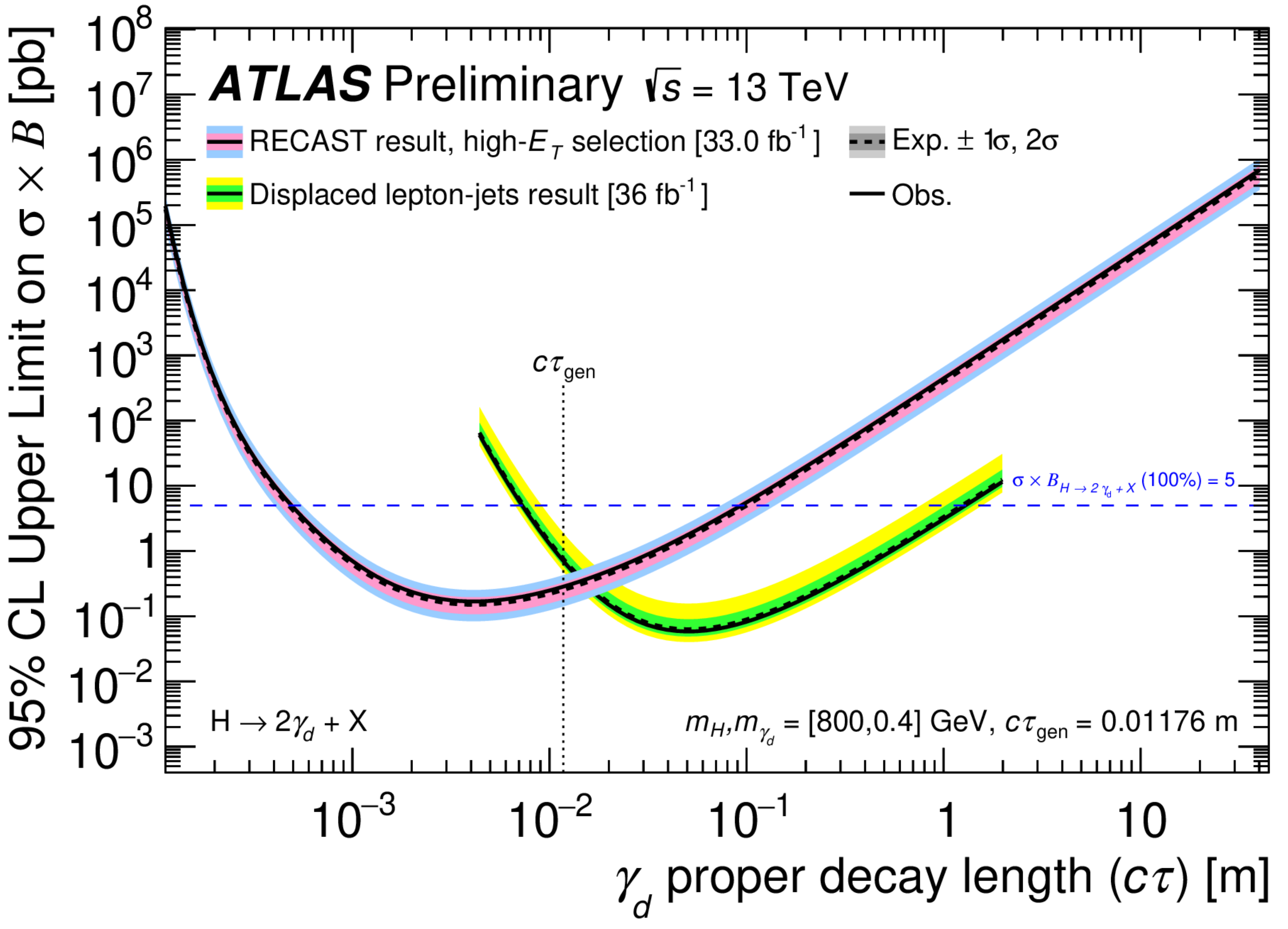
ATL-PHYS-PUB-2020-007

Displaced jet recast

Reinterpretation of the search low electromagnetic fraction jet analysis preserved with RECAST to exclude new models not included in the paper: Stealth SUSY, Baryogenesis, dark photon







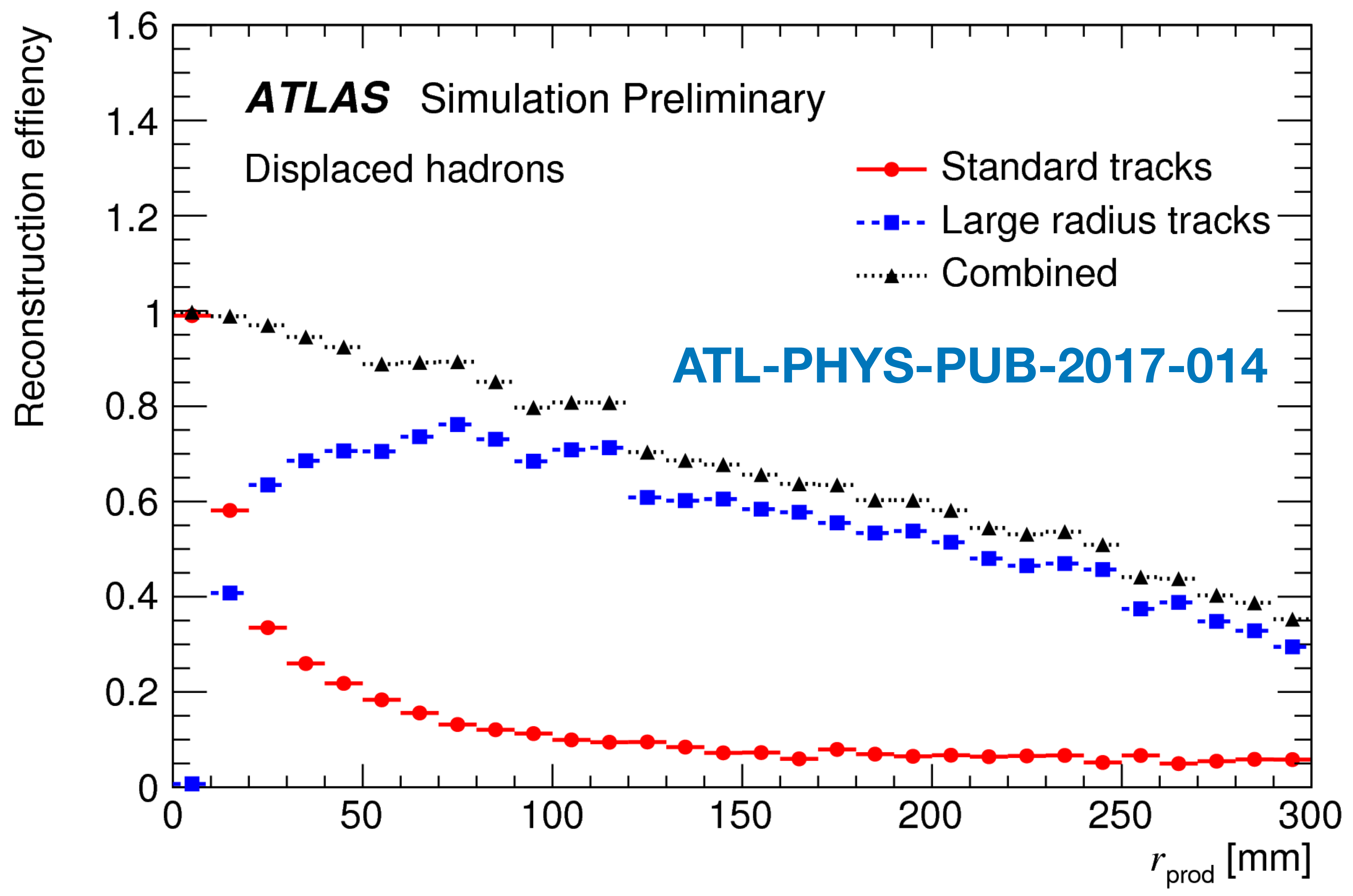
The analysis allows to extend displaced jet exclusion from dark sector scenarios to lower lifetimes

ATLAS-CONF-2021-005

Displaced Vh 4b

Event selection and LLP reconstruction:

- Select displaced jets events with small charged fraction and few tracks associated to the primary vertex
- Reconstruct large d_0 tracks with Large Radius Tracking (LRT) algorithm
- Build displaced vertices (DV) with LRT tracks
- Match DV with displaced jet

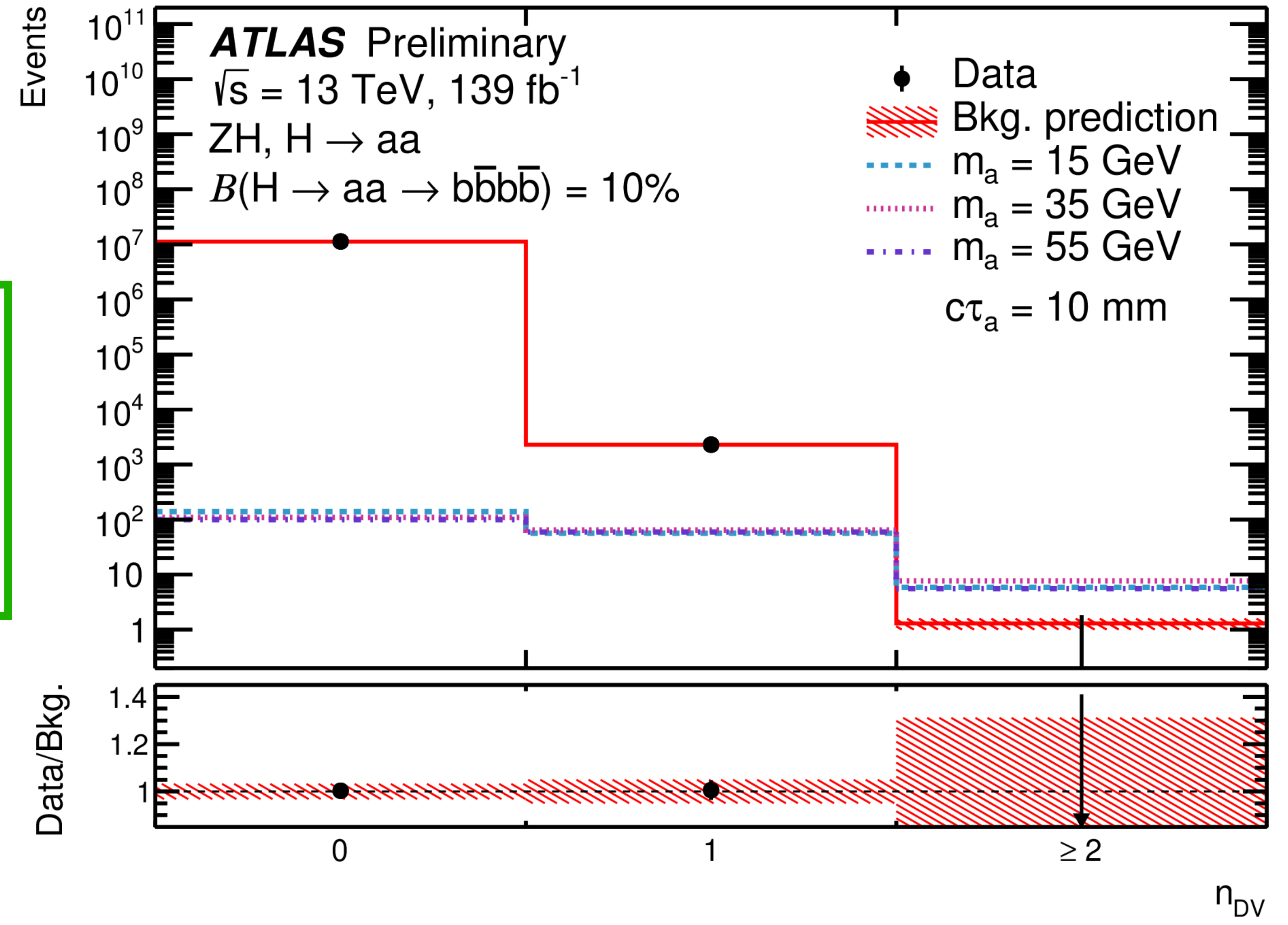


Control region < 2 DV:

Derive per-jet efficiency map pT (jet) vs b-tag score in 0 DV and 1 DV events

Signal region >= 2 DV:

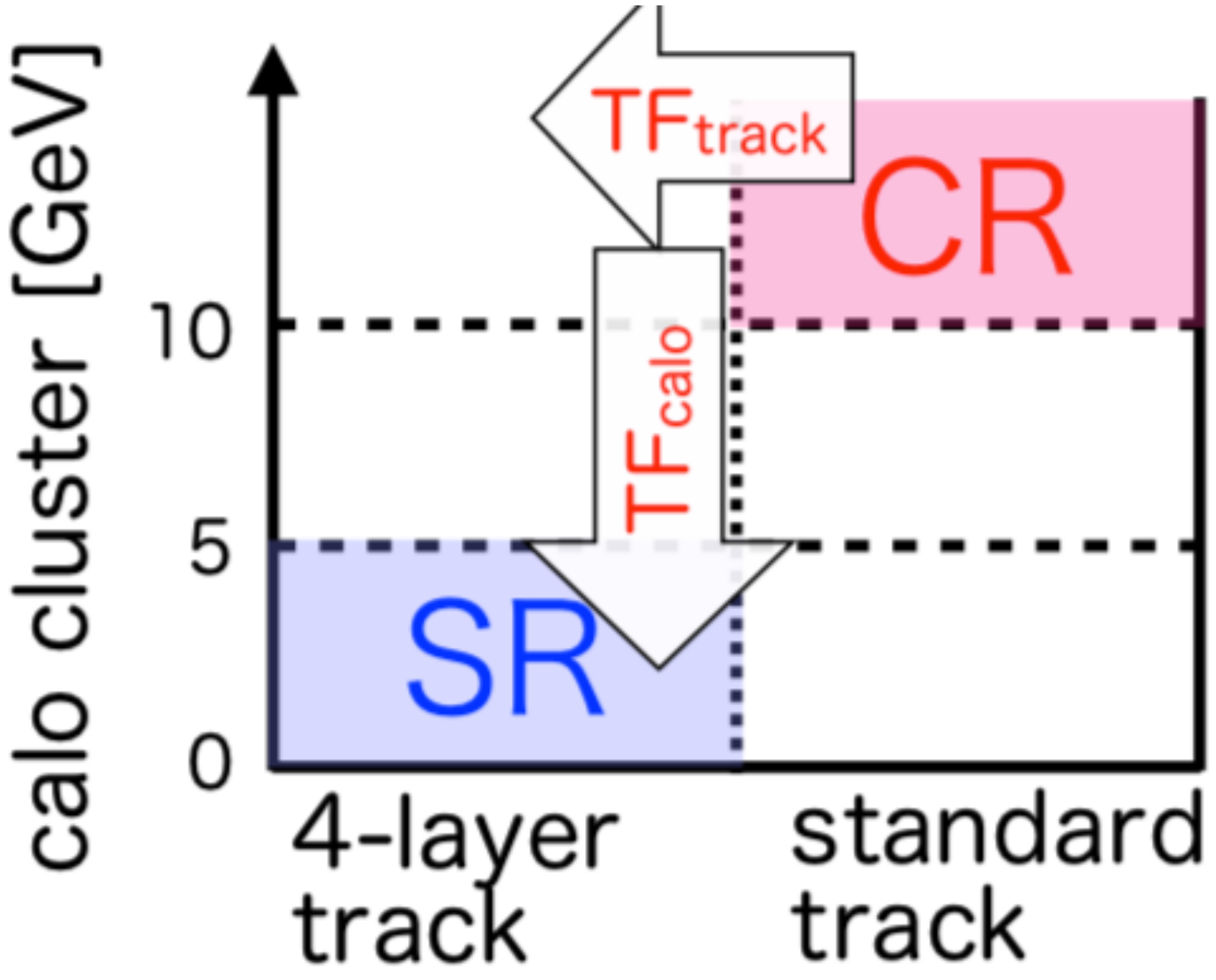
Predict background from DV probability efficiency map

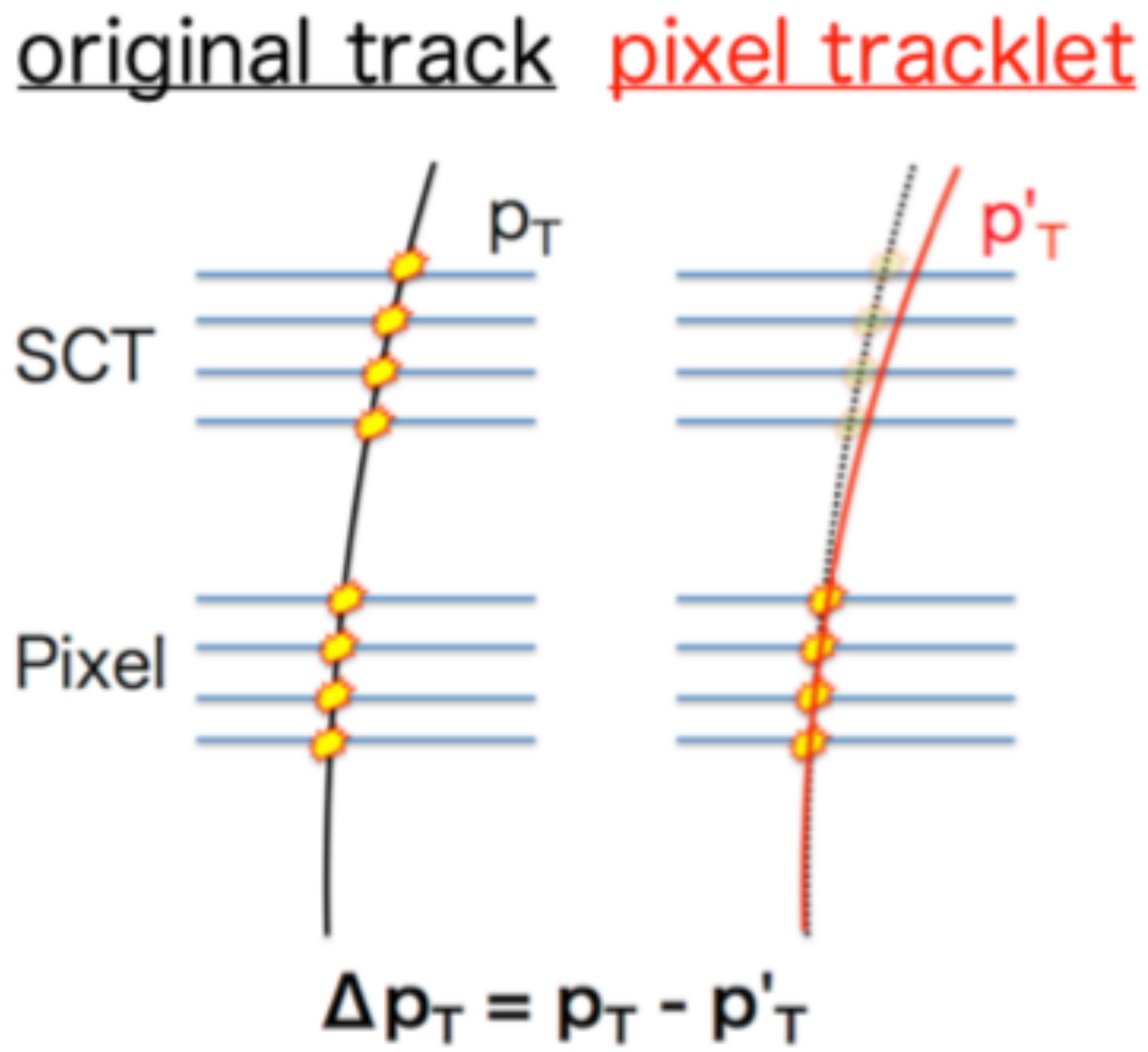


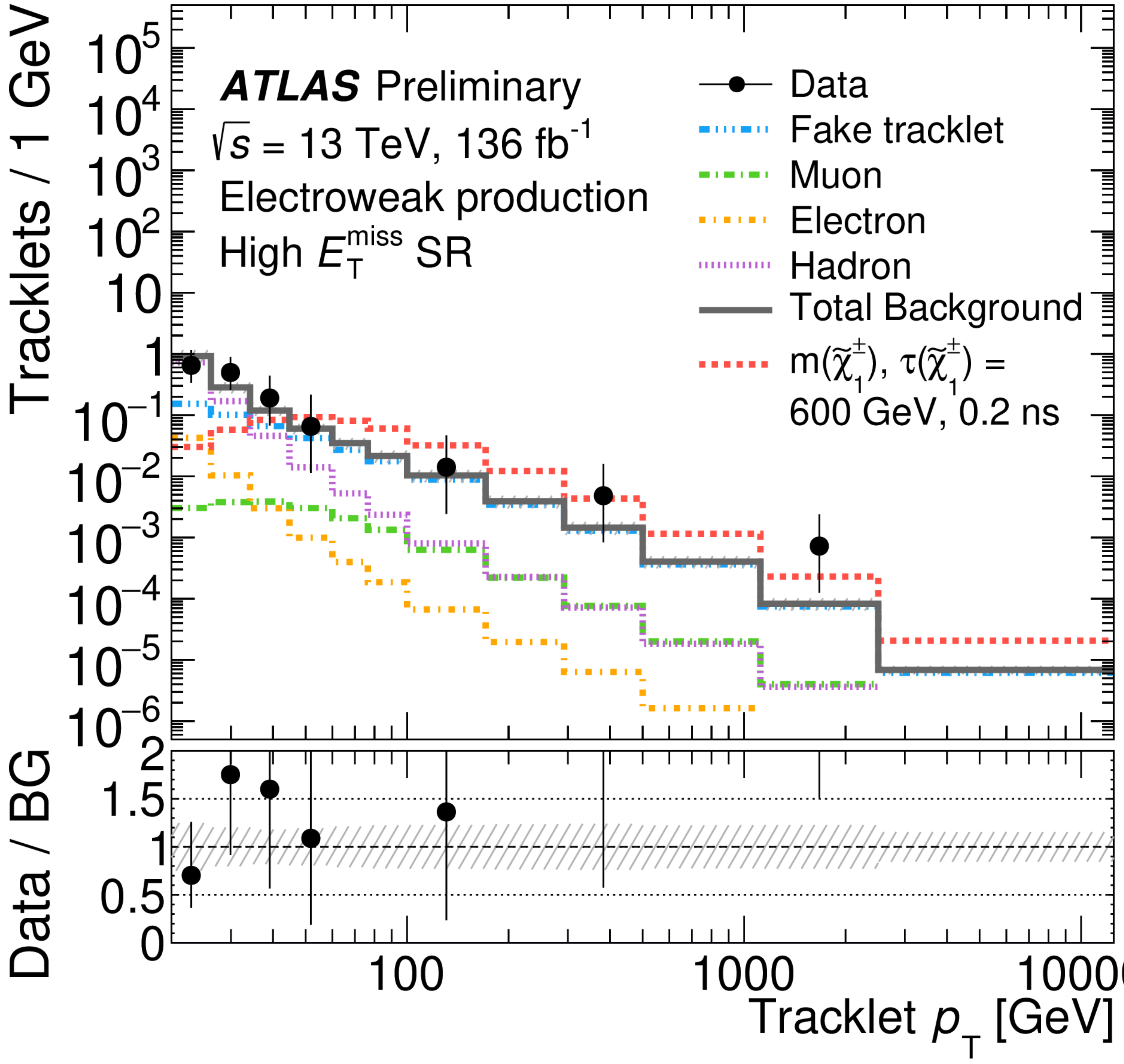
ATLAS-CONF-2021-015 Disappearing tracks

Background tracklet pT-shape estimated via control regions:

- Fakes shape directly from CR
- e/mu/had shape by applying transfer factors and smearing functions to CR events







Final background estimate:
3.10 ± 0.74 (4 observed)

(strong production results in backup)