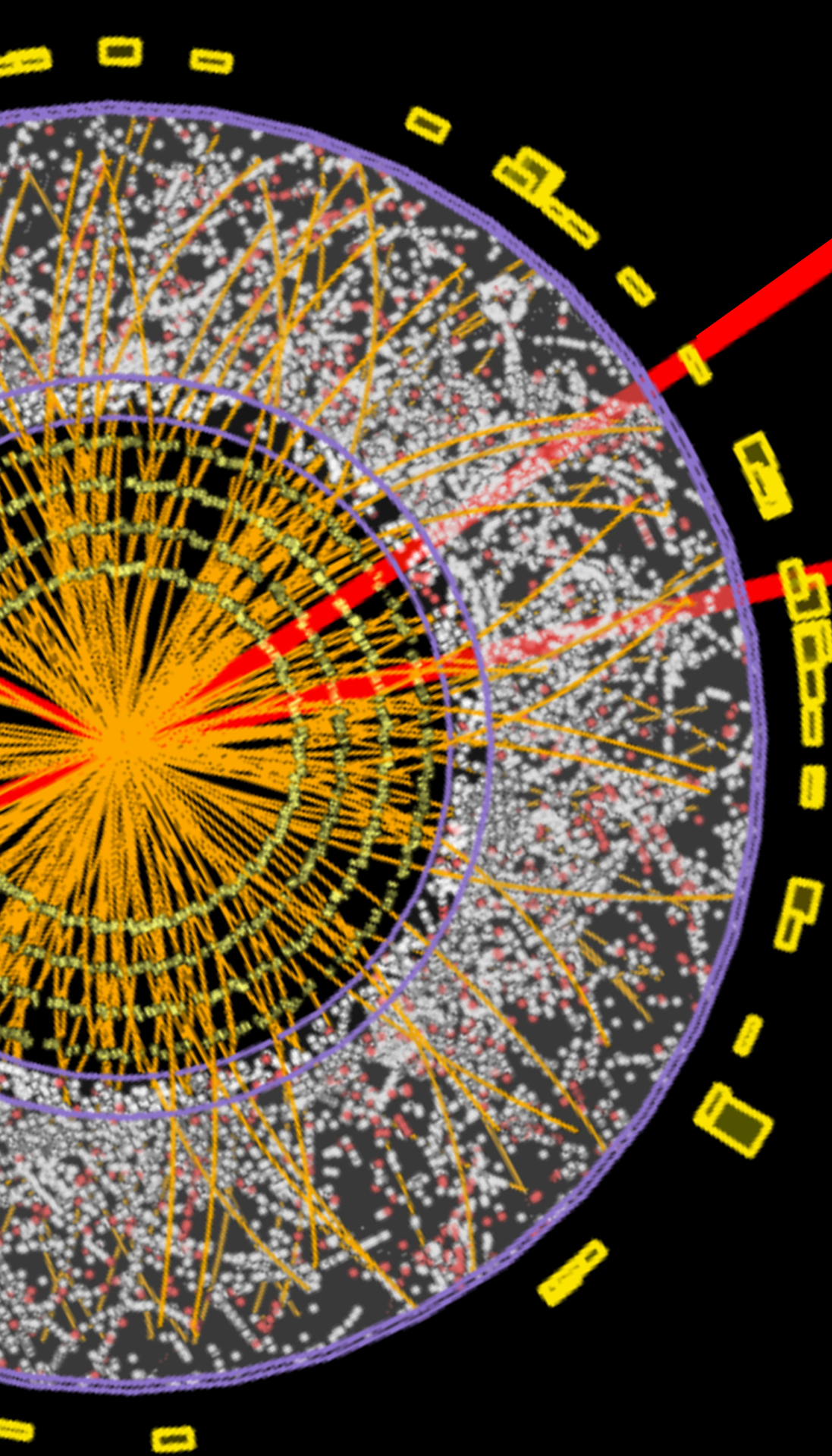


Searches for supersymmetry in signatures with long-lived particles with ATLAS

Karri Folan DiPetrillo
for the ATLAS Collaboration

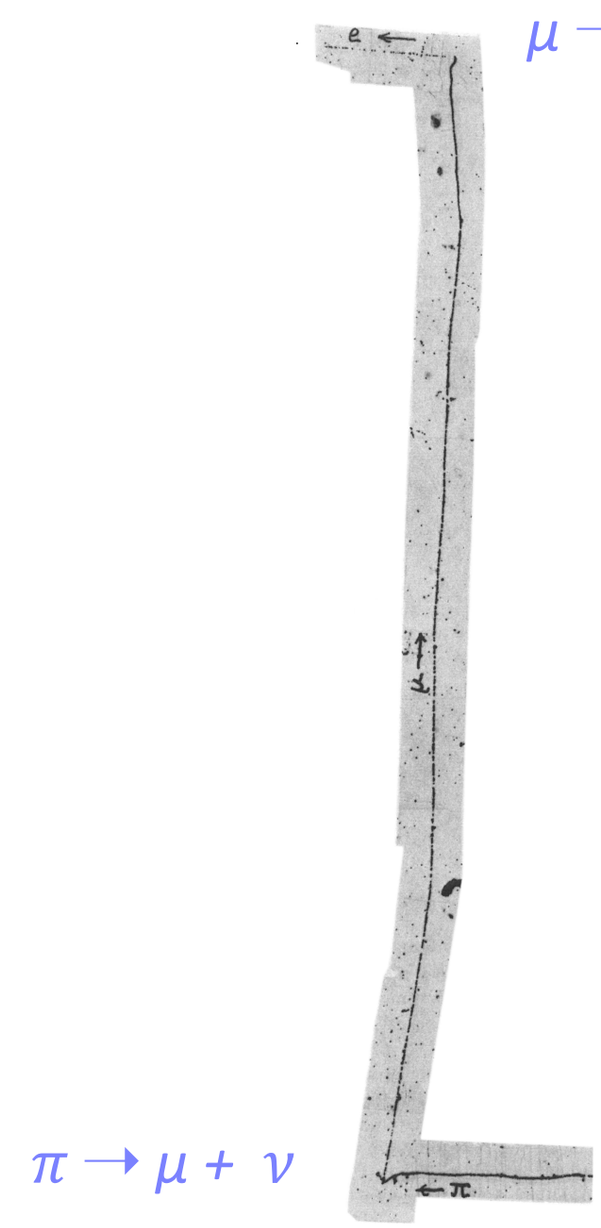
Rencontres du Vietnam
7 August 2018

ATLAS EXPERIMENT

Why look for long-lived particles?

Why look for long-lived particles?

Standard Model is full of long-lived particles



$\mu \rightarrow e + 2\nu$

$\pi \rightarrow \mu + \nu$

(1949) *Nature* **163**, 82.

Why look for long-lived particles?

Standard Model is full of long-lived particles

small couplings

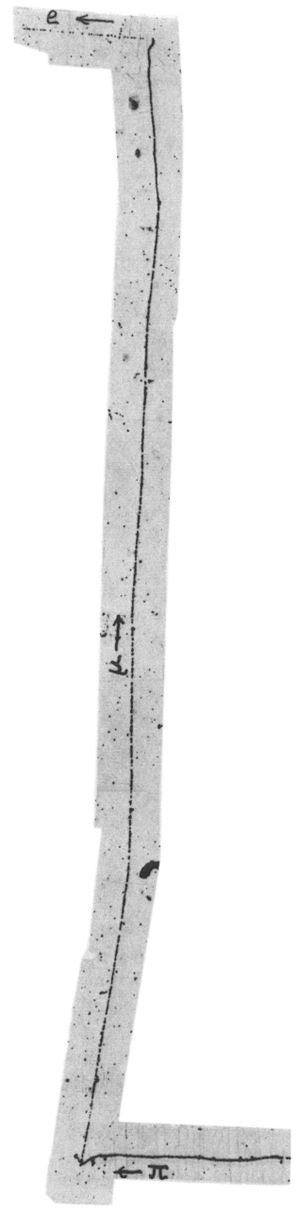
b-mesons, off-diagonal CKM, $\tau \approx$ ps

high mass mediator

μ, π, via W, $\tau \approx$ 2 μs, 26 ns

small mass splittings

neutron, m_n-$m_p \approx$ 1 MeV, τ = 15 min



(1949) *Nature* **163**, 82.

Why look for long-lived particles?

Standard Model is full of long-lived particles

These same mechanisms come into play with SUSY

small couplings

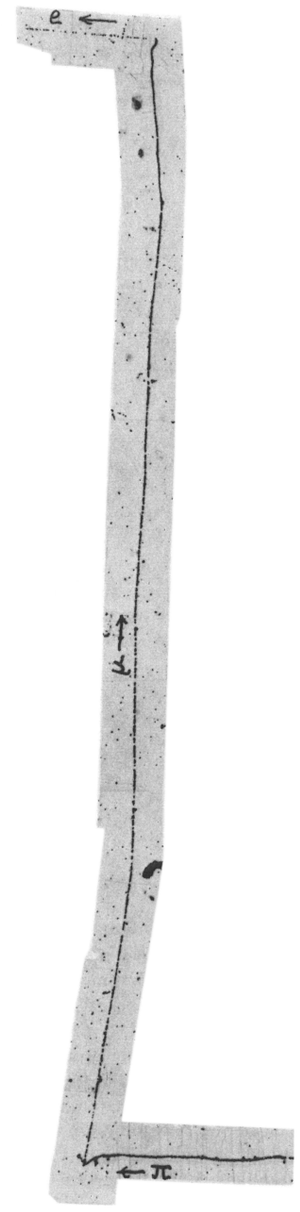
b-mesons, off-diagonal CKM, $\tau \approx$ ps

high mass mediator

μ, π, via W, $\tau \approx 2$ μs, 26 ns

small mass splittings

neutron, m_n-$m_p \approx 1$ MeV, $\tau = 15$ min



(1949) *Nature* **163**, 82.

R-parity violation

long-lived $\tilde{\chi}_1^0$

Split SUSY

long-lived $\tilde{g}$

pure electroweakinos

long-lived $\tilde{\chi}_1^\pm$

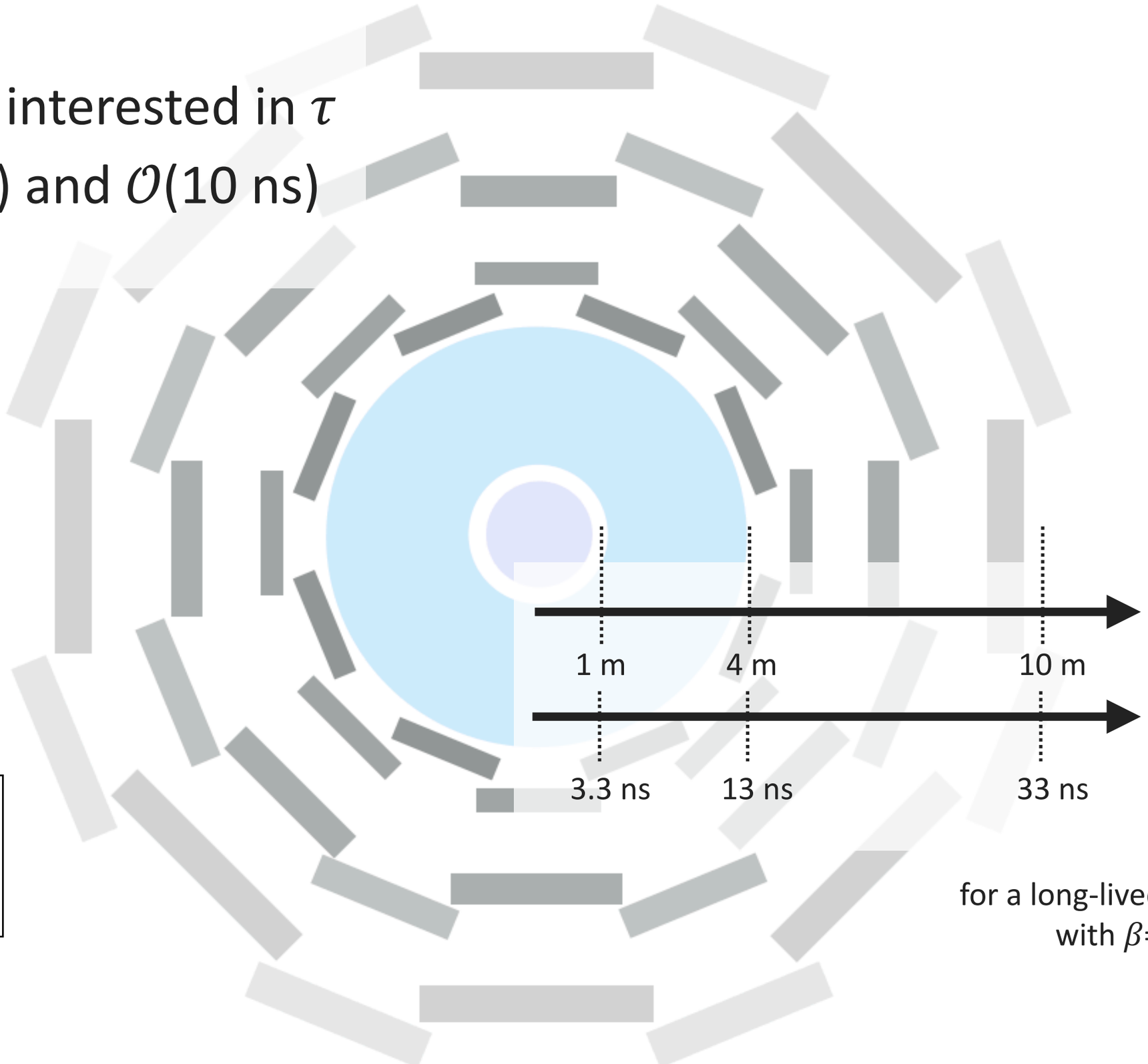
Why look for long-lived particles?

in ATLAS, most interested in τ between $\mathcal{O}$(ps) and $\mathcal{O}$(10 ns)

Tracker

Calorimeter

Muon Spectrometer



for a long-lived particle with β=1

Why look for long-lived particles?

If you like a challenge…

long-lived particles make striking signatures
charged or neutral
light or massive
a variety of lifetimes
and decay products

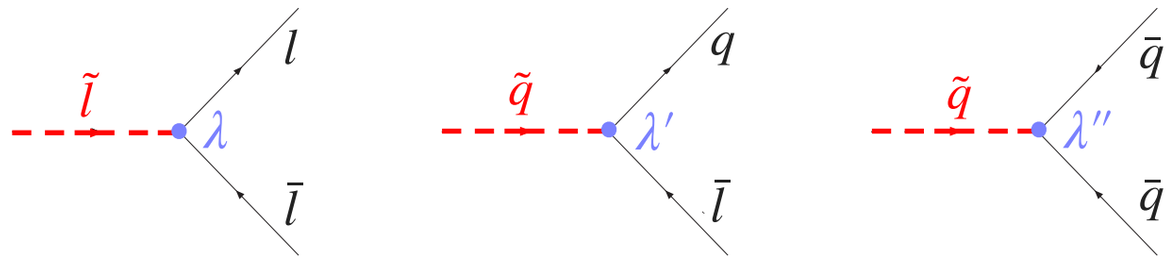
often require specialized reconstruction/triggers

An example: R-Parity Violating SUSY

When we write down SUSY in its most generic form

we get couplings that violate lepton and baryon number

$$W_{\Delta B,L} = \lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k + \lambda'_{ijk} U_i D_j D_k + \kappa_i L_i H_u$$



Standard SUSY searches assume one of two extremes

R-parity conservation (RPC), λ=0, stable LSP

or maximal R-parity violation (RPV), λ=large, prompt LSP decay

R-parity = +1 for ordinary particles
R-parity = -1 for superpartners

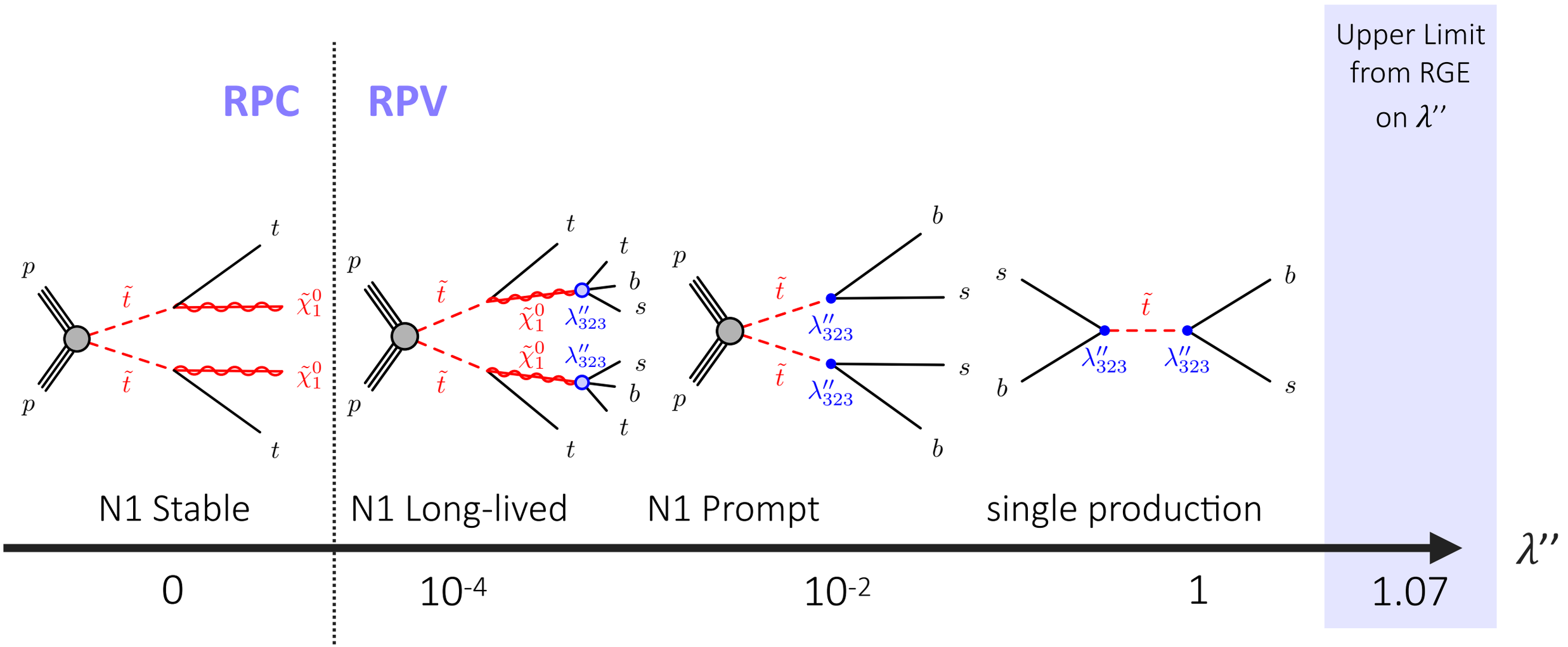
An example: R-Parity Violating SUSY

ATLAS-CONF-2018-003

But these couplings could be anything in between

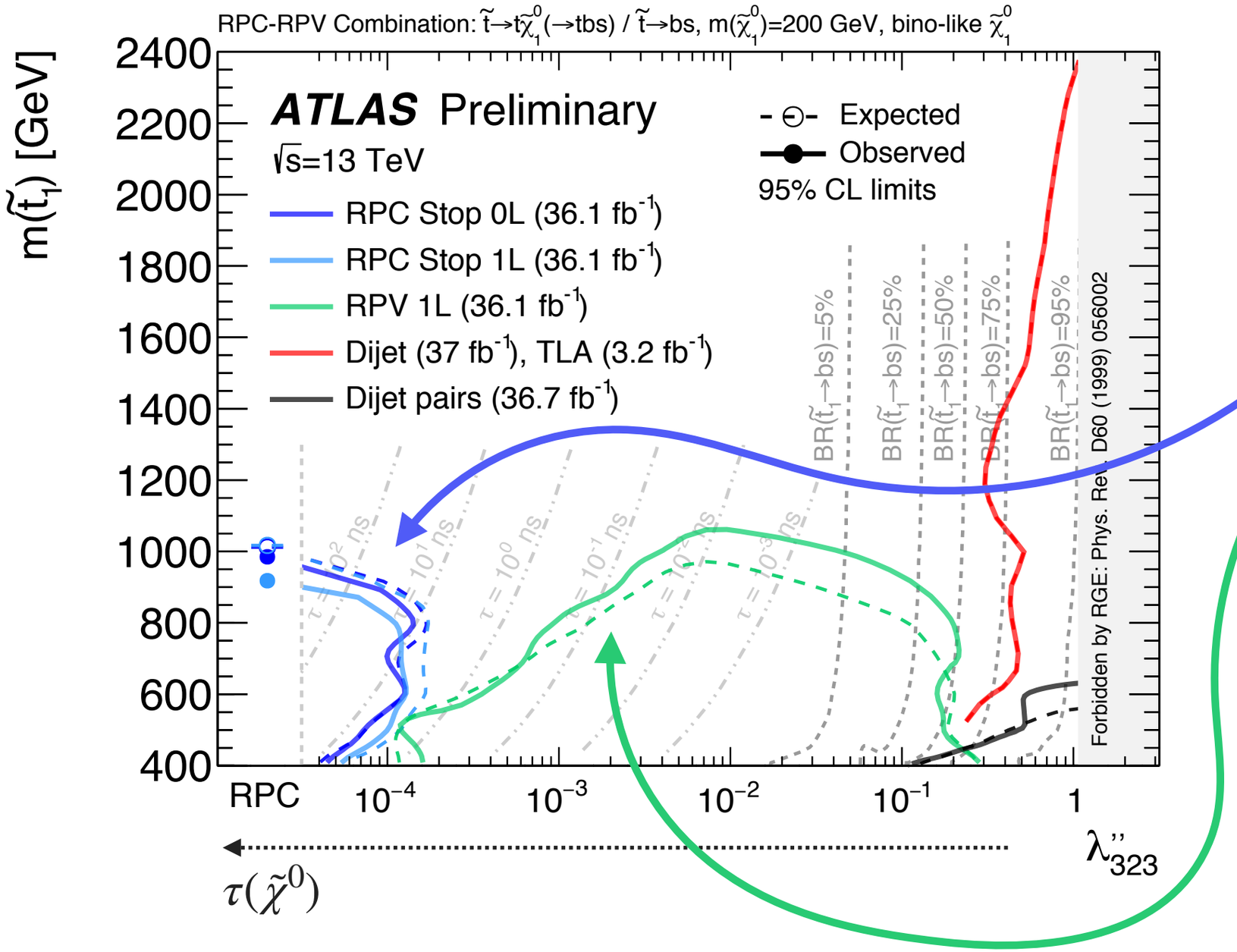
→ reinterpret prompt searches as a function of RPV coupling (LLP lifetime)

RPC | **RPV**



An example: R-Parity Violating SUSY

ATLAS-CONF-2018-003



Standard searches do a great job

assume lightest SUSY particle is stable

assume lightest SUSY particle decays promptly

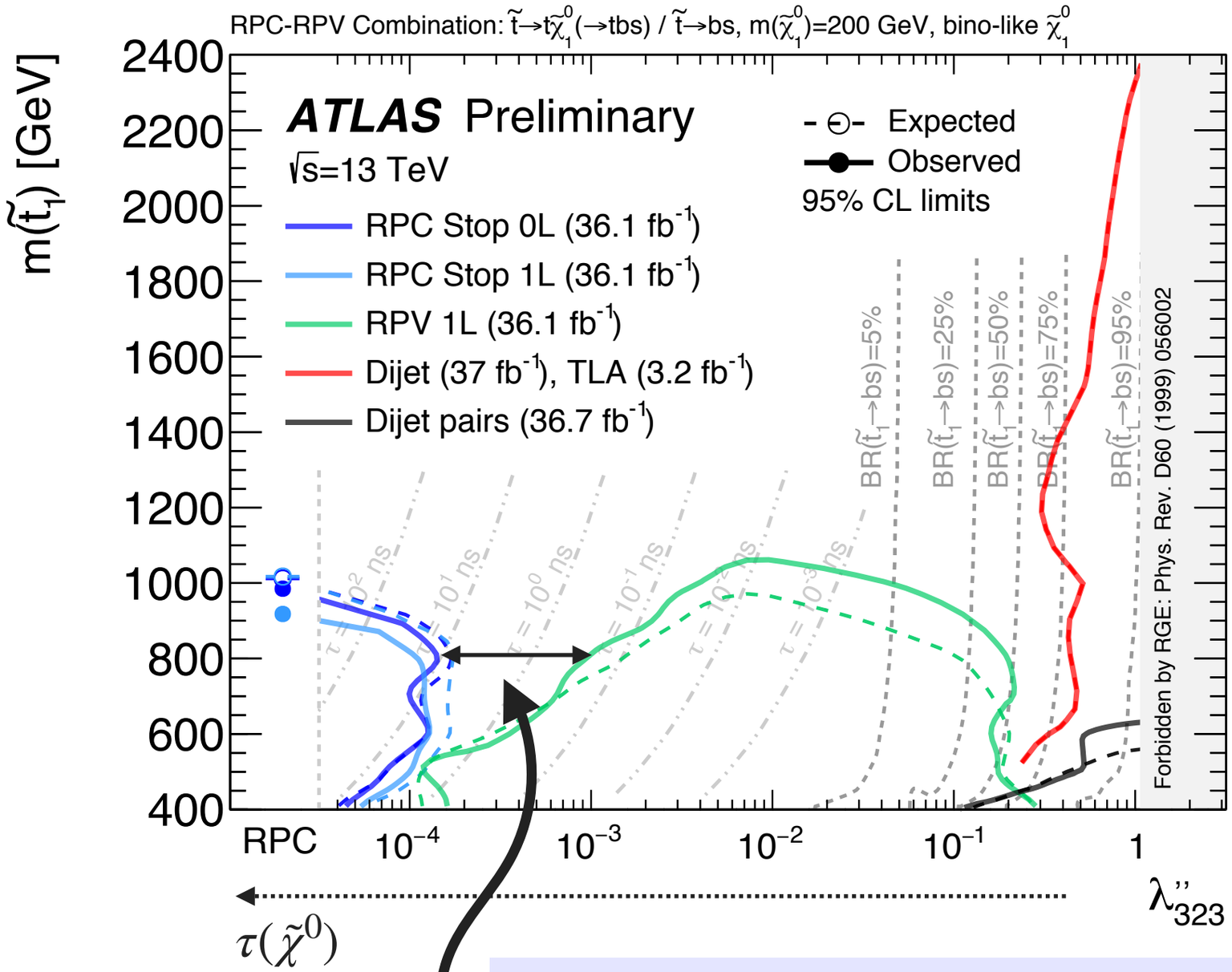
direct stop decay

single stop production

see more in backup!

An example: R-Parity Violating SUSY

ATLAS-CONF-2018-003



Standard searches do a great job

assume lightest SUSY particle is stable

assume lightest SUSY particle decays promptly

direct stop decay

single stop production

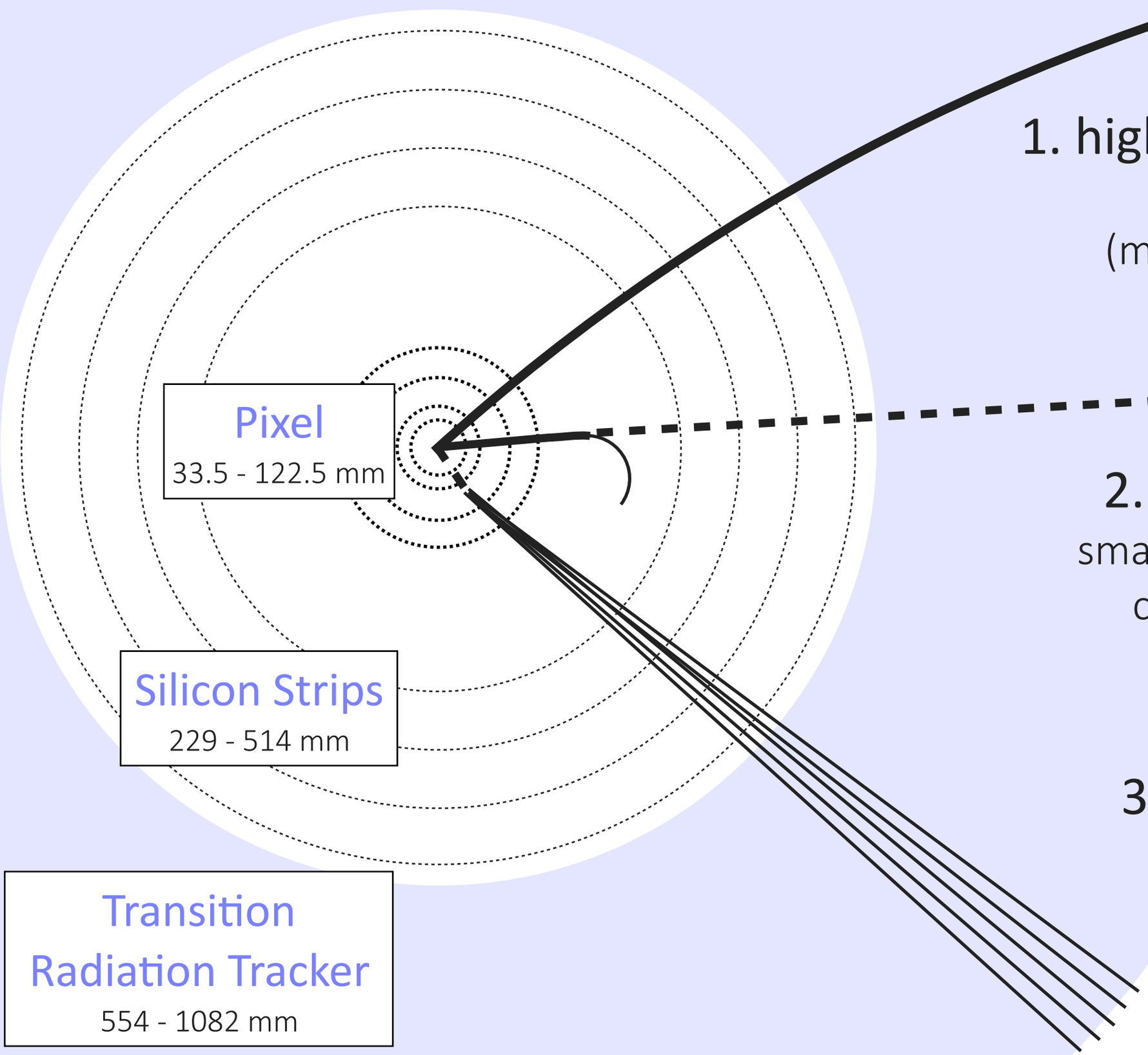
But!

Gaps in coverage highlight need for dedicated long-lived particle searches!

eg. room for light stops with neutralino lifetimes between 0.5 ns and 10 ns

see more in backup!

A few long-lived SUSY searches in ATLAS



1. highly ionizing particles

massive, charged,
(meta-)stable particles

SUSY-2016-31

2. disappearing tracks

small mass splittings between
charginos & neutralinos

JHEP 06 (2018) 022

3. displaced vertices

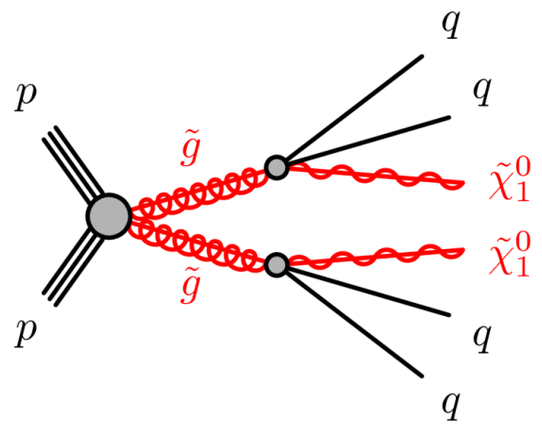
hadronic decays of
long-lived particles

Phys. Rev. D 97 (2018) 052012

1. Highly Ionizing particles

Search for long-lived massive charged particles, which are slow moving and highly ionizing

eg. gluino in Split SUSY, decays via heavy squarks, hadronizes with Standard Model particles



Step 1: calibrate dE/dx

Time over threshold for each pixel hit ≈ charge

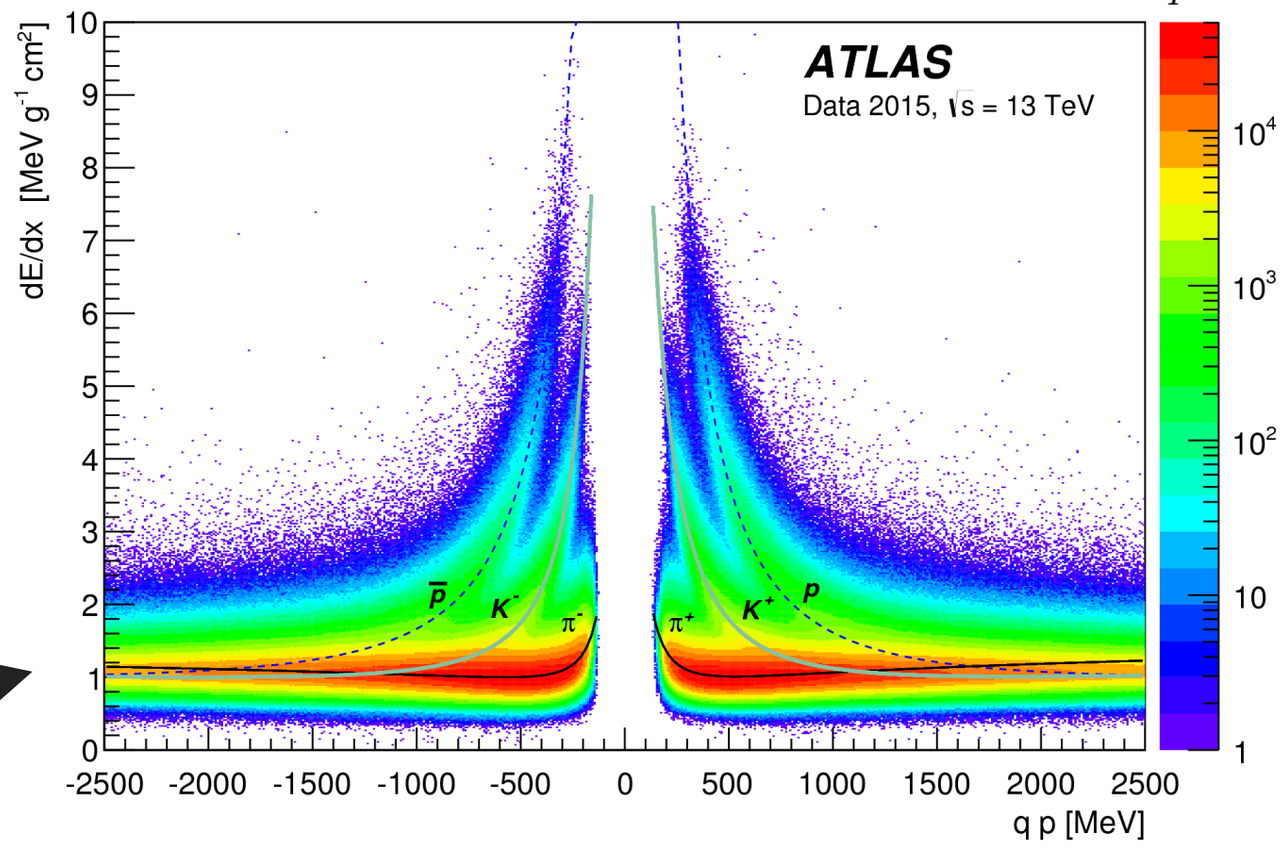
average cluster charge = dE/dx

$$\mathrm{MPV}_{\mathrm{d}E/\mathrm{d}x} = \mathrm{A}/(\beta\gamma)^{\mathrm{C}} + \mathrm{B}$$

Step 2:

with dE/dx, and track momentum

use $\beta\gamma$= p/m to measure particle mass



Improvements with full 2015+2016 dataset!

run dependent scale factors, low momentum correction for protons & kaons,

η-correction (traversed thickness) , and radiation damage correction

1. Highly Ionizing particles

Selection:

MET Trigger, MET > 170 GeV
track pT > 150 GeV
dE/dx > 1.8 MeV $g^{-1}cm^2$
meta-stable & stable signal regions

Backgrounds:

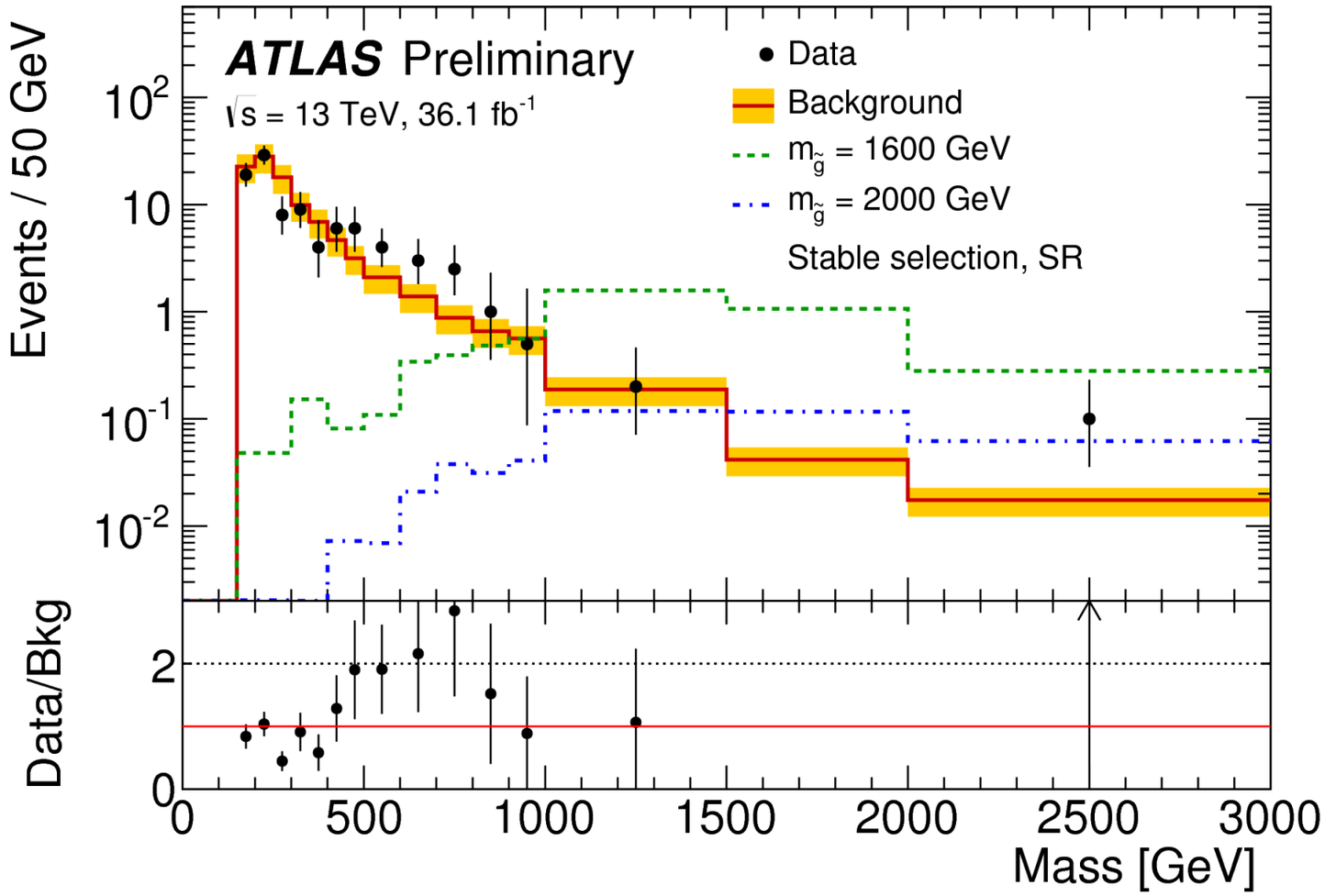
from long Landau tail,
shared hits, or spurious hits

Data-driven bkg estimation:

Measure p in low dE/dx
Measure dE/dx in low MET
normalize in M < 160 GeV

Results

mild excess: 2.4σ local in stable SR
targeting 600 GeV gluino
no excess in meta-stable signal regions



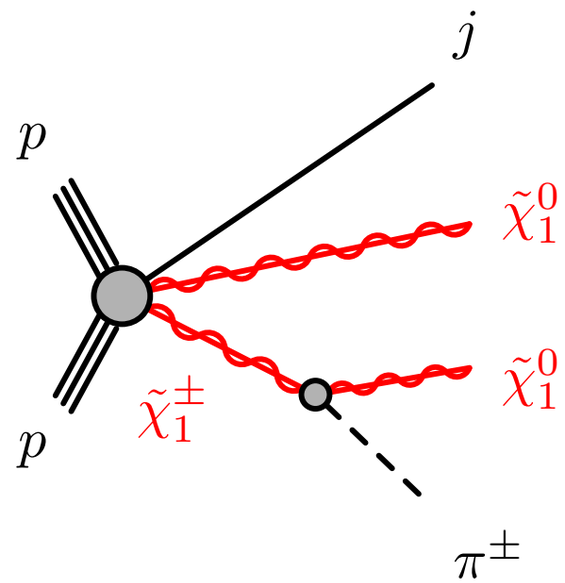
lifetimes probed: τ > 0.4 ns
masses excluded
τ ~ 10 ns : 2060 GeV
stable : 1890 GeV

2. Disappearing tracks

small $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) \rightarrow$ long-lived charginos,

pure wino-LSP: Δm = 160 MeV, τ = 0.2 ns

pure higgsino-LSP: Δm = 350 MeV, τ = 0.05 ns



neutralinos make good candidates for DM!

non standard reconstruction

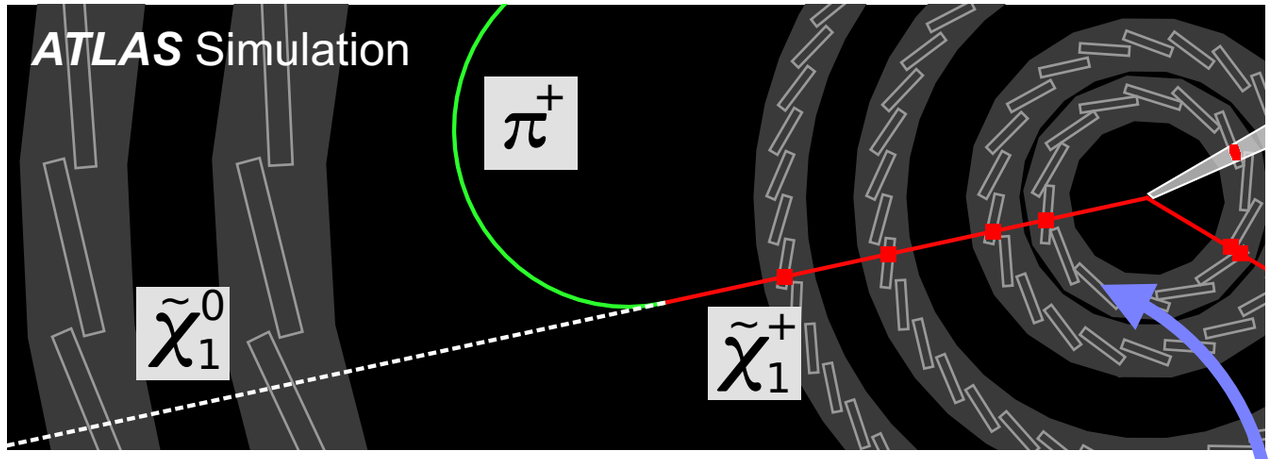
short pixel tracks with 4 hits = tracklet

Selection:

MET trigger,

1 high pT jet, lepton veto

1 isolated pixel tracklet



Improvements w.r.t Run 1!

addition of IBL → shorter tracklets

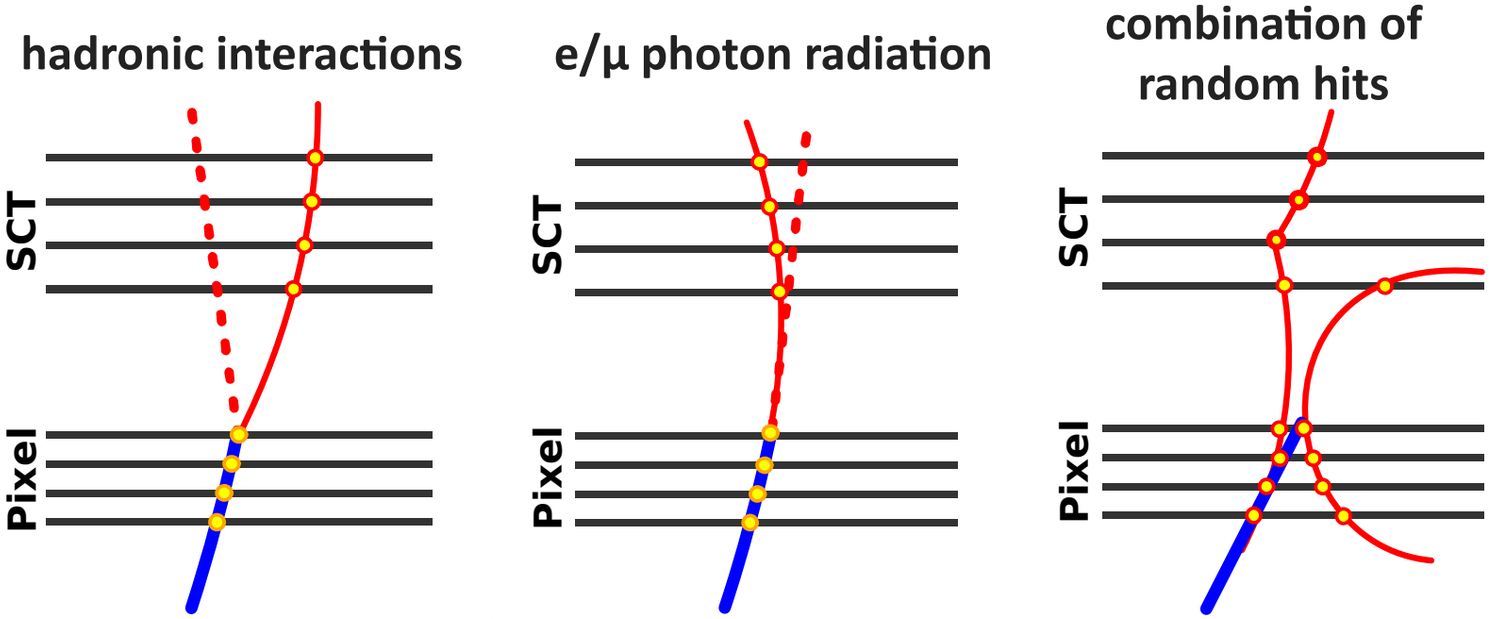
probe shorter lifetimes

2. Disappearing tracks

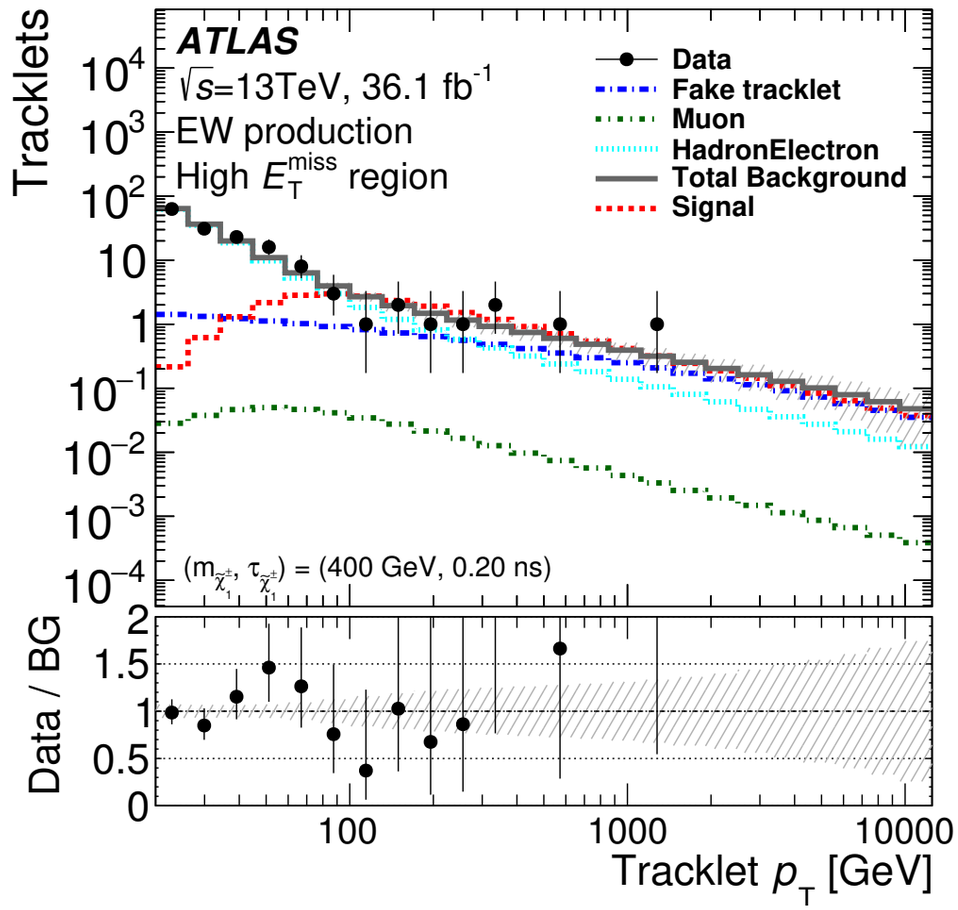
Background estimation

measure data-driven templates

likelihood fit to pixel tracklet pT spectrum



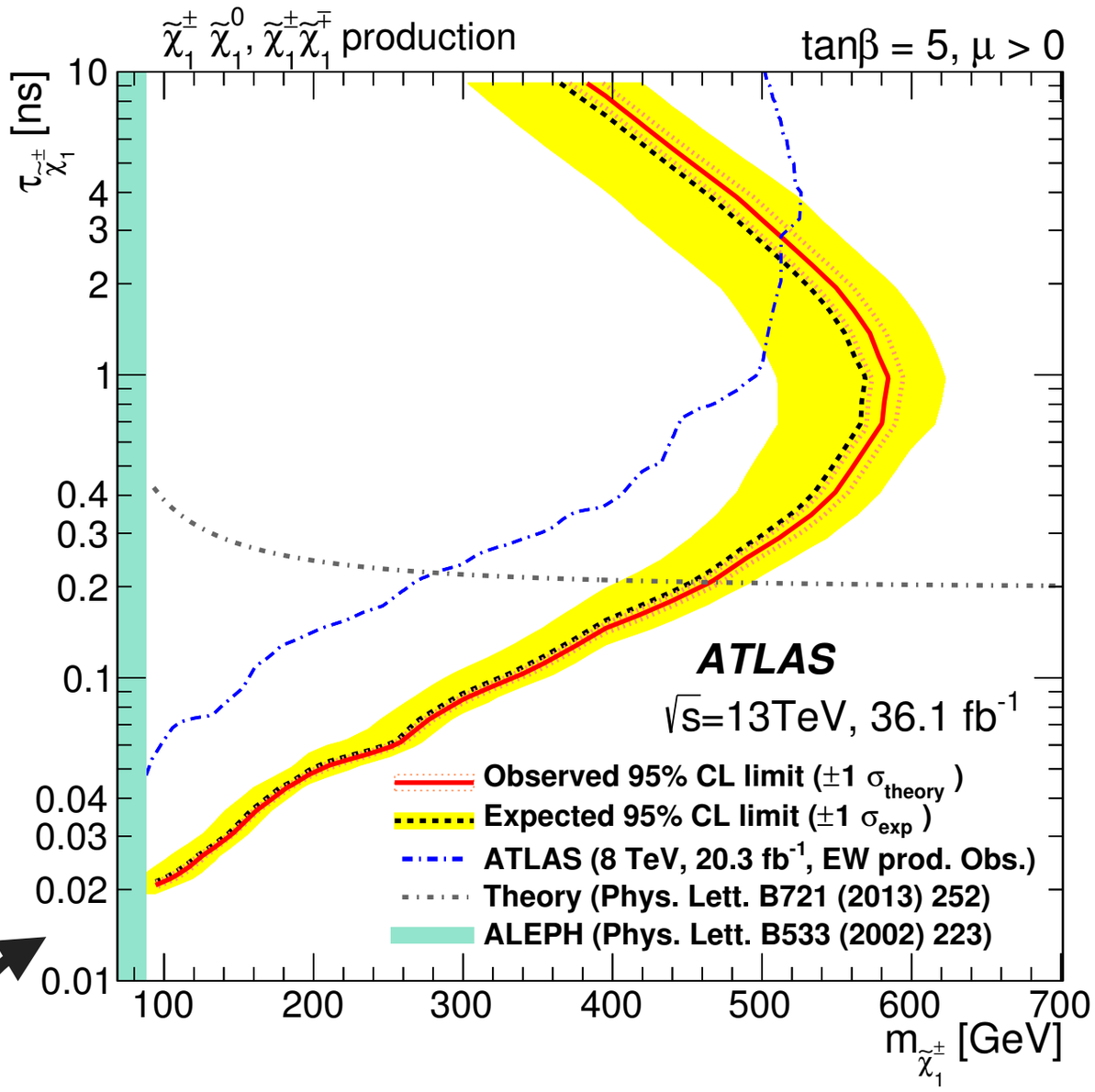
red = particle's path, blue = reconstructed tracklet



1. measure pT of standard tracks from non-scattered hadrons and leptons
2. e/μ: account for P(lepton → tracklet)
3. smear to account for track v. tracklet pT resolution (measured in Z → μμ)

1. shape: drop MET requirement and $|d0|/\sigma(d0) > 10$
2. normalization: low MET region

2. Disappearing tracks



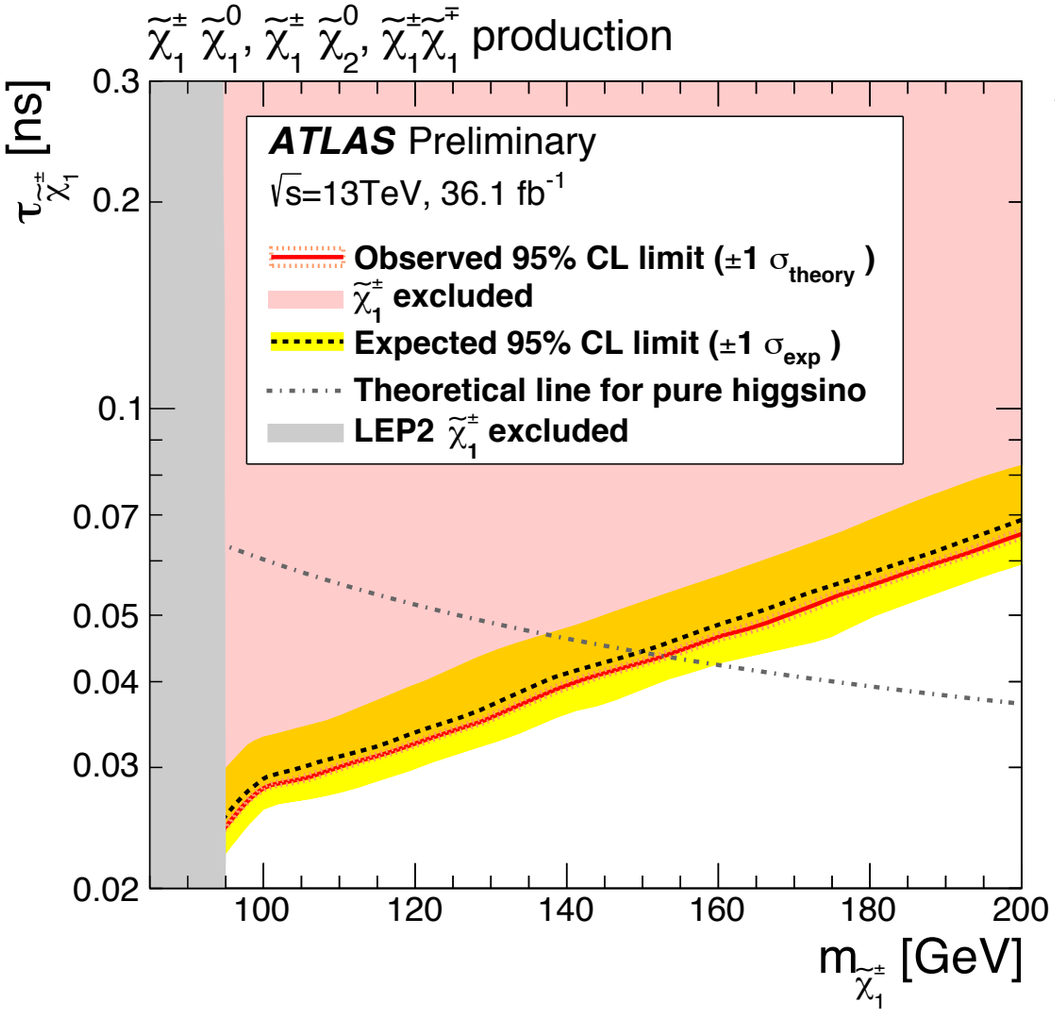
pure wino $\tilde{\chi}_1^0$

exclude chargino masses up to 460 GeV

ATL-PHYS-PUB-2017-019

pure higgsino $\tilde{\chi}_1^0$

exclude chargino masses up to 152 GeV



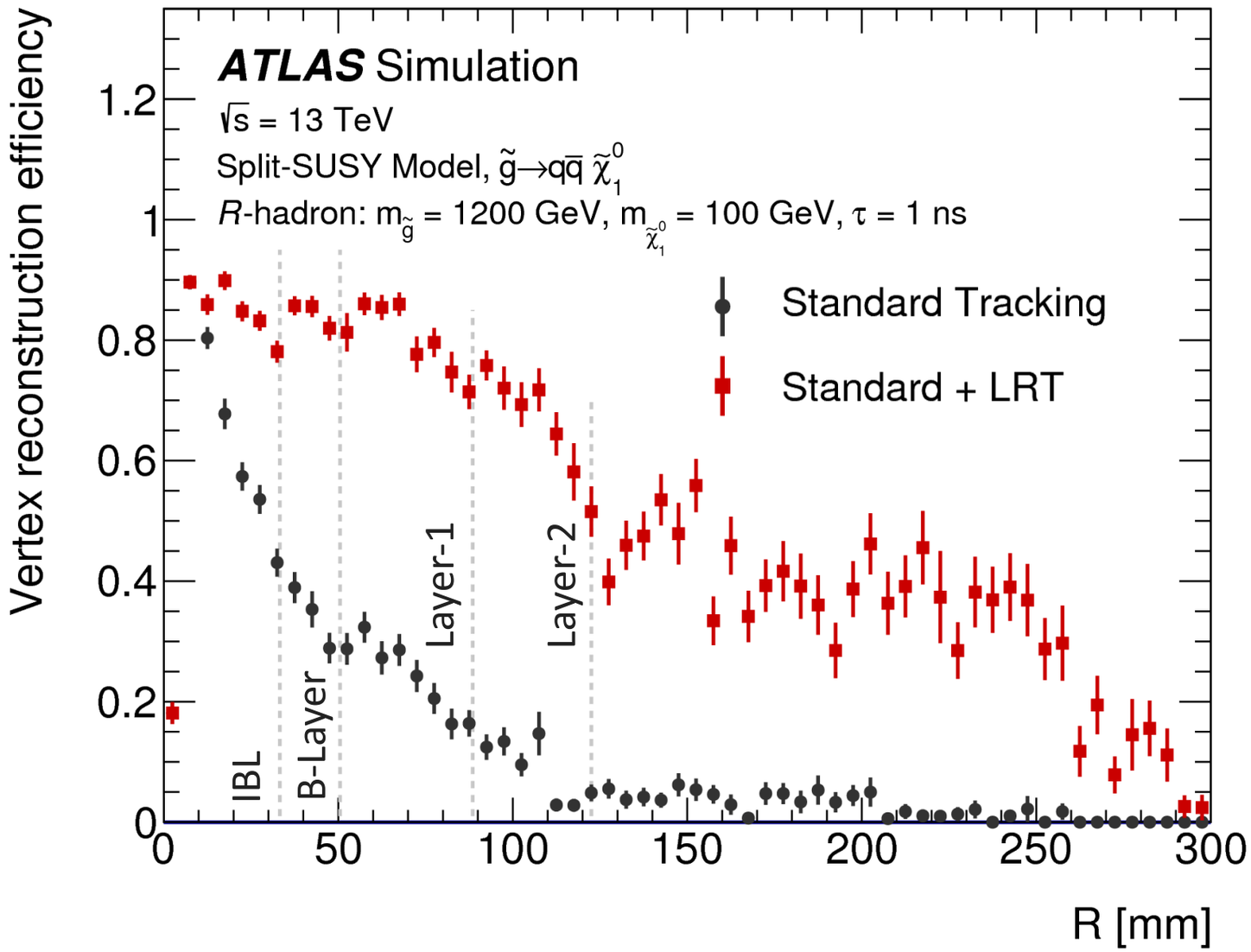
3. Displaced Vertices + MET

Phys. Rev. D 97 (2018) 052012

targeting hadronic decays in pixel barrel

non standard reconstruction

large radius tracking (LRT) and secondary vertexing



3. Displaced Vertices + MET

Selection

trigger on MET, MET > 250 GeV

at least 1 displaced vertex with

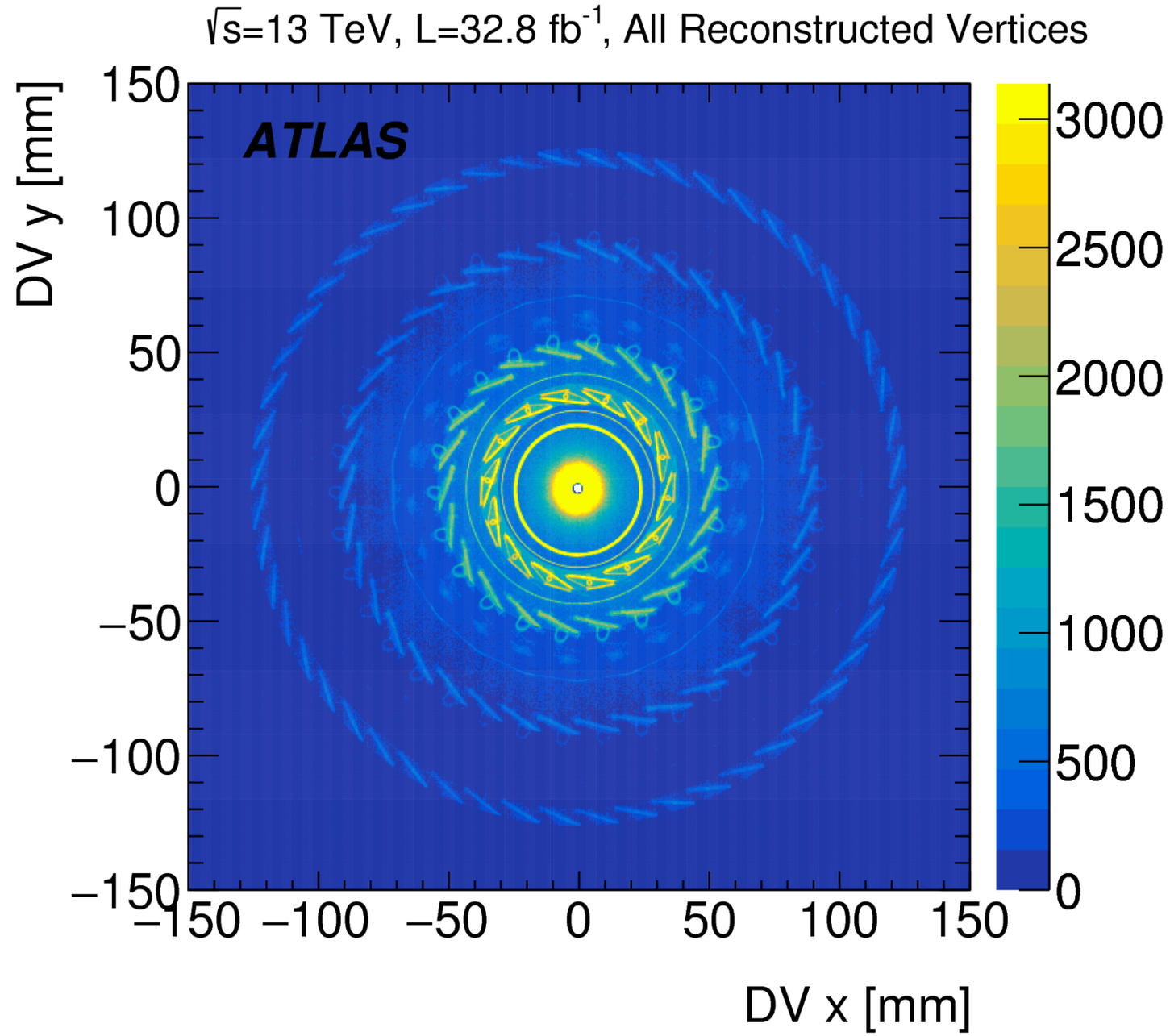
Ntrk ≥ 5, mDV > 10 GeV

Backgrounds

hadronic interactions

random track crossings

merged vertices

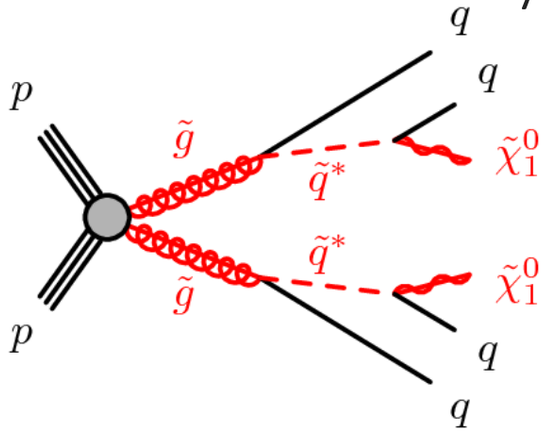


3. Displaced Vertices + MET

Phys. Rev. D 97 (2018) 052012

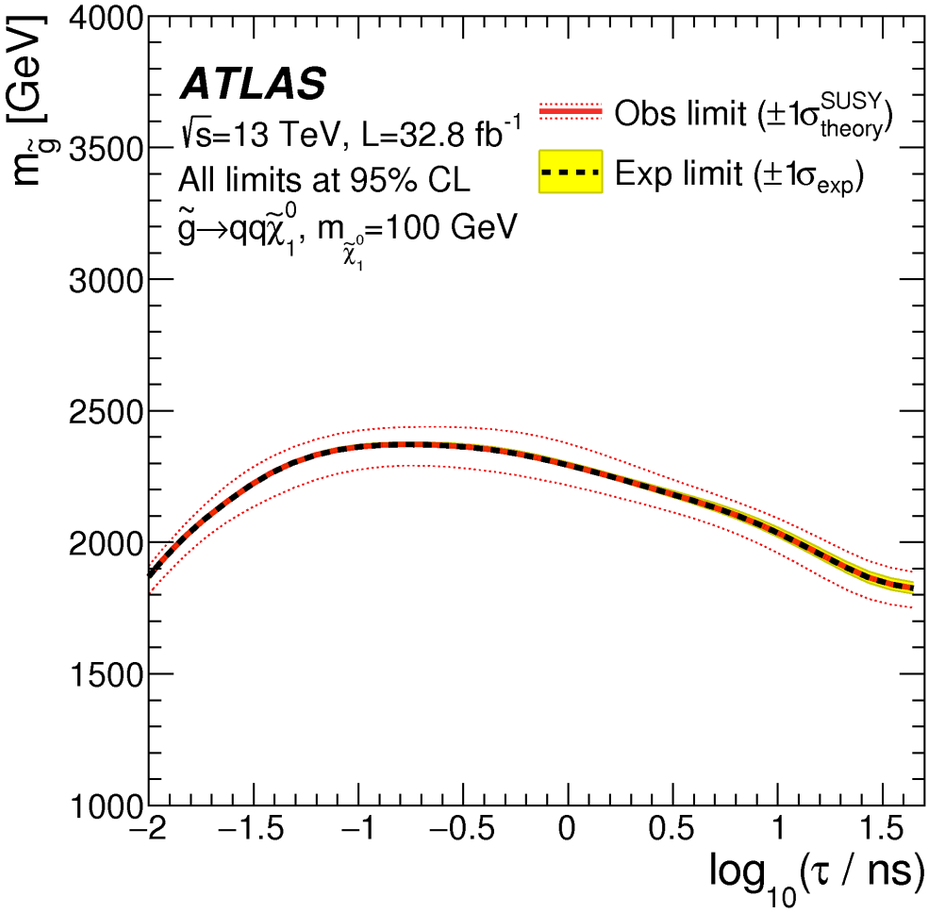
0 events expected / observed

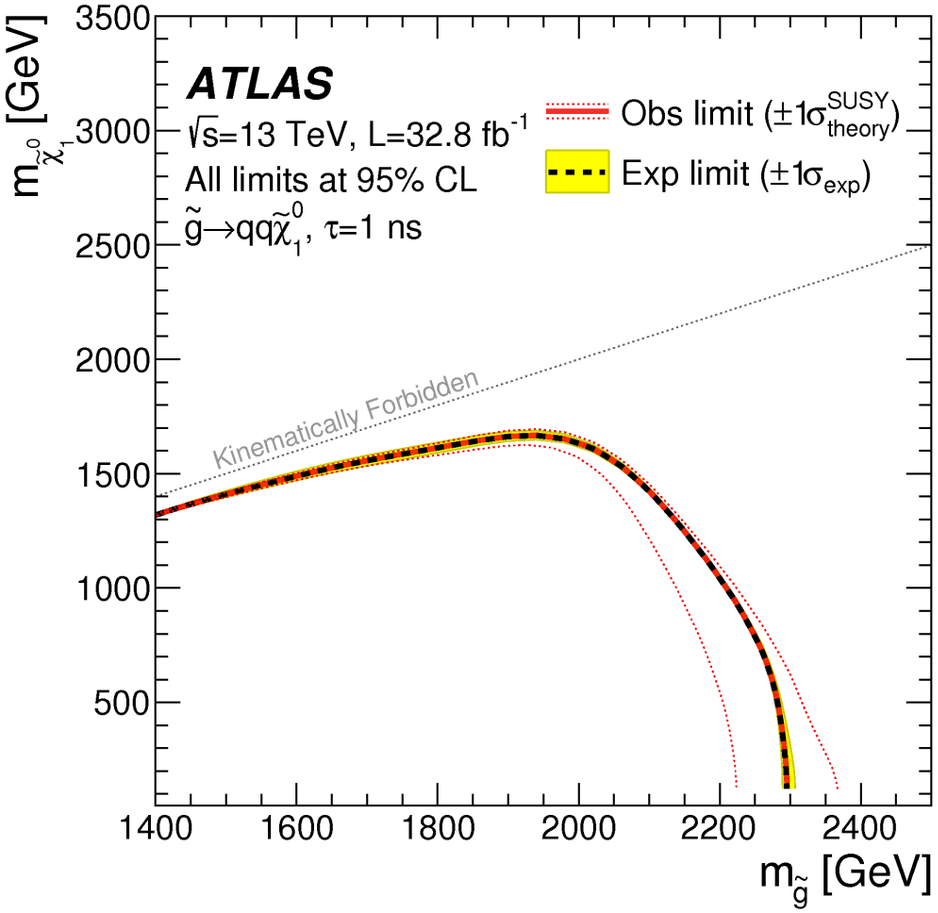
best sensitivity: 2.37 TeV gluinos excluded at τ = 0.1 ns, m(LSP) = 100 GeV



Exploring gluino-neutralino mass splittings

more difficult to get compressed scenarios,
fewer tracks and lower MET





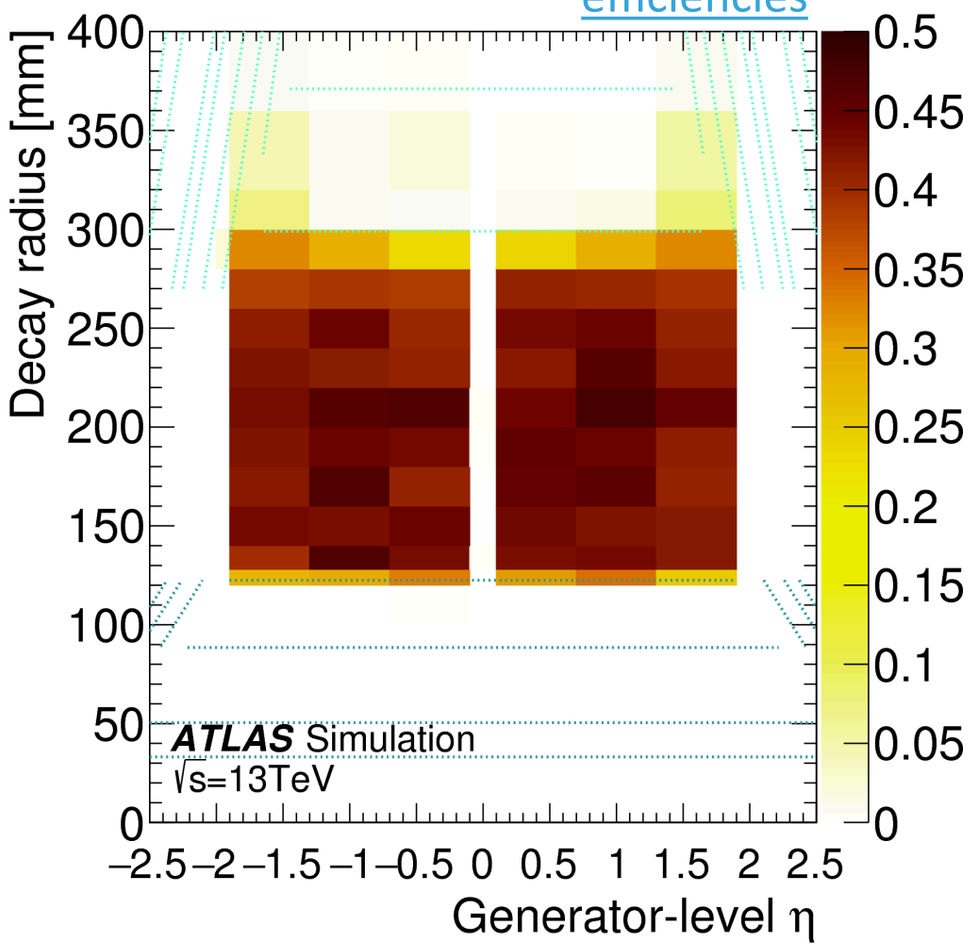
Parameterized efficiencies

If you prefer another interpretation…

take a look at our parametrized efficiencies

with prescriptions for easy use!

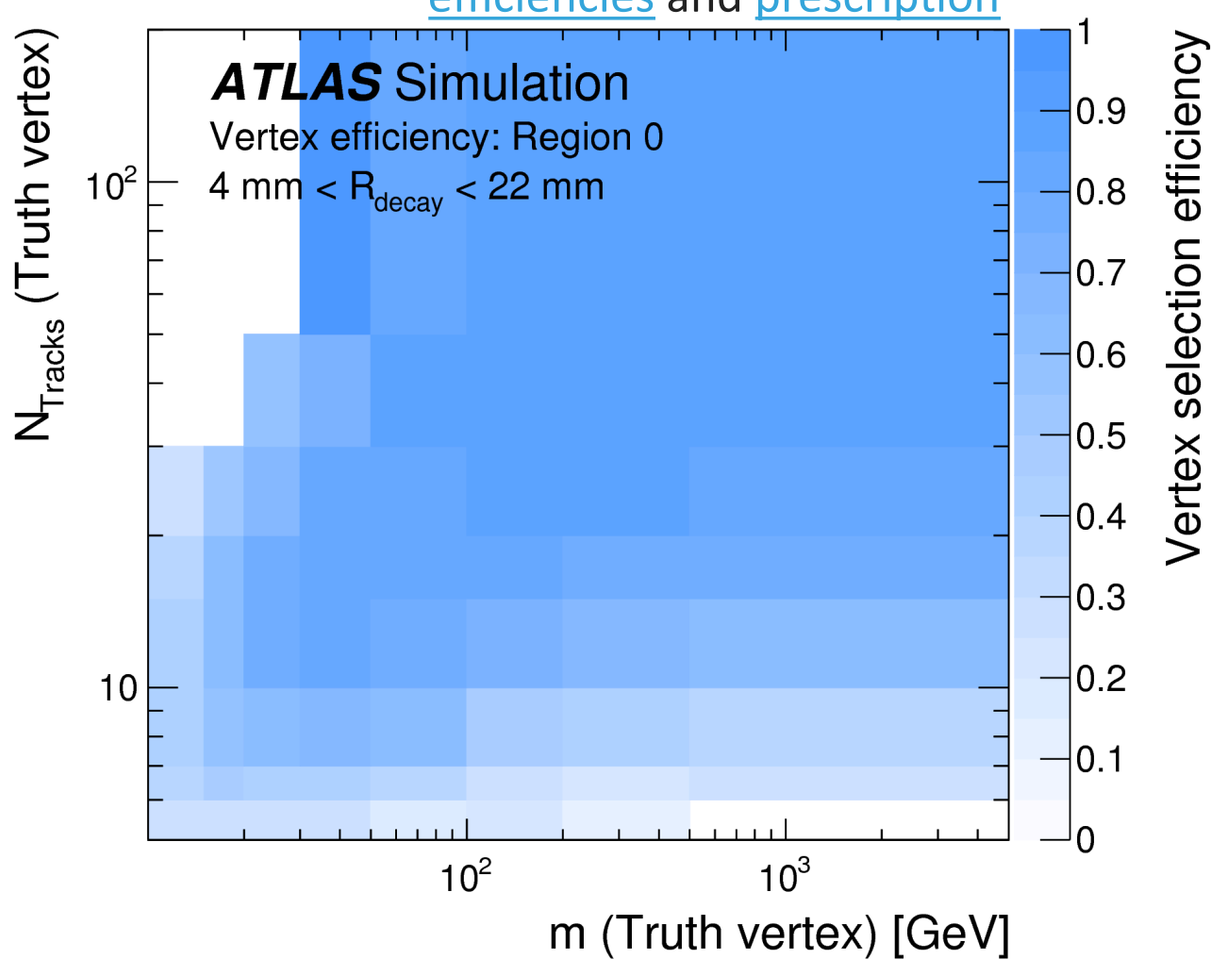
efficiencies



disappearing track

acceptance x efficiency

efficiencies and prescription



displaced vertices + MET

vertex efficiency

Conclusions

Long-lived SUSY

is well motivated

creates challenging and spectacular signatures

which require dedicated searches

No discovery yet…

but there is more phase space to explore in Run 2

Stay tuned!

ATLAS SUSY LLP results

Pixel dE/dx SUSY-2016-31

Disappearing Track JHEP 06 (2018) 022

Higgsino Reinterpretation ATL-PHYS-PUB-2017-019

Displaced Vertices + MET Phys. Rev. D 97 (2018) 052012

Reinterpretation in long-lived scenarios ATLAS-CONF-2018-003

Stable massive particles Physics Letters B 760 (2016) 647

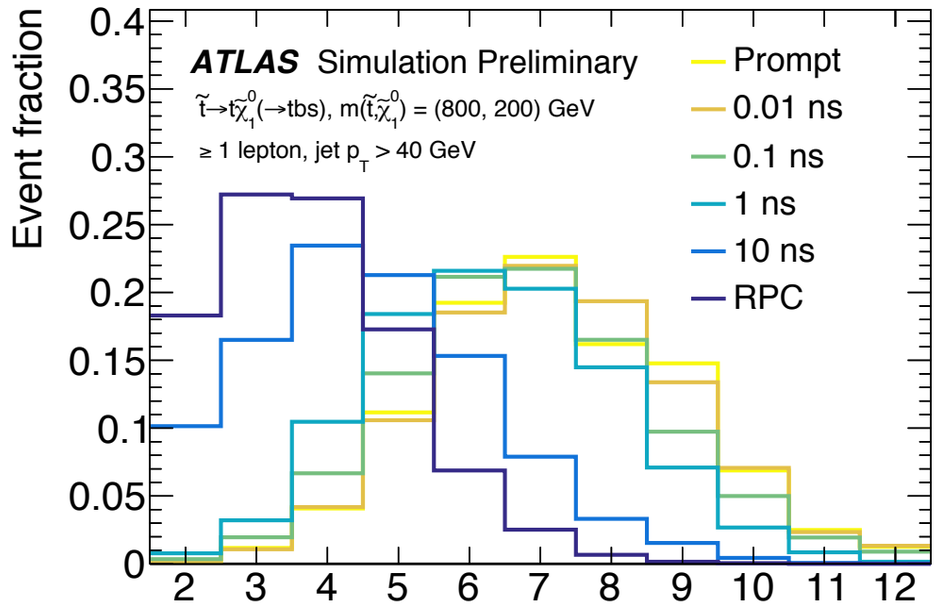
Displaced Vertices + Jets, Leptons, Dilepton DVs Phys. Rev. D 92, 072004 (2015)

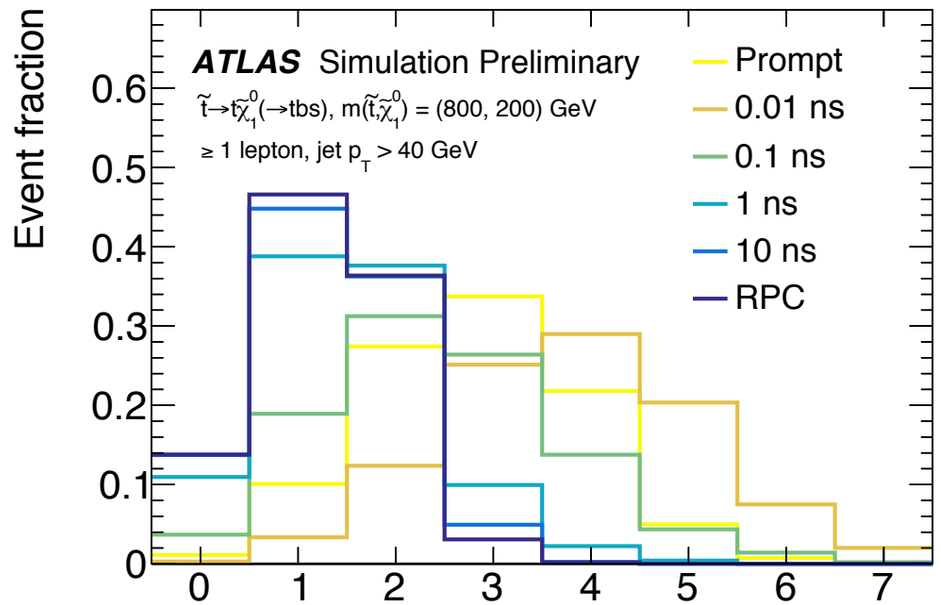
Stopped Particles Phys. Rev. D 88, 112003 (2013)

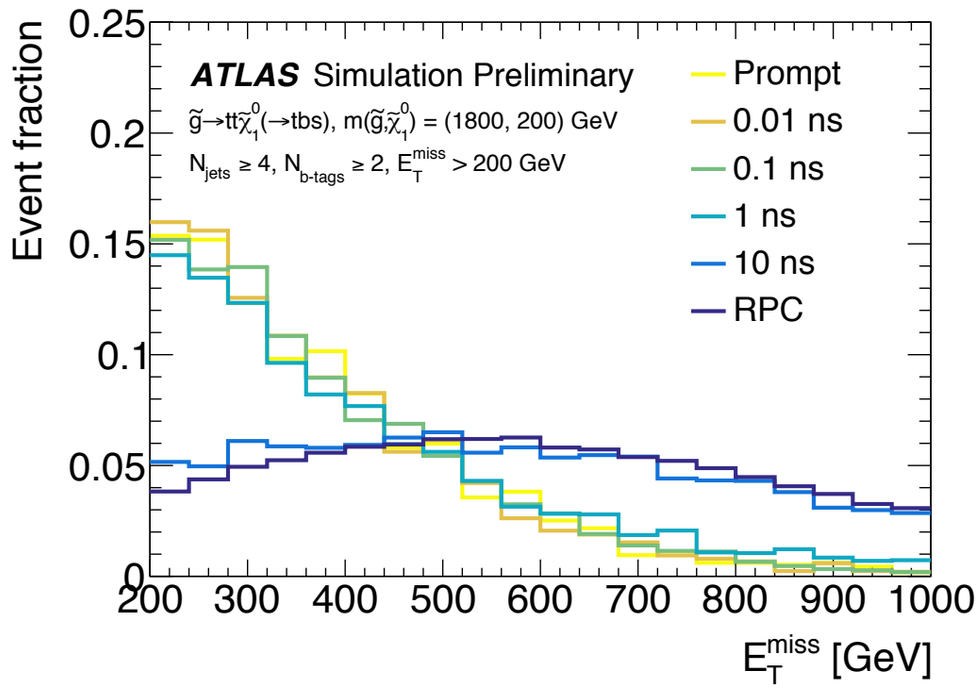
Non-pointing photons Phys. Rev. D 88, 012001 (2013)

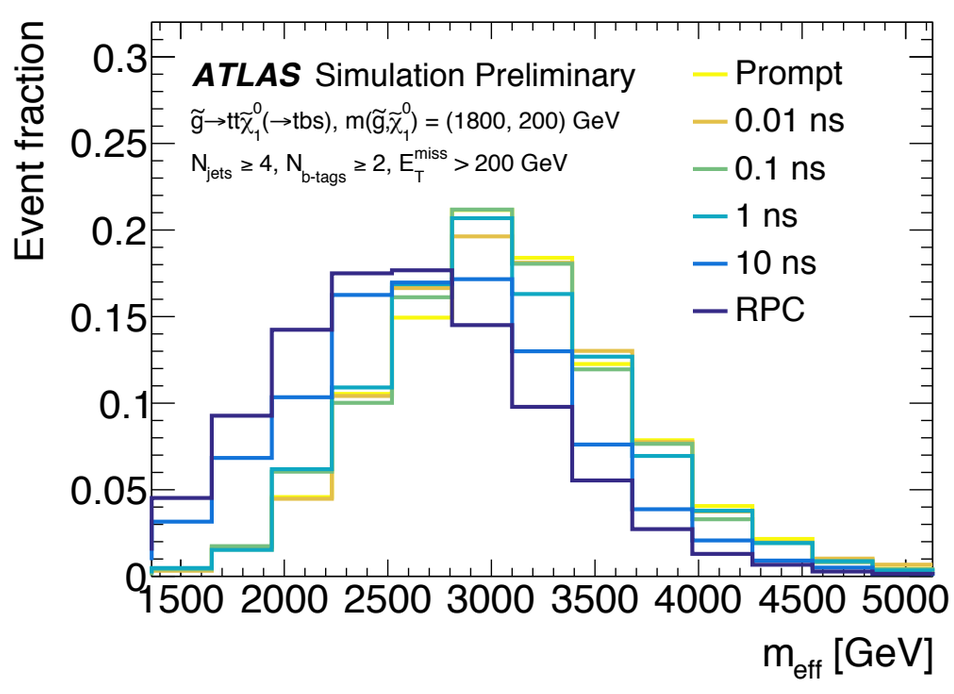
Reinterpreting prompt searches in RPV scenarios

impact of neutralino decay on key kinematic distributions

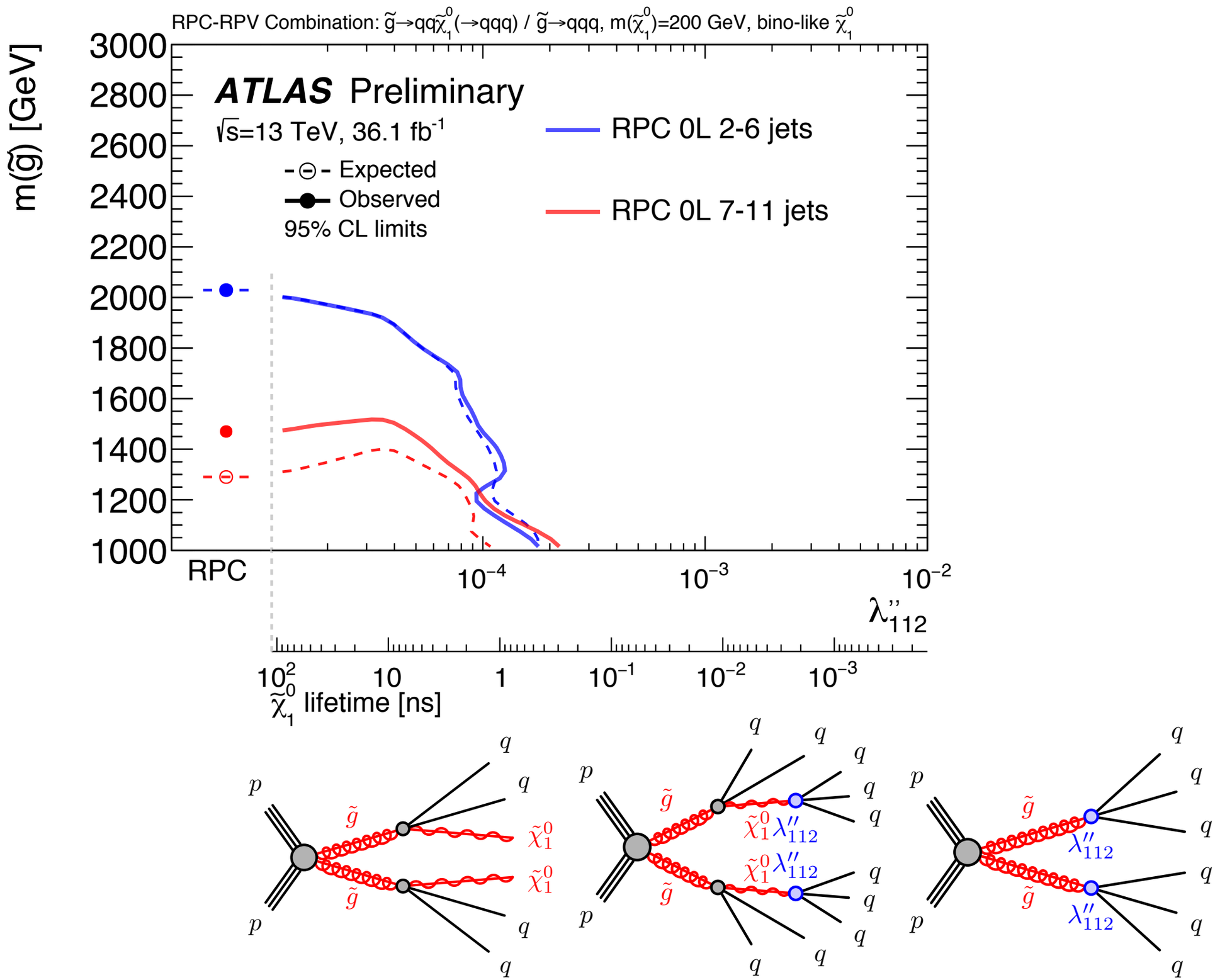




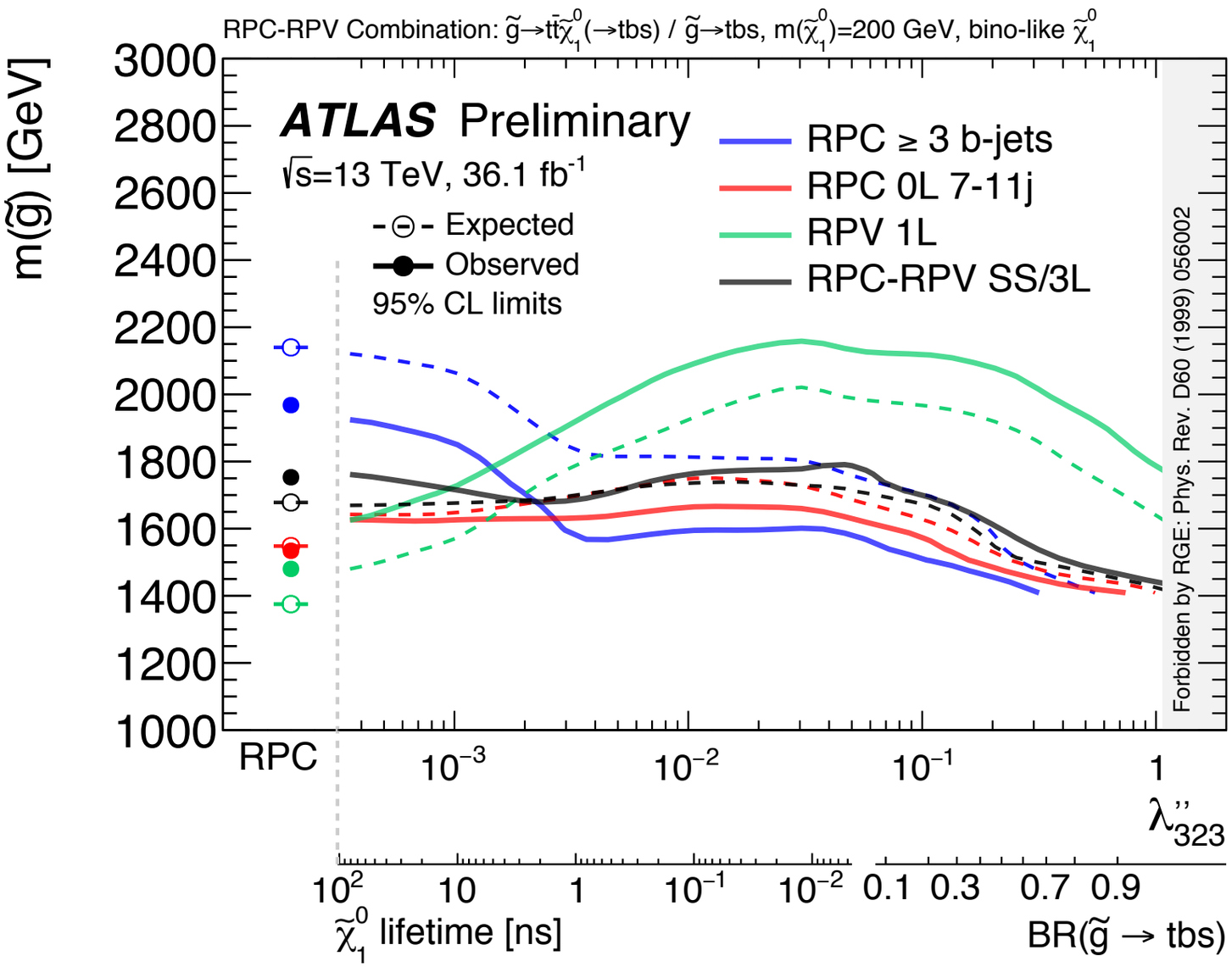


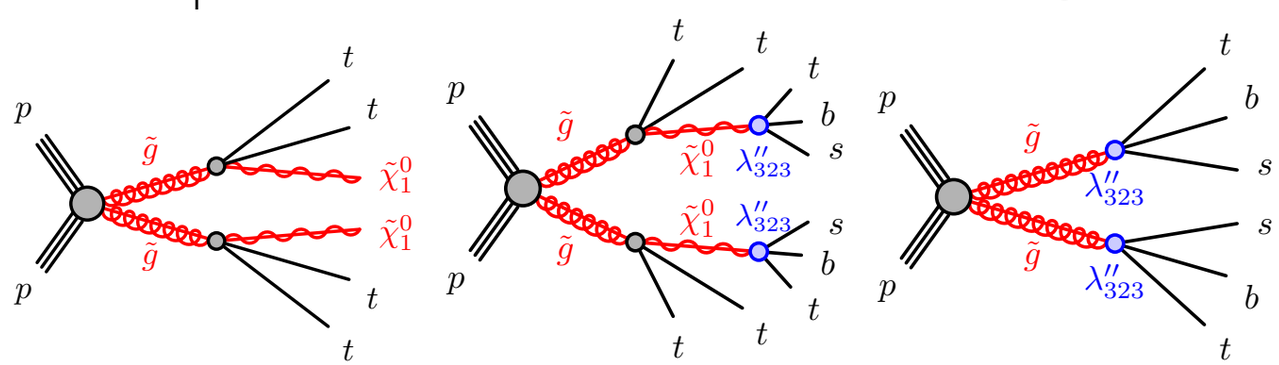


Reinterpreting prompt searches in RPV scenarios



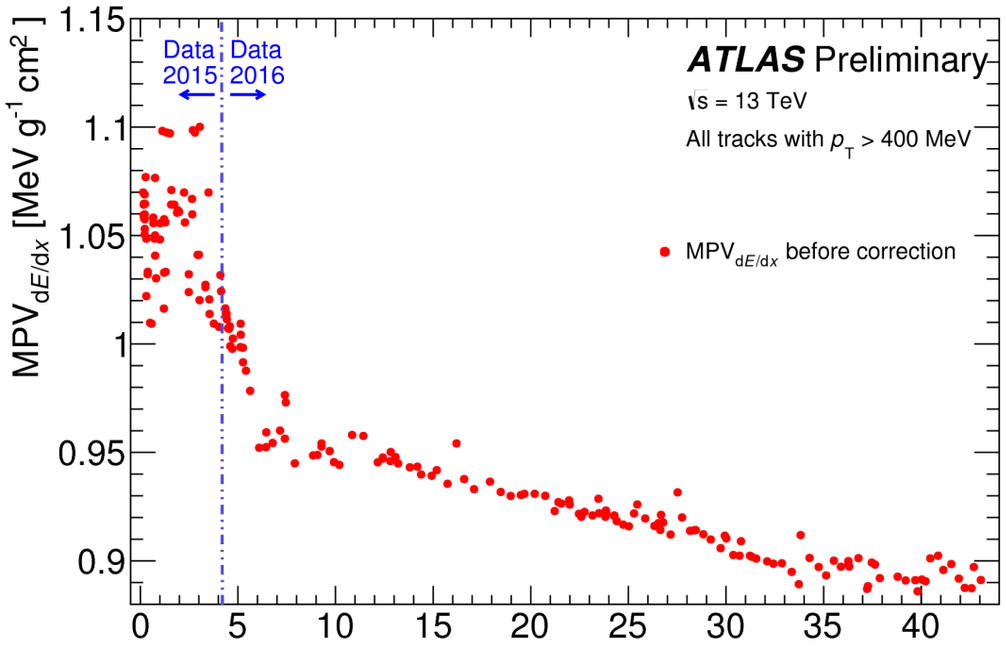
Reinterpreting prompt searches in RPV scenarios



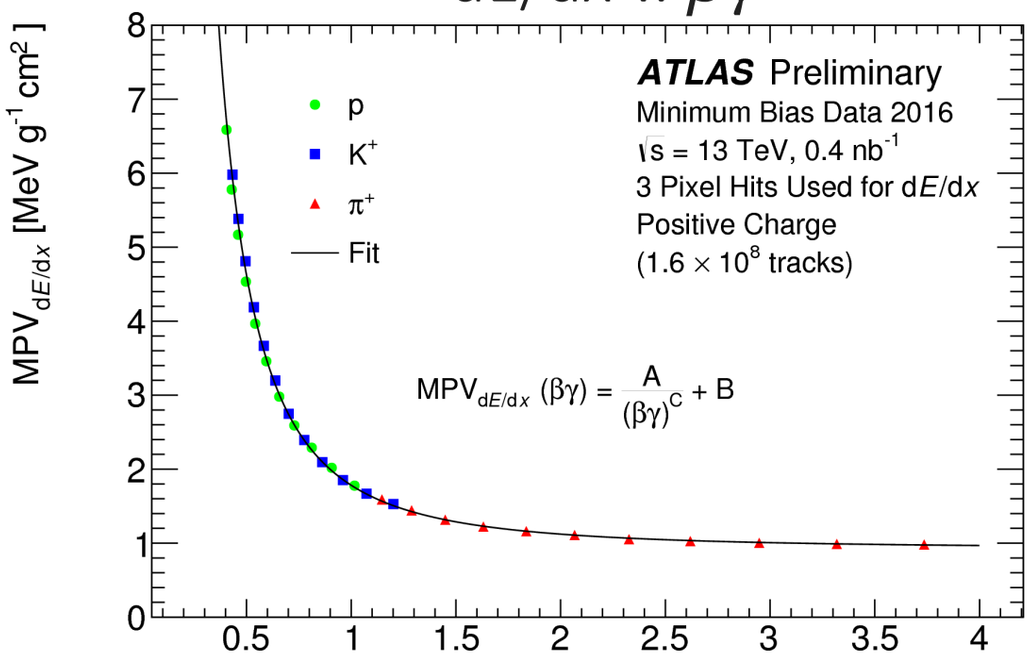


Pixel dE/dx

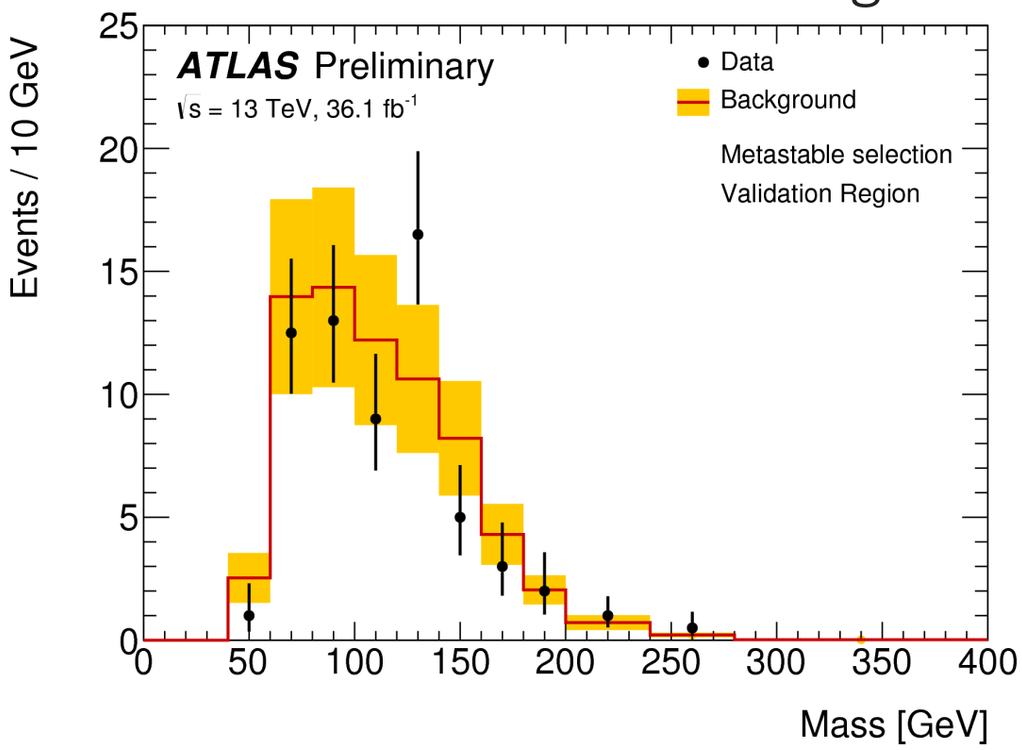
Run dependent dE/dx



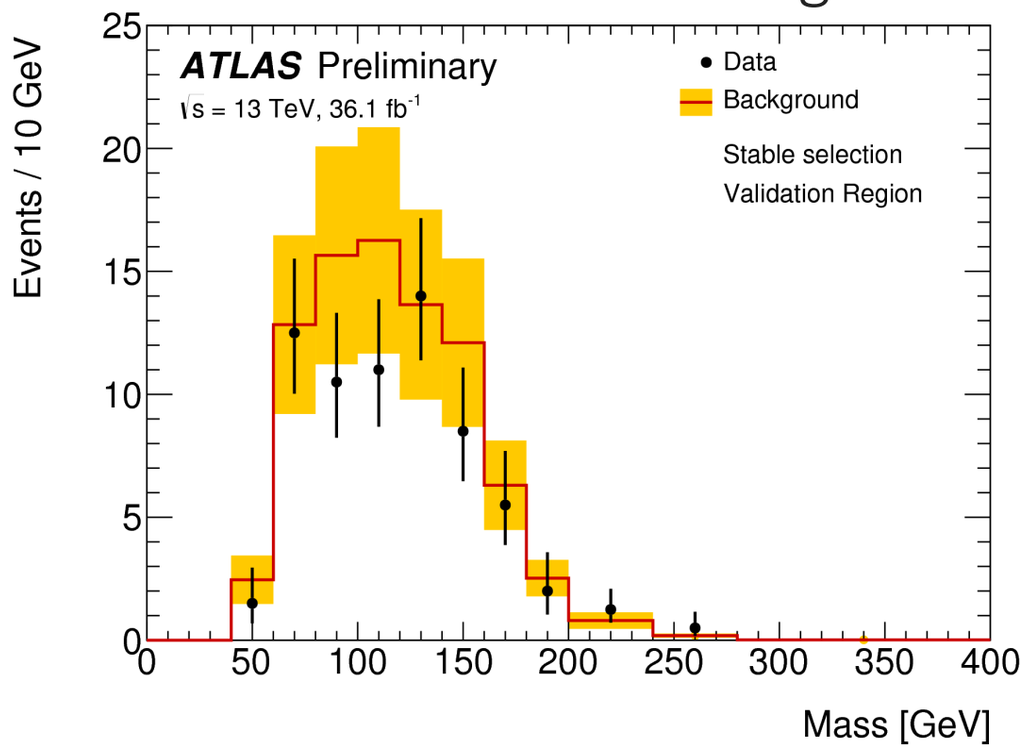
dE/dx v. $\beta\gamma$



Metastable validation region

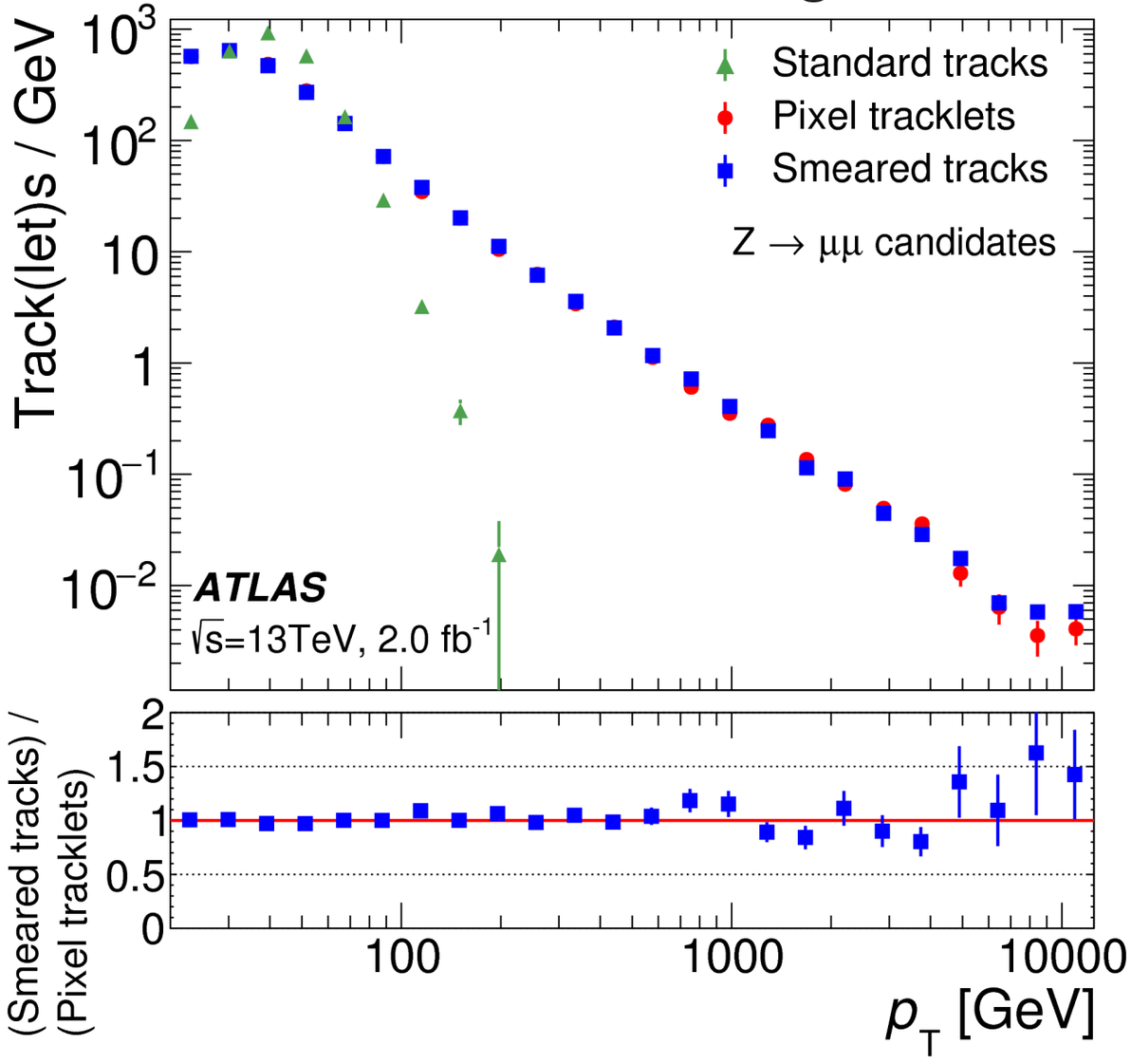


Stable validation region

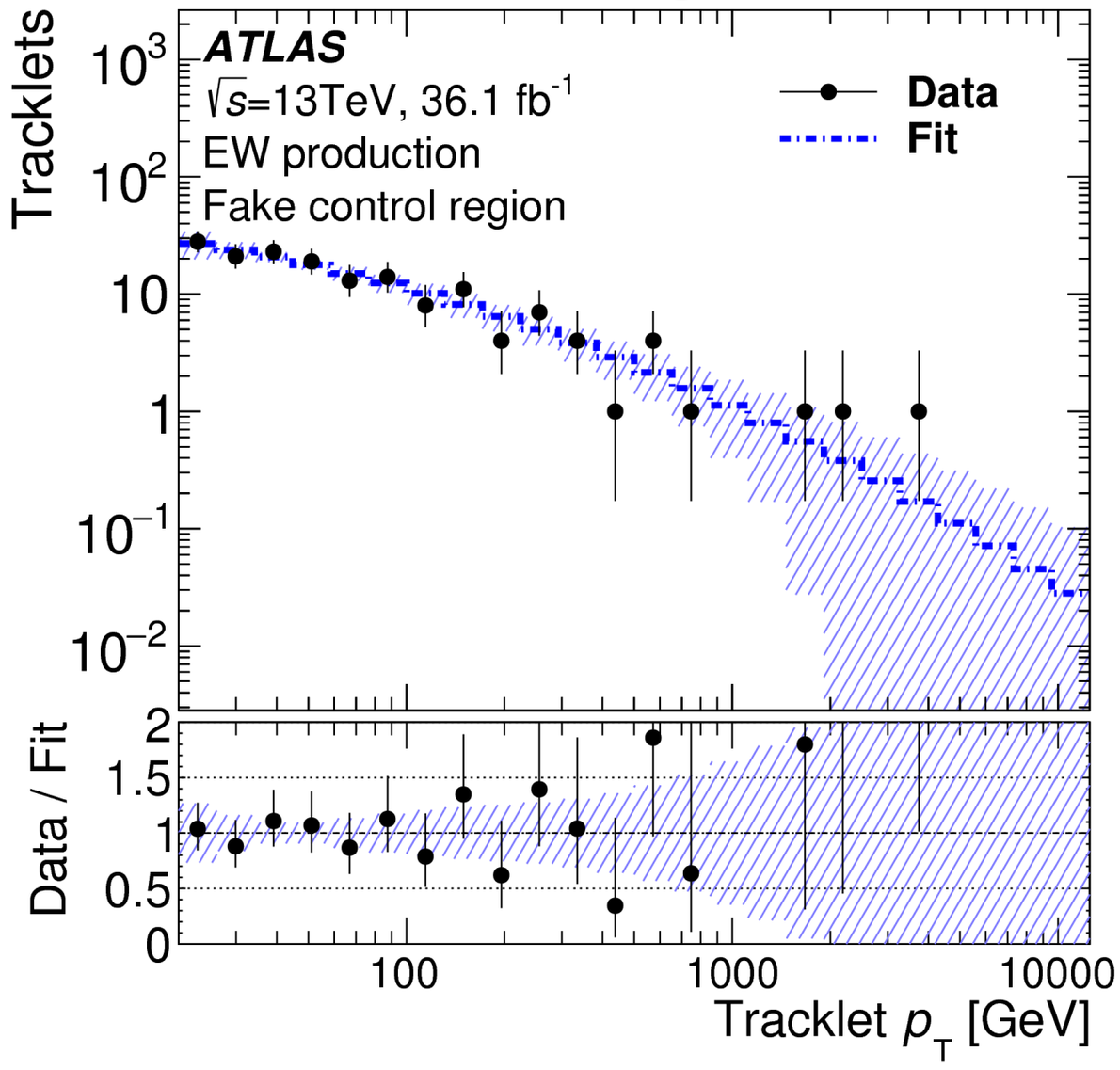


Disappearing Track

Track smearing

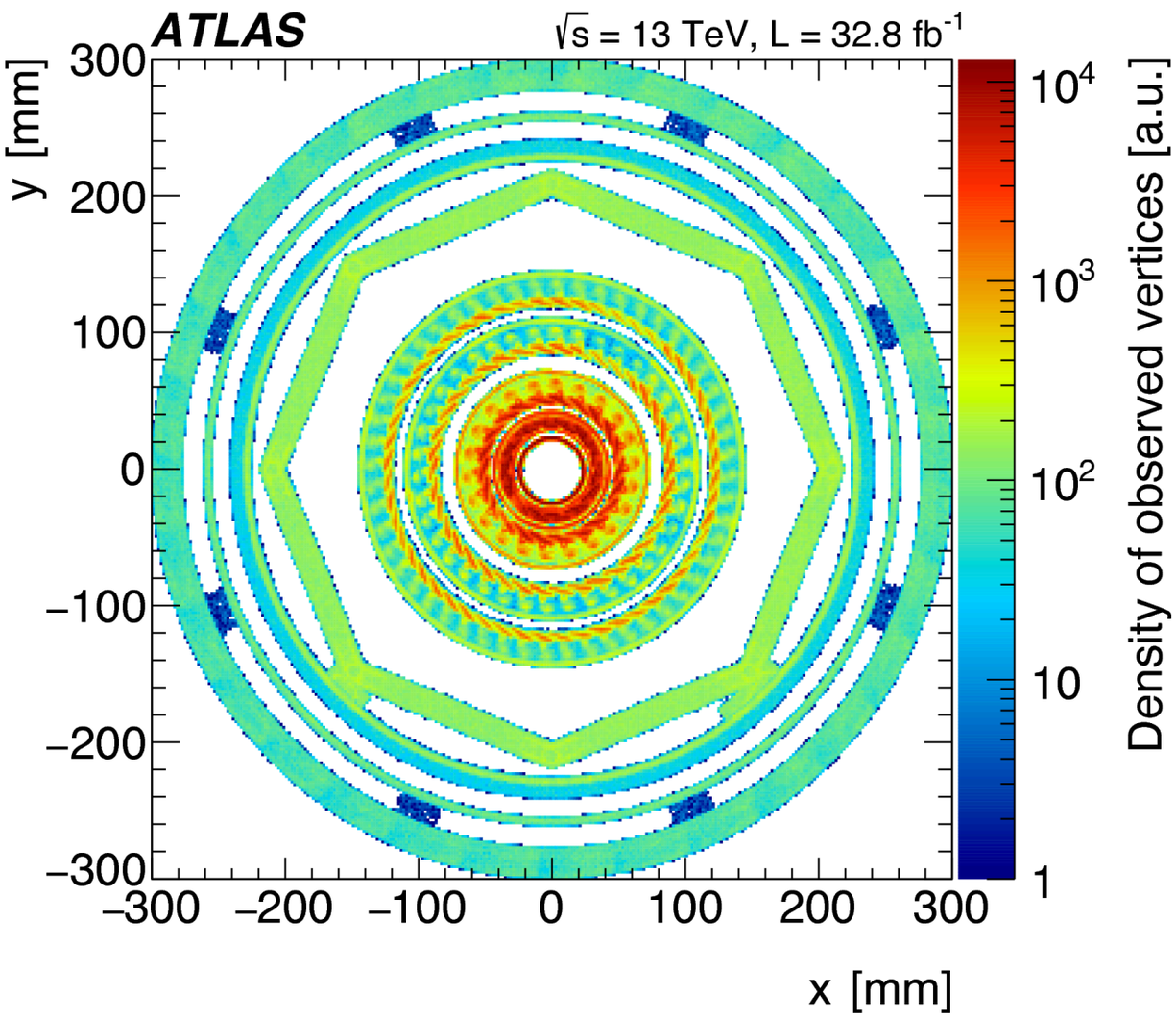


Fake background

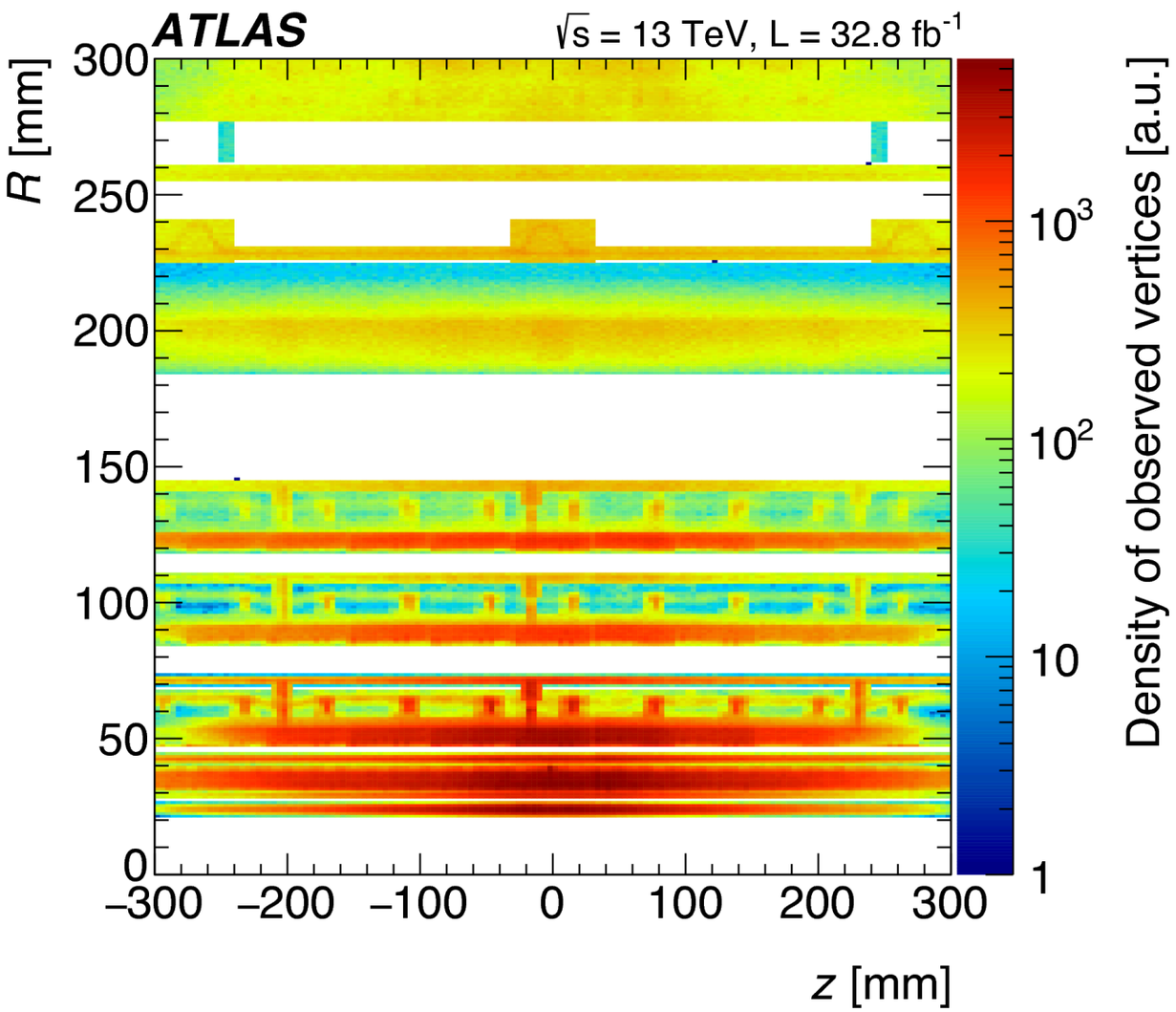


Displaced vertices + MET

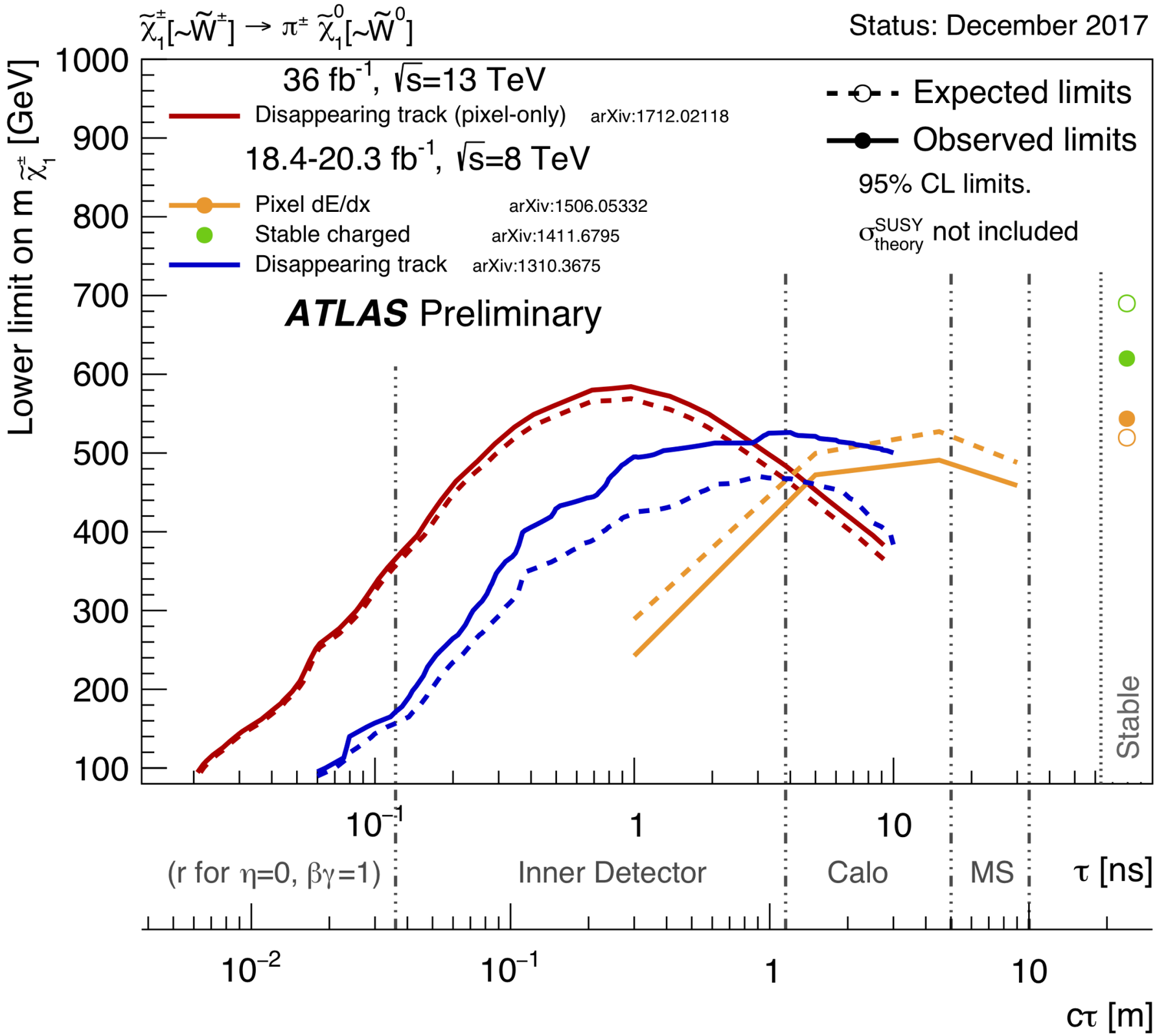
Material Veto



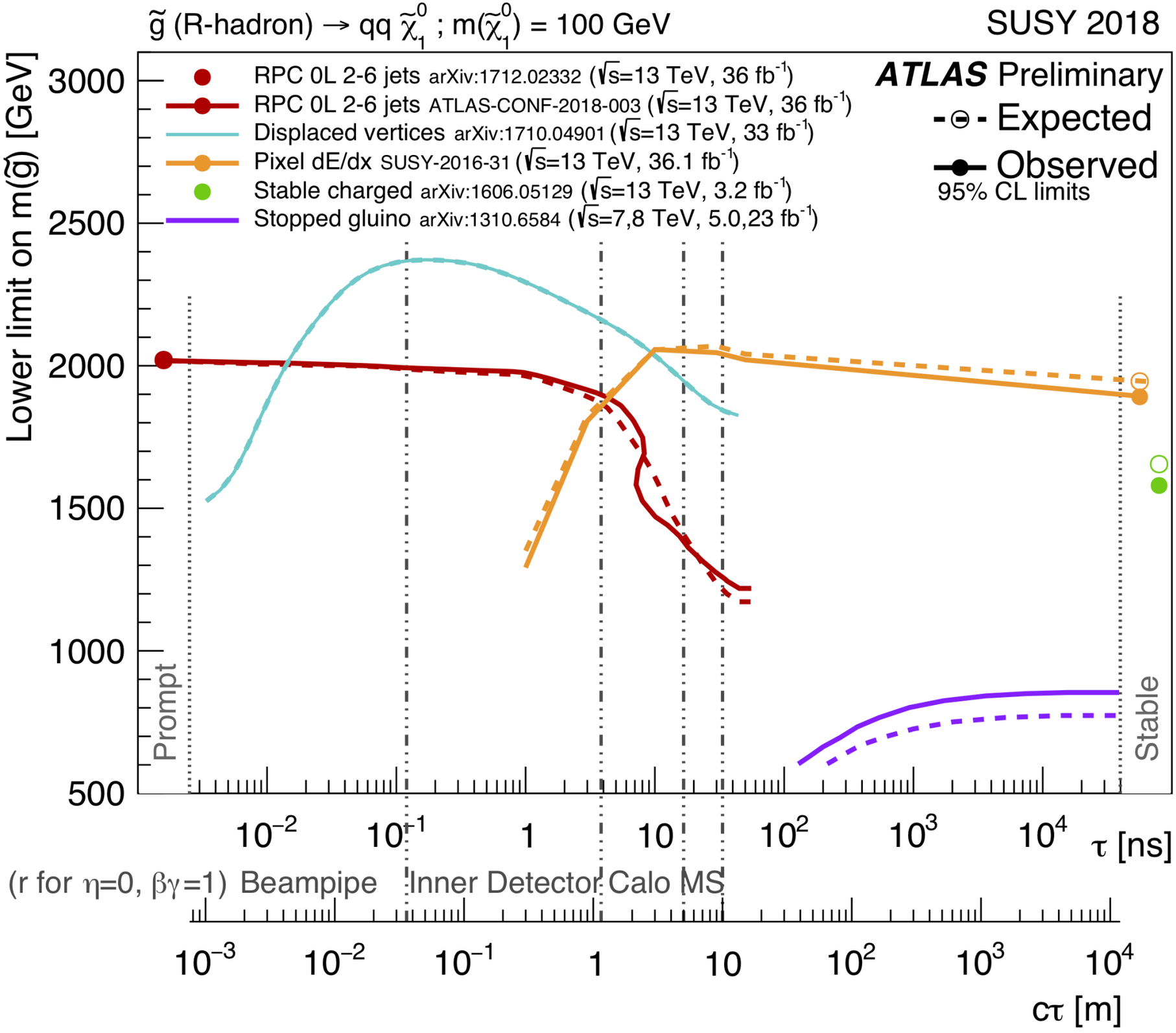
Material Veto



Summary: charginos (small mass splittings)



Summary: gluino R-hadrons



Summary: all ATLAS LLP searches