Reconstruction Techniques in SUSY Searches with Soft Objects in the ATLAS Experiment

Shion Chen

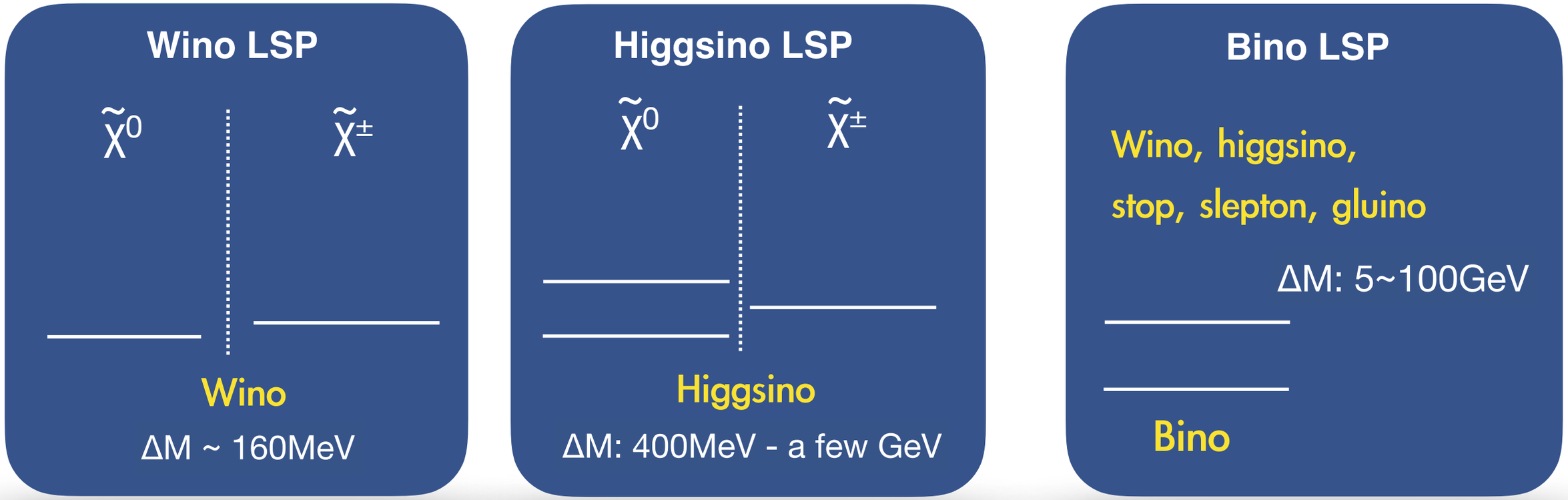
on behalf of the ATLAS collaboration

ICHEP2020 @Prague

28 Jul. - 6 Oct. 2020

The 'Compressed Regime' in SUSY

"(N)LSP" = (Next-to-) Lightest SUSY Particle



- **Compressed LSP & NLSP: generic feature of typical SUSY DM scenarios.**

  e.g. R-parity conserving neutralino LSP:

  - If wino/higgsino is LSP: Compressed wino doublet / higgsino triplet.
  - If bino is LSP: Needs NLSP close in mass to mix/co-annihilate for $\Omega h^2 \leq 0.12$.

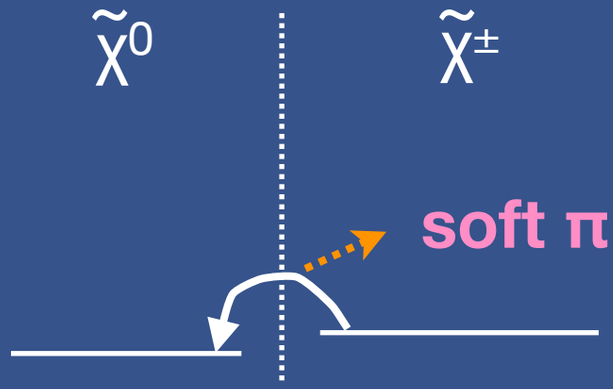
- **Direct search benefits from minimal assumptions**

  Unique probe to scenarios where everything else is heavy.

The 'Compressed Regime' in SUSY

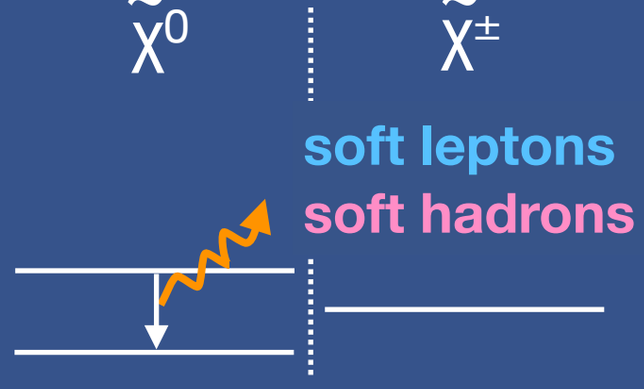
"(N)LSP" = (Next-to-) Lightest SUSY Particle

Wino LSP



ΔM ~ 160MeV

Higgsino LSP



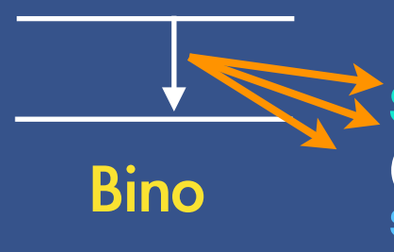
ΔM: 400MeV - a few GeV

Bino LSP

Wino, higgsino,

stop, slepton, gluino

ΔM: 5~100GeV



<u>Search strategy:</u>

- Hard ISRs + MET for triggering (mono-jet like approach)
- **Soft objects** (+ long-lived objects) for BG suppression.

Typically limited by:

- **low acceptance** of signal due to the p_T threshold (min p_T ~ Δm we can reach)
- **high fake BG** because of the 'low-p_T ness'.

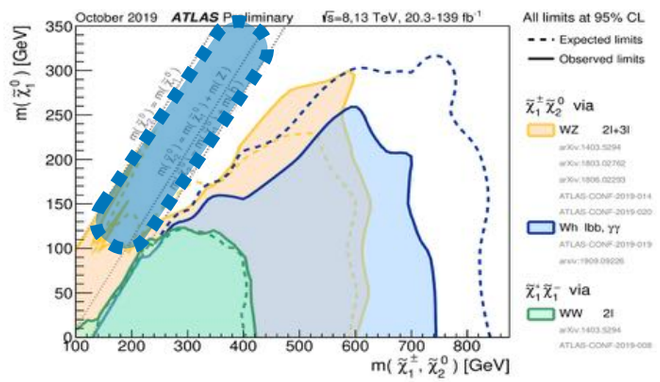
→ **Lowest possible p_T threshold & elaborated fake rejection**

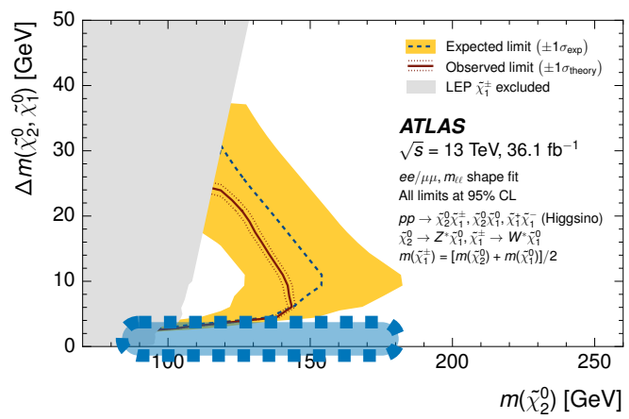
This talk covers…

- **Soft leptons** for general compressed spectra searches
- **Soft b-jets** for compressed stop & EWKino searches.
- **Soft pions** for long-lived wino/higgsino searches

Old summary plots when we haven't had the latest compressed search results… (The latest ones are here)

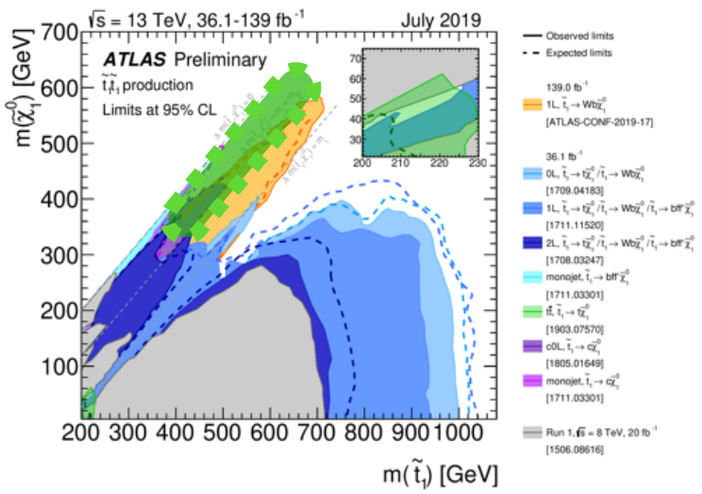
Wino→Bino
(C1N2→WZ)

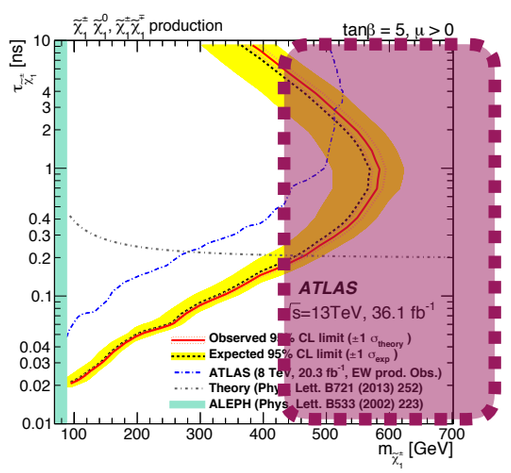




Higgsino triplet

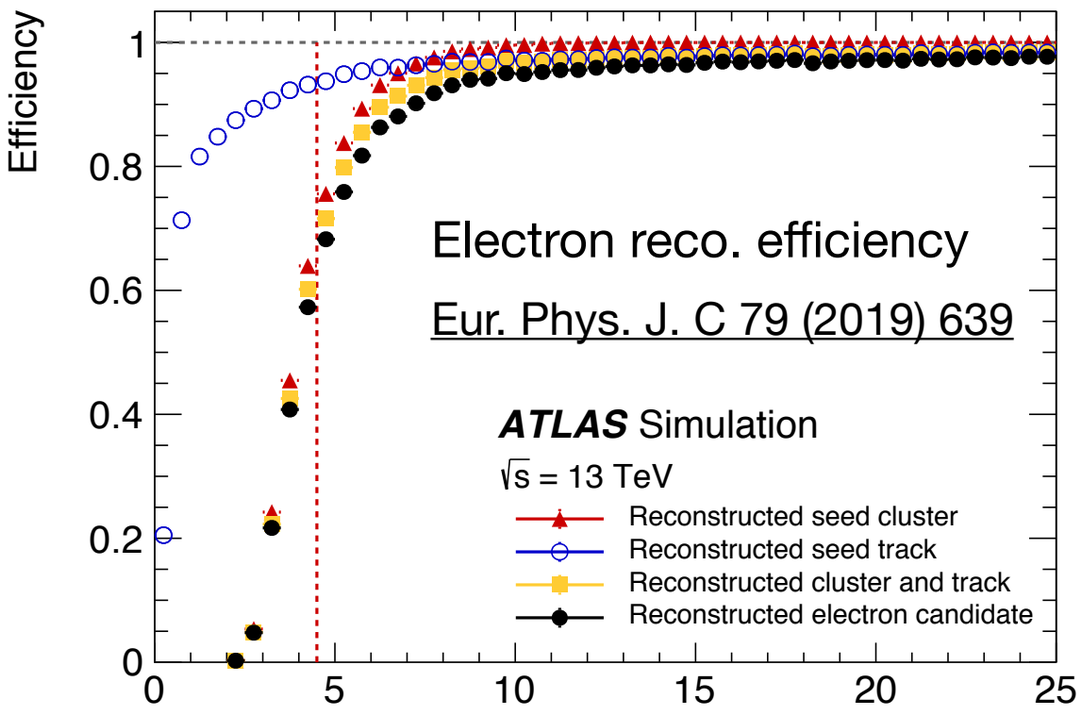
Stop→Bino
(stop→tN1)

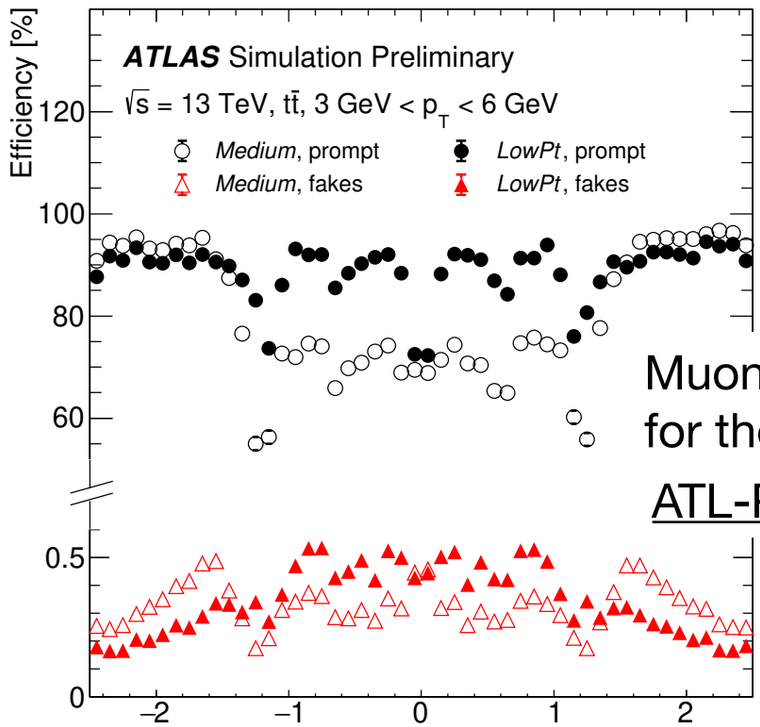




Long-lived wino
(same as the latest)

Soft lepton - Reconstruction/ID





Muon reco. & ID efficiency for the *LowPt* WP

ATL-PHYS-PUB-2020-002

Currently 4.5GeV electrons & 3GeV muons are available in ATLAS:

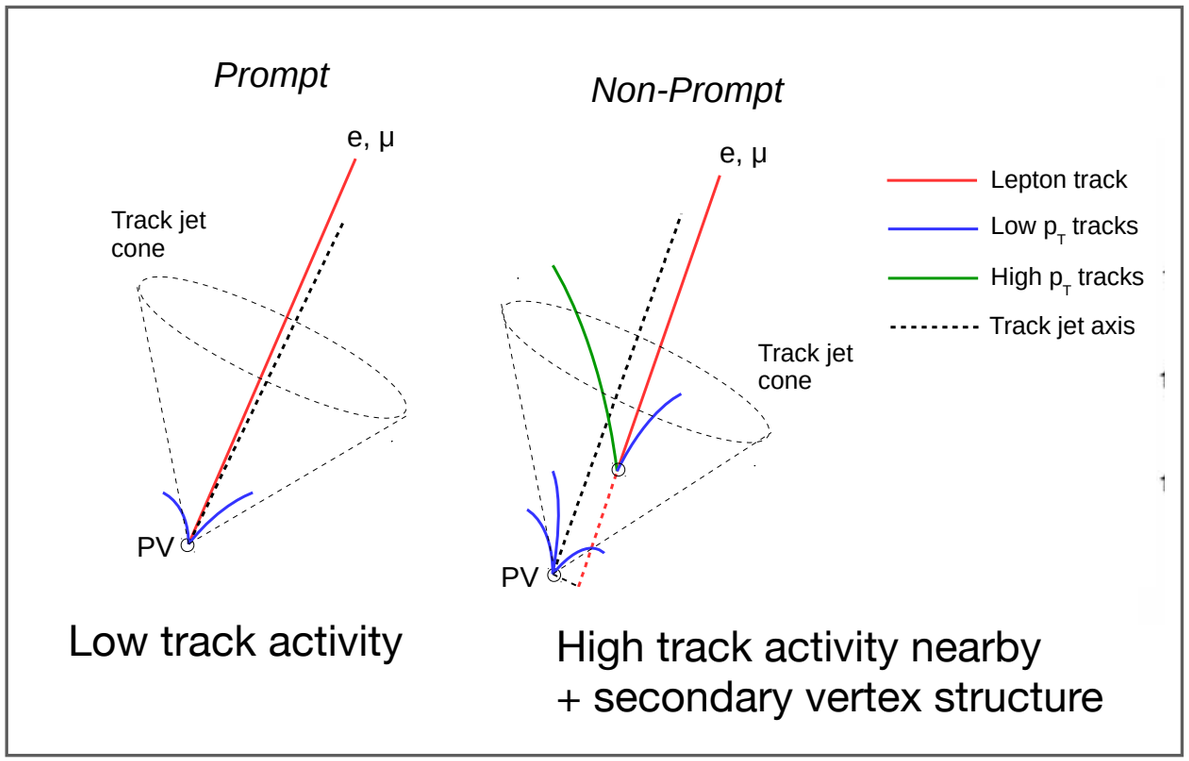
Electrons: "Super-cluster" reconstruction. 70(95)% efficient @4.5(10)GeV

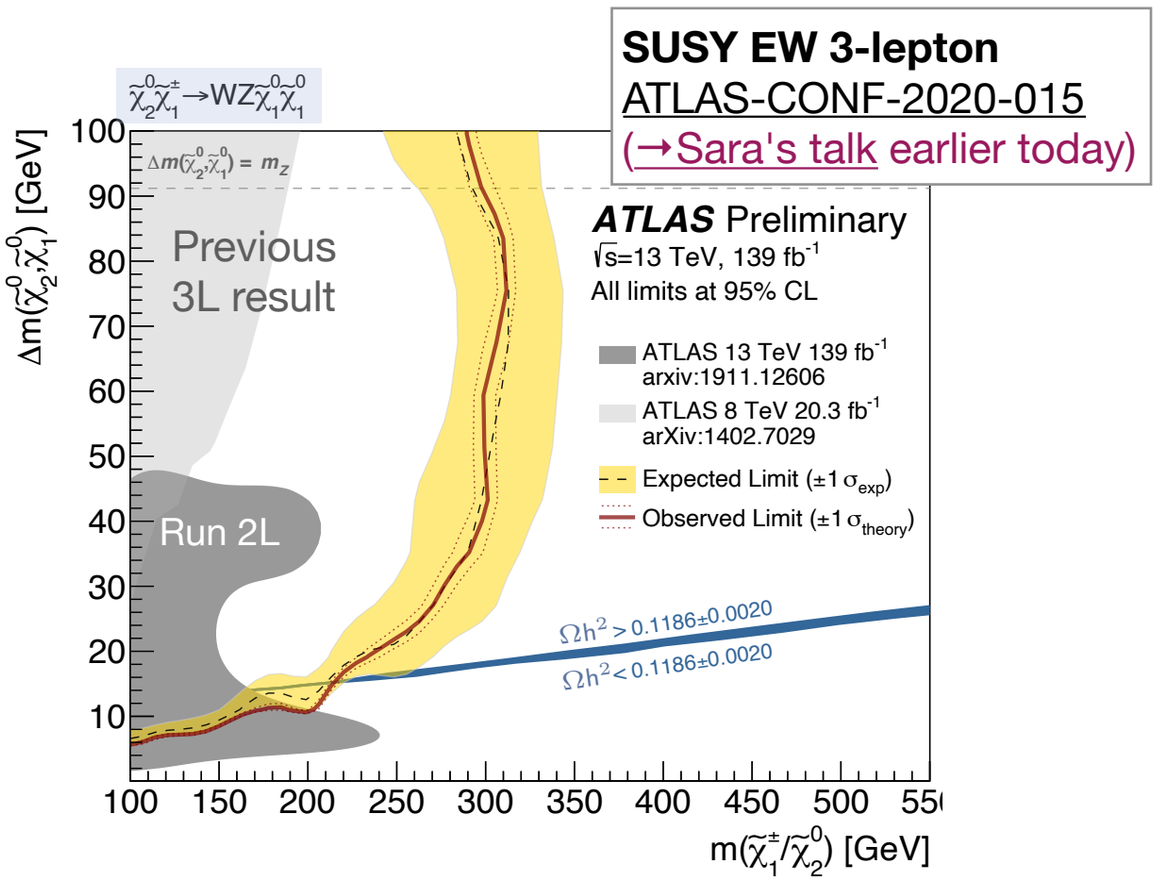
Likelihood-based ID to further reject the BG (~75% eff. @Medium WP).

Muons: Reco/ID working point for dedicated low-p_T muons.

Re-tuned selection in barrel ($|\eta|<1.37$) maintaining ~90% efficiency.

Soft lepton - "Non-prompt BDT" Isolation





- **"Isolation": make sure e/μ are separated from any jet activity.**

  Aim to further reject fakes and e/μ from b/c-hadron decays ('non-prompt leptons').

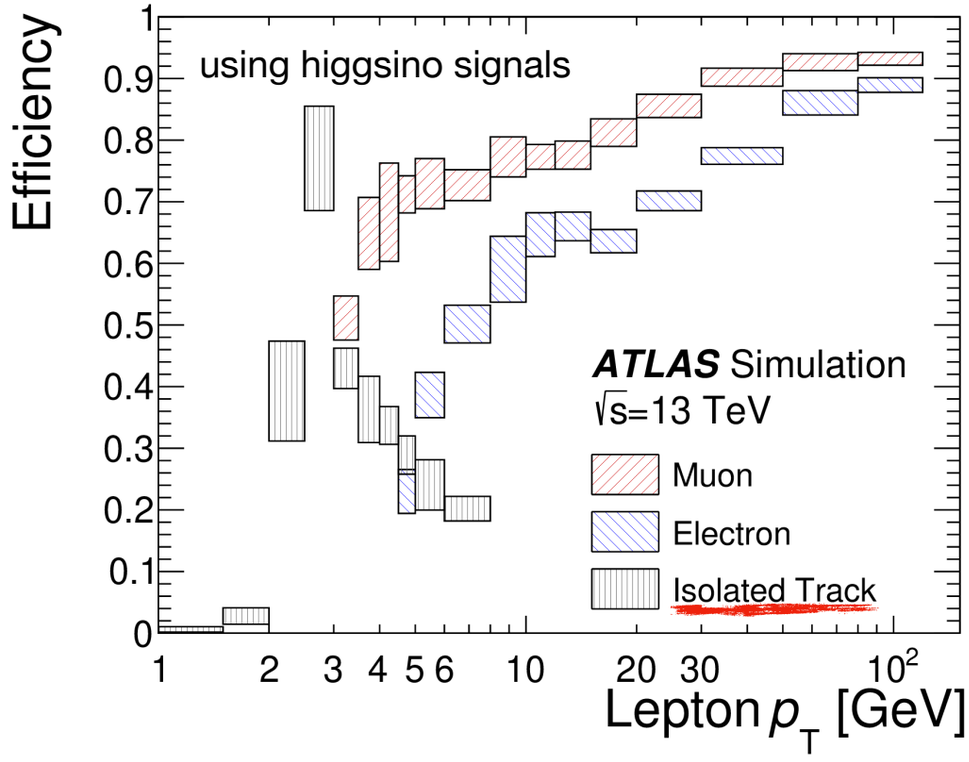
- ***Non-prompt BDT:*** a BDT-based isolation designed for the higgs analysis.
  - Use high-level features of nearby tracks (e.g. 'track jet' axis, SV structure etc.).
  - **Retuned for compressed SUSY. Significant gain in the recent 3-lepton search.**

    Fake e/μ passing the standard isolation are further reduced to 1/4 with 90% efficiency.

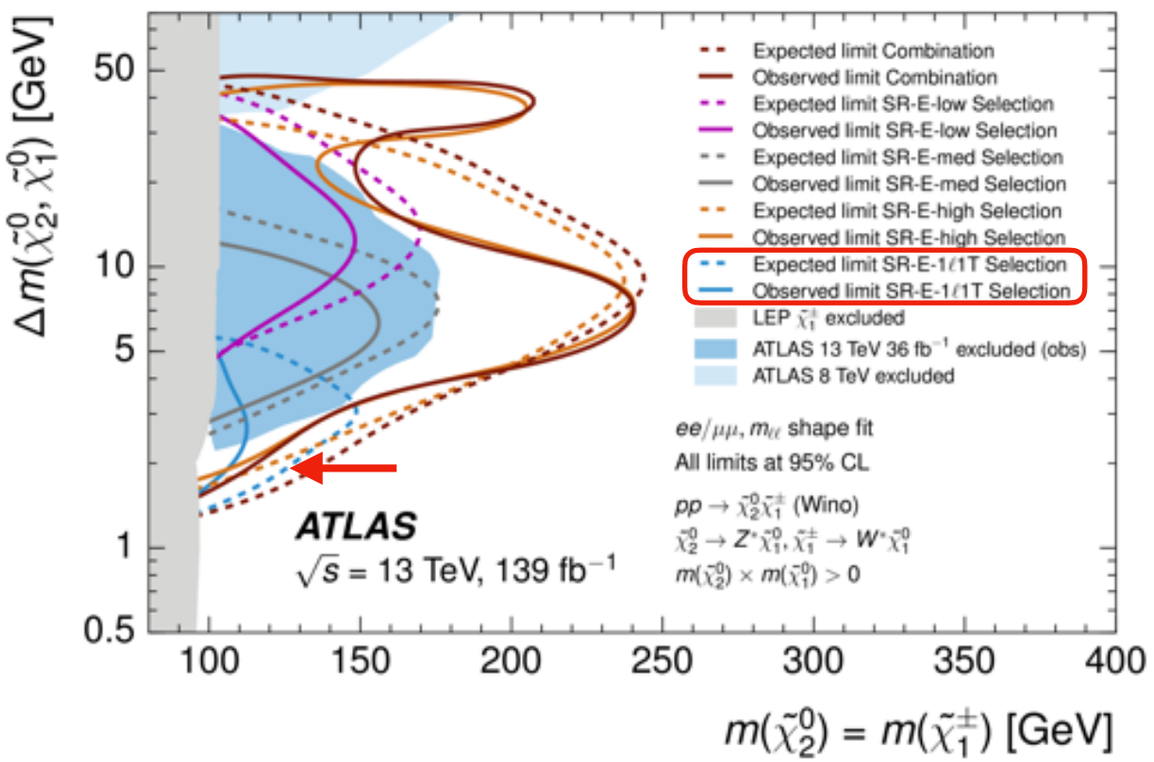
Too low-p_T? → Just use the track

EWK compressed 2L @139fb^{-1}
Phys. Rev. D 101 (2020) 052005
arXiv: 1911.12606

Combined lepton tagging eff. (reco×ID×Iso)



Exclusion on the higgsino triplet



- **Bottleneck of e/μ reconstruction below 4.5GeV/3GeV:**

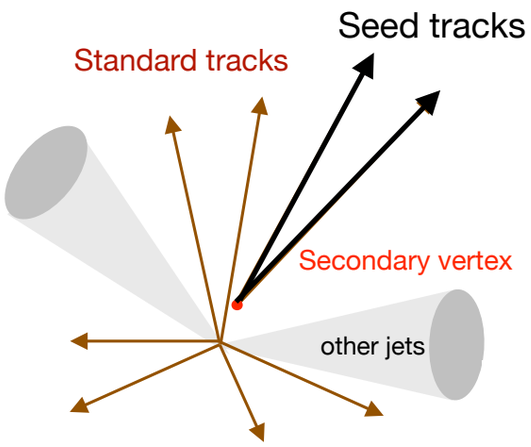
  Electron: Calo-cluster energy is too low with respect to the noise threshold.

  Muon: Don't reach the muon detector (stopped in the calorimeter).

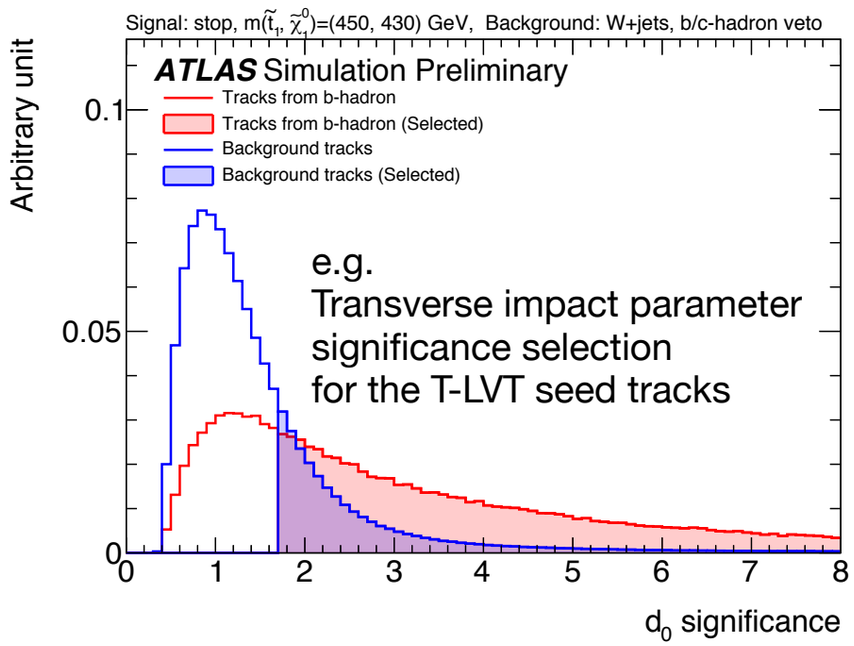
- **An attempt to tag those e/μ by just using inner-detector tracks in the higgsino search.**
  - Good efficiency down to p_T=2GeV.
  - Unique sensitivity below Δm<2GeV for higgsino triplet.

Soft-b tagging

ATLAS-CONF-2019-027

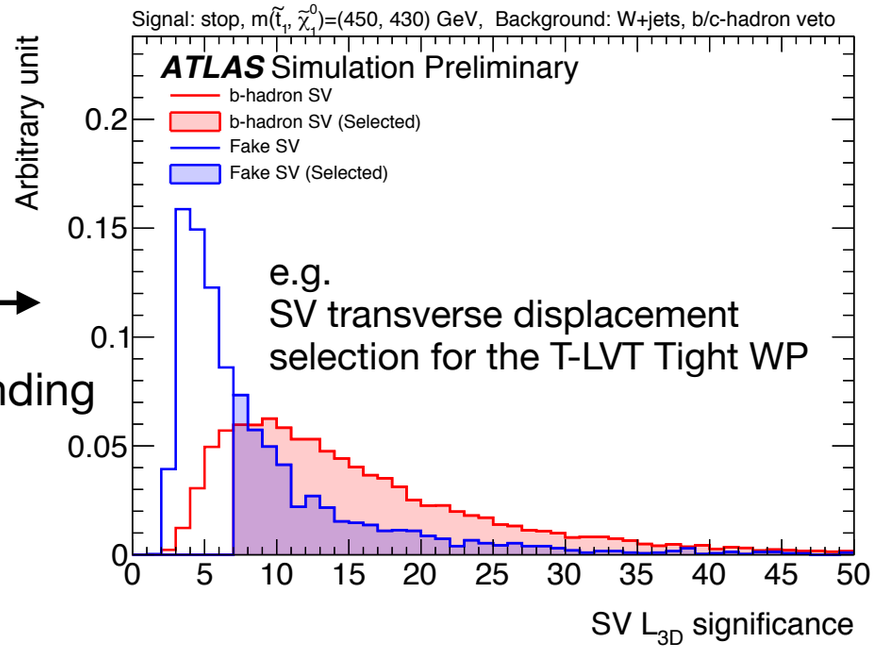


Seed track selection



SV finding

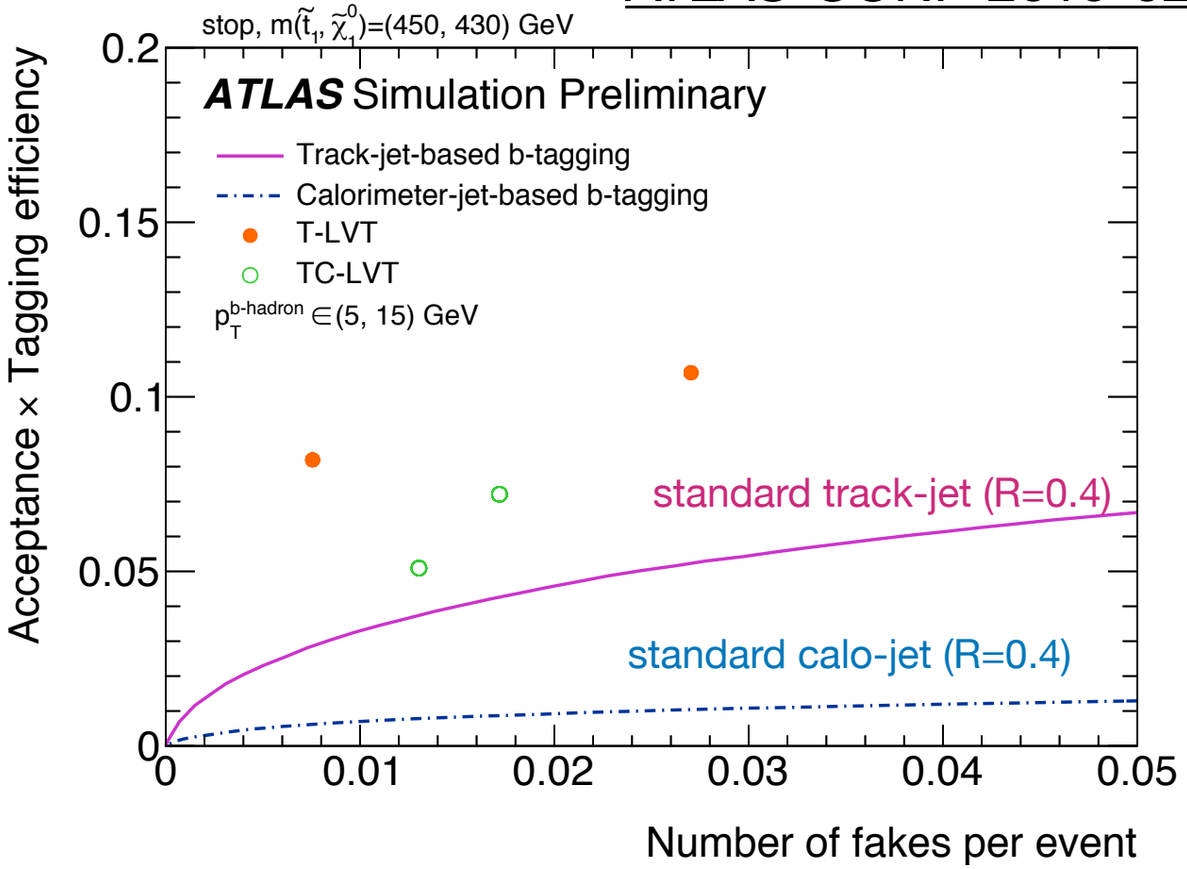
Cuts on SV properties



- **Bottleneck of low-p_T b-tagging:** **It doesn't form a 'jet' anymore**
  - e.g. 5GeV initial b-quark → ΔR(final-state particles)~1.0, while standard jet clustering is with R=0.4.
  - Also fewer final-state particles due to the soft initial quark.
- **New dedicated algorithm based only on secondary vertex (SV) finding** seeded by:
  - mildly displaced tracks isolated from jets (T-LVT), or
  - a system of collimated low-p_T tracks (TC-LVT).
- **Optimized selection after the SV formation** (e.g. mass, transverse displacement of SV)

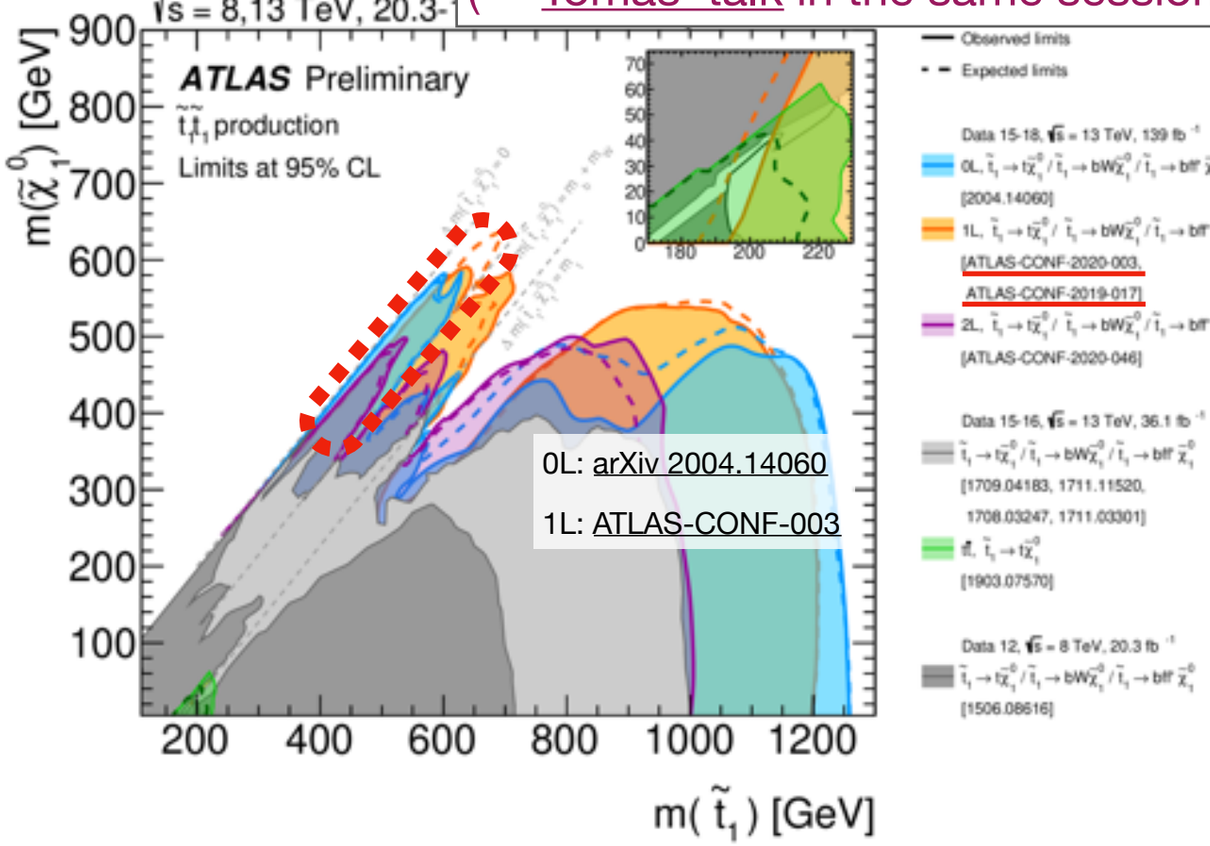
Soft-b tagging

ATLAS-CONF-2019-027



stop→t+bino limit summary

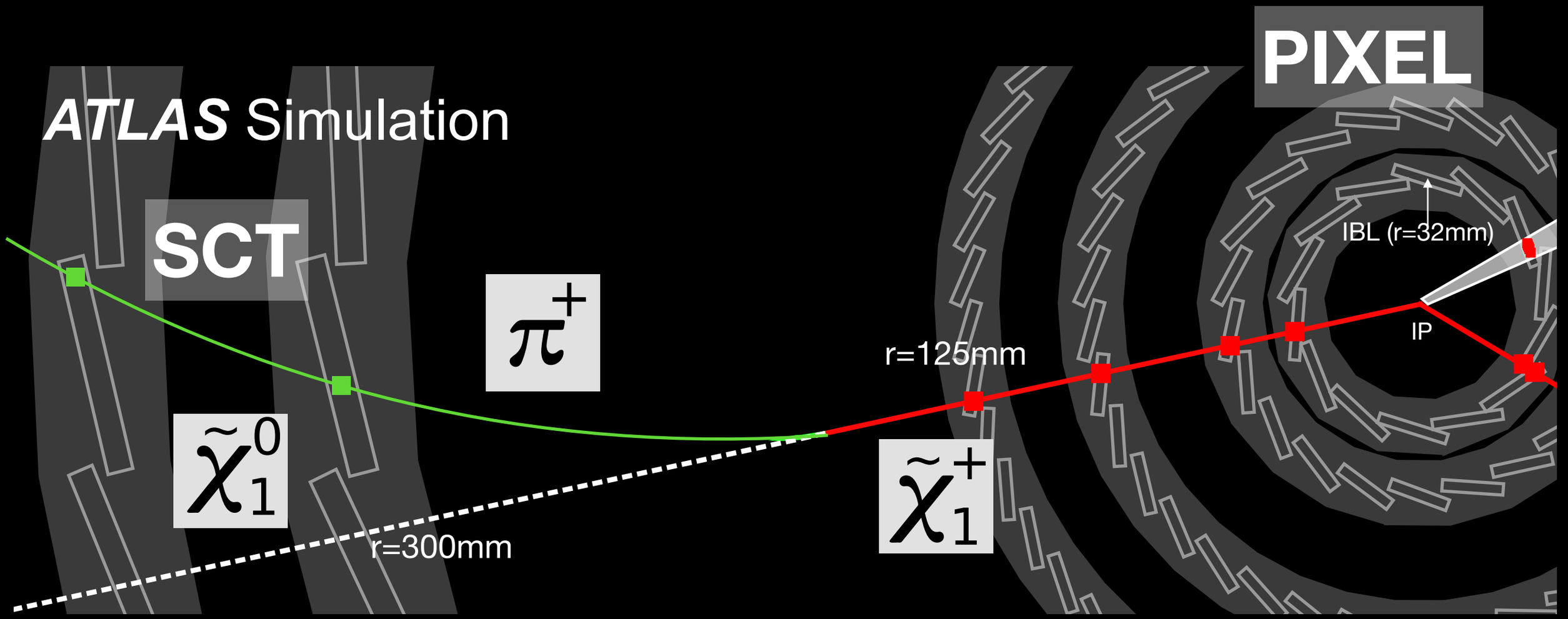
(→ Tomas' talk in the same session)



- **Significantly outperforming the jet-based** (particularly calo-jets) **b-tagging @p_T<15GeV**
  - ×2-3 improvement in efficiency at the same rejection.
- Good signal modeling by MC confirmed with di-leptonic ttbar data.
- **Drastically improved the sensitivity to the compressed stop NLSP-bino LSP scenario.**

  Track-jet/T-LVT b-tagging (p_T>5GeV) is used in recent 0-lepton /1-lepton results.

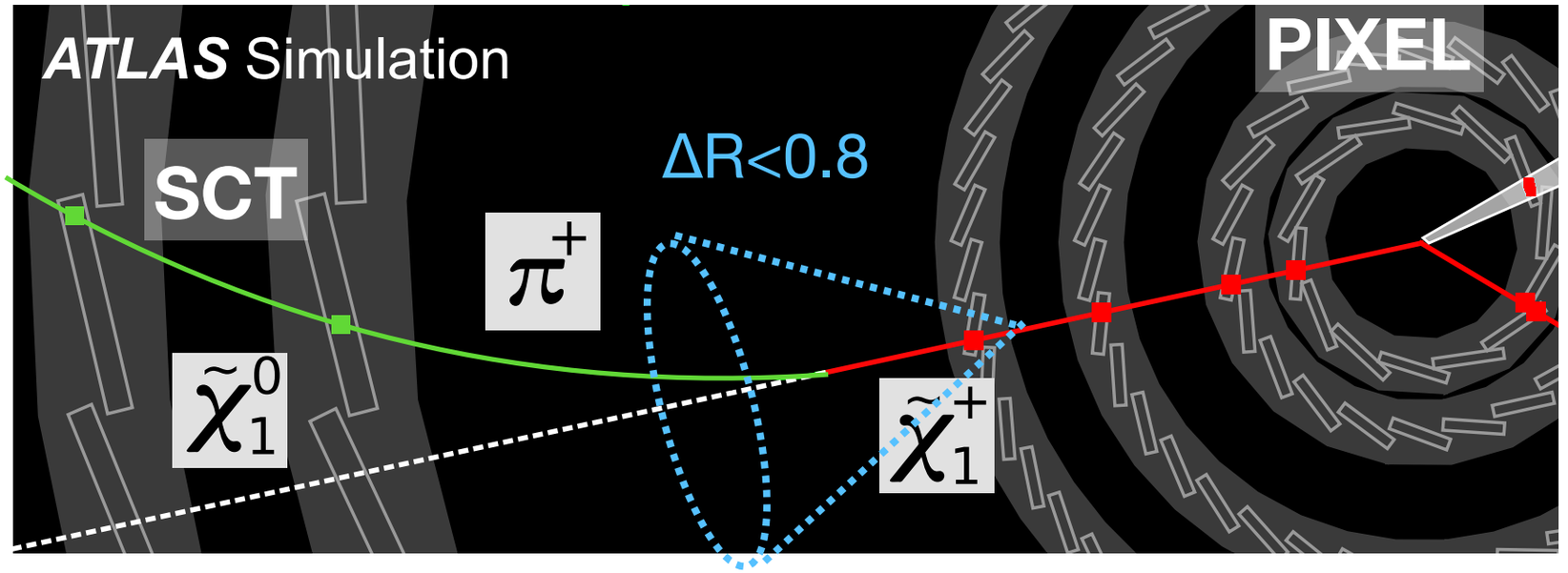
Soft-pion tagging for the disappearing track search



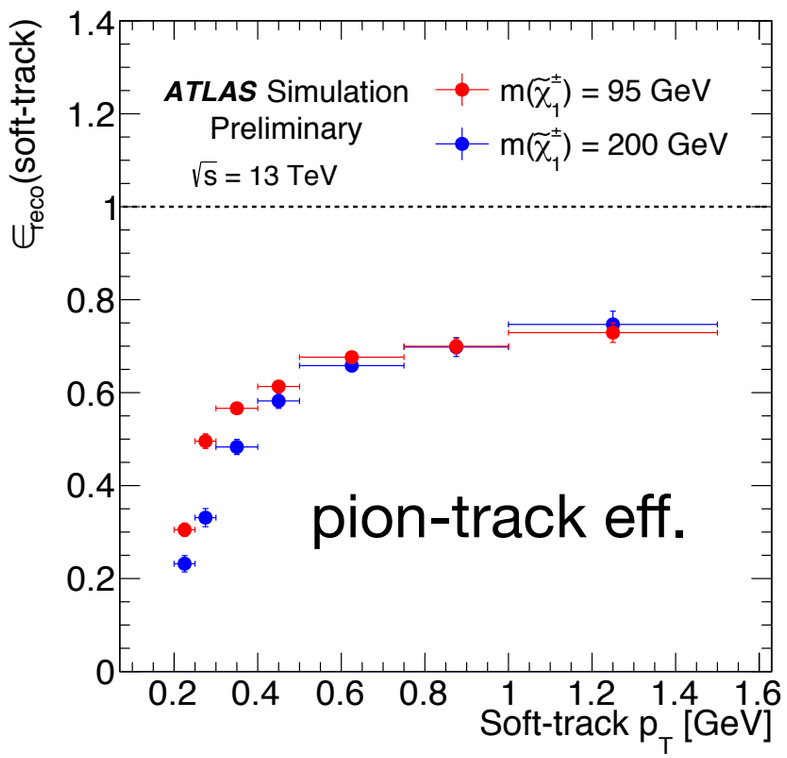
- **Pure wino/higgsino has long enough life-time to create a "disappearing track" .**
  Mass splitting of 160 (350) MeV leads to lifetime of $c\tau$~6 (1) cm for wino (higgsino).
- **Short PIXEL-only tracks ("tracklets") to tag the chargino.** (→**Monica** on 29th Jul)
- **New R&D targets also the associated soft-pion (p_T~O(100 MeV)).**

Soft-pion - Tracking

ATL-PHYS-PUB-2019-011



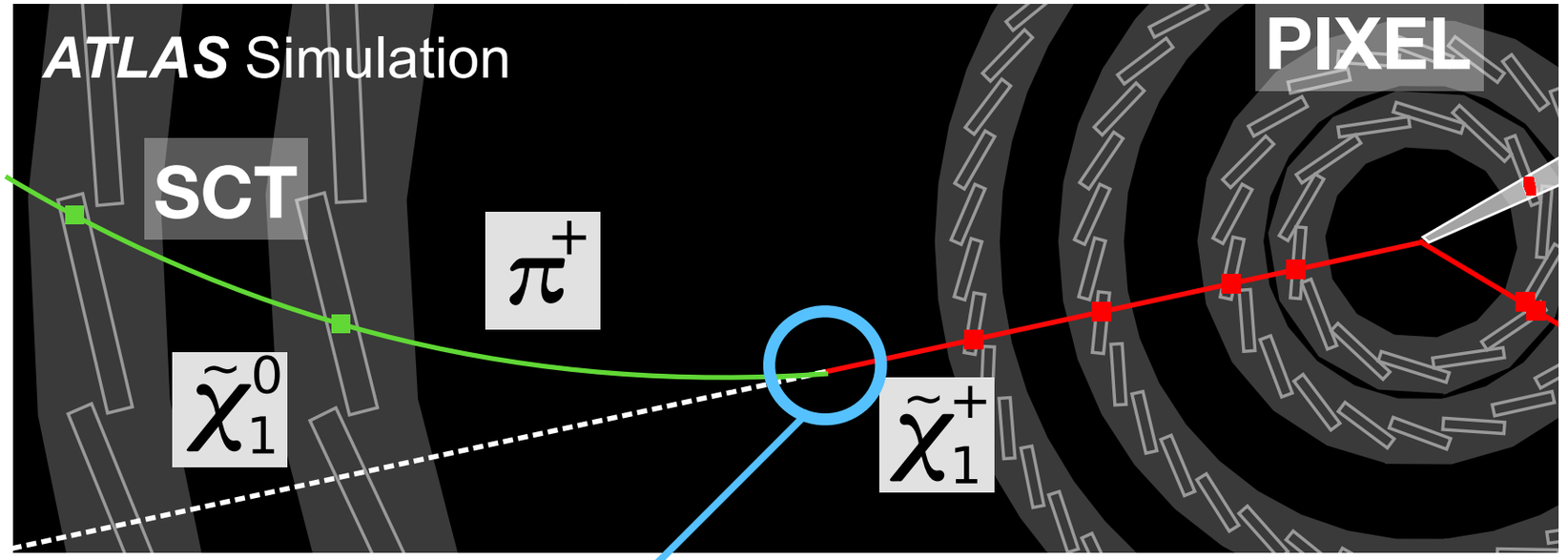
Pion reconstruction



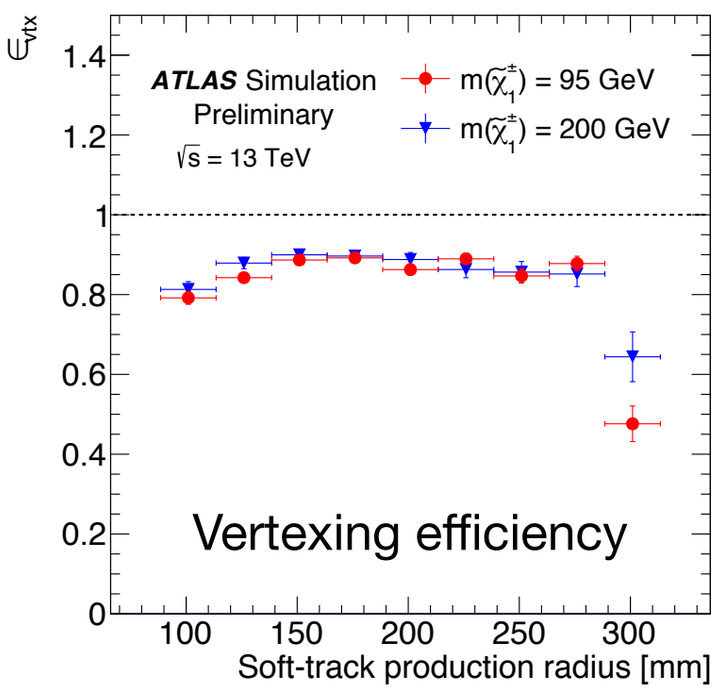
- **Tracking with only SCT hits aligned with isolated tracklets**
  - Take the outermost hit of the tracklet as the new 'origin'.
  - RoI = cone of ΔR<0.8 wrt the new origin.
  - Track seeding/finding proceeds as with the standard tracking.
- **>70% efficiency @>600MeV**
- **Reconstruction works down to 200MeV.**

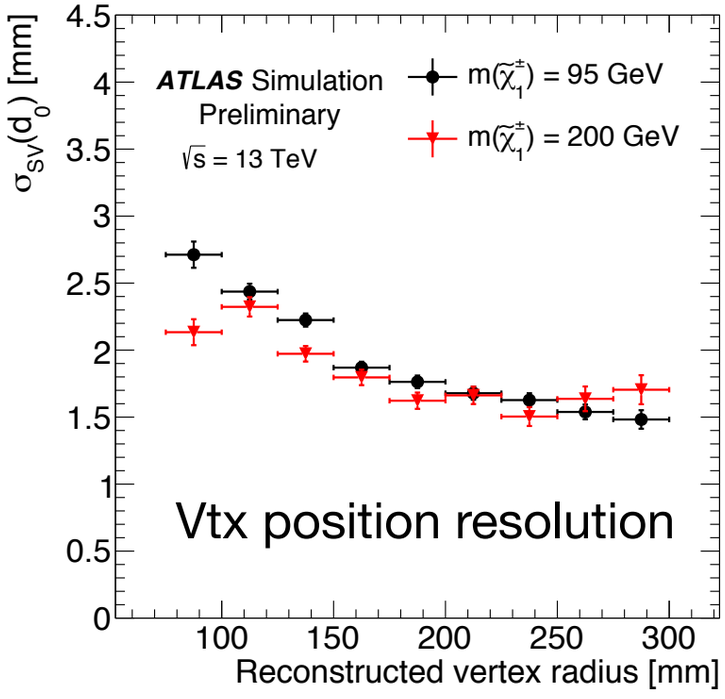
Soft-pion - Vertexing to the seed tracklet

ATL-PHYS-PUB-2019-011



Pion-tracklet vertex reconstruction





- **Reconstructed pion tracks can be vertexed with the parent tracklet with eff>90%.**
- Vertex position resolution is good enough to distinguished against the primary vertex.
- **Still many BG tracks at this point.**
  - For a chargino tracklet it finds O(10) pion tracks associated by the SVs.
  - Rejection algorithm being studied.

Summary

- **Soft object reconstruction is key to the compressed spectra searches**
  - Lowest possible p_T threshold & efficient fake rejection.

- **Recent achievements (targeted searches):**
  - **Lepton tagging** down to **3GeV** (EWKinos, stop etc.)
  - **Track-based soft e/μ tagging** down to **2GeV** (higgsino)
  - **Soft-b tagging** down to **5GeV** (stop→EWKinos)
  - Tracklet-seeded **soft pion tagging** down to **200MeV** (pure wino/higgsino)

- **Analyses with the new techniques applied are starting to arrive.**
  - Stay tuned for the up-coming results!

References

Soft-lepton

- Latest electron reconstruction in ATLAS: Eur. Phys. J. C 79 (2019) 639
- Low-p_T muon reconstruction & ID: ATL-PHYS-PUB-2020-002
- SUSY EWK 3-lepton @139 fb^{-1}: ATLAS-CONF-2020-015
  (using 'non-prompt BDT')
- SUSY EWK compressed @139 fb^{-1}: Phys. Rev. D 101 (2020) 052005
  (using soft isolated tracks)

Soft-b

- Soft b-tagging (track jets, T-LVT, TC-LVT): ATLAS-CONF-2019-027
- Stop tt+MET 0-lepton @139fb^{-1} (using soft track jets): arXiv:2004.14060
- Stop tt+MET 1-lepton @139fb^{-1} (using T-LVT): ATLAS-CONF-2020-003

Soft-pion

- Tracklet reconstruction and soft pion tagging: ATL-PHYS-PUB-2019-011

General

- ATLAS SUSY summary plots: 28 Jul 2020 ver

BACKUP

LHC-ATLAS Experiment

Mont. Blanc

Geneva city

ATLAS

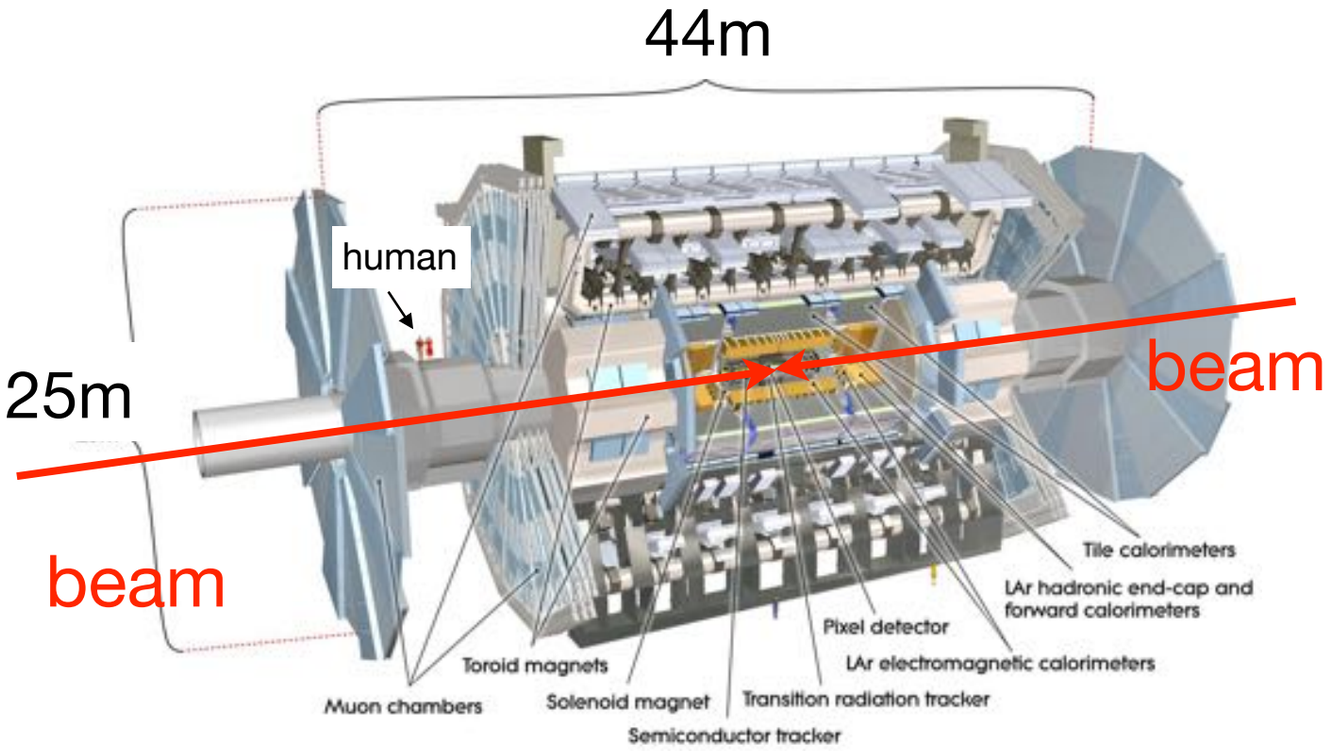
LHC (27km)

Run2 (2015-2018)

Center-of-mass energy: 13TeV

Peak lumi: 2.0×10^{34} $cm^{2}s^{-1}$

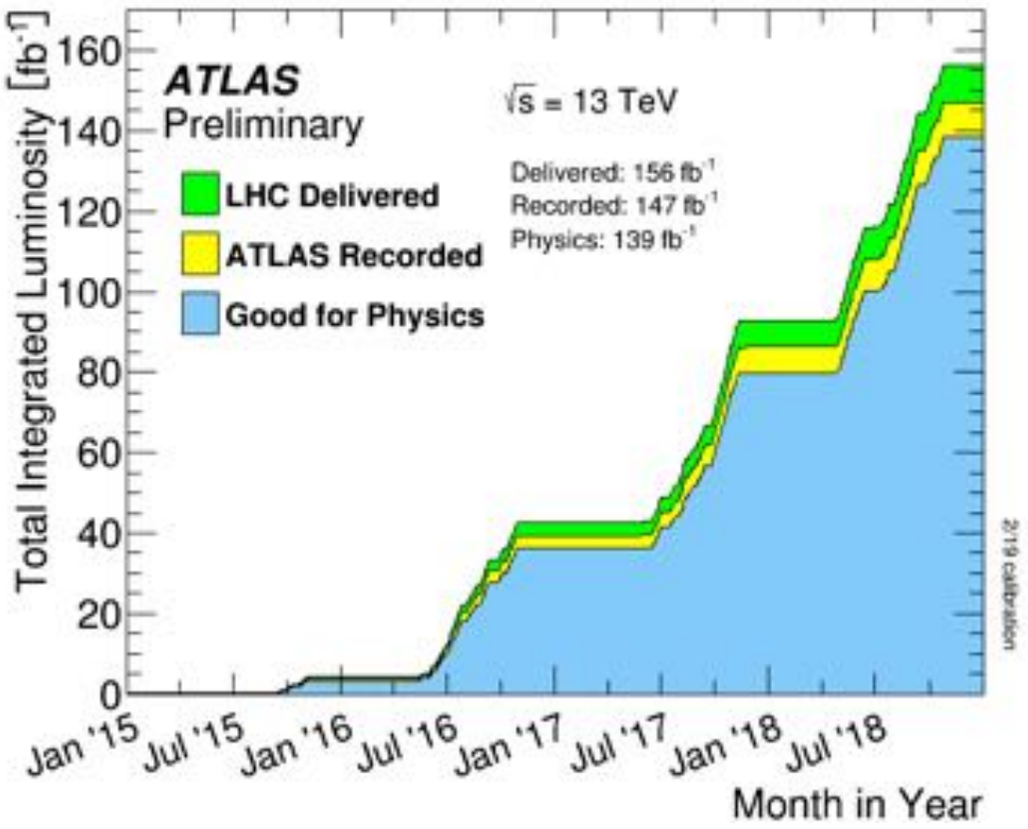
ATLAS Detector



How it looks like inside?

See google map street view!

"ATLAS Experiment, Route de Meyrin, Meyrin, Switzerland"



innermost→outermost

- **Inner detector for tracking / calorimeters (EM/had) / μ-spectrometer.**
- Bunch-crossing every 25ns w/ ~10^{11} protons per bunch.
- Pile-up: 20-60
- **140fb^{-1} data good for physics by whole Run2 (>95% of recorded data).**

ATLAS Inner Detector

Transition radiation tracker (TRT)

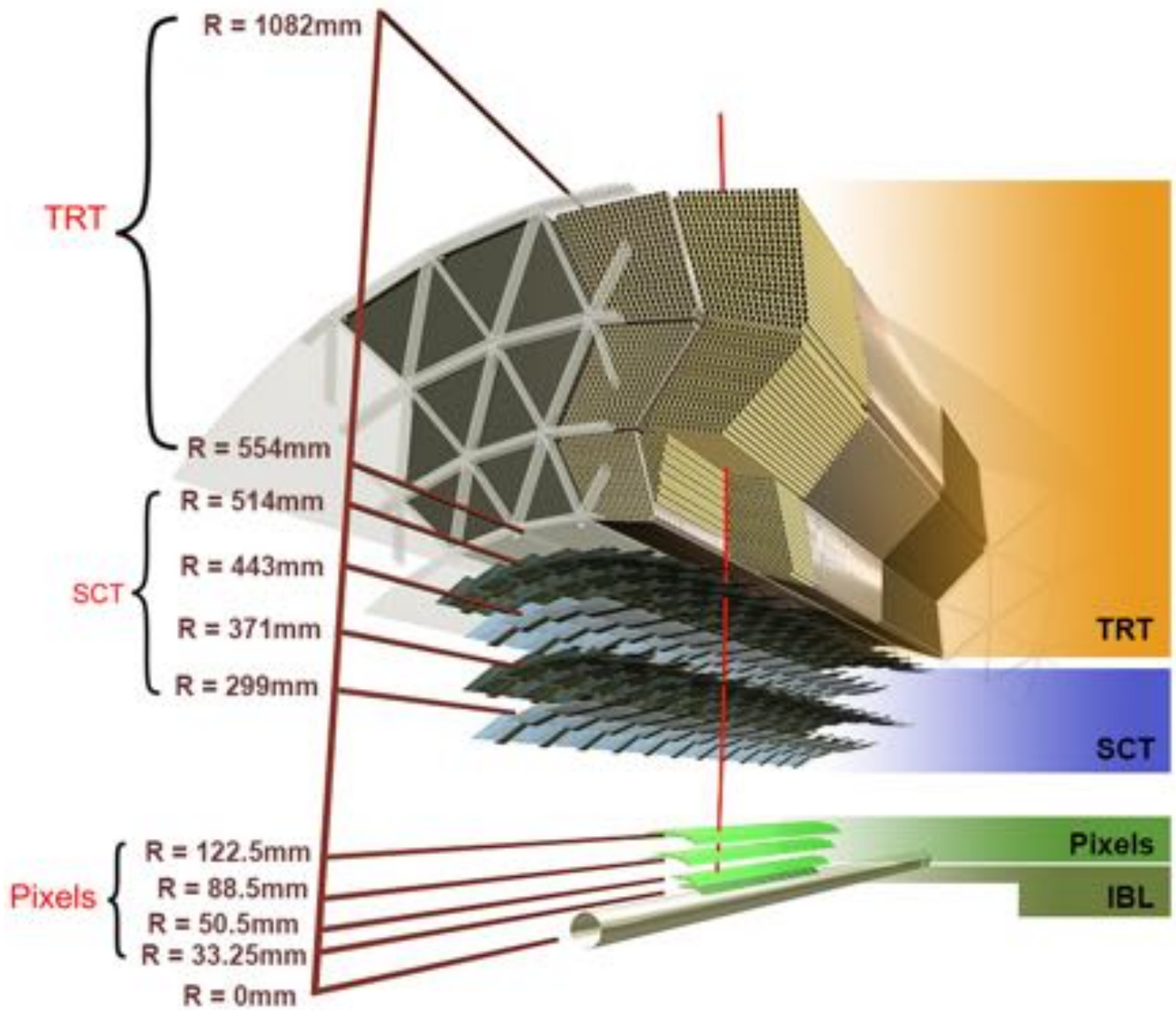
- Continuous tracker (#hit=32).
  Drift tubes filled with Xe-Ar mix.
- e-ID using transition radiation

Scilicon tracker (SCT)

- Silicon strip sensor (6-9 layers)
- Less hit position resolution
  & better hit statistics

Pixel Detector (PIX)

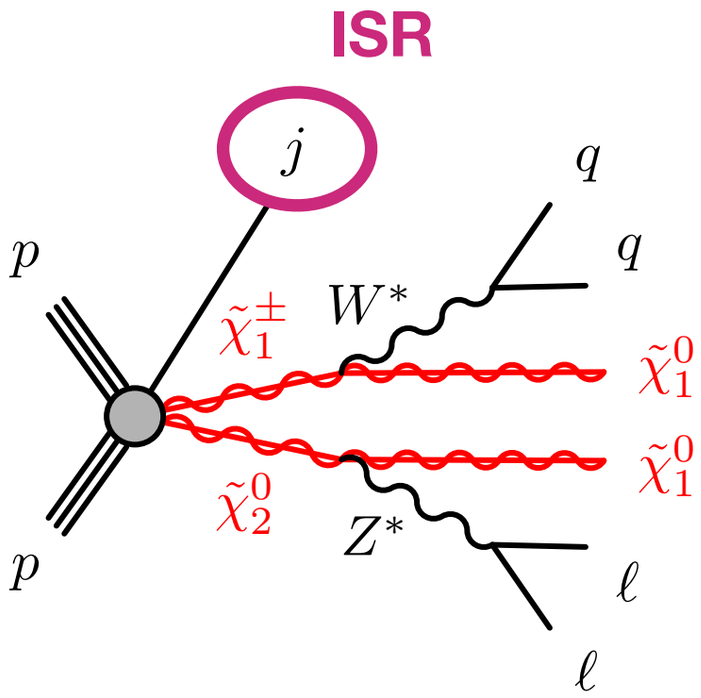
- Silicon pixel sensor (3-4 layers)
- Optimized for hit position resolution



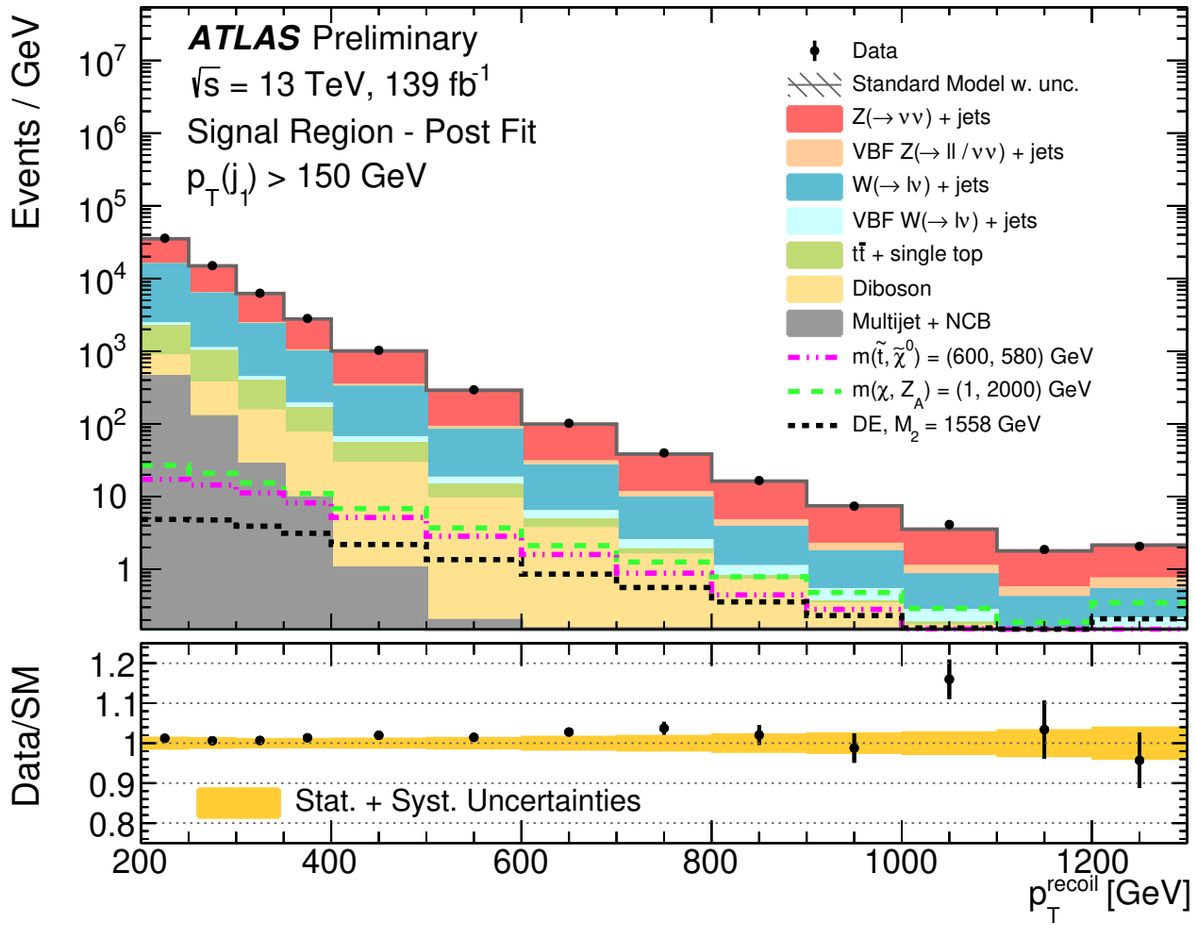
Challenges of soft objects tagging

- **High background:** "Fake" objects blow up in low-pT.
  - Need harsh discrimination to get reasonable S/N.
  - Need to keep all those fakes in data → tough file size management.
  - End up in large uncertainty in the eff measurement → large systematics in analysis.
- **Less handles to reject fakes:** e.g.
  - Less number of hits (muons)
  - Lower particle multiplicity (b-jets) etc.
- **Technical challenges**
  - Data
  - Too many particles tagged → blow up the data size

The 'Compressed Regime' in SUSY



A SR in the mono-jet search See also Ben's talk on 28th



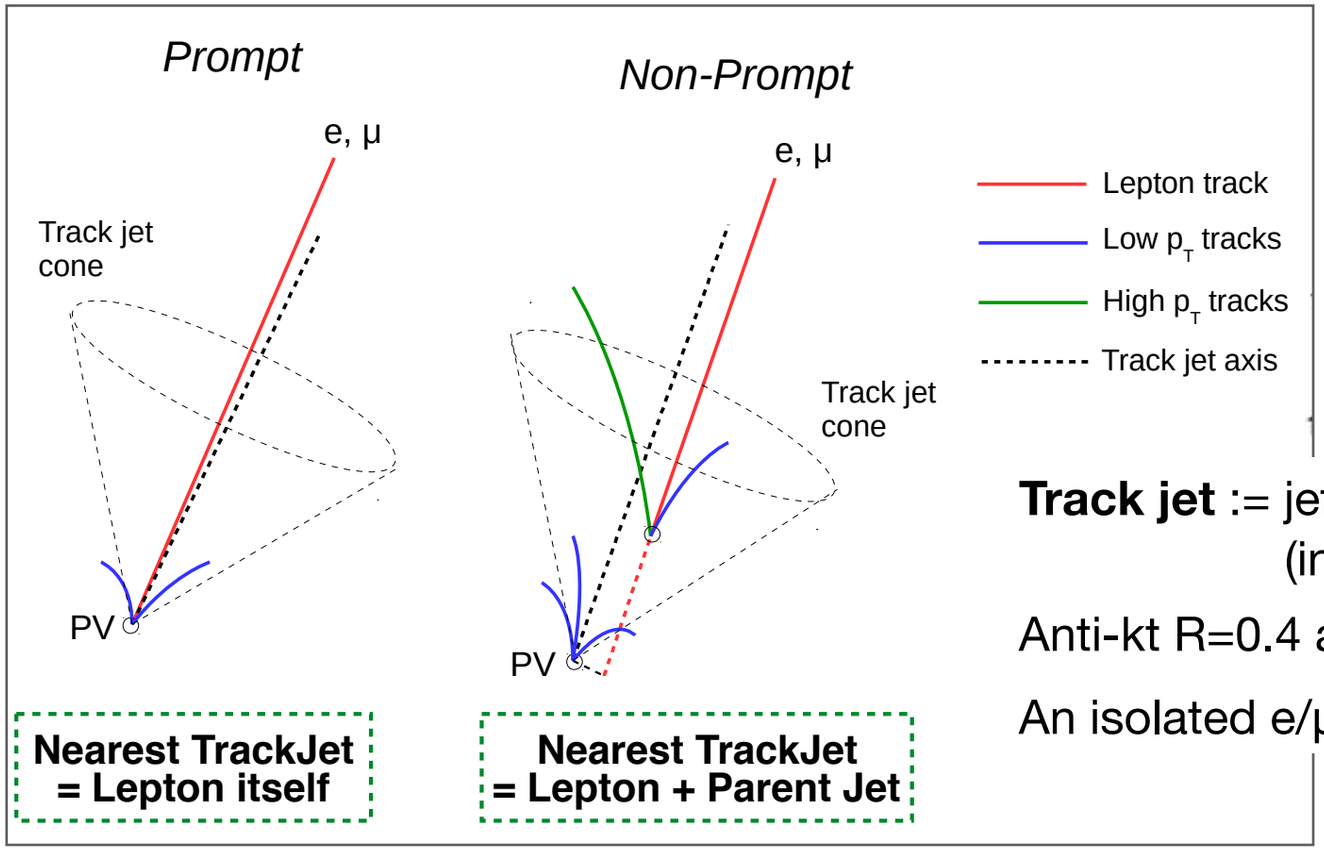
Search strategy:

- Hard ISRs + MET for triggering (mono-jet like approach)

BG is too high: O(10k),

while our SUSY signal in question has O(10-100) events.

"Non-prompt BDT"



Track jet := jet clustered using tracks as input
(instead calo-clusters for the the standard jets)

Anti-kt R=0.4 algorithm is used.

An isolated e/μ can be clustered as a track jet as well.

Input for the BDT (8 variables):

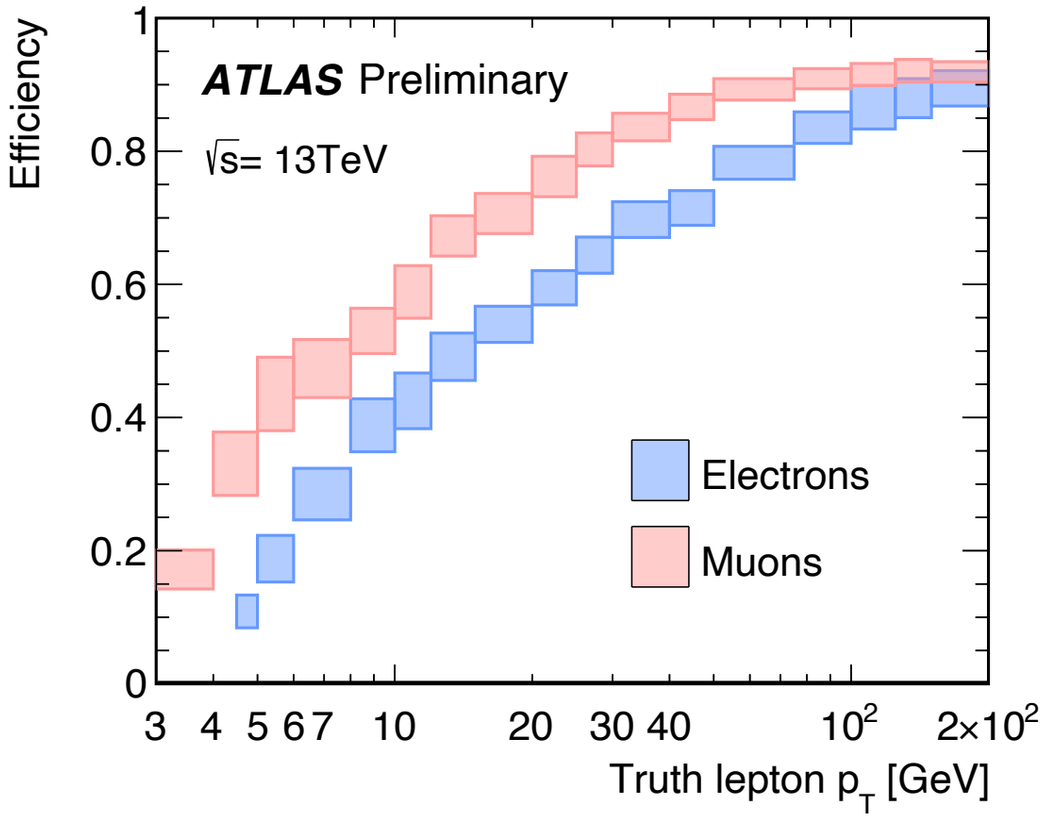
- #track in the track jet.
- Two b-tagging scores of the track jet.
- $p_T(\ell)/p_T(j_{trk})$, $\Delta R(\ell, j_{trk})$, $p_\perp(\ell$ w.r.t. $j_{trk})$.
- Scalar sum of calo-cluster E_T (or track p_T) within the cone R=0.2 (0.3) around the lepton.

Training:

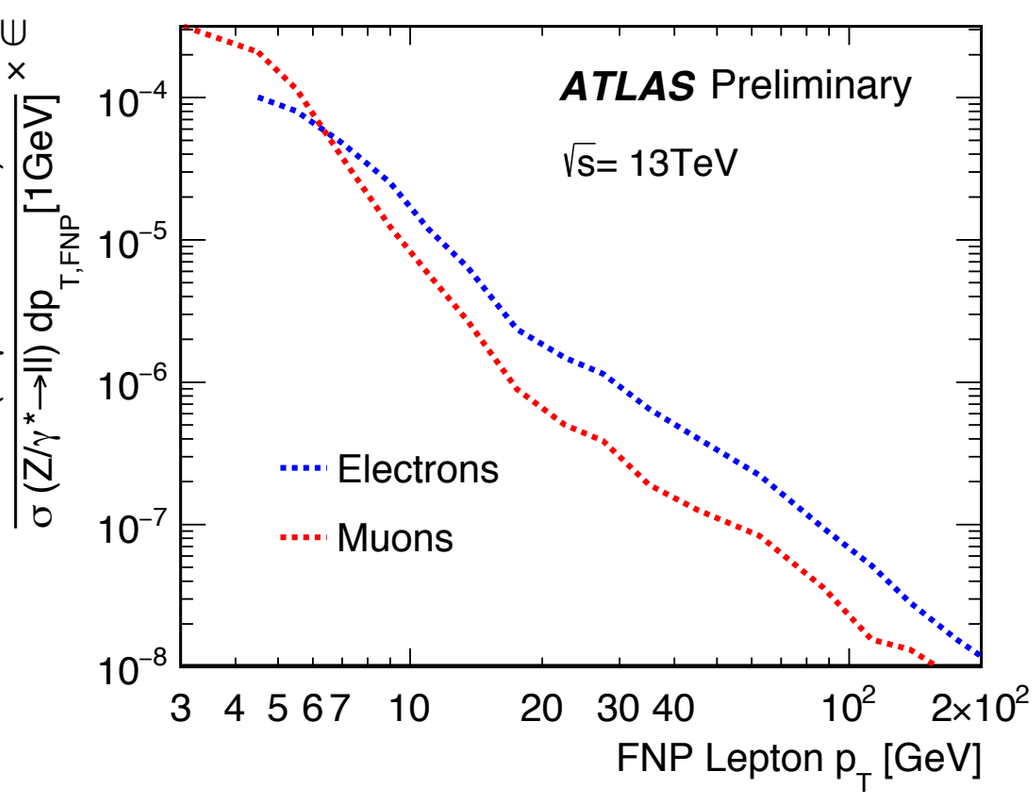
- Using prompt/non-prompt leptons samples with $p_T(\ell)$>10 GeV in ttbar MC.
- Applicable down to 4.5/3 GeV

Lepton efficiency in SUSY EWK 3-lepton analysis

Combined lepton tagging eff.
(reco × ID × IP cut × Iso × non-prompt BDT)



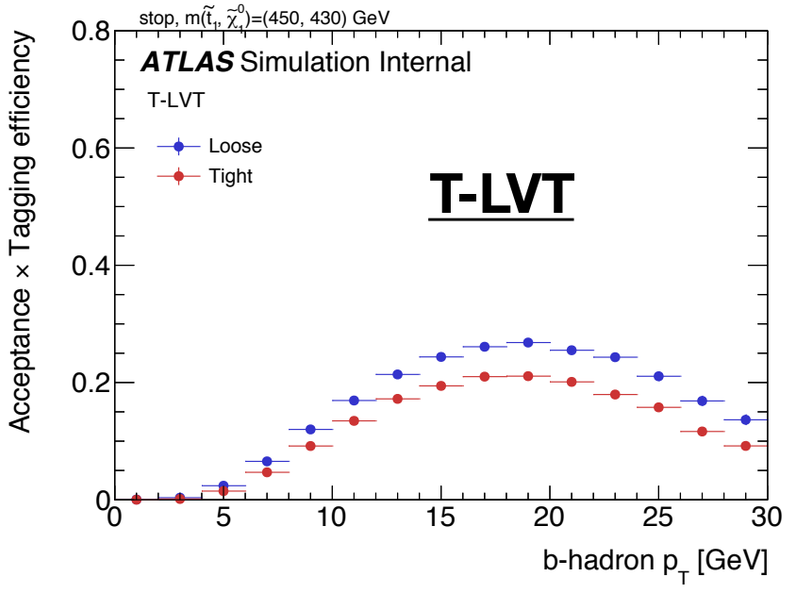
Prob. of a fake lepton from a Z/γ*+jet event

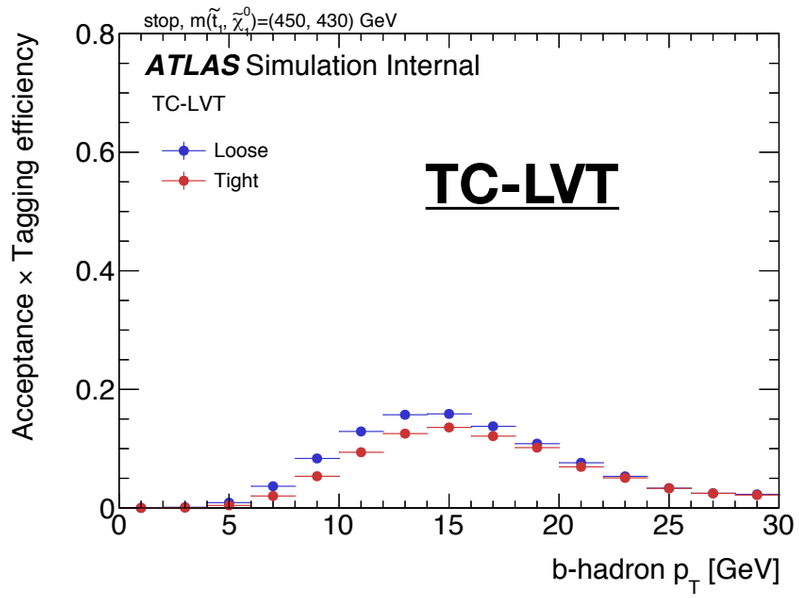


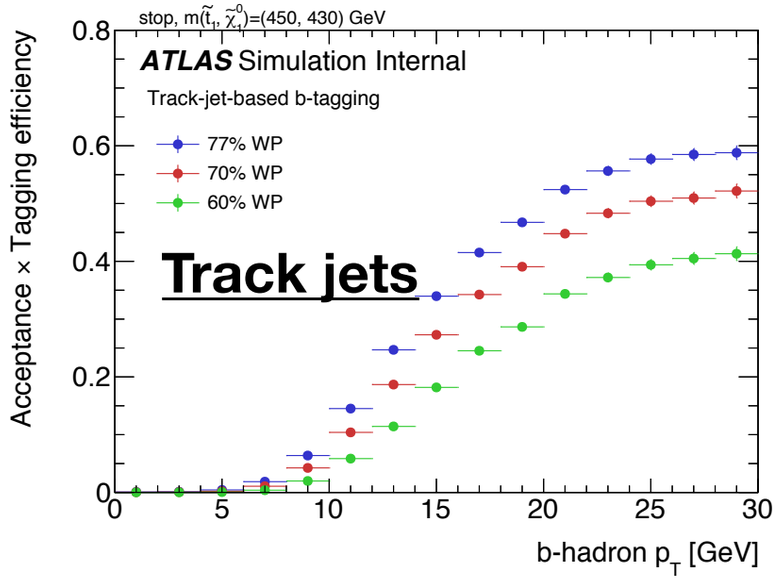
- Efficiency from the non-prompt BDT along: 70-90%
- Fake rate is typically 1/1000 (p_T inclusive)

Soft b-tagging - Working Points

ATLAS-CONF-2019-027







Selection for the T-LVT working points

Working point	L_{3D}^{sig}	L_{xy} (mm)	$\cos\theta(\mathbf{r}, \mathbf{p}^{vtx})$	m_{vtx} (MeV)	p_T^{vtx} (GeV)	ΔR_{mean}	$\lvert\eta_{vtx}\rvert$
`Loose`	> 5	> 0.2	> 0.9	> 600	> 3	< 1.0	–
`Tight`	> 7	> 0.5 and < 5	> 0.95	> 600	> 3	< 1.0	< 1.5

Selection for the TC-LVT working points

	Seed track		Cluster			Vertex	
Working point	$\frac{d_0}{\sigma(d_0)}$	p_T	$\frac{d_0}{\sigma(d_0)}$	ΔR_{seed}^{track}	r_{seed}^{track}	m_{vtx}	p_T^{vtx}
`Loose`	>0.5	> 1.5 GeV	> 1.5	< 0.75	< 0.25 mm	> 600 MeV	> 3 GeV
`Tight`	>0.9	> 2 GeV	> 0.9	< 0.7	< 0.6 mm	> 600 MeV	> 3 GeV

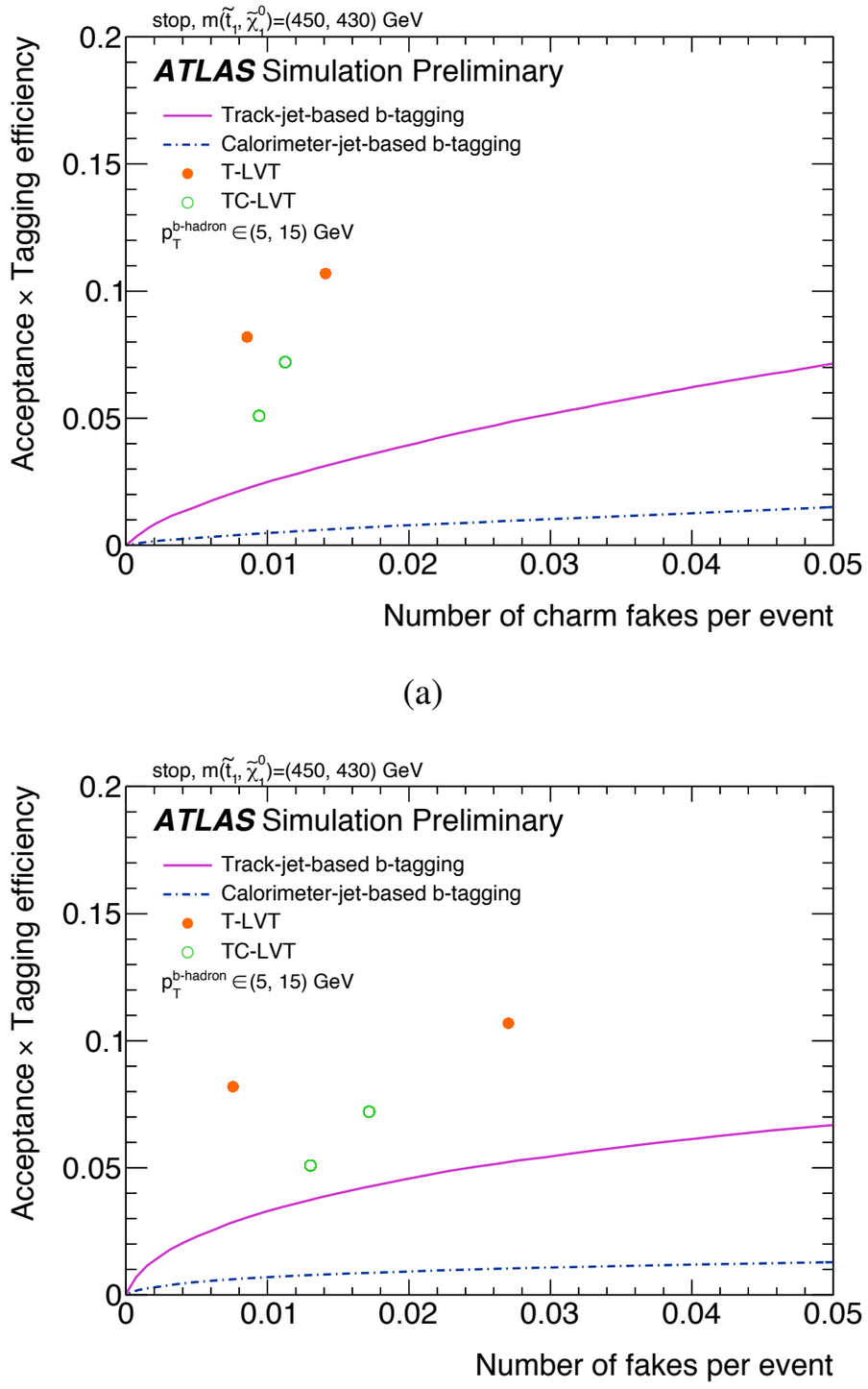
Soft b-tagging - Performances

ATLAS-CONF-2019-027

vs charm fake

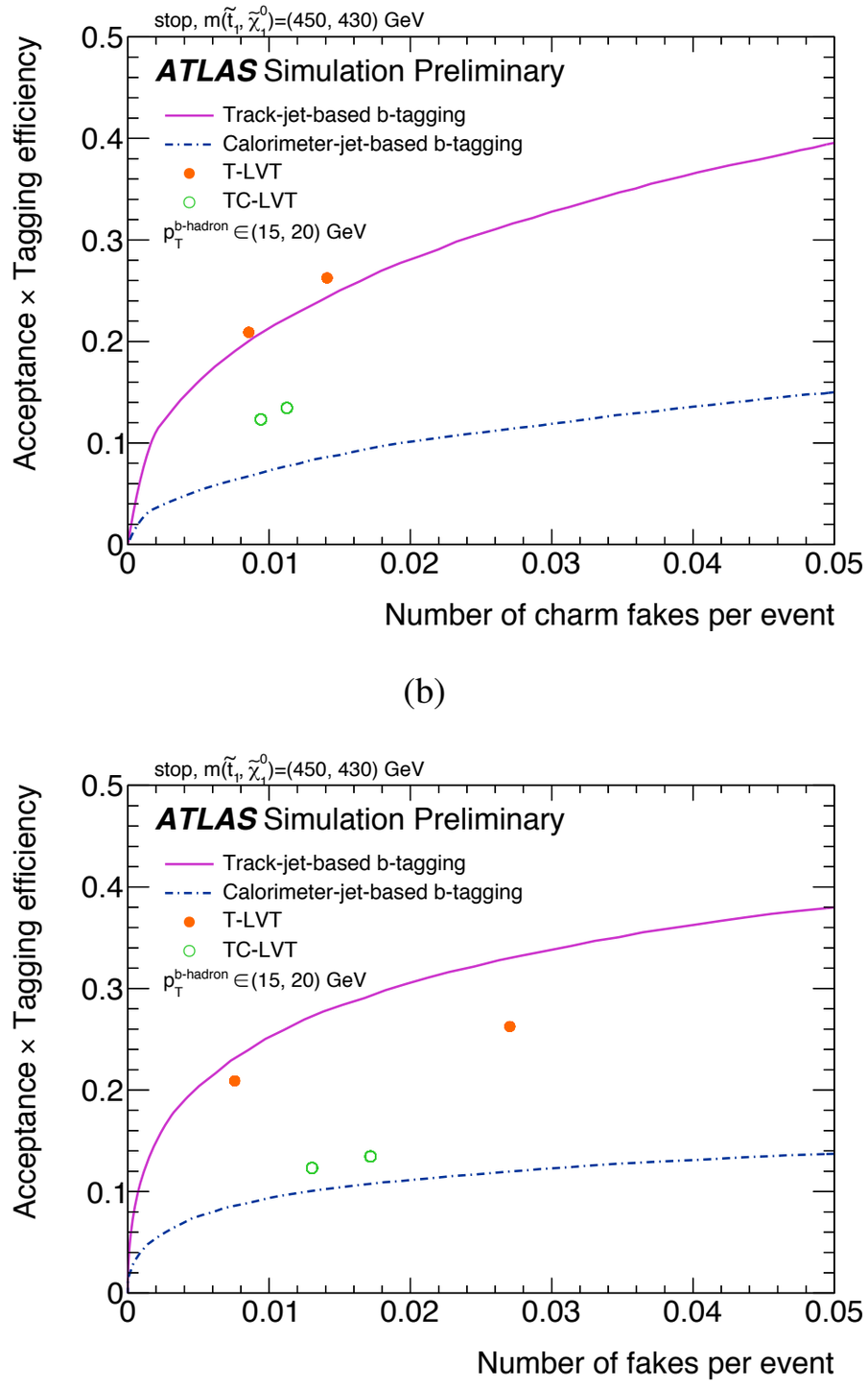
vs light-flavor fake

$p_T \in [5,15]$GeV



(a)

$p_T \in [15,20]$GeV

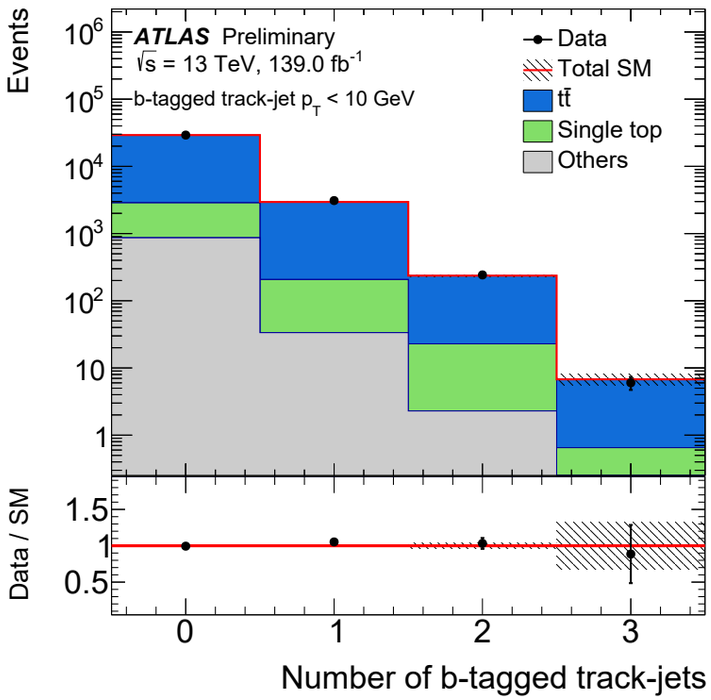


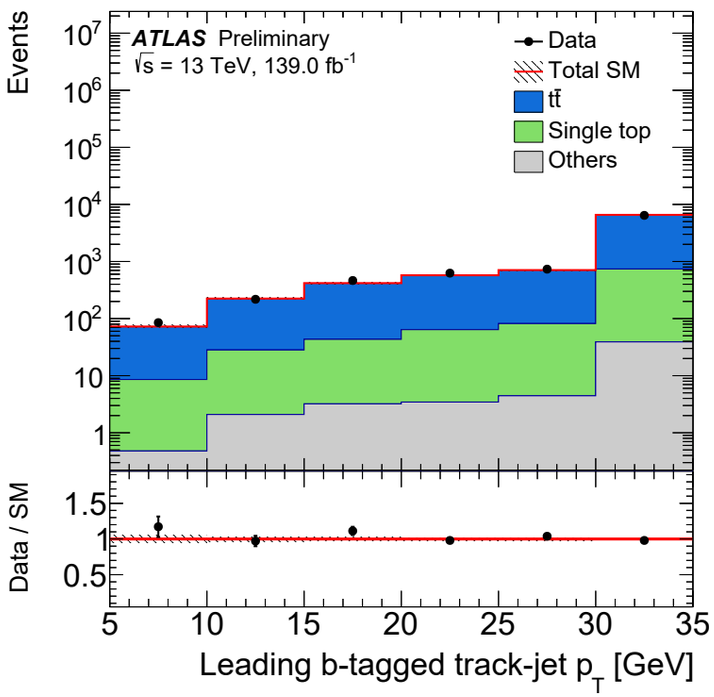
(b)

Soft b-tagging - MC modeling validation

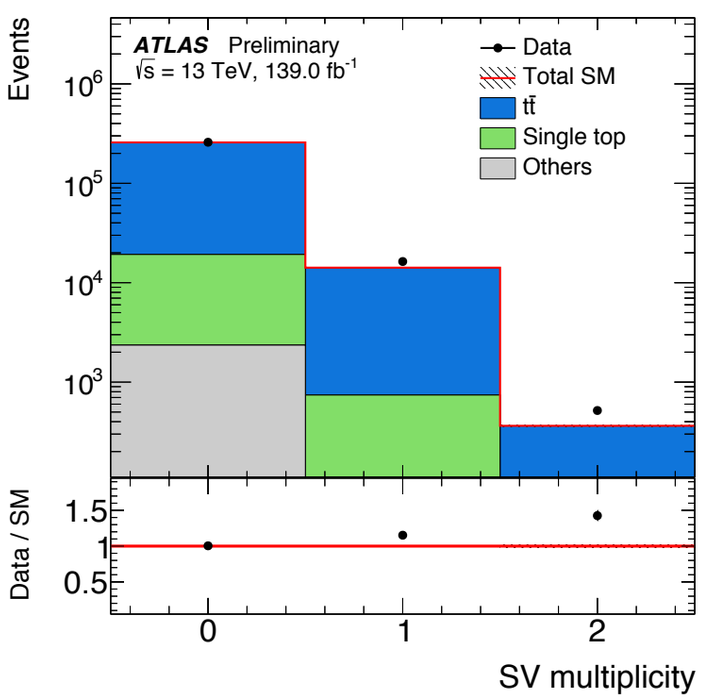
ATLAS-CONF-2019-027

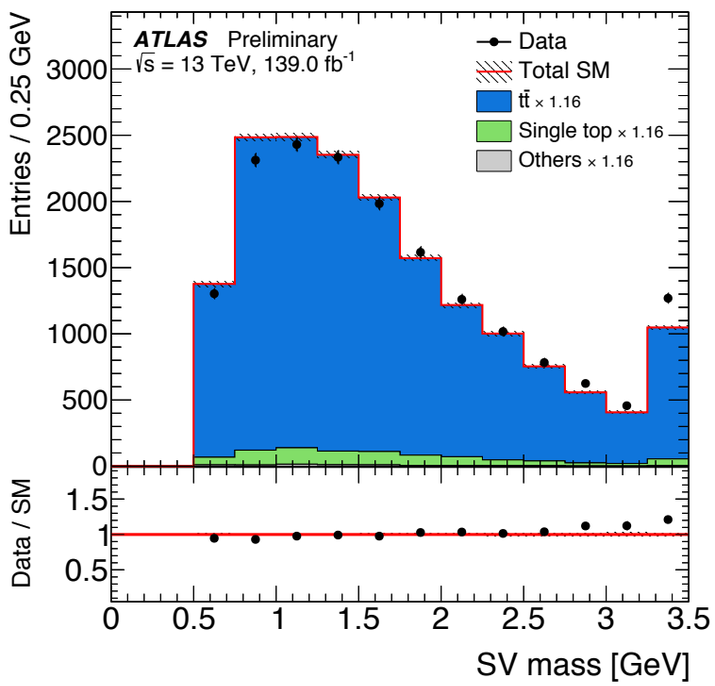
Track jets



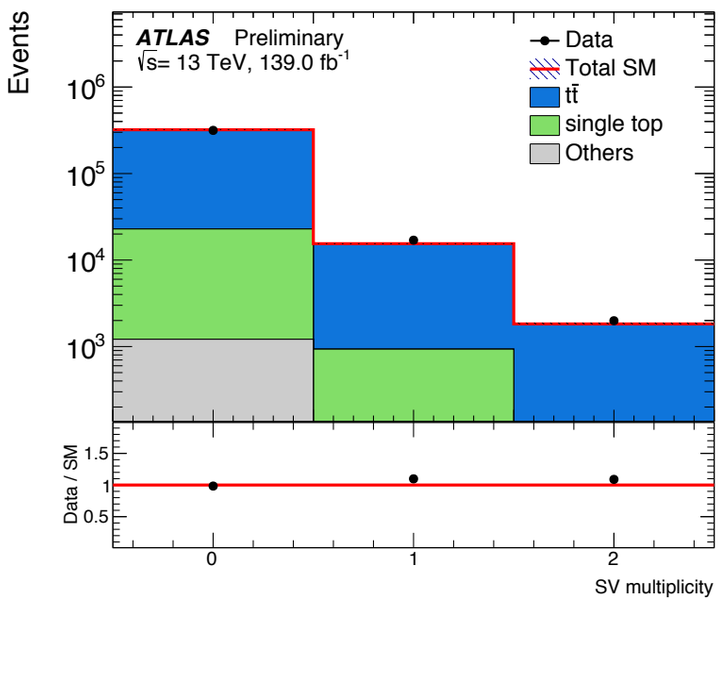


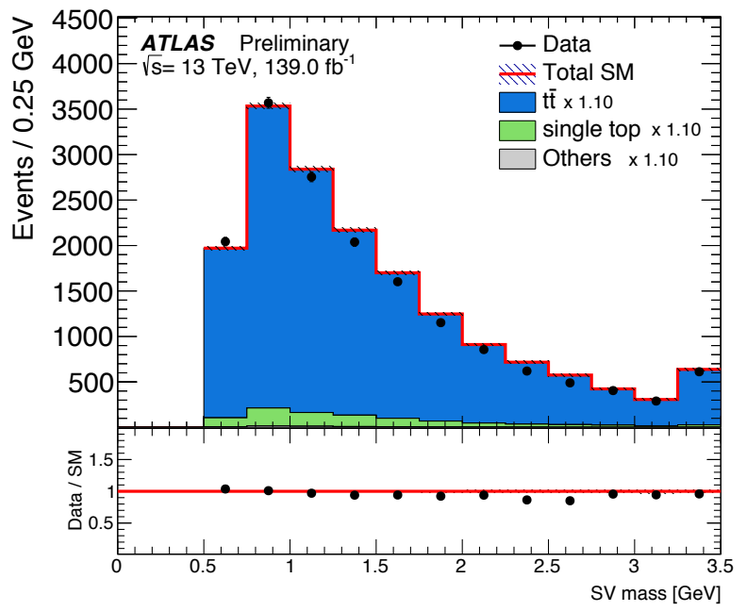
T-LVT





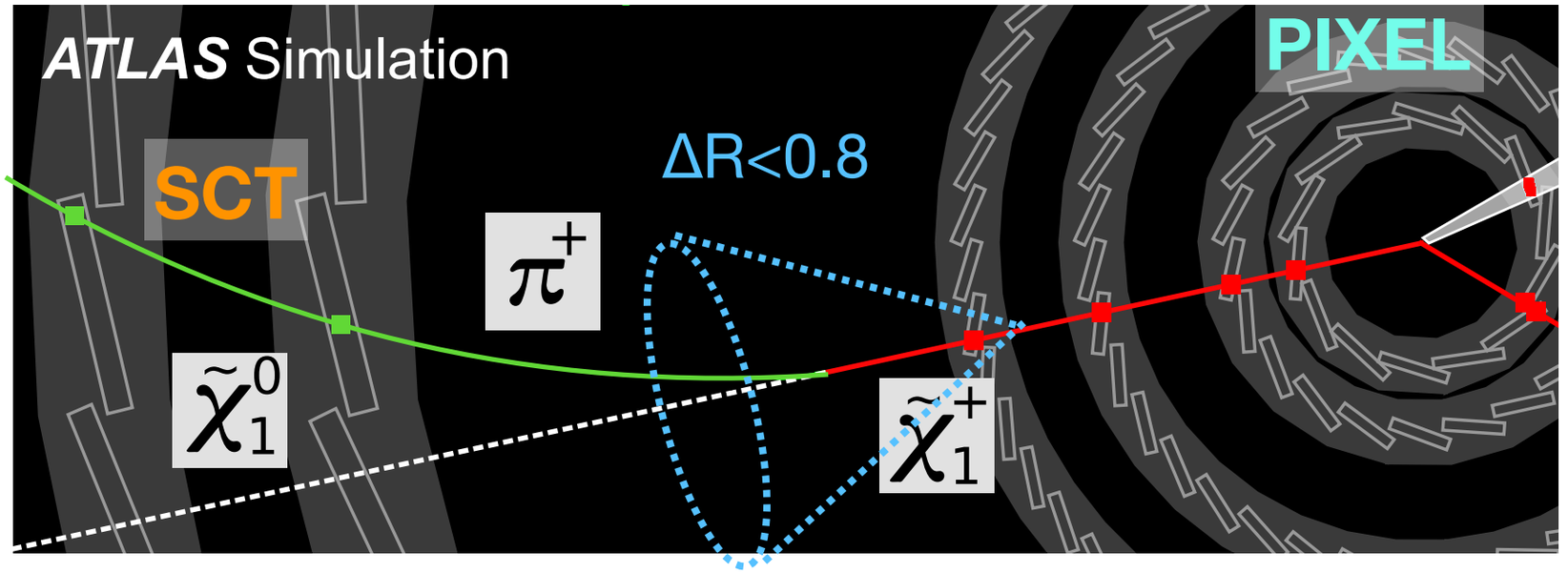
TC-LVT

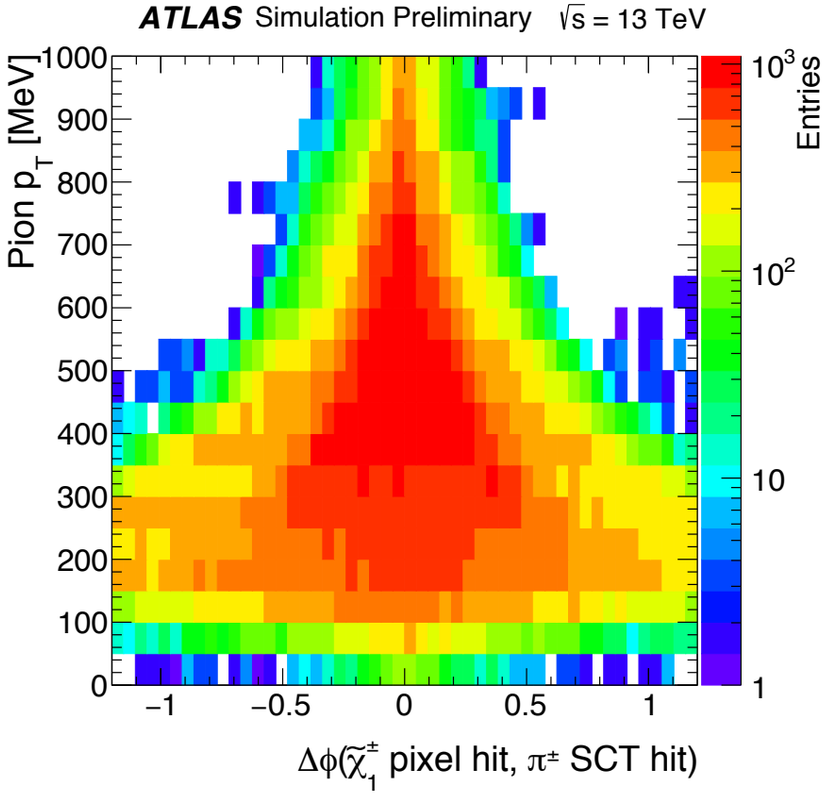


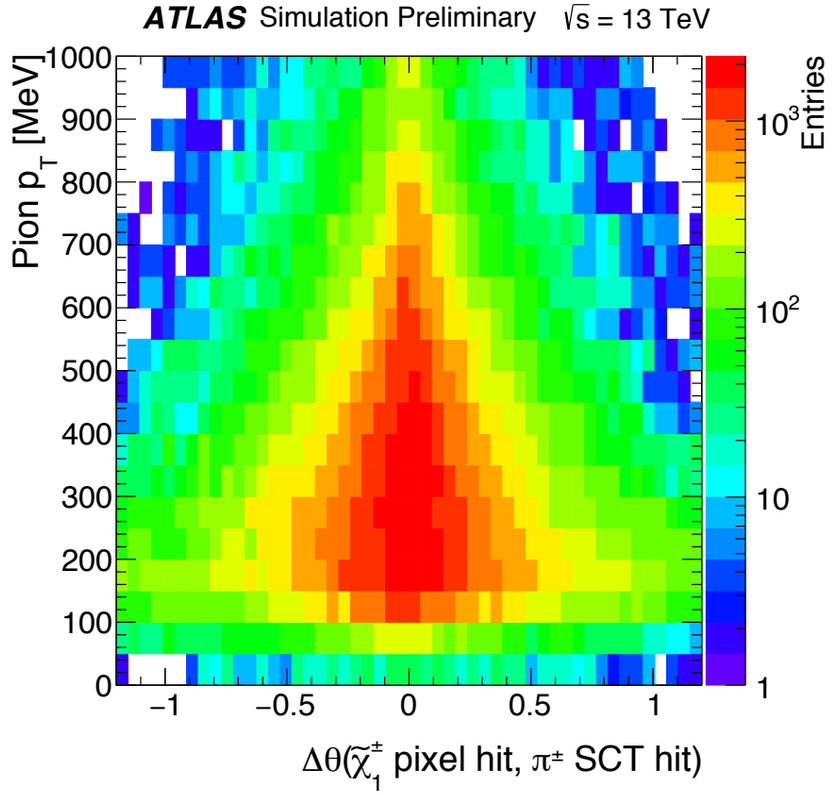


Soft pion tracking - RoI definition

ATL-PHYS-PUB-2019-011

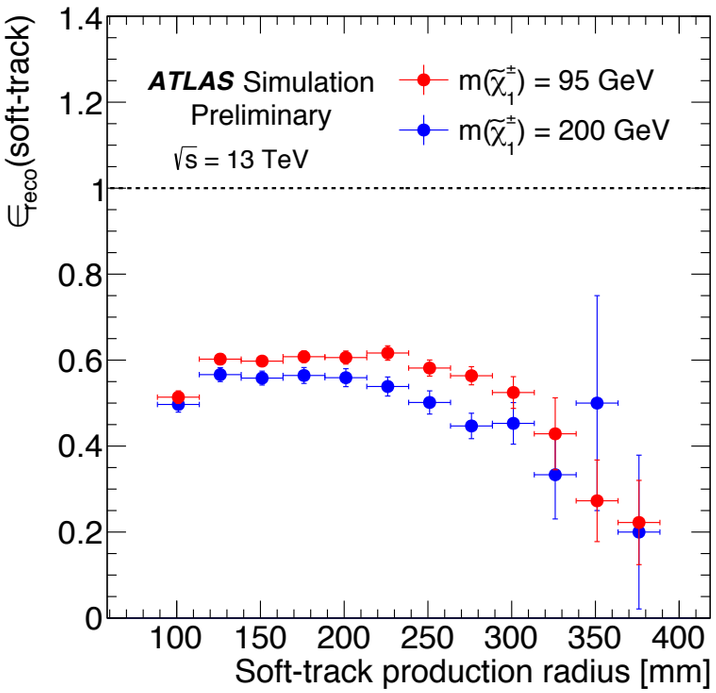


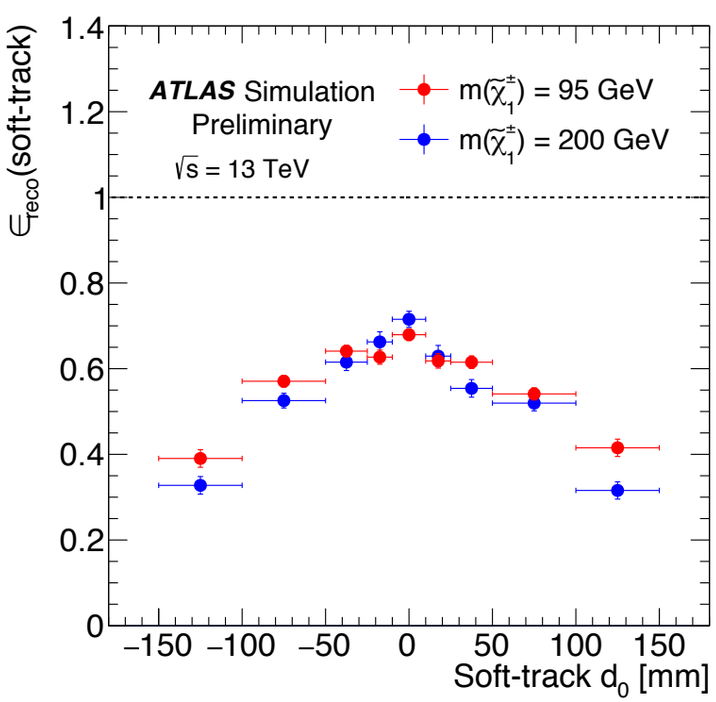


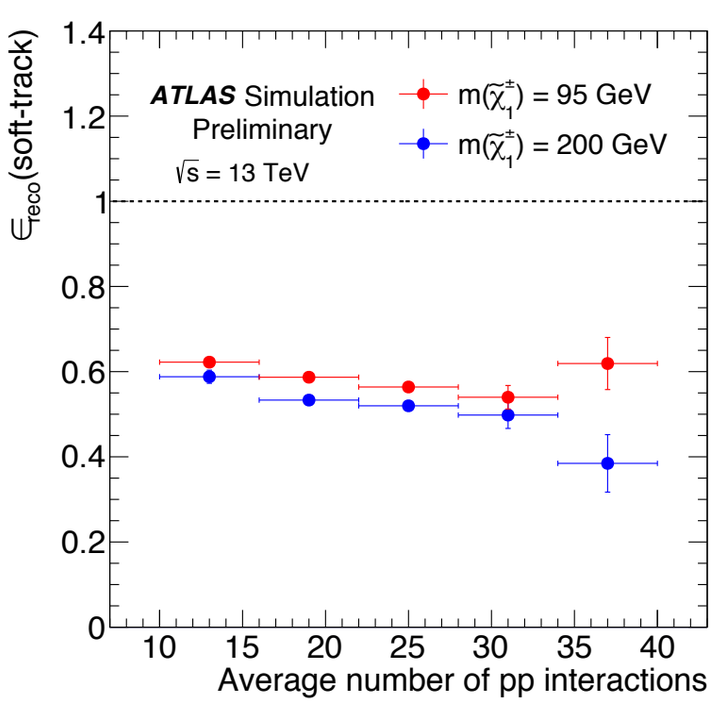


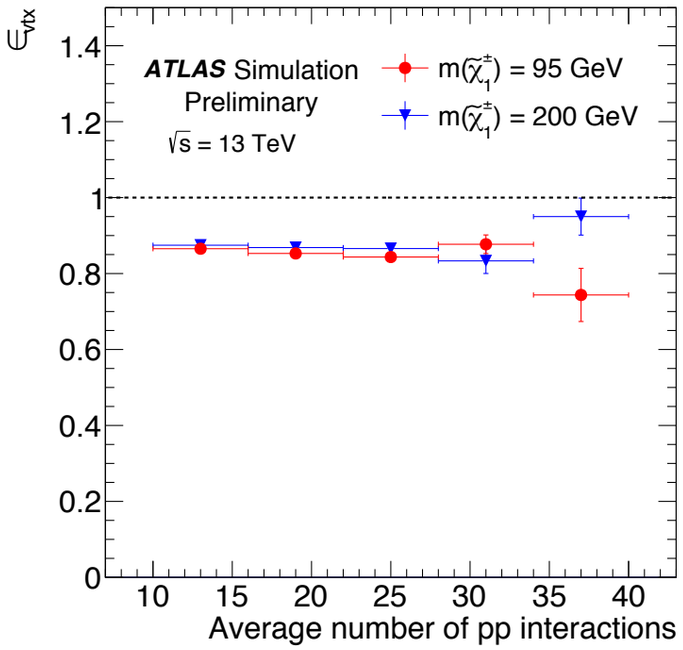
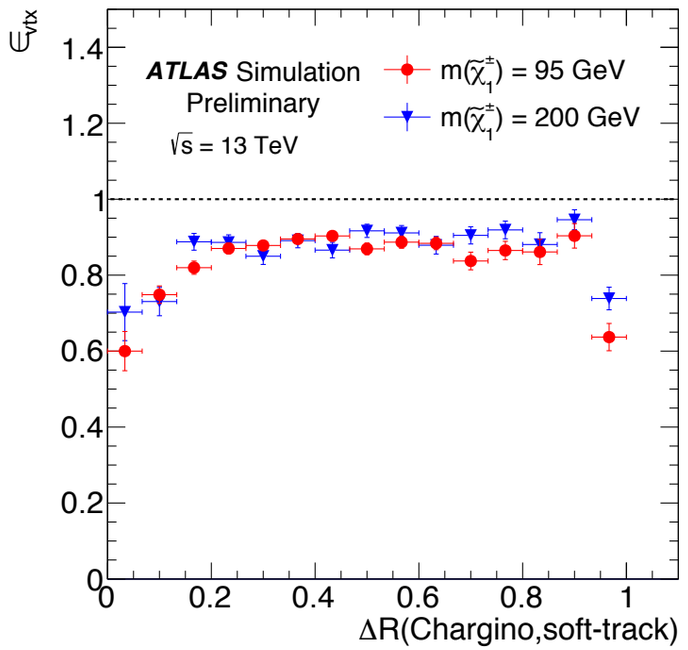
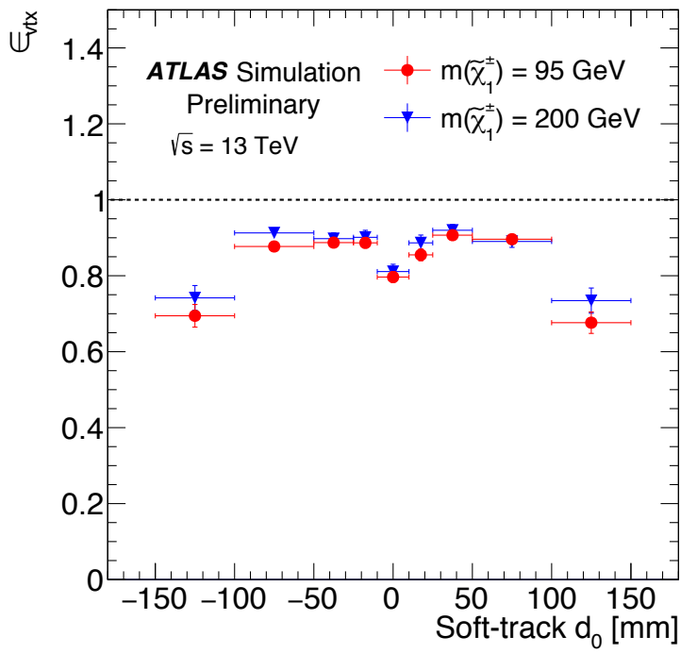
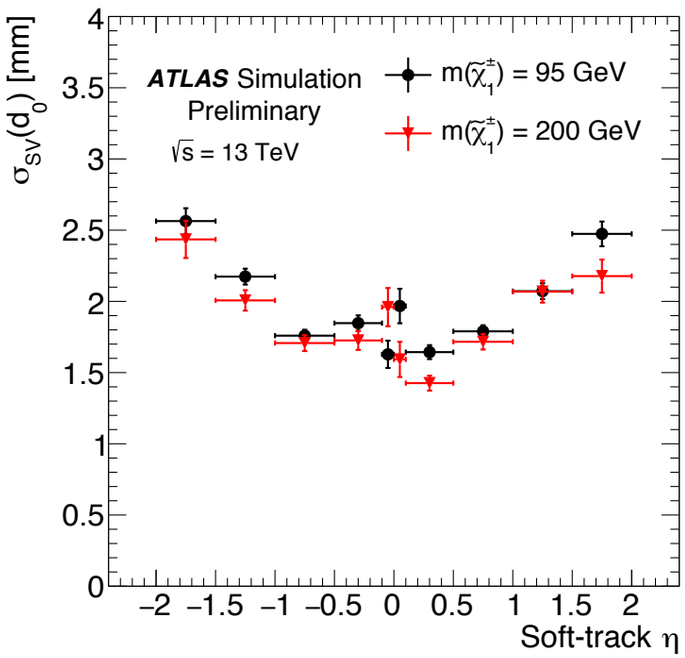
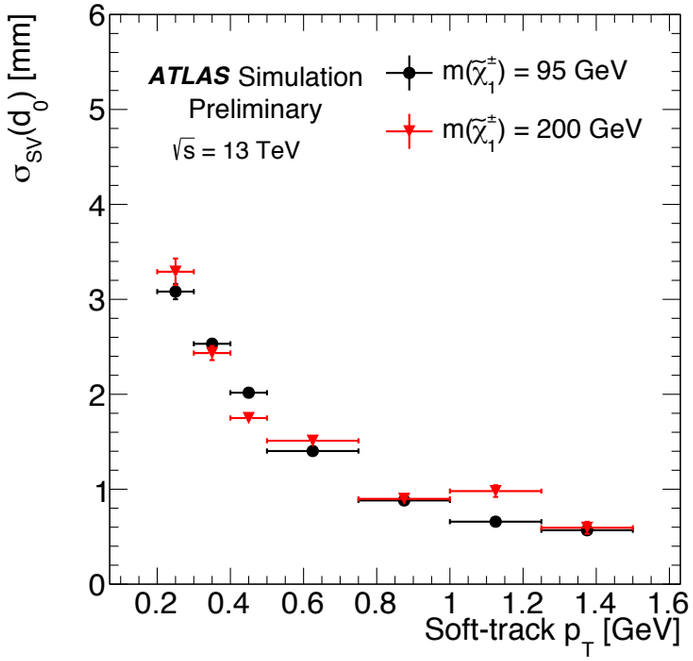
Soft pion tracking - Performance

ATL-PHYS-PUB-2019-011







Soft pion vs tracklet vertexing - Performance

ATL-PHYS-PUB-2019-011