Search for displaced top quark in the tracker of the CMS experiment at the LHC

Phenomenology : Eur. Phys. J. C 83, 299 (2023)

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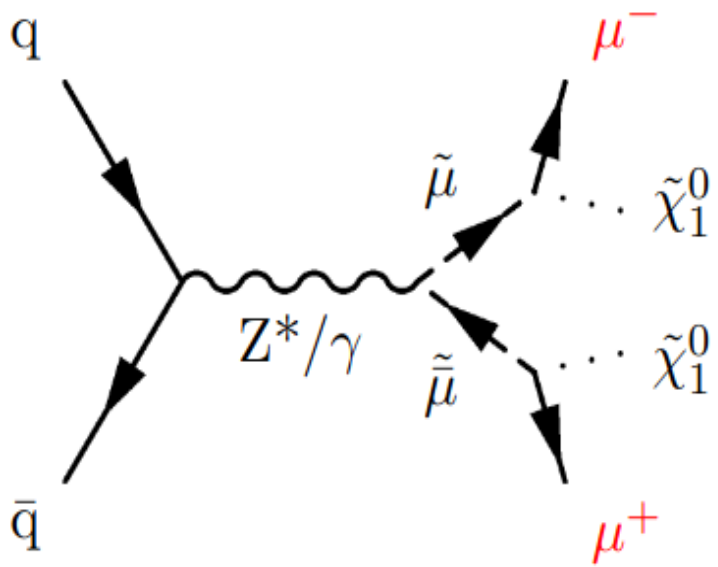
Looking for **displaced top quarks + prompt leptons**

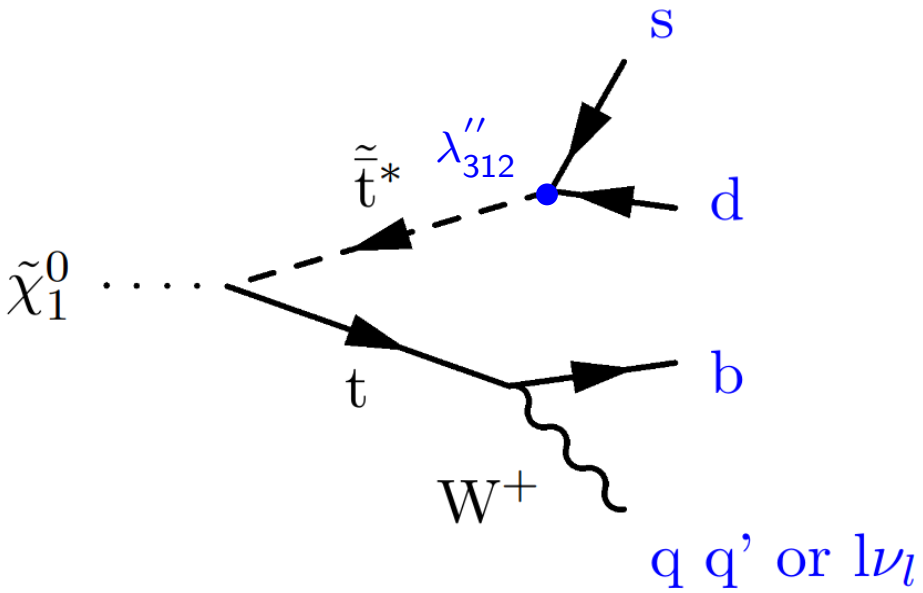
Based on *a phenomenological study*[1] to look for displaced top quarks, we focus on the RPV process with a Bino-like neutralino production from slepton decay

[1] : Andrea, J., Bloch, D., Conte, É. et al. Probing displaced top quark signature at the LHC Run 3. Eur. Phys. J. C 83, 299 (2023).

smuon pair production



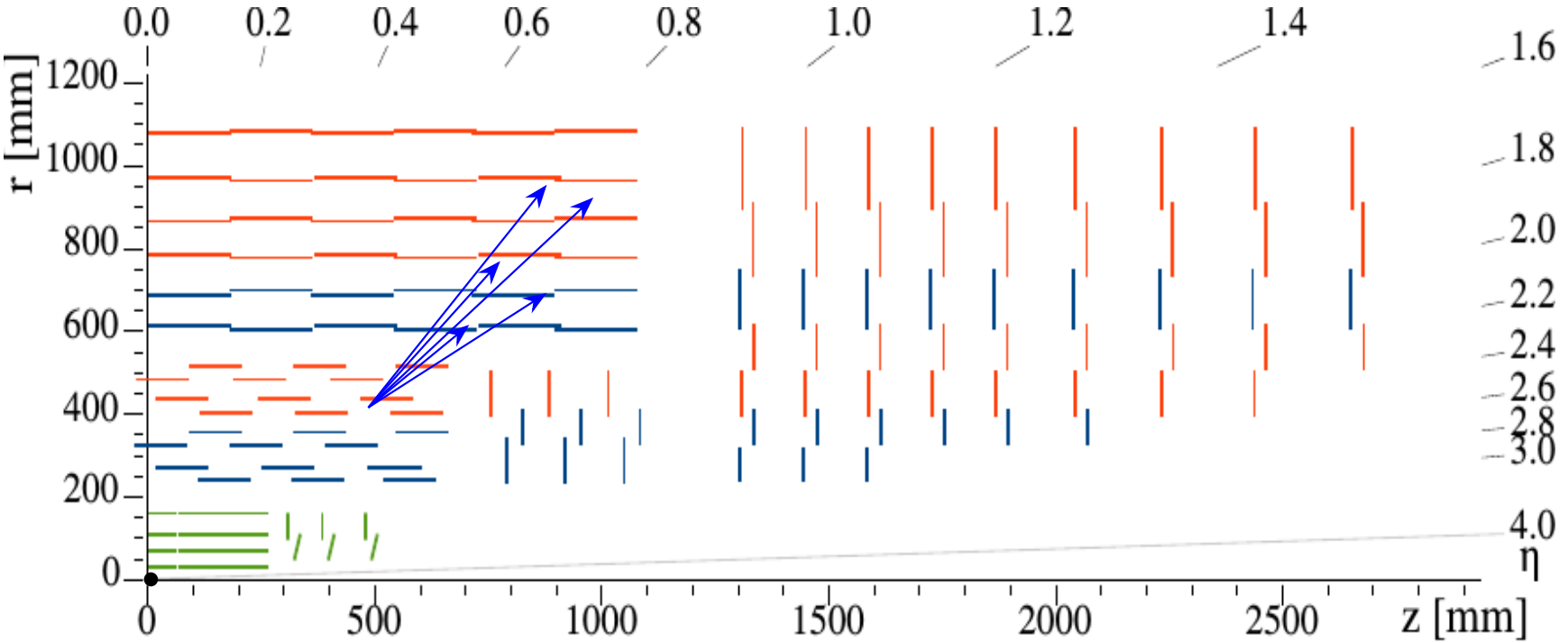
neutralino decay



- $Br(\tilde{\mu} \to \mu\chi_1^0) = 1$
- 2 long-lived neutralinos
- Two prompt muons (Trigger)

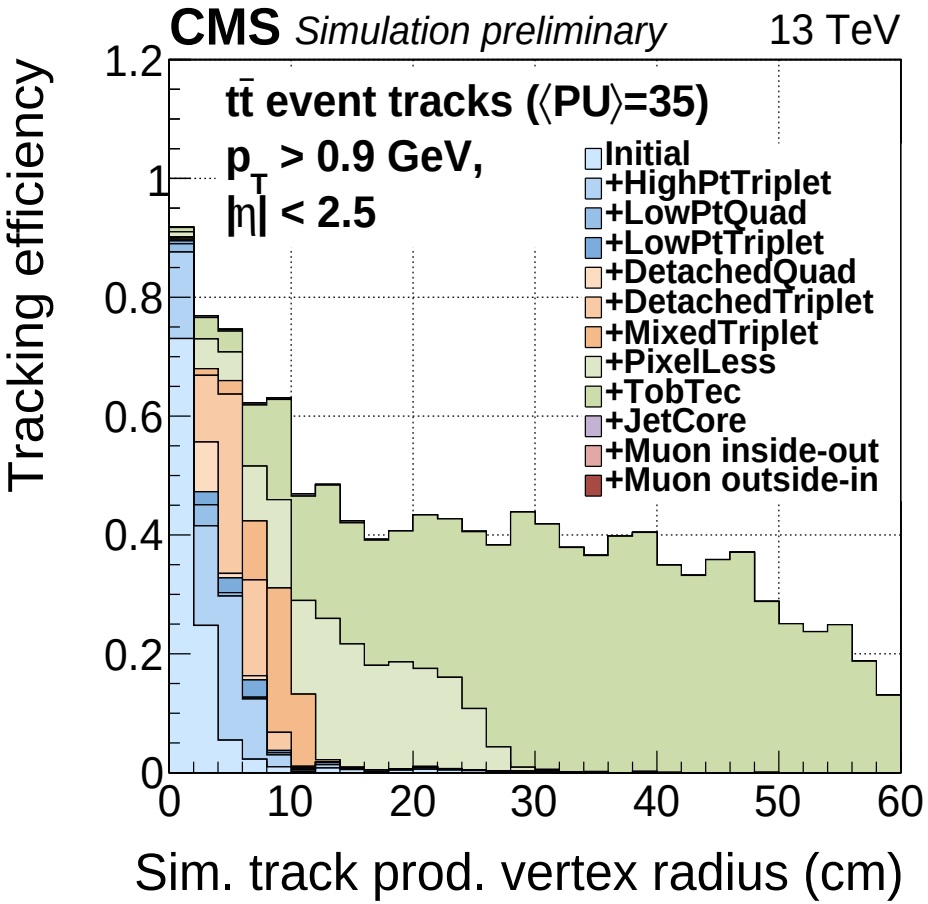
- λ''_{312} RPV Coupling
- displaced $\tilde{\chi}_0^1$ decays → 3 to 5 jets
- Up to 2 displaced vertices

Schematic view of the signal process in the CMS tracker



- The two neutralinos are back-to-back in ϕ
- Jets / tracks emerging from the decay of a long-lived neutralino
- Information from those displaced jets / tracks is used to disentangle the expected signal from the very large background

Tracking Efficiency



- Tracking efficiency drops significantly after pixels
- Make use of the large track multiplicity of the signal
- $\sim$ 10 tracks at gen level
- CERN-CMS-DP-2017-015

Monte-Carlo samples

Generation of MC Samples for the full Run2 + beginning of Run 3 (2022-2024)

χ_1^0 $c\tau$(cm)	$\tilde{\mu}$ Mass (GeV)	$\tilde{\chi}_1^0$ Mass (GeV)	$\tilde{t}$ Mass (GeV)	λ''_{312} Coupling
0.1 to 30	**200 to 500**	**180 to 480**	>1000	10^{-5} to 10^{-1}

Table – SUSY particle masses and neutralino $c\tau$ and λ''_{312} coupling. Average $\tilde{\chi}_1^0$ $\beta\gamma = 2.5$

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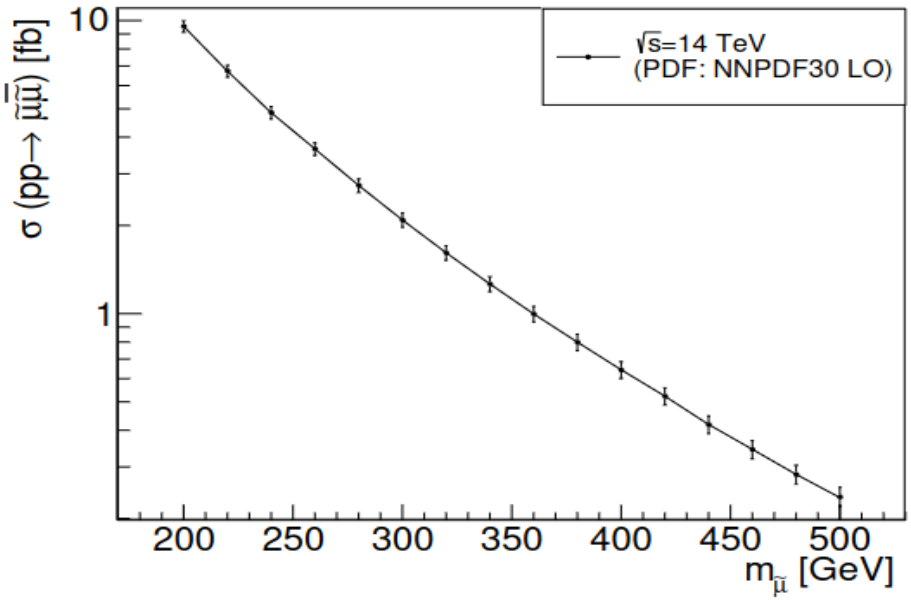
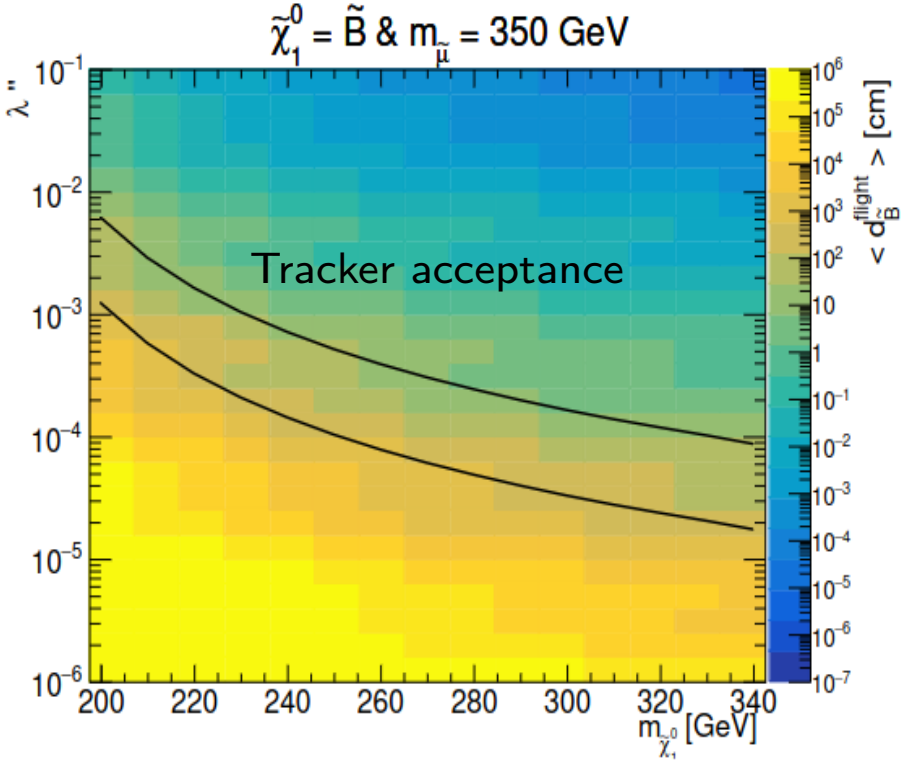
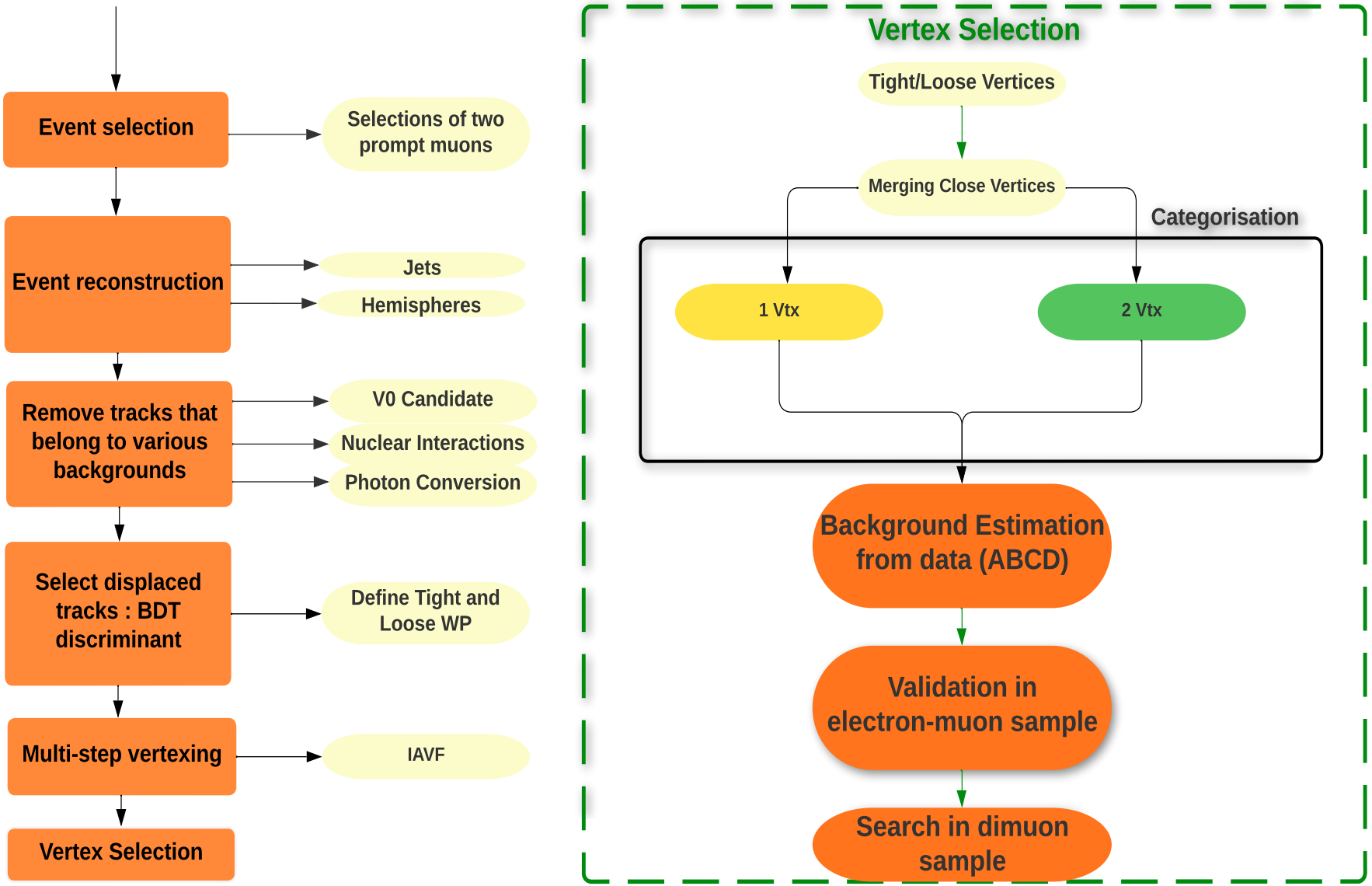




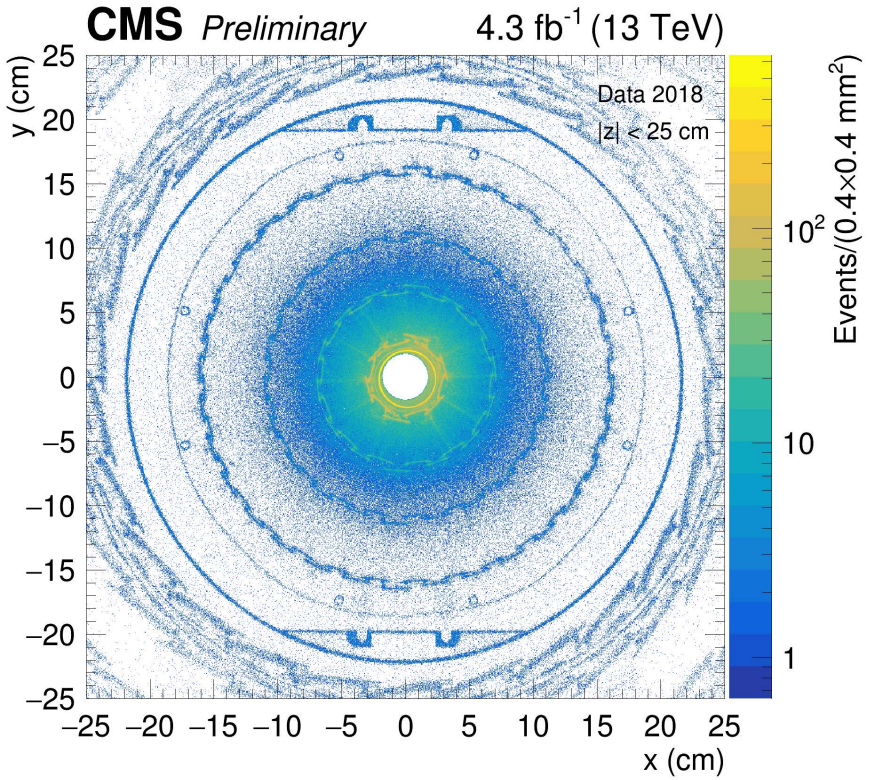
Analysis Strategy



Remove tracks from various backgrounds

Secondary Interactions : Photon Conversions and Nuclear Interactions

- Matching of the secondary interactions vertices with the material of the tracker is done using an approximate map of the tracker
- **Active layers** : pixel and silicon strip layers
- **Passive layers** : Beam pipe, Pixels inner and outer support, rails
- Reject pair of tracks associated to a Sec.Int vertex matched with an active or passive layer
- A.M. Sirunyan et al 2018 JINST 13 P10034

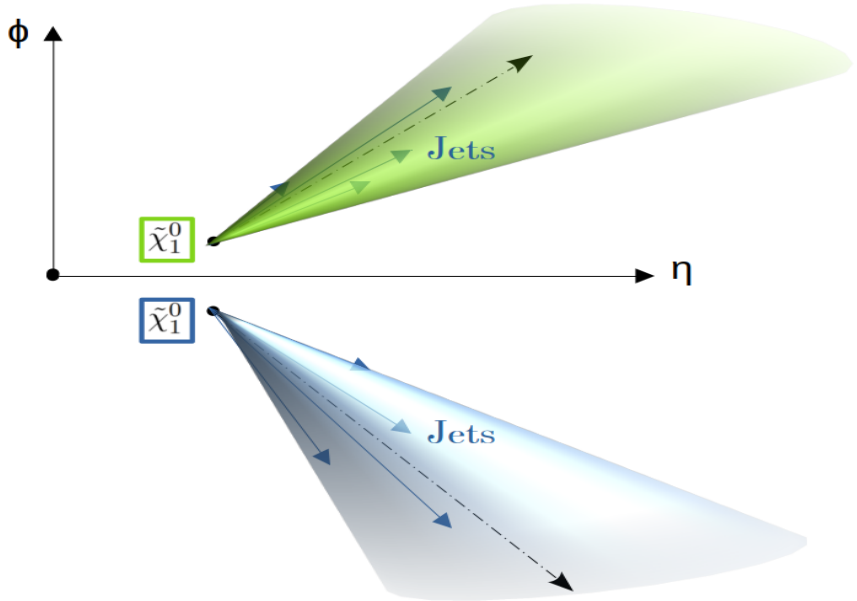


V^0 Candidates

1. $K_s^0 \rightarrow \pi^+\pi^-$
2. $\Lambda \rightarrow p\pi^-$ or $\bar{p}\pi^+$
3. $c\tau \sim 10^{-2}$ m
4. Track pairs in K0 or Λ mass window are rejected

Event reconstruction : two cones

Goal : Reconstruct **one vertex** in each hemisphere



- Construct two axes from the (AK4) jets
  - 1^{st} Hemisphere : Take the jet of highest p_t and we associate successively the nearest jets ($\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 1.5$)
  - 2^{nd} Hemisphere : jets non-associated with the 1^{st} hemisphere and associated within $\Delta R < 1.5$

Note : If a prompt muon belongs to a jet, its 4-vector is removed from the axis building procedure

Track selection and Vertex Reconstruction

Track selection using a Boosted Decision Tree

- All Signal Samples ($c\tilde{\tau} = 10$cm) tracks & Bkg ($e\mu$ data) tracks
- Association of each track to its closest hemisphere
- Implementation of a BDT to distinguish tracks from neutralino decay and tracks from background
- Define two working points (WP)
  - Tight : $\sim 10^3$ rejection of background
  - Loose : $\sim 10^2$ rejection of background

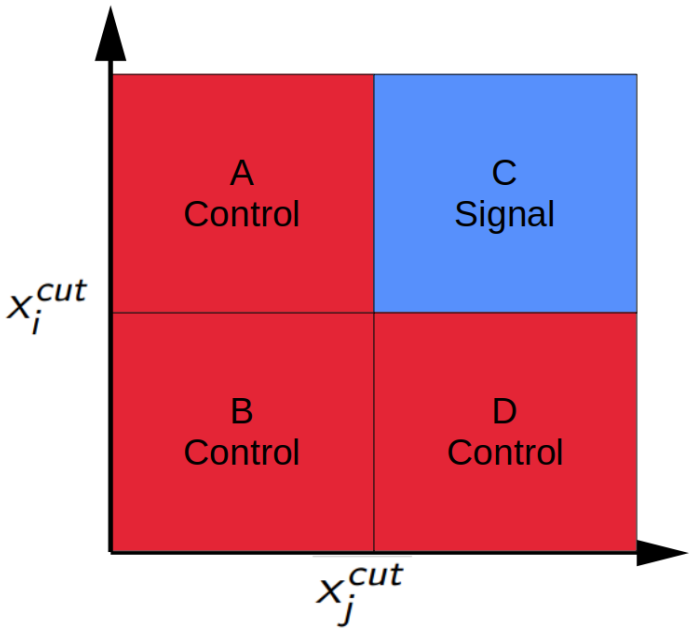
Vertex Reconstruction

Goal : Multi-step vertexing using an Iterative Adaptive Vertex Fitter (IAVF) to **reconstruct one vertex per hemisphere**

- 4 Steps of vertexing : two for each WP (Tight and Loose)

This workflow allows to reconstruct between 25% and 95% of the vertices (depending on the parameters) while rejecting $t\bar{t} \to \mu\mu$ + jets by a factor $\sim 10^5$

Background estimation from data



- $N_C^{BKG} = \frac{N_A^{BKG} * N_D^{BKG}}{N_B^{BKG}}$
- x_i and x_j being two decorrelated variables with their associated optimized cuts x_i^{cut} and x_j^{cut}

Background estimation

Combine event level information and vertex feature :

- $x_i \rightarrow$Vertex with Loose or Tight track selection
- $x_j \rightarrow$Hemisphere p_t

$\rightarrow$Choose a discriminating variable between signal and background :

Sum of the probabilities of the tracks to belong to their associated vertex

Conclusion

- Defined an analysis strategy in the context of the CMS experiment to look for smuon production into a long lived neutralino decaying into a top quark and two light quarks in the tracker volume
- Benefit from the large number of jets and tracks in these events to reconstruct the displaced vertices in the tracker volume and reduce the huge SM background
- Aims at putting limits on direct smuon production cross-section
- Going towards a CMS approval during next year

Thanks a lot !!

Back-up

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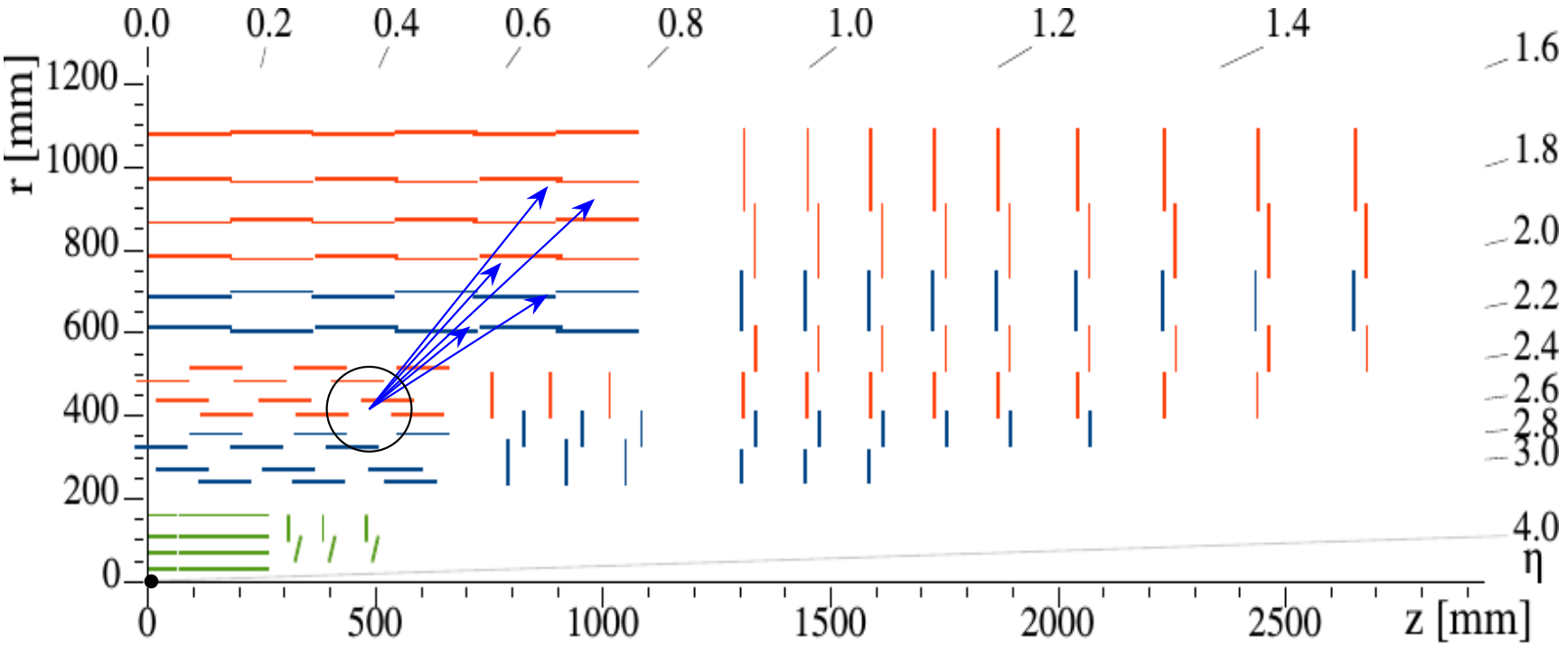
Track variables as input to the BDT



- For a given track with a firsthit (x1, y1, z1), we count the **number of other tracks having their firsthit within** 10, 20, 30 up to 40cm
- **Impact parameters** : $|\frac{d_{xy}}{\sigma_{xy}}|$, $|\frac{d_z}{\sigma_z}|$
- **Others** : p_t, η, n_{hits}, within a jet or not
- ΔR between the tracks and each hemisphere axis