Search for displaced top quark in the tracker of CMS

Top LHC France 2024

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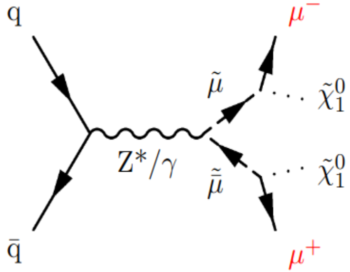
Looking for **displaced top quarks + prompt leptons**

Based on *a phenomenological study*[1][2] to look for displaced top quarks, we focus on the RPV process with a Bino-like neutralino production from slepton decay

[1] : J.Andrea, D.Bloch, É.Conte, D.Darej, R.Ducrocq, E.Nibigira, arXiv:2212.06678 (2023)

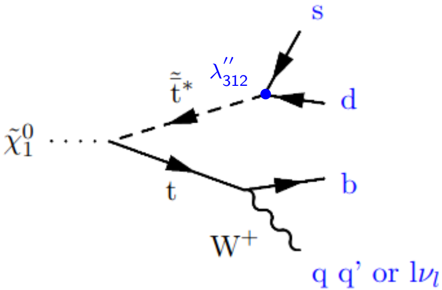
[2] : R.Ducrocq (Top LHC France, 2022)

smuon pair production



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

Neutralino decay



- λ''_{312} RPV Coupling
- displaced $\tilde{\chi}_0^1$ decays → 6 to 10 jets

Monte-Carlo samples

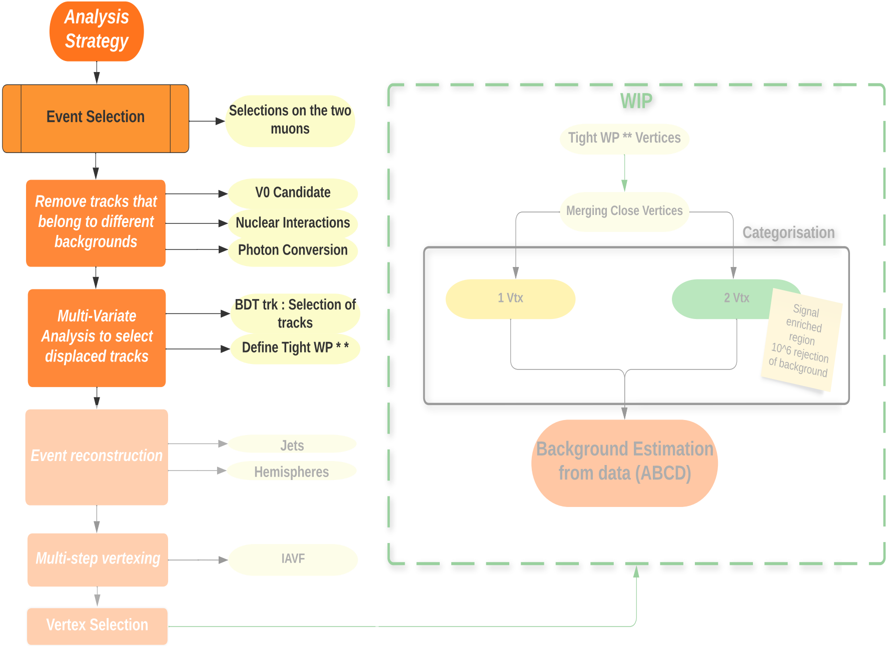
$\sim$240 private Monte-Carlo samples of $\sim$10000 events each have been generated at LO+1jet for each year of Run 2, simulated and reconstructed to cover the available phase space :

χ_1^0 $c\tau$(cm)	$\tilde{\mu}$ Mass (GeV)	$\tilde{\chi}_1^0$ Mass (GeV)	$\tilde{t}$ Mass (GeV)	$\lambda_{312}^{''}$ Coupling
0.1 to 100	**200 to 500**	**180 to 480**	>1000	10^{-3} to 10^{-1}

Table – SUSY particle masses and neutralino $c\tau$ and $\lambda_{312}^{''}$ coupling . The cross-section range is from 0.1 to 10 fb.

Generator :

- MadGraph5_aMC@NLO : 2.9.15 LO+1jet (ISR)
- NNPDF31_nnlo_hessian_pdfas (lhaid 90500)
- Shower Program : PYTHIA 8.306
- xqcut for merging = 30 GeV
- $\beta\gamma_{\tilde{\chi}_0^1}$ $\sim$2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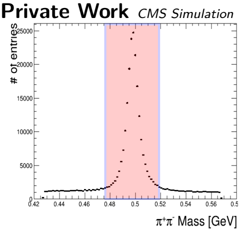
V^0 Candidates and Secondary interactions reconstruction

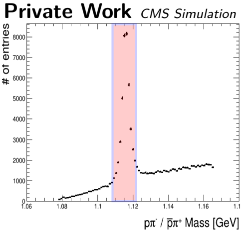
Goal : Remove tracks coming from V^0 Candidates

V^0 Candidates : Standard Model long-lived particles

1. $K_s^0 \to \pi^+\pi^-$
2. $\Lambda \to p\pi^-$ or $\bar{p}\pi^+$

- example from $t\bar{t}$ sample
- reject what is in the red mass window



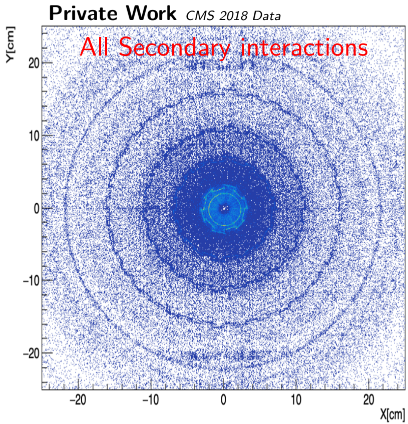


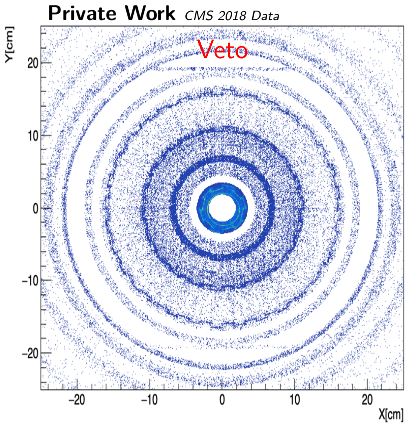
Goal : Remove tracks from secondary interactions **occurring in the material of the tracker**

Secondary Interactions : Photon Conversions and Nuclear Interaction

- Matching of the secondary interactions vertices with the material of the tracker is done using an approximate map of the tracker
- **Active layers** : PXBL1, L2 ,..., TIB L1,L2 ...
- **Passive layers** : Beam pipe, Pixels inner and outer support

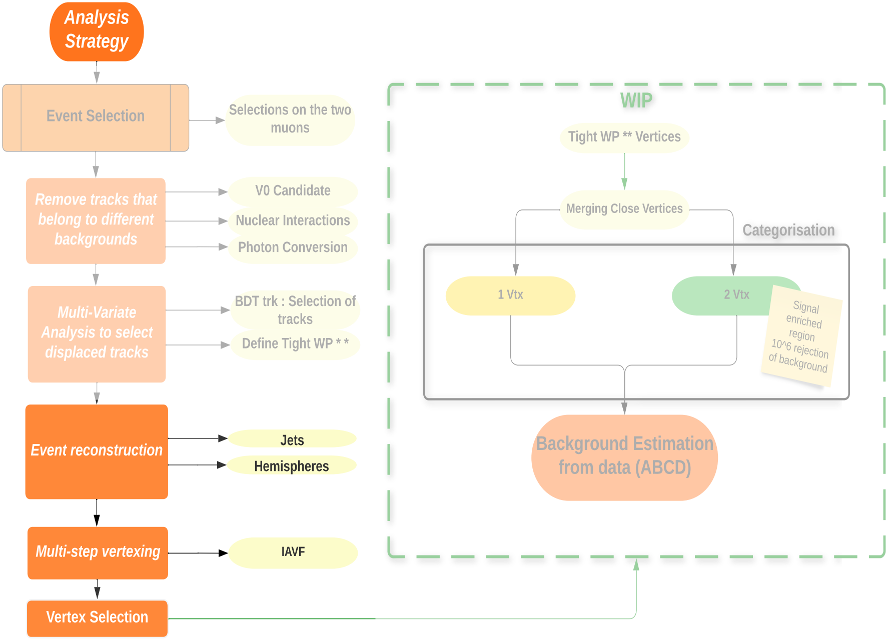
Spatial Distribution of Secondary Interactions





Note : We reject the tracks associated to the vertices of the plot on the right

- On average, 0.5 secondary vertices are matched with the material of the tracker per $t\bar{t}$ evt but 3.5 per signal event
- Data : eμ control sample enriched in $t\bar{t}$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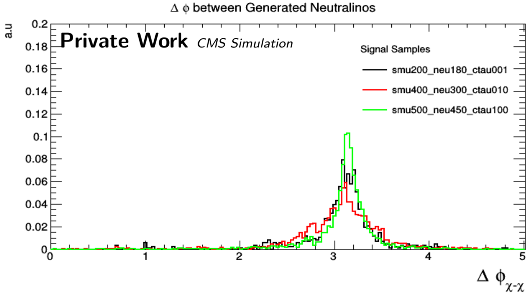
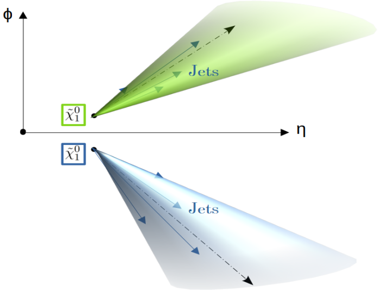
Separation of the event into two cones (hemispheres)

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





- Construct two axes from the AK4PF jets ($p_t > 20$ GeV)
  - 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 pre-selections after veto

$p_t > 1$ GeV AND $\chi^2/dof < 5$ AND $|\frac{d_{xy}}{\sigma_{xy}}| > 5$

=> ~95% of the tracks from generated neutralinos are kept
90% of the bkg tracks are removed (from primary vertex or pileup or fake tracks)

↓

After preselection

<nbr of tracks from LLP> ~15 & <nbr of tracks from bkg> ~17

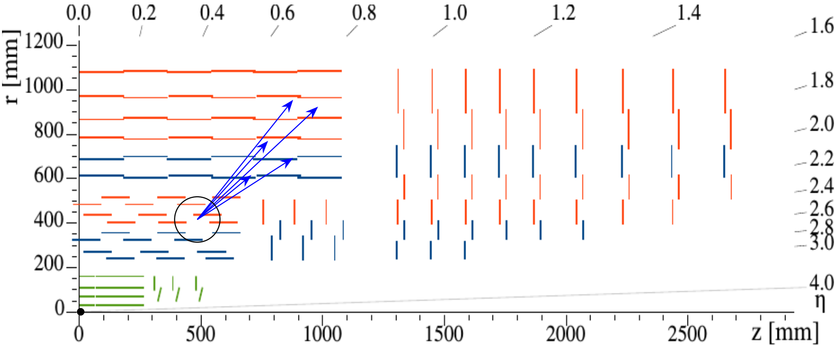
per signal event

~ 94% of the tracks from $t\bar{t}$ are rejected

Input for a Boosted Decision tree

→ Distinguish tracks from neutralino signal and tracks from $t\bar{t}$ SM background

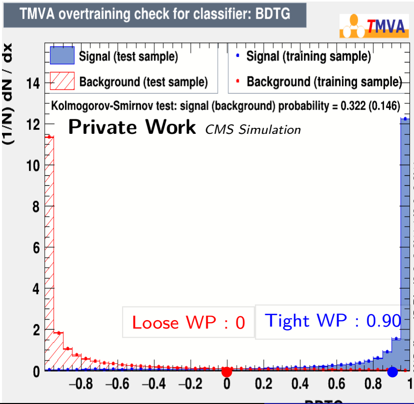
Track variables as input to the BDT

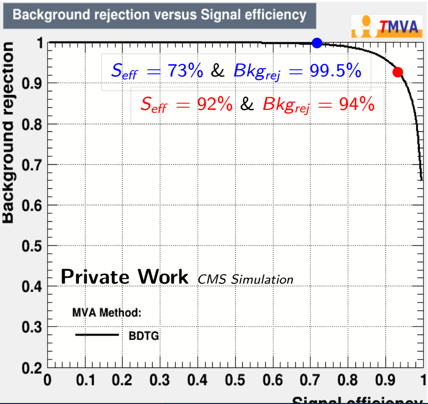


- For a given track with a firsthit (x1, y1, z1), we count the **number of other tracks having their firsthit within** 10, 20, 30 up to 40cm
- **Impact parameters** : $|d_{xy}|$, $|d_z|$, $|\frac{d_{xy}}{\sigma_{xy}}|$, $|\frac{d_z}{\sigma_z}|$
- **Others** : p_t, η, χ^2/dof, n_{hits}, within a jet or not
- ΔR between the tracks and each hemisphere axis

Track selection BDT

- All Signal Samples ($c\tilde{\tau} = 10$cm) 1M tracks & Bkg 1M tracks
- Association of the track to its closest hemisphere
- Tight : 10^3 rejection of background
- Loose : reference working point





Vertexing Strategy

Goal : Multi-step vertexing using the Adaptive Vertex Fitter (AVF) to **reconstruct one vertex per hemisphere** by :

- Using Tight+Loose track collections with the tracks ordered by decreasing value of BDT
- Using an Iterative AVF with 4 steps
- considering a step to be successful if the vertex has : $0 < \frac{\chi^2}{DoF} < 10$

1. Tight Tracks (no requirement on $\frac{\chi^2}{DoF}$ for each iteration)
2. Tight Tracks (with requirement on $\frac{\chi^2}{DoF}$ for each iteration)
3. Loose Tracks (no requirement on $\frac{\chi^2}{DoF}$ for each iteration)
4. Loose Tracks (with requirement on $\frac{\chi^2}{DoF}$ for each iteration)

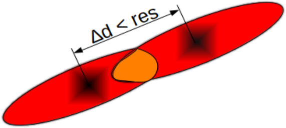
Note : The Vertexing is robust (not affected) with respect to the :

- Input parameters given in input to AVF
- Hemisphere building procedure

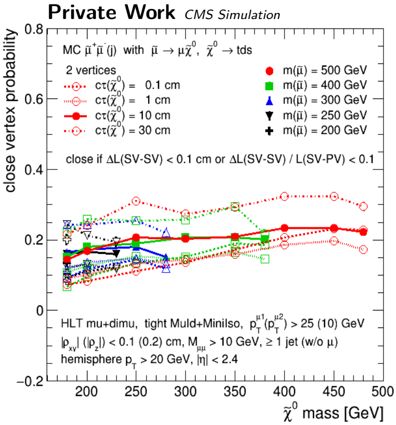
Merging of two vertices

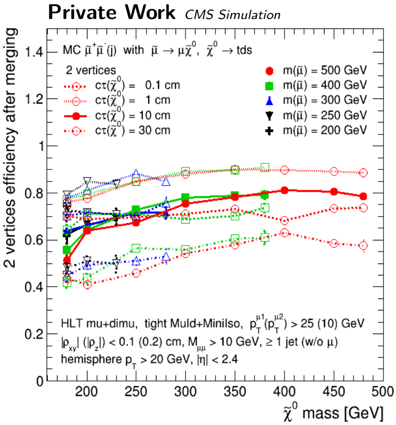
Vertex Merging

- Reconstruction of one vertex per hemisphere but jets from a neutralino can be in two different hemispheres→reconstruct twice the same vertex
- Merge the **information** of the two original vertices to build the merged one (position, nbr of tracks, χ^2, etc)
- The merged vertex belongs to an hemisphere
- **The remaining tracks (after merging) from the other hemisphere are used to find a new secondary vertex**
- It affects mostly the signal



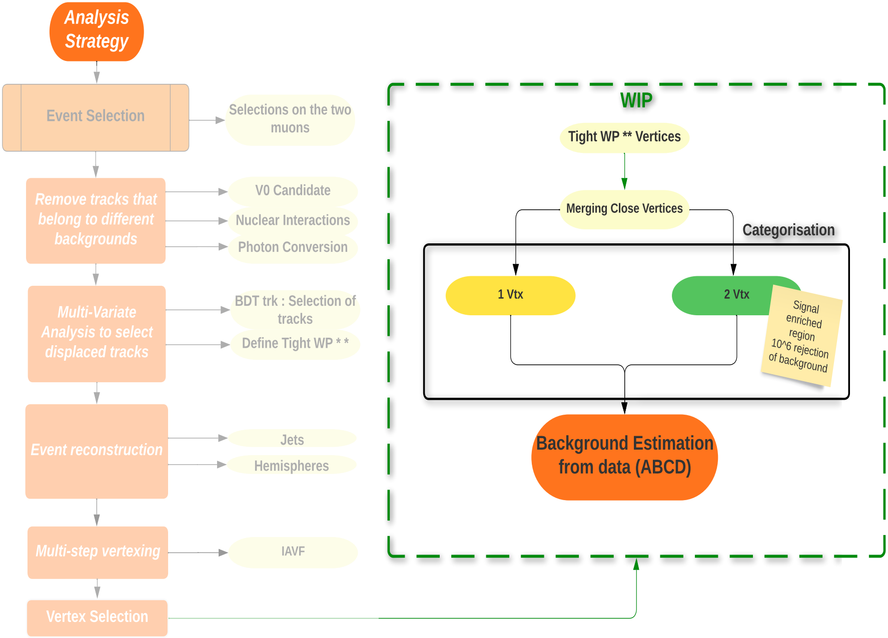
Merging Summary





Close Vertex Probability — Efficiency of having two vertices after Merging

The remaining tracks (after merging) from the other hemisphere are used to find a new secondary vertex, distinct from the other (merged) vertex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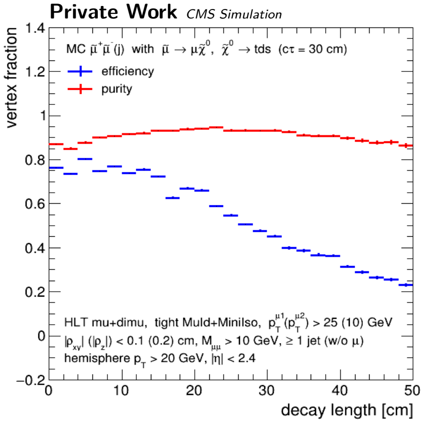
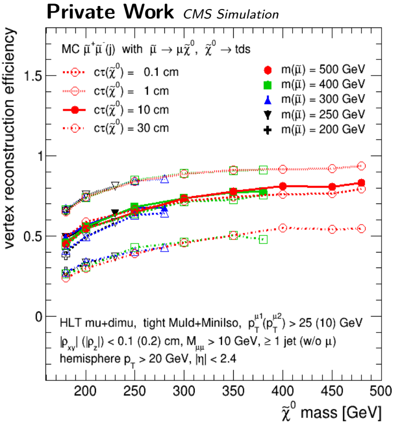
Efficiency for Tight WP

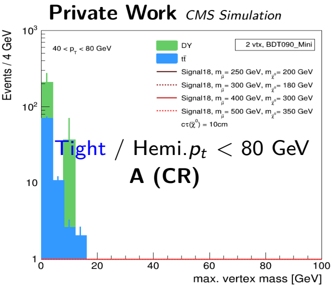


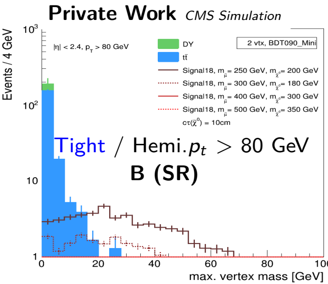


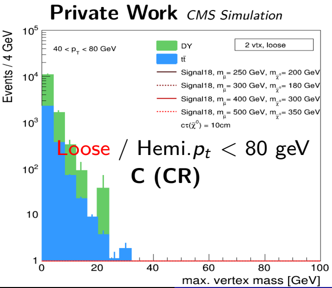
Efficiency : ratio of the number of matched vertices ($\Delta L_{SV-\chi}$<0.1cm **or** $\frac{\Delta L_{SV-\chi}}{\Delta L_{SV-PV}} < 0.1$) with the number of vertices that should be reconstructed

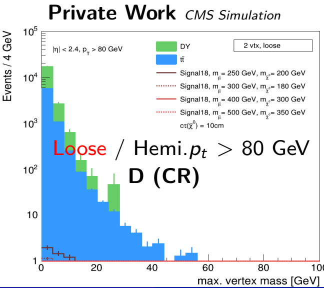
Purity : ratio of matched vertices (with gen vertices) with the number of vertices having a good χ^2 $(0 < \frac{\chi^2}{Dof} < 10)$

Event Yields 2018 (2 vertex category, 13 TeV, $60 fb^{-1}$)









Conclusion

1. Clear analysis strategy
2. Efficient Vertexing procedure
3. Finishing the tuning of the background estimation method

Future :

1. Study Run 3 data
2. Implement Systematic uncertainties
3. Perform statistics analysis, look for excess or limit

Thanks a lot !!

Trugarez Vras !!