Searches for stop production 8 & 13 TeV

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LIP Jornadas
16/02/2018

Outline

- Motivation for stop production
- “Landscape” for a Susy, stop search
- Innovations we (LIP-CMS) have brought to these searches
- Searches of stop in 2- & 3-body decays
  - 8 TeV
- Searches of stop in 4-body decays
  - 8 & 13 TeV
- Conclusions & perspectives

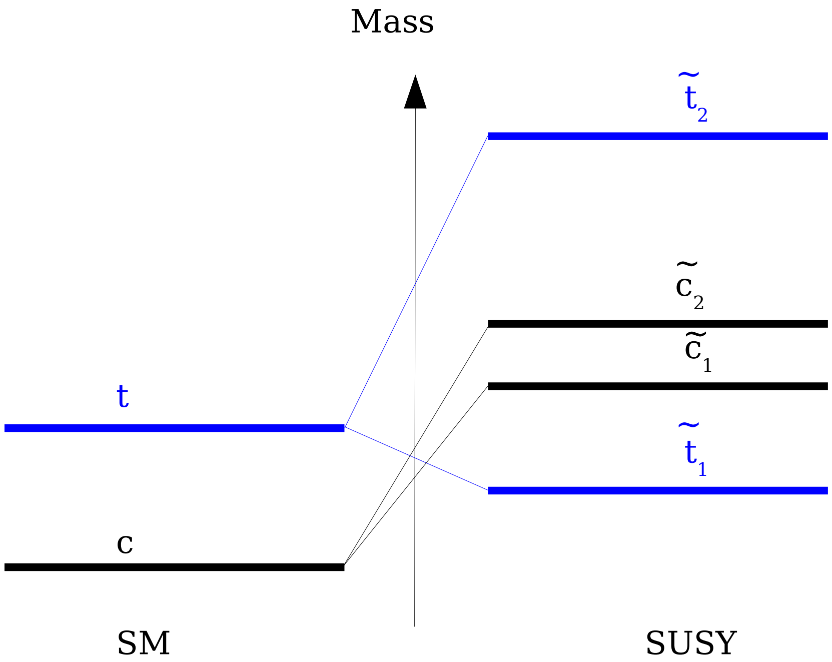
Motivation for stop production

$$M^2_{\tilde{t}} = \begin{pmatrix} \tilde{M}_Q^2 + M_T^2 + M_Z^2\left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right)\cos 2\beta & M_T\left(A_T + \mu\cot\beta\right) \\ M_T\left(A_T + \mu\cot\beta\right) & \tilde{M}_U^2 + M_T^2 + \frac{2}{3}M_Z^2\sin^2\theta_W\cos 2\beta \end{pmatrix}_{\text{Up squarks}}$$

Mass difference of quark superpartners proportional to $M_Q = M_t$:

Strong mixing in the stops $t_{1,2}$ sector ?

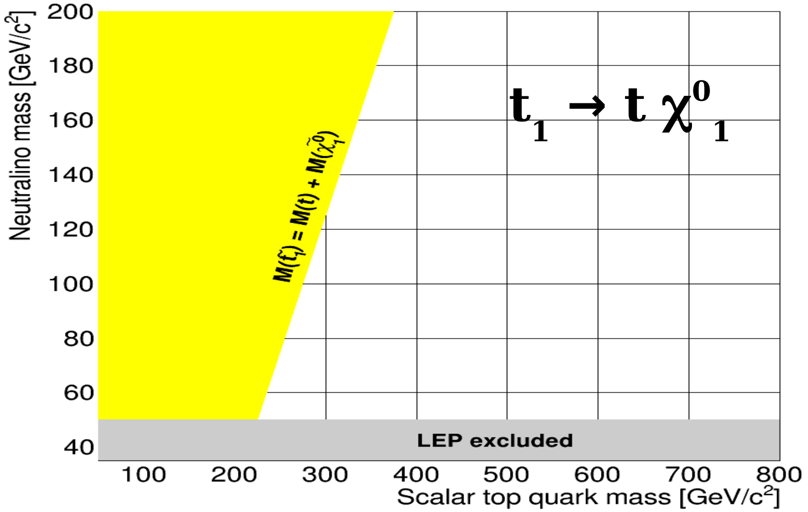
t_1 might be the lightest squark

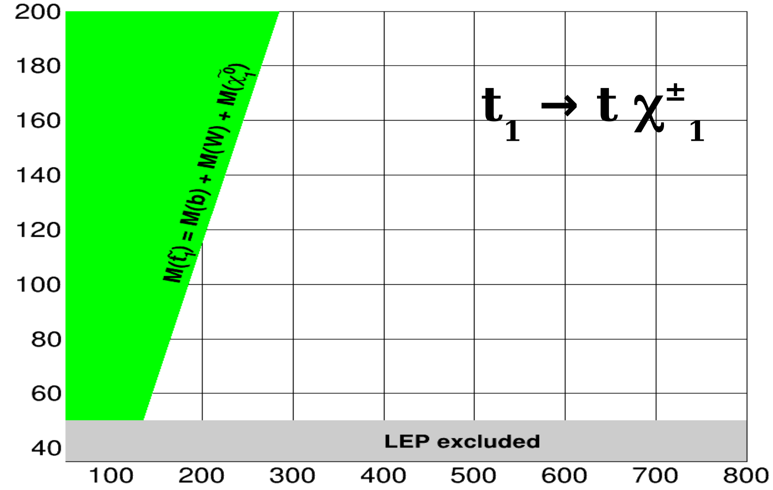


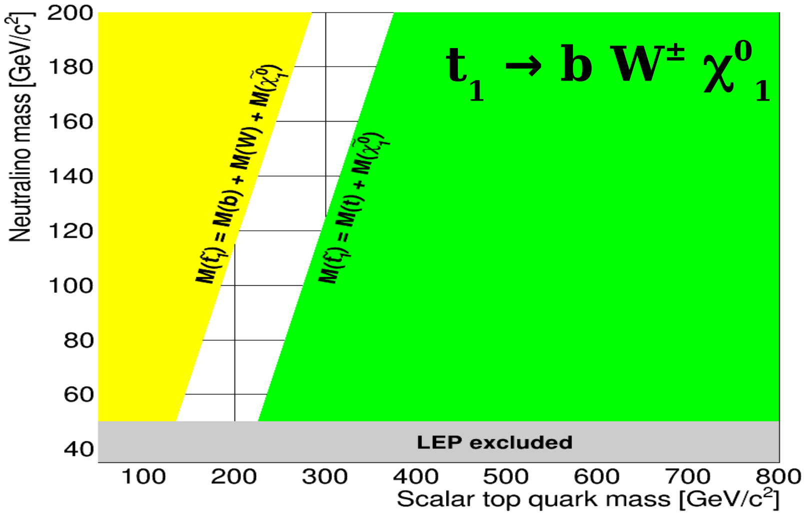
“Landscape” for a Susy/stop search

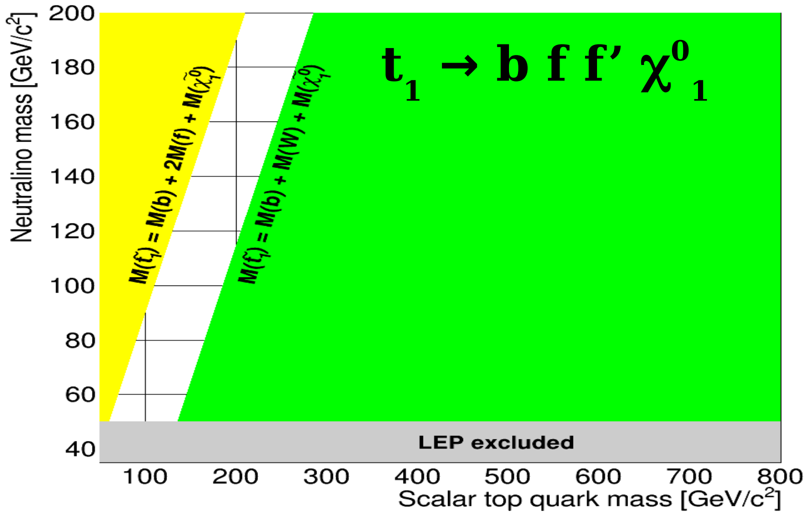
Cover as much mass hypothesis & decay scenarios as possible:

Be as model-independent as possible



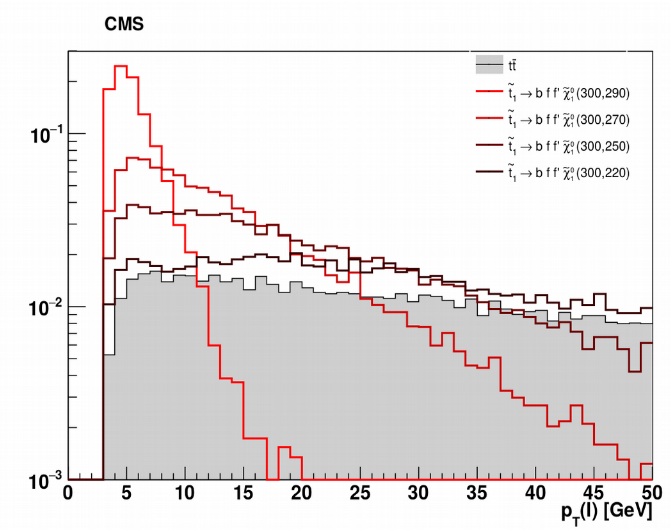


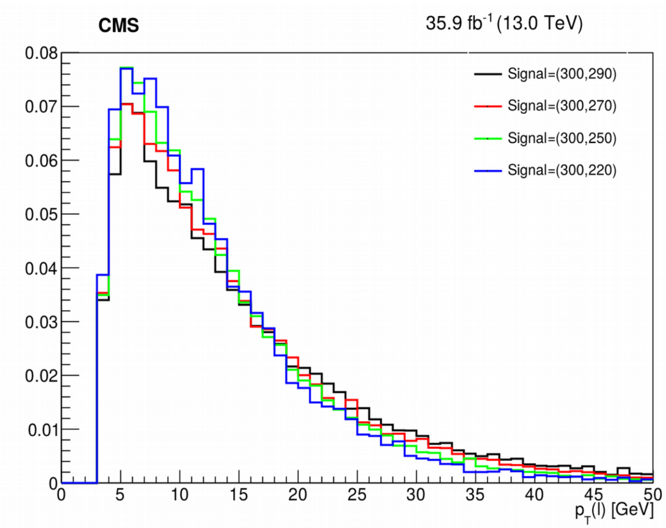




Innovations brought by LIP-CMS

- MVA approach for 3rd generation Susy searches
- Variation of signal versus Δm: Main parameter describing kinematically different signals

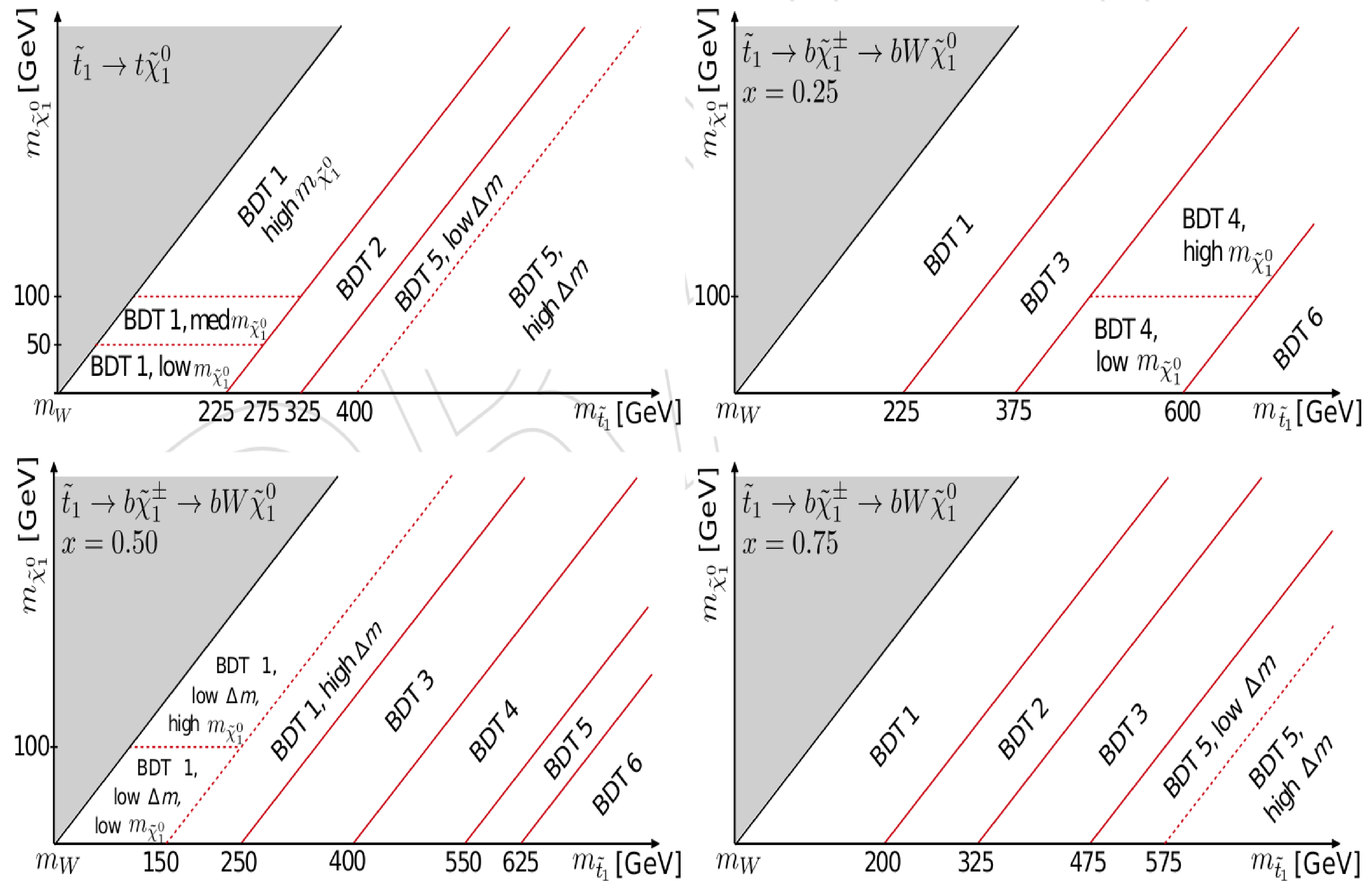




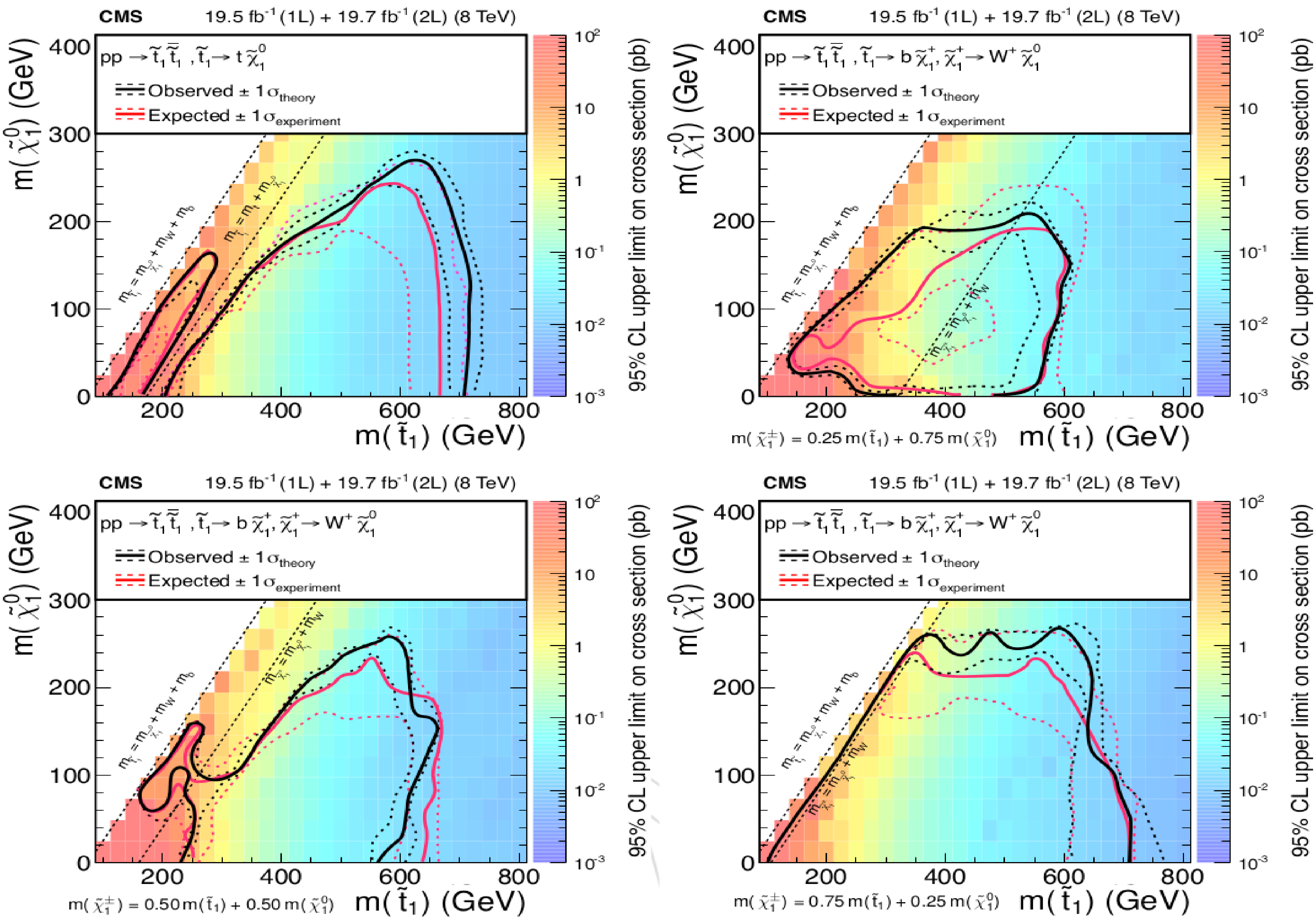
- → One MVA tool per each Δm of signal: Best selection for each signal hypothesis
- Quantitative rationale for including input parameters for MVA tool: Maximization of FOM: Obtain most reduced & best performing set of input variables

$$FOM = \sqrt{2\left((S+B)\,ln\left(\frac{(S+B)\cdot(B+\sigma_B^2)}{B^2+(S+B)\cdot\sigma_B^2}\right) - \frac{B^2}{\sigma_B^2}\,ln\left(1+\frac{\sigma_B^2\cdot S}{B\cdot(B+\sigma_B^2)}\right)\right)}$$

2- & 3-body decays: 8 TeV 1 lepton final state



2- & 3-body decays: 8 TeV 1 lepton final state



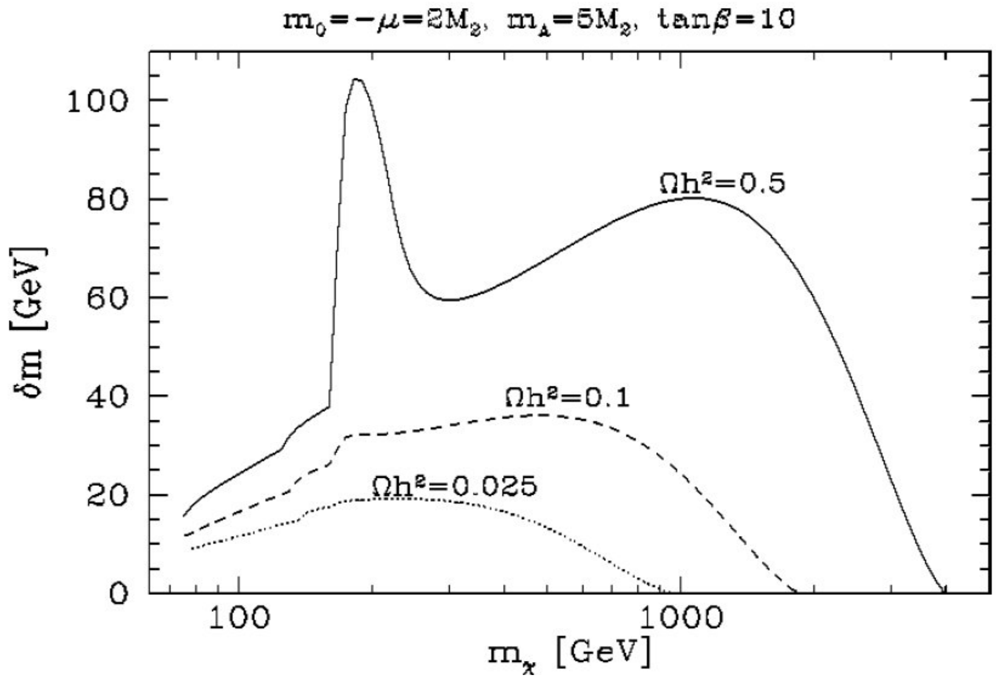
2- & 3-body decays: 8 TeV 1 lepton final state

LIP-CMS manpower involved: 1 researcher + 1 postdoctoral fellow

- **Responsable of signal selection**
- **Collaboration:** 6 people involved through 3 institutes
- **Editorial:** Editor of the 8 TeV legacy paper:
  - “Search for direct pair production of scalar top quarks in the single- and dilepton channels in proton-proton collisions at $\sqrt{s}$=8 TeV” JHEP 07 (2016) 027

Motivation for 4-body decays of stop

SUSY's candidate for Cold Dark Matter: χ_1^0



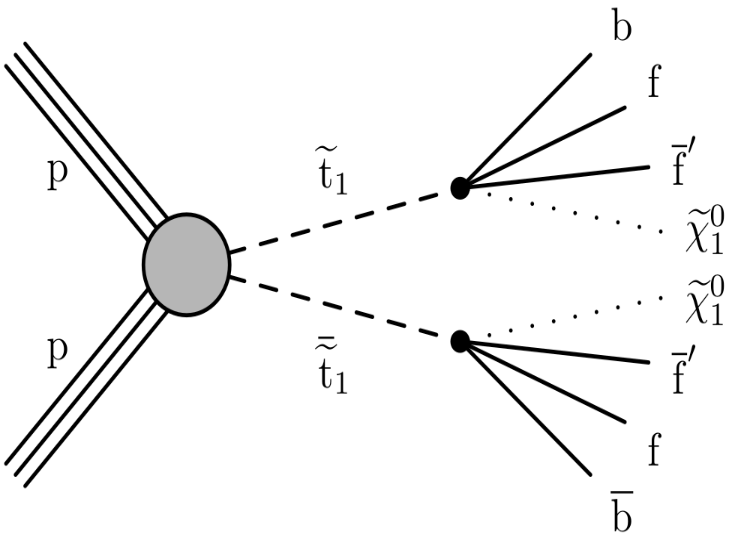
$\Delta m = M(t_1) - M(\chi^0_1) \leq 50\ GeV/c^2$:

Compatible with

$\Omega_{CDM}h^2$ = 0.11 ± 0.01 @ 95% CL (WMAP)

Kinematically closes 3-, 2-body decays:

Open phase-space for 4-body decays



Challenging because limited phase-space:
Very soft decay products

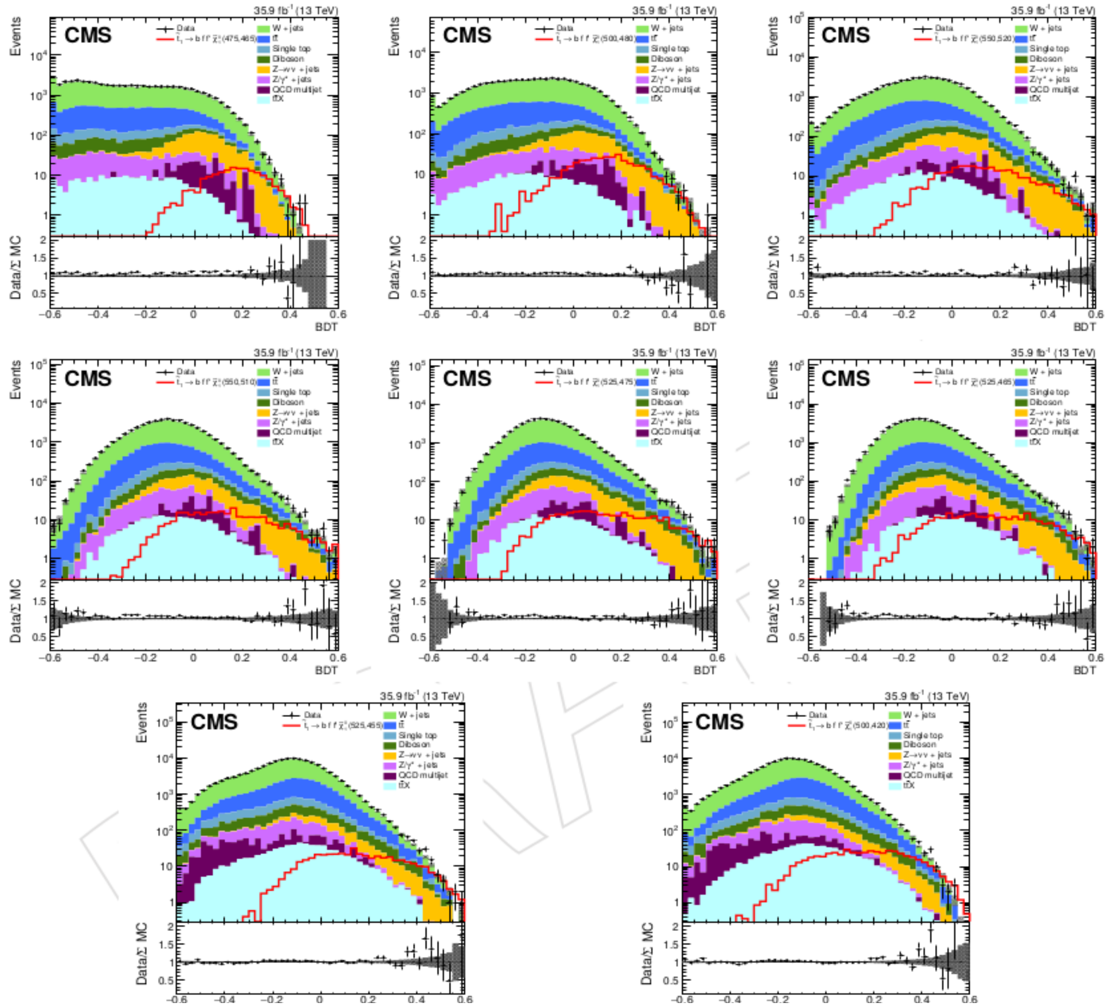
4-body decays: 8 TeV 1 lepton final state

LIP-CMS manpower involved: 1 researcher collaborating with colleagues of Vienna

- **Cut & Count approach**
- **Signal selection:**
  - Introduced new selection variables: $p_T(j)$, H_T, b-tag, $\eta(l)$
  - Optimization: Definition of signal regions
- "Search for supersymmetry in events with soft leptons, low jet multiplicity, and missing transverse energy in proton-proton collisions at $\sqrt{s}=8$ TeV" Phys. Lett. B 759 (2016) 9-35

4-body decays: 13 TeV 1 lepton final state

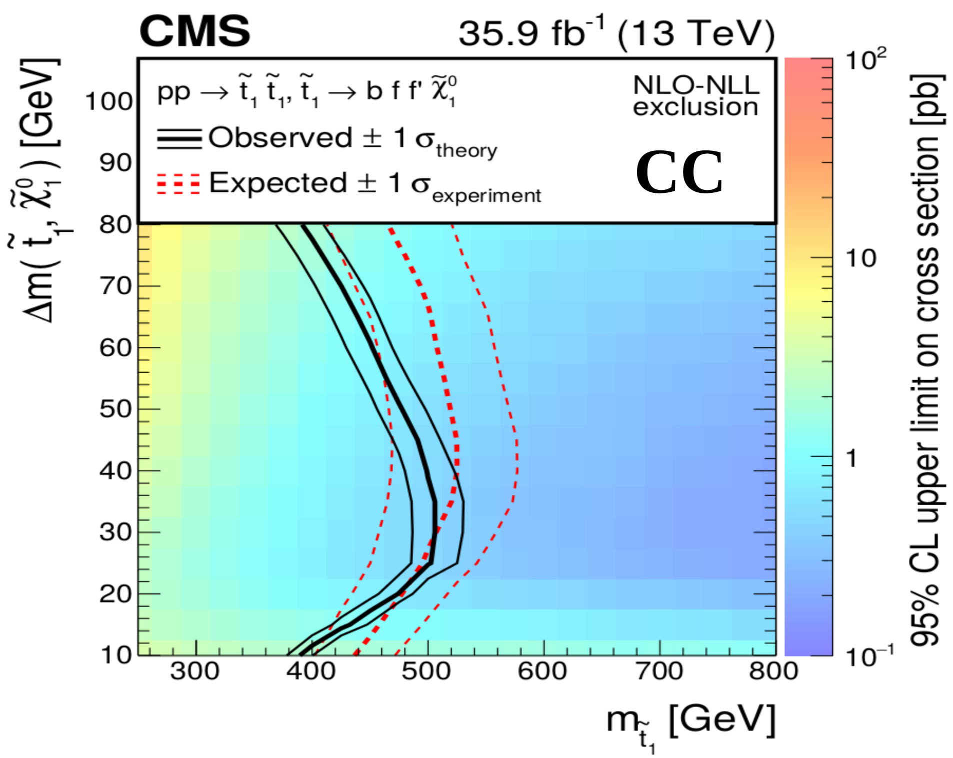
- 8 different BDTs trained, 1 per each Δm. Same set of input variables
  - $p_T(l)$, $Q(l)$, $\eta(l)$,
  - MET, M_T,
  - N(jet), p_T(jet1), H_T,
  - N(b), $p_T(b)$, $\Delta R(l,b)$
  - CSV(jet w high b-disc)

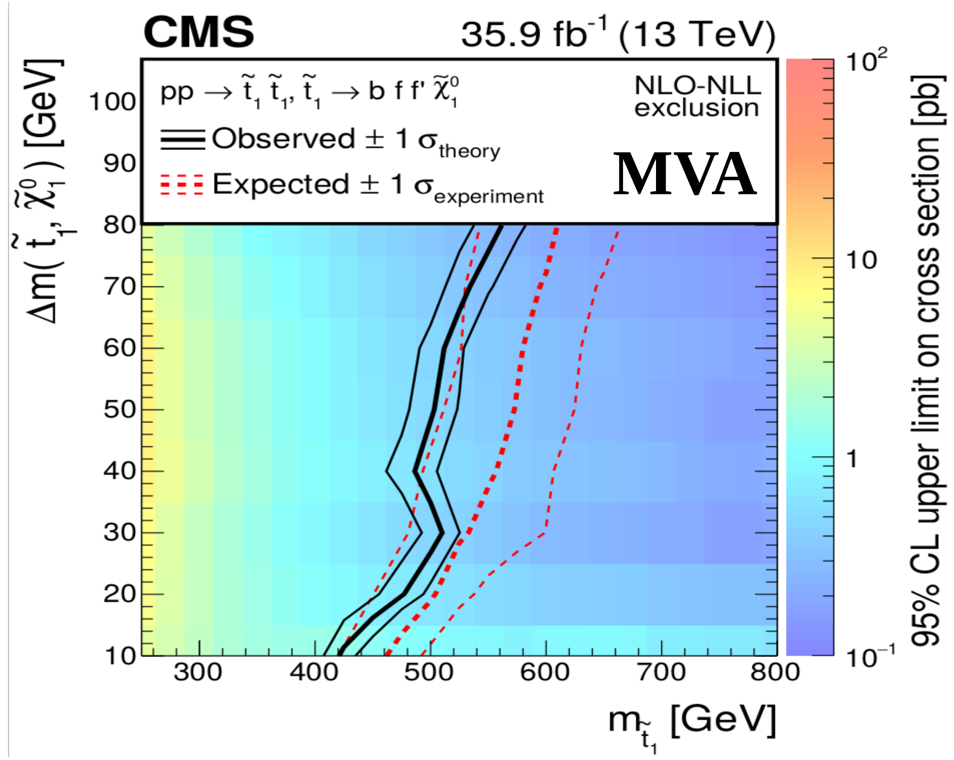


Premiere: 1st search to make a DD background prediction based on output of MVA

$$N^{SR}_{\text{DDprompt}}(X) = \quad T_X \cdot N^{CR} = \left[\frac{N^{SR}_{\text{prompt}}(X)}{N^{CR}_{\text{prompt}}(X)}\right] \cdot \left[N^{CR}(\text{Data}) - N^{CR}_{\text{prompt}}(\text{Other}) - N^{CR}_{\text{DDfake}}\right]$$

4-body decays: 13 TeV 1 lepton final state





LIP-CMS manpower involved: 1 researcher + 1 postdoctoral fellow

- **Entire MVA search**
- **Collaboration:** 2 (LIP) + 4 Vienna
- **Editorial:** Editor of the draft paper:
  - "Search for top squarks decaying via four-body or chargino-mediated modes in the single-lepton final state at $\sqrt{s}$ = 13 TeV". Under CWR, to be sent to JHEP

Conclusions & perspectives

- **CMS-LIP had/has seminal contributions in searches of stop @ CMS**
- **2015-2018:** Two published results, one coming
- **Manpower @ LIP:** 1 researcher +
  - 2 postdoctoral fellows: L. Lloret, C. Da Cruz e Silva
  - 2 + 3 summer students in 2016 & 2017
- **Perspectives:**
  - Search of stop in 4-body decays with MVA continues: Deep NN where we expect better results than with BDT
    - D. de Bastos joined PhD programme through IDPASC
      - See poster
  - Investing our MVA expertise in $H \rightarrow \tau\tau$ measurement... but that is another story

Back-up

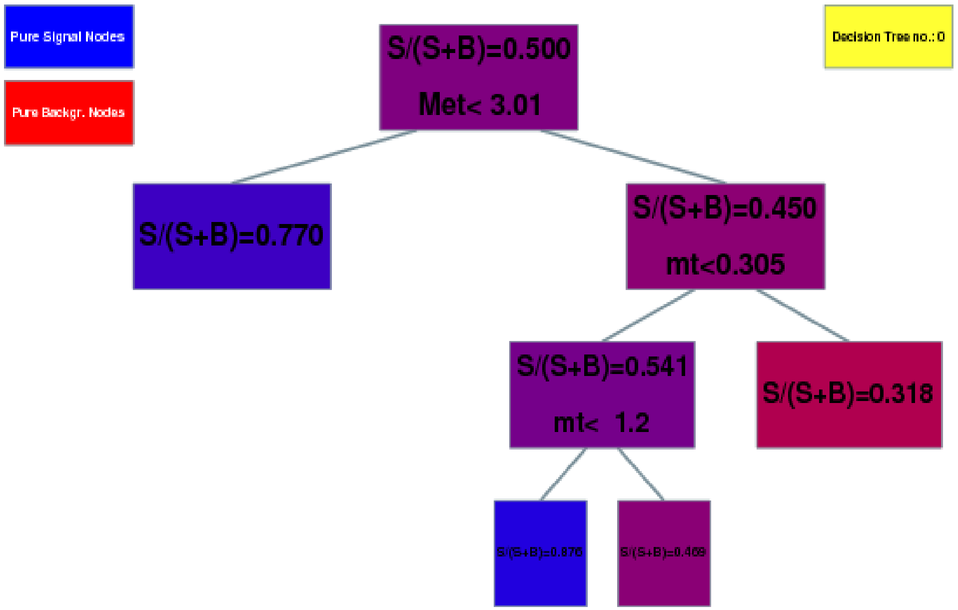
BDT training: Internal parameters

Ntrees=400:MinNodeSize=2.5%:MaxDepth=3:VarTransform=D

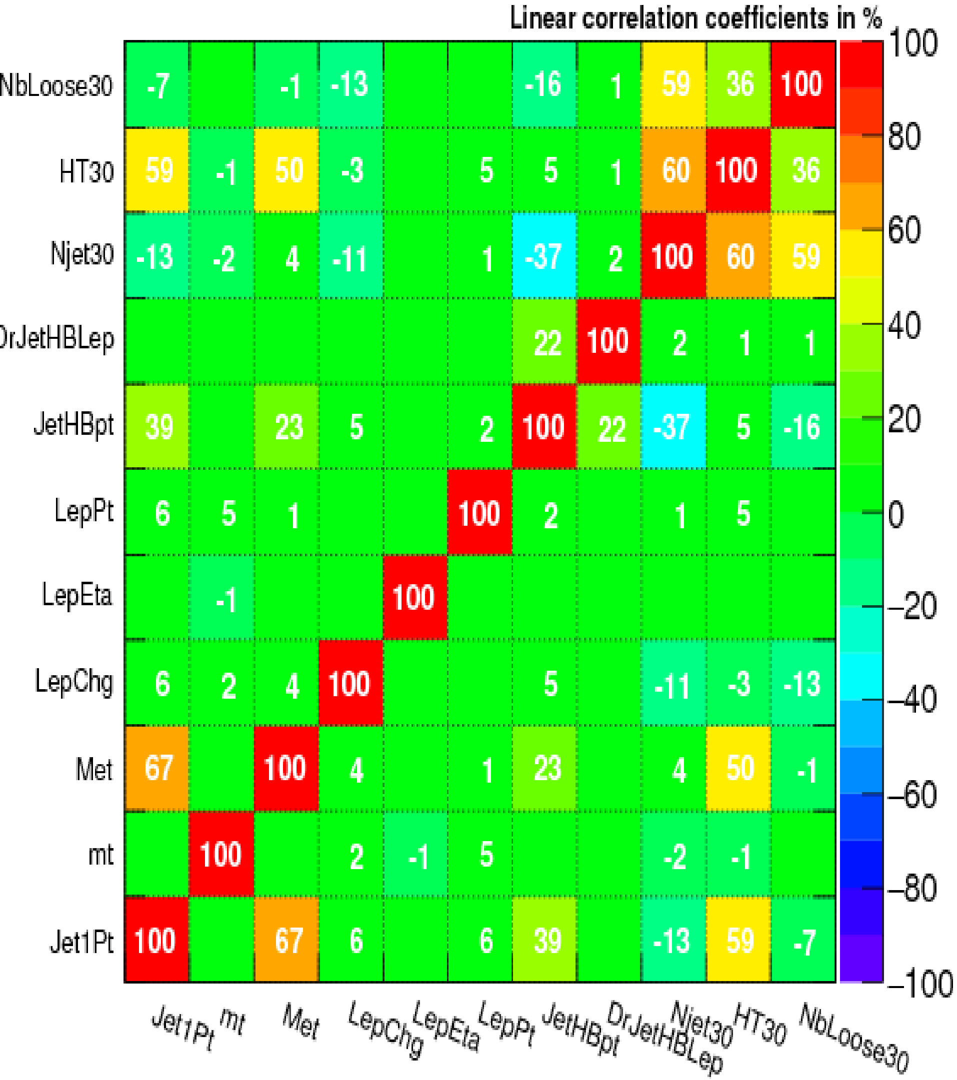
- Ntrees: Number of trees in BDT
- MinNodeSize: Percentage of N_S or N_B @ which splitting of data stops
- MaxDepth: Maximal number of cut levels the BDT can reach
  - 2 last parameters: Stopping conditions of the training
- Optimal use of a BDT: "VarTransform=D"

  Diagonalize the n-Dimensional space of input variables before feeding them to the BDT, for BDT to cut on them linearly. i.e. rotates the basis of variables along axis where more 1D discrimination is more present

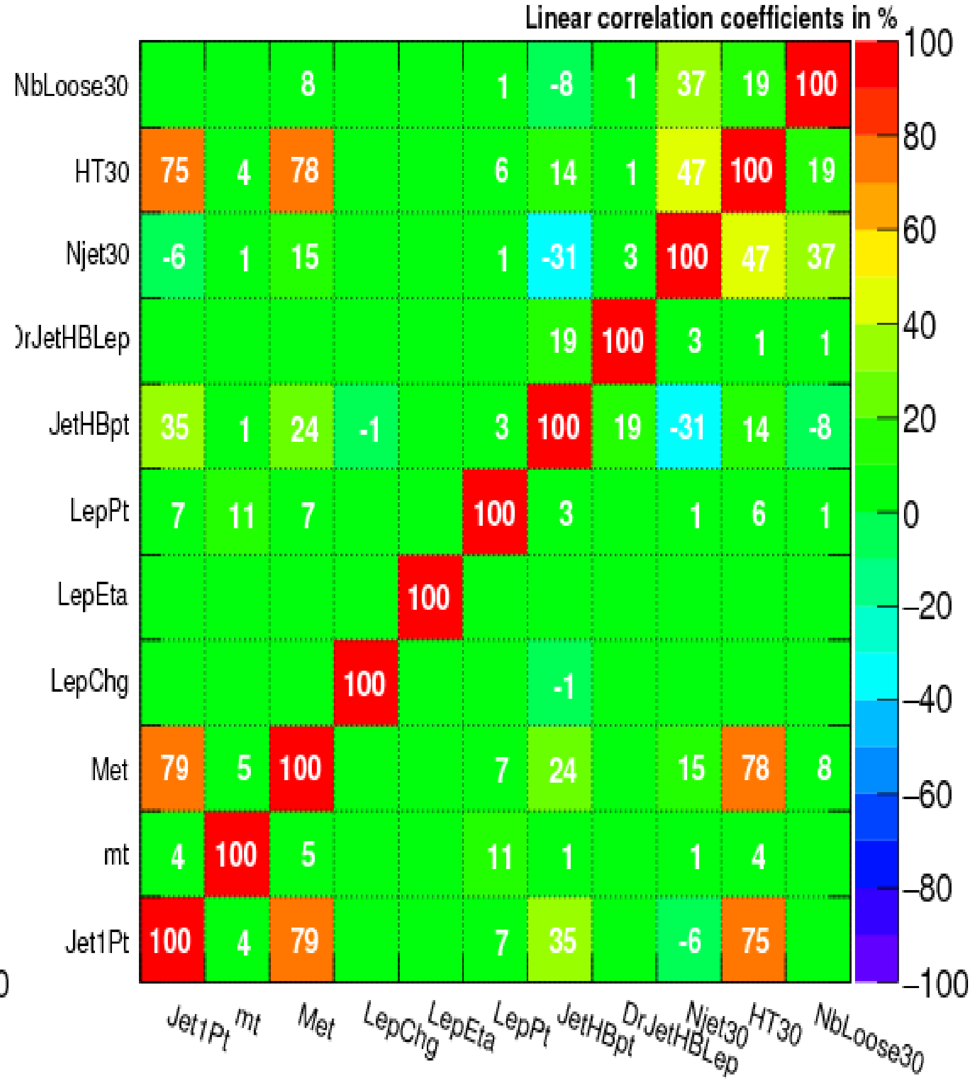
<u>Internal parameters</u>:
Optimized with a base set of variables to have best performance while no over-training



Correlation Matrix (background)



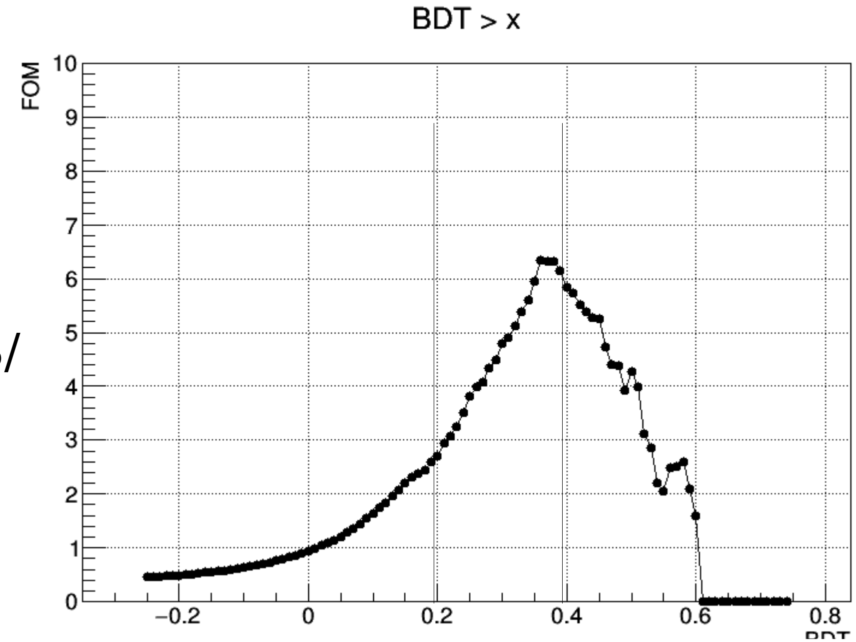
Correlation Matrix (signal)

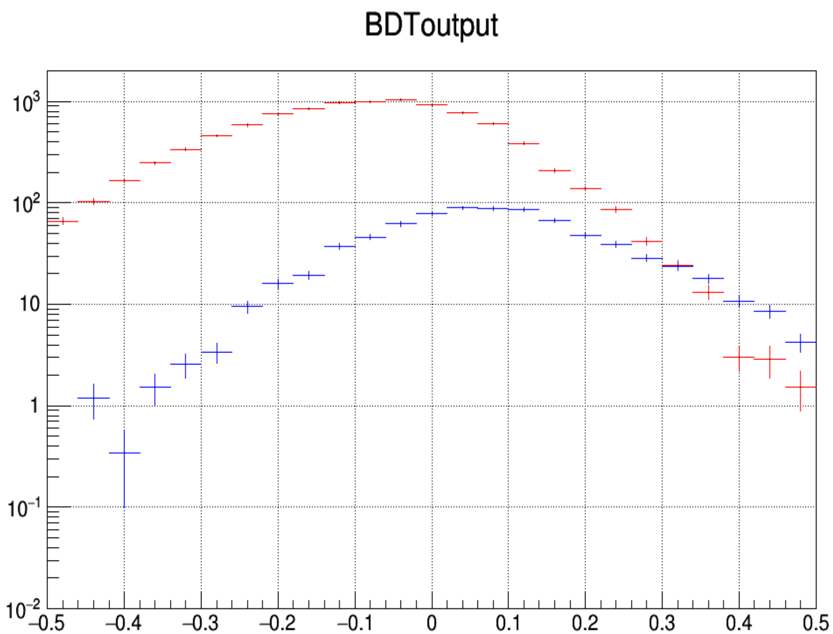


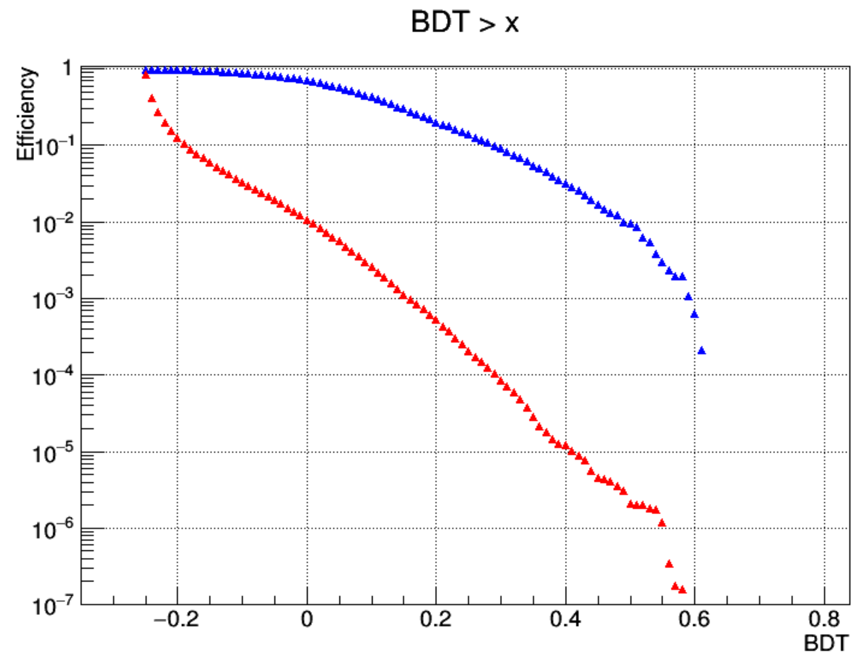
Selection for Δm = 30: Input variables

SetBase1

- FOM(300,270)=6.34 @ BDT>0.36
- S=50.5
- B=17.0
  - Wjets1/2/3/4/5/6/7=0/2.3/3.9/3.8/3.6/0.5/0
  - ttbar=2.9

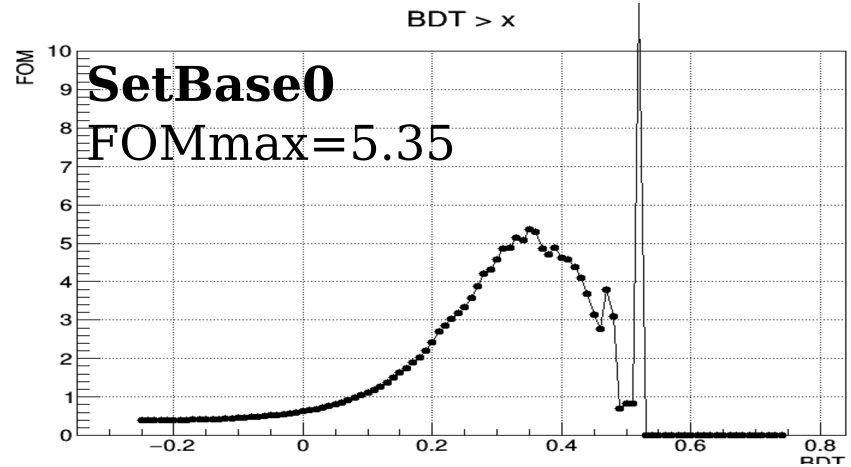


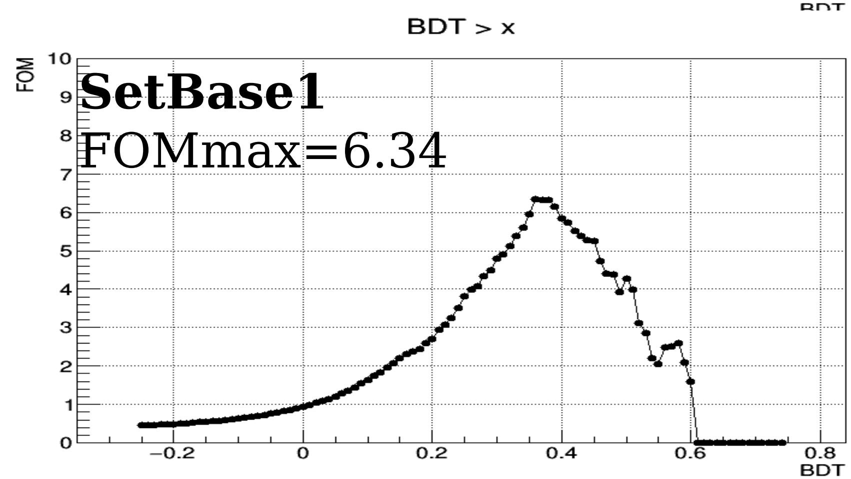


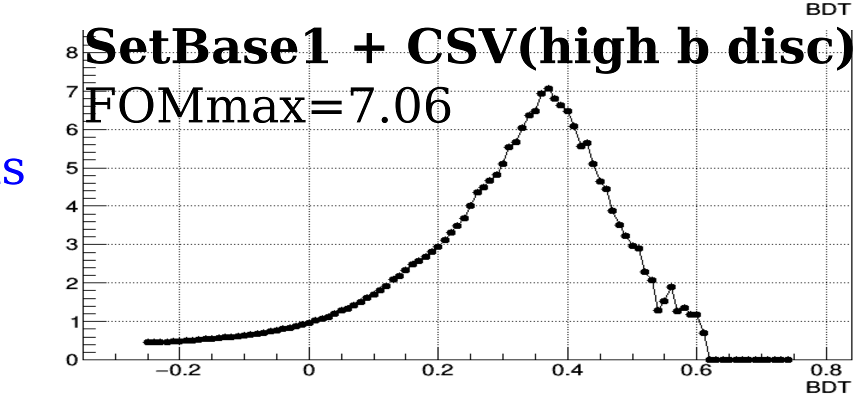


Comparison with CC via σ^{exp}(UL)

- **CC**
  - Expected 50.0%: r < 0.5332
- **SetBase0**
  - Expected 50.0%: r < 0.3135
- **SetBase1**
  - Expected 50.0%: r < 0.2412
- **SetBase1 + CSV**
  - Expected 50.0%: r < 0.2197







1/ The σ^{exp}(UL) picture confirms the FOM picture
2/ Even when taking the most reduced set of variables (variables of CC analysis = SetBase0), the BDT performs better than CC
3/ The improvement across the 3 sets is clear