Search for $\tilde{t}_1$ production in single lepton signatures

Pedrame Bargassa

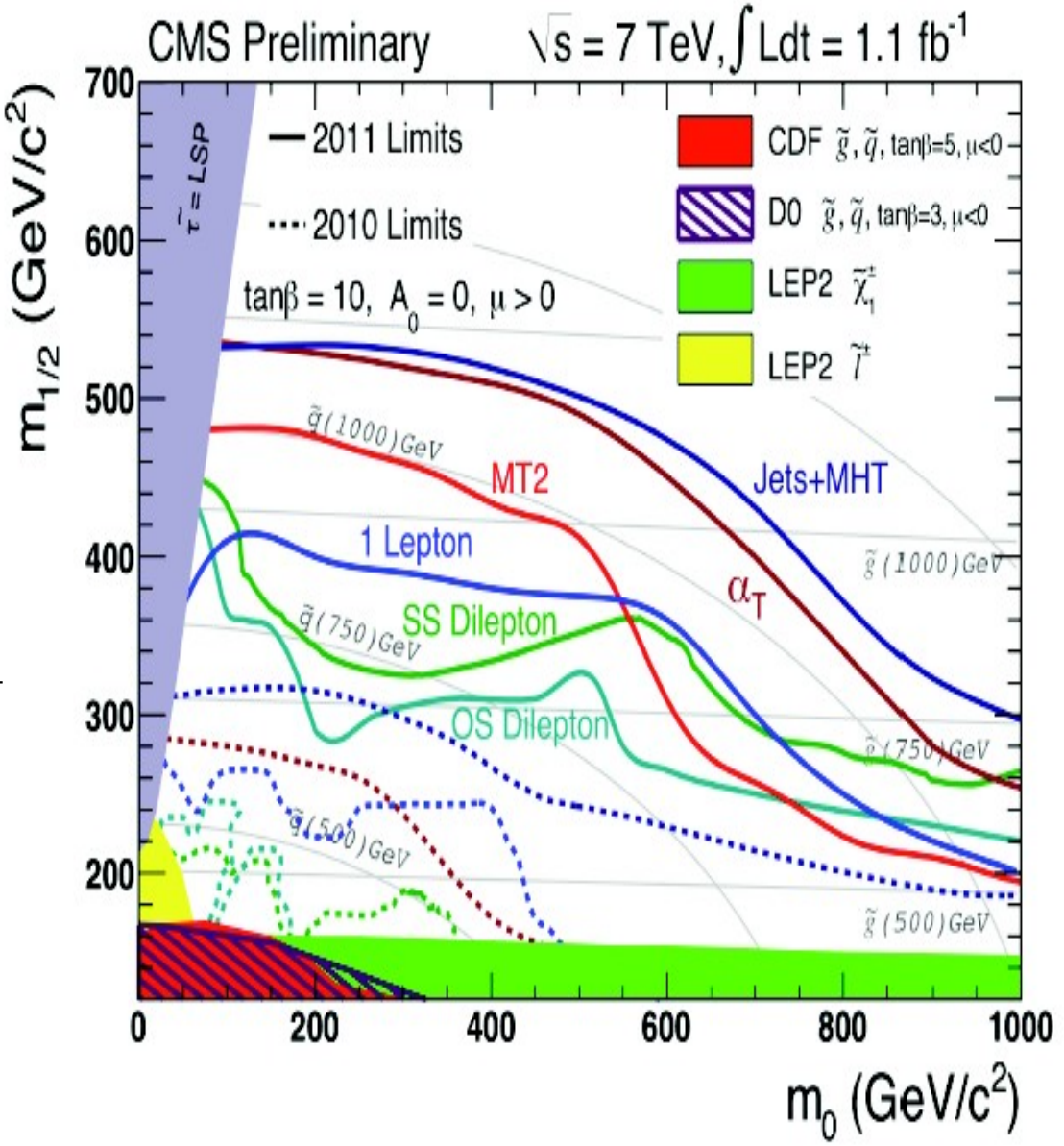
LIP jornadas
22/04/2012

Summary of all CMS Susy searches, interpreted within mSUGRA

We can (very well) have the scenario where:
→ Squarks & gluino are so massive that out of reach of LHC
→ But $\tilde{t}_1$ is within reach: All these searches were quite general, not specifically looking for a given sParticle

A lot of interest for $\tilde{t}_1$ now:

It's rather low σ
It's sometimes "sitting on" SM
But it might be the only sParticle reachable



Motivation for 3rd generation squarks

MSSM Lagrangian with soft breaking terms :

Quark left- & -right superpartners (scalars) can strongly mix to form mass eigenstates :

$$M^2_{\tilde{q}} = \begin{pmatrix} \tilde{M}^2_Q + M^2_Q + M^2_Z\left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right)\cos 2\beta & M_Q\left(A_T + \frac{\mu}{\tan\beta}\right) \\ M_Q\left(A_T + \frac{\mu}{\tan\beta}\right) & \tilde{M}^2_U + M^2_Q + \frac{2}{3}M^2_Z\sin^2\theta_W\cos 2\beta \end{pmatrix}$$

"Up" squarks

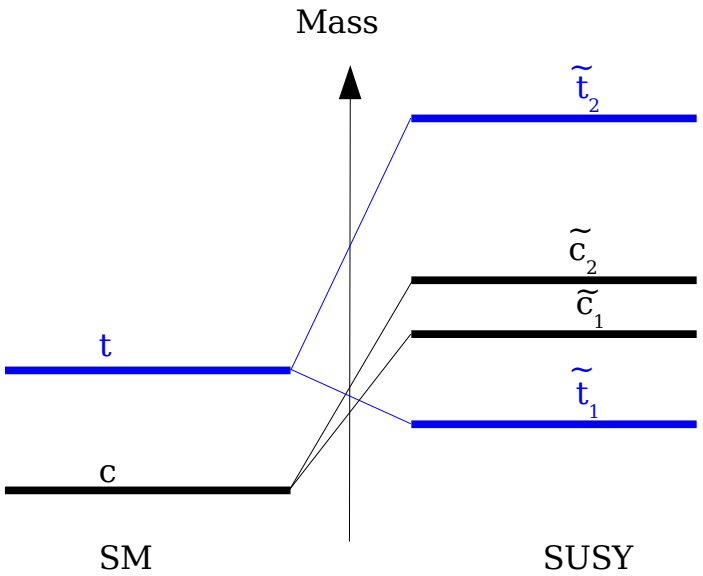
A_T : Tri-linear (stop) mixing term

M_Q = SM quark mass

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

Strong mixing in the stops $\tilde{t}_{1,2}$ sector

→ $\tilde{t}_1$ might be the lightest squark



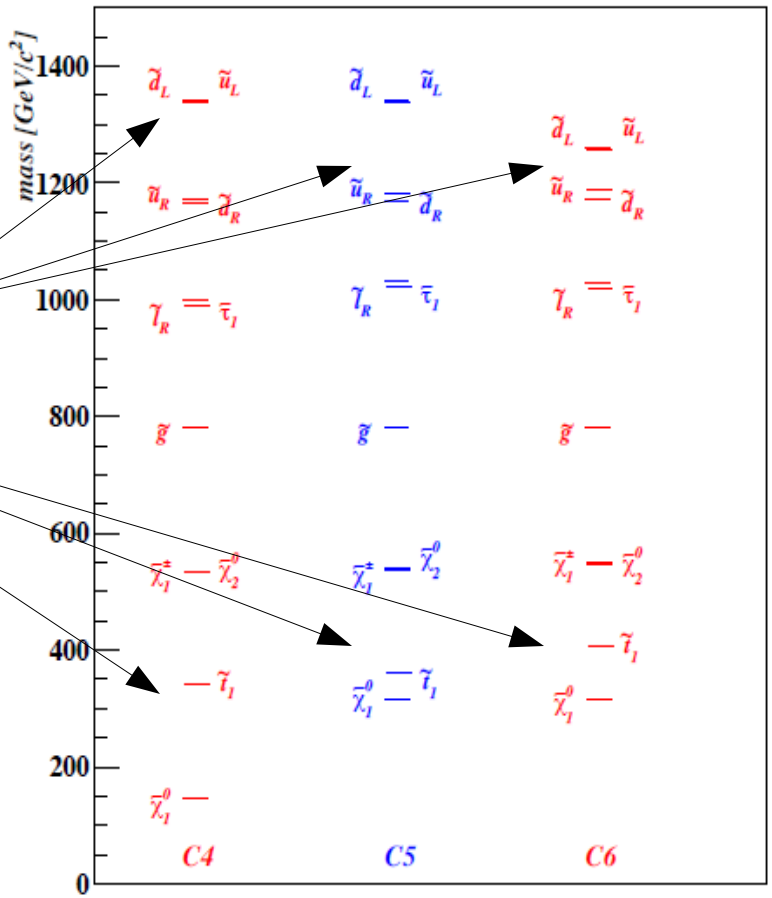
Where are we standing now: SUSY picture

compressed SUSY with light stops

“Decoupled” SUSY:

1/ Squarks & Gluino can be (quite) heavy
2/ $\tilde{t}_1$ can be (much) light(er)

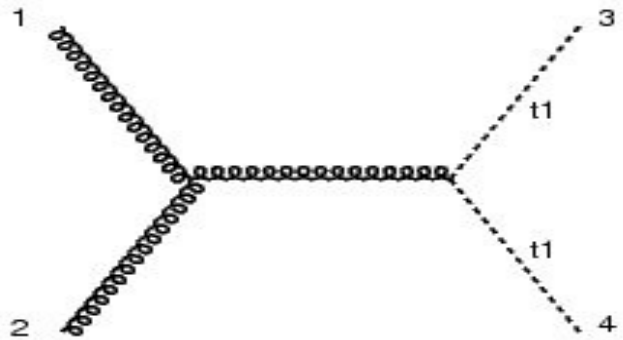
→ We can still solve the Higgs hierarchy problem @ TeV scale :-)

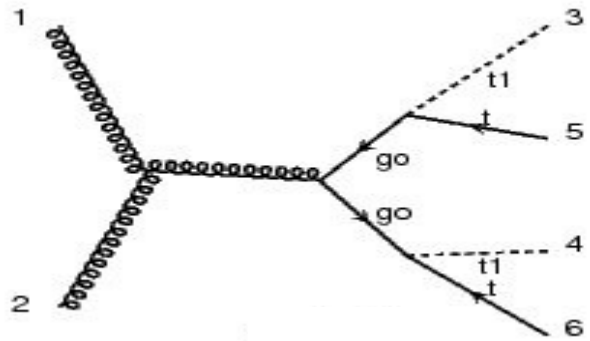


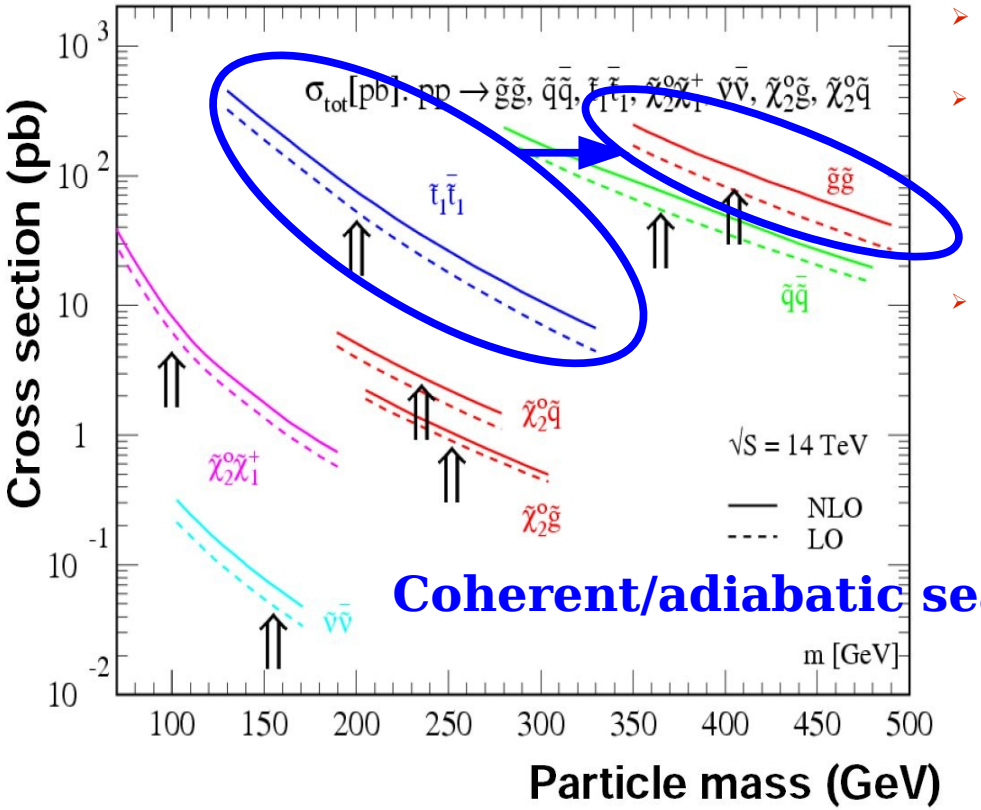
Joseph Lykken Fermilab

Strategy of search: From low to higher masses

Let's consider the 2 simplest & most abundant sources of $\tilde{t}_1$, if not SUSY...

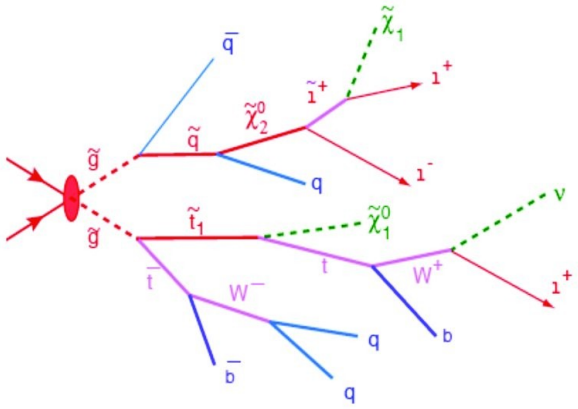






Coherent/adiabatic search

- σ: Most abundant
- Type of search: Simplest topologies, shortest decay chains while blessed by α_S @ production
- Kinematically: Decay objects still benefitting from larger phase-space than in long decay chains:

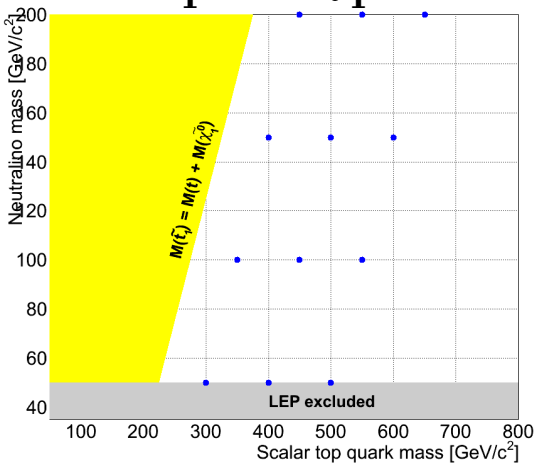


Strategy of search: As generic as possible

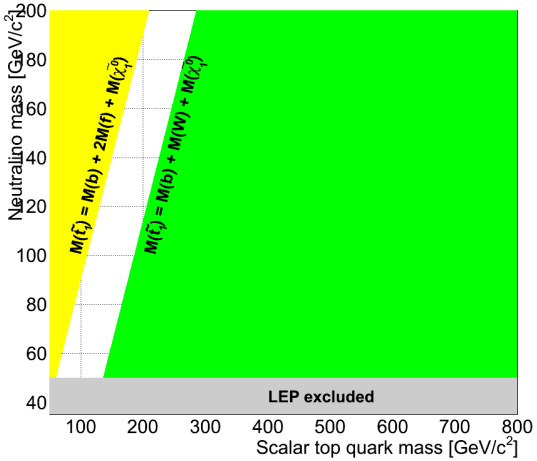
Be as **model-independent** as possible:
Only assume SUSY: Choose the less constrained SUSY framework: MSSM, and...

- **Scan across various unknow masses**
- **Consider as much as possible decay chains**

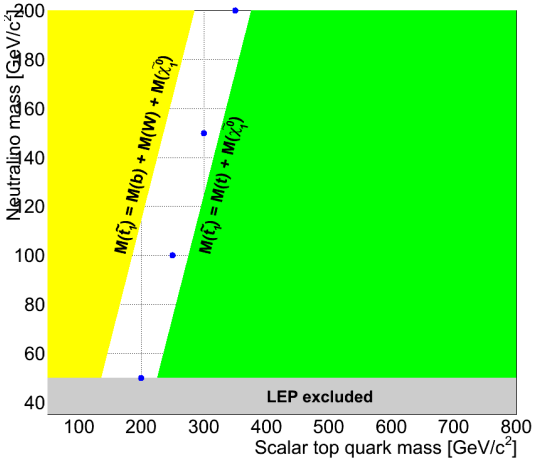
$\tilde{t}_1 \rightarrow t\,\tilde{\chi}_1^0$



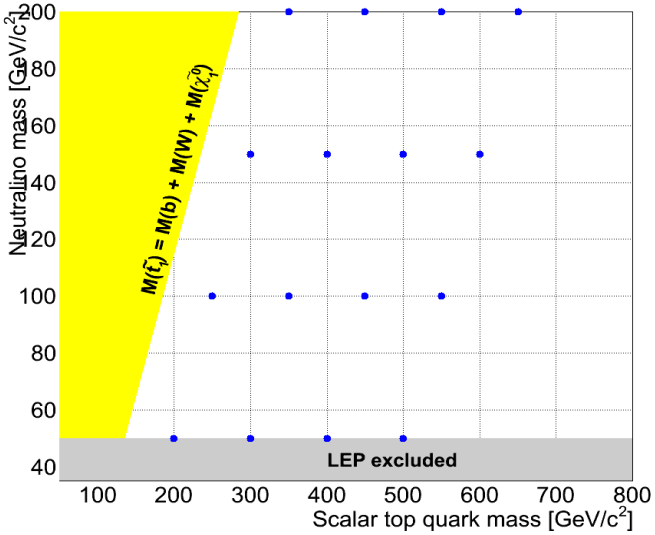
$\tilde{t}_1 \rightarrow b\,ff'\,\tilde{\chi}_1^0$



$\tilde{t}_1 \rightarrow b\,W^+\,\tilde{\chi}_1^0$



$\tilde{t}_1 \rightarrow b\,\tilde{\chi}_1^+$



$\tilde{t}_1$ searches: Final states

$\tilde{t}_1\tilde{t}_1$:

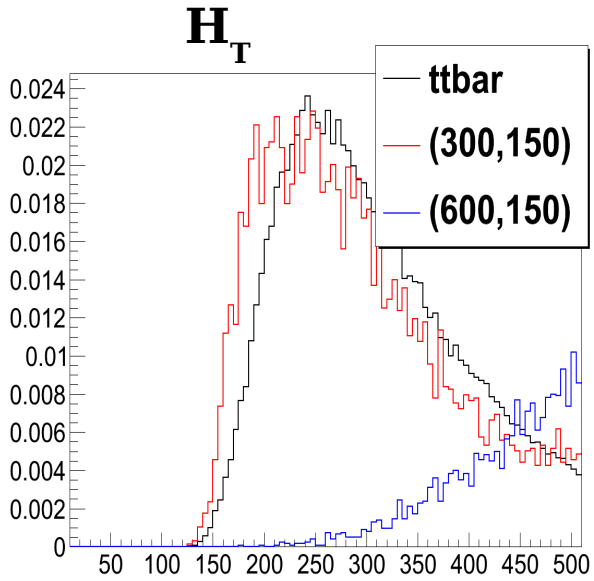
- 0 lepton + 2 b + 4 jets + MET
- 1 lepton + 2 b + 2 jets + MET
- 2 leptons: ~Negiligble impact because of Br (back-up)

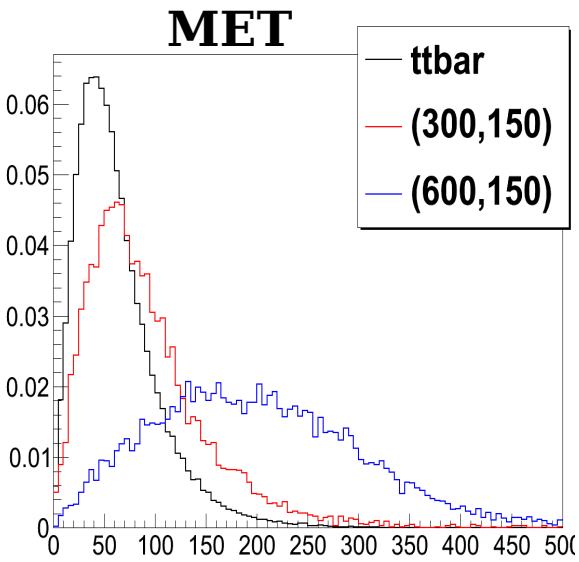
$\tilde{g}\tilde{g} \rightarrow t\,t\,\tilde{t}_1\tilde{t}_1$:

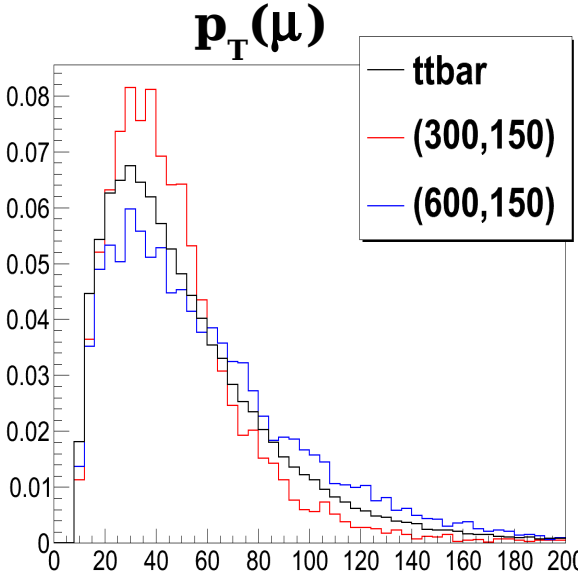
	4 l	2j + 3 l	4j + 2 l	6j + 1 l	8j + 0 l
4b + MET +	4e 4μ 2e2μ 1e3μ 3e1μ	2j 3e 2j 3μ 2j 2e1μ 2j 1e2μ	4j 2e 4j 2μ 4j eμ	6j 1e 6j 1μ	8j

$\tilde{t}_1\tilde{t}_1$ **production mode:** The challenge of top

Low Δm signal points, preferred by cosmology, **are very "top-like"**







→ If we want search for t_1 with "classic" variables/approach, we're on *route sans (grand) espoir....*

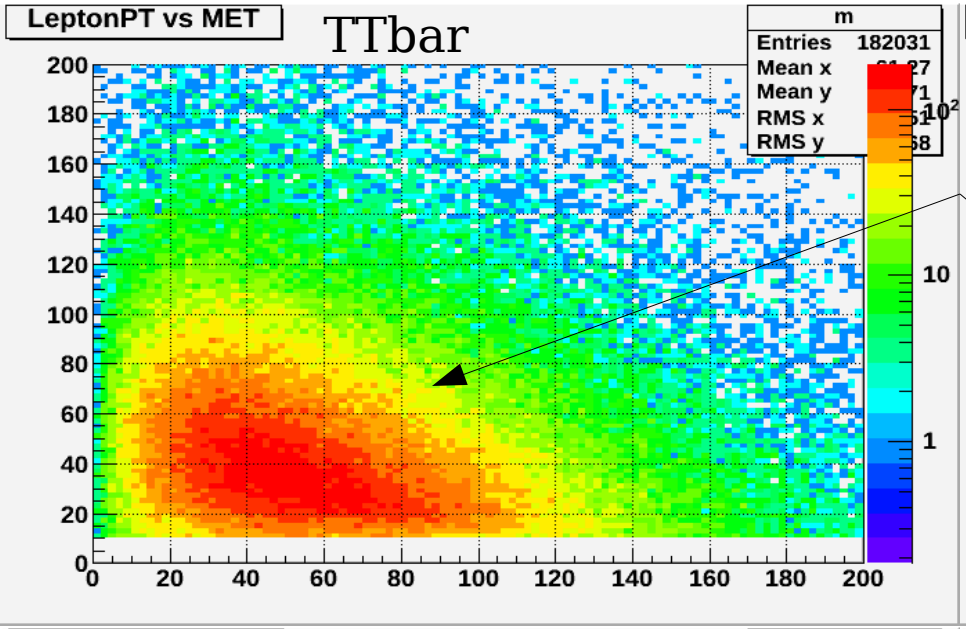
Developing a "anti-top-tagger"

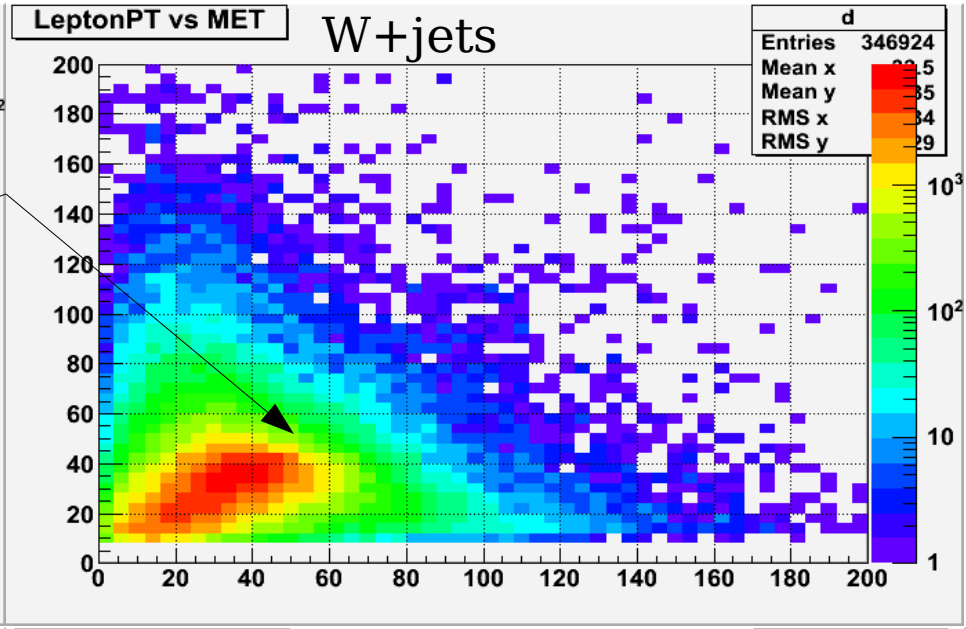
1/ Exploiting differences of correlation S ↔ B

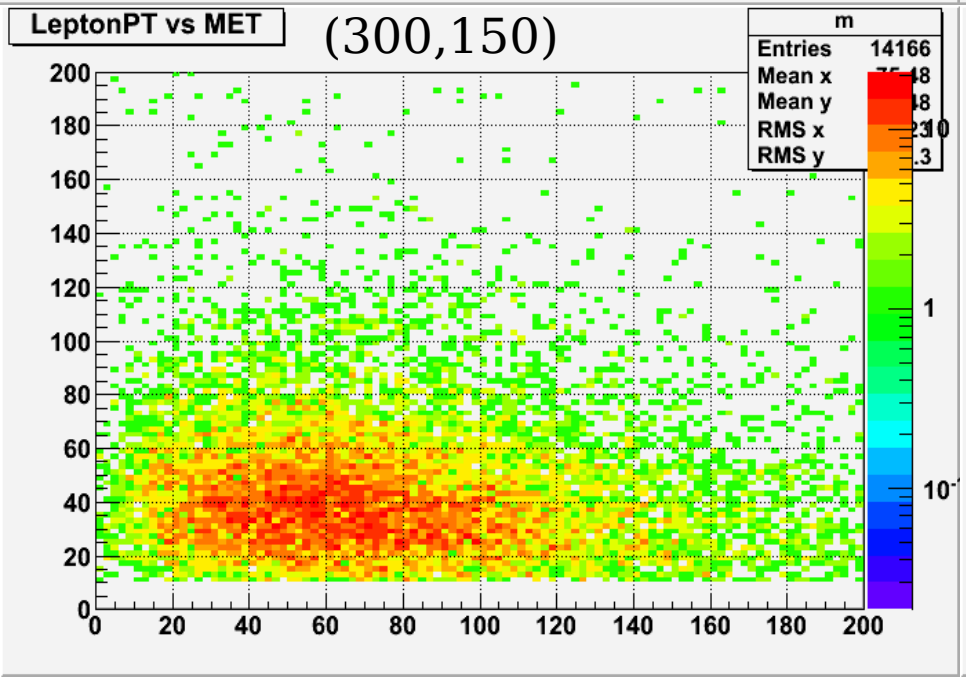
2/ Pioneering 3-jet invariant-mass variables

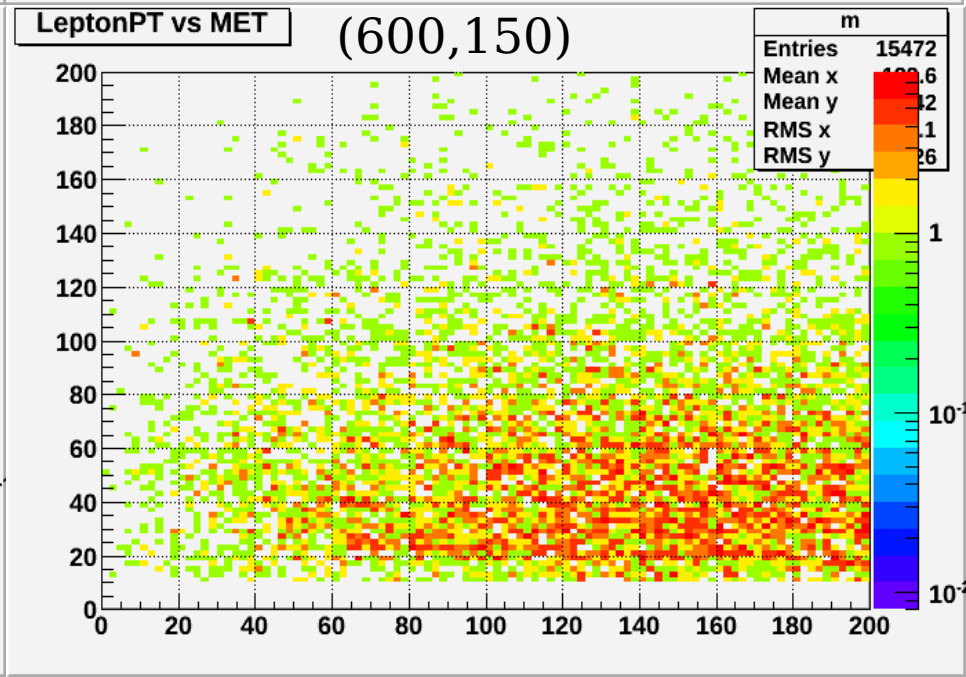
3/ Integrating this in a MVA approach

MVA: Variables & correlations

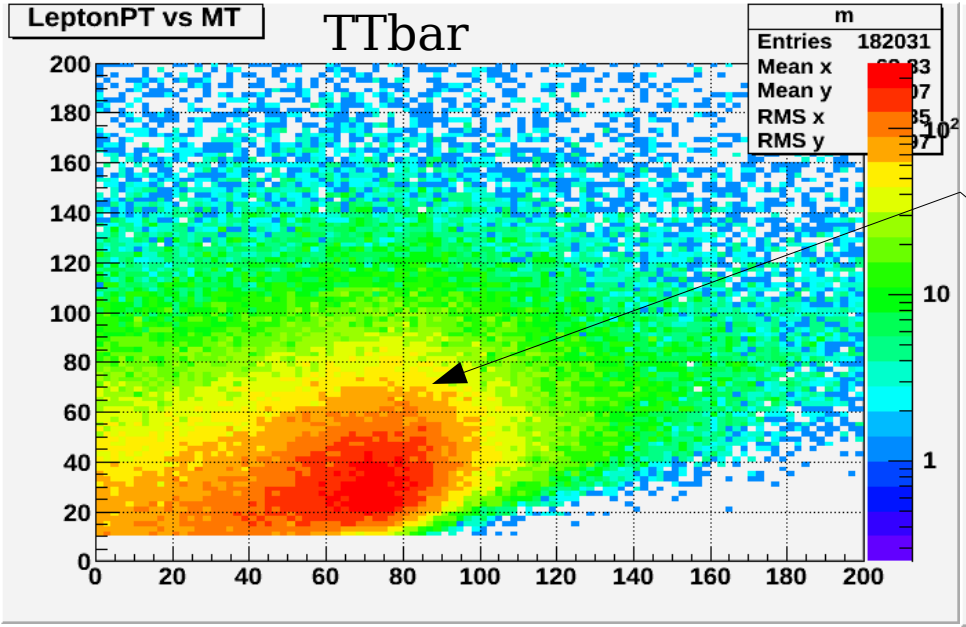


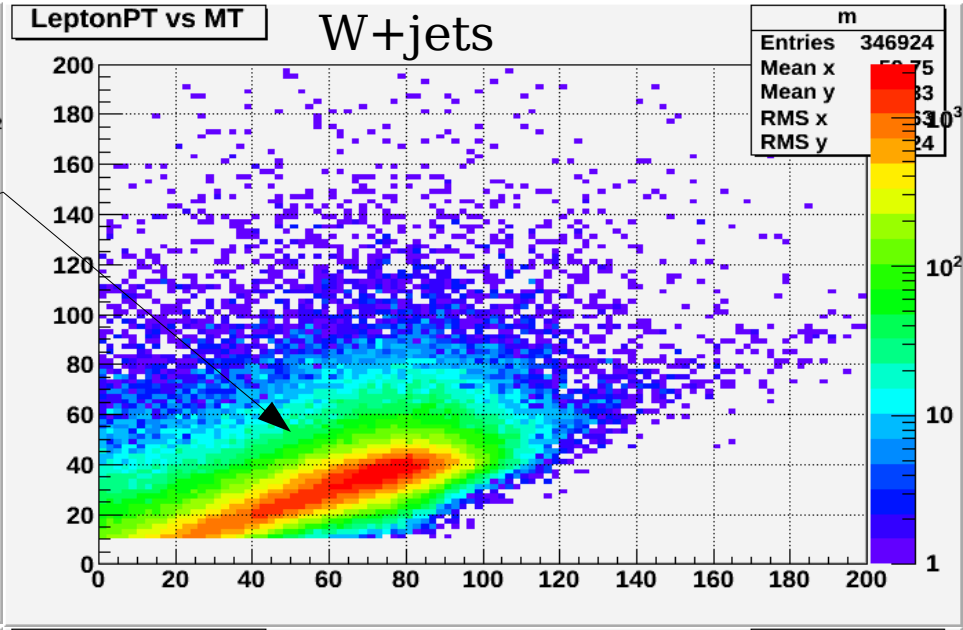


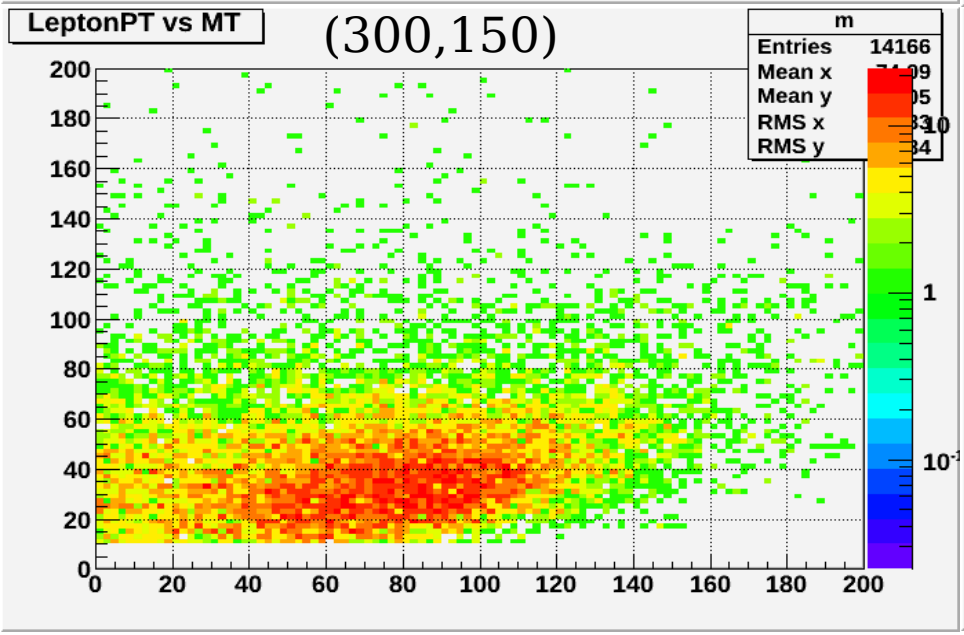


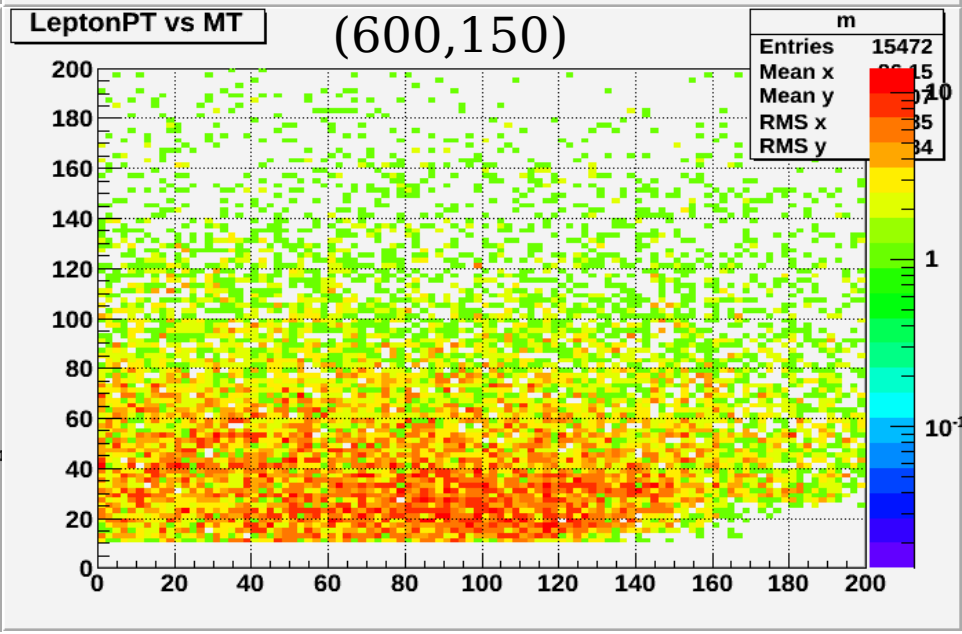


MVA: Variables & correlations



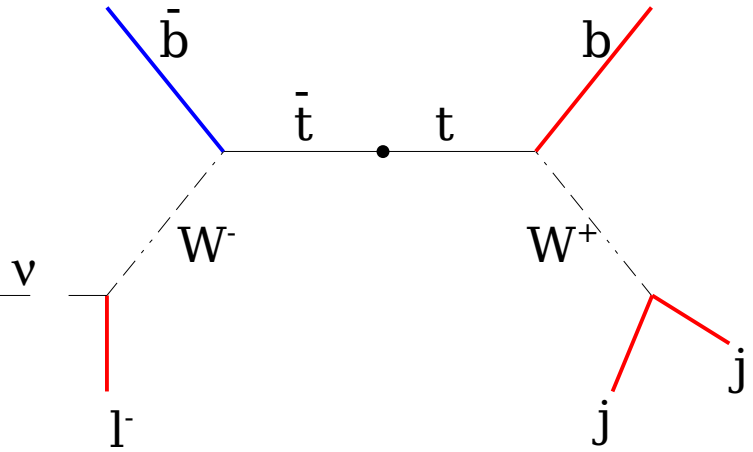


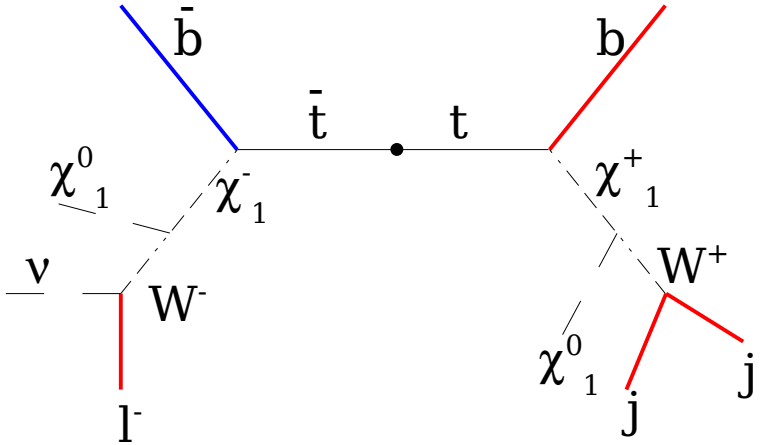




$\tilde{t}_1\tilde{t}_1$ **production mode:** 3-jet invariant-mass

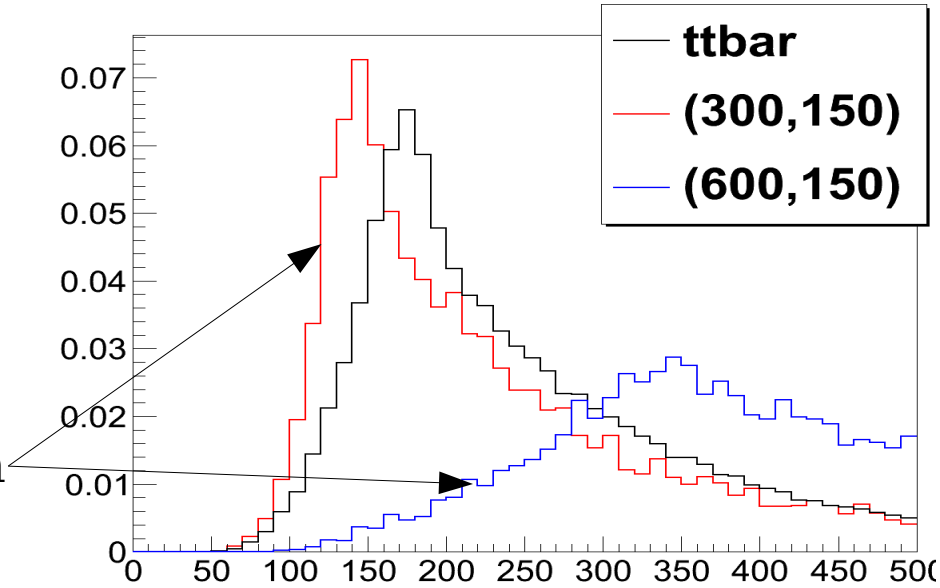
M3b: Invariant-mass of 3 jets out of 4 most energetic, most back-to-back ($\Delta\phi$) to the lepton



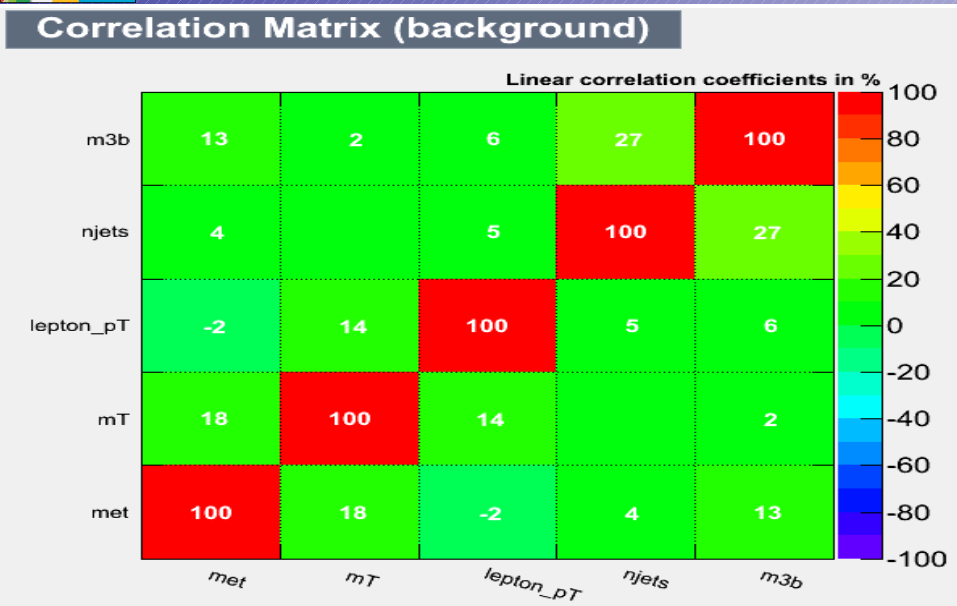


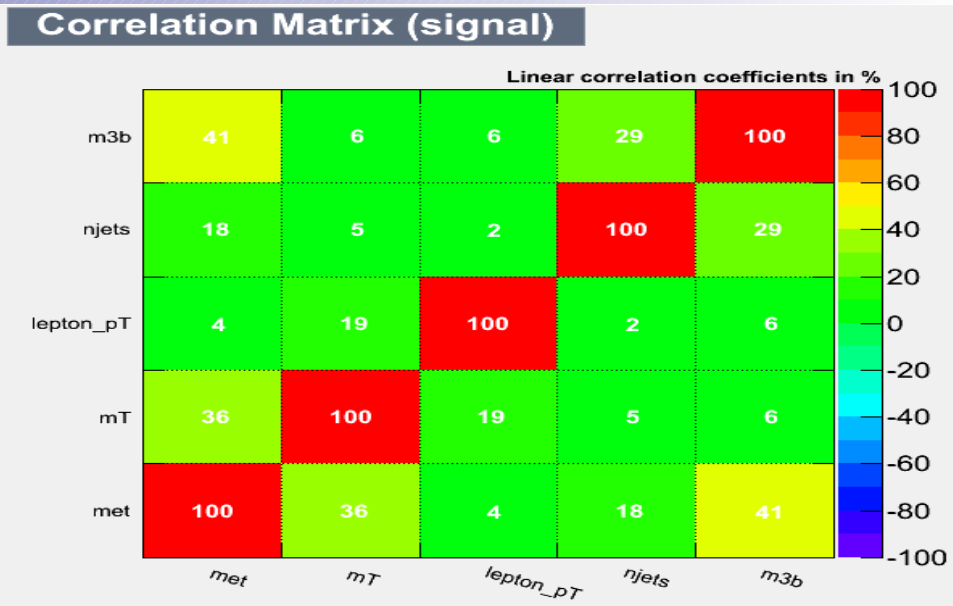
→ Constructed & tested ~15 different invariant-masses for this final state
→ Chose the most discriminating variable according to best MVA performance...

→ Different selections for different Δm signals

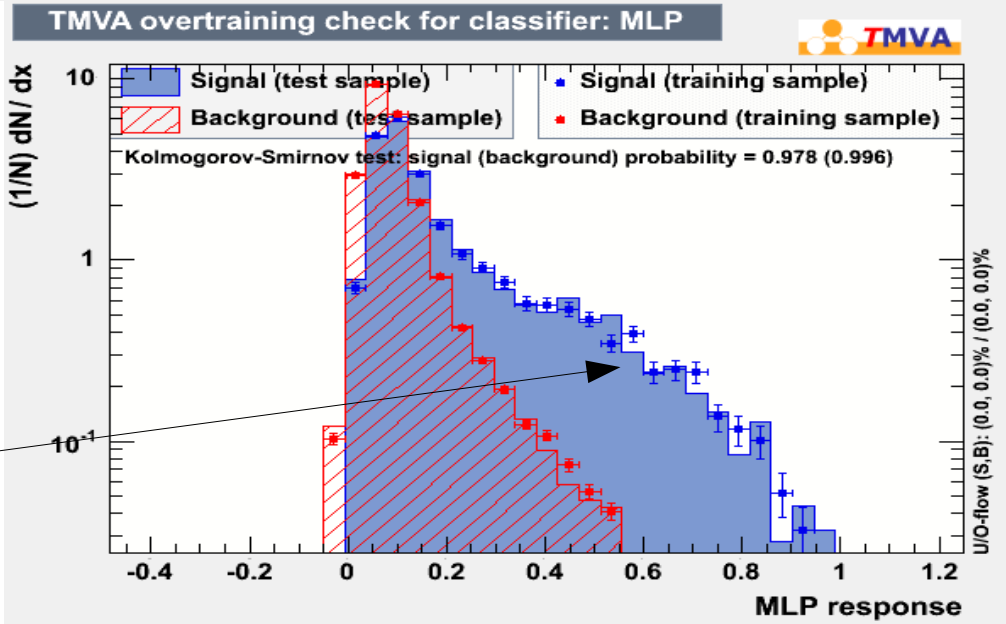


$\tilde{t}_1\tilde{t}_1$ production mode: A glimpse of the MVA





- Differences of correlation between soft-signal and ttbar
- Prob(NN) used as final selection variable
- This might be the only SUSY we see @ LHC



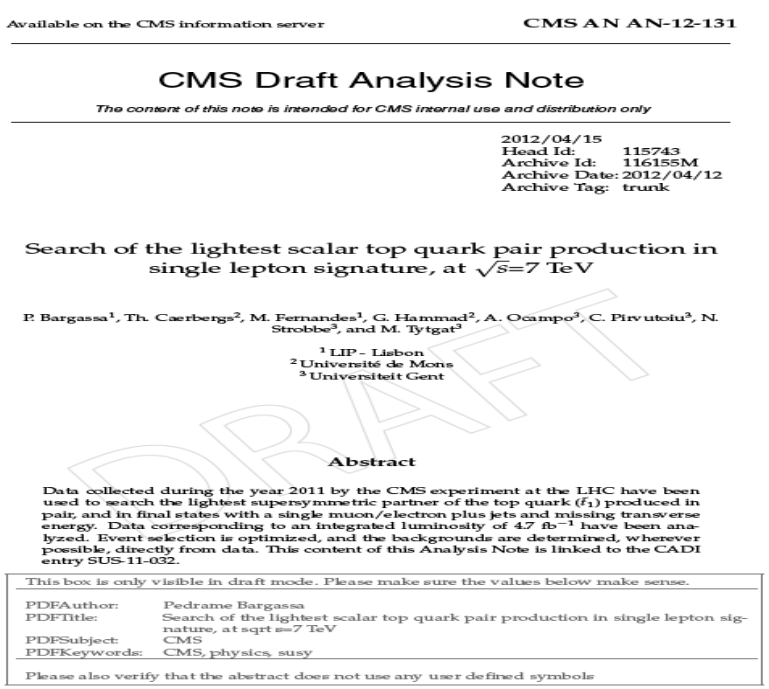
$\tilde{t}_1$ searches, CMS and LIP

LIP: Initiator of this new search

5 seminars to cover & launch these searches

Leading now the effort across 4 groups:

- **$\tilde{t}_1$ direct pair production:**
  - LIP, U. Gent (Be), U. Mons (Be): 1 researcher, 2 postdocs, 4 students
- **$\tilde{t}_1$ production via gluino pair production:**
  - LIP, IPNL (F): 1 researcher, 1 student
- 2 Analysis Notes for 5fb^{-1} data, followed by reloades for 2012 data



Available on the CMS information server CMS AN AN-12-131

CMS Draft Analysis Note

The content of this note is intended for CMS internal use and distribution only

2012/04/15
Head Id: 115743
Archive Id: 116155M
Archive Date: 2012/04/12
Archive Tag: trunk

Search of the lightest scalar top quark pair production in single lepton signature, at $\sqrt{s}$=7 TeV

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DRAFT

Abstract

Data collected during the year 2011 by the CMS experiment at the LHC have been used to search the lightest supersymmetric partner of the top quark ($\tilde{t}_1$) produced in pair, and in final states with a single muon/electron plus jets and missing transverse energy. Data corresponding to an integrated luminosity of 4.7 fb^{-1} have been analyzed. Event selection is optimized, and the backgrounds are determined, wherever possible, directly from data. This content of this Analysis Note is linked to the CADI entry SUS-11-032.

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PDFAuthor: Pedrame Bargassa
PDFTitle: Search of the lightest scalar top quark pair production in single lepton signature, at sqrt s=7 TeV
PDFSubject: CMS
PDFKeywords: CMS, physics, susy

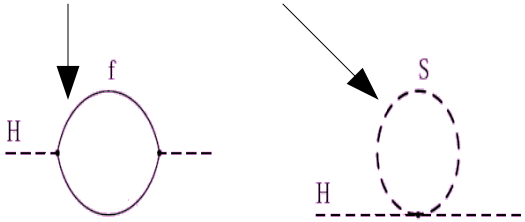
Please also verify that the abstract does not use any user defined symbols

Backup slides

Where are we standing now: Higgs & SUSY picture

In practice: The Δm^2_H quadratic divergence can be canceled @ TeV scale with only stops: Invoke only top & stop1 here

$$\Delta m_H^2 = \frac{\lambda_f^2}{16\pi^2}\cdot[-2\Lambda_{UV}^2 + \ldots]$$



$$\Delta m_H^2 = \frac{\lambda_s}{16\pi^2}\cdot[\Lambda_{UV}^2 - \ldots]$$

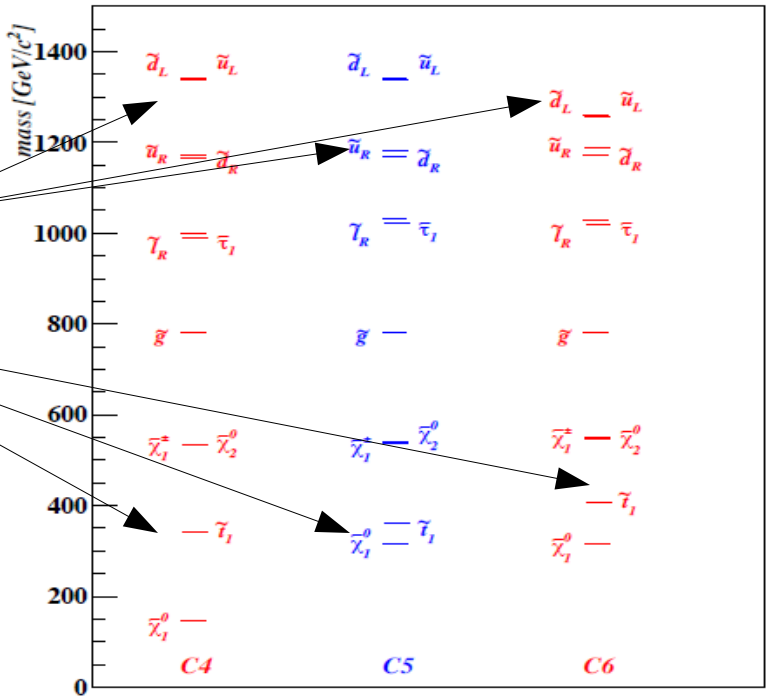
compressed SUSY with light stops

"Decoupled" SUSY:

1/ Squarks & Gluino can be (quite) heavy

2/ $\tilde{t}_1$ can be (much) light(er)

→ We can still solve the Higgs hierarchy problem @ TeV scale :-)



Motivation for the $\tilde{t}_1$: Cold Dark Matter

Lightest Neutralino $\tilde{\chi}^0_1$ stable: Natural candidate for Cold Dark Matter

$0.1 < \Omega_{CDM} h^2 < 1$: "Reproduced" in most of SUSY parameter space...

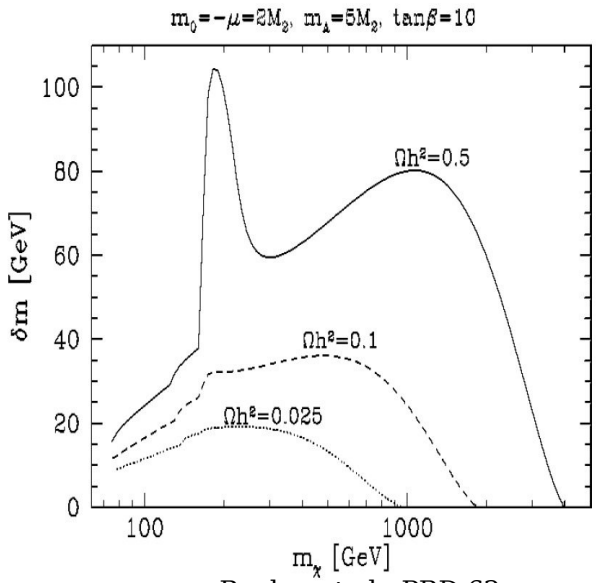
...if $\tilde{\chi}^0_1 \tilde{\chi}^0_1$ annihilation : Only process changing N(Superparticles)

IF : $\delta m = M(\tilde{P}) - M(\tilde{\chi}^0_1)$ small, co-annihilations dominates → $\Omega_{CDM} h^2 \approx 0.1$

- $\tilde{\chi}^0_1 \tilde{t}_1$ ---> tg, tH^0_i, bH^+
- $\tilde{t}_1 \tilde{t}^{(*)}_1$ ---> $t\bar{t}$, gg, $H^0_i H^0_j$, $H^- H^+$, $b\bar{b}$

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

Compatible with **$\Omega_{CDM} h^2 = 0.11 \pm 0.01$ @ 95% CL** (WMAP)



Boehm et al., PRD 62, 35012

Exciting times for SUSY searches in view of Cosmology Data:
Is stop degenerate with LSP ? NLSP ?

Higgs & stop picture

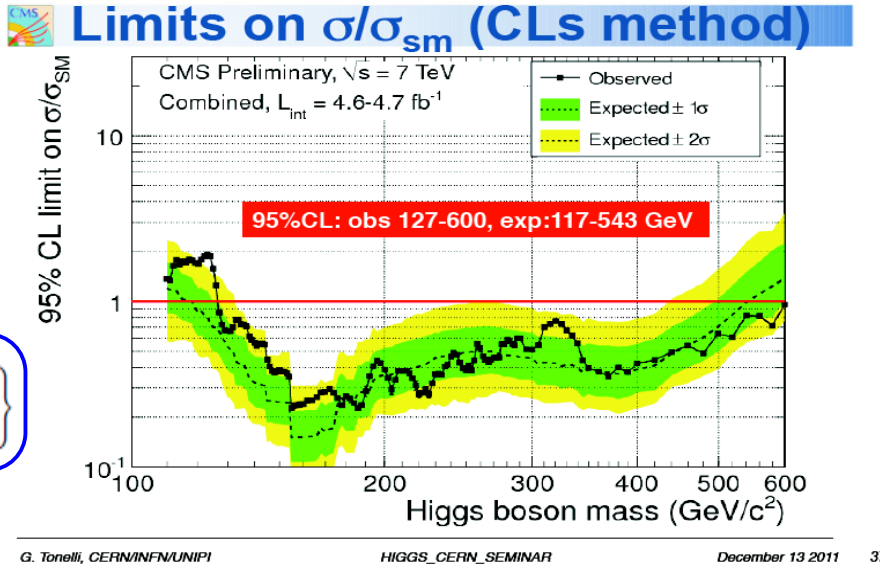
Higgs: IF there, is “more & more pushed towards” low-mass region

Implication for the $\sim t_{1,2}$ sector ?

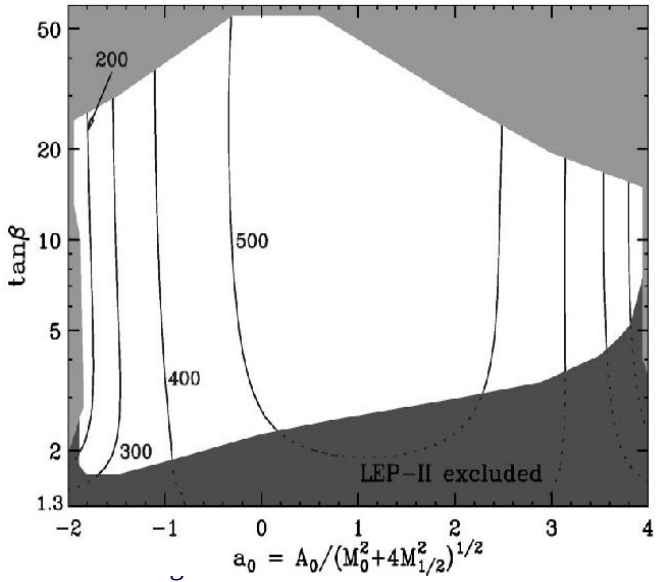
Remember:

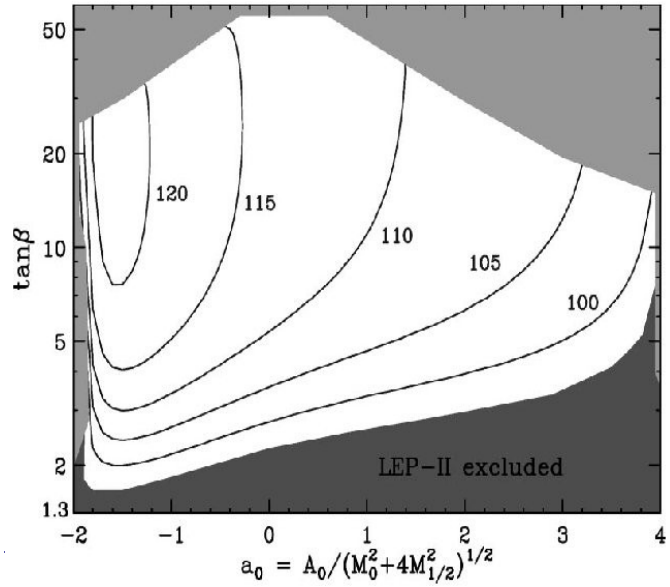
$$M^2_{h,H} = \frac{1}{2}\left\{ M^2_A + M^2_Z + \frac{\epsilon_h}{\sin^2\beta} \pm \left[\left(M^2_A - M^2_Z \right) \cos 2\beta + \frac{\epsilon_h}{\sin^2\beta} \right)^2 + \left(M^2_A + M^2_Z \right)^2 \sin^2 2\beta \right]^{1/2} \right\}$$

with: $\epsilon_h \equiv \frac{3 G_F}{\sqrt{2}\pi^2} M_T^4 \log\left(\frac{\tilde{m}^2}{M_T^2} \right)$



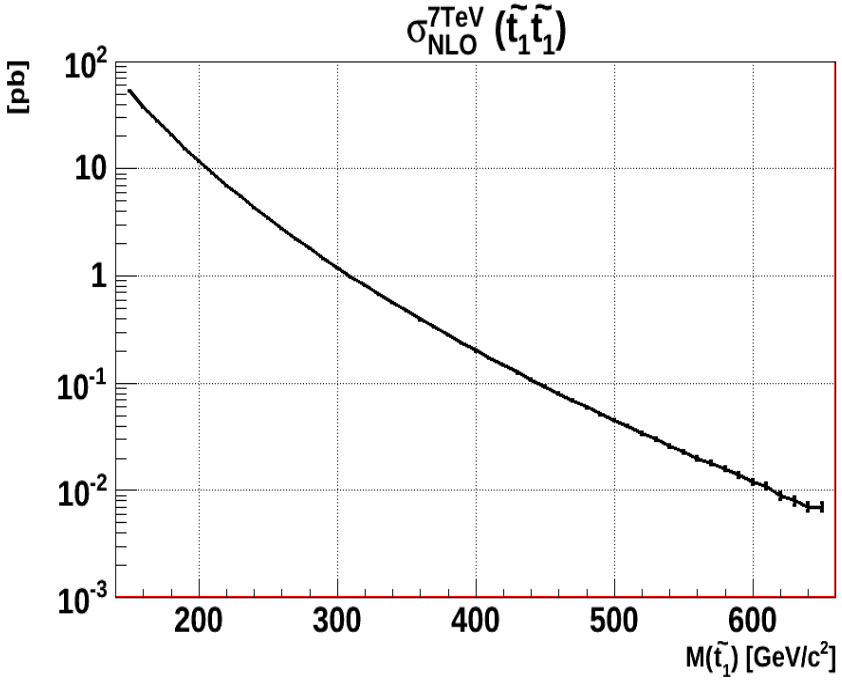
Squark masses: Higgs mass particularly sensitive to $\sim t_{1,2}$ system

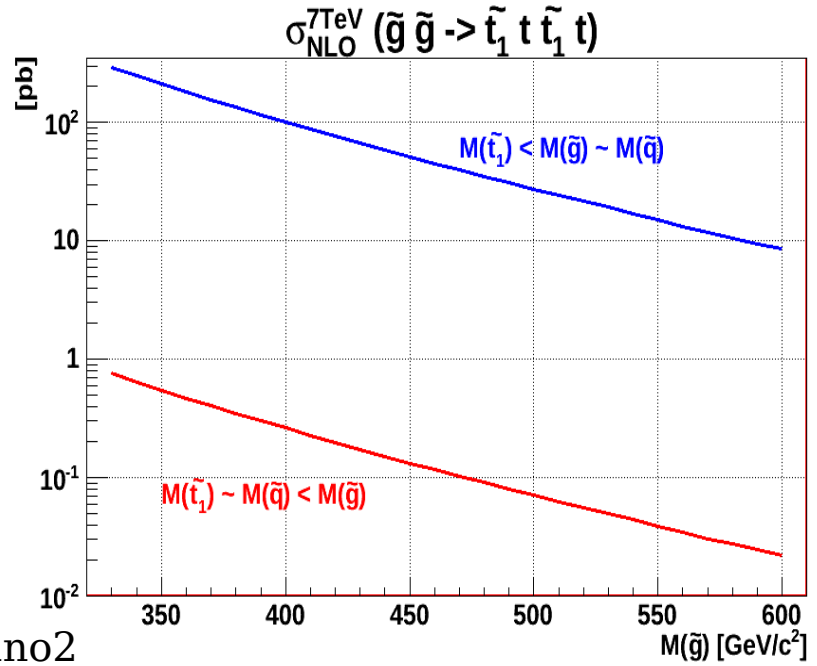




Subsisting Higgs window “pushes” stop1 towards M<500 GeV :-)

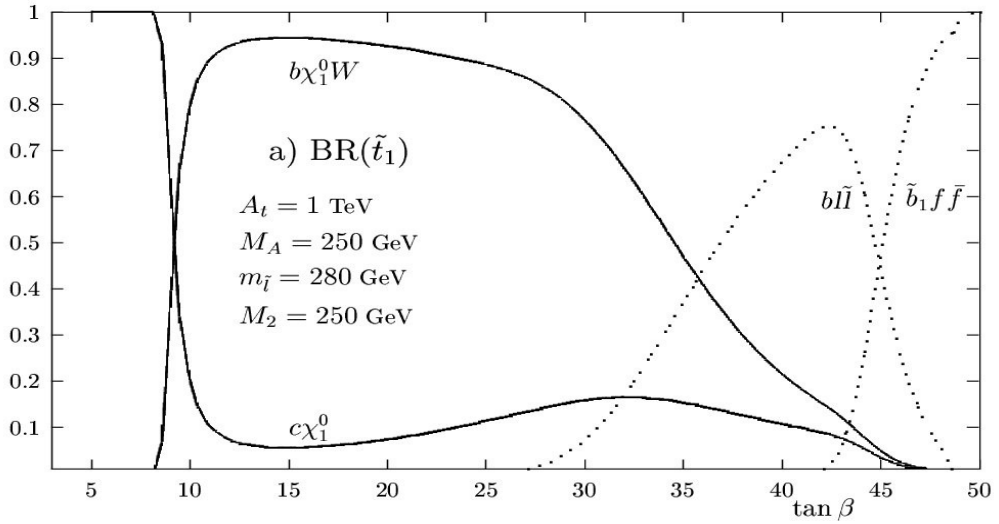
Cross-sections & decays





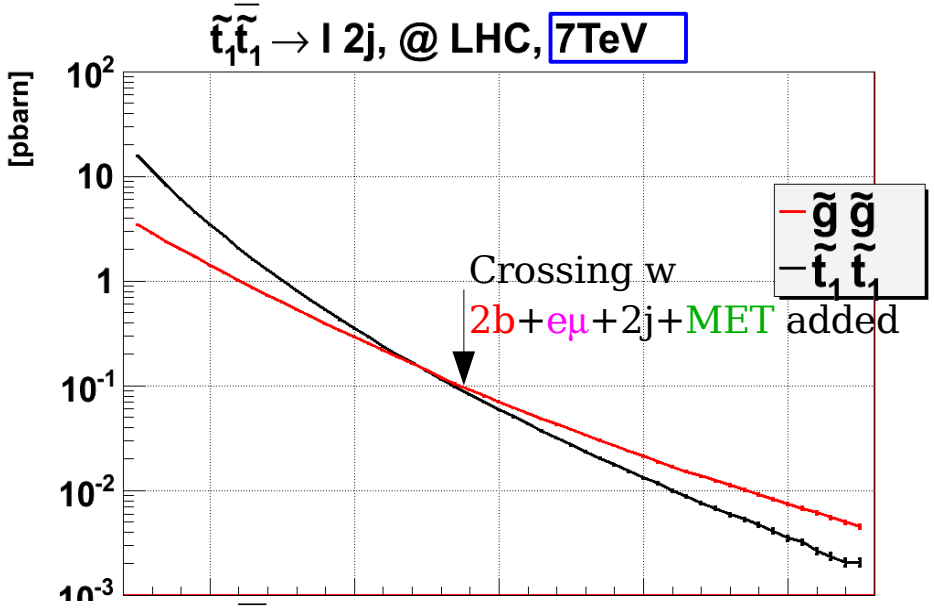
Prospino2

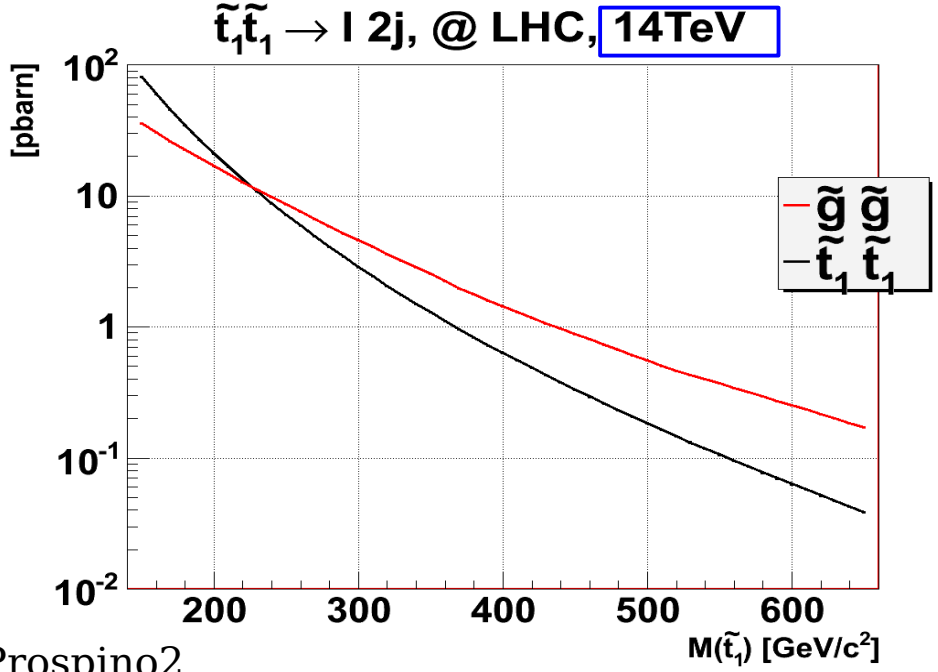
$\tilde{t}_1 \rightarrow b\,W^+\,\tilde{\chi}_1^0$ decays



Djouadi et al. : PR D, Vol. 63, 115005

Cross-sections: 7 / 14 TeV





Let's 1st calculate total cross sections for $\tilde{t}_1\tilde{t}_1$ & $\tilde{g}\tilde{g}$:

$\tilde{t}_1\tilde{t}_1 \rightarrow 2b + e+\mu+2j + MET$

$\tilde{g}\tilde{g} \rightarrow 4l+3l+2l$ (just for exercise)

For given selection efficiency:
The $\tilde{g}\tilde{g}$ production mode dominates more at lower stop mass @ 14 TeV

→ 7-8 TeV runs: More $\tilde{t}_1\tilde{t}_1$ oriented

Prospino2

Equations: Higgs in MSSM

2 Higgs complex doublets:

$$V_H = \left(|\mu|^2 + m_1^2\right)|H_1|^2 + \left(|\mu|^2 + m_2^2\right)|H_2|^2 - \mu B \epsilon_{ij}\left(H_1^i H_2^j + \text{h.c.}\right) + \frac{g^2 + g'^2}{8}\left(|H_1|^2 - |H_2|^2\right)^2 + \frac{1}{2}g^2 |H_1^* H_2|^2 \quad .$$

8 degrees of freedom – 3 (massive gauge bosons) = 5 physical Higgs fields:
h / H / H$^{\pm}$ / A (CP-odd)

2 VEVs: $\langle H_1^0 \rangle \equiv v_1$, $\langle H_2^0 \rangle \equiv v_2$ → Key MSSM parameter: $\tan\beta \equiv \frac{v_2}{v_1}$

3 parameters to describe the MSSM Higgs sector

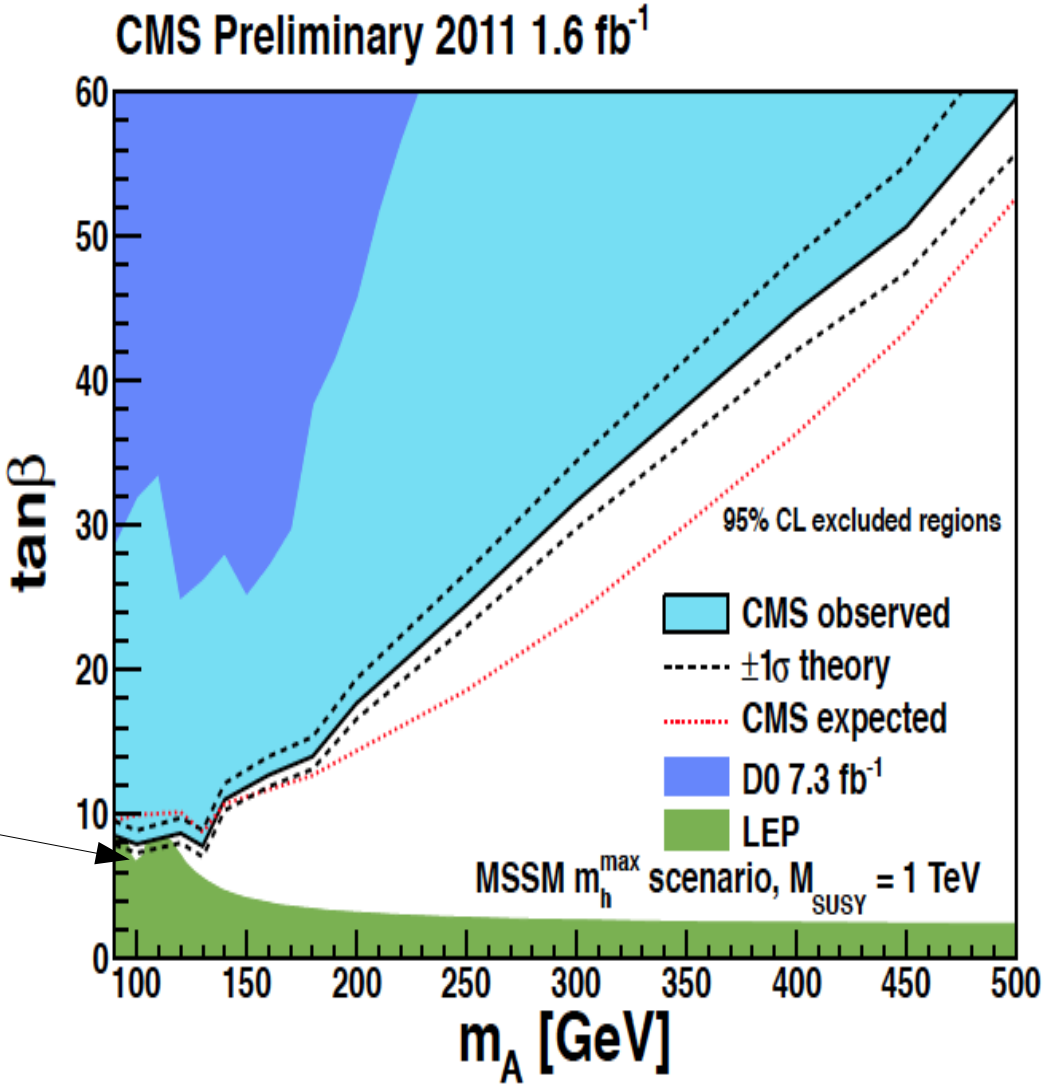
Once $v_{1,2}$ are fixed such that: $M_W^2 = \frac{g^2}{2}(v_1^2 + v_2^2)$

This whole sector is described by (only) 2 other parameters:
→ tanβ
→ M_A: $M_A^2 = \frac{2|\mu B|}{\sin 2\beta}$

Do present Higgs search limits exclude MSSM ?

Not really:

- M_A has no (dynamic) reason to be < 500, 700 GeV/c^2
  - High M_A region still quite open
- Be careful: Do not interpret this plot as a "probability density plot for something to exist": **IF** SUSY exists, it will be in 1 given spot
  - Could be here



The 1st M in MSSM means Minimal: We are dealing with 124 parameters here... "Not constrained at all" framework

{No h -> 2γ} = {End of SUSY} ?

Let's 1st look at places where MSSM looks like SM: **Decoupled regime**

1/ Light h "SM like":

→ Mass: Rather low

→ Br(h -> γγ) ~ Like in SM

2/ {H, H±, A} much heavier & degenerate

→ Couplings of lightest Higgs to fermions/γ/W/Z ~ Like in SM

→ Couplings of "additional" Higgs to fermions/γ/W/Z ~ 0

$$Z^\mu Z^\nu h : \quad \frac{igM_Z}{\cos\theta_W}\sin(\beta-\alpha)g^{\mu\nu}$$

$$Z^\mu Z^\nu H : \quad \frac{igM_Z}{\cos\theta_W}\cos(\beta-\alpha)g^{\mu\nu}$$

$$W^\mu W^\nu h : \quad igM_W \sin(\beta-\alpha)g^{\mu\nu}$$

SM couplings

$$\sin(\beta-\alpha) \to 1 \text{ for } M_A \to \infty$$
$$\cos(\beta-\alpha) \to 0 \quad .$$

Similar for coupling to γ & fermions

If SM Higgs, i.e. h → 2γ, not found over [115,...] GeV/c²:

→ No Higgs and/or MSSM at all

→ {There is an MSSM Higgs} & {couplings to 2γ are disfavored, i.e. we're not in a decoupled regime mode}

I doubt that LHC will have enough stat to mesure Higgs couplings...

More on Higgs <-> SUSY bounds

Equation governing lightest Higgs mass:

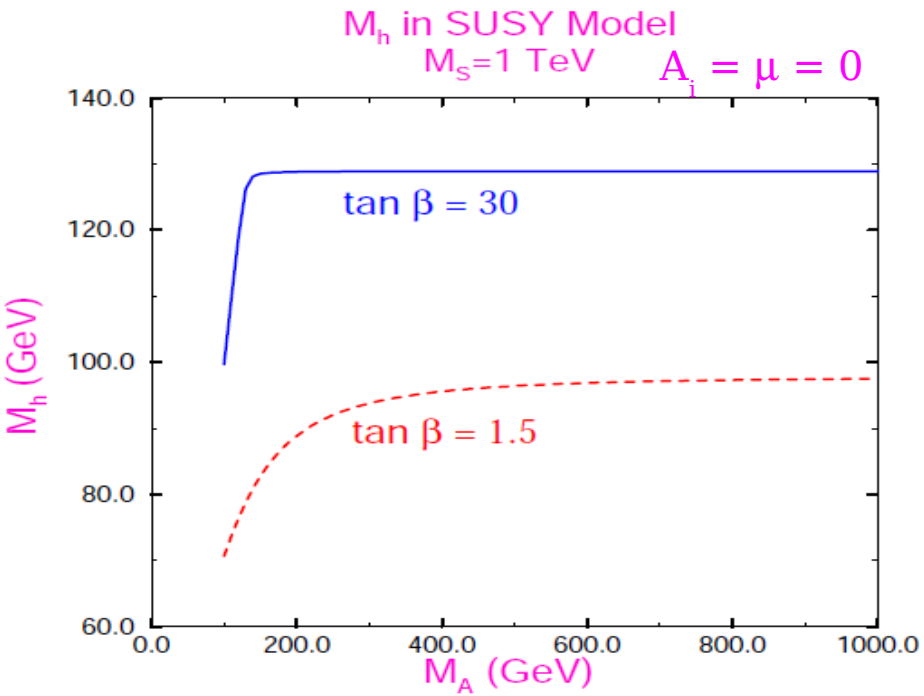
$$M^2_{h,H} = \frac{1}{2}\left\{ M^2_A + M^2_Z + \frac{\epsilon_h}{\sin^2\beta} \pm \left[\left(M^2_A - M^2_Z \right) \cos 2\beta + \frac{\epsilon_h}{\sin^2\beta} \right)^2 + \left(M^2_A + M^2_Z \right)^2 \sin^2 2\beta \right]^{1/2} \right\}$$

with: $\epsilon_h \equiv \frac{3G_F}{\sqrt{2}\pi^2} M_T^4 \log\left(\frac{\tilde{m}^2}{M_T^2} \right)$

Contribution of 1-loop correction only !
Squark masses: Higgs mass particularly sensitive to ~$t_{1,2}$ system

Upper bound:

$$M_h^2 < M_Z^2 \cos^2 2\beta + \epsilon_h$$



→ The "well-known" $M_h < 135$ GeV/c^2 limit for any-SUSY lightest Higgs
→ ...is dependent on
→ 2-loop calculations
→ Renormalization calculations
which can evolve...