Introduction

Search for an LSP Gluino from Stop Decay with DELPHI

DELPHI collaboration

Patrice Verdier

Outline :

- A heavy gluino LSP ?
- Gluino interactions
- DELPHI gluino search
- Conclusion and Outlook

A heavy gluino LSP ?

SUGRA model: (J. Gunion)

- **Usually from the RGE:**

$$M3 : M2 : M1 \ \sim \alpha_3 : \alpha_2 : \alpha_1$$

  and $m_{\tilde{g}} \ \sim \ M3$ **is heavier than** $m_{\tilde{\chi}_1^0}$

- **But models exist where** $m_{\tilde{g}} \ < \ $ **M1,M2**
- **0-II String model :**

$$M3 : M2 : M1 \ \sim \ -(3+\delta_{GS}) : (1-\delta_{GS}) : (33/5-\delta_{GS})$$

- **If** $\delta_{GS} \ \sim \ -3$ **: M3 is the lightest**
  $\Longrightarrow$ **The gluino is the LSP**

GMSB model: (S. Raby)

$$M_3 \ \sim \ \frac{\alpha_3(M)}{4\pi}\left(\frac{M}{M_{GUT}}\right)^2\Lambda$$
$$M_2 \ \sim \ \frac{\alpha_2(M)}{4\pi}\Lambda$$
$$M_1 \ \sim \ \frac{\alpha_1(M)}{4\pi}\Lambda$$

- **The** $\tilde{\mathrm{g}}$ **can be the LSP**
- **A** $\tilde{\mathrm{g}}$ **NLSP (**$\widetilde{\mathrm{G}}$ **LSP) will have a life-time** $>$ **100 years.**
  $\Longrightarrow$ **stable Gluino**

Gluino production

- **Gluino Hadronization:**

A stable $\tilde{g}$ hadronizes to form color singlet hadrons (R-hadron):

- Isoscalar $R_o = \tilde{g}g$ (gluballino)
- Isotriplet $\tilde{\rho} = \tilde{g}q\bar{q}'$ (glumesino)
- flavor singlet $S_o = \tilde{g}uds$ (glubarino)
  $n\tilde{g} = \tilde{g}\tilde{g}$ (gluinoball)

$\Longrightarrow$ **We consider 2 R-hadron states:** R_O , $R^{\pm}$

P is the probability that the $\tilde{g}$ fragments into $R^{\pm}$

- **Limits :**

- **A NLSP Gluino : $\tilde{g} \rightarrow qq\tilde{\chi}_1^0$:**
  - **kTeV excludes $m_{\tilde{g}}$= 1-5 GeV**
  - **CDF excludes $m_{\tilde{g}}$= 5-173 GeV**
- **Constraints in case of a stable $\tilde{g}$:**
  - **Fermilab (beam dump) excludes $m_{\tilde{g}}$= 2-4 GeV**
  - **Running of α_s excludes $m_{\tilde{g}}$< 6 GeV**

- **Additional Constraints:**

- **Cosmology : the relic density could be sufficiently low**
- **Heavy and stable Isotopes**

- **Motivations:**

- **A stable gluino is a UHECRon candidate**

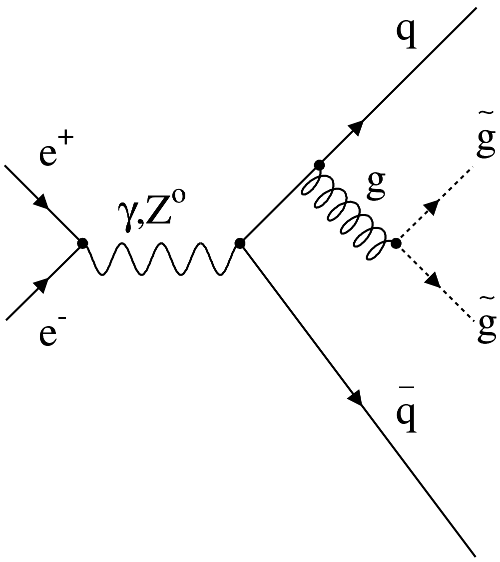
$\tilde{g}$ production

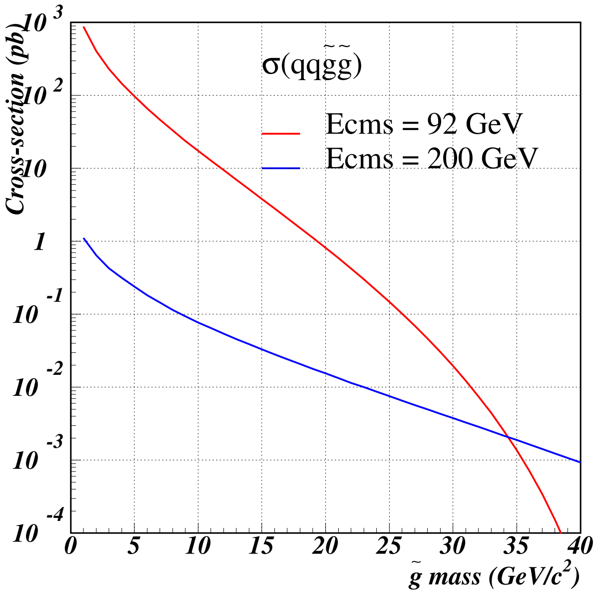
• In SUSY particle decays:

- $e^+e^- \rightarrow \tilde{\chi}^0_1\tilde{\chi}^0_1 \rightarrow$ qq'$\tilde{g}$ qq'$\tilde{g}$ **(6 jets)**
- $\rightarrow \tilde{\chi}^+\tilde{\chi}^- \rightarrow$ qq'$\tilde{g}$ qq'$\tilde{g}$ **(6 jets)**
- $\rightarrow \tilde{t}_1\tilde{t}_1 \rightarrow c\tilde{g}c\tilde{g}$ **(4 jets)**

• Gluon splitting

$$e^+e^- \rightarrow q\bar{q}\tilde{g}\tilde{g}$$



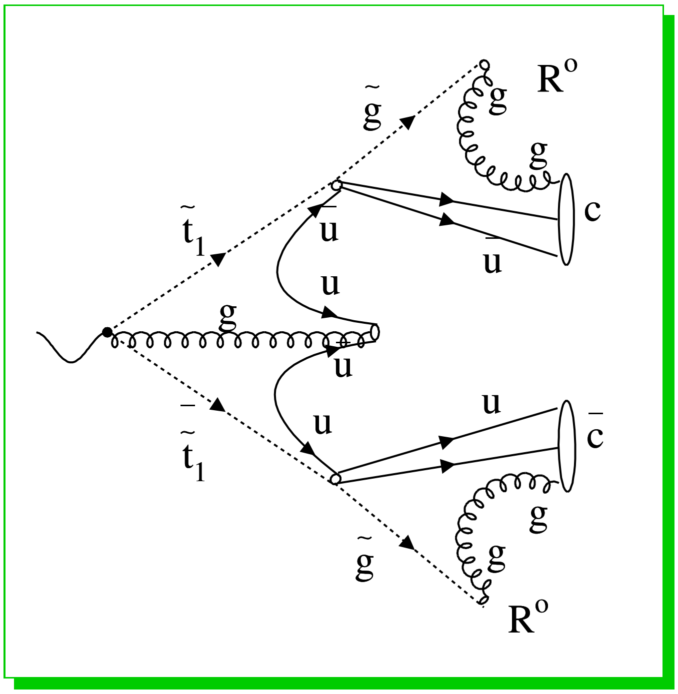


The STOPGEN generator

- **Flavor changing decay:** $\tilde{\mathrm{t}}_1 \longrightarrow c\tilde{\mathrm{g}}$

$$\tau_{\tilde{t}_1} \gg \tau_{QCD}$$

$\Longrightarrow$ $\tilde{\mathrm{t}}_1$ **hadronizes before its decay**



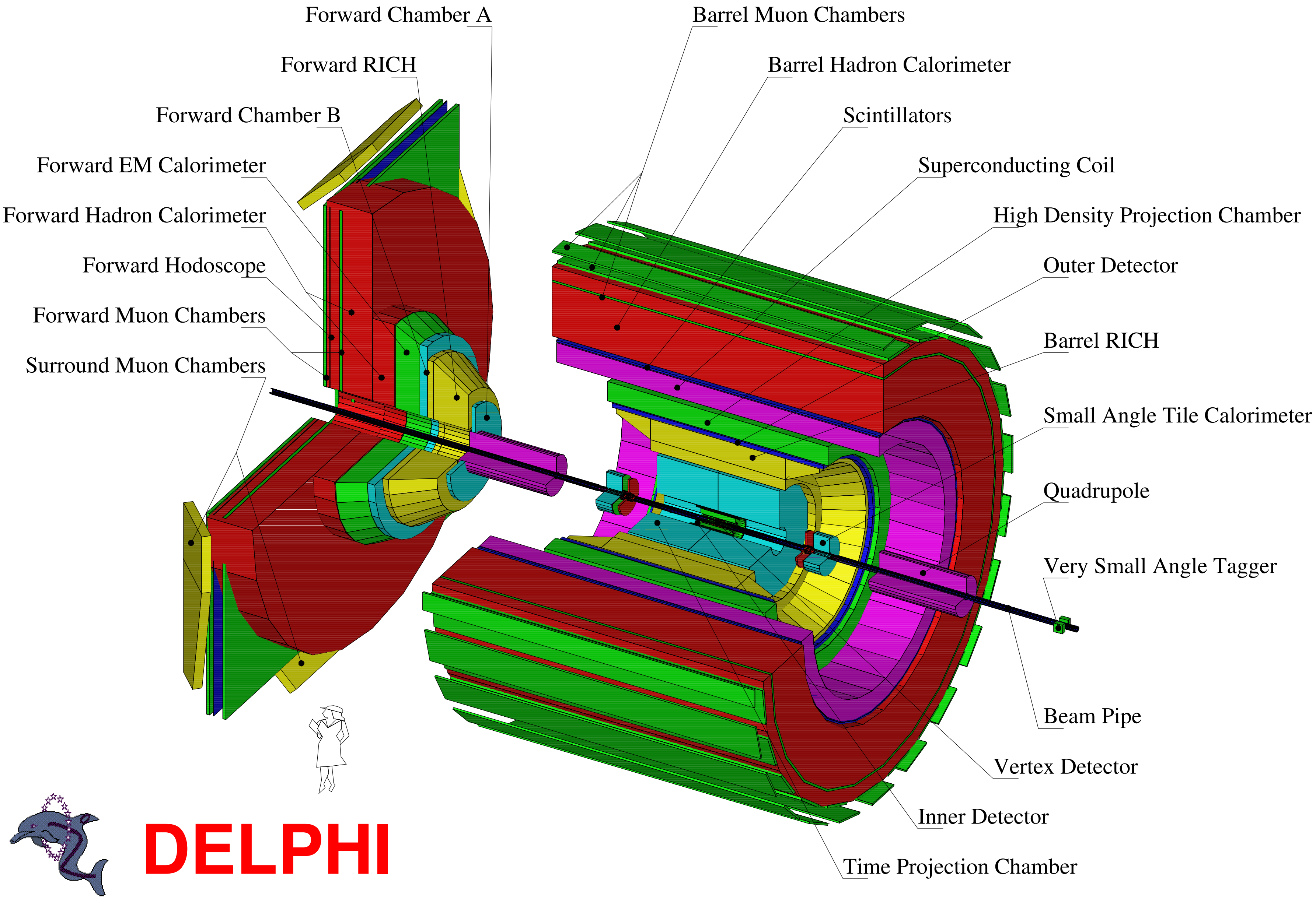
- **Hard gluon emission**
- **Non-perturbative hadronization**
- **Fermi motion**
- **Interface with JETSET**

Fortran code available from:
http://home.cern.ch/verdier/

- **R-hadron signatures:**

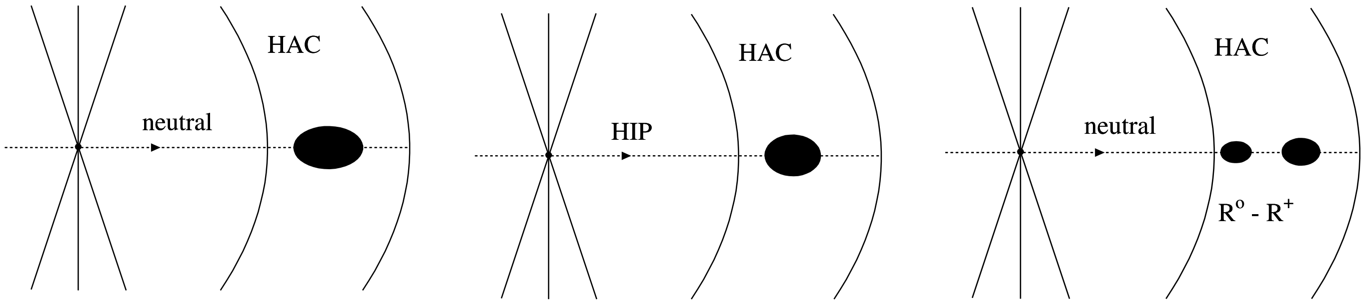
  - $R^{\pm}$: **Heavy ionising particle $\Longrightarrow$ anomalous dE/dx**
  - R^{o}: **low energy neutral cluster in the calorimeters**

The DELPHI detector



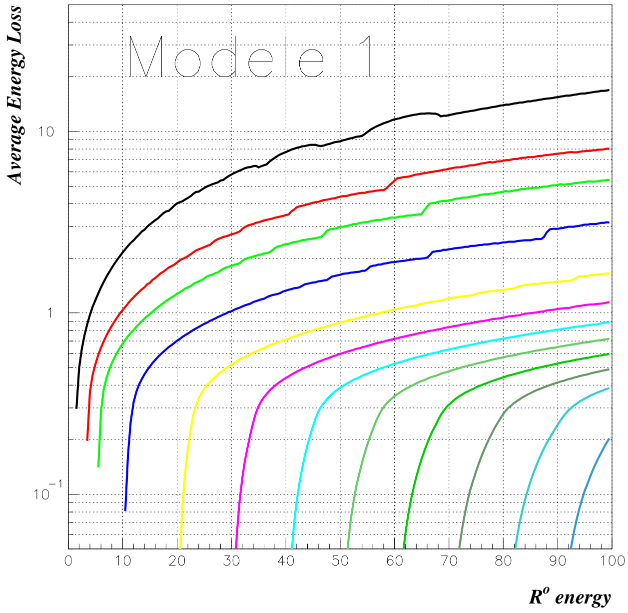
DELPHI

$\tilde{g}$ Interactions in DELPHI



• Neutral R-hadron interactions:

- Cross-section model to estimate the average energy loss in $R_0 N \to R_0 X$
- Corrections due to **the $\tilde{g}$ color octet nature** and to **the size of the R^o**:
  $\Lambda_T(R^o) = \mathbf{(16/9)}\ \Lambda_T(\pi)$
  7.6 Λ_T **in DELPHI**
  $\Longrightarrow$ **~4 collisions**
- $\langle \Delta E \rangle < 2$**GeV**
  if $m_{\tilde{g}} > 20\mathrm{GeV/c^2}$

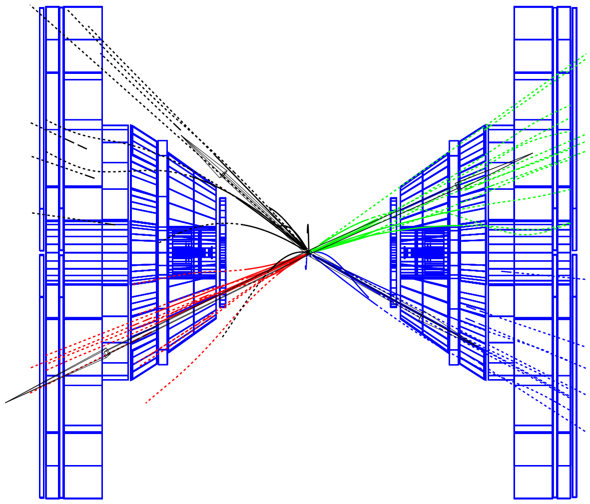


• R-hadron simulation:

R-hadrons are simulated as:

- **Heavy muons** for $R^{\pm}$
- K_L^o for R^o

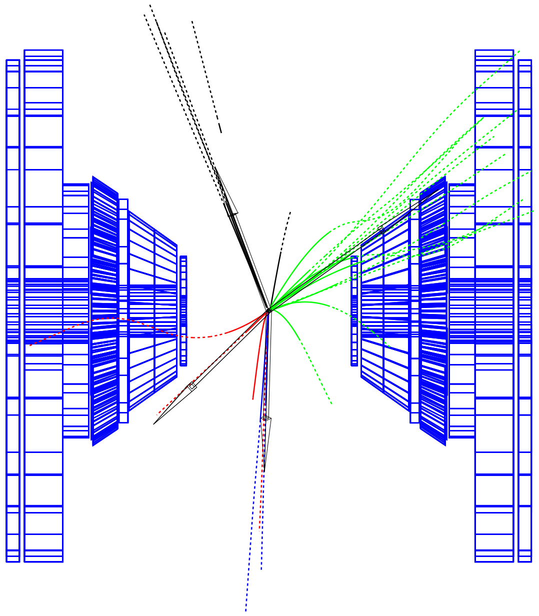
Simulation with DELPHI



- $m_{\tilde{t}_1} = $ **50,** $m_{\tilde{g}} = $ **1:**

  The fragmentation is soft leading to a high number of particles:

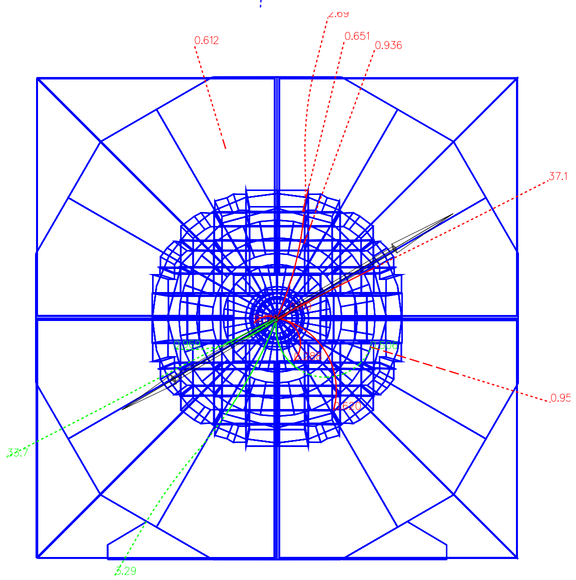
  4 jets



- $m_{\tilde{t}_1} = $ **70,** $m_{\tilde{g}} = $ **10:**

  few fragmented particles:

  2 jets + 2 "thin" jets



- $m_{\tilde{t}_1} = $ **90,** $m_{\tilde{g}} = $ **85:**

  the fragmentation is hard. The R-hadrons take most of the energy and are almost back-to-back:

  2 soft jets+ 2 isolated particles($R^{\pm}$) or 2 soft jets+ missing energy (R°)

R-hadron search

• Data samples:

	1998	1999				2000
$\sqrt{s}$ (GeV)	189.	192.	196.	200.	202.	~205.
$\mathcal{L}$ (pb^{-1})	158.	25.9	76.4	83.4	40.6	64.6

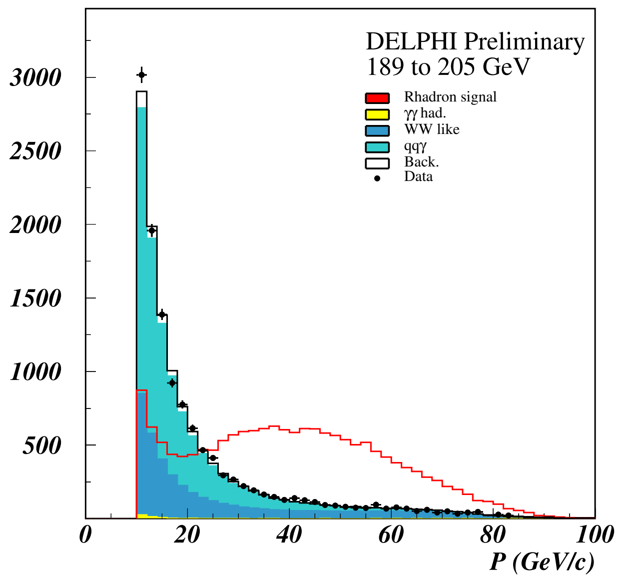
• Background processes:

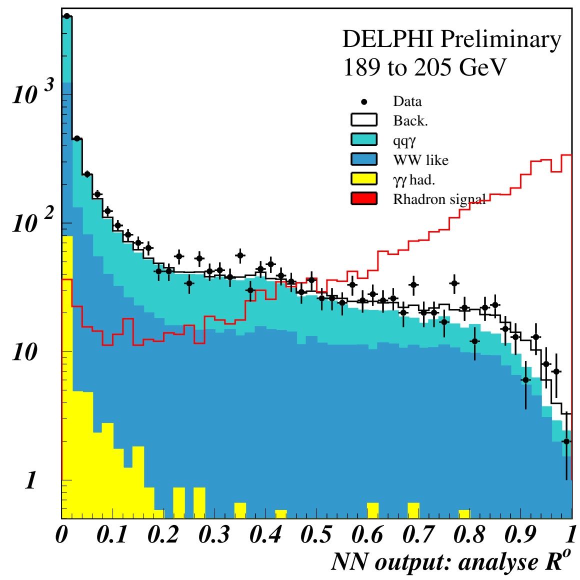
- **QCD and 4-fermions** backgrounds for **low gluino masses.**
- Also, $\gamma\gamma$ **interactions** leading to hadronic final states **in the** R°**search for** $\Delta M < 20$ **GeV**

• Analysis:

- **P=1:** $e^+e^- \rightarrow$**cc**$R^{\pm}R^{\pm}$**:** cuts in the plane ($|p|$,**dE/dx**)
- **P=0:** $e^+e^- \rightarrow$**cc**$R^{\circ}R^{\circ}$**:** **sequential cuts and neural networks**

• Data vs Monte-Carlo: $\mathcal{L}_{tot}$= 449 pb^{-1}





Results

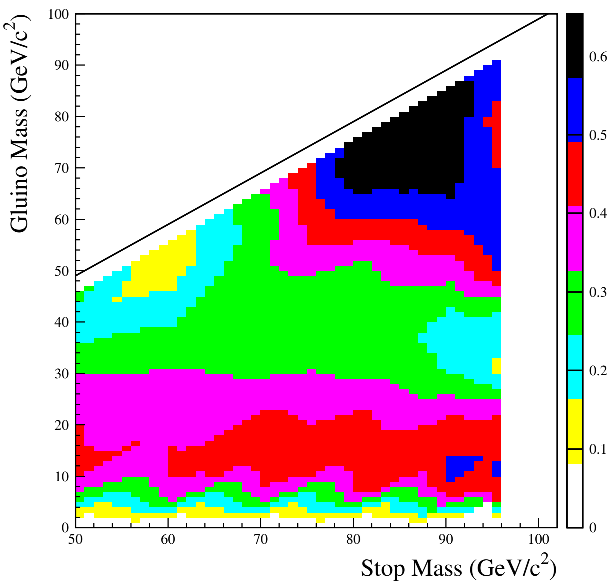
• Number of events selected:

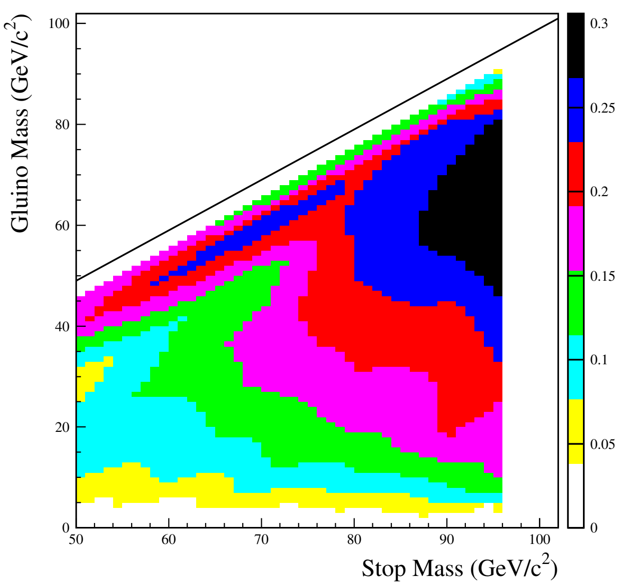
P=1: $e^+e^-\to \mathbf{cc}R^\pm R^\pm$						
	$m_{\tilde{g}}\leq$**30**		**30**$<m_{\tilde{g}}<$**60**		$m_{\tilde{g}}\geq$**60**	
	data	MC	data	MC	data	MC
total	13	13.17±0.75	0	0.390±0.076	0	0.306±0.100

P=0: $e^+e^-\to \mathbf{cc}R^\circ R^\circ$				
	$\Delta M \leq 20.$		$\Delta M > 20.$	
	data	MC	data	MC
total	14	13.26±1.71	30	24.94±0.75

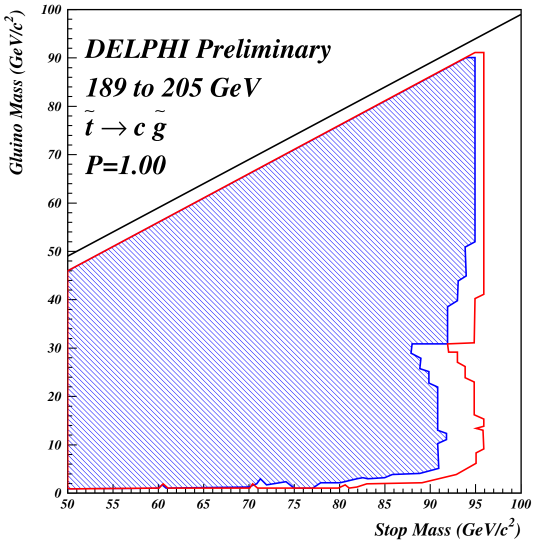
• Signal efficiencies:

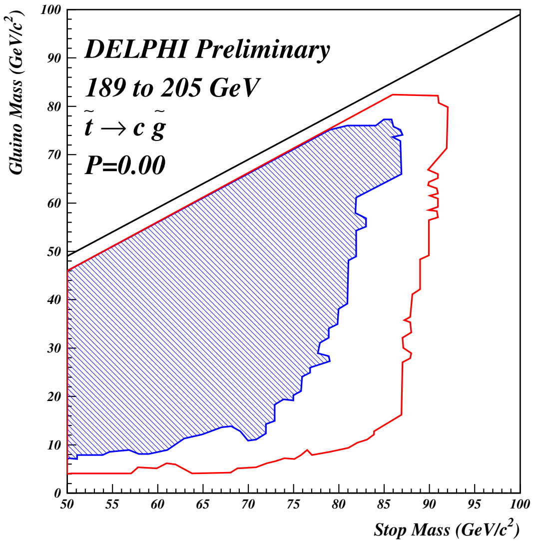
- $\sim$ **60 points** $(m_{\tilde{t}_1},m_{\tilde{g}})$ **were generated with STOPGEN and the full detector simulation.**
- **Detection efficiencies are calculated and then interpolated in the plane** $(m_{\tilde{t}_1},m_{\tilde{g}})$





Results


DELPHI Preliminary
189 to 205 GeV
$\tilde{t} \to c\,\tilde{g}$
P=1.00
Gluino Mass (GeV/c^2)
Stop Mass (GeV/c^2)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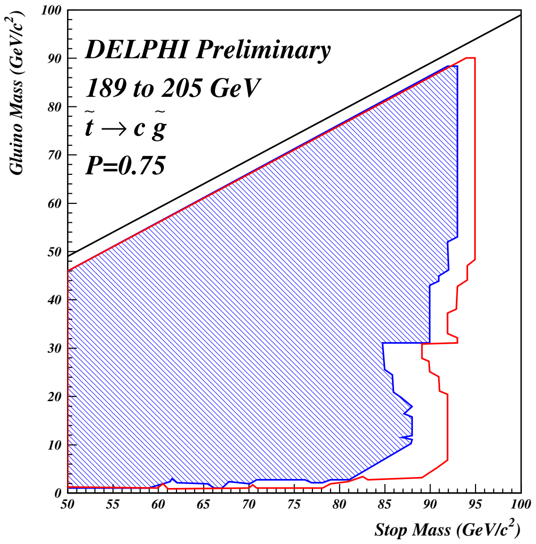
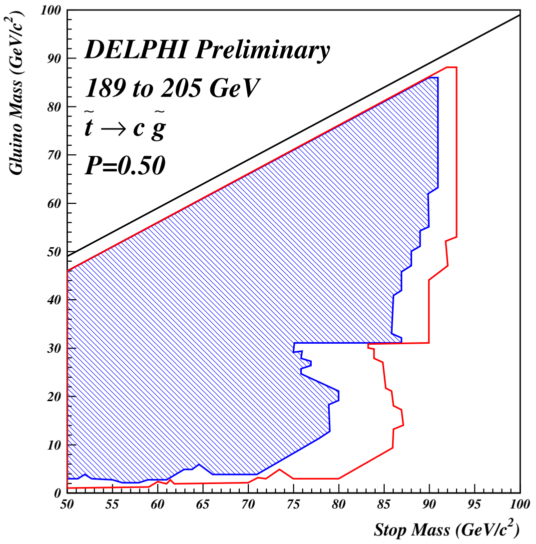
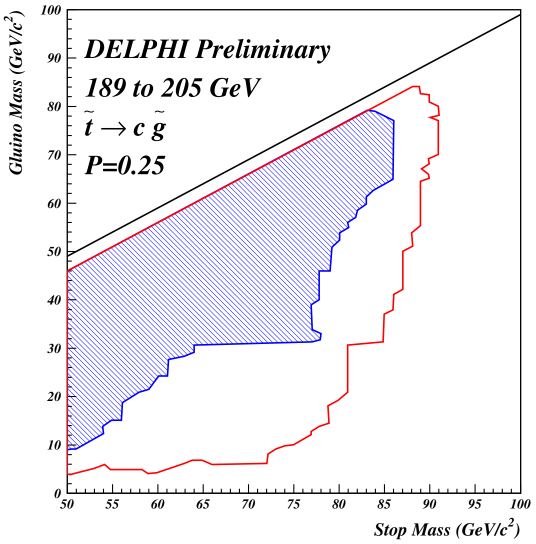

DELPHI Preliminary
189 to 205 GeV
$\tilde{t} \to c\,\tilde{g}$
P=0.75
Gluino Mass (GeV/c^2)
Stop Mass (GeV/c^2)


DELPHI Preliminary
189 to 205 GeV
$\tilde{t} \to c\,\tilde{g}$
P=0.50
Gluino Mass (GeV/c^2)
Stop Mass (GeV/c^2)


DELPHI Preliminary
189 to 205 GeV
$\tilde{t} \to c\,\tilde{g}$
P=0.25
Gluino Mass (GeV/c^2)
Stop Mass (GeV/c^2)

Conclusion

- **A heavy gluino LSP:**
  - Removes **the missing energy signatures**, while **conserving R-parity**
  - **New interesting topologies** to search for
- **Search for R-hadron from stop decay:**
  - A generator has been written **to model the stop and the gluino hadronization**
  - The search gave negative results for $\mathrm{e^+e^-} \rightarrow \mathbf{cc} R^{\pm} R^{\pm}$ and $\mathrm{e^+e^-} \rightarrow \mathbf{cc} R^{\circ} R^{\circ}$:
    - **For purely left-handed stops and for** $\Delta M \geq 5\mathrm{GeV/c^2}$**,**
      $m_{\tilde{\mathrm{g}}} \geq 20\mathrm{GeV/c^2}$**:**
      $m_{\tilde{\mathrm{t}}_1} \geq 80\mathrm{GeV/c^2}$ **for any value of P**
  - The search for $\mathrm{e^+e^-} \rightarrow \mathbf{cc} R^{\pm} R^{\circ}$ has to be done to improve these results.
- **Future:**
  - The search for R-hadrons has to be **extended to other sparticle decays**
  - **Gluon splitting into gluino:** complementarity between hadronic and leptonic colliders:
    - **LEP1** sensitive to gluino masses **lower than 30** $\mathrm{GeV/c^2}$
    - **Fermilab** sensitive to gluino masses **higher than 30** $\mathrm{GeV/c^2}$