Susy and Higgs Physics Results at CDF

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for the CDF collaborations

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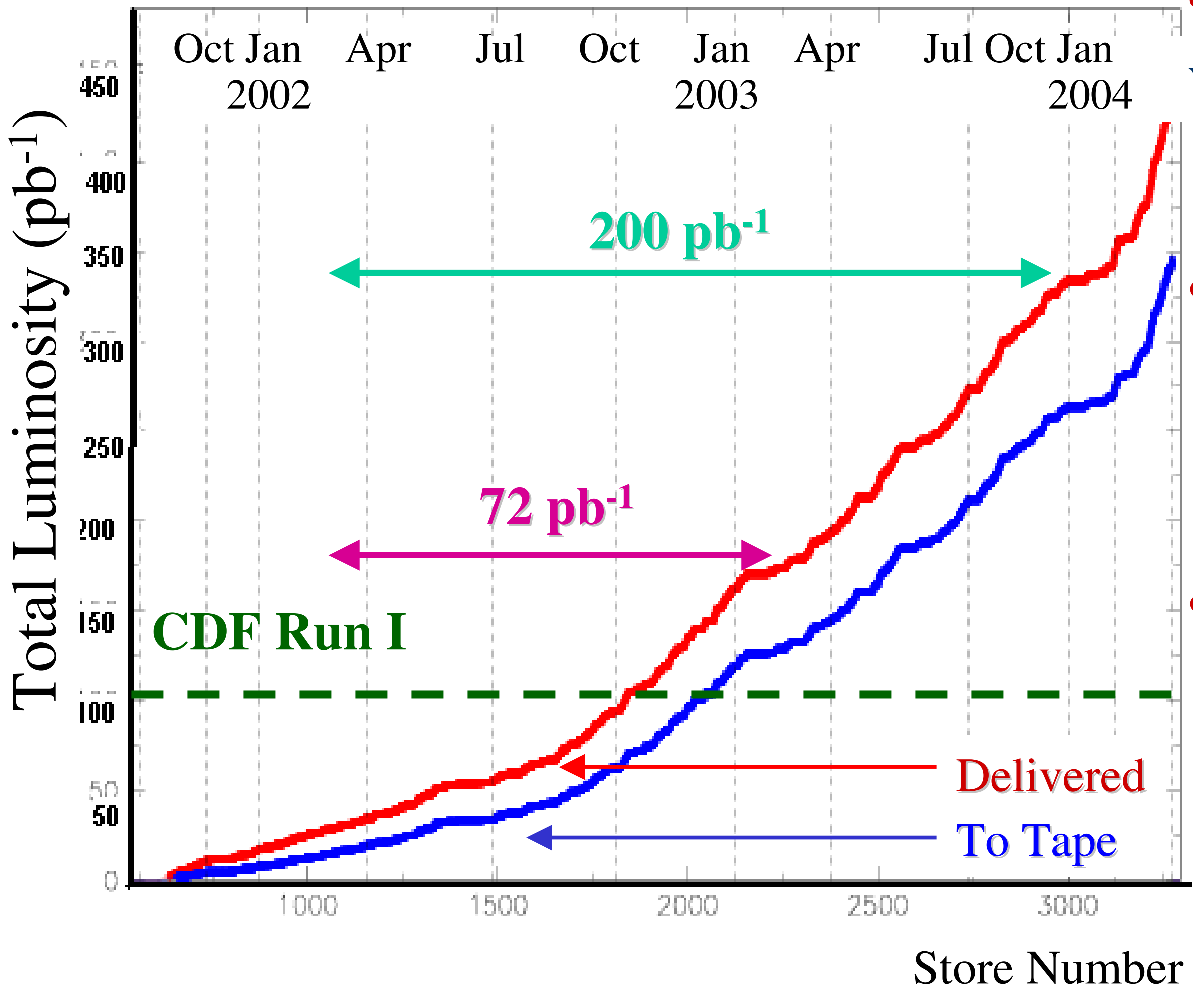
Outline

- Introduction
- **Tevatron** and **CDF** performances
- **Exotic physics** at CDF
  - Higgs in the SM and not
  - Supersymmetry
- Conclusions and future prospects

The Tevatron: Run II



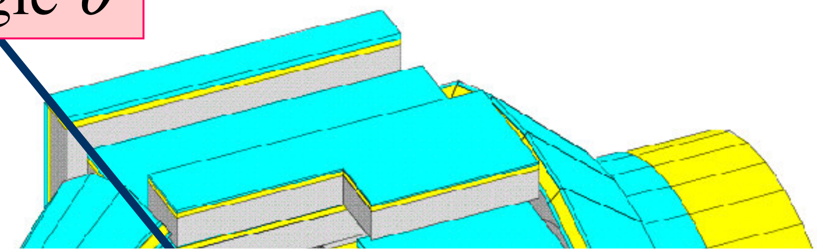
- **TEVATRON** performance very good : $\mathcal{L}_{del} \sim 400\ pb^{-1}$
  - $E_{CM} = 1.96$ TeV
- **CDF**:
  - ➡ data taking efficiency ~ 90%
  - ➡ on tape $\mathcal{L} \sim 350\ pb^{-1}$
- **Physics** Analyses:
  - ➡ 34 and 240 pb^{-1} taken Mar 2002 - Sep 2003
  - ➡ $\delta\mathcal{L} \sim 6\%$ (from σ_{inel})

The detector CDF-II

Retained From Run I :

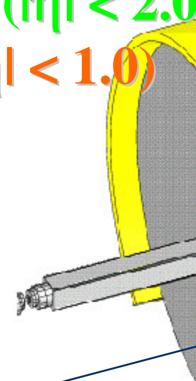
- Solenoid Coil
- Central Muon Systems
- Central EM and HAD Calorimeters

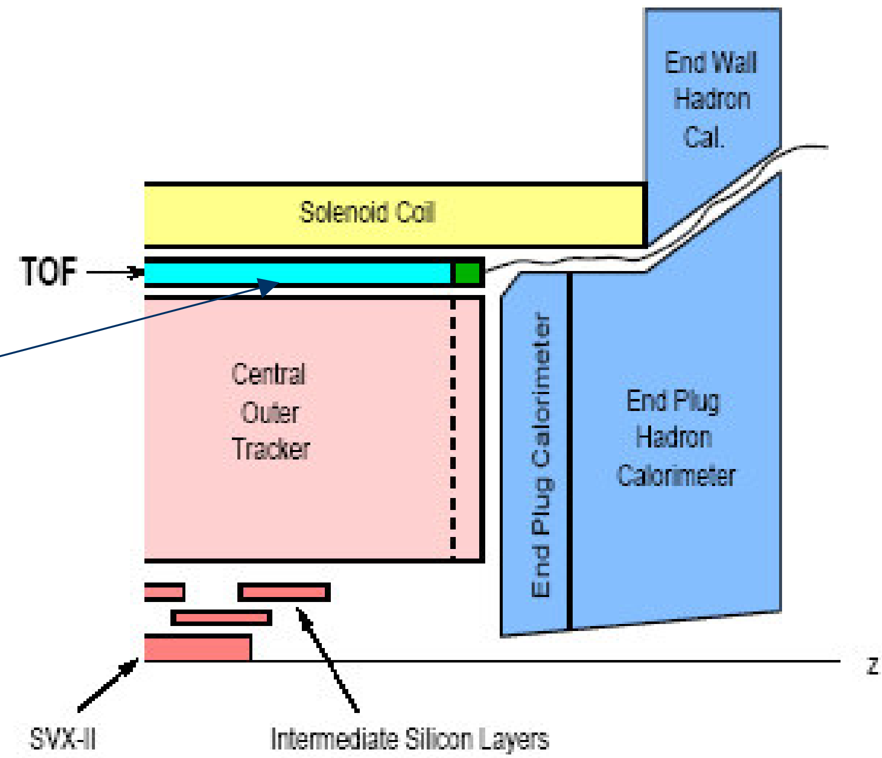
polar angle θ



New for Run II :

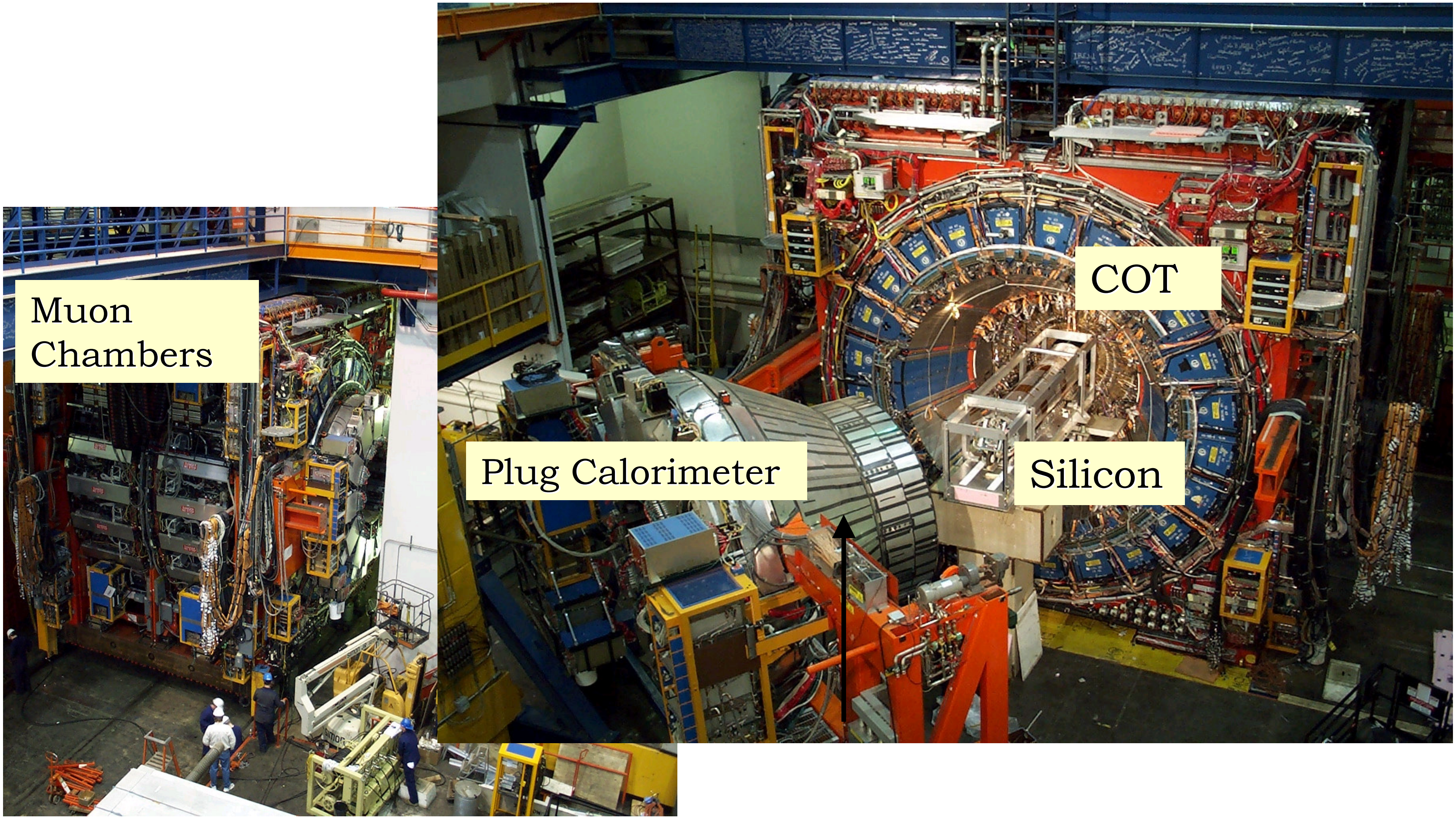
- Silicon Tracking Detectors ($|\eta| < 2.0$
- Central Drift Chambers ($|\eta| < 1.0$)
- "Plug" EM and HAD calorimeters ($1 < |\eta| < 3.6$)
- Forward Muon Systems ($|\eta| < 1.5$, filled gaps)
- Time-Of-Flight system



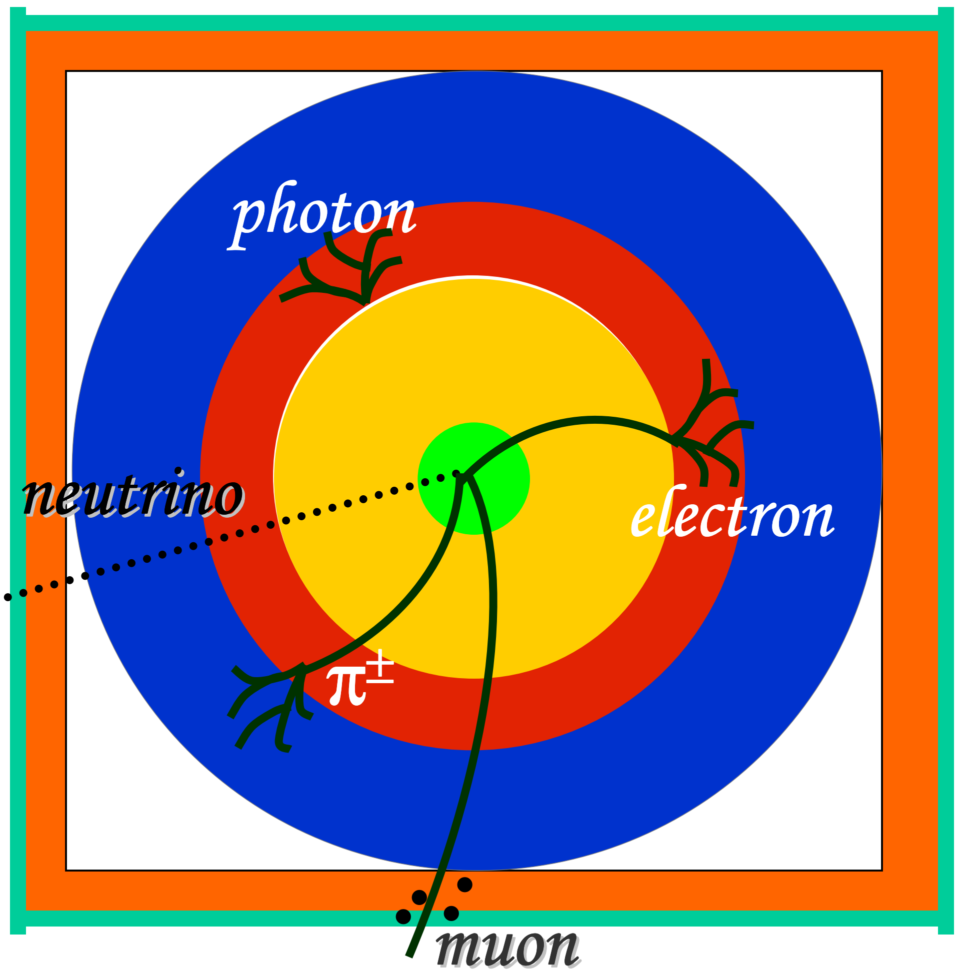


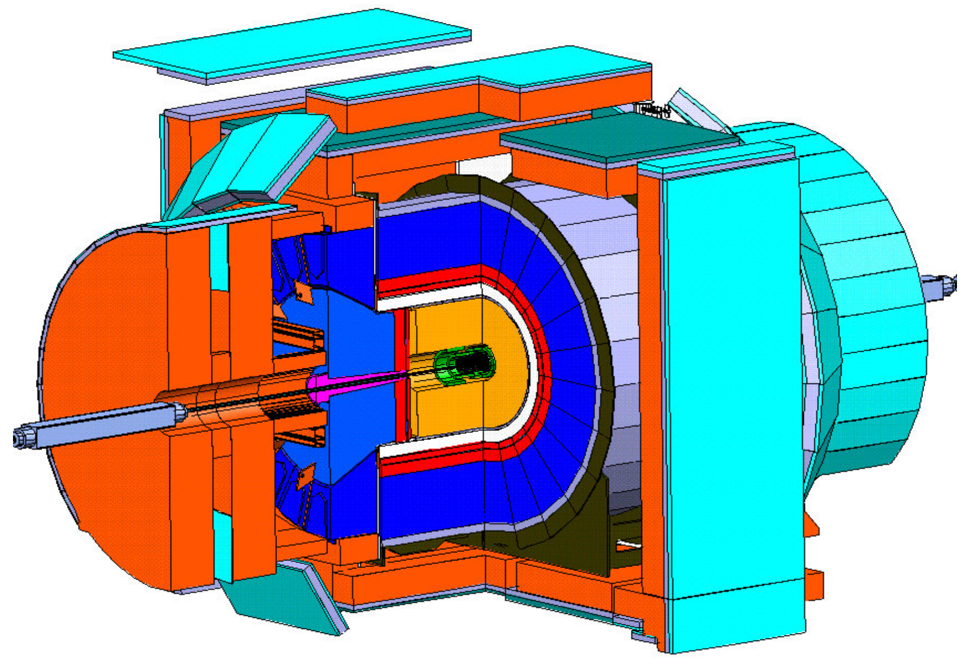
- Front-end electronics (132 ns)
- Trigger System (pipelined)
- DAQ system

The detector CDF-II



How we reconstruct particles





In these analyses :

- *electrons :* $|\eta| < 2.8$
- *muons :* $|\eta| < 1.0$
- *photons :* $|\eta| < 1.0$
- *neutrinos* ($\not{E}_T$)*: everywhere*

The Standard Model of Particle Physics

- 3 generations of quarks and leptons interact via exchange of gauge bosons:
  - Electroweak SU(2)xU(1): W, Z, γ
  - Strong SU(3): g
- Symmetry breaking caused by Higgs field
  - Generates Goldstone bosons
  - Longitudinal degrees of freedom for W and Z
  - 3 massive and one massless gauge bosons
- Standard Model survived all experimental challenges in past 30 years!
  - electroweak and QCD precision data
  - No New Physics despite many efforts!

Gauge Bosons

Particle	Mass (GeV/c^2)	Force
Photon (γ)	0	Electroweak
$W^{\pm}$	80.450	Electroweak
Z^0	91.187	Electroweak
Gluons (g)	0	Strong

Higgs Boson

-Vacuum quantum numbers (0^{++})

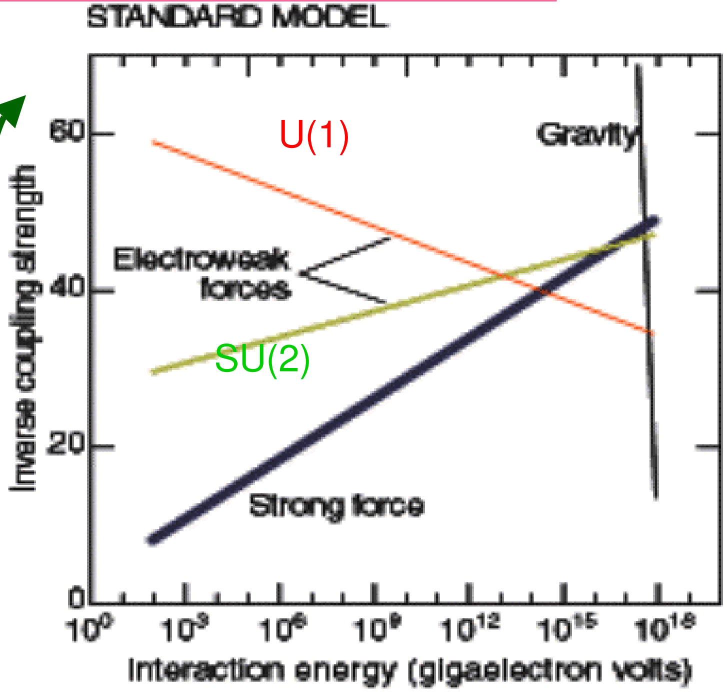
-Couples to mass

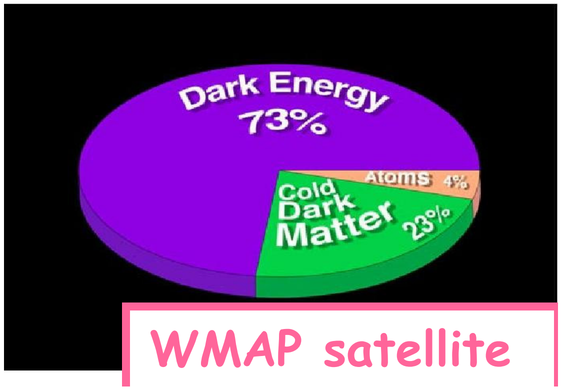
-M_h = ?

Why not the Standard Model?

- Radiative corrections to Higgs mass: electroweak scale (100 GeV) much much lower than Planck Scale (10^{19} GeV): "hierarchy" or "naturalness" problem
- No unification of forces at any scale
- Higgs boson not yet found: is it there?
- No explanation for matter/ anti-matter asymmetry in universe
- No accounting for dark matter in universe
- Many free parameters, e.g. masses of all particles: unsatisfactory

Coupling constants

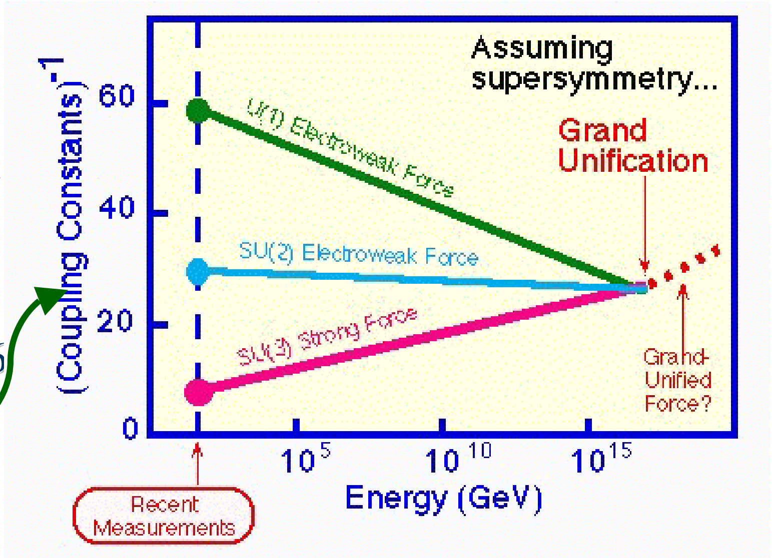




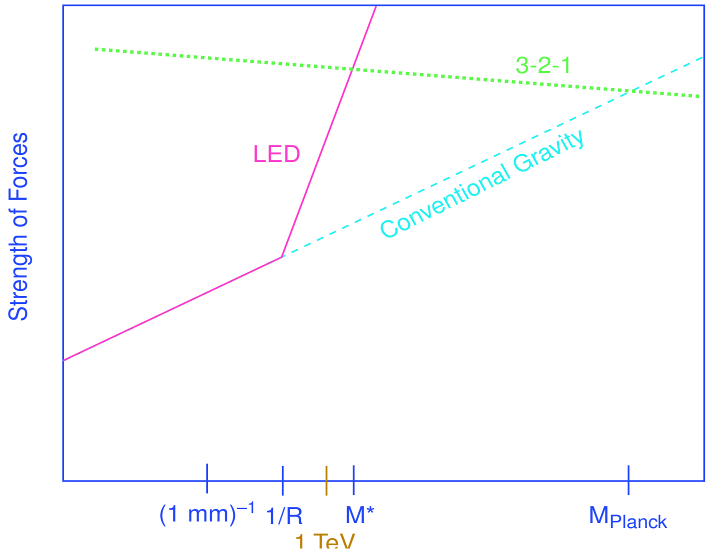
WMAP satellite

What could be Beyond the SM?

- Supersymmetry (SUSY):
  - Each SM particle has a “super”-partner with same quantum numbers apart from spin (top ↔stop, photon ↔photino, etc.)
  - Masses are O(1 TeV)
  - Unification of forces at GUT scale (10^{16} GeV)
  - Hierarchy problem solved



- Extra Dimensions
  - String theory: links gravity to other forces
  - Could be large (0.1mm): probed at TeV scale
  - Hierarchy problem solved
- The unexpected…



Supersymmetry Intro

$\tilde{\chi}_1^0$

SM Fermions	→	Boson Superpartners
SM Bosons	→	Fermion Superpartners

- **Physical SUSY sparticles:** ***neutralinos (Higgs, Photon, Z partners), charginos (Higgs, W partners), squarks (quark partners), sleptons (lepton partners)***

Different SUSY models:

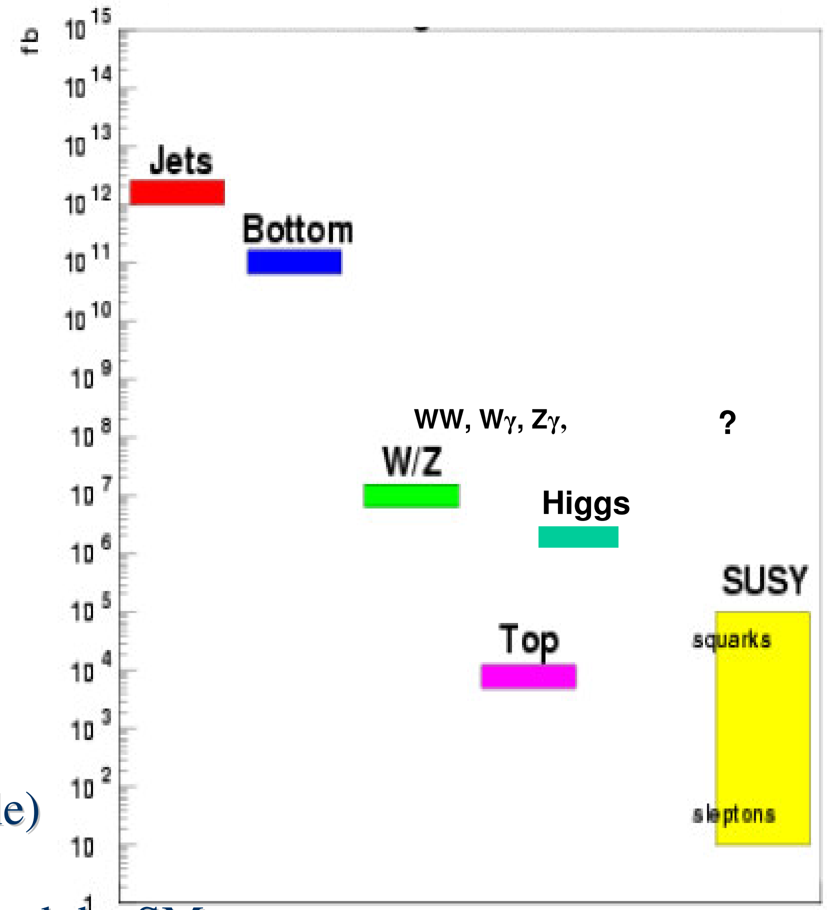
- **Supergravity: SUSY broken near GUT scale**
  - **GUT scale parameters: scalar mass m_0 , gaugino mass $m_{1/2}$, ratio of Higgs v.e.v's $\tan\beta$, Higgs mixing parameter μ**
  - **LSP is neutralino χ^0 or sneutrino $\tilde{\nu}$**
- **Gauge-mediated models (GMSB): SUSY broken at lower energies – breaking scale F an important parameter.**
  - **Gravitino $\tilde{G}$ is the LSP (NLSP $\chi^0 \rightarrow \tilde{G}\gamma$)**
- **If "R-Parity" conserved:**
  - **SUSY particles can only be pair-produced**
  - **Lightest SUSY Particle (LSP) stable and escapes detection→carries away missing E_T**

Searches for New Physics: CDF Strategy

1. Establish good understanding of data in EWK/QCD physics in Run 2:
   - ➡ Backgrounds to new physics searches
   - ➡ Indirect sensitivity to New Physics
   - ➡ Gain understanding of detector
2. Search for as many signatures as possible, involving:
   - High Pt leptons
   - Large imbalance in transverse momentum (e.g. due to neutrino or neutralino)
   - High Et jets
   - High Et photons
   - Rare decays of charm- and bottom-mesons
1. Interpret:
   - Provide cross section limits and acceptances

   (try to be as generic/model-independent as possible)
   ➔ applicable to future models!
   - In context of specific models of physics beyond the SM

Cross Sections (fb)

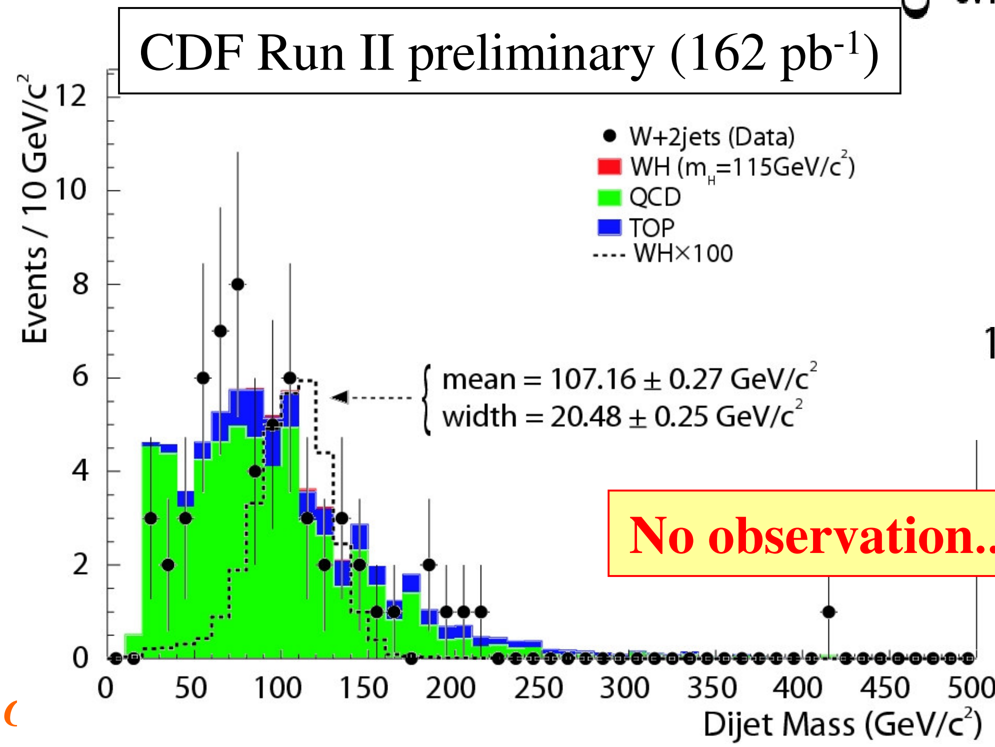


Searches for SM Higgs

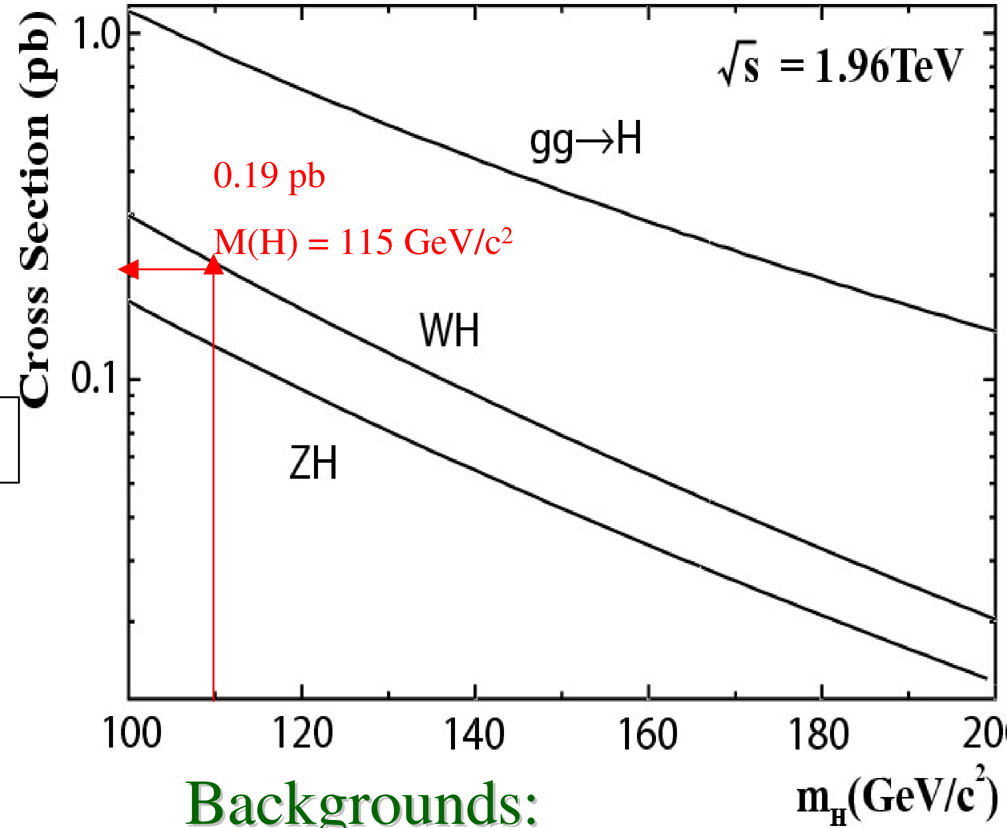
- $p\bar{p} \rightarrow WH \rightarrow l\nu\, b\bar{b}$

Selection:

- 1 high pt central (e or μ), MET>20 GeV
- 2 jets (>=1 b-jet)
- veto 2nd ℓ/track(suppress ttbar), Z mass windows, cosmics



No observation...



Backgrounds:

- Mistags
- Wbb, Wcc, Wc
- QCD
- $t\bar{t}$, single t, di-boson, Z(→ττ)

SM Higgs: results

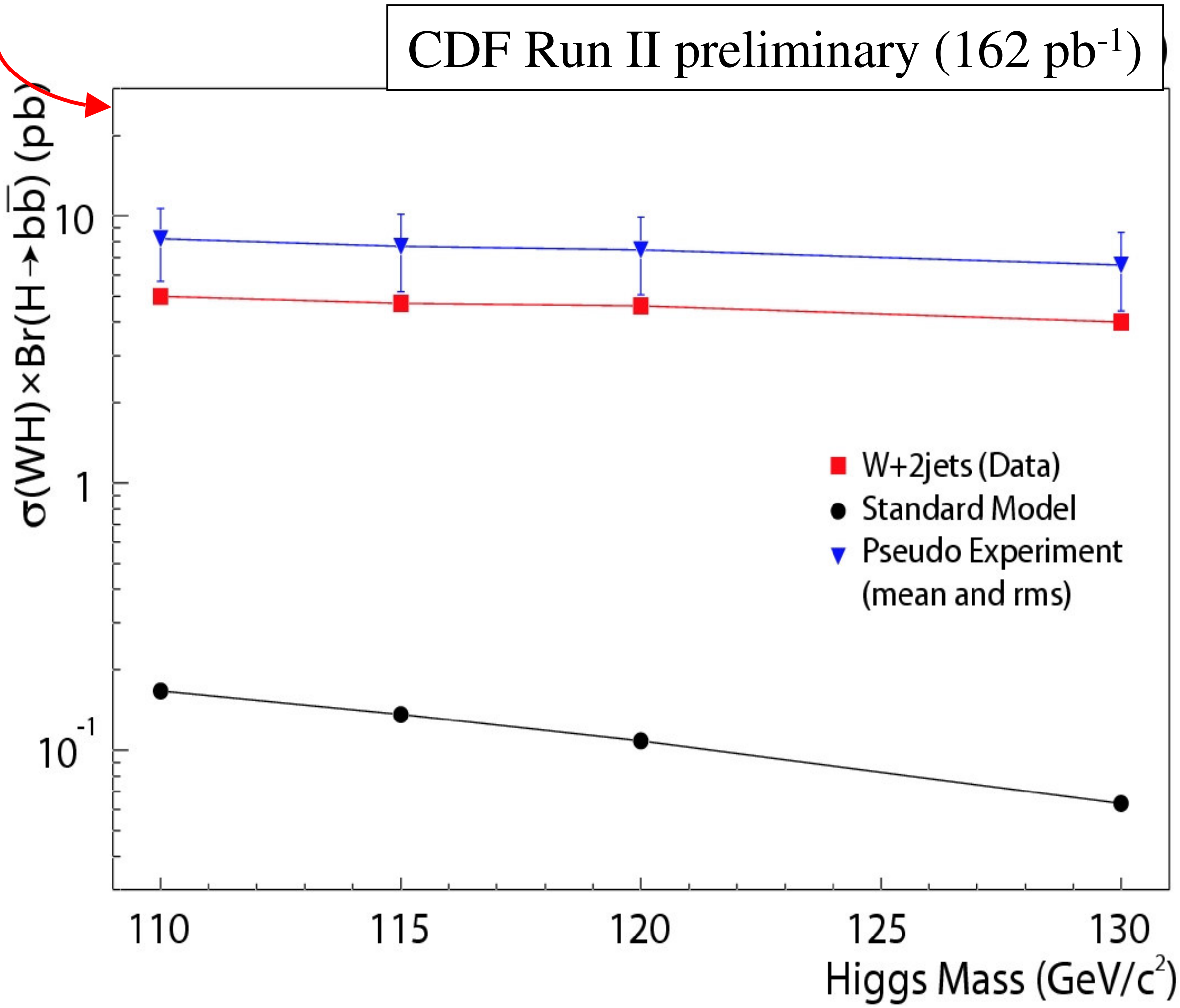
...We set limits

☺ Improved Run I result

😐 Limited Statistics

Future improvement :

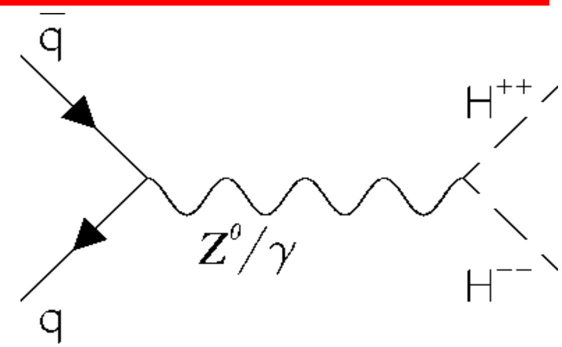
- Include plug electrons
- Improvement jet energy resolution
- Study ISR/FSR more detail
- Improve b-tagging
- Combine with other channels ($ZH \to \nu\nu b\bar{b}$)



Searches for $H^{++/--}$

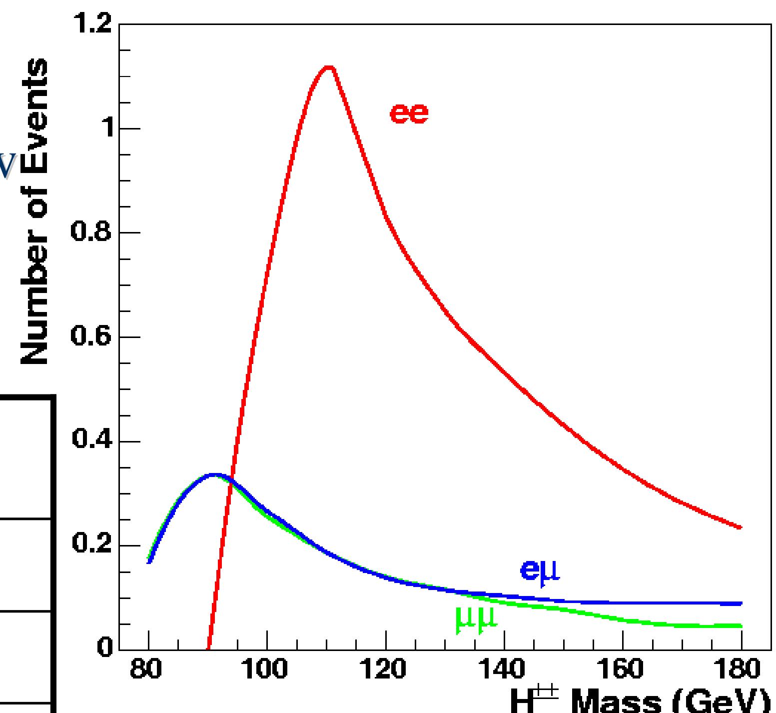
Motivation:

- Left-Right(LR) symmetric models
- Susy LR models: low mass (~100 GeV→1 TeV)
- ➡ Supposed to decay to Like-Sign di-leptons



Event Selection (L~ 240 pb^{-1}):

- 1 pair of LS ee, or μμ, or eμ in mass window of ±10%*M(H^{++}) (~3σ detector resolution)
- Veto Z events, cosmics(for muons)



Backgrounds:

m(ℓℓ)/GeVc^{-2} > 80(100)

- QCD
- cosmics(for muons)
- $Z/\gamma \rightarrow \ell\ell$, W jj→ℓν jj
- di-boson (WZ)

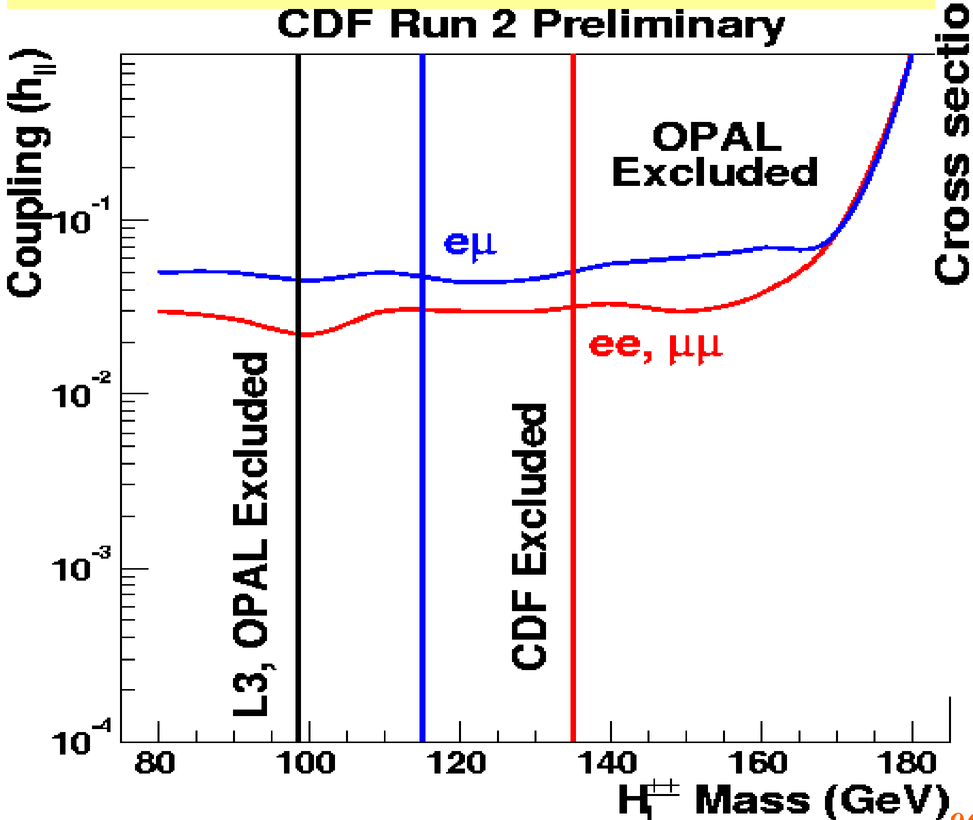
Decay Channels	# predicted Evts
ee	$1.8^{+0.8}_{-0.6}$
μμ	$0.8^{+0.6}_{-0.5}$
eμ	$0.9^{+0.4}_{-0.4}$

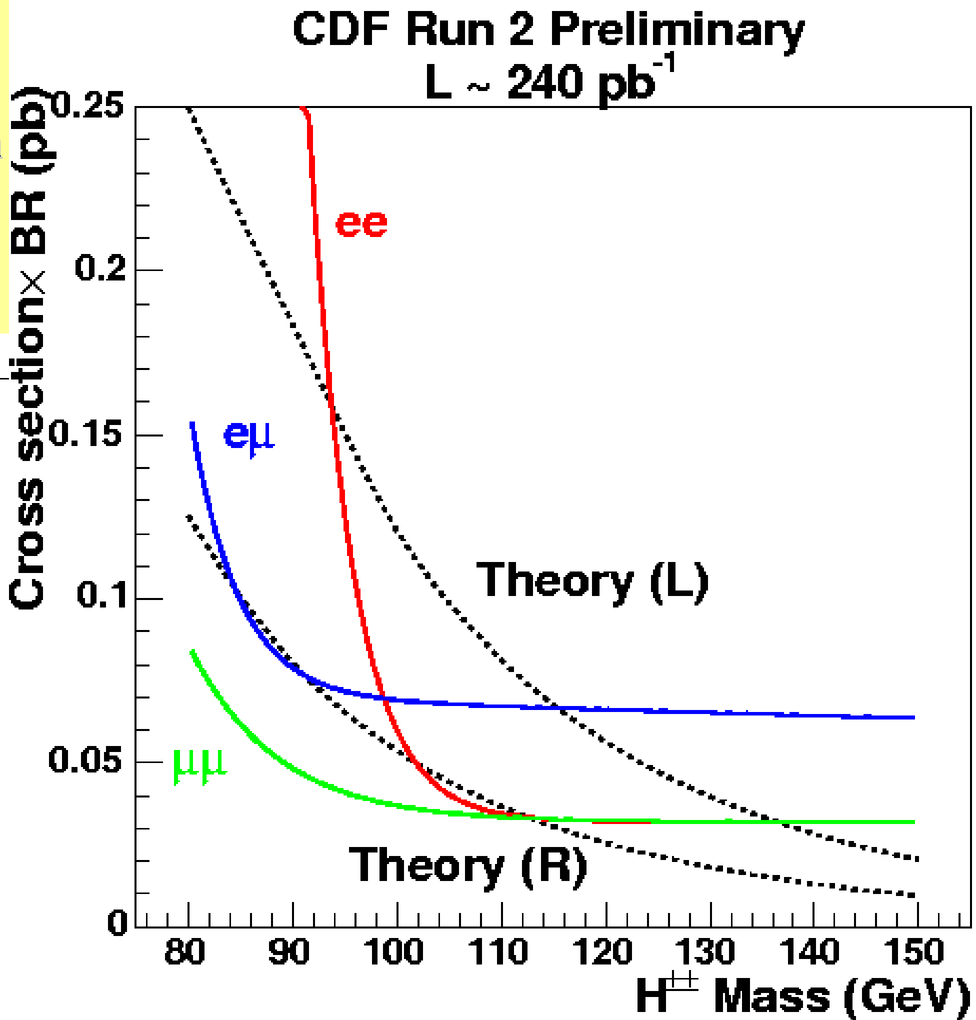
Data : observe 0 event

Searches for H^{++} : results

Result: 95% C.L. upper limit on

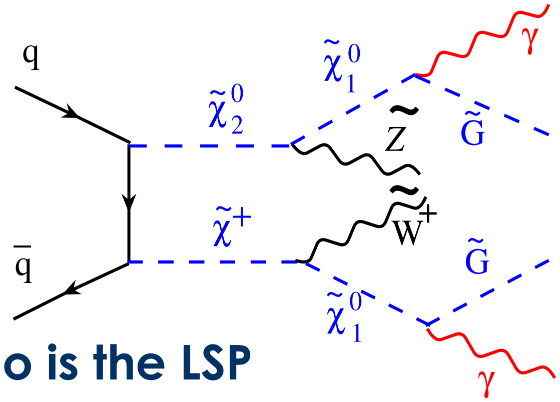
- ➡cross section x BR for pair production ($pp \rightarrow H^{++} H^{--} \rightarrow \ell^+ \ell^+ \ell^- \ell^-$)
- ➡$M(H^{++}) > 130$ GeV





GMSB search for $\gamma\gamma + \not\!\!E_T$

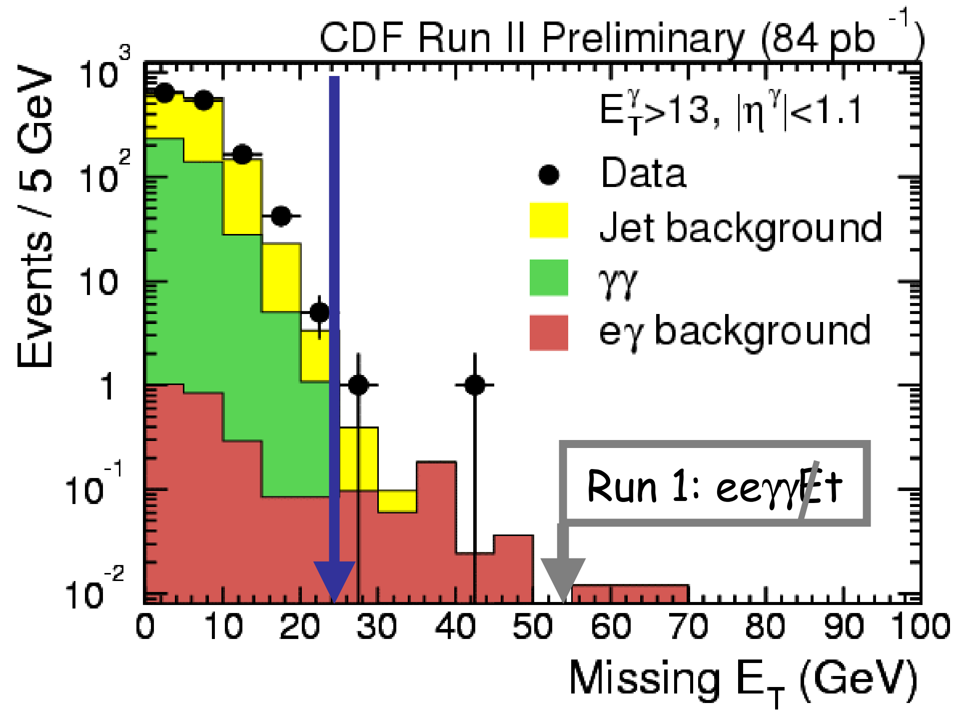
e.g.



- Gravitino is the LSP
- NLSP: Neutralino $\chi_1 \rightarrow \gamma\tilde{G}$

$$pp \rightarrow \tilde{\chi}\tilde{\chi} + Y \rightarrow \gamma\gamma\tilde{G}\tilde{G} + Y$$

- Experimental Signature: $\gamma\gamma + \not\!\!E_T$



SUSY would show up as an excess of events with large Missing Energy

- Search Selection:

  2 central photons w/ Et>13

  Cosmic/beam halo removal

For Missing Et>25GeV (L=84 pb^{-1})

Expected background: 2 ± 2
Observed: 2

→ **Set cross section limit**

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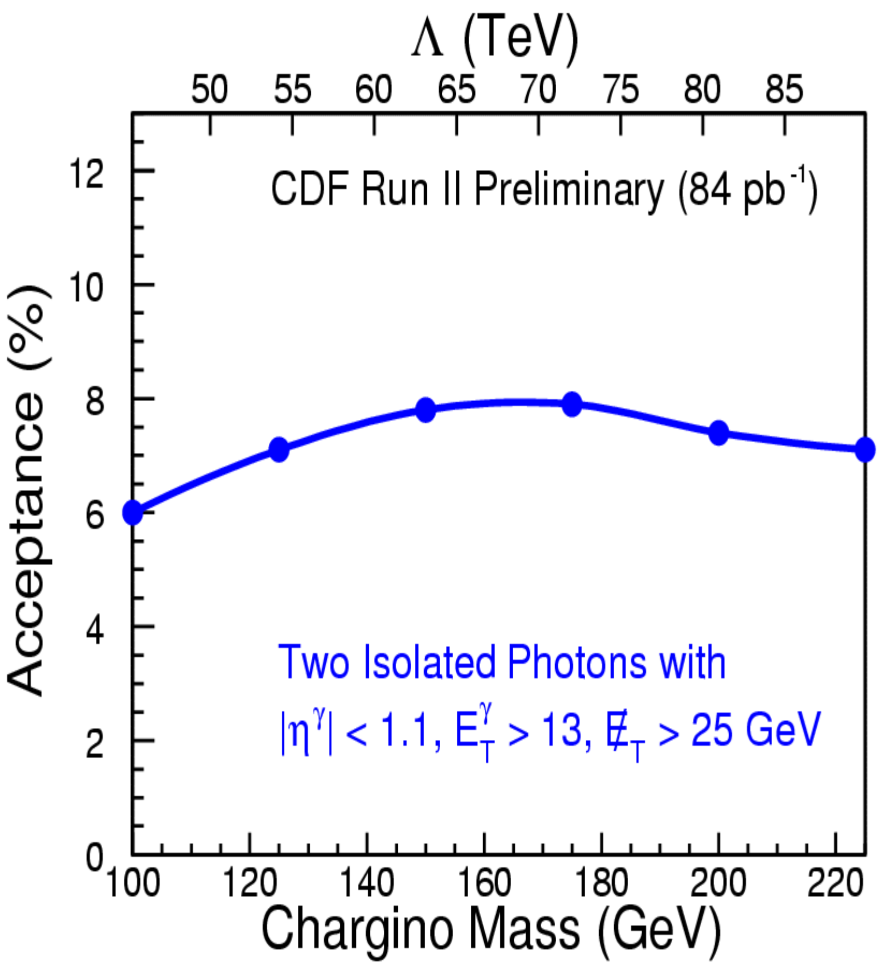
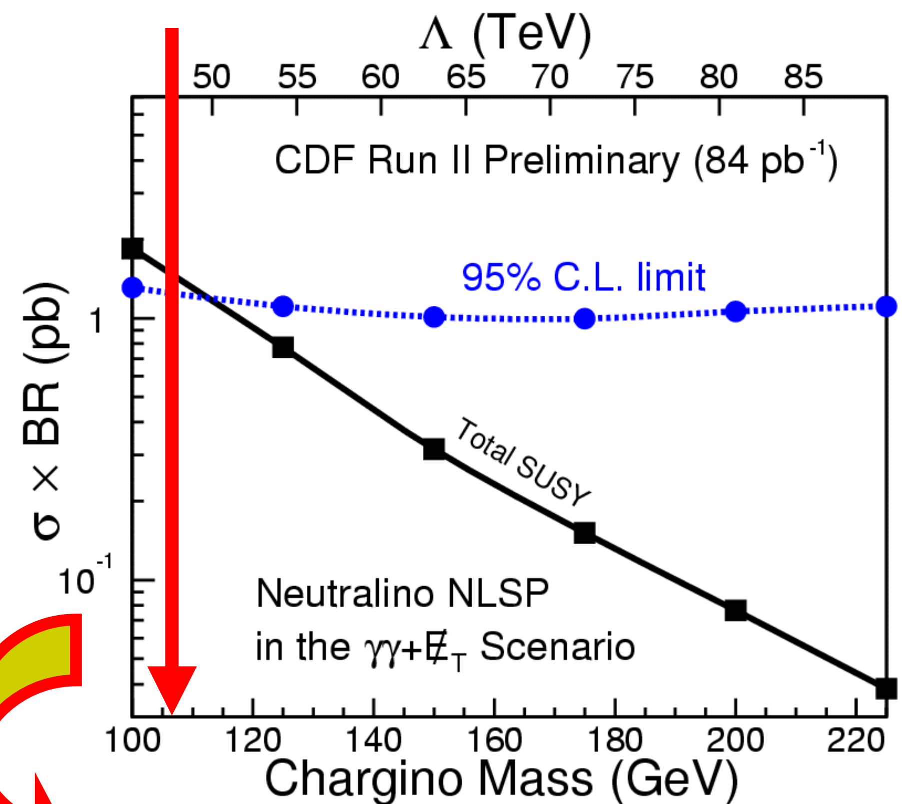
GMSB Search in $\gamma\gamma + \not{E}_T$

Acceptance x Efficiency





Set the lower mass limit on the lightest chargino in GMSB:

M_c>113 GeV @ 95% C.L.

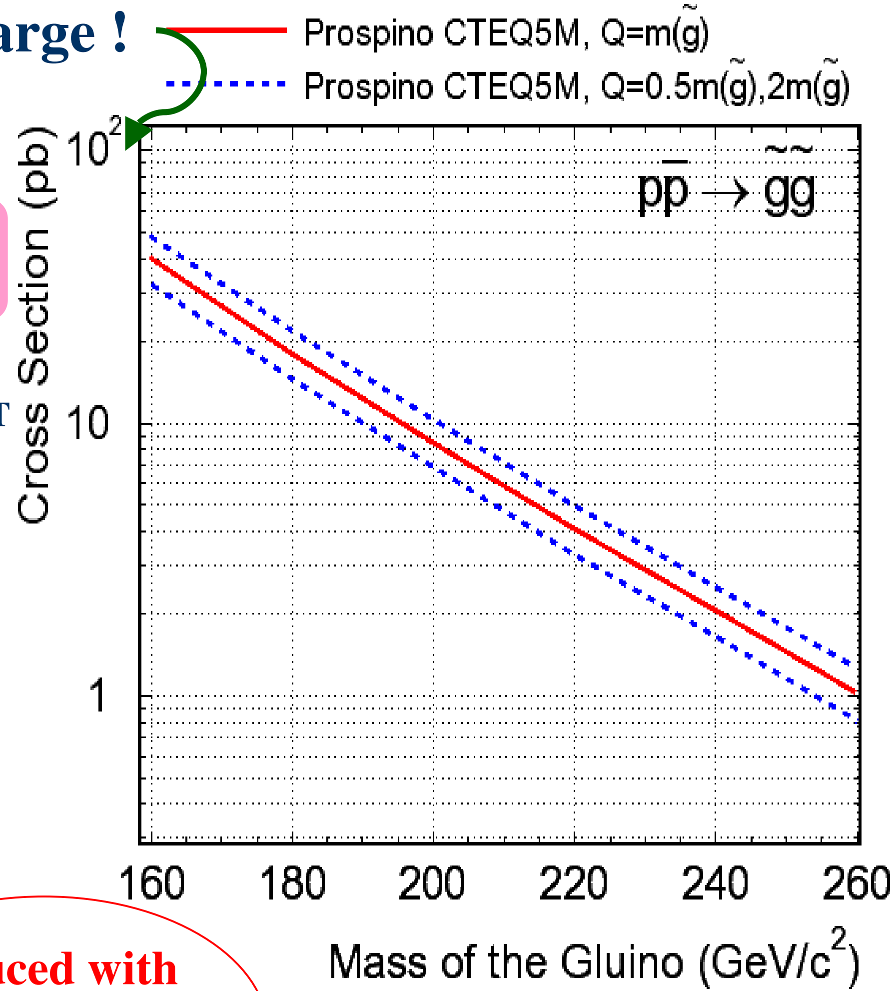
Sbottoms from Gluino decays

- **Gluino pair production cross section large !**

$$if \quad m_{\tilde{g}} > m_{\tilde{b}} > m_{\tilde{\chi}_1^0}$$

$$\tilde{g}\tilde{g} \xrightarrow{100\%} (b\tilde{b}_1)(b\tilde{b}_1) \rightarrow (bb\tilde{\chi}_1^0)(bb\tilde{\chi}_1^0)$$

➡ **Very distinctive signature: 4 b-jets, $\not{E}_T$**



Events selection:

→ $\not{E}_T > 50$ GeV

→ 1-2 btag(s)

$\mathcal{L} = 38.4\ \text{pb}^{-1}$

Background:

→ $b\bar{b}$ QCD

→ $t\bar{t}$, W/Z+jets

Reduced with secondary vertex tagging algorithm

Sbottoms from Gluino decays

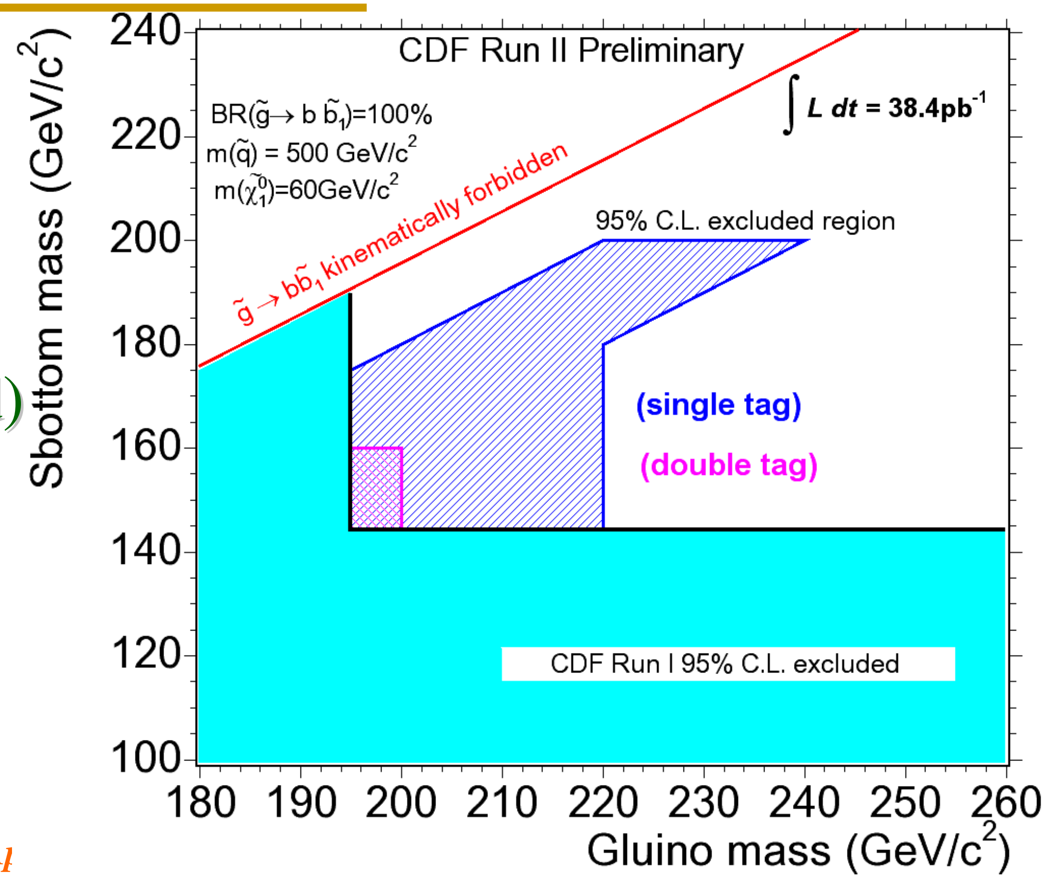
b-*tag*	Observed	Expected Background	Expected Signal
Single	4	5.6±1.4	10.6±1.7
Double	1	0.5±0.1	4.4±0.9

Assuming $m_{\tilde{\chi}_1^0} = 60GeV$

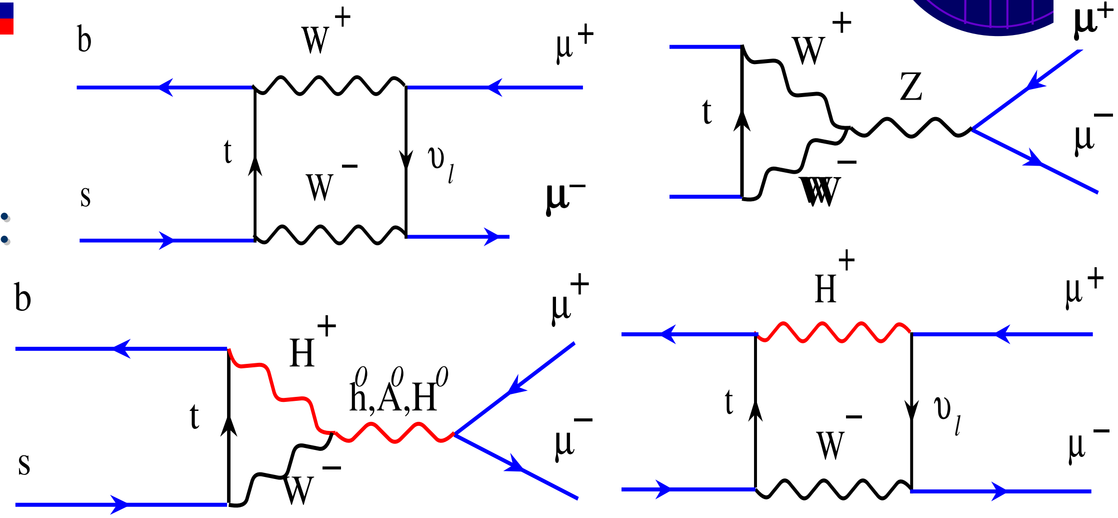
$m_{\tilde{g}} = 220GeV$ $m_{\tilde{b}_1} = 160GeV$

Future :

- Soften the selection criteria (understand QCD backgorund) → larger efficiency
- To be updated with full luminosity !



Rare Decays: $B_s \rightarrow \mu^+\mu^-$



New Physics can enhance branching ratios of B-mesons:

- Measure BR in decay modes suppressed in SM

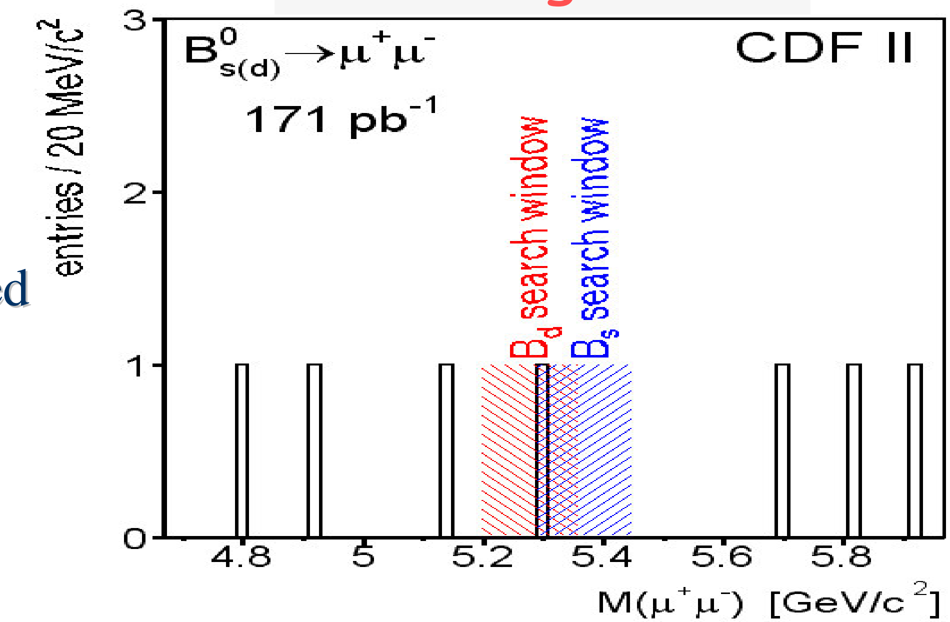
e.g. $B_s \rightarrow \mu\mu$:

- B_s = bound state of b and s
- SM: $BR(B_s \rightarrow \mu\mu) \sim 10^{-9}$
- SUSY: BR may be A LOT higher ($\sim \tan^6\beta$?)

Blind analysis with a priori optimisation:

- 1 event observed, ~1 ± 0.3 expected

SM vs e.g. SUSY

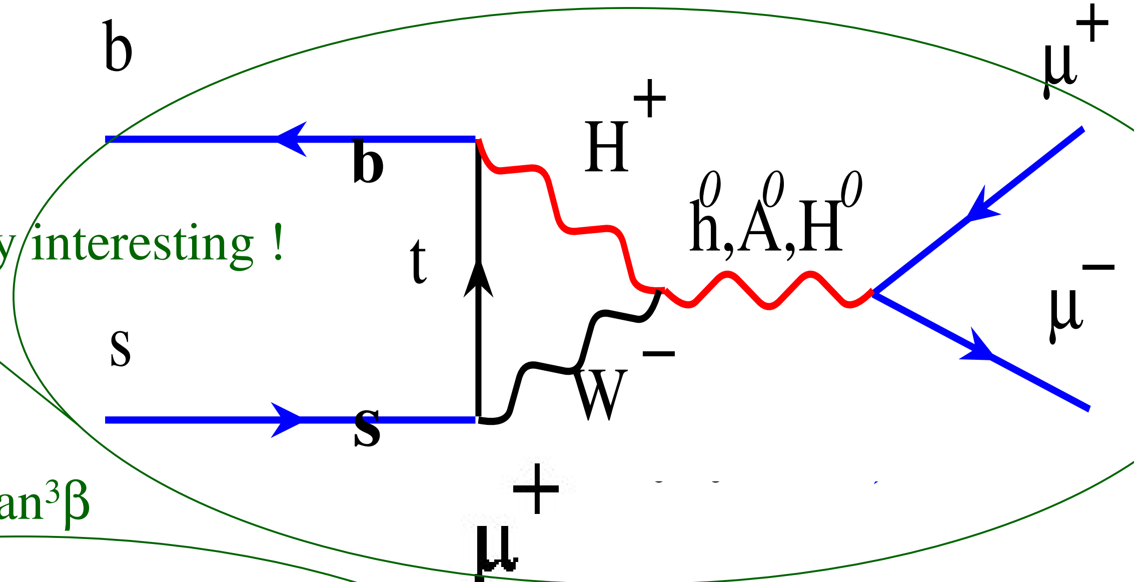


90% CL limits:

- $BR(B_s \rightarrow \mu\mu) < 5.8 \times 10^{-7}$
- $BR(B_d \rightarrow \mu\mu) < 1.5 \times 10^{-7}$

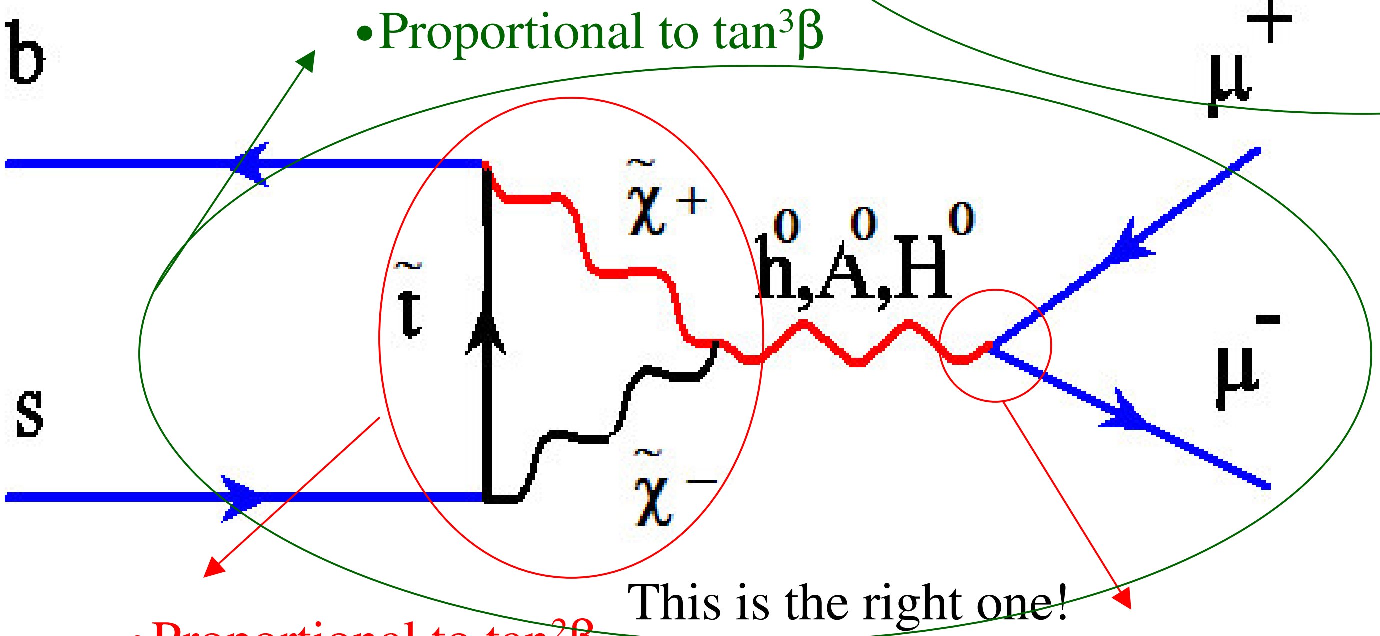
Rare Decays: $B_s \to \mu^+\mu^-$

SM vs e.g. SUSY



- Only proportional to $\tan^2\beta$-not very interesting !

- Proportional to $\tan^3\beta$



This is the right one!

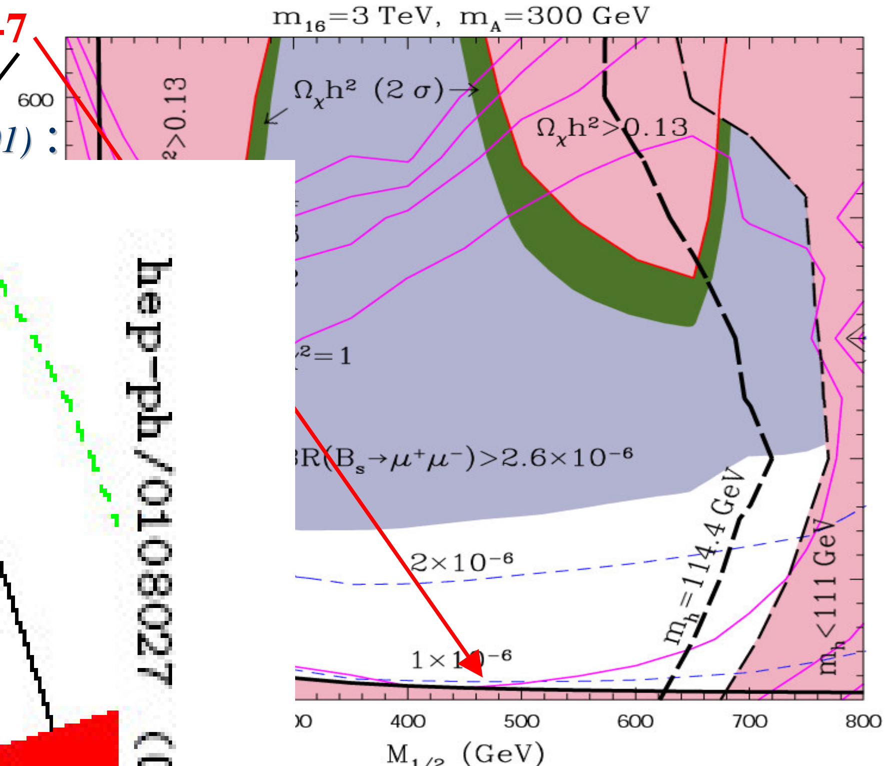
- Proportional to $\tan^2\beta$

- Proportional to $\tan\beta$

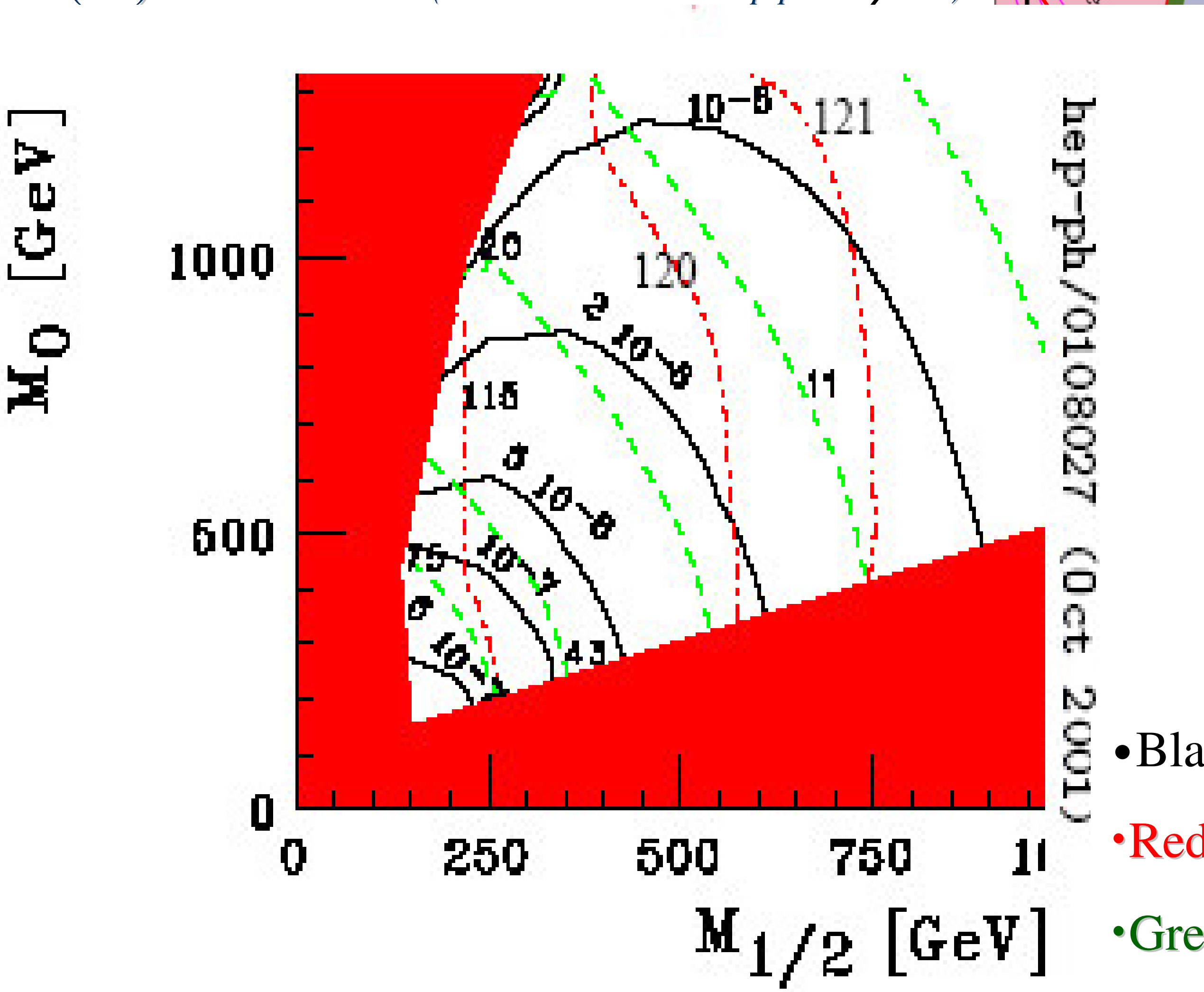
SUSY Sensitivity: $B_s \rightarrow \mu\mu$

90% CL limit: BR(Bs→μμ)<5.8x10^{-7}

- SO(10) GUT model *(R. Dermisek et al.: hep/ph-0304101)* :



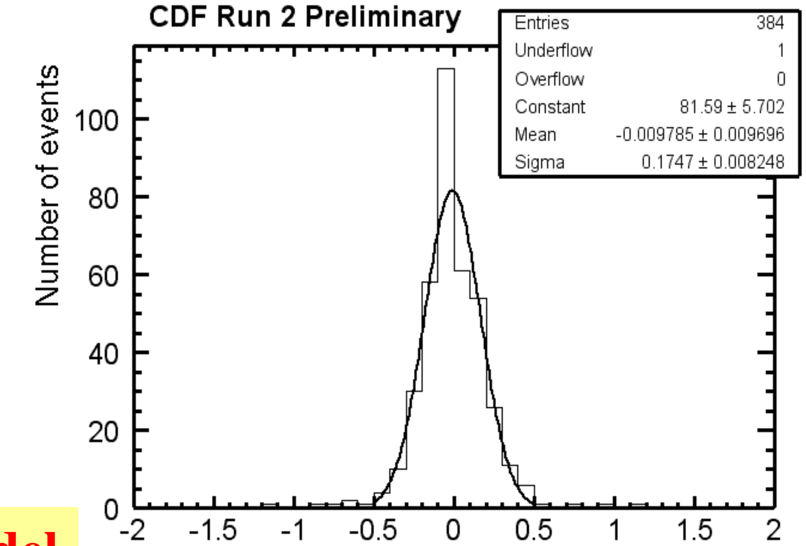
gh tanβ



- Black: BR($B_s \rightarrow \mu\mu$)
- Red: Mass of the lightest Higgs
- Green: $\delta a_\mu/10^{-10}$

CHarged Massive ParticleS

- **Motivations:**
  - **Champs predicted in different models (LQ,GMSB SUSY,..)**
  - **→distinctive signature:**
    - *Isolated slow-moving high P_T particle*
    - *Large dE/dx, long time-of-flight, escapes from detector*



Δt resolution form tight Z sample

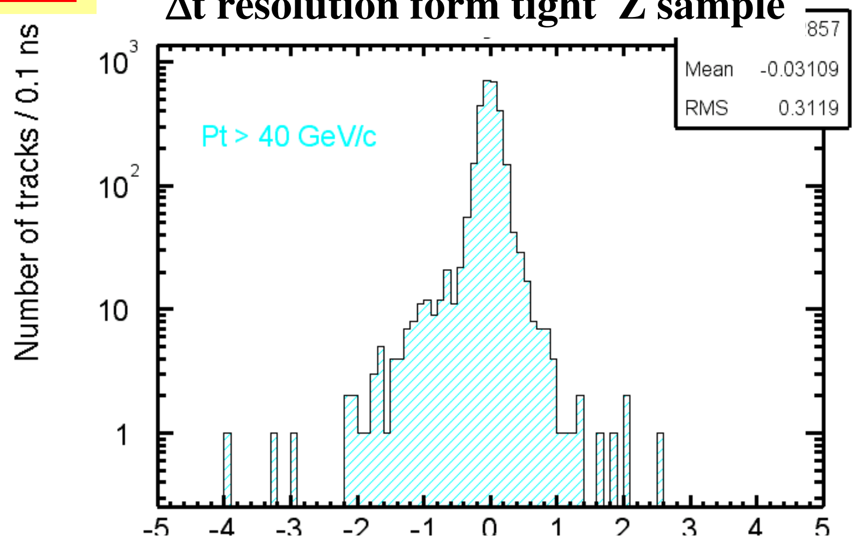
Search performed independently from the model

Events selection:

- *High P_T muons (>18 GeV/c)* ***53 pb^{-1}***
- *Tracks with P_T>40 GeV /c (full tracking efficiency)*
- *TOF_{track}-t_0 > 2.5 ns*

Background:

- *Cosmic Rays (Removed Δt>2.5 ns)*
- *t_0 anomalous early*



TOF_{track} – t_0 (t_0 fitted with all TOF tracks)

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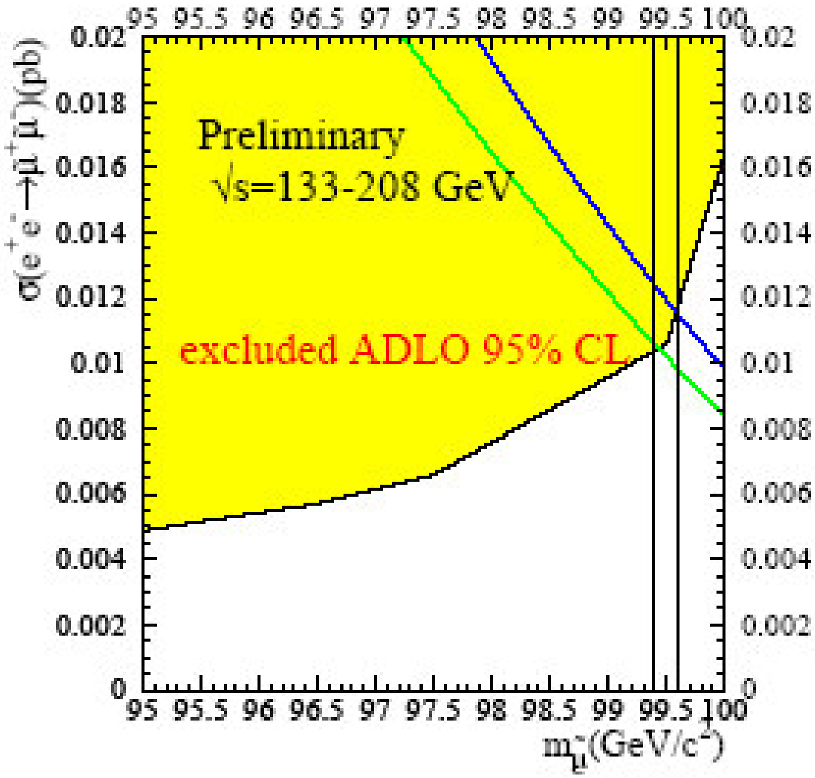
CHAMPS: existing limits(Susy)

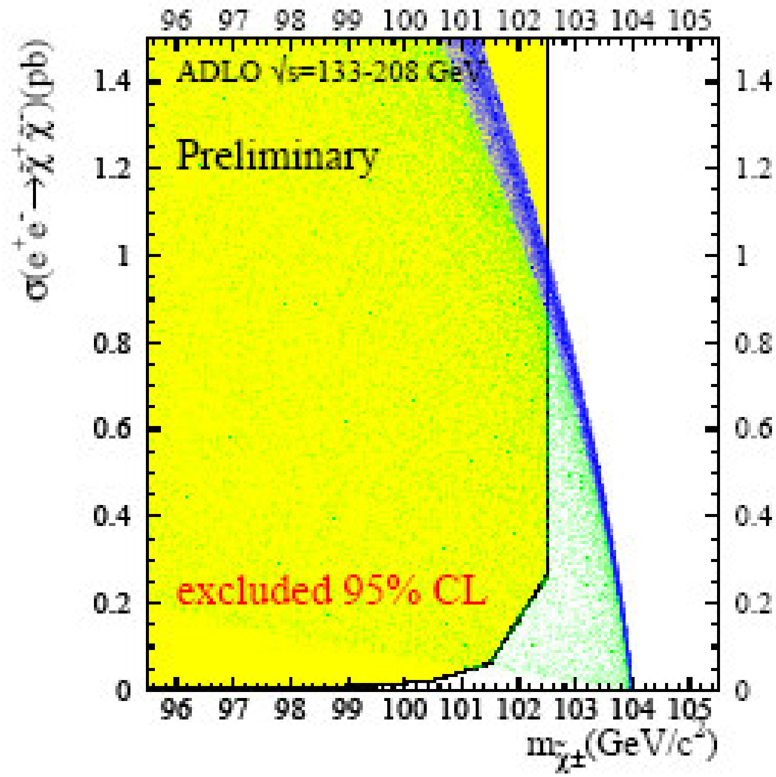
Combined LEP limits, stable slepton

M > 99.4 GeV/c^2 (right-handed)
M > 99.6 GeV/c^2 (left -handed)

Combined LEP limit, stable chargino:

M> 101.2 GeV/c^2
(sneutrino mass > 41 GeV/c^2)





CHarged Massive ParticleS

Interpreted for stop particles

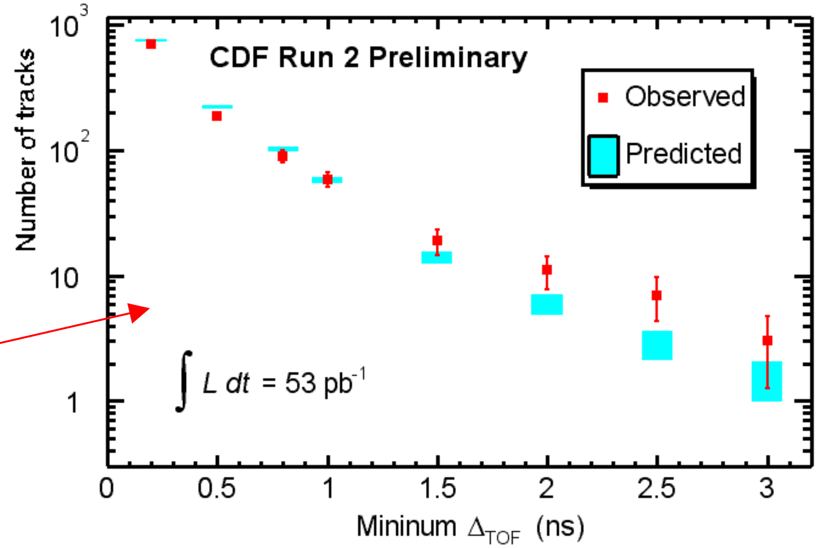
GMSB models, NLSP stable particle

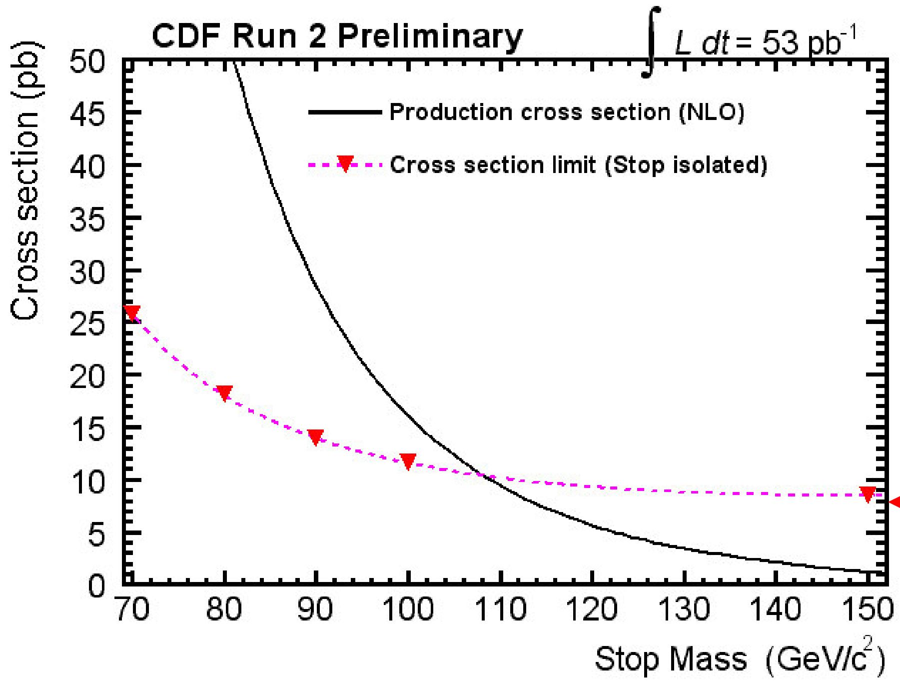
Signal region:

$\Delta t > 2.5$ ns, track $P_t > 40$ GeV/c

Systematics

Background prediction W-tight and top multijet samples (high # tracks)





Predicted: 2.9 ±0.7 (stat) ±3.1 (sys)

Observed: 7

• Check this value

➢ **Exclusion Limits**

-M_{stop}> 108 GeV/c^2 at 95 % C.L.

-LEP M_{stop}> 95 GeV/c^2

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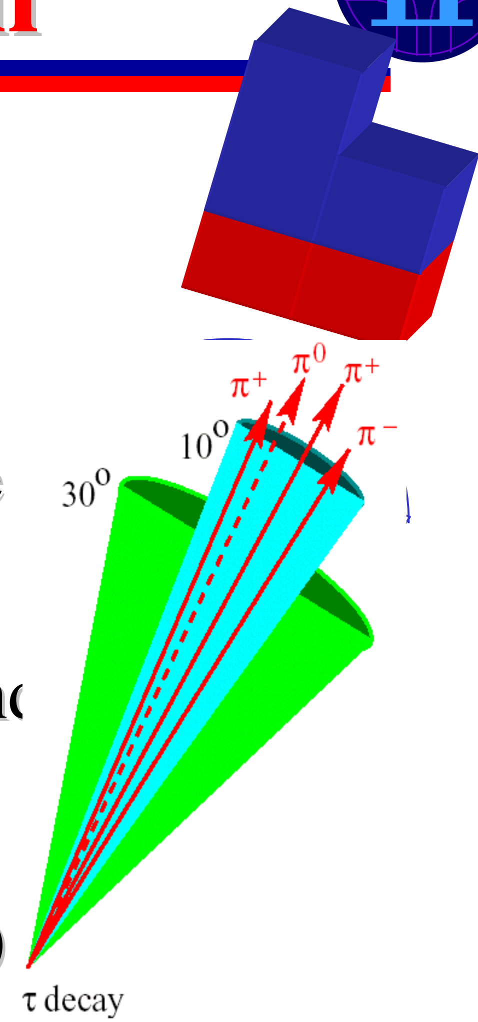
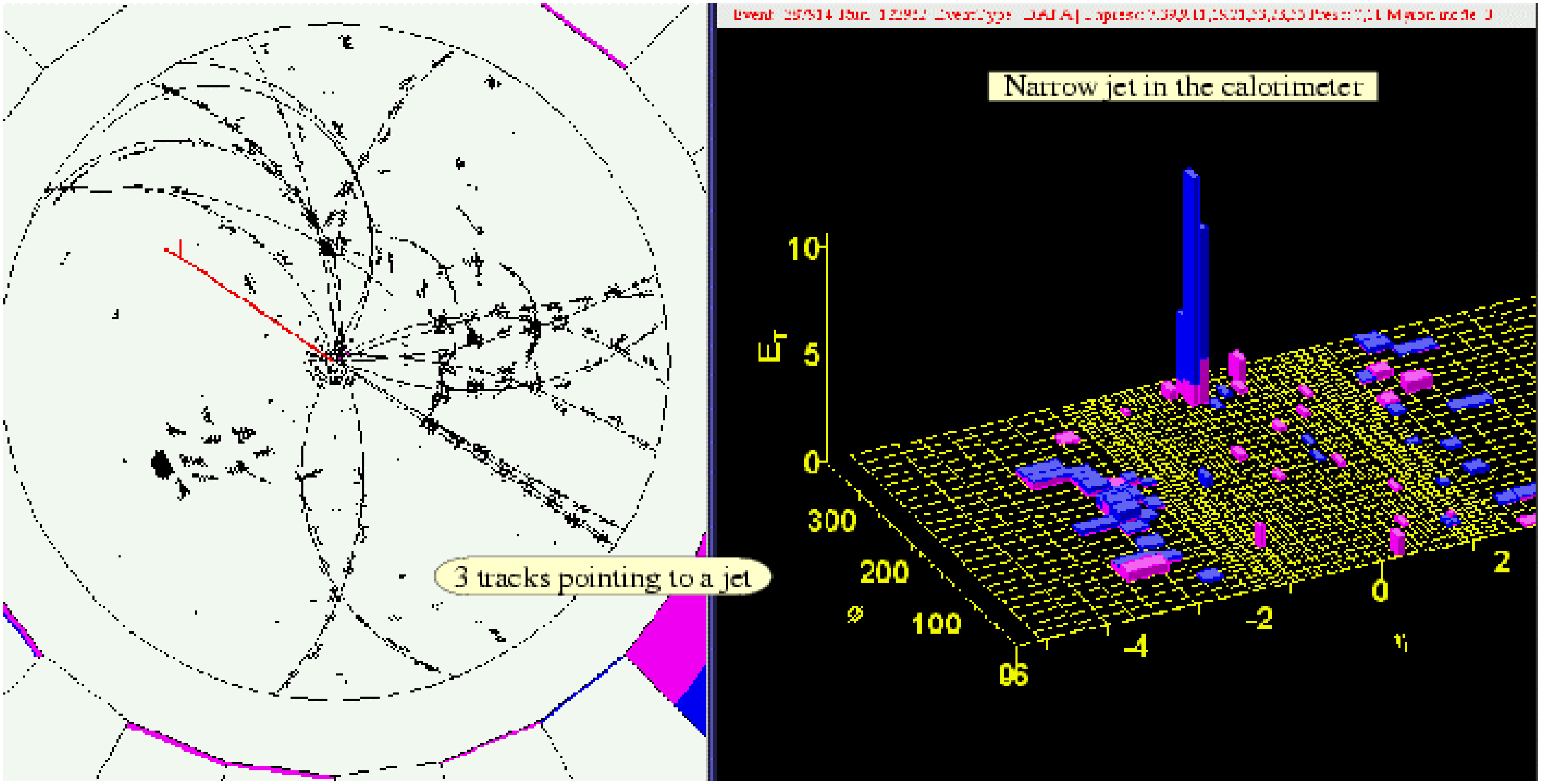
Tau identification

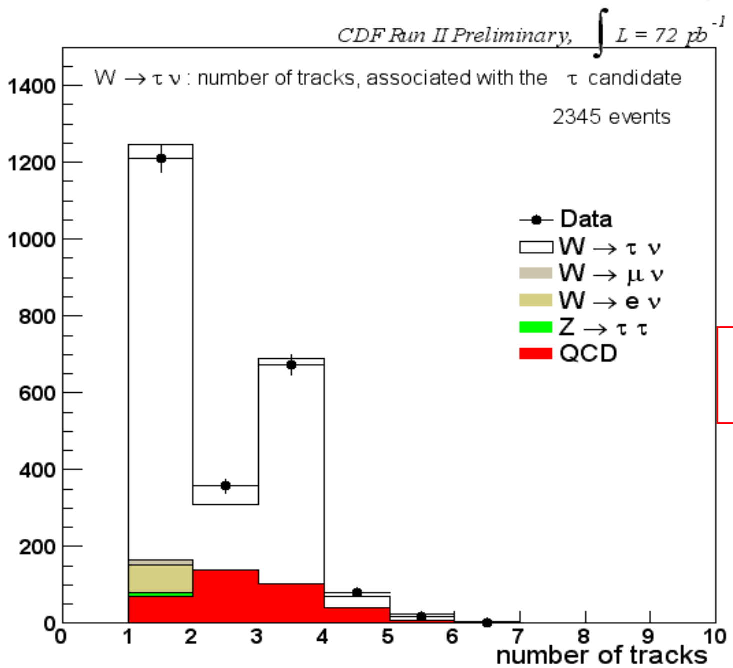
- narrow cluster in central calorimeter
  - search for matching high-Pt track
  - define 2 cones 10^o and 30^o around the track
  - let more tracks to enter in the inner cone
  - discard event if there are tracks between the 2 cones
  - reconstruct the cluster in the ShowerMax and create a π^0
  - select events with mass(π^0 ,tracks) < M(tau)
  - check E(cal) = sum(P)(tracks+ π^0)



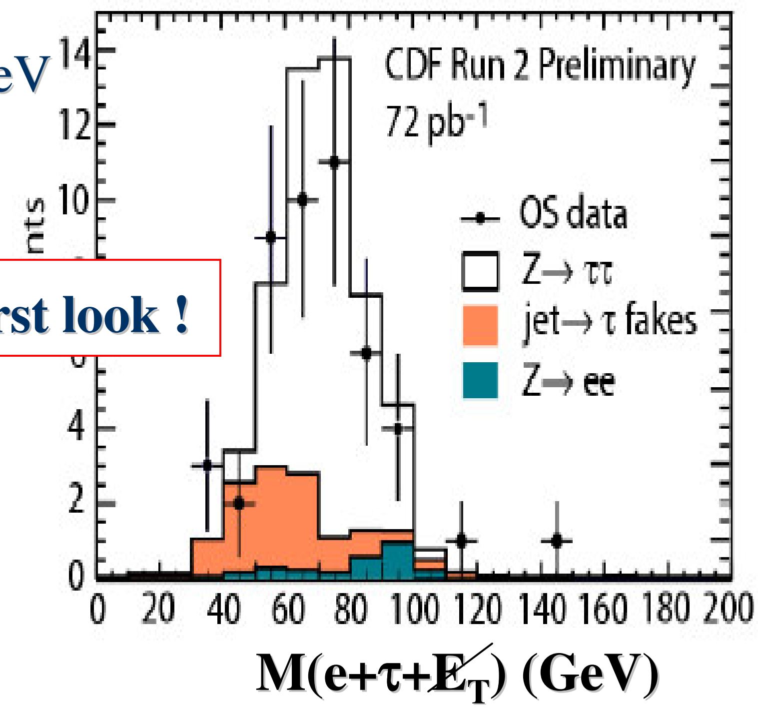
Tau event candidate



$W \to \tau\nu_\tau$ and $Z \to \tau_h^+\tau_\ell^-$ Signals



- **Tau selection :**
  - $|\eta| < 1.0$
  - $E_T > 25$ GeV



$Z \to \tau_h^+\tau_\ell^-$: first look !

$W \to \tau\nu_\tau$: 2345 in ~72 pb^{-1}
Background ~ 26 % (dominated QCD)

$\sigma \cdot BR(W \to \tau\nu) = 2.62 \pm 0.07_{stat} \pm 0.21_{sys} \pm 0.16_{lum}$ nb

- **Benchmark towards exotic analyses including tau signal (e.g. Higgs, Susy @ high tanβ**

Conclusions and Outlook

- Physics at CDF is back:
  - Have twice the Run I luminosity and excellent detector
- Searches for New Physics have started:
  - Expect new physics at the TeV scale (hierarchy problem)
  - Z', Large extra dimensions, Leptoquarks (Tracey's talk), SUSY, Higgs
  - Cover broad range of possible signals
  - no signals yet but constraining theoretical models
- Work in progress :
  - Tri-lepton signature (e, mu and taus)
  - Gluino/squark production

$\left.\right\}$ Results expected by the summer !

Many New Exciting Results coming soon!