SUSY at CMS

Shuichi Kunori
U. of Maryland

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Outline

LHC and CMS
SUSY: MSSM and mSUGRA
SYSY Signature
Trigger
Inclusive SUSY Search
SUSY Spectroscopy
SUSY Higgs
Plan for CMS Physics TDR
Summary

My talk is not a review talk. Although I had given talks on “SUSY at CMS” long time ago, I re-started working on SUSY with Taylan recently and gathering information. Today, I want to share those information with you. CMS needs to be ready for SUSY search on day-1. Also, the Physics TDR is due in December this year. Let’s work together for a successful LHC/CMS research program.

Links and Talks

Web pages:

CMS SUSY/BSM group meeting agenda page:
agnda.cern.ch > experiment > cms > CPT > PRS > SUSY/BSM

CMS SUSY/BSM group:
cmsdoc.cern.ch/cms.html > PRS > PRS Groups:Web pages > SUSY/BSM

Talks:

"What is the Scale of Supersymmetry?" J.Ellis, CMS (09-Dec-2005)
agenda.cern.ch > experiment > cms > cms week > Dec 2004 > 9-Dec-2005

"SUSY at LHC" Frank Paige, LHC Physics @ Vienna (14-July-2004)
agenda.cern.ch > Conferences, Workshops > Conferences > 12-17 July 2004
See references in his talk.

"SUSY Searches (Review)" S.Abdullin, LHC Physics @ Prague (8 July 2003)
agenda.cern.ch > Conferences, Workshops > Conferences > 07-12 July 2003

"Discovery of potential of MSSM Higgs Bosons …", CMS Thesis Award. F.Mootgat, (14-Mar-2005)
ageanda/cms > cms week > March 2005 > 14 March 2005
http://hep.uia.ac.be/moortgat/PublicDefense_FilipMoortgat.ppt
http://hep.uia.ac.be/moortgat/Thesis_FilipMoortgat.pdf

More Talks and Links

Workshops/conferences:

CMS101 at LHC Physics Center (LPS) at Fermilab

agnda.cern.ch > experiment > cms > uscms > LPC > Workshops > 17 Nov 2004
"Introduction to CMS" Dan Green
"The CMS Detector" Jim Freeman
"The CMS Trigger" Darin Acosta

Tev4LHC Workshop at Fermilab, 16-18 Sept. 2004

http://conferences.fnal.gov/tev4lhc/

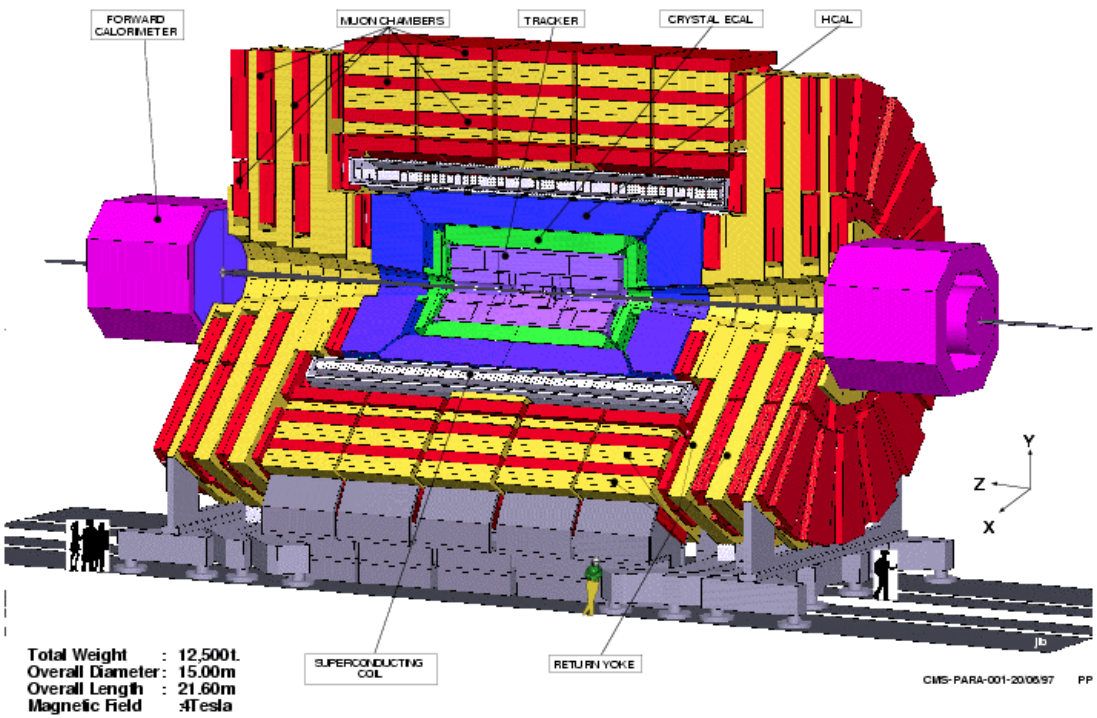
TeV4LHC Workshop at Brookhaven, 3-5 Feb. 2005

cmsdoc.cern.ch > conferences > workshops > HEP > 03-05 Feb 2005

List of HEP Conferences from (cmsdoc.cern.ch/cms.html) > conferences

2005 http://cmsdoc.cern.ch/cms/conferences/conf05.html
2004 http://cmsdoc.cern.ch/cms/conferences/conf04.html
2003 http://cmsdoc.cern.ch/cms/conferences/conf03.html
2002 http://cmsdoc.cern.ch/cms/conferences/conf02.html
2001 http://cmsdoc.cern.ch/cms/conferences/conf01.html

The CMS detector



Toal weight	12500 t
Overall diameter	15 m
Overall length	21.6 m

All silicon tracker
- micro strips (10M ch)
- pixel (40M? ch)
- (5.4m long, 2.4m Φ: $|\eta| < 2.4$)

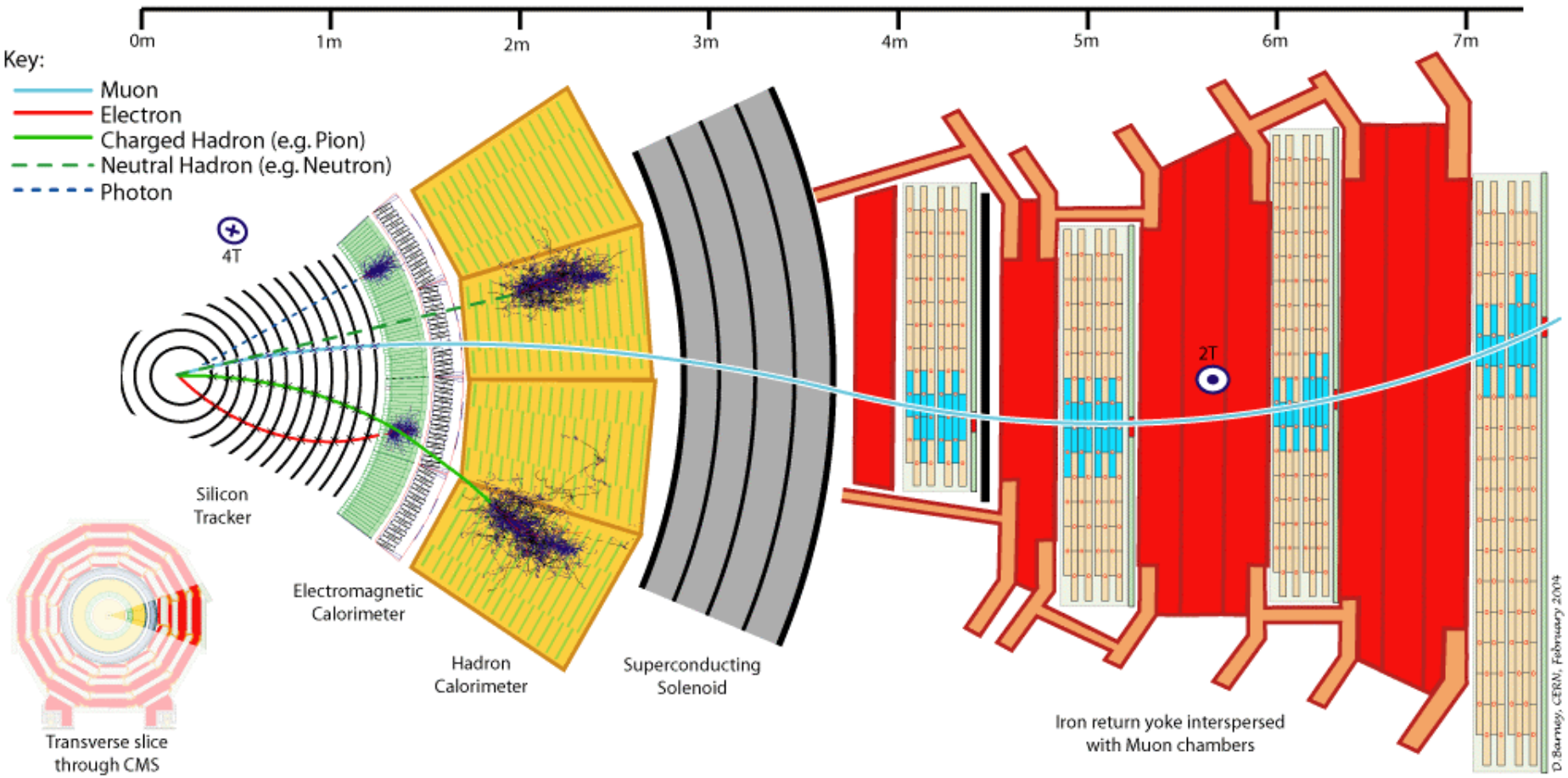
Hermetic calorimeter
- ECAL: PbWO4 crystal
- HCAL: brass+scinti.
- ($|\eta| < 3.0$)

in 4 Tesla solenoid
- (12.5m long, 6m Φ in)

Robust muon system
- DT+RPC (barrel)
- CSC+RPC (endcap)
- (in iron yoke: $|\eta| < 2.4$)

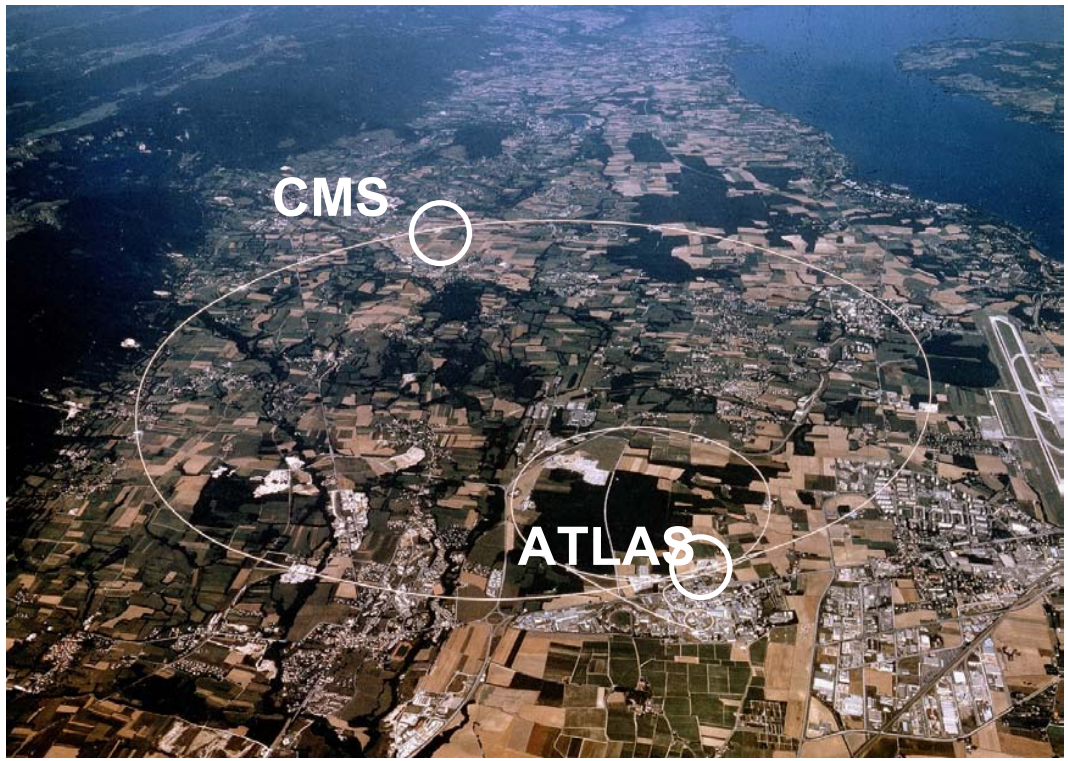
Fast cerenkov calor.
- quartz fibber
- ($3 < |\eta| < 5$)

The CMS detector



CMS_Slice.mov

The LHC

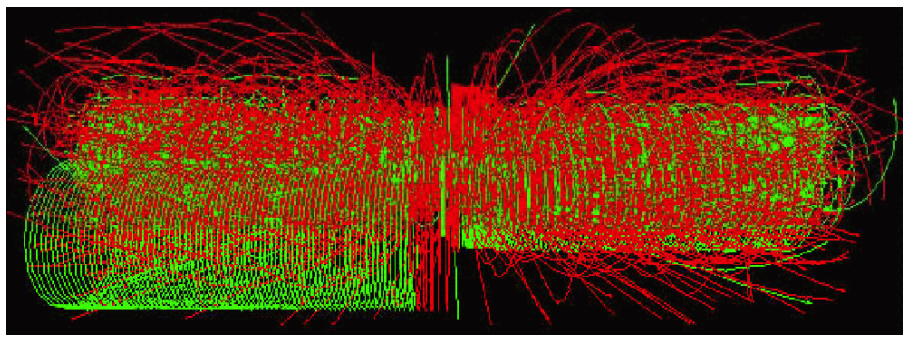


R = 4.5 Km
E = 7+7 TeV (pp)

crossing rate
=40MHz
(25nsec)

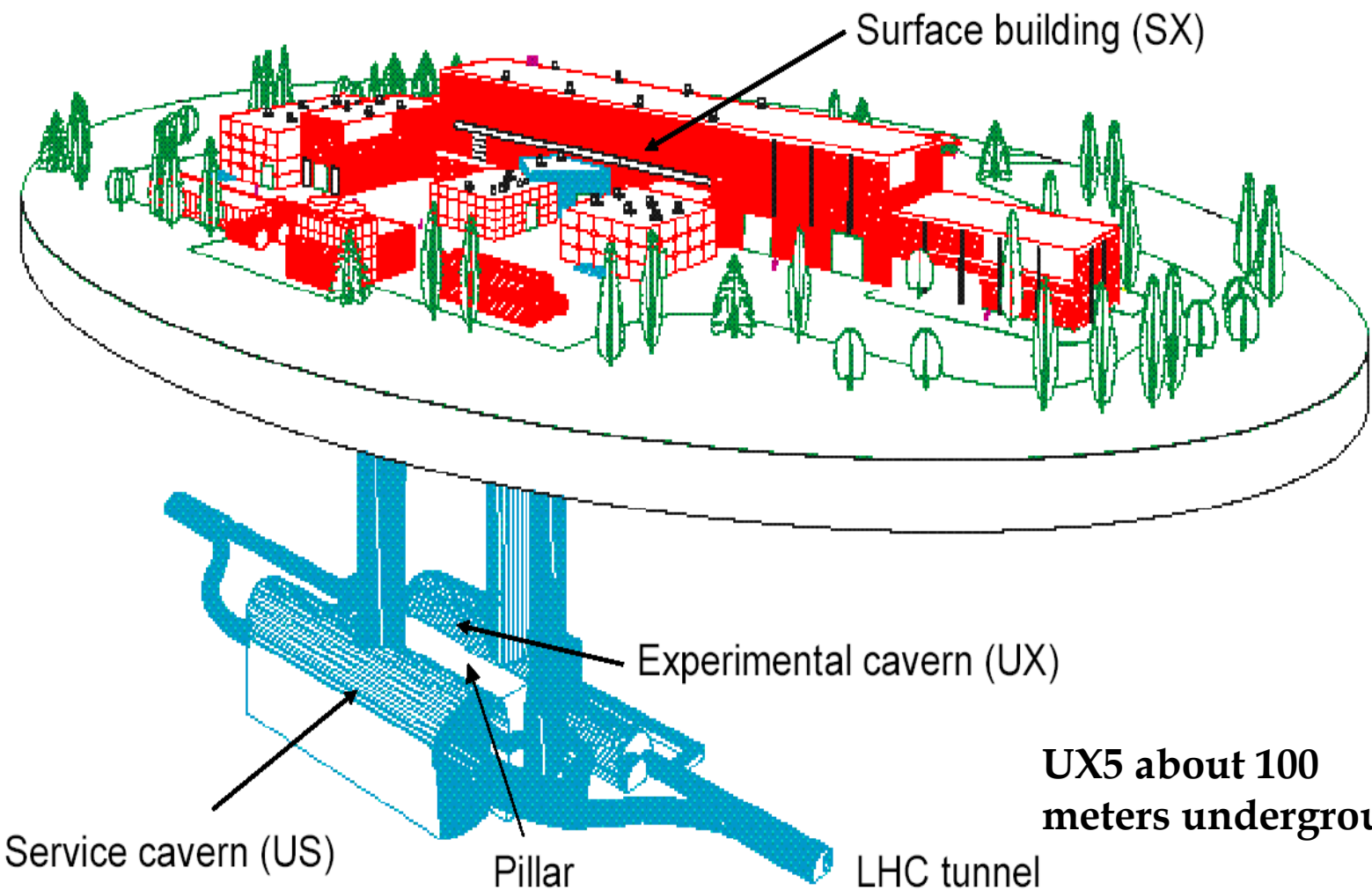
design luminosity
= $10^{34} cm^{-2} s^{-1}$

~20 pp interactions
per crossing
at design luminosity



h → 4 μ with 20 min. bias evt.

CMS at LHC Point 5



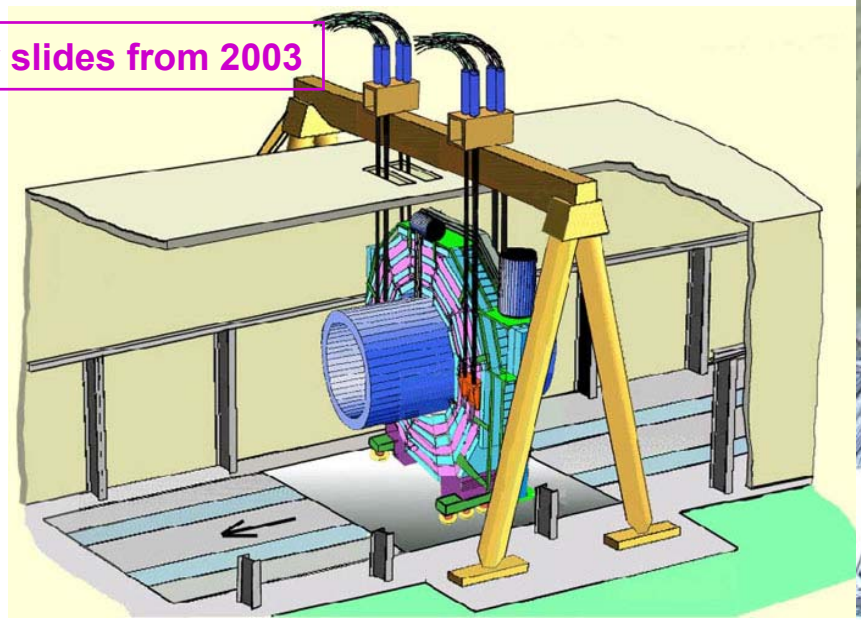
UX5 about 100 meters underground

Surface buildings and main shaft

My slides from 2003

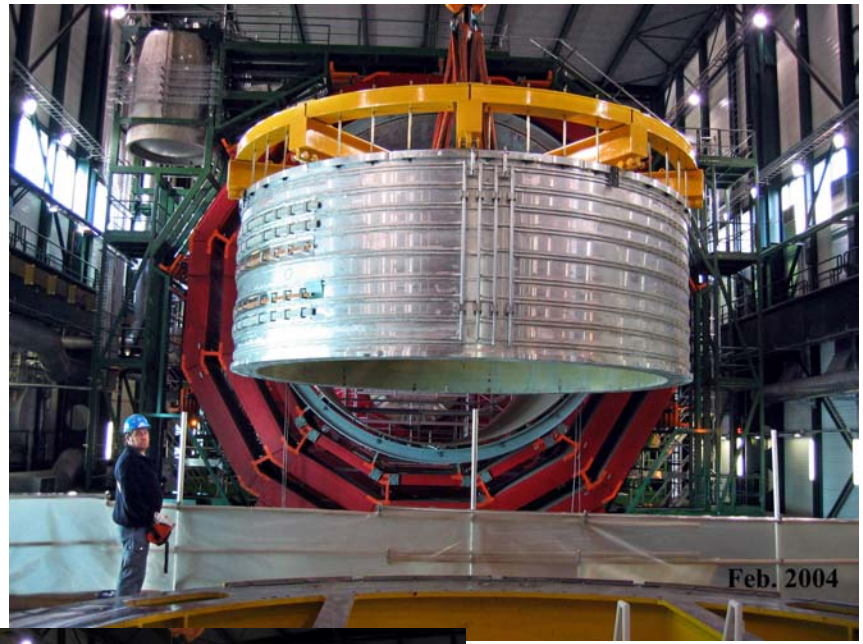
Installation of the first muon chamber

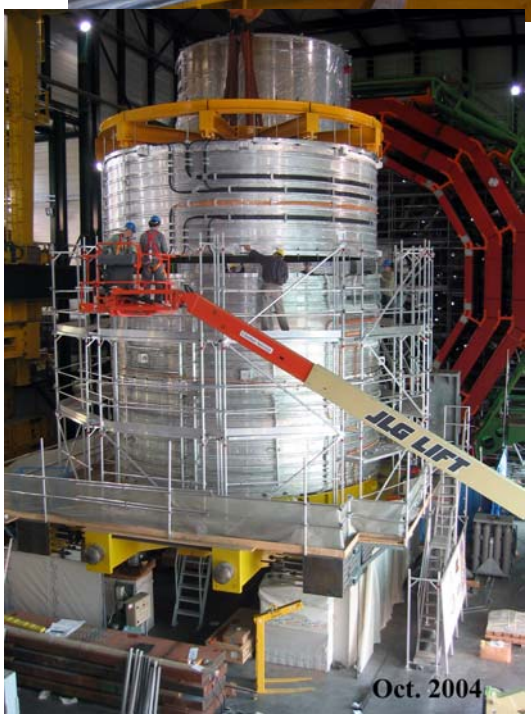
My slides from 2003



Transfer YB0 (2000t) in 2006

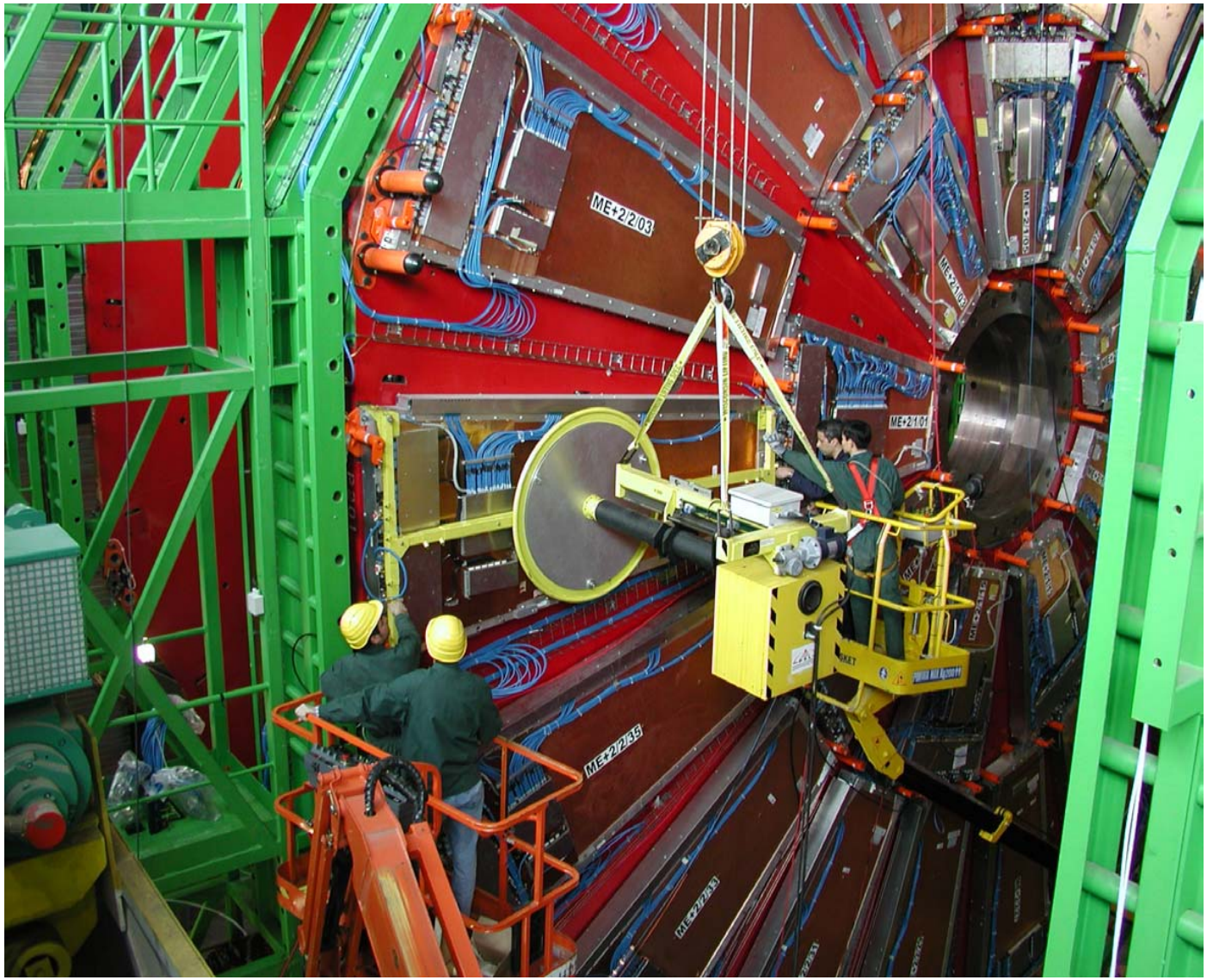
February 1st, 2005





Superconducting Solenoidal Magnet

Endcap Muon: CSC Installation



HF Status

HF are first Items to be lowered in Jan. 2006

Fibers inserted in all 36 wedges

+ end assembled in Bat 186

MSSM
Minimal Supersymmetric Extension of Standard Model

- SUSY – symmetry between bosons and fermions
- MSSM – minimal …
  - Two Higgs doublets which couple to fermions T = -1/2 and T = 1/2, (after 3 out of 8 degrees of freedom absorbed to give W/Z masses) 5 physical Higgs bosons - $h, H^0, A, H^{\pm}$
  - SUSY partner for each SM particle and every Higgs boson, so e.g. squarks and sleptons: $\tilde{q}, \tilde{l}$ - scalar counterparts to fermions
  - Conserved $R_p = (-1)^{3(B-L)+2S}$
    - ☞ LSP is stable and sparticles produced in pairs
  - Charginos and neutralinos : $\tilde{\chi}^{\pm}_{1,2}$, $\tilde{\chi}^{0}_{1,2,3,4}$ - eigenstates of mixing of fermionic partners of EW gauge and Higgs bosons (gauginos and Higgsinos)
  - LSP = $\tilde{\chi}^{0}_{1}$ is a possible candidate for the Cold Dark Matter
- 105 new parameters (for arbitrary soft SUSY breaking), but cancels Higgs mass loop divergence (SM fine tuning problem)

mSUGRA
Minimal Supergravity Model

- Motivated by SUperGRAvity unification
- Universal gravitational interactions communicate symmetry breaking from (introduced) hidden sector to the MSSM sector.
- SUSY breaking scale sqrt(F)~10^{11} GeV close to Planck mass scale
- Five free parameters
  - m_0 – common scalar mass
  - $m_{1/2}$ – common gaugino mass
  - A_0 – common scalar trilinear (Higgs-sfermion-sfermion) coupling

    } at the GUT scale
  - $\tan\beta$ – ratio of v.e.v. of Higgs doublets } at the EW scale
  - sign(μ) – sign of Higgsino mixing parameters

- Renormalization Group Equations (RGE) translate masses from SUSY-breaking to EW scale

- Some typical mass relations
  - $M(\tilde{\chi}^{\pm}_1) \approx M(\tilde{\chi}^0_2) \approx 2M(\tilde{\chi}^0_1) \approx 1/3\, M(\tilde{g})$
  - $M(\tilde{g}) \gtrsim M(\tilde{q})^* > M(\tilde{\chi})$

    * for large $m_{1/2}$ squarks can be heavy
  - $\tilde{t}_1$ – lightest squark

SUSY Signature: MET + Jets + …

mSUGRA : $m_0 = 1000$ GeV, $m_{1/2} = 500$ GeV, $A_0 = 0$, $\tan\beta = 35$, $\mu > 0$

$\tilde{g} \to \tilde{t}_1 \bar{t}$

- $\tilde{t}_1 \to W^- + \bar{b}$ (jet4, $E_T = 113$ GeV)
  - $W^- \to s$ (jet5, $E_T = 79$ GeV) + $\bar{c}$
- $\tilde{t}_1 \to \tilde{\chi}_2^+ + b$ (jet3, $E_T = 536$ GeV)
  - $\tilde{\chi}_2^+ \to \tilde{\chi}_1^+ + Z \to \nu\bar{\nu}$
    - $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 + W^+ \to \tau^+\nu$, $\to e^+\nu$

$\tilde{u}_L \to \tilde{\chi}_2^0 + u$ (jet6, $E_T = 1196$ GeV)

- $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 + h$
  - $h \to b$ (jet1, $E_T = 206$ GeV)
  - $h \to \bar{b}$ (jet2, $E_T = 320$ GeV)

$E_T^{miss} = 380$ GeV

4 hard b-jets
+2 hard jets
+2 LSP + > 4ν
(+ leptons)

$m_{\tilde{g}} = 1266$ GeV

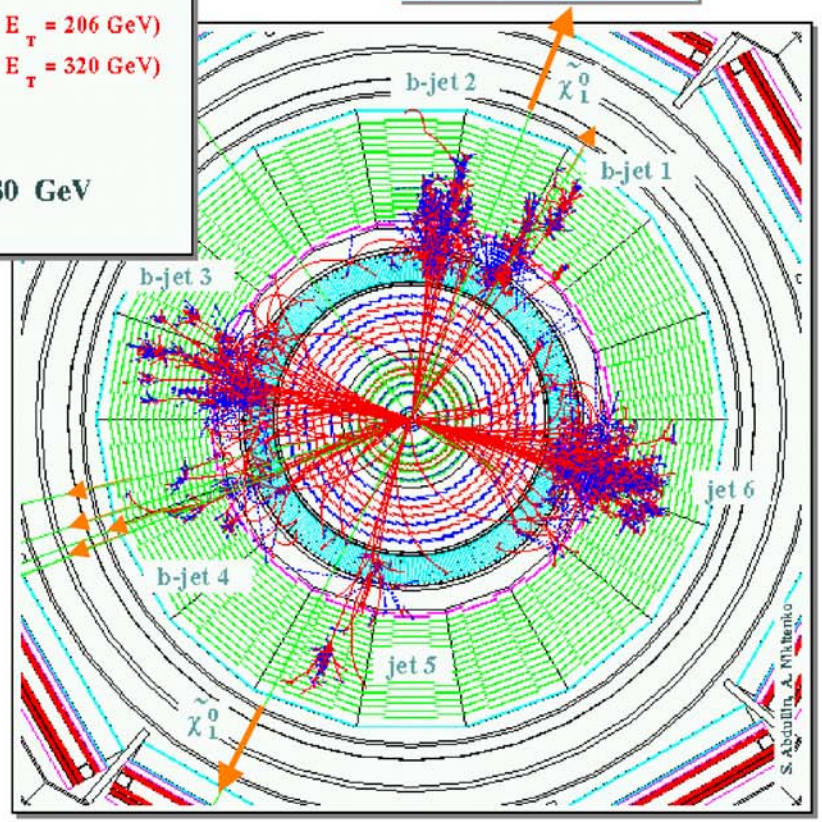
$m_{\tilde{u}_L} = 1450$ GeV

$m_{\tilde{t}_1} = 1026$ GeV

$m_{\tilde{\chi}_2^0} = 410$ GeV

$m_{\tilde{\chi}_1^0} = 214$ GeV

$m_h = 119$ GeV



- Squark-gluino production
- Full simulation in CMS detector yet with GEANT3 ☹

S.Abdullin, Physics at LHC @ Prague (08 July 2003)

LM1 Parameters (2)

8 x 10^5 events/year
@ low luminosity (2 x 10^{33})

Cross-Section

Process	$\sigma(pb)$
All Process	*41.66*
$\tilde{q}_L\tilde{q}_R$	*4.044*
$\tilde{q}_L\tilde{q}_L$	*2.939*
$\tilde{q}_R\tilde{q}_R$	*3.395*
$\tilde{q}_L\tilde{g}$	*9.530*
$\tilde{q}_R\tilde{g}$	*10.280*
$\tilde{g}\tilde{g}$	*4.331*
$\tilde{b}_2\tilde{b}_2$	*0.257*
$\tilde{b}_1\tilde{b}_1$	*0.312*
$\tilde{t}_2\tilde{t}_2$	*0.162*
$\tilde{t}_1\tilde{t}_1$	*1.077*
$pp \to \tilde{l}\tilde{l}$	*0.645*
$pp \to \tilde{g}\tilde{\chi}$	*0.506*
$pp \to \tilde{\chi}\tilde{\chi}$	*2.010*
$pp \to \tilde{q}\tilde{\chi}$	*1.380*

Sparticle masses

	$\tilde{u}$	$\tilde{d}$	$\tilde{s}$	$\tilde{c}$	$\tilde{b}$	$\tilde{b}_{12}$	$\tilde{t}$	$\tilde{t}_{12}$
Left	557.99	563.99	563.99	557.99	492.77	514.17	492.77	411.91
Right	541.52	541.18	541.18	541.52	511.42	534.96	427.20	575.85

	$\tilde{e}$	$\tilde{\mu}$	$\tilde{\tau}$	$\tilde{\tau}_{1,2}$	$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$
Left	188.61	188.61	179.25	110.53	168.46	168.46	167.88
Right	118.81	118.81	108.50	191.69			
	g	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$	$\tilde{\chi}_1^+$	$\tilde{\chi}_2^+$
	611.32	94.93	179.56	-341.29	361.81	179.50	360.99
	h^0	H^0	A^0	$H^\pm$			
	112.87	374.18	373.01	382.17			

CMS Physics TDR Study Point
Low Mass Point #1
M_0 = 60, $M_{1/2}$=250, A_0=0, μ=+, tanβ=10

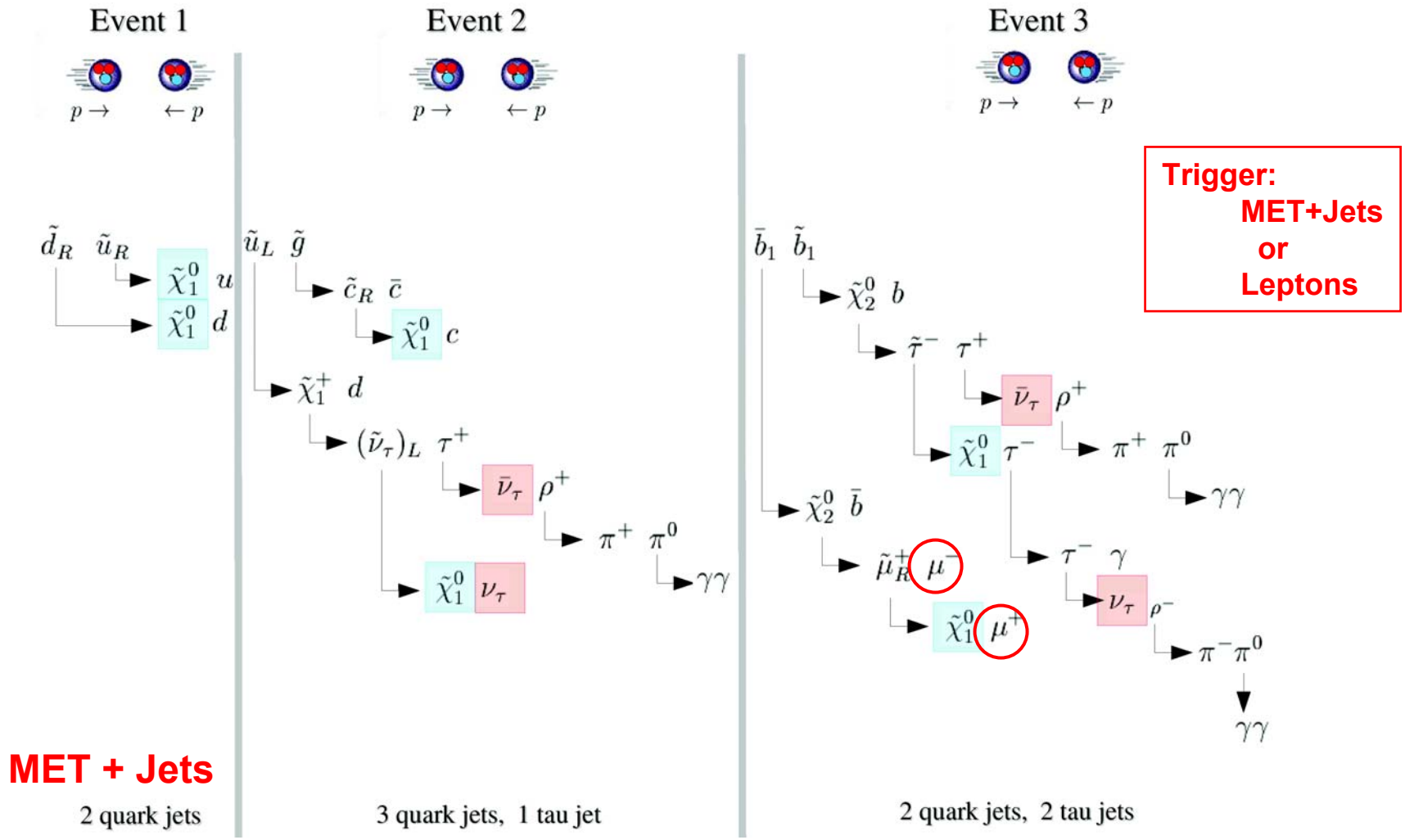
→Detailed study by Taylan Yetkin

Branching Ratios

Decay Mode	BR(%)
$\tilde{d}_L \to \tilde{\chi}_1^- u$	59
$\tilde{u}_L \to \tilde{\chi}_1^+ d$	64
$\tilde{s}_L \to \tilde{\chi}_1^- c$	59
$\tilde{c}_L \to \tilde{\chi}_1^+ s$	64
$\tilde{b}_1 \to \tilde{\chi}_1^- t$	48
$\tilde{b}_1 \to \tilde{\chi}_2^0 b$	37
$\tilde{t}_1 \to \tilde{\chi}_1^+ b$	62
$\tilde{t}_1 \to \tilde{\chi}_2^0 t$	12
$\tilde{q}_R \to \tilde{\chi}_1^0 q$	98
$\tilde{b}_1 \to \tilde{\chi}_1^- t$	48
$\tilde{b}_1 \to \tilde{\chi}_2^0 b$	37
$\tilde{t}_1 \to \tilde{\chi}_1^+ b$	63
$\tilde{t}_1 \to \tilde{\chi}_1^0 t$	17
$\tilde{b}_2 \to \tilde{\chi}_1^- t$	24
$\tilde{b}_2 \to \tilde{\chi}_1^0 b$	24
$\tilde{b}_2 \to \tilde{\chi}_2^0 b$	18
$\tilde{b}_2 \to \tilde{t}_1 W^-$	16
$\tilde{t}_2 \to \tilde{\chi}_1^+ b$	22
$\tilde{t}_2 \to \tilde{\chi}_2^+ b$	22
$\tilde{t}_2 \to \tilde{\chi}_4^0 t$	22
$\tilde{t}_2 \to \tilde{t}_1 Z^0$	12
$\tilde{e}_L^- \to \tilde{\chi}_1^0 e^-$	85
$\tilde{\mu}_L^- \to \tilde{\chi}_1^0 \mu^-$	85
$\tilde{\tau}_1^- \to \tilde{\chi}_1^0 \tau^-$	100
$\tilde{\nu}_{e_L} \to \tilde{\chi}_1^0 \nu_e$	100
$\tilde{\nu}_{\mu_L} \to \tilde{\chi}_1^0 \nu_\mu$	100
$\tilde{\nu}_{\tau_L} \to \tilde{\chi}_1^0 \nu_\tau$	100
$\tilde{g} \to \tilde{q}_L \bar{q}$	22
$\tilde{g} \to \tilde{q}_R \bar{q}$	31
$\tilde{g} \to \tilde{b}_1 \bar{b}$	18
$\tilde{g} \to \tilde{b}_2 \bar{b}$	13
$\tilde{g} \to \tilde{t}_2 \bar{t}$	6
$\tilde{\chi}_2^0 \to \tilde{\tau}_1^\pm \tau^\mp$	46 ← τ
$\tilde{\chi}_1^\pm \to \tilde{\nu}_{l_L} l^\pm$	56
$\tilde{\chi}_1^\pm \to \tilde{\tau}_1^\pm \nu_\tau$	42
$\tilde{\chi}_2^\pm \to \tilde{\chi}_2^0 W^\pm$	29
$\tilde{\chi}_2^\pm \to \tilde{\chi}_1^\pm Z^0$	21
$\tilde{\chi}_2^\pm \to \tilde{\chi}_1^\pm h^0$	15
$\tilde{\chi}_4^0 \to \tilde{\chi}_1^\pm W^\mp$	46
$\tilde{\chi}_4^0 \to \tilde{\chi}_2^0 h^0$	13

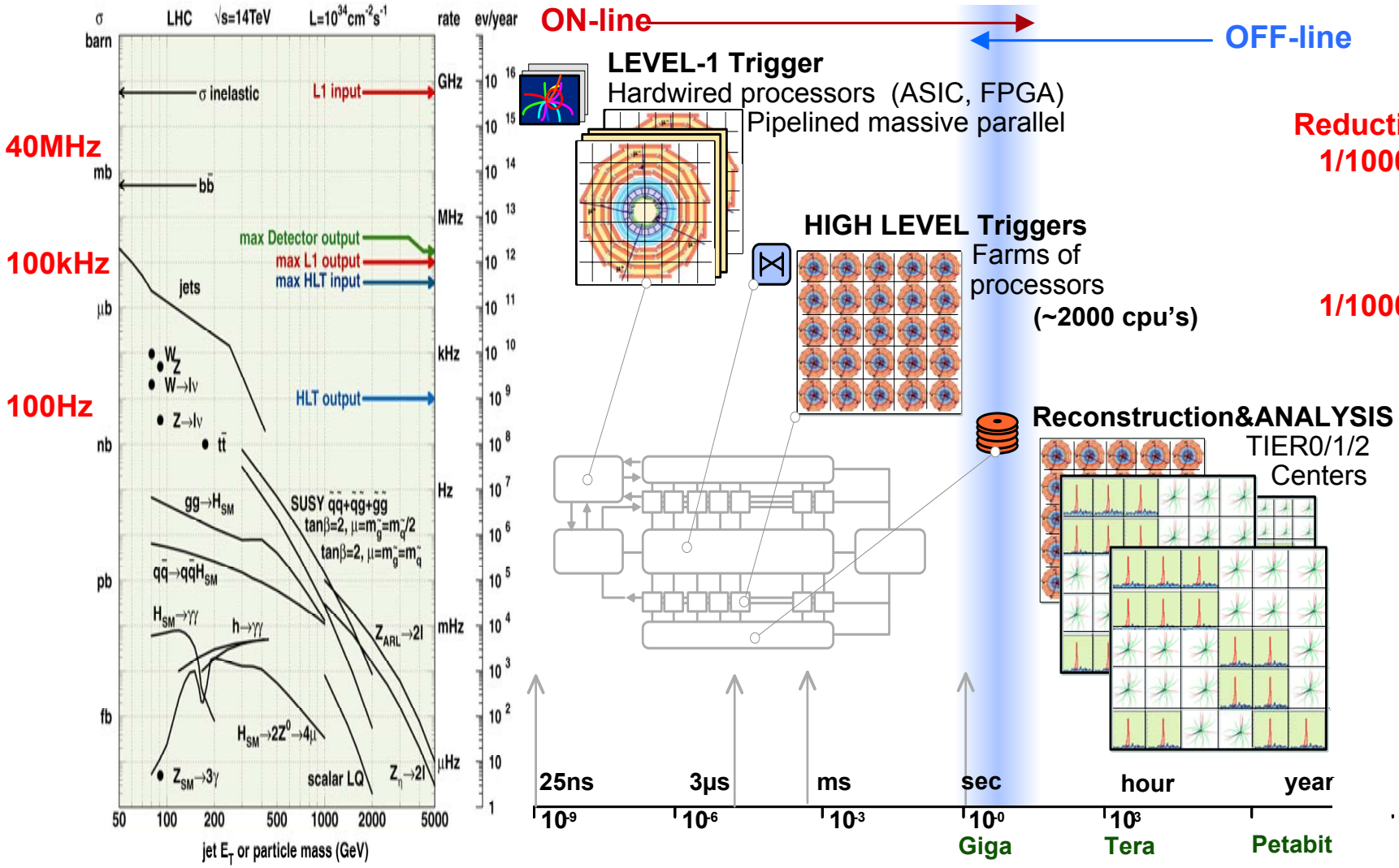
Event Signature (LM1)

M_0 = 60, $M_{1/2}$=250, A_0=0, μ=+, tanβ=10



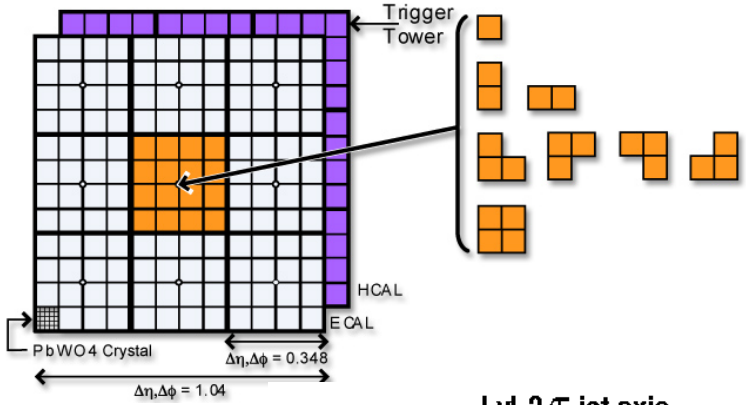
Taylan Yekin, FNAL Physics Meeting (09-March-2005)

Physics Selection



Example: τ trigger

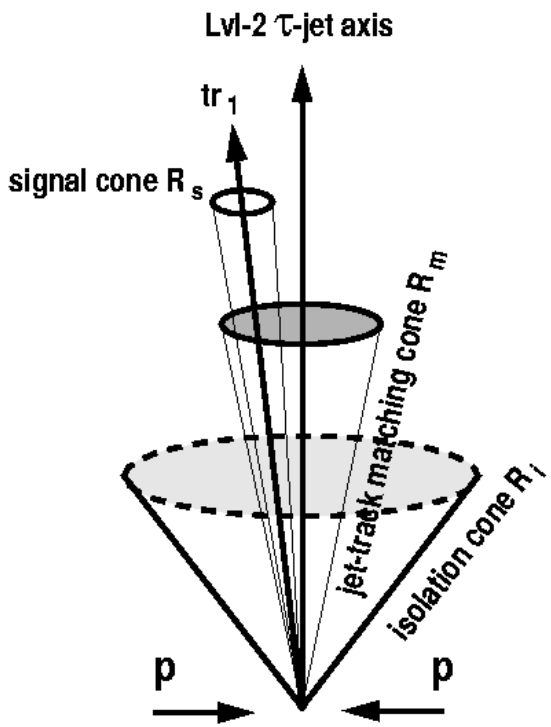
Level-1: calorimeter based
Look for narrow jets in pattern in the calorimeter towers.



HLT (L2): two options
a) using calorimeter -purify narrow jet with fine grain ECAL .
b) using pixel tracker- look for isolated track(s) in L1 jet cone

HLT (L3): pixel and silicon strips tracker
Regional tracking - reconstruct track(s) in L2 jet cone. Six hits are enough for good momentum resolution.

H/A(200GeV) → ττ
eff =45% with QCD rejection ~ 10^6



Offline(L4): full detector information
(e.g. decay vertex)

CMS Trigger is very flexible!

HLT for Low Luminosity $2x10^{33}$ $cm^{-2}s^{-1}$

Results from full detector and trigger simulation – 7M events used in 2001-02.

Trigger	Threshold (GeV or GeV/c)	Rate (Hz)	Cuml. rate (Hz)
Inclusive electron	29	33	33
Di-electron	17	1	34
Inclusive photon	80	4	38
Di-photon	40, 25	5	43
Inclusive muon	19	25	68
Di-muon	7	4	72
Inclusive tau-jet	86	3	75
Di-tau-jet	59	1	76
1-jet * E_T^{miss}	180 * 123	5	81
1-jet OR 3-jet OR 4-jet	657, 247, 113	9	89
Electron * jet	19 * 45	2	90
Inclusive b-jet	237	5	95
Calibration etc		10	105
TOTAL			**105**

CMS DAQ TDR, Dec. 2002 (CERN/LHCC 2002-26)

Straw man trigger table. → Need to build a real table!

HLT performance — signal efficiency

With previous selection cuts for low luminosity.

Channel	Efficiency (for fiducial objects)
$H(115\ GeV) \rightarrow \gamma\gamma$	77%
$H(160\ GeV) \rightarrow WW^* \rightarrow 2\mu$	92%
$H(150\ GeV) \rightarrow ZZ \rightarrow 4\mu$	98%
$A/H(200\ GeV) \rightarrow 2\tau$	45%
SUSY (~0.5 TeV sparticles)	~60%
With R_P-violation	~20%
$W \rightarrow e\nu$	67% (fid: 60%)
$W \rightarrow \mu\nu$	69% (fid: 50%)
$Top \rightarrow \mu X$	72%

Good efficiencies for low mass (100-200GeV) objects!

SUSY Search

Production: pp→ ~g/~q
R parity conserve: 2 missing χ_0's

Search: MET + jets

Jets + MET signal

Search for SUSY Particles at LHC

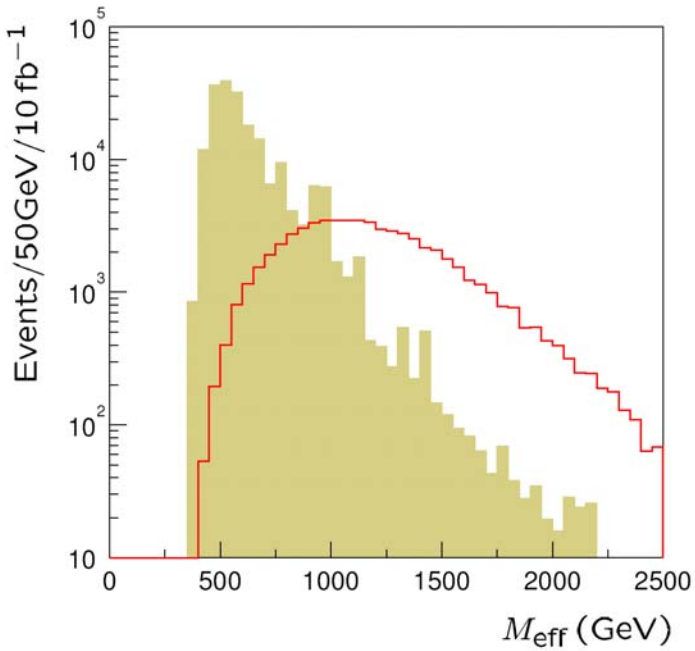
SUSY production at LHC dominated by $\tilde{g}$ and $\tilde{q}$ if masses $\lesssim 1\,\text{TeV}$.

Strongly produced, so cross sections comparable to jets at similar Q^2.
Decays to $\tilde{\chi}_1^0$ give large $\not{E}_T$.

Example: mSUGRA with
$m_0 = 100\,\text{GeV}$, $m_{1/2} = 300\,\text{GeV}$,
$A_0 = 0$, $\tan\beta = 10$, $\text{sgn}\,\mu = +$.

Require $\not{E}_T > 100\,\text{GeV}$, ≥ 4 jets with $E_T > 100, 50, 50, 50\,\text{GeV}$, and plot

$$M_{\text{eff}} = \not{E}_T + \sum_j E_{T,j}$$



Clean SUSY signal for large M_{eff} with reasonable efficiency.

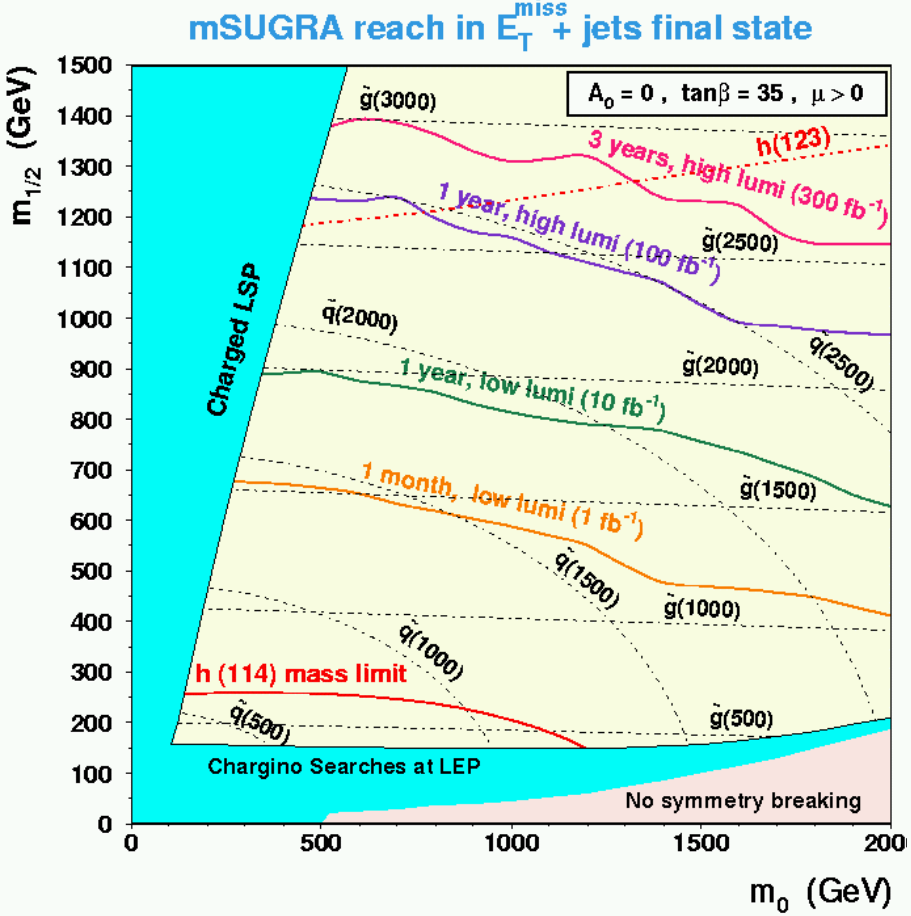
Frank Paige, Physics at LHC 2004 @ Vienna (agenda > conferences > conferences > July 12-17, 2004)

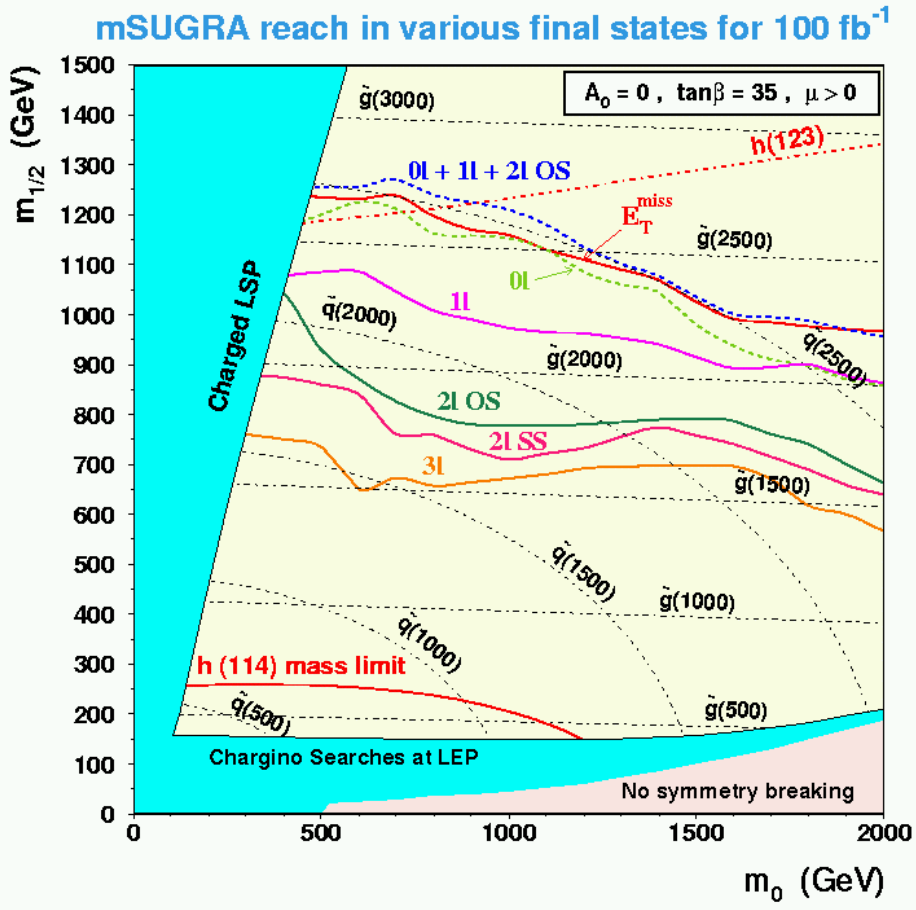
Inclusive Search

- Counting excess of events over SM expectations
  - Discovery mode SUSY search
  - Explicit sparticle reconstruction not done
- Multitude of final states analysed
- Standard model background (a few x10^8 events)
- Simulated with fast MC : ATLFAST, CMSJET **(FAMOS)**
- CMS Study :
  - Common cuts : missing E_T >200 GeV, min. 2 jets with E_T >40 GeV in $|\eta|<3$
  - Electrons: isolated, with p_T >20 GeV in $|\eta|<2.4$
  - Muons: isolated or not, with p_T>10 GeV in $|\eta|<2.4$
  - Vary cuts in 6 categories (~ 10^4 combinations) : #Jets & E_T^{jet} , MET, angular and shape variables, muon isolation
  - Optimize S/sqrt(S+B) in a counting experiment and plot 5σ sensitivity contours

– E_T^{miss}:	jets+MET
– 2lOS:	2 leptons, opposite sign
– Ol:	no leptons
– 1l:	1 lepton
– 2lSS:	2 leptons, same sign
– 3l:	3 leptons

Inclusive Search (mSUGRA)

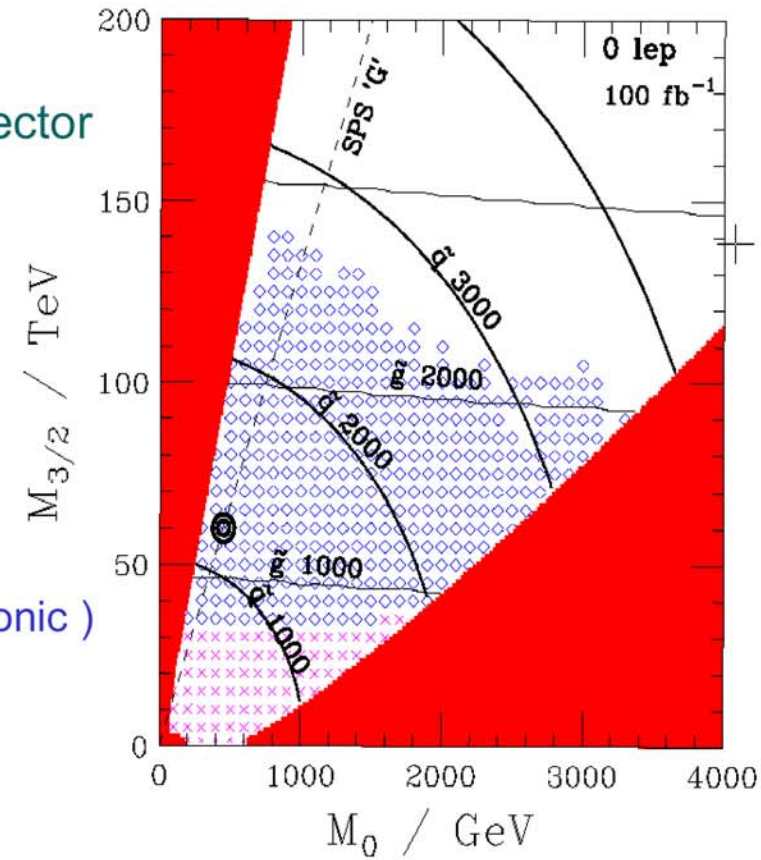




S.Abdullin @ PRS SUSY/BSM Meeting, 17-Sep-2003 (agenda/cms > CPT > PRC > BSM > 17Sep03)

Inclusive Search (AMSB)

- Special case of gravity mediation :
  No direct tree-level coupling to transmit SUSY breaking from hidden to visible sector
- SUSY breaking on a separate membrane is communicated to the visible sector via super-Weyl anomaly
- Four parameters :
  - $m_{3/2}$ – SUSY breaking scale
  - m_0 – additional mass scale for scalars (to keep sleptons from being tachyonic)
  - tan β
  - sign(μ)
- Distinctive feature
  - $M(\tilde{\chi}_1^{\pm}) \approx M(\tilde{\chi}_1^0)$



☞ Similar reach in $M(\tilde{g})$, $M(\tilde{q})$ as for mSUGRA, > 2.5 TeV for 100 fb^{-1}

Measurement of SUSY Properties

2 missing χ_0's – no way to reconstruct mass
Long decay chain – measure mass difference

Mass Measurement

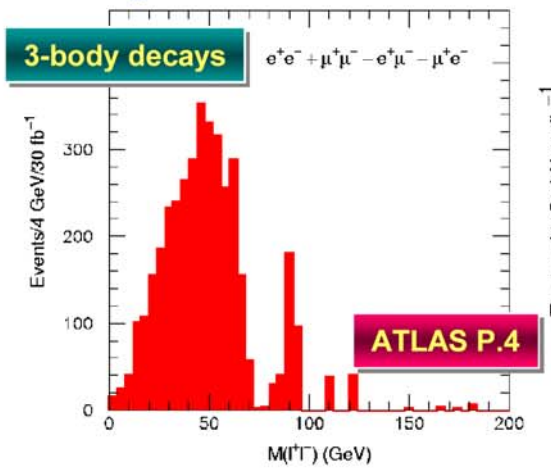
- Measure invariant mass distribution of OS SF leptons
  - Simplest case: $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell^+ \ell^-$ gives dilepton endpoint at

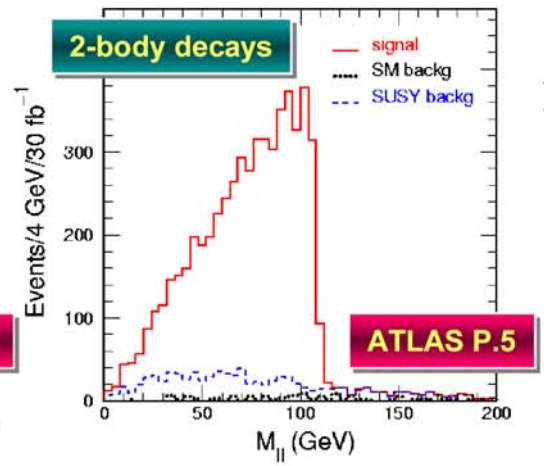
$$M_{\ell\ell} = M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0}$$

Cascade decay $\tilde{\chi}_2^0 \to \tilde{\ell}^\pm \ell^\mp \to \tilde{\chi}_1^0 \ell^+ \ell^-$ gives endpoint at

$$M_{\ell\ell} = \frac{1}{M_{\tilde{\ell}}} \sqrt{(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{\ell}}^2)(M_{\tilde{\ell}}^2 - M_{\tilde{\chi}_1^0}^2)}$$

  - Require 2 isolated leptons, jets + large E_T -main SM background is $t\bar{t}$
  - Form combination $e^+e^- + \mu^+\mu^- - e^\pm\mu^\pm$ to cancel independent decays (SM & SUSY)
  - $\tilde{\chi}_2^0$ can be produced via Drell-Yan, but more abundant in decays of $\tilde{q}, \tilde{g}$





  - 2-body and 3-body decays can be distinguished by additional shapes

SUSY Spectroscopy

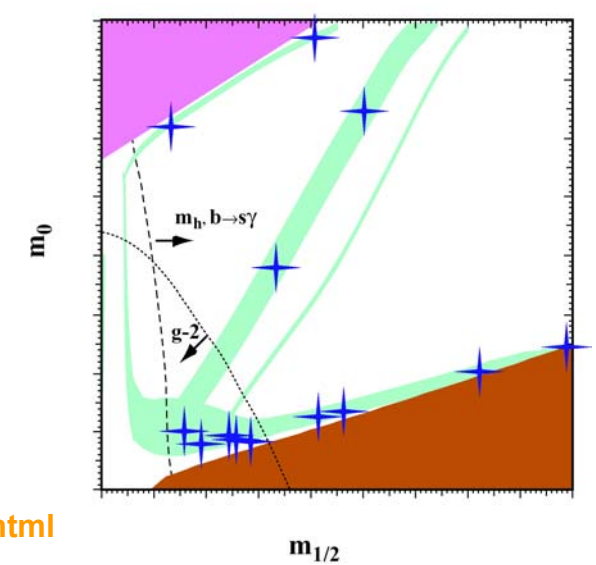
An exercise at two points using a fast parameterized simulation.

Post LEP SUSY benchmark points:
M.Battaglia et al. Eur Phys. J (2001) 535 (hep-ph/0106204)

Model	A	B	C	D	E	F	G	H	I	J	K	L	M
$m_{1/2}$	600	250	400	525	300	1000	375	1500	350	750	1150	450	1900
m_0	140	100	90	125	1500	3450	120	419	180	300	1000	350	1500
$\tan\beta$	5	10	10	10	10	10	20	20	35	35	35	50	50
$\mathrm{sign}(\mu)$	+	+	+	−	+	+	+	+	+	+	−	+	+
$\alpha_s(m_Z)$	120	123	121	121	123	120	122	117	122	119	117	121	116
m_t	175	175	175	175	171	171	175	175	175	175	175	175	175

Sparticles reconstructed in 10fb^{-1}

Sparticles reconstructed in 300fb^{-1}

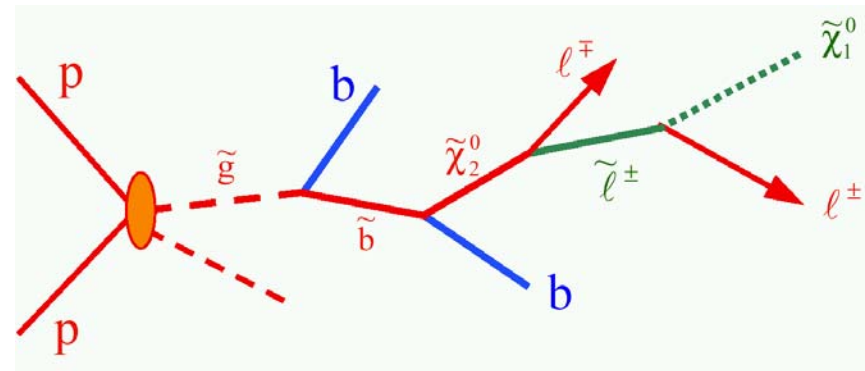


(More updated info)
M.Chiorboli, LHC Physics @ Prague (08-July-2003)
http://cms.ct.infn.it/cms_general_site/software/talks_conf/talks_conf_susy.html

Point B

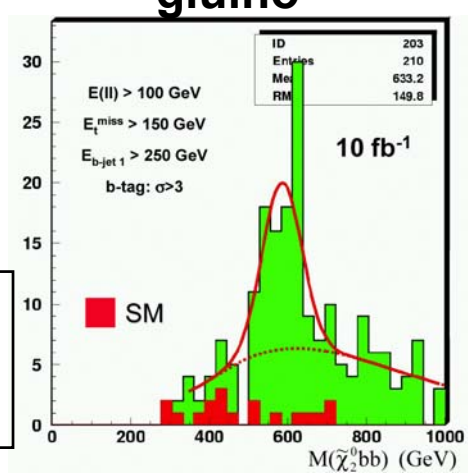
g	595.1	t_L	392.9
b_L	496.0	t_R	575.9
b_R	524.0	χ_4^0	361.1
q_L	540	χ_3^0	339.9
q_R	520	χ_2^0	174.4
l_L	196.5	$\chi_2^\pm$	361.6
l_R	136.2	$\chi_1^\pm$	173.8
		χ_1^0 = LSP	95.6

$$\sigma_{SUSY}^{TOT} = 57.77 \text{ pb}$$



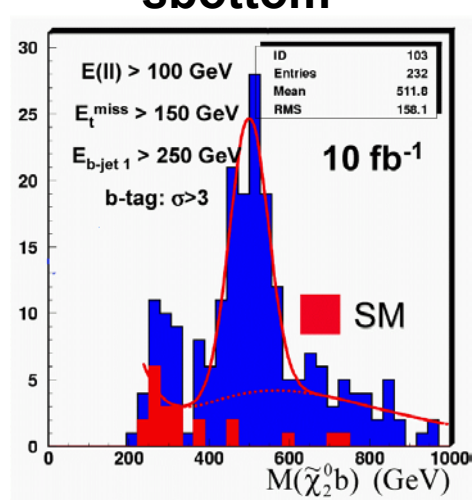
$$M_{\ell^+\ell^-}^{max} = \frac{\sqrt{(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{\ell}}^2)(M_{\tilde{\ell}}^2 - M_{\tilde{\chi}_1^0}^2)}}{M_{\tilde{\ell}}}$$

gluino

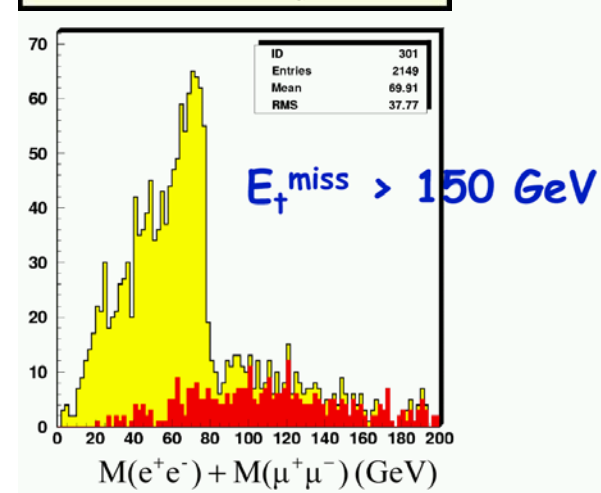


585.1 +/- 11.1 GeV

sbottom



499.4 +/- 6.6 GeV



edge 78.9 +/- 2.1 GeV (generated 78.2)

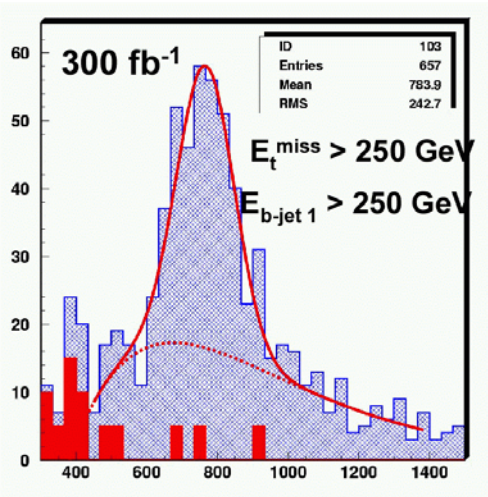
repeat for non-b squarks.

Point G

- heavier sparticles: M(squark) ≅ 800 GeV, M(gluino) ≅ 900 GeV
- lower SUSY cross section (6 pb)
- higher tanβ: smaller BR to electrons and muons. More to taus.

→ Need higher statistcis.

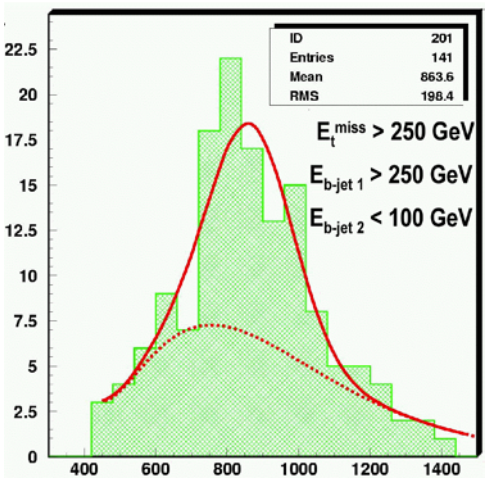
squark



$M(\tilde{\chi}_2^0 q) = 767 \pm 6$ GeV

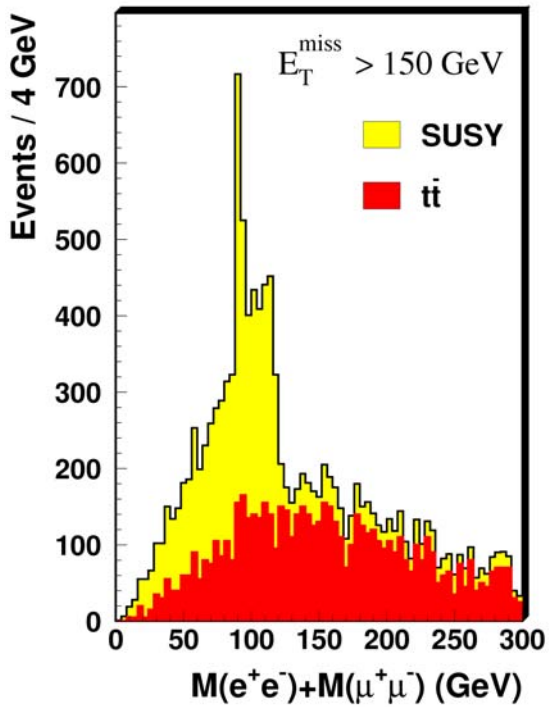
$\sigma = 80$ GeV

gluino



$M(\tilde{\chi}_2^0 qq) = 867 \pm 30$ GeV

$\sigma = 115$



Generated: $M(d_L)=M(s_L)=778.0$ GeV $M(g)=860.8$ GeV
$M(u_L)=M(c_L)=773.9$ GeV

SUSY Higgs

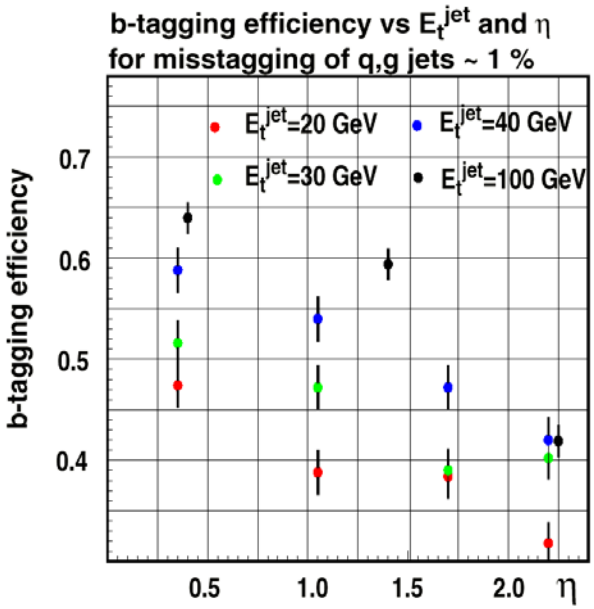
Higgs production in decay chain.
Direct Higgs production.

$bbH_{SUSY} \rightarrow \tau\tau$

- τ-jet trigger at Level 1- 3
  - calo: narrow jet, pixel: 1 charged track

    See A.Nikitenko's talk at Higgs & SUSY at Orsey
    http://www.lal.in2p3.fr/actualite/conferences/higgs2001/index.html

- b tagging

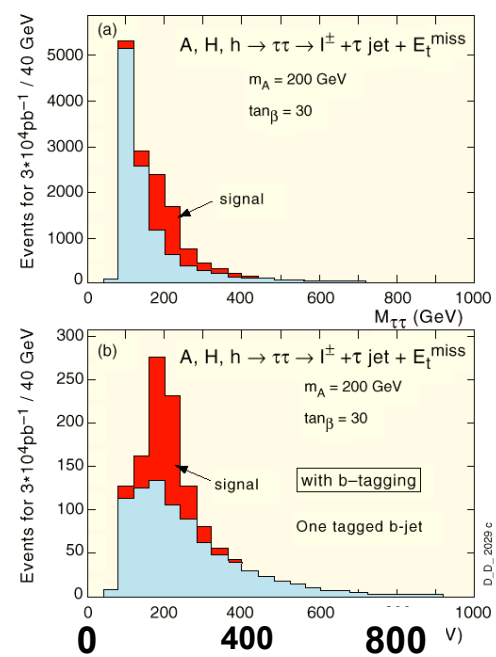


b-tag

M_A=200GeV

$H_{SUSY} \rightarrow \tau\tau \rightarrow l^+ + h^- + X$

Events selected as : $P_t^{jet} > 40$ GeV, $P_t > 15$ GeV, $\Delta\phi(jl) < 175^o$, $Et^{miss} > 20$ GeV



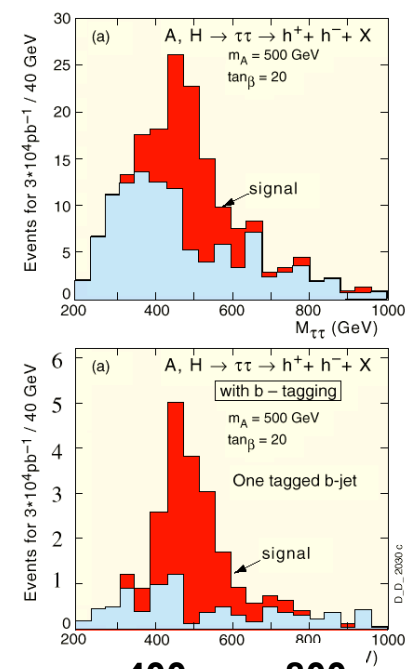
0 400 800

M(ττ)

M_A=500GeV

$H_{SUSY} \rightarrow \tau\tau \rightarrow h^+ + h^- + X$

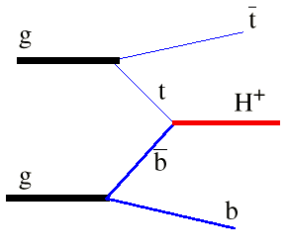
Events selected as: $E_t^{jet} > 60$ GeV $p_t^h > 40$ GeV, $\Delta\phi(jj) < 175^o$, $E_t^{miss} > 40$ GeV



400 800

M(ττ)

$H^+ \to \tau\nu \to \tau$-jet in tbH



t→Wb - W, top mass window

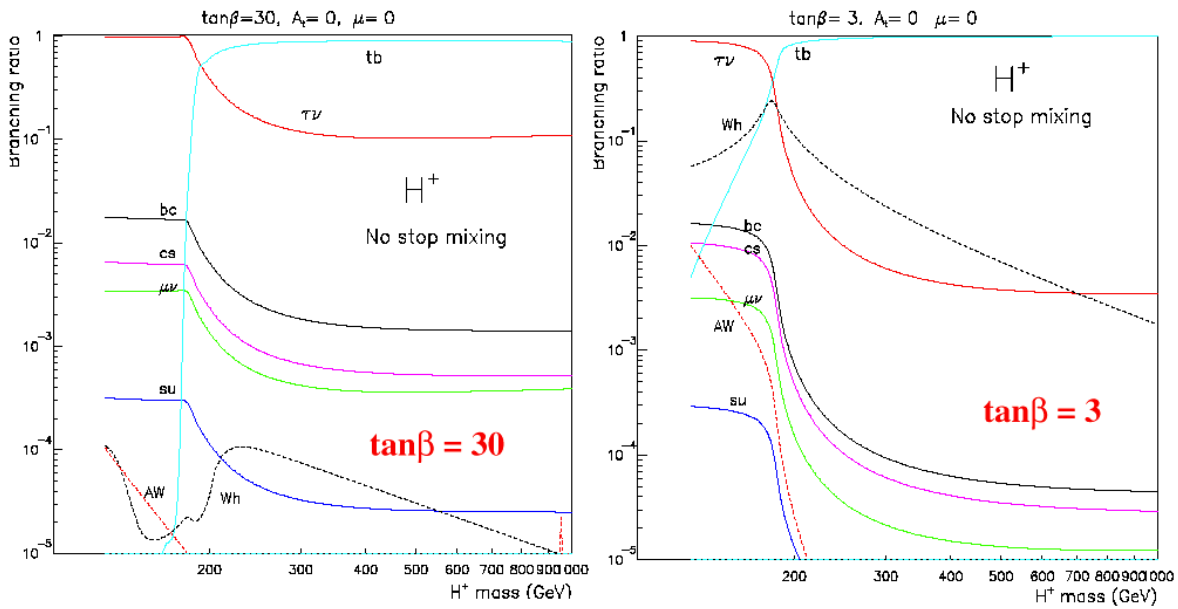
τ - tau-jet

ν - missingET

b - b tagging

bg:
tt, Wtb, Wjj

no stop mixing



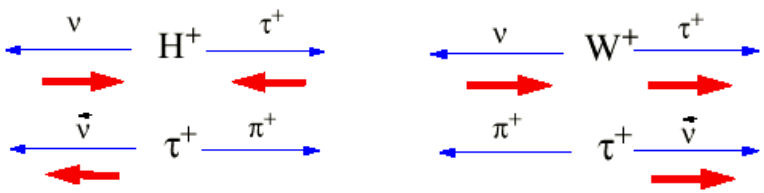
$\tau\nu$ mode is cleaner than tb mode!

$\Gamma(H^+ \to tb) / \Gamma(H^+ \to \tau\nu)$ could provide a measurement of $\tan\beta$

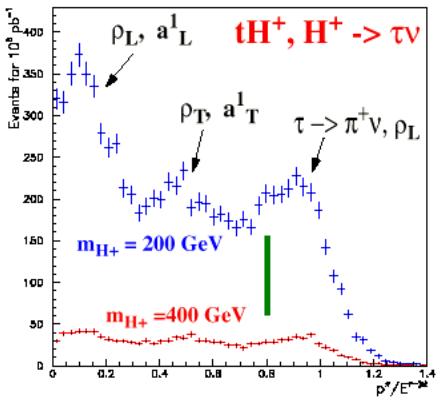
τ polarization & Δϕ cut

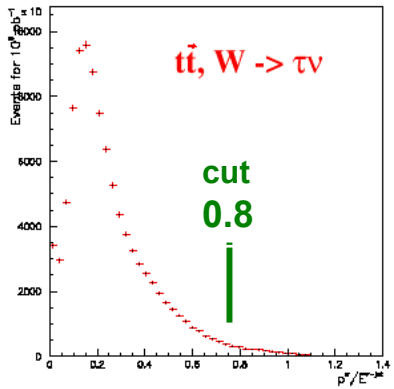
Tau polarization in H^+ decay

(pointed out by D.P.Roy)



Reconstructed τ-jets, $E_t^{\tau\text{-jet}} > 100$ GeV

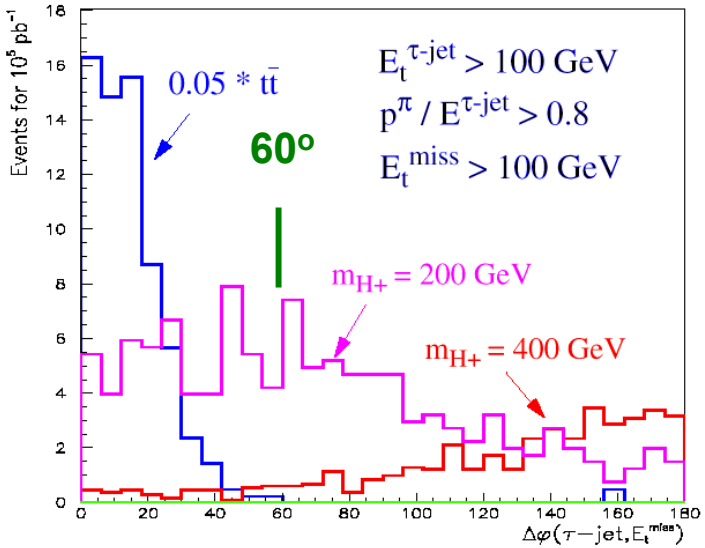




$p^{\pi}/E^{\tau\text{-jet}}$ $p^{\pi}/E^{\tau\text{-jet}}$

$\tau^+ \to \pi^+\nu$	12.5%
$\tau^+ \to \rho^+\nu \to \pi^+\pi^0\nu$	26%
$\tau^+ \to a_1\nu \to \pi^+\pi^0\pi^0\nu$	7.5%

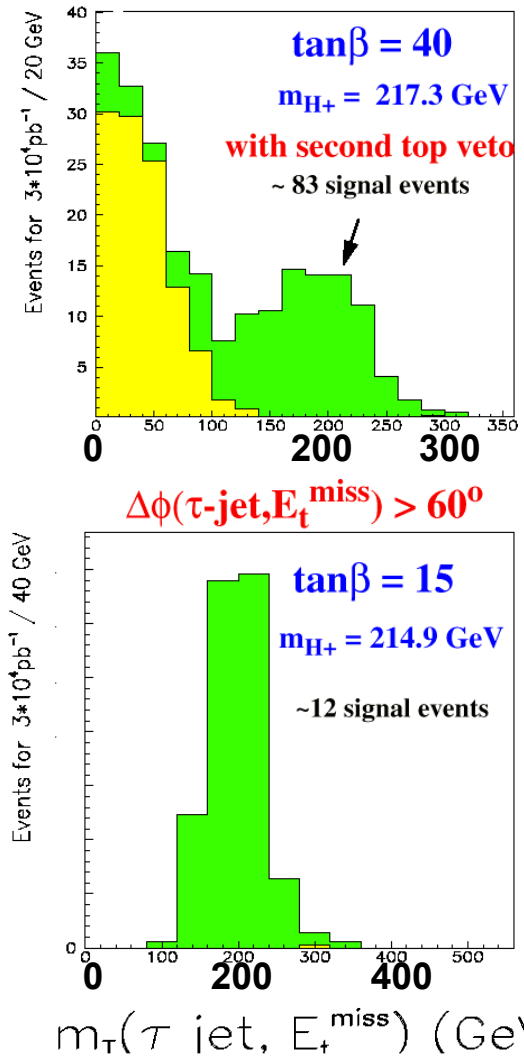
Δϕ > 60° cut



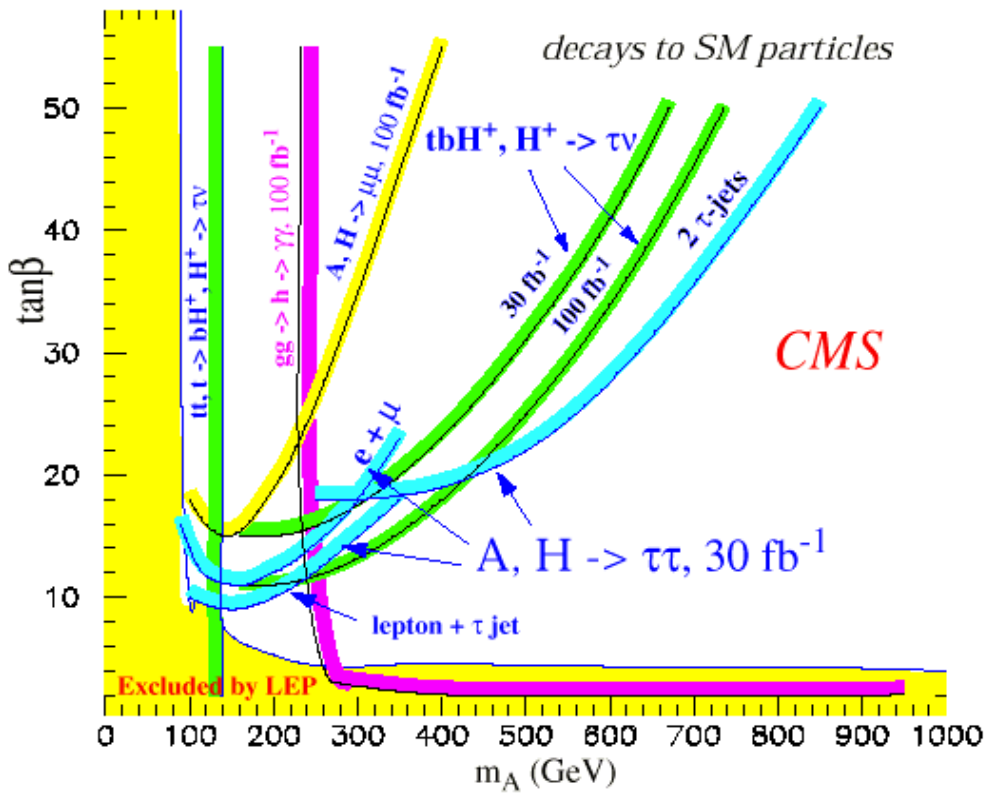
$\Delta\phi(\tau\text{-jet}, E_t^{miss})$

Mass and Discovery potential

M_A=200GeV, 30fb^{-1}



5s significance countours



Experimental Issues

Major Issues

Understanding Detector

- Calibration / Alignment
- MET is the most difficult
  - depends on all other detectors.

Standard Model Background

- Top
- Z + jets
- W + jets
- …

SUSY Background

- Other SUSY processes

→ Need good plan to go through these as quick as possible once LHC/CMS start.

Software and Computing

- Event reconstruction
- Data access and analysis
  - Need good plan

Tevatron Experience: MET

Song Ming Wang

Signatures for New Physics from Jets and Missing Energy

- $\not{E}_T$ analysis very sensitive to jet energy scale uncertainties
- experience from the Tevatron
  - electroweak backgrounds - natural source of $\not{E}_T$ - measure them!
  - jet energy scale!
  - large geometric converage + hermiticity for $\not{E}_T$ resolution (especially tails)
  - calorimeter channel inter-calibration is not easy but very important
  - must be quick to handle dead or hot channels – and fix them!
  - monitoring important to catch bad channels
  - good operation of other sub-detectors important, such as muon detectors and vertex reconstruction
  - watch out for beam halo, large beam losses, and cosmic rays

From M.Schmitt's summary, TeV4LHC Workshop at Fermilab, Sep-2004

Plan for Physics TDR

Due date: December 2005 (a few months delay?)
All results ready: October 2005

SUSY/BSM – Topic 1/9

SUSY with χ^0_1 as LSP(1)

Inclusive with MET + jets	MET	S.Abdullin+M.Spiropulu+Fermilab
Inclusive with MET + jets + leptons	e, μ	Florida
Inclusive SS di-leptons	μ	Florida
Inclusive with di-leptons	e, μ	Athens
Inclusive with di-taus	τ	Mumbai?
Cascades, $\chi^0_2 \rightarrow l\, l\, \chi^0_1$	e, μ	Catania + *Helsinki?*
Cascades, $\chi^0_2 \rightarrow l\, l\, \chi^0_1$, spin	e, μ	Athens
Cascades, $\chi^0_2 \rightarrow \tau\, \tau\, \chi^0_1$	$\tau \rightarrow \rho$,a1	ETHZ, Santander, Strasbourg F.Moortgat
Cascades, $\chi^0_2 \rightarrow \tau\, \tau\, \chi^0_1$, spin	τ	Mumbai
Cascades, $\chi^0_2 \rightarrow h^0\, \chi^0_1$	b	F.Moortgat+Mons+Brussels?
Cascades, $\chi^0_2 \rightarrow Z^0\, \chi^0_1$	l	Demokritos+Aachen I+ Minnesota?

L. Pape SUSY/BSM group 09 February 2005 2

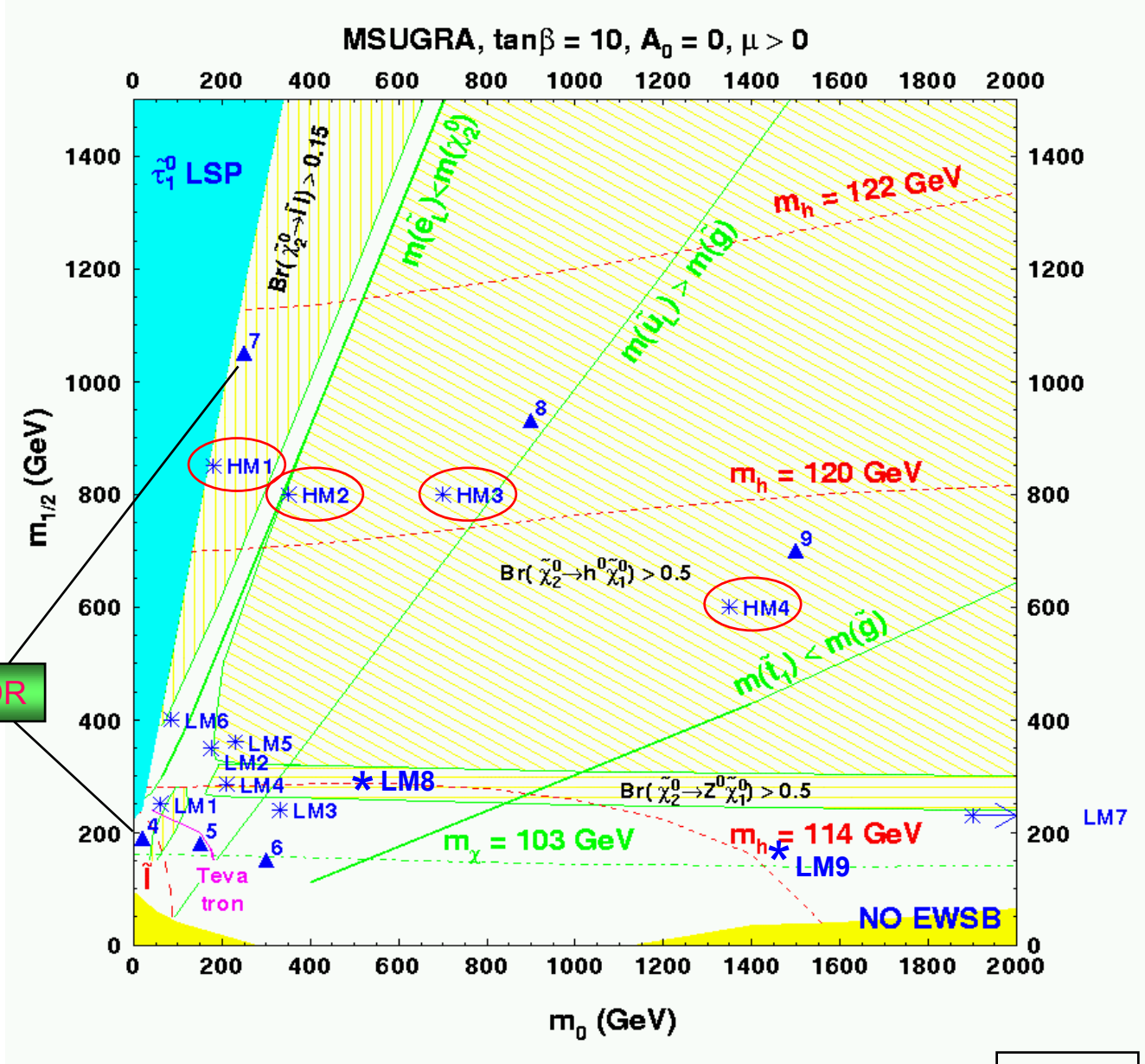
Detailed study
- **LM1 – T.Yetkin**
- **Others - ?**

Parameter space scan
- **?**

See Luc Pape's slides for other topics (available at CMS SUSY/BSM group page)

CMS mSUGRA Test Points

DAQ TDR



LM1 – Taylan
Other points - ?

http://cmsdoc.cern.ch/cms/PRS/susybsm/msugra_testpts/msugra_testpts.html

Local link

LM Points (1)

ISASUGRA 7.69

- LM1: m0=60, m1/2=250 (B')

  $\tilde{\chi}_2^0 \rightarrow \tilde{l}_R\, l$ (11.2 %), $\tilde{\tau}_1\, \tau$ (46 %), $\tilde{\chi}_1^+ \rightarrow \tilde{\nu}_L l$ (36 %),

  $M(\tilde{g}) > M(\tilde{q})$: $\tilde{g} \rightarrow \tilde{q}\, q$

  Near DAQ TDR point 4, Post-LEP benchmark point B'

- LM2: m0=175, m1/2=350, tan β=35 (I')

  Br ($\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1\, \tau$) = 96 % Br ($\tilde{\chi}_1^+ \rightarrow \tilde{\tau}_1\, \nu$) = 95 %

  $M(g) > M(q)$: $\tilde{g} \rightarrow \tilde{q}\, q$ Post-LEP benchmark point I'

- LM3: m0=330, m1/2=240, tan β = 20

  $M(\tilde{g}) < M(\tilde{q})$: $\tilde{g} \rightarrow \tilde{b}_{1,2}\, b$ (85 %),

  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z^*$, $\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 W$ (100 %)

- LM4: m0=210, m1/2=285

  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z$ (97 %), $\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 W$ (99.5 %)

  Z-mass constraint can be applied

LM Points (2)

- LM5: m0=230, m1/2=360

$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\, h\ (85\ \%), \quad \tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 W\ (97\ \%)$$
$$\hookrightarrow b\,\bar{b}\ (83\ \%)$$

Abundant h production

- LM6: m0=85, m1/2=400 (C')

$$\tilde{\chi}_2^0 \rightarrow \tilde{l}_{L,R}\, l\ (14\ \%) : \mu, e \qquad \tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0\, \tilde{l}\, \nu (\tilde{\nu} l)\ (54\ \%)$$
$$\searrow \tilde{\tau}_{1,2}\, \tau\ (\sim 18\ \%)$$

Post-LEP benchmark point C'

- LM7: m0=3000 GeV, m1/2=230 GeV

☞ Squarks are too heavy to play any role,
$m(\tilde{g})$ = 678 GeV, $m(\tilde{\chi}_1^+)$ = 133 GeV
EW chargino-neutralino production cross section is ~73 % of the total one.

$$\mathrm{Br}\,(\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\, l^+ l^-) = 7\ \% \qquad \mathrm{Br}\,(\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0\, l^+ \nu) = 22\ \%, \qquad l = e, \mu$$

LM Points (3)

- LM8: m0=500 GeV, m1/2=300 GeV, A0 = -300 GeV

  $M(\tilde{g}) < M(\tilde{q})$: $\tilde{g} \rightarrow \tilde{b}_1\ b$ (14 %), $\tilde{g} \rightarrow \tilde{t}_1\ t$ (80 %),

  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z$, $\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 W$ (100 %)

  Vienna-Budapest group : search for stop in squark-gluino production in Z + 2b-jets + MET final state

- LM9: m0=1450 GeV, m1/2=175 GeV, tan β=50

  Similar to LM7

  $m(\tilde{g})$ = 507 GeV, $m(\tilde{\chi}_1^+)$ = 118 GeV

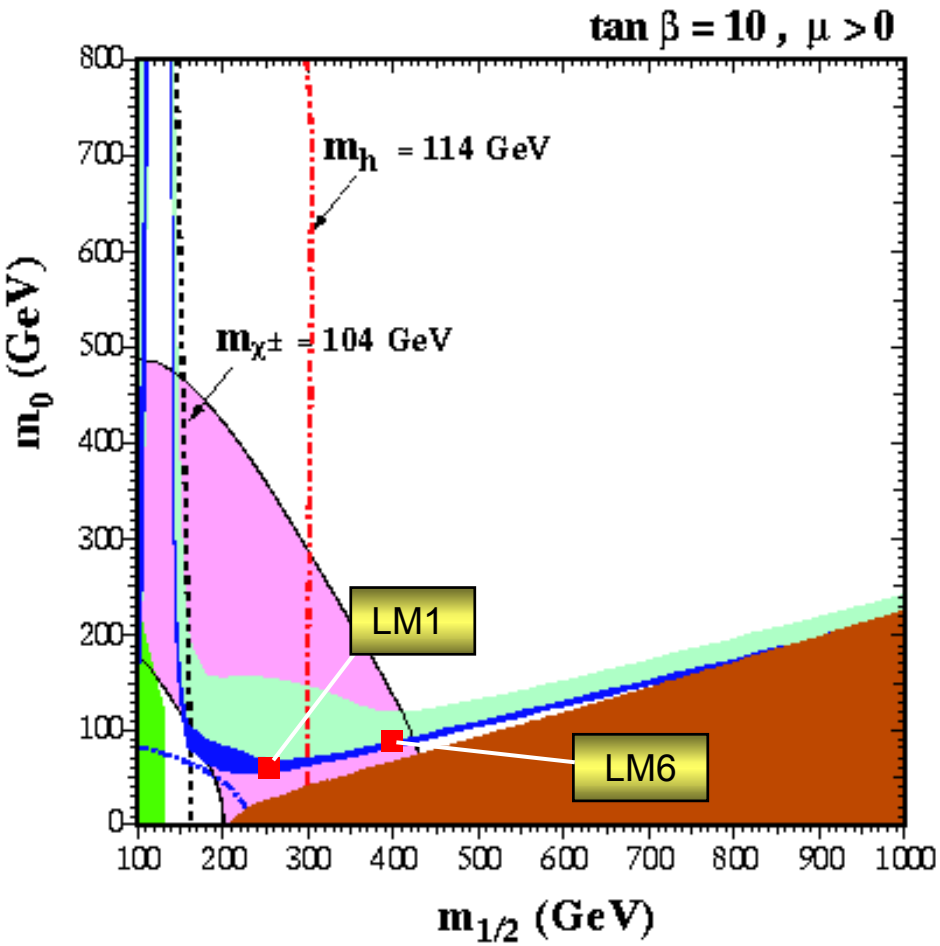
  $Br(\tilde{\chi}^0 \rightarrow \tilde{\chi}_1^0 l^+ l^-) = 6.5\ \%$ $Br(\tilde{\chi}^+ \rightarrow \tilde{\chi}^0 l^+ \nu) = 22\ \%$ $l = e, \mu$

  Karsruhe group : study of point where ERGET data on diffuse gamma rays consistent with WMAP data on CDM with heavy squarks and sleptons

☞ Only 4 points (LM1, LM2, LM6 and LM9) "directly" compatible with the CDM constraints.

Compatibility with CDM Constratint

- J.Ellis et al., hep-ph/0303043



Legend :

- older cosmological constraint $0.1 < \Omega_x h^2 < 0.3$
- newer cosmological constraint $0.094 < \Omega_x h^2 < 0.129$
- $\tilde{\chi}_1^0$ is not LSP
- excluded by b -> s γ
- favored by $g_\mu - 2$ at 2-σ level

S.Abdullin @ PRS SUSY/BSM Meeting, 17-Sep-2003 (agenda/cms > CPT > PRC > BSM > 17Sep03)

HM Points

- HM1: m0=180 GeV, m1/2=850 GeV, tan β=10

  $\tilde{\chi}_2^0 \rightarrow \tilde{l}_L\, l$ (27.5 %), $\tilde{\tau}_2 \tau$ (15 %), $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\nu}_L\, e(\mu)$ (37 %),

  $M(\tilde{g}) > M(\tilde{q})$: $\tilde{g} \rightarrow \tilde{q}\, q$

- HM2: m0=350 GeV, m1/2=800 GeV, tan β=35

  $\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1 \tau$ (78 %), $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\nu}_L \tau + \tilde{\tau}_1 \nu$ (13+76 %)

- HM3: m0=700 GeV, m1/2=800 GeV, tan β=10 ("resembles" LM5)

  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\, h$ (94 %), $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0\, W$ (~100 %)

  $M(\tilde{g}) > M(\tilde{q})$: $\tilde{g} \rightarrow \tilde{b}_{1,2}\, b + \tilde{t}_{1,2}\, t$ (80 %)

  $\tilde{q}_L \rightarrow \tilde{\chi}_2^0\, q$ (~1/3) + $\tilde{\chi}_1^{\pm}\, q$ (2/3), $\tilde{q}_R \rightarrow \tilde{\chi}_1^0\, q$ (100 %)

- HM4: m0=1350 GeV, m1/2=650 GeV, tan β=10, σ_{EW} ~ 45 % of the total

  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\, h$ (94 %), $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0\, W$ (~100 %)

  $M(\tilde{g}) < M(\tilde{q})$: $\tilde{g} \rightarrow \tilde{t}_1 t$ (82 %), $\tilde{q}_L \rightarrow \tilde{g}\, q$ (> 40 %), $\tilde{q}_R \rightarrow \tilde{g}\, q$ (77-93 %)

Program for SUSY

Preparation

- Calibration/alignment
- Measurement of SM physics

Search

- Look for excess in MET+Jets signature

Measurement

- Count leptons/photons
- Count W/Z/b/top/…
- Look for long life heavy particles
- End point analysis in multi leptons system.
- Reconstruct decay chain.

→ SUSY Particle Spectroscopy

Summary

If TeV scale SUSY exists, we should find it in inclusive search and then measure properties.

- LM points may be found or excluded on very early days of LHC/CMS operation.

We need hard work to prepare for day-1 of operation and beyond. We must have

- Good understanding of detector, standard model background and SUSY background.
- Fully functioning software and computing system in place.

LHC/CMS starts in 2007 and first physics run will be in 2008. Let's have a lot of fun!