Physics with the CMS HCAL

U. of Maryland
Shuichi Kunori

4-Feb-2003

Jets and MET rates

Single Top

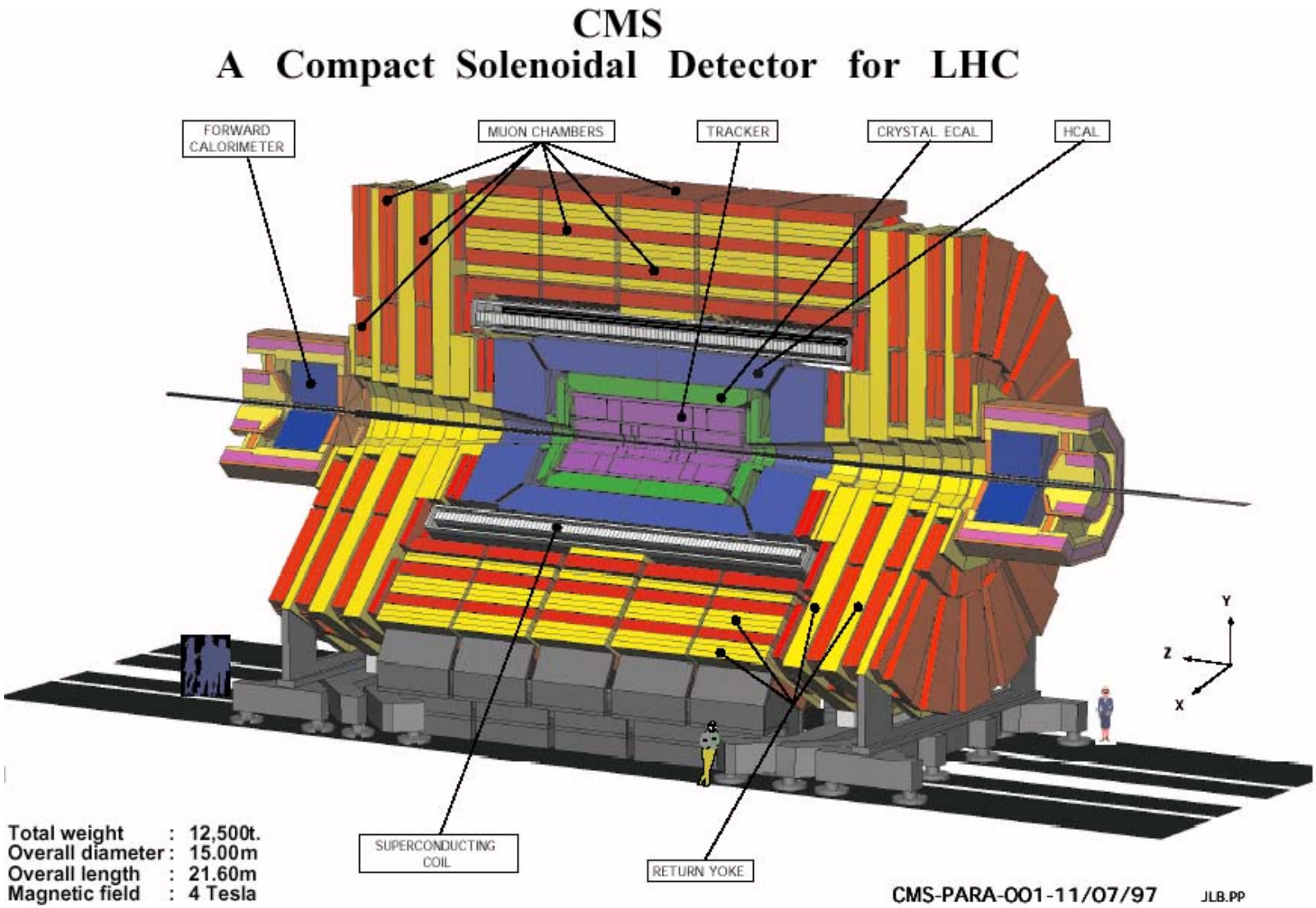
SUSY

Higgs

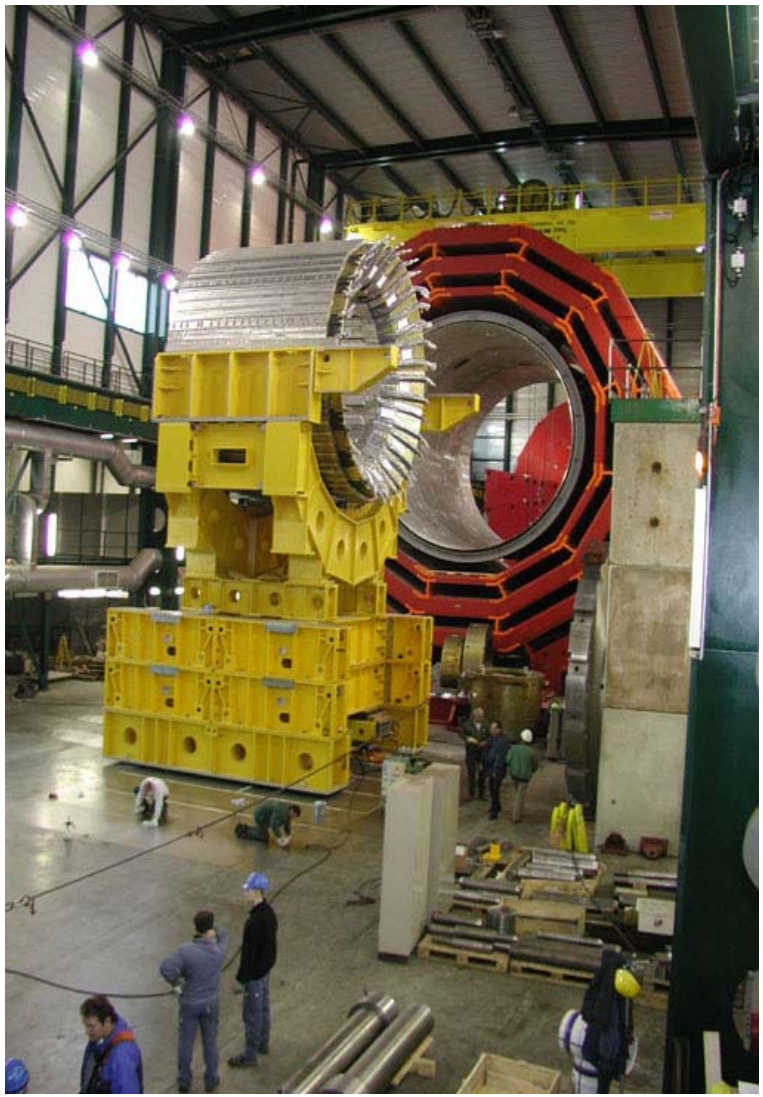
Jet/METReconstrutcion

Conclusions

CMS


CMS
A Compact Solenoidal Detector for LHC
FORWARD CALORIMETER
MUON CHAMBERS
TRACKER
CRYSTAL ECAL
HCAL
SUPERCONDUCTING COIL
RETURN YOKE
Y
Z
X
Total weight : 12,500t.
Overall diameter : 15.00m
Overall length : 21.60m
Magnetic field : 4 Tesla
CMS-PARA-001-11/07/97
JLB.PP

CMS HCAL/JetMET



- Completed the first calibration run with four production HB modules at CERN H2 test beam line.
  - 2002 Aug-Sep.
  - 3000 runs / 100 million events

  → HCAL calibration database under development.

- Completed assembly of both HB at SX5, CERN.
  - next- mount electronics
  - then- slice test with other detectors.

- Completed development of baseline Jet/MET Higher Level Trigger for SUSY/Higgs and other physics.

  → improve reconstruction algorithm
  → Physics performance study

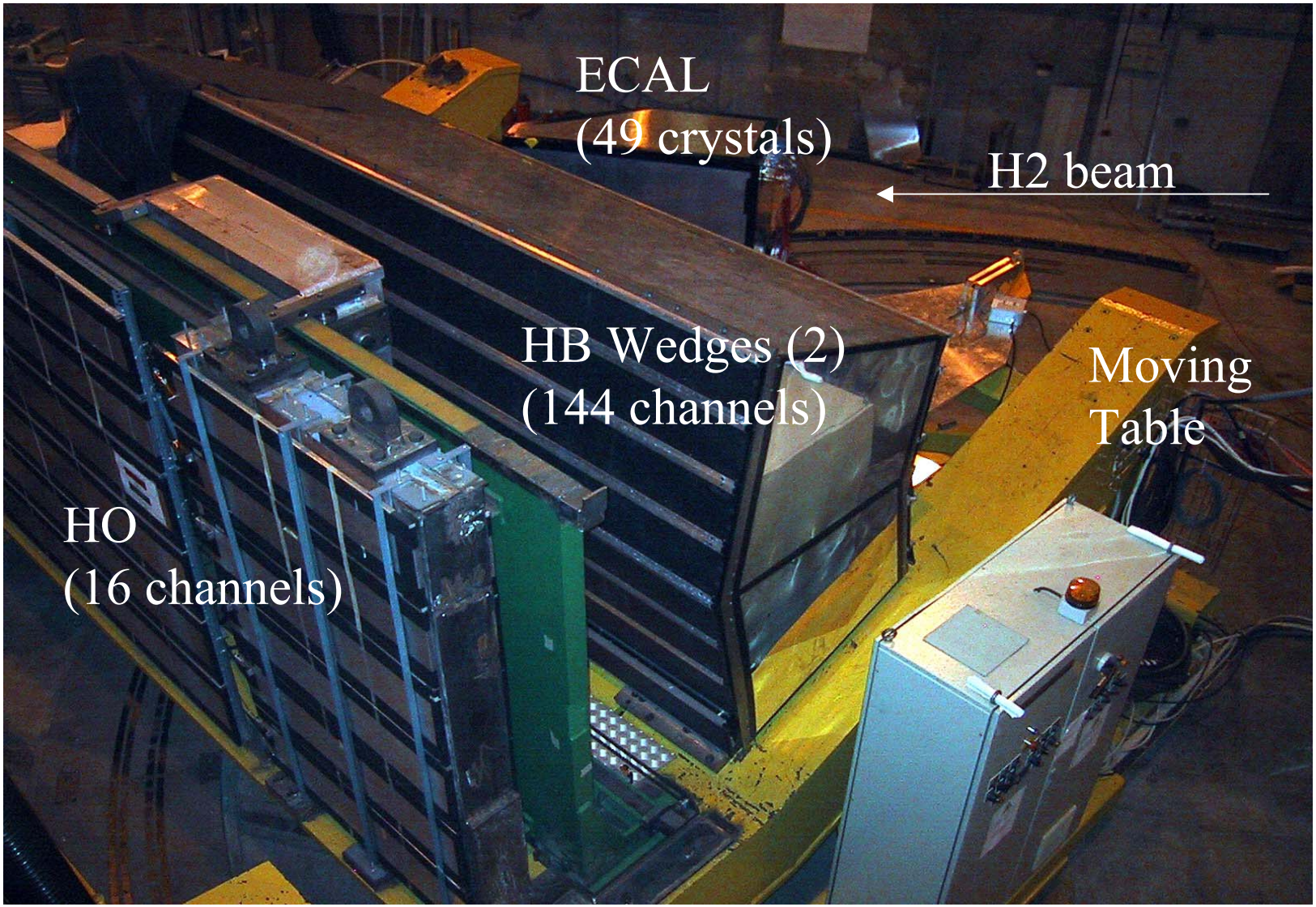
CERN Building 186
- summer 2002 -

All HE Scintillator Tiles, HB Wedges, HF Wedges

HCAL+"ECAL" Layout

Calibrate 4 wedges '02. Check HO response as tail catcher and as muon trigger element. In '03 use PPP to study 40 MHz beam and HE/HB transition region.

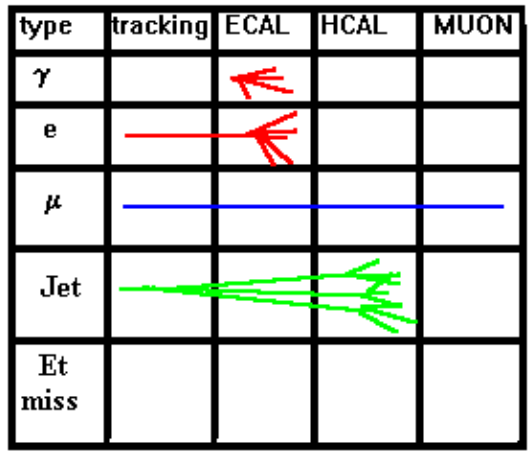
Testbeam Layout



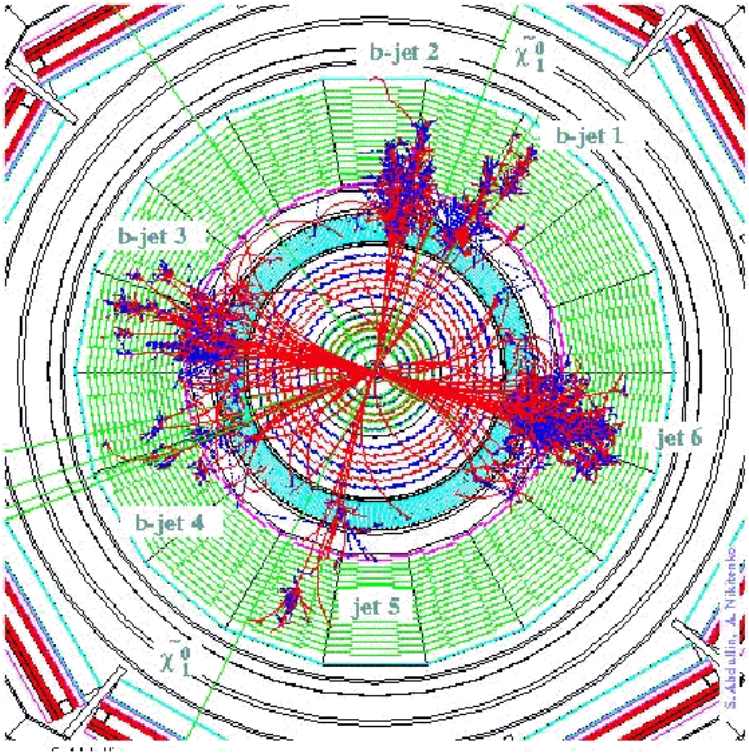
Detection of Fundamental Particles

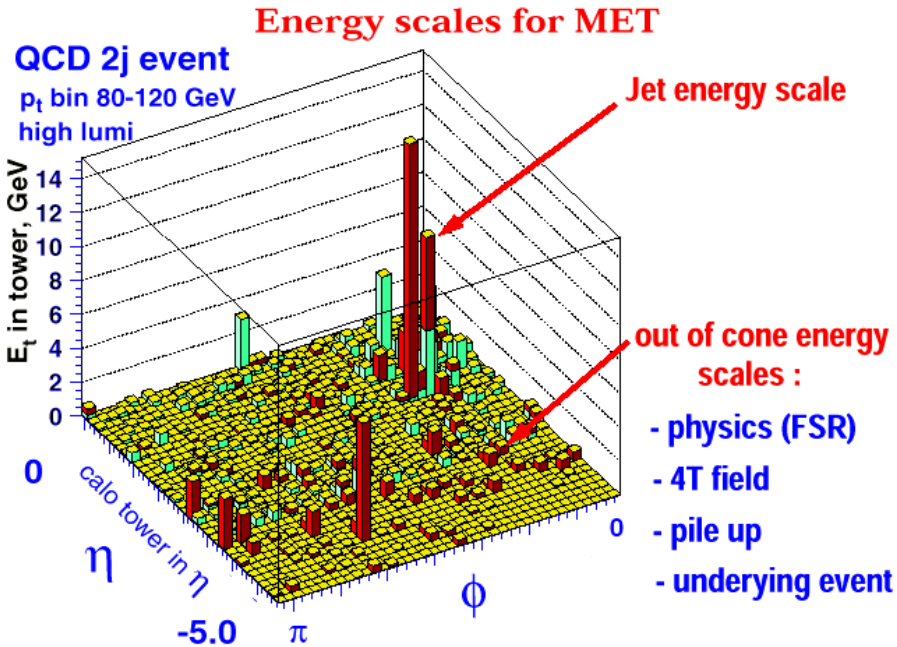
SM Fundamental Particle Appears As

γ	γ (ECAL shower, no track)
e	e (ECAL shower, with track)
μ	μ (ionization only)
τ	Jet (very narrow) + tracks
g	Jet in ECAL+ HCAL
q = u, d, s	Jet (narrow) in ECAL+HCAL
q = c, b	Jet (narrow) + Decay Vertex
t --> W +b	W + b (jets/MET+lepton)
$\nu_e \nu_\mu \nu_\tau$	MET in ECAL+HCAL
τ-->l + ν_τ + ν_l	MET + charged lepton
W --> l + ν_l	MET + charged lepton, Et~M/2
Z --> $l^+ + l^-$	charged lepton pair
--> $\nu_l + \nu_l$	MET in ECAL+HCAL



Jets





Simple cone algorithm:

Jet energy in a cone

$\Delta R = \mathrm{sqrt}[(\Delta\eta)^2+(\Delta\phi)^2] < 0.5$

Physics Rates

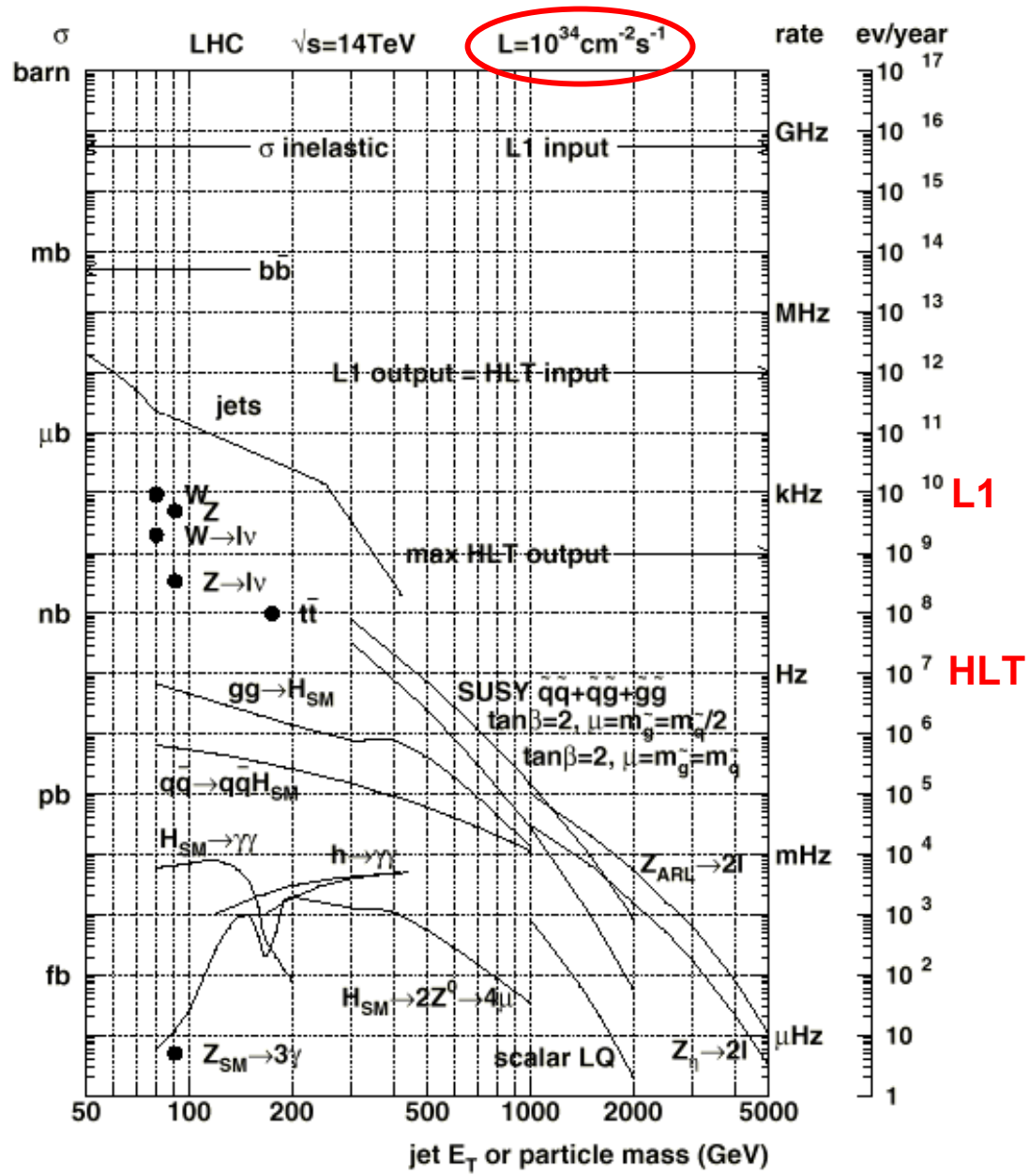
large background
- QCD
- W+jets,Z+jets,
- tt, t

to discovery channels.

e.g.

Jets (100GeV)	10KHZ
W-> lν	>100Hz
tt	10Hz

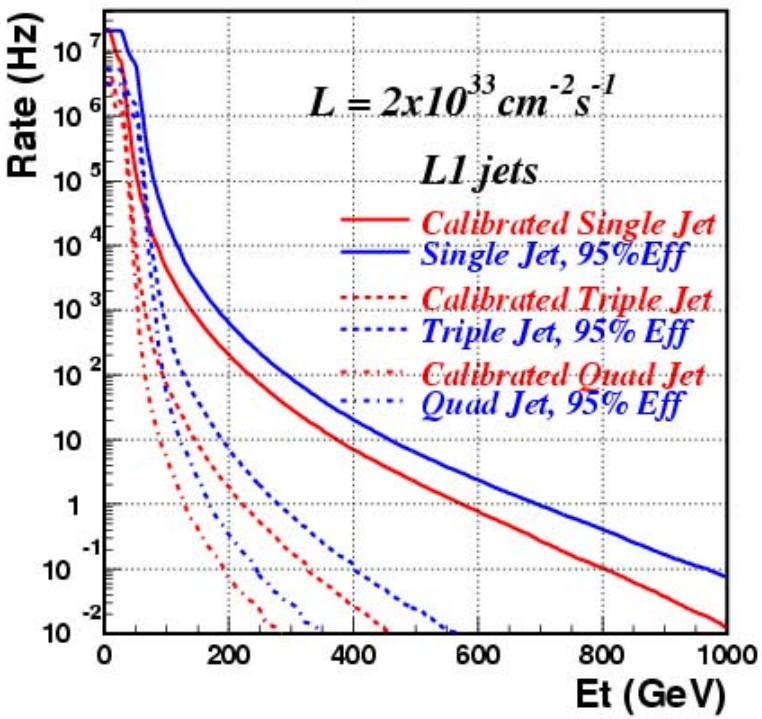
at 10E34.



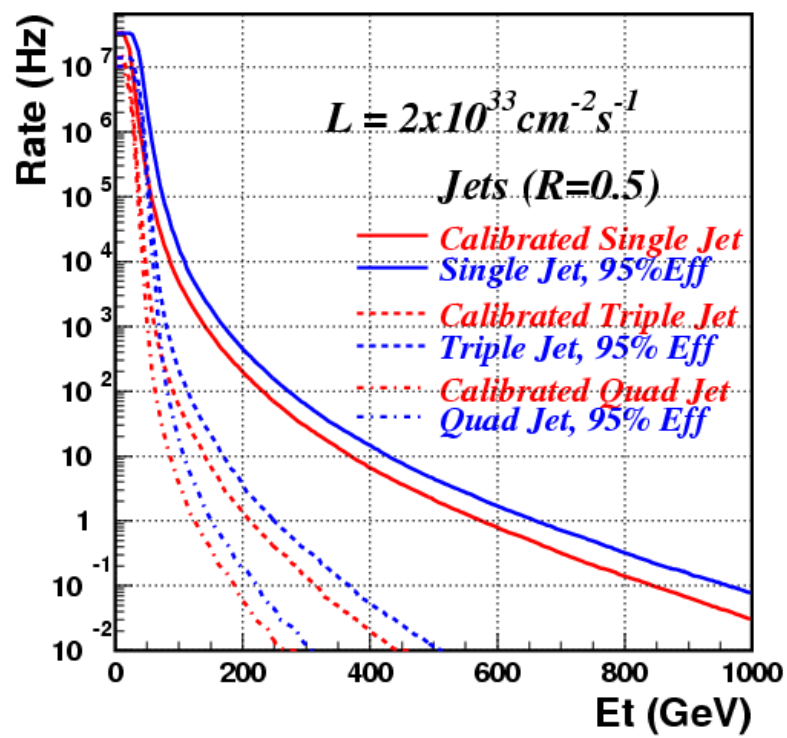
Jet Rates: Low Lum (2E33)

Rates very similar at L1 and HLT

L1



HLT

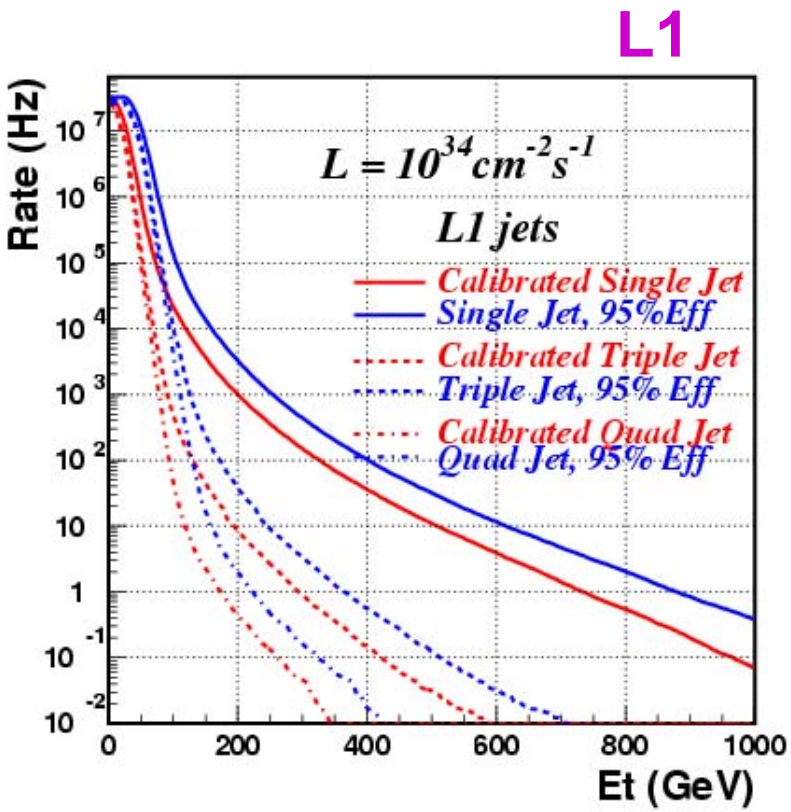


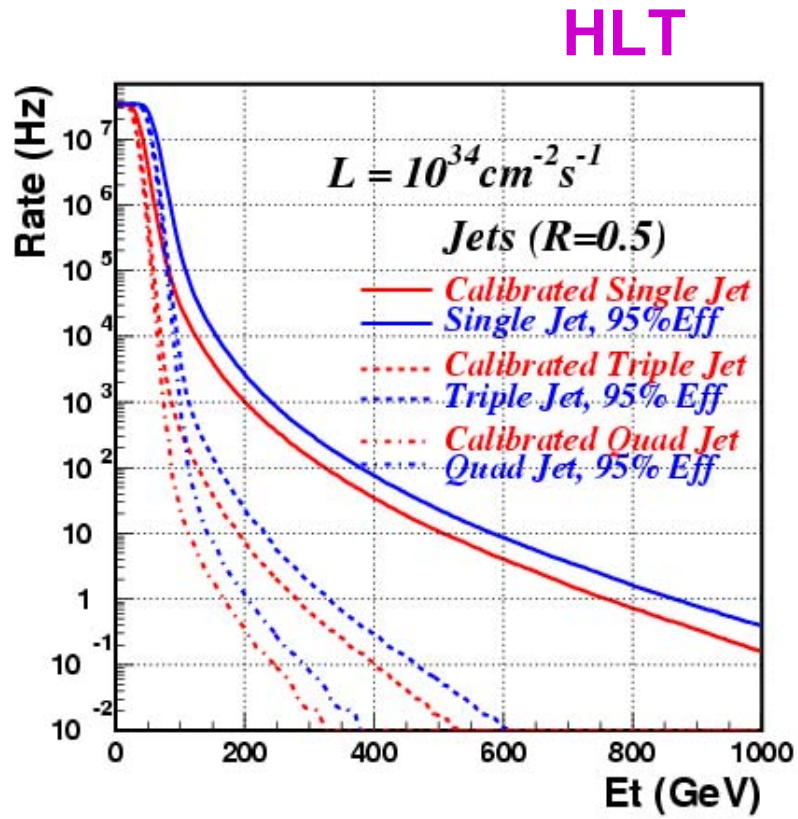
1 kHz at Level-1: 180 GeV (1 jet), 95 GeV (3 jet), 80 GeV (4 jet)

1 Hz at HLT: 660 GeV (1 jet), 250 GeV (3 jet), 150 GeV (4 jet)

Jet Rates: High Lum (E34)

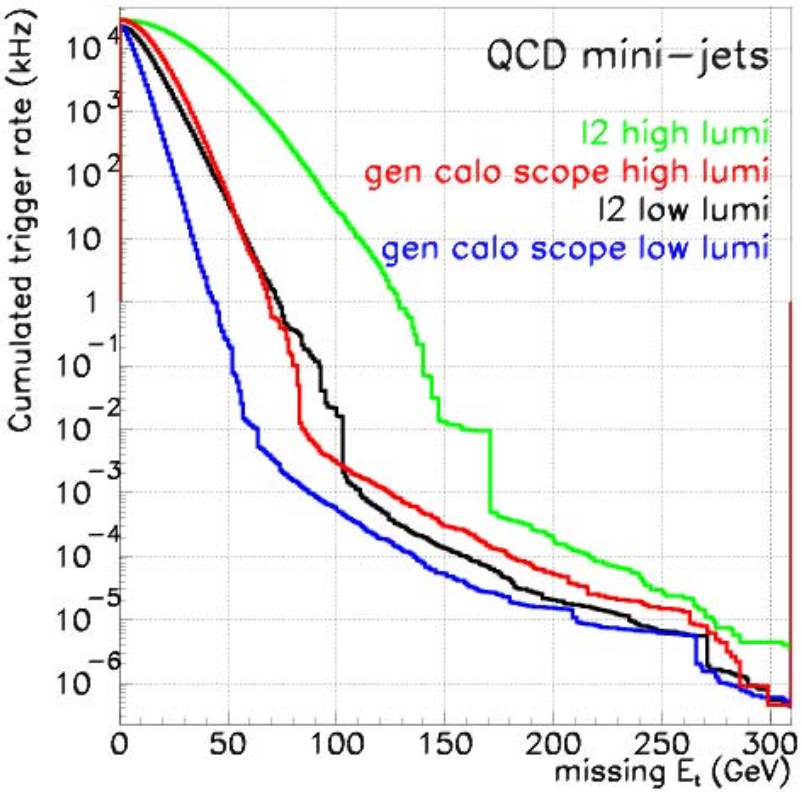
Rates very similar at L1 and HLT





1 kHz at Level-1: 250 GeV (1 jet), 125 GeV (3 jet), 110 GeV (4 jet)
1 Hz at HLT: 865 GeV (1 jet), 330 GeV (3 jet), 200 GeV (4 jet)

Met Rates



Very sensitive to details of the simulation (and a great way to find bugs in the calorimeter simulation ☺)

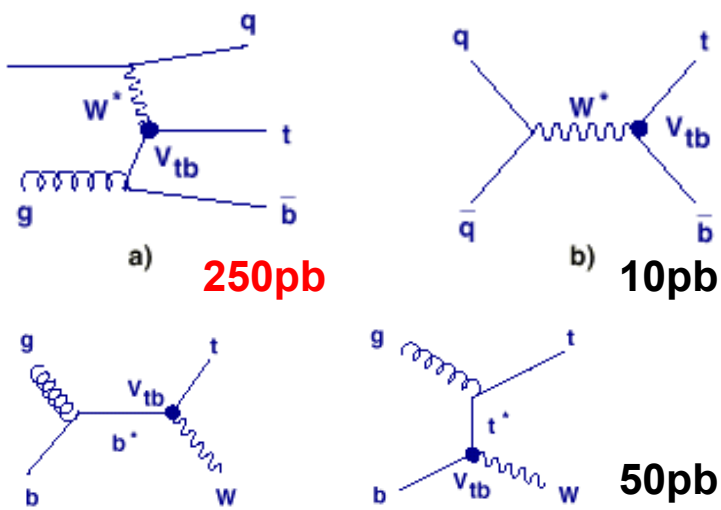
→Sensitive to hardware problem.
→Need good monitoring and quick cure.

Raw rates are very difficult to interpret because of the large and algorithm-dependent difference between HLT and generator MET

Single Top -> Wb -> lνb

CMS Note 1999/048

Measurement of
- CKM $|V_{tb}|$
- properties and decays of top
- background process to new physics

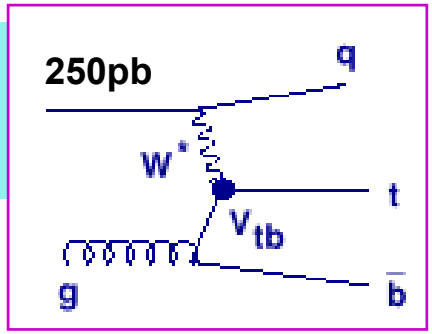


Background:
- top+top 800pb
- W+2jets
- W+3jets

Event Selection:
- only one charged lepton
  - PT > 20GeV in $|\eta|<2.5$
- only one cnetral jet
  - ET > 20GeV in $|\eta|<2.5$
  - (jet veto to remove tt)
  - b-tagged (20<ET<100GeV)
- forward tagging jet
  - ET>50GeV in $2.5<|\eta|<4.0$
- MET
  - > 20GeV
- W Mass (lepton + MET)
  - 50<MT<100GeV
- Di-jet mass outside $M(Z^0)$

- top mass cut
  - 140<M(Wb)<180GeV

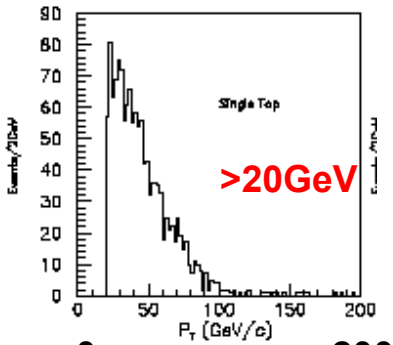
Single Top - Kinematics

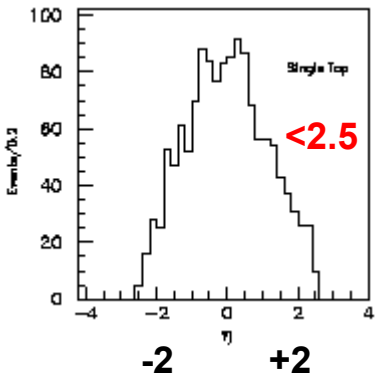


Measurement of

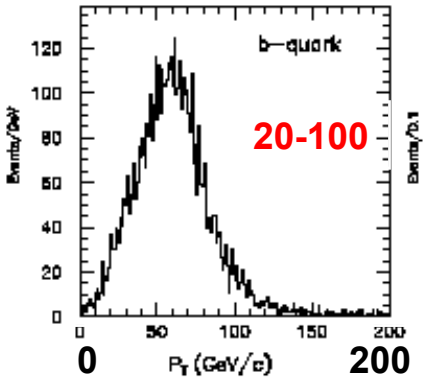
- V_{tb} / top decay properties / background to new physics

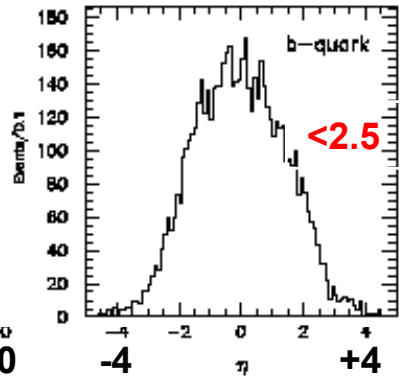
P_T (lepton) η



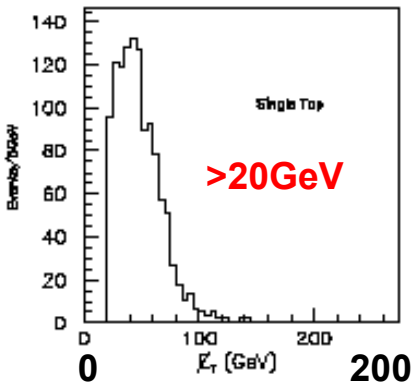


E_T (b-quark) η

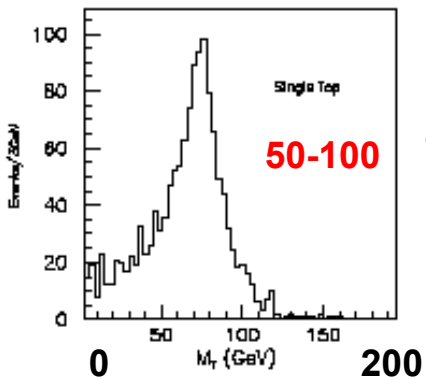




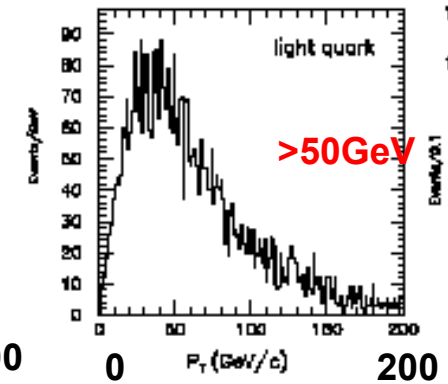
MET

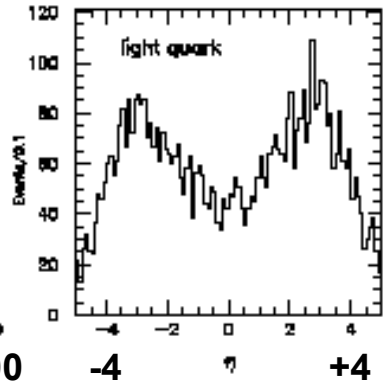


M_T (l+ν)



E_T (tagging jet) η 2.5-4.0



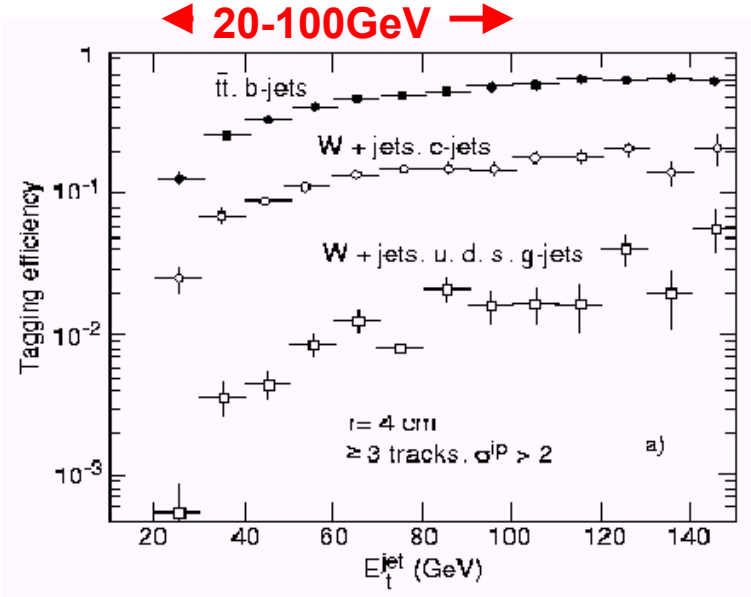


Top Mass

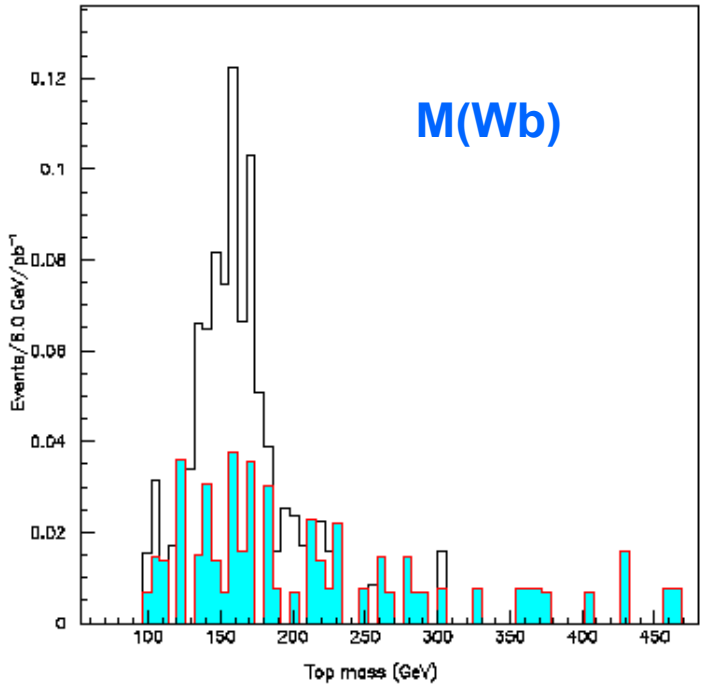
b/c tagging efficiency and fake

- very old parametrization used in this analysis-

◄ 20-100GeV ►



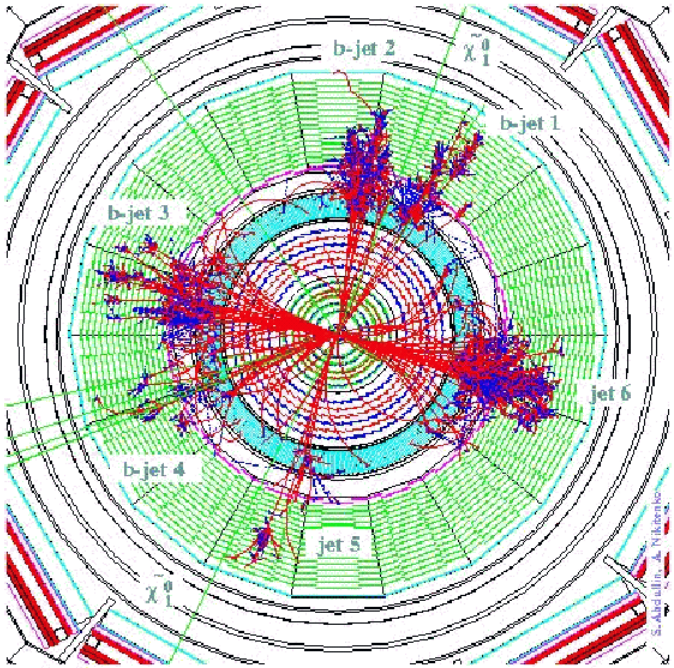
Charm rate and fake rate play important role in background rejection.

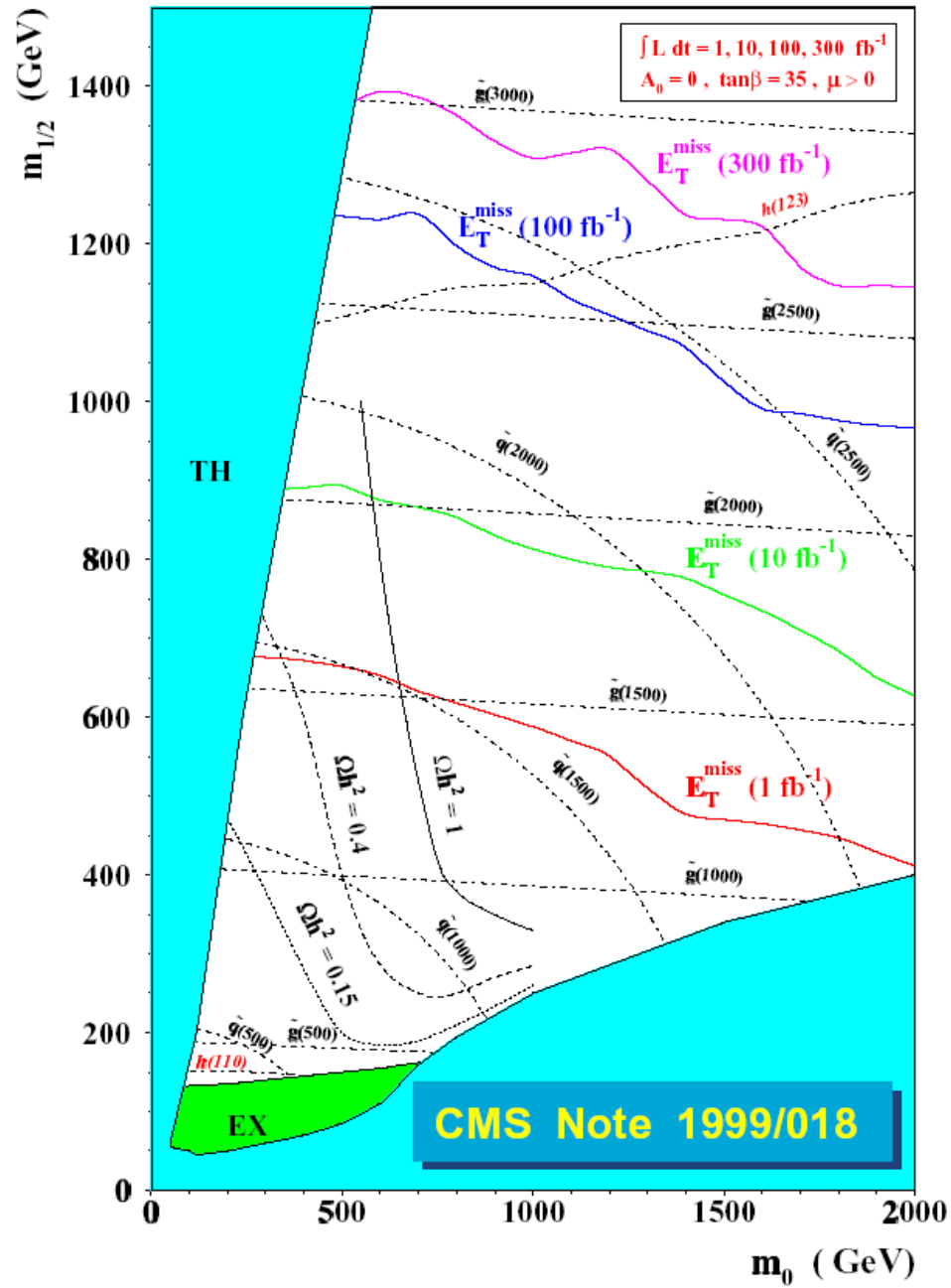


S / N = 3.5 / 1.0

66 signal events / 100pb
30 housrs @ 10E33.
Efficiency: 1.2%

SUSY

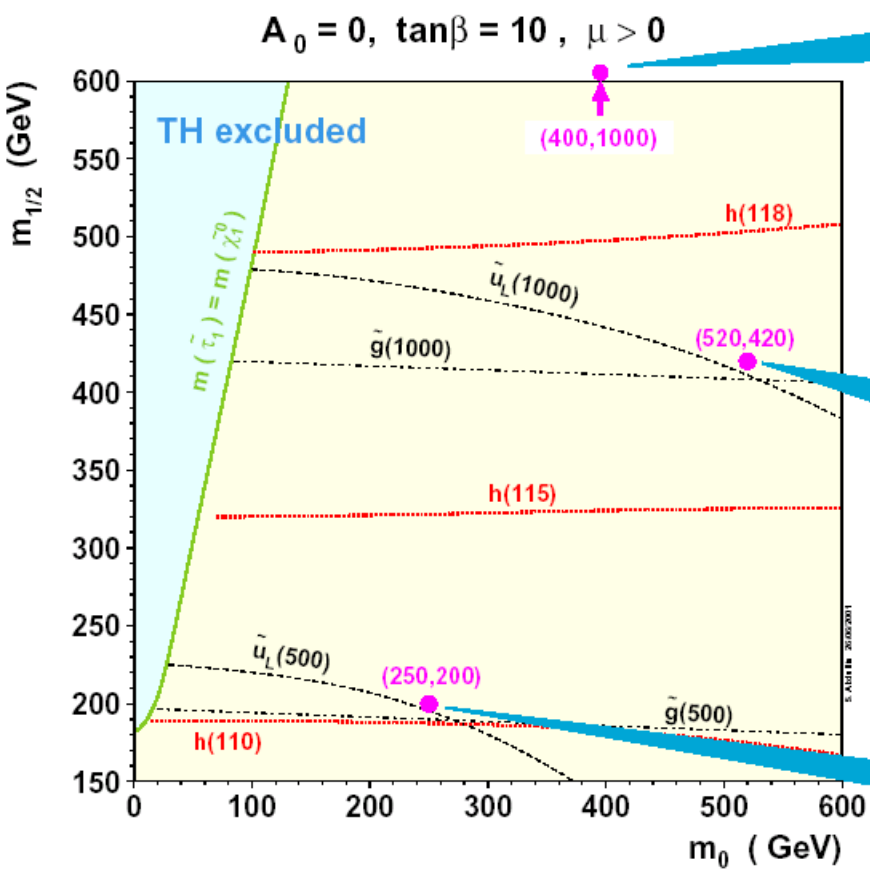




Signal for discovery:

Multi jets
MET

Probing Points



$m(\tilde{\chi}_1^0) = 423$ GeV $m(h) = 121.9$ GeV

$m(\tilde{g}) = 2154$ GeV $m(\tilde{u}_L) = 1993$ GeV

$\sigma \sim 18$ fb, requires $\int Ldt \sim 20\text{-}25\ fb^{-1}$

typical cuts : $\not{E}_T > 800$ GeV, $N_j \geq 2$

3 $E_T^j > 300, 150$ GeV

$m(\tilde{\chi}_1^0) = 177.5$ GeV $m(h) = 116.8$ GeV

$m(\tilde{t}_1) = 726$ GeV

$\sigma = 2.24$ pb, requires $\int Ldt < 100\ pb^{-1}$

typical cuts : $\not{E}_T > 300$ GeV, $N_j \geq 3$

2 $E_T^j > 200, 100, 50$ GeV

$m(\tilde{\chi}_1^0) = 79.0$ GeV $m(h) = 110.7$ GeV

$m(\tilde{t}_1) = 352$ GeV

$\sigma = 115$ pb, requires $\int Ldt < 10\ pb^{-1}$

typical cuts : $\not{E}_T > 200$ GeV, $N_j \geq 2$

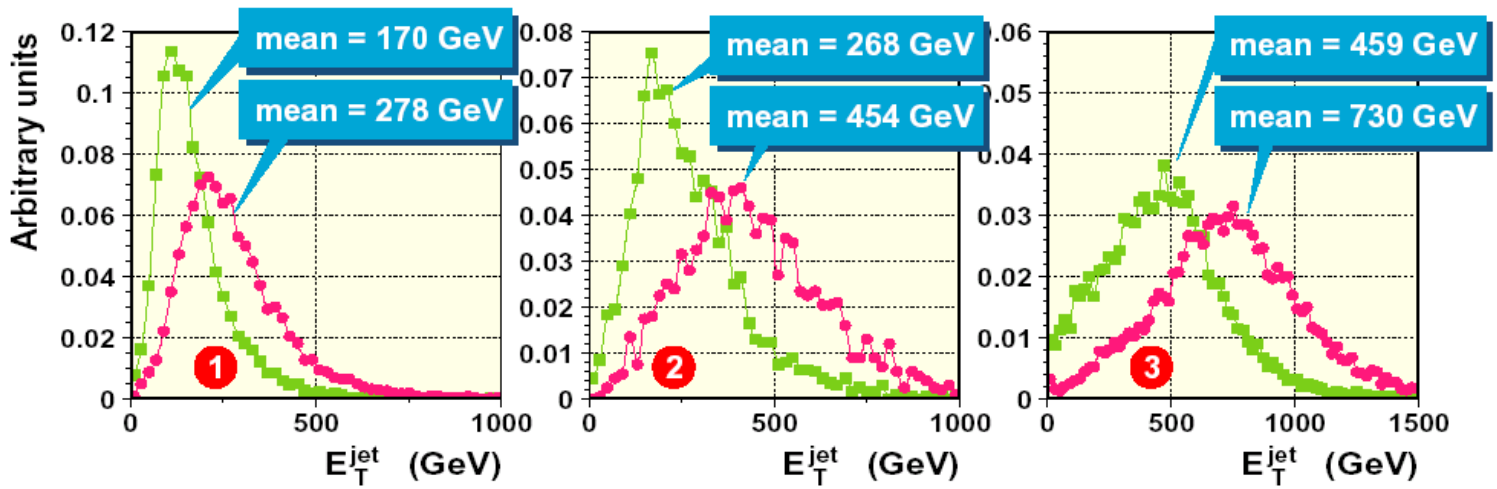
1 $E_T^j > 100, 50, 50$ GeV

- Typical off-line signal efficiency : 20 - 70 % (@ 0.5 - 2 TeV)

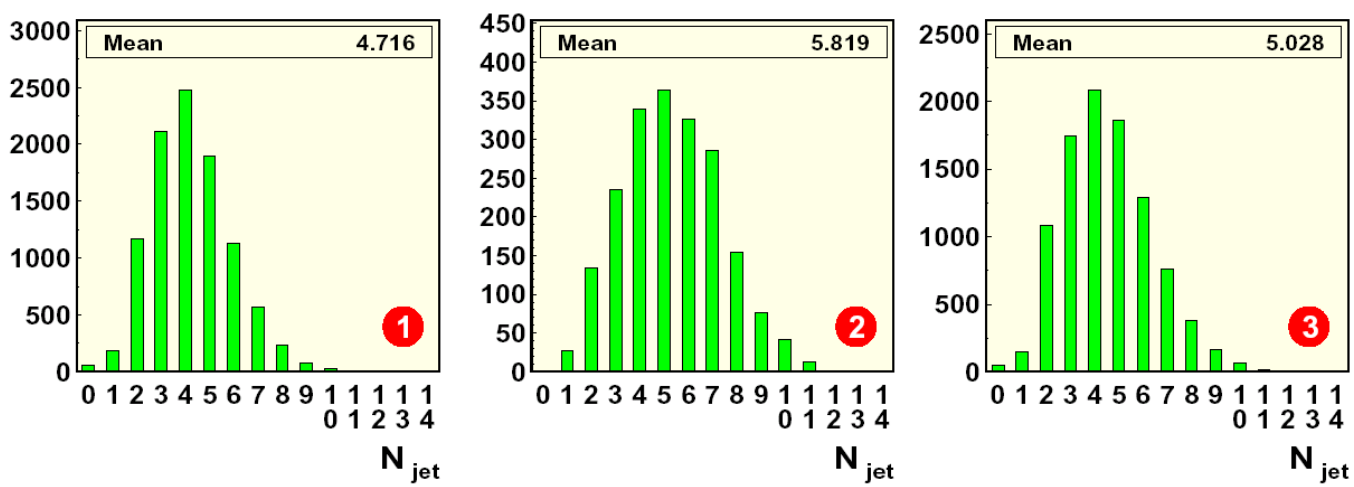
(S.Abdullin)

Jets

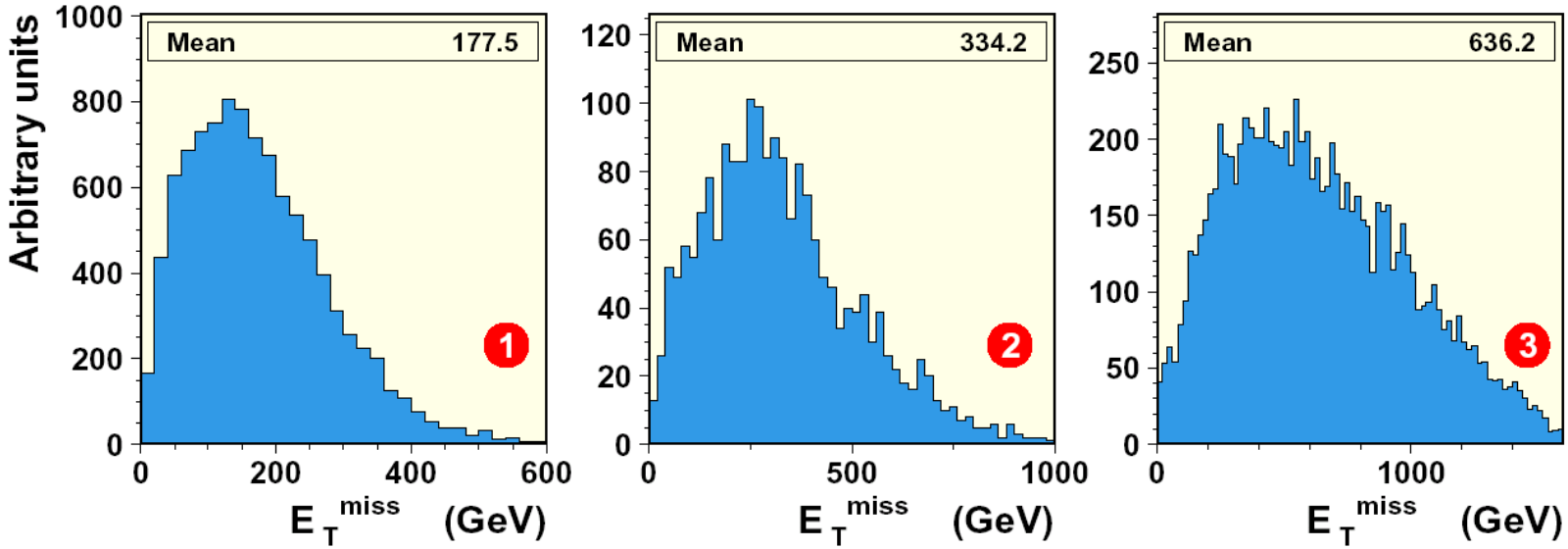
Et of 1st & 2nd highest Et jets



Jet Multiplicity (Et>40GeV)



MET

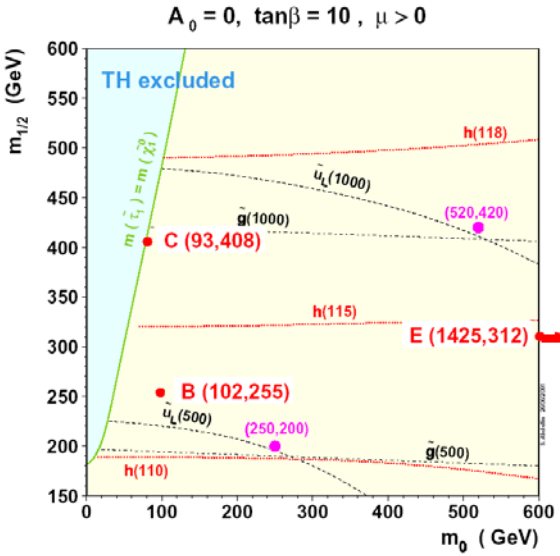


Multi-jets and MET will provide discovery of SUSY.

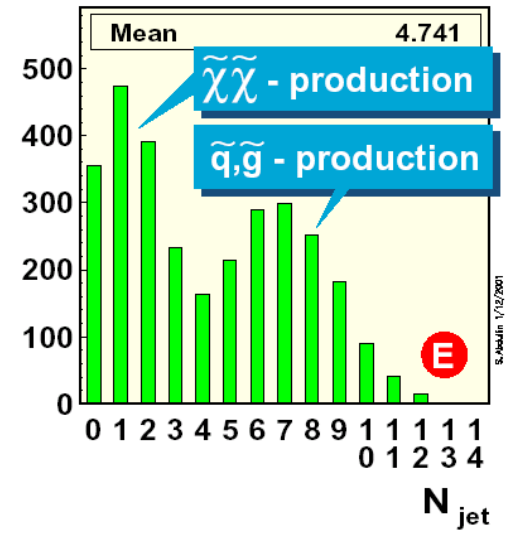
How to measure SUSY parameters?
→ need a lot of work.

By the way…

Complex SUSY Channel
- an example -



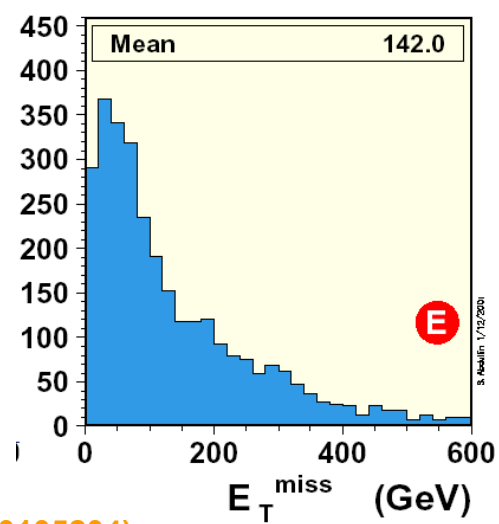
m_0 $m_{1/2}$
(1425,312)

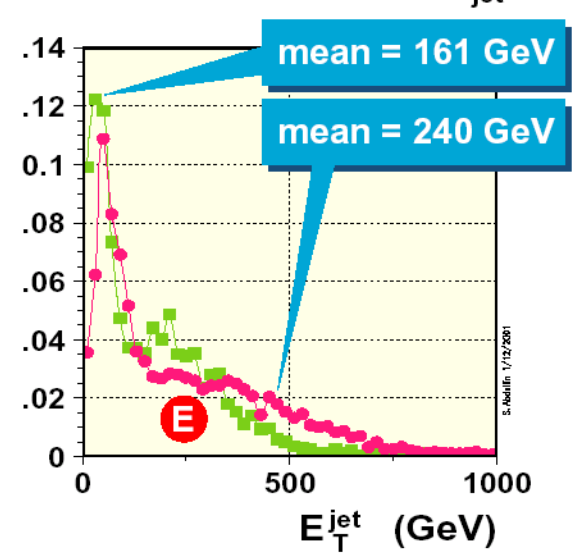


M_h 116GeV

M_{gluino} 804GeV

M_{squark} 1500GeV





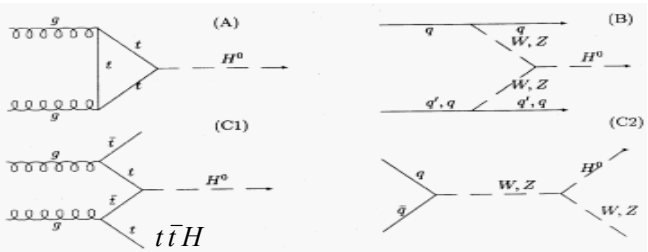
(a SUSY point from hep-ph/0105204)

SM Higgs

production

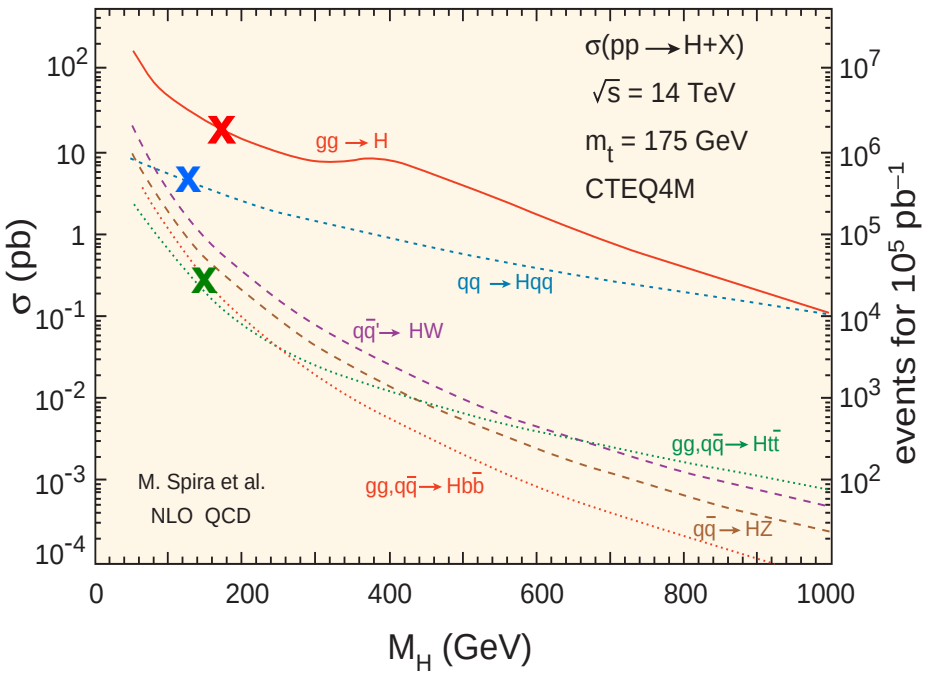
gg fusion

WW/ZZ fusion

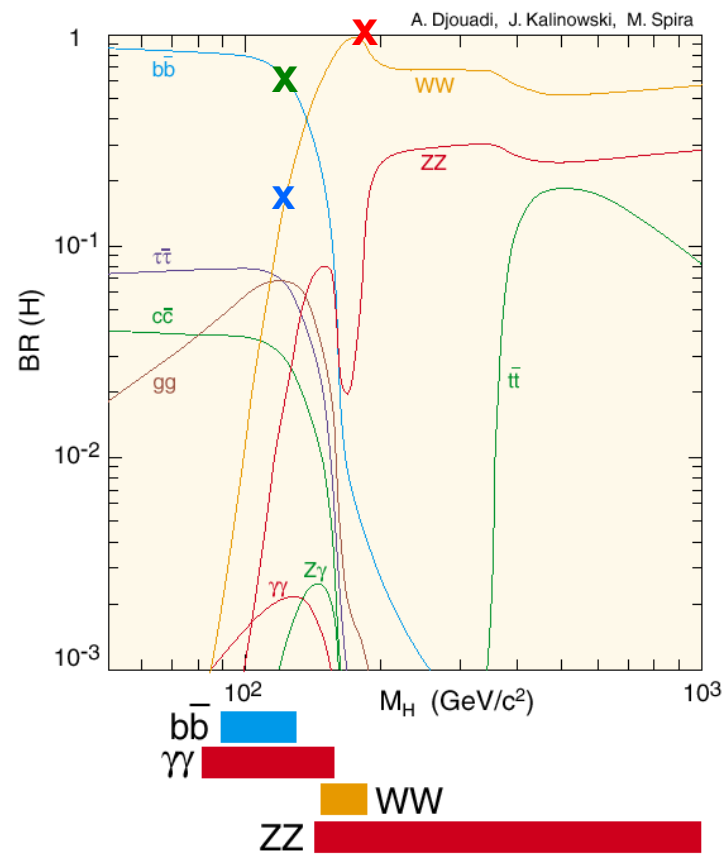


associated

associated WH, ZH

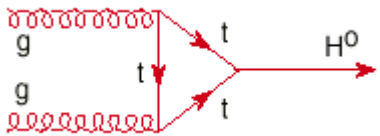


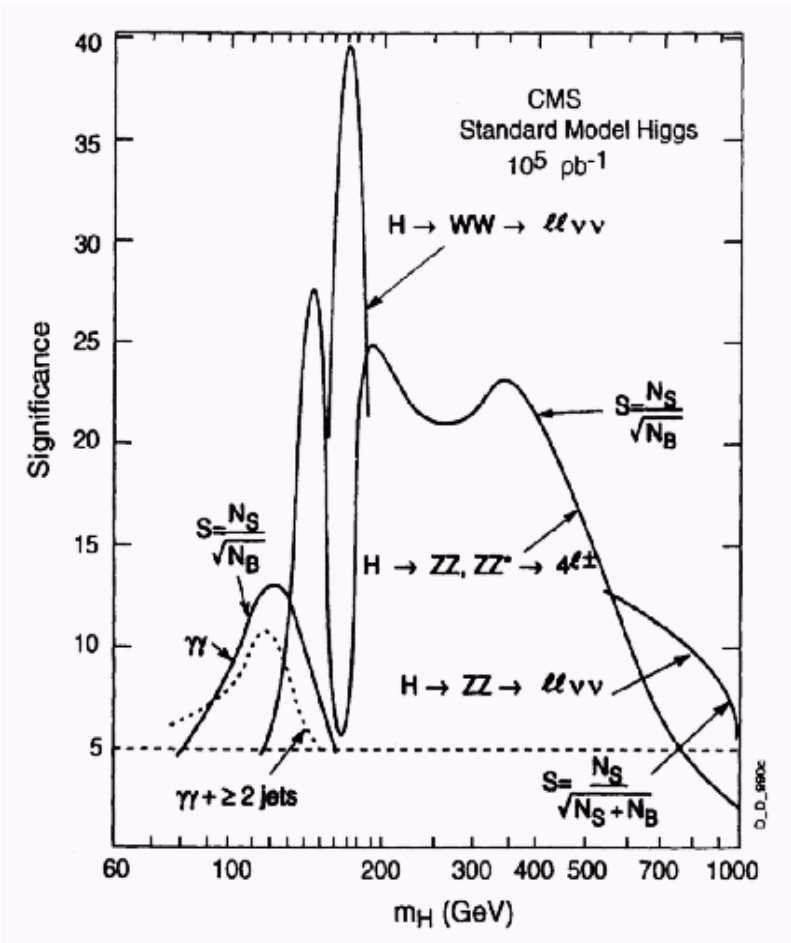
decay

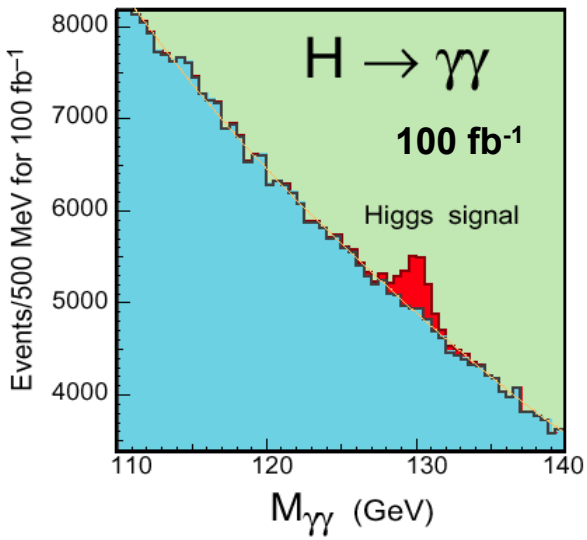


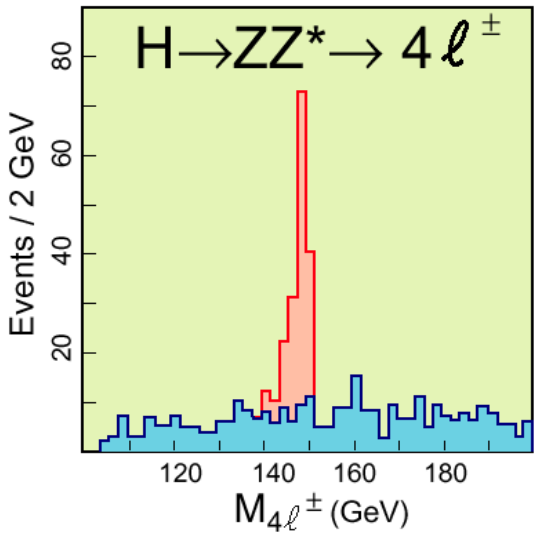
A.Nikitenko talked on ττ decay mode on Wednesday.

gg -> H_{SM}


g
g
t
t
t
H0


CMS
Standard Model Higgs
10^5 pb^-1
H → WW → ℓℓνν
S = N_S / √N_B
H → ZZ, ZZ* → 4ℓ±
γγ
H → ZZ → ℓℓνν
γγ + ≥ 2 jets
S = N_S / √(N_S + N_B)
Significance
m_H (GeV)

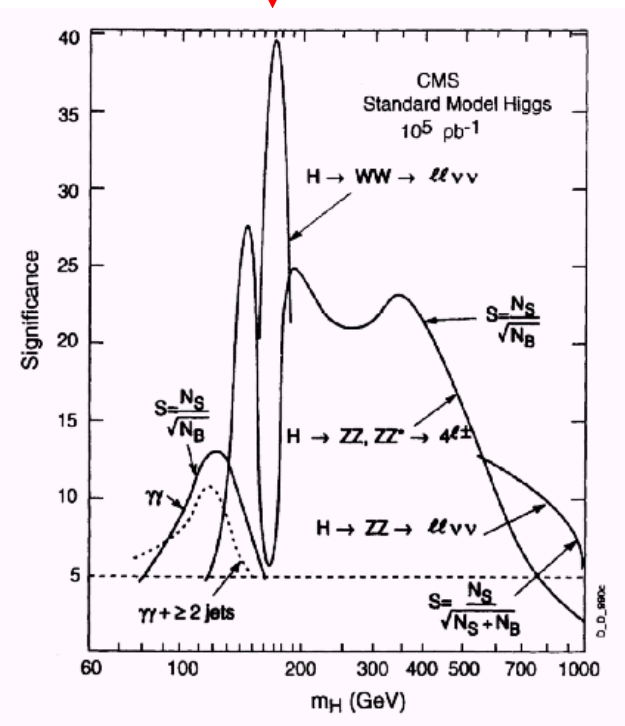

H → γγ
100 fb^-1
Higgs signal
Events/500 MeV for 100 fb^-1
M_γγ (GeV)


H→ZZ*→ 4ℓ±
Events / 2 GeV
M_4ℓ± (GeV)

H(170) -> WW -> lνlν

(CMS Note 1998/089)

1.24pb



Event Selection:

(total 11 cuts)

two opposite sign leptos

- PT cuts (20GeV,10GeV)
- angle between two leptons

jet veto

- ET>20GeV in |η|<2.4: removed

Mass (WW)

- M > 140GeV

Results:

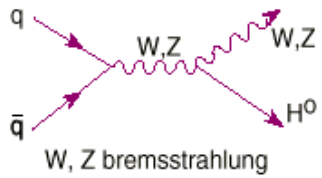
- number of events (5fb^{-1})
  H / tt / WW = 54 / 35 / 28
- good channel for discovery
- background: need good understanding
- jet veto: important.

Background:

tt -> (Wb)(Wb) ->(lνb)(lνb) 62.5pb

WW(continum) -> lνlν 7.4pb

$W^{\pm} H^0_{SM} \longrightarrow l^{\pm} \nu b\bar{b}$

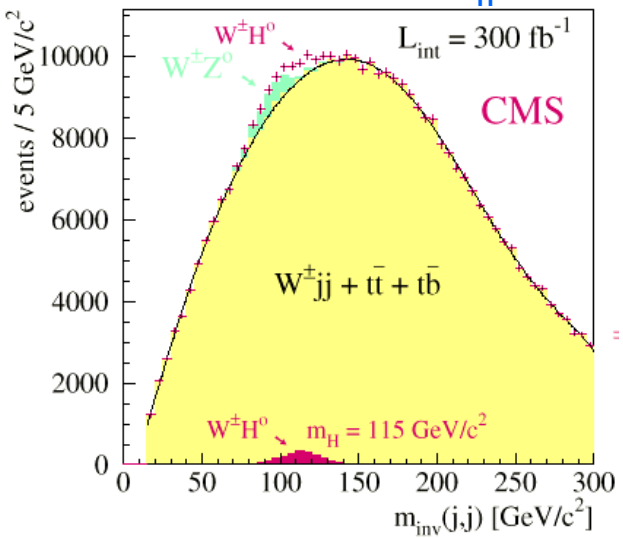


bb

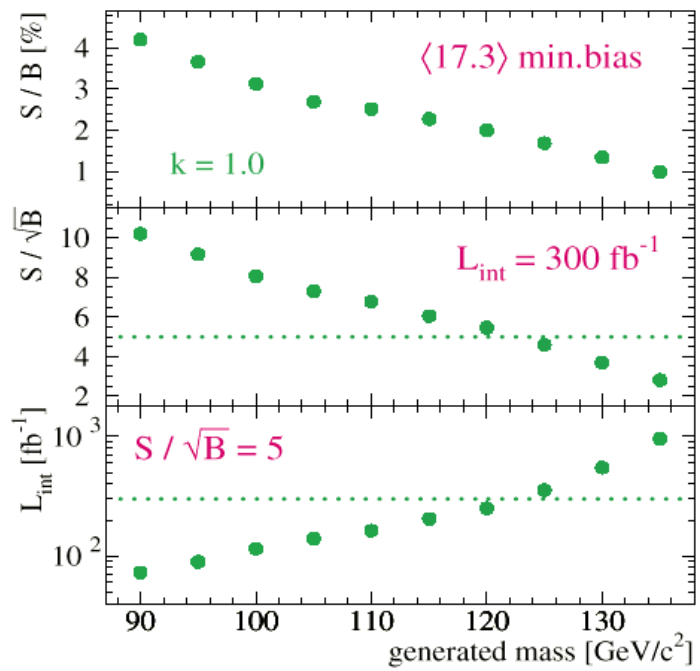
1 iso. lepton (e,μ) (P_T>20GeV)
only 2 jets (b-tag) (E_T>30GeV)
$M_T(W)$
-> events in higgs mass window

Bg:
Wjj, tt, tb

M_H=115 GeV



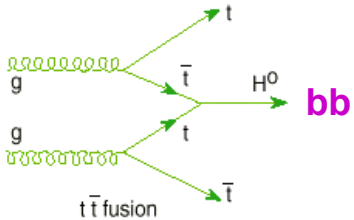
$\sigma_{W^{\pm}H^0} \times BR_{H^0 \to b\bar{b}}$	=	1.28 - 0.54 pb
m_{H^0}	=	110 - 130 GeV/c^2
$\sigma_{W^{\pm}Z^0}$	=	18.2 pb
$\sigma_{W^{\pm}jj}$	=	27.1 nb
$\sigma_{t\bar{t}}$	=	569 pb
$\sigma_{t\bar{b}}$	=	318 pb



5

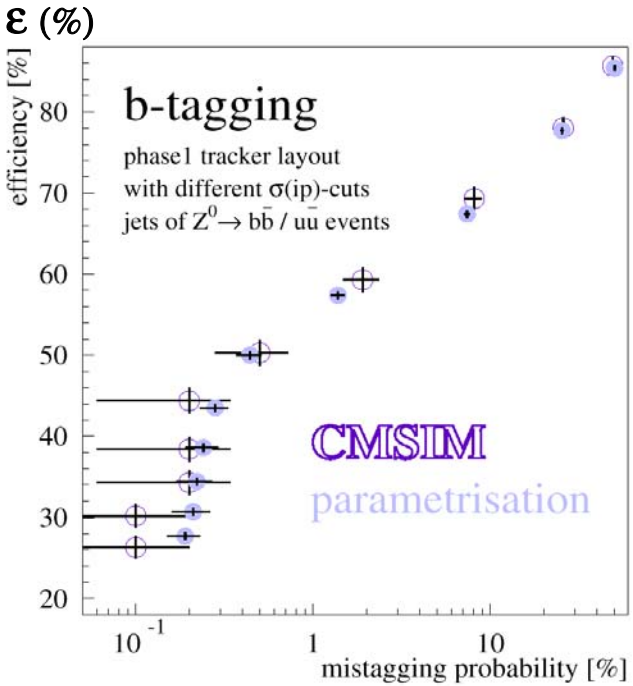
300fb^{-1}

$t\bar{t}H^0_{SM} \rightarrow l^{\pm}\nu q\bar{q}b\bar{b}b\bar{b}$



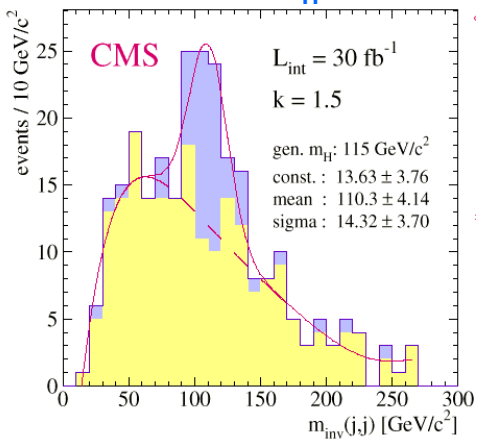
1 iso. lepton (PT>10GeV)
6 jets (*4 b tag*) (ET>20GeV)
-> max. likelihood
(b likeliness, W mass, top mass …)

Bg:
ttbb, ttjj, ttZ⁰



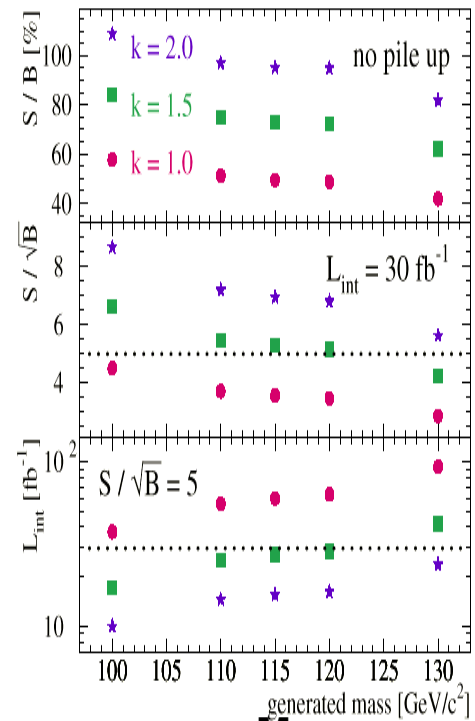
mistagging probability (%)

M_H=115 GeV



Mass(jj)

Δm/m=3.8% (stat)



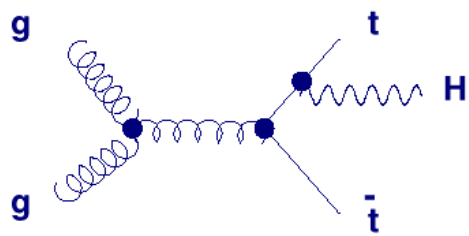
5

30fb⁻¹

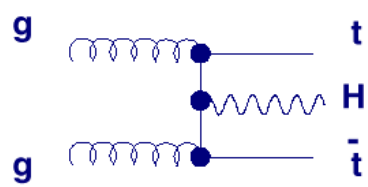
M_H

ttH(120), H→bb

(CMS Note 2001/039)



a)



b)

Final state:

t → Wb → lνb
t → Wb → jjb
H →bb

1 isolated lepton
MET
6 jets
- 4 b-tags

Signal: (σ*Br) 0.78pb

Background:

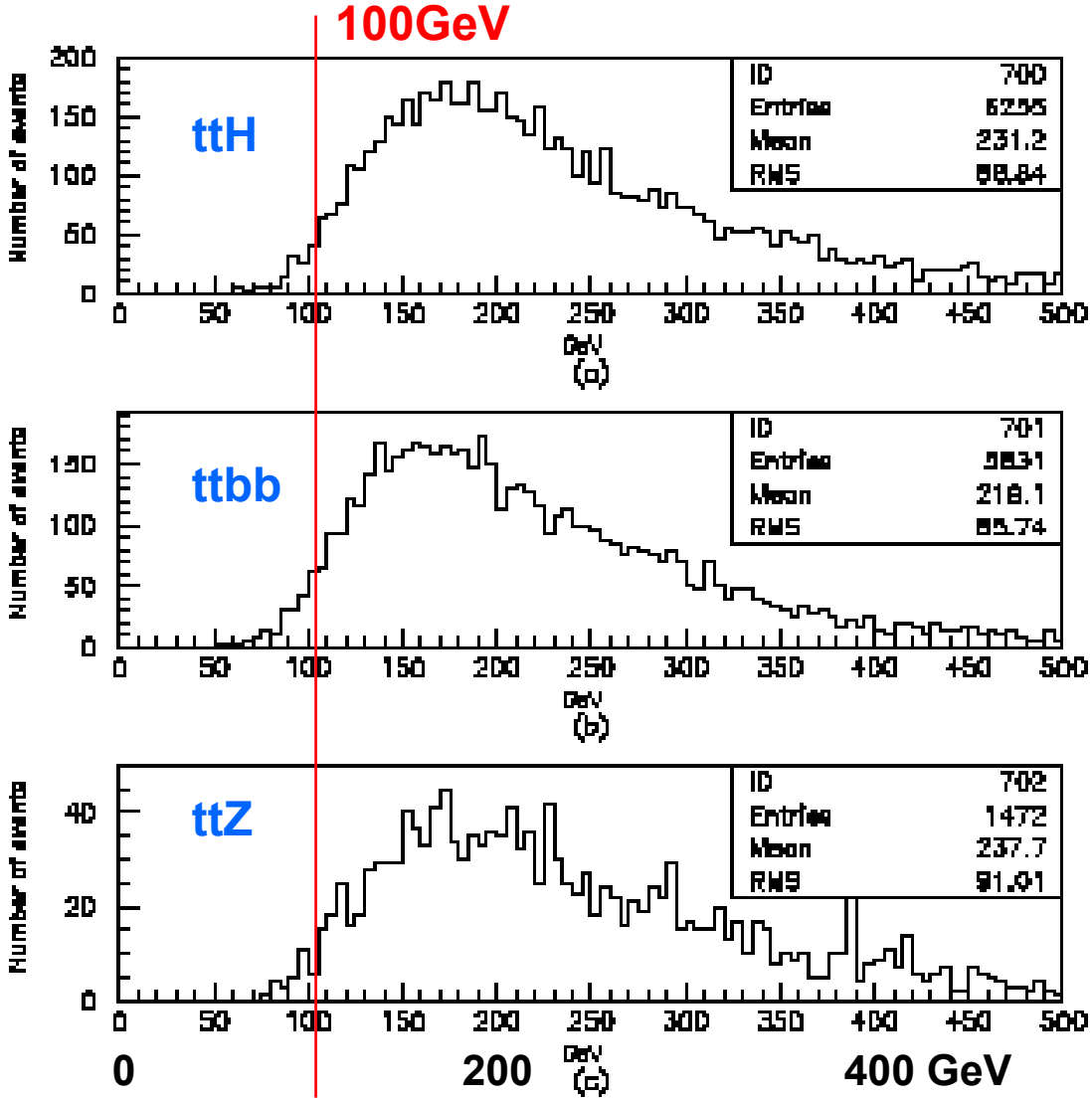
ttbb	3.3	pb
ttjj	507	pb
ttZ	0.65	pb

NB: ttjj will not be a major background after b-tag.

CompHEP V41.10 (V.Ilyin, A.Krykov)
CMGEN
- CompHEP-PYTHIA interface V46
- PYTHIA 6.157
- b-tag simulator for pre-selection

CMSIM 120
Analysis
- cone jet finder

Envent Selection (1)
Leading Jets & lepton



L1 Trigger:

1 lepton
+
E_T(jet)>100GeV

HLT

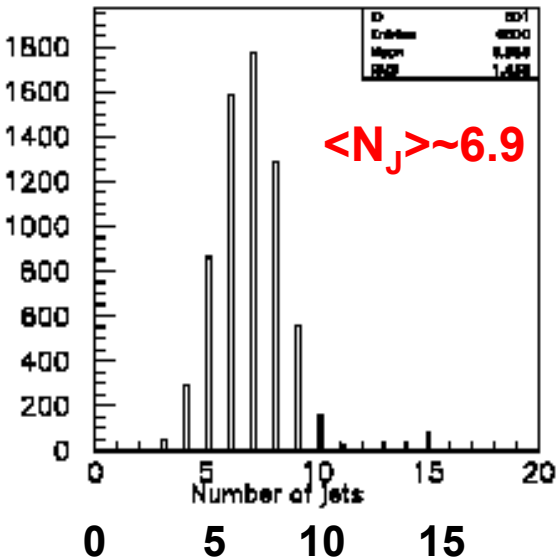
4 b-tags

Offline:

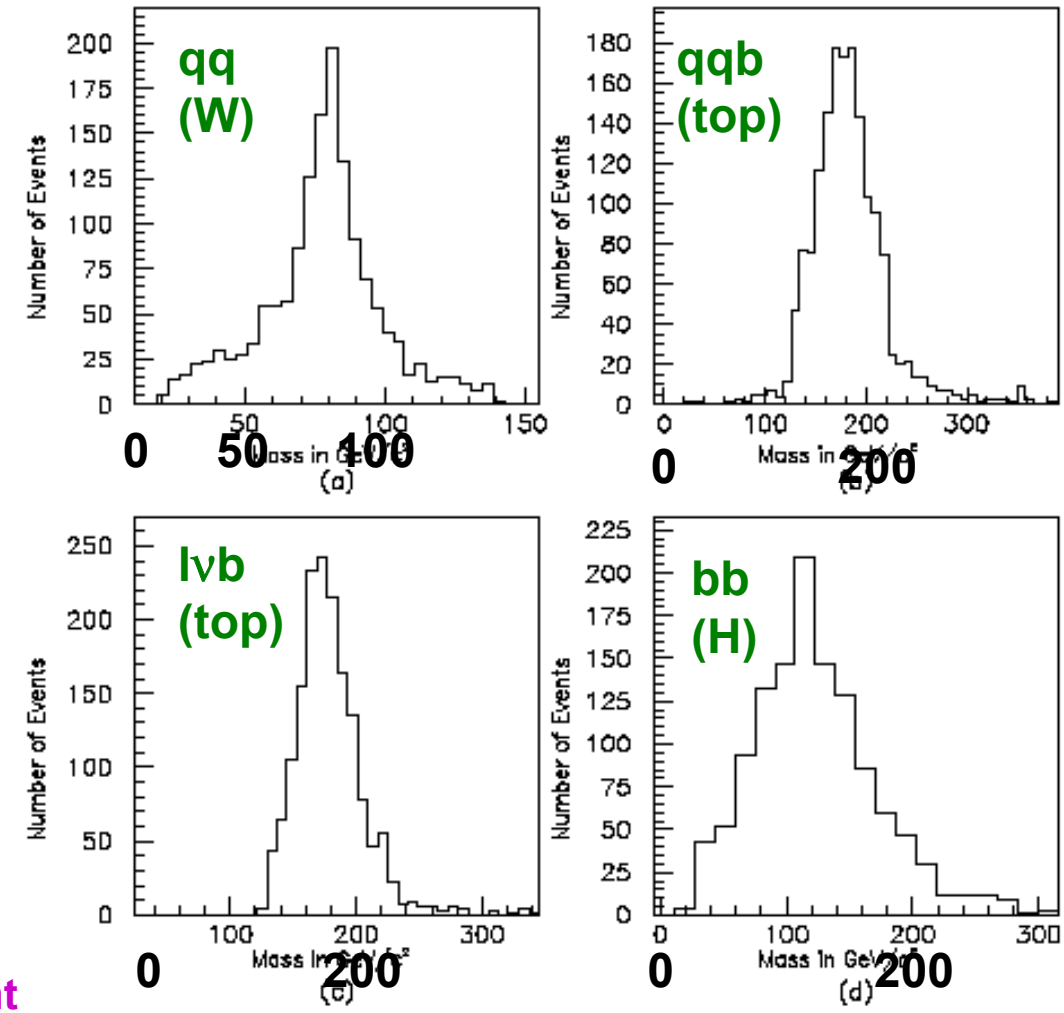
- 1 isolated lepton
- ≥ 5 jets. (ET>20GeV) with 4 b-tagged
- mass constraints for W and top

ttH sample

Jet multiplicity (ET>20GeV)

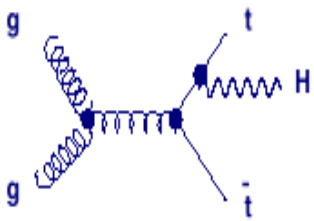


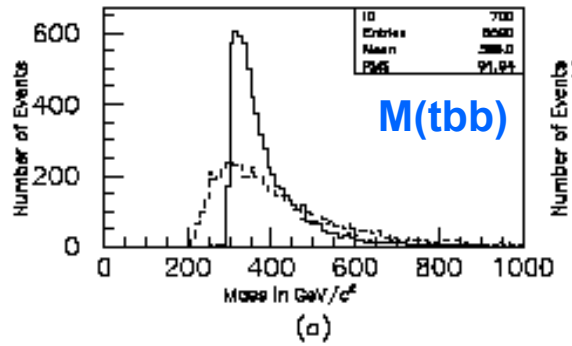
Mass Resolution

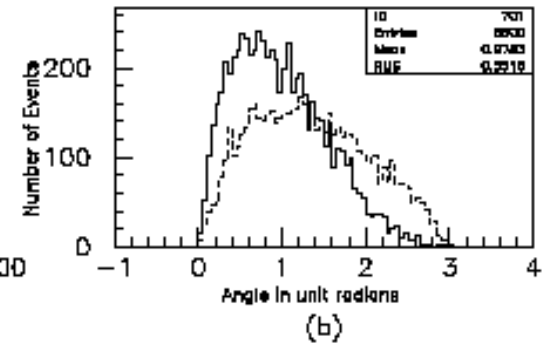


- Multi jet reconstruction
- W & Top mass constraint

Kinematics Variables
ttH (solid) ttbb (dash)

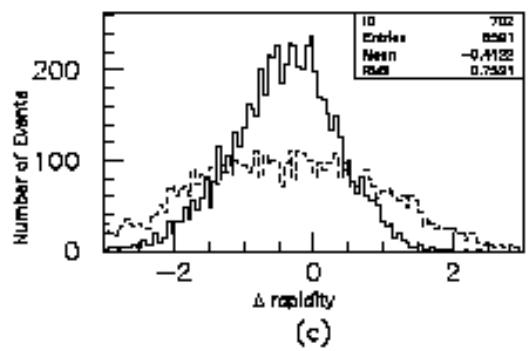


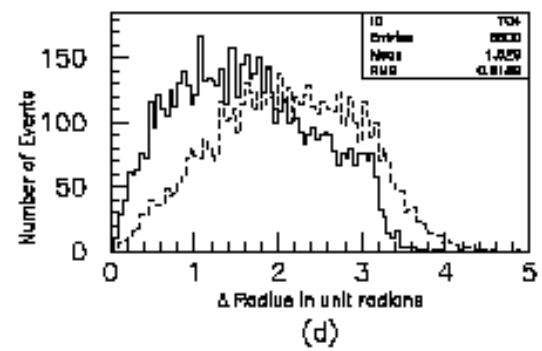




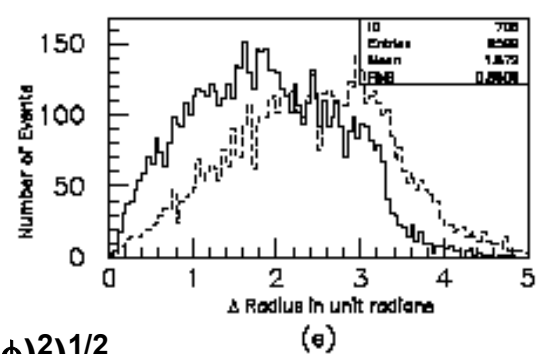
Δy(t-bb)

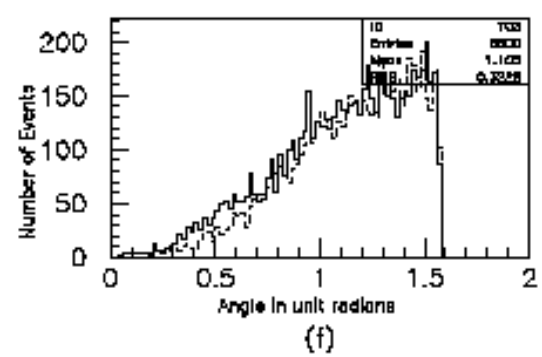
|Δy|<1





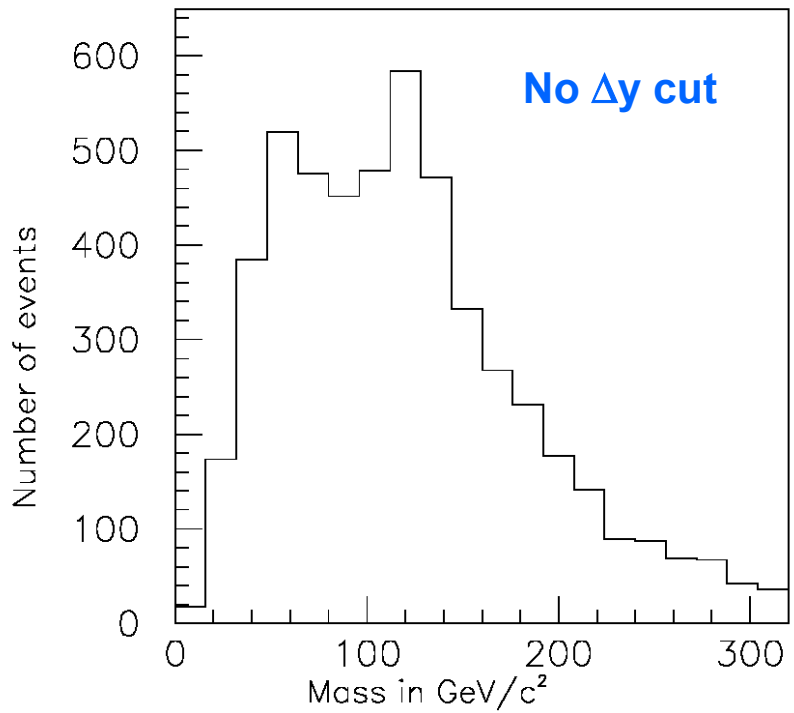
ΔR$_\eta$(t-bb)

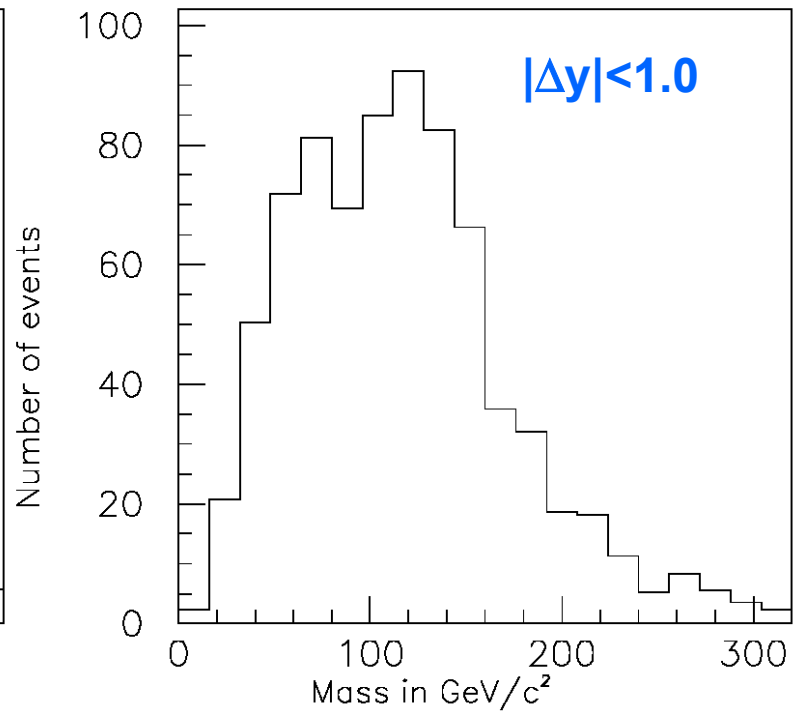




$R\eta=((\Delta\eta)^2+(\Delta\phi)^2)^{1/2}$

Mass(bb) for ttH + ttbb + ttZ





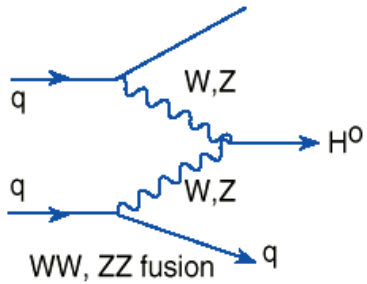
S/B $^{1/2}$ ~11.8

(S/B~1/1)

for 700fb^{-1}

S/B strongly depend on b-tagging efficiency.
Same S/B may be obtained with 90fb^{-1}
If the tagging efficiency is 60%.
→ Need good b-tagging !

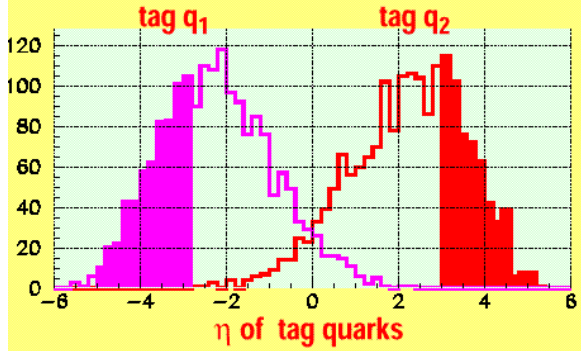
VB Fusion / Forward Jet Tag



σ ~ 10% of gg-fusion
at smaller M_H

qqH → ZZ → ll$\nu\nu$	400-1000GeV
qqH → WW → lνjj	400-1000GeV
qqH → $\tau\tau$ → (l$\nu\nu$)(jν)	100-150GeV
qqH → WW → (lν)(lν)	115-190GeV [1]
qqH_{SUSY} → invisible	110-400GeV [2]

HF acceptance for tagging quarks of E_t^q > 30 GeV		
no q	1 q	2 q's
0.47	0.46	0.07



Typical selection for forward jets

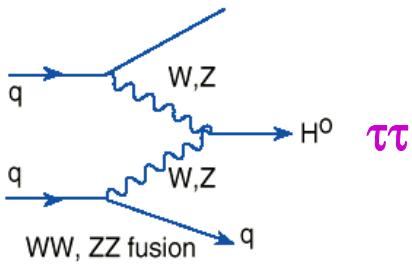
$E_t(q)$ > 40GeV, $|\eta(q)|$<5.0

$|\Delta\eta(q1q2)|$>4.4, M(q1q2) >1TeV

$\eta(q1)*\eta(q2)$<0

1) N.Kauer, T.Plehn, D.Rainwater, D.Zeppenfeld PL B (2001) 113
5σ signal with 35fb-1 for M_H~115 GeV
2) O.J.Eboil and D.Zeppenfeld, hep-ph 009158
limit: BR(invisible) 13%
Mass 480GeV (for BR~100%) with 10fb^{-1}
→ forward jet trigger

qqH, H -> 2τ -> (lνν)(jν)



Trigger:
- 1 lepton
- 1 tau-jet

Event selection:

$E_t(e,\mu) > 15GeV$, $|\eta(e,\mu)|<2.4$

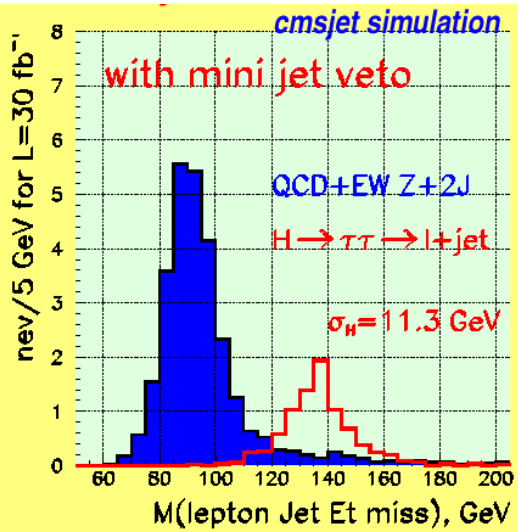
$E_t(\tau) > 30GeV$, $|\eta(\tau)|<2.4$

$E_t(q) > 40GeV$, $|\eta(q)|<5.0$

$|\Delta\eta(q1q2)|>4.4$, $M(q1q2) >1TeV$

mini-jet veto

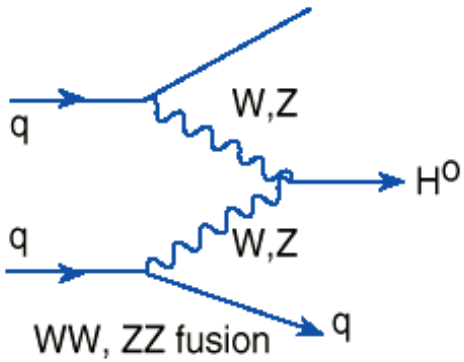
Bg:
Zjj, Wjj, bbjj



Data for 30 fb^{-1} at low luminosity running

Mass, GeV	115	125	135	145
σ, pb	4.49	4.15	3.81	3.57
Br, %	7.2	6.1	4.5	2.6
S	12.6	9.9	6.7(6.2)	3.6
B	5.5	2.3	1.5(1.1)	1.1

qqH(120), H→WW*→lνlν



q

W→ lν

W→ lν

q

Signal: (σ*BR) 13 fb

Background:
(dilepton +ν's)

ttjj	18 662 fb
QCD WWjj	1 640
EW WWjj	32
ττjj	42 140

NB: ttjj may be cut out effectively.

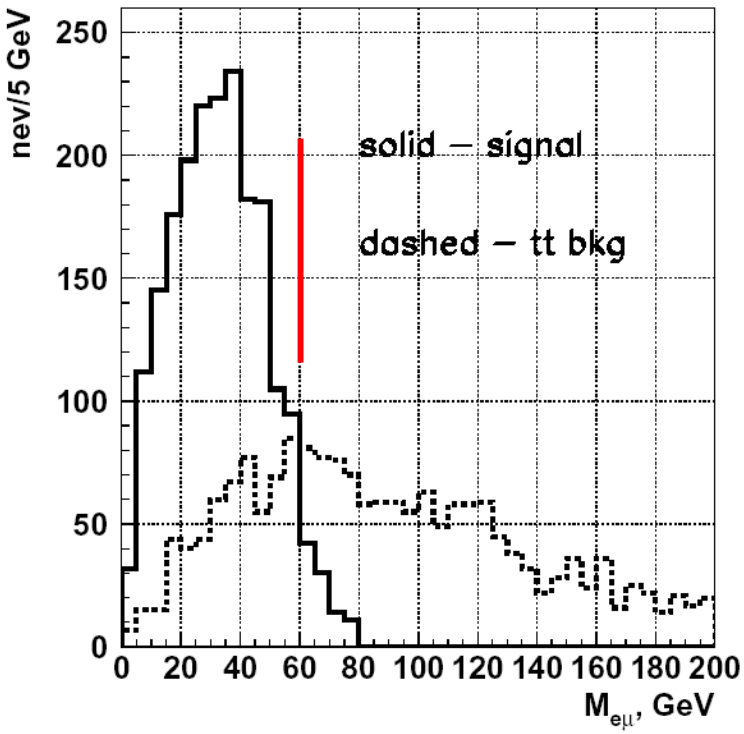
Event selection:
(not all cuts shown)

- 2 FWD tag jets
  - Et > 30GeV
  - $|\Delta\eta|>4.2$, $\eta_1*\eta_2<0.0$
  - M(jj) > 600GeV
  - no b-tag
- Between 2 FWD jets
  - no jet
    - Et>20GeV
  - 2 isolated leptons
    - Pt > 20 (10GeV)
    - M(ll) > 60GeV
    - Φ(ll) > 140 deg
- Event counts in a mass window in MT(WW).

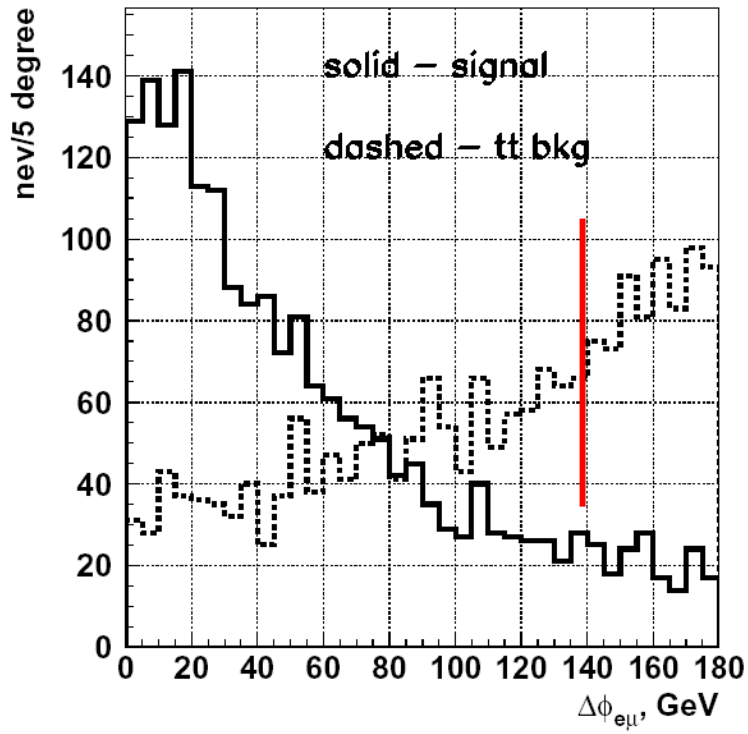
tt cuts

After selection with 2 FWD tagging jets and veto on central jets.

$M_{e\mu}$



$\Delta\phi_{e\mu}$

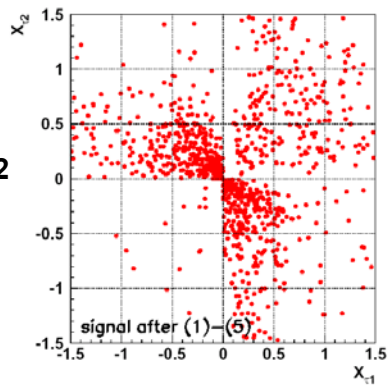


ττ jj cuts

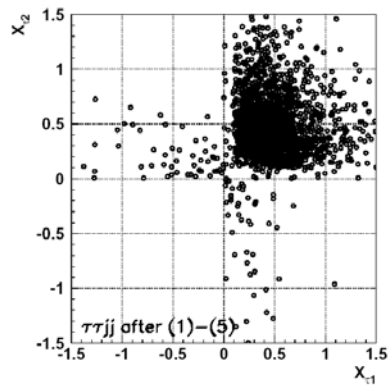
After M(ll) and ΔΦ(ll) cuts.

X_τ is visible τ energy

Higgs



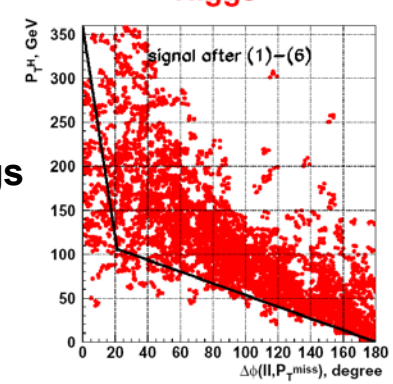
ττ jj



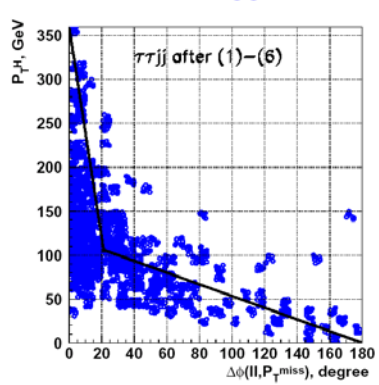
angle between miss E_T and two leptons v.s. p_T Higgs

Pt Higgs

Higgs

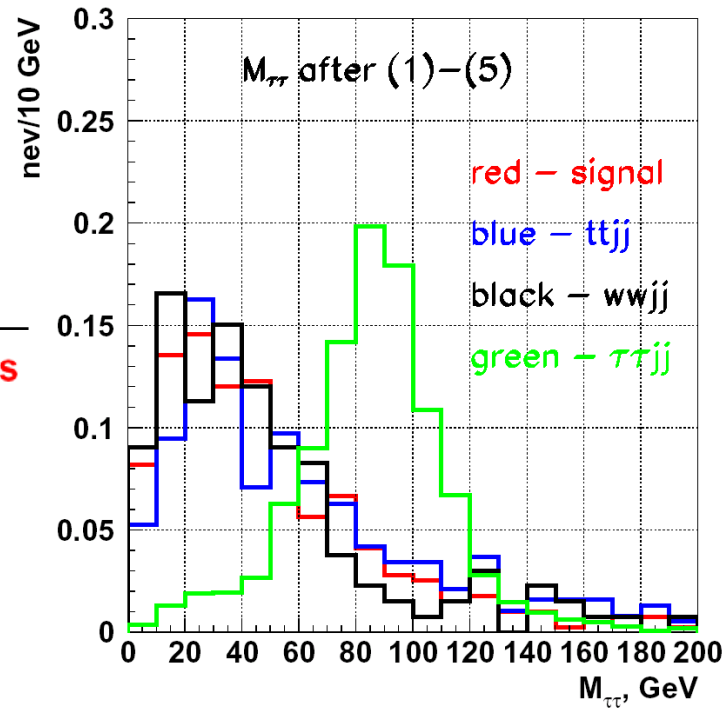


ττ jj



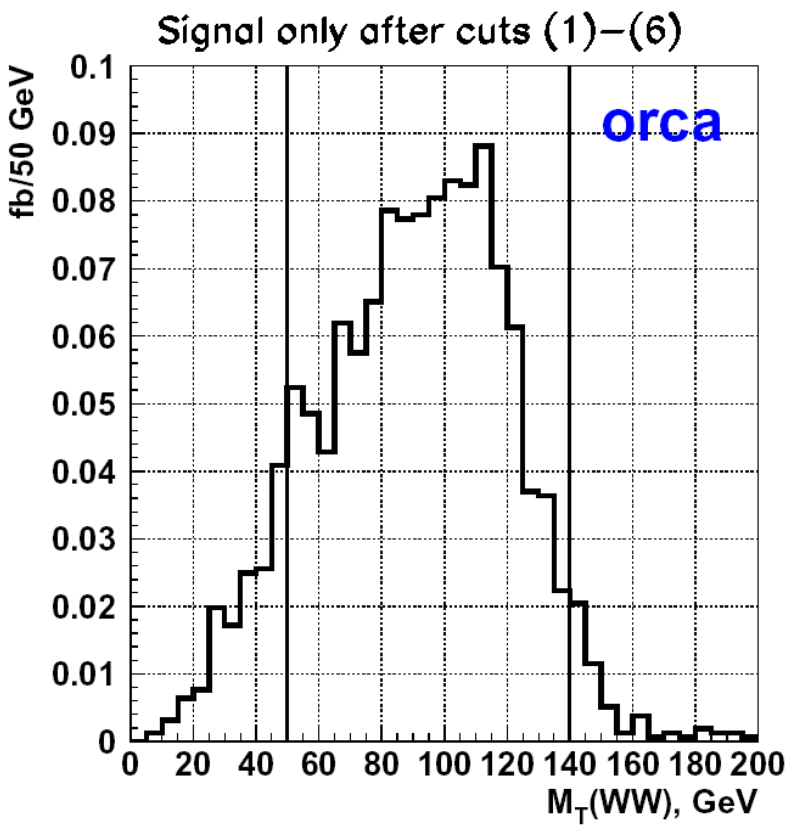
Angle (MET <-> 2 leptons)

Mass (ττ)



$M_T(WW)$

$$M_T(WW) = \left((E_T^{miss} + E_T^{ll})^2 - (P_T^{miss} + P_T^{ll})^2 \right)^{1/2}$$



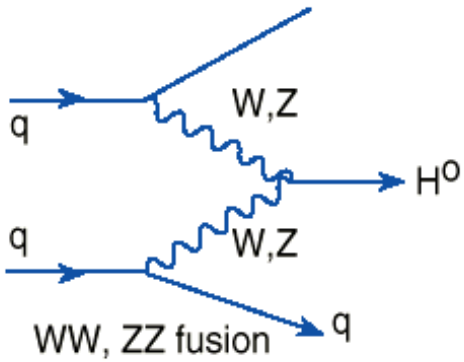
- Very preliminary -

	- this-	-DZ(*)-
H(120)	0.65	(1.32) fb
tt	1.14	(0.48)
WWjj (QCD)	0.015	(0.066)
ττjj (QCD)	0.057	(0.032)

WWjj(EW), ττjj(EW) still running

(*) D.Zeppenfeld et al.

qqH(120), H→invisible



q

Invisible
(neutralinos)
(gravitinos)

q

Signal: (σ*BR) 4300fb (BR=1)

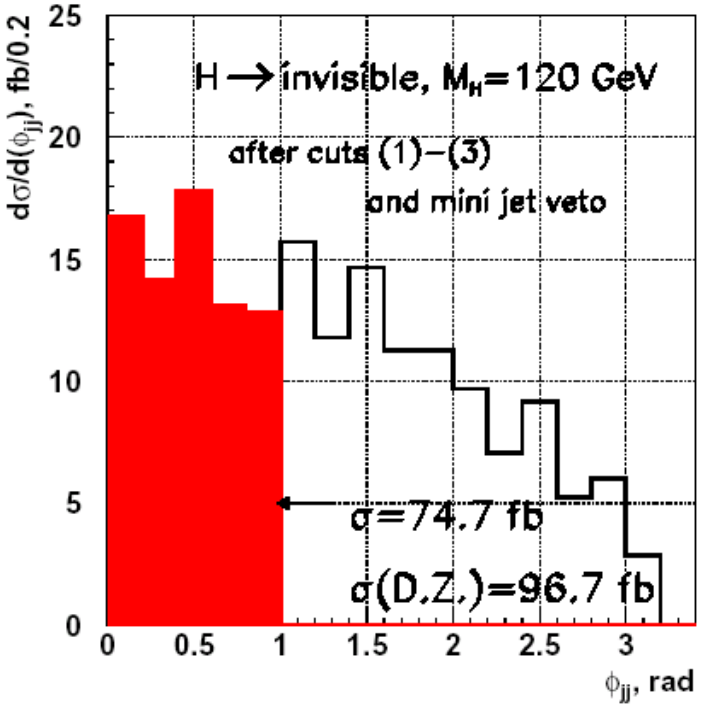
Background:
- QCD Zjj
- QCD Wjj
- EW Zjj
- EW Wjj

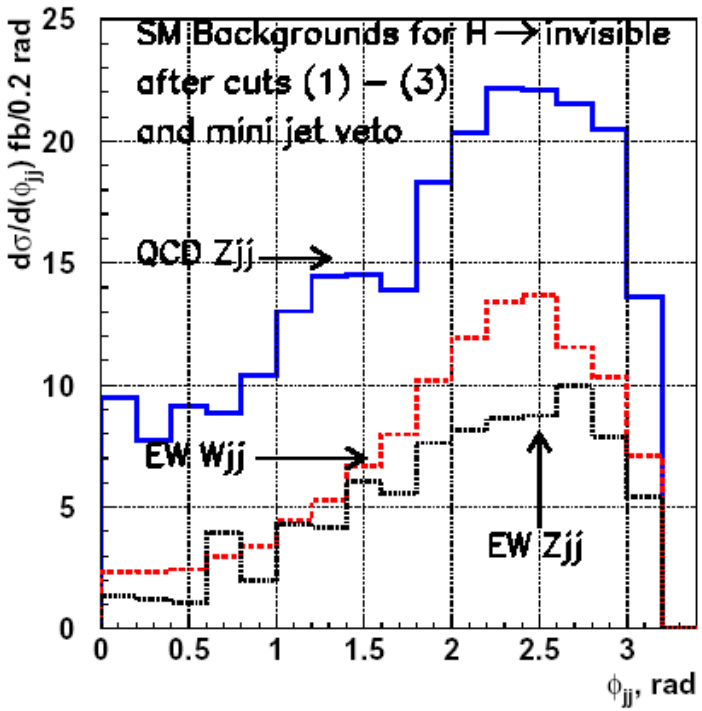
NB: tt is no more major background.

Event selection:

- 2 FWD tag jets
  - Et > 40GeV
  - $|\Delta\eta|>4.4$, $\eta_1*\eta_2<0.0$
  - M(jj) > 1200GeV
- Between 2 FWD jets
  - no jet
    - Et>20GeV
  - no lepton
    - pt(m) > 5 GeV
    - pt(e) > 10GeV
- MET>100GeV
- Φ(jj)

$\Delta\Phi_{JJ}$ cuts and results





	- this -	- DZ -	
Higgs	74.7	(96.7)	fb
QCD Zjj	48.0	(71.8)	
QCD Wjj	job running		
EW Zjj	12.8	(14.8)	
EW Wjj	8.9	(9.9)	

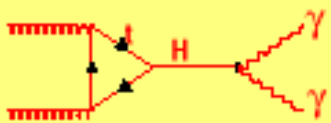
(very preliminary)

Set upper limit on σ*BR(H→inv)

Higgs Couplings

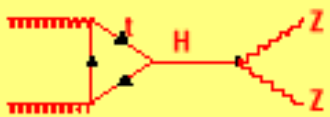
D.Zeppenfeld, R.Kinnunen, A.Nikitenko, E.Richter-Was, Phys.Rev.,D62(2000) pp13009

gg->H->γγ — M_H < 150 GeV



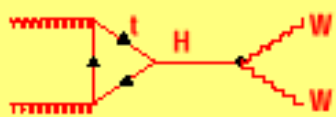
$\sim \Gamma_g(\Gamma_\gamma/\Gamma) = Y_\gamma$

gg->H->ZZ->4lept — M_H > 120 GeV



$\sim \Gamma_g(\Gamma_Z/\Gamma) = Y_Z$

gg->H->WW->2lept — M_H > 120 GeV

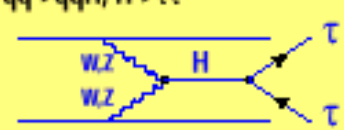


$\sim \Gamma_g(\Gamma_W/\Gamma) = Y_W$

qq->qqH, H->γγ — M_H < 150 GeV

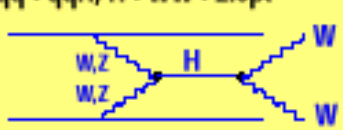
$\sim \Gamma_W(\Gamma_\gamma/\Gamma) = X_\gamma$

qq->qqH, H->ττ — 100 < M_H < 150 GeV



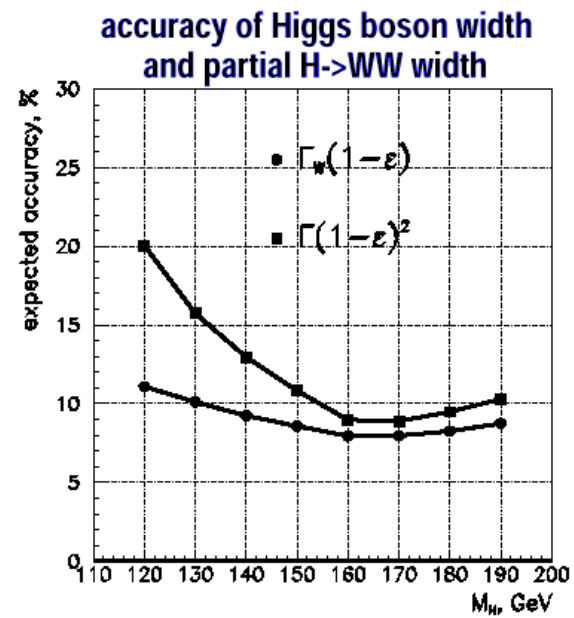
$\sim \Gamma_W(\Gamma_\tau/\Gamma) = X_\tau$

qq->qqH, H->WW->2lept — M_H > 120 GeV



$\sim \Gamma_W(\Gamma_W/\Gamma) = X_W$

Accuracy expected with 200 fb^{-1} of data with ATLAS+CMS detectors at LHC

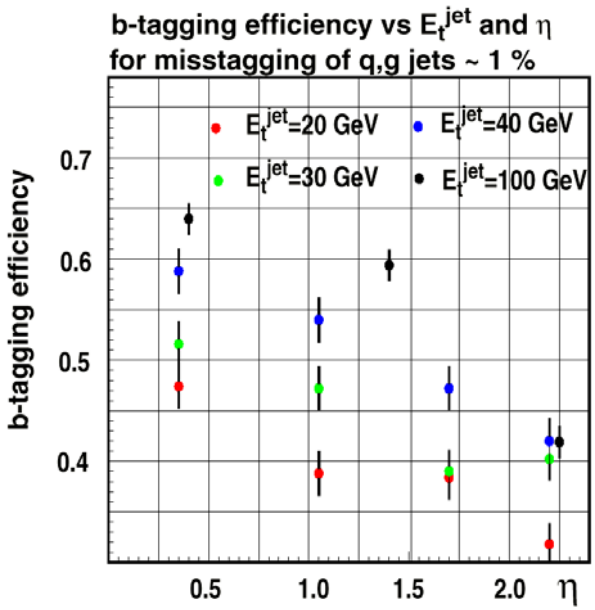


- measure Hγγ, Hττ, Hgg couplings at 10 % level
- hWW coupling can be measured at 5% level

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

- 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

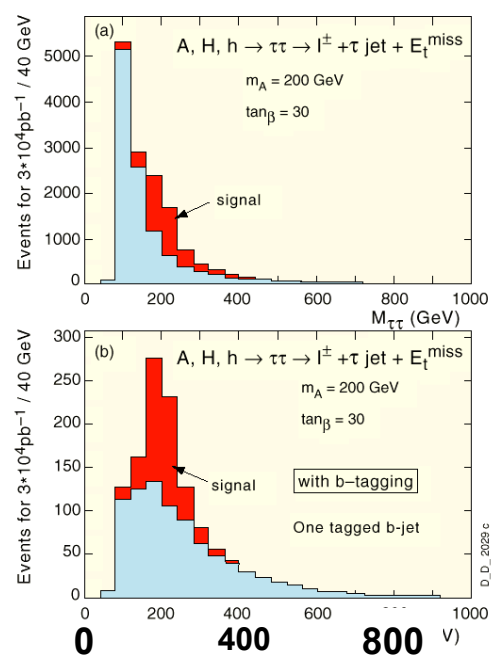


b-tag

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



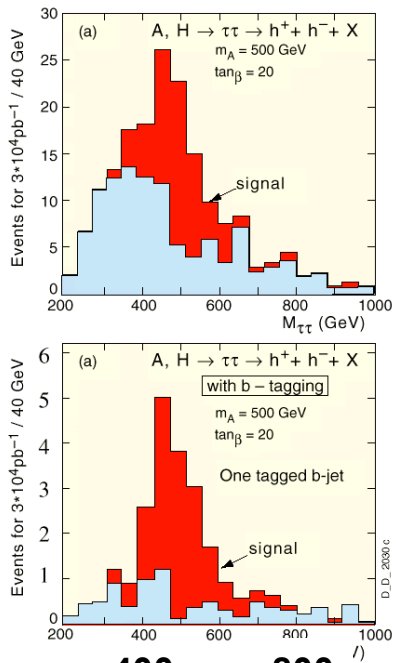
0 400 800

M($\tau\tau$)

M_A=500GeV

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

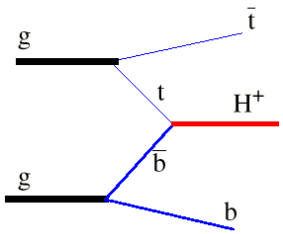
Events selected as: $E_t^{jet} > 60$ GeV $p_t^h > 40$ GeV, $\Delta\phi(jj) < 175^o$, $E_t^{miss} > 40$ GeV



400 800

M($\tau\tau$)

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



t→Wb - W, top mass window

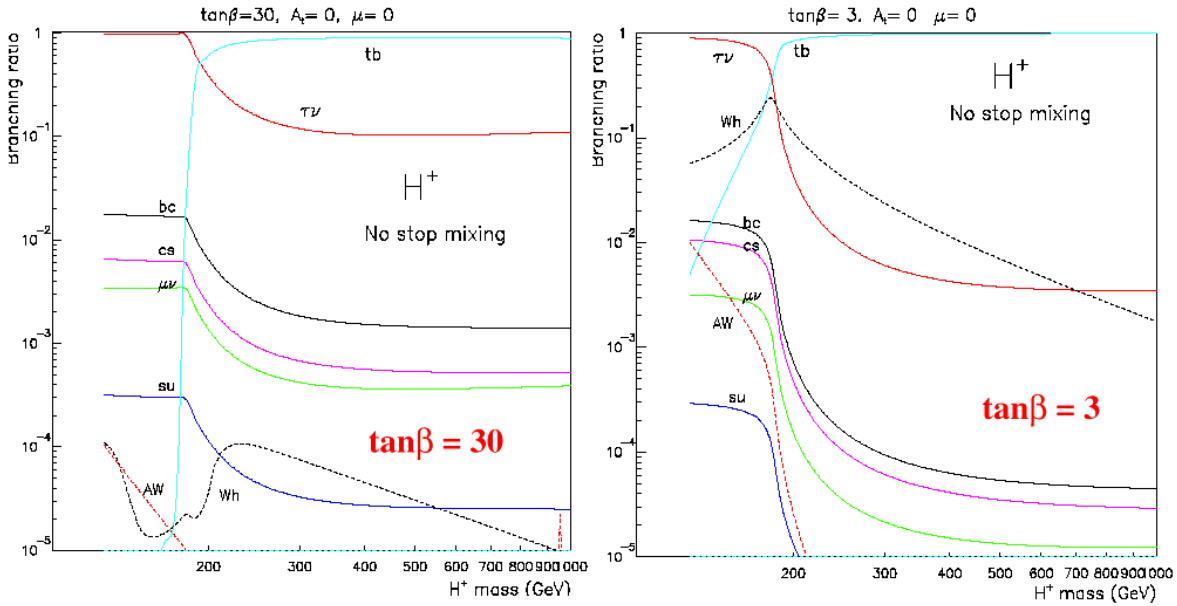
τ - tau-jet

ν - missingET

b - b tagging

bg:
tt, Wtb, Wjj

no stop mixing



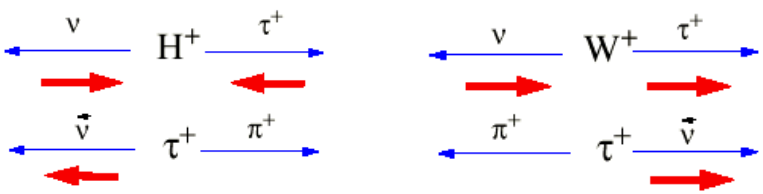
$\tau\nu$ mode is cleaner than tb mode!

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

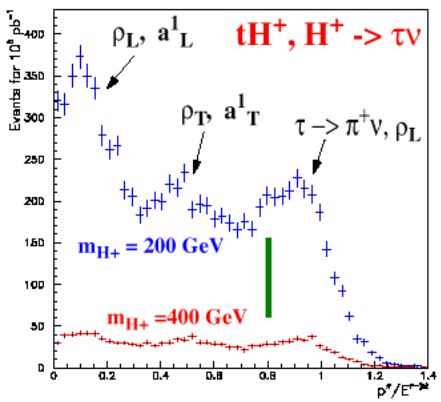
τ polarization & Δϕ cut

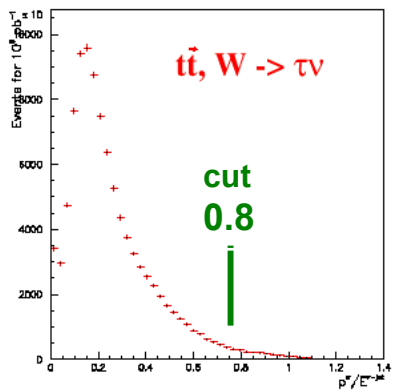
Tau polarization in H^+ decay

(pointed out by D.P.Roy)



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

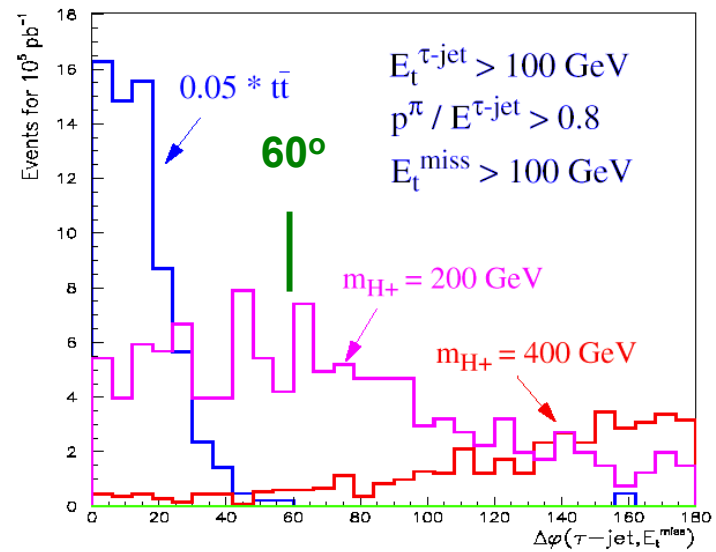




$p^{\pi}/E^{\tau\text{-jet}}$ $p^{\pi}/E^{\tau\text{-jet}}$

$\tau^+ \to \pi^+\nu$	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%

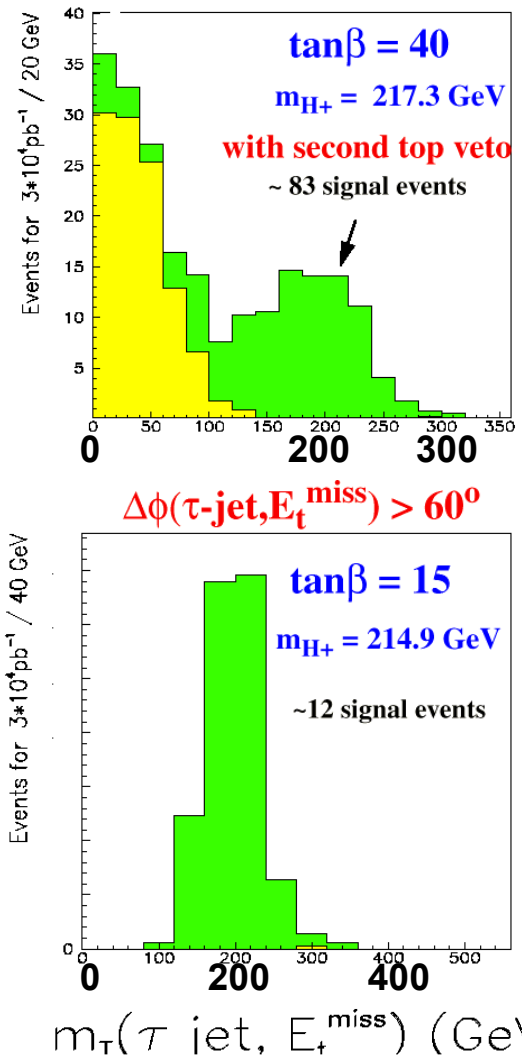
Δϕ > 60° cut



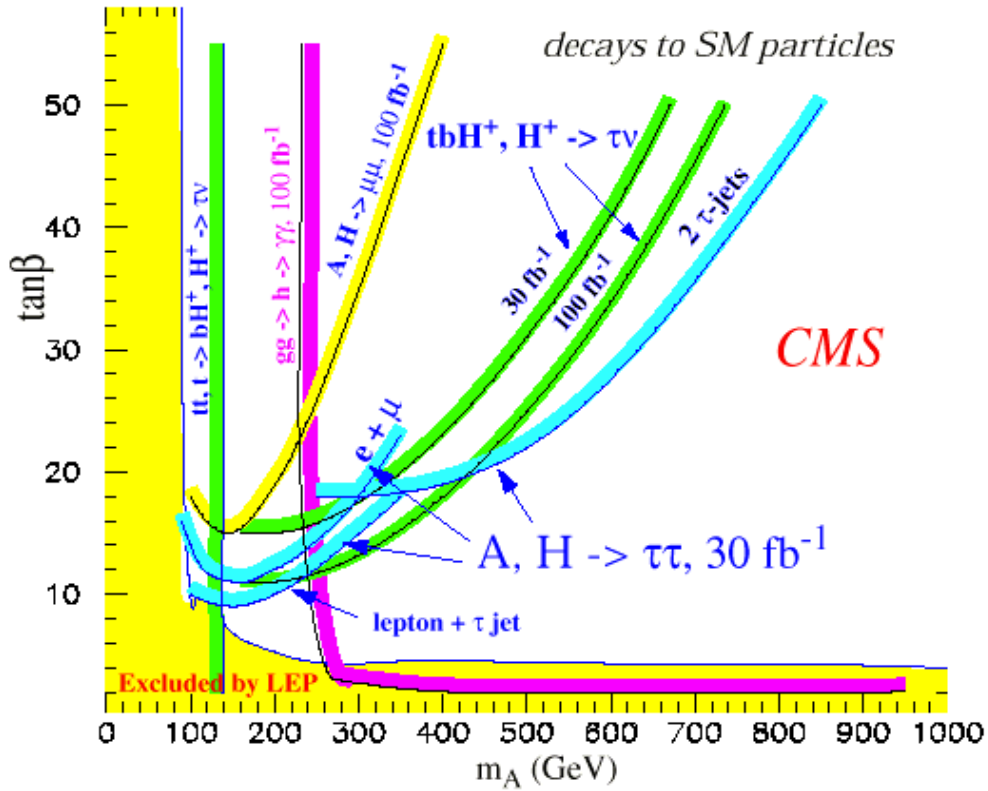
$\Delta\phi(\tau\text{-jet}, E_t^{miss})$

Mass and Discovery potential

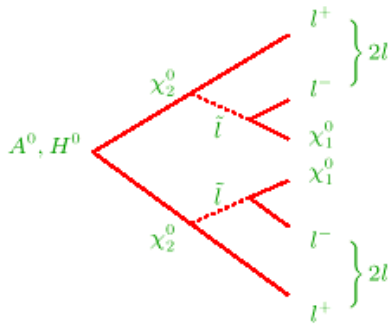
M_A=200GeV, 30fb^{-1}



5s significance countours



$H^0, A^0 \rightarrow \chi_2^0 \chi_2^0 \rightarrow 4\,l$



MSSM parameters: $M2 = 120$ GeV, $M1 = 60$ GeV, $\mu = -500$ GeV, $M_{\tilde{l}} = 250$ GeV, $M_{\tilde{q},\tilde{g}} = 1000$ GeV

4 iso. Lept (Pt<80GeV)
20 < MissEt < 130GeV
ET jet <100 GeV

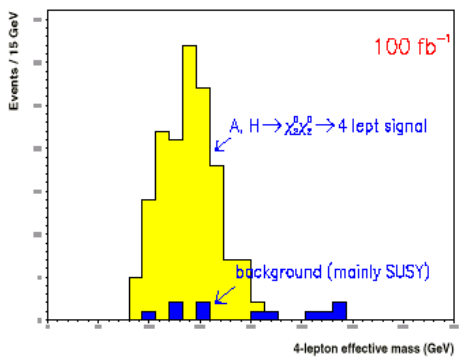
bg

SM : ZZ, $Zb\bar{b}$, $Zc\bar{c}$, $t\bar{t}$, Wtb
SUSY : $\tilde{q}/\tilde{g}$, $\tilde{l}\tilde{l}$, $\tilde{\nu}\tilde{\nu}$, $\tilde{q}\tilde{\chi}$, $\tilde{\chi}\tilde{\chi}$

Low $\tan\beta$:

$M_A = 350$ GeV

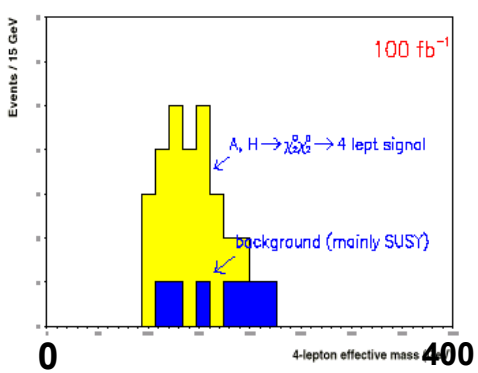
$\tan\beta = 5$



High $\tan\beta$:

$M_A = 350$ GeV

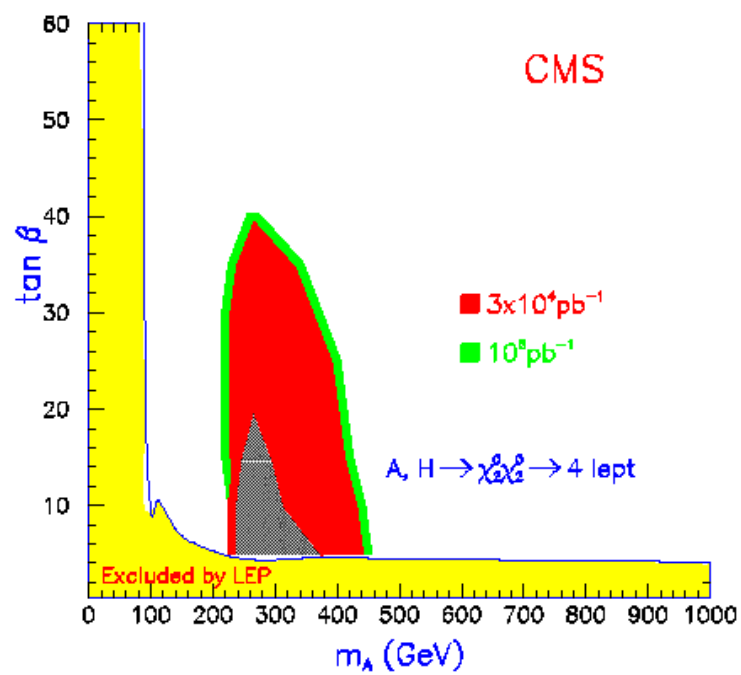
$\tan\beta = 35$



0 400

Mass(4 leptons) GeV

5s significance contours



Conclusion

Role of Jets and MET:

- **In SUSY search**
  - Signature
    - **Multi jets (50GeV~ multi-TeV) and MET (100GeV)**
- **In Higgs search**
  - Reconstruction of mass (e.g. H→bb, WW)
    - **Need good resolution and right energy scale. (>20GeV)**
  - Rejection of top background
    - **Jet veto down to ~20GeV. (15GeV cut is seen!)**
      - Needs good handling of fake/pile-up jets
  - Rejection of QCD background
    - **FWD tagging jets. (down to ~20GeV)**

We continue to work on

- **Improvement of Jets and MET energy scale and resolution.**
- **Rejection of fake and/or pile-up jets.**

→Tracker will be used for the improvement and rejection.