Collider Physics and Dark matter

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Conclusion: There has not been much yet in that direction

- LHCPhysics now.
- Impact of "Higgs discovery"
- SUSY search strategy
- SUSY DM study at collider
- SUSY study in 2012

Why we have NOT found anything <<so far>>

Because we understand QCD better now

- In 90's: We do not know how to calculate process at the hadrdon collider   "I do not trust hadron collider physics" is typical attitudes in e+e-collider funs in 90's

photo 1972

- Now: we understand higher oder QCD (multijet process) better . (but only very recently.)

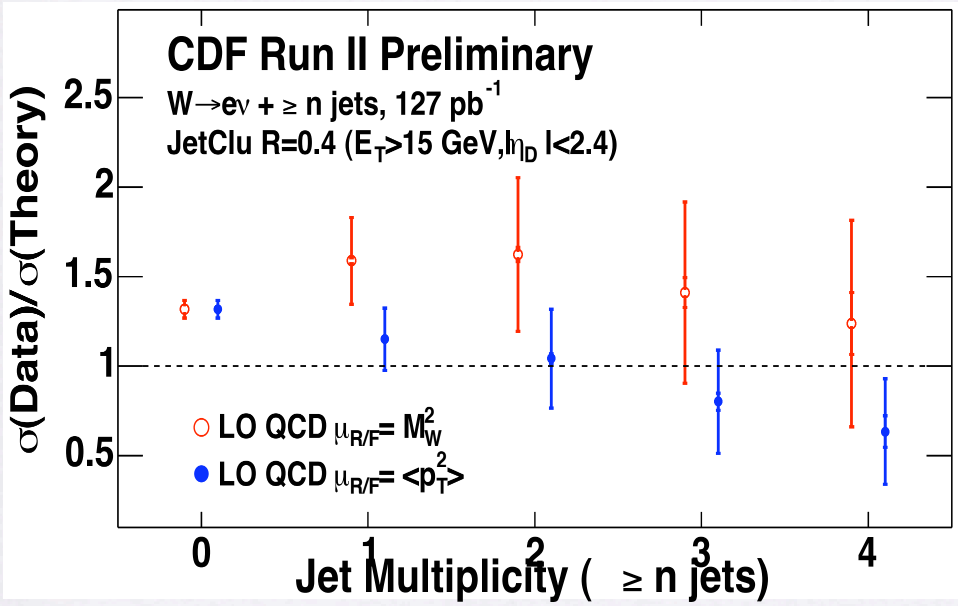
- Therefore we do not "discover" much until we should discover them. (unlike the era of SPS)

- Collider physics is more mature as we can "calibrate" using plenty of data, unlike dark matter search.)

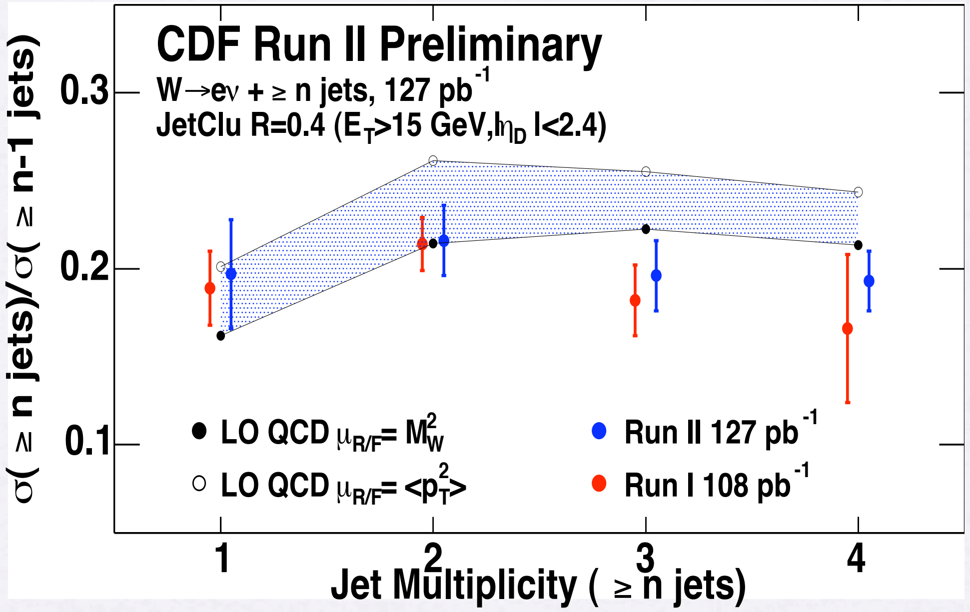
Cross Section

2003

Data vs Theory



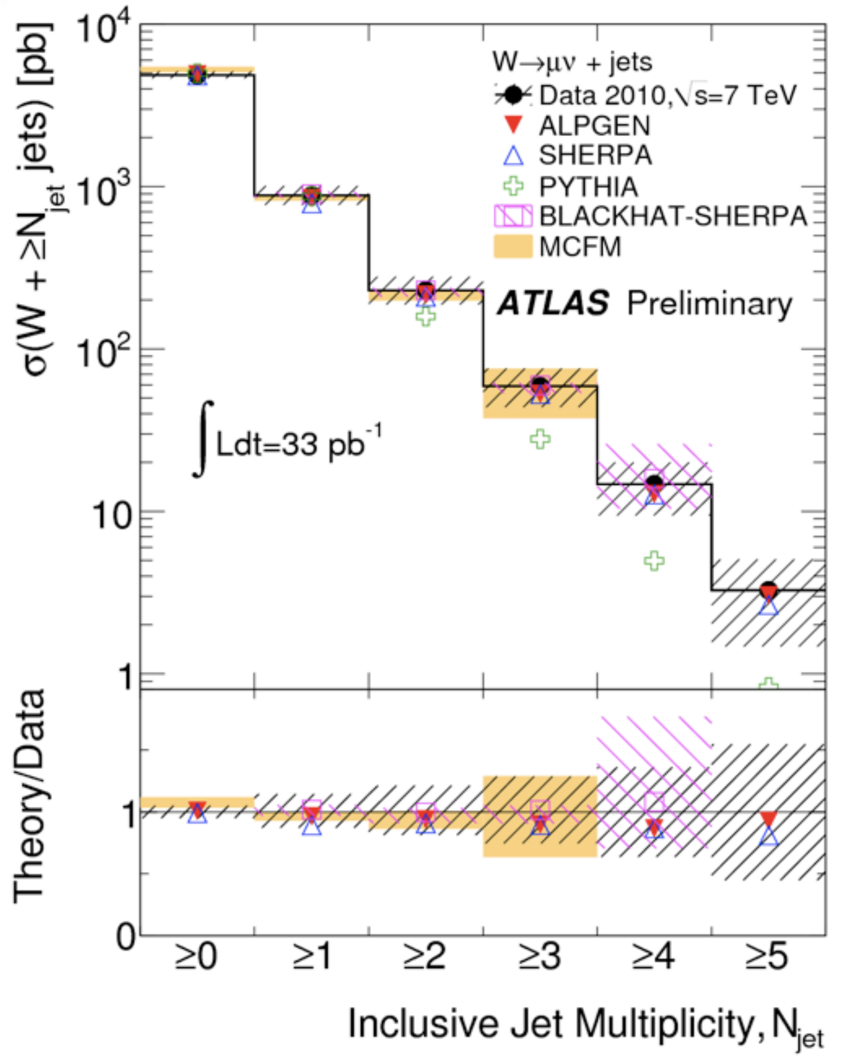
Ratio of Cross-sections

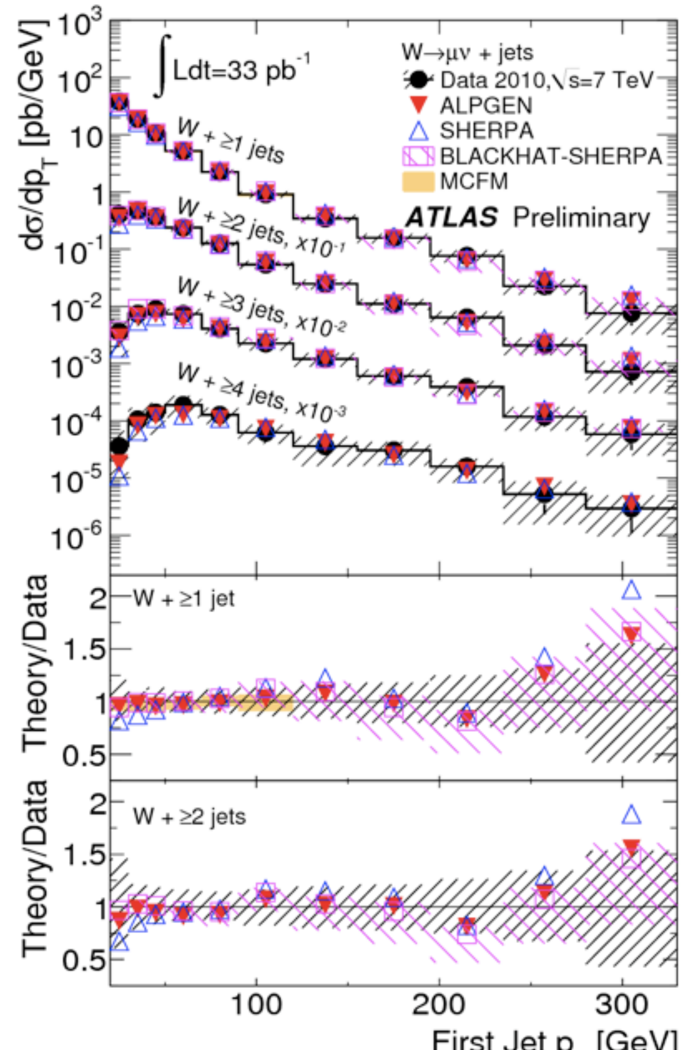


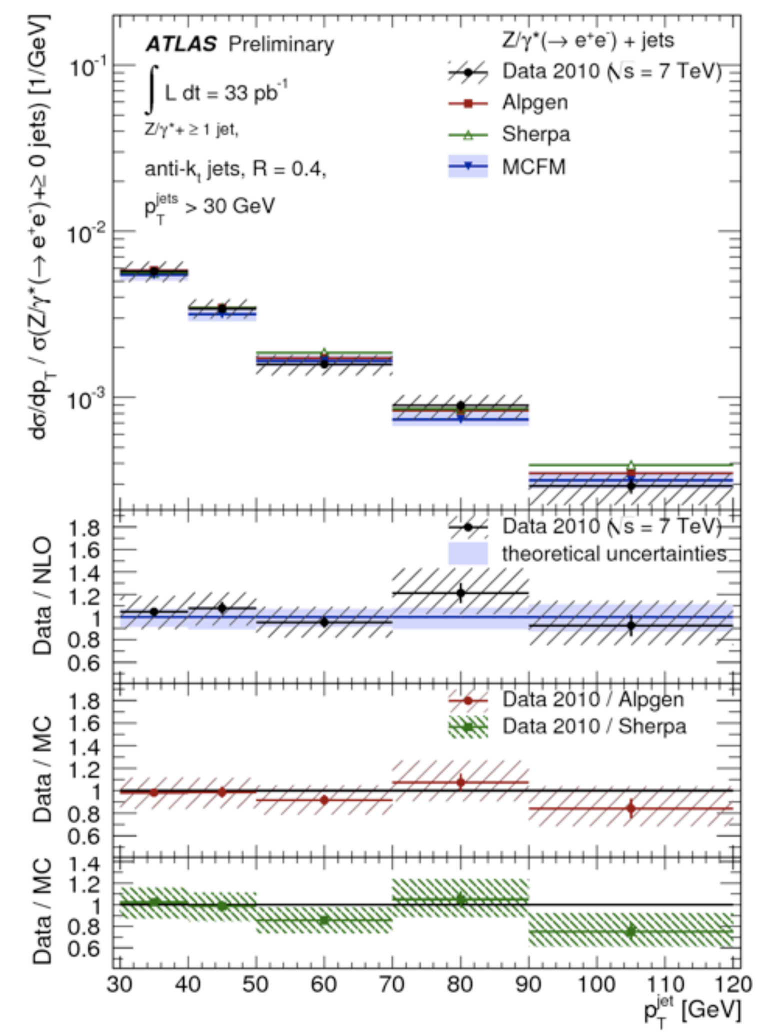
The smaller renormalization scale yields a higher cross section since α_s has a higher value at low q^2; moreover, this scale is strongly dependent on the kinematics of the process through the p_t of the jets. The cross section with this scale crosses the measured values for W + ≥ 2 jets.

The ratio measures the decrease in the cross section with the addition of 1 jet. The behaviour as a function of n-jets is compatible with a straight line; the deviation could be interpreted as a contribution to the W + ≥ 2 jet cross section from parton level topologies not present in the W + ≥ 1 jet.

W/Z + jet results







<u>dominant systematics</u>

- JES: 8(26)% for $N_j \geq 1(4)$
- jets from pile-up ≈7%
- lep. reco. ≈ 2%
- QCD bkgd ≈ 2%
- unfolding ≈ 2%

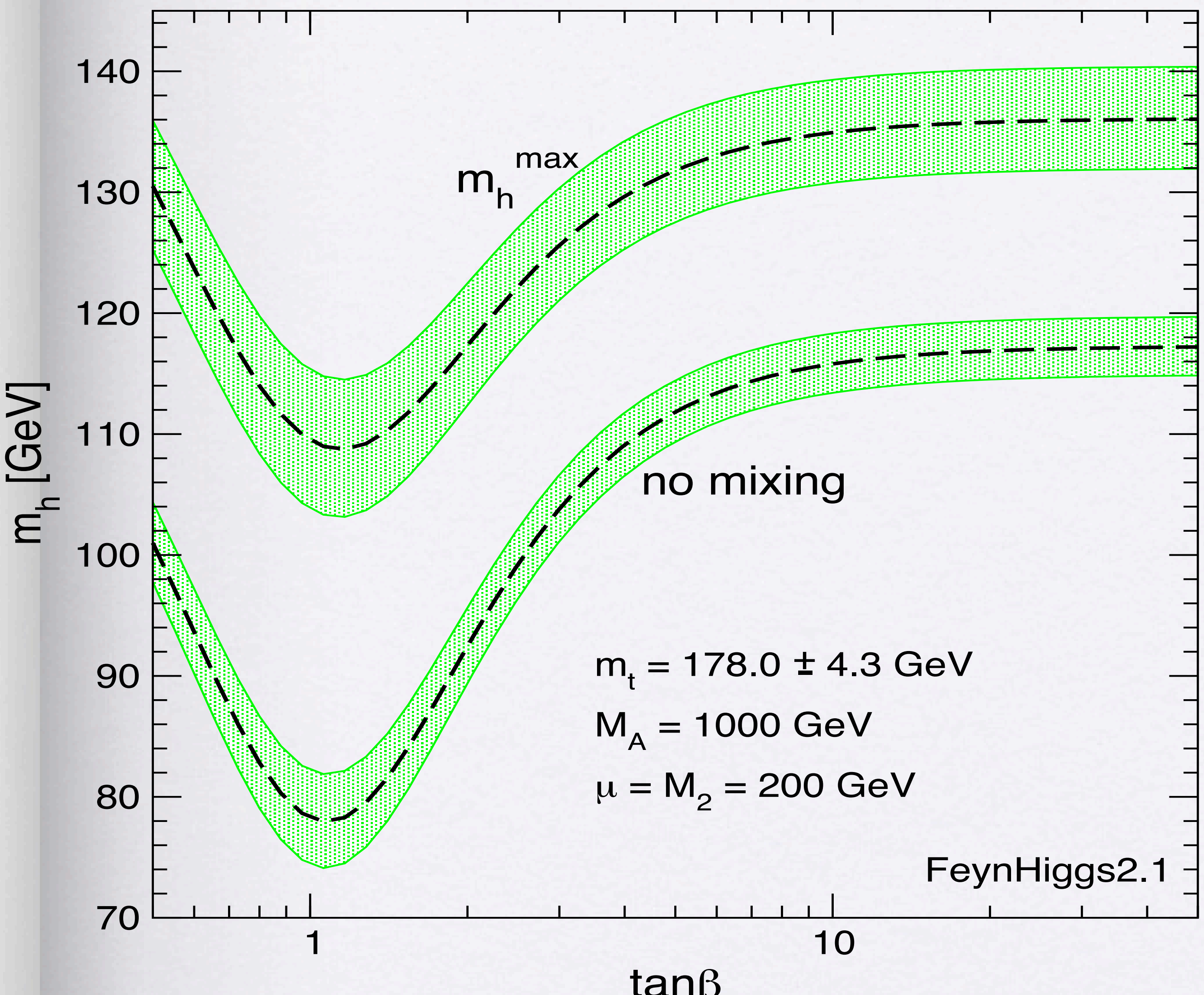
- cross section measured as a function of several kinematic variables (see end of this talk)
- very good agreement with NLO predictions from MCFM and Blackhat-Sherpa in the total and differential cross sections
- good agreement with matched LO prediction from AlpGen and Sherpa once normalized to the NNLO prediction
- Poor agreement with LO PYTHIA in the high jet multiplicity

Background and discovery

- Jets + gauge boson distribution at LHC are with simulation thanks to the multi-jet calculation and matching by Sherpa, Alpgen, Madgraph, and various NLO generators.
- On the other hand, once you apply cuts, cuts, cuts, to estimate the backgrounds in the signal region, there are still some error. We are not in the level to discuss the distribution where only 1/1000 of total events exists. In addition there are mis-measurements
- This is where some Higgs searches and SUSY searches are.
- background is estimated from the control region, for example the tail of missing ET is estimed by the sample where Z->ee is observed and so on.

Higgs searches and SUSY scale

SM Higgs mass and MSSM



from famous review

MSUSY =1TeV

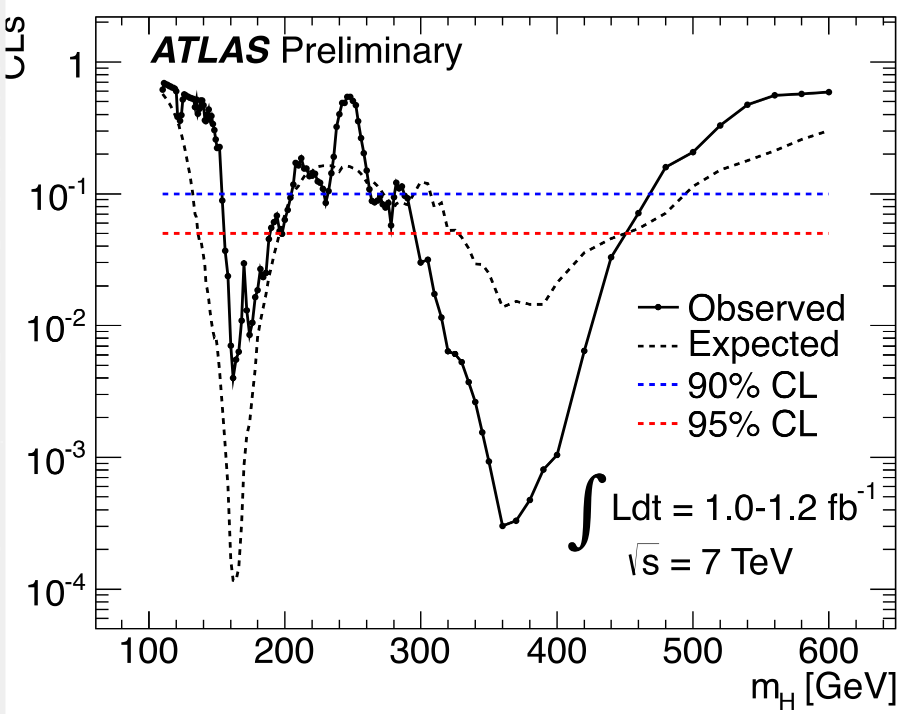
- current value of top mass is 172±2.2
- Higgs mass above 130 GeV is very difficult for MSUSY (mstop) ~1TeV
- On the other hand current higgs mass data may favor the region **above 130 GeV** (see detail in the following slides)

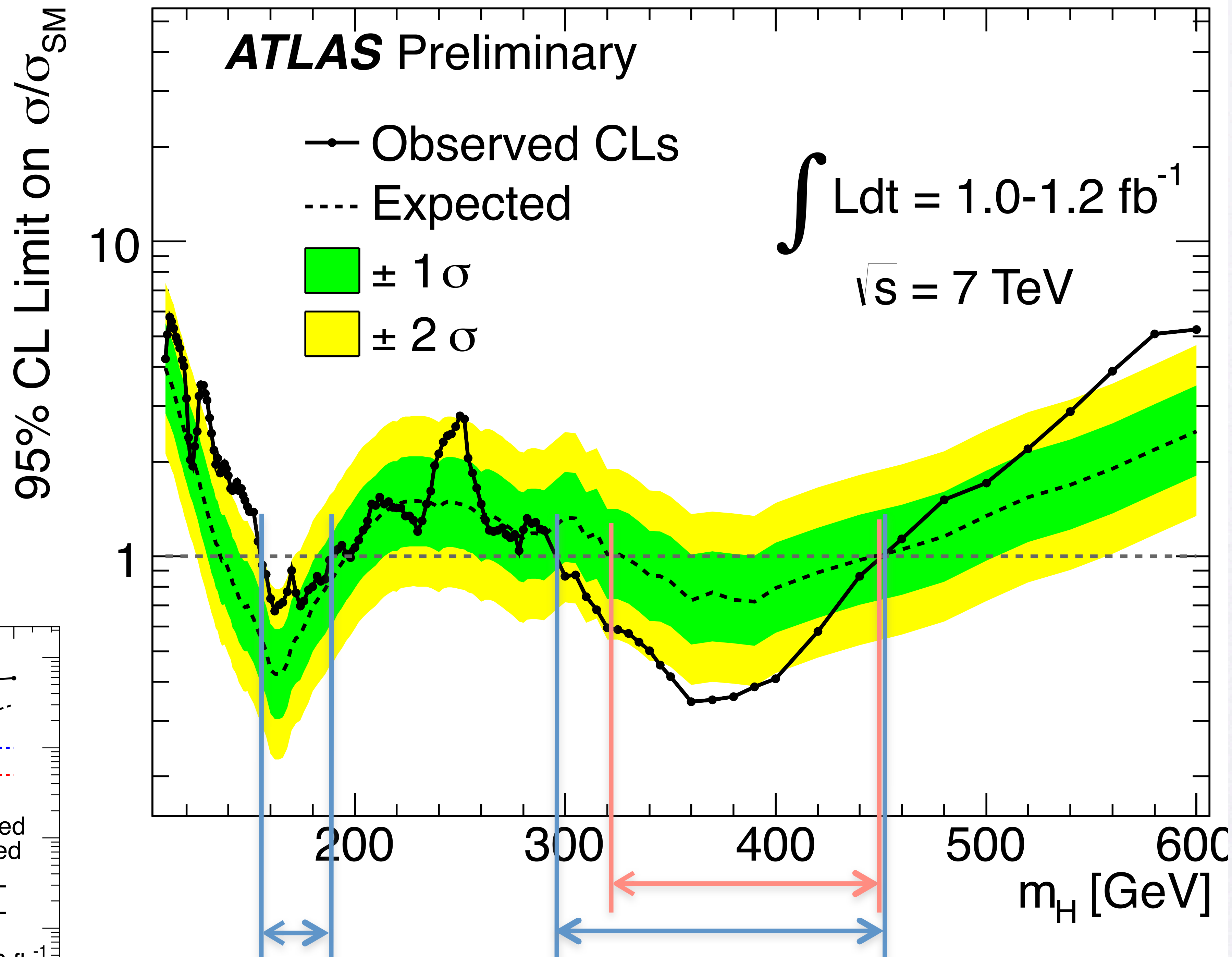
Limits full mass range

Center for Cosmology and Particle Physics

Additional High-mass channels extend the $H \rightarrow ZZ \rightarrow ll\nu\nu$ exclusion

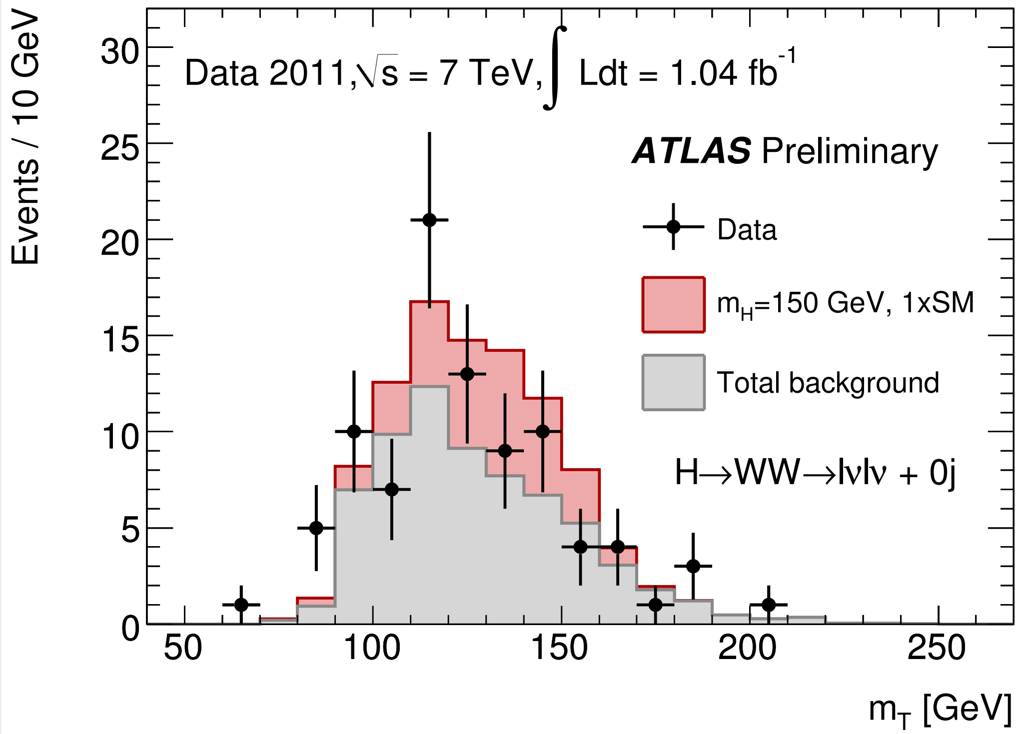
Noticeable excess around 250 GeV from $H \rightarrow ZZ \rightarrow 4l$ candidates

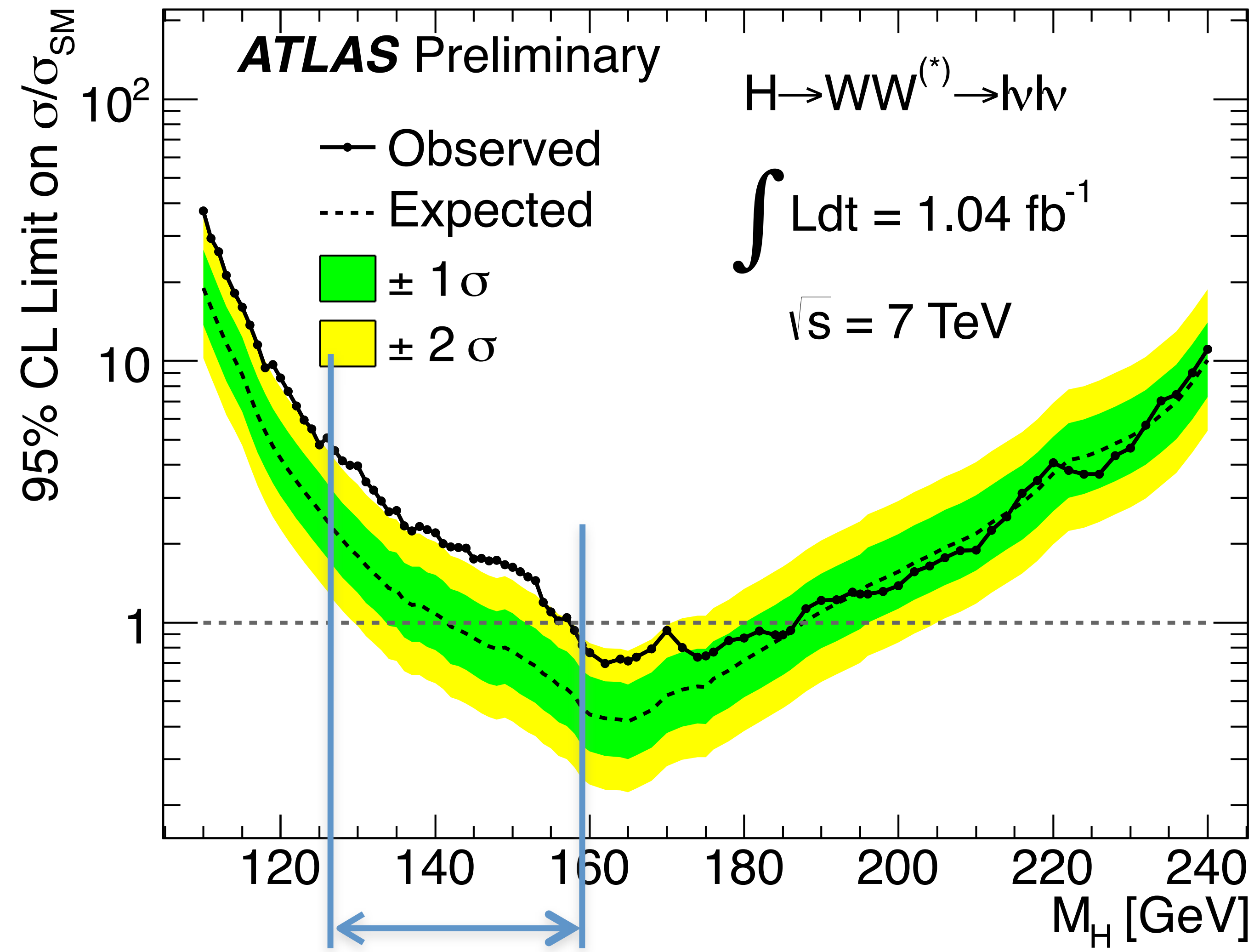


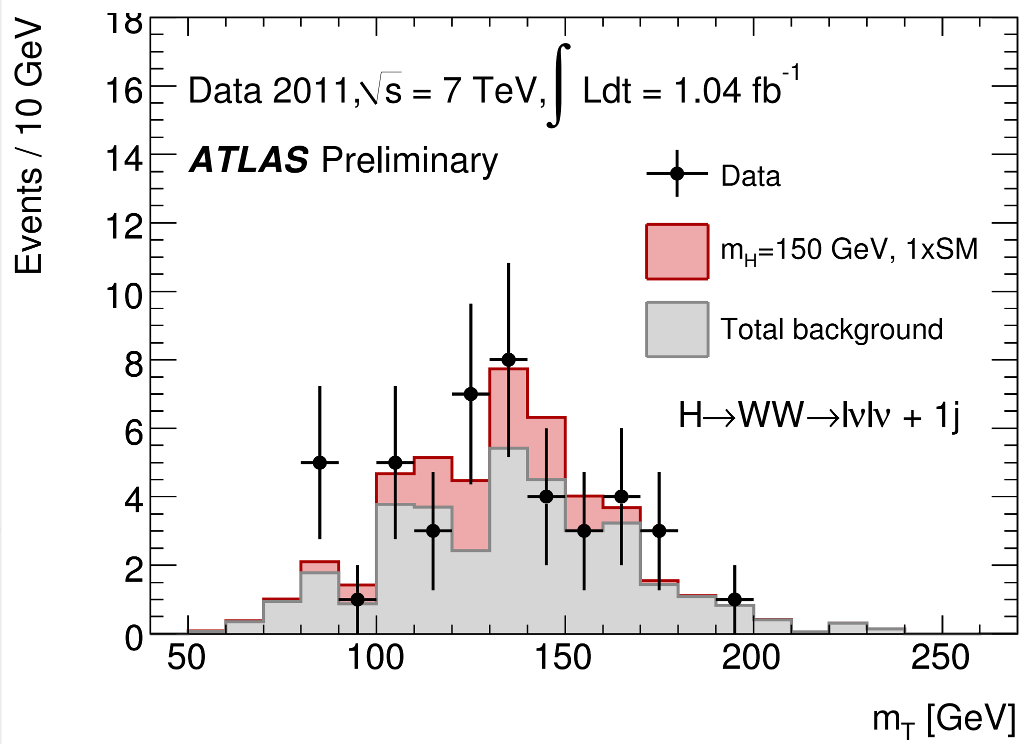


$155 < M_H < 190$ and $295 < M_H < 450$ GeV/c^2 excluded at @ 95% CL

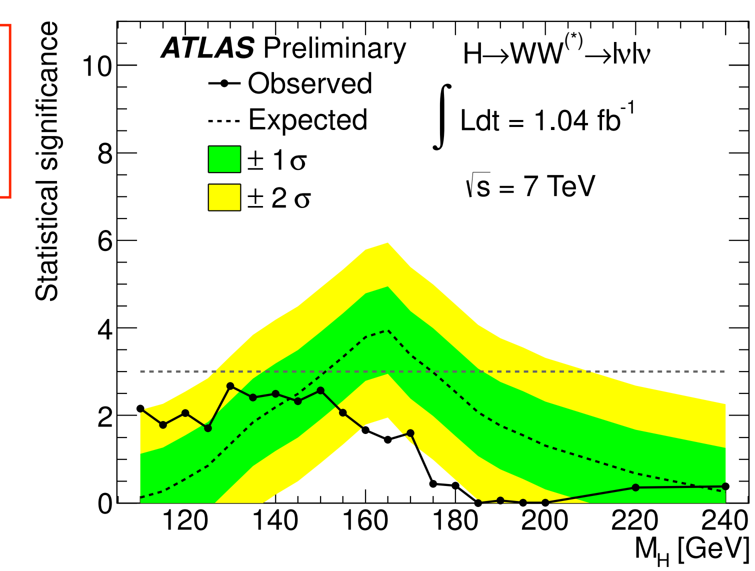
The H→ WW → lνlν Channels





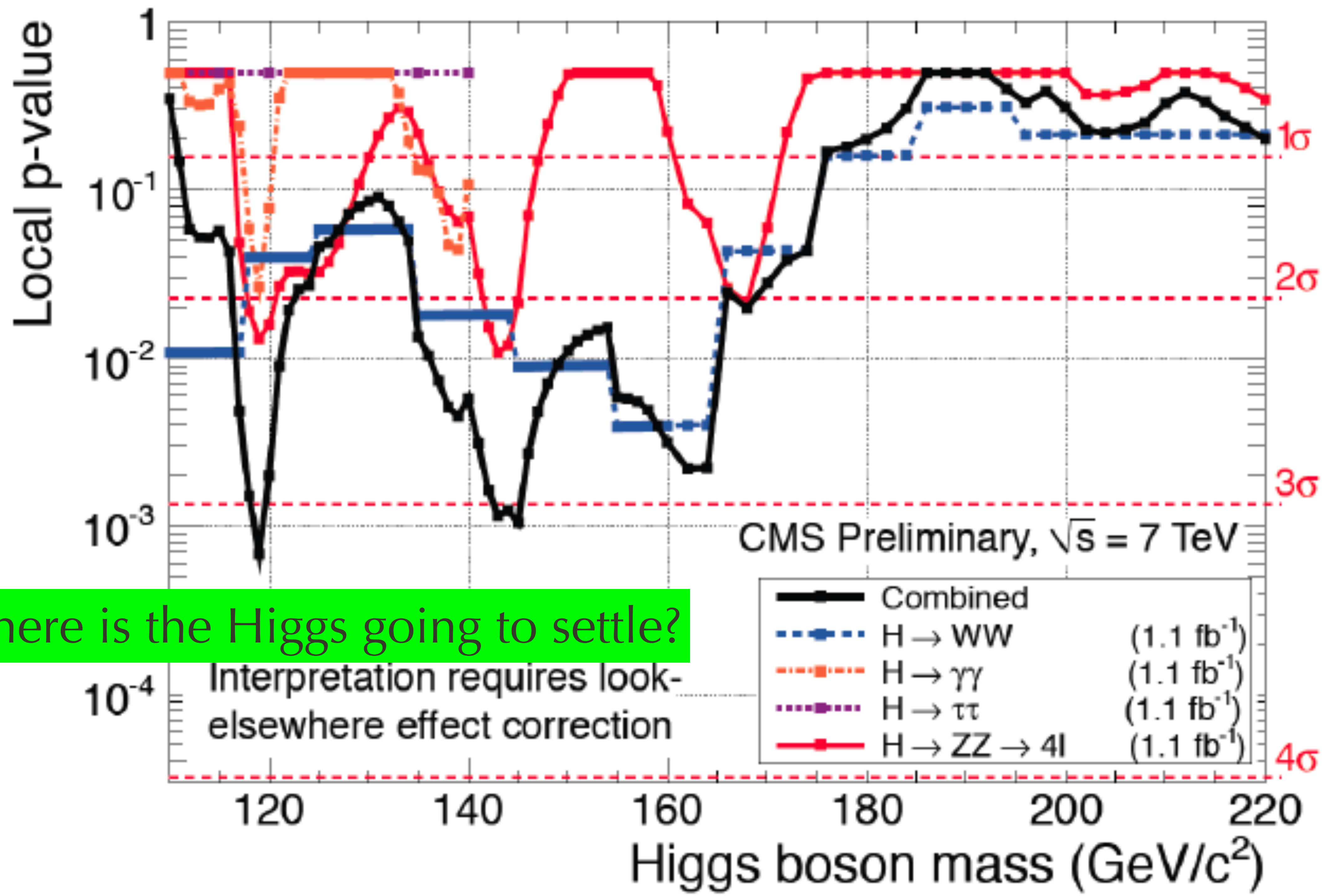


Broad excess >2σ
$126 < m_H < 158$ GeV/c²



$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\text{miss}})^2 - (\mathbf{P}_T^{\ell\ell} + \mathbf{P}_T^{\text{miss}})^2},$$

COMBINE (CMS)



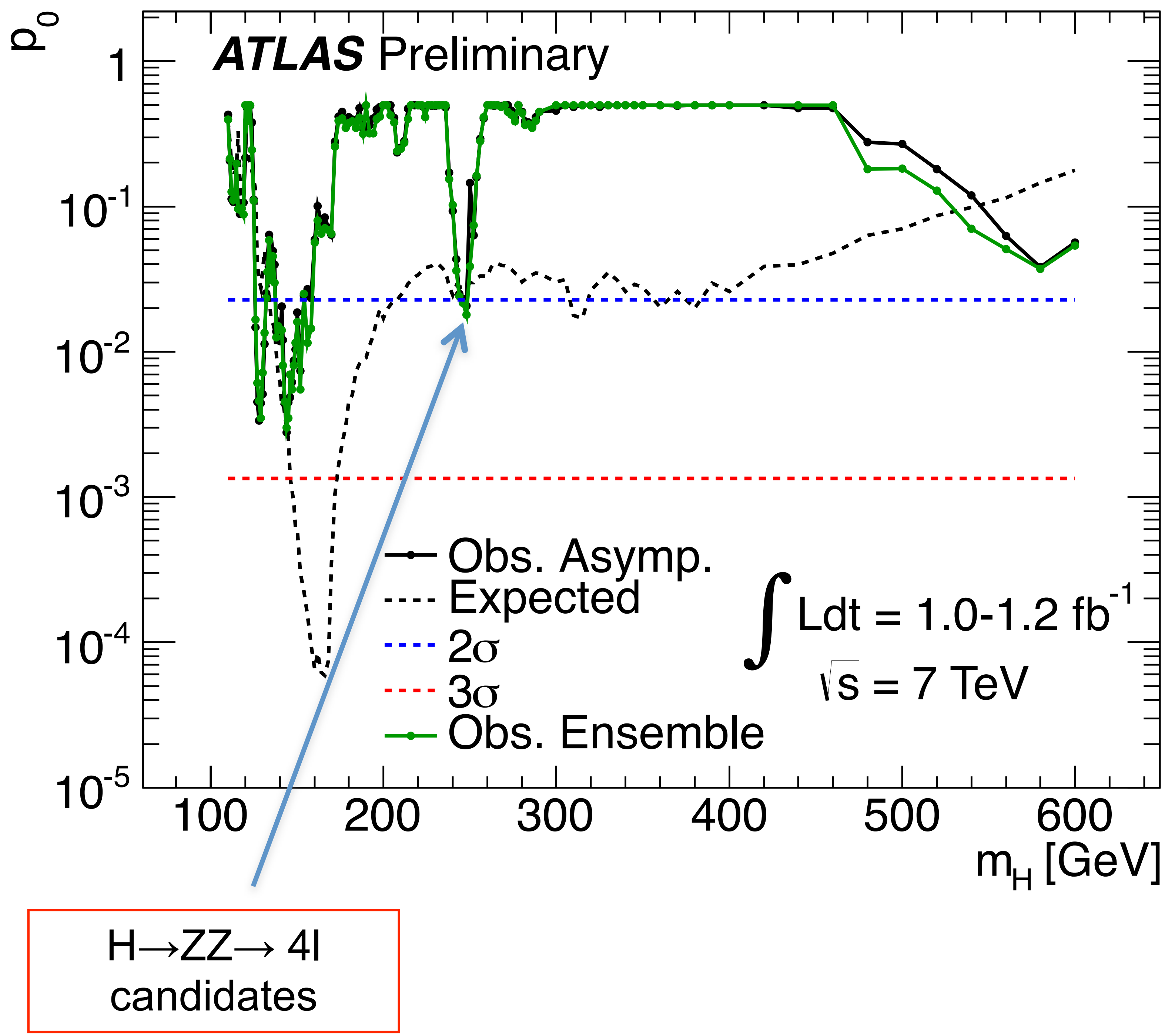
Where is the Higgs going to settle?

p-values full mass range

Approximately 8% chance of background-only fluctuation this large anywhere in range

No combined excess beyond 3σ is observed

Asymptotic approximation in good agreement with ensemble tests



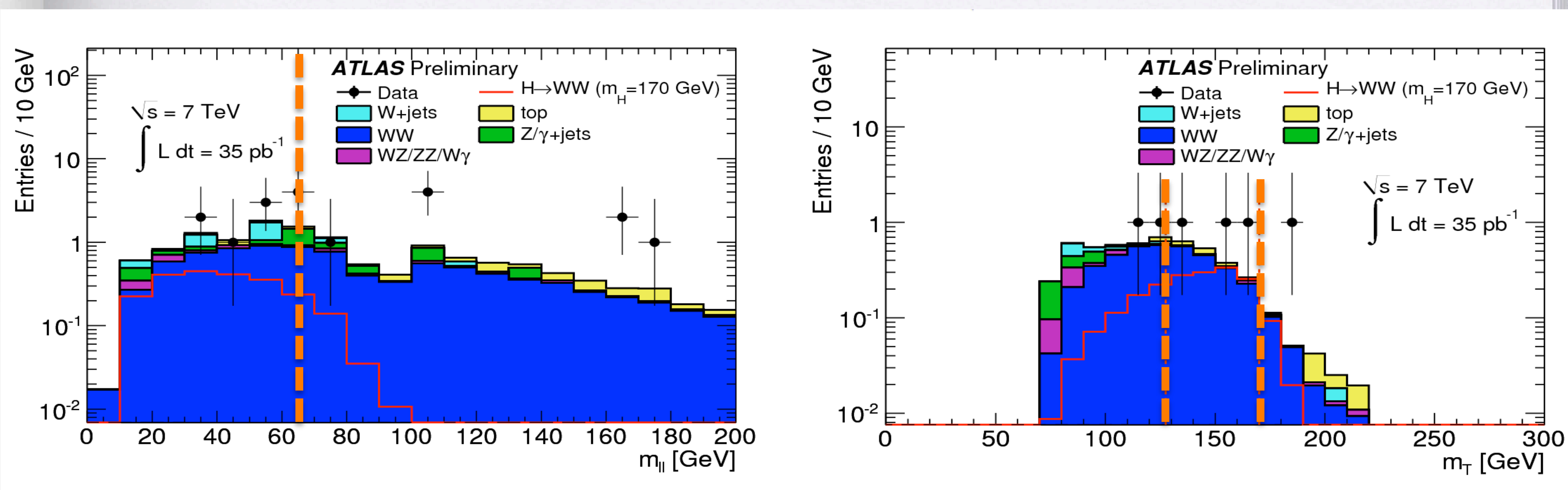
be careful!

- $h \to WW \to l\nu l\nu$ is a channel without good kinematical constraint.

- ATLAS Basic cuts are mll<50(60)GeV, $\Delta\varphi$< 1.3(1.8) $0.75m_H<M_T<m_H$. And you counts the number of events in the bin. This is **a counting experiment**.

- The background is WW for 0 jet channel and tt and WW for 1 jet channel.

- Background and signal distribution: not much different. No "discovery" this year.



Singlet and no additinonal matter up to GUT scale

Ellwanger et al arXive 0612133

- Largest Higgs mass achieved around tanβ=2, no enhancement ∝ tanβ^2 is expected, which is generally bad for SUSY DM searches.
- In addition singlet component of LSP (of cource reduce the coupling to the matter. For large λ there are always some mixing.

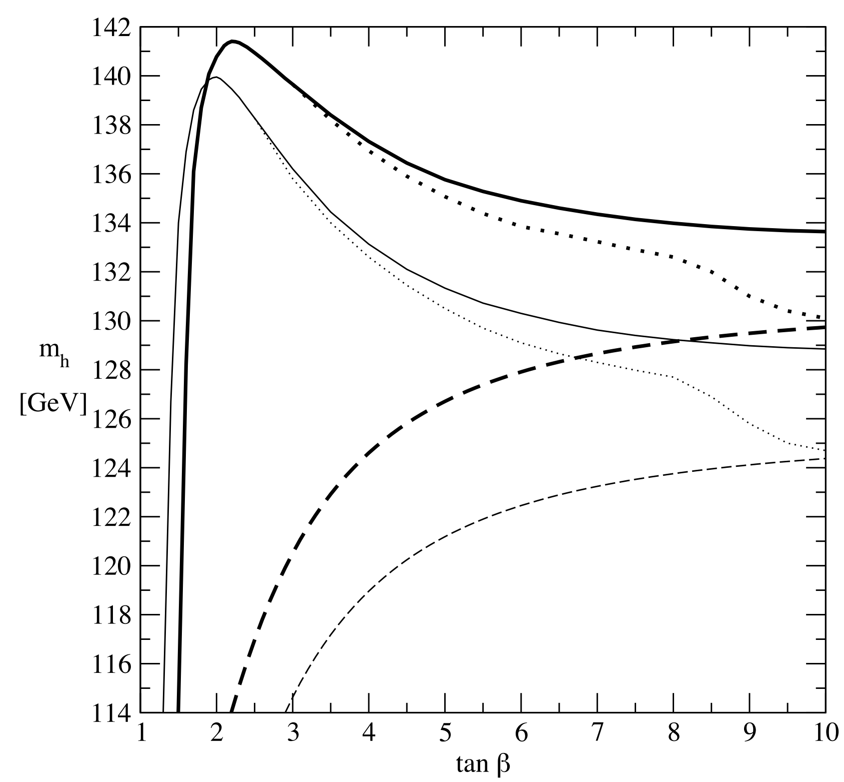


Figure 1: Upper bound on the lightest Higgs mass in the NMSSM for $m_{top} = 178$ GeV (thick full line: m_A arbitrary, thick dotted line: $m_A = 1$ TeV) and $m_{top} = 171.4$ GeV (thin full line: m_A arbitrary, thick dotted line: $m_A = 1$ TeV) and in the MSSM (with $m_A = 1$ TeV) for $m_{top} = 178$ GeV (thick dashed line) and $m_{top} = 171.4$ GeV (thin dashed line) as obtained with NMHDECAY as a function of tanβ. Squark and gluino masses are 1 TeV and $A_{top} = 2.5$ TeV.

Higgs mass in NMSSM

- Higgs mass above 130 GeV is very difficult to achieve in MSSM
- Higgs mass above 140 GeV is also hard to achieve for NMSSM
- in NMSSM upper limit of coupling is determined by finiteness at GUT scale.

Truely max value achived by adding additional matters to reduce the coupling at GUT scale

$$W = \lambda_1 H_1 \cdot H_2 S + \lambda_2 H_1 \cdot T_0 H_2 + \chi_1 H_1 \cdot T_1 H_1 + \chi_2 H_2 \cdot T_{-1} H_2,$$

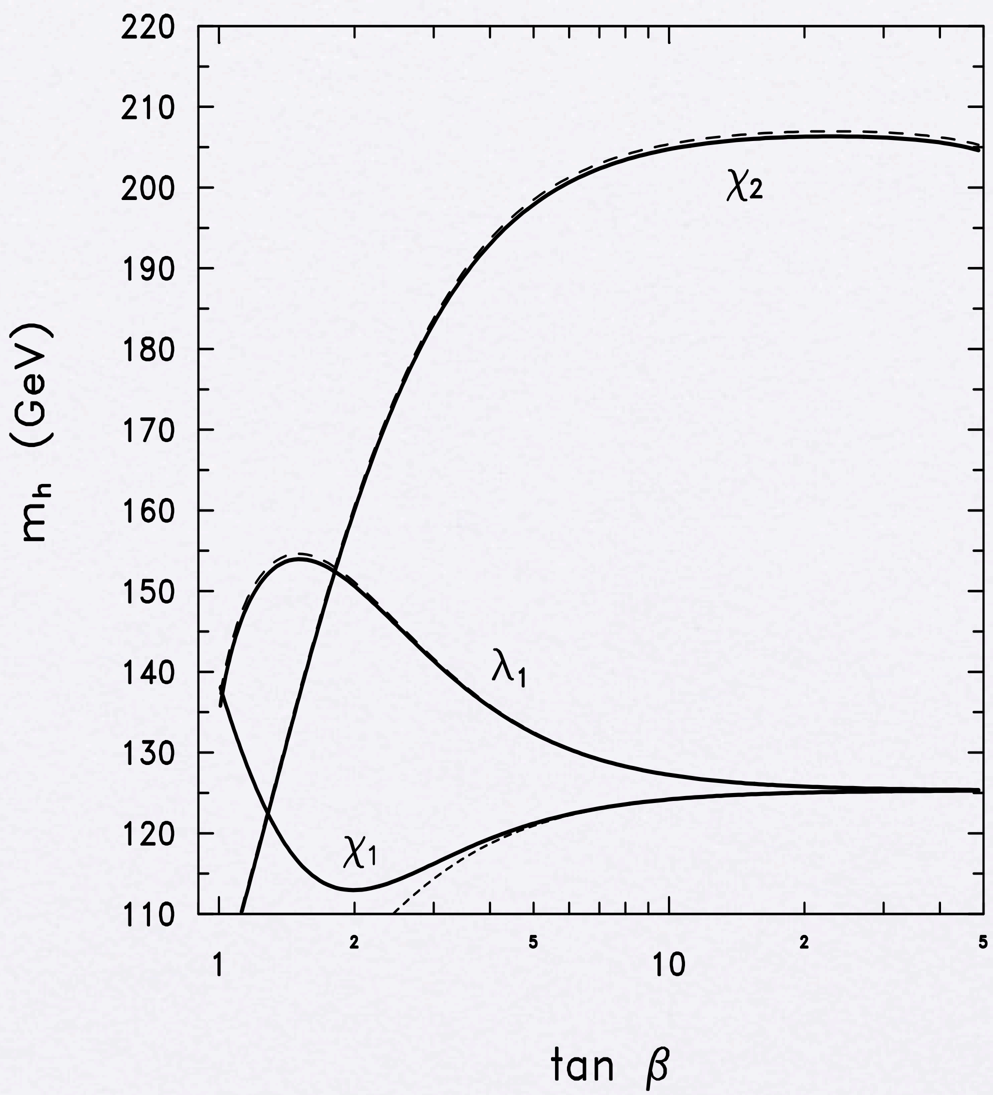


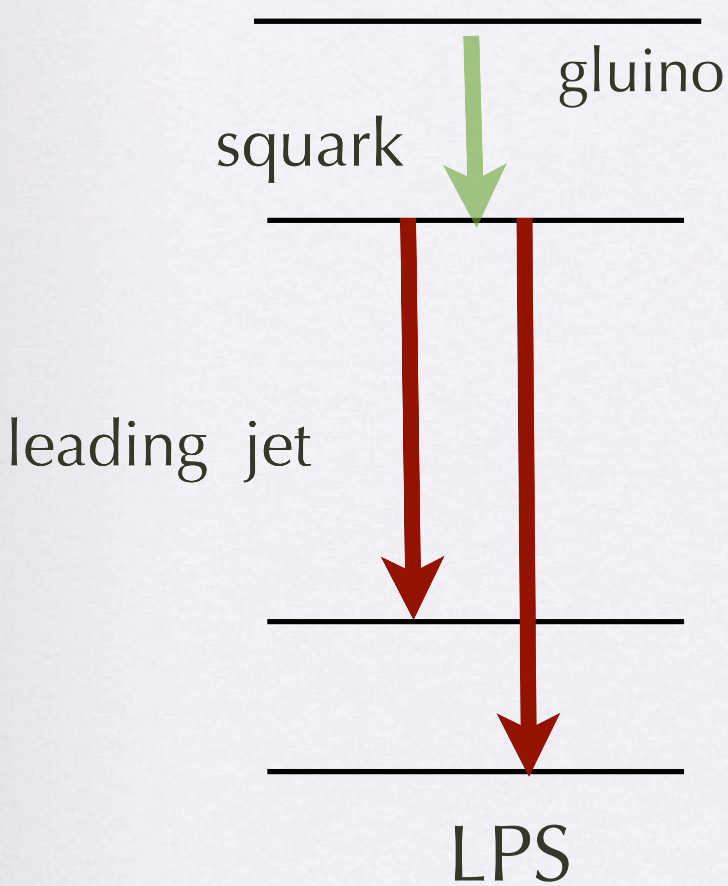
FIG. 2. Radiatively corrected upper bounds on m_h when different Yukawa couplings are present in the model and for different assumptions on the running of gauge couplings. The short-dashed line gives the upper bound in the MSSM.

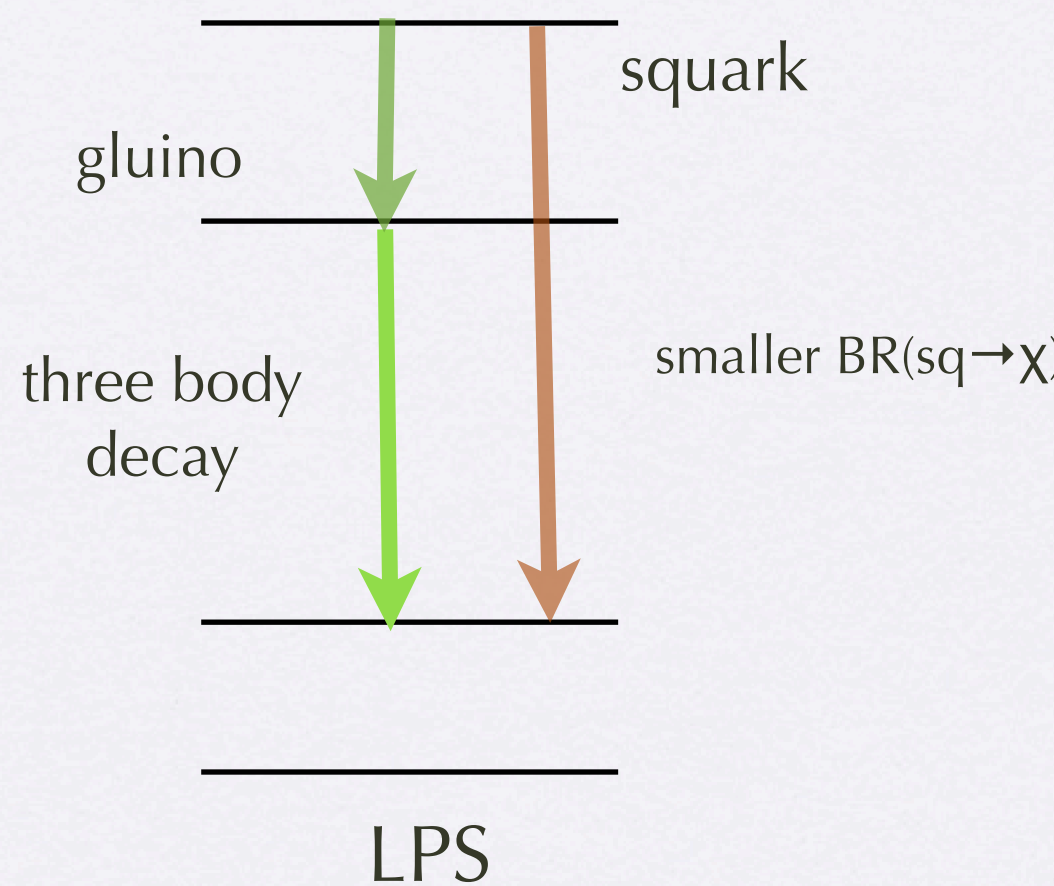
The final bounds, with radiative corrections included, are presented in Figure 2. Solid lines are the mass lim-

SUSY searches

Signature of Supersymmety

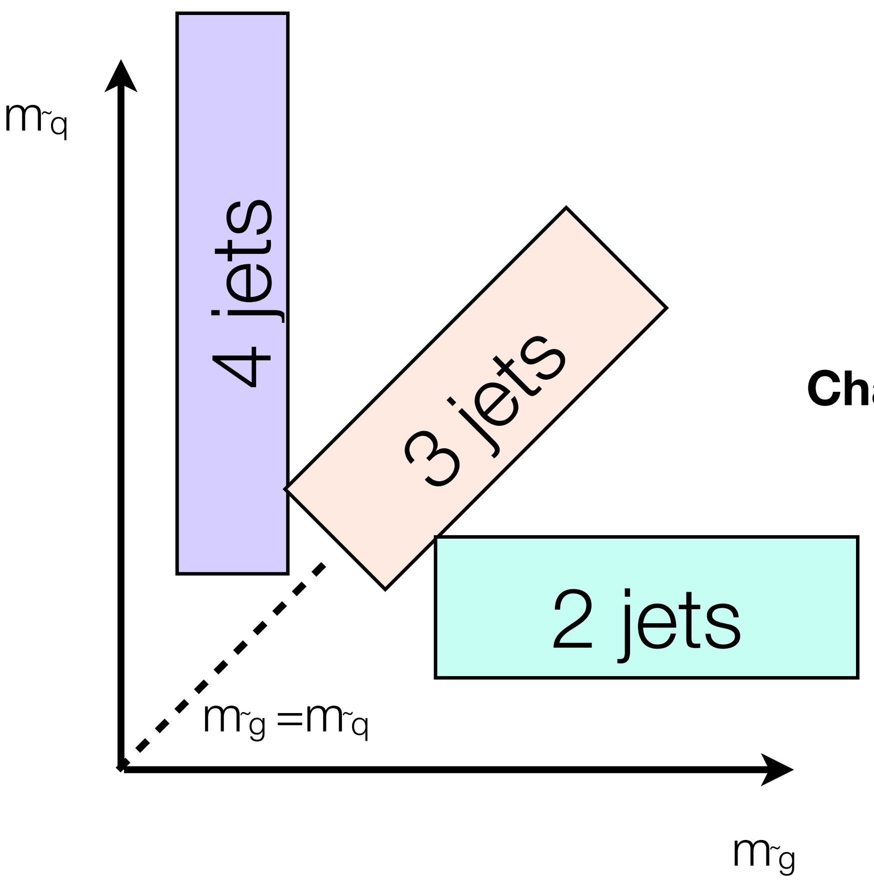
- squark-gluino production is more than 40% of total production cross section if the masses are about same
- squark squark -> **2hard jets** gluino gluino -> **4jets**
- Ino decay -> might be some **leptons**
- Two dark matter-> **missing momentum**
- **Little Higgs model with T parity and UED also falls in this category**





Event selection

- Depending on the SUSY mass hierarchy, different production processes favoured ($\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q}$)
  - Signal regions optimised to maximise sensitivity to different production processes



	Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
Trigger requirements	E_T^{miss}	> 130	> 130	> 130	> 130
	Leading jet p_T	> 130	> 130	> 130	> 130
Channel definition	Second jet p_T	> 40	> 40	> 40	> 80
	Third jet p_T	–	> 40	> 40	> 80
	Fourth jet p_T	–	–	> 40	> 80
Reduce QCD	$\Delta\phi(\text{jet}, E_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
Enhance signal	m_{eff} [GeV]	> 1000	> 1000	$> 500/1000$	> 1100

$$m_{eff} = \sum_{i=1}^{n} |\vec{p}_T^{\,jet\ i}| + E_T^{miss}$$

Results

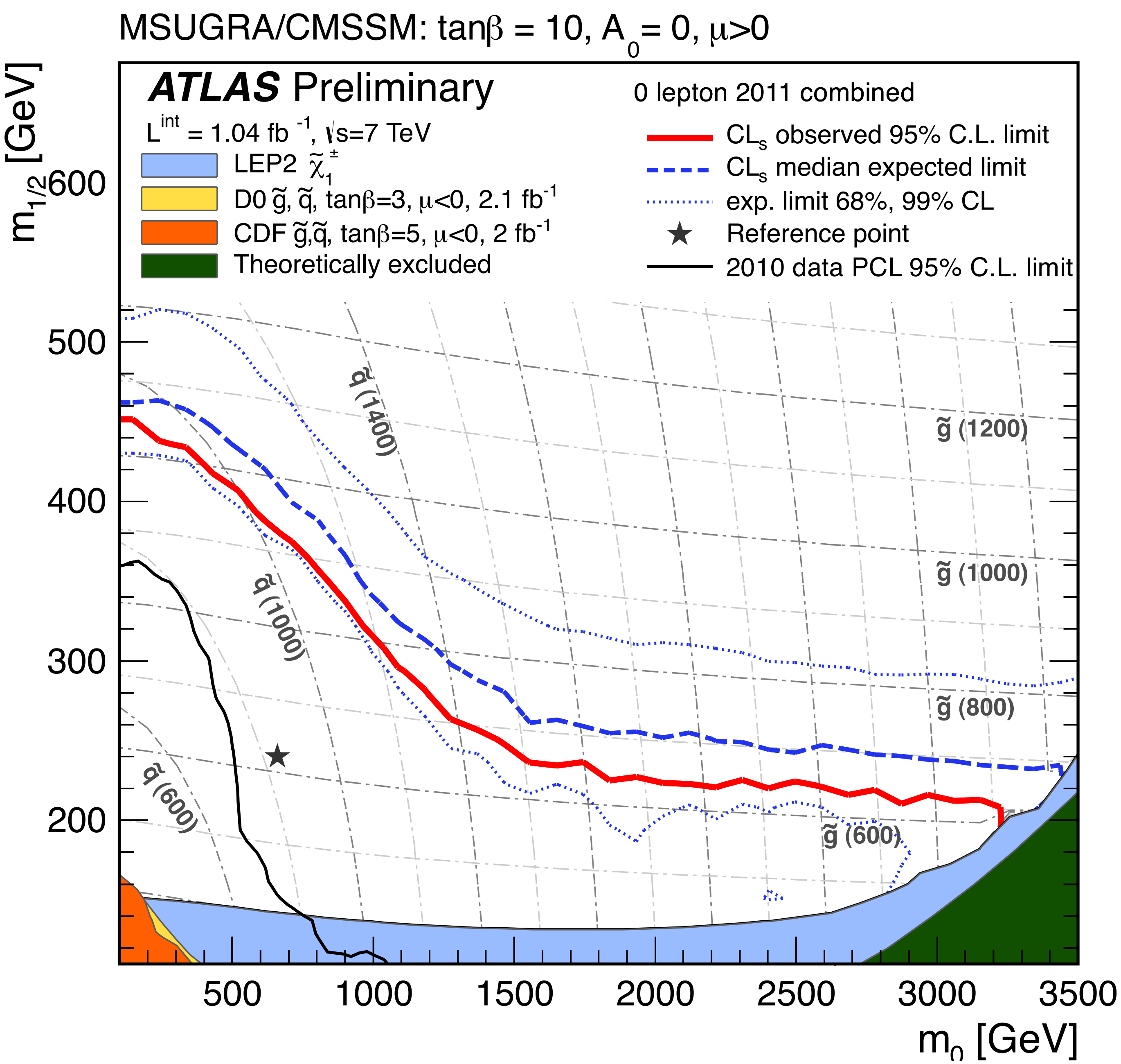
In my view, this is THE BEST way to presenting data

Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\text{eff}} > 500$ GeV	$\geq$ 4-jet, $m_{\text{eff}} > 1000$ GeV	High mass
Z/γ+jets	32.5 ± 2.6 ± 6.8	25.8 ± 2.6 ± 4.9	208 ± 9 ± 37	16.2 ± 2.1 ± 3.6	3.3 ± 1.0 ± 1.3
W+jets	26.2 ± 3.9 ± 6.7	22.7 ± 3.5 ± 5.8	367 ± 30 ± 126	12.7 ± 2.1 ± 4.7	2.2 ± 0.9 ± 1.2
$t\bar{t}$+ single top	3.4 ± 1.5 ± 1.6	5.6 ± 2.0 ± 2.2	375 ± 37 ± 74	3.7 ± 1.2 ± 2.0	5.6 ± 1.7 ± 2.1
QCD jets	0.22 ± 0.06 ± 0.24	0.92 ± 0.12 ± 0.46	34 ± 2 ± 29	0.74 ± 0.14 ± 0.51	2.10 ± 0.37 ± 0.83
Total	62.3 ± 4.3 ± 9.2	55 ± 3.8 ± 7.3	984 ± 39 ± 145	33.4 ± 2.9 ± 6.3	13.2 ± 1.9 ± 2.6
Data	58	59	1118	40	18
excluded σx acc (fb)	24	30	477	32	17

- No discrepancy with respect to SM predictions.
- The result is interpreted as a 95% CL exclusion limit on effective cross sections using a profile likelihood ratio approach following the CLs prescriptions.
- Analysis giving best expected limit used in each point.

Result interpretation (2)

You can interpret the data as you like.



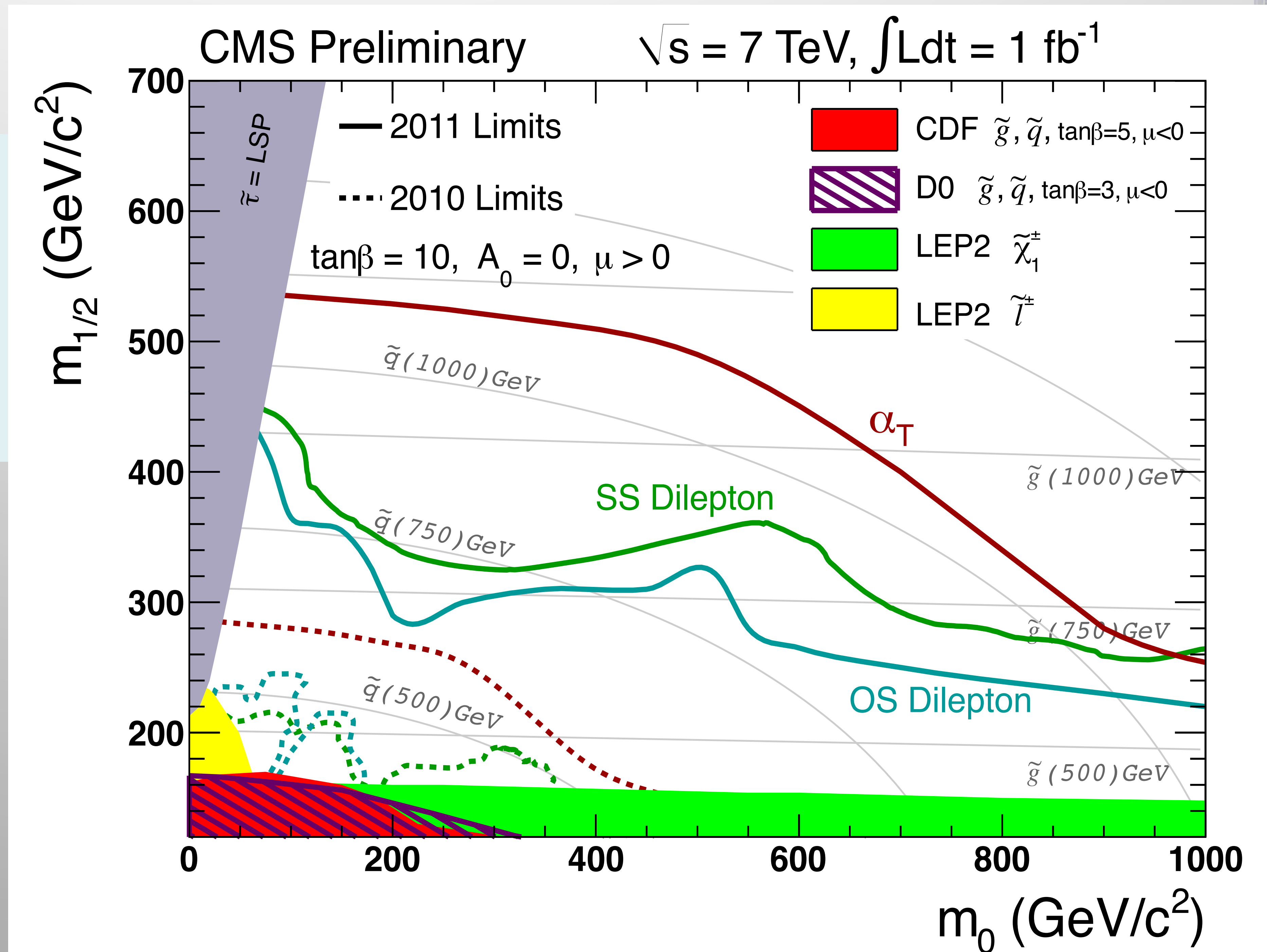
- Results interpreted in mSUGRA/CMSSM (A_0 = 0, tanβ = 10, μ>0)
- Limit in large m_0 region profits from the introduction of signal regions with large jet multiplicities.
- Equal squark-gluino masses excluded below 980 GeV

Results of three SUSY analyses completed on 2011 data (α_T , Same Sign and Opposite Sign dileptons).

CMS-SUS-11-003

CMS-SUS-11-010

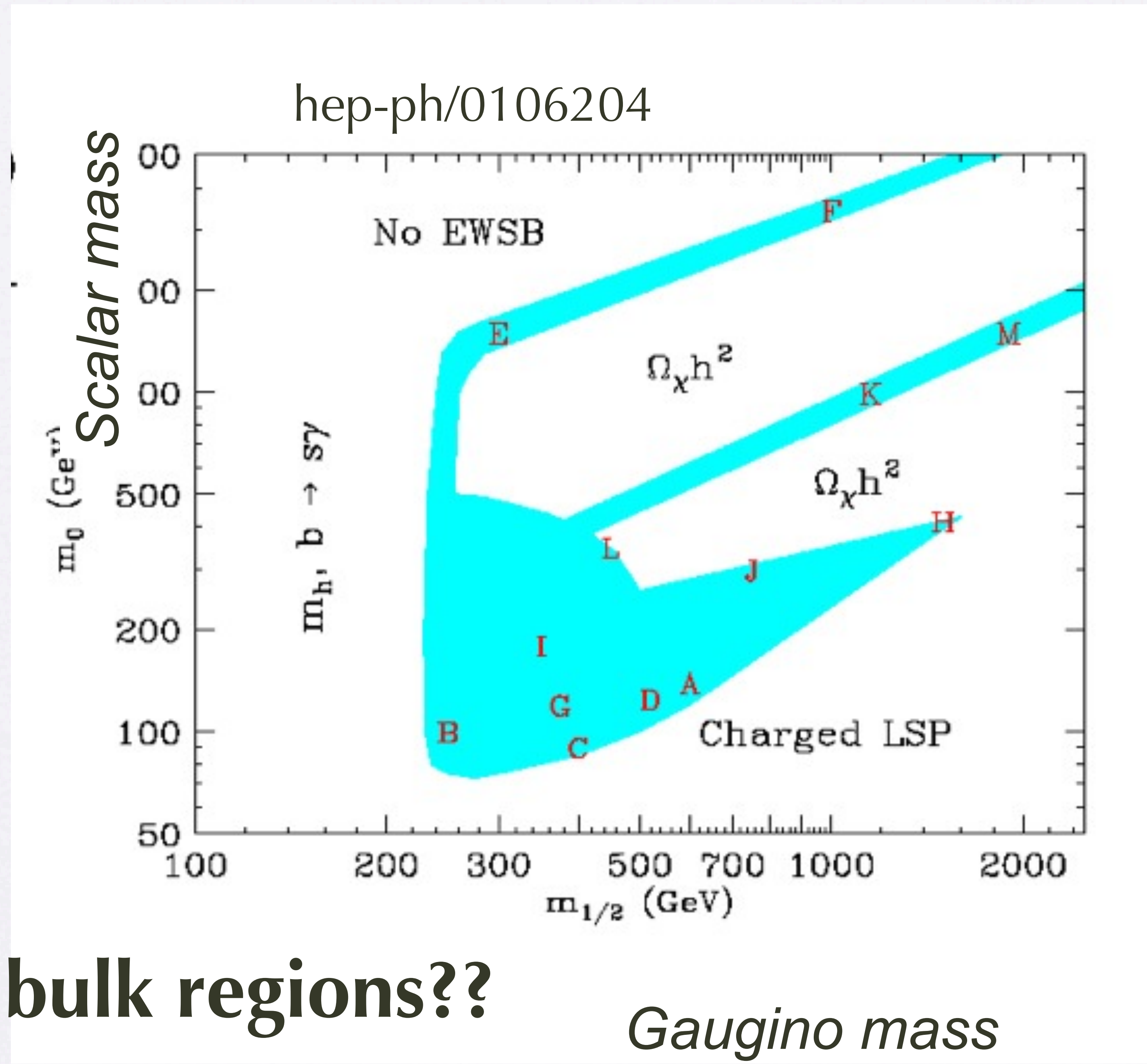
CMS-SUS-11-011



Within the Constrained MSSM model we are crossing the border of excluding gluinos up to 1TeV and squarks up to 1.25TeV

Dark Matter and Collider

DM density constraint is important in “MSUGRA” a



Have we excluded “bulk regions??

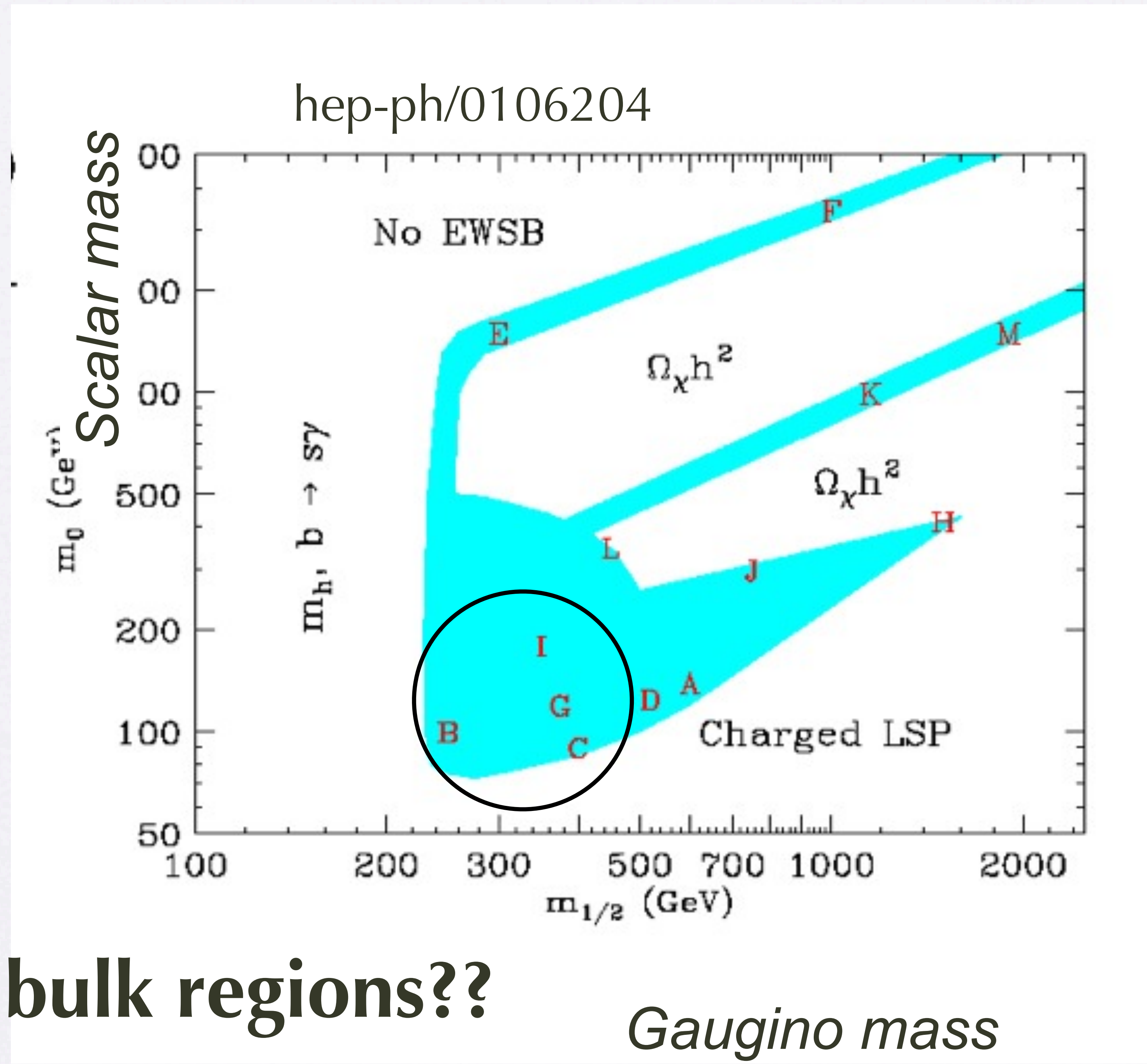
DM density constraint is important in "MSUGRA" a

1)bulk region : LSP Bino like.

→ Slepton exchange

$$\Omega h^2 \propto m_{\tilde{l}}^4 / m_{\tilde{\chi}}^2$$

too large mass density



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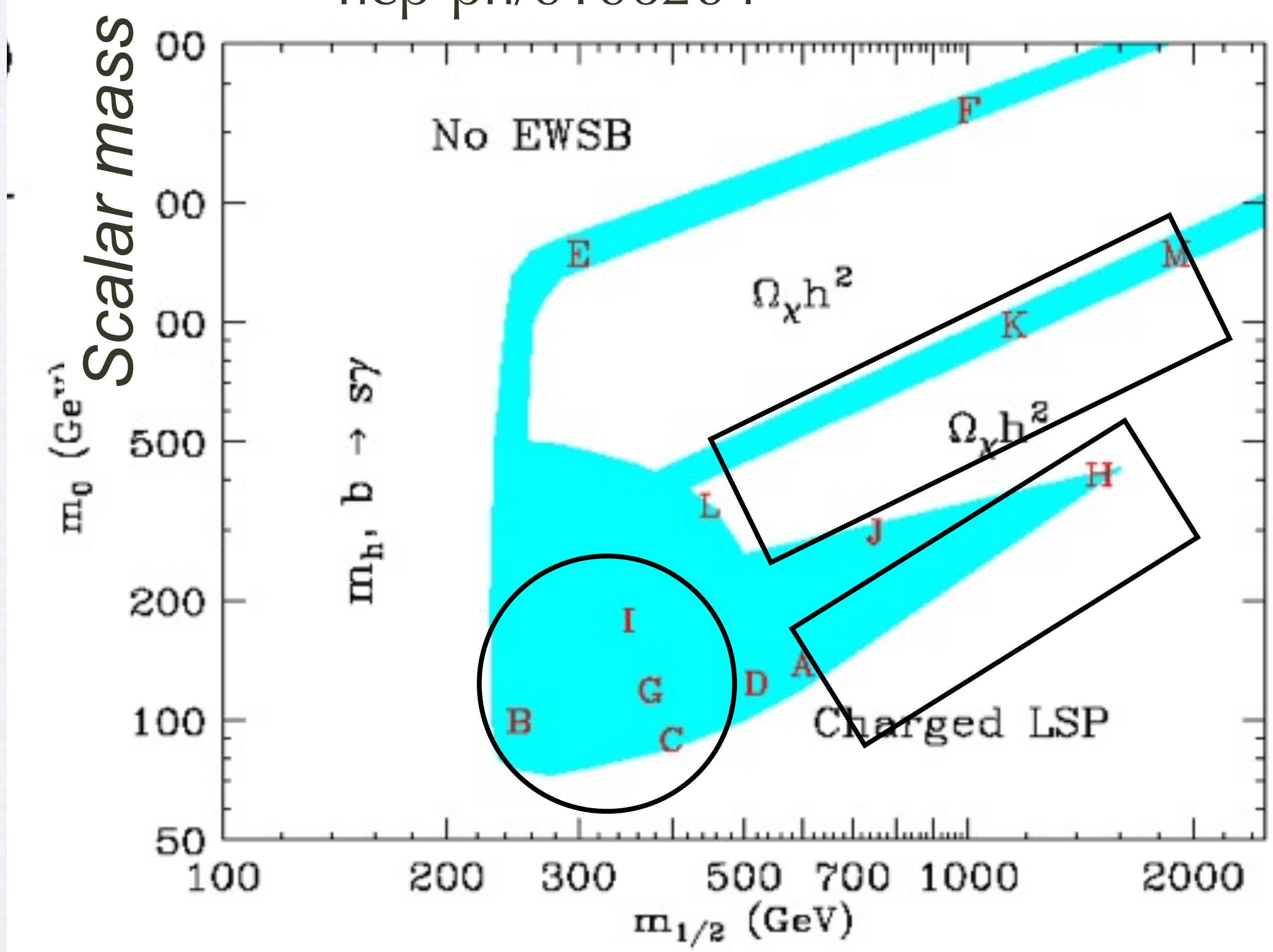
2)Higgs pole effect $m_H=2m_\chi$

3)coannihilation

hep-ph/0106204



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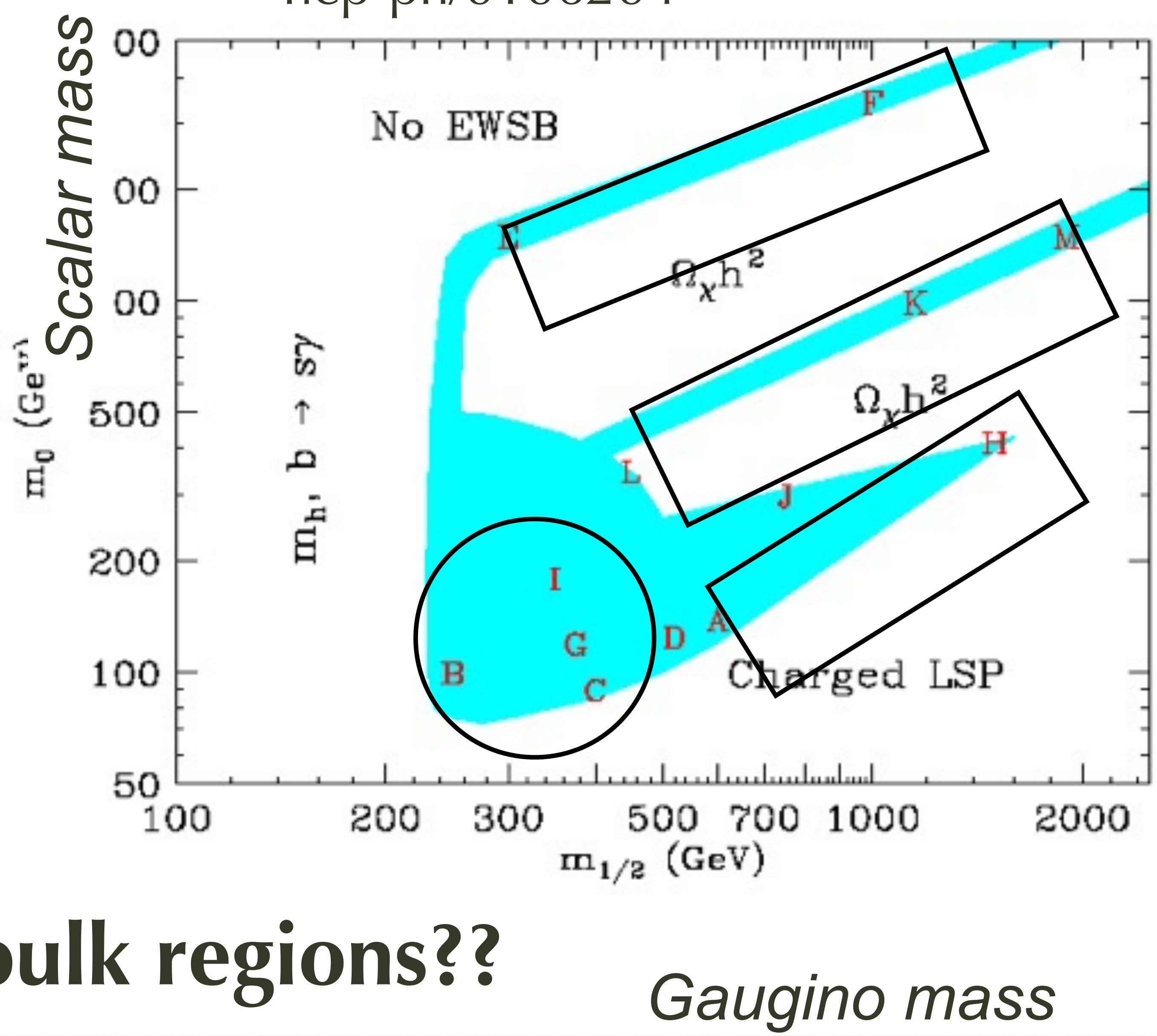
3)coannihilation

4)focus point region:
higgsino-gaugino mixing

hep-ph/0106204



Have we excluded "bulk regions??

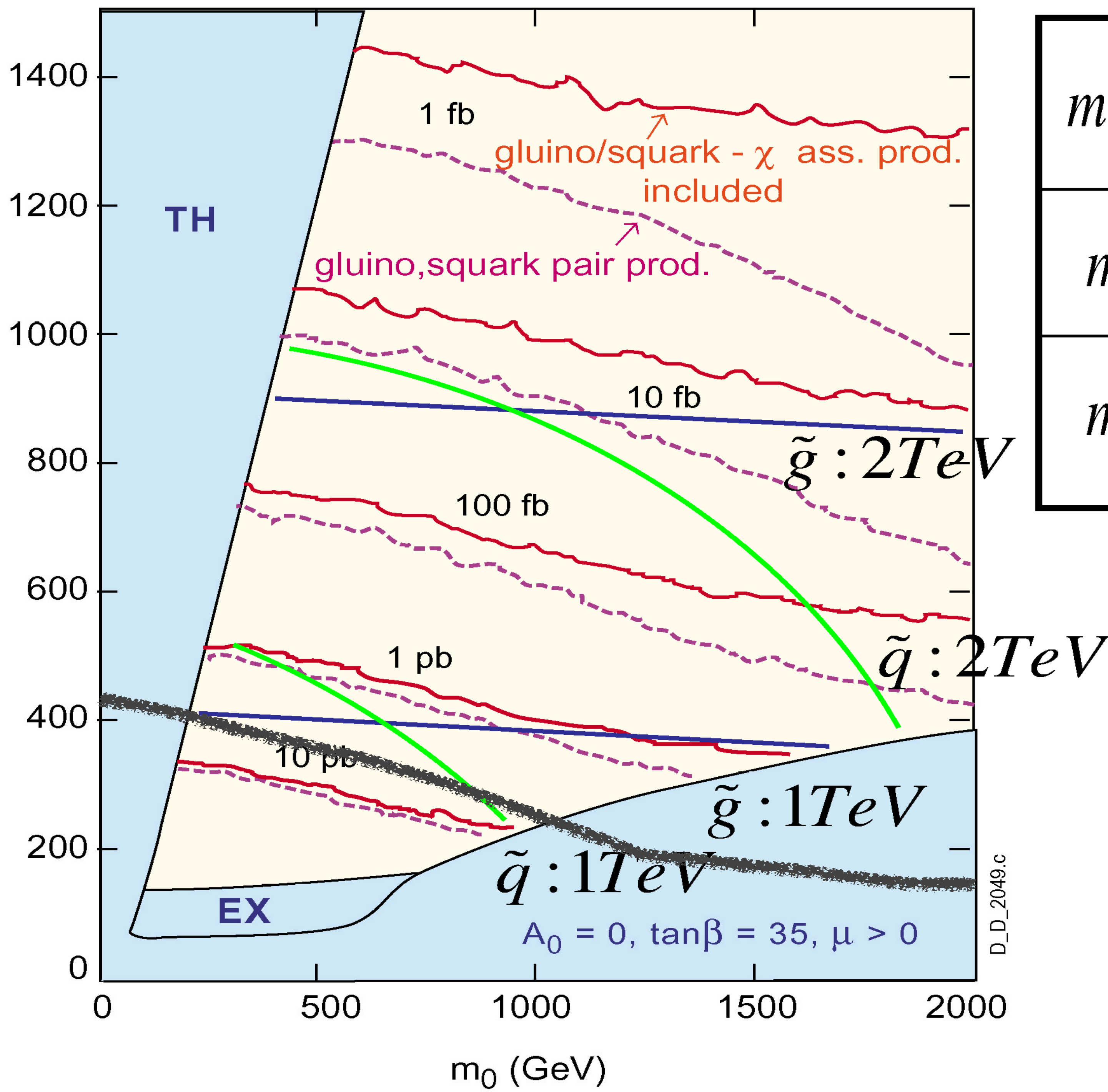
2011年7月29日金曜日

such thing doesn’t exist

- LSP may be light even if light squark and gluino are excluded **(lifting GUT relations)** .
- the LSP maybe higgsino even if scalar masses are small. **(lifting GUT relation of higgs mass)**
- any particle can degenerate with LSP...
  - **More direct and model independent information needed.**
  - Direct bounds on chargino and neutralino/no tau excess/are we too much relying on GUT relation?
  - what is the general cuts you want to propose???

expectation at 14TeV and sparticle measurements

14TeV projection



$m(\tilde{q}) = m(\tilde{g}) = 0.5TeV$	σ ～100pb $\tilde{g}\tilde{g}$ がmain
$m(\tilde{q}) = m(\tilde{g}) = 1TeV$	σ ～3pb
$m(\tilde{q}) = m(\tilde{g}) = 2TeV$	σ ～20fb $\tilde{u}\tilde{u},\tilde{u}\tilde{d}$がmain

- production at 14TeV would be 5pb or less. significantly limits statistics at 14TeV run already.

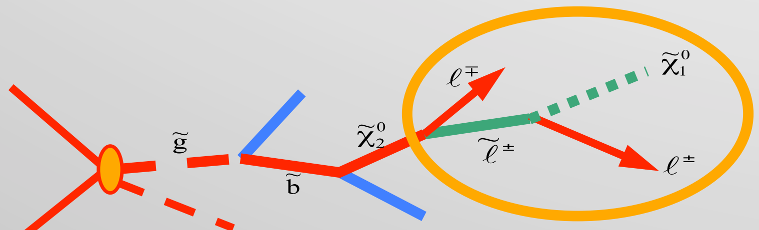
SUSY mass determination using 2 lepton channel

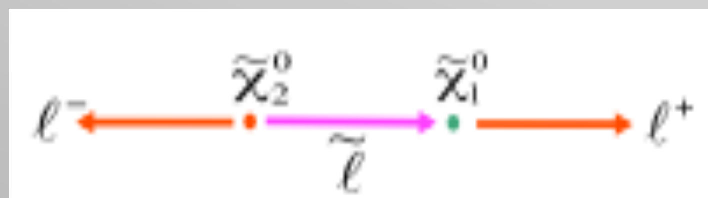
- production cross section dominated by SUSY
- Branching ration into second lightest neutralino 30% , lepton branch 6~20%→ 2~6%. 4 lepton channel certainly not feasible.
- 10fb-1 x 3pb =30000~600 events are not enough to determine EW SUSY particles masses precisely but probably oder of mass scale can be determined.
- **Need full use of hadronic channel to determine SUSY scale if discovered.**
- e+e- Linear collider necessary to determine thermal relic density?

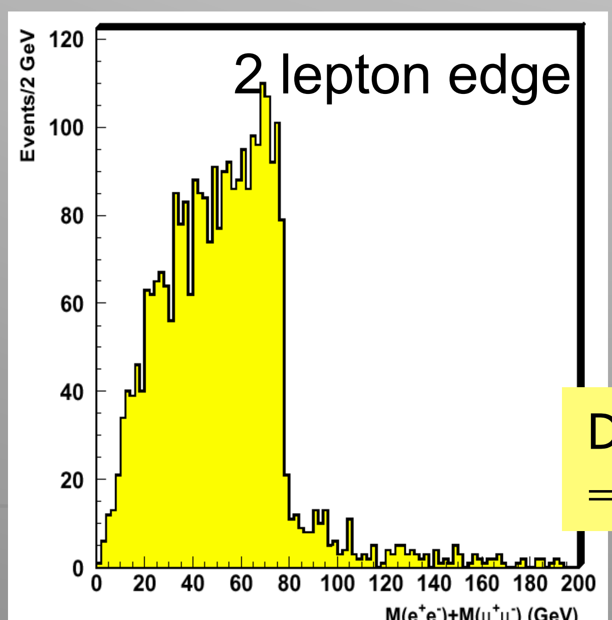
Sparticle Detection & Reconstruction

Mass precision for a favorable benchmark point at the LHC
LCC1~ SPS1a~ point B′

m_0=100 GeV
$m_{1/2}$= 250 GeV
A_0=-100
tanβ = 10
sign(μ)=+





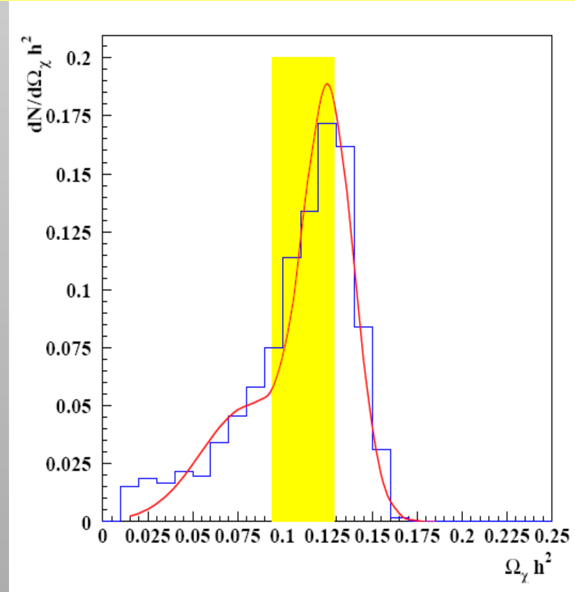


D. Miller et al
⇒Use shapes

hep-ph/0508198
100 fb^{-1}, 14 TeV

GeV	LHC
$\Delta m_{\tilde{\chi}_1^0}$	4.8
$\Delta m_{\tilde{\chi}_2^0}$	4.7
$\Delta m_{\tilde{\chi}_4^0}$	5.1
$\Delta m_{\tilde{l}_R}$	4.8
$\Delta m_{\tilde{\ell}_L}$	5.0
Δm_{τ_1}	5-8
$\Delta m_{\tilde{q}L}$	8.7
$\Delta m_{\tilde{q}R}$	7-12
$\Delta m_{\tilde{b}_1}$	7.5
$\Delta m_{\tilde{b}_2}$	7.9
$\Delta m_{\tilde{g}}$	8.0

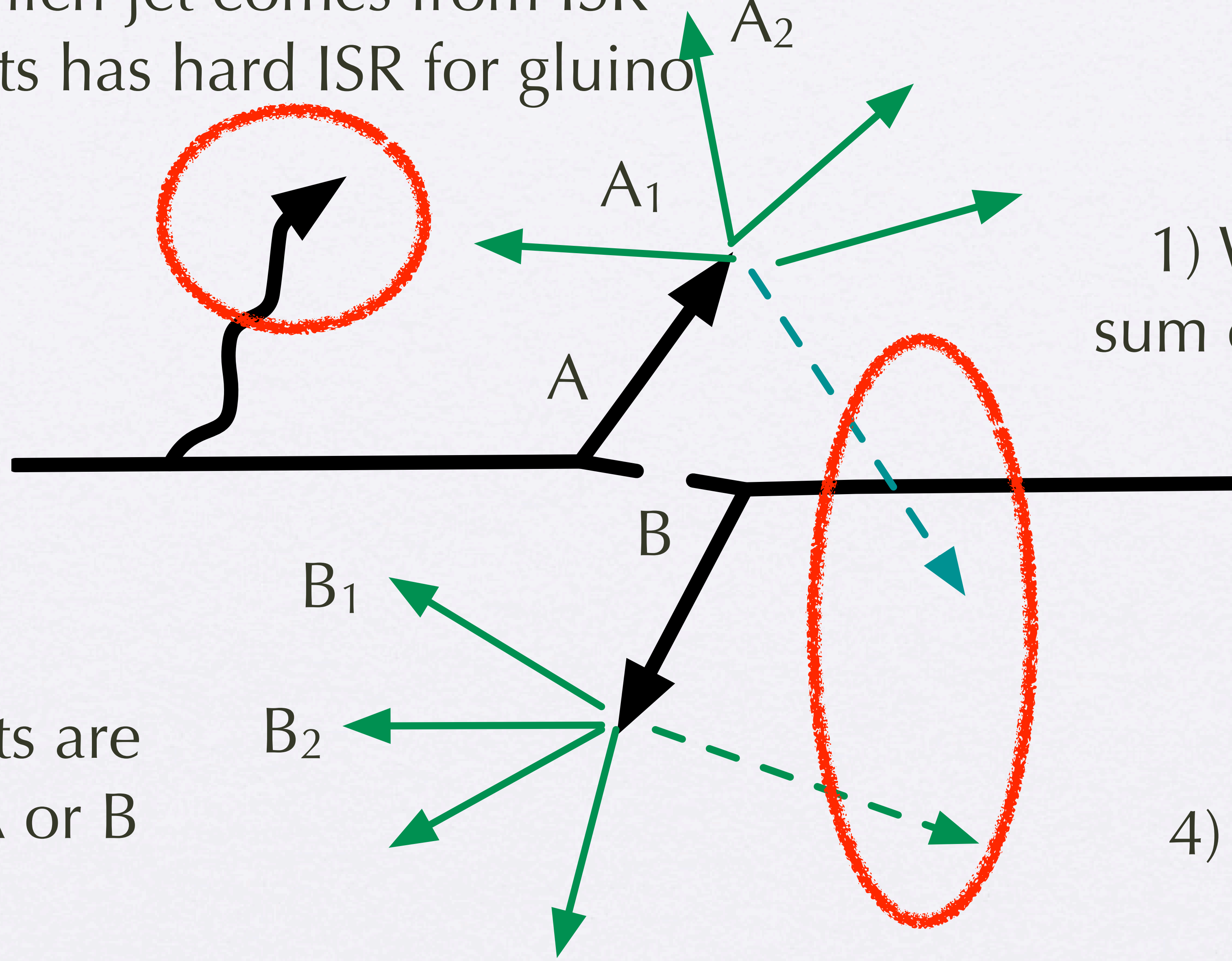
Lightest neutralino → Dark Matter?
Fit SUSY model parameters to the measured SUSY particle masses to extract $\Omega_\chi h^2$ ⇒ O(10%) for LCC1



This point and much more of the CMSSM space is ruled out
What can LHC still say on DM?

hadronic channnel
we don't know...

2) ISR;which jet comes from ISR
Most events has hard ISR for gluino



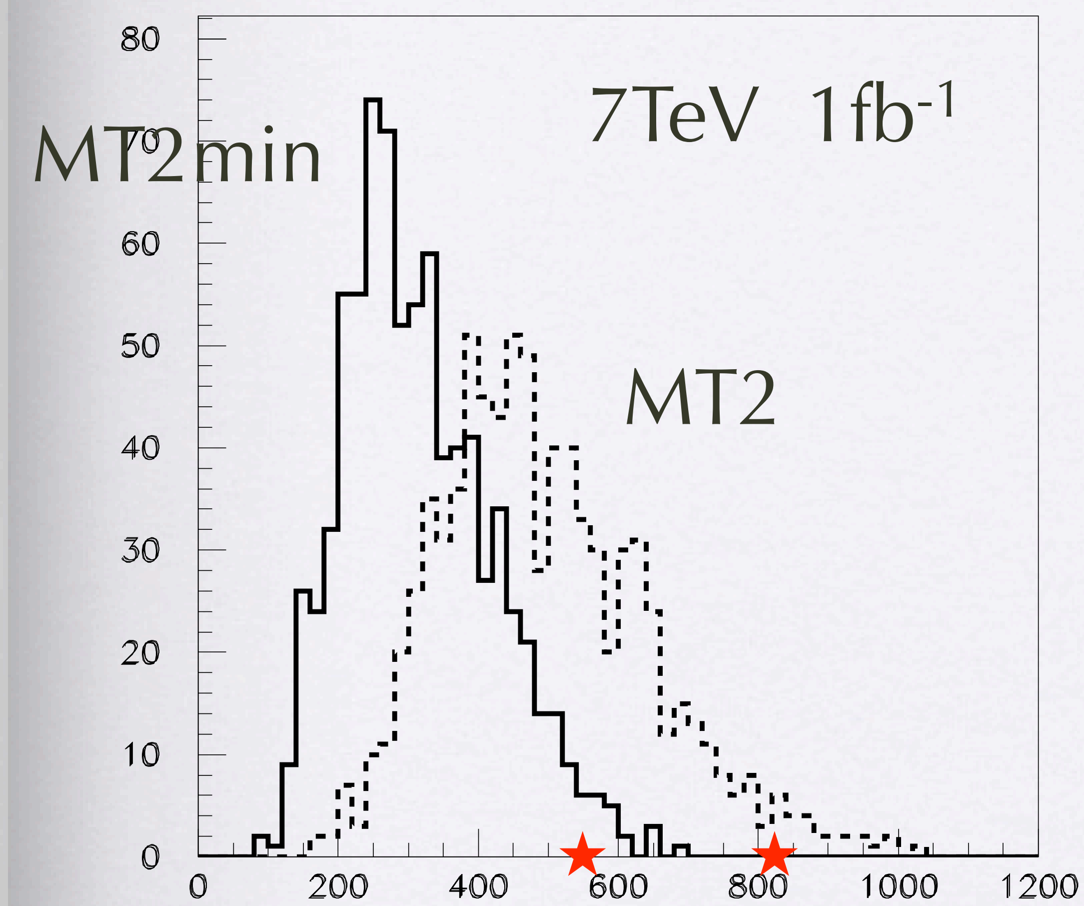
1) We only know
sum of LSP momenta
$=E_{Tmiss}$

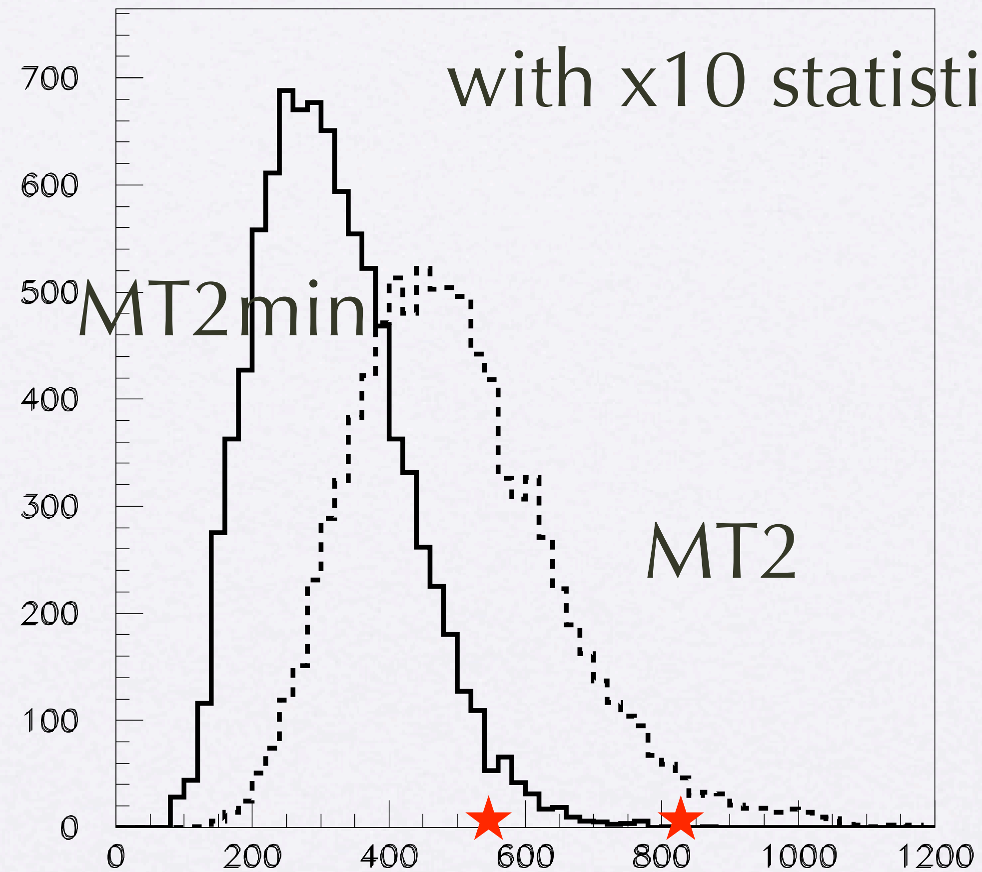
3) if jets are
from A or B

4) what A,B,...are

$$m_{T2}(\mathbf{p}_T^{vis(1)}, m_{vis}^{(1)}, \mathbf{p}_T^{vis(2)}, m_{vis}^{(2)}, m_\chi) \equiv \min_{\{\mathbf{p}_T^{\chi(1)}+\mathbf{p}_T^{\chi(2)}=-\mathbf{p}_T^{vis(1)}-\mathbf{p}_T^{vis(2)}\}} \left[\max\{m_T^{(1)}, m_T^{(2)}\}\right],$$

mgl=558GeV mul=825 GeV MT2min=remove one jet from the system and evaluate kinematical quantity for mass reconstruction



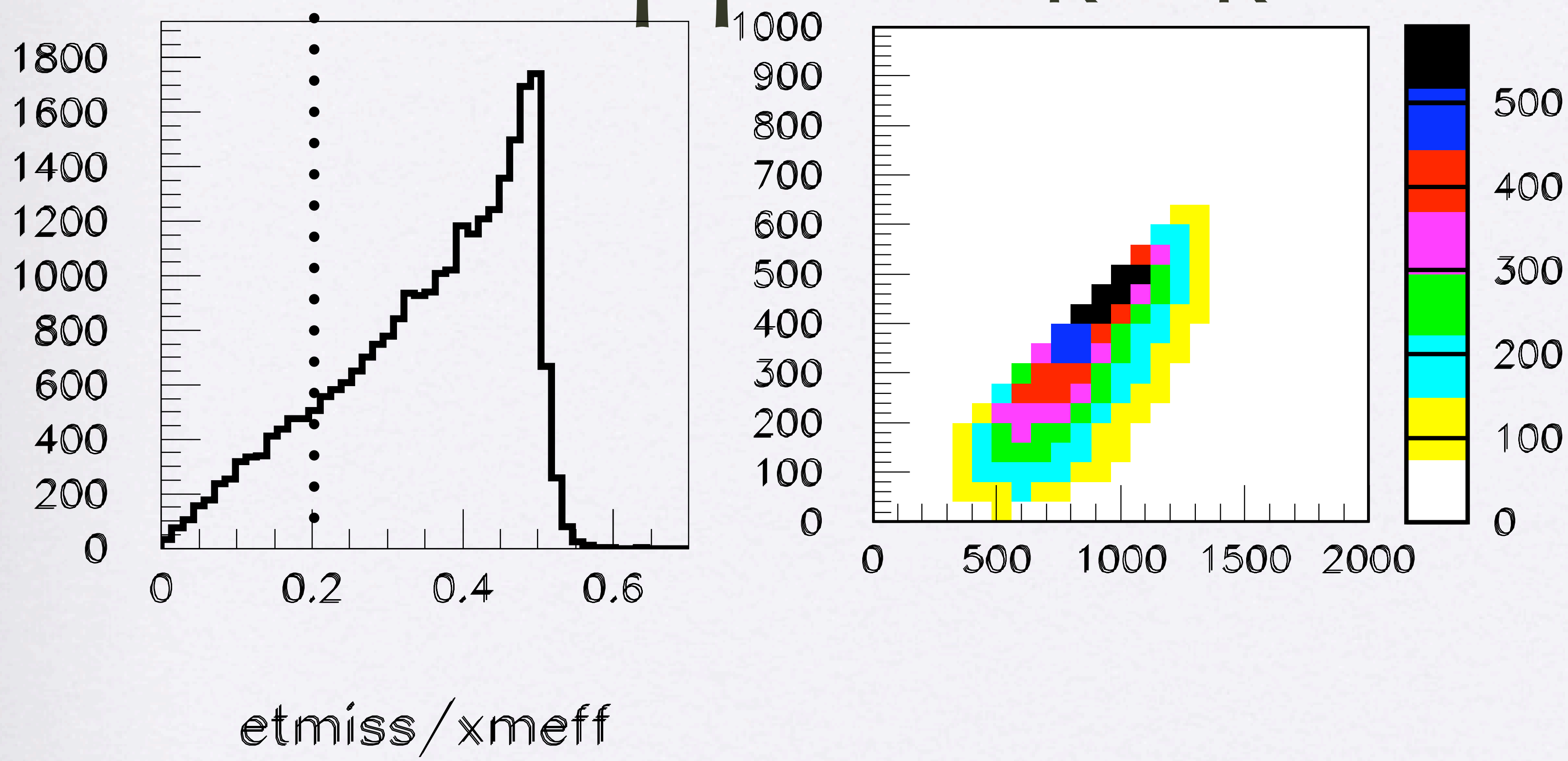


using global shape probably more useful.

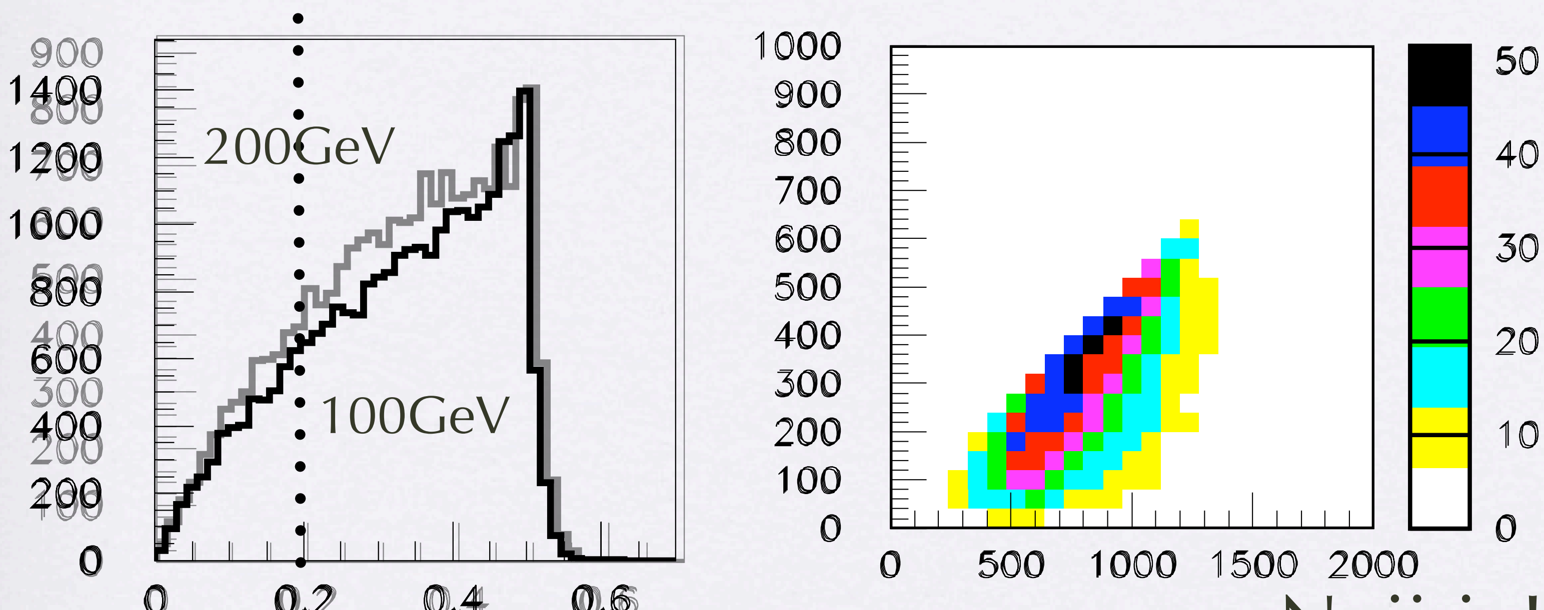
Reconstruction of (squark /gluino mass -LSP mass) may be possible

Spin measurements in jet channel

for pp→$U_R U_R$ channel



No spin
(Madgraph 2 by 2
→pythia/bridge)



Madgraph
2 by 4

Nojiri, J. Shu to appear

ETmiss =見えない横運動量の絶対値　Meff=ETmiss + Σ pT

SUSY study in 2012

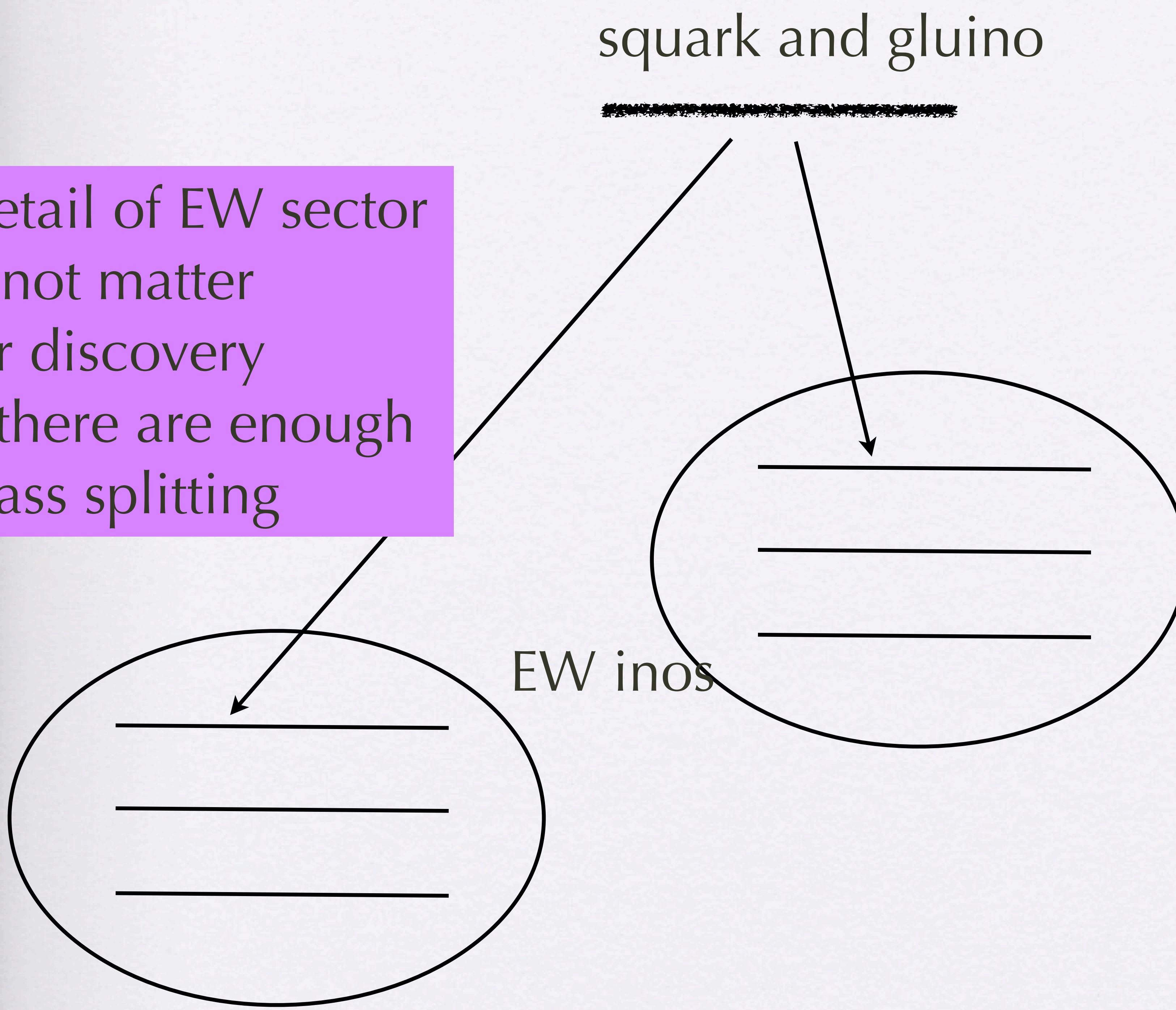
1fb-1→ 5fb-1 this year, probably reaching up to 1.2TeV, and not much extension at 7TeV

It will be **High energy luminosity frontia**→better understanding of W, top productions → increase of discovery potential

good chance to study **non-standard SUSY** case

If SUSY particles are degenerate, search strategy changes completely. Current study relies on a few high pT leading jets arising from large mass splitting between colored SUSY particles and dark matter.

Mass spectrum and signal



Detail of EW sector
is not matter
for discovery
if there are enough
mass splitting

Degenerate case

1) LSP is not too
relativistic

2) Cross section is
small compared
with visible energy
(more overlap with SM

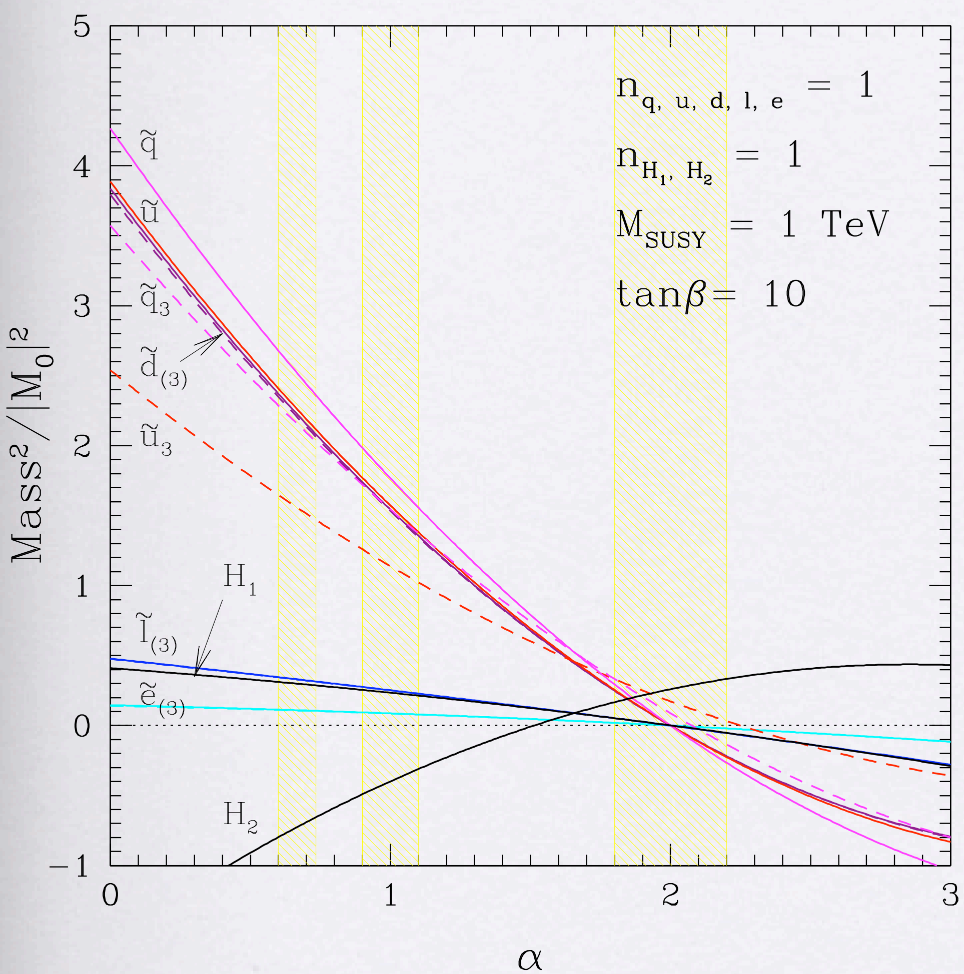
3) Difficult to
identify the parents

Evading limits

SUSY model with degenerate mass spectrum ex.Mixed Modulus Anomaly Mediation(two source of SUSY breaking)

M. N. and Kawagoe **Phys.Rev.D74:115011,2006**.

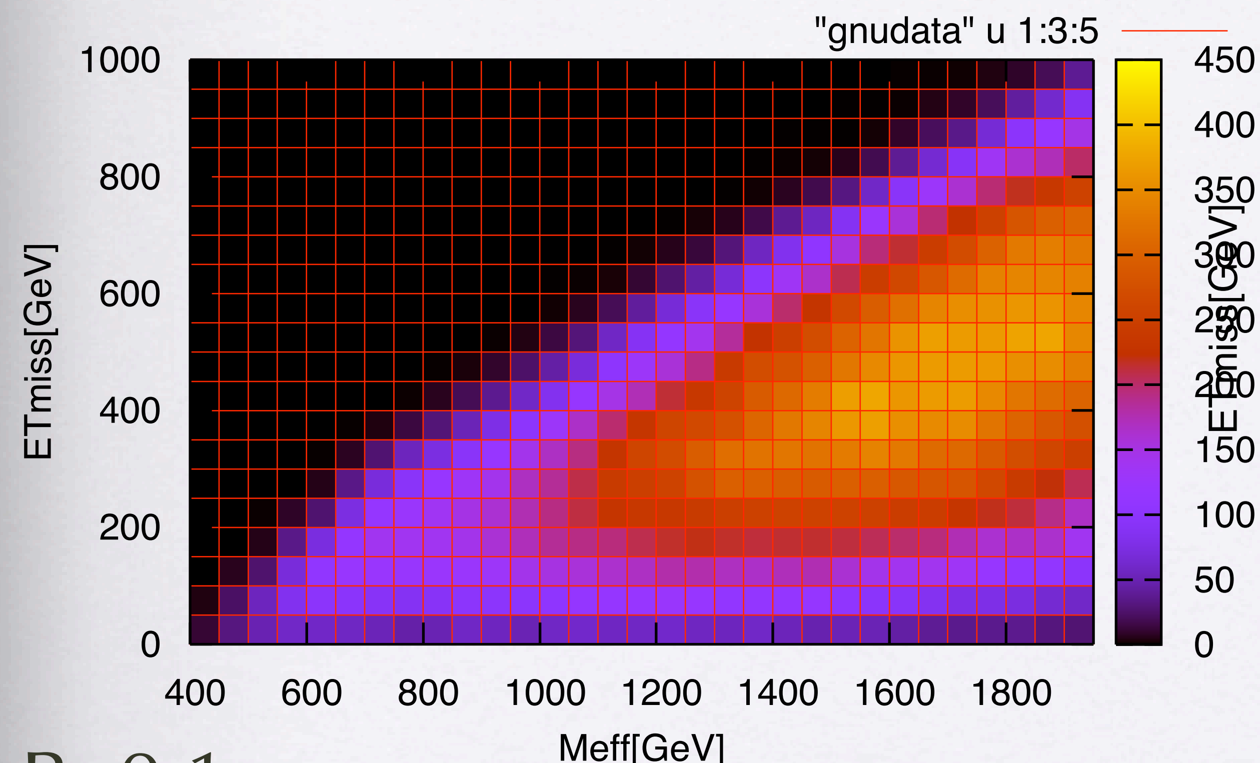
$$2p_{\rm CM} = (m_{\tilde{q}}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{q}}$$



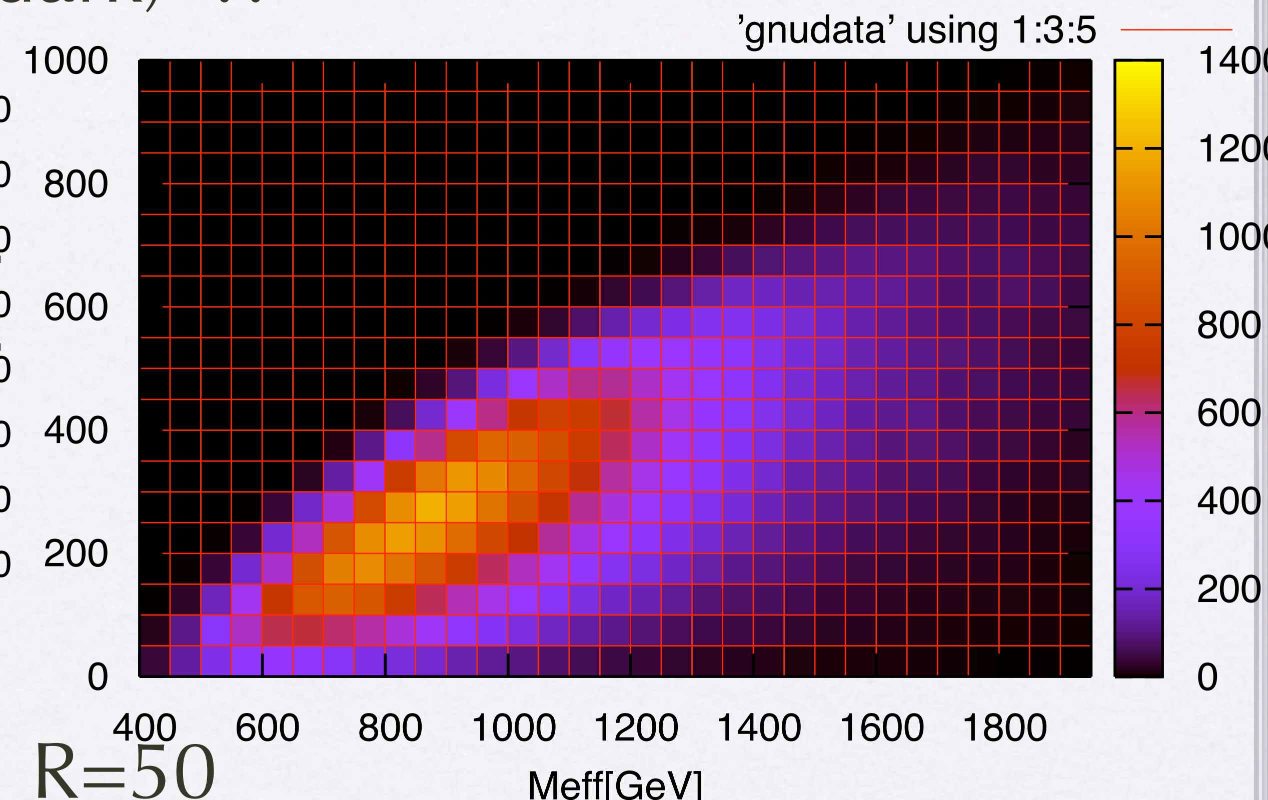
	set A		set B	
R	$m_{\tilde{u}_L}(m_{\tilde{g}})m_{\tilde{\chi}_1^0}$	$2p_{\rm CM}$	$m_{\tilde{u}_L}(m_{\tilde{g}})m_{\tilde{\chi}_1^0}$	$2p_{\rm CM}$
0	995 (1055) 182	961	1041 (1061) 189	1007
10	986 (1053) 246	924	1043 (1061) 248	984
20	973 (1049) 326	793	1044 (1060) 330	940
30	951 (1045) 426	726	1045 (1060) 434	865
40	916 (1038) 507	635	1044 (1059) 569	733
50	854 (1027) 426	641	1038 (1057) 713	548
55	803 (1021) 335	663	1033 (1056) 721	529
60	no EWSB		1023 (1055) 700	543

$$R \equiv m_{3/2}(T+T^*)/F_T$$

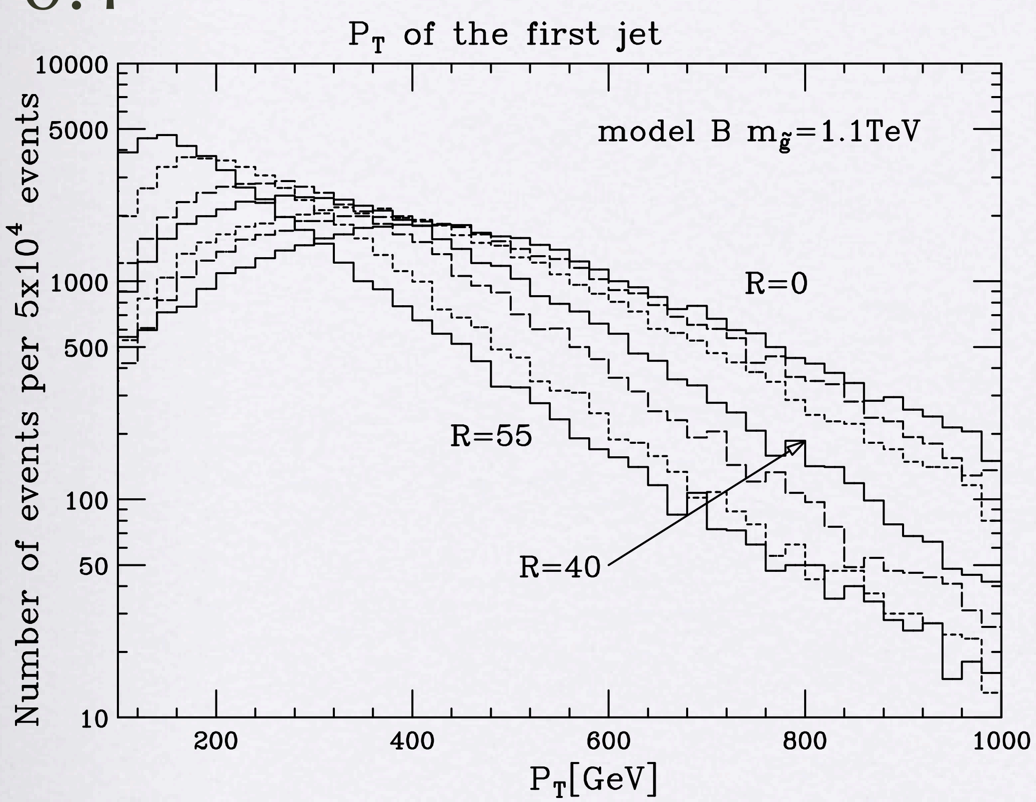
signal distribution of degenerate case. No way if mLSP> 0.7 m(squark) ??

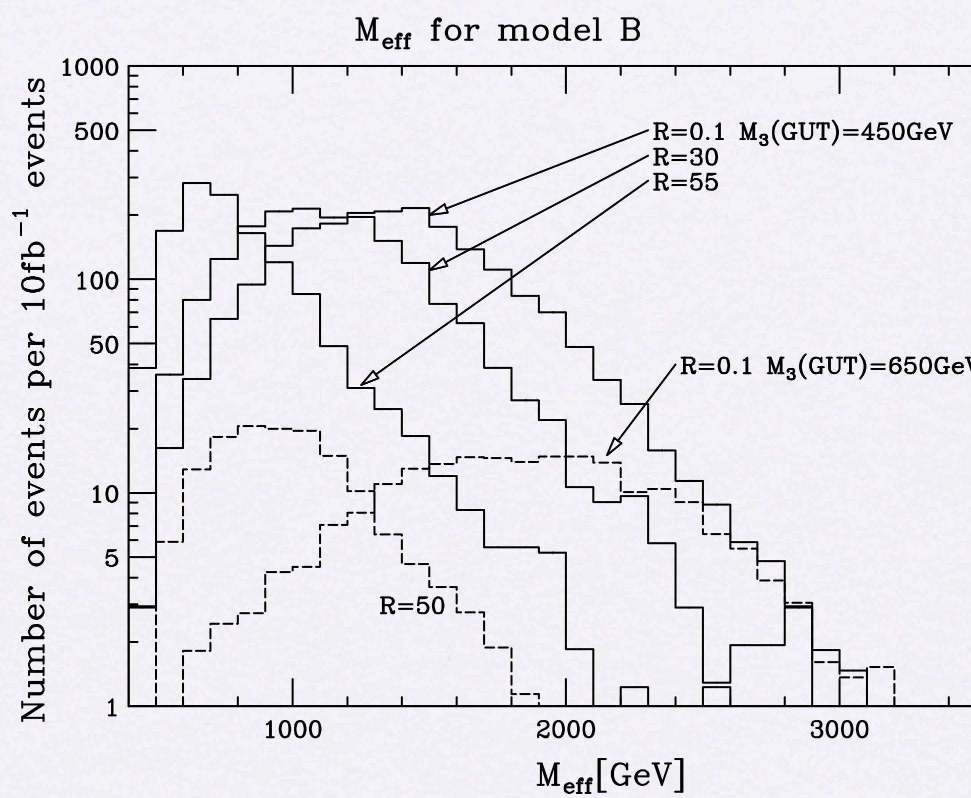


R=0.1



R=50





MUED and LHC

- all SM particle lives in 5th dimention, Z2 compactification for KK parity

- small mass splitting as in KKLT model. particles in same KK levels are degenerate.

$$m^2_{X^{(n)}} = \frac{n^2}{R^2} + m^2_{X^{(0)}} + \delta m^2_{X^{(n)}} \quad \text{(Boson)},$$
$$m_{X^{(n)}} = \frac{n}{R} + m_{X^{(0)}} + \delta m_{X^{(n)}} \quad \text{(Fermion)},$$

- gauge boson KK modes are in current eigenstate

- Dark matter is lightest KK odd particle~ U(1) gauge boson KK mode

- Co-annihilation and resonances reduce DM density

$m_{\gamma^{(1)}}$	$m_{W^{(1)}}$	$m_{Z^{(1)}}$	$m_{e^{(1)}}$	$m_{L^{(1)}}$	$m_{d^{(1)}}$	$m_{u^{(1)}}$	$m_{Q^{(1)}}$	$m_{g^{(1)}}$	
800.1	847.3	847.4	808.2	822.3	909.8	912.5	929.3	986.4	GeV

Table 1: Mass spectrum of first KK level for a benchmark point $(1/R, \Lambda R) = (800, 20)$

background reduction

$$M_{T2} \equiv \min_{\mathbf{p}_T^{inv(1)}+\mathbf{p}_T^{inv(2)}=\mathbf{p}_T^{miss}} \left[\max\left\{M_T^{(1)},\ M_T^{(2)}\right\}\right]$$

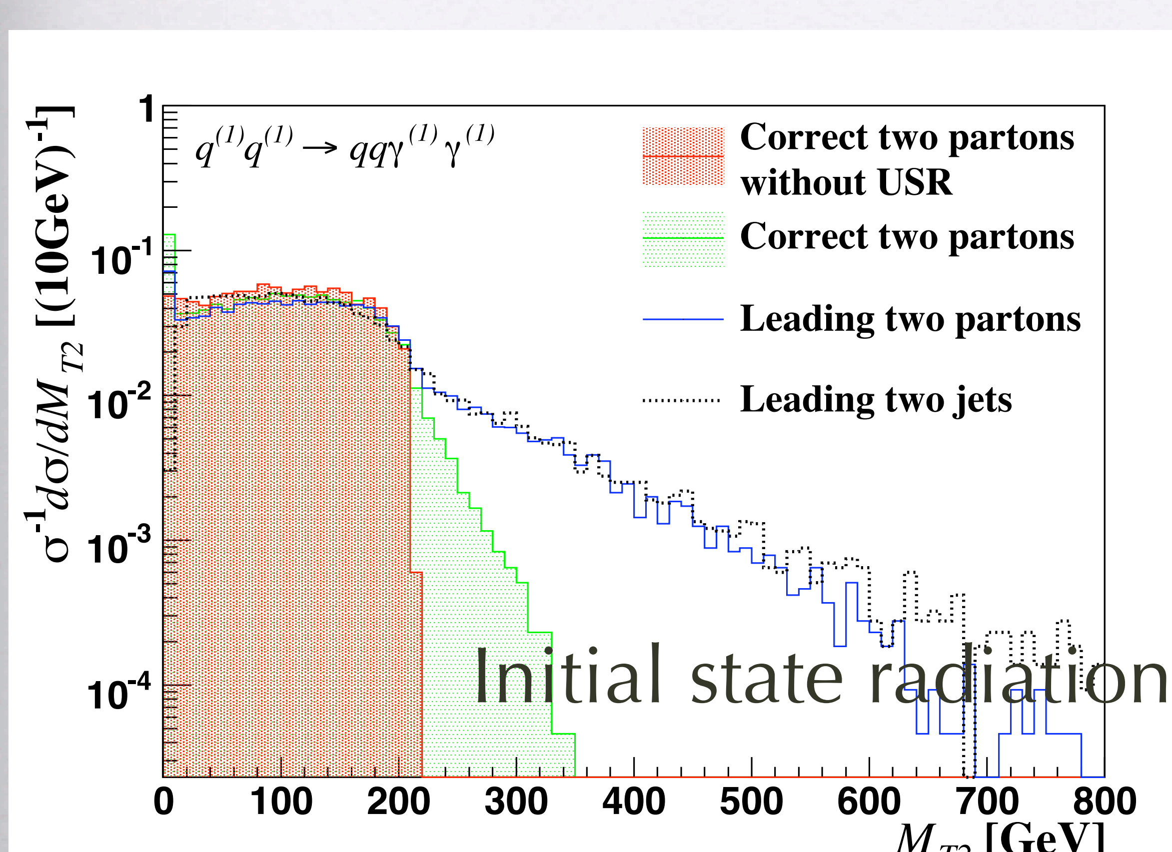
$$M_T^{(i)} = M_T(m_{vis(i)}, m_{inv(i)}, \mathbf{p}_T^{vis(1)}, \mathbf{p}_T^{inv(1)})$$

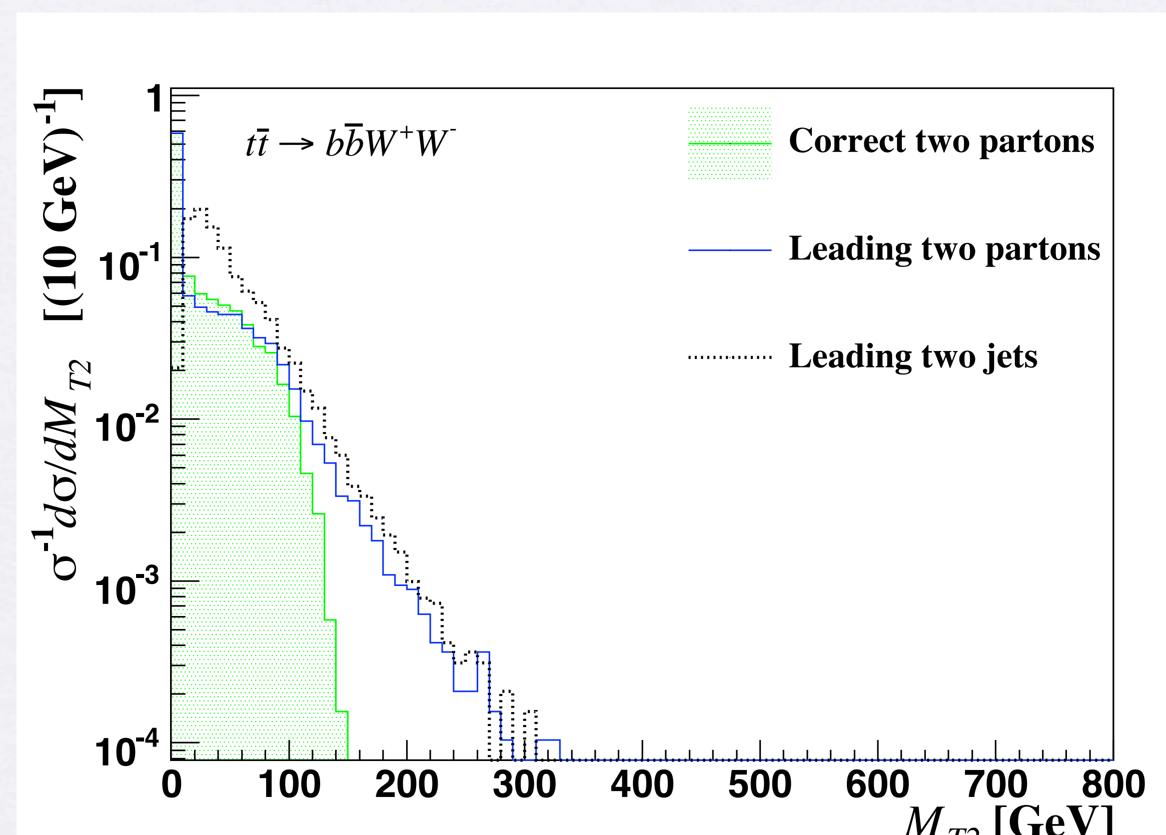
$$\equiv \sqrt{m^2_{vis(i)} + m^2_{inv(i)} + 2\left(E_T^{vis(i)}E_T^{inv(i)} - \mathbf{p}_T^{vis(i)}\cdot\mathbf{p}_T^{inv(i)}\right)},$$

- If there are some quantity sensitive to the mass of pair produced particles, it can be used to reduce background.
- MT2 reconstruct the parent mass when there are two missing particle from both side of decay chain. (all SM production M_T<mt
- MT2 End point is boost independent when input mass is correct

MUED case

- calculate MT2 for leading two jet.
- ttbar distribution leading jets tend to be b jets, and input test mass is correct. therefore they do not extend too much beyond mt.
- signal distribution. Not much jets from MUED particle decay. The leading jet is initial state radiation.

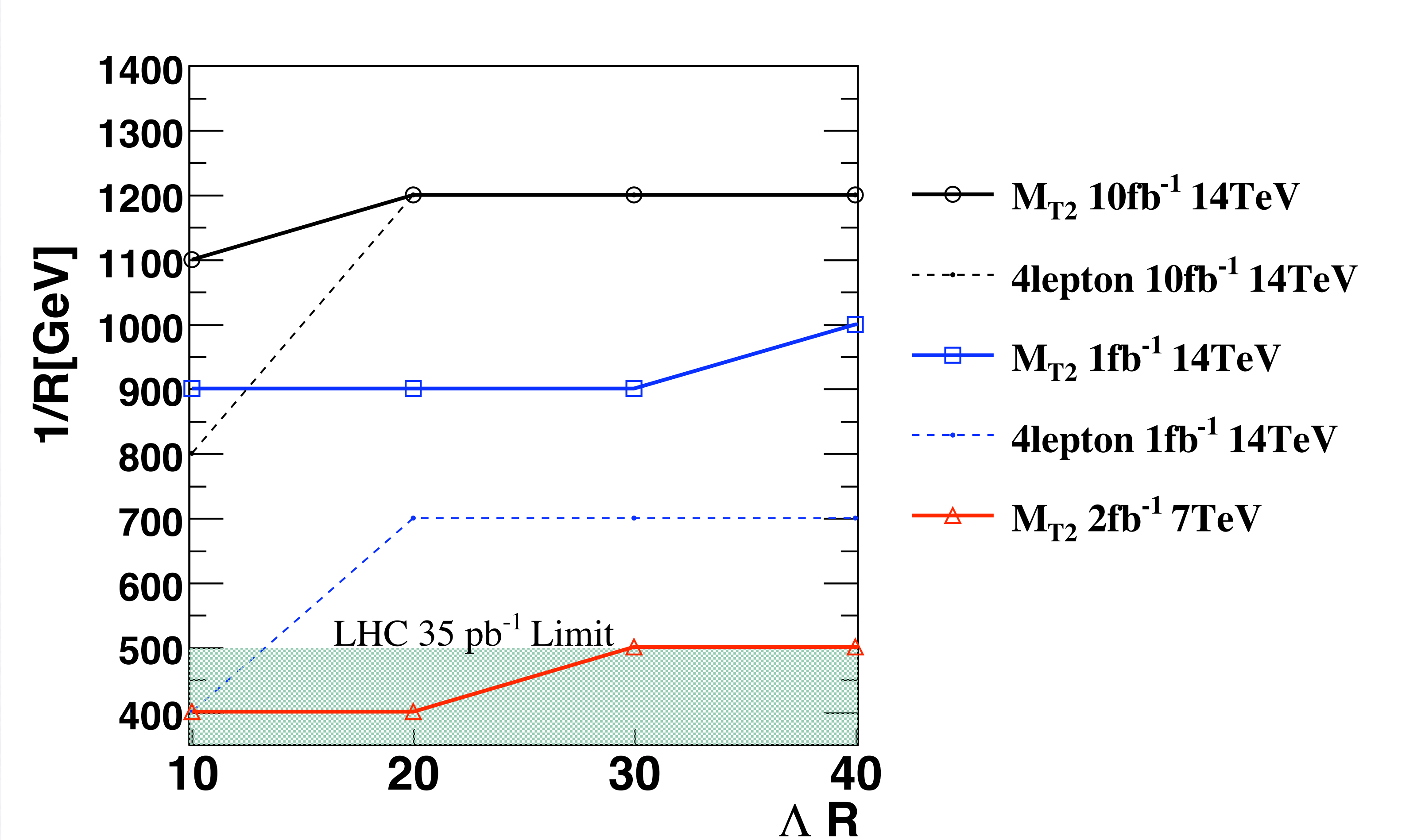




Murayama, Nojiri , Tobioka

Discovery in jets + lepton mode(theorist calculation)

- up to 1.2TeV for 10fb-1 and 14TeV



- Theorist calculation but no b veto assumed. matrix element correction is in for SM background, and not for MUED signal (conservative)

- Decent dark matter candidate in MUED at 1/R~1.5 TeV.

Question?