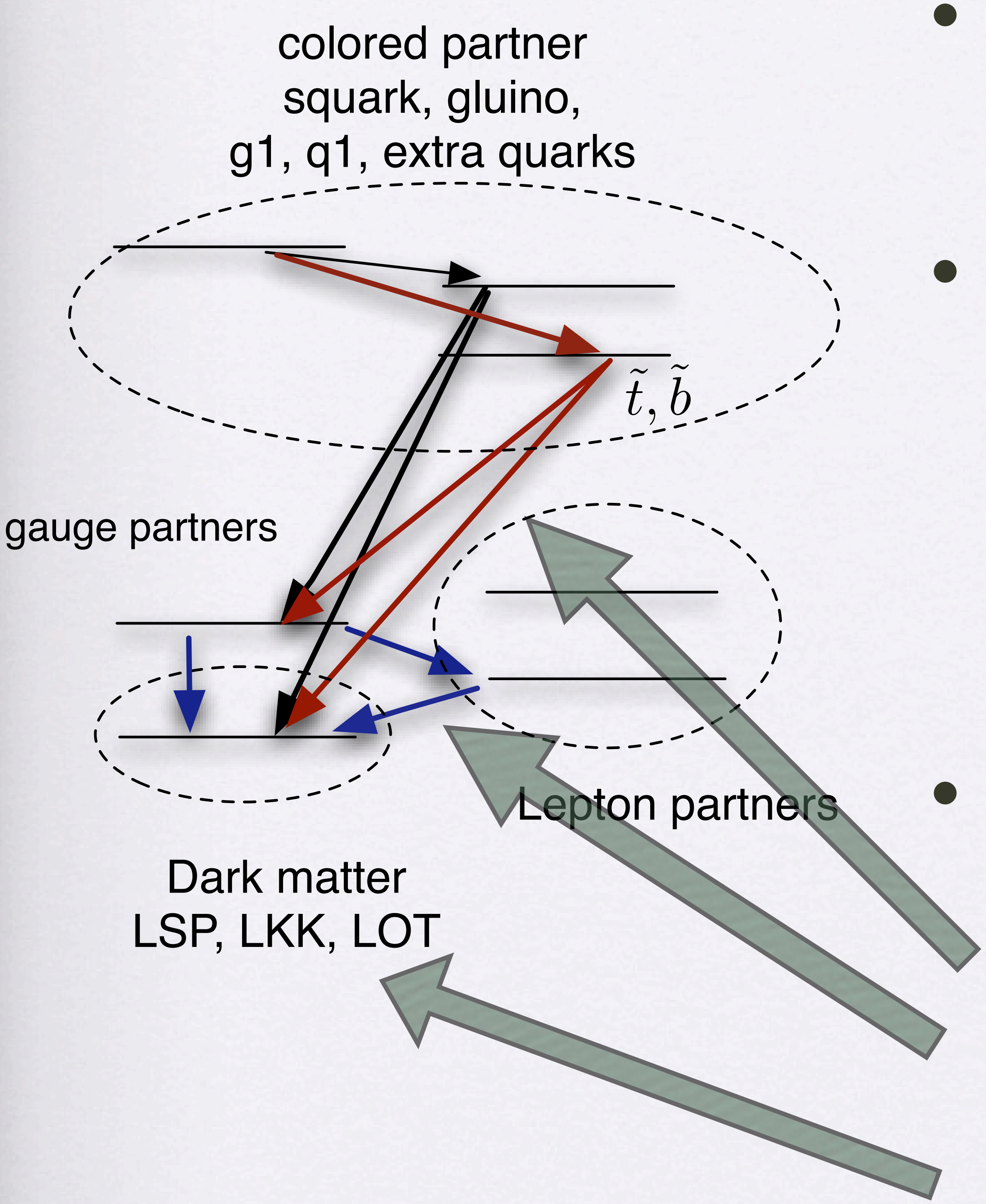
Discovery and measurement of Supersymmetry at LHC

- Discovery of Supersymmetry
- Parameter measurements
- +connection to the cosmology
- Fulll reconstructions
- jets at LHC

DM and collider signature



- **"SUSY signature"** "Models with new colored particles decaying into a stable neutral particle--LSP"
- "New physics" are migrated into SUSY category.
  - Universal extra dimension lightest of first level KK is stable. .
  - Little Higgs model with T parity. T parity in the model, T odd sector has stable particle (B_H)
- Signal: assume mass difference is large

  High P_T jets (p_{T1}>100GeV, $p_{T2,3,4}$>50GeV)

  p_{Tl}>20GeV, S_T>0.2

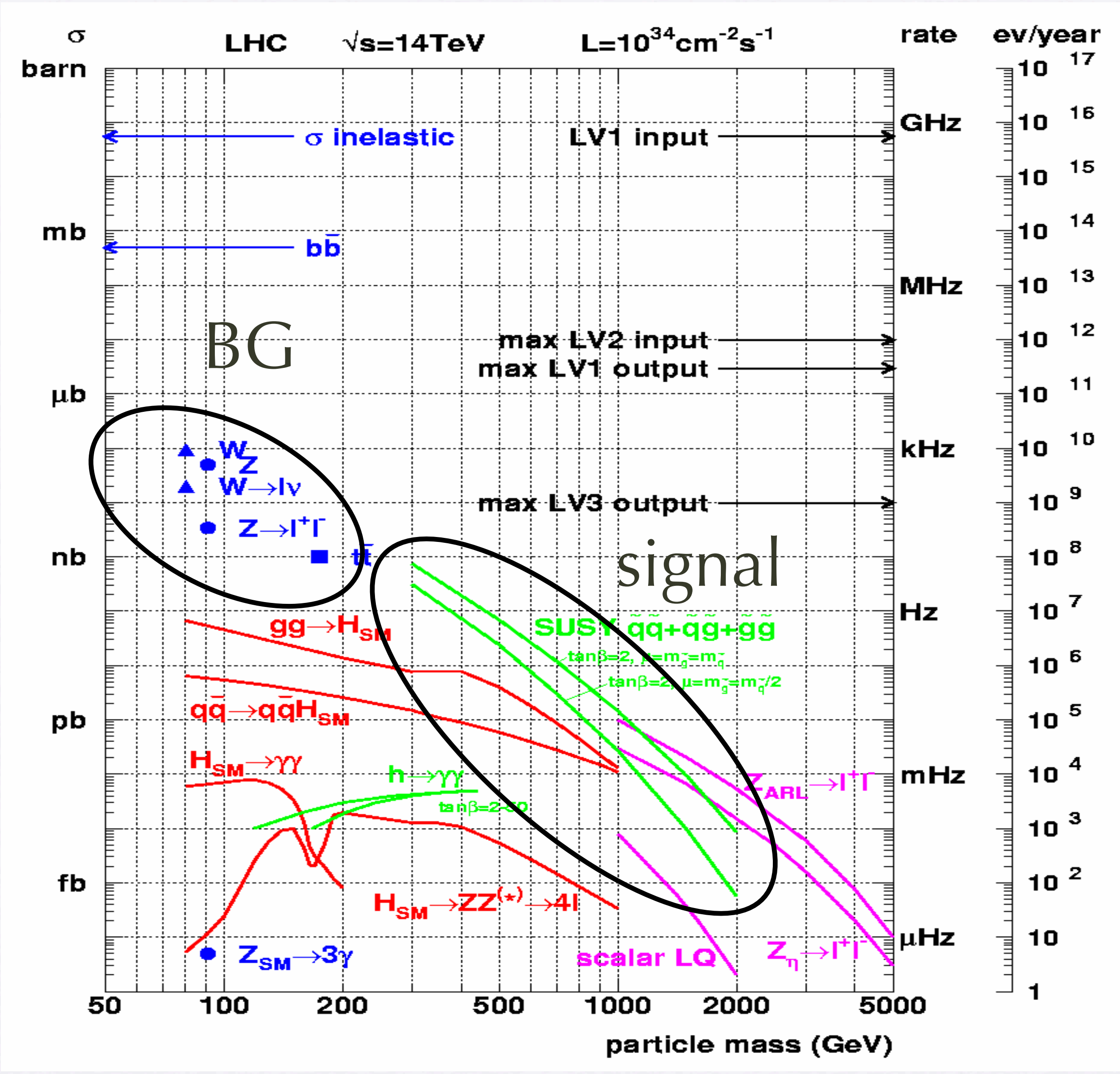
  E_{Tmiss}> max(100GeV, 0.2M_{eff})

Background and discovery

- The typical number of SUSY events are 10^5 for 10 fb^{-1}, while BG rate is 10^{9-8} for W, Z and ttbar productions. 10^{-4} rejection of SM process is required.

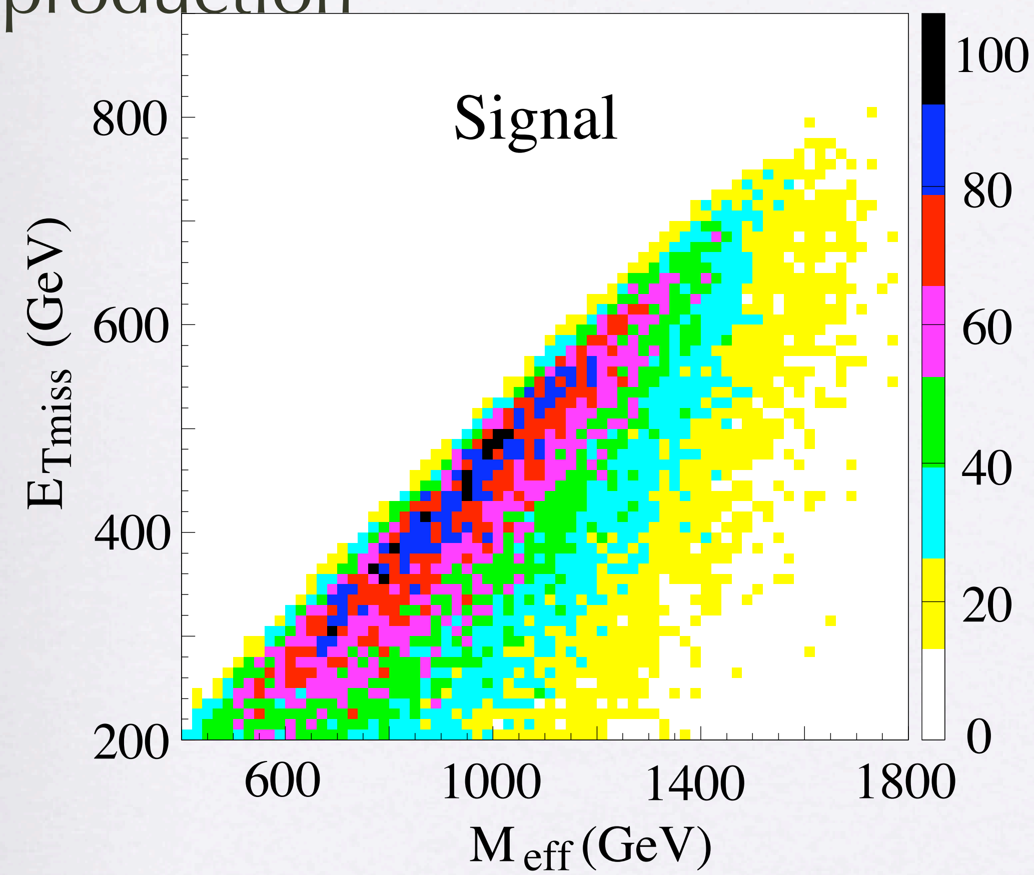
- Understanding of the distribution is the key issue. For discovery
  - P_T distribution of the jets, M_{eff} distribution. (theoretical complexities)
  - E_{tmiss} distributions (Experimental complexities)

CMS

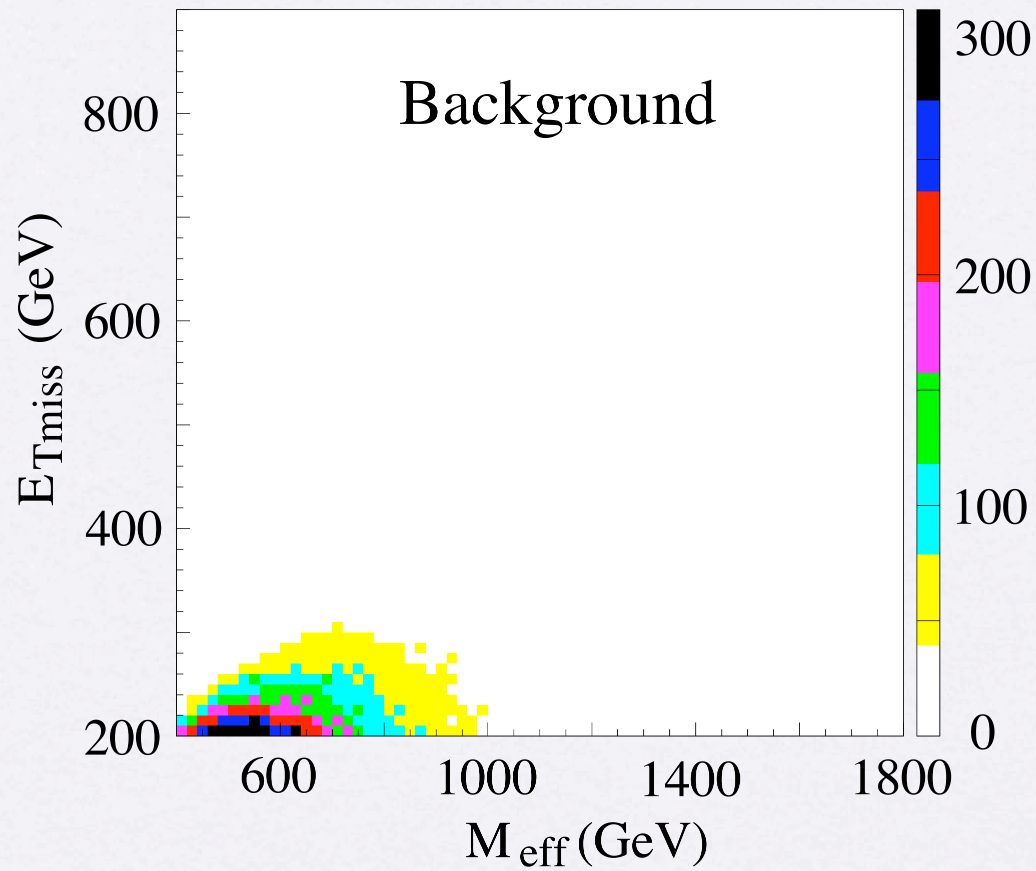


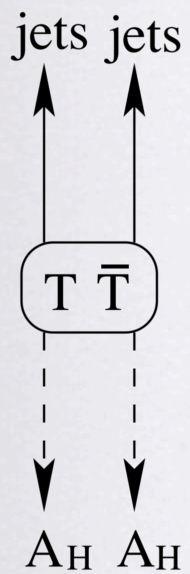
signal and background separation

top partner pair production



ttbar pair production

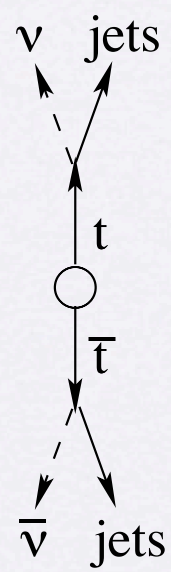




(T T̄ production)

- Two particles produced at threshold
- Two DMs can escape same direction
- Higher ETmiss/Meff

Typical signal structure when 2DM's is in a event !!!!



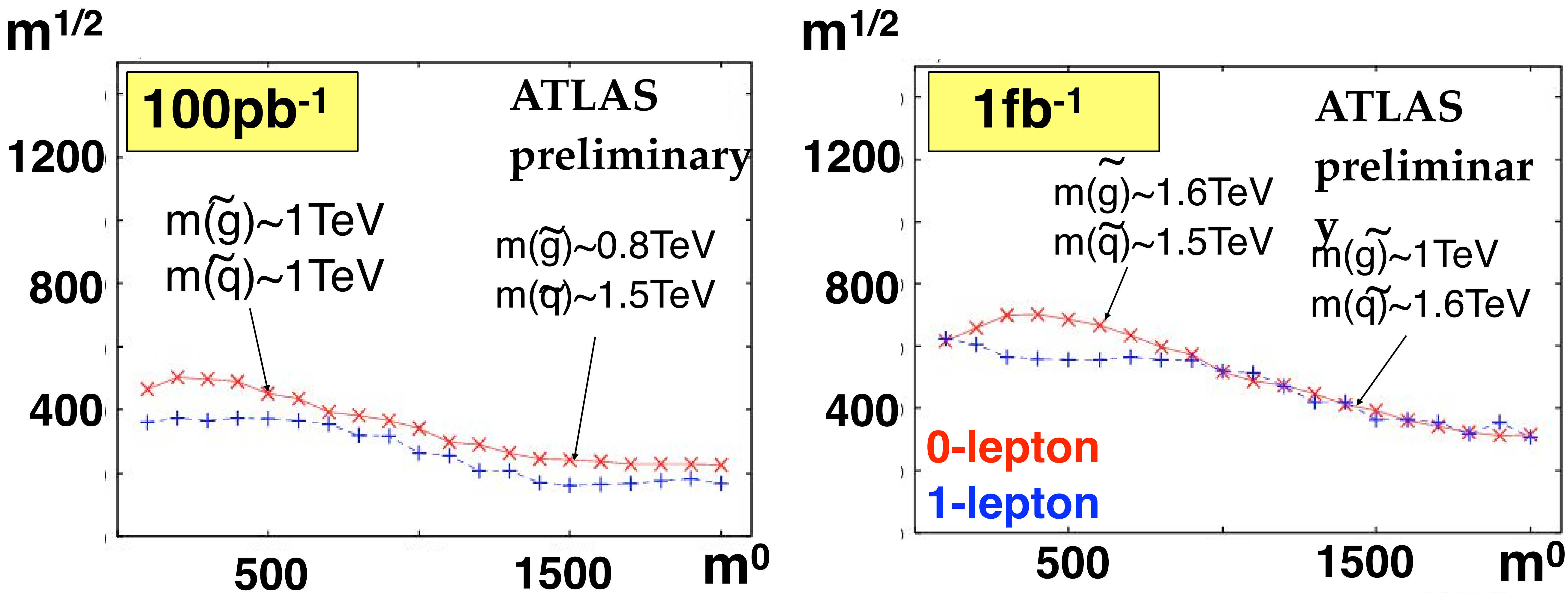
(t t̄ production)

- SM particles are boosted for large Meff
- neutrinos are back to back
- lower Etmiss /Meff

From Kanay's Slide in SUSY06

Discovery Potential

5-sigma discovery potential on m_0-$m_{1/2}$ plane



Fast simulation result
Signal : Isawig/Jimmy
Background : Alpgen

- **<u>Only statistical error is included</u>.**
- **Backgound is estimated by Alpgen.**
- **0-lepton mode : More statistics is available.**
- **1-lepton mode : Relatively smaller background uncertainty. Major background is tt(+njets) is comparatively predictable.**

The “discovery reach” depends on “MSUGRA” assumptions.

choice for large μ

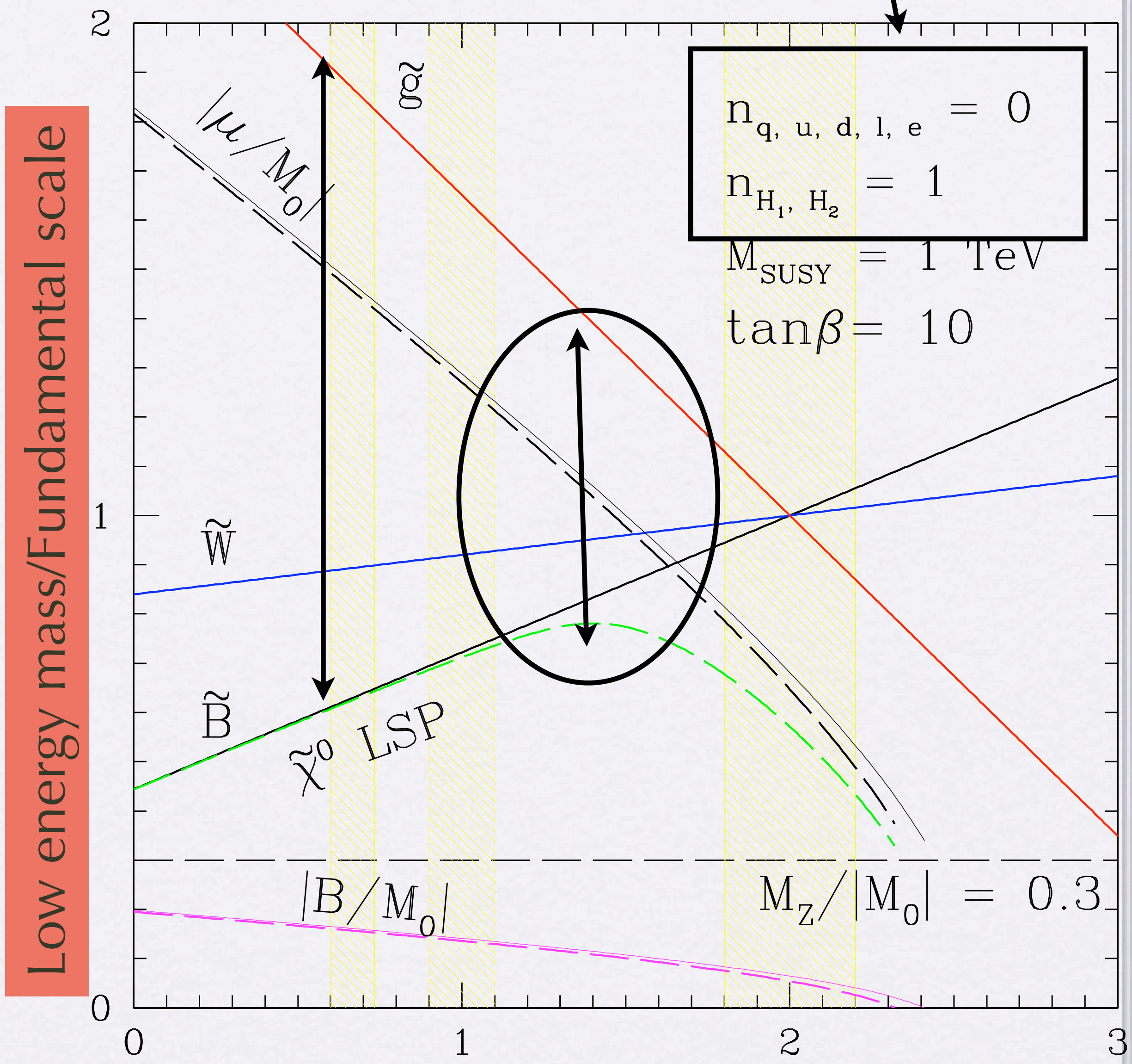
Choi et al (2005)

- Ex. KKLT (or MMAM mixed modulas anomaly mediation model) If both volume modulas T and compensator C contribute to the SUSY breaking.

$$M_a = \left(\frac{l_a}{R} + \frac{b_a g_{GUT}^2}{16\pi^2} \right) m_{3/2}$$

- mass spectrum can be quite degenerated. Change FT/FC, MSUGRA→ UED like→ AM

- The most degenerate spectrum corresponds to mixed dark matter. Consistent to ΩM



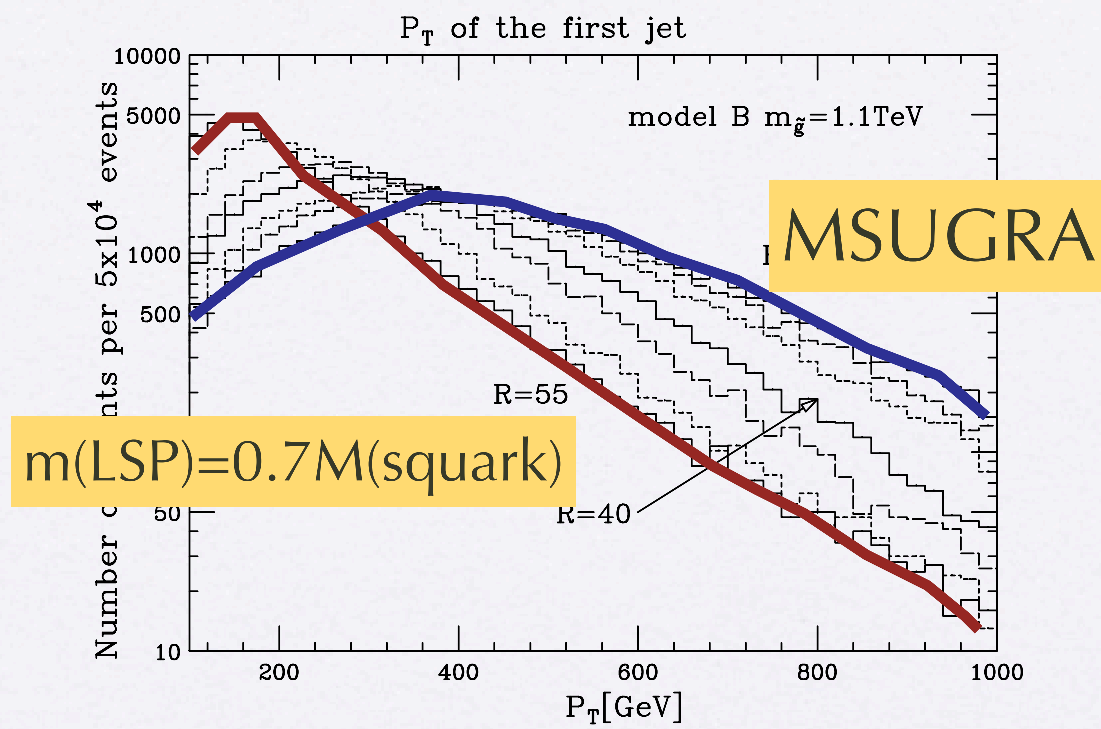
$$\alpha = \frac{m_{3/2}(T + T^*)}{F_T \log(M_{pl}/m_{3/2})}$$

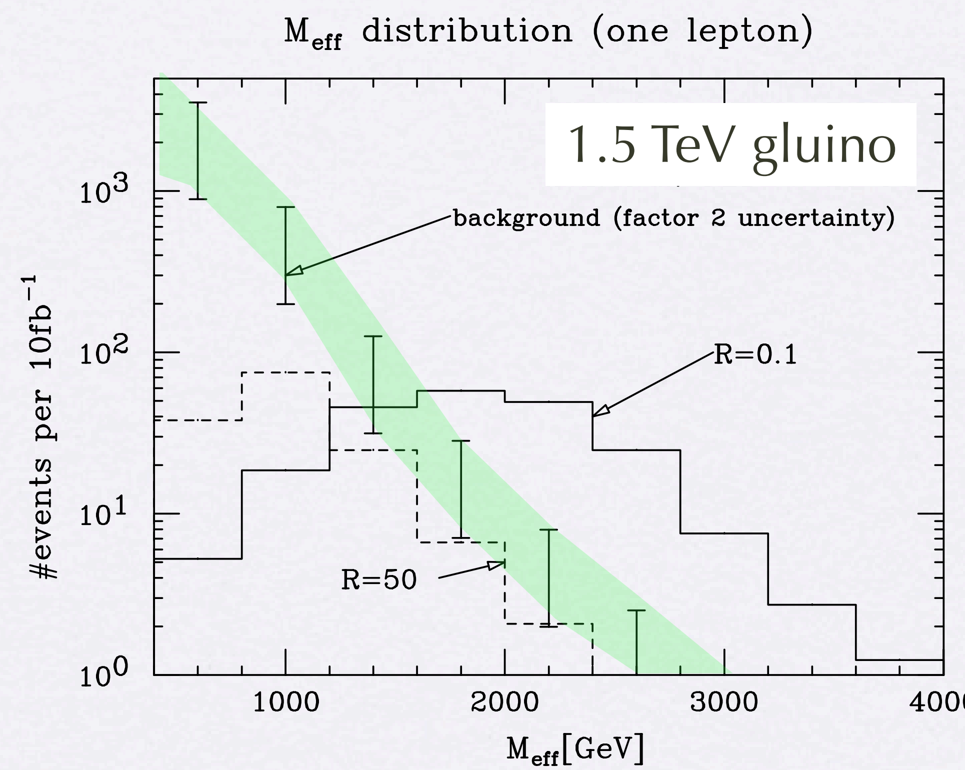
SUSY at LHC in degenerated limit

- degenerate SUSY= lower P_T jets, small M_{eff},, Small missing energy. Discovery gets difficult (no chance if all masses are same of couse)

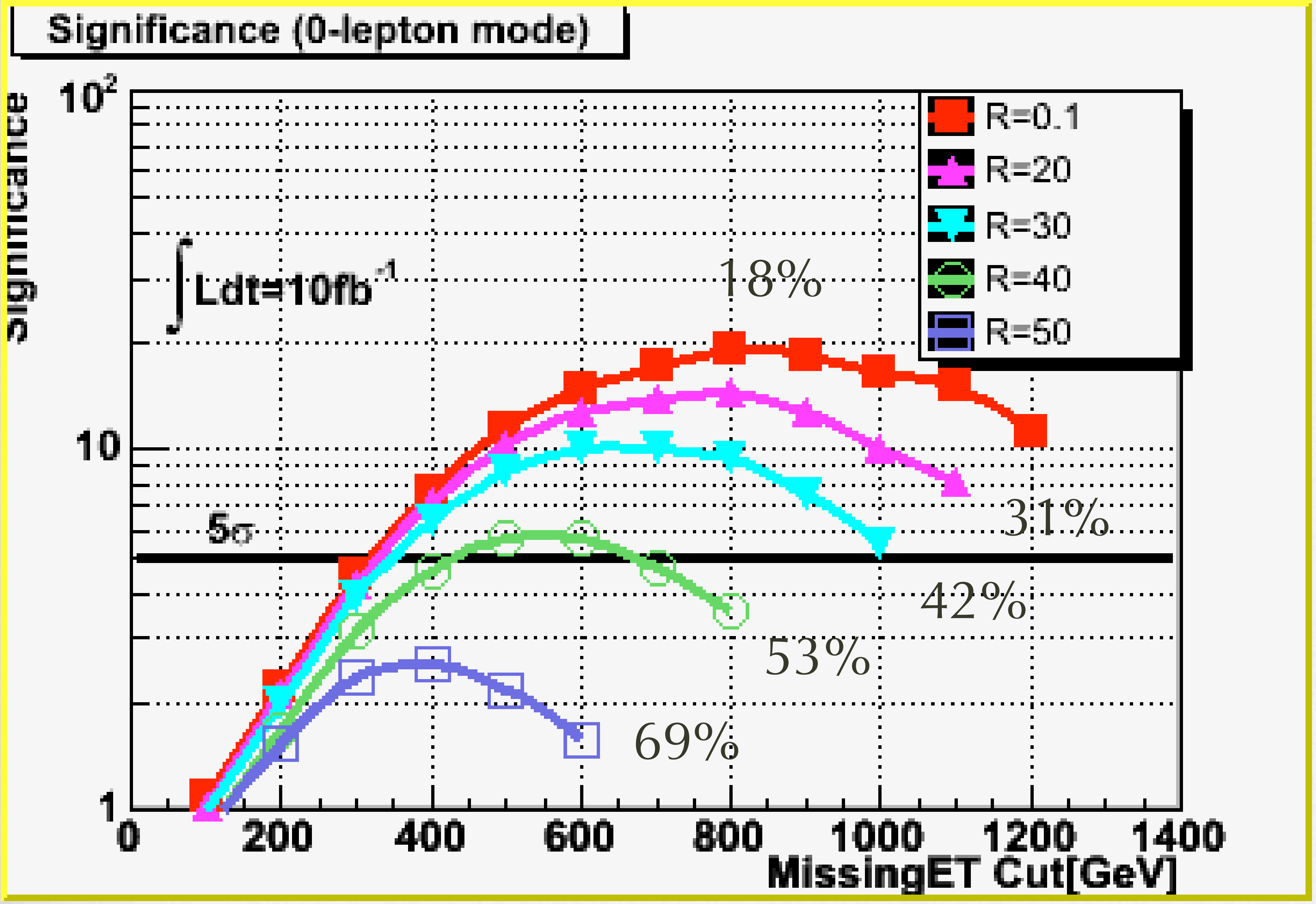
- Need to take into account the background seriously. S/N<1, discovery is in ?? because of the background uncertainty

- Recent preliminary ATLAS simulation (by S. Okada +et al Kobe group including QCD, W, Z, ttbar background with ME collections) confirms the same tendency. Discovery is extremely tough if m (LSP)>0.7 M(squark.





Kawagoe and Nojiri



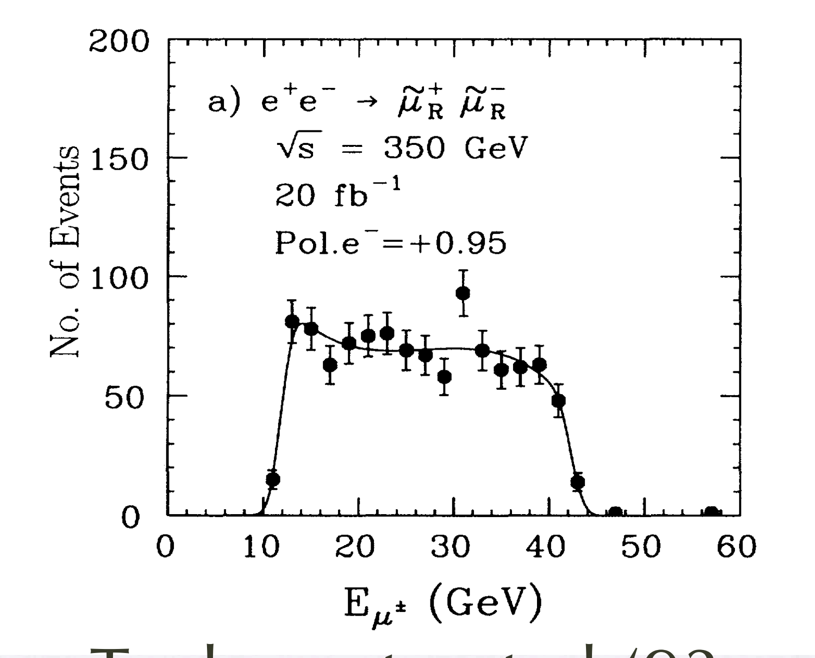
S. Okada et al (Kobe group
very preliminary

We need to study more
on degenerate cases

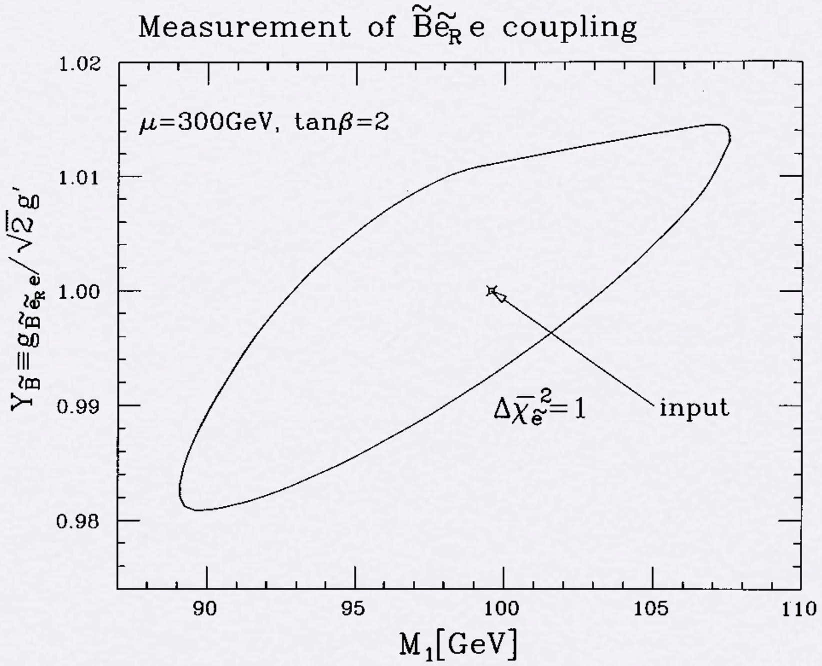
Measurement of basic parameters

SUSY parameter measurement
A brief history

- early 1990
  - JLC study: define LC as the machine to measure SUSY parameters, spin, and interaction. check GUT relation M_1:M_2
  - LHC = a discovery machine.
- Snowmass 1996:
  - Trying to establish US participation at LHC, "(ex-) Theorists"(Hinchliffe, Paige, ...) took LC concepts. Techniques for mass reconstruction were established at that time.
  - ILC: SUSY coupling measurements ('96 Nojiri et al , Feng et al....): physics point of LC over LHC



Tsukamoto et al '93

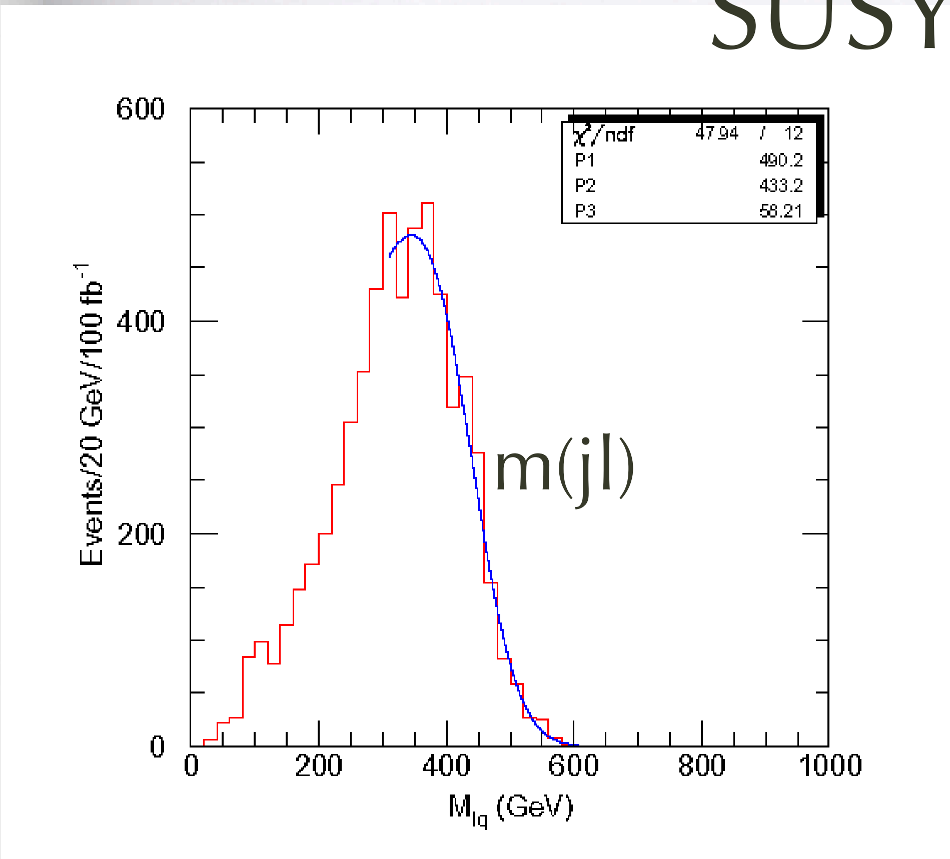


Nojiri et al '96

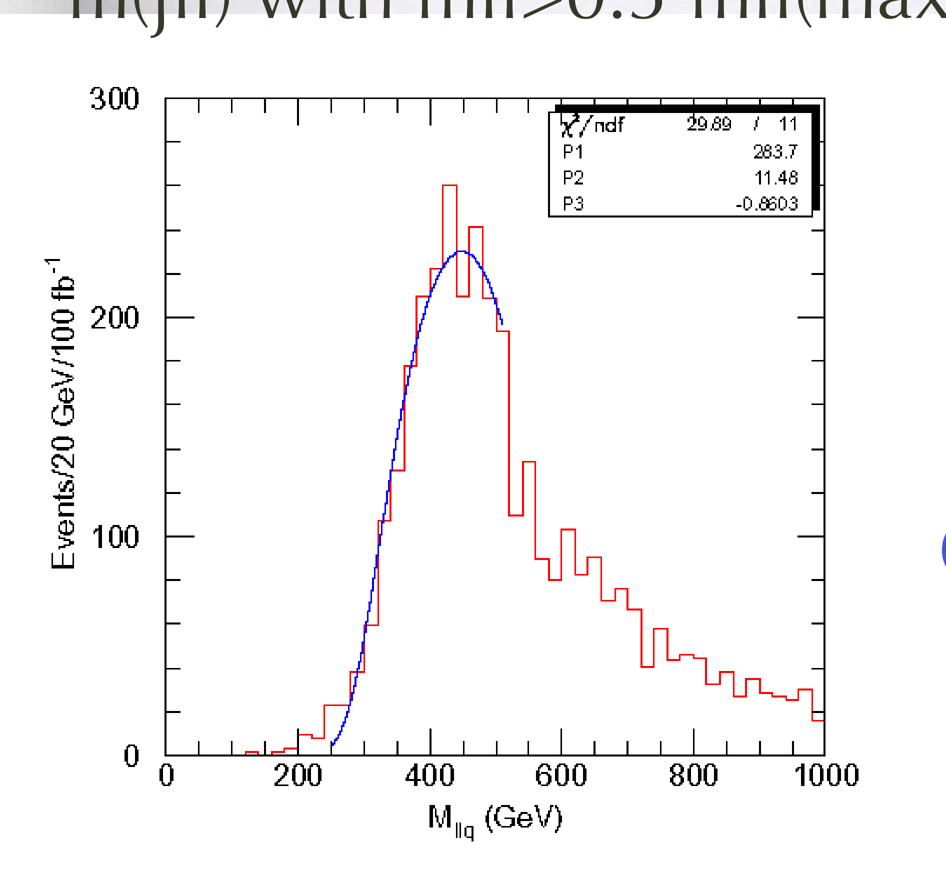
measurement at LHC a check list

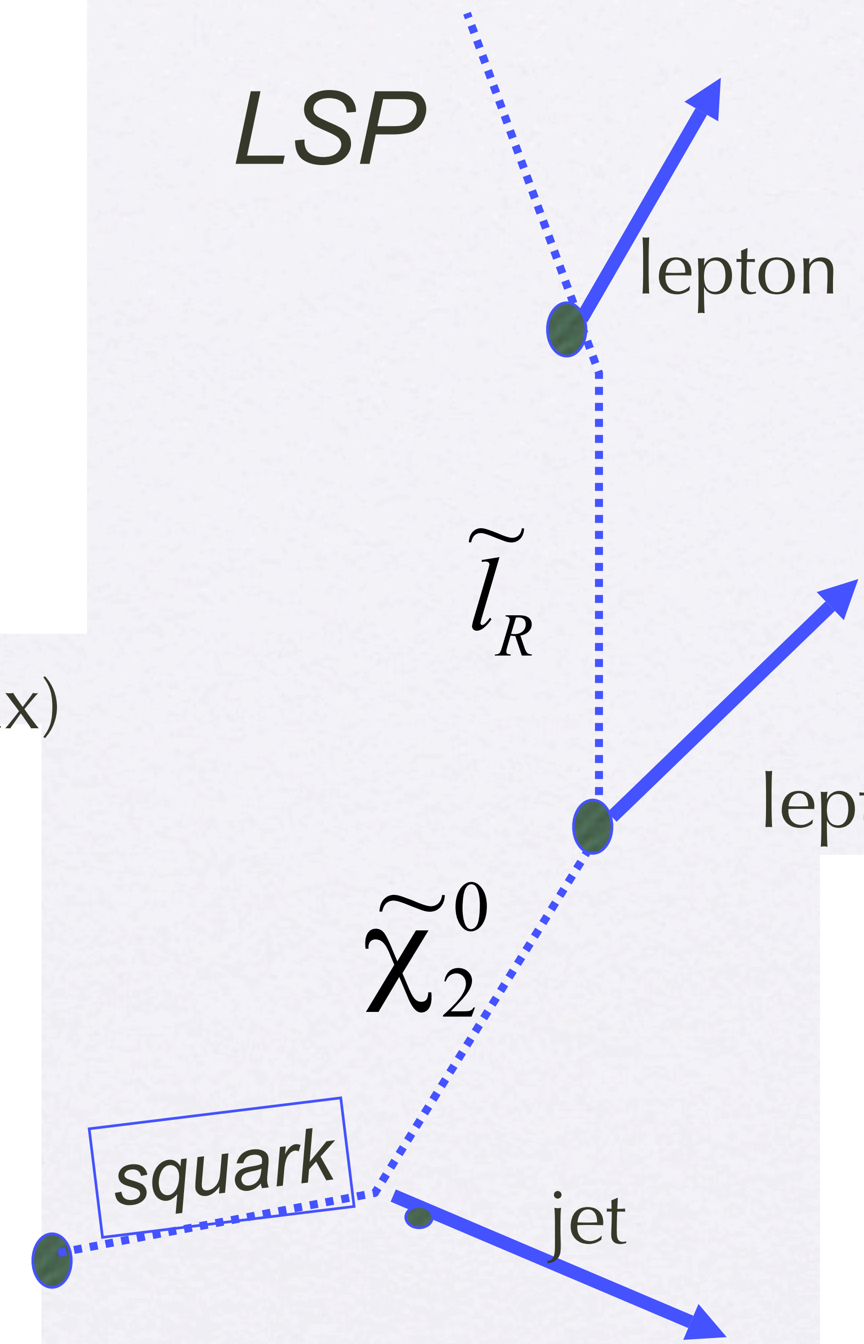
- In the past ILC study, emphases were on the measurements on Supersymmetric parameters. Let check how much LHC can do.
  - mass — possible using end point method and transverse parameters (such as MT2
  - MSSM parameters — Some guess using branching ratios
  - spin — charge asymmetry and cross section
  - SUSY couplings — not yet

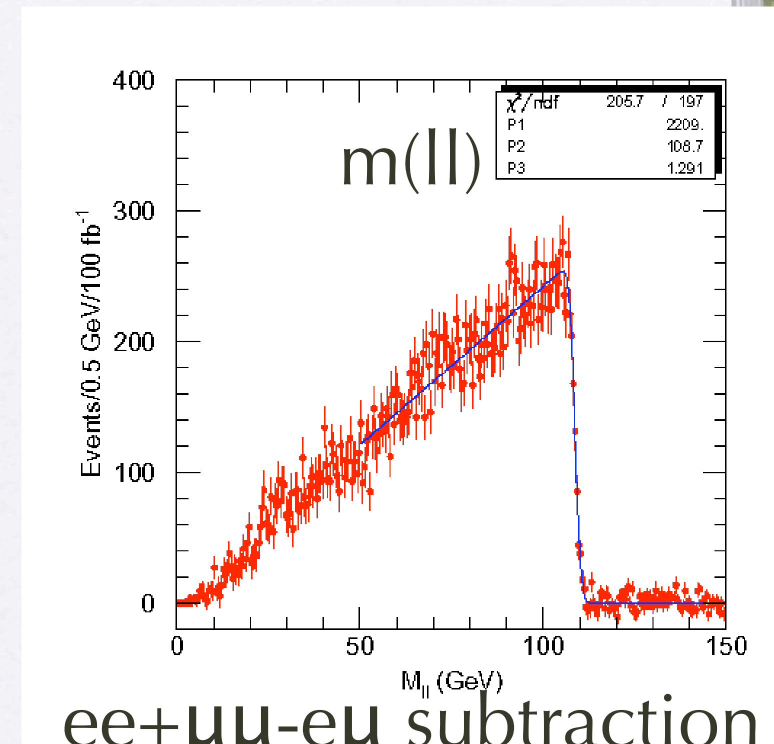
SUSY parameter measurements



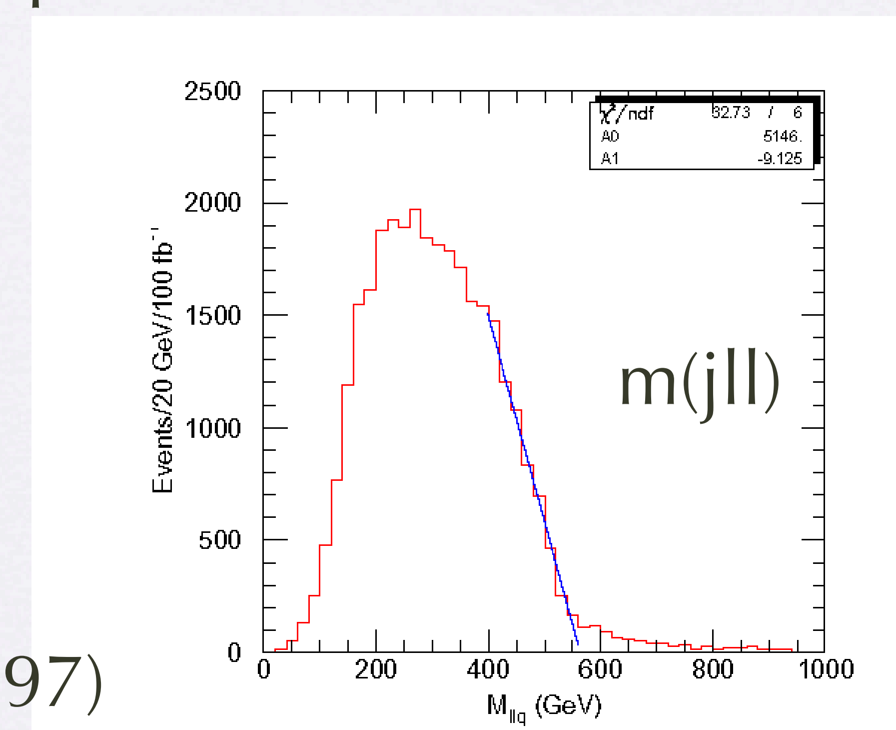
m(jll) with mll>0.5 mll(max)







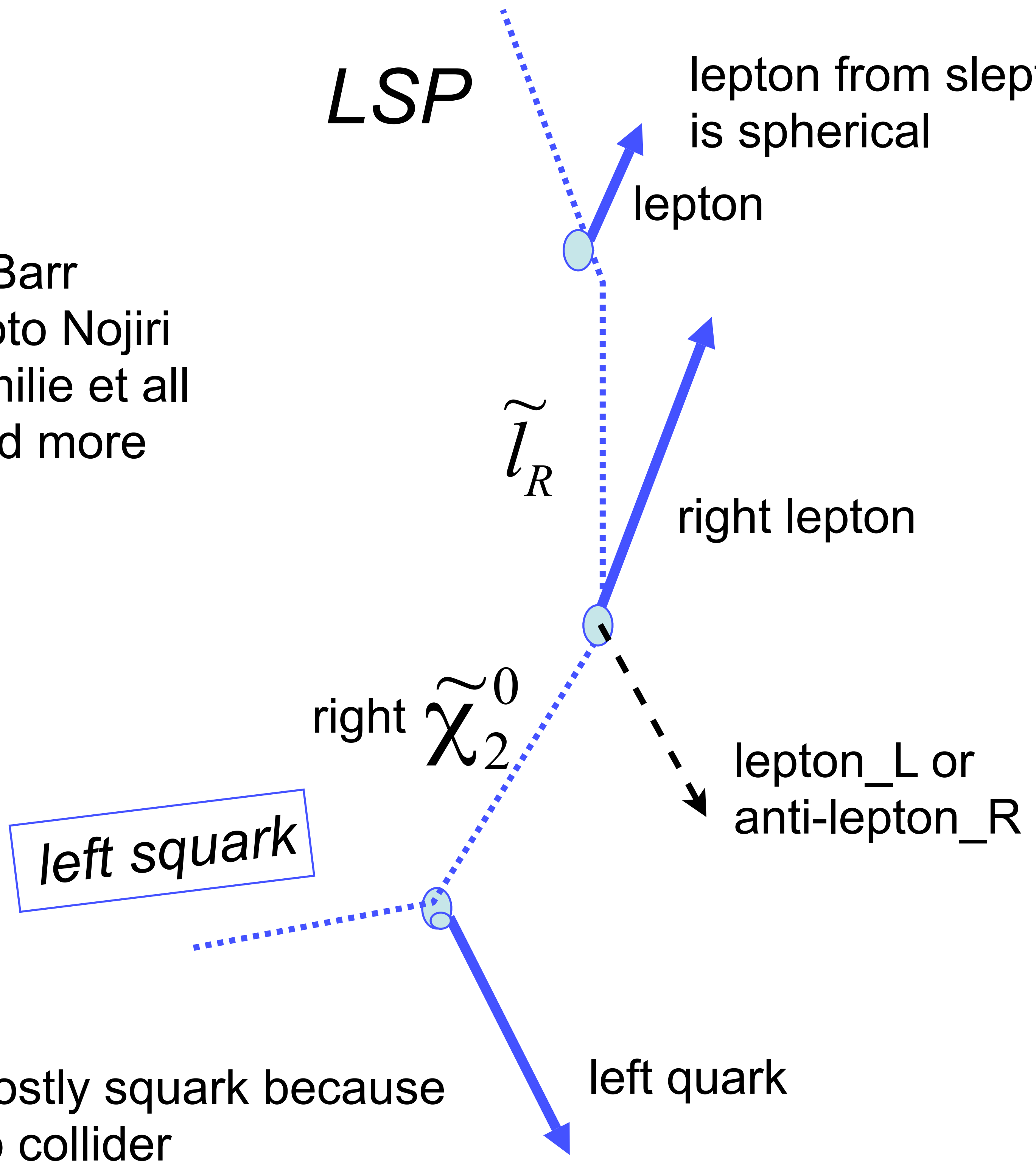
ee+μμ-eμ subtraction is effective to select single channel



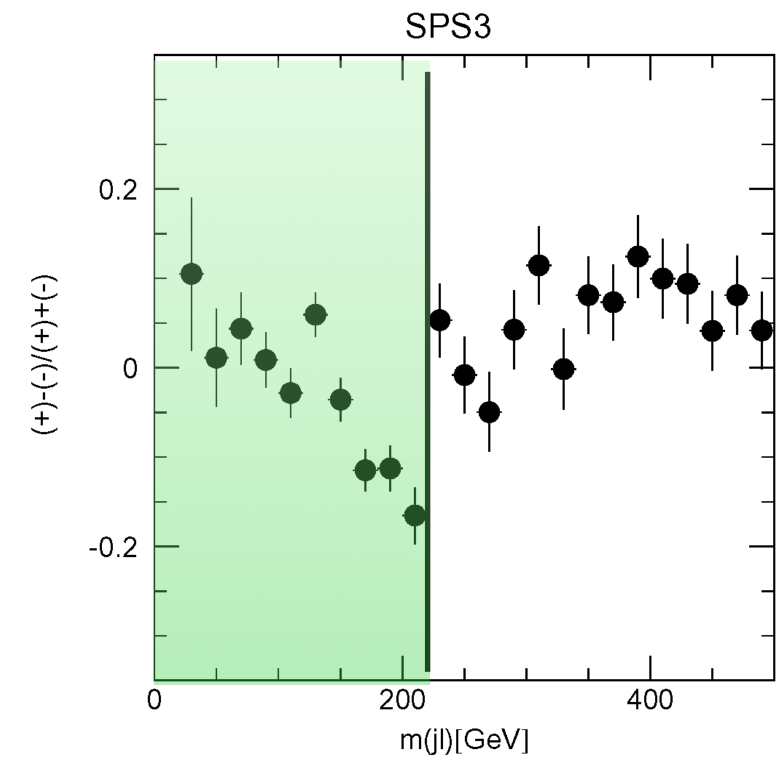
Hinchliffe et al (97)

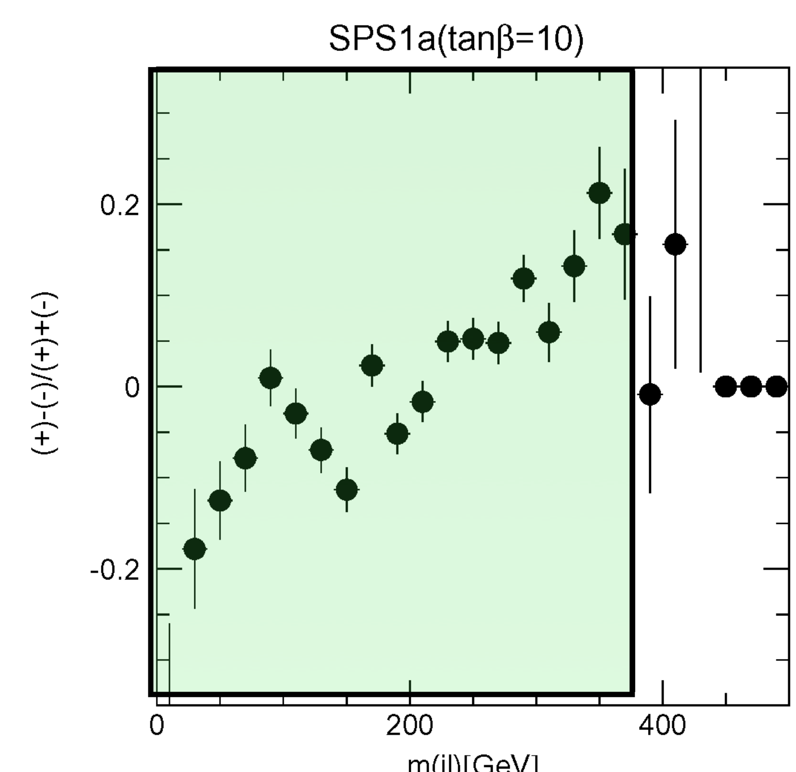
Spin Effect (fermion ino + chiral interaction)

A Barr
Goto Nojiri
Smilie et all
and more

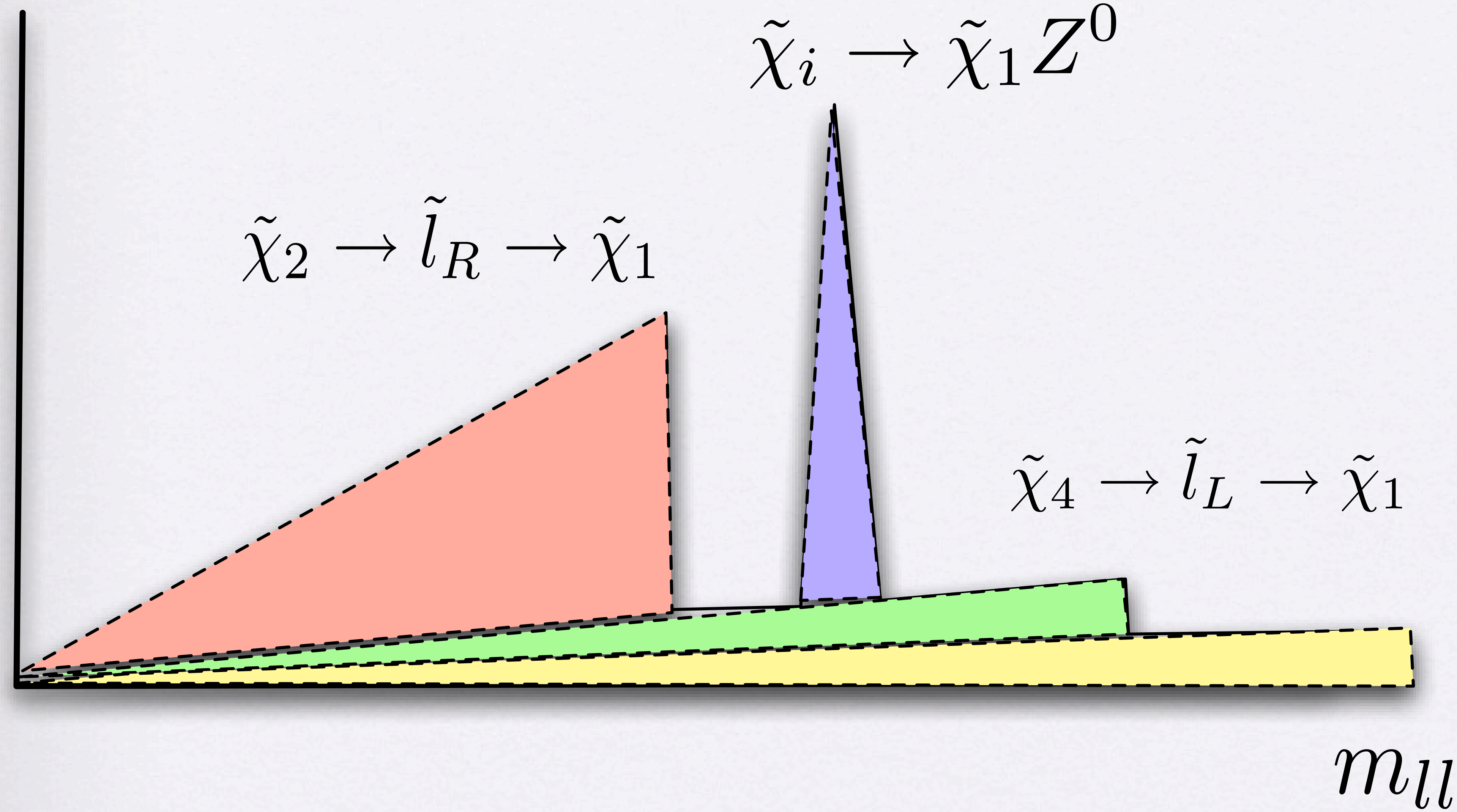


mostly squark because
pp collider





Best Case at LHC



- Evidence of multiple ino give our access to ino masses, thus μ and M_i
- squarks and gluino work as the source of EW sector of Supersymmetry.

Summary in SPS1a (most lucky case)

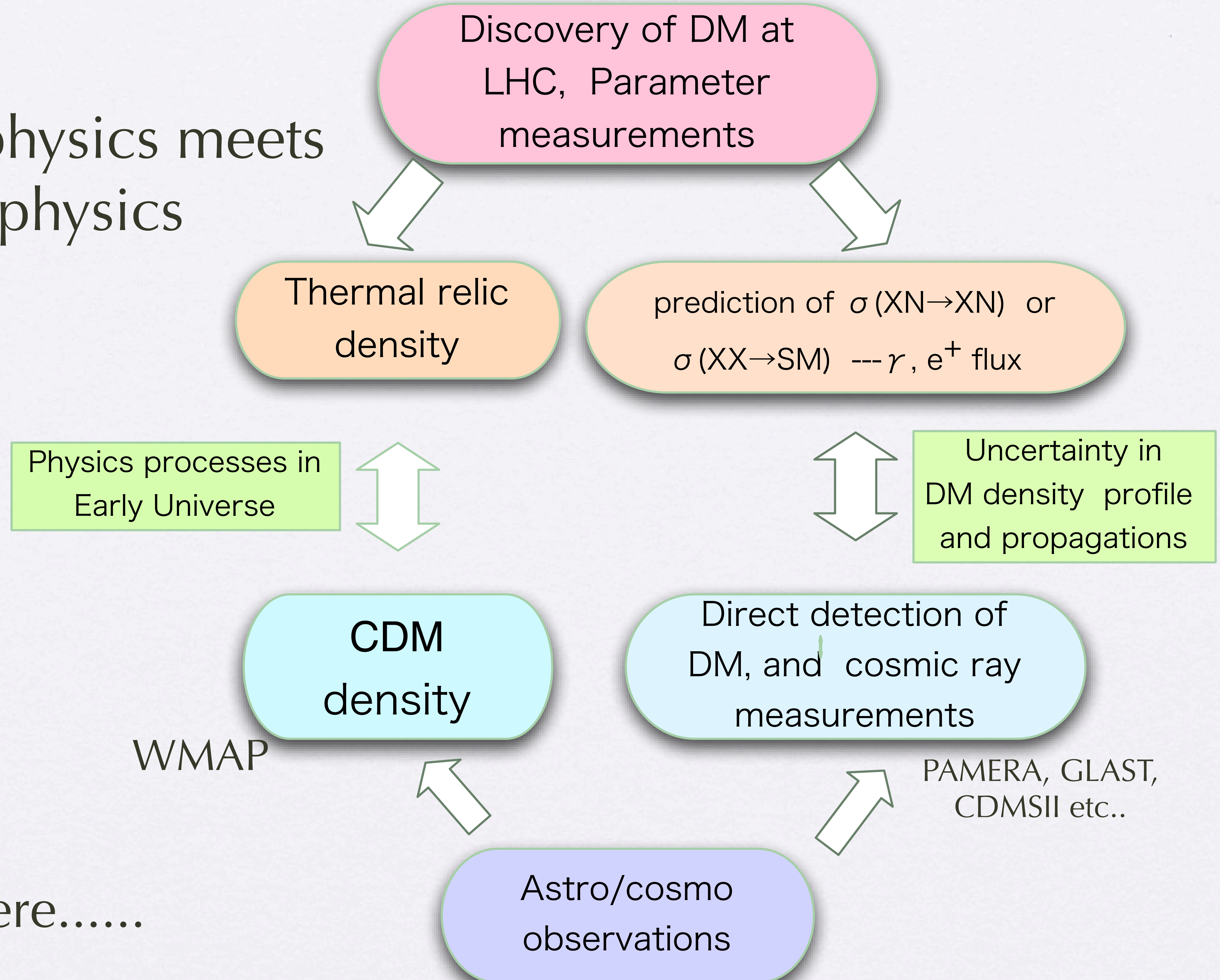
from LHC/LC study

particle	mass	error(low)	error(high)	
gluino	595	16.3	8.0	bbll
squark(L)	540	21.2	8.7	jll
squark(R)	520	17.7	11.8	M_{T2} 10GeV sys
$\tilde{\chi}_4^0$	378	14.6	5.1	
$\tilde{\chi}_2^0$	177	13.4	4.7	
$\tilde{\chi}_1^0$	96	13.2	4.7	

- LSP mass error is large, but mass differences are known precisely. There are correlated overall error to the mass scale.
- Access to 2 or 3 neutralino mass, information on 2 of 4 LSP parameters
- selectron and smuon mass error is about same to that of LSP

Connection to Cosmos.

At LHC
Collider physics meets
Astrophysics



if it is there......

DM density control parameters

1)bulk : LSP=Bino like.
Slepton exchange

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

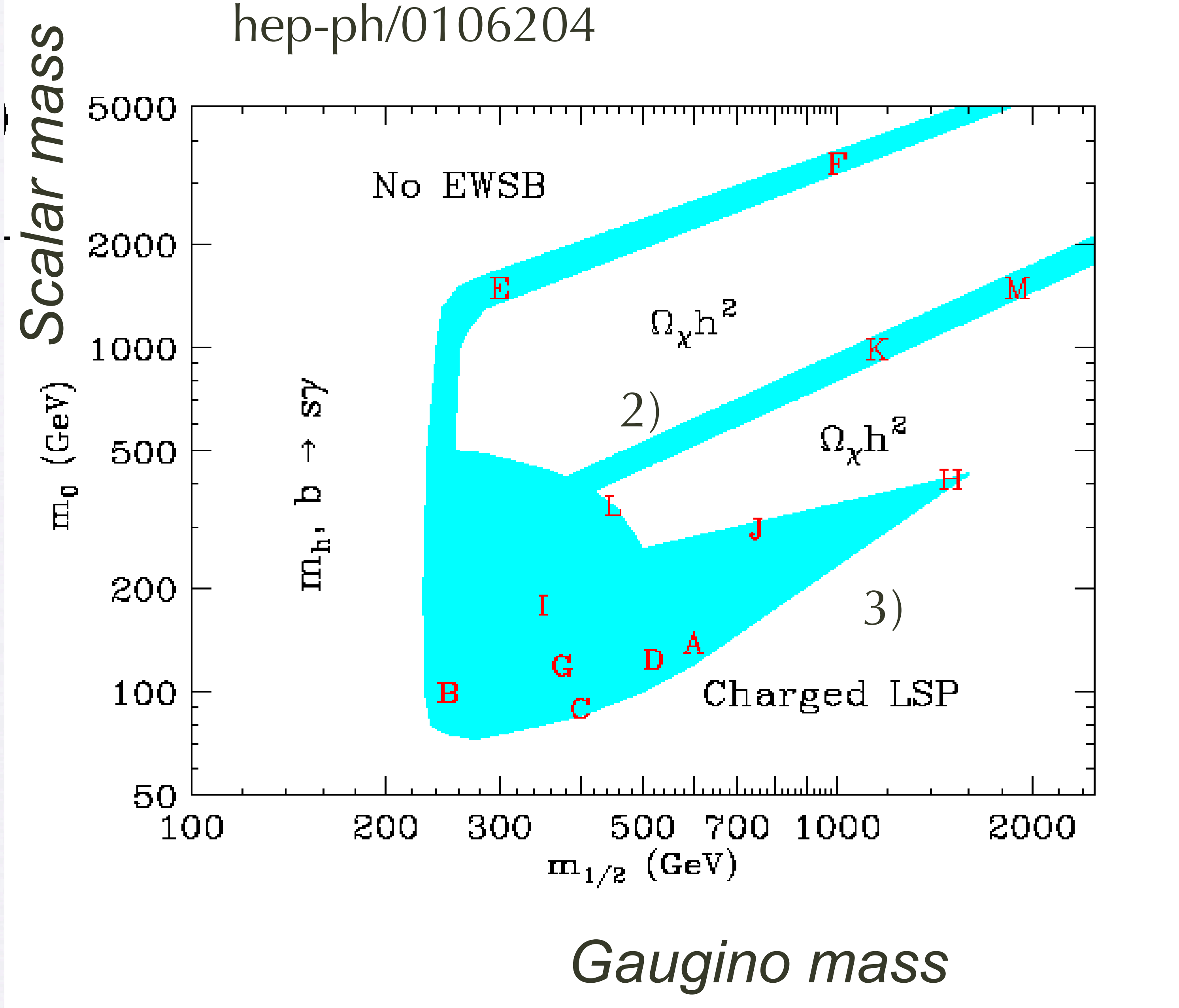
too large mass density

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

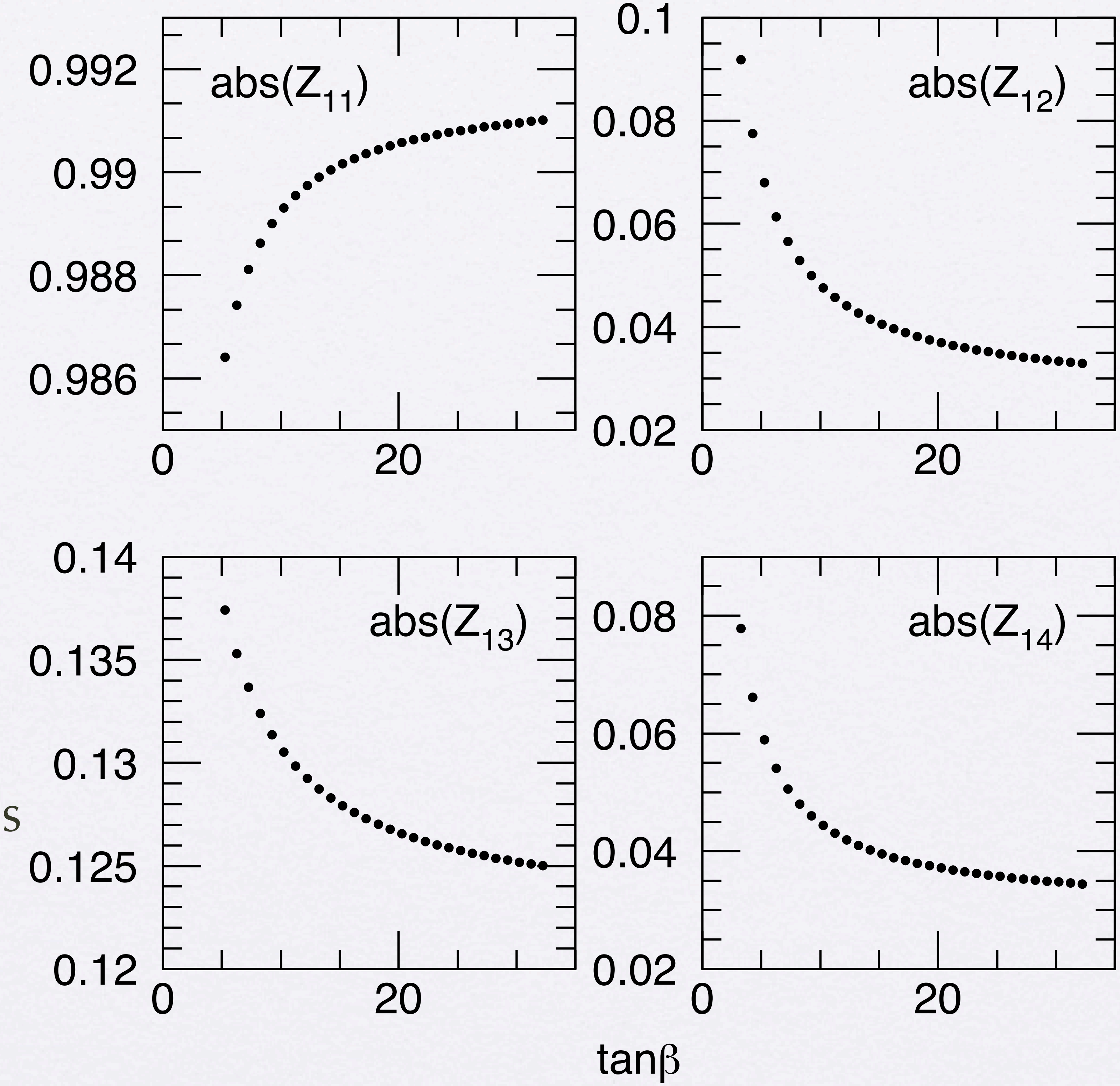
3) coannihilation $\tilde{\tau}\tilde{\chi}$

4)focus point region:
higgsino-gaugino mixing

hep-ph/0106204

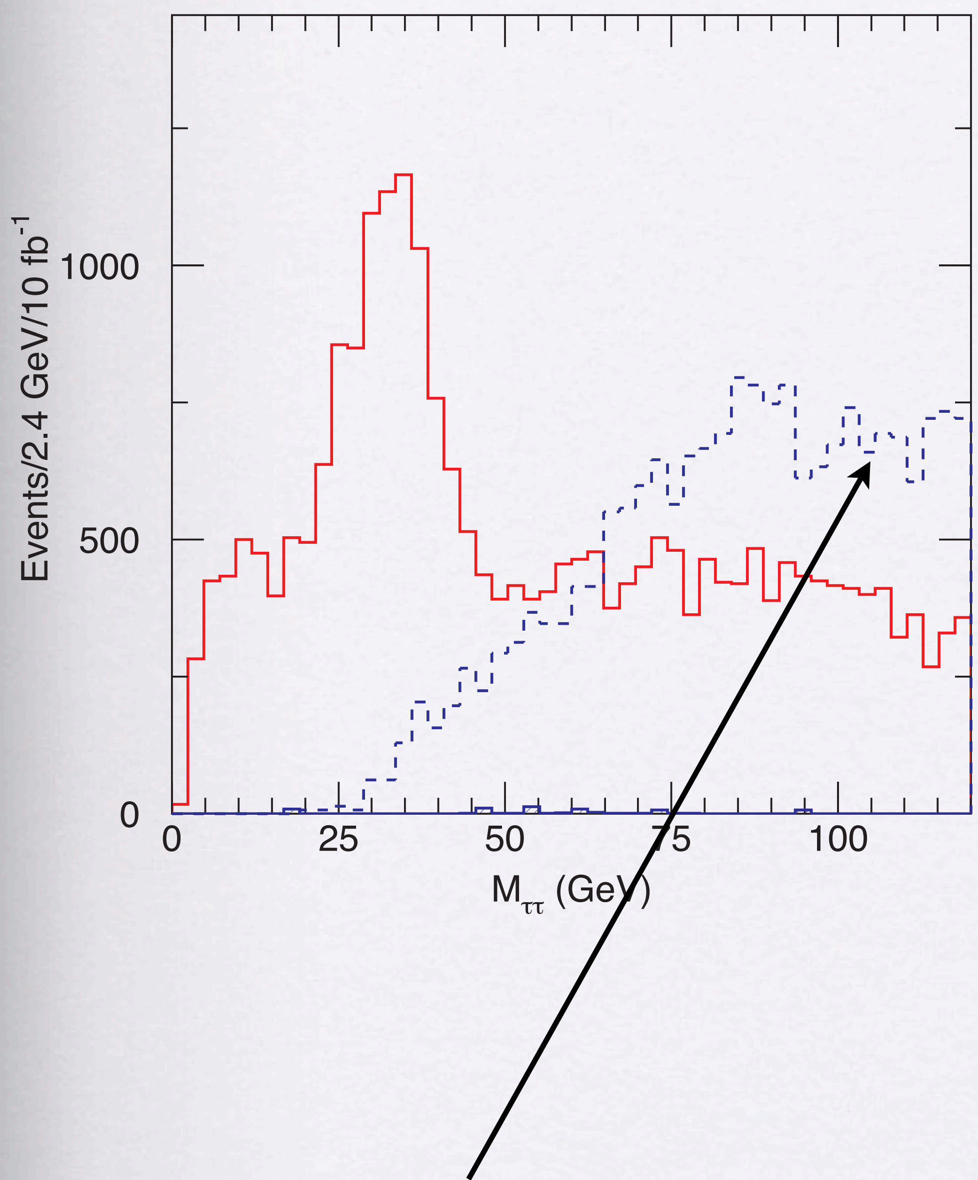


Dominant uncertainty of ino mixing angle comes from tanβ



constraint to the LSP-N cross section is not strong

Importance to measure tau mode.

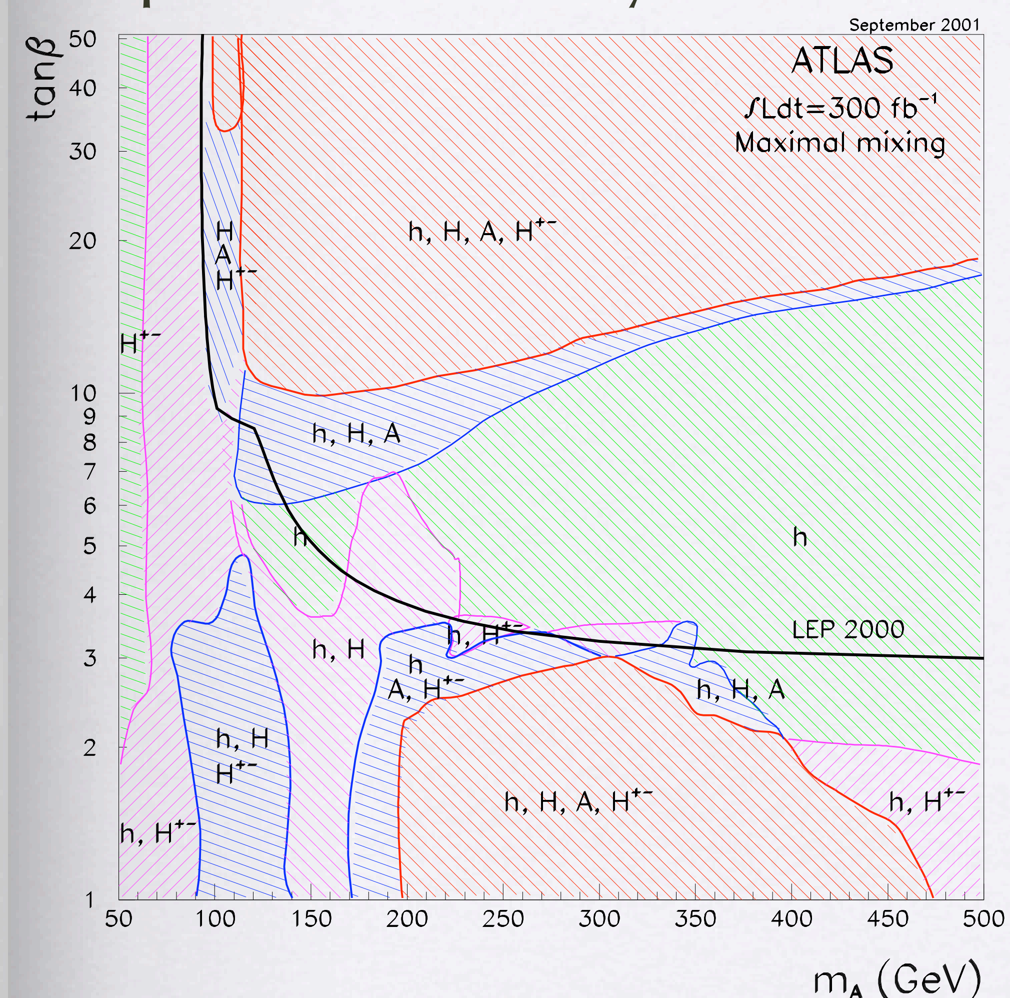


tau -fake tau

- If tau coannihilation is on, the mass density is very sensitive to the stau LSP mass difference.
- Due to the left right mixing, 2nd lighest neutralino tend to go to tau mode. finding edges exclude the possibility of stau LSP coannihilation.
- tau jets are identified as narrow jets. Tau is experimentally difficult because QCD fake tau + particles converted at inner trackers. 41% tau tagging efficiency with significant background.
- we took 62GeV \pm 5 GeV for this point.

Importance to get lower limit on MA

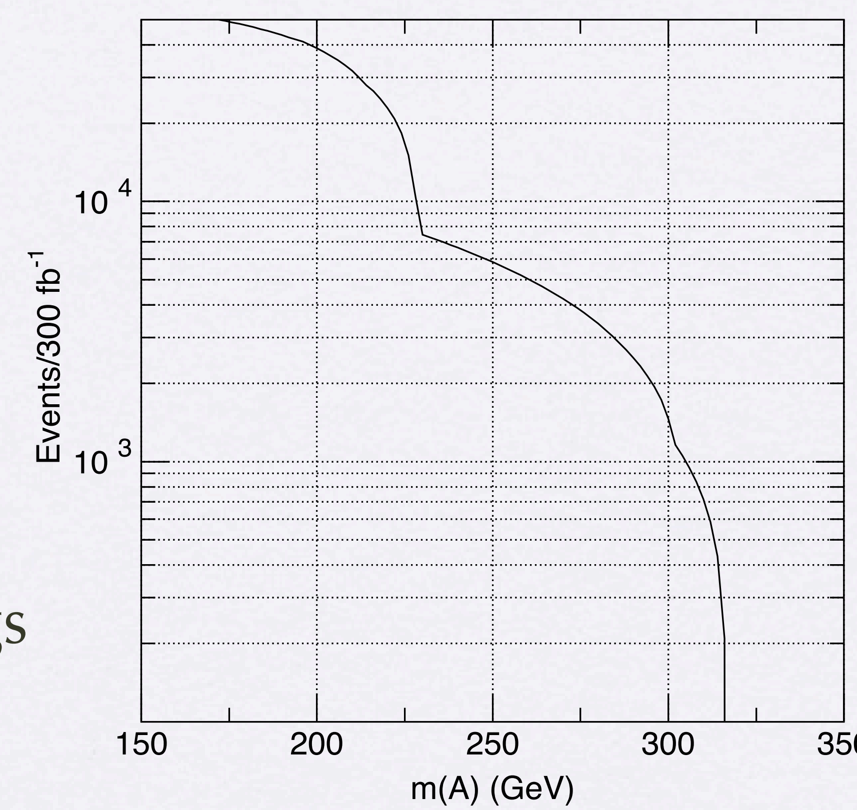
Assumes all SUSY particle is heavy



The limit from non -SUSY production for tanβ=10 is around 250 GeV

We also have heavy Higgs from SUSY production with significant cross section

- $m(A/H) \leq 315$ GeV for $\tilde{\chi}^0_{4(3)} \to \tilde{\chi}^0_1 A/H$
- $m(A/H) \leq 230$ GeV for $\tilde{\chi}^0_{4(3)} \to \tilde{\chi}^0_2 A/H$ and $\tilde{\chi}^\pm_2 \to \tilde{\chi}^\pm_1 A/H$.

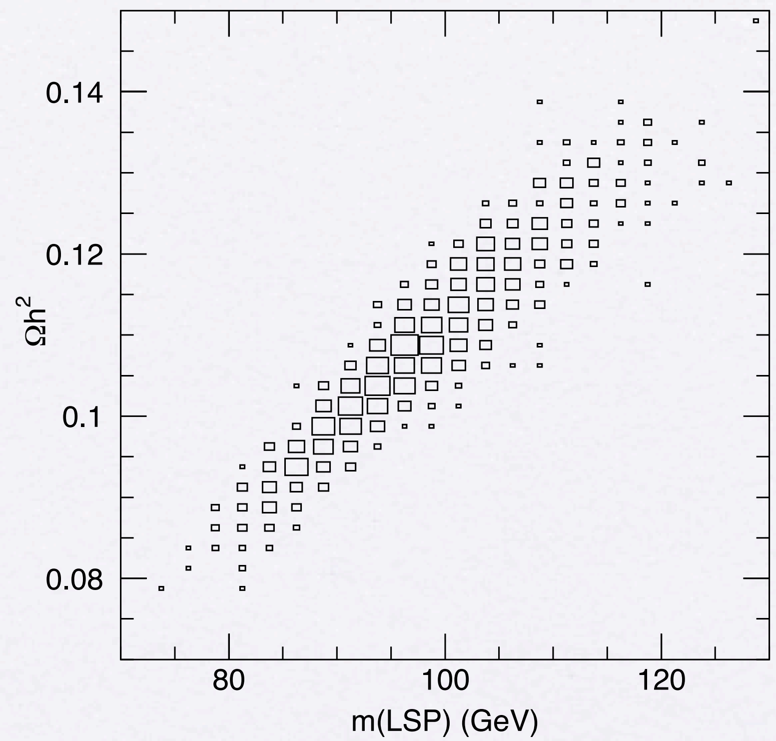


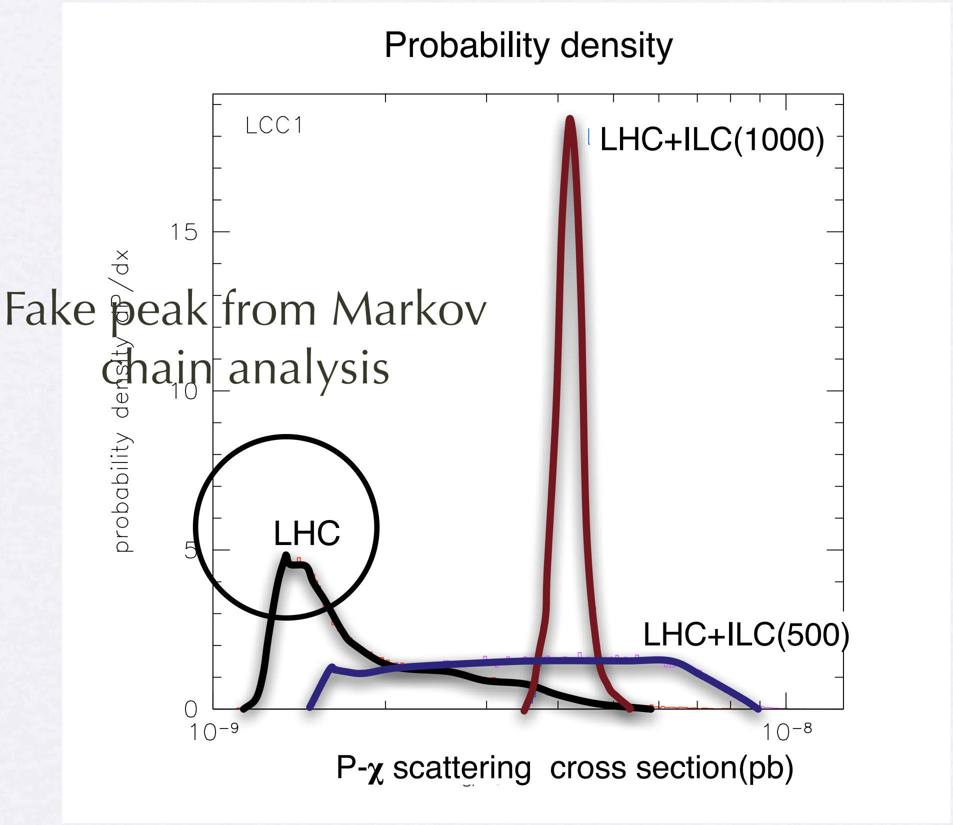
- We may have an access to heavy higgs sector up to 300 GeV also for tanbeta=10 for this point .

Trying to pin down Dark matter nature

MN, Polesello and Tovey
hep-ph/0512204

- DM density: for SPS1a
  - roughly 20 % at LHC. The plots are based on reconstruction of O (10000) different experiments-- Giacomo likes this....
- LSP-N cross section. almost no bound for LHC. Disregard fake peak....
- It is certainly not general, no conclusions.. at Les Houches, we have selected several points to cover NUHM case (mixed DM)





Baltz et al (2006)

Full reconstruction at LHC

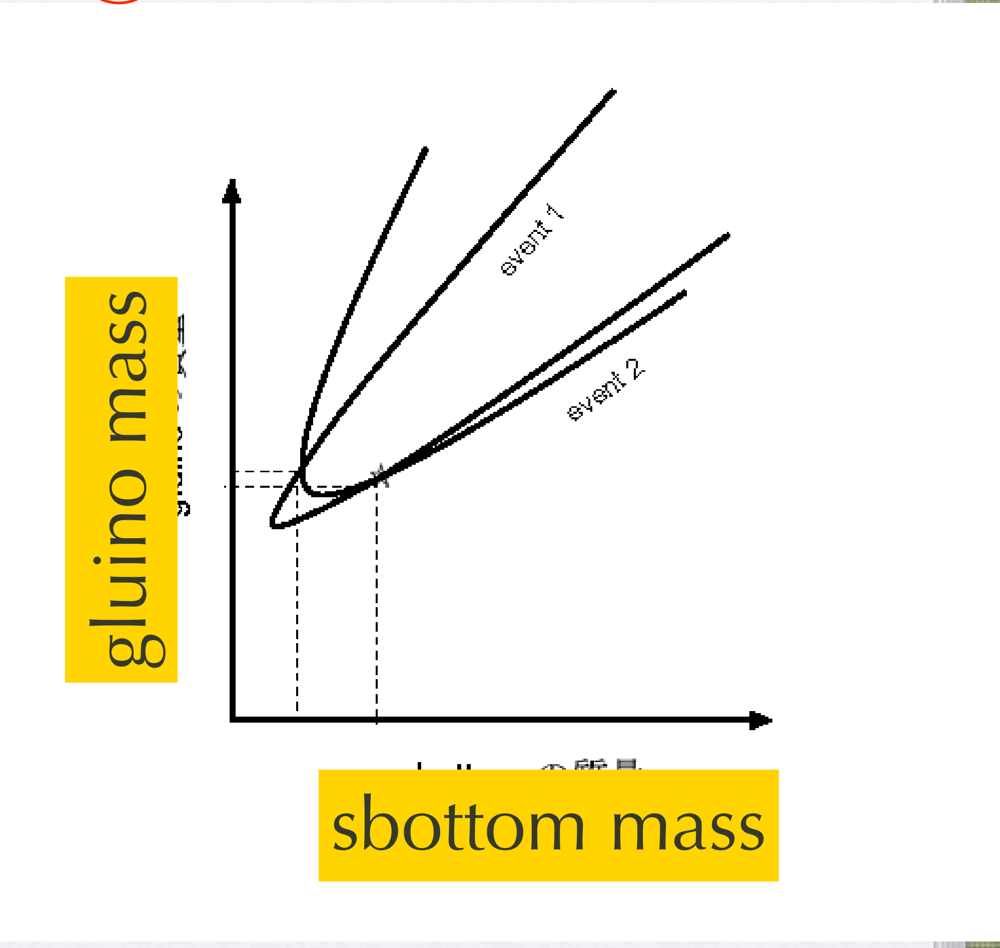
Solving missing momentum

$$\tilde{g} \longrightarrow \tilde{b}b \longrightarrow \tilde{\chi}_2^0 bb \longrightarrow \tilde{l}lbb \longrightarrow \tilde{\chi}_1^0 llbb$$

If we know all masses, there are 5 mass constraints for LSP momentum, therefore event can be fully solved.

If we do not know any of those masses, each event gives you 4 dim hyper surface in the 5 dim mass space. (one constraint.)

5 events=> all masses



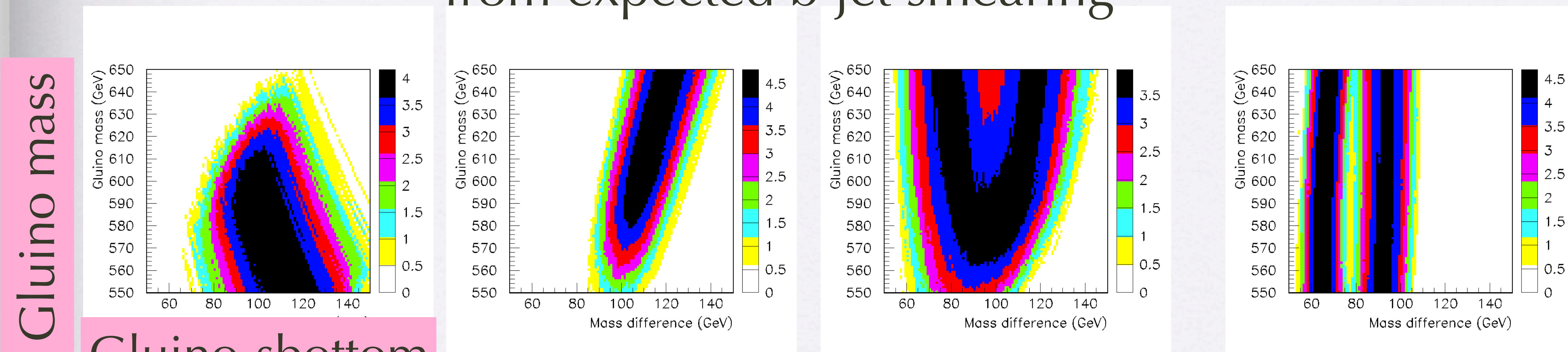
For presentation, assume we know mass of

$\chi_1^0, \chi_2^0, \tilde{l}$

One event ⇨

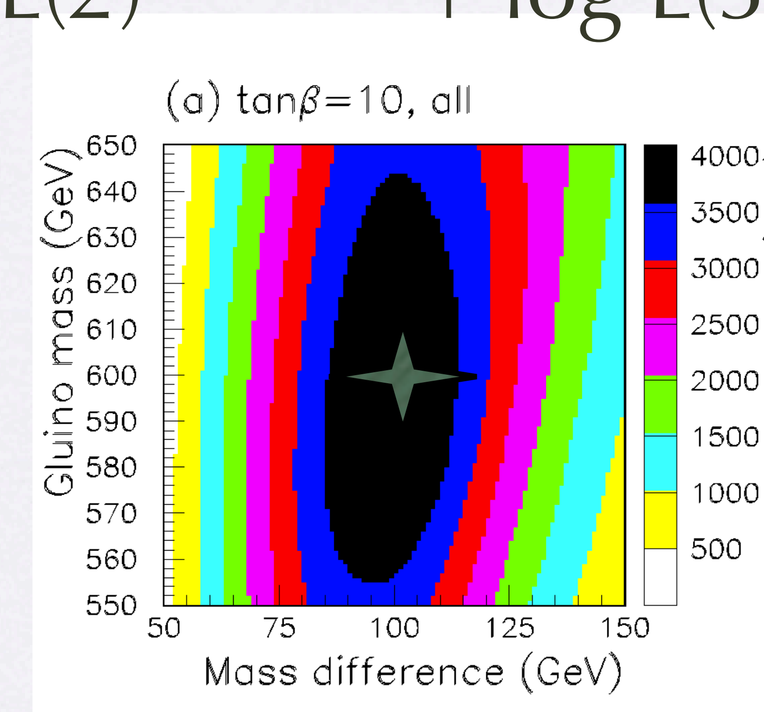
probability density for true masses(logL)

from expected b jet smearing



log L(1) + logL(2) + log L(3)+ logL(4)+…

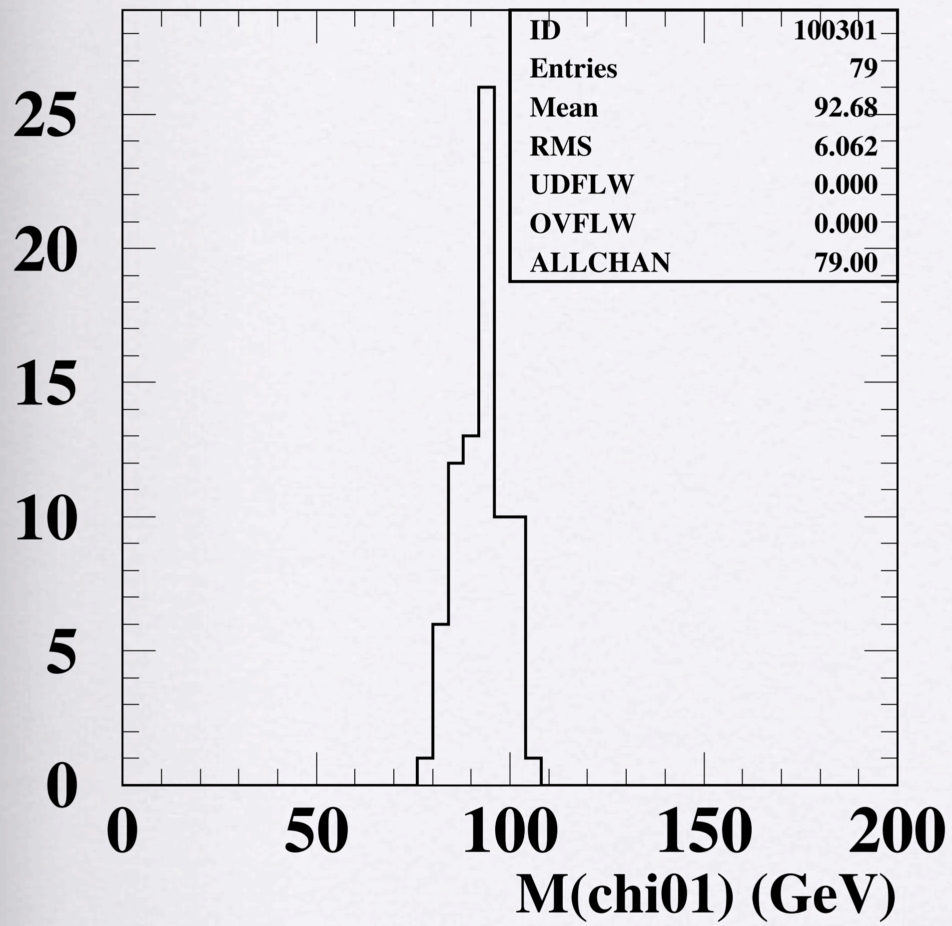
$= \Sigma \log L(\sim\Delta\chi^2)$



Kawagoe, Nojiri, Polesello (2004)

Other application

(Tovey, Polesello, very very preliminary)



idea
End point method does not have much constraint to the overall mass scale

Look for 4 leptons events,with two golden cascades, when ETmiss can be compared with solved ETmiss for the assumed masses.

This may be more sensitive to the overall mass scale.

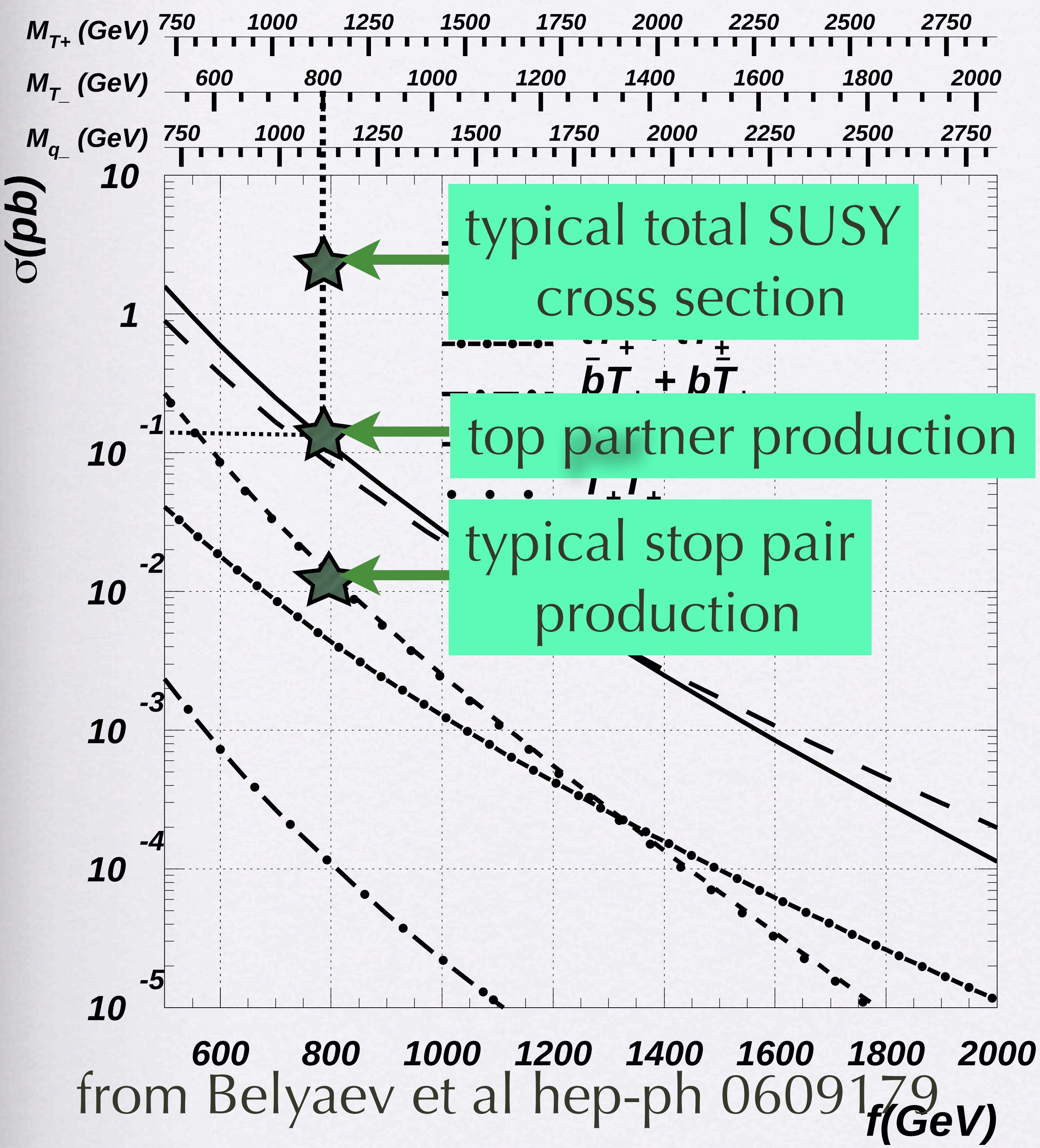
- Error of LSP improves from 8.0% -> 6.5%

jets! at LHC

What hell we can if your signals are all jets- Example: study of “top-partners”.

- Lepton + jets are easy because we study the events with relatively small number of jets and jets are isolated. however, there are important process with many jets in the same direction.
  - in MSUGRA, stops are lighter than other squarks want to establish gluino-> stop cascade decays
  - in Little Higgs model, top partner is again the lightest among quark partners. The cross section is high because it is fermion. Want to establish top partner productions

Little Higgs model with T parity



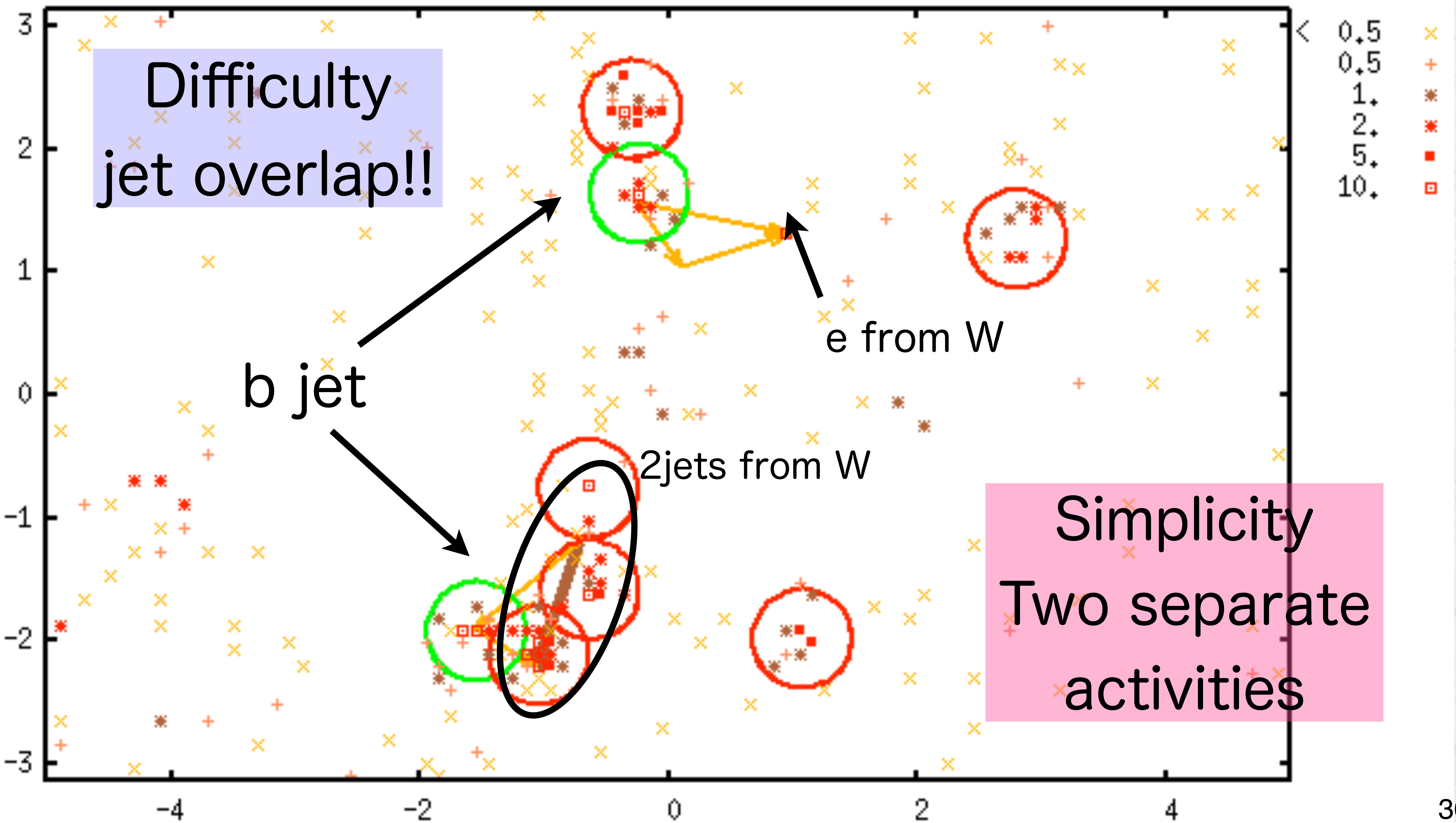
from Belyaev et al hep-ph 0609179

- fermion partner instead of scalar partner
- top partner is important
- σ(boson) /σ(fermion)=0.1
- The difference comes from spin structure. scalar top production is "mostly" p wave. Evidence of top partner pair production immediately means non-SUSY BSM

After jet reconstructions

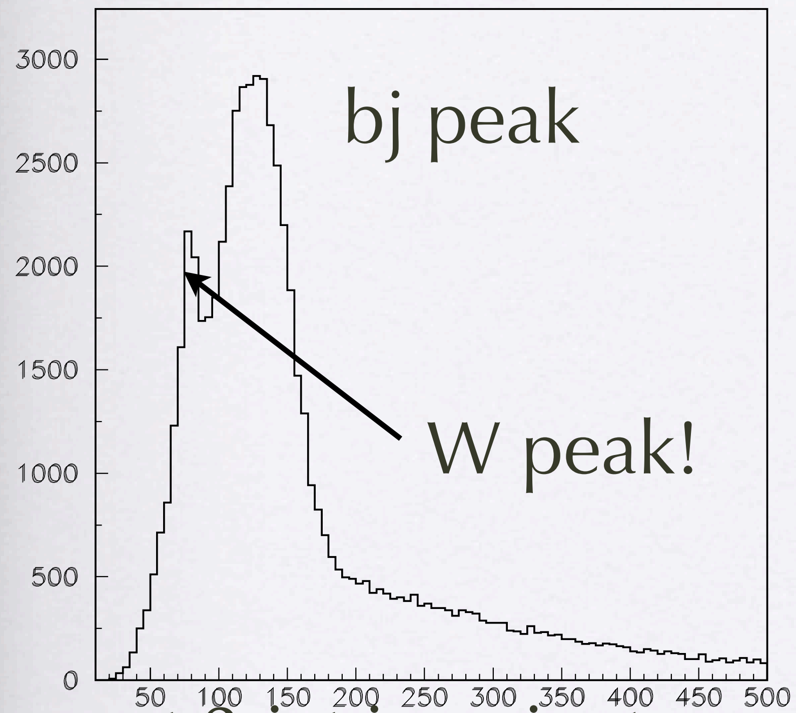
reconstruction with jet cone R=0.4

In AcerDET(<ATLFAST)

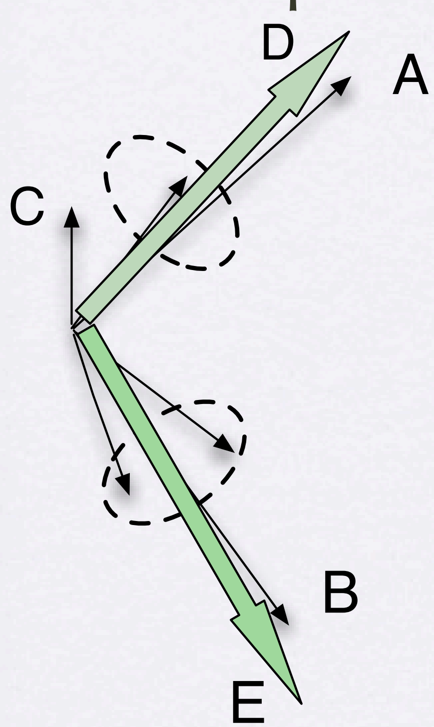


Top reconstruction

Signal, without b tagging



largest 2 jet invariant mass in the heminsphare



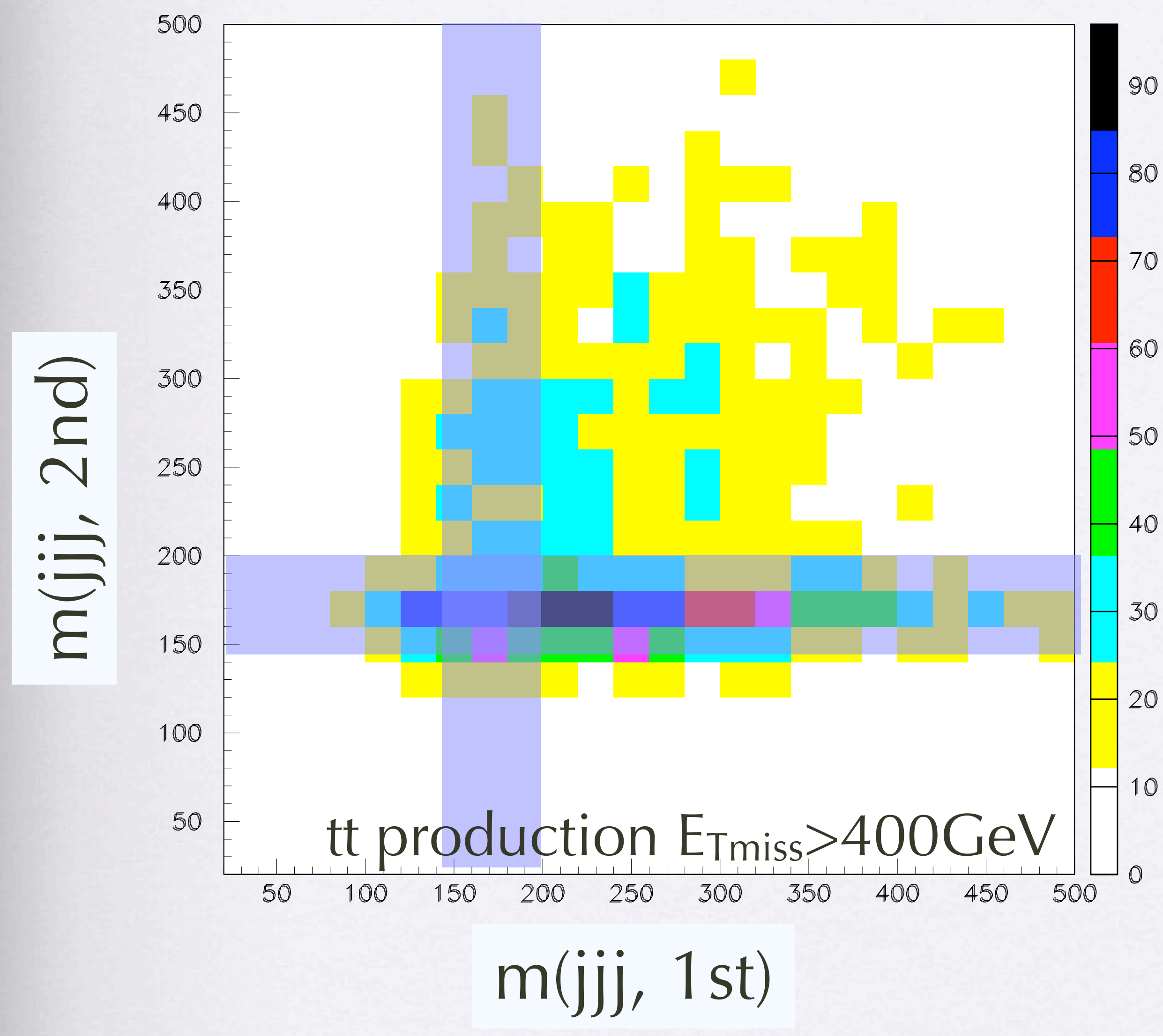
- hemisphare algorithm by Moortgat (CMS)
  - take highest PT jet as seed of an axis. (A)
  - take 2nd jet with max Px∆R from the 1st jet as the seed of the 2nd axis (B)
  - assign jet and lepton activities to the “closer axis”. (C)
  - recalculate “axis=sum of particle in the hemisphere” , repeat . (D,E)

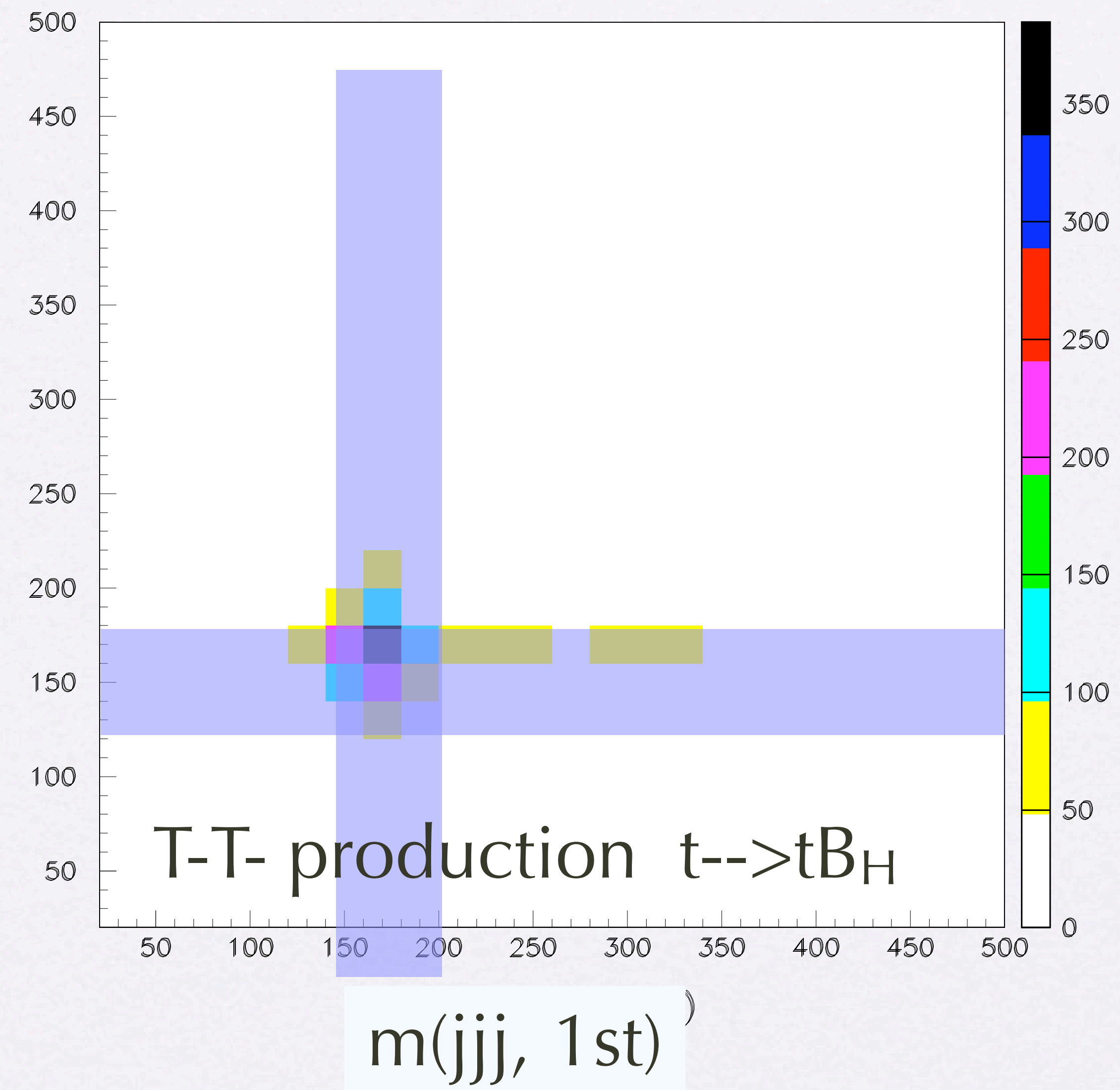
Note:the jet energy resolution is better in ATLAS(50%/√E
is better than CMS (100%)/√E

Matsumoto Nojiri Nomura 2006

Signal and BG

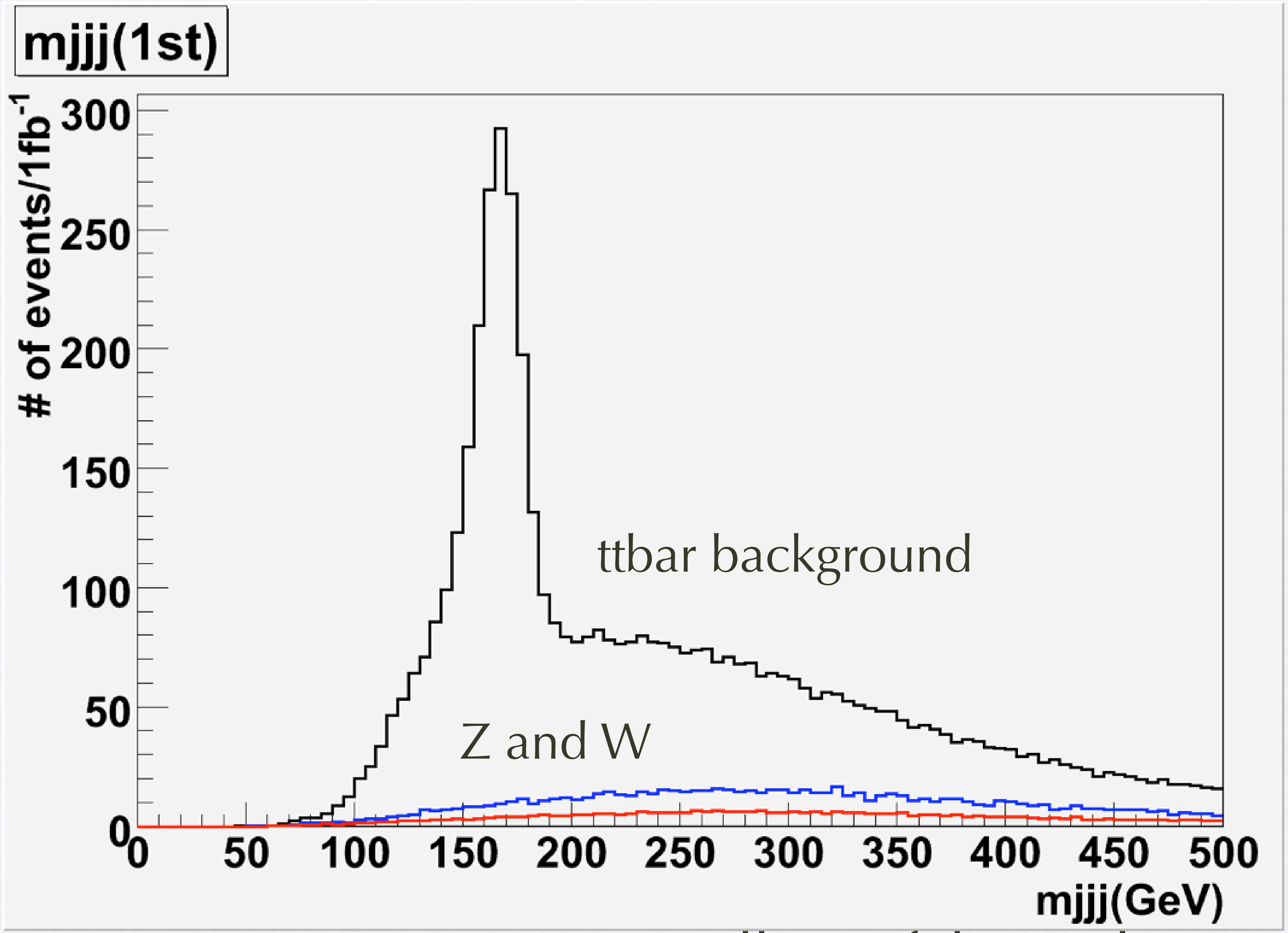
from Matsumoto et al





- tops are seen in both of the hemisphere
- probability of top reconstruction is small for the ttbar background (because of E_{Tmiss} cut)
- top reconstruction helps to reduces QCD, W, Z background. (preliminary ATLAS simulations by Kiyamura at Kobe

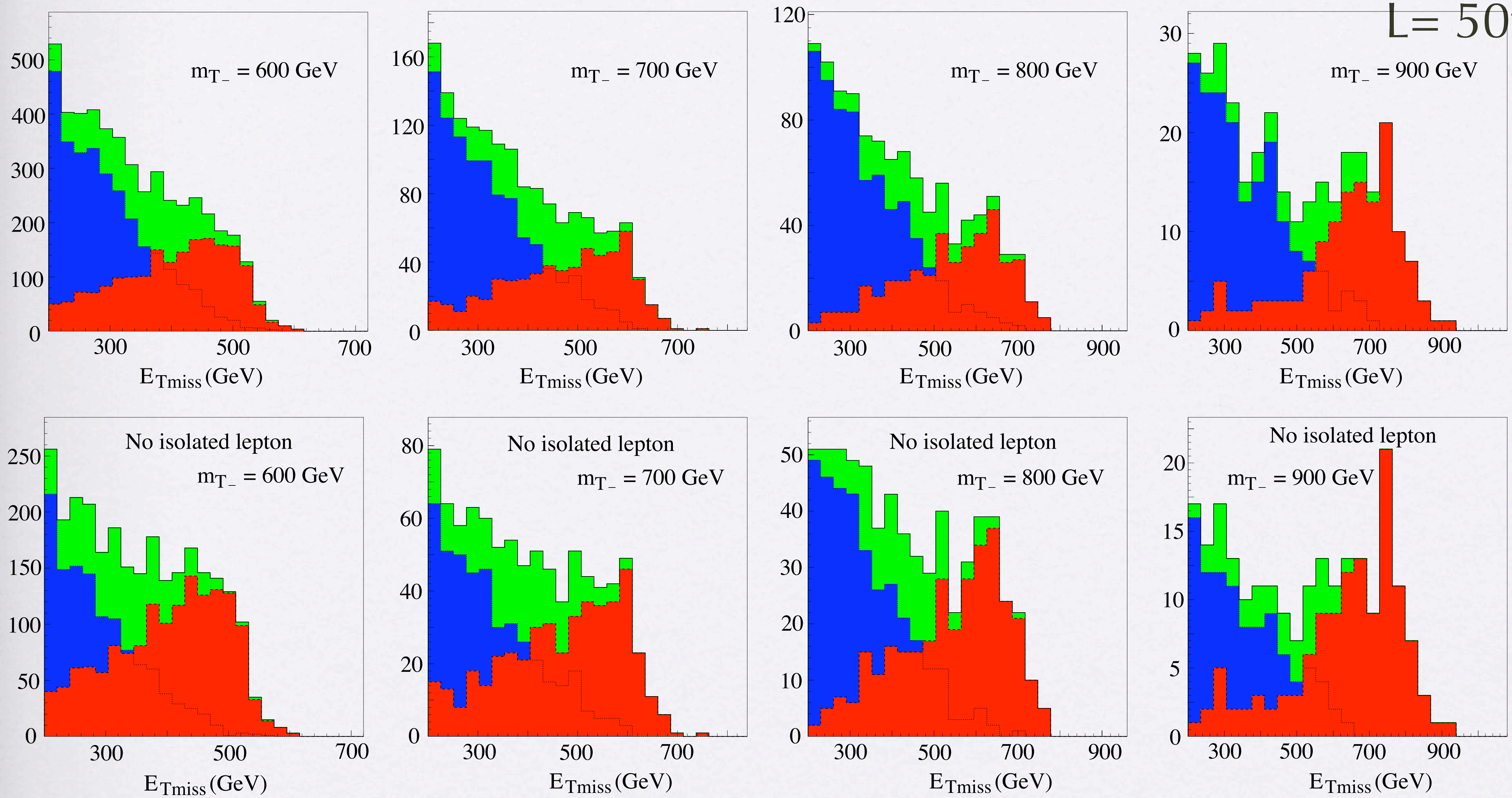
ATLAS simulation



- top reconstruction is actually useful to reduce W, and Z backgrounds (Kiyamura et al Kobe very preliminary)

signal distribution & top background

L= 50fb-1



- signal E_{Tmiss} distribution has a peak near $M_{eff}/2$
- BG peaks at $E_{tmiss} << M_{eff}$

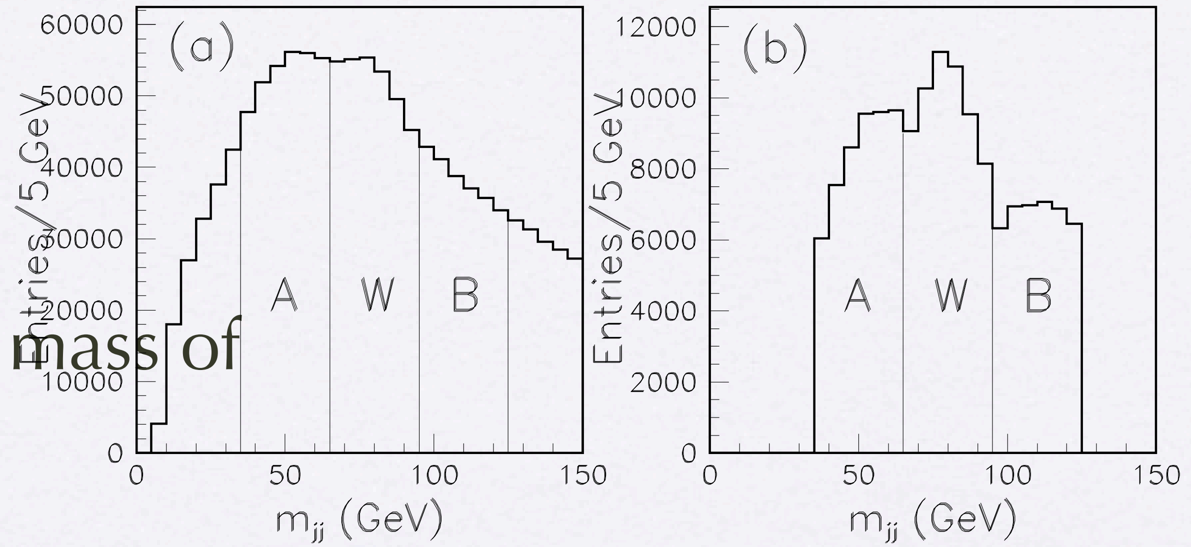
we see DM!

- good margin for discovery due to the bump structure.

top quark in SUSY
non relativistic top quark

- top quark in SUSY

$$\tilde{g} \to (t\tilde{t} \text{ or } b\tilde{b}) \to tb\tilde{\chi}_1^{\pm}$$



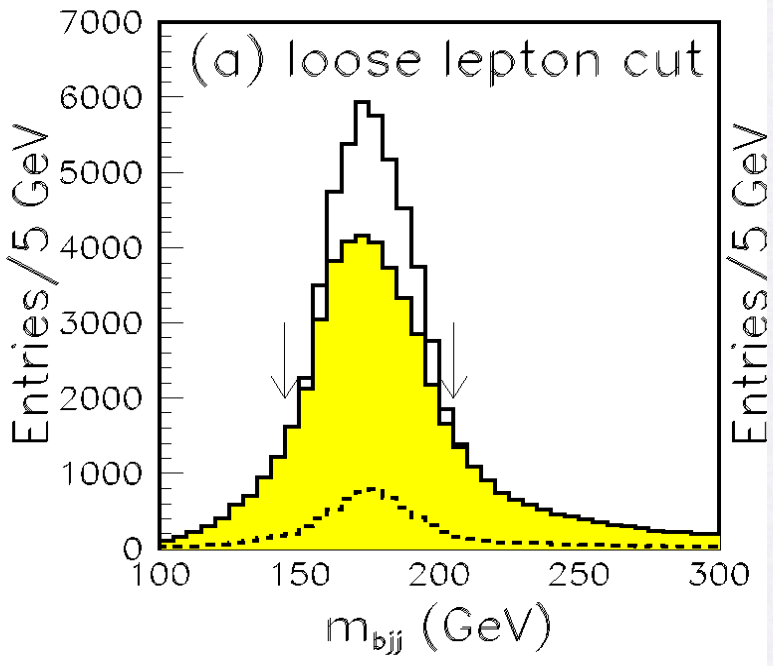
  - reconstruct tb end points tell us mass of stop and sbottom

  - Background to t ⇨bW⇨bjj is estimated from events in the sideband

m_{jj}<Mw-15GeV

m_{jj}>Mw+15 GeV.

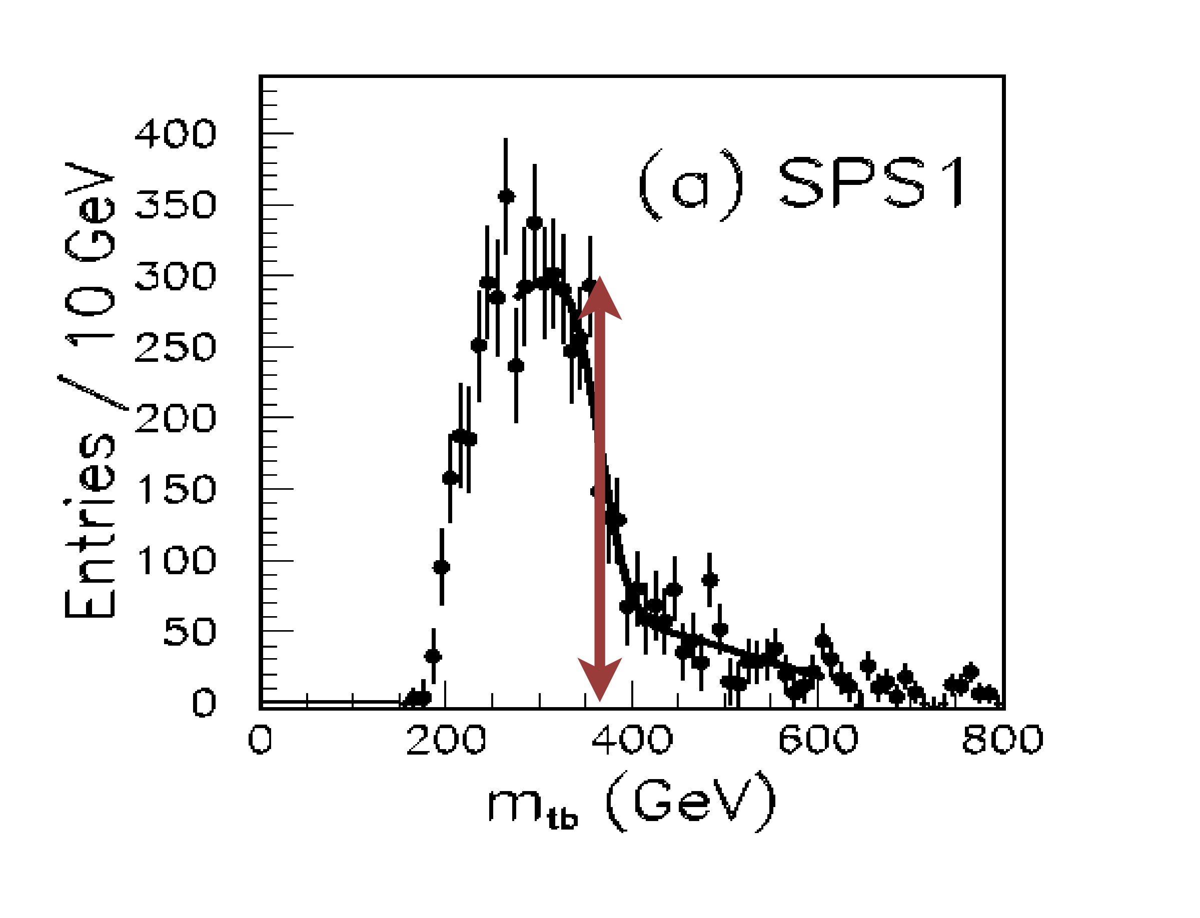
rescale the jet energies so that they are in W mass range. look for the consistent samples with t ⇨ bW ⇨ bjj



(Hisano, Kawagoe, Nojiri 2003)

KT vs Jet cone in stop reconstruction

- Measure the efficiency of clustering algorithm in New Physics signal simulation (it must contain truth.)
- high reconstruction efficiency of tb end point (height) ~efficiency
- small R is better because we expect many jets in the final state. R=0.4.
- Low efficiency in simple jet cone(in ATLFAST at that time). overlapping? or infrared unsafety?
- KT works OK for small R. without underlying events. "Splash in effect"

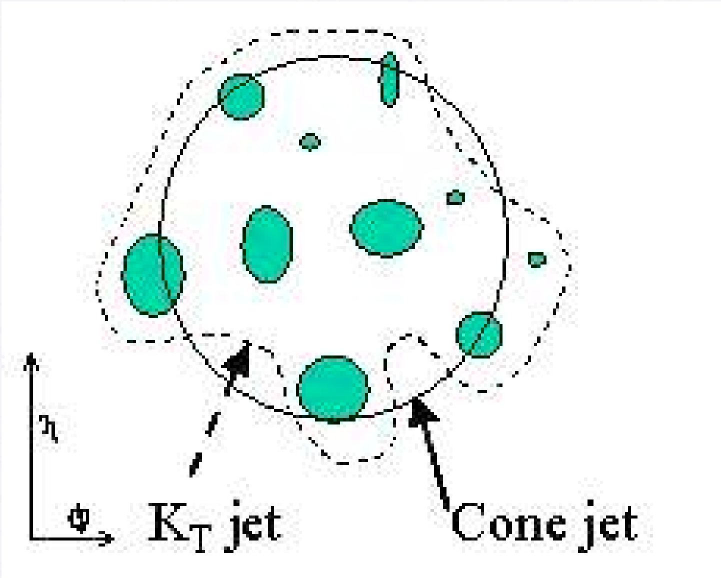


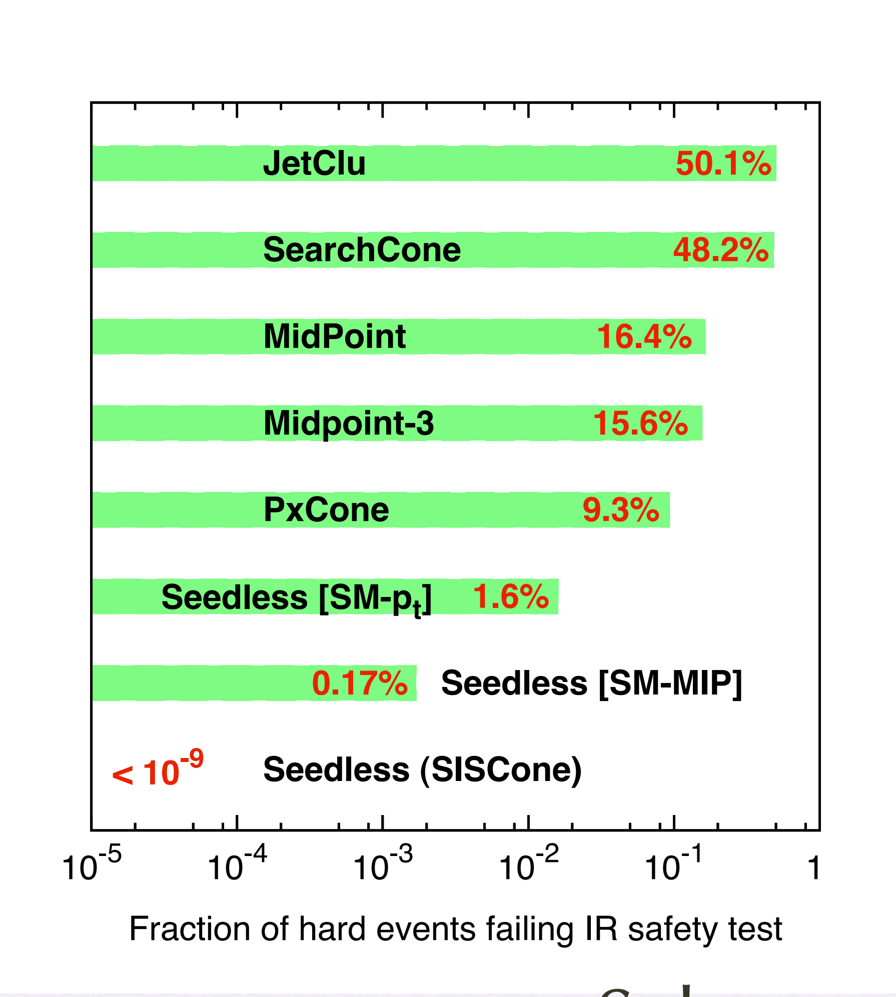
		R	end point	height
HW	cone	0.4	434.5 ± 5.8	354.8 ± 23.3
		0.5	460.2 ± 4.9	349.2 ± 22.8
		0.6	440.9 ± 7.1	305.3 ± 33.7
	K_T	0.4	434.9 ± 4.3	406.5 ± 22.1
		0.5	460.0 ± 5.5	379.6 ± 33.5
		0.6	468.4 ± 5.8	314.3 ± 20.7

Hisano Kawagoe Nojiri (2003)

Comparison between KT and cone

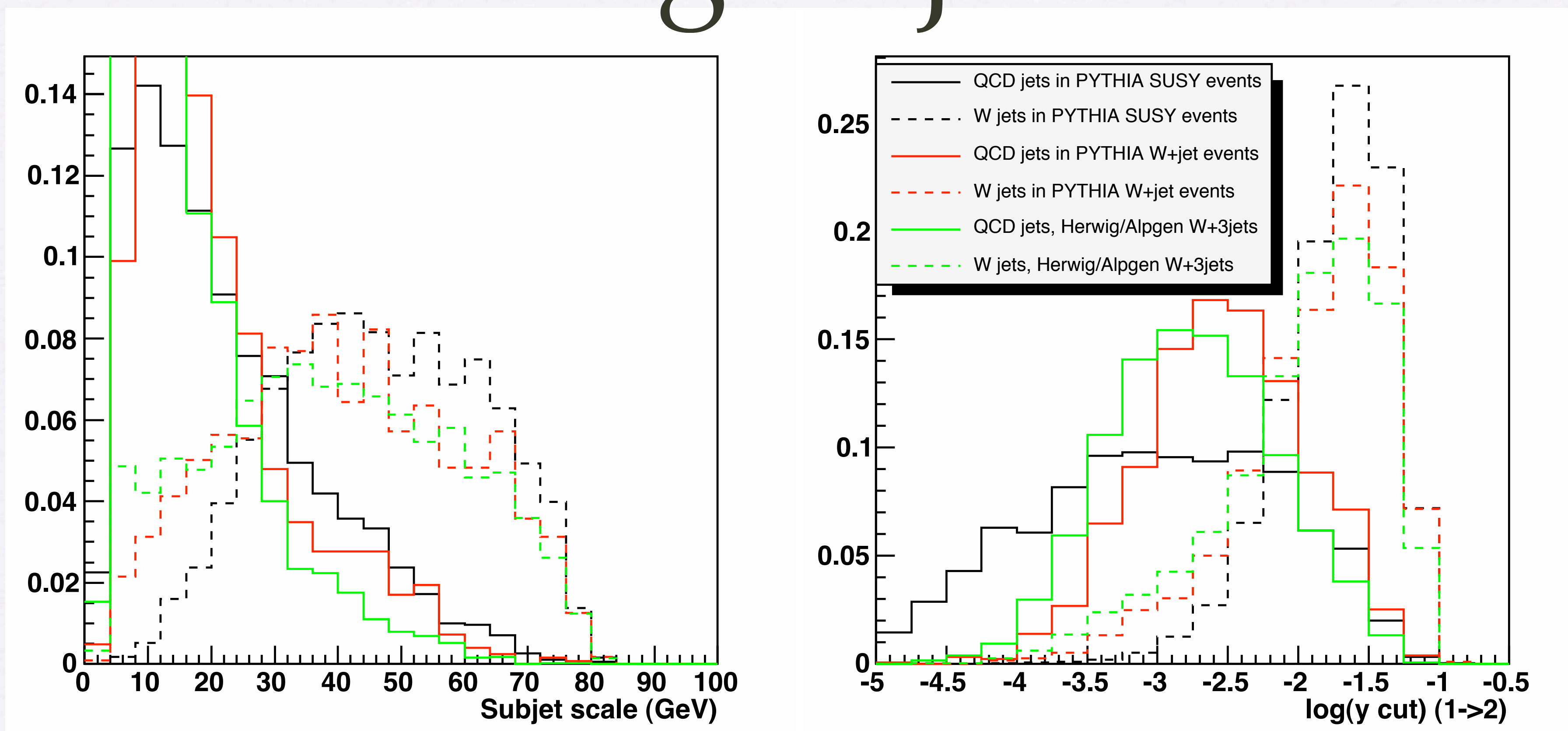
- To deal with jet-jet system, the definition of “jet” matters. How can we use measured end points to the mass spectrum?
- Cone--Simple cone alg. takes the hardest PT cluster, add the activities nearby the cluster. (Some adjustment for overlapping jets) infra unstable except SISCone.
- KT merges soft collinear activity to nearby hard ones. (infra safe) use $\min(kt_k^2\ kt_j^2)\ xR_{kj}^2/R^2$
- cf. Camblidge KT Use R_{ij} to merge particles (motivated by angular ordering.....)





Salam

merged jets?



$p_T\sqrt{y}$ $y \equiv d_{kl}/(p_T^{\text{jet}})^2$

- Butterworth et al looked into jet with mass ~80GeV from W with P_T~200GeV in KT.
- the subjet structure is defined as the last marged jet. This may be used to separate QCD jets and marged jet (like relativistic W in SUSY)

New physics with LHC

- I do not care much about “inverse problem”.
- Want to add more stable quantity that can be used at LHC, ... toward something which has same taste of “what is expected at ILC”.
- We can learn lots from lepton mode at LHC, but we need more improvement on understanding jet signals.