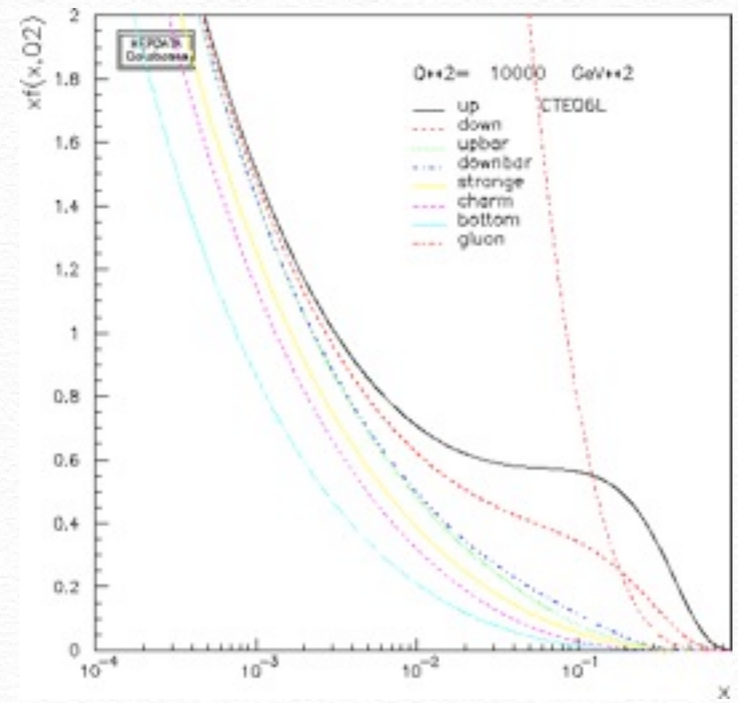
# BSM and collider search

# SUSY search

- R parity conserving Supersymmetric model  is “attractive” given the fact that dark matter truely exists in nature
- SUSY offers  weakly interacting dark matter consistent with current limit.
- At Hadron collider, SUSY particles are copiously produced. How do we find them. (What is the main differences between SM process and SUSY process？)

# Parton distribution, cross section

- PDF ---quark and gluon energy  distribution as seen by hard collisions.




- cross section is given as ....

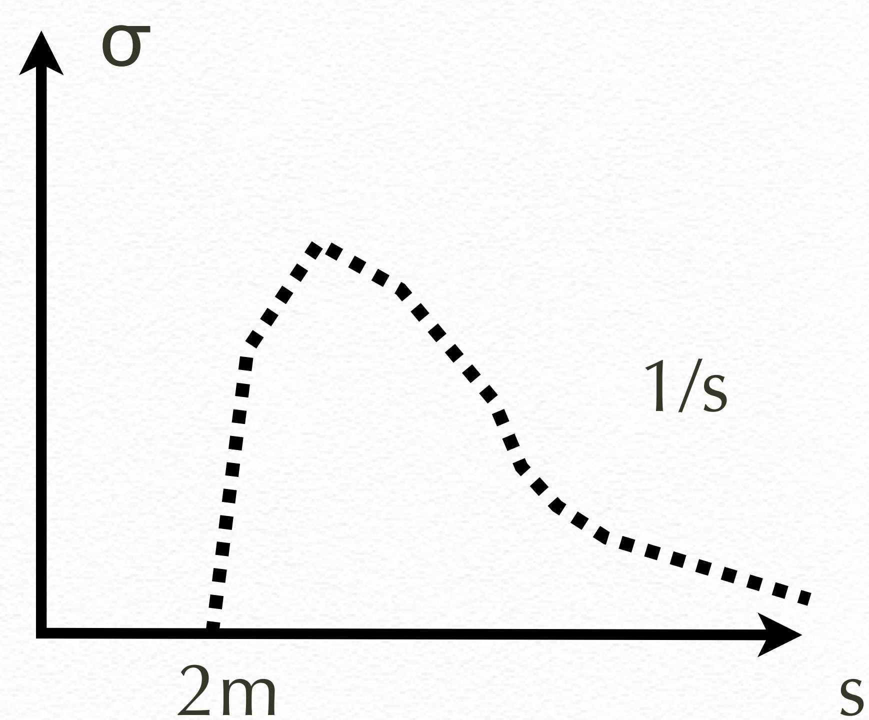
$$\sigma_{\rm tot} = \int dx_1 dx_2 f_i(x_1) f_j(x_2) \sigma_{ij\to X}(x_1 x_2 Q^2)$$

X=E_i/ Ebeam  x=0.1~1.4 TeV at LHC.

parton distribution and cross sections are largest at the threshold of the particle.

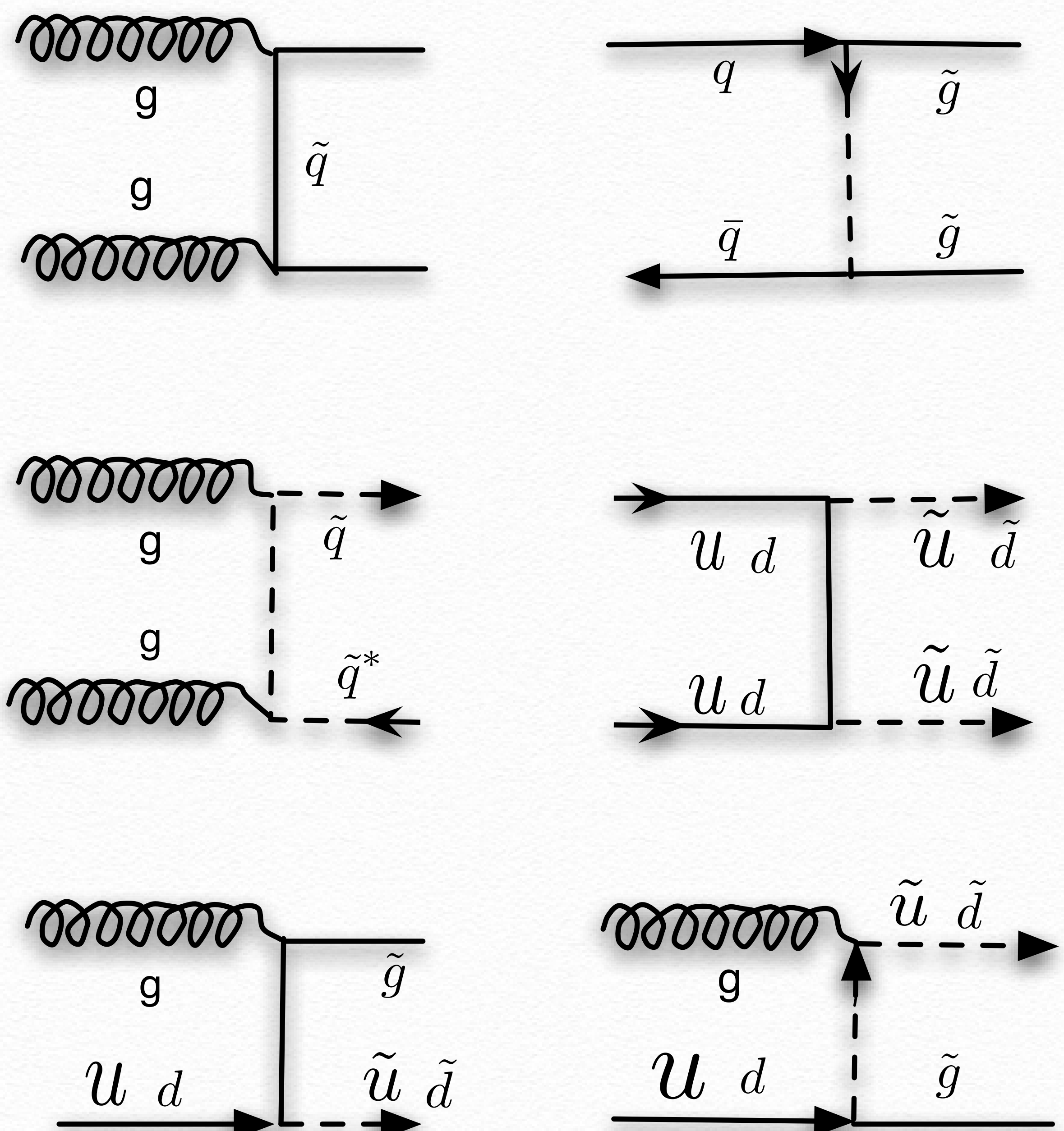
for TeV particle discovery  u >d > g
for 100 GeV particles g>> u>d

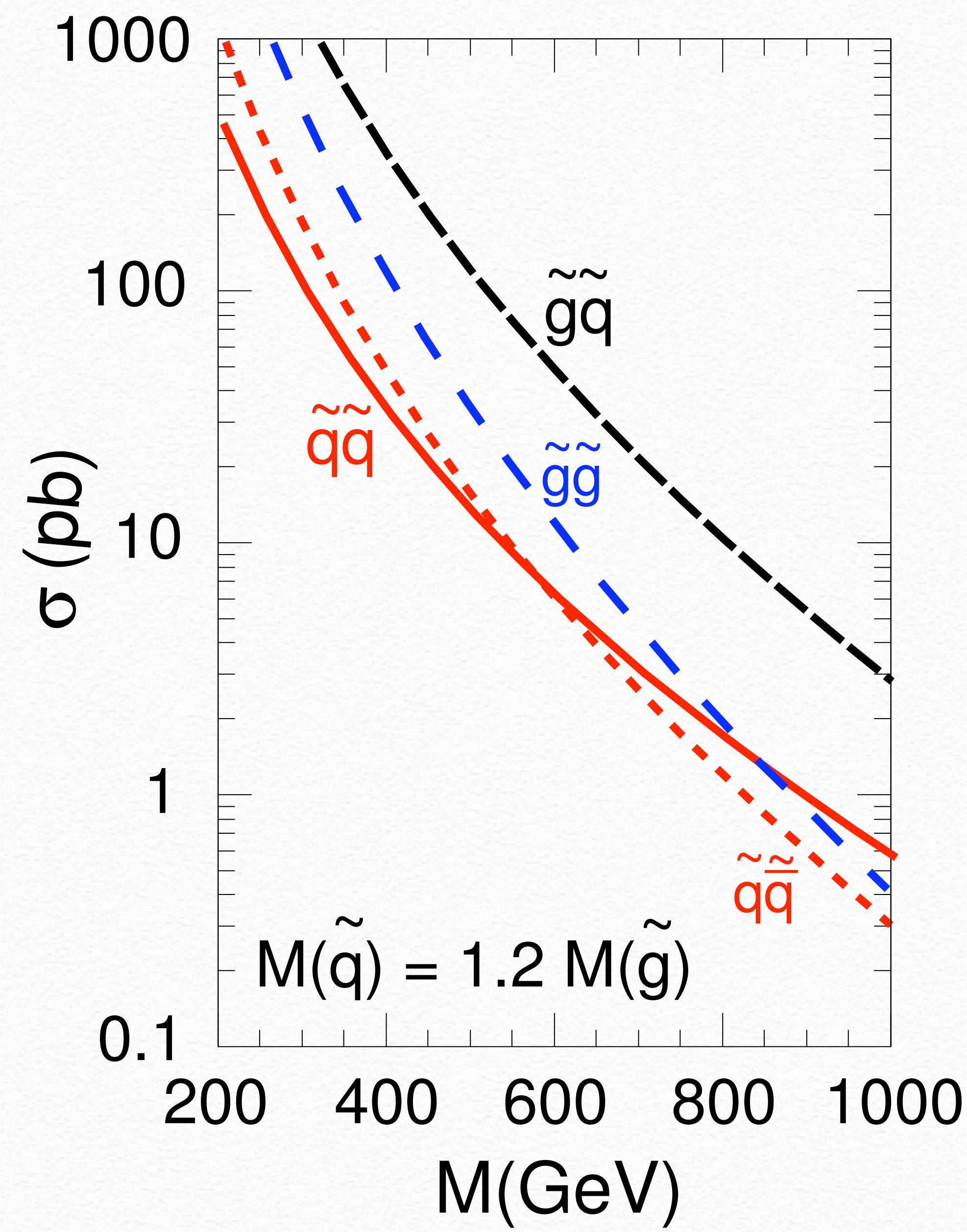
new particles will be boosted to one of the beam direction in general .



# production process

Large in small M(SUSY) | Large in high M(SUSY)



# Basic collider objects and supersymmetry

- jet and lepton momenta

  $p_{j1}, p_{j2}, \ldots.\ p_{l1}, p_{l2} \ldots.$

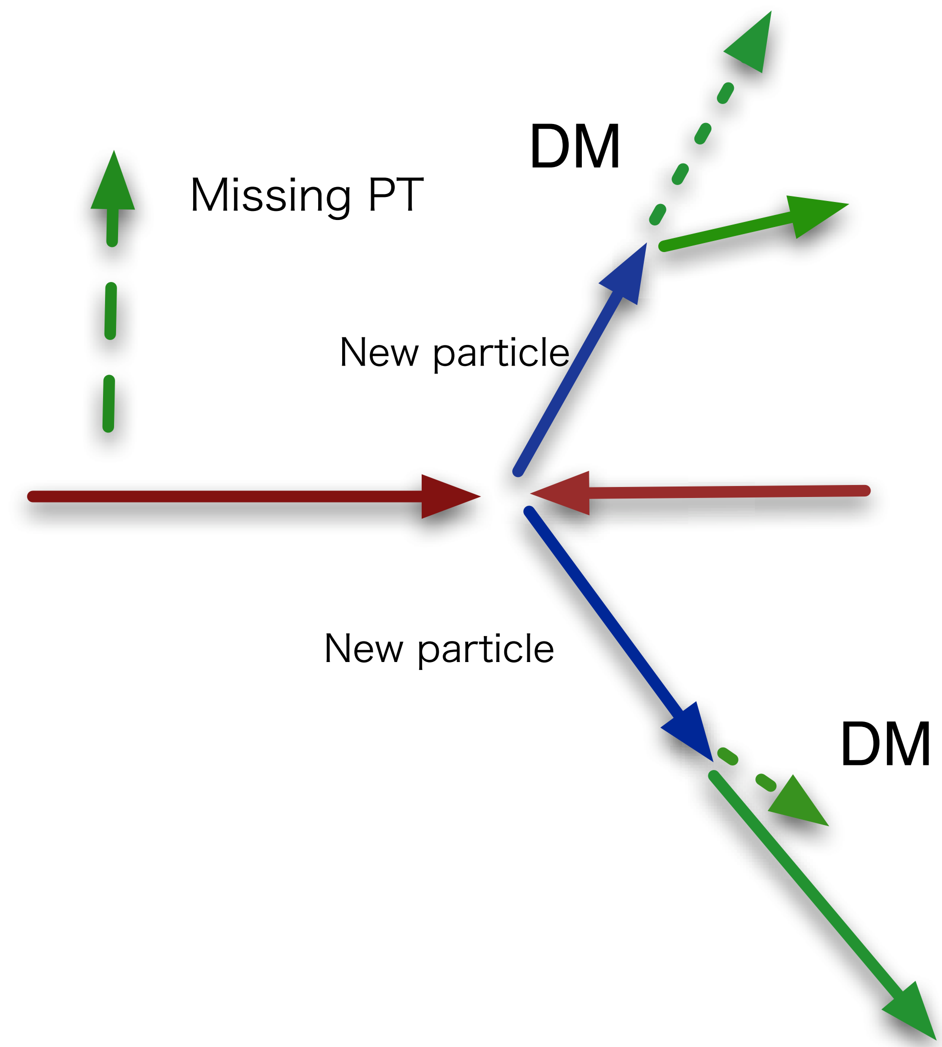
- Jet and lepton transverse momenta (to the beam)

  $p_{T1}, p_{T2}, p_{T3} \ldots..$

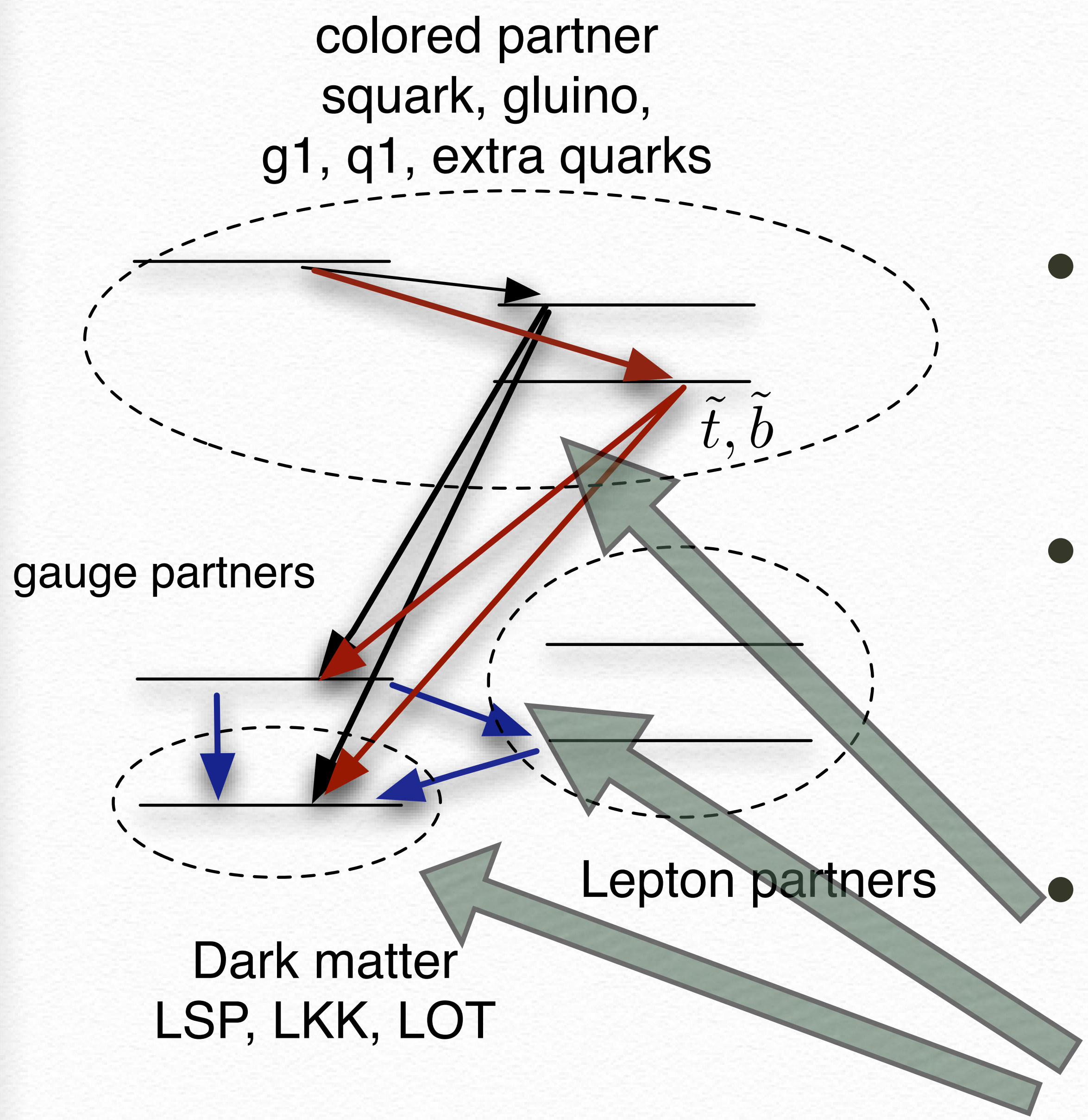
- $E_{Tmiss}$: Sum of the transverse momenta of all particles.

- $M_{eff}$ Sum of the transverse energies of a few hard jets + $E_{Tmiss}$

$$M_{\text{eff}} \equiv \sum_{i=1,\ldots 4} p_{Ti} + \sum_{\text{leptons}} p_{Tl} + E_{\text{Tmiss}}$$



# Mass spectrum and collider signature




- **"SUSY signature"** "Models with new colored particles decaying into a stable neutral particle--LSP"
- Some "New physics" are migrated into SUSY category
  - Little Higgs model with T parity. UED
- Signal:

High $P_T$ jets(several) , hard leptons, $E_{Tmiss}$

assume mass difference is large

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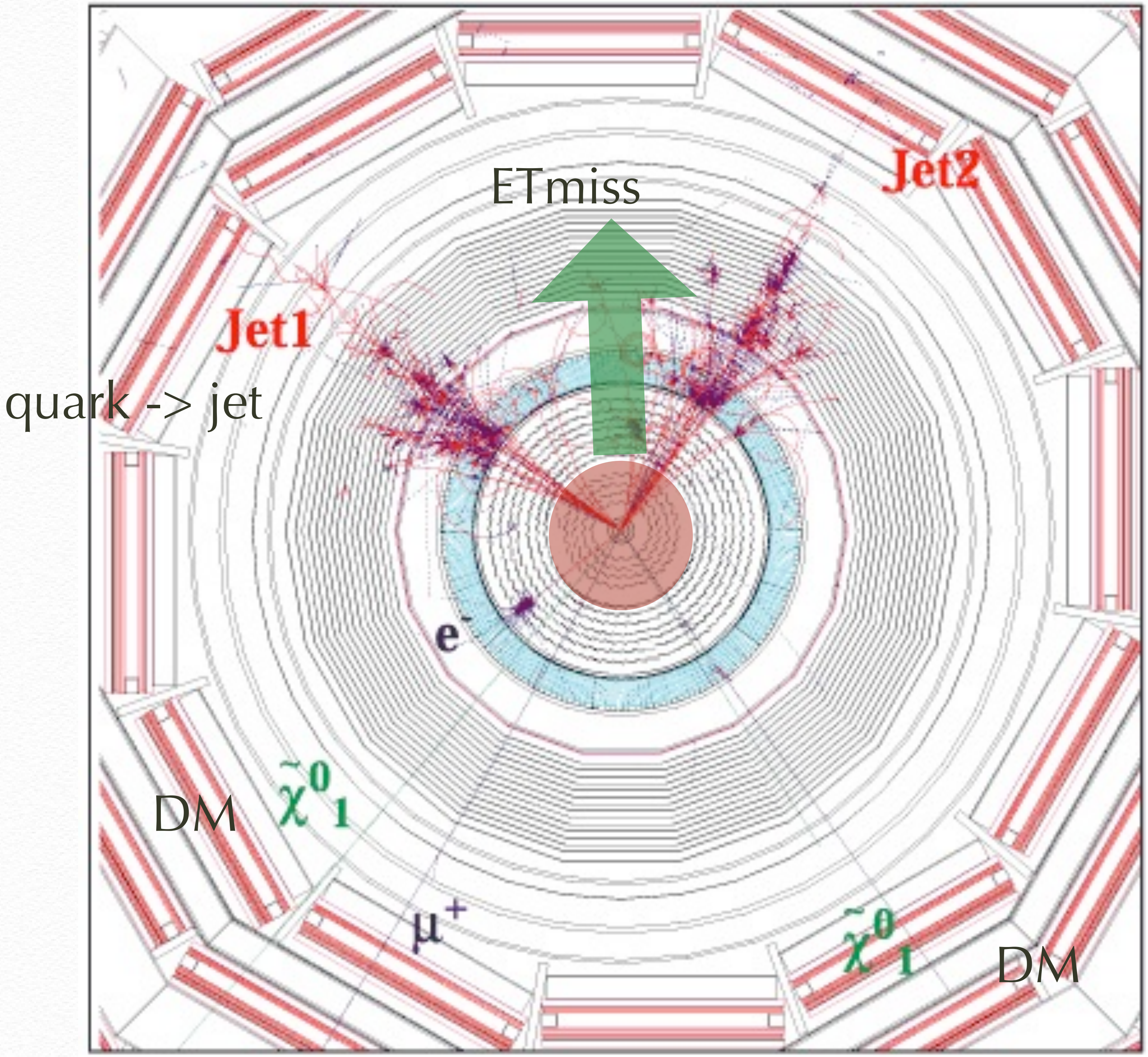


ETmiss
Jet2
Jet1
quark -> jet
e⁻
DM
$\tilde{\chi}^0_1$
$\mu^+$
$\tilde{\chi}^0_1$
DM

# Background and discovery

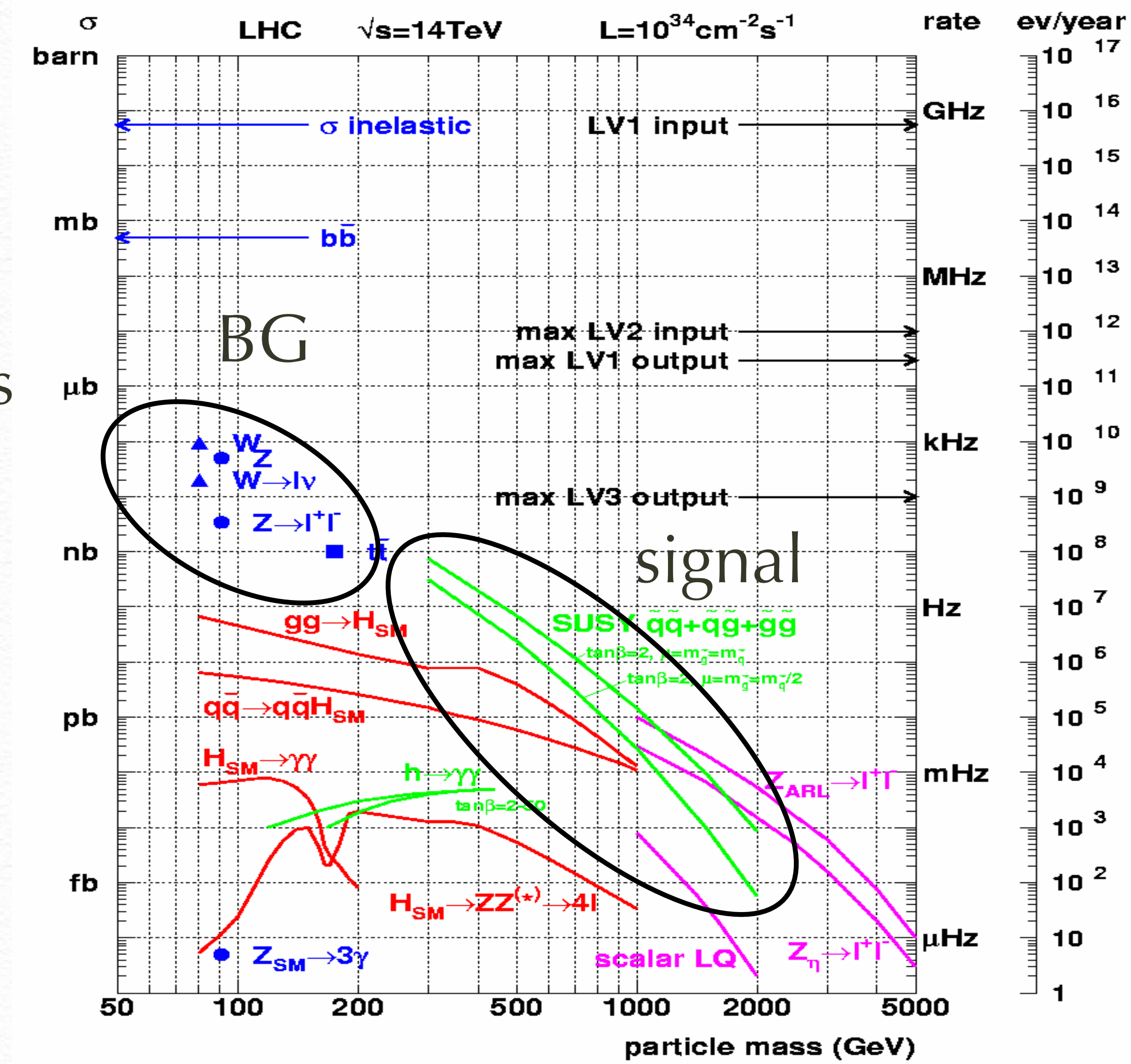
- The typical number of SUSY events are $10^5$ for 10 $fb^{-1}$, while BG rate is $10^{9\text{-}8}$ for W, Z and ttbar productions. $10^{-4}$ rejection of SM process is required.

- Understanding of the distribution is the key issue

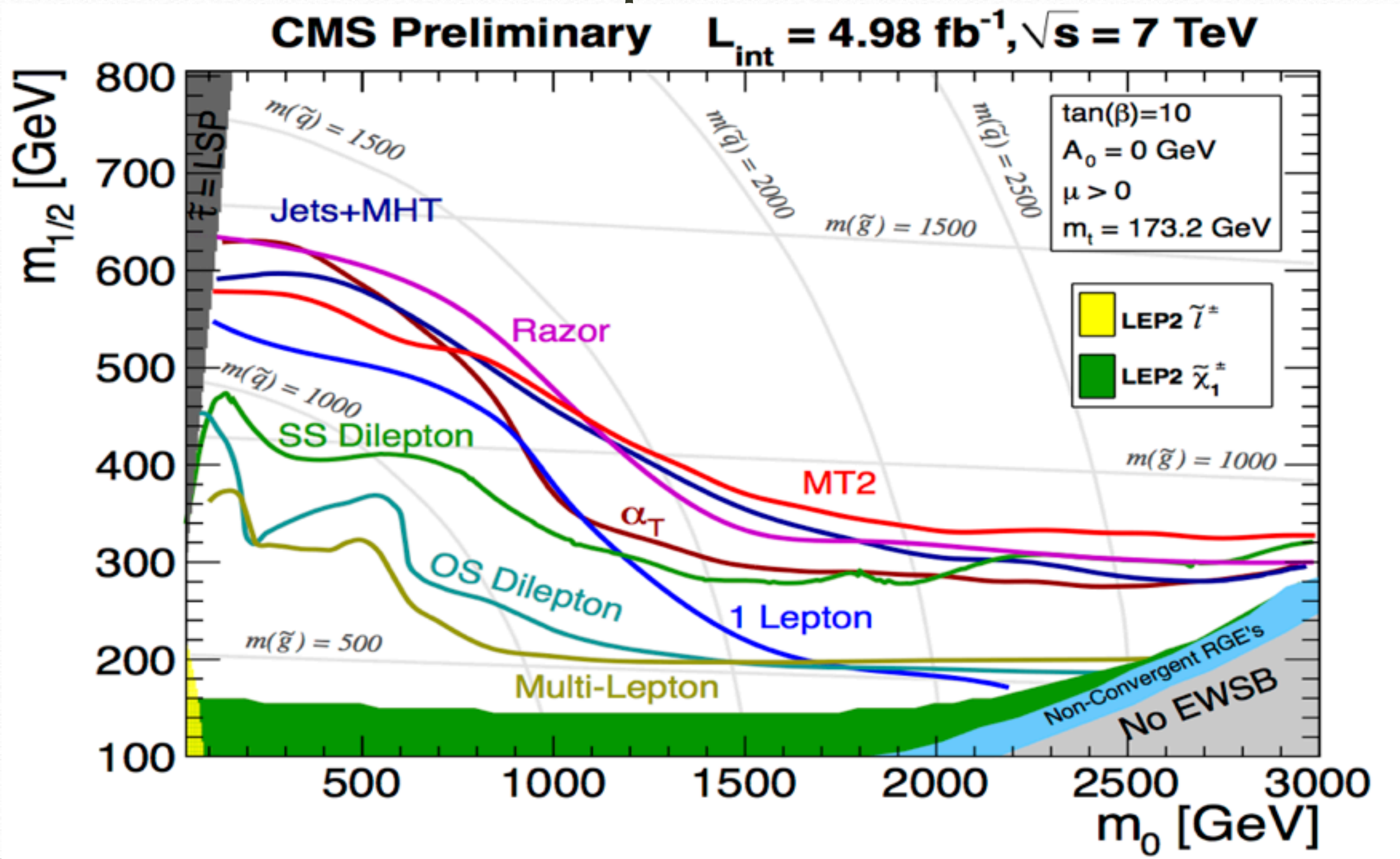
  - $P_T$ distribution of the jets, $M_{eff}$ distribution. (theoretical complexities)

  - $E_{tmiss}$ distributions(Experimental complexities)

CMS



# to make short long story short current limits to the SUSY searches (up to 2011 data)



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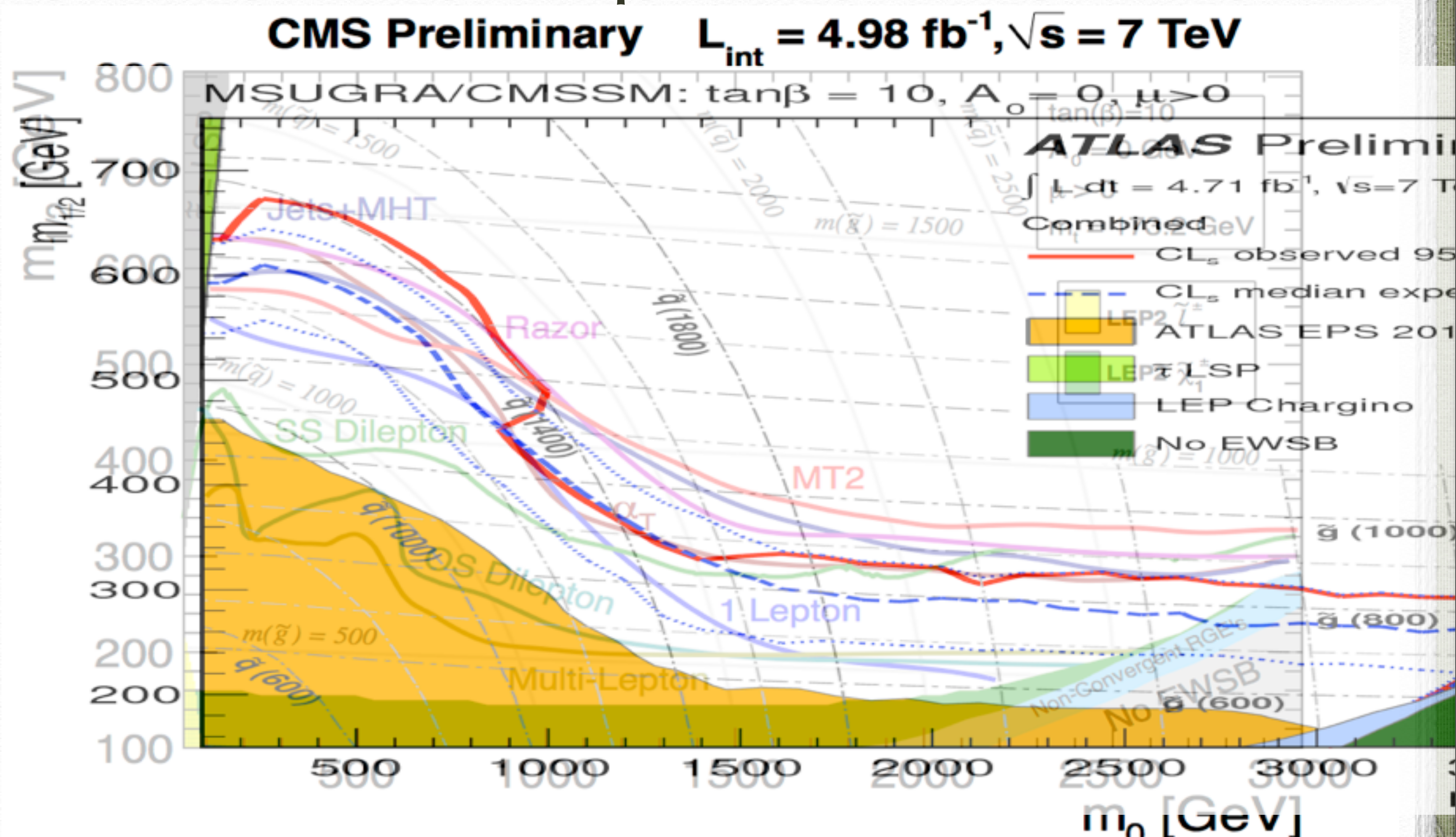


“really nothing so far ”
Why haven’t we found anything?
“Is this a dead end of particle physics?”

My impression is different

# Hadron collider searches:past and now

- To calculate SUSY background, we need to know W, t, Z with multiple jets in the final state. In 90's: we do not know how to calculate the processes appropriately at the hadron collider "I do not trust hadron collider physics" is typical attitudes in $e^+e^-$collider funs in 90's

- It took very long time to get limit from hadron collider data, and there were fake discovery as well

photo 1972

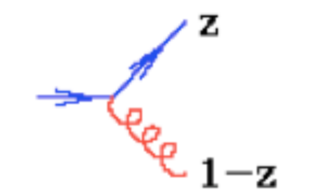
- **Progress in "Matching" and NLO,** we have better background prediction now.

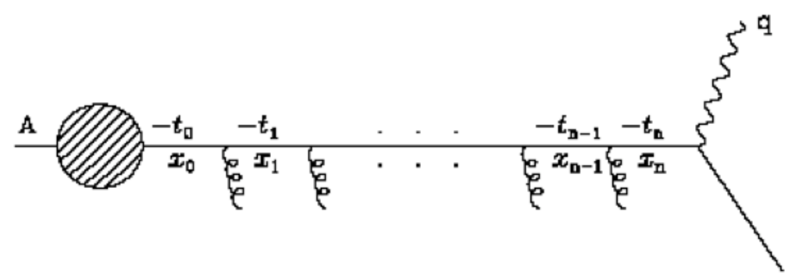
- We can "exclude" the model rather easity, and we do not "discover" much until we reach **the point to discover**. ( unlike the era of SPS )

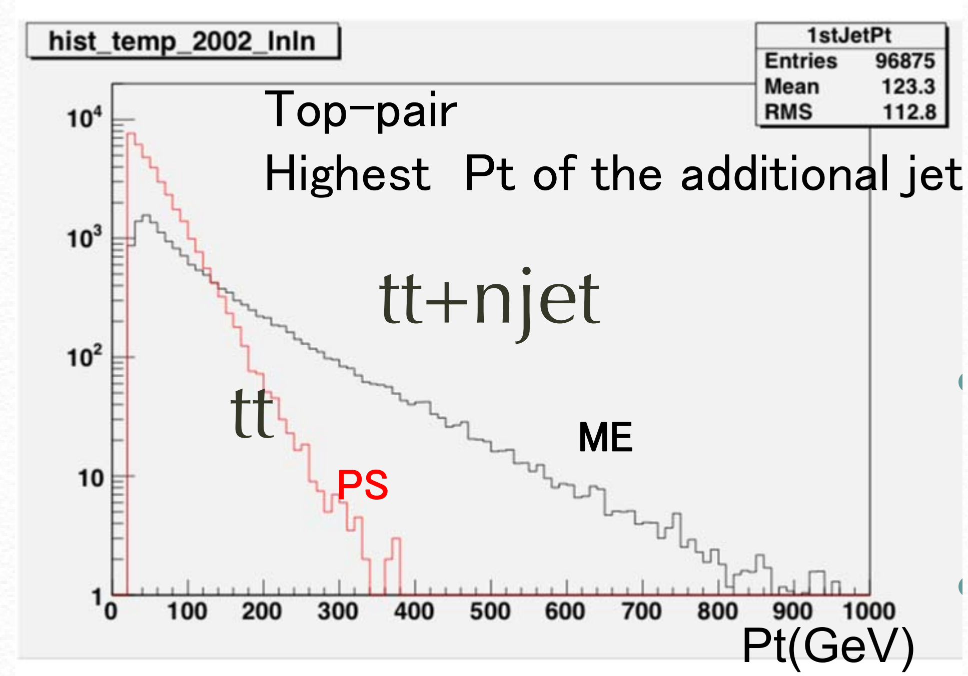
# Parton shower and hard process

- MC simulation for hadron collider roughly divided into three things
  - Initial state radiation:multiple emission of collinear gluon and quarks is summed(ofte done by numerical simulation )
  - partons from hard process (either by hand numerically
  - final state radiation: similar to initial state radiation but from large off-shellness to on-shell state (again often done by numerical simulaiton)
- the process with multiple hard jets =hard process of W+n parton: but some of the partons overlap with parton showers.

$$d\sigma_{n+1} = d\sigma_n \frac{dt}{t} dz \frac{\alpha_s}{2\pi} \widehat{P}_{ba}(z)$$



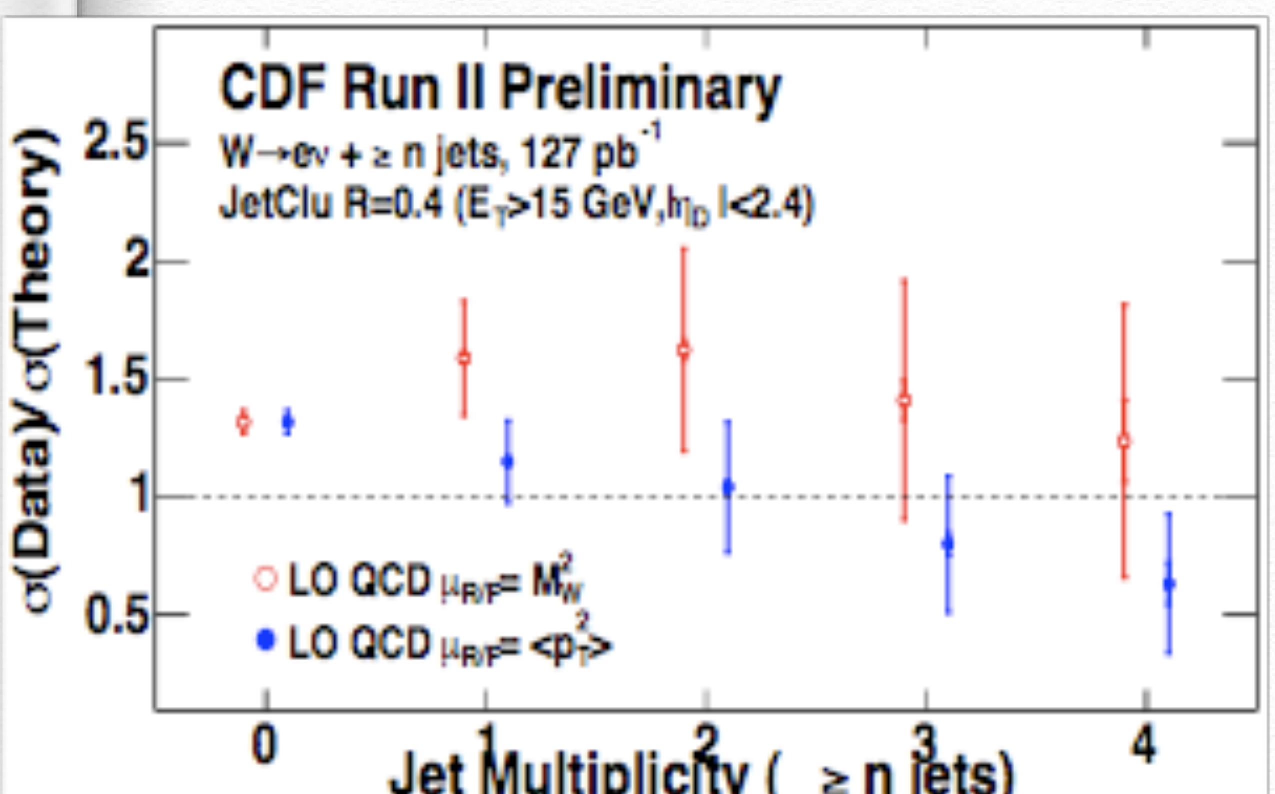



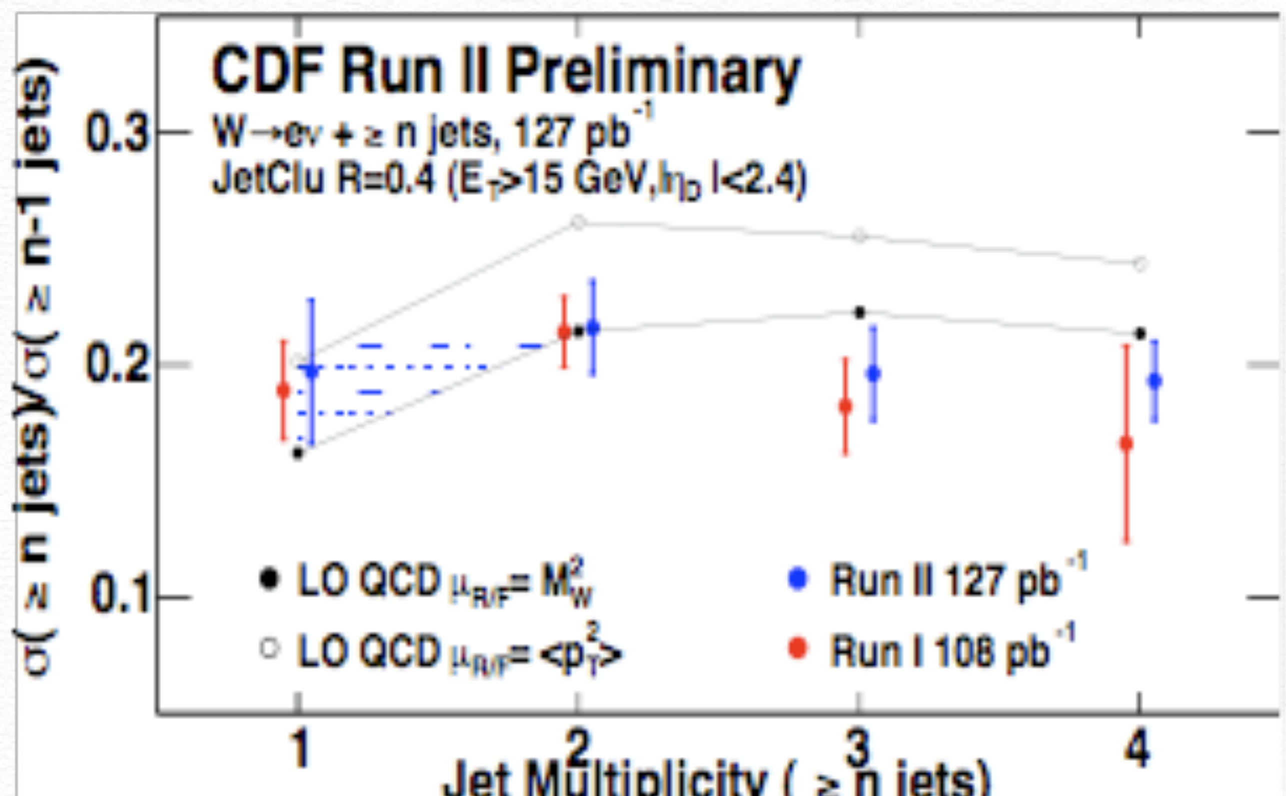
# W+jets (leading SUSY BG at 7TeV )

Data vs Theory in 2003

Data vs Theory




Ratio of Cross-sections



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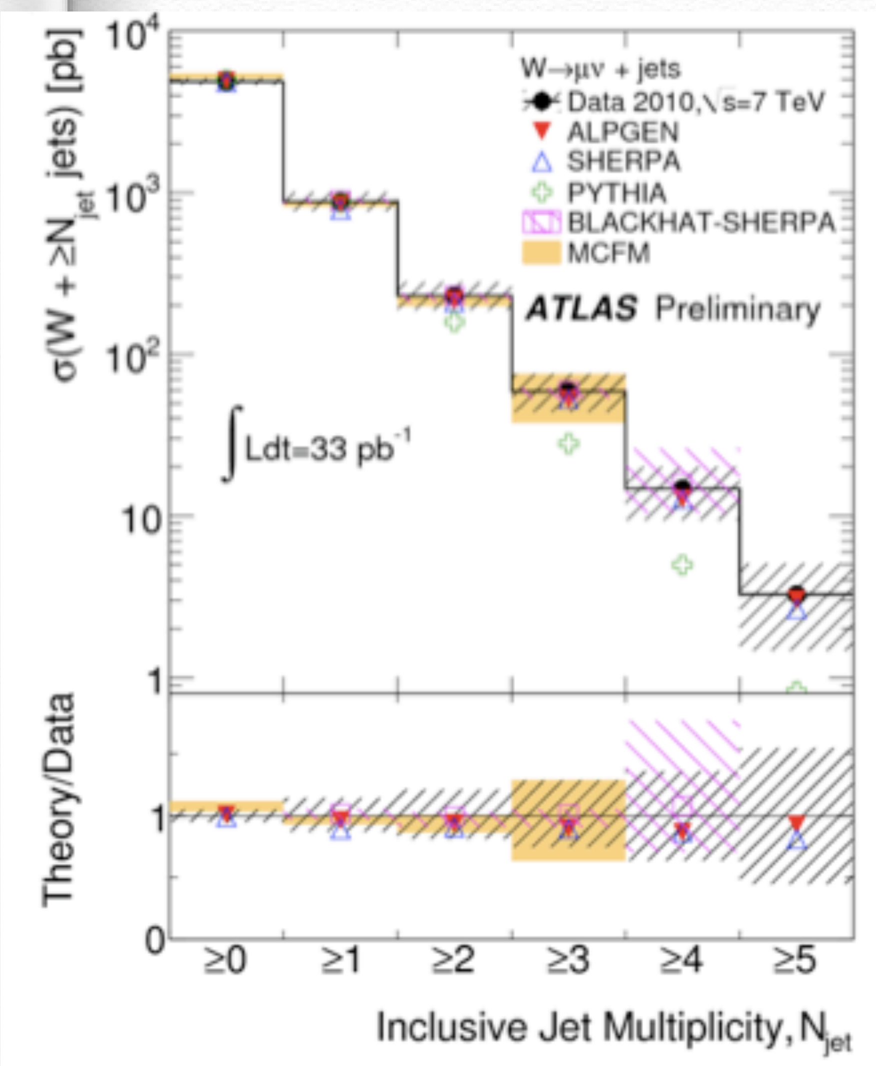
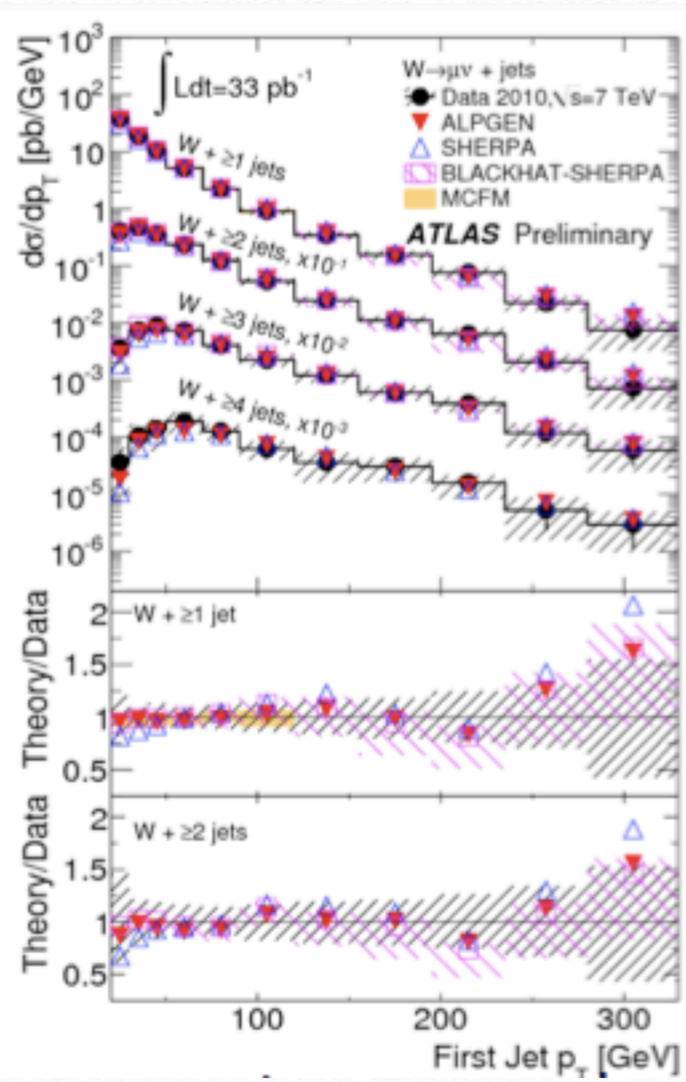
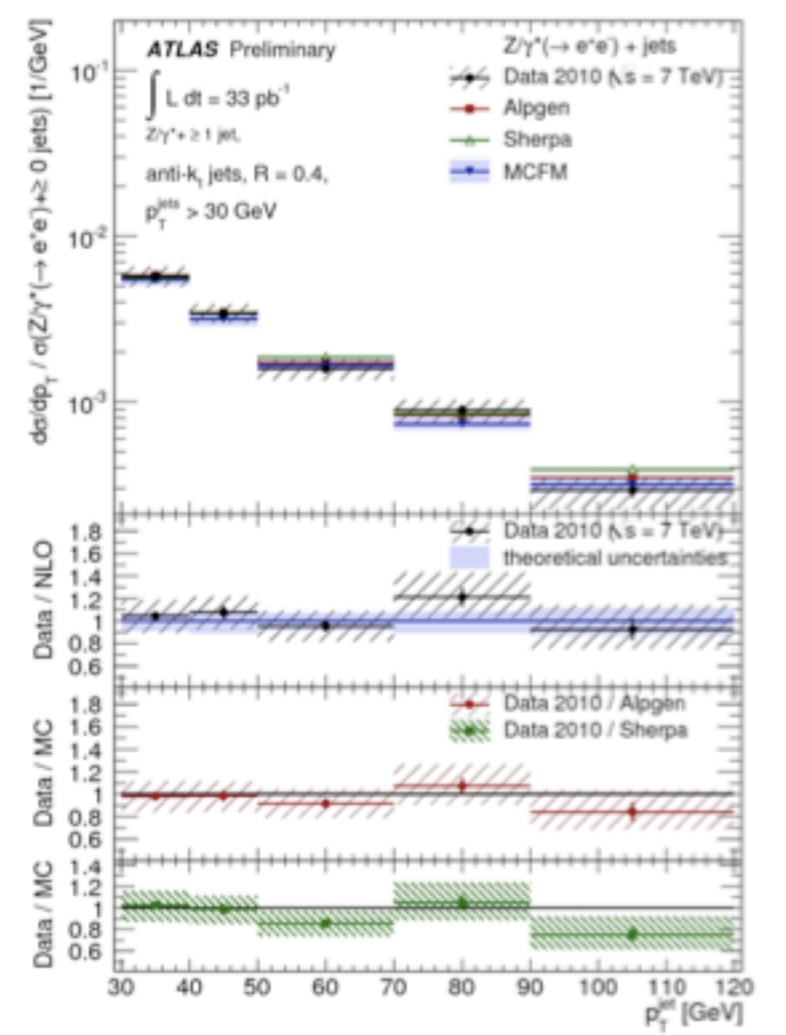


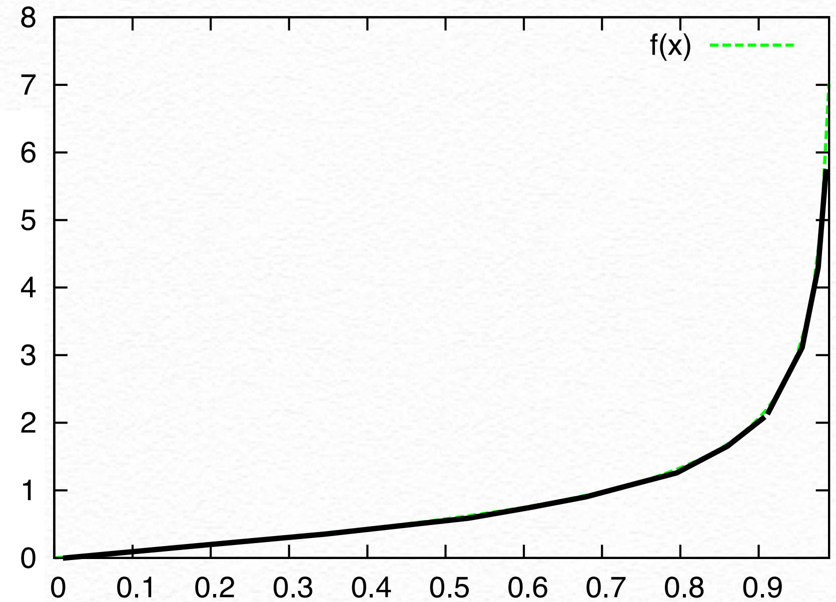
Learns about kinematics

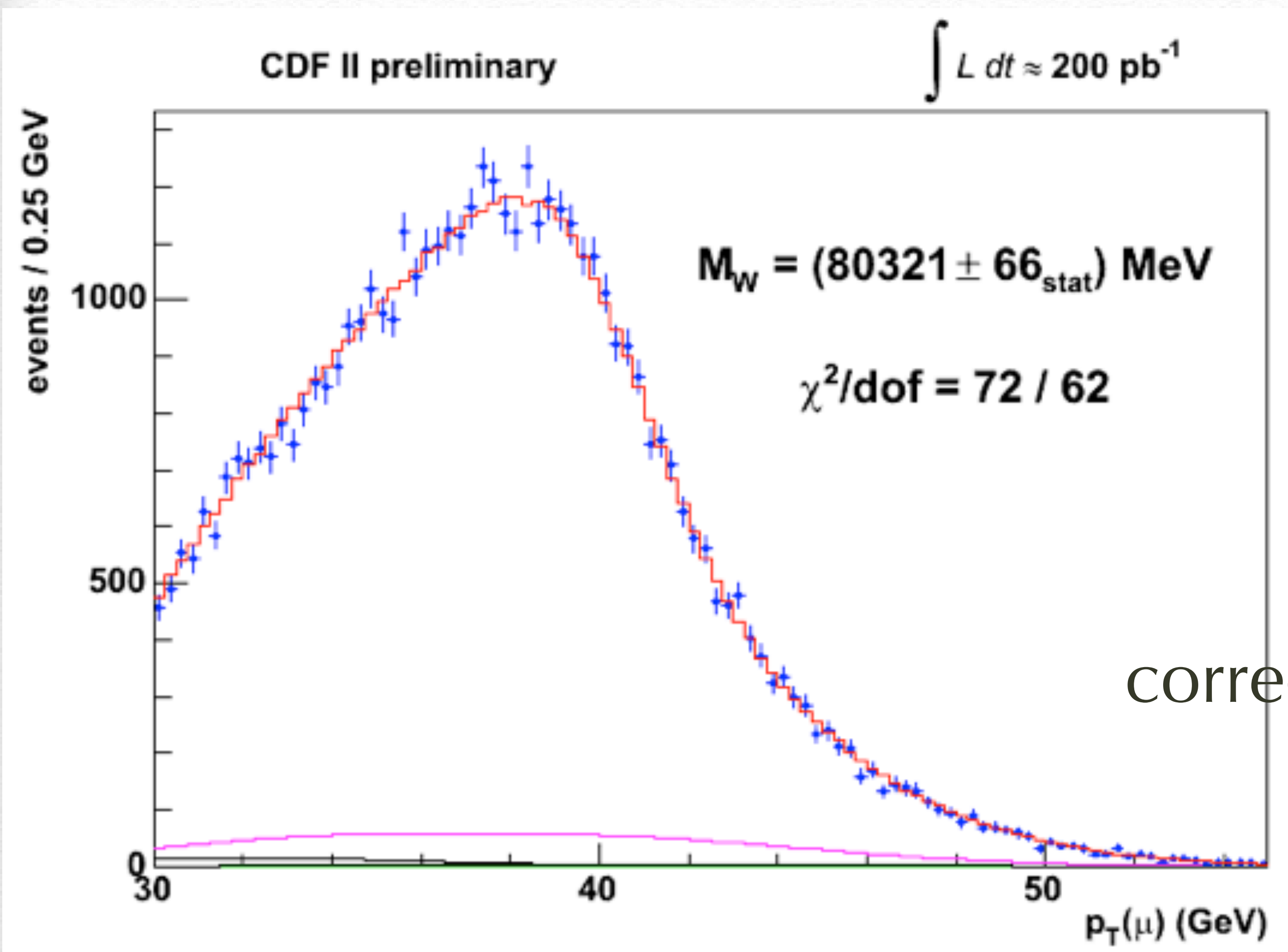
# Kinamatial Variable pT
# W mass and lepton pT

typical pt is half of W bosn mass    distribution

$$d\cos\theta = d\sqrt{1-\sin^2\theta} = \frac{2x}{\sqrt{1-x^2}}dx$$

x= pT/pT(max)
distribution peaks at pTmax




correct tail shape estimated from
QCD resummation

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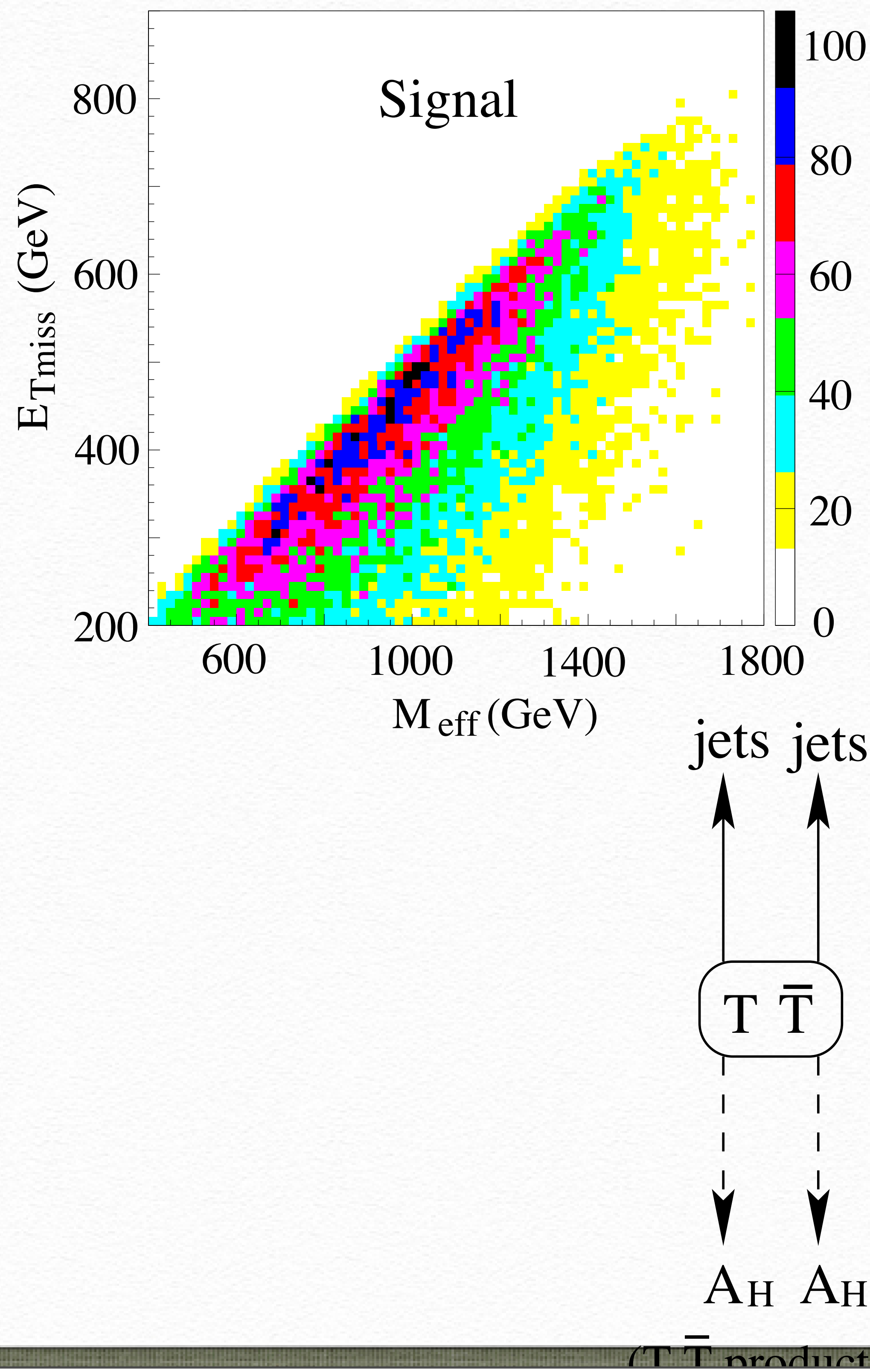
# signal discriminator:  Meff( or HT) and ETmiss

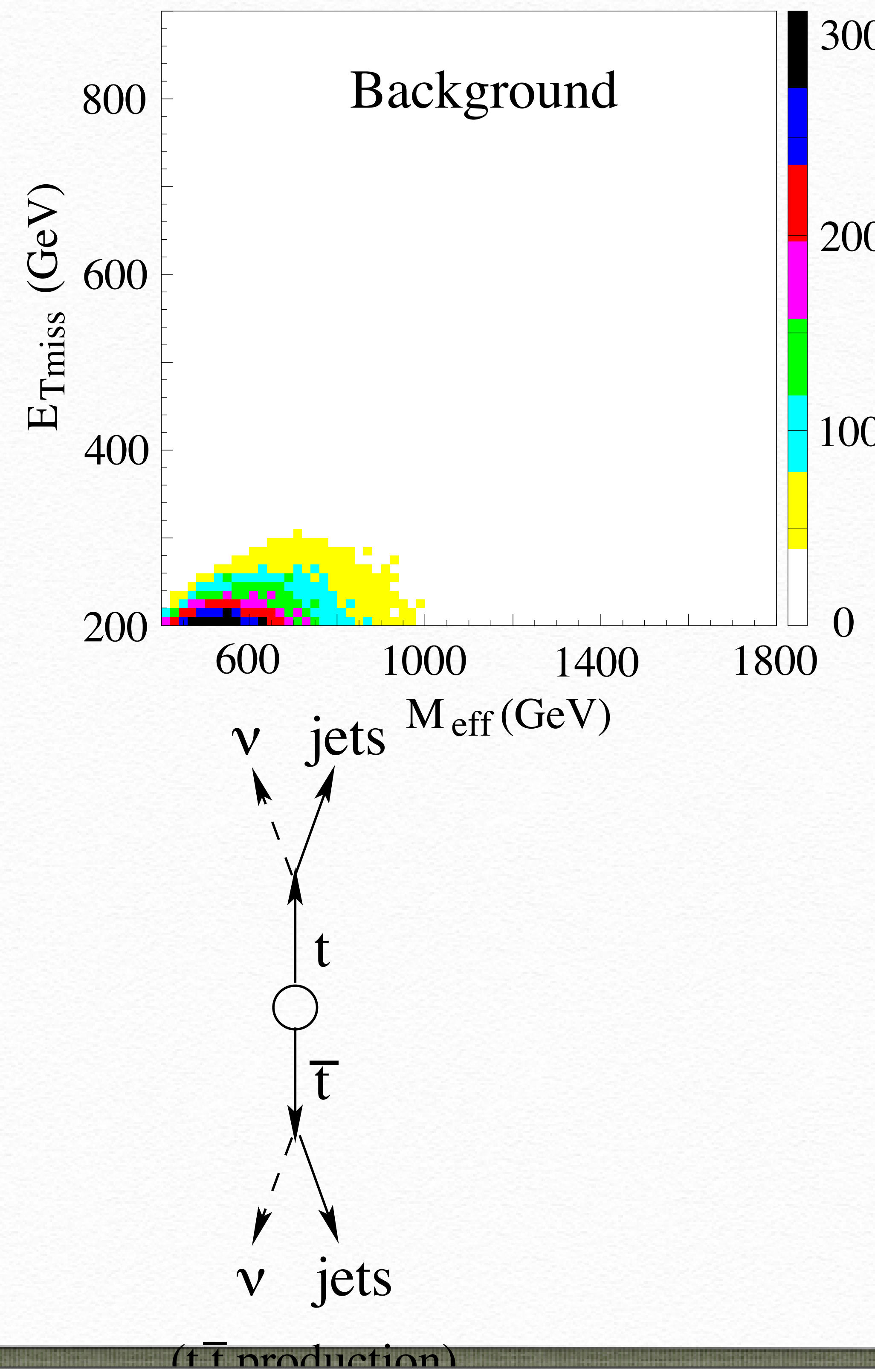
- All SUSY particles produced in pairs, near the threshold because
  - cross section is largest near the threshold
  - PDF is large for low X regions.
- Typical PT∝mass of the parent particles. If you produce heavy particle, sum of the PT must be large, you may even add the missing PT
- Dark matter from squark/gluino decay also have missing momentum and can be counted by ETmiss

# Etmiss cut

$gg \to T_- T_-^*, T_- \to t B_H$




pp→ttbar

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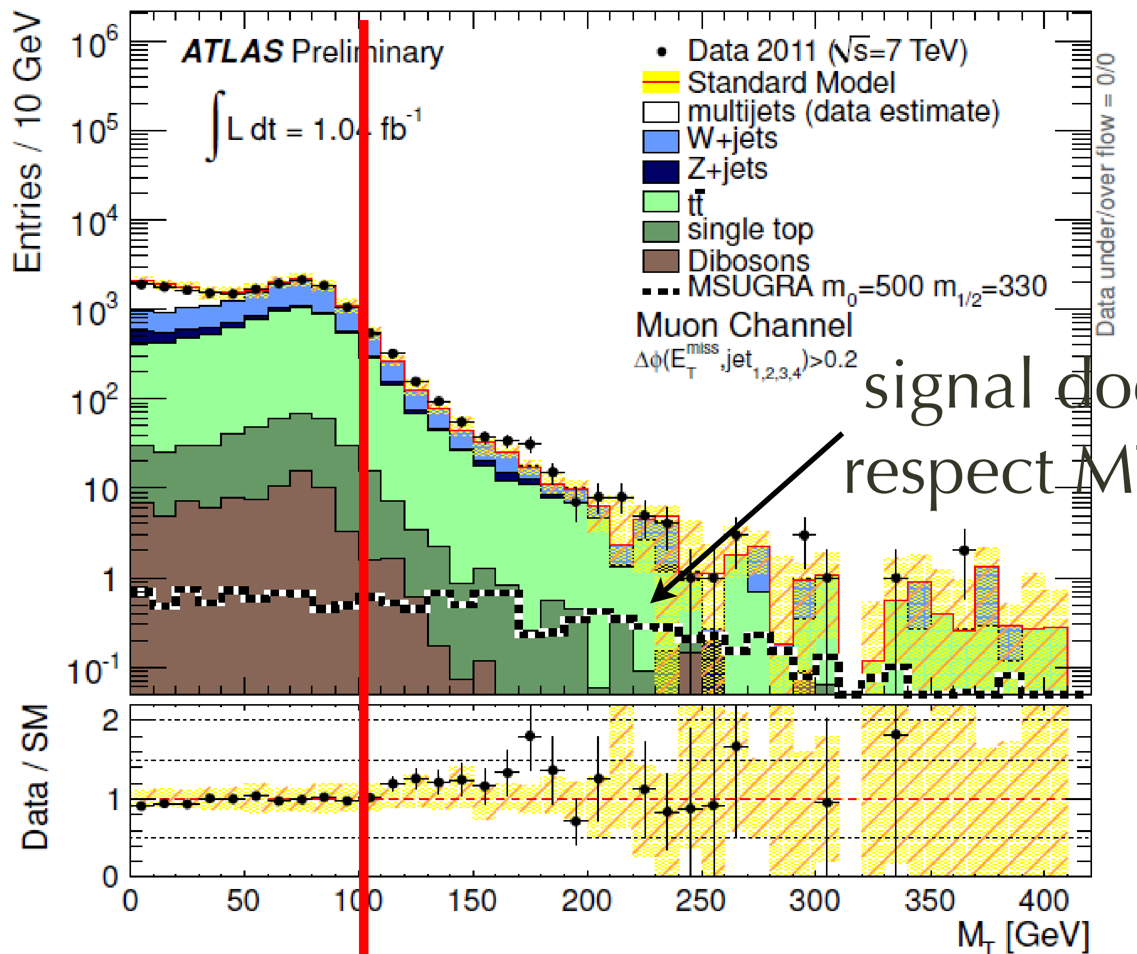
# background isolator: $M_T$

MT (1muon)




signal does not respect MT<100

control region

Signal region

tails from jet resolution and so on...

- Missing momentum comes from “neutrino” for SM, while from “two dark matter particles” for SUSY events.
- Therefore, the kinematical variable involving missing momentum is most important for SUSY background rejections.
- MT: calculated from lepton and transverse momentum is most important.

$$m_T = \sqrt{2 p_T^{\ell} E_T^{miss}(1 - \cos(\Delta\phi(\vec{\ell}, \vec{p}_T)))}$$

if $E_{Tmiss} = (P_\nu)_T$ MT<MW

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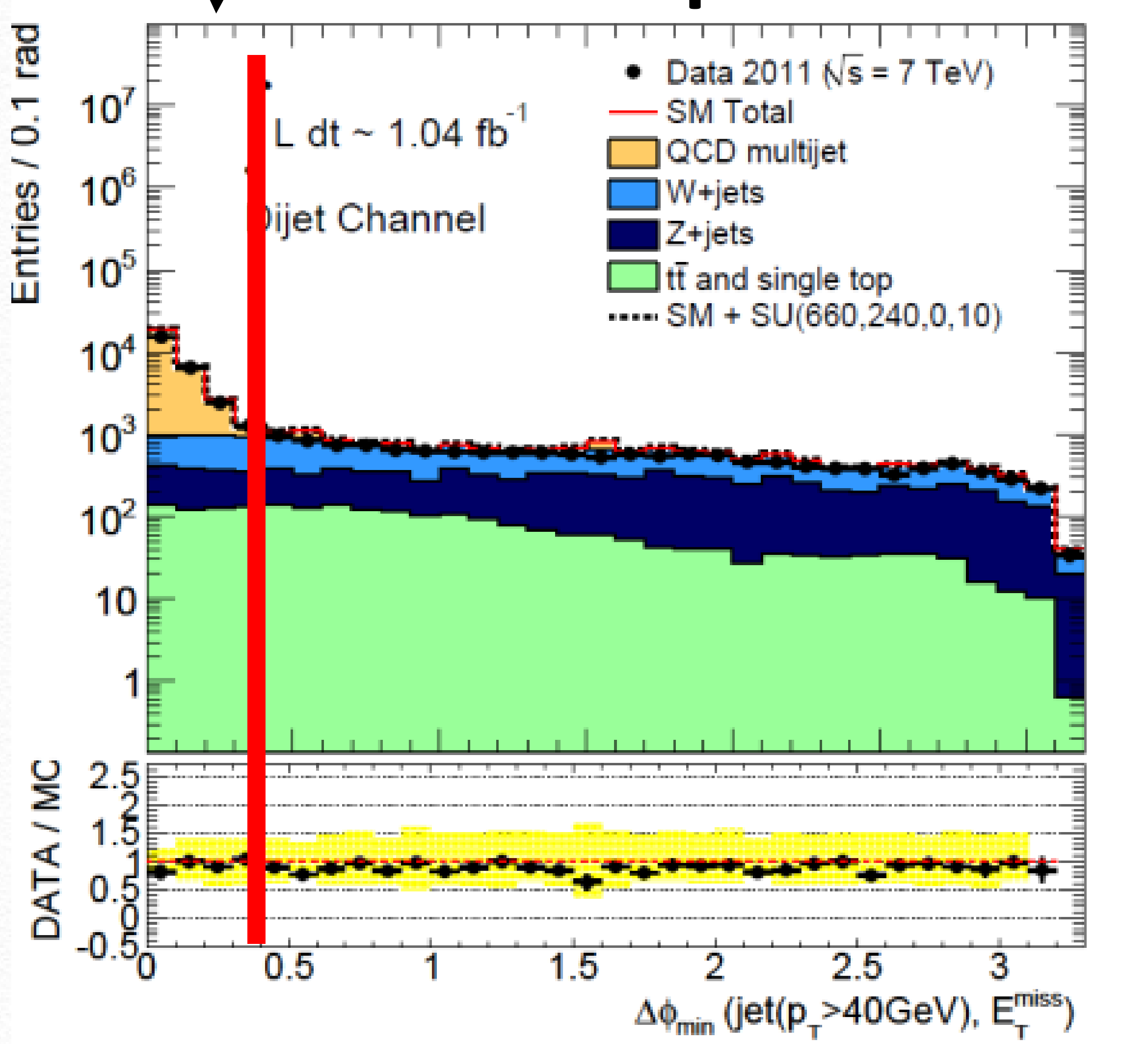
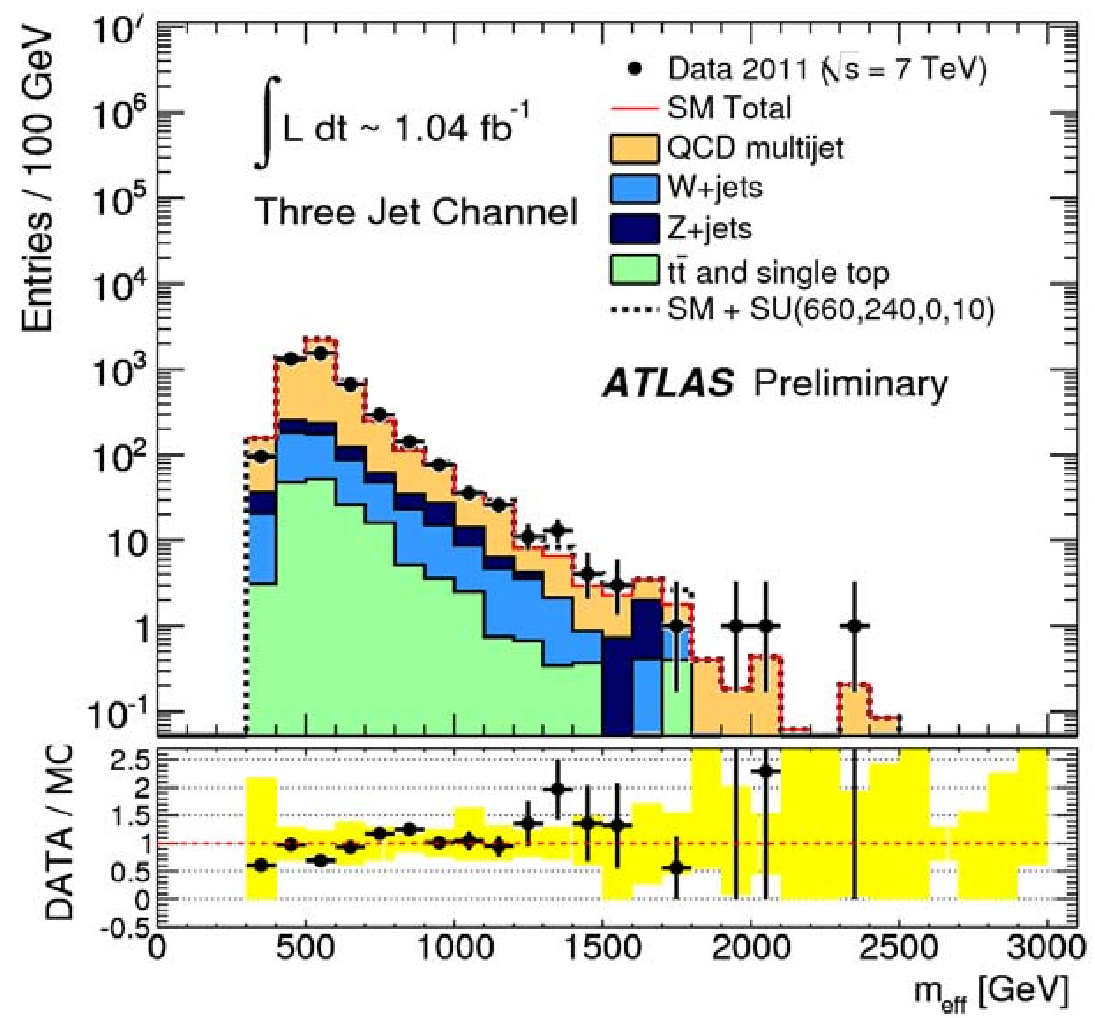
# detector effect isolator :Δφ cut for QCD background

dominated by QCD here

min dphi

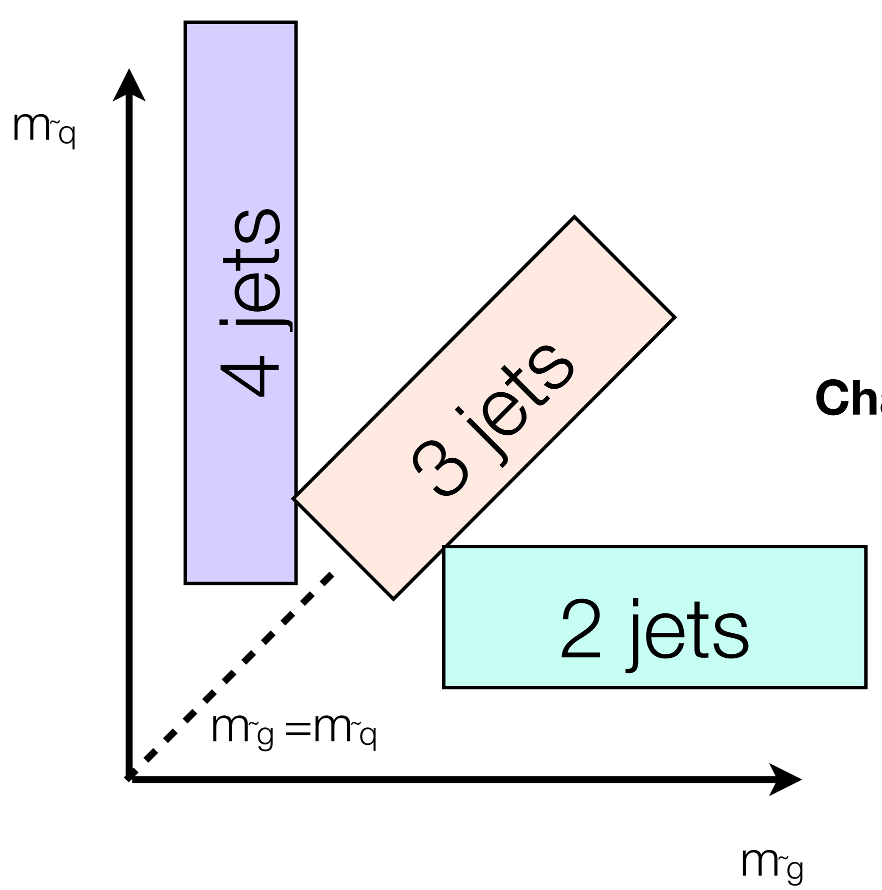



background shape is also generated from low ETmiss multijet sample by replacing jets containing semileptonic decays

# 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 |

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



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

# Results

| Process | Signal Region | | | | |
|---|---|---|---|---|---|
| | ≥ 2-jet | ≥ 3-jet | ≥ 4-jet, $m_{\rm eff} > 500$ GeV | ≥ 4-jet, $m_{\rm eff} > 1000$ GeV | High mass |
| $Z/\gamma$+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 |

upper limit of each search channel

- 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.

# at 4.7fb-1 (increasing cuts)

| Requirement | Channel | | | | | |
|---|---|---|---|---|---|---|
| | A | A' | B | C | D | E |
| $E_T^{miss}$[GeV] > | 160 | | | | | |
| $p_T(j_1)$ [GeV] > | 130 | | | | | |
| $p_T(j_2)$ [GeV] > | 60 | | | | | |
| $p_T(j_3)$ [GeV] > | – | – | 60 | 60 | 60 | 60 |
| $p_T(j_4)$ [GeV] > | – | – | – | 60 | 60 | 60 |
| $p_T(j_5)$ [GeV] > | – | – | – | – | 40 | 40 |
| $p_T(j_6)$ [GeV] > | – | – | – | – | – | 40 |
| $\Delta\phi(\text{jet}, E_T^{miss})_{min}$ > | 0.4 ($i = \{1, 2, (3)\}$) | | | 0.4 ($i = \{1, 2, 3\}$), 0.2 ($p_T$ > 40 GeV jets) | | |
| $E_T^{miss}/m_{eff}(Nj)$ > | 0.3 (2j) | 0.4 (2j) | 0.25 (3j) | 0.25 (4j) | 0.2 (5j) | 0.15 (6j) |
| $m_{eff}$(incl.) [GeV] > | 1900/1400/– | –/1200/– | 1900/–/– | 1500/1200/900 | 1500/–/– | 1400/1200/900 |

Table 1: Cuts used to define each of the channels in the analysis. The $E_T^{miss}/m_{eff}$ cut in any $N$ jet channel uses a value of $m_{eff}$ constructed from only the leading $N$ jets (indicated in parentheses). However, the final $m_{eff}$(incl.) selection, which is used to define the signal regions, includes all jets with $p_T > 40$ GeV. The three $m_{eff}$(incl.) selections listed in the final row denote the 'tight', 'medium' and 'loose' selections respectively. Not all channels include all three SRs.

# Higgs sector and sparticle mass
# stop mass is most important

- Higgs sector and sparticle masses: stop mass and mixings are most impoartant

- We have seen already, there are parameter space where stop mass is light and squark and gluino mass is heavy

- LHC search:cross section reduces very quickly with increasing squark mass, because it does not couple with valence quark

- decay mode

$$\tilde{t} \to t\tilde{\chi}_1^0$$
$$\tilde{t} \to b\tilde{\chi}_1^+$$

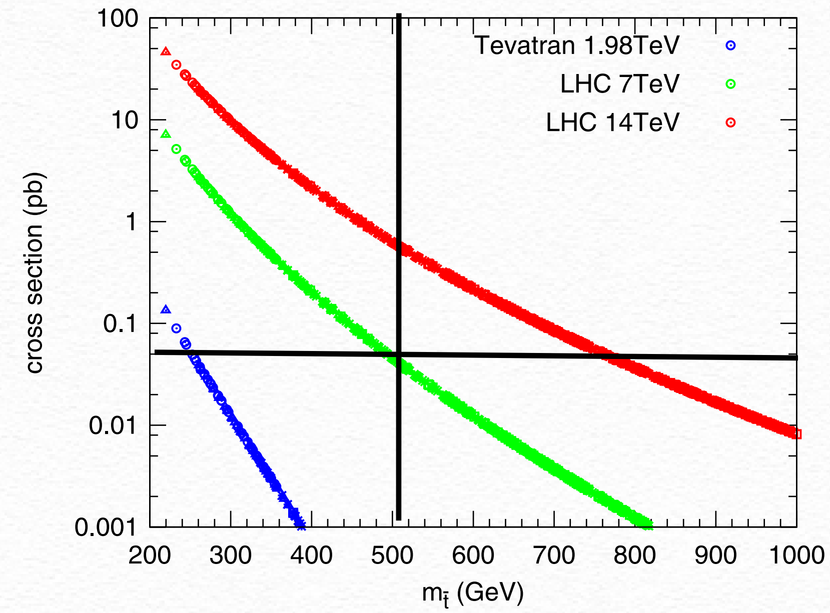
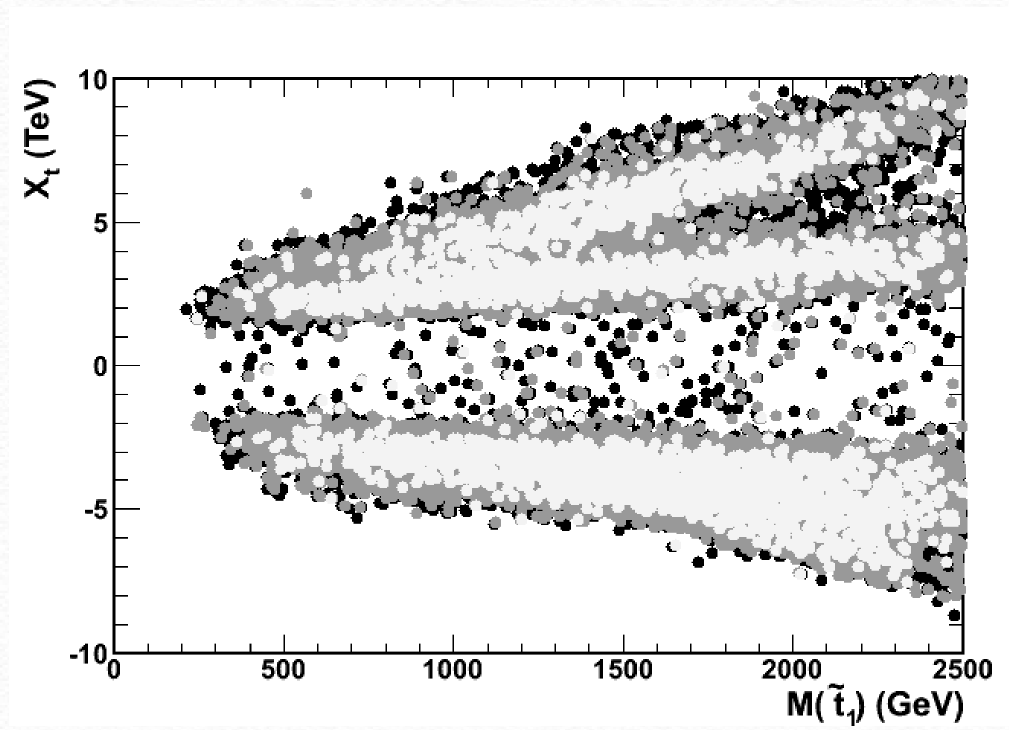


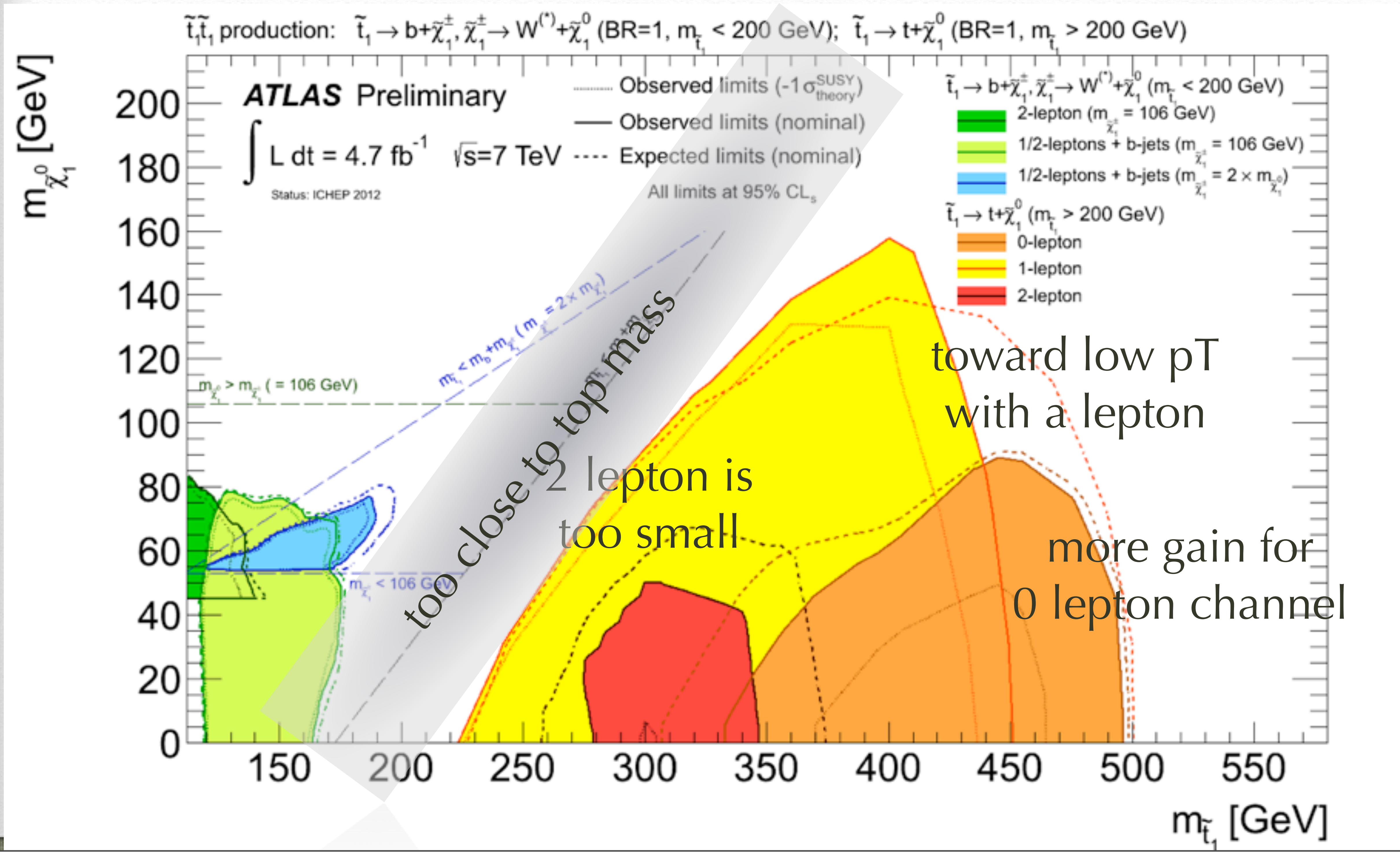

FIG. 4 (color online). The cross sections of stop pair production at Tevatron, LHC-7 TeV and LHC-14 TeV are shown.

50fb x 5fb$^{-1}$=250
(current discovery limit)
14TeV →800GeV?

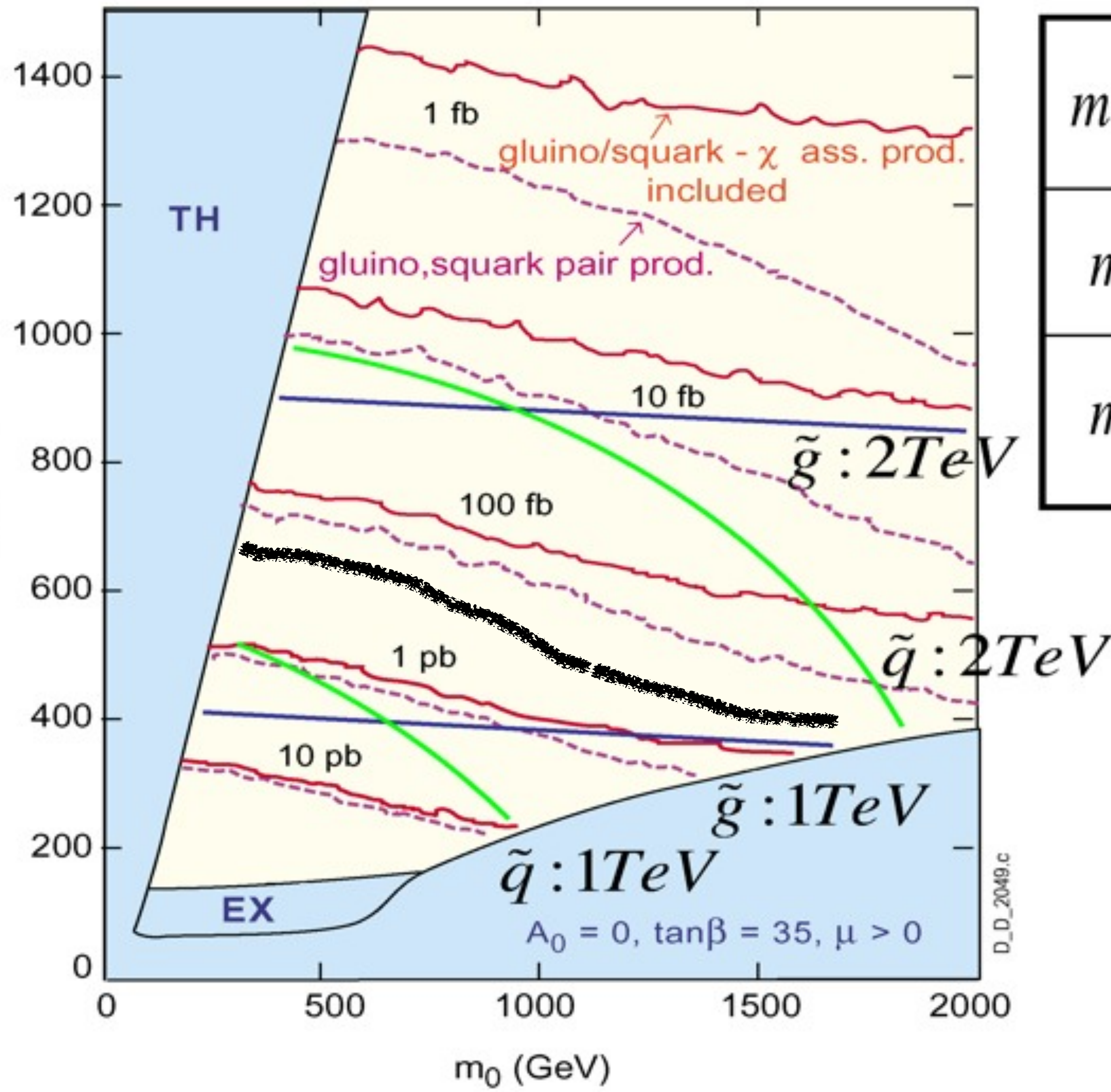



stop mass with HIggs mass constraint

# stop searches



# cross section at 14TeV.




| | |
|---|---|
| $m(\tilde{q}) = m(\tilde{g}) = 0.5TeV$ | $\sigma \sim 100pb$<br>$\tilde{g}\tilde{g}$ がmain |
| $m(\tilde{q}) = m(\tilde{g}) = 1TeV$ | $\sigma \sim 3pb$ |
| $m(\tilde{q}) = m(\tilde{g}) = 2TeV$ | $\sigma \sim 20fb$<br>$\tilde{u}\tilde{u}, \tilde{u}\tilde{d}$ がmain |

large production cross section determined by mass and QCD coupling.
high x PDF needed
K factor is 1.4

S.Asai 2003 JPS meeting