SUSY @LHC

バックグランドの研究

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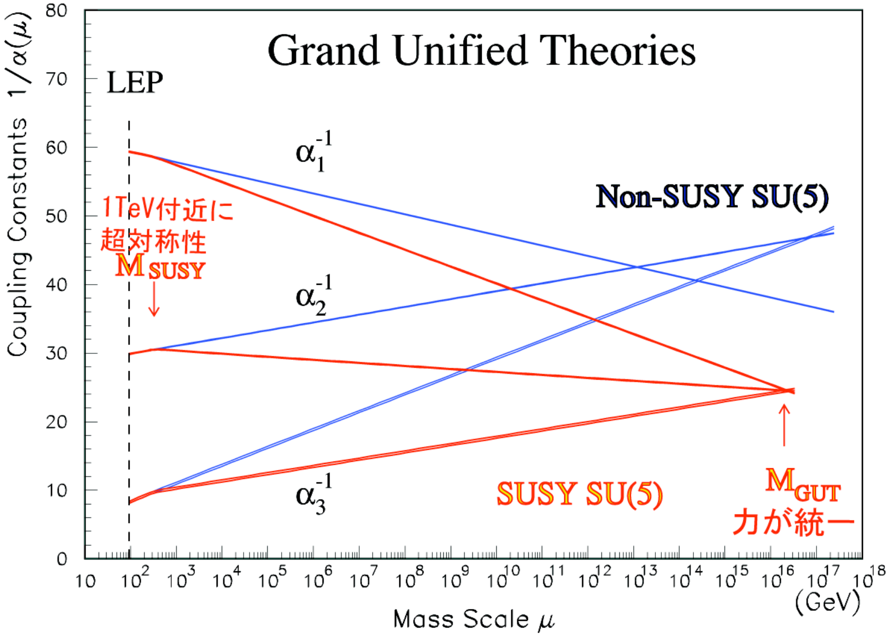
TeVスケールSUSYの御利益

GUT,Dark Matter, 階層問題解決など
ーー＞　Beyond SMの最有力候補
LHC のメジャーな研究対象



mSUGRAの簡単な纏め

☆ ５つのパラメター ： m_o, $m_{1/2}$, $\tan\beta$, A_0, $\mathrm{sign}(\mu)$

(mass @GUT) (VEV) (scalar 3点) (Higgsino mass)

☆ 一般的な傾向

- Coloured partciles $(\tilde{g}, \tilde{q})$ は重い
- $\tilde{\chi}_1^0$ はLSPで安定(R-parity) Cold DMの良い候補
- Higgsino mass (|μ|) > 0.8$m_{1/2}$(Wino) (m_0>>$m_{1/2}$の場合以外)

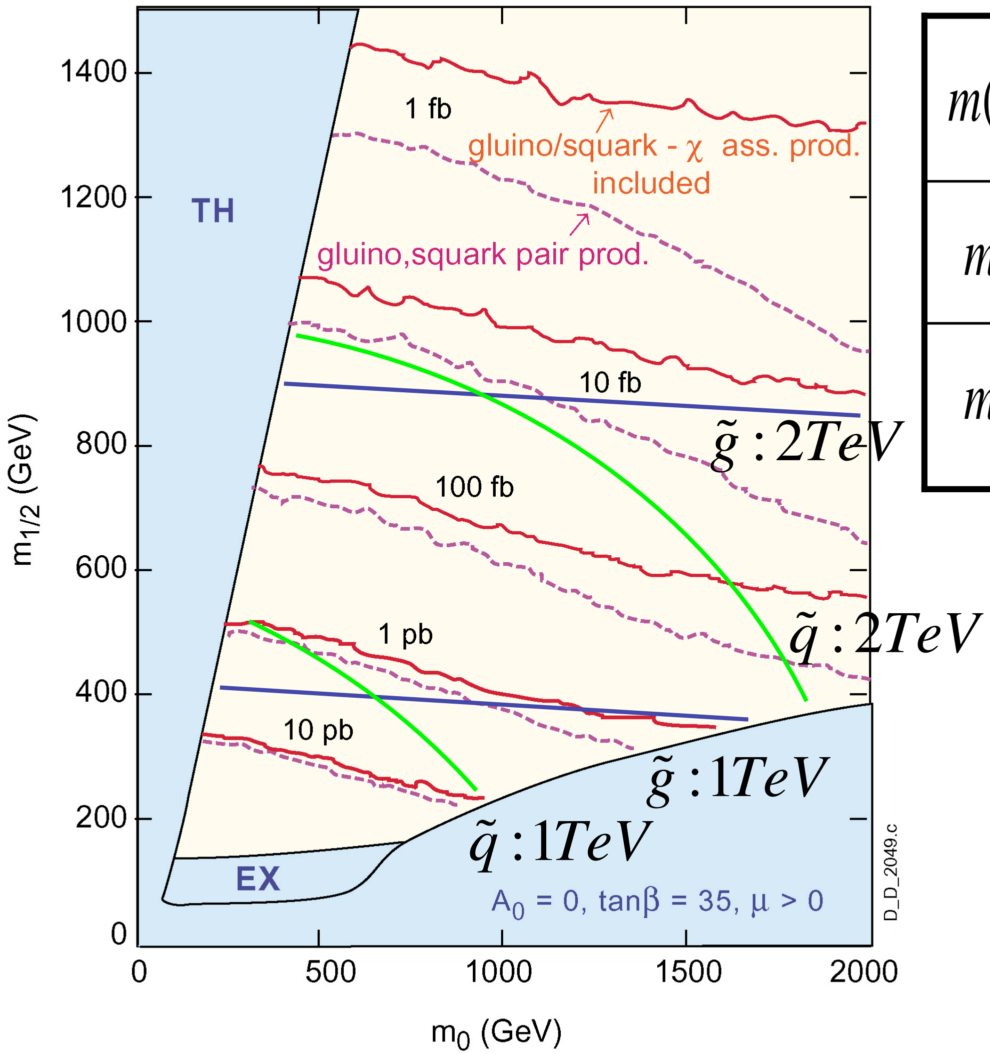
$$\rightarrow \quad \tilde{\chi}_1^0 \approx \tilde{B}^0, \tilde{\chi}_2^0 \approx \tilde{W}^0, \tilde{\chi}_1^\pm \approx \tilde{W}^\pm, \tilde{\chi}_{3,4}^0, \tilde{\chi}_2^\pm \approx \tilde{H}$$

- 第３世代の $\tilde{f}$ は軽い。(Yukawa+LR mixingの効果)

☆ ＬＨＣでの主なSUSY生成過程は、$(\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q})$ である。
生成断面積は、これらのmass以外にはモデル依存性が小さい。
ただのstrong interaction

$\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{l}$ らは、 $\tilde{g}, \tilde{q}$の崩壊過程で出てくる
（多段cascade崩壊）LEP,Tevatronとの大きな違い

$(\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q})$ 生成断面積 at LHC



$m(\tilde{q}) = m(\tilde{g}) = 0.5TeV$	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

- 大きな生成断面積
- ただの強い相互作用:
  mass以外は SUSY parameter
  に強く依存しない。
- High x のpdfが大切
- K-factor 1.4 SUSY NLO
  --> 後で D.R

$\tilde{g}, \tilde{q}$ のdecay table

	$m(\tilde{g}) < m(\tilde{q})$	$m(\tilde{g}) \approx m(\tilde{q})$	$m(\tilde{g}) > m(\tilde{q})$
$\tilde{g}$	$\tilde{g} \rightarrow$ $q\bar{q}\tilde{B}^0(\approx 1)$ $q\bar{q}\tilde{W}^0(\approx 2)$ $q\bar{q}\tilde{W}^\pm(\approx 4)$	$\tilde{g} \rightarrow$ $t\tilde{t}_1$ $b\tilde{b}_1$	$\tilde{g} \rightarrow q\tilde{q}$
$\tilde{q}_L$	$\tilde{q}_L \rightarrow q\tilde{g}$	$\tilde{q}_L \rightarrow$ $q\tilde{W}^0(\approx 1)$ $q\tilde{W}^\pm(\approx 2)$	
$\tilde{q}_R$	$\tilde{q}_R \rightarrow q\tilde{g}$	$\tilde{q}_R \rightarrow q\tilde{B}^0$	

$\tilde{g}, \tilde{q}$ のdecay table

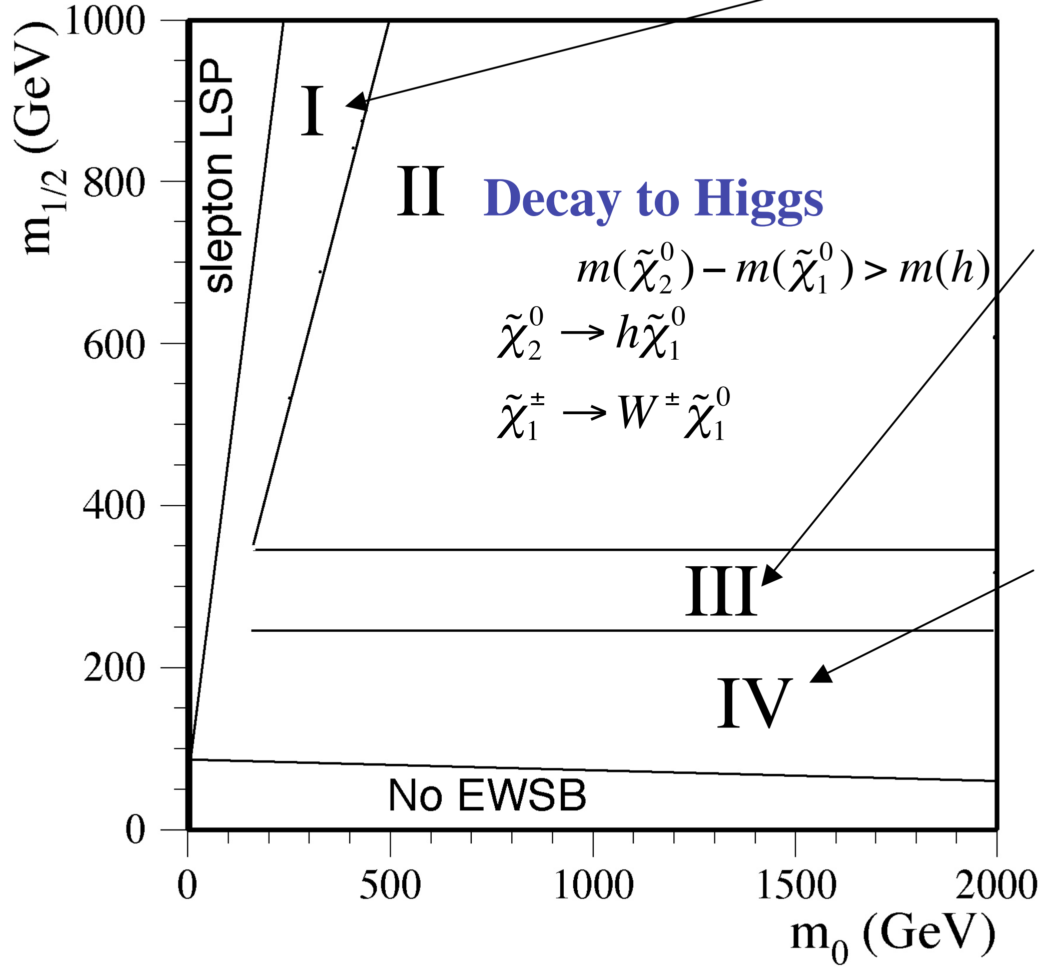
	$m(\tilde{g}) < m(\tilde{q})$	$m(\tilde{g}) \approx m(\tilde{q})$	$m(\tilde{g}) > m(\tilde{q})$
$\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{B}^0 (\approx 1)$, $q\bar{q}\tilde{W}^0 (\approx 2)$, $q\bar{q}\tilde{W}^{\pm} (\approx 4)$	$\tilde{g} \to t\tilde{t}_1$, $b\tilde{b}_1$	$\tilde{g} \to q\tilde{q}$
$\tilde{q}_L$	$\tilde{q}_L \to q\tilde{g}$	$\tilde{q}_L \to q\tilde{W}^0 (\approx 1)$, $q\tilde{W}^{\pm} (\approx 2)$	
$\tilde{q}_R$	$\tilde{q}_R \to q\tilde{g}$	$\tilde{q}_R \to q\tilde{B}^0$	

Strong interaction

EW interaction

ここら辺はあまりモデルによらない。Massの関係やB,Wとχの関係、第３世代などが依存、、

$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ の崩壊モードについて



2-Body decay chain

$m(\tilde{\chi}_1^{\pm}), m(\tilde{\chi}_2^0) > m(\tilde{\ell}^{\pm})$

$\tilde{\chi}_1^{\pm} \to \tilde{\ell}^{\pm}\nu \to \ell^{\pm}\tilde{\chi}_1^0\nu$

$\tilde{\chi}_2^0 \to \tilde{\ell}^{\pm}\ell^{\mp} \to \ell^{\pm}\ell^{\mp}\tilde{\chi}_1^0$

Decay to W/Z

$m(h) > \Delta m > m(W,Z)$

$\tilde{\chi}_2^0 \to Z^0\tilde{\chi}_1^0$

$\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0$

3-Body decay $\Delta m < m(W,Z)$

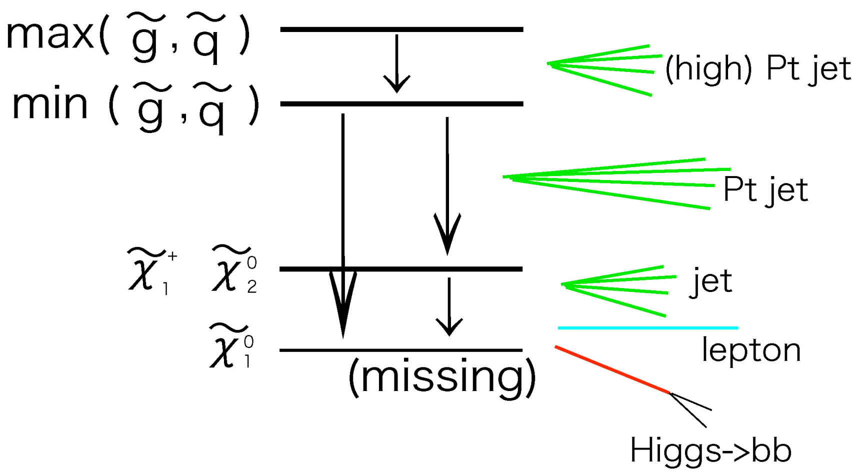
$\tilde{\chi}_2^0 \to f\bar{f}\tilde{\chi}_1^0$

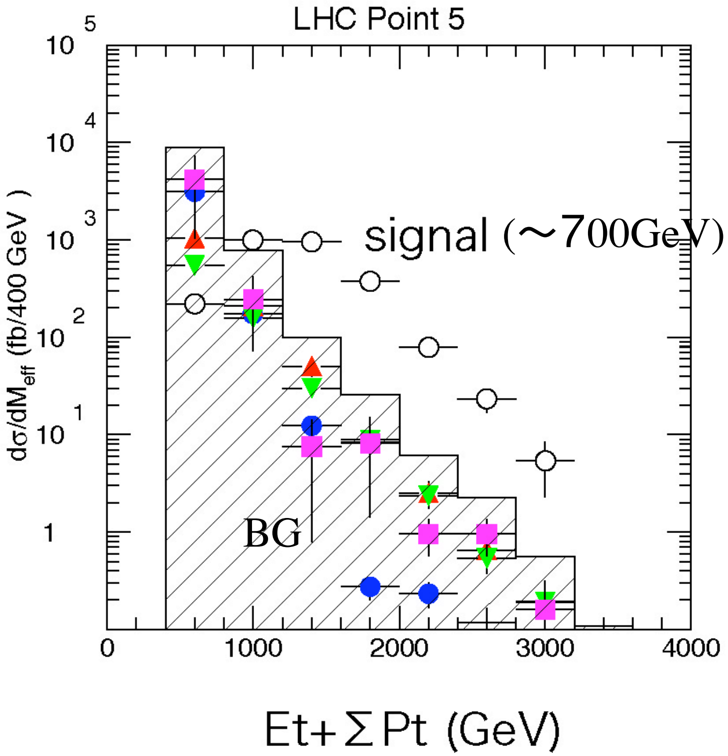
$\tilde{\chi}_1^{\pm} \to f\bar{f}\tilde{\chi}_1^0$

これらは基本的にkinematics
だけであり、依存性は少ない。
Sfermion propagatorで3body

$tan\beta >> 1$の時 $\tilde{\tau}_1$ が軽くなり、τへのdecay branchingが増える。
τ-IDが大切。Higgsino成分が多くなると、然り。

非常に大雑把に言うと





期待されるevent topologyは、

multi leptons

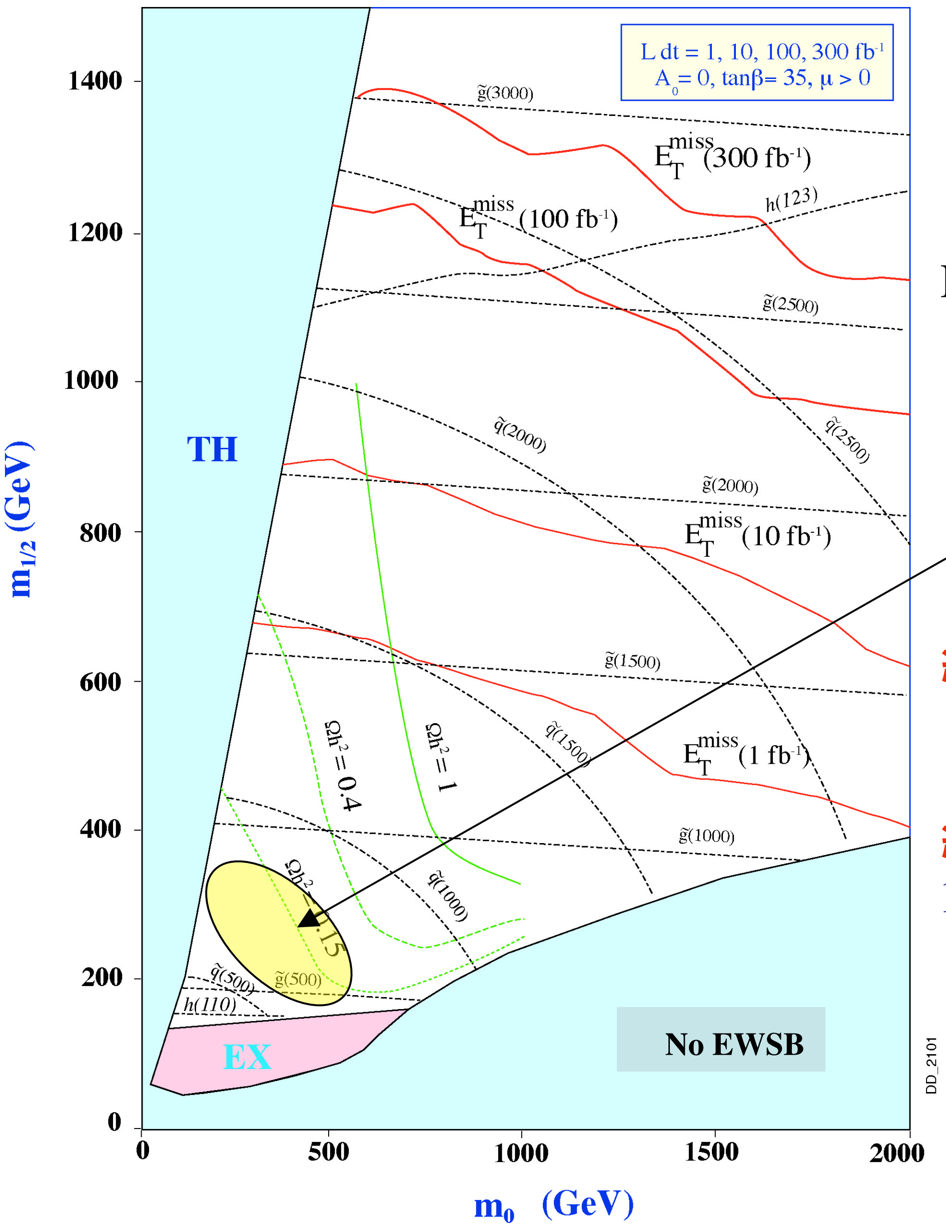
$\not{E}_T$ + High P_T jets + b-jets

τ-jets

Discoveryは容易 !?!?!?

- BGは、tt, QCD, Z+njets, W+njets
- Missing E_Tの測定、
  high Pt jetの較正がkeyになる。

mSUGRAの発見能力



L=300fb^{-1} で約**2.5TeV**まで

Cold DMとして面白い領域はほぼ**一週間のrun**で十分(後述)

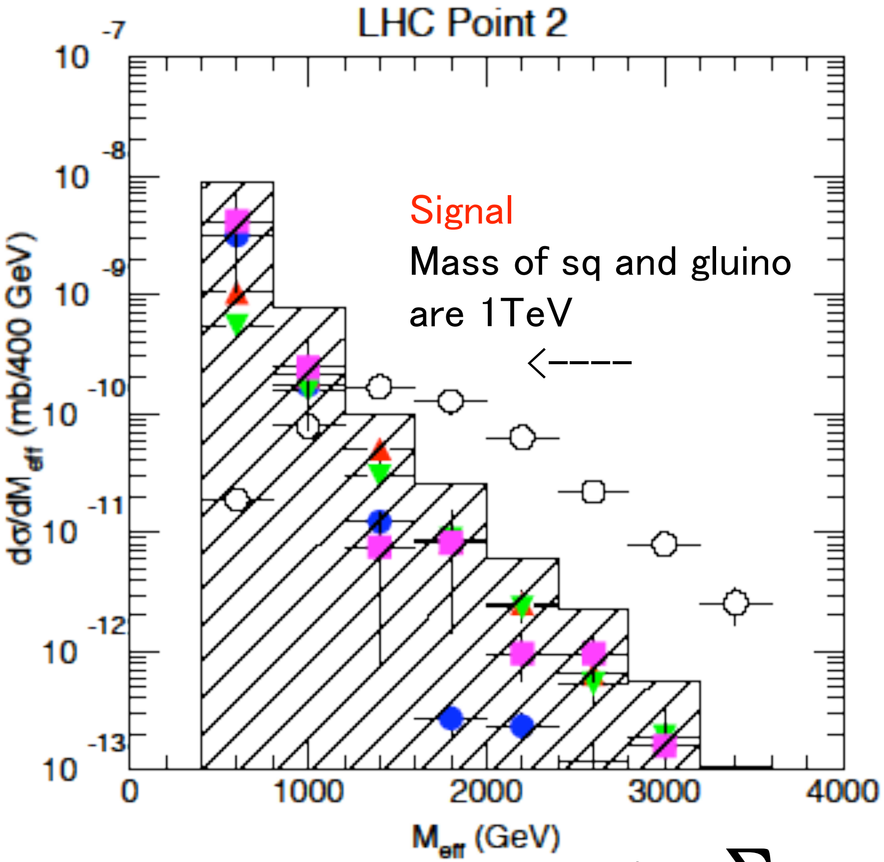
約1年のrun(L=10fb^{-1})で、約**2TeV**まで

約1ヶ月のrun(L=1fb^{-1})で $\tilde{g},\tilde{q}$ ~ **1.5TeV**
まで５σ可能 $\tilde{\chi}_1^{\pm}$
GUT: 約500GeVに相当する。LEP-IIの５倍

SM Background processes

No lepton mode: Z (ν ν , τ τ)+ N jets
W (τ ν) + N jets
tt + N jets
QCD multi-jets
(Fake-missing Et)

One lepton mode: W + N jets
tt + N jets
Z(τ τ) + Njets
(--> のちほど)



$= \not{E}_T + \sum P_T$

Up to 4jets

High Pt multi-jet also contribute
to separate signal from BG.

Multi-jetの評価:　Parton Shower Model　vs　ME

gg-> ggg を例に、　切り分け：Hard: PS: Hadronization（次のページ）

gg -> gg

g-> gg emition:　　　DGLAP Eq でシャワーの成長はLL or NLL までの精度で予言できる。　PS：はシミュレーションに入っている。(LL)

gg->ggにあとは、シャワーをいれる。

具体的には、

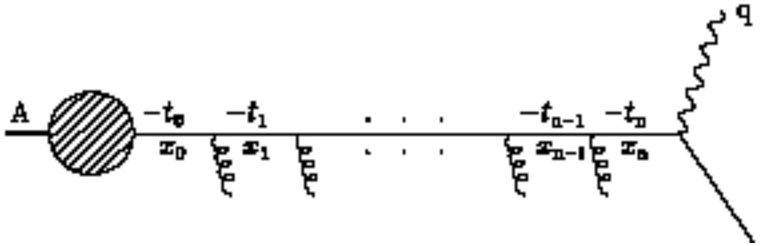
バーチャリティー:　max shower scale　-t　t=0 -> max shower

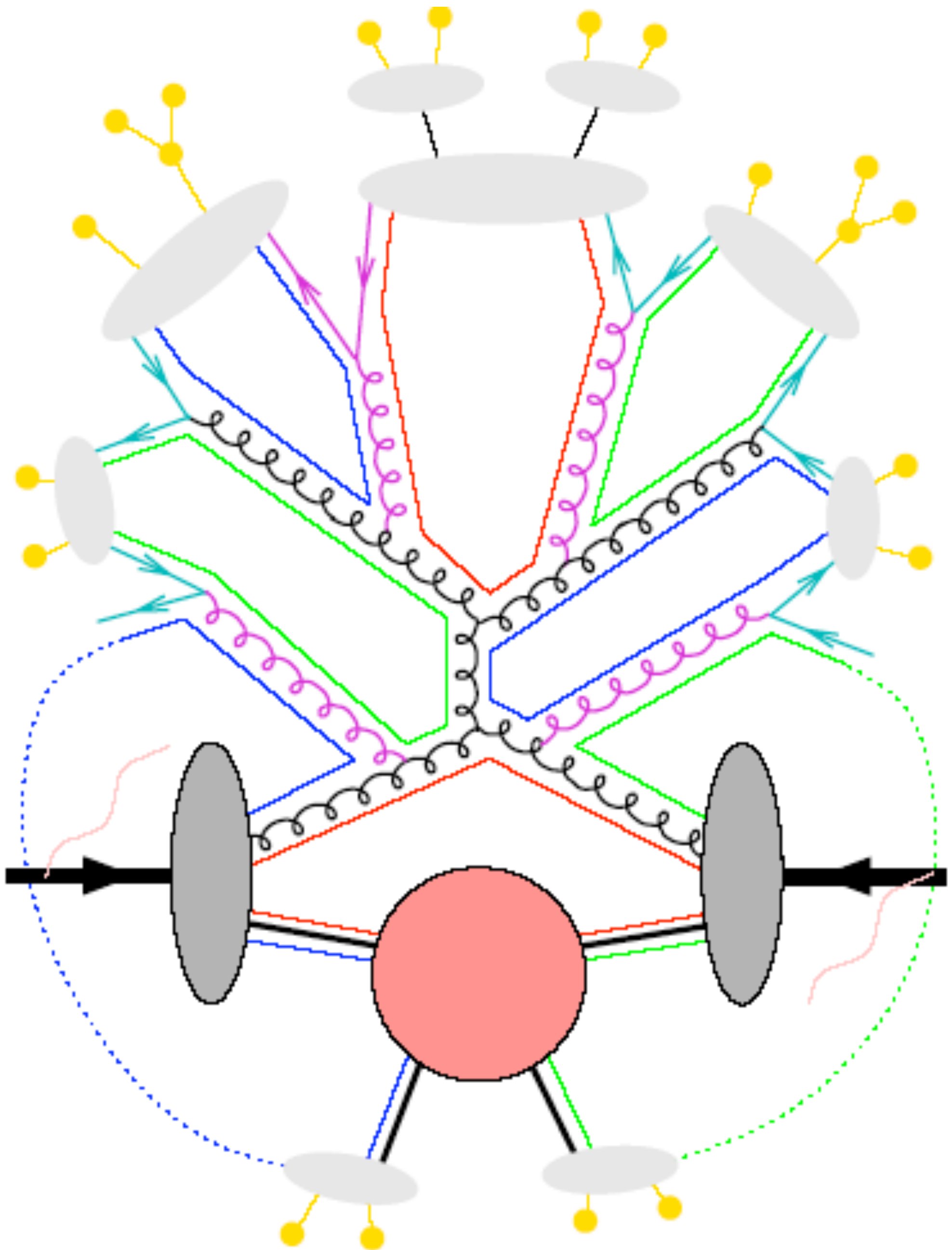
Low Pt:　inclusiveにいっぱいjetを正しく出せる。

$$|M_{p+1}|^2 d\Phi_{p+1} \approx |M_p|^2 d\Phi_p \frac{dt}{t}\frac{\alpha_s}{2\pi}P(z)dzd\phi$$

$$P(z) = C_F \frac{1+z^2}{1-z}$$

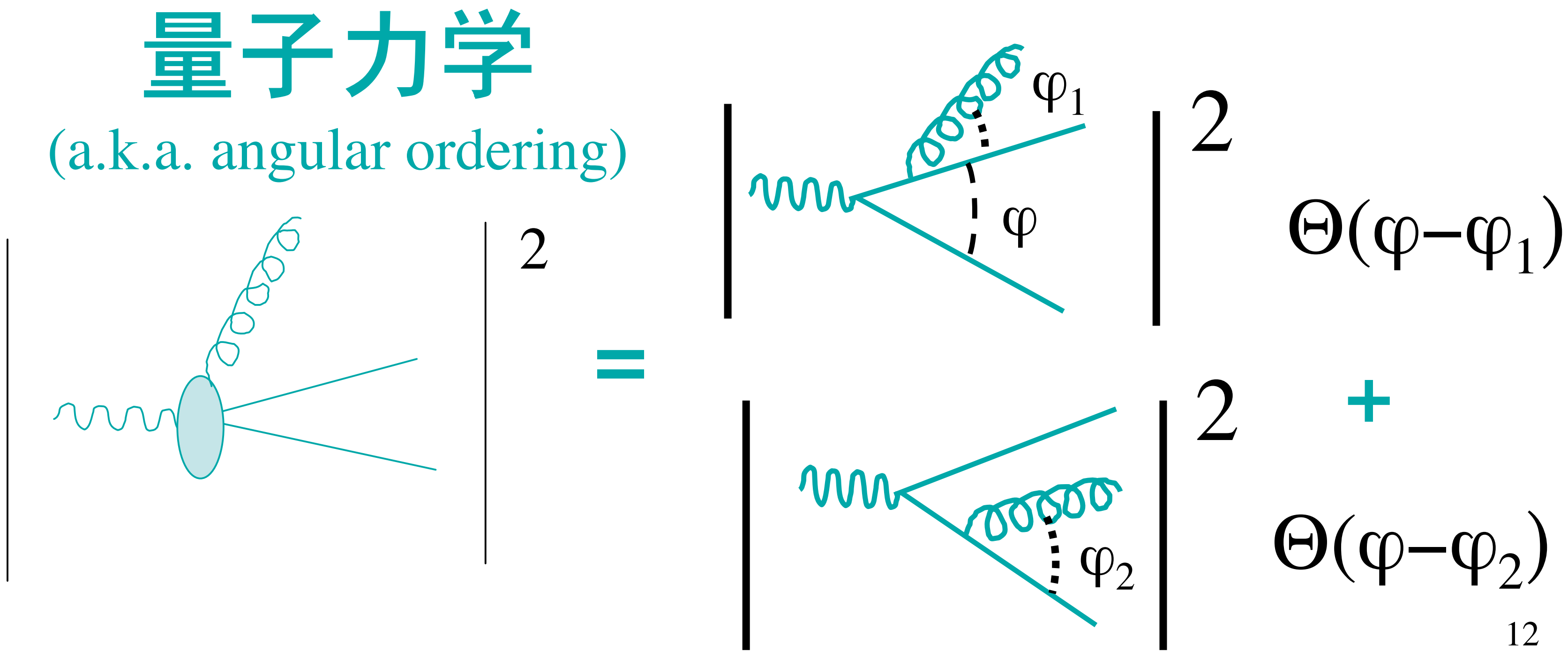
⇒ Parton shower MC.





Multi-jetの評価： Parton Shower Model vs ME

バーチャリティー： max shower scale −t t=0 −> max shower
Low Pt: inclusiveにいっぱいjetを正しく出せる。
Pt ordering, angle ordering
−> Low Pt が良い近似だが 高いPt領域はよくない。



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-> Low Pt が良い近似だが 高いPt領域はよくない。

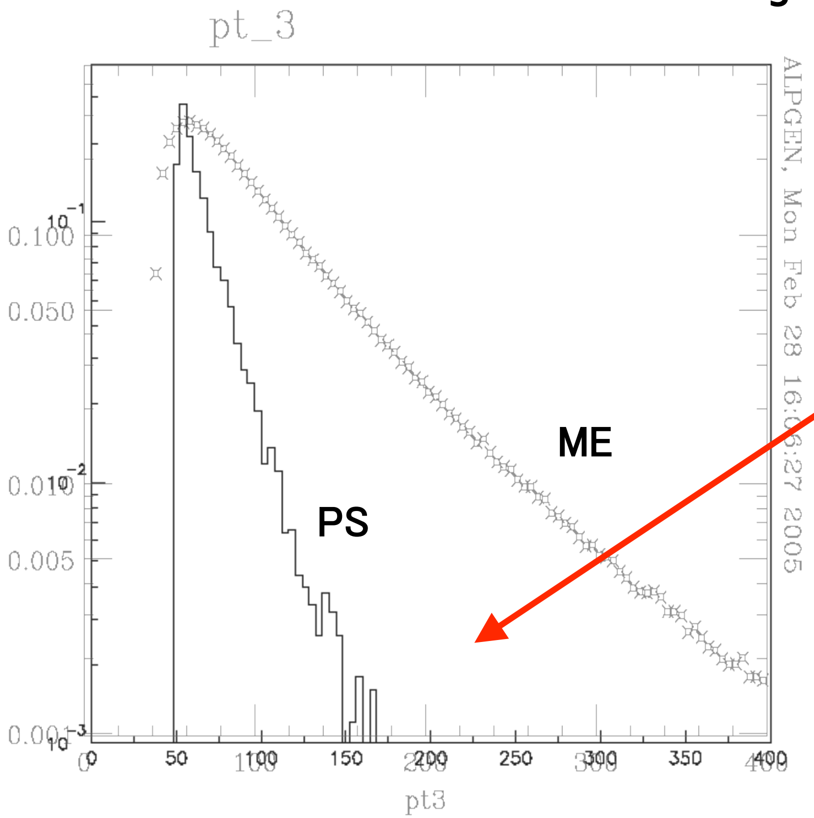
MEは、exclusiveになる。Soft Collinear発散の問題

PDFとの関係 （factorization scale: 切り分け）

Vertexの定義 multi-scale問題 （renormalization） NLOの時難しい

3. Problem in the current estimation of background

Pt distributions of 3rd jet for Z+ Njets processes



Hard jet is not emitted in Parton Show:
(It is famous problem.)

·Factor of more then 100 is different.
·The same problem is in 2nd,3rd,4th,,,, jets

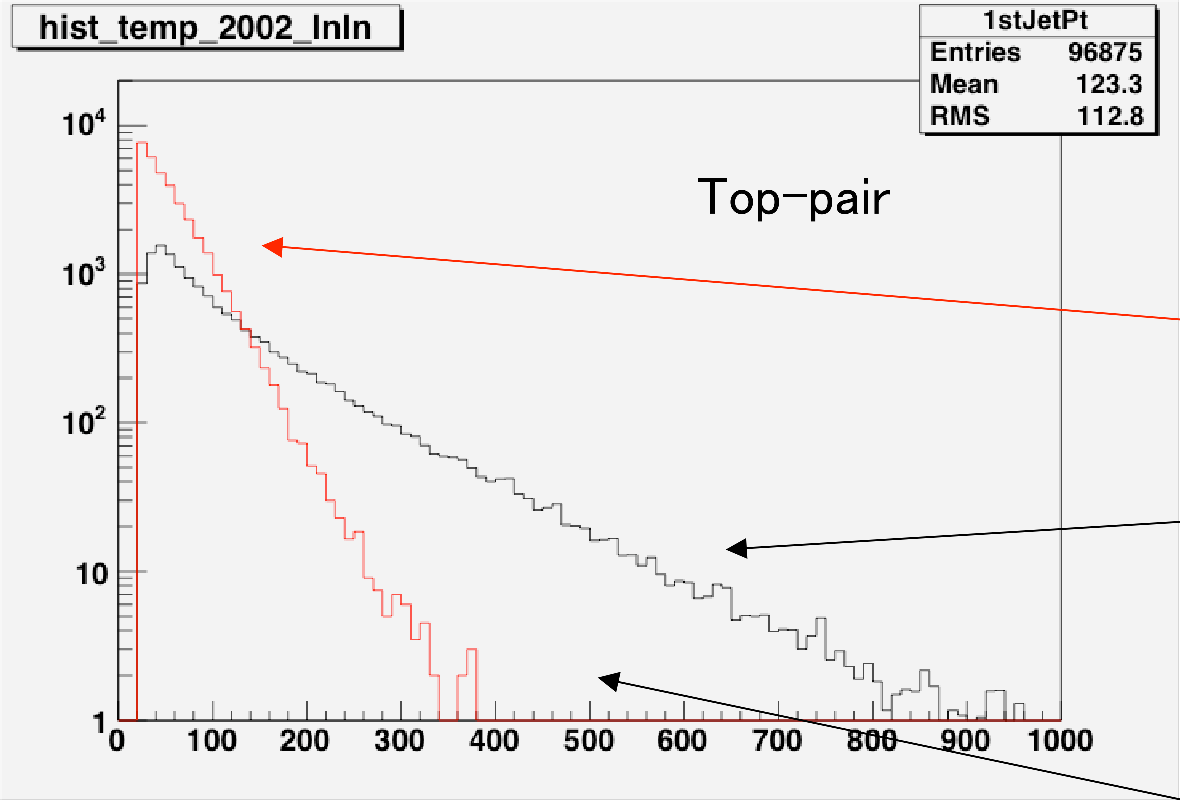
Parton Shower (PYTHIA 6.203)

Matrix Element (ALPGEN) Parton level

Missing Et > 100GeV
At least one jet(parton) has pt > 100GeV
At least four jets(partons) have pt>50GeV

Qfac=Qren=SQRT(Mz^2+Pt^2)
for both calculations.

The same problem is observed in the top-pair production.



Red: PS prediction estimated with PYTHIA

Black shows ME prediction (ALPGEN)

High Pt jets are emitted in tt production.

tt system is boosted

The Pt distribution (GeV) of the highest Pt of the additional jets.

おそらく、Multijet QCDでもそう。
2->2　を PSでmultijetにしている。
3,4,5,,, jetのhigh Ptは嘘。

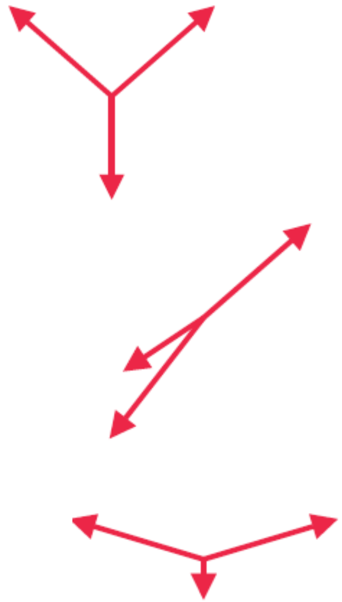
Missing Etへの効果？
　-> missing Et を決めるもの
　　　それは主に, total Hadron activity Multijetになるほど大きい

ＯＰＡＬでの経験
MH ee->qq　or qqg　３jetの方が分解のはじめ、missingなどが大きくなる。（うちのハドロンは最低でした。120/SQRT(E)　）

くらっく問題：
　くらっくが検出器にある。Multiになるほどヒットする割合が
　多い。Veto?

4. Production with ME

High Pt 3rd jet



◆ME has advantage for high Pt jet
as you can see in the previous section.
To remove collinear and soft divergence
Pt>20GeV and Rjj>0.7 are required
for production.

ALPGEN(V133) is used for ME

◆Soft and collinear kinematic regions are
covered by Parton Shower model (PYTHIA)

◆ATLAS detector effect is taken into account using
ATLFAST (Smear Monte Carlo : ATHENA9)

	Generated Num	Luminosity(fb^{-1})
tt(WW→lvqq)+Njets	~ 3×10^7	~100
tt(WW→lvlv)+Njets	~ 1×10^7	~ 100
W(W→lv)+Njets	~ 5×10^6	~ 50
Z(Z→ll)+Njets	~ 1×10^6	~ 100
Z(Z→vv)+Njets	~ 1×10^6	~ 100
QCD (PS by PYTHIA)	5 ~ 3×10^7	~ 0.5

<-

Temporary

- Fot toptop　N upto 3
  For W/Z　N upto 6
- They are generated with ALPGEN.
- QCD is generated with Pythia (Not ME just PS. tentative)

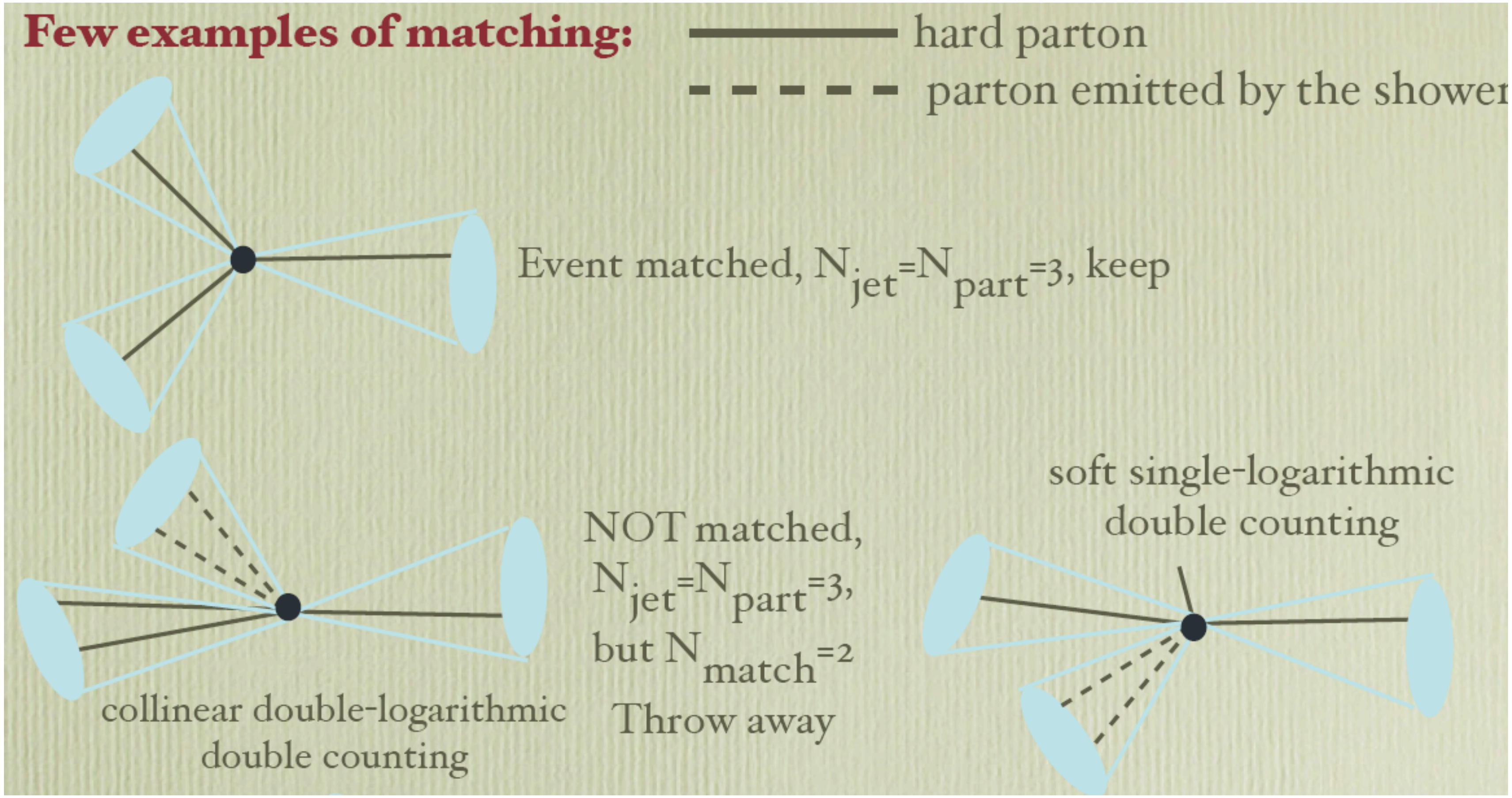
Fake mEt (multi-jet)は研究中

今 Qfac=Qrem=high scaleで作った。今はmidle scaleで生成中

5. ME-PS matching

MLM matching http://mlm.home.cern.xh/mlm

M. Mangano [Merging matrix element and Shower] @ Lund, Univ. Oct. 2004



Jet is defined : Et> 15GeV cone R=0.4 These are matching parameters:

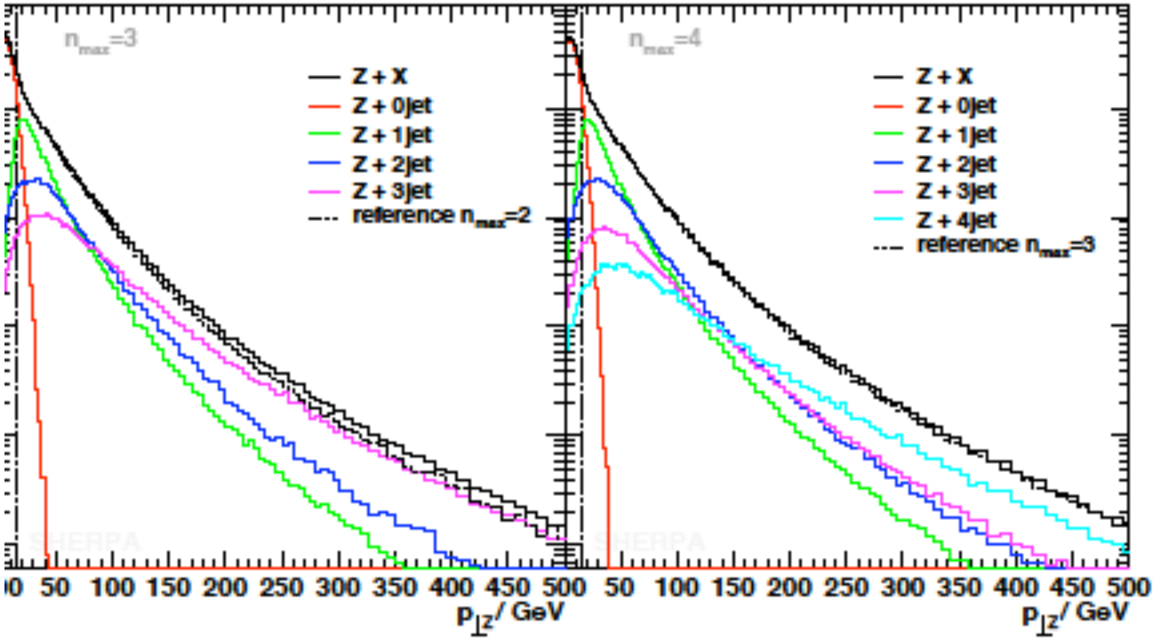
Double Count問題

PSのjetとMEのjetがかぶってしまう。Kinematicsで切り分ける。
Mejetがカバーするkinematicsを決めて、ここにjetが入ったら
Vetoする。
今 At least two jets Pt > 80GeV
at least 4jets Pt > 40 GeV eta < 2.7
このKinematicsにPSが入ったら捨てる。

Exclusive: NjetはNjet(Nparton)
Sudakov factor に対応する。

そうでないなら、inclusiveにして、N=4だけ作って、PSを足す。

CKKW: Sherpa :



CKKWの説明（電車の中で作ったので申し訳ない
黒板でやります）

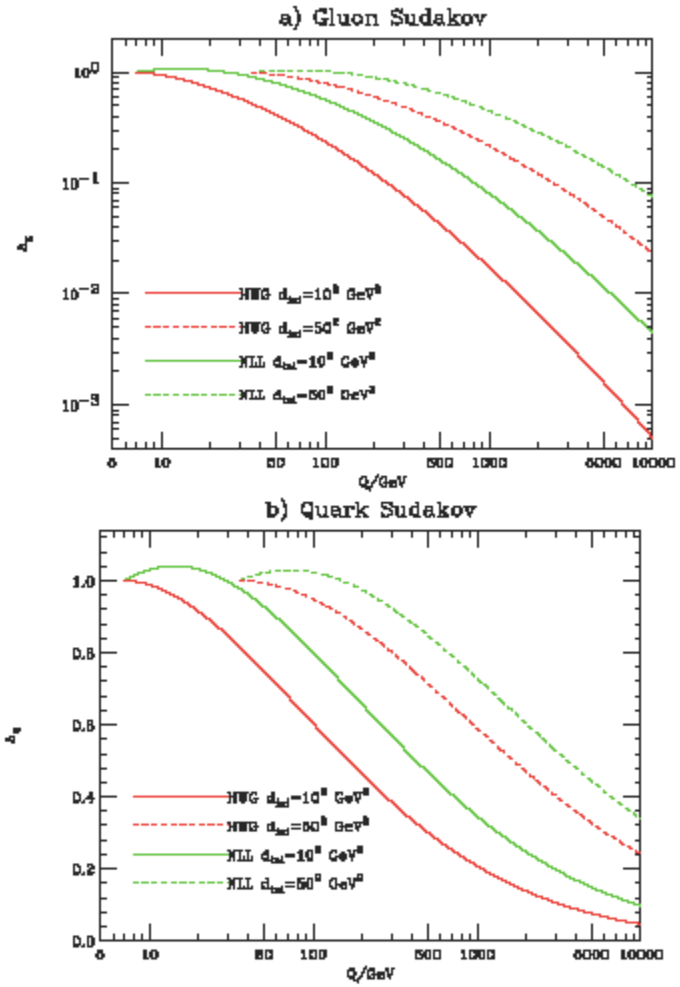
o ME partons are generated with Pt>20GeV and R>0.7
and some preselections for SUSY.

o Event is rejected if PS jet in the kinematics of ME region
(Shower Veto to avoid "double counting")

o ME parton should be matched to "jet"
jet is defined with Et_cut >15GeV and R=0.4 cone

Results are stable against the matching condition:
R=0.4 -> 0.7 results change within 20%

o This rejection is corresponding to "Sudakov factor":
mean rejection factor is about 0.5
Results depend on Qps : (Δ (Qo,Qps))
Qo～Pt_cut and Qps=Mean of Pt of ME jets

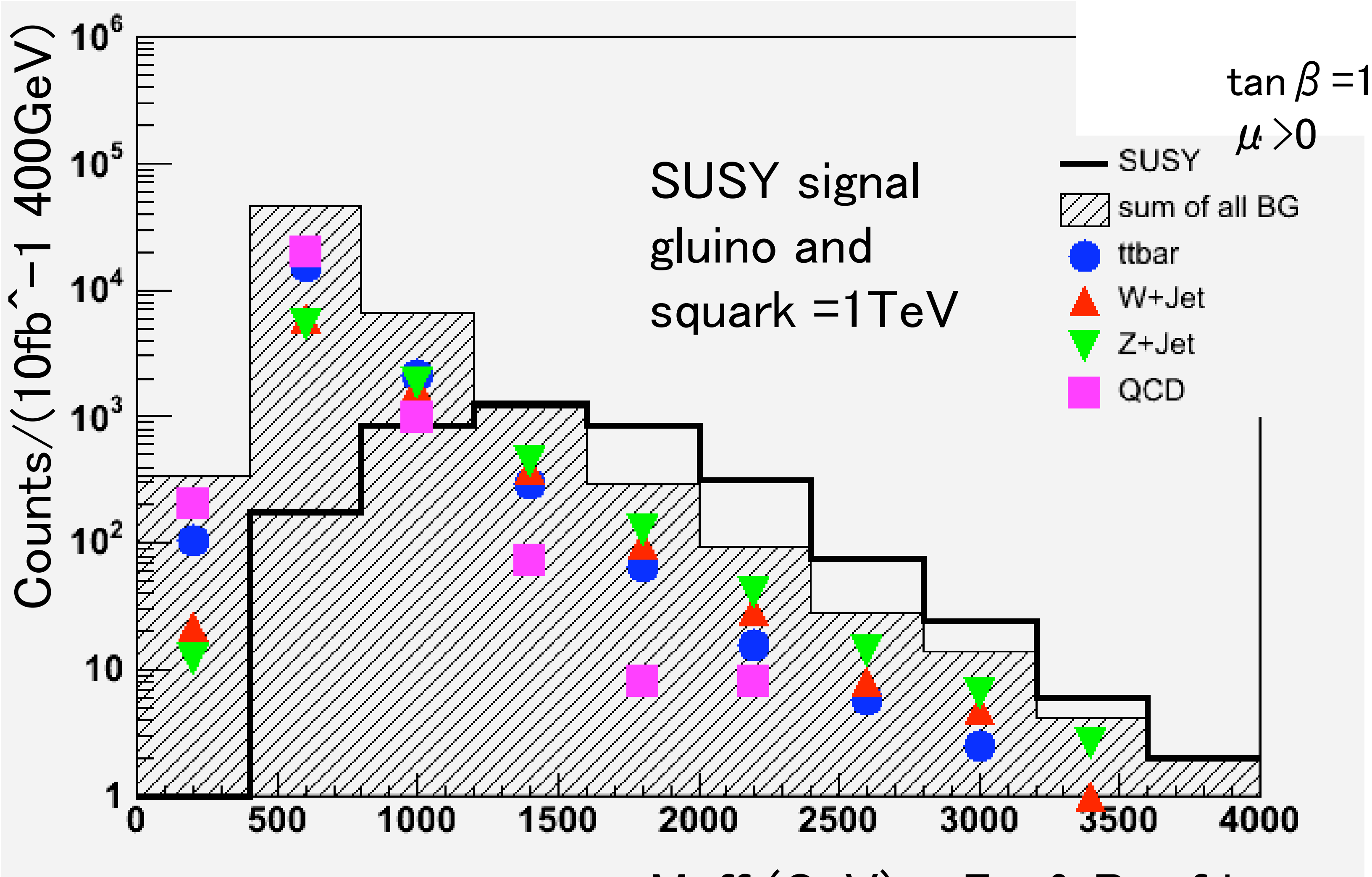


S.Mrenna hep-ph/0312274

Rejection factor is consistent
with Sudakow (?)
still checking

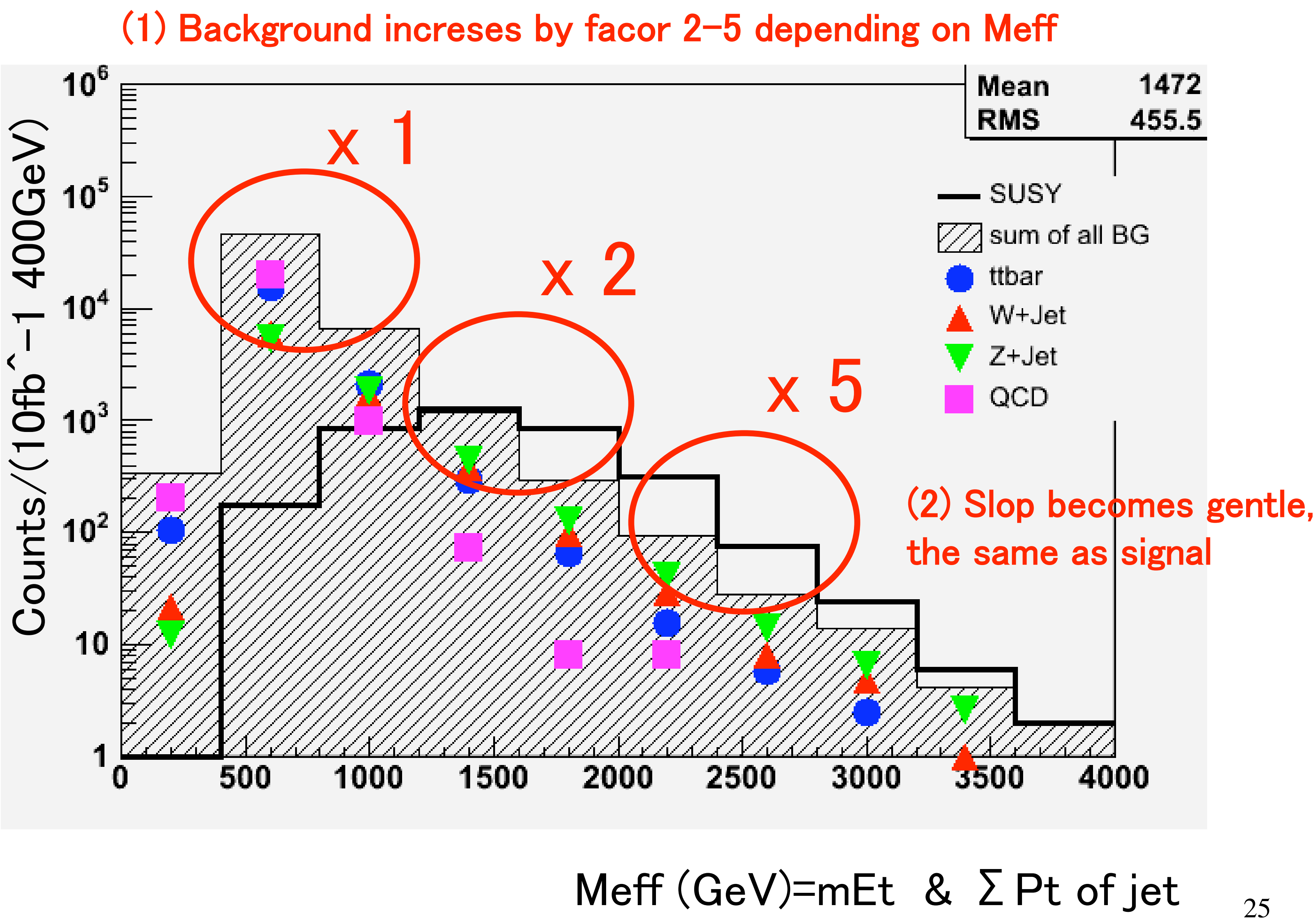
- This rejection is corresponding to "Sudakow factor":
  mean rejection factor is about 0.5
  Results depend on Qps : (Δ (Qo,Qps))
  Qo∽Pt_cut and Qps=Mean of Pt of ME jets

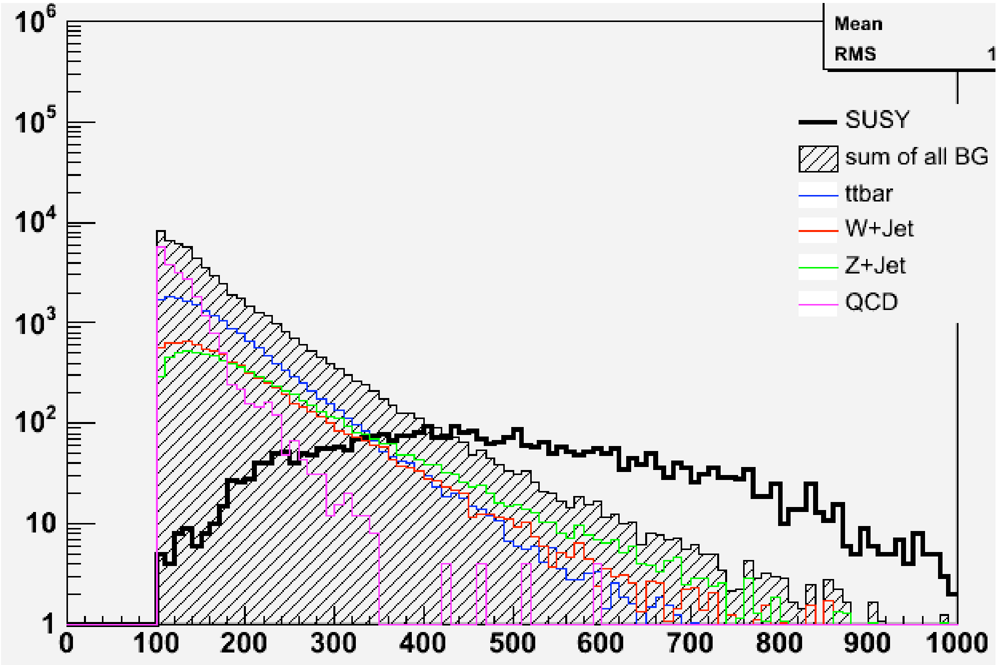
6. Results (Background estimated with ME info)



tan β =10,
μ >0

Meff (GeV)=mEt & Pt of jet

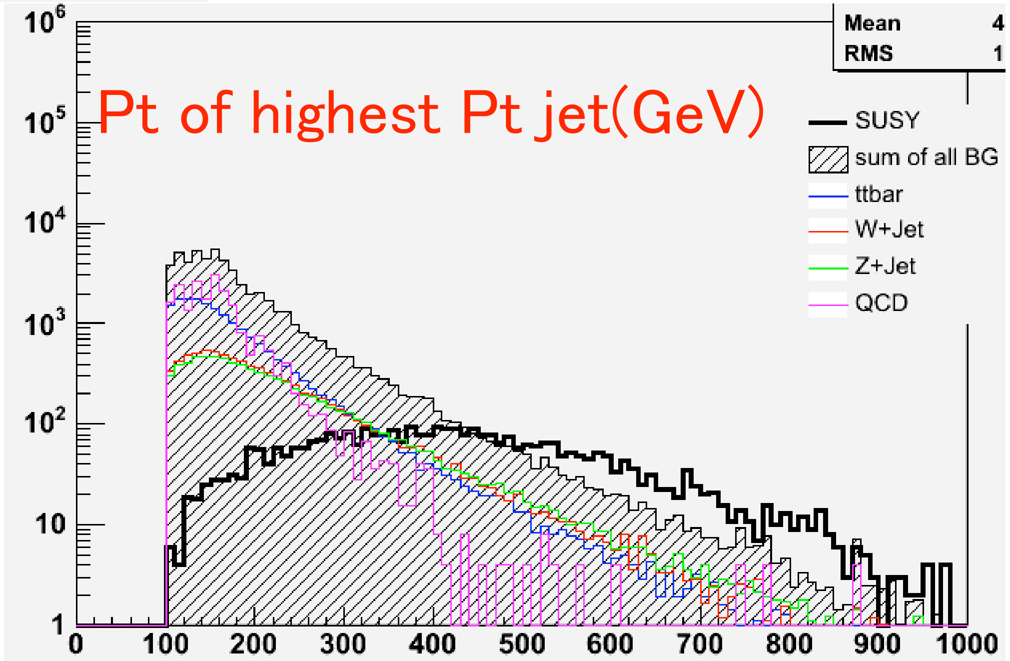

(1) Background increses by facor 2–5 depending on Meff
Mean 1472
RMS 455.5
x 1
x 2
x 5
SUSY
sum of all BG
ttbar
W+Jet
Z+Jet
QCD
(2) Slop becomes gentle,
the same as signal
Counts/(10fb^-1 400GeV)
0
500
1000
1500
2000
2500
3000
3500
4000
Meff (GeV)=mEt & Σ Pt of jet



Meff is sum of mEt and
Pt of high Pt jets:
Let's see separately.

For mEt>700GeV
Clear excess can be observed

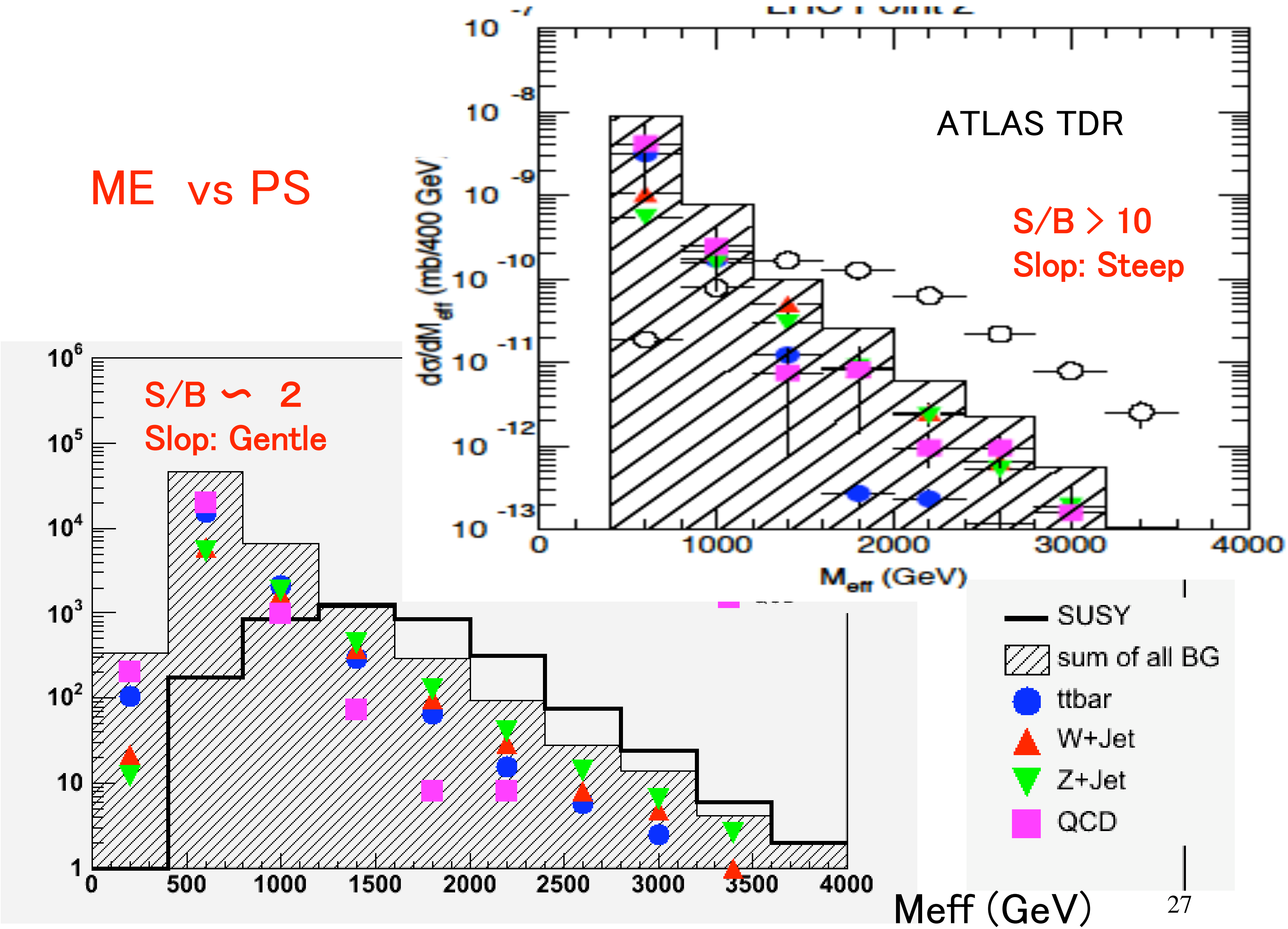
Missing Et (GeV)



Pt of highest Pt jet(GeV)

High Pt jet is also emitted
in background
Not good separation

ME vs PS



ATLAS TDR
S/B > 10
Slop: Steep
$d\sigma/dM_{eff}$ (mb/400 GeV)
M_{eff} (GeV)
0
1000
2000
3000
4000
S/B 〜 2
Slop: Gentle
0
500
1000
1500
2000
2500
3000
3500
4000
SUSY
sum of all BG
ttbar
W+Jet
Z+Jet
QCD
Meff (GeV)

まだやらねばならない問題がいっぱいある。（データからの外挿確立）

(1) Contribution of Multijet
Now we estimate this using 2 parton + PS model (PYTHIA or Herwig)
When we estimate multi-jet contibution using ME generator,
Number of BG events increases significantly. ↑↑↑↑
(cross-section is huge, we need some trick)
Discrepancy becomes larger as N is larger.

(2) Now we use common renormalization scale for all vertex: Q^2= Mz^2 + Pt_z^2.
If we use the scale of Q=mean of Pt for all jet,
Number of BG events increases or decrease ↑↑ or ↓↓
(See Tevatron Data -> Next Page But many error.)

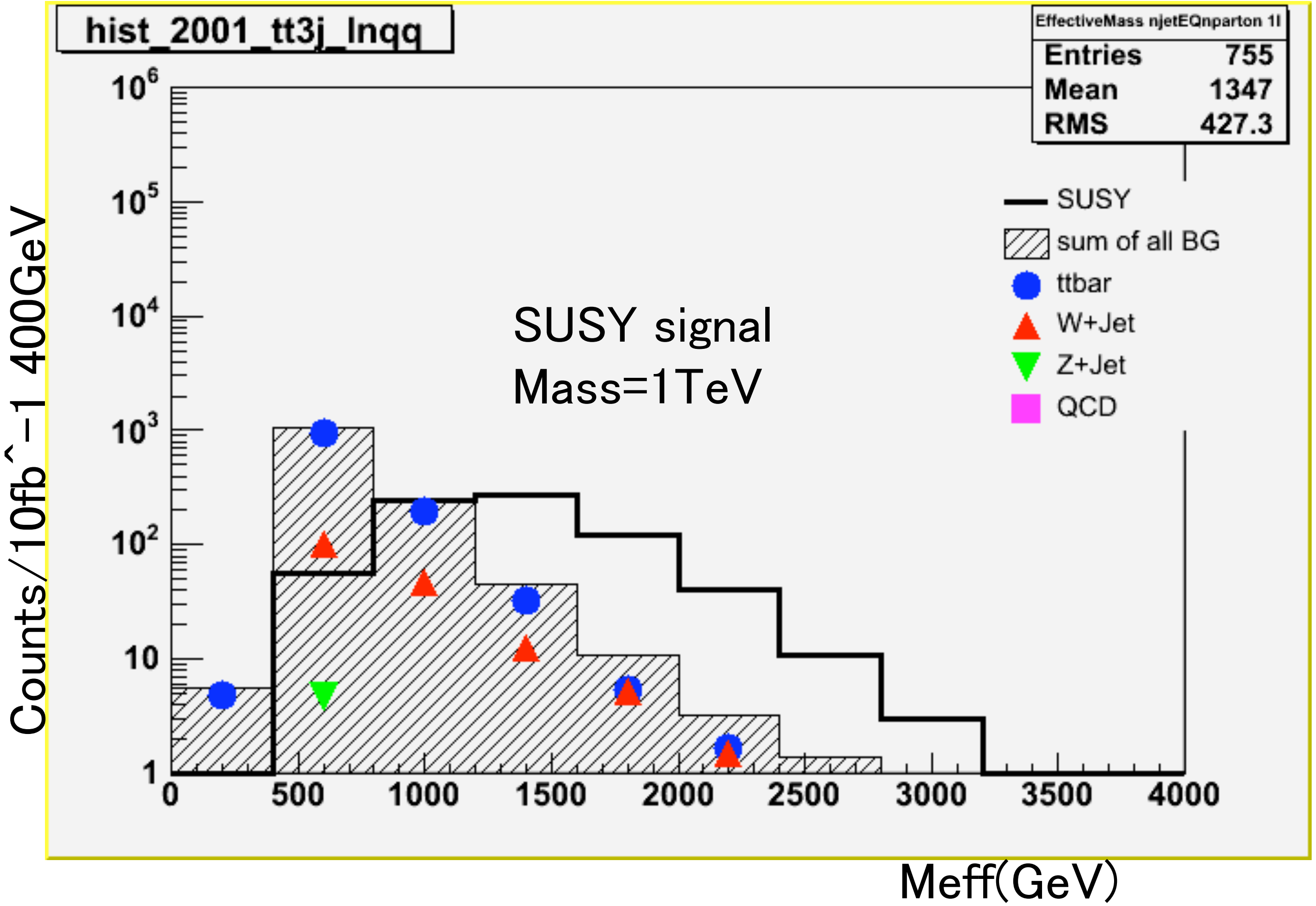
(3) Factorization scale and PS scale affect on the Sdakov factor:
if we use smaller shower scale
Number of BG events increases. ↑↑

-> Current estimations are still underestimated. We need more careful study on both background and signal.

One lepton mode : tt + N jets ●
: W + N jets ▲

Signal is reduced to 20–40% of no lepton mode,
Background suppress by about factor 20–30

S/B is better than
no lepton mode.

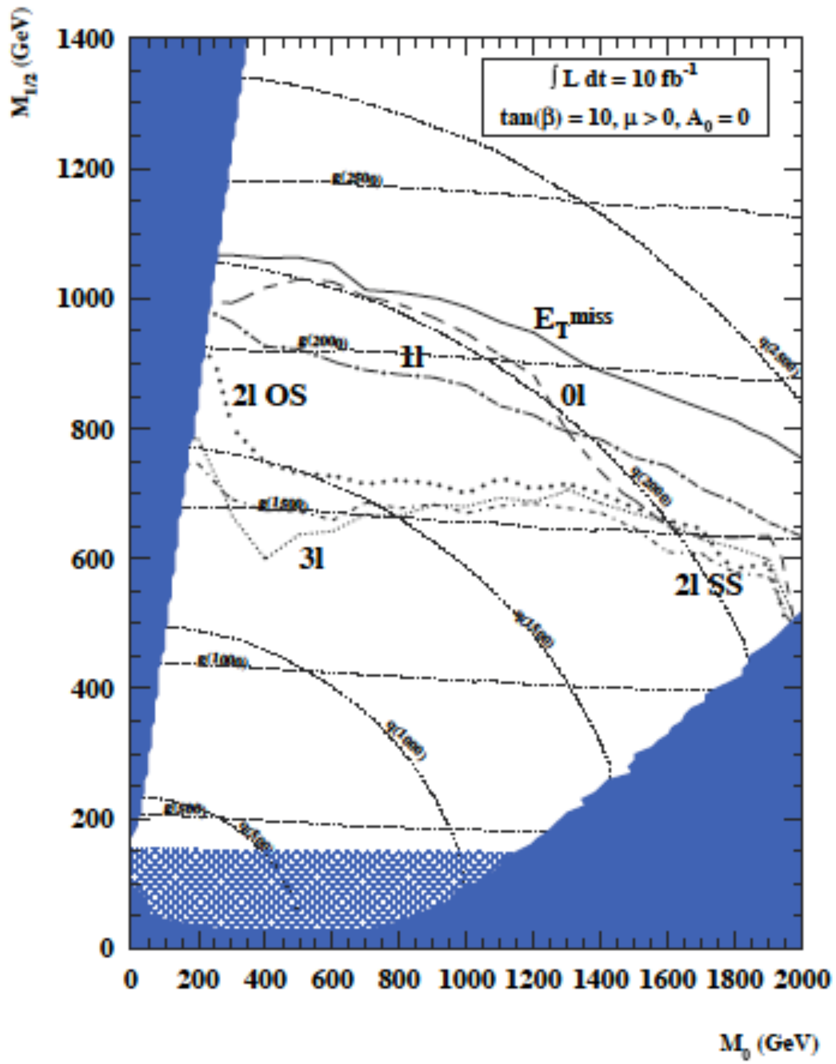


発見の為のselectionを
調整中。No leptonはきつい
One lepton mode
（stauがべらぼうに効く領域？）

（1） Background increase
（2） High Pt jets
（3） Top pair significantly increases

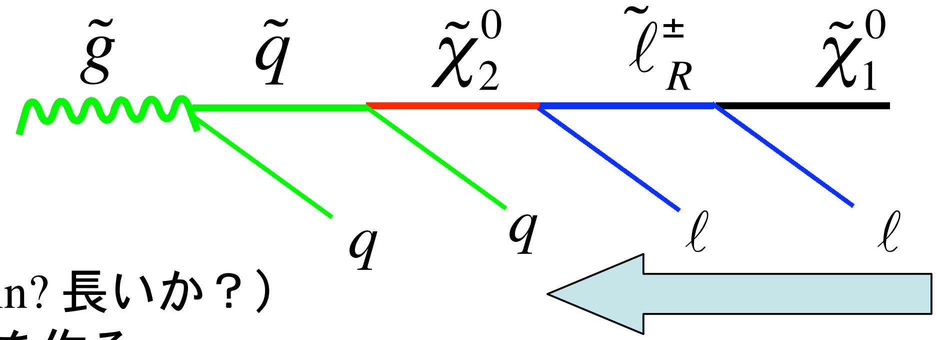
（4） QCD Multijetも増えるでしょう

QCD stableなcutにしています。
Njetなどナンセンス。



D.Tovey Eur.Phys. J. Direct C4 N4

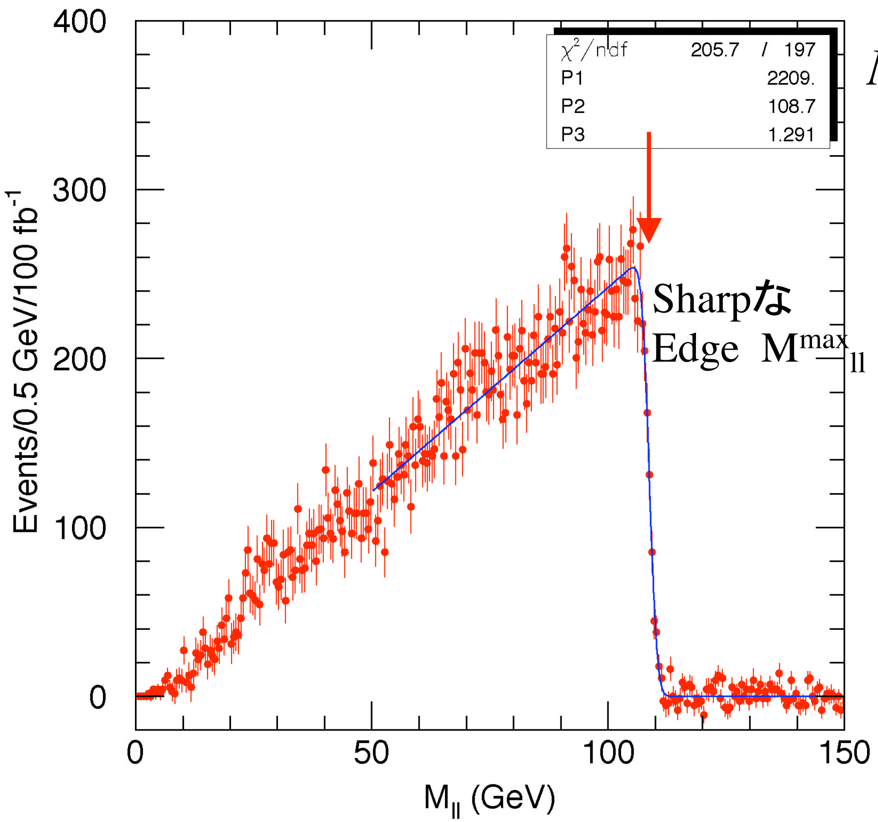
質量の再構成に関して



下から攻めあげる

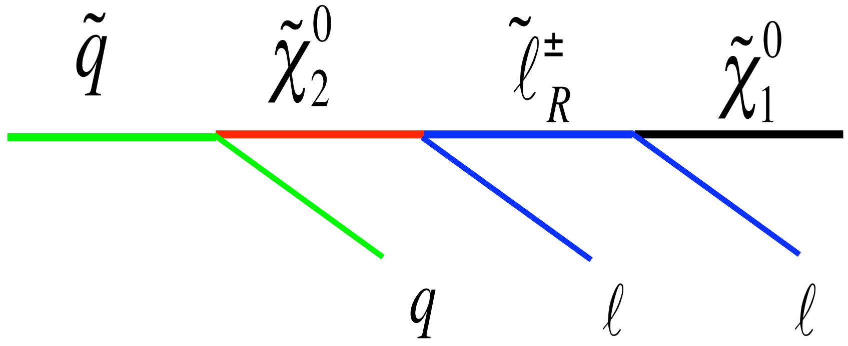
1. 適当なdecay chainを選ぶ **(key point!)**
   （奇麗か？　他のSUSY Decay chain? 長いか？）
2. mass やP_Tなどのkinematic distributionを作る
3. Edgeやendpointからmassの関係に束縛を与える

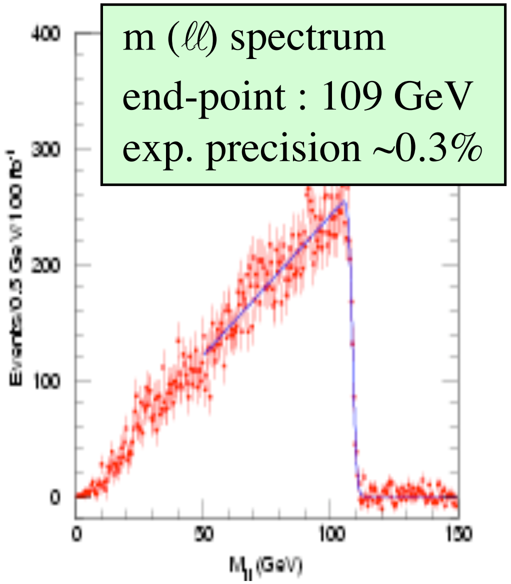
$$M_{\ell\ell}^{\max} = m(\tilde{\chi}_2^0)\sqrt{1-\left(\frac{m(\tilde{\ell}_R^\pm)}{m(\tilde{\chi}_2^0)}\right)^2}\sqrt{1-\left(\frac{m(\tilde{\chi}_1^0)}{m(\tilde{\ell}_R^\pm)}\right)^2}$$

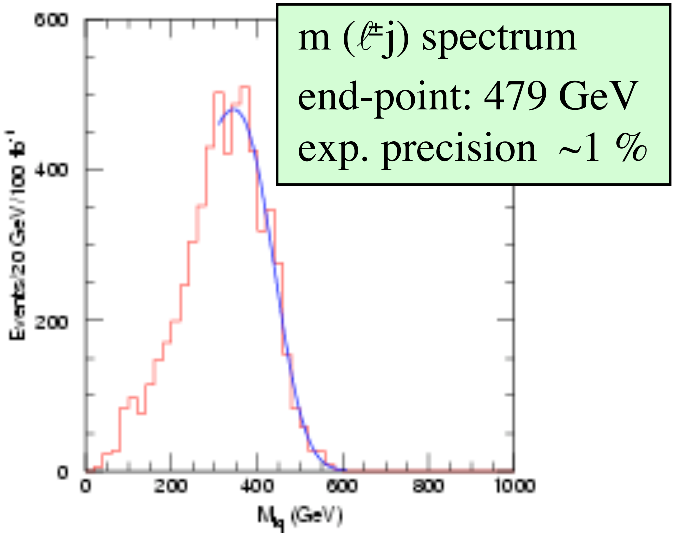


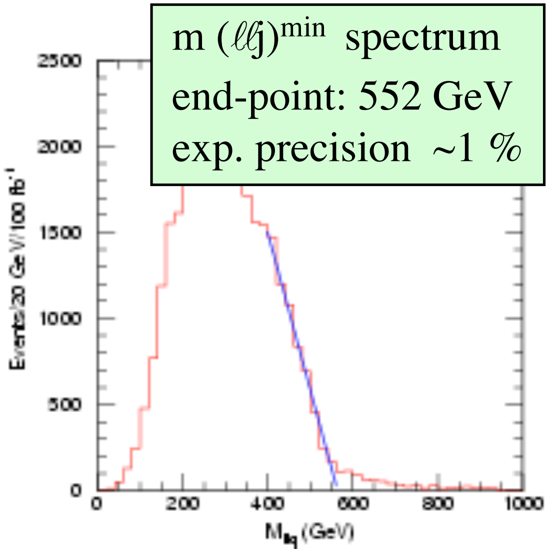
- 一般に関係式の方が未知数（質量）より少ない。Modelの助けを借りてMassの絶対値を決める。
- 2body decay chainが最低３連発した場合は model independentに決めることが出来る。(次のページ)
- tanβが大きいと段数が増えたり、τ、ｂが多くなる。
- 発見と違って、model依存性が強い。
- Br測定は難しい

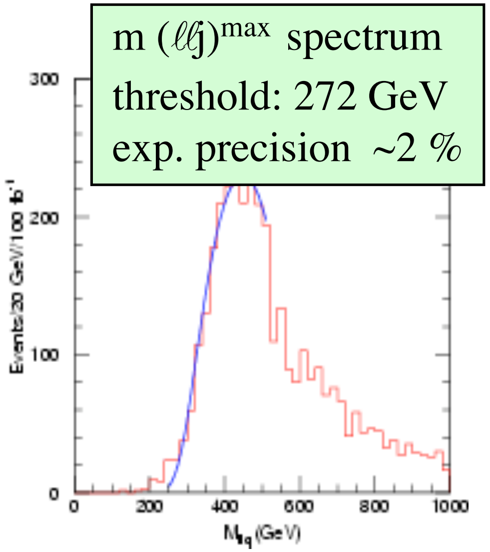
登場人物４人









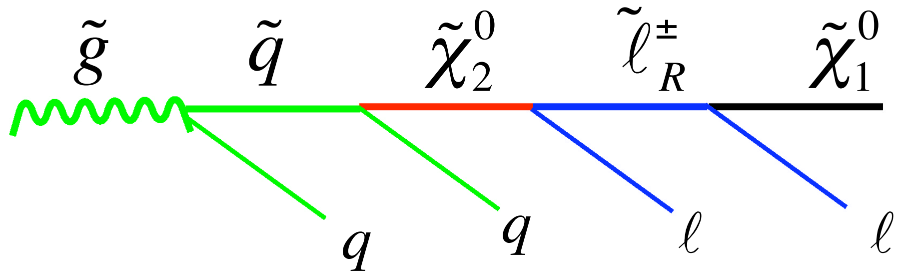


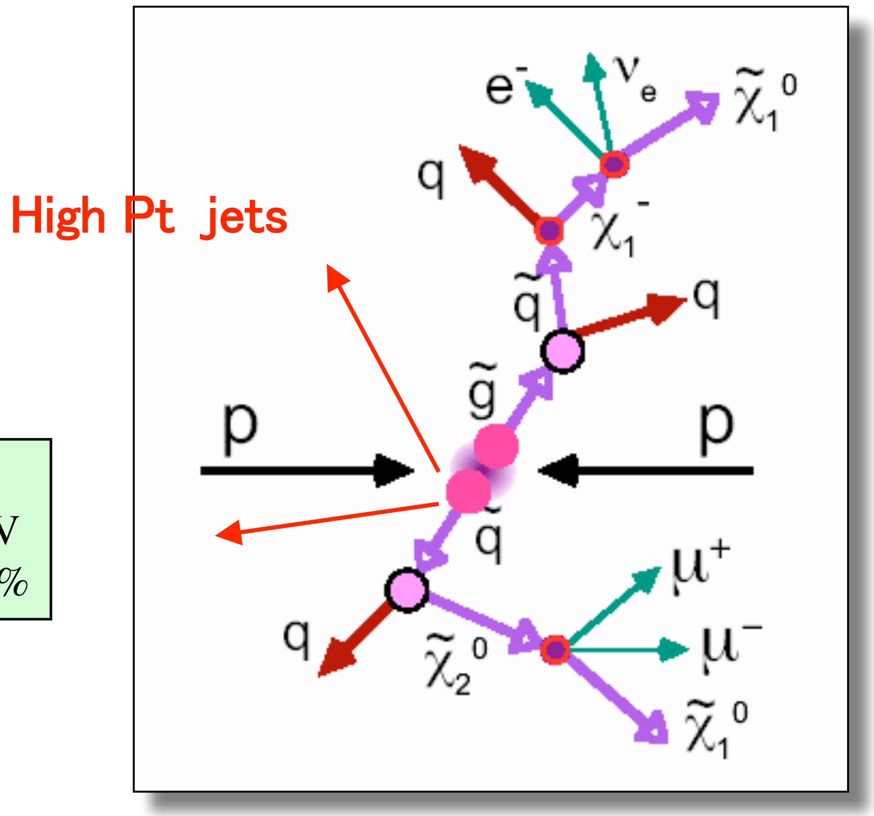
4未知数 vs 4条件 → model independentにmassが決まる。(3-12%程度 for 700-800 GeV squark, gluino）

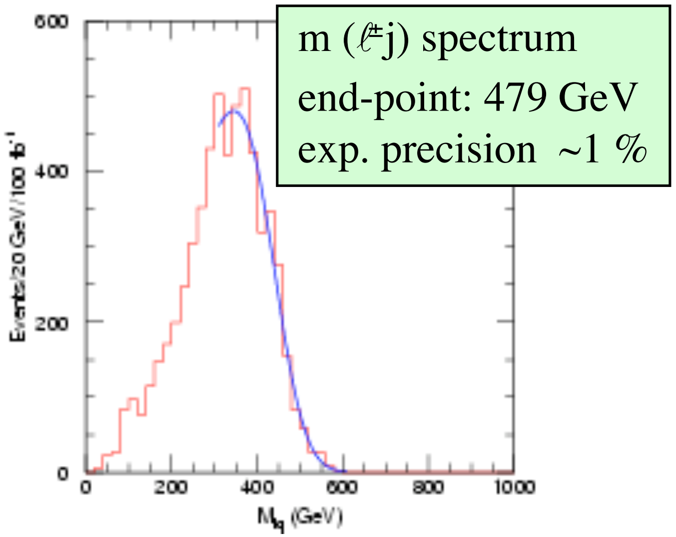
再構成にあたえる影響

High pt jets due to BG and additional jets in SUSY signal increases.
(SUSY+Njets should be estimated with ME as the same as BG)

Contamination of high Pt jet increases, and purification of these quarks becomes worse.







7. Extrapolation

We have good control sample of Z(->ee,mumu) + N jets.

Only 16 events are expected in the first year (L=10fb^-1) for Z(->ee,mumu) + N jets with Meff > 2000GeV region.
Stat. is too limited to use this control sample directly.

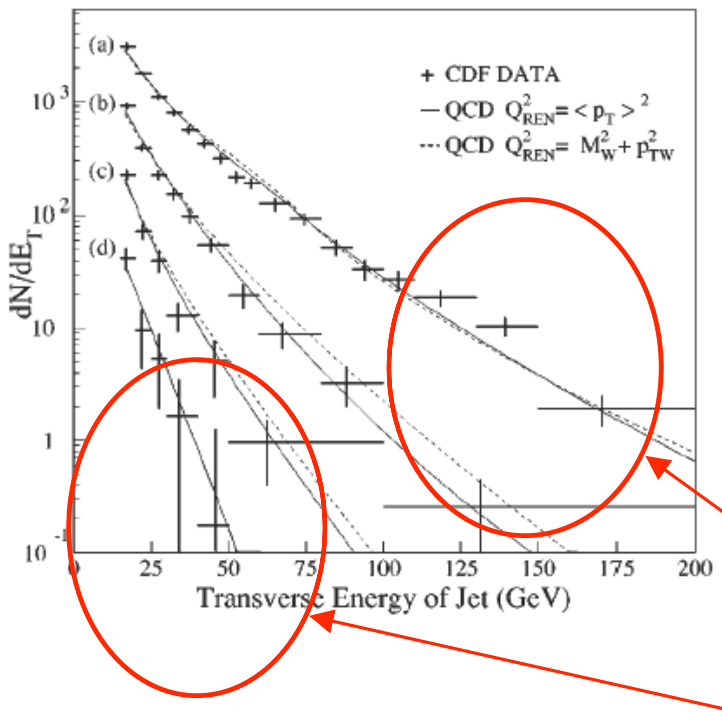
We need extrapolation form low Pt region to SUSY signal region.

◆Dependence on Pt and multiplicity can be very precisely study at Tevatron Run-II (There is RunI result but, not stat. not enough --> Next Page)
◆Not trivial extrapolation from Tevatron to LHC

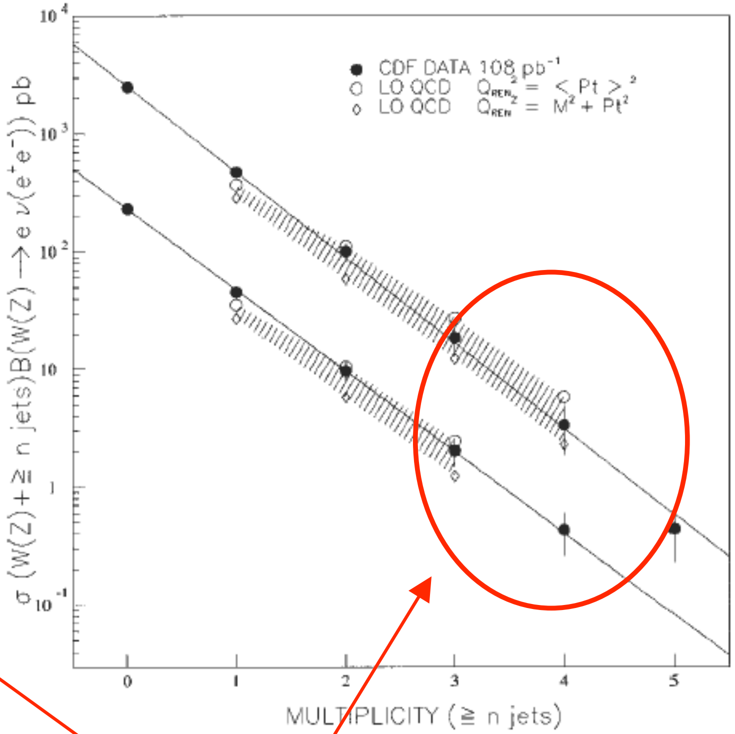
Establish method to estimate BG in early stage of LHC (a few fb^-1) using LHC data, Tevatron results and theoritcal works.

Run1 Phys. Rev. D 63, 072003 (2001)

Pt dependence



N-dependence



interesting regions

8. Summary

(1) We estimated Background with ME generator. (W/Z and top pair)

(2) ME-PS matching is performed with MLM method, and result is stable.

(3) The contributions of the background increases by factor 2-5.
Background contribution including high Pt jets increases significantly

(4) Results and knowledge at Tevatron is crucial to estimation BG for SUSY search in early stage of LHC.

W/Z + Njets
tt+Njets @ Tevatron (-> some hint to squark pair + Njets at LHC ?)
mEt
How to extrapolate these results to LHC energy？