2 jets +missing ET signature and spin of new particles

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with Jing Shu arXive 1102.0293

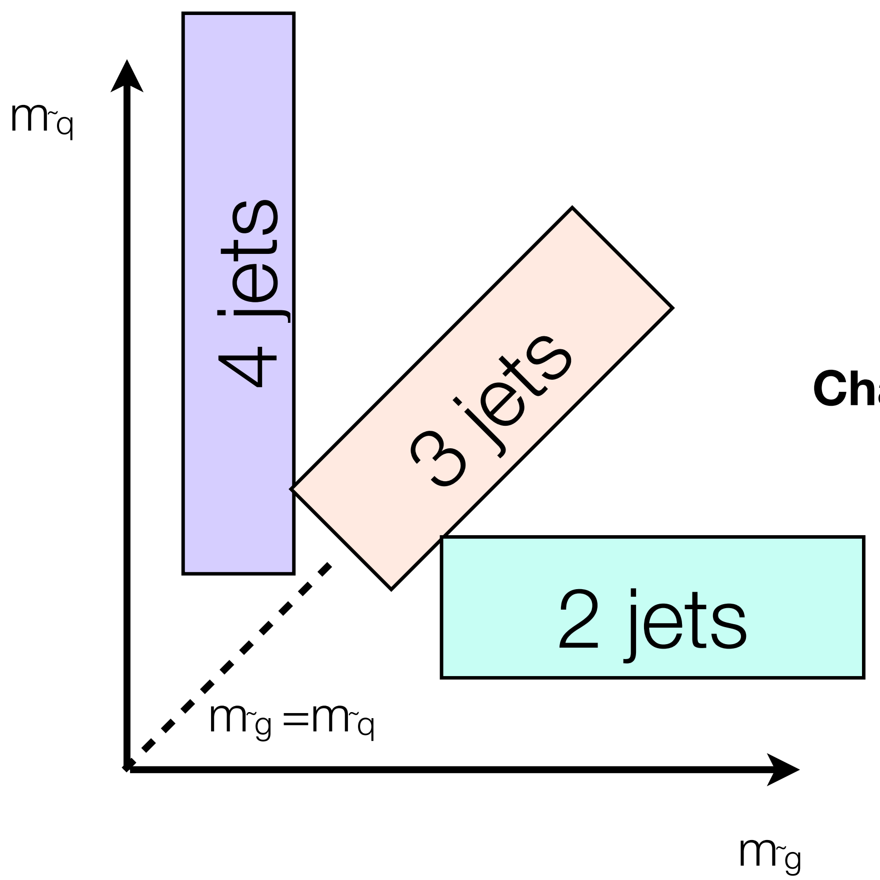
Why Study SUSY models

- Beautiful Symmetry
- Gauge coupling Unification
- New particles that can be searched for at LHC
- Dark matter candidate with R parity
- Can be consistent with low energy measurements.
- Signature missing energy(dark matter) with lots of jets and leptons in the final state.

SUSY search and measurement Now and future

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

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

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

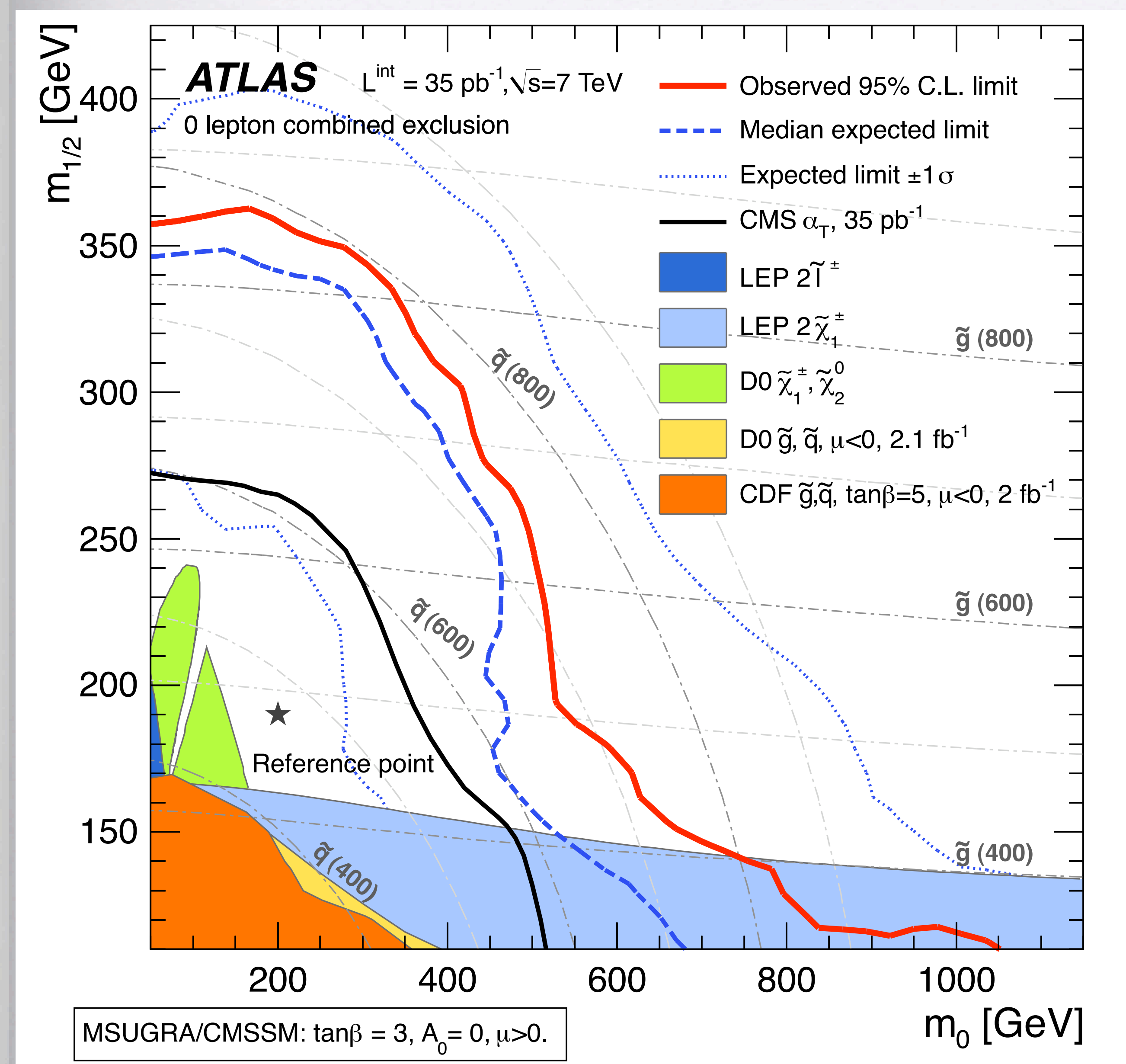
Results

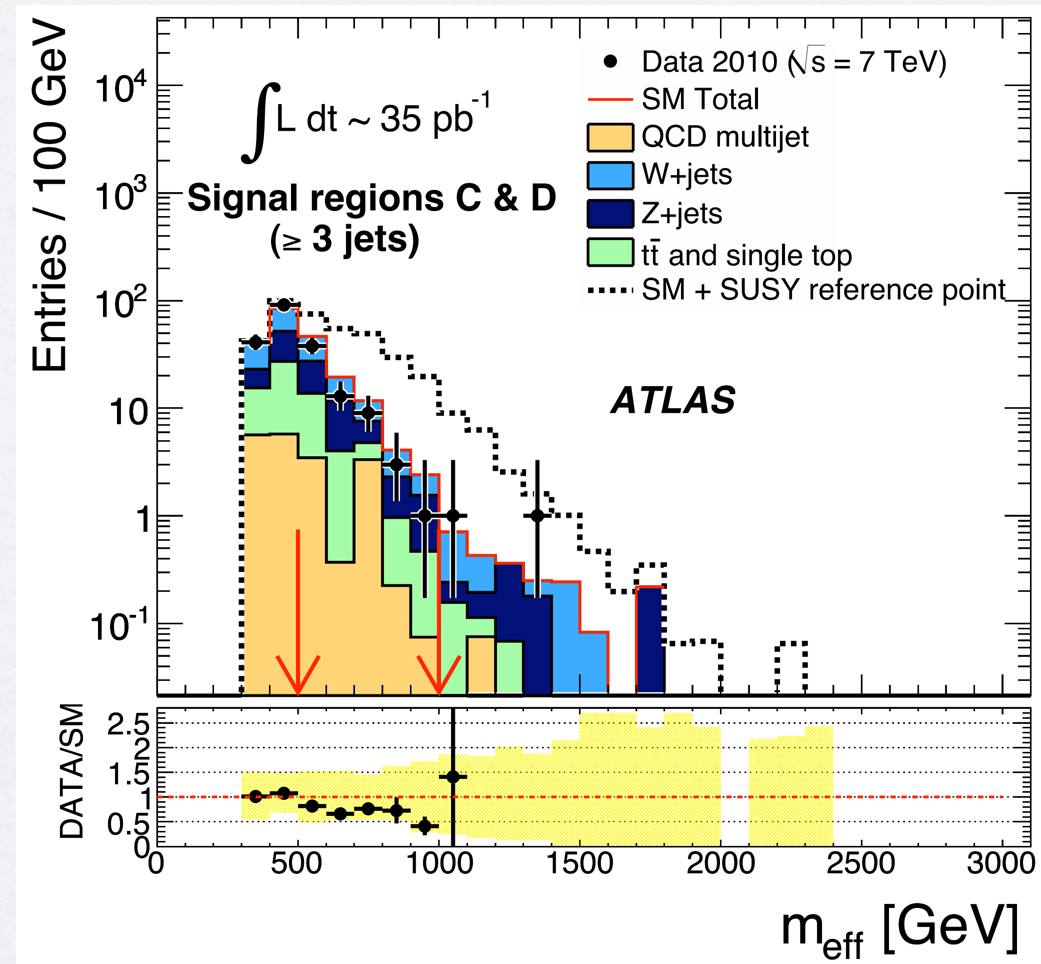
Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{eff} > 500$ GeV	$\geq$ 4-jet, $m_{eff} > 1000$ GeV	High mass
Z/γ+jets	32.5 ± 2.6 ± 6.8	25.8 ± 2.6 ± 4.9	208 ± 9 ± 37	16.2 ± 2.1 ± 3.6	3.3 ± 1.0 ± 1.3
W+jets	26.2 ± 3.9 ± 6.7	22.7 ± 3.5 ± 5.8	367 ± 30 ± 126	12.7 ± 2.1 ± 4.7	2.2 ± 0.9 ± 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

upper limit of each search channel

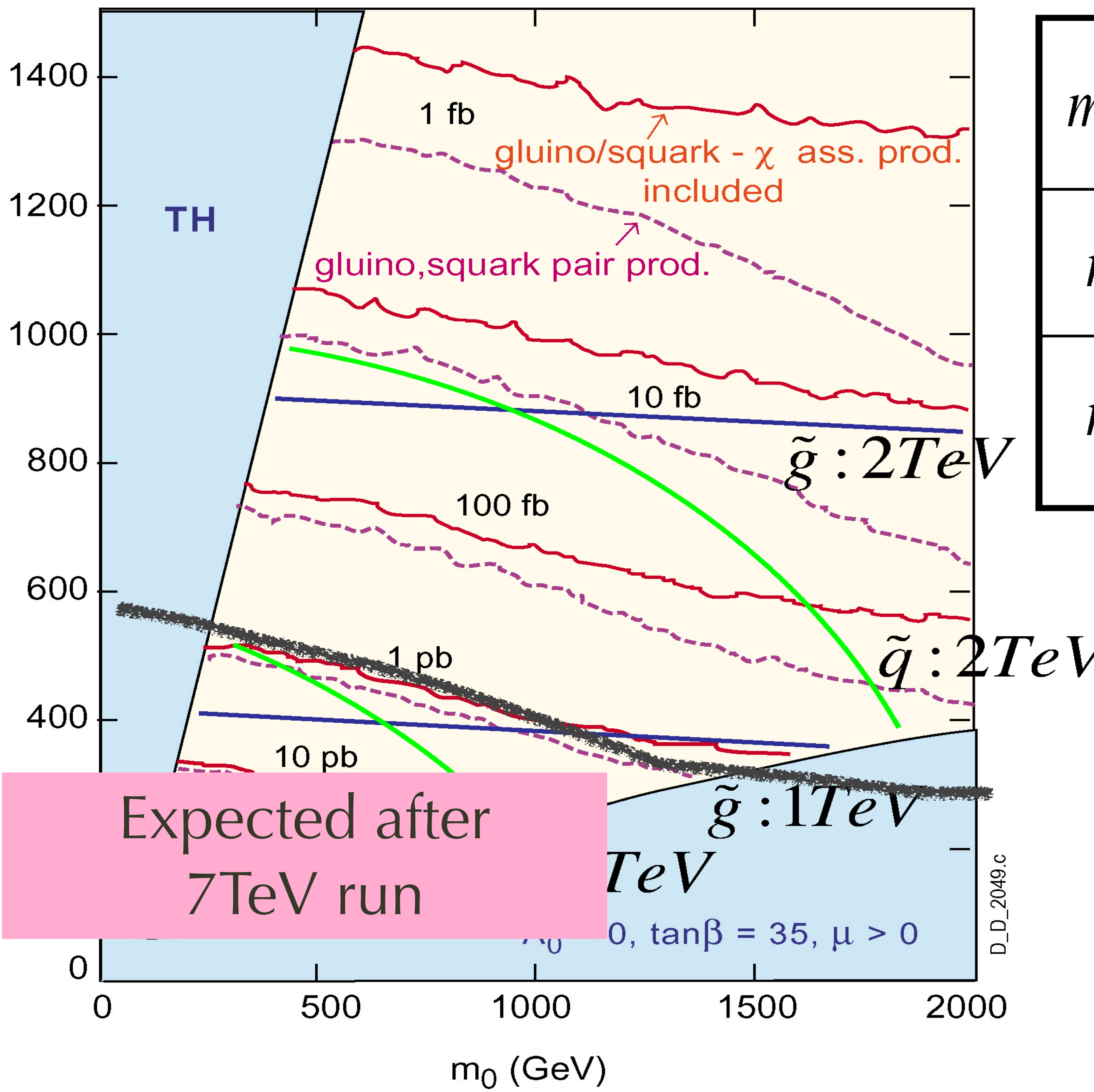
- No discrepancy with respect to SM predictions.
- The result is interpreted as a 95% CL exclusion limit on effective cross sections using a profile likelihood ratio approach following the CLs prescriptions.
- Analysis giving best expected limit used in each point.

LHC SUSY search





14TeV projection



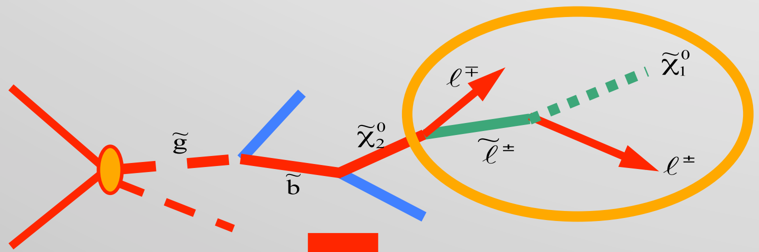
$m(\tilde q) = m(\tilde g) = 0.5TeV$	σ ～100pb $\tilde g \tilde g$ がmain
$m(\tilde q) = m(\tilde g) = 1TeV$	σ ～3pb
$m(\tilde q) = m(\tilde g) = 2TeV$	σ ～20fb $\tilde u \tilde u, \tilde u \tilde d$ がmain

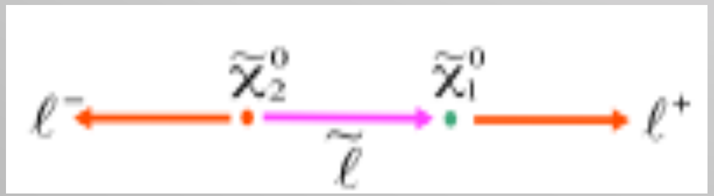
- 7TeV run excluded significant parameter space
- production at 14TeV would be 1 pb or less. significantly limits statistics at 14TeV run already.

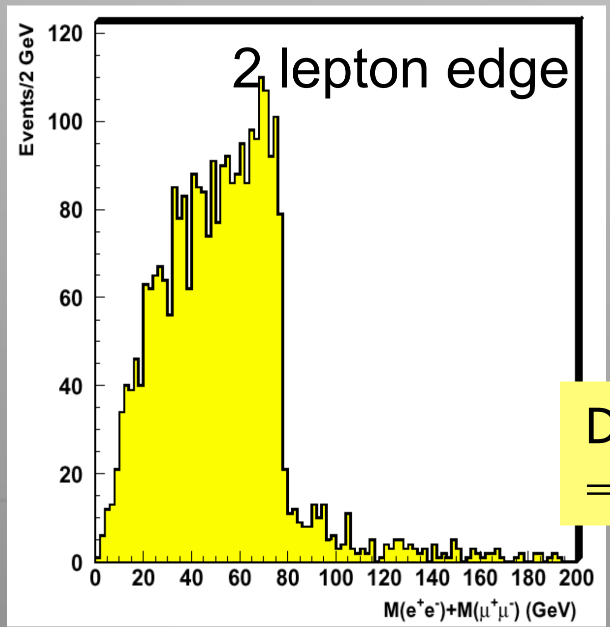
Sparticle Detection & Reconstruction

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
$\tan\beta$ = 10
sign(μ)=+





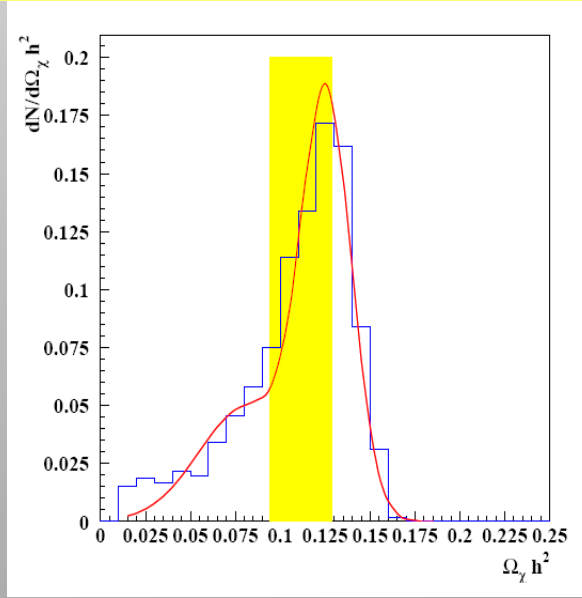


D. Miller et al
⇒Use shapes

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?

SUSY mass determination using jets+ 2 lepton channel

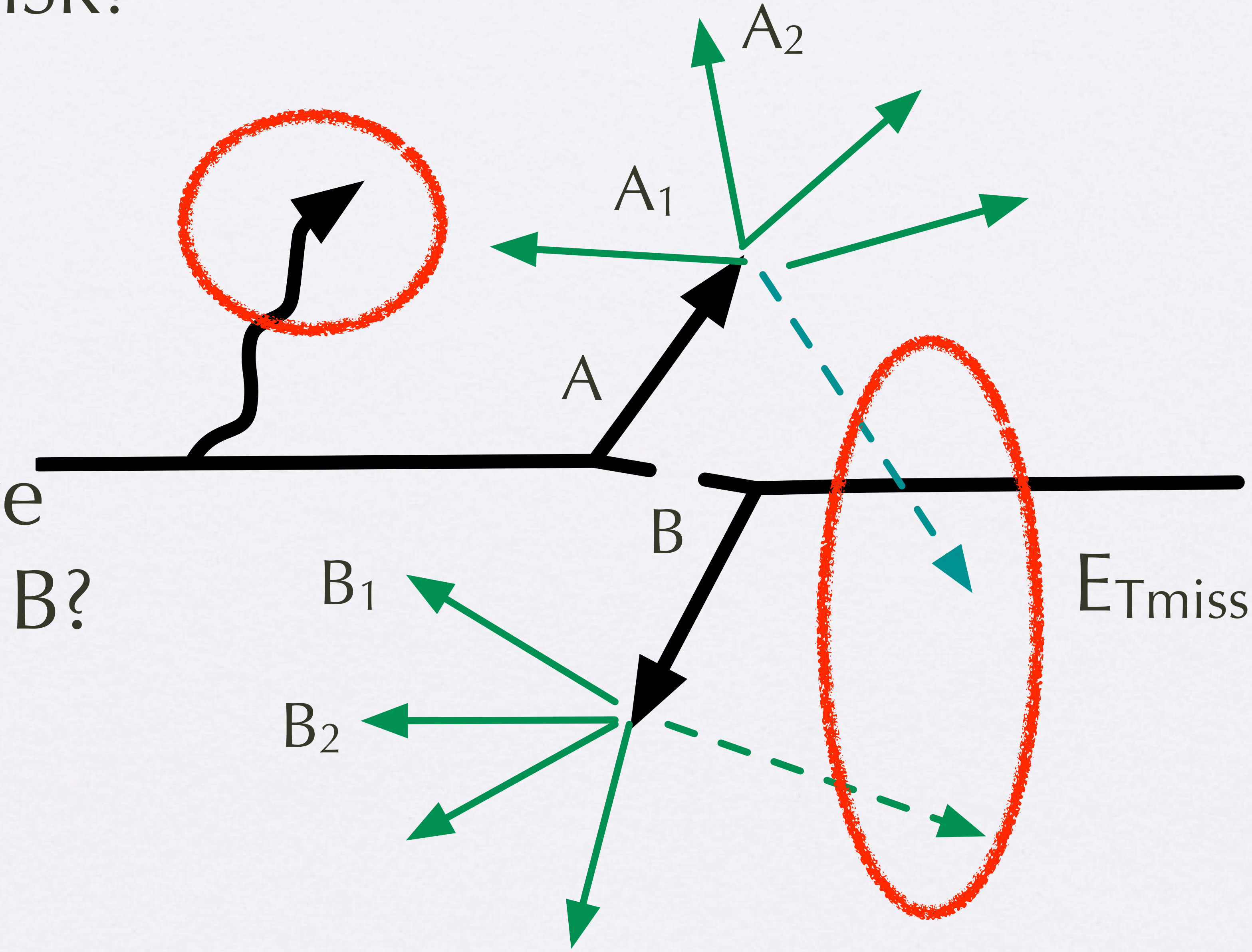
- production cross section is determined by squark gluino mass
- Branching ration into the second lightest neutralino 30% , lepton branch 6~20%→ total 2~6%.
- 30fb^{-1} x 1pb =30000-> **600 events(2% branch) are not enough** to determine EW SUSY particles masses precisely
- **Need full use of hadronic channels to determine SUSY scale when it is discovered.**

Combinatorial background in hadronic channel

USE MT2~mass of parents

2) ISR; Which jet comes from ISR?

1) jets are from A or B?



2011年9月10日土曜日

Combinatorial background in hadronic channel

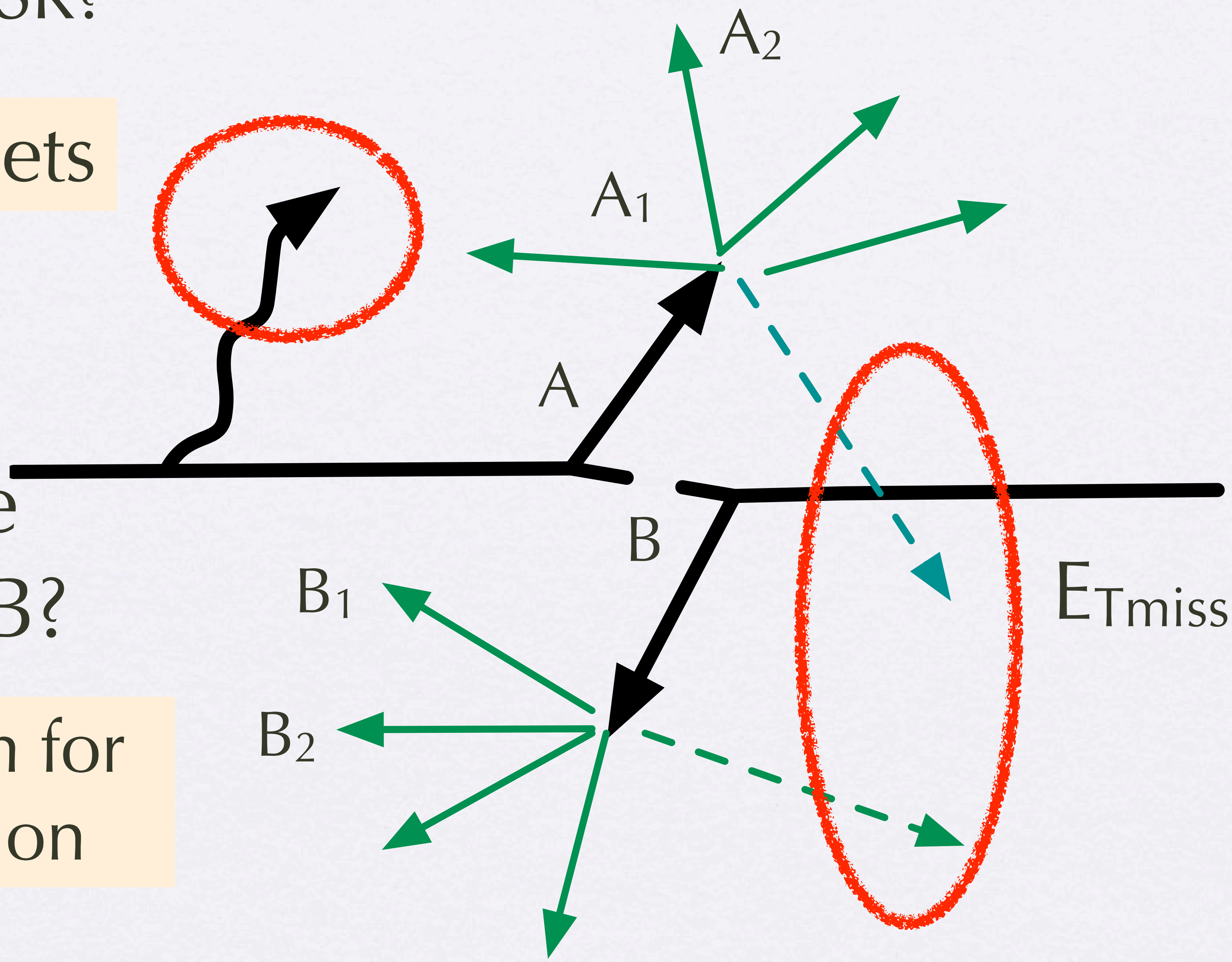
USE MT2~mass of parents

2) ISR; Which jet comes from ISR?

use part of the jets

1) jets are from A or B?

Take minimum for jet combination

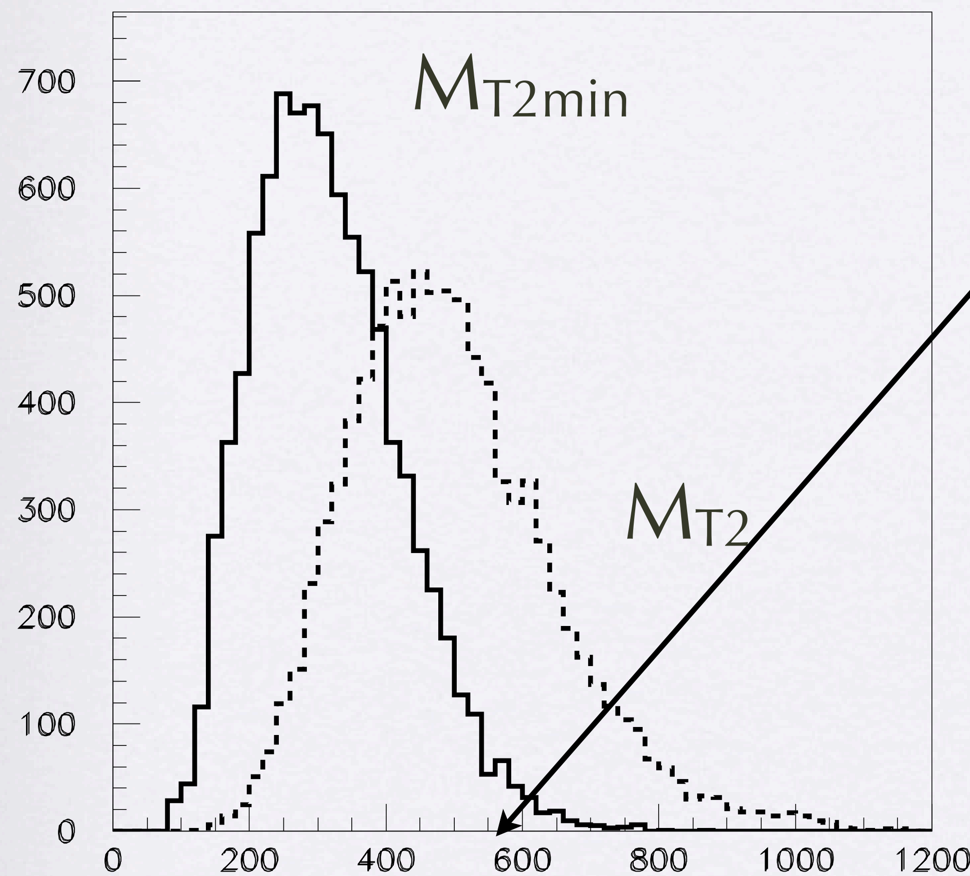


MT2 and mass reconstruction

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

7TeV 100fb^{-1}

mgl=558GeV mul=825 GeV



input gluino mass

M_{T2} for multijet final state = minimization for all jet combination

M_{T2min}=ISR removal ~remove one jet from the minimization (among 5 leading jets)

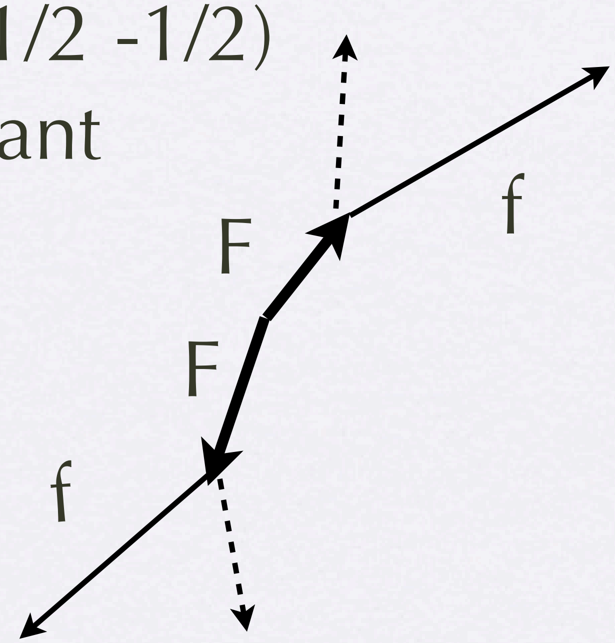
Nojiri Sakurai 2010

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

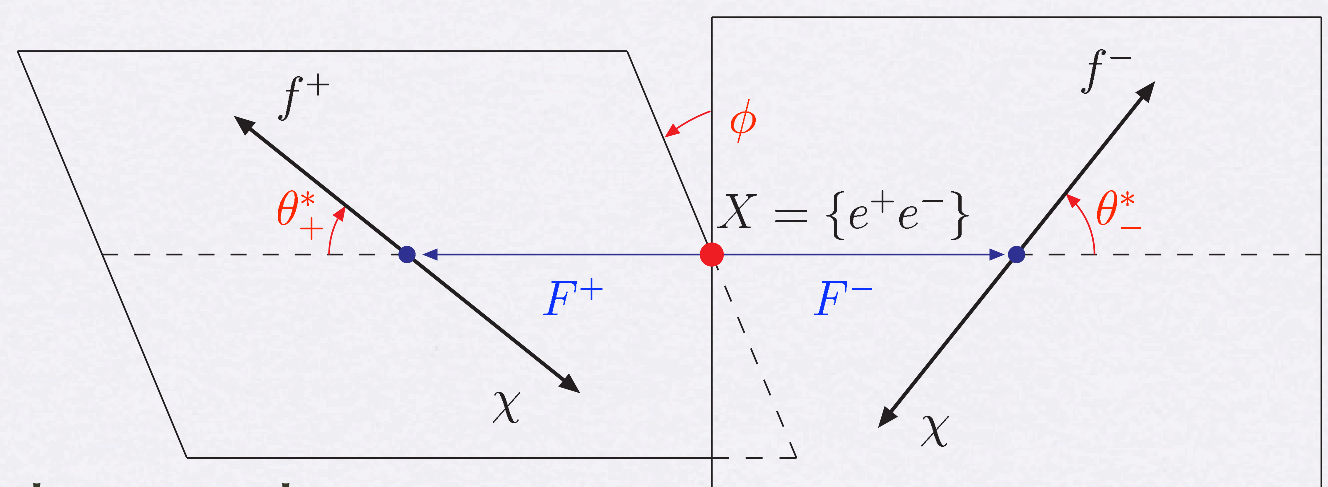
How about spin measurements

- in Jet +2 lepton channel spin effect in the inv. mass distribution, able to distinguish SUSY vs "Same spin partner" models (such as LHT, UED)
- jet channel: there are jet ID problem, but jets from two body decay of quark partner is easy to identify because of the PT
- If the interaction of quark partner is chiral, there are visible spin effect

polarization
(1/2 1/2) **or** (-1/2 -1/2)
is dominant

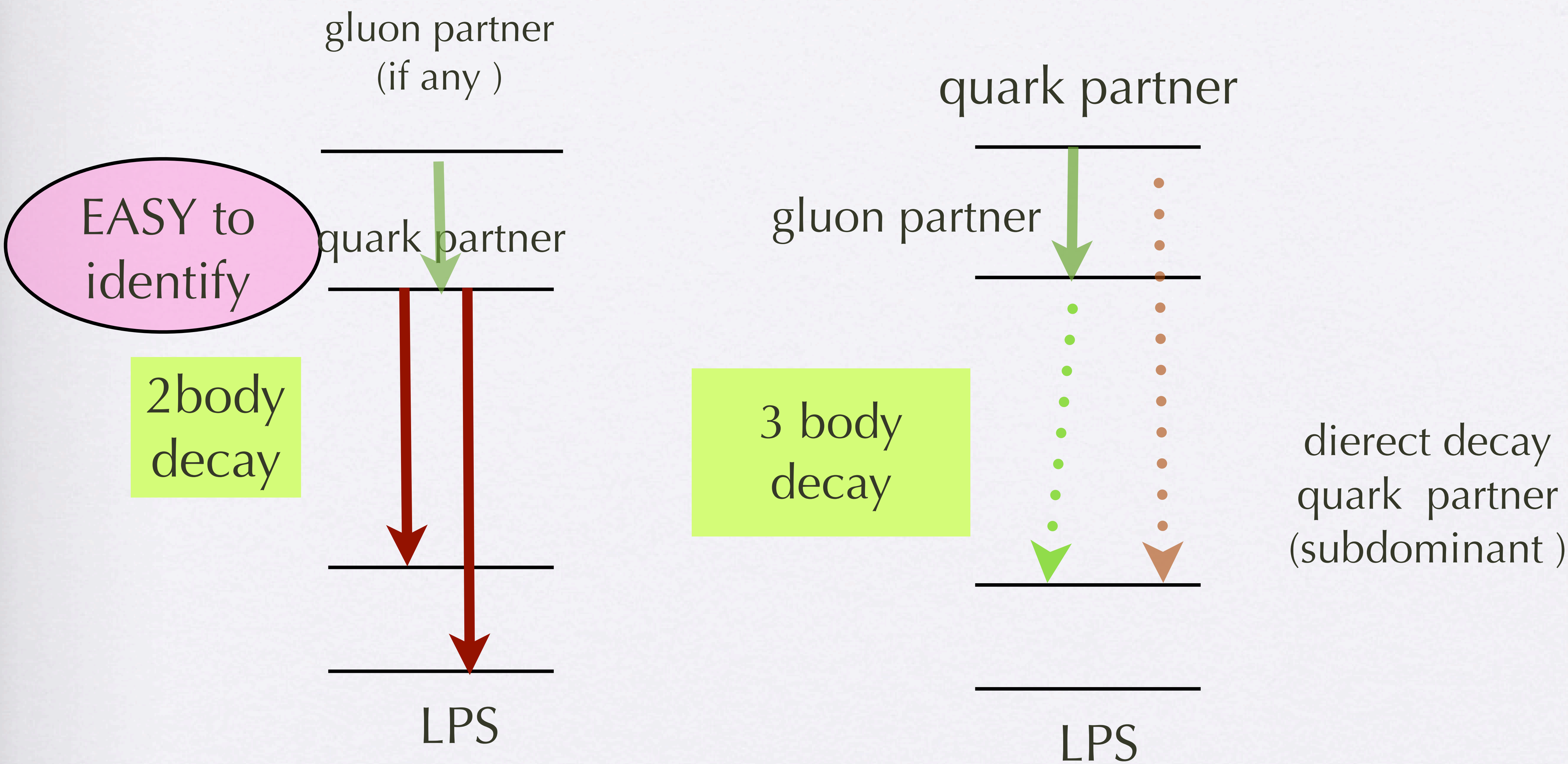


Azimuthal angle correlation
(1/2,1/2) **and** (-1/2,-1/2)
amplitude is same order



Buckley et al 2008

leading objects and new particle decays



SUSY quark partner=spin 0
UED/LHT=Spin 1/2

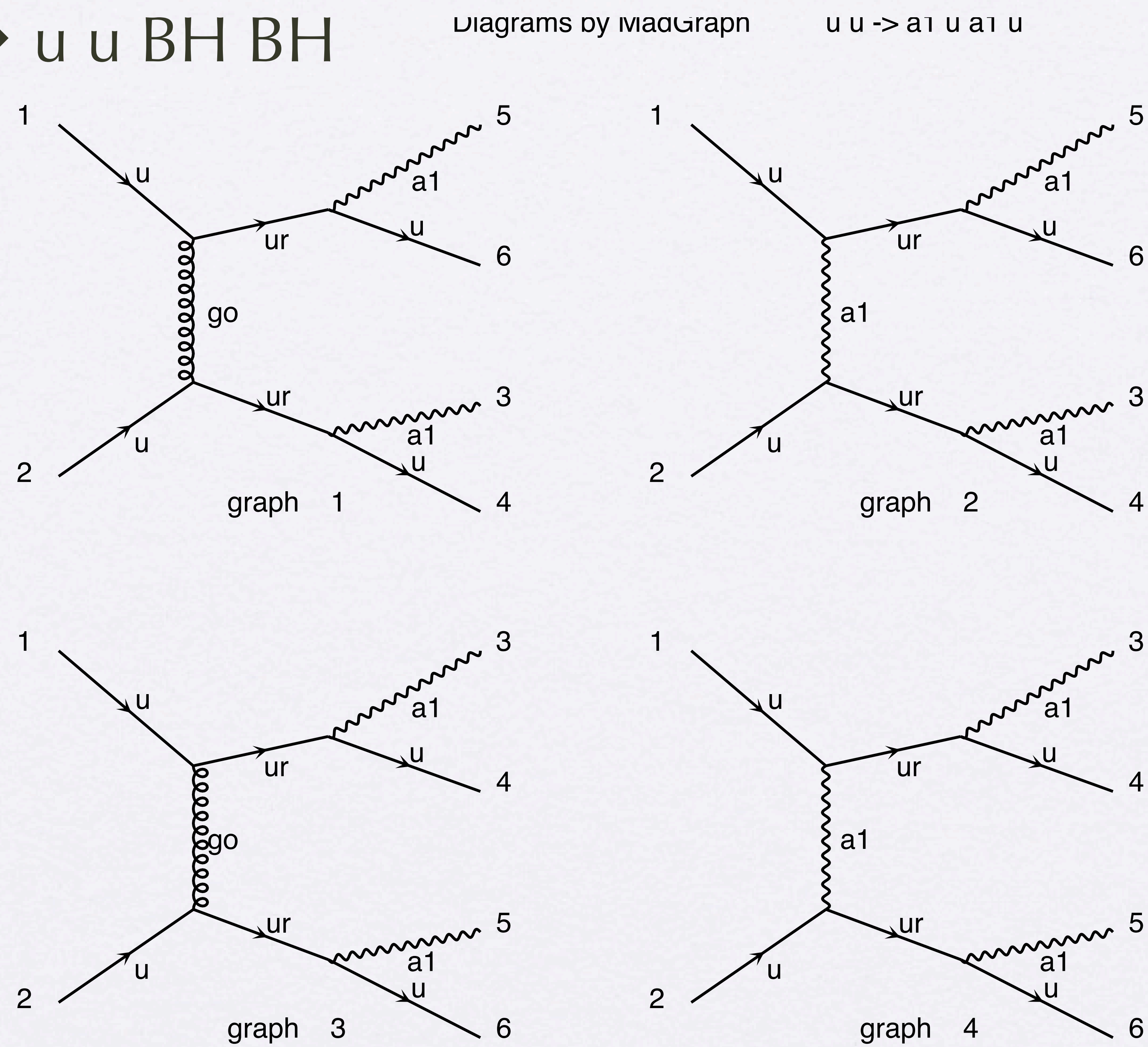
Interactions of the same spin partner model

$$L_{int} = \int dx^4 \left[g_s G_H^{\mu a} \bar{Q} T^a \gamma_\mu q + g W_H^{\mu a} \bar{Q}_L T^a \gamma_\mu P_L q_L \right.$$
$$\left. + g' B_H^\mu (Y_L \bar{Q}_L \gamma_\mu P_L q_L + Y_L \bar{Q}_R \gamma_\mu P_R q_R) + (\text{Lepton part}) + h.c \right]$$

- Heavy gauge boson(spin1) and quark partners(spin 1/2) have Z_2=-1
- Haven't specify Higgs sector: Gauge invariance of the amplitude must be carefully checked.
    - in UED like model: 5th component of gauge boson is the goldstone boson.
    - split UED/ a three site model allow mass splitting of the partners
    - big difference in the distributions

Production process at LHC and decay

pp→ UR UR → u u BH BH



Amplitude Tips

- Production and chiral interaction

$$iM(uu \to U_R U_R) = \frac{ig'^2 Y_u^2 \delta_{aa'}\delta_{bb'}\left(-g^{\mu\nu} + \frac{q^\mu q^\nu}{m_{B_H}^2}\right)}{q^2 - m_B^2} \bar{u}_{h_f}(p_f)\gamma_\mu P_R u_{h_i}(p_i)\bar{u}_{h'_f}(p'_f)\gamma_\nu P_R u_{h'_i}(p'_i)$$
$$+\text{cross diagram} + \text{gluon exchange contribution} \qquad (2)$$

$$\frac{-ig'^2 \delta_{aa'}\delta_{bb'} m_Q^2}{(q^2 - m_B^2) m_B^2} \bar{u}(p'_f) P_R u(p_i) \bar{u}(p'_f) P_R u(p'_i)$$

chirality flip

helicity (-1/2, -1/2)

$$4ig^2 \frac{\delta_{aa'}\delta bb'}{q^2 - m_A^2} p_i \left[2p_f \delta_{h_f,1/2} - (-)^{\bar{h}_f + 1/2}(E_f - p_f)\right]$$

helicity conserving in the

β→∞ limit

helicity (1/2,1/2)

Decay and polarization

- Polarized particle decay non-spherically

$$iM \propto \epsilon^{*\mu}\epsilon^{\nu}\mathrm{Tr}\left[\gamma_\mu P_R \not{p}_f \gamma_\nu P_R \frac{1+\not{h}\gamma_5}{2}(\not{p}_i + m_Q)\frac{1+\not{h}\gamma_5}{2}\right] = \frac{2k_B\cdot p_f m_Q}{m_B^2}(E_B - k_{B//})$$

chiral vertex

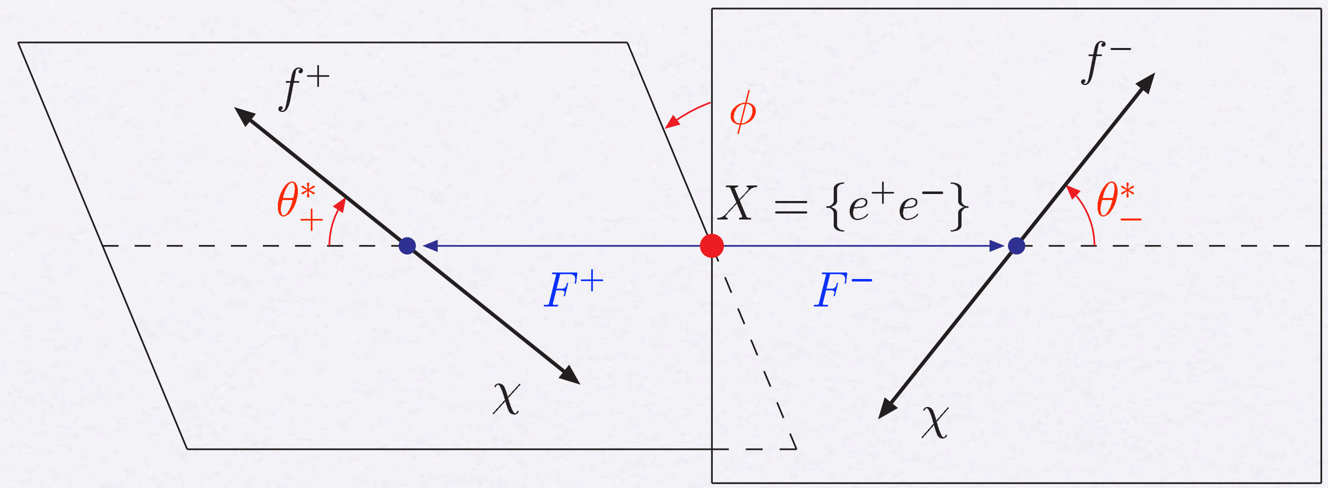
projection to the helicity state

h=1/2 particle+ chiral vertex → quark distribution is ∝ 1+cos θ
(The distribution is same for Q_L decay into $q_L\chi$)

If number of particle is larger than number of antiparticle(LHC) effect remains.

Note :h=0 massive gauge boson dominates in the decay.

Azimuthal Angle Correlations



amplitude till decay

decay matrix

$$W(E_{\rm cm};\Theta;\theta^*_\pm,\phi^*_\pm) = \sum_{\lambda_\pm,\lambda'_\pm=-j}^{j} \mathcal{P}^{\lambda_-\lambda_+}_{\lambda'_-\lambda'_+}(E_{\rm cm},\Theta)\,\mathcal{D}^-_{\lambda_-\lambda'_-}(\theta^*_-,\phi^*_-)\,\mathcal{D}^+_{\lambda_+\lambda'_+}(\theta^*_+,\phi^*_+),$$

spin dependent phase

$$\mathcal{P}^{\lambda_-\lambda_+}_{\lambda'_-\lambda'_+} = \sum_{\sigma_\pm=\pm 1/2} \mathcal{T}_{\sigma_-\sigma_+;\lambda_-\lambda_+}\mathcal{T}^*_{\sigma_-\sigma_+;\lambda'_-\lambda'_+}, \qquad \mathcal{D}^\pm_{\lambda_\pm\lambda'_\pm}(\theta^*_\pm,\phi^*_\pm) = D^\pm_{\lambda_\pm\lambda'_\pm}(\theta^*_\pm)\, e^{\mp i(\lambda_\pm-\lambda'_\pm)\phi^*_\pm},$$

If spin= 0 no azimuthal angle correlation correlation.
If a helicity state dominates no azimuthal angle correlation
→ independent information

- Amplitude of spin j particle pair production and decay

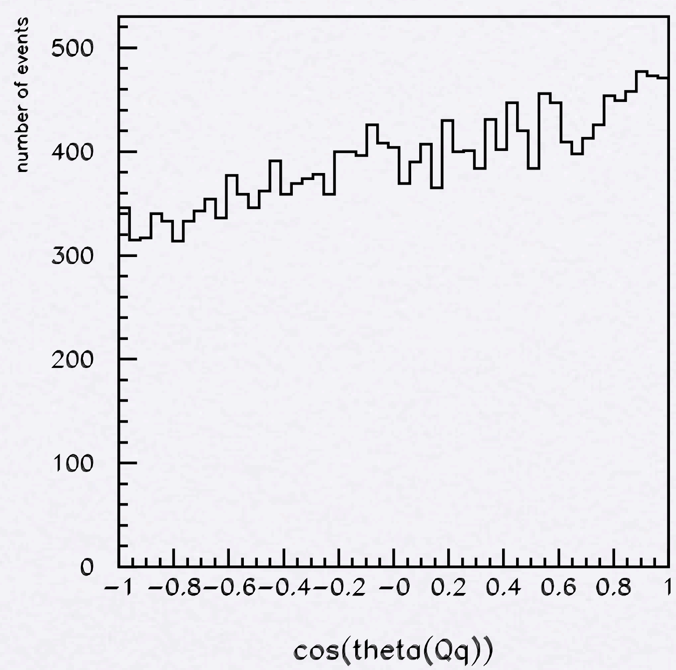
$$\frac{1}{\mathcal{C}}\frac{d\mathcal{C}}{d\phi} = \frac{1}{2\pi}\left[1 + A_1\cos(\phi) + \cdots + A_{2j}\cos(2j\phi)\right].$$

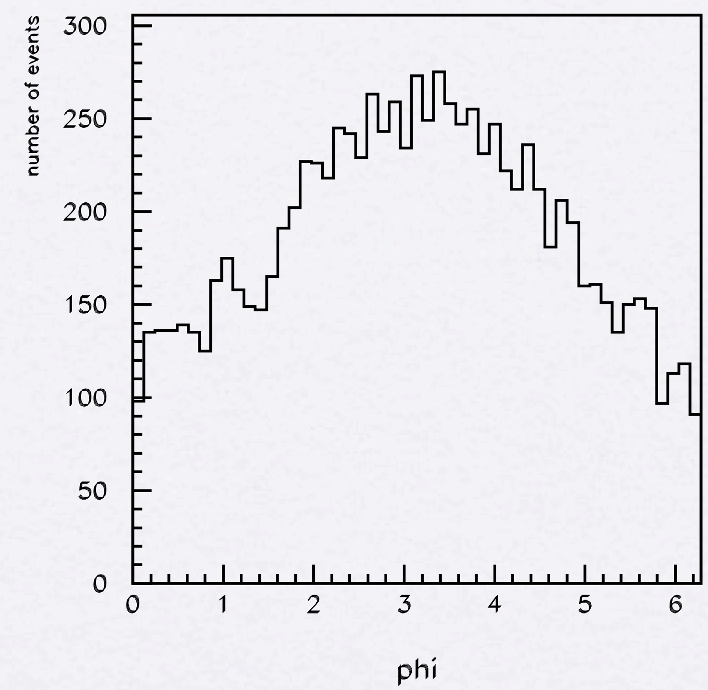
parton level distribution

- m_{BH}=100 GeV/200GeV mQ=600GeV mG=700GeV

m_{BH}=100 GeV

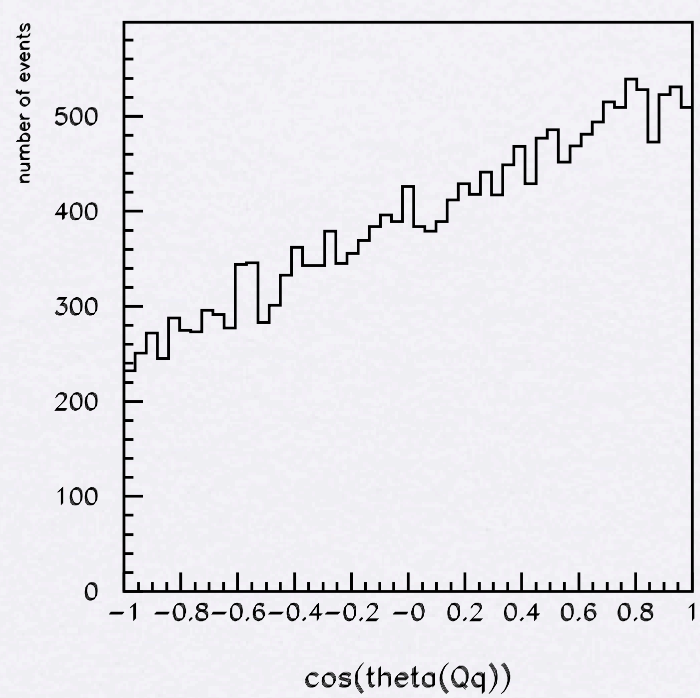
both (1/2,1/2) (-1/2, -1/2) are large

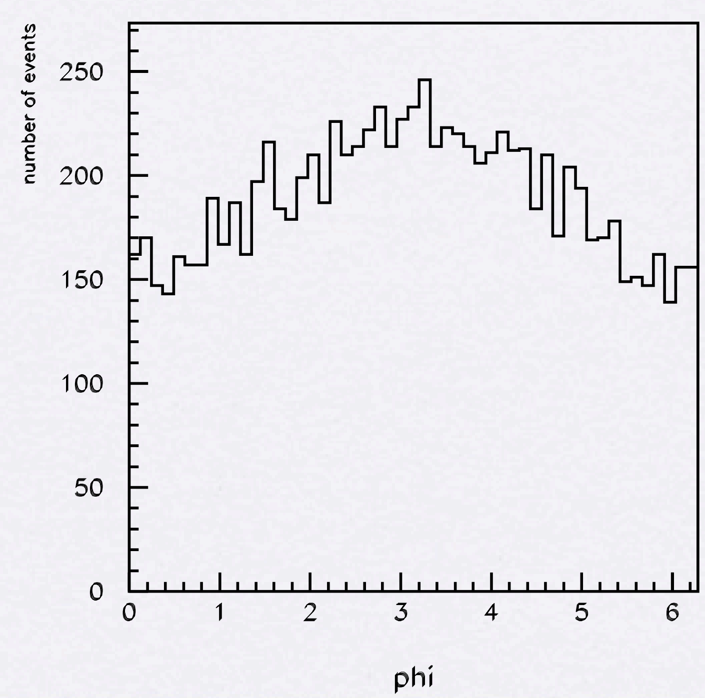




m_{BH}=200 GeV

(1/2,1/2) dominates





How to see it

schimatical figure of distributions

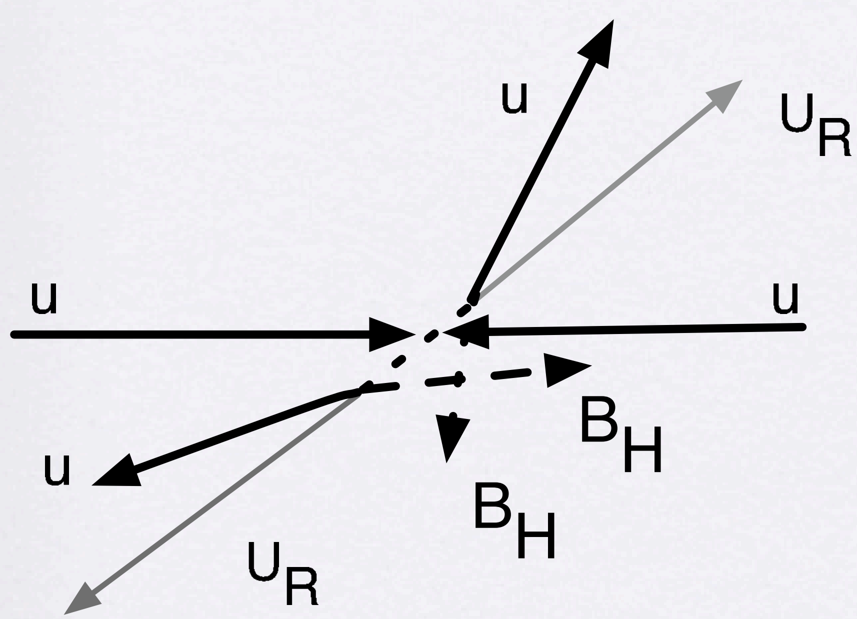
m_{BH} =200 GeV

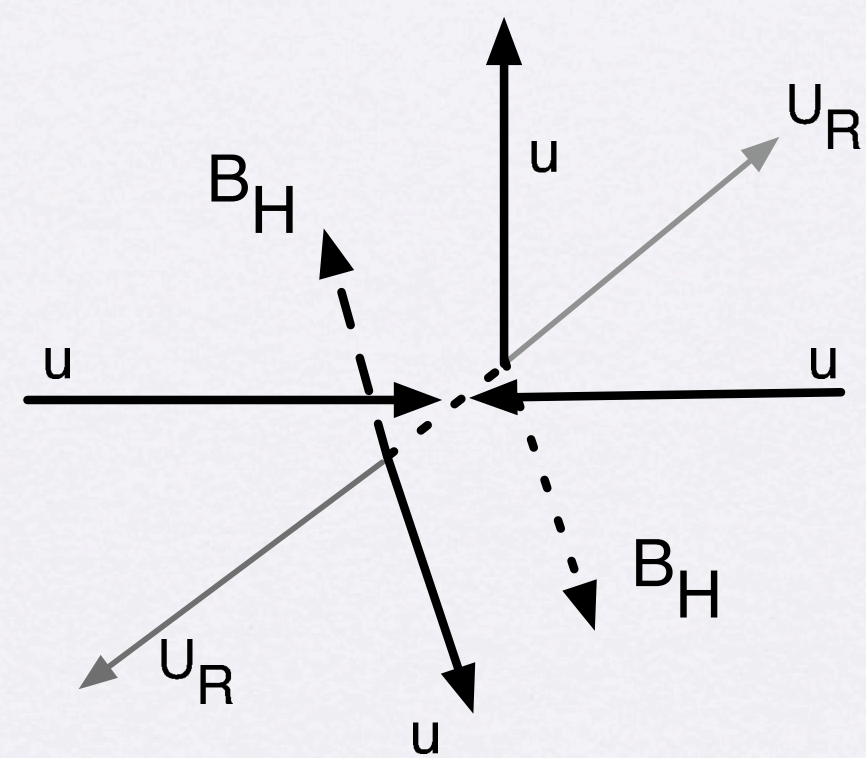
q goes direction of Q

or

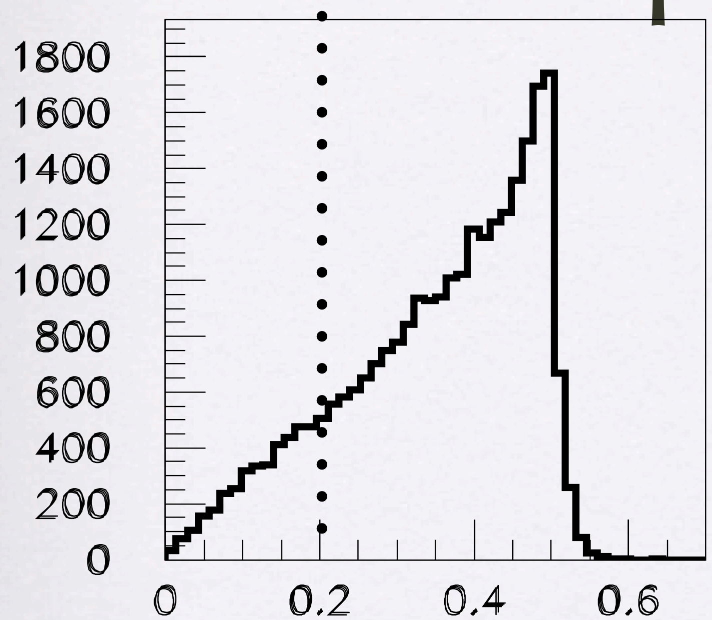
m_{BH}=100 GeV

q goes to back to back

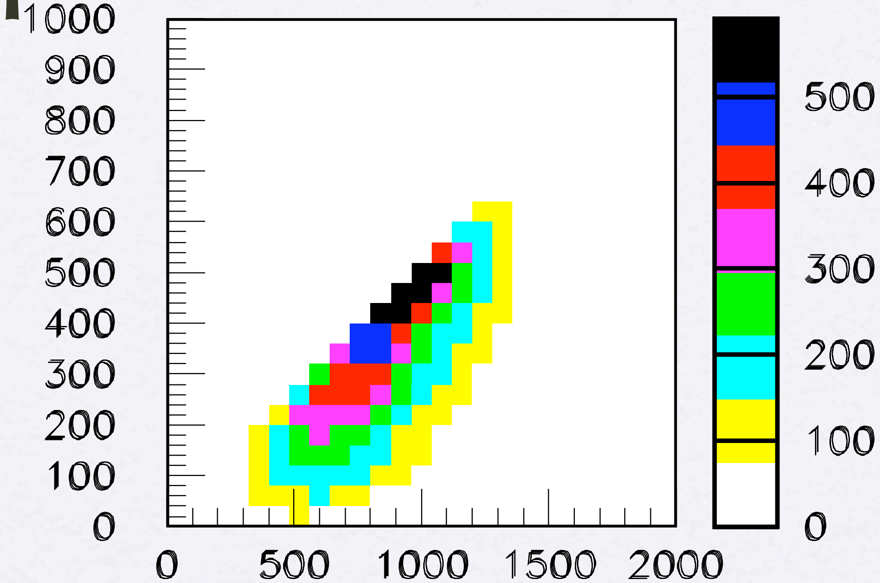




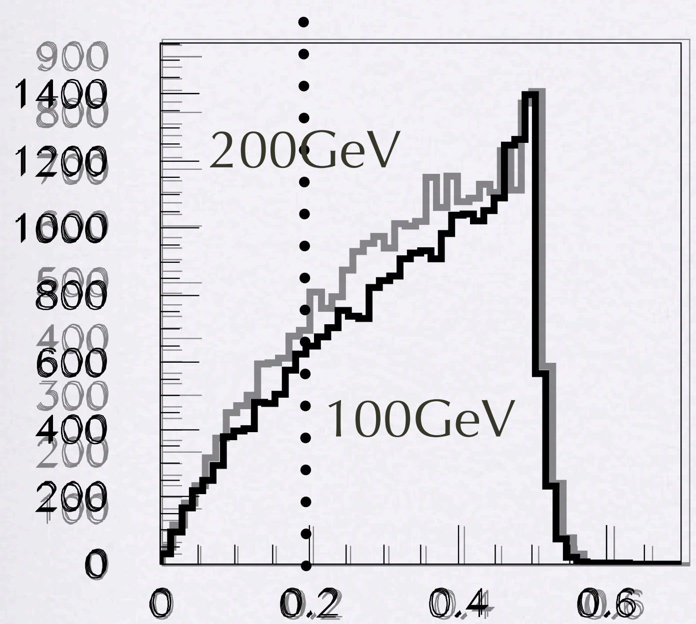
The jet level distribution for pp→$U_R U_R$ channel



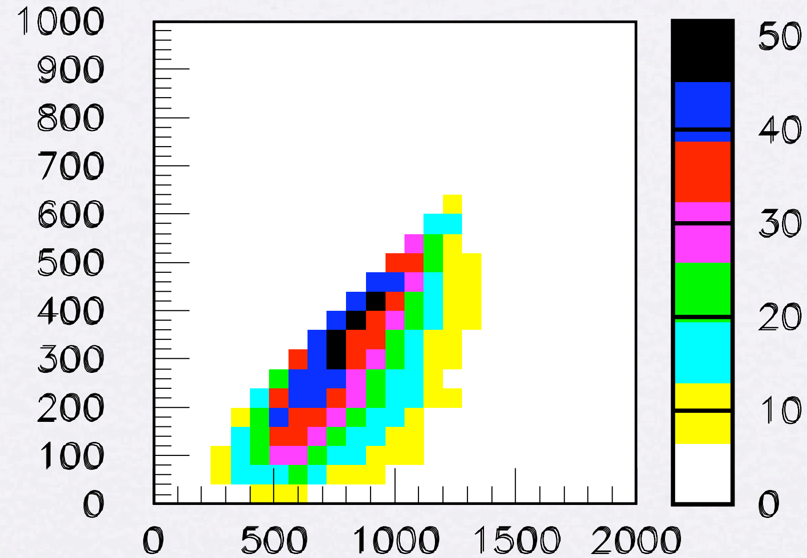
etmiss/xmeff



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



etmiss/xmeff



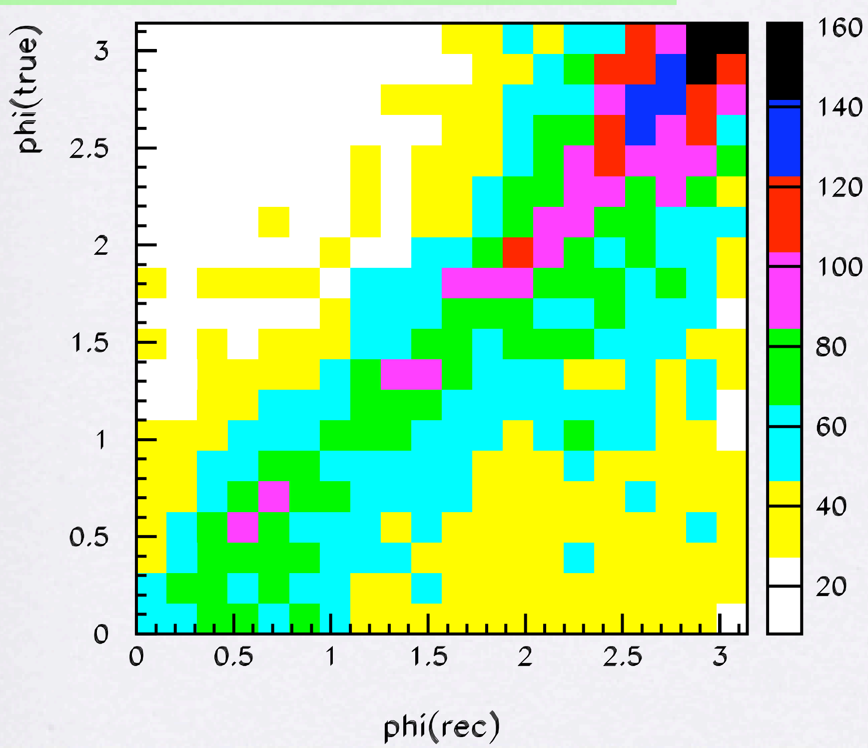
Madgraph
2 by 4

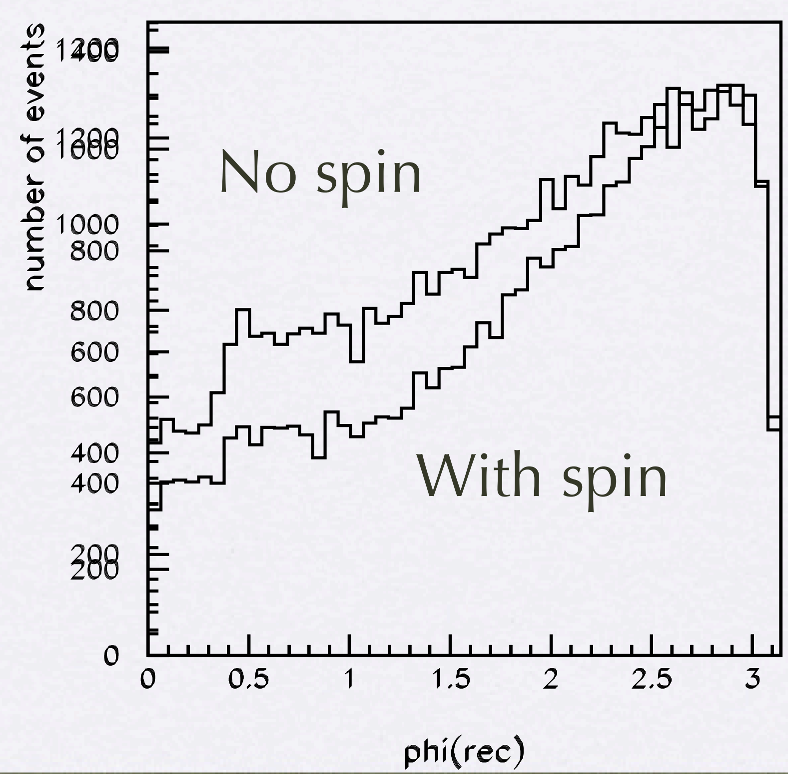
Nojiri, J. Shu to appear

M_{T2} and reconstruction of a-angle in jet level

- MT2 $$M_{T2} = \min_{p_1^T + p_2^T = p_{\mathrm{Tmiss}}} \left[\max \left(m_{T2}(p_{\mathrm{vis}}^{(1)}, p_1^T), m_{T2}(p_{\mathrm{vis}}^{(2)}, p_2^T) \right) \right]$$
- MT2 assisted reconstruction:The process give transverse test LSP momentum $p_{(1)}$, $p_{(2)}$ of that gives M_{T2}. calculate p_z momentum that gives correct m_Q, and $m\chi$
$$(p_i + p_{\mathrm{vis}}^{(i)})^2 = m_Q^2, \quad (p^{(i)})^2 = m_{B_H}^2$$
- calculate φ for the momentum.

Small phi tend to fail



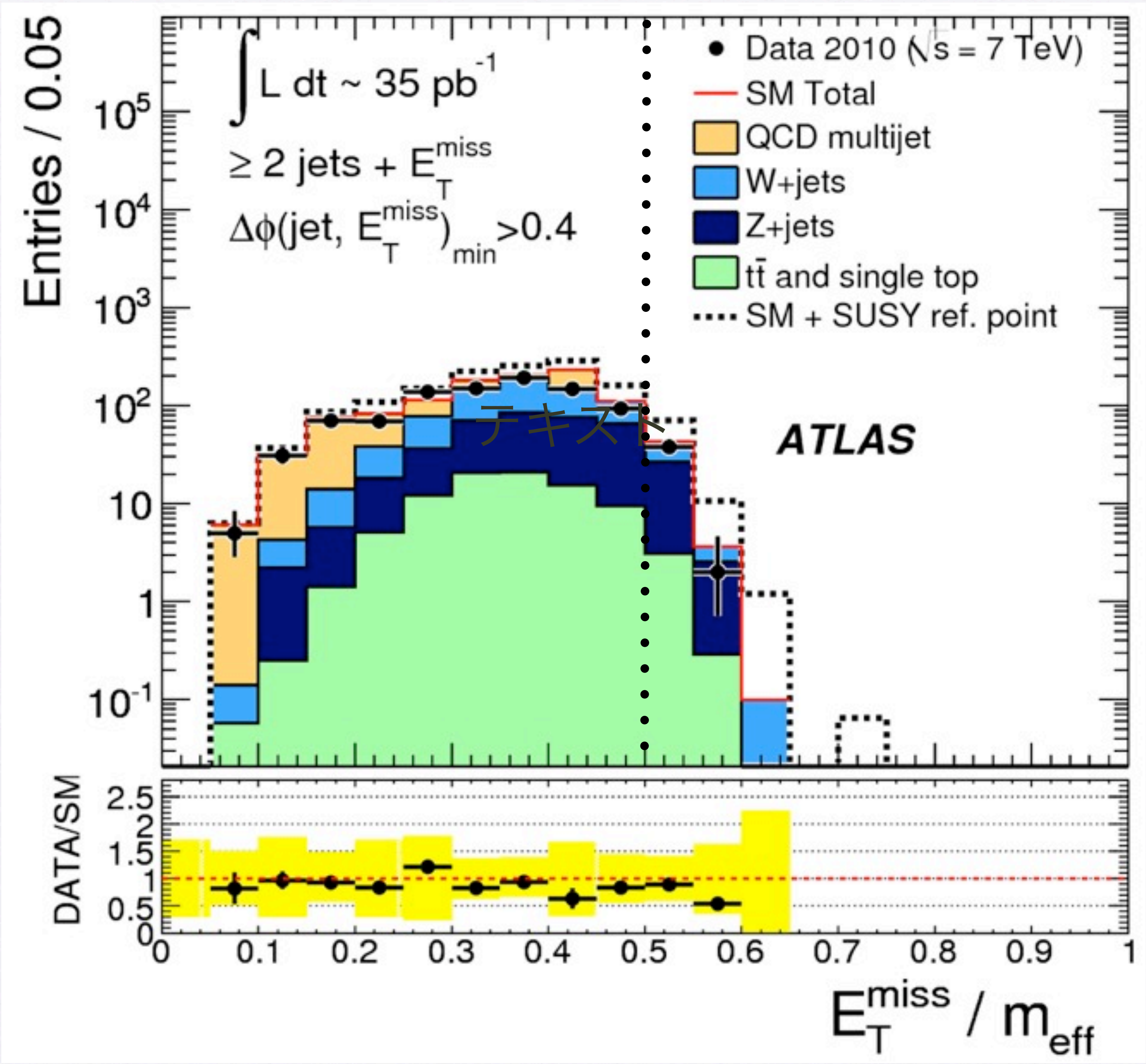


Lessons and some info

- "phase space decay" for leading objects fails to reproduce physics processes even in such simple case. (Some phase sphace generators are not useful)
    - Moortgat-Pick et al : distribution of production cross section in forward region is also different
- "Consistent treatment": Production in T channel and decay are correlated.
    - Full amplitude generator (Madgrap and Herwig++) work. No Pythia.
- Working on little higgs model with T parity (no gluon partner, heavy wino like object)

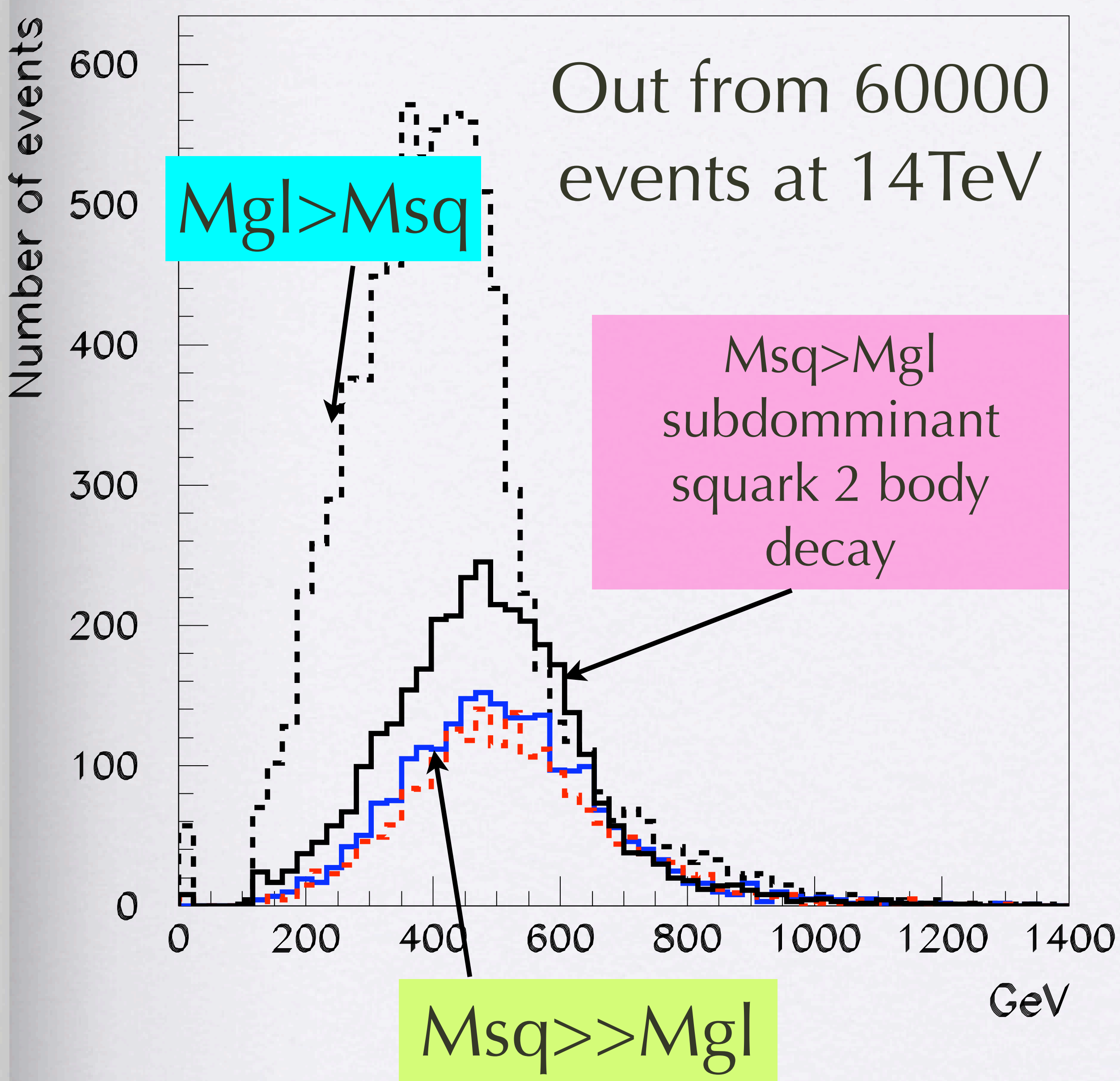
おまけ(ATLAS distribution)

Meff =
ETmiss+ two highest pT jet



予備

two high pT jets in SUSY events



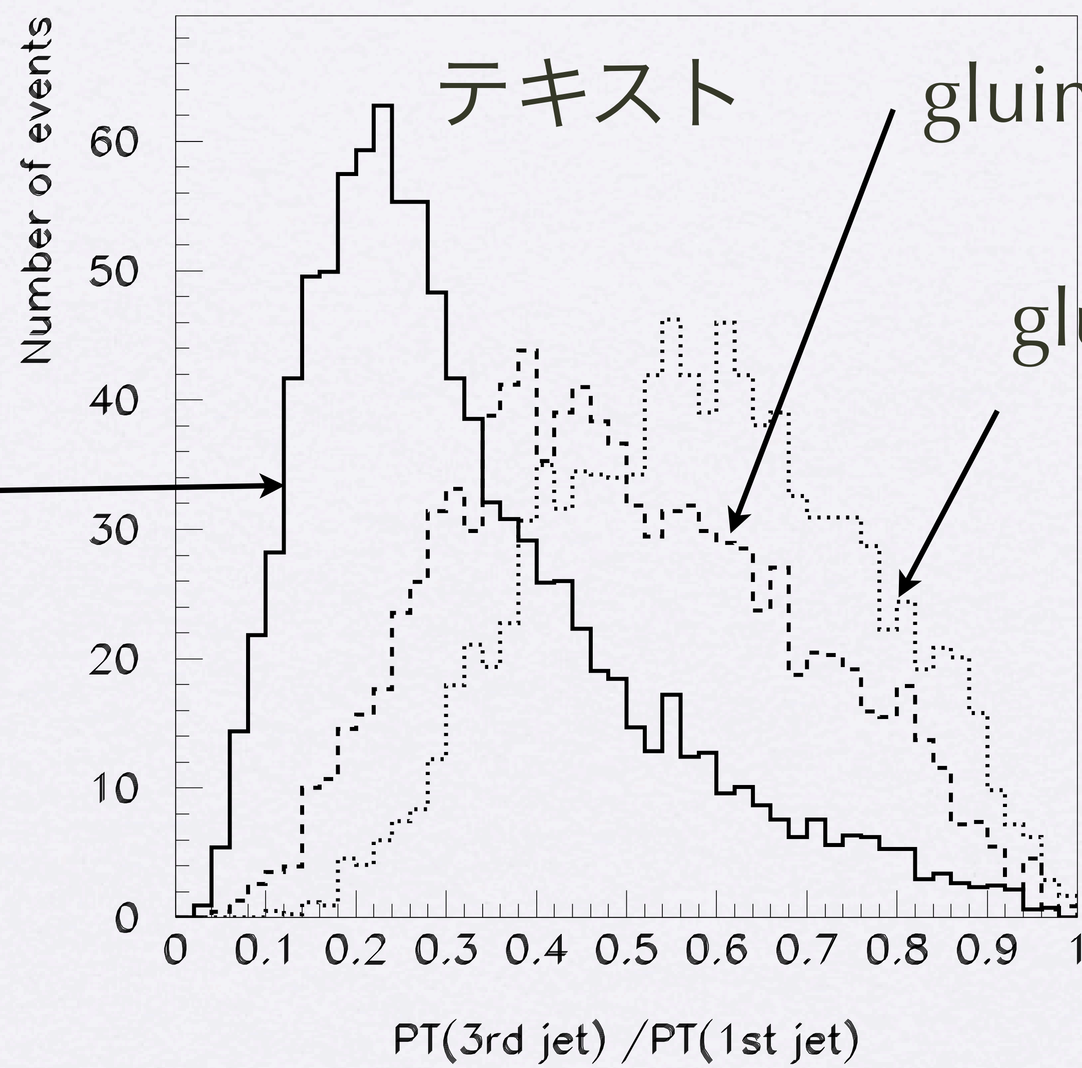
Nojiri, Sakurai

- Inclusive MT2 distribution for Mgl~600 GeV
    - divide events into two using Lund distance and calculate MT2 from two visible system
- Selection: Events at least 2 jets with pT>200GeV
- msq<mgl: large branch sharp edge. The mode with 2 high pT jet stands!

under mixed SUSY production

- In SUGRA like mass spectrum（msq, mgl>>mχ）jets from sq→q χ is prominent .

(pT of the 3rd jet) /pT of the 1st jet



gluino → jj χ is dominant

gluino→ tbχ, ttχ

gluino→squark→χ
is dominant

Nojiri & Sakurai