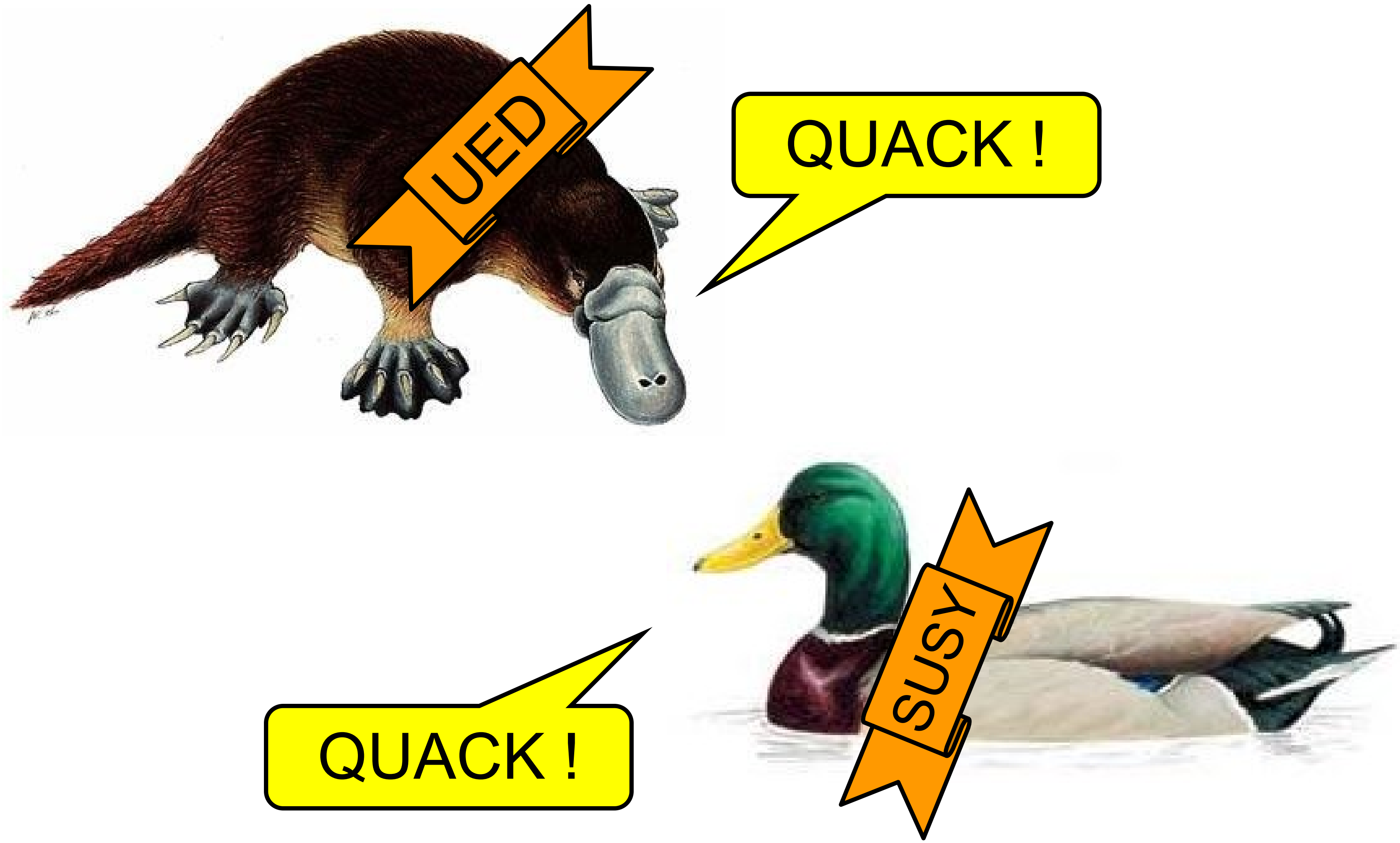
What is "Discovering SUSY" ?

- E.g. – what makes Supersymmetry different to Universal Extra Dimensional models with Kaluza-Klein particles.
- One part of the answer:

SPIN



Not all things that quack are ducks!

We will see two important themes:

- Mass measurements will precede(*) spin determinations
- “Spin measurement”(**) should not be confused with “sensitivity to spin”

(*) or will at best be simultaneous with

(**) Here “spin measurement” means “determining unambiguously the correct nature (scalar, fermion, vector) of one or more particles in a decay chain or model

(more info at)

A REVIEW OF SPIN DETERMINATION AT THE LHC

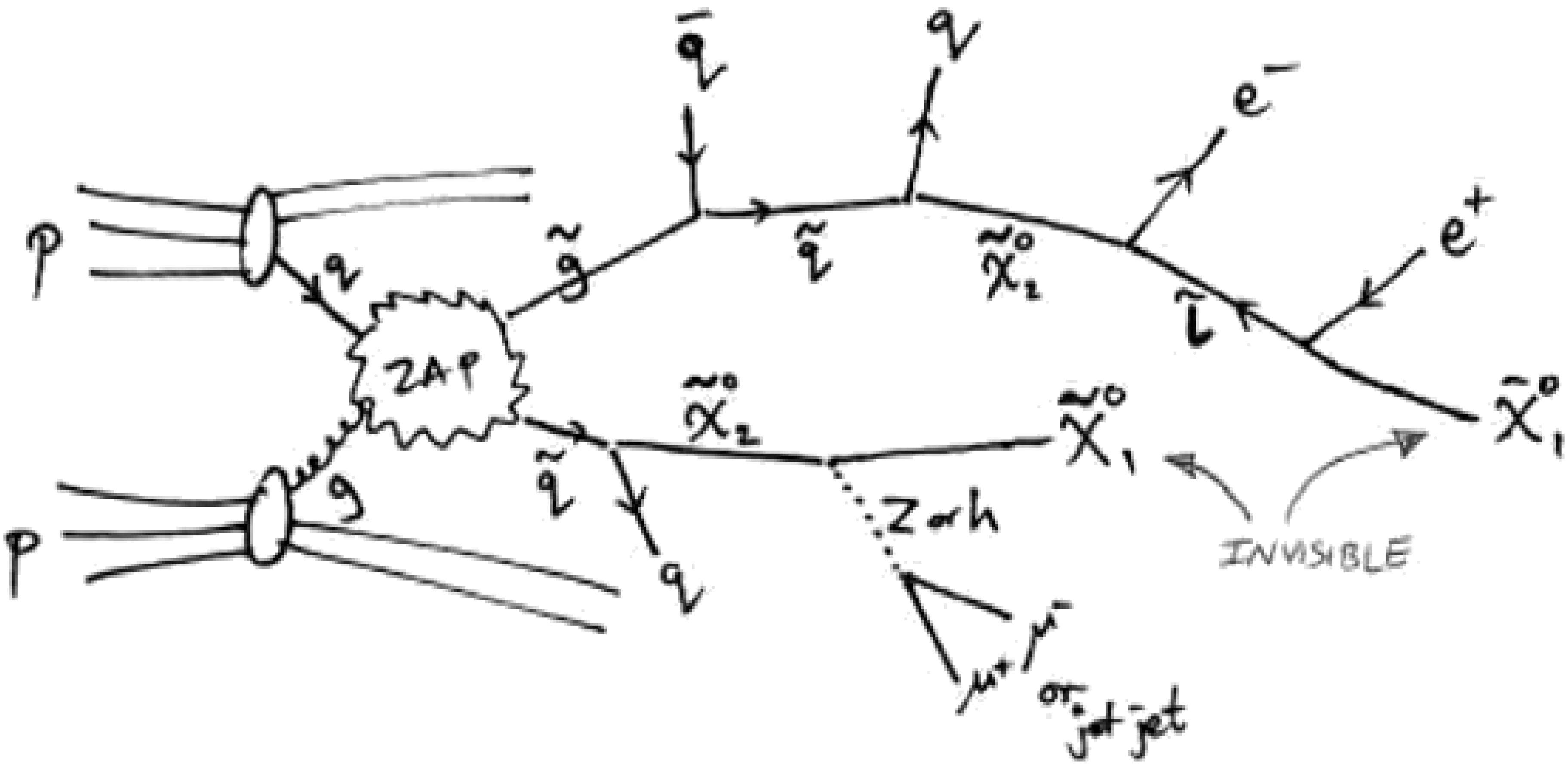
Lian-Tao Wang and Itay Yavin

arXiv:0802:2726

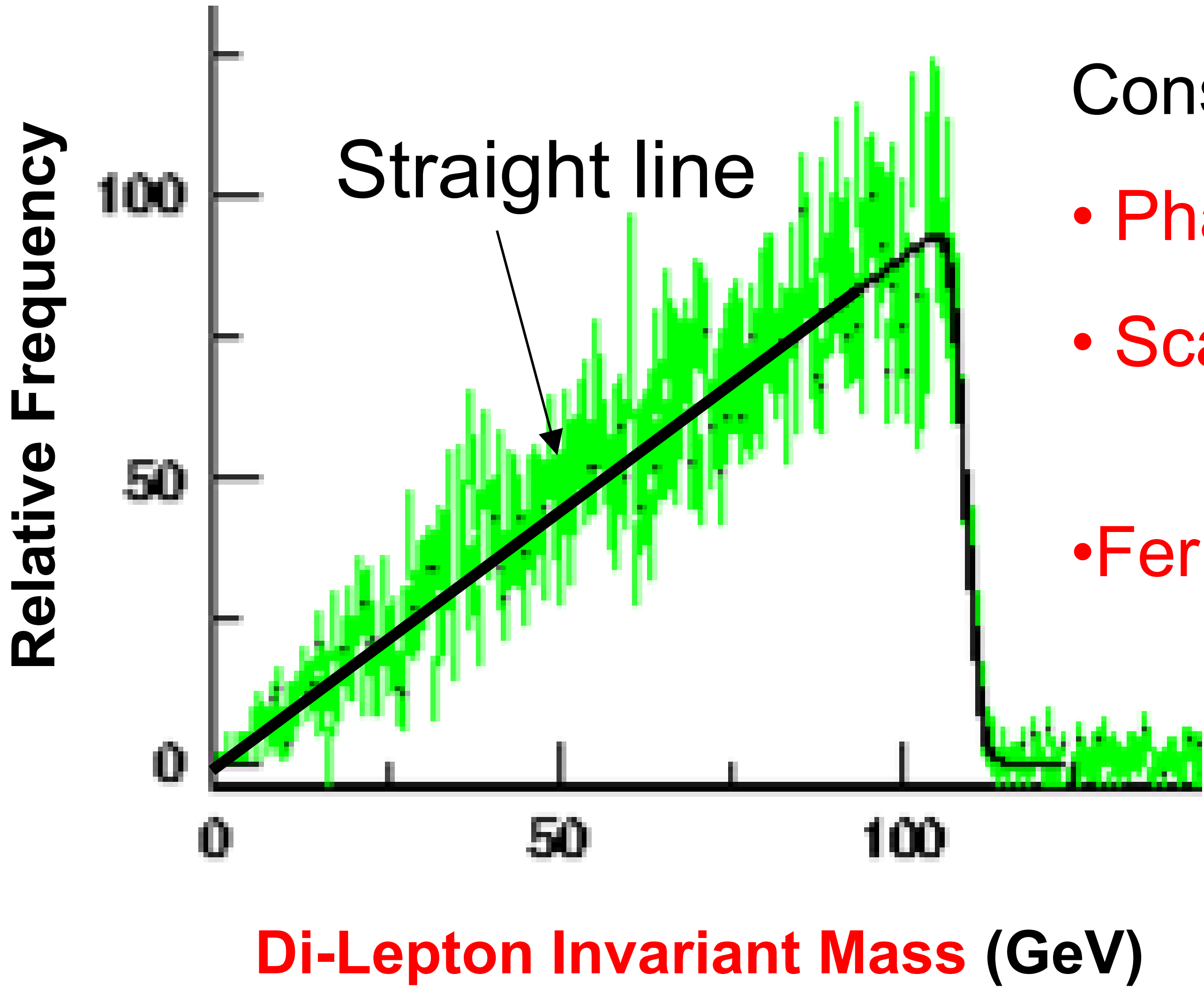
Spin determination topics

- Consistency checks
- Spins in “QLL chain”
  - A.Barr hep-ph/0405052
  - Smillie et al hep-ph/0605286
  - Florida etc arXiv:0808.2472
  - Biglietti et al ATL-PHYS-PUB-2007-004
- Slepton Spin (production)
  - A.Barr hep-ph/0511115
- MAOS method
  - Cho, Kong, Kim, Park arXiv:0810.4853
- Gluino chain spin
  - Alvez, Eboli, Plehn hep-ph/0605067
- Spins in chains with charginos
  - Wang and Yavin hep-ph/0605296
  - Smillie hep-ph/0609296
- Spins in chains radiating photons
  - Ehrenfeld et al arXiv:0904.1293

Spin Consistency Check



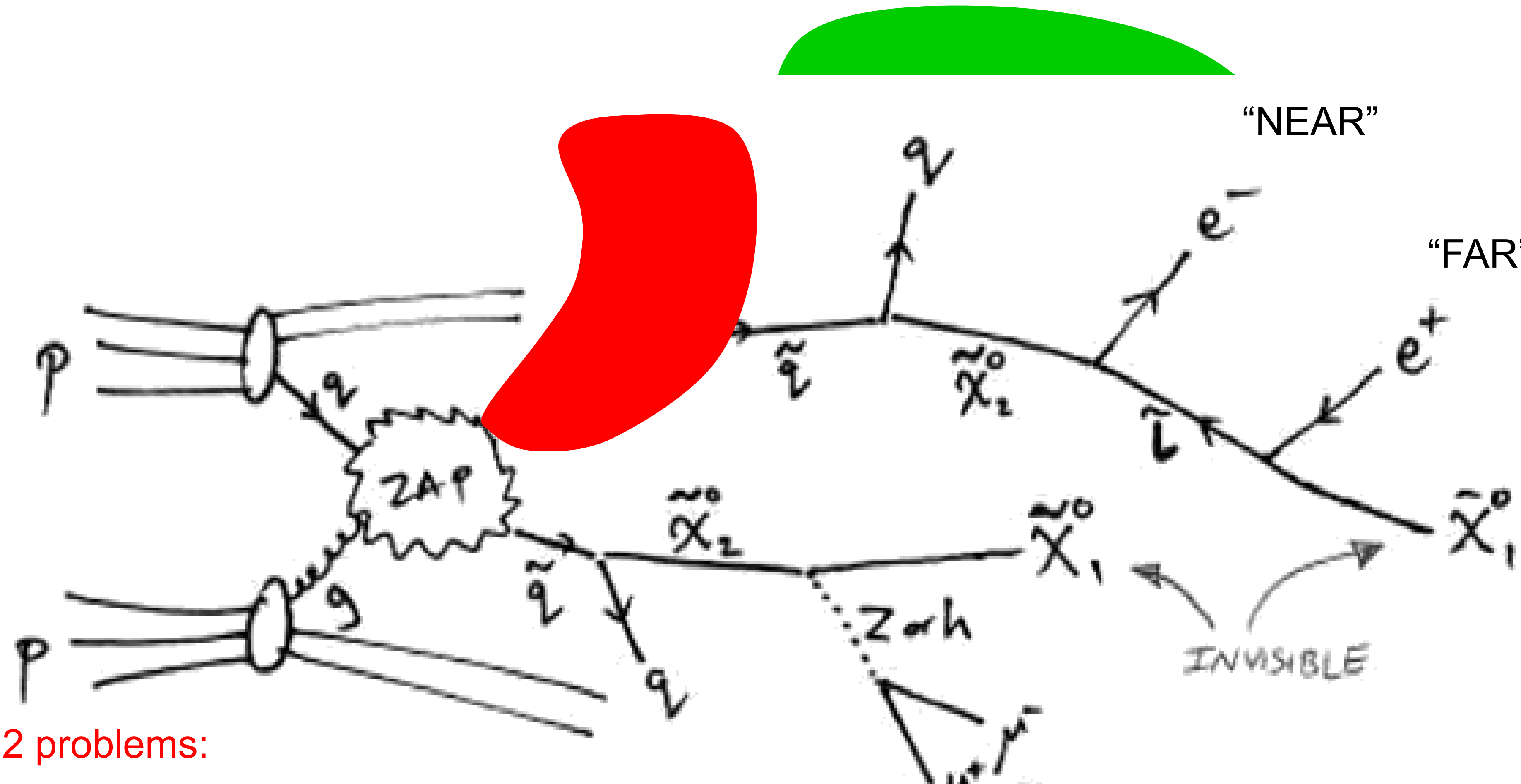
Spin Consistency Check



Consistent with:

- Phase-space
- Scalar slepton (SFSF)
- Fermion KK lepton (FVFV)

QL Spin Determination (A.Barr)



2 problems:

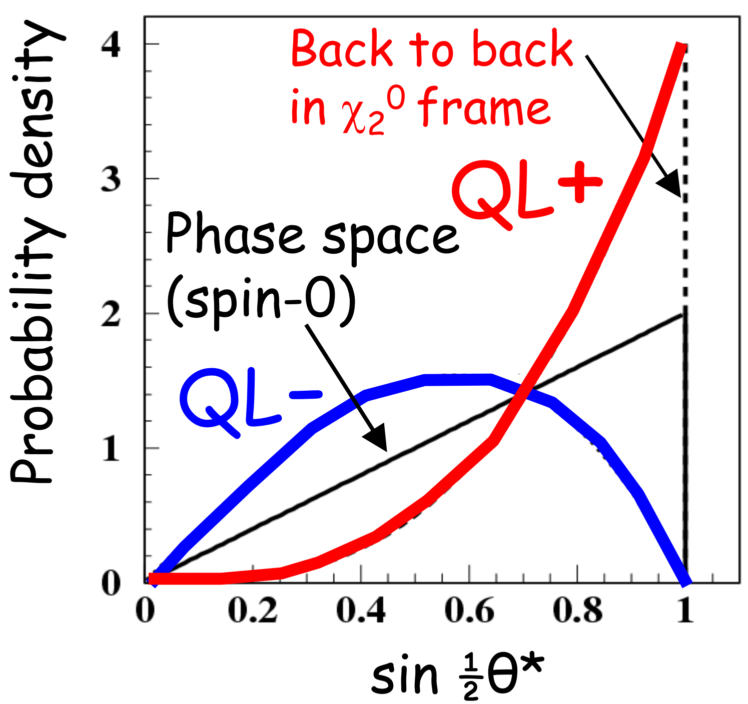
How can we distinguish the ‘near’ lepton from the ‘far’ lepton?

How can we tell l^+q from $l^+\bar{q}$?

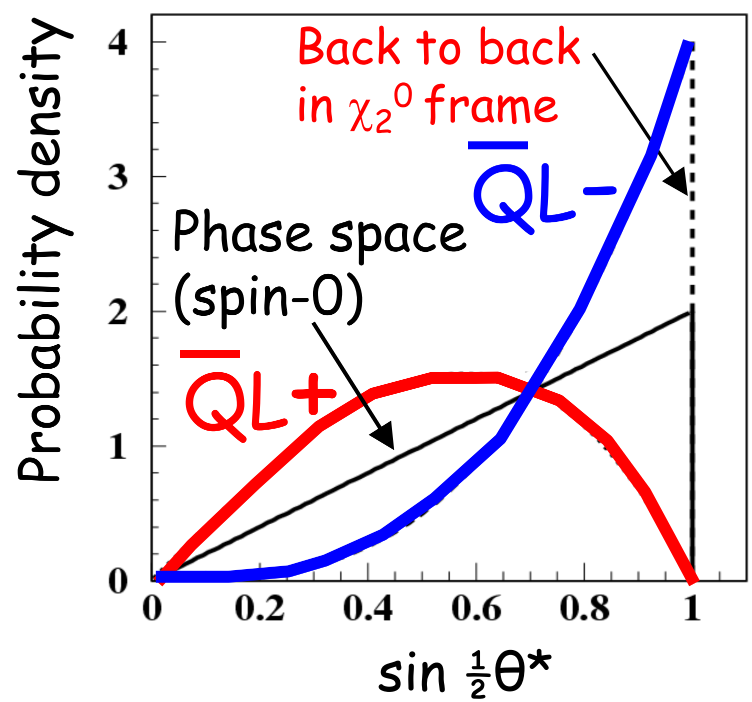
Quark+NearLepton

invariant mass distributions for:

L+ L- and QUARKS



L+ L- and ANTI-QUARKS



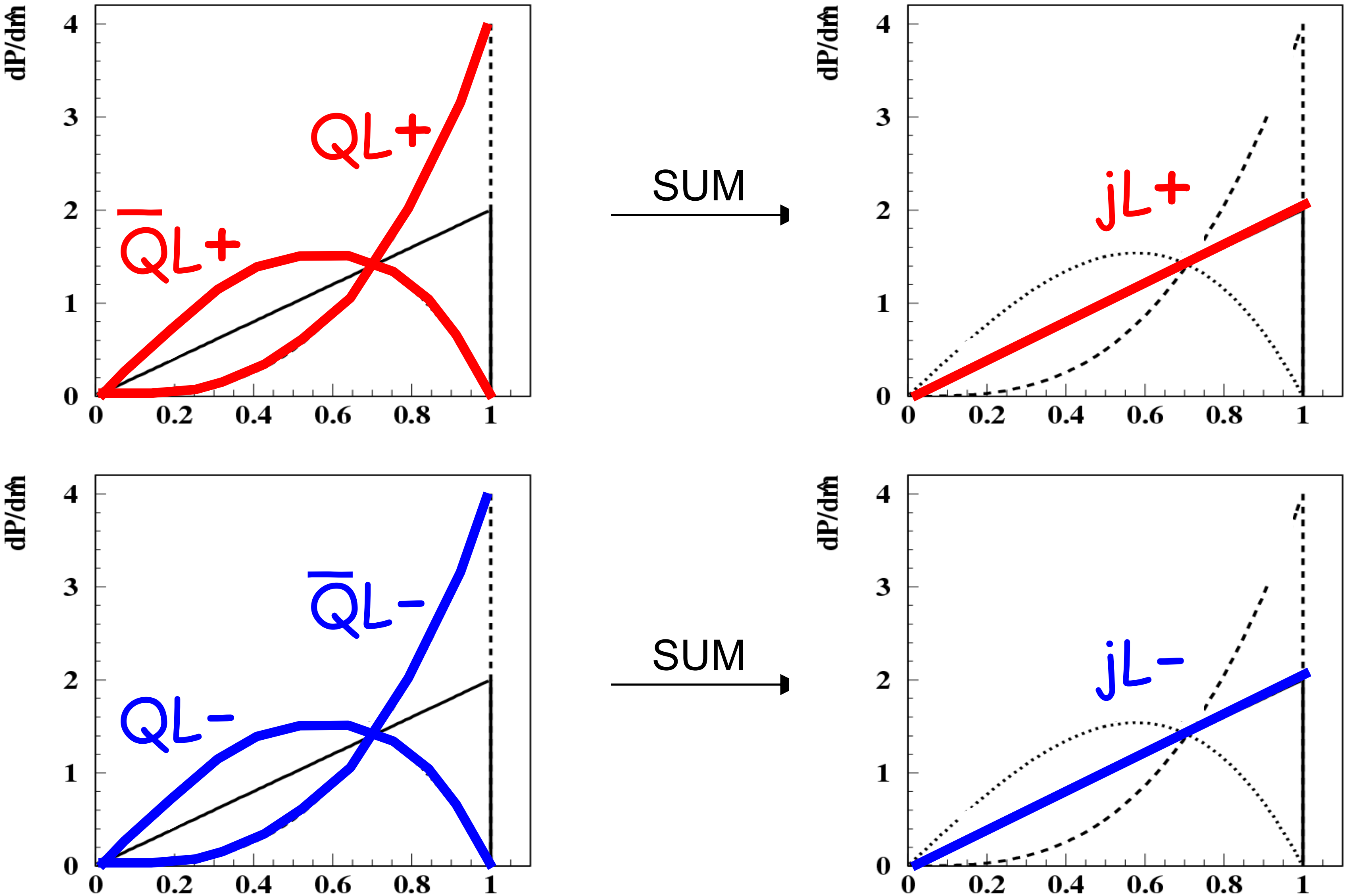
hep-ph/0405052

Experimental problem

- Cannot reliably distinguish QUARKs from ANTI-QUARKs

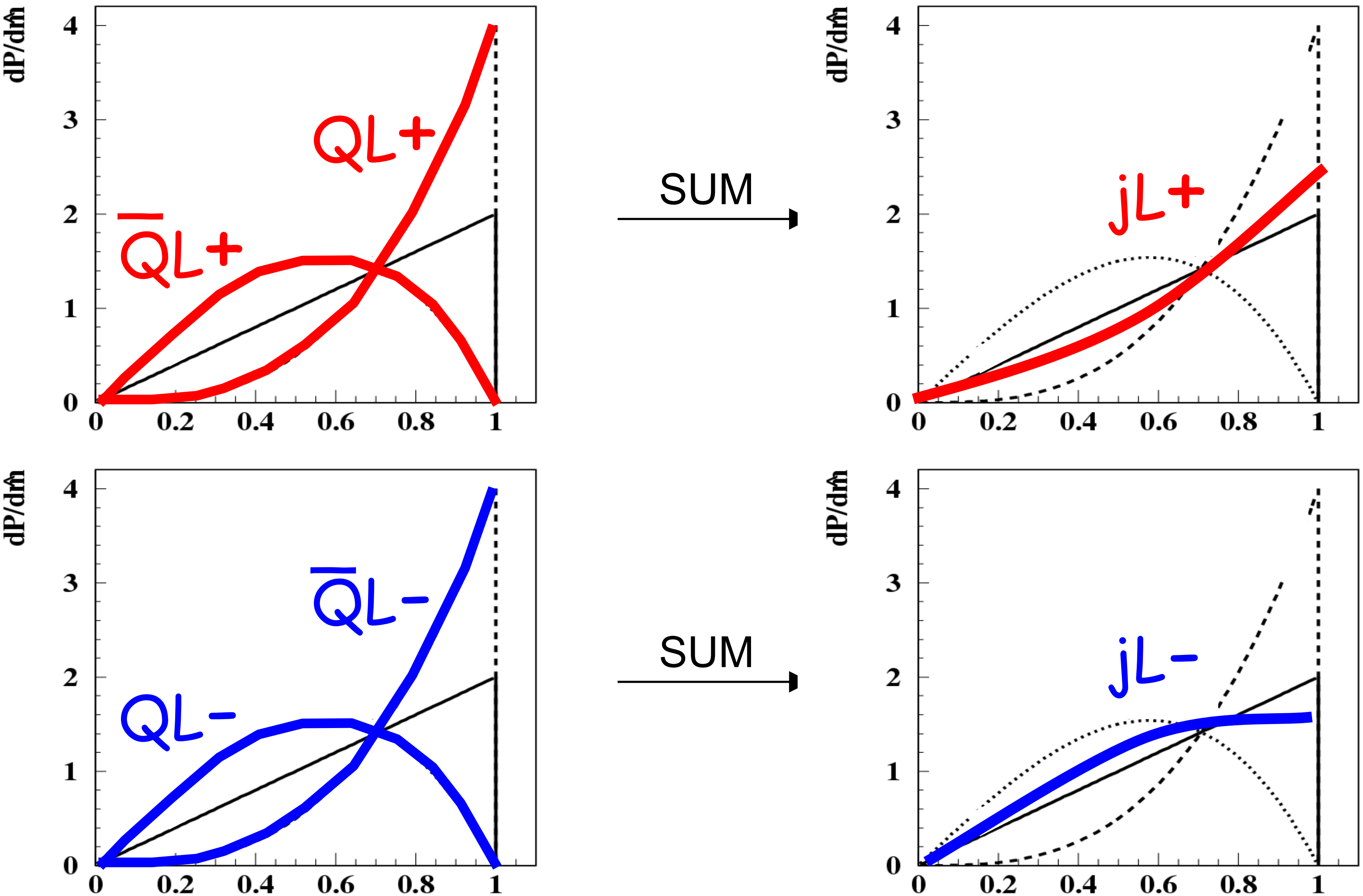
Can only distinguish lepton charge
RED(QL+,$\bar{Q}$L+) from BLUE(QL-,$\bar{Q}$L-)

Expect QUARK and ANTI-QUARK contributions to cancel:



But LHC is Proton-Proton machine

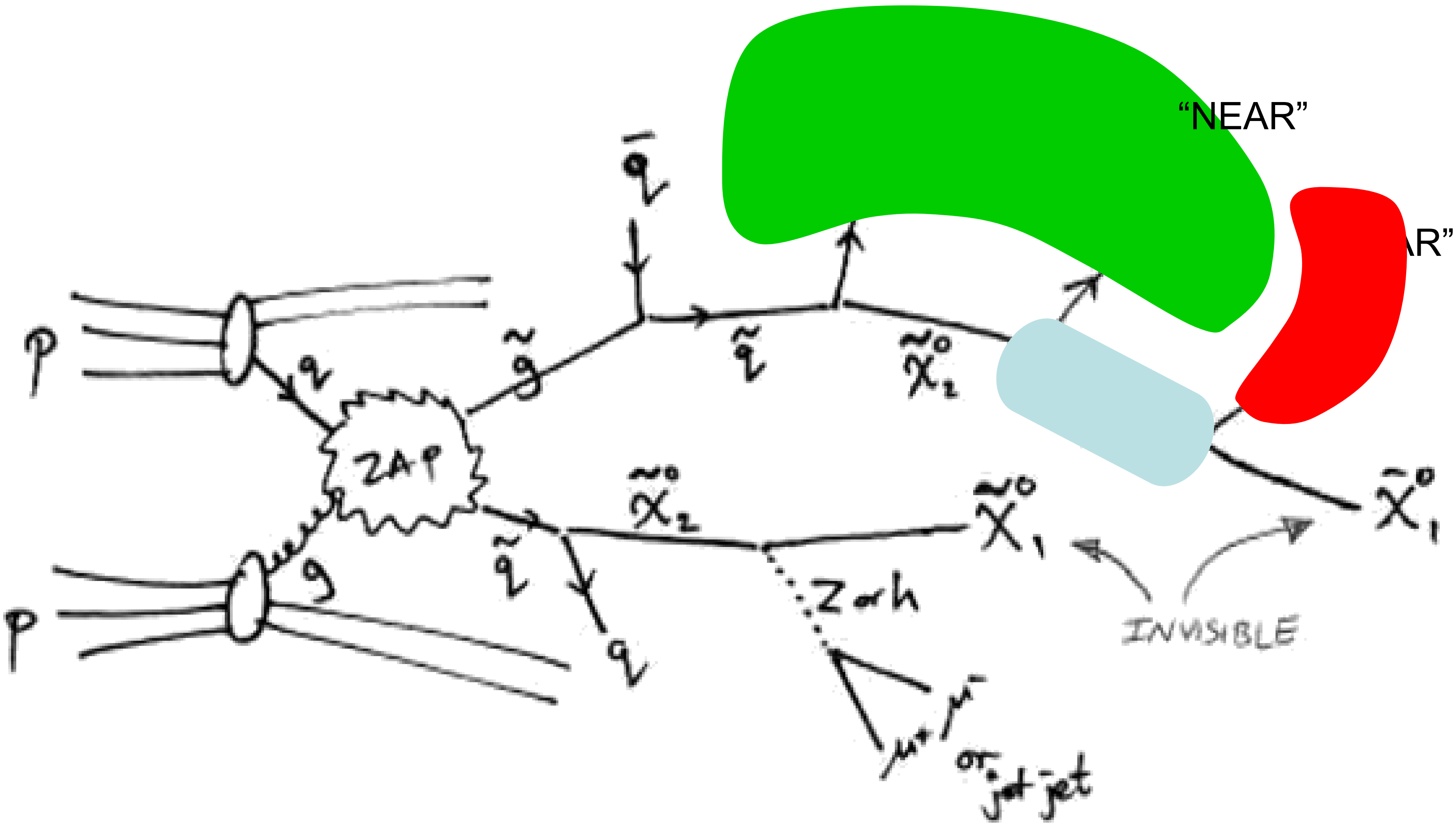
- More Quarks than Anti-Quarks! So get:



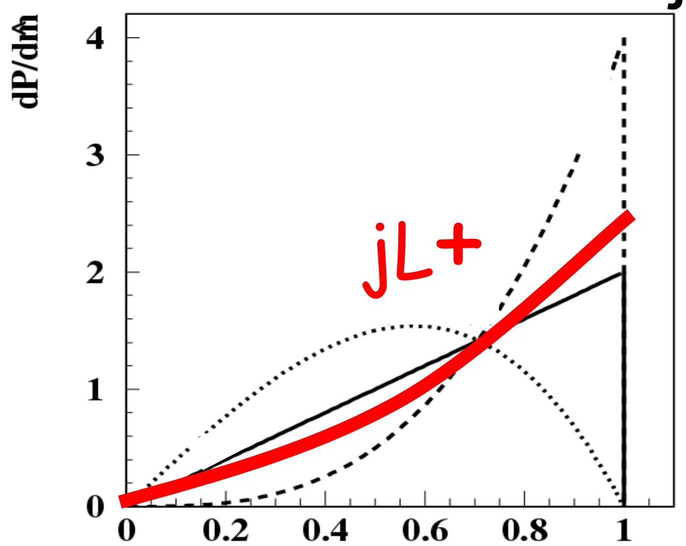
Asymmetry!

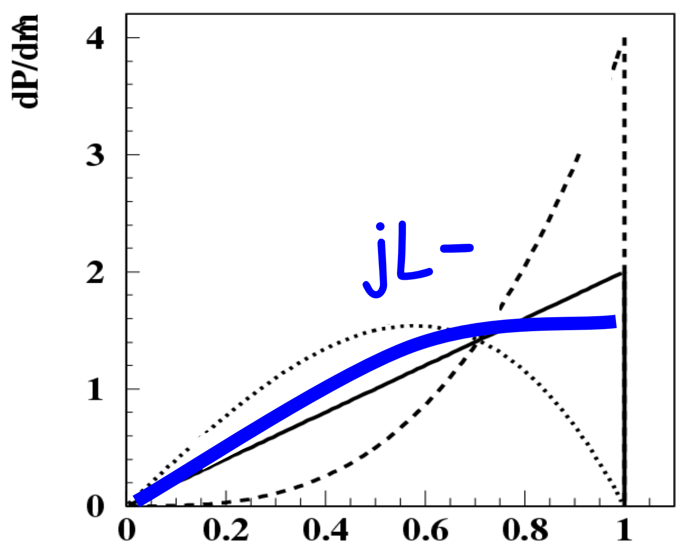
hep-ph/0405052

“Far” Lepton washout?



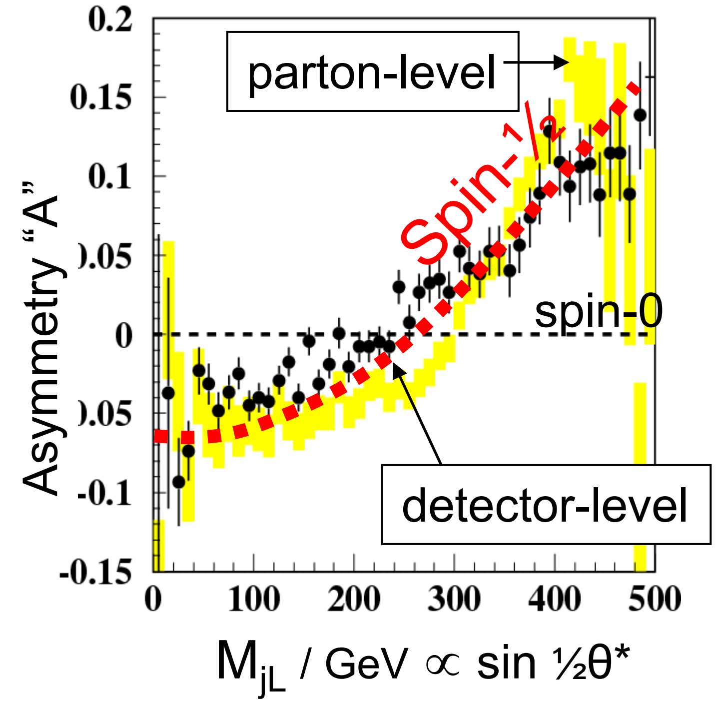
So define m_{jL^+}, m_{jL^-} asymmetry





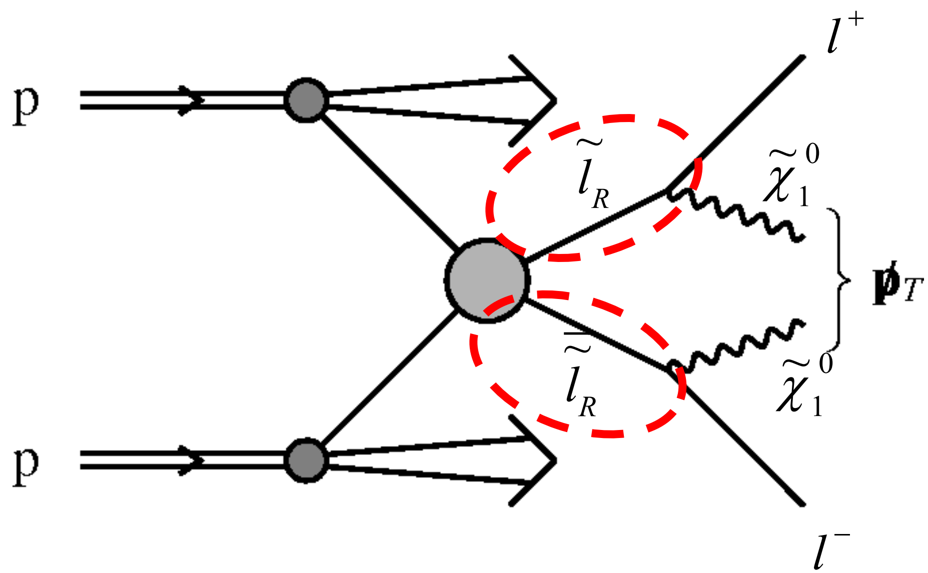
$$A = \frac{s^+ - s^-}{s^+ + s^-}$$

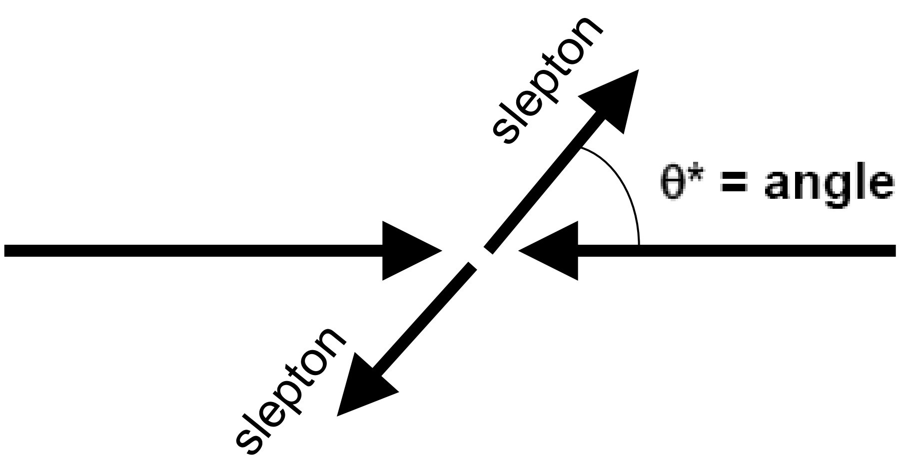
where $s^{\pm} = \frac{d\sigma}{dm_{jL^{\pm}}}$



Different method altogether

Direct slepton spin detection: $qq \rightarrow Z\gamma^* \rightarrow$ slepton slepton



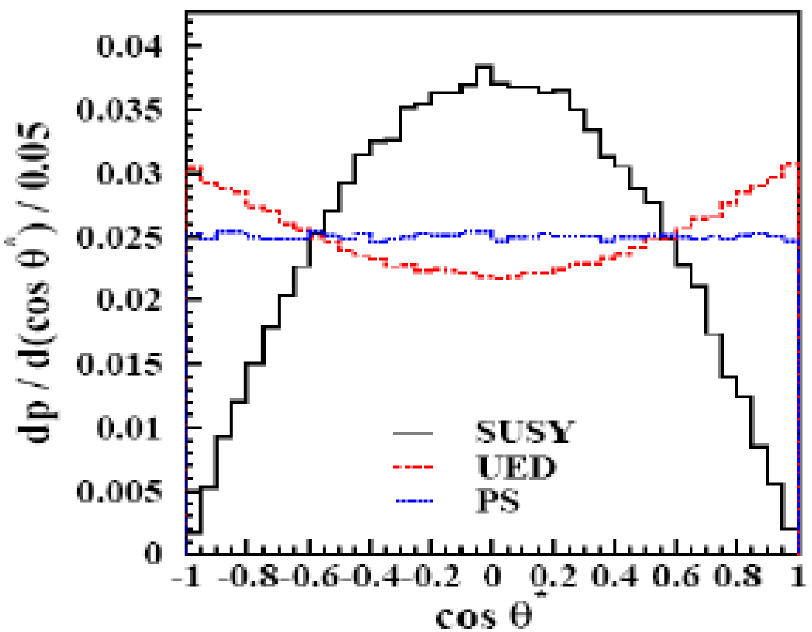


θ* = angle between incoming quark and slepton

hep-ph/0511115

Look at slepton production angle in c.o.m.

- θ^* = angle between incoming quark and slepton



$$\left(\frac{d\sigma}{d\cos\theta^*}\right)_{\mathrm{SUSY}} \propto 1 - \cos^2\theta^*$$

SUSY = LHC point 5

$$\left(\frac{d\sigma}{d\cos\theta^*}\right)_{\mathrm{PS}} \propto \text{constant}$$

$$\left(\frac{d\sigma}{d\cos\theta^*}\right)_{UED} \propto 1 + \left(\frac{E_{\ell_1}^2 - M_{\ell_1}^2}{E_{\ell_1}^2 + M_{\ell_1}^2}\right)\cos^2\theta^*$$

Sensitive to spin, but can we measure θ^*?

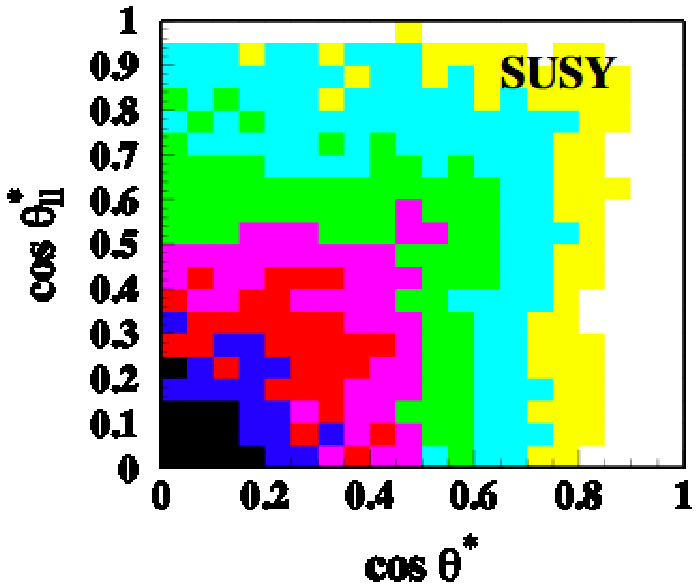
Define: $\cos\theta^*_{ll} \equiv \cos\left(2\tan^{-1}\exp(\Delta\eta_{\ell^+\ell^-}/2)\right) = \tanh(\Delta\eta_{\ell^+\ell^-}/2)$

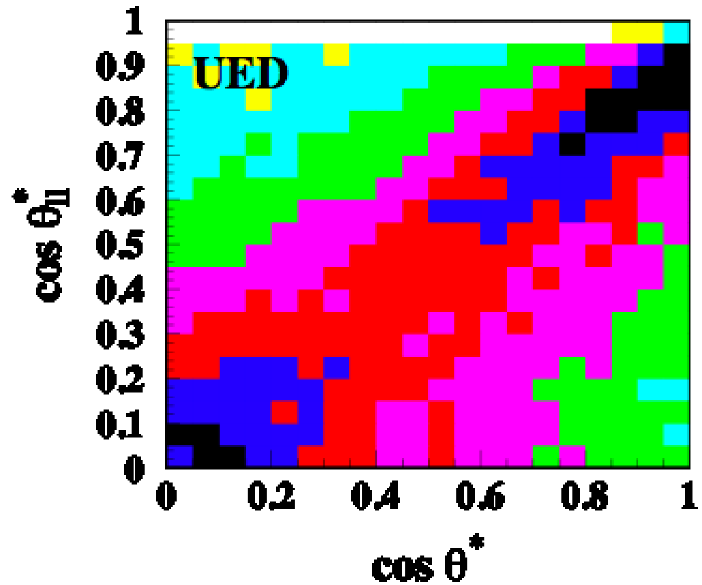
hep-ph/0511115 ATL-PHYS-PUB-2005-023

Have some access to desired angle

Distribution of $\cos\theta^*_{ll} \equiv \tanh(\Delta\eta_{\ell^+\ell^-}/2)$

is correlated with Z^0/γ decay angle θ^*



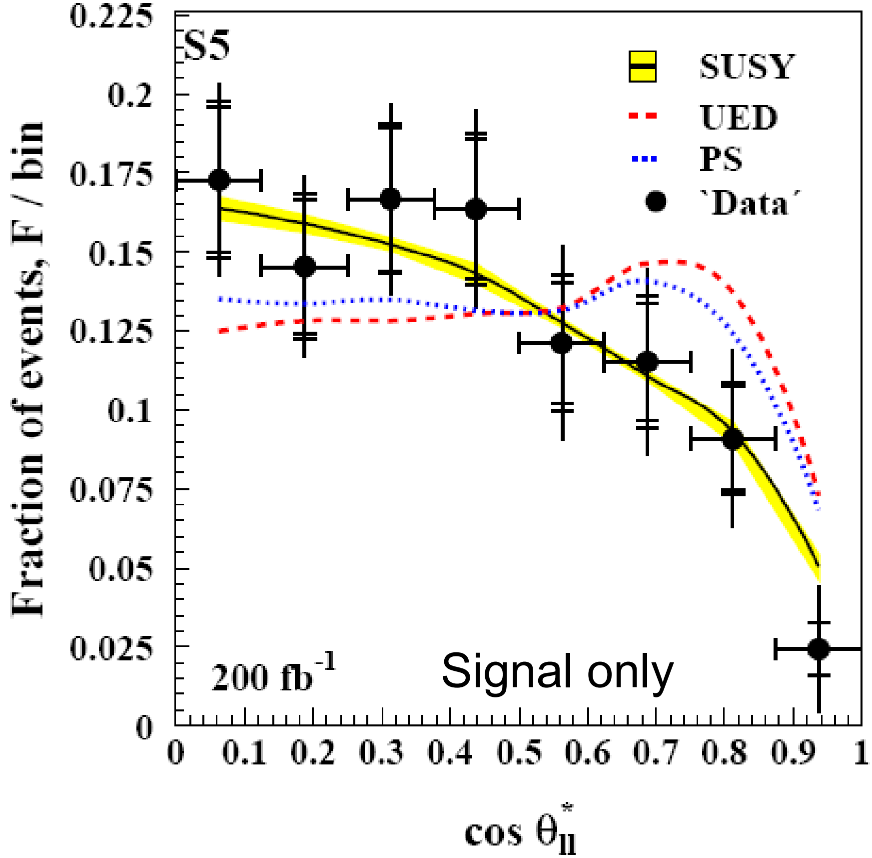


hep-ph/0511115 ATL-PHYS-PUB-2005-023

Direct slepton spin (A.Barr)

hep-ph/0511115

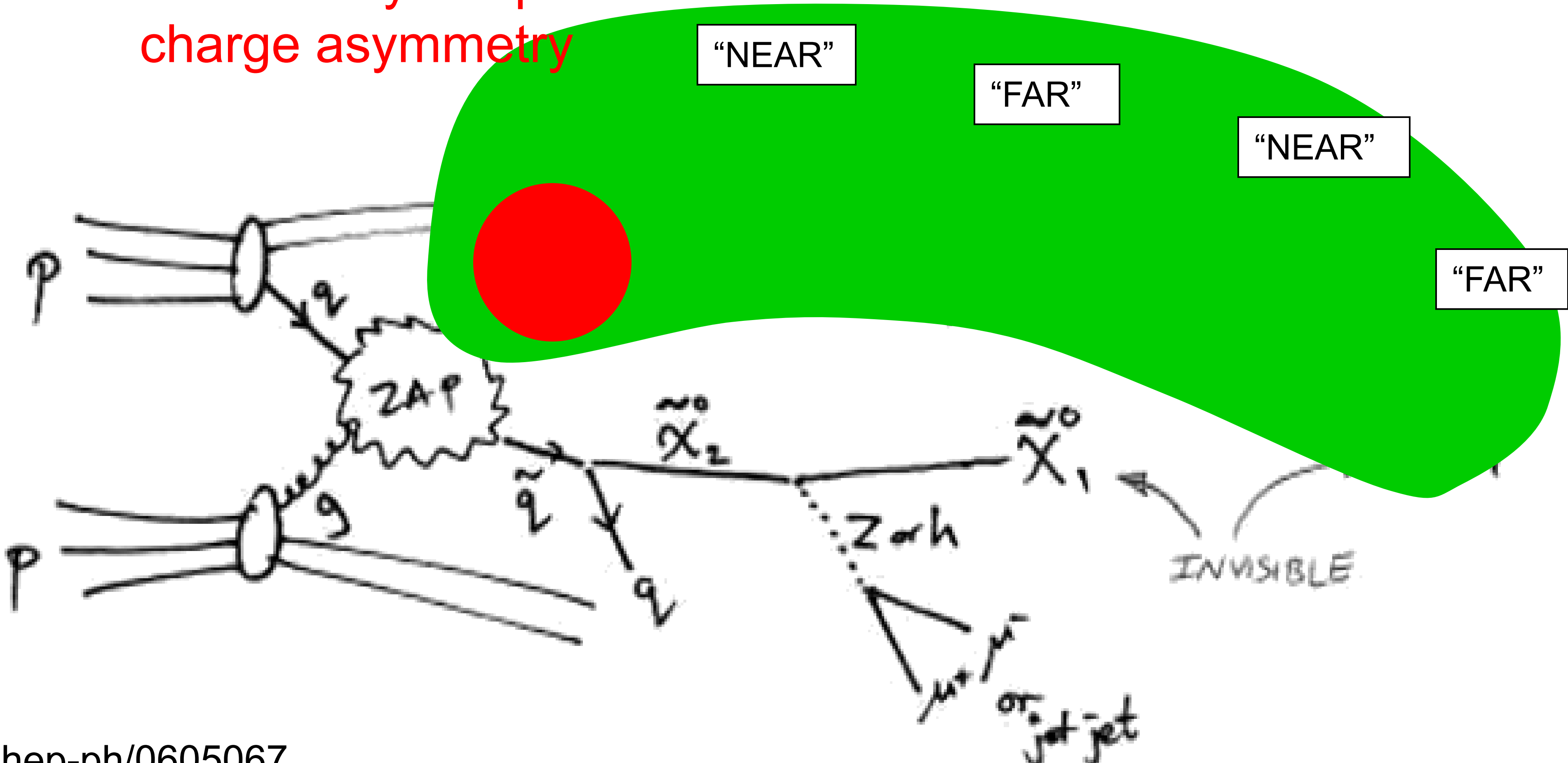
2 years high luminosity?



Different again

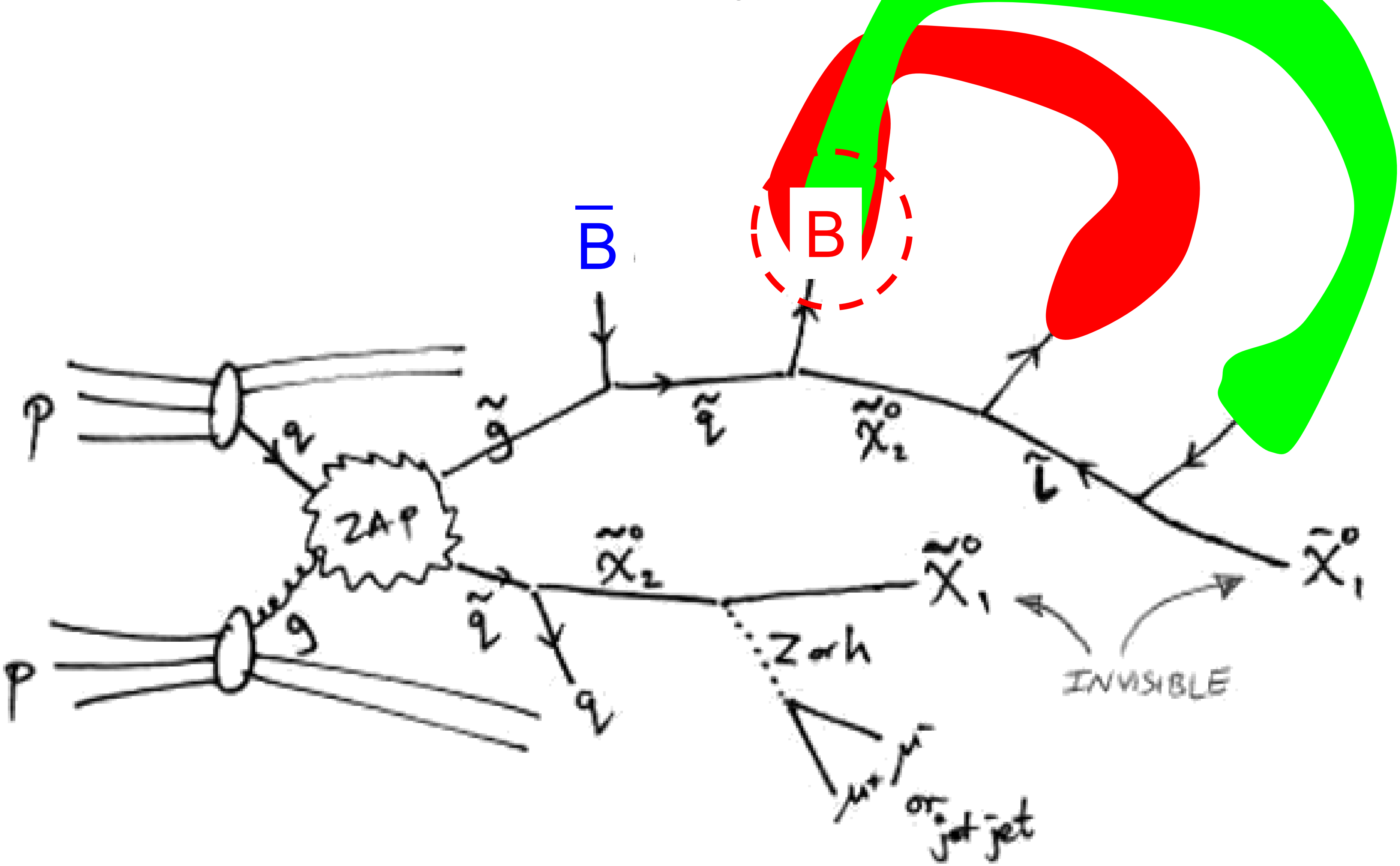
Spin Determination (T.Plehn et.al.)

- What if we want to investigate chain from gluino?
- Crucial to test gluino nature
- Cannot rely on quark charge asymmetry

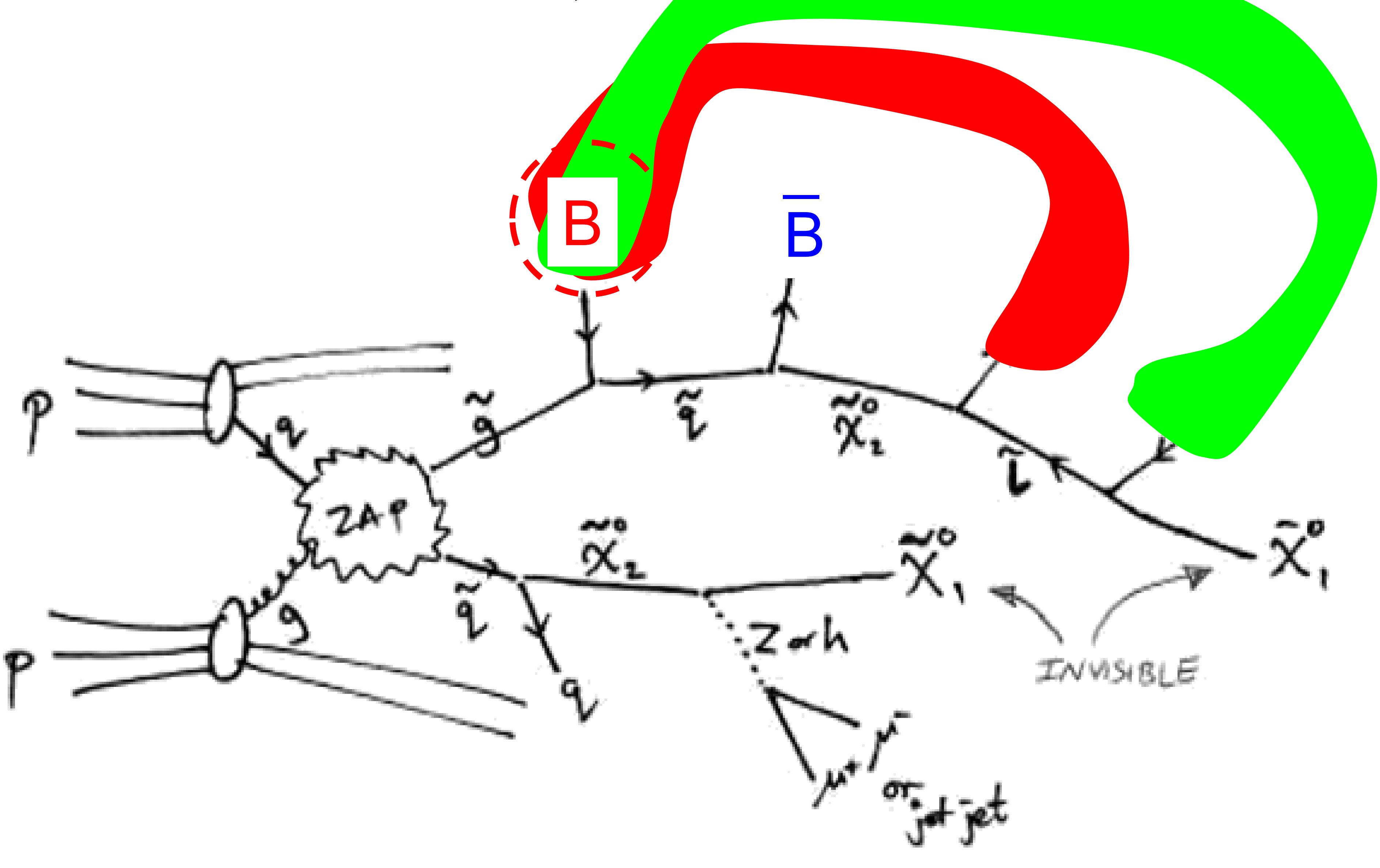


hep-ph/0605067

Instead, rely on

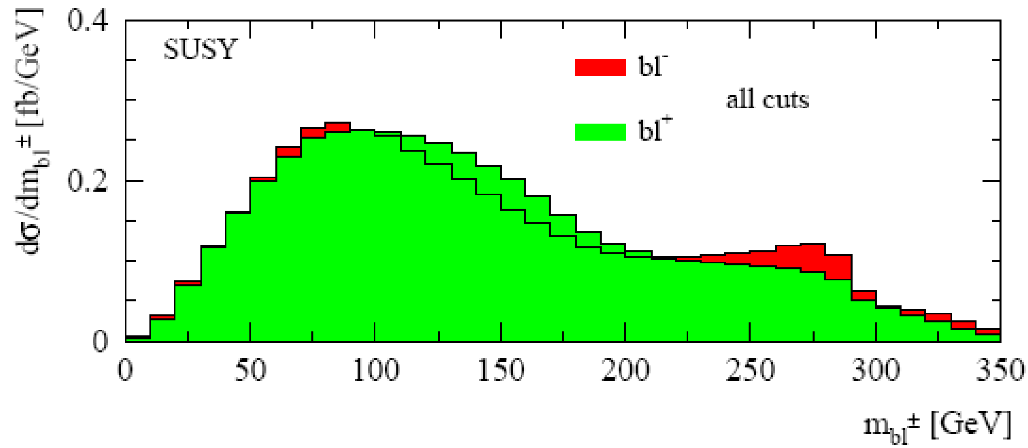


Instead, rel… g

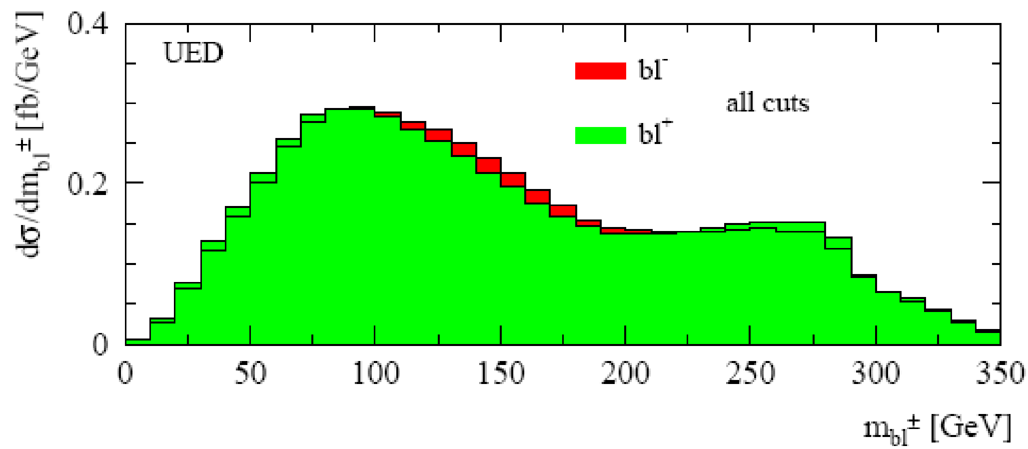


$M_{BL}+$ and $M_{BL}-$ distributions

SUSY



UED



Room for an asymmetry!

hep-ph/0605067

So define asymmetry

$$A^{\pm}(m_{b\ell}) = \frac{d\sigma/dm_{b\ell^+} - d\sigma/dm_{b\ell^-}}{d\sigma/dm_{b\ell^+} + d\sigma/dm_{b\ell^-}}$$

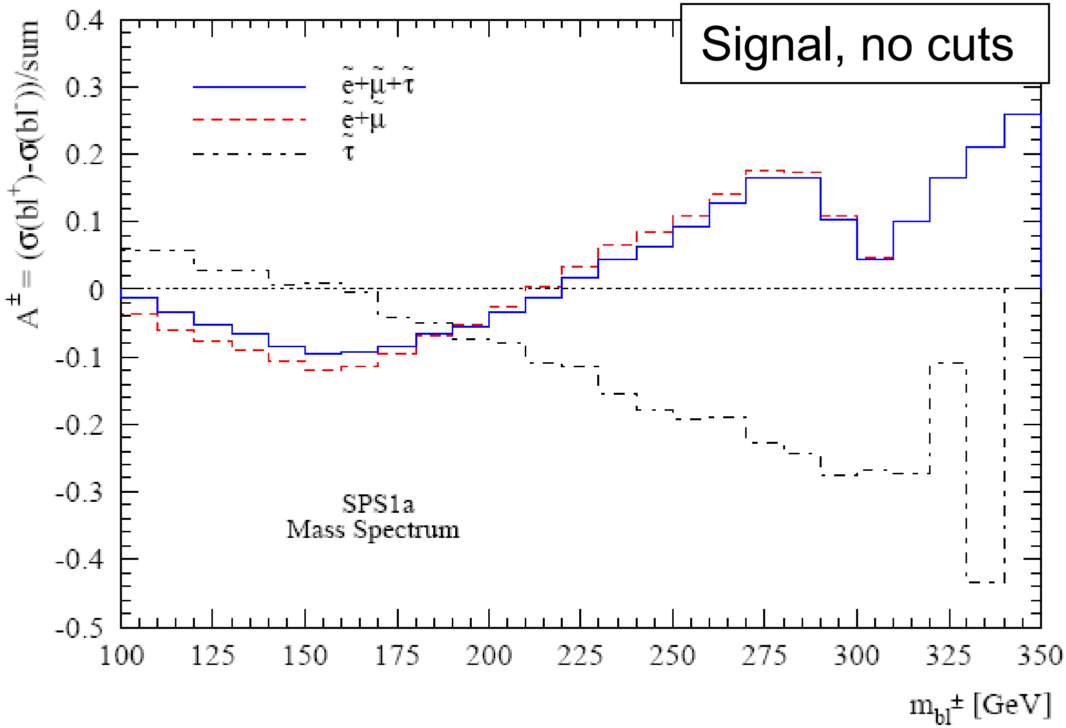
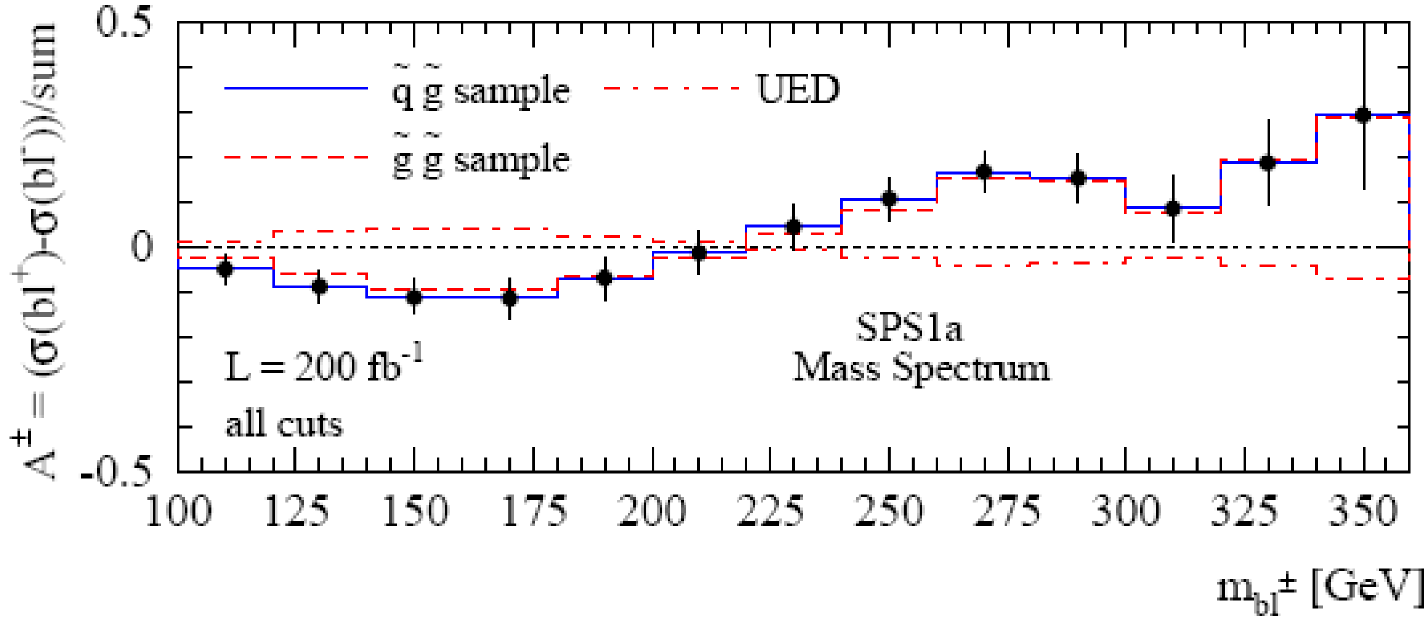


Figure 3: Bottom–lepton asymmetry for the SUSY signal only. The curves shown are for the first and second generation sleptons and for leptons coming from an intermediate $\tilde{\tau}$.

hep-ph/0605067

After realistic cuts, SPS1A, 200 fb^{-1}

Asymmetry still observable



Acceptance cuts:

$$p_{T,b} > 50 \text{ GeV} \qquad p_{T,\ell} > 10 \text{ GeV}$$
$$p_{T,j}^{\text{min}} > 40 \text{ GeV} \qquad p_{T,j}^{\text{max}} > 150 \text{ GeV}$$
$$|\eta_i| < 2.4 \qquad \Delta R_{ik} > 0.4 \qquad (i,k = b,j,\ell)$$

Cuts to reject Standard Model

$$m_{\ell\ell} < 80 \text{ GeV} \quad M_{\text{eff}} > 450 \text{ GeV} \quad m_{jj} < 300 \text{ GeV}$$

For a quantitative study we choose the (collider friendly) parameter point SPS1a. The masses in the gluino decay cascade are $m_{\tilde{g}} = 608$ GeV, $m_{\tilde{b}_1} = 517$ GeV, $m_{\tilde{b}_2} = 547$ GeV, $m_{\tilde{\chi}_2^0} = 181$ GeV, $m_{\tilde{\ell}_1} = 145$ GeV, $m_{\tilde{\ell}_2} = 202$ GeV, $m_{\tilde{\tau}_1} = 136$ GeV, $m_{\tilde{\tau}_2} = 208$ GeV, and $m_{\tilde{\chi}_1^0} = 97$ GeV. The NLO production cross sections are 7.96 pb for $\tilde{g}\tilde{g}$, 8.02 pb for $\tilde{q}\tilde{q}^*$, 26.6 pb for $\tilde{q}\tilde{g}$, and 7.51 pb for $\tilde{q}\tilde{q}$. For the SPS1a parameter choice the lighter of the

hep-ph/0605067

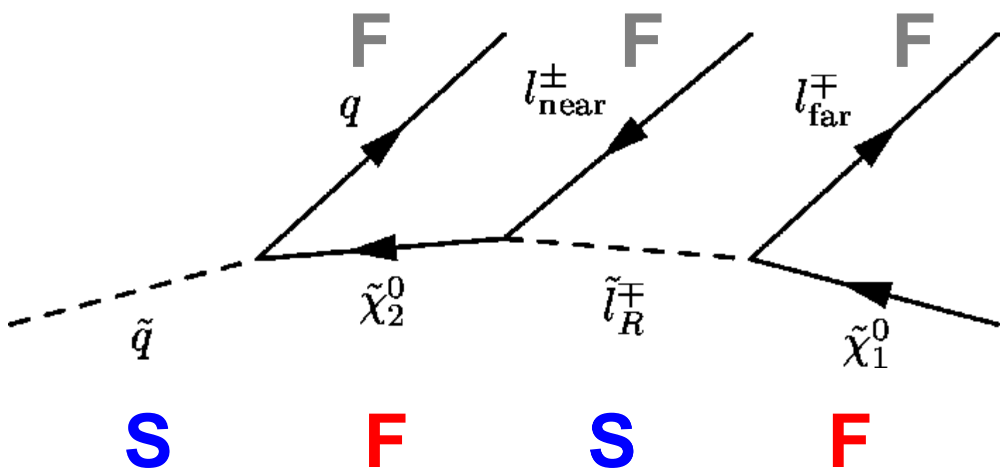
Back to long chains

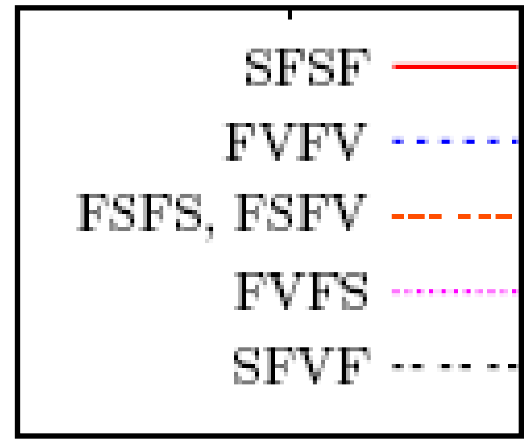
Spin sensitivity elsewhere in the llq chain (Smillie et.al.)
Later more general follow-up (Matchev, Kong, et al)

arXiv:0808.2472

hep-ph/06052286

$$\bar{\Psi}_F(g_L P_L + g_R P_R)\Psi_f \Phi + h.c.$$





Scalar	Fermion	Scalar	Fermion
Fermion	Vector	Fermion	Vector
Fermion	Scalar	Fermion	Scalar
Fermion	Vector	Fermion	Scalar
Fermion	Scalar	Fermion	Vector
Scalar	Fermion	Vector	Fermion

Cannot distinguish:

{FSFS, FSFV} and {FVFS, FVFV}

But masses matter

SPS1a mass spectrum: (GeV)

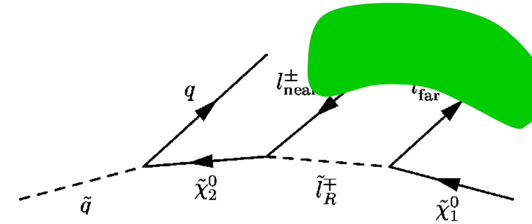
A	B	C	D
$\tilde{\chi}_1^0$	$\tilde{e}_R$	$\tilde{\chi}_2^0$	$\tilde{u}_L$
96	143	177	537

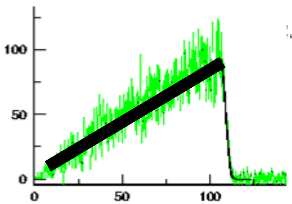
UED-type mass spectrum: (GeV)

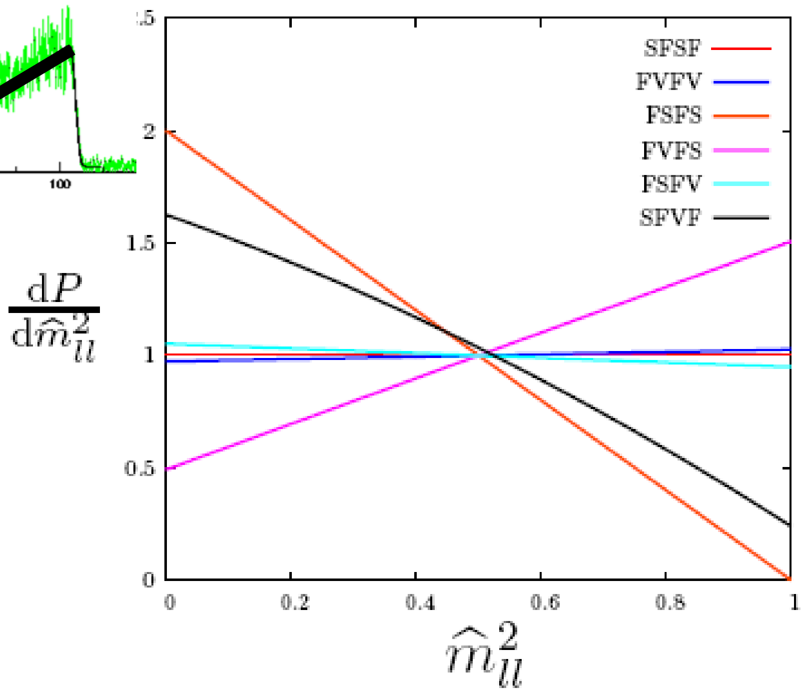
(R^{-1} ~ 800 GeV)

A	B	C	D
γ^*	l_L^*	Z^*	q_L^*
800	824	851	956

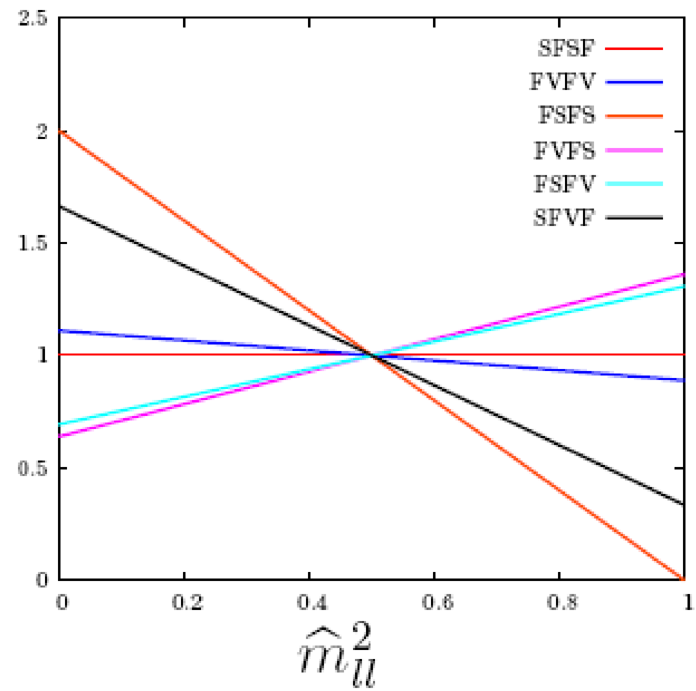
Maybe masses are not too important for m_{ll} distribution





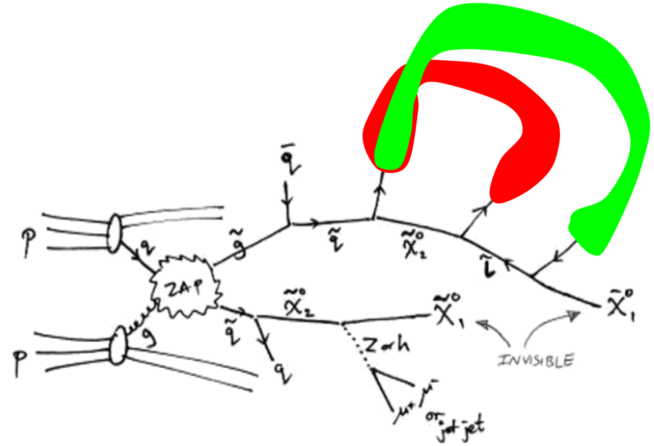


SPS1a masses



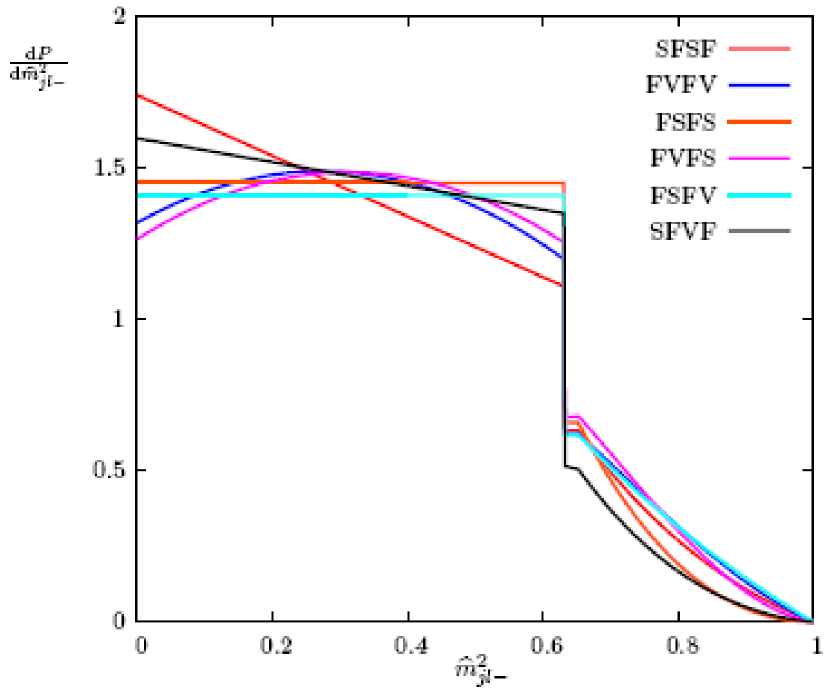
UED type masses

… but this fun ….

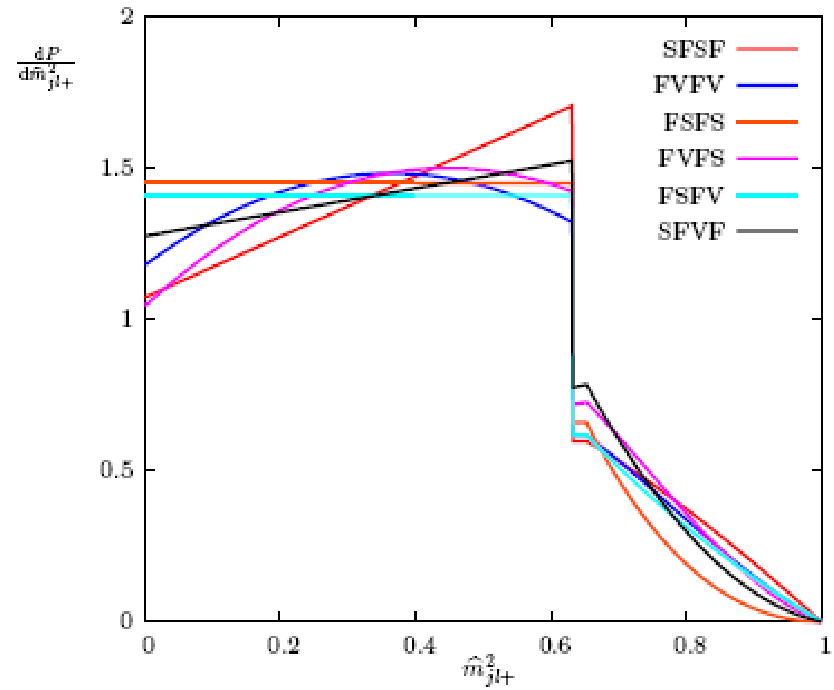


$\mathbf{jet} + l^{\pm}$

At SPS 1a:



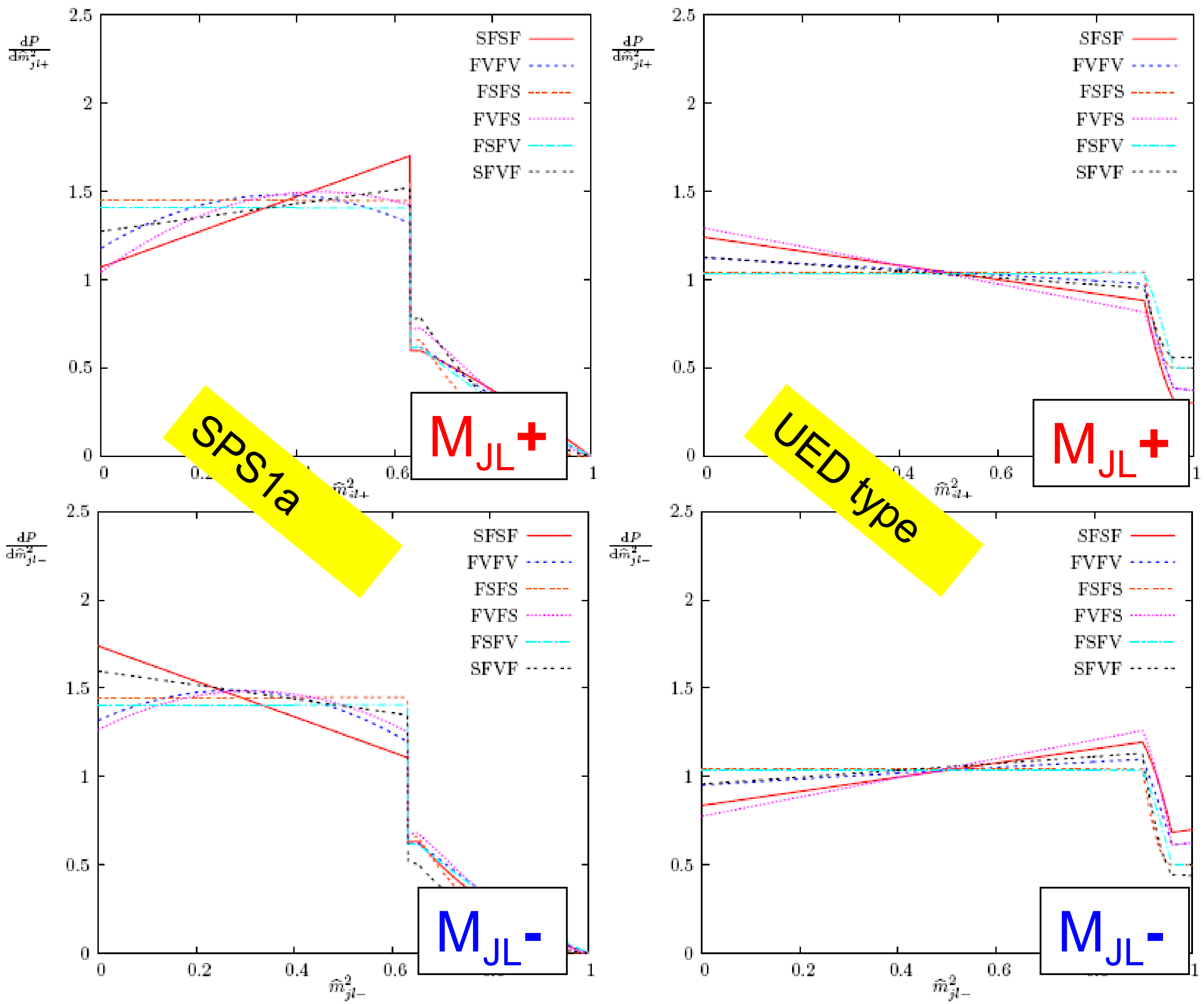
jet + ℓ^{-}



jet + ℓ^{+}

hep-ph/06052286

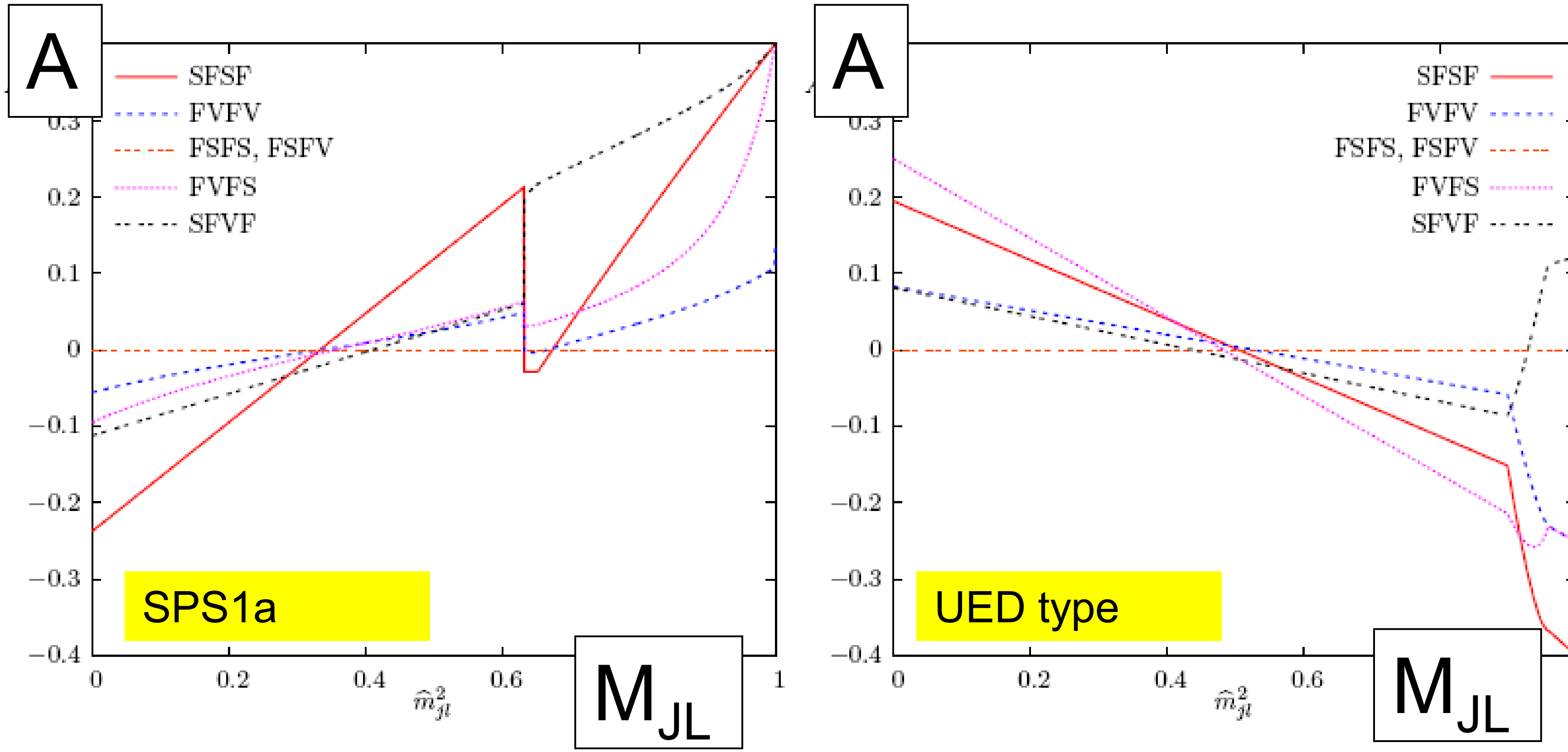
…. is spoiled. ☹

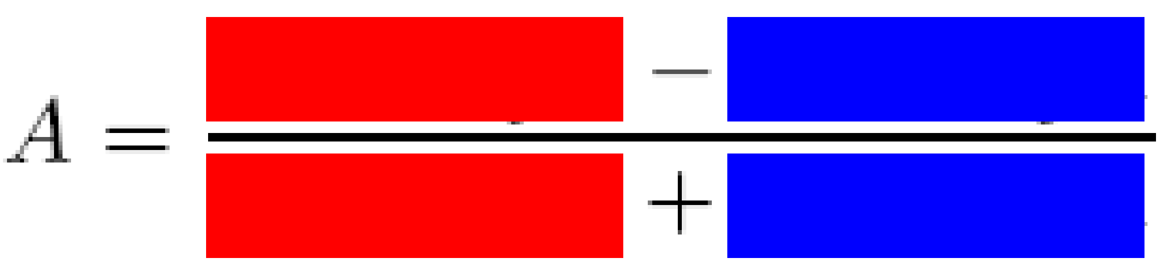


hep-ph/06052286

Example asymmetries:

(a big mix of spin and mass spectrum) ☹





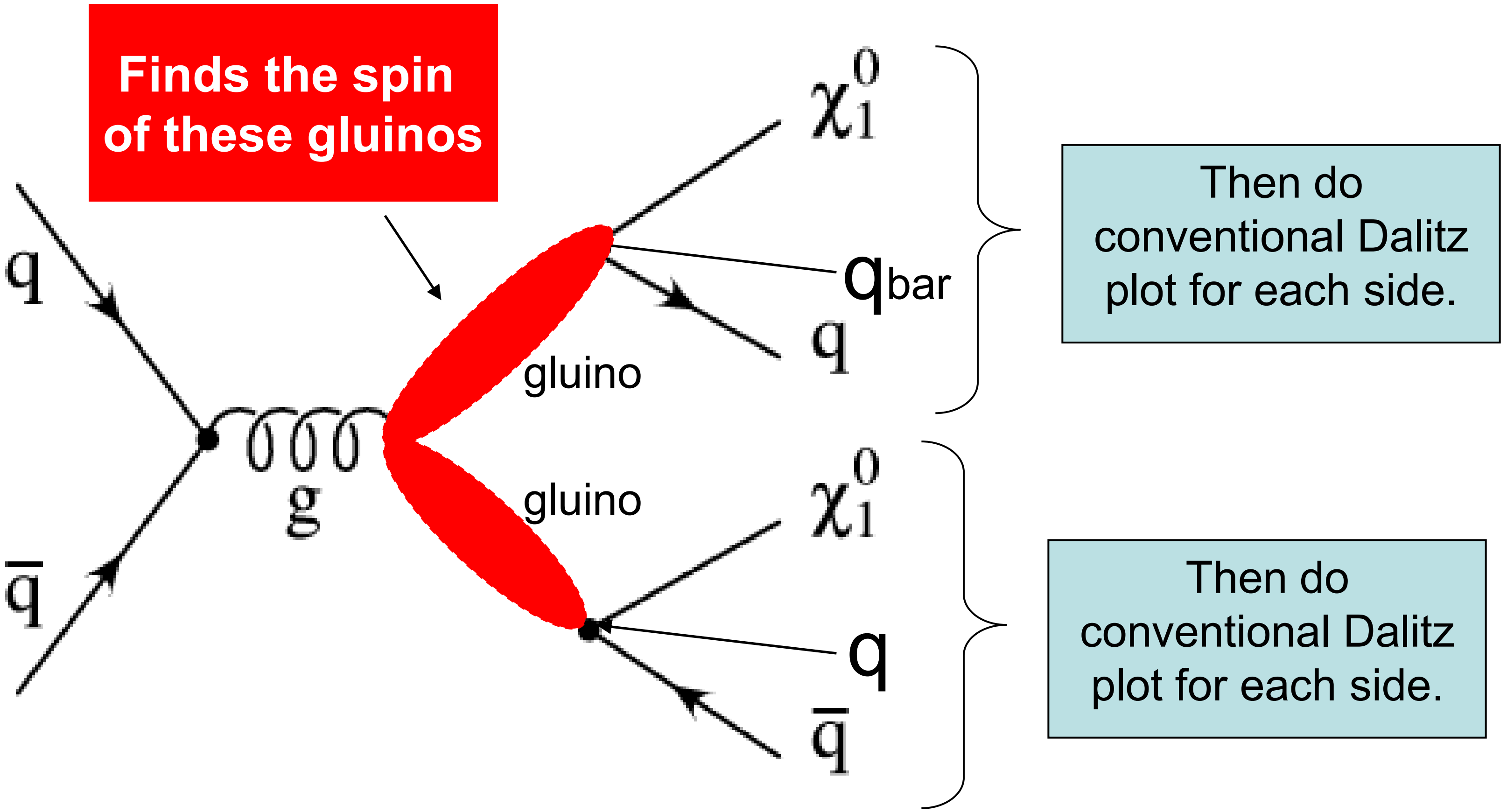
hep-ph/06052286

Yet another game one can play

M_{T2}-assisted (MAOS) spin determination

$$pp \to Y(1) + \bar{Y}(2) \to V(p_1)\chi(k_1) + V(p_2)\chi(k_2), \quad Y \to q(p_q)\bar{q}(p_{\bar{q}})\chi(k);$$

Use splitting for which leads to MT2 solution to assign 4-momenta to invisible particles:

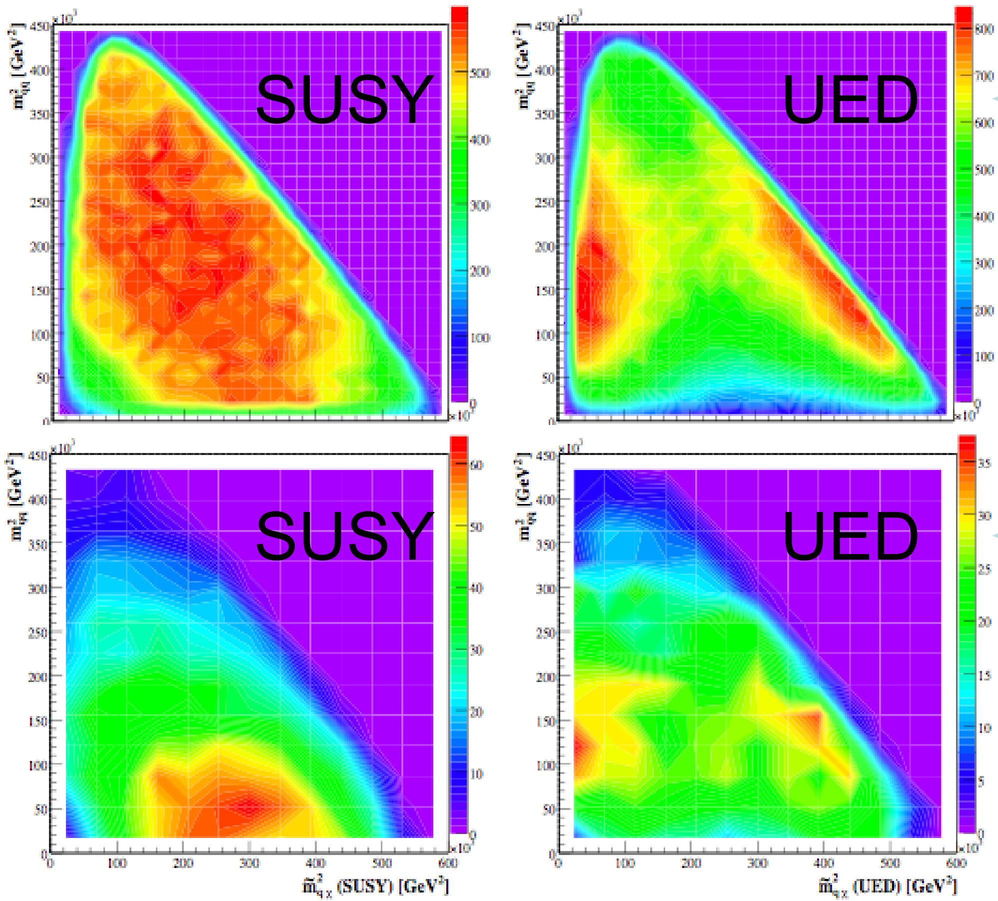


Cho, Choi, Kim, Park, 0810.4853

M_{T2}-assisted (MAOS) spin determination

$$pp \to Y(1) + \bar{Y}(2) \to V(p_1)\chi(k_1) + V(p_2)\chi(k_2), \quad Y \to q(p_q)\bar{q}(p_{\bar{q}})\chi(k);$$

$$M_{T2}(p_i, m_\chi) \equiv \min_{\mathbf{k}_{1T}+\mathbf{k}_{2T}=\mathbf{p}_T^{\text{miss}}} \left[\max\{M_T^{(1)}, M_T^{(2)}\}\right]$$ → assign 4-momenta



← $m_{\chi,Y} = m_{\chi,Y}^{\text{true}}$

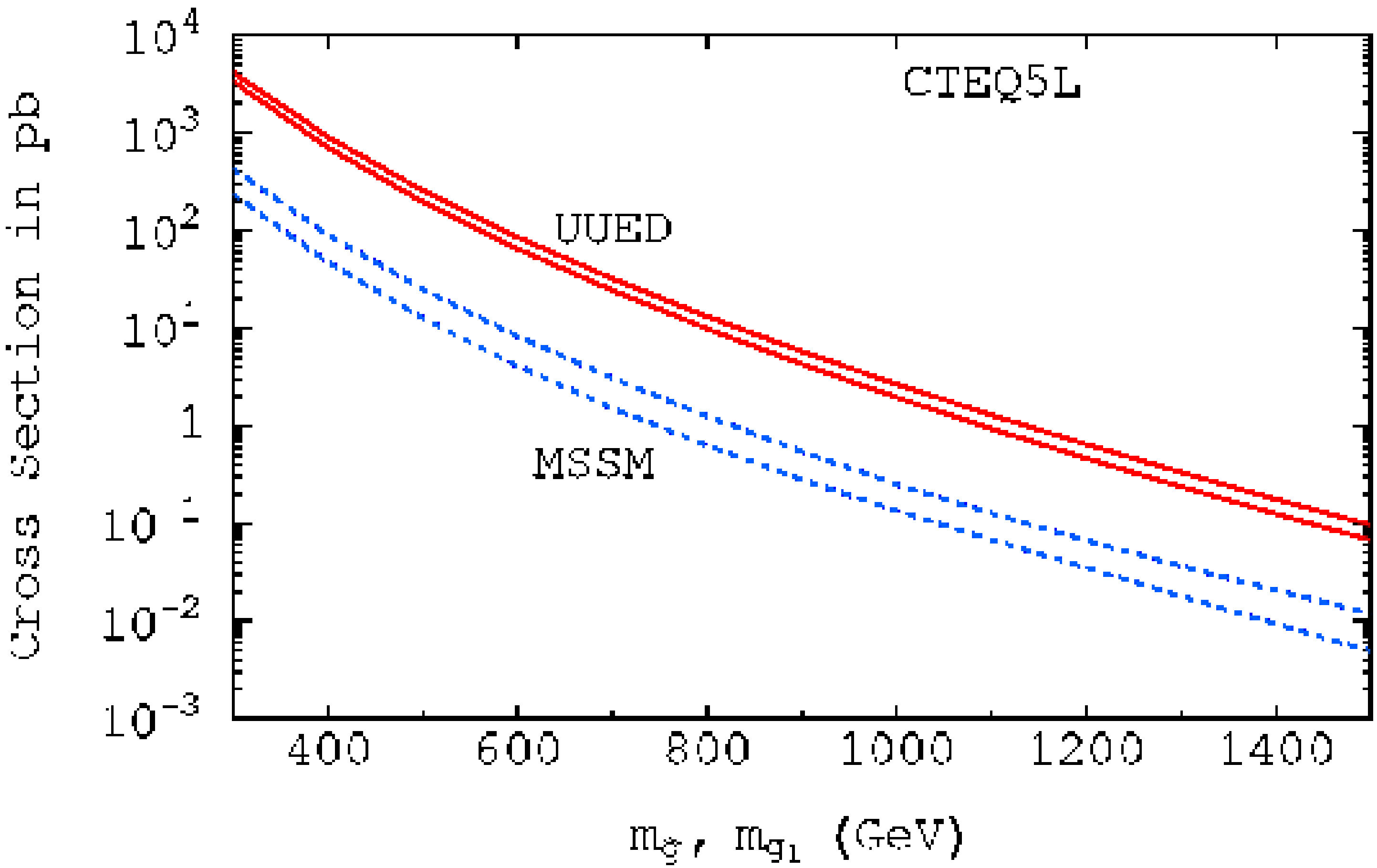
$\mathcal{L} = \infty$

← $m_\chi = 0,\ m_Y = M_{T2}^{\max}(m_\chi = 0)$

$\mathcal{L} = 300\,\text{fb}^{-1}$

Cho, Choi,Kim,Park, 0810.4853

Reminder: cross sections reveal spins



⇨ Higher spins mean higher cross sections (for given masses)

Datta, Kane, Toharia hep-ph/0510204

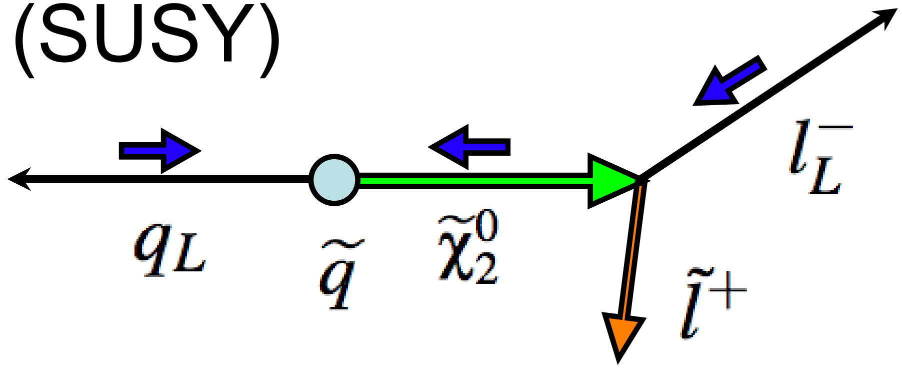
End Notes

- QLL chain
  - Some spin “sensitivity” – but no strong UED/SUSY separation
  - Reduced discriminatory power when considering general couplings (Matchev/Kong).
- Di-slepton production
  - Better chance of separating UED/SUSY
  - Still model dependent
- Both require large cross sections
- Masses inextricably intertwined.

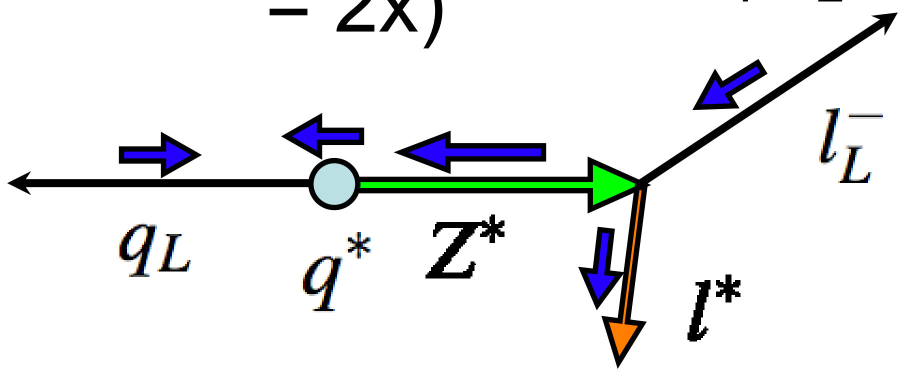
Backup slides

Helicity dependence

- Process 1 (SUSY)



- Process 1 (UED, transverse Z*: P_T/P_L = 2x)



⇨ Both prefer high $(ql^-)^{near}$ invariant mass