Non-Susy BSM – Summary

A broad spectrum of ideas.....

- Universal Extra Dimensions
- Little Higgs Models
- Black Holes (in 'finite length' models)
- ADD extra dimensions
- Radions in RS + ADD
- Z′ ⊕ TeV^{-1} KK
- Heavy Neutral Leptons : Dirac vs Majorana
- NC QED $\quad [\hat{x}_\mu, \hat{x}_\nu] = i\theta_{\mu\nu}\,(\underline{x})$

⇛ Can't cover everything in a short time...

⇛ Apologies to contributors for any misrepresentations or brevity of presentation

T. Rizzo
6/6/03

- Black Holes in 'finite length' models... DeRoeck, Rizzo

$$\Delta x \, \Delta p \gtrsim \hbar \left[1 + \left(\alpha' \, l_{Pl} \, \frac{\Delta p}{\hbar} \right)^2 \right]$$

Some NC/String theories

O(1) parameter

planck length

O(1)

so: $r_{schw.} \gtrsim \alpha \, l_{pl} \rightarrow \boxed{M_{BH} \gtrsim f(\delta) \, M_*}$

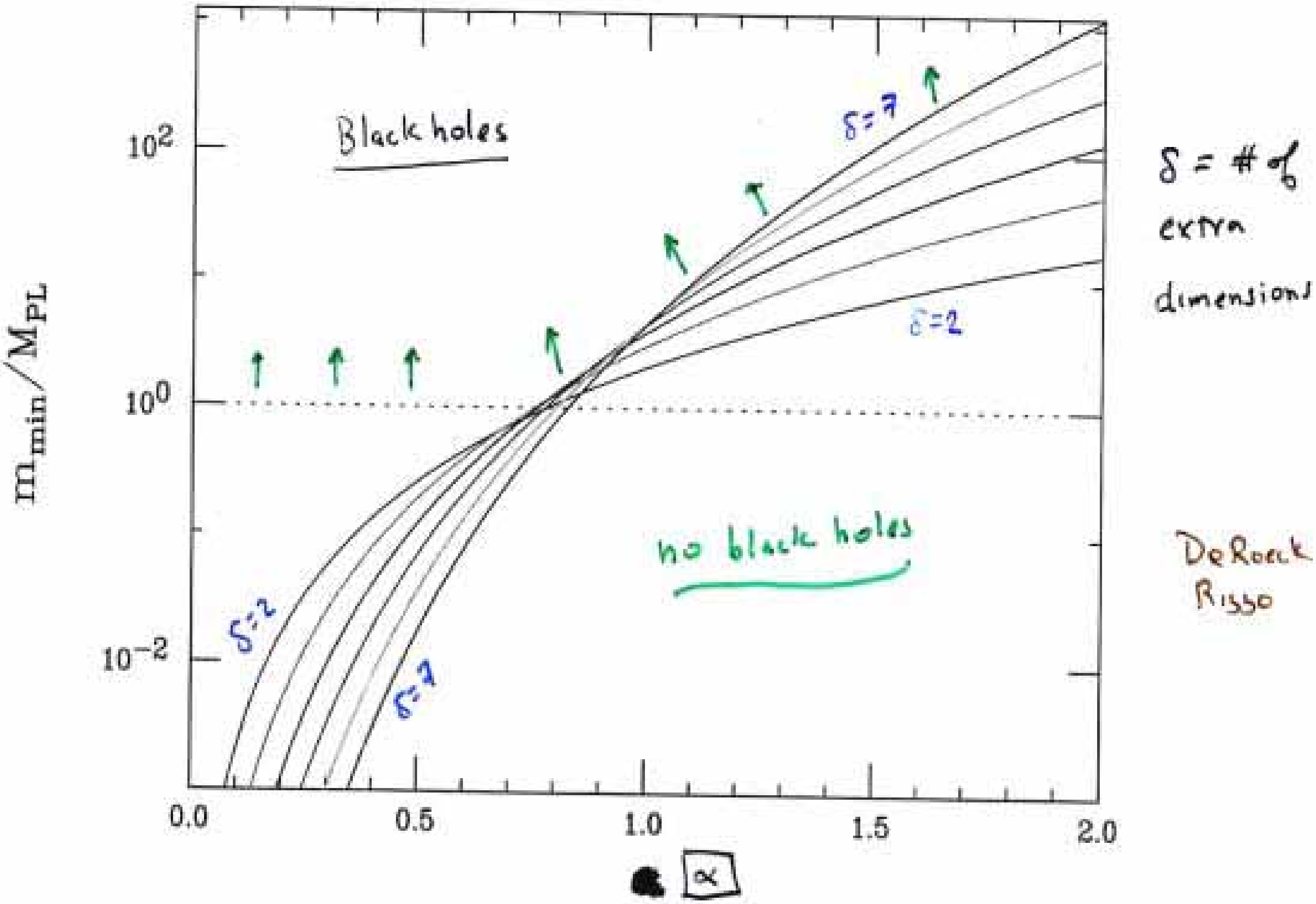
$\boxed{\text{Will LHC see them ?}}$

- Statistics ?
- "Decay" signature ....

$\Rightarrow \alpha \uparrow \quad E_{miss} \uparrow \quad N_{mult} \downarrow$ (Simulation)

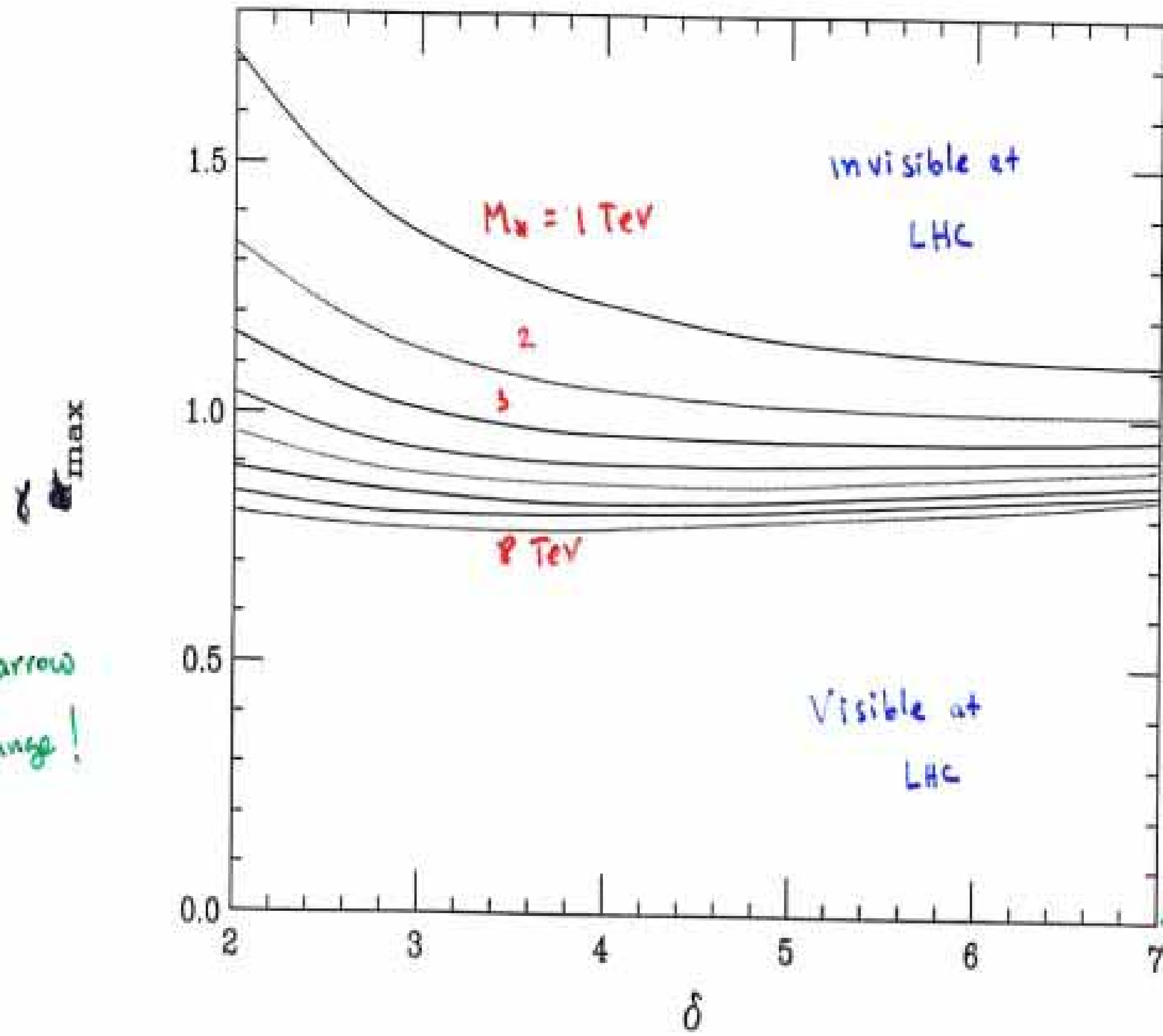
— work in progress...

minimum BH mass in finite-length model



O(1) length parameter

(Upper) Bound on α parameter from LHC visibility (100 BH's in 300 fb^{-1})



DeRoeck Rizzo

Narrow Range!

"Usual" BH models

# of extra dimensions

- Universal Extra Dim's : $R^{-1} \sim 1$ TeV

SM in bulk

KK spectrum mimics SUSY ... (sometimes)

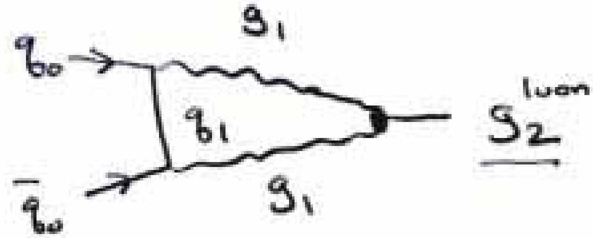
? Distinguish ?

* Measure their spin : SUSY / KK differ by ½ħ !!

* See More KK's ...

$\bar{f}_0 f_0 \to GB_2$ via a loop only (KK-parity)

e.g.,



resonance

How large are the couplings ? [Rizzo]

Can you see them ? [Comphep - Battaglia]

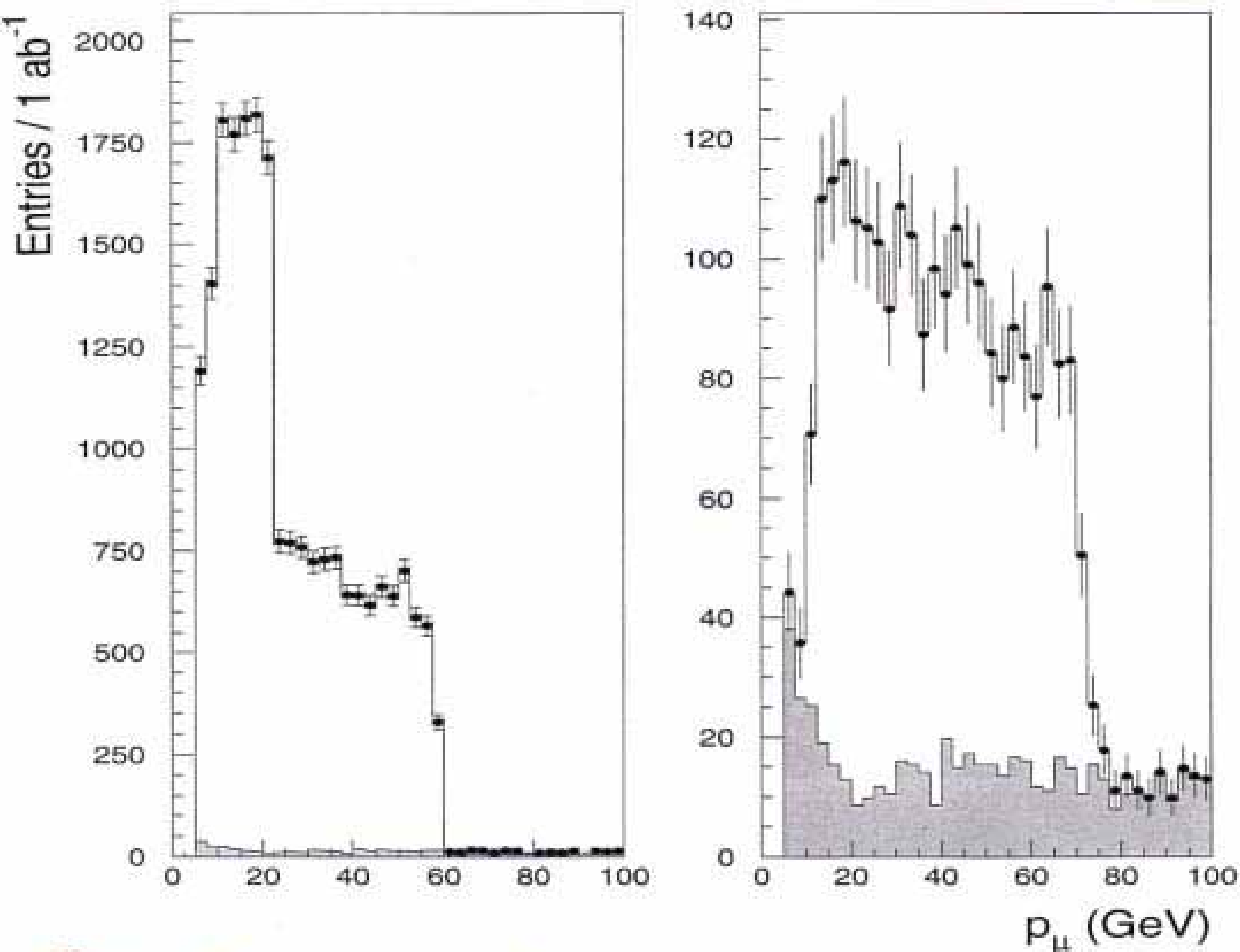
→ Battaglia, Tovey, De Roeck, TGR,

→ Hewett, Guasch, Polesello ....

CLIC $\sqrt{s} = 3$ TeV

$e^+e^- \to$ "$\tilde{\mu}\tilde{\mu}$" $\to \mu^+\mu^- + \not{E}$ (large)
(χ^0_1's or γ_1)

UED SUSY

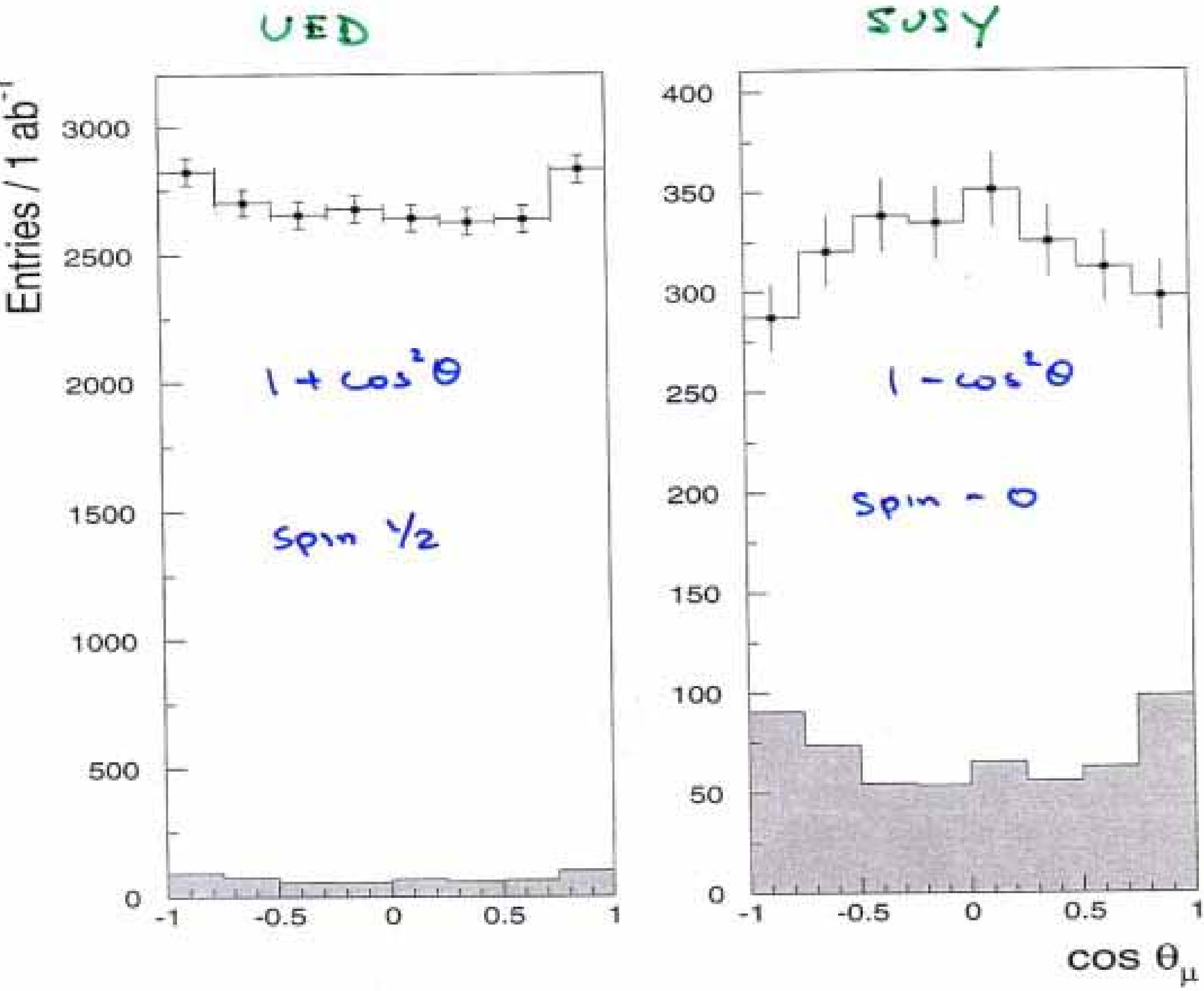


Battaglia
Matchev

"$\tilde{\mu}^\pm$" $= \begin{cases} \text{smuon} \\ \text{or } \tilde{\mu}^\pm_1 \text{ KK} \end{cases}$

M. Battaglia
K. Matchev

reconstruct primary
μ distribution



Distinguishing Universal Extra-Dim from SUSY

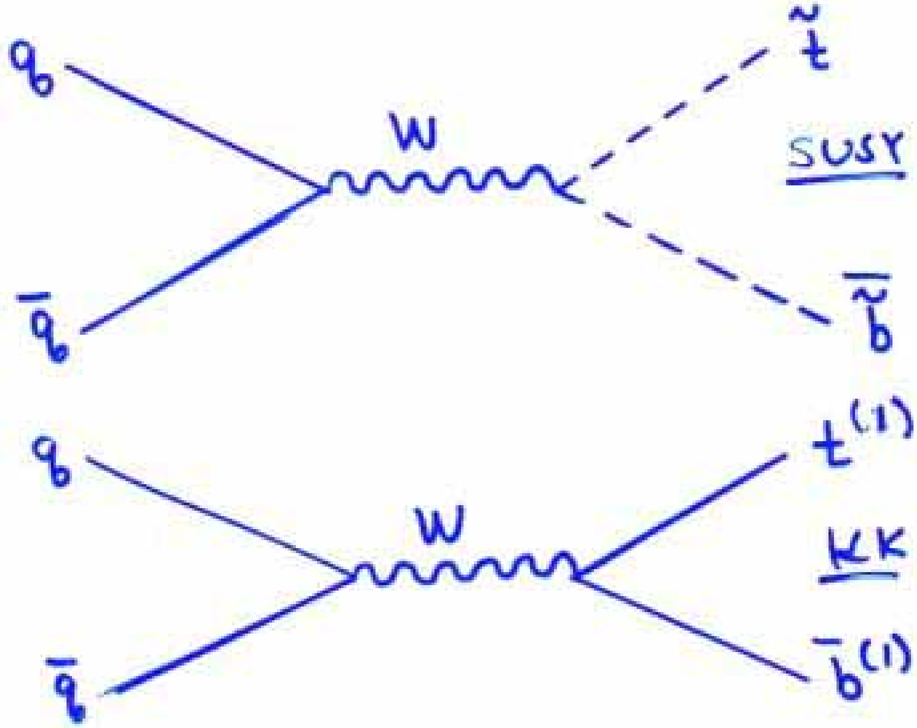
- Final state angular distributions reveal S-wave vs. P-wave production

P-wave

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

S-wave

$t^{(1)}\bar{b}^{(1)} \to b W^{(1)} \bar{b} \gamma^{(1)}$



Lots of b's in final state ⇒ isolate EW production

Analytical x-section computed

Numerics underway....

Hewett, Rizzo, Tait

Zero mode couplings to n=2 KK gauges

- $\underline{\bar{\Psi}_0 \Psi_0 A_2}$

$$-\frac{ig}{\sqrt{2}} \gamma_\mu T^a P_\pm \left[\frac{\bar{\delta}(m_{A_2}^2)}{m_2^2} - 2 \frac{\bar{\delta}(m_{f_2})}{m_2} \right]$$

... thanks to $\left\{ \begin{array}{l} \text{Cheng, Matchev +} \\ \text{Schmaltz} \end{array} \right\}$

$\bar{q}_0 q_0 g_2$:

$$-i g_s T_a \gamma_\mu \underbrace{\left[\frac{11 \alpha_s}{4\sqrt{2}\pi} \ln(\Lambda R) \right]}_{\simeq 0.185 \left(\frac{\alpha_s}{0.1}\right) \frac{\ln(\Lambda R)}{\ln(20)}}$$

$\left. \begin{array}{l} \bar{u}_0 d_0 \\ \bar{\nu}_0 l_0 \end{array} \right\} W_2^\pm$:

$$-\frac{ig}{2\sqrt{2}} \gamma_\mu (1-\gamma_5) \left[\frac{33 G_F m_W^2}{8\sqrt{2}\pi^2} \ln(\Lambda R) \right]$$

$$\simeq 0.0668 \ \ln(\Lambda R)/\ln(20)$$

$\left. \begin{array}{l} \bar{u}_0 u_0 \\ \bar{d}_0 d_0 \\ \bar{\nu}_0 \nu_0 \\ \bar{e}_0 e_0 \end{array} \right\} W_2^0$:

$$-i g \gamma_\mu (1-\gamma_5) T_{3L} \left[\frac{33 G_F m_W^2}{64\pi^2} \ln(\Lambda R) \right]$$

$$\simeq 0.0118 \ \ln(\Lambda R)/\ln(20)$$

Lastly, ...

$\bar{f}_0 f_0 B_2^0$:

$$-i g' Y \gamma_\mu (1 \pm \gamma_5) \left[\frac{G_F M_W^2}{8\pi^2} \ln(\Lambda R) \frac{\sin^2\theta_W}{\cos^2\theta_W} \right] \underline{X}$$

	$\underline{X}$ =
$\begin{pmatrix} u \\ d \end{pmatrix}_L$	$-7/12$
u_R	$-13/3$
d_R	$-4/3$
$\begin{pmatrix} \nu \\ \ell \end{pmatrix}_L$	$-31/4$
e_R	$-28/3$

$$[\ \ ] = 8.55 \cdot 10^{-4} \ \frac{\ln(\Lambda R)}{\ln(20)}$$

Missing : $g_0 \, g_0 \, g_2$ coupling

to calculate g_2 production [Guasch]

ADD Extra Dimensions :

- if true, how many dims + M_* $(M_D) = ?$

$\rightarrow$ Use shape of $j\not{E}_T$ data in $\eta / \not{E}_T$ to extract (δ, M_D) ...

Backgrounds !!

- $\Rightarrow$ get bound on $M_H \sim M_*$ from e^+e^-

Transverse polarization asymmetry (2 beams polarized)

$e^+e^- \rightarrow f\bar{f}$ / $\underbrace{\gamma\gamma / ZZ / WW}$ / $\underbrace{e^+e^-, e^-e^- \rightarrow e^-e^-}$

$f\bar{f}$: very large reach $(\sim 20\sqrt{s})$

$\gamma\gamma / ZZ / WW$: partly analysed $(\sim 6\sqrt{s})$

$e^+e^-, e^-e^- \rightarrow e^-e^-$: studied here first (TGR)

The signal is the little guy on top...

Vacavant + Hinchliffe

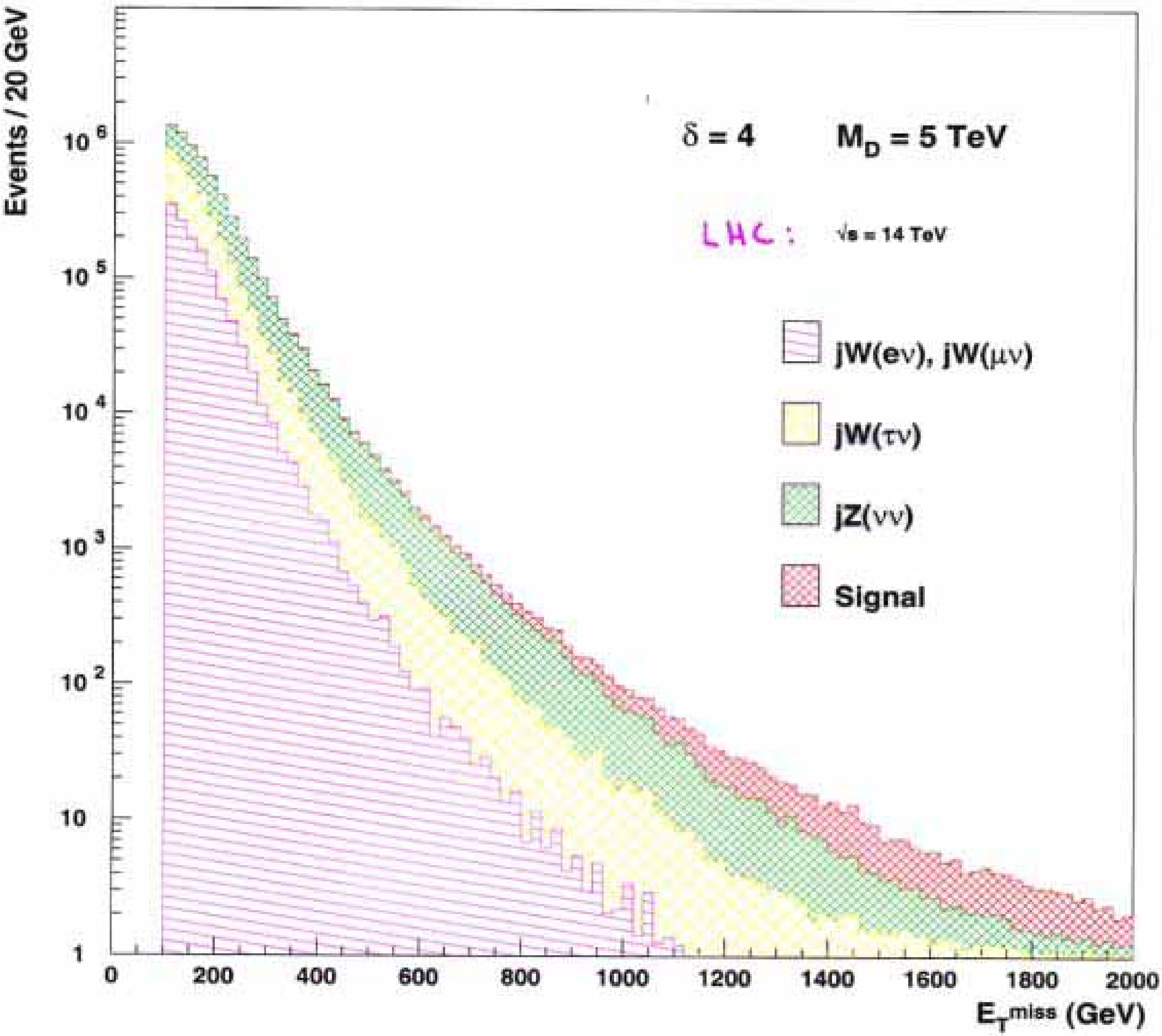


Figure 1: Missing energy spectrum at the LHC.

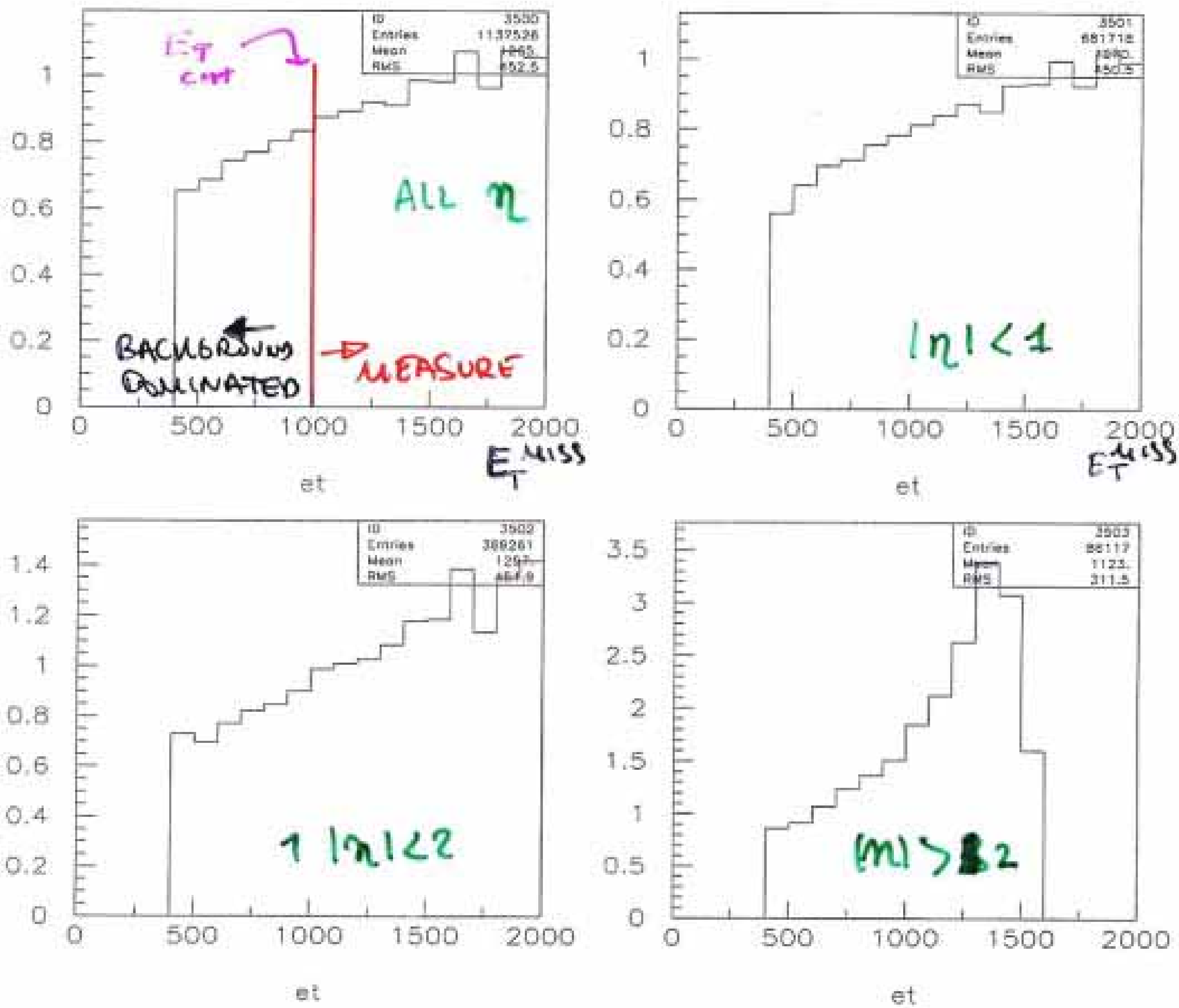
DeRoeck
Spiropulu
TCR

EXAMPLE

Consider

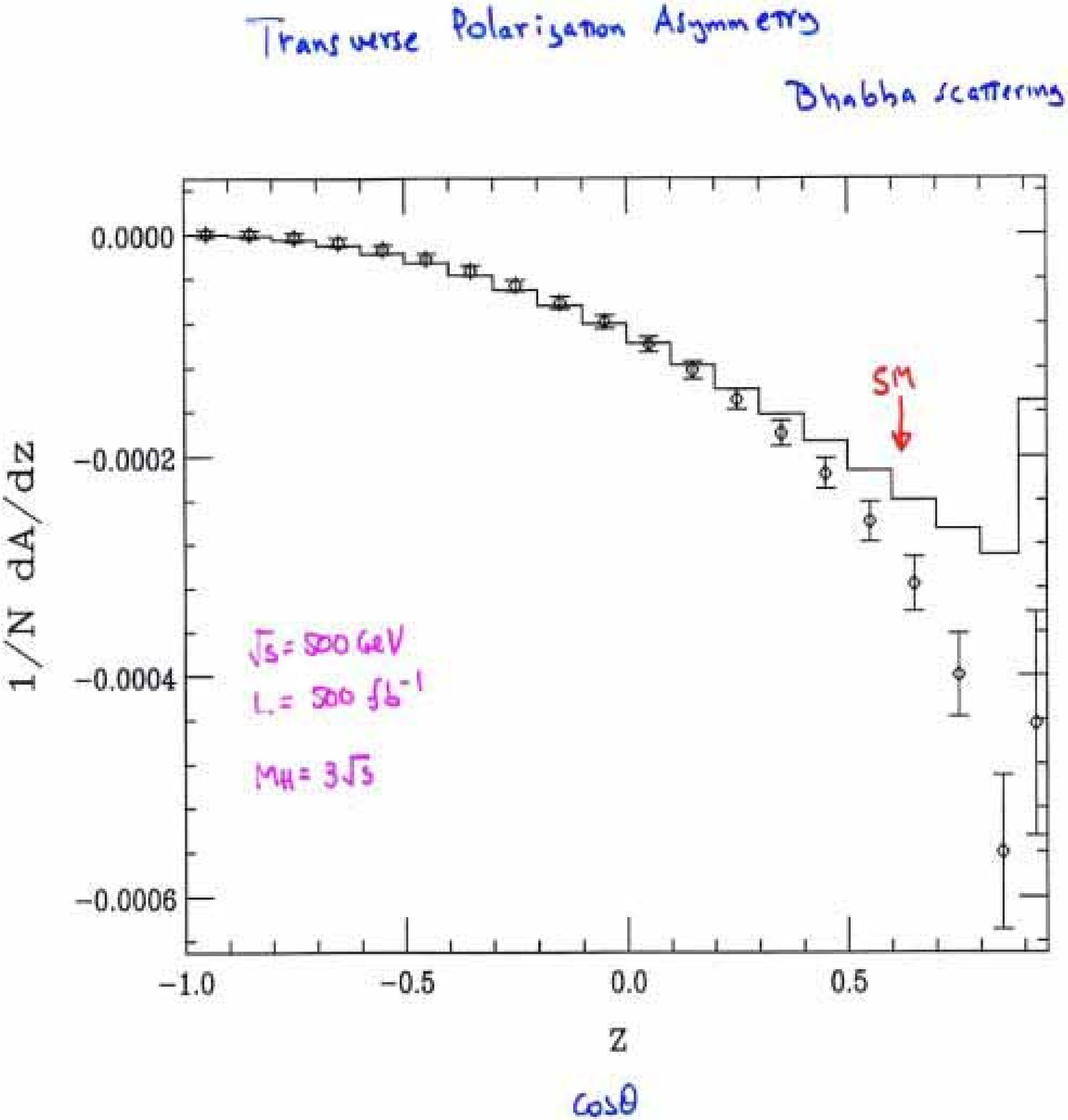
$$R = \frac{\sigma(\delta=3, M_D=4\,\mathrm{TeV})}{\sigma(\delta=5, M_D=3.7\,\mathrm{TeV})} \quad \text{FOR } E_T^{MISS}$$

R



DeRoeck

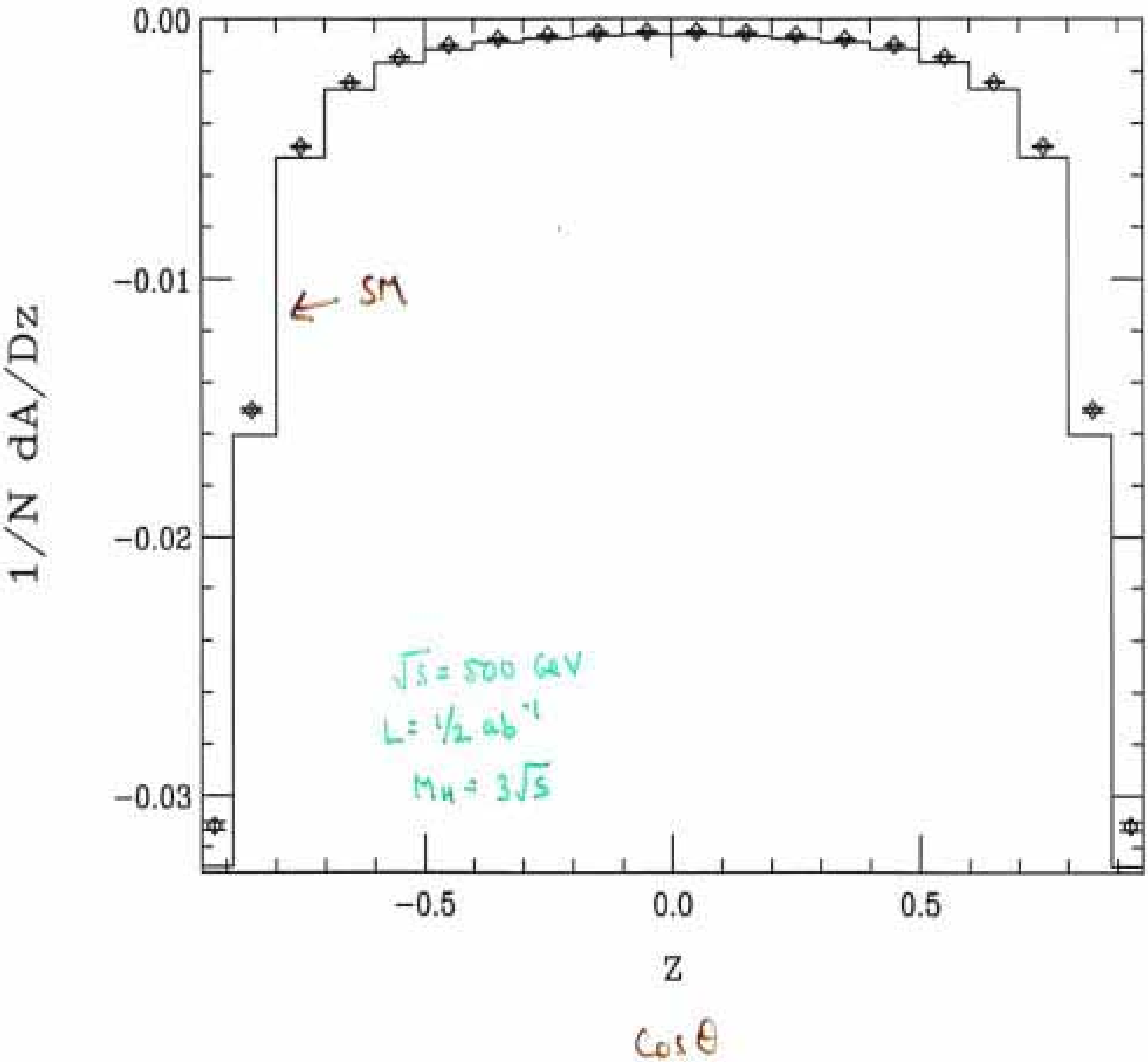
Central + forward spectra differ... more work needed to get (δ, M_*)



Transverse Polarization Asymmetry
Bhabha scattering
SM
$\sqrt{s} = 500$ GeV
$L = 500$ fb^{-1}
$M_H = 3\sqrt{s}$
1/N dA/dz
0.0000
−0.0002
−0.0004
−0.0006
−1.0
−0.5
0.0
0.5
z
cosθ

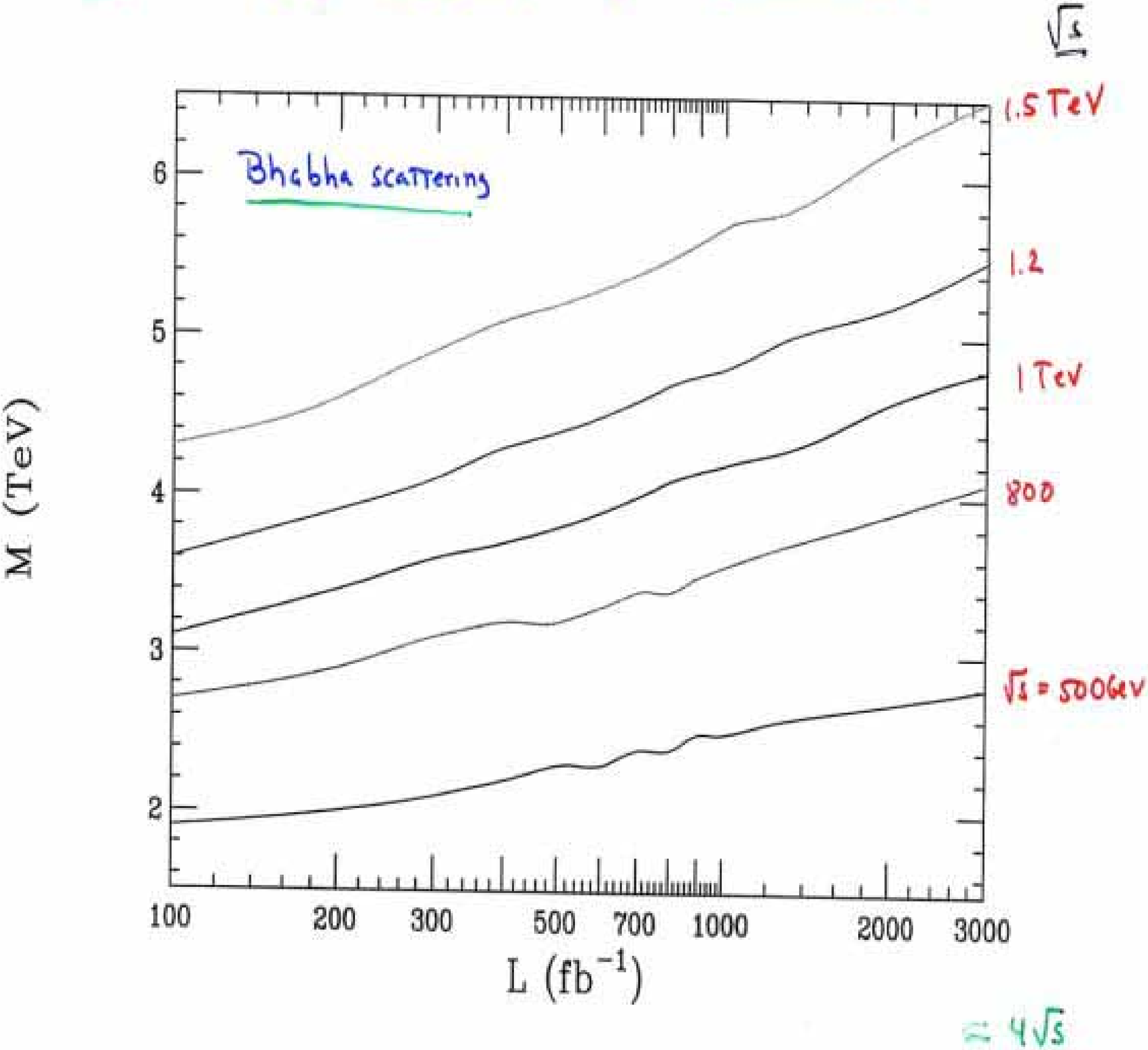
Transverse Polarization Asymmetry

Møller scattering

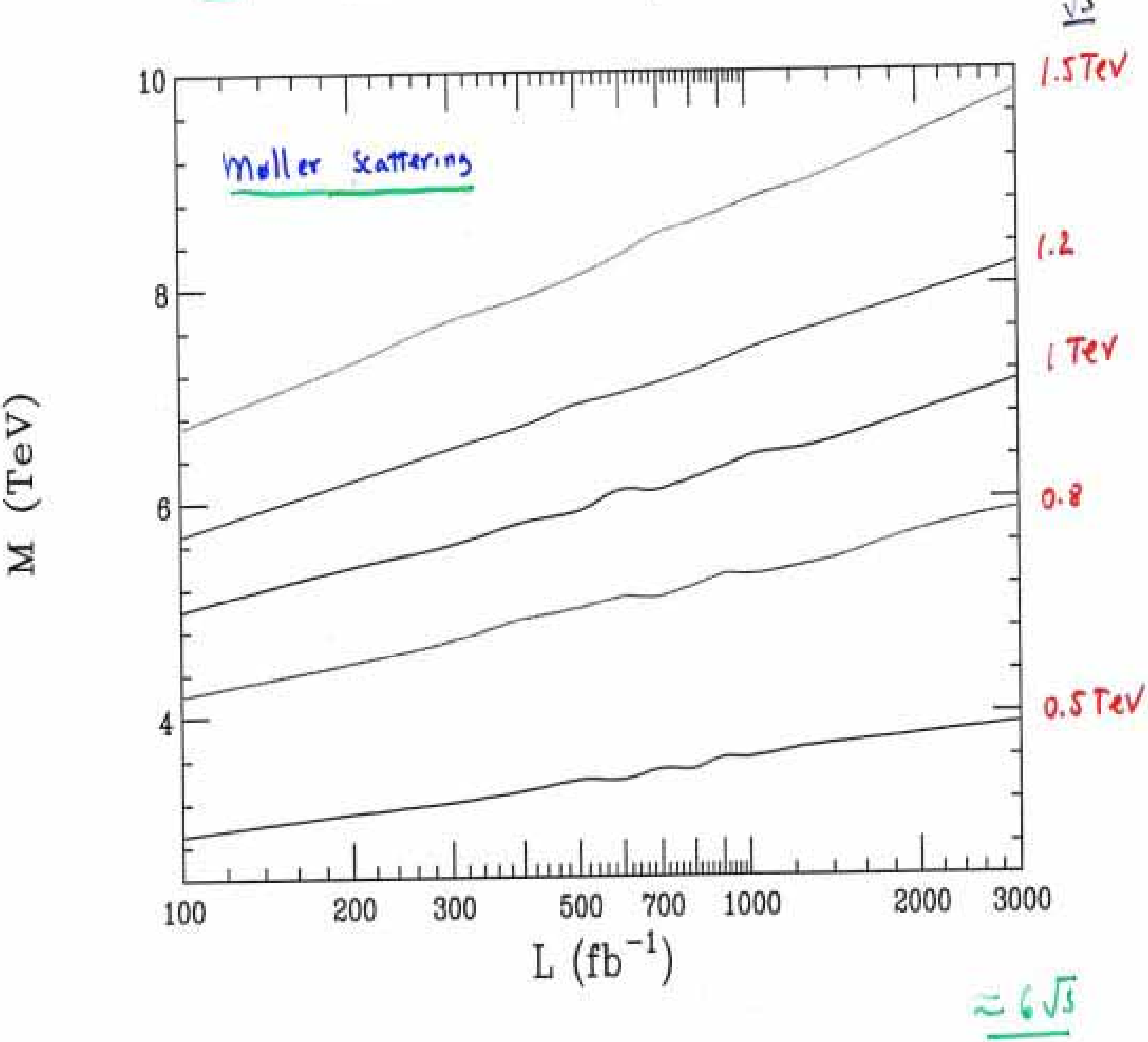


LC

95% Transverse polarization search reach



LC 95% CL Transverse polarization search reach



Z' and KK TeV^{-1} resonances.

- If we find a Z', we want to measure it's couplings to ID the model ... how??

- KK or Z'? answer known in TeV^{-1} simplest case (no brane terms etc)

  more generally ?

  work in progress (TGR)

- Look for modified α_s running from KK sums .... E_T distribution of dijets

- Check higgs production σ's; deviations due to KK exchange ... work in progress

- Search for weakly coupled KK's from brane term models

$$\mathcal{L} = \int d^5x \left\{ -\frac{1}{4} F_{AB}F^{AB} + r_0 \delta(y) \cdot -\frac{1}{4} F_{\mu\nu}F^{\mu\nu} \right\}$$

Z′ STUDY AT THE LHC − AN UPDATE

M. DITTMAR, A. DJOUADI, A-S NICOLLERAT

* NEW GAUGE BOSONS : SEARCH AND IDENTIFICATION
* MODELS : E6, LR, Z′ (WITH SM-Z COUPLINGS)

* OBSERVABLES :

LHC, $\sqrt{s} = 14$ TeV, $pp \to q\bar{q} \to Z' \to \ell^+\ell^-$

↳ RECONSTRUCT A MASS PEAK

↳ WIDTH : NON-RELATIVISTIC BREIT WIGNER FIT

↳ CROSS-SECTION : COUNT EVENTS WITHIN 3Γ AROUND PEAK

↳ FORWARD-BACKWARD ASYMMETRY (LEPTON)

COS θ DISTRIBUTION IN THE Z′ REST FRAME

$$\frac{d\sigma}{d\cos\theta^*} \propto \frac{3}{8}\left(1+\cos^2\theta^*\right) + A_{FB}^{\ell}\cos\theta^*$$

↳ UNBINNED MAXIMUM LIKELIHOOD FIT

ASYMMETRY IN SYMMETRIC COLLISIONS ??? (LHC : pp)
⇒ Z′ BOOST ≈ INITIAL QUARK DIRECTION

* LHC WITH $\mathcal{L} = 100\ fb^{-1}$

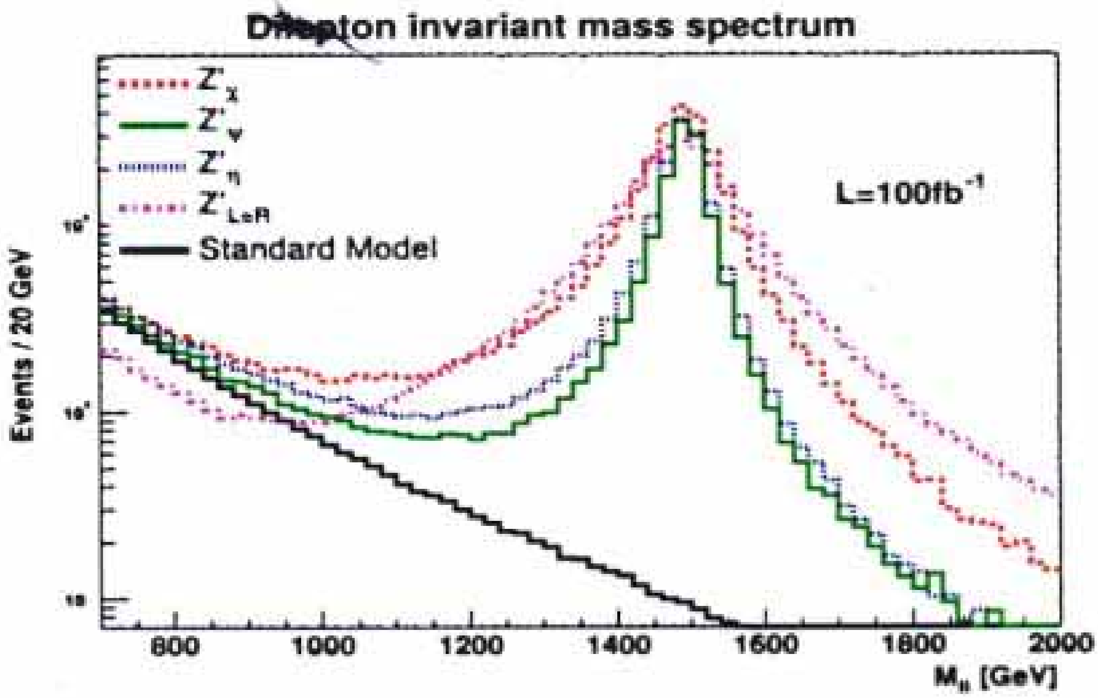
DISCOVER Z′ UP TO $M_{Z'} = 4 - 5$ TeV

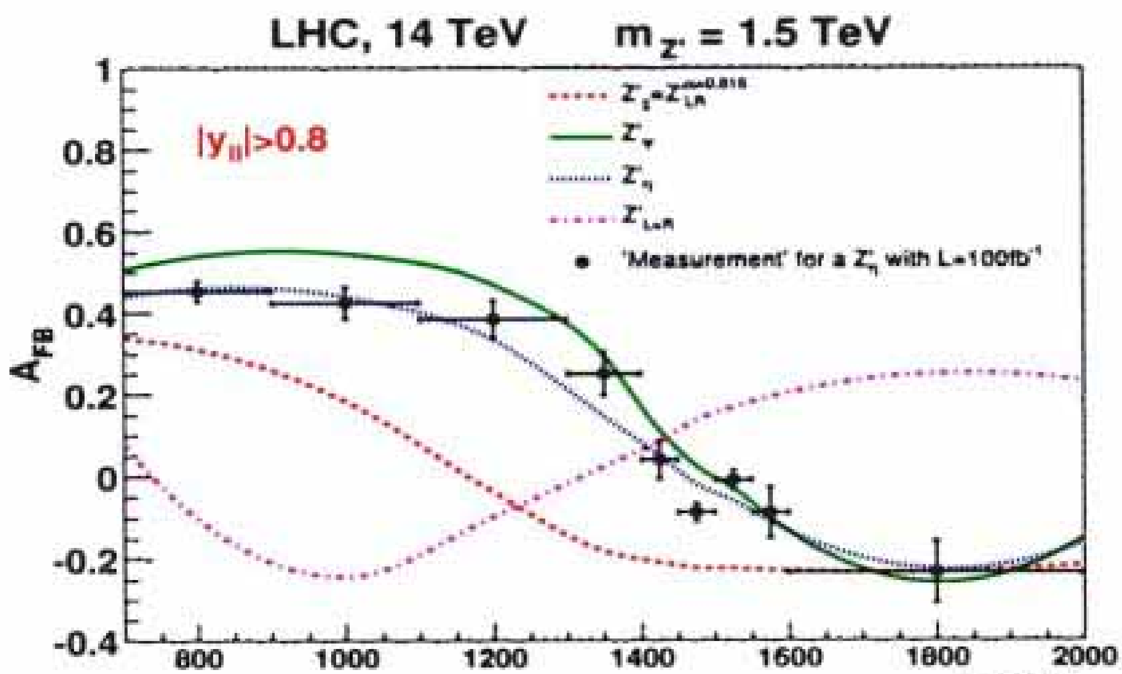
IDENTIFY Z′ ORIGIN WITH : $A_{FB}^{\text{ON PEAK}}$, $A_{FB}^{\text{INTERFERENCE}}$, $\sigma * \Gamma$

UP TO $M_{Z'} = 2.5$ TeV

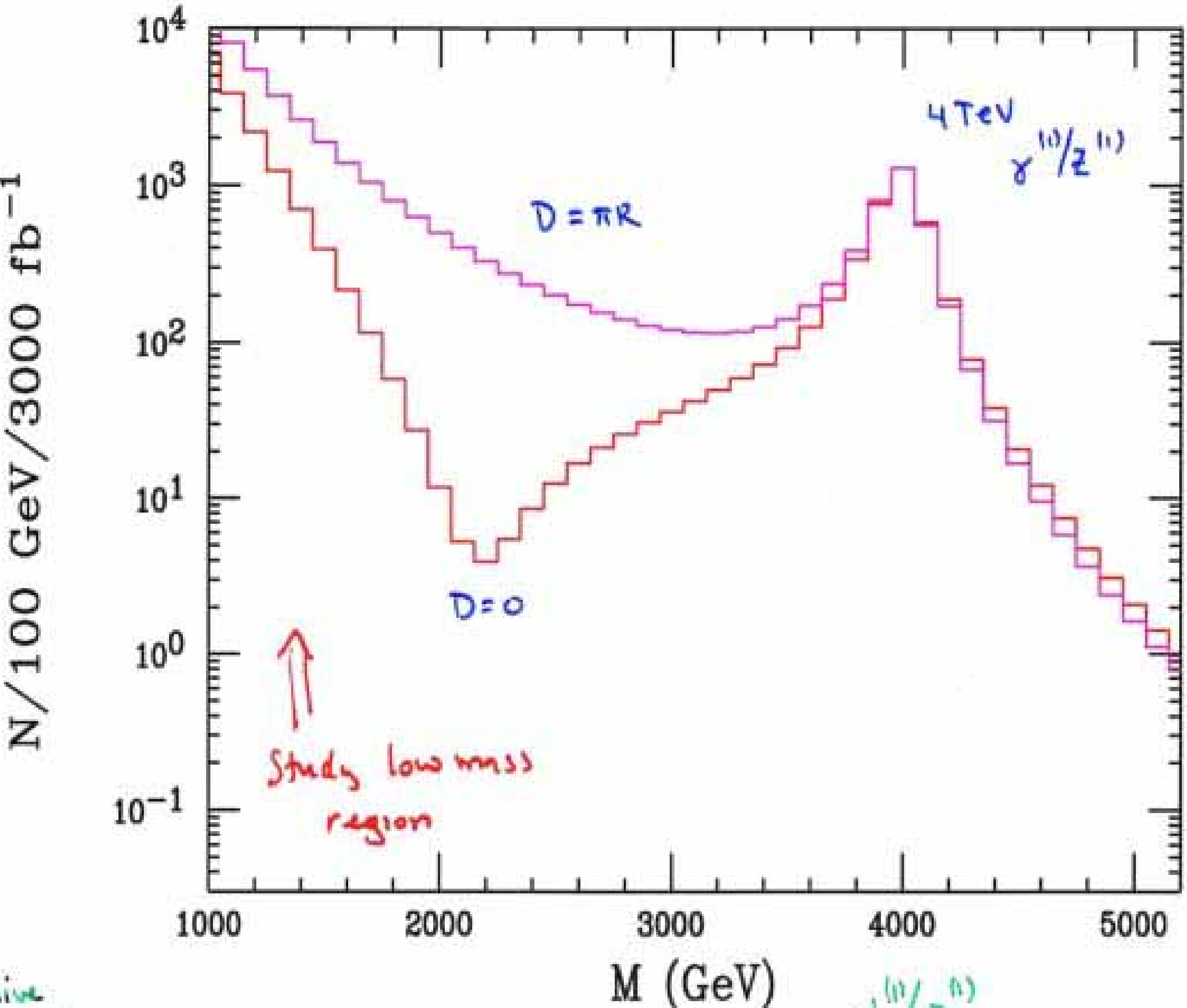
CONSTRAIN Z′ TO $u\bar{u}$ AND Z′ TO $d\bar{d}$ COUPLINGS
USING THE Z′ RAPIDITY DISTRIBUTION

Discriminating the models





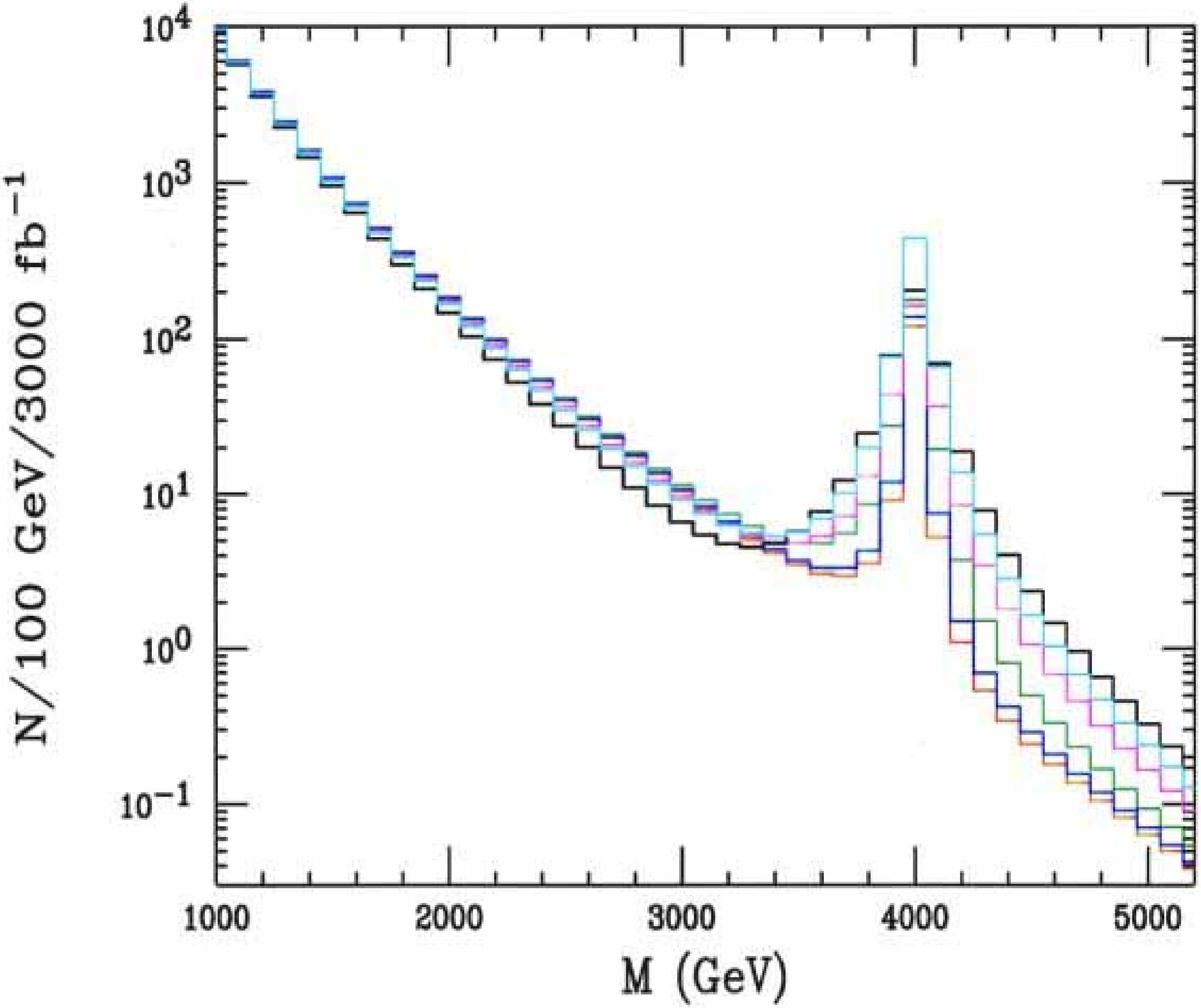
$pp \to \ell^+\ell^- + X$

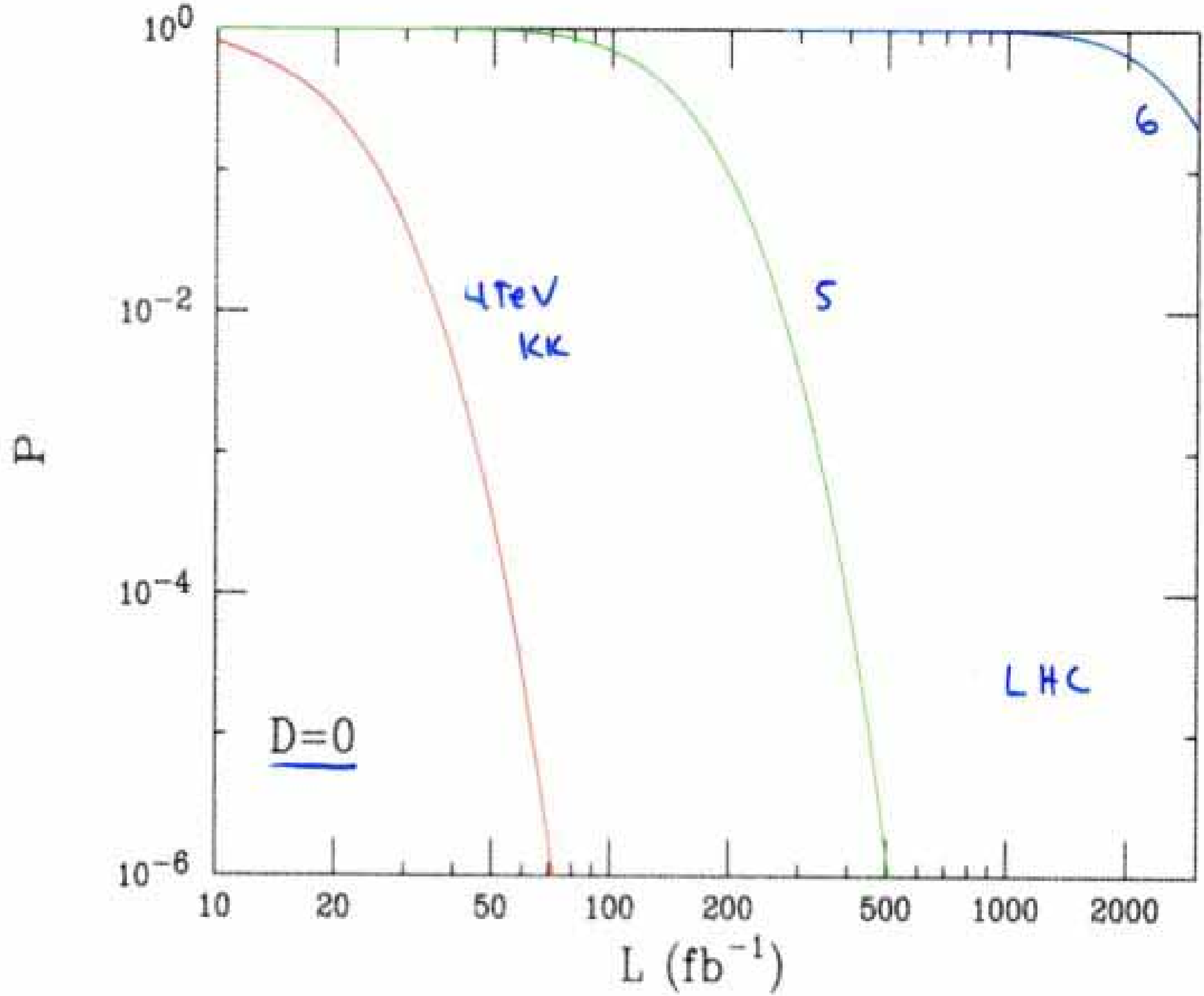


naive
TeV^{-1}
no brane terms

$\gamma^{(1)}/Z^{(1)}$
KK resonance

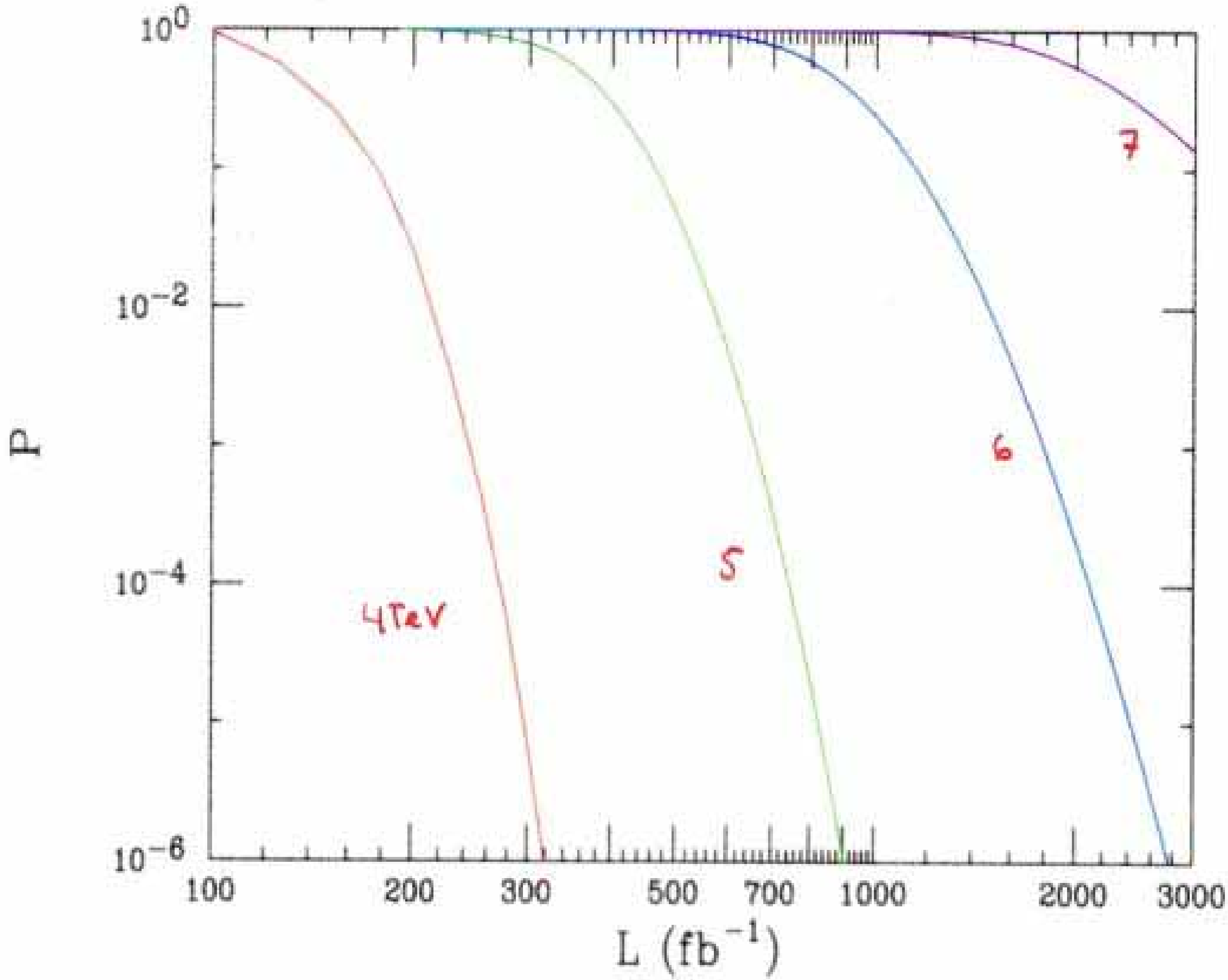
6 Favorite
Z' models





10^0
10^{-2}
10^{-4}
10^{-6}
P
4TeV
KK
5
6
LHC
D=0
10
20
50
100
200
500
1000
2000
L (fb^{-1})

LC $\sqrt{s} = 500$ GeV "$M_{Z'}$" from LHC



Dijet production in TeV^{-1}-size extra dimensions

Csaba Balázs, Marc Escalier, Samir Ferrag, Giacomo Polesello

(1) modified running of α_S implemented in PYTHIA 6.210

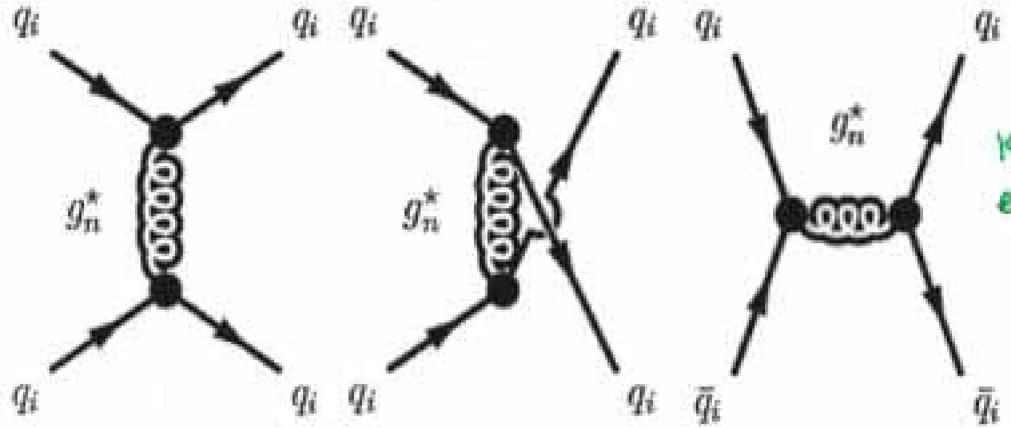
(*PLB436,55,1998; PLB525,219,2002*)

KK sum effect in extra dims

$$\alpha_i^{-1}(\mu) = \alpha_i^{-1}(\mu_0) - \frac{b_i - \tilde{b}_i}{2\pi} \ln\frac{\mu}{\mu_0} - \frac{\tilde{b}_i}{4\pi} \int_{r\mu^{-2}}^{r\mu_0^{-2}} \frac{dt}{t} \left[\vartheta_3\left(\frac{it}{\pi R^2}\right)\right]^{\delta},$$

(2) gluon KK's are included in PYTHIA for dijet production

(*PRD65,076007,2002; PLB525,219,2002*)



... etc.

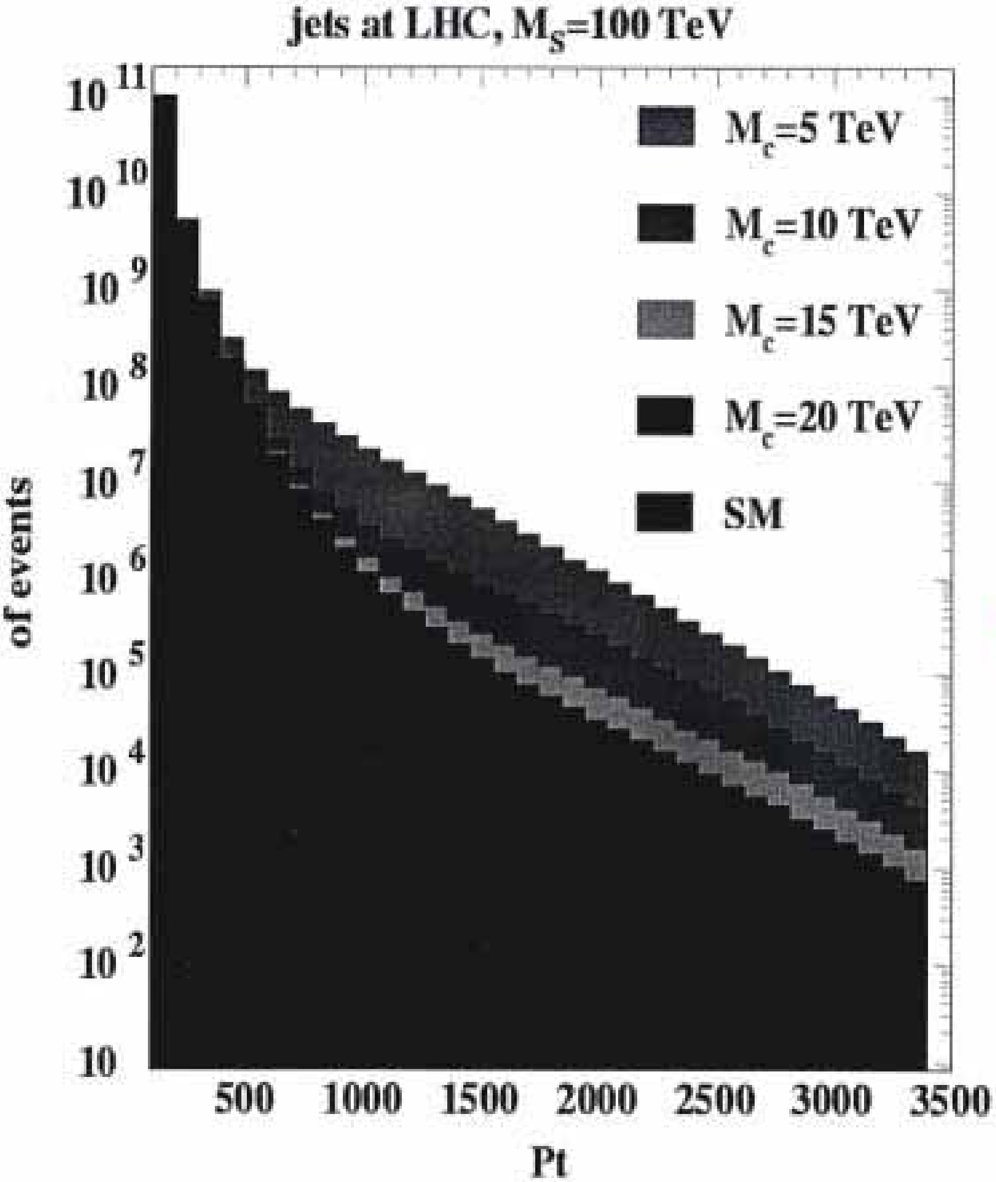
KK exchange

alteration of dijet spectrum

e.g., $\boxed{P_T}$

Status: LHC detectability/significance: ((**1**) done before) started at Les Houches

PDF uncertainties ((**1**) done before) will be estimated after Les Houches



Dijet Pt excess from gluon KK's and α_s running combo.

Higgs production at the LHC in the 5D2HDM

Csaba Balázs, Susan Shotkin Gascon, Olivier Ravat

— **Implemented pp→Zh and pp→$W^{\pm}$h for the 5D2HDM in CompHEP**

- along the lines of *hep-ph/0212133:*
- ZZh and WWh vertices just like in the 2HDM
- Z and W propagators → KK-tower propagators
- checking results in *hep-ph/0212133* (no new plots yet:)

gauge boson KK's modify h production rates

— **In near future**

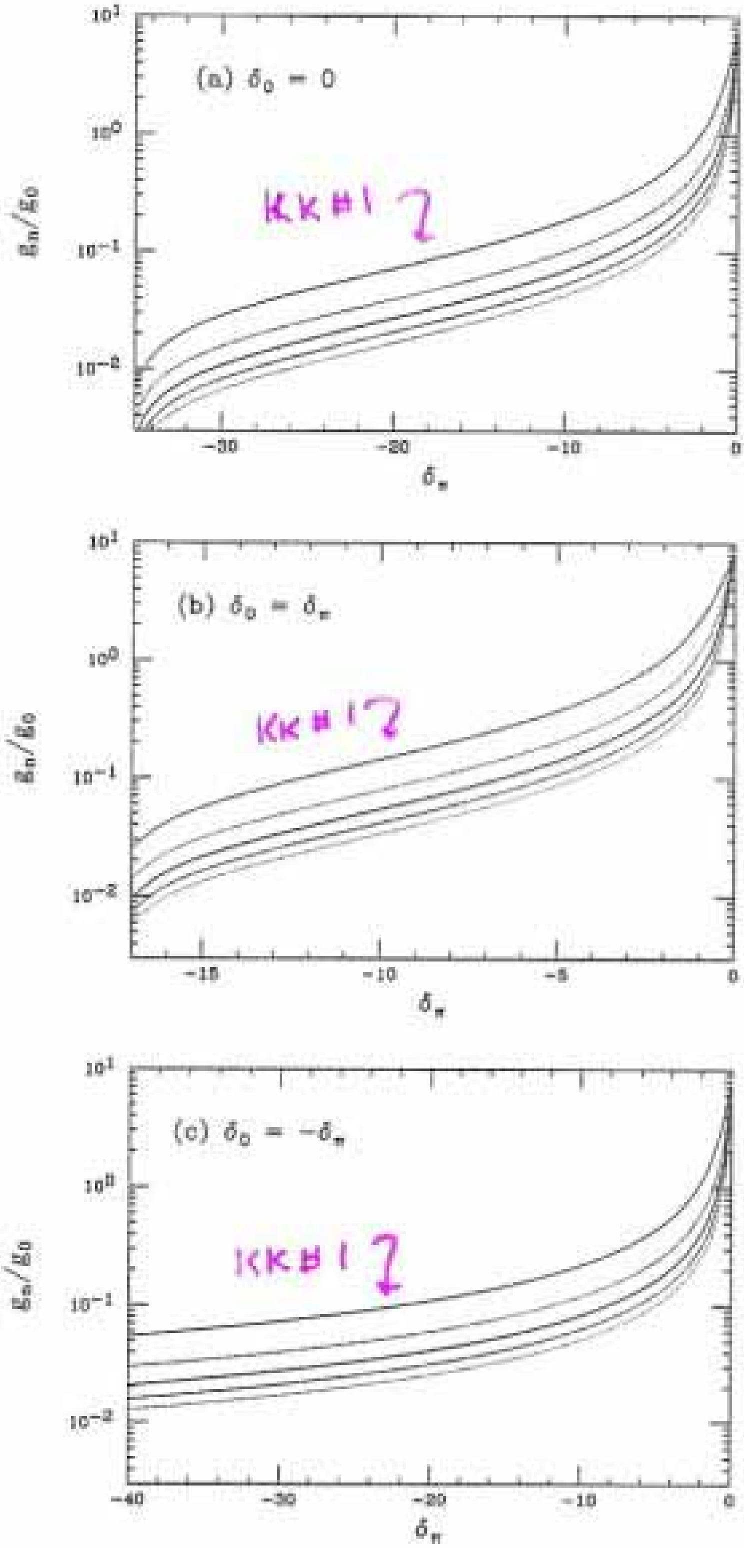
- including widht of W/Z KK's to regulate cross section near resonance
- same modifications for the backgrounds in CompHEP
- LHC detectability study with backgrounds
- special cases to study: 5DSM, ...

in progress

reduction in gauge coupling strength

RS
Brane
Kinetic
terms

Davoudiasl
Hewett
Rizzo



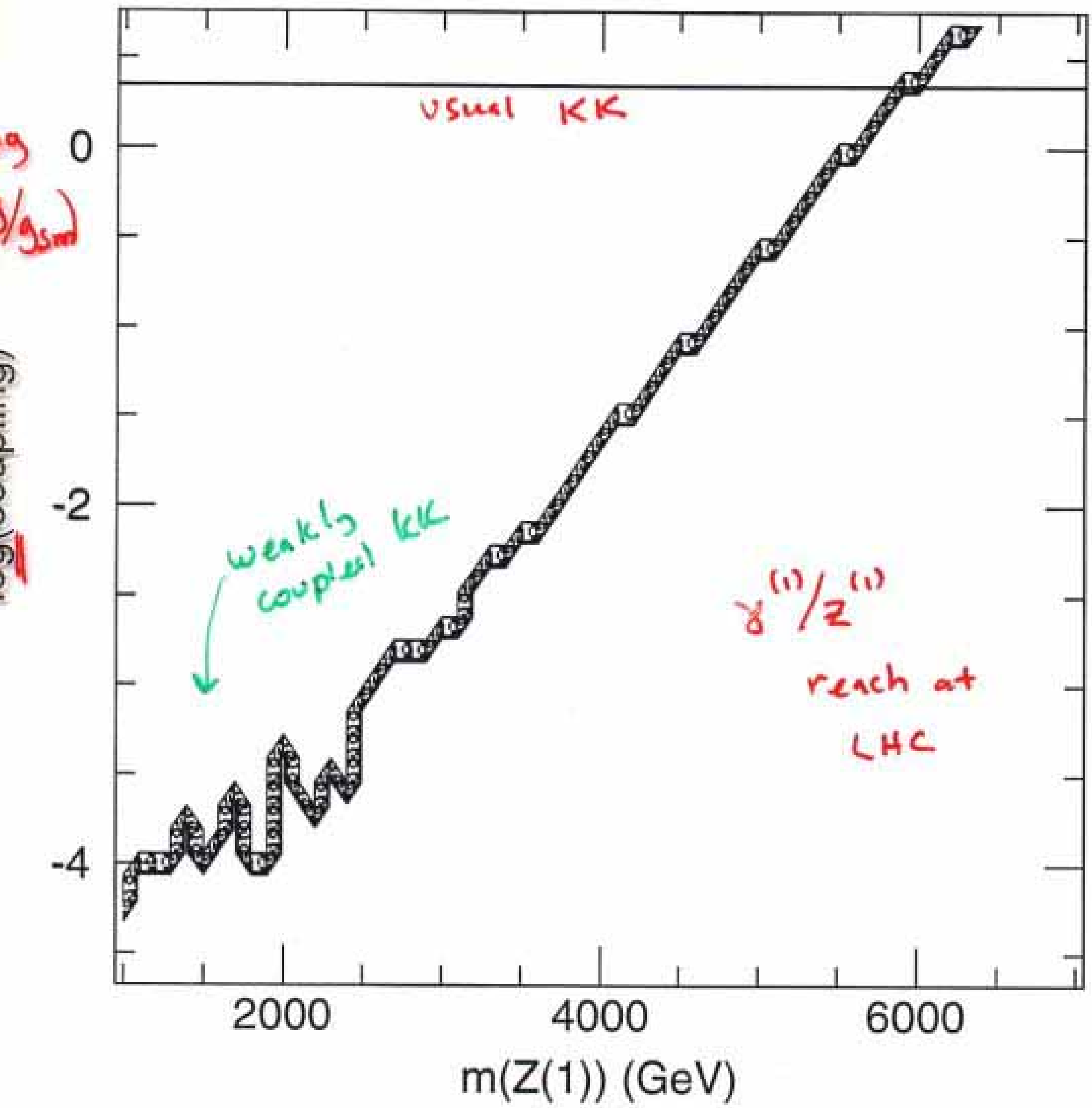
reduction
down to
$\sim 10^{-2}$ of
SM
strength
possible!

reaches??

Figure 5: The ratios of the first five KK couplings to that of the zero-mode as a function of negative δ_π for the cases (a) $\delta_0 = 0$, (b) $\delta_0 = \delta_\pi$, and (c) $\delta_0 = -\delta_\pi$. The lightest (heaviest) KK mode corresponds to the top (bottom) curve in each case.

Polesello

Z(1)→ee 5 σ reach for 100 fb^{-1}



Radions : lots of projects...

DeRoeck, Battaglia, Dominici, DeCurtis,
Gunion, Hewett + TGR

eg,

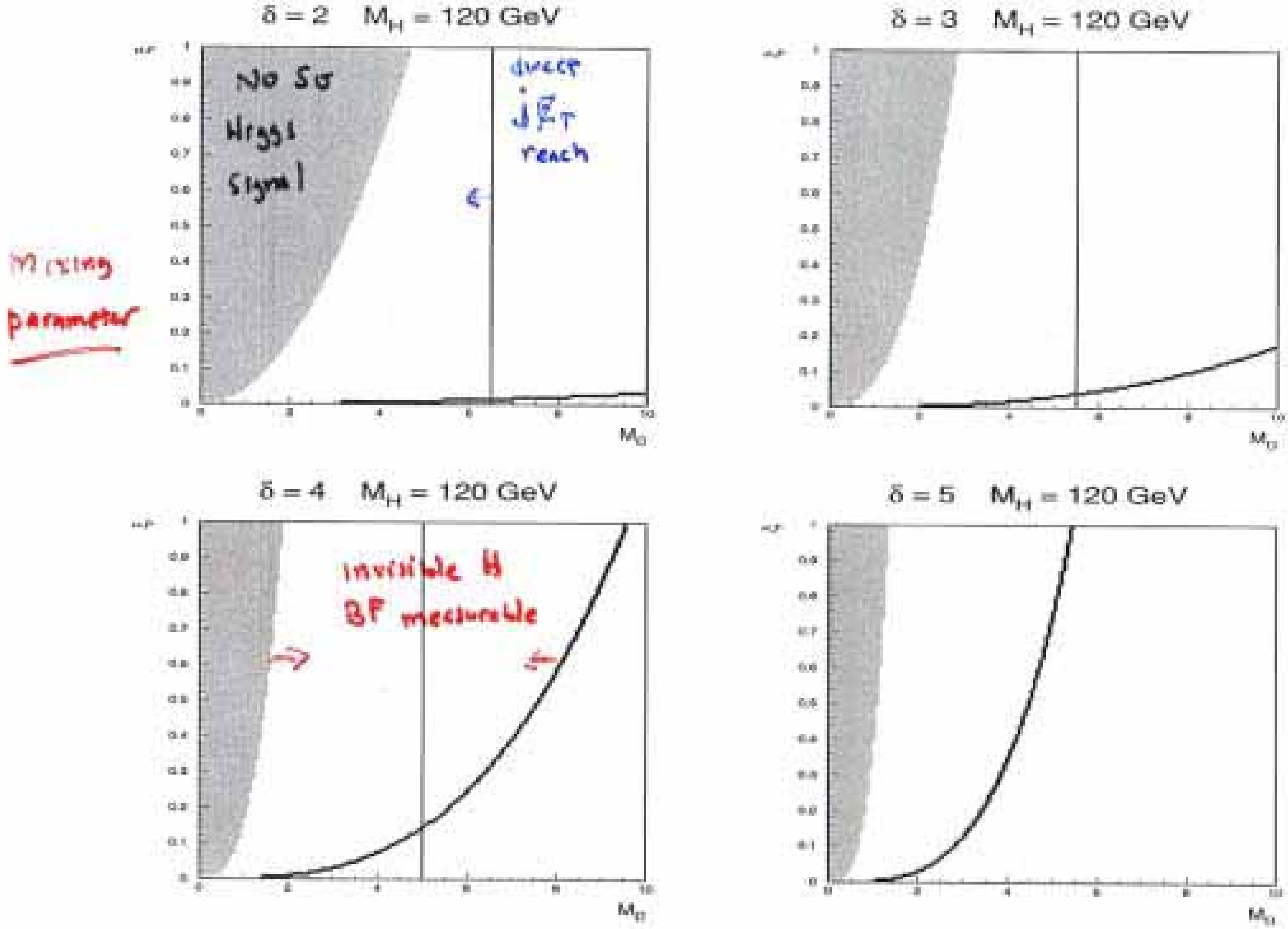
(1) Higgs/radion mixing $\Rightarrow$ Γ_{inv} large for 'Higgs' in ADD $\Rightarrow$ LHC/LC

(2) RS radion mixing may be observable EVEN when graviton is too heavy to be seen at LHC ...

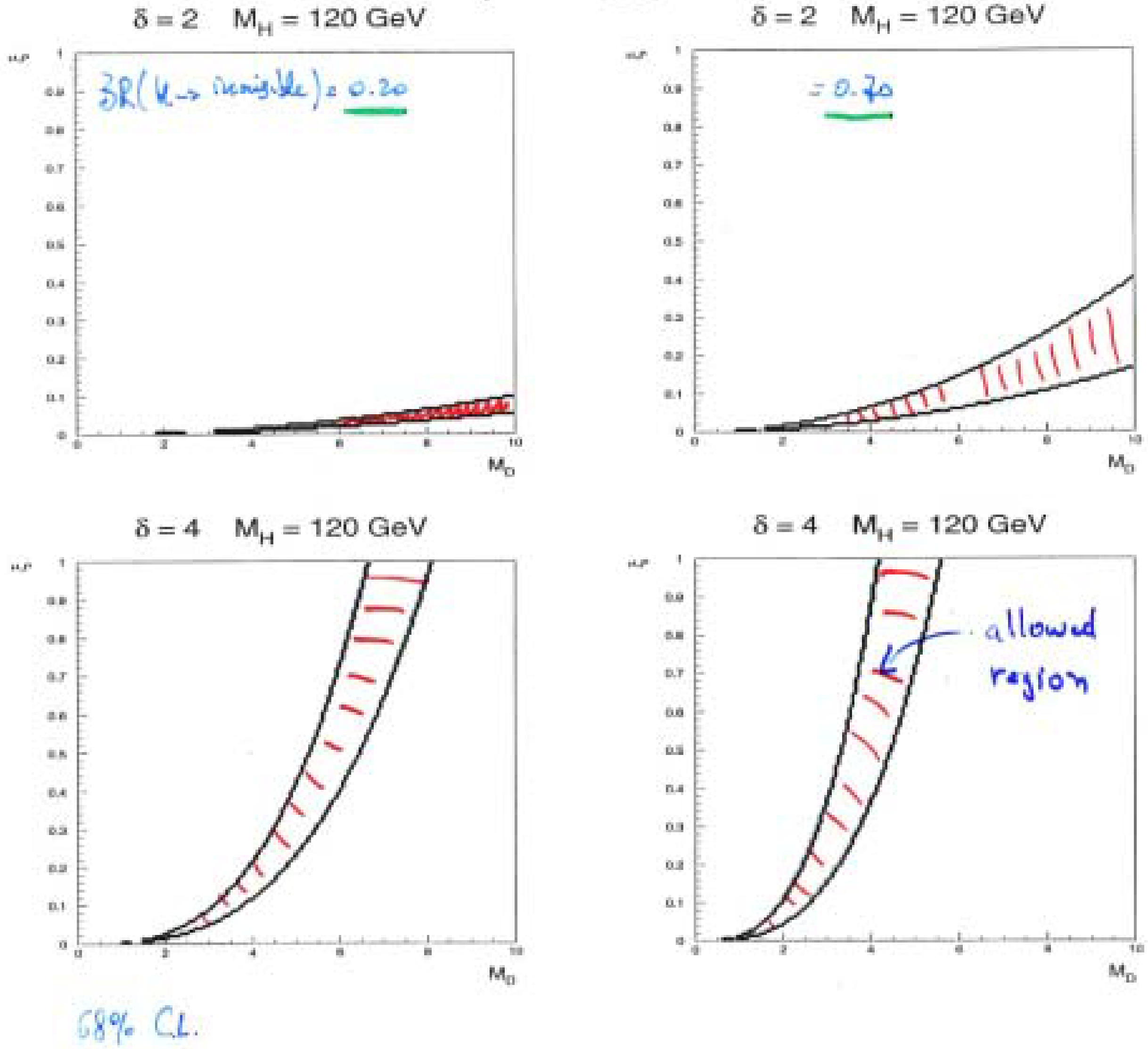
(3) etc, etc, etc...

M. Battaglia
D. Dominici
J. Wells

Sensitivity to ADD Γ_{inv} at LHC

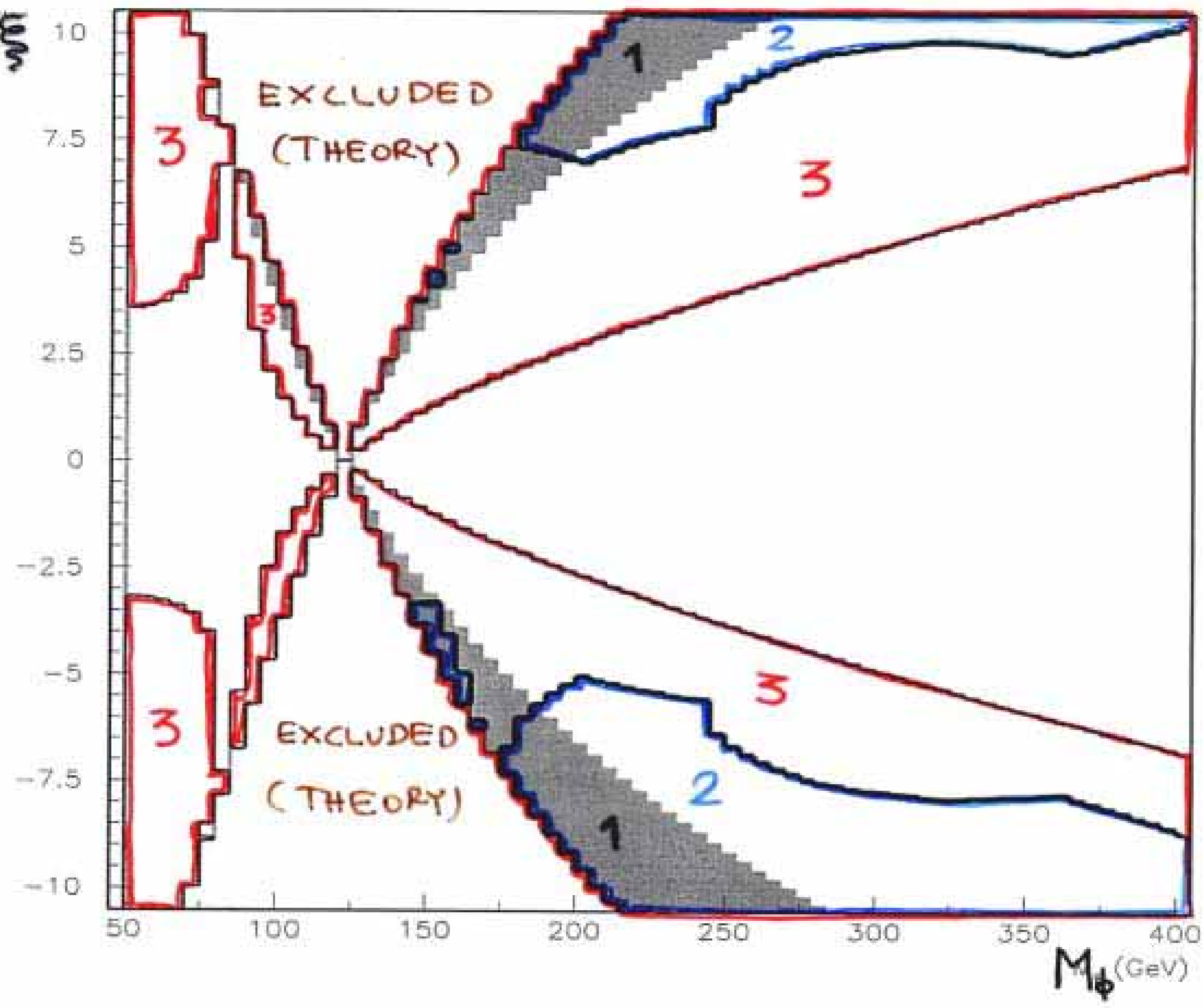


Sensitivity to M_D-ξ at LC-500



M. Battaglia, S. De Curtis, A. De Roeck,
D. Dominici, J.F. Gunion

$\Lambda_\phi = 30$ TeV $\qquad M_h = 120$ GeV



1: $\not{h}$ at LHC

2: $\phi \to ZZ \to 4\ell$ at LHC

3: $\dfrac{\Gamma_h - \Gamma_{H_{SM}}}{\Gamma_{H_{SM}}} > 2.5\sigma$ at LC
for $h \to b\bar{b}$, W^+W^-

Little Higgs :   New GB, t' + Higgs in TeV range

eg, $t' \to tZ,\ bW,\ th$

- Signatures of direct production

  model dependence (work in progress)

- indirect signatures from coupling modifications..

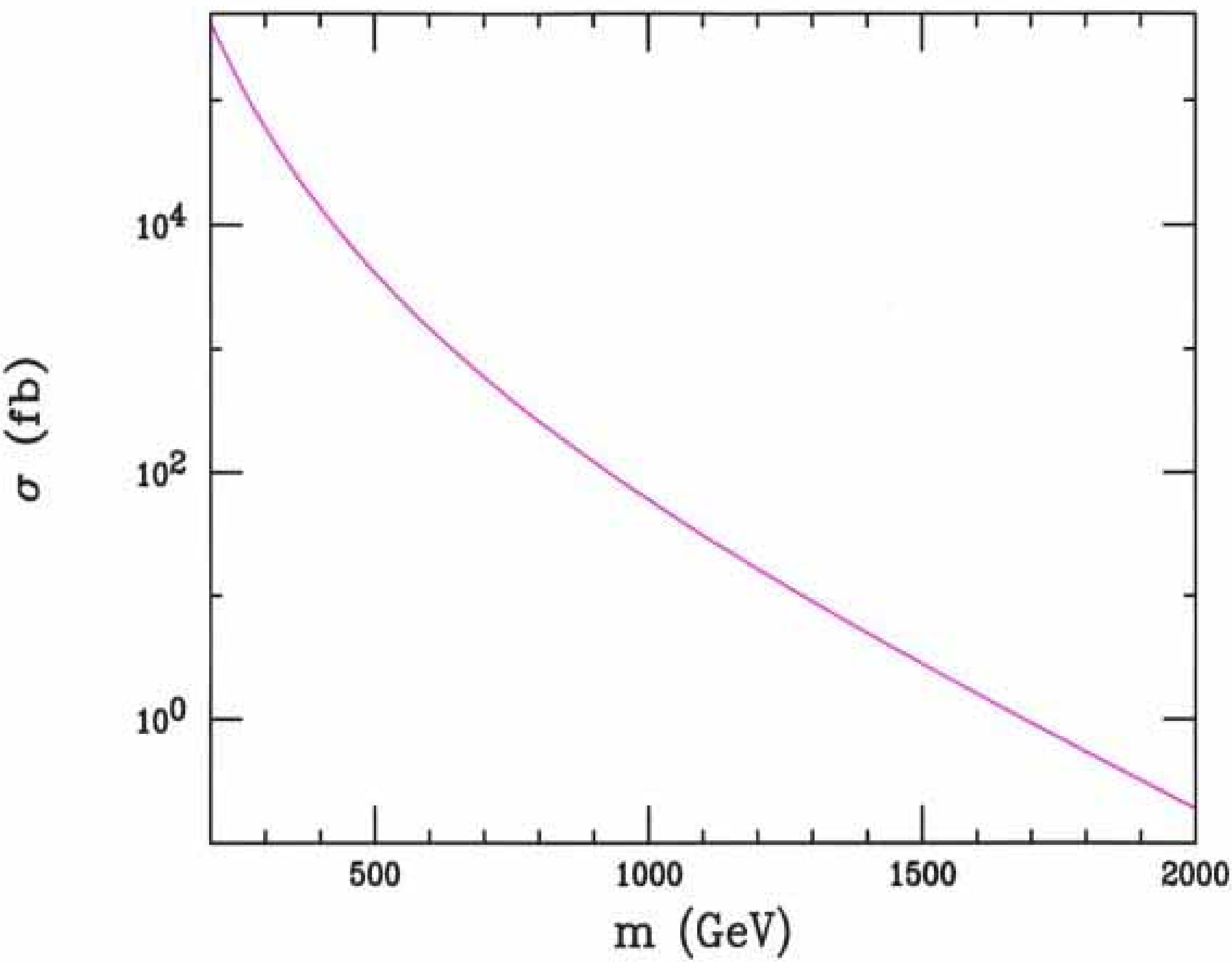
  (work in progress)

e.g, $Z \to t\bar{c}$ FC (Wacker)

or "ZZh" (Hewett)

Hewett
Rizzo, Wacker

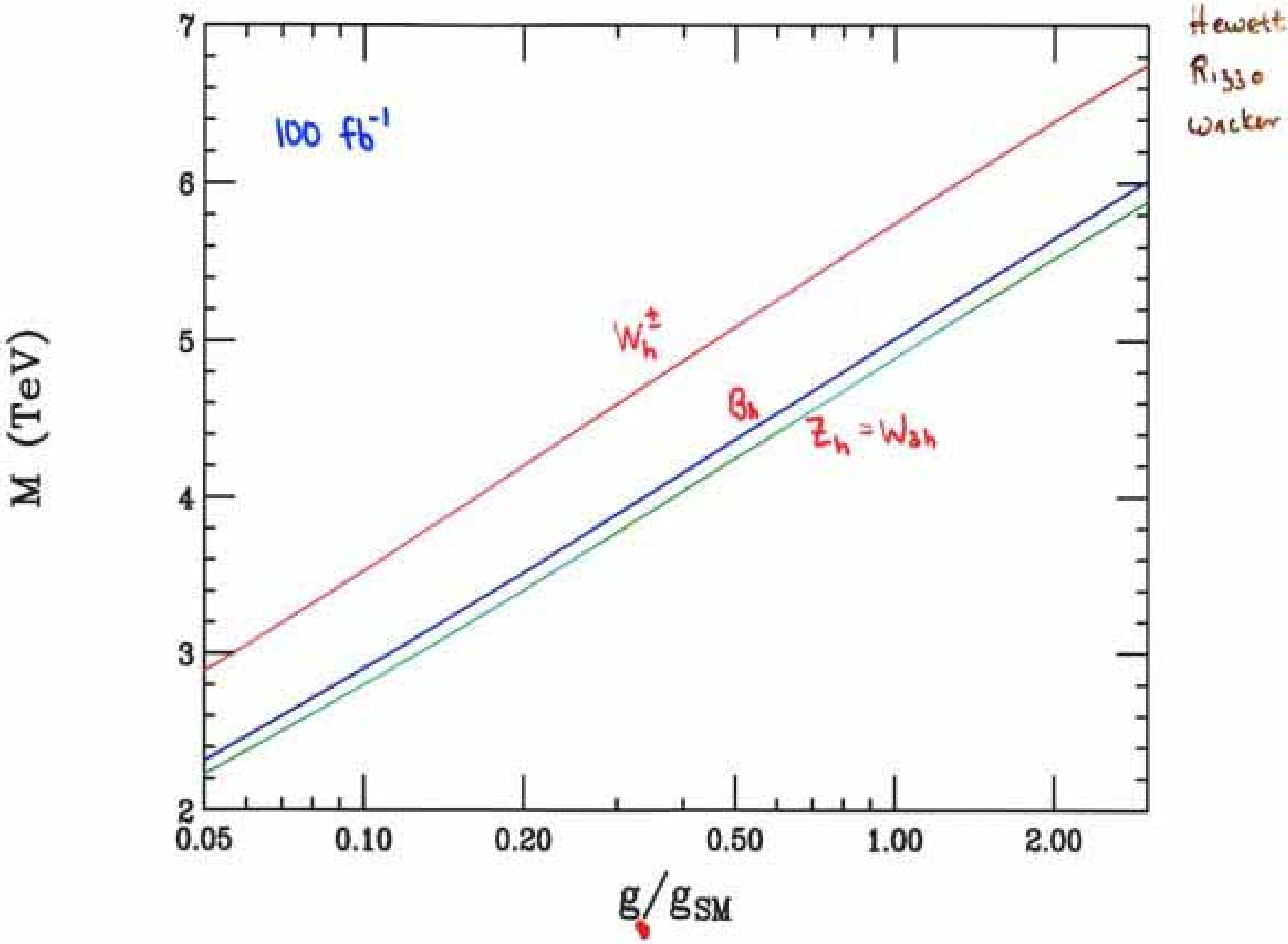
$t'\bar{t}'$ pair production at LHC



t' decays via mixing; $t' \to th, tZ, bW$

reaches?

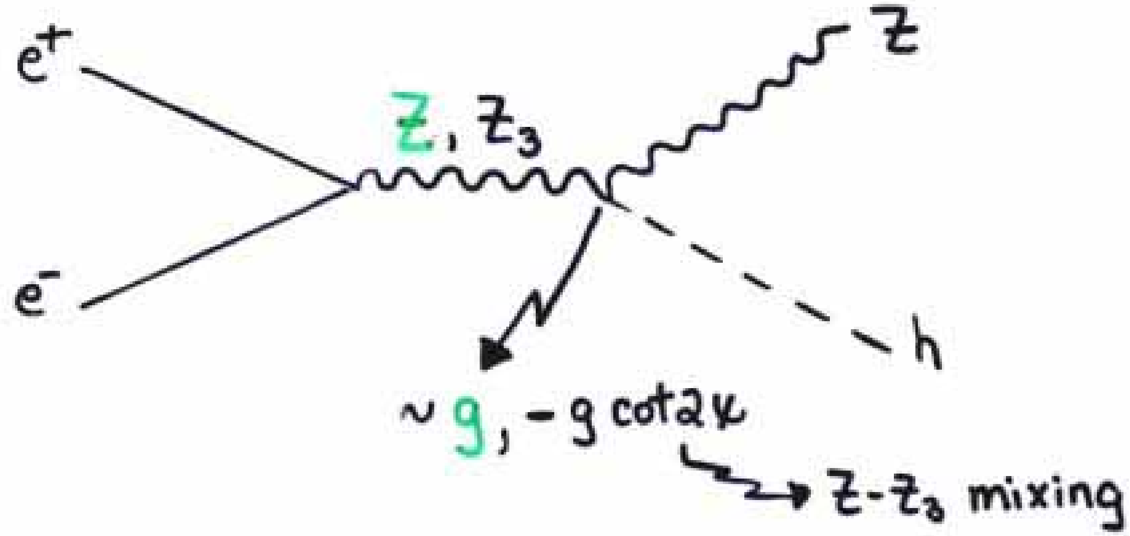
New Gauge Boson Search Reach at LHC (Drell-Yan)



Little Higgs Phenomenology

- Determine h couplings to new gauge fields
  ⇒ hallmark of Little Higgs models!

- Use precision of Linear Collider :



Input m_{Z_3} from LHC measurement

Measure $e^+e^- \to Zh$ at LC (2 values of $\sqrt{s}$)

determine $Z_3 Z h$ coupling

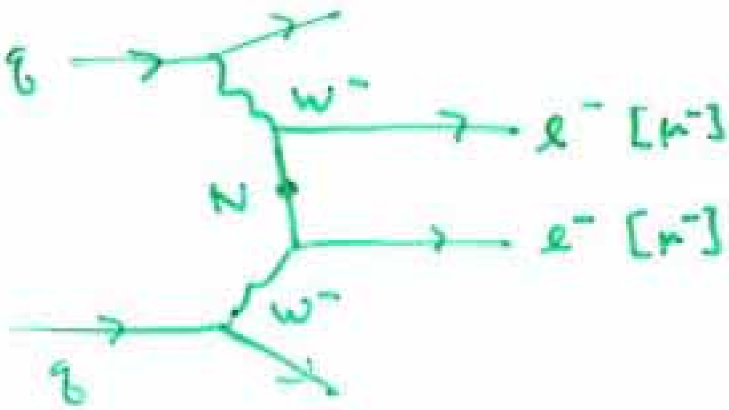
Numerics underway...

Hewett

Heavy Neutral Leptons :

Dirac or Majorana ?

- Indirect $\ell^\pm \ell^\pm$ signatures at LHC :

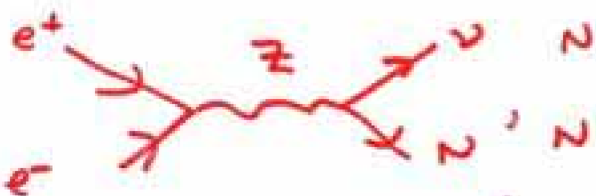


{ Hewett
Rizzo
Spiropulu

weak bounds in $\ell = \mu/\tau$ case

– work in progress

- Direct Signatures

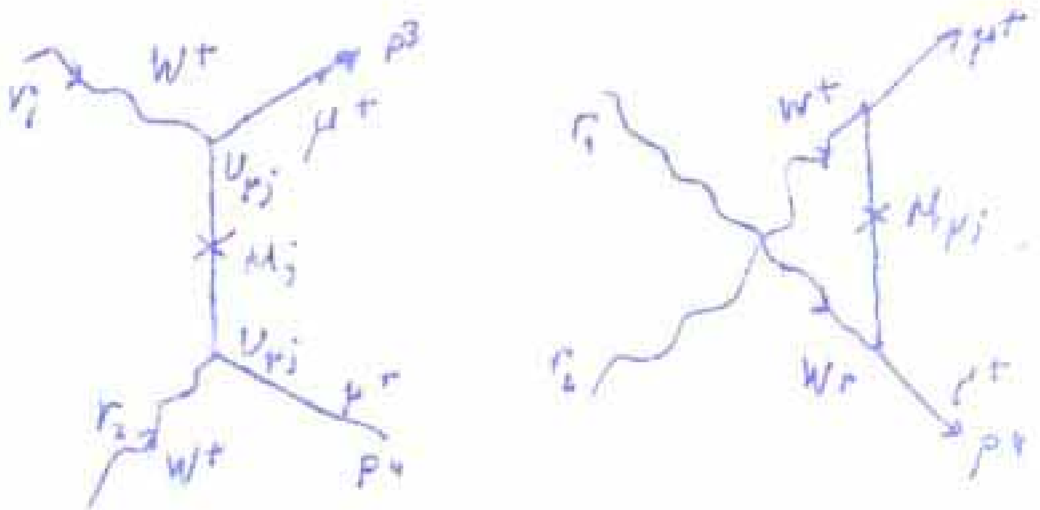


{ JoAnne
Gudi
Tom

study spin correlations – work in progress

HEAVY MAJORANA NEUTRINOS AND SAME SIGN DI-MUONS

JH, TR, MS



MODEL DEPENDENT, MIXING ANGLE THAT CONNECTS A W TO A μ CAN BE ANYTHING

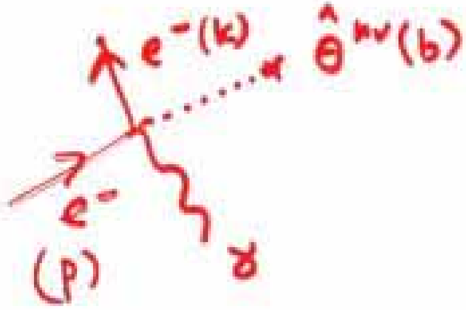
CALCULATE X-SEC FOR TEVATRON ($p\bar{p}$)

* CHECK LIMITS WITH EXISTING CDF DI-MUON ANALYSIS
* CHECK LHC SENSITIVITY

Co-ordinate Dependent non-c QED (T&R)

$$[\hat{x}_\mu, \hat{x}_\nu] = i\,\underbrace{\hat{\theta}_{\mu\nu}(x)}_{\text{a space-time dependent field}}$$

Construct FT using Seiberg-Witten maps (Calmet, ...)



$$-\frac{e}{2}\, k_\alpha\, \hat{\theta}^{\alpha\beta}(b)\, p_\beta\, \gamma^\mu$$

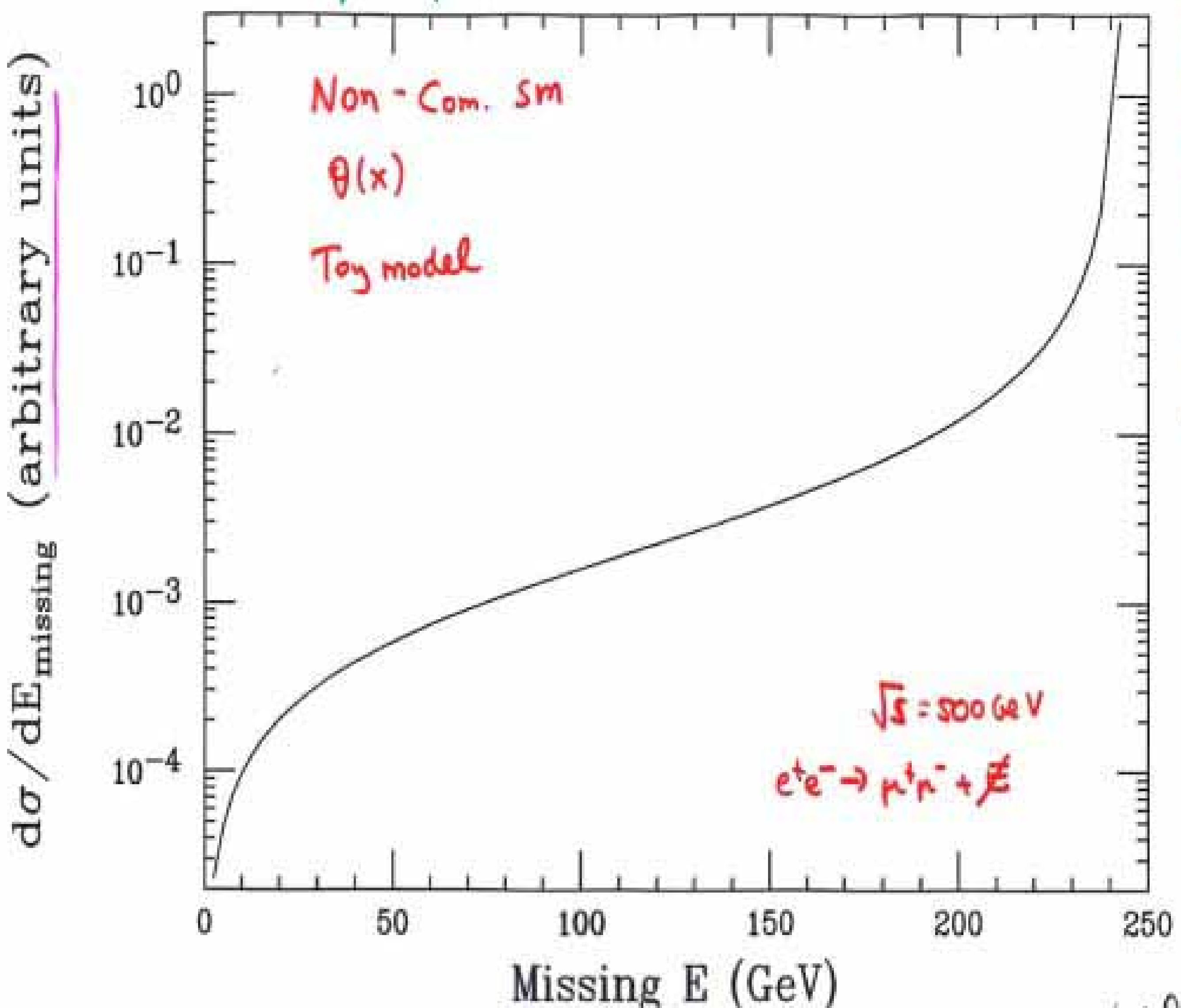
$\hat{\theta}$ acts as p absorbed by the vacuum (!)

- Test in $e^+e^- \to \mu^+\mu^- + \not{E}$

$\rightarrow$ Toy model so far... (in progress)

VERY preliminary !!

TGR



Missing energy peaks at hi-end due to higher-dim 8 operator source

cos θ integrated

Summary

Lots of ideas + hard work ...

more ahead !