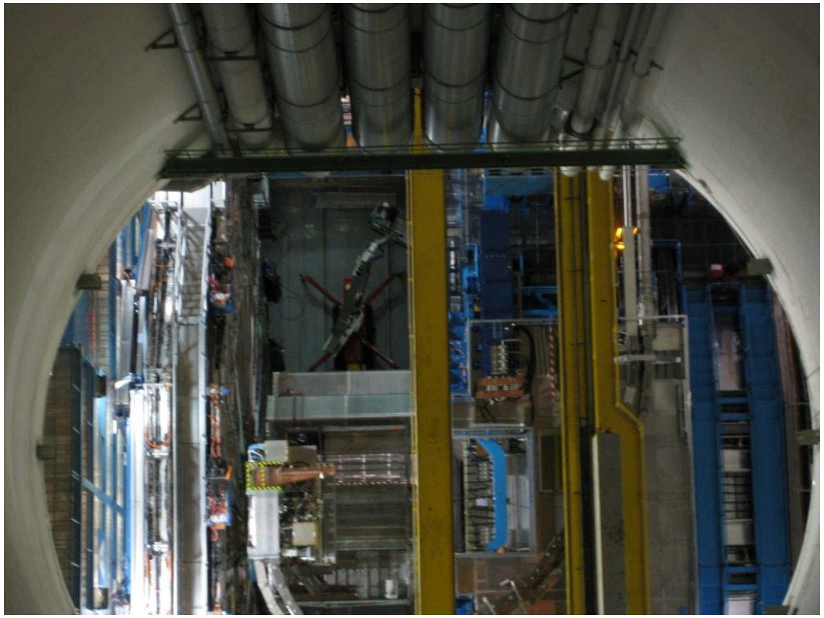
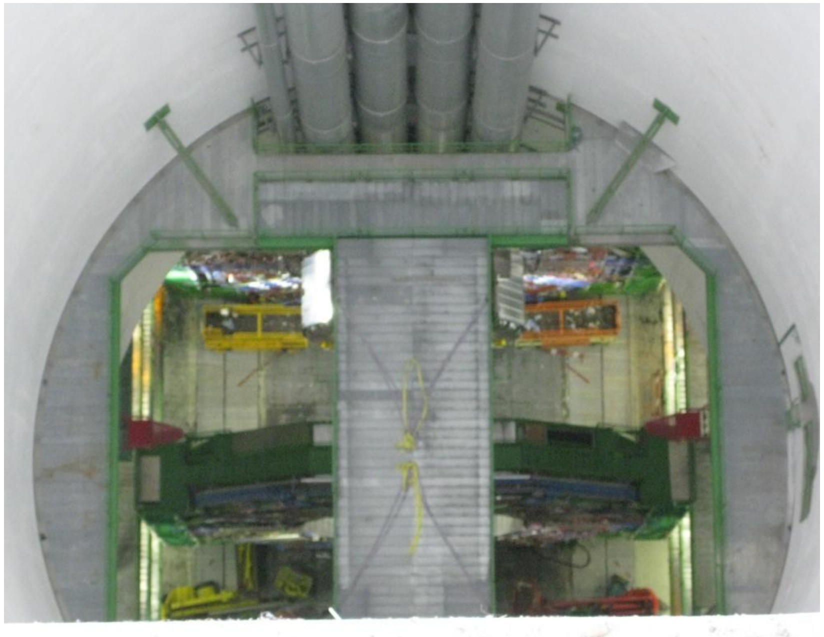
# Transverse Polarization as a Different View into New Physics at CLIC





SLAC NATIONAL ACCELERATOR LABORATORY

T.G. Rizzo 20/10/2010

# There has been lots of work showing the power of transverse polarization in finding & exploring the details of new physics:

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# Is there anything else we can do with it ??

## (I) Discriminating the spin of new particles

There are already 2 well-known ways to do this at $e^+e^-$ colliders :

- Threshold scans can tell us $\sim\beta$ or $\sim\beta^3$ cross section turn on.. what if this is 'degraded' for some reason?
- Far above threshold, the production angular distribution, i.e., $\sim 1 \pm \cos^2\theta$, is fixed by the s-channel exchange & particle spin

→ Both of these approaches can have their own strengths & weaknesses but it may be useful to have a further technique & TP may provide it !

- Only an outline of this approach is available right now & more work is needed..beyond these preliminary results

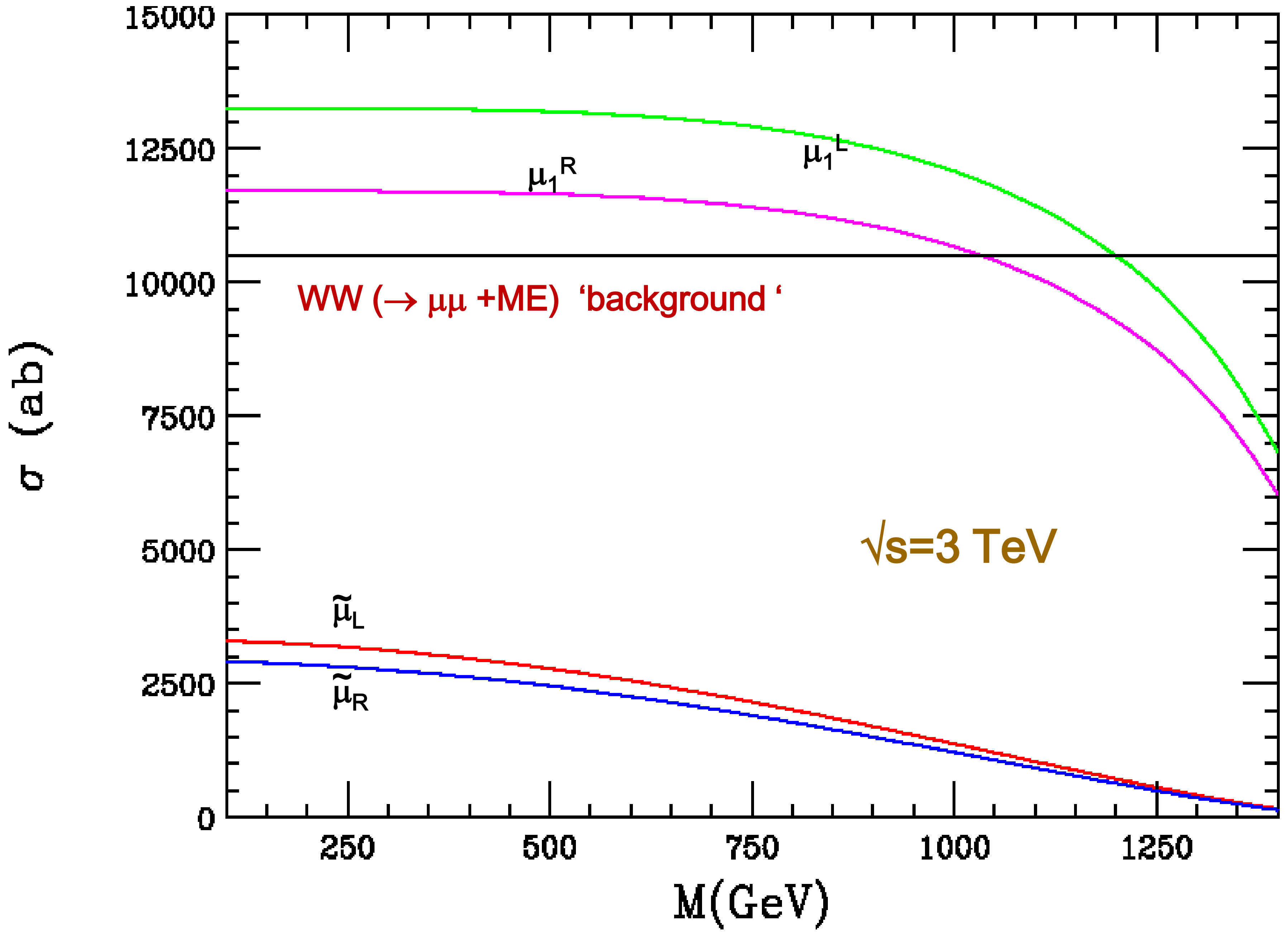
- Transverse polarization, pointing out of the interaction plane, allows azimuthal asymmetries to be formed to probe spins

- To be specific ,we will consider & contrast smuon production from that of the first muon KK excitation in UED at CLIC.

- Recall that the fermion KK excitations are vector-like so have $A_{FB}$ =0 as do smuons so no angular asymmetries to look at..

- Production rates for these new states will be substantial at CLIC ($\sqrt{s}$=3 TeV & lumi ~ a few $ab^{-1}$ ) as will rates for the WW background

- We will assume that smuons & KK UED states will both decay w/ unit probability to muons + missing energy in this analysis


15000
12500
10000
7500
5000
2500
0
250
500
750
1000
1250
M(GeV)
σ (ab)
$\mu_1^L$
$\mu_1^R$
WW (→ μμ +ME) 'background '
√s=3 TeV
$\tilde{\mu}_L$
$\tilde{\mu}_R$

# So, e.g., for smuons we obtain

$$\frac{d\sigma}{dz\,d\phi} = \frac{\alpha^2\beta^3}{8s}(1-z^2)\ [F_A - \boxed{P_1^T P_2^T} F_B \cos 2\phi]$$

(..neglecting small Im parts)

$$F_{A(B)} = Q_e^2 Q_f^2 + 2Q_e Q_f v_e G_V R_1 + (v_e^2 \pm a_e^2) G_V^2 R_2$$

$$G_V = B(T_{3f} - x_w Q_f),\quad v_e = B(-1/4 + x_w),\quad a_e = -B/4 \qquad B = [\frac{\sqrt{2}G_F M_Z^2}{\pi\alpha}]^{1/2}$$

$$R_1 = s(s-m_Z^2)/[(s-m_Z^2)^2 + \Gamma_Z^2 M_Z^2],\quad R_2 = s^2/[(s-m_Z^2)^2 + \Gamma_Z^2 M_Z^2]$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\phi} = \frac{1}{2\pi}(1 + \lambda\cos 2\phi)\ ,$$

$$A = \frac{\int_{odd} d\sigma}{\int_{all} d\sigma} = \frac{2\lambda}{\pi}\,, \qquad \frac{dA}{dz} = \frac{3}{4}(1-z^2)\ A$$

$$\lambda = -P_1^T P_2^T \frac{F_B}{F_A}\,,$$

- For smuons, A is negative & β-independent, has a ~sin$^2$θ angular distribution and can be large provided the product of the polarizations is large (=0.5 will be assumed here)

- For the KK fermions in UED one finds that they ALSO have an azimuthal asymmetry with a ~sin$^2$ θ distribution but of opposite sign and, furthermore, it is β-dependent & is vanishing at threshold. The angular distribution for KK muons is given by

$$\frac{d\sigma}{dz\,d\phi} = \frac{\alpha^2\beta}{4s}\left(F_A[(1+z^2)+(1-\beta^2)(1-z^2)] + P_1^T P_2^T(1-z^2)\beta^2 F_B \cos 2\phi\right)$$

& employing the same definitions as above

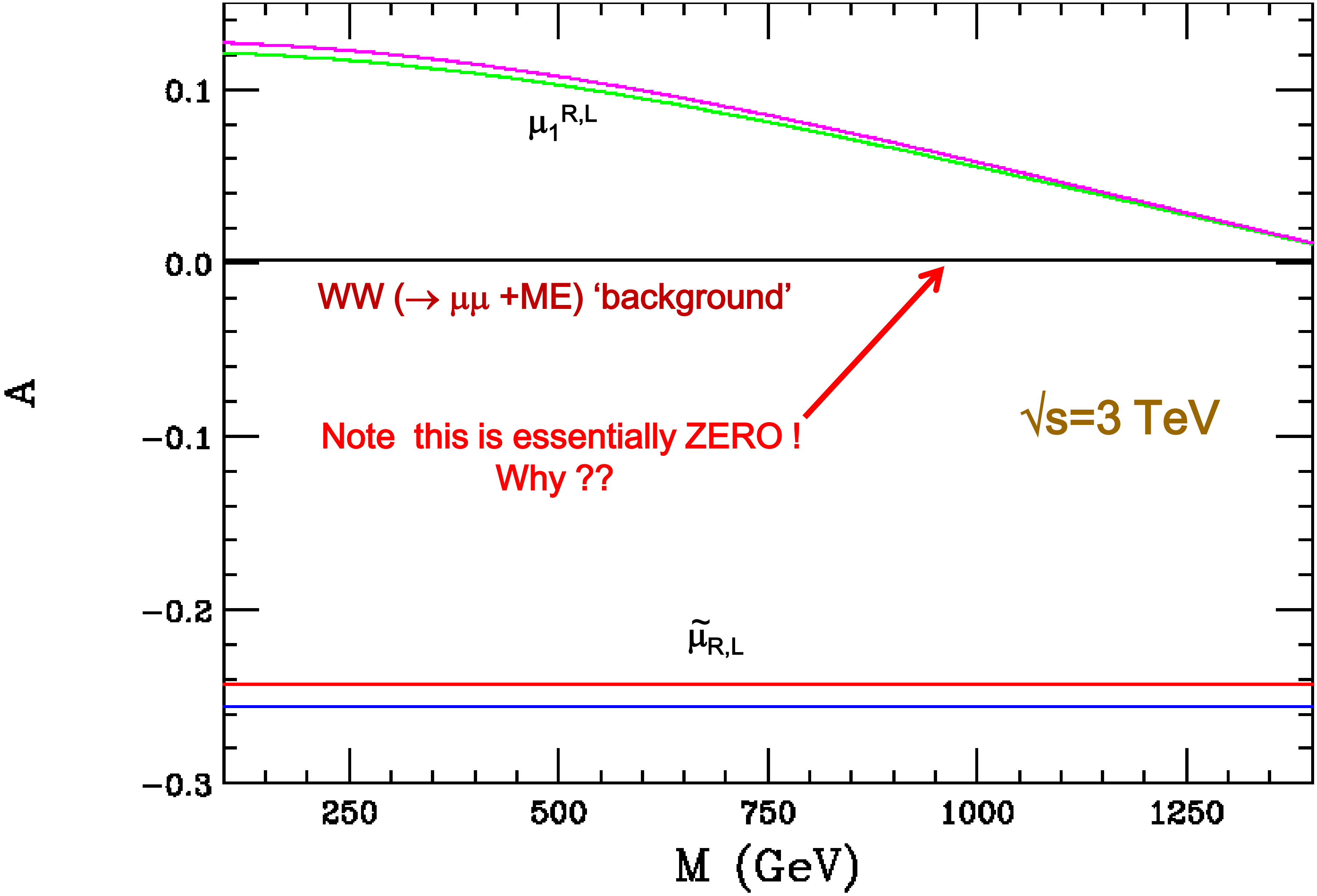
From these expressions we see that the smuon and KK asymmetries are directly related in a rather simple way:

$$A_{KK} = \frac{-\beta^2}{3-\beta^2}\, A_{\tilde{\mu}}$$

for states with the same charge & weak isospin …

→Thus a determination of the sign of the azimuthal asymmetry,  A, alone can provide a measure of the new particle's spin !!

What about SM backgrounds from , e.g., WW production?
Do these also have an azimuthal asymmetry?

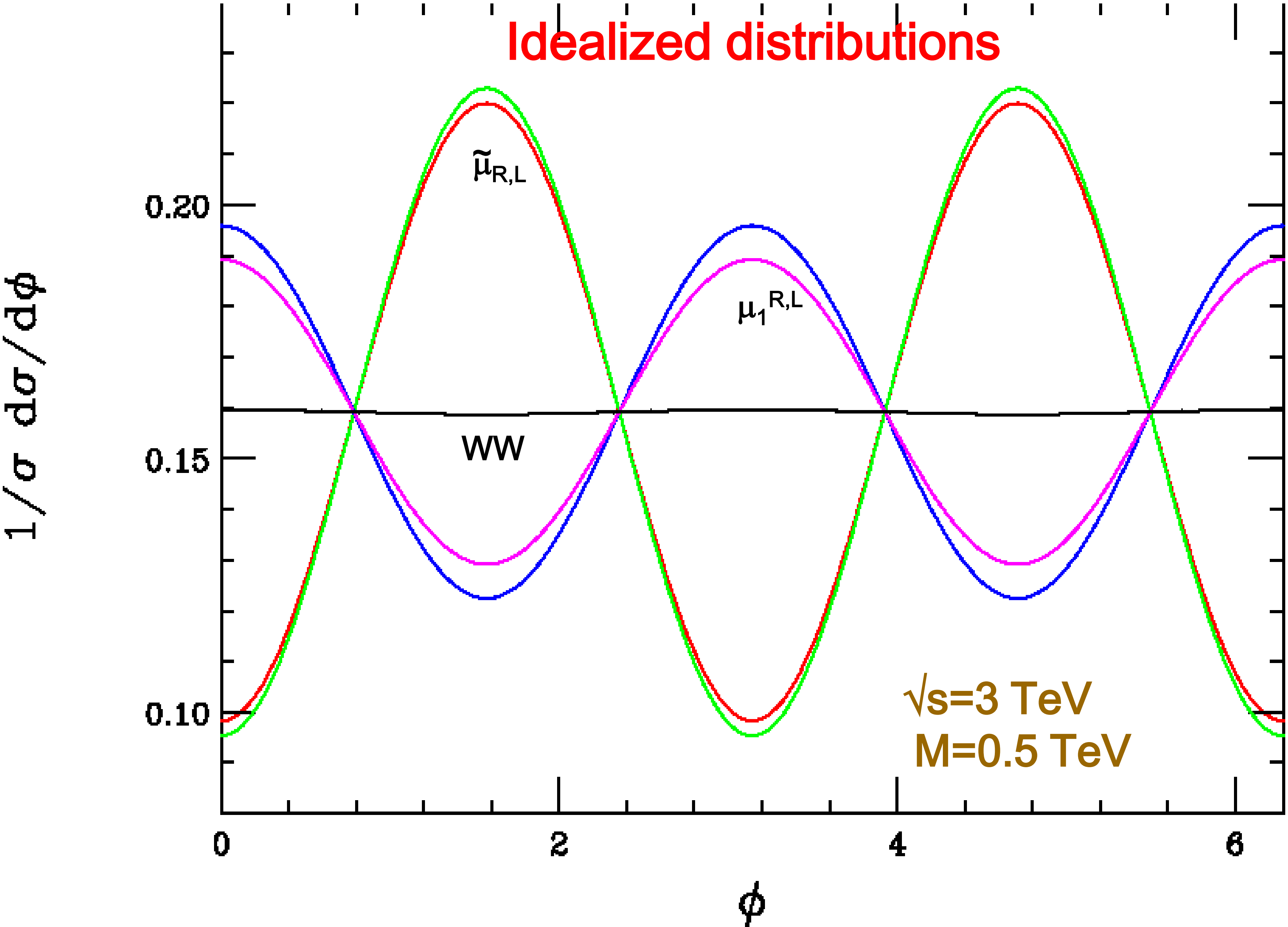


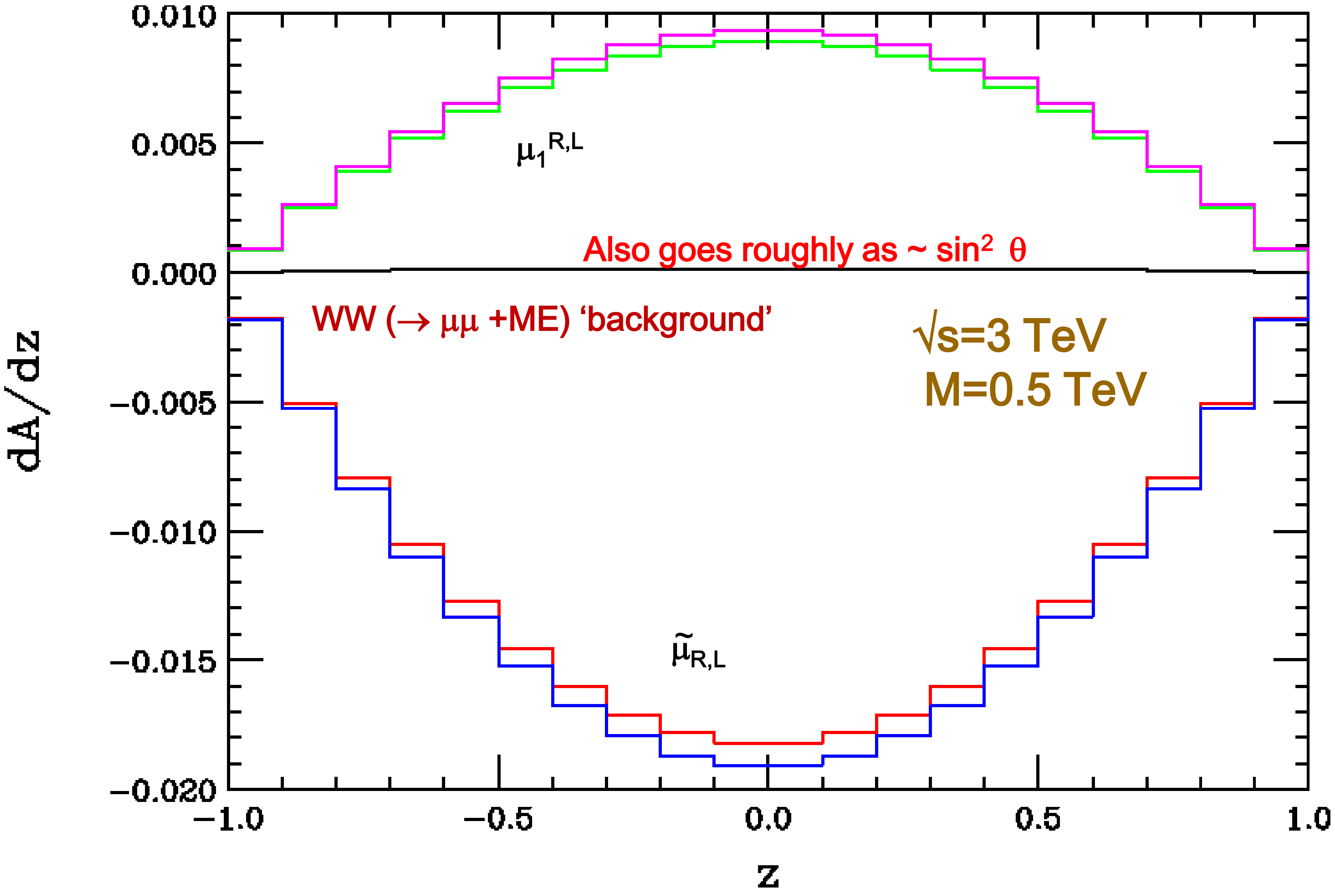
WW ($\rightarrow \mu\mu$ +ME) ‘background’

Note this is essentially ZERO !
Why ??

$\sqrt{s}$=3 TeV

# Idealized distributions





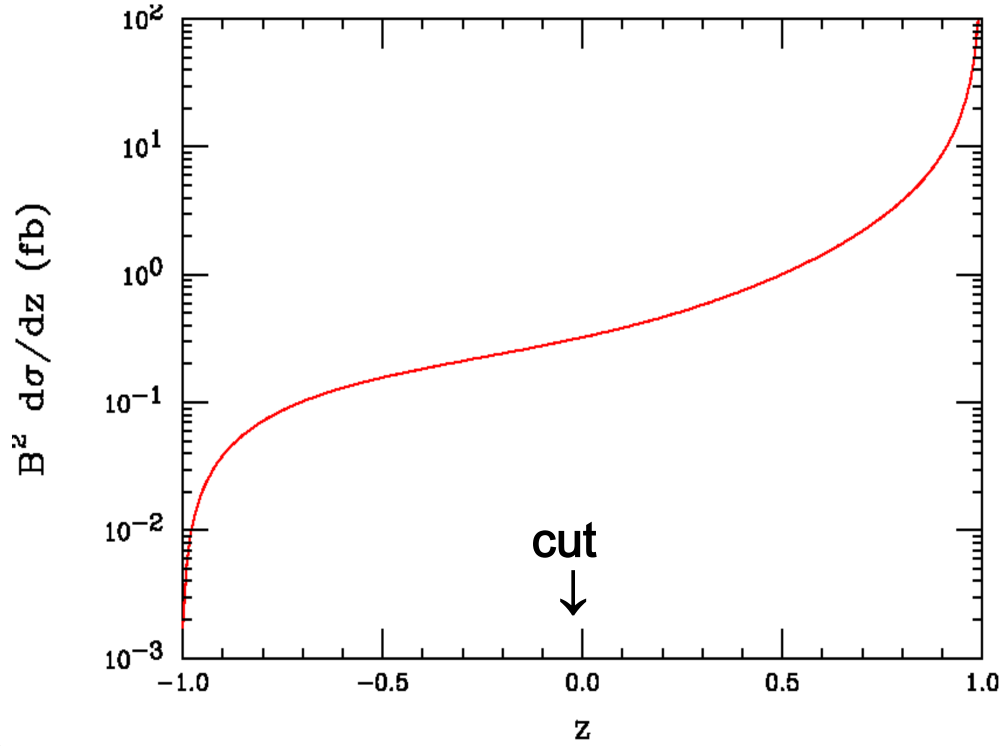
Also goes roughly as ~ $\sin^2\ \theta$

WW (→ μμ +ME) ‘background’

$\sqrt{s}$=3 TeV
M=0.5 TeV

$A_W \sim \int dz\ (2M_L M_R)/\int dz\ (M_L^2 + M_R^2) \ll 1$ since $M_R \ll M_L$

The most serious background* will only dilute the observed azimuthal asymmetry (unless it is removed). However, as is well known, most of the $W^-$ produced muons are highly peaked in the forward direction… but those from the signal are equally likely in both hemispheres.



Note that we cannot use the longitudinal polarization here to reduce these SM backgrounds !

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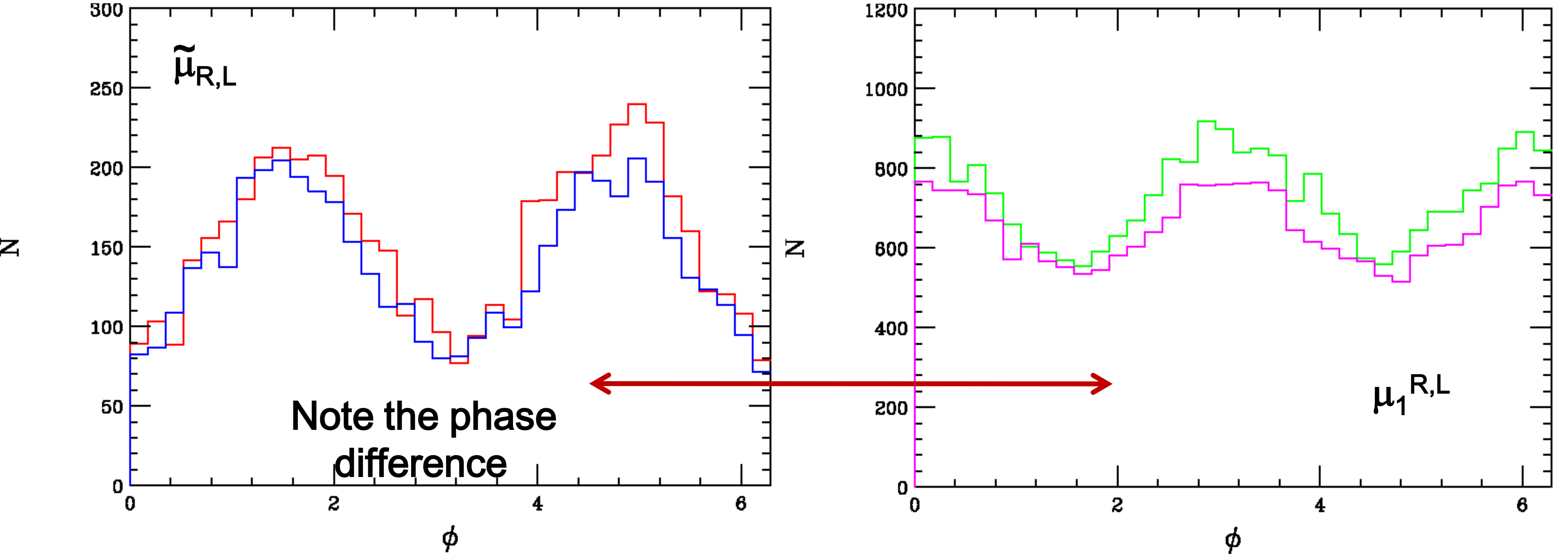
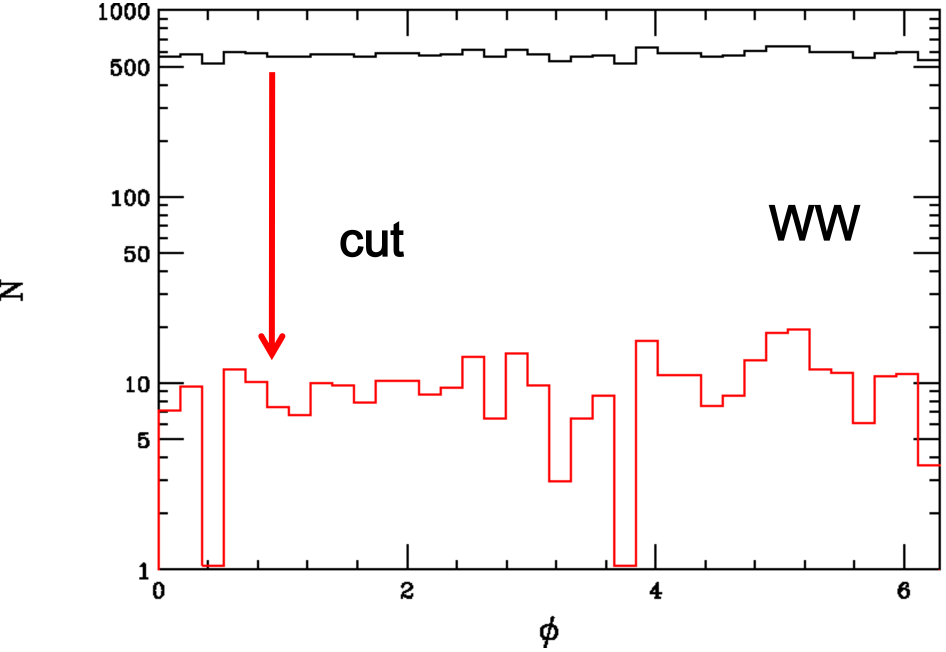
* The $\gamma\gamma$ background is removable with the standard acoplanarity etc. cuts & ZZ by dimuon invariant mass cuts



Note the phase difference



The azimuthal dependence is easily seen to have opposite signs in the 2 signal samples.

$\sqrt{s}$=3 TeV
L= 2 $ab^{-1}$
M=0.5 TeV

- Employing the simple cos $\theta(\mu^-) < 0$ cut reduces the signal by only a factor of 2 but the WW background, which is somewhat comparable in rate to the signal, is reduced by more than a factor of 60 !!

- This looks like a potentially promising approach to spin discrimination in the case of 'SUSY vs UED'

- However, this is just a 'proposal' for a REAL study with all the usual bells & whistles: decay simulations, full SM backgrounds, ISR/beamstrahlung for CLIC , other new physics BG sources, etc. etc.

These need to be done to understand the viability of this idea

# (II) Z' Coupling Measurements On-Resonance

- A Z'-like object within the CLIC energy reach may be found @ the LHC. We then can sit on the pole & measure everything

- With longitudinal polarization, the on-resonance observables used to determine Z' couplings are the familiar ones: $\Gamma_f$, $A_{FB}^f$, $A_{FB}^{pol}(f)$ & $A_{LR}$ . The last two require this polarization.

- If only transverse polarization were available, what are the alternatives to these last 2 observables & are they useful??

- On the Z' pole, the azimuthal angular distribution is given by

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\phi} \sim 1 + \frac{1}{2} P_1^T P_2^T (\lambda \cos 2\phi - \tau_f \sin 2\phi)$$

Hewett & TGR
'86

# What are these ??

$$\lambda = \frac{v'^2_e - a'^2_e}{v'^2_e + a'^2_e}$$

'Replaces' $A_{LR}$ & depends only on leptonic couplings

$$\tau_f = 2\,\frac{Q_e Q_f a'_e v'_f + v_e a'_e (v_f v'_f + a_f a'_f)}{(v'^2_e + a'^2_e)(v'^2_f + a'^2_f)}\boxed{\frac{\Gamma_{Z'}}{M_{Z'}}}$$

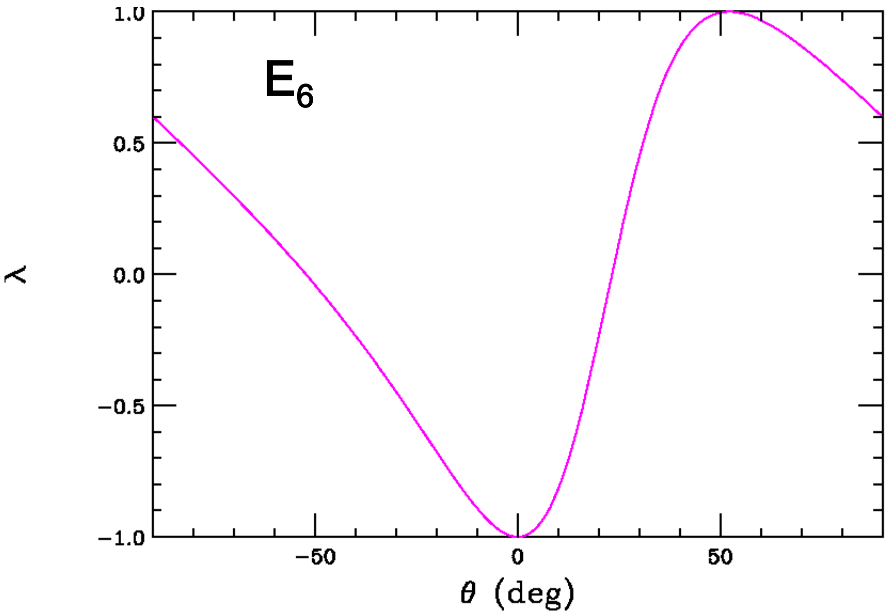
'Replaces' $A_{FB}^{pol}$ (f) & depends on leptonic & final fermion couplings

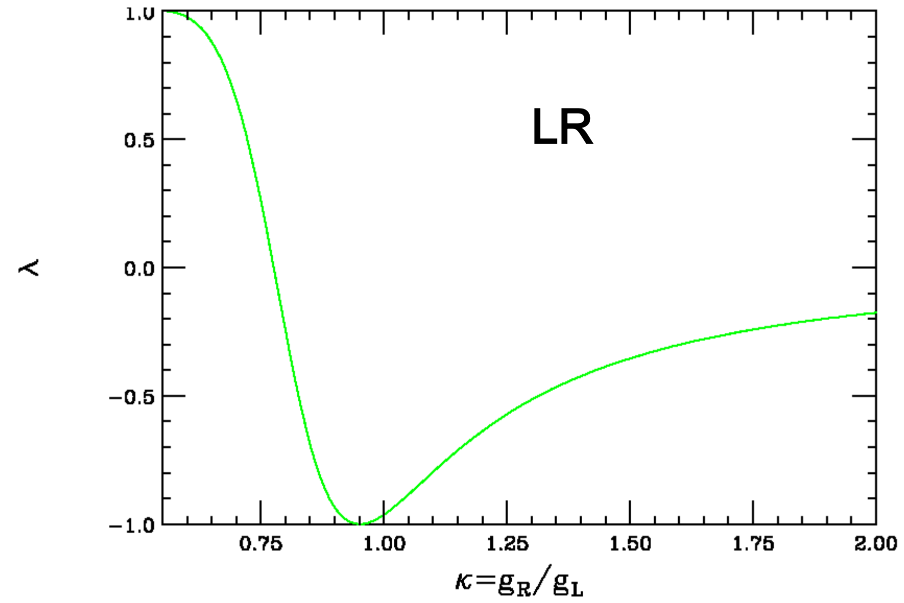
Both go as ~ $\sin^2 \theta$

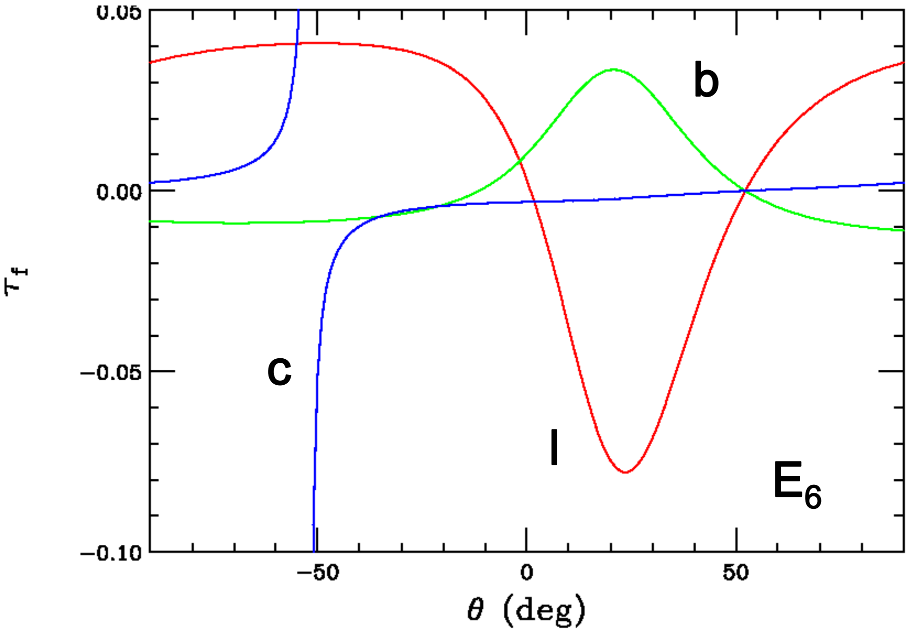
One may worry that this is hard to measure since most Z' are relatively narrow ..but the rates on the pole will be very large ~ $10^7$ ($B_e B_f$ /0.02 ) events/ $ab^{-1}$ even after ISR/beamstr. !!

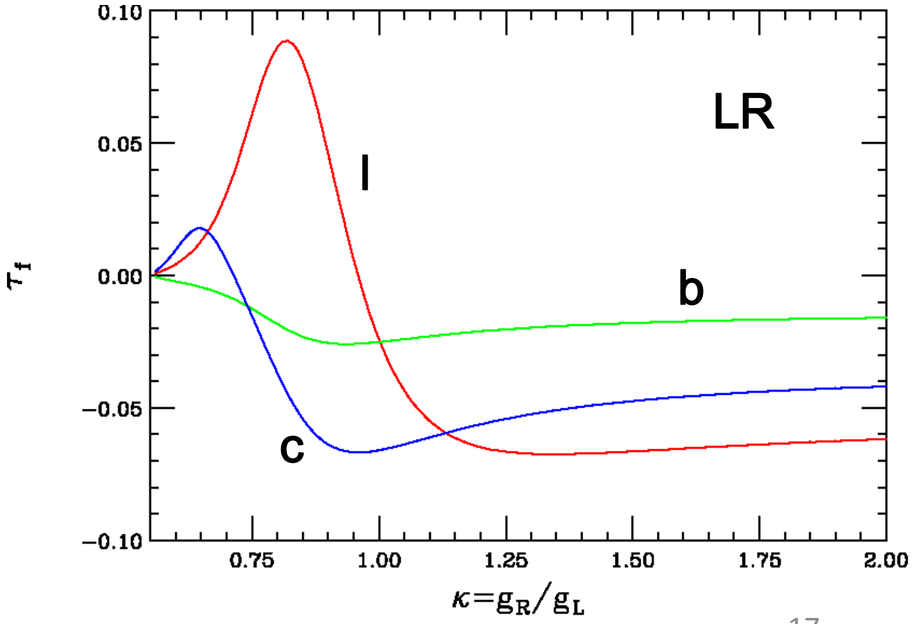
But are these observables sensitive to Z' model couplings??

YES !! Let's look at some examples…


E$_6$
λ
1.0
0.5
0.0
−0.5
−1.0
−50
0
50
θ (deg)


LR
λ
1.0
0.5
0.0
−0.5
−1.0
0.75
1.00
1.25
1.50
1.75
2.00
κ=g$_R$/g$_L$


b
c
l
E$_6$
τ$_f$
0.05
0.00
−0.05
−0.10
−50
0
50
θ (deg)


LR
l
b
c
τ$_f$
0.10
0.05
0.00
−0.05
−0.10
0.75
1.00
1.25
1.50
1.75
2.00
κ=g$_R$/g$_L$

# These asymmetries are useful even if the Z’ is a really a graviton KK :

$$\frac{d\Gamma}{dz\,d\phi} \sim (1-3z^2+4z^4)\left[1-P_1^T P_2^T \cos 2\phi\right]+\epsilon\frac{\Gamma}{M}P_1^T P_2^T F(z,v,a)\sin 2\phi$$

- Longitudinal polarization asymmetries vanish on the poles of spin-2 KK resonances but NOT the transverse polarization asymmetries! Note $\lambda_{\text{spin-2}}$ =-1 with a more complex angular (i.e, z) dependence.

- There even remains interference between the spin-2 & spin1 exchanges in the width suppressed Im term after integration over z .

# Summary

- A preliminary analysis indicates that transverse polarization may provide an additional tool to discriminate the spins of new particles

- Transverse polarization can also provide new tools to probe Z’ couplings using ‘different’ on-resonance observables

- In both of these cases further more detailed analyses seem to be warranted

- Transverse polarization continues to be interesting for many new physics studies