Forward-Backward Asymmetries of Fourth Family Fermions at CLIC

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- mainly based on arXiv:1108.2908 [hep-ph]
- FB asymmetry
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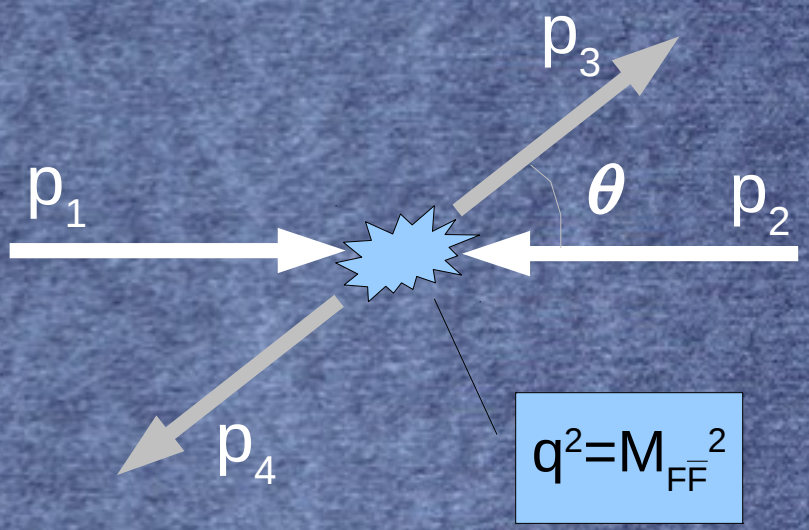
FB Asymmetry

- hard scattering cm-frame generically



- forward-backward asymmetry of pair production can be defined according to the scattering angle θ with respect to incoming particle direction

$$A_{FB} = \frac{\sigma(\cos\theta > 0) - \sigma(\cos\theta < 0)}{\sigma(\cos\theta > 0) + \sigma(\cos\theta < 0)}$$

where $\sigma(\cos\theta>0)$ is the cross section integrated out in the forward direction.

Motivation from top FB asymmetry

- The FB asymmetry in $t\bar{t}$ production with intriguing deviations from the SM prediction(6%).
- In the lepton+jets or dilepton channel @5.3/fb:

  $A_{FB}(CDF)=(15.8\pm7.4)\%$

  $A_{FB}(D0)=(19.6\pm6.5)\%$

  which are more than 2σ above the SM result.

- However, the FB asymmetry is observed (CDF) to be more pronounced in the large $t\bar{t}$ invariant mass region

  $A_{FB}=(47.5\pm11.4)\%$ for $M_{tt}>450$ GeV

  $A_{FB}=-(11.6\pm15.3)\%$ for $M_{tt}<450$ GeV

  while the SM prediction 9% and 4%, respectively.

Motivation from top charge asymmetry

- It would also constitute an independent confirmation of FB asymmetry.
- Measurement of a **charge asymmetry**

$$A_C = [N(\Delta|\eta|>0) - N(\Delta|\eta|<0)] / [N(\Delta|\eta|>0) + N(\Delta|\eta|<0)]$$

where $\Delta|\eta| = |\eta_t| - |\eta_{\bar{t}}|$.

in $t\bar{t}$ production at LHC:

- A_C=6% with a large statistical uncertainty, and need more analysis to reduce uncertainties at LHC.

Fourth Family

- Even though we observe three families of quarks and leptons of the SM, there could be a fourth family if their masses are beyond our present experimental reach.

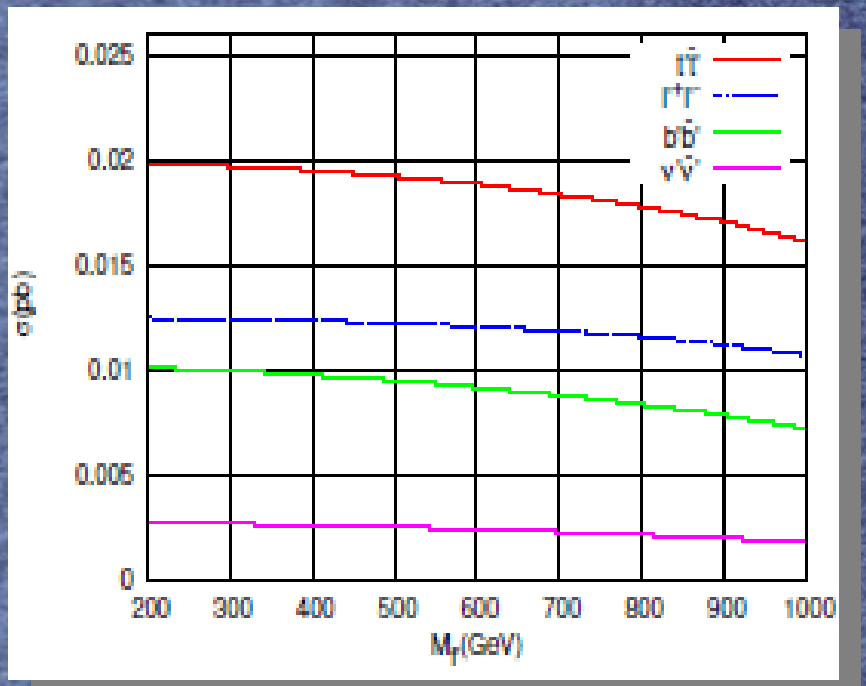
- The allowed parameter space is restricted by experimental searches, precision EW data, theoretical constraints (unit. & pert.):
  - * $|M_{t'}-M_{b'}| \approx 50\text{-}70$ GeV
  - * $|M_{l'}-M_{\nu'}| \approx 30-60$ GeV

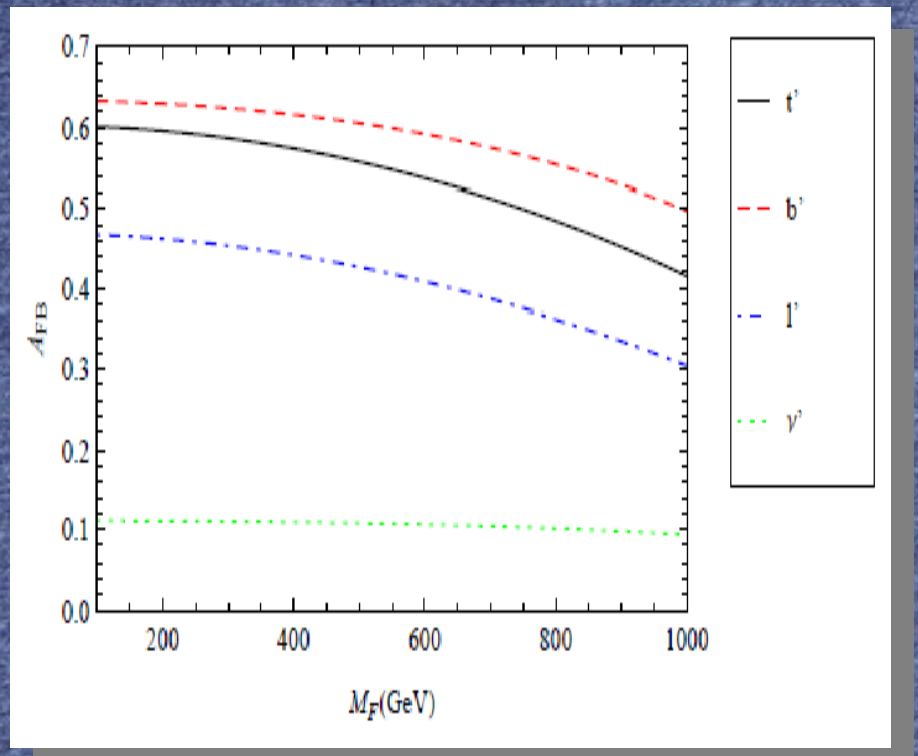
[He01,Kribs07,Erler10,Lenz10]

Today's experiments restrict the masses of 4th family: $M_{b'}>385$ GeV, $M_{t'}>400$ GeV [CDF11]

$M_{l'}>100$ GeV, $M_{\nu'}>50$ GeV [LEPII]

σ and A_{FB} vs M_F





Family independent V-A couplings to Z' bosons predicted by BSM4

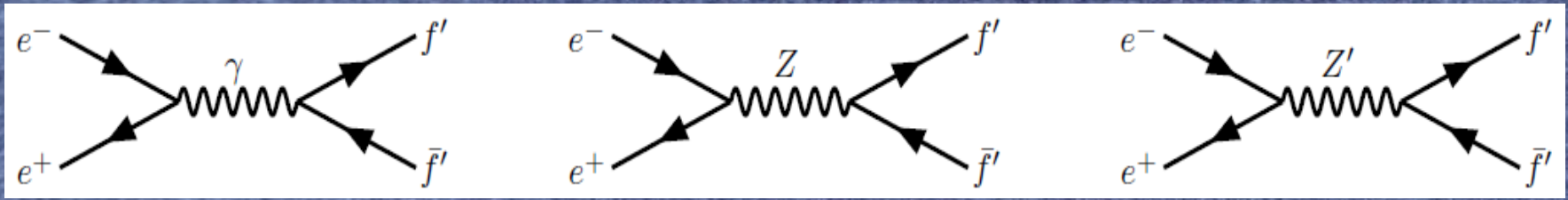
Interaction Lagrangian

$$L' = -g_s\overline{Q}_i T^a \gamma^\mu Q_i G^a_\mu - g_e Q_F \overline{F}_i \gamma^\mu F_i A_\mu - \frac{g}{2\sqrt{2}} V_{ij} \overline{F}_i \gamma^\mu (1-\gamma^5) f_j W_\mu$$
$$-\frac{g_Z}{2}\overline{F}_i\gamma^\mu(C_V^F - C_A^F\gamma^5)F_i Z_\mu - \frac{g_{Z'}}{2}\overline{F}_i\gamma^\mu(C_V'^F - C_A'^F\gamma^5)F_i Z'_\mu + \text{H.c.}$$

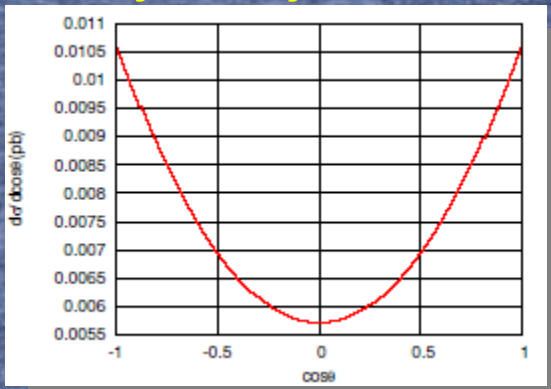
V-A couplings to Z'

down-type quarks		up-type quarks		charged leptons		neutrinos	
C'_V	C'_A	C'_V	C'_A	C'_V	C'_A	C'_V	C'_A
Z'_S							
$-\frac{1}{2}+\frac{2}{3}\sin^2\theta_W$	$-\frac{1}{2}$	$\frac{1}{2}-\frac{4}{3}\sin^2\theta_W$	$\frac{1}{2}$	$-\frac{1}{2}+2\sin^2\theta_W$	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Z'_ψ							
0	$\frac{\sqrt{10}}{6}\sin\theta_W$	0	$\frac{\sqrt{10}}{6}\sin\theta_W$	0	$\frac{\sqrt{10}}{6}\sin\theta_W$	$\frac{\sqrt{10}}{12}\sin\theta_W$	$\frac{\sqrt{10}}{12}\sin\theta_W$
Z'_χ							
$\frac{\sqrt{6}}{3}\sin\theta_W$	$-\frac{\sqrt{6}}{6}\sin\theta_W$	0	$\frac{\sqrt{6}}{6}\sin\theta_W$	$-\frac{\sqrt{6}}{3}\sin\theta_W$	$-\frac{\sqrt{6}}{6}\sin\theta_W$	$-\frac{\sqrt{6}}{4}\sin\theta_W$	$-\frac{\sqrt{6}}{4}\sin\theta_W$
Z'_η							
$\frac{1}{2}\sin\theta_W$	$\frac{1}{6}\sin\theta_W$	0	$2\sin\theta_W$	$-\frac{1}{2}\sin\theta_W$	$\frac{1}{6}\sin\theta_W$	$-\frac{1}{6}\sin\theta_W$	$-\frac{1}{6}\sin\theta_W$
Z'_{B-L}							
$\frac{2}{3}$	0	$\frac{2}{3}$	0	-2	0	-1	-1

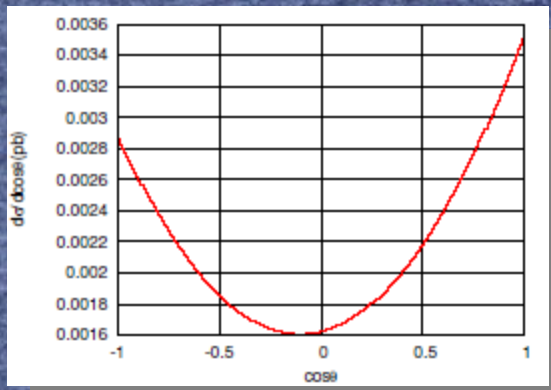
4thF Quarks and 4thF Lepton



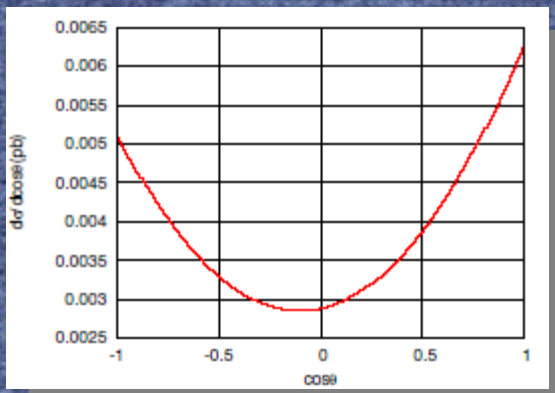
This diagram doesn't produce asymmetry



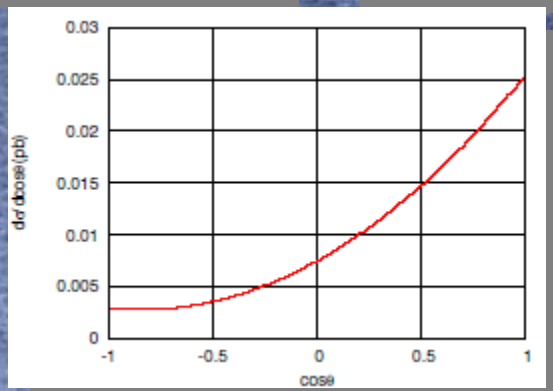
This diagram produces a bit asymmetry

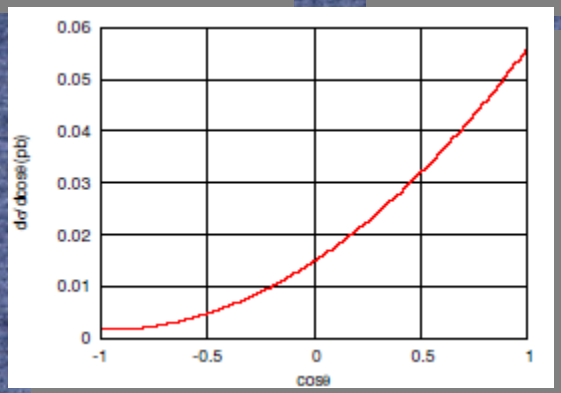


BSM4: This diagram produces a bit asymmetry



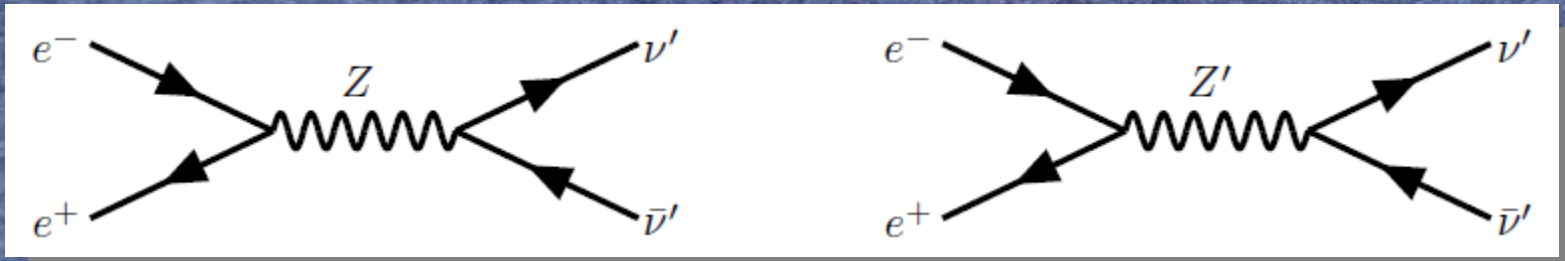
But the interference produces more asymmetry



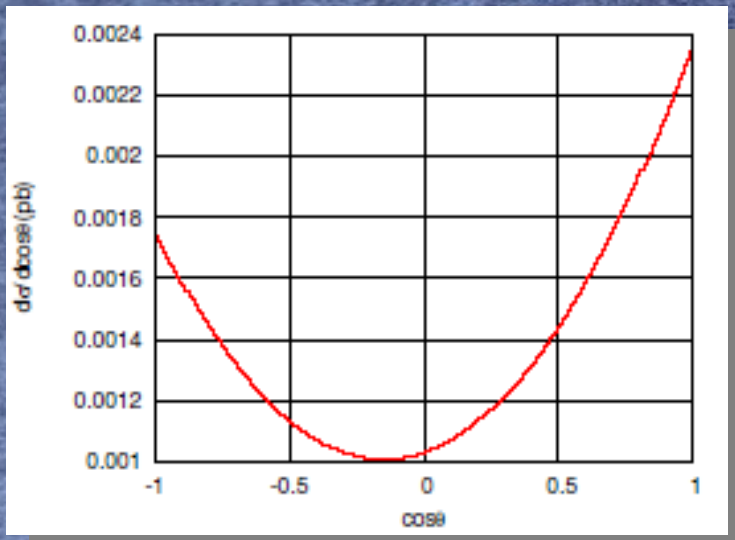


BSM4: all interferences produces much more asymmetry! (ex: seq. Z')

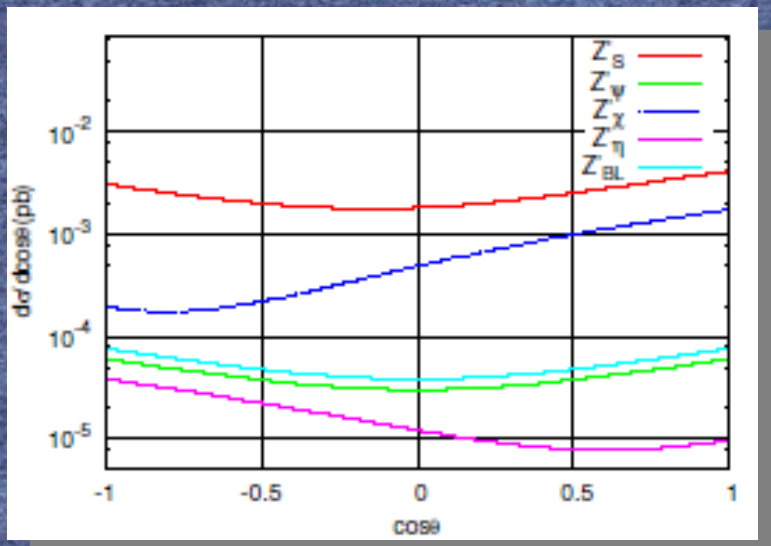
4thF Neutrino



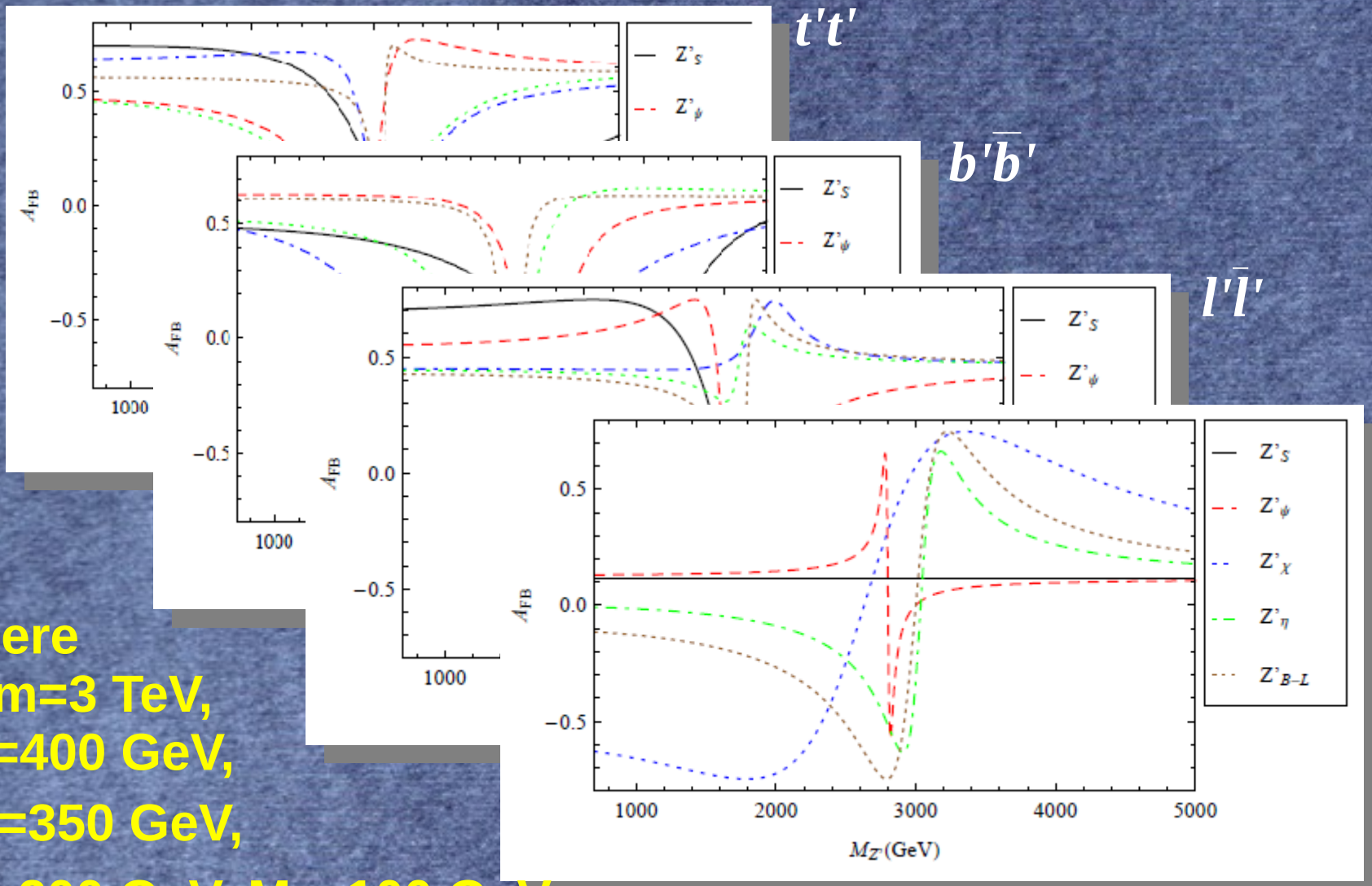
Z-boson exchange produces a bit asymmetry



BSM4: Z' models produces different asymmetries



FB Asymmetries for 4thF with Z'



where
Ecm=3 TeV,
$M_{t'}$=400 GeV,
$M_{b'}$=350 GeV,
$M_{l'}$=200 GeV, $M_{\nu'}$=100 GeV

Cross sections (in fb)

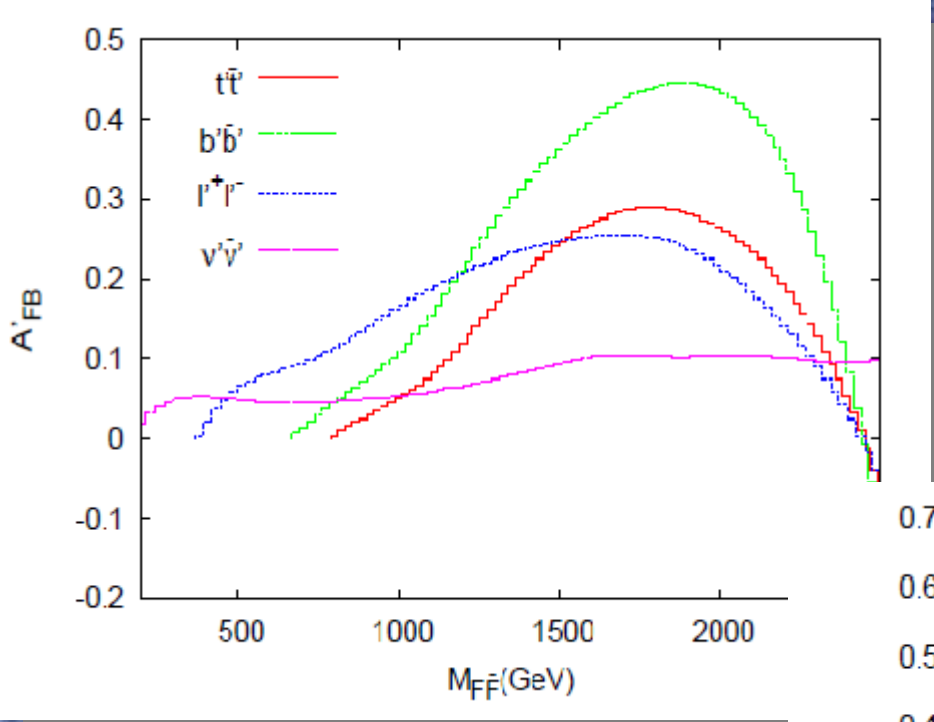
Mass (GeV)	$l'l'$	$\nu'\nu'$
100	12.47	2.74
200	12.44	2.71
300	12.39	2.67
400	12.31	2.60
500	12.20	2.52

Mass (GeV)	$t't'$	$b'b'$
300	19.70	9.93
400	19.40	9.74
500	19.20	9.48
600	18.80	9.17
700	18.30	8.79

For Z' effects the parameters: $M_{Z'}$=1.5 TeV, g_{BL}=0.1, $M_{t'}$=400 GeV, $M_{b'}$=350 GeV, $M_{l'}$=200 GeV, $M_{\nu'}$=100 GeV.

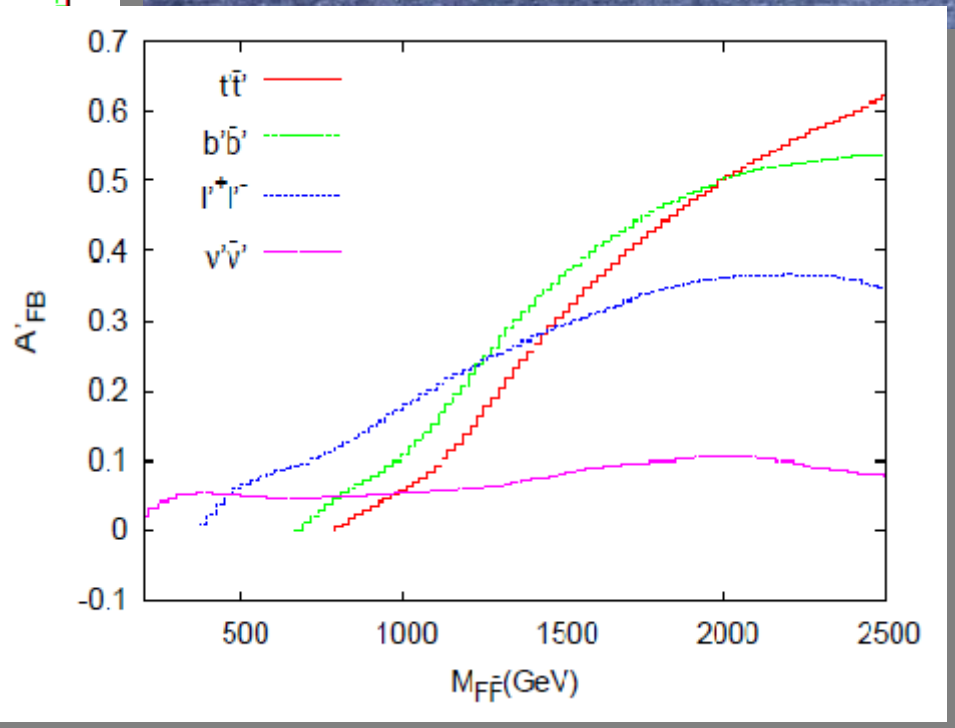
σ(fb)	Z'_S	Z'_ψ	Z'_χ	Z'_η	Z'_{BL}
t't'	39.10	17.40	22.00	23.31	21.54
b'b'	35.94	12.87	6.81	8.58	8.85
l'l'	18.47	13.51	20.99	15.05	15.65
ν'ν'	14.90	1.89	2.11	2.92	2.76

FB Asymmetry vs Invariant Mass



where ISR+BS included, Ecm=3 TeV, $M_{Z'}$=3.5 TeV $M_{t'}$=400 GeV, $M_{b'}$=350 GeV, $M_{l'}$=200 GeV, $M_{\nu'}$=100 GeV.

Z'_S model



Z'_ψ model

Conclusions

- The t' and b' quarks produce A_{FB}=0.5 for M_{FF}=2 TeV if the Z_{ψ} model is realized beyond the SM4.
- Heavy charged lepton FB asymmetry can be measured at relatively low invariant mass region.
- We have predicted a new physics around TeV scale, however the specific signals are model dependent at this level of description and would be interesting to pursue as future work.