

# *Summary and Plans: Electroweak and alternative Theories*

*G. Pásztor*

*UC Riverside, KFKI RMKI Budapest*

*WG conveners:*

*A.Denner, T. Ohl, M.Spira*

*K. Mönig, G. Pásztor*

*Montpellier, ECFA LC Study, Nov 13-16, 2004*

# *New LC notes since 2003 summer*

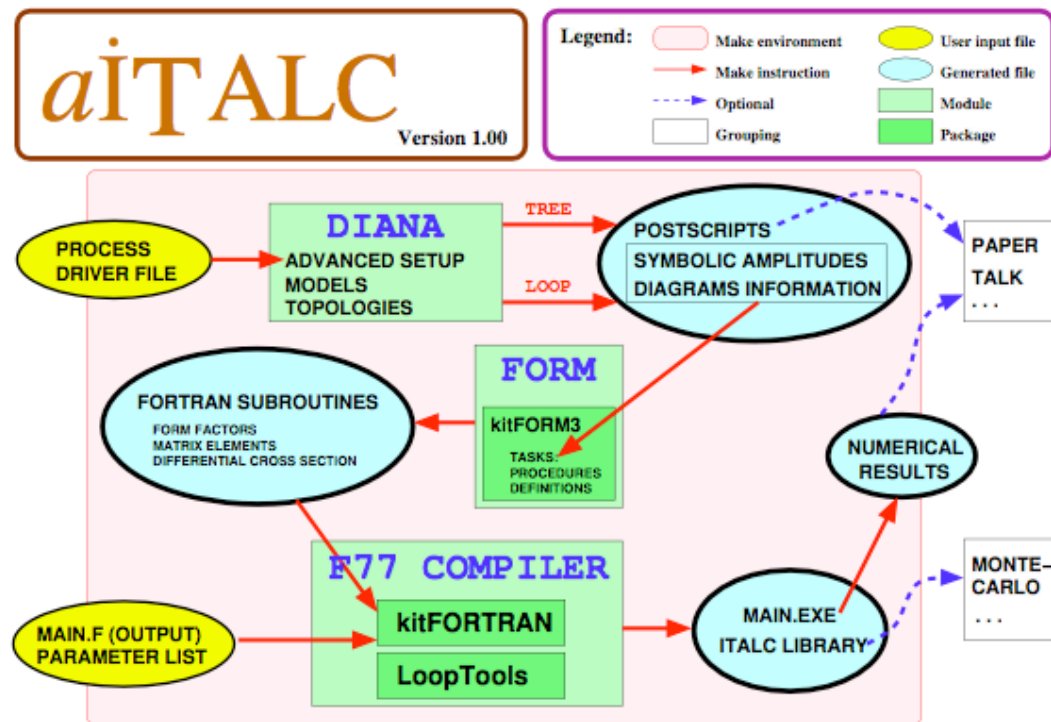
- ✗ I. Marfin, V. Mossolov, T. Shishkina: Anomalous quartic boson couplings via  $\gamma\gamma WW$  and  $\gamma\gamma WWZ$  at the TESLA kinematics*
- ✗ K.Mönig, J.Sekaric: A Study of Charged Current Triple Gauge Couplings at  $e^+e^-$  collider*
- ✗ O. Nachtmann, C. Schwanenberger: CP Violation in the 3 Jet and 4 Jet Decays of the Z-Boson at GigaZ*
- ✗ M. Czakon, J. Gluza, J. Hejczyk: Tree and one-loop level tests of the minimal LR-symmetric model*
- ✗ M. Diehl, O. Nachtmann, F. Nagel: Probing triple gauge couplings with transverse beam polarization in  $e^+e^- \rightarrow W^+W^-$*
- ✗ S. De Curtis: Electro-weak Fits at CLIC*
- ✗ P. Osland, A.A. Pankov, N. Paver: Discriminating graviton exchange effects from other new physics scenarios in  $e^+e^-$  collision*

# *Presentations in Montpellier*

- ✘ Francois Richard: Benefits of an improved  $e^-$  polarization accuracy*
- ✘ Jadranka Sekaric: TGCs from  $e^+e^- W^+$*
- ✘ Felix Nagel: TGCs with transverse polarization*
- ✘ Alejandro Lorca: Complete  $O(\alpha_s)$  massive corrections to Bhabha scattering; automatization with aITALC*
- ✘ Christian Schwanenberger: CP violation in 3- and 4-jet decays of the Z boson at GigaZ*

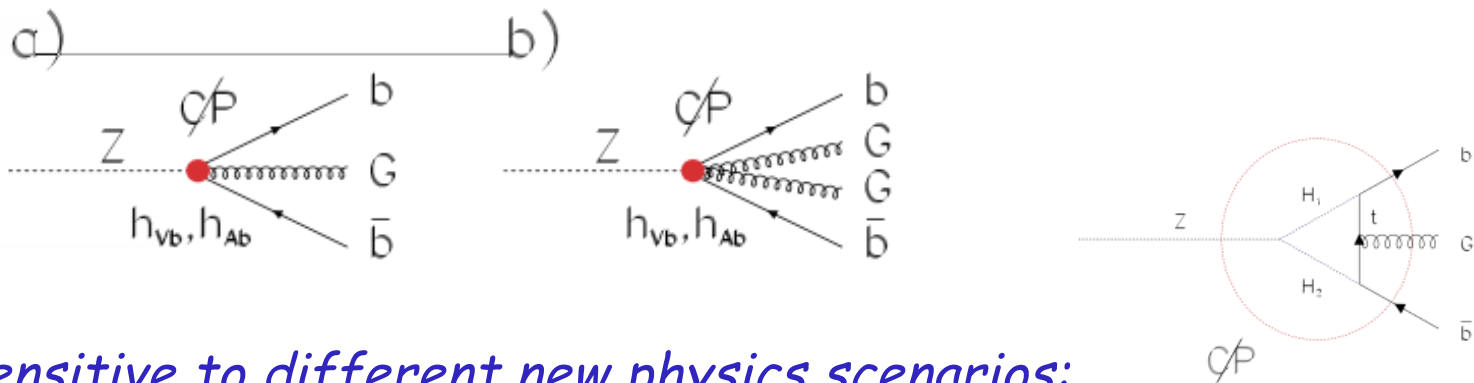
# $O(\square)$ massive Bhabha scattering calculation with aITALC

- ✗ aITALC: automatic tool to compute  $2 \square 2$  processes, planned launch 2004 February (A. Lorca, T. Riemann)
- ✗ Agreement with FeynArts + FormCalc + LoopTools calculation (T. Hahn) to 14 digits  
~double precision



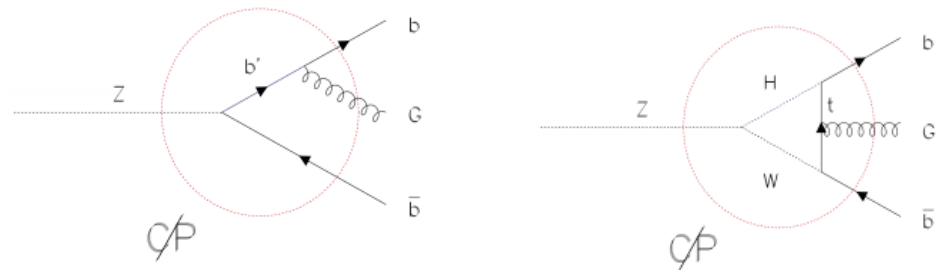
# CP violation in $Z \rightarrow 3, 4$ jets

- Search for CP-violating  $Zbbg$  and  $Zbbgg$  couplings using CP-odd vector and tensor observables constructed from the momentum vectors of the  $b$  and anti- $b$  quarks

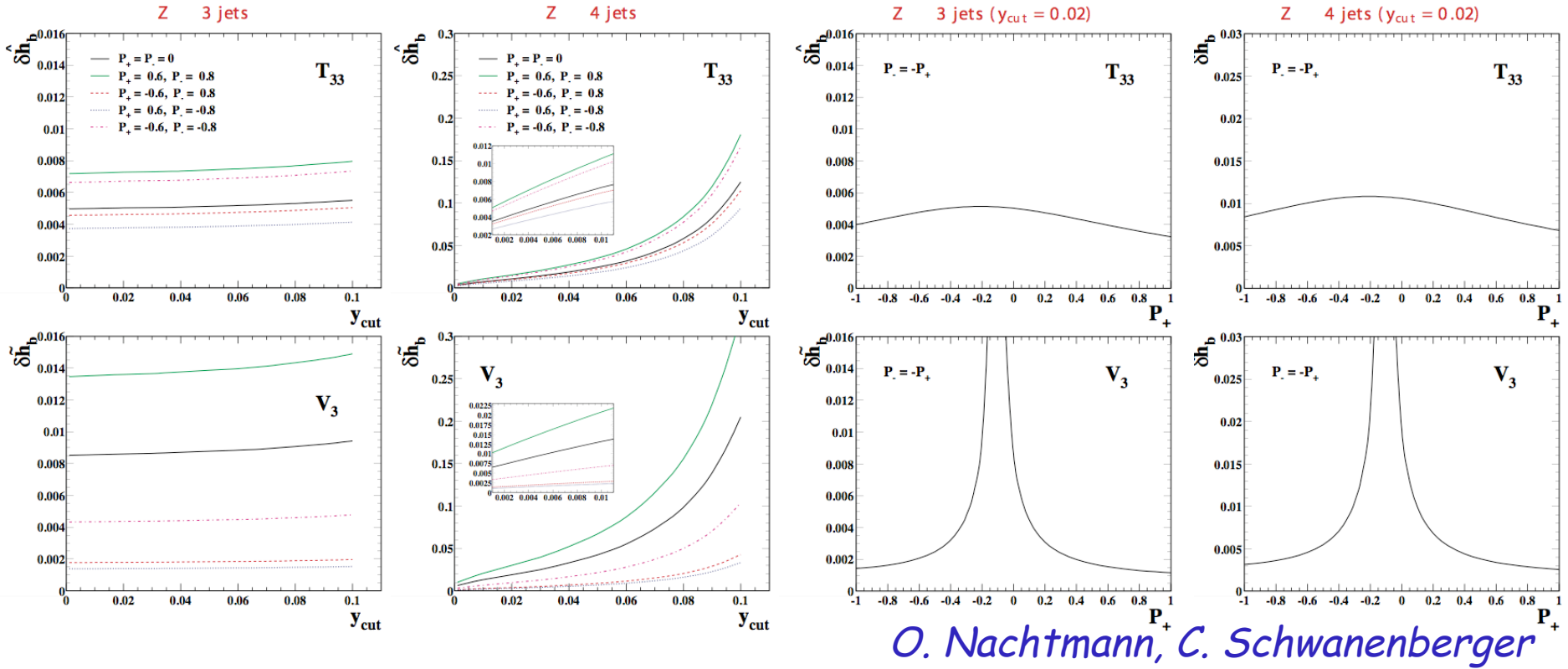


- Sensitive to different new physics scenarios: excited  $b'$  quarks, charged Higgs, ...

e.g. charged Higgs



# CP violation in $Z \rightarrow 3, 4$ jets



O. Nachtmann, C. Schwanenberger

- ✗ *GigaZ can increase sensitivity by a factor of 10 with respect to LEP*
- ✗ *Choice of polarization effects sensitivity greatly for vector observable*
- ✗ *Code for MC reweighting available for interested experimentalists*

# *$e^-$ polarization systematics*

- ✗ Precision measurements limited by systematics on  $P(e^-)$  using polarimeters  $dP \sim 0.5\%$  (SLC)  $\square$   $0.25\%$   $\square$  ?*
- ✗ De-polarization effects of  $0.2\%$  @  $500 \text{ GeV}$ 
  - ✗ How well is it understood?**
- ✗ If  $P(e^+)$  also available, systematics on effective polarization is much reduced due to favorable error propagation
  - ✗ Need to know correlated time variations from polarimeters**
- ✗ At GigaZ: Blondel scheme based on  $ee \square ff$  with pure  $s$ -channel vector exchange
  - ✗ De-polarization accounted for*
  - ✗ Automatically luminosity weighted*
  - ✗ Assumed: only sign flips, absolute value of  $P$  remains the same, polarimeters needed for relative measurements*
  - ✗ Need to know correlated time variations*
  - ✗ Luminosity needs to be spent on less interesting polarization combinations**

# $e^-$ polarization systematics

- ✗ *Blondel scheme can be used at high energy using  $ff$  with  $s=s'$  (5-2 pb at 350-500 GeV,  $A_{LR} \sim 0.5$ ) or radiative return  $ff$  (17-7 pb,  $A_{LR} \sim 0.2$ , need to reject Zee background:  $\sim 10\%$  efficiency)*
- ✗  *$W$  couples to L-handed  $e^-$ :  $WW$ ,  $We$  natural tools to measure  $P$*   
*large forward peak in  $WW$  dominated by t-channel  $\square$  exchange:*  
 *$A_{LR}$  in this region not sensitive to anomalous couplings*
- ✗ *Typically a factor 3-4 improvement w.r.t. polarimeter measurement*

K. Mönig, Snowmass 2001 proceedings (for 500 GeV errors a factor of 2 larger)

$A_{LR}$  with s-channel  
vector exchange

$\square$  suppression /  
enhancement  
for s-channel  
vector exchange

... for t-channel

$WW$  production

L=500 fb <sup>-1</sup> E <sub>cm</sub> =350 GeV	value	Rel. error [%]							
		L <sub>ee</sub> /L = 0.5			L <sub>ee</sub> /L = 0.1			Polarimeter	
		HE	rr	WW	HE	rr	WW	= 0	= 0.5
$P_{e^+}/P_{e^-}$ [%]	0.8	0.10	0.51	0.07	0.21	1.11	0.11	0.25	0.25
$P_{e^+}/P_{e^-}$ [%]	0.6	0.12	0.53	0.11	0.15	1.13	0.21	0.25	0.25
corr		$\pm 0.49$	$\pm 0.91$	0	$\pm 0.56$	$\pm 0.93$	$\pm 0.52$	0	0.50
$(P_{e^+} + P_{e^-}) / (1 + P_{e^+} P_{e^-})$	0.95	0.02	0.08	0.02	0.05	0.17	0.02	0.07	0.08
$P_{e^+} P_{e^-}$	0.48	0.11	0.22	0.13	0.18	0.42	0.18	0.35	0.43
$P_{e^+} + P_{e^-} \pm P_{e^+} P_{e^-}$	0.92	0.03	0.12	0.03	0.06	0.25	0.03	0.09	0.11

ECFA LC Study, Montpellier, Nov 13-16, 2004

G. Pasztor: EW and Alternatives

# *$e^-$ polarization systematics*

- × WW can also be used in the absence of  $P(e^+)$  to recover sensitivity for  $A_{LR}$*
- × F. Richard 's quick estimate for  $1 \text{ ab}^{-1}$  at 1 TeV:  
gain of 14 on  $dP$  □ gain of 5 on  $A_{LR}$  accuracy (w.r.t.  $dP=0.5\%$ ) □  
discriminate between  $Z'$  models and measure  $Z'$  mass with  $<10\%$  error up  
to 7 TeV (LHC: direct observation up to 5 TeV, identification up to 2 TeV)*

*Open questions:*

- × No study at all for  $We$  □*
- × F.R.'s estimate does not take into account any detector effect*
- × K.M.'s WW study based on tree-level analytic calculation only*
- × Radiative corrections?*
- × New physics (e.g. KK towers...) can contribute  
angular distribution can be used to estimate / handle this effect*

*Common interest with machine experts!*

# TGCs from $ee \rightarrow WW$

- ✗ *New phenomenological study using semi-leptonic WW*
- ✗ *Most general Lorentz invariant parametrization: 28 real parameters  
7-7  $\Gamma_{WW}$ ,  $ZWW$  couplings (4 CP conserving, 3 CP violating)  
 $CPT^{\sim}$  symmetry: real and imaginary parts*
- ✗ *In SM  $g_1^W = g_1^Z = \kappa_W = \kappa_Z = 1$ , others = 0*
- ✗ *Only loose constraints from LEP*
- ✗ *6 experimental observables: W production and decay angles*
- ✗ *Construct optimal observables to get highest statistical sensitivity*
- ✗ *4 symmetry classes of couplings (CP,  $CPT^{\sim}$ ) with no correlation between classes*
- ✗ *Fit all 28 couplings simultaneously*

# TGCs from $ee \rightarrow WW$

Errors in units of  $10^{-3}$

M. Diehl, O. Nachtmann, F. Nagel

<i>CP conserving, real part</i>	$\square g_1^{\square}$	$\square g_1^Z$	$\square \square_{\square}$	$\square \square_Z$	$\square_{\square}$	$\square_Z$	$g_5^{\square}$	$g_5^Z$
No polarization	6.5	5.2	1.3	1.4	2.3	1.8	4.4	3.3
$(P_-, P_+) = (\pm 80\%, 0)$	3.2	2.6	0.61	0.58	1.1	0.86	2.2	1.7
$(P_-, P_+) = (\pm 80\%, \pm 60\%)$	1.9	1.6	0.40	0.36	0.62	0.50	1.4	1.1
$(P_-, P_+) = (80\%, 60\%)$	2.8	2.4	0.69	0.82	0.69	0.55	2.5	1.9

*Similar sensitivity for all classes (e.g. 0.36-2.5 with  $e^+, e^-$  polarization)*

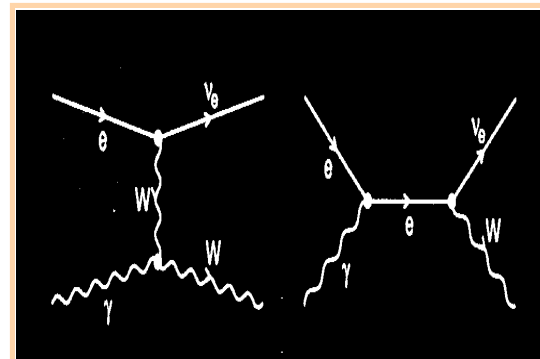
*Large correlations  $\square$  use LR basis to reduce correlation*

*$h_+ = \text{Im}(g_1^R + \square_R) / 2$  only measurable with transverse polarization!*

- ✗ No polarization: 27 couplings measurable*
- ✗  $e^-$  polarization: factor 2 improvement on sensitivity*
- ✗  $e^-, e^+$  polarization: factor 3-4 improvement*
- ✗ Transverse polarization: factor 2-4 improvement, access to  $\text{Im}(g_1^R + \square_R) / 2$*

# TGCs from $e^+e^- \rightarrow W^+W^-$

- ✗ L-handed  $e$ , R-handed  $\nu$  to suppress s-channel  $e$  exchange
- ✗ Pythia for event generation at 450 GeV  
SIMDET v3 for detector simulation
- ✗ Hadronic  $W$  decays only
- ✗ Real  $e^+e^-$  mode: main background  $e^+e^- \rightarrow e^+Z, (e^+e^-) \rightarrow qq$   
Parasitic  $e^+e^-$  mode at  $ee$  collider:  
new backgrounds  $ee \rightarrow WW$  (semi-leptonic),  $ee \rightarrow qq$
- ✗ High  $\sim 90\%$  efficiency with 82% / 73% purity
- ✗ 3 kinematic variables:  $W$  polar angle,  $W$  decay polar & azimuthal angles
- ✗ WHIZARD ME to reweight distributions for TGCs
- ✗ Only  $\nu_e$  and  $\nu_\mu$  considered in the fit



# TGCs from $e^+e^- \rightarrow W^+W^-$

Errors in units of  $10^{-3}$

K.Mönig, J.Sekaric

Real / Parasitic	$\sigma_{\text{sig}}$			$\sigma_{\text{bkg}}$		
	1%	0.1%	0%	1%	0.1%	0%
dL						
Generator level	3.3/3.4	1.0/1.0	0.4/0.4	0.29/0.31	0.27/0.29	0.27/0.29
Efficiency	3.4/3.5	1.0/1.0	0.5/0.5	0.33/0.34	0.30/0.32	0.30/0.32
Variable $E_{\text{beam}}$ , WHIZARD	3.6/3.7	1.0/1.0	0.5/0.5	0.44/0.45	0.40/0.41	0.39/0.40
Background	3.6/3.7	1.0/1.0	0.5/0.5	0.44/0.45	0.40/0.41	0.39/0.40

Systematics (for  $dL=0.1\%$ )

- ✗ 1% change in photon polarization at  $P=+90\%$ :  $\sigma_{\text{sig}} \sim 5\%$ ,  $\sigma_{\text{bkg}} \sim 1\%$  effect
- ✗ 50 MeV error on  $W$  mass:  $\sigma_{\text{sig}}$ ,  $\sigma_{\text{bkg}} \sim 1\%$  effect
- ✗ Beam energy spectrum: no effect

Ongoing study of low energy  $\gamma\gamma$  events (beam strahlung)

# Remarks on charged TGCs

- x  $ee \rightarrow WW$  phenomenological study on its way but using a different effective Lagrangian, will be difficult to compare with  $ee$  results*
  - x Understand differences for non-polarized  $ee \rightarrow WW$  results between TDR spin-density matrix and new  $OO$  analyses ( $OO_V$ )*
  - x Physics interpretation of measured anomalous couplings depends on process*
    - x  $ee \rightarrow WW$  sensitive to vector resonances*
    - x  $ee \rightarrow WW$  sensitive to scalar and tensor resonances*
    - x  $e \rightarrow eW$  no effect from close by resonances*
- need all information to understand the nature of new physics*

# Possible subjects for the group

*Suggestions to initiate the discussion in Montpellier:*

- × Definition of suitable pseudo-observables for  $W$  pair-production that allow to interpret published data within different models
  - × SUSY:  $WW$  production through chargino box... no TGC involved*
  - × Expectation from loop corrections  $\sim 3 \cdot 10^{-3}$  but sensitivity to  $\sim 10^{-4}$ : able to test SM in the same way as  $\sin^2 \theta_{eff}$  and  $m_W$  do now**
- × A complete evaluation of Strong EWSB signals ( $ee \rightarrow WW, VVV, VV\gamma\gamma; \gamma\gamma \rightarrow WW, WWZ; e\gamma\gamma \rightarrow W\gamma, WZ\gamma, \dots$ ). Which parameters can we extract with which accuracy?
  - × Interaction among gauge bosons given by gauge structure*
  - × Longitudinal gauge bosons connected to the EWSB mechanism: their interactions can teach us about this mechanism if there is no elementary Higgs*
  - × In strongly interacting theory longitudinal gauge bosons expected to have similar interactions to pions in QCD: expect to see effects from the dynamics of the new theory**

# Possible subjects for the group

- × *Which signals can we expect from Little Higgs theories?*
  - ×  *$Z'$ ,  $W'$ , vector-like fermion states, new scalars*
  - × *Direct detection is not very probable at LC look for indirect effects: contact interactions, TGCs*
- × *Are we able to observe and analyze the unexpected (BBSM ~ Beyond 'traditional' BSM)?*
  - × *Non-commutative QED? ...*
- × *ED theories*
  - × *KK excitations, stringy effects, ...*
  - × *Radions (studied in the Higgs group)*
- × *Tree vs. one-loop level*
  - × *Recent study on minimal LR symmetric model (M. Czakon, J. Gluza, J. Heyczyk) shows that corrections from SM particles have a different structure from their SM counterpart: in fits it is not sufficient to use only tree-level couplings modified by SM radiative corrections... where does this happen in other models?*

# Possible subjects for the group

- ✘ *Lack of realistic experimental studies... especially on fermion-pair production: studies by experimentalists so far ~ phenomenological studies including some experimental systematics*
- ✘ *A lot to learn and give as input to the machine design*  
*Example: What precision do we really need on luminosity?*
  - ✘ *If decision on crossing angle, we need new mask design which has an influence on luminosity measurement*
  - ✘ *WW self-calibrating due to large forward peak but 2f sensitive... at what extent?*
  - ✘ *Can we use large angle Bhabha scattering? Effect of new physics...*