Quartic gauge couplings from triple boson production

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- a bit theory
- an overview
- observables, analysis
- results, status

Strong EWSB scenario

- strongly interacting Higgs sector

$$V_{\text{Higgs}}(\phi) = -\mu^2\phi^\dagger\phi + \lambda\left(\phi^\dagger\phi\right)^2, \qquad \text{e.g. } M_H = 1.4\,\text{TeV}$$

$$\lambda = \frac{1}{2}\frac{M_H^2}{v^2} = \frac{1}{2}\frac{(1.4\text{TeV})^2}{(0.25\text{TeV})^2} \approx 16$$

- effective $SU_R(2) \times SU_L(2)$ chiral theory

$$U(x) = \exp\left(i\underset{\sim}{\tau}\cdot\underset{\sim}{\phi}(x)/v\right) \qquad v = \left(\sqrt{2}G_F\right)^{-1/2} \approx 246\,\text{GeV}$$

nonlinear realization

- @one loop counter terms needed

$$\mathcal{L}_0, \mathcal{L}_1, \mathcal{L}_2, \mathcal{L}_3, \mathcal{L}_4, \mathcal{L}_5, \ldots, \mathcal{L}_{10} \qquad E < \Lambda \approx 4\pi v \sim 3\text{TeV}$$

Quartic Gauge Couplings

- $2 \longrightarrow 2$ scattering
    - Chieri, Rosati und Kobel LC-PHSM-2001-038
    - K. Mönig, P. Krstonosic next talk
- $1 \longrightarrow 3$ production

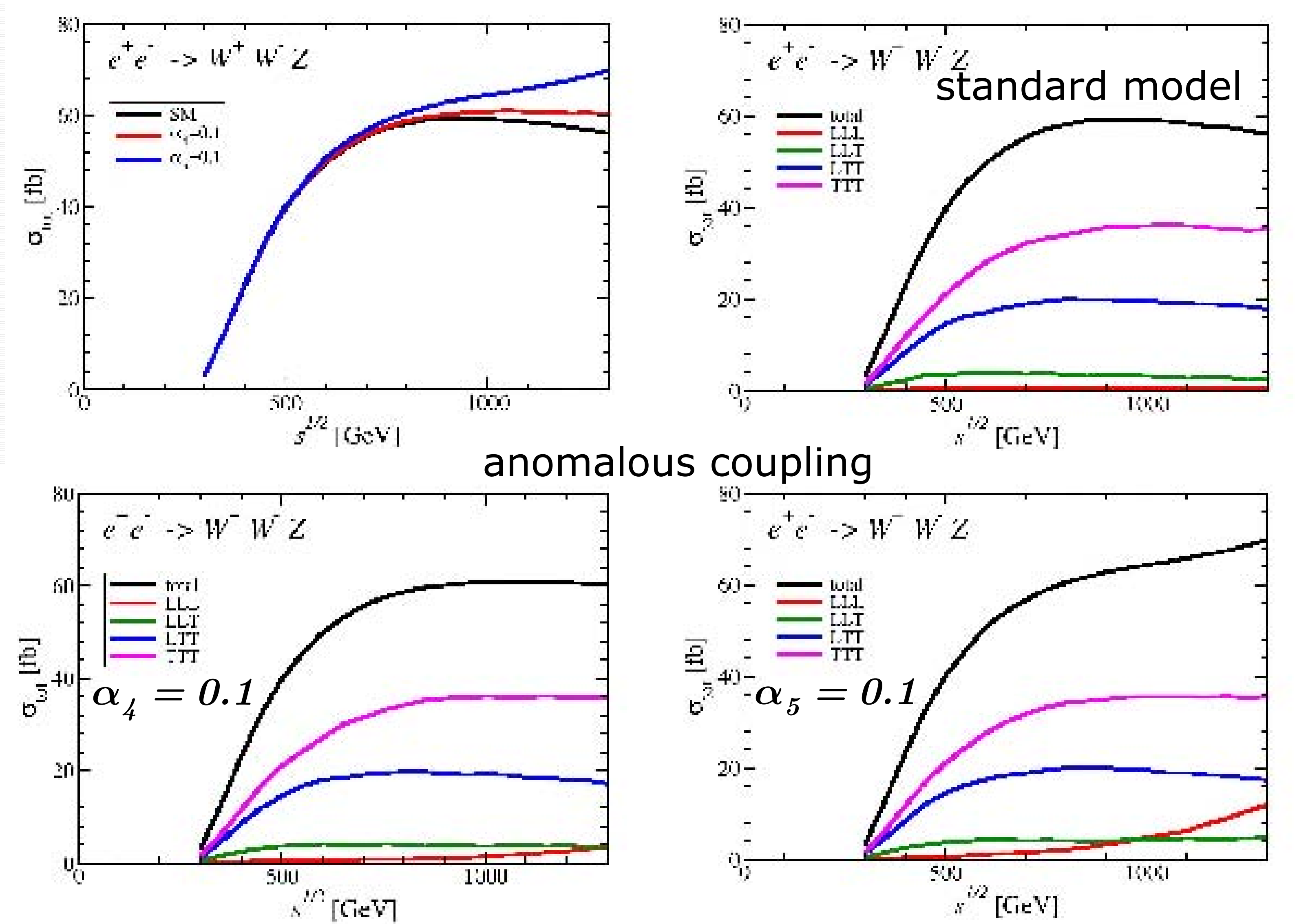
$$WWZ\colon \quad \langle \mathcal{L}_4 \rangle = \langle \mathcal{L}_6 \rangle, \quad \langle \mathcal{L}_5 \rangle = \langle \mathcal{L}_7 \rangle, \quad \langle \mathcal{L}_{10} \rangle = 0$$

$$ZZZ\colon \quad \langle \mathcal{L}_5 \rangle = \langle \mathcal{L}_6 \rangle = \tfrac{1}{2}\langle \mathcal{L}_5 \rangle = \tfrac{1}{2}\langle \mathcal{L}_7 \rangle = \tfrac{1}{2}\langle \mathcal{L}_{10} \rangle$$

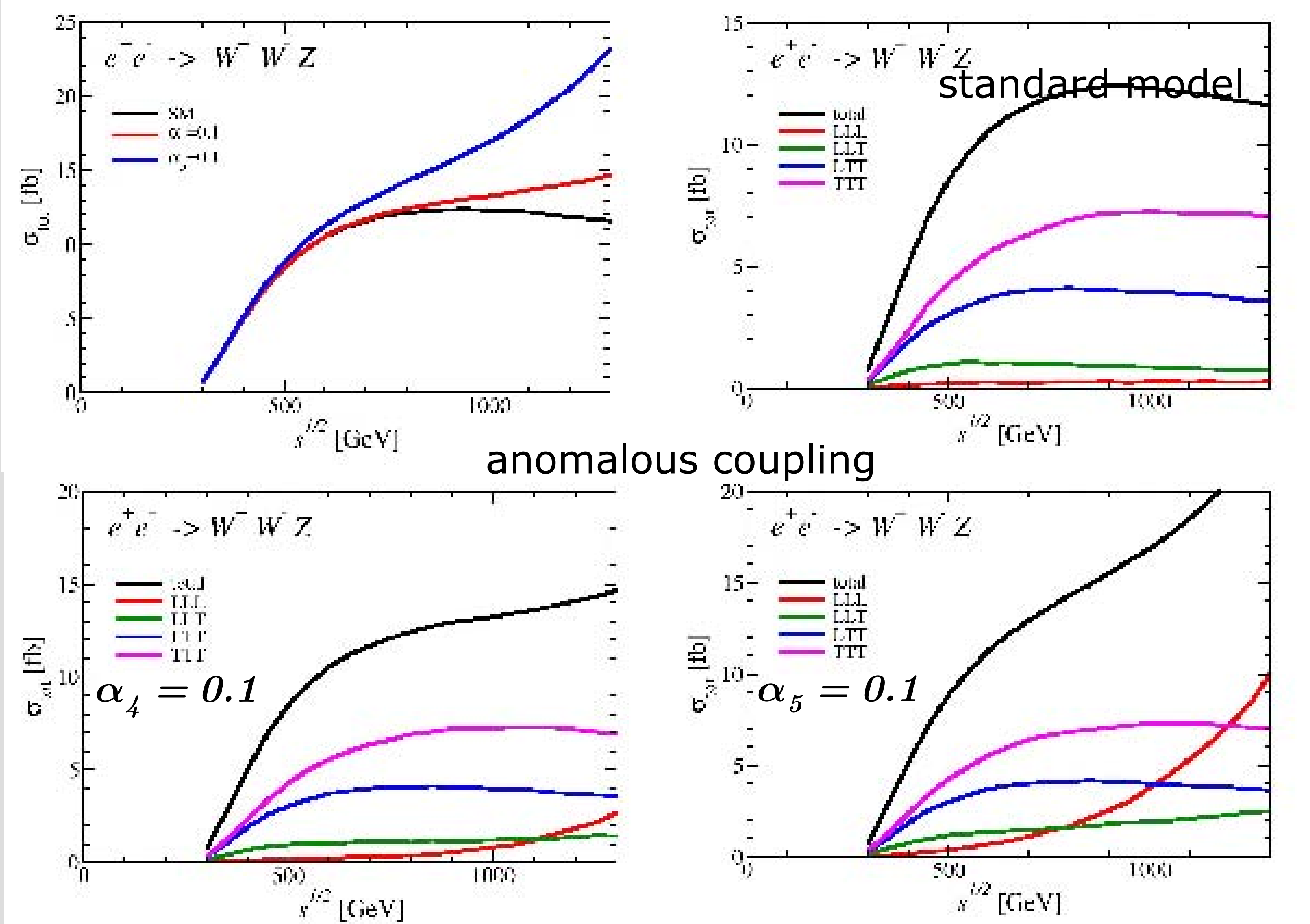
Feynman diagrams $e^+e^-\to W^+ W^- Z$

standard model background

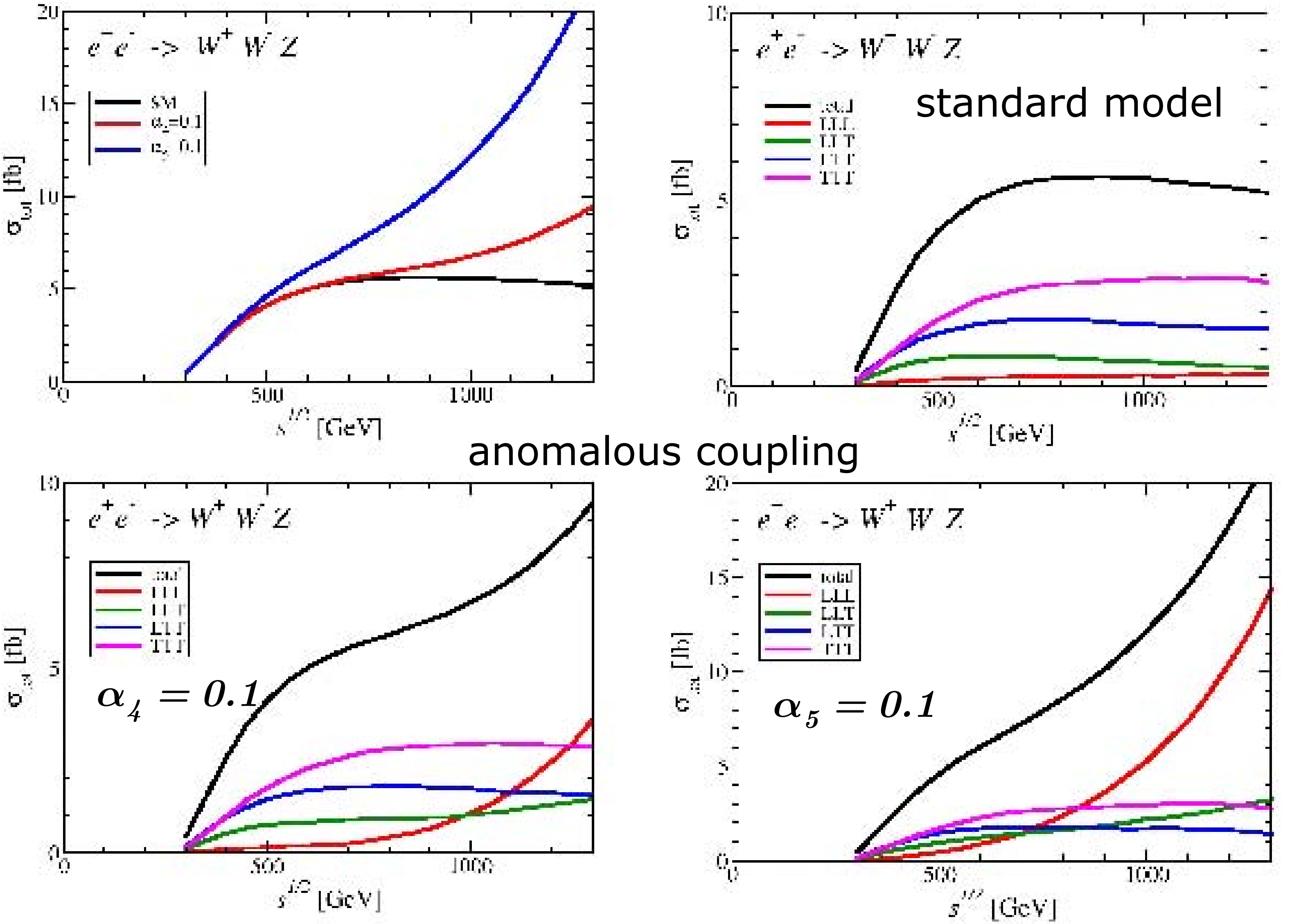
WWZ: no polarization of e^-e^+



WWZ: e⁻ 80% right polarization



WWZ: e⁻ 80% right, e⁺ 60% left



Cross section

- energy

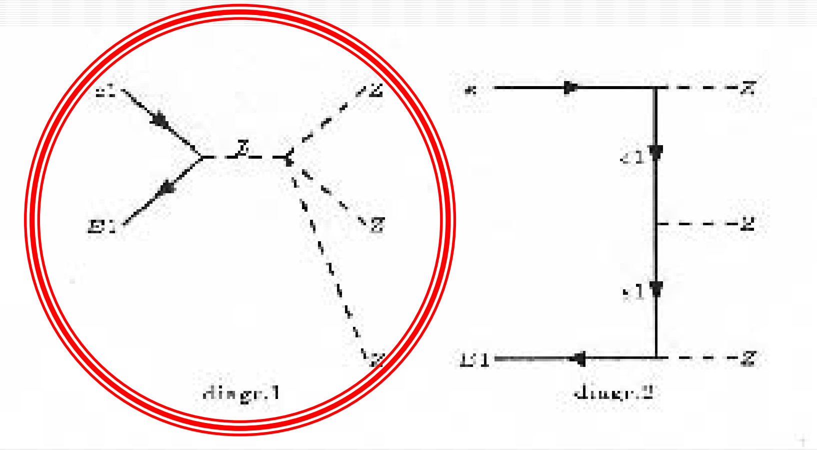
  $\sqrt{s} = 1000$ GeV

- cross section

e^+e^- unpolarised	59.1 fb
e^- 80% right	12.3 fb
e^+60% left e^- 80% right	5.57 fb
ZZZ unpolarised	0.79 fb

- luminosity

  $\mathcal{L} = 1000$ fb^{-1}



Three-body kinematics

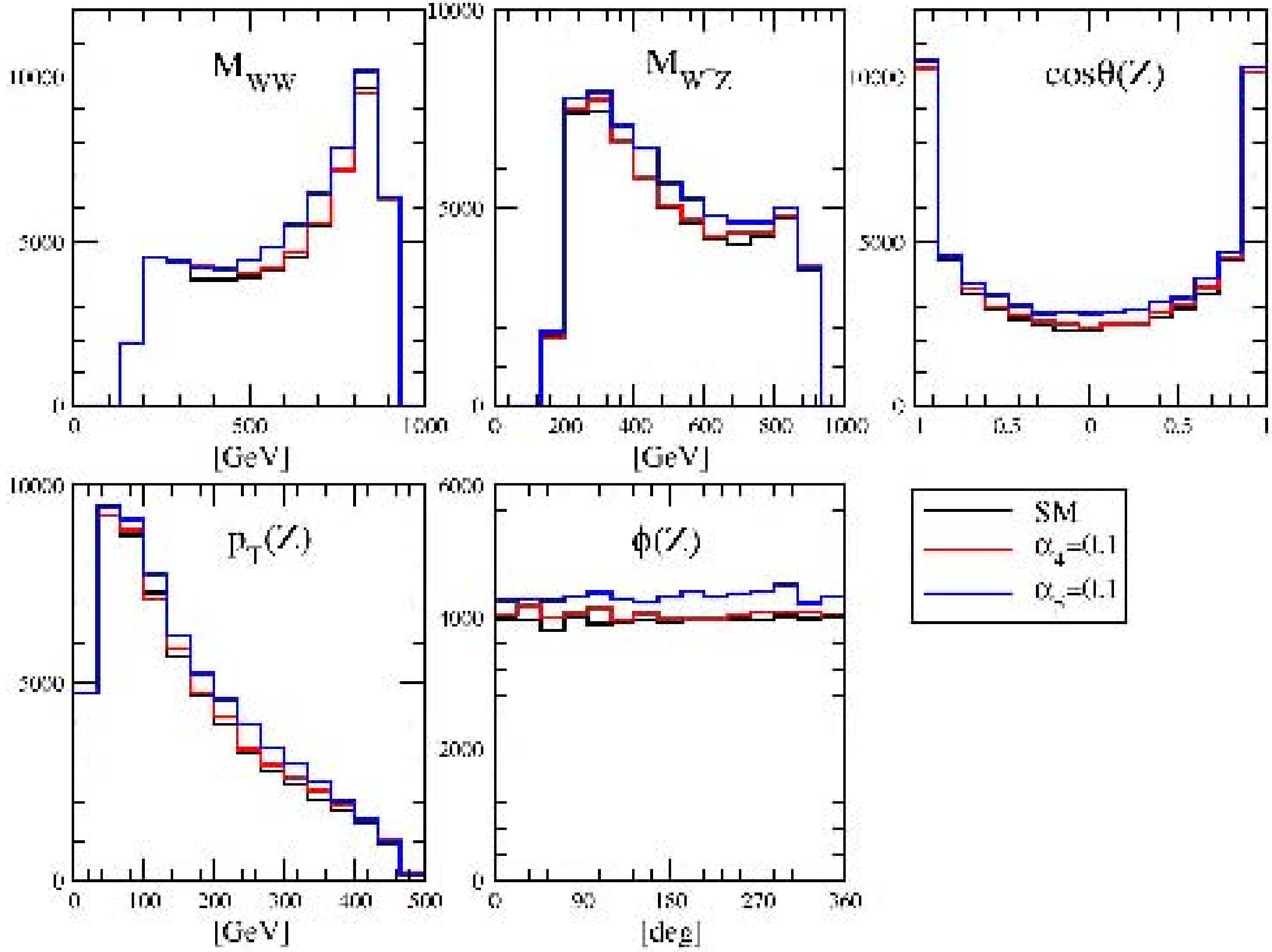
- momenta
  - 3 particles x 4 components 12
  - energy momentum conservation - 4
  - on-shell condition - 3
  - axial invariance (φ-dependence) - 2
    - e.g. eZ plane, ZW plane
  - total **3**
  - kinematical variables:

$$M_{WZ}, M_{WW}, \theta(Z)$$

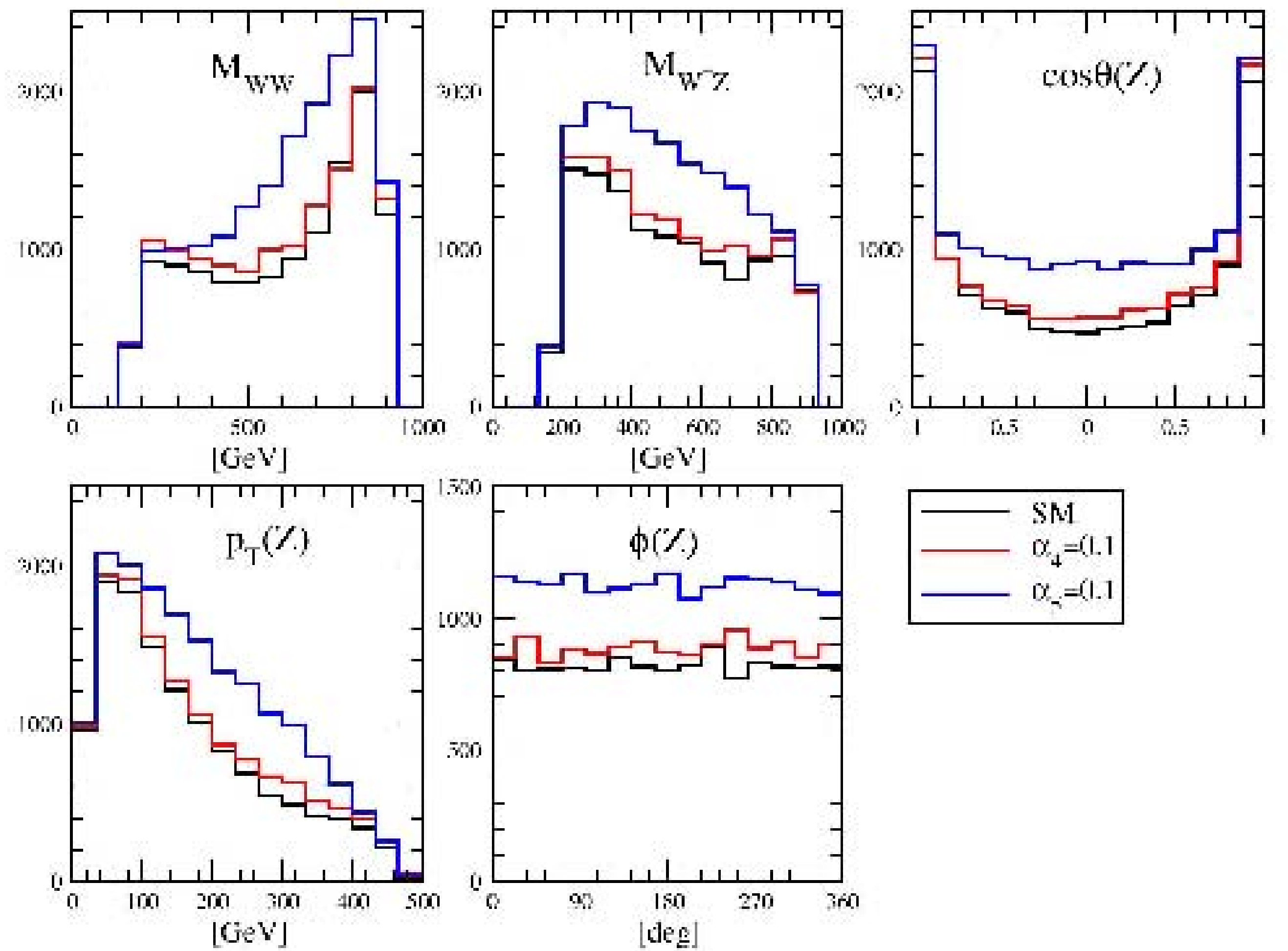
↖ e.g. beam vs. $\vec{p}_Z$

- spins, 3 d.o.f
  - $\sigma \sim \sigma_{LLL}, \sigma_{LLT}, \sigma_{LTL}, \ldots, \sigma_{TTT}$

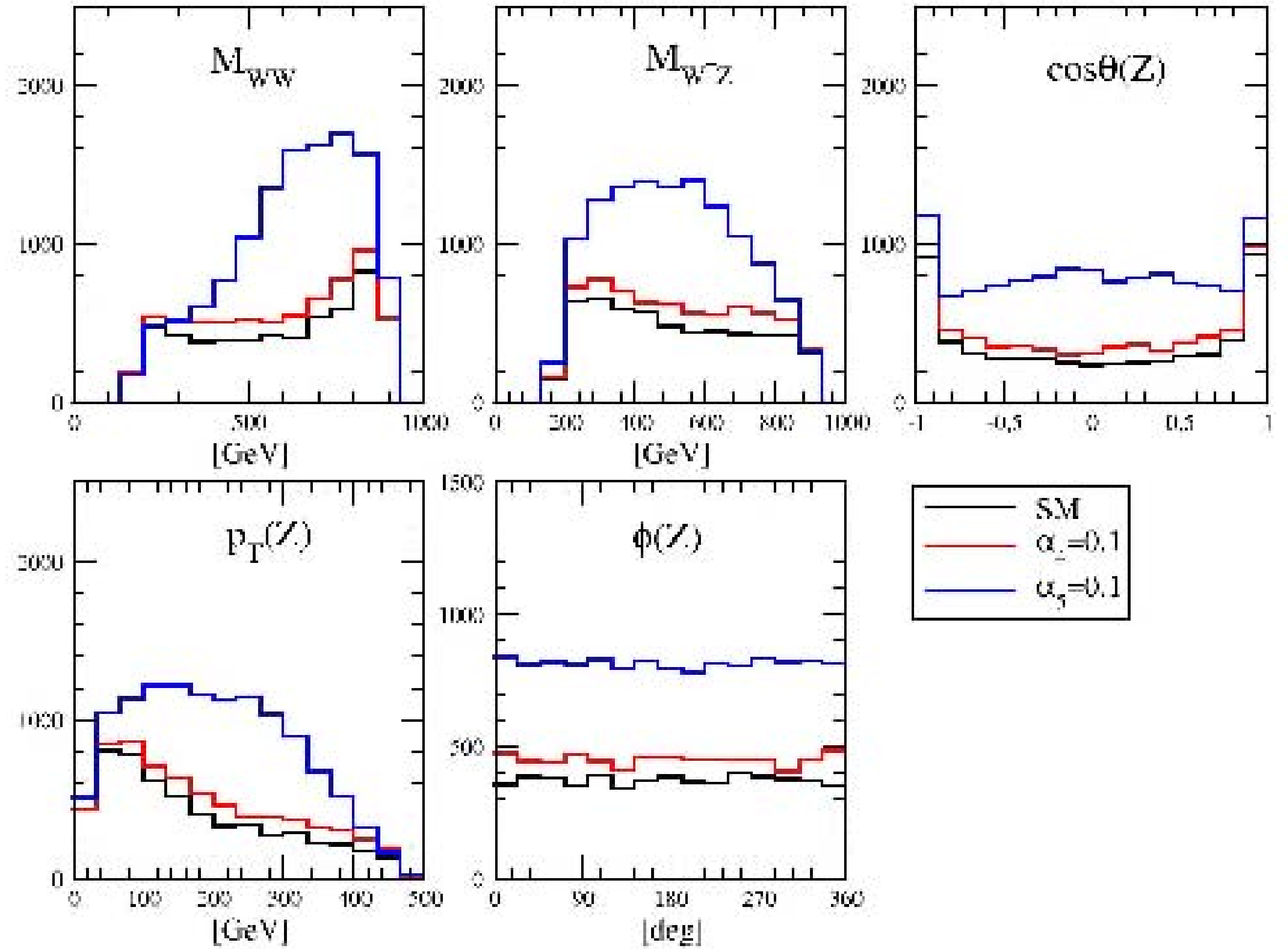
Monte Carlo WWZ: no polarization



Monte Carlo WWZ: e⁻ 80% right polarization



Monte Carlo WWZ: e^- 80% right, e^+ 60% left



χ^2 Test of Sensitivity

- Discretize observable into bins N_{ijk}

$$\chi^2 = \sum_{i,j,k=1}^{15} \frac{\left(N_{ijk}^{\text{exp}} - N_{ijk}^{\text{theo}}\right)^2}{\sigma_{ijk}^2}$$

binning of	M_{WW}	M_{WZ}	$\cos\theta$
e^+e^- nopol	10	10	8
Rest	7	7	5

  - N^{exp} ↩ Simdet ↩ Pythia ↩ Whizard
    - with L = 1000 fb^{-1}
  - N^{theo} ↩ Whizard
    - reweighting of events

Fitting procedure

- calculate (reweight SM events)

$$N_{ijk}^{\text{theo}}(\alpha_4\alpha_5) = N_{ijk}^{\text{sm}} \underbrace{\left(1 + A_{ijk}\alpha_4 + B_{ijk}\alpha_4^2 + C_{ijk}\alpha_5 + D_{ijk}\alpha_5^2 + E_{ijk}\alpha_4\alpha_5\right)}_{=R_{ijk}(\alpha_4\alpha_5)}$$

- determine the coefficients

$$A_{ijk}, B_{ijk}, C_{ijk}, C_{ijk}, E_{ijk}$$

- minimize

$$\chi^2 = \sum_{ijk} \frac{\left(N_{ijk}^{\text{exp}} - N_{ijk}^{\text{theo}}(\alpha_4\alpha_5)\right)^2}{\sigma_{ijk}^2}$$

$$\alpha_4 \pm \Delta\alpha_4$$
$$\alpha_5 \pm \Delta\alpha_5$$

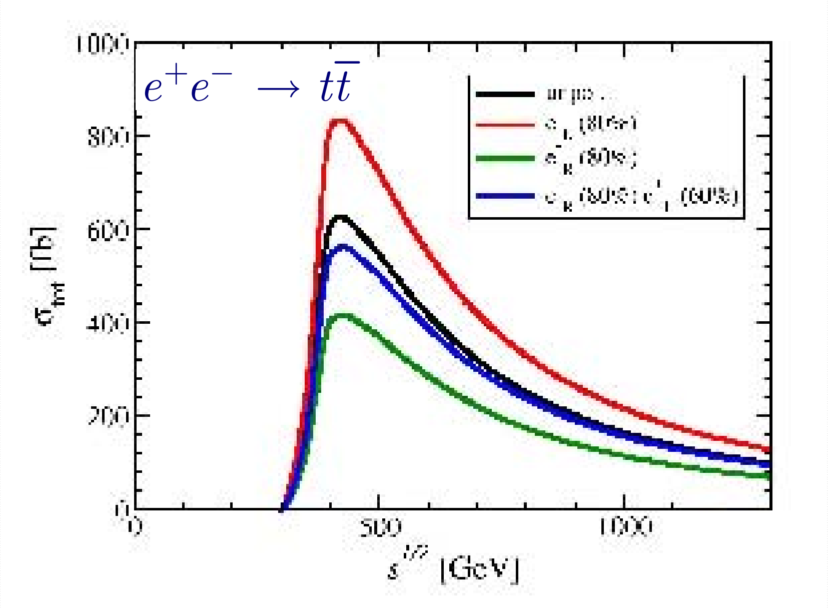
Finding WWZ‘s

- dominant decay topology

$WWZ \rightarrow 6\,\text{jets} \sim 32\%$

- dominant background

$t\bar{t} \rightarrow b\bar{b}W^+W^- \rightarrow 6\,\text{jets}$



- further topologies

$WWZ \rightarrow 4\,\text{jets}\,2\ell,\ WWZ \rightarrow 4\,\text{jets}\,\nu\ell,\ WWZ \rightarrow 4\,\text{jets}\,2\nu$

Reconstructing WWZ's

- Event selection
  - enforce 6 jets
  - $E^2_{\text{mis}} + p^2_{\perp,\text{mis}} < (65\,\text{GeV})^2$

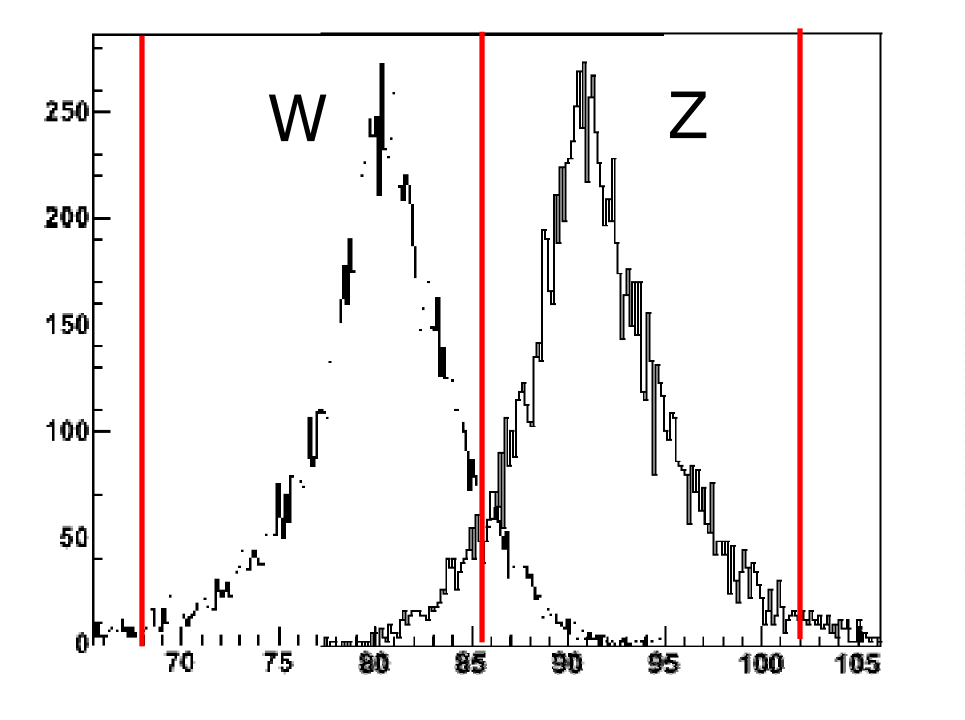
    $E^{\text{min}}_{\text{jet}} > 5\,\text{GeV}$
- Top selection
  - combine
    - from t →bW
  - $m_W^{\text{cand}} \oplus 1\,\text{jet}$
  - E, p consistent with tt-topology

    $\left| m_t^{\text{cand}} - m_t \right| < 15\,\text{GeV}$

- WWZ reconstruction
  - 6 jets → 15 pairs
  - take best combination
  - use kinematical fit

- efficiency ~ 12% (36%)
- purity
  - unpolarized ~ 98%
  - e^- only pol. ~ 94%
  - both pol. ~ 85%

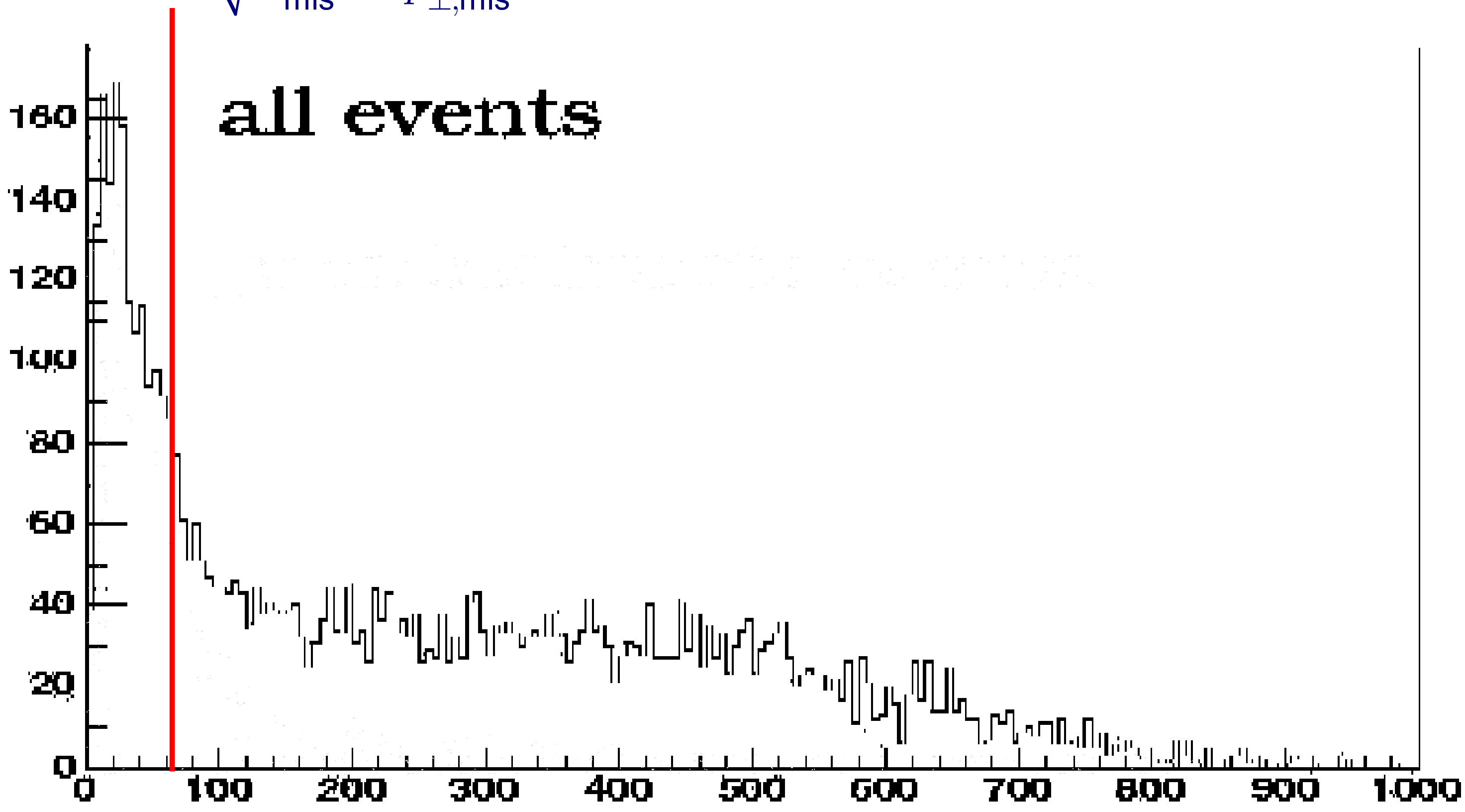
Mass resolution



$$12\,\text{GeV} < \left| m_{W^\pm}^{\text{cand}} - m_{W^\pm} \right| \lesssim 5.3\,\text{GeV} \lesssim \left| m_Z^{\text{cand}} - m_Z \right| < 12\,\text{GeV}$$

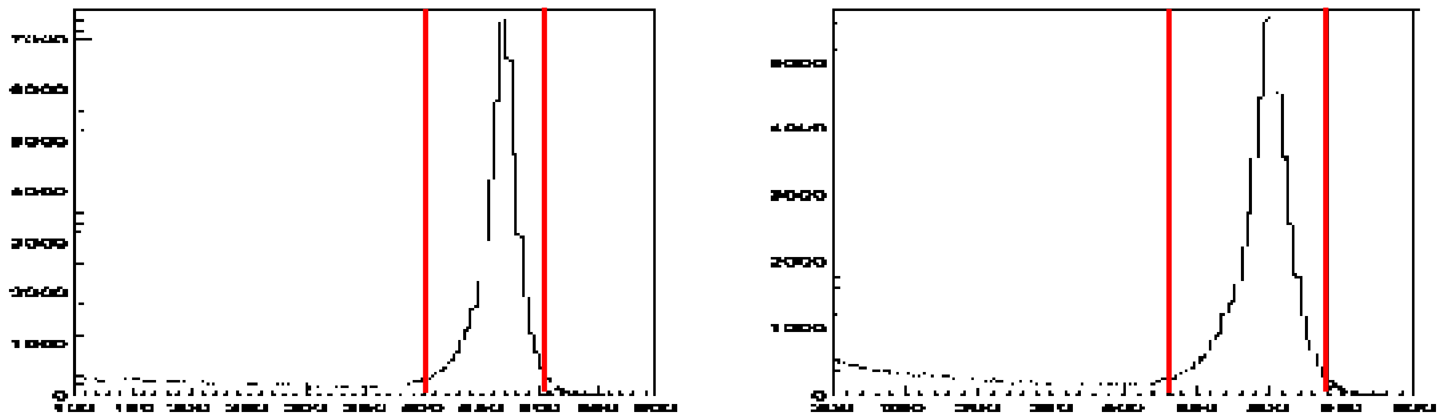
Missing energy/momentum cut

$$\sqrt{E_{\text{mis}}^2 + p_{\perp,\text{mis}}^2} < 65\,\text{GeV}$$

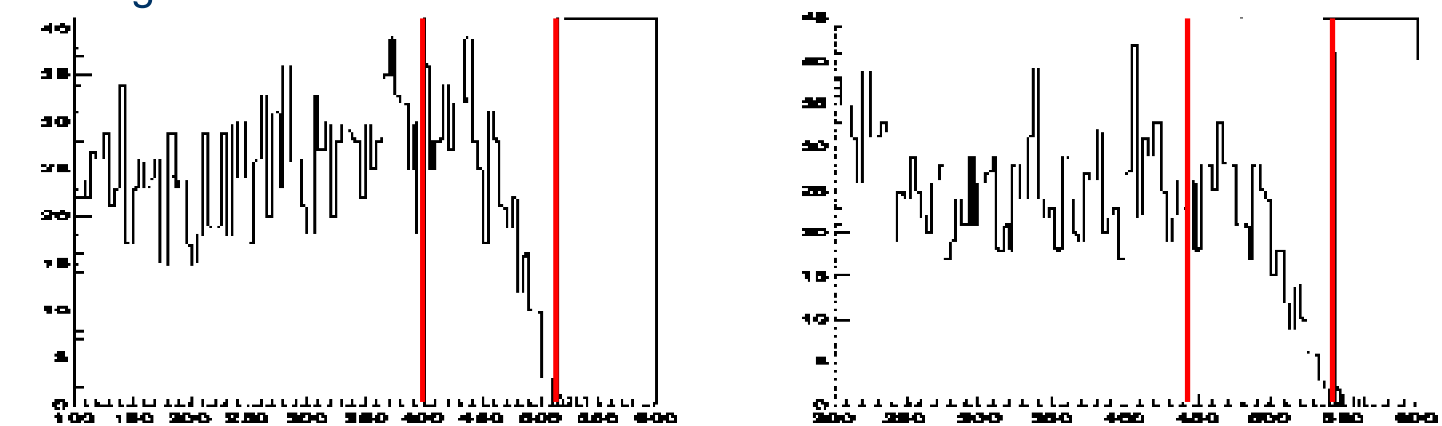


Top Cut, „two-body“ kinematics

top events



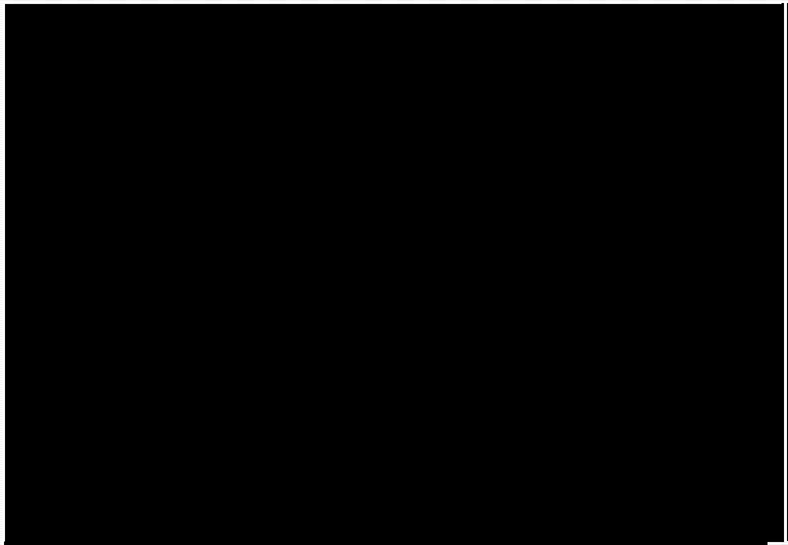
signal events

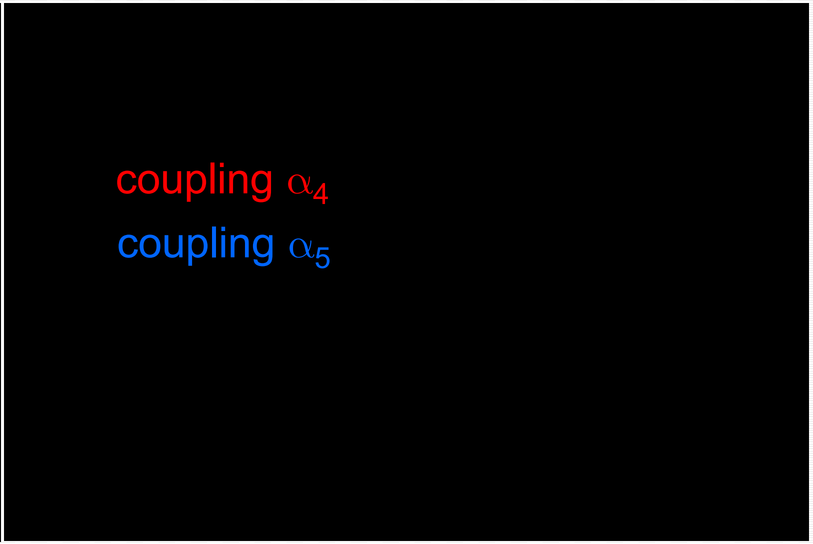


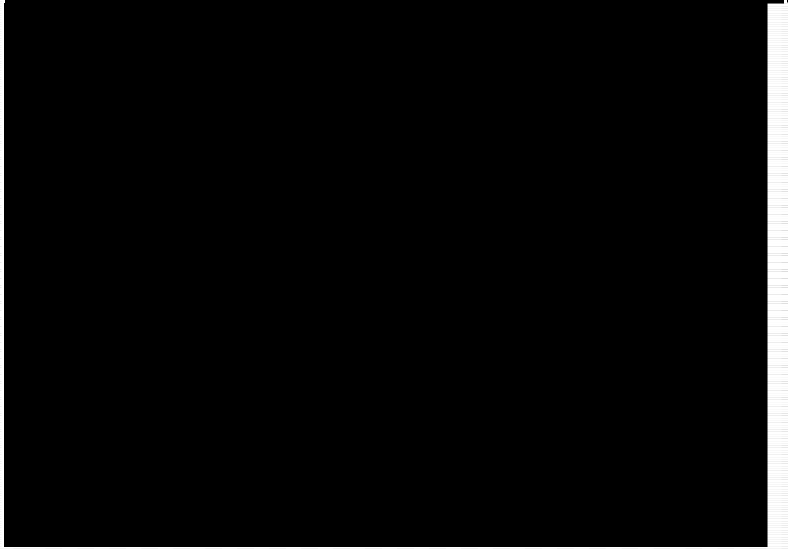
E_{top} = 486±55 GeV

p_{top} = 452±63 GeV

reconstructed WWZ with polarisation

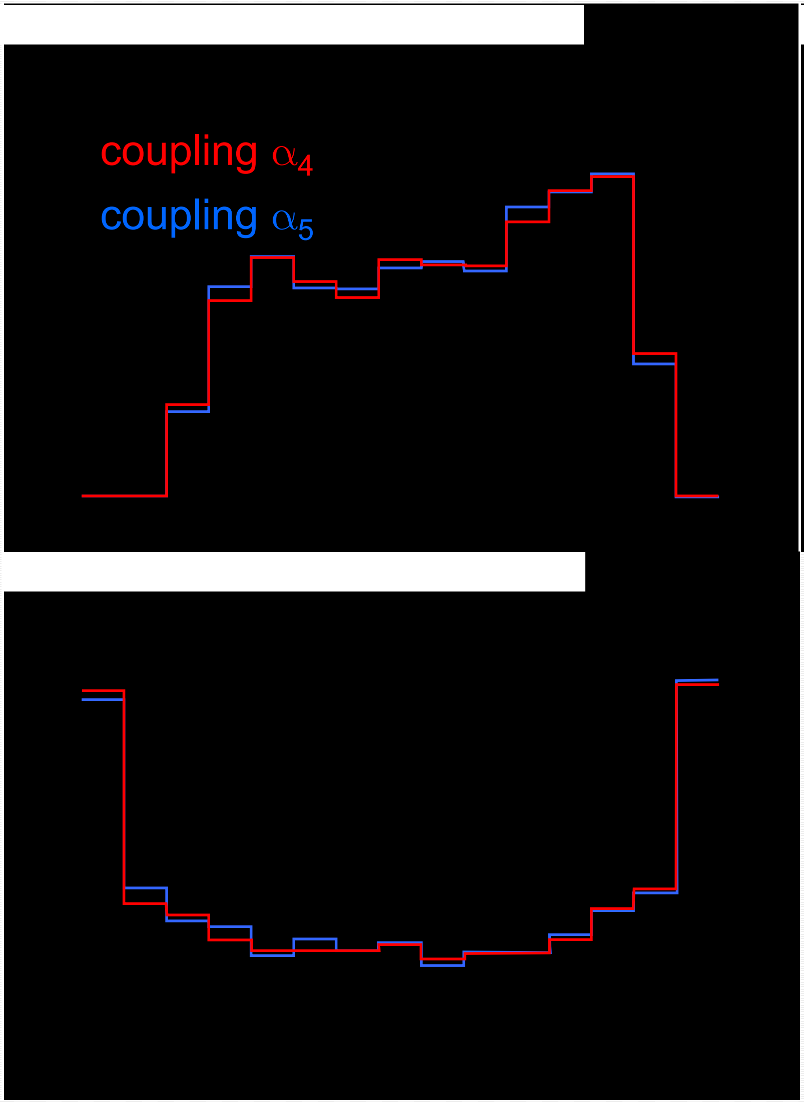


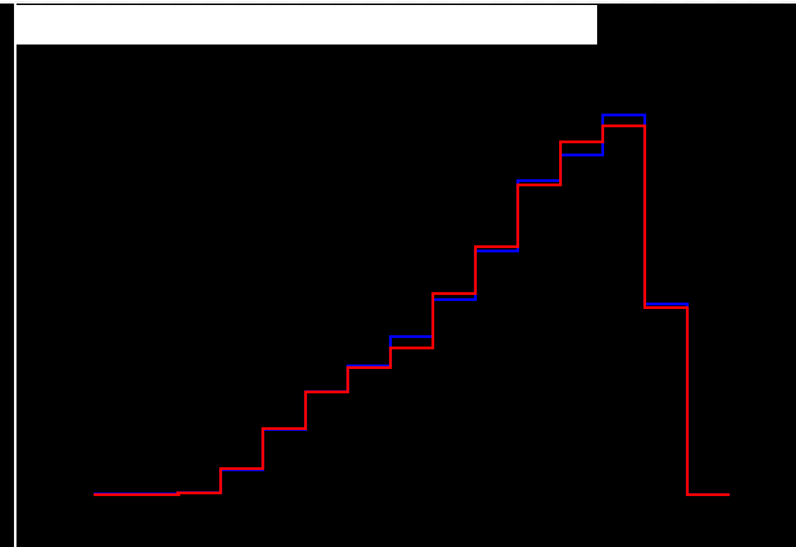




- dependence on rates
- shape?
  - ➥ devide N by rate

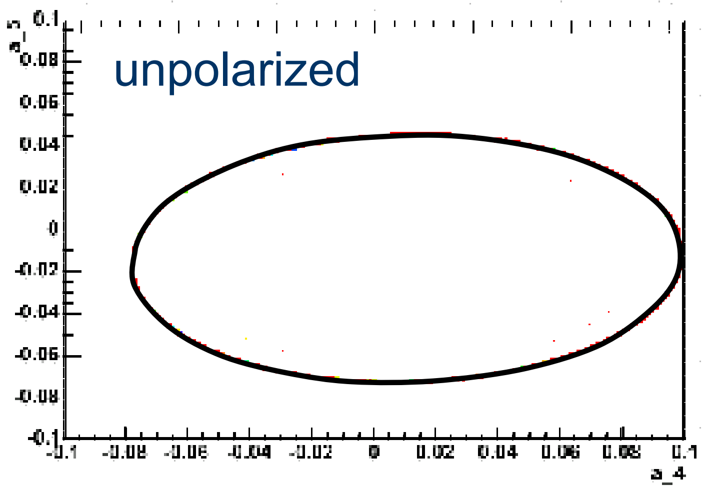
WWZ with polarisation (shape dependence)

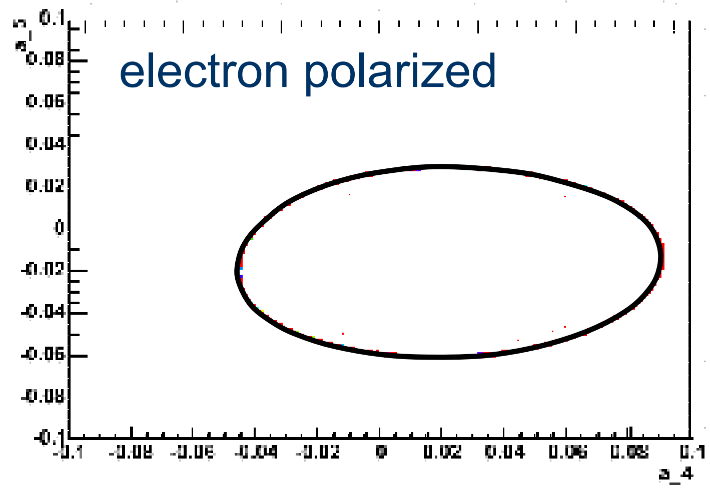


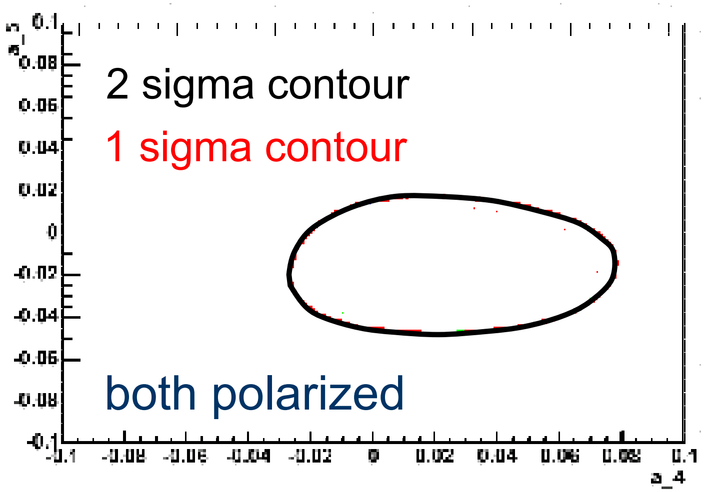


- not sensitive to shape
  - use jet-jet correlation to get further information, e.g. on longitudinal vs transverse bosons

χ^2 contour for WWZ

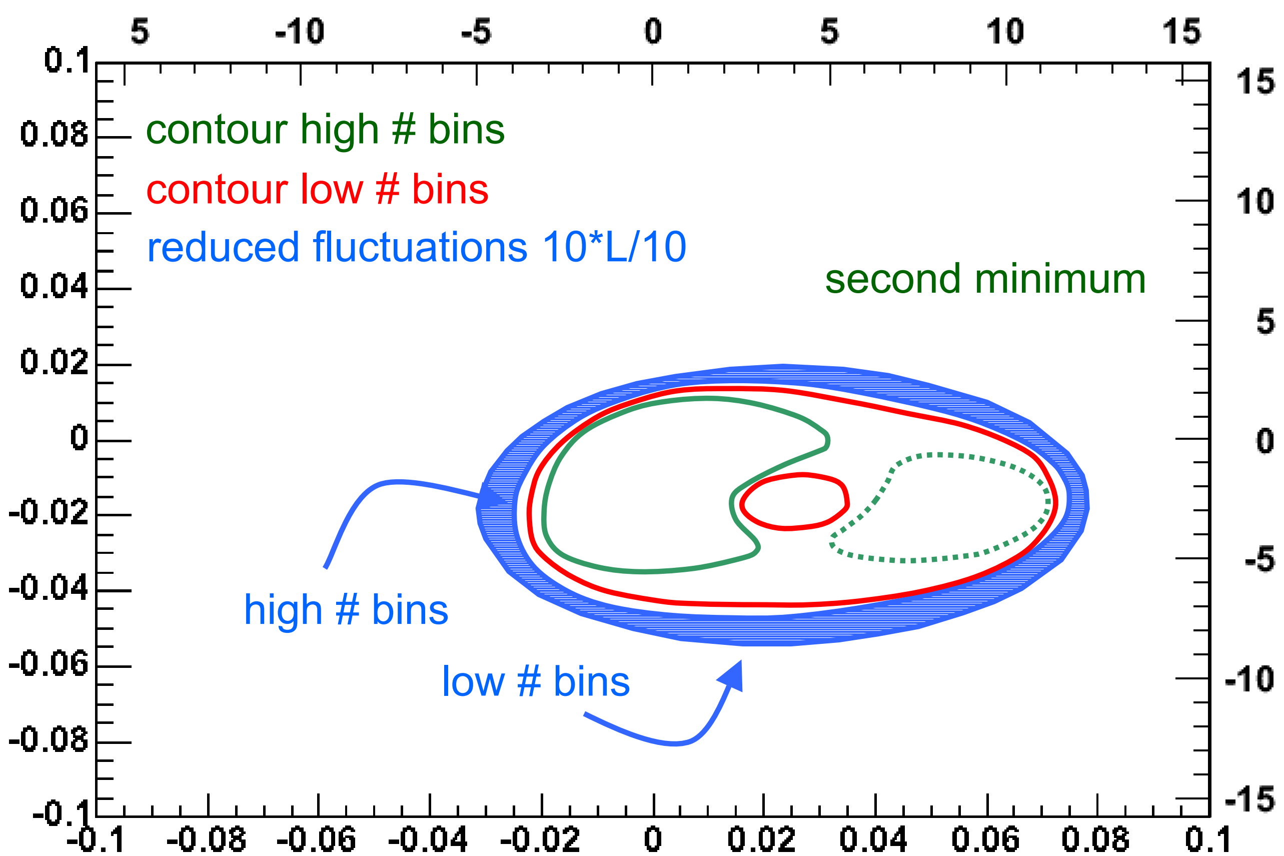






- polarisation useful to enhance sensitivity
- flat χ^2 distribution for $\alpha_4 < 0$
  - fluctuations
  - difference to previous results

Closer look to 1 sigma contour



More to come ... near future

- include other topologies
  - $WWZ \to 4$ jets 2ℓ, $WWZ \to 4$ jets $\nu\ell$, $WWZ \to 4$ jets 2ν
- ZZZ: about 100 reconstructed hadronic decays
  - background top and WWZ events, ~ 100
- six fermion event generation
  - full Whizard potential
- include angular distribution of jets
  - $W_{L/T} \to 2$ jets/particles angle depends on polarization state