Update on top pair production at 380 GeV

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Outline

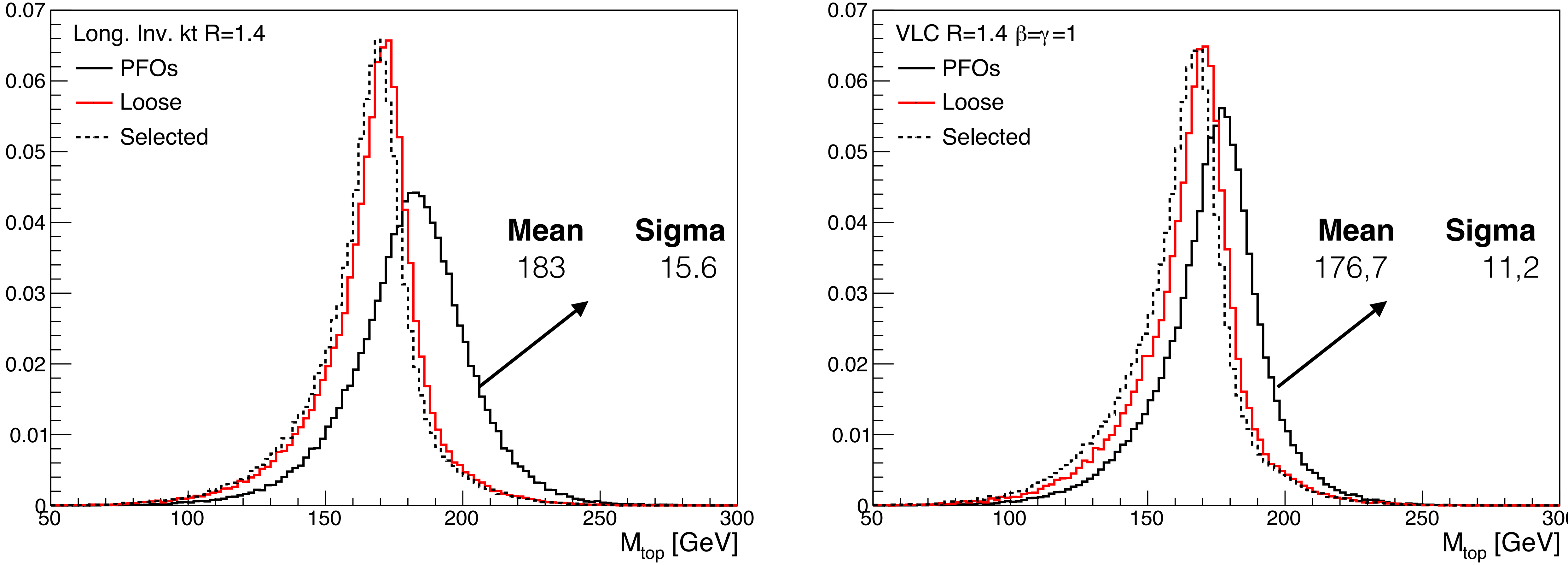
- **Jet reconstruction optimisation**
  - **Timing cuts**
  - **Jet algorithm parameters**
  - **Choosing the most optimal configuration**

- **From ILC@500GeV to CLIC@380GeV (NEWS)**

- **Top quark couplings studies at CLIC@380GeV**
  - **Lepton+jets tt CLIC@380GeV reconstruction**
  - **Observables**
  - **CP conserving top quark couplings uncertainties**
  - **Preliminary studies of the CPV top quark couplings**

- **Conclusions**

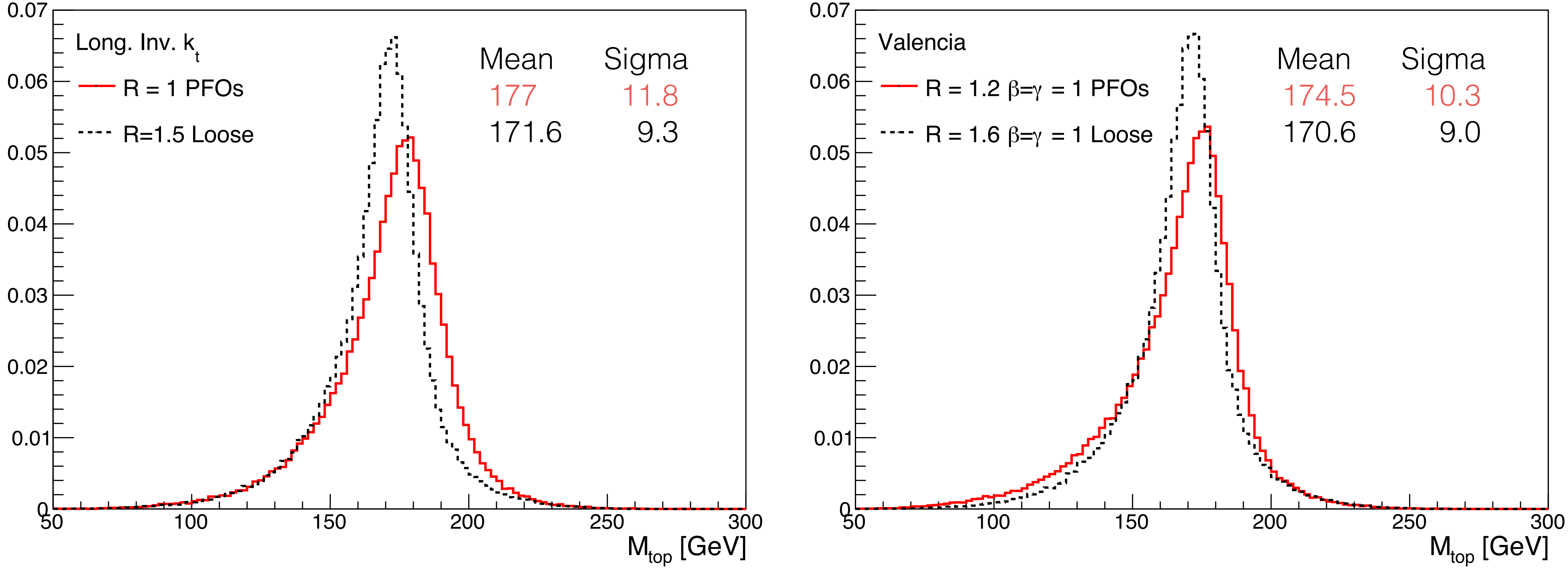
Timing cuts impact in jet reconstruction



1) For a R=1.4 using **all PFOs** without timing cuts **M_{top} is clearly degraded** for both algorithms

2) **Selected timing cuts** seem **too hard** at 380GeV -> ~5GeV below the M_{top} expected value

Jet Algorithms performance



Use **PandoraPFANewPFOs** collection with a **small R**
or use **Loose** collection with a **large R**??

Loose + large R offers better jet performance

Choosing the jet algorithm

- Top mass hadronic candidate mean value and width have been taken for choosing the best configuration for the jet reconstruction

		Timing cuts					
Jet algorithm	Parameters	PFOs		Loose		Selected	
		Mtop [GeV]	σ [GeV]	Mtop [GeV]	σ [GeV]	Mtop [GeV]	σ [GeV]
VLC	R=1.2 β=γ=1	-	-	-	-	166	10
	R=1.2 β=1 γ=1.4	174.5	10.3	-	-	-	-
	R=1.4 β=γ=1	176.7	11.2	170	8.9	-	-
	R=1.6 β=γ=1	-	-	170.6	9	-	-
	R=1.6 β=γ=0.8	-	-	171.3	8.7	-	-
	R=1.8 β=γ=0.8	-	-	171.5	9.2	-	-
Long. Inv. k_t	R=1	177	11.8	-	-	-	-
	R=1.2	180.2	13.5	-	-	-	-
	R=1.4	183.0	15.6	171.3	9.0	168.4	9.6
	R=1.5	-	-	171.6	9.1	-	-

Choosing the jet algorithm

- VLC jet algorithm with R=1.6 β=γ=0.8

		Timing cuts					
		PFOs		Loose		Selected	
Jet algorithm	Parameters	Mtop [GeV]	σ [GeV]	Mtop [GeV]	σ [GeV]	Mtop [GeV]	σ [GeV]
VLC	R=1.2 β=γ=1	-	-	-	-	166	10
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	R=1.6 β=γ=1	-	-	170.6	9	-	-
	R=1.6 β=γ=0.8	**-**	**-**	**171.3**	**8.7**	**-**	**-**
	R=1.8 β=γ=0.8	-	-	171.5	9.2	-	-
Long. Inv. k_t	R=1	177	11.8	-	-	-	-
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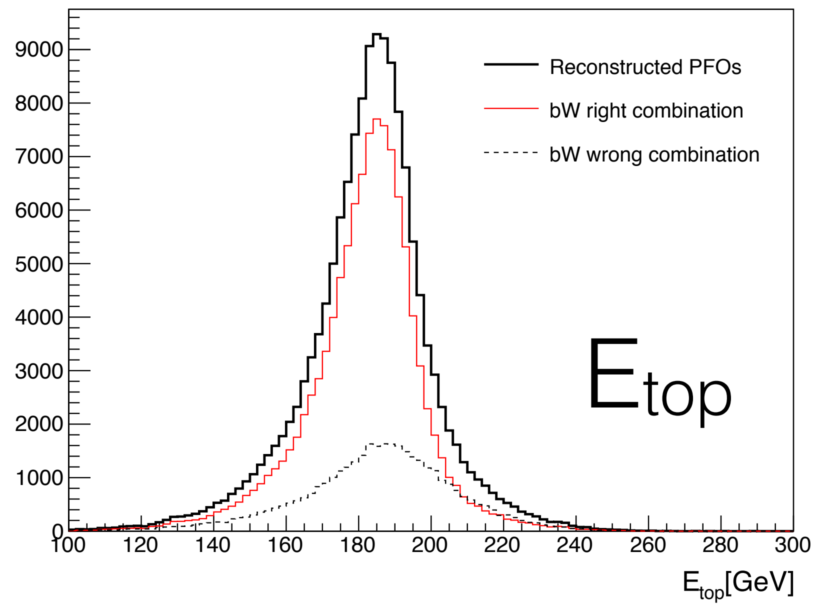
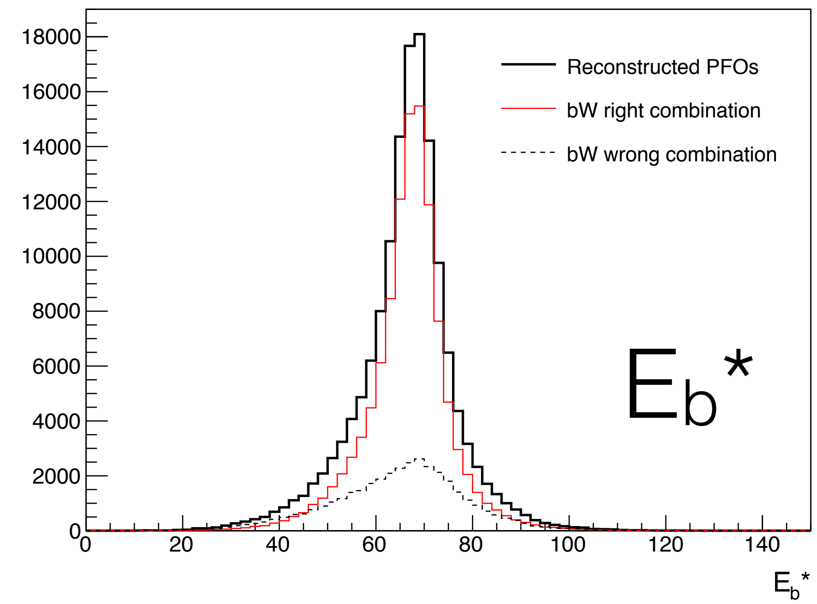
	R=1.4	183.0	15.6	171.3	9.0	168.4	9.6
	R=1.5	-	-	171.6	9.1	-	-

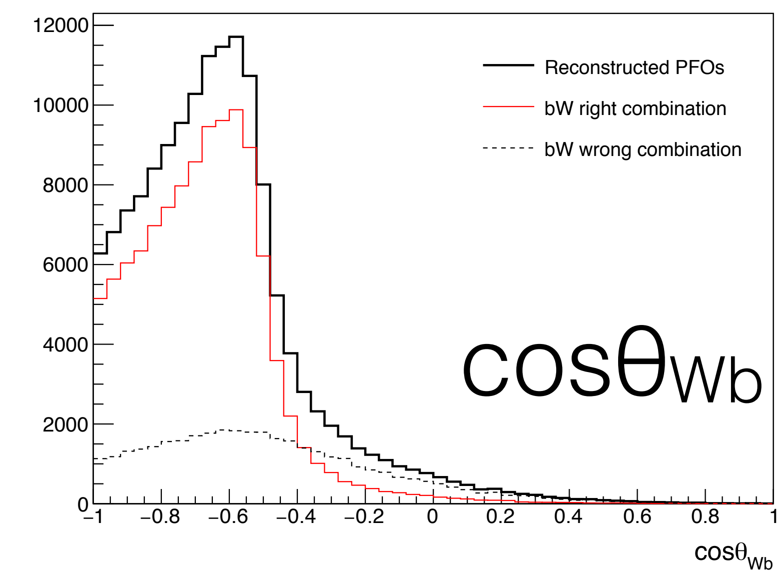
From ILC@500GeV to CLIC@380GeV

	ILC@500GeV	CLIC@380GeV	
$\sqrt{s}$	500 GeV	380 GeV	
E_{top}	250 GeV	190 GeV	
BX rate	300 ns	0,67 ns	
$\gamma\gamma \rightarrow$hadrons	1.7 $\gamma\gamma \rightarrow$had/BX	0.0464 $\gamma\gamma \rightarrow$had/ BX	
PFOs Collections	PandoraPFOs	PandoraPFANewPFOs LoosePandoraPFANewPFOs TightPandoraPFANewPFOs SelectedPandoraPFANewPFOs	
Detector Model	ILD_o1_v05	CLIC_ILD_CDR500	
Beam polarisation	$P_{e-}=\pm100\%$ $P_{e+}=\mp100\%$	**$P_{e-}=\pm80\%$ $P_{e+}=0\%$**	**NEW**
ISR/FSR	YES	YES	

lepton+jets tt CLIC@380GeV reconstruction







The **signal is reconstructed** by choosing the combination of *b* quark jet and W boson that minimises the following equation

$$\chi^2 = \left(\frac{M_t - 172.5}{\sigma_{M_{top}}}\right)^2 + \left(\frac{E_t - 190}{\sigma_{E_{top}}}\right)^2 + \left(\frac{E_b^* - 68}{\sigma_{E_b^*}}\right)^2 + \left(\frac{cos\theta_{bW} + (-0.6)}{\sigma_{cos\theta_{bW}}}\right)^2$$

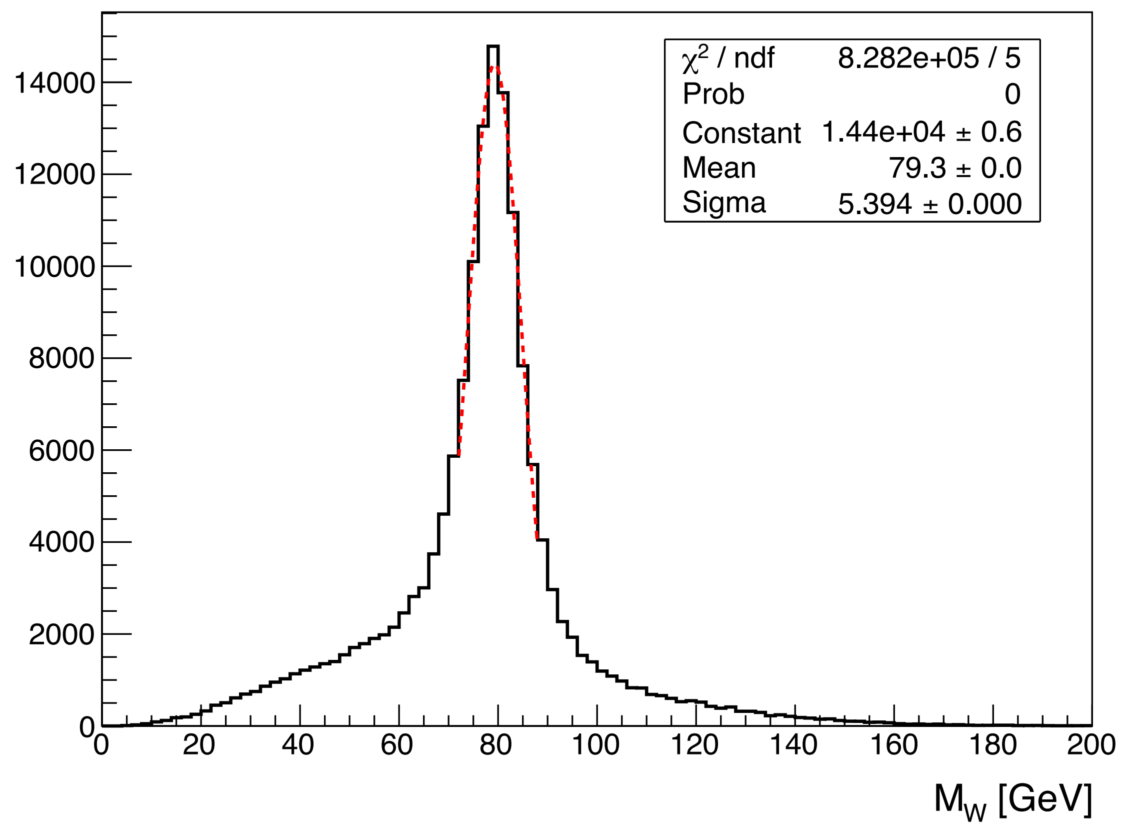
Selection cuts:

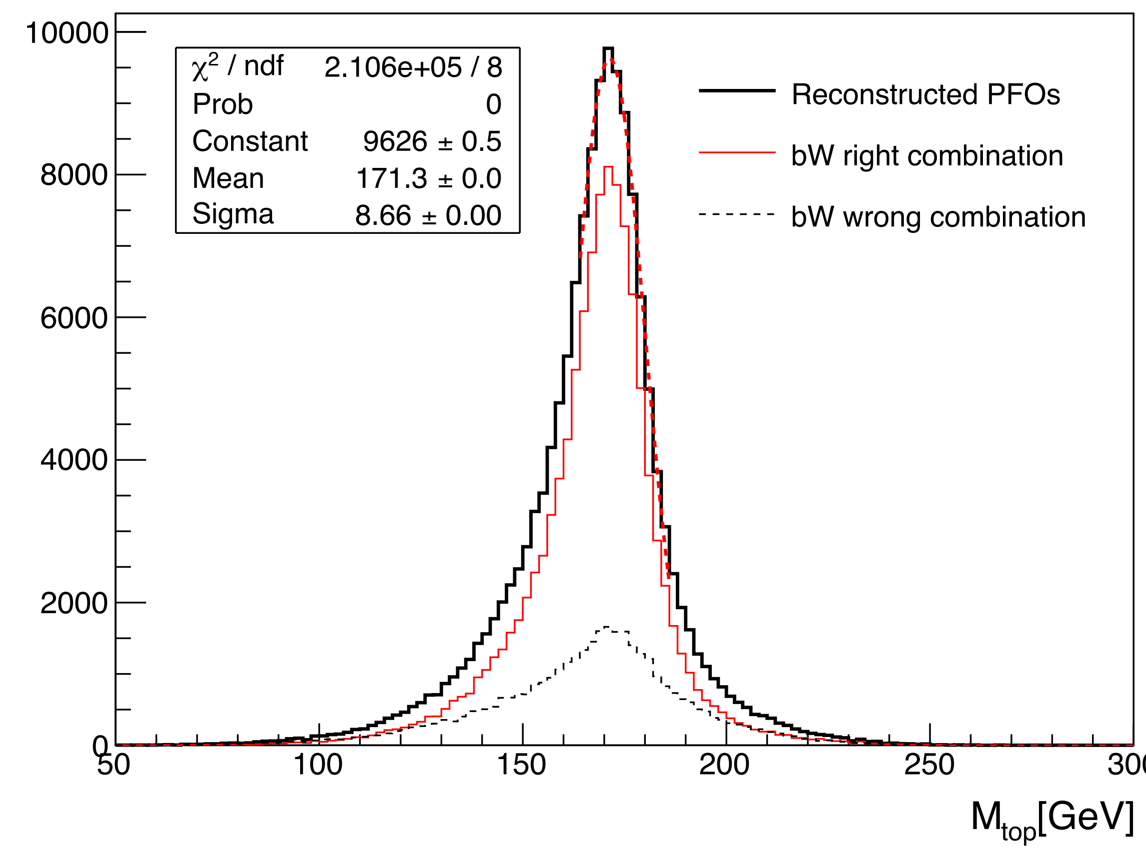
- Semi-leptonic events ->**1 lepton event**
- *b*-tag values: ***b-tag$_1$ > 0.8 & b-tag$_2$ > 0.5***

The **entire selection** retains:

- **59.3%** for the configuration P(e$^-$) = -0.8 (Left-handed electrons)
- **53.7%** for P(e$^-$) = +0.8 (Right-handed electrons)

Top and W mass distributions

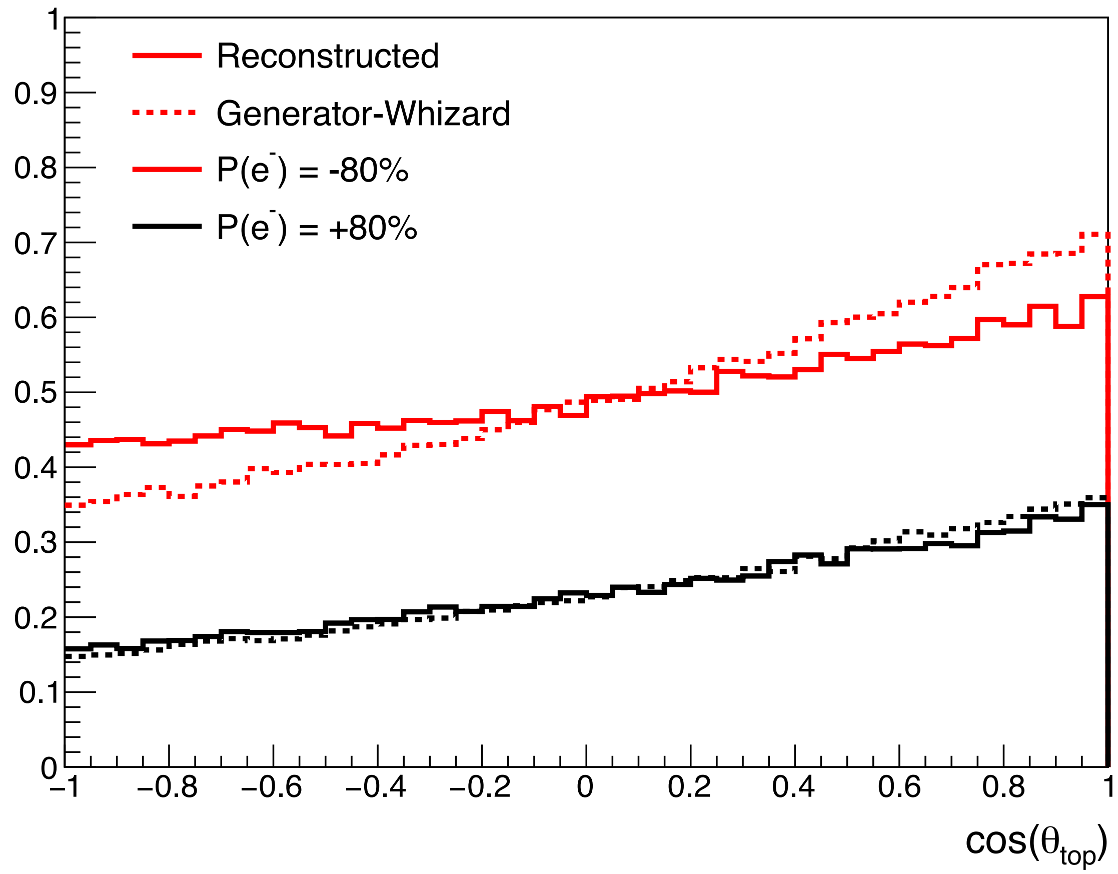


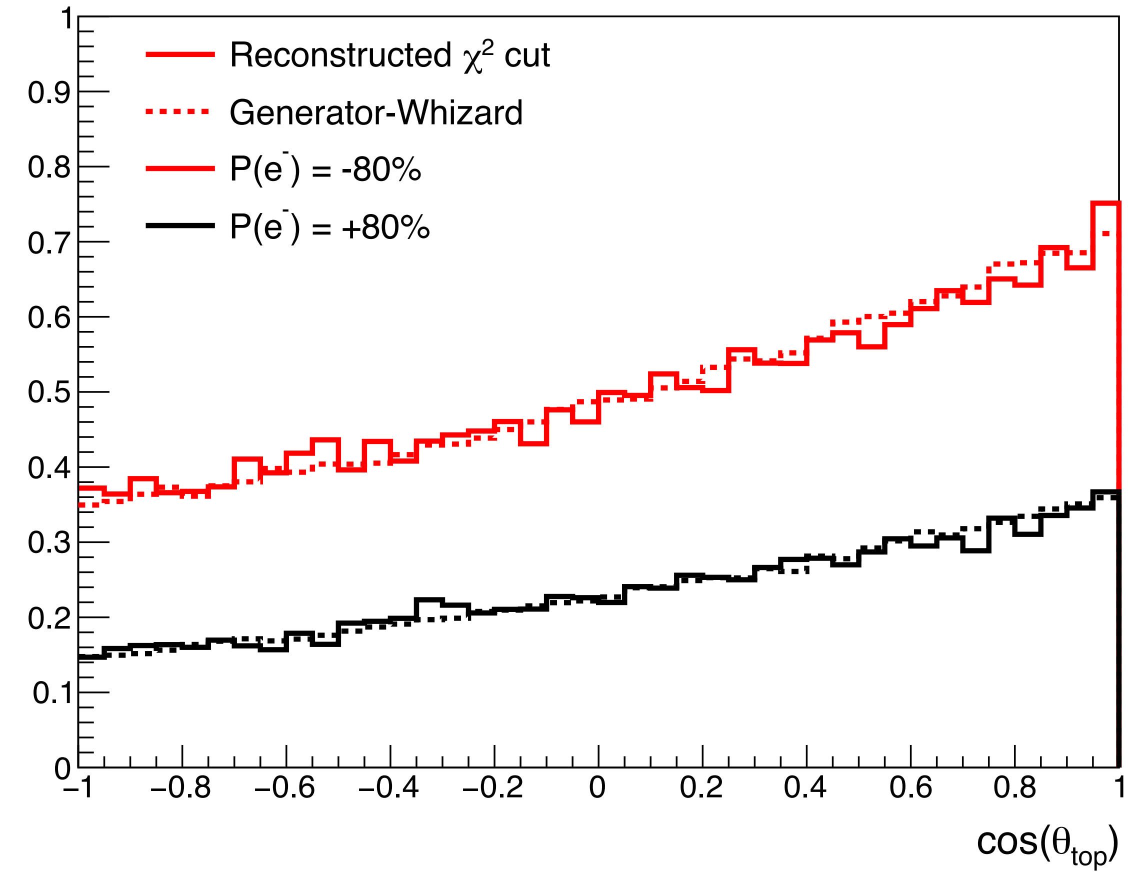


We observe a **shift of ~1 GeV** in the mean value of the W and top candidates mass distributions (expected values M_W=80.4GeV and M_{top}=172.5GeV)

Is not posible to recover the **particles removed by the Loose timing cut** even with the best jet performance -> *Solution: "UltraLoose" selection??*

Forward-Backward Asymmetry





A_{FB} much smaller and migrations due to ambiguity in b-W pairing more severe at 380 GeV than at 500 GeV (esp. for -80%, +30% polarization)

Curing migration

$\chi^2 < 1$ (very tight cut -> lower statistics)

Reconstruction efficiency ~18%

Pe-	A_{FB}^{MC}	A_{FB}	A_{FB} ($\chi^2 < 1$)
-80 %	0,185	0,096	0,172
+80 %	0,227	0,194	0,211

Observables and couplings

- **Total cross section** (σ)
- The **Forward-Backward Asymmetry** (A_{FB})

$$\Gamma_\mu^{t\bar{t}X}(k^2,q,\bar{q}) = ie\left\{\gamma_\mu(F_{1V}^X(k^2)+\gamma_5 F_{1A}^X(k^2)) - \frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\nu(iF_{2V}^X(k^2)+\gamma_5 F_{2A}^X(k^2))\right\},$$

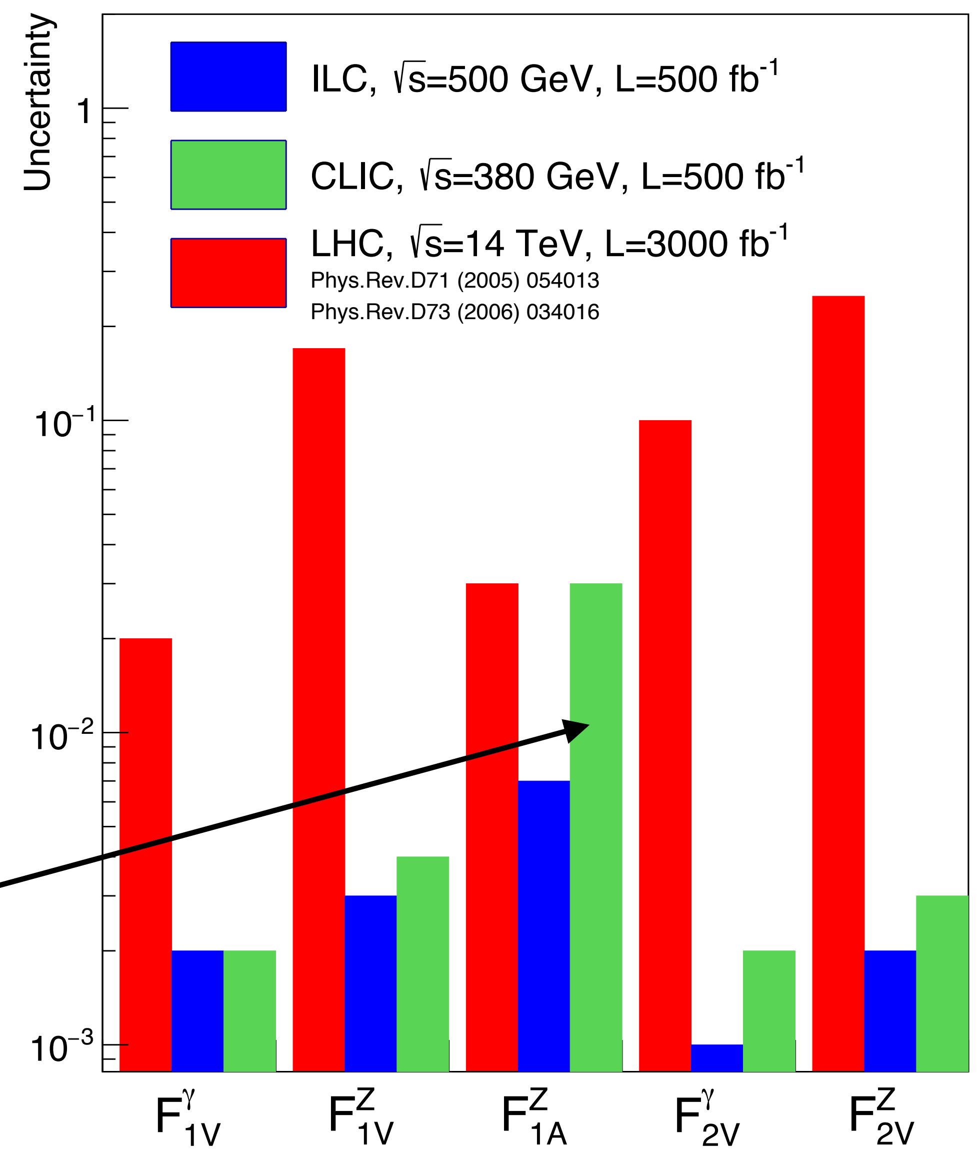
$$\left.\begin{matrix}\sigma(+) & A_{FB}(+) & (+=e_R^-)\\ \sigma(-) & A_{FB}(-) & (-=e_L^-)\end{matrix}\right\} \Rightarrow \left\{\begin{matrix}F_{1V}^\gamma & * & F_{2V}^\gamma\\ F_{1V}^Z & F_{1A}^Z & F_{2V}^Z\end{matrix}\right\}$$

So once 4 observables are measured, we can obtain the following **CP conserving 5 couplings** separately in groups of 3 (F_{1X}) and 2 (F_{2X})

$F_{1A}^\gamma = 0$ always because of the gauge invariance

CLIC, √s=380GeV L=500fb^{-1}

$\mathcal{P}_{e^-}, \mathcal{P}_{e^+}$	$(\delta\sigma/\sigma)_{\text{stat.}}$ (%)	$(\delta A_{FB}^t/A_{FB}^t)_{\text{stat.}}$ (%)
−0.8, 0	0.81	4.6
+0.8, 0	0.90	5.5



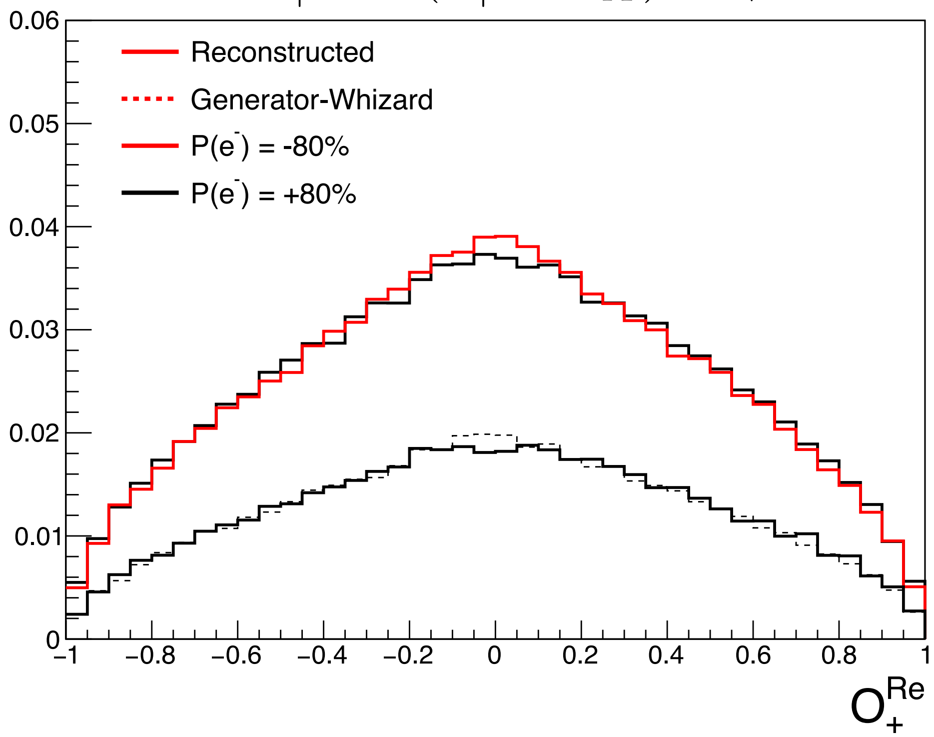
Similar precision to ILC except for the coupling F_{1A}^Z that suffers the large statistical error of **A_{FB} ~5%**

CPV observables studies

The “baseline” study is limited to CP-conserving form factors, but **e^+e^-** is known to **do well also for CP-violationg F_{2A}** at least since TESLA times

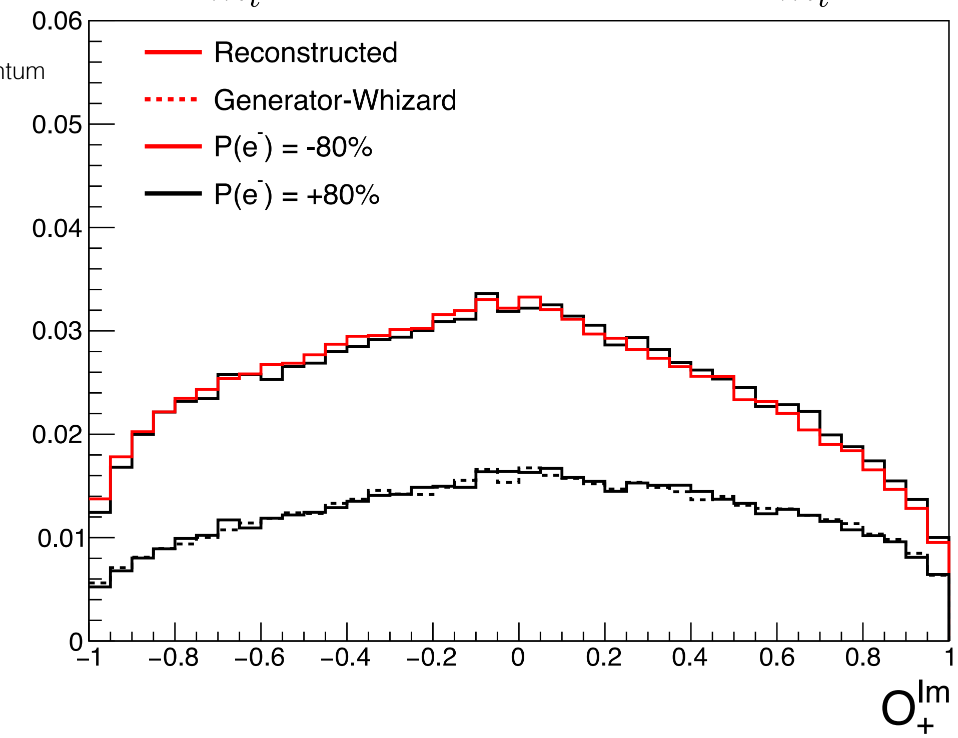
Reconstructing **optimal CP observables** from W. Bernreuther et. al. arXiv:hep-ph/9602273 that measure differences in top polarization orthogonal to production plane and also differences in top quark flight direction. In the lepton + jets final state:

$$O_+^{Re} = (\hat{q}_+^* \times \hat{q}_{\bar{X}}) \cdot \hat{e}_+$$



Where
q= charged lepton momentum
X = hadronic top system
e = positron momentum

$$O_+^{Im} = -[1 + (\frac{\sqrt{s}}{2m_t} - 1)(\hat{q}_{\bar{X}} \cdot \hat{e}_+)^2]\hat{q}_+^* \cdot \hat{q}_{\bar{X}} + \frac{\sqrt{s}}{2m_t}\hat{q}_{\bar{X}} \cdot \hat{e}_+ \hat{q}_+^* \cdot \hat{e}_+$$



These observables have simple relations to the four F_{2A} form factors

$$A_{\gamma,Z}^{Re} = \langle O_+^{Re} \rangle - \langle O_-^{Re} \rangle = c_\gamma [P Re(F_{2A}^\gamma) + KZ Re(F_{2A}^Z)]$$

$$A_{\gamma,Z}^{Im} = \langle O_+^{Im} \rangle - \langle O_-^{Im} \rangle = d_\gamma [Im(F_{2A}^\gamma) + PKZ Im(F_{2A}^Z)]$$

CPV observables preliminary results

No migrations observed for these observables -> **No χ^2 cut** needed

50-60% efficiency retained (better statistics than for A_{FB})

Left-handed electron	Mean value Reco	RMS	δstat ($500 fb^{-1}$)
ORe+	0,00134	0,47	0,001
ORe-	0,0014	0,47	0,001
OIm+	-0,0295	0,52	0,001
OIm-	-0,0285	0,52	0,001
ARe	**-0,0001**	**-**	**0,001**
AIm	**-0,0010**	**-**	**0,002**

Standard Error propagation →

Uncertainty	CLIC@380GeV $500\ fb^{-1}$	ILC@500GeV $500\ fb^{-1}$	TDR TESLA $300\ fb^{-1}$
Re{F_{2A}^{γ}}	**0,004**	**0,004**	**0,007**
Re{F_{2A}^{Z}}	**0,007**	**0,006**	**0,008**
Im{F_{2A}^{γ}}	**0,004**	**0,006**	**0,008**
Im{F_{2A}^{Z}}	**0,007**	**0,010**	**0,010**

The potential of CLIC@380 GeV for measuring CPV couplings, assuming a $L = 500\ fb^{-1}$, is comparable to previous studies

Summary and conclusions

- **LoosePandoraPFANewPFOs with VLC jet algorithm (R=1.6 β=γ=0.8) offers the best jet reconstruction**
- **We have to cut very hard in the χ^2 to cure the migration on A_{FB} -> we pay a high price in statistics (~18%)**
- **It translates into a statistical error of ~5% for A_{FB} that increases the uncertainty in the top quark couplings -> An improvement of the quality cuts is needed or more statistics**
- **A great precision in the measurement of CPV couplings could be reached with e+e->tt CLIC@380GeV (L=500fb^{-1})**
- **It would interesting to extend the study to CLIC@500 GeV (cross check), CLIC@1.4TeV (boosted tops, minor migrations due to ambiguity Wb pairing)**

Thank you for your attention

BACKUP SLIDES

Valencia Jet Algorithm

A robust jet reconstruction algorithm for high-energy lepton colliders doi:10.1016/j.physletb.2015.08.055

A new clustering jet reconstruction algorithm that combines the good features of lepton collider algorithms, in particular the **Durham-like distance criterion;**

$$d_{ij} = min(E_i^{2\beta}, E_j^{2\beta})(1 - \cos\theta_{ij})/R^2$$

with the **robustness against background of** the longitudinally

invariant $\mathbf{k_t}$ **algorithm**

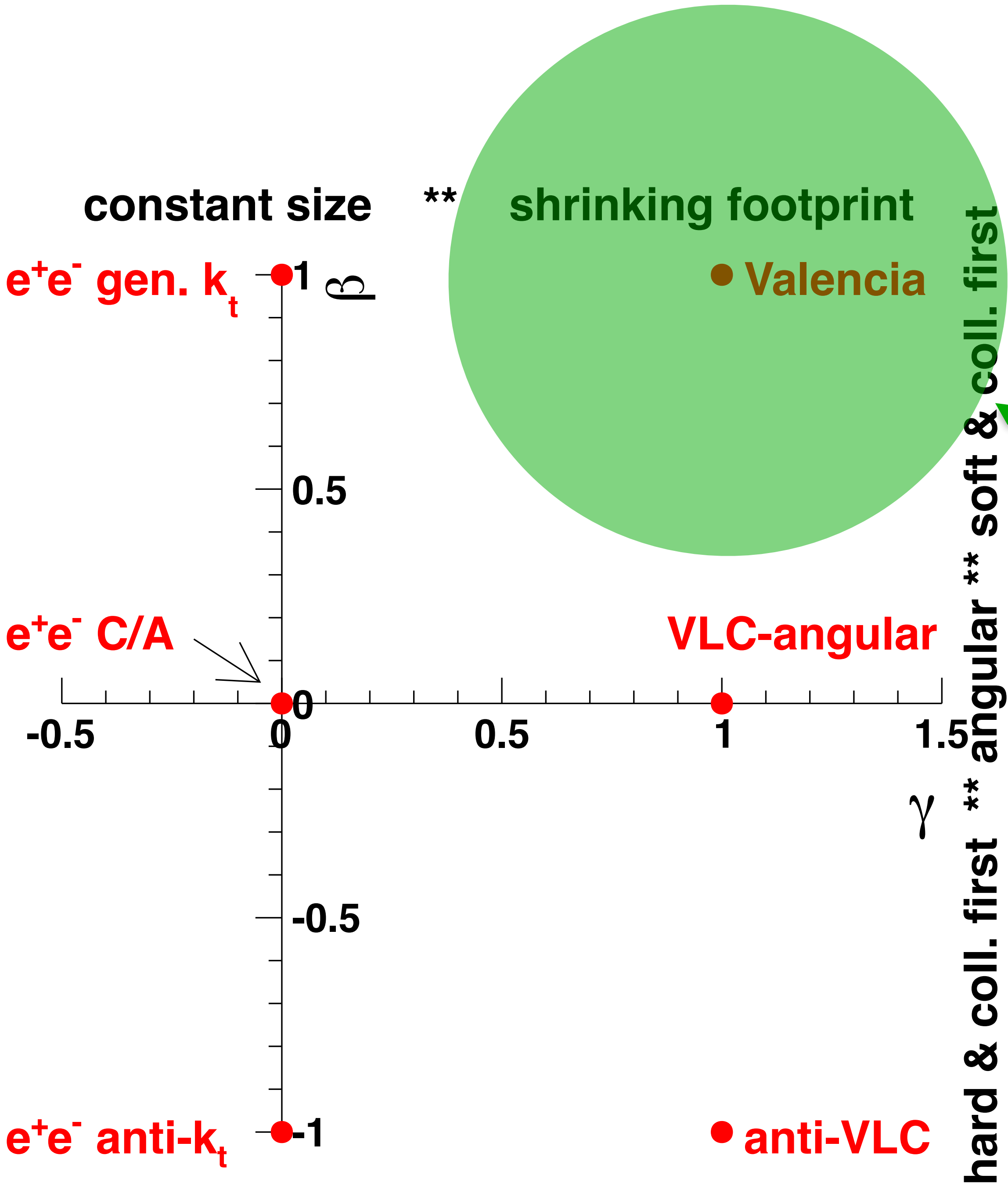
$$d_{iB} = E^{2\beta} \sin^{2\gamma} \theta_{iB}$$

The γ parameter governs the evolution of the jet area with polar angle

and β allows to ***change the clustering order.***

*In the default settings the two exponents β and γ are equal. For **β=γ=1** the expression simplifies to $d_{iB} = E^2 \sin^2 \theta_{iB} = p^2_{ti}$

The (β,γ) space

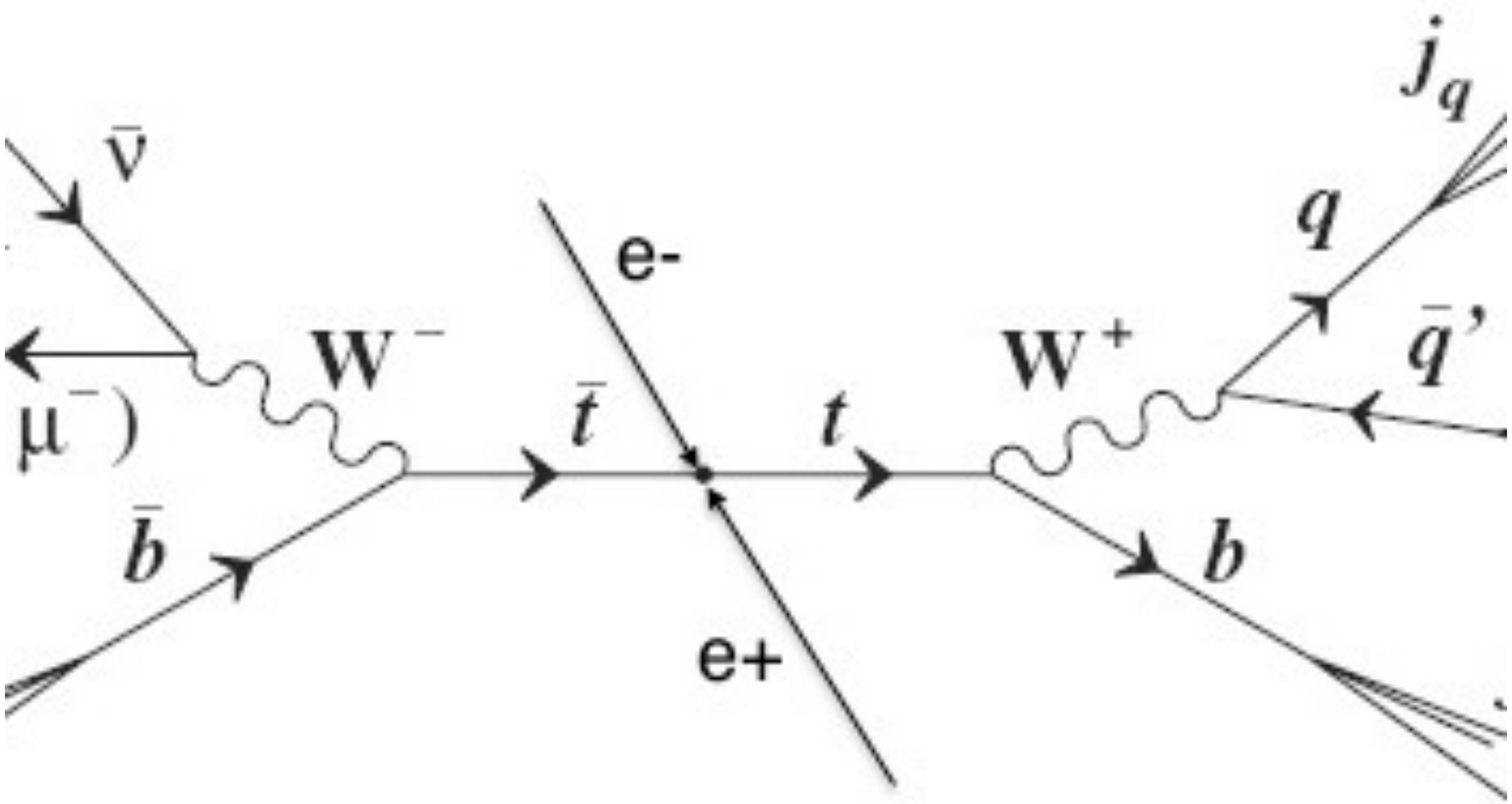


We only work close to the default configuration of the VLC algorithm

$\beta \simeq \gamma \simeq 1$

Jet reconstruction performance

- Events are selected in which the top pair decays semi-leptonically



Event generation

1) WHIZARD: event generation (*samples for the DBD*)
2) PYTHIA: Parton shower and hadronisation
3) FASTJET: Durham for primary jet reconstruction and Long. Inv. k_t for $\gamma\gamma \rightarrow$hadrons removal

Event selection

- The signal is reconstructed by choosing the combination of *b* quark jet and W boson that minimises the following equation:

$$d^2 = \left(\frac{m_{cand.} - m_t}{\sigma_{m_t}}\right)^2 + \left(\frac{E_{cand.} - E_{beam}}{\sigma_{E_{cand.}}}\right)^2 + \left(\frac{p_b^* - 68}{\sigma_{p_b^*}}\right)^2 + \left(\frac{cos\theta_{bW} - 0.23}{\sigma_{cos\theta_{bW}}}\right)^2$$

- Some cuts:
  - Hadronic mass of the final state: $180 < m_{had.} < 420\,\mathrm{GeV}$
  - Reconstructed W mass: $50 < m_W < 250\,\mathrm{GeV}$
  - Reconstructed top mass: $120 < m_t < 270\,\mathrm{GeV}$
  - Isolated lepton: *the best candidate*
  - b-tag values: *b-tag*$_1$ *> 0.8 & b-tag*$_2$ *> 0.3*

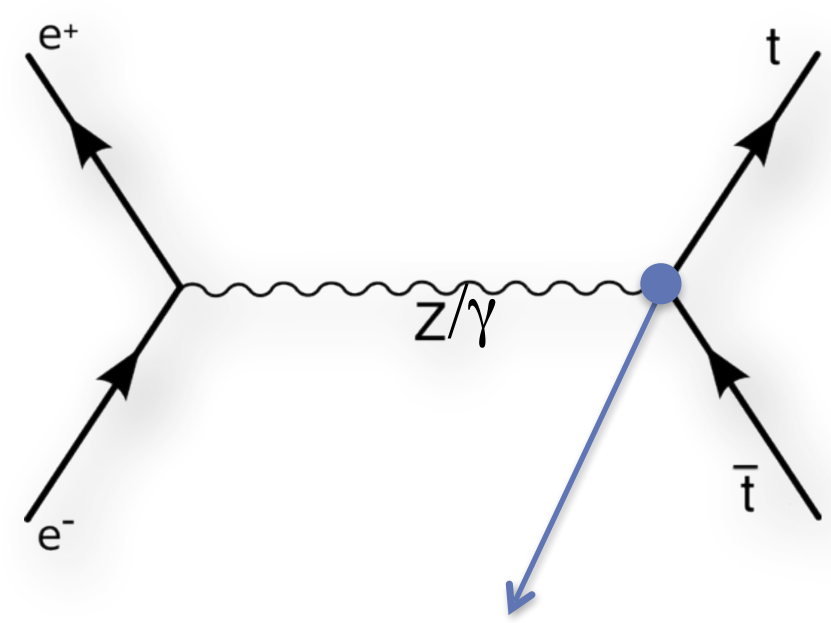
- The **entire selection** retains:
  - **51.9%** for the configuration P,P' = -1,+1 (Left-handed electrons)
  - **55.0%** for P,P' = +1, -1 (Right-handed electrons)

lepton+jets tt ILC@500GeV

- This study, based on a detailed simulation of the ILD detector concept for ILC, assumes a $\sqrt{s}$=500GeV and L=500fb^{-1} and polarised beams.
- The vector, axial and tensorial CP conserving couplings are extracted separately for the Z and γ component
- A way to describe the current of *ttZ*^{0} and *tt*γ primary vertices:

  - *X = Z*^{0}*, γ*
  - *V = Vector coupling*
  - *A = Axial coupling*

$$\Gamma_\mu^{t\bar{t}X}(k^2, q, \bar{q}) = ie\left\{\gamma_\mu(F_{1V}^X(k^2) + \gamma_5 F_{1A}^X(k^2))\right.$$
$$\left. - \frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\nu(iF_{2V}^X(k^2) + \gamma_5 F_{2A}^X(k^2))\right\},$$



A precise characterisation of the top quark electro-weak vertices at the ILC arXiv:1505.06020

From ILC@500GeV to CLIC@380GeV

- **ee→ 6 fermions** samples (selecting **only lepton+jets decays**) from the Monte Carlo samples for top reconstruction studies (https://twiki.cern.ch/twiki/bin/view/CLIC/MonteCarloSamplesForTopPhysics)
- **ILCDirac software** (Marlin, FastJet, Pandora…)
- **Full simulation CLIC_ILD_CDR500** detector model
- Jet algorithms: **Longitudinally invariant k_t** and **Valencia jet algorithm**
- **Analysis chain** and the **code** (adapted) from ILC@500GeV studies