Laboratoire d'Annecy de Physique des Particules

Angular analysis for $e^+e^- \longrightarrow W^+W^-$ final states at $\sqrt{s} = 240GeV$

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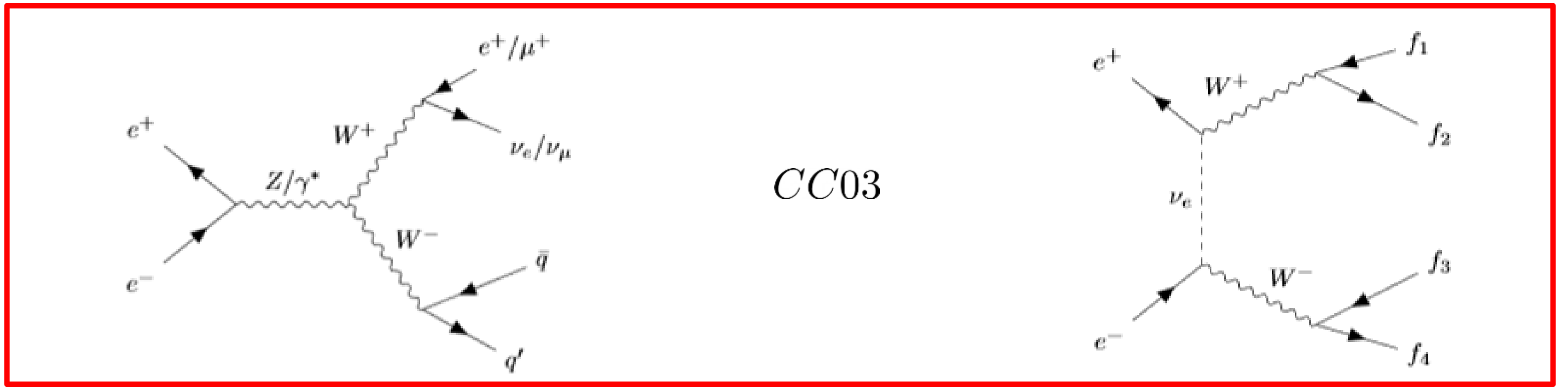
$$\text{Signal} = \text{WW semi-leptonic } e, \mu$$



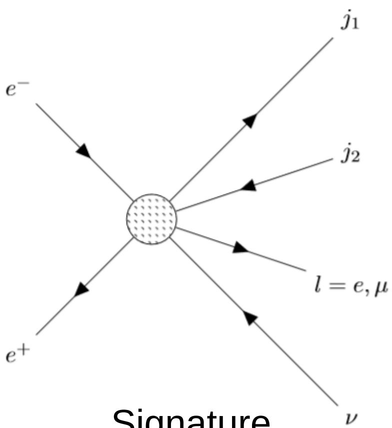
Anomalous TGC may give different contributions to different helicity states of the W bosons (wrt SM) and give access to BSM effects

→ W pair production and decay defined by 5 angles (neglecting ISR):

Spin density matrix

$$\rho^{W^-}_{\tau\tau'}(s,\cos\theta_W) = \frac{\sum_{\lambda,\lambda'} F_{\tau}^{(\lambda,\lambda')}\left(F_{\tau'}^{(\lambda,\lambda')}\right)^*}{\sum_{\lambda,\lambda',\tau}\left|F_{\tau}^{(\lambda,\lambda')}\right|^2}$$

Amplitude to produce a W^- with helicity τ from an electron with helicity λ and a positron with helicity λ'



Signature

θ_{W^-}

θ^*_1, ϕ^*_1 — angles of the fermion in the W^- rest frame

θ^*_2, ϕ^*_2 — angles of the antifermion in the W^+ rest frame

Event selection

Simulation : Pythia + FCCAnalyses (Thanks to Emmanuel Perez & Clement Helsens)

Cut defintion :

- C1 : Charged multiplicity > 5
- C2 : Charged multiplicity < 25
- C3 : Charged energy > $0.3\sqrt{s}$
- C4 : 1 Lepton with 20 GeV
- C5 : Missing momentum > 15 GeV
- C6 : Missing momentum < 100 GeV
- C7 : Transverse energy > $0.3\sqrt{s}$

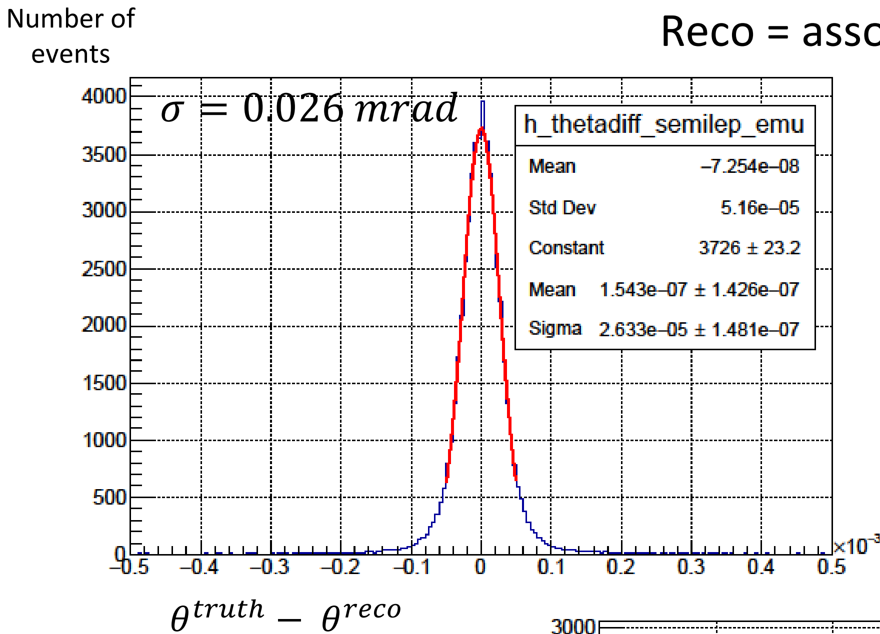
Cut	Signal		BKG 1		BKG 2	BKG 3	BKG 4	BKG 5	$\frac{S}{S+B}$ %
	WW sl e, μ		WW sl τ had	WW sl τ lep	WW lep	WW had	Zqq(γ)	Zll	
No	23932530		7685700	4308924	8666757	37606089	263200000	68800000	5.778 ± 0.001
C1	23916090	0.999	7681179	4306458	32880	37606089	257843880	652912	7.203 ± 0.001
C2	22975311	0.961	7293606	4135482	32880	8554143	225733480	652912	8.529 ± 0.002
C3	22143036	0.964	5499180	3212376	25071	8100399	137943120	536984	12.478 ± 0.002
C4	19670460	0.888	12330	1987596	10275	35757	2982056	31304	79.542 ± 0.008
C5	19361799	0.984	12325	1946090	9864	15207	2188508	20640	82.200 ± 0.008
C6	19331796	0.998	12325	1946090	9864	15207	1997688	19952	82.852 ± 0.008
C7	19006695	0.983	12325	1828955	7809	15207	1179136	14792	86.140 ± 0.007
ε	79.4 ± 0.5		0.16 ± 0.03	42.4 ± 0.4	0.09 ± 0.02	0.040 ± 0.007	0.45 ± 0.02	0.022 ± 0.003	

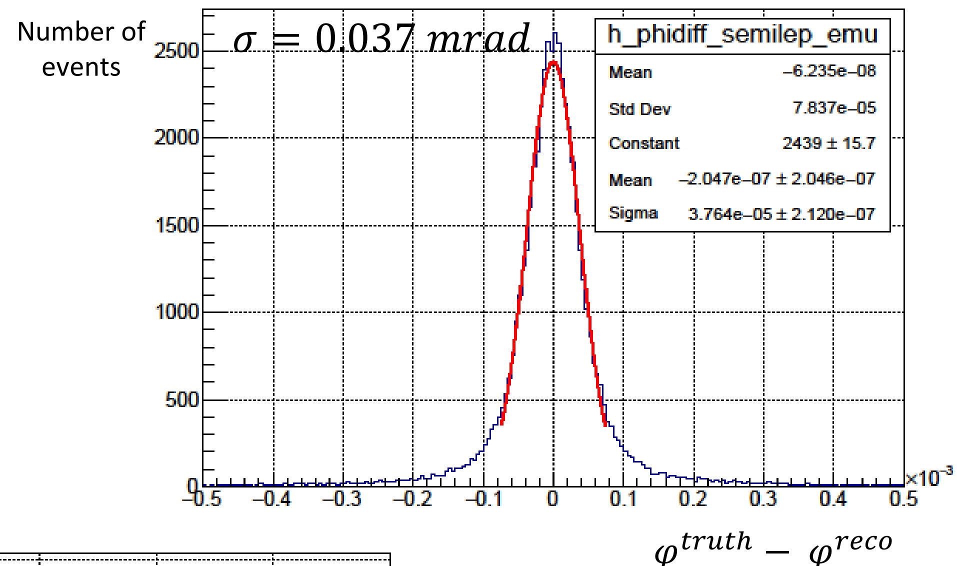
- WW semi-leptonic tau (decaying to hadrons),WW fully leptonic, fully hadronic, Zll events almost entirely rejected
- WW Semi-leptonic tau (decaying to leptons) and Zqq need further attention
- Signal efficiency goes up to 81.4% in the new Delphes version due to improved Cut 4 efficiency

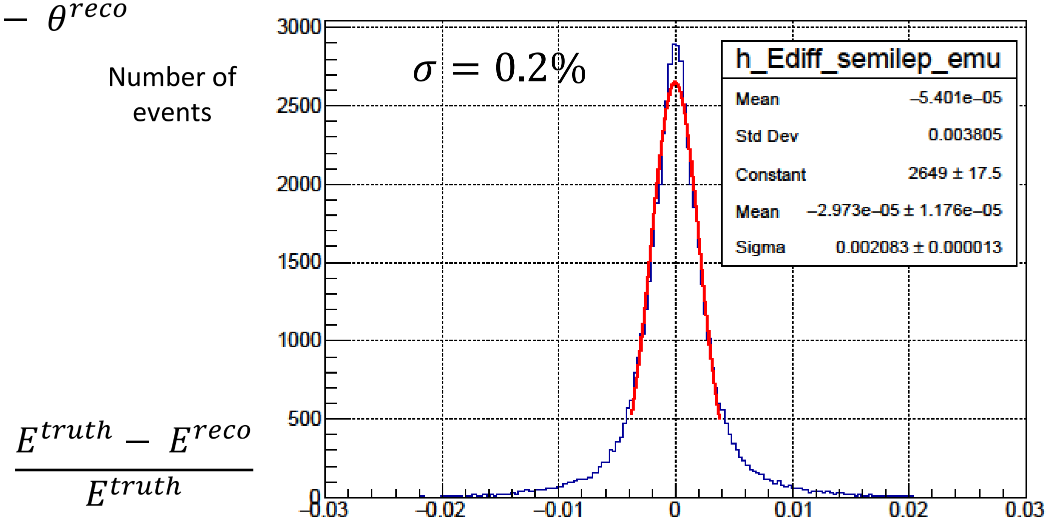
WW – sl e, μ - Charged leptons resolution

Truth = lepton from W

Reco = associated reco lepton







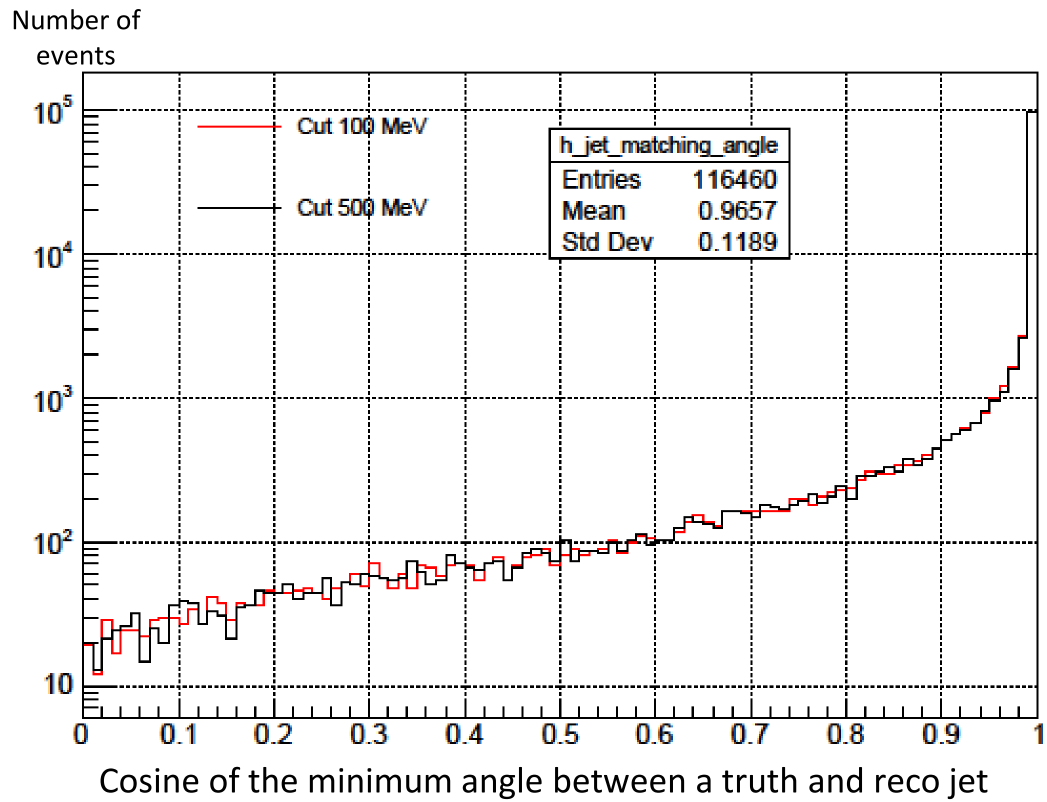
IDEA detector fast simulation :
→ Charged lepton resolution is very good

- Jets are reconstructed using Durham algorithm ($e^{+}e^{-}k_{\perp}$), forcing exactly 2 jets
- Input Particles :

- Jet reco :
All particles > 500MeV except highest energy lepton
- Jet truth :
All particles > 500MeV Status = 1, except highest energy lepton & neutrinos

- Slightly worse results w.r.t. the same reference plot by Julie Torndal

- No improvement decreasing the 500MeV cut to 100MeV



Jet resolutions by fitting distributions with a gaussian

$\sigma_\theta = 24\,mrad \qquad \sigma_\varphi = 27\,mrad \qquad \sigma_E = 4.8\%$

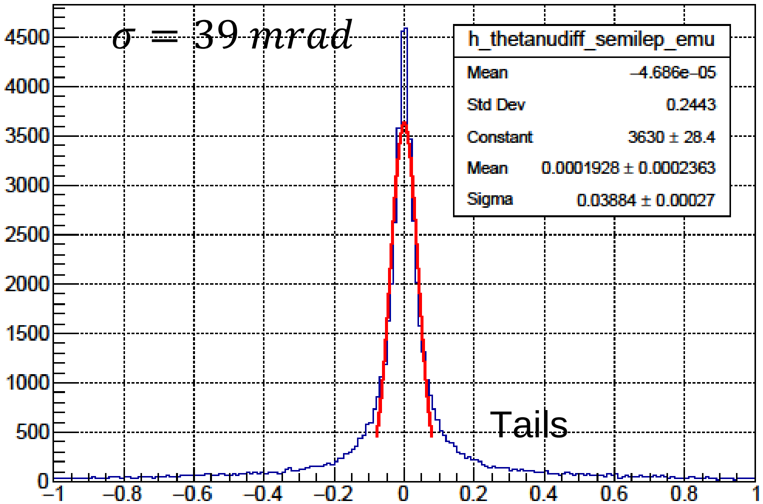
Worse resolution w.r.t. charged lepton due to clustering and detector effects

WW – sl e, μ - Neutrinos resolution before fit

Truth : neutrino from W

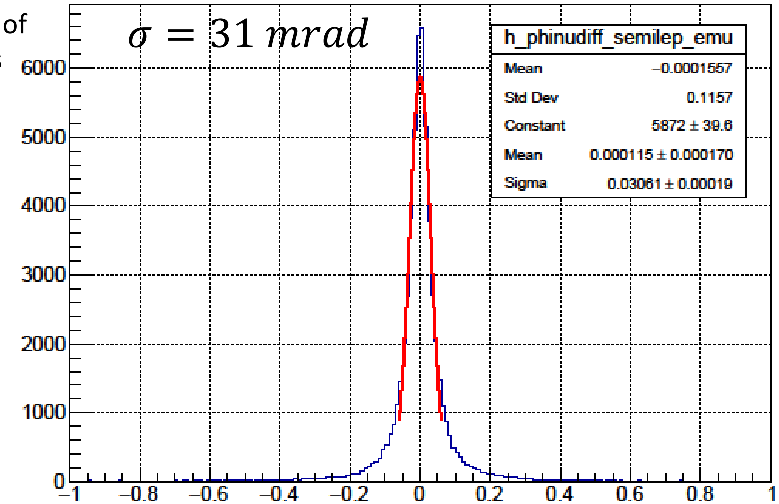
Reco : $\not{\vec{p}} = -\sum_{all\ reco} \vec{p}$

Number of events



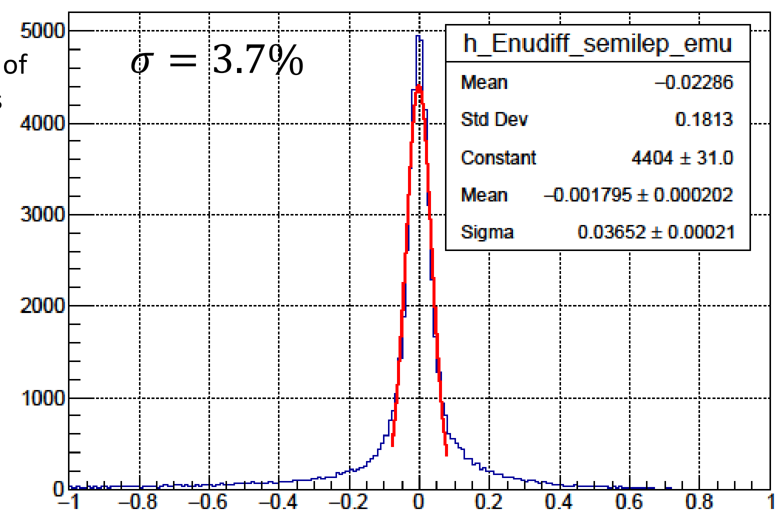
$\theta^{truth} - \theta^{reco}$

Number of events



$\varphi^{truth} - \varphi^{reco}$

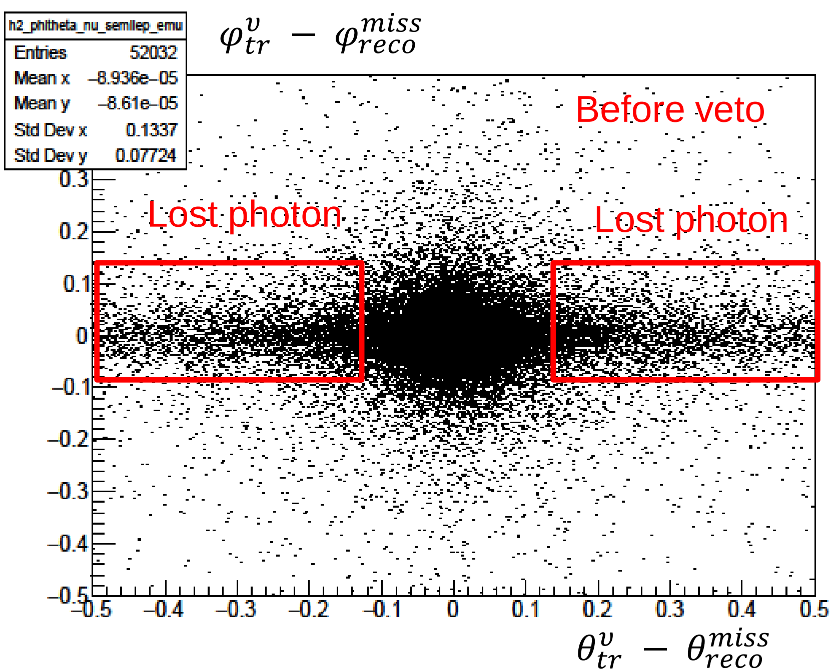
Number of events

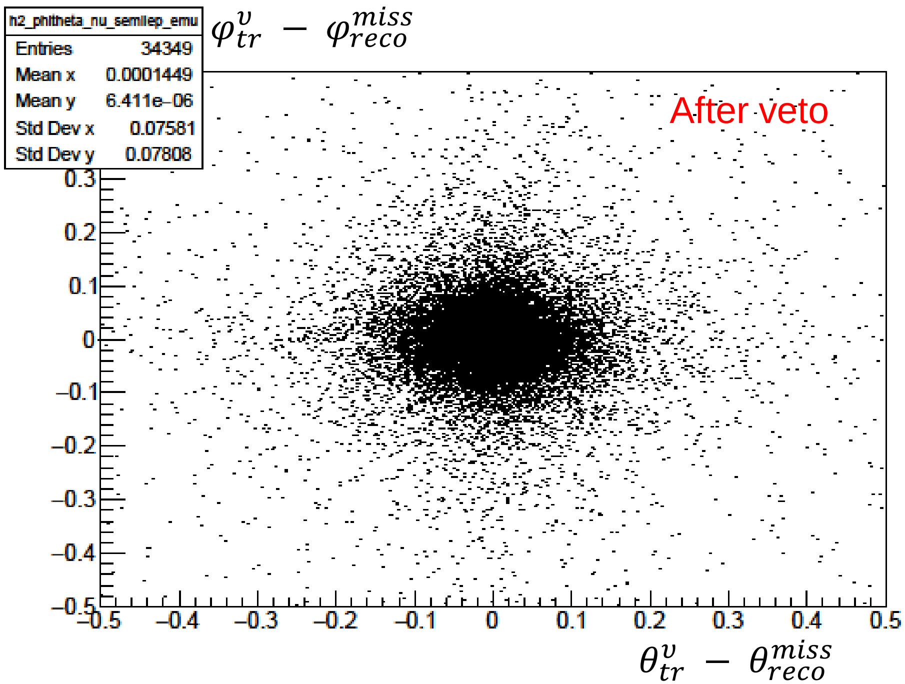


$\frac{E^{truth} - E^{reco}}{E^{truth}}$

→ We would like to improve the energy and angle resolution using a kinematic fit

- Effect of the losses (ISR, …) in the beam pipe : veto the event if there is at least a truth photon with E > 2 GeV and θ < 0.1 rad
- Photon lost in beam pipe : 34% of signal events
- Lost prompt charged lepton : ~2% of signal events



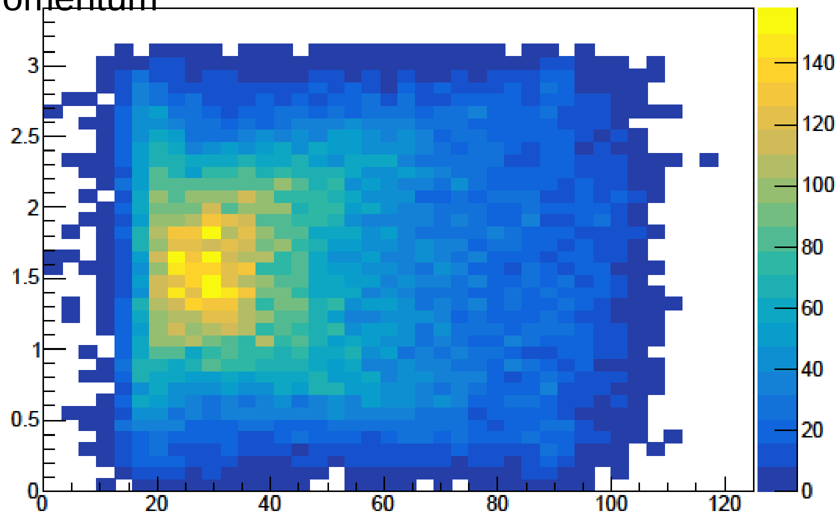


→ Losses in the beam pipe (mainly ISR) are responsible for tails in θ and E resolution
→ Need to treat differently ISR and non-ISR events
→ Events with lost prompt charged lepton events can be removed by a cut on missing momentum and visible energy (see backup)

Simple cuts are not efficient even though the shapes are different for ISR and non-ISR events

θ of the missing momentum

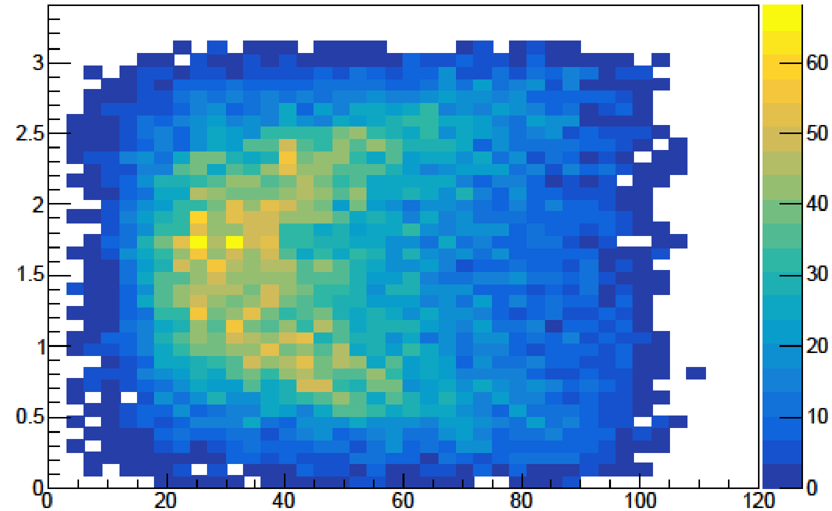
No ISR events (38k events)



Magnitude of the missing momentum

θ of the missing momentum

Only ISR events (20k events)



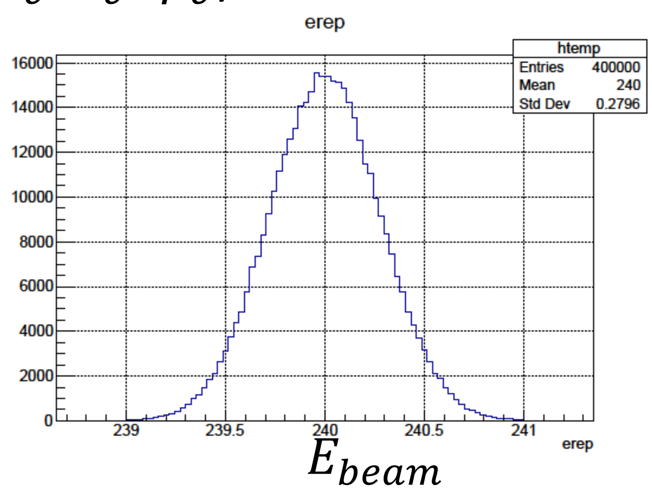
Magnitude of the missing momentum

→ Need to implement MVA method to discriminate and treat ISR and non-ISR events (DNN, BDT, likelihood …)

https://github.com/Torndal/ABCfitplusplus

- Use ABCFit++ (Julie Munch Torndal, Jørgen Beck Hansen)
- Constraints :
  - The sum of the momenta of the 2 jets and the 2 leptons, projected on all 3 axis, is null (3C)
  - The total energy follows a gaussian distribution : 240 ± 0.28 GeV (1C)
  - The W_{lep} mass follows a gaussian distribution : 80.5 ± 13.5 GeV (value found iteratively from the original mass distribution) (1C)

- The fit has 2 degrees of freedom (equal to 5C – 3 parameters $E_{\upsilon}, \theta_{\upsilon}, \varphi_{\upsilon}$)



Kinematic fit behaves well if a charged lepton has more than 15 GeV

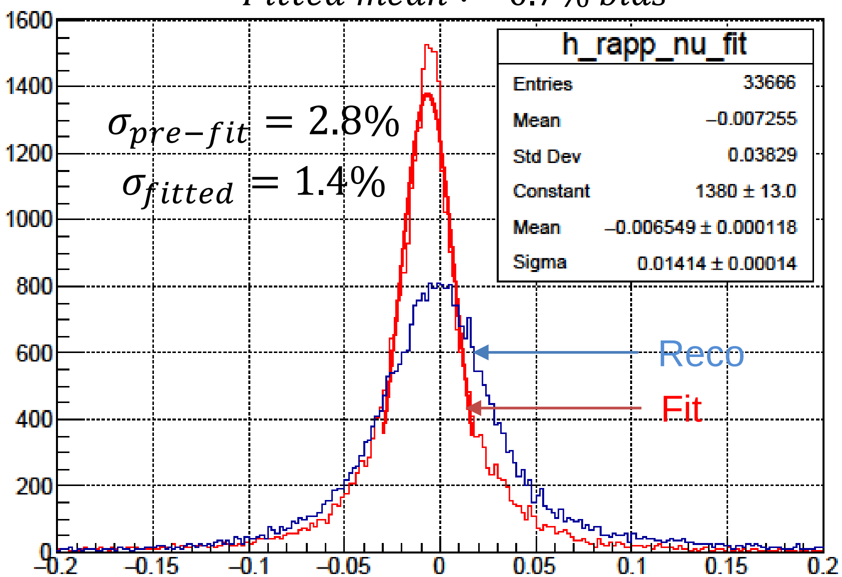
Neutrino resolution after kinematic fit

- Fit improves the neutrino resolution, but creates a bias
- Bias depends on the values in the covariance matrix, trade off with resolution
- Lepton energy and angular resolutions slightly degraded

Signal events
Cuts :
- No photon with E>2GeV in the beam pipe
- Highest energy lepton has E>15GeV

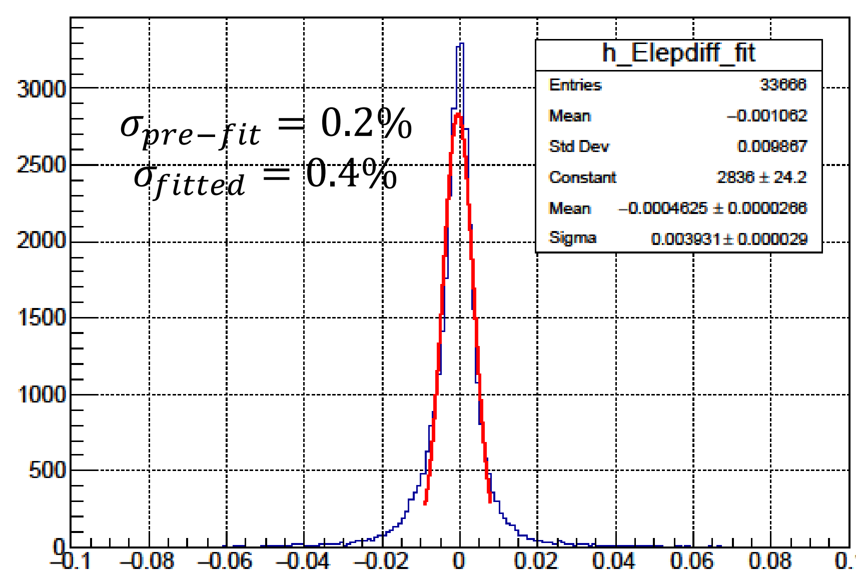
Number of events

$Fitted\ mean : -0.7\%\ bias$



$$\frac{E^{\nu}_{tr} - E^{\nu}_{fit}}{E^{\nu}_{tr}}$$

Number of events

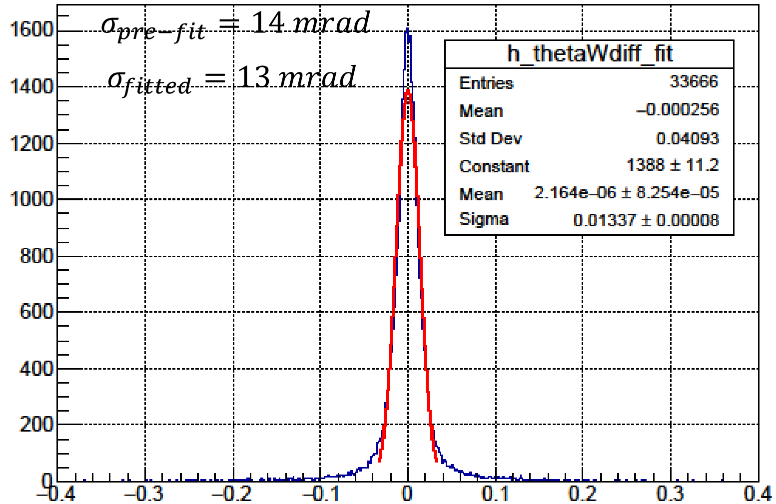


$$\frac{E^{l}_{tr} - E^{l}_{fit}}{E^{l}_{tr}}$$

W resolution after kinematic fit

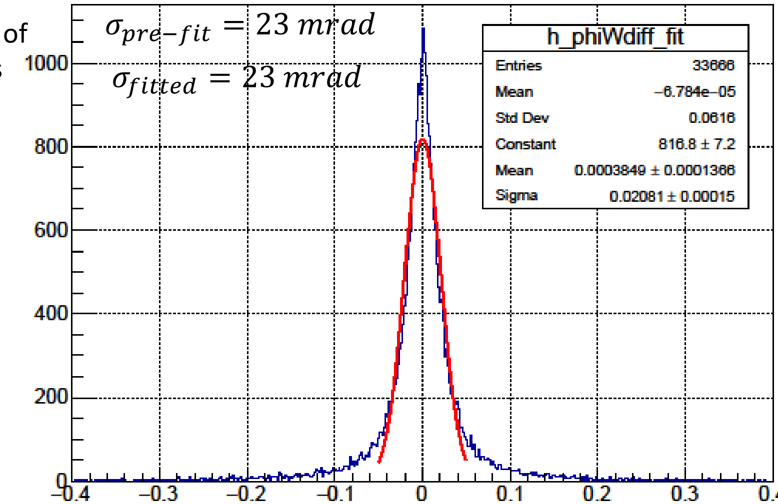
Truth variables are taken directly from W (truth), reco variables are built from highest momentum charged lepton and missing momentum

Number of events



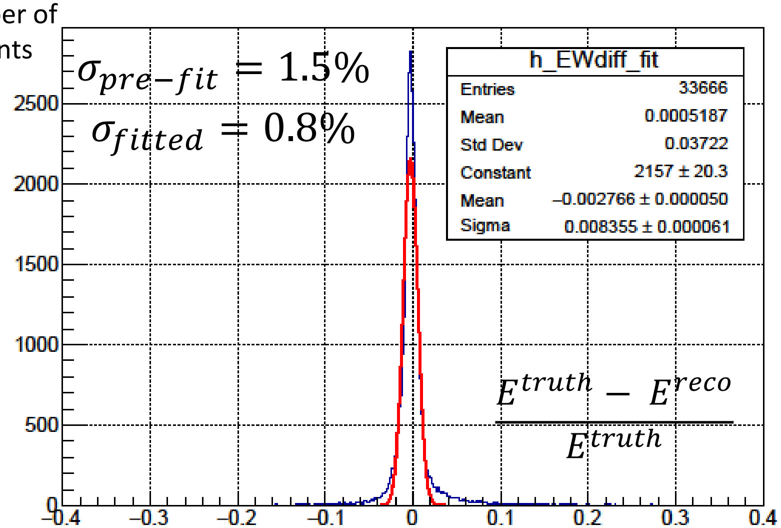
$\theta^{truth} - \theta^{reco}$

Number of events



$\varphi^{truth} - \varphi^{reco}$

Number of events

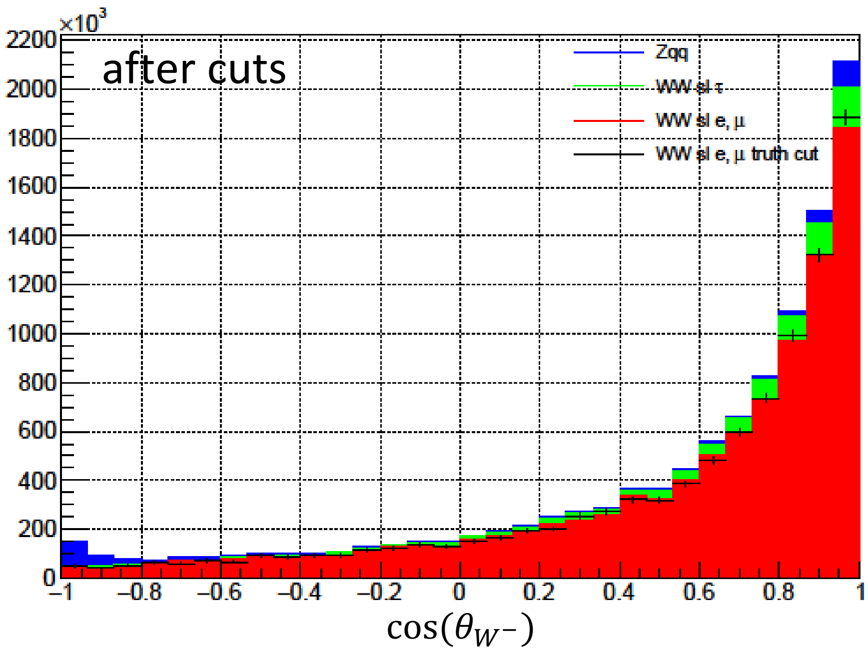


Signal events
Cuts :
- No truth γ with E>2GeV in the beam pipe
- Highest energy lepton has E>15GeV

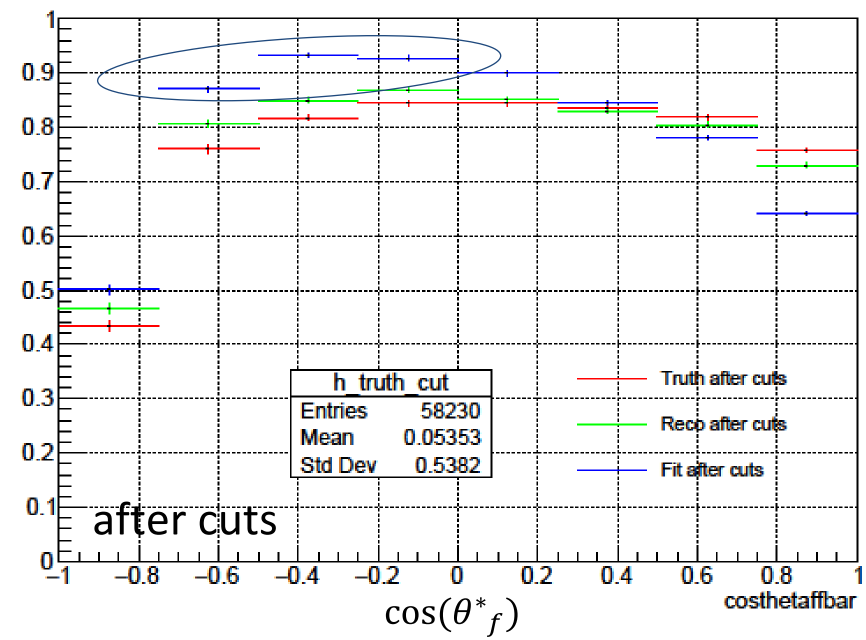
$\longrightarrow$ θ and φ distribution unchanged
$\longrightarrow$ E resolution is improved and the tails are reduced

- After signal selection cuts (plots include ISR events):
  - $\cos(\theta_{W^-})$ is improved (closer to truth shape than reco)
  - But the fit changes the shape of $\cos\left(\theta^*{}_f\right)$ because of ISR events

Distribution after kin. fit for selected events



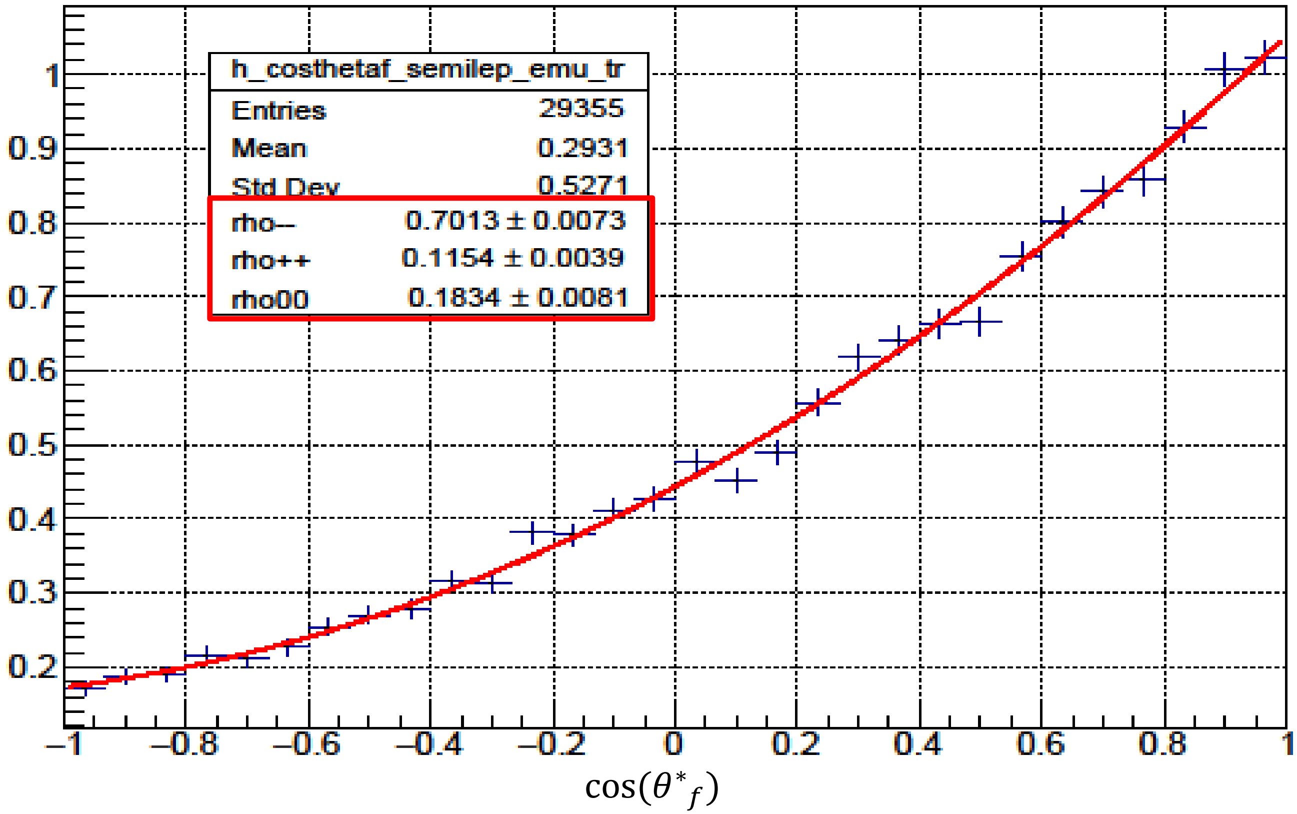
Ratio : N_{events} after event selection cut / N_{events} before cuts



Closure test

Fitted $\frac{d\sigma}{d\cos(\theta_f^*)} = \frac{3}{8}\left(\rho_{--}\,(1+\cos(\theta_f^*))^2 + 2\rho_{00}\sin(\theta_f^*)^2 + \rho_{++}\,(1-\cos(\theta_f^*))^2\right)$

Fitted distribution of $\cos(\theta_f^*)$ for all truth signal, normalized to the number of events

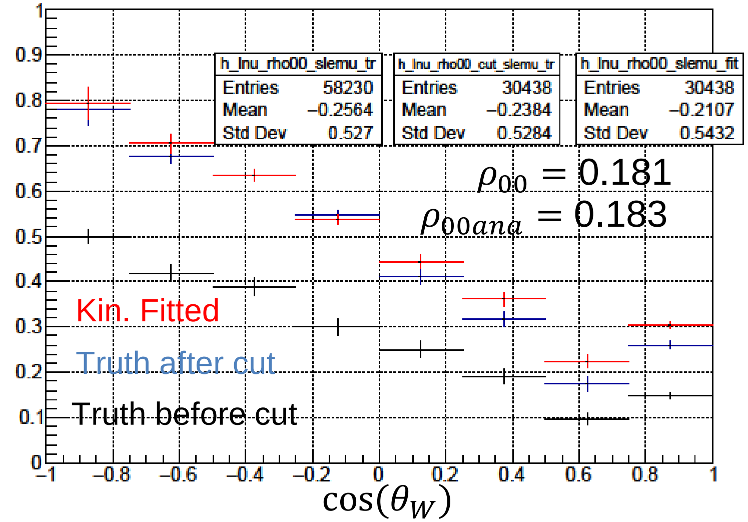


Diagonal elements of the W spin density matrix

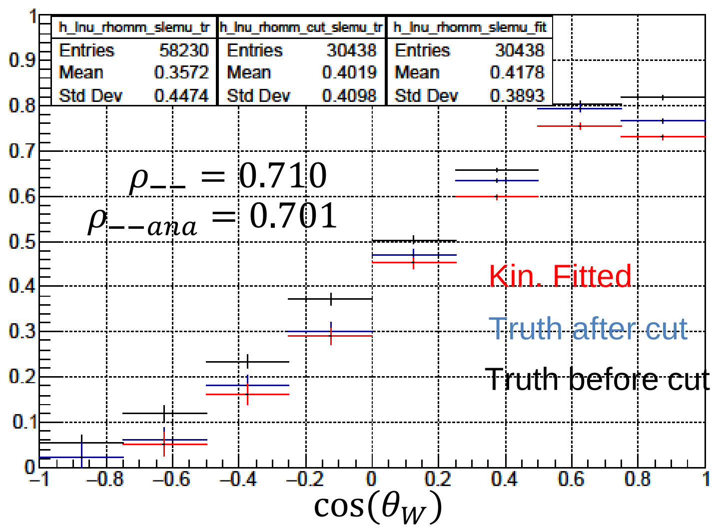
$$\rho^{W^-}_{\tau\tau'}(s,\cos\theta_W) = \frac{\int \frac{d^3\sigma}{d\cos\theta_W d\cos\theta^*_f d\phi^*_f}\cdot\Lambda_{\tau\tau'} d\cos\theta^*_f d\phi^*_f}{\frac{d\sigma}{d\cos\theta_W}}$$

$$\Lambda_{--} = \tfrac{1}{2}(5\cos^2\theta^*_f + 2\cos\theta^*_f - 1)$$
$$\Lambda_{00} = 2 - 5\cos^2\theta^*_f$$
$$\Lambda_{++} = \tfrac{1}{2}(5\cos^2\theta^*_f - 2\cos\theta^*_f - 1)$$

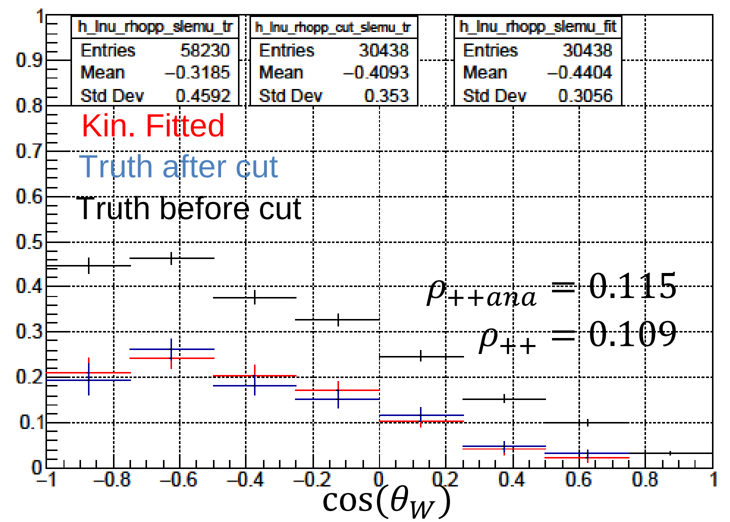
Distribution of ρ_{00} on the leptonic side



Distribution of ρ_{--} on the leptonic side



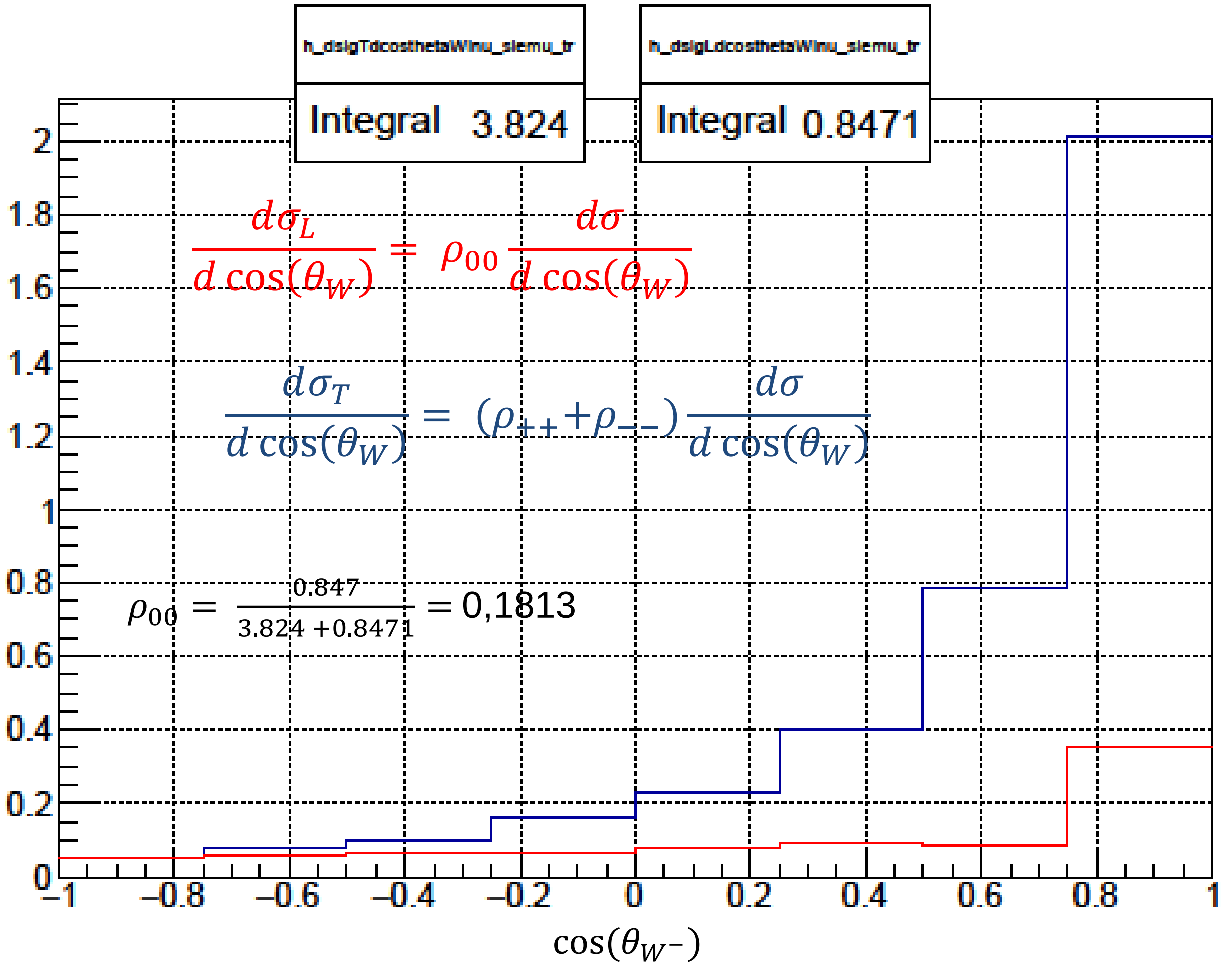
Distribution of ρ_{++} on the leptonic side



- The results for diagonal elements are the same for fit and projection operators

Longitudinal & transversal cross-sections

Distribution of differential cross-sections on the leptonic side



$$\frac{d\sigma_L}{d\cos(\theta_W)} = \rho_{00}\,\frac{d\sigma}{d\cos(\theta_W)}$$

$$\frac{d\sigma_T}{d\cos(\theta_W)} = (\rho_{++}+\rho_{--})\,\frac{d\sigma}{d\cos(\theta_W)}$$

$$\rho_{00} = \frac{0.847}{3.824+0.8471} = 0{,}1813$$

Conclusion :

- The fit improves mainly the missing energy resolution, smaller effect on the angles
- Important to select (discard and treat separately) the “ISR events”
- Statistical uncertainty much smaller than previous experiments
- Possibility to access non-diagonal elements of SDM and perform a test of CP violation

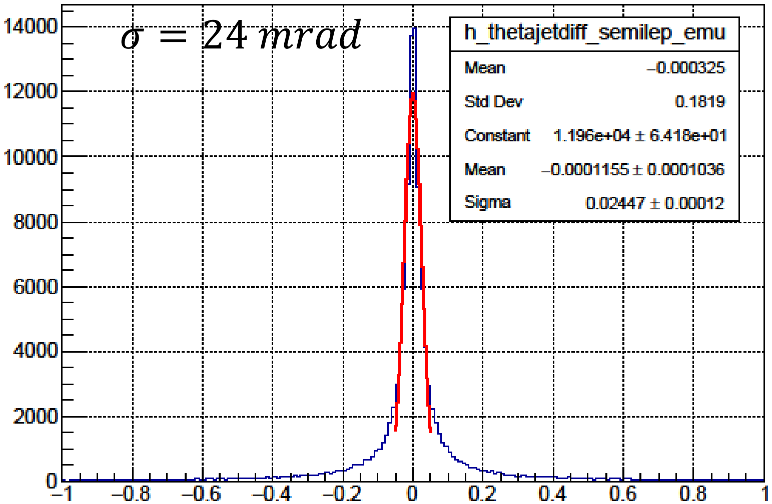
Next steps :

- Consolidate the extraction of the variables of interest
- Study the $WW \rightarrow jj\ \tau\upsilon$ contribution
- Find a way to distinguish ISR events on reco level

Truth = quarks from W ;

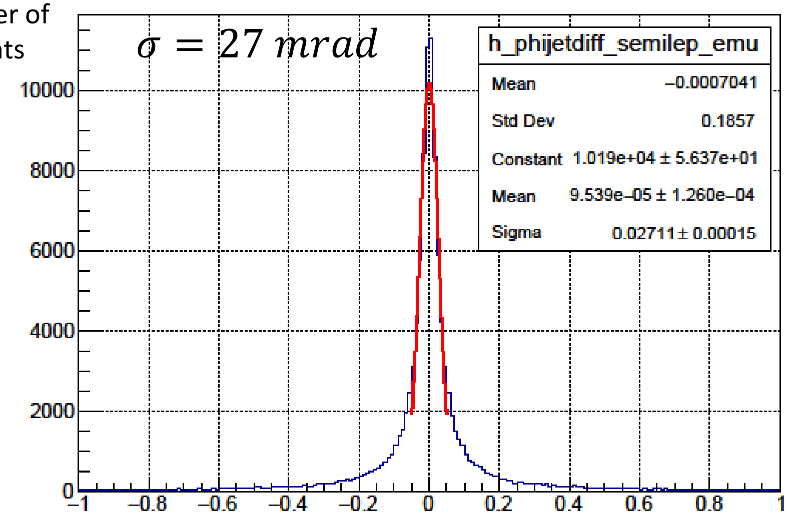
Reco = associated reco jet (Closest jet in angle to the leading quark and the other jet to the orther quark)

Number of events



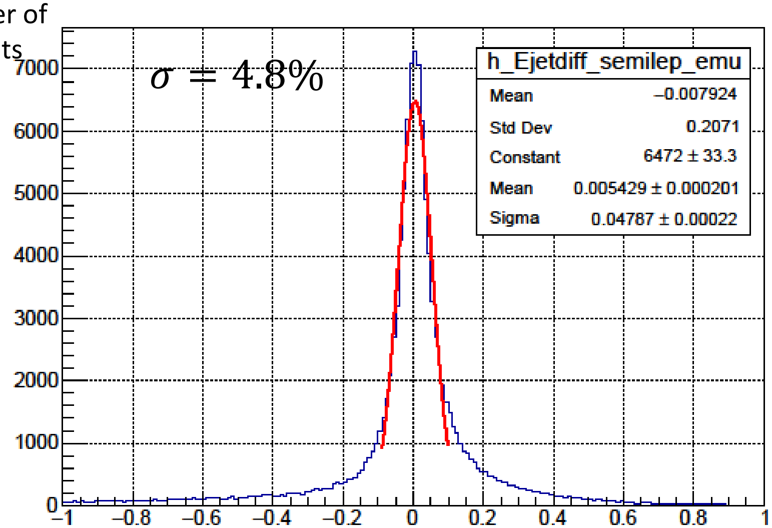
$\theta^{truth} - \theta^{reco}$

Number of events



$\varphi^{truth} - \varphi^{reco}$

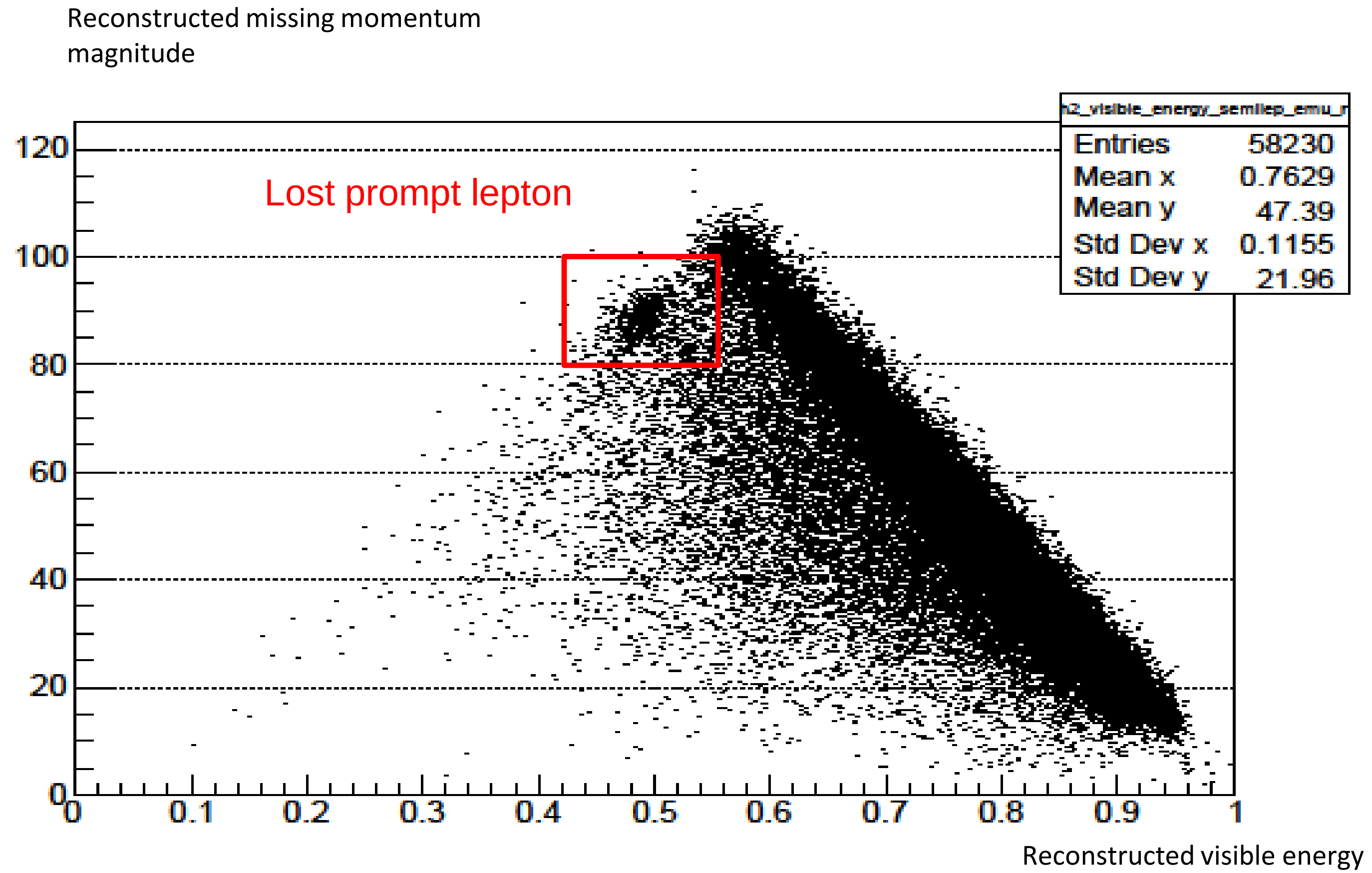
Number of events



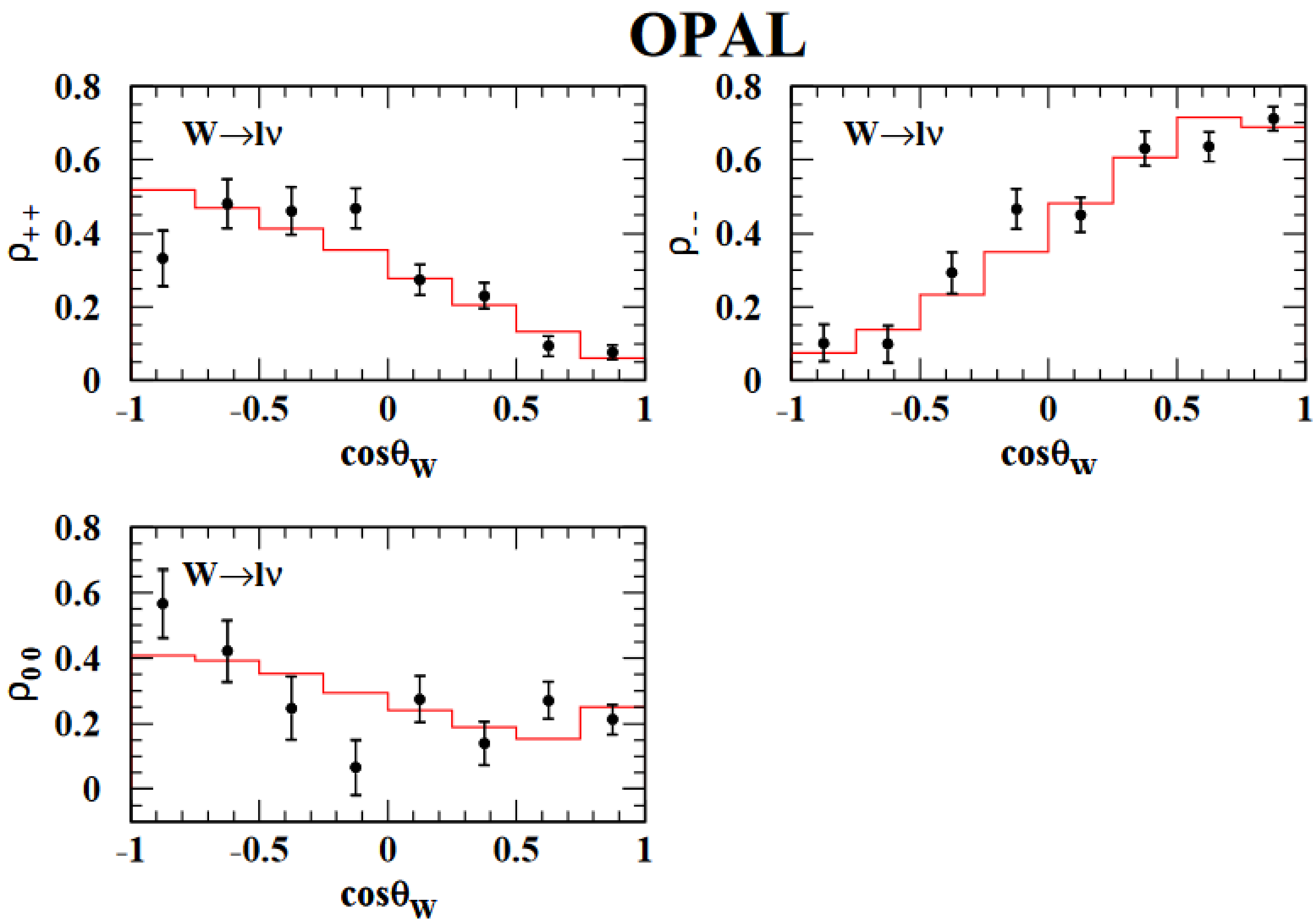
$\frac{E^{truth} - E^{reco}}{E^{truth}}$

Worse resolution due to :
→ Clustering
→ Detector effects (efficiency)

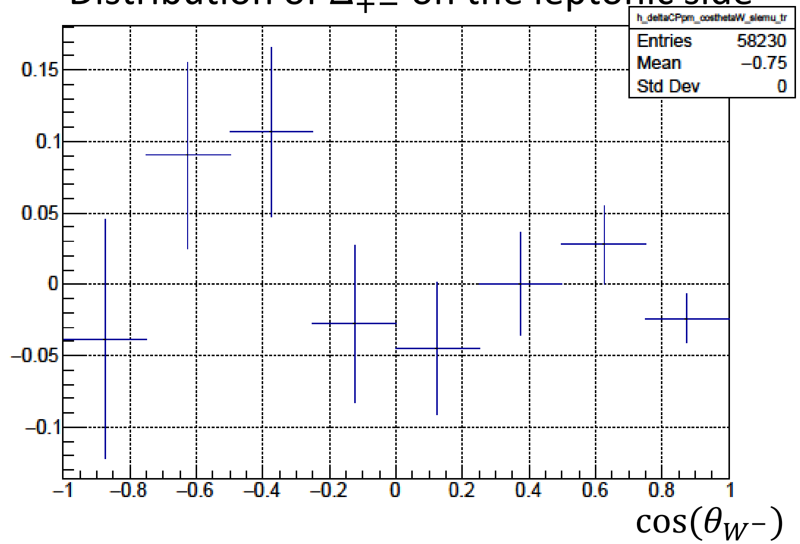
- Lost prompt charged lepton : ~2% of signal events



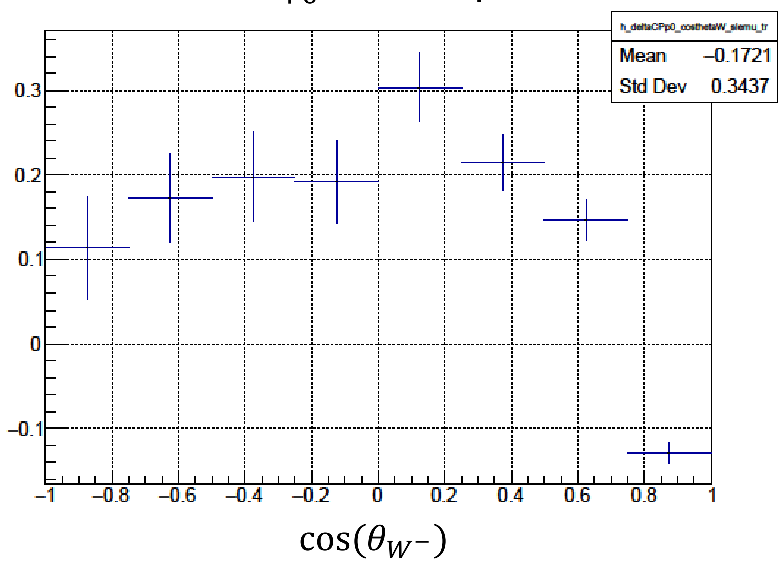
→ Lost prompt lepton events can be removed by the cut on visible energy and missing momentum magnitude


OPAL
W→lν
W→lν
W→lν
ρ++
ρ--
ρ00
0.8
0.6
0.4
0.2
0
-1
-0.5
0
0.5
1
cosθW
cosθW
cosθW

Distribution of Δ_{+-} on the leptonic side



Distribution of Δ_{+0} on the leptonic side



Distribution of Δ_{-0} on the leptonic side