WW Scattering in the LDC00Sc and LDC01Sc

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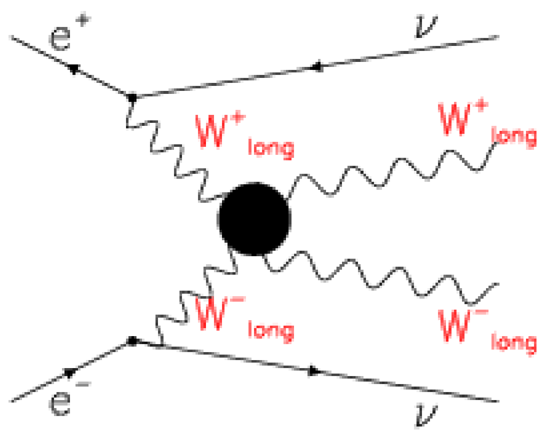
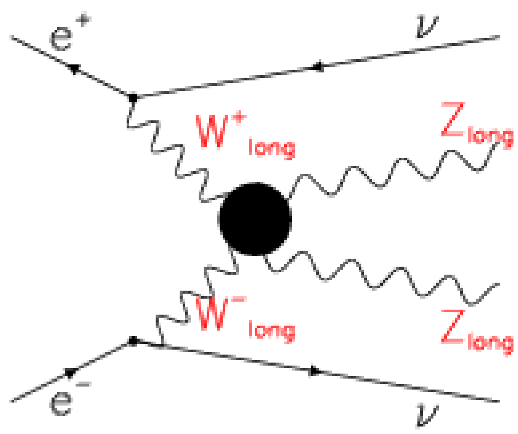
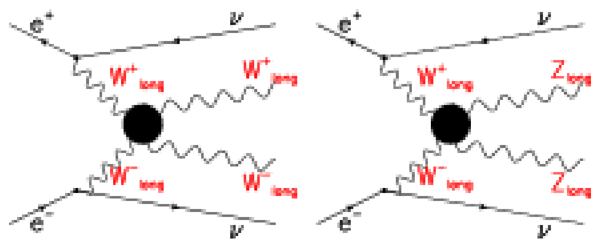




Motivation

- WW scattering @ e^+e^-



- Parameters: anomalous couplings α_4 & α_5, which are zero in the SM and are related to the scale of new physics.

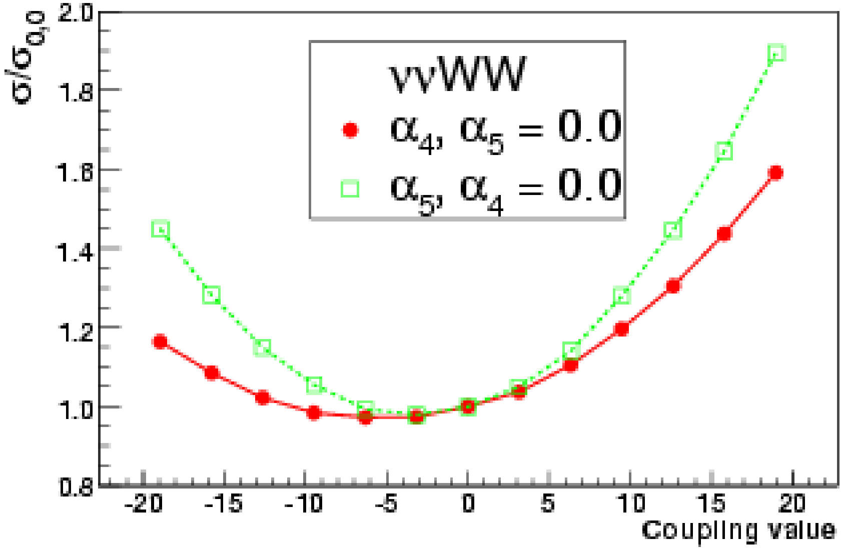
- Sensitivity of α_4 & α_5 at linear collider ?
  - LC-PHSM-2001-038: SIMDET for TESLA @ 800 GeV
  - hep-ph/0604048: SIMDET for TESLA @ 1000 GeV
  - Andres F. Osorio's thesis: SIMDET for TESLA @ 800 GeV

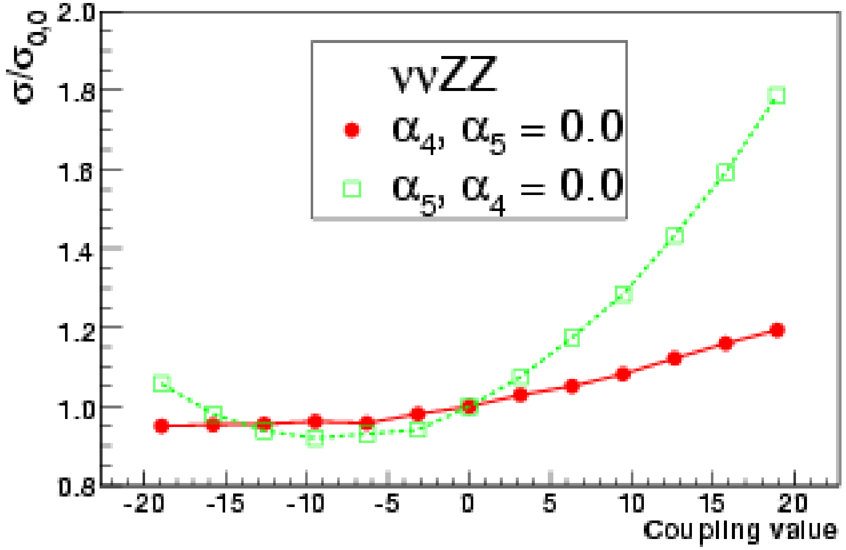
Motivation

- Motivation @ this work
  - WW/ZZ separation
  - Extract α_4 & α_5:
    - * Detector model: LDC00, LDC00Sc, LDC01, LDC01Sc
    - * PFA: Pandora PFA vs. Wolf PFA
- This talk: apply Pandora PFA for LDC00Sc & LDC01Sc detector models, and extract α_4 & α_5.
- LDC00Sc vs. LDC01Sc
  - Ecal
    - * LDC00Sc: 30X 1.4mm + 10X 4.2 mm as W radiator
    - * LDC01Sc: 20X 2.1mm + 10X 4.2 mm as W radiator
  - Detector size
    - * LDC00Sc: tpcOuterRadius = 1690; TPC_Ecal_Hcal_barrel_halfZ = 2730
    - * LDC01Sc: tpcOuterRadius = 1580; TPC_Ecal_Hcal_barrel_halfZ = 2200

WW/ZZ signal

- **WW/ZZ Signal events**
  - $147.0 < m_{qq}^1 + m_{qq}^2 < 171.0$ **GeV: WW**
  - $171.0 < m_{qq}^1 + m_{qq}^2 < 195.0$ **GeV: ZZ**
  - $|m_{qq}^1 - m_{qq}^2| <= 20.0$ **GeV**
  - $m_{\nu_e \bar{\nu}_e} >= 100.0$ **GeV**





- $\nu\nu WW$ **events are more sensitive than** $\nu\nu ZZ$ **events**
- α_5 **is more sensitive than** α_4

WW/ZZ MC production

- $\sqrt{s} = 800$ GeV; polarization RL 40% 80%; with ISR; w/o beamstrahlung

Channel	σ_{800GeV} (fb)	Generator
$\nu_e\bar{\nu}_e\mathrm{WW} \rightarrow \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$	8.55	Whizard 1.50
$\nu_e\bar{\nu}_e\mathrm{ZZ} \rightarrow \nu_e\bar{\nu}_e q\bar{q}q\bar{q}$	3.97	Whizard 1.50
$\nu_e\bar{\nu}_e q\bar{q}q\bar{q}$ (background)	5.46	Whizard 1.50
$e\nu_e\mathrm{WZ} \rightarrow e\nu_e q\bar{q}q\bar{q}$	38.75	Whizard 1.50
$ee\mathrm{WW/ZZ} \rightarrow eeq\bar{q}q\bar{q}$	289.43	Whizard 1.50
$t\bar{t} \rightarrow \mathrm{X}$	299.63	PYTHIA 6.1
$\nu_e e\mathrm{W} \rightarrow \nu_e eq\bar{q}$	108.59	Whizard 1.50
$\nu_{\mu,\tau}\bar{\nu}_{\mu,\tau}\mathrm{WW/ZZ} \rightarrow \nu_{\mu,\tau}\bar{\nu}_{\mu,\tau}q\bar{q}q\bar{q}$	8.85	Whizard 1.50

- process with $\sigma < 100$: sample with $\mathcal{L} = 1000$ fb^{-1}
- process with $\sigma > 100$: sample with $\mathcal{L} = 500$ fb^{-1}

Event reconstruction

- Detector simulation: LDC00Sc & LDC01Sc detector models @ Mokka v6.2;
- Marlin v00-09-06; MarlinReco v00-02; MarlinUtil v00-02
- Pandora PFA v01-00
- Processors for Digitization
  - VTXDigi FTDDigi TPCDigi
  - SimpleCaloDigi
    - two calibration constants for two Ecal parts
    - one calibration constants for Hcal
- Processors for Wolf PFA
  - tracking finding: TrackCheater
  - cluster finding: TrackwiseClustering
  - track-cluster match: Wolf

Event reconstruction

- Processors for Pandora PFA
  - tracking finding: TrackCheater
  - cluster finding & track-cluster match: PandoraPFAProcessor
- Processors for perfect Pandora PFA
  - tracking finding: TrackCheater
  - Pandora PFA @ perfect module
- Wolf PFA vs. Pandora PFA
  - tracking finding: same
  - cluster finding: TrackwiseClustering vs. PandoraPFAProcessor
  - track-cluster match: Wolf vs. PandoraPFAProcessor

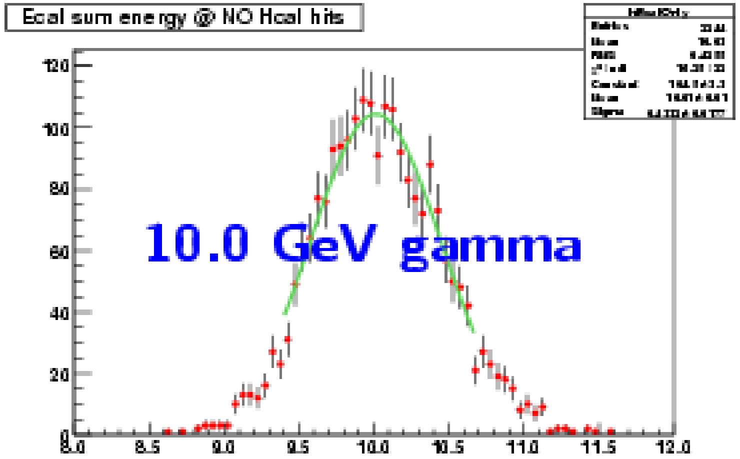
Calibration constants @ PFAs

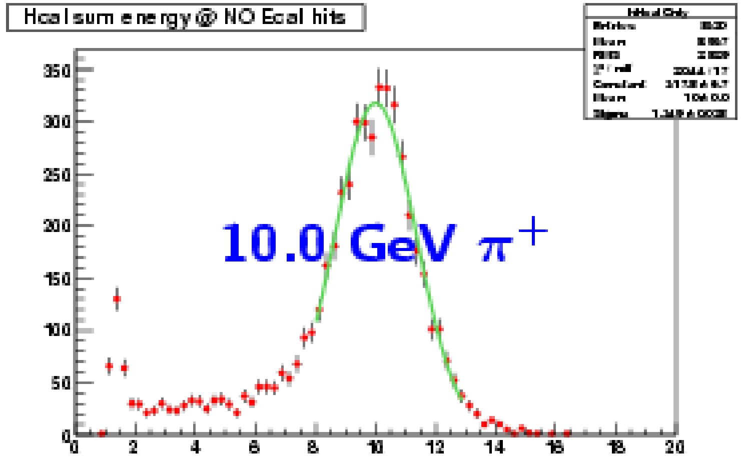
- different PFAs @ same detector model
  - avoid different value for the same calibration constants
  - distribution: sum of hit energy in a event
  - special calibration constants of a PFA: sum of PFA energy in a event

- different detector model
  - wrong calibration constants $\Longrightarrow$ unreliable conclusion ???
  - seperately determine calibration constants for different detector model

- common calibration constants SimpleCaloDigi
  - Ecal: two calibration constants for two Ecal parts
    - * fix ratio 1:3 (LDC00Sc); 1:2 (LDC01Sc) by radiation length
    - * 10.0 GeV gamma events without Hcal hits
  - Hcal: one calibration constant
    - * 10.0 GeV pion in front of Hcal without Ecal hits

Calibration constants @ PFAs

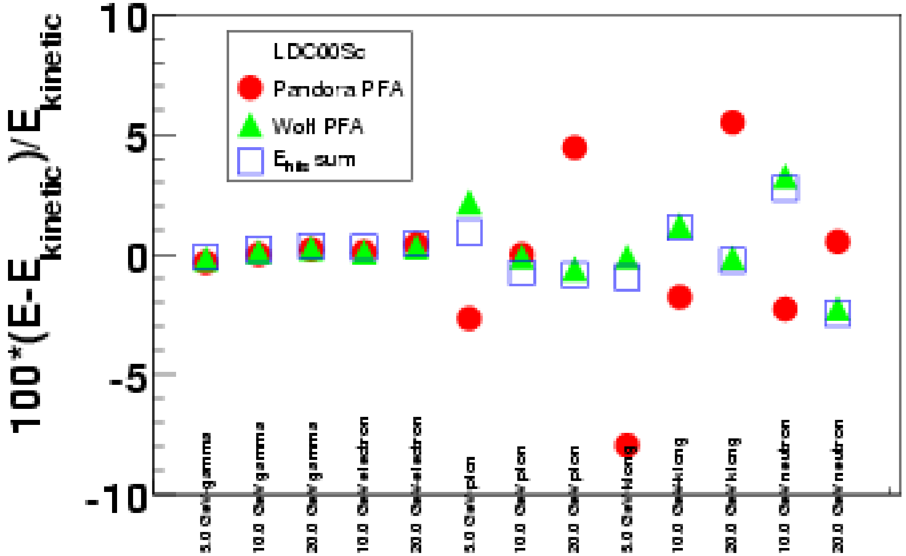


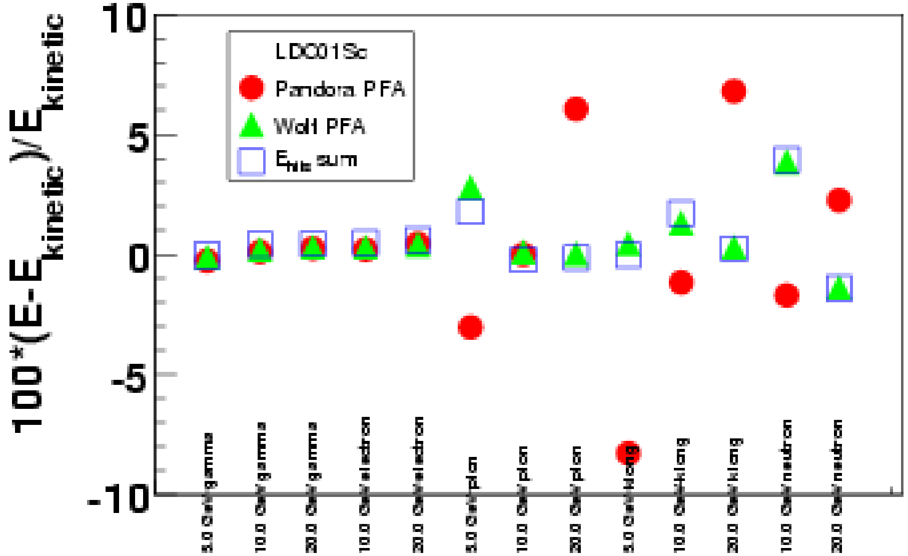


- calibration constants @ PFAs
  - Wolf PFA: no more parameters
  - Pandora PFA: ECALEMMIPToGeV, ECALHadMIPToGeV, HCALEMMIPToGeV, HCALHadMIPToGeV
- calibration constants @ Pandora PFA
  - ECALEMMIPToGeV: 10.0 GeV gamma w/o Hcal hits
  - ECALHadMIPToGeV: 10.0 GeV gamma in front of Hcal w/o Ecal hits
  - HCALEMMIPToGeV: 10.0 GeV pion
  - HCALHadMIPToGeV: 10.0 GeV pion in front of Hcal w/o Ecal hits

Calibration constants @ PFAs

- **calibration constants determined by 10.0 GeV gamma & pion**
- **valid for different type particles with different energies ?**





- **kinetic energy** $E_{particle}$**; neutron: kinetic energy** $E_{neutron} - M_{neutron}$

WW/ZZ event selection

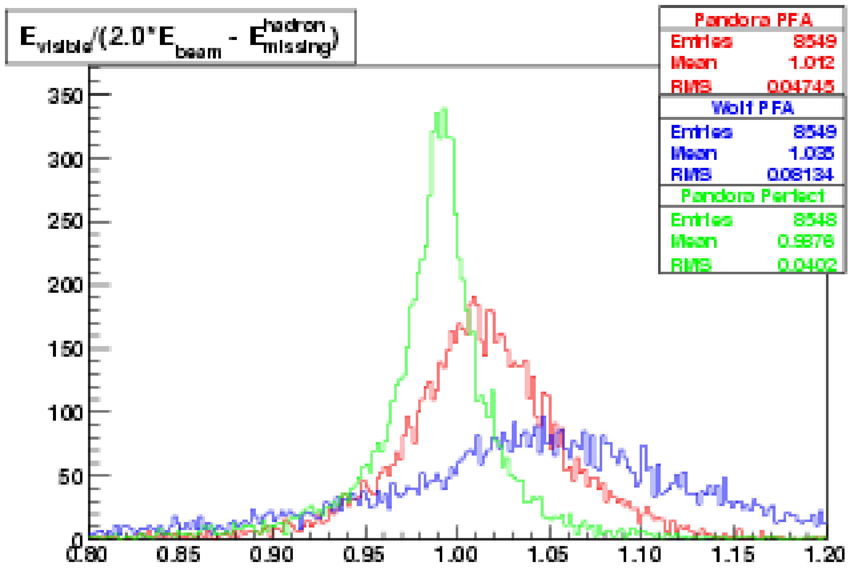
- We follow LC-PHSM-2001-038, and unify selection cuts for WW/ZZ

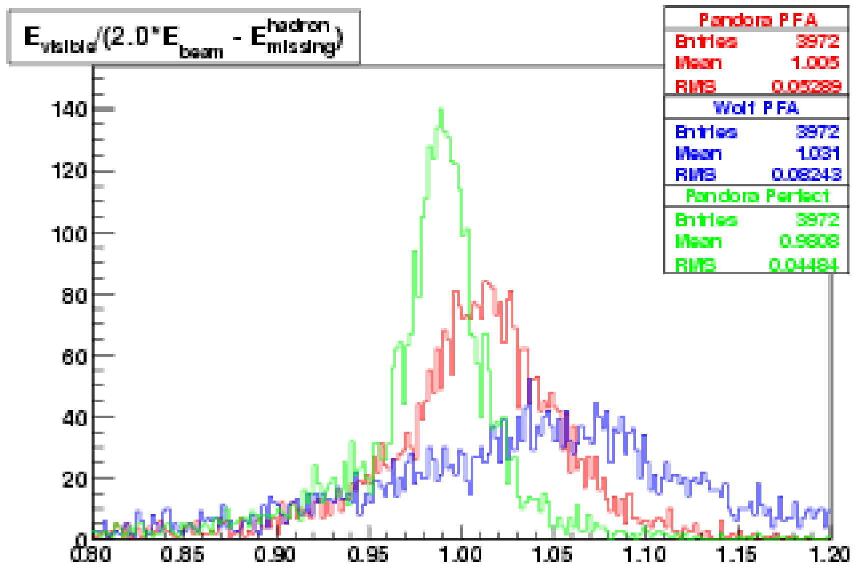
- Event selection: select events with a significant fraction of neutrinos
  - Recoil mass: $M_{recoil} \geq 200.0$ GeV
  - Total transverse momentum: $P_T \geq 40$ GeV
  - Total transverse energy: $E_T \geq 150$ GeV
  - Total missing momentum and most energetic track: $|\cos\theta| < 0.99$
  - Energy in a 10^o cone of most energy track: $E_{cone} \geq 2.0$ GeV
  - Force events to have 4 jets, and $Y_{34} > 0.0001$
    - Ktjet package for jet finding
    - Jet selection: $E_{jet} > 10.0$ GeV and $|\cos\theta_{jet}| < 0.99$

- WW/ZZ selection
  - WW: $60 < M_W < 88$ GeV
  - ZZ: $85 < M_Z < 100$ GeV

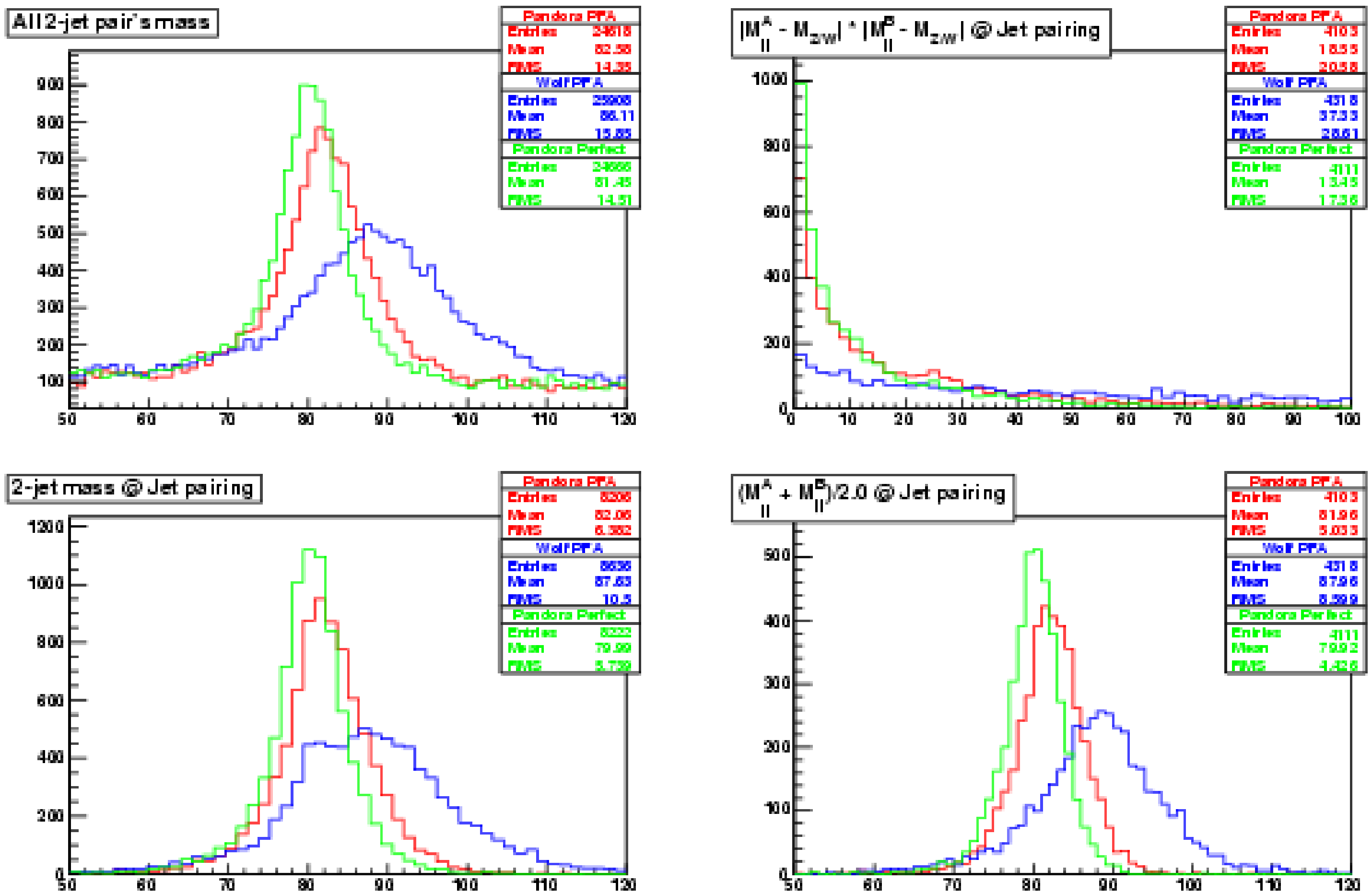
Event energy: Pandora PFA vs. Wolf PFA

- $E_{missing}^{hadron}$: sum of energy for neutrinos and particles in beam pipe at hadron level
- $E_{beam} = 400.0$ GeV; $E_{visible}$: visible energy at detector level
- Left: $\nu_e \bar{\nu}_e WW$; Right: $\nu_e \bar{\nu}_e ZZ$



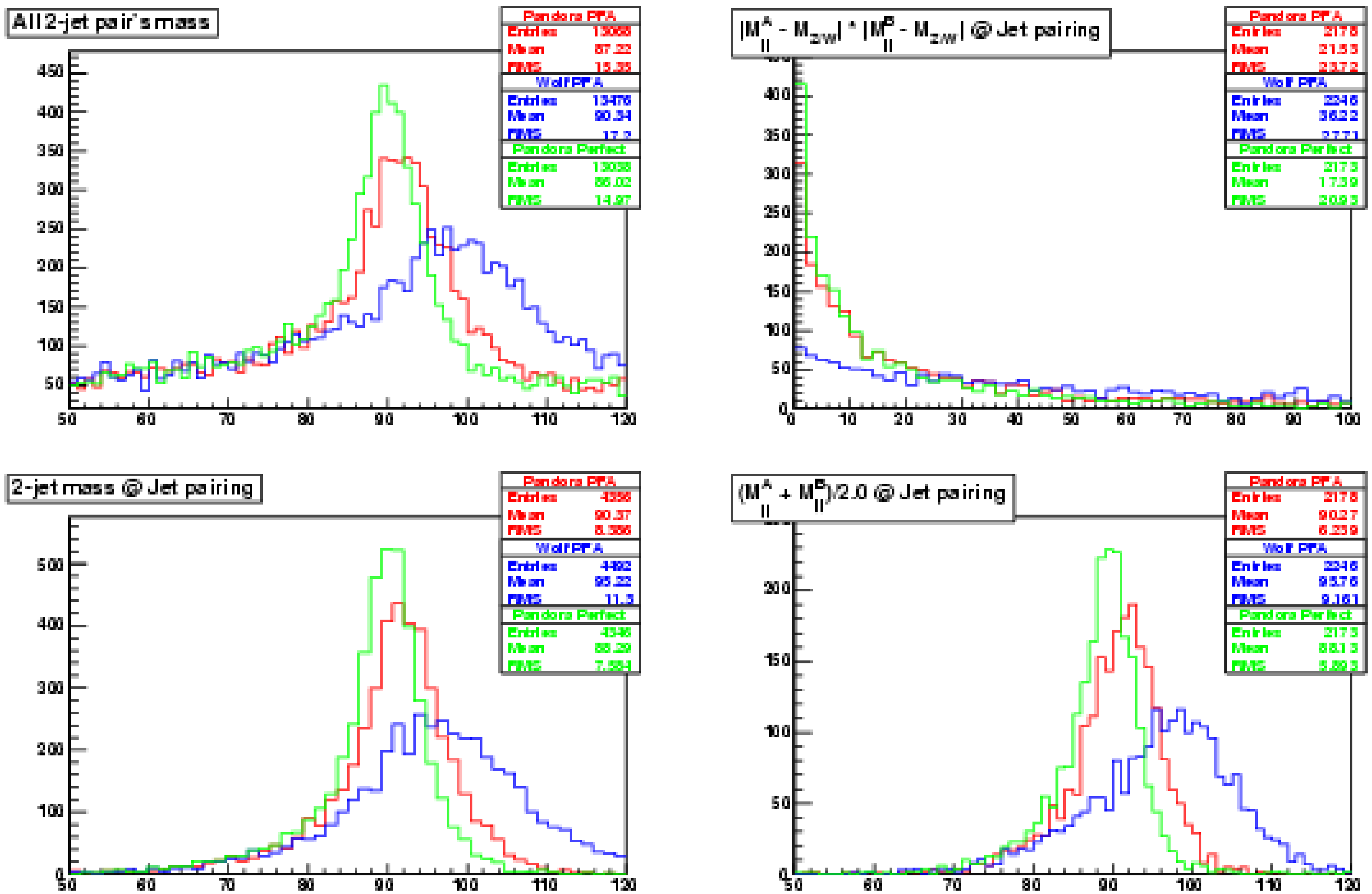


WW: Pandora PFA vs. Wolf PFA



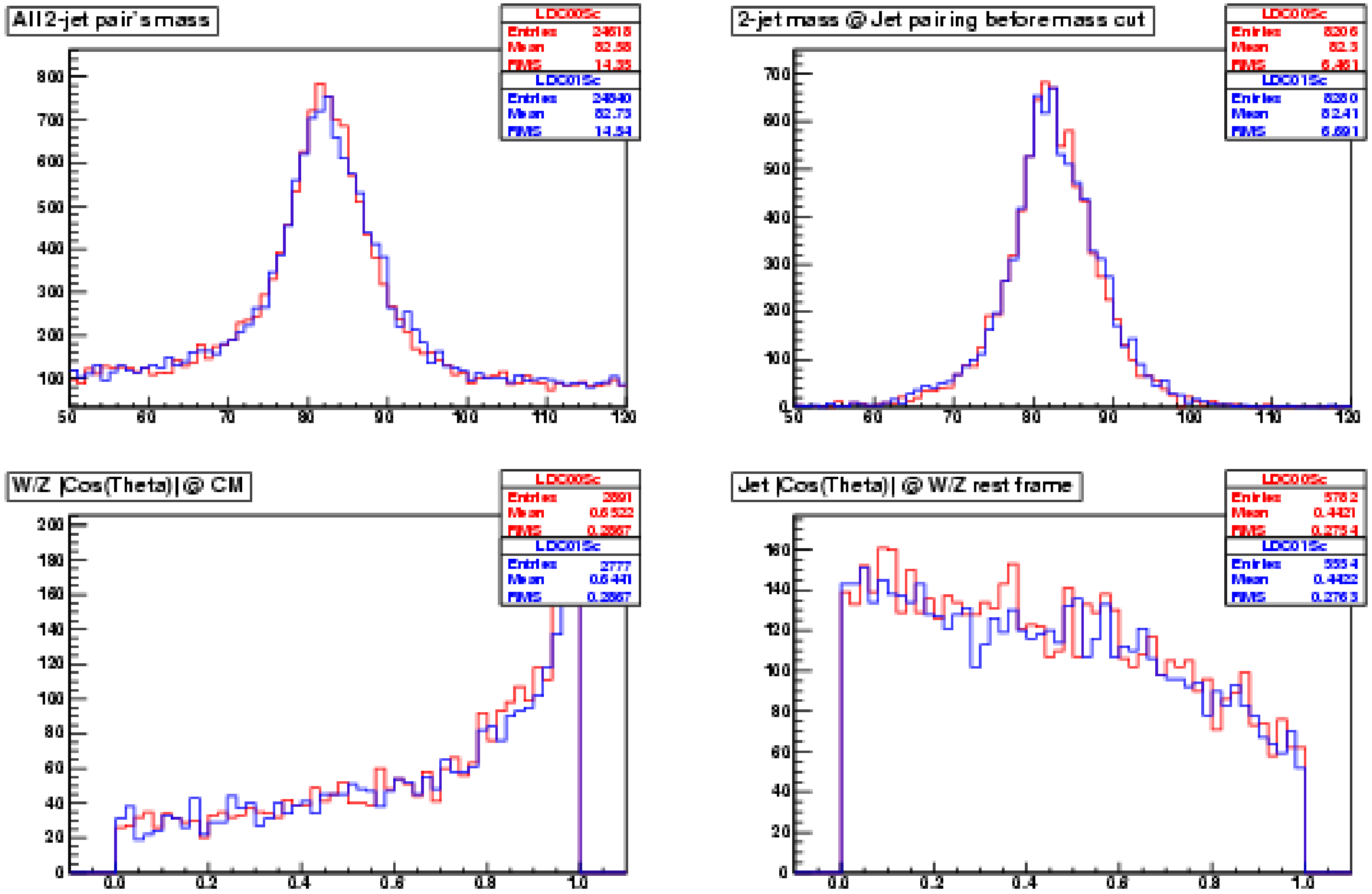
- **Without W mass cut @ LDC00Sc: W peak @ Wolf PFA ???**

ZZ: Pandora PFA vs. Wolf PFA



- **Without Z mass cut @ LDC00Sc: Z peak @ Wolf PFA ???**

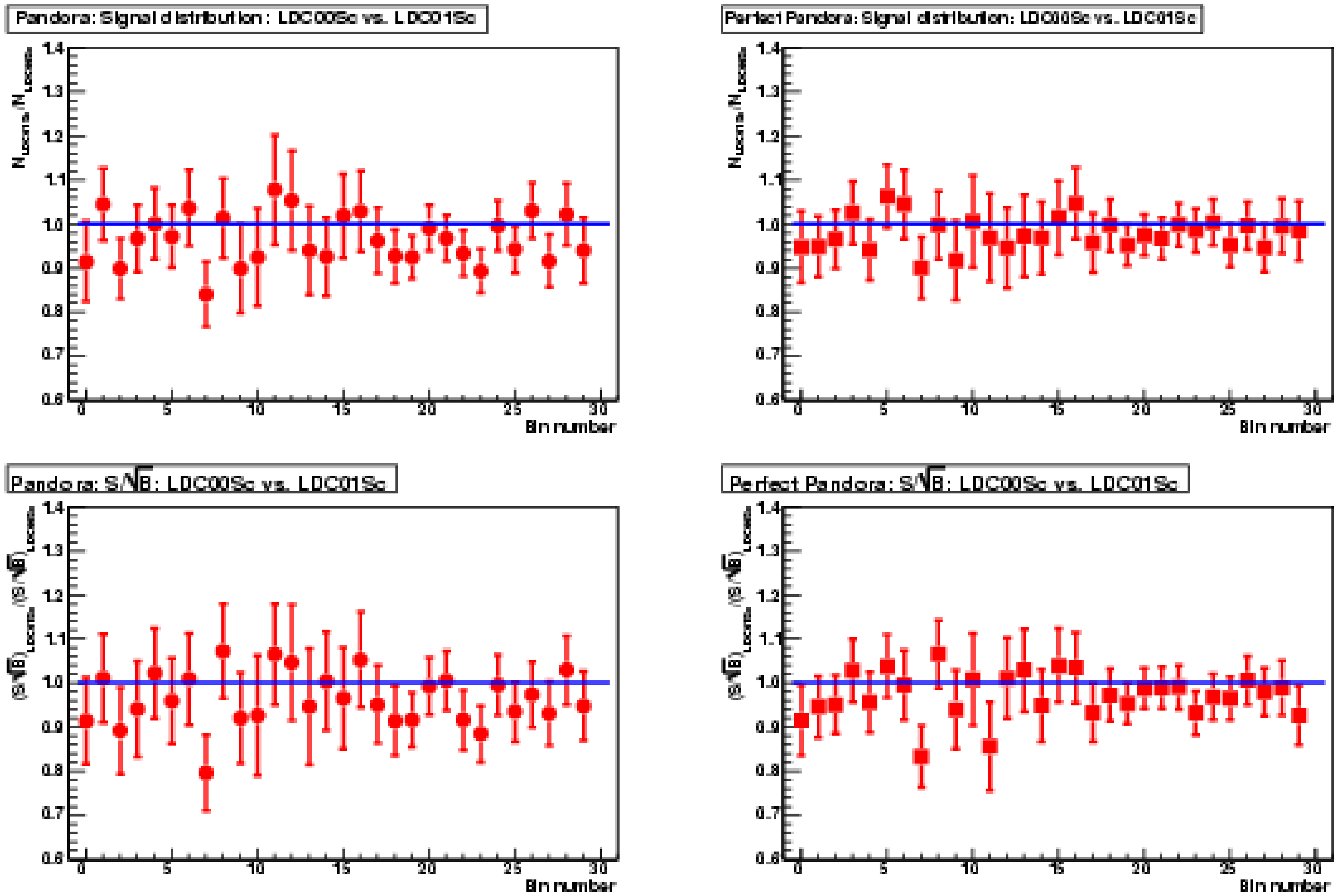
Pandora PFA @ WW: LDC00Sc vs. LDC01Sc



- **selected events number, LDC00Sc : LDC01Sc = 1: 0.96**

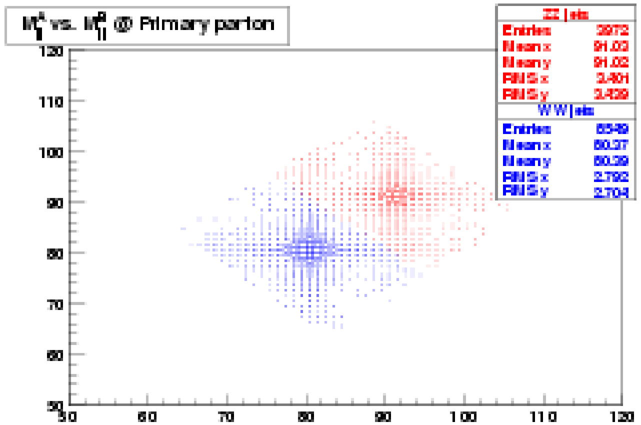
Pandora PFA @ WW: LDC00Sc vs. LDC01Sc

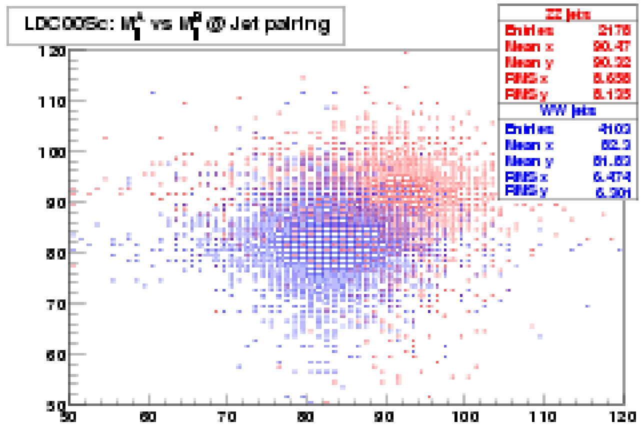
- **10 bins** $d\sigma/dM_{WW}$; **10 bins** $d\sigma/d|\cos\theta^\star_W|$; **10 bins** $d\sigma/d|\cos\theta^\star_{Jet}|$;

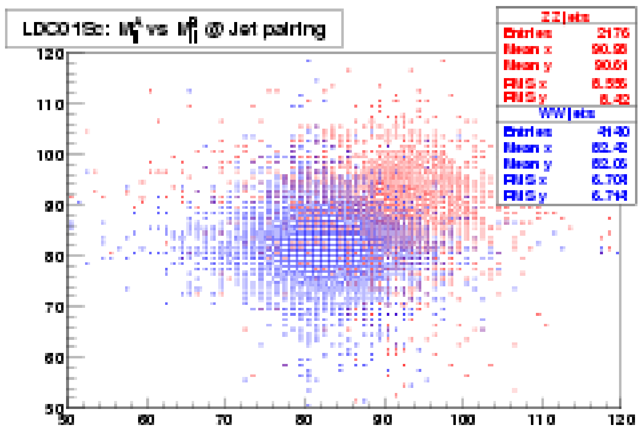


WW/ZZ separation

- **WW/ZZ: SAME selection @ detector level; without W/Z mass cut**



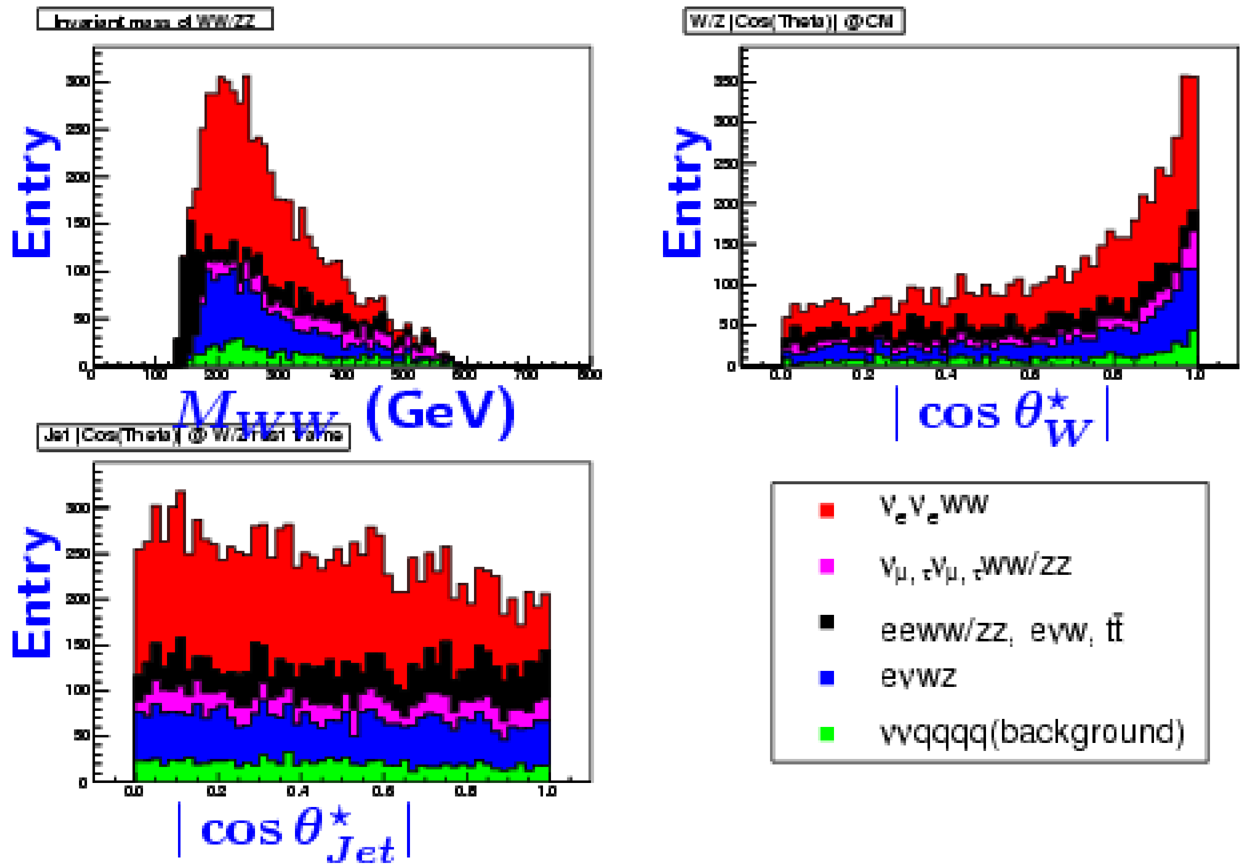




Binned maximum likelihood fit

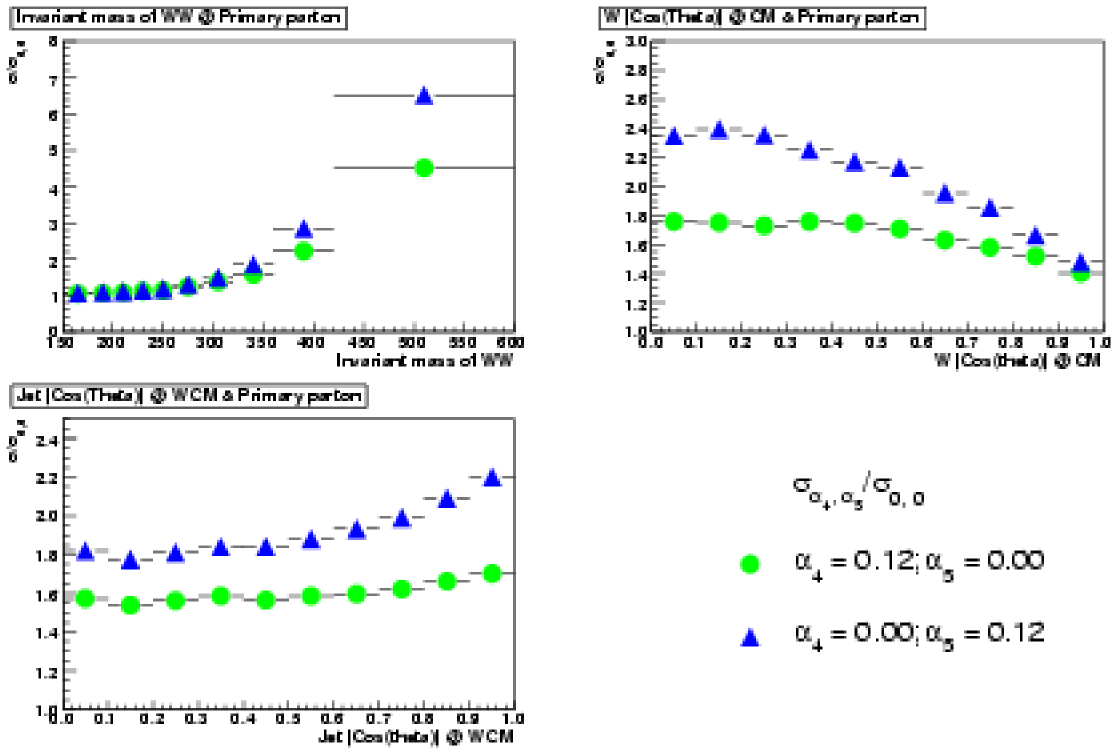
- Fitting distributions at detector level
  - SM sample with (0.0, 0.0) as "data"
  - each bin $p(n) = e^{-\lambda}\lambda^n/n!$
    - * n: observed number @ "data" sample and background event samples
    - * λ: expected number; $\lambda = m^{signal}(\alpha_4, \alpha_5) + m^{bcg1}(\alpha_4, \alpha_5) + m^{bcg2}$
  - $-\ln \mathcal{L} = -\sum \ln p(n_i) = -\sum n_i \ln \lambda_i + \sum \lambda_i + \sum \ln(n_i!)$
- $m^{signal}(\alpha_4, \alpha_5)$ and $m^{bcg1}(\alpha_4, \alpha_5)$
  - Each MC event (ith event) is weighted by
    $R_i(\alpha_4, \alpha_5) = 1.0 + A_i\alpha_4 + B_i\alpha_4^2 + C_i\alpha_5 + D_i\alpha_5^2 + E_i\alpha_4\alpha_5$
    R_i is the ratio of matrix element to SM sample with (0.0, 0.0)
  - Decide A_i, B_i, C_i, D_i, E_i @ each event
    - * Using generated SM sample with (0.0, 0.0), we recalculate matrix elements for each events with 20 sets of (α_4, α_5) value, and decide $(A_i, B_i, C_i, D_i, E_i)$ by TMinuit fitting to 20 R for ith event.
  - Count selected events with $R_i(\alpha_4, \alpha_5) \rightarrow m^{signal}(\alpha_4, \alpha_5)$
- Selection performance independent of (α_4, α_5)

Fit distributions



- **$150 < M_{WW} < 600$ GeV; 10 bins for M_{WW}; 10 bins for $|\cos\theta^\star_W|$ & $|\cos\theta^\star_{Jet}| \Longleftarrow \sim 2900$ WW events and ~ 1100 ZZ events**

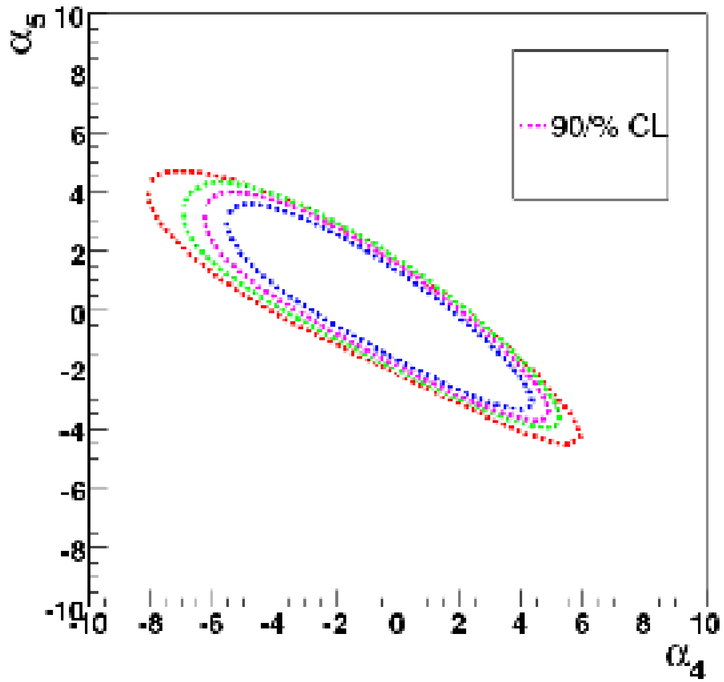
Fit distributions



- **sensitive** (α_4, α_5) **at high** M_{WW}, $|\cos\theta^\star_W|$ **and** $|\cos\theta^\star_{Jet}|$, **low S/B at high** M_{WW}

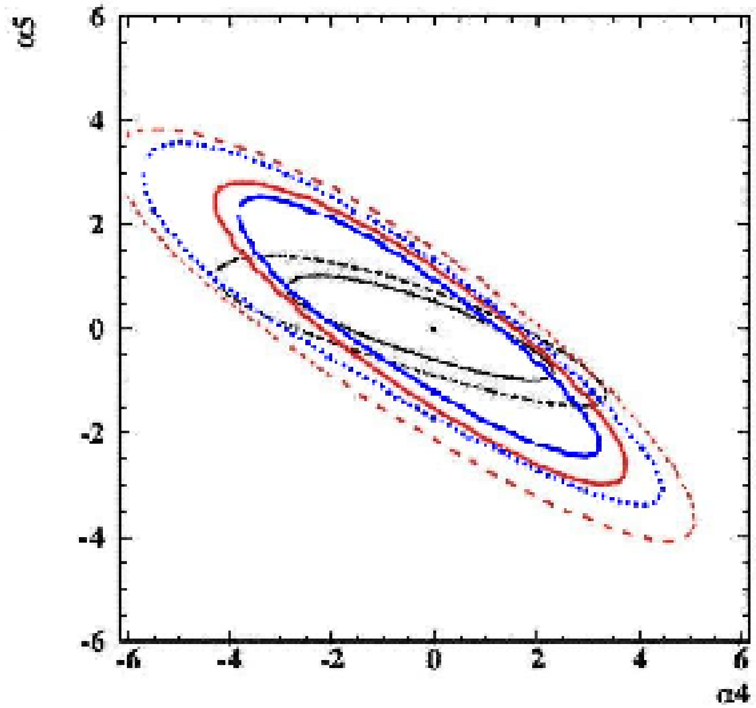
- **fit distributions:** $d^2\sigma/(d|\cos\theta^\star_W|d|\cos\theta^\star_{Jet}|) \oplus \cdots$

Fit distributions



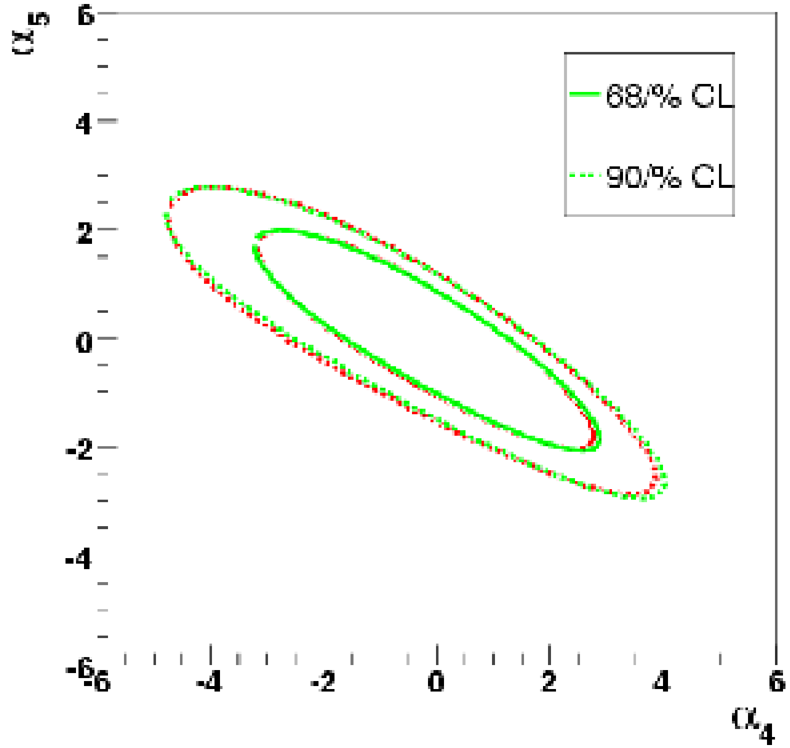
- **Red:** $d^2\sigma/(dM_{WW}d|\cos\theta^\star_W|)$
- **Green:** $d^2\sigma/(d|\cos\theta^\star_W|d|\cos\theta^\star_{Jet}|)$
- **Pink:** $d^2\sigma/(d|\cos\theta^\star_W|d|\cos\theta^\star_{Jet}|) \oplus \sigma^{total}_{ww} \oplus \sigma^{total}_{zz}$
- **Blue:** $d^2\sigma/(d|\cos\theta^\star_W|d|\cos\theta^\star_{Jet}|) \oplus \sigma^{total}_{ww} \oplus \sigma^{total}_{zz} \oplus d\sigma/dM_{WW}$

Likelihood from combined WW/ZZ



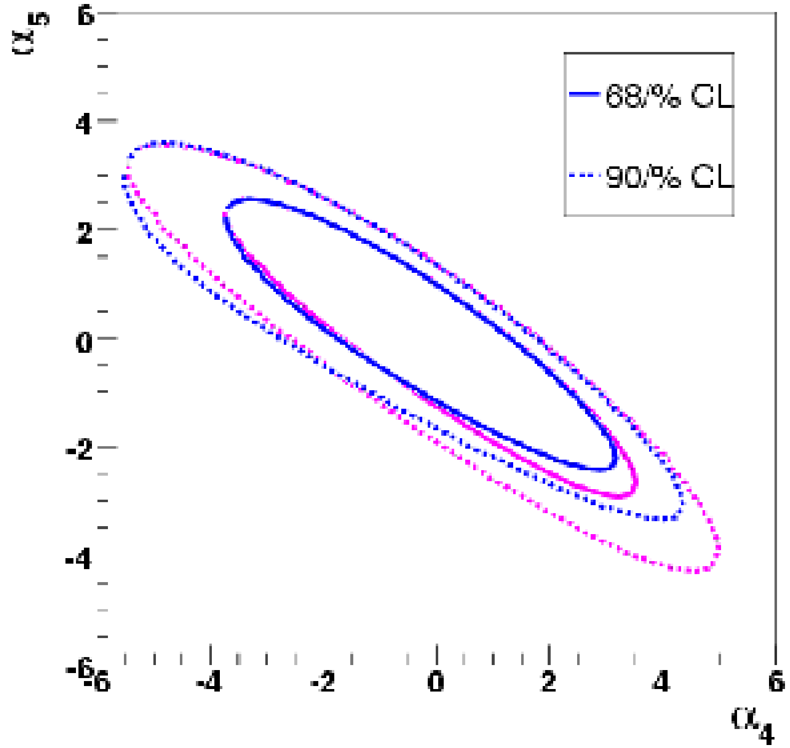
- **Blue: results on LDC00Sc detector model**
- **Red: Predrag Krstonosic's results @ LCWS 2005 on TESLA fast simulation**
- **Black: LC-PHSM-2001-038 on TESLA fast simulation**

Perfect Pandora PFA: LDC00Sc vs. LDC01Sc



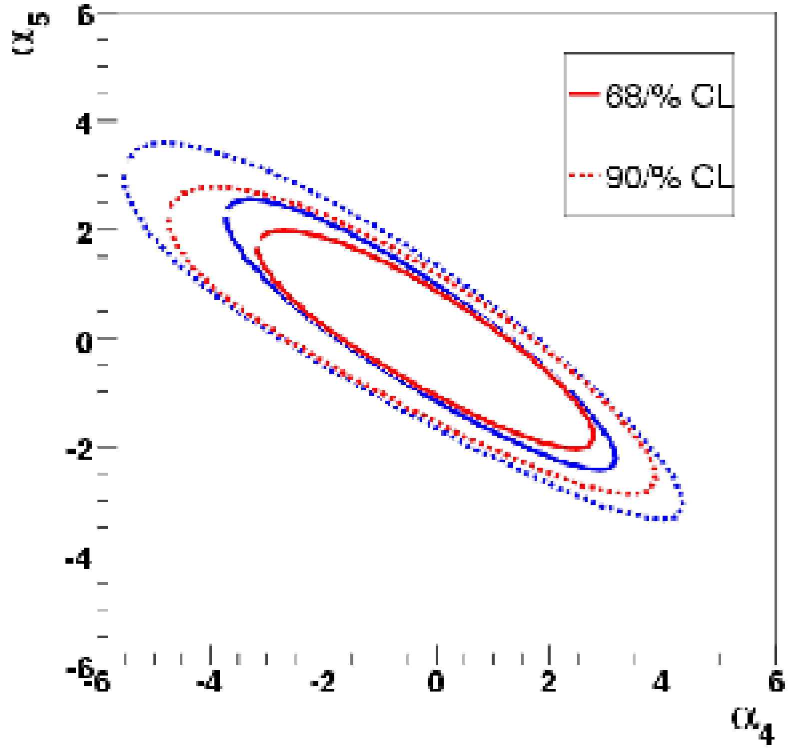
- likelihood from combined WW/ZZ fitting
- Red: results on LDC00Sc detector model
- Green: results on LDC01Sc detector model

Pandora PFA: LDC00Sc vs. LDC01Sc



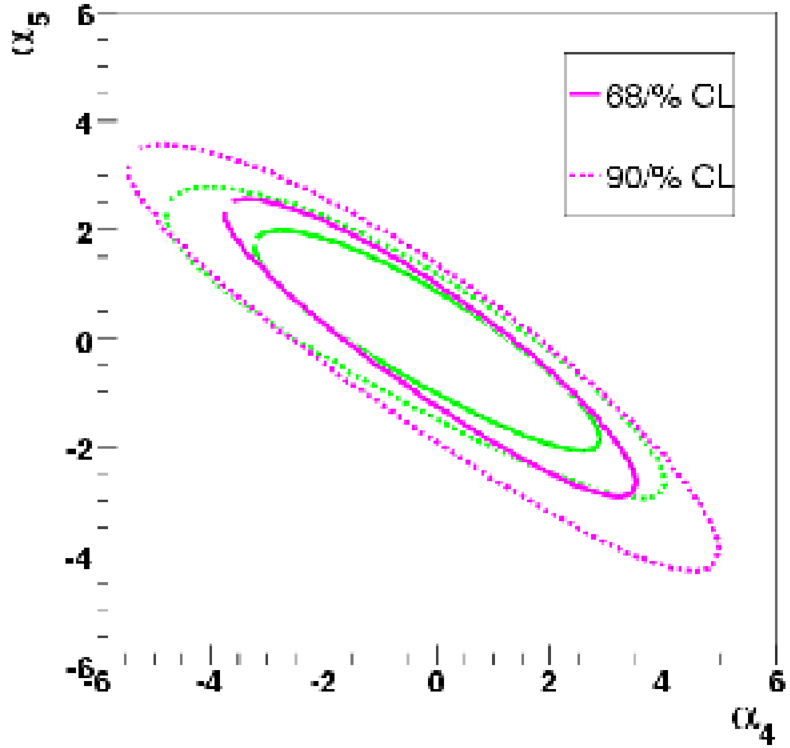
- likelihood from combined WW/ZZ fitting
- Blue: results on LDC00Sc detector model
- Pink: results on LDC01Sc detector model

LDC00Sc: Pandora PFA vs. Perfect case



- likelihood from combined WW/ZZ fitting
- Blue: Pandora PFA
- Red: Perfect Pandora PFA

LDC01Sc: Pandora PFA vs. Perfect case



- likelihood from combined WW/ZZ fitting
- Pink: Pandora PFA
- Green: Perfect Pandora PFA

Summary and outlook

- We study WW scattering with LDC00Sc & LDC01Sc detector model, and extract α_4 & α_5, which are comparable with that of TESLA fast simulation.
- Calibration constants @ PFAs for LDC00Sc and LDC01Sc
  - wrong calibration constants $\Longrightarrow$ unreliable conclusion ???
- Pandora PFA vs. Wolf PFA
  - W/Z peak @ Wolf PFA ???
    - not used for α_4 & α_5 fitting due to W/Z mass cut in the analysis
  - Pandora PFA $\sim$ Perfect Pandora PFA
- LDC00Sc vs. LDC01Sc
  - fitted α_4 & α_5 are comparable.
  - for selected events number, LDC00Sc : LDC01Sc = 1: 0.96
  - distributions of LDC00Sc are comparable with that of LDC01Sc

Summary and outlook

- **Plans for future**
  - latest version of software @ SL4
  - different PFAs: track-based PFA
  - different detector models: LDC00 and LDC01
    - MC samples are available.
  - track finding: TrackCheater $\longrightarrow$ full LDC tracking