# $e^+e^- \to \nu_e\bar{\nu}_e W^+W^-$ and $e^+e^- \to \nu_e\bar{\nu}_e Z^0Z^0$


**Mark Thomson, David Ward and Wenbiao Yan**

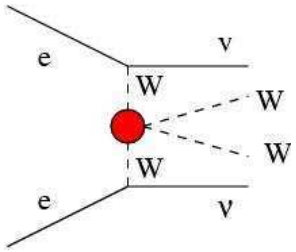


- WW scattering analysis
- Breit-Wigner width @ W/Z
- Z/W separation
- Summary and outlook

# WW scattering: Motivation

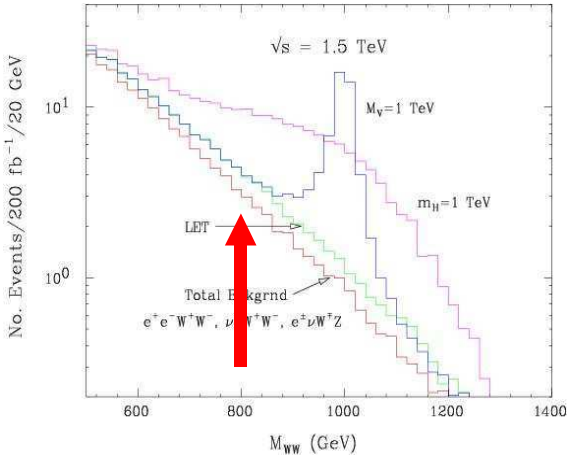
## The Higgs does not exist...

- if no Higgs is found at LEP, Tevatron, LHC, LC:
  - very fundamental arguments require: something must happen on the TeV scale
  - one possibility: a new strong interaction (WW rescattering) plays the role of the Higgs
    there are no fundamental scalars in nature, "fermioncentric" world,
    either no Higgs exists, or the Higgs is composite



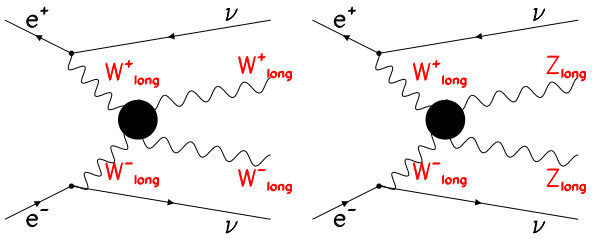

- main access: study of WW scattering
- effects already visible at "low" energies

consistent models for this type are difficult



# WW scattering

- **WW scattering**




- **Published works @ Linear Collider**
  - **LC-PHSM-2001-038: SIMDET for TESLA @ 800 GeV**
  - **. . . . . .**
- **Improvement @ this work**
  - **LDC00Sc detector model**
  - **PandoraPFO PFA**
  - **C++ $k_t$ jet finder: KtJet package in Marlin**

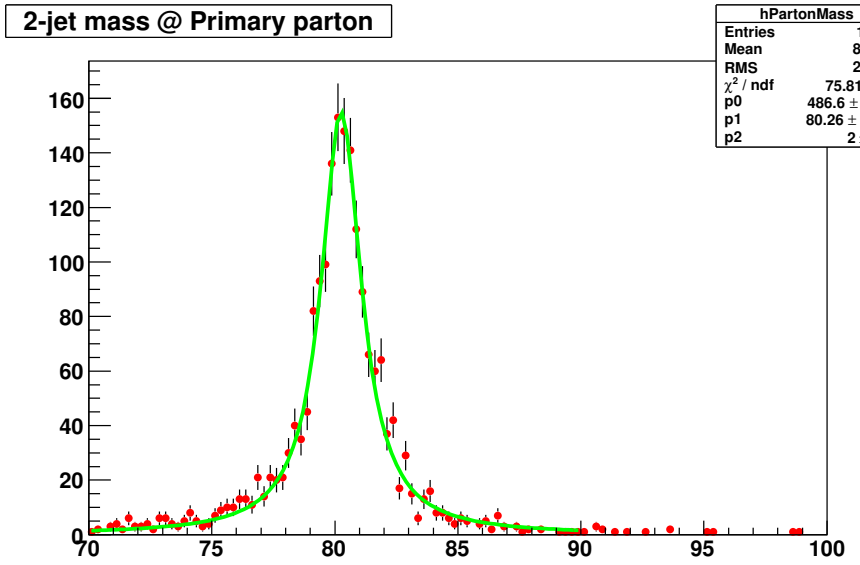
# WW/ZZ event selection @ 500 GeV

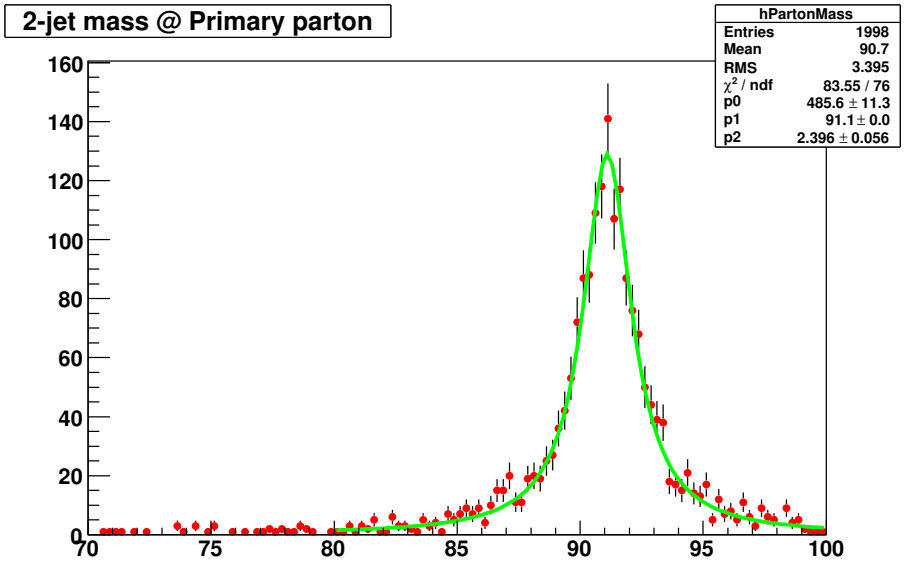
- **We follow the paper LC-PHSM-2001-038, and need to tune cut value in the future.**

- **Event selection: reject events with a significant fraction of neutrinos**
  - **Recoil mass:** $M_{recoil} >= 120.0$ **GeV**
  - **Total transverse momentum:** $p_T >= 12$ **GeV**
  - **Total transverse energy:** $E_T >= 90$ **GeV**
  - **Total missing momentum and most energetic track:** $|\cos(\theta)| < 0.99$
  - **Energy in a** $5^o$ **cone of most energy track:** $E_{cone} >= 2.0$ **GeV**
  - **Force events to have 4 jets, and** $Y_{34} > 0.001$
    - **Jet energy:** $E_{jet} > 10.0$ **GeV**
    - **Jet theta:** $|\cos(\theta)| < 0.99$

# Breit-Wigner width @ four primary partons

- **4 primary quarks @ $e^+e^- \to \nu_e\bar{\nu}_e W^+W^- \to \nu_e\bar{\nu}_e q_1q_2q_3q_4$**
- **4 primary quarks @ $e^+e^- \to \nu_e\bar{\nu}_e Z^0Z^0 \to \nu_e\bar{\nu}_e q_1q_2q_3q_4$**

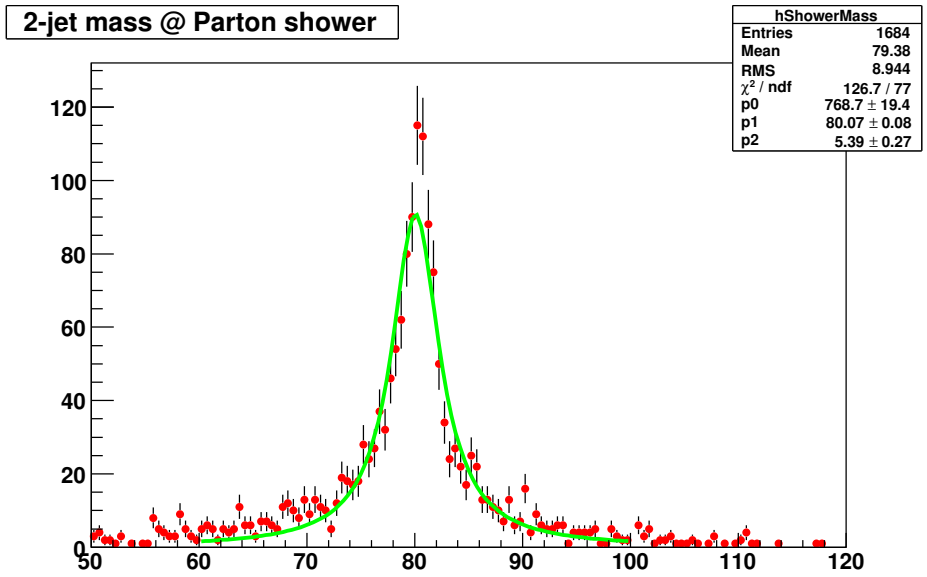


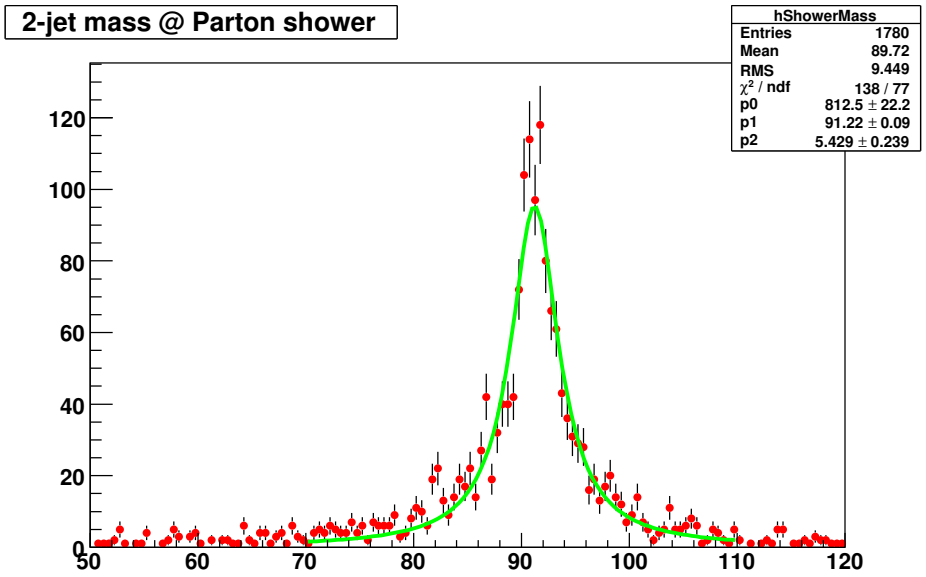




- **Breit-Wigner width $\Gamma$ is close to natural widths**

# Breit-Wigner width @ parton shower

- **Partons after parton shower by four primary partons**
- **Matching four primary partons to reconstructed jets in $\eta - \phi$ plane**

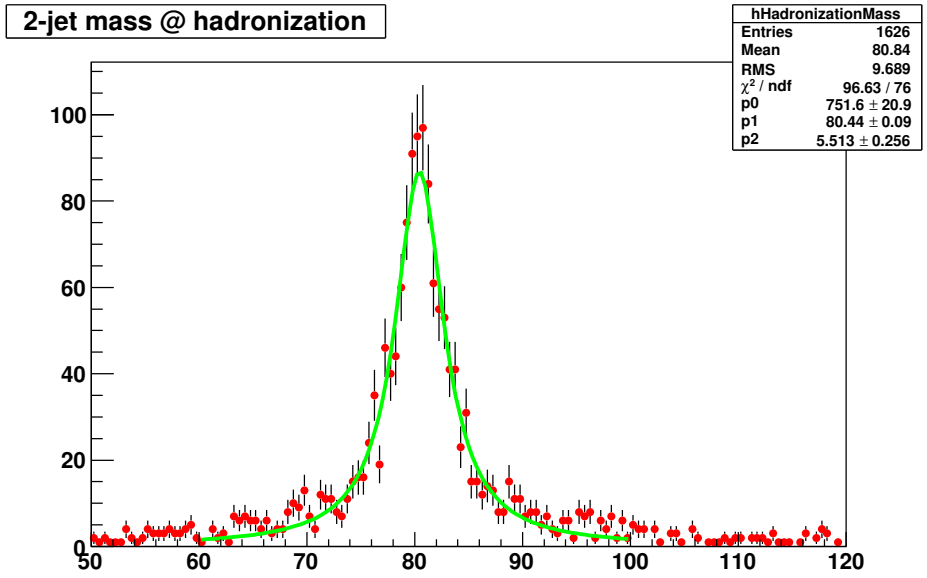


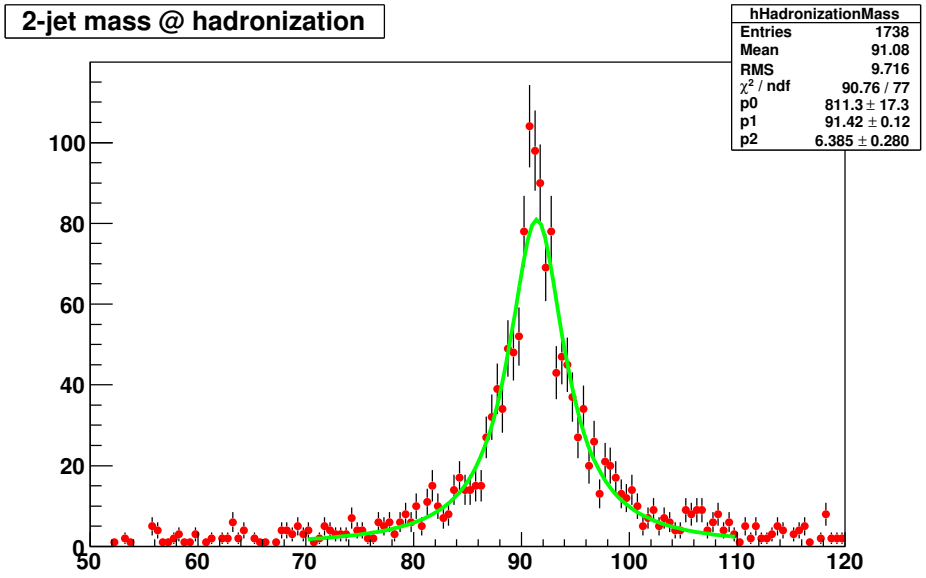




- **Breit-Wigner $\Gamma$: increase by factor $\sim$ 2.5 with respect to four primary partons**

# Breit-Wigner width @ hadronization

- **Stable hadrons after hadronization**
- **Matching four primary partons to reconstructed jets in $\eta - \phi$ plane**



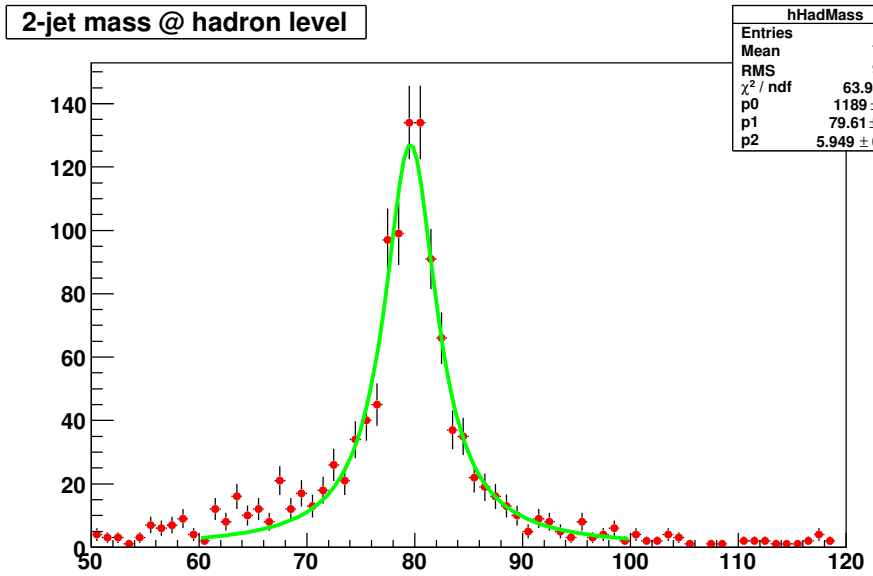



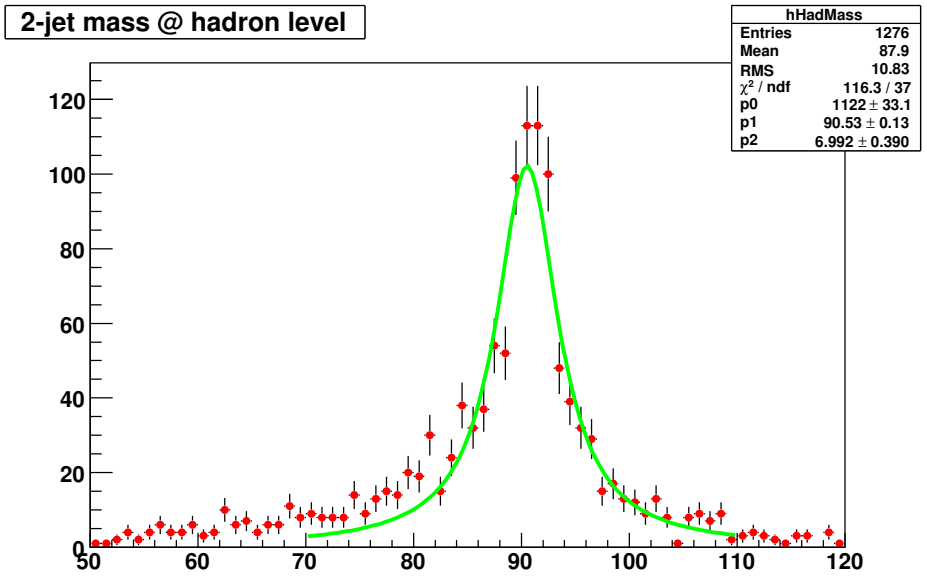

- **Breit-Wigner $\Gamma$: increase by factor $\sim$ 1.1 with respect to parton level**

# Breit-Wigner width @ before detector simulation

- **Hadrons after hadronization: stable particle in the generator, remove neutrinos and particle in beam pipe ($TMath :: Abs(\cos(\theta)) < 0.995$)**

- **Matching four primary partons to reconstructed jets in $\eta - \phi$ plane**

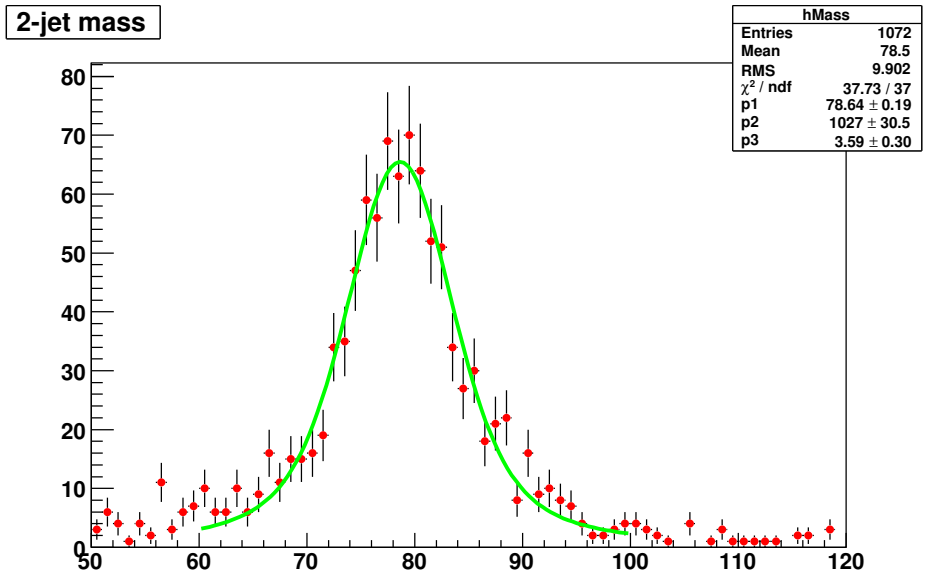


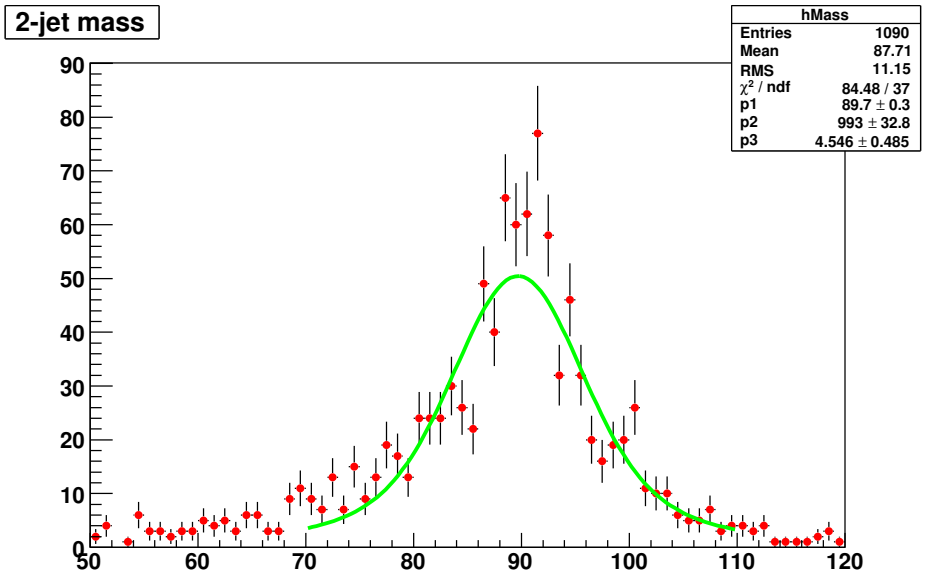




- **Breit-Wigner $\Gamma$: $\sim$ 1.1 with respect to complete hadronic final state**

# Breit-Wigner width @ detector level

- **Particle flow objects: PandoraPFO PFA**
- **Matching four primary partons to reconstructed jets in $\eta - \phi$ plane**

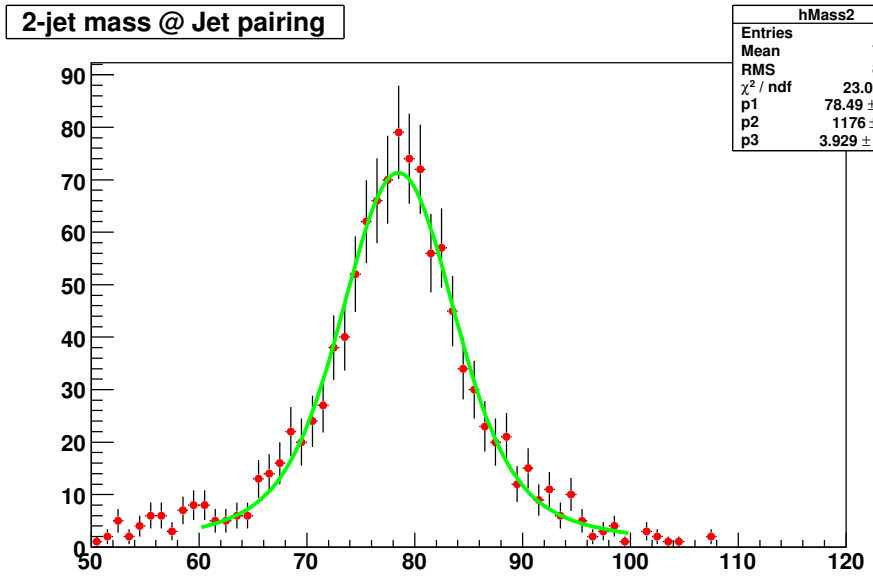


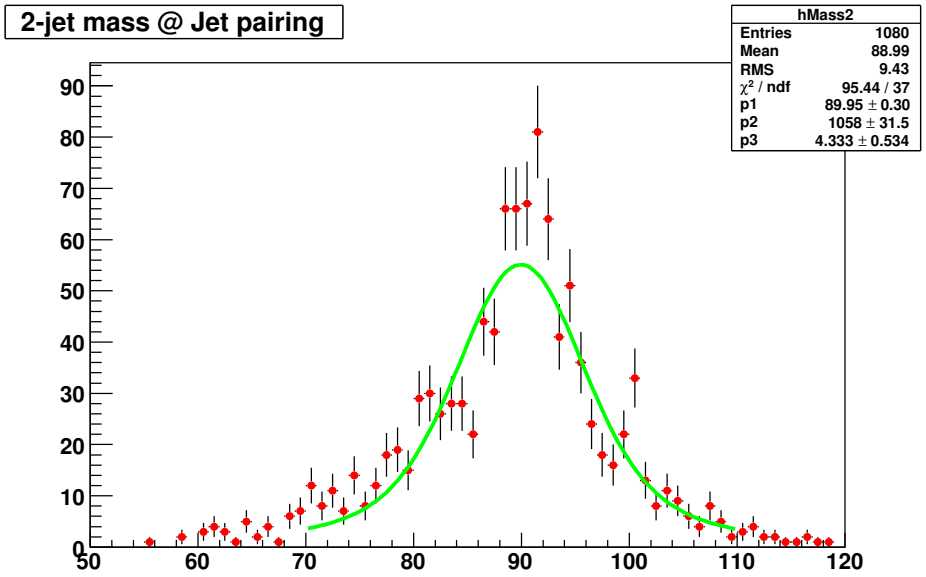




- **Fixing Breit-Wigner width (W: 5.95 GeV; Z: 6.99 GeV) and using Breit-Wigner $\otimes$ Gaussian when fitting mass distribution**

# Breit-Wigner width @ detector level

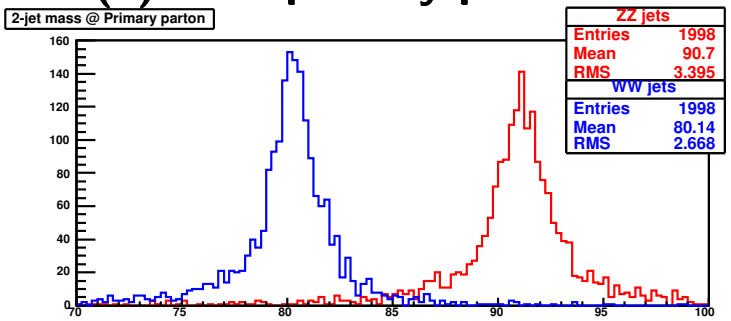
- **Particle flow objects: PandoraPFO PFA**
- **Four jets $\Longrightarrow C_4^2/2 = 6/2 = 3$ pairs (pair: two 2-jet groups) per event**
  - **$|M_{jj}^A - M_{W/Z}| + |M_{jj}^B - M_{W/Z}|$: Min. value**
  - **Min. $|M_{jj}^A - M_{W/Z}| + |M_{jj}^B - M_{W/Z}| < 36.0$ GeV**



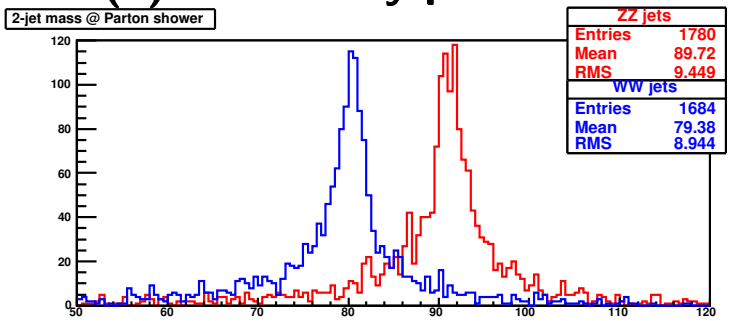



# Z/W separation

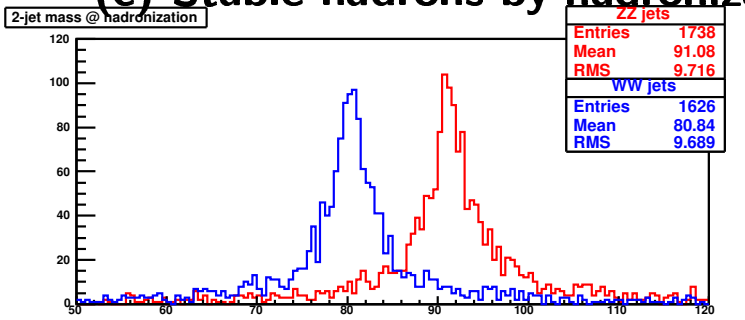
(a) Four primary partons



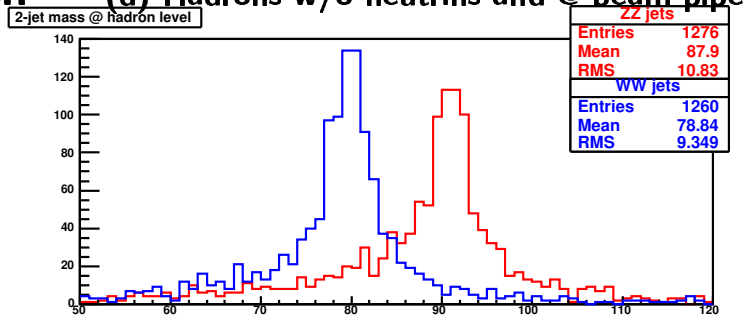

(b) Partons by parton shower



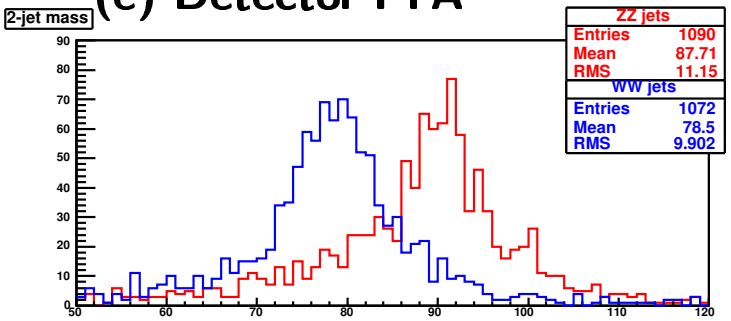

(c) Stable hadrons by hadronization



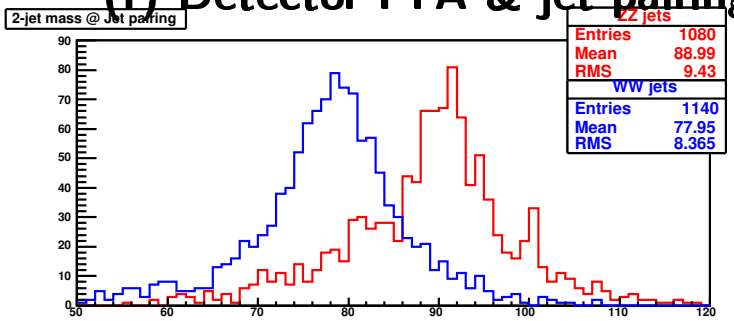

(d) Hadrons w/o neutrins and @ beam pipe




(e) Detector PFA

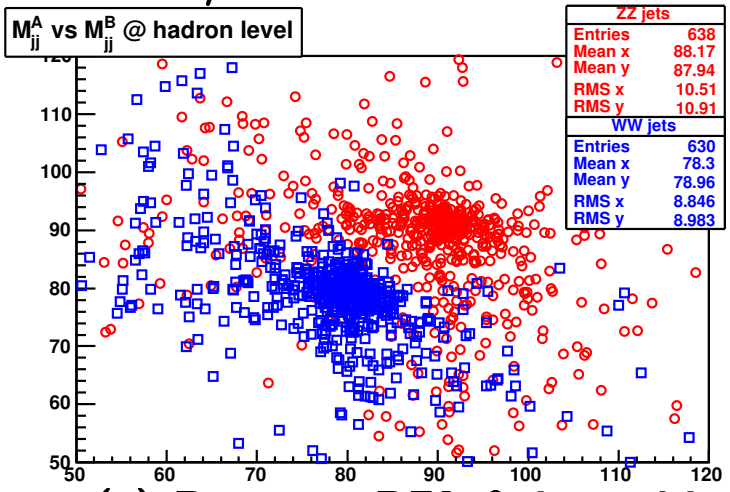



(f) Detector PFA & jet pairing

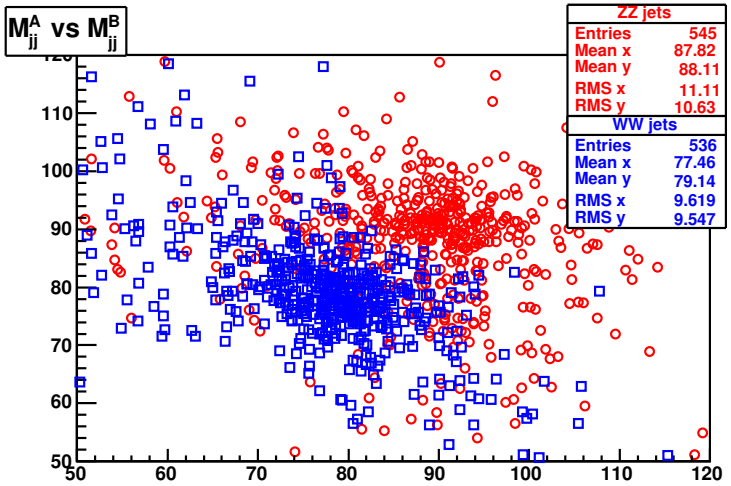


# Z/W separation

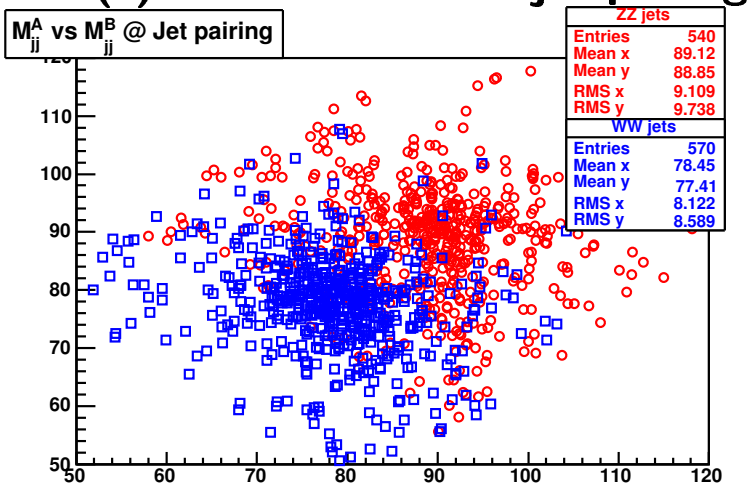
## (a) Stable hadrons by hadronization w/o neutrins and @ beam pipe




## (b) Detector PFA




## (c) Detector PFA & jet pairing



# Summary and outlook

- **We begin to have WW analysis.**
- **Breit-Wigner width of W/Z by using the partons at parton level and $k_T$ jet finder increase by factor $\sim$ 2.5 with respect the natural width.**
- **Hadronization and missing particle (neutrinos and particle in beam pipe) have small effect ($\sim$ 10%) to Breit-Wigner width.**
- **Breit-Wigner $\otimes$ Gaussian fitting have $\sim$ 3.9/4.3 GeV for detector and PFA effect.**
- **W/Z separation plots are available.**