Jet Energy Measurement - Physics Needs

J. List

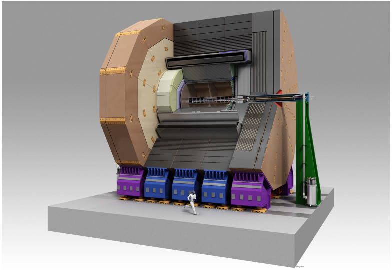
DESY

ILD Optimisation Meeting, January 22 2014

ILD (Re-)Optimisation

- we have a excellent detector design
- but: need to justify expenses by *physics arguments*

⇒ **connect detector performance to physics goals!**



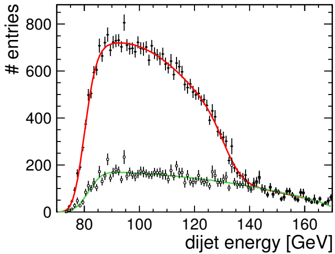
Today:

- *jets only*
- won't comment on any other capability of ILD

What do we measure jet energies for?

- **invariant masses** of
  - 2 jets e.g. W, Z, H
  - 3 jets e.g. t
- **event-level observables:** event shape, total energy after overlay removal
- **energy of dijet-system:** e.g. SUSY, physics with Dark Matter candidate

e.g. $\chi_1^+\chi_1^- \rightarrow W^+W^-\chi_1^0\chi_1^0$ (M.Chera):



- edge positions $\rightarrow M_{\chi_1^\pm}$, $M_{\chi_1^0}$
- low edge: W natural width, JER
- high edge: ISR, beamstrahlung, JER

Resolution on Dijet Mass

invariant mass of j1 and j2

$$m_{12}^2 = m_1^2 + m_2^2 + 2E_1E_2(1 - \beta_1\beta_2\cos\theta_{12})$$

for massless jets, neglecting error on $\cos\theta_{12}$:

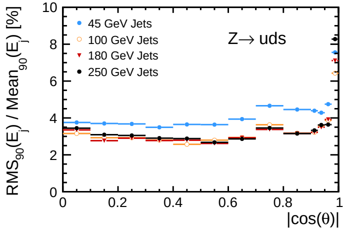
$$\Rightarrow \frac{\delta m_{12}}{m_{12}} = \frac{\delta m_{12}^2}{2m_{12}^2} = \frac{2(1-\cos\theta_{12})\sqrt{E_1^2\delta E_2^2 + E_2^2\delta E_1^2}}{2m_{12}^2}$$

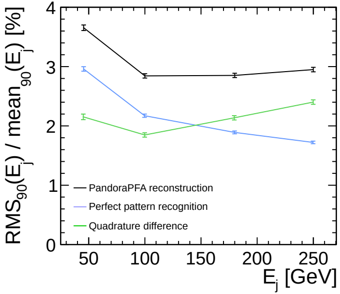
$$= \frac{1}{2}\sqrt{(\frac{\delta E_2}{E_2})^2 + (\frac{\delta E_1}{E_1})^2}$$

$\Rightarrow$ dominated by the worst measured jet![1]

[1]What about jet mass? Proton mass non-neglible for %-level JER...

Status of ILD JER (J. Marshall, M.Thomson)



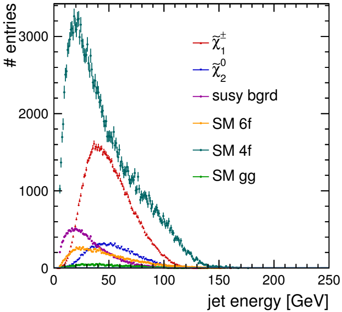


- low jet energies worst
- $|\cos\theta| > 0.7$ worse

- low energies: intrinsic calo resolution dominates
- high energies: confusion dominates

Jet energies at $\sqrt{s} = 500$ GeV: SM 4f and $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0 \to q\bar{q}\tilde{\chi}_1^0$ (M. Chera)

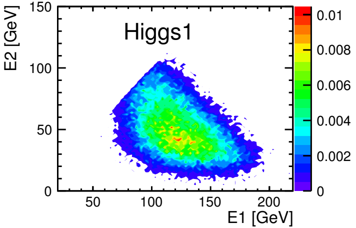
- signal: all jets below 100 GeV, peak at $30 - 40$ GeV

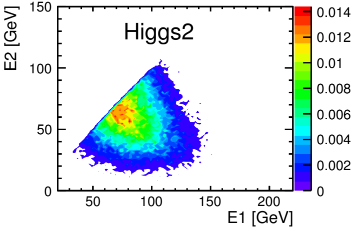


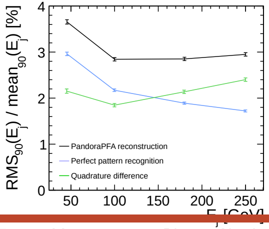
Jet energies at $\sqrt{s} = 500$ GeV: ZHH (C.F.Dürig)

$E_{Higgs1} > E_{Higgs2}$:

- Higgs1: one low (≤ 75 GeV), one high energetic (≤ 150 GeV) jet
- Higgs2: jet energies about equal, peak at 75 GeV



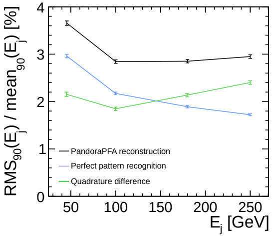


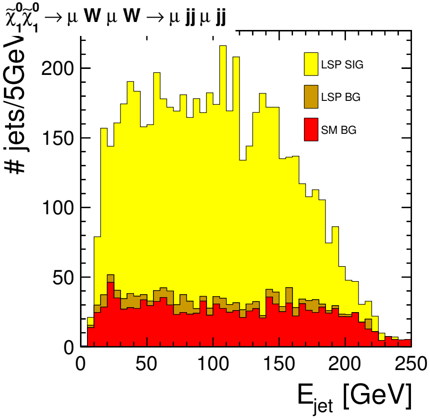


Jet energies at $\sqrt{s} = 500$ GeV: bRPV SUSY (B.Vormwald)

$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \mu^+ W^- \mu^- W^+$

- bulk of jets flat between 10 (!) and 150 GeV

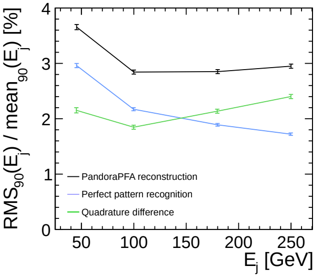


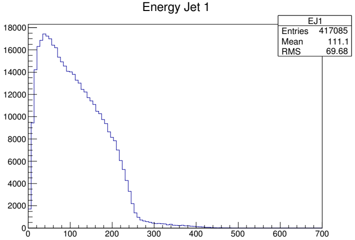


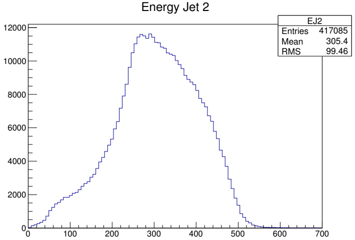
Jet energies at $\sqrt{s} = 1$ TeV: W^+W^- (A.Rosca)

$W^+W^- \rightarrow l\nu qq$

- one jet peaks at 50 GeV
- other jet peaks at 250 GeV



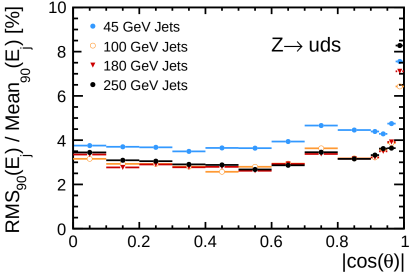


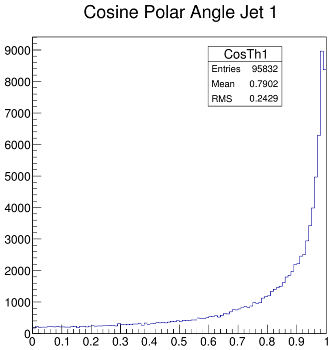


Jet polar angles at $\sqrt{s} = 1$ TeV: W^+W^- (A.Rosca)

$W^+W^- \to l\nu qq$

- basically all jets $|\cos\theta| > 0.7$





Detector Performance

Consequences for detector level performance studies:

- $E_{jet} \leq 100\,\text{GeV}$ very important, even at $\sqrt{s} = 1\,\text{TeV}$
- also don't forget $|\cos\theta| > 0.7$
- remember: worst measured jet will determine invariant mass resolution

From Detector to Physics Performance

Current definition of JER:

- $Z \rightarrow uds$: light dijets, Z at rest, no ISR
- no jet finding, but use total energy: $\frac{\delta E_j}{E_j} = \sqrt{2}\frac{\delta E_j j}{E_j j}$
- excellent definition for *pure* detector performance...
- ...but a long way to Higgs couplings, $t\bar{t}$ asymmetries & Co:
  - many other performance aspects enter
  - relative impact of JER analysis-dependent

Can we have something intermediate?

From Detector to Physics Performance - Proposal

Collect from ongoing analyses **“analysis level” JER**:

- on physics events after jet finding, overlay removal etc
- for various signals (number of jets, different flavours)
- as function of E_{jet}, $\cos\theta_{jet}$
- with $< N_{overlay} >= 0, 1.2, 1.7$

$\Rightarrow$ Quantify impact of pure Pflow performance via comparison with “detector-level” JER

Physics Performance

But in the end: final physics observables! - Requirements:

- important physics message
- small number of jets: $\leq 4 \rightarrow$ limit impact of jet finding
- ≥ 2 "invisible" particles $\rightarrow$ limit benefit of kinematic fitting

Candidates:

1. **Higgs total width / model-independent** HWW **coupling** from $e^+e^- \to \nu_e\bar{\nu}_e H$, $H \to b\bar{b}$ (however: b-jets $\to$ neutrinos....)
2. **model-independent** HZZ **coupling:** exploit statistics from Higgs recoil with $Z \to q\bar{q}$?
3. search for **Higgs** $\to$ **invisible**: clear improvement over LHC
4. particles decaying into **W/Z + Dark Matter candidate**: SUSY? - LHC will discover/exclude leptonic modes in 14 TeV run, even in electroweak production.
   $\Rightarrow$ *Could* be very important – or marginalized....

Conclusions

- detector reoptimisation: improve (or at least don't degrade) **JER for jet energies** < 100 **GeV**
- non-trivial to find a convincing physics channel where JER is *far dominating* over other effects $\Rightarrow$ candidates: **invisible Higgs, recoil with Z $\rightarrow$ q$\bar{q}$, Γ_H from WW fusion**
- maybe intermediate, analysis-level observables can help to develop a clearer picture and to quantify the relevant contributions?

Outlook

Benefit of high granularity goes **beyond pure JER**: Detail!

- particle ID in jets $\rightarrow$ flavour tagging?
- more clever schemes for overlay removal? $\rightarrow$ eg ZHH
- systematics: will final physics performance depend on ability to re-measure particle multiplicities, fragmentation functions and other unsexy stuff?
- and what about JES calibration?

$\Rightarrow$ Are we exploiting *all* the information a Pflow detector offers?

Where ever we claim statistical precisions $\leq 1\%$, mass resolutions $\leq 100\,\text{MeV}$: Studying means to control systematic uncertainties is obligatory!

Backup

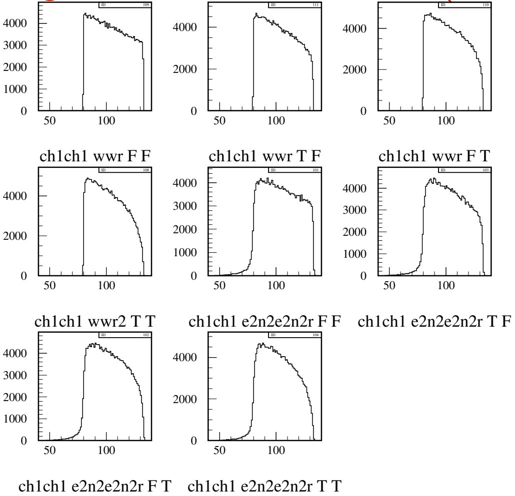
“Analysis-level” JER

reconstructed jet energy on physics events after jet finding:

- compare to “true” jet energy from
  1. running same jet algorithm on hadron level
  2. primary u, d, s, c, b quarks
- match eg by
  - minimizing sum of angle differences
  - or follow RecoMCTruthLink for leading particle in jet
- as function of E_{jet}, $\cos\theta_{jet}$
- with $< N_{overlay} >= 0, 1.2, 1.7$

Agree on unique procedure, public processor in MarlinReco

Chargino mass reconstruction (M.Berggren)



- ISR
- Beamstrahlung
- *W* natural width

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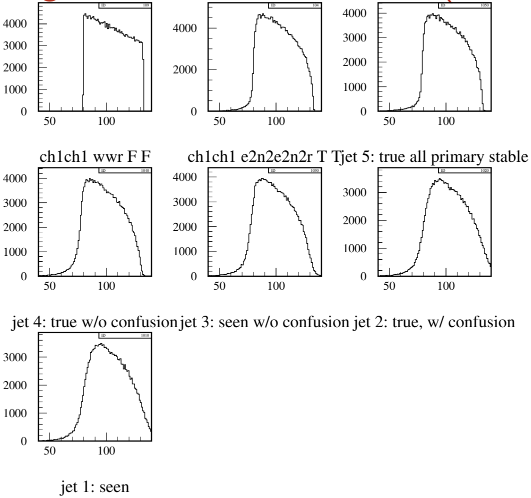
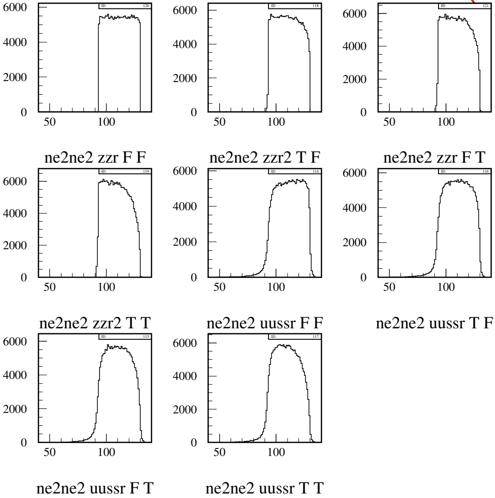


- true hadron level
- seen perfect Pflow
- seen Pflow with confusion

Neutralino mass reconstruction (M.Berggren)



- ISR
- Beamstrahlung
- W natural width

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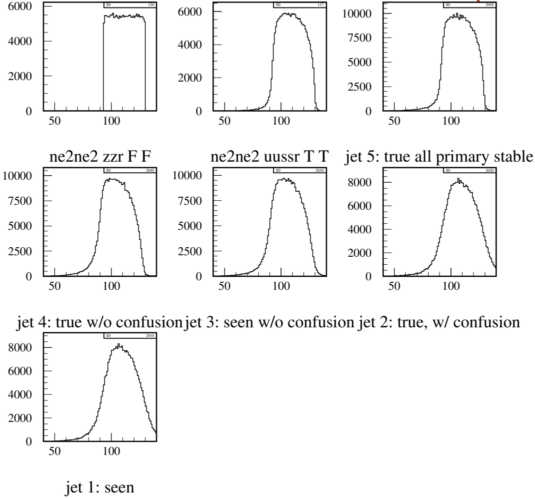

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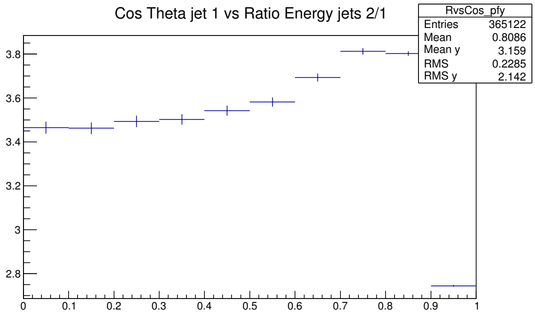
W^+W^- at 1 TeV (A.Rosca)



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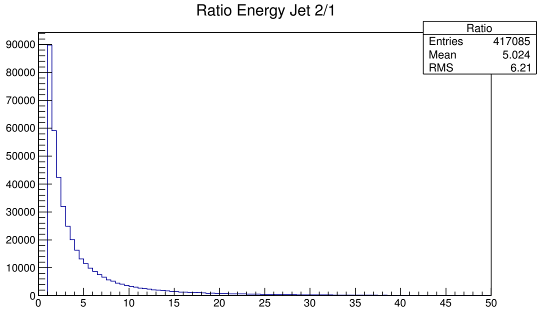
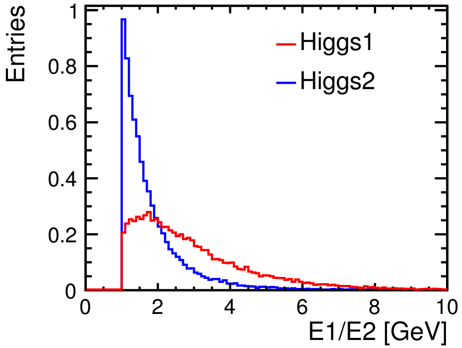


ZHH at 500 GeV (C.F.Dürig)



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