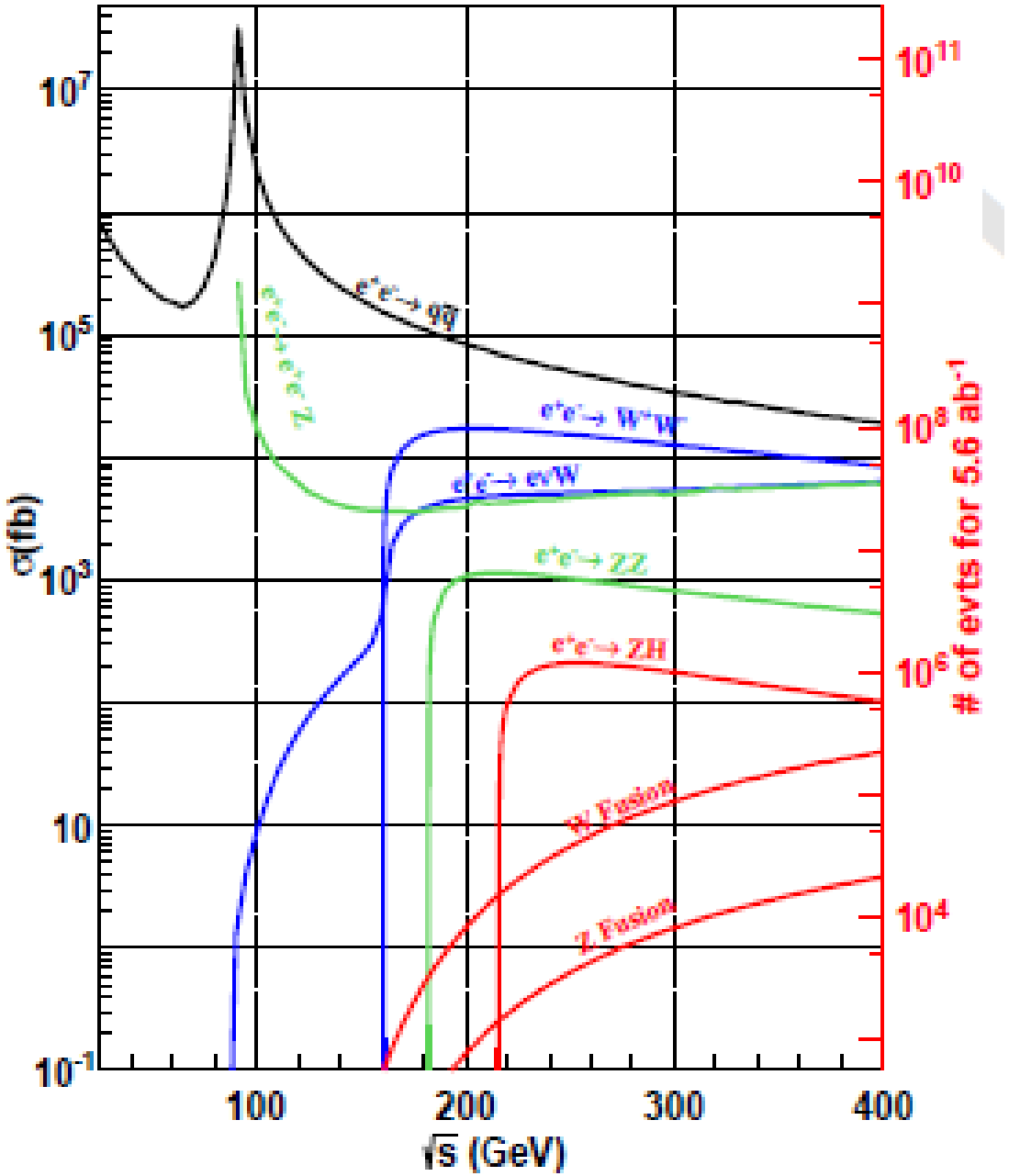
Why JER and τ reconstruction are essential for physics program at √s = 250 GeV

Jean-Claude Brient – LLR - IPP

Colleagues from IJCLAB and ALERGO project,
at FCC-France meeting Oct. 2023

“ JER and BMR not important at 250 GeV center of mass”



$\sqrt{s}$ = 250 GeV

$$\frac{\sigma(e^+e^- \to ZZ)}{\sigma(e^+e^- \to ZH)} \approx 6$$

$$\frac{\sigma(e^+e^- \to WW)}{\sigma(e^+e^- \to ZZ)} \approx 16$$

$$\frac{\sigma(e^+e^- \to WW)}{\sigma(e^+e^- \to ZH)} \approx 100$$

Tagging the bosons

Multi bosons	Multifermions + Boson(s)
ZH	e^+e^- H , e+e− Z
WW	νν H , νν Z
ZZ	ttH
ZHH	e ν W
ZZZ	νν WW, νν ZZ
ZWW	ttbar

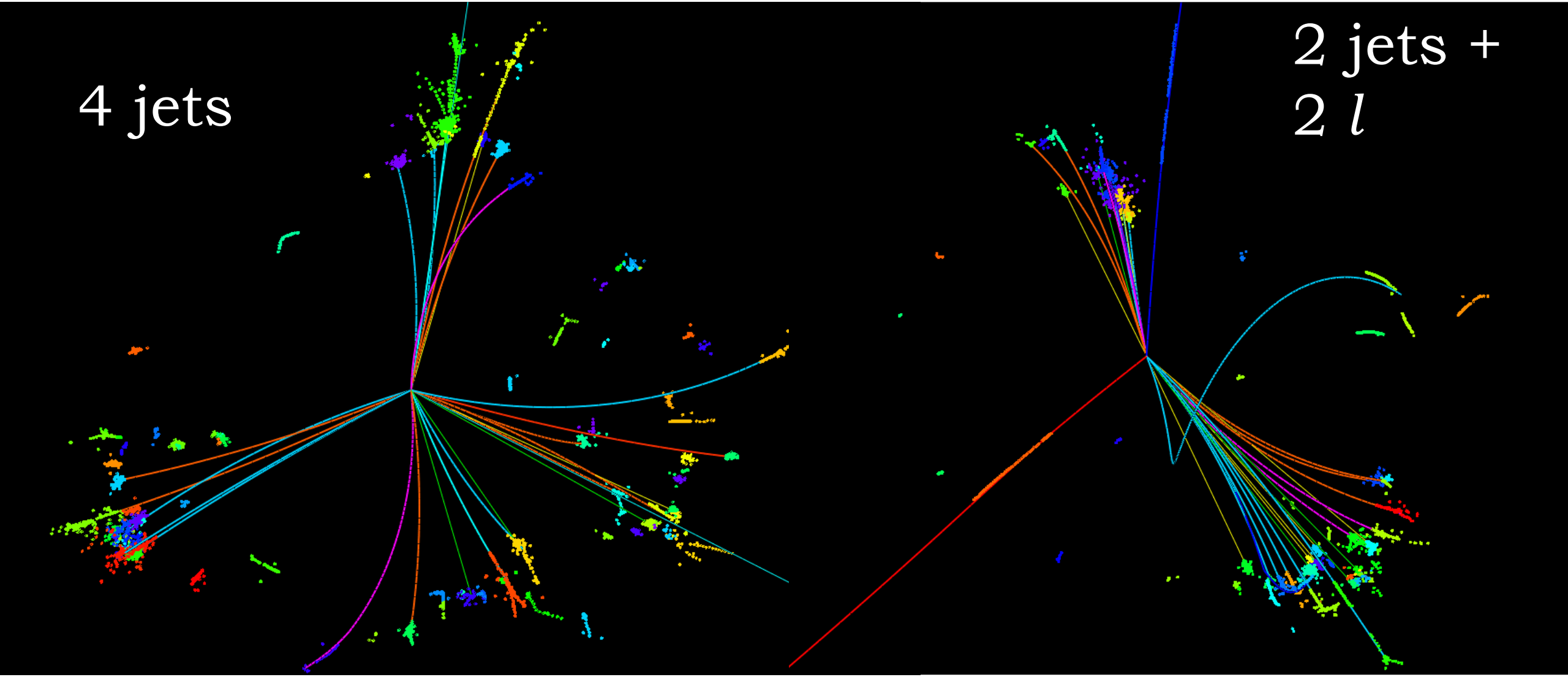
Z to	Fraction
$\ell^+ \ell^-$	10%
qq (jets)	70%

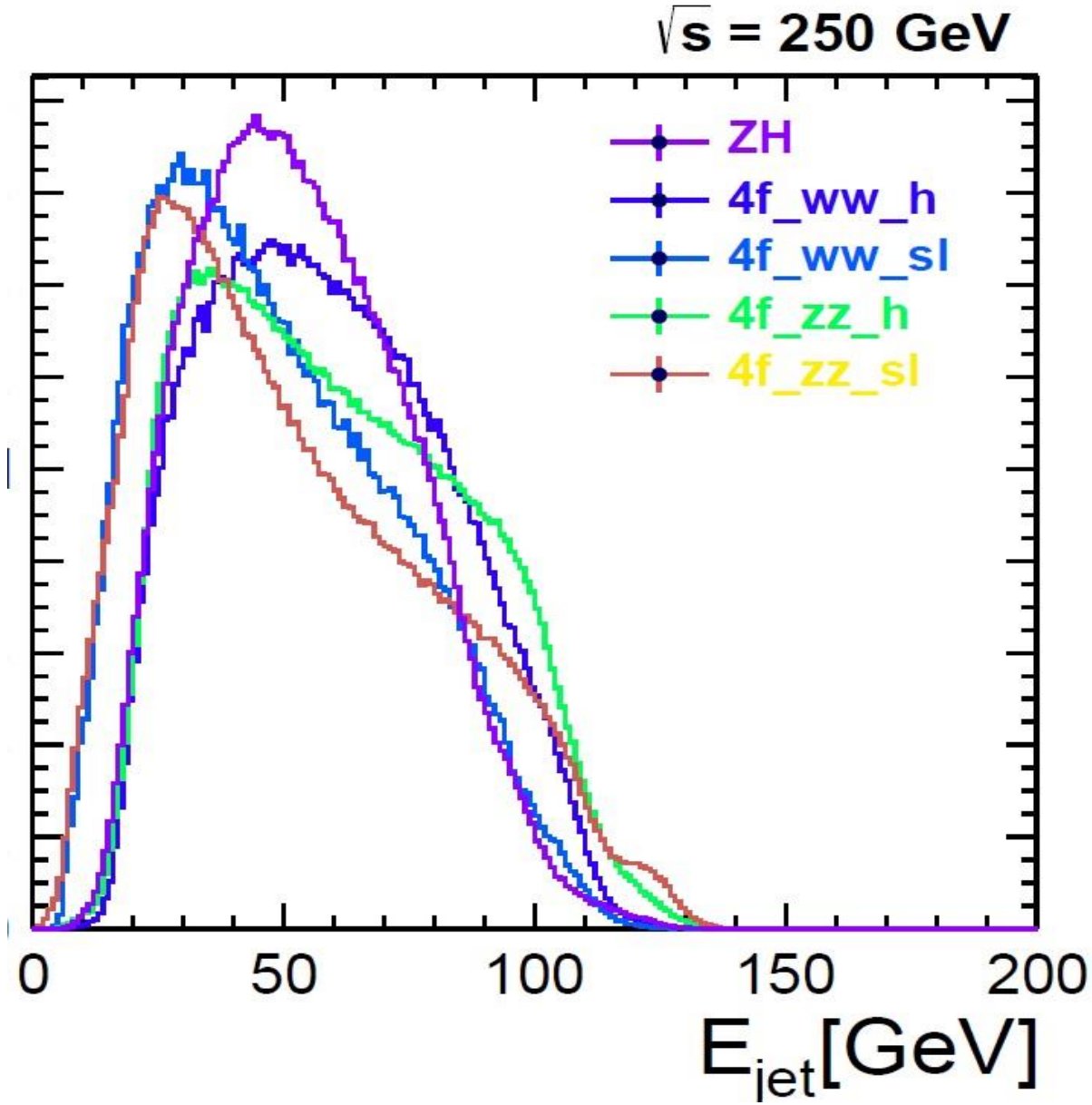
W to	Fraction
$\ell^\pm$ ν	32%
qq' (jets)	68%

H to	Fraction
$\ell^+ \ell^-$	<15%
qq(jets) ,WW,ZZ	>85%

Optimal use of the luminosity needs to reconstruct and tag the bosons through their hadronic decays

ZH final state at 250 GeV centre of mass energy

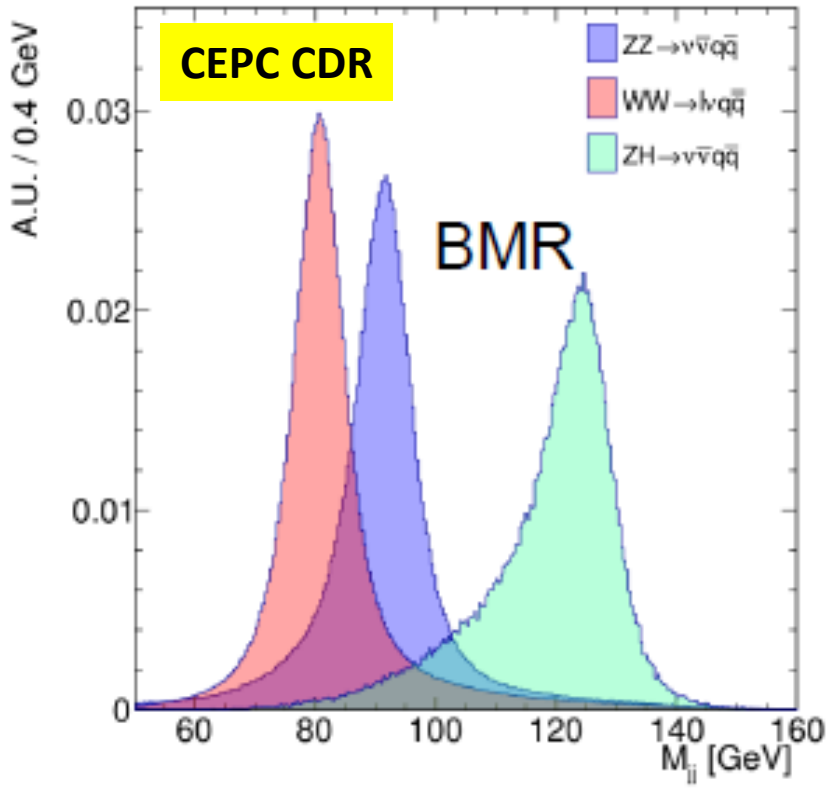




Which energy for the jets ?

- Standard Higgs boson couplings measurement

i.e. for example measurement Higgs to qqbar →



- Exotic Higgs boson decays
  see next slide

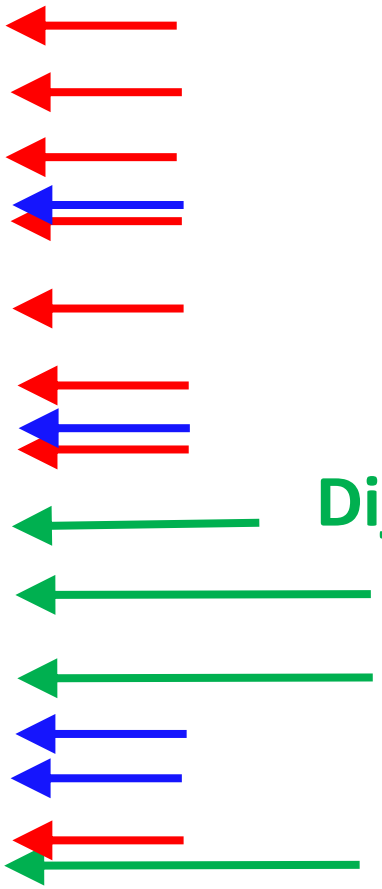
Source CEPC TDR

Higgs Boson exotic decays mode

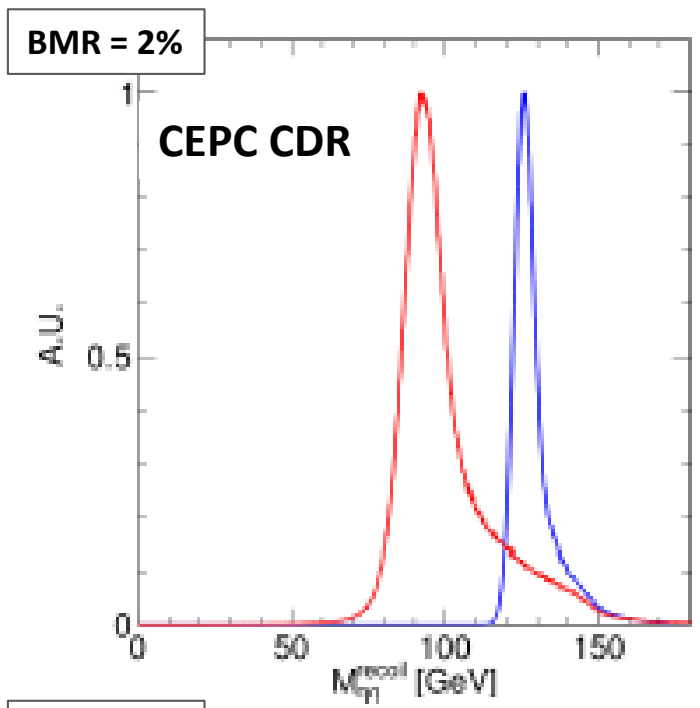
Higgs Decay mode	95% CL limit on BR		
	LHC	HL-LHC	CEPC
E_T^{miss}	0.23	0.056	0.030
$(b\bar{b}) + E_T^{miss}$	–	[0.2]	1×10^{-4}
$(jj) + E_T^{miss}$	–	–	4×10^{-4}
$(\tau^+\tau^-) + E_T^{miss}$	–	[1]	8×10^{-5}
$b\bar{b} + E_T^{miss}$	–	[0.2]	2×10^{-4}
$jj + E_T^{miss}$	–	–	5×10^{-4}
$\tau^+\tau^- + E_T^{miss}$	–	–	8×10^{-5}
$(b\bar{b})(b\bar{b})$	1.7	(0.2)	6×10^{-4}
$(c\bar{c})(c\bar{c})$	–	(0.2)	8×10^{-4}
$(jj)(jj)$	–	[0.1]	2×10^{-3}
$(b\bar{b})(\tau^+\tau^-)$	[0.1]	[0.15]	4×10^{-4}
$(\tau^+\tau^-)(\tau^+\tau^-)$	[1.2]	$[0.2\sim0.4]$	2×10^{-4}
$(jj)(\gamma\gamma)$	–	[0.01]	1×10^{-4}
$(\gamma\gamma)(\gamma\gamma)$	$[7\times10^{-3}]$	4×10^{-4}	8×10^{-5}

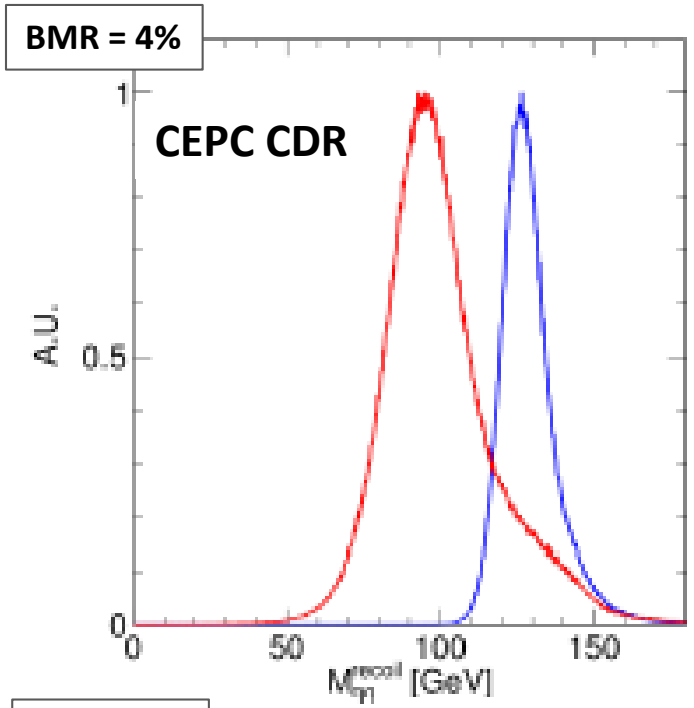
JER & E_T^{mis}

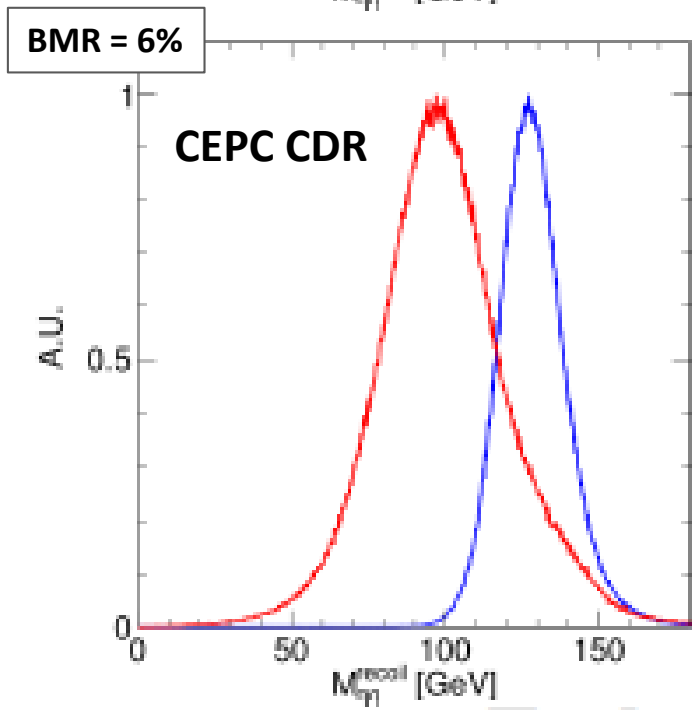
τ_{rec}

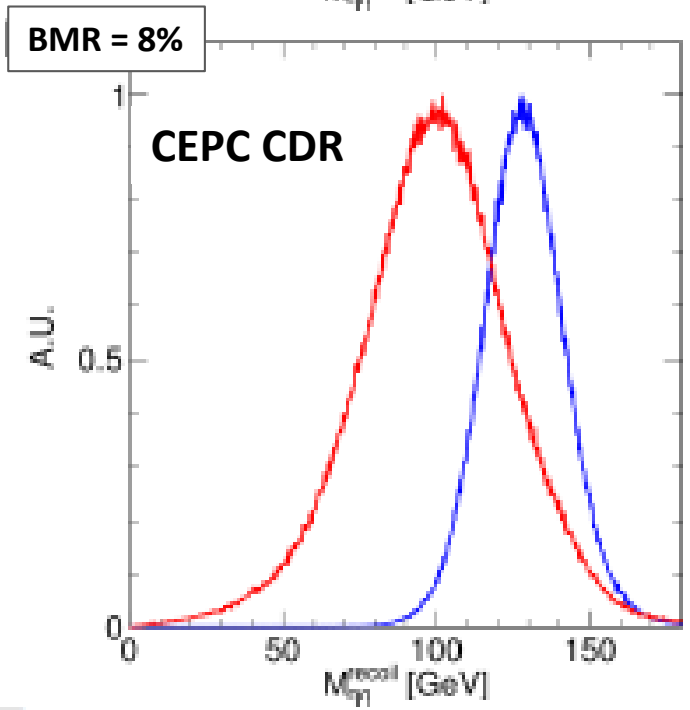


Dijets mass









Importance of the dijets mass resolution

For measuring Higgs → invisible

ZZ versus ZH

$ZZ \rightarrow qq\ \nu\nu$

And

$ZH \rightarrow qq\ H\ (H \rightarrow \text{invisible})$

Obvious effect due to BMR, but

Need to quantify the effect on
the precision on BR(Higgs to invisible)

Higgs Measurement at $\sqrt{s}$ = 350 GeV

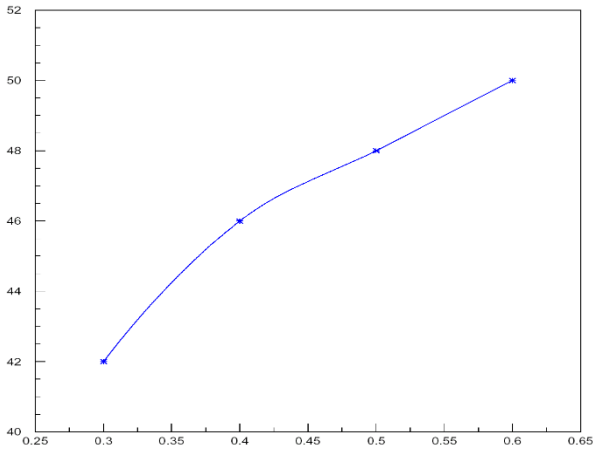
From T.Barklow (SLAC)

$e^+e^- \rightarrow ZH$

$\rightarrow qqb\bar{b}$

$\sqrt{s} = 350\ GeV$

$L = 500\ fb^{-1}$ $\quad \Delta M_h$ (MeV)



$\frac{\delta E_{jet}}{\sqrt{E_{jet}}}$ $(GeV^{\frac{1}{2}})$

From Thesis Jonas Kunath (IPP) - 2022
It is <u>essential</u> also at **$\sqrt{s}$ = 250 GeV**
to extract all the BRs of the Higgs
But the curve remains to be done

WHY it wa not done ?
Jonas used GEANT4 and PANDORA
It is not easy to do this type of curve

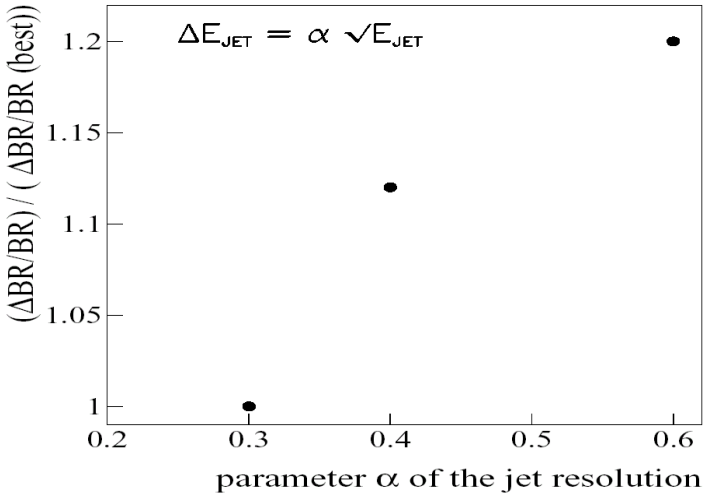
From J-C. Brient (LLR-IPP)

Error on $BR(H \rightarrow WW^*)$ from measurement of

$e^+e^- \rightarrow ZH \rightarrow q\bar{q}WW^* \rightarrow q\bar{q}q\bar{q}l\nu$

at $\sqrt{s} = 360$ GeV, L=500 fb^{-1}

J.-C. Brient, LC-PHSM-2004-001

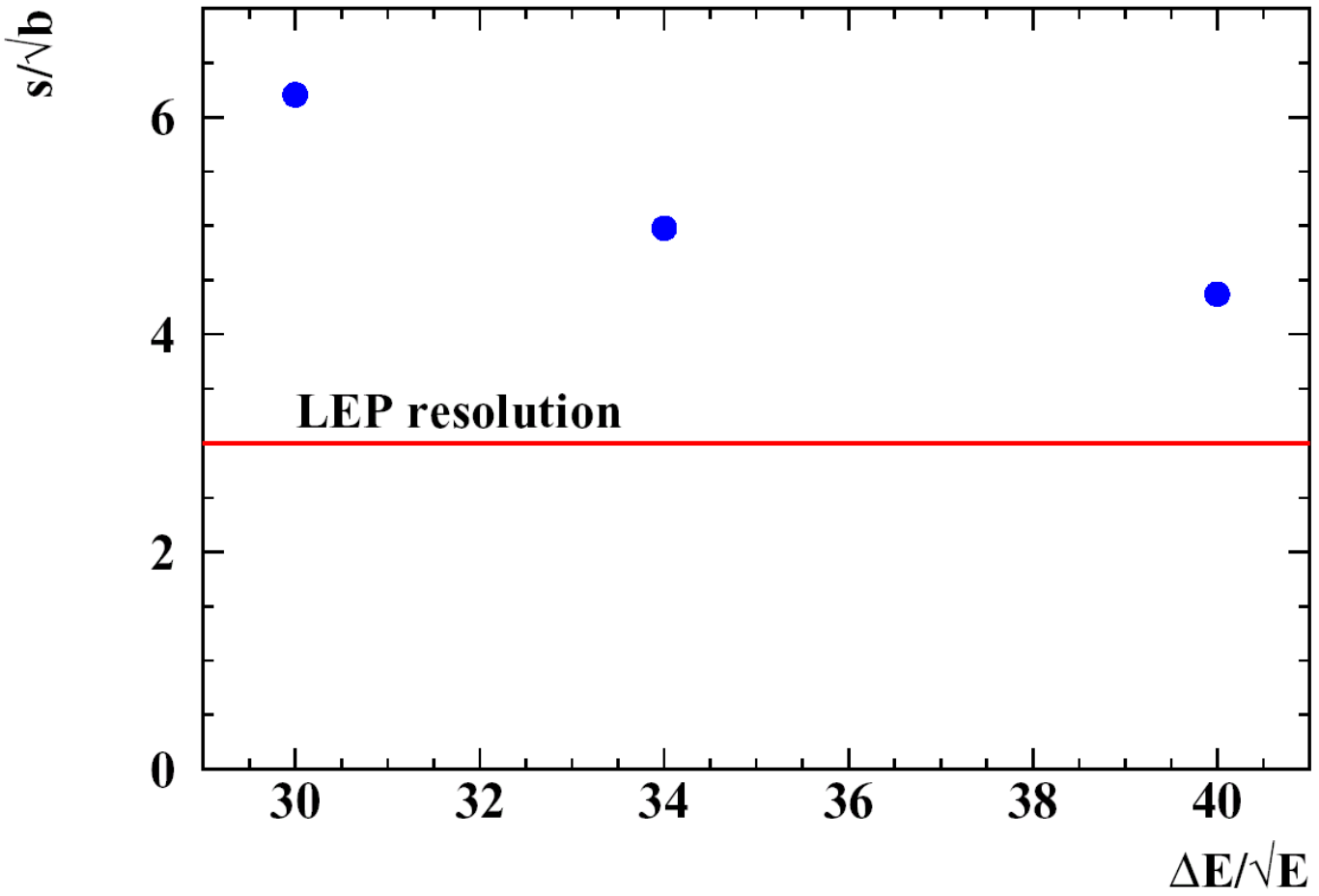


Higgs Measurement at $\sqrt{s}$ = 500 GeV

Signal significance at $\sqrt{s}$ = 500 GeV

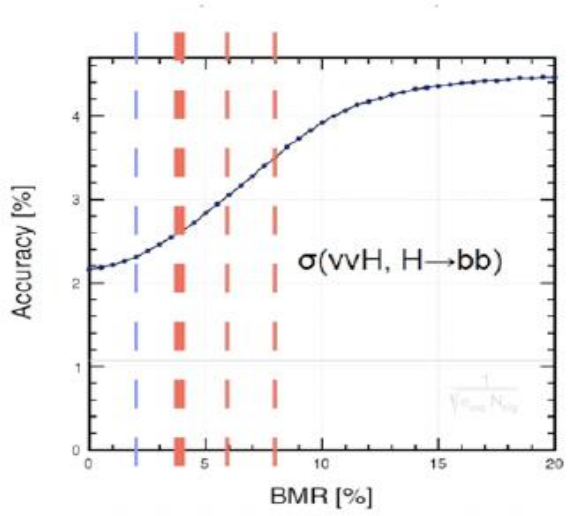
for $e^+e^- \to ZHH \to q\bar{q}b\bar{b}b\bar{b}$

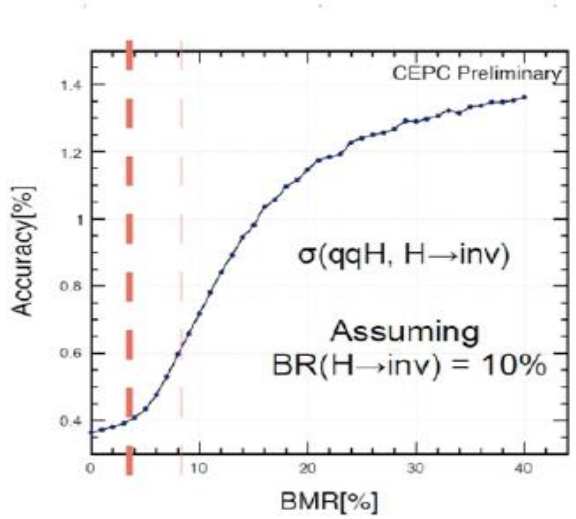
C. Castanier et al. hep-ex/0101028

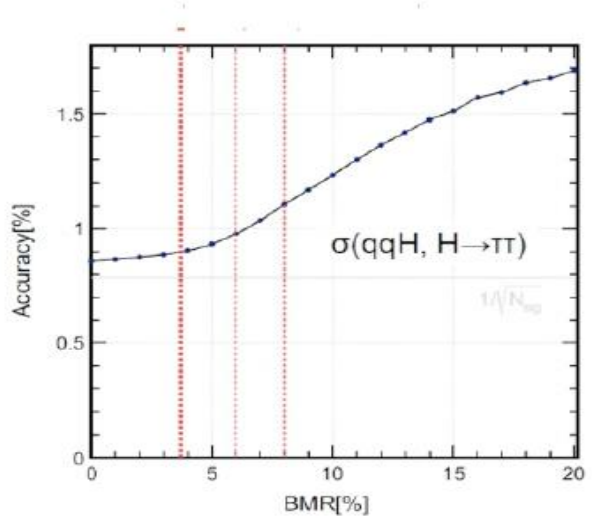


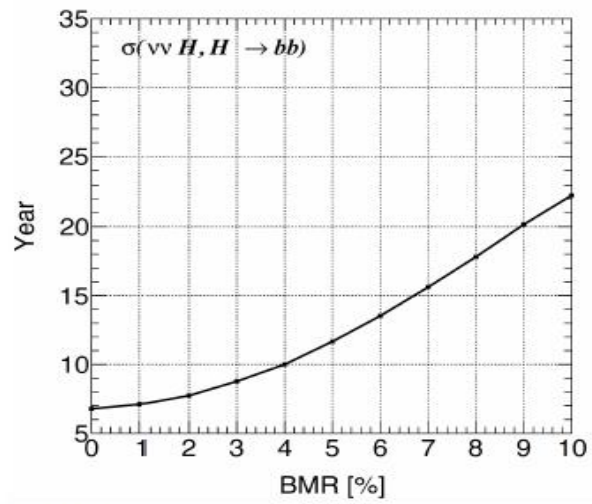
Higgs Measurement at √s = 250 GeV

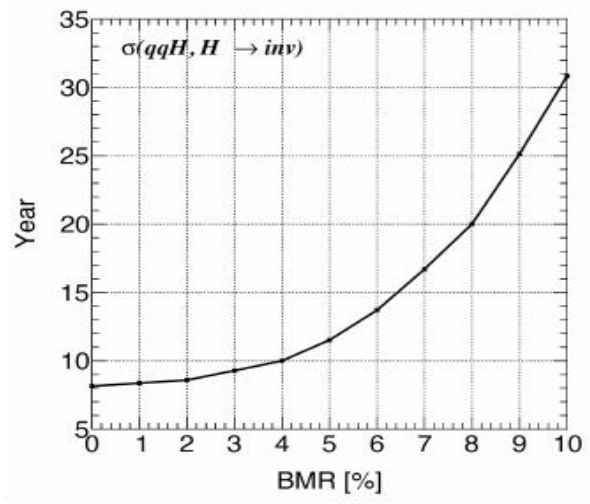
BMR: impact on critical measurements

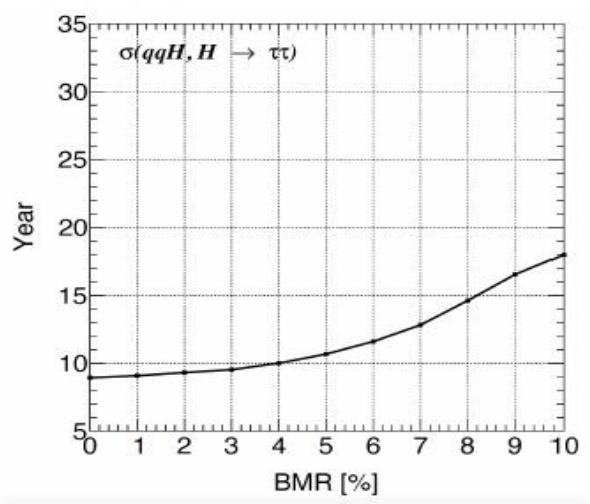




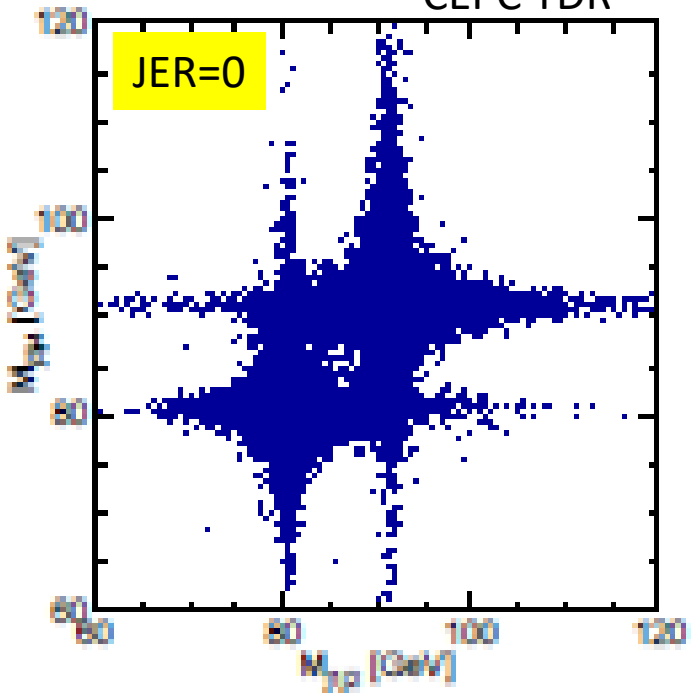


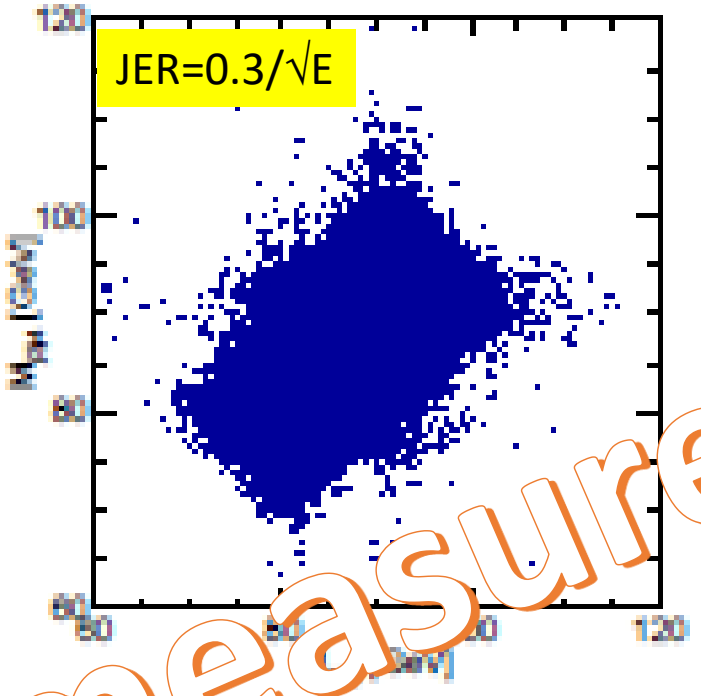


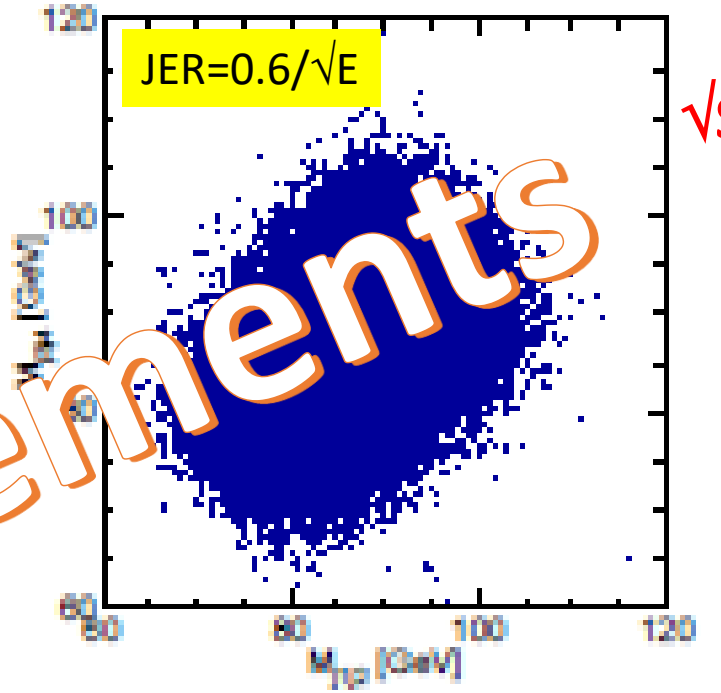




CEPC TDR



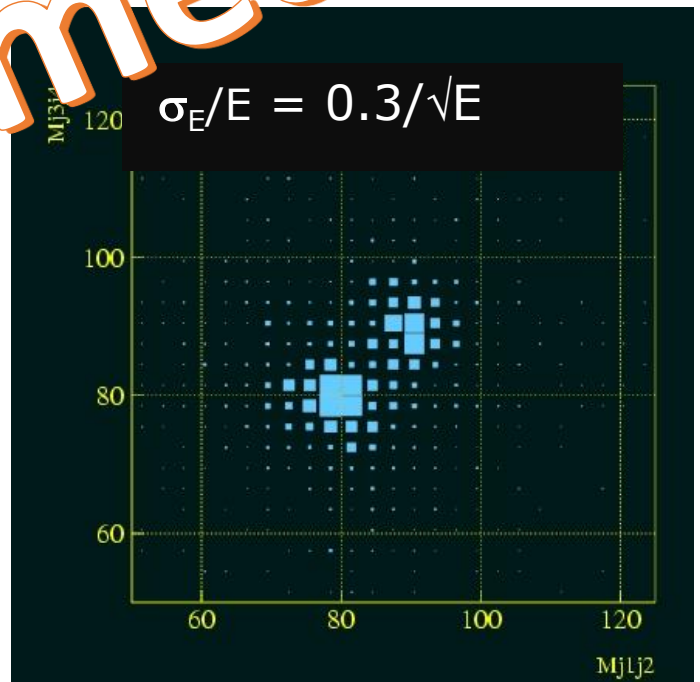


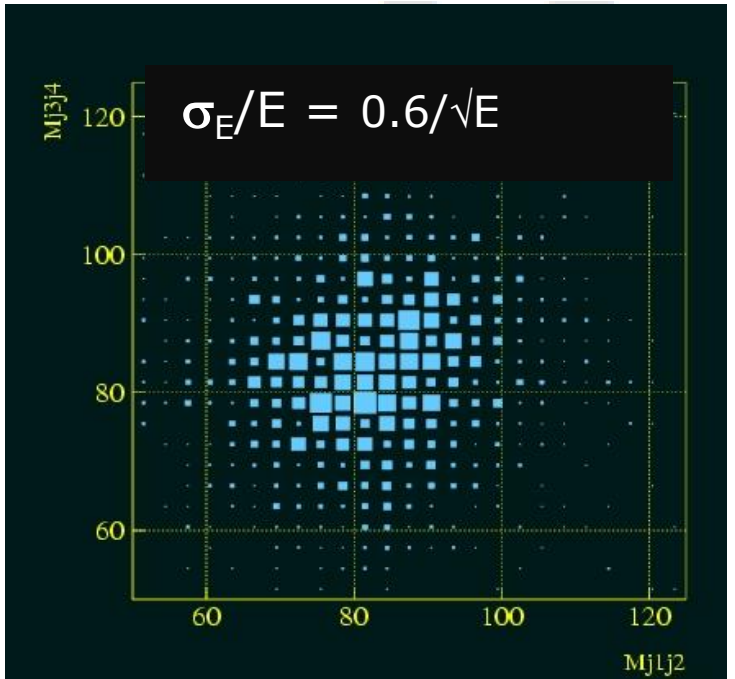


√S=240 GeV

EW measurements

√S=800 GeV





Proposed method
(not perfect but not unreasonable)

- Use the charged track(s) with momentum above **150** MeV/C
- Use photon(s) with energy> **200** MeV/c and at distance> **2** cm from extrapolated charged at the CALO. Entrance
- Use neutral hadron(s) with energy > **500** MeV/c and distance> **15** cm from extrapolated charged at the HCAL entrance
- Reconstruct the jets with particle(s) defined above, using jet algo (i.e. DURHAM)
- Smear the energy of the jet(s) using MC jet energy
- Do the analysis, each smearing give the different points to quantify the JER dependence of the analysis

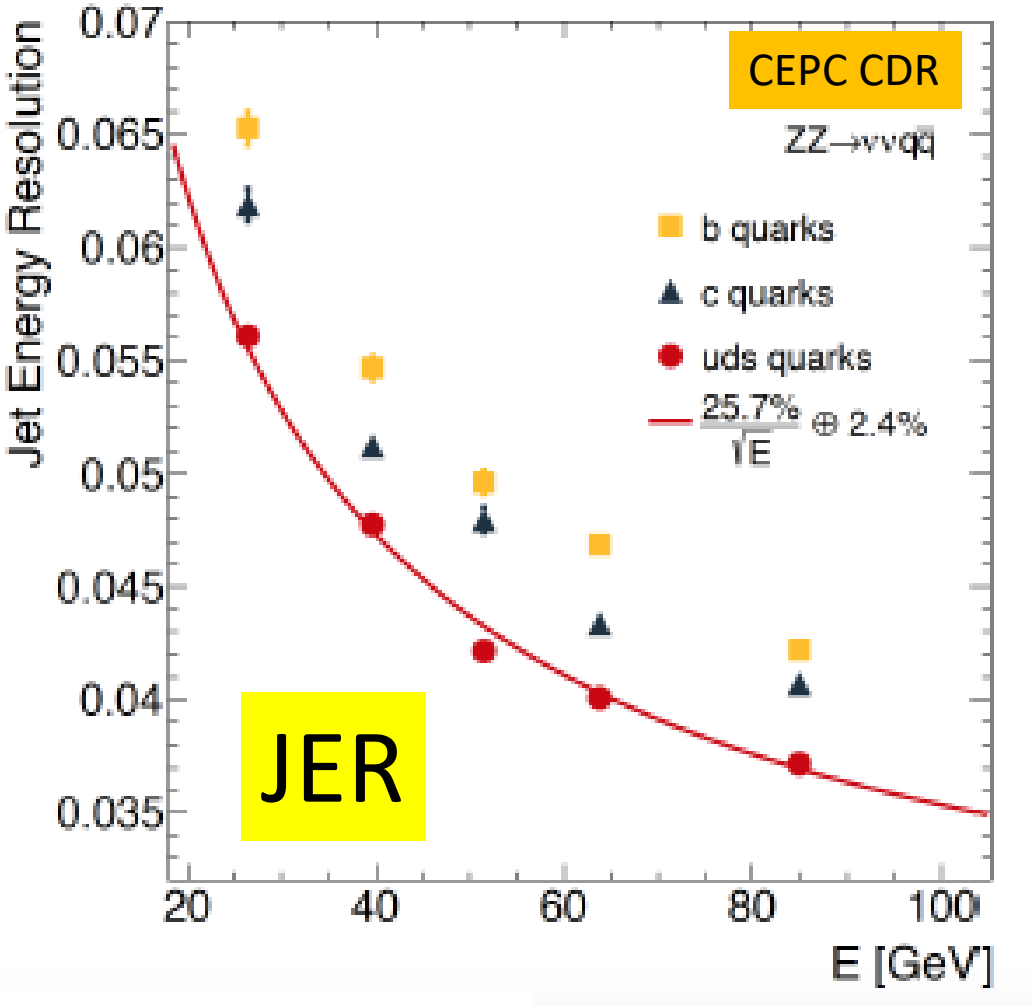
This Fast simulation would give performances closer to PANDORA whatever the jets multiplicity and jets energy
It is a good way to take into account for confusion term , contrary to DELPHES which downgrade performance of ILD,
At least at high energy or for large jets multiplicity events. Volunteers to put in SGV ?

In red, the parameters which has to be verified by Test beam data analysis or at least by full sim and rec

Just to finish with jets….

2 reminders for peoples asking for relevant questions,

but already treated in the past analysis for ILC



WARNING, PLOT MISLEADING !!!!

Point 1

It is due to semi-leptonics decays of the heavy quarks
(QCD and therefore fragmentation don't care about quarks family)

A basic method consist to disentangle jet with or without a lepton inside*
(at 1st order, but it can refined using PT lepton versus jets direction)

Create 2 samples

- No SL decays
- At least one lepton indicating SL decays

The tail on BMR will be the same for Higgs or Z

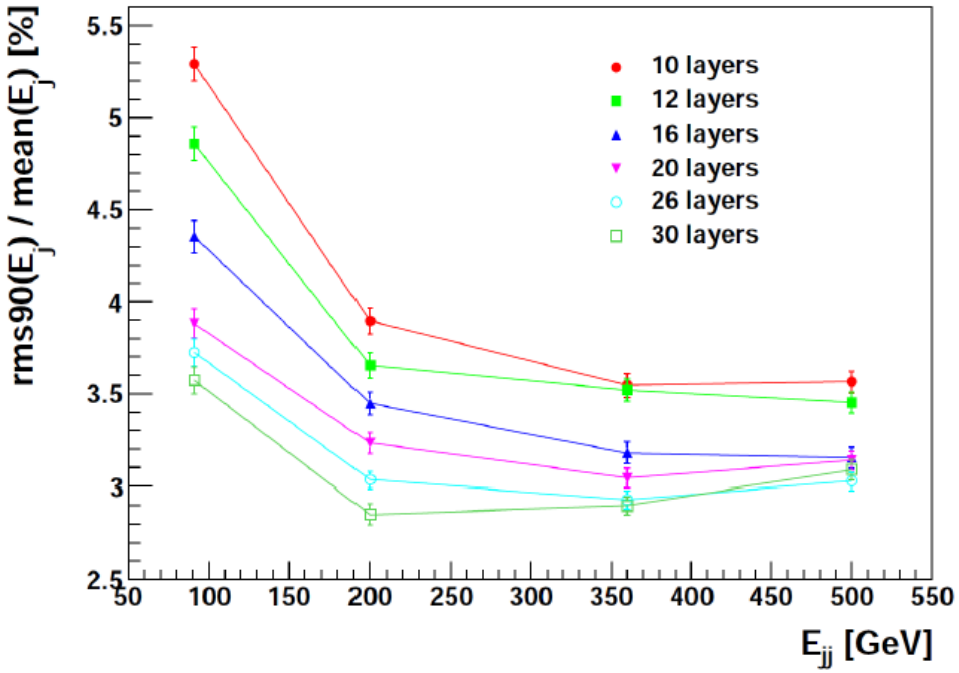
Conclusion : the separations between H and Z remains unchanged
As soon as you create 2 samples, but the JER keep its importance

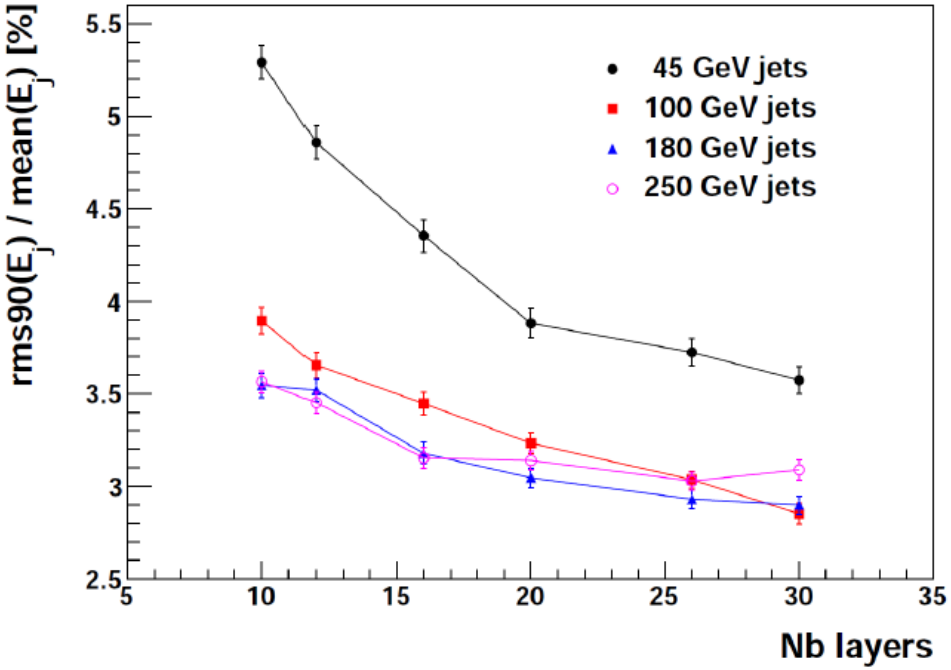
* The importance of e,μ ID capability IN JET is clearly for that type of situation

How the segmentation plays a role for JER (and not only for em resolution)

Point 2

Longitudinal segmentation for PFA





100 GeV jets
Resolution move from
3% to 4% when going from
26 layers to 10 layers

- Silicon-Tugnsten and AHCAL or SDHCAL :
- just a question of cost (large Radius and 26 layers give a cost about CMS ECAL)

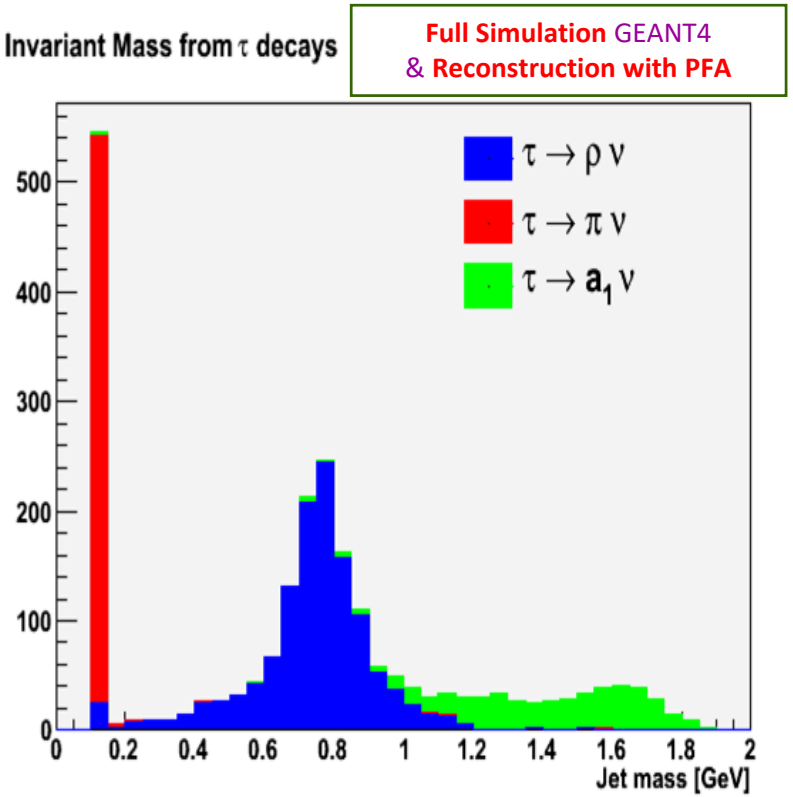
- 25 layers DE/E up by 11%
- 20 Layers DE/E up by 26%
- 10-15 layers (LAr for FCCee ?) …

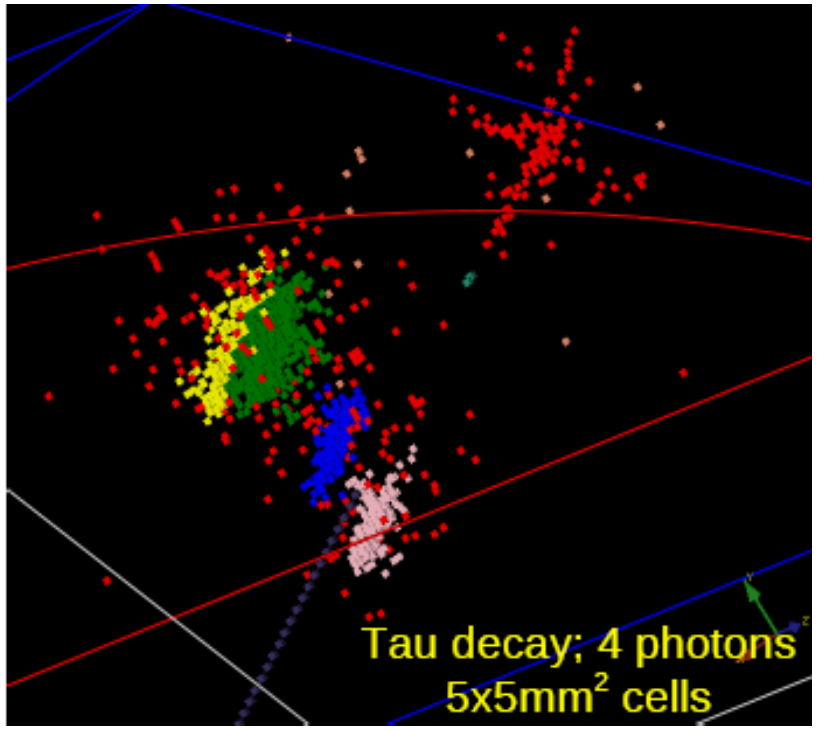
Using and analysing events with τ lepton(s) ,

the capability of the detectors comes
together with the JER

$\tau^{\pm}$ as a polarisation analyser

→ Need to reconstruct photon(s) in dense environment….





	Jet mass < 0.2	Jet mass in 0.2-1.1	Jet mass >1.1
$\tau \rightarrow \pi\nu$	90.2 %	1.7 %	8.1 %
$\tau \rightarrow \rho\nu$	1.7 %	87.3 %	7.4%
$\tau \rightarrow a_1\nu$	0.6 %	7.4 %	92.0 %

Performances depends strongly on ECAL granularity Not so much to radius

CONCLUSIONS

- The different cross sections of multi-bosons is clearly telling the JER importance
- The study to quantify JER importance on physics perf. remains to be done at 250 Ge/C
  (could be done for at least the ILD-list of benchmarks processes)
- In order to do these curves which quantify the JER importance,
  A proposal is made for a Fast Simulation much closer to PANDORA perf. (and so adapted to ILD)
  than DELPHES adapted to calorimeter a la CMS crystal (like the CMS flow) or IDEA
- However, I have no doubt about it, due to the JER importance at 350GeV
- Tau reconstruction and JER at twin parameters for a detector using PFA
- Longitudinal segmentation remains the key parameter for the performances

BACKUP

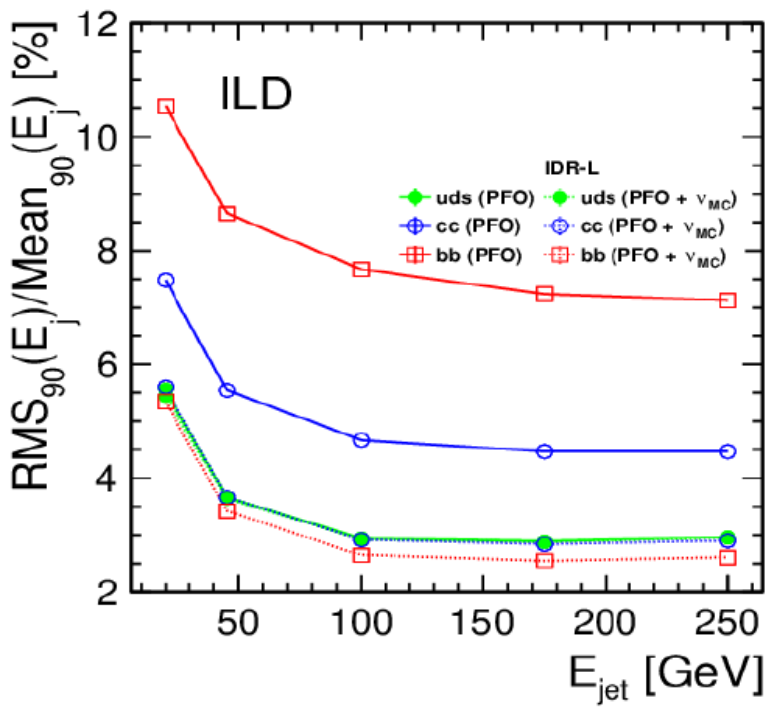
Model validation

Jet energy resolution

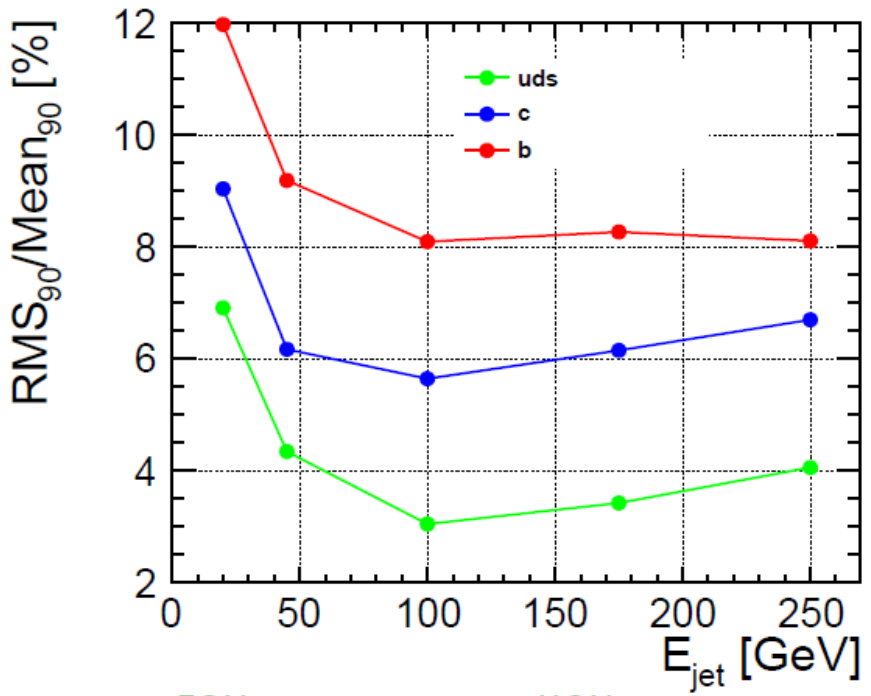
Surprisingly well reproduced with DELPHES (very simplified) Particle Flow

Calorimeter granularity and energy response thresholds important!

ILD IDR Fig. 8.3 d ($Z \to q\bar{q}$)



DELPHES simulation tests



$E_{min}^{ECAL} = 0.5$ GeV, $E_{min}^{HCAL} = 1.0$ GeV

45 GeV
3.5%
Goes to 4.5 %

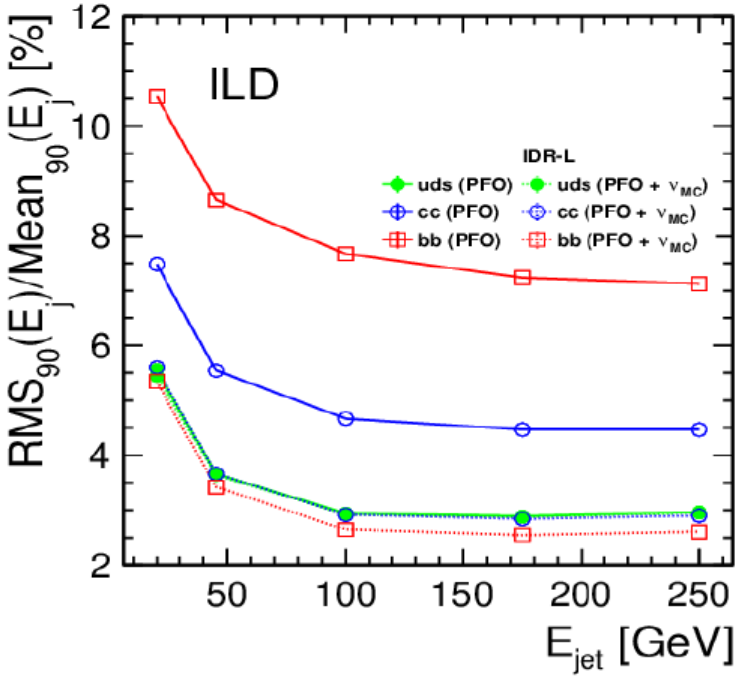
Model validation

Jet energy resolution

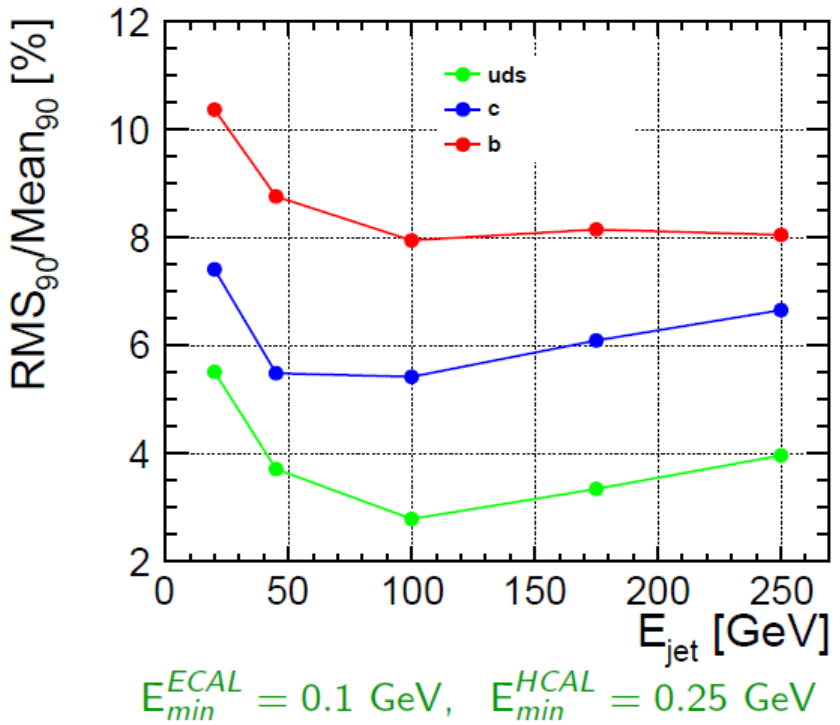
Surprisingly well reproduced with DELPHES (very simplified) Particle Flow

Calorimeter granularity and energy response thresholds important!

ILD IDR Fig. 8.3 d ($Z \to q\bar{q}$)



DELPHES simulation final implementation



$E_{min}^{ECAL} = 0.1$ GeV, $E_{min}^{HCAL} = 0.25$ GeV

Much better
But 3.5 to 3.8% , almost OK

But
threshold at 0.1 GeV on photon
Not realistic or must include
Debris of pion fragments
Like CEPC Fast Sim.

Worth on the threshold
On Neutral Hadron at 0.25GeV

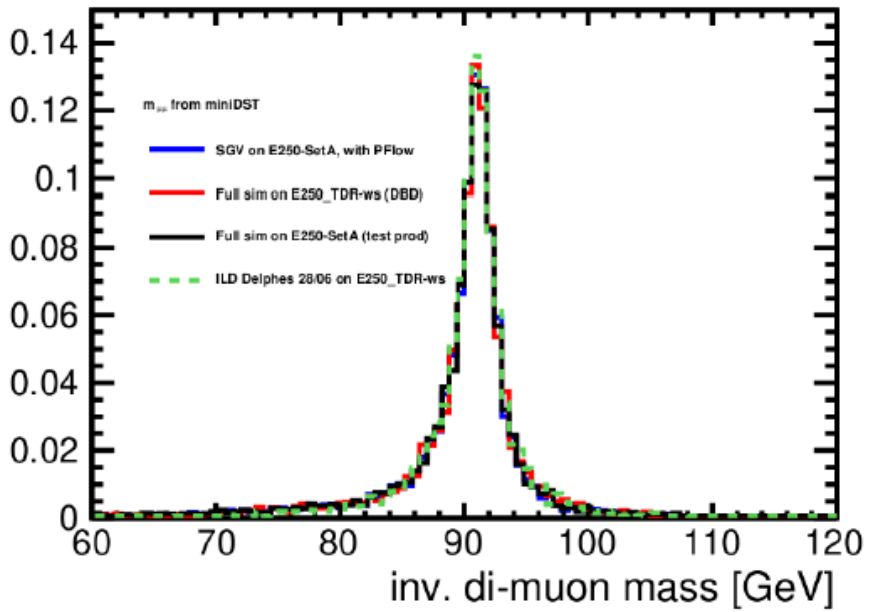
Artificial adjustment For low-medium energy

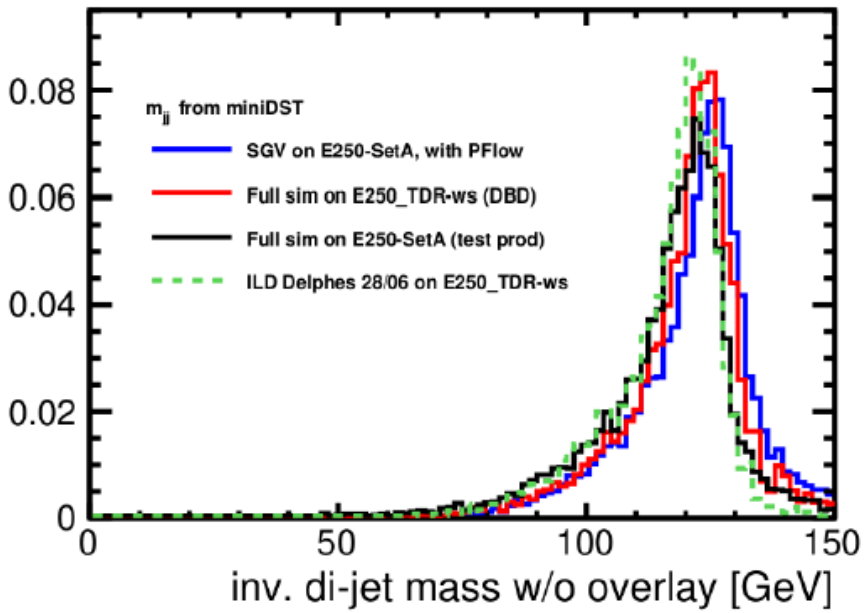
Higgs production at 250 GeV first checks, July 2020

Comparison of new Delphes model to SGV and full simulation results for

$$e^+e^- \rightarrow Z\,H \rightarrow \mu^+\mu^- q\,\bar{q}$$

Almost perfect agreement...





Plots prepared by Jenny List

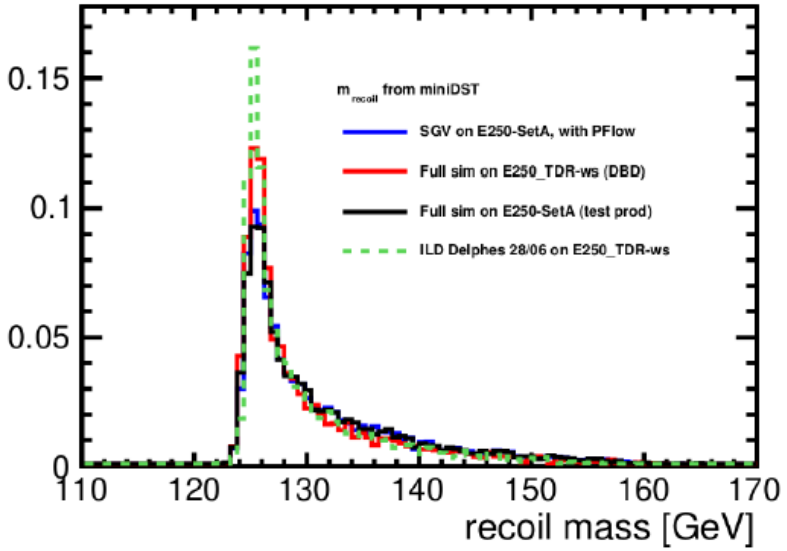
Example results

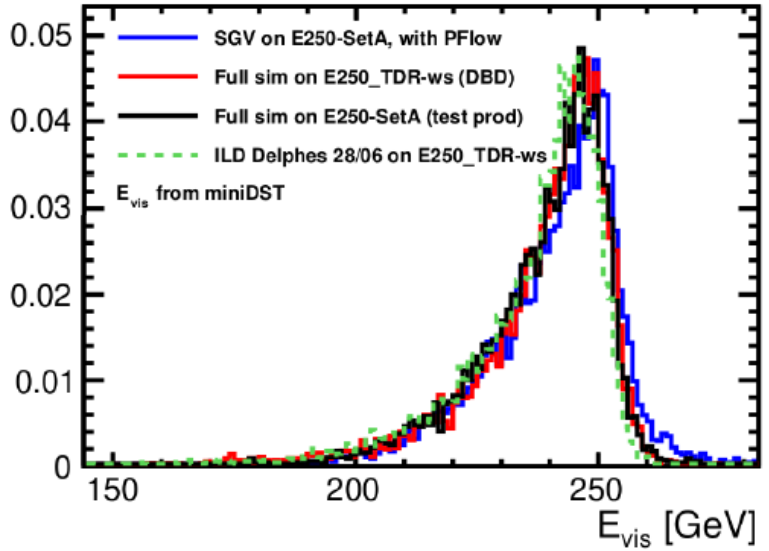
Higgs production at 250 GeV first checks, July 2020

Comparison of new Delphes model to SGV and full simulation results for

$$e^+e^- \rightarrow Z\,H \rightarrow \mu^+\mu^-\,q\,\bar{q}$$

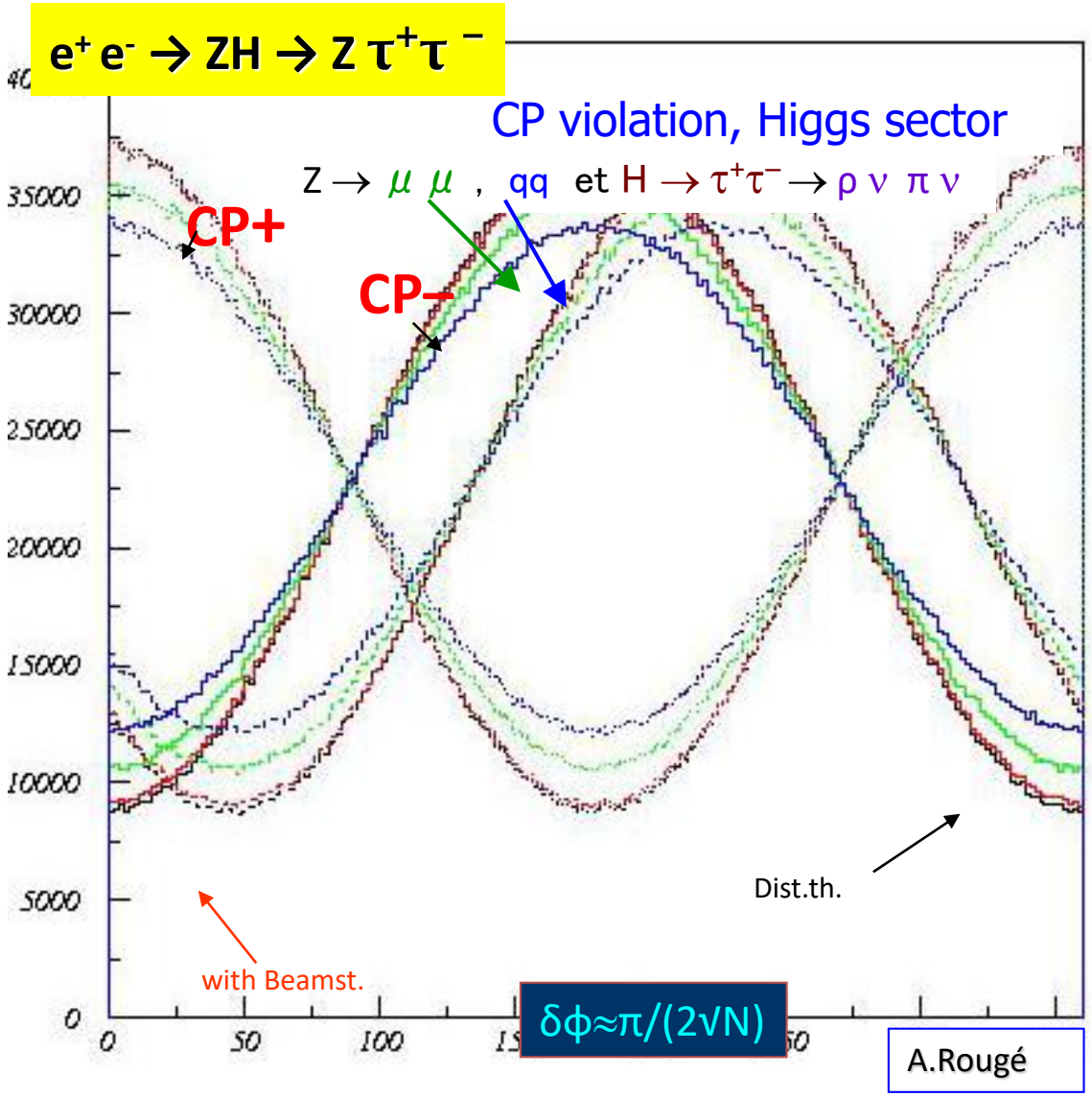
Almost perfect agreement...



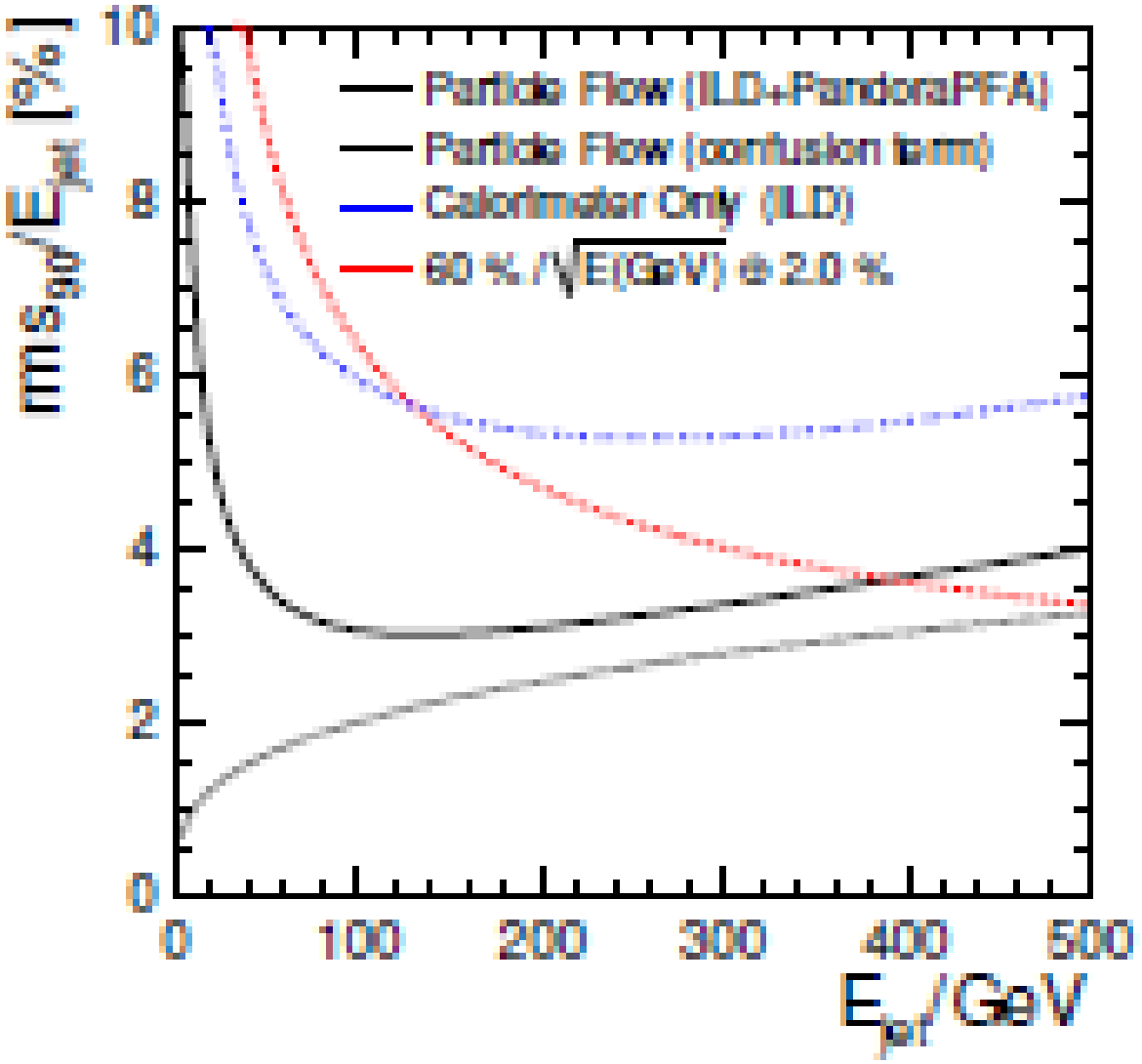


Plots prepared by Jenny List

To some extend ,
SVG better than DELPHES



CP angle analyser


Particle Flow (ILD+PandoraPFA)
Particle Flow (confusion term)
Calorimeter Only (ILD)
60 % /√E(GeV) ⊕ 2.0 %
10
8
6
4
2
0
0
100
200
300
400
500
E_jet/GeV