Physics Data for Detector Calibration at Ecm = 91 & 500 GeV

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Q15: Is Z-pole calibration data needed? If so, how frequently and how much? What solenoid field would be used for Z-pole calibration? Are beam energy or polarization measurements needed for Z-pole calibration

SiD : We have not yet given this issue real study, but expect to need some runs at the Z to get enough tracks to align the tracking detectors and perhaps to cross calibrate the calorimeters. Ideally these would be at full field. Experience from SLD shows that of order 500k Zs was just about sufficient to align a system of 96 CCDs including non-planar shape corrections for the sensors in the vertex detector. We think that the trackers need to be designed with an alignment friendly awareness - nice overlap regions and lever-arms and preferably a high degree of symmetry.

We have not thought much about aligning the endcap yet. That could require more data.

If the central tracker alignment were based on the SLD VXD alignment strategy, the statistics required may well be higher given the larger volume and many more overlapping regions to deal with.

We would expect to have to (re-)align after each major detector access. In principle this ought to be no more than a few times per year.

LDC : In general Z-pole data are considered to be very useful for detector calibration. No detailed study exists at the moment on the needed luminosity and/or precision. Based on the experience at LEP2, and folding in the fact that the granularity of the detectors is much larger and the requirements on the precision more stringent, one run with 10pb^{-1} at the beginning of a year and an additional approximately 1pb^{-1} per year are deemed sufficient, to establish and track the calibration. At the start of the ILC larger data samples might be needed to establish a base calibration.

The Z calibration is particularly important for the precision period of the ILC. A good calibration can probably be established without extensive Z running, based on Z or WW events. However this needs to be studied in more detail.

GLD : We are evaluating these issues for each detector. Also, we need how much luminosity is extected on Z-pole during the usual experimental run at ECM=500GeV. At present, we assume the luminosity(L) of $10^{33}/cm^2/s$ for VTX and CAL calibration runs, while L= $10^{32}/cm^2/s$ is assumed in the TPC calibration. Preliminary results are listed below;

VTX; If we have 1 fb^{-1} integrated luminosity, which can be achieved by 10 days run with 10^{33} luminosity, we can accumulate $3x10^6$ muons (50M Z). Then we can get $1000hits/cm^2$ at the outermost layer of the VTX. This number would be enough to get precise position calibration of the VTX. So we would like to propose to have; 1 fb^{-1} Z-pole run: Once per run period (=one year?) and 100 pb^{-1} Z-pole run : Once per month.

CAL requires sufficient number, about 100, of MIP particles passing in every 1cm x 1cm segmentation for 100 m^2 scintillator in the electromagnetic calorimeter. If muon pairs are only used (BR is 3.3%) on Z-pole, integrated luminosity of 10 fb^{-1} would be necessary, i.e. 100 days with L= 10^{33}!. CAL group must study seriously if hadronic events can be used for the calibration, or some clever method.

TPC by R.Settles and M.Thomson: The answer needs a guess at how often problems with the detector will occur that require calibration data. To not just make a blind guess, we took the data from Lep2 running, where this procedure (Z pole running for calibration) was used several times when detector problems cropped up. The last year of Lep2 running (2000), where things were really being pushed by the machine, the track record was: Z Running needed at Lep2: =>per detector<= 3/pb at the beginning of the year, and one run of 0.5/pb during the year. So, we propose then to use the following working hypothesis: Z Running for ILC: =>per detector<= 10/pb at the beginning of a year, and one run of 1/pb during a year , since the detector(s) will be more complicated. If I remember correctly, the projected Z-pole luminosity for Tesla for "calibration" (i.e. no special beam gymnastics to push up the luminosity like would be needed for the "GigaZ") would be $10^{32}/cm^2sec$ so that calibration at the beginning of the year would take =>per detector<= 30hours of beam and during the year =>per detector<= 3hours of beam. To repeat, this is just a guess, but at least it is based on past experience. At the very beginning of the ILC operation, much more Z running would be needed for calibration of the detector(s). This will mainly be determined by the calorimeter; Calice has studied this but I don't remember what their number is, maybe somebody else does...

Are Z0 Calibration Runs Necessary?

- How many particles are available for calibration from running at Ecm=500 GeV?
  - There are many processes with very large cross-sections at Ecm=500 GeV:

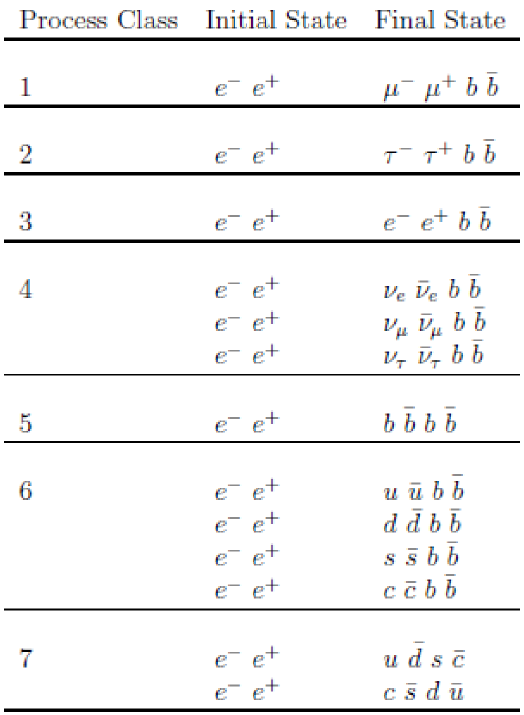
$$e^+e^- \to e\nu W, eeZ, \gamma Z$$

$$\gamma e \to \nu W, eZ$$

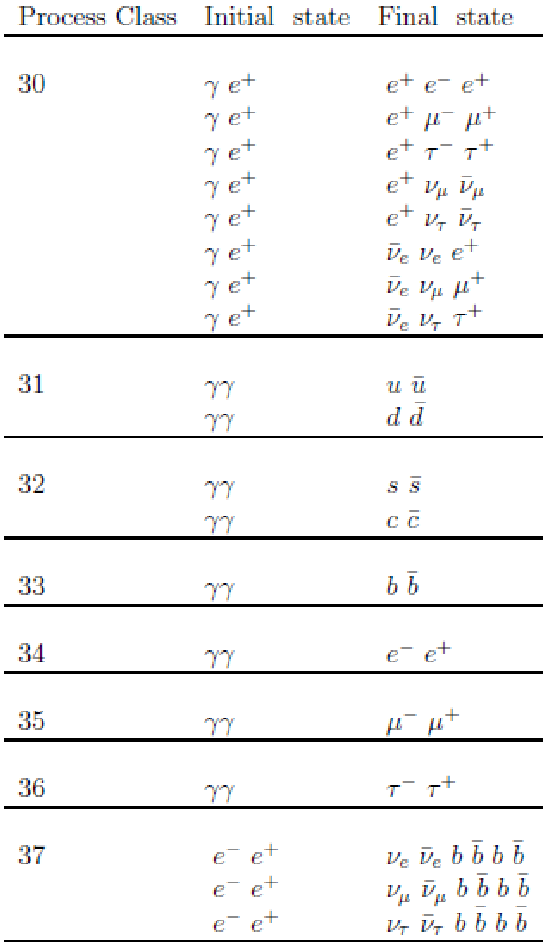
Assume in the following that Z0 Lumi = 0.01 Lumi at Ecm=500 GeV

Run Over All SM Processes at Ecm=500 GeV Using WHIZARD MC and compare with Distributions on the Z0 Resonances

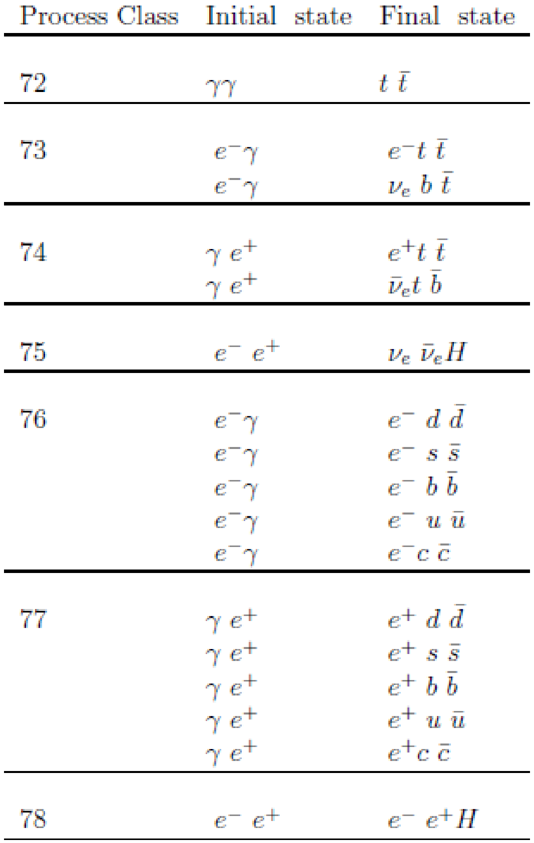
Examples of SM Processes (Divided into 78 Process Classes):



Process Class	Initial State	Final State
1	$e^- \; e^+$	$\mu^- \; \mu^+ \; b \; \bar{b}$
2	$e^- \; e^+$	$\tau^- \; \tau^+ \; b \; \bar{b}$
3	$e^- \; e^+$	$e^- \; e^+ \; b \; \bar{b}$
4	$e^- \; e^+$	$\nu_e \; \bar{\nu}_e \; b \; \bar{b}$
	$e^- \; e^+$	$\nu_\mu \; \bar{\nu}_\mu \; b \; \bar{b}$
	$e^- \; e^+$	$\nu_\tau \; \bar{\nu}_\tau \; b \; \bar{b}$
5	$e^- \; e^+$	$b \; \bar{b} \; b \; \bar{b}$
6	$e^- \; e^+$	$u \; \bar{u} \; b \; \bar{b}$
	$e^- \; e^+$	$d \; \bar{d} \; b \; \bar{b}$
	$e^- \; e^+$	$s \; \bar{s} \; b \; \bar{b}$
	$e^- \; e^+$	$c \; \bar{c} \; b \; \bar{b}$
7	$e^- \; e^+$	$u \; \bar{d} \; s \; \bar{c}$
	$e^- \; e^+$	$c \; \bar{s} \; d \; \bar{u}$



Process Class	Initial state	Final state
30	$\gamma \; e^+$	$e^+ \; e^- \; e^+$
	$\gamma \; e^+$	$e^+ \; \mu^- \; \mu^+$
	$\gamma \; e^+$	$e^+ \; \tau^- \; \tau^+$
	$\gamma \; e^+$	$e^+ \; \nu_\mu \; \bar{\nu}_\mu$
	$\gamma \; e^+$	$e^+ \; \nu_\tau \; \bar{\nu}_\tau$
	$\gamma \; e^+$	$\bar{\nu}_e \; \nu_e \; e^+$
	$\gamma \; e^+$	$\bar{\nu}_e \; \nu_\mu \; \mu^+$
	$\gamma \; e^+$	$\bar{\nu}_e \; \nu_\tau \; \tau^+$
31	$\gamma\gamma$	$u \; \bar{u}$
	$\gamma\gamma$	$d \; \bar{d}$
32	$\gamma\gamma$	$s \; \bar{s}$
	$\gamma\gamma$	$c \; \bar{c}$
33	$\gamma\gamma$	$b \; \bar{b}$
34	$\gamma\gamma$	$e^- \; e^+$
35	$\gamma\gamma$	$\mu^- \; \mu^+$
36	$\gamma\gamma$	$\tau^- \; \tau^+$
37	$e^- \; e^+$	$\nu_e \; \bar{\nu}_e \; b \; \bar{b} \; b \; \bar{b}$
	$e^- \; e^+$	$\nu_\mu \; \bar{\nu}_\mu \; b \; \bar{b} \; b \; \bar{b}$
	$e^- \; e^+$	$\nu_\tau \; \bar{\nu}_\tau \; b \; \bar{b} \; b \; \bar{b}$

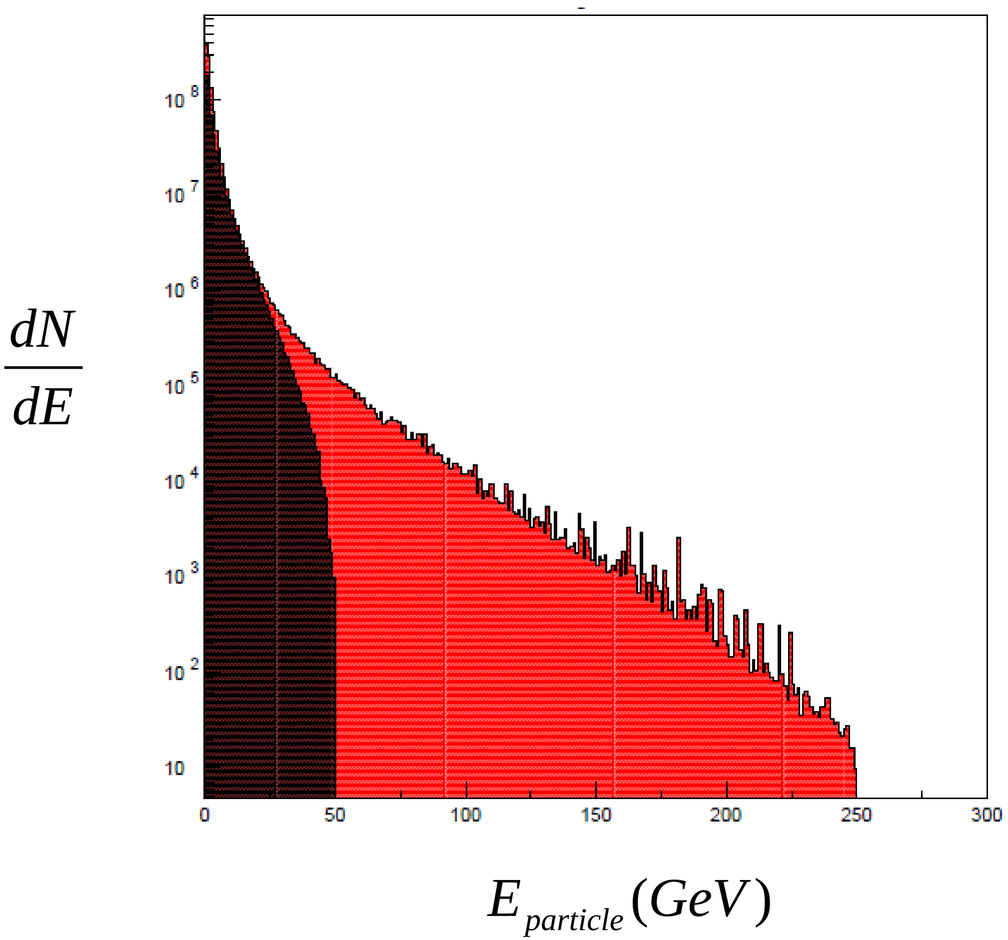


Process Class	Initial state	Final state
72	$\gamma\gamma$	$t \; \bar{t}$
73	$e^-\gamma$	$e^- t \; \bar{t}$
	$e^-\gamma$	$\nu_e \; b \; \bar{t}$
74	$\gamma \; e^+$	$e^+ t \; \bar{t}$
	$\gamma \; e^+$	$\bar{\nu}_e t \; \bar{b}$
75	$e^- \; e^+$	$\nu_e \; \bar{\nu}_e H$
76	$e^-\gamma$	$e^- \; d \; \bar{d}$
	$e^-\gamma$	$e^- \; s \; \bar{s}$
	$e^-\gamma$	$e^- \; b \; \bar{b}$
	$e^-\gamma$	$e^- \; u \; \bar{u}$
	$e^-\gamma$	$e^- c \; \bar{c}$
77	$\gamma \; e^+$	$e^+ \; d \; \bar{d}$
	$\gamma \; e^+$	$e^+ \; s \; \bar{s}$
	$\gamma \; e^+$	$e^+ \; b \; \bar{b}$
	$\gamma \; e^+$	$e^+ \; u \; \bar{u}$
	$\gamma \; e^+$	$e^+ c \; \bar{c}$
78	$e^- \; e^+$	$e^- \; e^+ H$

🟥 Ecm= 500 GeV All SM Processes 100 fb^{-1}

⬛ Ecm= 91 GeV Z → qq 1 fb^{-1}

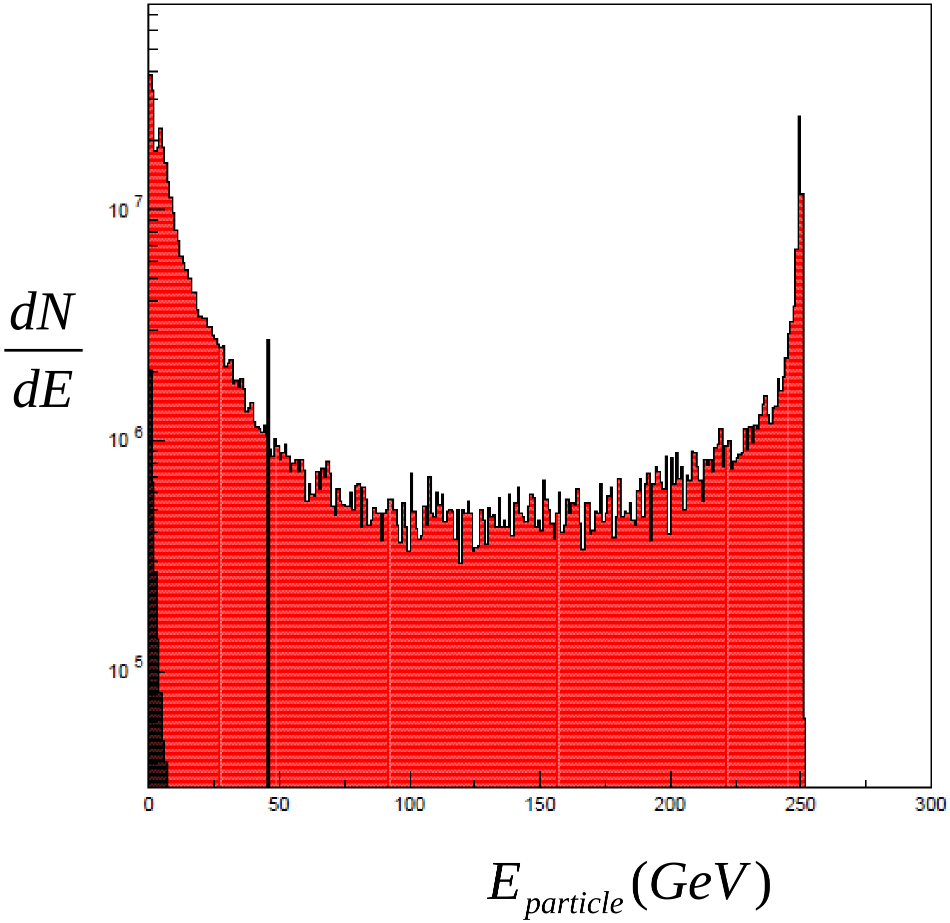
Charged Hadrons



🟥 Ecm= 500 GeV All SM Processes 100 fb^{-1}

⬛ Ecm= 91 GeV Z →qq, ee 1 fb^{-1}

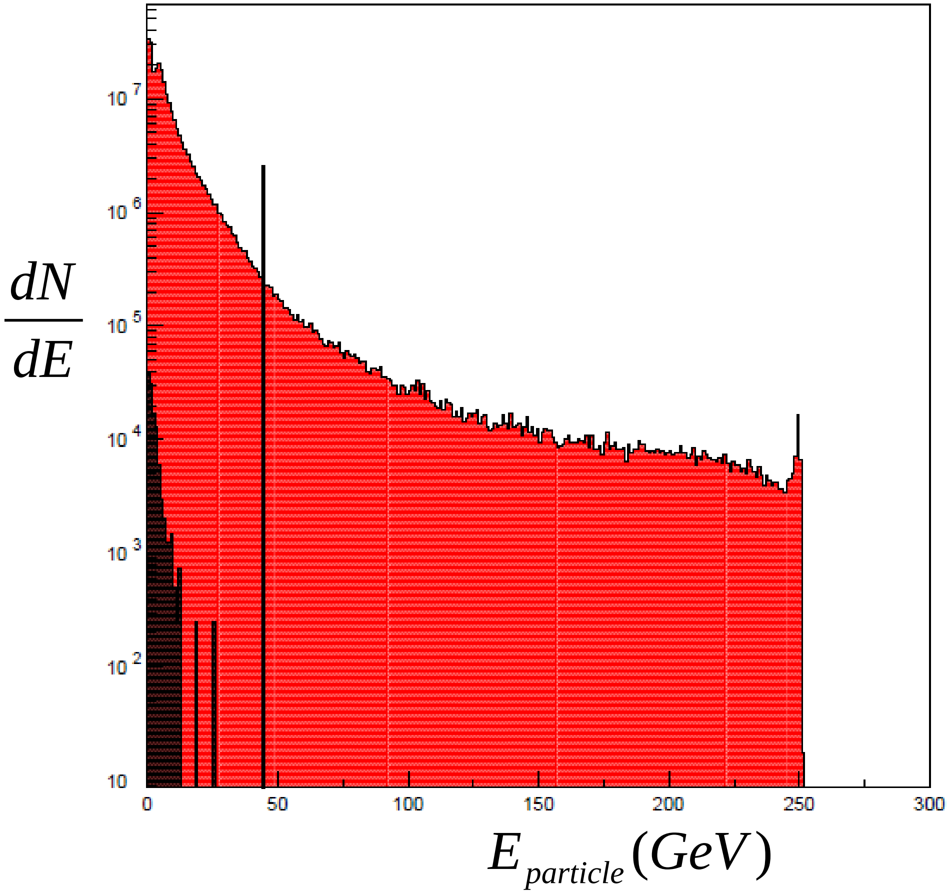
Electrons



🟥 Ecm= 500 GeV All SM Processes 100 fb^{-1}

⬛ Ecm= 91 GeV Z →qq, μμ 1 fb^{-1}

Muons



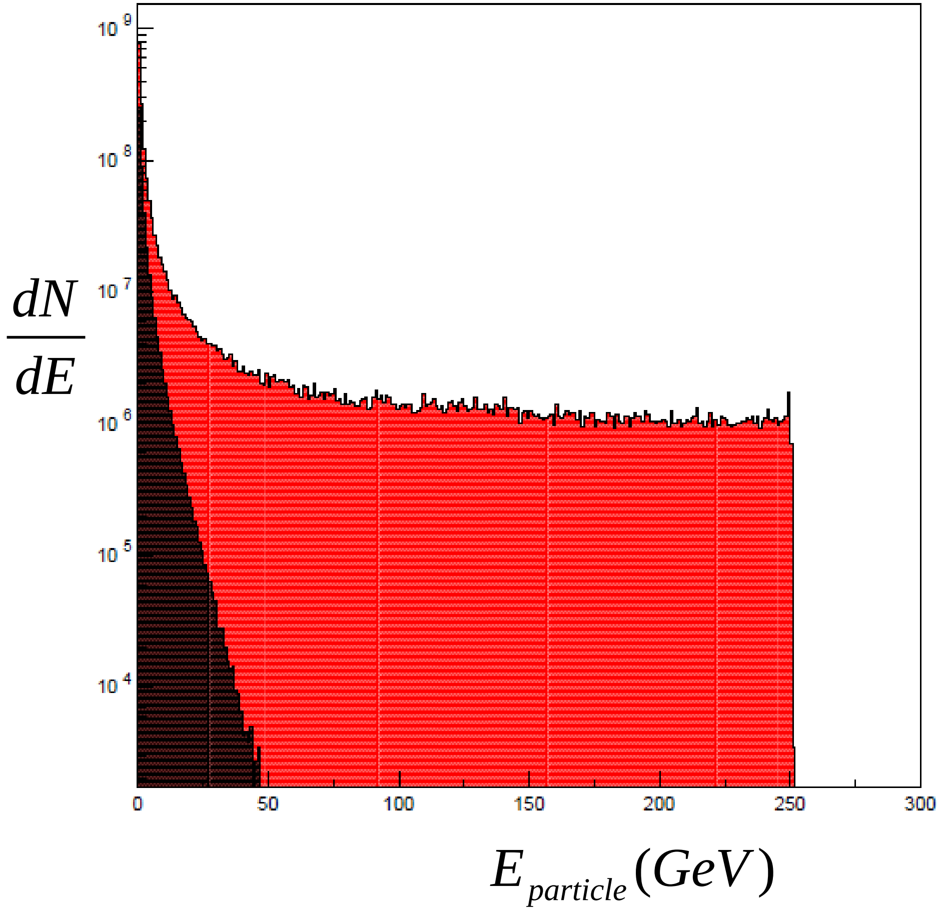
Ecm=500 GeV L=100 fb^{-1} :

E_μ range	# Muons
$E_\mu > 10$ GeV	0.6×10^8
$E_\mu > 50$ GeV	0.5×10^7
$E_\mu > 150$ GeV	0.7×10^6

🟥 Ecm= 500 GeV All SM Processes 100 fb^{-1}

⬛ Ecm= 91 GeV $Z \rightarrow qq$ 1 fb^{-1}

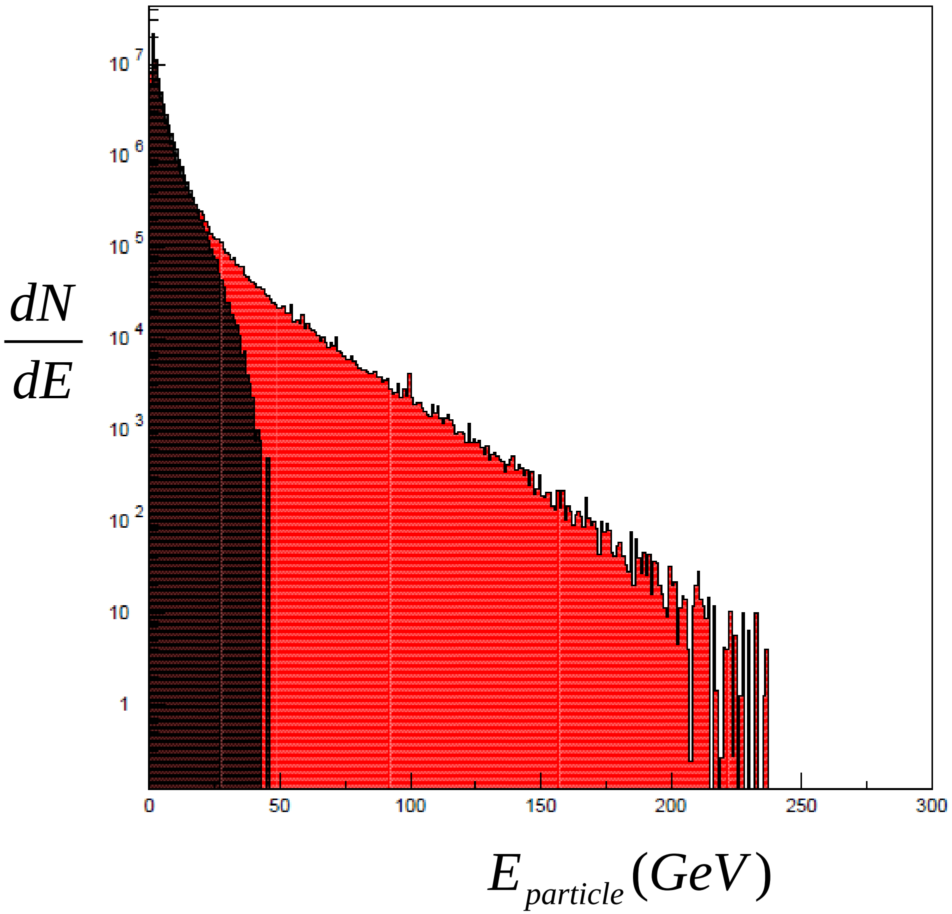
Photons



🟥 Ecm= 500 GeV All SM Processes 100 fb^{-1}

⬛ Ecm= 91 GeV Z →qq 1 fb^{-1}

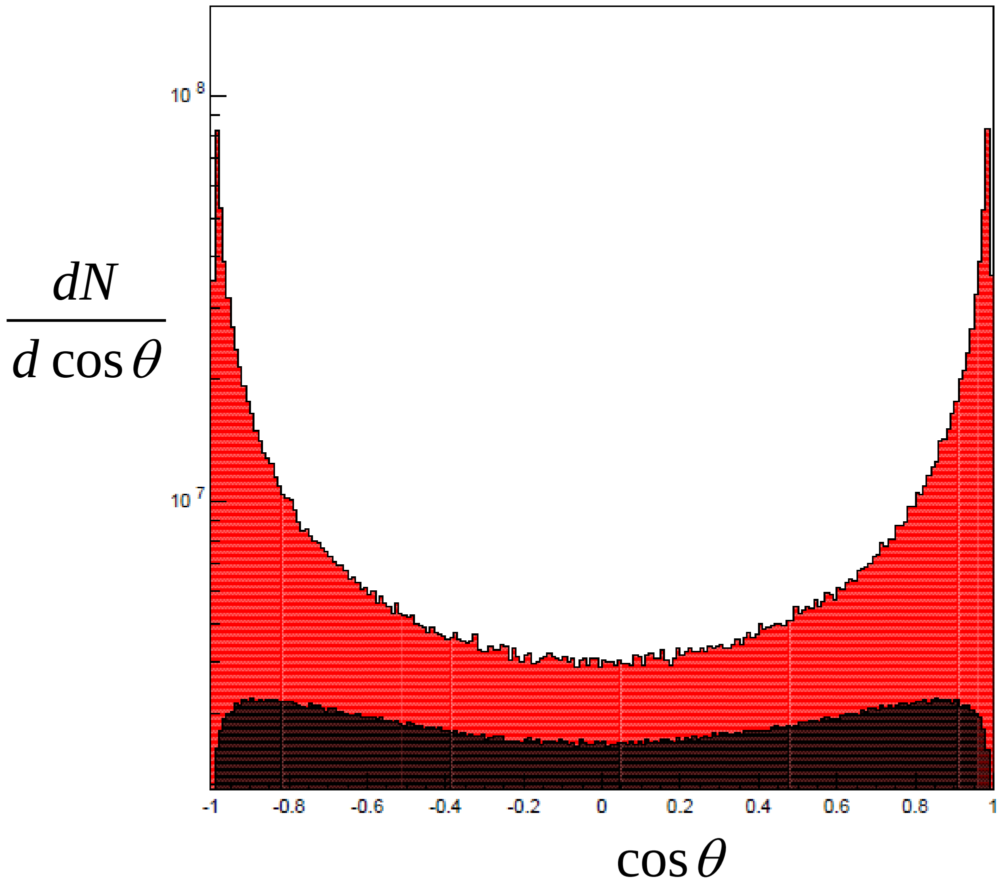
Neutral Hadrons



🟥 Ecm= 500 GeV All SM Processes 100 fb^{-1}

▬ Ecm= 91 GeV Z →qq 1 fb^{-1}

Charged Particles



Ecm=500 GeV L=100 fb^{-1} :

$\cos\theta$ range	# Charged Tracks
$-0.4 < \cos\theta < 0.4$	0.3×10^9
$-0.8 < \cos\theta < 0.8$	0.8×10^9
$-0.95 < \cos\theta < 0.95$	1.3×10^9

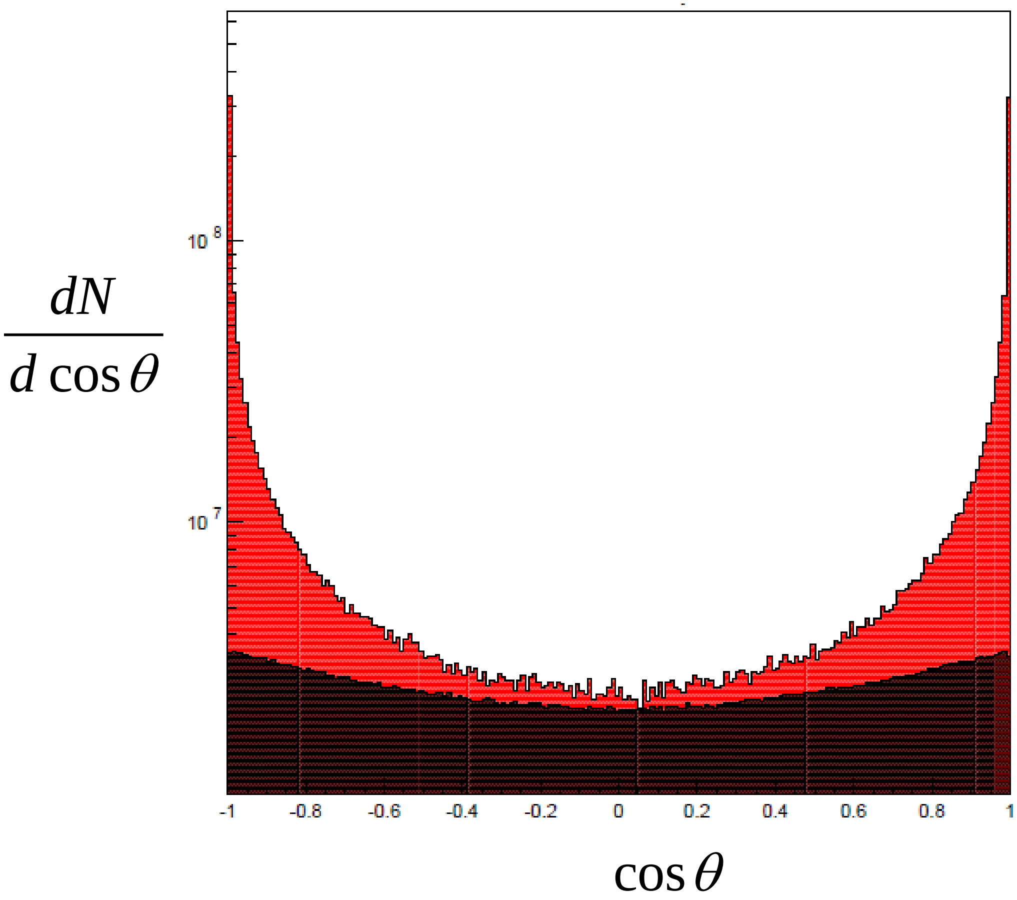
Ecm=91 GeV L=1 fb^{-1} :

$\cos\theta$ range	# Charged Tracks
$-0.4 < \cos\theta < 0.4$	0.2×10^9
$-0.8 < \cos\theta < 0.8$	0.4×10^9
$-0.95 < \cos\theta < 0.95$	0.5×10^9

🟥 Ecm= 500 GeV All SM Processes 100 fb^{-1}

⬛ Ecm= 91 GeV Z →qq 1 fb^{-1}

Neutral Particles



Conclusions

- There are many more charged tracks, photons and neutral hadrons in 100 fb^{-1} of data at Ecm=500 GeV than in 1 fb^{-1} of data at Ecm=91 GeV due to high cross-section processes such as

$$e^+e^- \to e\nu W,\, eeZ,\, \gamma Z$$

$$\gamma e \to \nu W, eZ$$

This is true at all angles and energies

- The charged tracks, photons and neutral hadrons at Ecm=500 GeV are not restricted to $E_{\text{particle}} < 50$ GeV

Conclusions (cont)

- What is missing at Ecm=500 GeV is the large number of 45 GeV monochromatic back-to-back quark jets and leptons. This will make some calibration tasks more complicated if only Ecm=500 GeV data is used.
- Note, however, that many charged track pairs at Ecm=500 GeV will be back-to-back in r-ϕ . Also, knowledge of the Z and W masses along with precise cross-section calculations can probably be used to obtain excellent energy scale calibrations using Ecm=500 GeV only.

We might very well be able to perform all detector calibrations without Z0 running.