# Occupancy Study

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# Goal

- Produce the occupancy distribution for FCAL channels for a single train

# ILC Design Table

| | | | Baseline 500 GeV Machine | | | 1st Stage | L Upgrade | $E_{CM}$ Upgrade | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | A | B |
| Centre-of-mass energy | $E_{CM}$ | GeV | 250 | 350 | 500 | 250 | 500 | 1000 | 1000 |
| Collision rate | $f_{rep}$ | Hz | 5 | 5 | 5 | 5 | 5 | 4 | 4 |
| Electron linac rate | $f_{linac}$ | Hz | 10 | 5 | 5 | 10 | 5 | 4 | 4 |
| Number of bunches | $n_b$ | | 1312 | 1312 | 1312 | 1312 | 2625 | 2450 | 2450 |
| Bunch population | $N$ | $\times 10^{10}$ | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.74 | 1.74 |
| Bunch separation | $\Delta t_b$ | ns | 554 | 554 | 554 | 554 | 366 | 366 | 366 |
| Pulse current | $I_{beam}$ | mA | 5.8 | 5.8 | 5.8 | 5.8 | 8.8 | 7.6 | 7.6 |
| Main linac average gradient | $G_a$ | $MV\,m^{-1}$ | 14.7 | 21.4 | 31.5 | 31.5 | 31.5 | 38.2 | 39.2 |
| Average total beam power | $P_{beam}$ | MW | 5.9 | 7.3 | 10.5 | 5.9 | 21.0 | 27.2 | 27.2 |
| Estimated AC power | $P_{AC}$ | MW | 122 | 121 | 163 | 129 | 204 | 300 | 300 |
| RMS bunch length | $\sigma_z$ | mm | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.250 | 0.225 |
| Electron RMS energy spread | $\Delta p/p$ | % | 0.190 | 0.158 | 0.124 | 0.190 | 0.124 | 0.083 | 0.085 |
| Positron RMS energy spread | $\Delta p/p$ | % | 0.152 | 0.100 | 0.070 | 0.152 | 0.070 | 0.043 | 0.047 |
| Electron polarisation | $P_-$ | % | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| Positron polarisation | $P_+$ | % | 30 | 30 | 30 | 30 | 30 | 20 | 20 |
| Horizontal emittance | $\gamma\epsilon_x$ | μm | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Vertical emittance | $\gamma\epsilon_y$ | nm | 35 | 35 | 35 | 35 | 35 | 30 | 30 |
| IP horizontal beta function | $\beta_x^*$ | mm | 13.0 | 16.0 | 11.0 | 13.0 | 11.0 | 22.6 | 11.0 |
| IP vertical beta function | $\beta_y^*$ | mm | 0.41 | 0.34 | 0.48 | 0.41 | 0.48 | 0.25 | 0.23 |
| IP RMS horizontal beam size | $\sigma_x^*$ | nm | 729.0 | 683.5 | 474 | 729 | 474 | 481 | 335 |
| IP RMS veritcal beam size | $\sigma_y^*$ | nm | 7.7 | 5.9 | 5.9 | 7.7 | 5.9 | 2.8 | 2.7 |
| Luminosity | $L$ | $\times 10^{34}\,cm^{-2}s^{-1}$ | 0.75 | 1.0 | 1.8 | 0.75 | 3.6 | 3.6 | 4.9 |
| Fraction of luminosity in top 1% | $L_{0.01}/L$ | | 87.1% | 77.4% | 58.3% | 87.1% | 58.3% | 59.2% | 44.5% |
| Average energy loss | $\delta_{BS}$ | | 0.97% | 1.9% | 4.5% | 0.97% | 4.5% | 5.6% | 10.5% |
| Number of pairs per bunch crossing | $N_{pairs}$ | $\times 10^3$ | 62.4 | 93.6 | 139.0 | 62.4 | 139.0 | 200.5 | 382.6 |
| Total pair energy per bunch crossing | $E_{pairs}$ | TeV | 46.5 | 115.0 | 344.1 | 46.5 | 344.1 | 1338.0 | 3441.0 |

# Derivation of Luminosity

- The train luminosity  with a 5hz collision rate is given by:

$$L_{TRAIN} = 3.6 * 10^{-5} fb^{-1} s^{-1} * \frac{1}{5} s = 7.2 * 10^{-6} fb^{-1}$$

# Processes Included

- Pair backgrounds
- γγ->hadrons
- Bhabha's
- 32 lower cross section processes

- Criterion: Included processes with expected event number $^{3}$ 0.1 per train

# Method

- Used Norman Graf's Calorimeter Occupancy Driver to extract event number cell ID and position per hit for FCAL
- Printed the information for each hit in a text file
- One text file per process
- A python script was written to input the text files and output train occupancy results

# Method

- For each physical process in the study, the expected number of events per train was calculated
- The number of events included was randomly selected according to the Poisson distribution based on the expected number
- The information from each event was combined  to calculate the hits per detector cell

# Treatment of polarization

- The polarization of the beam was assumed to be 80% for electrons 30% for positrons
- Processes had 1(γγ) , 2 (e±γ or bhabha), or 4 (mostly e+e-) polarization states
- We assumed equal luminosity of each polarization state

$$N_{events} = \frac{L_{train} s}{P}$$

# Question about bhabhas

- There are two kinds of bhabha files

-80e-|+30e+ and +80e-|-30e+

- What about -80e-|-30e+ and +80e-|+30e+?
- Even if cross section is 0 for e-L/e+L and e-R/e+R the event rate should not be 0 since the polarization is not 100%
- For now we have ignored the -80e-|-30e+ and +80e-|+30e+ polarizations and assumed 100% of the luminosity is in -80e-|+30e+ and +80e-|-30e+

# Limitations

- Available pair background events are 1024, only enough for 39% of a single train
- True division between the polarization states is not known

# Calculation of expected event numbers

- Pair background: 1 per bunch crossing, 2625 events (but only 39% of a single train available)
- γγ->hadrons: 1.2 per bunch crossing, 2625*1.2=3150 events
- The bhabha sample has a total Luminosity of $3.6*10^{-4} fb^{-1}$ hence $\frac{3.6*10^{-4} fb^{-1}}{7.20^{-6} fb^{-1} trains^{-1}} = 50 trains$ .
- Total number of Bhabha events is 100,334 hence 2006.68 is the expected event number per train.
- Bhabhas depend on polarization, since assumed a 50-50 polarization ~1003 events were included for each beam polarization

# Estimation of number of cells

- Assumed FCAL is an annulus shaped detector
- Found the hits with the greatest and lowest registered radius in the FCAL, r=1295mm & r=197mm, and the number of layers, n= 62.
- Used the cell geometry, 3.5x3.5 mm per cell

$$N_{cells} = \pi \frac{(r_{max}^2 - r_{min}^2)}{3.5^2} \cdot 62 = 2.6 \cdot 10^7$$

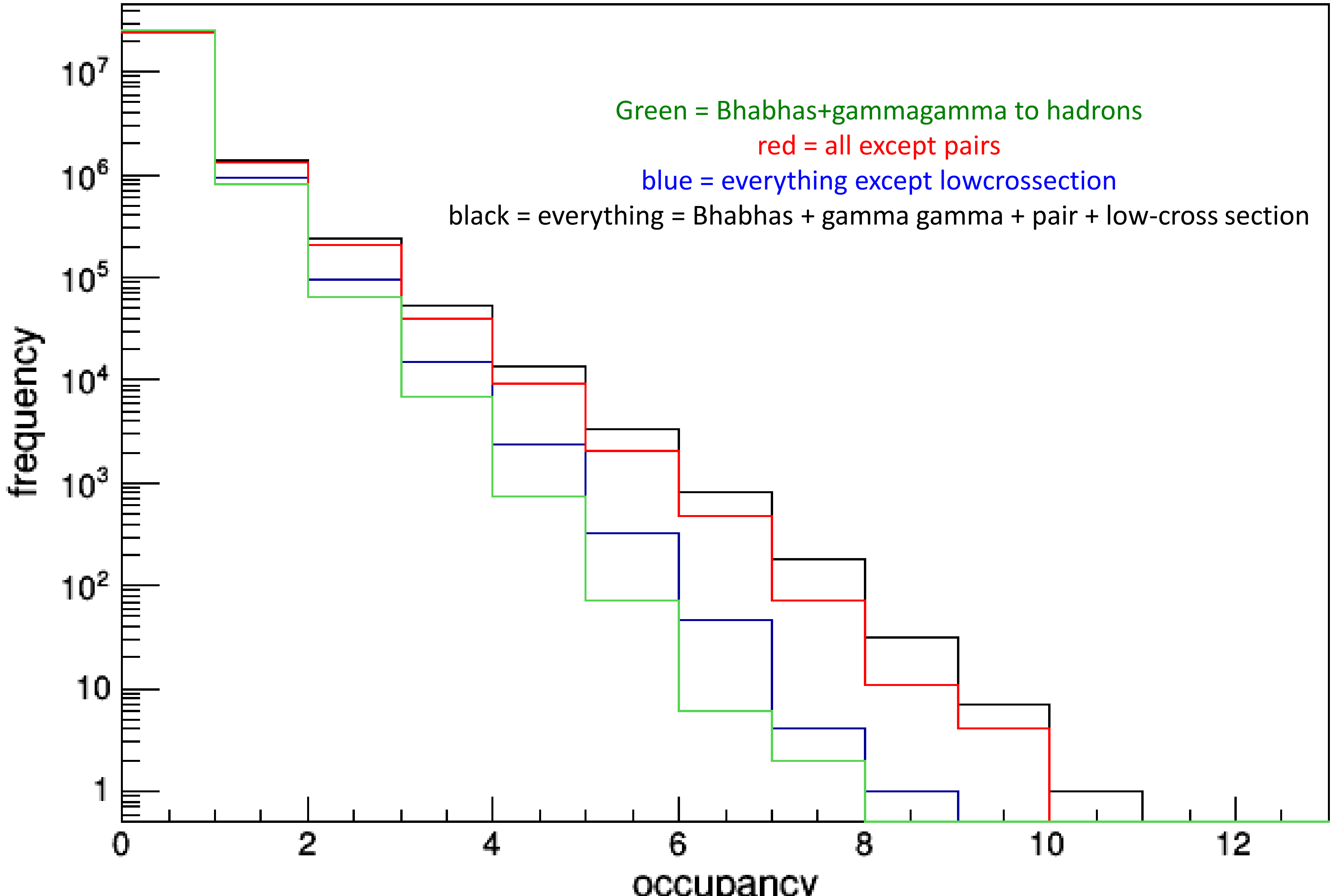
# Output

- Histograms of number of hits per cell (occupancy) vs. number of cells, both exclusive and integrated over above a given frequency
- Text file with numerical display of results

# Single train: Results in printed form

- **Channel occupancy 0** 24289956 **percent** 0.934229076923
- **Channel occupancy 1** 1404692 **percent** 0.0540266153846
- **Channel occupancy 2** 235374 **percent** 0.00905284615385
- **Channel occupancy 3** 52012 **percent** 0.00200046153846
- **Channel occupancy 4** 13609 **percent** 0.00052342307692
- **Channel occupancy 5** 3346 **percent** 0.00012869230769
- **Channel occupancy 6** 790 **percent** 3.03846153846e-05
- **Channel occupancy 7** 179 **percent** 6.88461538462e-06
- **Channel occupancy 8** 34 **percent** 1.30769230769e-06
- **Channel occupancy 9** 7 **percent** 2.69230769231e-07
- **Channel occupancy 10** 1 **percent** 3.84615384615e-08

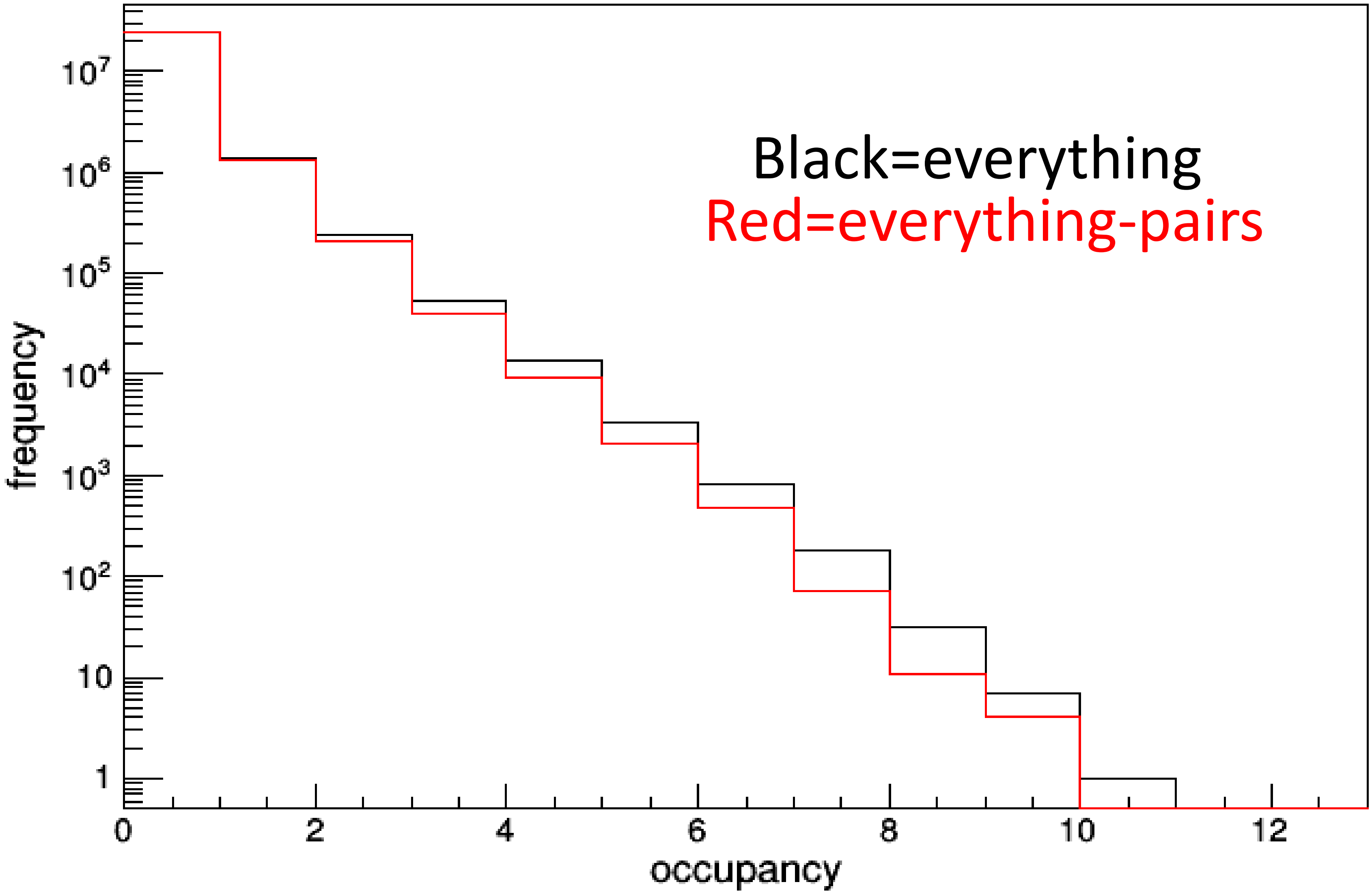
# Insight on the contribution of each process



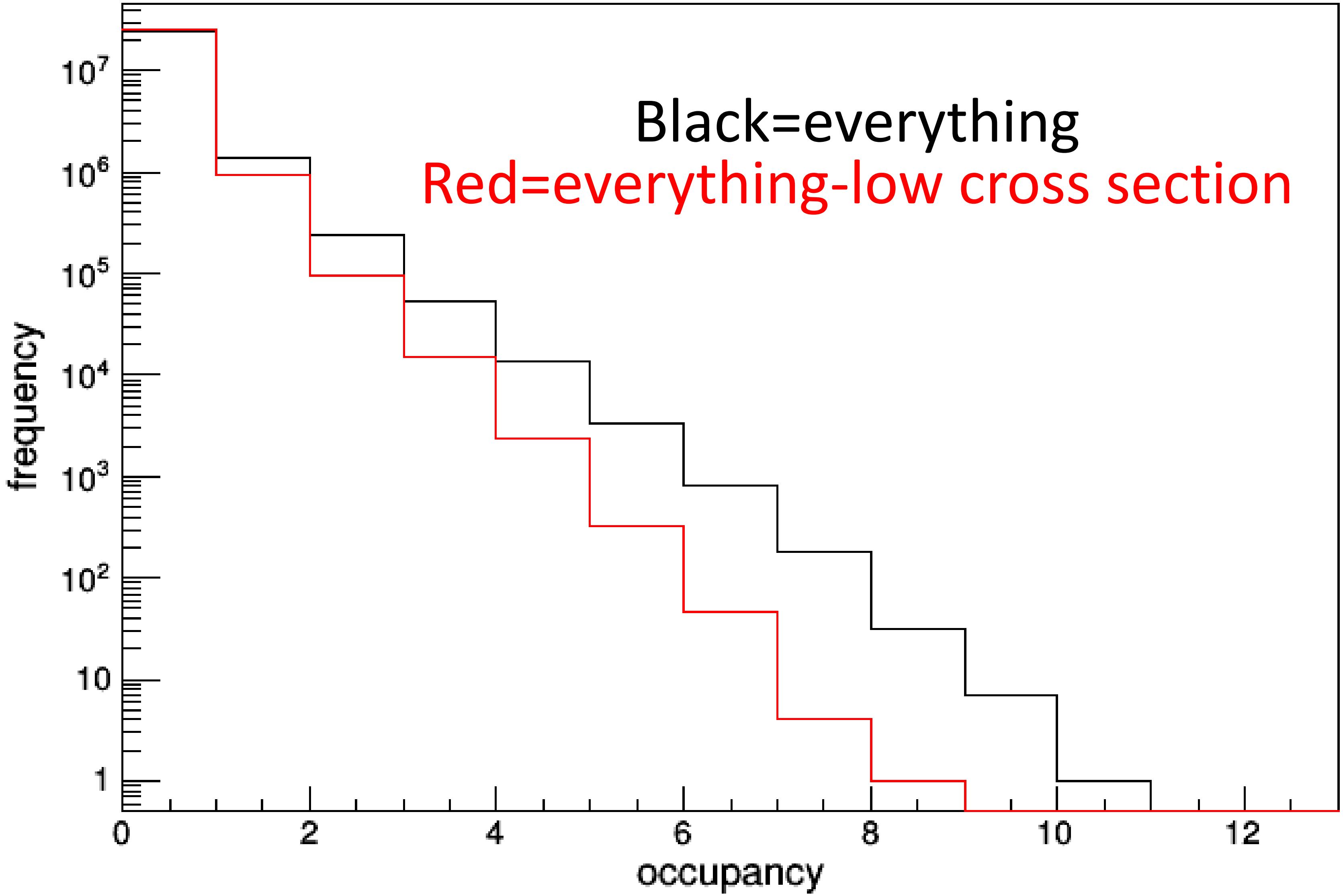
# Not that “Low cross section”

- Under the title of low cross section, there are two processes with high cross sections
- Two fermion production via electron positron annihilation (ids: 39068, 39069, 39070 and 39071) have a total event number of ~2006 per train.
- Down and anti-down quark production via two photon interaction (ids: 37577  709 events,37578 ~1100 events, 37579 ~1100 events,  37580 ~1648 events) has a total number of ~4550.

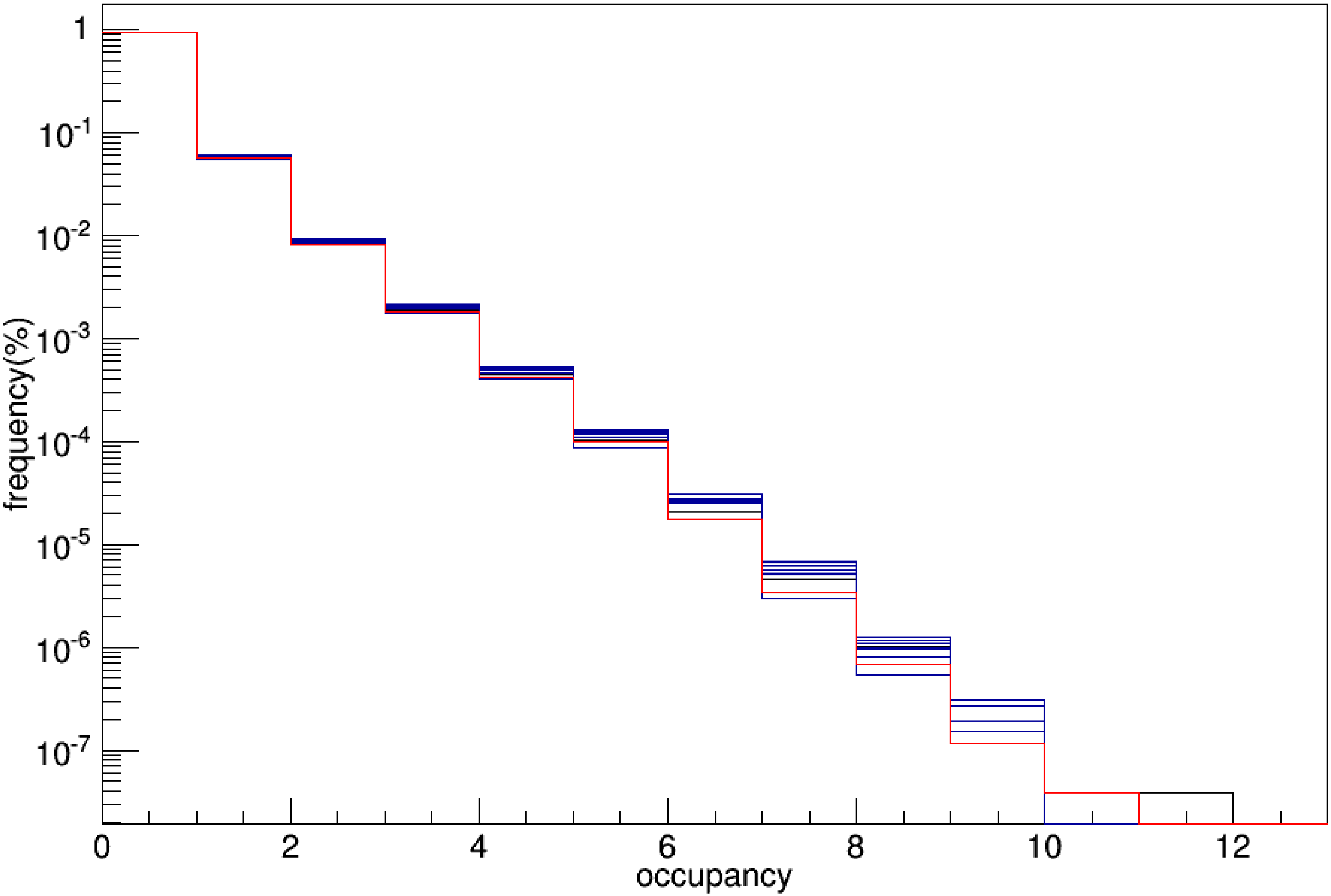
# Occupancy contribution of pairs



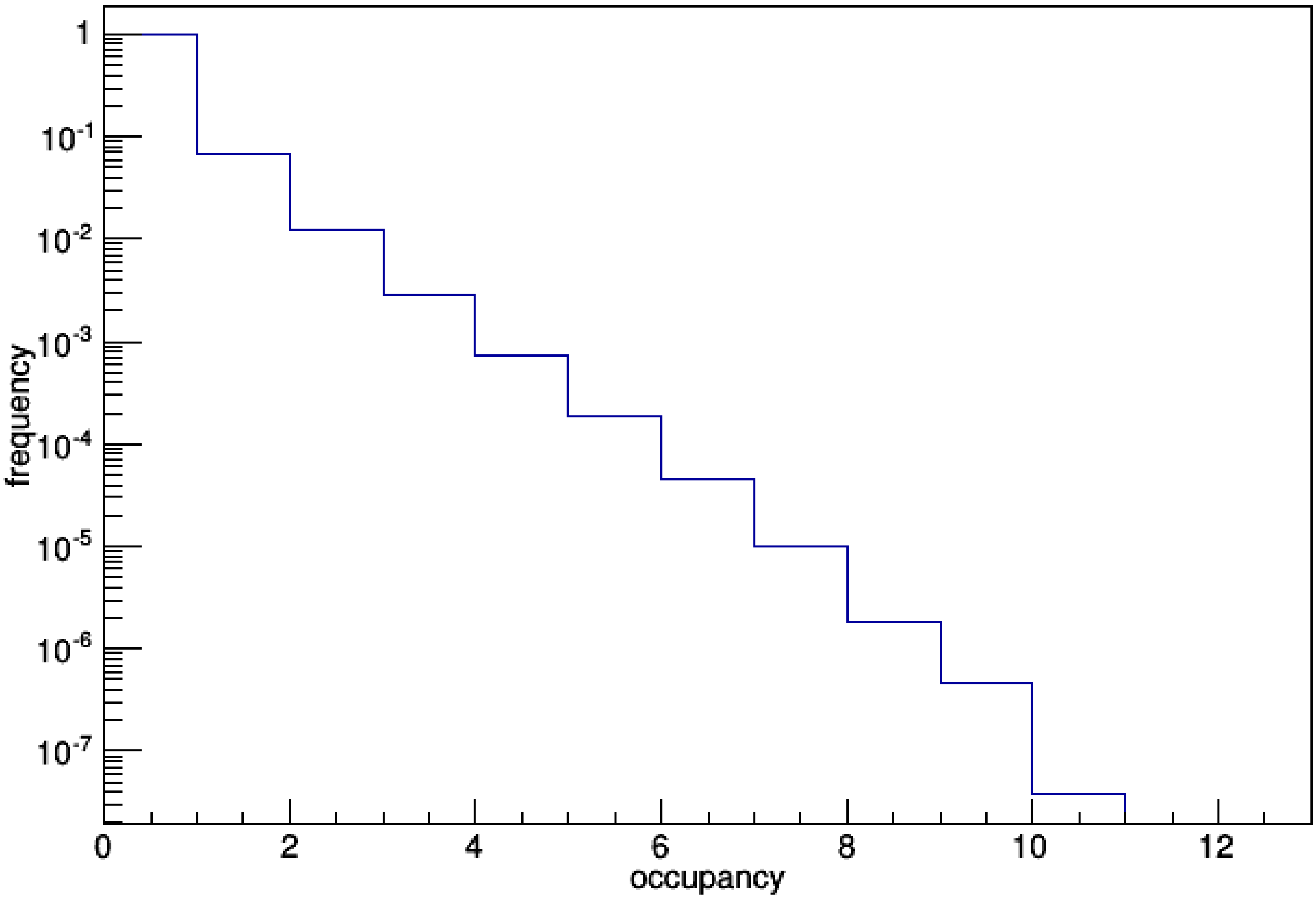
# Occupancy contribution of low cross section processes



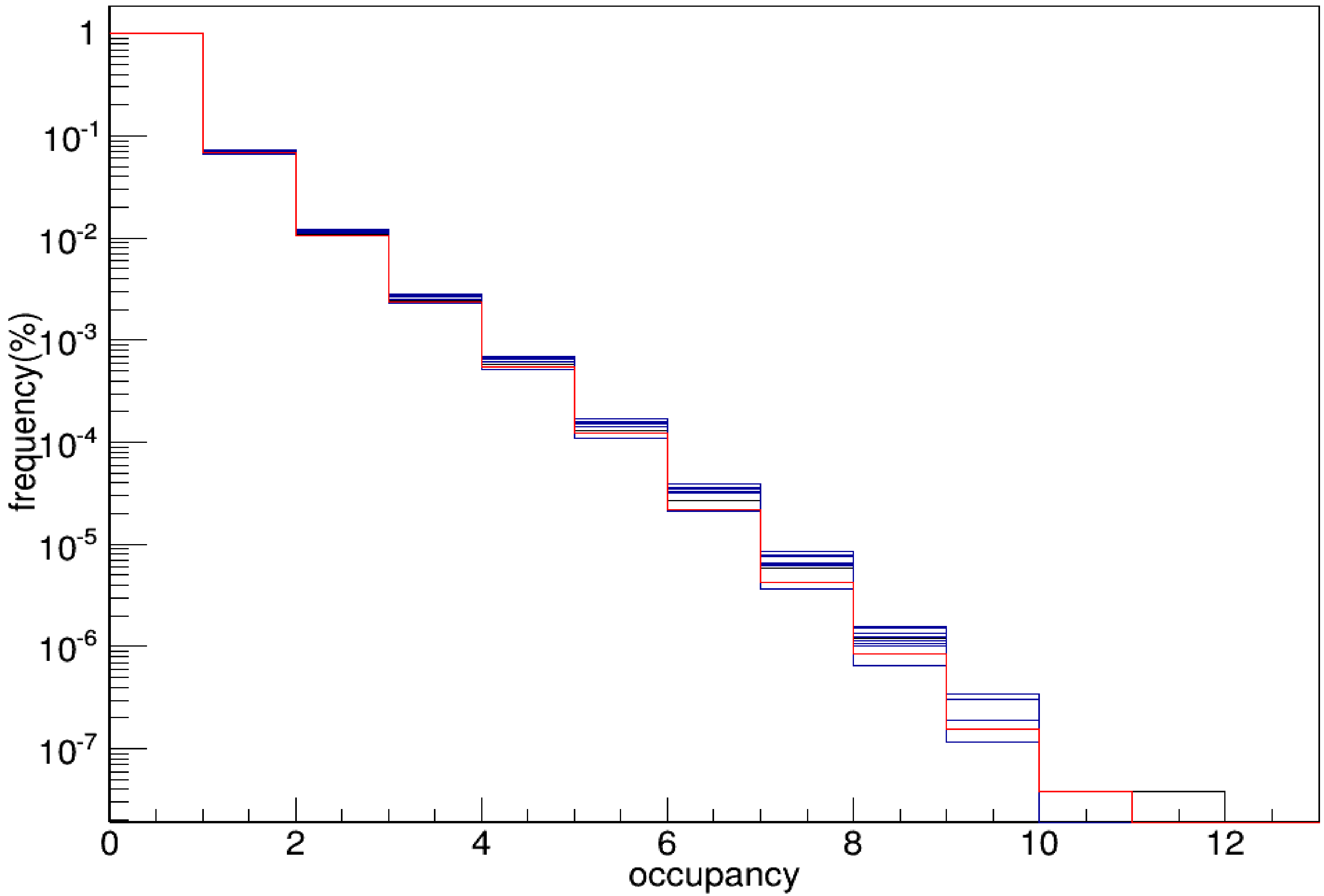
# All processes, ten distinct trains in terms of prevalence in percent



# Integrated occupancy



# Integrated occupancy, ten distinct trains



# Additional Plans

- Acquire more pairs
- Refine treatment of polarizations, especially bhabhas
- Study occupancy by layer
- Radial occupancy study
- Share the tools for further studies

# Calculation of expected event numbers

- For the lower crossection processes

$$N_{events} = \frac{L_{train}\sigma}{P}$$

- Where σ is crossection, P is number of polarisation states
- P is 1,2 or 4 since it depends on the polarization state of the electrons and positrons.
- 1 for processes involving photons , 2 for processes involving one positron (or electron) and a photon and 4 for processes involving an electron and a positron