Determination of nuclear fission reactor range using a Boulby based antineutrino detector

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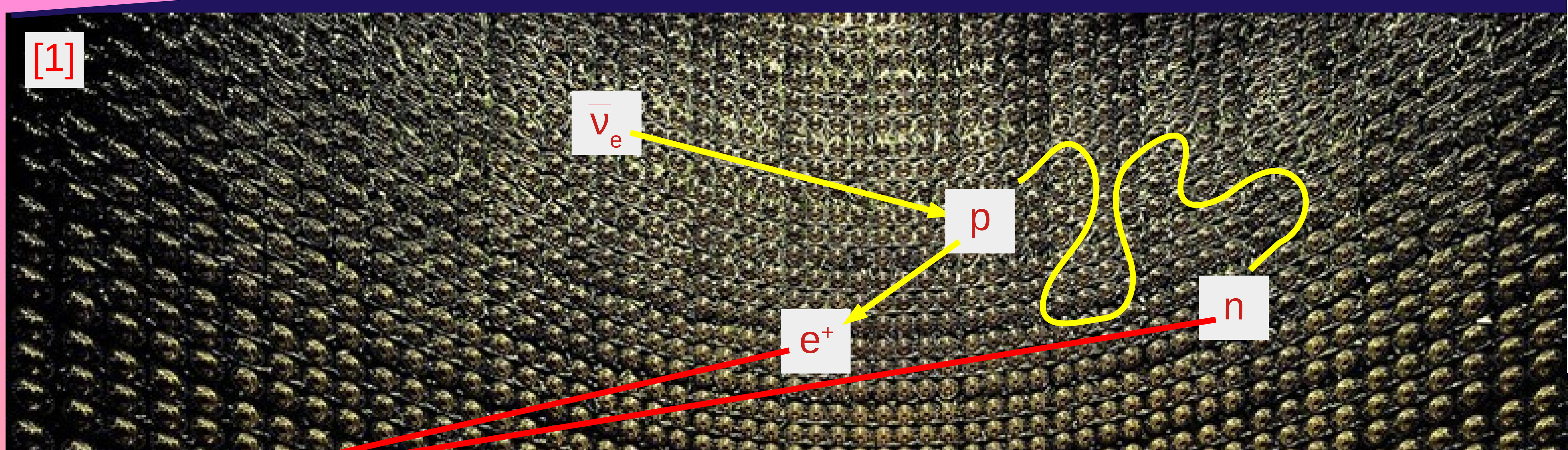

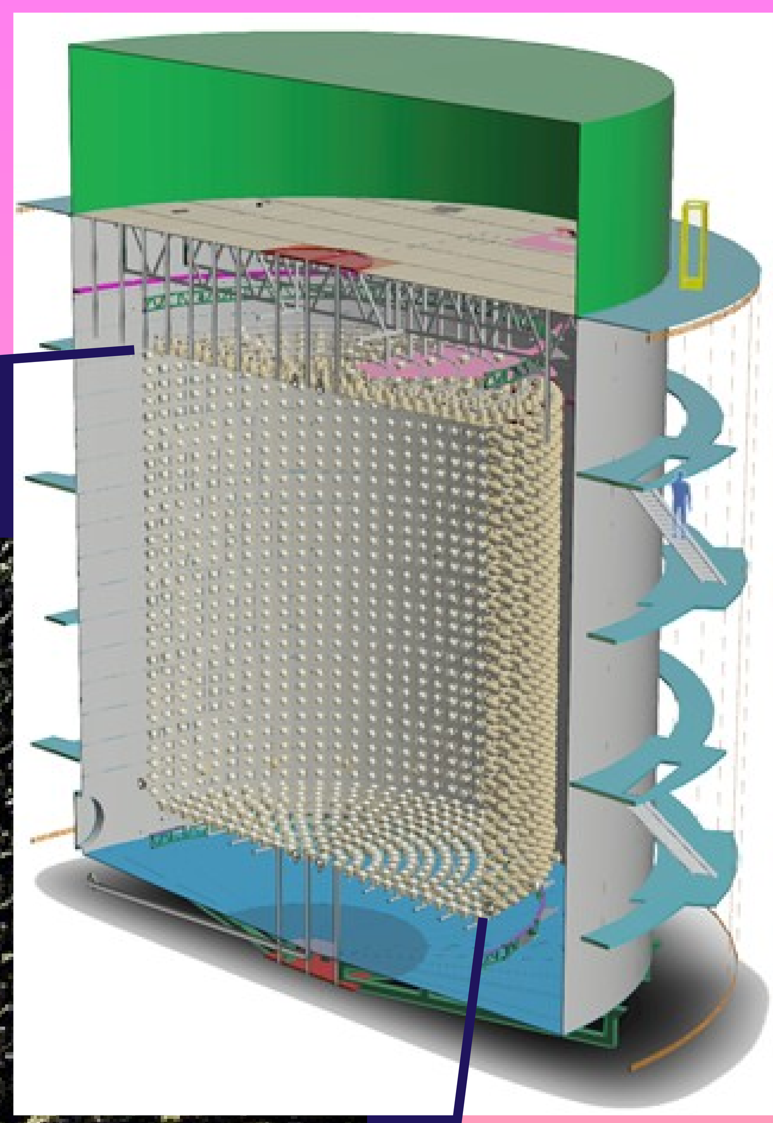

Figure 1: Cutaway of the cylindrical tank used.

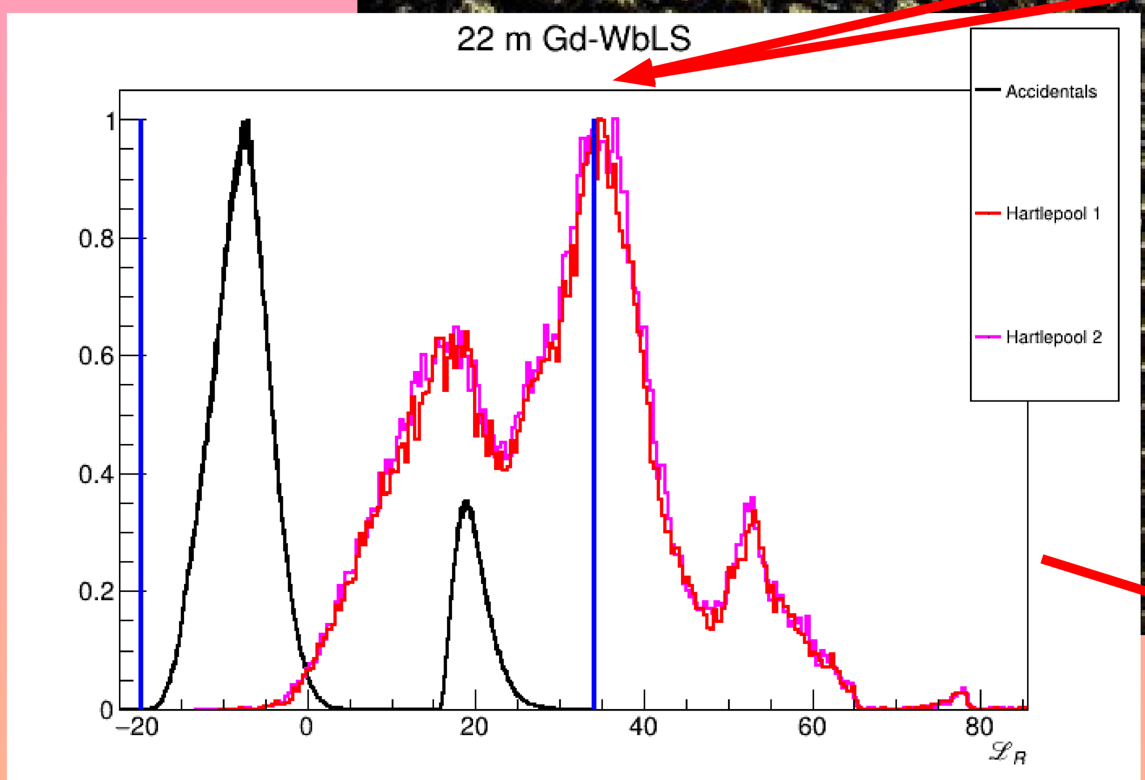

Figure 2: IBD detected and likelihood ratio test used to remove accidental coincidences.

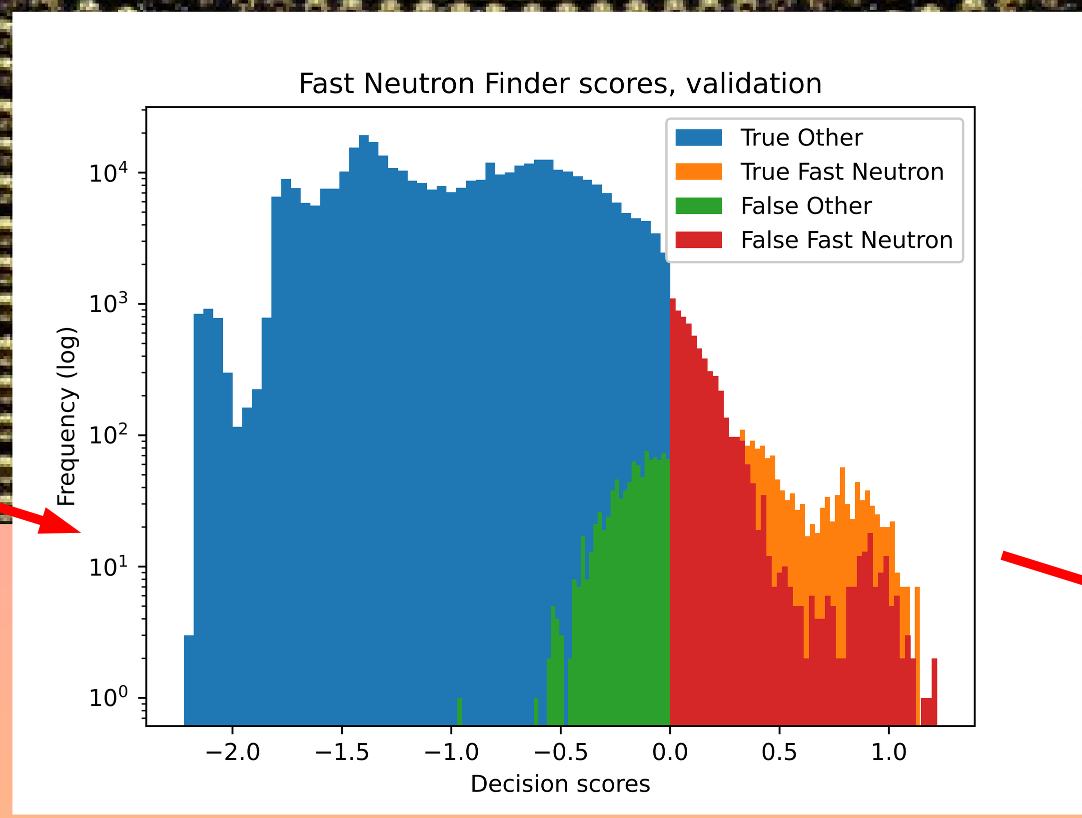

Figure 3: AdaBoost [2] machine learning algorithm used to suppress muogenic fast neutrons.

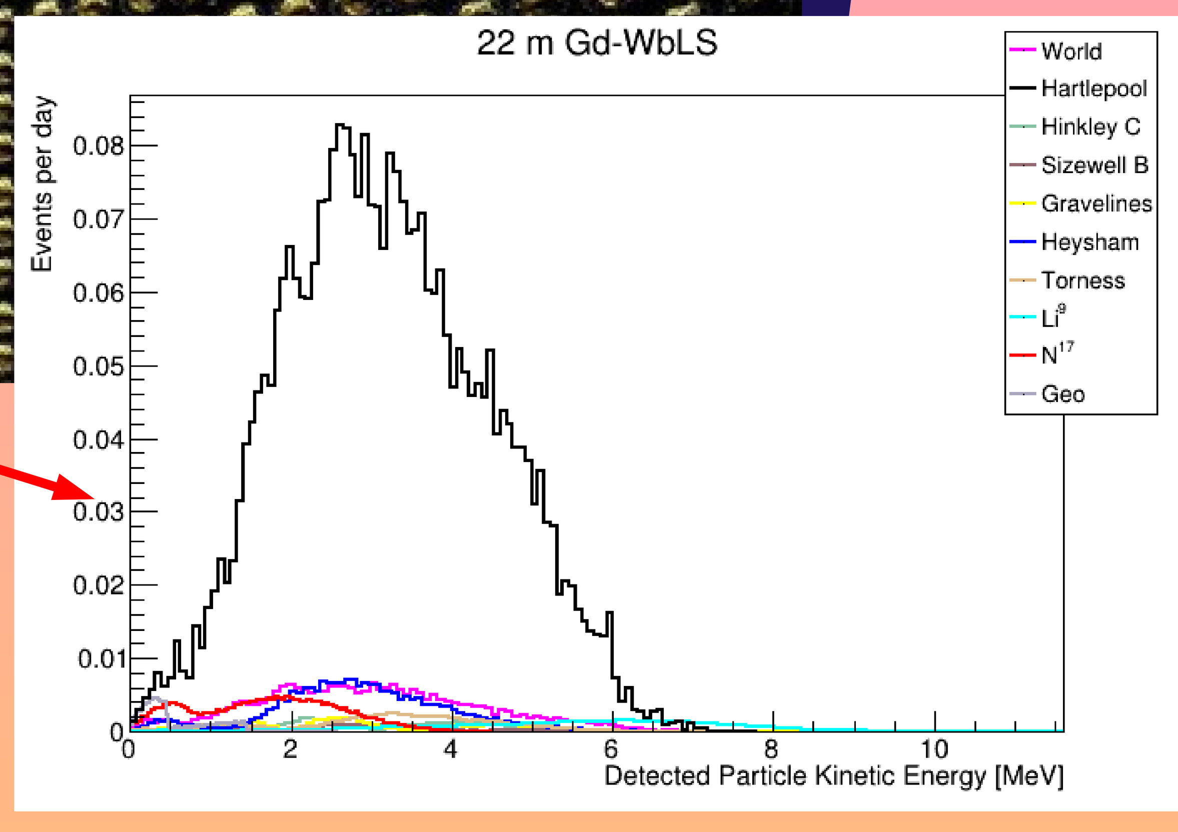

Figure 4: Energy cuts used to reduce coincidence backgrounds.

Neutrinos are the only particles that carry information about their **distance travelled**. Fission reactors can be ranged via the neutrino **oscillation** pattern in the detected **antineutrino spectrum**.

The output of the **LEARN** analysis (Figs 2-4, **see Liz Kneale's talk**) is compared to PDFs of reactor IBD energy spectra at known distances.

$$F\left(\frac{L}{E}\right)=\phi(E)\,\sigma(E)\,P\left(\frac{L}{E}\right)$$

$\phi(E)$ = reactor antineutrino flux

$\sigma(E)$ = IBD cross-section

$P\left(\frac{L}{E}\right)$ = Survival probability of electron antineutrino

The PDFs are compared to the data via the magnitude of the differences between their log-likelihoods across all events

$$|l_{R,i}|=\sqrt{[\log(F(E_i|L))-\log(F(E_i|event_i))]^2}$$

$$|l_R|=\sum_{i=0}^{N\ events}|l_{R,i}|$$

The range with the minimum **$|l_R|$** is the observed range.

The nearest reactor to **Boulby**, **26 km** away at **Hartlepool**, can be ranged to within approximately **30%** of the true range as shown in Fig 5. Full results are displayed in Table 1.

Reactors at larger distances e.g. **Heysham** and **Torness** can be accurately ranged due to prominent **θ_{12}** oscillations only if backgrounds can be sufficiently suppressed. Ongoing work is examining whether **Fourier** analysis can be used to extract the oscillation angle even when the signal to background ratio is low.

Reactor	Ideal	Energy Resolution	Background
Hartlepool (26 km)	26.1 km	32.3 ± 0.6 km	35 ± 1 km
Heysham 2 (149 km)	149 km	157 ± 4 km	No useful result
Torness (187 km)	186.7 km	191 ± 2 km	No useful result

Table 1: The determined ranges for an ideal case with no backgrounds, application of energy resolution effecs and full Monte Carlo backgrounds.

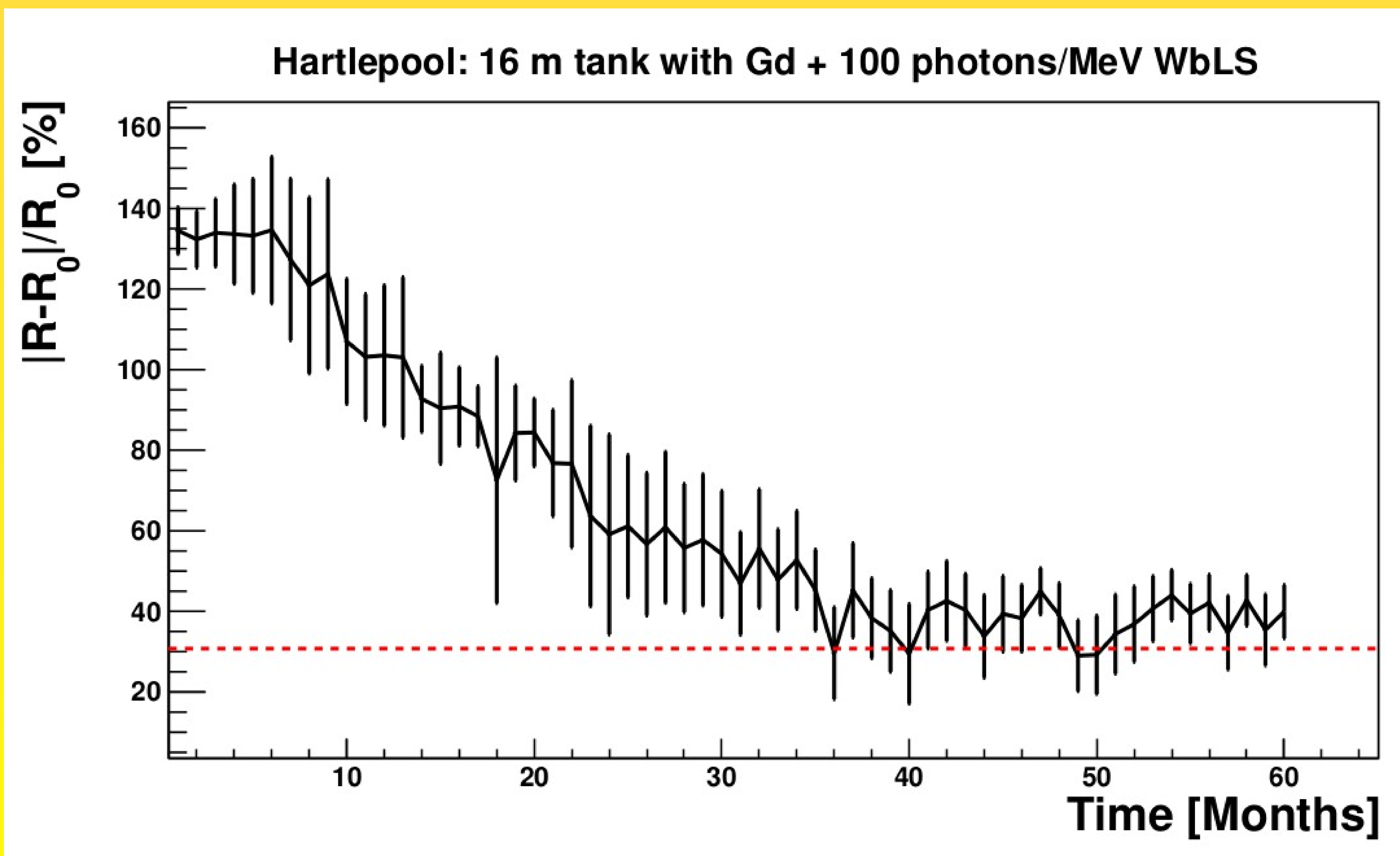

Figure 5: Percentage difference between observed and true reactor range with increasing observation time.

References:
[1] Super-Kamiokande, Kamioka Observatory, ICRR, Uni. Of Tokyo
[2] F. Pedregosa *et al.*, Scikit-learn: Machine learning in python, J. Mach. Learn. Res., **12**:2825-2830, 2011