Combine PDFs

- Rotate the components w.r.t. each other and plot PDFs.
- Check: narrow angle, Cherenkov angle, wide angle between the two components
- NB: time residual on the plot is that w.r.t. muon hypothesis

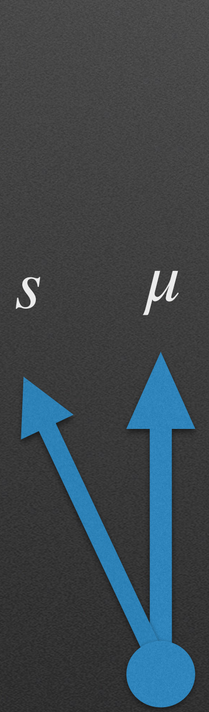
Combined PDFs

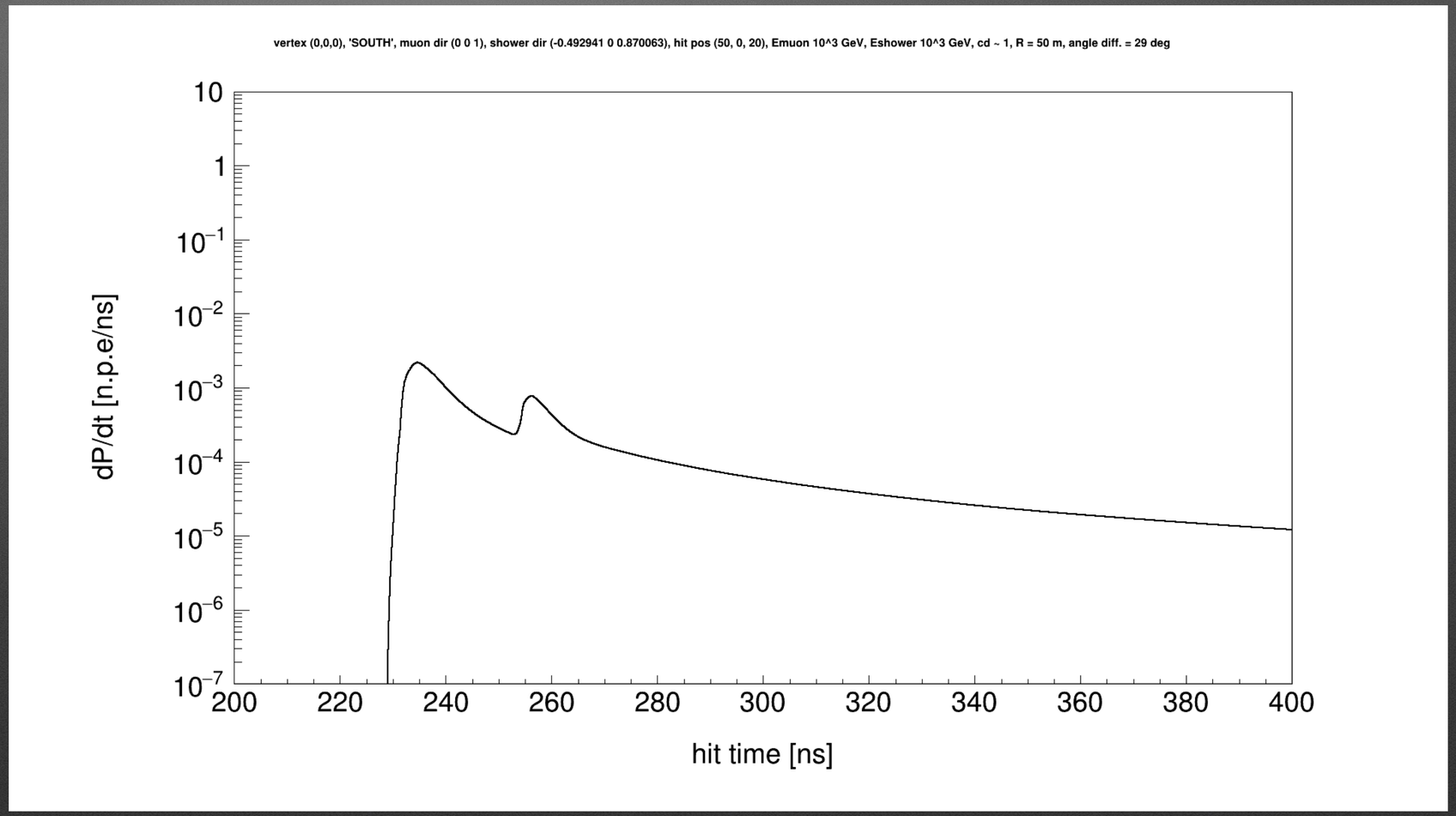
- Likelihood: will begin with first hit probability
- $P_{\text{first hit}} = f \cdot \dfrac{e^{-v}}{1 - e^{-V}}$
- f rate of photoelectrons, v cumulative number of p.e.'s up to that time, V total number of p.e.'s

Combined PDFs

- So for one example..

‘SOUTH’





Combined PDFs

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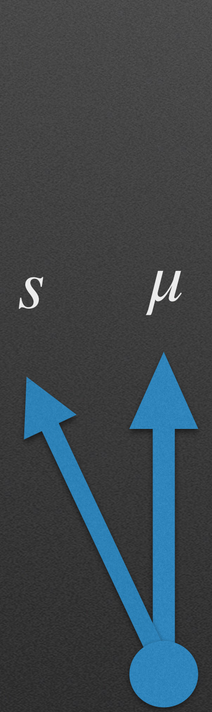
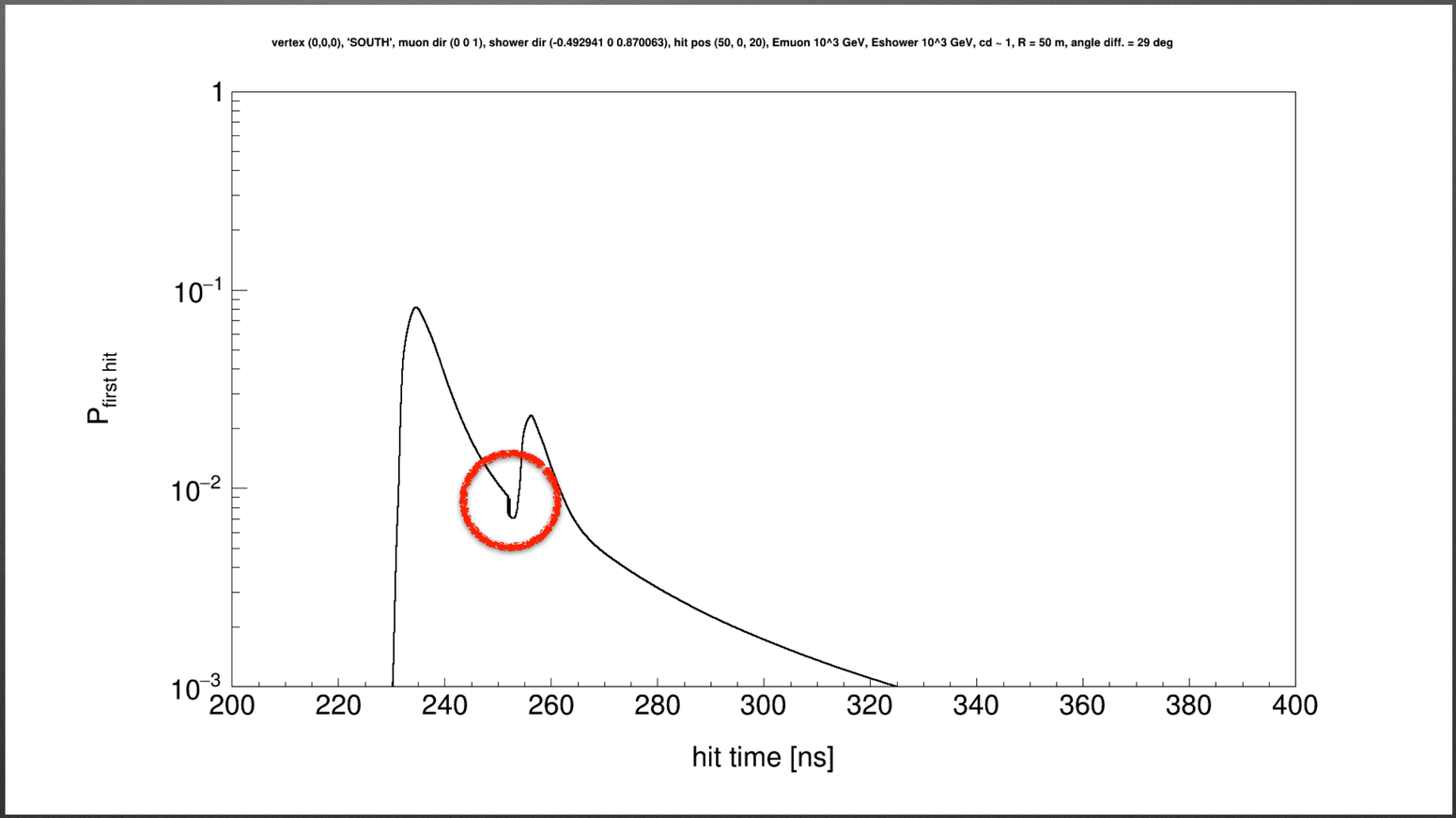
‘SOUTH’





Combined PDFs

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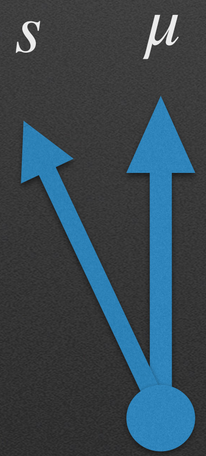
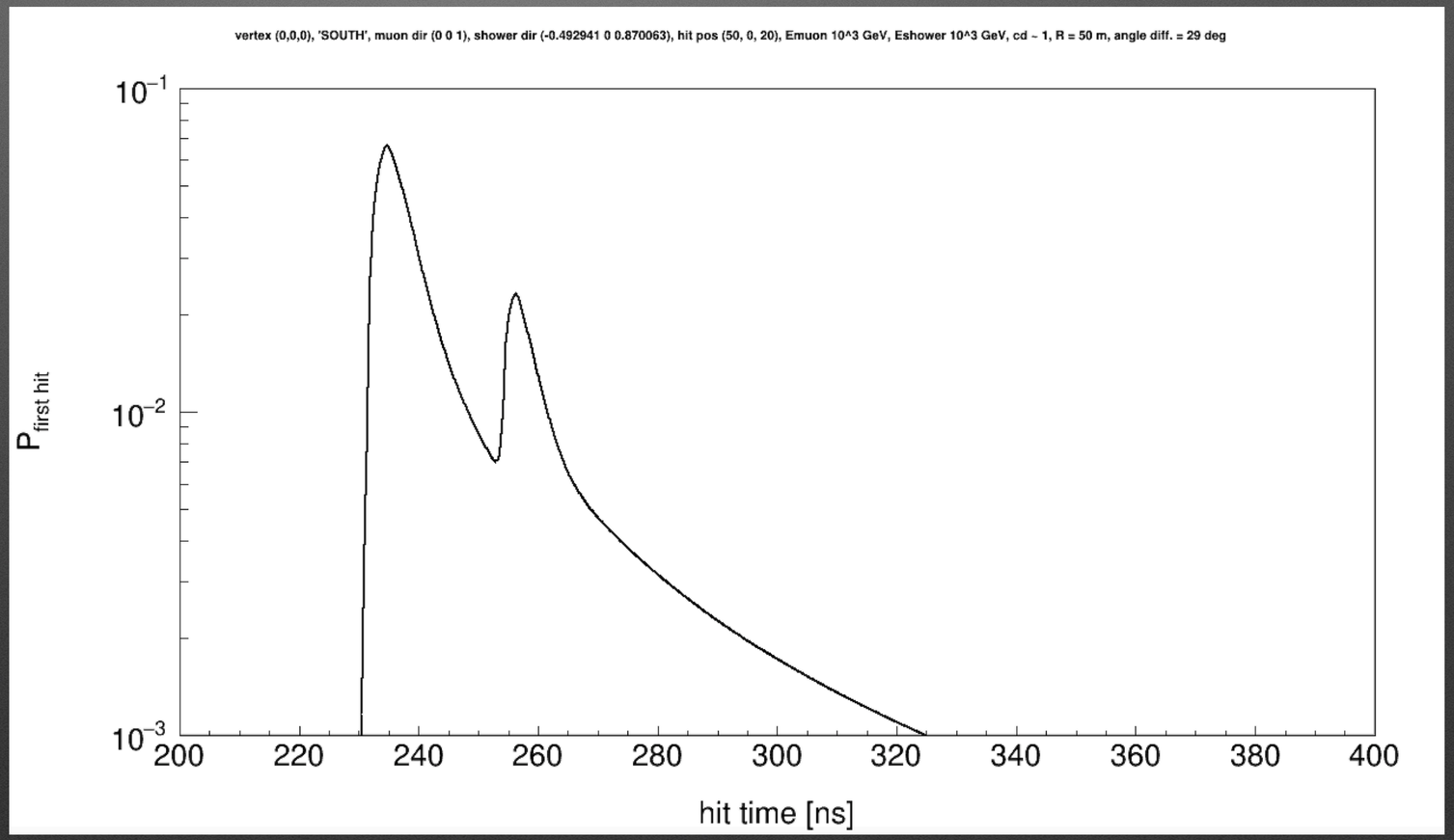
‘SOUTH’

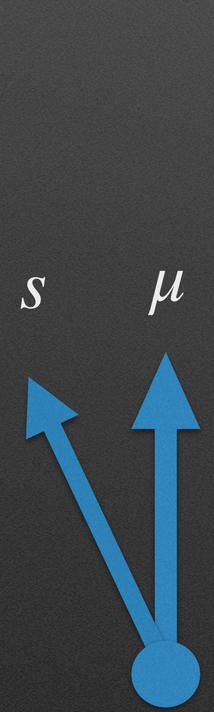


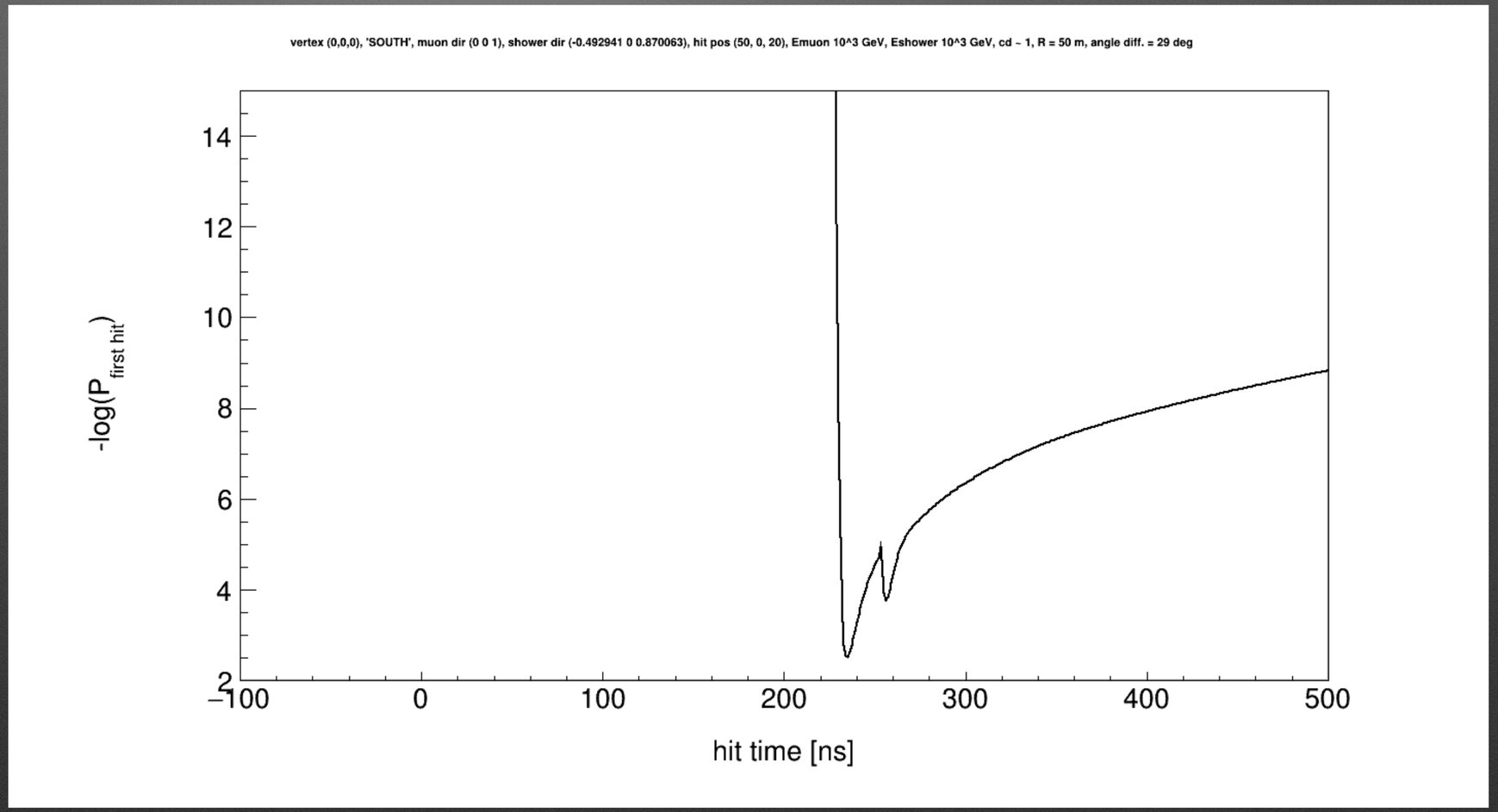


Combined PDFs

- So for one example..

‘SOUTH’

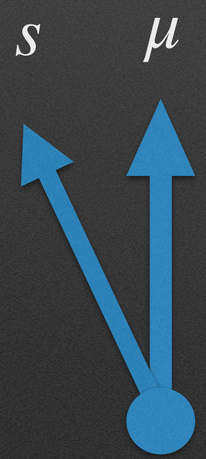


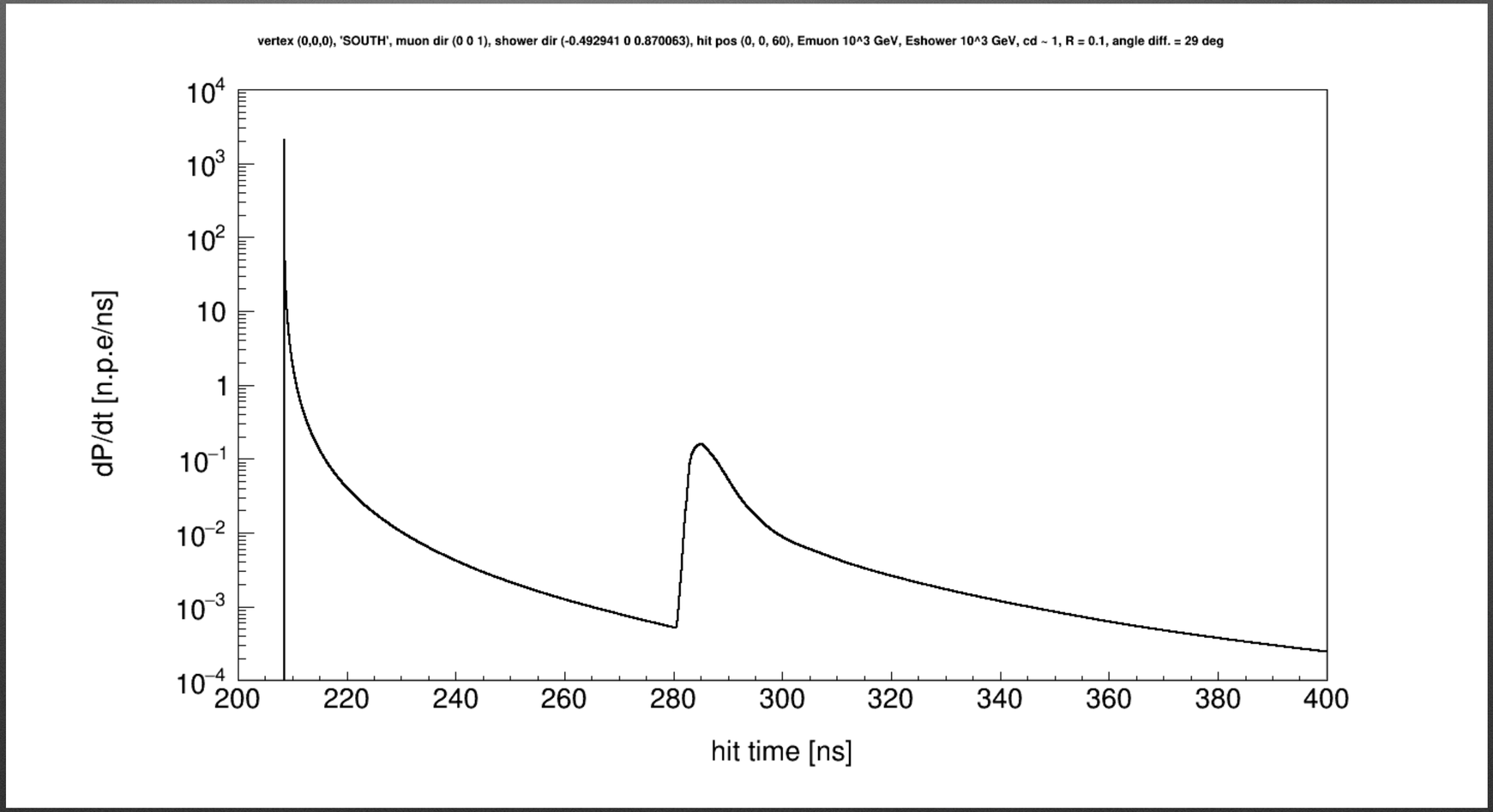


Combined PDFs

- An edge case..

‘SOUTH’

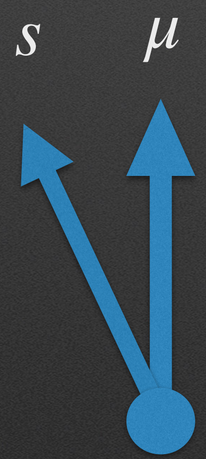


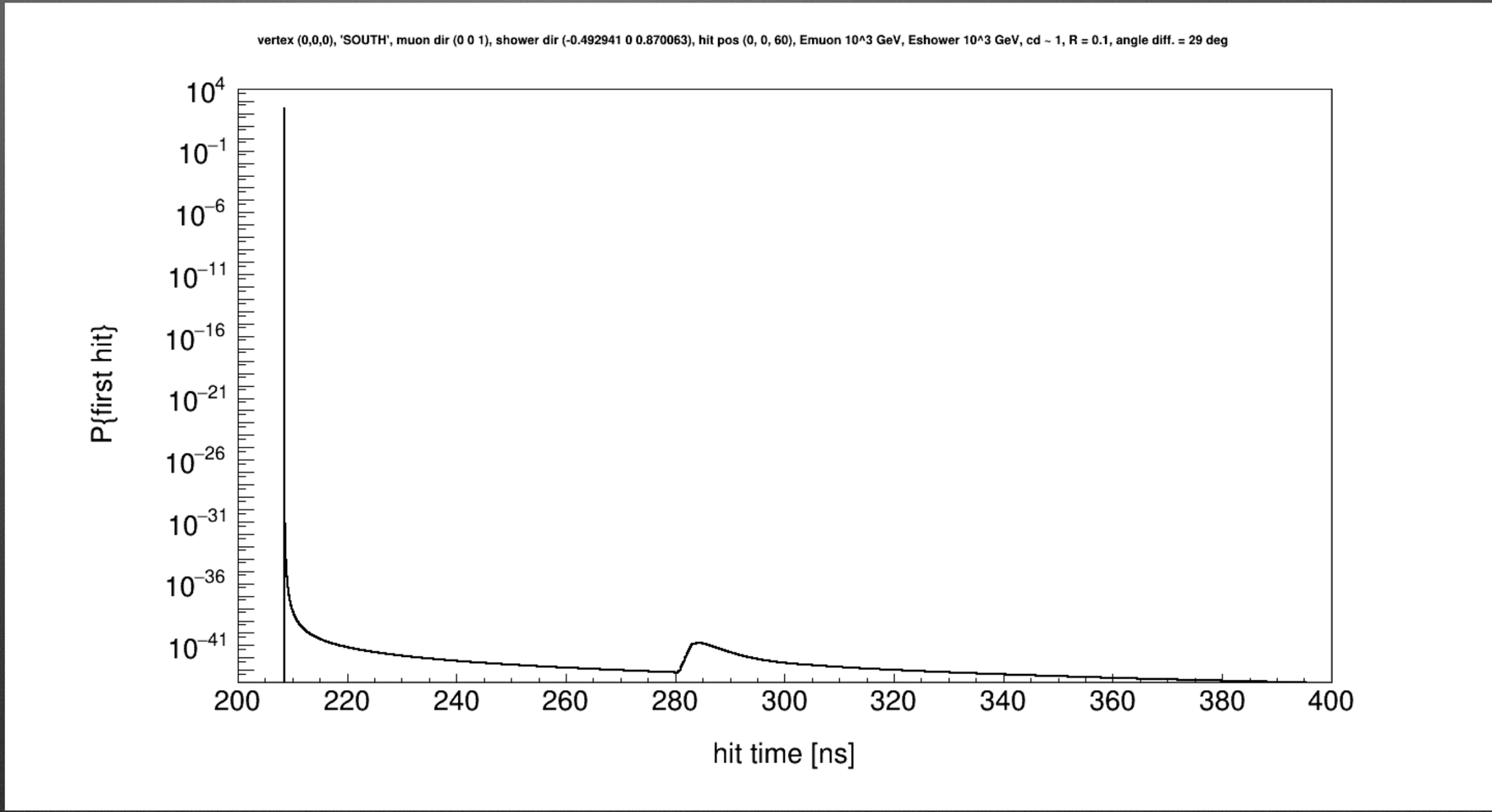


Combined PDFs

- An edge case..

‘SOUTH’

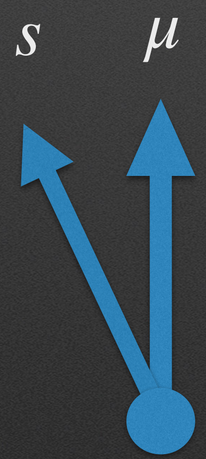


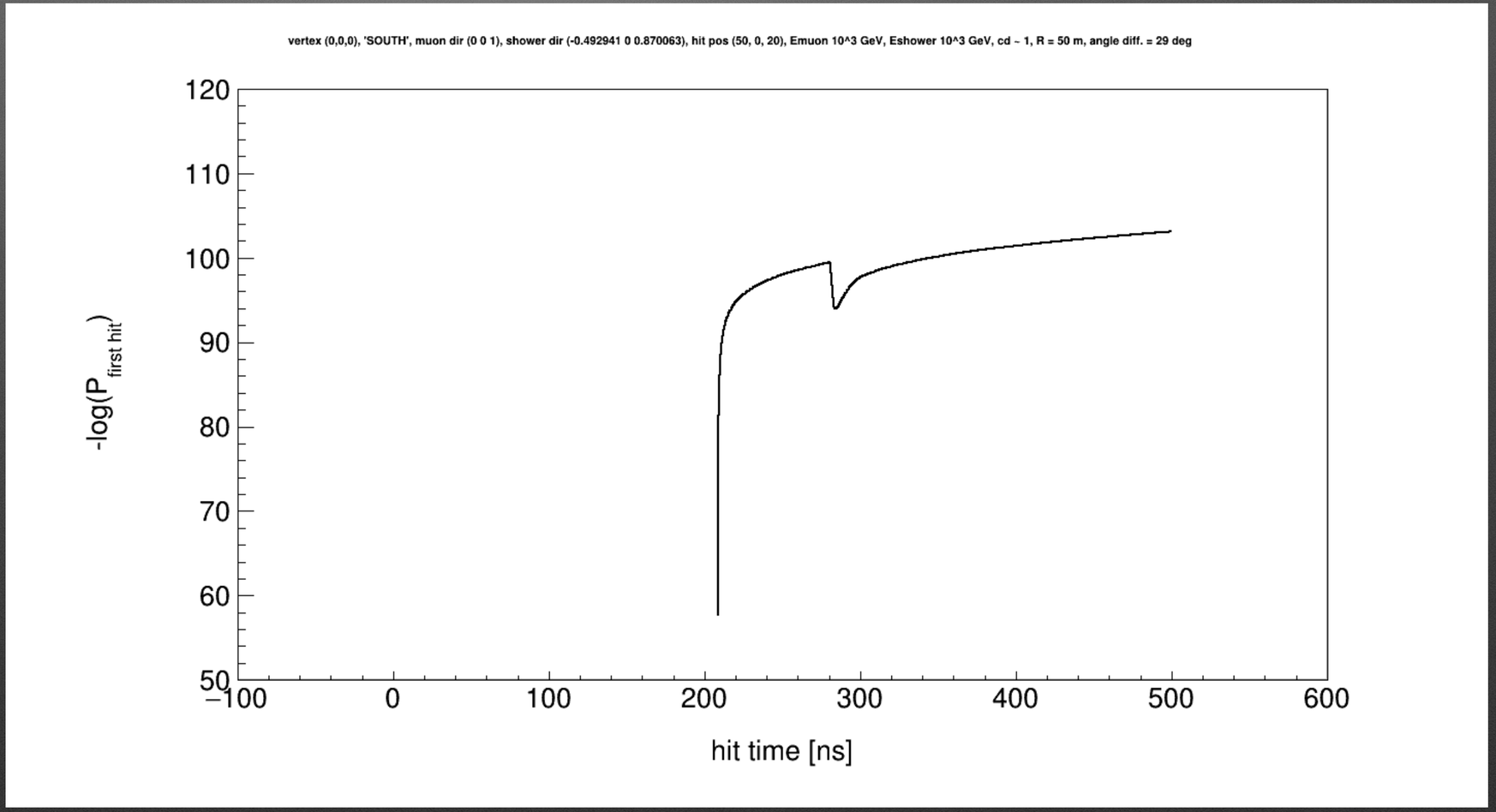


Combined PDFs

- An edge case..

‘SOUTH’





- Move from a hit-based likelihood study to event-based likelihood
- Deviate true model parameters from likelihood minimum
- Choose a clean sample of events to test likelihood on..

- Choose a set of events from a triggered data file: well-understood, clean events.
- Store the DAQ events & MC truth info in parallel.
- Choose clean samples with cuts: e.g.

  - vertex is inside detector volume
  - number of PMTs hit, e.g. 10
  - number of muons per event, e.g. 1 minimum
  - track length cut, e.g. 50 m track - strict one only for muons

- Cuts can be optimised as we go along

- Script to loop through input events, calculate first hit likelihood and no-hit likelihood for those events
- Within this script: call function which takes (daq event, mc event)
- fill event vertex model of vertex with track + shower with true parameters: vertex position, Emu, Esh, muon dir, shower dir
- At the moment, using “hadronic cascade” particles for my shower - average direction and total energy of a hadronic cascade
- For all the first hits, calculate likelihood assuming track+shower model

$$-log\mathscr{L} = \sum_{hits} log\left(n(t) \cdot \frac{e^{-N(t)}}{1 - e^{-N_{total}}}\right) + \sum_{non-hit\ PMTS} log\left(e^{-N_{total}}\right)$$

Prob_first hit

Prob_no hit

- Initially, testing on a trigger-level file (ORCA 115, 10-100 GeV) mcv5.0.gsg_muon-CC_10-100GeV.km3sim.jte.100.root - only first hits

```
sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: -nan
sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: inf
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sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: -nan
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sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: inf
```

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```
sum likelihoods: inf
sum likelihoods: inf
sum likelihoods: -nan
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sum likelihoods: inf
sum likelihoods: inf
```

Inclusion of time window
w.r.t Cherenkov hypothesis
e.g. (-50, 900) ns

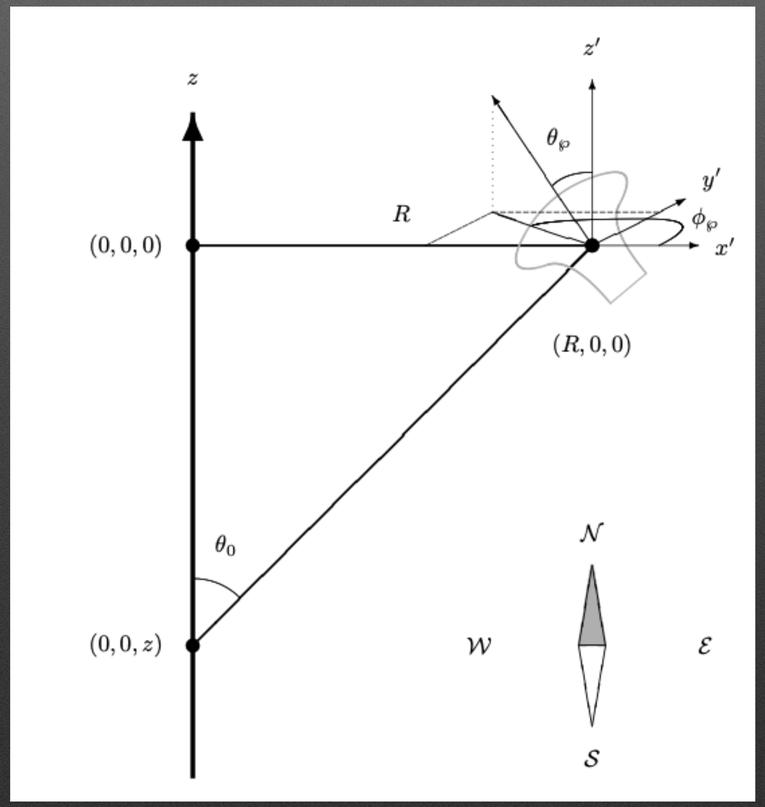
&

using clean events from before

```
sum likelihoods: 20309
sum likelihoods: 23713.7
sum likelihoods: 19507.3
sum likelihoods: 23991.3
sum likelihoods: 19650.2
sum likelihoods: 21357.6
sum likelihoods: 26073.3
sum likelihoods: 22144.8
sum likelihoods: 20188.5
sum likelihoods: 20926
sum likelihoods: 20168.8
sum likelihoods: 22634.7
sum likelihoods: 18806.3
sum likelihoods: 24547.8
sum likelihoods: 26260.6
sum likelihoods: 24187.6
sum likelihoods: 21874.1
sum likelihoods: 22447.5
sum likelihoods: 23825.2
sum likelihoods: 18779.2
sum likelihoods: 20598.3
sum likelihoods: 21006.1
sum likelihoods: 21310.8
sum likelihoods: 21398.4
sum likelihoods: 19915.1
sum likelihoods: 21036.1
sum likelihoods: 18773.3
sum likelihoods: 20431
sum likelihoods: 25762.4
sum likelihoods: 23943.3
sum likelihoods: 22023.3
sum likelihoods: 26015.9
sum likelihoods: 18722.2
sum likelihoods: 22192.3
sum likelihoods: 23910.3
sum likelihoods: 22863.1
```

- Operating in JPP framework. One needs to rotate the hits to be in the direction of the muon or shower - PDFs are evaluated assuming muon/shower in *z*-direction with PMT position in the *x*-*z* plane.

- For this, I assume the muon and shower components are co-linear - seems reasonable, having checked values..rotating according to muon direction.



- To include background:
  combinedPDF = PDF_muon + PDF_shower

For time-integrated PDFs:
Just input time-window into function?

```
/**
 * Get background hypothesis value for time integrated PDF.
 *
 * \param  R_Hz                rate [Hz]
 * \return                     hypothesis value
 */
JNPE_t::result_type getH0(const double R_Hz) const
{
  return JNPE_t::result_type(R_Hz * 1e-9 * T_ns.getLength(), 0.0);
}
```

For time-differentiated PDFs:

- takes time residual as an argument

- Can’t use PDF_muon_background
+ PDF_sh_background - overlapping times

```
/**
 * Get background hypothesis value for time differentiated PDF.
 *
 * \param  R_Hz                rate [Hz]
 * \param  t1                  time [ns]
 * \return                     hypothesis value
 */
JPDF_t::result_type getH0(const double R_Hz,
                          const double t1) const
{
  return JPDF_t::result_type(R_Hz * 1e-9, t1, T_ns);
}
```

- just use muon time residual (always earliest) and consider that over the time range?

- Clearly, my likelihood values are not very small considering I am using the truth information - expect a minimum.
- Missing the peak of my PDFs?
- Just numbers to show today, but plots coming soon :-)