nuSTORM facility

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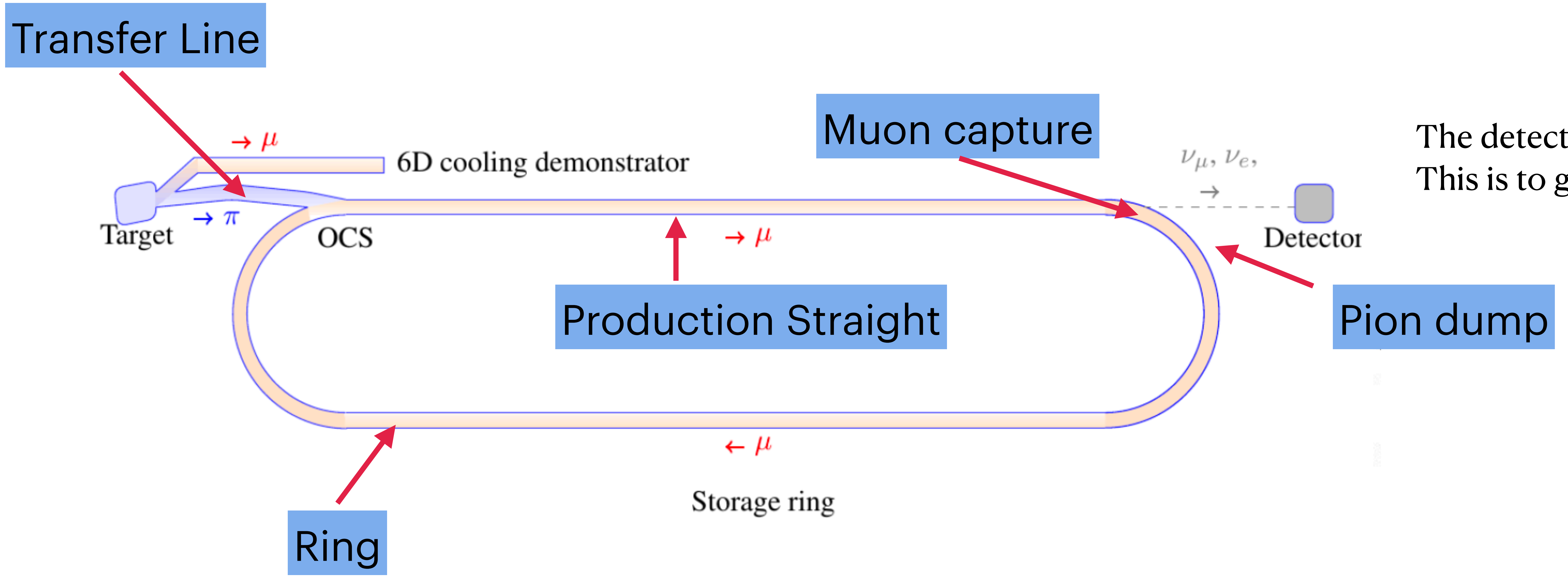
12 December 2022

nuSTORM beam



The detector is 50m downstream from the end of the ring
This is to give room for the pion dump

The transfer line and OCS at the end of the transfer line allow us to capture and transport a pion beam with an energy of 1-7 GeV and an energy spread of ± 10%

The ring and the OCS at the end of the production straight allow us to capture and store muons with energies of 1-6 GeV and an energy spread of ± 15%

The result is a tuneable neutrino beam with a flux normalisation of better than 1%

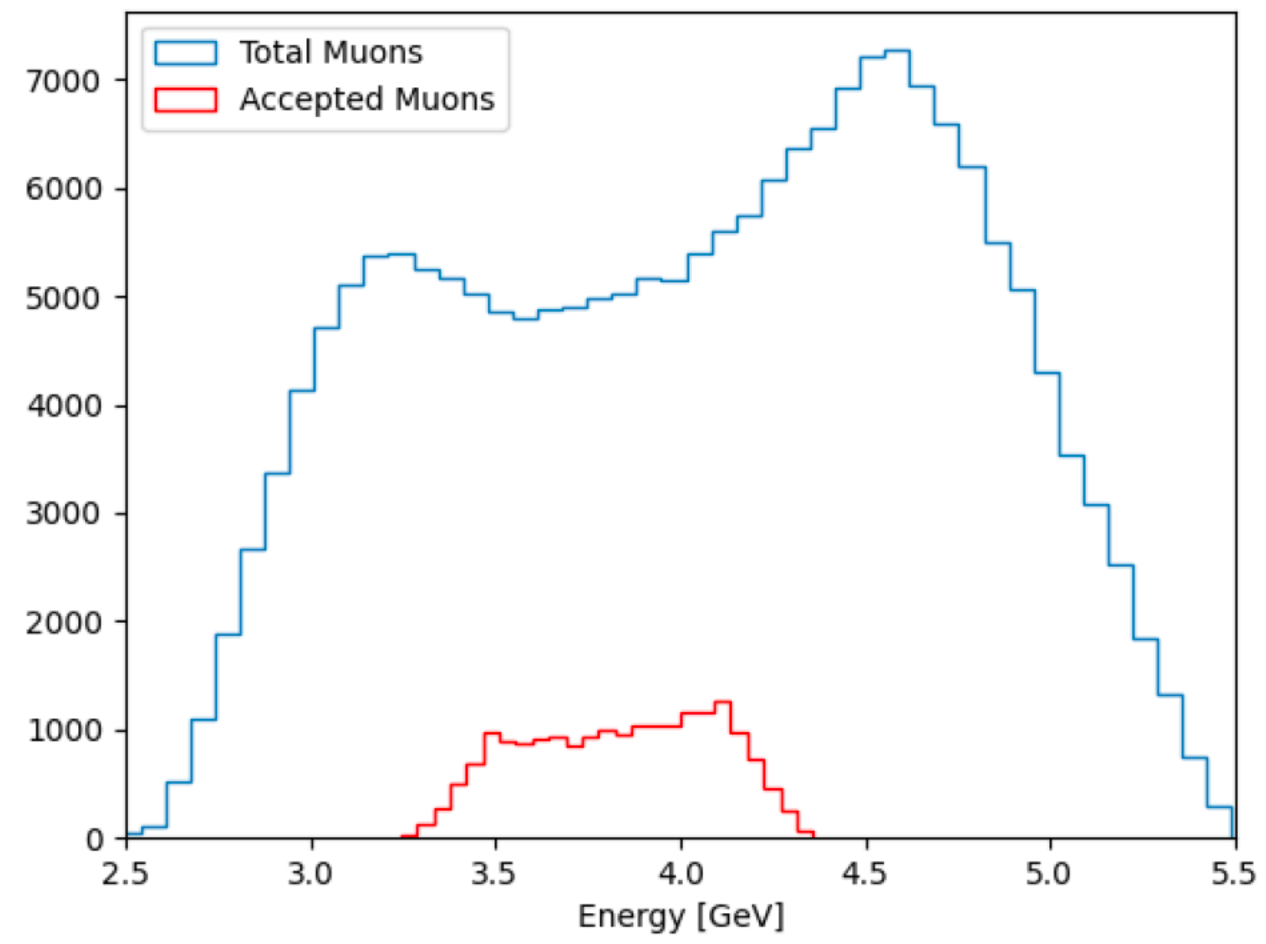


Fig 9 – The Energy Spectrum for the Total Muons and the Accepted Muons for a 5GeV/c Reference Pion Momenta

The momentum acceptance of the ring is tuned to exclude pions

nuSTORM simulation

Orbital Combination System

- nuSTORM is a hybrid facility, using FODO cells and Fixed Field Alternating gradient (FFA) magnets
- The OCS is an FFA combined function magnet that combines pions and muons incoming from different positions and with different momenta
- No Geant4 toolkit as of yet can accurately simulate the magnetic fields of an FFA combined function magnet

- We've had to create our on field maps for the OCS FFA

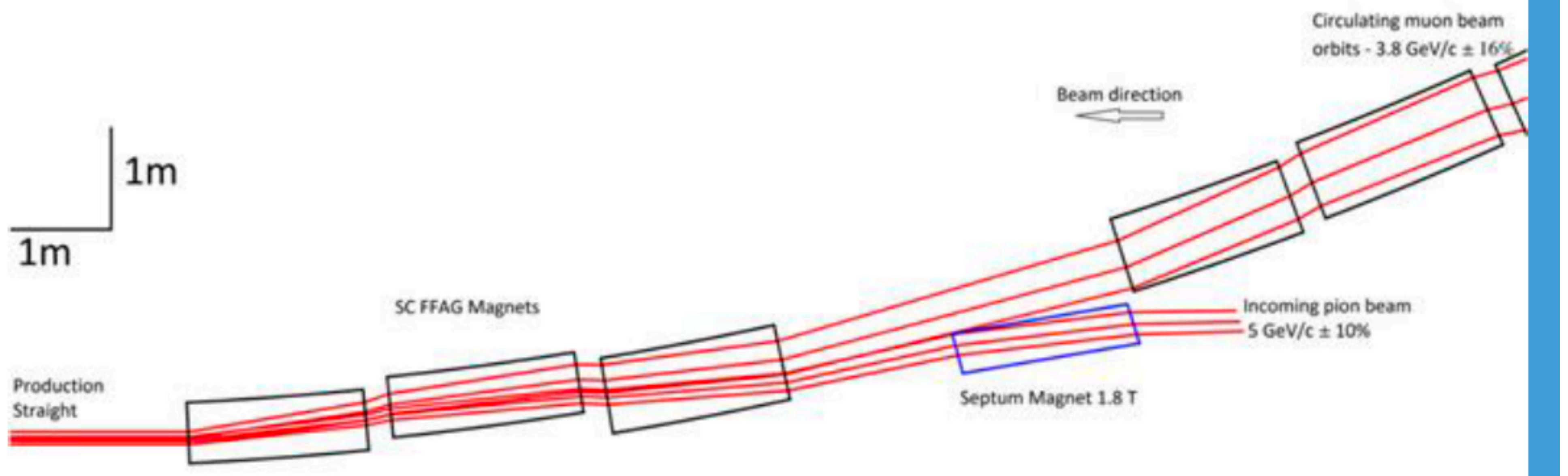
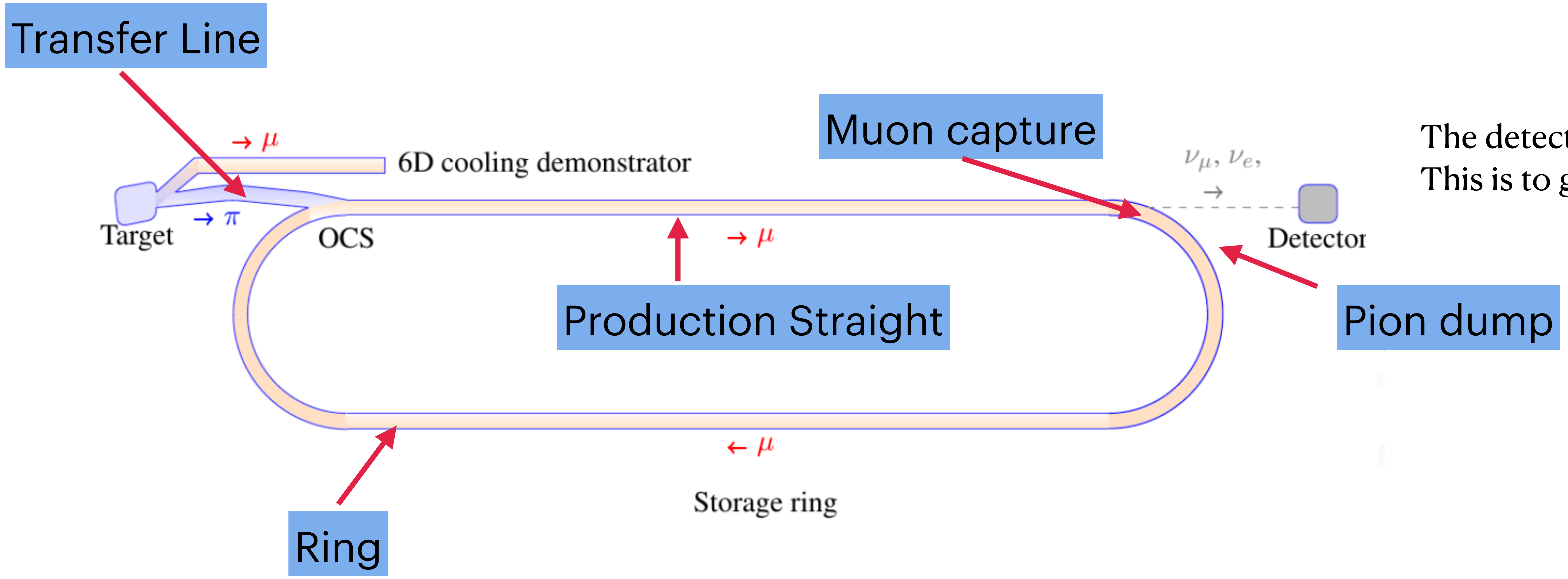


Fig 3 – A diagram showing how the OCS Magnets work. Beams are going right to left

nuSTORM simulation



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This is to give room for the pion dump

Different from most existing experiments in that the accelerator and the ring need to be designed as a whole

We use FLUKA to design and optimise the horn to get the best pion flux - which leads to captured muons

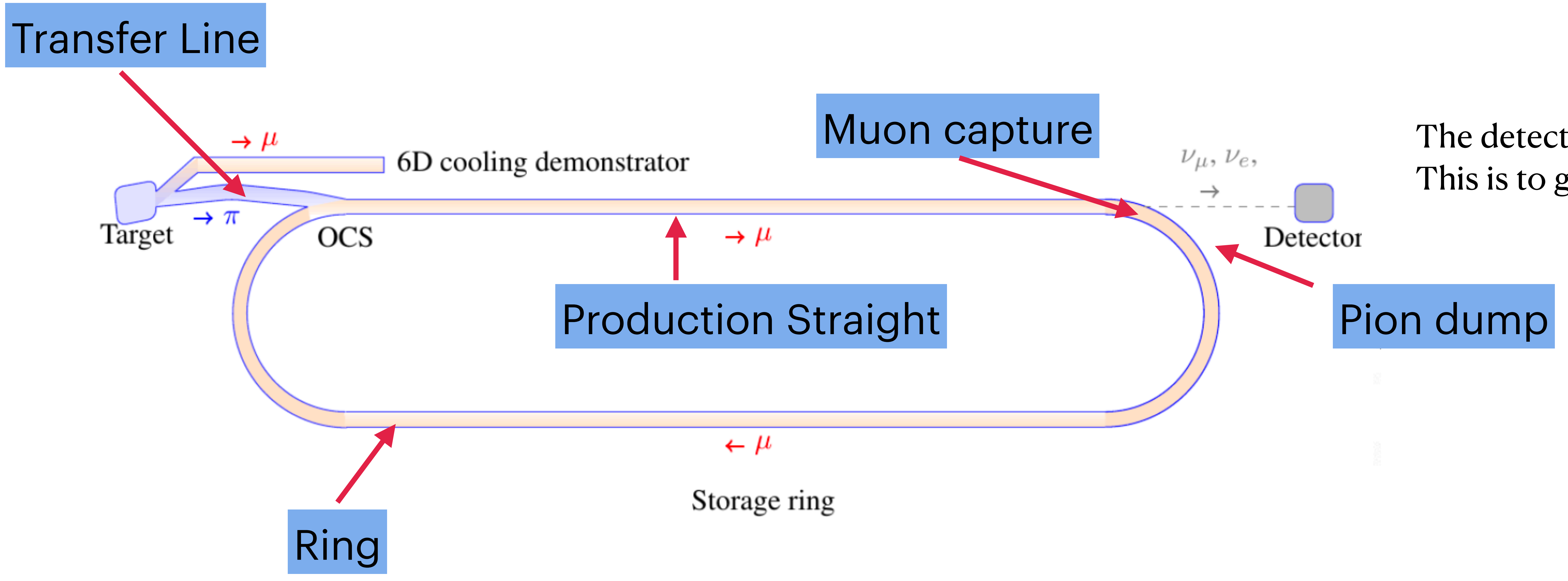
At present a special purpose programme nuSIM, takes a pion flux from the target and performs a "parallel transport"* on it along the transfer line and down the production straight applies the acceptance at the muon capture. Pions and the daughter muons are decayed with the correct time dependance and kinematics. bdSIM model in development.

Neutrinos are propagated from their point of production and their position and momentum is recorded if they cross the front face of the detector.

GENIE is used to go from neutrino flux to interactions
A GEANT4 model of the detector is under construction

* Whatever the momentum of the pion or muon is at the point of production, relative to the machine axis, is assumed to be the momentum relative to the (local) machine axis at the point of decay

nuSTORM simulation



The detector is 50m downstream from the end of the ring
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A bdSIM model of the facility is being prepared.

A model exists for the facility from the start of the transfer line to the muon capture

Work with the authors of bdSIM, to model the whole ring.

By comparing distributions generated from bdSIM, with those from nuSIM we are confident that the differences in the beam distributions will be small. Variation in the beam distributions for nuSIM show that the level of differences we expect do not have a significant effect on the neutrino distributions

The neutrino distributions are strongly forward peaked. Only decays in the production straight lead to neutrinos which reach the detector

nuSTORM Beams

The beam that enters the production straight is pions with a small admixture of muons.

Kaons have all decayed and the only a few muons survive the bend and injection in to the production straight.

Some of the muons produced in the production straight, will decay before the end of the straight providing a background to the pion neutrinos, but this is a maximum contamination of 0.84% (ratio of lifetimes)

The neutrinos from the captured muons only start arriving at the detector long after the last pion has decayed or been absorbed.

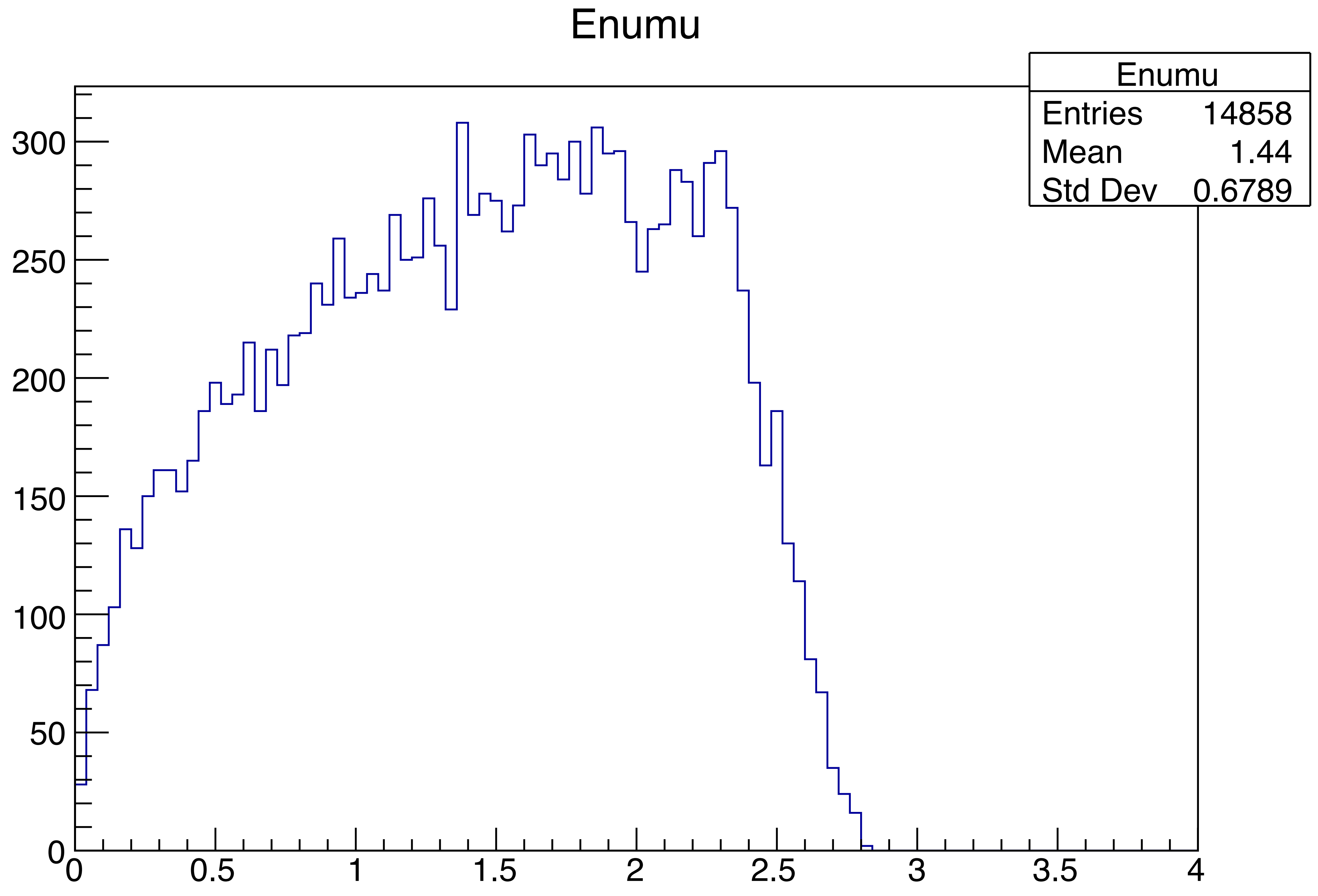
The muon decays from muons in the ring have zero beam associated background.

Beams

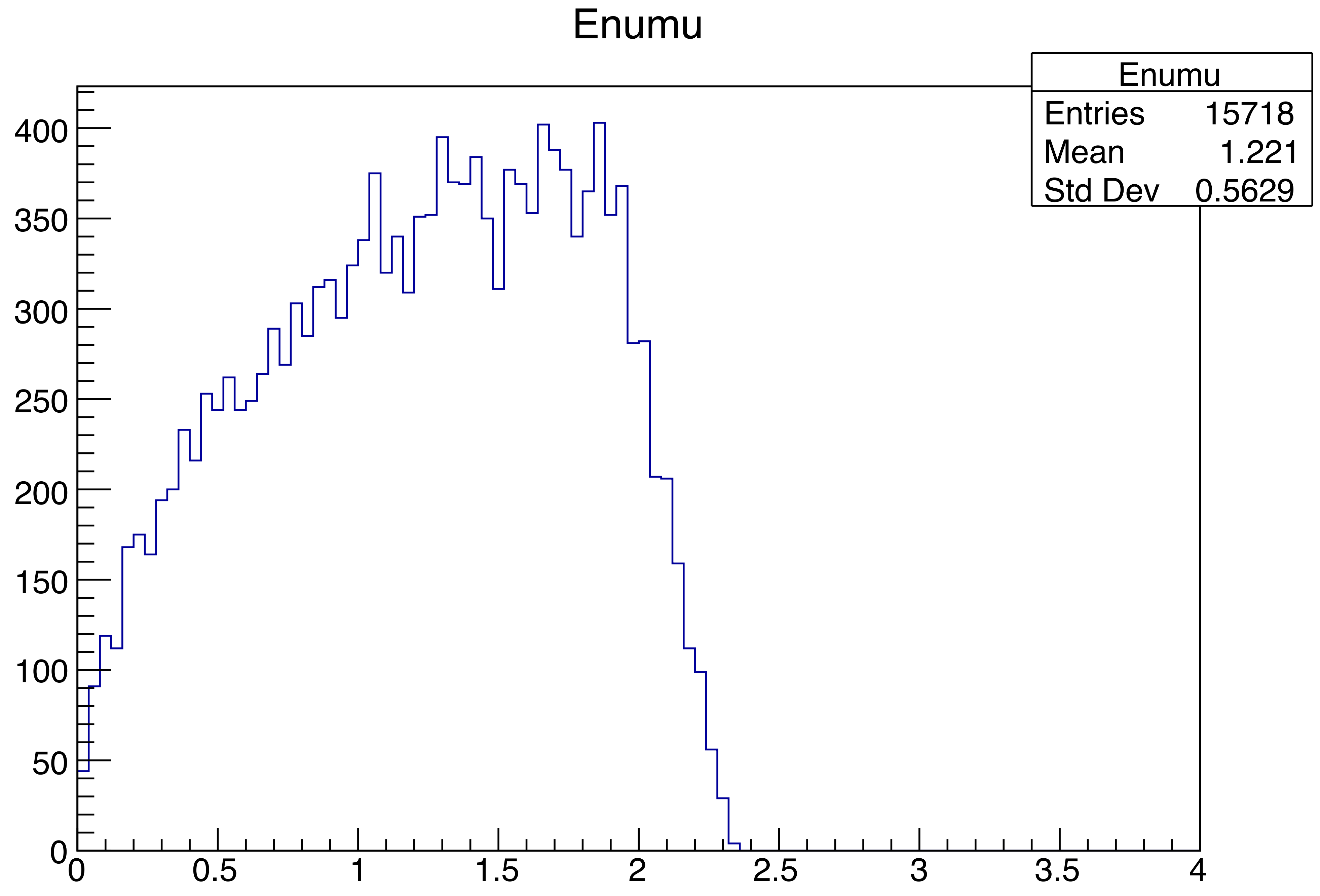
Beams of electron anti-neutrinos and muon neutrinos in equal amounts with no background
Beams of muon anti-neutrinos with backgrounds of electron anti-neutrinos and muon neutrinos at less then 1%

Charged conjugate of the above

Synthetic Beam - pion flash



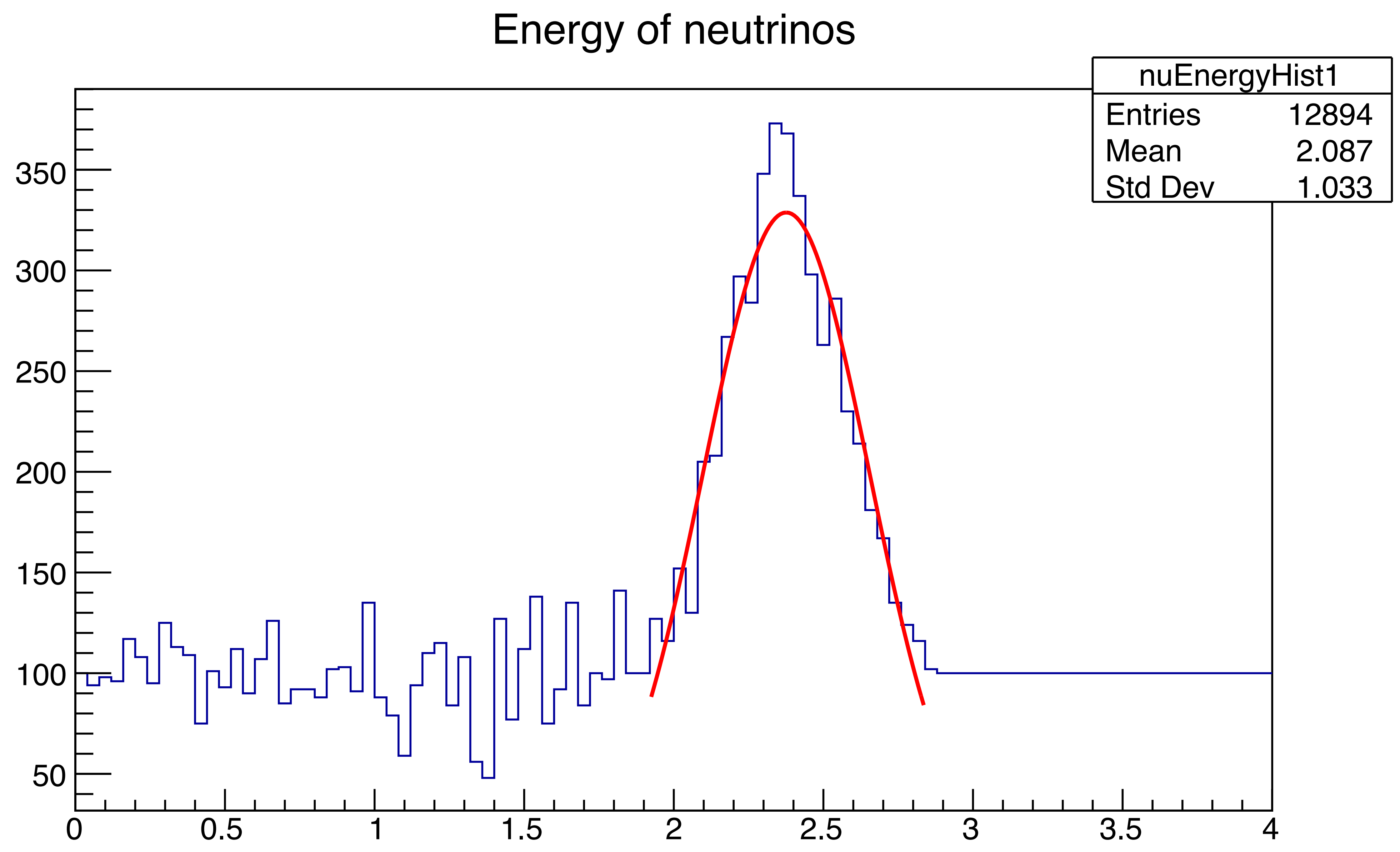
6 GeV pions. 5x10^4 pions at the production target from 10^6 protons on target
Fluka + nuSIM

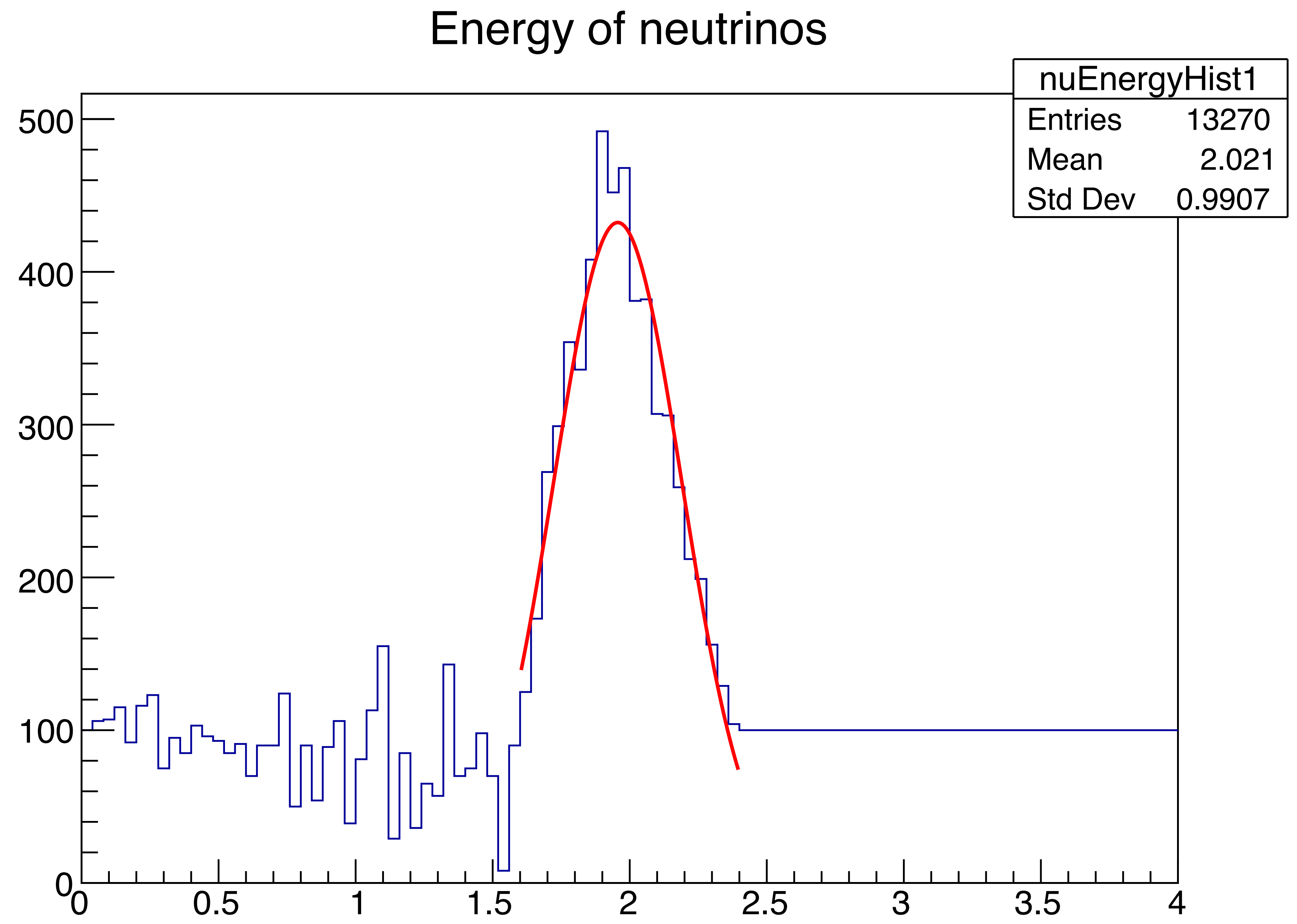


5 GeV pions. 5x10^4 pions at the production target from 10^6 protons on target
Fluka + nuSIM

Subtract the 5 Gev distribution from the 6 Gev distribution
Normalised by the ratio of the number of neutrinos 14858/15718 and the ratio of the end points 2.3/2.8

Synthetic Beam - pion flash





Gaussian fit 2.38 ± 0.28

100 added to each bin to show negative bins
Normalisation tweaked to make the sum of the bins
upto the peak equal to zero

Gaussian fit 1.95 ± 0.23

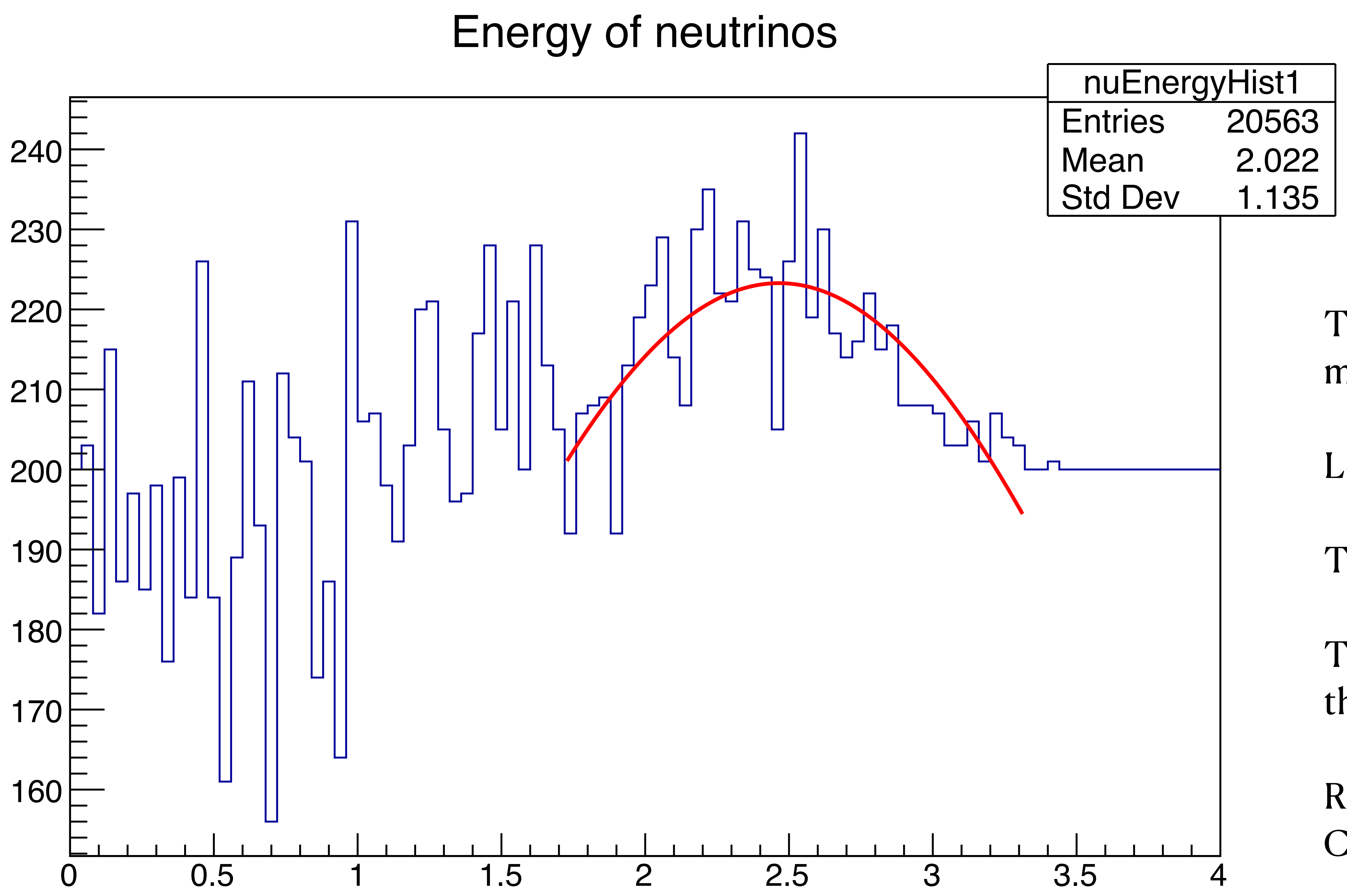
100 added to each bin to show negative bins
Normalisation tweaked to make the sum of the bins
upto the peak equal to zero

Compared to DUNE and the Prism concept (linear combination of many angles):

the analysis is much simpler and potentially more computationally stable
at wide angles the DUNE beam contains Kaons: pi/K ratio required

DUNE needs to worry about efficiency variations over the face of their detector
For nuSTORM all the detector is used at all energies, reducing systematics

Synthetic Beam - muon decays



The same trick with decays from the muons in the ring needs more data.

Looks promising

This is from 2 million pions at the target

There are only 500 events in the peak region - so we need about 30 times the statistics

Run on my laptop (about 15 minutes) going to repeat on the Imperial Cluster.

2 million pions is less than 1% of the pions we expect to get per SPS pulse

nuSTORM Detector

nuStorm detector will be a 5mx5mx5m cube

Current baseline is liquid argon

The new "opaque scintillator" technology being explored by the LiquidO consortium will also be investigated.
The resolution does not look as good as liquid argon, but the target density is at least 700 times as great (WBLS) and there is no need for cryogenics

Optimisation on the basis of detailed studies

nuSTORM - physics

nuStorm will provide beams of neutrinos with little or no background at a range of energies and with well understood kinematic distributions and from parent particles with limited, and well defined momentum bites

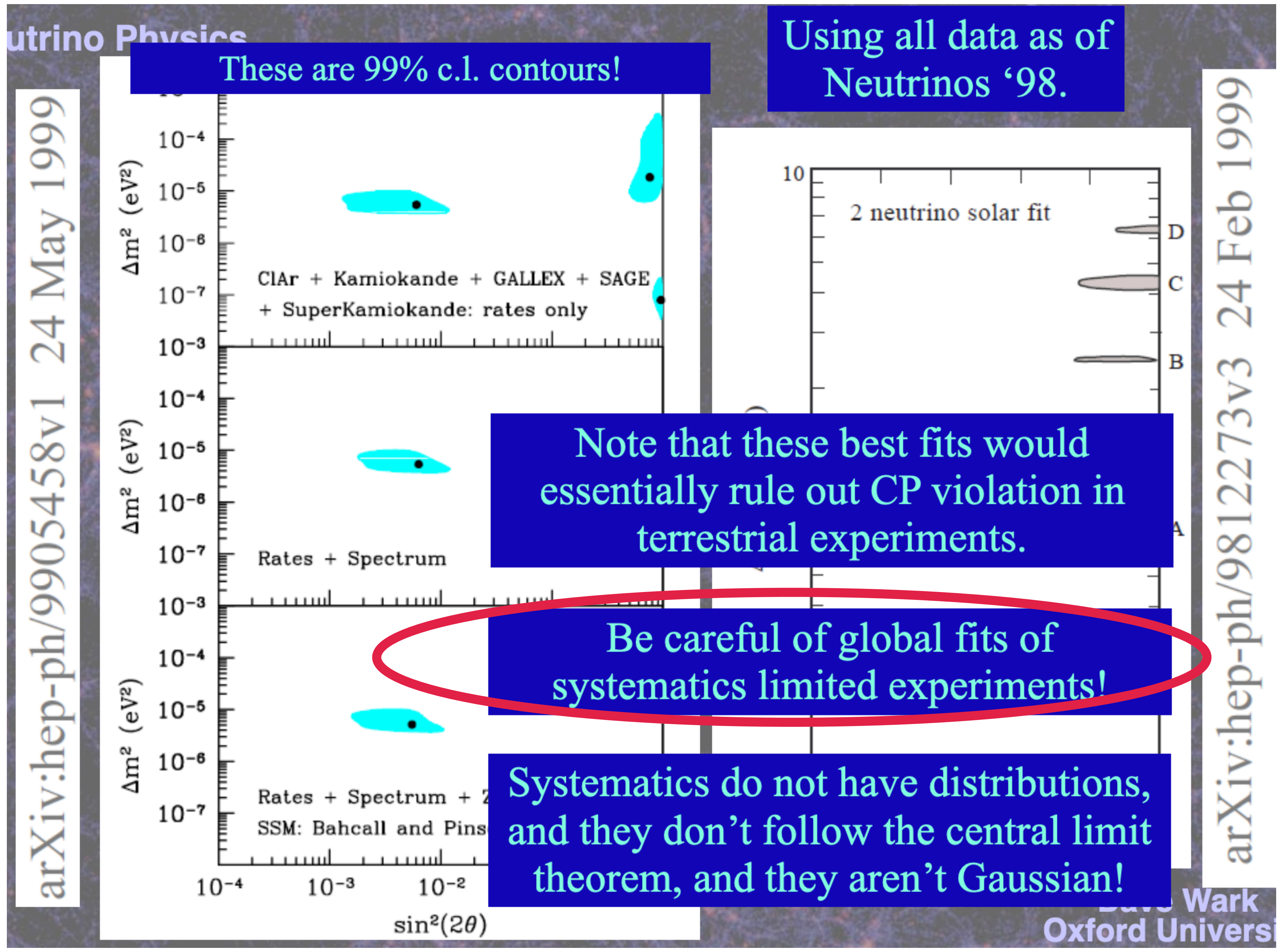
Outlook

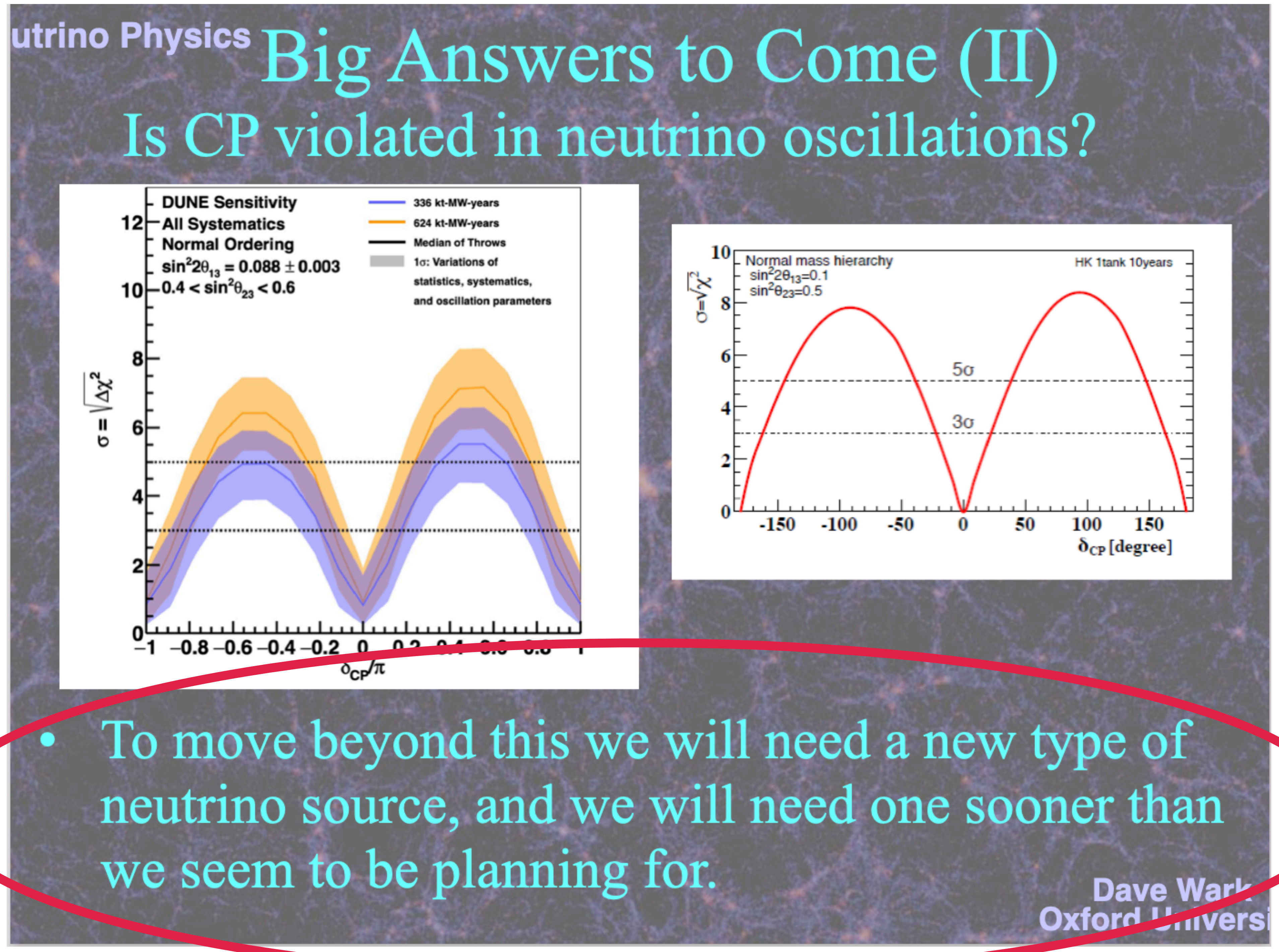
- Our present understanding of (few-GeV) neutrino interactions with matter would be **greatly improved** by new precise measurements with well-understood **νSTORM** flux at **advanced detectors.**
- The future neutrino oscillation program can **greatly benefit**.
- Progress in **hadron** and **nuclear physics**.
- Potential to **discover/constrain non-standard interactions** and **exotic processes.**
- Sensitive searches for **short-baseline flavor transitions**: potential to **discover sterile neutrinos** or **exclude (10 σ)** the presently allowed parameter space.

L. Alvarez-Ruso, IFIC EP-NU Group Meeting @ CERN

Summary of a talk by Luis Alvarez-Rush

nuSTORM Programme





At the UK HEP Forum 2022: 22-23 Nov.
Dave Wark in his concluding talks made two related points

We need a new type of neutrino source

Systematics is a problem in neutrino physics

nuSTORM will provide a new type of source, with a tuneable energy, little to no background and much reduced systematics
Which includes a knowledge of the beam intensity at the 1% or better level

nuSTORM Summary

- We can do BSM physics
- We can look at nuclear physics measurements.
- We can do cross-section measurements

- We will provide data which could be useful to the Long Baseline experiments
- We will provide a test bed for problems which need to be solved for the muon collider

BONUS

We have a unique neutrino beam and with that beam we can do measurements with a smaller uncertainty than any existing beam

If something new emerges, in the study of neutrinos using beams, by the time nuSTORM is taking data, we will be able to contribute to it.