Particle and Nuclear Physics Beyond the Lab

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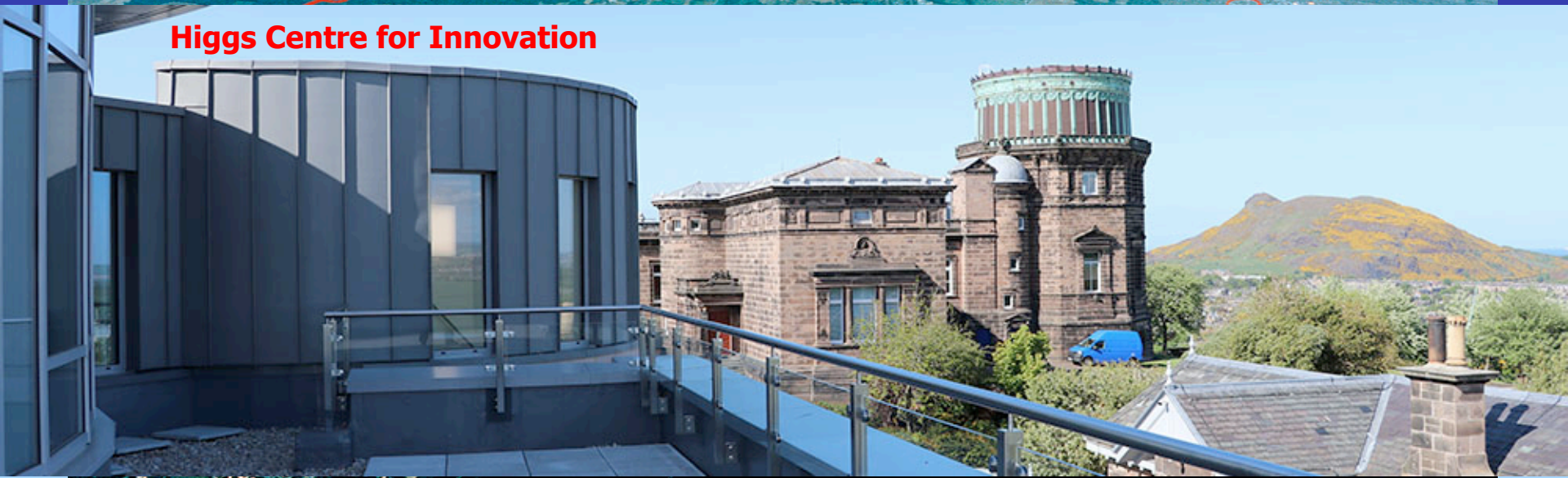
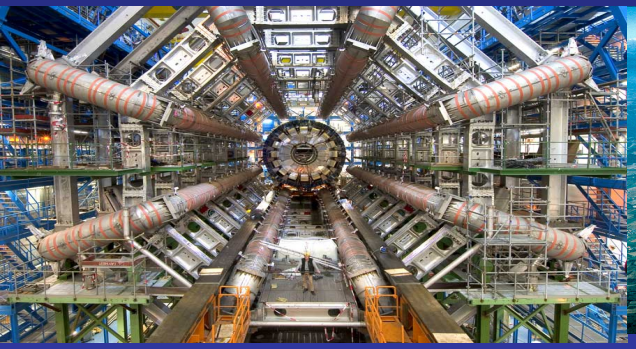
University of Edinburgh

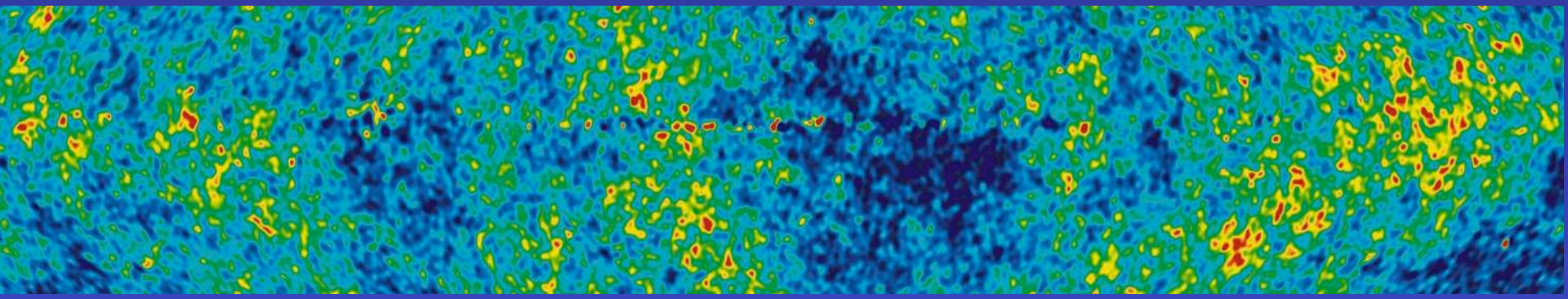


Institute for Particle and Nuclear Physics

- Particle Physics Experiment (PPE)



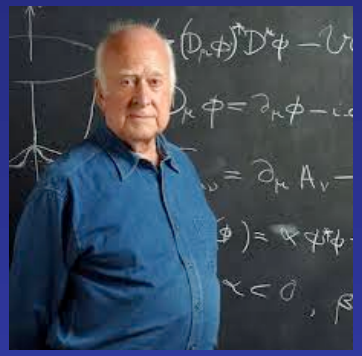
- Particle Physics Theory (PPT)

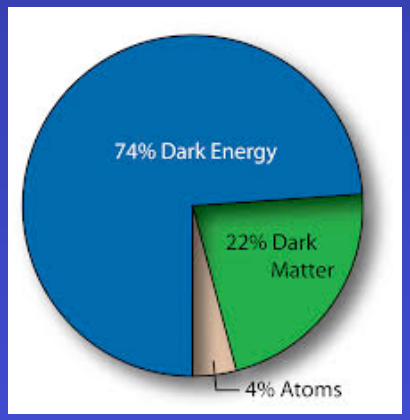


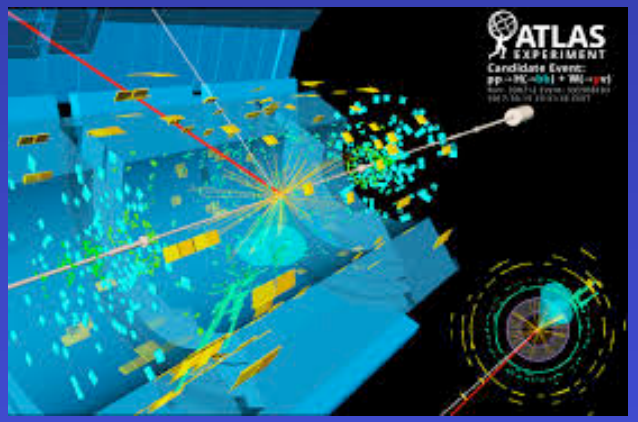
- Nuclear Physcis (NP)

IPNP Research

- **Push forward the frontiers of knowledge**
  - What is the universe made of
    and how do we find out?
  - What happened at the Big Bang?
  - Is there a unified theory?
  - Why is there so much matter and almost no antimatter?
  - What happens in nuclei under extreme conditions?
  - What are dark matter and dark energy (Cosmology)?







IPNP Engagement with Industry

- **Develop new technologies for detectors and accelerators**
  - Toolbox required for frontiers research
  - Processes of interest are rare
  - Challenging environments, e.g. radiation, state-of-the-art detector technologies, small, fast and thin
  - Data intensive science –
    e.g. huge date rates and CPU requirements at the Large Hadron Collider,

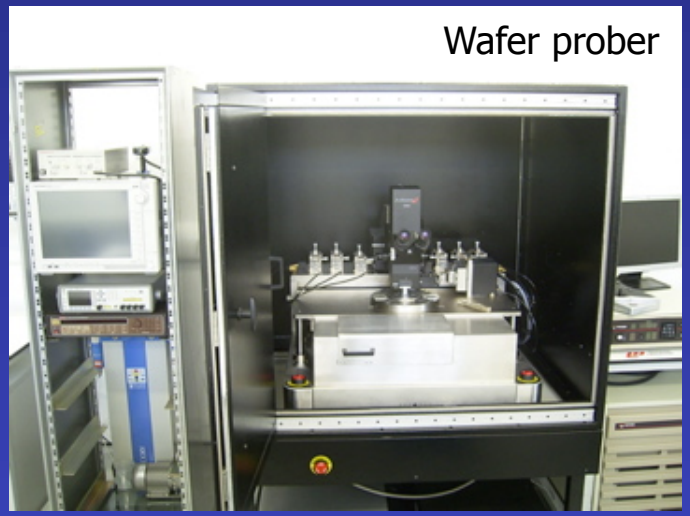
- **Challenges and Opportunities**
  - High performance computing - Lattice QCD
  - Silicon sensors
  - Fast photon detectors
  - Medical physics
  - Nuclear non-proliferation
  - GPUs
  - Machine Learning

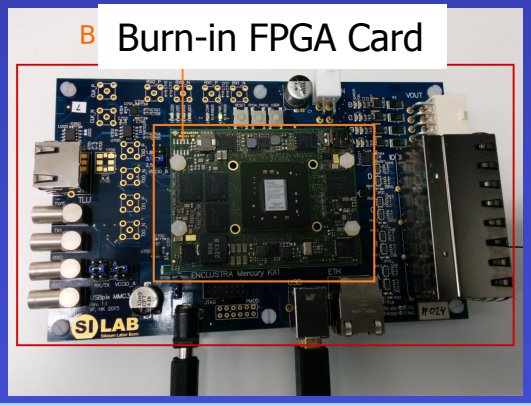
High Performance Computing

- **Research in Lattice QCD**
  - is extremely computationally demanding
  - field is closely connected to modern chip design
  - PPT group works at the leading edge of this area
- **Activities**
  - In 2001 – 2009 UKQCD obtained £ 6.6M for a multi-Teraflops scale computer, QCDOC
  - From 2009 STFC grant
  - Super computer development
- **Partners**
  - Columbia University and IBM TJ Watson Blue Gene supercomputer
  - Intel, Nvidia
  - …

Silicon detectors

- **LHC High Luminosity running**
  - Hostile environment with large occupancy in detectors
  - Many challenges for charged particle tracking sensors – electronics - mechanics
- **Activities**
  - Wafer probing FEI4 chips
  - Monolithic Active Pixel Sensor MAPS
  - HV-CMOS
  - Electronics - FPGA
  - FlexTapes – flexible readout cables
- **Partners**
  - Micron
  - Xilinx
  - Zot
  - …





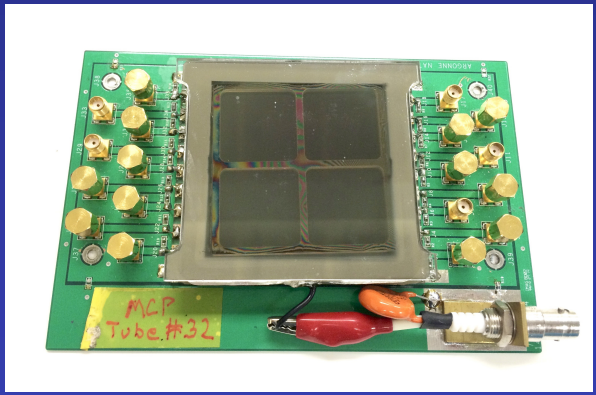
Advanced Detector Development Centre

- **Advanced Detector Development Centre (ADDC)**
  - Rooms 5203/04 in JCMB
  - Investment of £1.7M SUPA and University

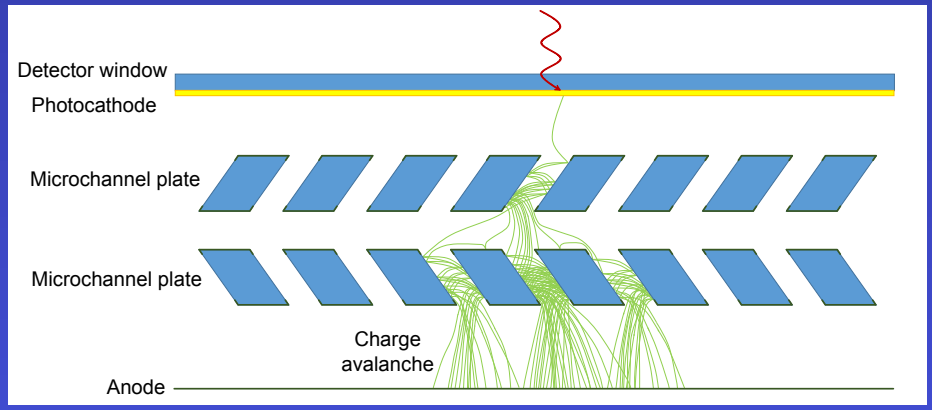
- **ADDC equipment**
  - Wafer prober
  - Wire bonder
  - Silicon placement machine
  - Climate chamber
  - RF tester
  - Single photon detector laboratory
  - Spectrophotometer
  - Si and Ge crystal detectors

Fast Photon Detectors

- **LHC High Luminosity running**
  - Hostile environment with large occupancy in detectors
  - Picosecond time resolution will be required for photon sensors
- **Micro channel plate photon detectors**
  - O(60 ps) time resolution for single photons
  - Pixellisation possible
  - Fast electronics required
  - potential for applications in neutrino physics, medical applications, security
- **Partners**
  - Photek
  - Incom Inc - LAPPD
  - DMI
  - …



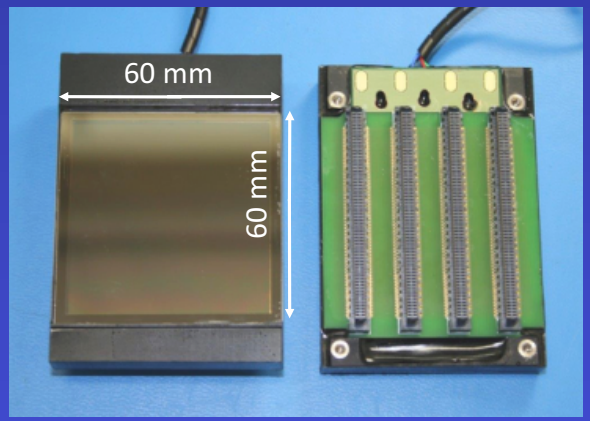
LAPPD ANL prototype



MCP-PMT

Fast Photon Detectors

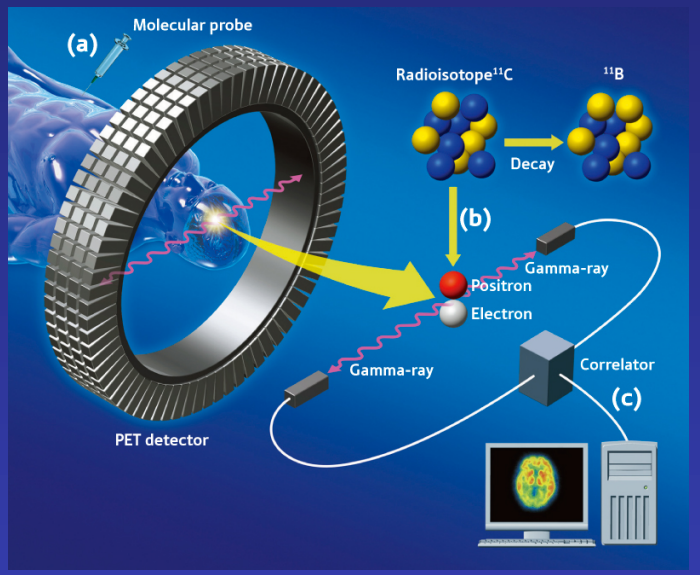
- **TORCH**
  - Time Of internally Reflected Cherenkov light
- **Activities**
  - R&D project UK universities, CERN and industrial partner Photek
  - Local company (DMI) built part of protoTORCH
  - Is now on preferred
  - CERN supplier list

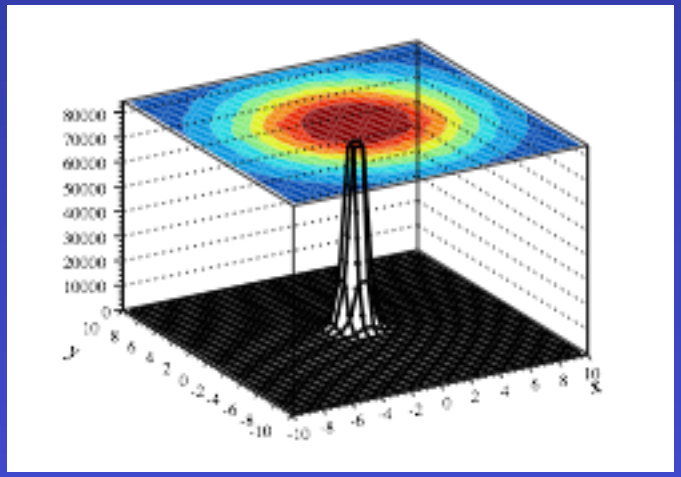


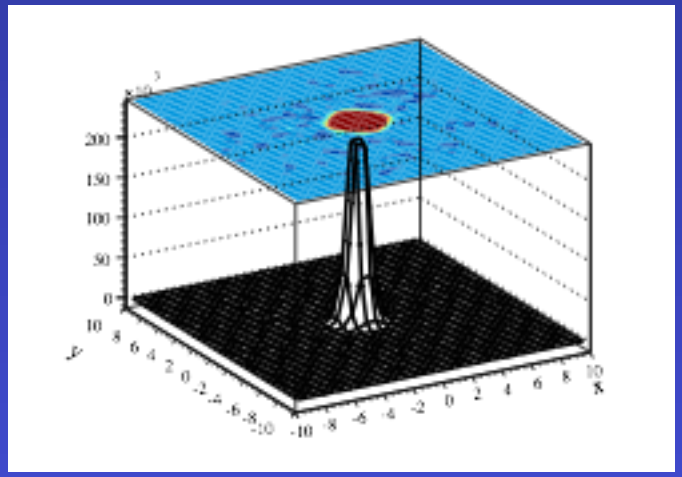
Photek prototype

Medical Physics

- **Positron Emission Tomography**
  - Using quantum entanglement to make better images
- **Partners**
  - Innovation UK, Kromek
  - Edinburgh Imaging
  - …

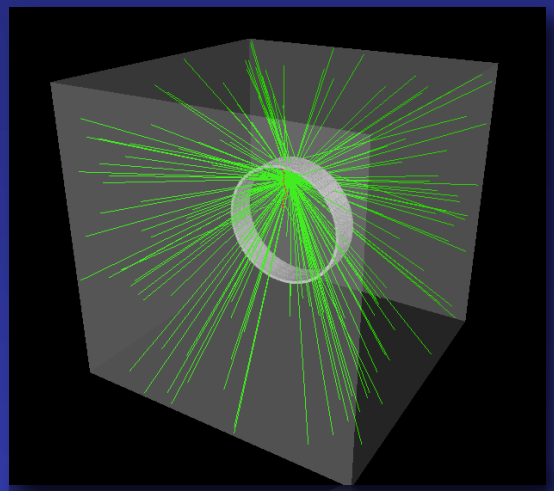




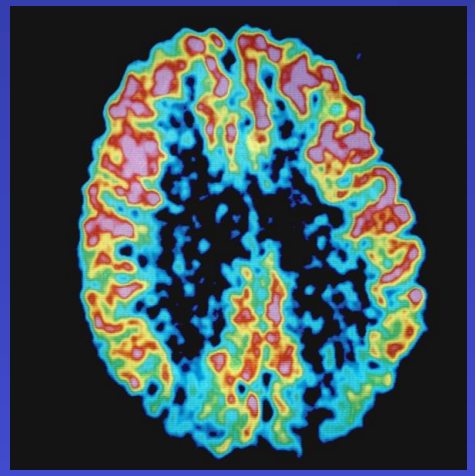


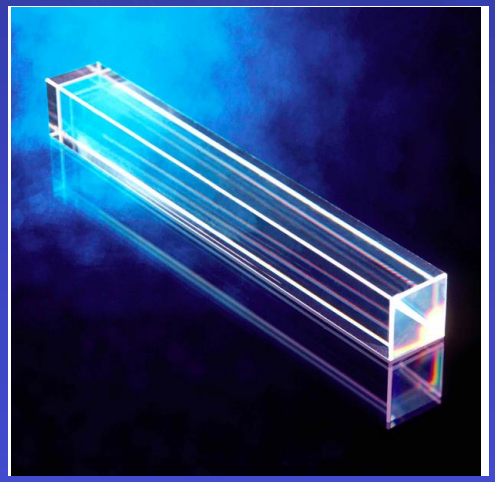
Medical Physics

- **Medical Imaging**
  - Better simulations
    - GEANT4 toolkit
  - Improving detectors
    - Crystals Silicon Photomultipliers
    - SPAD
  - Better image reconstruction
    - See machine learning slides



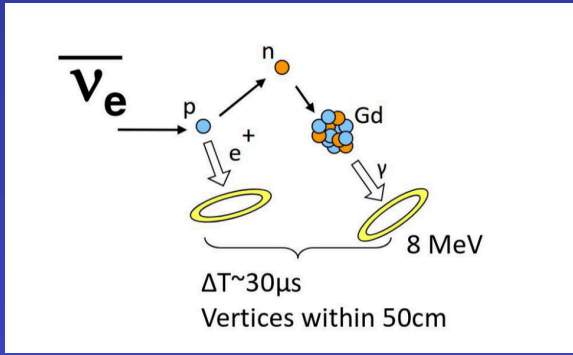
- **Partners**
  - This is a growth area
    - Looking for new partners
  - Mirion?
  - Edinburgh Imaging
  - Medipix
  - …

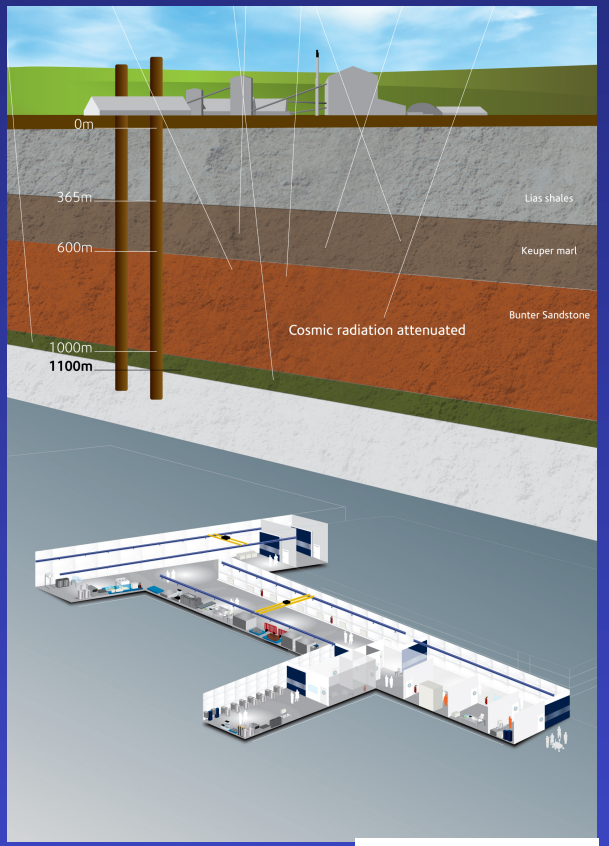




Nuclear Industries

- **WATCHMAN-AIT**
  - Advanced Instrumentation Testbed
  - Measure anti-neutrinos from Hartlepool reactors at 25km in a 6.5kt water Cherenkov detector underground in Boulby mine



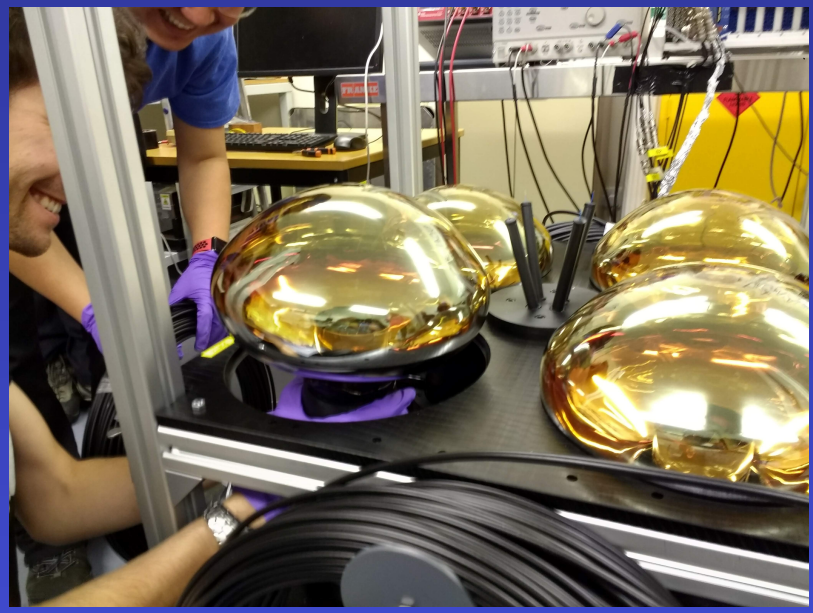


Boulby mine

- **Nuclear non-proliferation**
  - Deploy detectors to monitor nuclear power plants and other activity

Nuclear Industries

- **WATCHMAN-AIT**
  - Is a particle physics detector
  - ~4500 large 10" photomultiplier tubes
  - Synergies with LHCb and Hyper-K
- **22 Jan 2019**
  - UKRI and STFC announcement
  - £9.7M for WATCHMAN-AIT
  - Expect ~$33M in US
- **Partners**
  - AWE
  - Hamamatsu
  - CAEN
  - Enterprises Limited
  - …



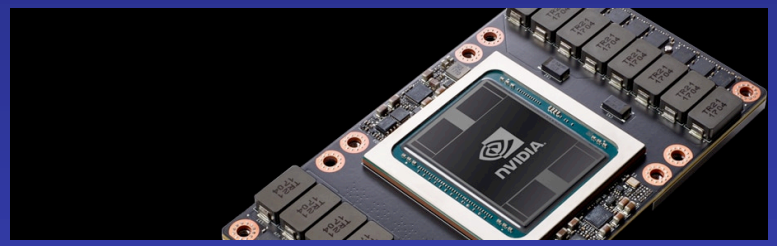
Machine Learning

- **Pattern recognition**
  - Reconstruction of particle physics events
  - Data intensive science - requires huge amount of CPU
  - Change of scope over last two decades - apply machine learning techniques
- **Adversarial Neural Networks**
  - Searches for exotic particles
  - Interdisciplinary
    - face recognition
    - Medical imaging
  - New - Machine learning forum
- **Partners**
  - Tindeco
  - Nvidia
  - Data Lab
  - Bayes Centre
  - ….

See poster by Andreas Sogaard

Big Data

- **Data intensive science**
  - Particle physics requires huge amount of CPU
  - Approaching limitations of chip size ~10 nm a few atomic layers
  - Increasingly use GPU applications
  - e.g. trigger for rare signal
- **Distributed Data storage**
  - Large data volumes
  - GridPP for particle physics in UK
  - Worldwide LHC Computing Grid (WLCG)
  - Cloud Computing
- **Partners**
  - Tindeco
  - Data Lab
  - Nvidia
  - Bayes Centre
  - ….



Nvidia TESLA GPU

WLCG

GridPP
UK Computing for Particle Physics

IPNP Industrial Strategy

- **Increasing IPNP engagement with industry**
  - Existing range of activities
  - Scope for increase
- **Funding Opportunities**
  - Innovation Partnership Scheme (IPS)
    - Cultivate innovation opportunities
    - Facilitating the transfer of technologies, skills and knowledge, developed through STFC funding, to industry and other users of research outputs
    - Focus on commercial exploitation to ensure UK economic impact
  - Challenge Led Applied Systems Programme (CLASP)
  - CASE studentships
  - Potential for UK companies

IPNP Industrial Strategy

- **Doctoral Training Centres**
  - ScotDIST - The Scottish Data-Intensive Science Triangle
    - partnership between Edinburgh, Glasgow and St. Andrews for PhD studentships in data-instensive science
  - New DTC application (Artifical Intelligence) with Glasgow expect decision soon
- **New - MSc for Particle and Nuclear Physics**
  - with modules on Machine Learning and Medical Physics
- **Opportunities with Higgs Centre for Innovation**
  - Networking
    - for companies with an interest in collaboration with STFC scientists
    - Access to scientists, academics, researchers, PhD & MSc students
  - CERN Business Incubator
    - Support for startups – office
    - For details, see https://www.cernbic.stfc.ac.uk
  - CERN Alumni

IPNP Contacts

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Backup

Major Open Questions

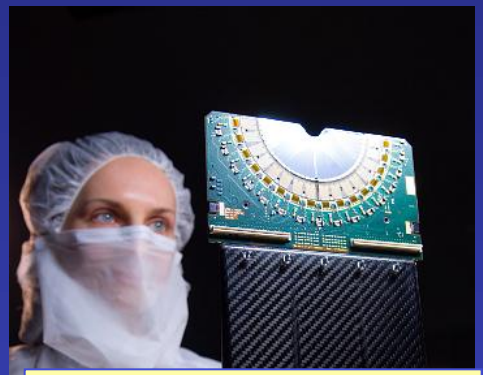
- **What gives fundamental particles mass?**
  - **Quantum Electro Dynamics (QED)** - exceptionally successful theory
  - QED makes accurate prediction to 12 decimal places
    equivalent to knowing distance of Edinburgh – New York to the thickness of a human hair
  - **Standard Model of Particle Physics** - QED, QCD & weak interaction
  - Major problem with theory - particles don't have mass

- **What is the universe made of?**
  - only 4% of observed universe is made of known matter
    96% is not understood

- **Why is there so much matter and almost no antimatter?**
  - only one in a billion particles are antimatter

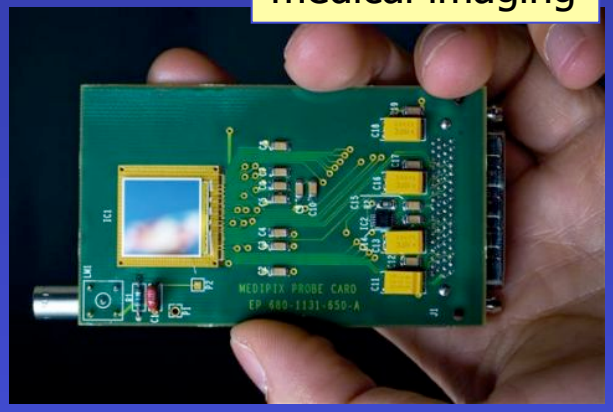
Scotland at CERN

- **Experimental and Theoretical Particle Physics groups**
  - at Universities of Edinburgh and Glasgow
  - 80 staff and 60 PhD students
  - from many countries world wide, including Switzerland, Brazil, China, US, Germany, Italy, ….
- **Scottish Involvement includes**
  - Design and construction of detectors

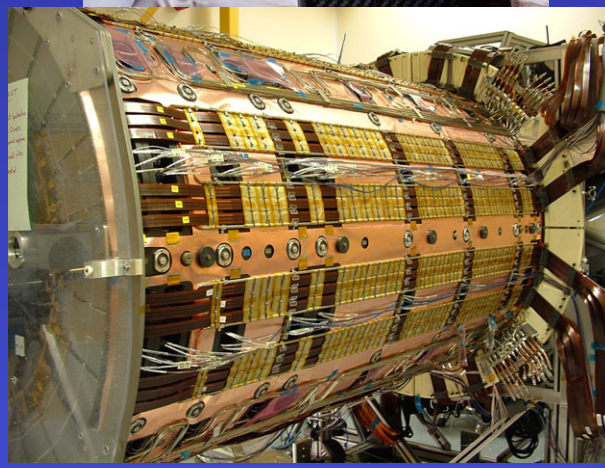


LHCb Silicon Tracker

Medipix Chip for medical imaging



LHCb Ring Imaging Cherenkov Detector



ATLAS Silicon Tracker

PPE and NP Laboraties

- **Probe station to probe silicon sensors or integrated circuits at wafer level**
  - Wafer probing up to 8" (200 mm)
  - Wafer, single die or chard; silicon component characterisation, currents to fAmp, capicitance to fF
  - ASIC functionality testing
  - Temperature range -40 to 200 degree C
- **Wirebonding machine**
  - Ball and wedge wire-bonding, bond area up 10x10 cm^2
  - Pull and shear testing
- **Silicon placement machine**
  - Glueing silicon or equivalent to substrates with high precision better than 10mm in 3-dim
  - Different process include epoxy glue, UV cured glue, eutectic bonding, silver glass bonding, ultra-sonic bonding
  - Temperature control up to 450 degree C
  - Force control up to 500 N

PPE and NP Laboraties

- **Climate chamber**
  - Size 70x70x40 cm^3
  - Operating from -60 to +200 degree C
  - Relative humidity control from +10 to 100 degree C
- **RF waveform testing**
  - At frequencies up to 6 GHz
  - With arbitrary waveform generator, oscilloscope and probes and a spectrum analyser
  - Vector network analyser up to 18 GHz
  - Time domain reflectometer, vector voltmeter
- **Single photon detection laboratory**
  - Pico-second laser pulser, nano-second LED pulser
  - Large variety of detectors, HPDs, MaPMTs, Spadnet,
  - Crystals and sources
  - Quantum efficiency setup : monochromator, Xe light source
  - Readout electronics for voltage or charge pulse and time measurement

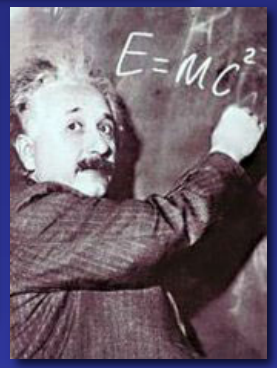
PPE and NP Laboraties

- **Spectrophotometer**
  - Transmission UV to visible wavelengths
  - Need to add specs, is this the same as the monochromator or complementary? (Comment Stephan: this is different from the monochromator)
- **Semiconductor (silicon and germanium) detectors**
  - for high resolution,
    low background alpha, beta and gamma spectroscopy.
  - Shielding for low background measurements
- **VME based data acquisition electronics**
  - 32-ch charge sensitive ADC (12-bit, 0-400pC, 100fC resolution)
  - 32-ch TDC (21-bit, 0-52ms, 25ps resolution)
  - 32-ch peak sensing ADC (12-bit, 0-4V, 1mV resolution)
  - 64-ch 65MS/s sampling ADC (12-bit, 0-2V, 0.5mV resolution)
  - 8-ch 250MS/s sampling ADC (12-bit, 0-2V, 0.5mV resolution)
- **High vacuum chambers**
  - Down to 1e-06 mbar pressure

The Mission of CERN

- **Push forward** the frontiers of knowledge

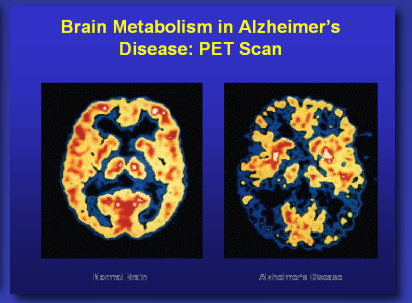
  E.g. the secrets of the Big Bang … what was the matter like within the first moments of the Universe's existence?

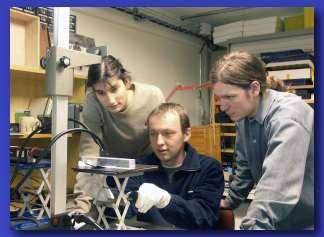


- **Develop** new technologies for accelerators and detectors

  Information technology - the Web and the GRID

  Medicine - diagnosis and therapy





- **Train** scientists and engineers of tomorrow

- **Unite** people from different countries and cultures

The End