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THE COCKCROFT INSTITUTE *of*
ACCELERATOR SCIENCE and TECHNOLOGY
http://www.lancs.ac.uk/cockcroft-institute/

The Cockcroft Institute

John Dainton

Sir John Cockcroft FRS
b. Todmorden (Lancashire *and* Yorkshire!)
ed. Manchester University: Maths
Manchester College of Technology (UMIST): Elec. Eng.
Metropolitan-Vickers, Manchester
PhD then post-doc, Cambridge Univ.
Nobel Laureate, Physics, 1951

CCLRC
LANCASTER UNIVERSITY
THE UNIVERSITY of LIVERPOOL
MANCHESTER 1824
The University of Manchester
Northwest REGIONAL DEVELOPMENT AGENCY
PPARC

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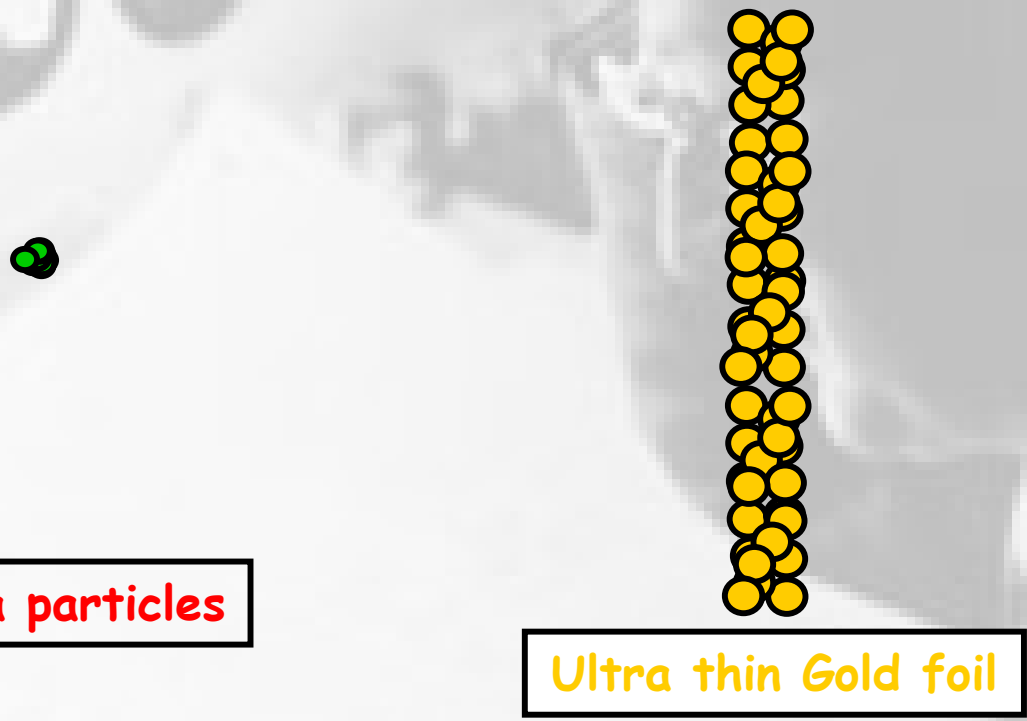
1. Introductory Remarks

The NW: birthplace of our Science

- matter @ MeV scale: the discovery of the "point-like" atomic nucleus

Marsden and Rutherford, Manchester 1909



- **large** energy transfer Q
- **large** scattering angle

$$\sigma \sim 1/Q^4$$

Manchester: discovery of the Atomic Nucleus

"… something like that of a cat delivering a choice mouse to his mistress."

Ernest Marsden FRS
when a PhD student, describing his feelings reporting the discovery of the atomic nucleus to his supervisor Ernest Rutherford at Manchester University
(from Rutherford Memorial Lecture, Royal Society London, 1954)

"… quite the most memorable event that ever happened to me in my whole life."

Ernest Rutherford, 1909
then Professor of Physics at Manchester University

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England: the birthplace of Nuclear and High Energy Physics

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"It would be of great scientific interest if it were possible in scientific experiments to have a supply of electrons and atoms in general, of which the individual energy of motion is greater even than that of the alpha particle. This would open up an extraordinarily interesting field of investigation which could not fail to give us information of great value, **not only in the constitution and stability of atomic nuclei, but in many other directions.**"

Professor Sir Ernest Rutherford PRS
(formerly Professor of Physics at Manchester University
later Cavendish Professor of Physics at Cambridge University
and Lord Rutherford FRS)
at the Royal Society, London, 30th November 1927

Cambridge: splitting the atom

- splitting the atom 14th April 1932
  the birth of the energy frontier
  - 800 KeV p + Li $\rightarrow$ He + He fundamental

John Cockcroft

b. Todmorden (Lancs and Yorks!)
ed. Manchester Univ (Maths)
Manchester College of Technology (Elec. Eng.)
Metropolitan-Vickers, Manchester
PhD then post-doc Cambridge Univ.

Ernest Walton

ed. TC Dublin, MSc hydrodynamics
PhD student, Cambridge Univ.

Li

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Cambridge: splitting the atom with NW industry

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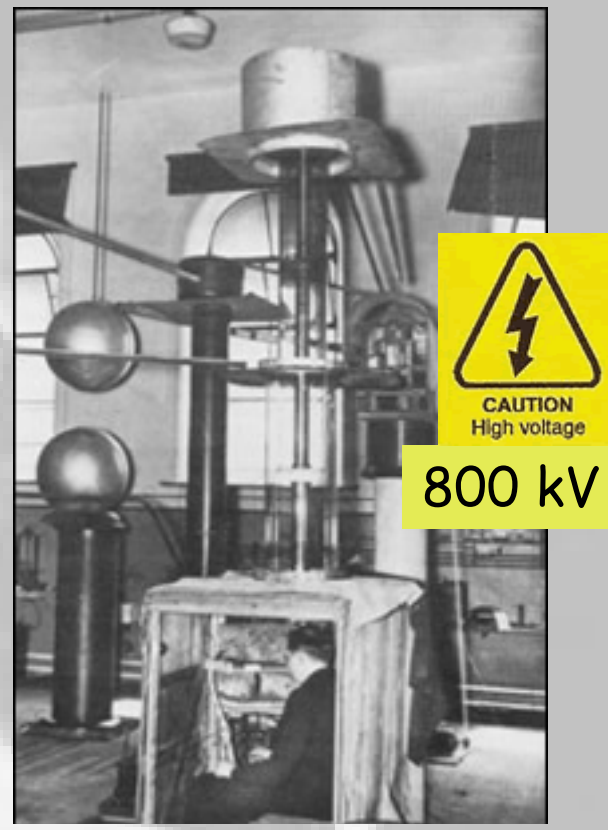
"The facts are that we looked first for gamma rays and not alpha particles, since at that time we had a fixed idea that gamma rays would be the most likely disintegration products."

Sir John Cockcroft FRS 1938

"… a singularly modest and self-effacing life."

C P Snow on John Cockcroft in "Physicists"



"… they were fortunate to have the support of Metropolitan Vickers: … the Manchester company."

B Cathcart in "The Fly in the Cathedral"

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The Global AST Horizon

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- major R&D in UK for UK participation
- UK high-tech industrial production

?

now

2010

2020

start LHC physics

ILC ready for approval?

CLIC technology proven?

new generation n, ν

ERLP

DIAMOND

4GLS

XFEL

ESS

ν superbeams?

GSI Darmstadt

start ILC physics?

CLIC ready for approval?

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Over the Horizon?

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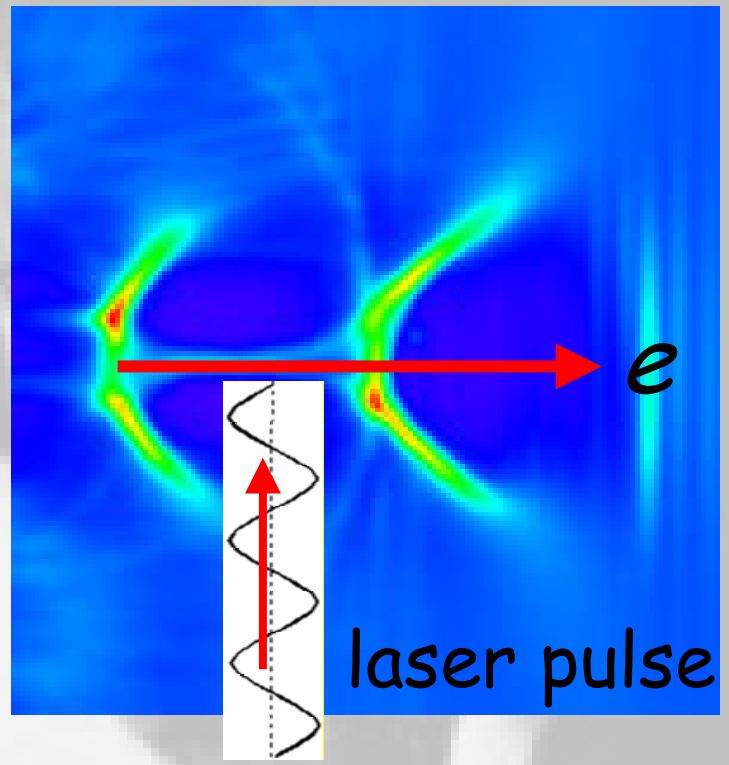
- laser pulse stresses *e* plasma
  - *e* accelerated
  - ion accelerated



http://www.nature.com/nature/journal/v439/n7075/abs/nature04400.html

- ~~very~~ "blue sky"
  - KWDL

The Cockcroft Institute

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- unique collaboration of established research excellence in NW England

THE UNIVERSITY of LIVERPOOL
The University of Manchester
MANCHESTER 1824
LANCASTER UNIVERSITY
PPARC
CCLRC
Northwest REGIONAL DEVELOPMENT AGENCY

- synergy of basic science (unavoidably global)
  technology
  industry

↳ UK inward investment
  - science → people, skills, innovation, progress
  - high-tech → industrial production
  - economic development (national + regional)

The Cockcroft Institute

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- why here in NW England?
  - Daresbury ↔ universities
    - High Energy Physics
    - Synchrotron Radiation science
    - Nuclear Physics
  - all require new accelerator systems for progress
  - all have been on Daresbury campus in their time

- Cockcroft/Walton experience 70 years on

"… they were fortunate to have the support of Metropolitan Vickers: … the Manchester company."

B Cathcart in "The Fly in the Cathedral"

Mission

The Institute's "mission" is summarised in the following "deliverables":

- generic R&D in Accelerator Science and Technology (AST);
- project specific R&D in AST
  (e.g. a linear collider and a Neutrino Factory);
- leadership and management of national deliverables to international facilities (which may be UK-situated);
- competence in crucial and specific technologies;
- technology transfer to industry;
- staff complement of internationally acknowledged expertise;
- seamless involvement of the HEI and CCLRC sectors;
- education and training to ensure a flourishing staff supply side.

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laboratories worldwide
CCLRC DESY LAL
CERN Fermilab KEK
Dubna Budker SLAC
ESRF GSI …

universities worldwide

universities UK

Northwest
REGIONAL DEVELOPMENT AGENCY

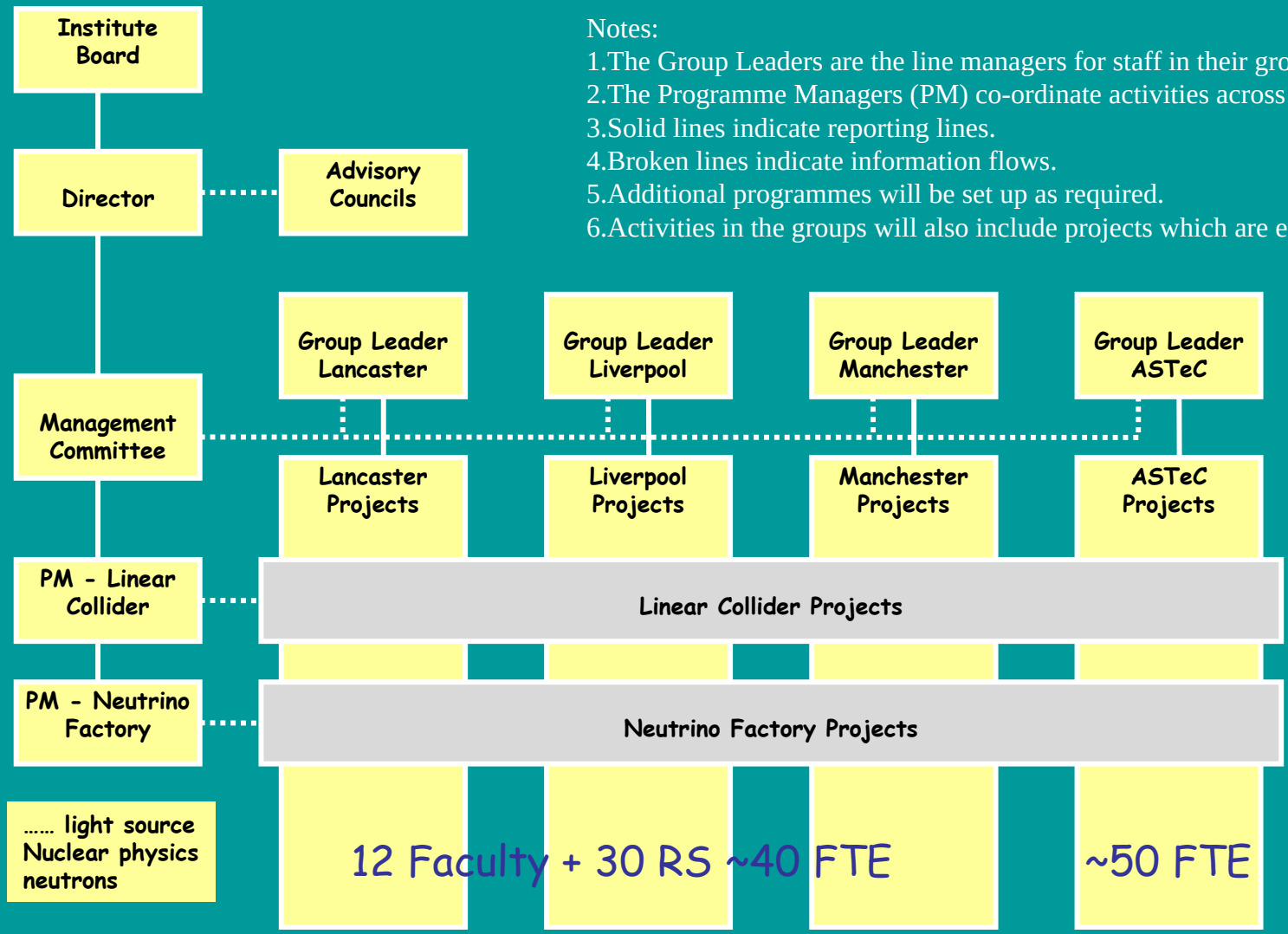
UK plc

national wealth

national expertise

global accelerator projects
ILC NF FAIR XFEL 4GLS
LHC DIAMOND ESS …

Management, Governance, Size (initial)



Notes:

1. The Group Leaders are the line managers for staff in their groups.
2. The Programme Managers (PM) co-ordinate activities across the groups.
3. Solid lines indicate reporting lines.
4. Broken lines indicate information flows.
5. Additional programmes will be set up as required.
6. Activities in the groups will also include projects which are external to the Institute.

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2. High Energy

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PPARC PP Strategy

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- elucidation of the origin of mass
  - LHC e^+e^- (ILC …)
- understanding the hadronic interaction
  - LHC e^+e^- (ILC …) ν-superbeam NF
- reason for the existence of three generations of elementary particles
  - LHC e^+e^- (ILC …) ν-superbeam NF
- reason for the matter-antimatter asymmetry in the Universe
  - LHC e^+e^- (ILC …) ν-superbeam NF
- nature of the 'dark matter' in the Universe
  - LHC e^+e^- (ILC …) cosmic

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Acceleration for PPARC Science

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- LHC
  energy, intensity, monitoring+control, reliability
  hadron, ion

- e^+e^- (ILC …)
  energy, intensity, monitoring+control, reliability
  electron, positron

- ν-superbeam, NF
  intensity, monitoring+control, reliability
  hadron, neutrino

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AST Challenges for PPARC Science

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- LHC

  intensity: cavity load/multi-pacting, wake-field, e-cloud, bunch-bunch

- e^+e^- (ILC and …)

  energy: cavity MV/m, beam-beam

  intensity: cavity load/multi-pacting, wake-field, e^+, e-cloud, bunch compression, bunch-bunch, beam disposal, damping

  monitoring+control: (nm, feedback, collimation, optics) → beam delivery

  reliability: single pass → components×10^3

- ν-superbeam, NF

  intensity: cavity load/multi-pacting, cavity scale, targetry, capture, *p*-driver, cooling

  monitoring: rad-hard

  reliability: environmental damage/survival

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Cockcroft and AST Challenges @ Dec05

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• cavity MV/m, load/multi-pacting, e-cloud	Lanc	RS
• wake-field	Lanc/Manch (LCABD)	groups+RJ
• bunch-bunch	Liv [heLiCal] (LCABD)	groups+IB
• bunch manipulation	Lanc crab cavity (LCABD)	Lanc group
• e^+ source	Liv [heLiCal] (LCABD+ASTeC+RAL)	groups+IB
• optics/coll^n/transp^t	Manch [LCABD] Liv [heLiCal]	RA/LM/LJ
• BBU	Liv+ASTeC [heLiCal] Manch [LCABD]	IB RA
• cavity scale	Lanc+IC [MICE]	RS
• targetry and capture	Liv [heLiCal] (LCABD+ASTeC)	IB
• damping	Liv+ASTeC	LM/AW
• beam-beam accel^n	Lanc (CLIC+CTF3)	Lanc group
• muon cooling	Liv HEP + Lanc RF	RG RS

[nm feedback, monitoring and control Adams]

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Example: BBU - ILC 2mrad extraction line

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Manchester

Shared Large Aperture Magnets

QD0 SD0 QF1 SF1 Q,S,QEXF1

Disrupted beam & Sync radiations

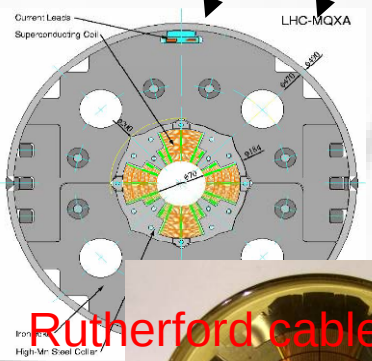
250 GeV e!

60 m

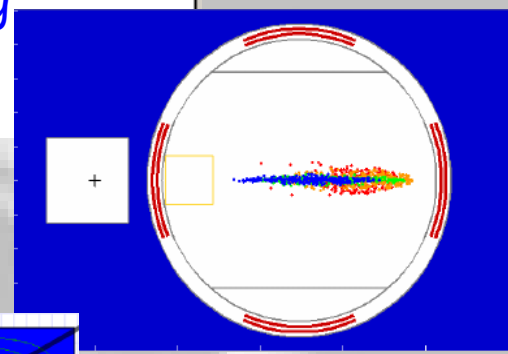
Beamstrahlung

Incoming beam

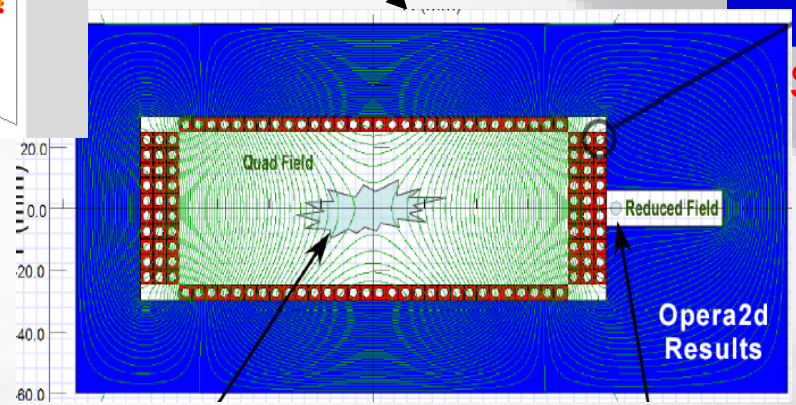
No beam & γ losses for nominal parameters



pocket coil quad



Super Septum Quad (B.Parker) or Warm Panofsky septum quad (C.Spencer)



Rutherford cable SC quad and sextupole

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Wake Fields

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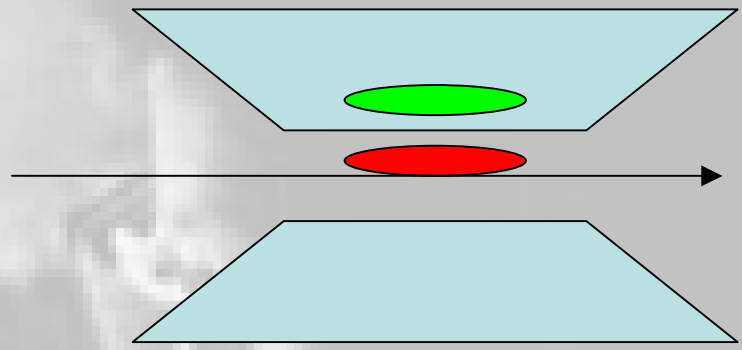
Manchester

- Beam particles passing through an aperture produce image charges and currents
- Image charges and currents push beam particles around
- Wake fields in Collimators are a big concern for Linear Collider



1. Kick depends on bunch position. Jitter in x gives jitter in x'. Kick factor. Low luminosity
2. Particles within bunch get different kick. Increase in emittance. Low luminosity.
3. Particles in tail see bigger effect than particles in head. Banana bunches. Need particle-by-particle simulation as bunches non Gaussian

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High Lumi Polarised e⁺ @ ILC

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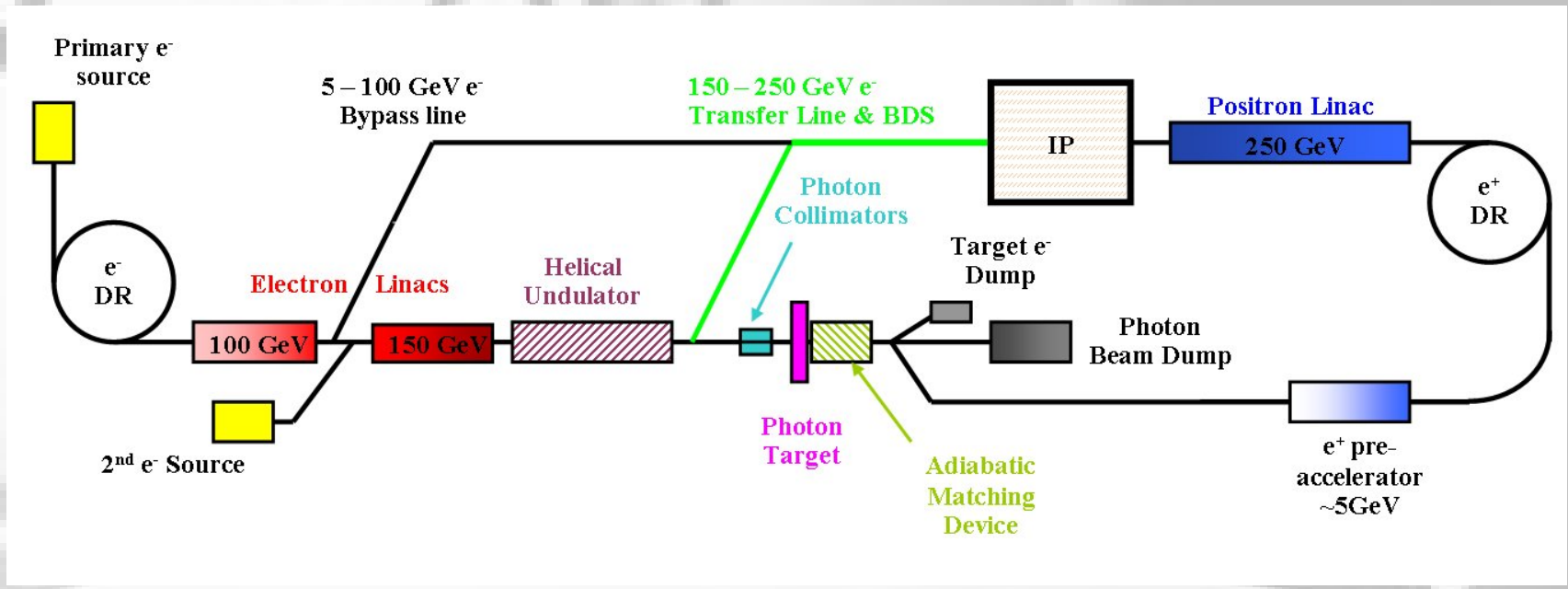
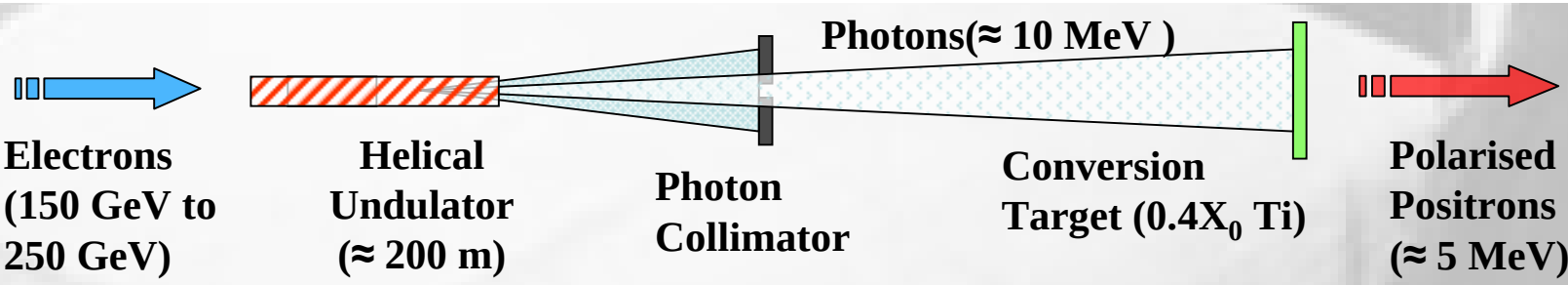
Liverpool

- ILC baseline (+ ASTeC, Cornell, LLRL, DESY, RAL, SLAC)
- 10^{14} pol^{d} e^+ s^{-1}, 2820 bunches/pulse, 5 pulses s^{-1}





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High Lumi Polarised e^+ @ ILC

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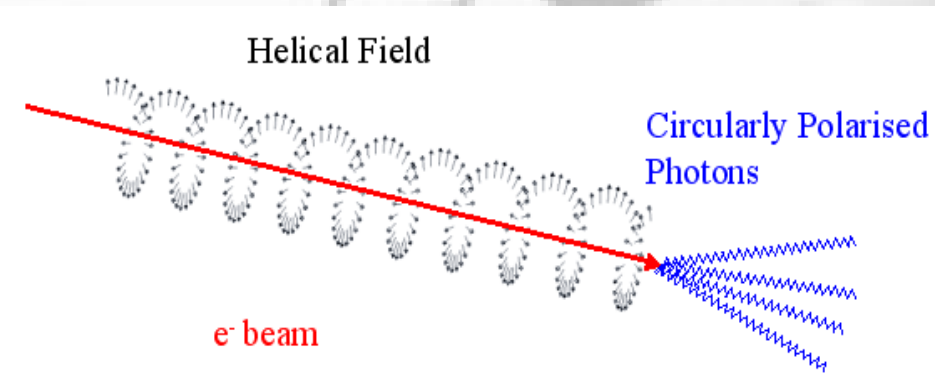
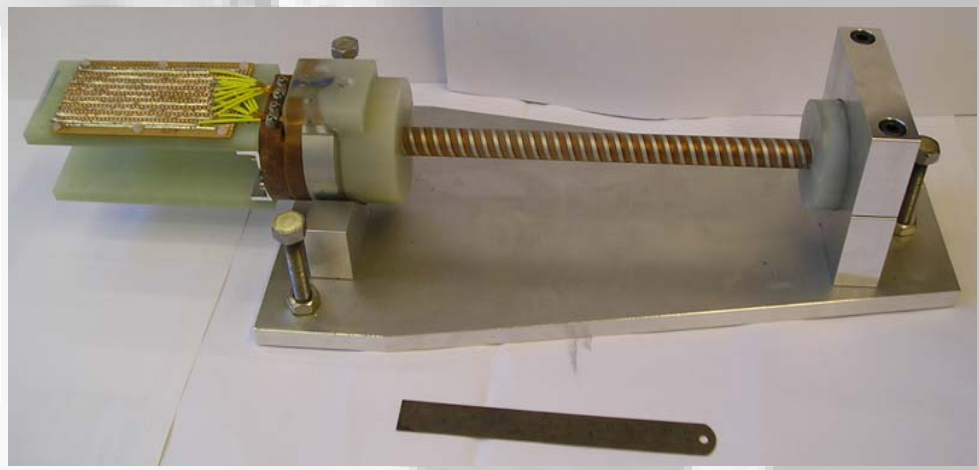
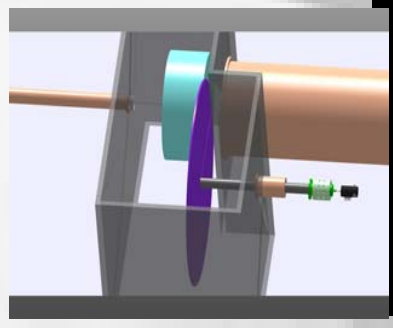
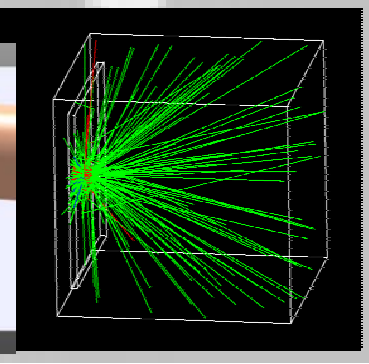
- small p'type → ~~warm/permanent~~ or cold technology √
  → full scale (2×2m) sector p'type ?
  → ILC polarised γ-source ~200 m ! ?





- pairs target:
  engineering challenge
- e^+ capture ? e^- dump ?





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High Lumi Polarised e+ @ ILC

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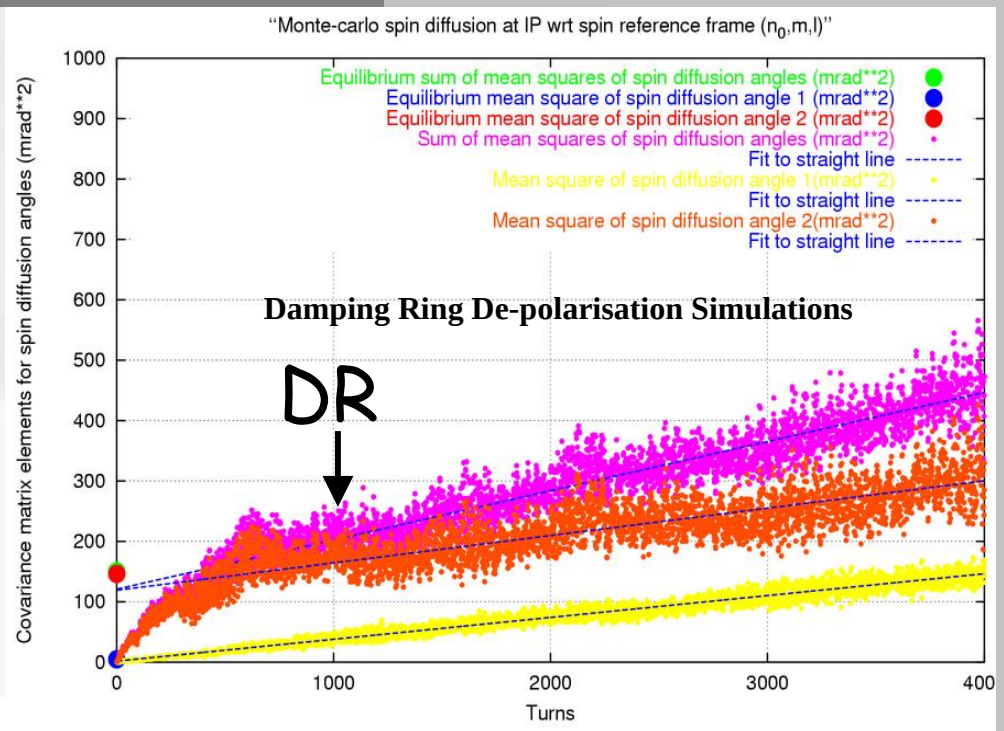
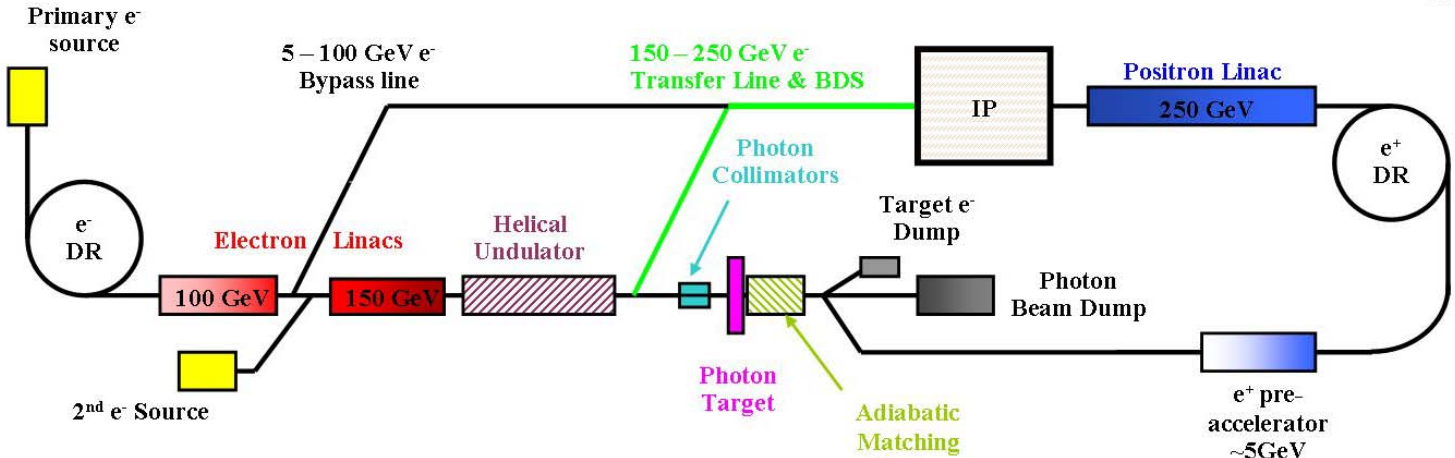
- polarised e+ → ILC IP
  - spin "tracking"
  - spin dynamics
  - HERA experience
  - $\sigma(\Uparrow)^2 < 300$ mrad^2

↳ DR baseline choice





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Beam-beam @ Cockcroft

PPARC
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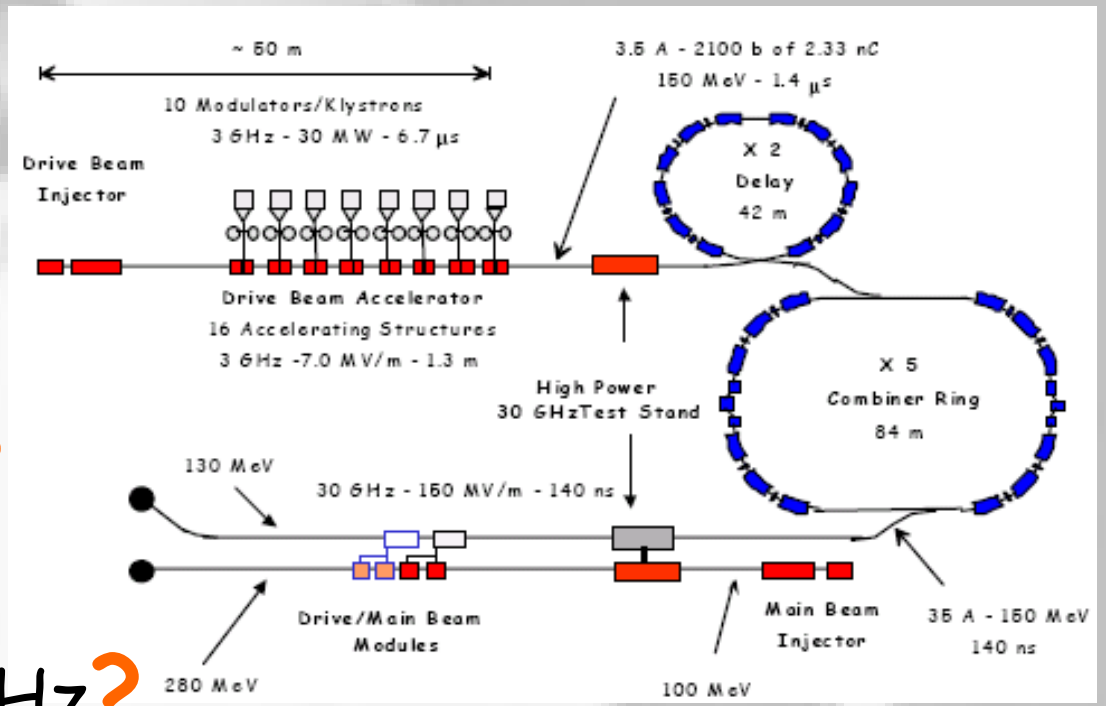
Lancaster

- beam-beam acceleration @ CERN: CTF3 e^+e^-
  - CLIC Test Facility
  - 150 MV/m ?
- drive beam
  - time structure ?
  - 30 GHz power out ?
- probe beam acceleration @ 30 GHz?



→ 2 students + Cockcroft/Lancaster supervision
  - coherent radiation dynamics
  - crab cavity

Project Examples

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Lancaster
Manchester

- add huge value to future PPARC science:

e g LHC "FP420"

- R&D project detectors close to LHC beam
- world's most challenging new beam

pp 7 ⊗ 7 TeV 10^{34} cm^{-2}s^{-1}

"hands-on" LHC commissioning

- enable project with essential AST:
  wake-fields, BBU

e g MICE RF

- large volume, warm, cavity in ***B***
- enable project with essential AST:
  multi-pacting ↔ surface chemistry and topology

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PPARC Science @ Cockcroft Dec05

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- focused on issues underpinning PPARC PP strategy
  - ILC …, intense ν, LHC
- leadership roles in aspects of LCABD/ILC with international collaboration
  - design: optics, RF crab, wake-field, e^+ intensity, DR
  - prototyping: undulator, target
- strengthening new involvement in intense ν
  - MICE: RF
  - NF global scoping study
- building expertise and starting new work in
  - RF cavity R&D: surface, multi-pacting, e-cloud
- beginning beam-beam collaboration @ CTF3 (ERLP)

3. New Generation

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RC-UK Facilities

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- prioritisation to come (SR06/7) ?

Large Facility	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20
Supermemo (PPARC)													
Upgrade the Mega Amp Spherical Tokamak (MAST) at Culham (EPSRC)													
Household Panel Study (ESRC)													
A New Scientific Opportunities at the European Synchrotron Radiation Facility (CCLRC)							EPSRC						
A 4GLS (CCLRC)							EPSRC						
A UK Participation in the construction of a facility for antiproton and ion research (EPSRC)							EPSRC						
Oceanographic Research Ship (NERC)													
National Institute for Medical Research (NIMR) (MRC)													
! ISIS Second Target Station Instruments (CCLRC)													
A The European X-Ray Laser Project (CCLRC)									EPSRC				
A Linear Collider (PPARC)									PPARC				
Gravitational Wave Detection Facilities (PPARC)													
! A A Megawatt Class Spallation Neutron Source for Europe (CCLRC)									EPSRC				
Extremely Large Telescope (ELT) (PPARC)													
European High Performance Computing Service (EPSRC)													
A Diamond Phase II (CCLRC)										EPSRC			
A Neutrino Factory (PPARC)										PPARC			
HIPER: High Power Experimental Research facility (CCLRC)													
Mini Fabrication facility for Nanotechnology (EPSRC)													
Square Kilometre Array (PPARC)													

Key: £0-10m | £10-25m | £25-50m | £50m+

! SNS (1 MW) from 2007

! JPARC (1 MW) from 2009/10 ?

EPSRC science
PPARC science

A accelerator science and technology

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AST for EPSRC Science

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- energy
  - European *X*-ray laser - RF structure
  - 4GLS (energy recovery ERLP†) - beam-beam (fs !)
- intensity …
  - European *X*-ray laser - RF structure
  - 4GLS (energy recovery ERLP†) - fs bunch control
    - fs bunch manipulⁿ
  - FAIR/ISOLDE - hadron/ion
  - ISIS/ESS - neutron
- monitoring+control
  - everywhere

†available now adjacent to CI (hands on)

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Fourth Generation Light

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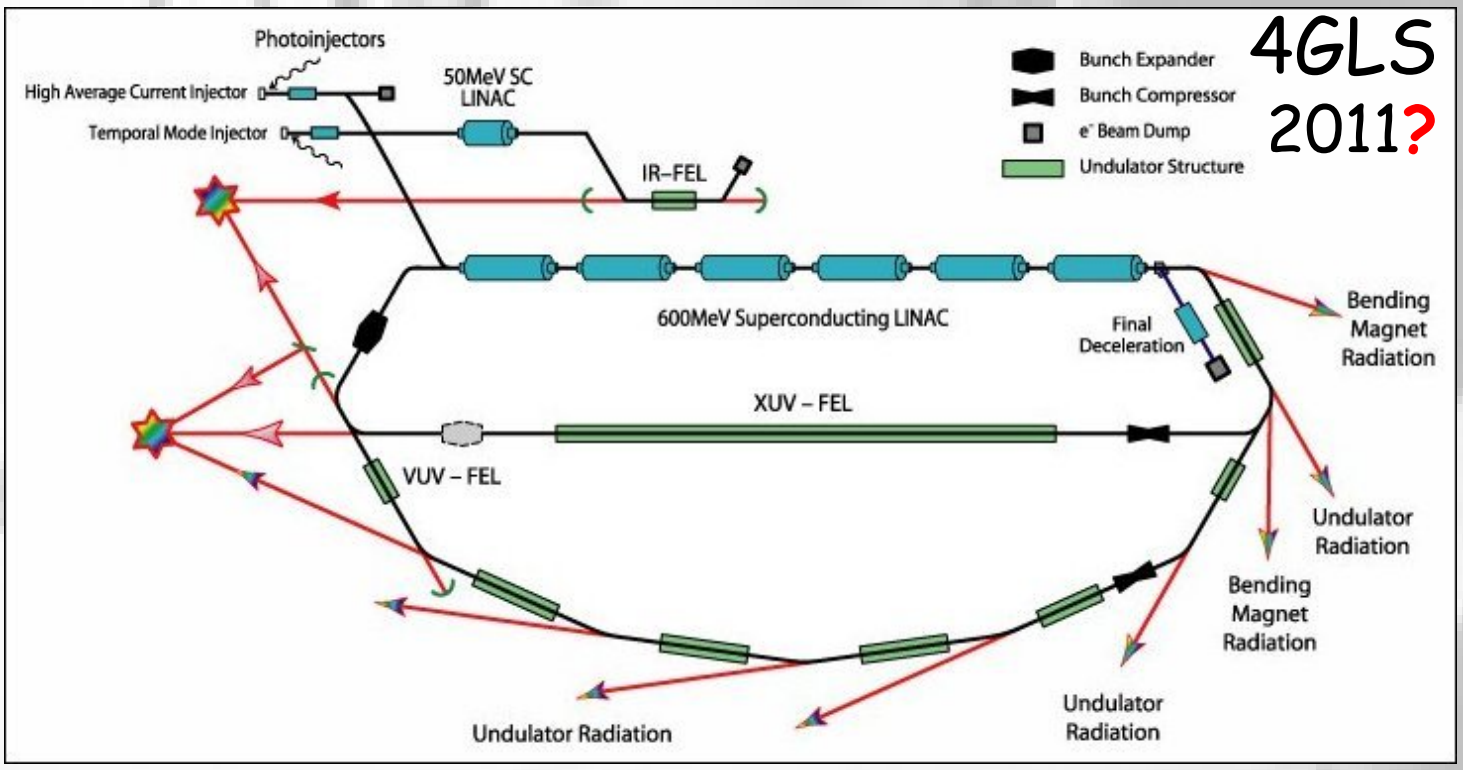
- single pass acceleration and deceleration
  energy recovery
- e⁻ energy storage ring ← non-equilibrium e⁻ beam



- synchronise fs bunches → dynamics: pump/probe

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Energy Recovery Linac

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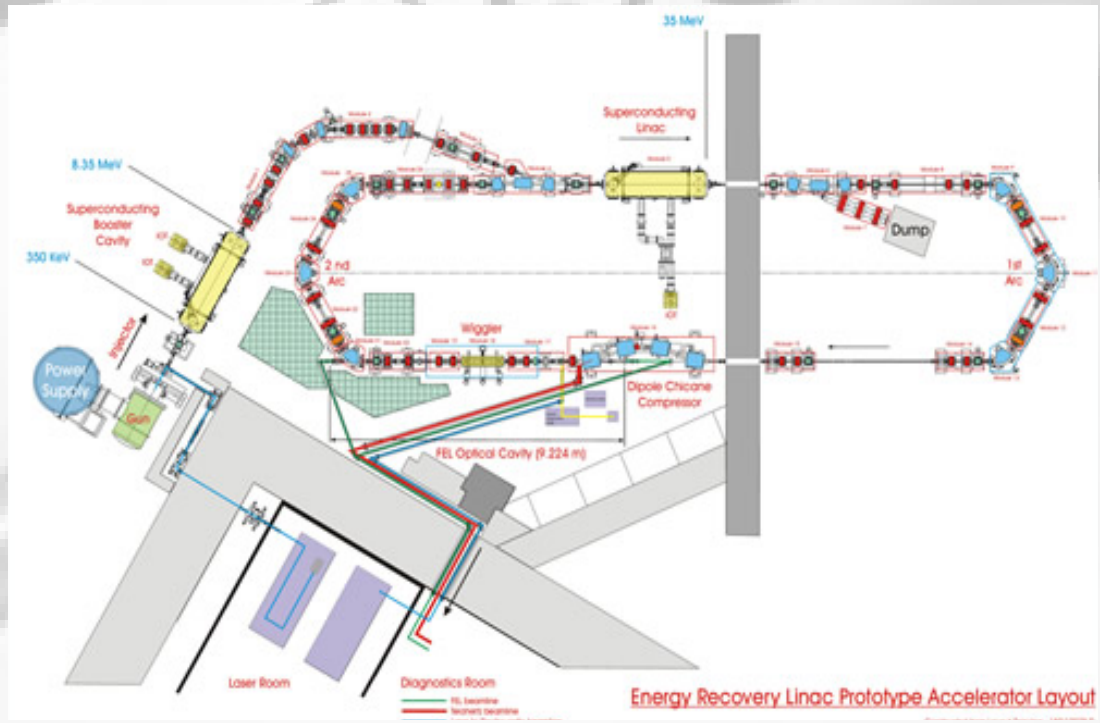
- 4GLS proof of principle
  - "hands-on" beam-beam ERL
  - ATF ?



ERLP 2006!

http://www.4gls.ac.uk/ERLP.htm

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On-going New Generation AST

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Lancaster (+4GLS+ASTeC)

- multipactor discharge
  - 2ndary electron rf field emission (e2V)
- phase locked magnetrons
  - low power phase locking
- radial inductive output tube (IOT for ERLP)
  - high power rf for ν-factory and ILC crab
- high brightness gun - 4GLS
  - x10 state of art with ERLP measurements
- stability of an energy recovery linac
  - additional energy recovery instabilities

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New Generation Theoretical AST

EPSRC NEST
PPARC CCLRC
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- stability analysis of magnetically focussed, non-planar, particle trajectories — Lanc
- develop^{ts} in "spin-field" theory — Liv DESY
- field analysis of accelerator beams based on a relativistic charged fluid model — Lanc
- beam-beam coherent synchr radn — Lanc @ CLIC
- laser plasma-wave acceleration — Lanc S'clyde (ALPHA-X)
  - coherent transition radiation
  - plasma undulation
- non-linear partial differential equns in relativistic beam dynamics + radiation reaction — Lanc
- QED in AST — IPP Durham
  - bunch-bunch blow-up/depolarisation

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Charged Continua *with* Self-fields

NEST
PPARC
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- new approach to dynamic behaviour of charged particle distributions in EM field
  - intrinsic divergence in Lorentz-Dirac
- linear equations (asymptotic) for self-consistent radiation fields and charged currents in ultra-relativistic configurations
- tensor analysis with symmetries and light-cone structure of space-time

↳
- analysis of coherent radiation in complex devices
- controlling charged particles with laser beam

John Dainton
UK Nuclear Physics @ FAIR
DL/CI
Jan 25/26 2006

Charged Continua *with* Self-fields

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- charged fluid field equ^{ns} → bunch profile dynamics
  - inherent limitations of Lorentz-Dirac equation (divergence)
  - charged continuum + self-consistent vacuum field
    + space-time symmetry and light cone structure

$$\nabla \cdot e = \frac{m_0 c^2}{q_0}\gamma\rho,$$

$$\nabla \times b = \frac{1}{q_0}\rho p + \frac{1}{c^2}\frac{\partial e}{\partial t},$$

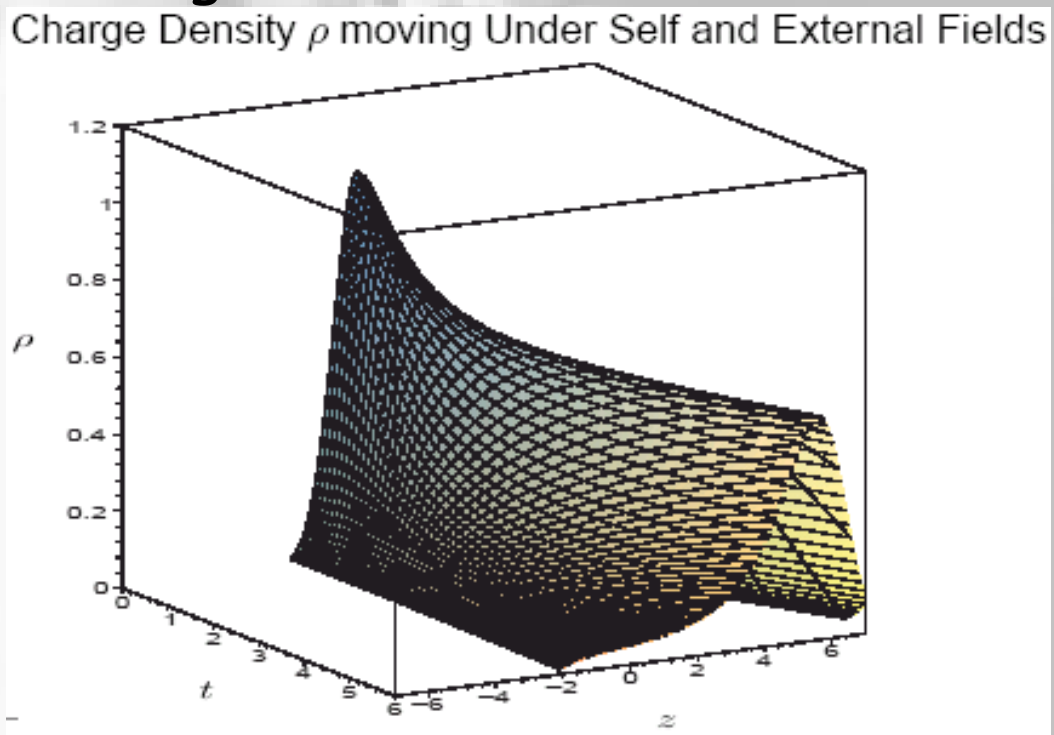
$$\nabla \times e + \frac{\partial b}{\partial t} = 0,$$

$$\nabla \cdot b = 0,$$

$$\gamma\frac{\partial p}{\partial t} + \left(\frac{p}{m_0}\cdot\nabla\right)p = q_0\left(\gamma e + \frac{1}{m_0}p \times b\right)$$

$$-\gamma^2 + \frac{p\cdot p}{m_0^2 c^2} = -1,$$

$$m_0\frac{\partial}{\partial t}(\gamma\rho) + \nabla\cdot(\rho p) = 0$$



http://www.lancs.ac.uk/cockcroft-institute/papers/Cockcroft-05-04.pdf

New Generation AST @ Cockcroft Dec05

- building on
  - on-site facilities: ERLP → 4GLS
  - inherited expertise
    RF @ Lancaster/DL
    mathematical physics @ Lancaster+collabs
  - inherited collaboration e g ALPHA-X
  - new synergies developing with ASTeC/CCLRC
- build new projects in AST relevant to EPSRC science (EPSRC responsive project) and CCLRC (ASTeC and EPSRC science facilities)

↳ Nuclear Physics ?

John Dainton
UK Nuclear
Physics @ FAIR
DL/CI
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Intense Secondaries

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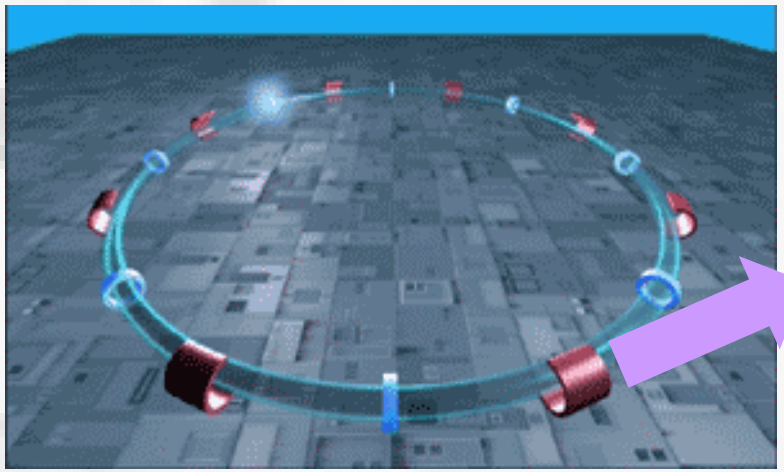
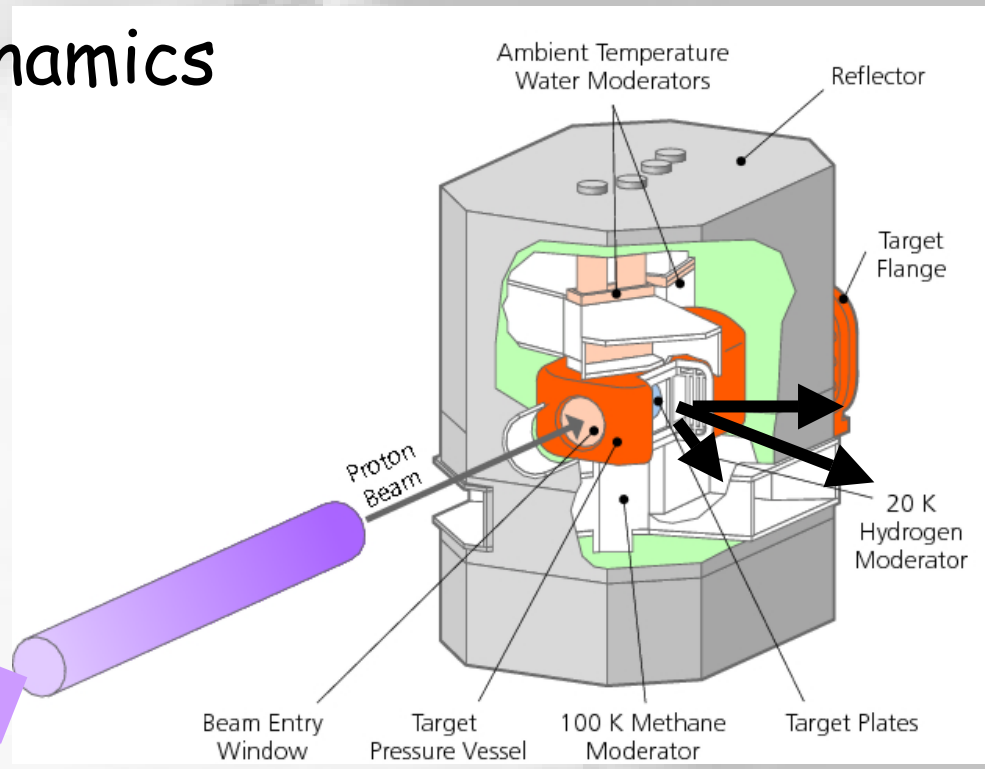
- accelerate protons and bombard target
  - intense "spallation" neutron pulses
    - structure and dynamics
      timed pulses
      uncharged probe
      magnetic probe





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Intense Secondaries

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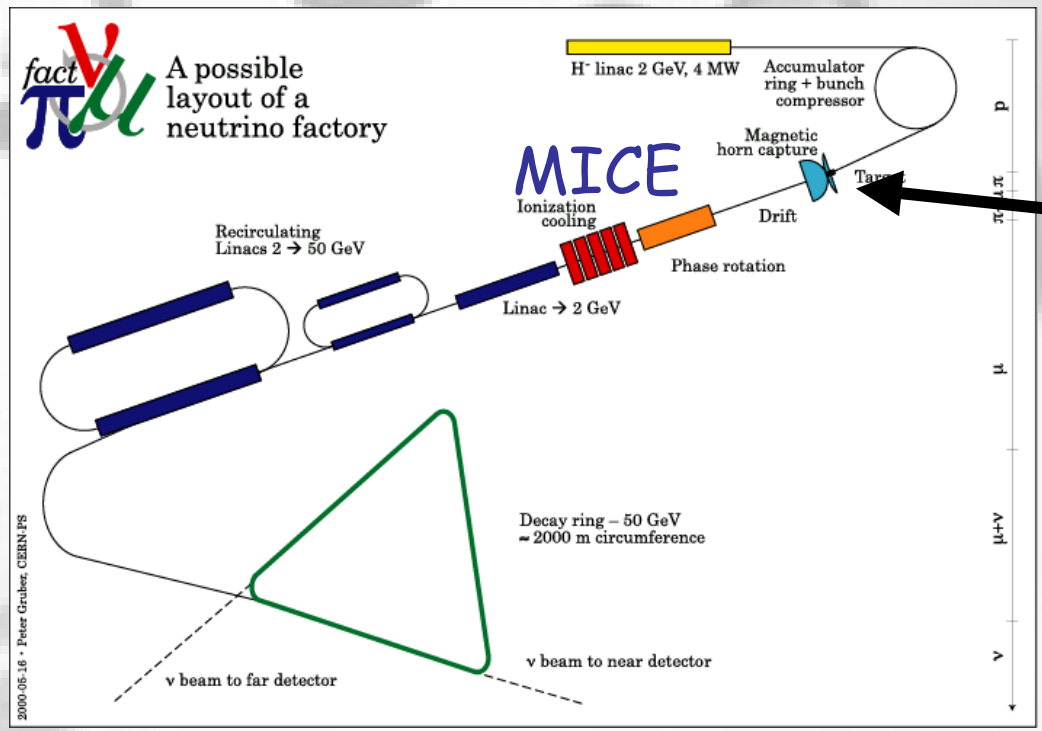
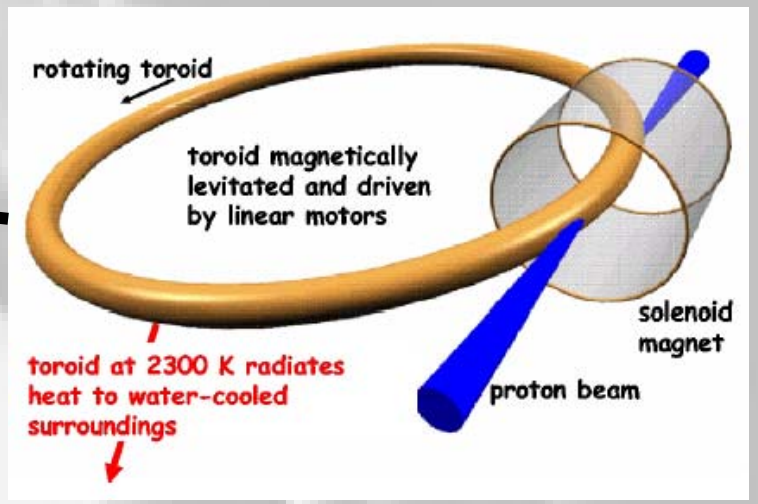
- accelerate intense protons into target





- "drivers" for next generation isotope, neutron, and neutrino beams

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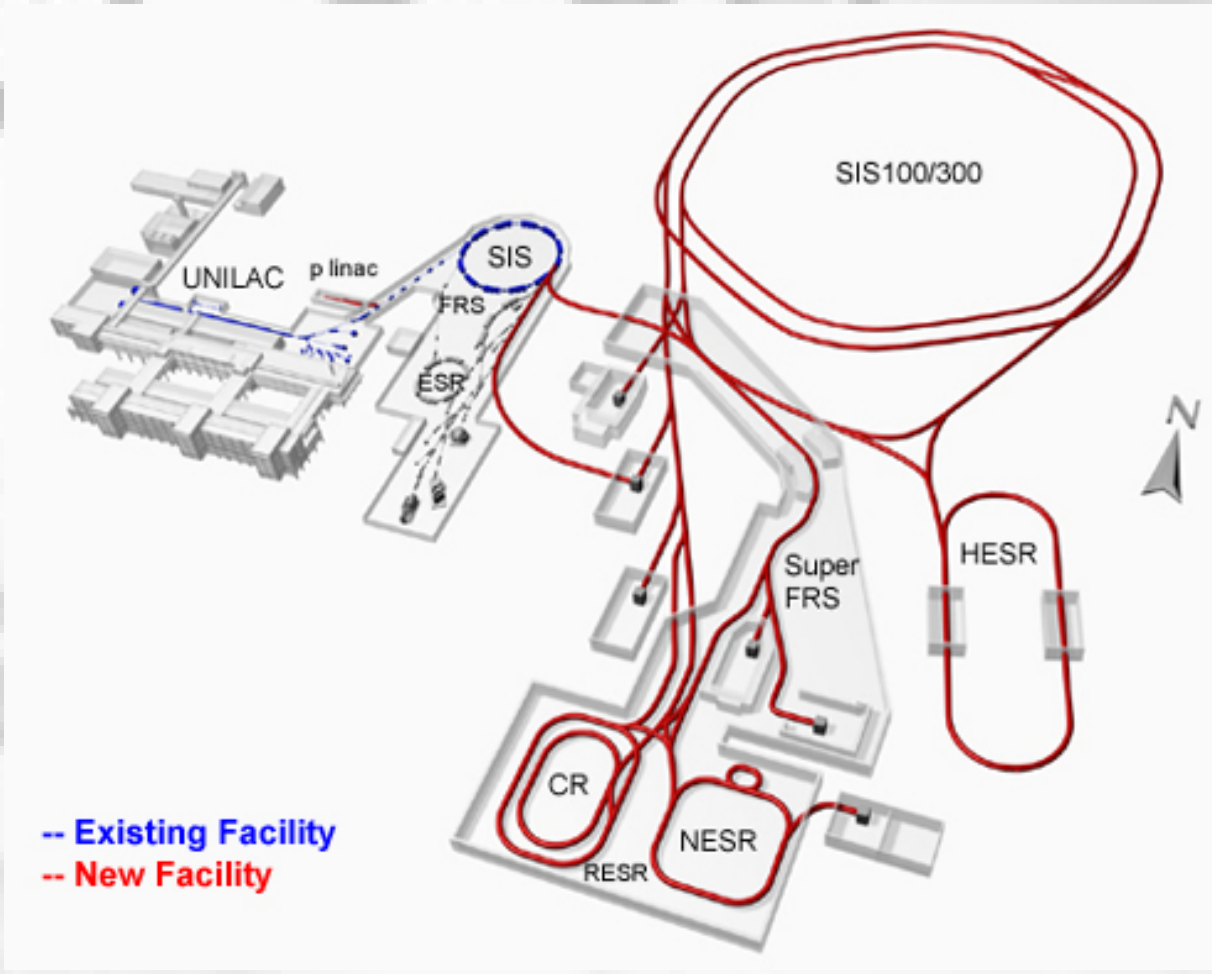
- intense ions

(polarised) protons

unstable ions

high energy cooling

beam delivery



4. Education and Training

http://www.lancs.ac.uk/cockcroft-institute/education.htm

Education and Training

- education + training panel
  (Chair: R Tucker → N Marks)
  - basic CI courses
    R Appleby: "Introductory AST" (term 1)
    N Marks et al: "Magnets" (terms 1 and 2)
    R Jones: "Wakefields & Impedance" (term 2)
  - specialist courses
    LeDuff, Holzer : "Advanced L and T dynamics"
    D Barber: "Spin Dynamics" (date tba)
    tbc: "SC Magnets"

Education and Training

- education + training panel
  (Chair: R Tucker → N Marks)
  - internal QC/QA
  - univs QC/QA
    course accreditation and assessment
    lecturer accreditation
  - distinguished colloquia (with ASTeC)
  - monitor weekly seminar (with ASTeC)

5. Summary

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Cockcroft Institute

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- continue to build mix of expertise with new appointments
- encourage staff to build portfolio of "responsive" projects with external collaboration in next generation accelerator science and technology
- use collaboration in present consortia within and beyond CI (ILC GDE, BENE, LCABD, UKNF, CTF3 …) to build large scale proposals ready for machine approval e g e^+ source? RF?
- exploit local facilities to bring added value to new proposals

  ERLP/4GLS/ISIS/DIAMOND

… and Issues

- adequate funding within PPARC ?
  - student/PDRA throughput
  - kit
- open-mindedness in agencies beyond PPARC ?
  e g EPSRC/BT (in view of CCLRC and PPARC)
- cross-disciplinary synergy
- direct industrial involvement wherever possible
  → coordinate for enabling high-tech
  PPARC, RDA, RCUK
- scale of industrial involvement ?
  ↳ scale of R&D investment

Northwest
REGIONAL DEVELOPMENT AGENCY