Transport of ultra-short electron bunches in a free-electron laser driven by a laser-plasma wakefield accelerator

University of Strathclyde Glasgow

SUPA

M. P. Anania,
D. Clark, R. Issac, A.W. Reitsma, S. M. Wiggins and D. A. Jaroszynski

Pulsar Physics

Science & Technology Facilities Council

ASTeC

The Cockroft Institute

S. B. van der Geer, M. J. de Loos, C. A. J. van der Geer

M.W. Poole, J. Clarke,
B. Shepherd

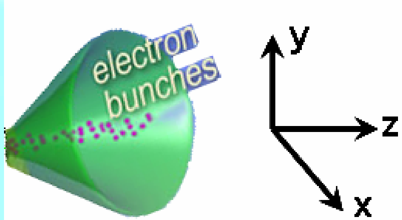
Outline:

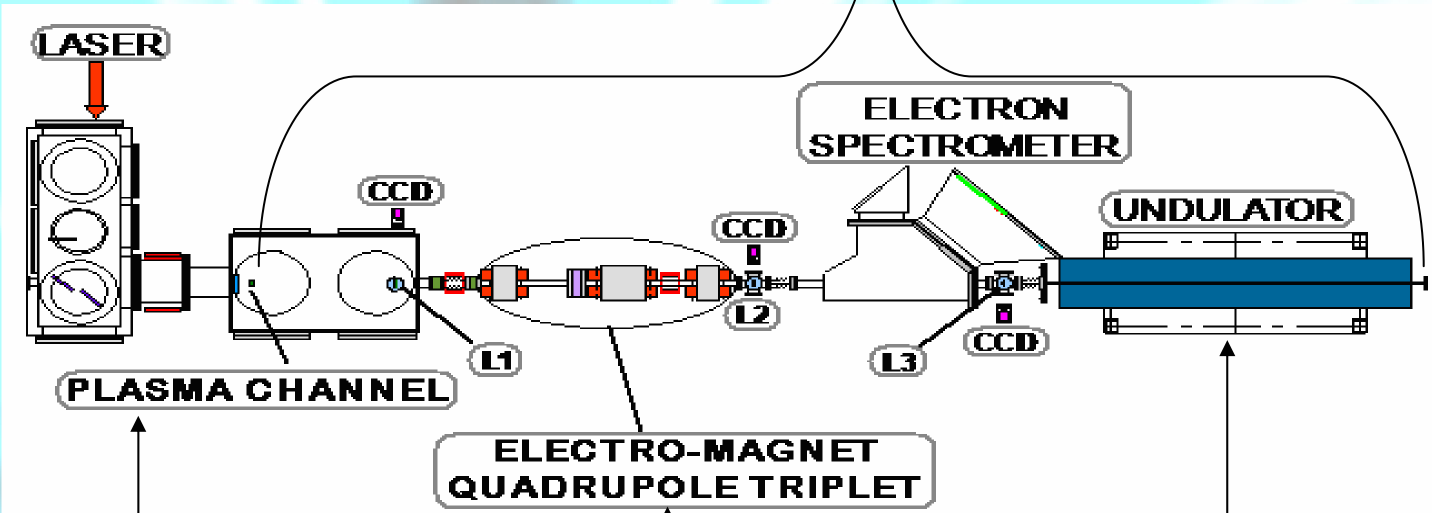
1. Motivation
2. The present ALPHA-X transport section
3. Design of the improved ALPHA-X transport section
4. Beam transport simulation results
5. Free-Electron Laser simulation
6. Conclusions and future work

Motivation: the present ALPHA-X transport line

Transport section (5 m)

The geometry:

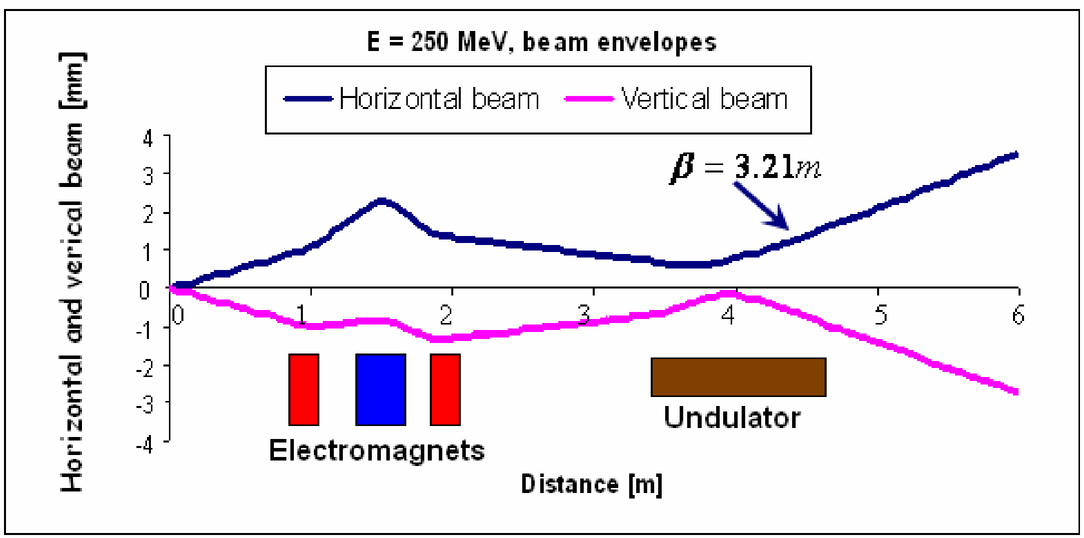




Gas jet or capillary

Current: 0 – 20 A

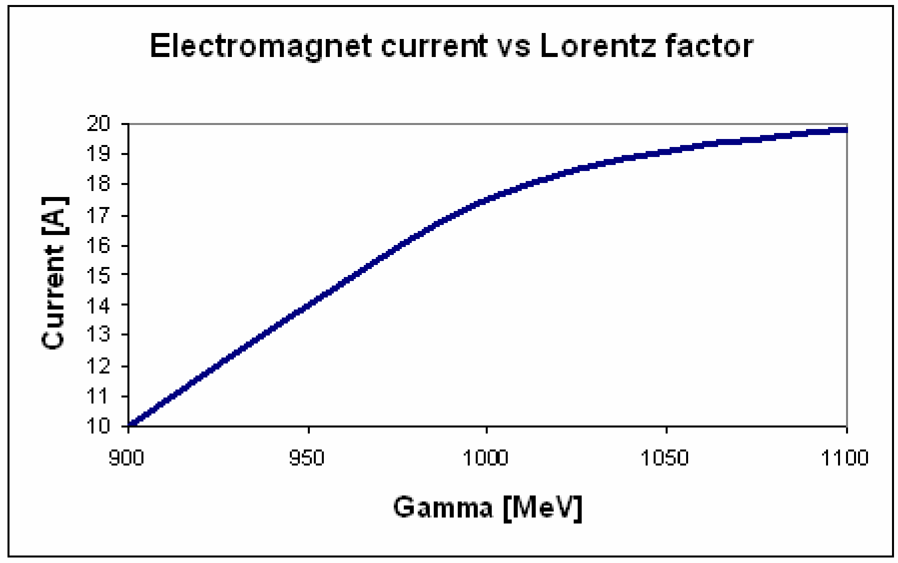
Undulator
Period: λ_u = 15 mm
\# periods: N_u = 100 – 200
Magnet gap: 3.5 – 10 mm
a_u = 0.25 – 1

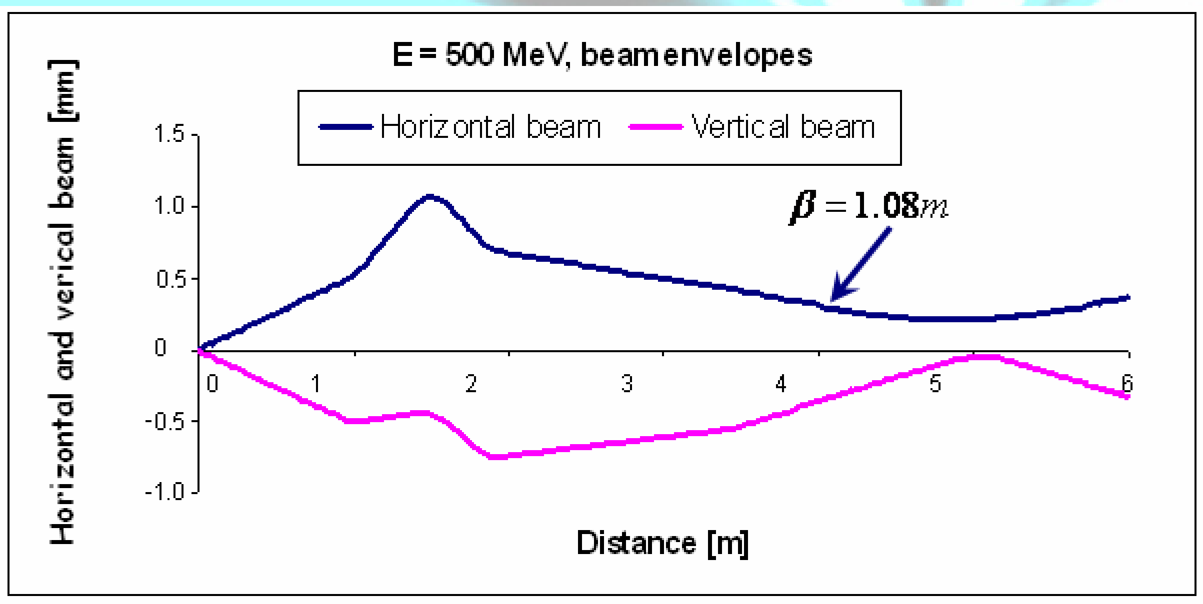


$$\beta = \frac{\pi \omega_0^2}{\varepsilon}$$

Motivation: the present ALPHA-X transport line

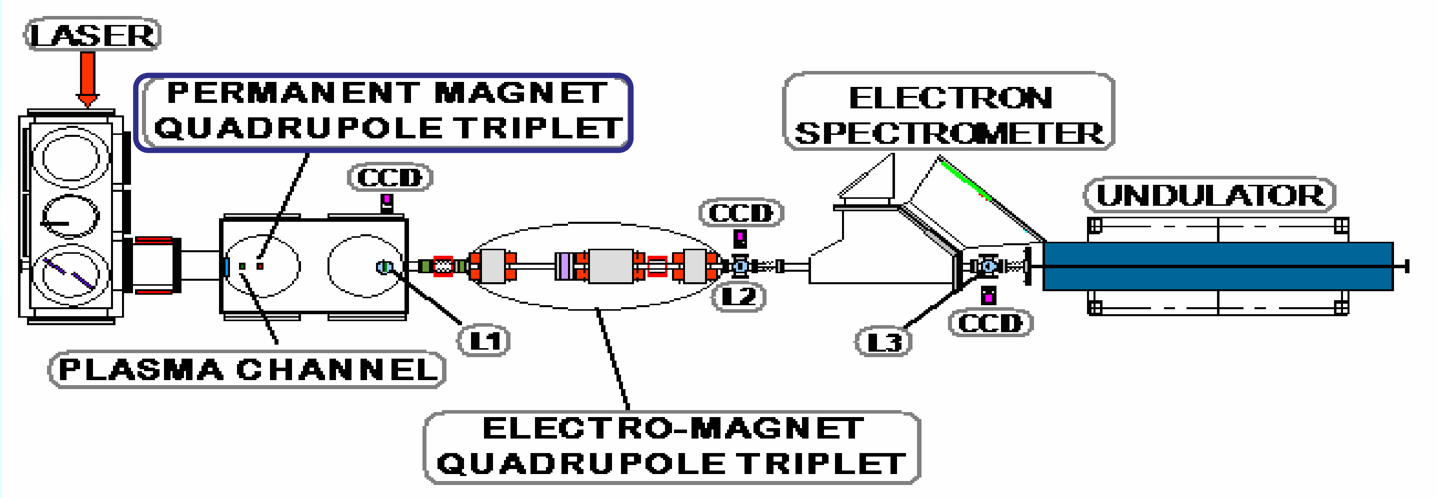
Maximum current in electro-magnets at about 600 MeV, where the magnetic field saturates.

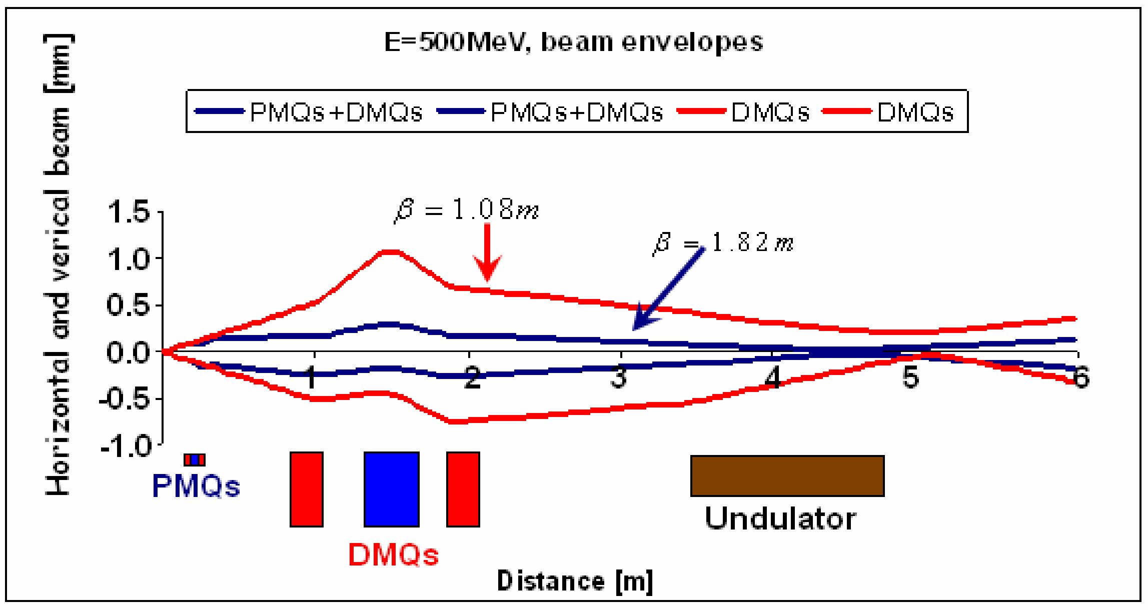




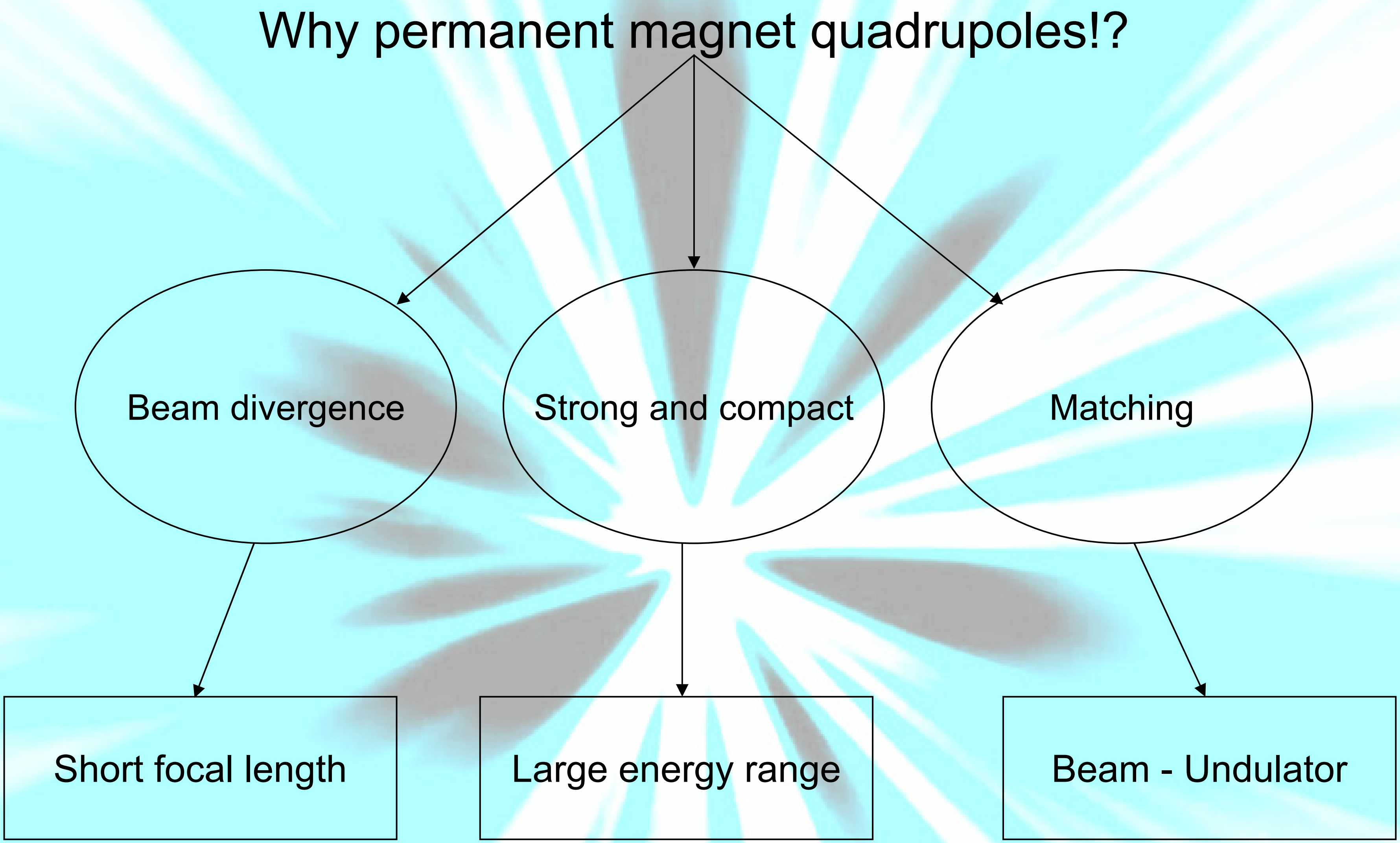
Still possible to focus beam up to 600 MeV, but beam parameters not ideal.

Motivation: the present ALPHA-X transport line

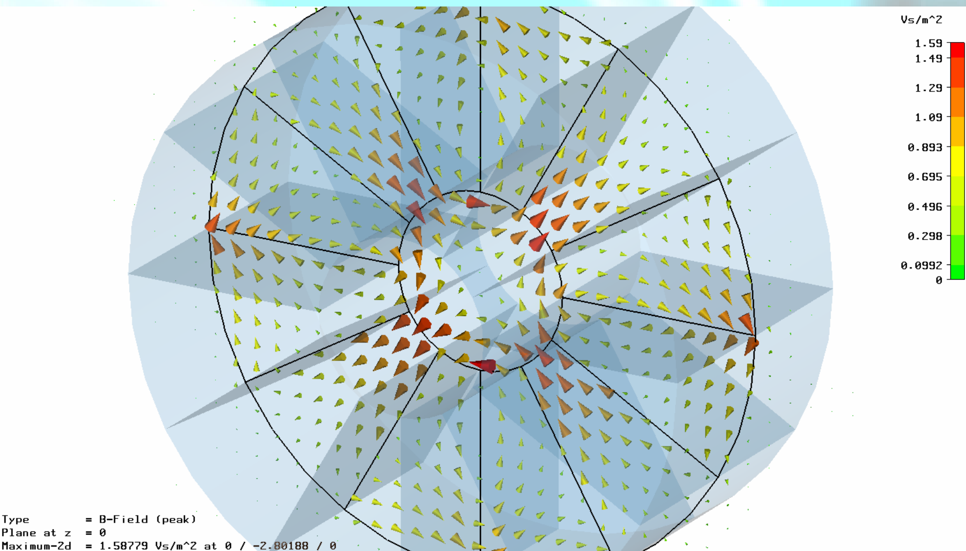


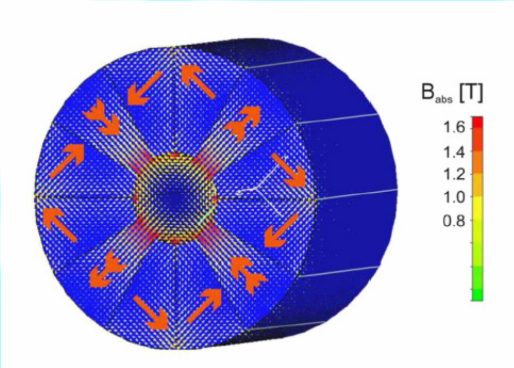


Design of the new ALPHA-X beam line



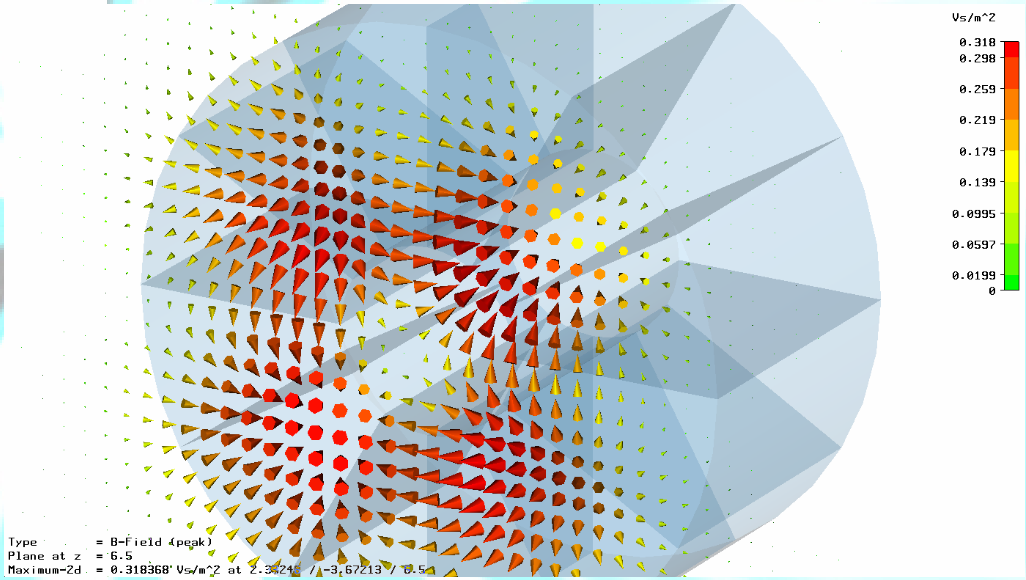
Design of the new ALPHA-X beam line

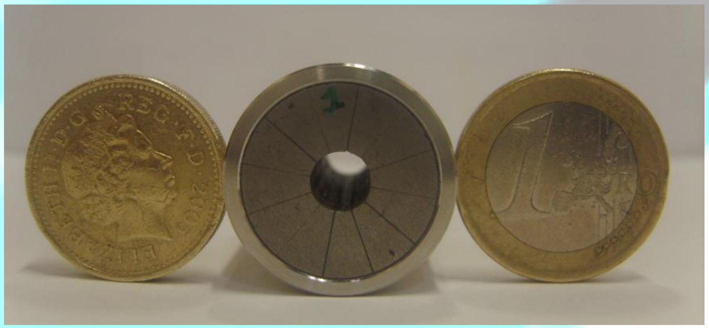




Magnetic field map in magnet.

Magnetic field map outside magnet – fringe fields.





How to cover all energies in range 50 – 1000 MeV?

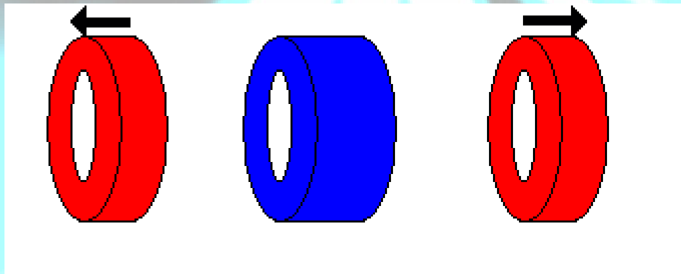
THE PROBLEM:

For different energies → beam geometry changes.

Properties of magnets → unchangeable

THE SOLUTION:

Move the exterior magnets of the triplet and, if necessary, the centre of the triplet.



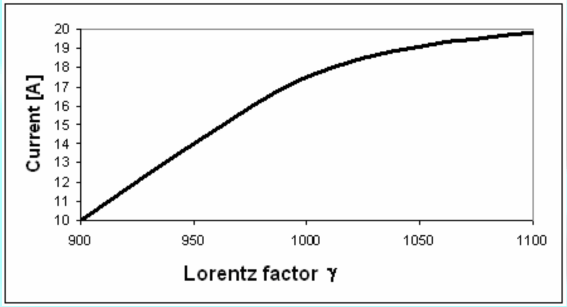
The problem

Uncertainty in the precise beam energy from shot to shot (focal point will change!)

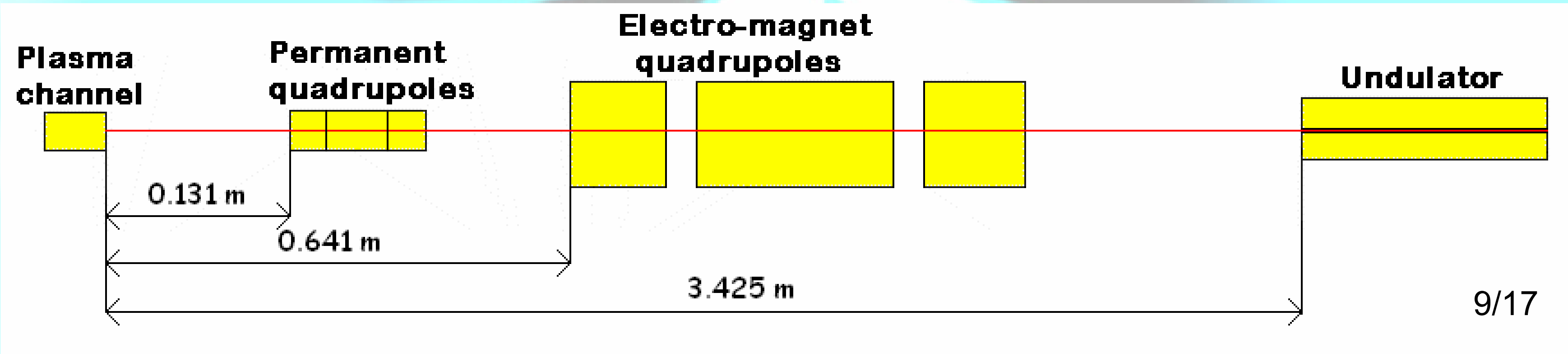
The solution

Permanent magnet position fixed and use electromagnetic quadrupoles to adjust focal point by varying the current (beta function varies only slightly)

The compromise



Above a certain energy, the magnetic field is not strong enough to focus the beam. Beyond 600 MeV we adjust the permanent magnet position!



Results: 250 MeV case

How do the permanent magnets change the beam properties?

Note: In simulation the permanent magnets are sandwiched together and the focal point is adjusted by varying the current in the electro-magnets.

Initial parameters

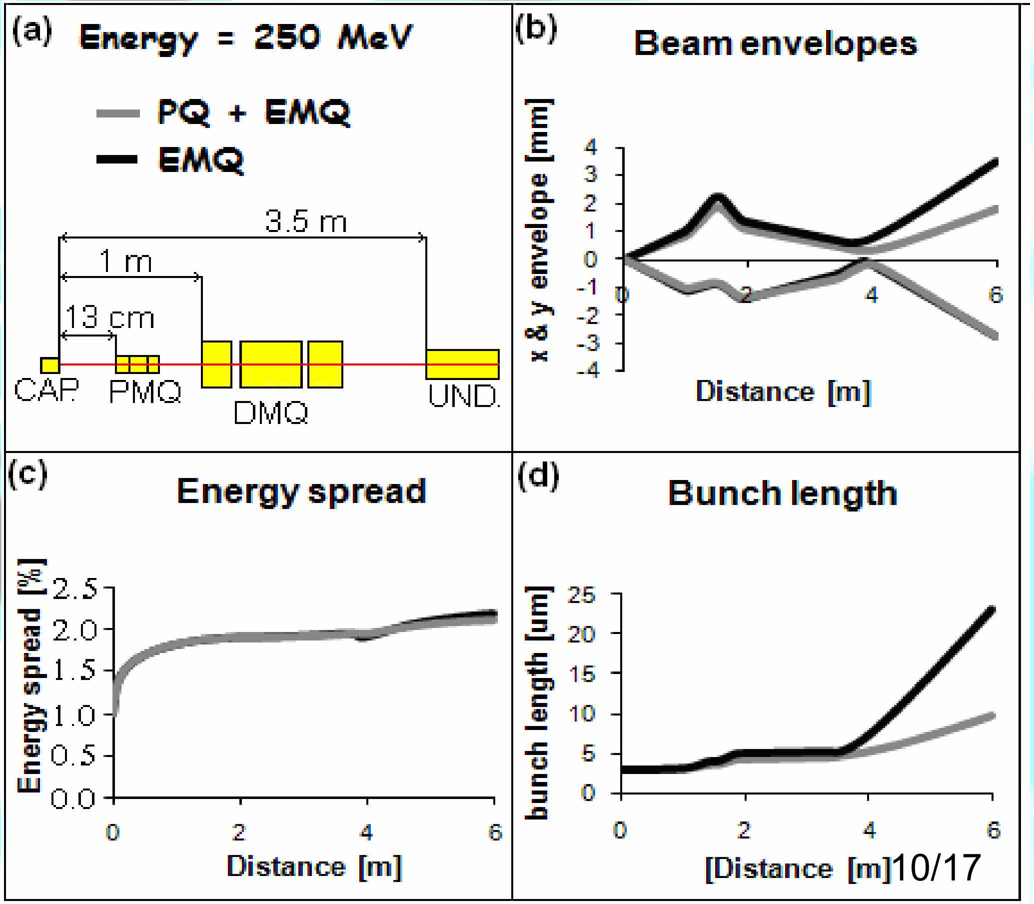
Energy spread: $\sigma_{\gamma} / \gamma = 0.01$

r.m.s. normalised emittance:
$\varepsilon_n = 1\ \pi$ mm-mrad

Bunch radius: 2 μm

Bunch length: 3 μm

Charge: 10 pC



Results: 500 MeV case

How do the permanent magnets change the beam properties?

Note: In simulation the permanent magnets are sandwiched together and the focal point is adjusted by varying the current in the electro-magnets.

Initial parameters

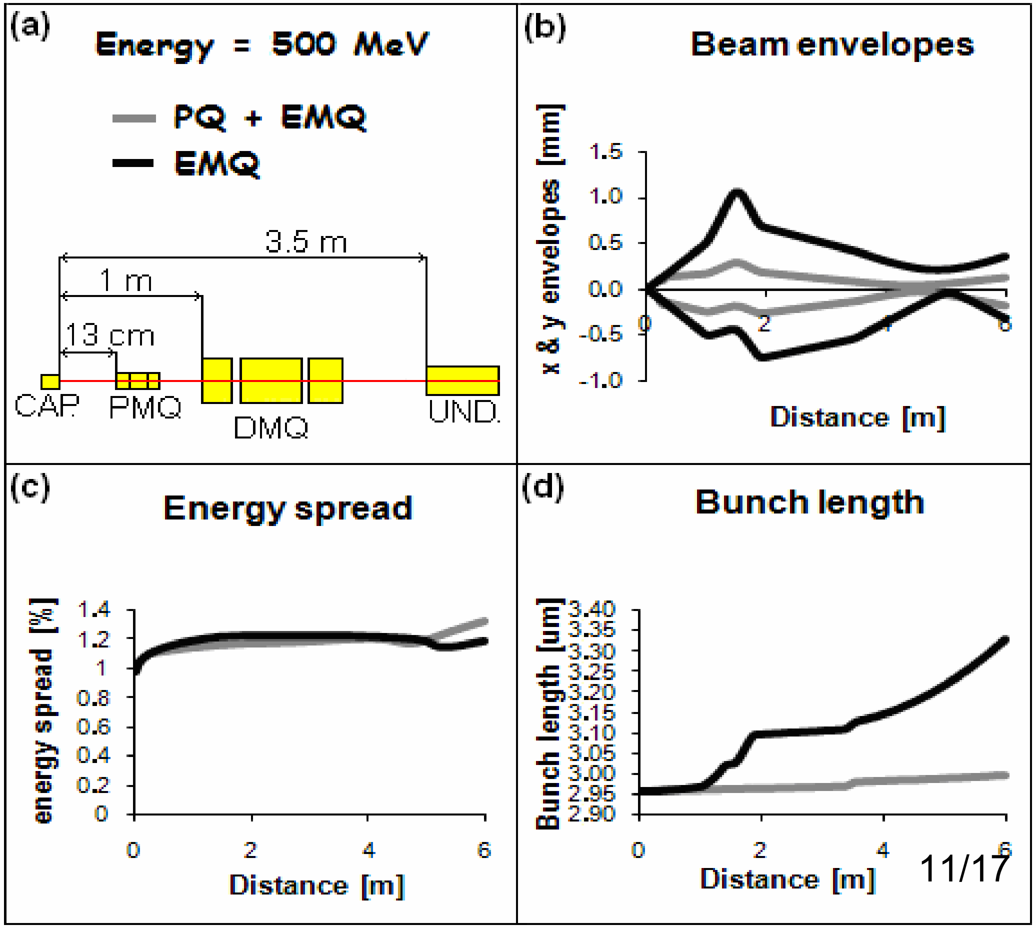
Energy spread: $\sigma_\gamma / \gamma = 0.01$

r.m.s. normalised emittance: $\varepsilon_n = 1\ \pi$ mm-mrad

Bunch radius: 2 μm

Bunch length: 3 μm

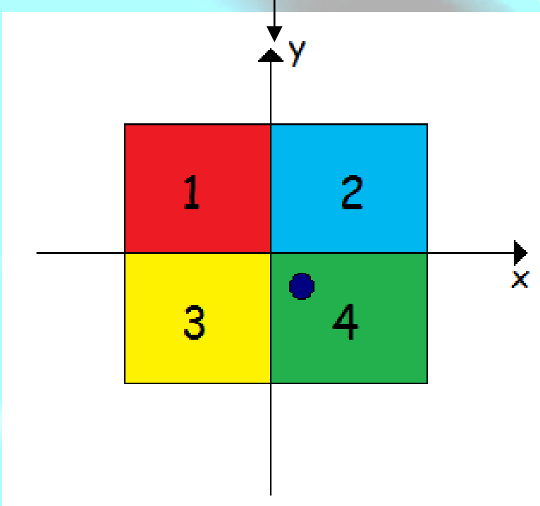
Charge: 10 pC



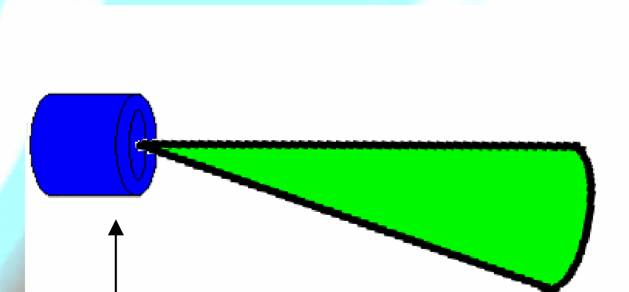
Results: off axis propagation

First type

Capillary: front view



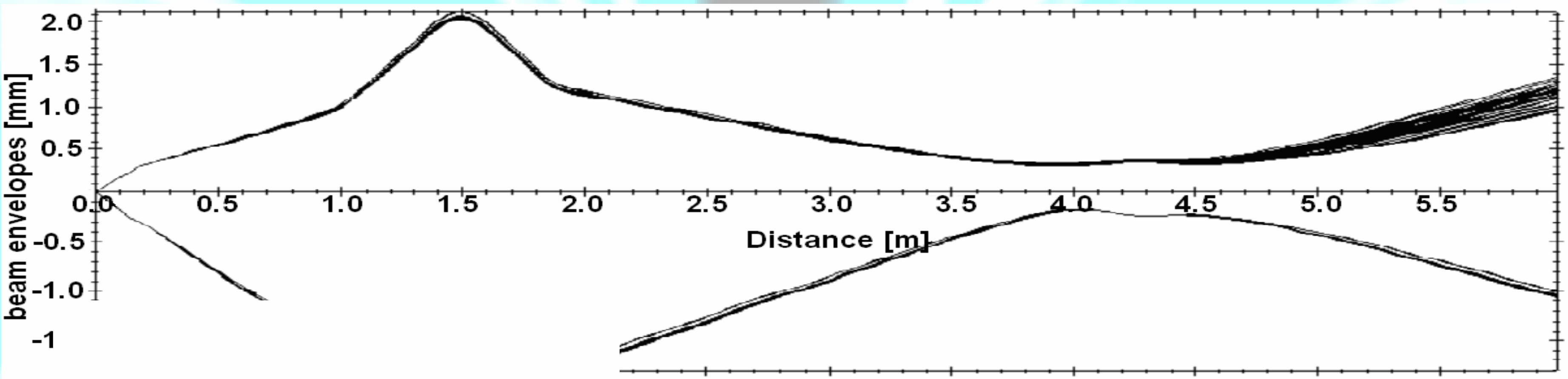
Second type

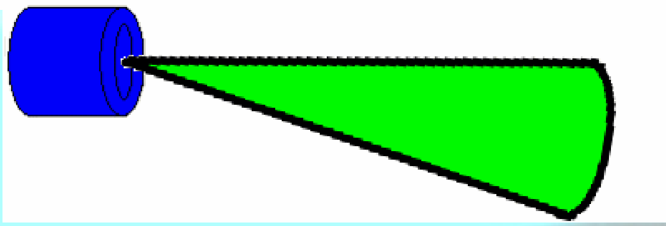


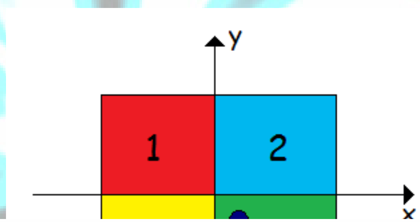
Capillary: side view

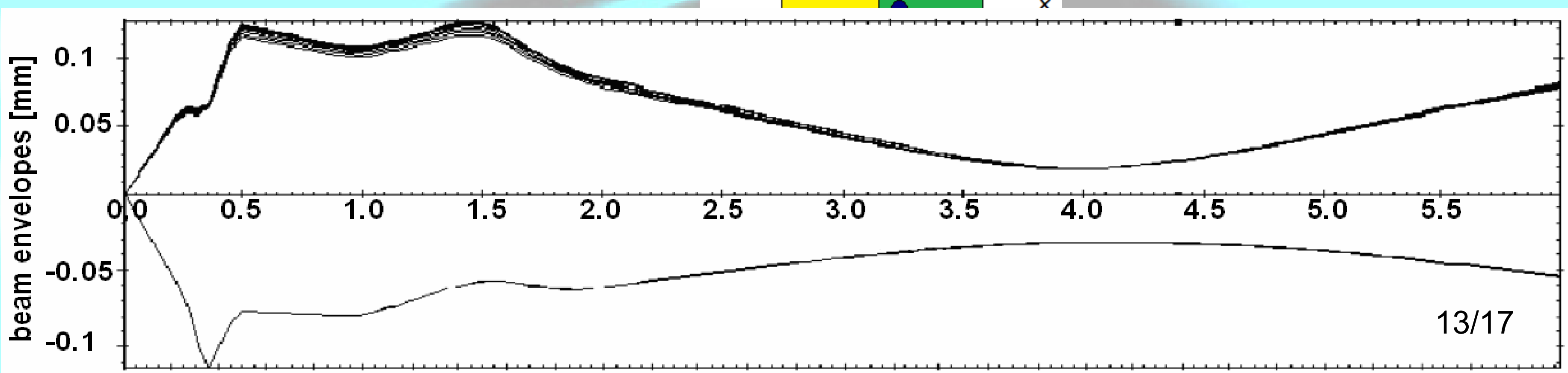
Results

Off-axis propagation









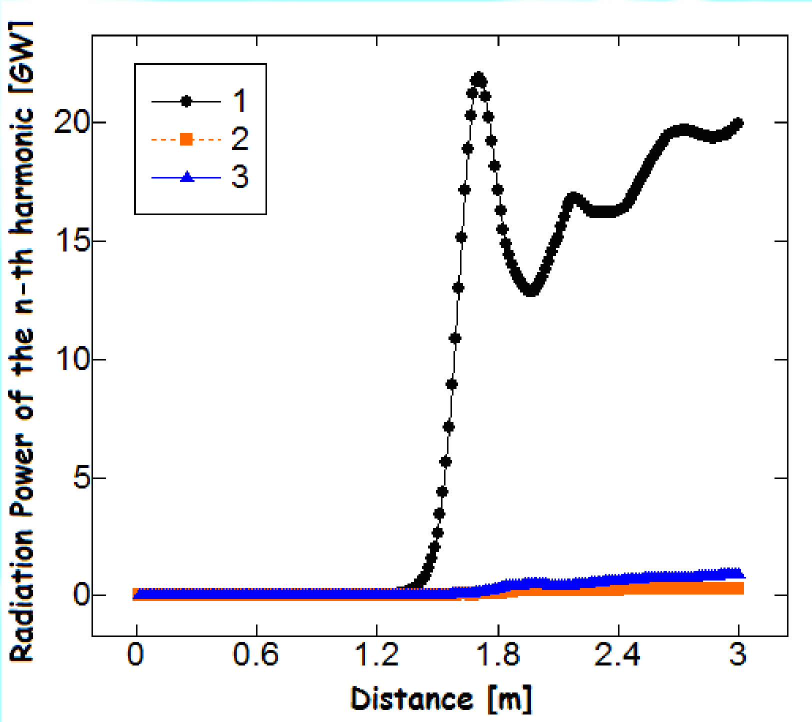
ALPHA-X as a FEL

Transport simulations demonstrate that the new PMQs are suitable for producing beam parameters that are ideal for driving a FEL

Electron Energy	100 MeV
Bunch length	1 μm
Bunch charge	50 pC
x emittance	1 π mm mrad
y emittance	1 π mm mrad
Relative energy spread	0.01
x beta function (average)	1.5 m
y beta function (average)	1.5 m
Seeding	Shot noise with λ = 241 nm
FEL ρ parameter	0.01114

Transport simulations demonstrate that the new PMQs are suitable for producing beam parameters that are ideal for driving a FEL

ALPHA-X as a FEL: Results



SIMULATIONS RESULTS:

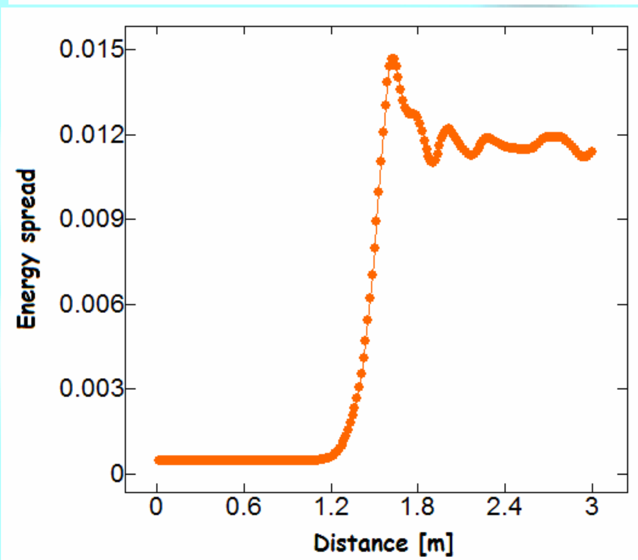
Saturation power(1st harmonic): 20 GW

@ saturation distance: 1.8 m,

THEORETICAL PREDICTIONS:

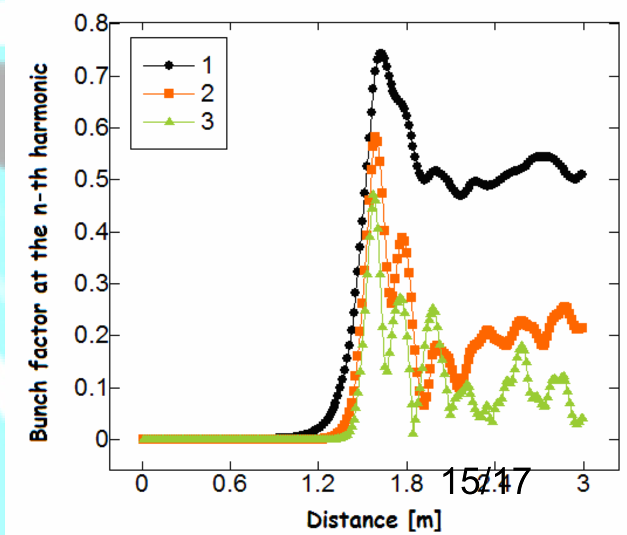
Saturation power: 21.44 GW

@ saturation distance: 1.735 m.



Relative energy spread initially 0.1%, reaches 1.5% at saturation (≈ FEL gain parameter ρ).

Bunching factor b ≈ 0.8 (as expected for a FEL).



Conclusions

Present beam line useable up to 600 MeV, but beam properties not ideal at high Energies.

Designed a triplet of permanent magnets → better transport (β, ☆, •z) → FEL amplification → possible to focus beams up to 1 GeV. Well matched.

FEL amplification is possible: obtain saturated power of ≈ 20 GW @ saturation length of ≈ 1.8 m for a wavelength of 241 nm and an energy of 100 MeV! First step.

Future work

PMQs have been assembled and are ready to be installed on ALPHA-X beam line.

Use GPT and TRANSPORT codes to simulate the electron spectrometer installed on ALPHA-X beam line (with W.A. Gillespie and A. MacLeod).

Use TRANSPORT as on-line tool during experiments to optimise quadrupole settings (both electromagnetic quads and new PMQs) for electron spectrometer.

Further FEL simulations for various beam parameters (in particular towards XUV wavelengths).