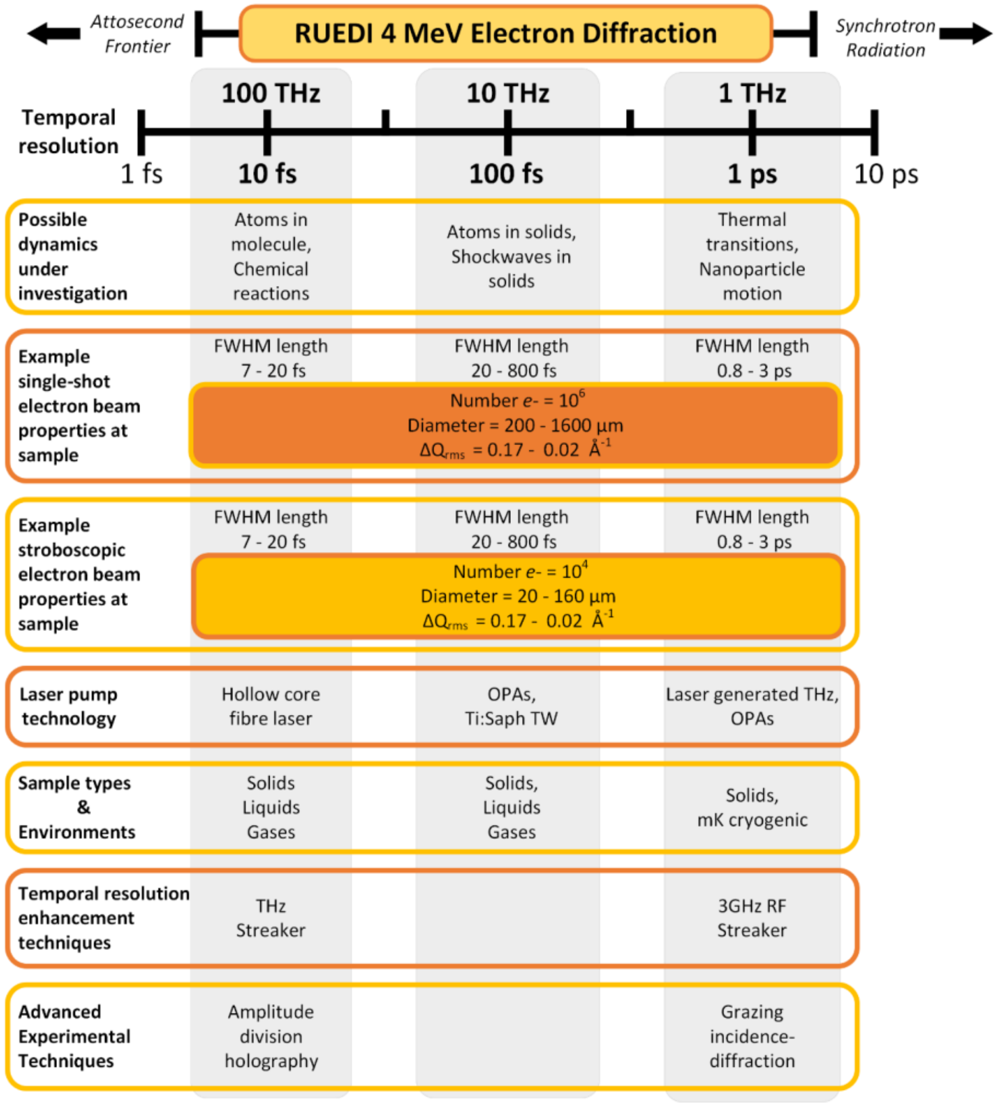
RUEDI

Ultrafast Diffraction Line

Julian McKenzie
Technical Design Lead, STFC Daresbury Laboratory

RUEDI Vendors Symposium
4h July 2025

Ultrafast Diffraction Line Performance

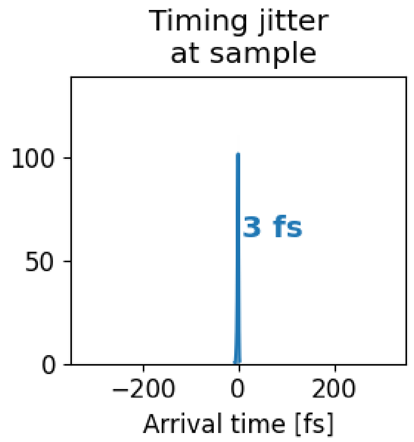


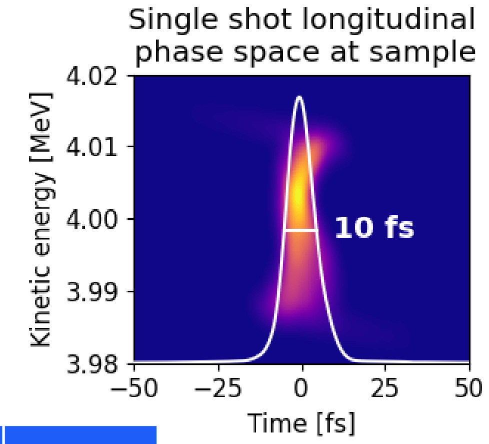
- 4 MeV
- 400 fC produced at the gun
- 1.6-160 fC charge at the sample after collimation
- Few fs time of arrival jitter at the sample
- < 10 fs bunch length
- Up to 7 nm coherence lengths
- Emittance 2-50 nm rad level

RUEDI

RUEDI Capabilities

- Electron beam parameters:
  - <4 MeV
  - <10 fs temporal resolution
  - <7 nm coherance lengths
  - Single-shot capable
  - Tuneable magnification/camera length (0.4 – 40 m)





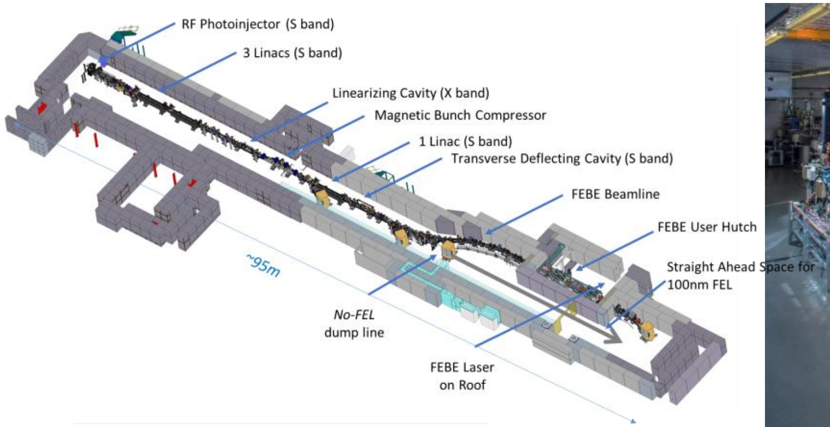
Parameter	Min	Max	Unit
Number of electrons	10^4	10^6	
Spot size *(diameter)*	30	400	um
Temporal resolution *(FWHM)*	5	500	fs
ΔQ *(FWHM)*	0.04	0.2	$Å^{-1}$

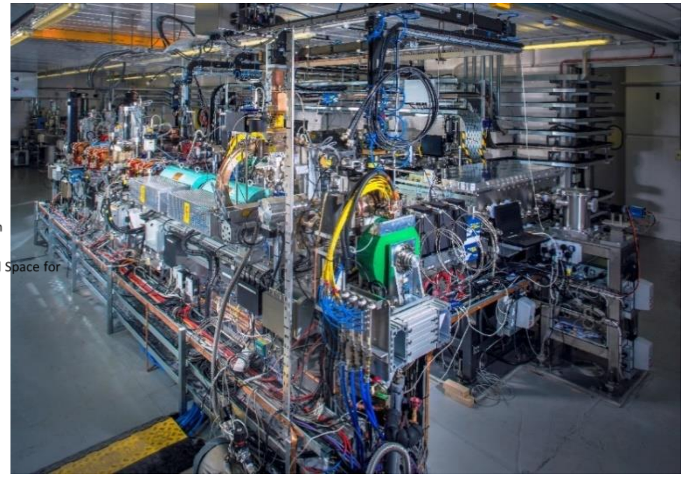
- Sample environments:
  - Solid state
  - Liquid + gas jets
  - Cryogenic temperatures

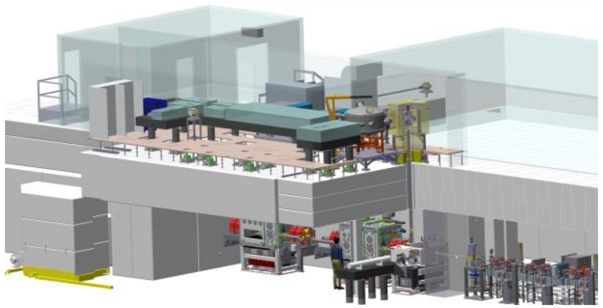
- Laser pumps
  - UV-IR-THz wavelengths
  - HCF for <10 fs pulse lengths
  - *High intensity TW ($>10^{18}$ W.cm^{-2})*

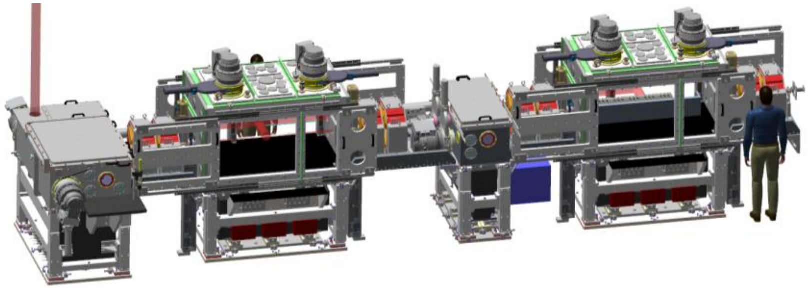
STFC Expertise

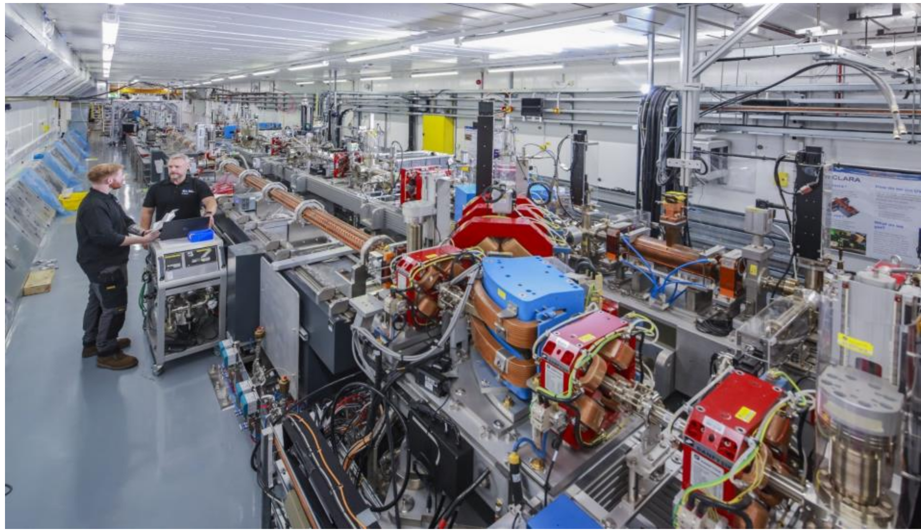
- Large-scale accelerator systems that cover most of the known RUEDI components
- More limited experience in pump-probe electron diffraction
  - Sample chambers:
    - Environments, control, exchange, diagnostics
  - Detectors







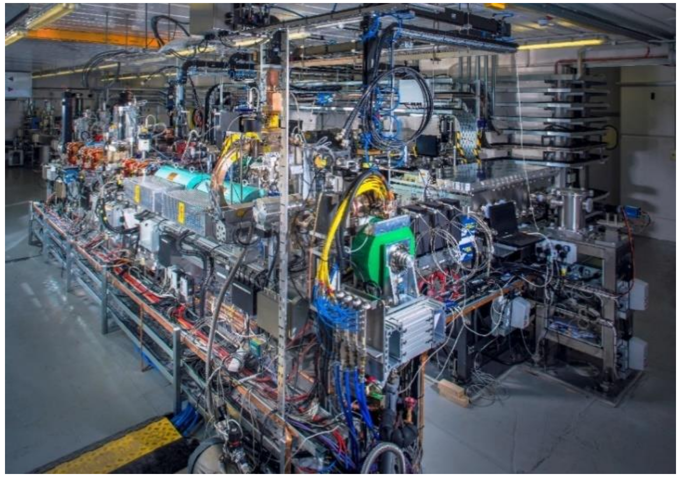




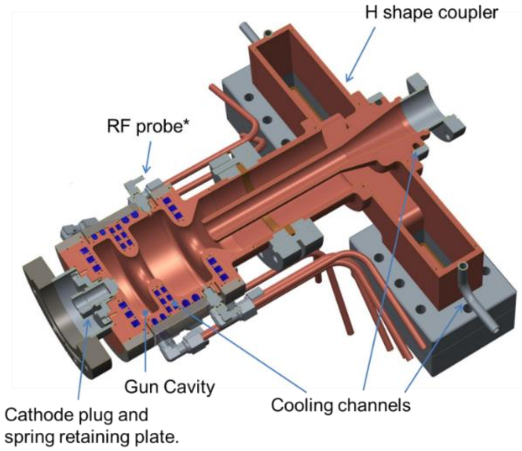
Example images of CLARA, co-located with RUEDI in Electron Hall at STFC Daresbury Laboratory

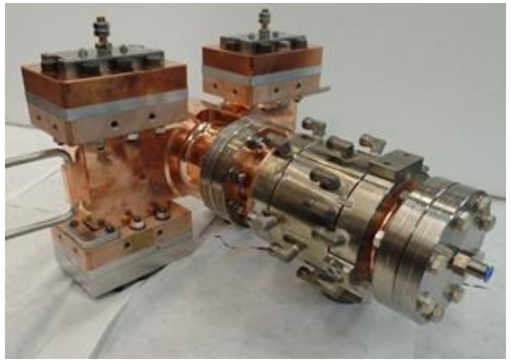
Daresbury Laboratory Expertise

Design, build, and operation of particle accelerator facilities

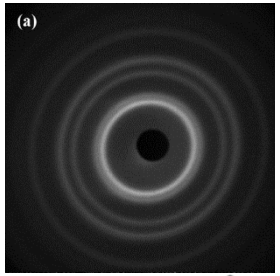


Femtosecond photoinjector development

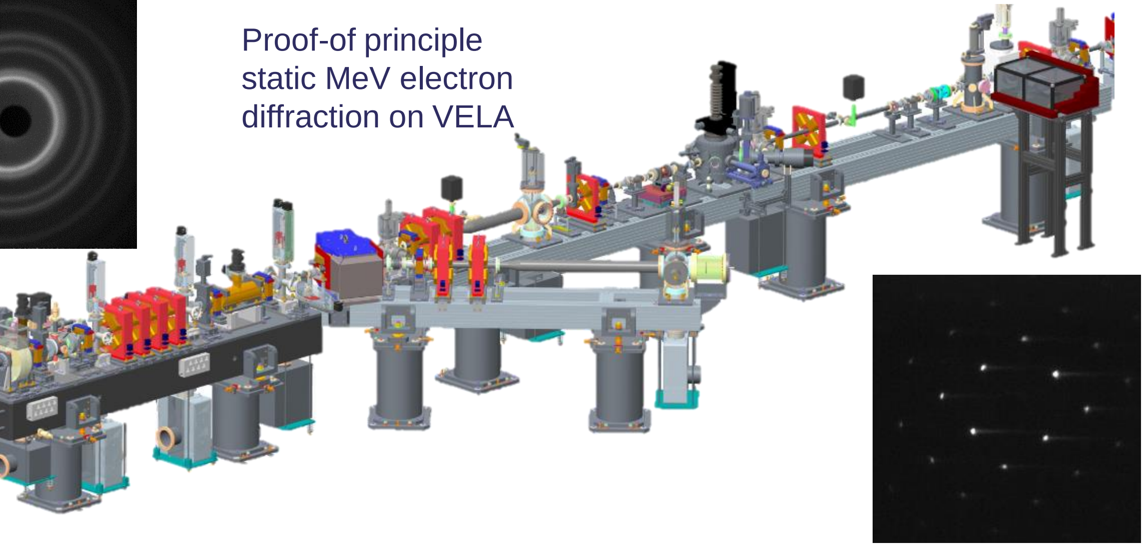




MeV UED Experience



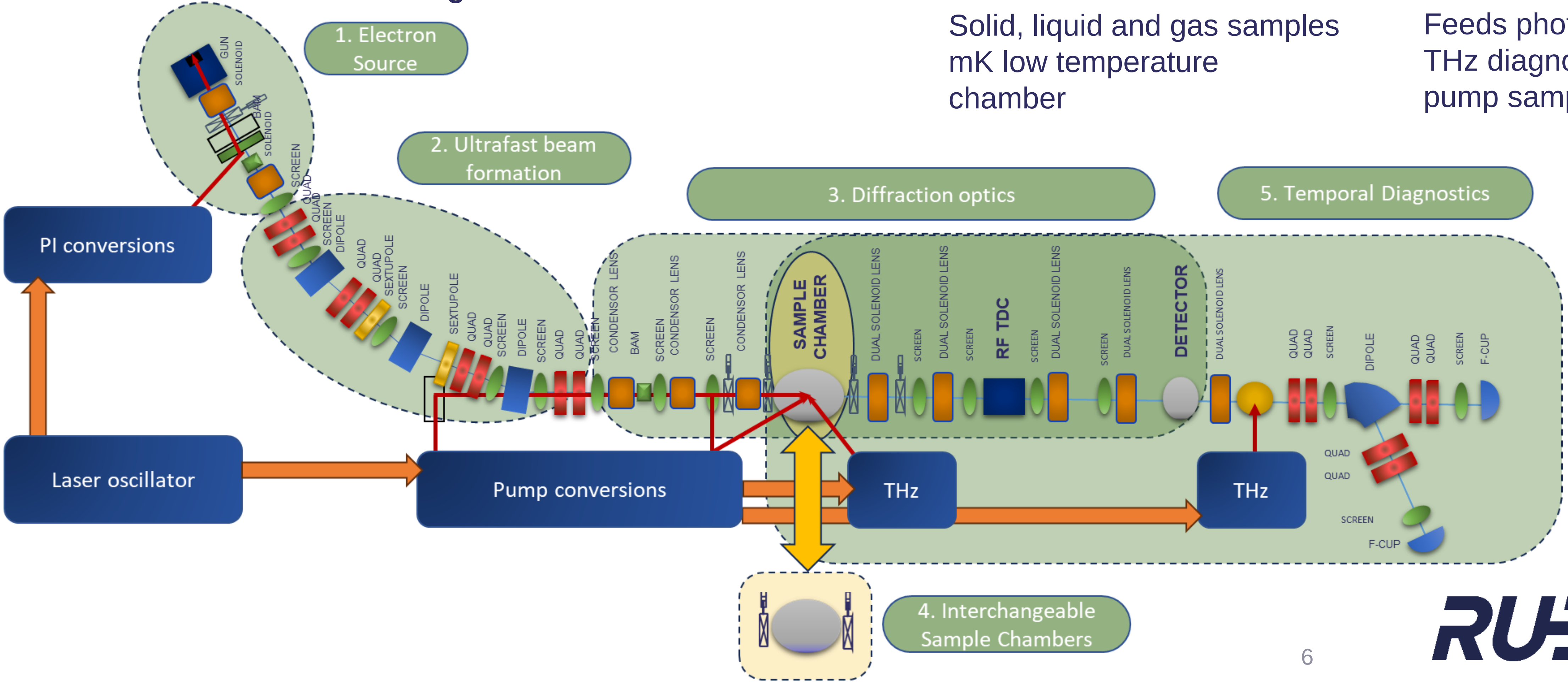
Proof-of principle static MeV electron diffraction on VELA



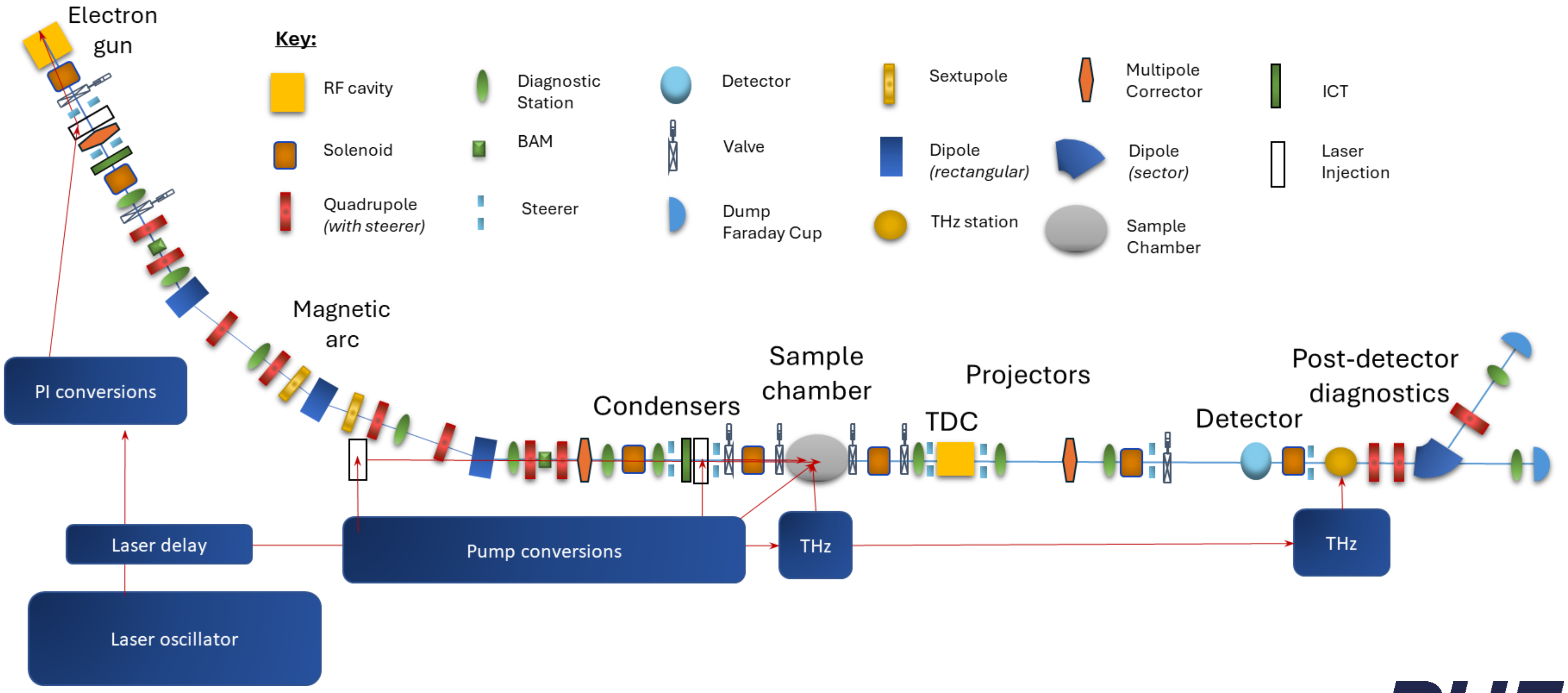
Measurement of dynamics of relativistic electrons with laser-driven THz sources, and high power TW lasers

Ultrafast Diffraction Line

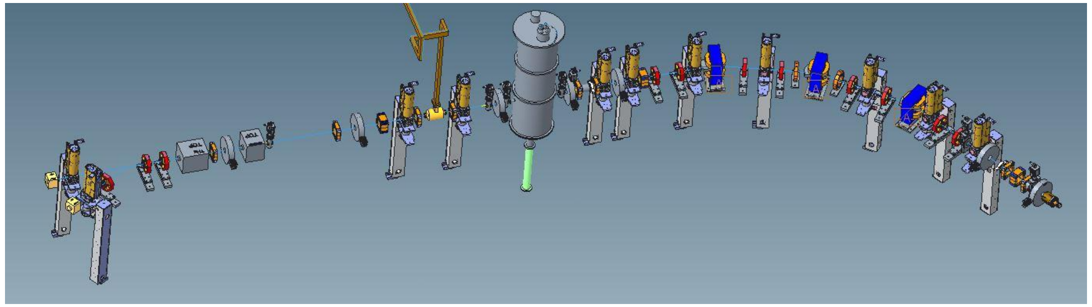
1. Electron source
   - S-band RF photoinjector
   - Creates high brightness, short pulse beams
2. Ultrafast beam formation
   - Simultaneously compresses bunch length and reduces jitter for overall time resolution <**10fs single shot**
3. Diffraction optics
   - Variable magnification + camera length
   - Direct electron detector
4. Chambers
   - Solid, liquid and gas samples
   - mK low temperature chamber
5. Temporal diagnostics
   - Shot-by-shot arrival time and fs bunch length measurements
6. Lasers
   - Feeds photoinjector, THz diagnostics and pump samples



Key components to procure:



Components and priorities



List and number of main beamline components largely complete, component design ongoing

“Standard” components

- Beamline – girders, support, vibrational stability
- Vacuum – pumps, gauges, valves etc
- Magnets – dipoles, steerers, quadrupoles, sextupoles, solenoids, high-order correctors, power supplies, movers
- Diagnostics – scintillators, cameras, ICT, BAM, motion control, Faraday cups, front-end electronics
- Cooling, synchronisation hardware, controls hardware etc

Critical long-lead time items

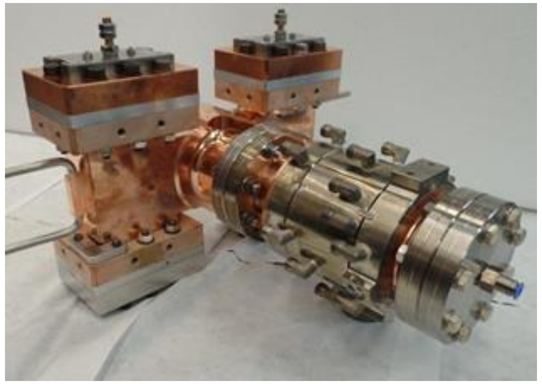
- RF – normal conducting cavities, high power RF, LLRF
- Laser systems

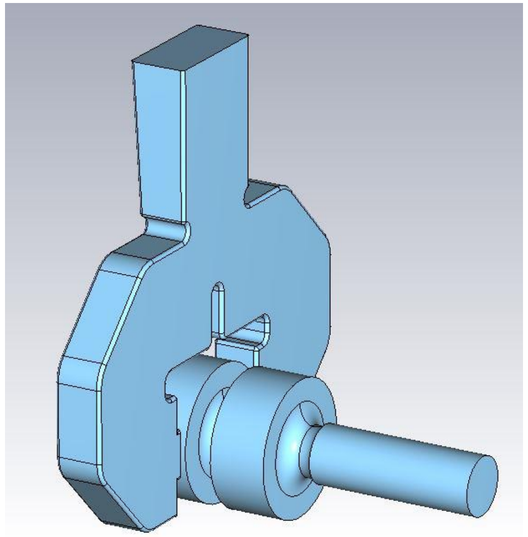
Requires further consideration

- Sample control and environments
- Direct electron detector

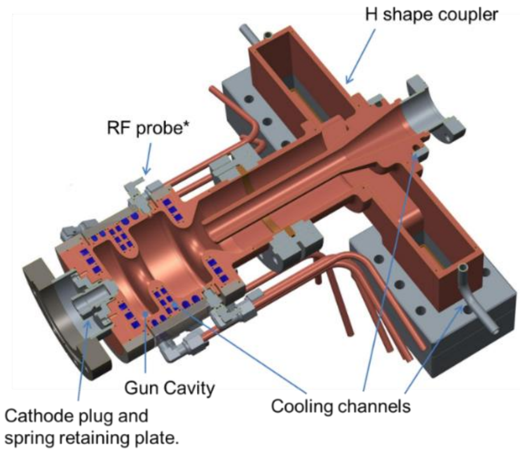
Electron gun overview

- Normal conducting S-band RF gun, 4 MeV, <0.5pC
- Photoinjector laser
  - Front laser injection
  - Out of vacuum final laser mirror
  - Short ~60 fs pulse duration
  - Variable laser spot size: 100 um – 400 um diameter
- Cathode
  - Copper – backwall of electron gun
- Cooling channels around cavity to cope with heat load
- 1 kHz repetition rate
- 10 MW peak power, ~1.5us pulse width
- RF sub-systems
  - High power RF (klystron, modulator)
  - Waveguide network (in-vacuum, apart from circulator)
  - Low-Level RF system
  - RF monitoring

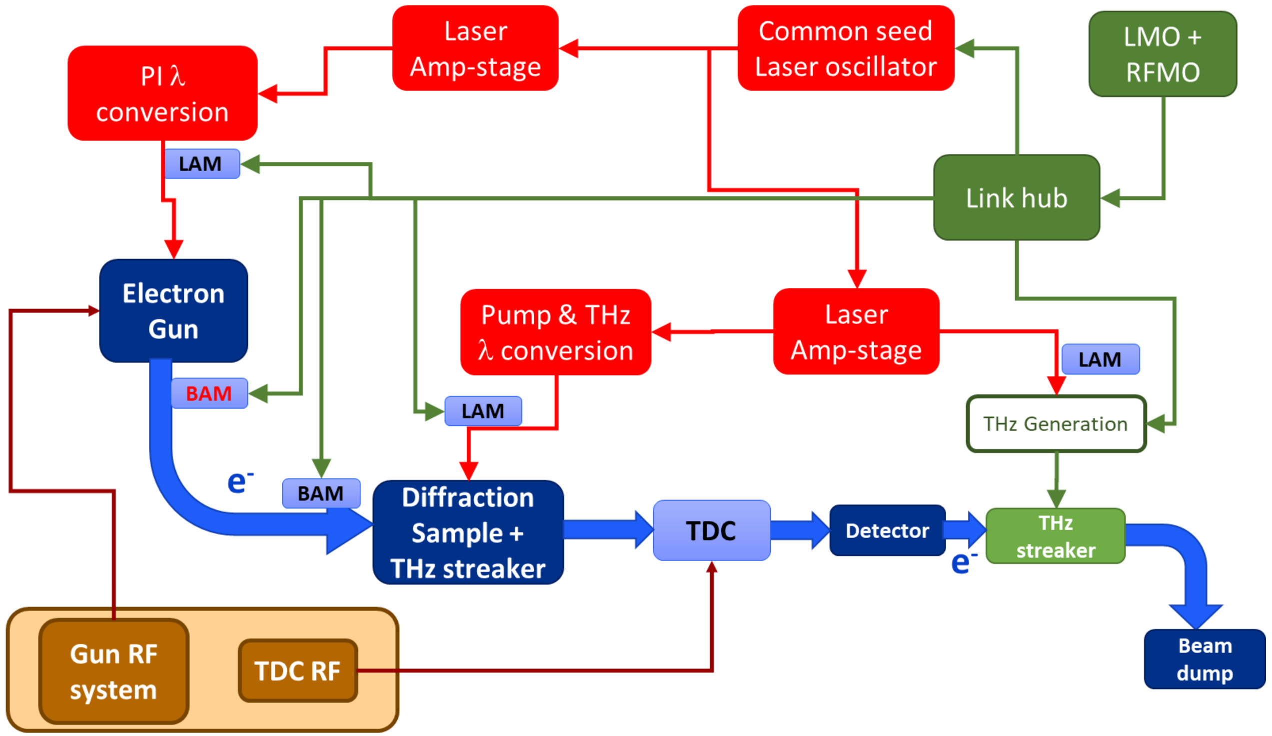




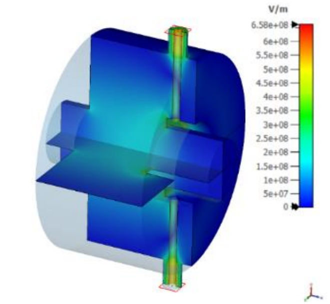
Operating frequency (GHz)	2.9985
Mode separation (MHz)	15.6
Coupling beta	2.000
Cathode field (MV/m)	70
RF voltage (MV)	5.97
Effective shunt impedance (MΩ)	3.36
Beam kinetic energy (MeV)	4
Steady state power loss (MW)	4.77
Steady state input power (MW)	5.34
Average power loss 200 Hz (W)	782
Average power loss 1 kHz (W)	3913
Peak surface E field (outside cathode) (MV/m)	69.1
Peak surface H field (kA/m)	251
Peak temp rise (on coupler) (°C)	16.95
Pulse length (ns)	975 + flat top

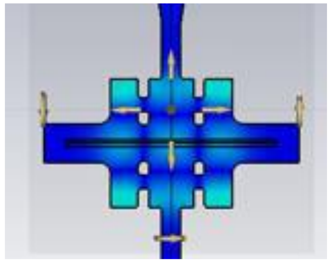


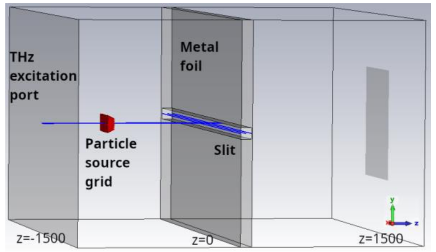
Synchronisation + Longitudinal Diagnostics



- Temporal properties:
  - Time of arrival
  - Bunch length
- Diagnostic suite:
  - RF Beam Arrival Monitors*
  - RF TDC
  - THz at sample position
  - THz post-detector
  - Spectrometer







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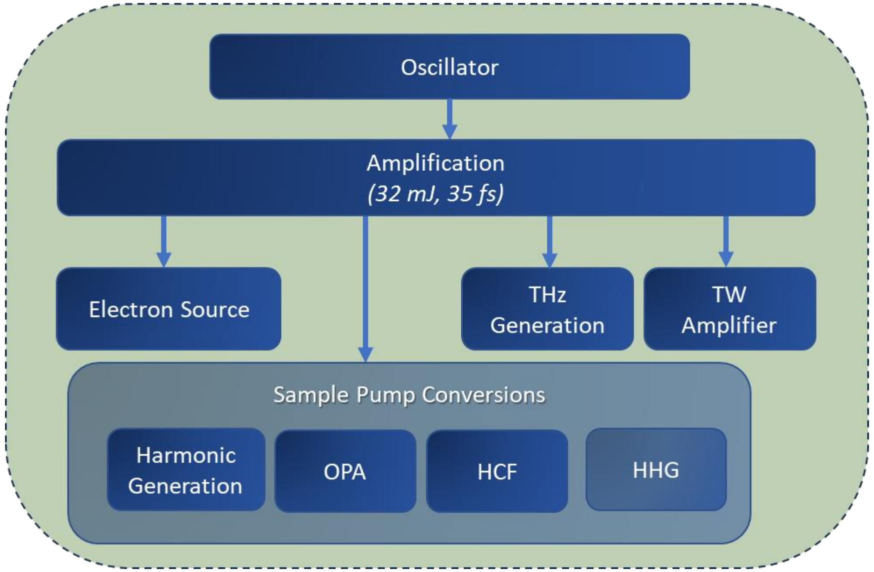
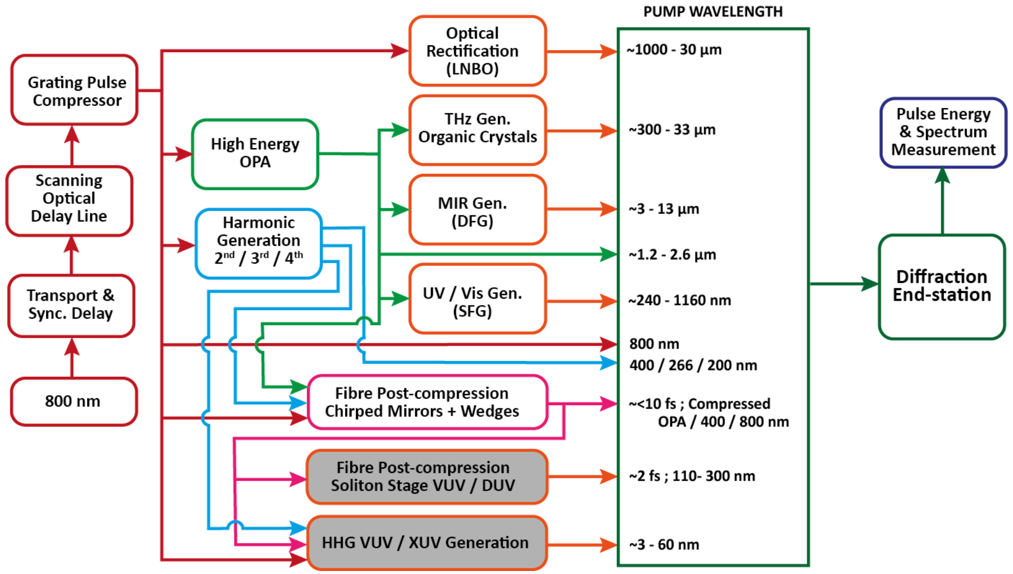
Laser Systems

- Lasers feed:
  - Electron source(s)
  - Sample pumps
  - fs diagnostics

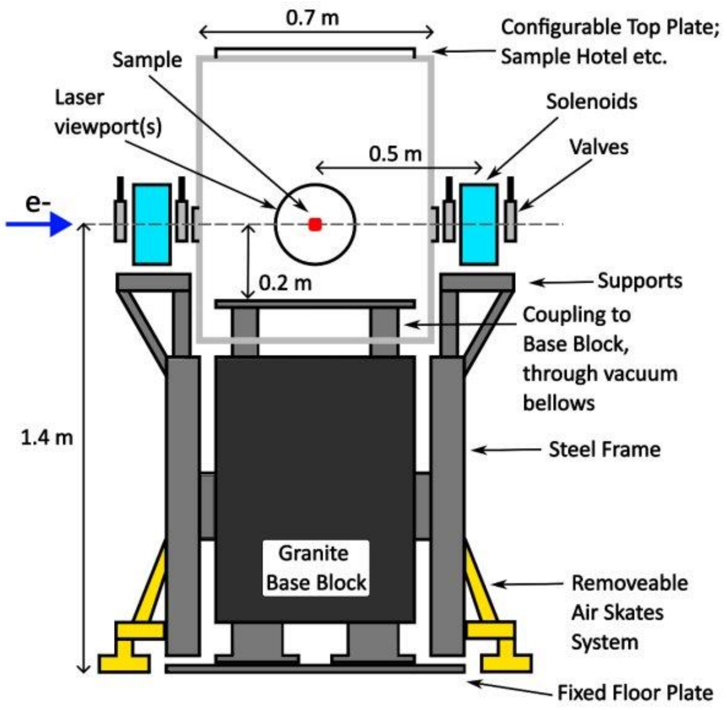


- Laser pumps:
  - UV-IR-THz
    - 200nm - 5um
    - OPAs + harmonic generation
  - HCF for <10 fs
  - *High intensity TW (>10^{18} W.cm^{-2})*
  - *Potential HHG + others*



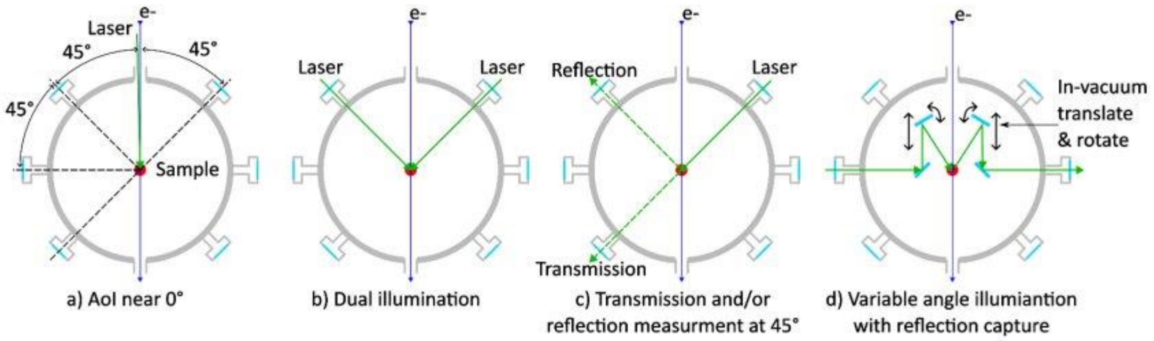
Sample chambers

- Interchangeable sample chambers for different environments
  - Potential for interchangeable inserts in chamber
- In conversation with science team about requirements:
  - Sample control (position, rotation)
  - Load-lock/sample exchange
  - Type of gas/liquid jets
  - Temperature (mK – 1000K ?)
  - Laser injection
  - Diagnostics needs
- Potentially 3 chambers:
  - “Clean chamber” - solid state, good sample control, lots of diagnostics
  - “Dirty chamber” – gas/liquid jets, differential pumping
  - Cryo chamber – possibly down to mK level

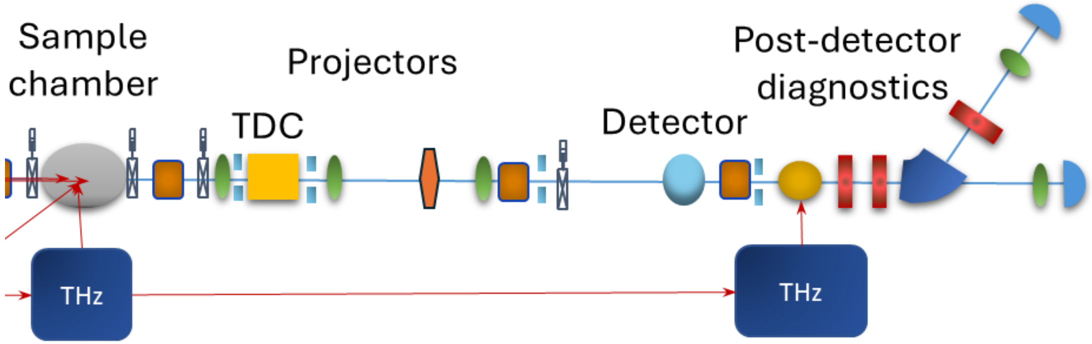


Mock-up sketch for dimensions, not internal design

Potential laser illumination modes



Detector



- 4 MeV electrons
- Up to 10^6 electrons, high dynamic range
- Single electron detection
- Number of pixels/pixel size
- Total sensor size *(cf standard beampipe Ø35mm)*
- Vacuum compatible
- Ability to withdraw detector from beam path
- Ability to pass undiffracted core beam through
- 1 kHz repetition rate

- Integration into EPICS control system and STFC data systems
- Co-location with standard scintillator + CCD system
- Gated to reduce background noise

End/Backup

- Feel free to contact me on julian.mckenzie@stfc.ac.uk