IFAST IIF PITCH

A Field Emission Cathode for a Travelling-Wave RF gun for High Brightness Beams in Industrial and Small Research Facility Settings

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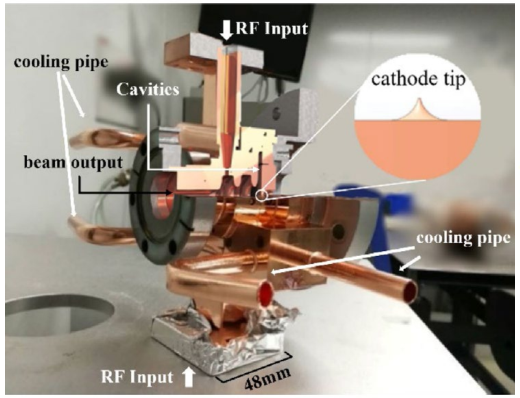
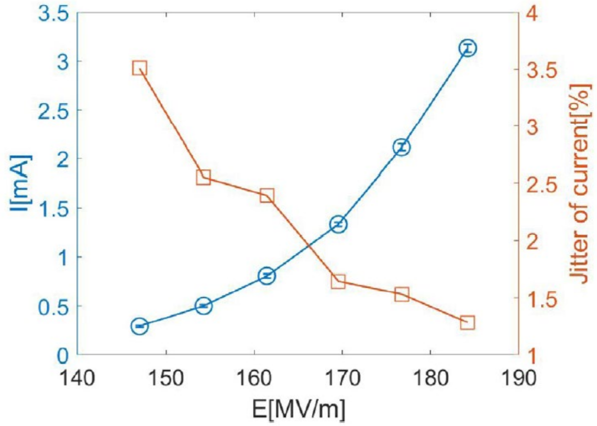
Background and aim

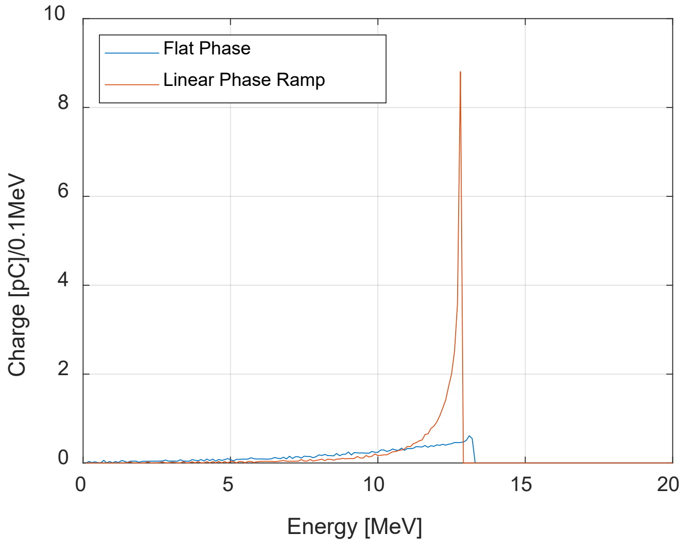
- RF photoguns are an invaluable technology in the accelerator physics world. They act as high brightness electron sources for a wide variety of applications. However, these sources require complex laser which make them infeasible in industrial applications.
- Comparatively, thermionic DC guns are overwhelmingly used in industry settings. Unfortunately, these sources are inherently lower brightness due to a high thermal emittance from the cathode.
- An alternative electron source is through field emission. Such sources are commonly used in electron microscopes however they have yet to become a common source of high energy electrons.
- **The ultimate aim of this project is to develop a versatile high brightness MeV electron source based on a field emission cathode. This will be achieved through the following steps:**
  1. **Production of a field emission cathode for the Travelling-Wave (TW) RF gun under development as part of IFAST Work package 7.4.**
  2. **Test of the new field emission cathode at high power, measuring the current produced and establishing stable operation.**
  3. **Measurement of the beam properties downstream using a dedicated diagnostics system, including a faraday cup and spectrometer.**

Technical overview

- A proof-of-concept of an RF gun with a field emission cathode (top, left) operating with a stable output beam current (top, right) was published here in [1].
- Rather than using a standing-wave RF gun, in this project we have chosen a travelling-wave RF gun which has several advantages, the most significant of which is the possibility to perform LLRF manipulation. This can be used to reduce the energy spread of the output beam. A demonstration of the reduce energy spread is plotted to the right.







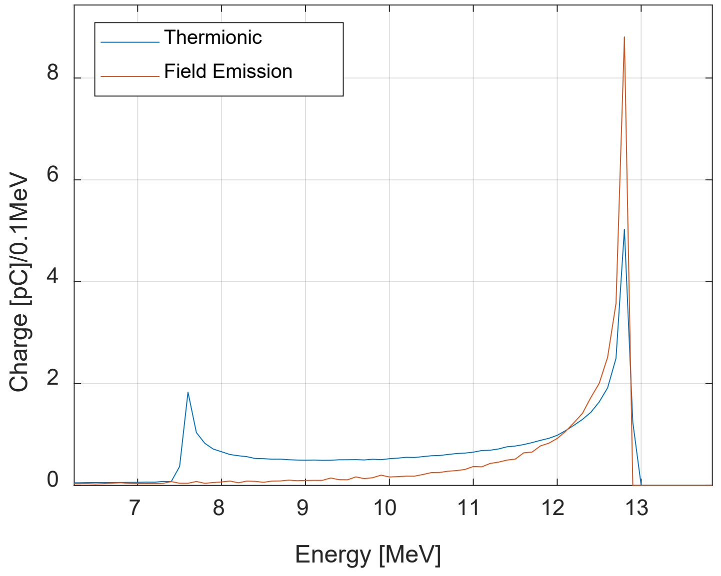
[1] Liuyuan Zhou, et al., Development of a high-gradient X-band RF gun with replaceable field emission cathodes for RF breakdown studies, NIM-A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 1027, 2022, 166206, ISSN 0168-9002.

Technical overview

- State-of-the-art industrial 10 MeV electron sources are based on thermionic electron gun joint to a short accelerating structure.
- We expect improvements in the following areas:
  1. Energy Spread: The E-field dependence of the emission leads to intrinsic bunching and one can reduce the energy spread through a ramping of the phase (RHS).
  2. Emittance: The emittance is linked to the temperature of the cathode and the size of the emission area.

$$\epsilon_{th} = \sigma_x \sqrt{\frac{kT}{mc^2}}$$

We expect at least 10-100 times reduction in transverse emittance.



Parameter	Value	Units
Energy	10-12.8	MeV
Energy Spread	2	%
Bunch Charge	1-30	pC
Bunch Repetition Rate	5.712	GHz
RF Pulse Repetition Rate	< 100	Hz
Emittance	200	nmrad

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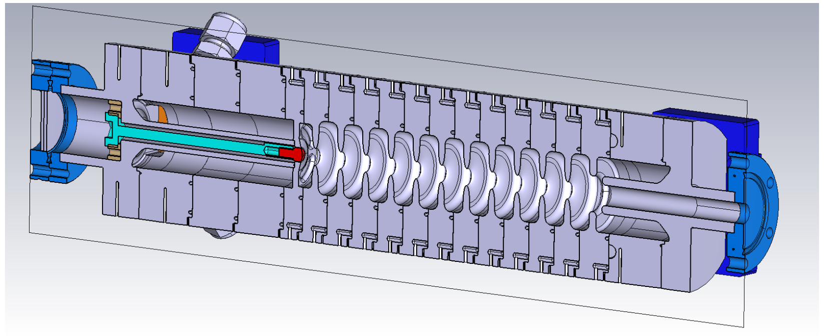
Technical overview

- The design of the TW RF gun is well-advanced and soon to be fabricated (top).
- A weakness of a field emission source is RF breakdown. In this RF gun, we aim to increase reliability through two steps:
  1. The size of the field emission tips will be on the hundreds of micron level compared to the sub-micron used in past tests.
  2. The tips will be conditioned to higher surface electric fields which will then be reduced for nominal operation, reducing output current but more importantly reducing the chance of RF breakdown.
- The test facility for this device is currently under construction in the framework of IFAST W.P. 7.4 (bottom).



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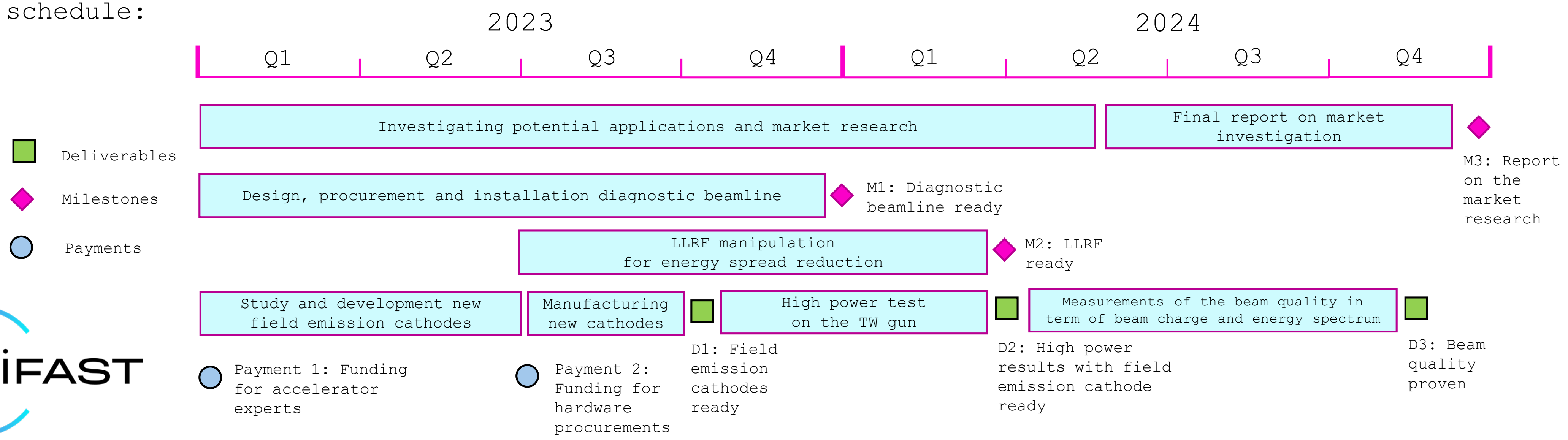
Work Plan and risk analysis

- The team working on this at PSI consists of three experienced accelerator physicists: Dr Paolo Craievich, Dr Thomas Lucas and Dr Riccardo Zennaro, who have a combined total of over 40 years experience in accelerator physics.
- Responsibilities:
  - PSI are responsible for the high power testing of the new cathode and demonstration of its abilities at high power. They are also responsible for the characterisation of the electron beam produced by the gun.
  - VDL are responsible for the manufacturing of the cathode and for investigating potential applications
- Risk Analysis
  - This project essentially has two potential technological risks, the production of the field emission (tip) cathode and its subsequent conditioning with high rf power. To mitigate both of these risks, it is planned to produce multiple cathodes to be tested in the RF gun, and perform the rf conditioning at higher rf power than the nominal operational power.
  - There are always risks in marketing a new product. This risk will be mitigated by using VDL’s past knowledge of bringing products to market and applying market research techniques.
- Time schedule:

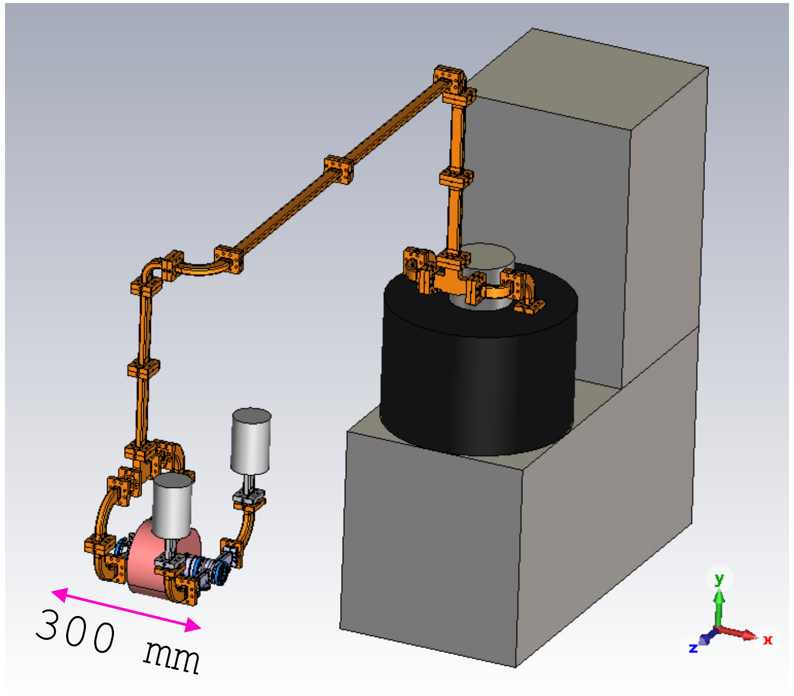


Technological Readiness Level

- The experimental verification of a current producing field emission tip (Slide 3) gives a current Technological Readiness Level (TRL) of 3.
- By the end of this project we aim to have the project at a TRL of 4 which will be a functioning prototype ready to hand over to industry.
- It is expected that the travelling-wave gun with field emission cathode could be moved towards a TRL of 5 and 6 with the outcome of the market research report. The functioning prototype could be handed over to an industrial partner at the end of this IIF project. This partner will then be able to bring this gun to market in the years following.

Applications and Impact

- **It is foreseen that such an rf gun would be used in a small-scale research institute or medical centre acting as a high brightness source for a wide variety of applications.**
- This gun will open up the possibilities for several techniques only available in larger institutes such as:
  - MeV electron microscopy
  - MeV electron diffraction
- Furthermore the injector can serve as a source for medical applications, sample irradiation or security applications which require better quality beam than available from thermionic sources. Please see references.
- As part of this IIF project, **VDL will produce a market study into the possible clientele** which this gun could serve and also look for a possible original equipment manufacturer (OEM).



A mockup of the travelling-wave gun with the klystron-modulator source.

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Linac 2022 conference proceedings:
- S. Biedron et al., Accelerator development for Global Security, TH1AA03
- J.B. Farr, The Future of Medical Linacs, FR2AA02

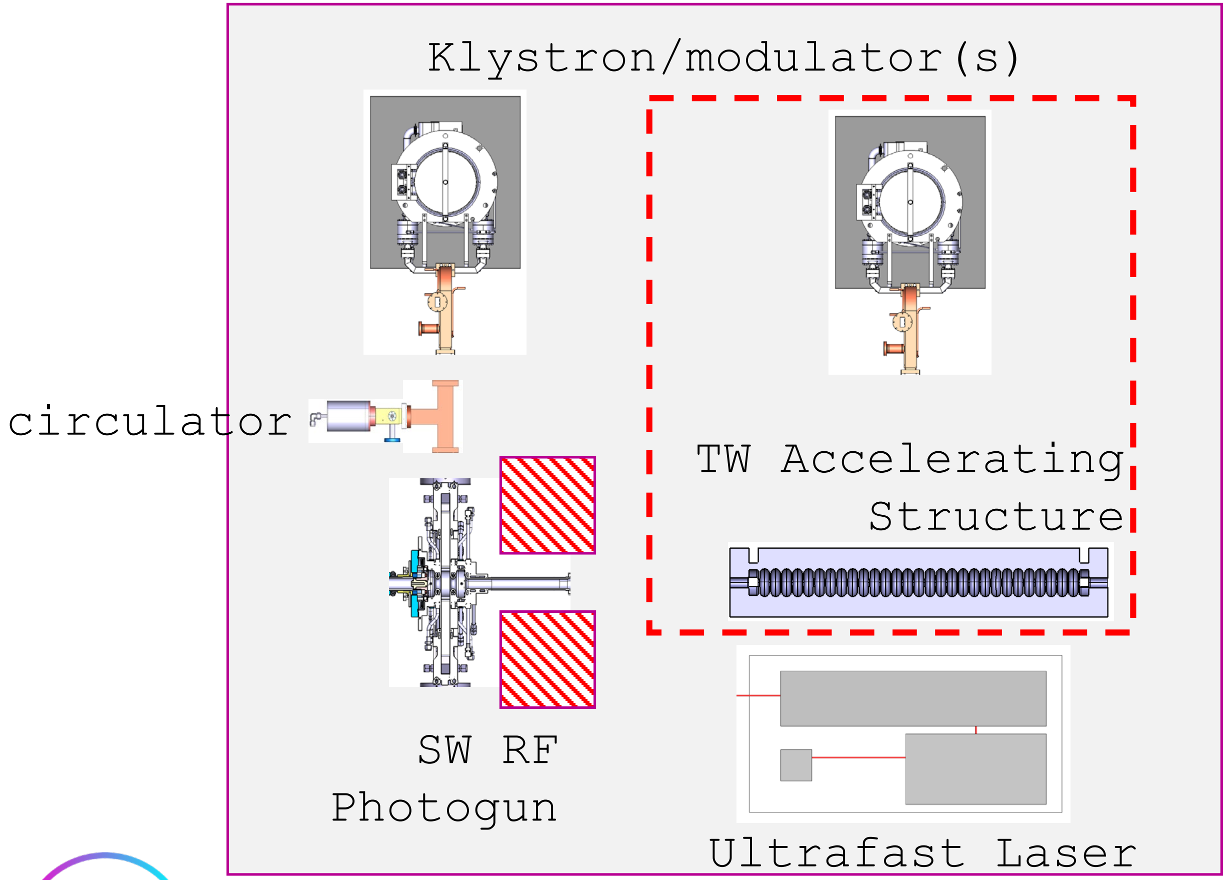
Costings and Environmental impact

- The cost of the Field Emission TW RF gun is expected to be lower than other electron sources with similar beam quality. The reasons for are, when a compared to:
  - **A DC or SW RF Photogun,** The travelling wave gun does not require an ultrafast laser system.
  - **A DC Thermionic Gun,** The travelling wave gun does not require a high voltage DC source for the gun and bunching system.
- These same arguments will make the field emission gun’s overall footprint smaller, consequently, it will have a reduced environmental impact.

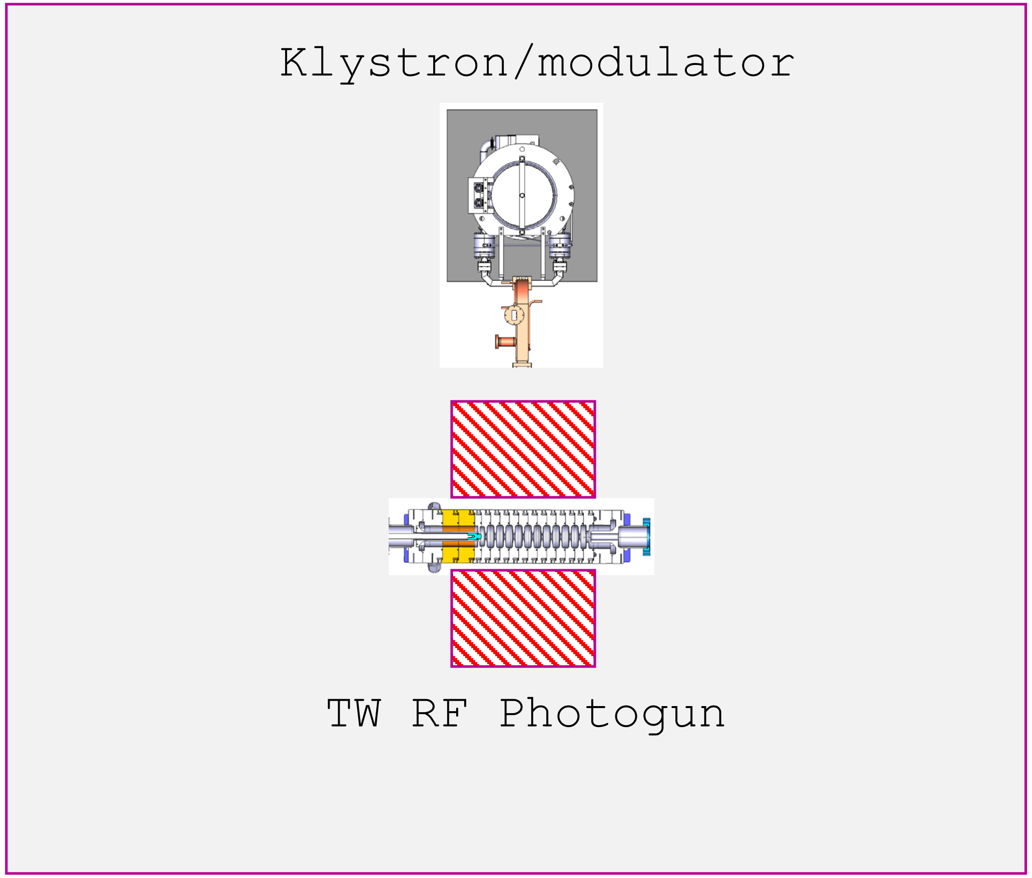
Costings and Environmental impact (2)

Compactness: The field emission travelling wave gun aims to reduce the size, and significantly reduce the complexity, of high brightness electron sources.

Photocathode Source



Field Emission Source



Funding

- This project is partially funded through the IFAST project work package 7.4 ‘Very high gradient RF Guns operating in the C-band RF technology’.
- PSI is providing the high power test facility for this project including the high-voltage klystron-modulator, bunker and technical personnel to construct the facility.

Business Plan

- The attractiveness of our new gun is that it is a simple MeV high brightness source of electrons.
- The IP for this RF gun will be owned by PSI. Following the study there will be a review of the IPR and there will be the aim of extending these rights to include our industrial partner and chosen OEM from the investigation.
- **As part of this IIF investigation, there will be a study into market potential performed by our industrial partner, VDL. This will also include approaching businesses to become the OEM of this product.**
- Early involvement of industry/VDL ensures focus on industrialisation, manufacturability, and cost. Together with PSI, VDL is able to translate the proof of concept into a tangible product meeting market requirements.

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The commercialisation

- Following the IIF, the aim will be the commercialisation of this product, together with the OEM. This will include the sharing of the IPR.
- A potential OEM will be responsible for bringing the new device to the market.
- During this proposal, the project team will approach the newly develop Swiss Innovation Centre 'Park Innovaare' which aims to work between research labs and industrial for the industrialisation of accelerator technologies. Particularly, we will discuss with the group of 'Advance Accelerator Technologies'(https://aa-t.ch/).

Resources and budget

- The expertise in these organisations
  - PSI: RF design and simulation of the RF gun, as well as operation. Furthermore PSI has the expertise of a unique brazing technology to fabricate such an RF gun.
  - VDL: Mechanical & NPI engineers to design for manufacturing at high precision.
- As part of the industrial participation, VDL will investigate the industrialisation of this new device and manufacture the field emission cathodes.
- The resources provided by the IIF will go towards:
  - The **funding of accelerator experts** to spend their time in studying, testing and investigating the properties of this field-emission gun and for the investigation, together with the industrial partner, into the industrialisation of the rf gun, 24 person-months **(150’000 Euro)**.
  - The **development and production of the field emission cathodes** for the TW gun **(10’000 Euro)**.
  - **Production of the diagnostic beamline**, particularly a dipole magnet, screen and vacuum components for the spectrometer **(40’000 Euro)**.
- Final deliverable (D3): **Measurements of beam quality in term of beam charge and energy spectrum at a high repetition rate.**

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Conclusions

- This project will aim to test field emission cathodes in a novel travelling-wave gun to provide high brightness beam without the need of an high peak power, ultra-fast laser system.
- This gun will open up a new range of analytical techniques, such as electron diffraction and electron microscopy, to industry. Making the generation of low emittance beams in industry possible.
- This new style of gun will produce a high brightness beam in a significantly more simple system compared to current state-of-the-art technology.
- This project will aim to develop an operating prototype and to hand this over to industry to move towards a commerically-available product.

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