This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

WP16: Intense, RF Modulated E-Beams

for Application in Pulsed Electron Lenses

Final Review / 15.07.2022

David Ondreka (GSI) for the WP16 collaboration

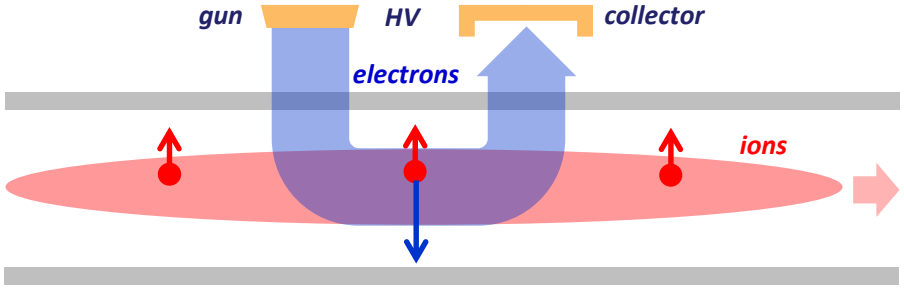
Outline

- Motivation
- WP16 objectives
- WP16 achievements
- Summary

Motivation

- Strong interest of accelerator community in pulsed electron lenses
  - Space charge compensation in bunched beams
  - Prevention of instabilities in bunched beams
  - Goal: increasing intensities
- Challenging requirements on electron gun
  - Currents of 10 to 20 A (factors more than present)
  - High bandwidth to follow bunch profiles
- Limitations of existing pulsed guns
  - Direct modulation of extraction voltage
  - Excessively high power for large currents

Space charge compensation with e-lenses in bunched beams



Pulsed electron lens TEL-2 at the Tevatron (Fermilab)

WP16 JRA goal:

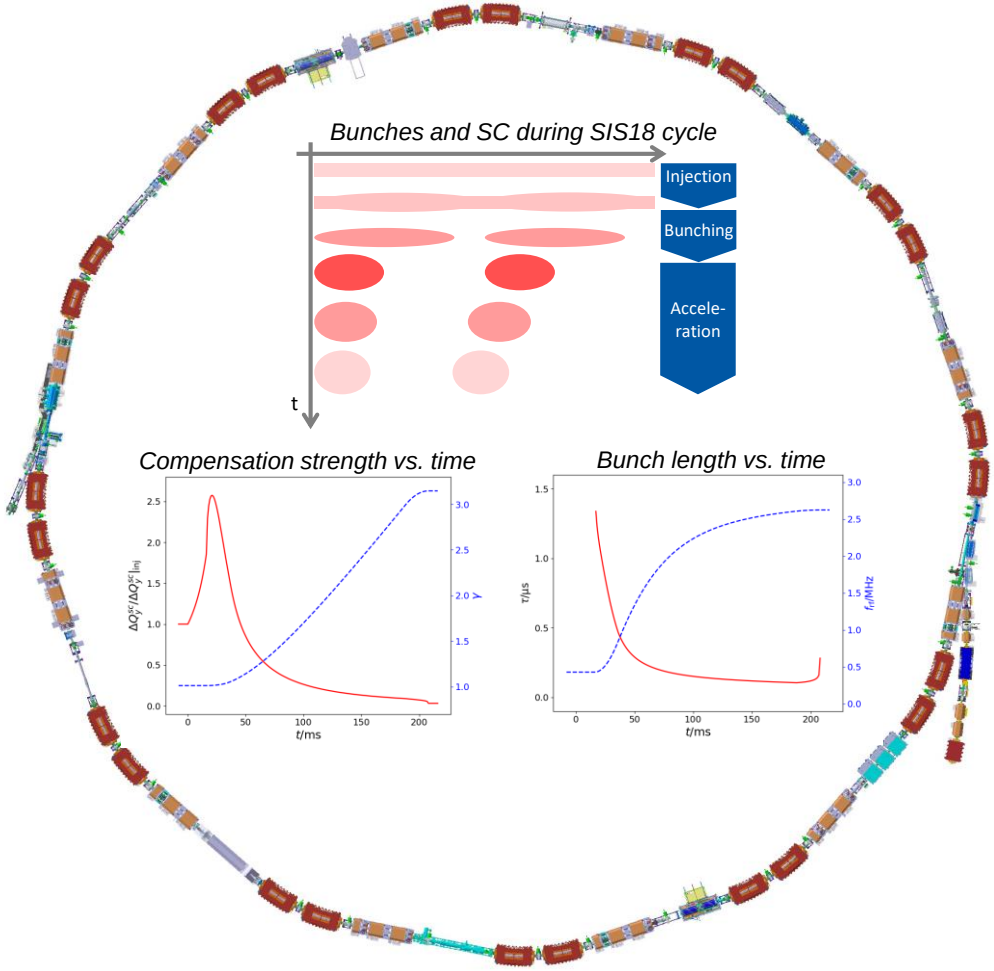
Build a ***pulsed electron gun*** for application in electron lenses for space charge compensation

WP16: Objectives and Organization

- JRA activity among four beneficiaries CERN, GSI, IAP, RTU
- Tasks
  - 16.1: Coordination and communication
  - 16.2: System integration
    - Definition of boundary conditions and requirements from reference case
  - 16.3: Manufacturing of an RF modulated electron gun for application in electron lenses
    - High electron currents up to 10 A
    - RF modulated at 0.4 to 1 MHz with a bandwidth of up to 10 MHz
    - Gaussian shaped transverse electron beam profile
    - Grid modulation to lower power requirements on modulator
  - 16.4: Operation of a test stand for the RF modulated electron gun
    - Construction of a test stand for qualification of the gun
    - Conduction of tests on the gun

Task 16.2: Reference Case

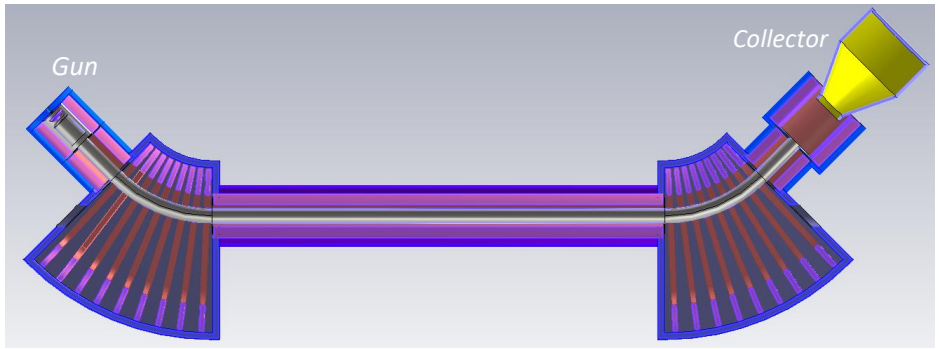
- Heavy ion synchrotron SIS18 at GSI
  - Circumference 216m, max. B field 1.8 T
  - Provides heavy ion across the periodic table
  - Intensity limited by space charge at low energies
- Time dependent space charge compensation
  - Compensation strength varies with time
  - Bunch length varies with time
- Advantages of low energy ions
  - Large ion beam radii ($\sigma_{x/y}$ ~ 10 / 20 mm)
  - Long ion bunches ($4\sigma_t$ > 300 ns)
- Main requirements on pulsed gun
  - Electron currents of 10 A at 30 kV
  - Modulation at 0.4 – 1 MHz with 10 MHz bandwidth
  - Gaussian transverse profile



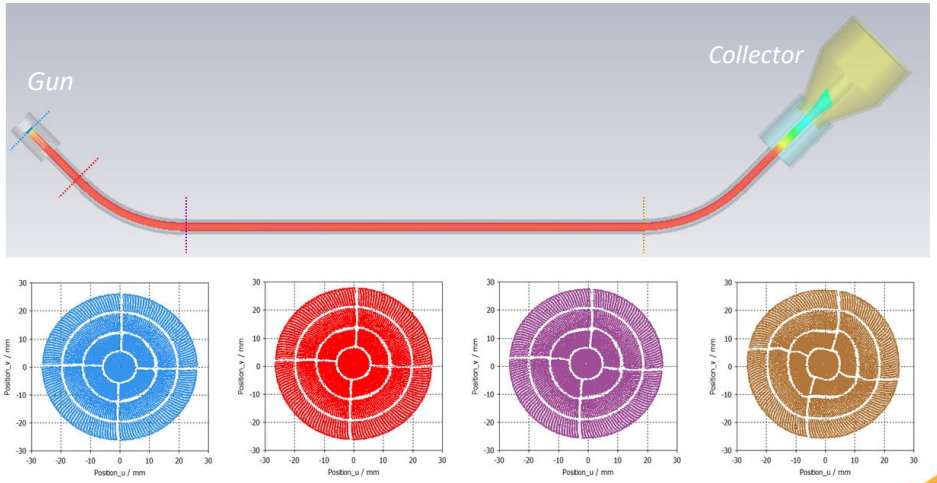
Task 16.2: Electron Beam Dynamics

- Layout of complete electron lens established
  - Magnet system of solenoids and toroids
  - Metallic boundaries and collector
- Simulation of electron beam dynamics
  - Extraction from IRME-gun including grid
  - Transport of electron beam through lens
  - Benchmarking with analytical models
- Gun fully compatible with lens requirements

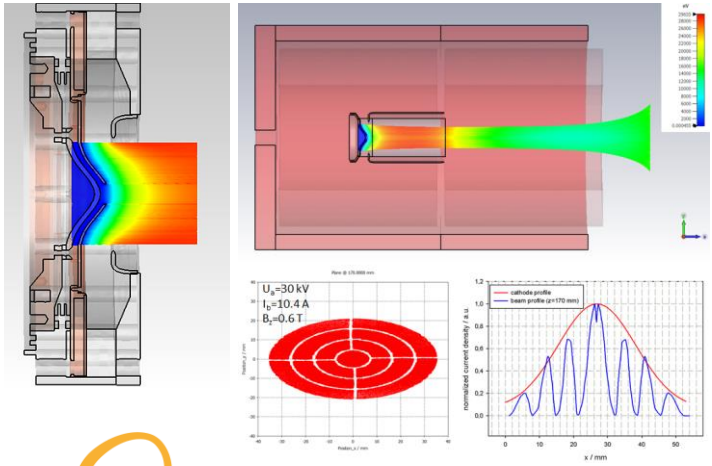
Layout of the electron lens for space charge compensation in SIS18



Electron beam transport simulation through the electron lens



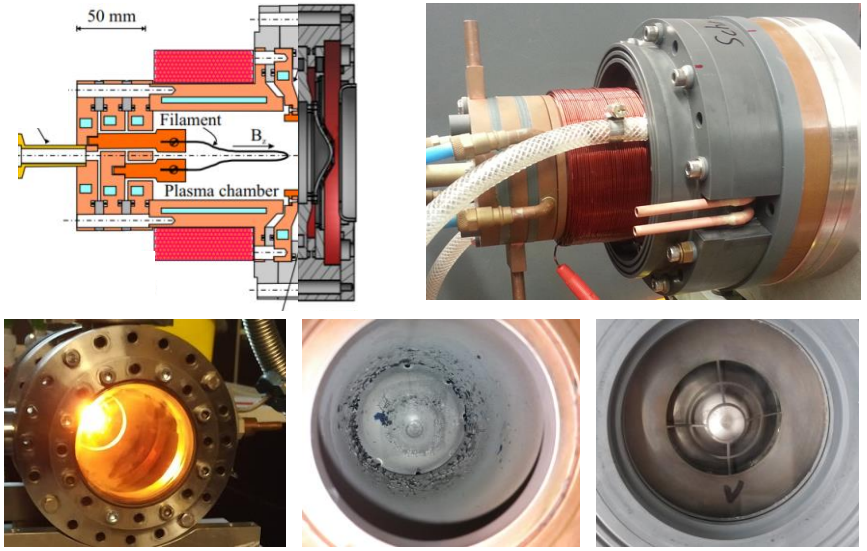
Simulation of extraction from the IRME-gun



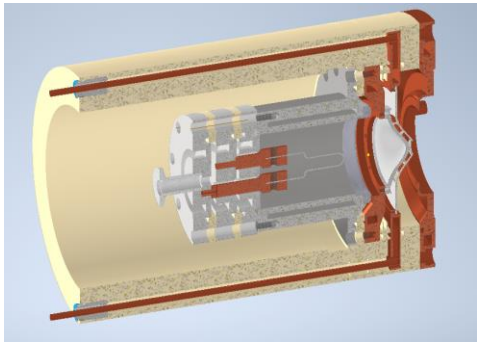
Task 16.3: RF Modulated Gun

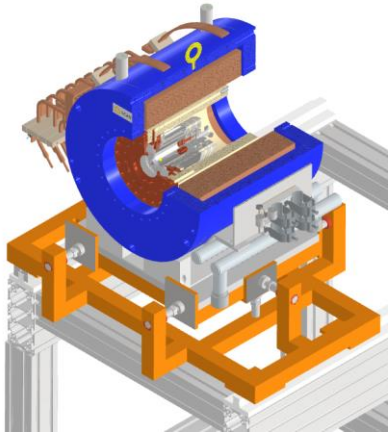
- Thermionic emission from tungsten cathode
- Gaussian profile by shaping of cathode
- Novel concepts
  - Heating by plasma stream from arc discharge
  - Modulation by grid to reduce power consumption
  - Compact and robust design for T ~ 2500 K
- Final design developed in two steps
  - Prototype (TE^2) based on ion source
  - Optimizations after tests with prototype

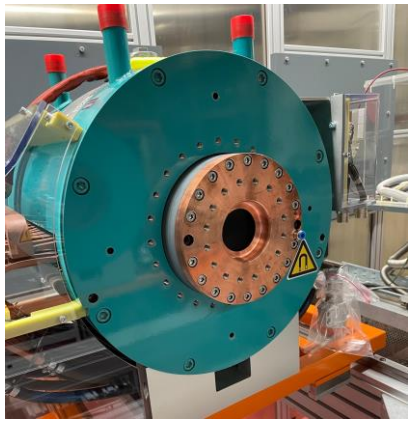
TE^2 prototype based on volume ion source



Final IRME gun: design and manufactured device



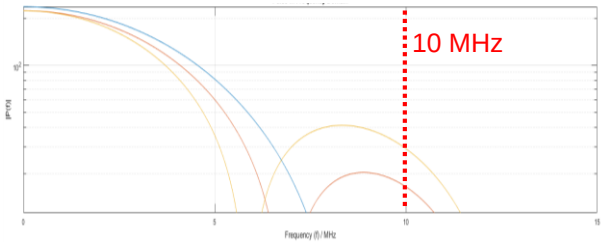




Task 16.3: RF Modulator

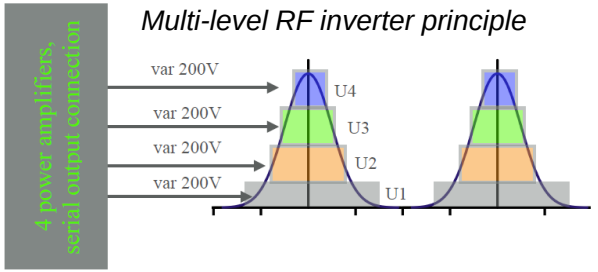
- Challenging requirements
  - Sweeping central frequency (0.4 – 1 MHz)
  - Bandwidth of 10 MHz for SIS18 bunches
  - 3 kV on capacitive load (~100 pF)

Frequency spectrum of SIS18 bunches



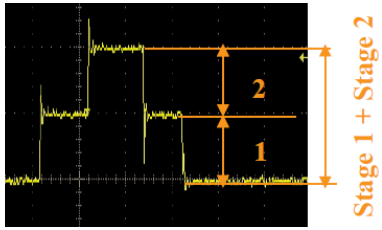
- Design iterations based on prototypes
  - Vacuum tube solution tried but discarded
  - Final design multi-level RF inverter topology
    - 26 modules supplying 150 V each
    - Allows operation outside tunnel
  - Prototypes with 4 modules built
  - Final device not ready due to supply problems

Multi-level RF inverter principle

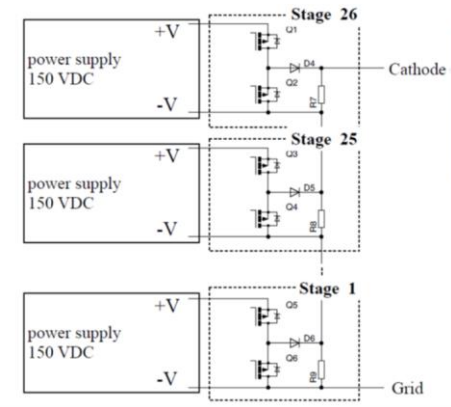


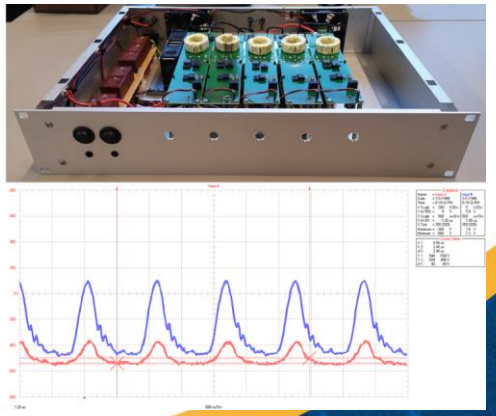
- Additional signal generator for testing

Output before filtering



Circuit layout and prototype of final modulator

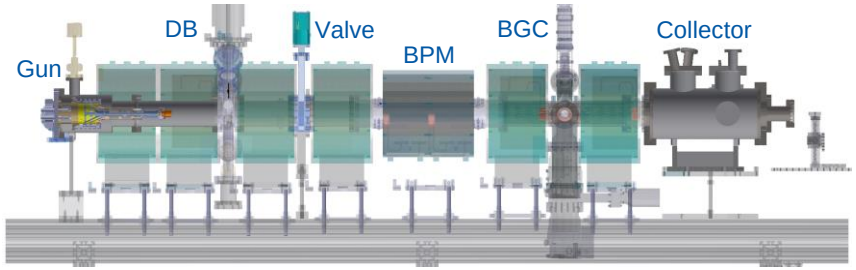




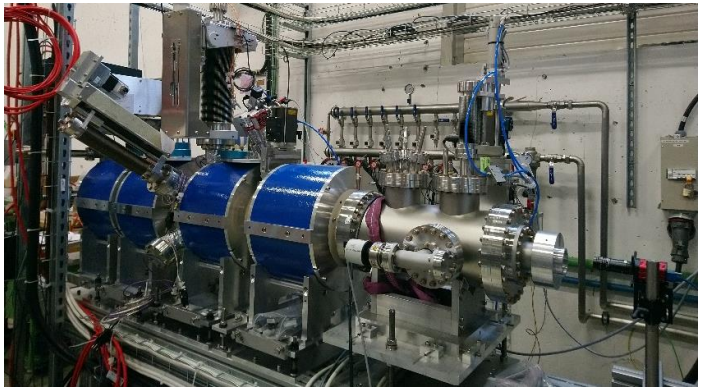
Task 16.4: Gun Test Stand at CERN

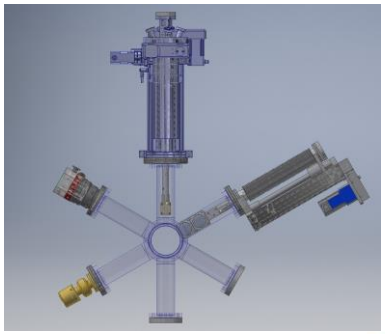
- Designed for CERN HEL gun and IRME gun
  - Co-founded by HiLumi-LHC and ARIES
- Goals
  - Testing components for HEL lens
  - Testing components for SCC lens
  - Operational experience
- Diagnostics equipment
  - Current transformer at cathode
  - Diagnostic box (YAG screen, movable pin-hole cup)
  - Collector measuring total current
- Test stand successfully completed
  - Available at beginning of P3
  - Inaccessible for IRME gun due to Covid-19 crisis
  - Decision to build second test stand at IAP

Layout of CERN test stand



Stage 1 of CERN test stand



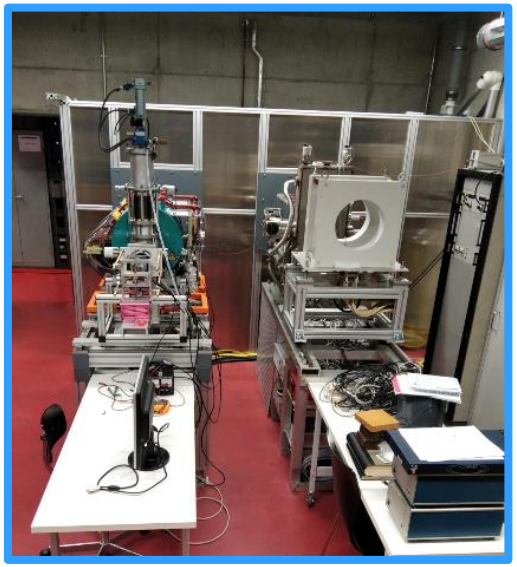


Diagnostic Box (DB)

Task 16.4: E-Lens-Lab at IAP

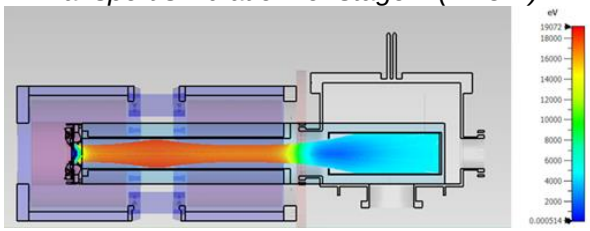
- Features
  - HV platform for 50 kV in Faraday cage
  - Collector Faraday cup up to 27 kW
  - Solenoids for beam transport
  - Remote control for safe operation
  - Pressure and temperature diagnostics
  - Transverse diagnostics
  - Two separate benches
- Construction started mid 2020
  - Floor space and infrastructure available
  - Huge work load on IAP personnel
  - Hampered by Covid-19 regulations
  - Completed thanks to prolongation

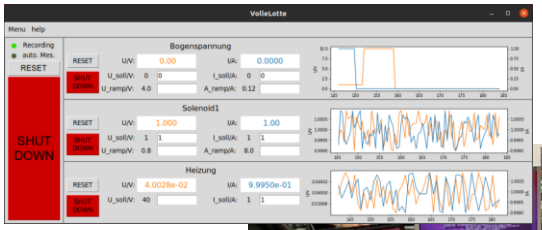
Two benches connected to HV cage



HV terminal inside cage

Transport simulation for stage 2 (I = 5 A)



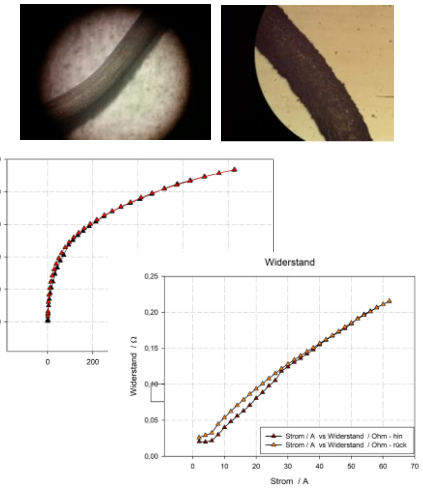


User interface for remote control

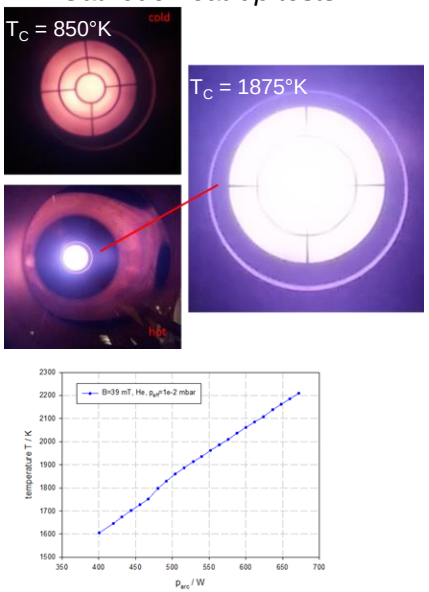
Task 16.4: Gun Tests at IAP

- Basic tests
  - Vacuum conditioning and pressure
  - Control of cooling circuit performance
- Cathode heating
  - Novel concept using directed arc discharge
  - Uniform heating of cathode essential
  - Pyrometric measurements
  - Characterization of filament performance
- Electrical tests on grid
  - Measurements of capacitance
  - Measurements of transmission properties
  - Grid characteristics at low temperatures
- Extraction tests in preparation

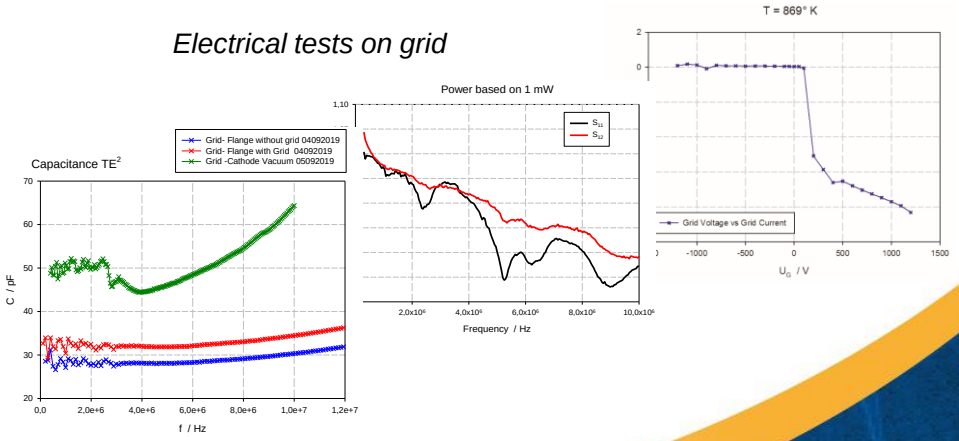
Filament characterization



Cathode heat-up tests



Electrical tests on grid



WP16: Summary

- Main objective achieved (D16.2)
  - Grid-modulated electron gun manufactured
  - Modulator prototype manufactured
- Electron beam dynamics studies done (D16.1)
- Completion of tests hampered by Covid-19
  - Testing at CERN test stand impossible
  - New test stand had to be built at IAP from mid 2020
    - Big amount of unforeseen work
    - Limited access to IAP facilities due to regulations
    - Zero time margin despite ARIES prolongation
  - Extraction testing delayed
    - Gun installed and ready for testing
    - Last minute problems with cooling
  - Project will be continued beyond ARIES
- Bonus: second gun test stand
  - Accessible to accelerator community mid-term
  - Fits with increased interest in pulsed e-lenses

Code	Deliverable	Type	Status
D16.1	Electron beam dynamics studies	Report	ACHIEVED
D16.2	**Manufacturing of electron gun and power modulator completed**	**Demonstrator**	**ACHIEVED**
D16.3	Tests of electron gun at test stand completed	Demonstrator	ACHIEVED*

Thanks for your attention!

Thanks to all the collaborators who contributed to WP16 during the ARIES project:

Adriana Rossi, Sergey Sadovich (CERN)

Kathrin Schulte-Urlichs, Sayyora Artikova, Katrin Thoma (GSI)

Oliver Meusel, Martin Droba, Julian Rausch, Thomas Dönges (GUF/IAP)

Peteris Apse-Apsitis, Ingars Steiks, Johann Van De Pol (RTU)