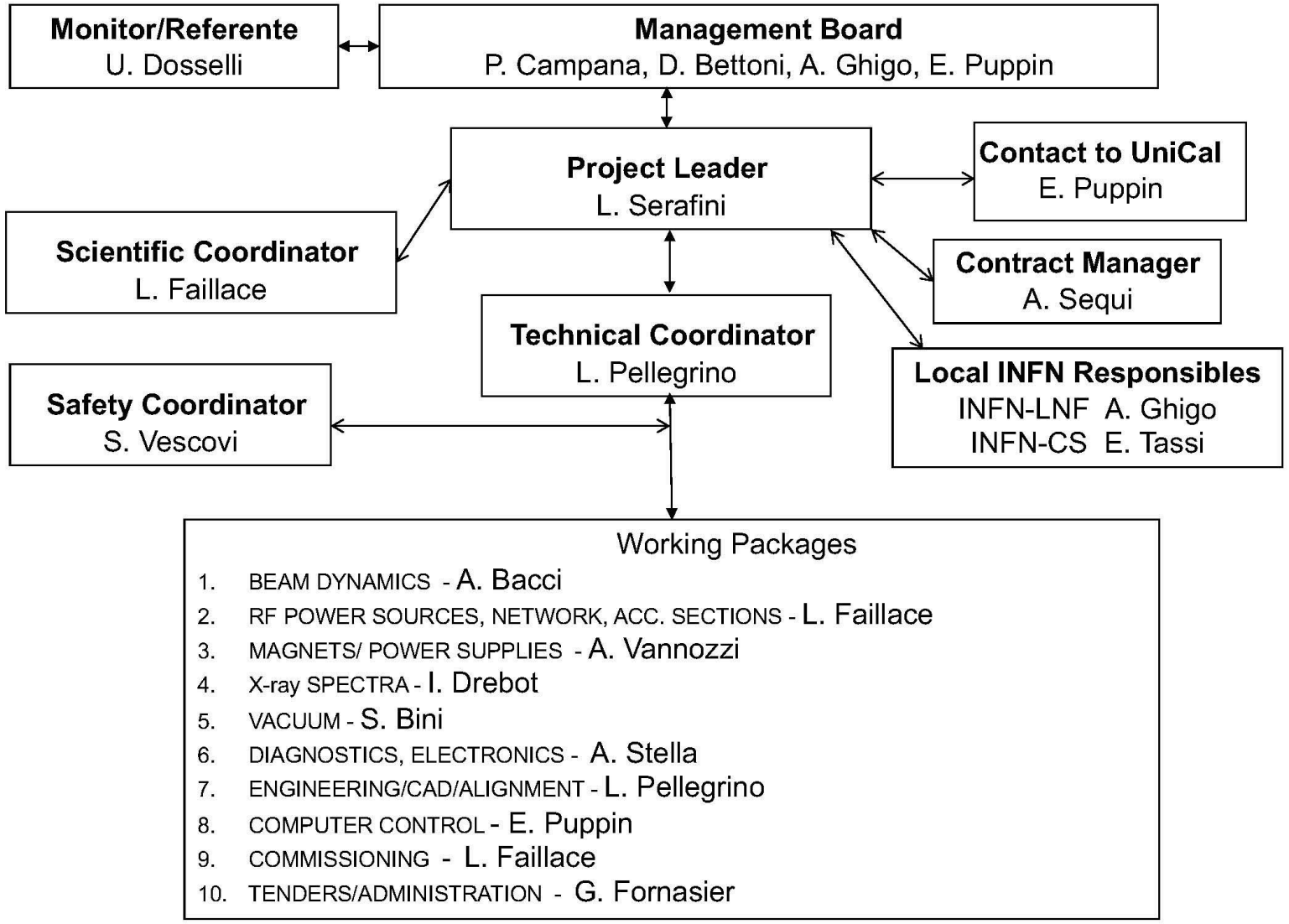
The STAR Project: Status of the Commissioning of the Compton Light-Source Infrastructure in Southern Italy.

Luigi Faillace

On behalf of the INFN-Unical STAR group

STAR High-Energy Upgrade: Organization Schematics



2024

National PI
A. Ghigo

Since April 2025

National PI
Luigi Faillace

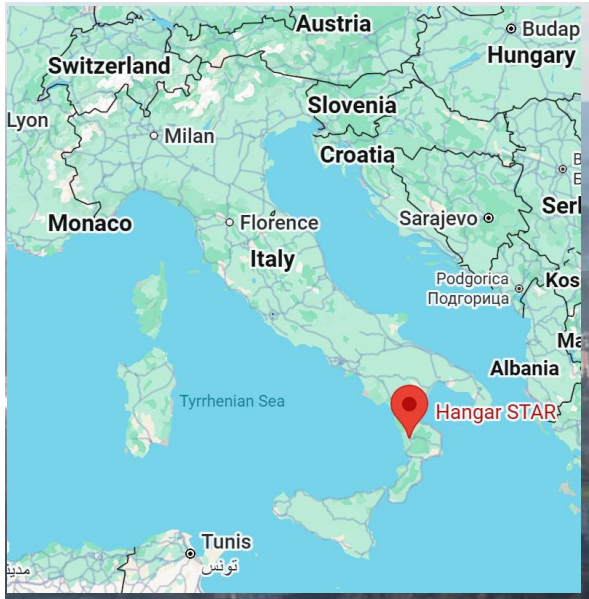
Local PI at Milano and LASA Lab
Alberto Bacci

TECH TRANSFER: FROM INFN TO UNIVERSITY OF CALABRIA (UNICAL)

Frascati National Labs and Milano Unit & LASA Lab

UNIVERSITÀ DELLA CALABRIA

PI: Prof. Raffaele Agostino and local STAR Group

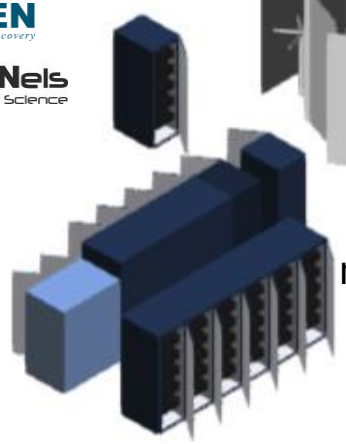


STAR: the X-ray source

STAR nominal parameters	HE-linac	LE-linac
Energy range [MeV]	40-150	23-65
Rep. rate [Hz]	100	
Bunch charge range [pC]	100 – 500	
Normalized emittance (x,y) [μm]	2.0	
Bunch energy spread [%]	0.5	
Bunch length – rms [ps]	≤ 5	
Bunch spot dimension at IP [μm]	50	
Max photon energy [keV]	350	70
Photon Flux	10^9 ph/sec	

Racks:
Magnet Power supplies
Personnel Safety System,
ion pump controllers

CAEN Tools for Discovery
CAENels Gear For Science

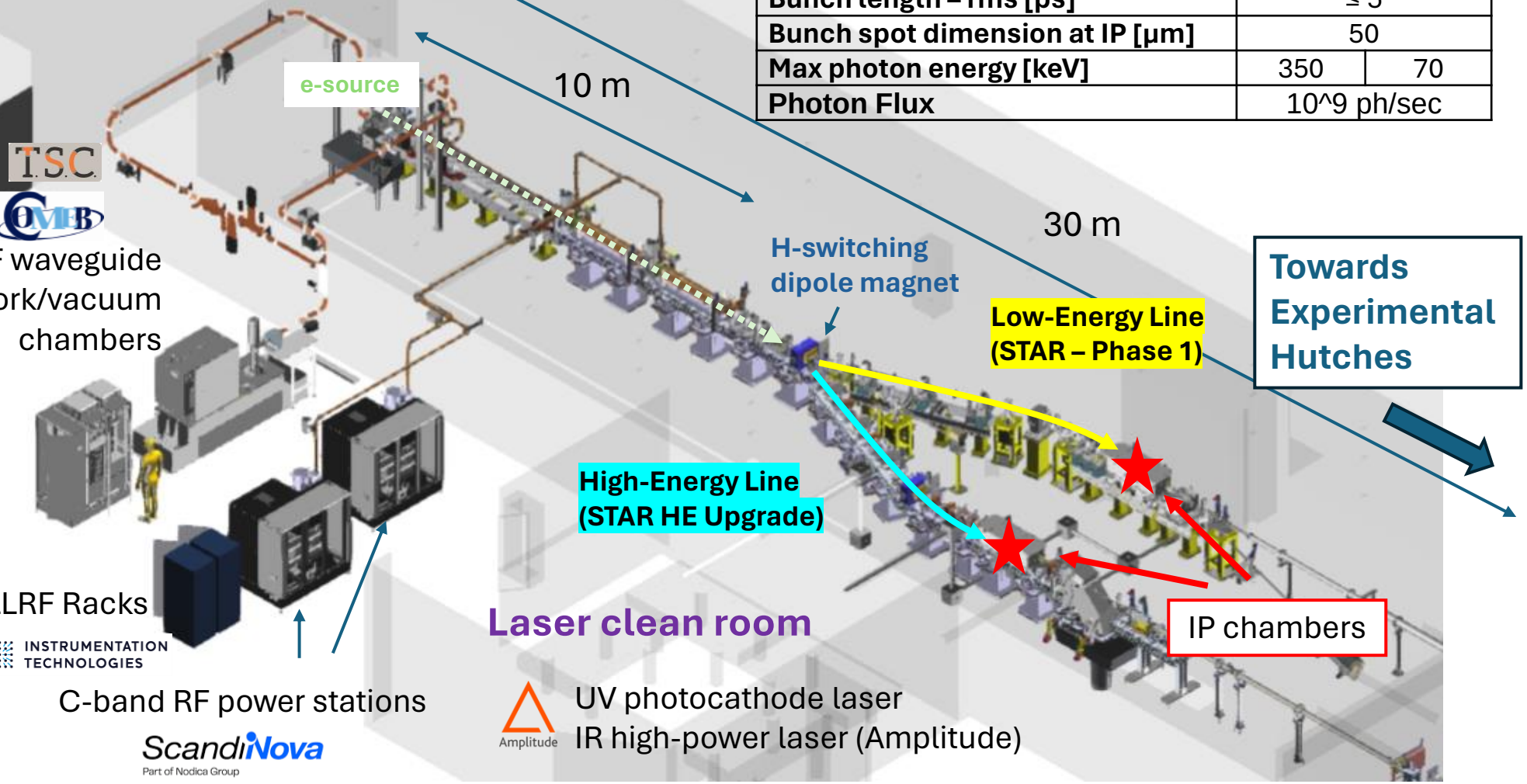


S-band RF power Station

OCEM POWER ELECTRONICS AMPEGON

Modulator and Racks area

STAR Accelerator Bunker



TSC

CMEB

RF waveguide network/vacuum chambers

LLRF Racks

INSTRUMENTATION TECHNOLOGIES

C-band RF power stations

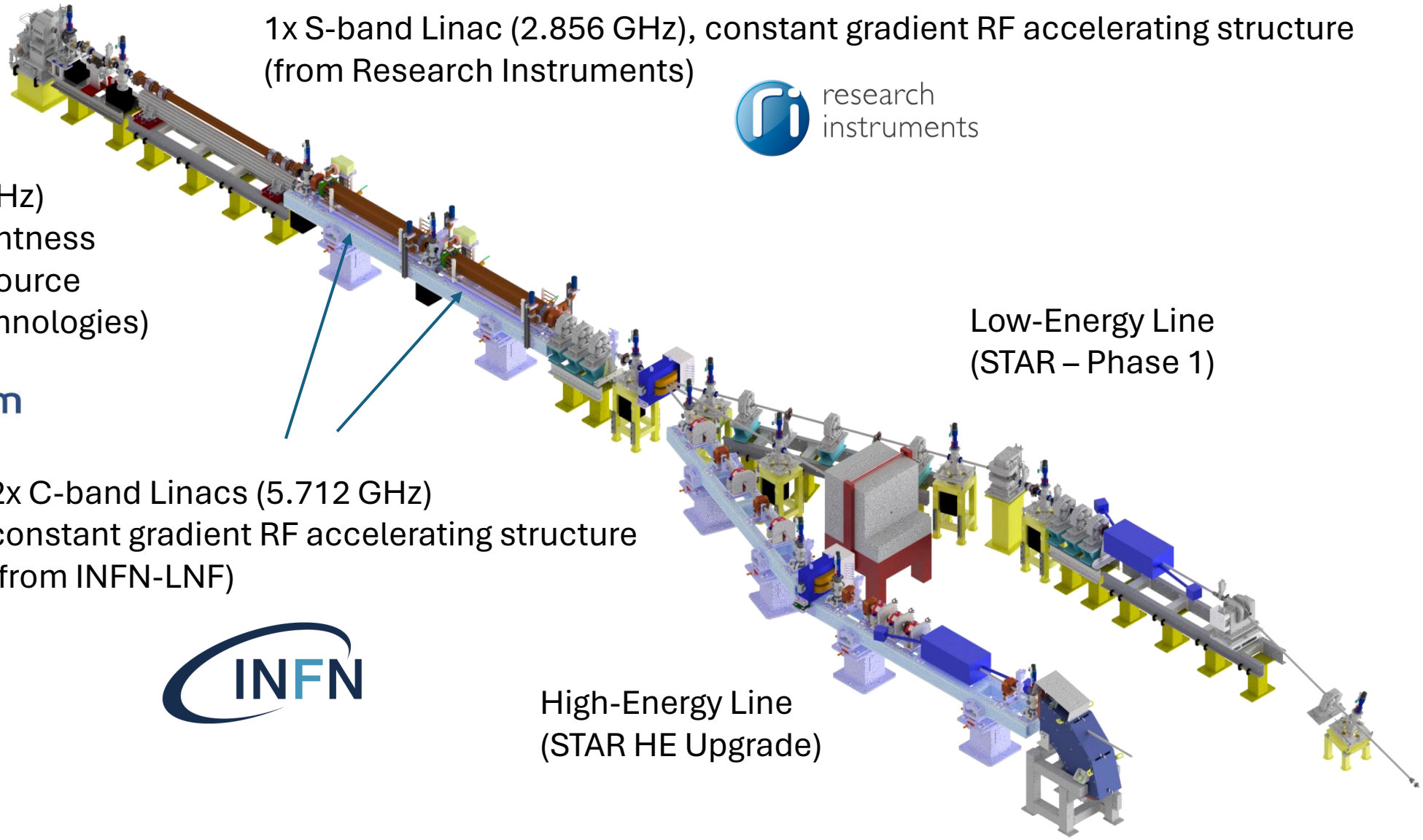
ScandiNova Part of Nodica Group

Laser clean room

Amplitude

UV photocathode laser
IR high-power laser (Amplitude)

RF Linac Layout



1x S-band Linac (2.856 GHz), constant gradient RF accelerating structure
(from Research Instruments)

RF Gun (2.856 GHz)
pulsed high-brightness
electron beam source
(Radiabeam Technologies)

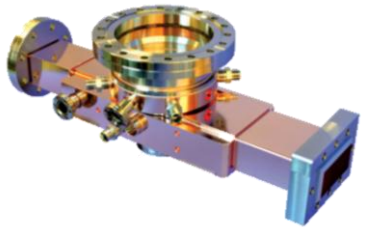
Low-Energy Line
(STAR – Phase 1)

2x C-band Linacs (5.712 GHz)
constant gradient RF accelerating structure
(from INFN-LNF)

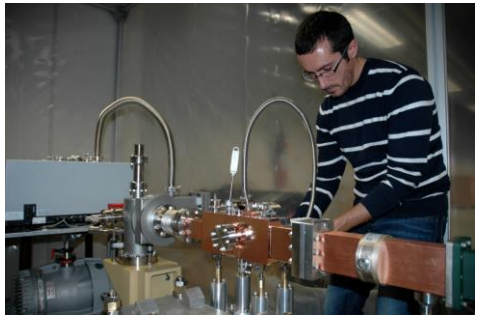
High-Energy Line
(STAR HE Upgrade)

First accelerating block: the RF Gun, September 2016

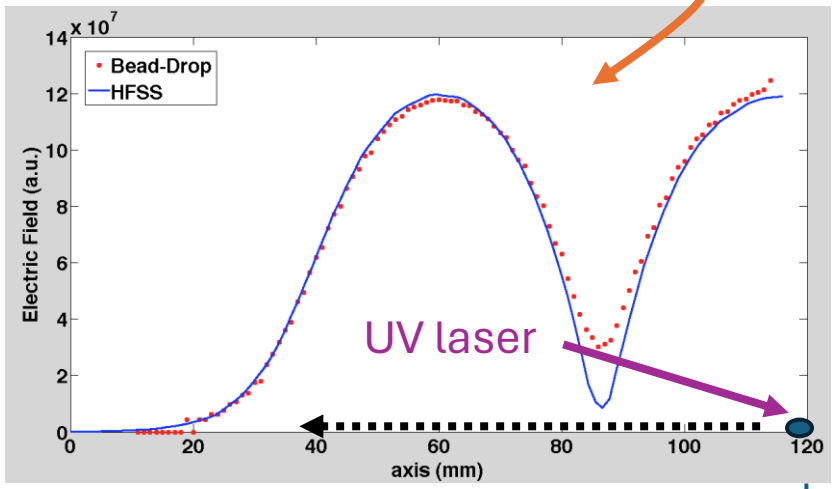
The RF Gun system developed, delivered and installed by Radiabeam Technologies LLC is now operational.

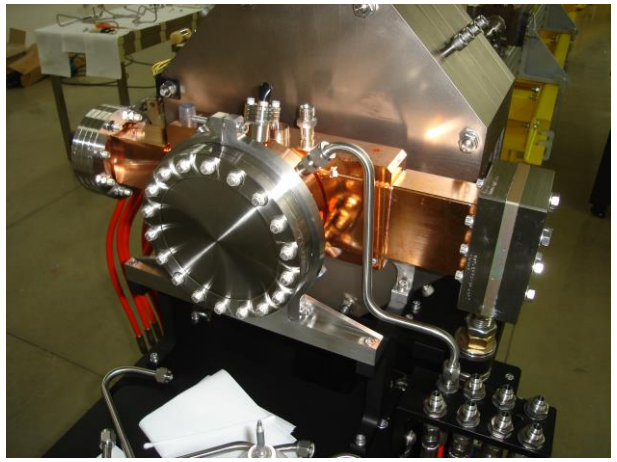


STAR gun after final brazing
(SLAC, 2015)



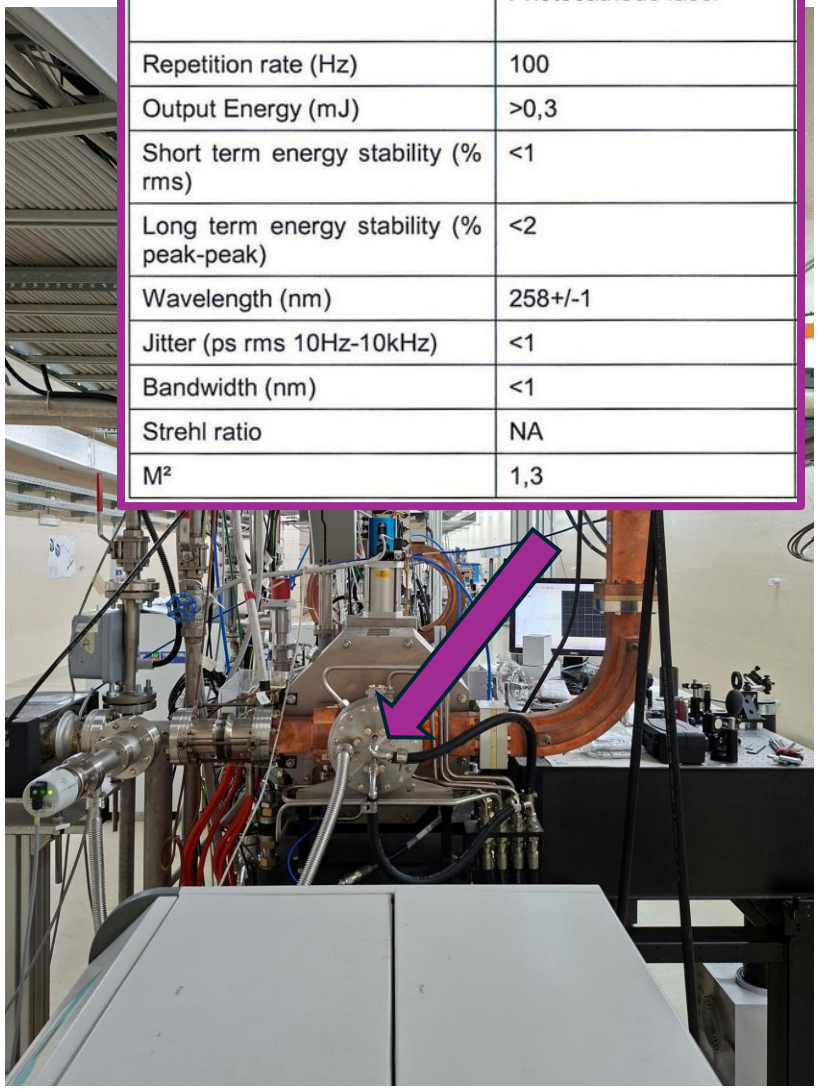
RF tuning



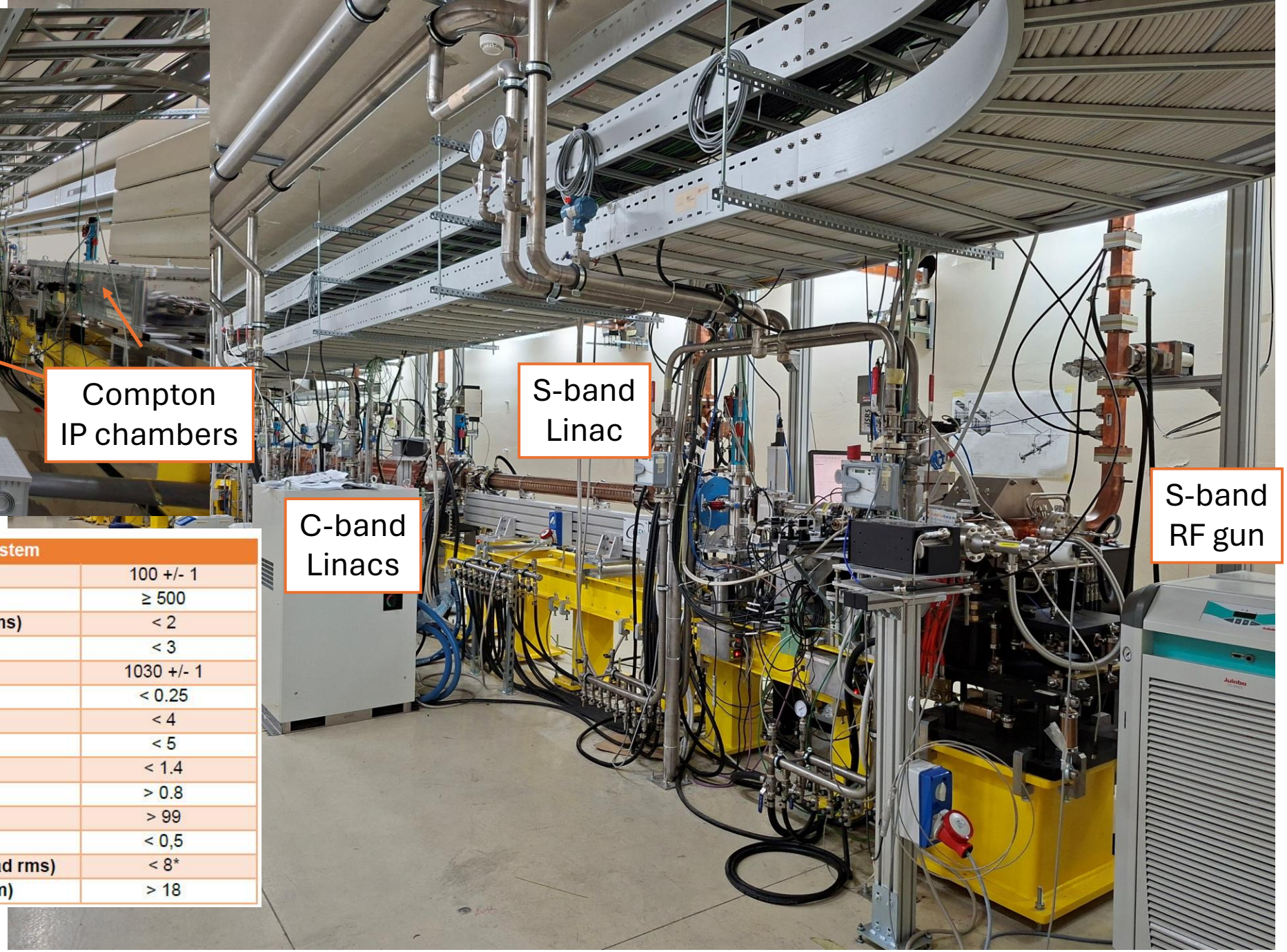


STAR, installation September 2016

	Photocathode laser
Repetition rate (Hz)	100
Output Energy (mJ)	>0,3
Short term energy stability (% rms)	<1
Long term energy stability (% peak-peak)	<2
Wavelength (nm)	258+/-1
Jitter (ps rms 10Hz-10kHz)	<1
Bandwidth (nm)	<1
Strehl ratio	NA
M^2	1,3



STAR today



Interaction line laser system	
Repetition rate (Hz)	100 +/- 1
Output Energy (mJ)	≥ 500
Short-term energy stability on 1000 pulses (% rms)	< 2
Long-term energy on 1 hour (% rms)	< 3
Central Wavelength (nm)	1030 +/- 1
Short-term jitter (ps rms) 10 Hz-10 MHz	< 0.25
Spectral Bandwidth (nm)	< 4
Pulse duration (ps FWHM)	< 5
Beam Quality M^2	< 1.4
Strehl ratio	> 0.8
Linear polarization (%)	> 99
Warm-up time (hours)	< 0,5
Short-term pointing stability on 1000 pulses (μrad rms)	< 8*
Beam diameter at compressor output at $1/e^2$ (mm)	> 18

The Beam Dynamics (BD) group developed two main software tools ad hoc for STAR

1) The **CONTROL ROOM SIMULATOR** (operative) **–** to tune the LINAC behavior VS Simulations

IT is a **Graphical interface for the** typical **CS-knobs value** as:

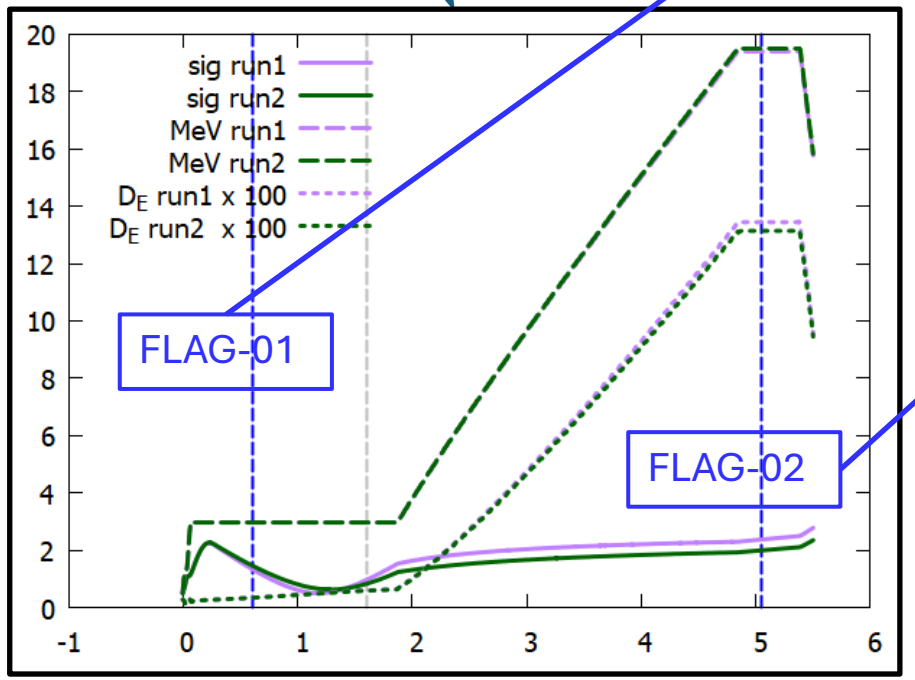
CURRENTS	[A]	VS	B [T]	for **SOLENOIDS**, **STEERINGS**, **DIPOLES**
Klystron Power	[MW]	VS	[MV/m]	for **Gun, Cavities peak field**
STEPS	[#]	VS	RF°	for **Phase shifter**, **Laser arrival time**
… … …				

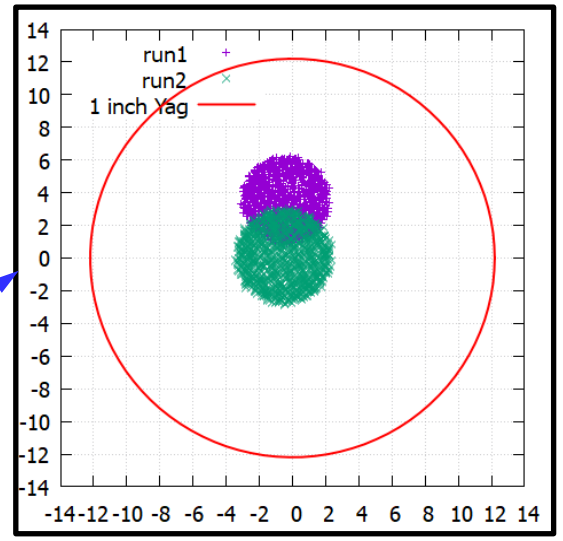
Further:
Virtual targets as primary diagnostic system BUT with the helps of BD parameters:
energy-gain, *beam-envelops, energy-spread* and *beam emittance*.

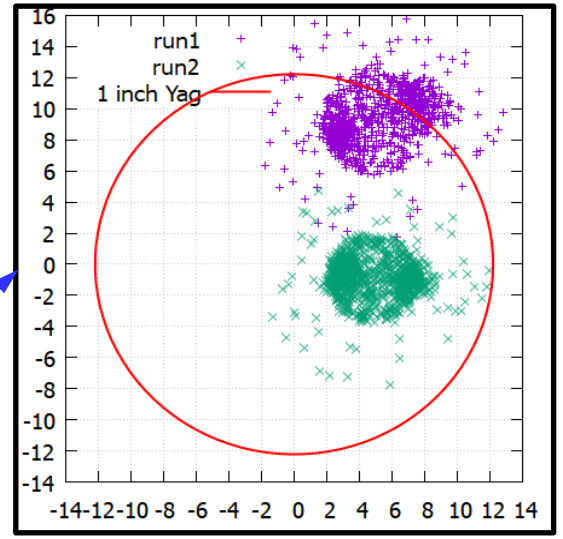
2) **GIOTTO on the EPICS** STAR CS (not still operative; Work in progress) **–** a Genetic Optimization tool

The CONTROL ROOM simulator

ASTRA: the core simulator engine
(*Klaus Floettmann. DESY)*
with a very physical approach

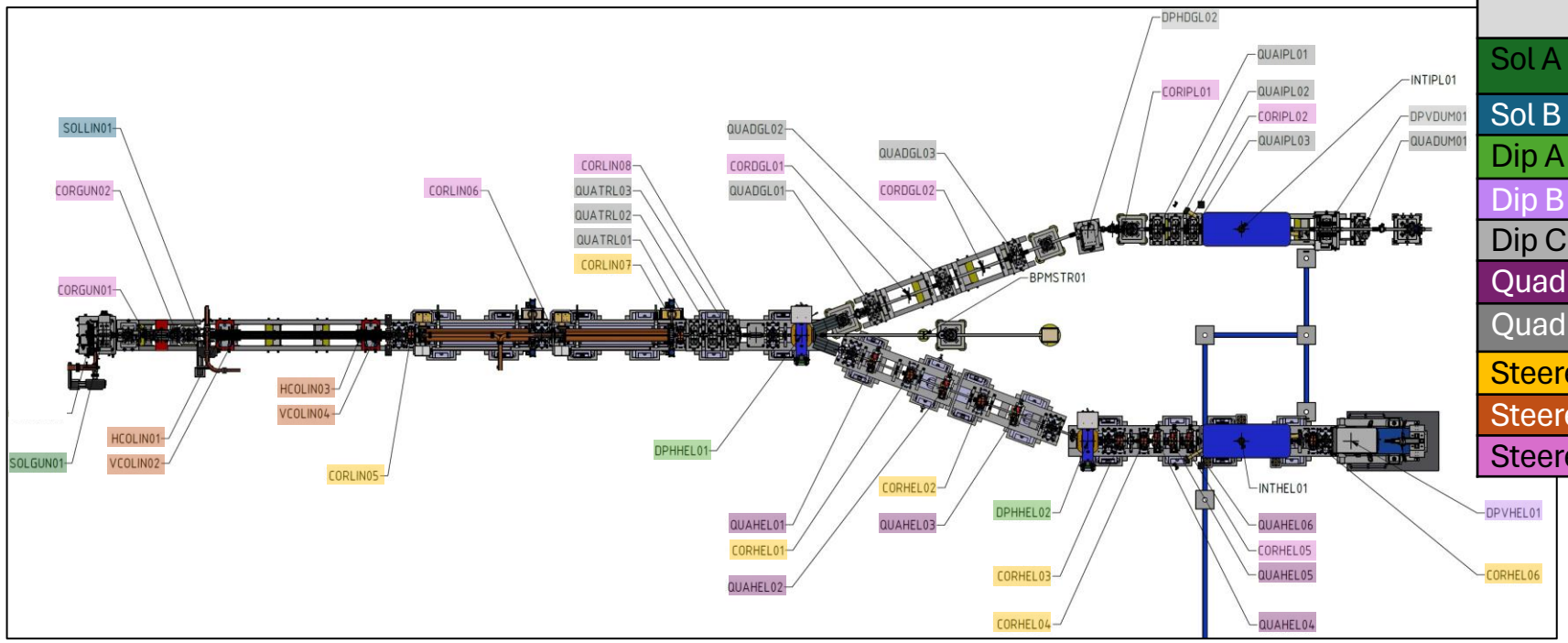






Here Gun and S-band cavity up to 6 m as example
We have the whole machine up to the IP

Magnetic elements

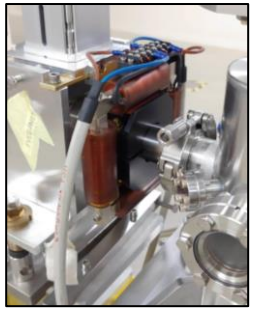


Mag type	Field/Grad	Nominal Current	Cooling*	QTY
Sol A	3000 G	144 A	WC	1
Sol B	1800 G	110 A	WC	1
Dip A	0.8 T	87 A	WC	2
Dip B	0.87 T	90 A	WC	1
Dip C	0.65 T	336 A	WC	2
Quad A	18 T/m	47 A	WC	6
Quad B	9 T/m	9 A	AC	10
Steerer A	70 G	1.3 A	AC	7
Steerer B	45 G	30 A	AC	4
Steerer C	38 G	3 A	AC	9

*WC and AC: water and air cooled respectively

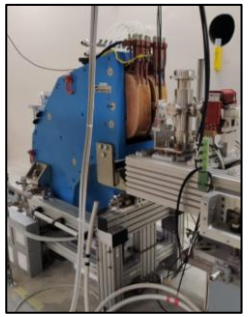
Courtesy of A. Vannozzi

From the left: Quad A triplet; Steerers A and Dip A



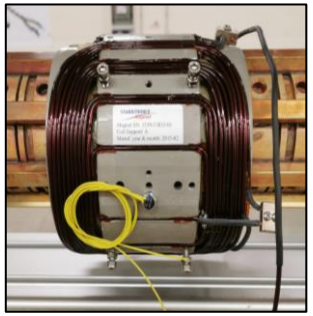
Steerer C

Dip C



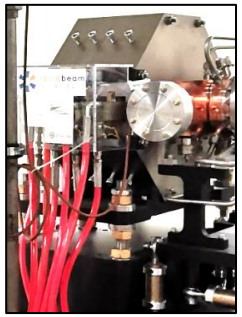
Dip B

Quad B triplet



Steerer B

Sol B



Sol A

2x*Doglegs* transport sections: effective filter for unwanted bremsstrahlung produced by dark current in the accelerating structures.

Beam Diagnostics

Type	LINAC (Star1)	LINAC upgrade (Star-HEL)	LE Line (Star1)	HE line (Star-HEL)
Beam Position Monitor	2	1	5	4
Beam Current Monitor	1	-	1	1
YAG screen	3	2	4	4
Beam spectrometer			1	1

Libera BPM processing module (Instrumentation Technology)

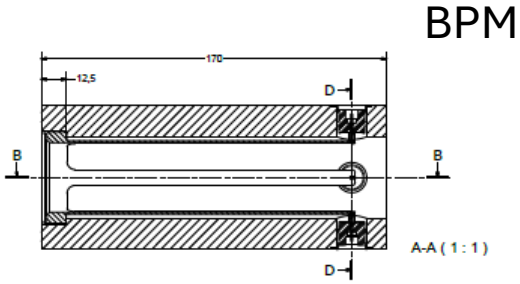
The system uses 12 Beam Position Monitors (BPMs) with strip-line geometry

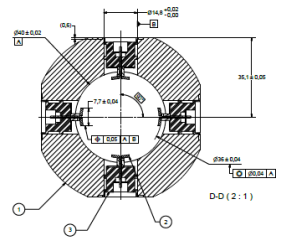
Beam charge is measured with integrating current transformers (ICTs) and fast current transformers (FCTs), plus external readout electronics

ICT

Beam size and profile in the linac are measured with Ce:YAG screens (cerium doped yttrium aluminium garnet crystal). The beam is imaged via a 45° in-vacuum mirror to a high-resolution Basler camera.

BPM

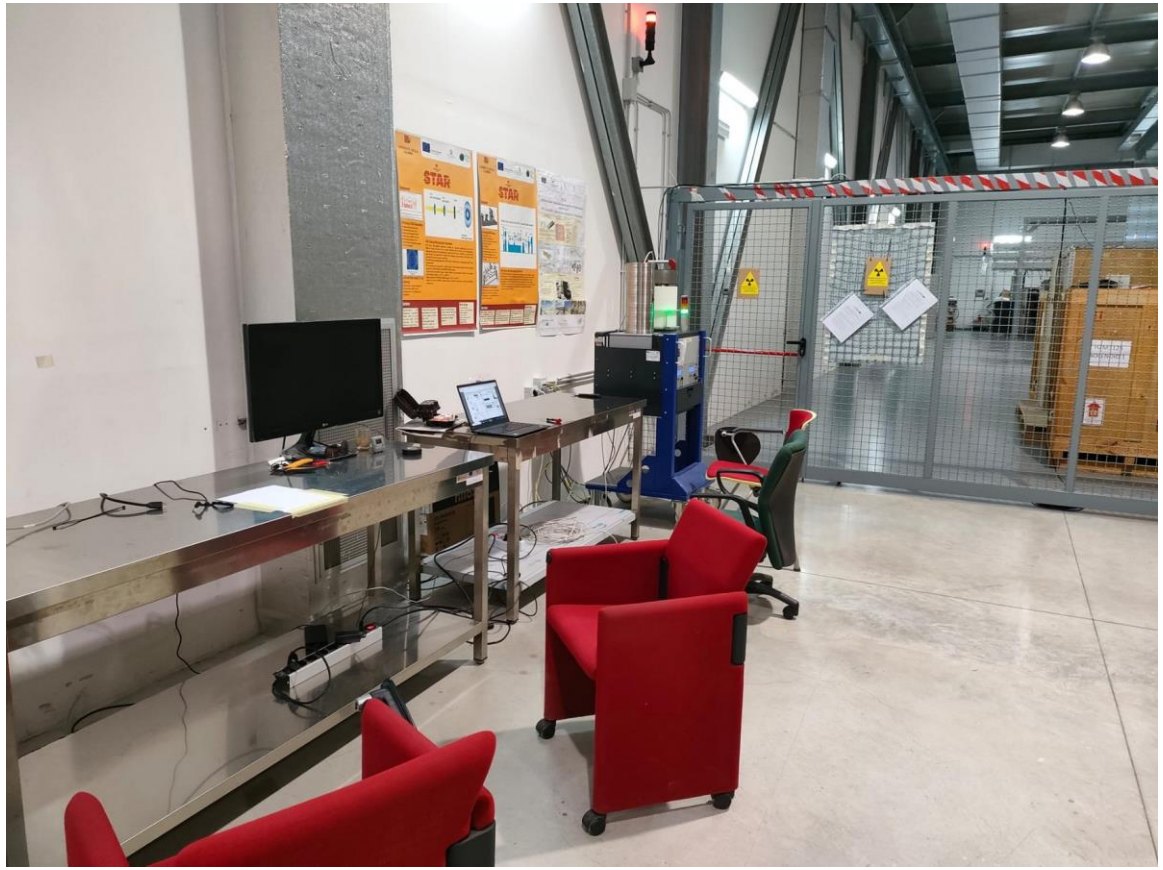




Two diagnostic chambers are installed downstream the H-shaper dipole in the high and low energy line.

Control room

Before

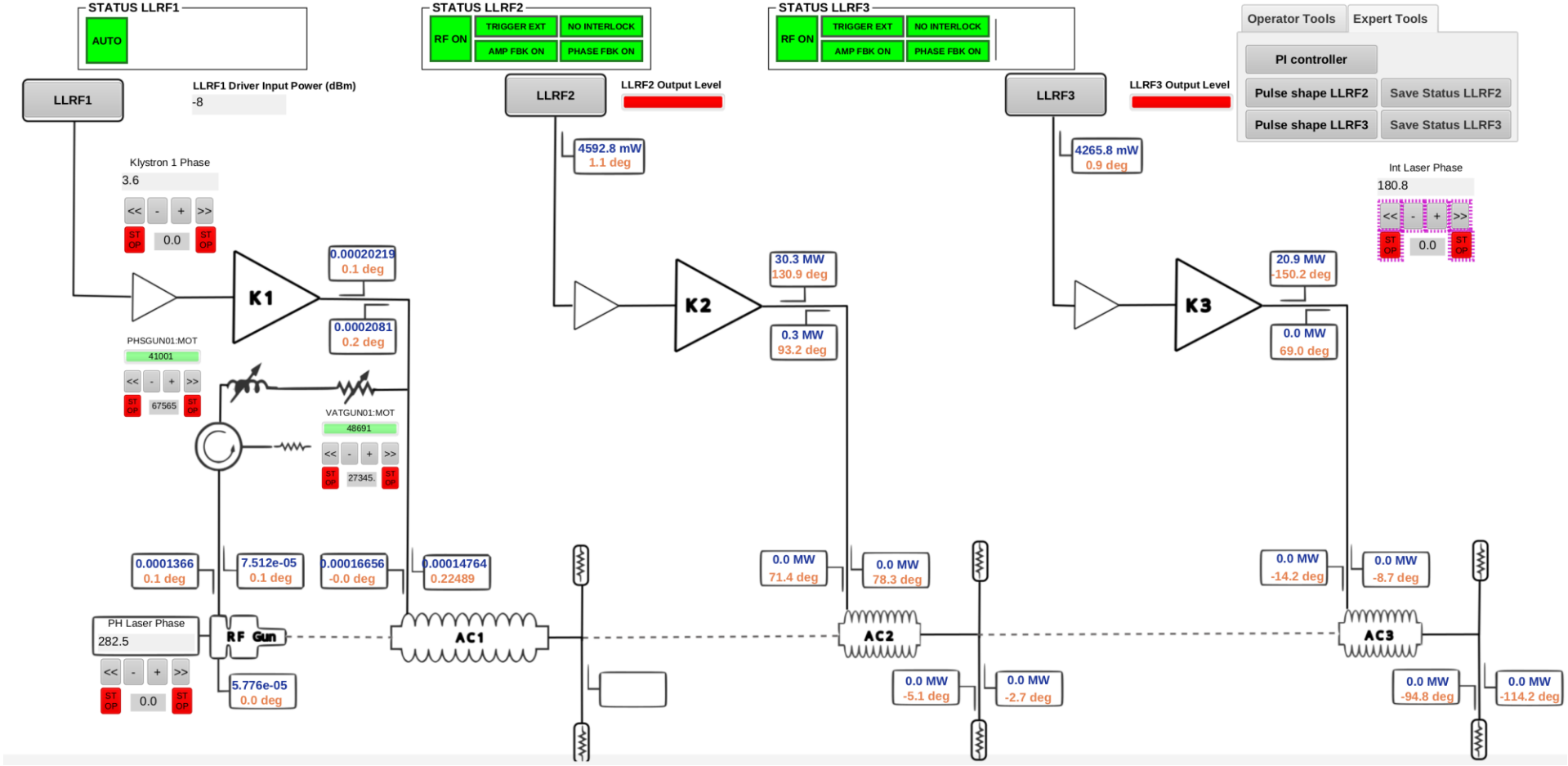


After

May 2025

Control System

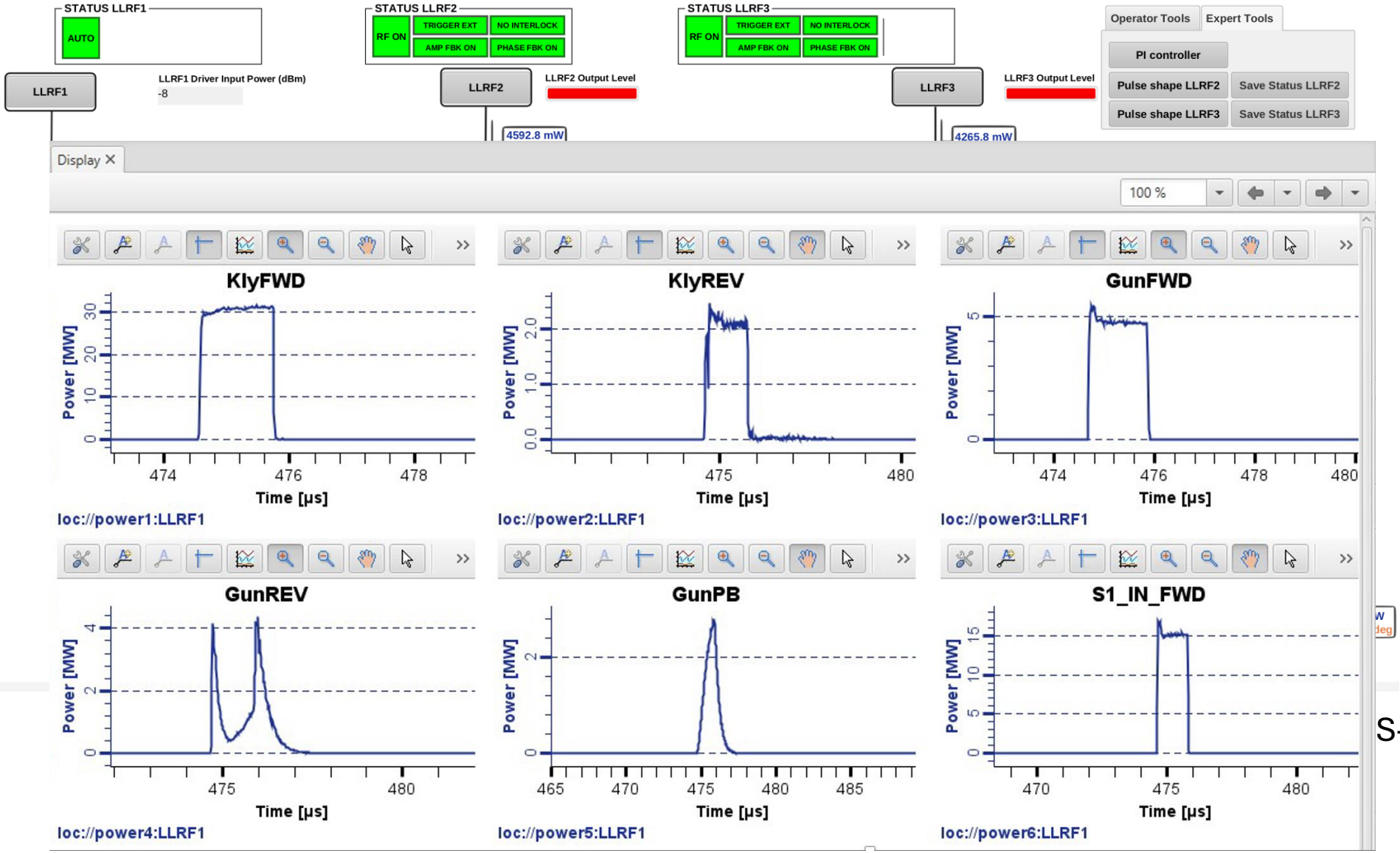
- EPICS (Experimental Physics and Industrial Control System) framework: software infrastructure for building distributed control systems.
- Handling all subsystems: LLRF, vacuum, magnets, BPMs, cameras, etc.
- Phoebus: operator interface.



STAR Phoebus display for the LLRF subsystem of the three Klystron referred as K1 (S-band), K2 and K3 (C-band).

Control System

- EPICS (Experimental Physics and Industrial Control System) framework: software infrastructure for building distributed control systems.
- Handling all subsystems: LLRF, vacuum, magnets, BPMs, cameras, etc.
- Phoebus: operator interface.

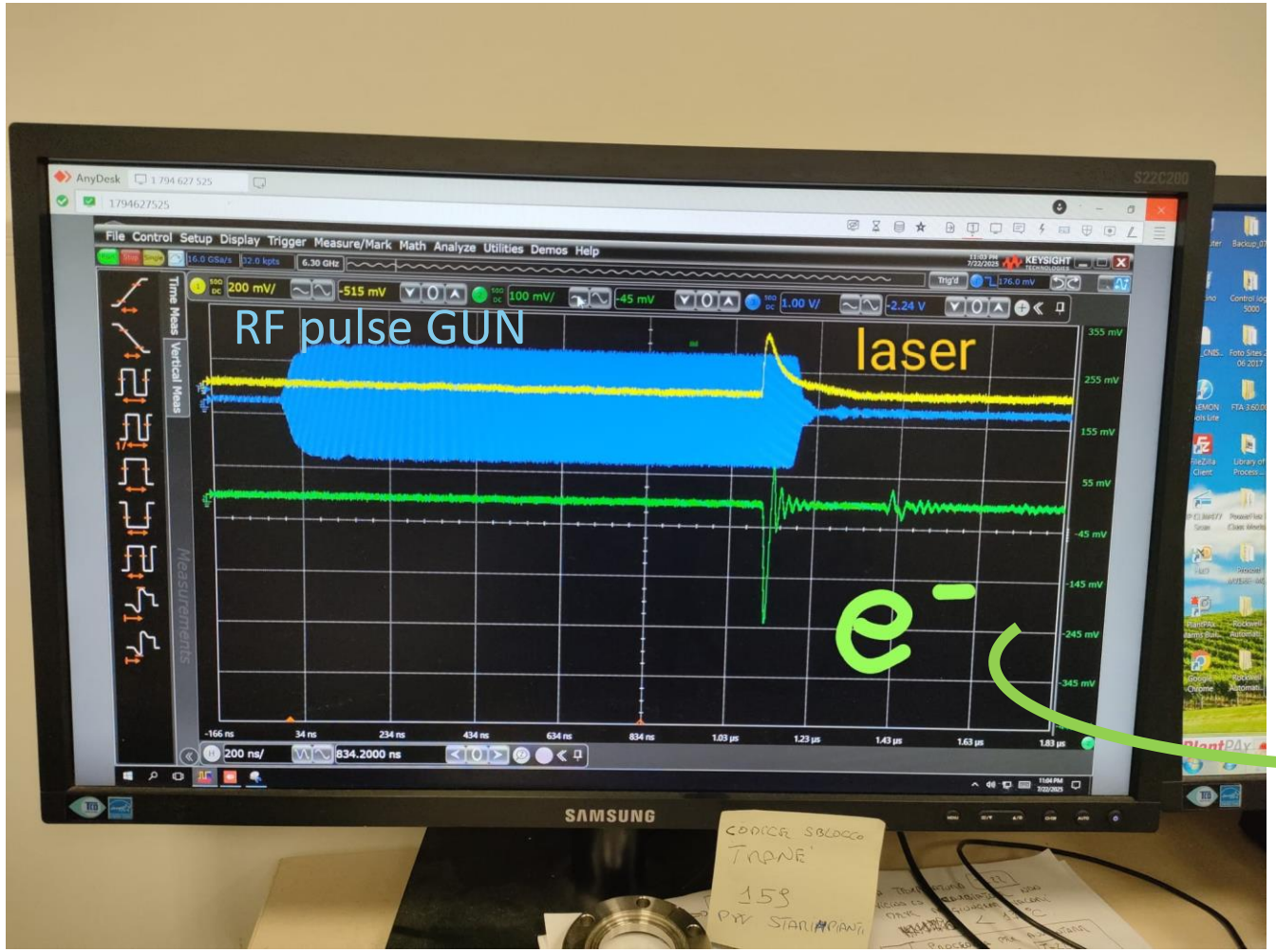


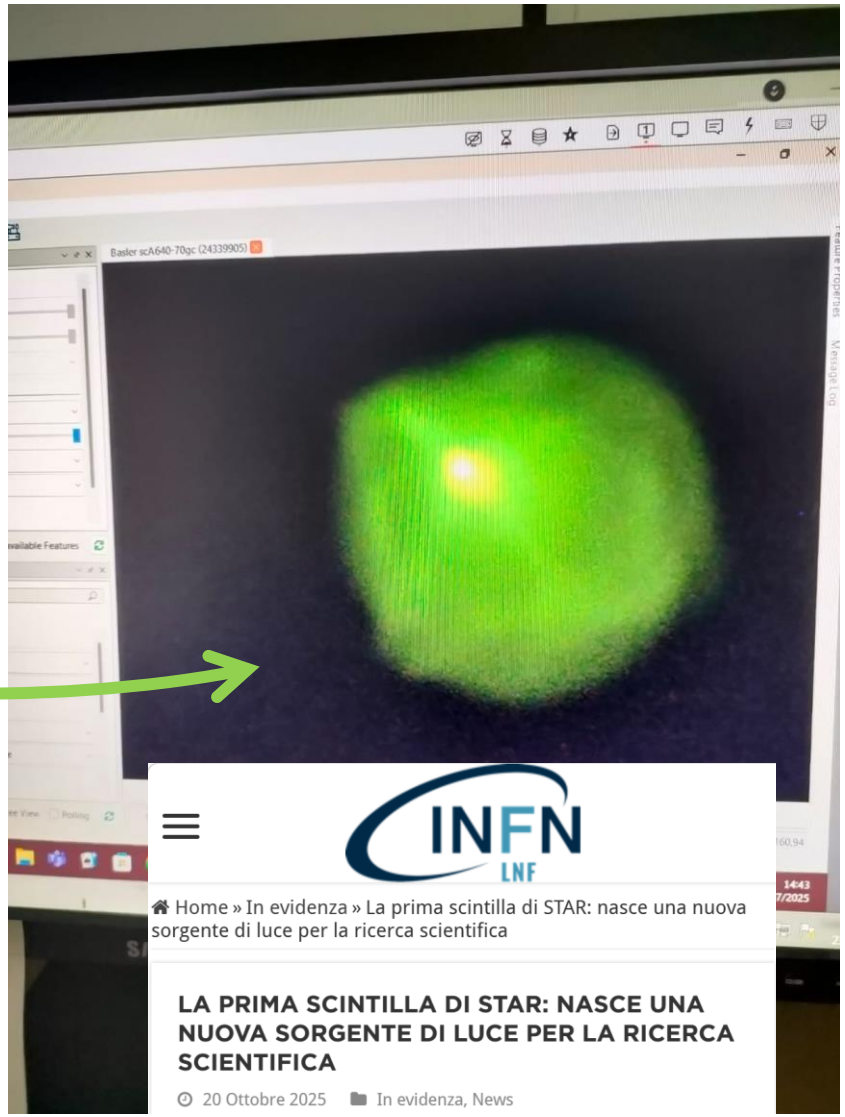
STAR Phoebus complete display for the LLRF subsystem.

First e beam

First photo-emitted electron beam, imaged on YAG screen after the rf GUN. Laser 10 ps.

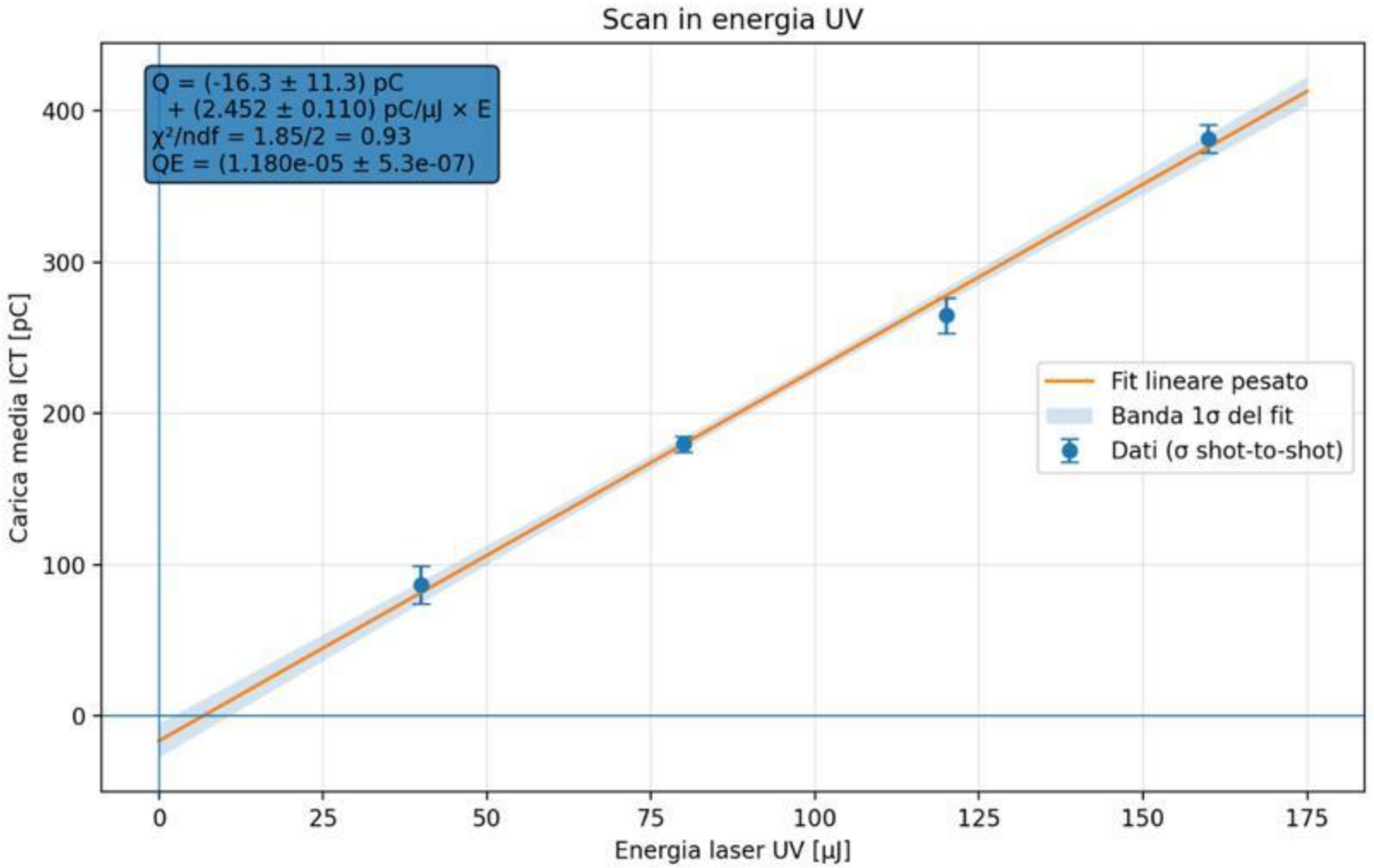
e-charge about 80-100pC





First e beam end of July 2025

Cathode QE Measurement



$$Q(E_{\mathrm{UV}}) = Q_{\mathrm{dark}} + mE_{\mathrm{UV}}$$

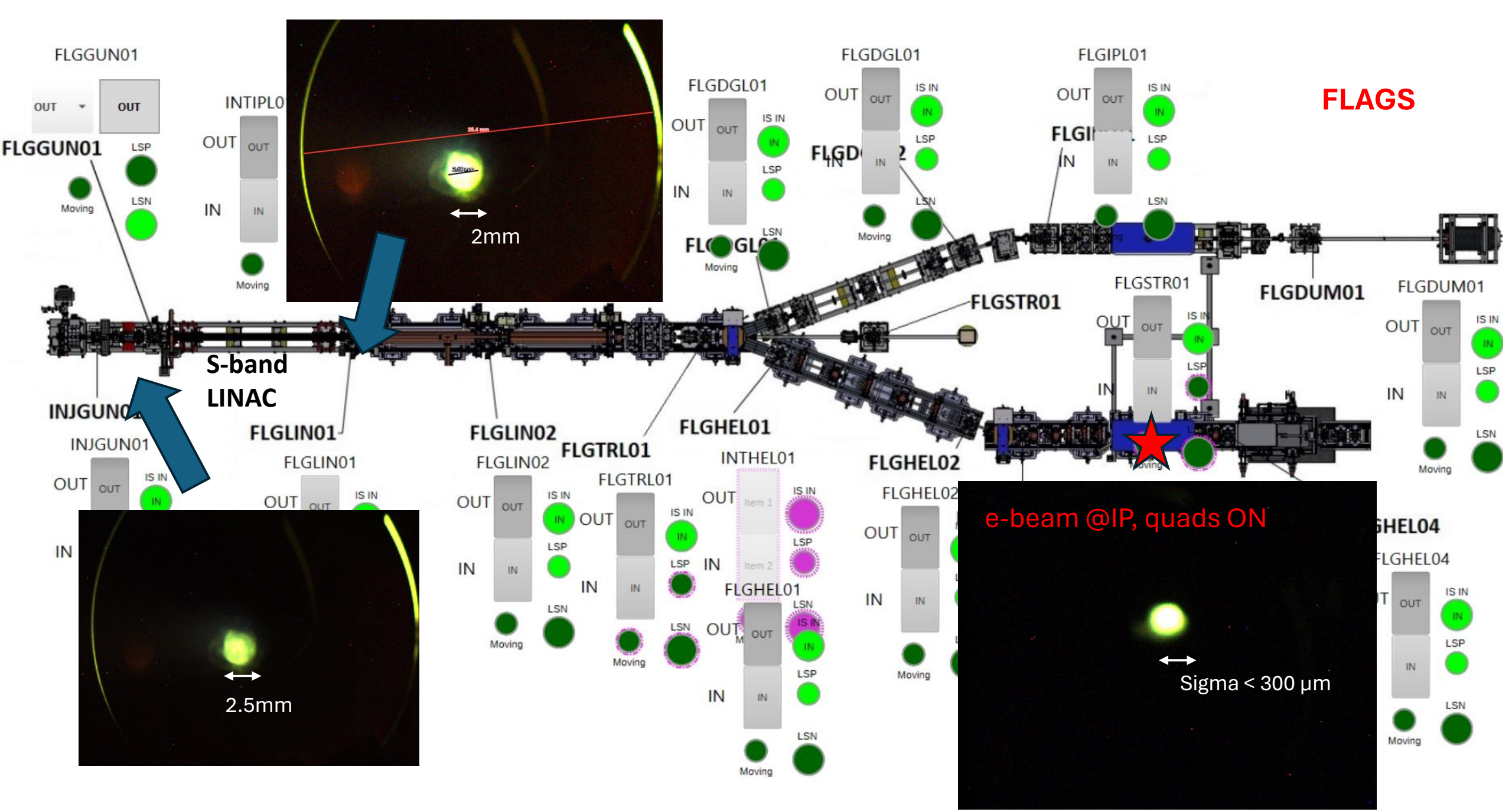
$$m = (2.4515 \pm 0.1103)\ \frac{\mathrm{pC}}{\mu\mathrm{J}}$$

$$Q_{\mathrm{dark}} = (-16.3 \pm 11.3)\ \mathrm{pC}$$

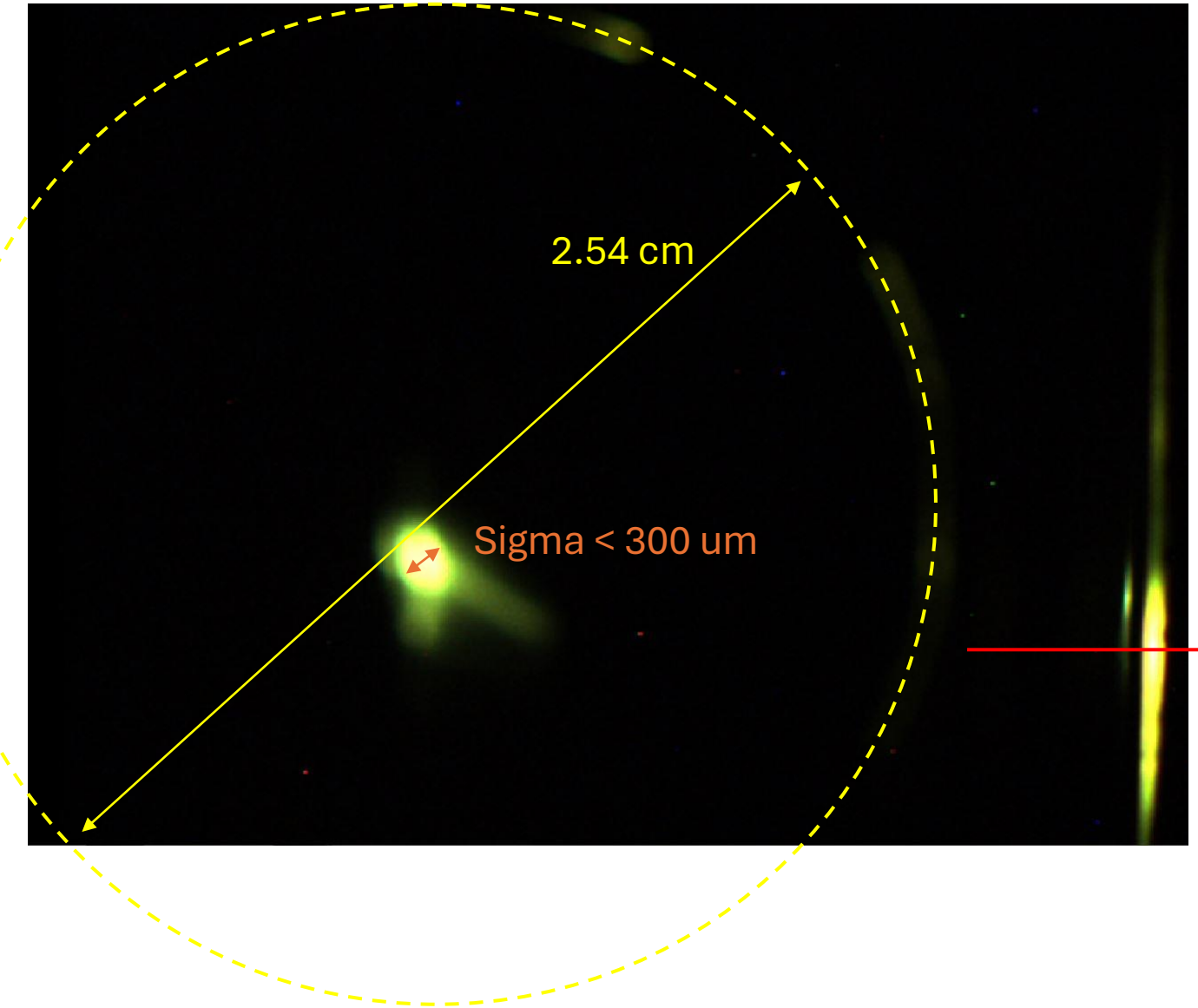
$$\mathrm{QE} = (1.180 \pm 0.053) \times 10^{-5}$$

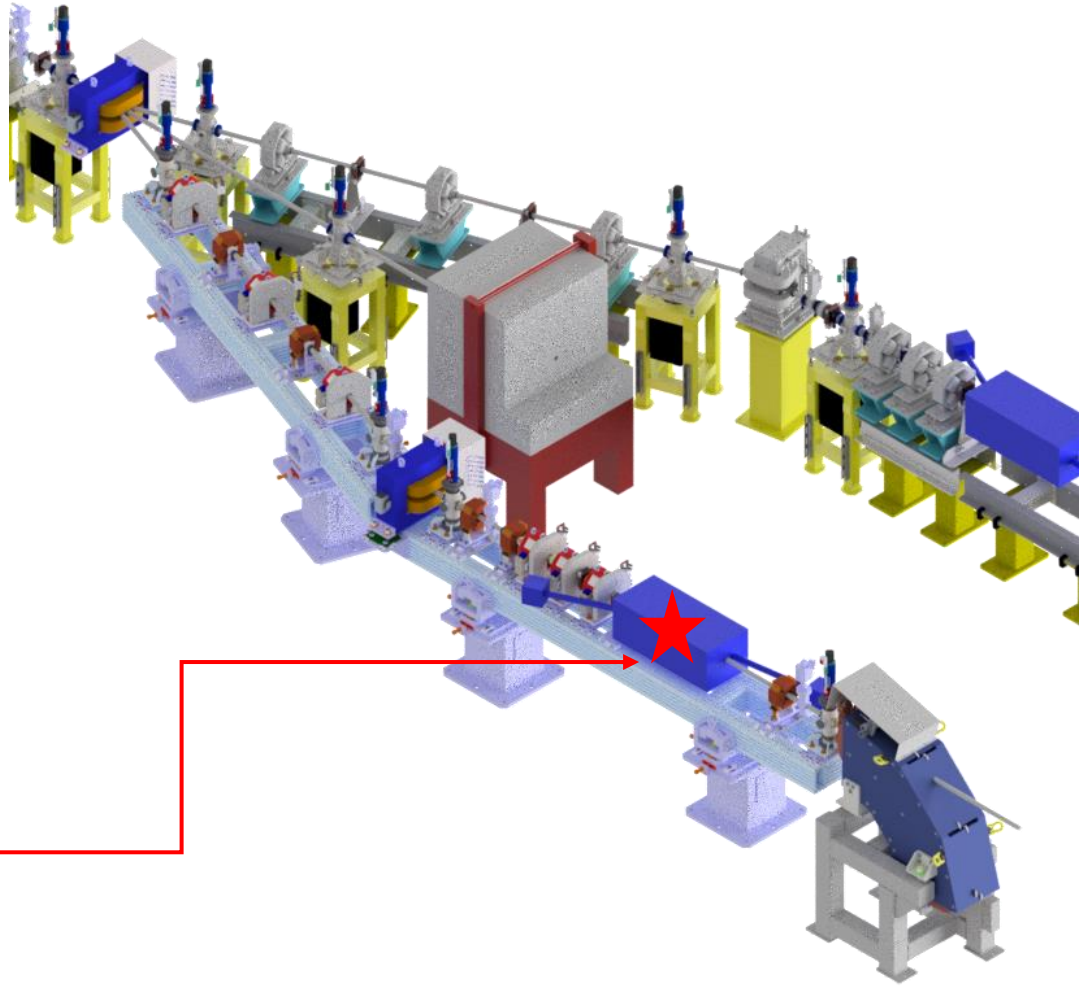
$$\lambda_{\mathrm{UV}} = 257.5\ \mathrm{nm}$$

Courtesy of E. Tassi


FLAGS
FLGGUN01
INTIPL0
FLGDGL01
FLGDGL01
FLGIPL01
FLGSTR01
FLGDUM01
FLGDUM01
S-band
LINAC
INJGUN0
INJGUN01
FLGLIN01
FLGLIN01
FLGLIN02
FLGLIN02
FLGTRL01
FLGTRL01
INTHEL01
FLGHEL01
FLGHEL01
FLGHEL02
FLGHEL02
FLGHEL04
FLGHEL04
2mm
2.5mm
e-beam @IP, quads ON
Sigma < 300 μm
OUT
IN
IS IN
LSP
LSN
Moving

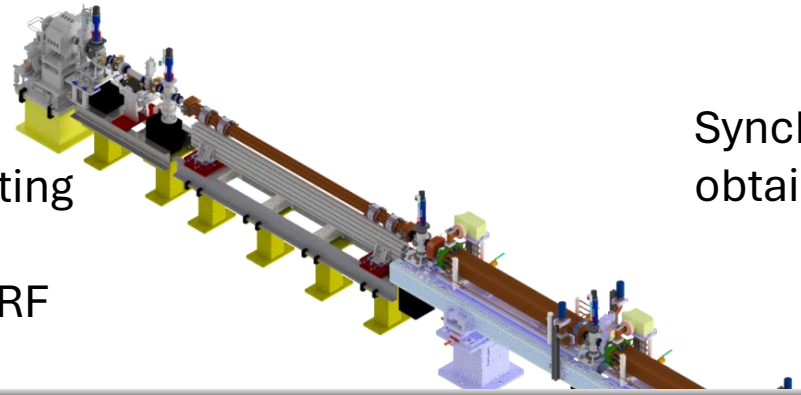
Electron beam at IP





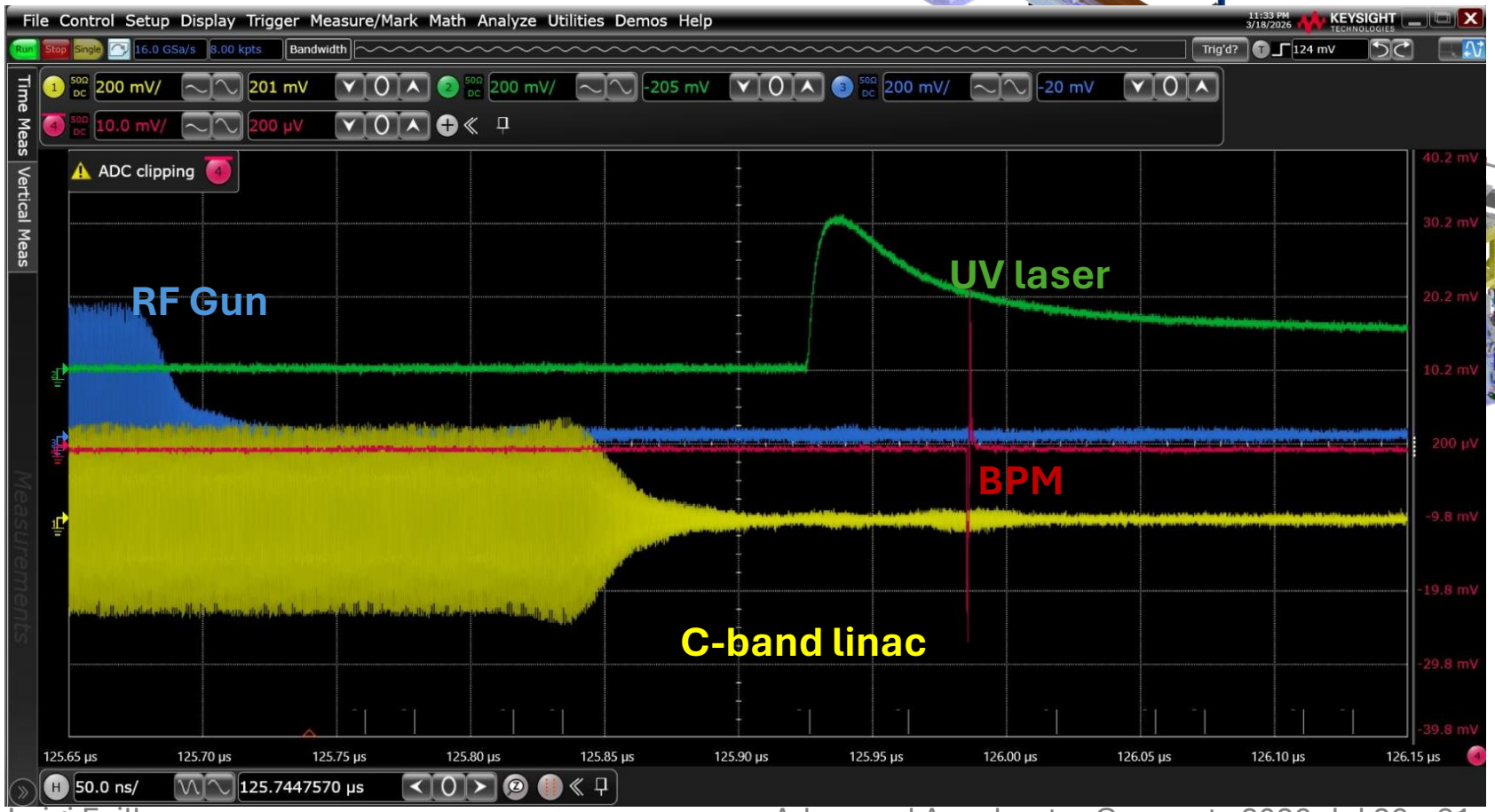
- ❑ Electron Energy up to 100 MeV
- ❑ The electron beam spot is adjustable by means of quadrupole magnets!

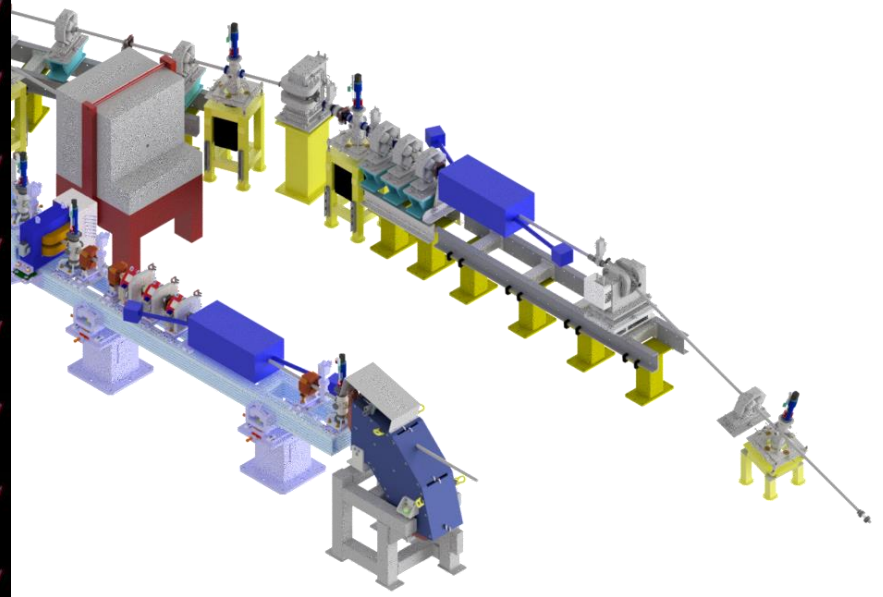
Timing and Synchronization



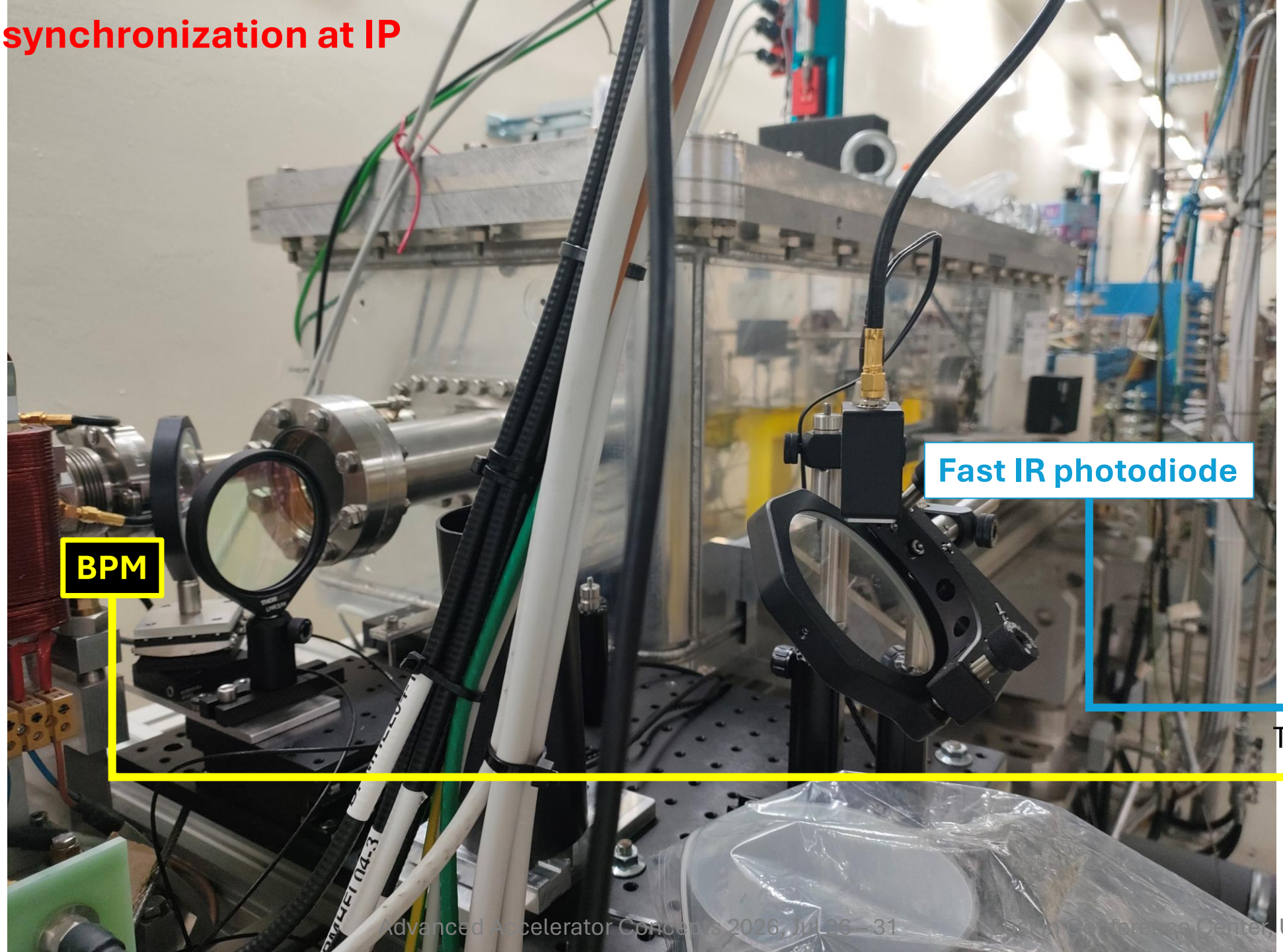
UV laser Pulse and Accelerating RF structure signals are monitored on oscilloscope (RF Gun, C-band linac, etc.)

Synchronization between UV laser pulse and RF Gun is obtained through the LLRF at <ps level.

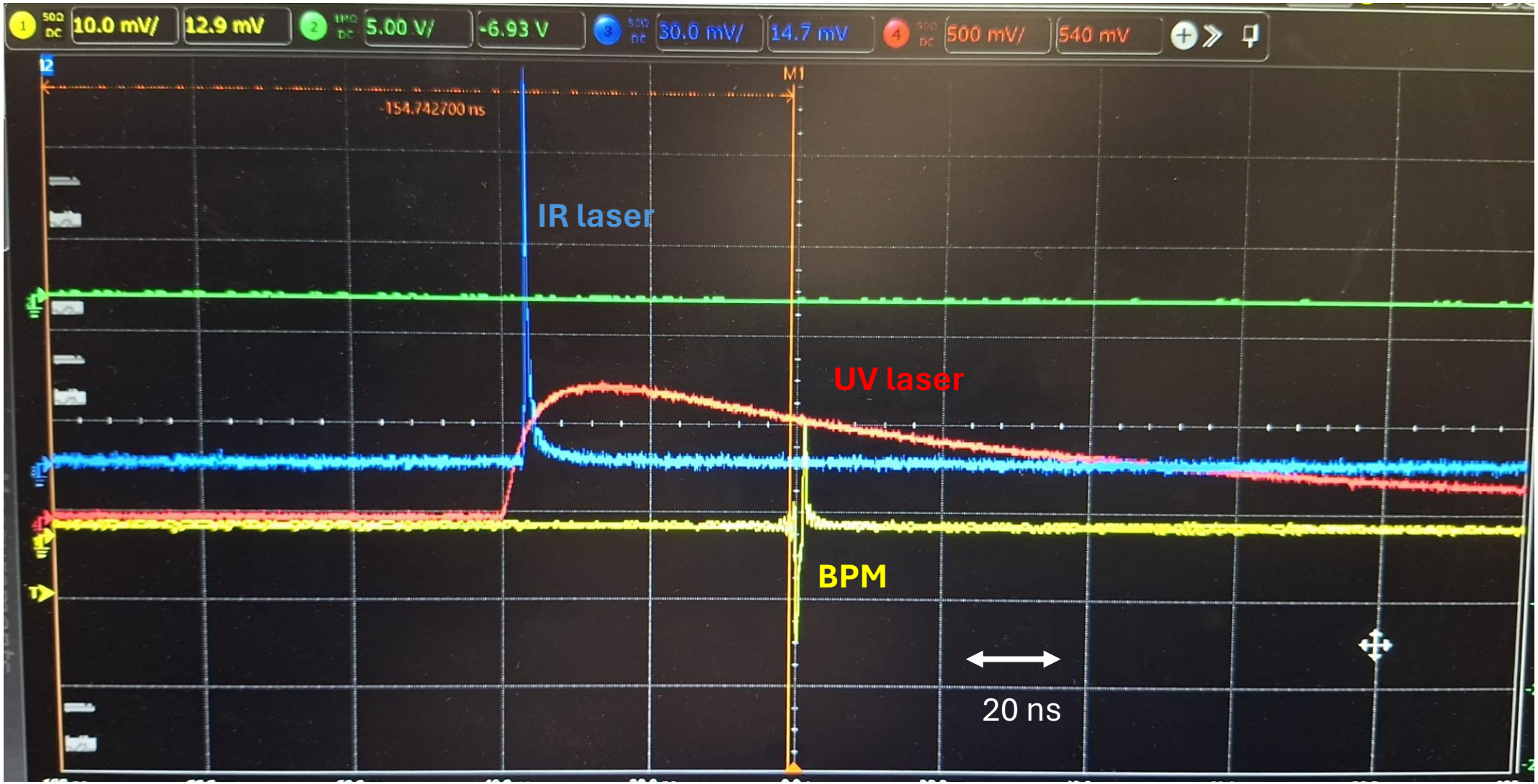




Temporal synchronization at IP

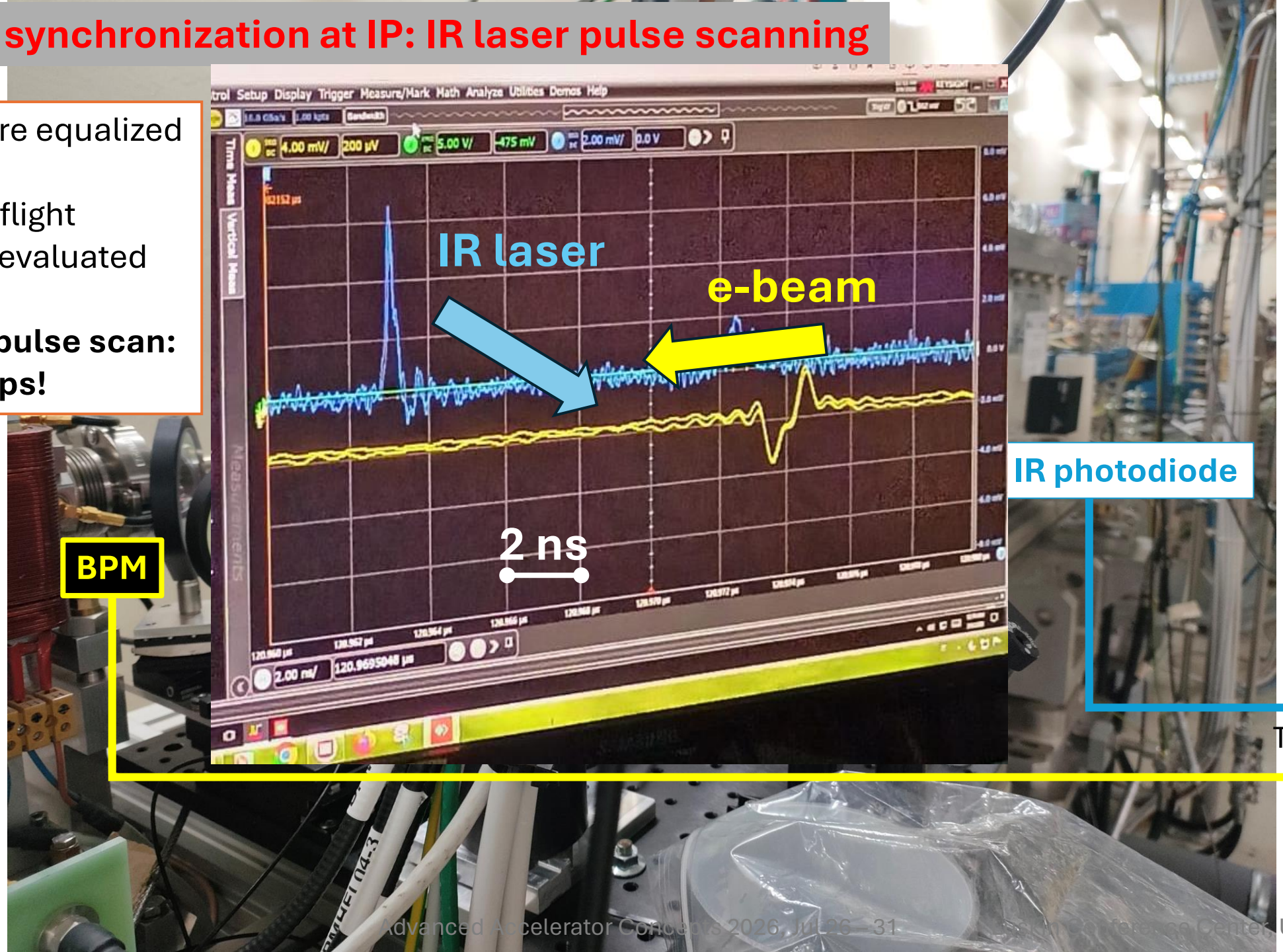


Temporal Synchronization at IP: traces on oscilloscope

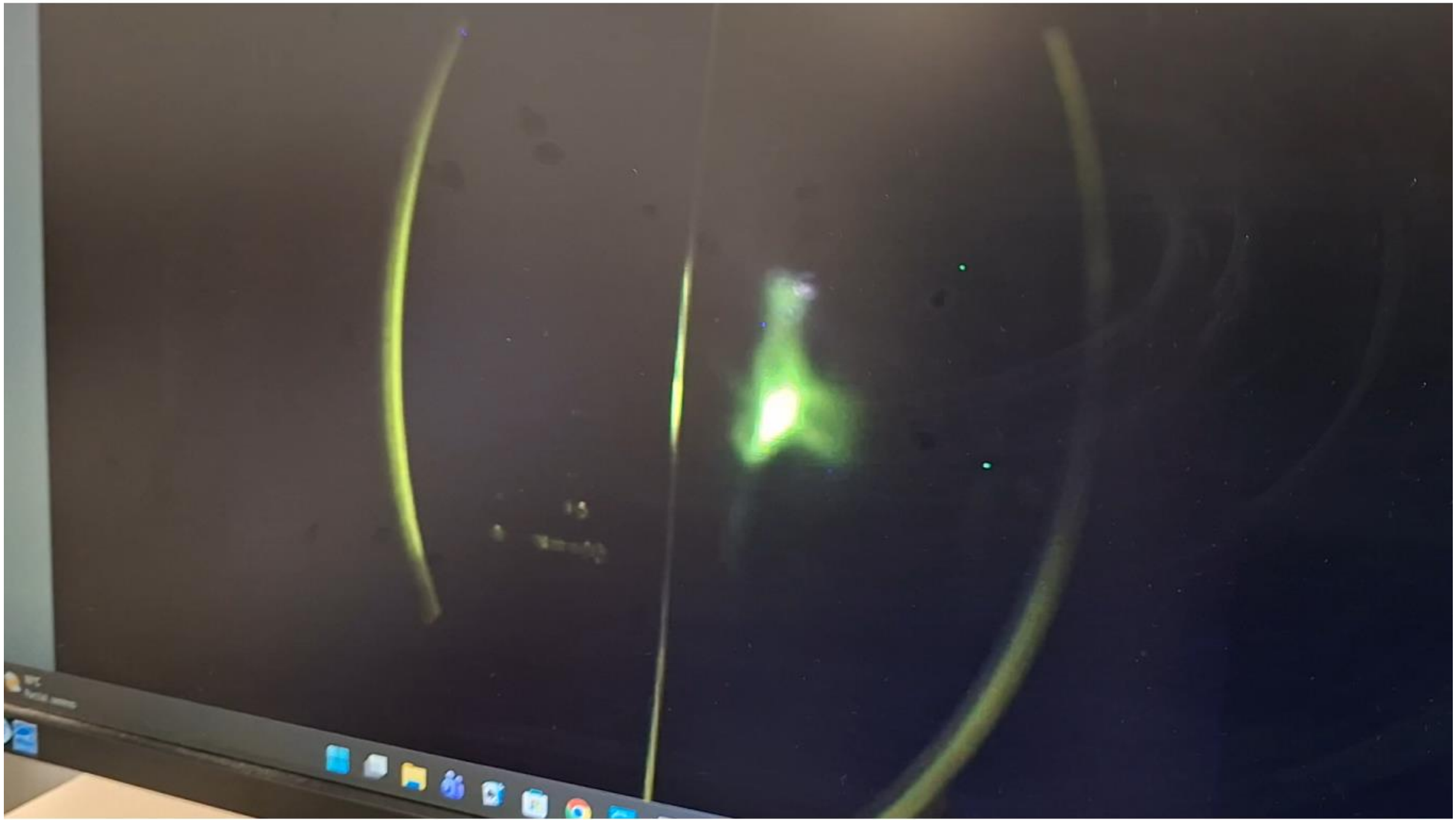


Temporal synchronization at IP: IR laser pulse scanning

- Cables are equalized
- Times of flight properly evaluated
- **IR laser pulse scan: <1ps steps!**



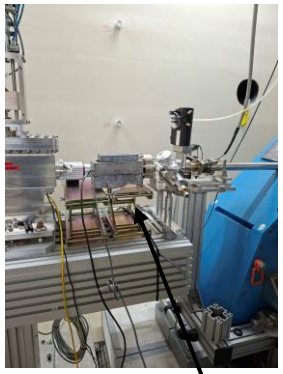
Spatial synchronization at IP

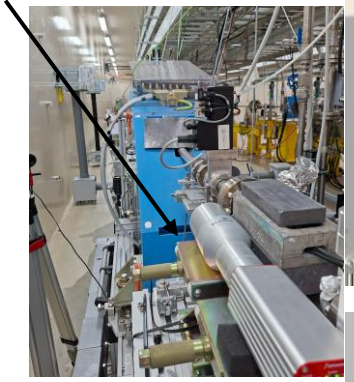


Interaction Chamber (HEL)

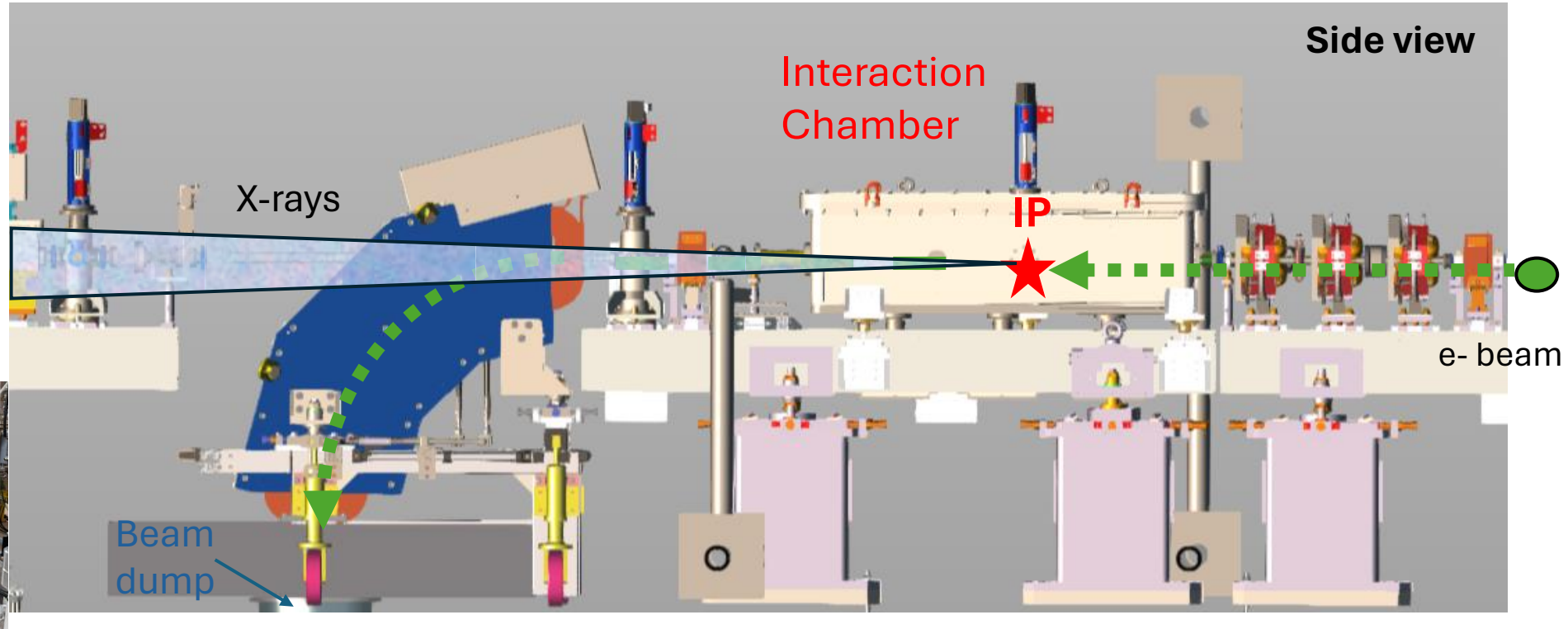
Else Nuclear Detector, NaI(Tl).
Energy Resolution: <9% at 662 keV (Cs-137)

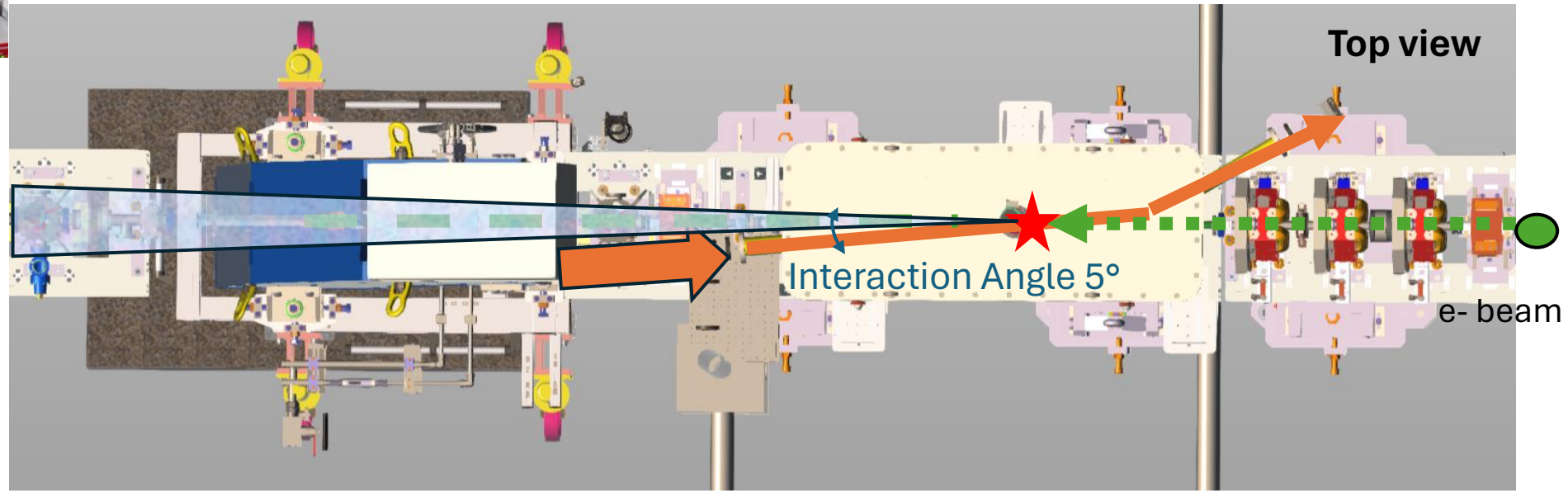
CAEN Multichannel Gammastream type S2580



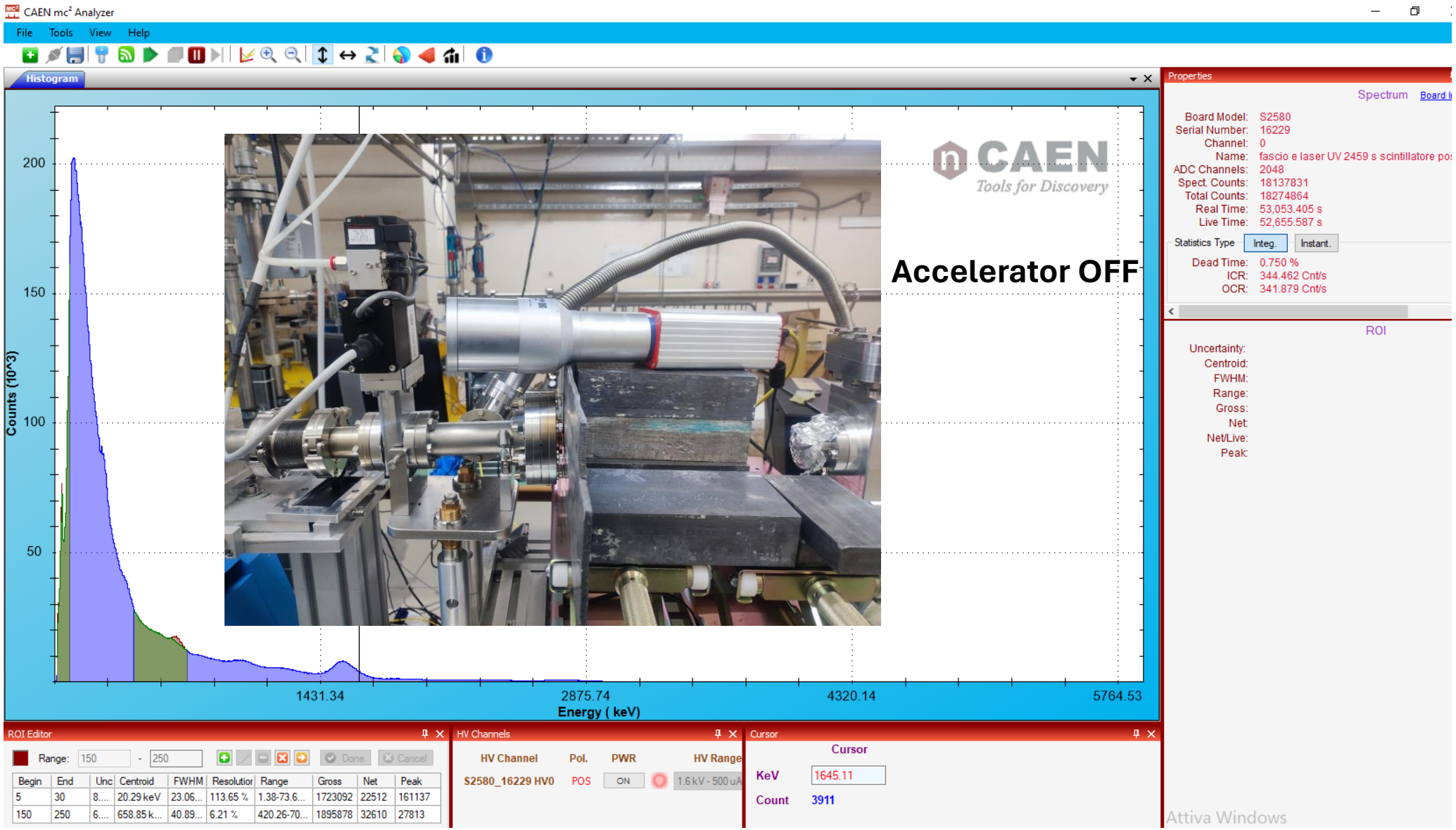


XR-100CR Si-PIN X-Ray Detector (AmpTek)





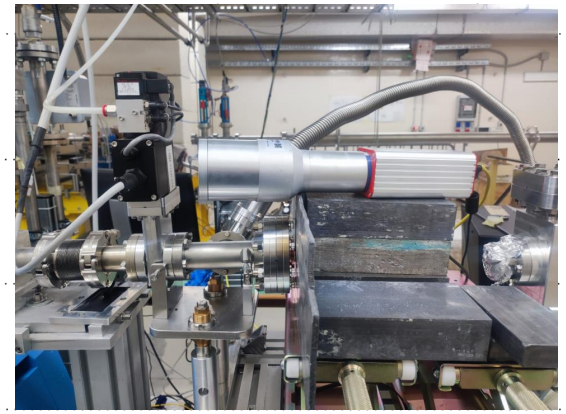
Background Radiation Characterization



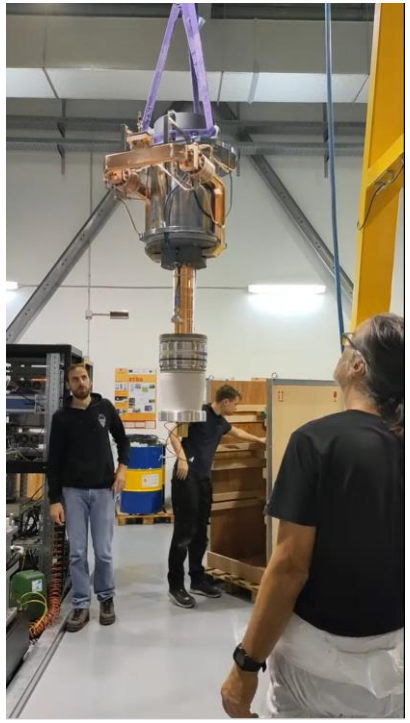
Background Radiation Characterization

Electron beam ON

- Properly aligned into the beam dump
- Ionization chamber monitoring placed on the roof above the dump

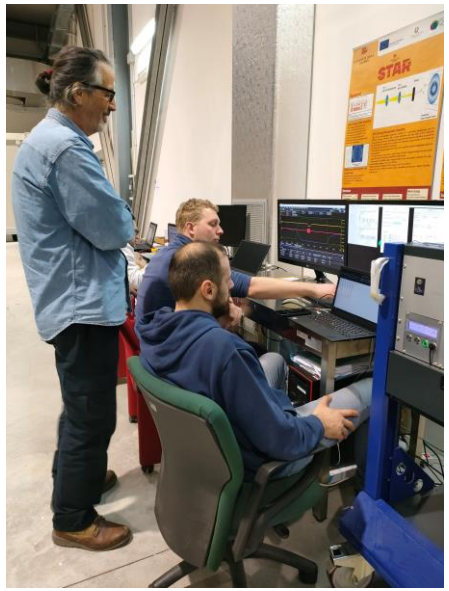


Expected X-rays



Looking for X-rays…
We have created a Great Accelerator Team!

Thank you all for your attention!!!



STAR will host the

International Symposium

on Compact X-ray Sources 2028