# (1/2) New diagnostics developments at the ESRF based on Spark platforms:

# **High Quality Phase-Monitor**

Libera Workshop – May, 12th 2022

ESRF, on behalf of the DIAG group, E. Buratin

# Outline

1) What is the phase and why it is important?

2) Past phase-monitor at ESRF

3) The new High Quality phase-monitor with a SPARK

4) Measurements

5) Conclusions

# 1)What is the phase and why it is important?

In a synchrotron **electrons travel electromagnetic waves**, generated by **RF accelerating structures**

↓

Why we need the RF cavities? **To accelerate and to overcome the electron energy loss** per turn (due to Synchrotron Radiation emission)

↓

To be properly accelerated, the **electrons** must be **in the right place at the right time**

↓

So these electrons **must be in phase** with the RF field at each acceleration stage:

- Linac: 2 structures (100 MeV each)
- Booster: 4 cavities
- EBS: 13 cavities (6 MV in total)

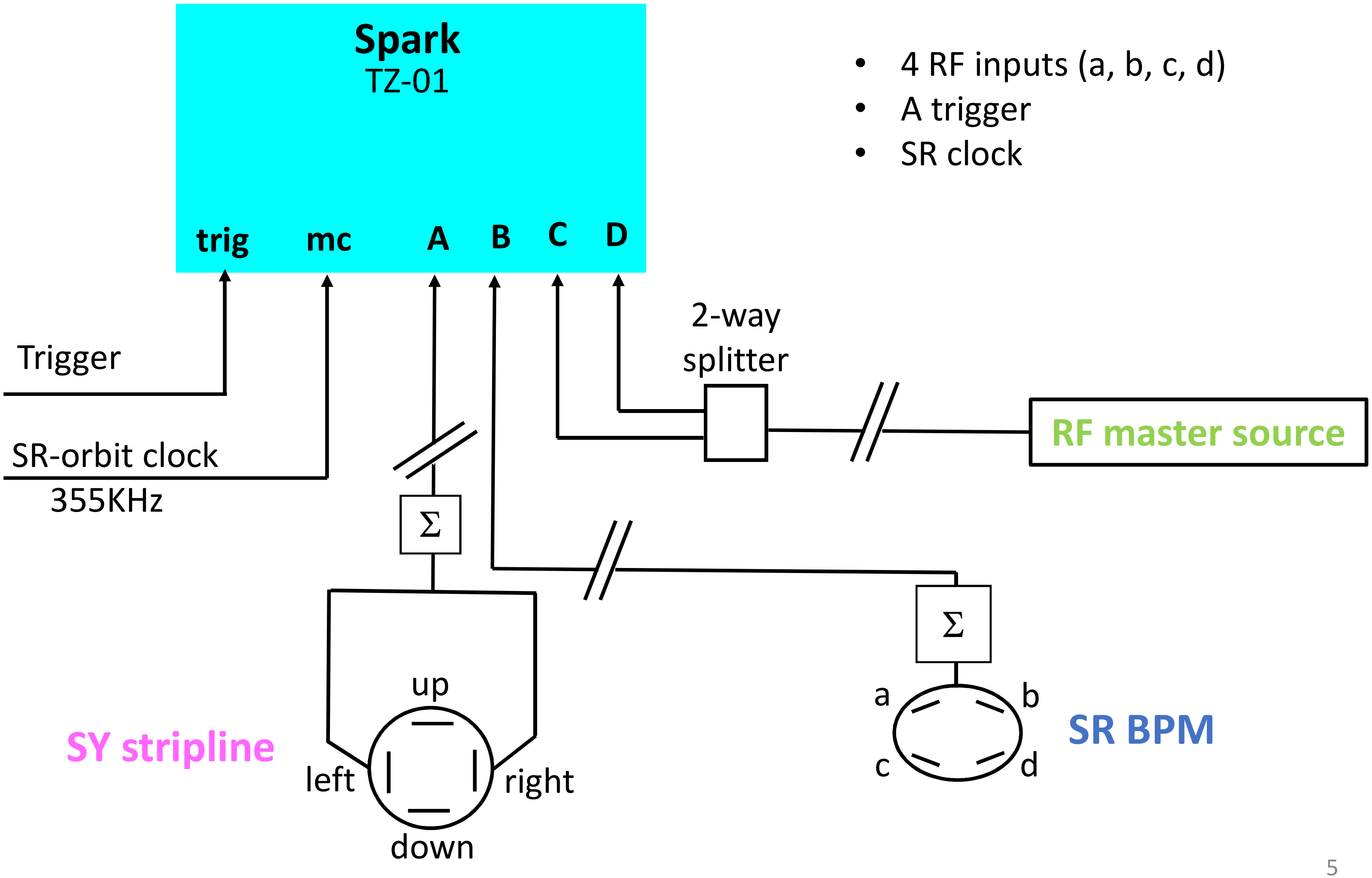
# 2) The Phase-Monitors at ESRF

- Since 2013 a Libera Brilliance had been used as Phase-Monitor at ESRF
- 4 RF inputs from Booster-beam, SR-beam and the RF-Master-Source
- I and Q data-buffers read from each channel (triggered, TbT-decimated)
- Angle calculation and then Phase calculation (done by MATLAB)
- Resolution of a few milli-degrees!

What is new?

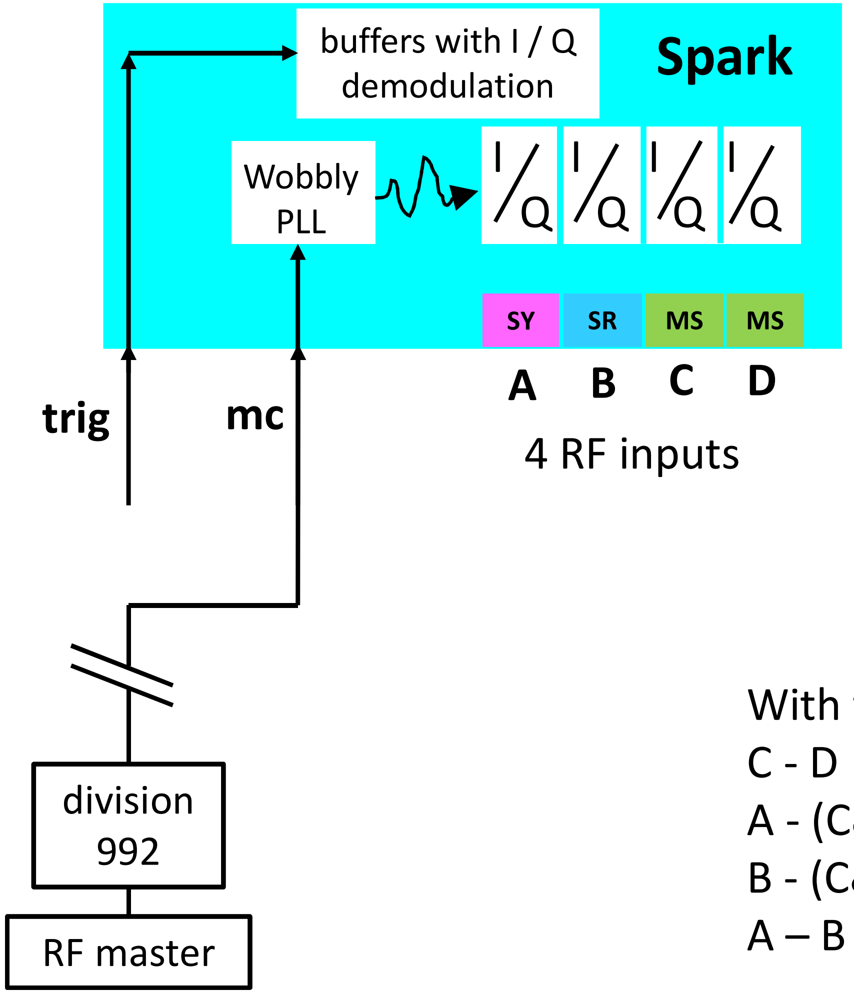
- Since 2022 a Libera Spark has been used as Phase-Monitor for the first time since EBS
- Same principle → I & Q data → angles → Phase
- It is now also generating a SA stream at 20Hz

# 3) The new Phase-Monitor




- 4 RF inputs (a, b, c, d)
- A trigger
- SR clock

# 3) The new Phase-Monitor




The wobbly PLL affects all 4 channels in a strictly identical way

Consequence:
the BPM is not a good phase meter (between SR-clock and RF-inputs)

But an excellent phase-meter, between the 4 RF input signals

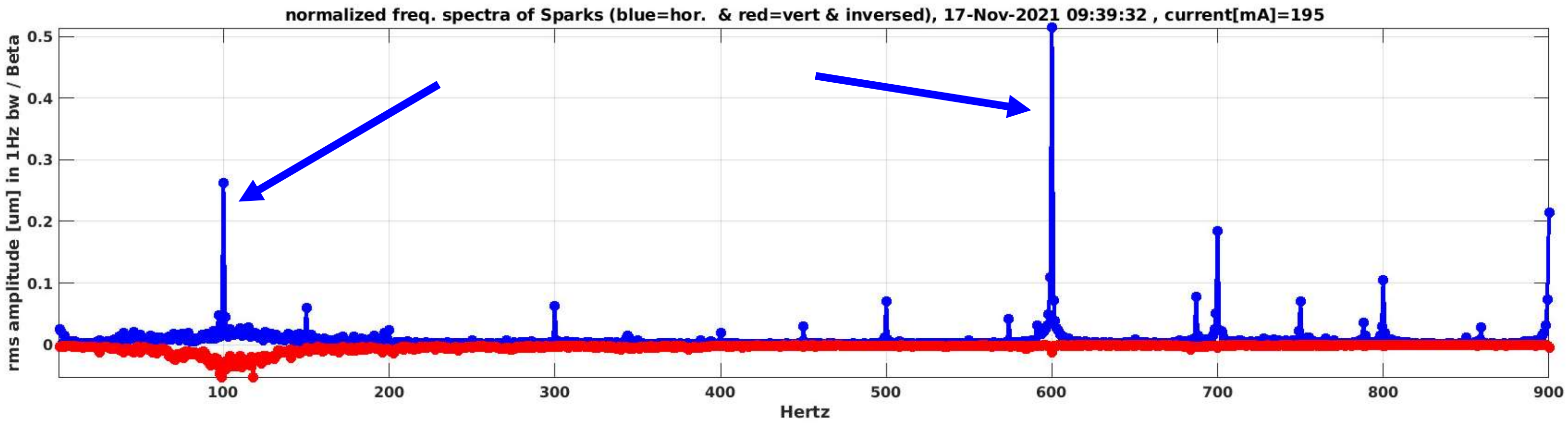
With the above we can measure very precisely :

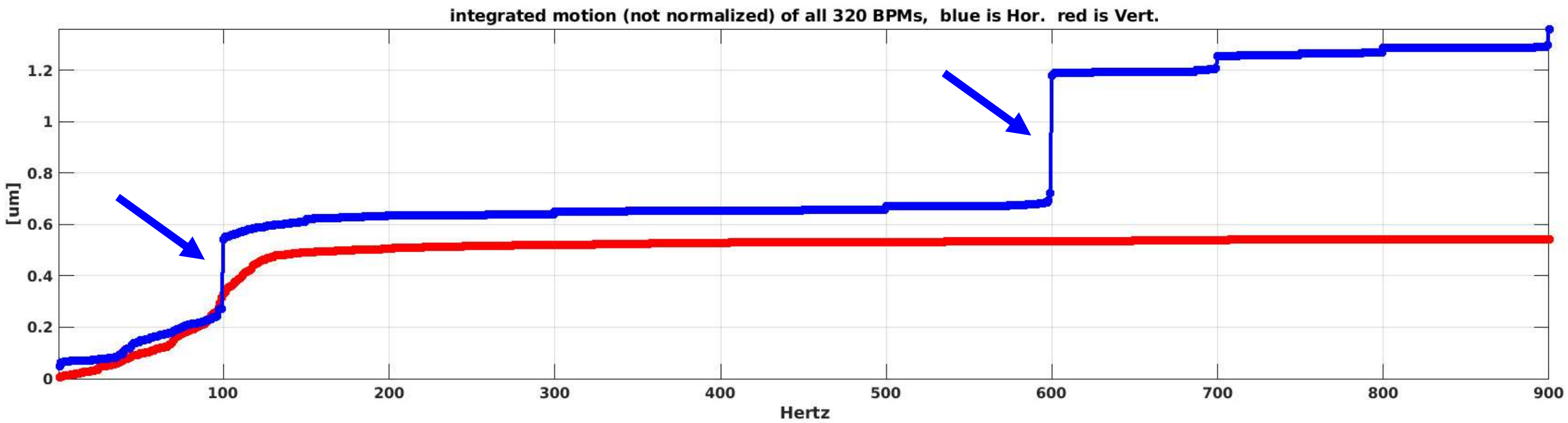
| | | |
|---|---|---|
| C - D | = | resolution of this phase monitor |
| A - (C&D) | = | phase of SY w.r.t. Master-Source |
| B - (C&D) | = | phase of SR w.r.t. Master-Source |
| A – B | = | phase of SY w.r.t. SR |

# 4) Measurements

## 4.1) **Strong phase fluctuations seen recently in the beam**

**Freq. spectral data from the BPMs** shows strong amplitudes at specific frequencies (100, 600Hz) in HOR. plane at dispersive location in the ring



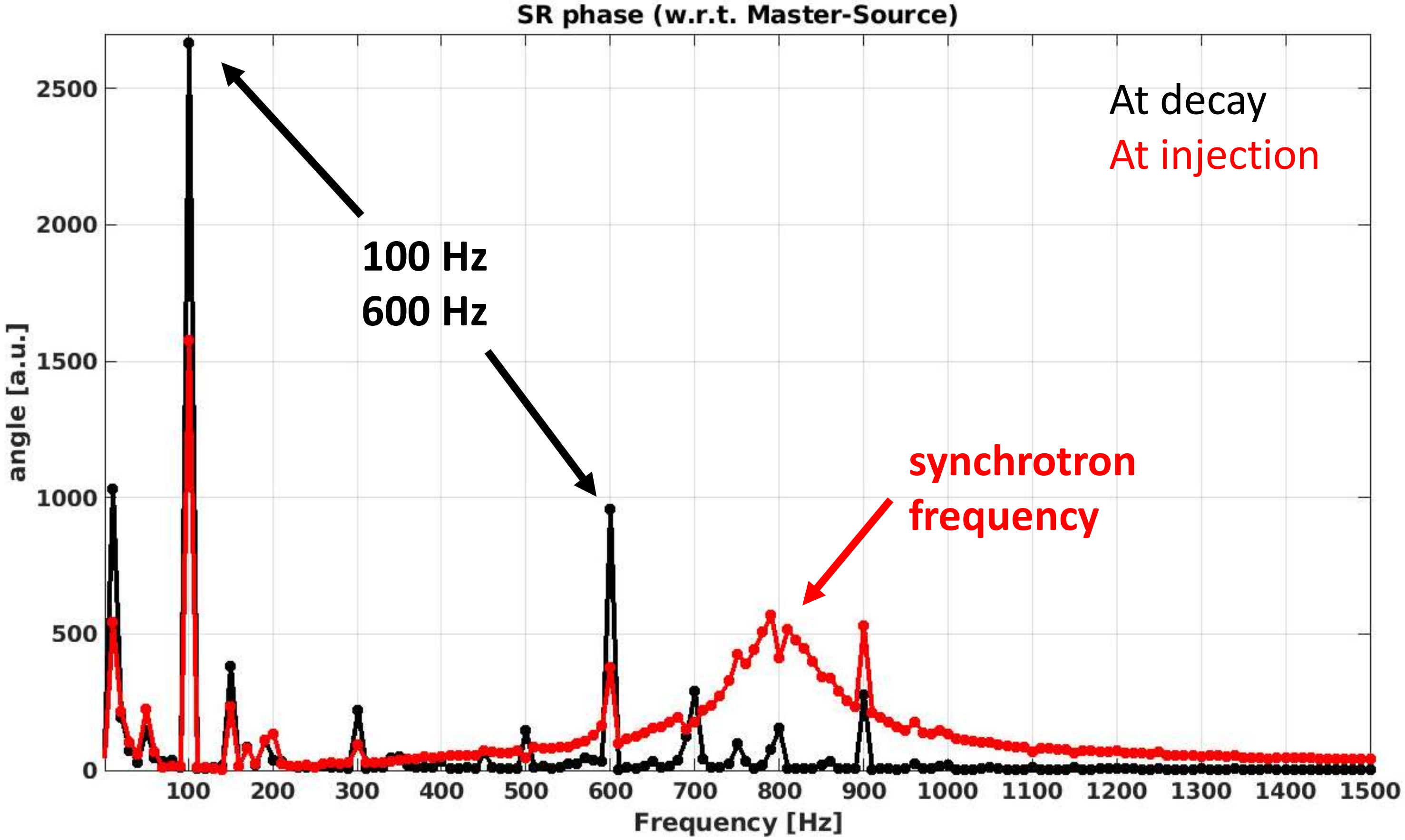



# 4) Measurements

## 4.1) **at decay and at injection**

**Data from the phase-monitor:**

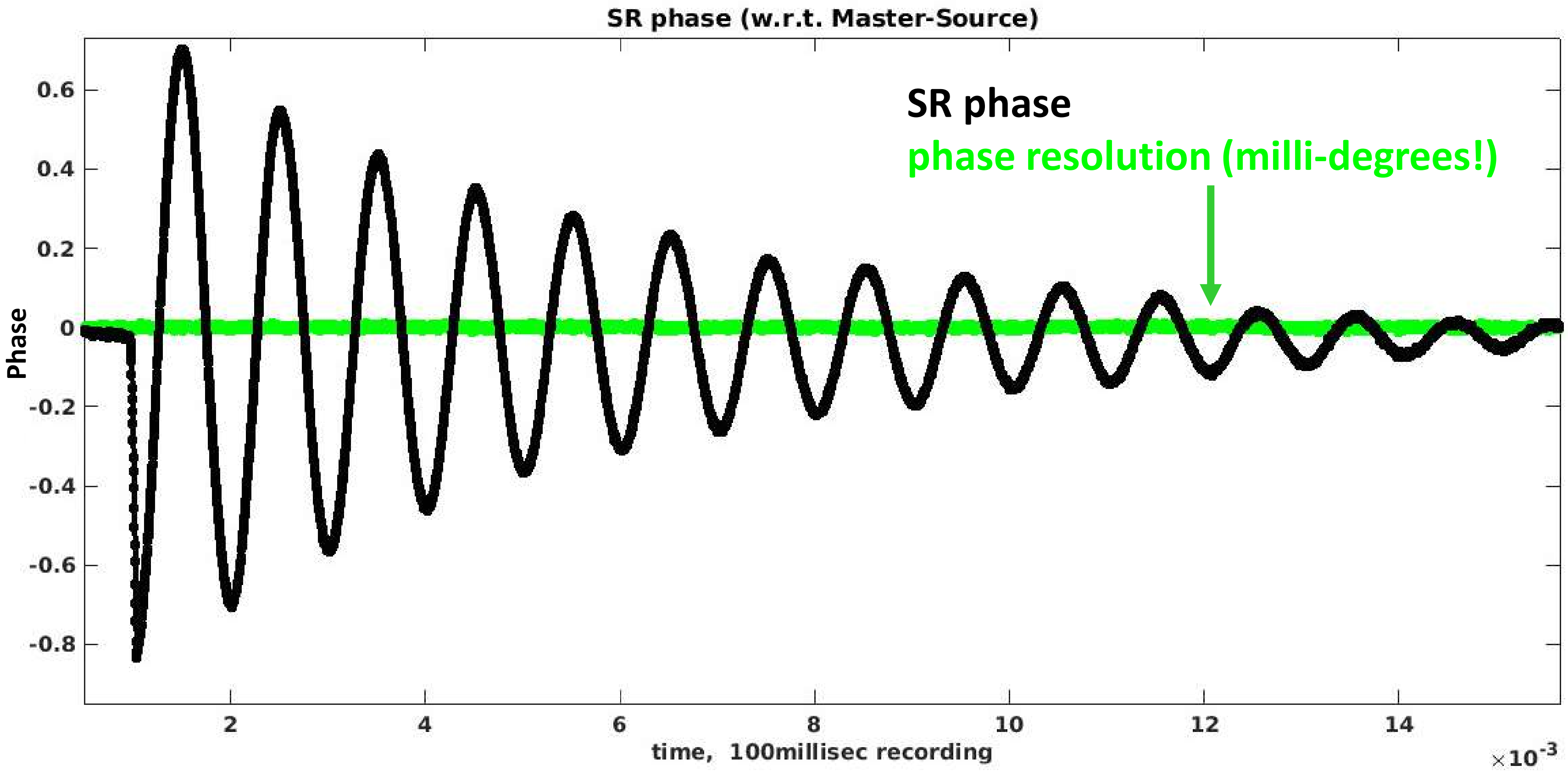
- Strong amplitudes at 100, 600Hz etc.
- At injection **the synchrotron frequency** shows-up (**800 Hz**)



# 4) Measurements

## 4.2) **At injection**

- time –recording,  fast buffer
- sample rate= T-b-T  (355 KHz, 2.816 μs)
- the synchrotron frequency is visible



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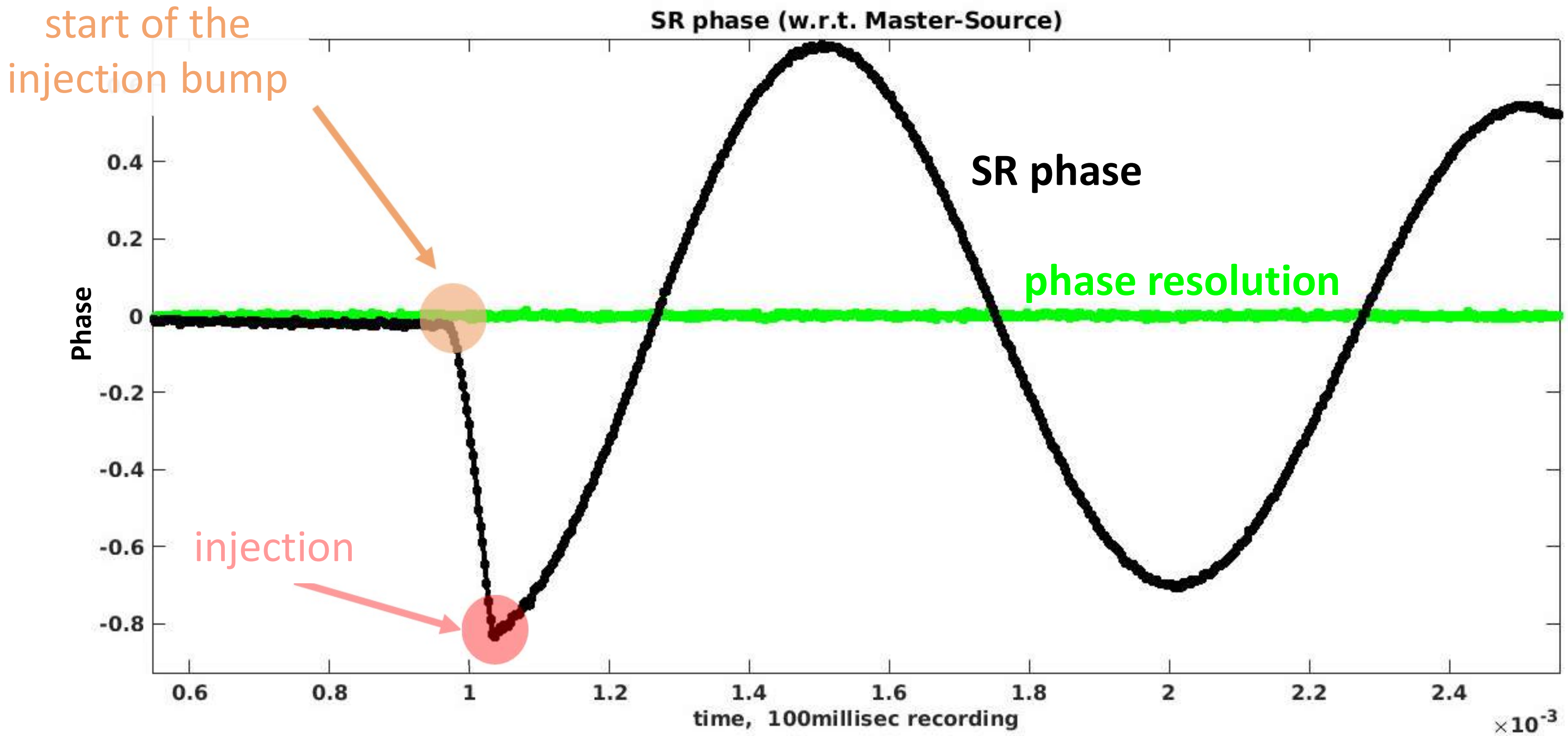
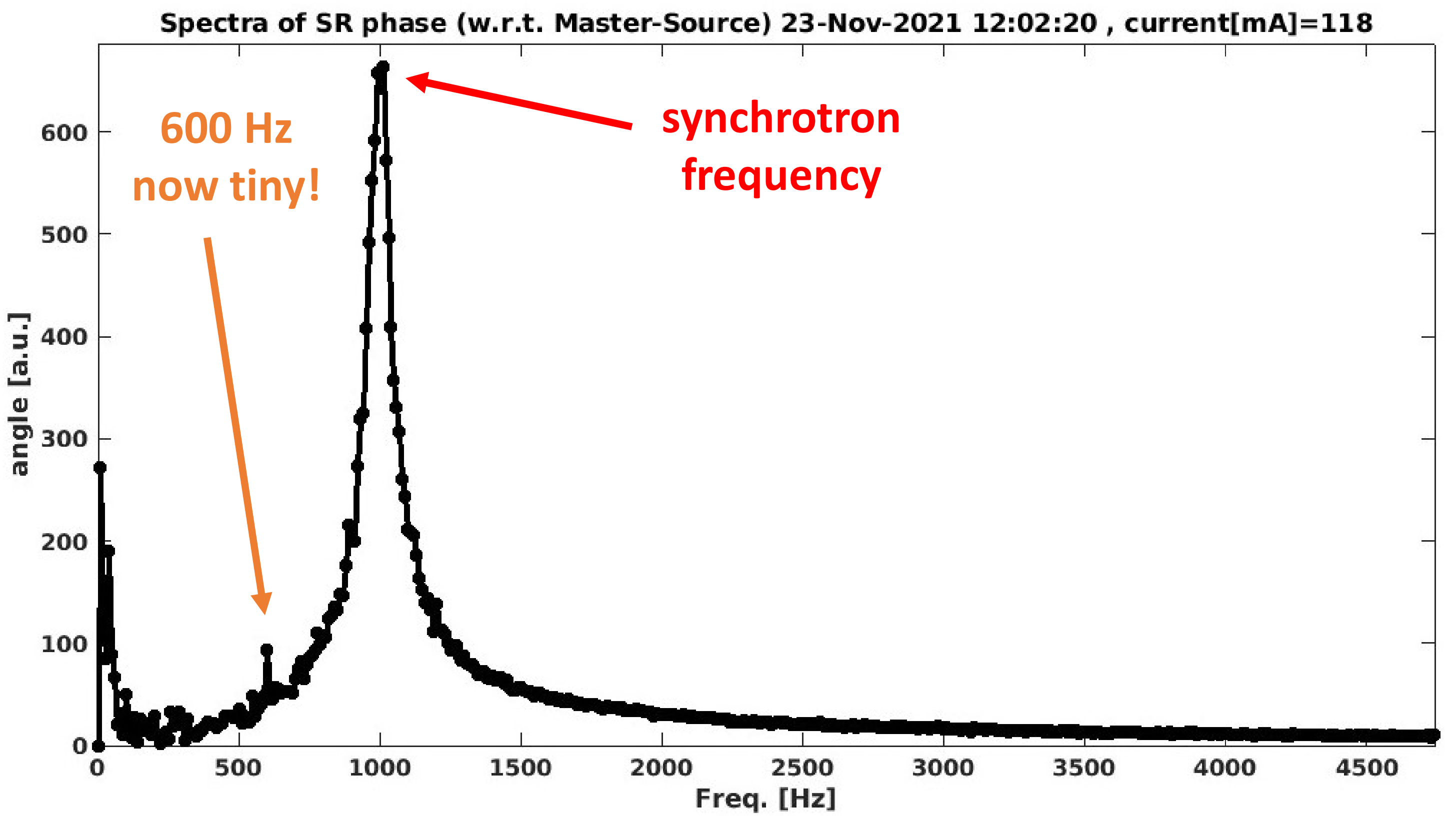


# 4) Measurements

## 4.2) **At injection**

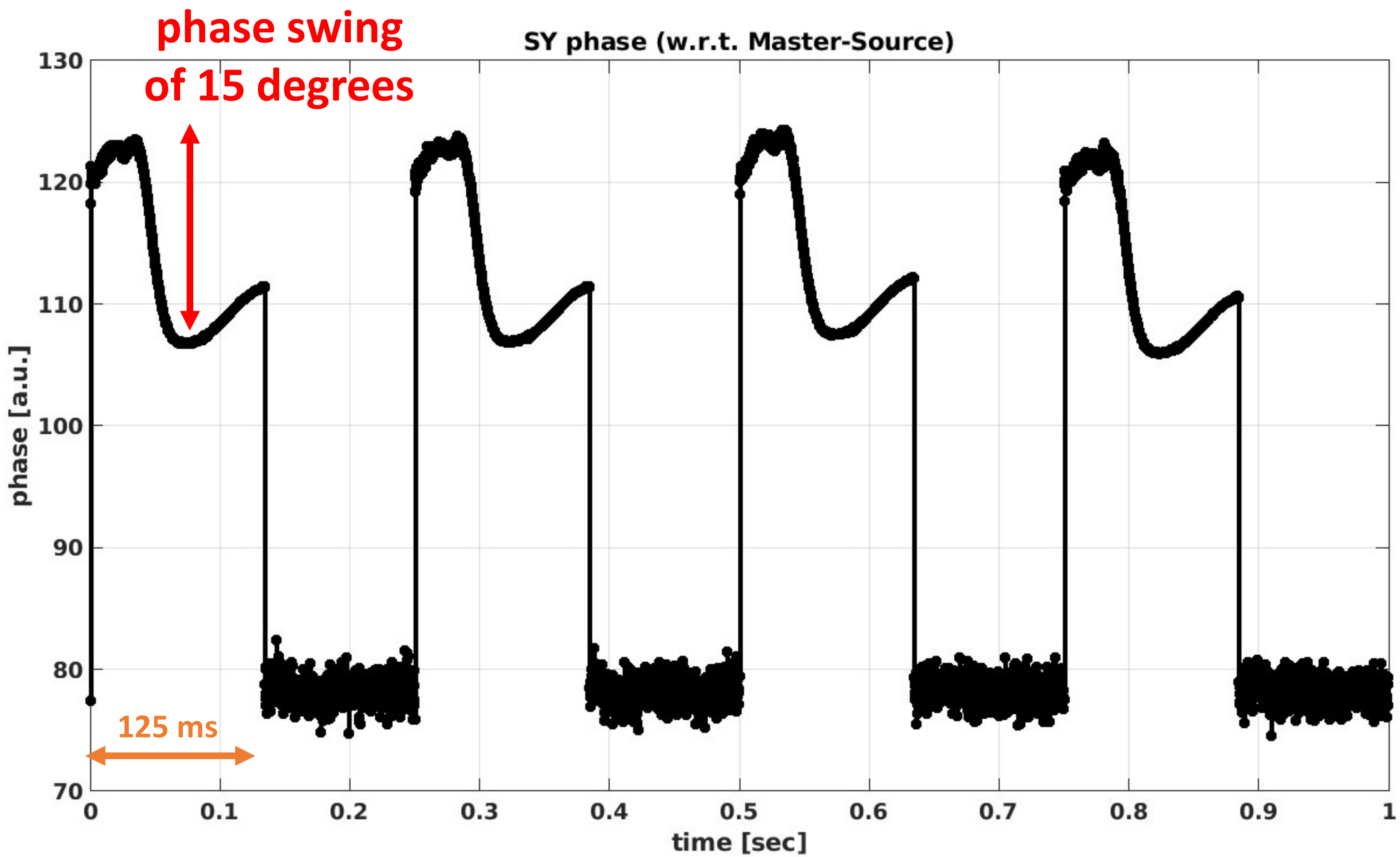
- FFT of the time-recording → spectrum
- sample rate= T-b-T (355 KHz, 2.816 μs)
- the **synchrotron frequency** is dominant



# 4) Measurements

## 4.3) In the Booster

- Slow Buffer, 4 consecutive injection cycles shown



# 6) Conclusions

A High Quality numeric **Phase Monitor** is now available with the use of a **Spark** with an updated firmware.

This **time-resolved phase** is available now both **in SA streams (20Hz)** and in **triggered buffers** and gives very good results.

The **frequency-domain** spectra give info on RF instabilities and synchrotron frequency.

We can follow the **EBS phase at decay and at injection**, the evolution of the **Booster phase** to match the EBS ring. Useful during MDTs to optimize the complex.

Questions?

# (2/2) New diagnostics developments at the ESRF based on Spark platforms:

## **low-cost detector-system for single-electron measurements**

# Outline

1) A few figures about **current** and **electrons**

2) **Single-electron injection**

3) The **visible-light set-up** and lab

4) **Single-electron measurements**

5) Conclusions

# 1) A few figures about current and electrons

**Current** = charge / time

- Time SR = 2.8 µs
- Time SY = 1 µs

min

**Smallest current = 1 electron** = $5.7 \cdot 10^{-14}$ A

**Dark current shot (Linac gun off)** = 10 to 100 electrons = $5.7 \cdot 10^{-13}$ to $5.7 \cdot 10^{-12}$ A

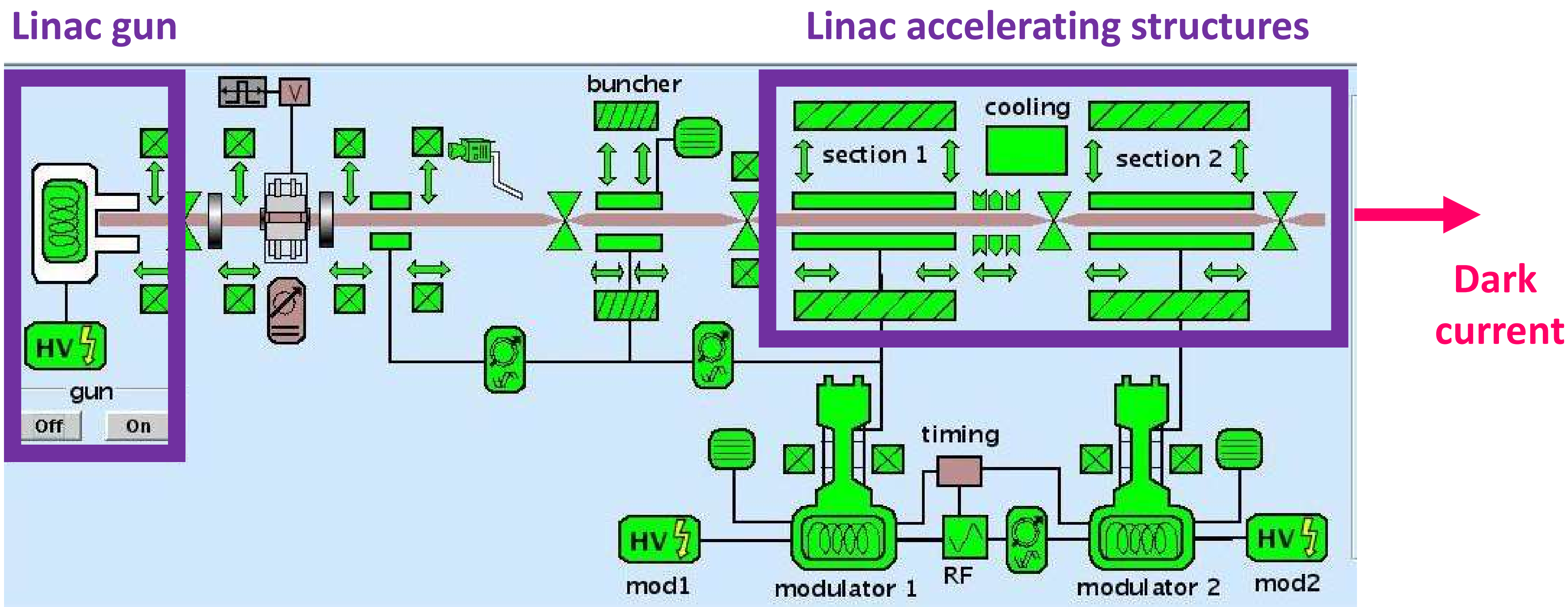
**Injection shot (Linac gun on)** = $6.3 \cdot 10^{9}$ electrons = 1 mA

**Standard beam =** $3.5 \cdot 10^{12}$ electrons = **200 mA**

max

# 2) Single-electron injection

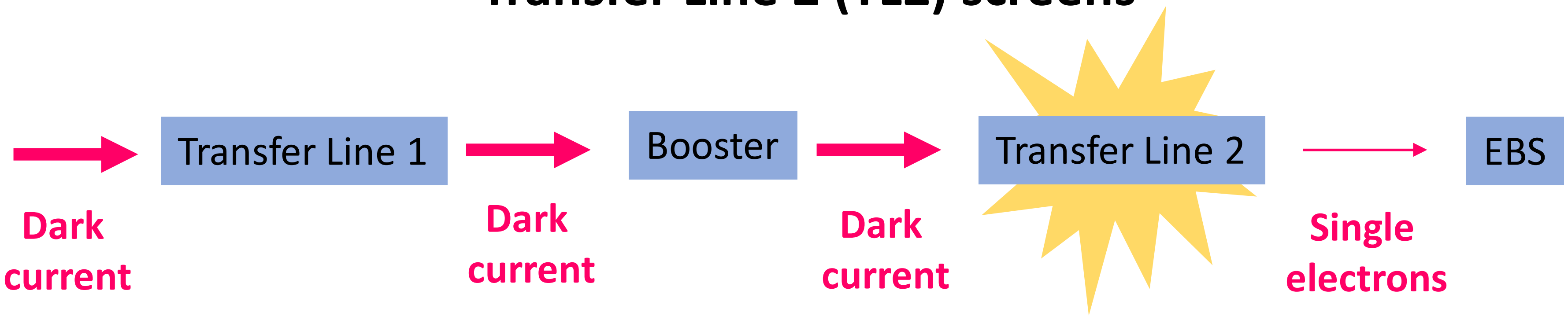
## Linac injection system

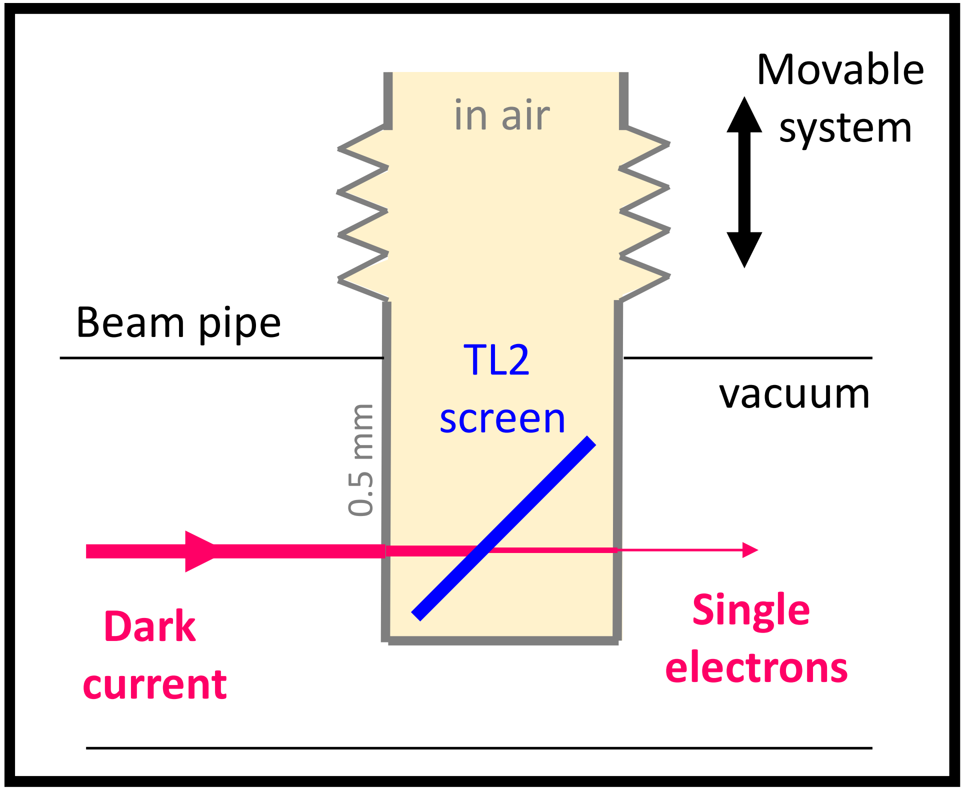



With **Linac gun off**, the **dark current** is only produced in **the Linac accelerating structures** [2 x 100 MeV]

# 2) Single-electron injection

## Transfer Line 2 (TL2) screens



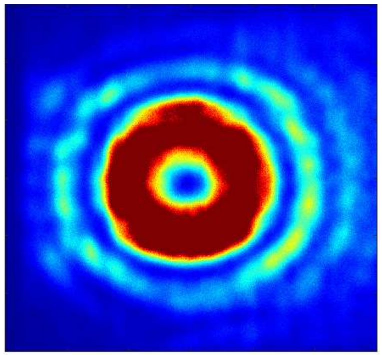

Insertion of the **interceptive Screens in the TL-2** (up to 4 screens in series): our electron attenuators

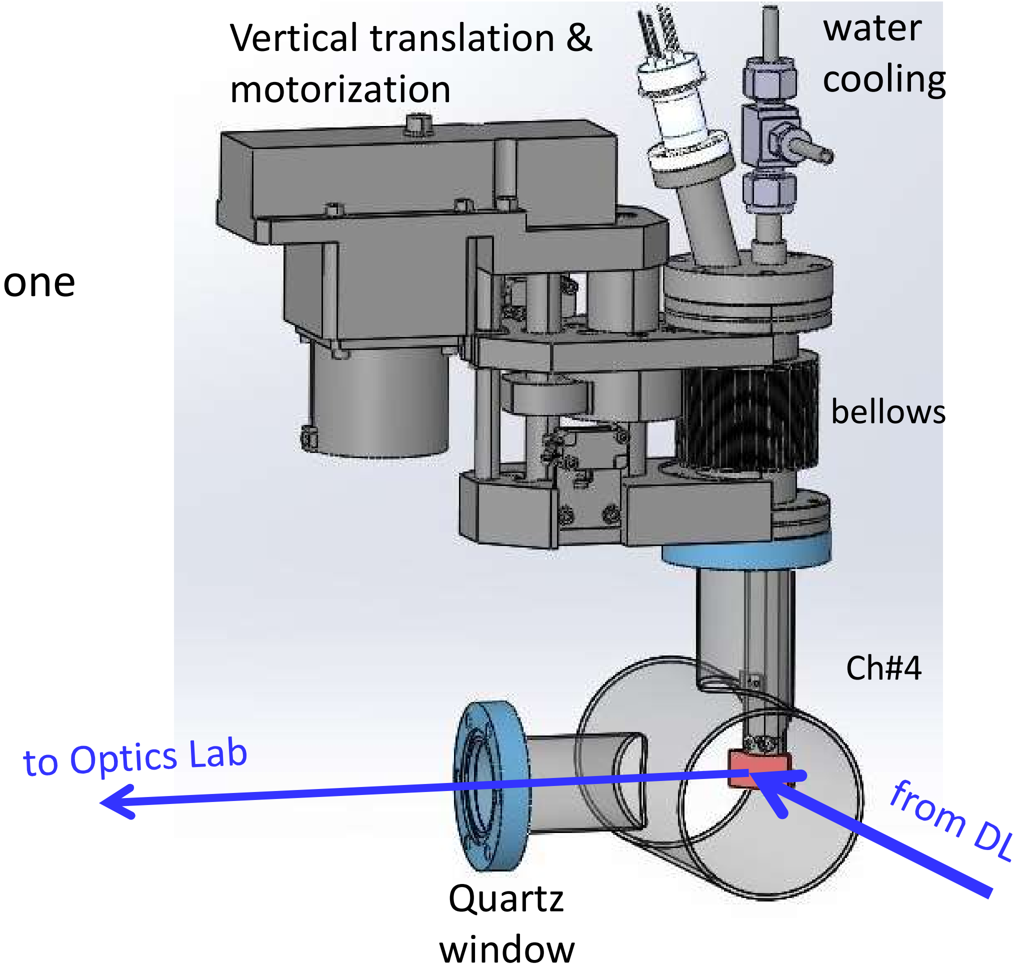
By drastically reducing the Injector current to a probability of **1 electron out of a few hundred injection shots**

# 3) The visible-light lab

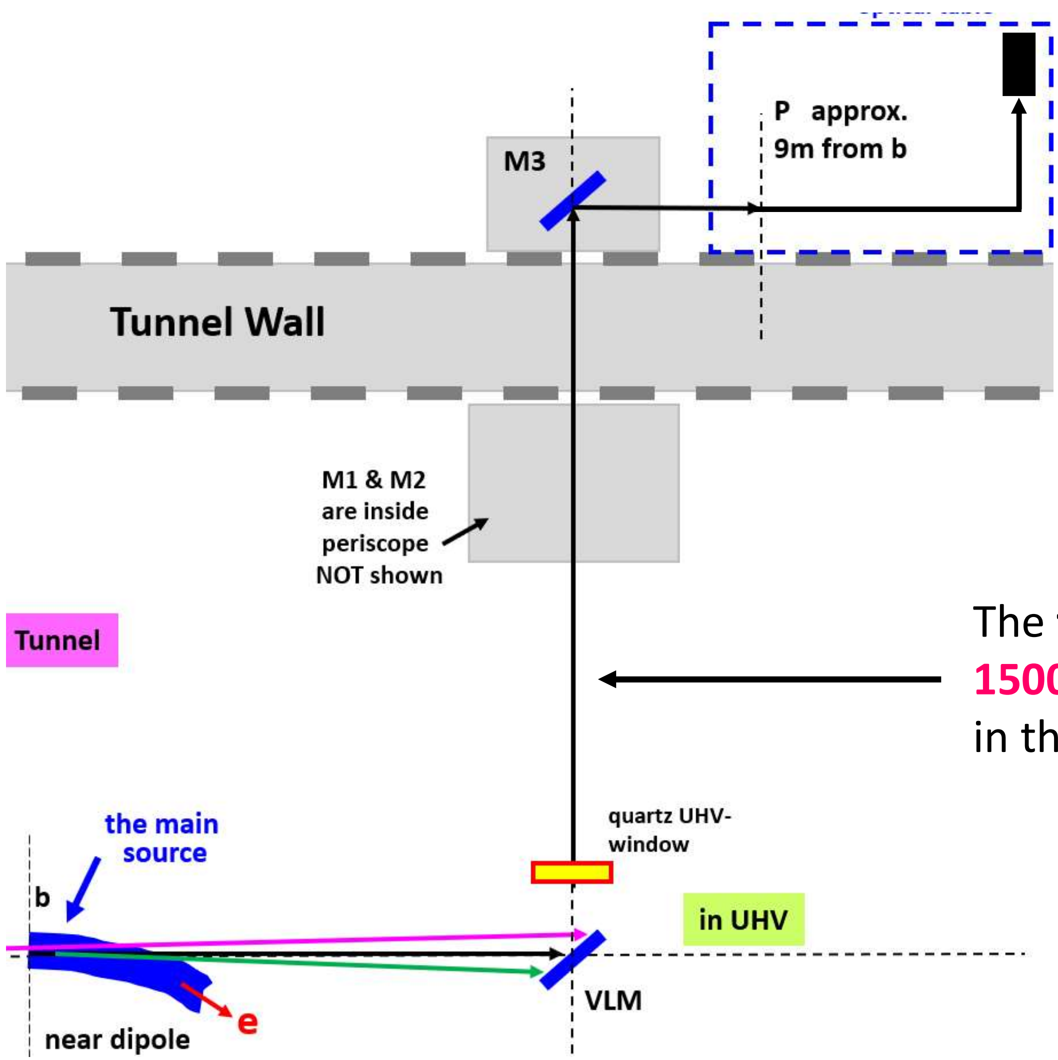
The ASD-visible light optics lab:

- Light has been fully characterized
- Streak Camera measurements been done





# 3) The visible-light set-up



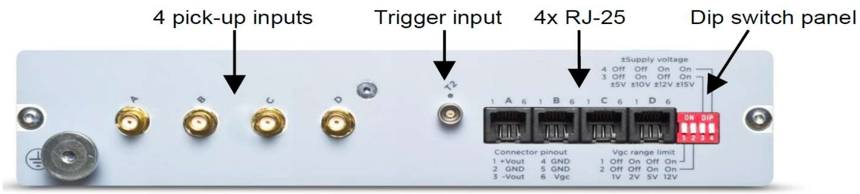

The light is focused on a cheap PMT that is controlled and measured by BLM electronics.

The **flux** is calculated at about **1500 photons/sec per electron stored** in the 400-700nm bandwidth of our PMT

# 3) The PMT and BLM electronics

- A cheap **Photomultiplier Tube (PMT)** from Hamamatsu (what we use for our Beam Loss Detectors)

- Connected to the **Beam Loss Monitor (BLM)** from I-Tech

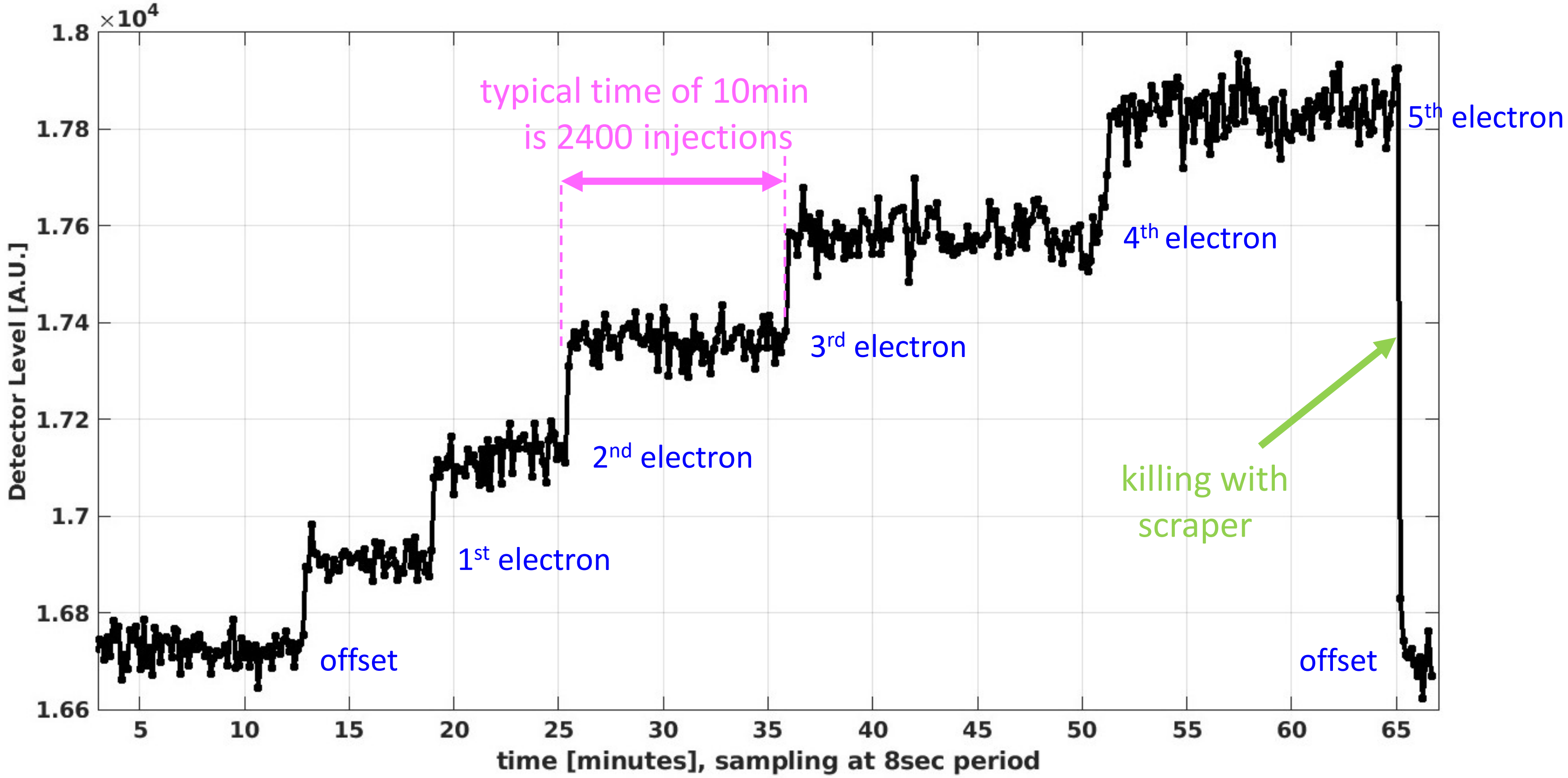



- Controlled by **TANGO application**

- Measurements performed in **integration mode** (1MΩ impedance & high gain)

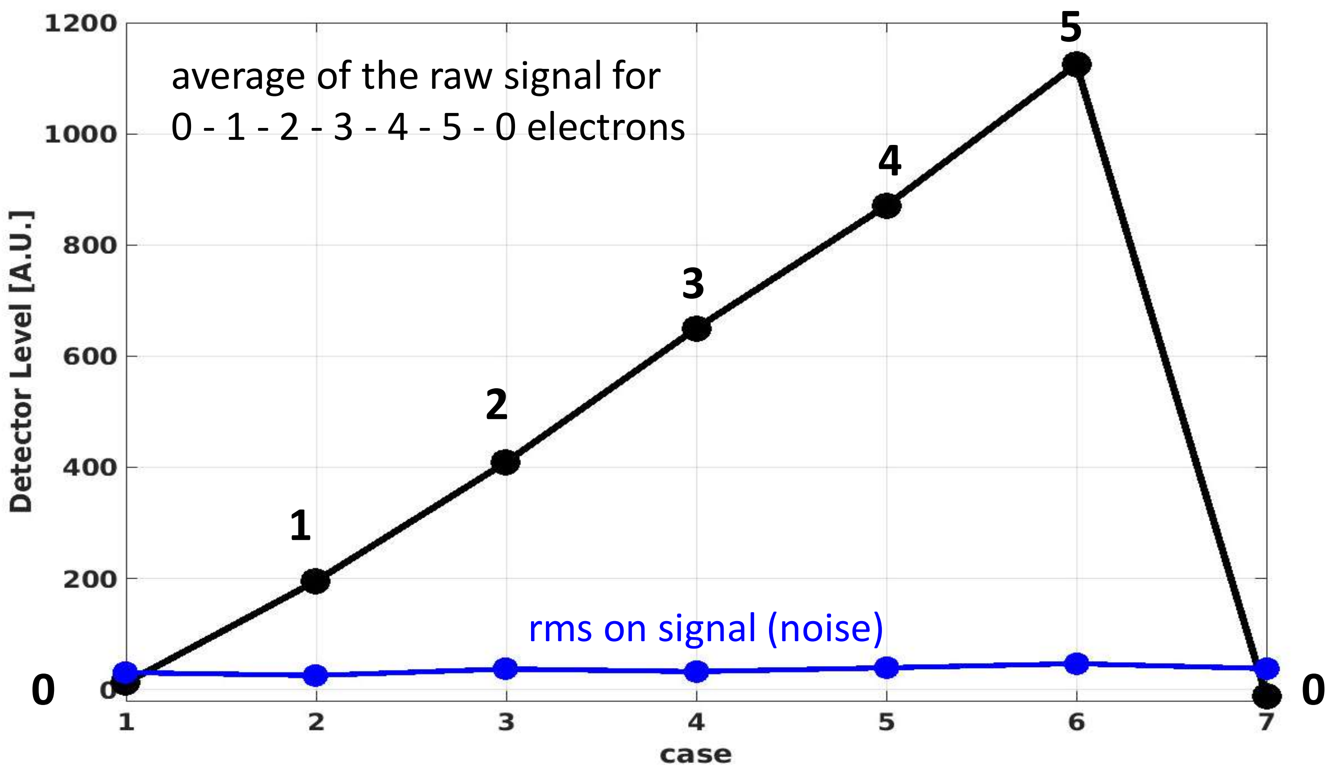
# 4) Single-electron measurements

- 1-2-3-4-5 electrons in about one hour
- Sampling time = 8 seconds



# 4) Single-electron measurements

- signal-to-noise ratio is just > 6, for 8-second integration time
- a **higher performance PMT can have less noise** → we would **reduce the measurement time**



# 6) Conclusions

It is fun to **explore the extremes like one single electron** in both control and measurement with a simple **low-cost PMT** and the **visible-light system**.

The **dark-current** is in general our enemy, it is **usually suppressed by SY-cleaning system**, and it is **ultra-weak** (~100 electrons), can **never be measured with ordinary devices**, but it can disturb **users** that **impose high bunch-purity.**

With this simple device, we can **optimize the cleaning process** and **minimize the electron pollutions**, but only **during MDT** for the moment.

The ultimate goal is to be able **to measure during USM the purity,** up to **$10^{11}$ dynamic range** with the visible-light system, to install a **better PMT** and then a **Time-Correlated-Photon-Counter (TCPC)**. Such a dynamic range has so far remained impossible for our ASD-Diag. purity measurements.

Many thanks to the Accelerator Control Unit, Beam Diagnostics, Beam Dynamics and Beam Operation groups for technical support.

Many Thanks
for your Attention!

Questions?