Study of a Cryogenic Current Comparator for the SPS slow extraction line

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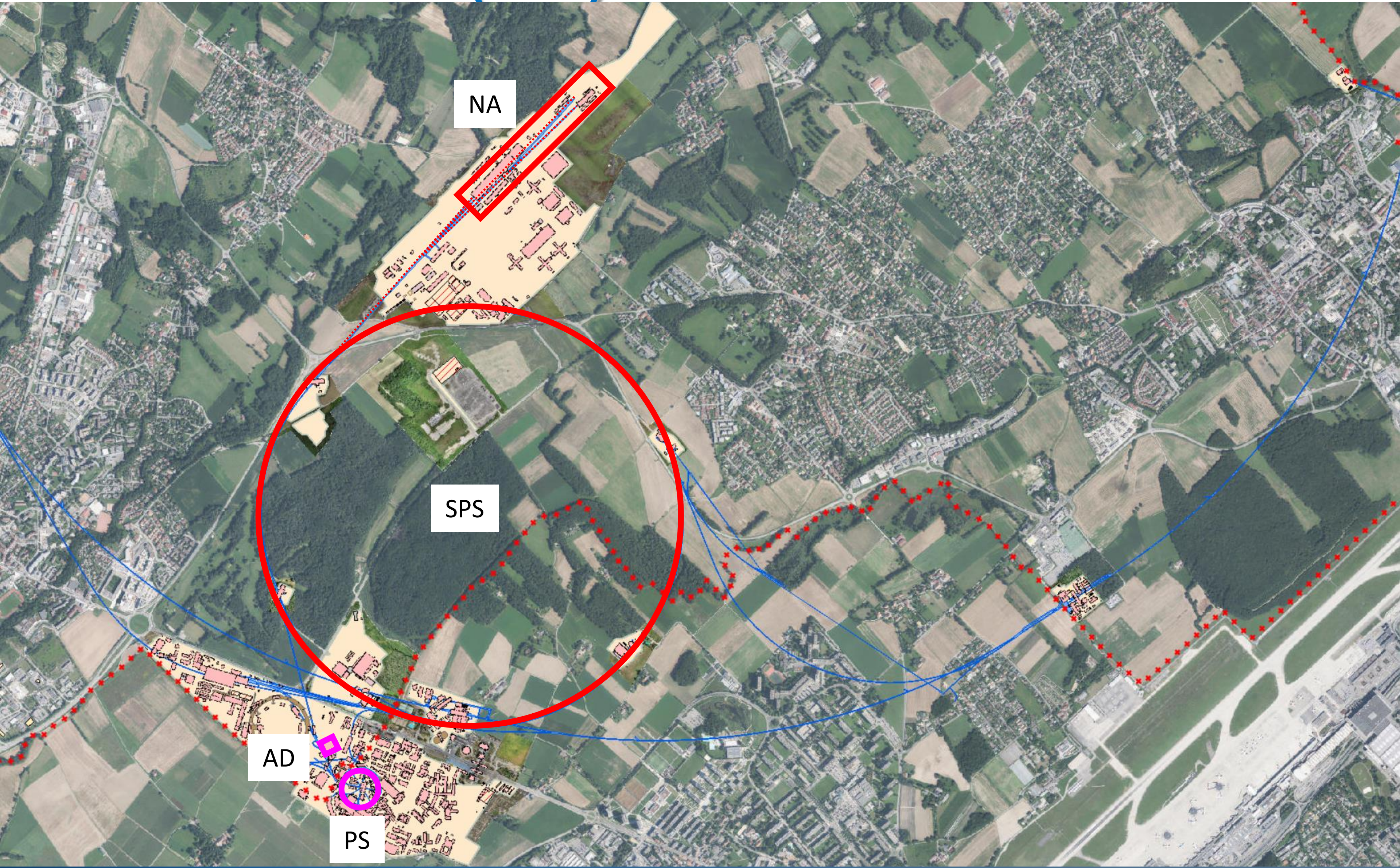
Outline

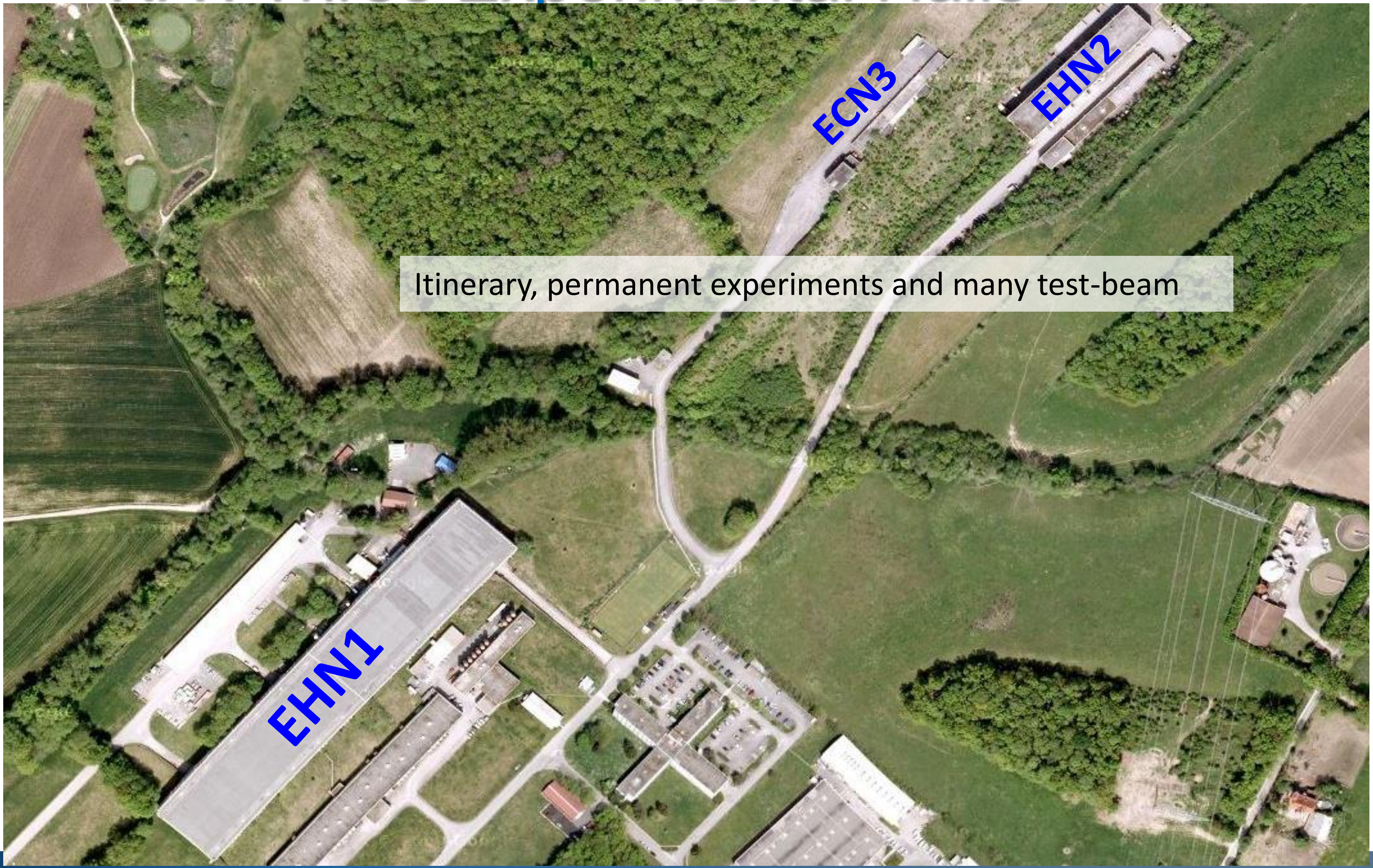
- **NORTH EXPERIMENTAL AREAS**
- **MOTIVATIONS**
- **SPECIFICATIONS & PROJECT**
- **SUMMARY**

NORTH EXPERIMENTAL AREAS

North Area (NA)

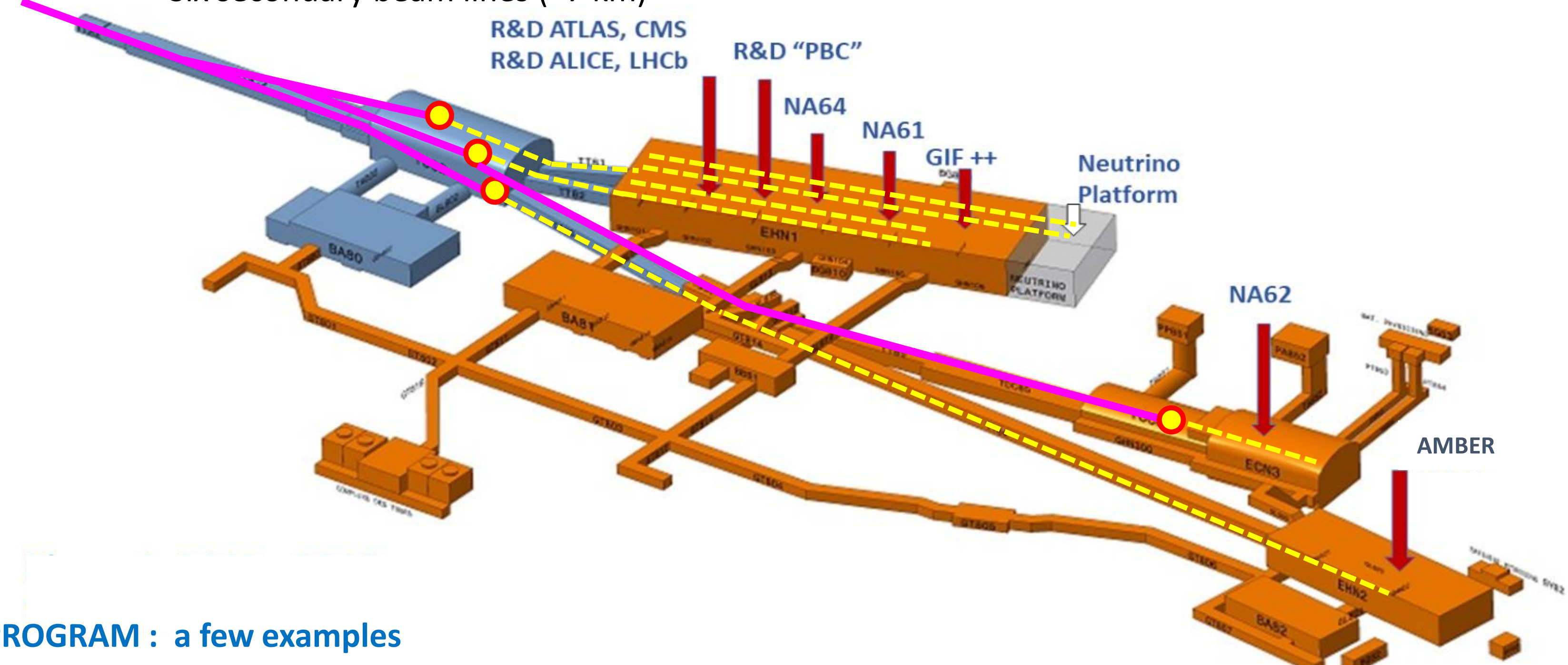


NA : Three Experimental Halls



North Area Complex

- Built in the **1970s** as part of the SPS Program
- Three experimental halls, service buildings and underground tunnels
- Total surface area : 60,000 m^2
- Four targets fired by protons/ions spills from SPS
- Six secondary beam lines (~7 km)

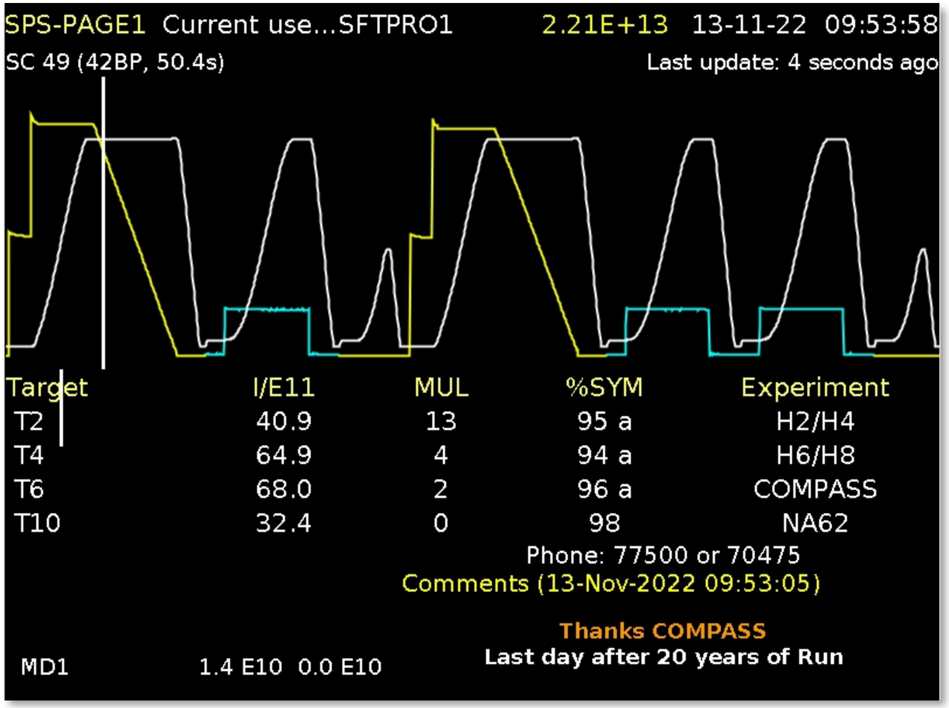


PHYSICS PROGRAM : a few examples

- **GIF++ :** Performs test beam exp. of gas detectors in an intense γ background field (14 TBq 137Cesium source)
- **NA66-AMBER** : Proposes measurements of the proton charge radius, Drell-Yan, and pbar production cross-sections…
- **NA62** (K) : Kaon factory, looking for New Physics through kaon decays
- **After LS3** BDF w/**SHiP :** Focus in the search for feebly interacting particles beyond the Standard Model

EHN1 Experimental Hall

SPS slows extracted beams to NA

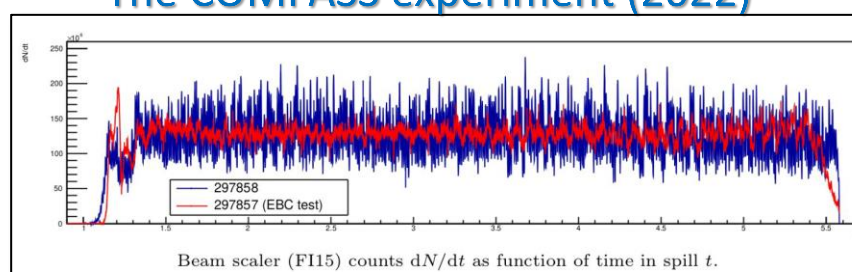


Proton beam characteristics	
Primary beam momentum	400 GeV/c
Spill intensity range	2 x10^{12} – 4.2 x10^{13} ppp
Spill duration	typ 4.8 s (1 to 10 s)
Extracted intensity /year	~1 x10^{19}
Typ ave. beam current	0.1 – 1.4 μA

Ion beam characteristics	
Particle	Pb^{82+}
Spill intensity range	>1 x10^{7}
Spill duration	<10 s

Secondary beams characteristics		
EHN1	205 – 360 GeV/c	p, e^-, e^+, μ, π
EHN2	250 – 280 GeV/c	h, μ
ECN3	75 GeV/c	K
Spill intensity range	10^5 – 3 x10^8 ppp	

The COMPASS experiment (2022)



Courtesy of Laura Molina Bueno (JAPW22)

MOTIVATIONS

Instrumentations in the primary transfer lines

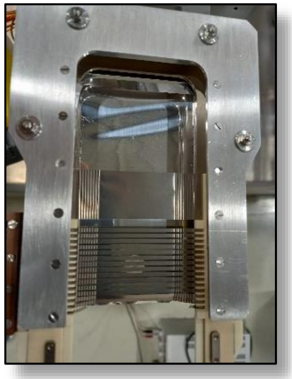
Present situation with DC beams: Diagnostics relies only on **beam intercepting devices**

Secondary Emission Monitors

Intensity

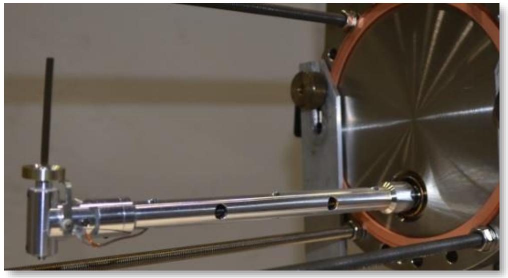
21 Intensity monitors: BSI

profile/position



32 SEM grids

67 Split foils



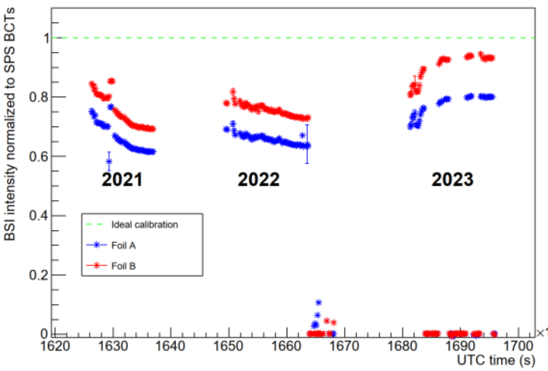
33 Scanner blades

Screens

position, profile

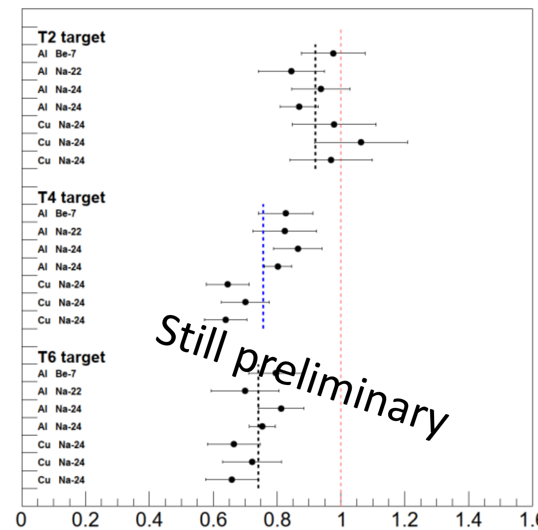
11 BTV screens

BSI calibration campaign since 2021



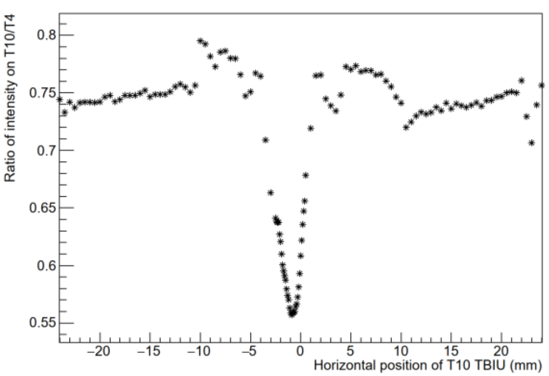
- Last calibration of BSI > 20 years ago (?)
- 2021 : a request for calibration from NA62
- Most upstream monitor in TT20 (210279)
  Measure 2foils signal vs SPS intensity (FBCT)
- Foil A and B have different slopes
- Unclear wheather differences are induced by losses or BSI

Activation method



- Put Alumimun , and Copper foil
- Measure activation after 100-200 shots
- Measured fewer POT in activation foil than on BSI
- **But with T10 target : calibration factor ~ 1**

T10 target scan



- But 12cm gap between BSI and BSP
- Spot size effect on the foil
- All in all intensity error could be > 20%

Courtesy of M. Van Dijk (JAPW23)

Calibration : the quest for Grail

Difficult with SEM

- Many uncertainties : foil material, vacuum level, beam-induced damage
- Should be done annually during commissioning : ~ 12 hours beam time each
- Foil calibration is unstable over year and from year to year

Fast BCT rulled out

- Bandwidth limitation : fast-pulsed slow extraction of 10-20 ms is too large $\Rightarrow$ baseline droop
- Fast kicker intensity limit

CCC

- "*Cryogenic Current Comparator is an excellent candidate*" JAPW 2023
- Non-intercepting current monitor
- Absolute measurement
- High resolution < 10 nA

SPECIFICATIONS & PROJECT

Current monitor specifications

Let's assume proton beams in TT20		Comments
• Beam structure:	Debunched 4.8 s/spill	*In the future 1 to 10 s*
• Spill intensity range:	2 $x10^{12}$ – 4.2 $x10^{13}$ ppp	
• Current range:	**0.1 – 1.4 μA average**	*Spikes: up to x3*

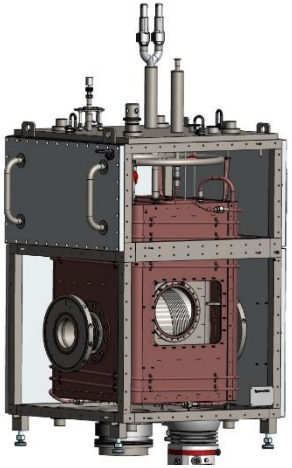
Monitor specifications

• Measurable:	Beam current	
• Method:	Non-invasive	
• Absolute monitor:	Calibrated device	Acuracy 1%
• Current resolution:	1%	***During physics run***
• Signal Bandwidth:	Sufficient to resolve spill fluctuations	*SPS F_{rev} = 43 kHz*

Cryostat specifications

Operation mode

- Stand-alone long term availability (cryo-cooler and pulsed tube)
- “Dry cooling” scheme preferable (from CRG)
- Temperature fluctuation: < 5mK
- Low mechanical vibrations
- Practical ports to ease intervention
- Not a copy/paste of the AD design



Cryostat 3D drawing

CCC in Cryring (GSI)

Dimensions/integration

- Low loss area : < 1 kGy/year
- Beam aperture : 80 mm typ.
- Longitudinal space : integrate ~1m-long element
- Accessibility: Should ease tunnel access

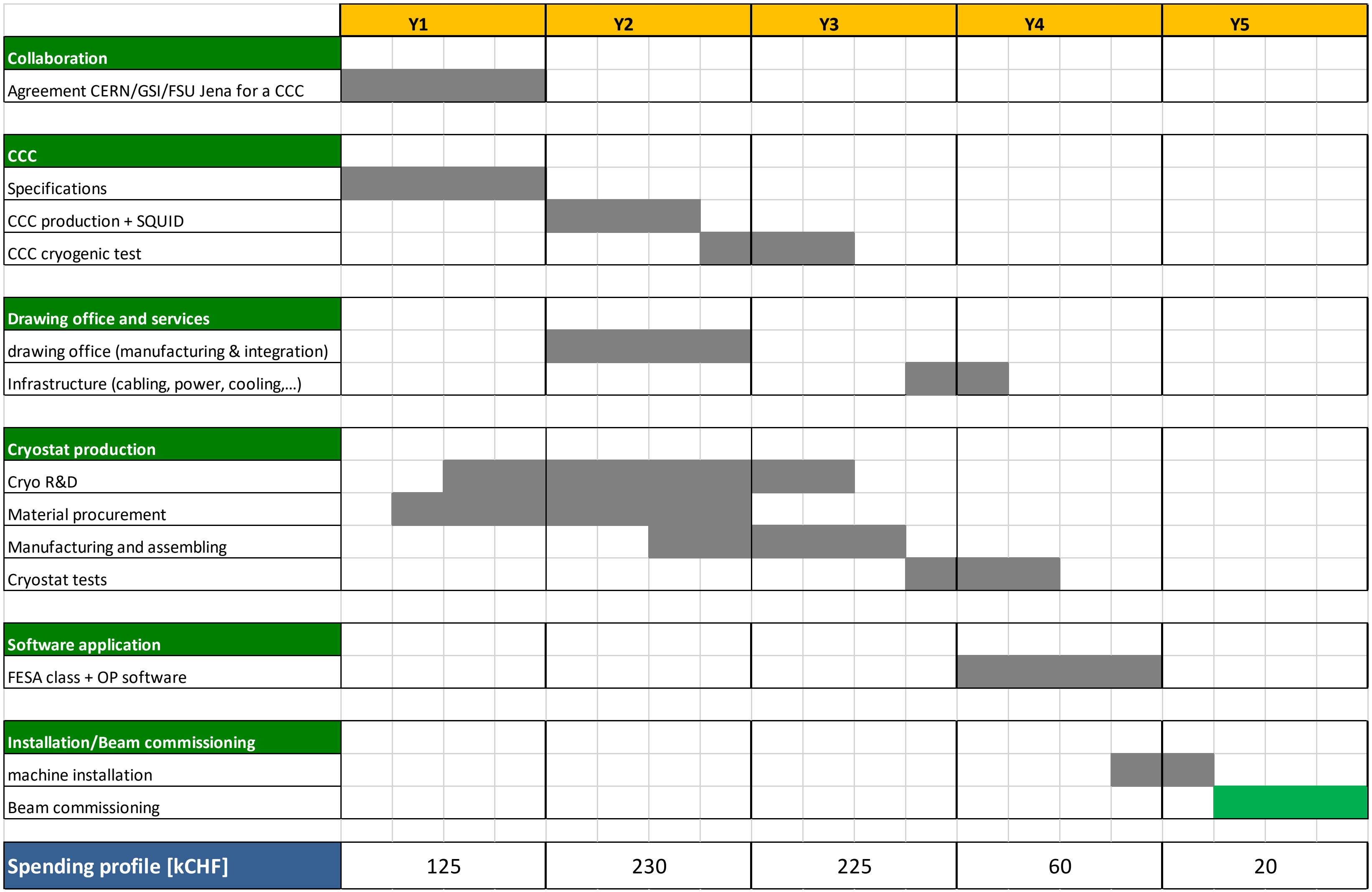
Cost estimate

Materials	Price [kCHF]	Comments
Cryocooler + cryo-Fan	100	Early stage of the project
Acquisition chain	25	Cabling, network, aqn chain, current source
Material procurement	110	Cryostat, vacuum
Pb CCC Shielding + SQUID/ FLL	80	Not an official quotation : To be confirmed w/ FSU-Jena
total materials	**315**	

Services + Student	Price [kCHF]	Comments
ORIGIN for CRG R&D: 2 FTE.Y	160	Early stage of the project
Infrastructure	15	Chilled water, power supply, etc
Vac. Test, PLC cryo controls, He recovery line	20	
CERN Design office + production/assembly	150	With simpler cryostat (~600 h)
total services	**345**	
GRAND TOTAL M+P	**660**	

CERN Manpower	FTE.Y	Comments
CRG Project follow-up over 2024-2029	1	Cryostat R&D supervision + tests, commissioning
BI Project follow-up over 2024-2029	1	Simulations, tests, commissioning, …
Software Engineer	0.3	FESA integration 0.2 FTE.Y Commissioning 0.1 FTE.Y

Timeline


Y1
Y2
Y3
Y4
Y5
Collaboration
Agreement CERN/GSI/FSU Jena for a CCC
CCC
Specifications
CCC production + SQUID
CCC cryogenic test
Drawing office and services
drawing office (manufacturing & integration)
Infrastructure (cabling, power, cooling,...)
Cryostat production
Cryo R&D
Material procurement
Manufacturing and assembling
Cryostat tests
Software application
FESA class + OP software
Installation/Beam commissioning
machine installation
Beam commissioning
Spending profile [kCHF]
125
230
225
60
20

Summary

Are stars aligned for a second CCC ?

- Fixed target physics now require **1×10^{19}** POT. Future physics programme : **5×10^{19}** POT
- Experiments/users : there is a request for absolute intensity calibration
- A CCC might serve to benchmark the existing SEMs and for monitor R&D
- 2023: Official request for a feasibility study for a CCC in the SPS transfer line
- Functional specifications being finalised : 90% written

It is technically feasible

- A 5-year-project from green light till commissioning with beam
- Includes R&D on remote cooling scheme

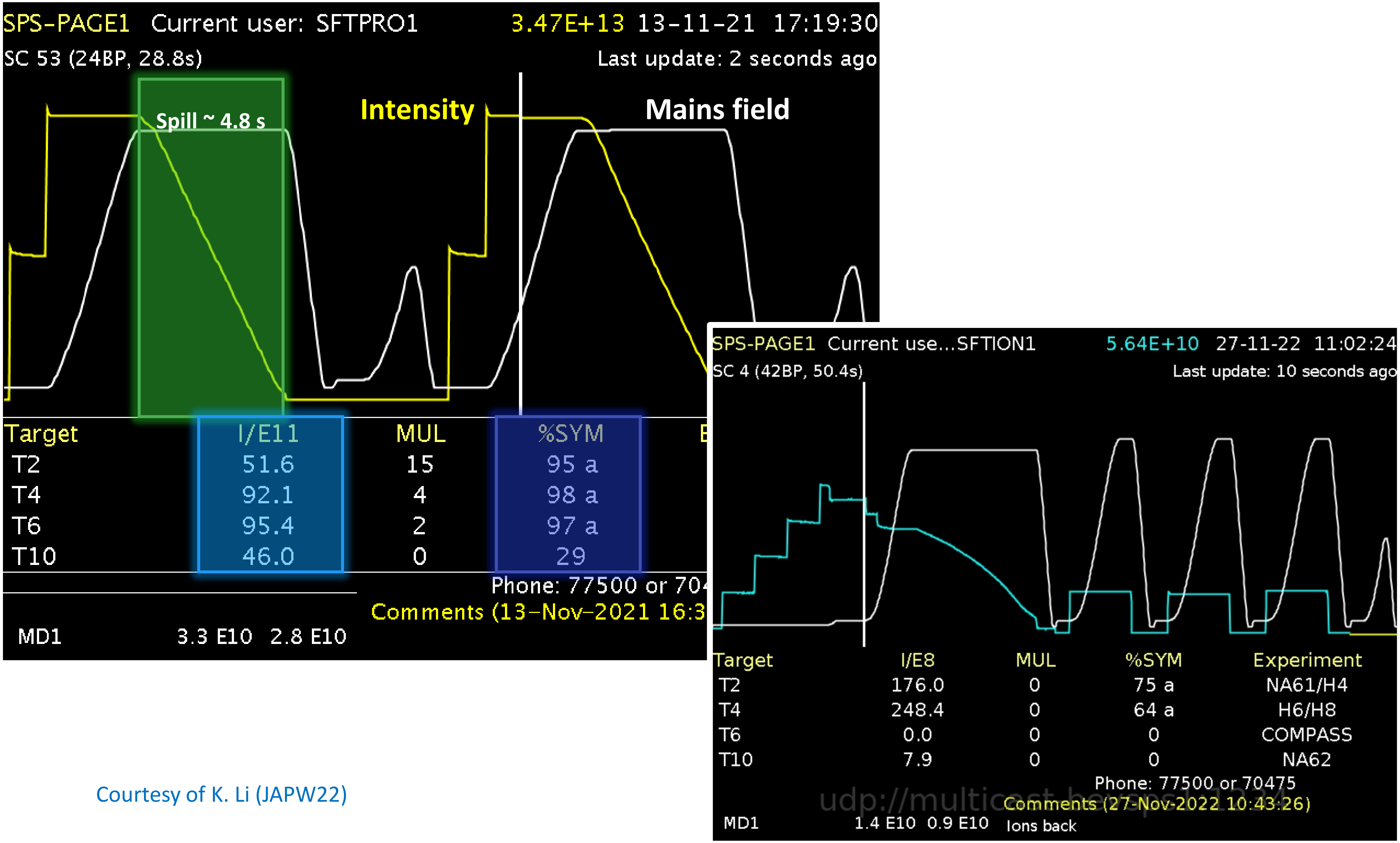
Like any project, money is the nerve of the war

- Estimate : 660 kCHF + 2 M.Y physicists + 0.3 M.Y SW engineer
- In Spring 2024, the CCC was ruled out for budget constraints
- A new funding request to be made in 2025…

Thank you for your attention

SPARE SLIDES

SPS : Proton and Ion cycles

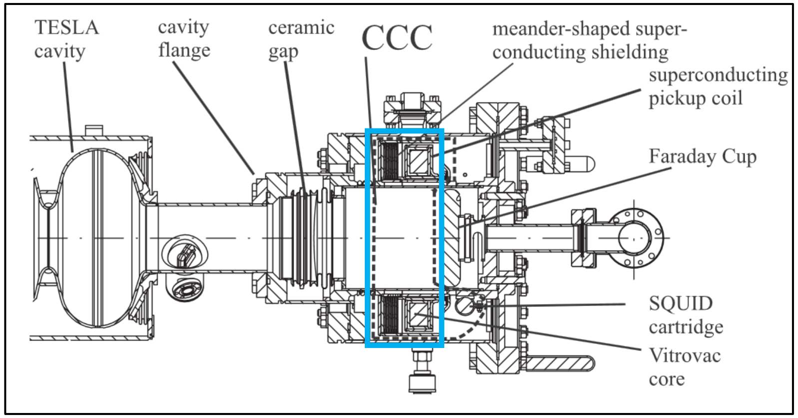


Courtesy of K. Li (JAPW22)

CCC for beam current meas.

2011 [3]: DESY, HoBiCaT, Berlin

Dark current (e-) from SC Tesla cavities



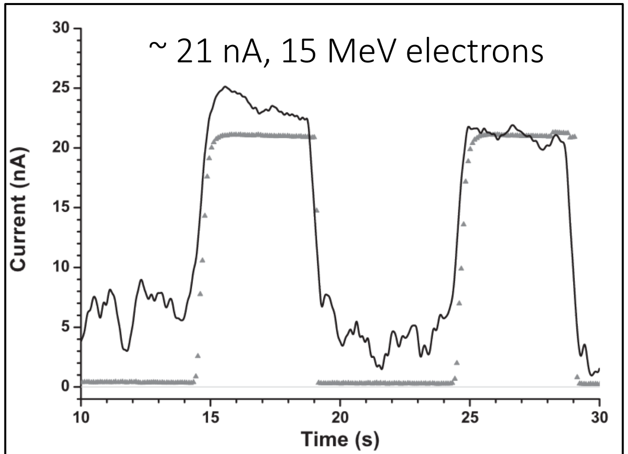
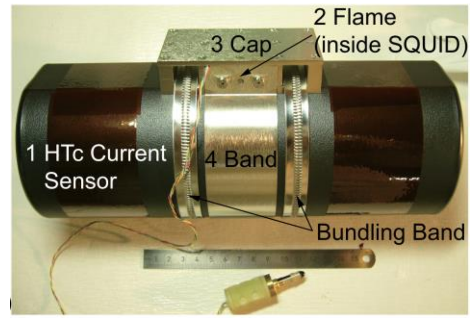


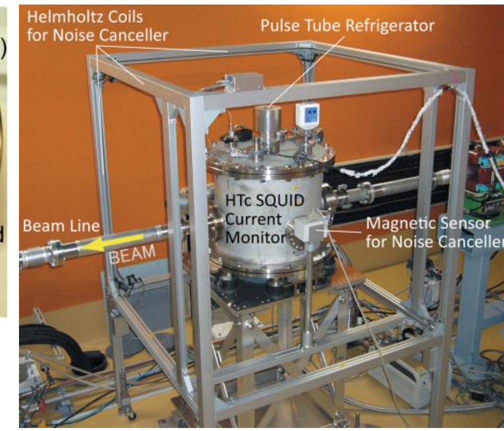
FIG. 8. Dark current of approximately 21 nA measured with the CCC (black curve, filtered and smoothed) and Faraday Cup (gray, triangles).

2016 [4, 5]: RIKEN, Saitama

Radioactive Isotope Beam Factory



HTc SQUID cooled at 77 K



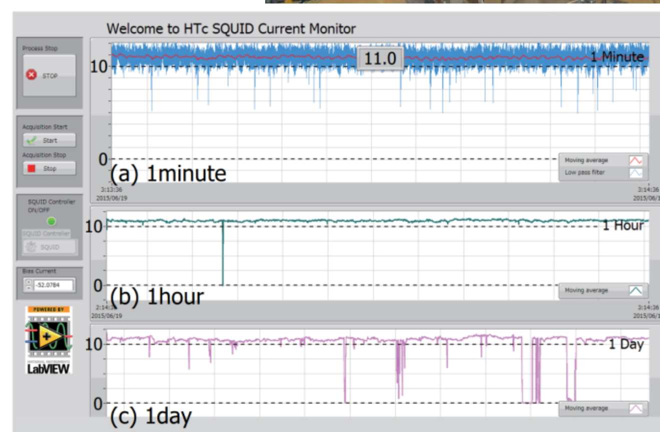
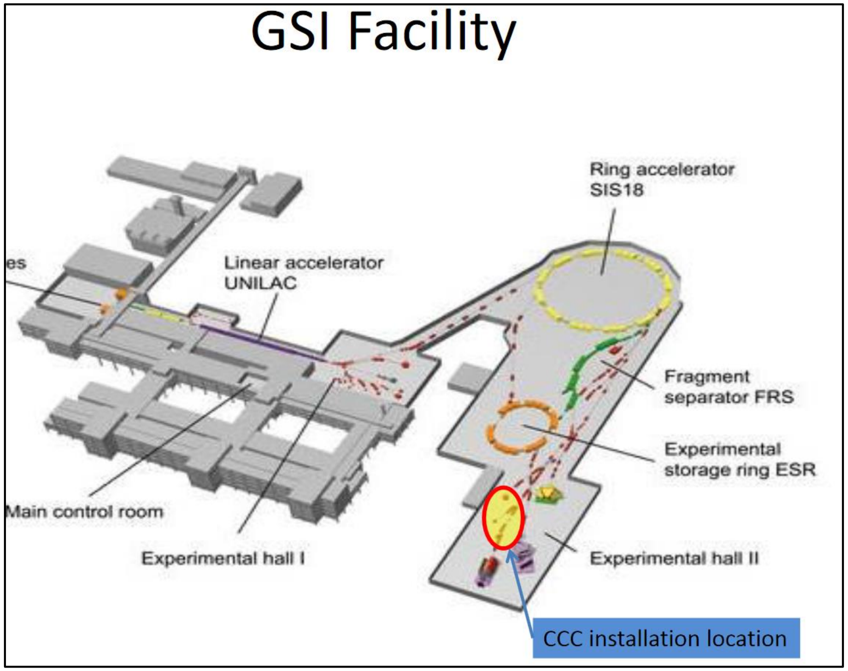
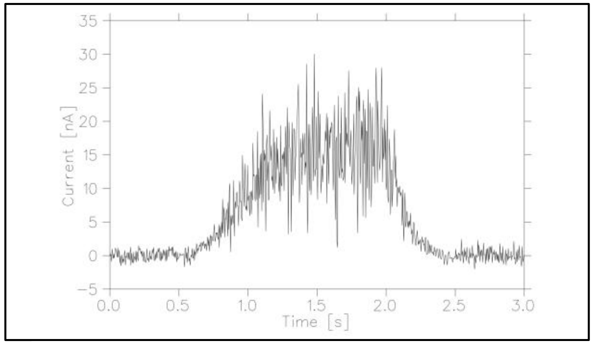


Fig. 2. The 11 μA ^{78}Kr^{36+} intensity of the beam (50 MeV/u) was successfully measured with a 500 nA resolution.

CCC for spill monitoring



A. Peters [1]: GSI, SIS target area, 1996



Spill duration: 2 s, Average current 12 nA
~2x10^{10} Ne^{10+} beam at 300 MeV/n

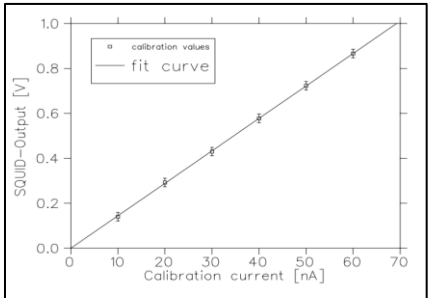
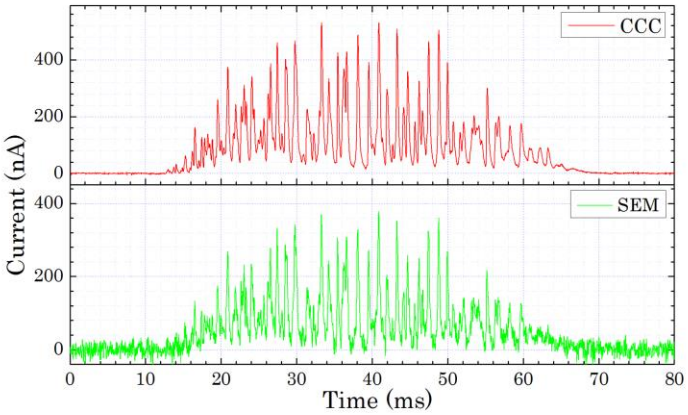


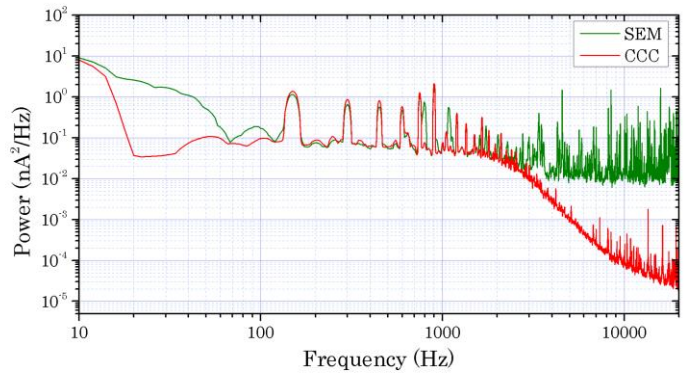
FIGURE 14. Calibration curve of the CCC

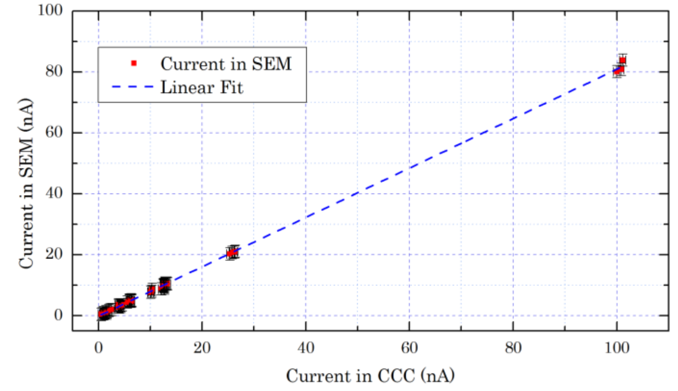
CCC vs current source

F. Kurian [2]: GSI, SIS target area, 2015

1.6×10^9 particles of Ni^{26+} ions extracted over $64\,ms$



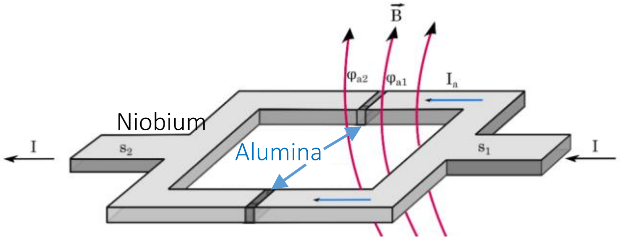




SQUID radiation hardness

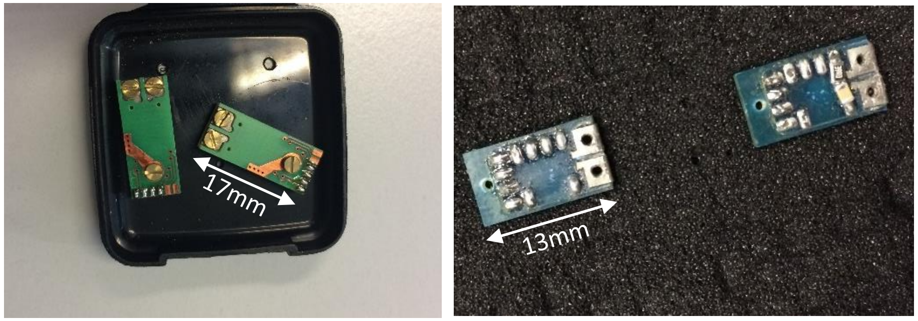
Motivation

Several hundreds of Gy expected along the SQUID lifetime
Irradiation tests undertaken in 2018 [6] - CERN/FAIR collaboration



Four SQUIDs from 2 manufacturers (Magnicon GmbH & Supracon AG)

- ❑ Characterization by the manufacturer
- ❑ Test at CHARM - East Area primary line:
  - SQUID on a fiber glass carrier
  - Irradiation of passive samples for 3 weeks
  - Accumulated dose: 1.37 kGy
- ❑ Characterization by the manufacturer



SQUID on a fiber glass carrier
Magnicon (left) and Supracon (right)

Results [7]

- ❑ **Magnicon:** no performance deterioration for boths
- ❑ **Supracon:** sample1: no performance deterioration
  sample2: reached 42% of the V-F curve (transfer function)
  large bias current: more of an effect of electrostatic damage

SQUIDs are not affected by moderate irradiation dose
Similar results for Josephson junctions from different materials are reported in literature [8]

Yes, but…

- ❑ SQUIDs were not cold and not powered during the tests in CHARM
- ❑ Local electronics (FLL, standard SC) are not rad hard
- ❑ Distance SQUID-FLL must be short (~1m) for BW limitation