HiRadMat
High-Radiation to Materials

HiRadMat at CERN SPS

A test facility for Accelerator Components with High Power Beam Pulses

Adrian Fabich
on behalf of the HiRadMat team

ATS seminar, 26. May 2016

EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

EuCARD²

EN Engineering Department

CERN

Overview

- Motivation
- Layout and features of the facility
- Experiments
- Conclusions

From Motivation to Proposal

- Beam intensity increases in particle accelerators
  → materials of near-beam equipment must be able to withstand the higher energy deposition/radiation

- Testing in an existing facility is difficult/inconvenient
  Typically an accelerator is already used for physics
  – Limited in access for installation works
  – Limited in space along the beam line
  – Missing infrastructure
  – Limited in beam time

There was the request for a **dedicated** test facility:

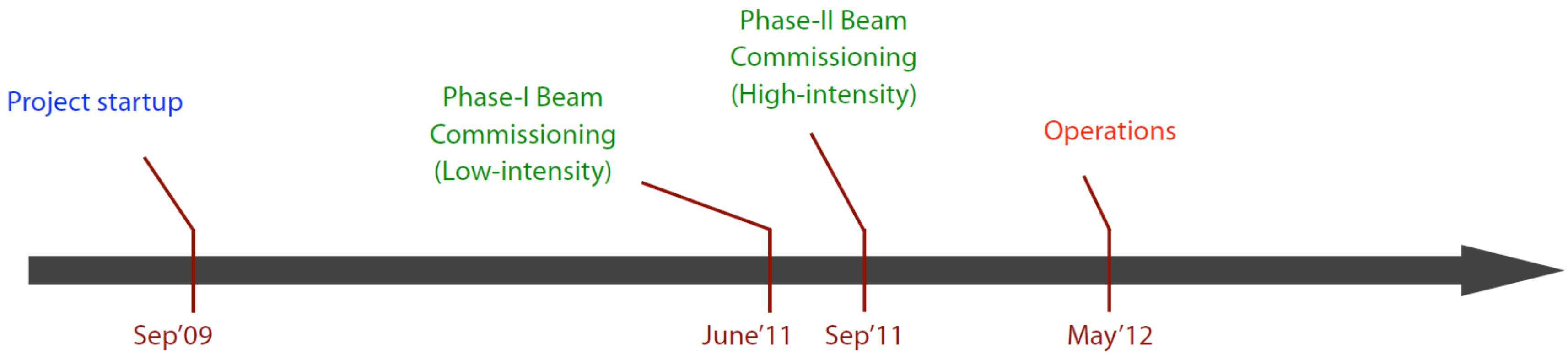
- **HighRadMat - High Radiation to Materials**
  Dedicated facility to study the impact of **intense pulsed beams** on materials investigating effects from heat & radiation with increasing intensity.

  – Thermal management (heating) & thermal shock (pressure waves)
  – Radiation damage to materials - change of mechanical properties

Facility target:
– provide irradiation area with beams similar to LHC injection regime
– with scanning possibilities in intensity and spot size
– Designed for single-pulse experiments (long-term irradiation is excluded for operational aspects)

Application targets:
- machine components, protection devices, targets, material studies, detector testing, electronics

Project Timeline



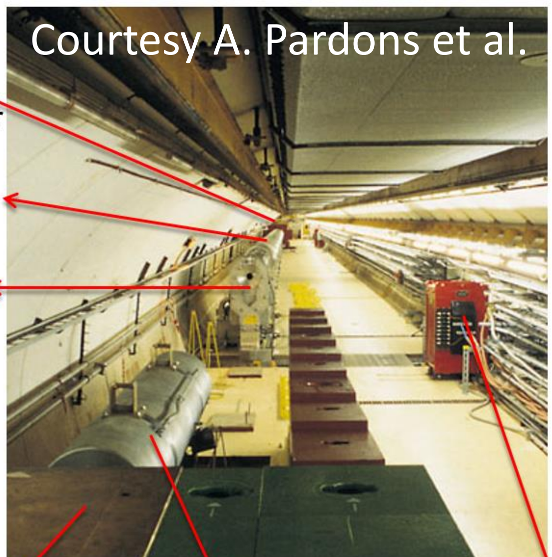
- Installed in place of former WANF

  proposed 2009 by R. Assmann and I. Efthymiopoulos

- Core team from EN/EA (formerly EN/MEF)

WANF dismantling

- WANF operation until 1998
- Dismantling in 2010



NBI 2012 https://indico.cern.ch/event/193710/

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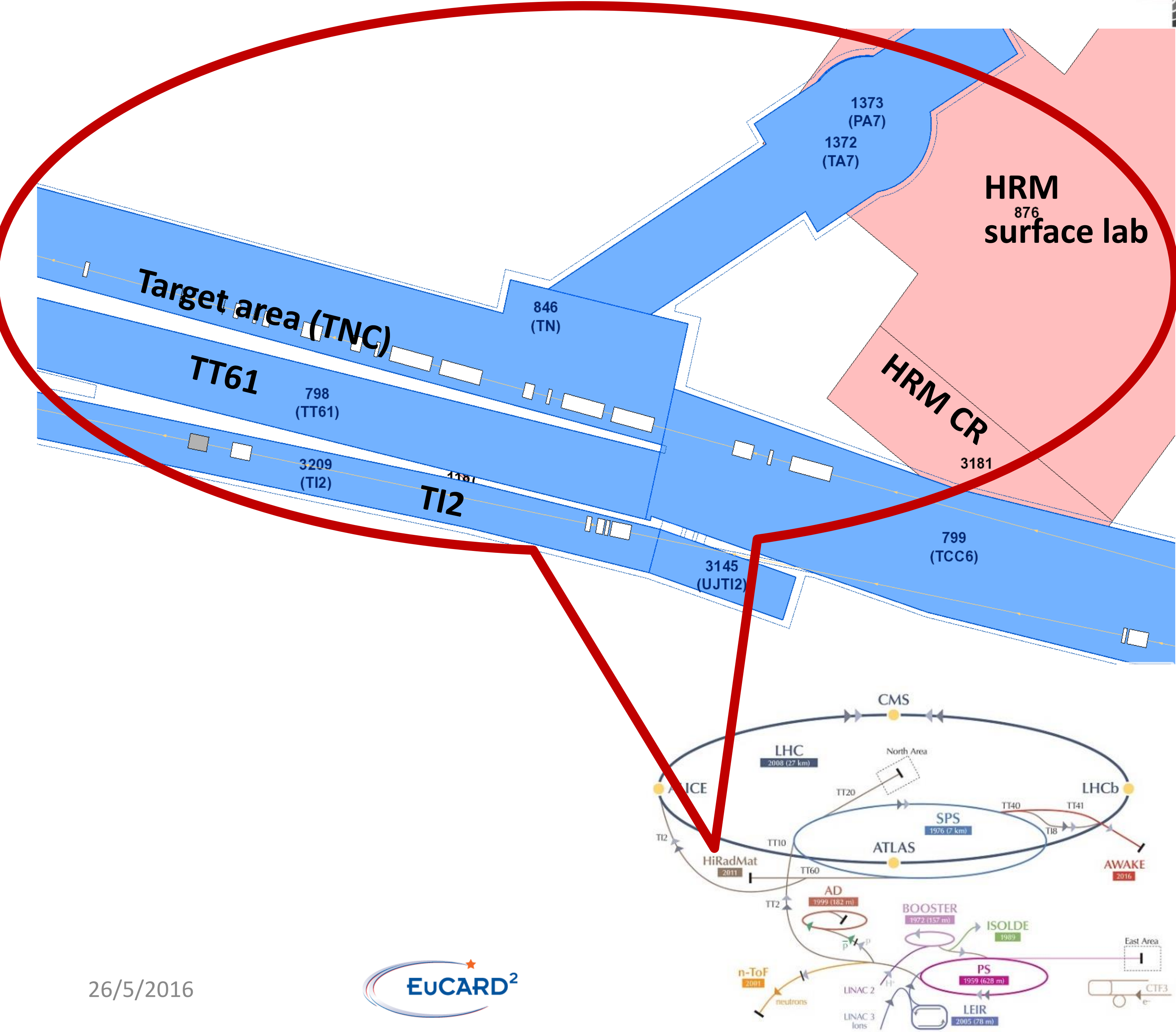
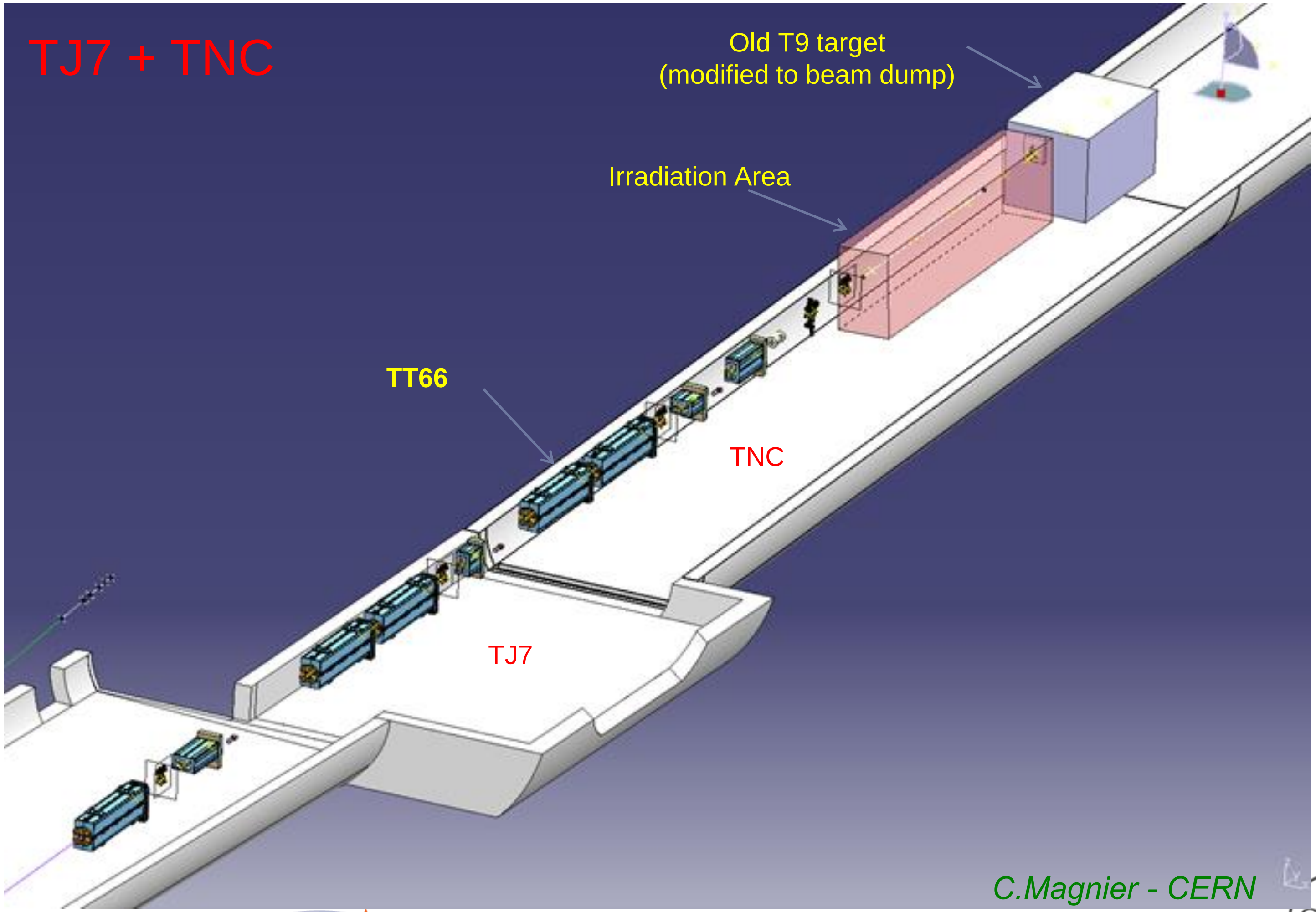


Facility services

Provision of dedicated irradiation infrastructure

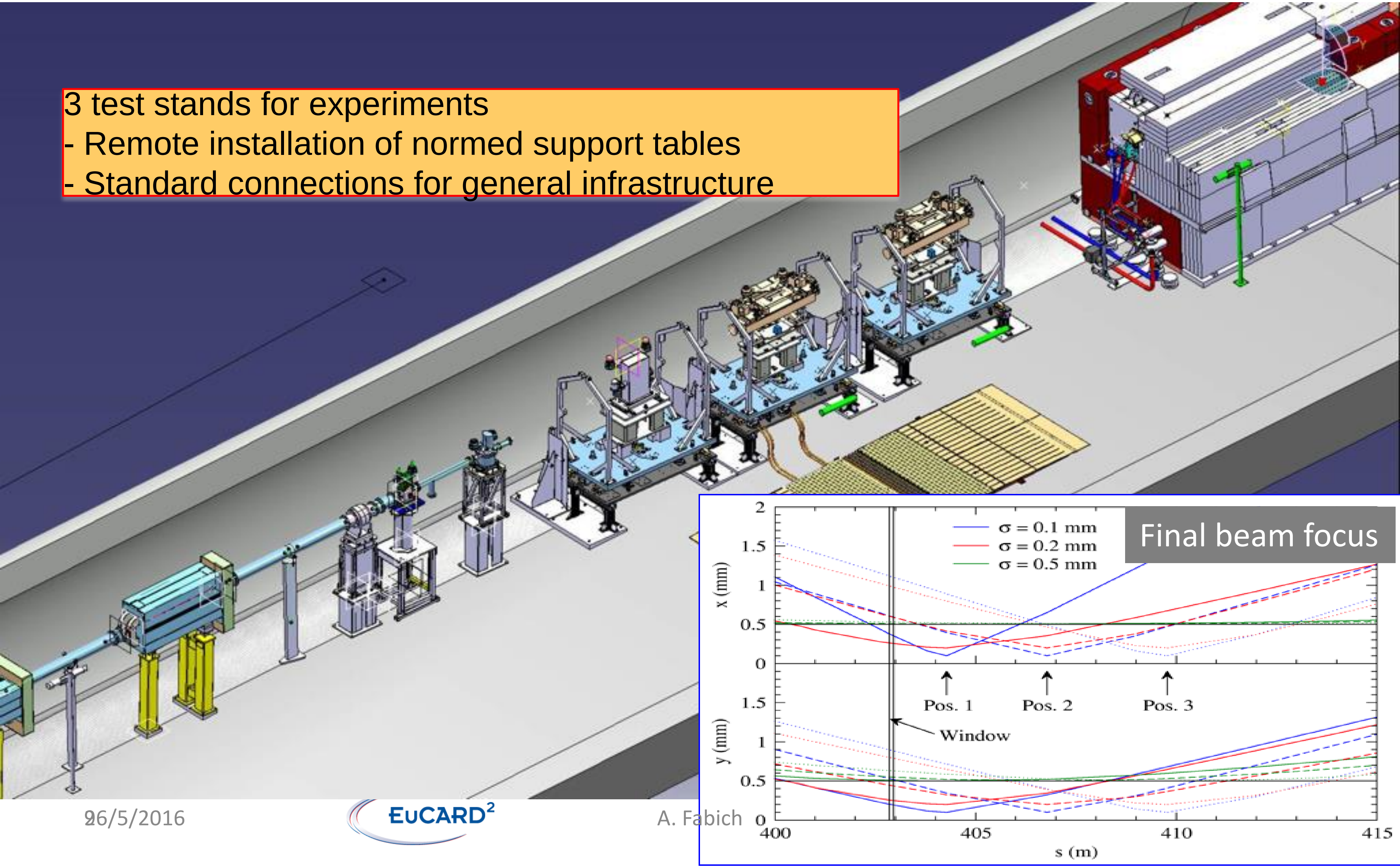
- Preparation lab at surface
  - Same interfaces as in the tunnel
- Control room
  - With pre-installed cabling for signal/HV/Ethernet to TNC
  - 140 meter cable distance to TNC
- Irradiation position
  - Standardized installation (remote)
  - General supplies (water, electricity, cabling)
  - Beam monitoring
- Assistance during design, preparation, installation, operation and follow-up
- Advising in safety matters and radiation-protection

Layout Target Area TNC (1)

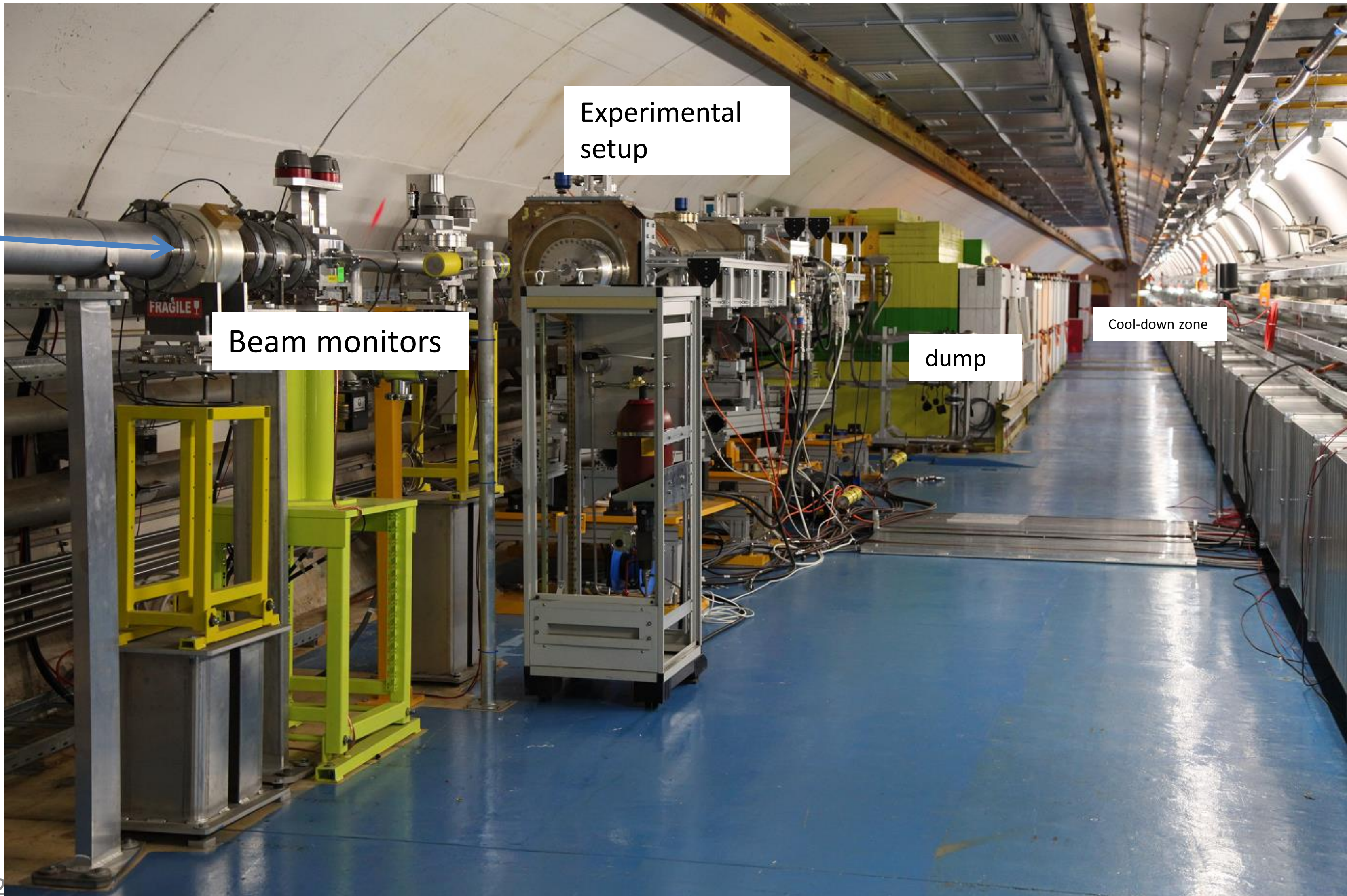


Layout Target Area TNC (2)

3 test stands for experiments
- Remote installation of normed support tables
- Standard connections for general infrastructure



Target area TNC



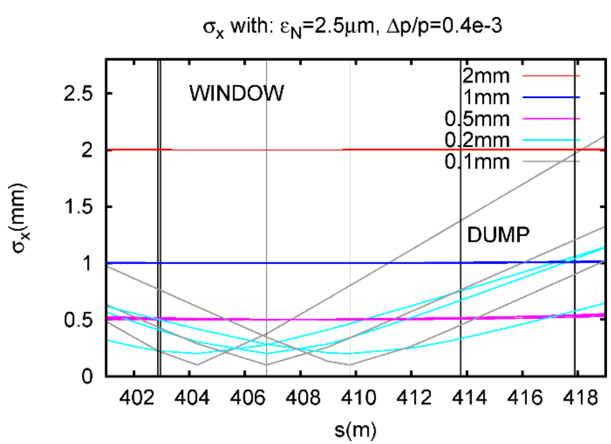
Beam Parameters

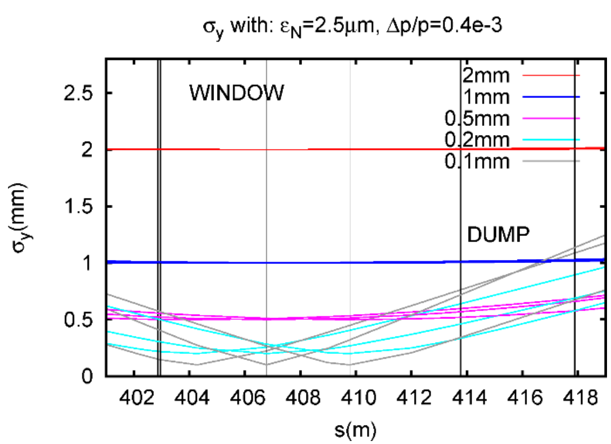
Similar to LHC injection

	Protons	Heavy ions (Pb^{82+})
Beam energy	440 GeV	173 GeV/u
Bunches/pulse (max)	288	52
Pulse intensity (max)	$3\ 10^{13}$	$4\ 10^{9}$
Bunch spacing	25, 50, 75 or 150 ns	100 ns
Pulse length (max)	7.2 µs	5.2 µs
Beam spot	variable around 1 mm^2	
Pulse energy (max)	3.4 MJ	21 kJ

Variable intensity

Variable beam focus





Courtesy C. Hessler

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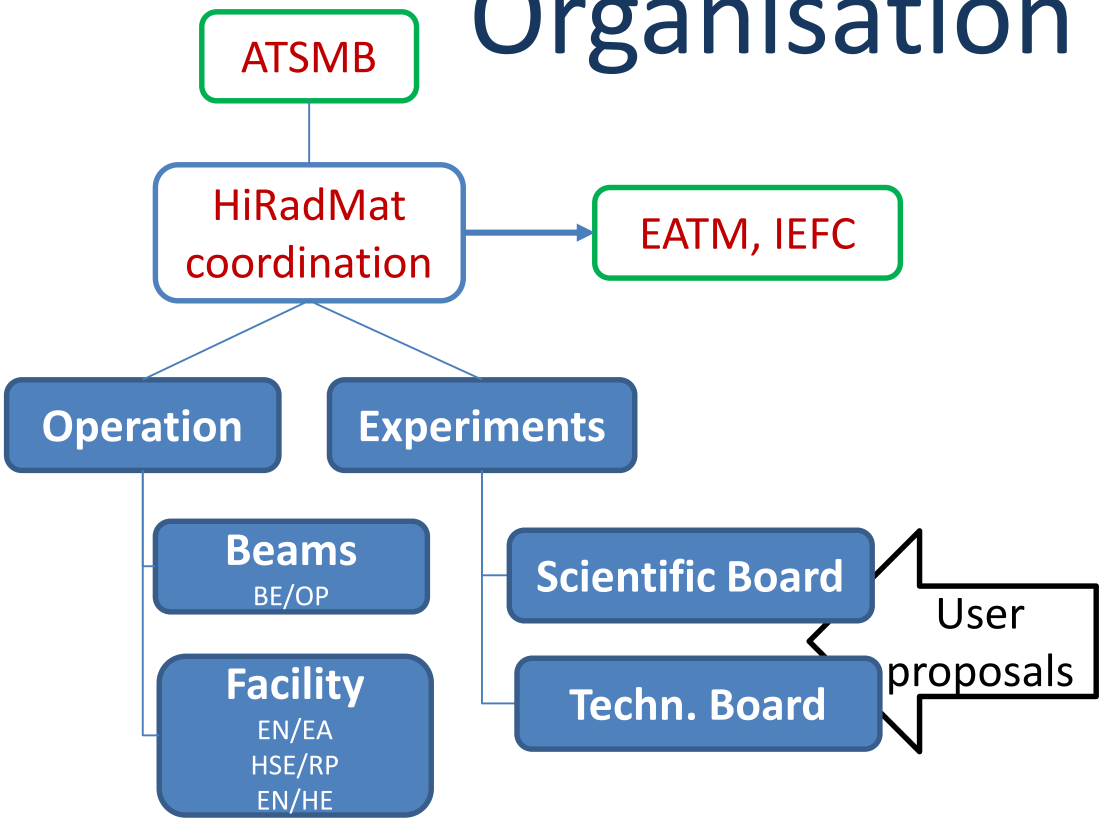
Organisation structure



Beam time application

Primary contact hiradmat.sps@cern.ch

- Experiment proposals are recommended by the HiRadMat Scientific Board
  - Scientific interest of the experiment, feasibility and post-irradiation analysis
  - Expected results and publications to the interest of the scientific community
- Approval validated by the HiRadMat Technical Board
  - Integration, operational and safety aspects, radiation protection and waste management

Board meeting about twice a year.

More information on http://cern.ch/hiradmat

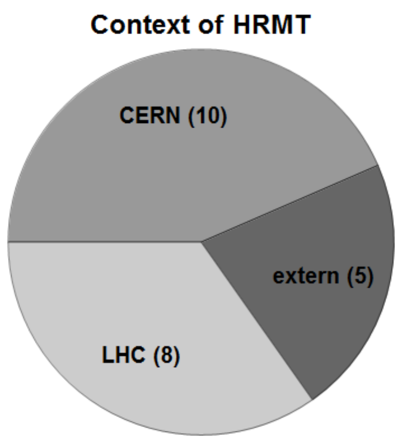
Regular meetings for daily operation:

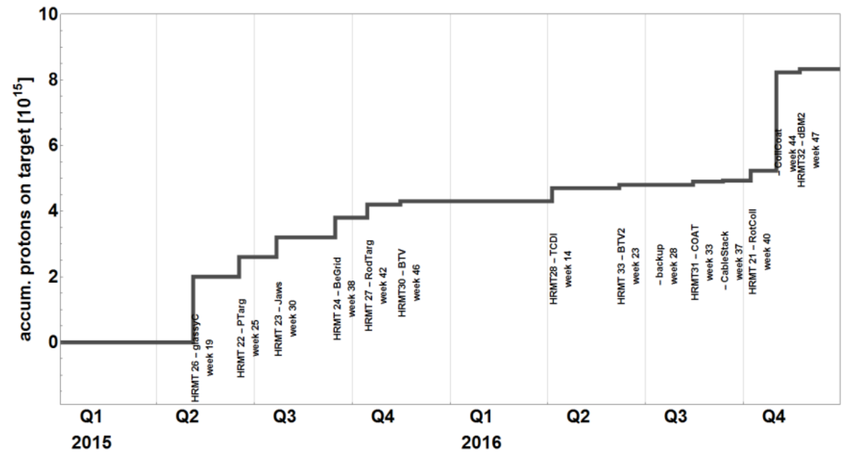
- Experimental Area management with CERN groups
- Users meeting (with video conferencing)

HRM user e-mail list: hiradmat-users@cern.ch

HRM beam program

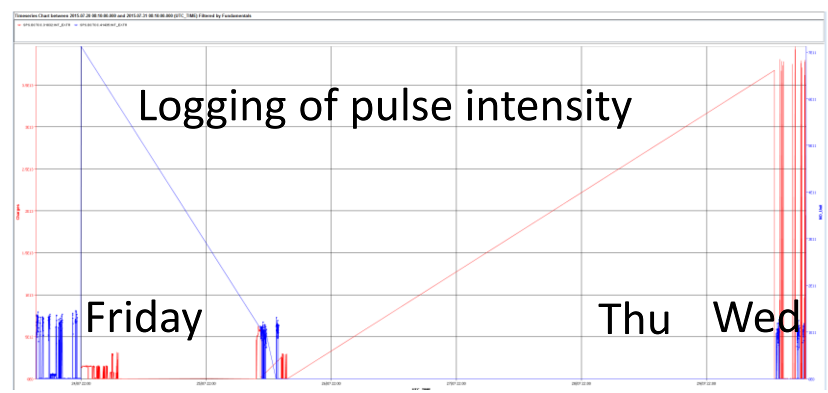
Target R&D
Wthimble - granular target technology
Ptarg
RIB target
RodTarg - AD target
Collimation (LHC and injectors)
Crystal collimation
tunneling experiment
Rotating collimator
Transfer lines collimators (3x)
SPS ejection septum protection
material studies
Prototyping (LHC and injector types)
Detectors
BLM - beam loss monitors
Optical microphone
Rpinst - RP Instrumentation R&D
diamond detectors
BTV beam monitors
More ...
GlassyC
Beryllium specimen
Cryogenic elements

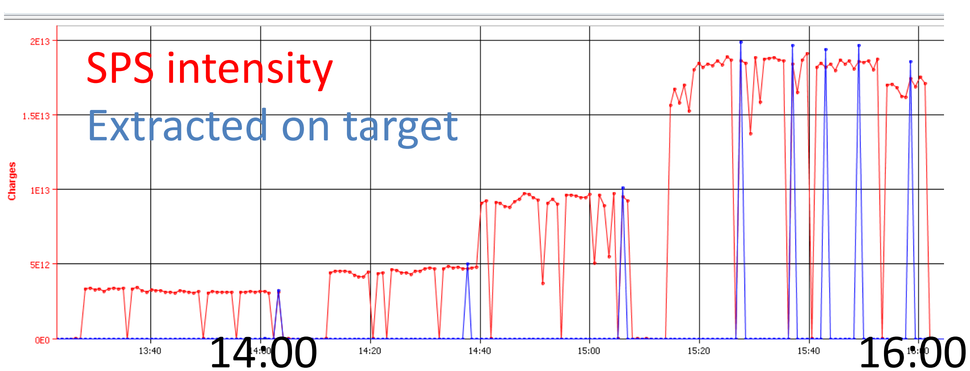




Single pulse experiments

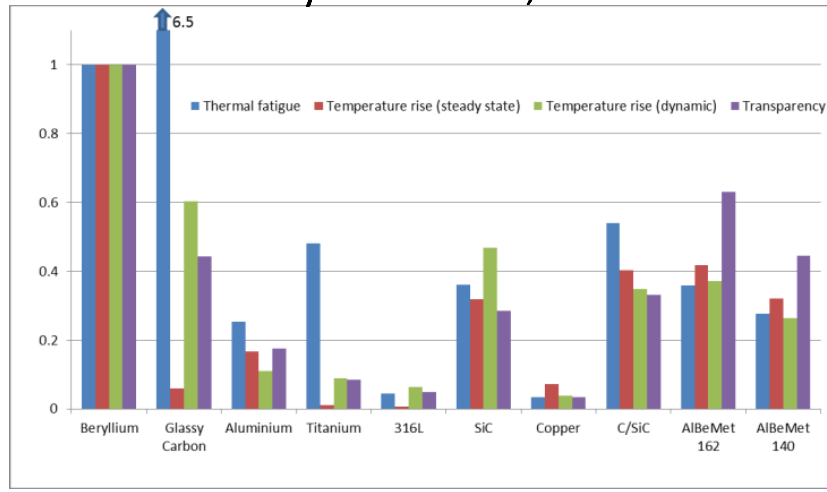
- Typically 100 pulses per experiment (10 exp./year)
  - Lasting a few shifts per experiment
- Limitation on air activation
- Allow personnel access to irradiation area





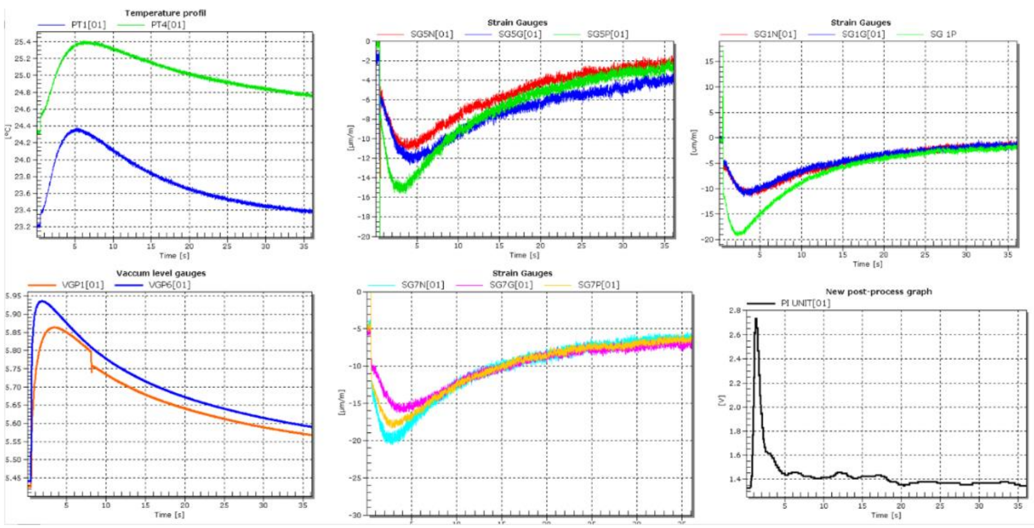
GlassyC experiment

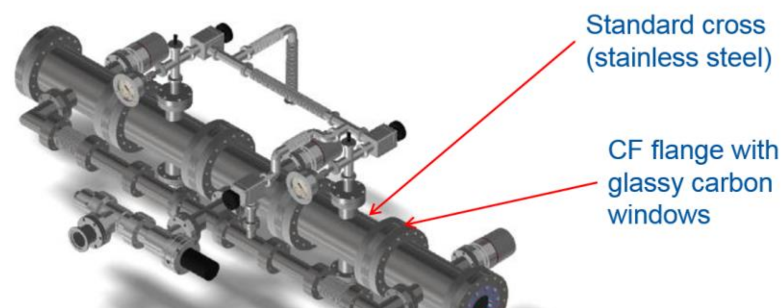
Courtesy: C. Garion, L. Baudin et al.



New material for vacuum windows

- Glassy Carbon obtained by the pyrolysis at high temperature of a highly reticulated resin
- 98 % (weight) of carbon and 2% of oxygen.





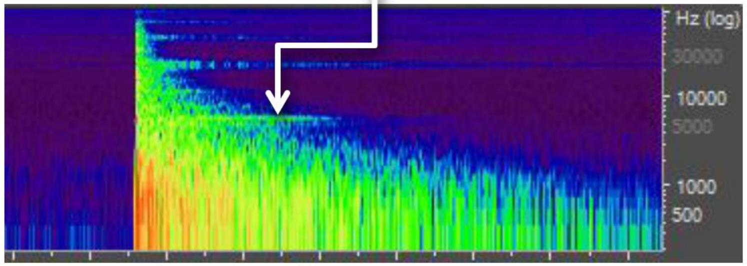
- Online monitoring using strain gauges and temperature sensors
- Post-irradiation evaluation (PIE) ongoing: microscopy

MicOpt: First data view

Courtesy:
Balthasar Fischer, Xarion (AT)
Daniel Deboy, KUG

Spectrogram (20Hz - 100 kHz)

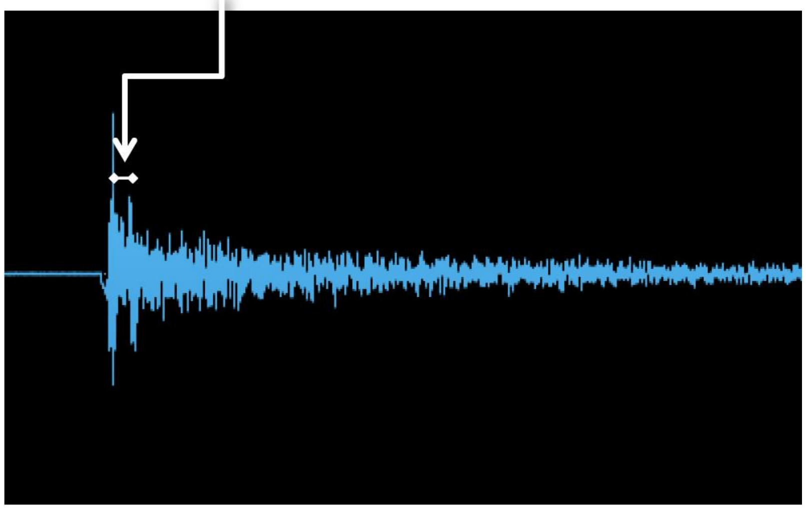
material resonance



0.5 s

Time signal

6ms reflection delay
(target is placed 1.05m away from tunnel wall)



0.1 s

- Impacts are clearly detected by Optical Microphone
- Peak sound pressure: 166 Pa; 138 dB SPL (tentative!)

- Thorough analysis:
  - radiation effects?
  - correlation between intensity and sound pressure level?
  - sound time-of-arrival for location detection?

Experimental setup

The employed all-optical microphone sensor head

EuCARD²

BPM diamond detectors

Development of

- Online monitoring of **beam position at experiment**
- Measuring of beam halo on four quadrants

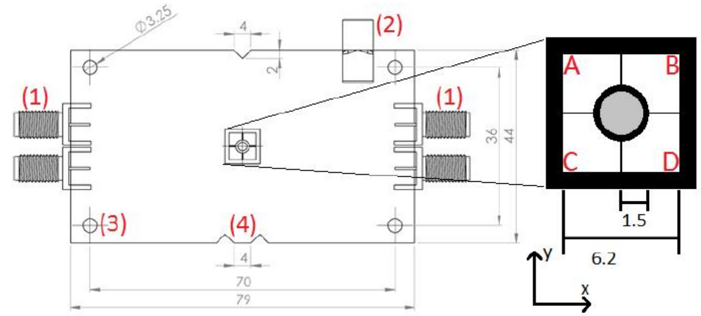
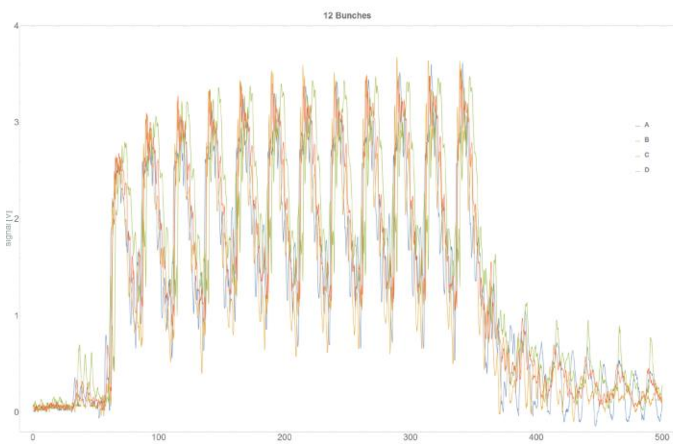


FIGURE 3.2: A schematical view of a detector module, with units in mm. Each gold pad has a side length of 3 mm and a separation to one another of 0.2 mm. The hole of the gold plating has a radius of 1.5 mm.



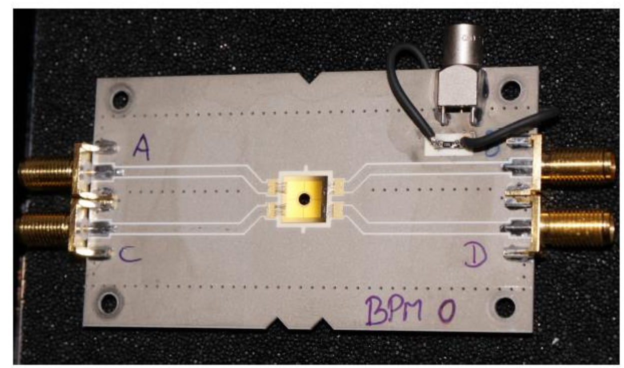
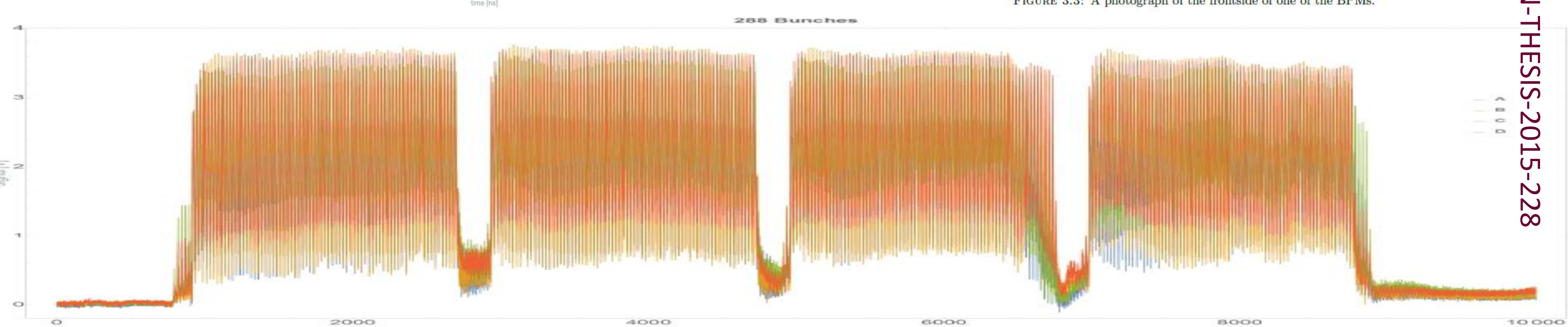


FIGURE 3.3: A photograph of the frontside of one of the BPMs.



Courtesy B. Lindstrom, CERN-THESIS-2015-228

I. Efthymiopoulos et al.

Beam position with TARGET downstream

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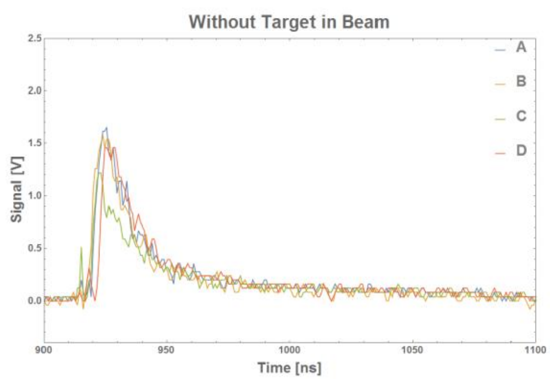
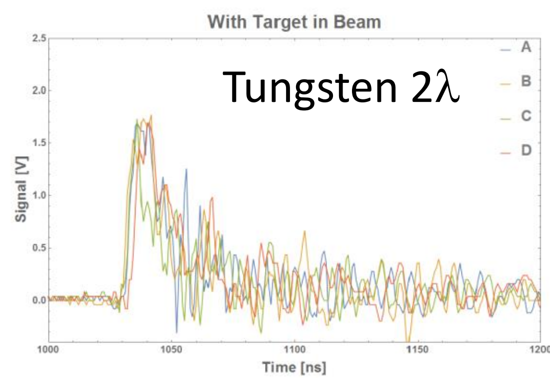
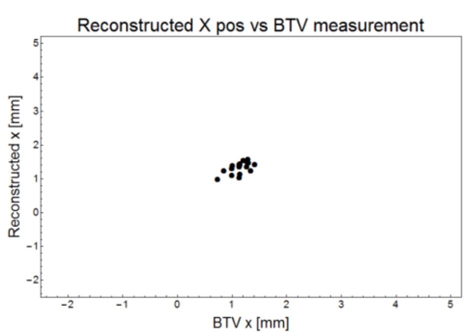
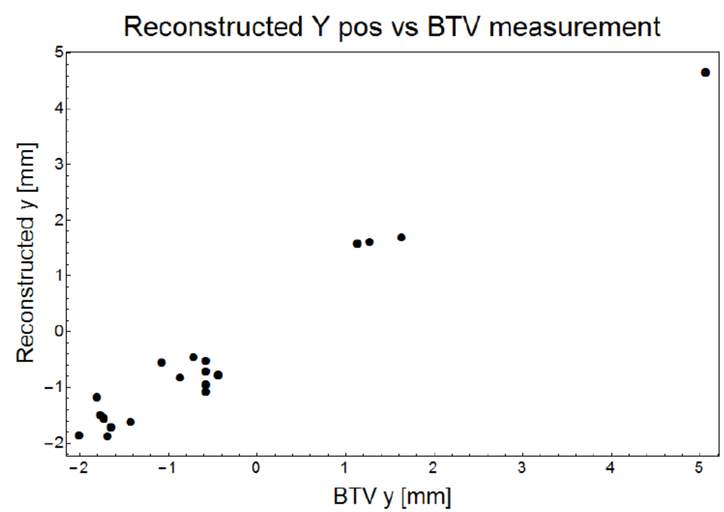
- Noise induced from backscattered particles





- Beam position still deducible





Courtesy B. Lindstrom, CERN-THESIS-2015-228

Online monitoring

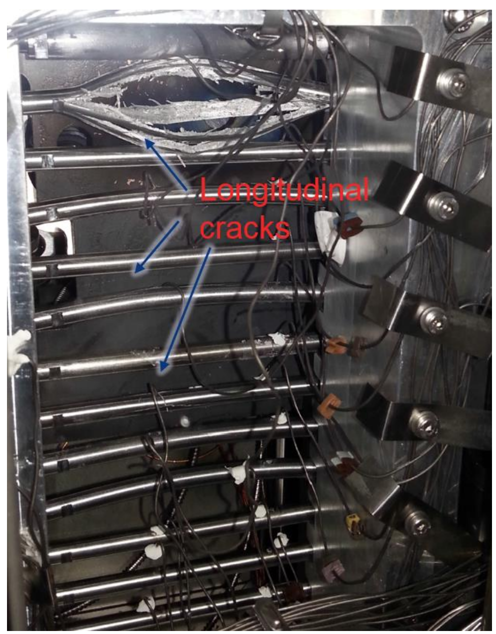
- **Beam performance**
  - Intensity: BCT transformers in SPS/transfer line
  - Beam profile
    - BPM in transfer line
    - Air core current transformer, BTV at experiment

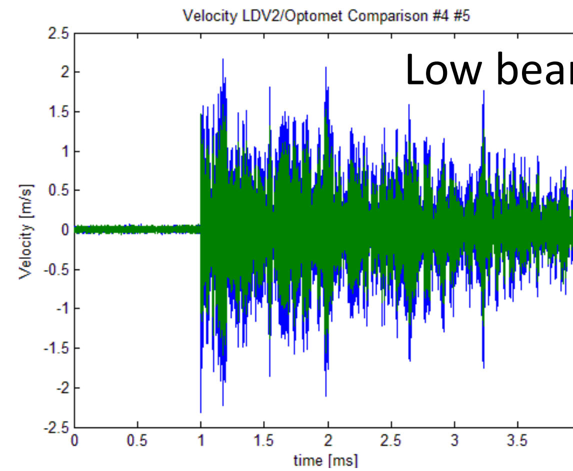
- **Radiation monitoring**
  - RadMons in TNC and TT61
  - BLMs along the transfer line and experimental setup

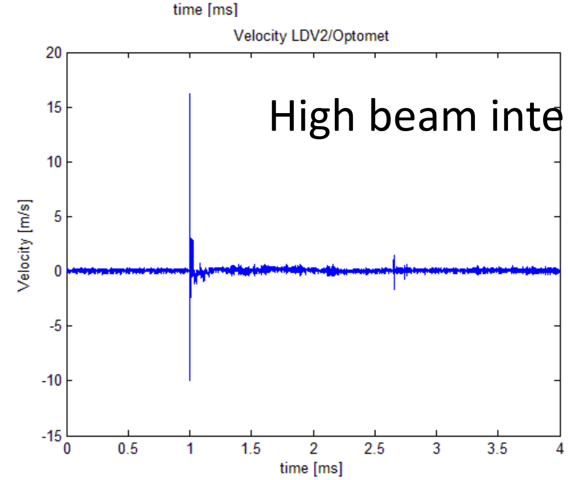
AD target

M. Calviani et al.

- **Motivation:**
  - Reduce the uncertainties existing in the core material response of the AD-Target
  - Assess the material selection for a new AD-Target for LS2
- **Goals:**
  - Recreate the same extreme conditions as reached in the AD-target in a controlled environment (validation of hydrocodes calculations)
  - **Identify mechanism of failure and limits** of the materials of interest impacted by proton beams



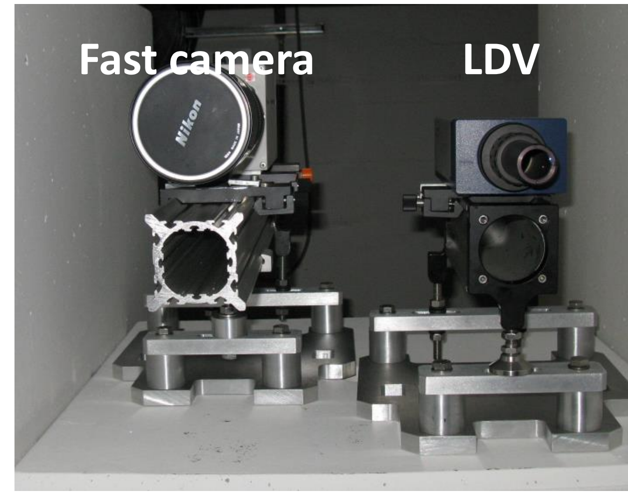




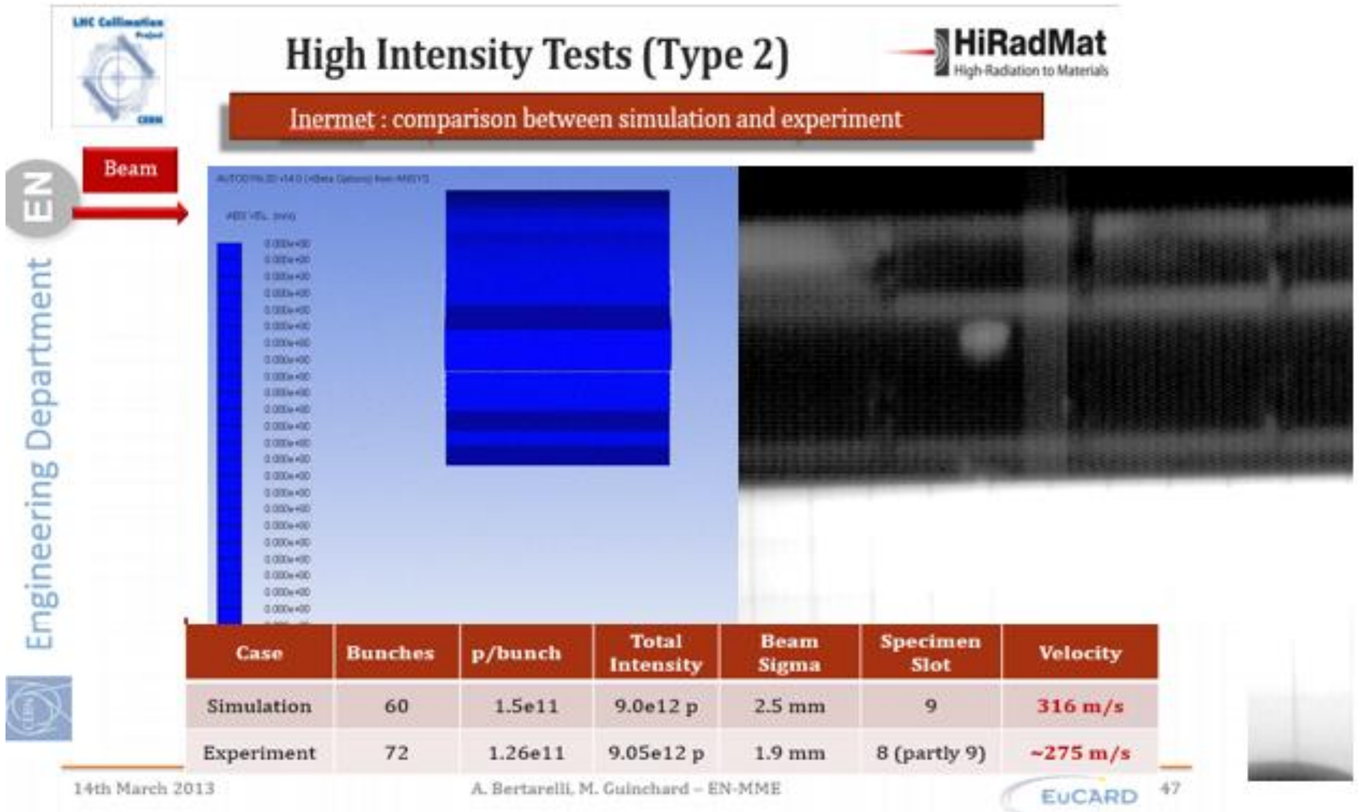
Measurement tools

Provided with the expertise of various groups at CERN

- Laser-Doppler vibrometer
  - Measuring surface velocities of several m/s
  - tens of MHz sampling
- Optical high-speed recording
  - High-speed camera with several kHz frame rate
- Diamond detectors, strain gauges, temperature sensors …
- Beam monitoring
  - High precision (< 0.1 mm) alignment/survey to experimental tables/beam
    Based on BTV/air core current transformer
  - Intensity monitoring
- Radiation monitoring with RadMons and beam loss monitoring



Validation of collimator materials



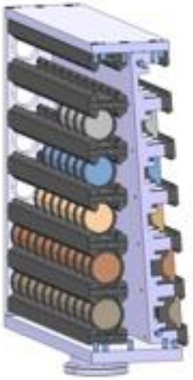
High Intensity Tests (Type 2)

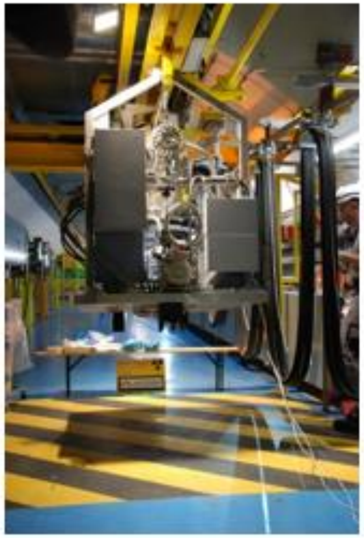
Inermet : comparison between simulation and experiment

Beam

Case	Bunches	p/bunch	Total Intensity	Beam Sigma	Specimen Slot	Velocity
Simulation	60	1.5e11	9.0e12 p	2.5 mm	9	316 m/s
Experiment	72	1.26e11	9.05e12 p	1.9 mm	8 (partly 9)	~275 m/s

14th March 2013 A. Bertarelli, M. Guinchard – EN-MME EuCARD 47





Courtesy: A. Bertarelli, M. Guinchard

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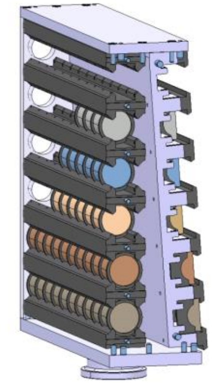

LHC Collimation Project

High Intensity Tests (Type 2)

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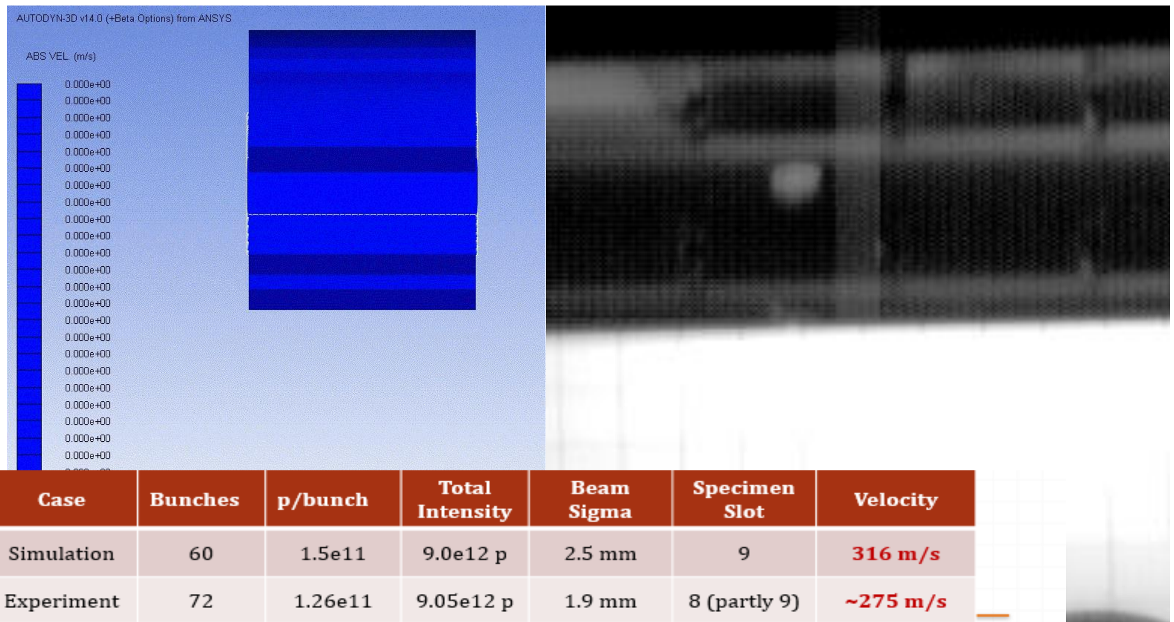
Beam



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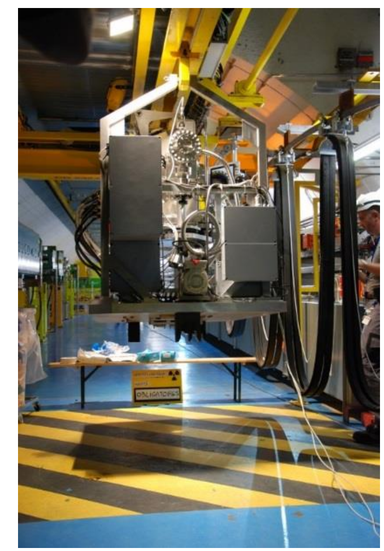
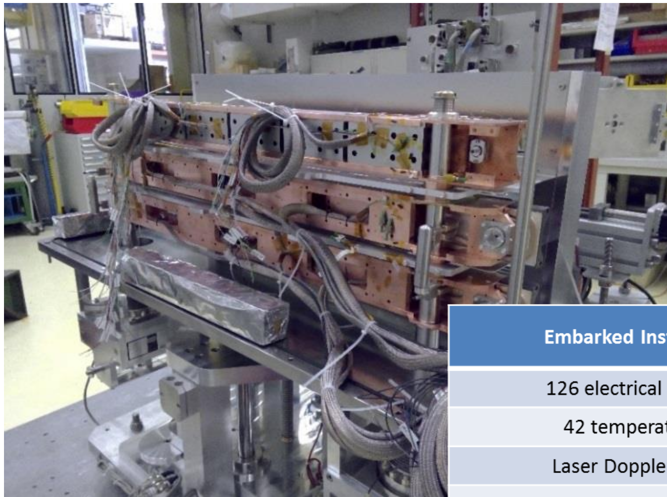


Courtesy: A. Bertarelli, M. Guinchard

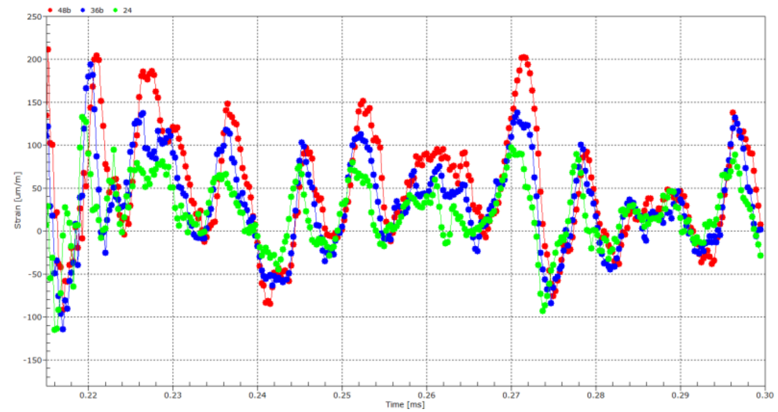
HRMT-23 JAWS

- designed to test and qualify against LHC and HL-LHC accident scenarios **three collimator jaws** (HL-LHC with MoGr, HL-LHC with CuCD, LHC with CFC)

Courtesy: M. Guinchard et al.



Embarked Instrumentation	Sampling frequency
126 electrical strain gauges	4 MHz
42 temperature probes	200 Hz
Laser Doppler Vibrometer	4 MHz
Water pressure sensor	100 kHz
60 strain Fibre Bragg Gratings	500 Hz
HD Camera inspection	*“ 4K ”*
Fast Speed Camera + LED lighting system	20 000 fps

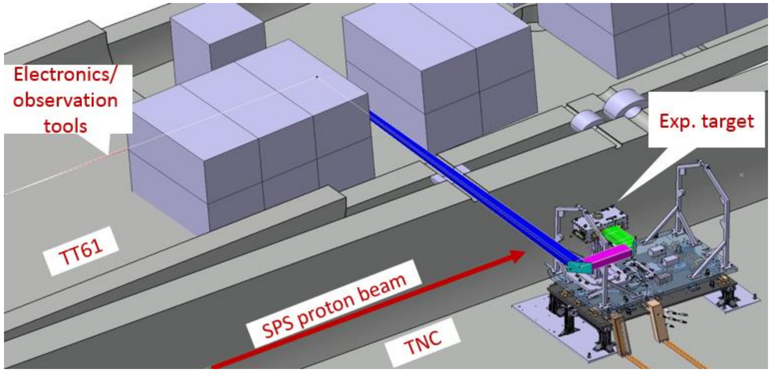


- With high intensity beam pulses on thick target - electronics in TT61 failed

	GlassyC	PTarg	Jaws	BeGrid	BLM2	RodTarg
Target	Thin 0.1 λ	Thick 2 λ	Thick >2λ	Thin 0.25 λ	Thin 0 λ	Thick 2 λ
p.o.t. (1e15)	1.2	0.03	1.1	0.3	0.3	0.2
Max. pulse intensity (1e13)	3.5	0.2	3.8	3.8	3.8	0.2
BLM411 response	0.016	0.0001	0.003	0.0004	0.0004	0.0003
BLM518 response	0.1	0.01	0.14	0.02	0.02	0.01
BLM526 response (just after nominal target position)	0.23	0.2	0.27 (sat.?)	0.22	0.15	0.2

Electronics/DAQ in TT61

with feed-through to TNC for direct cabling



Specifications

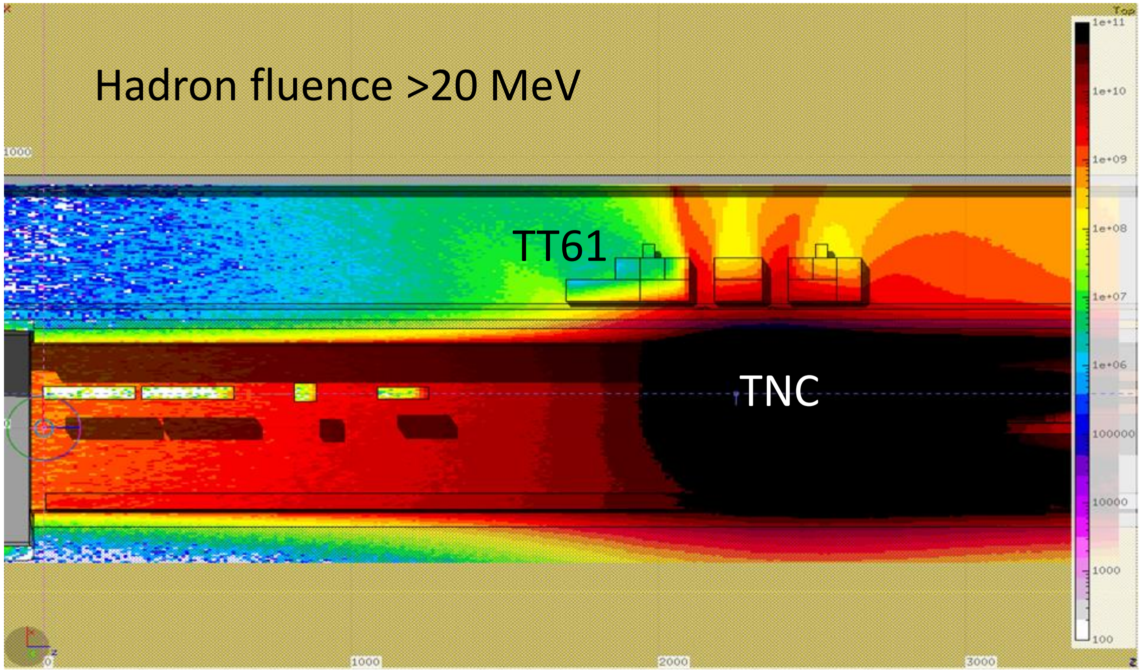
- Maximum cable length/optical path: 15 m
  - From electronics to target center
- Similar prompt radiation levels as in TJ7 bunker
  - Thick target, 3e12 ppp
  - 10e6 hadrons/cm2 for full intensity pulse

Additional shielding implemented (September 2015):

Optional counter measures: Increase distance (additional optical path/cable length)

Radiation levels

- 1e15 protons on target (1 experiment)
- Thick target – 2 nuclear interaction lengths



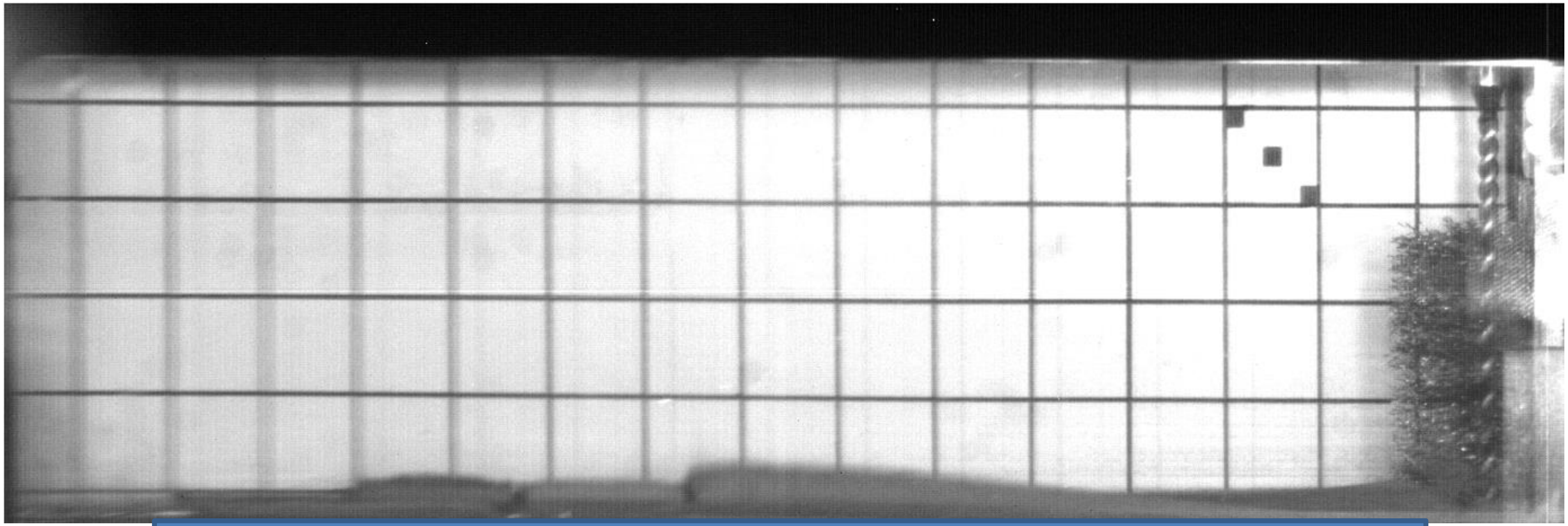
Courtesy: N. Charitonidis

- TT61 (at electronics): 1e7 heh/cm2 (for shielding 2016)
  TNC annual dose (for 1e16 pot): 1-5 kGy

Tungsten powder target

- Collaboration RAL-CERN

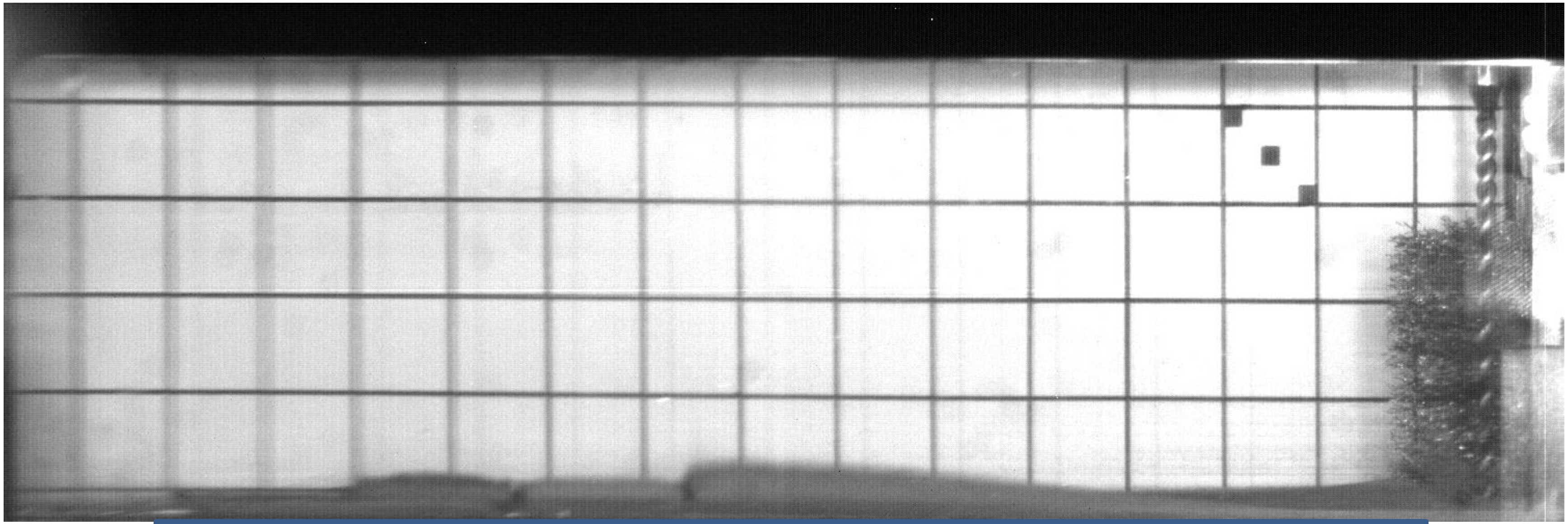
Courtesy C. Densham et al.



Trough with tungsten grains

proton beam

Tungsten powder target



proton beam

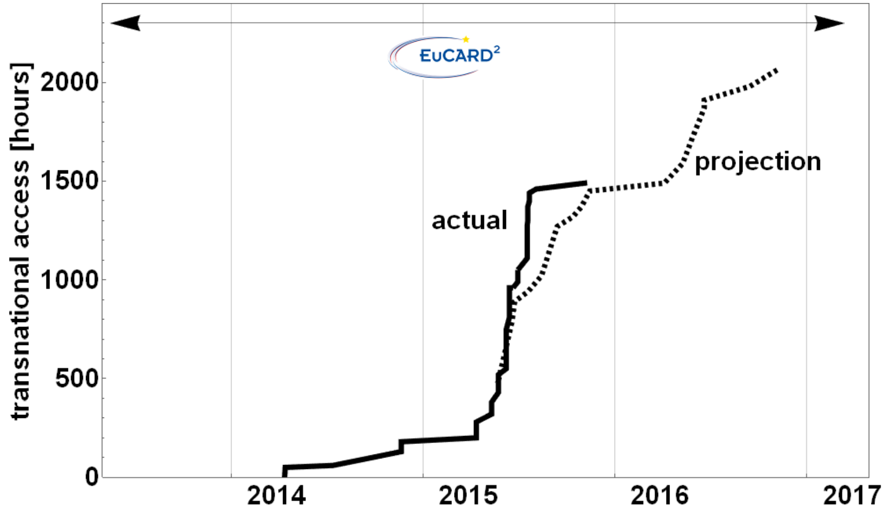
Different grain sizes along beam direction

High speed imaging equipment provided by HiRadMat (EN/EA)

EuCARD2 Transnational Access

HiRadMat is work package within FP7 EuCARD2

- supports travel/accommodation for external HRM users
- 150 user days at CERN enabled through HiRadMat within FP7



- Participant to the successor proposal "ARIES" (EuCARD3)

Conclusions

- HiRadMat as dedicated test facility successfully implemented
- Successful HiRadMat performance with large flexibility in performance parameters
- HiRadMat provides a great research opportunity on various accelerator components.

Dedicated THANK YOU to HSE/RP, EN/HE, BE/BI, EN/MME, BE/OP and EN/MEF (EN/EA) for the essential contributions to the implementation/operation of this facility!

All information published/linked at http://cern.ch/hiradmat

Announcement

HiRadMat Users Day

- 28th June 2016 at CERN

- Assess the scientific dissemination of HRM
- Discuss potential improvements/extensions of the facility

- Dedicated presentations on numerous research topics
- Open forum discussions with all participants

- Dedicated invite to all present and interested HRM users will follow these days

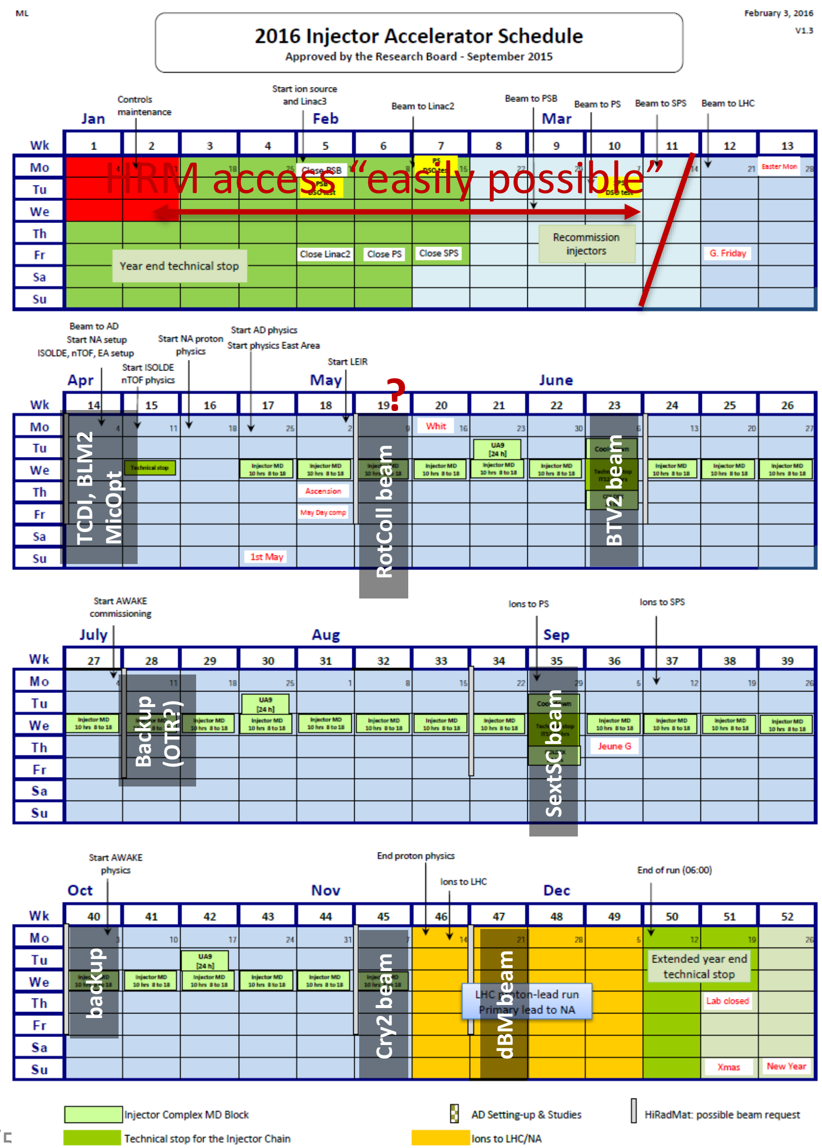
You are welcome to participate/contribute!

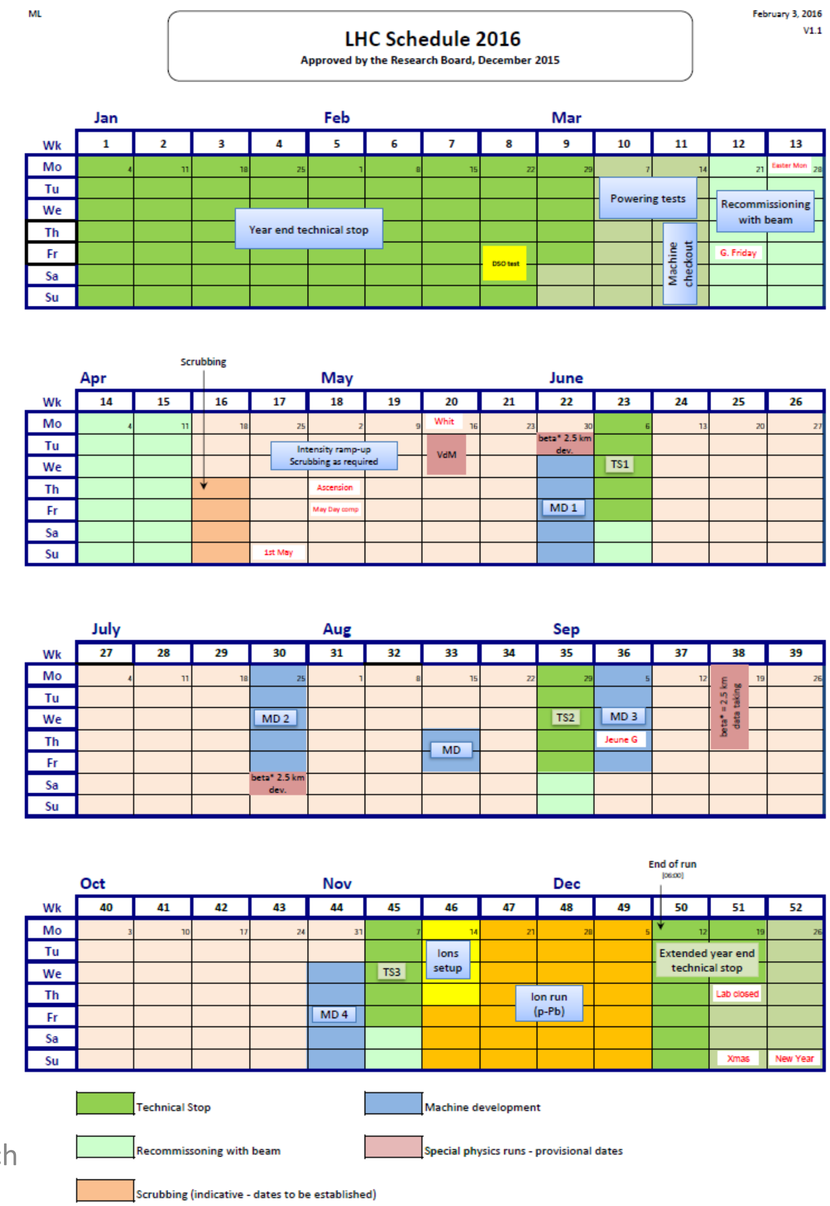
CERN

EN

ENGINEERING DEPARTMENT

Beam slot assignments





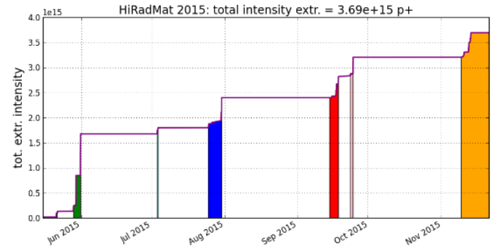
Injectors to HiRadMat in 2015

- Accumulated SPS cycle time: 4.0 days

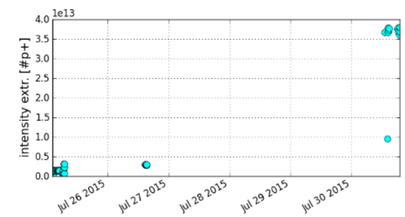
Variable Statistics between 2015-02-16 16:13:00.000 and 2015-12-01 16:13:00.000 (UTC_TIME)

Includes : MIN Value, MAX Value, AVG Value, Standard Deviation, Frequency | Selection Modes : Rows

Variable Name	# Values	MIN Timestamp	MAX Timestamp
SPS::FEI_HIRADMAT	0		
SPS::HIRADMAT1	0		
SPS::HIRADMAT2	0		
SPS:FEI_HIRADMAT:FEI_HIRADMAT	0		
SPS:HIRADMAT_4INJ_FB11100_FT500_Q20_2014_V1:HIRA...	0		
SPS:HIRADMAT_4INJ_FB11100_FT500_Q20_2014_V1:HIRA...	13531	2015-05-10 12:13:56.535	2015-09-28 19:24:24.135
SPS:HIRADMAT_HIGH_INTENSITY_2011_V1:HIRADMT1	0		
SPS:HIRADMAT_HIGH_INTENSITY_2011_V1:HIRADMT2	0		
SPS:HIRADMAT_L7200_2010_V1:HIRADMT1	0		
SPS:HIRADMAT_L7200_2011_V1:HIRADMT1	0		
SPS:HIRADMAT_L7200_2012_V1:HIRADMT1	0		
SPS:HIRADMAT_L7200_NORTHBUMP_2012_V1:HIRADMT1	0		
SPS:HIRADMAT_PILOT_Q20_2014_V1:HIRADMT1	11339	2015-04-04 16:55:49.335	2015-11-21 12:39:50.535
SPS:HIRADMAT_TEST_V1:HIRADMT1	0		



Courtesy V. Kain



- Total intensity extracted: 3.7e15 pot
- Excellent performance of the injectors providing beams with large flexibility, in the largest intensity range for multi-bunch pulses. All planned beams provided.

- 2012: 2 days, 1.4e16 pot

Variable Statistics between 2012-02-16 16:13:00.000 and 2012-12-15 16:13:00.000 (UTC_TIME)

Includes : MIN Value, MAX Value, AVG Value, Standard Deviation, Frequency | Selection Modes : Rows

Variable Name	# Values	MIN Timestamp	MAX Timestamp	MIN Value	MAX Value	AVG Value	Standard Deviation	Frequency
SPS::FEI_HIRADMAT	0							NaN/year
SPS::HIRADMAT1	0							NaN/year
SPS::HIRADMAT2	0							NaN/year
SPS:FEI_HIRADMAT:FEI_HIRADMAT	0							NaN/year
SPS:HIRADMAT_4INJ_FB11100_FT500_Q20_2014_V1:HIRA...	0							NaN/year
SPS:HIRADMAT_4INJ_FB11100_FT500_Q20_2014_V1:HIRA...	0							NaN/year
SPS:HIRADMAT_HIGH_INTENSITY_2011_V1:HIRADMT1	0							NaN/year
SPS:HIRADMAT_HIGH_INTENSITY_2011_V1:HIRADMT2	3734	2012-06-13 05:58:07.335	2012-11-30 09:42:34.935					22/day
SPS:HIRADMAT_L7200_2010_V1:HIRADMT1	0							NaN/year
SPS:HIRADMAT_L7200_2011_V1:HIRADMT1	8801	2012-05-09 06:40:19.335	2012-10-10 08:27:07.335					2/hour
SPS:HIRADMAT_L7200_2012_V1:HIRADMT1	3072	2012-10-11 09:36:02.535	2012-11-03 22:57:57.735					5/hour
SPS:HIRADMAT_L7200_NORTHBUMP_2012_V1:HIRADMT1	2197	2012-10-11 10:00:13.335	2012-10-22 15:09:31.335					8/hour
SPS:HIRADMAT_PILOT_Q20_2014_V1:HIRADMT1	0							NaN/year
SPS:HIRADMAT_TEST_V1:HIRADMT1	0							NaN/year

HiRadMat Scientific Board

HiRadMat High-Radiation to Materials

- Is the executive body that manages the facility.

- Evaluates the scientific merit of the proposed experiments, their feasibility, the proposed online information during beam time, the post-irradiation analysis plans and the expected results and publications to the interest of the scientific community.

- Distributes the EUCARD Transnational Access funds - contractual obligation from EC

- **Members:**

Bernie RIEMER, MSc
Senior Research Engineer
ORNL/SNS
Target development team leader

Nick SIMOS, Ph.D, P.E (chair)
Senior Scientist
Nuclear Science Department & Photon Sciences Directorate BNL
Project leader of BNL Linac Isotope Producer (BLIP)

Michael WOHLMUTHER, PhD
Senior Scientist
Paul Sherrer Institute - PSI
Radiation transport & Multiphysics Group
Head of Target Development Group

Adrian FABICH (scientific secretary)
Beam physicist – EN/EA group

Stefano SGOBBA
Materials Engineer – EN/MME group

Sebastien EVRARD
Mechanical Engineer – EN/EA group

Stefano Redaelli
Mechanical Engineer - BE/ABP group

Alfredo Ferrari
Senior physicist - EN/STI group

EN Engineering Department

BatMon reading (HRMT27)

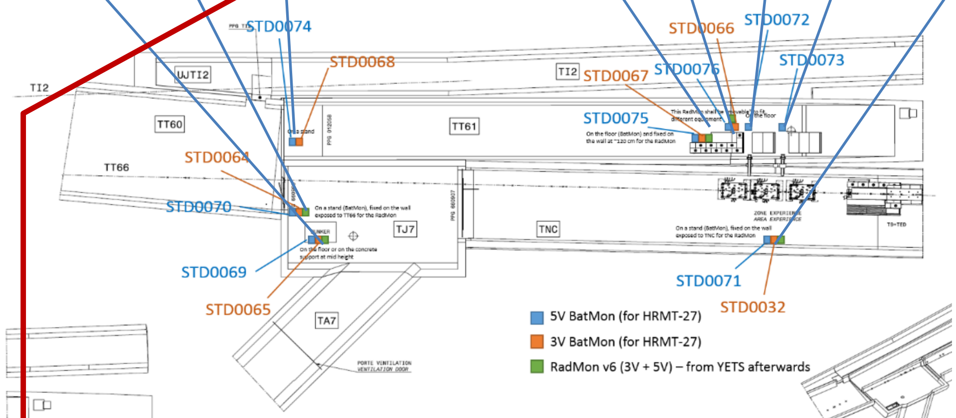
HiRadMat High-Radiation to Materials

	TJ7 bunker			TJ7 door			TT61 door			TT61 equipment table						feedthrough equipment side	feedthrough downstream	Experimental Zone			PROTON ON TARGET
	STD065	STD069		STD064	STD070		STD068	STD074		STD067	STD075		STD066	STD076		STD072	STD073	STD032	STD071		
	3V	5V	R factor	3V	5V	R factor	3V	5V		3V	5V	R factor	3V	5V	R factor	5V	5V	3V	5V	R factor	
02/11/2015																					
17/11/2015	56	1	2.02E+02	189	19	2.23	4	1	0.5	9	2	0.7	55	4	3.53	4	3	117323	7253	4.48	
Total	56	1	2.02E+02	189	19	2.23	4	1	0.5	9	2	0.7	55	4	3.53	4	3	117323	7253	4.48	8.44E+13
	Termal Neutrons	HEH		Termal Neutrons	HEH		Termal Neutrons	HEH		Termal Neutrons	HEH		Termal Neutrons	HEH		HEH	HEH	Termal Neutrons	HEH		
Total particles/cm2	1.07E+07	5.32E+04		3.10E+07	1.39E+07		4.52E+05	8.18E+05		1.10E+06	1.62E+06		9.53E+06	2.70E+06		3.41E+06	2.55E+06	2.08E+10	4.63E+09		
Total particles/cm2/pot	1.27E-07	6.30E-10		3.67E-07	1.64E-07		5.36E-09	9.69E-09		1.31E-08	1.92E-08	0.00E+00	1.13E-07	3.20E-08		4.04E-08	3.03E-08	2.46E-04	5.49E-05		

With new shielding in TT61:
still 1e6 to 1e7 heh/cm2 per experiment

Not easy to improve with present space restrictions, except distance

RadMon installed in YETS15/16

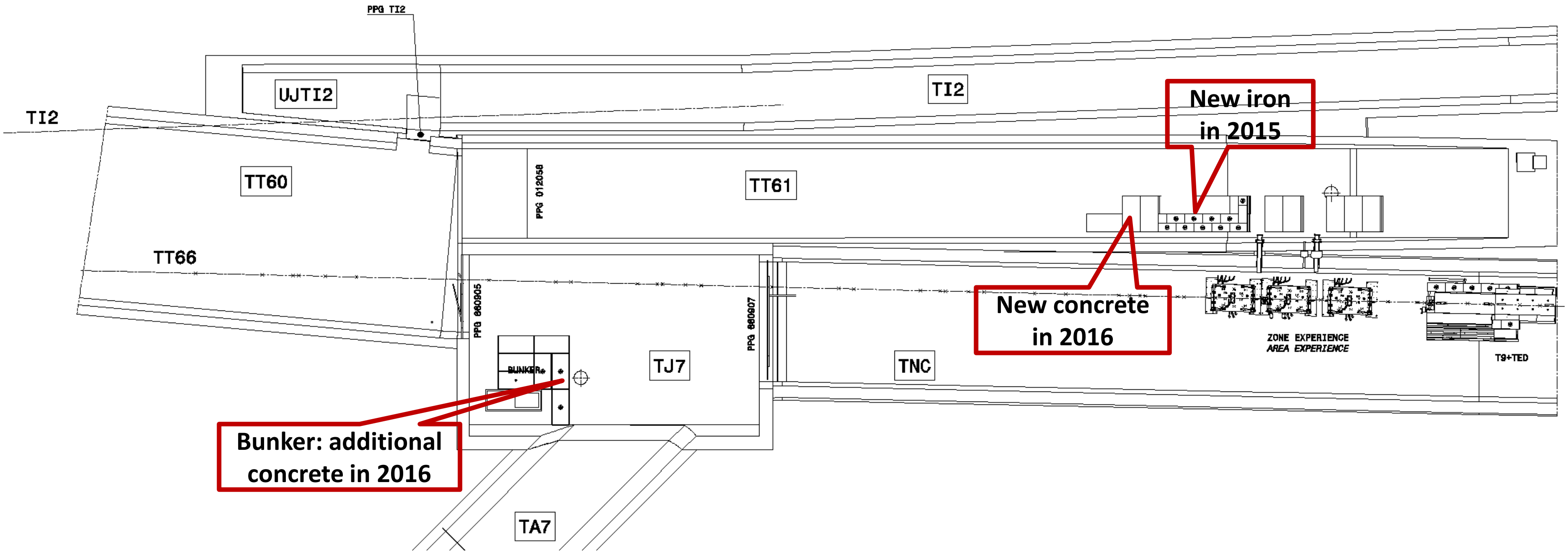


Proposition of BatMons installation for HRMT-27 run and fixed RadMons to be installed during YETS2015-2016

M. Calviani, 19th October 2015

Courtesy: EN/STI, R2E

Extended shielding



- Maximum radiation levels behind : 1e6 to 1e7 heh/cm2
- Further improvements only by increasing distance

Write-up with radiation fields in preparations