HiRadMat Potential and Perspectives for Muon Collider R&D

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Acknowledgements : J. Bernhard, M. Brugger, M. Calviani, I. Efthymiopoulos, Y.Kadi, P. Simon

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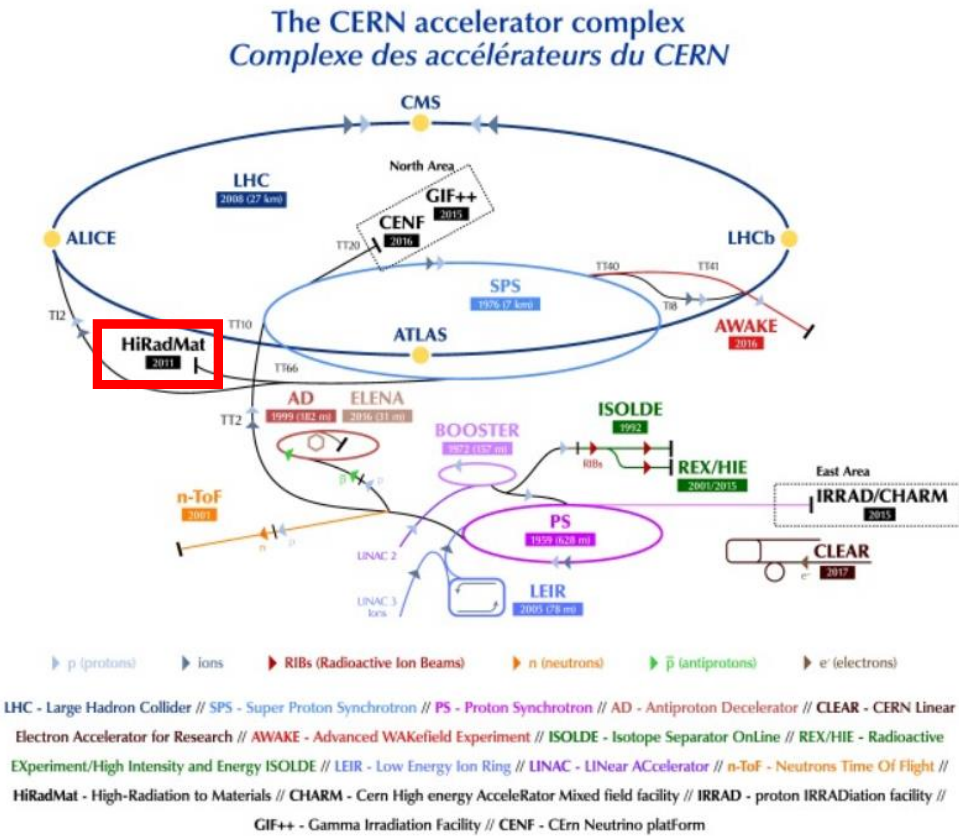
HiRadMat Facility Mandate

- **HiRadMat (High-Radiation to Materials)** is a user facility designed to provide high-energy, high-intensity pulsed beams to an irradiation area where material samples as well as accelerator component assemblies can be tested. **35 unique experiments since 2011.**



Originating in the need of testing accelerator components with the LHC type beams

→ R. Assmann et al., 2009

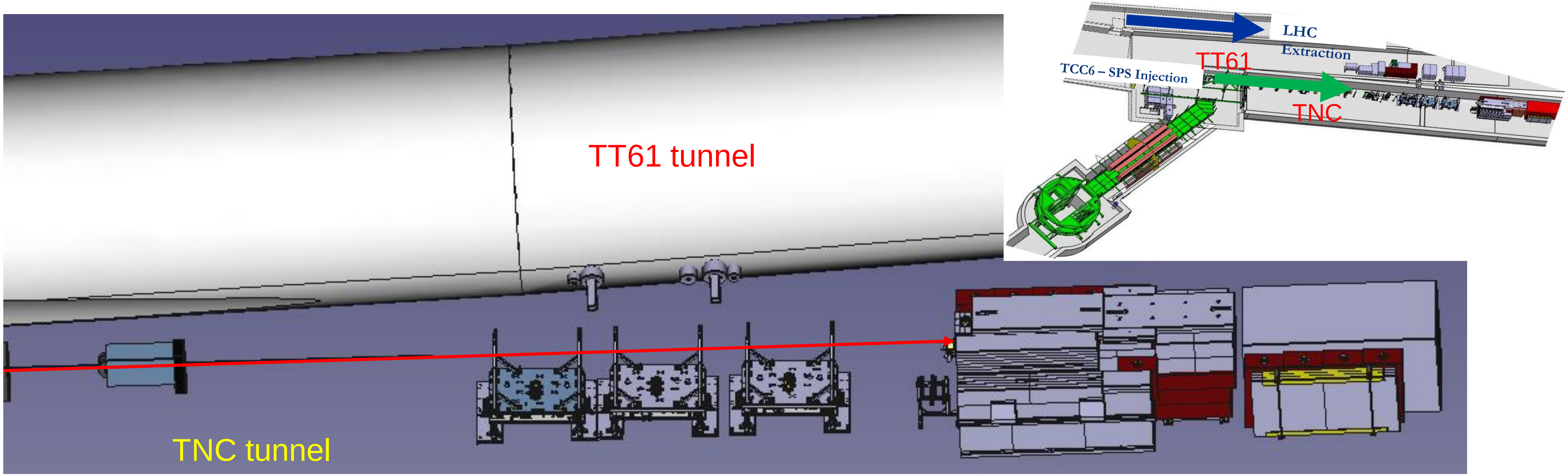
→ I. Efthymiopoulos et. al, comissioning in 2011

Operational mode :

→ **Approval from a scientific and a technical board** (judging merit, safety, technical feasibility and operational aspects). Beam time is **ultimately approved by the CERN IEFC comittee**.

Facility strongly supported by **ARIES – TNA**.

HiRadMat Facility Layout



- A specially designed **underground** facility, specially prepared and equipped with mobile supports, cabling, instrumentation for high intensity *pulsed* beam experiments.

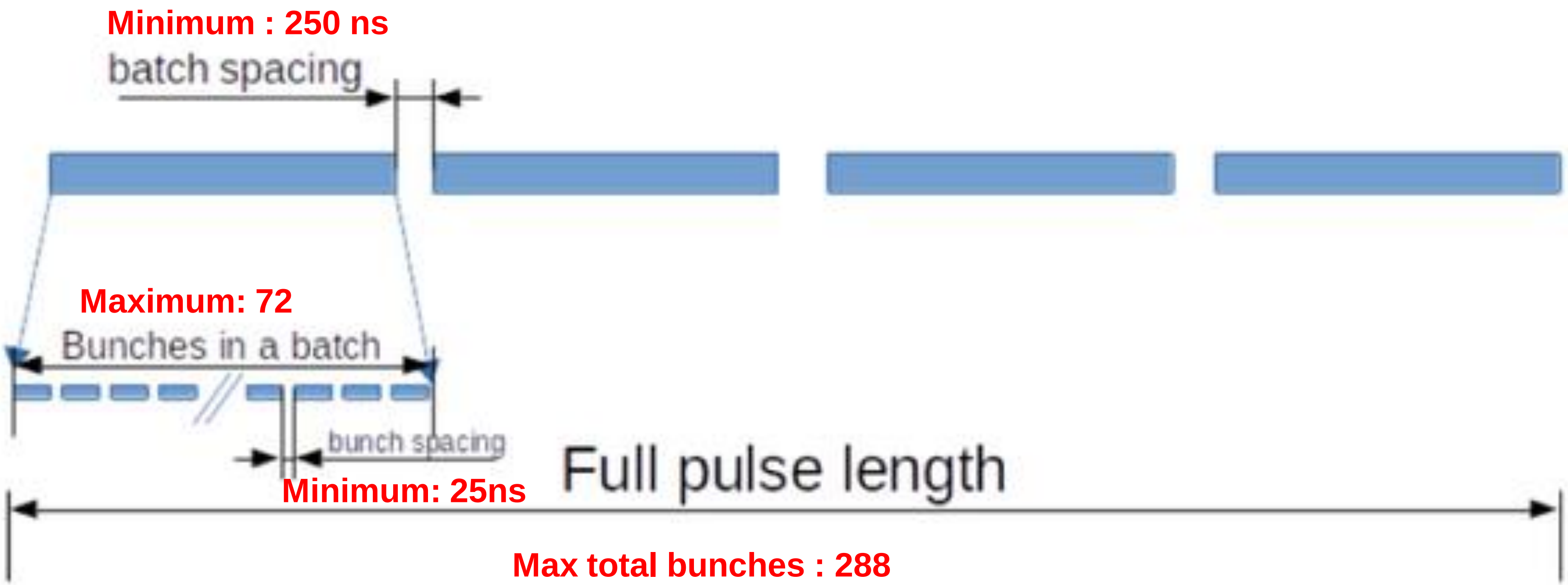
HiRadMat Beam Parameters

HiRadMat Proton Beam	
Beam Momentum	440 GeV +- 0.3%
Pulse Energy (max)	2.46 MJ
Bunch Intensity	5.0×10^{9} to 1.2×10^{11} protons
Number of Bunches	1 to 288
Minimum Pulse Intensity	5.0×10^{9} protons (1bunch)
Maximum Pulse Intensity	3.5×10^{13} protons (288b at 1.2×10^{11} ppb)
Bunch length (1σ r.m.s)	375 ps
Bunch Spacing	min. 25 ns, max 150 ns
Batch Spacing	250 ns
1 σ r.m.s. beam radius	0.5 to 4.0 mm

Total typically allocated protons/year	**$2\text{x}10^{16}$** protons (equivalent to approx. 10 experiments year)

An upgrade study of the beam dump and windows is ongoing, in order to be able to allow LIU beam parameters (smaller emittance & 2.3×10^{11} protons / bunch

HiRadMat Beam Structure



Courtesy: F. M. Velotti (SY/ABT)

Experiments in HiRadMat

- **A unique facility to test the effects of *high-power SINGLE pulsed beams* on materials**
  - Targets
  - Accelerator components
  - Beam instrumentation or machine protection
  - Highlights of experiments on various aspects have been presented e.g here

- **1 HiRadmat pulse with the maximum intensity (288 bunches, 3.5x10^{13} p/bunch) can be seen as having an instantaneous energy of :**

P[J/pulse] = 440 x 1.6E-10 x 3.5E13 = 2.46 MJ/pulse

- **This "power density" in tandem with the very short pulse length (7.2 us) certainly allows to test or simulate realistic energy depositions of high power beams like the ones mentioned for the future muon collider**

- **At the same time, only 1 pulse per ~min currently → Low average power, imposed mainly from availability and concurrence with LHC**

Towards a proton driver of a muon collider

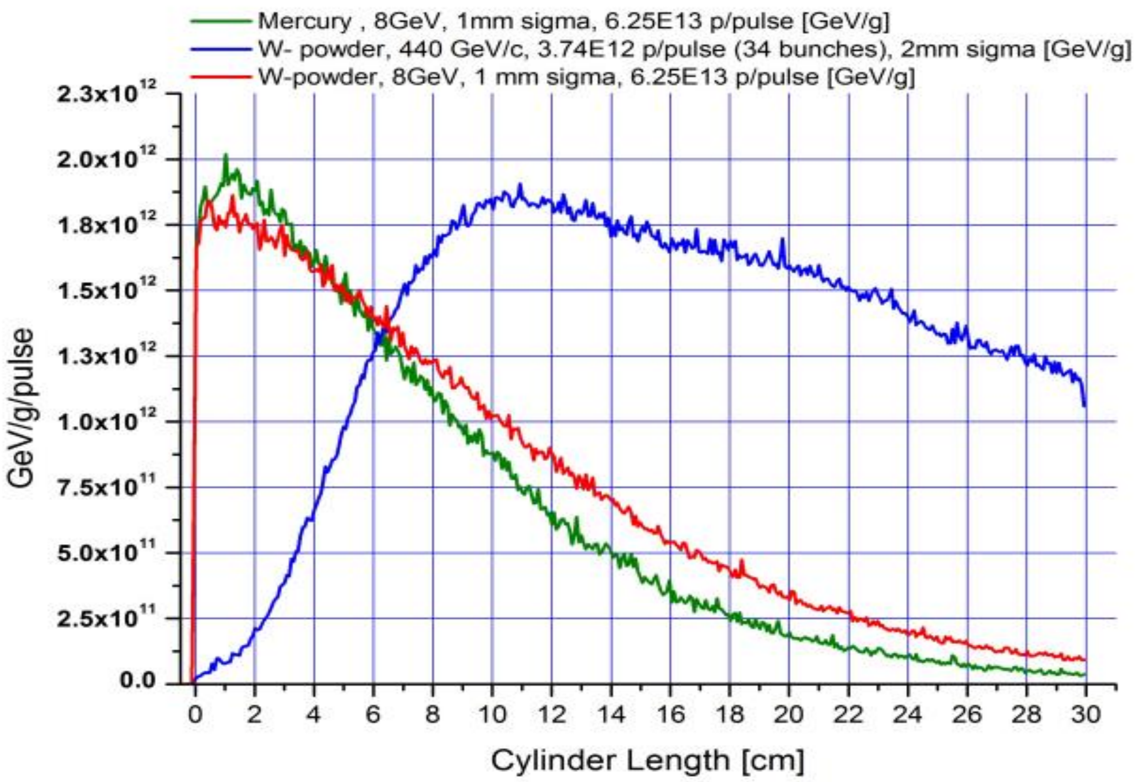
Table 1: Main parameters of the proton driver muon facilities

Parameter	Units	Higgs		Multi-TeV	
CoM Energy	TeV	0.126	1.5	3.0	6.0
Avg. Luminosity	$10^{34}\text{cm}^{-2}\text{s}^{-1}$	0.008	1.25	4.4	12
Beam Energy Spread	%	0.004	0.1	0.1	0.1
Higgs Production/10^7 sec		13'500	37'500	200'000	820'000
Circumference	km	0.3	2.5	4.5	6
No. of IP's		1	2	2	2
Repetition Rate	Hz	15	15	12	6
$\beta^*_{x,y}$	cm	1.7	1	0.5	0.25
No. muons/bunch	10^{12}	4	2	2	2
Norm. Trans. Emittance, ε_{TN}	μm-rad	200	25	25	25
Norm. Long. Emittance, ε_{LN}	μm-rad	1.5	70	70	70
Bunch Length, σ_S	cm	6.3	1	0.5	0.2
Proton Driver Power	MW	4	4	4	1.6
Wall Plug Power	MW	200	216	230	270

Source: Muon collider input for ESPP

An example emulating a multi-MW beam @ HiRadMat

- **Assumption :**
  - **4MW beam e.g :** 50 Hz, 6.25E13 p/pulse, 8 GeV/c, 1 mm sigma @ 30 cm **Mercury**
  - **Compared with :** 34 HiRadMat bunches, 3.74E12 p/pulse, 2 mm sigma @ 30 cm **Tungsten Powder**

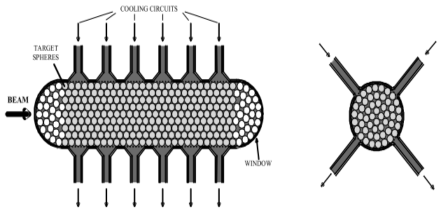


The HiRadMat beam parameters can be ‘tuned’ in order to emulate the same maximum energy density as expected in proposed multi-MW beams, as the one required in a future Muon Collider.

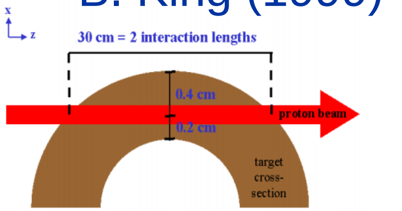
How can we profit from HiRadMat ?

- **Test Novel multi-MW (~4) target systems ?**
  - MERIT experiment (2007) proved that a liquid mercury jet target surrounded by a 20T solenoid could possibly work as a high-power target.
    - Still some open questions on the behaviour of liquid mercury
  - W-powder as alternative ? Two experiments (HRMT-10 and HRMT-22) already gave some hindsights on the dynamics of W powder under the high-power proton beam.
    - Still open questions and ideas of on the table
  - Other novel target ideas ?
  - Extensive Target R&D ongoing at CERN by SY-STI including many HiRadMat experiments

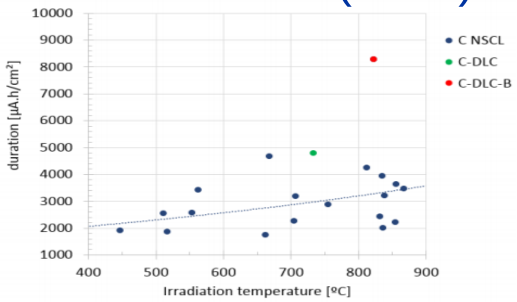
P. Sievers (2001)



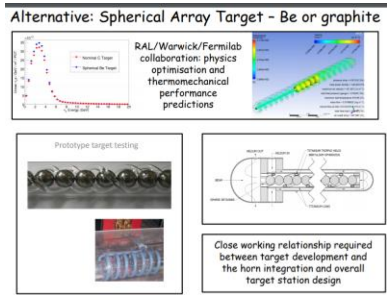
B. King (1999)



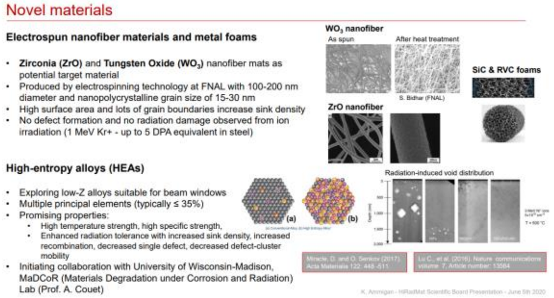
F. Pellemoine (2014)



C. Densham (2016)

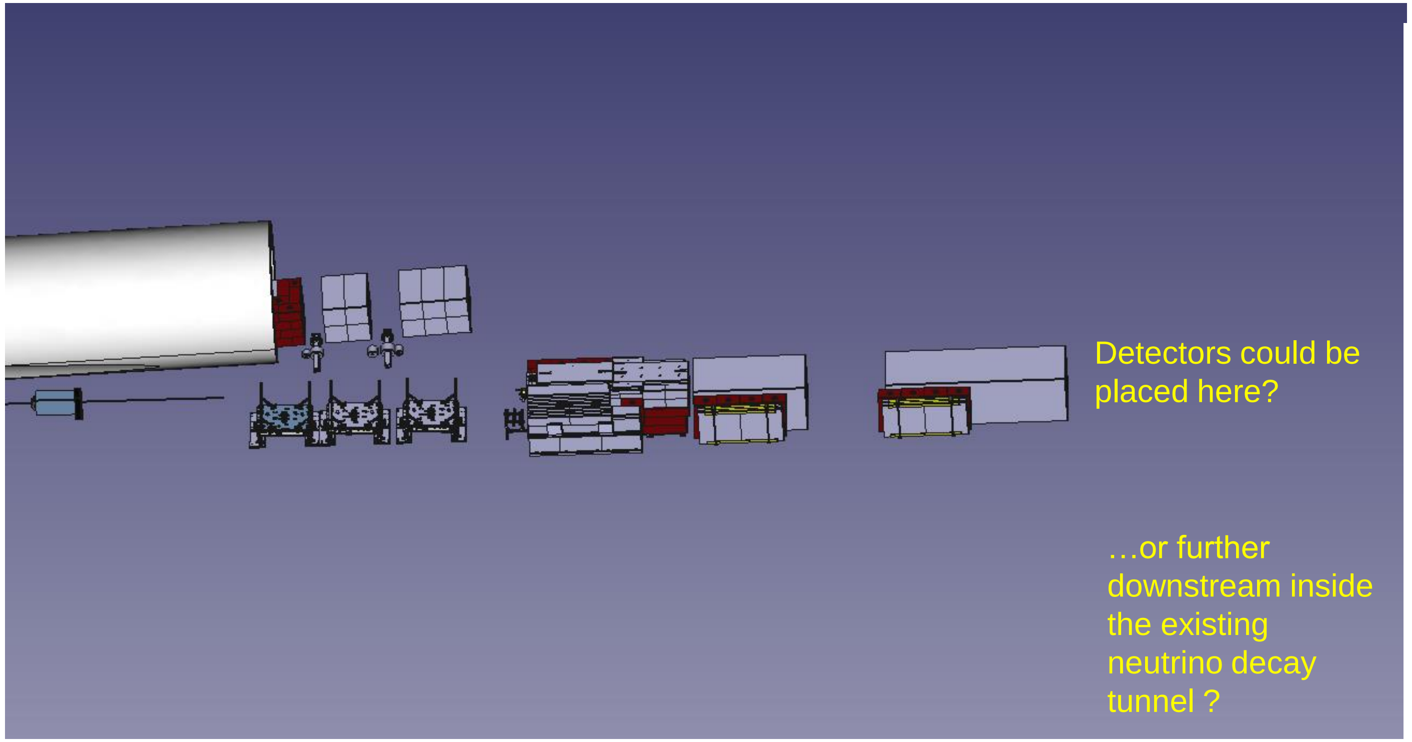


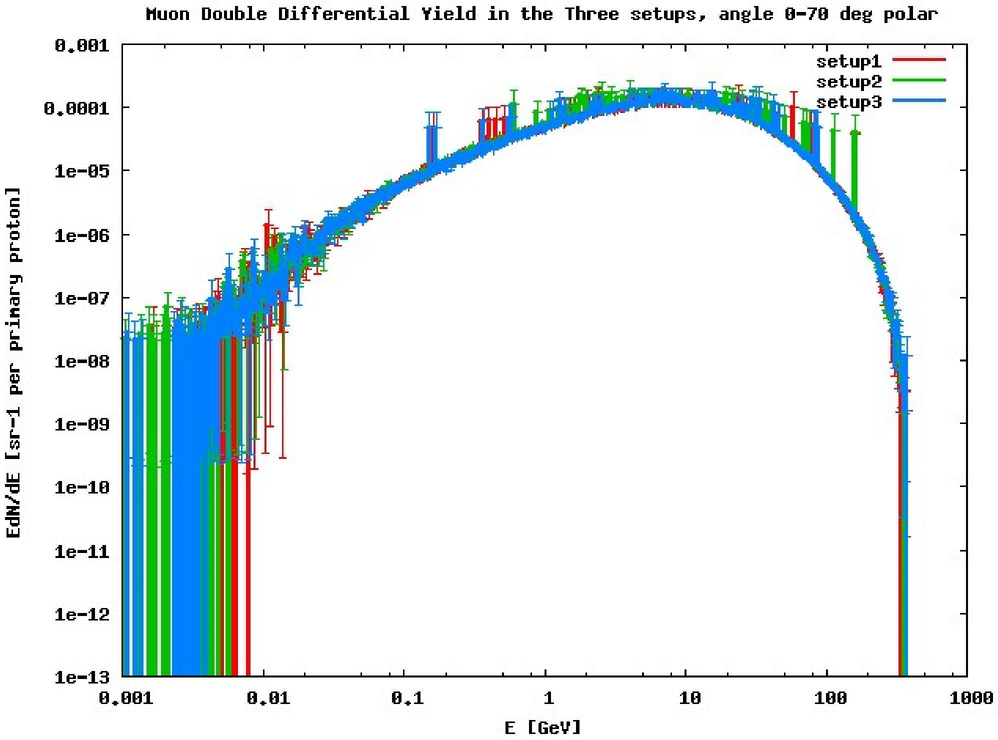
K. Ammigan (2019)



How can we profit from HiRadMat

- **Test detectors or components with very high energy muons ?**

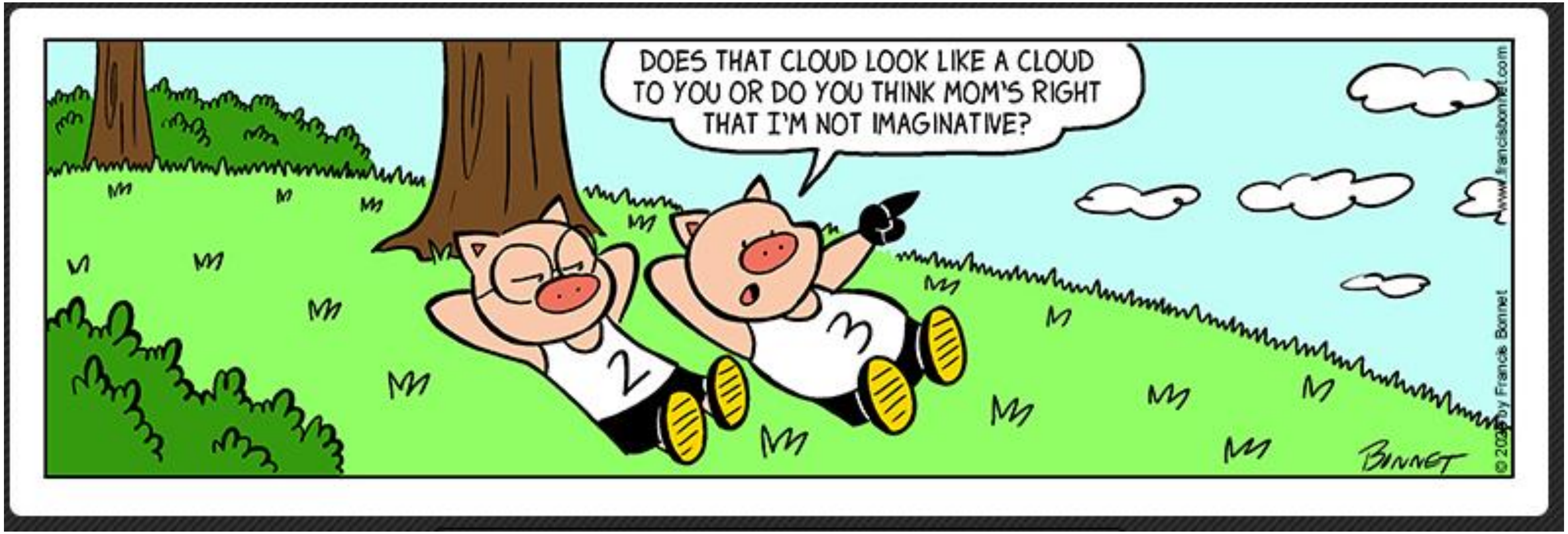




A high muon yield behind the dump could be used ?

Space and muons available for a demonstrator setup – e.g for placing/trying high-field fast-ramping dipoles ?

More ideas – Brainstorming



How we can profit from HiRadMat

- **Lower the monentum ?**
  - If we could have the HiRadMat **bunches** (~3 ns @ +-4σ) @ 24 GeV/c (injection energy) at HiRadMat ...
  - Intrinsicically implies larger proton beam emittance → Lower peak power deposition

Kirk Mc Donald, 2014

Specifications from the Muon Accelerator Staging Scenario

- 6.75 GeV (kinetic energy) proton beam with 3 ns (rms) pulse.
- 1 MW initial beam power, upgradable to 2 MW (perhaps even to 4 MW).
- 60 Hz initial rep rate for Neutrino Factory;
  15 Hz rep rate for later Muon Collider.
- The goal is to deliver a maximum number of soft muons, ~ 40 < KE < ~ 180 MeV.

How we can profit from HiRadMat

- **What about a TeV HiRadMat ?**
  - Talk by W. Bartmann (2016)

NEEDS AND PROSPECTS FOR A HIRADMAT-LIKE FACILITY IN THE HL-LHC AND FCC ERA

W. Bartmann, C. Bracco, F. Burkart, M. Fraser, B. Goddard, A. Lechner

HiRadMat USER DAY 2016, 28th June

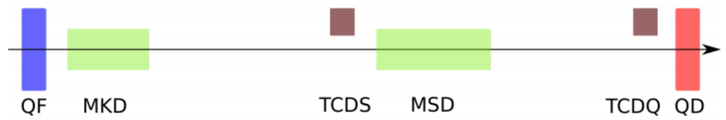
Prospects for TeV range facilities

- FCC injector possibilities

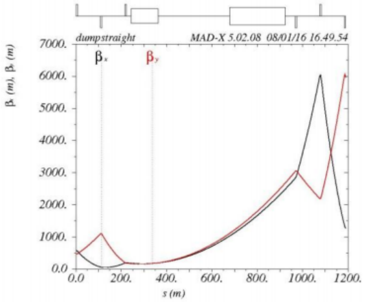
	LHC x5	HEB@SPS	HEB@FCC
Energy	3.3 TeV (1-6.5)	1.5 TeV	3.3 TeV (1-5.5)
FCC filling time	40 min	34 min	29 min

- Baseline parameters for the FCC injectors include the possibility of a fixed target program with slow extraction
- Extension for HiRadMat facility 'relatively' straight forward – add a fast extraction system/switching magnets/tunnels/galleries – but have to be aware that such a facility compares to the present LHC dump in terms of safety and machine protection requirements

FCC needs for HiRadMat Facility



- Design of FCC dump system is driven by absorber limits
  - 750 m drift between quads
  - Faster kicker systems (3 us -> 1 us)
  - High beta functions at absorbers



Certainly the muon collider R&D could profit from such an endeavor ?

Summary

- **HiRadMat facility is serving the applied physics community since 10 years, with great success, being flexible and adapting to a great variety of possible setups.**

- **Is the ideal place @ CERN to perform high-energy, high intensity single pulse experiments, either on targets, or accelerator components, or new technologies in general.**

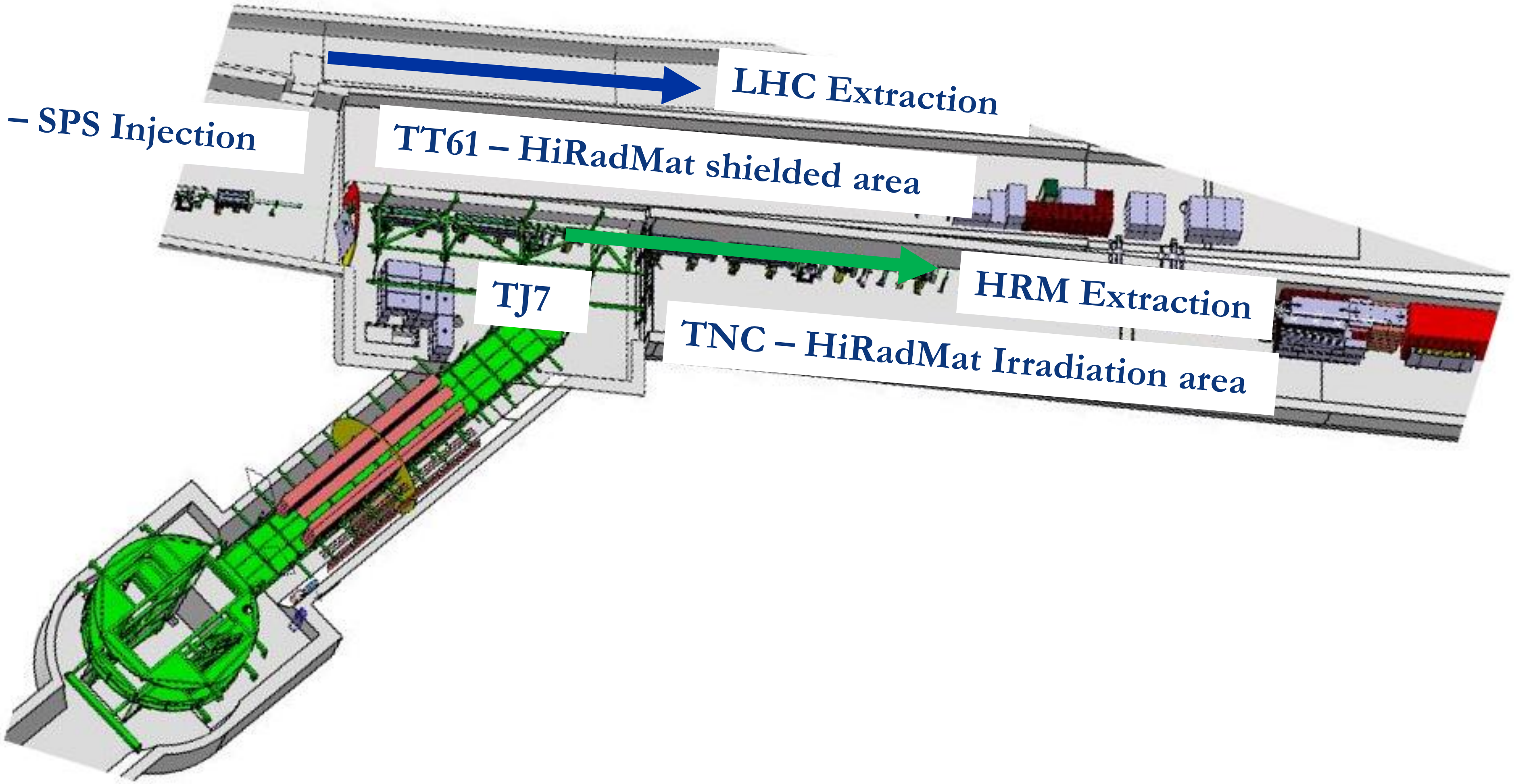
- **The beam properties and infrastructure can be used to do proof-of-principle experiments for a muon collider R&D, both in the target as well as in the detector side.**

A big thank you to all the groups along the ATS sector for their dedication and help in the operation of HiRadMat facility since 2011!

SY-STI EN-MME SY-BI BE-ASR TE-MPE BE-GM BE-CEM HSE-RP SY-ABT BE-OP EN-HE BE-EA

Layout


LHC
HiRadMat


TCC6 – SPS Injection
LHC Extraction
TT61 – HiRadMat shielded area
TJ7
HRM Extraction
TNC – HiRadMat Irradiation area

Highlights of past experiments

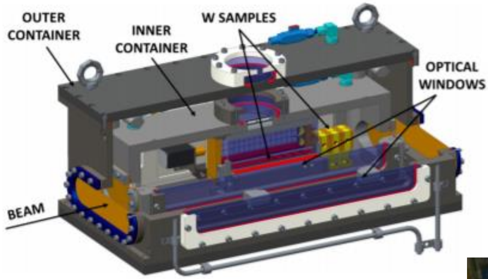
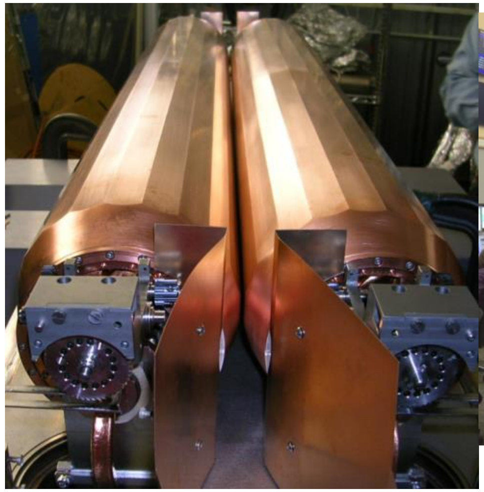
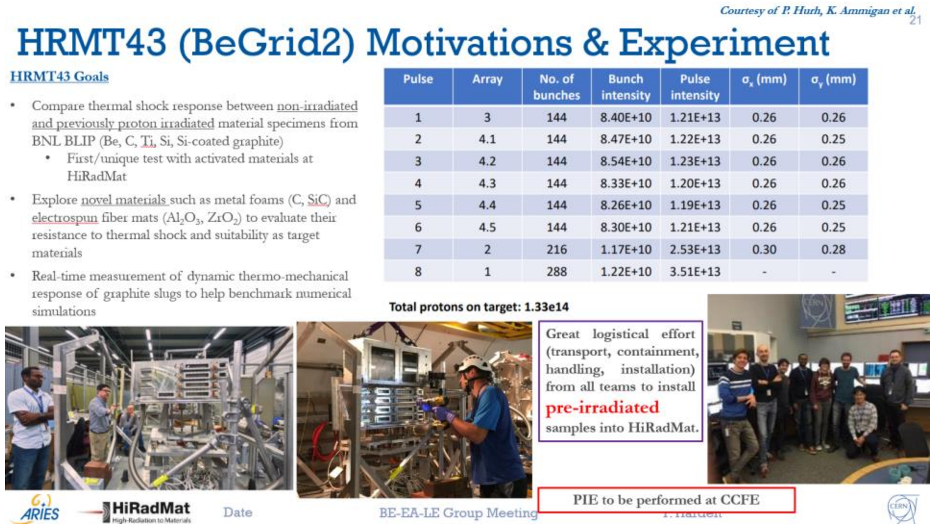


FIG. 2. Section drawing of the tungsten powder rig.

HRMT-10



HRMT-21



Courtesy of P. Hurh, K. Ammigan et al.

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HRMT43 (BeGrid2) Motivations & Experiment

HRMT43 Goals

- Compare thermal shock response between non-irradiated and previously proton irradiated material specimens from BNL BLIP (Be, C, Ti, Si, Si-coated graphite)
  - First/unique test with activated materials at HiRadMat
- Explore novel materials such as metal foams (C, SiC) and electrospun fiber mats (Al_2O_3, ZrO_2) to evaluate their resistance to thermal shock and suitability as target materials
- Real-time measurement of dynamic thermo-mechanical response of graphite slugs to help benchmark numerical simulations

Pulse	Array	No. of bunches	Bunch intensity	Pulse intensity	σ_x (mm)	σ_y (mm)
1	3	144	8.40E+10	1.21E+13	0.26	0.26
2	4.1	144	8.47E+10	1.22E+13	0.26	0.25
3	4.2	144	8.54E+10	1.23E+13	0.26	0.26
4	4.3	144	8.33E+10	1.20E+13	0.26	0.26
5	4.4	144	8.26E+10	1.19E+13	0.26	0.25
6	4.5	144	8.30E+10	1.21E+13	0.26	0.25
7	2	216	1.17E+10	2.53E+13	0.30	0.28
8	1	288	1.22E+10	3.51E+13	-	-

Total protons on target: 1.33e14

Great logistical effort (transport, containment, handling, installation) from all teams to install **pre-irradiated** samples into HiRadMat.

PIE to be performed at CCFE

ARIES HiRadMat High-Radiation to Materials Date BE-EA-LE Group Meeting