AIDA-2020-SLIDE-2016-016

AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators

Presentation

IRRAD: The New 24GeV/c Proton Irradiation Facility at CERN, Submitted for Proc. Twelfth International Topical Meeting on Nuclear Applications of Accelerators (AccApp'15)

F. Ravotti (CERN) *et al*

10 November 2015

The AIDA-2020 Advanced European Infrastructures for Detectors at Accelerators project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

This work is part of AIDA-2020 Work Package **15: Upgrade of beam and irradiation test infrastructure**.

IRRAD
The New 24GeV/c Proton Irradiation Facility at CERN

*Blerina Gkotse, Maurice Glaser, Michael Moll, **Federico Ravotti***
CERN PH/DT, IRRAD Facility Team

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

Outline

- Need for Proton Irradiation Facility & Phase II Requirements
- PS East Area Irradiation Facilities until 2012
- New PS East Area Irradiation Facilities from 2014
  - Proton Facility (IRRAD)
  - Mixed-Field Facility (CHARM)
- IRRAD Proton Facility Infrastructure & Equipment
- Beam Characterization & Dosimetry Measurements
- Summary

Proton Irradiation Facility: what for?

- **Radiation damage studies on:**
  - **materials** used around accelerators/experiments
    - structural material, glues, pipes, insulations, thermal materials, …
  - **electronic components**
    - transistors, memories, COTS, ASIC, …
  - **semiconductor** and **calorimetry** devices
    - silicon diodes, detector structures, scintillating crystals …
    - **equipment sitting in the inner/middle layers of HEP experiments**
- **Test and development of prototypes / final assemblies / electronics equipment before installation:**
  - performance **degradation after long exposure**/ageing (TID, NIEL, …)
  - functional **degradation of electronics** (SEU, latch-up, …)
- **Test and calibration of components:**
  - **dosimeters**, radiation monitoring / measurement devices

HL-LHC Upgrade Requirements

❑ Radiation levels for LHC Experiments phase II upgrade (2025)

Max expected hit rates and integrated charges

Numbers refer to the hottest regions extrapolating the behavior of the present systems

	ATLAS				CMS			LHCb		ALICE	
Lumi	CSC	MDT	RPC	TGC	CSC	DT	RPC	Lumi	MWPC	Lumi Pb-Pb	RPC
$7\times10^{33} cm^{-2}s^{-1}$ 25 fb^{-1}	20	10	3	21	3	0.1	3	$4\times10^{32} cm^{-2}s^{-1}$ 3 fb^{-1}			
	770	280	13	100	170	2	14				
$1\times10^{34} cm^{-2}s^{-1}$ 100 fb^{-1}	80	40	11	84	12	0.35	12	$4\times10^{32} cm^{-2}s^{-1}$ 8 fb^{-1}			
	1100	400	18	140	250	3	20				
$3\times10^{34} cm^{-2}s^{-1}$ 350 fb^{-1}	280	140	38	280	41	1.2	42	$1\times10^{33} cm^{-2}s^{-1}$ 23 fb^{-1}			
	3300	1200	54	430	750	9	60				
$7\times10^{34} cm^{-2}s^{-1}$ 3000 fb^{-1}	2400	1200	330	2450	350	10	360	$2\times10^{33} cm^{-2}s^{-1}$ 46 fb^{-1}			
	7700	2800	130	1000	1700	20	140				

Additional tests needed on some detectors to assess their behavior during all HL-LHC → Common test facility

9 P. Iengo - Muon longevity - ECFA HL-

© P. Iengo (ECFA HL-LHC 2013)

outer (muon) detectors:
γ–BKGD ~𝒪(10) w.r.t. LHC

Crosscheck with ATLAS Phase II LOI

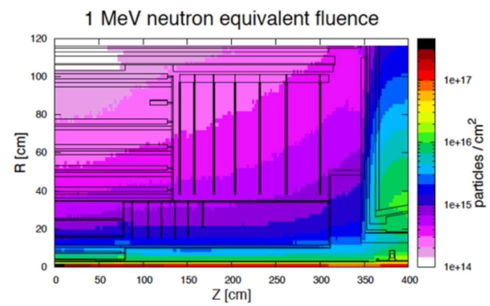


Figure 6.2: *RZ*-map of the 1 MeV neutron equivalent fluence in the Inner Tracker region, normalised to 3000 fb^{-1} of 14 TeV minimum bias events generated using PYTHIA8.

$3000\ fb^{-1}$
80mb inelastic pp crossection
2.4×10^{17} events
$dN/d\eta = N_0=5.4$ at 14 TeV
Pixel layer1 at r=3.7cm

$1MeV_{neq}$ Fluence =
$2.4\times10^{17}*5.4/(2*\pi*3.7^2)$ =
$1.5\times10^{16}\ cm^{-2}$

Dose = $3.2\times10^{-8}*1.5\times10^{16}$ =
4.8MGy

Layer	Occupancy with 200 pile-up events (%)				
	Radius mm	Barrel (z = 0 mm)		Z mm	Endcap
Pixel: layer 0	37	0.57	Disk 0	710	0.022– 0.076

The predictions for the maximum 1MeV-neq fluence and ionising dose for $3000 fb^{-1}$ in the pixel system is $1.4 \times 10^{16} cm^{-2}$ and 7.7 MGy at the centre of the innermost barrel layer. For the

04/06/2014 W. Riegler, CERN 23

© W. Riegler (TIPP 2014)

inner detectors (trackers):
> $10^{16}\ 1MeV_{neq}/cm^2$

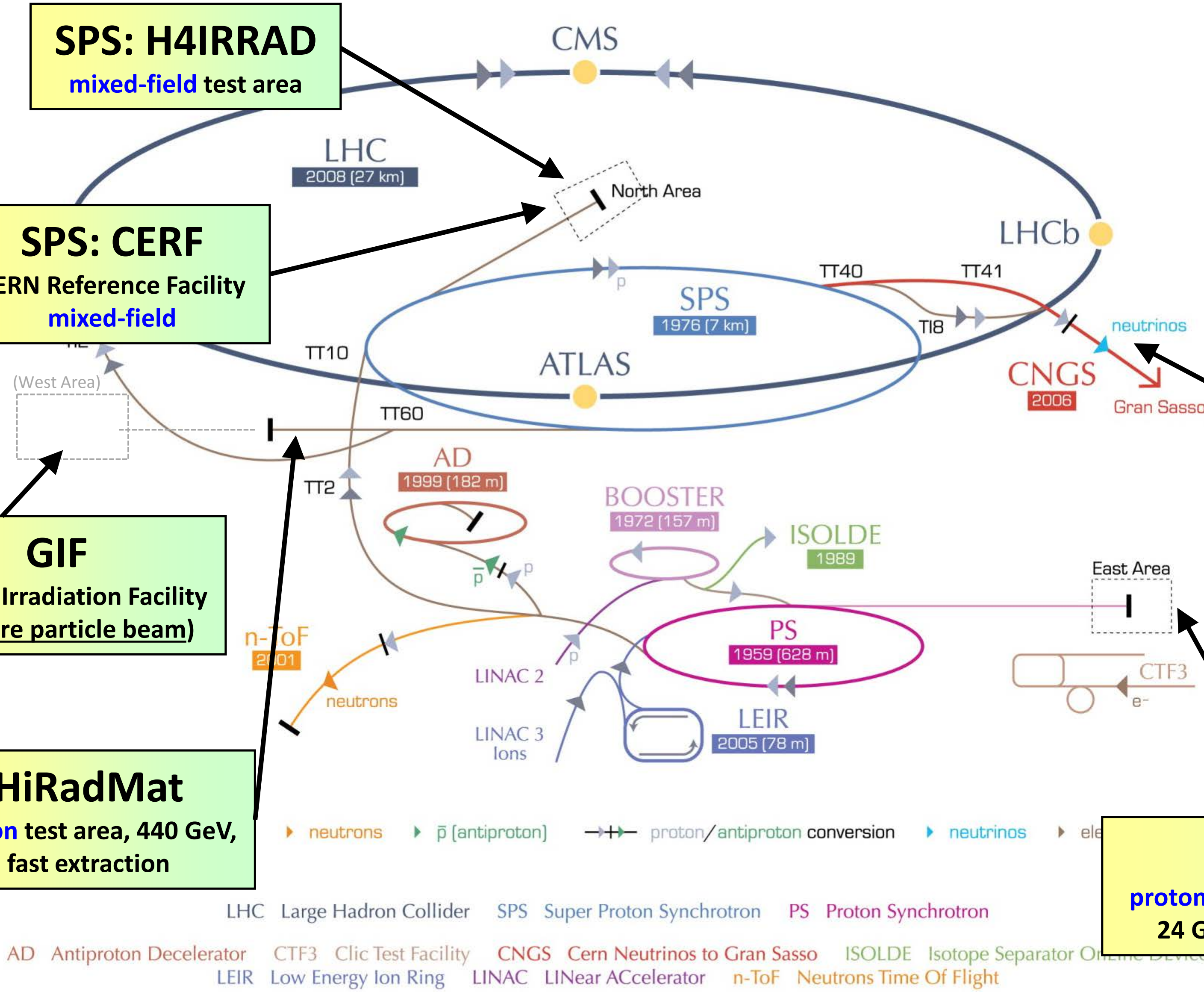
CERN Irradiation Facilities until 2012

SPS: H4IRRAD
mixed-field test area

SPS: CERF
CERN Reference Facility
mixed-field

GIF
Gamma Irradiation Facility
(no more particle beam)

HiRadMat
proton test area, 440 GeV,
fast extraction



Proton Energy

LHC	4 TeV
SPS	450 GeV
PS	23 GeV
PSB	1.4 GeV
Linac	50 MeV

CNRAD
mixed-field test area
(parasitic operation)

PS: IRRAD
proton & mixed-field facilities,
24 GeV/c, slow extraction

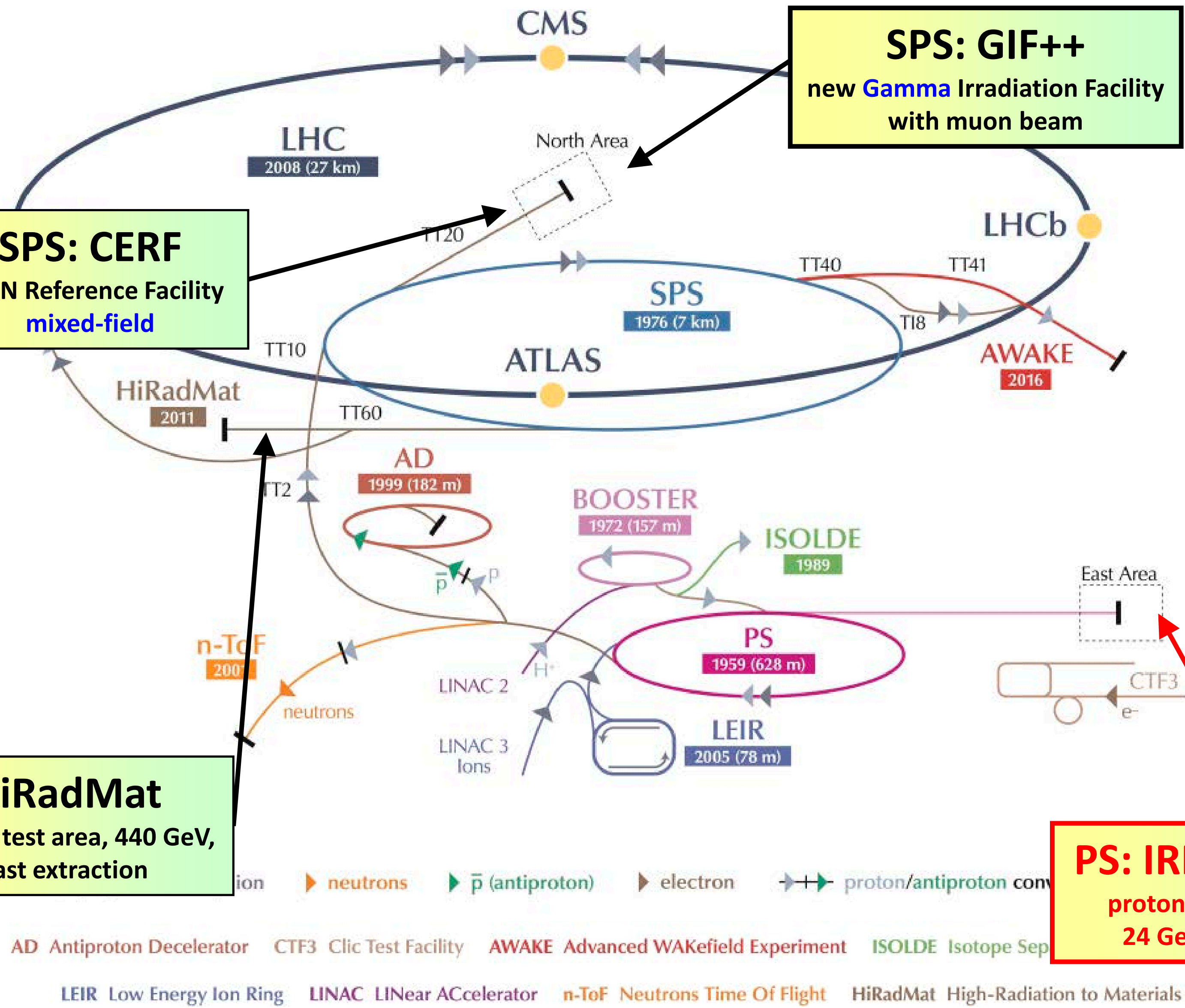
CERN Irradiation Facilities from 2014

SPS: GIF++
new Gamma Irradiation Facility with muon beam

SPS: CERF
CERN Reference Facility
mixed-field

HiRadMat
proton test area, 440 GeV, fast extraction

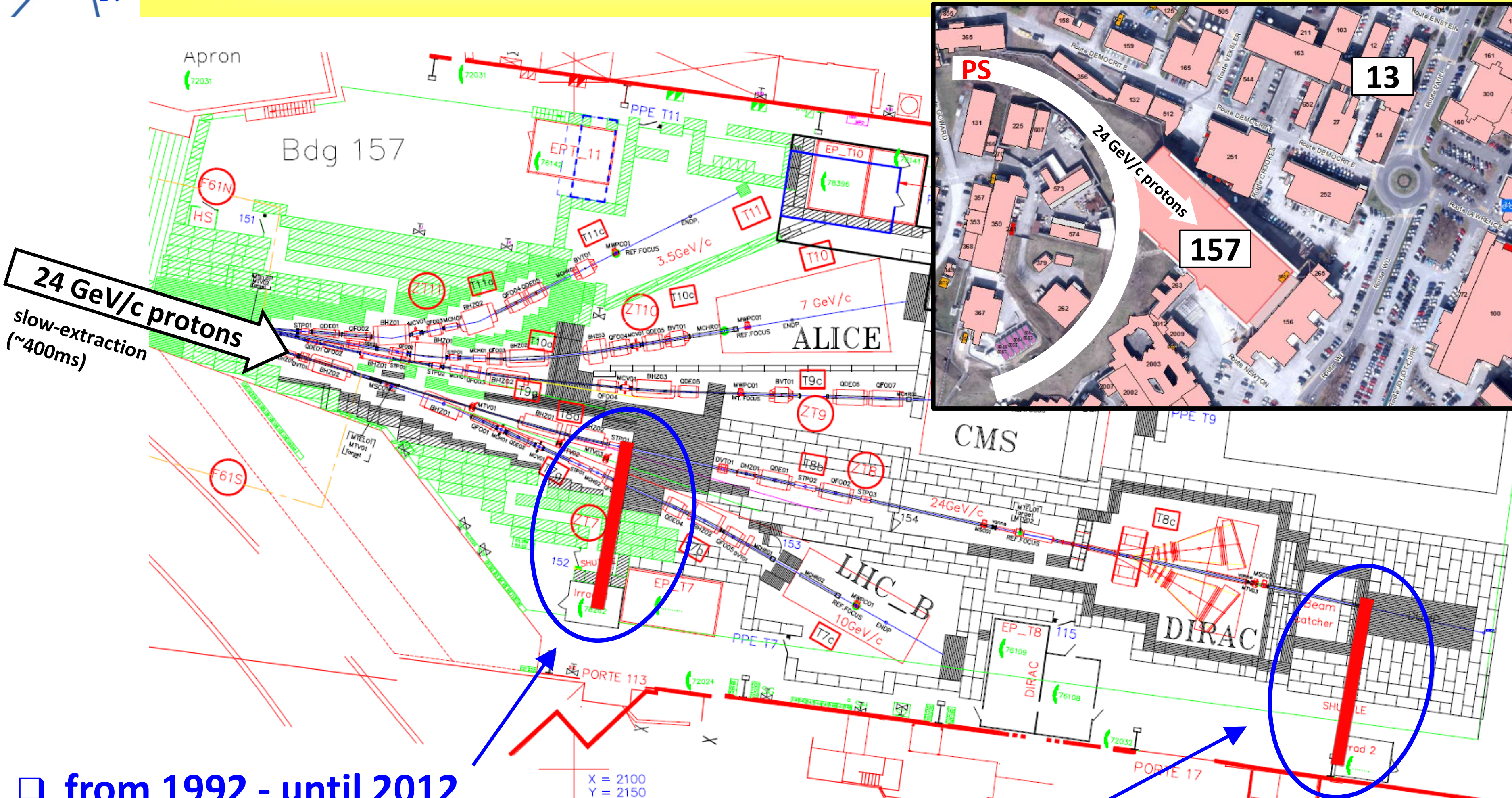
PS: IRRAD & CHARM
proton facility & mixed-field
24 GeV/c, slow extraction



Proton Energy

LHC	7 TeV
SPS	450 GeV
PS	23 GeV
PSB	1.4 GeV
Linac	50 MeV

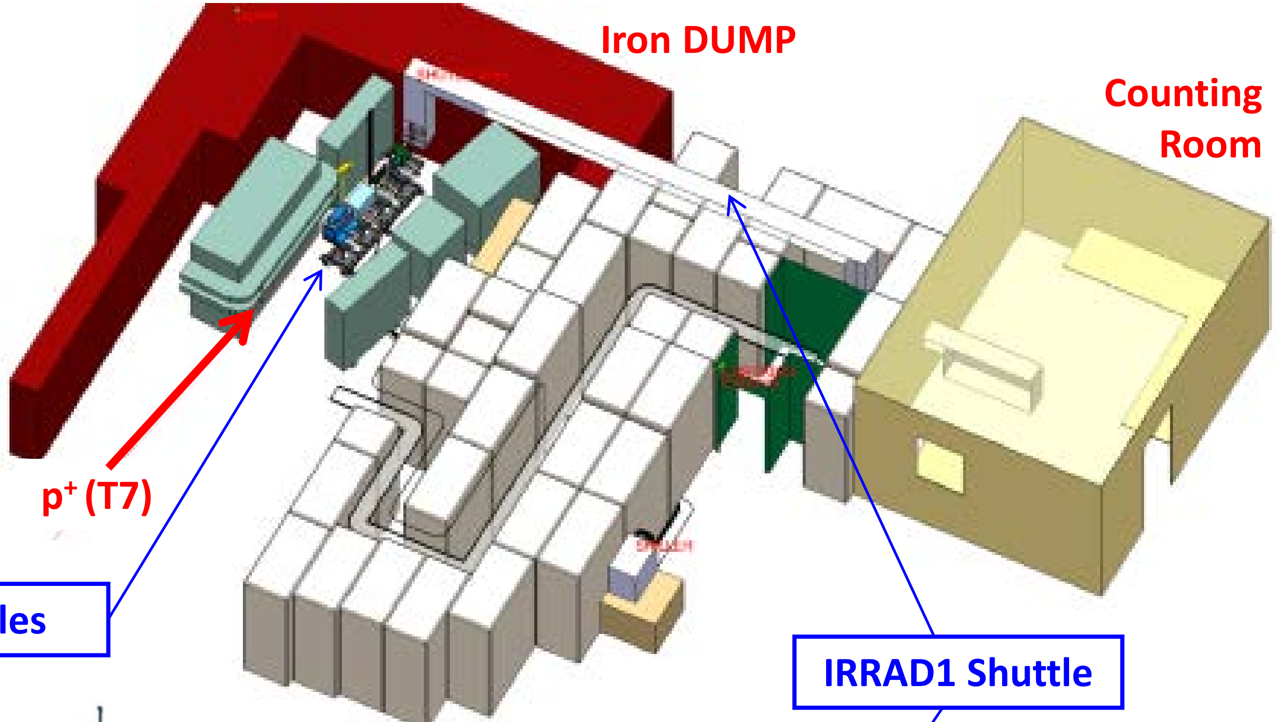
PS-EA Irradiation Facilities until 2012



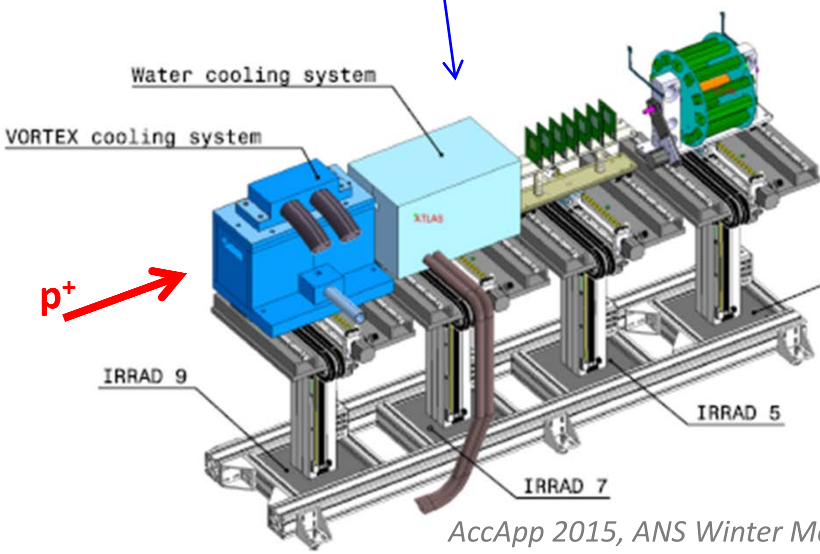
- from 1992 - until 2012
- Proton irradiations (T7)
  - **Primary 24 GeV/c proton beam** (IRRAD1, IRRAD3, IRRAD5, …)
- Mixed-field irradiations (T8)
  - **Mixed field produced in cavity** after **C** (50cm) - **Fe** (30cm) - **Pb** (5cm) **'target'** (IRRAD2)

Proton Irradiation Facility (2012)

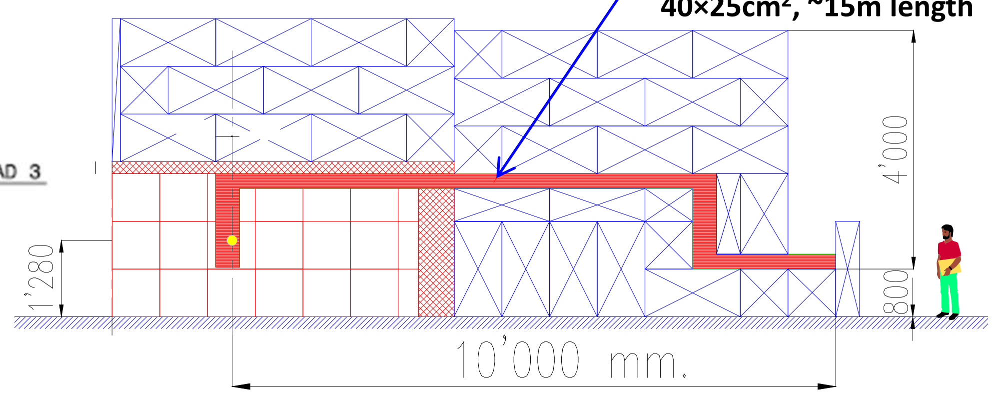
- **Beam spot**
  12×12 mm^2 (FWHM)
- **Beam momentum**
  24 GeV/c
- **Proton flux**
  ~1×10^{16} p cm^{-2} $20days^{-1}$
  (year average)



IRRAD3, IRRAD5, … Tables



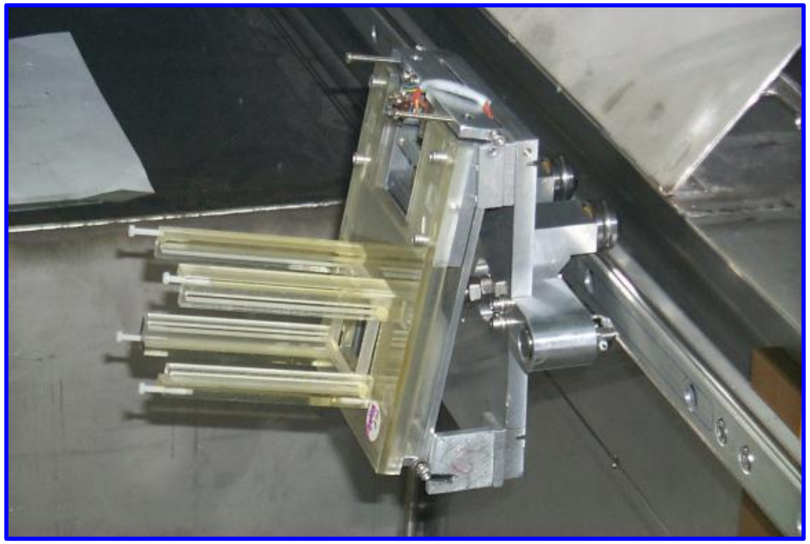
IRRAD1 Shuttle

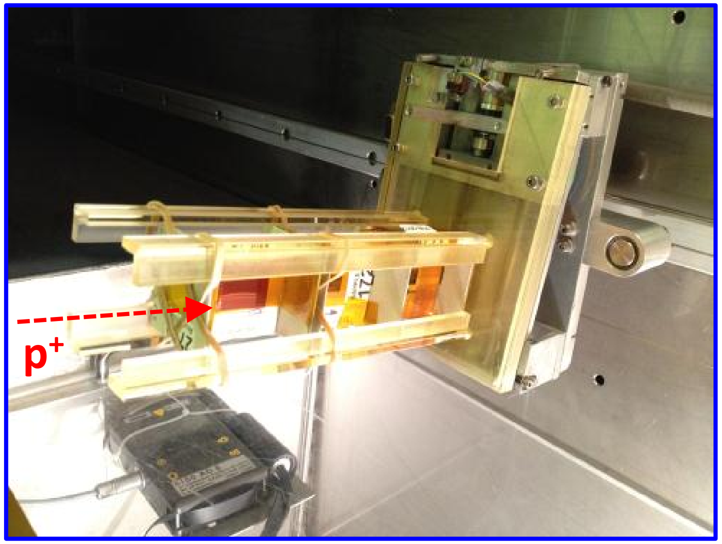


IRRAD1 Shuttle & IRRADx Tables

IRRAD1 Shuttle

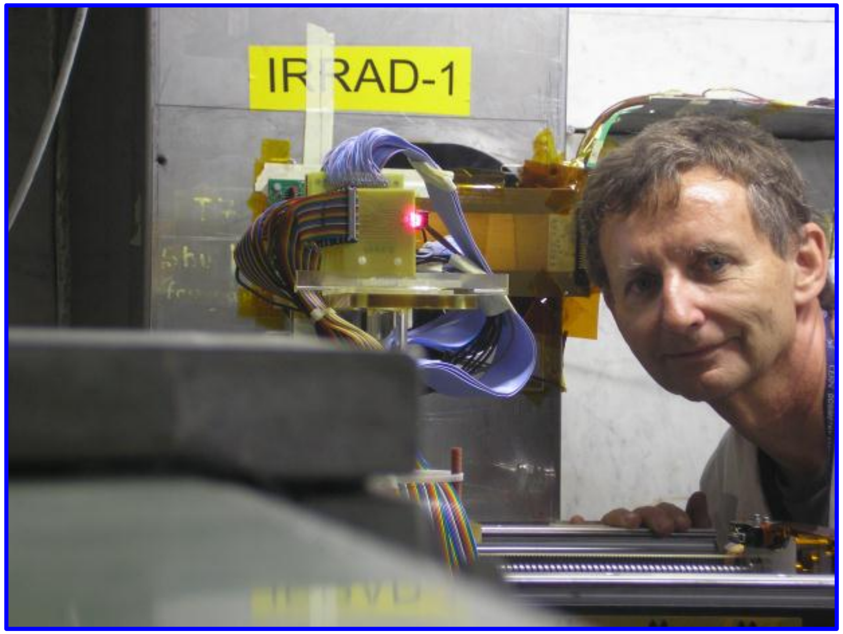
«small» samples

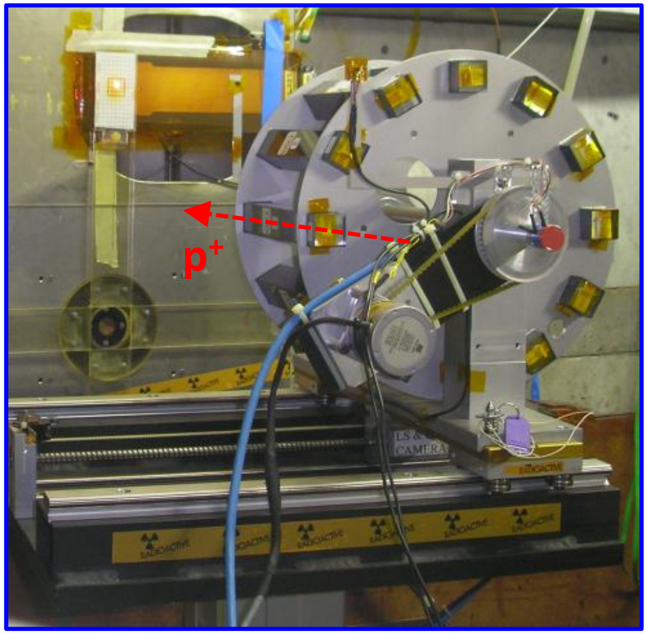




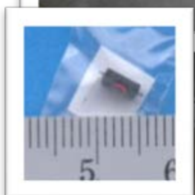
IRRAD3 & IRRAD7 Tables

«big» experimental setups

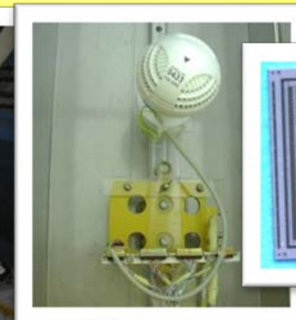
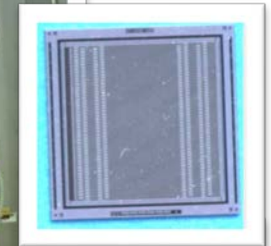




Irradiation Experiments

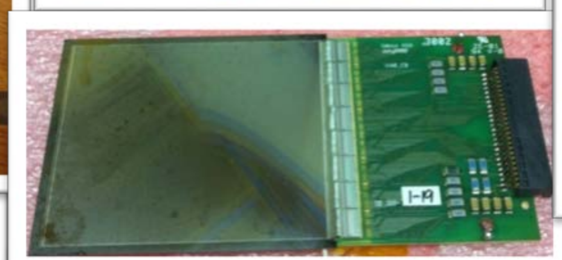






- **Former IRRAD facilities in numbers ...**
  - from **1999** to **2012** (no beam in 2005)
  - more than **8300** "pieces" irradiated (**~650 per year**)!
  - about **5800** dosimeters (Al foils) measured!



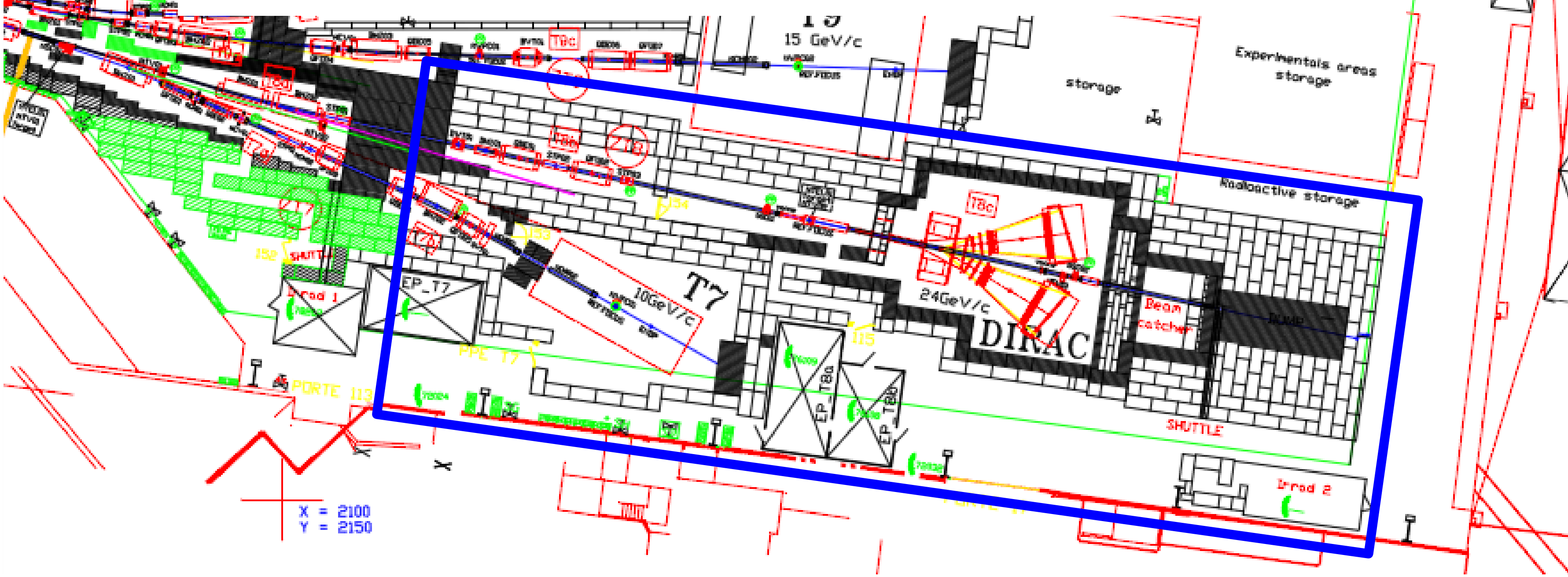




© IRRAD user community!

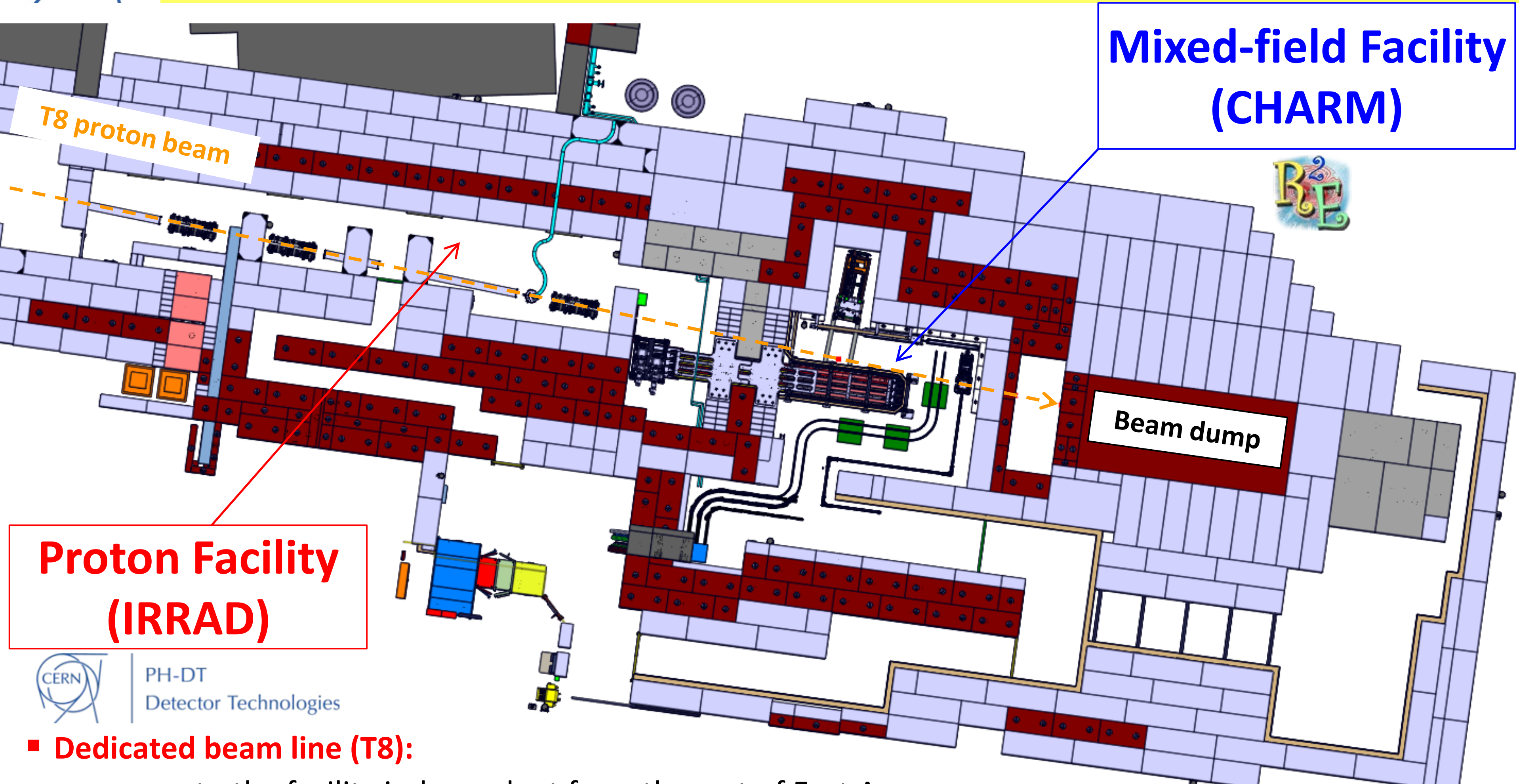
Towards a New Combined EA Facility

- **2012: CERN management agrees on East Area Facilities upgrade**
  - 19 Nov. 2012: first technical meeting on upgrade
  - 26 Nov. 2012: last day of operation for the DIRAC experiment
  - July 2013: dismantling DIRAC & old IRRAD1 and IRRAD2 Facilities
  - Nov. 2013: removal of IRRAD2 target & beginning of construction
  - 10 Oct. 2014: first pilot beam in the new EA facility for commissioning
- **17 Nov. 2014: first irradiation experiments in the new IRRAD!**



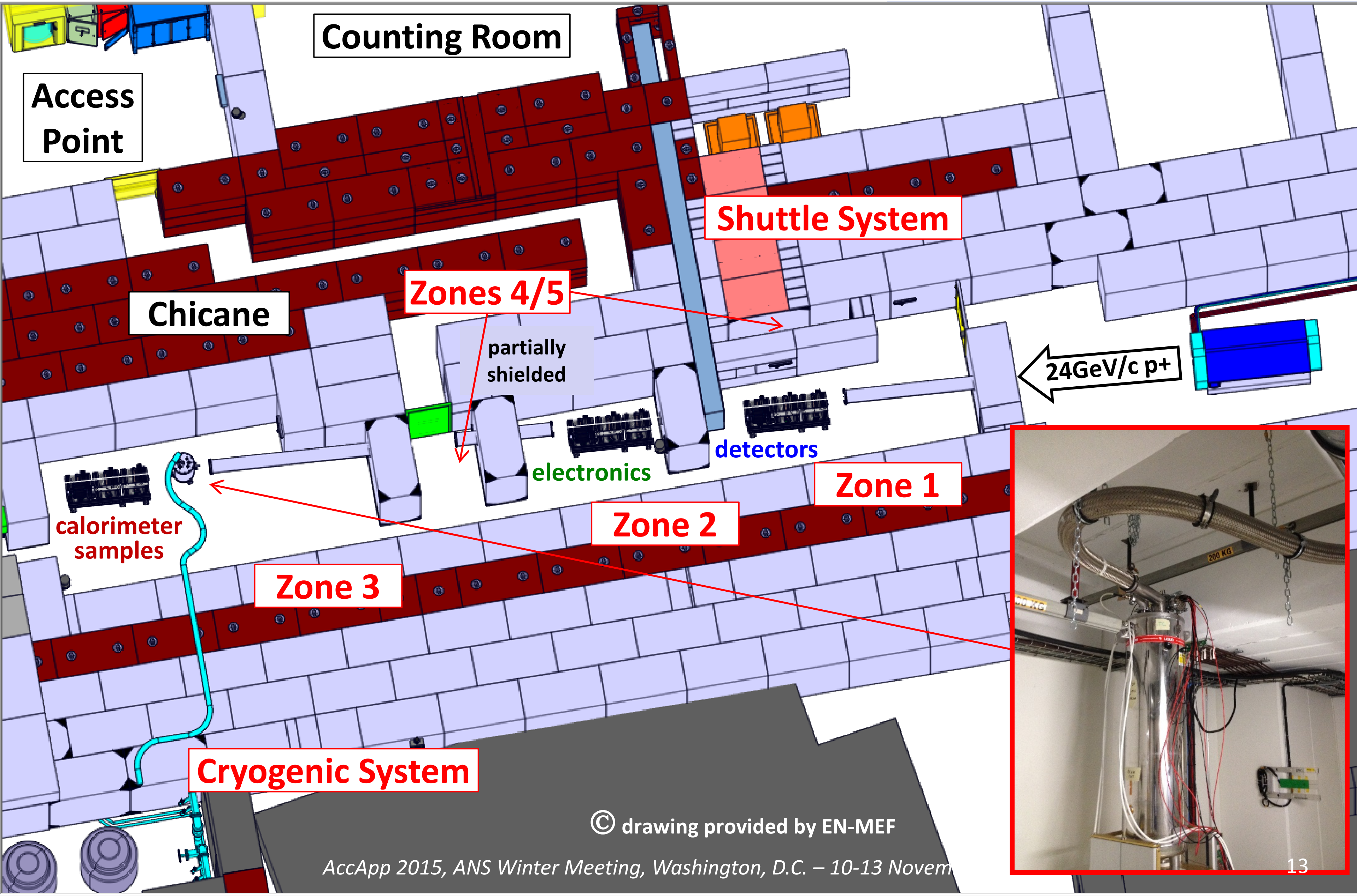
EA-IRRAD upgrade project: ***Joint effort of many CERN groups***. ***PH-DT, EN-MEF, EN-STI*** *(core teams),* ***HSE*** *and* ***EN-HDO*** *(Project Safety),* ***DGS-RP***, ***EN-CV*** *(ventilation),* ***EN-HE*** *(transports),* ***GS-ASE*** *(access control),* ***BE-BI*** *and* ***TE-CRG*** *(IRRAD cryogenic system), …*

New East Area Facilities Layout



- **Dedicated beam line (T8):**
  - access to the facility independent from the rest of East Area
  - serving two facilities → improved PS cycle economy **= increased beam availability!**
- **Optimised layout:**
  - shielding, ventilation, more space for installation and handling of samples, etc. (**= improved safety!**)

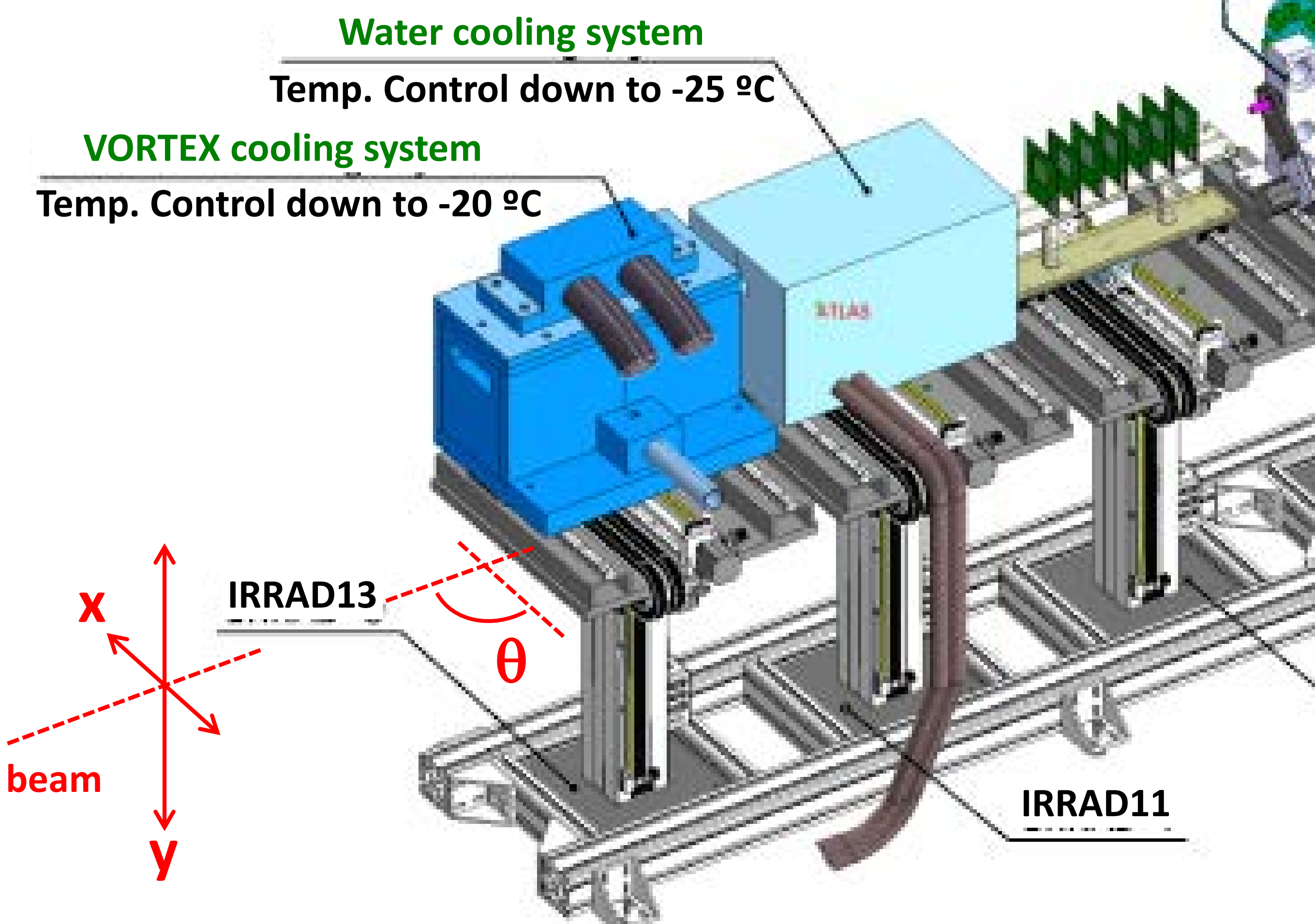
New IRRAD Proton Facility



© drawing provided by EN-MEF

IRRADx Remote-Controlled Tables

- DUTs powered and cooled
- V_{max} = 20×20×50cm³ (standard); «scanning» over surface

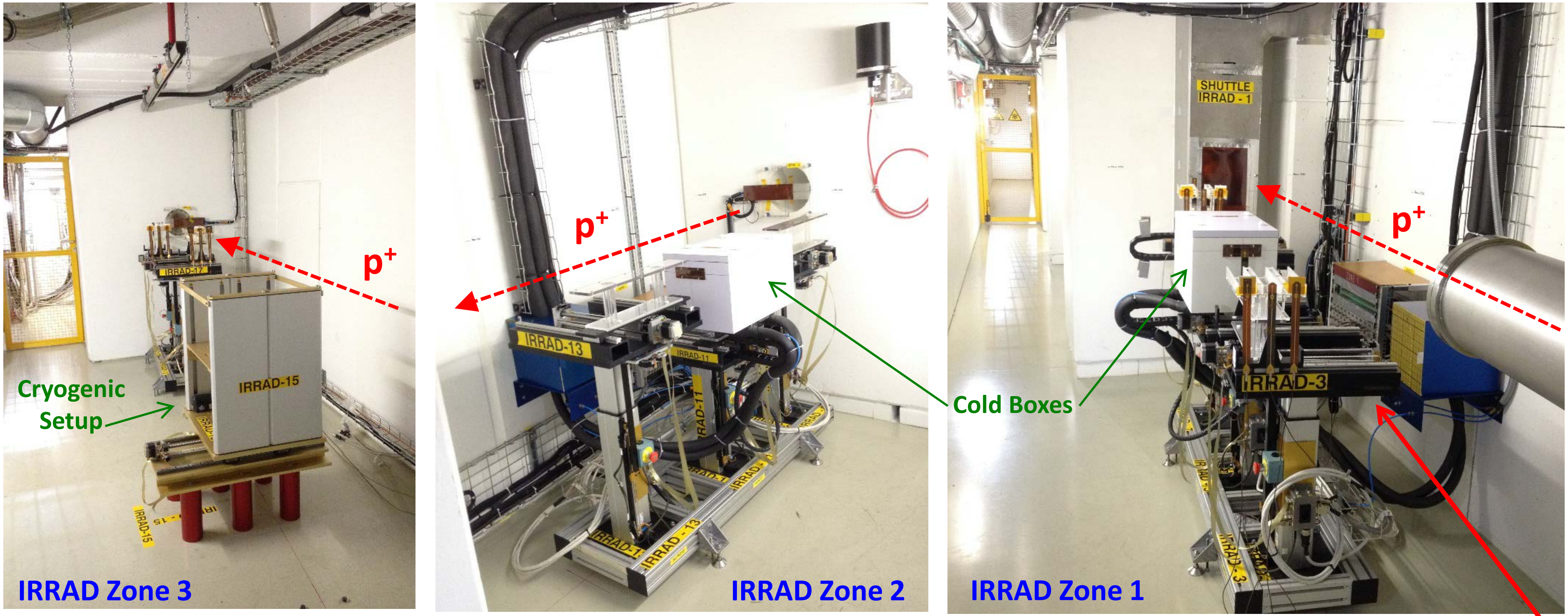



Control Unit


Irradiation Table

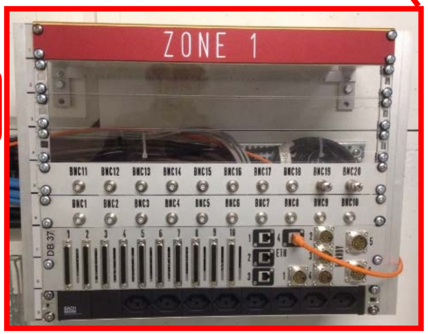
- stand-alone control unit (users) + software applications

IRRAD Zones Equipment



- ❑ **3 tables per IRRAD zone**
  - **9 irradiation tables operational from Oct. 1st 2015**
    - 6x RT irradiation (*IRRAD 3,7,9,13,17,19*)
    - 2x water-cooled cold boxes down to -25°C (*IRRAD 5,11*)
    - 1x dedicated to the cryogenic setup (*IRRAD 15*)

Cables length from ~13m to ~20m



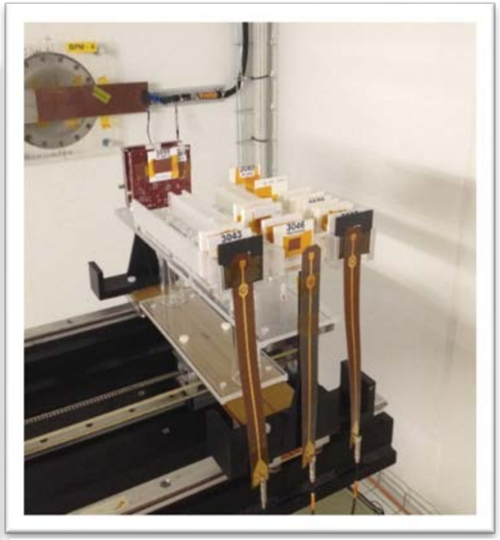
- ❑ **Pre-installed cabling infrastructure**

- **4 Patch-Panels** installed along IRRAD
  - twisted-pairs, coaxial, power HV/LV, …
- space for **custom user-cabling**
  - optical fibers, etc..

Cold & RT Irradiation Experiments

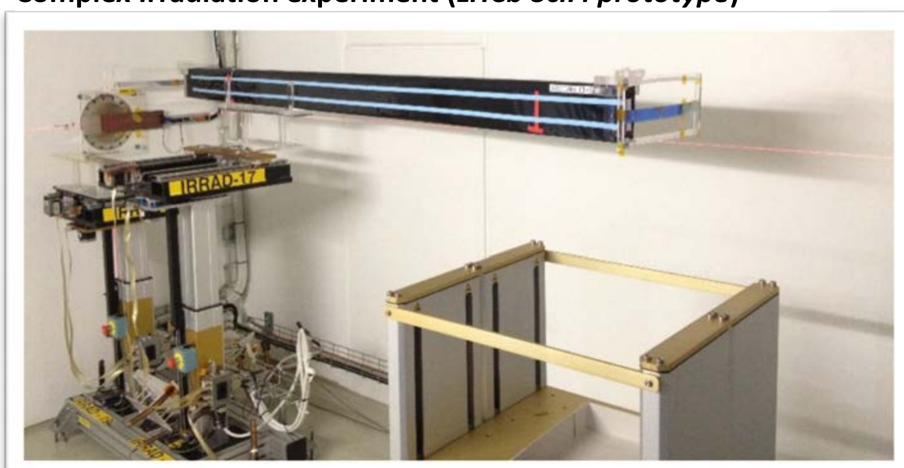
❑ RT Irradiation Setup

Users-made supports



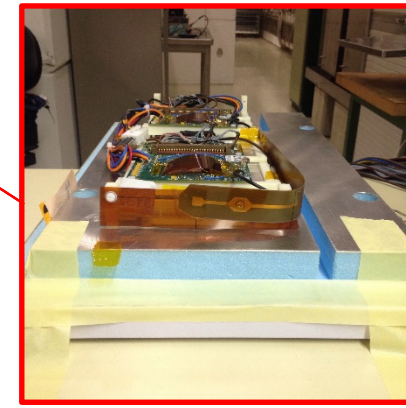
Small samples support (cardboards)

Complex Irradiation experiment (*LHCb SciFi prototype*)

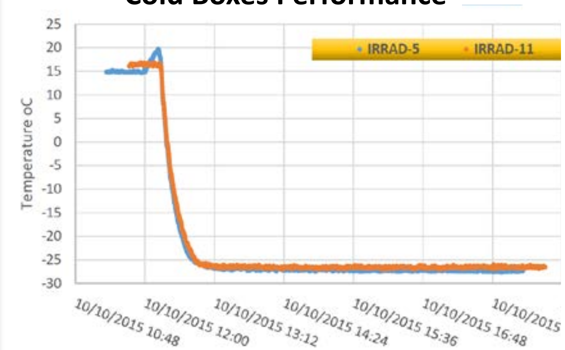


❑ Cold boxes from AIDA (QMUL/Sheffield, UK)

DUTs installed under the box cover lid



Cold Boxes Performance

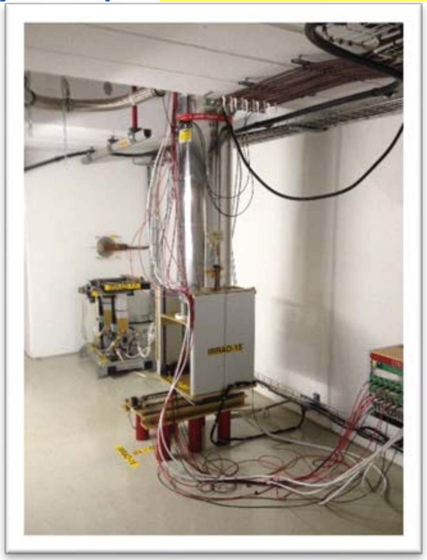


Chiller Units
Thermo-fluid: *SilOil*

IRRAD1 Shuttle System

- V_{max}=5×5×15cm^3 (passive samples on «cardboards» or PCBs)
- Possibility to irradiate samples under bias

Cryogenic Setup IRRAD15



Picture: Nov. 2015

- Setup for irradiation in cryogenic conditions (1.8K/4.2K) with L-He
  - Main user "*CryoBLM experiment*" (BE-BI)
  - Transfer line "embedded" in IRRAD shielding

Samples Holder

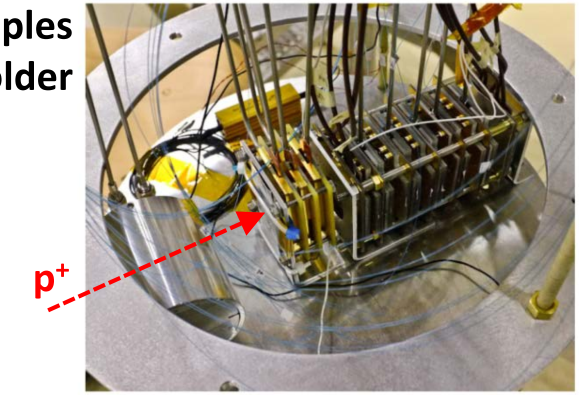
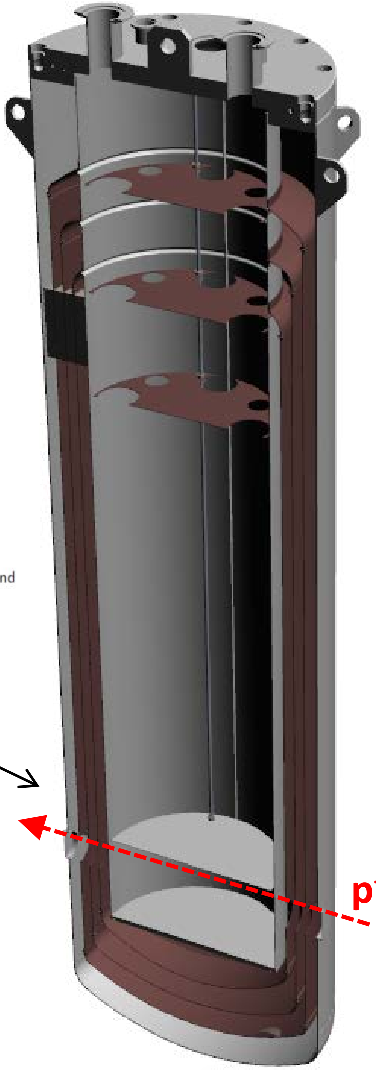
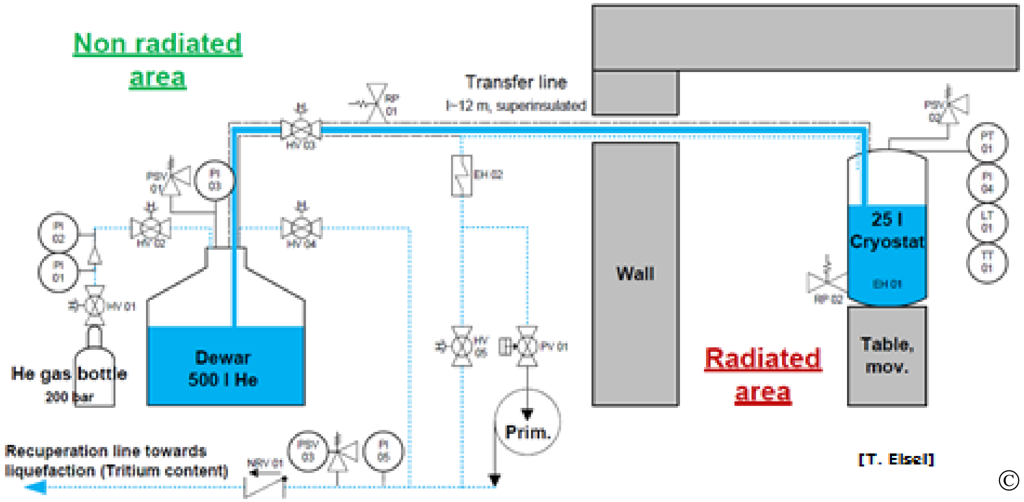


Figure 6.16: Detector modules mounted on the support plate and ready for cooling down and irradiating.



- P&I Diagram
  - Manual refilling
  - Temperatures between 1.8 K and 4.2 K



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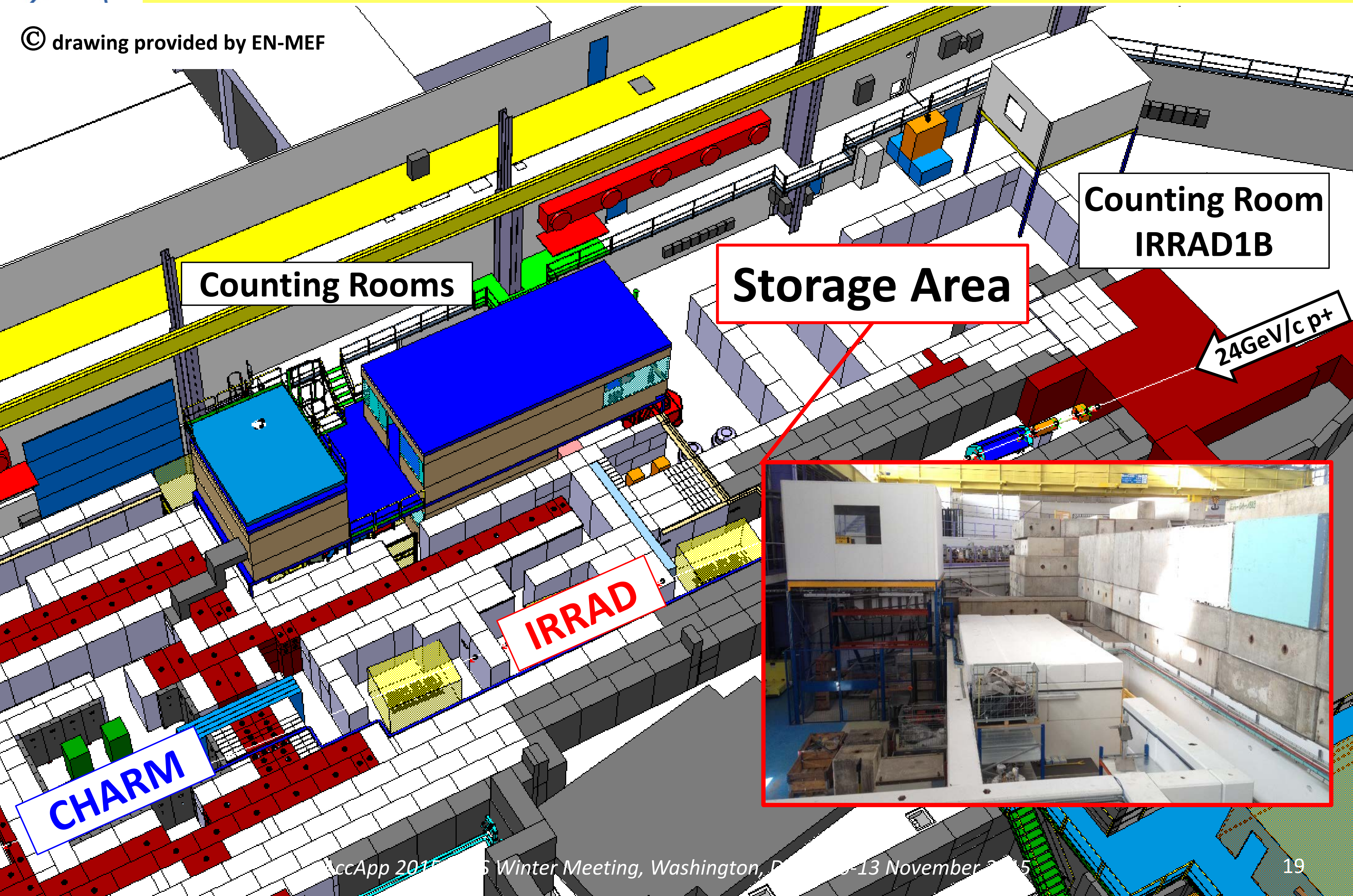
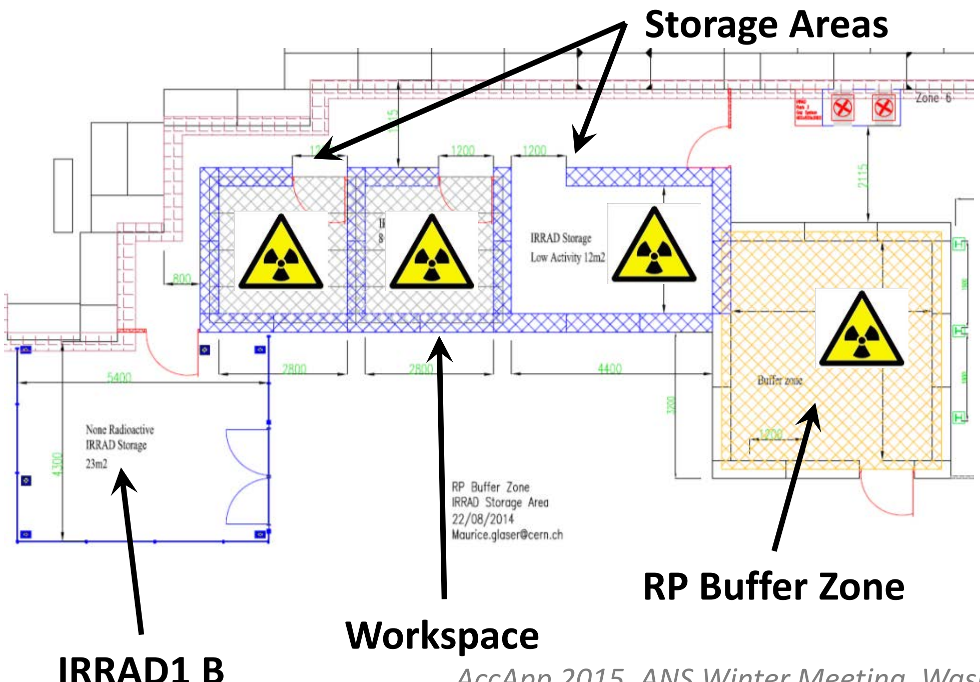
East Area EA-IRRAD Infrastructure

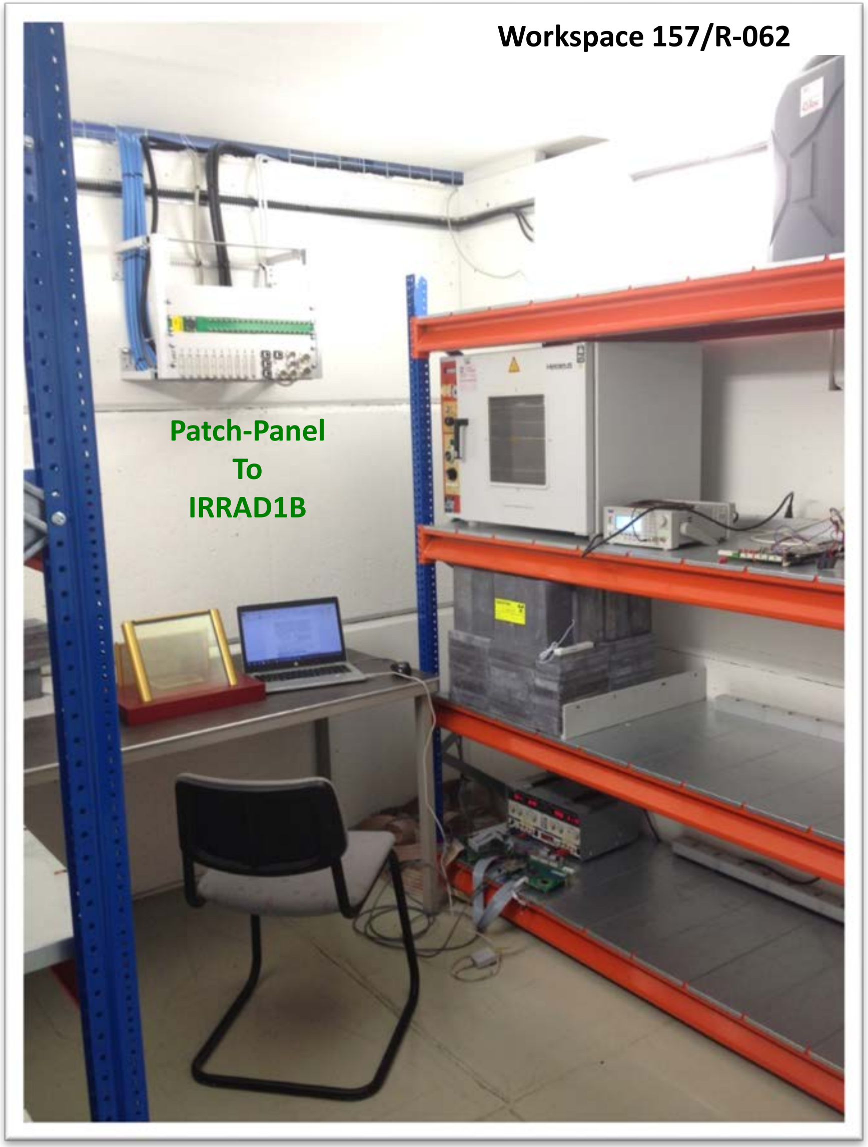


Proton IRRAD Infrastructure

Storage Area

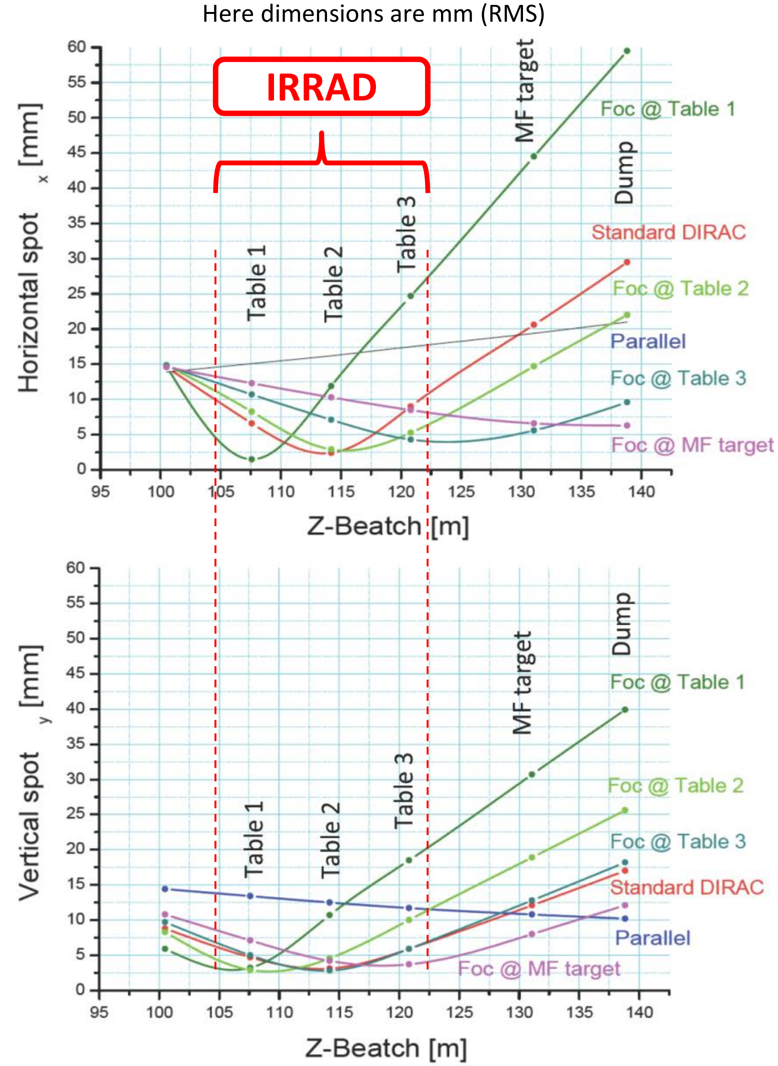
- 2x shielded zones for **cool-down** and **storage** at **room and low temperature**
- 1x **workspace** equipped to handle and characterize irradiated equipment
- dedicated **cabling infrastructure** from workspace to counting room IRRAD1B





Proton Beam Parameters

- **Beam dimension**
  - several optic variants possible on T8
  - standard **Gaussian**: **12x12 mm²** (FWHM)
  - from **5x5 mm²** to **20x20 mm²** (FWHM)
- **Beam intensity**
  - p^+ are delivered in "spills" of ~3.5×10^{11} p
  - number of spills/frequency depends on CPS
  - **Typical figure (high intensity)**
    - 3 spills per CPS of 36s.
    - **~1×10^{16} p cm^{-2} $5days^{-1}$** (12x12 mm²)
    - **~4x more than the old facilities**
  - **Maximum figure (design):** 6 spills per CPS
    - **~1×10^{17} p cm^{-2} $4days^{-1}$** (5x5 mm²)
  - **Year 2015 (average):** variable CPS + PS efficiency
    - **~1×10^{16} p cm^{-2} $10days^{-1}$** (12x12 mm²)



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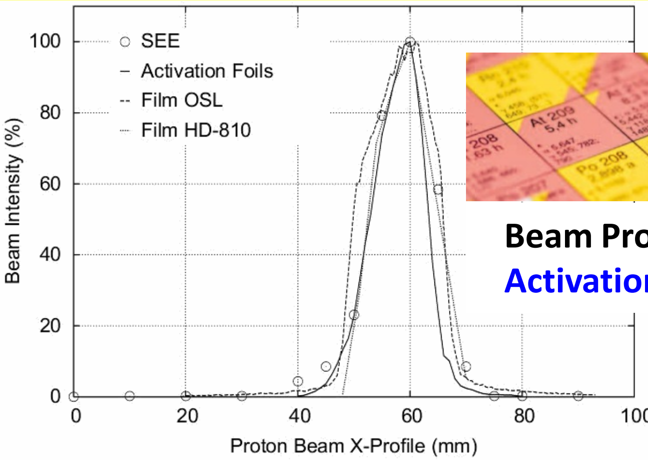
Beam Steering & Dosimetry

❑ Beam Profile Monitor (BPM)

- Metal Foil Detectors
- **Poster Session** on Thursday 6:30pm:

Maurice Glaser et al.,

"The Beam Profile Monitoring System for the IRRAD Proton Facility at the CERN PS East Area"



Beam Profile / Intensity from
Activation of Aluminium foils

$^{27}Al(p,3pn)^{24}Na$ $^{27}Al(p,3p3n)^{22}Na$

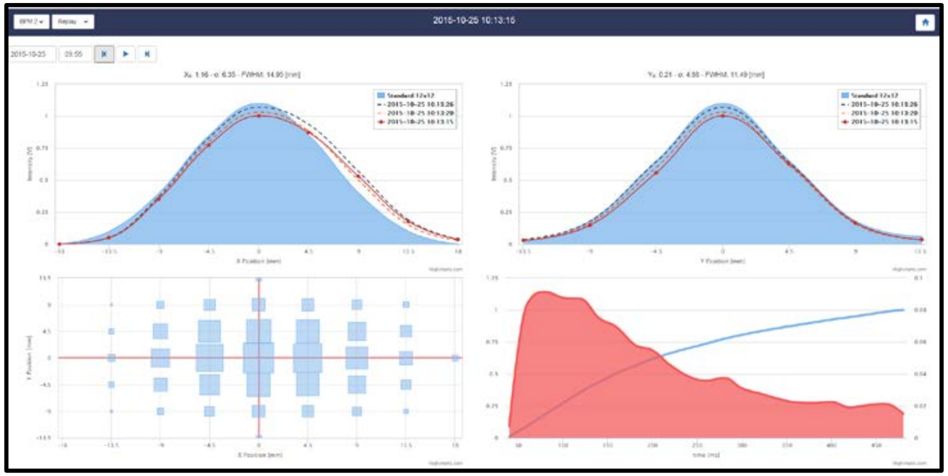
1x NaI spectrometer (+/- 6%)

^{24}**Na,** half-life 15h, Eγ = 1368.53 keV

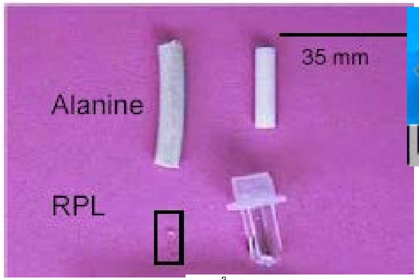
2x HpGe spectrometer (+/- 2%)

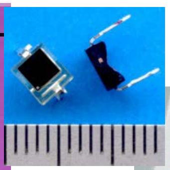
^{22}**Na,** half-life 2.6y, Eγ = 1274.54 keV

❑ BPM Display (web-based)

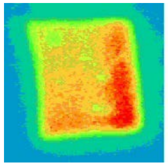


www.cern.ch/opwt/irrad

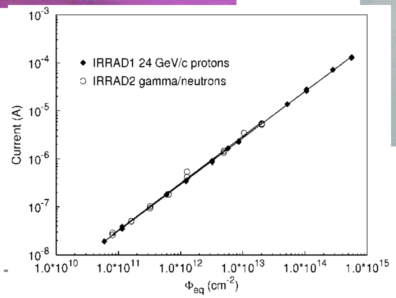




Si-PAD detectors



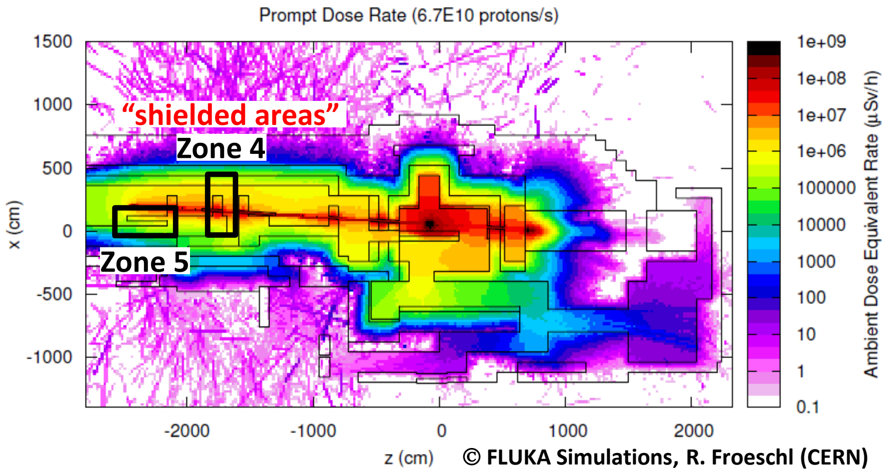
Radiochromic Films



Passive Dosimetry

Radiation Background & Proton NIEL

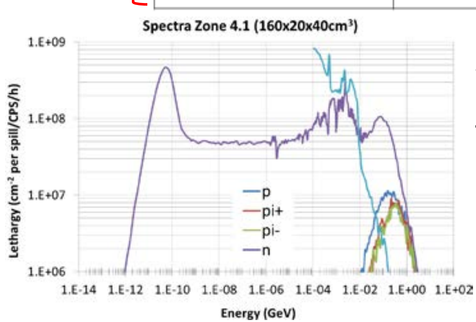
- Monte Carlo Simulations (FLUKA)
  - Radiation Protection Optimization
  - Evaluation of IRRAD Facility background



© FLUKA Simulations, R. Froeschl (CERN)

Zone 4

Radiation Type	Energy	Intensity (cm^{-2} h^{-1})
protons	~ 200 MeV (peak)	~ 5×10^7
pions (+)	~ 300 MeV (peak)	~ 3×10^7
pions (-)	~ 300 MeV (peak)	~ 3×10^7
neutrons (all)	thermal – few GeV	~ 2.5×10^9
neutrons	> 20 MeV	~ 3×10^8

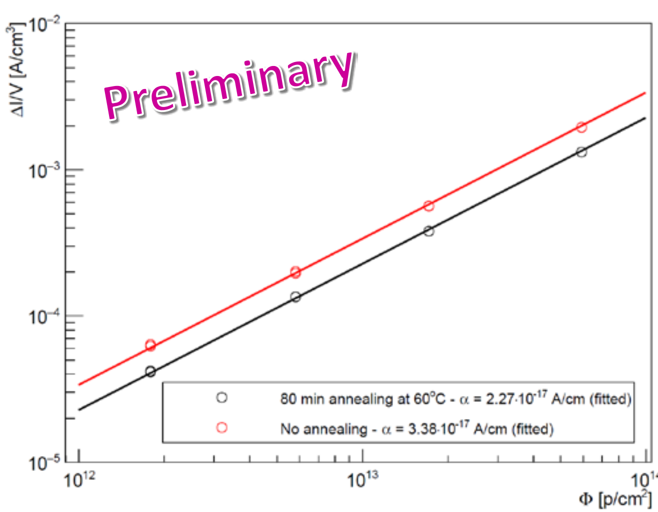


for 4×10^{13} **p/cm²/h** (std. spot size)

Total Dose in Zone 4:

~0.13-0.15 Gy/h (air KERMA)

- Dosimetric Measurements *Preliminary*
  - **Zone 4**
    - Total Dose **~0.10 Gy/h** (Film HD-810)
    - Φ_{eq} **~3.8×10^8 $n_{(1MeV)}$/cm²/h** (Si diodes)
  - **Zone 5**
    - Total Dose: **about x2 lower**
    - good agreement with simulations
- Non-Ionizing Energy Loss (NIEL)
  - **Experimental determination of hardness factor**
    - Silicon PAD detector samples
    - **k = 0.57-0.58** (theoretical k = 0.51)

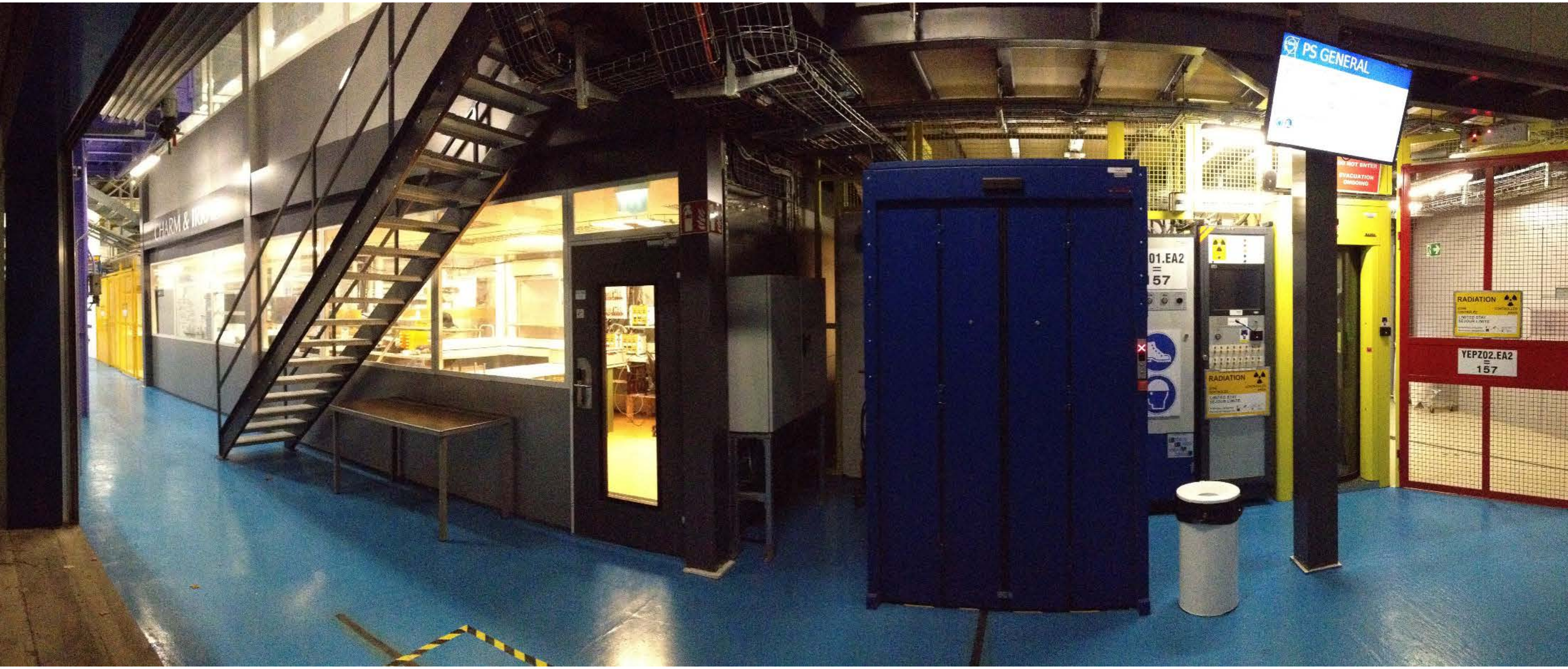


Summary

- New IRRAD Proton Facility is now completing its first year of operation
  - Extensive description of the new infrastructure and irradiation equipment
    - matches the requirements for High Luminosity upgrades
  - To be continued:
    - tuning/improvement of beam conditions
    - beam characterization & radiation background
- IRRAD Proton Facility in 2015
  - **25 user irradiations** completed
  - **13 different experiments** / CERN groups
    - **~300 samples** (active/passive)
    - RT & cold box; cryogenic setup running
  - **7 irradiations ongoing** (few days left!)
- Contacts:
  - URL: www.cern.ch/ps-irrad
  - e-mail: irradiation.facilities@cern.ch
  - Information / news / irradiation request form

EA-IRRAD: aerial view of radiation shielding

Thank you for your attention!

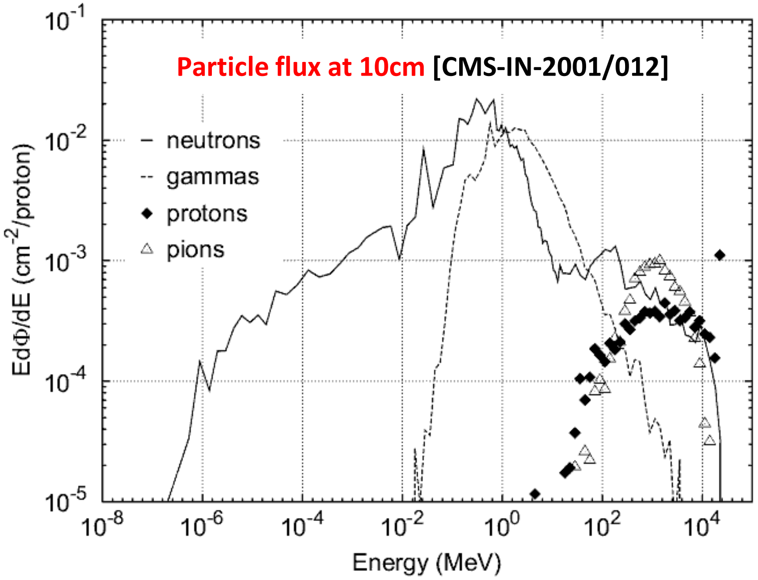


IRRAD Facility Control Room (left-hand side) and access point to the irradiation area (right-hand side)

Mixed-field Irradiation Facility (2012)

❑ Secondary particles in a cavity (IRRAD2)

- 24 GeV/c proton beam on a C/Fe/Pb target
- **Small volume** (max ~30×30×30cm^3) behind DIRAC
- Spectrum & flux of ***n, p⁺, π⁺, π⁻, γ*** simulated & measured
- **~1×10^{13} n$_{(E>1MeV)}$ cm^{-2} 5d^{-1}** @ 50cm from beam axis



IRRAD2 Shuttle