

# **Irradiation Facilities in the CERN PS EAST HALL**

## **WP 8.3. Status of work at CERN**

*Michael Moll, CERN PH-DT*

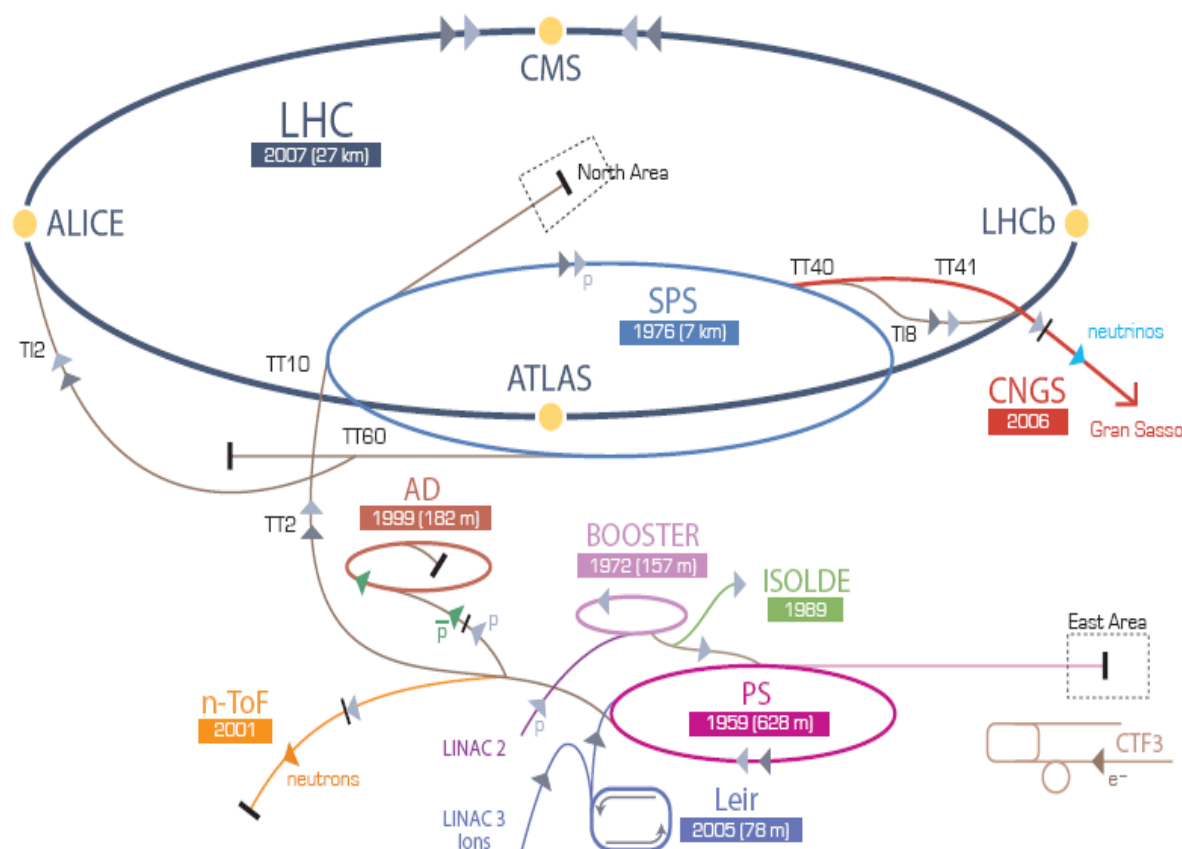
*CERN contributors: Markus Brugger, Lau Gatignon, Maurice Glaser, Elias Lebbos, Michael Moll, Federico Ravotti, Stefan Roesler*



[Fluka simulations]

### **Contents:**

- ***Irradiation Facilities at CERN***
- ***Existing irradiation Facilities in the CERN EAST HALL***
- ***Design Study on New Irradiation Facility***
- ***Infrastructure for new facility (8.3.2) ... see following talks***
- ***Outlook***



▶ p (proton)   ▶ ion   ▶ neutrons   ▶  $\bar{p}$  (antiproton)   ▶ proton/antiproton conversion   ▶ neutrinos   ▶ electron

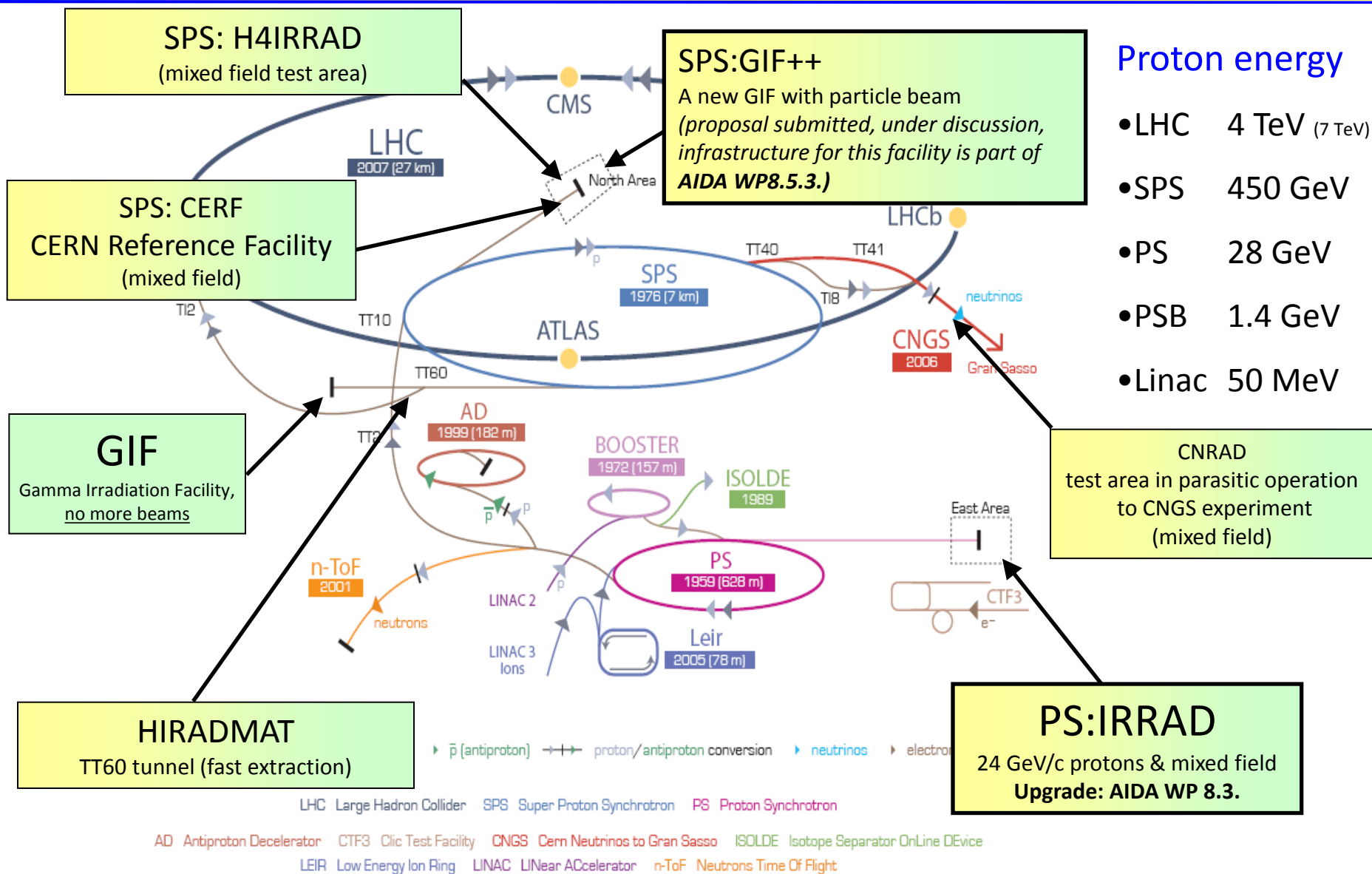
LHC Large Hadron Collider   SPS Super Proton Synchrotron   PS Proton Synchrotron

AD Antiproton Decelerator   CTF3 Clic Test Facility   CNGS Cern Neutrinos to Gran Sasso   ISOLDE Isotope Separator OnLine DEvice

LEIR Low Energy Ion Ring   LINAC LINear ACcelerator   n-ToF Neutrons Time Of Flight

## Proton energy

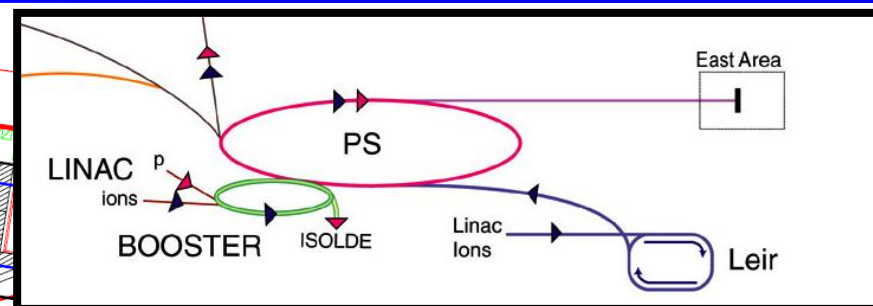
- LHC 4 TeV (7 TeV)
- SPS 450 GeV
- PS 28 GeV
- PSB 1.4 GeV
- Linac 50 MeV





## T7 & T8 beam lines in East Area

24 GeV/c protons

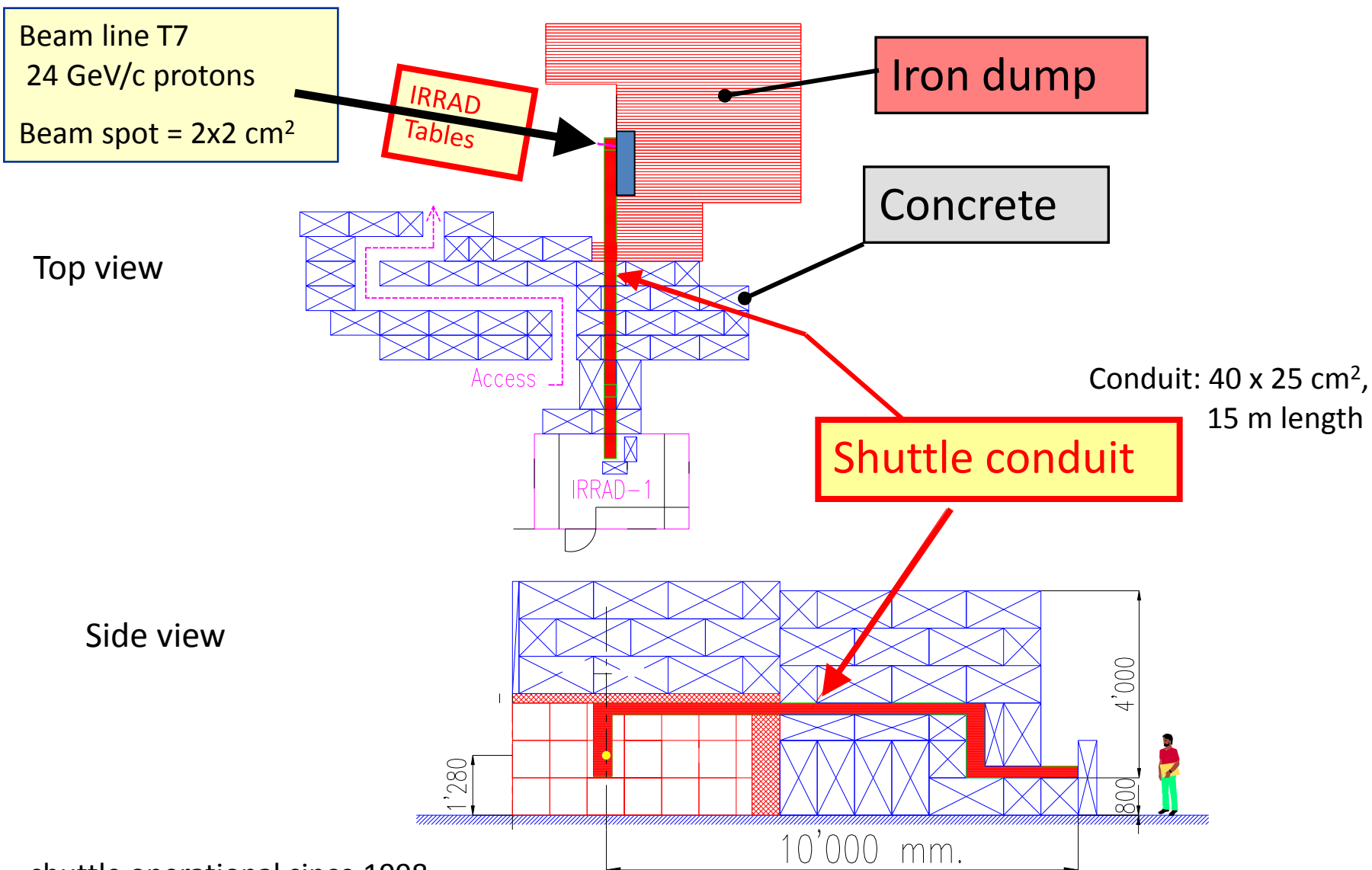


### • Proton irradiations

- Direct exposure to 24 GeV/c protons (IRRAD1, IRRAD3, IRRAD5)
- Low intensity radiation field of backscattered particles (SEU and Dosimeter testing) (IRRAD6)

### • Neutron (mixed field) irradiations

- Mixed field produced in cavity after carbon (50cm) iron (30cm) lead (5cm) 'target' (IRRAD2)







## Beam specifications:

- Primary PS proton beam

- Beam line: PS-T7
- Beam energy: 24 GeV/c

- Slow extraction

- Spills of protons (  $\sim 2 \times 10^{11}$  p, 400 ms)
- Beam spot: 1x1 to 5 x 5 cm<sup>2</sup>  
(typical 2x2cm<sup>2</sup>)

- Proton flux

- $\sim 1 - 9 \times 10^{13}$  p cm<sup>-2</sup> h<sup>-1</sup>
- $\sim 5 \times 10^{14}$  p cm<sup>-2</sup> day<sup>-1</sup>
- $\sim 1 \times 10^{17}$  p cm<sup>-2</sup> 150days<sup>-1</sup>

## Irradiation tables and boxes (IRRAD3 & 5)

- Irradiation on x-y-z movable tables (max 100 Kg)
- Irradiation inside cooled (-20°C) and atmosphere controlled boxes (max volume: 20 x 20 x 50 cm<sup>3</sup>)
- Scanning over surfaces up to 20 x 20 cm<sup>2</sup>

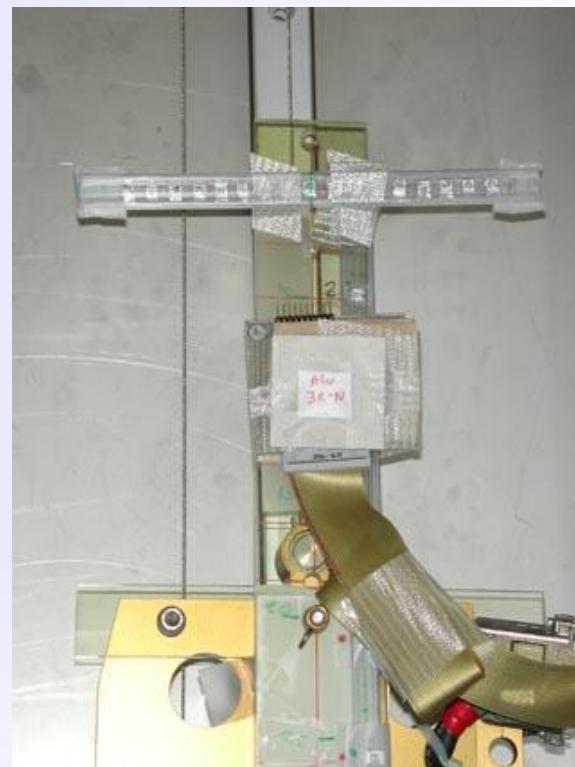


## Shuttle system (IRRAD1)

- Standard volume: 5 x 5 x 15 cm<sup>3</sup>
- Max volume (on request): 10 x 10 x 20 cm<sup>3</sup>
- Electrical connections



- Irradiations performed with a shuttle system very similar to proton shuttle
  - Conduit: 40x40 cm<sup>2</sup>, 15 m long
  - Standard volume for irradiations 20 x 20 x 20 cm<sup>3</sup> (on demand up to ~ 30 x 30 x 35 cm<sup>3</sup>)



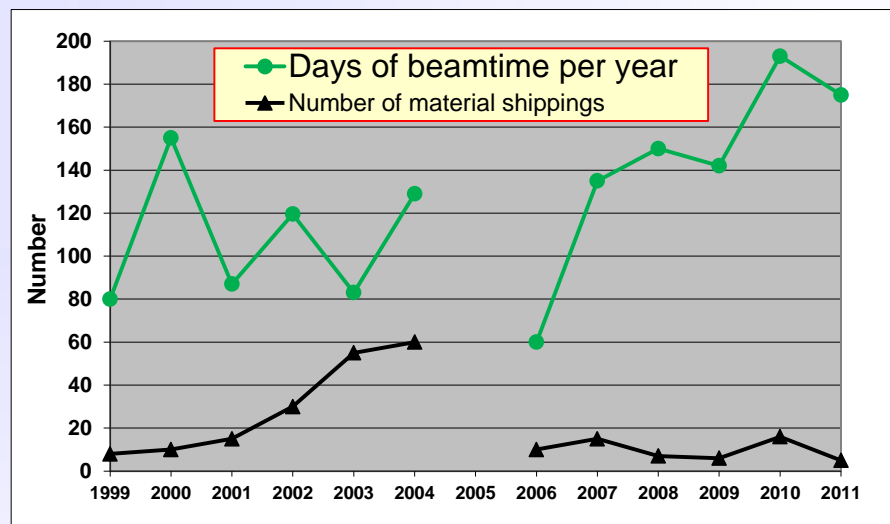
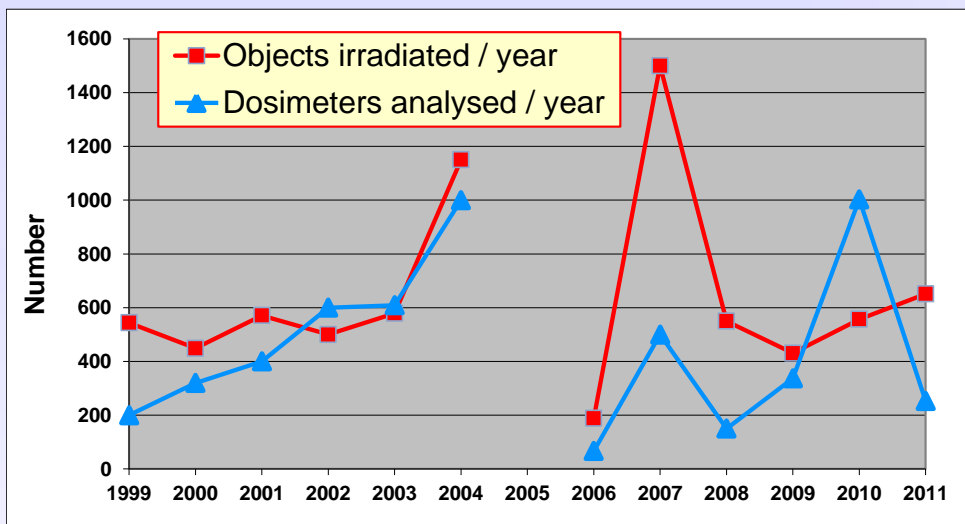
- Neutron flux
  - $1 - 3 \times 10^7 \text{ n cm}^{-2} \text{ s}^{-1}$  (  $E > 1 \text{ MeV}$  ) at 50 cm from beam axis (6 days for  $10^{13} \text{ n cm}^{-2}$ )
  - Tabulated fluxes for different energy cuts and irradiation positions available for users

- **Main users:**

- LHC Experiments (in particular innermost detector components – silicon tracking detectors)
- increasing requests linked to detector developments for LHC-upgrades (up to  $2 \times 10^{16}$  p/cm<sup>2</sup>)

- since 1999:

**More than 7500 objects have been irradiated in 1500 days of beam time!**



- **Irradiations in 2011**

- Main users: ATLAS, CMS, LHCb, RD50, RD39, LHC
- **651** objects irradiated, **253** dosimeters measured, **175** days of beam time



# AIDA Irradiation facility and its services

- Team (CERN-PH-DT): <http://www.cern.ch/irradiation/>
  - M.Glaser, M.Moll, F.Ravotti (*started in March 2012 – funded by AIDA project*)
  - Technical support from PH-DT
- Service:

A radiation facility is a complex infrastructure and service organization going far beyond 'providing just the beam'!

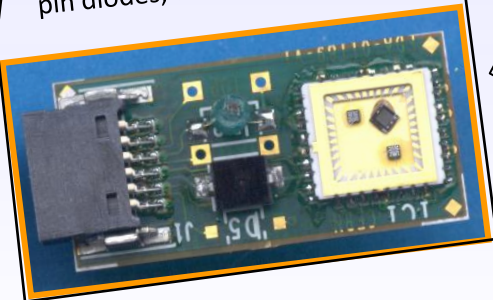
  - Operation of facility: Irradiations, support in producing sample holders, beam monitoring, dosimetry, safety, providing basic equipment (e.g. CV/IV for sensors), shipping of material, sample tracing,.....etc.
  - **To be considered when planning a new facility and its operation!**

## Handling of material, Shipping

Handling of activated test materials, shipping of samples in cold containers (silicon detectors), ...

## Dosimetry

PH Radmon boards, RADFETs, pin diodes, activation foils

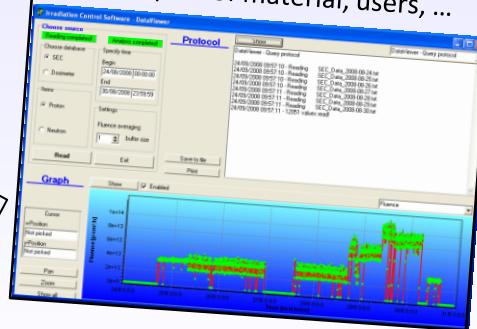


## Safety

Safety of operators, clients, ...

## Database system

Electronic logbook for irradiation history and condition for all samples, sample tracing, radiation levels, export of material, users, ...

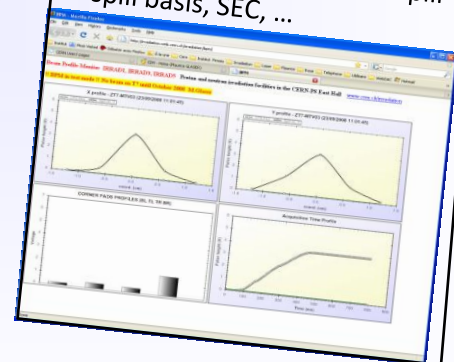


## Material testing, R&D

Equipment for tests, R&D, Expertise, consulting, recommendations to clients,...

## Beam monitoring

Beam profile monitoring on spill to spill basis, SEC, ...



## Drawbacks and Shortcomings of the present EAST Hall facilities:

- **Proton Irradiation facility**

- **Located in primary zone**  
*(limited access: stop all beam lines for access, wait for radioactive decay)*
- **Limited space**  
*(Personnel exposed to radiation, difficult to scan beam over big objects, backscattered particles)*
- **Safety standards to be improved!**

- **Mixed field irradiations (behind DIRAC)**

- **No irradiation position lateral to target** (missing an important 'particle mix' component)
- **Limited intensity** (with present flux not interesting for inner detector community)
- **Too little space and limited accessibility** (access only via shuttle system!)
- **Parasitic to DIRAC**

- **Proton & Mixed field facility located in different beam lines**

- **Facilities competing for beam**



- **Task leader: Michael Moll (CERN)**

- **Objectives:**

- Improvement of existing irradiation facilities at CERN PS
- Elaboration and evaluation of upgrade scenarios
- Design and test of common infrastructure for the facility



- **Sub-tasks and participants**

- 8.3.1. Improvement of existing irradiation facilities and evaluation of upgrade scenarios  
*CERN*

- 8.3.2. Common infrastructure for the facilities

*CERN, UNILIV, USFD - (Irradiation tables and boxes)*

*VU - (Radiation monitoring system)*

- **2 milestones and 2 deliverables:**

MS31	Installation of new equipment	CERN(1)	m26 <u>March 2013</u>	Movable irradiation tables operational ( <a href="#">Task 8.3.2</a> ) CERN, UK
MS35	Installation of infrastructure	(34)	m37 <u>Feb. 2014</u>	Cold boxes and Fluence monitoring system operational ( <a href="#">Task 8.3.2</a> ) CERN, UK, VU

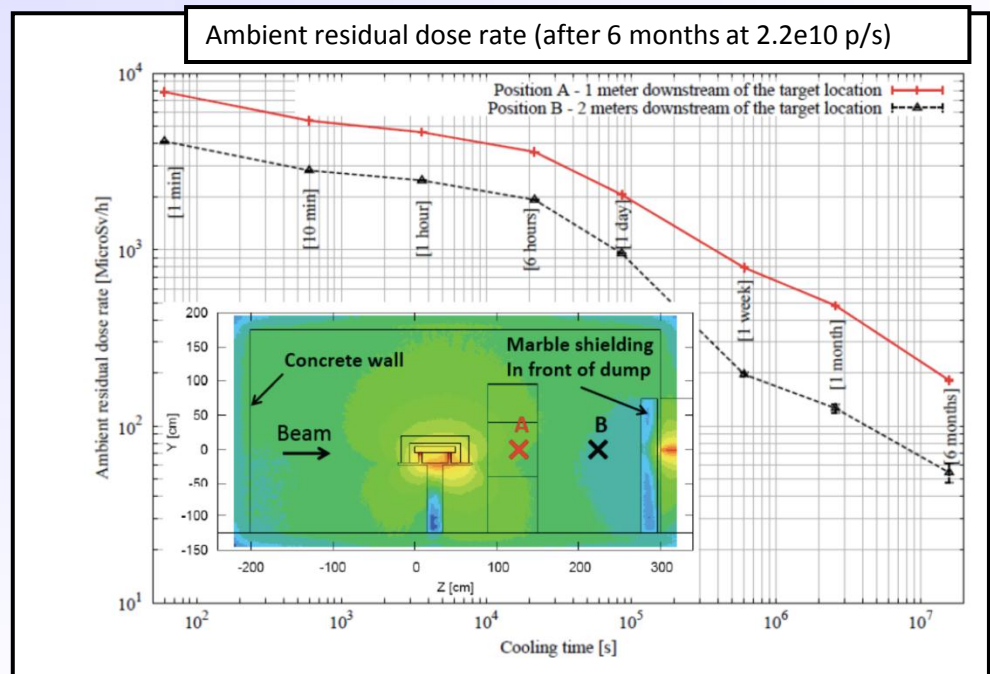
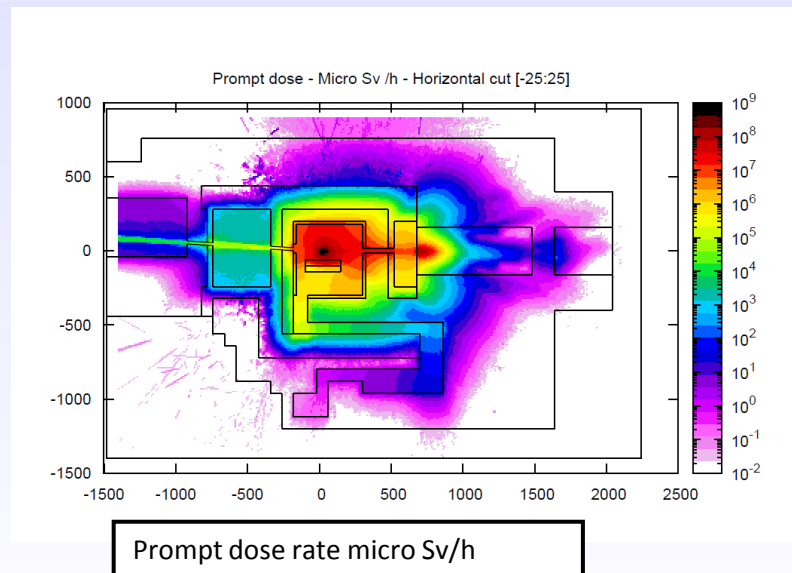
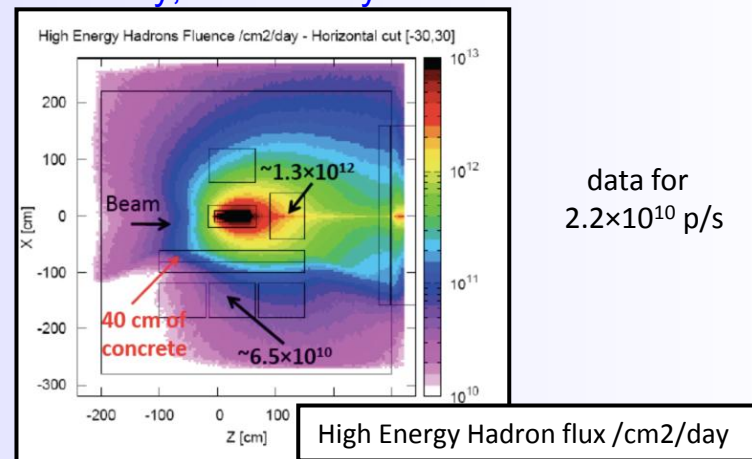
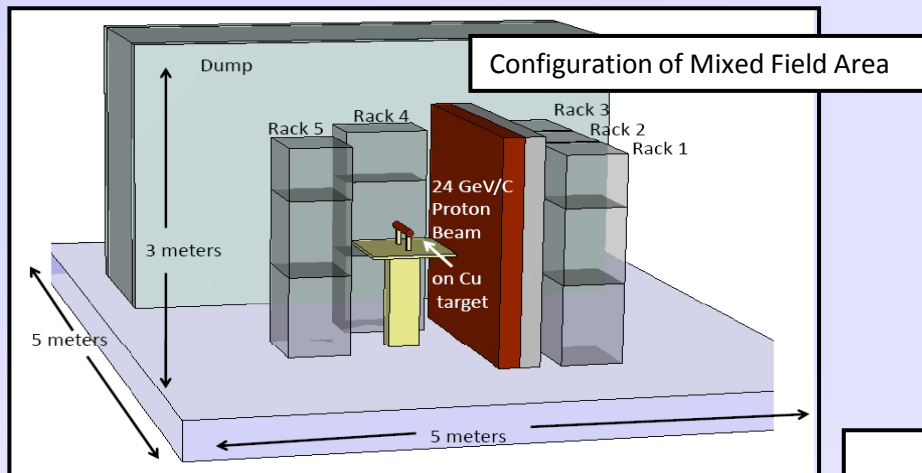
D8.4	Upgrade scenarios for irradiation lines: Design study on new or upgraded irradiation facilities at CERN based on slow extracted proton beams. Containing a proton and – if feasible – a mixed field irradiation facility.	[month 37] <u>Feb. 2014</u>	Task 8.3.1 CERN
D8.10	Commissioning of new facility equipment: Report on commissioning of shuttle systems, movable irradiation tables with cold boxes and a fluence monitoring system based on a microwave absorption technique in silicon.	[month 48] <u>January 2015</u>	Task 8.3.2 CERN, UK, VU





- Documented in AIDA-NOTE-2012-001 “East Area Irradiation Test Facility; Preliminary FLUKA calculations”

*E. Lebbos, M. Brugger, M. Calviani, L. Gatignon, M. Glaser, M. Moll*





- Workshop at CERN “EAST AREA DAY” on 1.Feb 2012 ([INDICO](#))
  - Organized by CERN EN Department (*Lau Gatignon*)
  - Presentations and Discussions on plans for renovation of the CERN EAST AREA
    - Outlook on future Experiments and Facilities in the EAST AREA
    - Consolidation of Infrastructure, Equipment and Building
    - Cost estimates, planning of work and coordination issues
- Irradiation Facility is part of these considerations
  - Document “FUTURE EXPLOITATION OF THE EAST AREA” existing as DRAFT
  - Preliminary cost estimate for irradiation facilities (as part of overall renovation project):

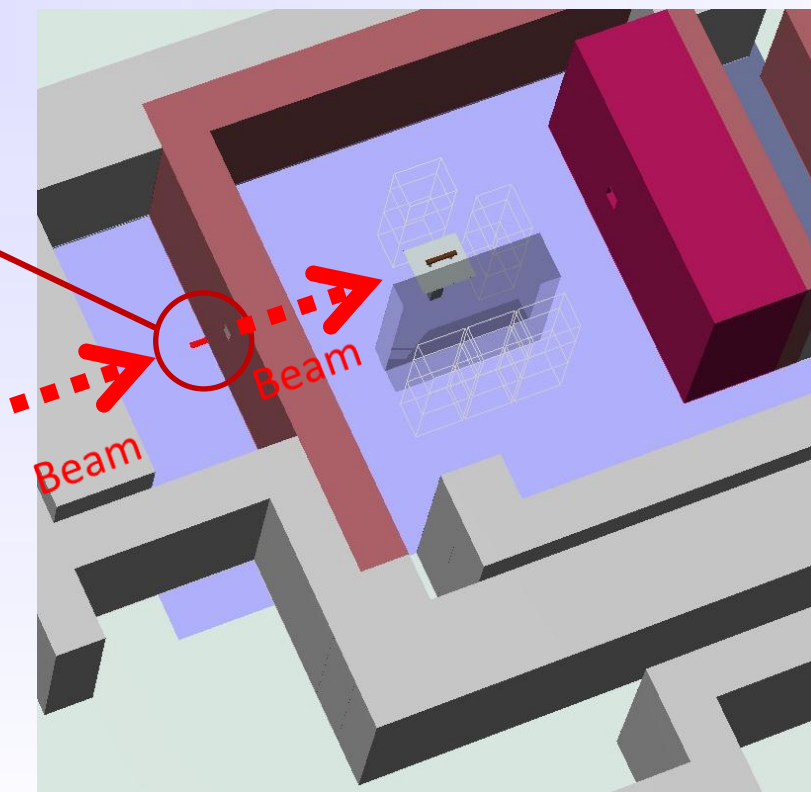
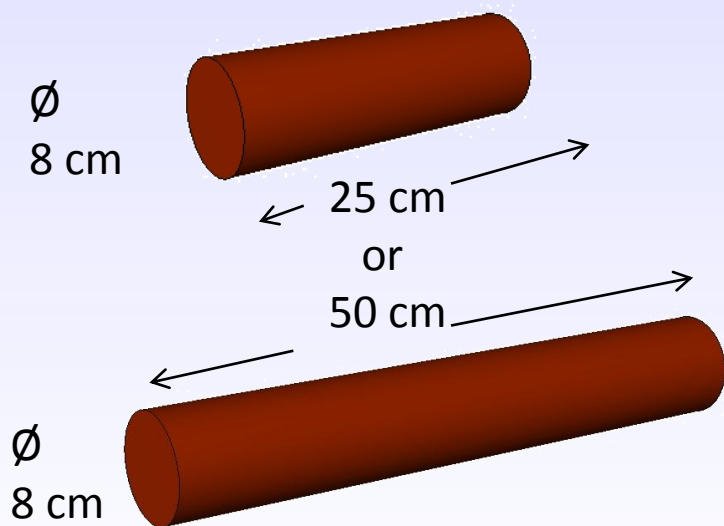
Sub-project	MCHF	FTE
East Area layout change	1.5	3
East Area consolidation	12.4	15
IRRADiation facility upgrade	2.1	2.5
<b>Total</b>	<b>16.0</b>	<b>20.5</b>

- Still some issues to be looked at in more detail (potential cost increase)
  - Ventilation, target and sample positioning systems, etc....

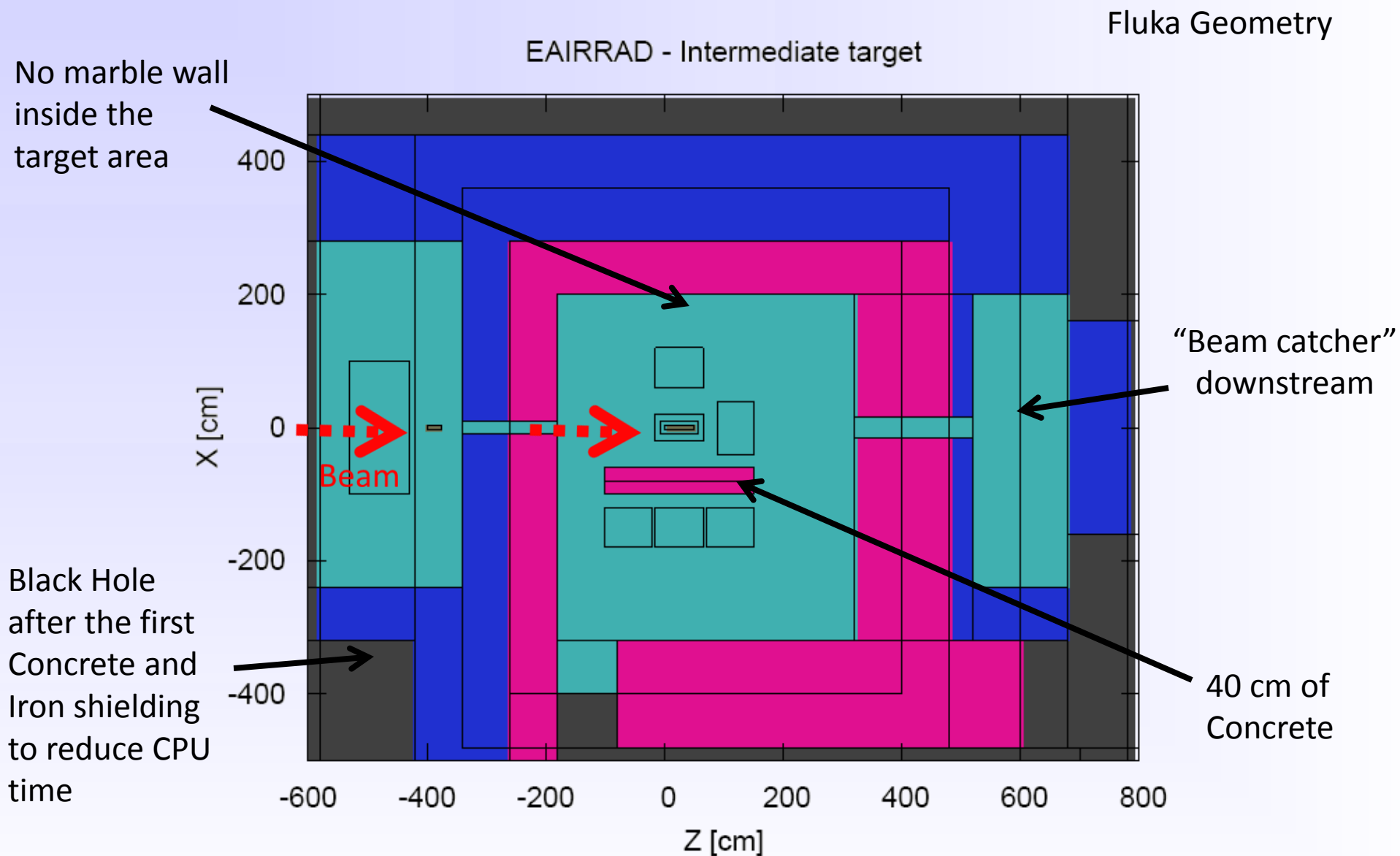


- **Problem:**
  - Proton facility requires most of the time a full intensity beam (*fast irradiations & reaching high fluences up to  $10^{16} \text{ cm}^{-2}$* )
  - Mixed field facility will require for some experiments a low particle flux
- **Searching for solutions (ongoing work)**
  - Placement of intermediate target (?), 'TAX'-like absorber (?) or modify target (?)

Cylindrical Cu target:  
2 options



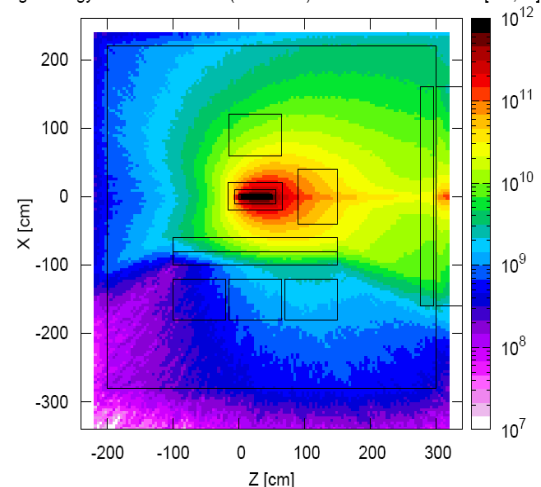
Simulations:  
E.Lebbos





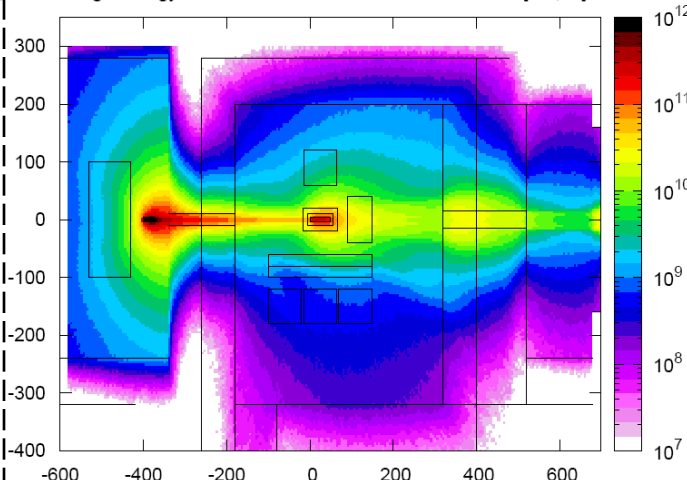
No intermediate target

High Energy Hadrons Fluence (> 20 MeV) /cm<sup>2</sup>/h - Horizontal cut [-30,30]



intermediate target  
25 cm

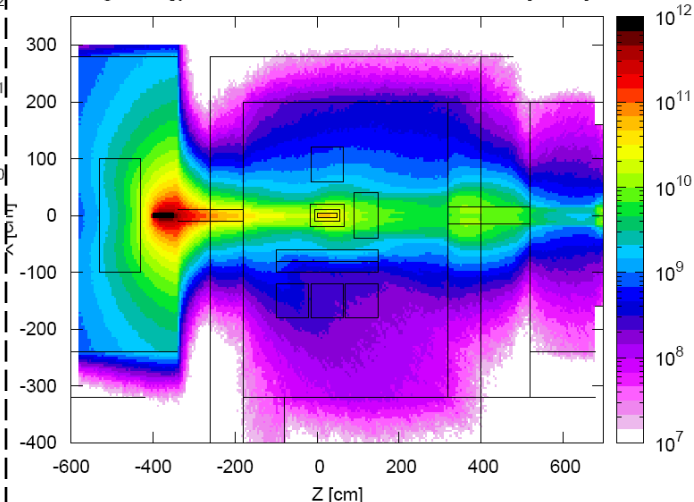
High Energy Hadrons Fluence /cm<sup>2</sup>/h - Horizontal cut [-30,30]



~ Factor 2 to 4 in less  
at rack location

intermediate target  
50 cm

High Energy Hadrons Fluence /cm<sup>2</sup>/h - Horizontal cut [-30,30]

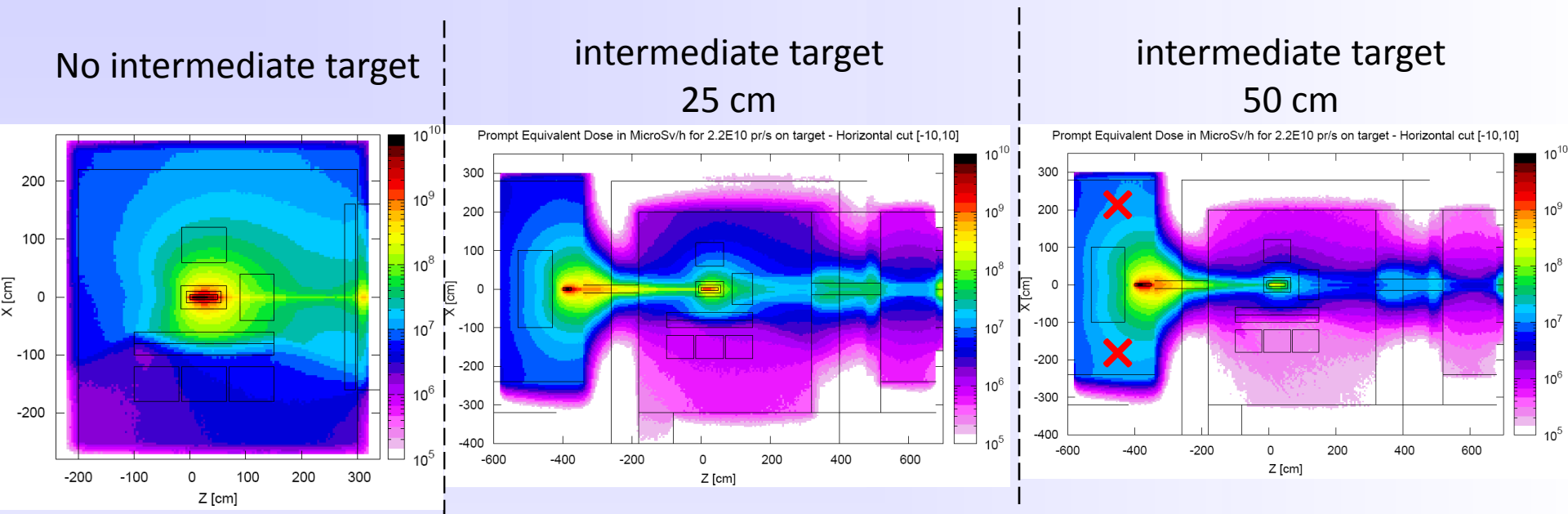


~ Factor 2 to 10 in less  
at rack location

Preliminary

Simulations:  
E.Lebbos

# Prompt equivalent dose ( $\mu\text{Sv/h}$ )



As calculated for the case without intermediate target:

**3.2 m concrete + 1.6 m iron** => required to reduce prompt equivalent dose down to **0.7  $\mu\text{Sv/h}$**

But:

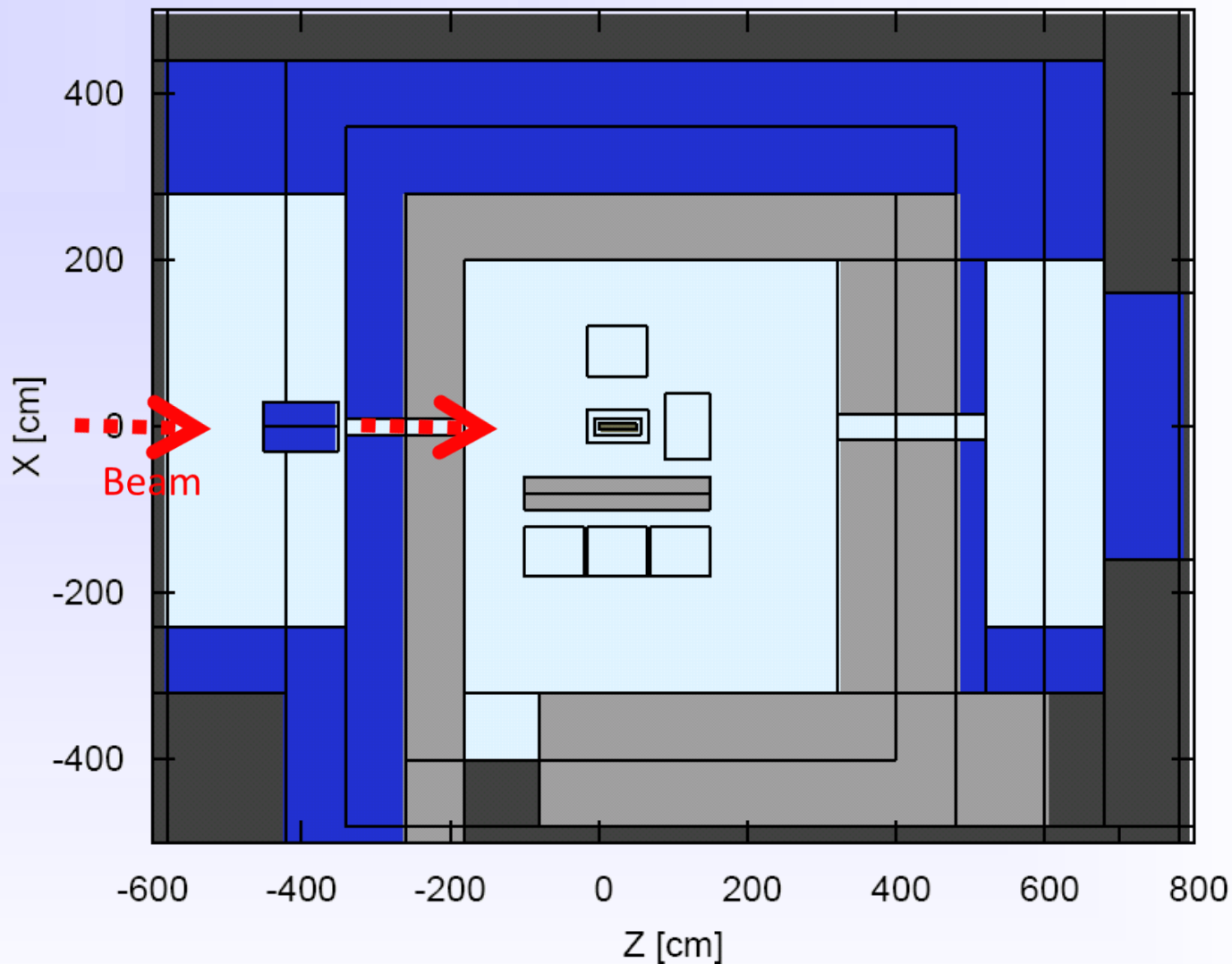
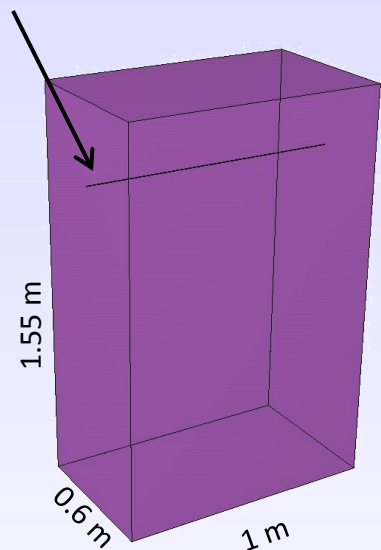
- ~ 1m of iron can be put laterally on both sides as indicated on the plot by “X”
- a bigger “self shielded” Cu/Fe target can be used

Preliminary



### Simplified model in cast iron

With aperture to reduce  
beam intensity



**2 solutions studied:**

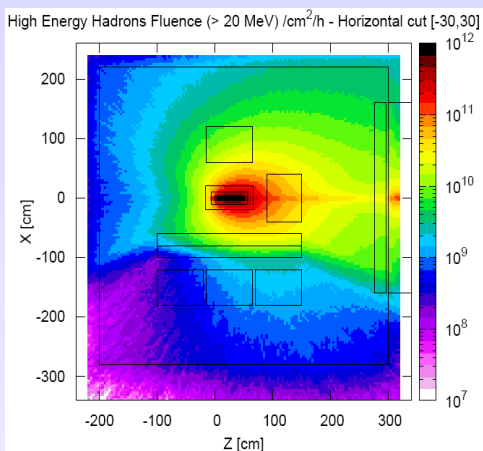
Ø 0.17 cm

Ø 0.5 cm

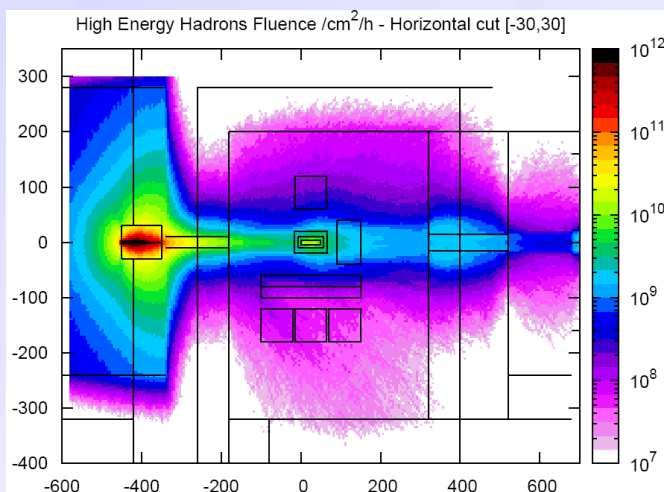


# AIDA High Energy Hadrons fluence (>20 MeV) per hour

No intermediate target

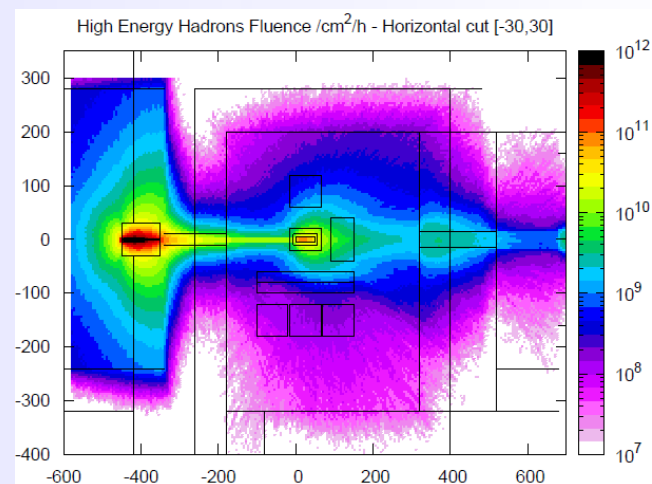


intermediate TAX  
 $\varnothing$  0.17 cm



~ Factor 20 to 100 in less  
at rack location

intermediate TAX  
 $\varnothing$  0.5 cm

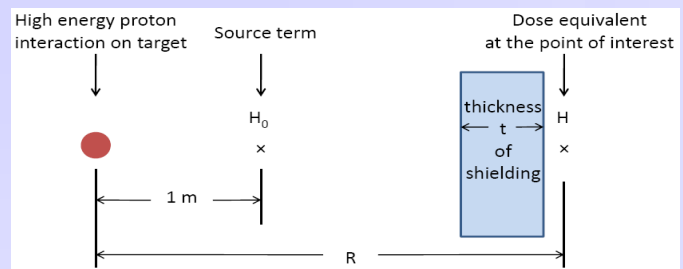


~ Factor 10 in less  
at rack location

Preliminary



# Prompt equivalent dose ( $\mu\text{Sv/h}$ )



$2.5 \times 10^7 \mu\text{Sv/h}$  at 1 m from the source



Prompt dose attenuation in  $1/R$   
(Linear source)

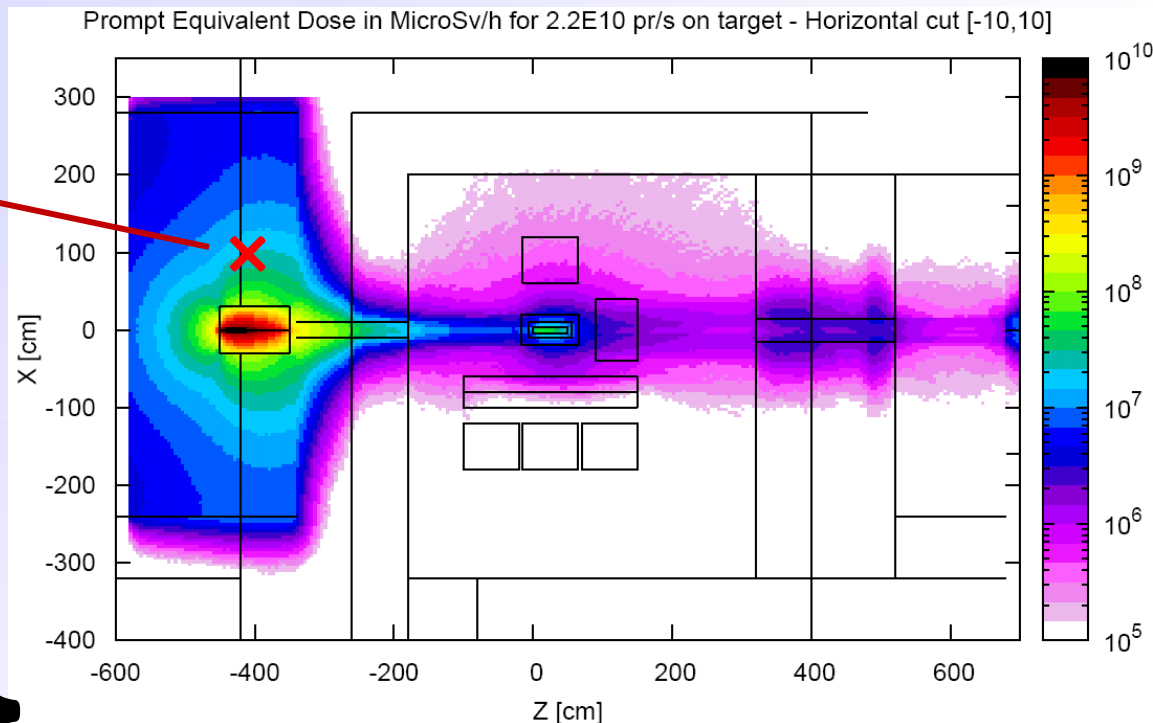
$$H = \frac{H_0 e^{-t/\lambda}}{R^2}$$

mean free path factor (mfp) :

$$\lambda_{\text{concrete}} = 0.43\text{ m}$$

$$\lambda_{\text{iron}} = 0.178\text{ m}$$

$$H_0 = 2.5 \times 10^7 \mu\text{Sv/h}$$



$H = 1 \mu\text{Sv/h}$  after 0.8 m of concrete and 2.4 m of iron  
= 5.2 mSv/y

[Ref] H. Sullivan, *A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators*, Nuclear Technology Publishing, ISBN 1 870965 18 3 (hardback), 1992.

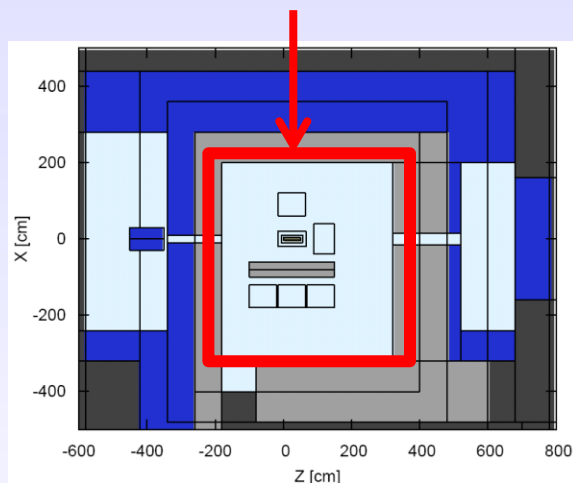


Assuming:

the following parameters:

Loss Rate Ejection	<b>2.20E+10</b>	pps
Volume target area	<b>5.29E+07</b>	cm <sup>3</sup>
Leak Rate	<b>0</b>	m <sup>3</sup> /h
Irradiation time	<b>1.58E+07</b>	s (6 months)

and this area only:



Without intermediate target  
(i.e. proton beam directly on the  
production target)

Isotopes	Yield	t 1/2	$\lambda$ [s <sup>-1</sup> ]	$\lambda'$ [s <sup>-1</sup> ]	Activity	CA value	Ratio	einh	Dose inh.
	Ejection				Bq/m <sup>3</sup>	Bq/m <sup>3</sup>	Act./CA	Sv/Bq	$\mu$ Sv/h
H-3	3.86E-03	12.35 y	1.78E-09	1.78E-09	4.45E+04	200000	0.22	4.1E-11	2.19
Be-7	8.20E-04	53.3 d	1.51E-07	1.51E-07	3.09E+05	100000	3.09	4.6E-11	17.08
Be-10	9.61E-04	1.6e+06 y	1.37E-14	1.37E-14	8.67E-02	90	0.00	1.9E-08	0.00
C-11	1.44E-03	20.38 m	5.67E-04	5.67E-04	5.99E+05	70000	8.56	3.2E-12	2.30
C-14	8.28E-01	5730 y	3.84E-12	3.84E-12	2.09E+04	10000	2.09	5.8E-10	14.52
N-13	2.47E-03	9.965 m	1.16E-03	1.16E-03	1.03E+06	70000	14.67	3.2E-12	3.94
O-14	1.22E-04	71 s	9.76E-03	9.76E-03	5.07E+04	70000	0.72	3.2E-12	0.19
O-15	1.72E-03	122.2 s	5.67E-03	5.67E-03	7.15E+05	70000	10.22	3.2E-12	2.75
O-19	7.05E-08	27.1 s	2.56E-02	2.56E-02	2.93E+01				
F-18	1.67E-06	109.8 m	1.05E-04	1.05E-04	6.95E+02	70000	0.01		
Ne-23	1.83E-07	28 s	2.48E-02	2.48E-02	7.61E+01				
Ne-24	3.76E-08	3.38 m	3.42E-03	3.42E-03	1.56E+01				
Na-22	6.29E-07	2.602 y	8.44E-09	8.44E-09	3.27E+01	4000	0.01	2E-09	0.08
Na-24	9.70E-07	15 h	1.28E-05	1.28E-05	4.03E+02	30000	0.01	5.3E-10	0.26
Na-25	3.42E-07	60 s	1.16E-02	1.16E-02	1.42E+02				
Mg-27	4.98E-07	9.5 m	1.22E-03	1.22E-03	2.07E+02				
Mg-28	2.09E-07	20.91 h	9.21E-06	9.21E-06	8.69E+01	6000	0.01	1.7E-09	0.18
Al-26	9.37E-07	7.16e+05 y	3.07E-14	3.07E-14	1.89E-04	400	0.00	1.4E-08	0.00
Al-28	2.75E-06	2.24 m	5.16E-03	5.16E-03	1.14E+03	6000	0.19	1.7E-09	2.33
Al-29	1.10E-06	6.6 m	1.75E-03	1.75E-03	4.57E+02				
Si-31	1.82E-06	157.3 m	7.34E-05	7.34E-05	7.57E+02	100000	0.01	1.1E-10	0.10
Si-32	1.07E-06	450 y	4.88E-11	4.88E-11	3.43E-01	30	0.01	5.5E-08	0.02
P-30	8.60E-07	2.499 m	4.62E-03	4.62E-03	3.58E+02				0.00
P-32	1.42E-05	14.29 d	5.61E-07	5.61E-07	5.90E+03	2000	2.95	2.9E-09	20.55
P-33	1.11E-05	25.4 d	3.16E-07	3.16E-07	4.58E+03	10000	0.46	1.3E-09	7.15
P-35	1.25E-06	47.4 s	1.46E-02	1.46E-02	5.20E+02				
S-35	1.50E-05	87.44 d	9.17E-08	9.17E-08	4.77E+03	10000	0.48	1.1E-09	6.30
S-37	6.36E-06	5.06 m	2.28E-03	2.28E-03	2.64E+03				
S-38	2.73E-06	2.87 h	6.71E-05	6.71E-05	1.14E+03				
Cl-34	5.11E-07	32 m	3.61E-04	3.61E-04	2.13E+02				
Cl-36	3.87E-05	3.01e+05 y	7.30E-14	7.30E-14	1.86E-02	1000	0.00	5.1E-09	0.00
Cl-38	2.86E-05	37.21 m	3.10E-04	3.10E-04	1.19E+04	40000	0.30	7.3E-11	1.04
Cl-39	4.91E-05	55.6 m	2.08E-04	2.08E-04	2.04E+04	200000	0.10	7.6E-11	1.86
Cl-40	8.33E-06	1.4 m	8.25E-03	8.25E-03	3.46E+03				
Ar-37	7.41E-05	35.02 d	2.29E-07	2.29E-07	3.00E+04	1E+11	0.00		
Ar-39	2.23E-04	269 y	8.17E-11	8.17E-11	1.20E+02	7000000	0.00		
Ar-41	1.74E-03	1.827 h	1.05E-04	1.05E-04	7.24E+05	50000	14.47		
K-38	4.11E-07	7.636 m	1.51E-03	1.51E-03	1.71E+02				
K-40	1.75E-06	1.28e+09 y	1.72E-17	1.72E-17	1.97E-07	3000	0.00	3E-09	0.00
Sum					3.58E+06		58.59		82.86

Conclusion: air activation is not an issue

- **Present facilities**
  - **Proton irradiation facilities**
    - Very heavily used; has reached its limits in terms of number of irradiations / year
  - **Mixed field irradiation facility**
    - Only sporadically used; several limitations (low particle flux, limited access), no lateral field ,parasitic)
- **Combined proton & mixed-field facility**
  - Efficient use of proton beam (used for both: proton and mixed-field irradiations)
  - Fluka simulations demonstrate that the mixed field particle composure and flux arising from 24 GeV/c protons fulfills requirements for anticipated radiation tests
  - First layout including optimization study in terms of area shielding at required highest proton flux presented and shown to be a feasible solution (published in AIDA NOTE 2012-001);
  - Study on beam attenuation between proton and mixed field facility under way (first results shown)
  - Air activation studies under way to understand ventilation issues (first results shown)
- **Next steps**
  - DIRAC end of data taking and dismantling to be confirmed, funded and executed
  - Preliminary cost estimate to be detailed and verified by more precise design/implementation study
  - Searching for implementation options in consensus with EAST AREA (staged) renovation/consolidation plans
  - Integration of facilities projects into medium term planning (& funding) by CERN management required
  - **Urgent**: Taking into account R&D and prototyping for the LHC Phase II upgrades and the R2E (Radiation to Electronics) needs an implementation starting in LS1 (end of 2012!) should be studied.