4 May 2010 – 101st LHCC Meeting

Future proton and mixed-field irradiation facilities with slow extraction for LHC operation phase and for LHC upgrades

M.Moll (PH-DT)

*on behalf of**

Ralph Wolfgang Assmann[a], Jeremie Bauche[b], Markus Brugger[c], Ilias Efthymiopoulos[c], Eduard Feldbaumer[a], Mar Capeans Garrido[d], Maurice Glaser[d], Daniel Kramer[c], Lucie Linssen[d], Roberto Losito[c], Michael Moll[d], Christoph Rembser[d], Marco Silari[e], Yves Thurel[b], Emmanuel Tsesmelis[f], Helmut Vincke[e]

[a]CERN-BE, [b]CERN-TE, [c]CERN-EN, [d]CERN-PH, [e]CERN-DGS, [f]CERN-DG

*** Most co-authors are members of the "Working Group on future irradiation facilities at CERN"***

Contents

- **Request towards the LHCC**
- **What is an irradiation facility?**
- **Irradiation facilities at CERN *(and their shortcomings)***
    - ***Overview***
    - ***IRRAD facilities – PS EAST HALL***
    - ***CERF – SPS North Hall***
    - ***CNRAD - CNGS***
- **Survey on needs for irradiation facilities at CERN**
    - ***Overview***
    - ***Proton irradiation facilities (slow extraction)***
    - ***Mixed-field facilities (slow extraction)***
- **Possible options for implementation and operation**
- **Why do we put forward this request now?**
- **Conclusions and request towards the LHCC**

Request to the LHCC

- **Main aim:**

Inform the LHCC and seek recognition of the scientific case for improved radiation facilities at CERN.

<u>In particular</u> this proposal concerns two types of facilities:

- **A proton irradiation facility with slow extraction.**
  The need for a mono-energetic charged hadron beam arises from requirements to produce a radiation environment similar to the experiments inner detectors (dominated by pions) and to gain a clearer understanding on the physics underlying the various damaging processes. The study of long-term degradation, readout under irradiation as well as constraints arising from dead-times in radiation monitor testing make a slow extraction for this facility indispensable.
- **A mixed field facility based on a slow extracted proton beam**
  A mixed field facility is mimicking the radiation fields within the LHC experiments and at accelerator regions (tunnel and partially shielded areas), where irradiation is composed of a mixed spectrum. Simultaneous readout of elements under irradiation is partly required.

- **Study on implementation options:**

We seek support from the LHCC for pursuing implementation studies.

<u>In particular</u>: Study a combined (proton & mixed-field) facility at a PS East Hall location, which could be a cost-effective option.

Setup and operate an irradiation facility

"A properly performed irradiation test is an experiment in itself !"

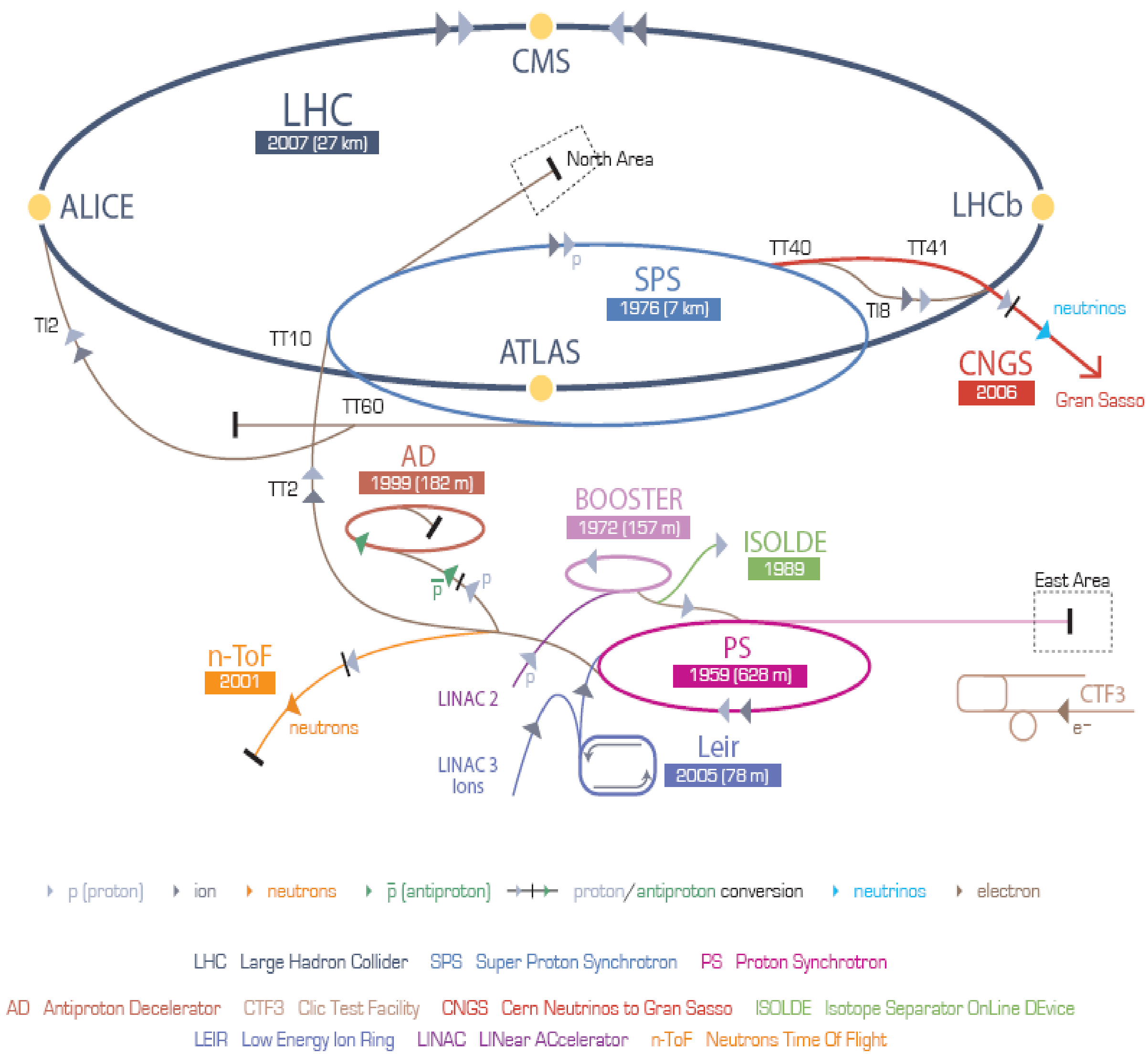
What a <u>facility</u> should provide to perform irradiation experiments:

- **Deliver the desired beam**
  - On demand (not parasitic) with required intensity, beam spot, time structure, …
- **Know and control the radiation environment**
  - well-defined and simulated spectra, in-situ dosimetry, proper shielding, …
- **Access conditions regulated**
  - pre-test documentation, preparation and optimization, logs, traceability of material, ….
- **Auxiliary installations**
  - remote handling tools, storage area, qualified lab, flexible infrastructure (gas, cooling),.
- **Final product: make scientific results available to the community**
  - document and spread out the knowledge; results databases;
- **Take care of radioactive waste from the beginning**

Irradiation Facilities vs. Irradiation Test Areas:

*Irradiation test locations which are not fulfilling the above requirements (ad-hoc tests, parasitic use of beam, …) are labeled as **"Irradiation Test Areas"** in the following.*

CERN ACCELERATORS & IRRADIATION FACILITIES



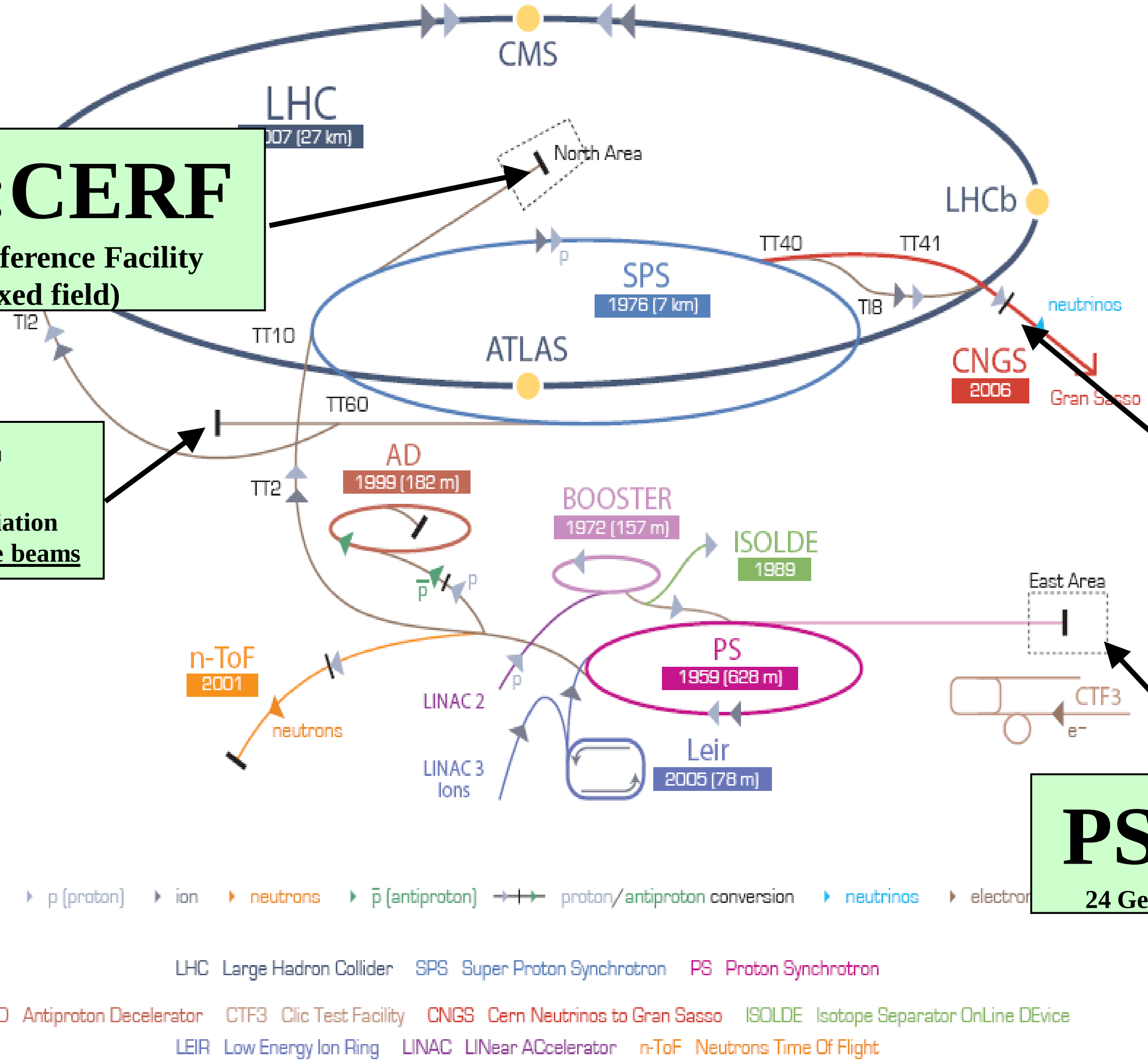
Proton energy

- **LHC 7 TeV**
- **SPS 450 GeV**
- **PS 28 GeV**
- **PSB 1.4 GeV**
- **Linac 50 MeV**

CERN ACCELERATORS & IRRADIATION FACILITIES

Proton energy

- •LHC 7 TeV
- •SPS 450 GeV
- •PS 28 GeV
- •PSB 1.4 GeV
- •Linac 50 MeV



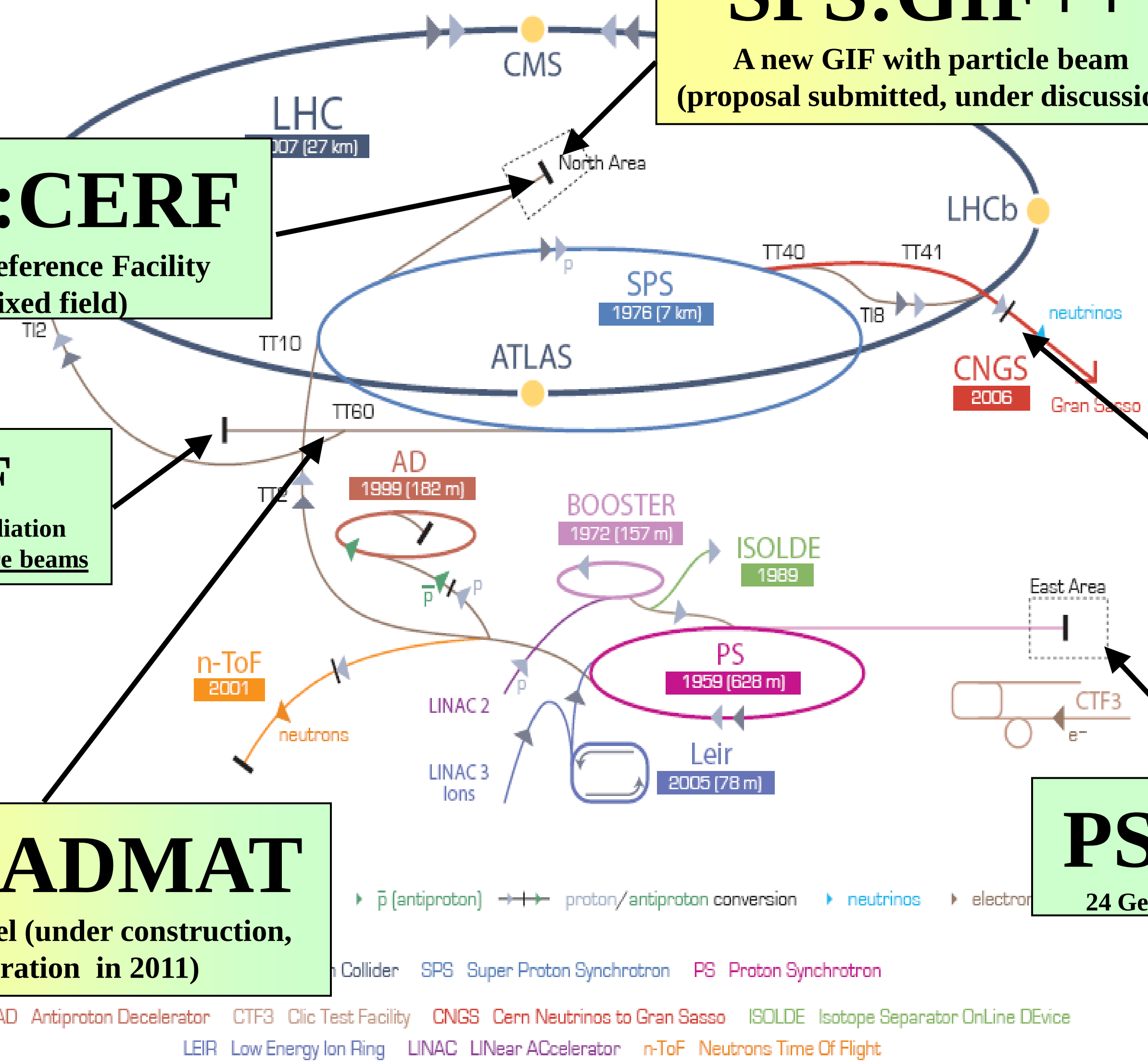
SPS:CERF
CERN Reference Facility (mixed field)

GIF
Gamma Irradiation Facility, <u>no more beams</u>

CNRAD
test area in parasitic operation to CNGS experiment (mixed field)

PS:IRRAD
24 GeV/c protons & mixed field

CERN ACCELERATORS & IRRADIATION FACILITIES



SPS:GIF++

A new GIF with particle beam (proposal submitted, under discussion)

SPS:CERF

CERN Reference Facility (mixed field)

GIF

Gamma Irradiation Facility, no more beams

HIRADMAT

TT60 tunnel (under construction, operation in 2011)

CNRAD

test area in parasitic operation to CNGS experiment (mixed field)

PS:IRRAD

24 GeV/c protons & mixed field

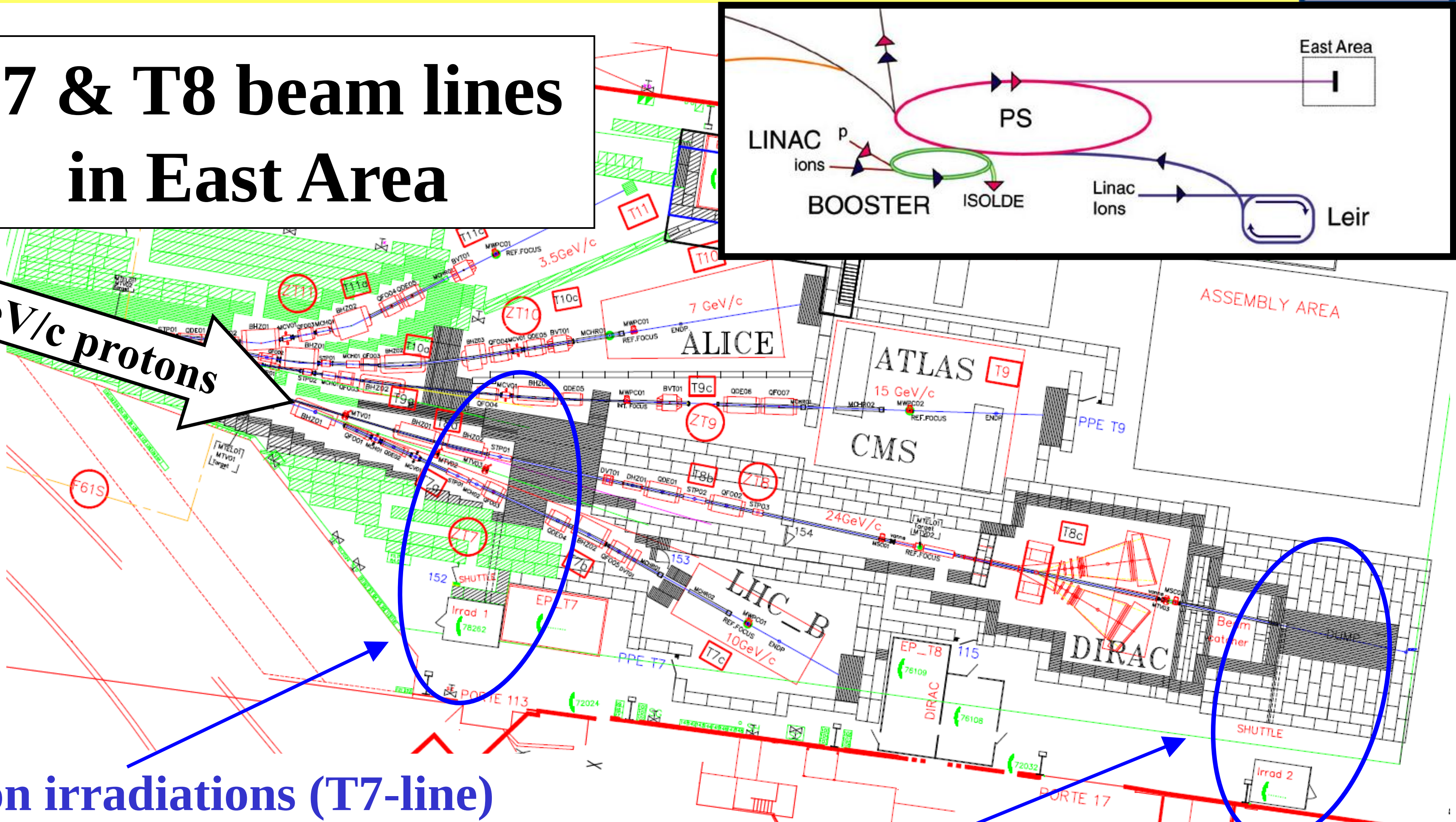
Proton energy

- **LHC 7 TeV**
- **SPS 450 GeV**
- **PS 28 GeV**
- **PSB 1.4 GeV**
- **Linac 50 MeV**

CERN PS East Hall - Irradiation Facilities

T7 & T8 beam lines in East Area

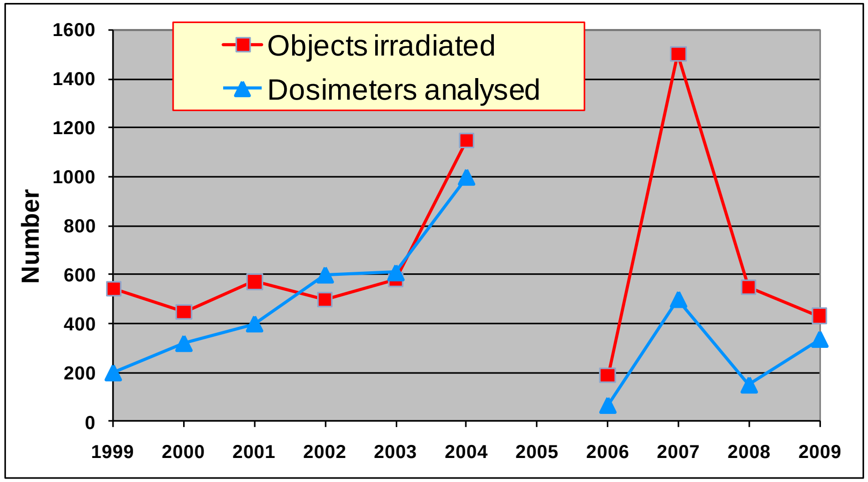
24 GeV/c protons

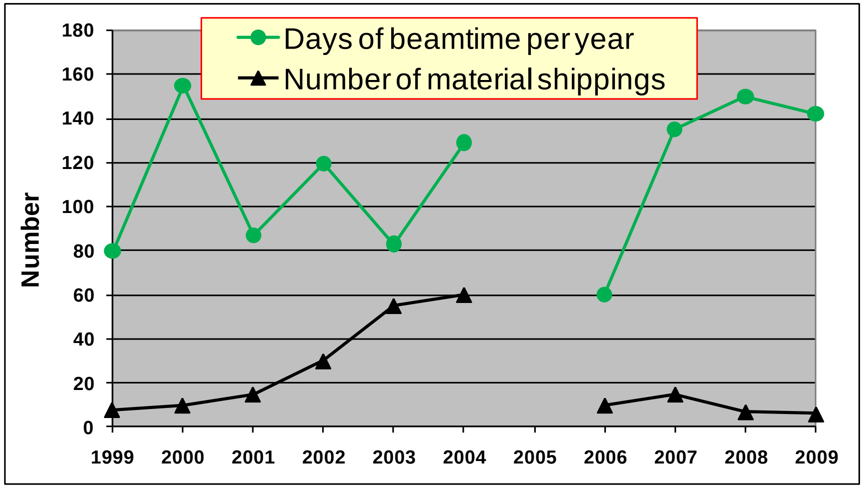


- **Proton irradiations (T7-line)**
  - **Direct exposure to 24 GeV/c protons** (shuttle + boxes in primary area)
  - **Flux: 1-10×10^{14} p/cm^2/hour** (on 2x2cm^2)
  - SEU testing field (IRRAD6)
- **Mixed field irradiations (T8-line)**
  - **Mixed field in cavity after carbon/lead 'target'**
  - **~5×10^{11} n_{eq}/hour** (at 50 cm from beam axis)

PS EAST HALL – User statistics

- **Facilities are heavily used** (in operation since 1992)
  - **Irradiation of 400 to 1500 objects/year (in 80-150 days of beamtime/year)**





Drawbacks of the EAST Hall facility:

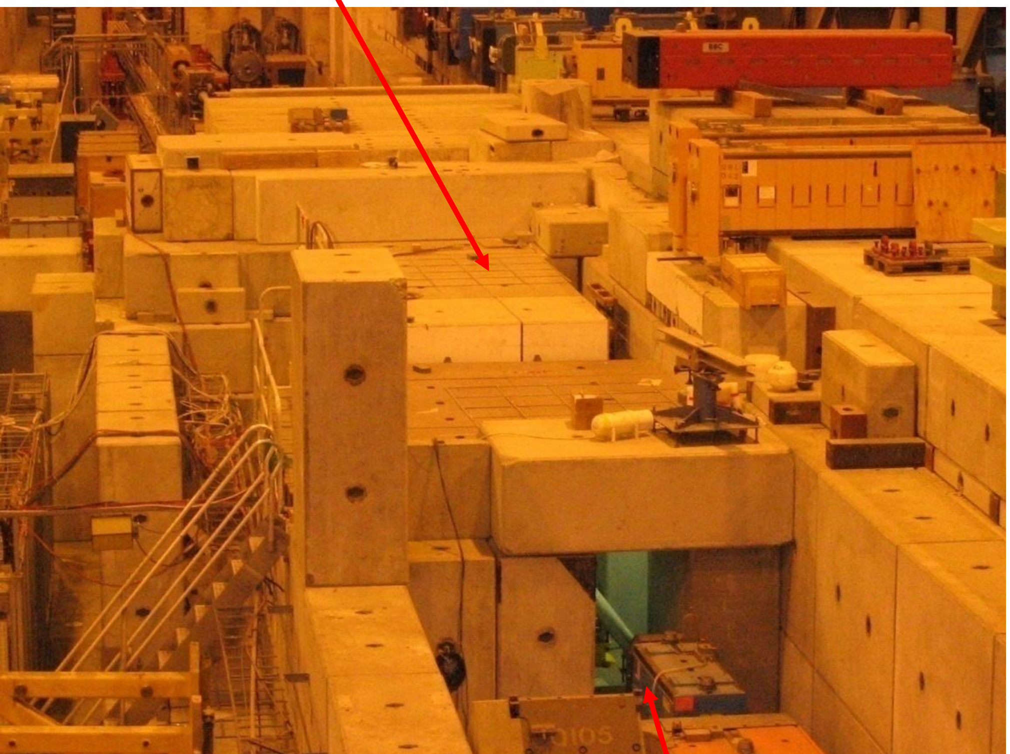
- **Proton Irradiation facility**
  - **Located in primary zone** *(limited access: stop all beam lines for access, wait for de-activation)*
  - **Limited space** *(Personnel exposed to radiation, difficult to scan beam over big objects, backscattered particles)*
- **Mixed field irradiations (behind DIRAC)**
  - **No irradiation position lateral to target, limited intensity, too little space (only shuttle), parasitic to DIRAC**
- **Proton & Mixed field facility located in different beam lines**
  - **Parallel operation of two facilities leads to competition for beam**

CERF - CERN Reference Facility

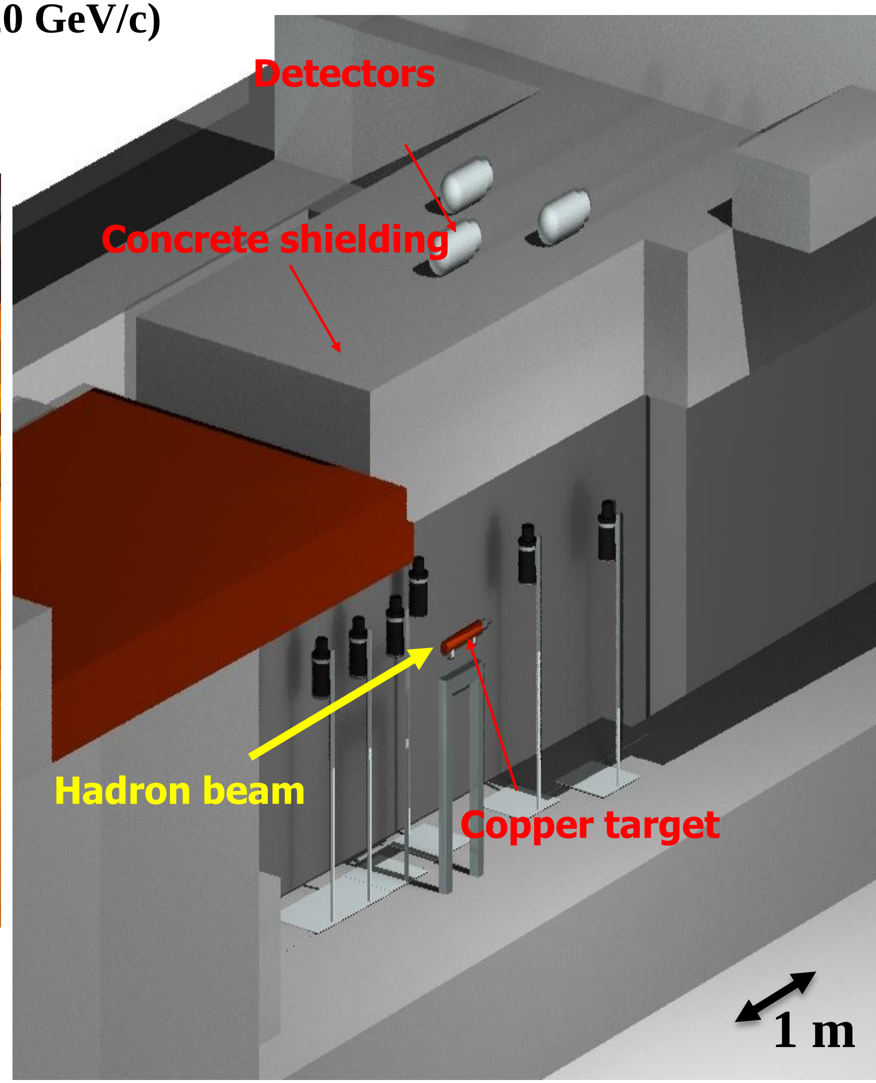
• H6 beam line in SPS North Area

- SPS secondary beam (usually hadrons of 120 GeV/c) impinging on copper target

locations



H6 beam



CERF - CERN Reference Facility

- **SPS (H6) secondary beam, 120 GeV/c hadrons**
  - **60.7% protons, 34.8% pions, 4.5% Kaons**
  - **well defined and simulated mixed radiation fields**

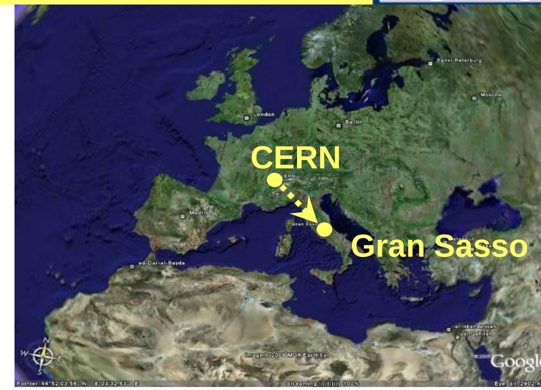
- **Intensities**
  - **max 10^8 particles/pulse (slow extraction) (resulting in up to few Gy/h)**

- **In operation since 1992, 1-2 weeks/year**
  - **mainly used for test/calibration of passive and active detectors for dosimetry or radiation monitoring**
  - ~20 teams/week, internal and external users
  - FLUKA benchmarking, beam loss monitor studies

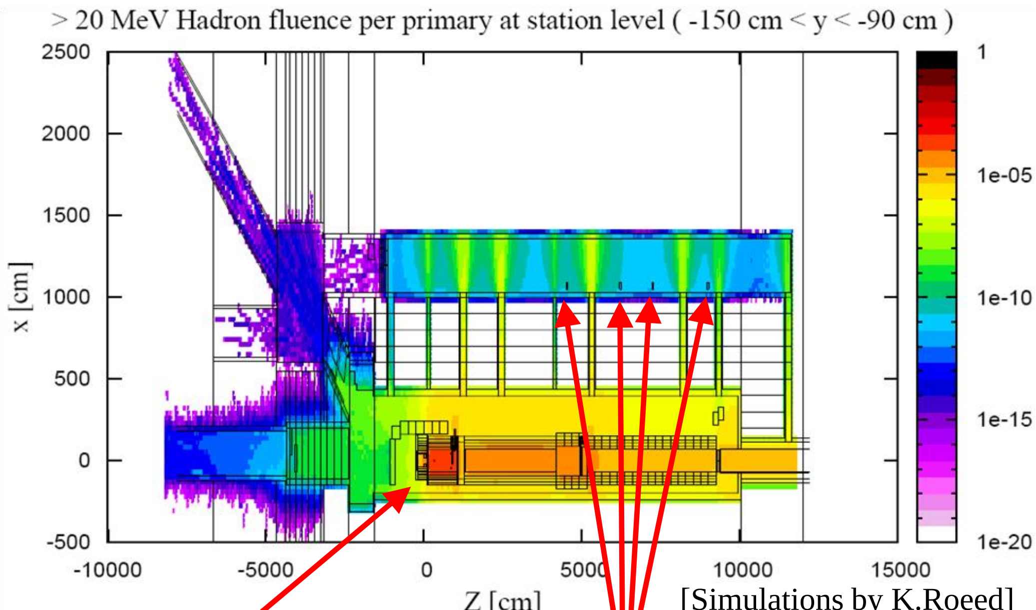
- **Drawback: ☹**
  - **limited dose rates** - max allowed intensity for one spill is 10^8 hadrons
    - limited beam time (presently 1-2 weeks/year)
  - **some muon and neutron background**

CNRAD electronics irradiation - CNGS

- **CNGS**
  - **Produce neutrino beam at CERN**
  - **Measure tau neutrinos in Gran Sasso, Italy (732km)**
  - **appr. 2 10^{17} 400 GeV/c protons on target per day**



- **Parasitic use of CNGS experiment radiation field**



[Simulations by K.Roeed]

Target

Radiation test stations in the service gallery

CNRAD electronics irradiation - CNGS

Note: 'CNRAD' given here as acronym for electronics irradiations in TCG4 (CNGS)

- **Characteristics**
  - **Exposure to mixed high-energy radiation fields**
    - **well-characterized thanks to extensive FLUKA simulations**
    - **stable conditions thanks to fixed 'operational mode' for CNGS**
  - **Mainly focused for SEE on installed LHC electronics**
    - **four stations fully equipped for remote control and readout of components**
    - **possible to test complete systems (crates)**
  - **Dose rates :**
    - **CNGS : 1 to 150 Gy per week**
    - **LHC ARC-DS : 1 to 200 Gy per year**
  - **Drawback: ☹**

    Parasitic to CNGS, access conditions, long access tunnel, safety

A survey on future needs

- **Survey performed by:**

'Working group on future irradiation facilities at CERN'

- Interdepartemental working group formed in 12/07 on request of several department heads
- Web-based survey on requirements and needs for irradiation facilities: Collected > 135 forms
- Details on the survey: **http://www.cern.ch/irradiation-facilities/**

- **Detailed questions asked on:**
  - Beam type (gamma, proton, ion, mixed field) and energy (spectrum)
  - Total dose, irradiation surface, exposure profile
  - Dimensions of experimental area, infrastructure
  - Access needs during exposure, …. etc.

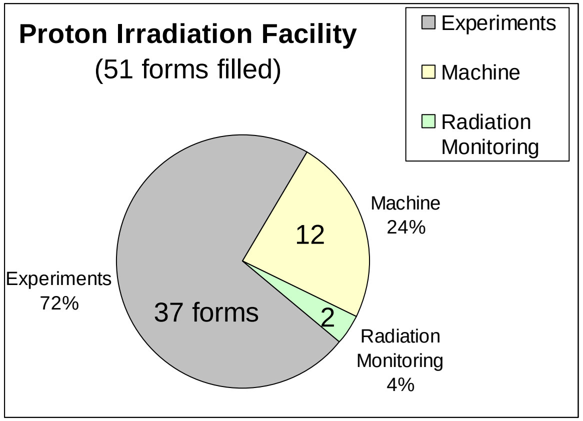
- **Conclusion**
  - 4 complementary irradiation facilities required to cover needs

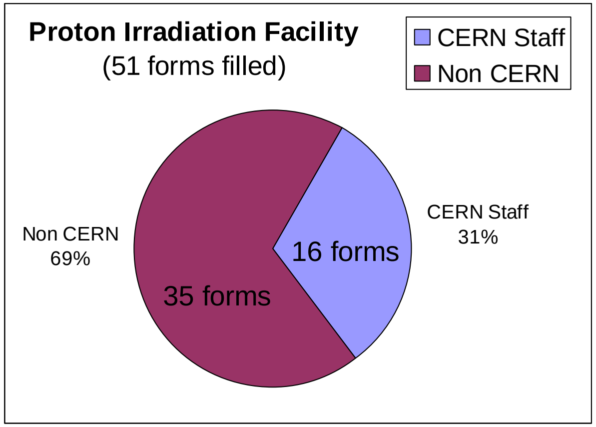
1) Proton and ion irradiations at high energy and high density (fast extraction) → **HiRadMat**
2) Gamma irradiations in the presence of a muon beam → **GIF++**
3) Proton irradiation at high intensity (slow extraction)
4) Mixed-field irradiations with slow extraction

→ **Subject to this proposal**

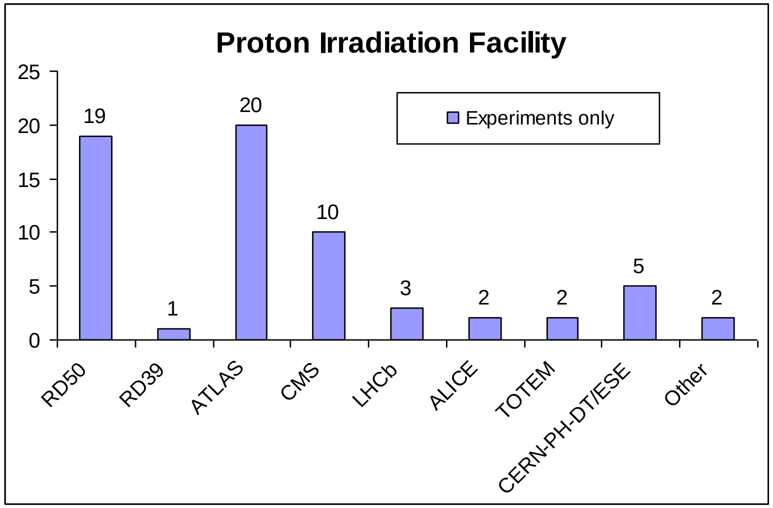
Survey on need for proton irradiation facility

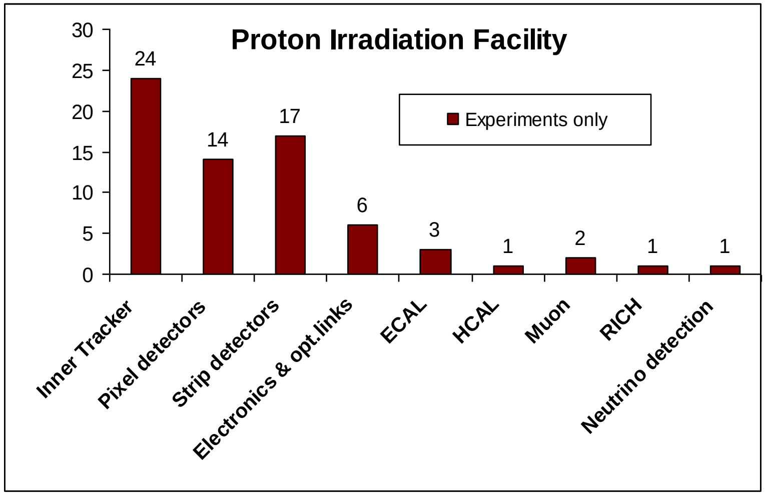
- **User community: Dominated by users from the Experiments (72%)**





- **Users from the (LHC) Experiments:**

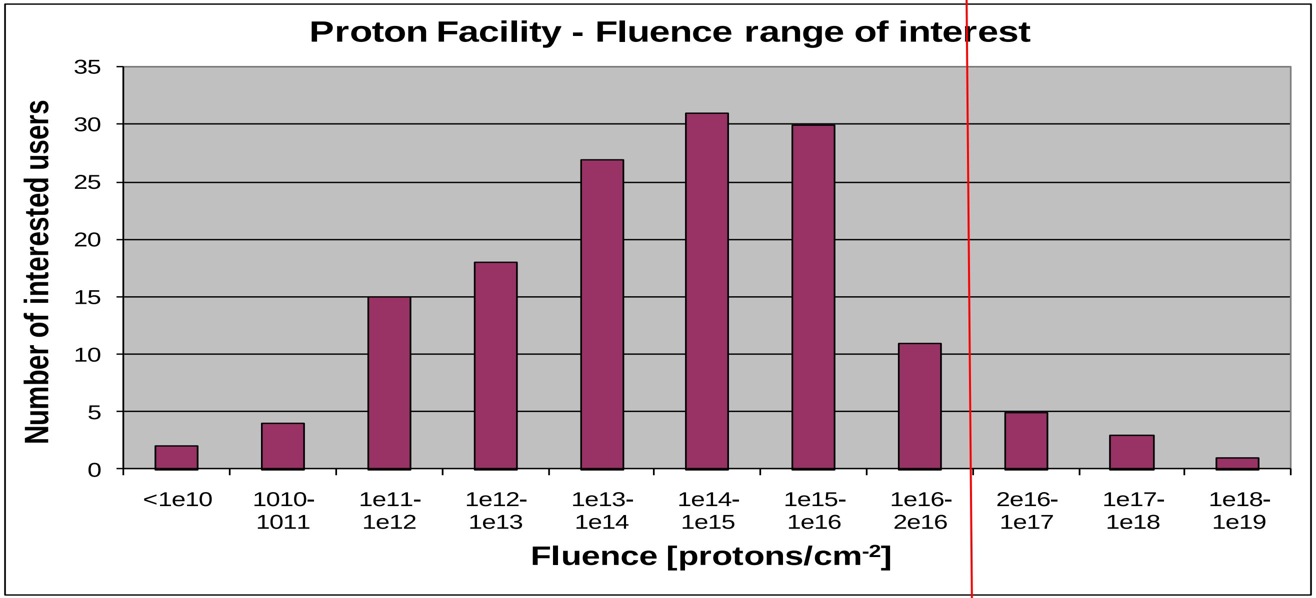




Survey on need for proton irradiation facility

- **24 GeV/c protons preferred against 450 GeV/c protons (slow extraction)**

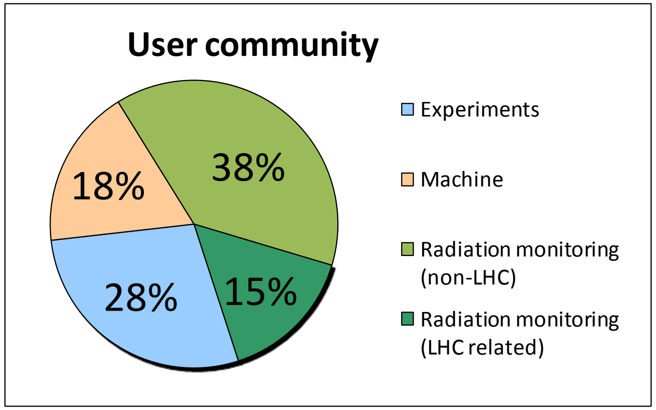
- **Required proton fluence for the requested experiments**

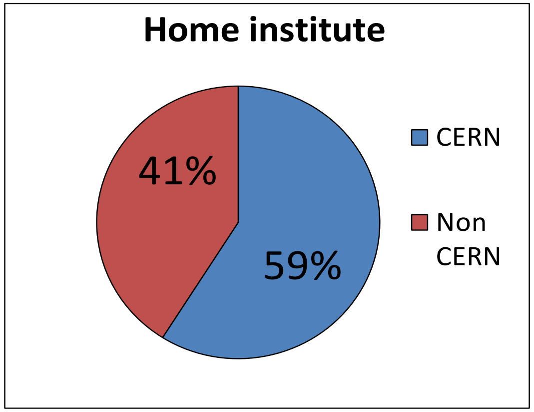


- **Conclusion:**
  - A particle fluence of $2\times10^{16}cm^{-2}$ with a homogeneous beam profile over $5cm^2$ should be reached in about 2 weeks to satisfy majority of users.
  - This corresponds to the need of the Pixel Detector Community for radiation levels cumulated with an integrated luminosity of 3000 fb^{-1}.

Survey on need for mixed field facility

- **User community: Mixture of different communities (based on 39 replies)**





- **Types of equipment intended to be irradiated**

Type of equipment	Fraction of votes (59 votes given)	Fraction of questionnaires (39 forms filled)	Examples
Detector or detector component	42.4%	64.1%	LHC detector components
Accelerator component	8.5%	12.8%	Radiation hardness to electronics (e.g.: power converter)
Material (generic)	10.2%	15.4%	E.g.: organic materials like cables
Radiation monitor or dosemeter	30.5%	46.2%	RP equipment
Others	8.5%	12.8%	

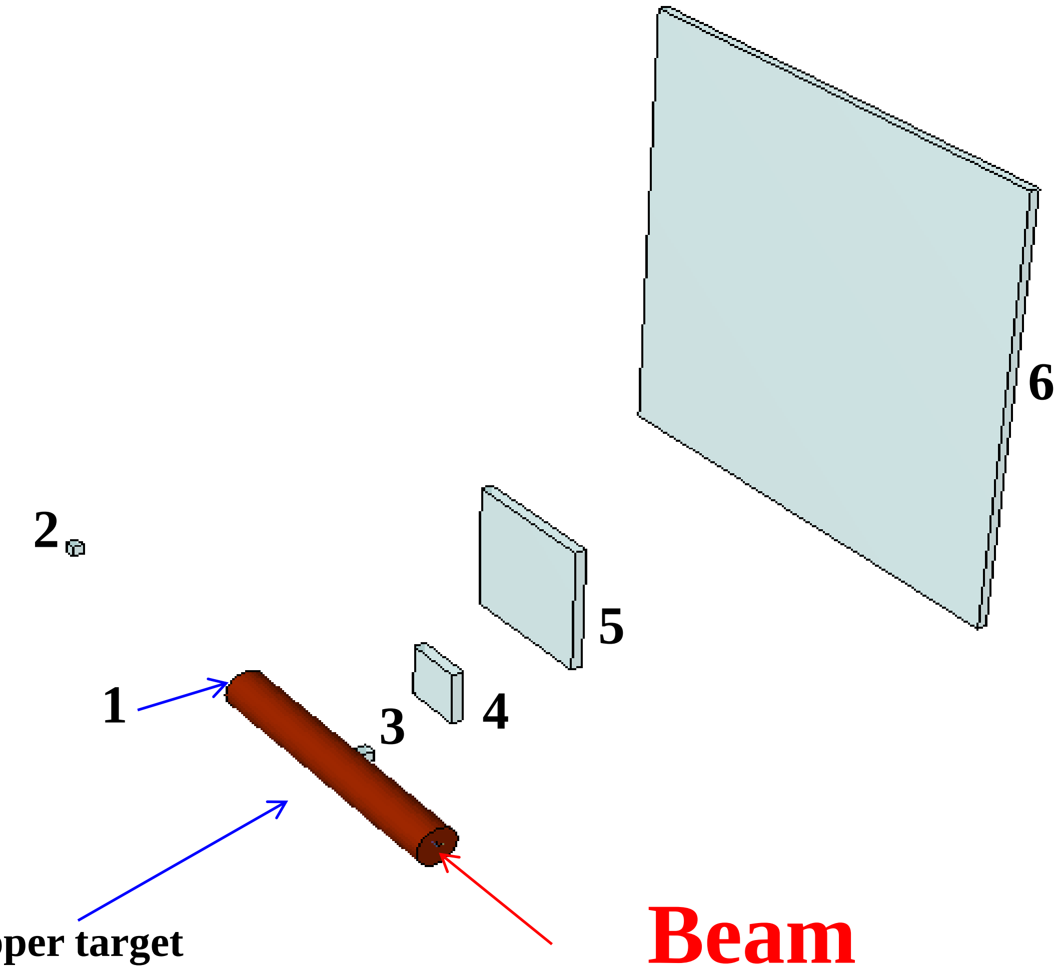
Survey on need for mixed field facility

- **No strong preference on energy of primary beam (24 vs 450 GeV/c), however strong preference on slow extraction operation.**
- ***'LHC like fields'* are mainly requested by LHC machine and LHC detector community**
- **Test to machine electronics would require radiation fields which occur in the LHC close to beam loss points or behind concrete shielding**
- **Radiation monitor and dosemeter tests would require radiation occurring behind thick shieldings**
- **Test to detector components would require radiation fields which occur close to the LHC collision points**

All these requested radiation fields can be reproduced in an irradiation facility using 24 GeV/c or 450 GeV/c protons hitting a 50 cm long beam target

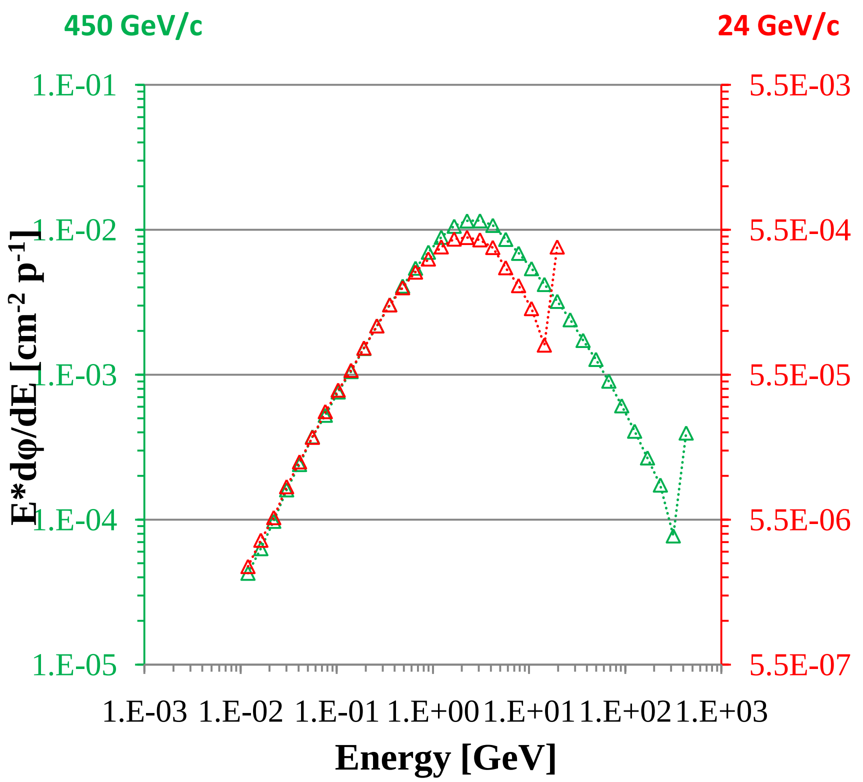
Dose and fluence calculation results for a beam on target situation at 24 GeV/c

Various irradiation positions reproduce radiation fields of the LHC operation

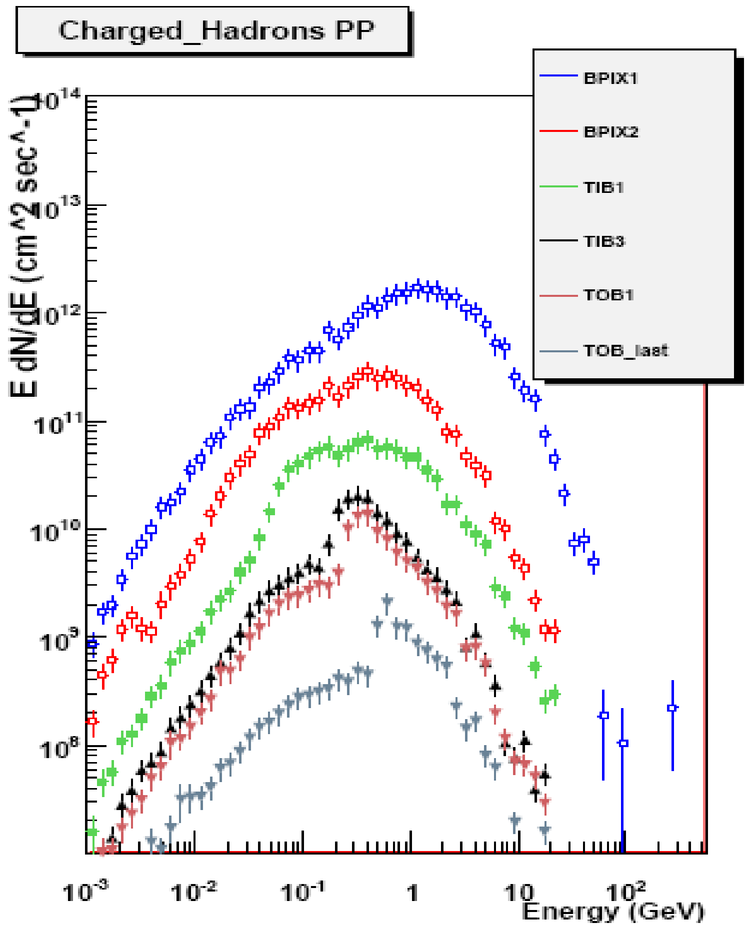


Copper target
(length: 50 cm, diameter: 7 cm)

Comparison: LHC vs. Irradiation facility
LHC Experiments (inner tracker)



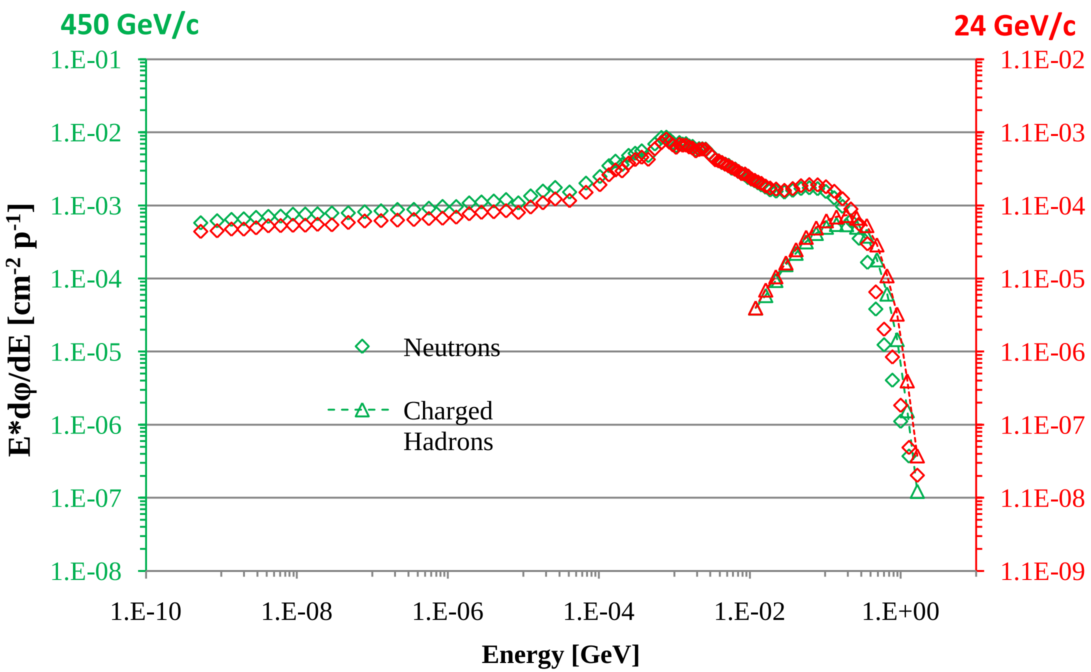
Charged hadron radiation field in a conceptual irradiation facility seen at a position downstream the target



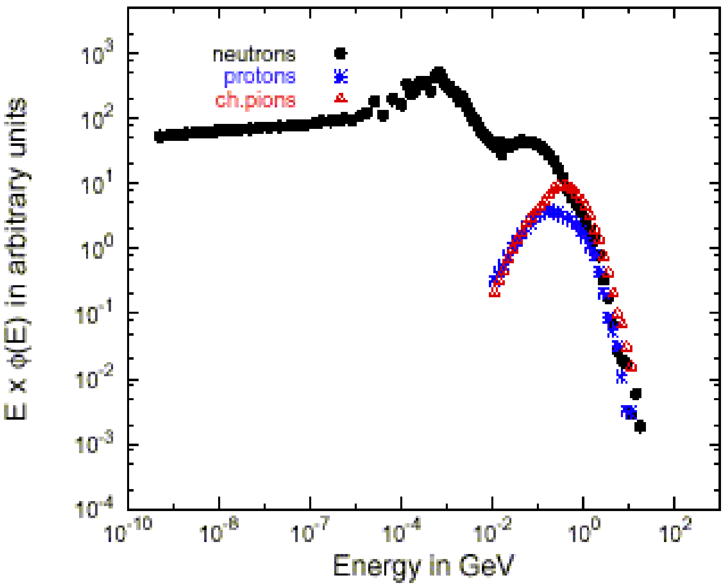
Radiation close to the innermost CMS detector layers surrounding the interaction point. (N. Mokhov)

- **Very similar shape of the spectra**

LHC Accelerator



Neutron radiation field in a conceptual irradiation facility seen lateral to target position



Fluences in the LHC tunnel (C. Fynbo, G. Stevenson, CERN, 2001)

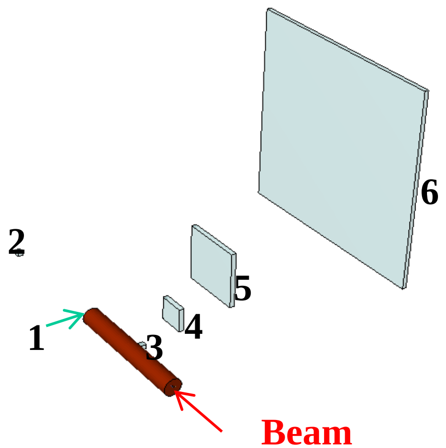
- **Very similar shape of the spectra**

Dose and fluence calculation results for a beam on target situation at 24 GeV/c (and 450 GeV/c)

Radiation field values are quoted per 2×10[16] 24 GeV/c protons (intensity per week)

	Position	Size	Dose	Neutrons 1MeV equiv.	Hadrons >20 MeV
		cm^2	Gy	cm^{-2}	cm^{-2}
1	Target end position	2x2	1.08E+06	1.90E+15	1.71E+15
2	50 cm downstream the target	2x2	7.20E+04	1.34E+14	2.32E+14
3	Target side position	2x2	1.76E+05	2.00E+15	7.72E+14
4	20 cm lateral to the target	10x10	3.00E+04	1.84E+14	5.60E+13
5	50 cm lateral to the target	25x25	6.80E+03	4.00E+13	1.26E+13
6	1.5 m lateral to the target	100x100	9.00E+02	5.20E+12	1.54E+12
7	3.5 m lateral +1 m concrete shield (estimated)	Min. 100x100	1.80E+01	1.06E+11	3.08E+10

Note: To reach similar values at 450 GeV/c ~10% of the intensity is required



- **Using a weekly beam intensity of 2×10^{16} protons at 24 GeV/c (or 2×10^{15} protons at 450 GeV/c) the minimum requirements of almost all users can be fulfilled**
- **Maximum fluence requirement: 2×10^{16} n/cm^2**
  (innermost Pixel Layers for sLHC – $3000fb^{-1}$)

Available protons at PS and SPS locations

- **Number of available protons at PS or SPS locations?**
  - **Experimental facilities and beam lines (users) are competing for beam!**
  - **Available beam depends very much on priority given to irradiation experiment!**
  - **Could in principle deliver in the order of 1.5×10^{17} protons/year into PS and SPS locations per year** (see Annex C of proposal)
  - **However, radiation protection and shielding issues have to be considered** (Clearly more severe for higher energetic protons! – Especially: Muons)

- **Comparison to operating irradiation facilities:**
  - **The PS irradiation facilities have received in 2008 and 2009 1.5×10^{17} protons/year**
  - **The CERF facility in the SPS North Area is limited to 10^8 hadrons/pulse !** (3 orders of magnitude lower than assumed in the above calculation for the SPS leading to the 1.5×10^{17} protons/year)

- **Conclude:**
  - **For a proton irradiation facility a PS location is clearly favored against a SPS location**
  - **For a mixed-field facility the fact that 450 GeV/c protons produce a 10 times higher field intensity than 24 GeV/c protons is 'compensated' by the fact that at the SPS less beam time (less protons) will be available.**

Why do we put forward this request now?

This proposal is timely for two reasons:

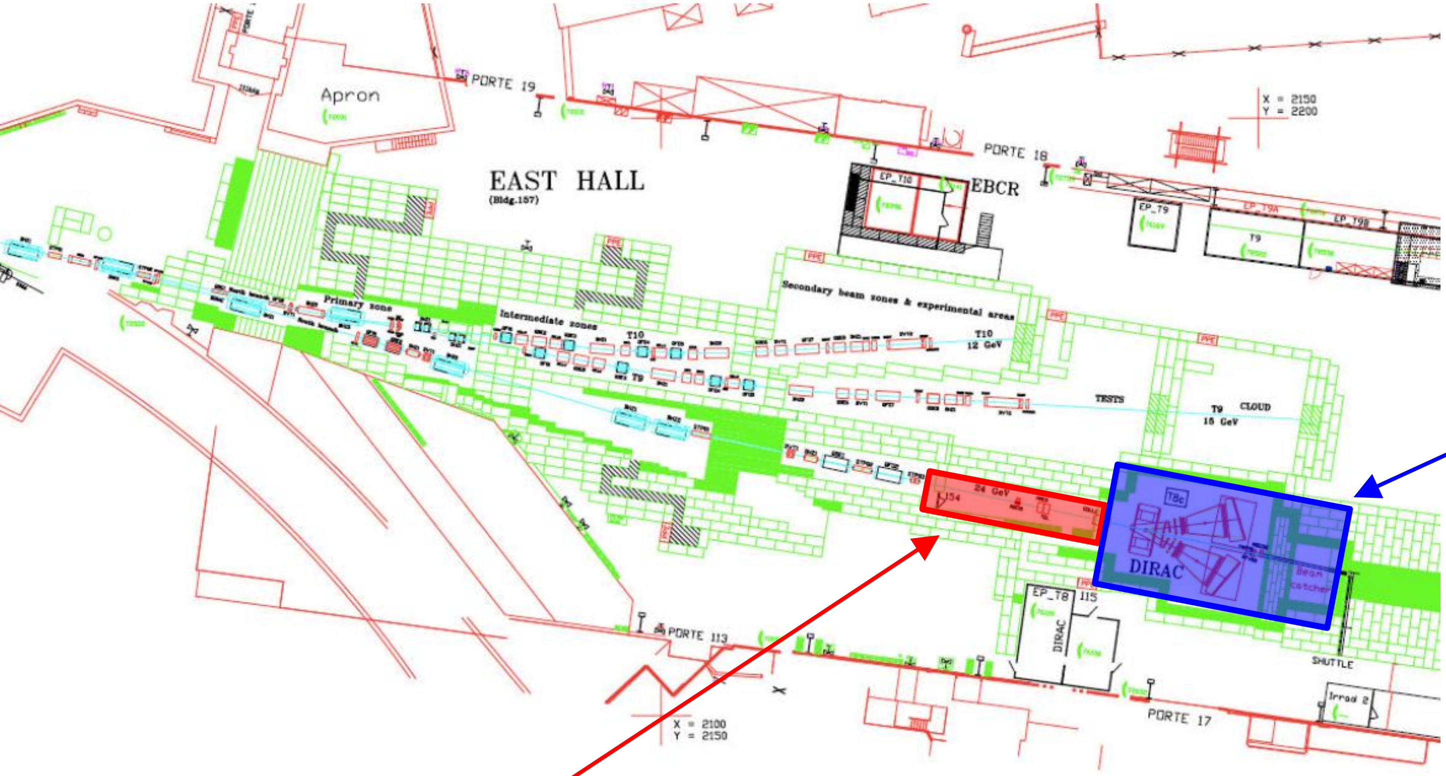
- **After Chamonix 2010: East Hall renovation plans progressing**
  - Renovation plans presented on IEFC Workshop 2010 (L.Gatignon)

Proposed layout, 2010 version:

- **AIDA proposal approved including EU-funding for facilities upgrade:**
  350 Keuros for facility and 150 Keuros for infrastructure (EU contribution)

Long term plans for facilities: Next steps

- **Assuming a close end of the data taking of the DIRAC Experiment in the near future, we would like to proceed and study an implementation option that combines the proton and the mixed field facility in the EAST HALL**



mixed field facility

(multiple user communities: LHC machine LHC Experiments, Dosimetry (RP), MC benchmarking)

Proton Facility

(main user community: LHC Experiments)

Conclusions & request to the LHCC

- **Main aim:**

Inform the LHCC and seek recognition of the scientific case for improved radiation facilities at CERN.

<u>In particular</u> this proposal concerns two types of facilities:

- **A proton irradiation facility with slow extraction.**
- **A mixed field facility based on a slow extracted proton beam**

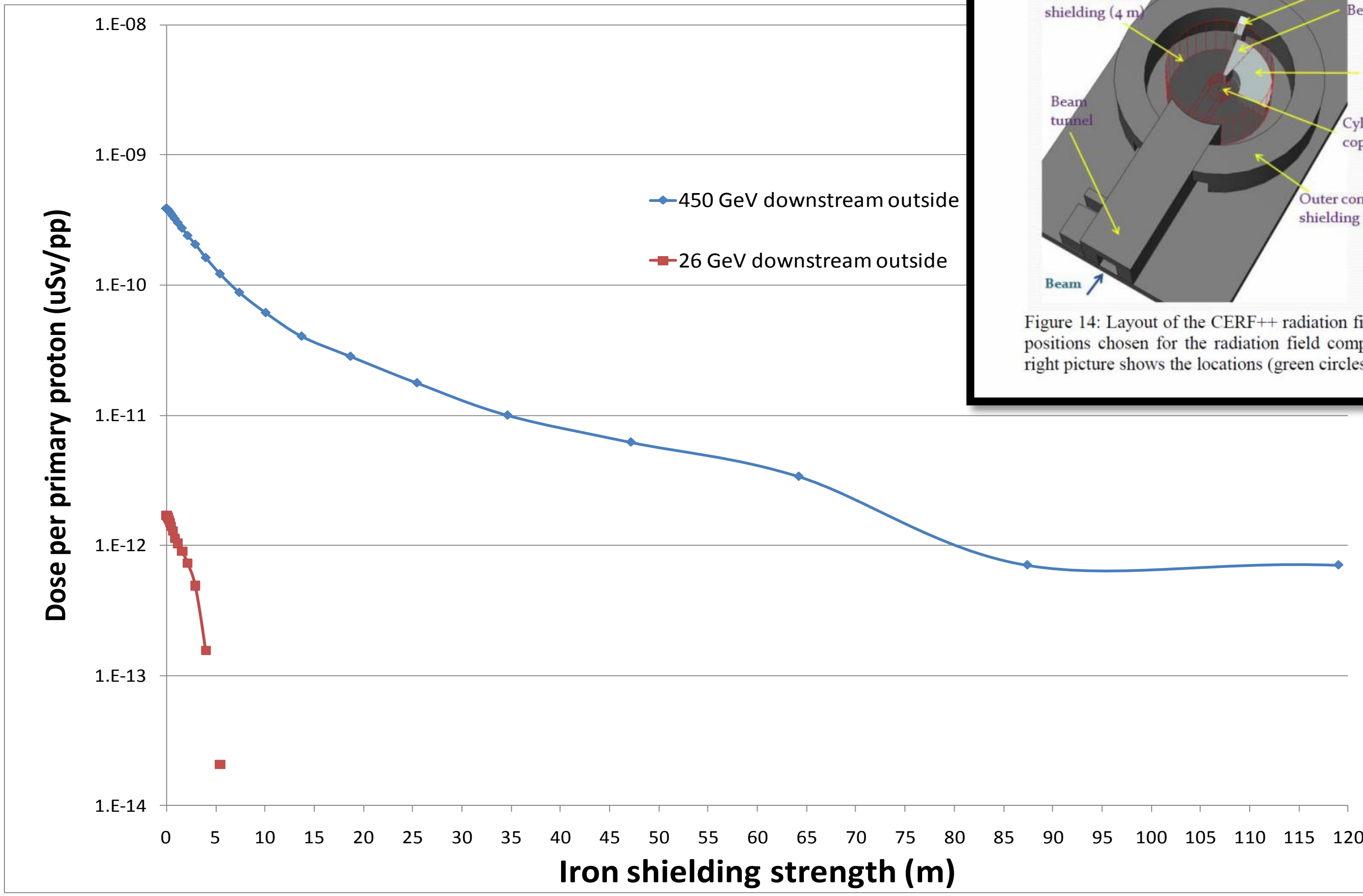
- **We seek support to proceed with implementation options and cost estimates, and <u>in particular</u>:**

We seek support from the LHCC for pursuing an implementation study of a combined proton and mixed-field facility in the PS EAST Hall.

SPARES

Muon shielding

- **Iron shielding strength (PS vs. SPS location):**



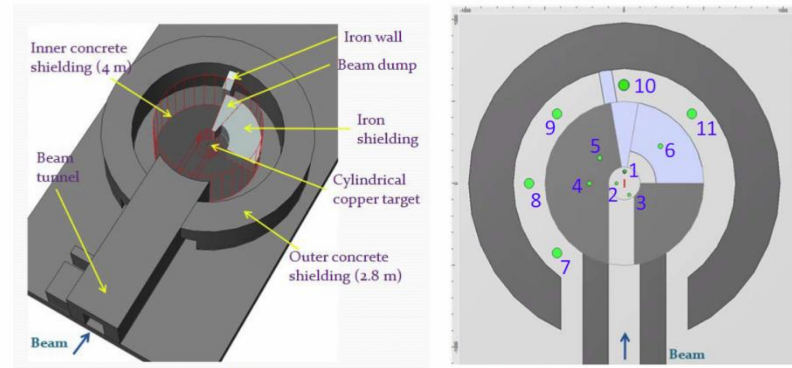


Figure 14: Layout of the CERF++ radiation field simulation study (left site) and hypothetical measurement positions chosen for the radiation field comparison between 24 and 450 GeV/c proton irradiations. The right picture shows the locations (green circles) used for the comparison of the radiation fields.

Figure 17: Muon dose outside the CERF++ installation as a function of additional iron shielding thickness added to the 4 m iron dump (see Position 10 in Figure 14). Note: the calculation considers a collimated muon beam without dispersion.

PS - Proton irradiation facility

Beam specifications:

- **Primary PS proton beam**
  - **Beam line: PS-T7**
  - **Beam energy: 24 GeV/c**
- **Slow extraction**
  - **Spills of protons (~ 2×10^{11} p, 400 ms)**
  - **Beam spot: ~ 2 x 2 cm^2**
- **Proton flux**
  - **~ 1 - 10 × 10^{13} p cm^{-2} h^{-1}**

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^3)
- **Scanning over surfaces up to 20 x 20 cm^2**

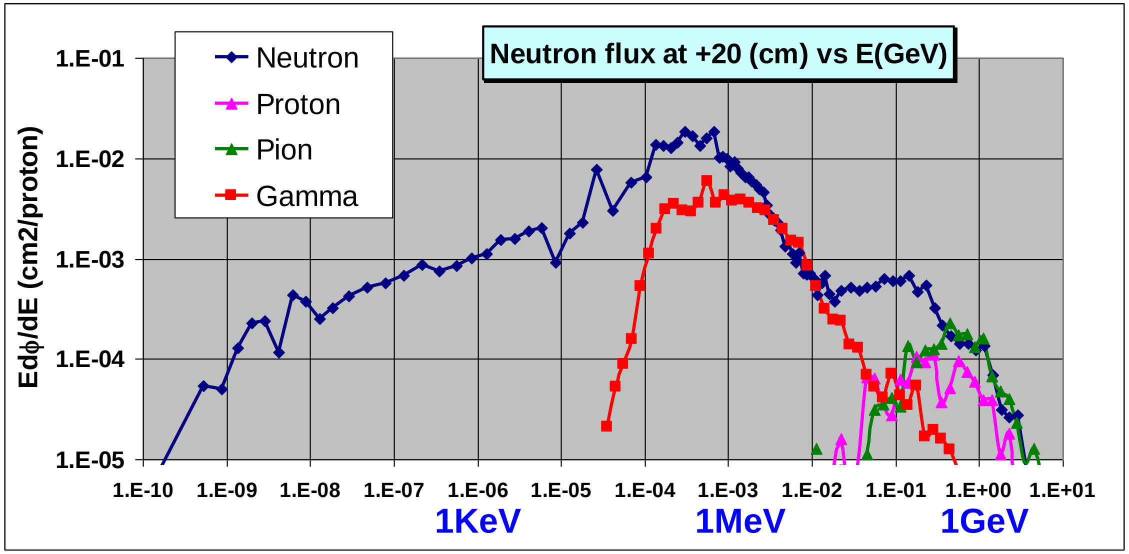
Shuttle system (IRRAD1)

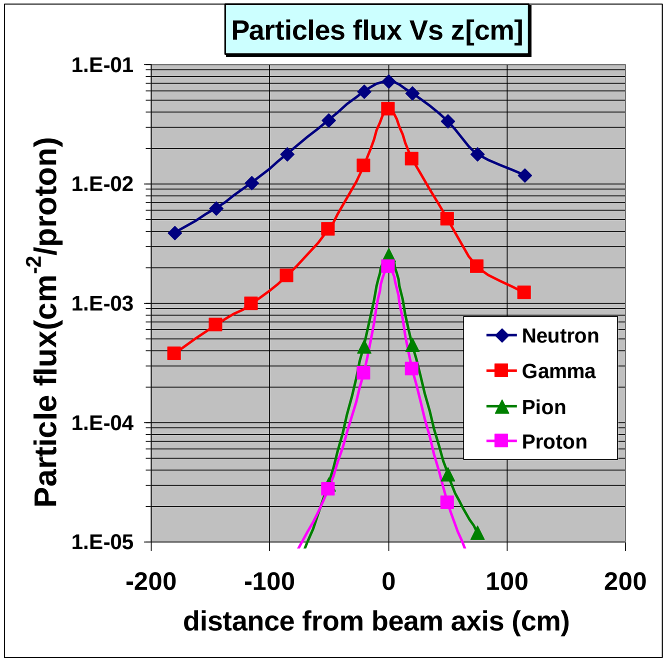
- **Standard volume: 5 x 5 x 15 cm^3**
- **Max volume (on request): 10 x 10 x 20 cm^3**
- **Electrical connections**

PS – mixed field (IRRAD2)

– parasitic to DIRAC experiment -

- **Irradiation with secondary particles in irradiation cavity**
  - **Field created by 24 GeV/c proton beam on carbon/lead 'target'**
  - **Spectrum and flux of neutrons, protons, π+, π- and, gammas simulated and measured**





- **Neutron flux**
  - **1 – 3 × 10^7 n cm^{-2} s^{-1} (E > 1 MeV) at 50 cm from beam axis** (6 days for 10^{13} n cm^{-2})
  - **Tabulated fluxes for different energy cuts and irradiation positions available for users**
- **Irradiations performed with a shuttle system very similar to proton shuttle**
  - **Conduit:** 40x40 cm^2, 15 m long conduit
  - **Standard volume for irradiations 20 x 20 x 20 cm^3** (on demand up to ~ 30 x 30 x 35 cm^3)

Setup and operate an irradiation facility (1/2)

"A properly performed irradiation test is an experiment in itself !"

What a facility should provide to perform irradiation experiments:

- **Deliver the desired beam**
  - **beam on demand, not without control in parasitic operation**
  - **intensity, beam spot, time structure (slow or fast extraction)**
  - **steering : beam and/or equipment (scanning table)**
  - **monitoring of beam intensity and radiation field**

- **Know and control the radiation environment**
  - **provide detailed Monte Carlo simulations in order to have well-defined spectra**
  - **in-situ dosimetry providing information on the actual doses accumulated**
  - **escaping radiation (by shielding) and internal activation (by design) must remain within limits**
  - **for high intensities:**
    - closed ventilation loop,
    - Impact on infrastructure – optimized maintenance procedures

- **Access conditions**
  - **pre-test documentation, preparation and optimization: materials, time**
  - **access authorization, training**
  - **traceability : in/out movements, logs, RP control**

Setup and operate an irradiation facility (2/2)

- **Auxiliary installations**
  - **nearby control room for “hot” tests during exposure**
  - **remote handling of equipment and services**
  - **storage area**
    - initial cool down just after exposure
    - medium/long term storage in view of future re-use
  - **qualified lab to work on exposed materials**
    - modify for re-use, analysis after irradiation
  - **flexible detector infrastructure**
    - e.g. gas systems, cooling

- **Final product: make scientific results available to the community**
    - document and spread out the knowledge
    - results database: materials, components, ..
  - **.. and radioactive waste**
    - must be considered from the beginning !

Irradiation Facilities vs. Irradiation Test Areas:
*Irradiation test locations which are not fulfilling the above requirements (ad-hoc tests, parasitic use of beam, …) are labeled as **“Irradiation Test Areas”** in the following.*