Radiation Protection Issues for a Top-Up Operation of BESSY

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Introduction

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- Laws, time schedule
- Basic considerations of top-up operation
- Annual Doses (wall and open beamshutter)
- Safety measures
- Determination of measurement errors
- Pulsed beam correction calculation
- Calibration of high energy moderator
- Summary

Radiation protection ordinance

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- Dose limits (since August 1st, 2001)

Personal doses:

Non-radiation worker	< 1 mSv/a
Radiation worker category B	< 6 mSv/a

Ambient doses:

General area	< 1 mSv/a, 0.3 mSv/a
Surveillance area	< 6 mSv/a (2000h/a)
Control area	> 6 mSv/a (2000h/a)
Exclusion area	< 3 mSv/h

Only in Germany; not dH/dt but ΔH/Δt ; Δt = 30 sec
Accepted by state authority at accelerators because of bunched beam

- Operating licence

Report completed according check list of BMdI	7th July 2012
Application of operation licence	7th July 2012
Secondary report completed (external expert)	23th Aug 2012
Operating licence test operation received	22nd Oct 2012

(1 year test operation)

BMdI = federal ministery of the interior

Basic considerations for top-up

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- BESSY has been designed as a decay mode operated machine. The design parameters include the number of electrons injected per year.
- The design parameters had been realistic (injection efficiency 30 %), the agreement between predicted and measured annual dose values are very good. Measurement errors have been determined accurately
- Top-Up means higher average current (shorter life time), so more electrons have to be injected/year. This must be compensated by an increased injection efficiency, to inject not more electrons/year than the shielding was designed for
- Radiation through the walls AND through the open front ends should hold the limit for non-radiation workers in the accessible part of the experimental hall

Measured annual doses @BESSY

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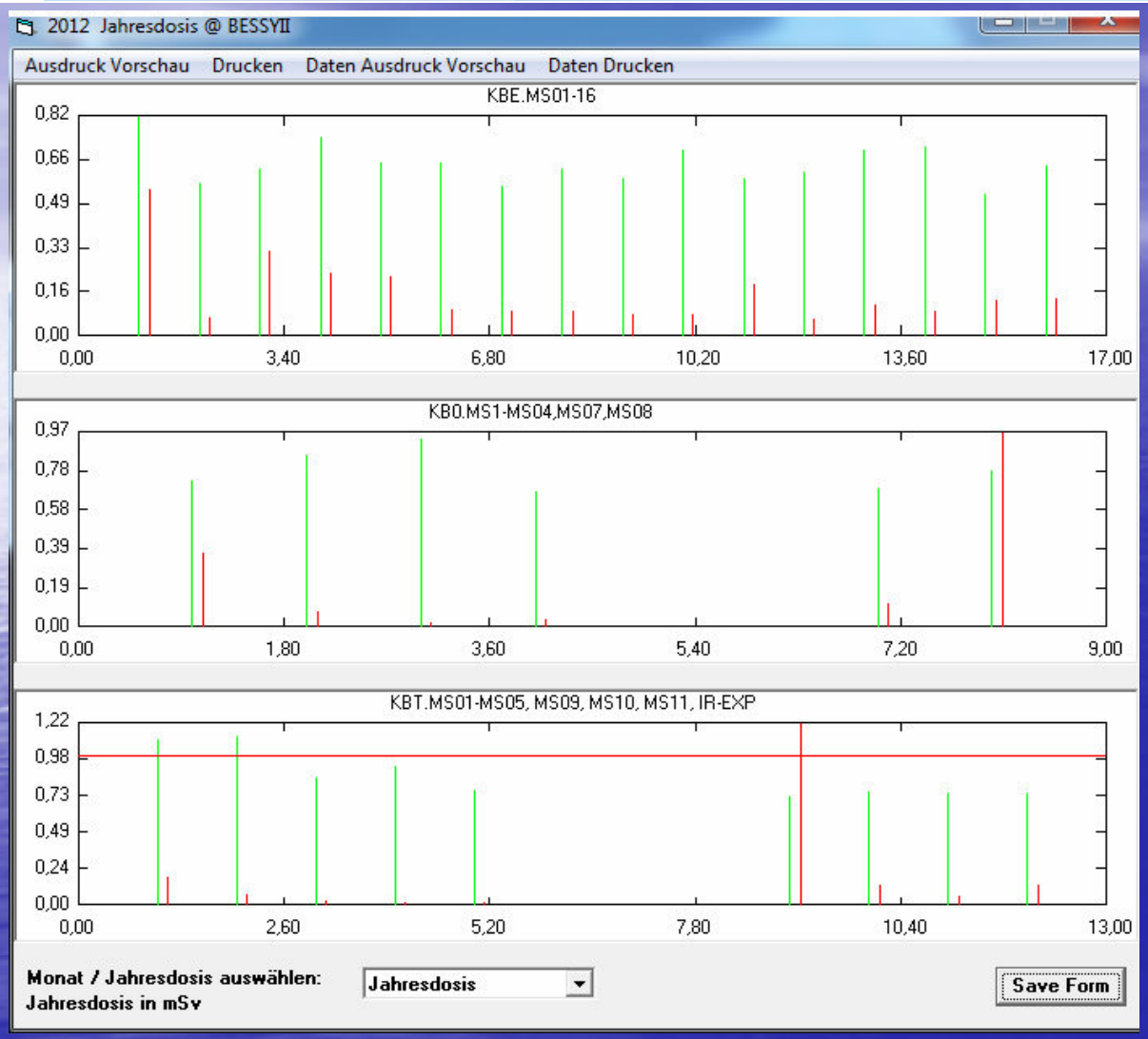

Gamma dose prediction
14 µSv/a
Cosmic gamma radiation in Berlin 0.6 mSv/a

Neutron dose
Prediction: 0.3 mSv/a GN
+0.8 mSv/a HEN

Measurement: 0.22 mSv/a
(section average 2-16)
HEN correction factor 3.72
0.22*3.72 = 0.82 mSv/a

Very good agreement with predicted annual doses

Radiation behind the walls

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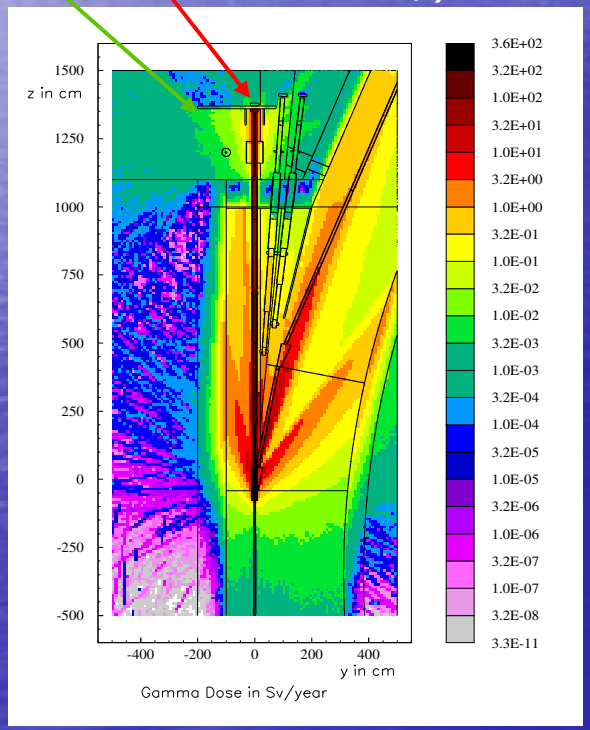
	Decay mode	Decay mode	Top-Up mode	Top-Up mode
Operation time	250 days/a	6000 h/a	250 days/a	6000 h/a
Injections	3/day	750/a	2880/day (30 sec)	720000/a
Current added in SR	150mA /injection	112.5 A/a	0.5 mA /injection	360 A/a
Charge		9.0E-5 C/a		2.88E-4 C/a
Efficiency		30%		90%
Electrons	5.62E14e-/a	**1.9E15e-/a**	1.80E15e-/a	**2.0E15e-/a**

Decay–mode and Top-Up mode inject the same number of electrons/a under the Top-Up conditions at BESSY. Therefore the annual dose behind the SR walls will be the same (1 mSv/a). (I max 300 mA)

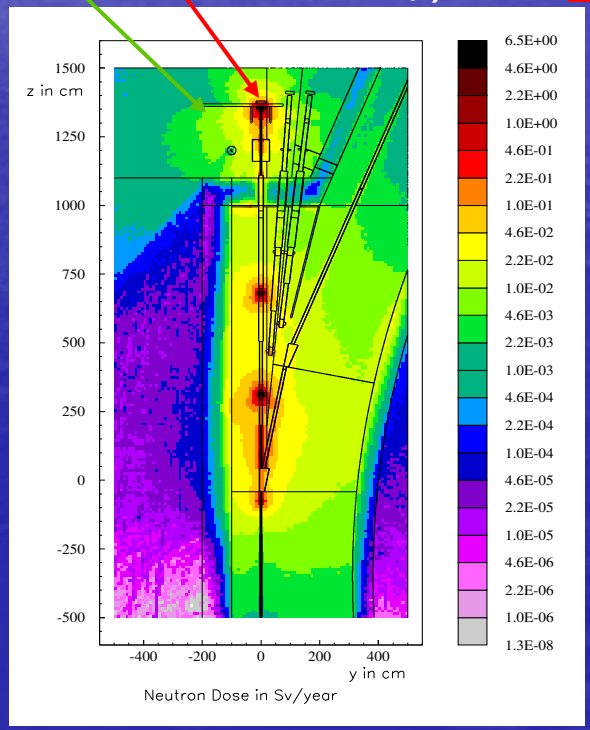
Annual dose through open BS

Top-Up mode: 6000 h/a user operation (250 days)
annual dose close to front ends: <11 mSv/a (fence)
(calculated with Fluka 90 % injection efficiency 2E15/16 e-/a)

Thin target (1 rad. length)
Gamma radiation
At fence: 3.2-10 mSv/year
Absorber:1.0-3.2 mSv/year



Thin target (1 rad. length)
Neutron radiation
At fence: 4.6-10 mSv/year
Absorber:10 -22 mSv/year

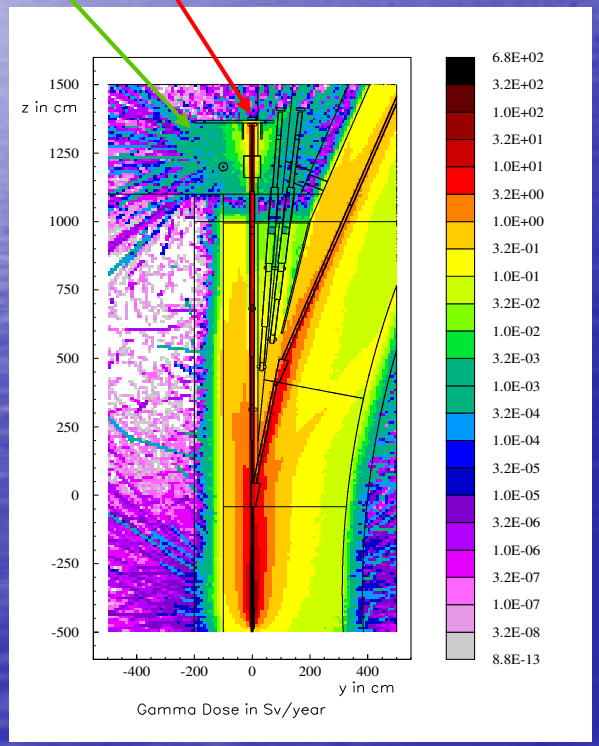


Absorber is now shielded 1 TVL PE Neutron dose/10

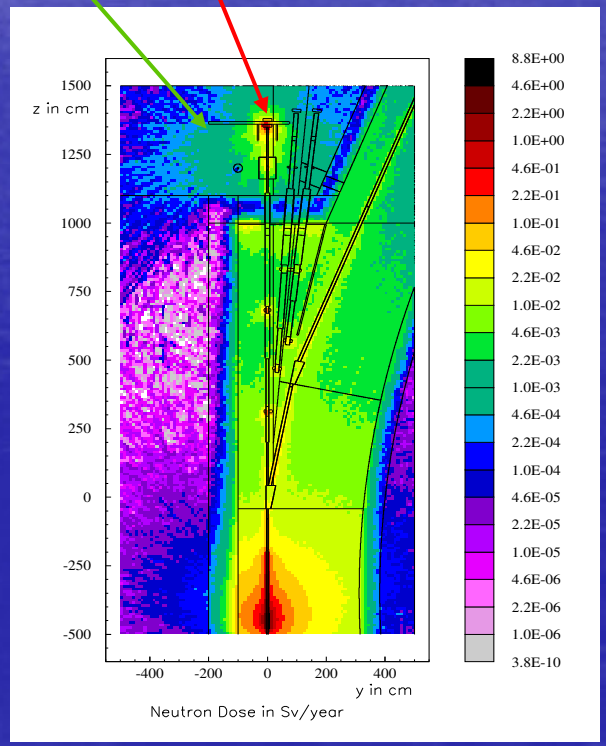
Annual dose through open BS

- Top-Up mode: 6000 h/a user operation (250 days)
  annual dose close to front ends: <3.2 mSv/a (fence)
  (calculated with Fluka 90 % injection efficiency 2E15/16 e-/a)

Undulator chamber
Gamma radiation
At fence: 0.32-1.0 mSv/year
Absorber:0.032-0.1mSv/year



Undulator chamber
Neutron radiation
At fence: 1.0-2.2 mSv/year
Absorber:4.6-10 mSv/year



Absorber is now shielded 1 TVL PE
Neutron dose/10

Annual dose through open BS

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Scenario	Gamma dose (average of range)	Neutron dose (average of range)	Sum
Thin target	6.6 mSv/a	7.3 mSv/a	13.9 mSv/a
Undulator chamber	0.66 mSv/a	1.6 mSv/a	2.26 mSv/a
Down-stream dipoles	0.066 mSv/a	0.16 mSv/a	0.226 mSv/a

Average annual dose: 5.46 mSv/a for 6000h/a 1.82 mSv/a for 2000 h/a

During test operation phase:
Experimental hall radiologically controlled area
Employees and users are radiation worker category B

Radiation through open BS

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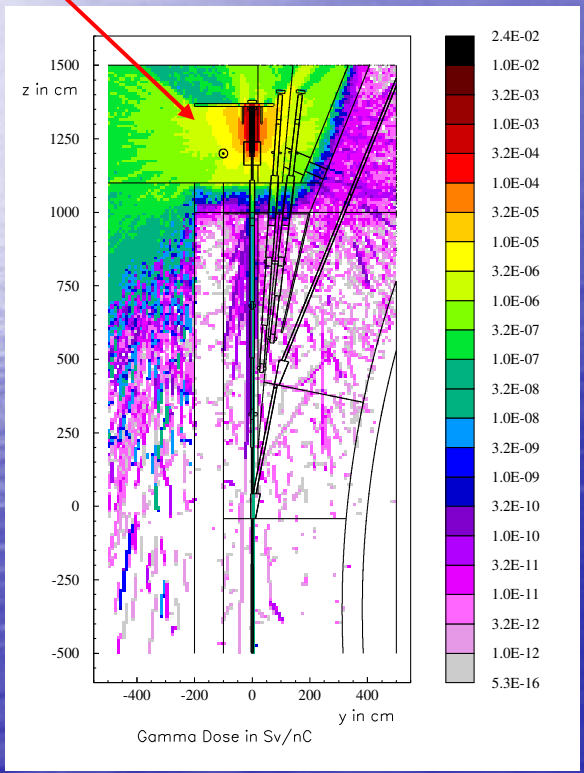
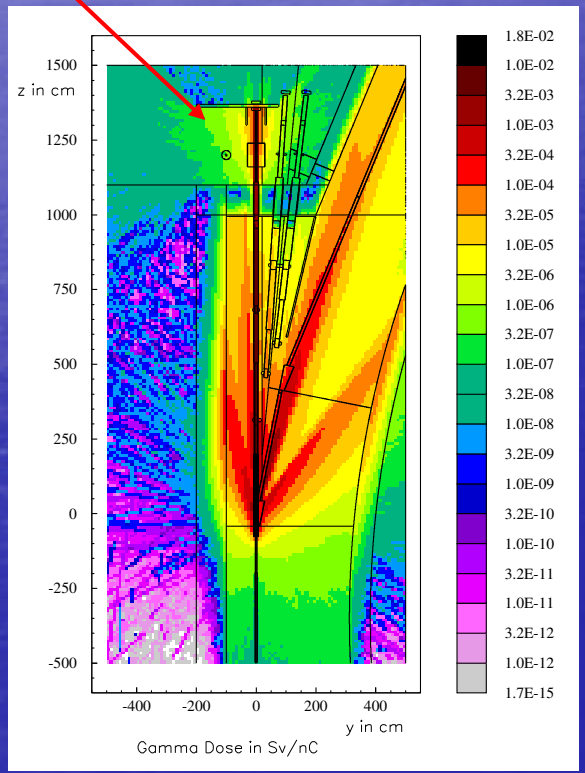
- Top-Up mode crash conditions: 1 nC/ shot (100 % losses)

Gamma radiation

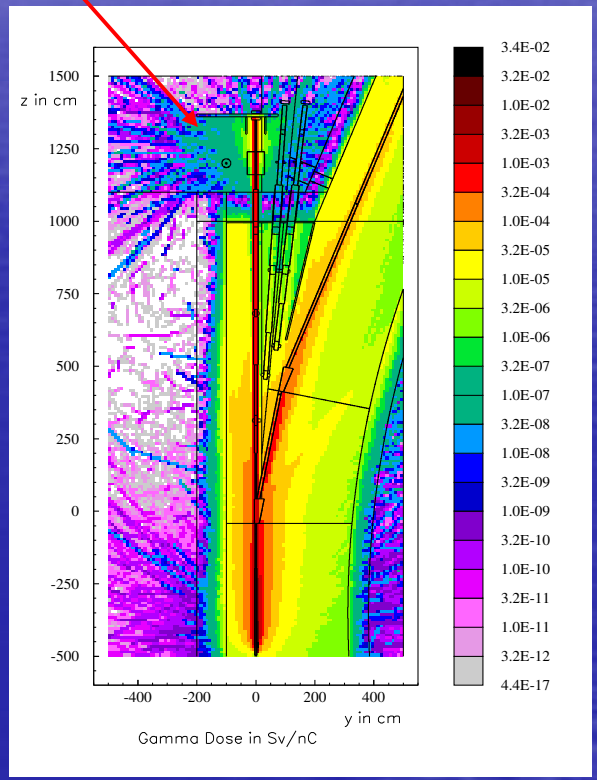
Injection in experimental hall
At fence: 1.0-3.2 µSv/shot



Loss at thin target in tunnel
At fence: 0.3-1.0 µSv/shot



Loss at ID chamber in tunnel
At fence: 0.03-0.1 µSv/shot



Doses by losses in E-hall or tunnel differ only by a factor of 3
Interlock safed exclusion area + absorber avoids dangerous doses under crash conditions

Radiation through open BS

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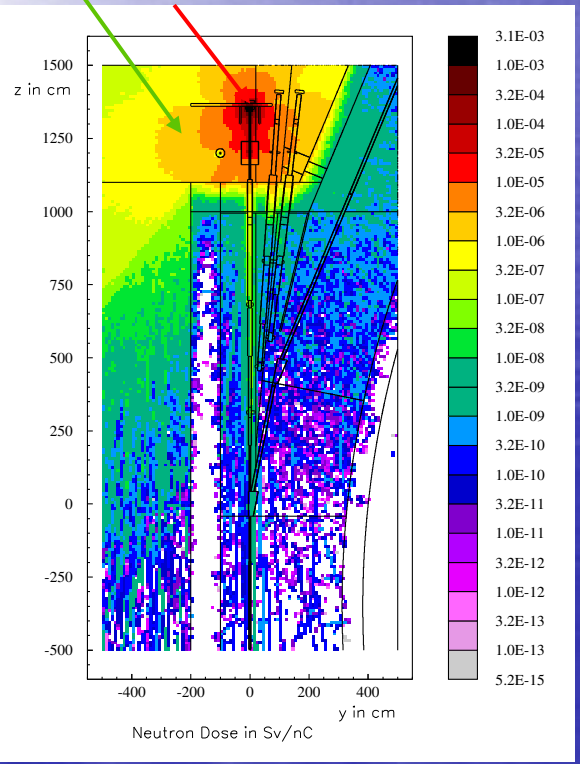
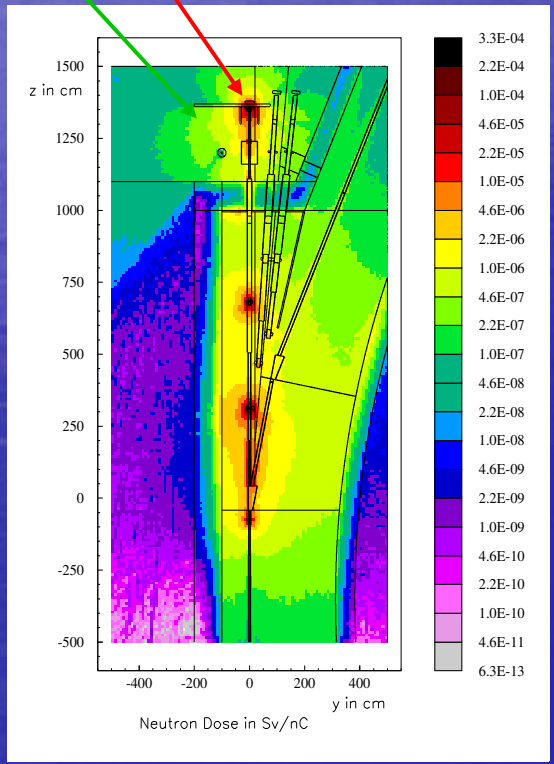
- Top-Up mode crash conditions: 1 nC/ shot (100 % losses)
  Neutron radiation

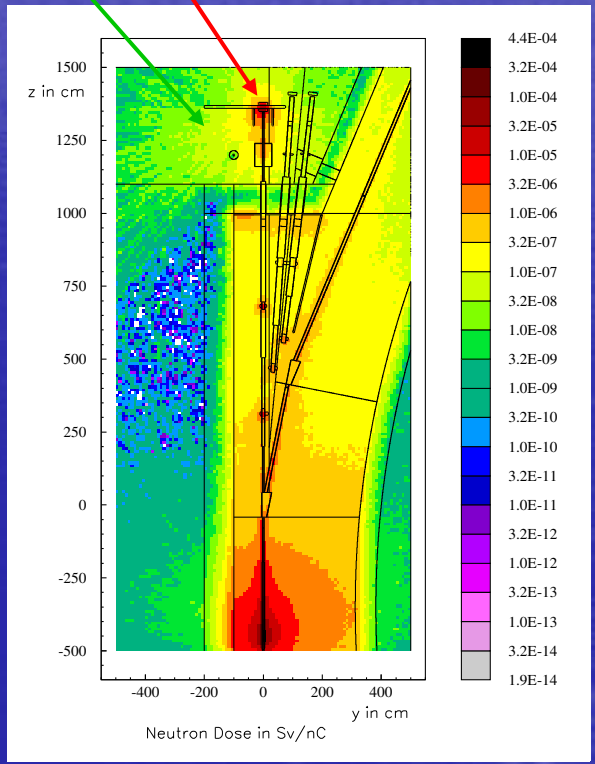
Injection in experimental hall
At fence: 3.2-10 µSv/shot
Absorber:10-32 µSv/shot



Loss at thin target in tunnel
At fence: 0.2-0.46 µSv/shot
Absorber:4.6-10 µSv/shot



Loss at ID chamber in tunnel
At fence: 0.03-0.1 µSv/shot
Absorber: 1.0-3.2 µSv/shot



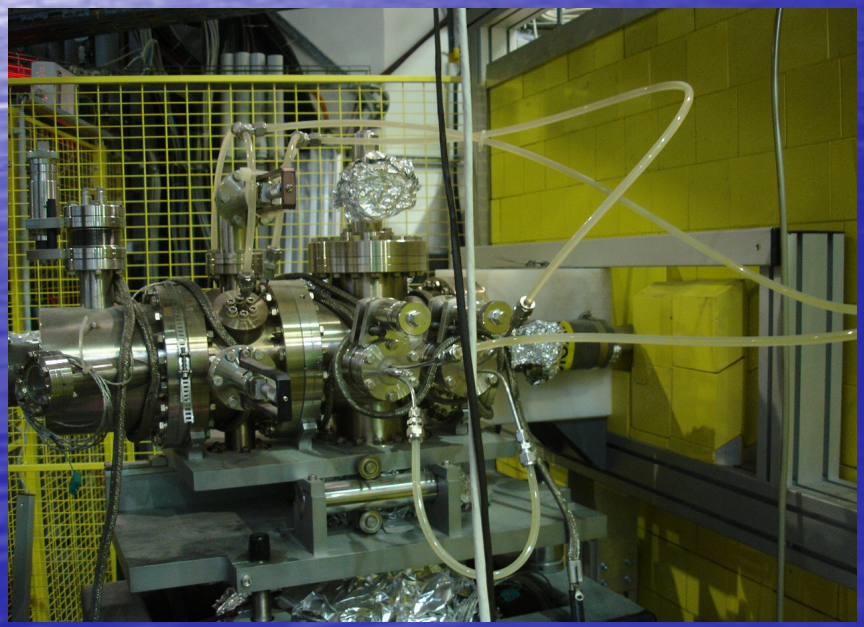
Absorber is now shielded with 1 TVL PE (neutron dose /10)
Doses by losses in E-hall or tunnel differ by a factor of 20 (fence)
Interlock safed exclusion area + absorber avoids dangerous doses under crash conditions

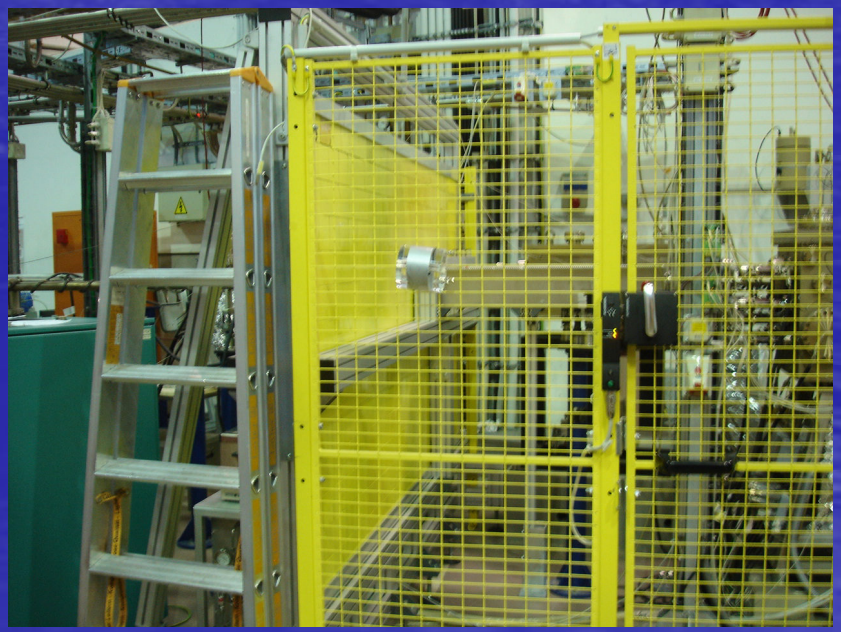
Safety measures

1. Linac charge <= 2 nC/shot (limits dose rate to microtron values)
2. Booster charge > 0.1 nC/shot (0.3 mA) (measurement accuracy)
3. Max. injection rate 0.1 Hz (reduces max dose rate by factor 100)
4. Top-up only if I > 200 mA (avoid severe error conditions)
5. Injection efficiency 90 % in 4 h average (annual dose)

$$\eta = \frac{\Delta I_{SR}}{2.5 \cdot I_{SY}}$$

6. Min. life time 5 h (annual dose)
7. Injection eff. < 60 % stops next shot (stop top-up if one shot failes)
8. Interlock safed exclusion areas (bremsstrahlung, beam dumps, injections)
9. PE behind absorber (absorb neutrons produced in absorber)





Measurement problems at synchrotron light sources

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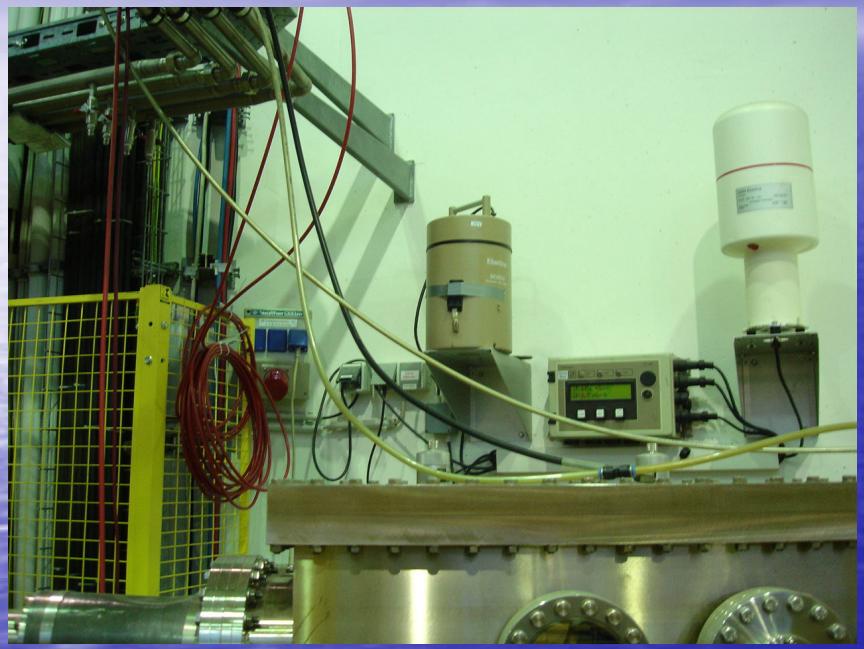
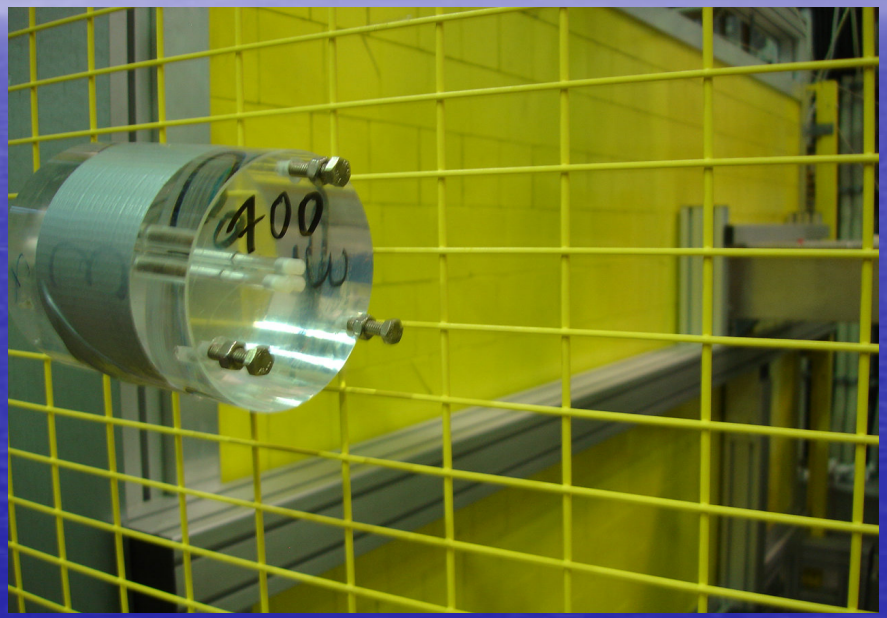
- High energy parts of the spectrum (esp. neutrons)
- Dead time effects: Pulsed radiation (300 nsec @10Hz, BESSY; 150 nsec @10 Hz MLS)
- Dead time effects: Radiation flashes (beam dumps with open beamshutters)
- Pulsed radiation at low rep. rate (esp. ionisation chambers, e.g. 1/30 Hz Top-Up) range switches

Passive dosimeters (LiF)



Albedo-Dosimeter



TLDs in plexiglass moderator

TLDs can measure pulsed radiation, but are not sensitive <50µSv

1st and 2nd Measurement series (22th Oct. – 5 th Dec., 5 th Dec. – 28 th Feb.) close to natural background

Pulsed radiation: determination of errors

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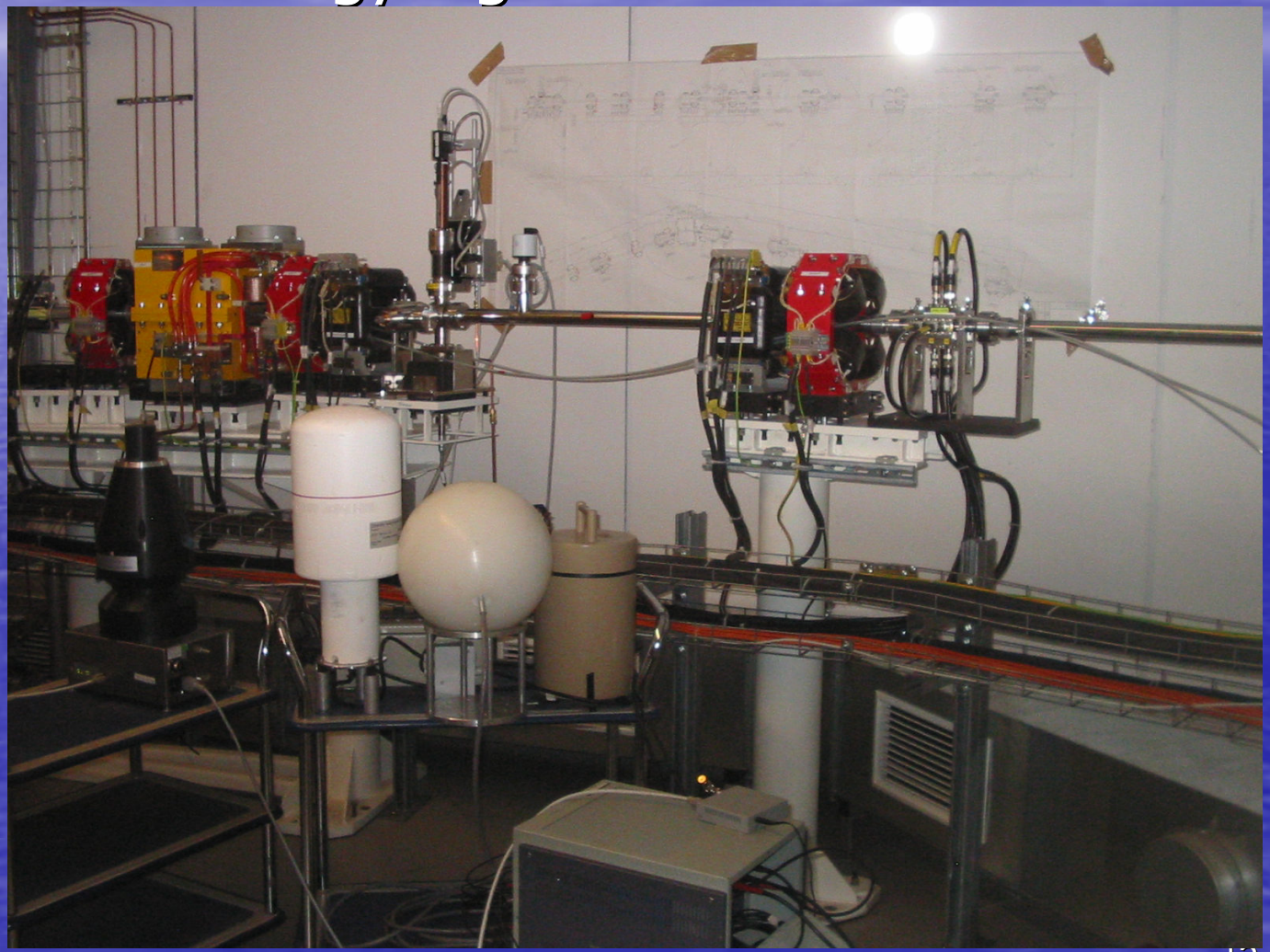
Experiment at transferline of Metrology Light Source

- LB6419
- I-Chamber
- AgRem
- Biorem
- Target 2 cm Al (FOM)



Calculations of neutron spectra

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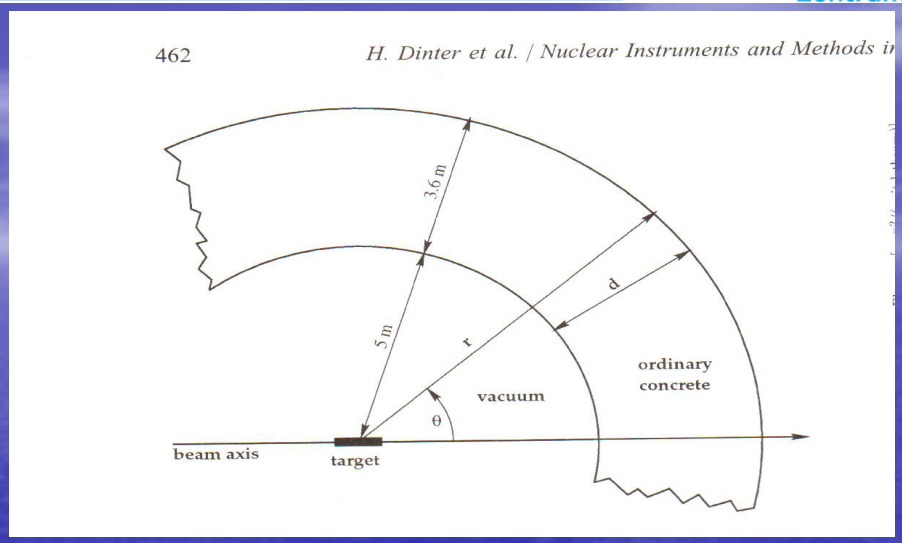
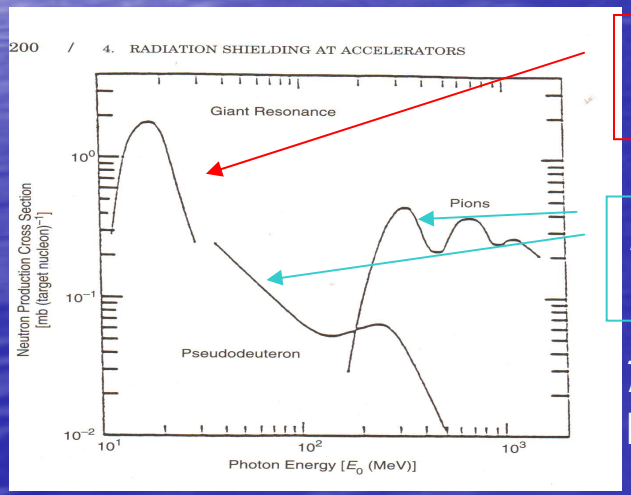
- Hollow sphere
- Thick Cu target
- Fluence to dose conv. ICRP74 H*(10)+Pell. data
- H>10MeV/H<10MeV = 2.72 (1m) = 3.65 (2m)



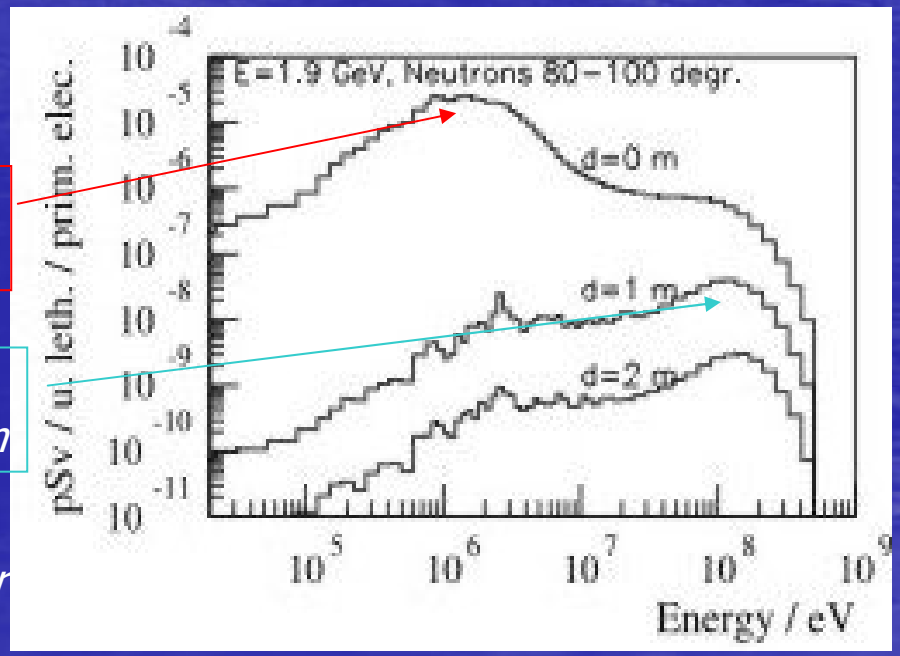
Energy limit for standard neutron monitors 10 MeV



GN
TVL 44cm

HEN
TVL 105cm

TVL Tenth Value Layer



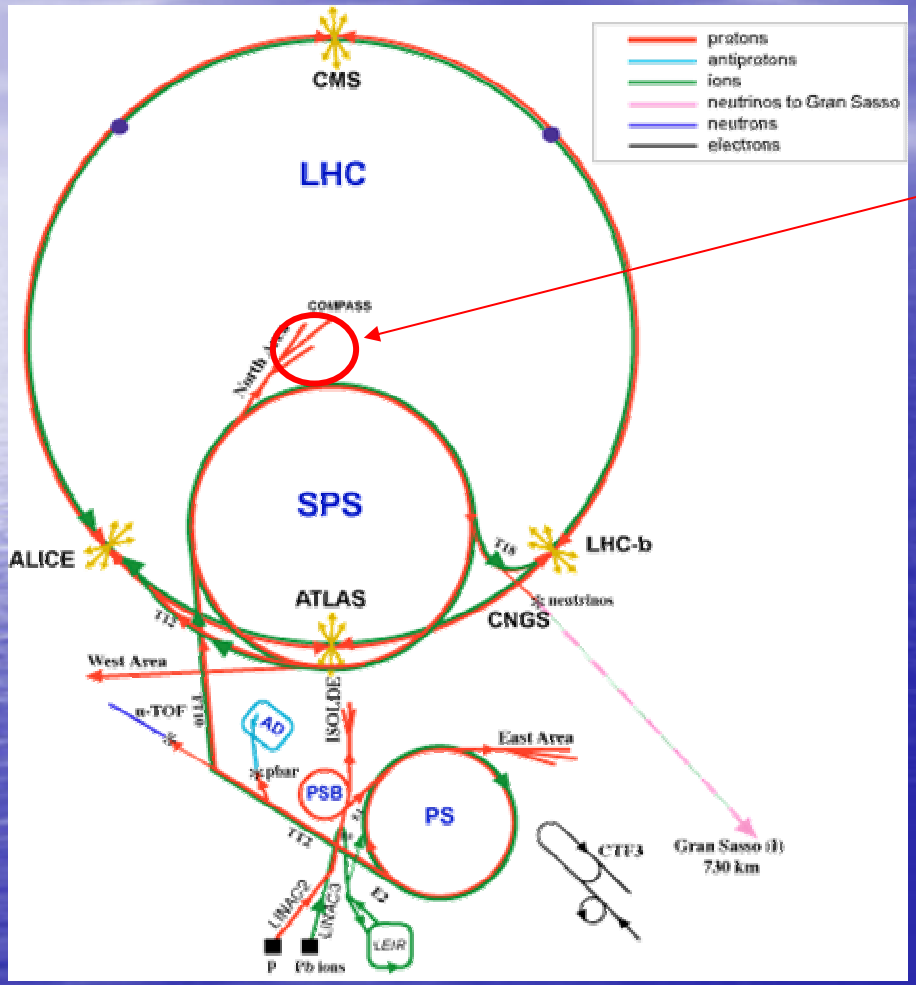
Pb moderator

In Pb nuclear reactions with high energy neutrons (n,2n) outgoing neutrons < 10 MeV

1 cm Pb with 4 % Sb to improve mechanical stability

Increases flux of thermal neutrons at detector tube by a factor of 3 (Fluka)
Simple and cheap solution to enable standard neutron monitors
to measure high energy neutrons up to 1 GeV. But calibration necessary

CERN reference field (CERF)



CERF location (Prevessin cite)

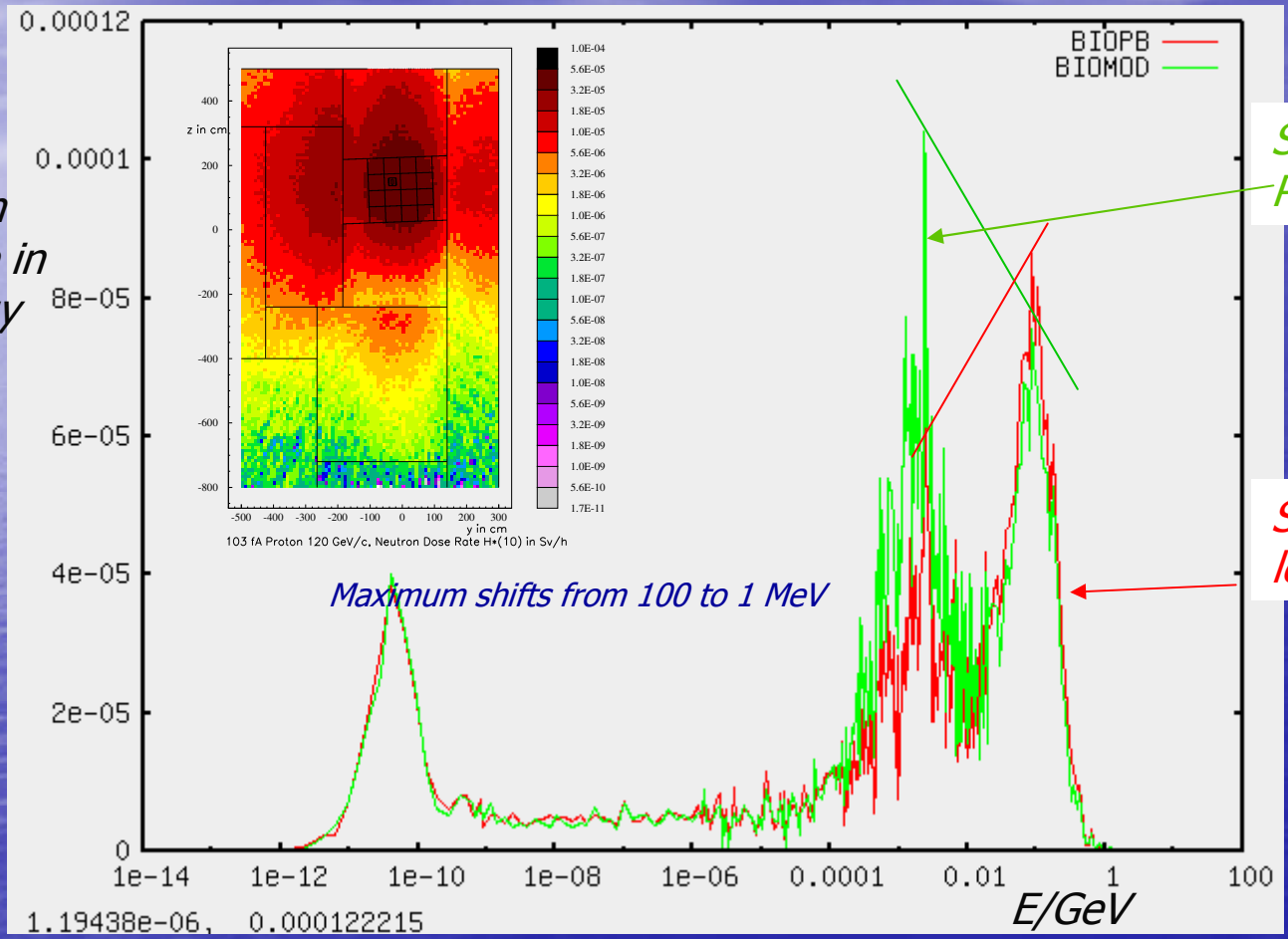
Mixed beam
Protons 35%
Pions+ 61 %
Kaons+ 4 %
Momentum 120 GeV/c
Target Cu 50 cm

Neutron spectrum similar to high energy electron or hadron accelerators

Effect of Pb moderator

Spectra calculated for Biorem on roof of CERF bunker

Neutron Fluence in Lethargy Units

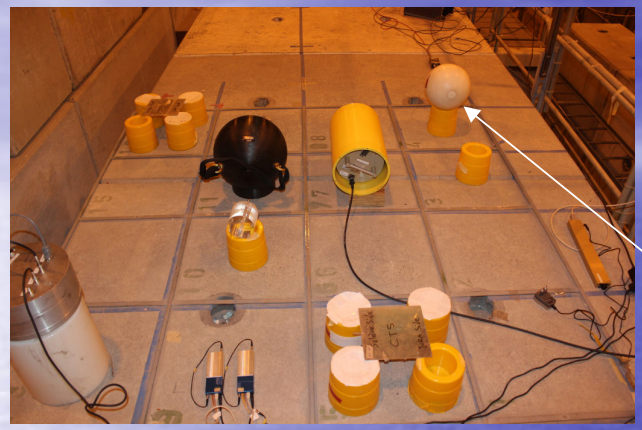


Spectrum on Biorem PE Surface

Spectrum on Biorem lead surface

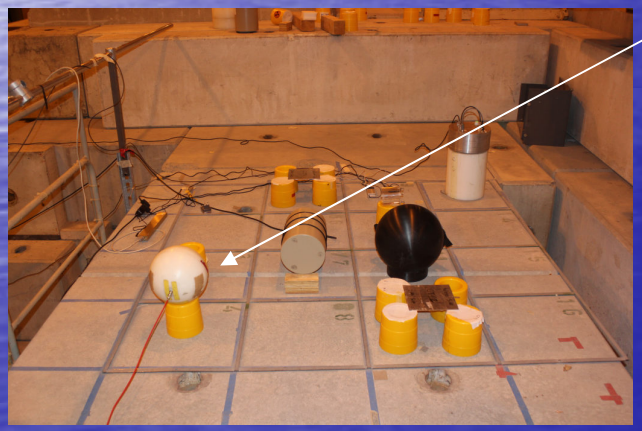
Red: Spectrum at Pb, Green: Spectrum at PE , neutron spectum
Summarized from the three contributions (p, pi+, K+)
Beamtime at CERF in June 2012 (M. Helmecke, K. Ott)

Roof CERF Bunker



1st Measurement T7 Biorem Pb
TLDs with Pb and without Pb

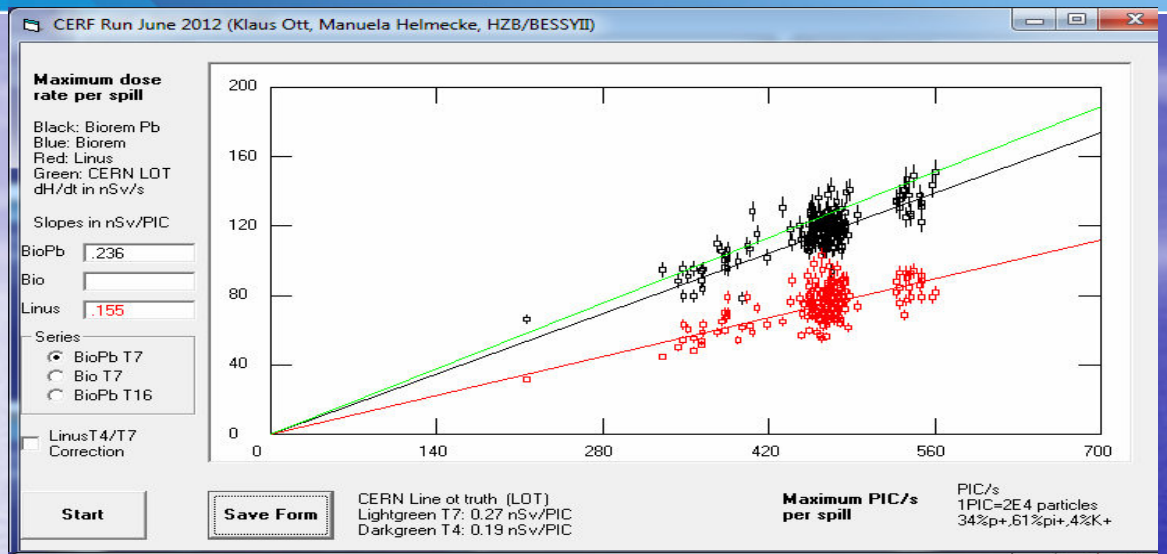
CERN
Detector
Reference



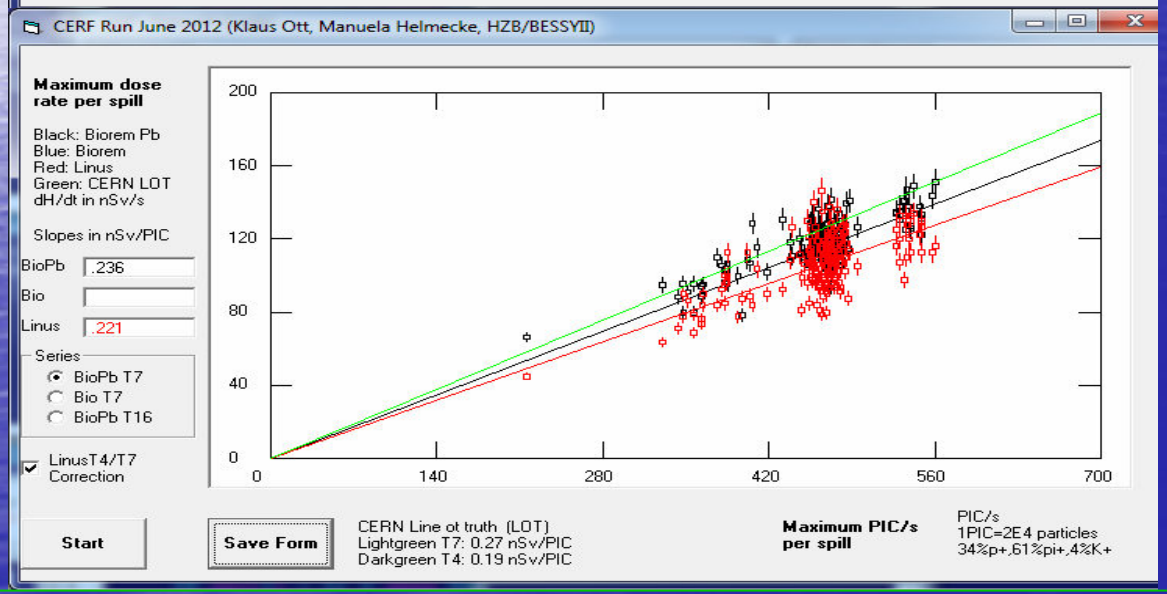
2nd Measurement T7 Biorem
TLDs with Pb and without Pb

3rd Measurement T7 Biorem Pb T16
TLDs with Pb and without Pb

Result



1st Measurement
Green: line of truth CERN
Black: Biorem with Pb on T7
Red: CERN detector on T4



1st Measurement
Green: line of truth CERN
Black: Biorem with Pb on T7 ,
Red: CERN detector on T4
corr. for T7

Biorem with Pb closer at line of truth than CERN detector (red)

First months of operation

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- Control of max. electron losses very effective
- Both active and passive dosimetry show no increased doses in comparison with decay mode
- From February to April top-up interruptions by interlock system:
  - Eta < 60 %: 11 occurences (stop of top-up mode)
  - Isy < 0.3 mA: 3 occ. (shot not extracted)
  - Isr < 200 mA: 2 occ. (stop of top-up mode)
  - Eta < 90 % 4 h average: 2 occ. (penalty time 38 min)
  - Life time < 5 h: 1 occ. (shot not extracted)

Summary

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- Operating licence for top-up received at 22nd October (exactly in time schedule)
- Investigations of dead-time behaviour of neutron monitors published in Radiation Protection Dosimetry (December 2012). Correction formulas achieved, that are applicable also for top-up operation
- Lead moderator for neutron monitors to enable measurements calibrated at CERF. Cheap possibility to upgrade standard neutron monitors to measure neutrons up to 1 GeV. Results to be published
- Electron loss control by interlock very effective, dose limit of 1 mSv seems reachable again in the accessible parts of experimental hall

Thanks for your attention