Radiation Protection Considerations for the Cryogenic In-Vacuum Undulator of the EMIL Project at BESSY

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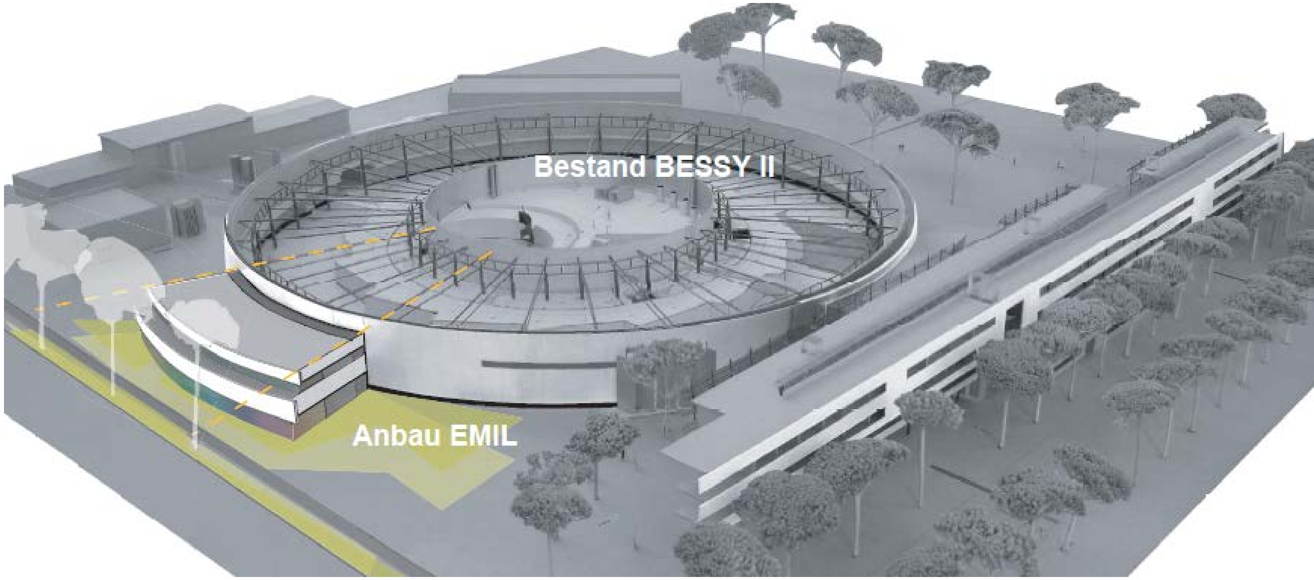
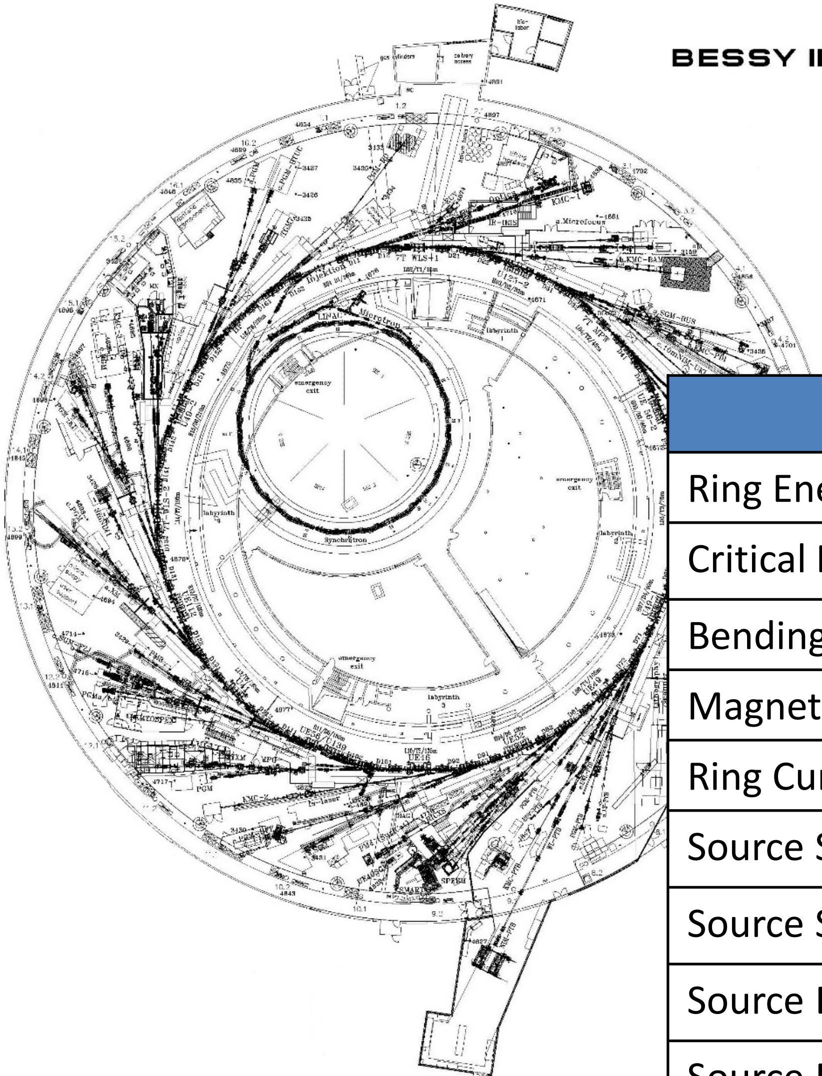
OUTLINE

- Overview Bessy II
- Overview EMIL
- New Undulators – UE-48 And U-17
- Calculation Of Synchrotron Radiation
- Sampling Of Synchrotron Spectra With FLUKA
- Results
- Summary and Outlook





Machine Parameters			
Ring Energy	E	[GeV]	1.7
Critical Energy		[keV]	2.5
Bending Radius	R	[m]	4.359
Magnetic Field	B	[T]	1.3
Ring Current (top up)	I	[mA]	300
Source Size hor. (UE48/U17)		[µm]	129/137
Source Size ver. (UE48/U17)		[µm]	19/9
Source Divergence hor. (UE48/U17)		[µrad]	81/83
Source Divergence ver. (UE48/U17)		[µrad]	6/10

WHAT IS EMIL?

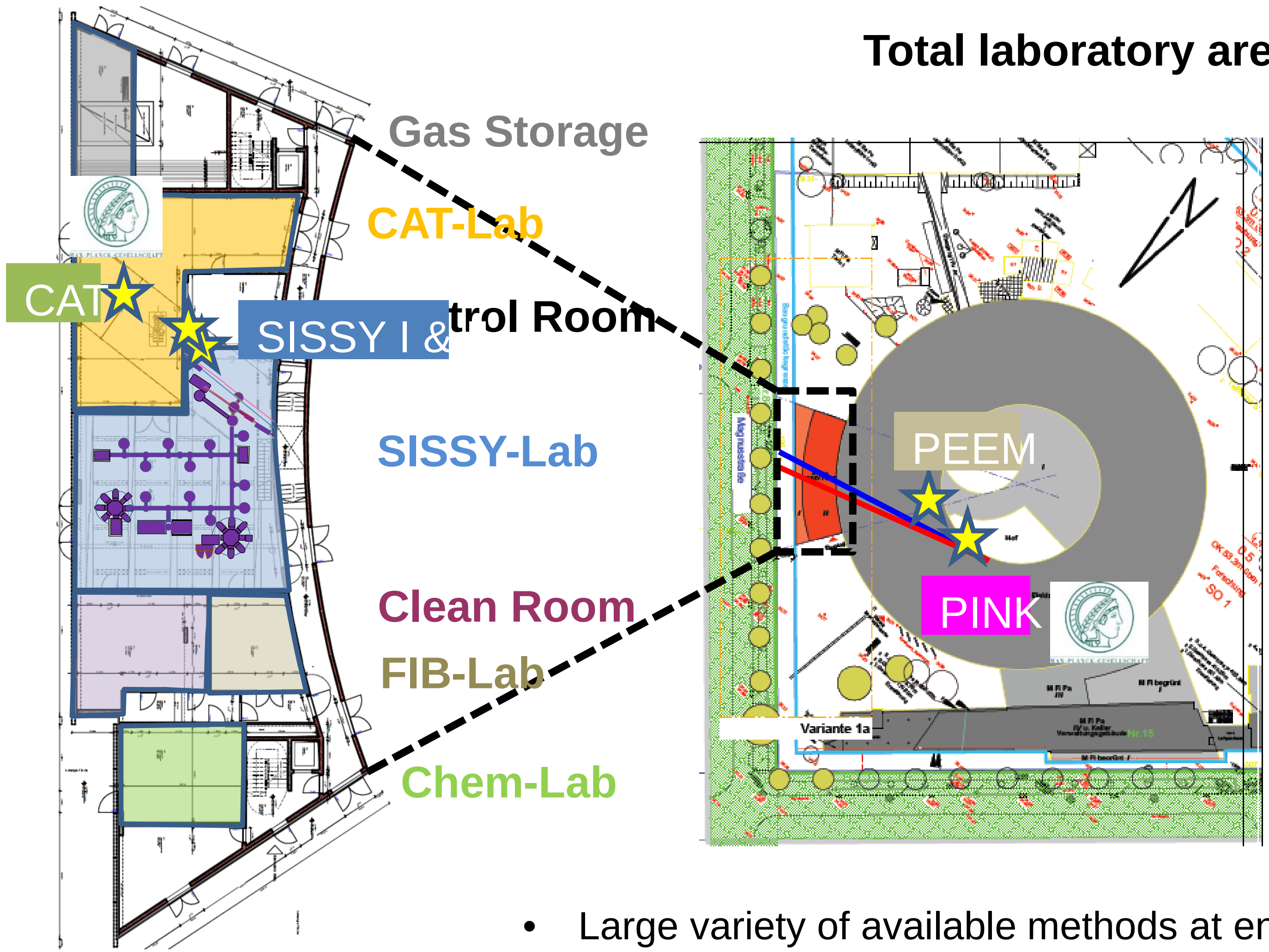
A state of the art laboratory for the preparation and analysis of energy materials

„Visible“ EMIL:

Currently established for EMIL:

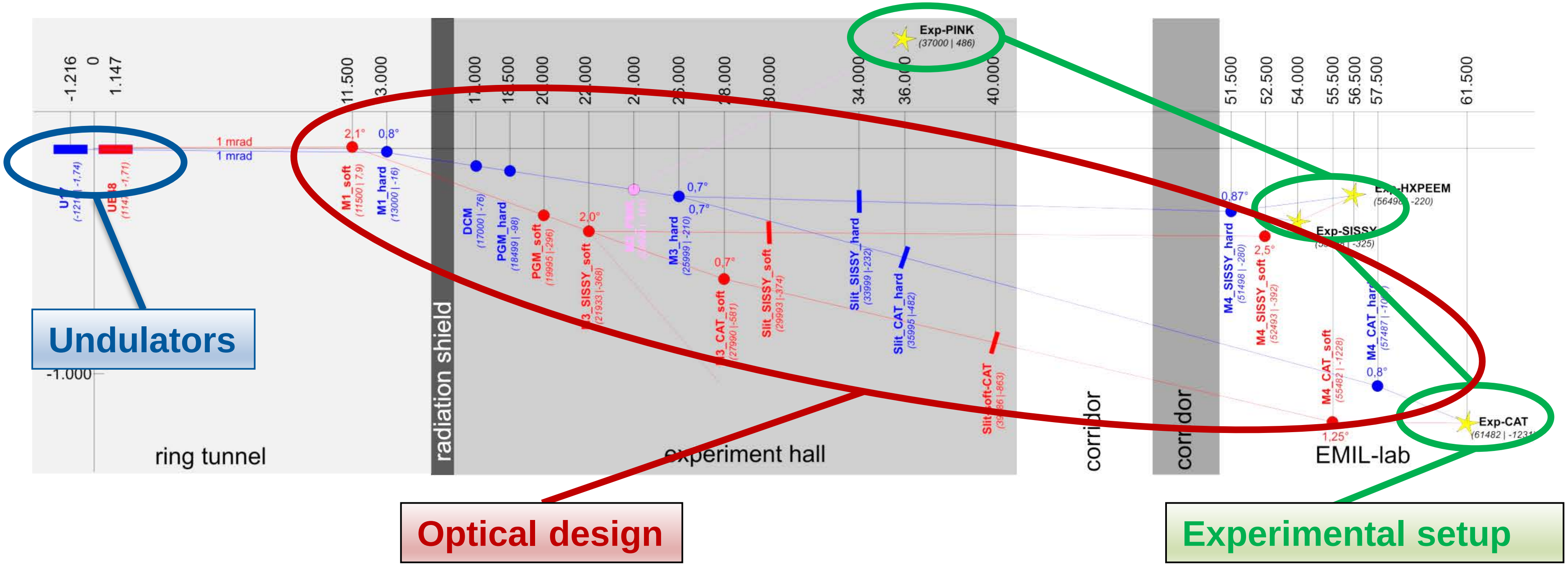
- *New Source (two undulators)*
- *Several Beamlines (for hard and soft branch)*
- *In sum five Endstations (3 in new building)*
- *Laboratory Equipment*
- *State-of-the-art layer deposition*

Total laboratory area 2000 m²

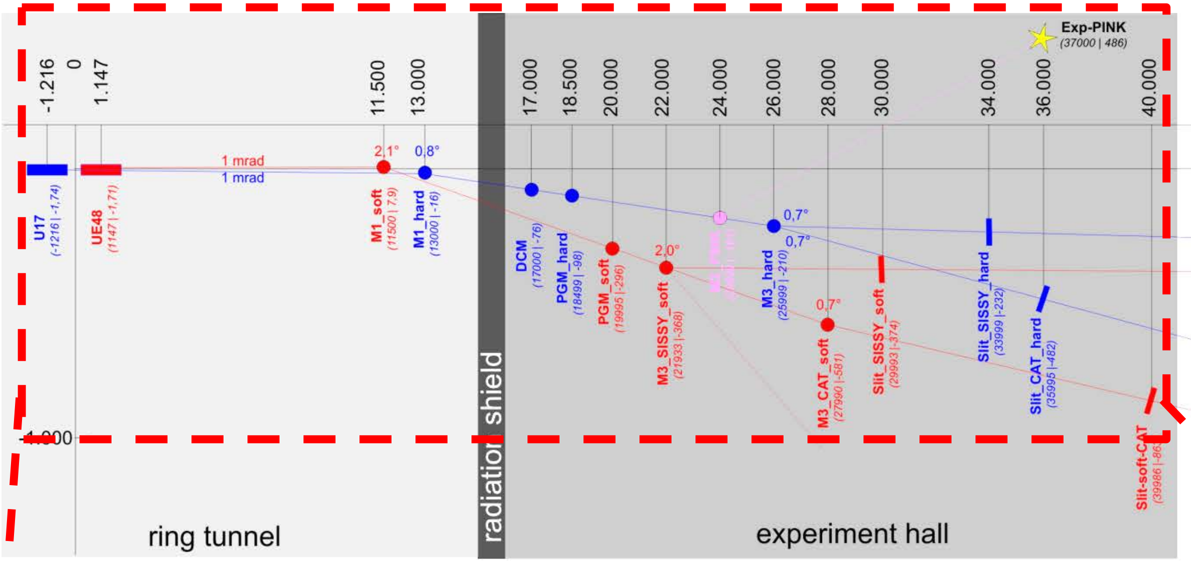


- Large variety of available methods at endstations
- Beamlines must deliver x-rays from 70 eV up to 12 keV
- you can use both beams or separate one

Schematic beamline layout of emil facility

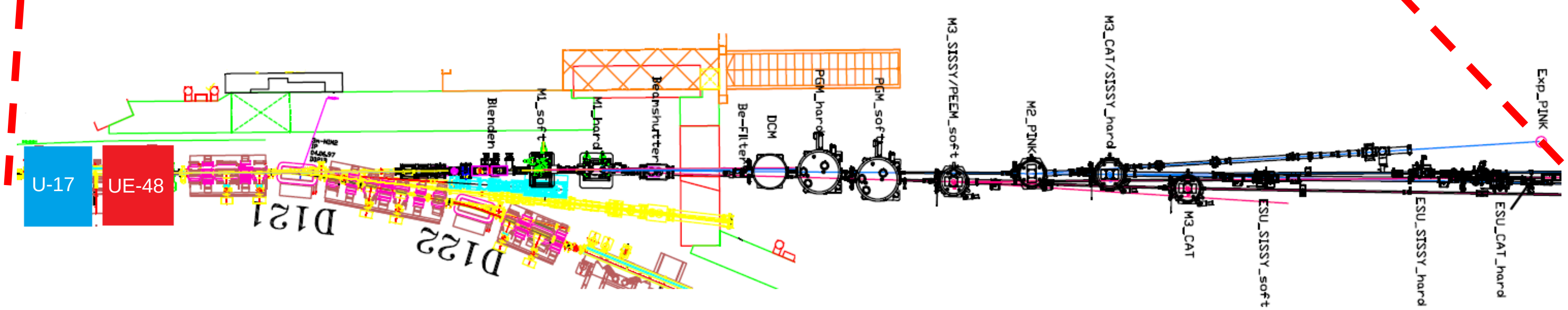


More than 20 optical elements like mirrors, gratings, crystals, etc. in this narrow corridor!

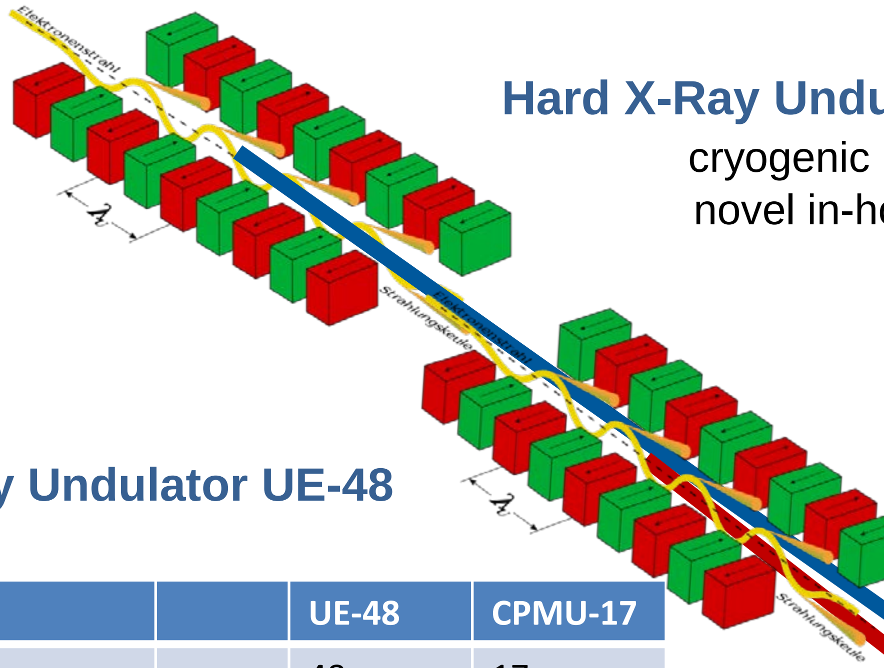


New IDs, beam lines inside experimental hall

- Consequence for Shielding?
- Which safety measures are necessary?

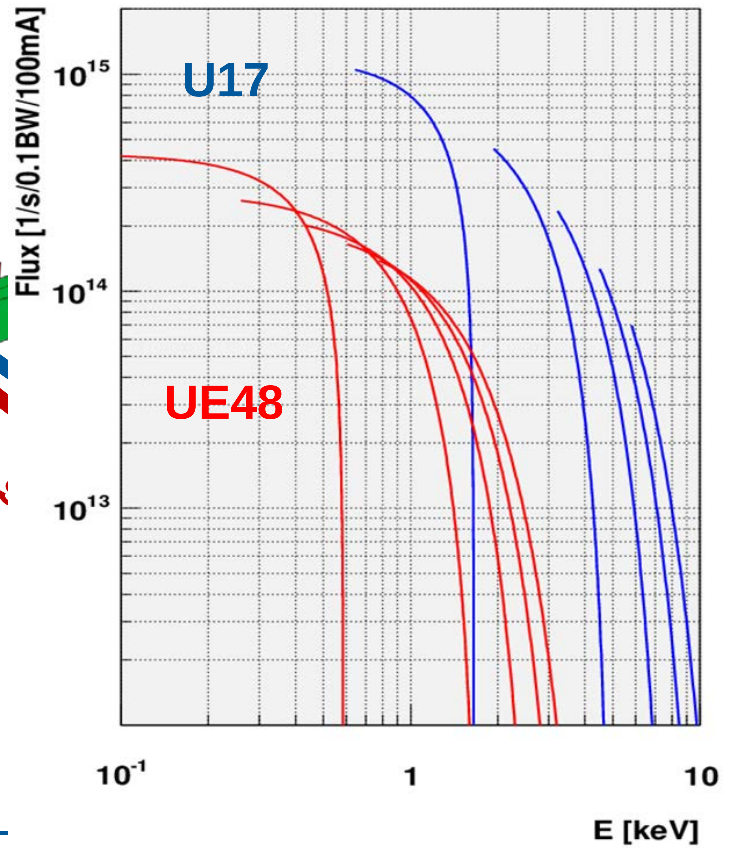


TWO UNDULATORS FOR A WIDE ENERGY RANGE



Hard X-Ray Undulator U-17:

cryogenic in-vacuum undulator
novel in-house development

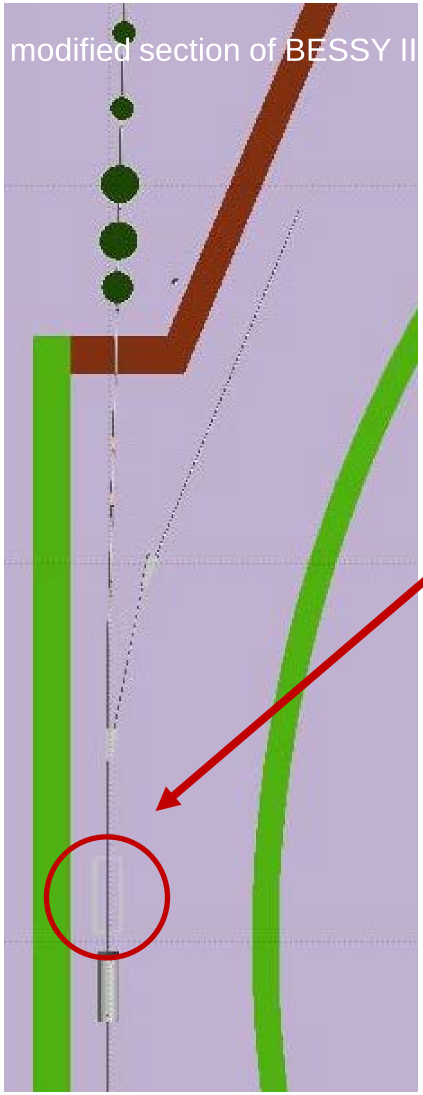


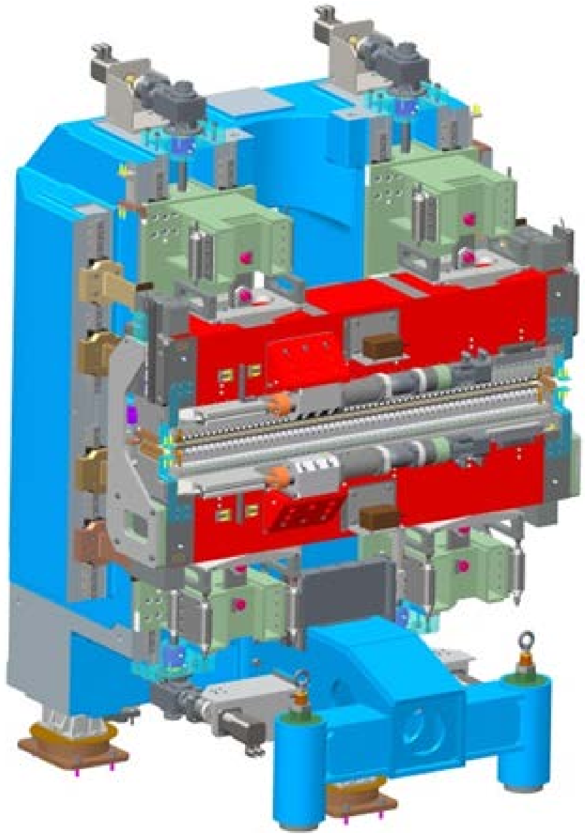
Soft X-Ray Undulator UE-48

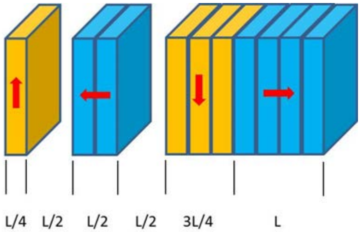
(APPLE II)

		UE-48	CPMU-17
Period length	mm	48	17
Periods		31	88
K		3,4	1,78
Gap_{min}	mm	15	5,5
Total Power (300mA)	W	479	1031
Max. central cone	µrad²	108 x 72	87 x 27

Soft X-ray Undulator UE-48 (APPLE II)







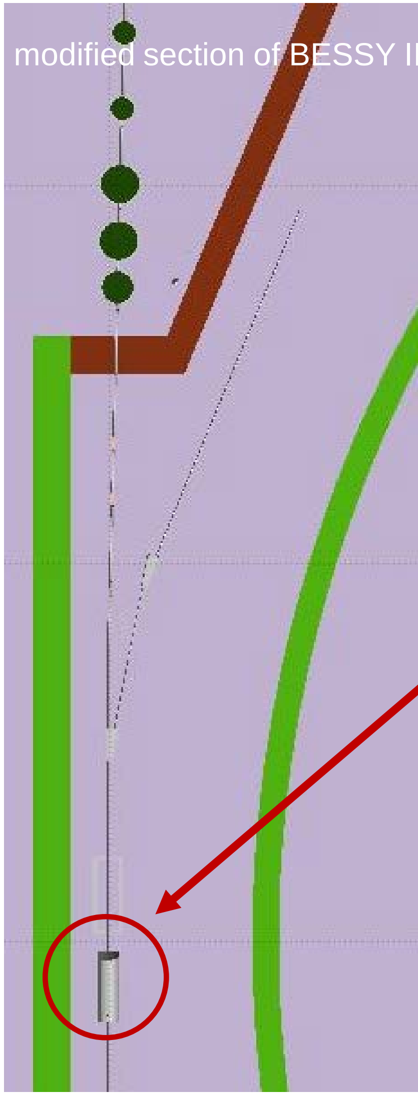
Magnets: neodymium iron boron

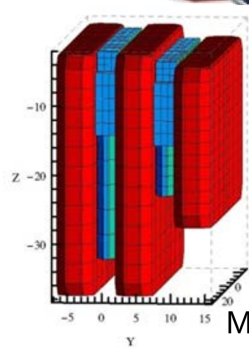
covered energy range:
80 eV up to 2.2 keV

low energy synchrotron radiation, absorbed in vacuum system

not considered for shielding design

Hard X-ray Undulator U-17 (Cryogenic In-vacuum)





covered energy range:
700 eV up to 12 keV

synchrotron radiation not absorbed in vacuum system

spectra of U-17 significant for shielding measures

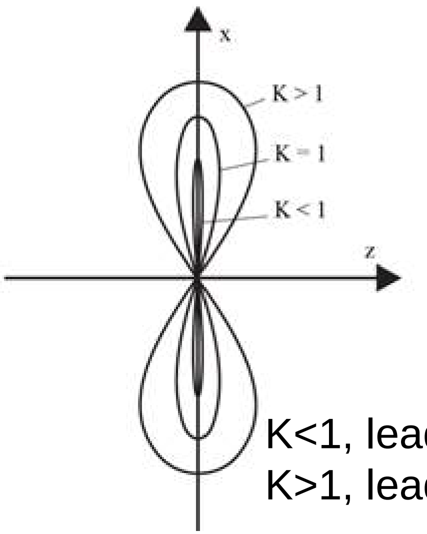
Magnets: (neodymium iron boron 20%)
(praseodymium iron boron 80%)

DETERMINE RADIATION INTENSITY

Strength parameter K, characterizes the nature of electron motion:

$$K = \frac{e \cdot B_0 \cdot \lambda_p}{2\pi \cdot m \cdot c} = 0.934 \cdot B_0 \cdot \lambda_p[\mathrm{cm}]$$

λ_p = period length,
B_0 = applied magnetic field



Maximum amplitude a of transverse particle oscillation:

$$a = \frac{K \cdot \lambda_p}{2\pi \cdot \gamma}$$

γ= rel. Faktor (≈3300)

K<1, lead to narrow energy brands
K>1, lead to broad energy spectrum

K = 1.78
a = 1.45 E-6 m

K > 1 : Not only a pure undulator spectrum, by contributions from farther transversal beam positions a hybrid wiggler/ undulator spectrum is produced

Simple formulas to calculate pure undulator or wiggler spectra are not suitable!

(1) Calculate synchrotron radiation spectrum ➔ f(E) (with SPECTRA 10)

(2) Integrate spectrum and normalize to 1 ➔ F(E) Calculation of inverse function analytically not possible

(3) Draw Random Number (x) ∈ [0,1], determine E by F(E) = x

➔ Distribution of R.N. corresponds f(E)

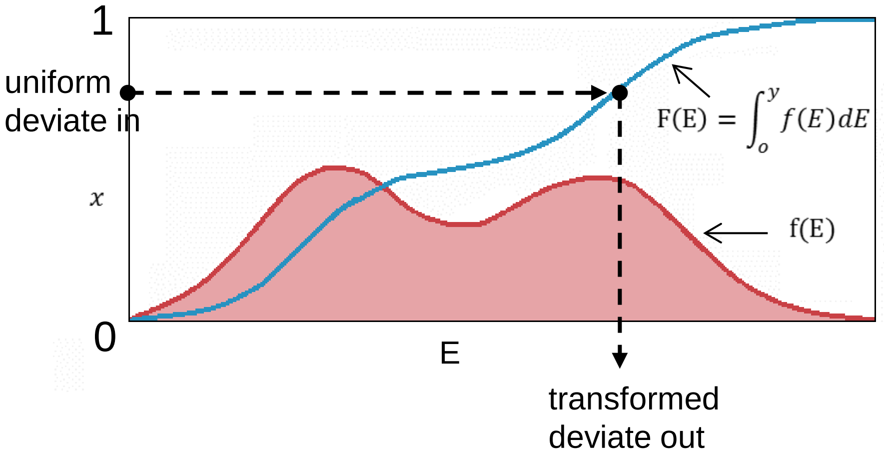
Software program written by Dr. Klaus Ott, It's called SynRad

Write process (3) in source.f

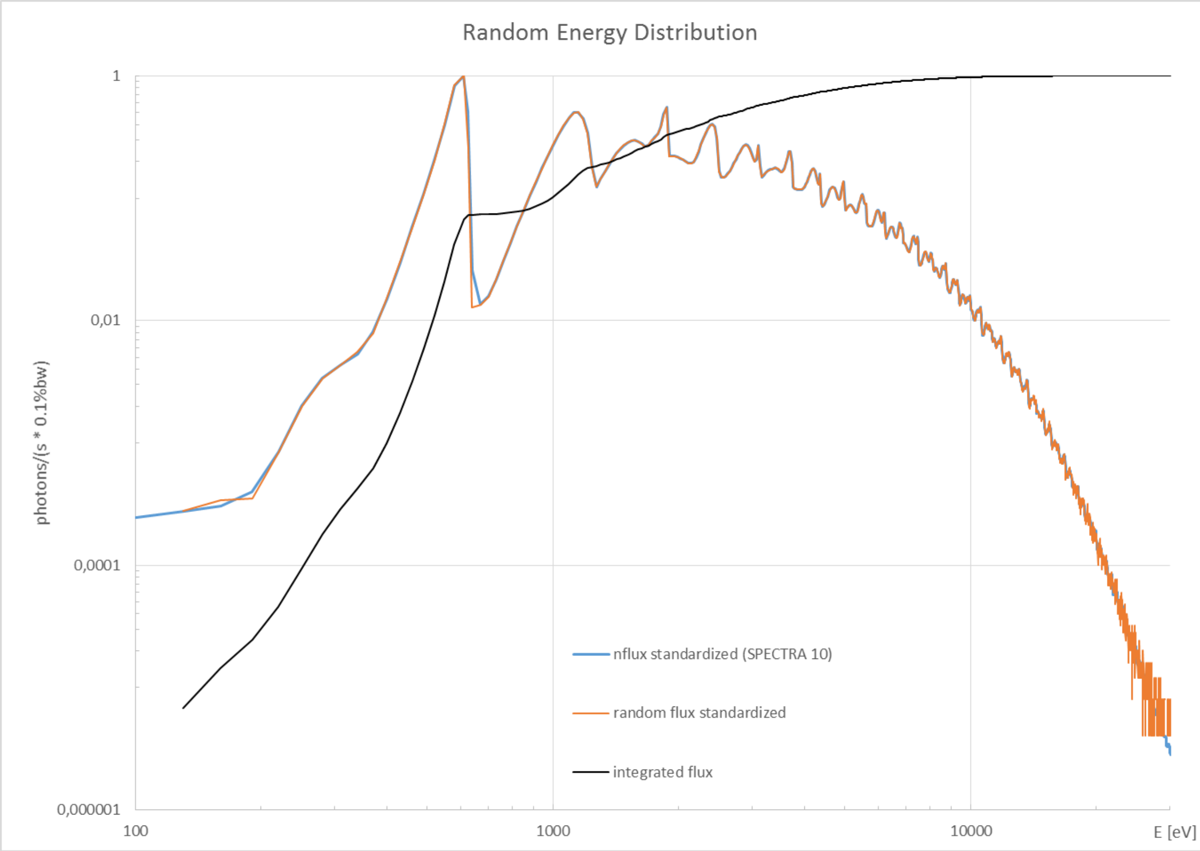
and link it with FLUKA

➔lfluka -m flukahps -o source.o

➔use flukahps as executable in flair instead flukahp



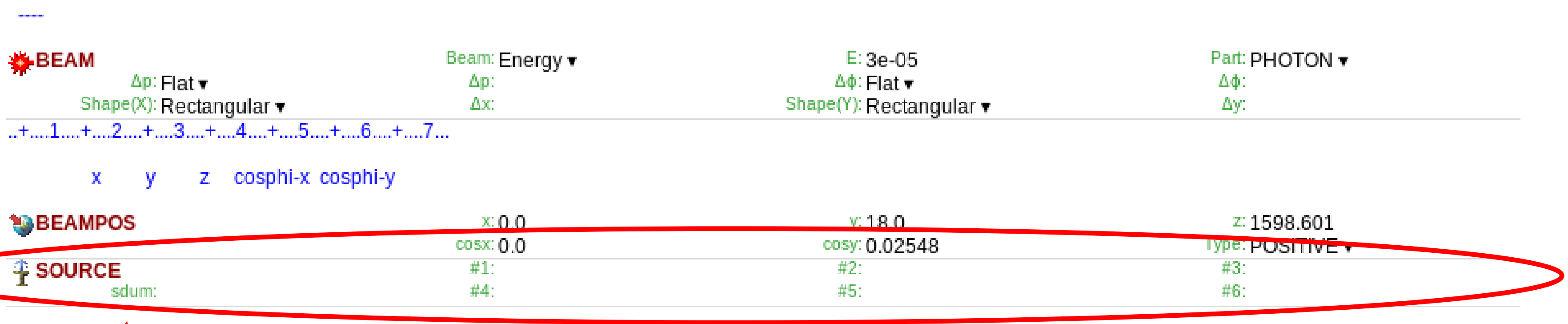
Calculated Energy Distribution of U-17



Parameters for calculation		
Period length	cm	1.7
Periods		88
K		1.78
Emittance x	mrad	6.91E-9
Emittance y	mrad	8.93E-11
Beam size x	m	9.49E-5
Beam size y	m	1.17E-5
Beta x	m	1.30
Beta y	m	1.53
Alpha x		0.604
Alpha y		-0.836
Div x	rad	8.51E-5
Div y	rad	9.98E-6
Eta		-3.1E-3
Theta x,y		0
dTheta x		1.0E-3
dTheta y		3.0E-4

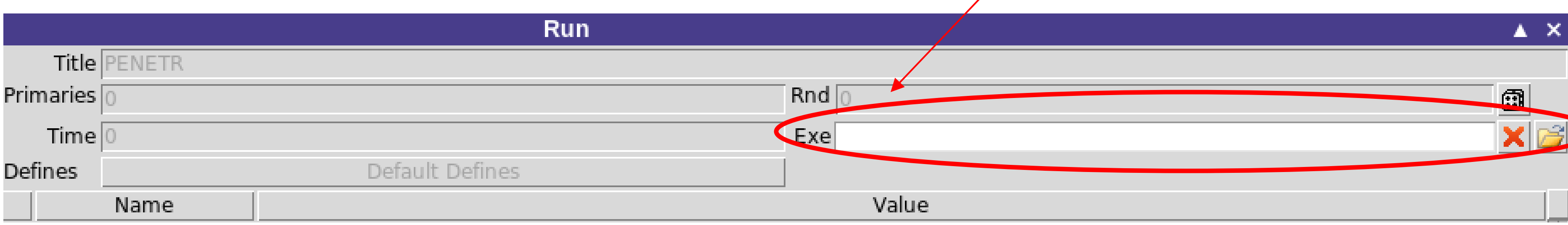
T. Tanaka and H. Kitamura:“SPECTRA: A synchrotron radiation calculation code“
J. Synchr. Rad. (2001), 8, 1221-1228

INPUT-FILE FLUKA



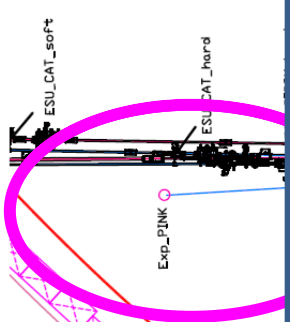
Insert source-card in flair input-file

Link executable

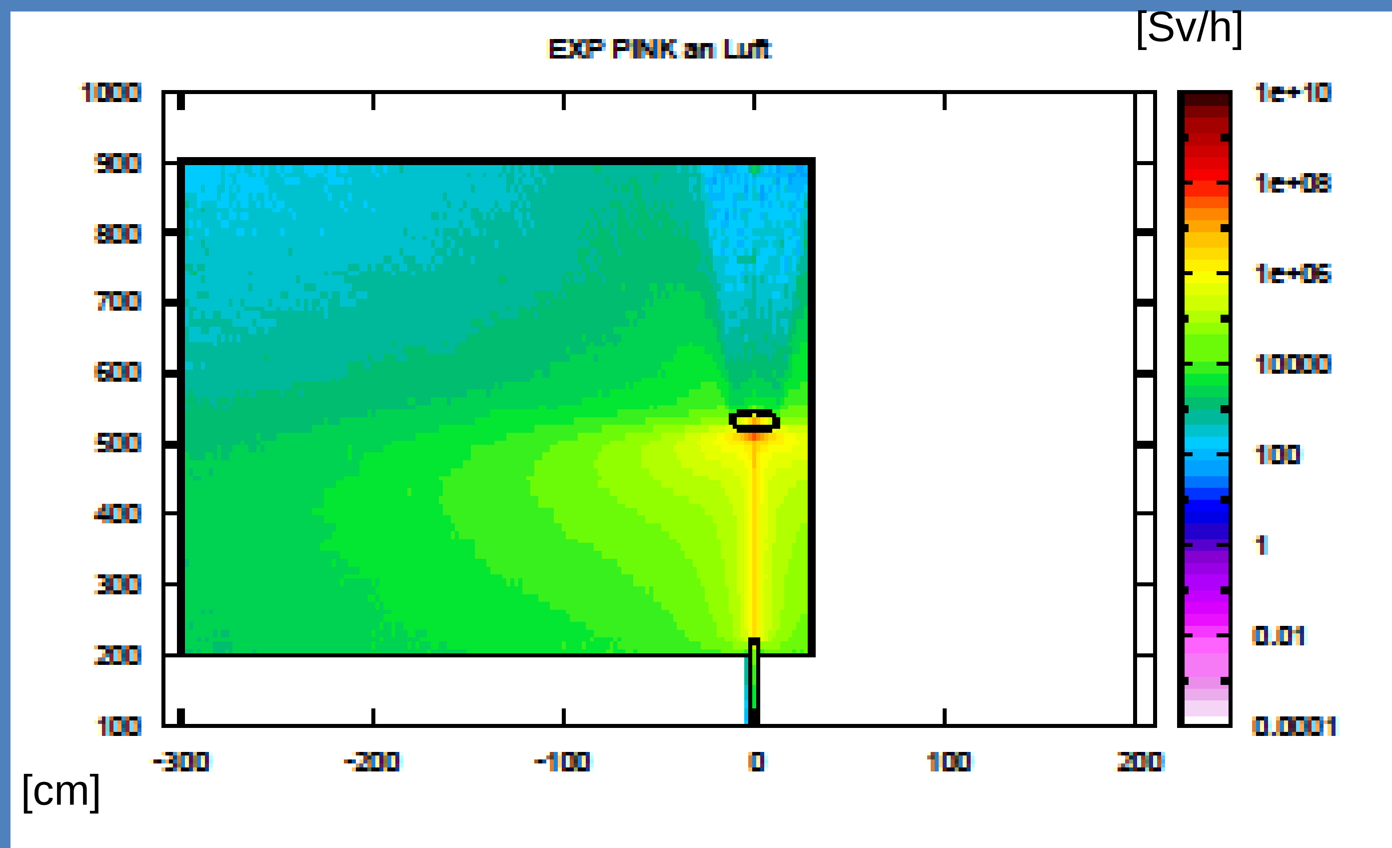


PINK: non- res

- Endstation fo
- Option to use
- synchrotron
- Inside experi



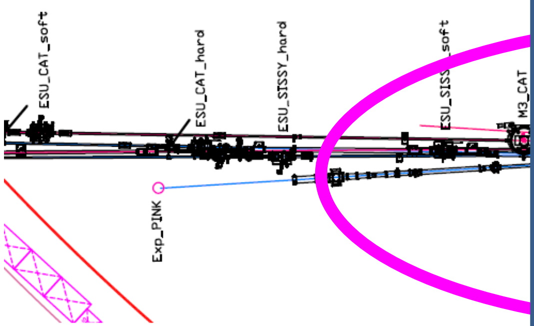
Equivalent Dose



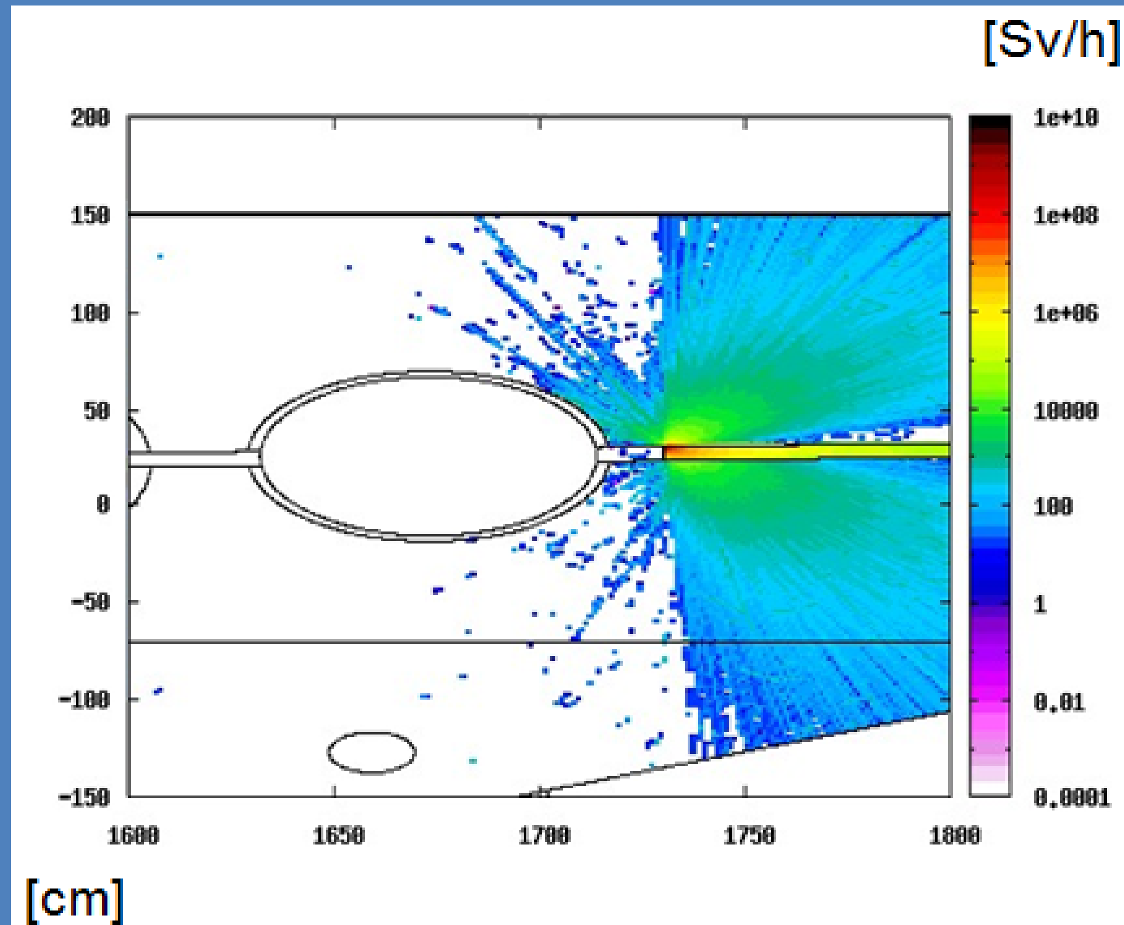
Optical hutch:

Simulation of synchrotro
to determine the measu

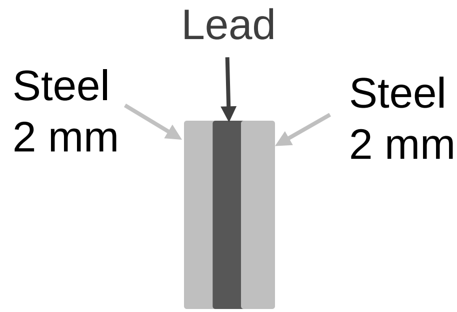
Conservative assumptio



Equivalent Dose

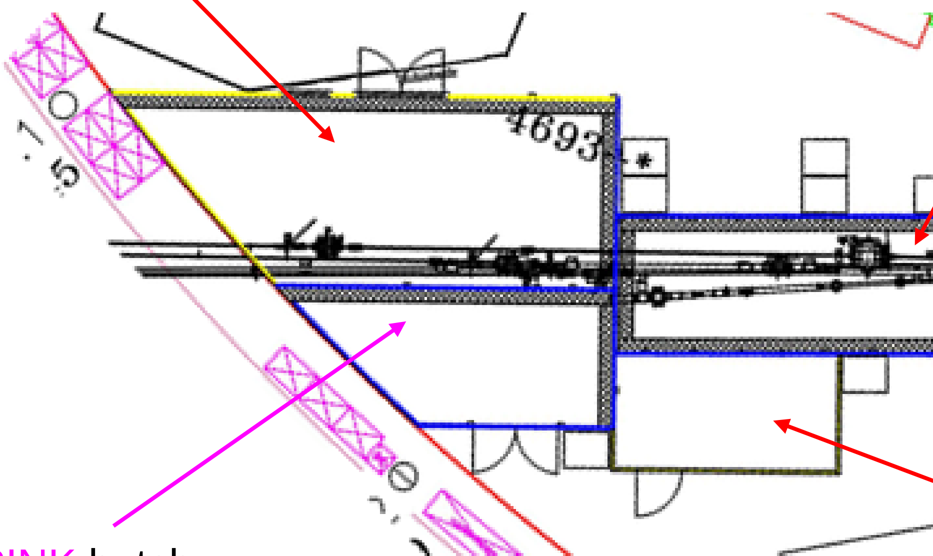


hutches as sandwich construction:



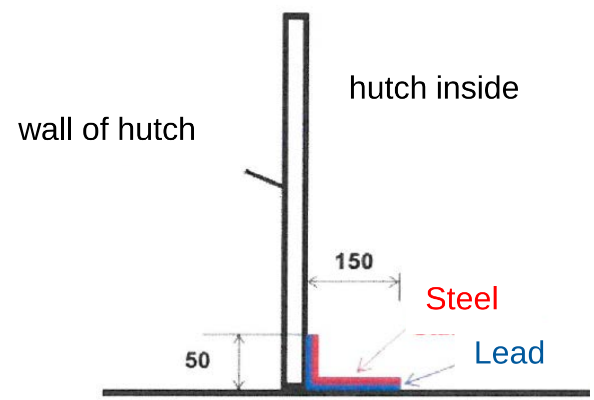
PEEM hutch:
no Lead necessary

Optical hutch:
2 mm Lead



PINK hutch:
3 mm Lead

floor and wall connections
as internal L section
coated with lead



facts and figures:

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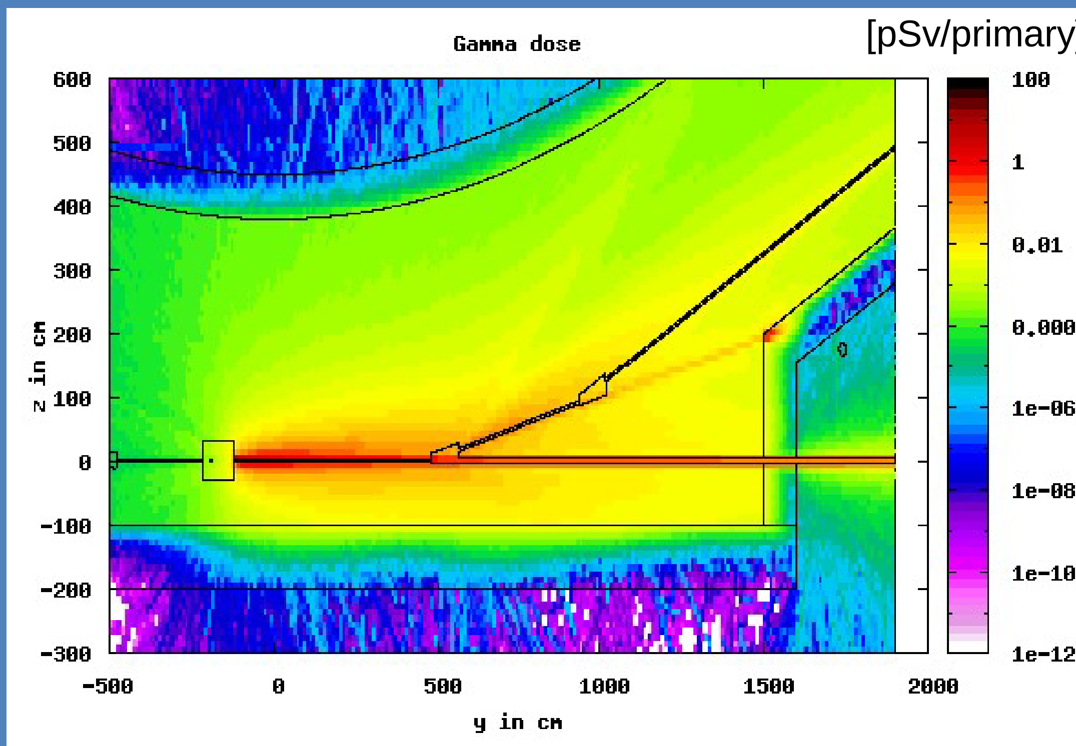
beam
in-vac

The gamma dose/primary e- for this scenario



end wall reduces gamma radiation in forward direction by five orders of magnitude *

* see: K. Ott, Y. Bergmann, „FLUKA Calculations of Gamma Spectra at BESSY“, IPAC 2014

EMIL TIMELINE

2013
- ◀ **5th HAXPES in Sweden, introducing EMIL by talk of K. Lips**
- ◀ **ground-breaking ceremony of EMIL building**

2014
- ◀ **final beamline design, beamline ordered**
- ◀ **first beamline parts delivered**

2015
- ◀ **clearence of future EMIL area**
- ◀ **hutches for EMIL beamlines**
- ◀ **delivery of last beamline elements, installation of ID's**
- ◀ **first beam, commissioning**

2016

2017
- ◀ **normal operation, open for external users (up to 30% of beamtime)**

SOME IMPRESSIONS

Summary

- Exact calculations of hutch design completed -> spectra calculations, simulation with FLUKA
- Not all hutches need lead shielding, only:
  - PINK hutch 3 mm lead (synchrotron radiation on air)
  - Optical hutch 2 mm lead
- Radiation Safety at experimental hall given with calculated shielding of hutches

Outlook

- Completion of hutches at the end of 2015 ➔ monitoring
- Implementation of the Radiation Safety System (e.g. Personnel Safety Interlock system)
- Support during installation of EMIL-Lab
- Safety Report for operating licence
- during comissioning control by measurements

Thank you for your attention!