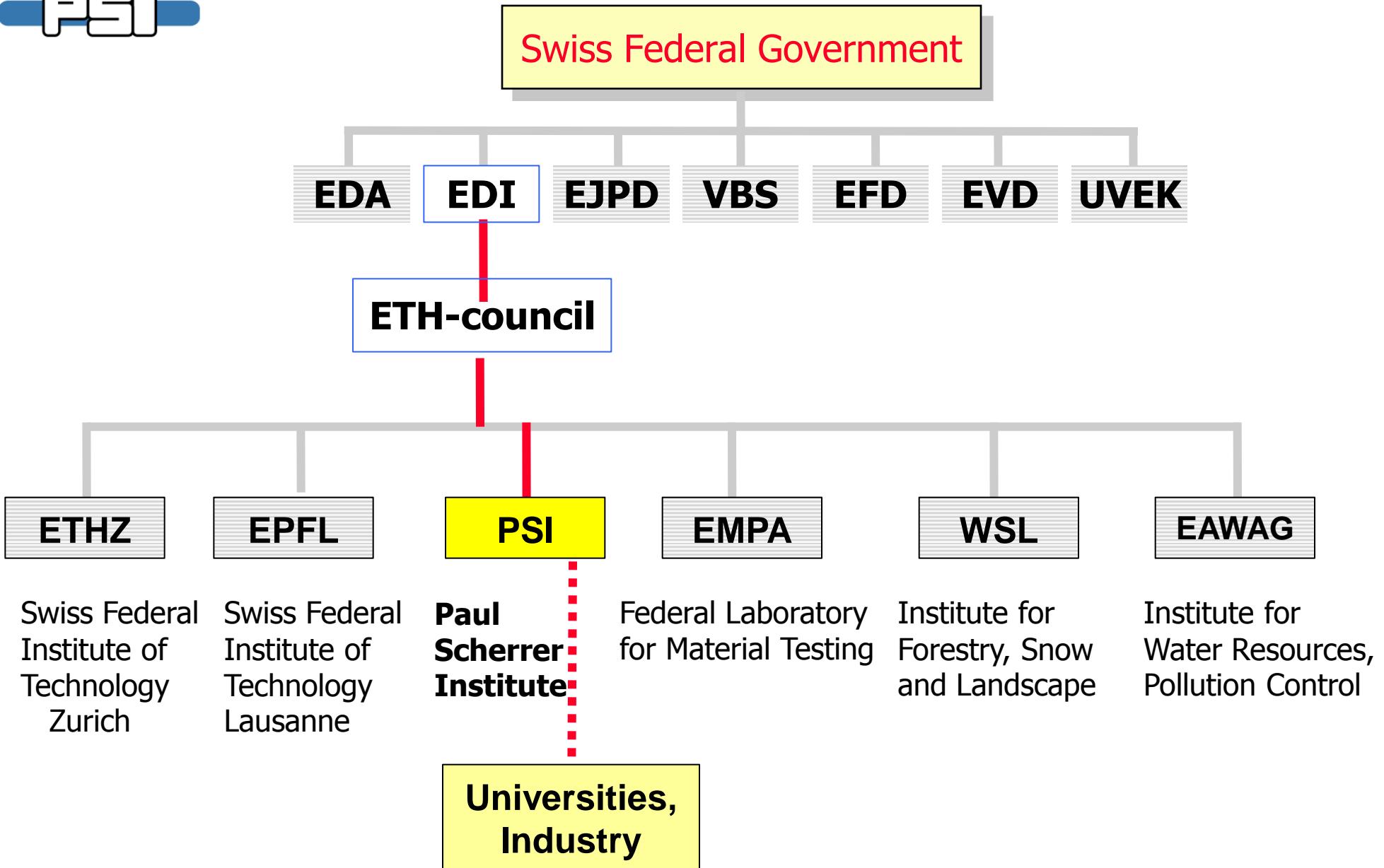


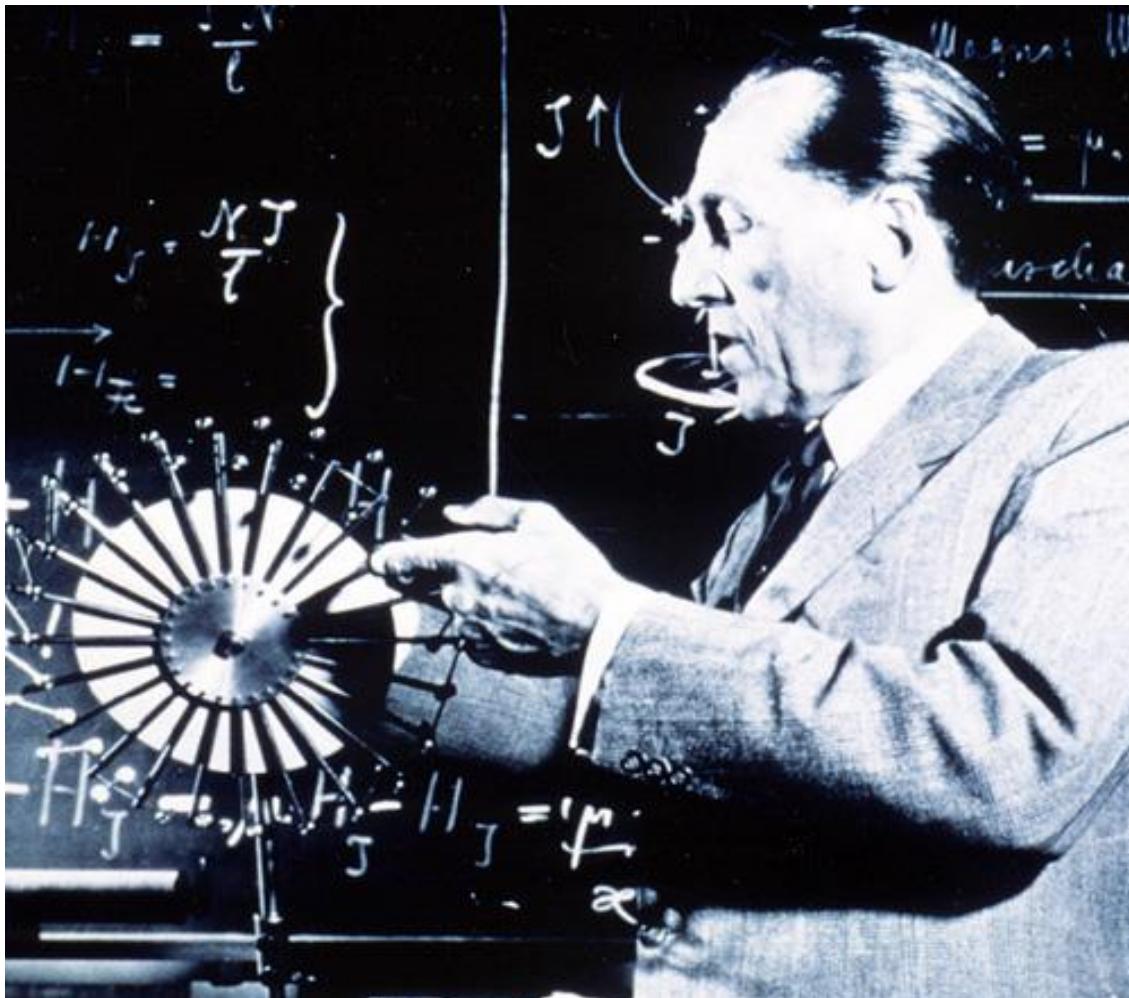
Visits at PSI

a collection of slides
used by Werner Joho

- Introduction to PSI
- Energy Research, Proton Therapy,
Neutron Source SINQ,
Swiss Light Source SLS
- 3D-Film
- Exposition in Forum
- Break with drinks and sandwiches
- Transfer to PSI West
- Visit of SLS, SINQ, Proton Therapy



Paul Scherrer (1890 – 1969)



- Study of Physics / Mathematics
ETH Zürich, Königsberg, Göttingen
- 1920: Director Physics Institute ETH.
popular Physics Lectures, Showman
- Research:
X-ray Diffraction, Nuclear Physics
- 1946: President of the Swiss Atomic
Energy Commission
- Member of the Founding Committee
of CERN in Geneva

Mission of PSI

Research at international Level

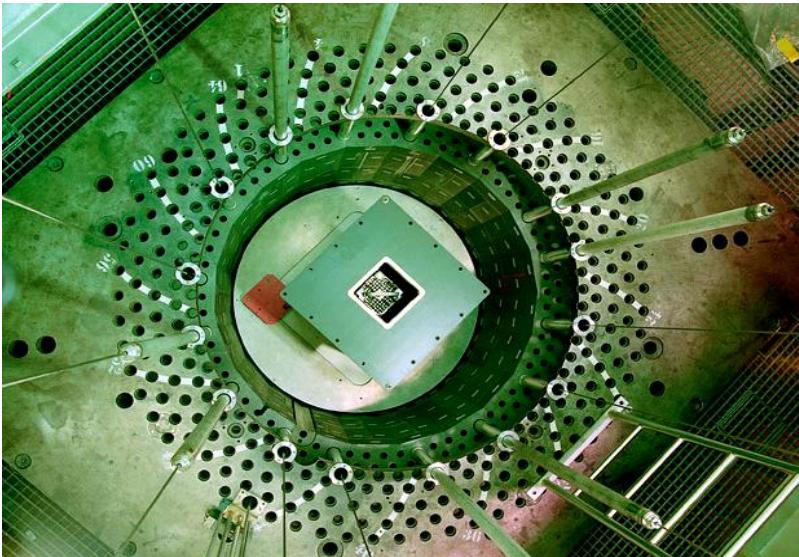
- **Material Sciences, Nano-technology**
- **fundamental Questions in Science,**
=> **Research with complex large Facilities**
- **structural Bio-Science**
- **Tumour Therapy with Protons**
- **Energy Research**



Research at PSI East

Alternative-Energies

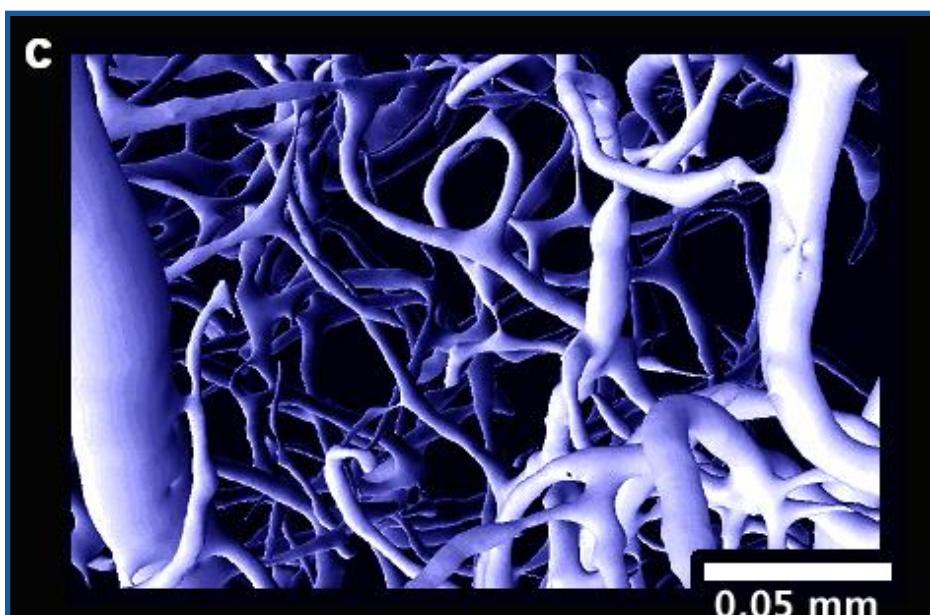
- hydrogen car, fuel cells
- efficient batteries
- solar-ofen, solar-cells



Nuclear Energy

- safety of nuclear power plants
- waste disposal
- transmutation of waste (vision !?)

Research at PSI West



Material Research with X-rays, Neutrons, Muons

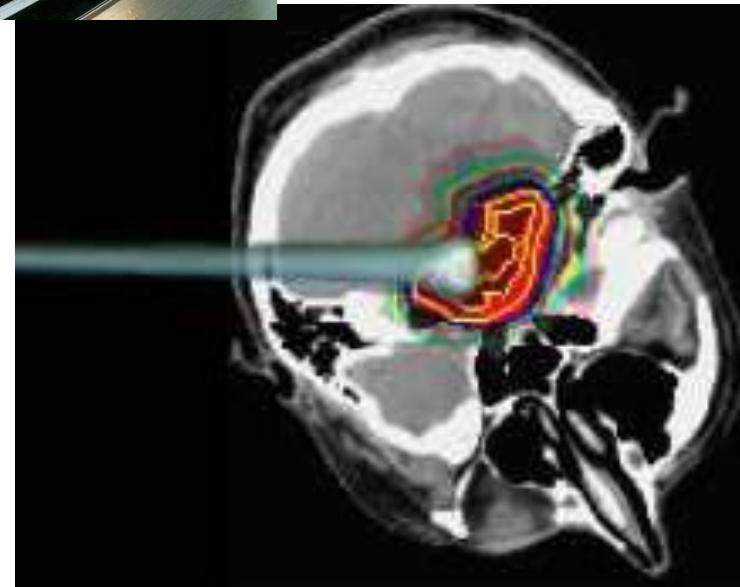
- Structure of Biomolecules for new Drugs
- 3D-Tomography of Microstructures
- magnetic Structure of Surfaces
- Superconductors
- internal magnetic Fields in Solids
- imaging of large Objects with Neutrons

Medical Applications

Tumour Therapy
with Protons



Isotope Production
for Hospitals



Research at PSI West

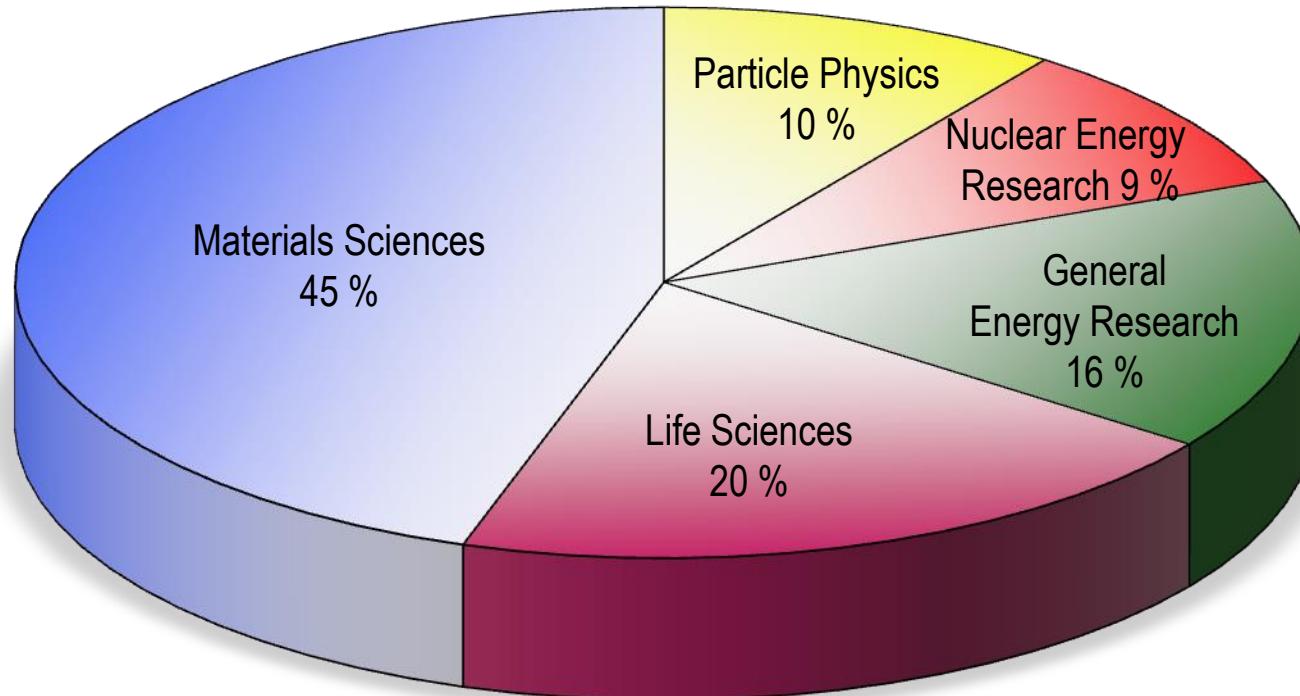
Budget 2012

PSI Global Budget	250 Mio. CHF
Research for Industry	80 Mio. CHF

Staff	1400
financed externally	300
PHD's	ca. 300
Apprentices	85
External Users	ca. 2100
PSI Employees lecturing at	
ETH/ Universities/ Engin. Institutes	ca. 70

Budget 2012

250 MCHF (PSI funds)



Research Topics

renewable Energy



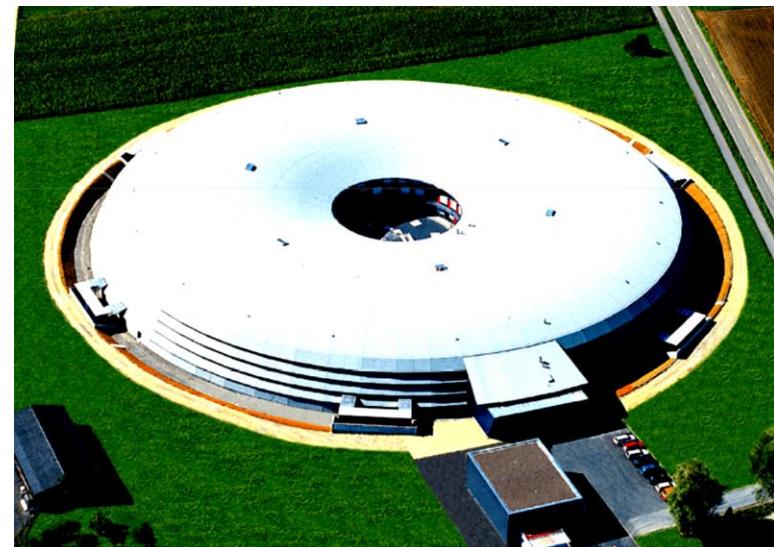
Proton-Cyclotron



Nuclear Energy & Safety



SLS: Swiss Light Source

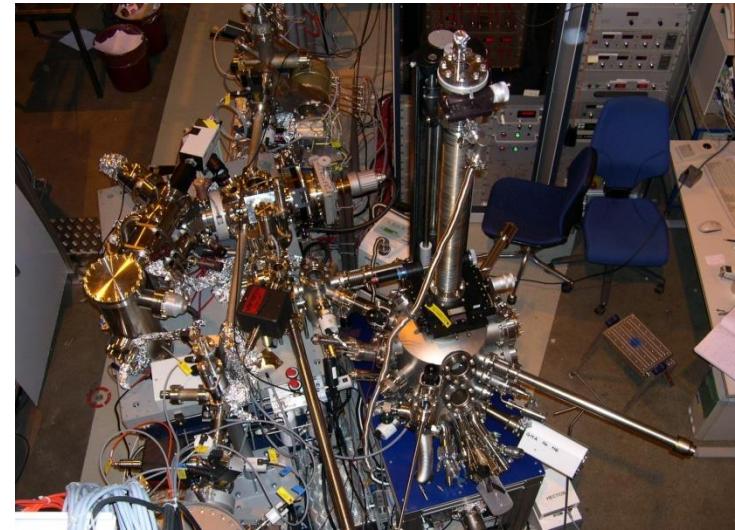


Research Topics

Human health



Microstructures, new Materials



Neutronsource SINQ



Myons as Microprobes



PSI has 3 Top-class Accelerators!

- **Ring-Cyclotron , 590 MeV Protons**
=> Neutrons, muons
- **Storage Ring , 2.4 GeV Electrons**
=> X-rays
- **compact-Cyclotron , 250 MeV Protons**
=> Cancer Therapy

Ring-Cyclotron 590 MeV Protons

2.4 mA, 1.4 MW average beam power
(world record!)

most intense

Muon Beams

$5 \cdot 10^8 \mu^+/s$, $10^8 \mu^-/s$

Spallation-Neutron-Source

$10^{14} n/s$

corresponds to
medium flux reactor
(without Uranium!)

Swiss Light Source (SLS)

2.4 GeV Electron Storage Ring

extreme stable X-ray beams
to better than 0.5 μm

superconducting Cyclotron 250 MeV Protons for Tumour Therapy

Eye Tumours

deeply seated Tumours

2 rotating Gantry

3D-Spot Scanning

Beam Therapy against Tumours

X-Rays

Conventional Method
in Hospitals

Disadvantage:
Healthy Tissue gets
substantial Dose

Proton Beams

Advantage: Proton stops after a well defined Range, Choice from 2-30cm
3-dimensional scanning

=> **Protection of critical Organs**

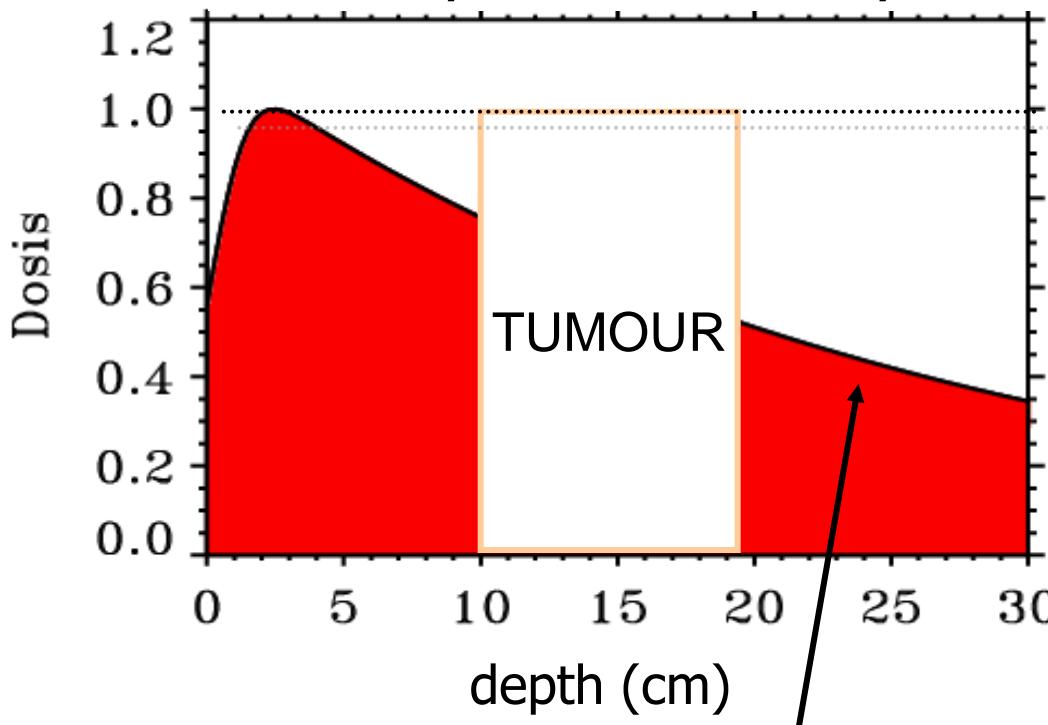
in Switzerland so far only at PSI !

⇒ Limitation to special Tumours

⇒ **Eyes, Brain, Spinal Cord**

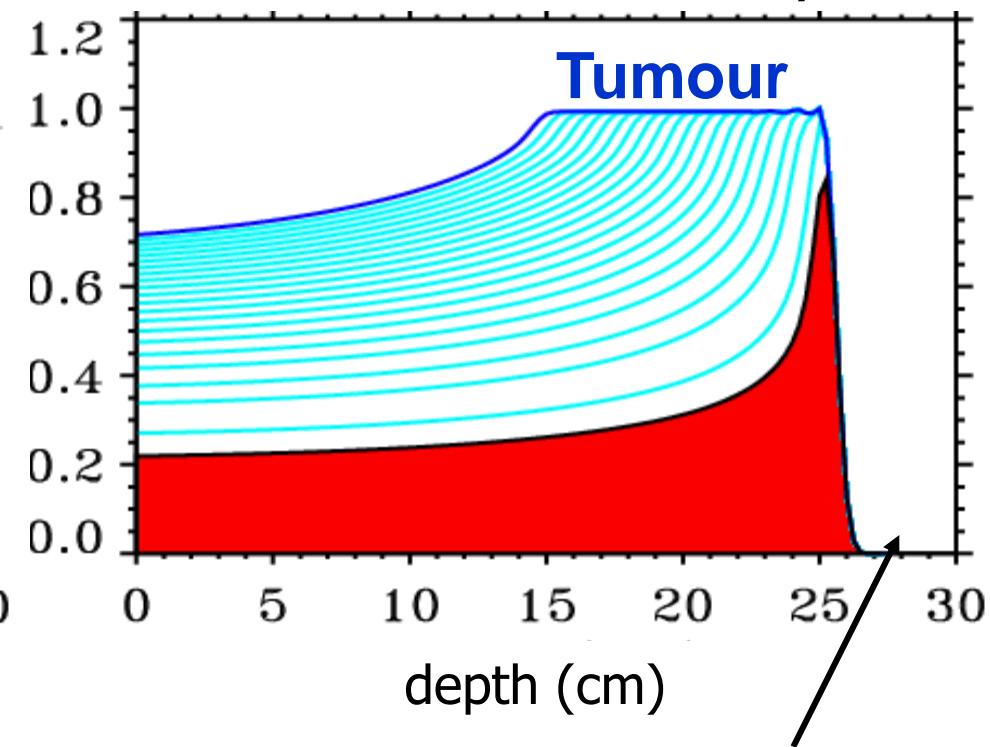
Dose distribution in human body

X-rays: dose in body



substantial dose
behind tumour

Protons: dose in body



no dose
behind tumour

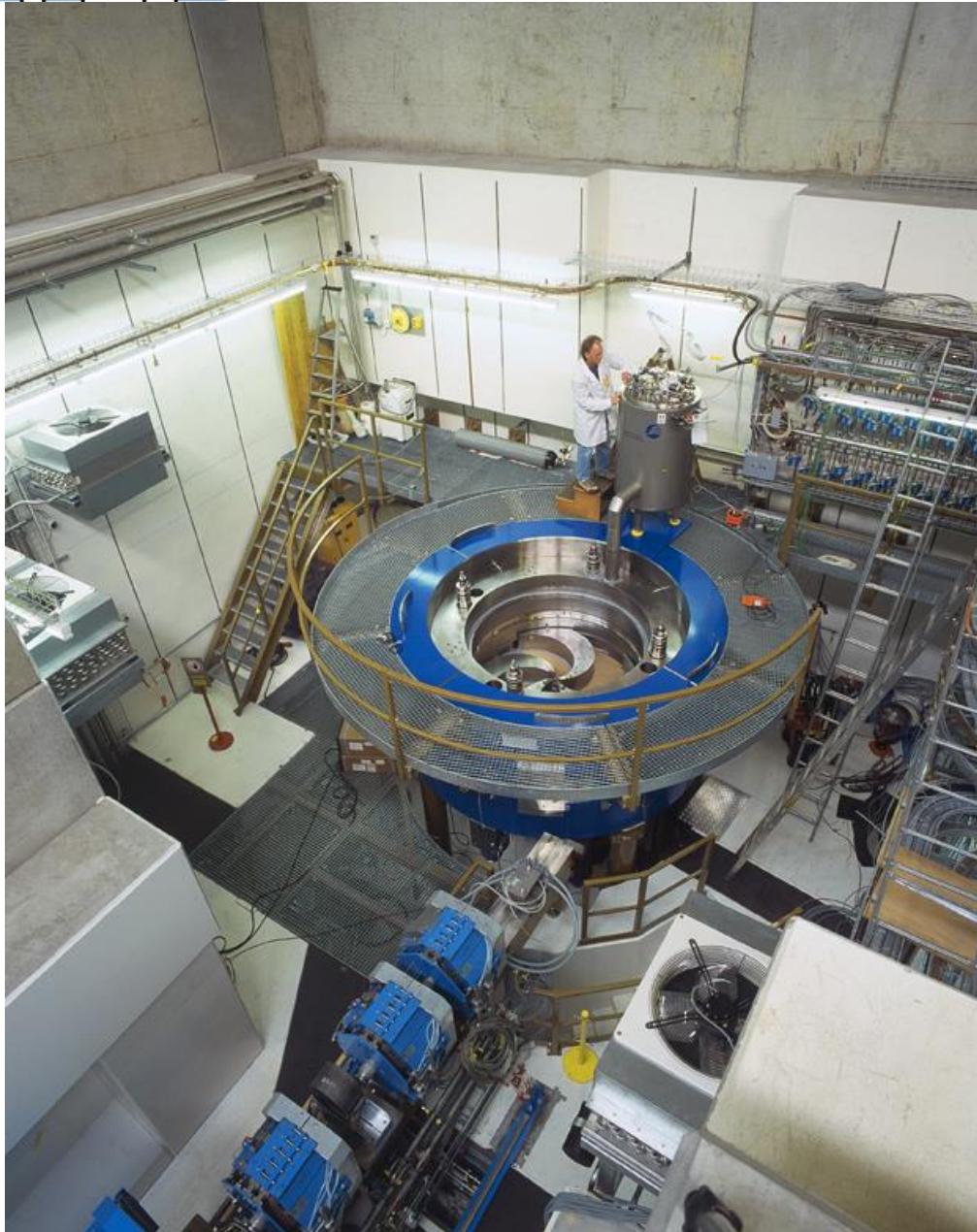
OPTIS

Eye Tumour Therapy with protons



1984-2012
5'500 Patients
from all over Europe

Tumour-control:
> 98%
(Collaboration with
Hospital Lausanne)
Irradiation on 4 days

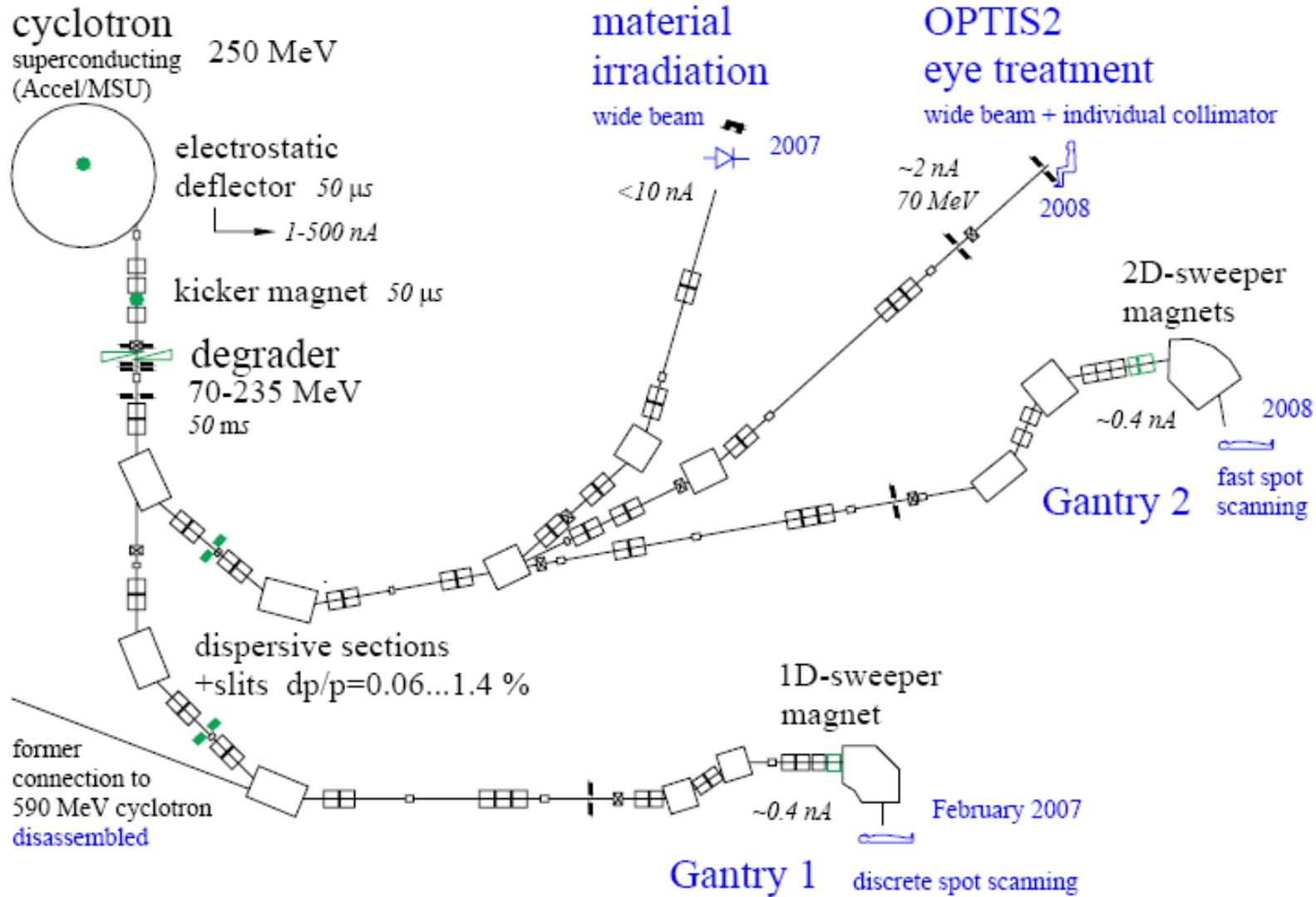


Comet Cyclotron

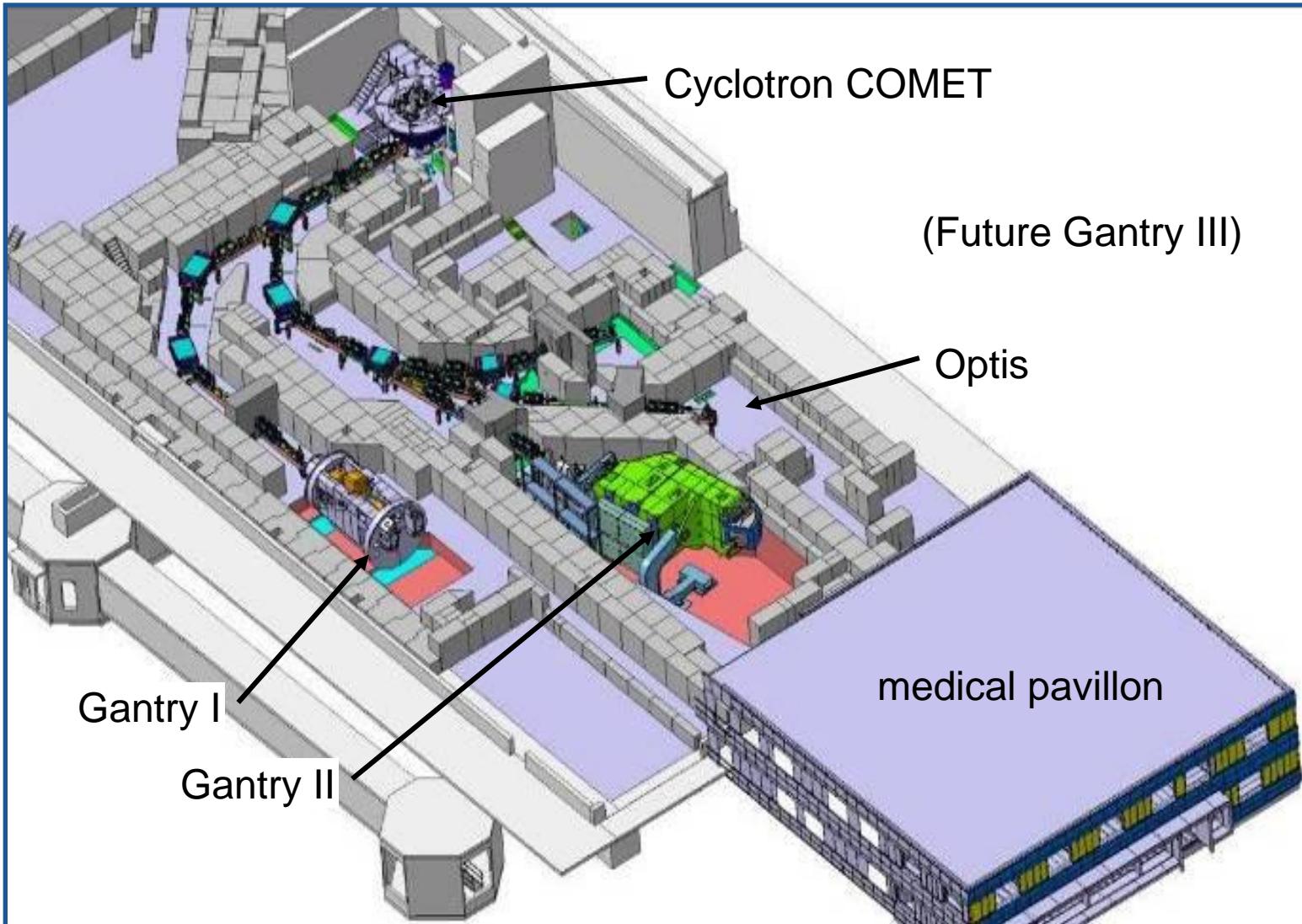
Beam Therapy with
250 MeV Protons

CYCotron:
superconducting Magnet, 3m Ø
collaboration ACCEL & PSI

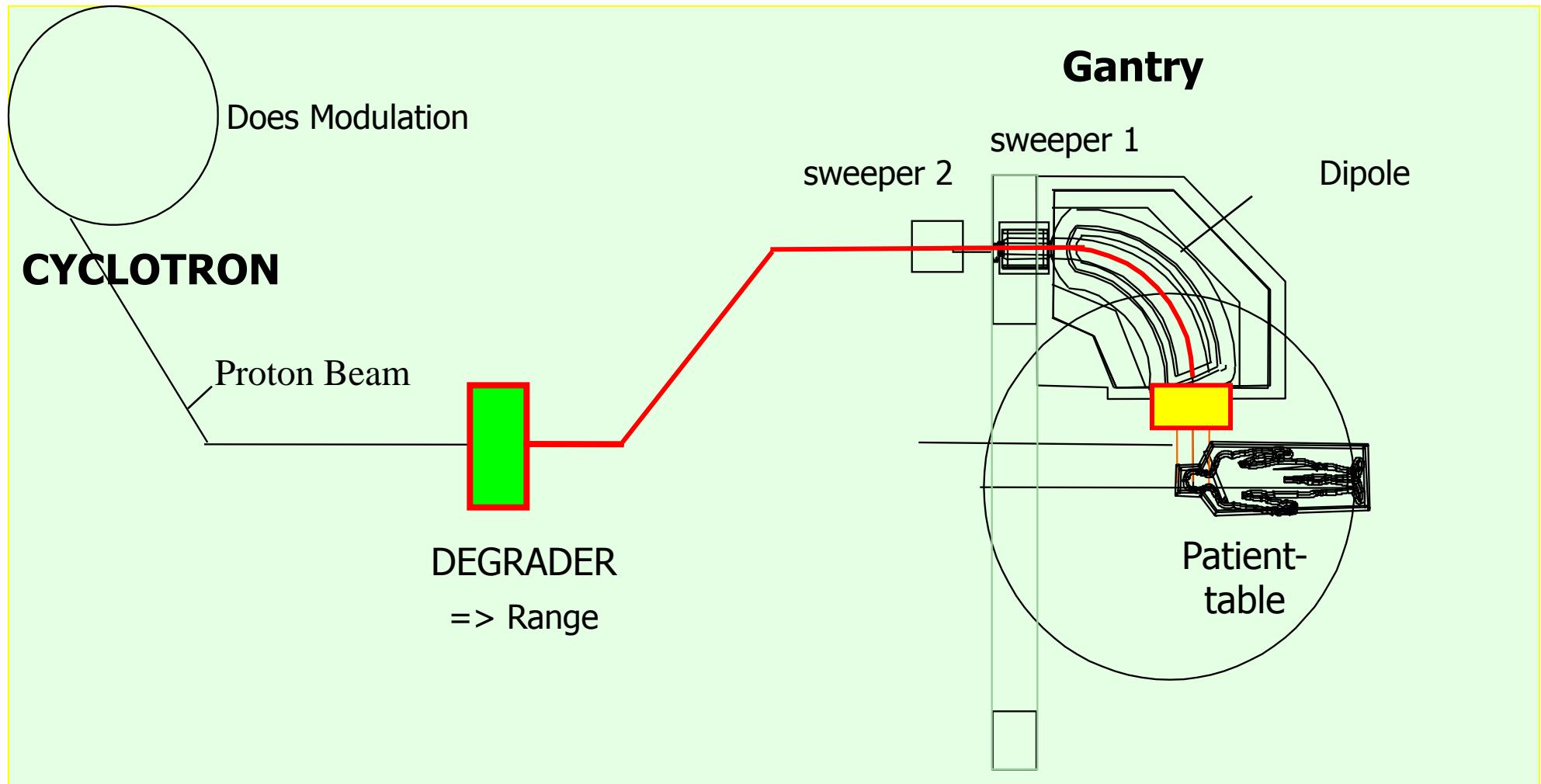
The PROSCAN Facility



The PROSCAN Facility



Proton Therapy with PROSCAN





Proton Therapy

Irradiation of Tumour
from different Directions
with Gantry

→ minimal Dose at
Surface

Spotscanning (E.Pedroni)

- Pencil Beam: 7 mm in Air
- Volume Scanning on a 5 mm Grid:
10'000 Application Points per Liter

still world wide the only Gantry with
Proton Scanning !

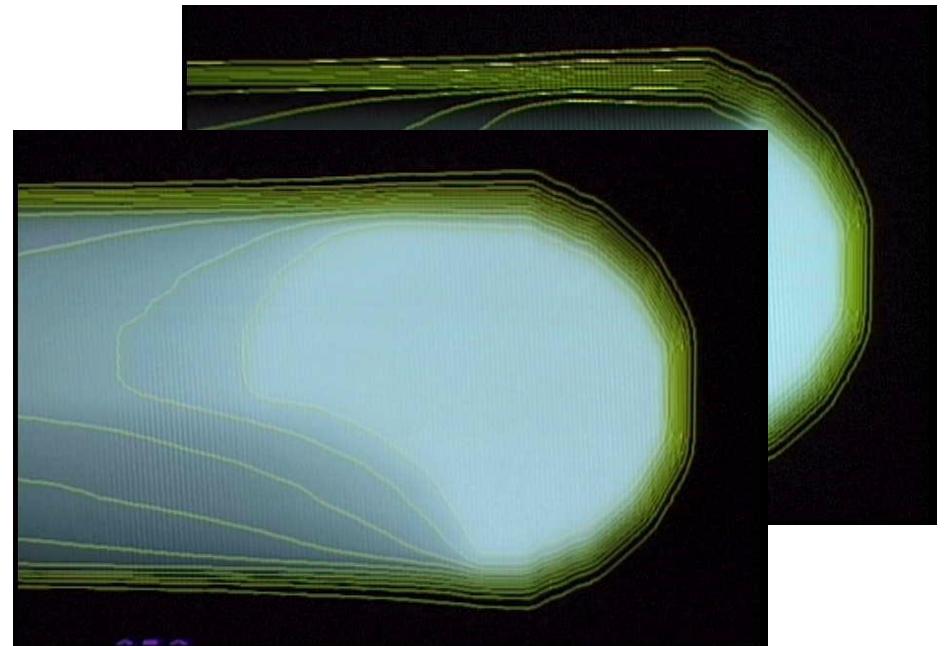
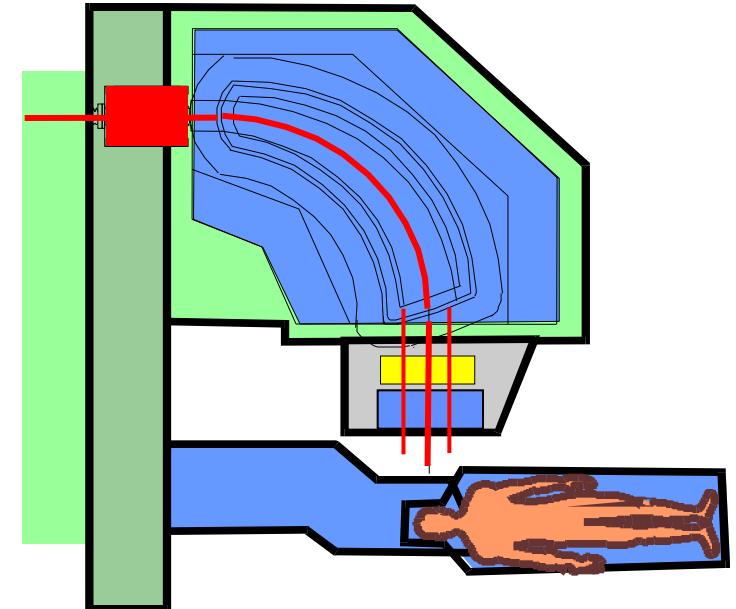
Scanning Elements :

Tim Spot-Dosis Monitor + Kicker
100 us

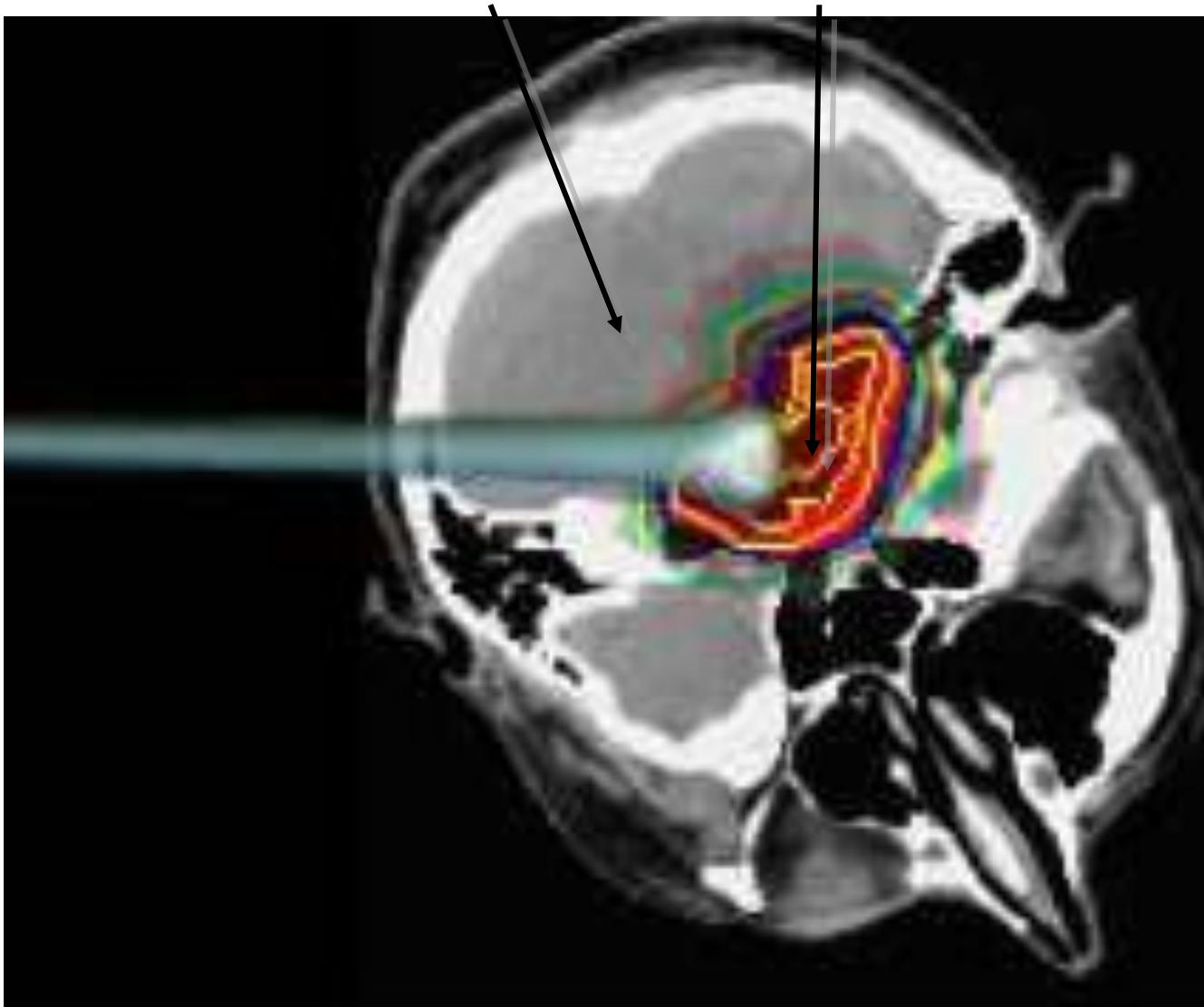
X Sweepermagnet (fast) 5 ms/step

Y Range-shifter (moderate speed)
30 ms

Z Patient Table (slow) 10 mm/s

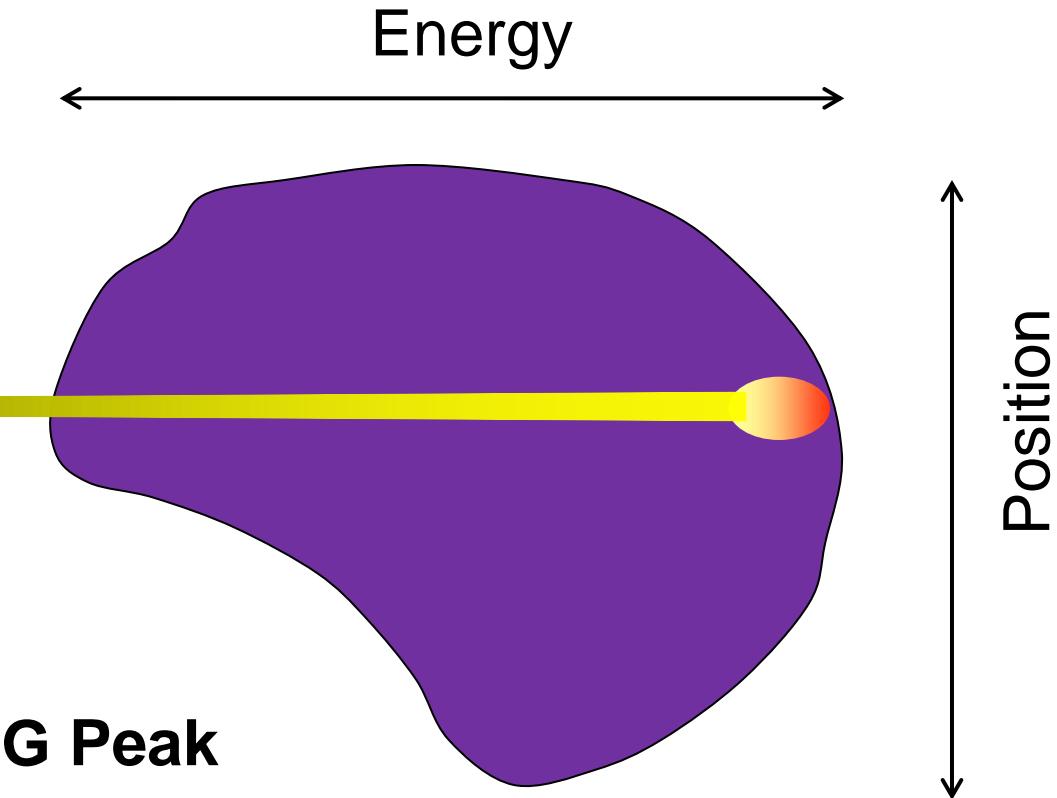
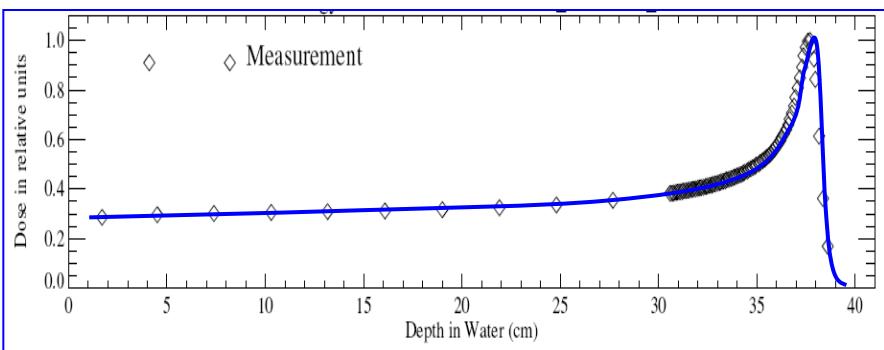


Dose below 5% Dose 100%



Brain Tumour

Irradiation with
Protons by
Spot-Scanning
(E.Pedroni, PSI)

SPOT SCANNING**BRAGG Peak**

Treatment of deep seated tumours with minimal damage to healthy tissue

Costs for Proton Therapy

Treatment at PSI

Eye Tumour:

8'000 Fr. , 4 Sessions

ca. 200 Patients/Year

Brain Tumour:

40'000 Fr. , 30 Sessions

ca. 50 Patients/Year

new Facility in Hospital

medical Building

50 MFr.

Cyclotron with 3 Gantry

100 MFr.

ca. 400 Patients/Year

3 Probes for Material Research

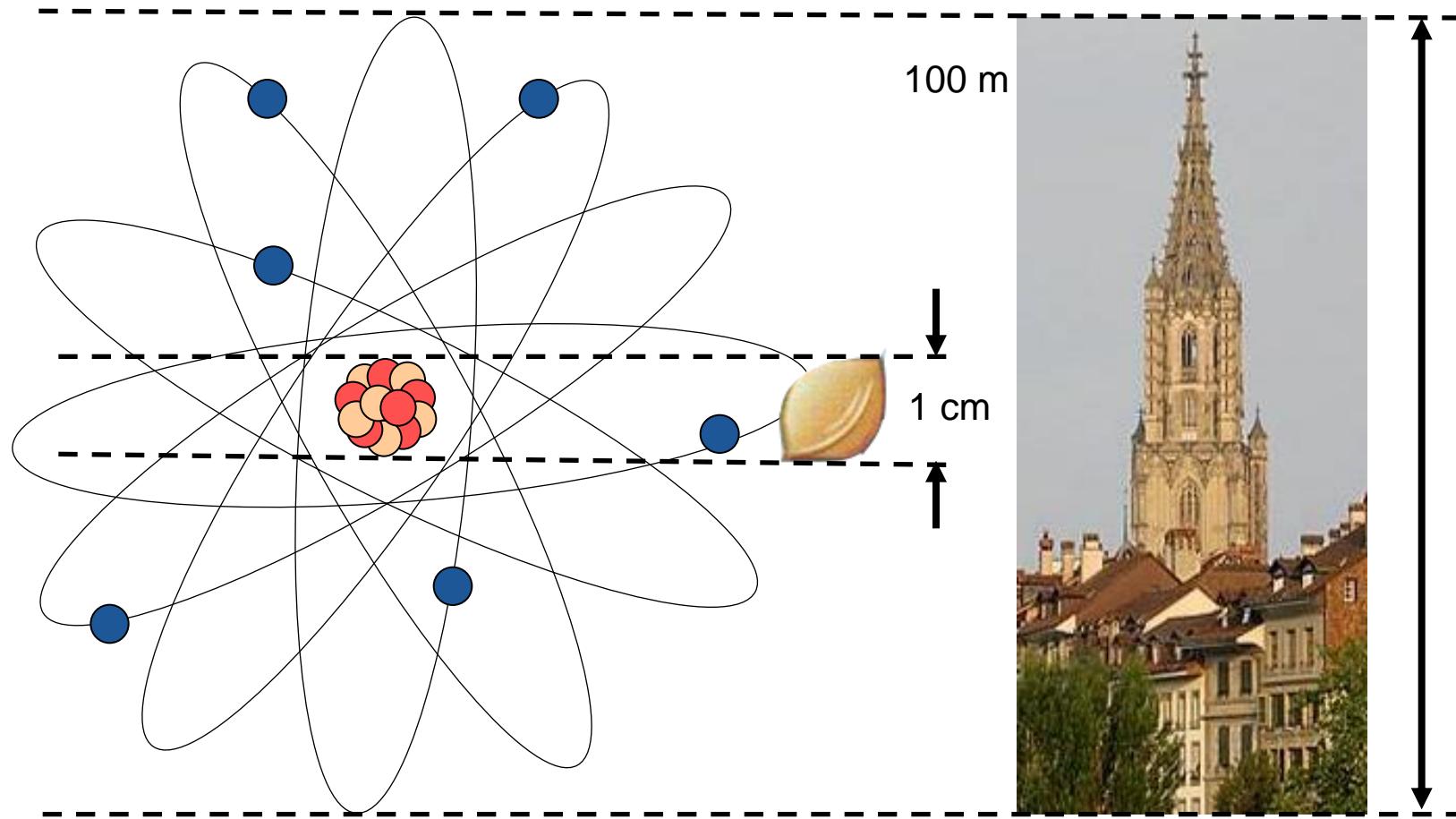
only at PSI and Rutherford Lab

Photons (SLS)  **Electron Cloud**

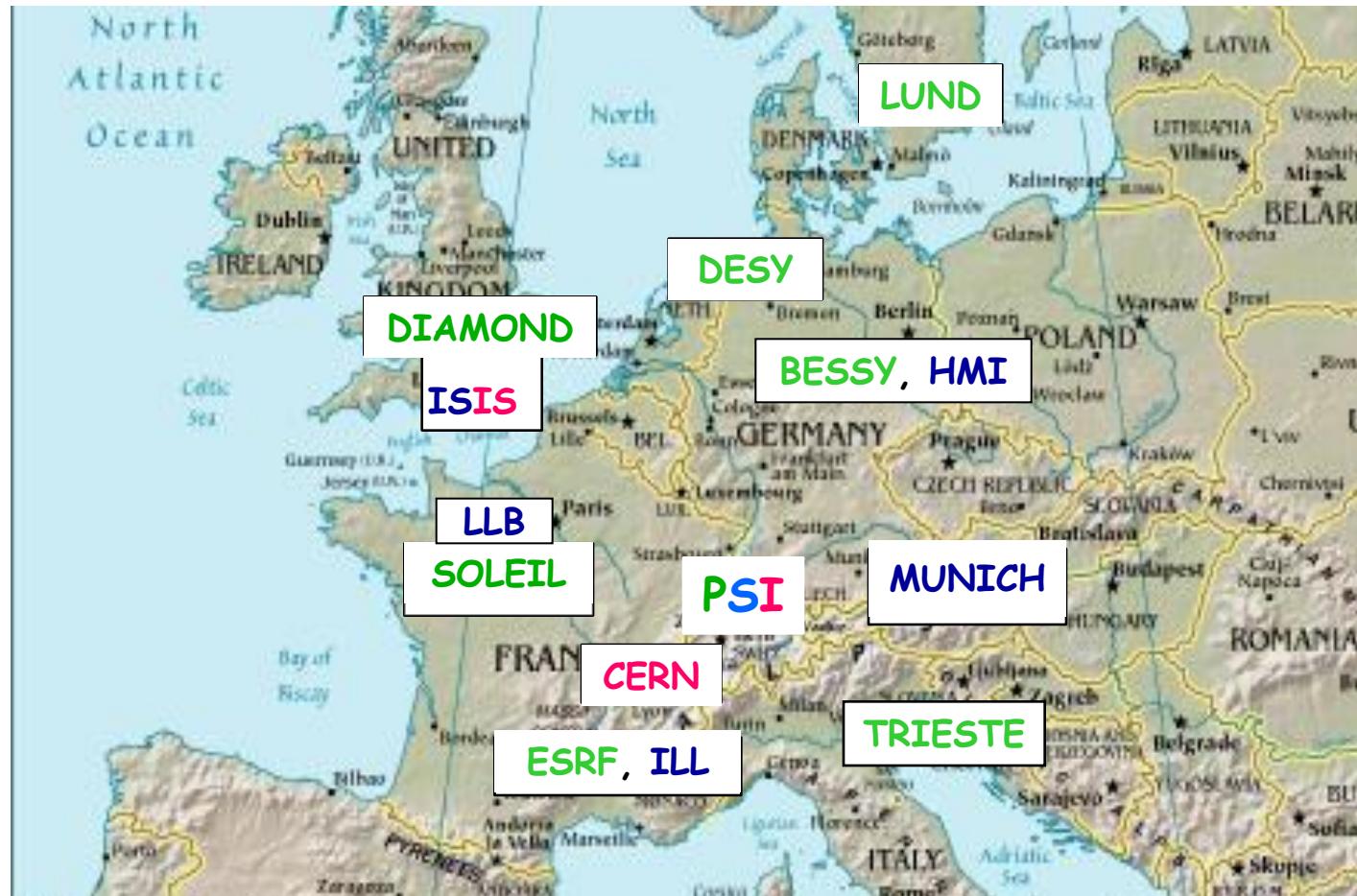
Neutrons (SINQ)  **Atomic Nuclei**

Muons (μ SR)  **internal magnetic
Fields in Crystals**

size comparison Nucleus => Atom

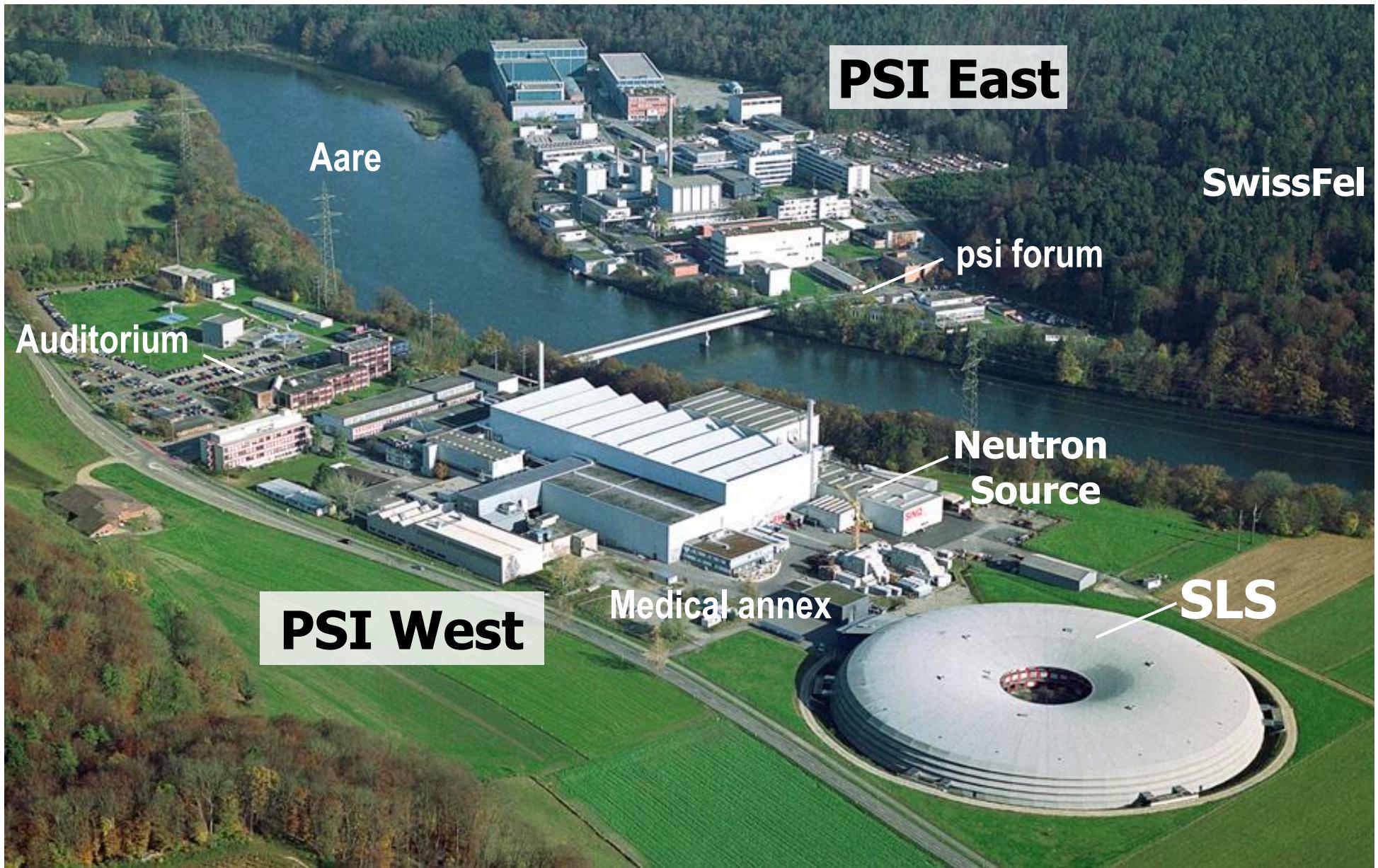


Facilities in Europe

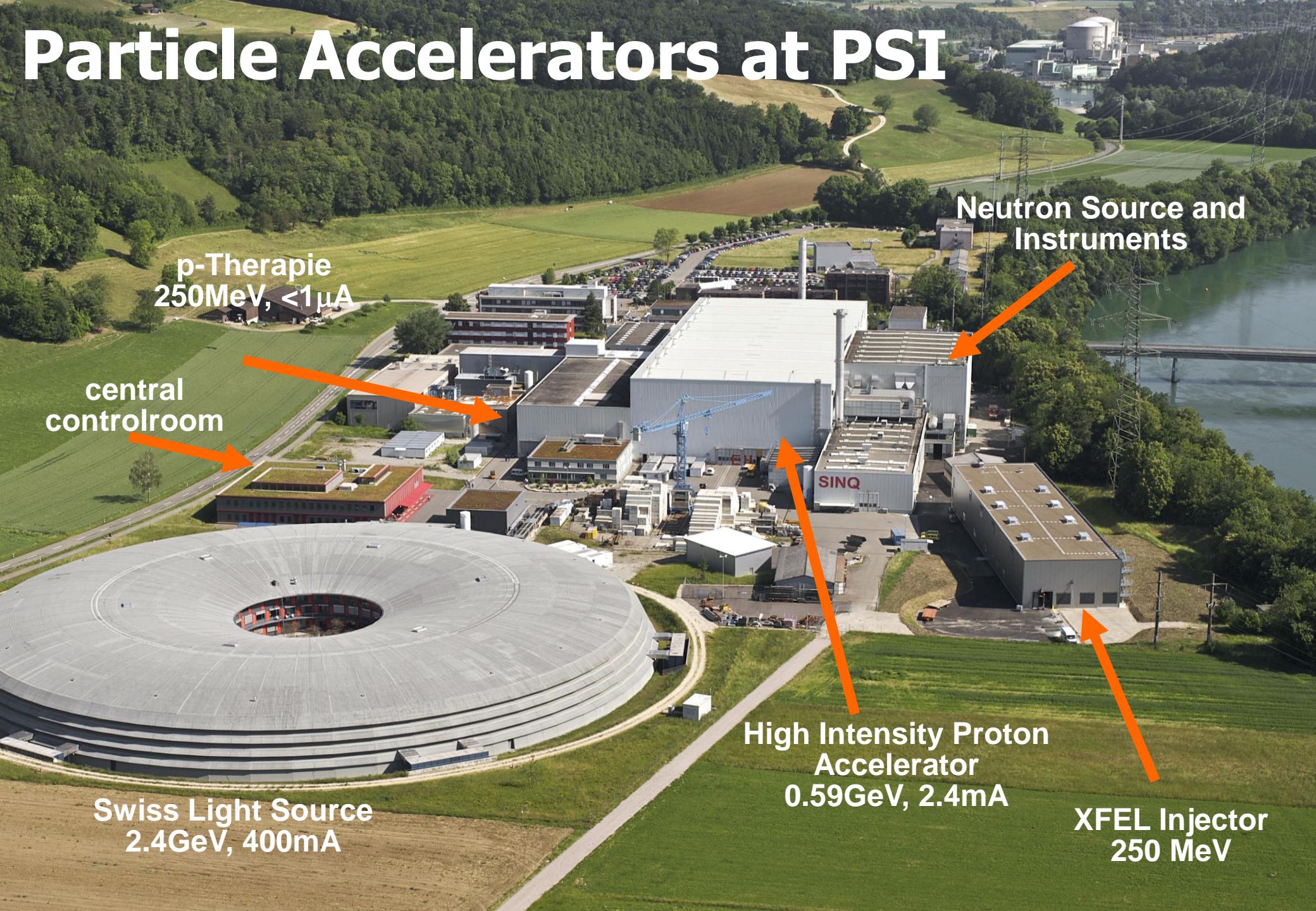


2010

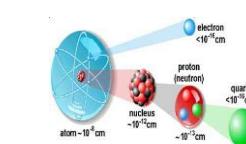
X-rays
Neutrons
Muons



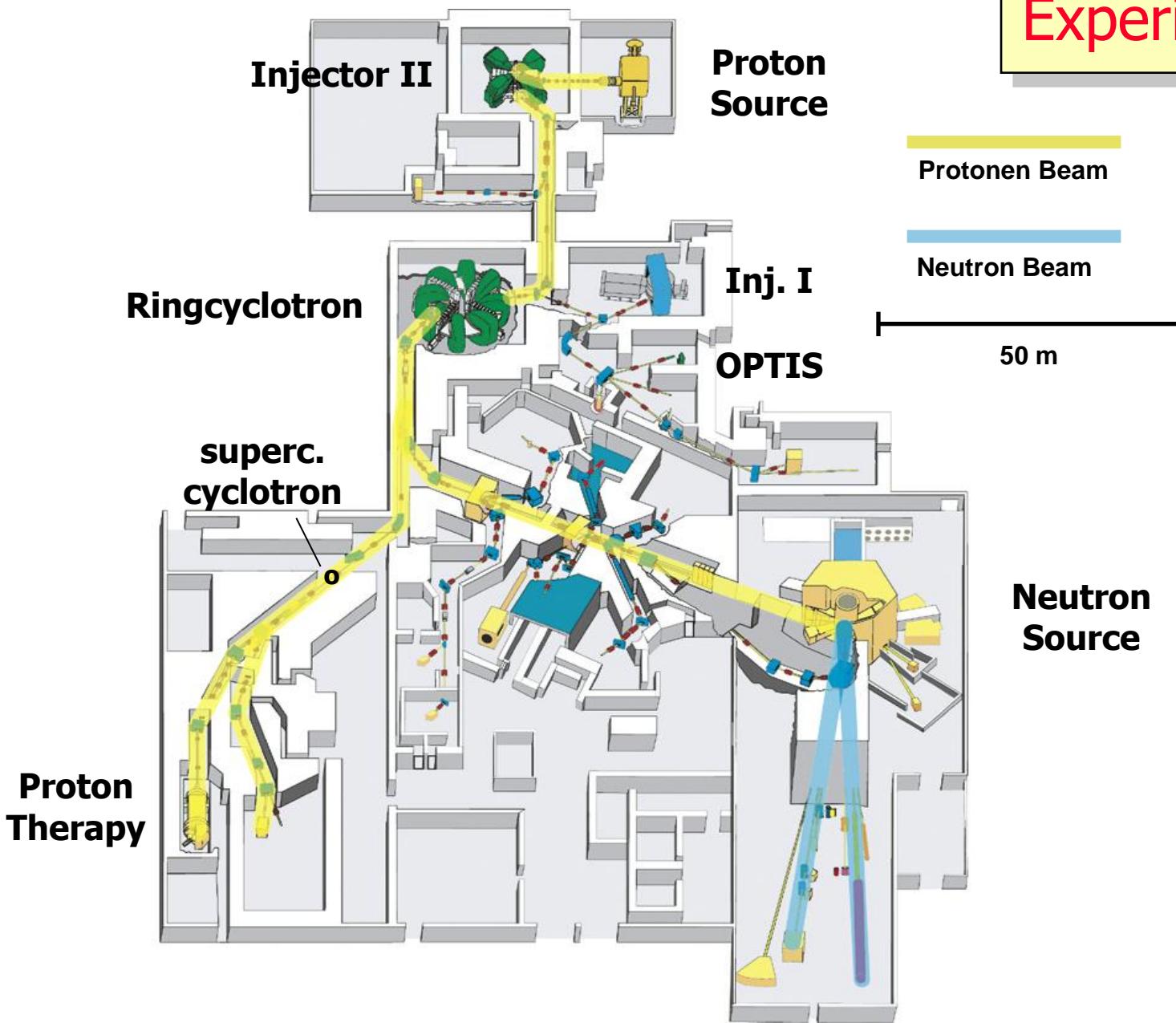
Particle Accelerators at PSI



PSI user laboratory key numbers 2011



2011	SLS	SINQ	SμS	LTP	PSI total
Beamlines	16	12	6	4	38
Instrument Days	1787	1939	669	350	4745
Experiments	1058	439	226	4	1727
User Visits	3338	826	319	594	5077
Individual Users	1565	441	160	240	2336
New Proposals	778	403	196	1	1378



Experimental Hall

Protonen Beam

Neutron Beam

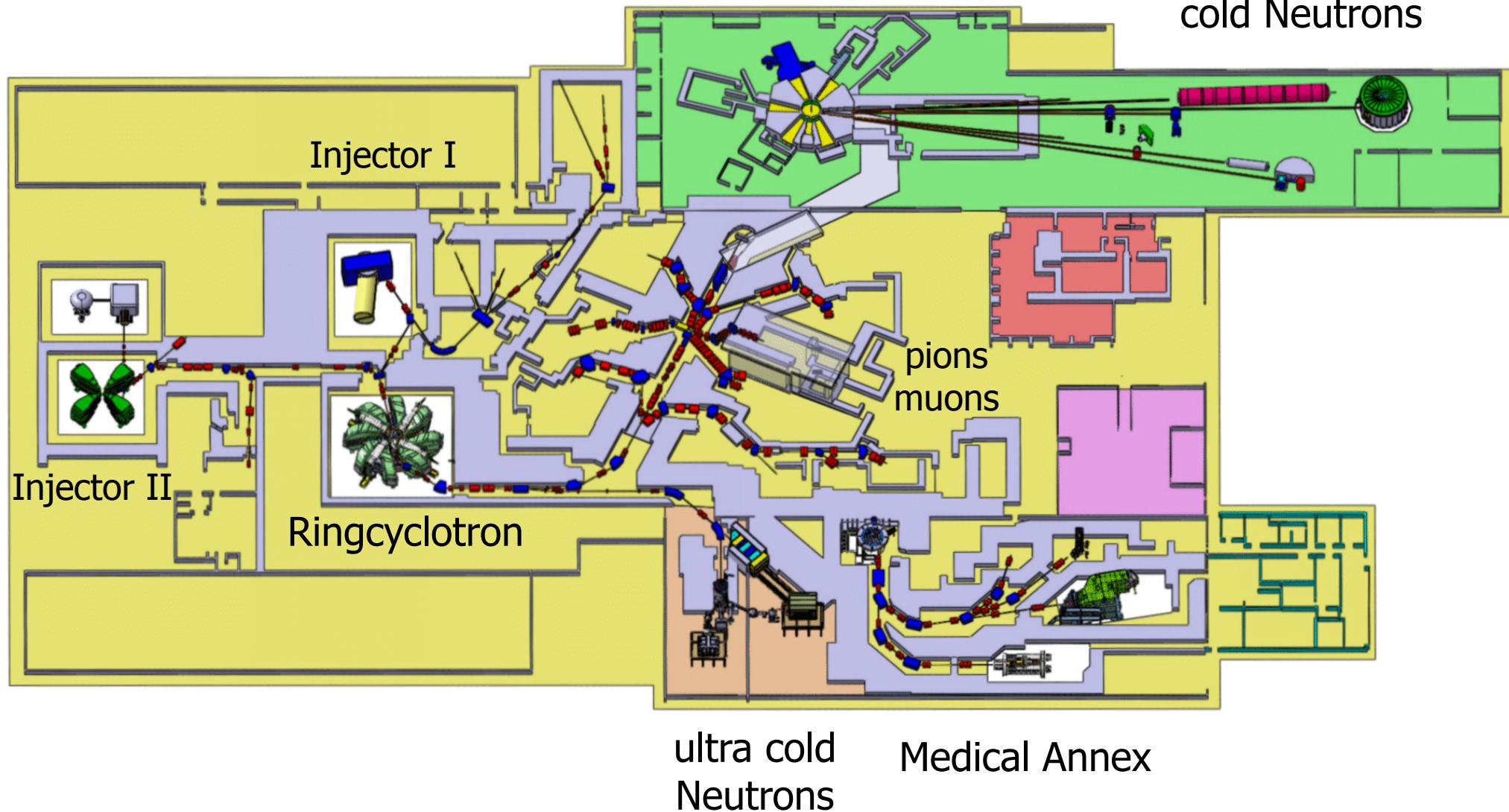
50 m

Neutron
Source

Experimental Hall

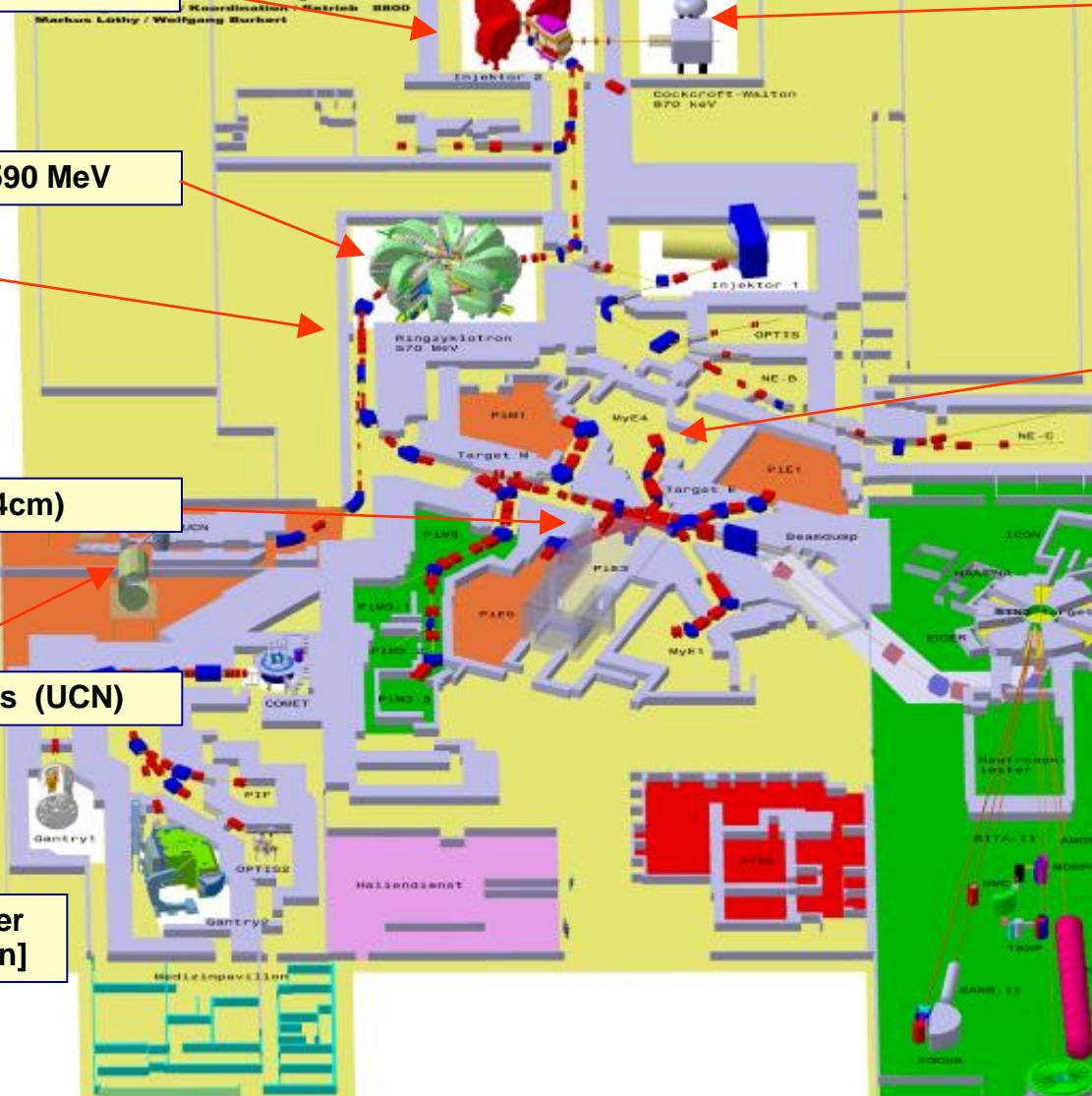
Neutronsource
SINQ

cold Neutrons



Overview High Intensity Proton Accelerator

Injector II Cyclotron 72 MeV

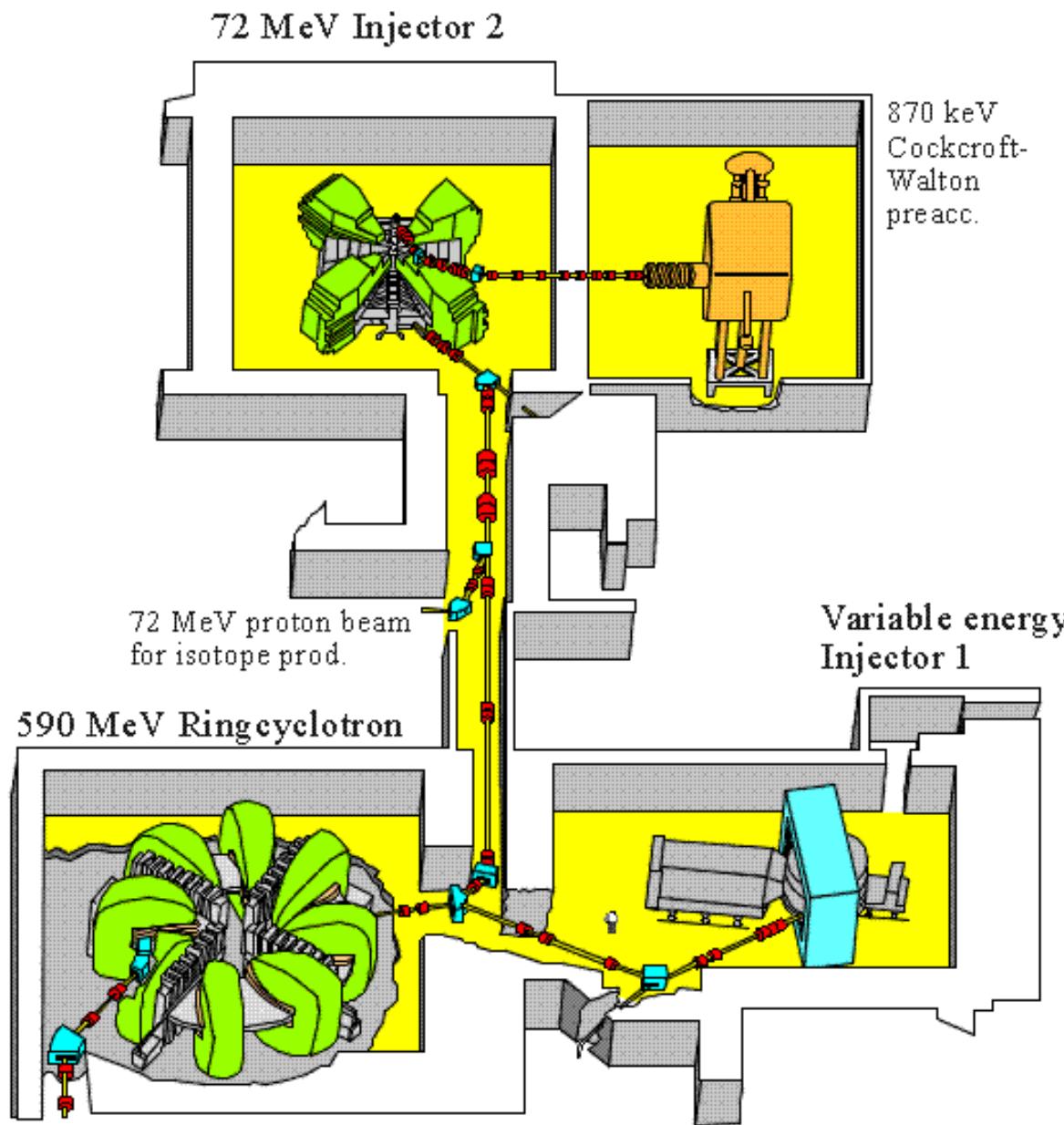


Cockcroft Walton

μ/π secondary beamlines

SINQ
spallation source

SINQ
instruments



Accelerator Facilities with 4 Cyclotrons

Injector 1:

Nuclear Physics + Eye Tumours

Injector 2:

Injection + Isotopes for Hospitals

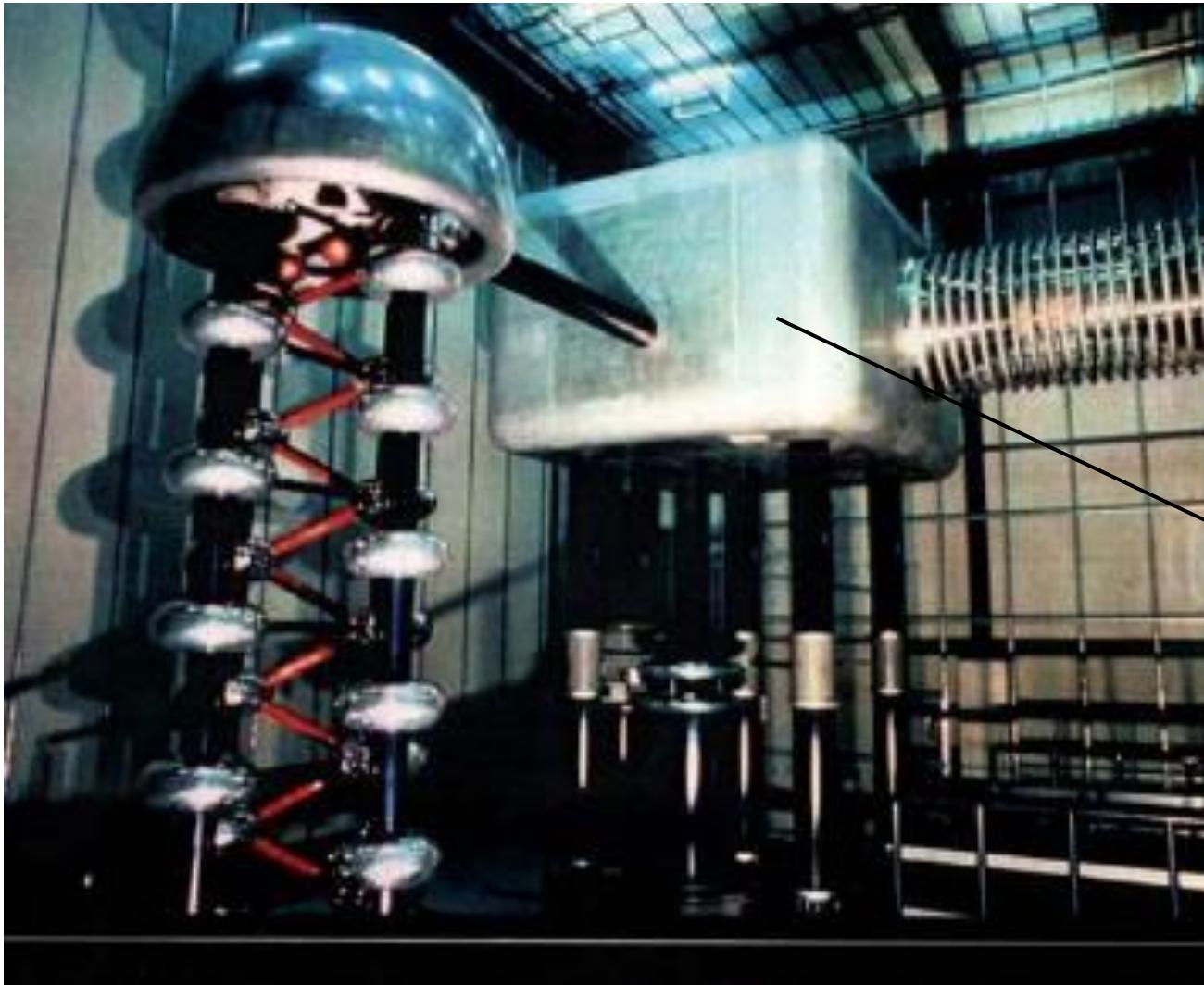
Ringcyclotron:

Muons, Pions, Neutrons,
Proton Therapy

superconducting Cyclotron:

Proton Therapy

Cockcroft-Walton Pre-accelerator

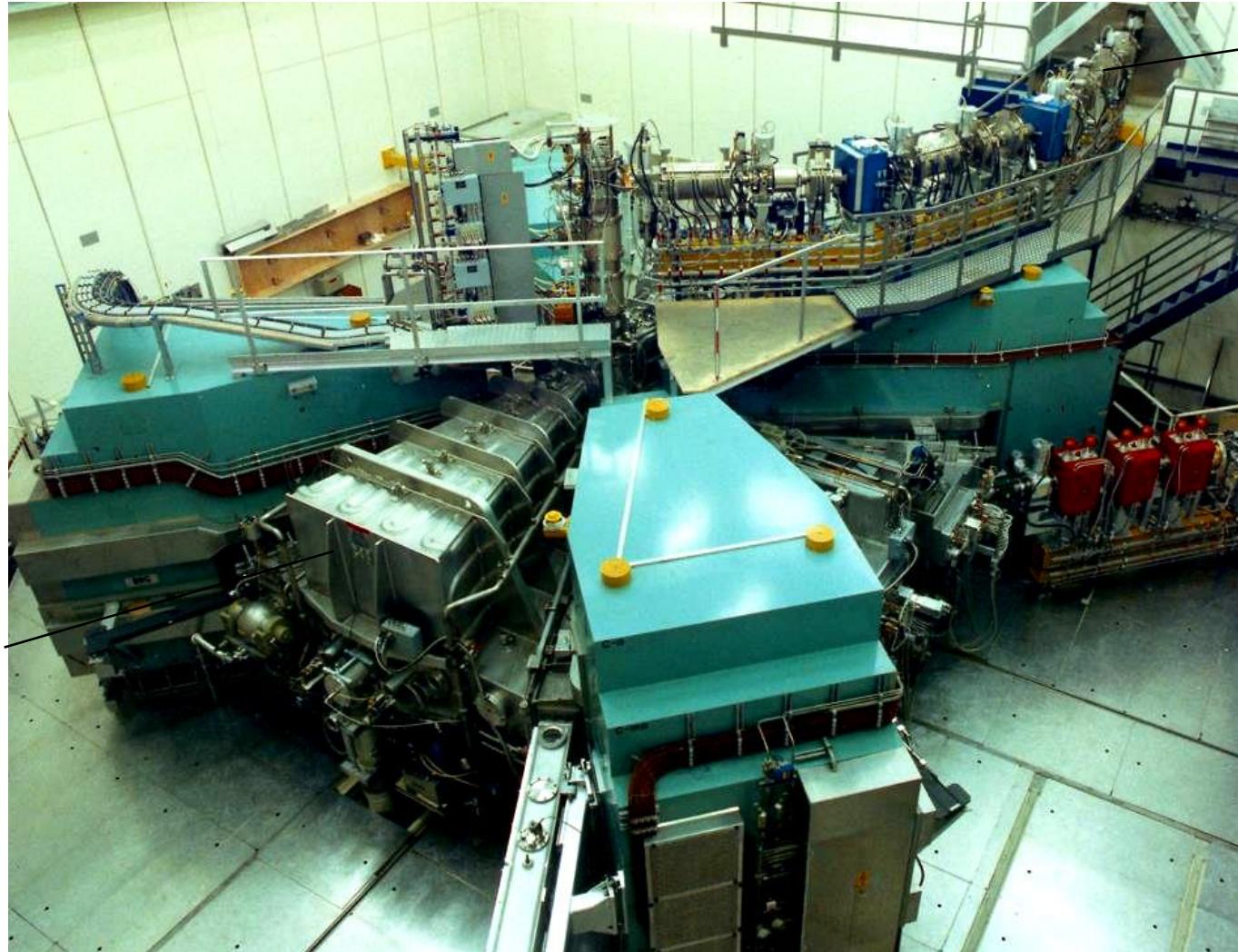


Voltage: 810 kV

→ Proton Beam
870 keV

Proton Source:
at 60 kV inside
„Faraday Cage“

Injector II

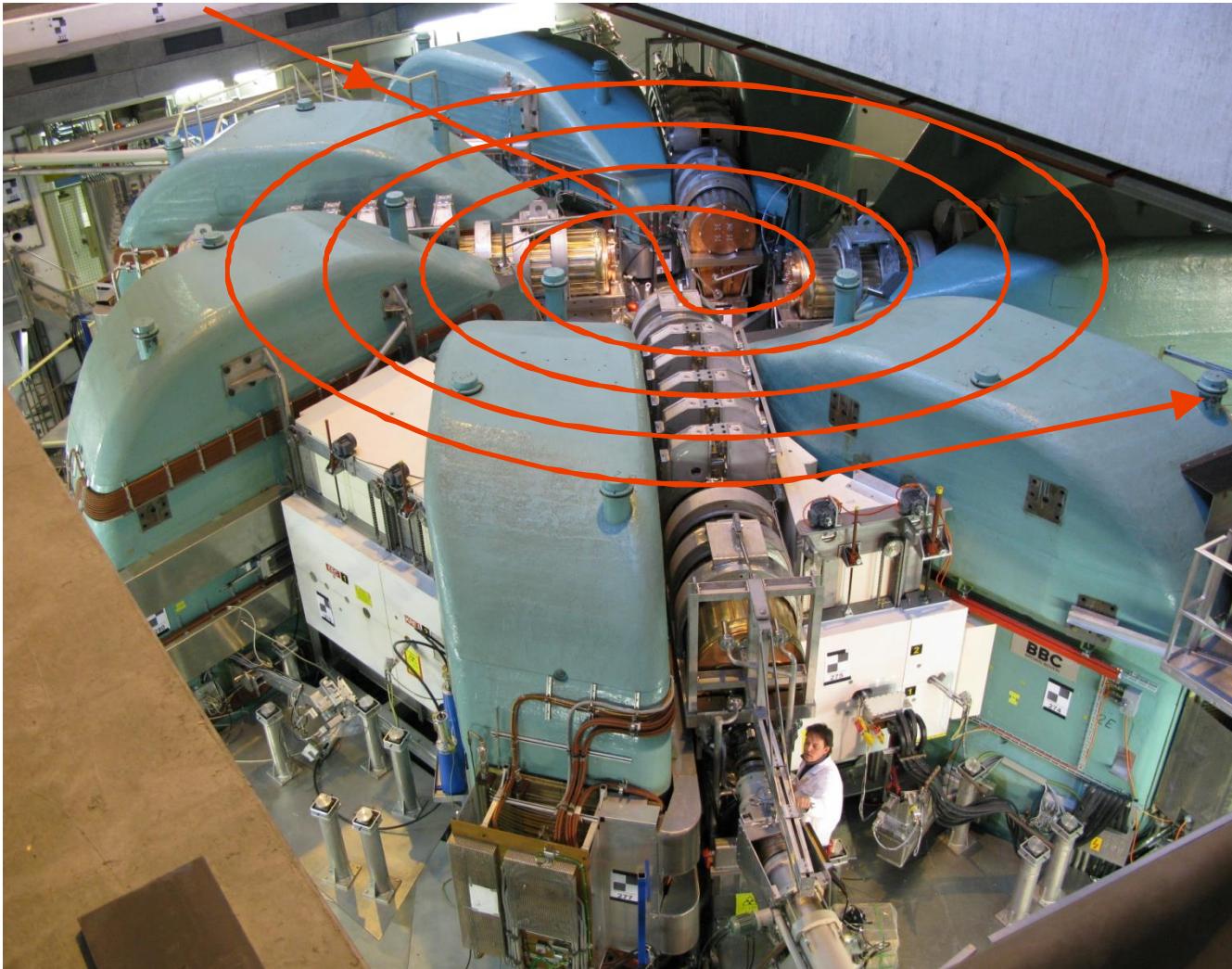


RF
Resonator
50 MHz

Injection Line
870 keV

Extraction Line
72 MeV Protons
(after 100 turns)

Ringcyclotron



590 MeV Protons

**2.4 mA,
1.4 MW Beam Power
(world record!)**

8 Magnet à 250 Tons

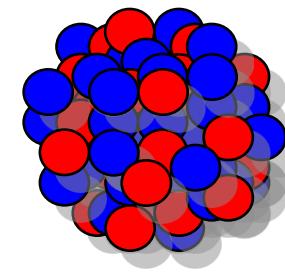
**4 Cavities à 900 kV
(1MV)**

Extraction ≈ 99.99%

Production of Neutrons



Proton

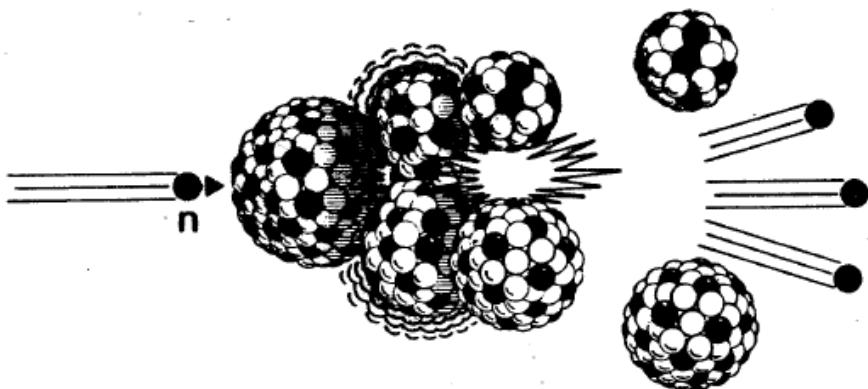


lead nucleus

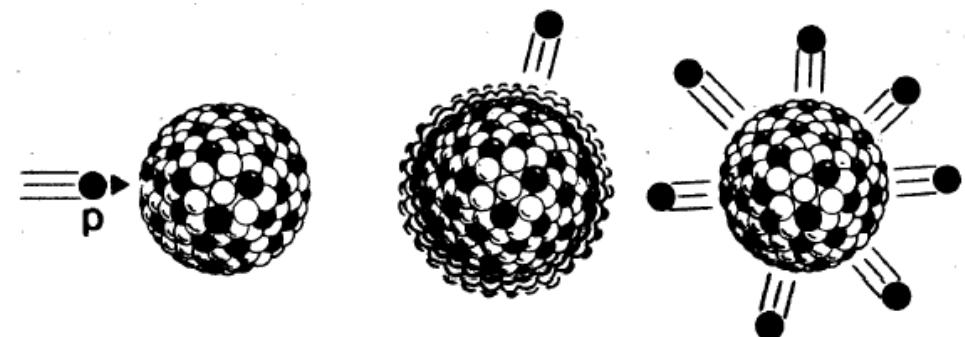
„slow“ Neutrons for Material Research

- Production of fast Neutrons
- slowing down in Moderator

1. **Fission** of Uranium (U^{235})
in a Reactor

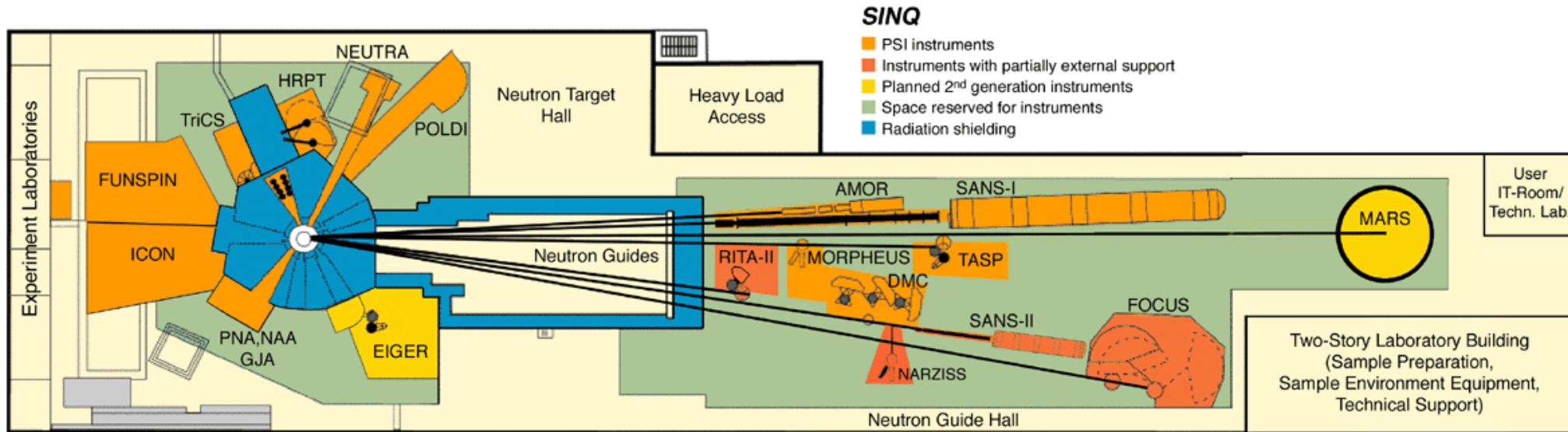


2. **Spallation** of heavy Nuclei
(e.g. lead) by Bombardment with
Protons from an Accelerator
=> allows fast turning off !



Neutron Spallation Source

Proton (590 MeV) => Lead Nucleus => ca. 10 Neutrons
=> Moderation to < 0.025 eV => Diffraction on Material Probes



SINQ

Neutron Spallation Source

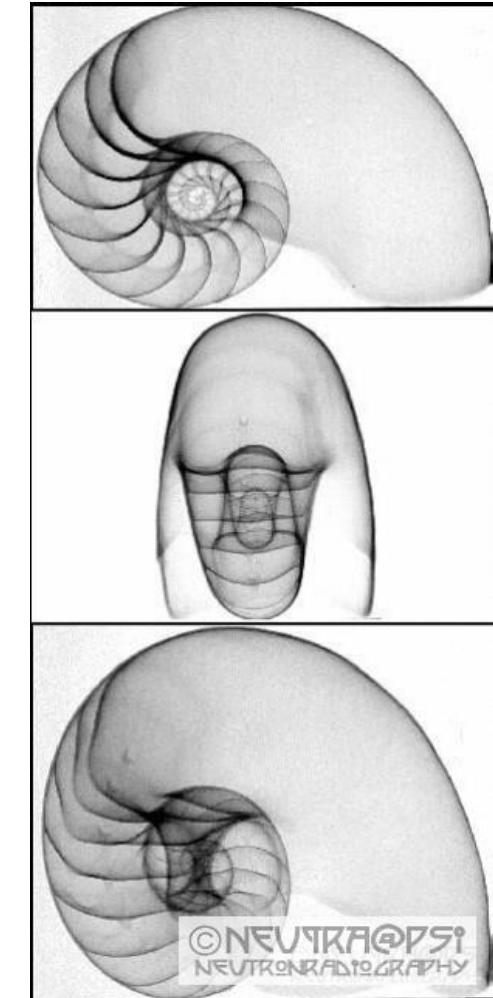
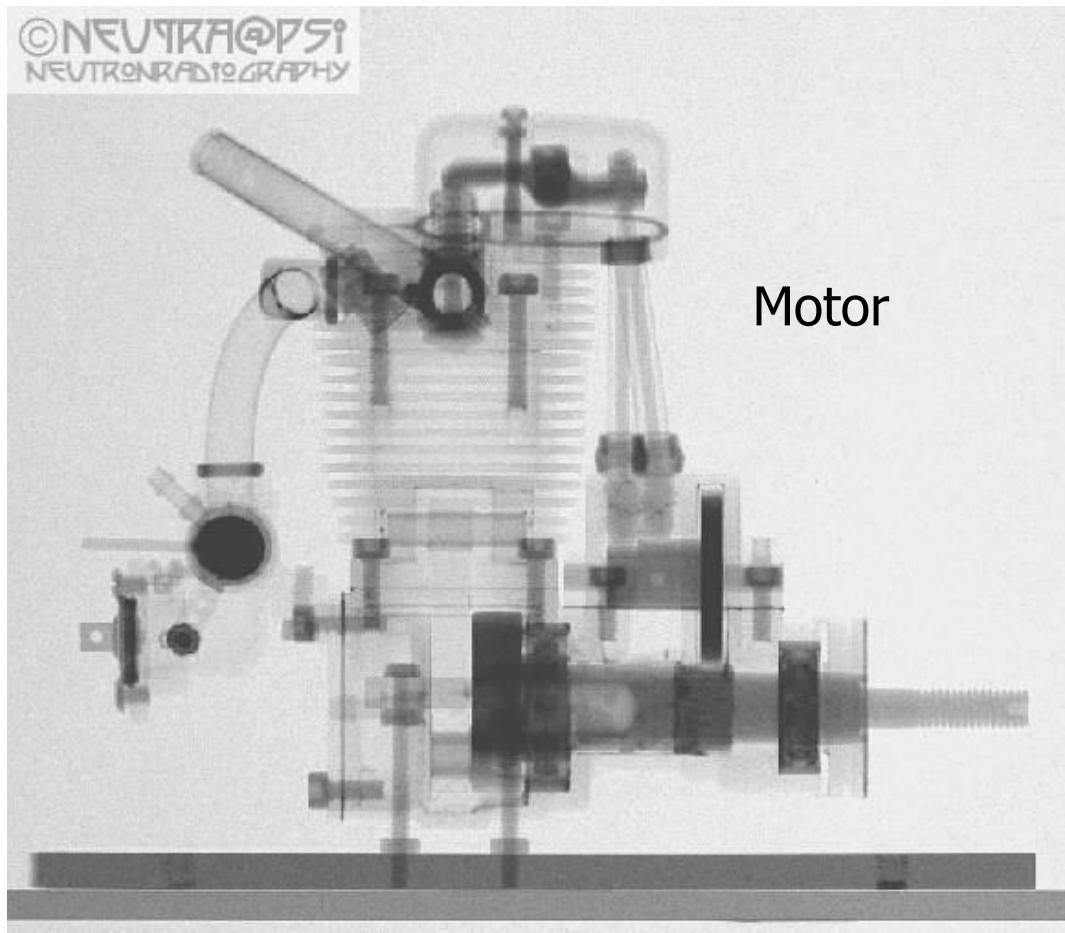
Shielding
7 m Concrete

Guide for
cold Neutrons



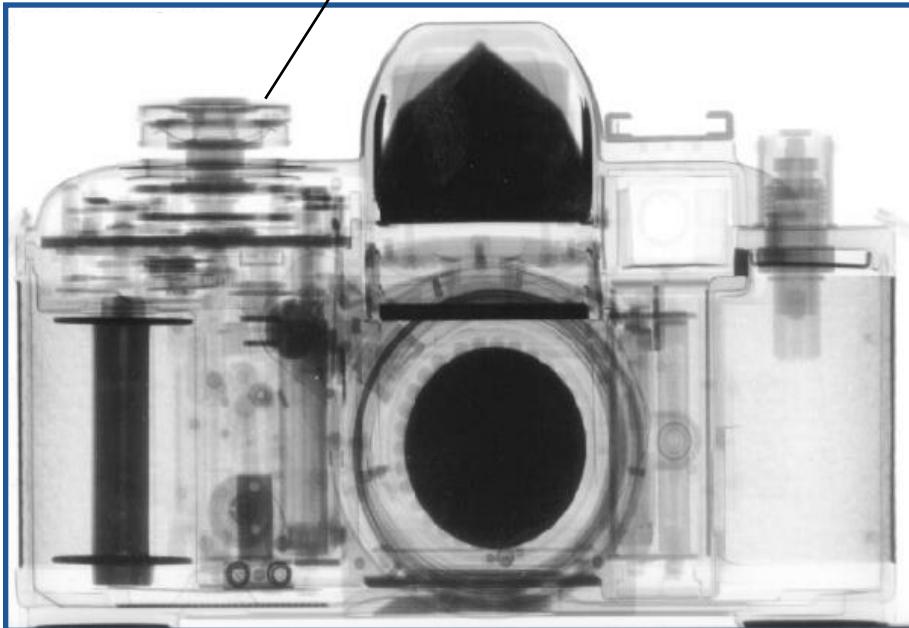
Radiography with Neutrons

=> the interior of big objects
becomes visible

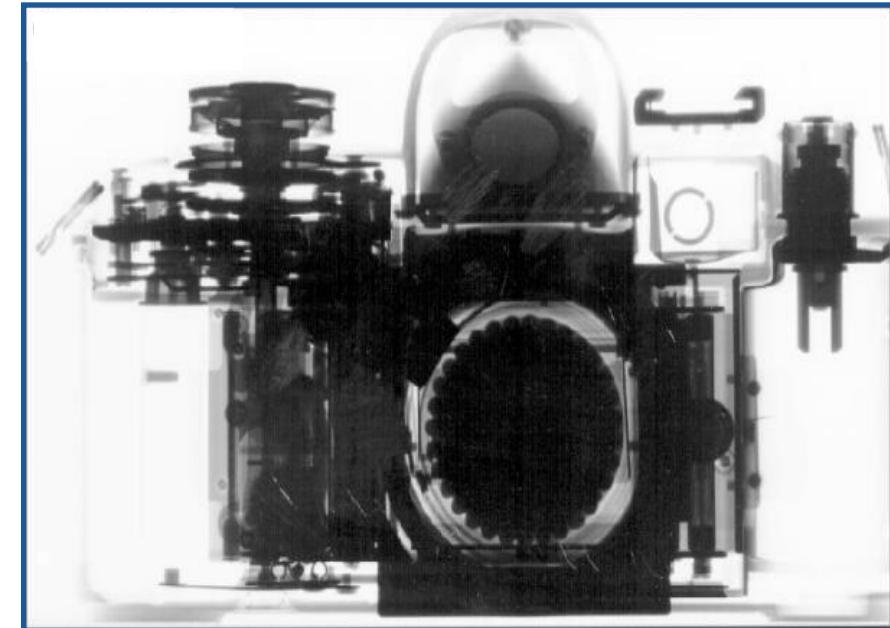


Neutron Radiography

**Large Material Probes are
examined without destruction
=> the Interior becomes visible**



Neutron Radiography

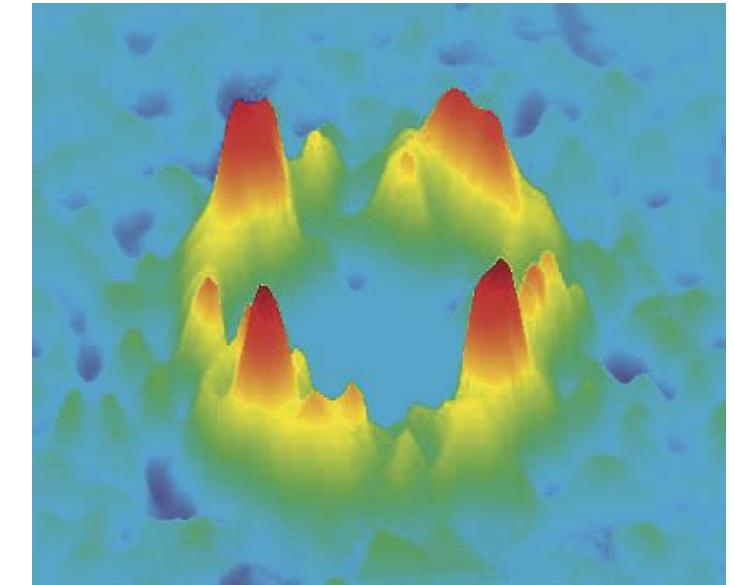


X-Rays

Research with Neutrons

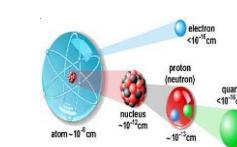


Experiments at the Spallation Neutron Source



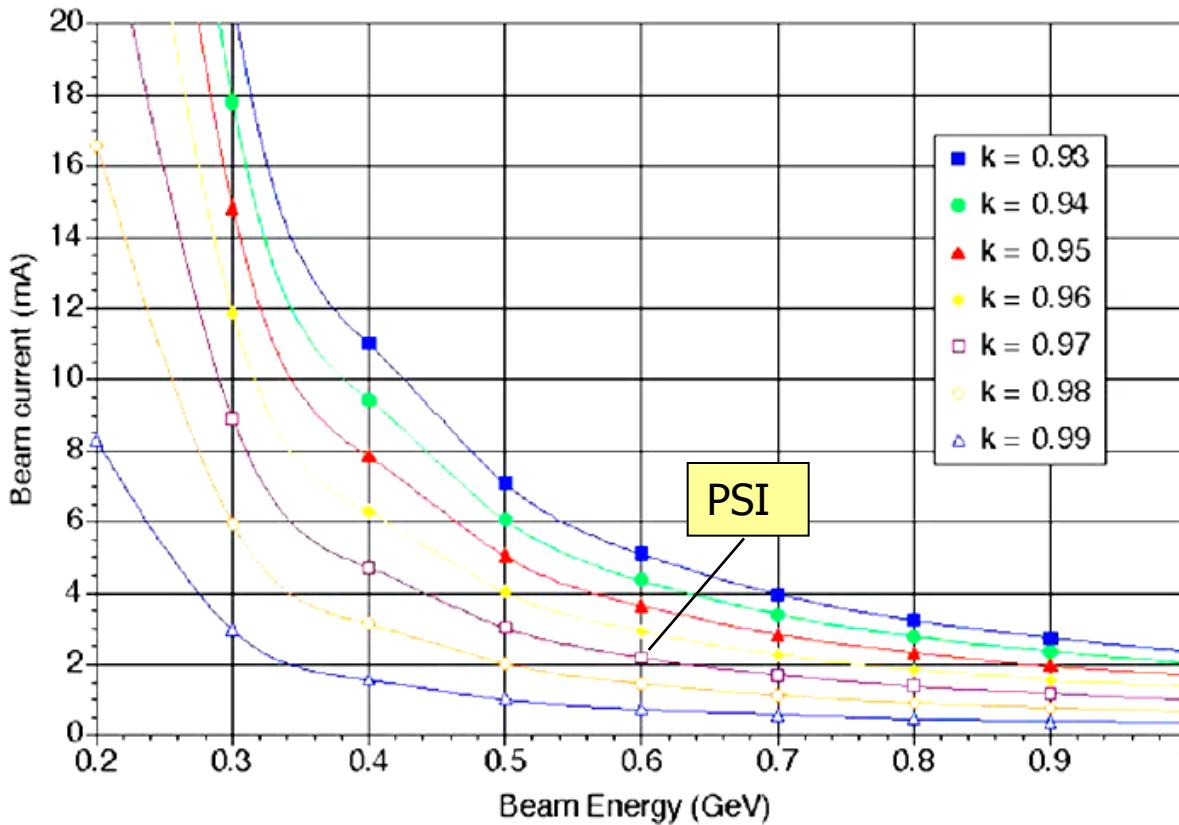
Neutrons as compasses: magnetic flux lines in a superconductor

PSI as User Lab



2011	SLS	SINQ	S_μS	LTP	PSI total
Beamlines	16	12	6	4	38
Instrument Days	1787	1939	669	350	4745
Experiments	1058	439	226	4	1727
User Visits	3338	826	319	594	5077
Individual Users	1565	441	160	240	2336
New Proposals	778	403	196	1	1378

Energy Amplifier Concept (C.Rubbia)



Beam current needed to produce $80 \text{ MW}_{\text{th}}$ with protons for different criticality factors k (ref. Ansaldo 2001)

example: 600 MeV PSI Cyclotron
in future with 3 mA => **1.8 MW**
=> production of neutrons in
subcritical reactor (**e.g. $k=0.97$**)
=> $110 \text{ MW}_{\text{th}}$ => **40 MW_{el}**
=> power plant with 1 GW_{el} needs
35 mA protons at 1 GeV => s.c. Linac

- **inherently safe**
- **use of Thorium (big reserves)**
- **no production of Plutonium for weapons**

reduction of lifetime of nuclear waste !

chem. separation of long lived actinides



high intensity protonen beam
≈ 40 MW (30*PSI) , ca. 2050 ?



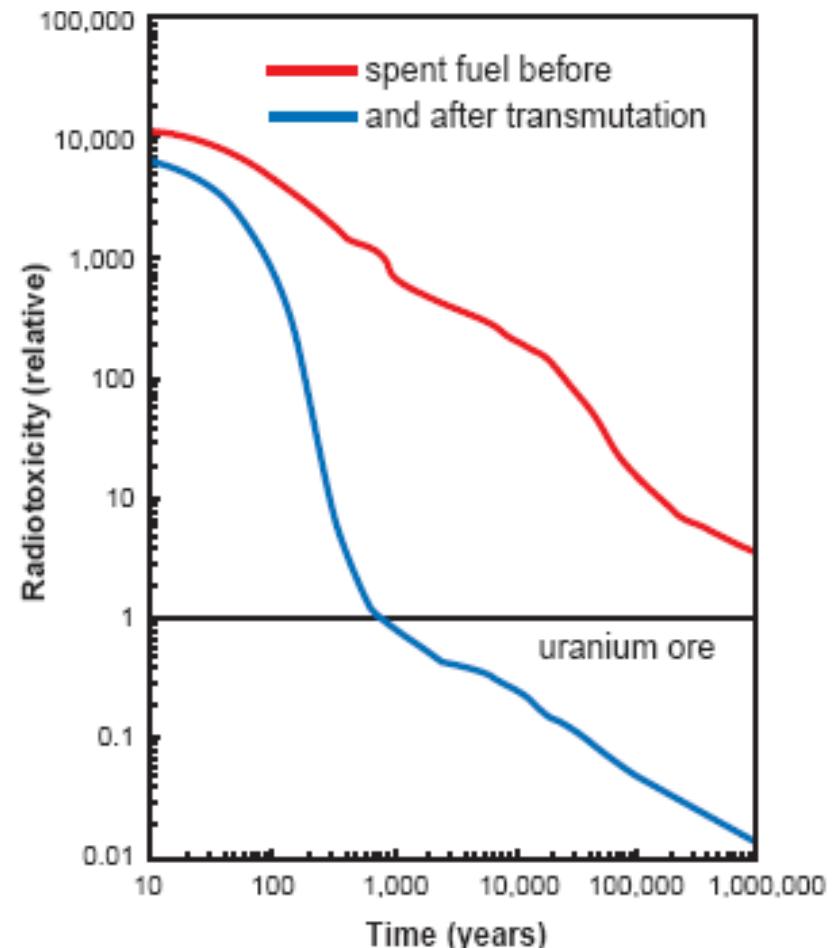
production of neutrons



transmutation of aktinides

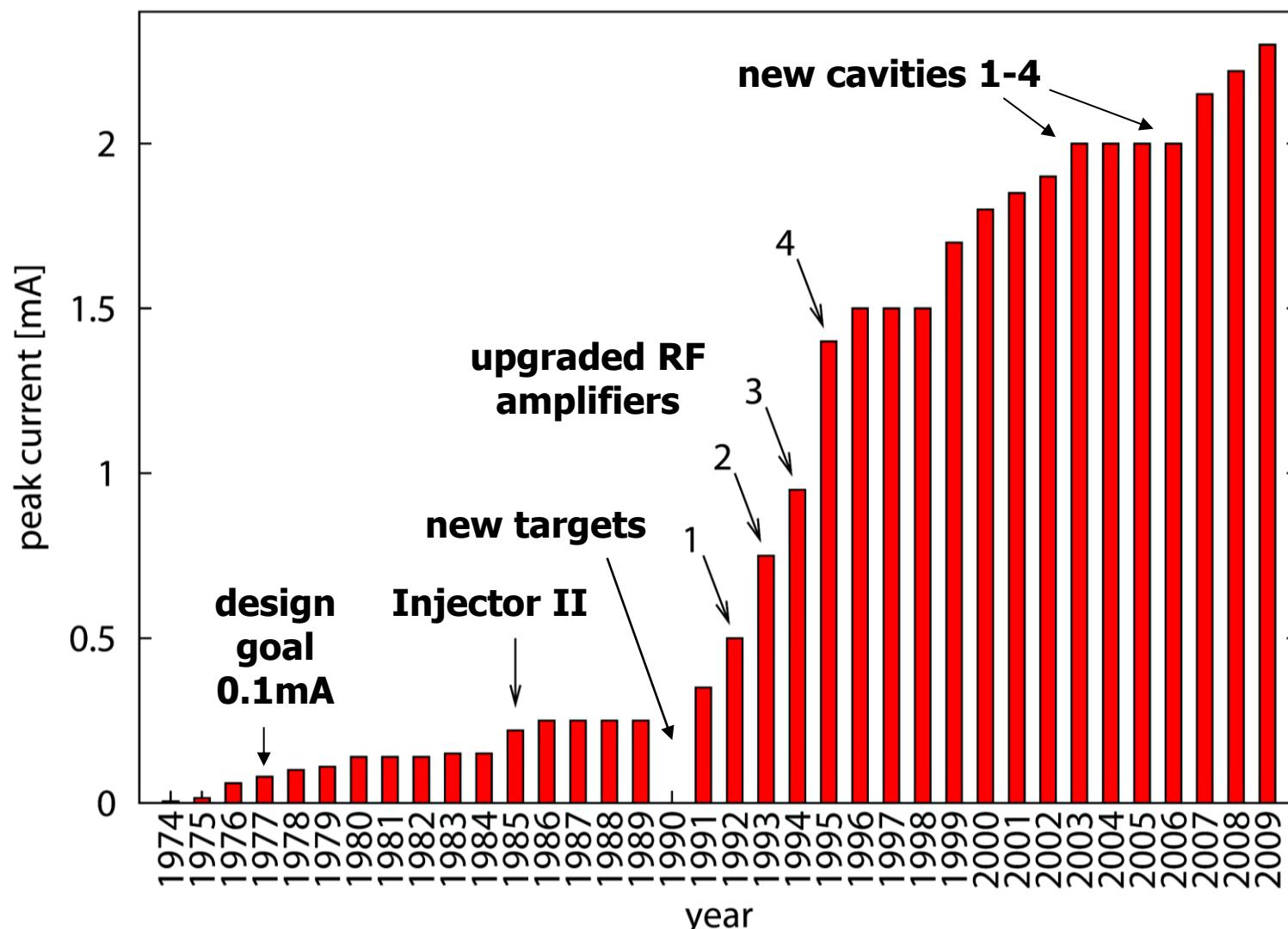


Reduction from 1 Mill. years to 400 years

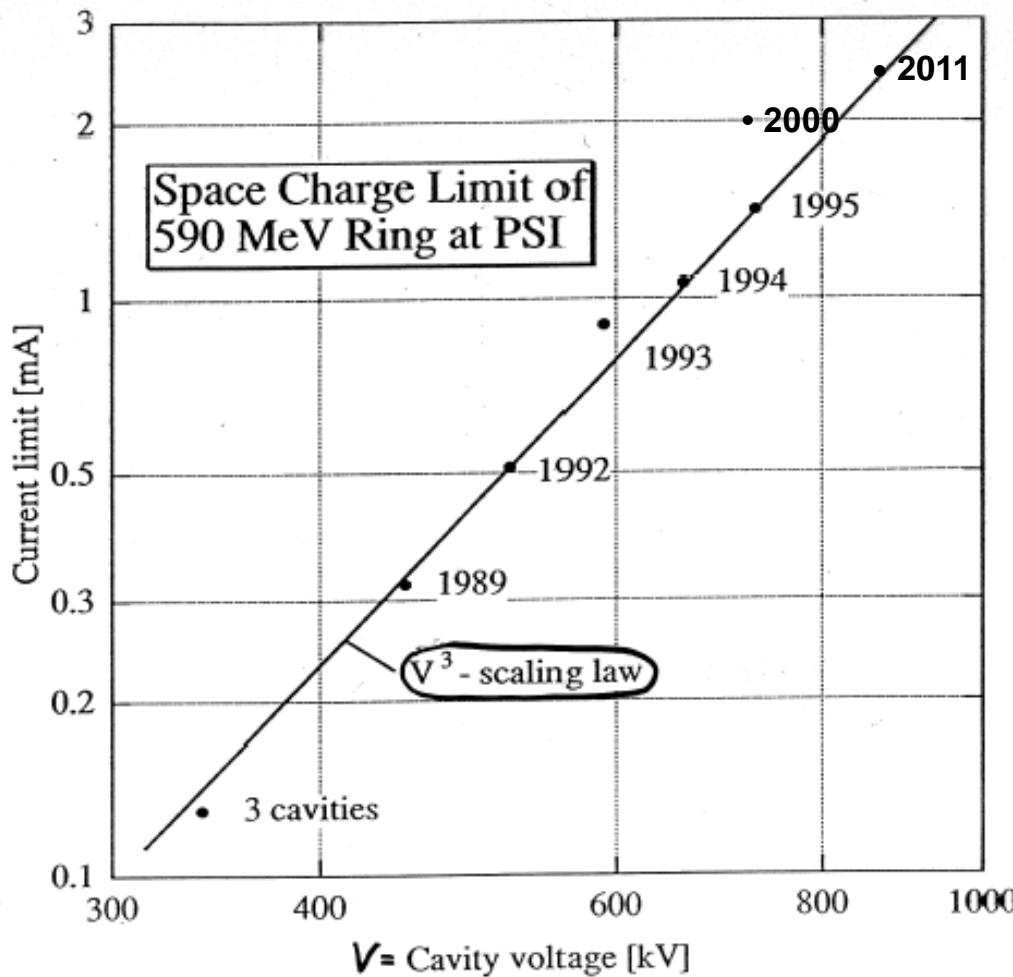


European Roadmap for Accelerator Driven Systems ... ENEA Italien 2001

Peak Current in PSI Ring Cyclotron



Longitudinal Space Charge



Longitudinal space charge forces

increase the energy spread

=> higher extraction losses

=> limit on beam current

Remedy:

higher voltage V on the RF cavities

=> lower turn number n ($V \cdot n = \text{const.}$)

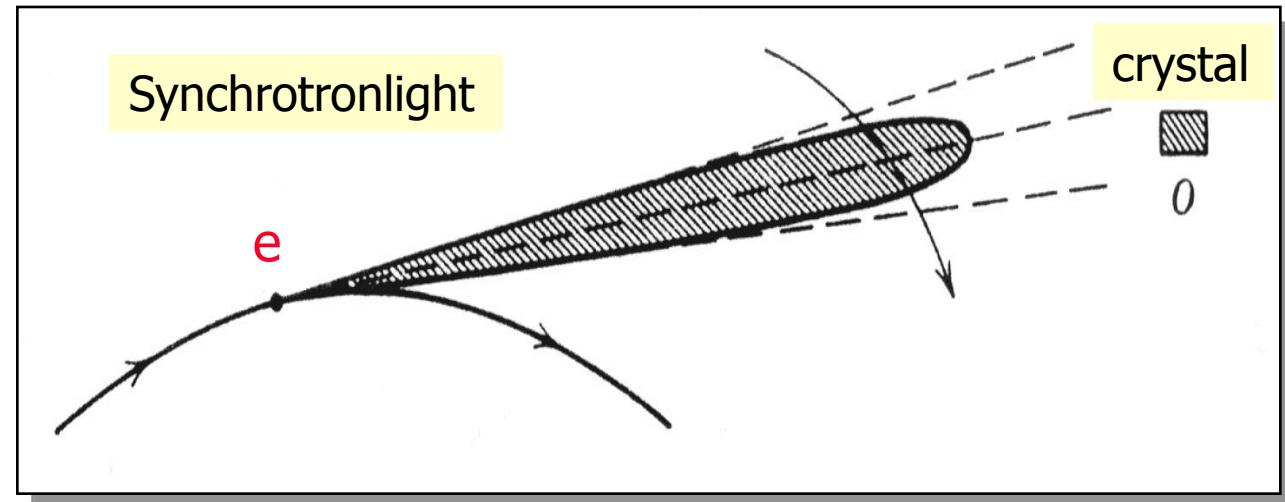
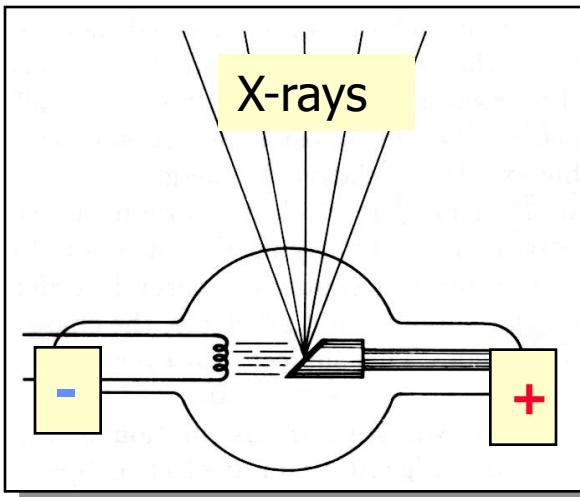
current limit $\sim V^3 \sim 1/n^3 !$

There are 3 effects,
each giving a factor $V(\sim 1/n)$:

- 1) beam charge density $\sim n$
- 2) total path length in the cyclotron $\sim n$
- 3) turn separation $\sim V$

W.Joho, 9th Int. Cyclotron conference CAEN (1981)

Production of X-rays



Production with X-ray Tube
(60-90kV)

broad beam => big objects

Produktion of X-rays with fast Electrons
in magnetic field

intensive, laser-like beam

=> Microstructures

Electromagnetic Waves

- 1) RF-fields shake the electrons back and forth in an antenna
=> **Radio/ TV/ Radar-waves, mobile phones**
- 2) in a X-Ray Tube electrons are accelerated to 50-90 keV and then stopped in an electrode
=> **X-Rays**
- 3) Electrons are deflected in a magnetic Field B through the Lorentz Force $e(v \times B)$
=> **Synchrotron Radiation**
increases dramatically with Energie $E = \gamma mc^2$

Synchrotron Radiation

- laser-like Beams (polarised),
generated by high Energy **Electrons**
- very high Intensity (Brightness)
- free choice of Wavelength
from infrared to hard X-Rays

what is needed?

⇒ a **Storage Ring** (with many Magnets), where
Electrons can circulate for hours

electromagnetic Spectrum

	Wavelength λ	Energy ϵ
FM-Radio (100 MHz)	3 m	
Radar (3 GHz)	0.1 m	
infrared light	1-1000 μm	1-1000 meV
red light	700 nm	1.8 eV
violett light	400 nm	3 eV
vacuum ultra violet	4-200 nm	6-300 eV
soft X-Rays	0.4 nm	3 keV
hard X-Rays	0.04 nm	30 keV
Gamma-Rays		1-10 MeV

$$\lambda \cdot \epsilon = 1.24 \text{ nm} \cdot \text{keV}$$

Synchrotron Radiation: free choice of wavelength λ

SLS-Components

Accelerators

- Electron gun 90 keV
- LINAC 100 MeV
- Booster, 3 Hz 0.1-2.4 GeV
- Storage Ring, 288m 2.4 GeV

Beamlines

- Protein Cristallography
- Material Sciences
- Surface Microscopy
- Surface Spectroscopy
- environment sciences

SLS Strategy

Quality

- high brightness , small emittance,
→ large circumference with many magnets

Flexibility

- large spectral range (VUV to hard x-rays)
- straights of 4 m, 7 m and 11 m => choice for undulators

Stability

- separation of building structure from floor
- stable temperature in tunnel and experimental hall
- positioning of the magnets on rigid girders
- fast orbit feedback (up to 100Hz)
with high accuracy (< 0.5 µm)
- constant beam current with **top-up injection** (every 3 min)
→ constant heatload on optical components

stable Beams with small Emittance

big Storage Ring with many Magnets

mechanical
Stability

Temperature
Stability

Orbit
Stability

Hall

Magnet
Girder

Hall
 $\pm 0.2^0$

Tunnel
 $\pm 0.03^0$

Optics
Comp.

Top-up

„Fast Orbit
Feed-Back“

high Brightness

- Investigation of small Microprobes (Cristals < 20 µm)
- small Beam Divergence
 - => compact Mirrors, small Aberrations
- short Measuring-Time
- high Coherence => Imaging with Phase Contrast

Research with Synchrotron Radiation

X-Ray Analysis

- Structure of Bio-Molecules (Proteins)
=> new drugs

- new Materials, Nano-Structures

- Micro-Tomography
(3-dim. Reconstruction
e.g. biological probes)

- high Temperature Superconductors

X-Ray Microscopy

- compact magnetic Structures
=> Data Storage

- Solar Cells

- special Surfaces
(Catalysts, new Plastics,
minimal Friction etc.)

- Detection of Trace Elements on
Surfaces => Analysis of Impurities

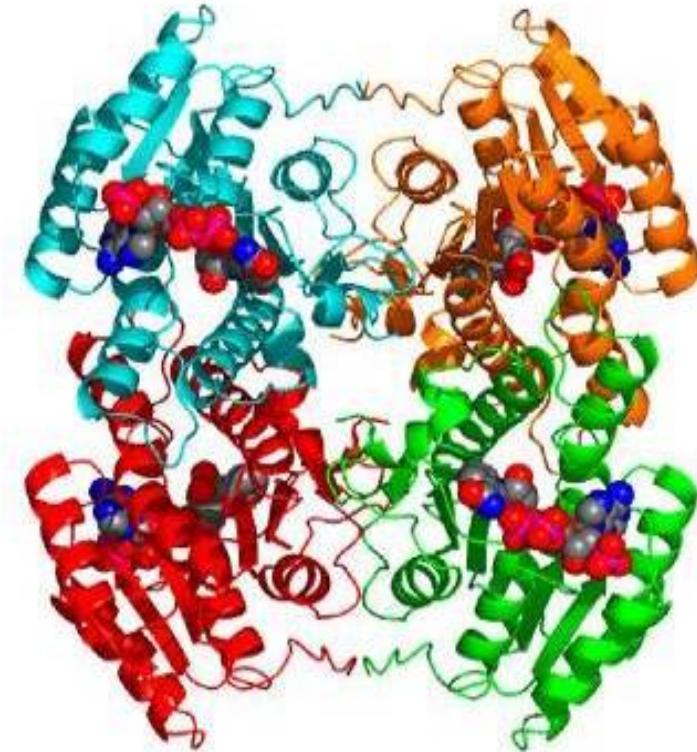
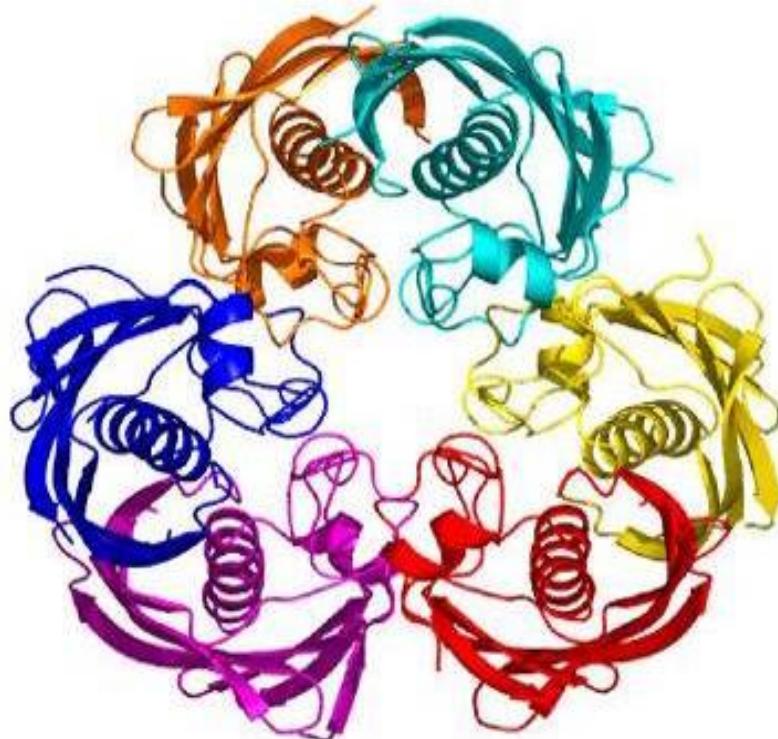
Nobel Prize in Chemistry 2009 !

V.Ramakrishnan won Nobel prize in chemistry

He is a user of a protein crystallography beam line at
the SLS at PSI

Investigation of Ribosomes with x-ray diffraction

Protein Crystallography



Structures of two important Enzymes of the Generator of Malaria

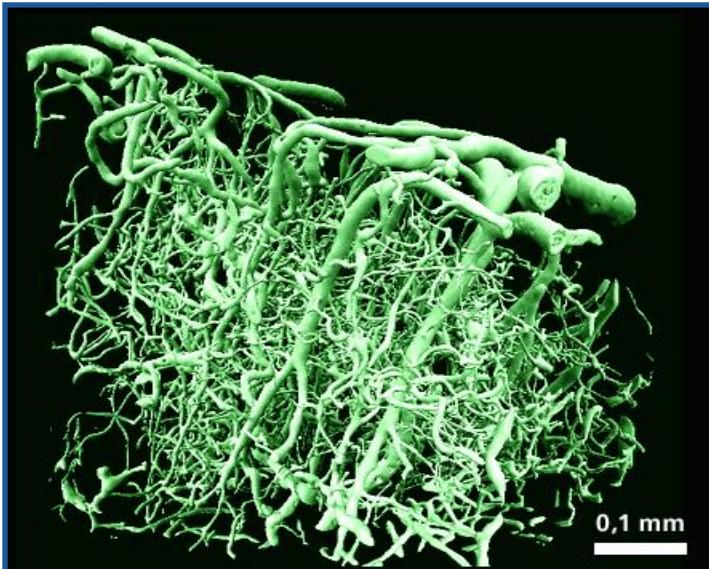
Growth of Bio Molecules to Crystals (size 5-50 μm)

=> Reconstruction with X-rays

Microtomography

Blood Vessels in the Brain of a Mouse (infected by Alzheimer)

full size



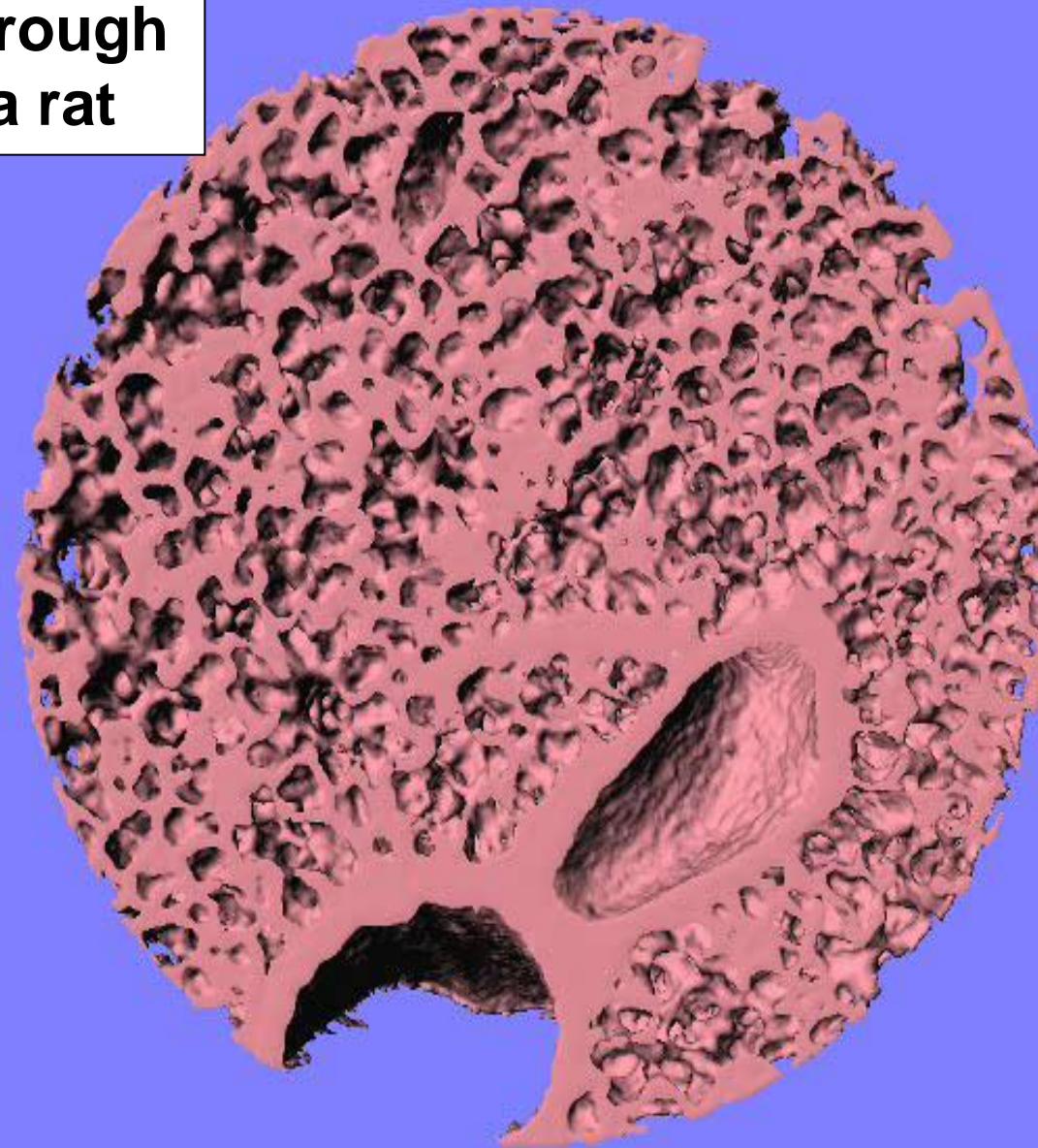
Details

insufficient Blood Circulation
⇒ Deficiency in Oxygen

⇒ Protein Deposits

⇒ Alzheimer

a voyage through the lung of a rat

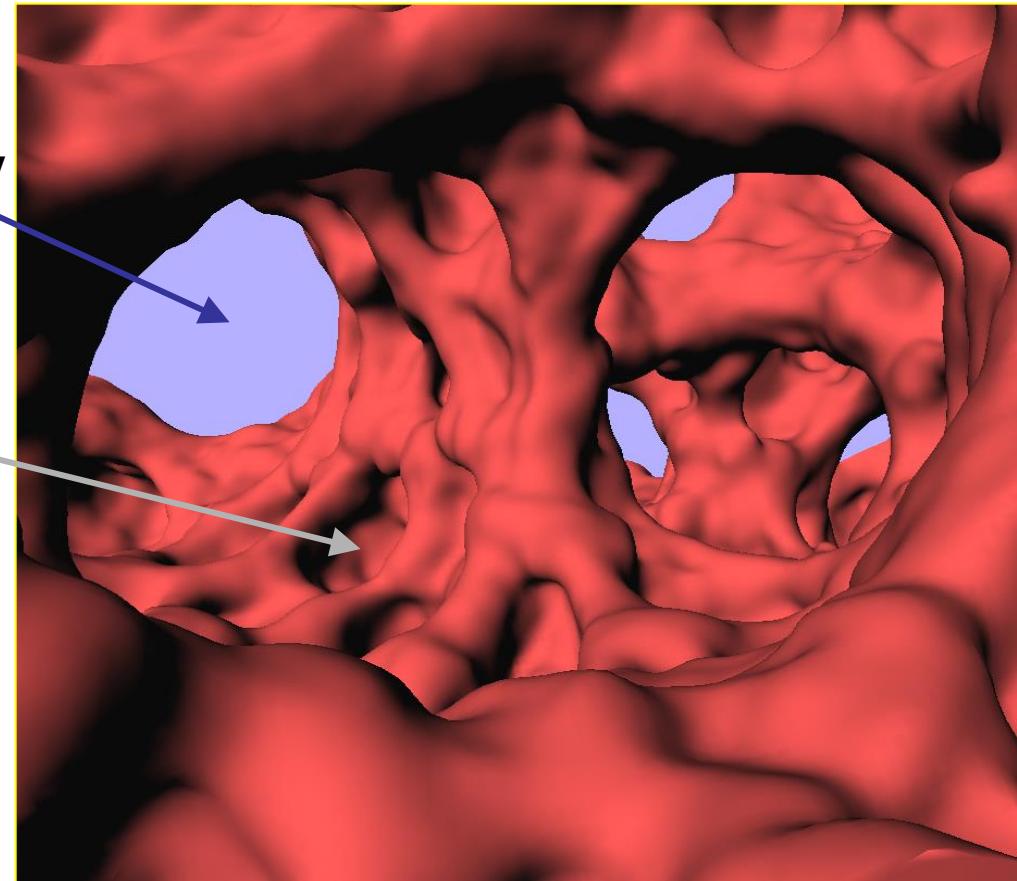


0.1 mm



X-ray Tomography

Gas exchange region in the lung of a rat



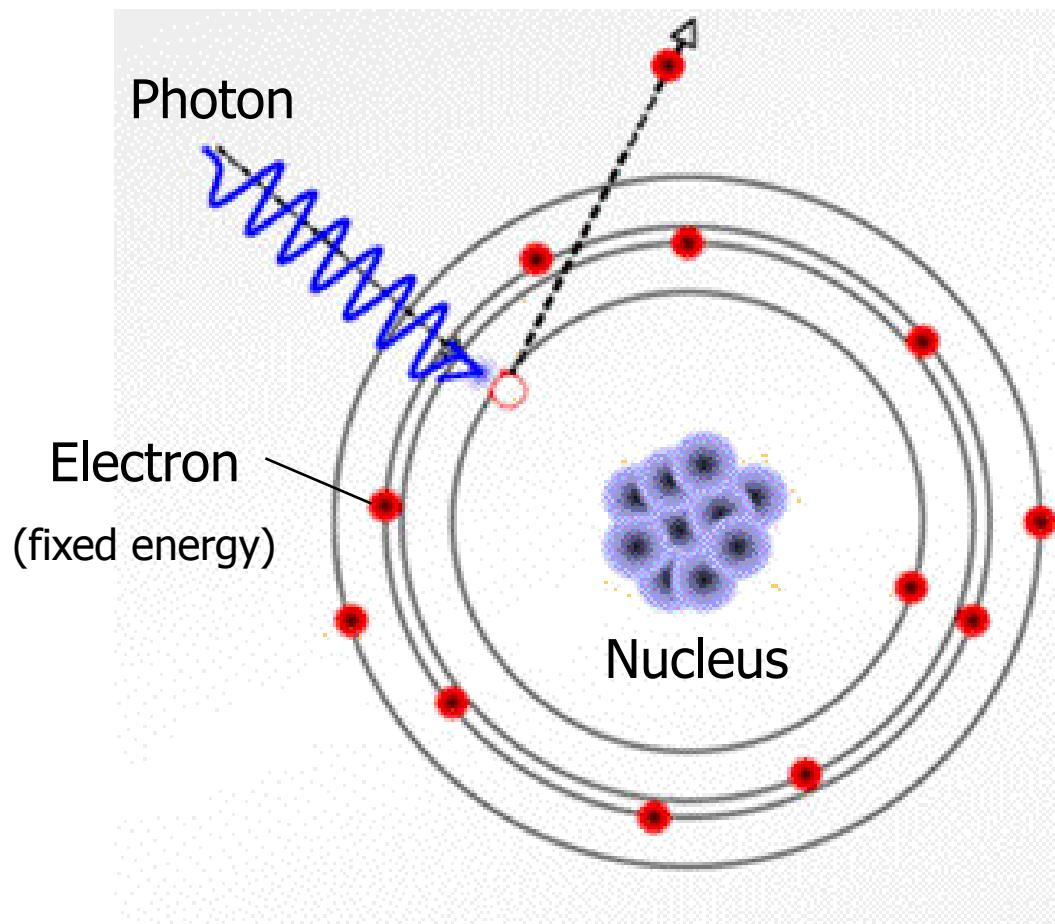
Prof. Schnitnny (Univ. Bern) et al
Tomogram taken at beamline X04SA-MS, M. Stampanoni et al.

Photo Effect

outgoing Electron

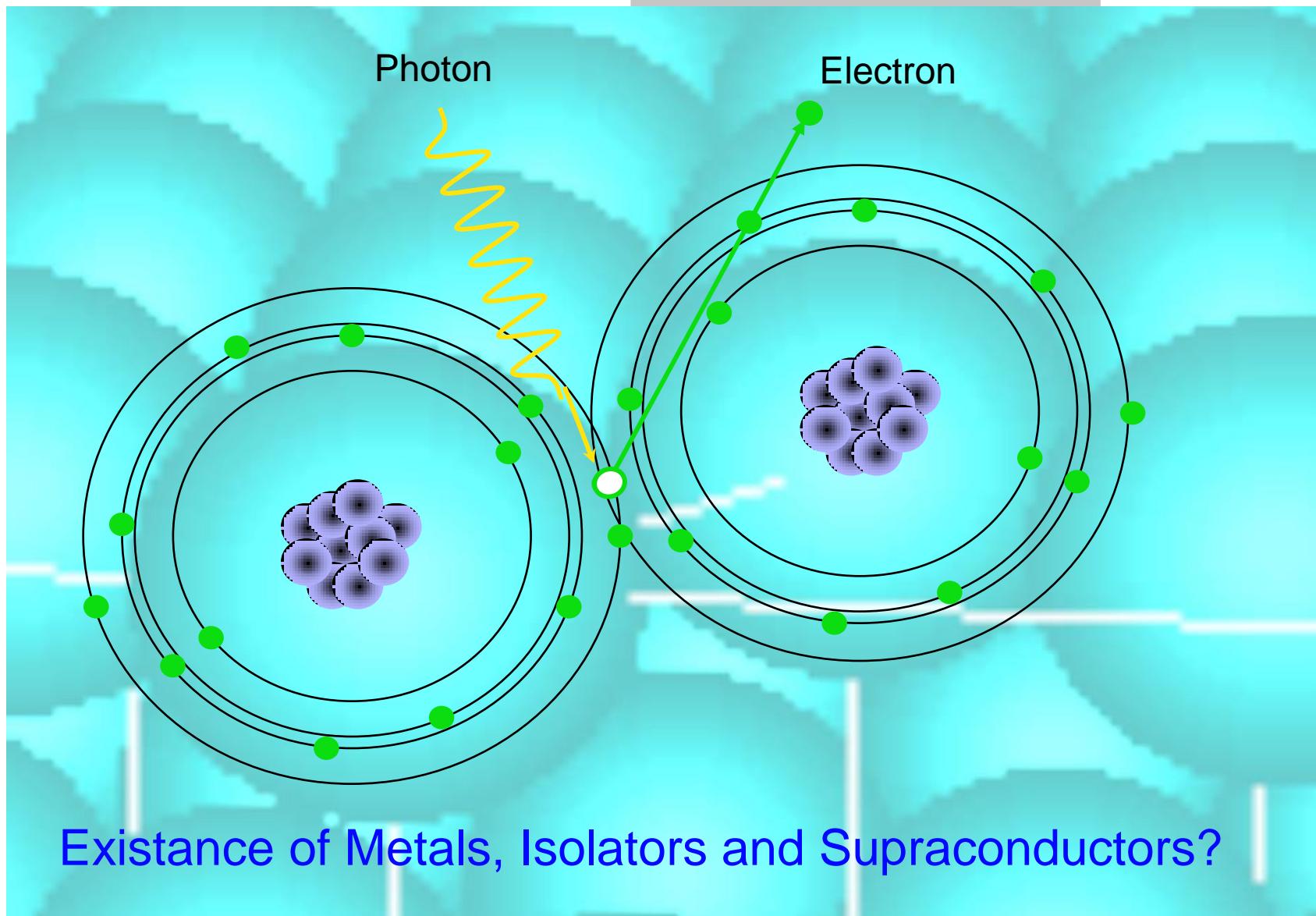
Photon in – Electron out

(Einstein 1905, Nobelprize 1921)

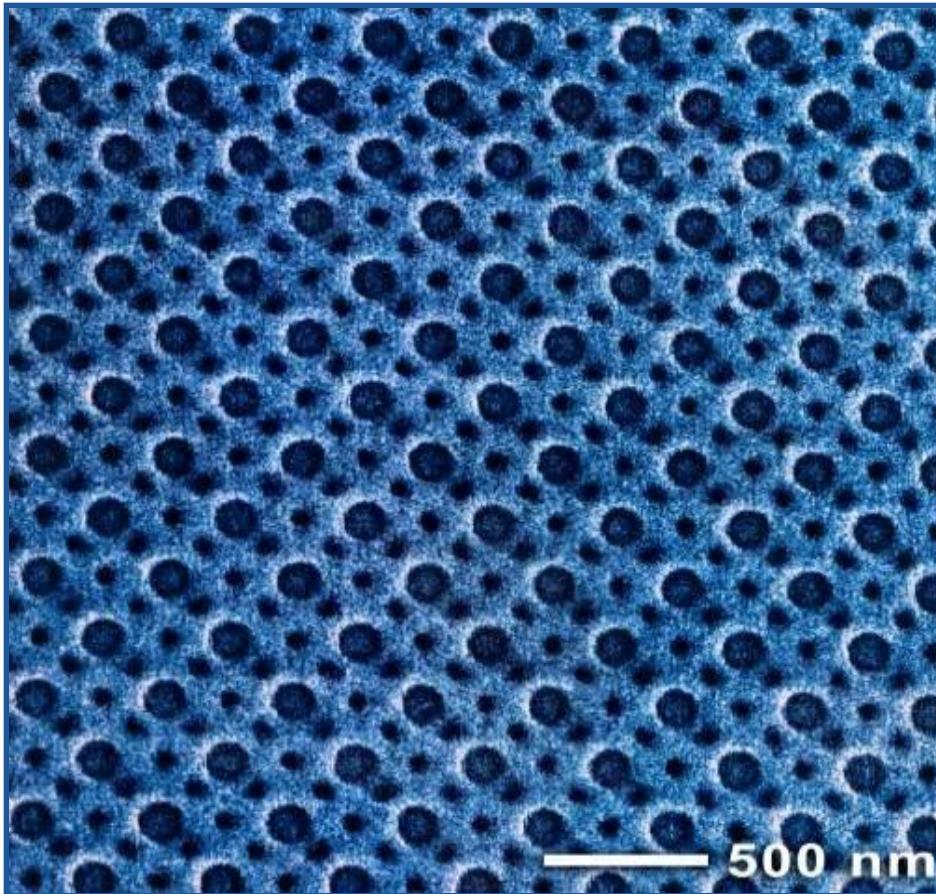


Energy Difference between
Electron and Photon gives
Binding Energy
(specific for each Atom)

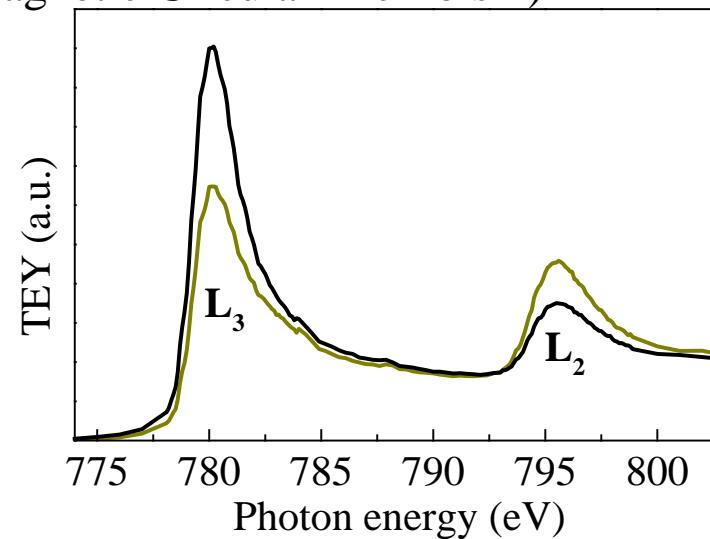
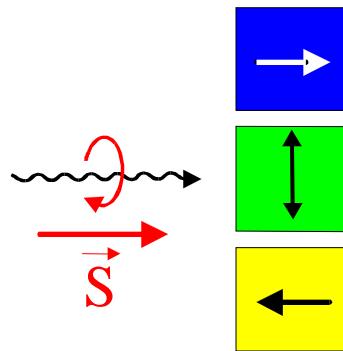
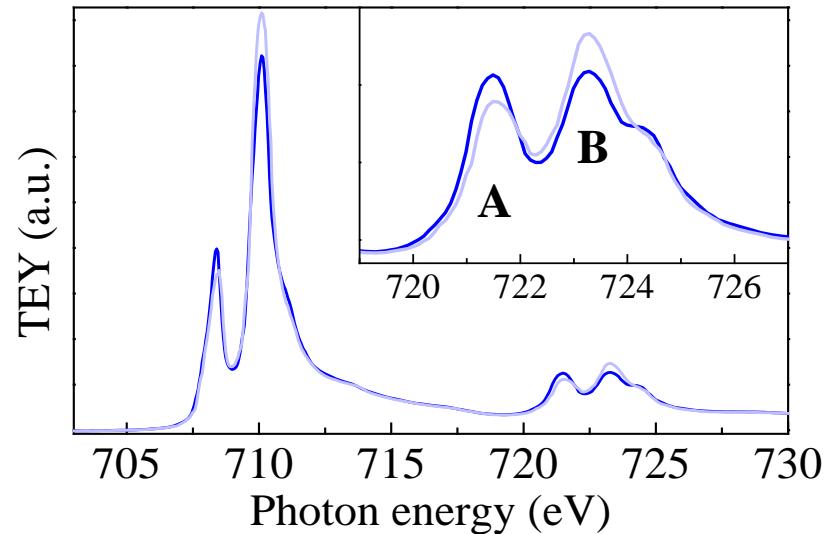
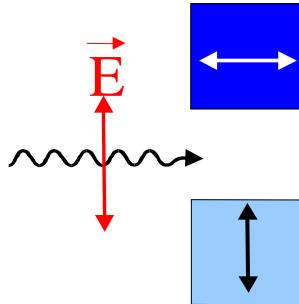
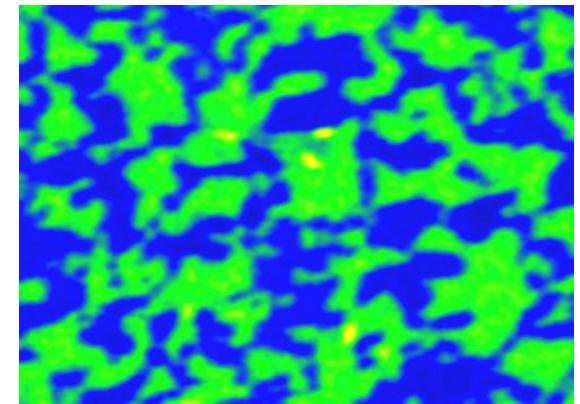
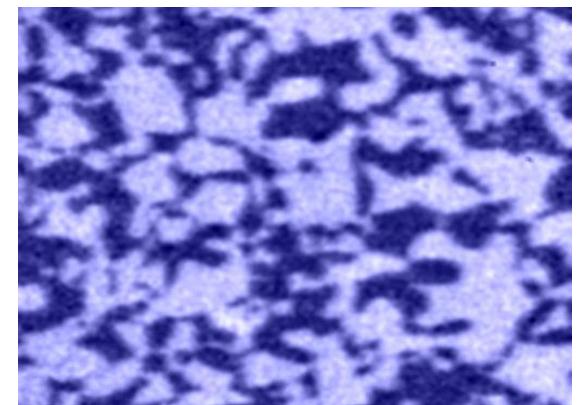
chemical Bond



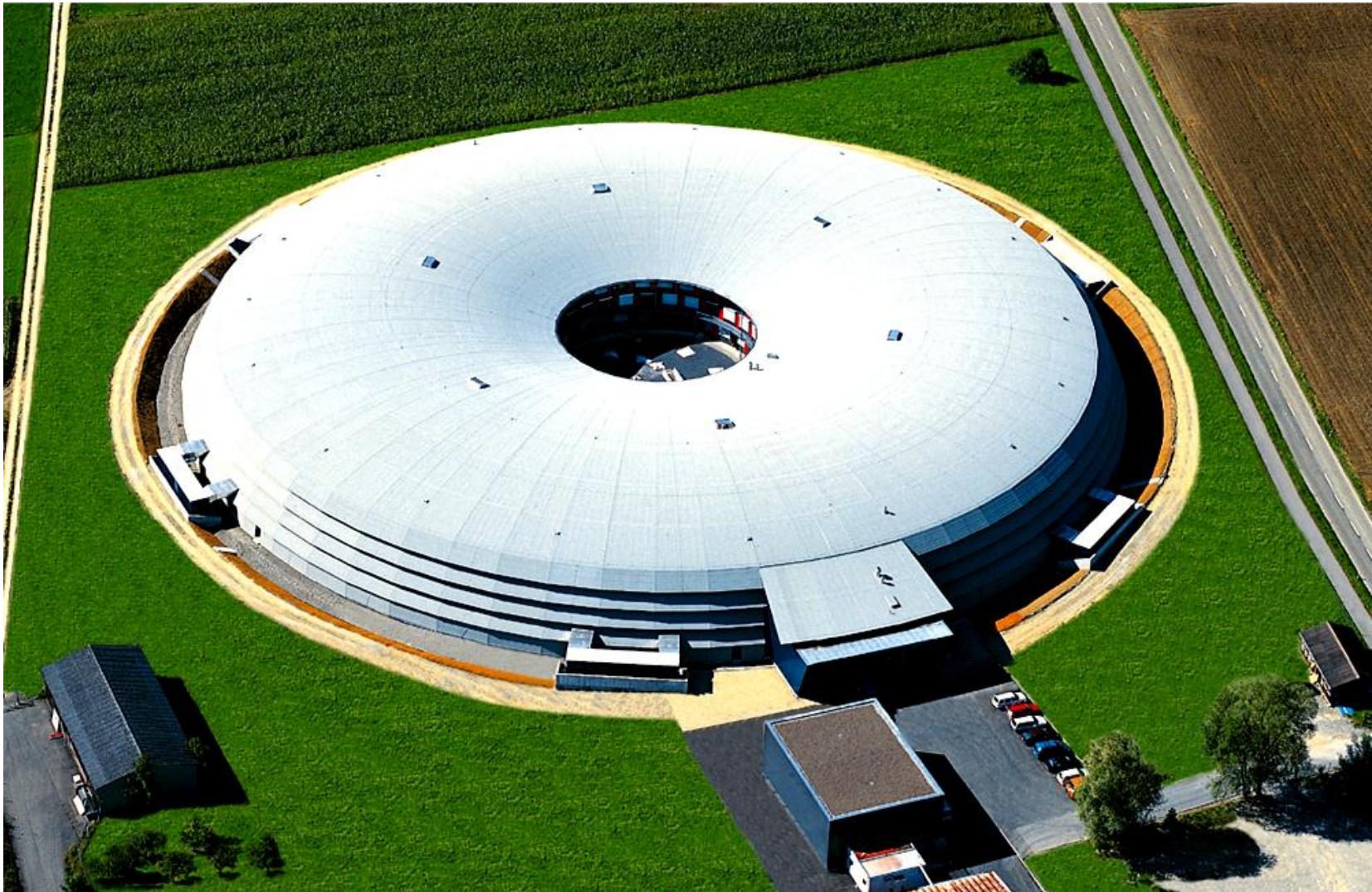
Nanolithography



- Nano-pattern, formed with Synchrotron Light,
useful for:
- Initiating Crystal Growth of Proteins
- Increasing the storage Capacity of Memory Discs

XMCD (X-ray Magnetic Circular Dichroism)**XMLD (X-ray Magnetic Linear Dichroism)****Co****LaFeO₃**

SLS Photo

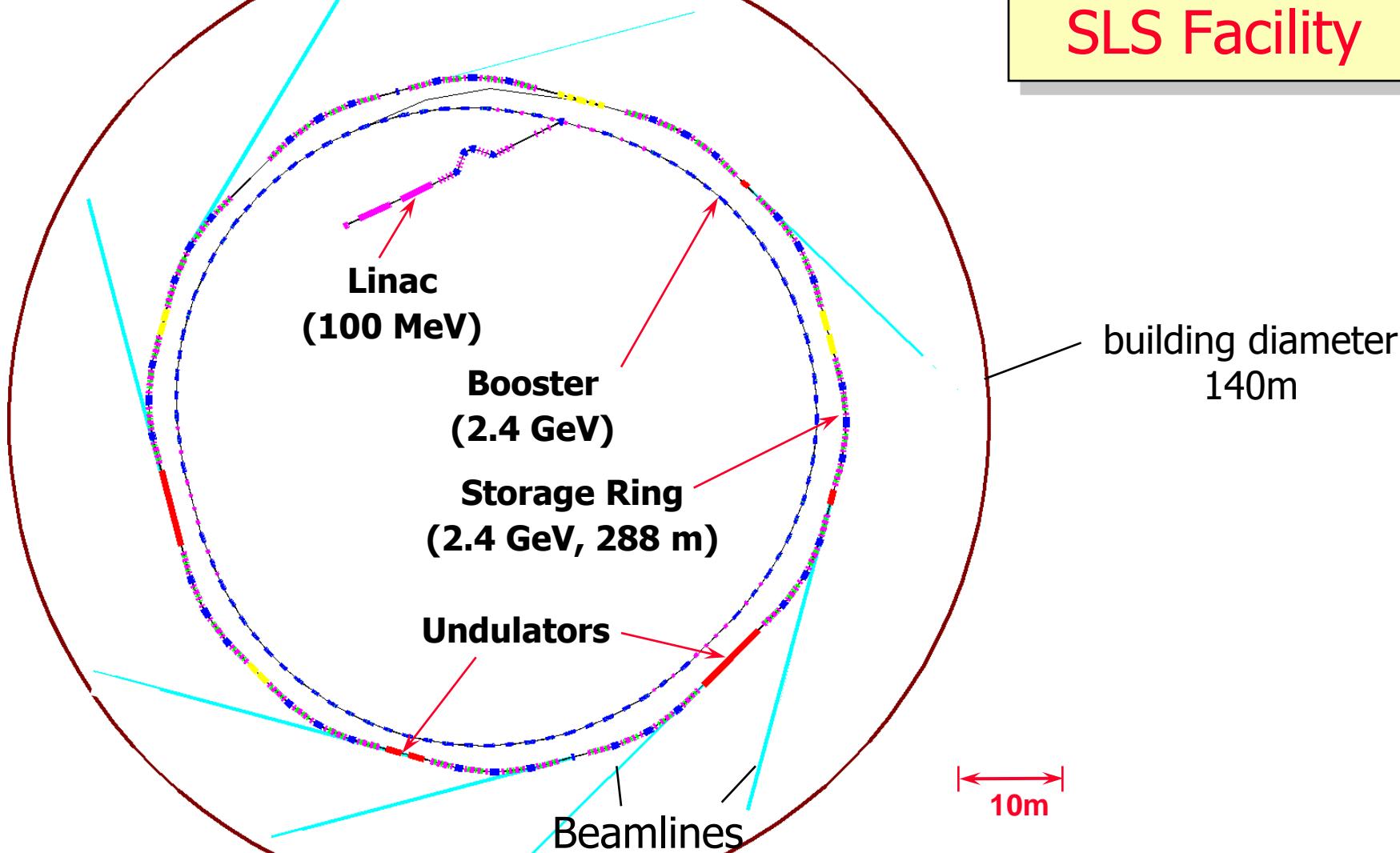


SLS Building

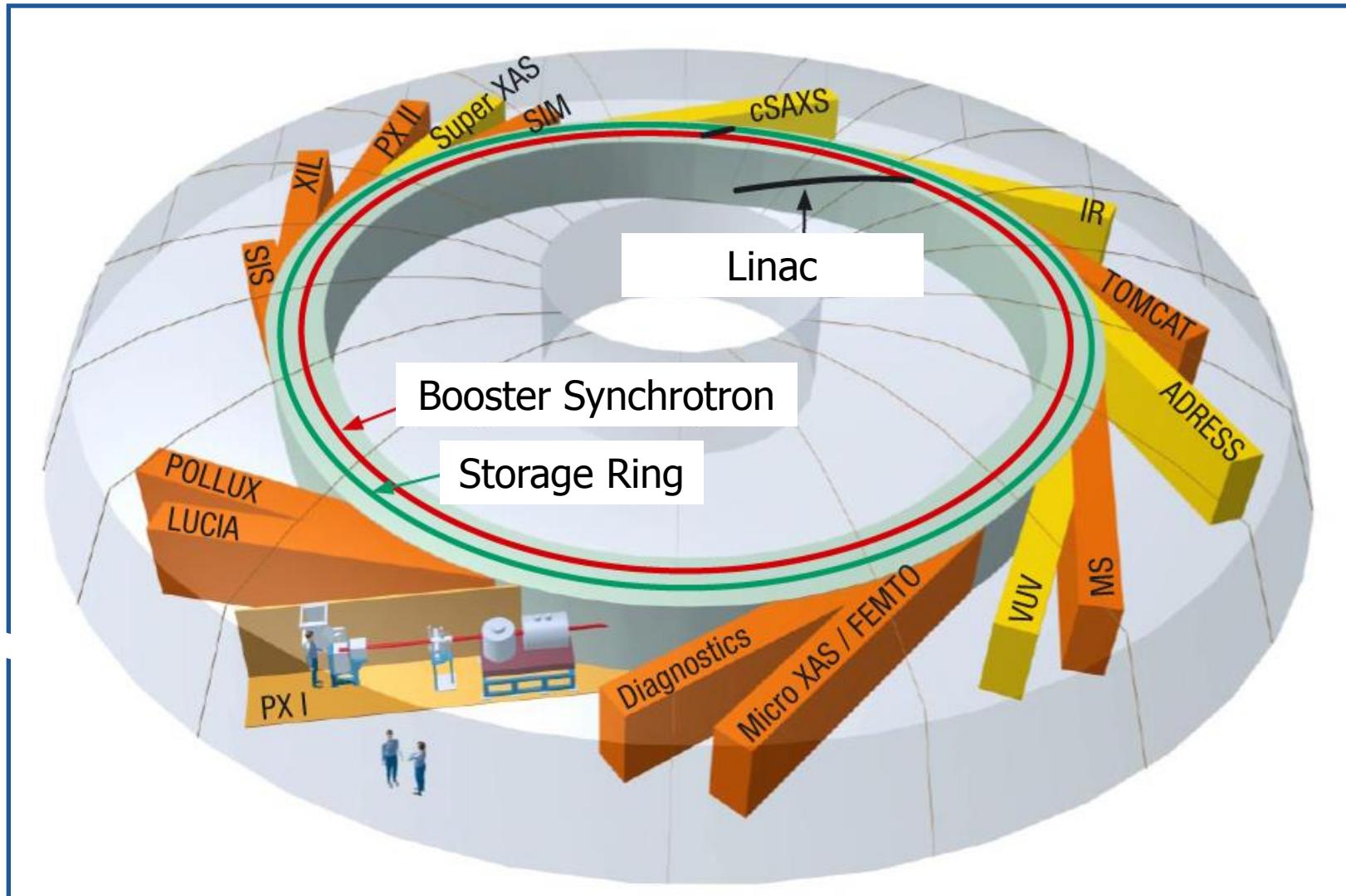


an architectural Juwel !

Architektenteam aus Bern
(Marchand, Jöhri, Gartenmann)



SLS Layout



SLS Beamlines

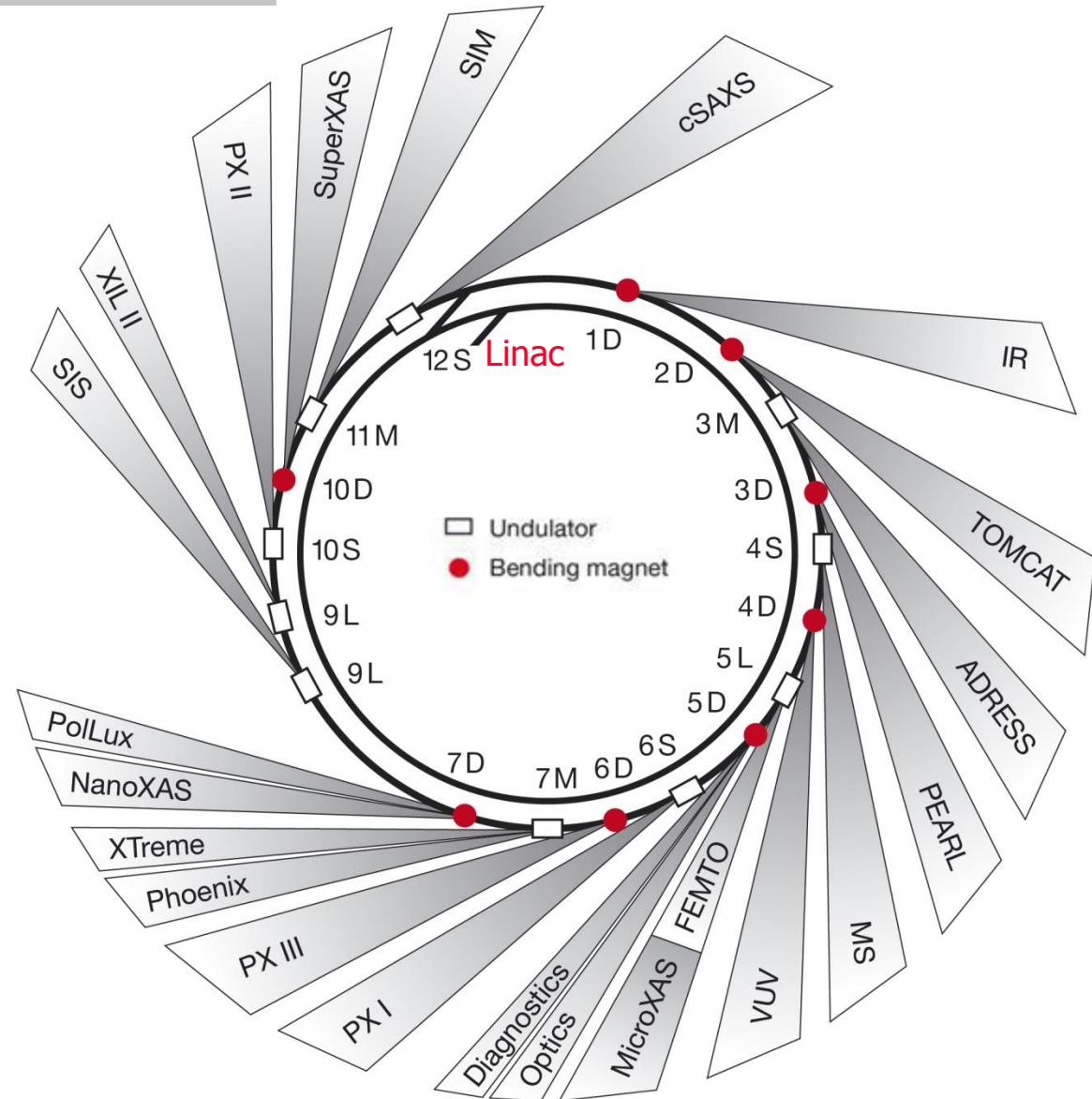
2013:

21 Beamlines in Operation:

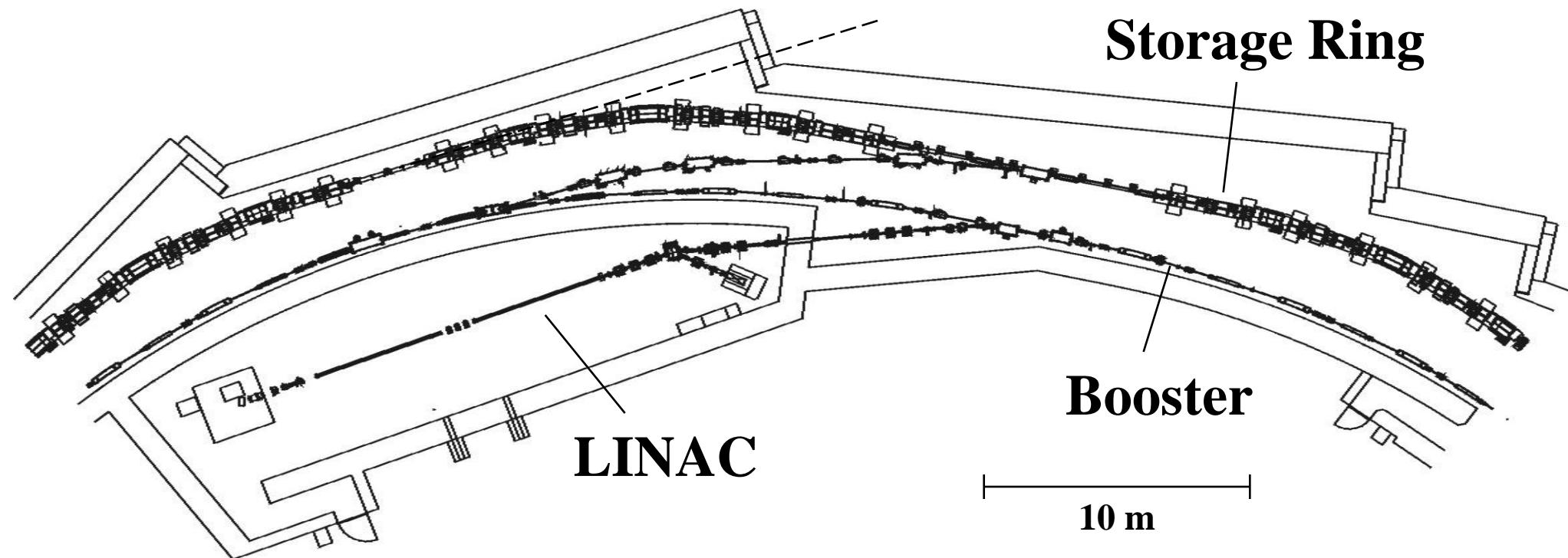
10 with Undulators

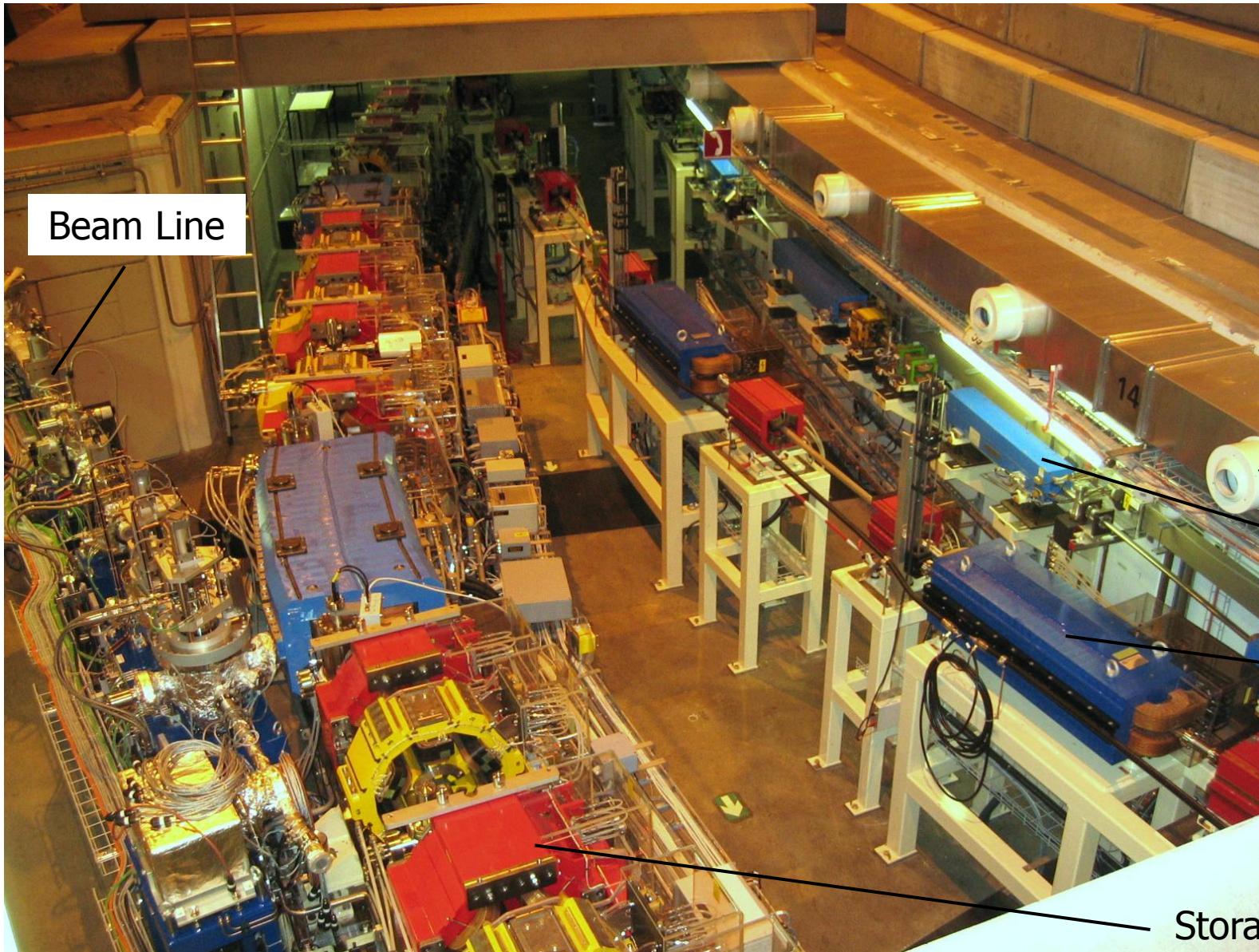
3 from Superbends

8 from Dipoles



Injection Region





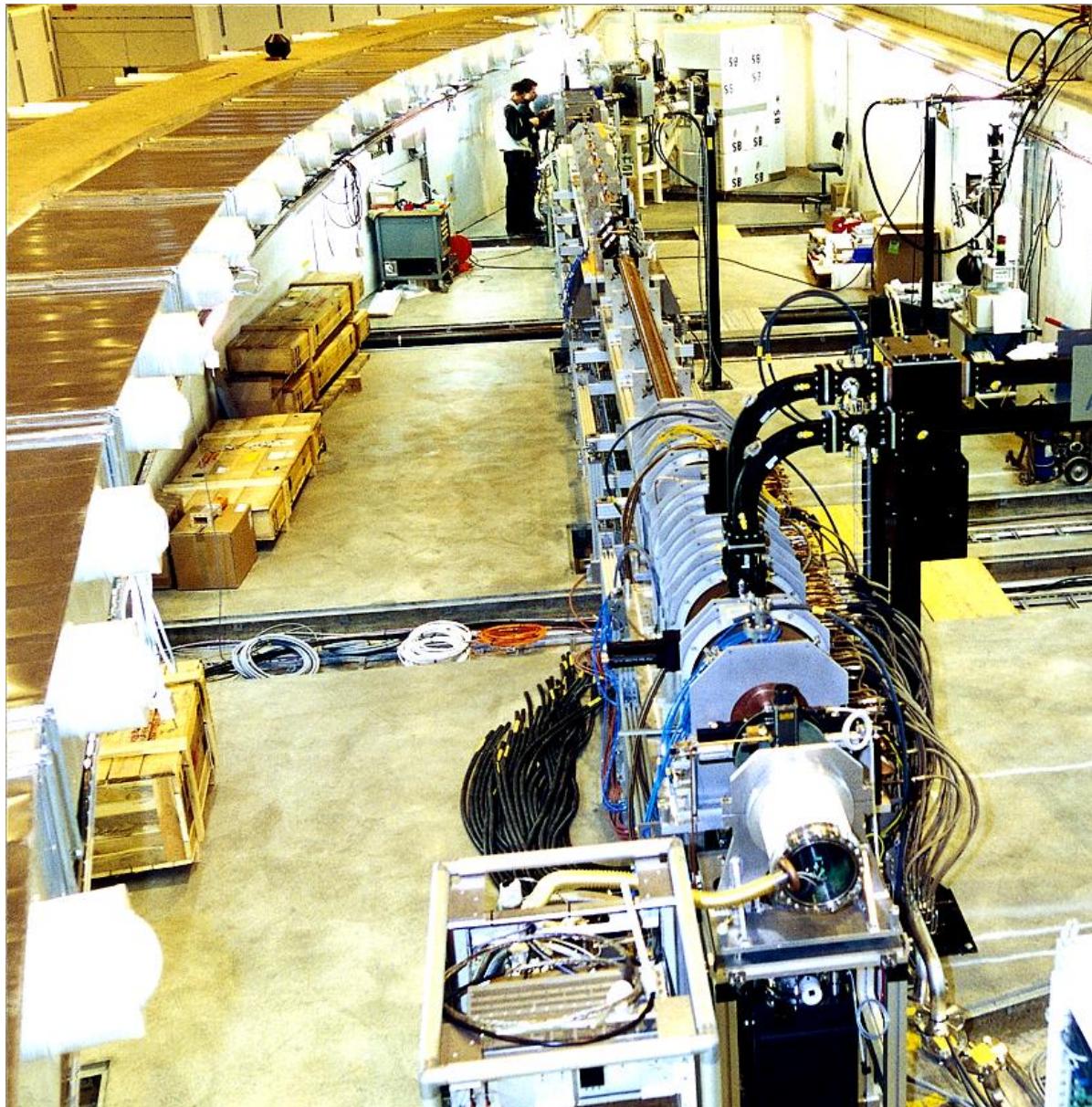
**Photo
Tunnel**

Air Jet

Booster

Transfer Line

Storage Ring



Linac

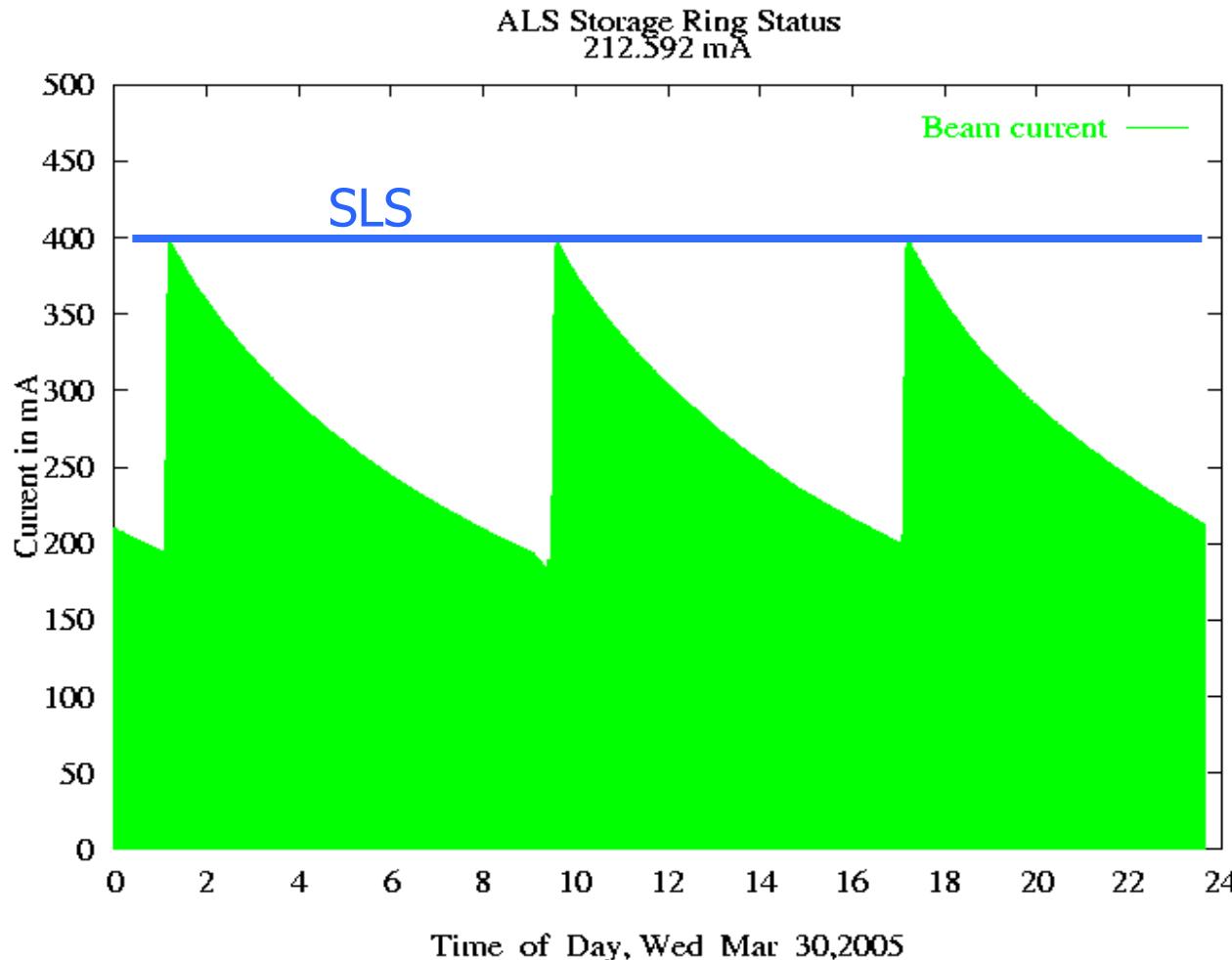
Electron Gun 90 keV

Linac (11m long) 100 MeV

Accelerator Components

- 600 Magnets
- 300 Vacuum Pumps
- 150 Beam Monitors
- 5 RF Cavities
- 600 m Vacuum Tubes
- 50 km Power Cables
- 500 km Signal Cables
- 3 MW Power Consumption

Lifetime vs. Top-up Injection



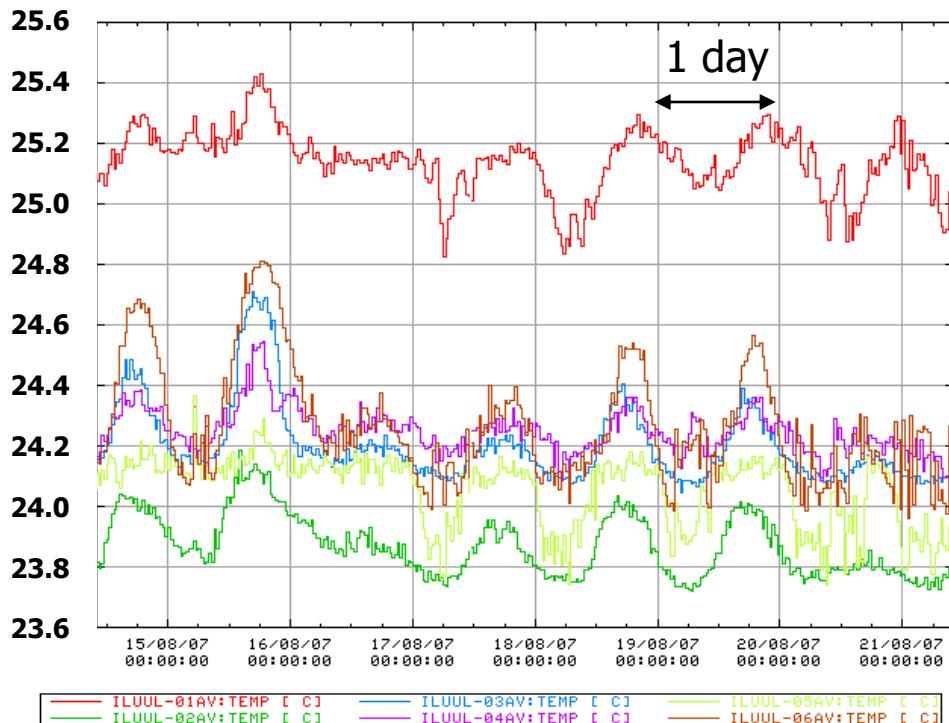
ALS (Berkeley , California):
Lifetime ~ 10 h ,
Refilling every 8 h
Current: **400 => 200 mA**

SLS:
Lifetime ~7 h ,
not relevant !
top-up every 2.5 min.
Current: **402 => 400 mA**

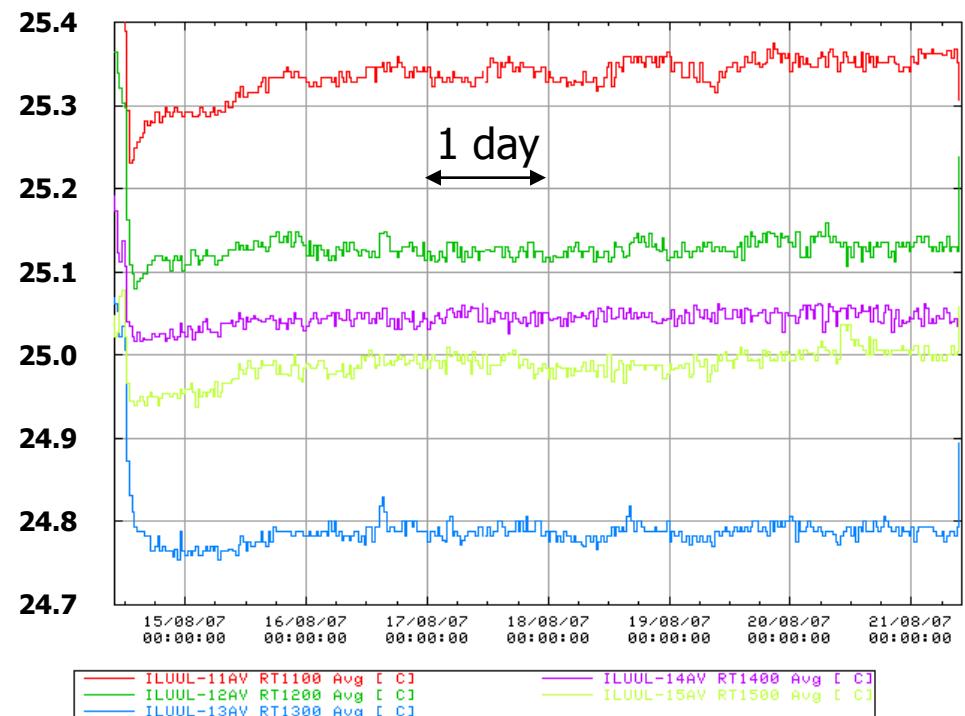
Stability of Temperature Exp.Hall and Beam Tunnel

7 days in August 2007

Hall Temperature [$^{\circ}\text{C}$] of 6 Sectors



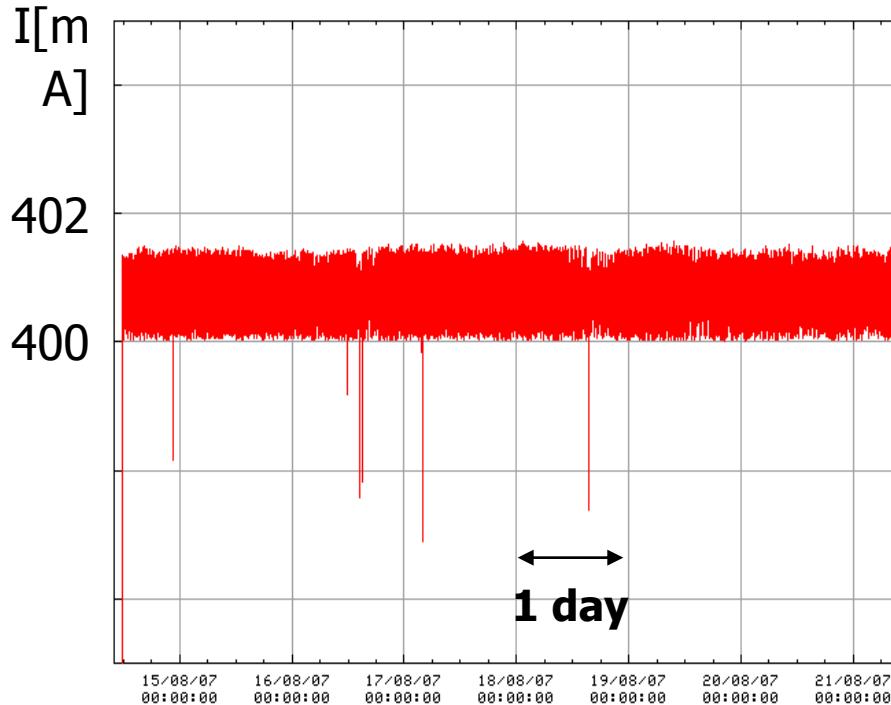
Tunnel Temperature [$^{\circ}\text{C}$] of 5 Sectors



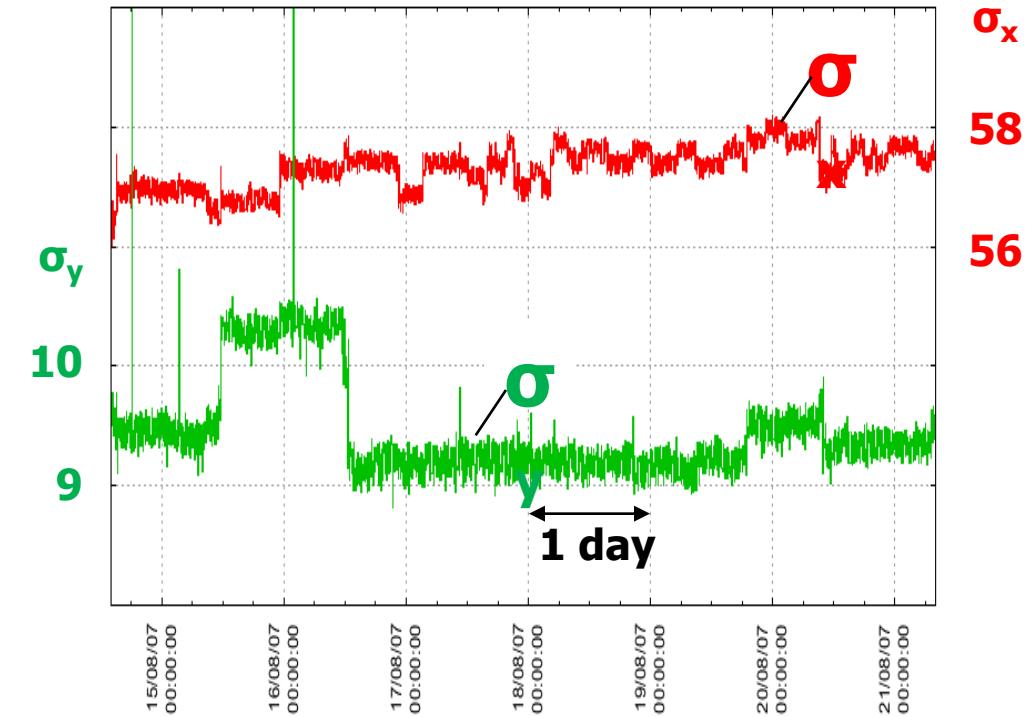
stable beams with top-up

7 days in August 2007 ,
without interruptions!

top-up every 2.5 min.
Beam current 400-401.5 mA



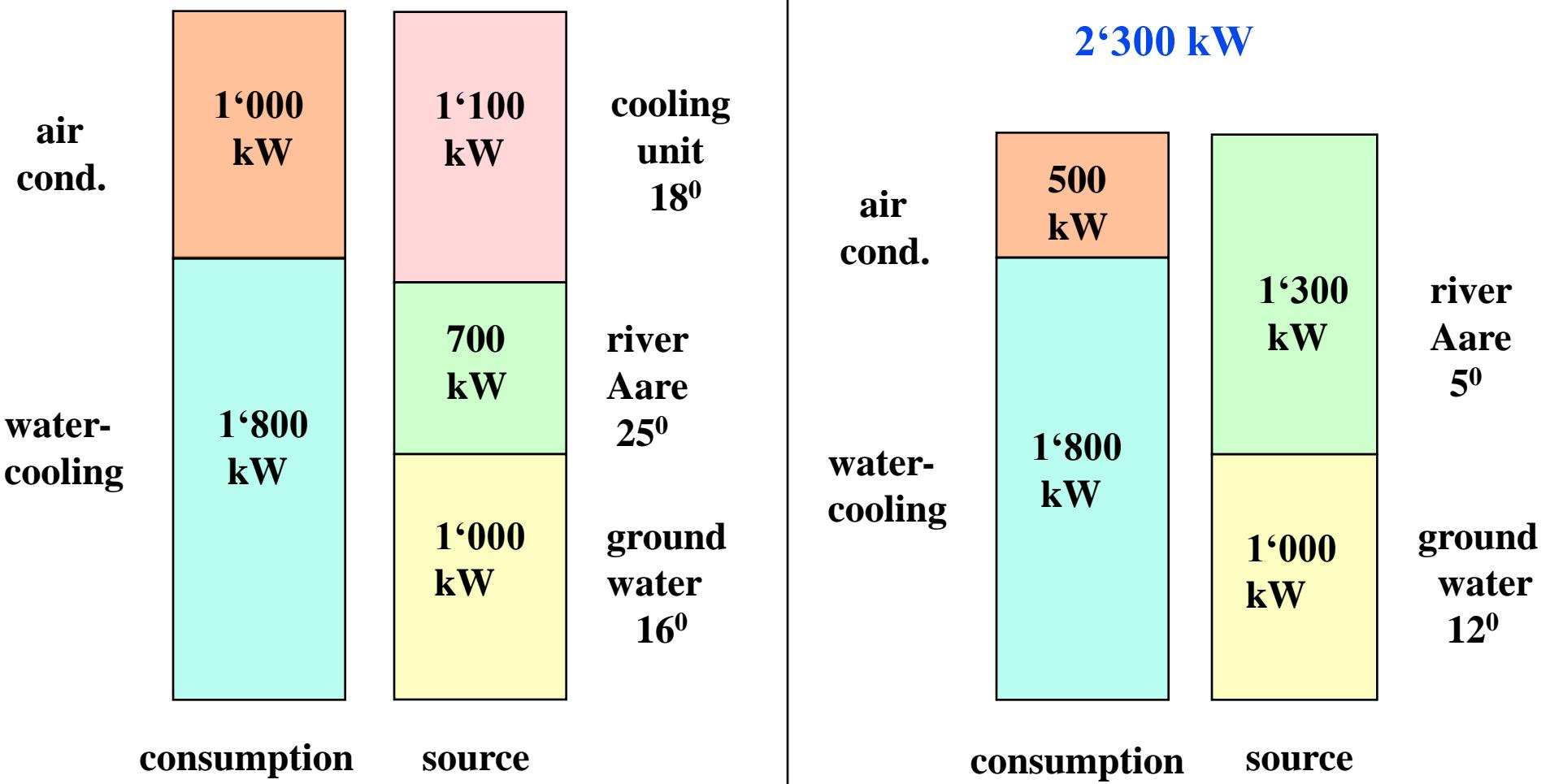
Beam size σ_x , σ_y [μm]



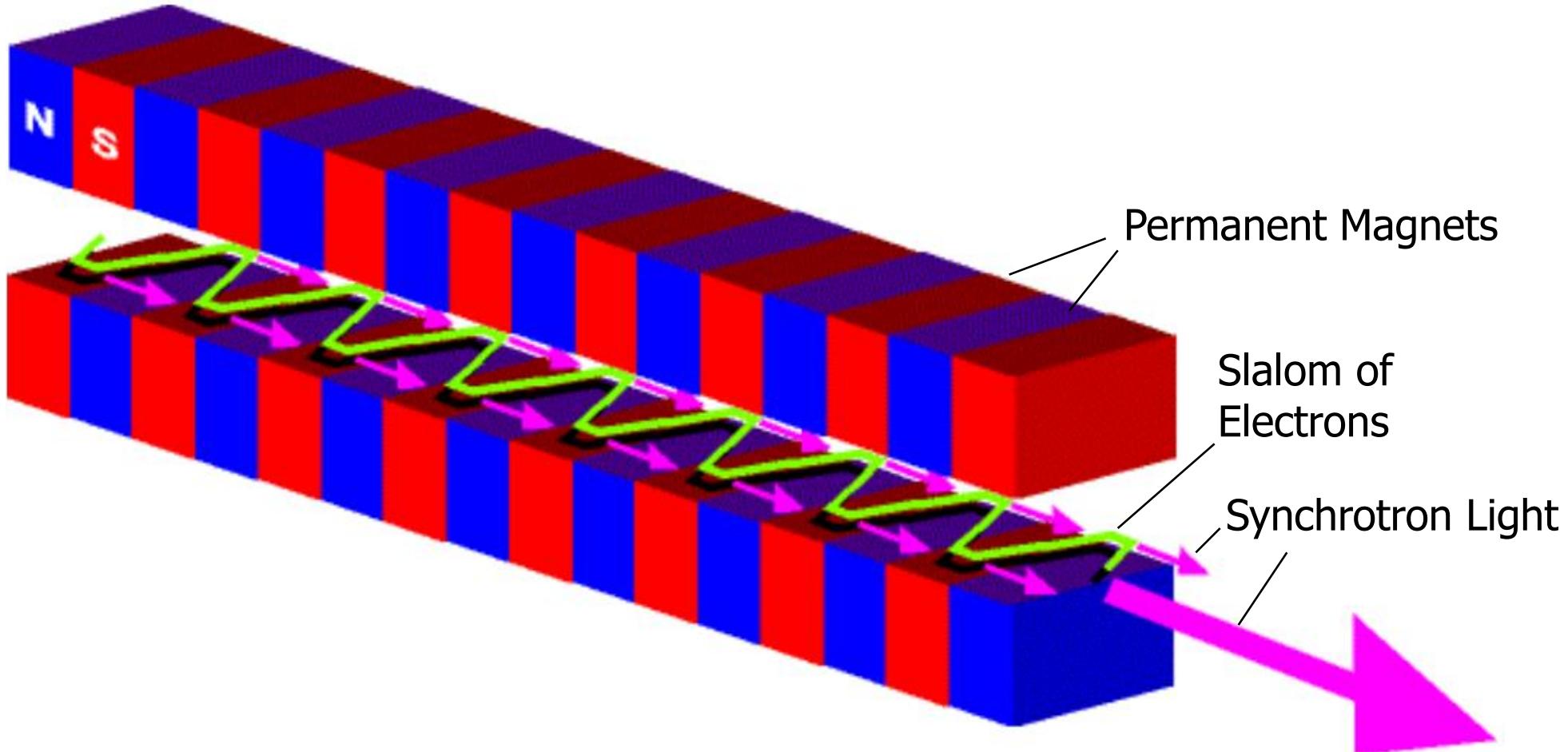
Cooling of SLS

Summer (35^0)

2'800 kW



Slalom Race in Undulator



fast Electrons in magnetic field generate Synchrotron Light

moving light source



Doppler effect

shift to higher frequencies
=> short wavelength λ

narrow light cone
=> strong collimation
(laserlike)

slalom course in undulator



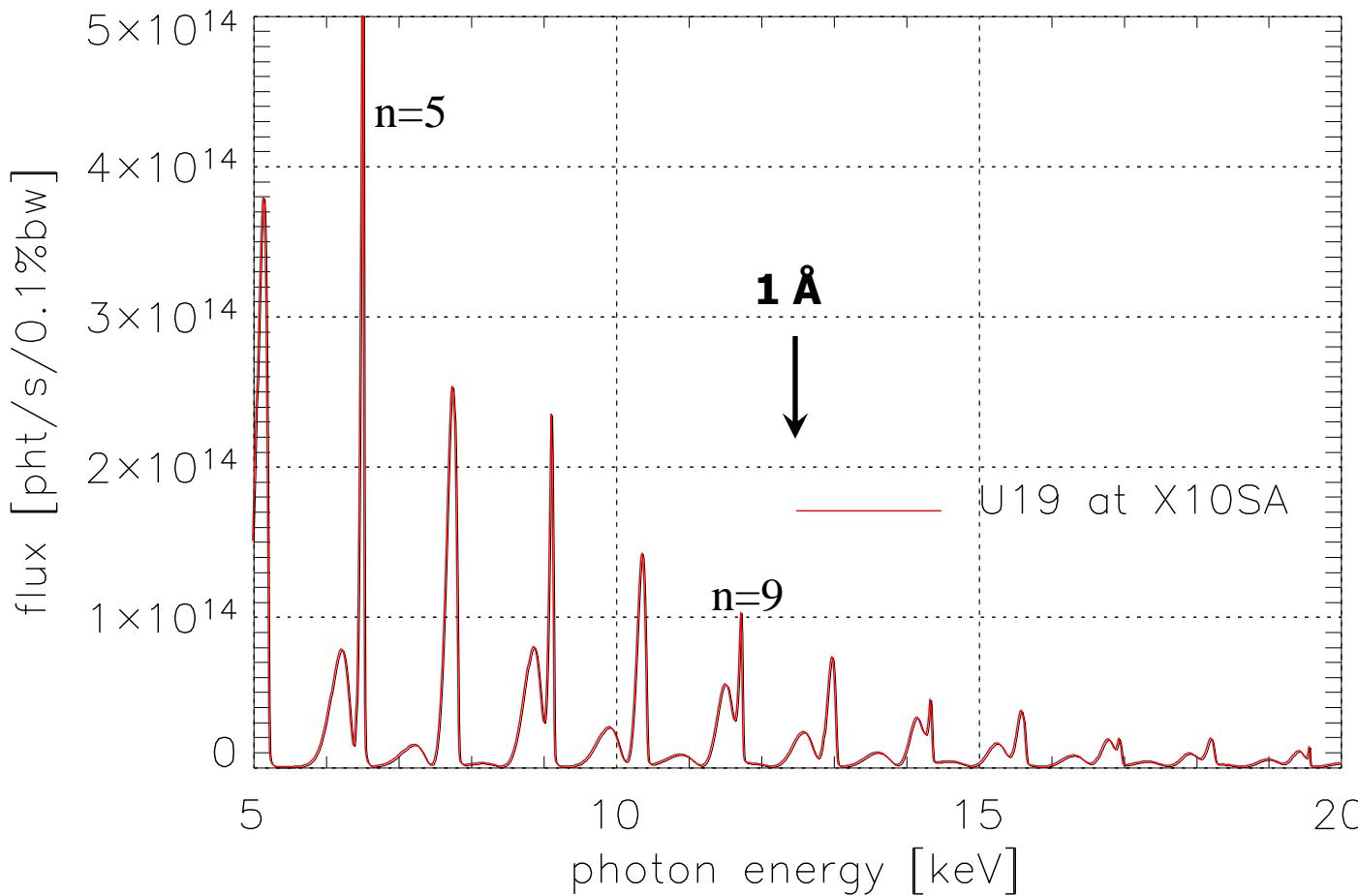
positive Interference

period λ_u gives sharp
spectral lines at harmonics n
=> high brightness

$$\lambda \sim \lambda_u (c - v_e) \sim n \lambda_u / E_e^2$$

- => short wavelength λ requires high electron energy E_e
=> large storage ring

Spectrum of Undulator U19



in-Vacuum Undulator

Protein Crystallography
(Clemens Schulze)

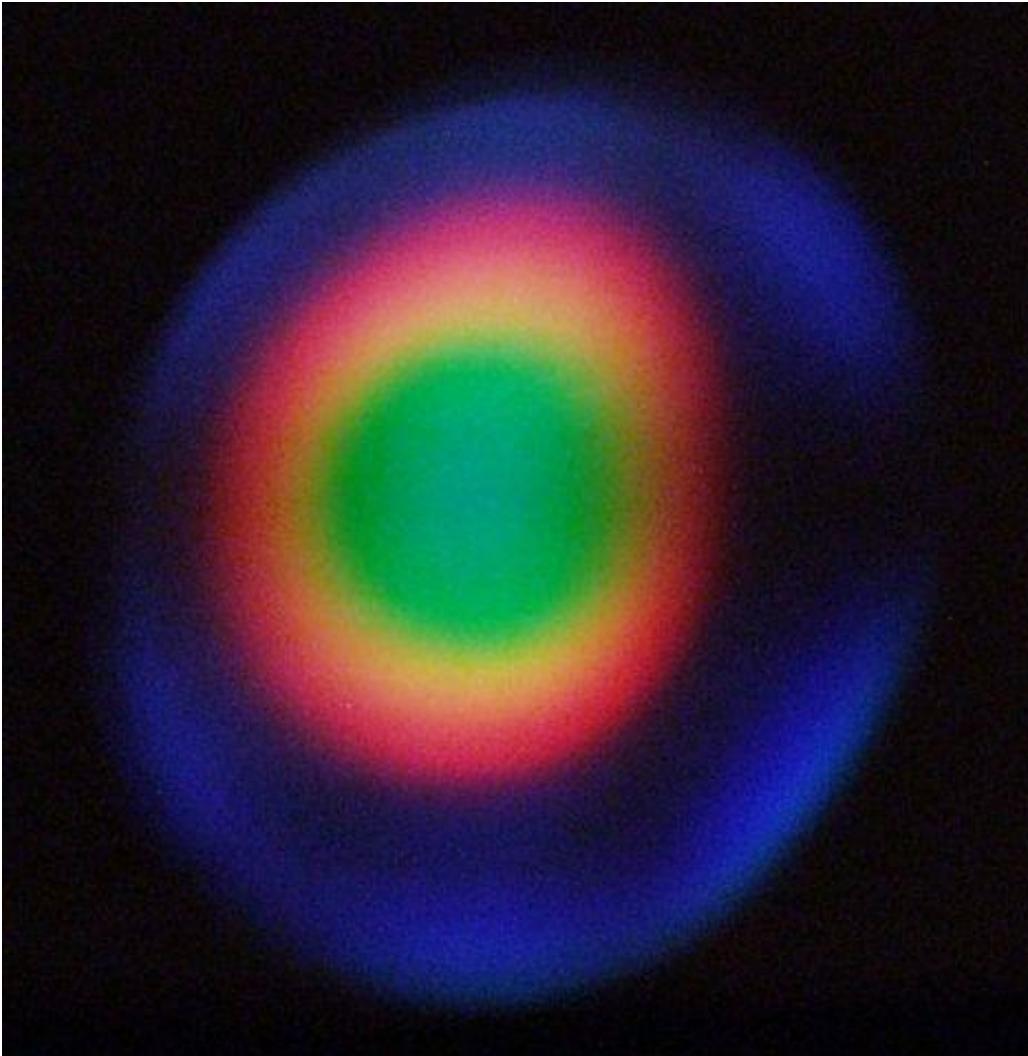
Undulator UE56



Permanent Magnets
62 Periods à 56mm

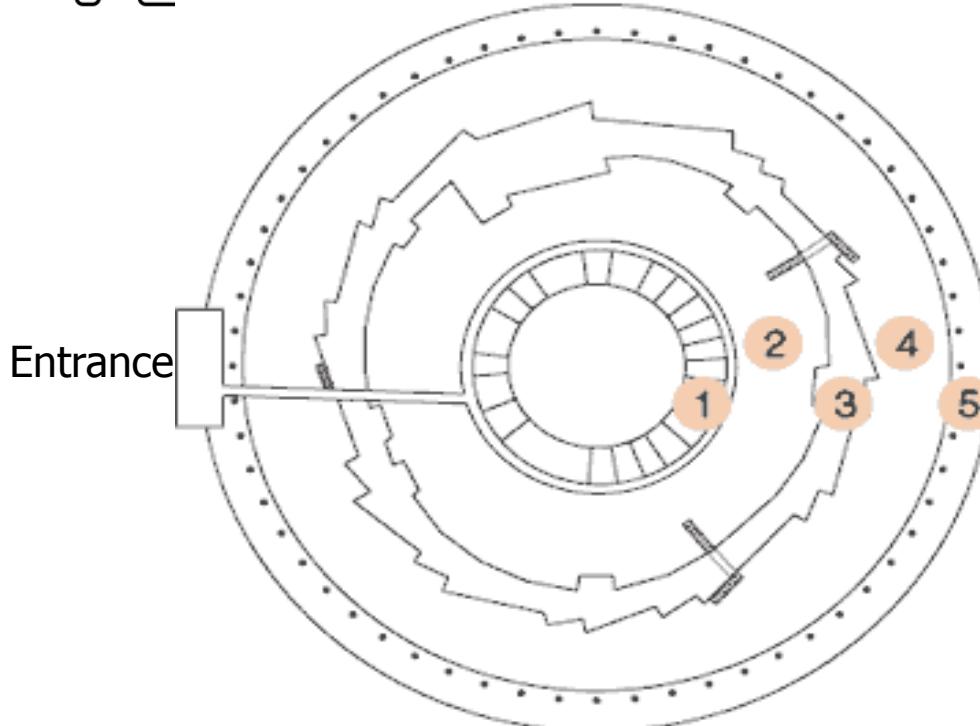
helical Fields give
circular and linear
Polarisation

Light Cone



Light Cone from Wiggler W138

1. harmonic, $K=18$ ($B=1.4$ T)



Zones:

- 1 Office Building (3 Floors)
- 2 Technical Galery
- 3 Tunnel (Storage Ring, Linac and Booster)
- 4 Area for Beam Lines
- 5 Outer Ring (60 Columns, Air Inlet System)

Building Concept

- separate annular Ring (40 cm) for Floor of Tunnel und Beam Lines (Zones 3, 4)
=> decouples Tunnel and Exp. Floor from Rest of Building
- very stable Temperatures in Tunnel und Hall

**=> stable Conditions for
Electron Beam and Beam Lines**

Building Parameter

outer Diameter	138 m
Height	14.3 m
Area	14'000 m ²
Columns, Roof Beams	60
Length of Roof Beams	43 m
Crane	16 t
Circumference Storage Ring	288 m
Tunnel, inner Height	2.4 m

Office Building:

3 Floors with Offices for 80 Persons, Control Room, Labs

Wooden Roof



Aufnahmedatum
18. November 1998
PSI / SLS

Temperature Stability

=> vital for stable Beams !

Tunnel

$25^{\circ} \pm 0.03^{\circ}$

- Air Conditioning: 5 Units à $6'000\text{m}^3/\text{h}$
- 150 Jets for stable Air Circulation
- 40kW Cooling, 90kW Heating (Shutdown)

Hall

$25^{\circ} \pm 0.2^{\circ}$ (Summer and Winter)

- Air Conditioning: 6 Units à $50'000\text{m}^3/\text{h}$
- 800kW Cooling Power
- gentle Air Inlet on 55% of outer Circumference

SLS Users

Institutes

Industry

- ETH Zürich, ETH Lausanne
- Universities
(CH und abroad)
- PSI
- Research Labs
(IBM Rüschlikon, EMPA,
Max Planck Institute Munich,....)
- Novartis
- Hoffmann-LaRoche

Milestones

First Ideas	1991	Start of Building:	2.June 1998
„Giessbach-Meeting“ (Users support SLS)	Oct. 1994	Building finished:	1.July 1999
ETH-council approves SLS	Sept. 1995	Beam in Linac:	23.March 2000
Parlament approves SLS	18.June 1997	Beam in Booster:	8.Aug. 2000
		Beam in Storage Ring	13.Dec. 2000
		goal of 400 mA reached	5.June 2001
		=> Begin Experiments:	2.Aug. 2001

Budget SLS (1997)

Building + Land 38 MFr.

Infrastructure, Labs, Ringtunnel 25 MFr.

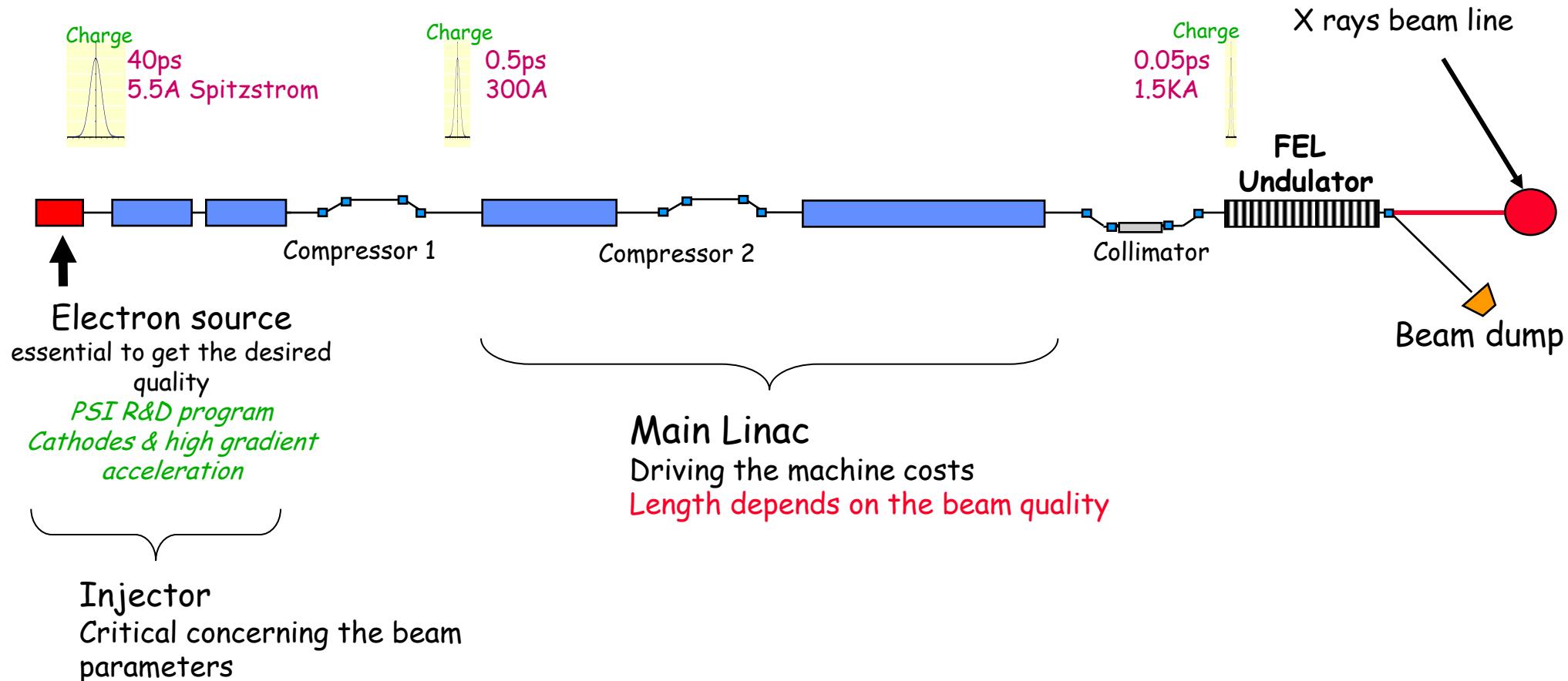
Storage Ring, Booster, Linac 68 MFr.

4 Beam Lines (2007: 8+3) 28 MFr.

Total Costs for SLS 159 MFr.

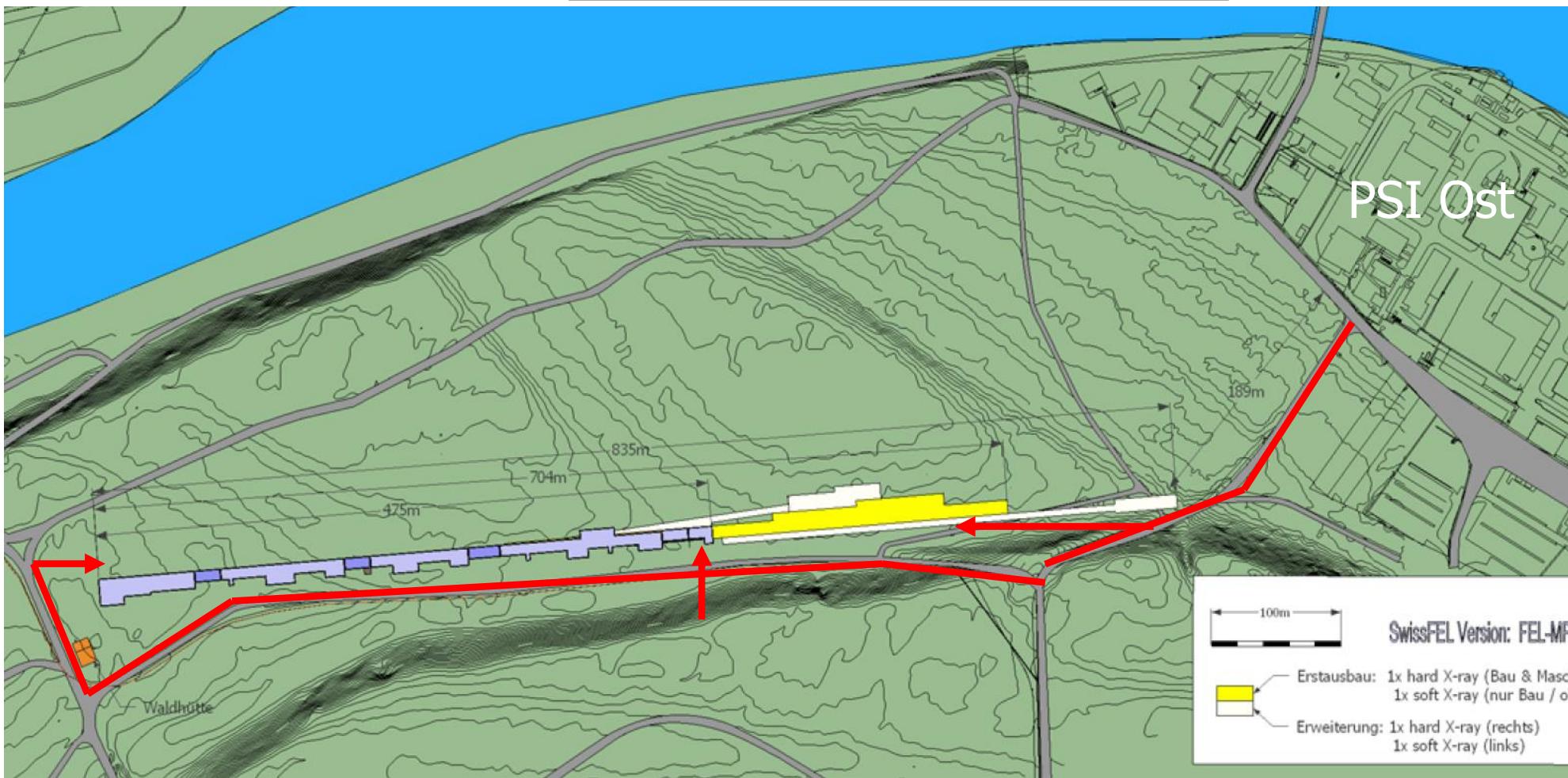
plus 400 man years

SWISSFEL Projekt



The FEL is a very high brightness light source
Fully coherent with very short photon pulse ~50 fs

SwissFEL Würenlingen



SwissFEL Würenlingen



Research Topics

- Protontherapy against cancer
- X-ray diagnostic with phasecontrast (=> breast cancer)
- Structure of Proteins with X-rays
(Nobelprize for Chemistry 2009, new drugs)
- Fuel Cells, efficient Batteries for Electro-Car
- Converting wood into Gas
- Superconductivity
- Nanostructures
- magnetic Surfaces (=> compact Data Storage ?)
- Detectors for Particle Physics (Hadron Collider at CERN)
- iLab for School Classes

positive proof of global warming



18th
Century 1900 ~ 1950 1970 1980 1990 2006

Prognosis for the next 90 Years

- Globally 2 - 5° warmer => **droughts reduce harvests**
(2003 was hottest Sommer for 500 years, ...soon the rule!)
- the global sea level rises about 30-60 cm
- less rain in middle Europe, but more **floods !**
- melting of arctic ice caps , retreating glaciers

global conflicts:

=> war on **Water, Energy, Nutrition**

=> migration pressure from south to north

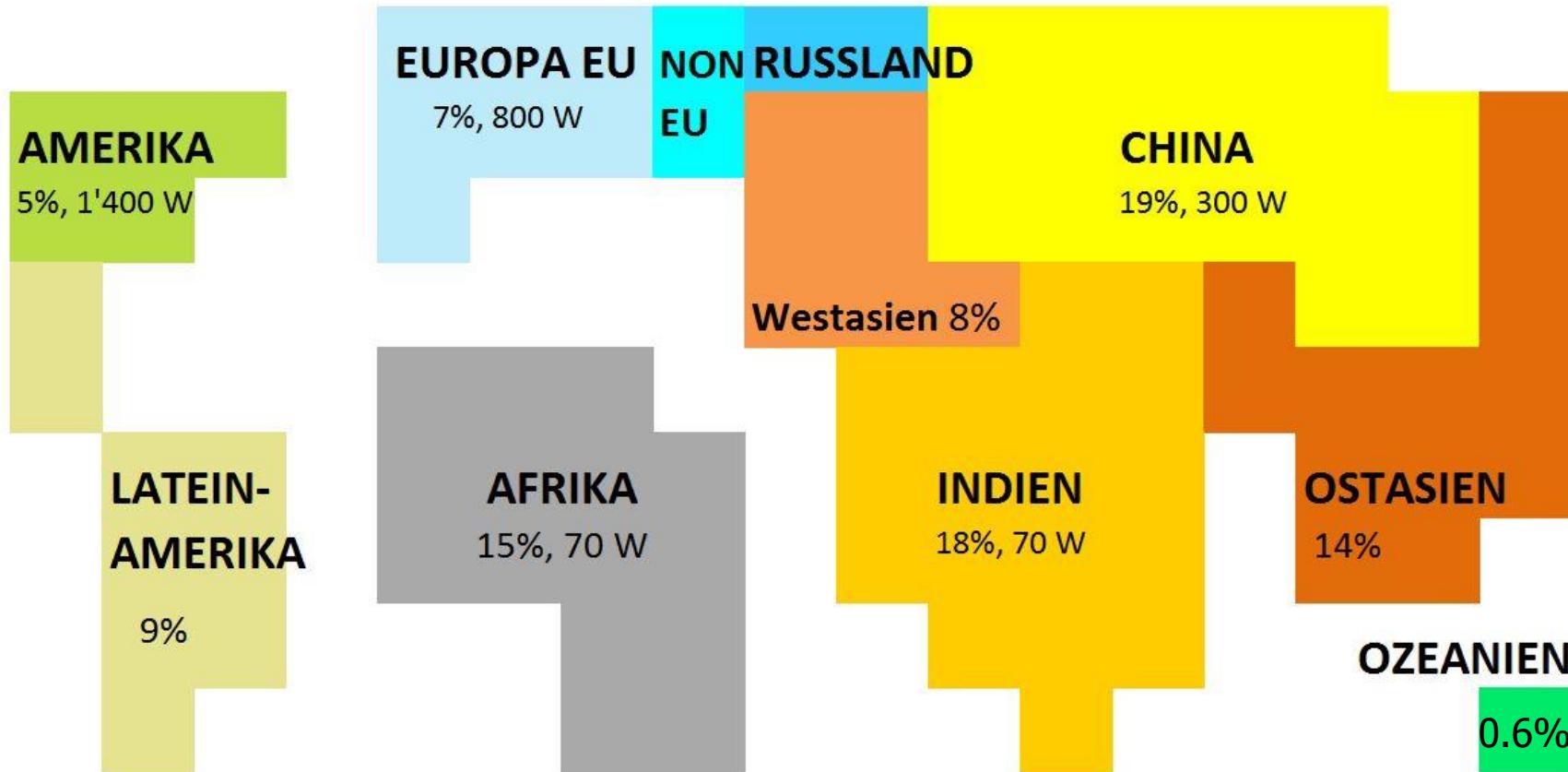
Energy

a challenge for the future

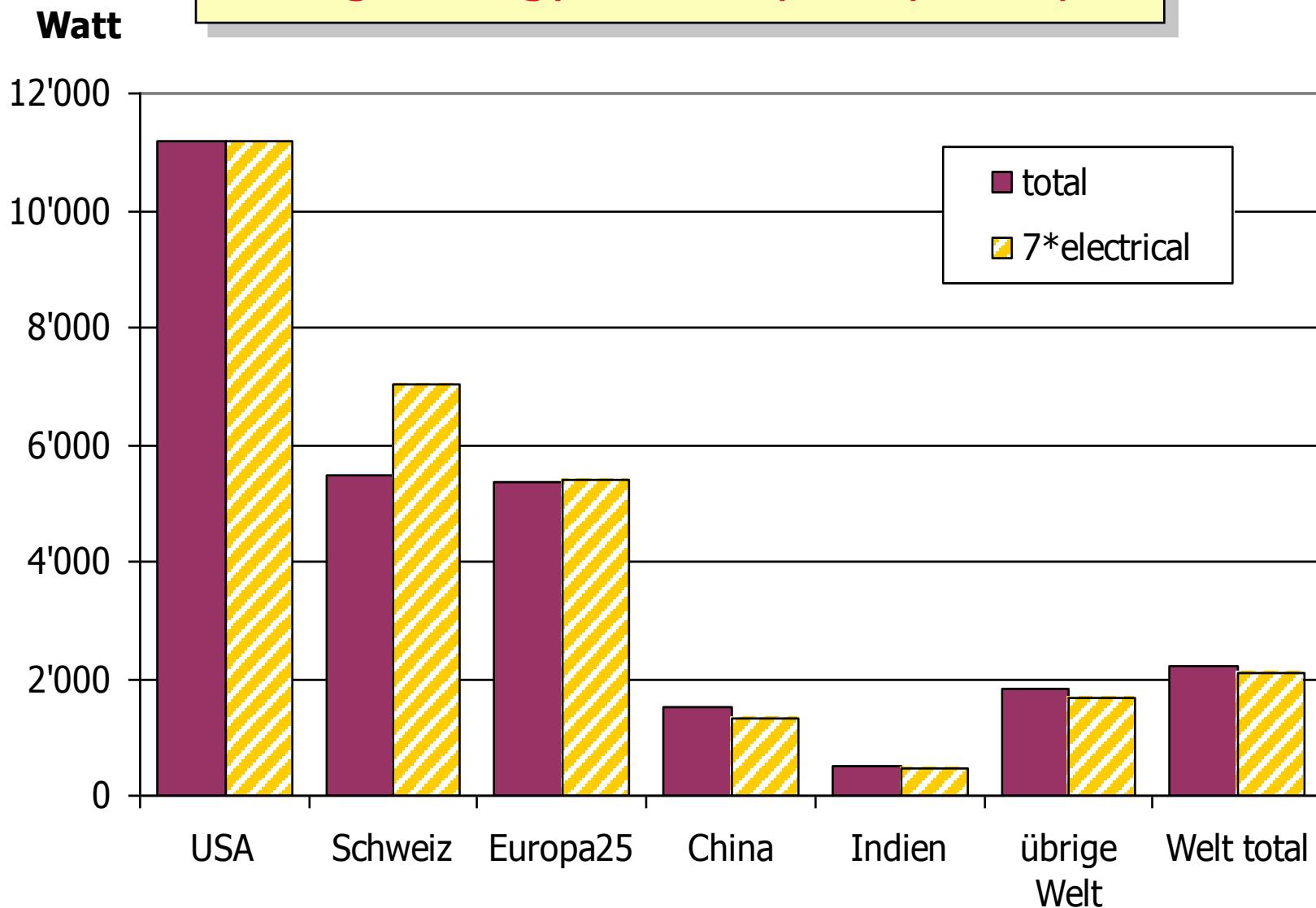
Werner Joho , a personal view

contribution to World population in (plus electric consuption per capita)

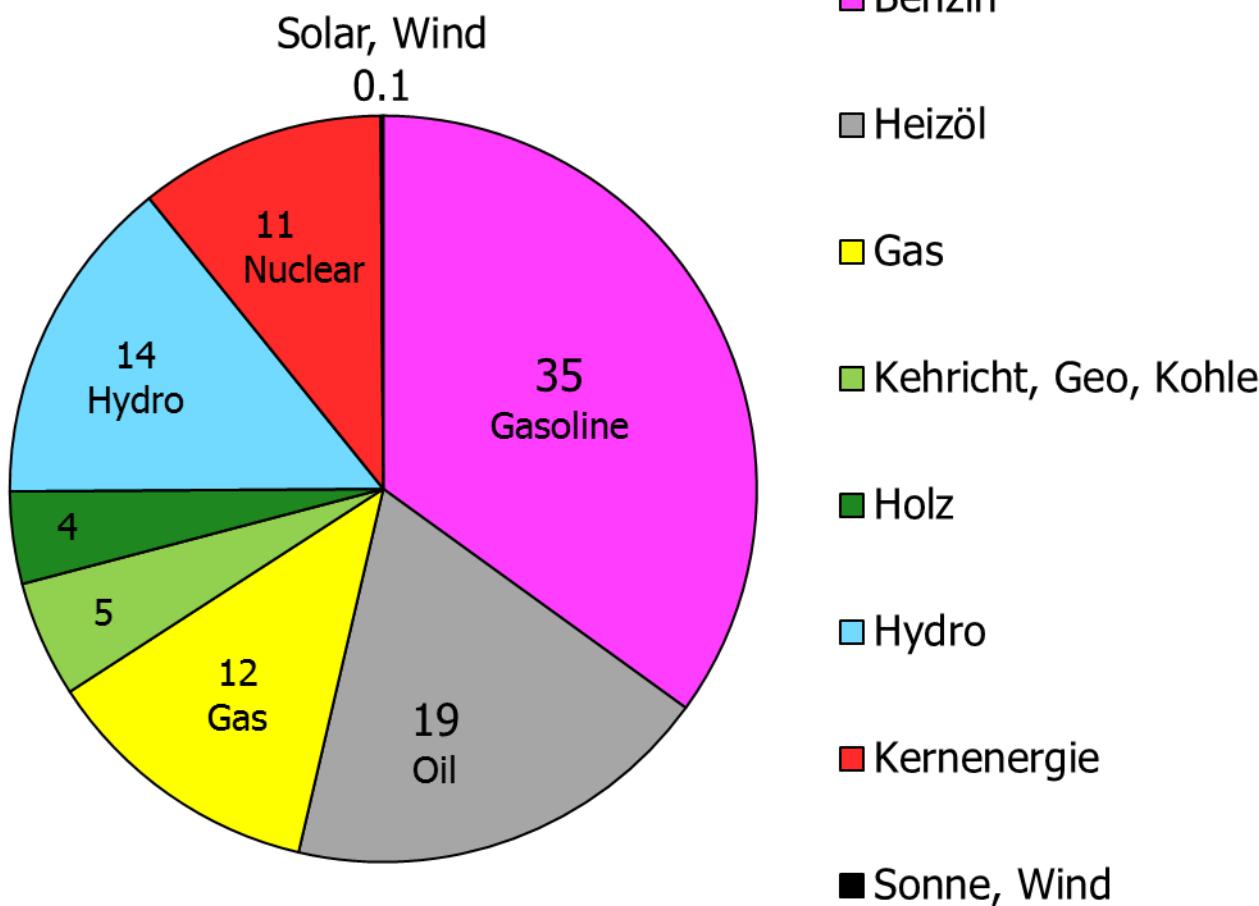
 1 square=1%
= 70 Mill. Inhab.



average Energy Consumption per Capita



Energy Consumption in Switzerland (%)



average: 3.4 kW/Person
(ca. 1kW electrical,
1/3 of this: households)

2'000 W Society?!

Replacing oil and gas:
=> more electrical energy!

Hydrogen Car

**Collaboration PSI / Michelin
new: Hayek**



Electro-motor with
30 kW Fuel Cells (H_2 / O_2)
45 kW Supercapacitors
400 km Range
0-100 km/h in 12s

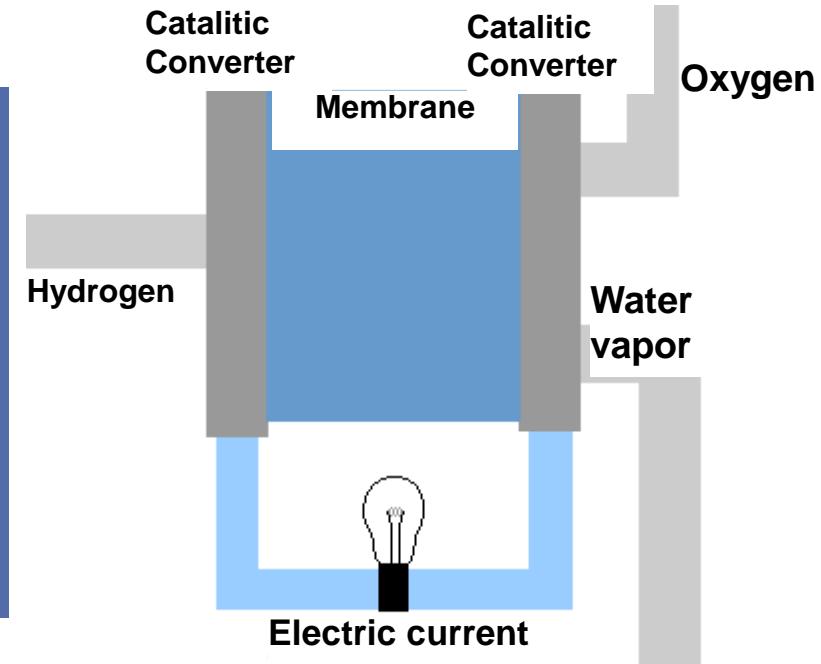
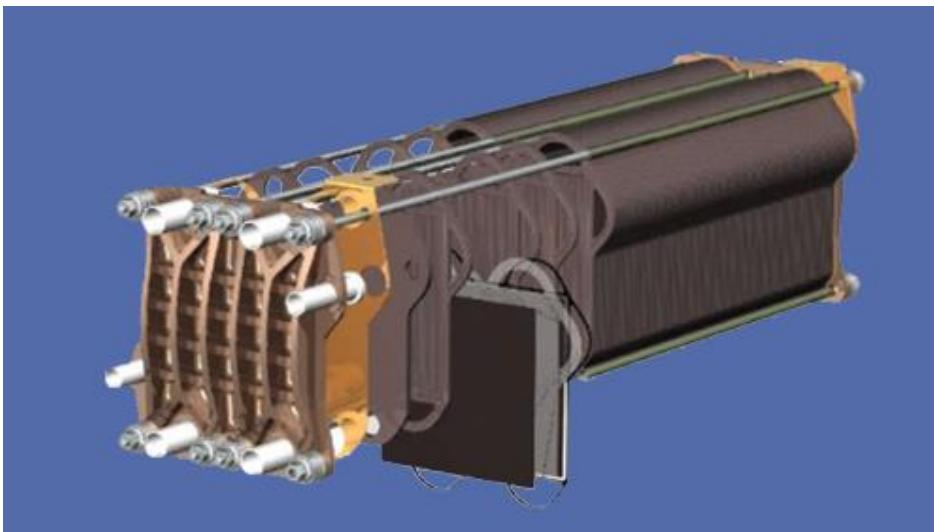
**no exhaust gas
pollution!!**
no gasoline !

Collaboration Belenos (Swatch Group) and PSI



Nick Hayek, Philipp Dietrich, Nicolas Hayek, Marco Stampanoni

Fuel Cell



Fuel Cell Block with 30kW

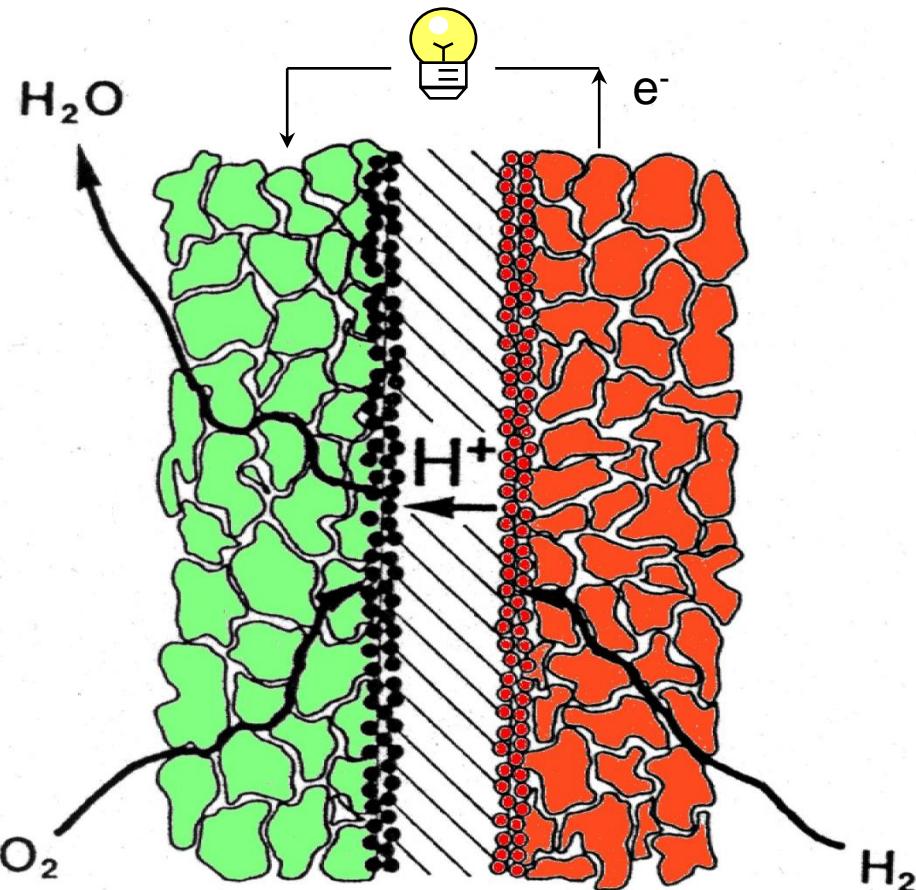
Energy Prize

Watt d'Or 2011

**Hydrogen + Oxygen = electr. Energy
(+Water)**

Efficiency ca. 60%

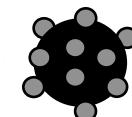
Fuel Cell



Anode:

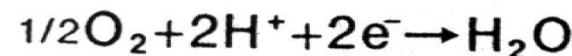


Cathode:

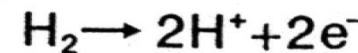


Catalytic Converter:
Soot encapsulated by
Platin Nanoparticle

CATHODE

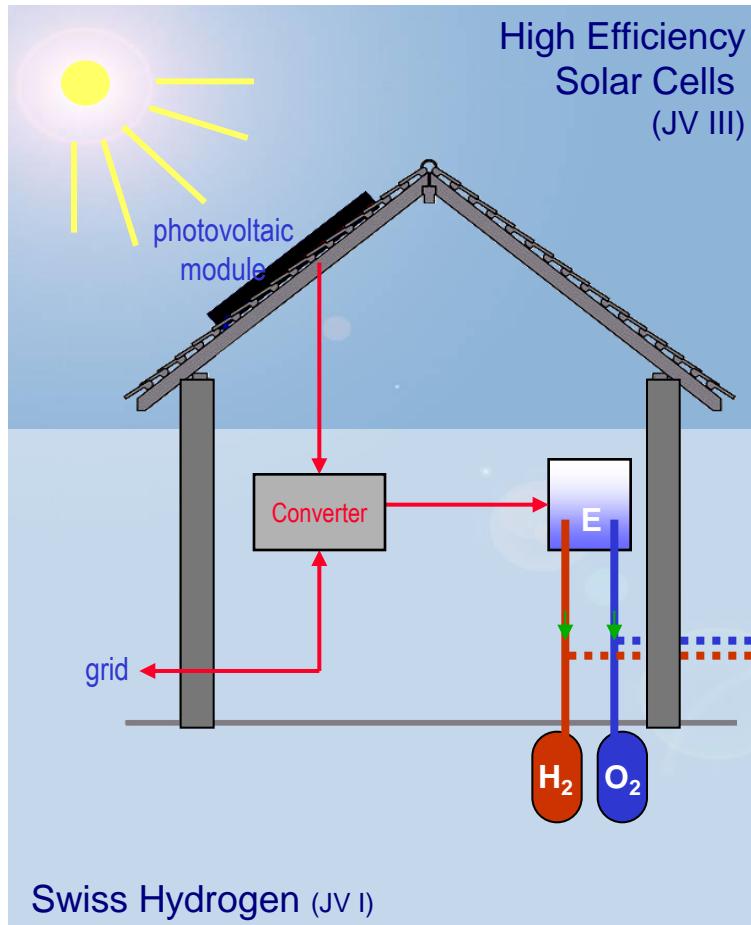


ANODE



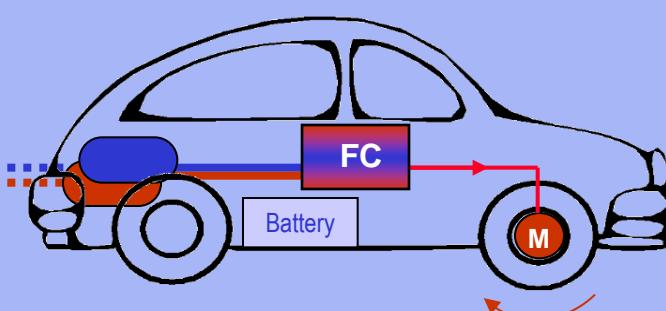
Hydrogen Car reloading at home ?!

Belenos Clean Power Holding



PV surface :	63 m²
Annual PV production :	8'600 kWh
Share used for mobility:	~ 70 %
Annual mobility :	13'000 km

— Electricity
 — Oxygen
 — Hydrogen



Swiss Fuel Cell (JV II)

How dangerous is the Hydrogen tank ?



Hydrogen Car

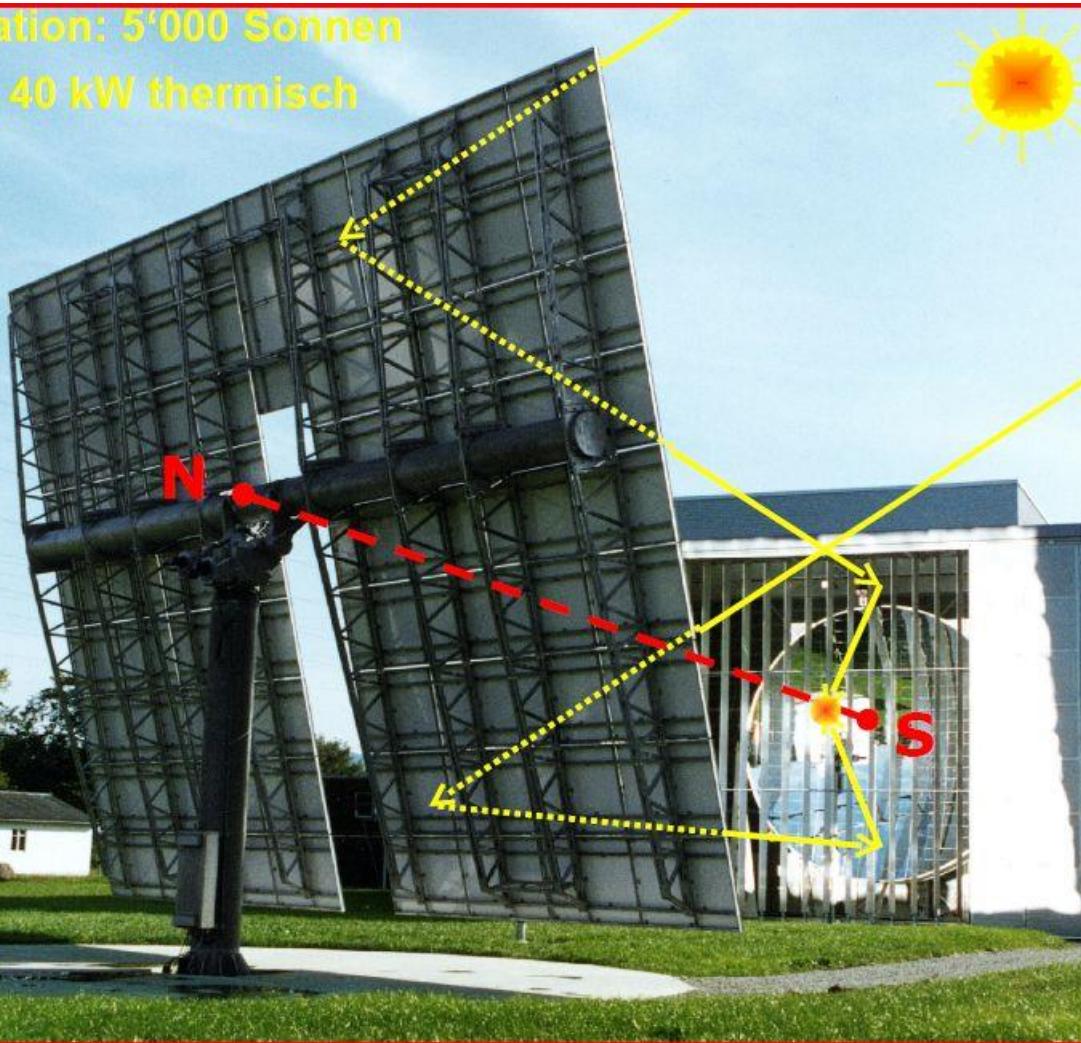
Gasoline Car



After a few seconds

Solar Concentrator at PSI

Konzentration: 5'000 Sonnen
Leistung: 40 kW thermisch



Solar Oven 2000°
40 kW thermal

e.g. Production of Zinc
from Zinc-oxyde
=> Storage possibility!!

Zinc => Hydrogen
=> Zinc-air Battery
=> Fuel Cells
=> Syn-gas