PAUL SCHERRER INSTITUT

Wir schaffen Wissen – heute für morgen

Cern Accelerator School
High Power Hadron Machines

Bilbao, Spain 24 May – 2 June

Introduction I – short version

25 May 2011

Kurt Clausen, Paul Scherrer Institut, CH

Outline

Introduction to Introduction ......

The two introductory lectures – Introduction I and II today will not be about Hadron machines or Acellerators!

The intention is instead through a series of examples to demonstrate why Hadron Machines provide such attractive tools for a very broad spectrum of science and technology, and why the users of these machines cry for ever increasing performance.

The introduction will by no means provide a comprehensive list of neither science at hadron machines nor the different centres operating hadron machines, but will be dominated by examples of work done by members of the NUM (Neutron and Muon) Department at PSI, using the facilities at PSI and Cern.

Acknowledgements: I would like to acknowledge my colleagues at PSI for providing material for this presentation – the names of contributers will be marked on the respective slides in the following format:

N. Nnnnnnn

Outline – Introduction I and II

Hadron Machines

Power diagramme

Accelerator driven systems – ADS

Proton therapy

Science at High Energy Machines:

Particle physics – Colliders - Example cms at Cern

Science at High Intensity/power Machines:

Muon - beams

Particle physics – Test of Standard model

Precision Measurements – example Muon lifetime

Rare/forbidden decay - example $\mu \rightarrow e + \gamma$

Condensed Matter Physics

Probing magnetism and Superconductivity

Neutron - beams

Particle physics – Test of Standard model

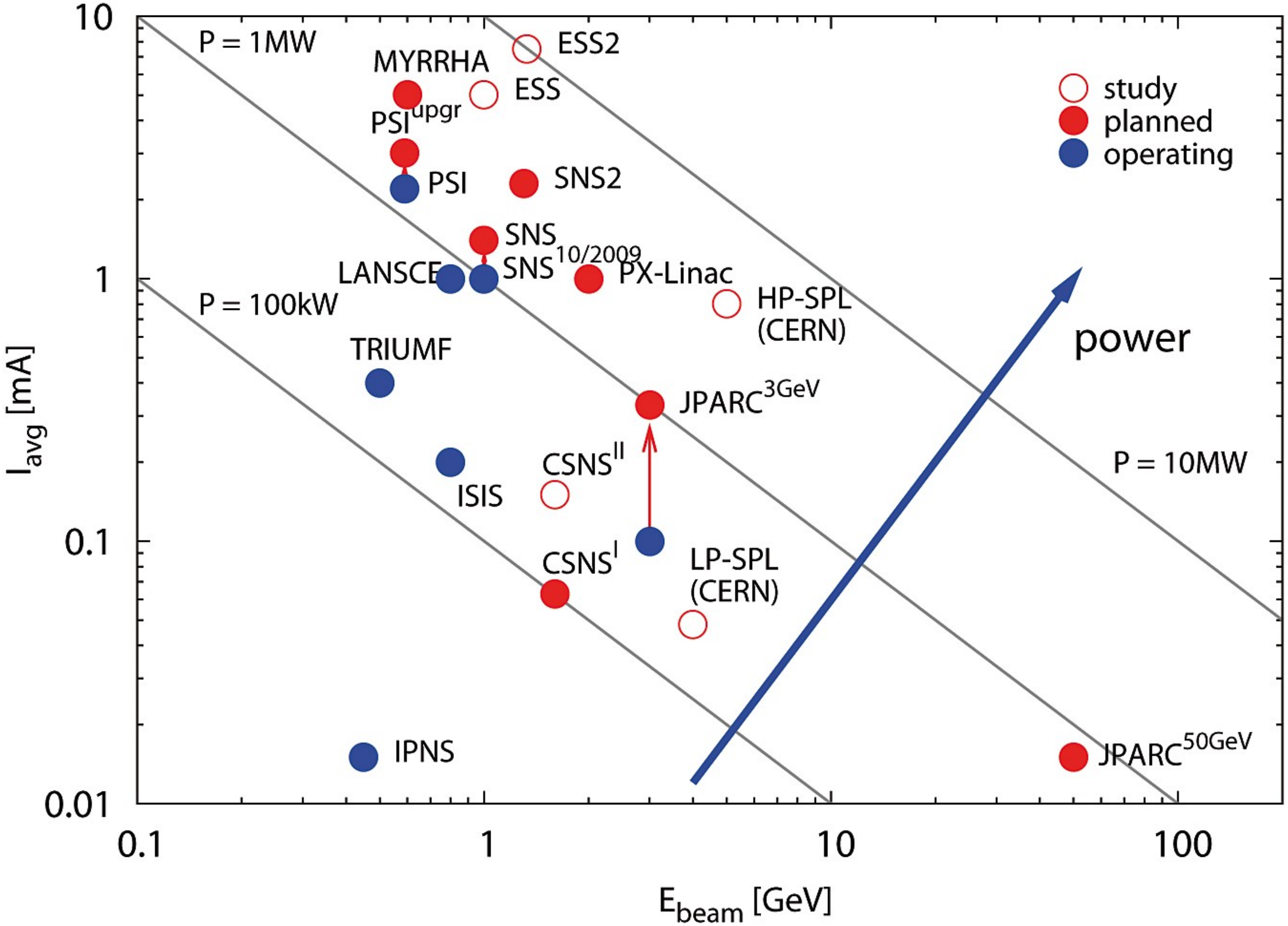
Search for neutron Electric Dipole Moment – nEdM

Solid State physics

Structure and dynamics of Matter

Tomography – imaging 3 D structures – in situ studies

High Power Proton Accelerators

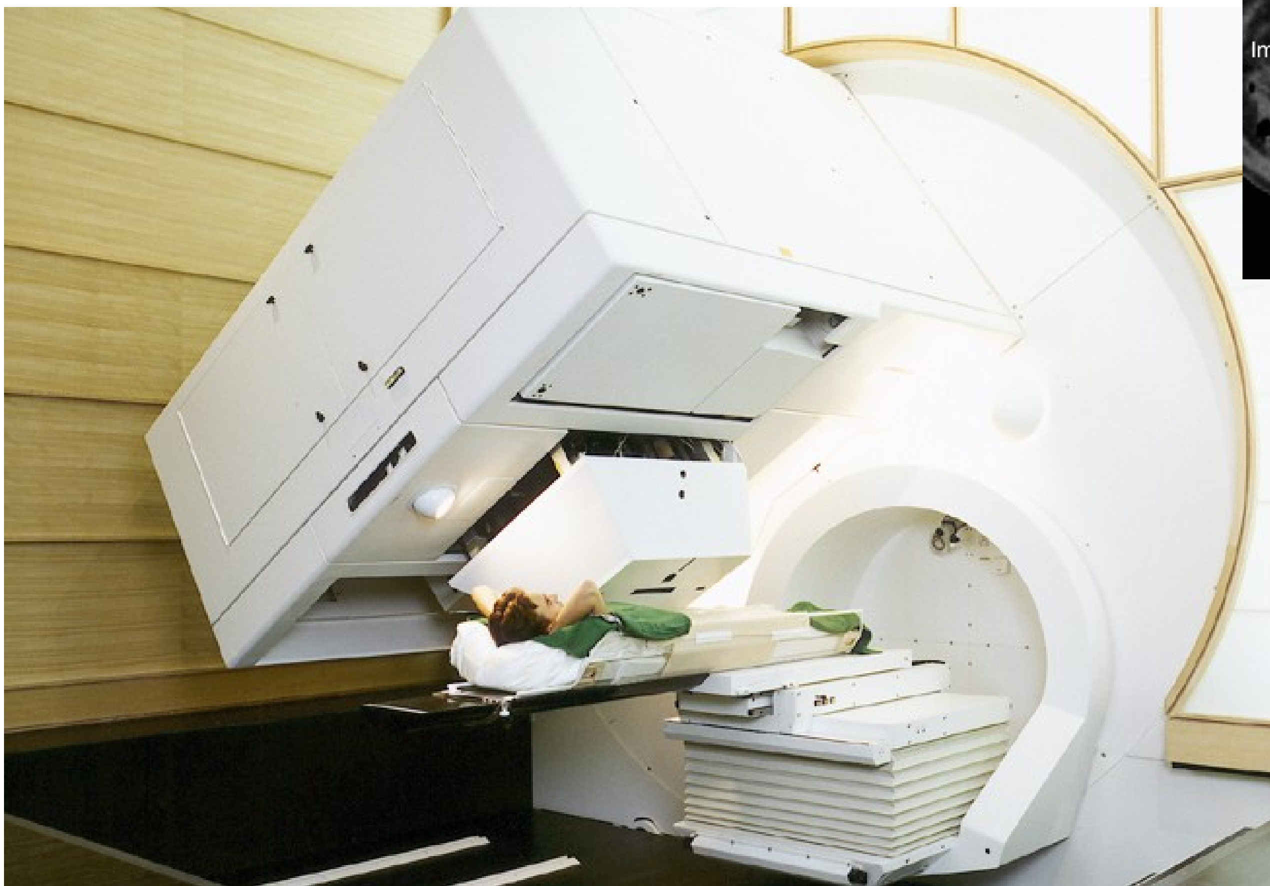


plot: selected accelerators current vs. energy

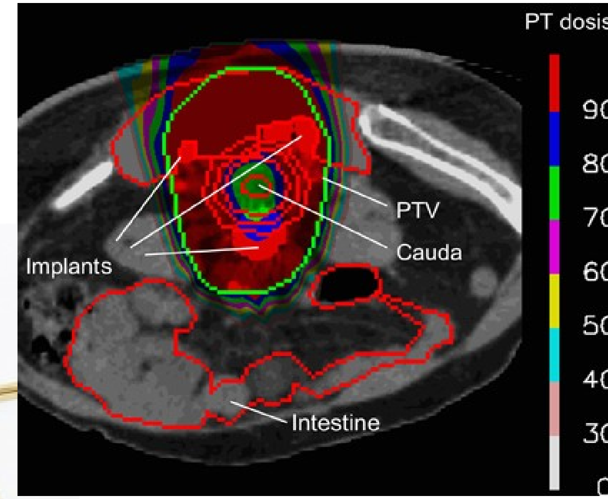
power ∝ current· energy

M. Seidel, PSI

Humans and health

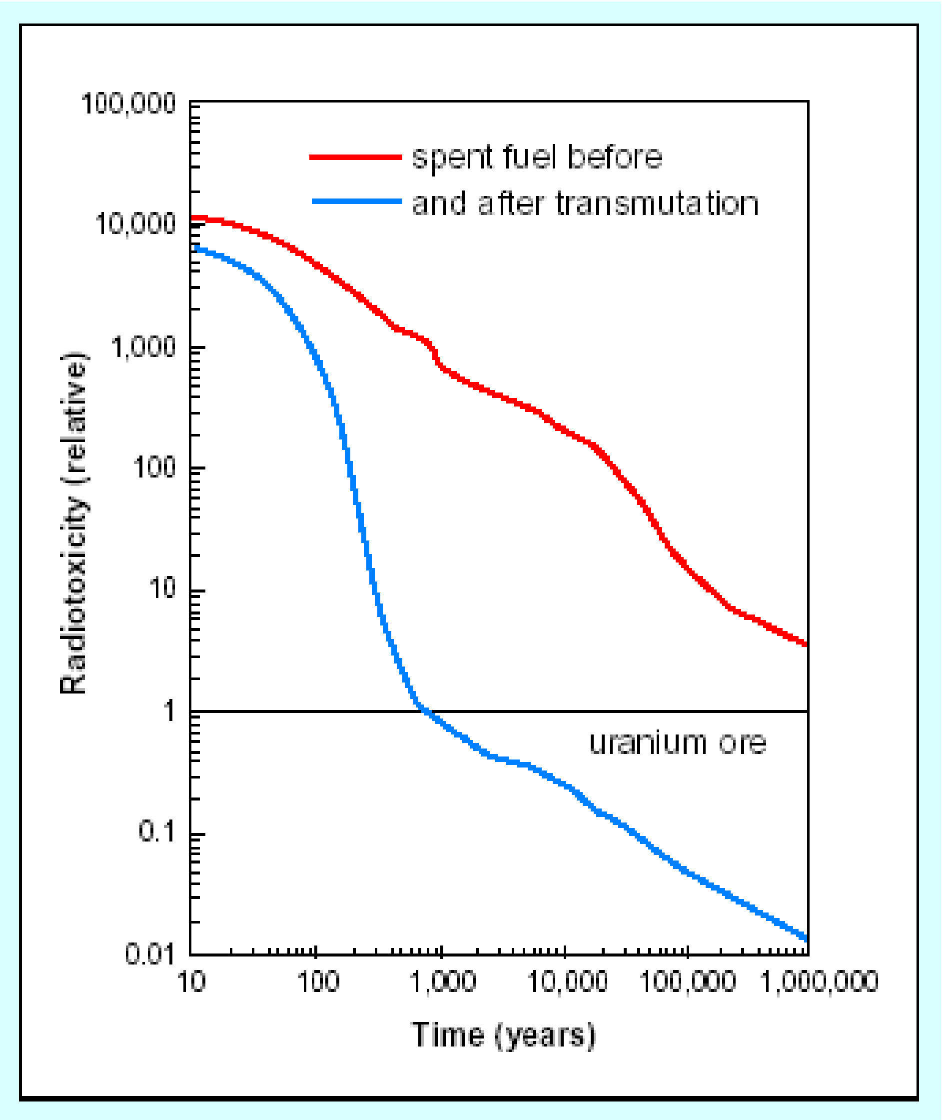


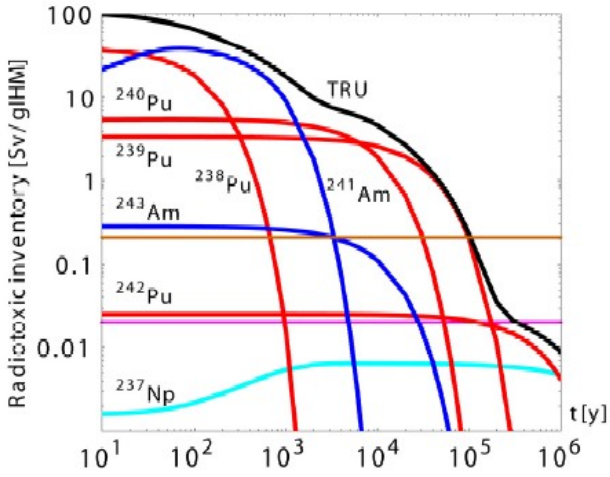
Radiation facility (Gantry) for proton therapy



Efficient spot-scanning technique: irradiaton plan for a tumour at the lower spine (spearing of healthy tissue)

How long time do we need to care about the waste from nuclear reactors?





Radiotoxic inventory of the main transuranic isotopes in spent nuclear fuel (3.7% ^{235}U, 42 MWd/kgIHM).

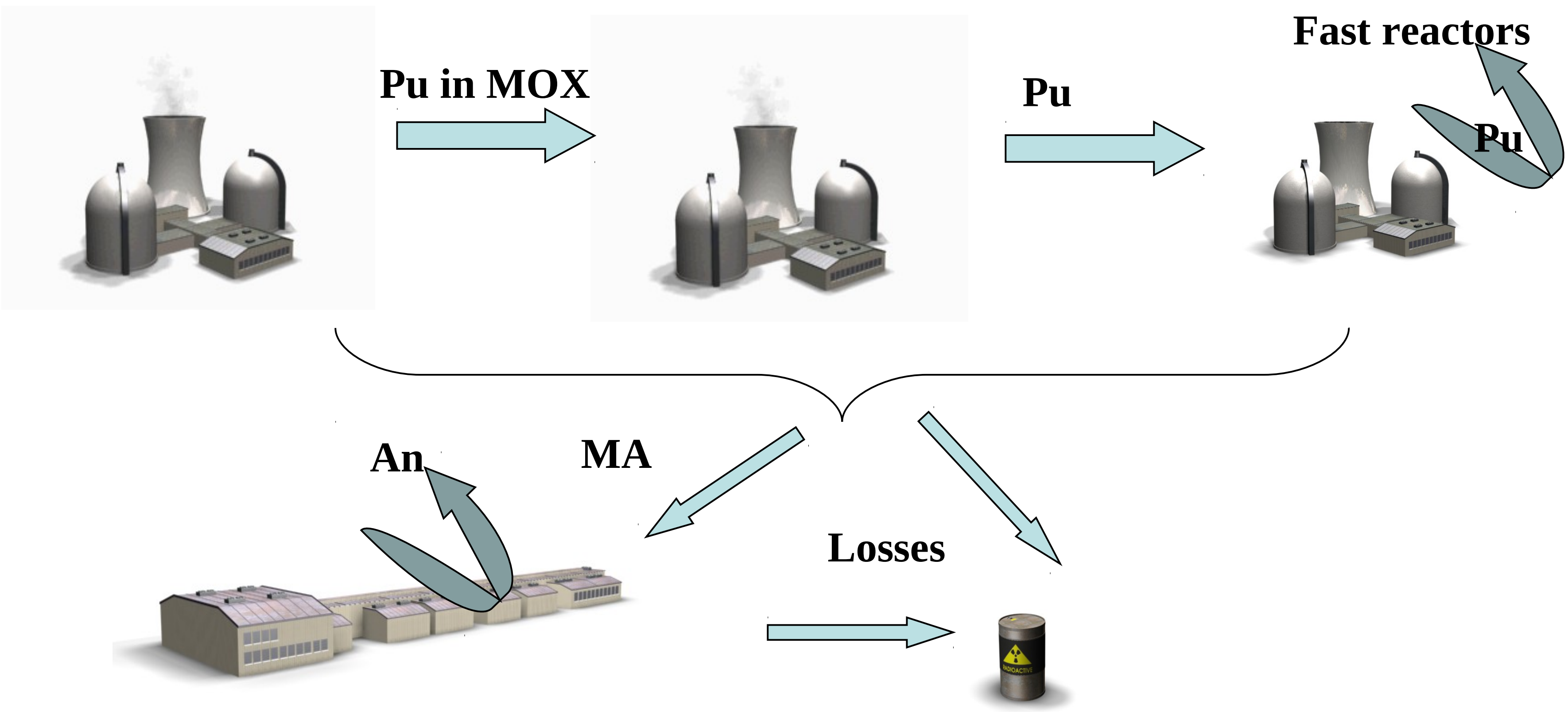
Transmute or "Burn" minor actinides and Pu in either Fast Reactors or subcritical systems:

Accelerator **D**riven **S**ystems

G Bauer

ADS ------------- *before Fukushima ????*

Vision of Advanced Fuel Cycle Scenario



Few ADS facilities

J-M Cavedon, PSI

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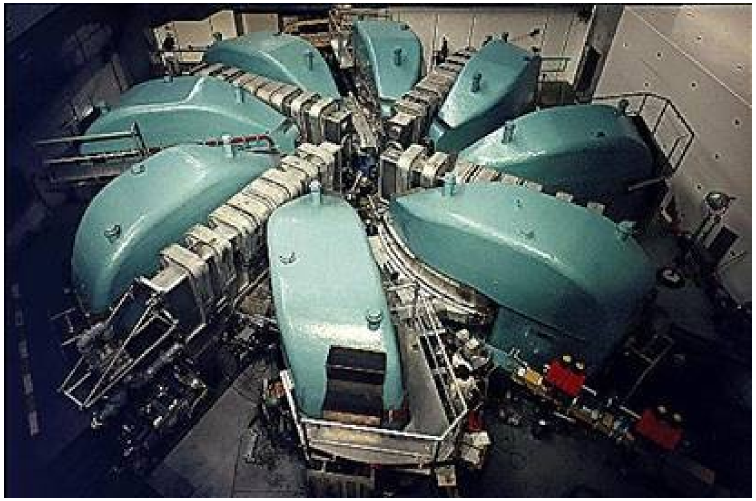
Physics at the LHC acellerator --- cms

R. Horisberger, PSI

Particle Physics Basics (1)

Accelerator particles allow collision and scattering experiments to determine the microscopic structure of matter. → creation of new particles (matter / antimatter)



PSI ring cyclotron accelerates ~10^{16} protons per sec to 590 MeV = 0.59 GeV ~ 0.0006TeV

Production of pions:

$p + p \rightarrow p + n + \pi^{+}$

	Mass
proton	938.3 MeV/c^2
proton	938.3 MeV/c^2
Total	**1876.6 MeV/c^2**

	Mass
proton	938.3 MeV/c^2
neutron	939.6 MeV/c^2
π+	139.7 MeV/c^2
Total	**2017.6 MeV/c^2**

mass difference
- = **141 MeV/c^2**

Massive particles created from collision energy

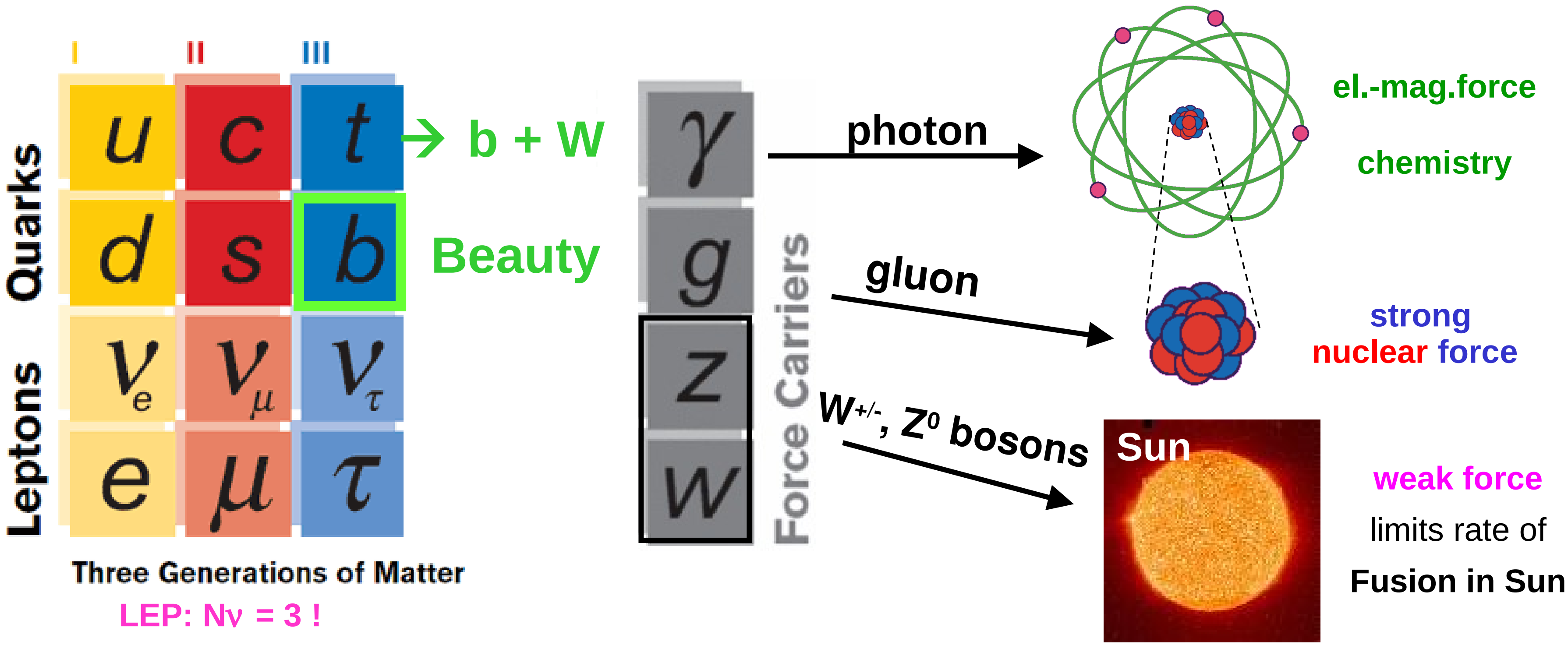
$E=mc^2$

R. Horisberger, PSI

R. Horisberger, PSI

Relativistic QFT of Matter & Forces

QFT = **Q**uantum **F**ield **T**heory of Matter & Forces based on Lagrange formalism

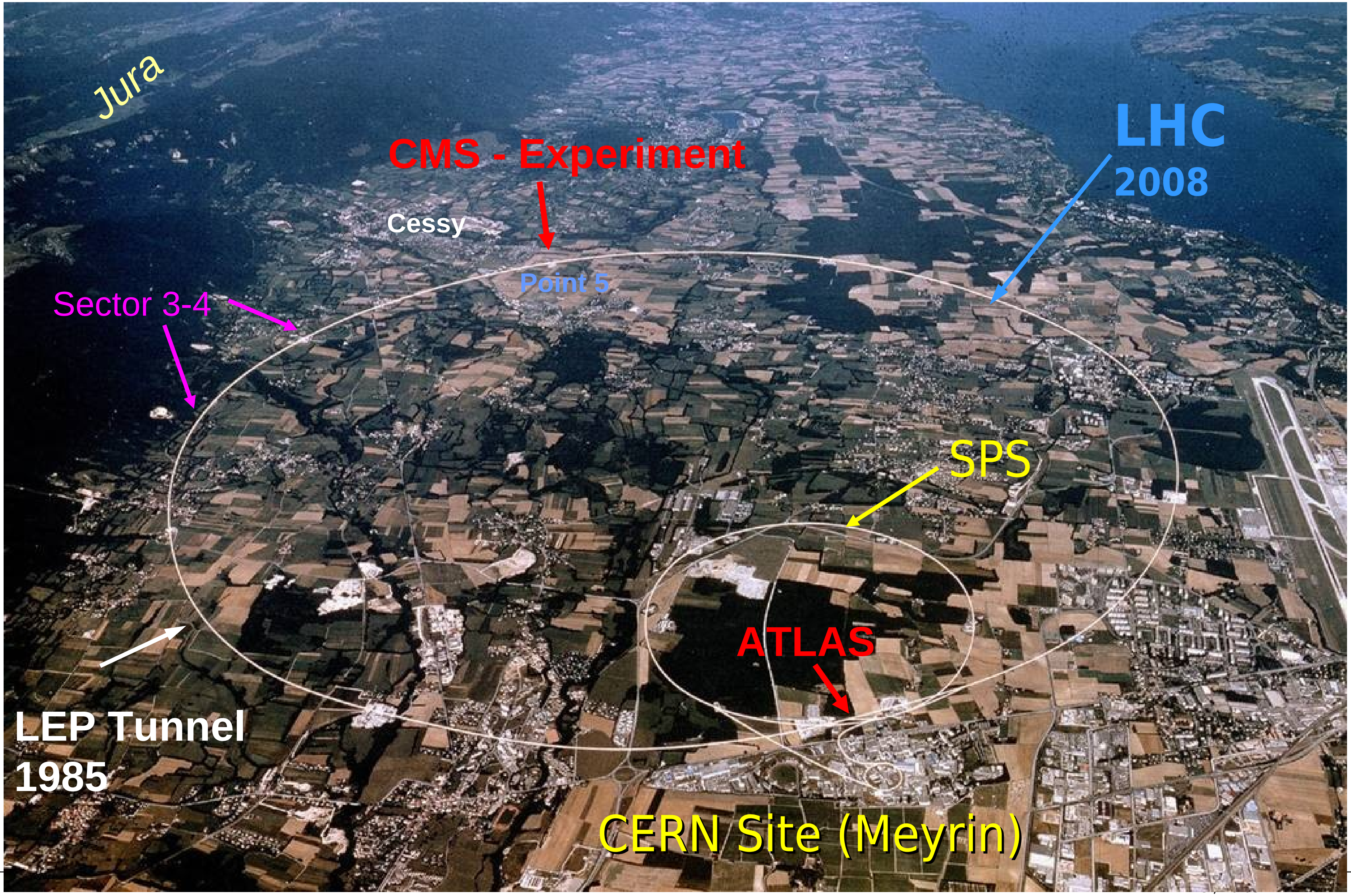


Lagrange density with mass less matter particles needs **Higgs mechanism** to create gauge symmetric ($SU(3)_c \times SU(2)_L \times U(1)_Y$) invariant masses for leptons and quarks as well as the 4 types of gauge bosons for all 3 forces.

Beauty quark detection crucial for **3rd generation physics analysis** ! → **b-tagging**

Standard Model of quarks, leptons & forces → all particles found except **Higgs !**

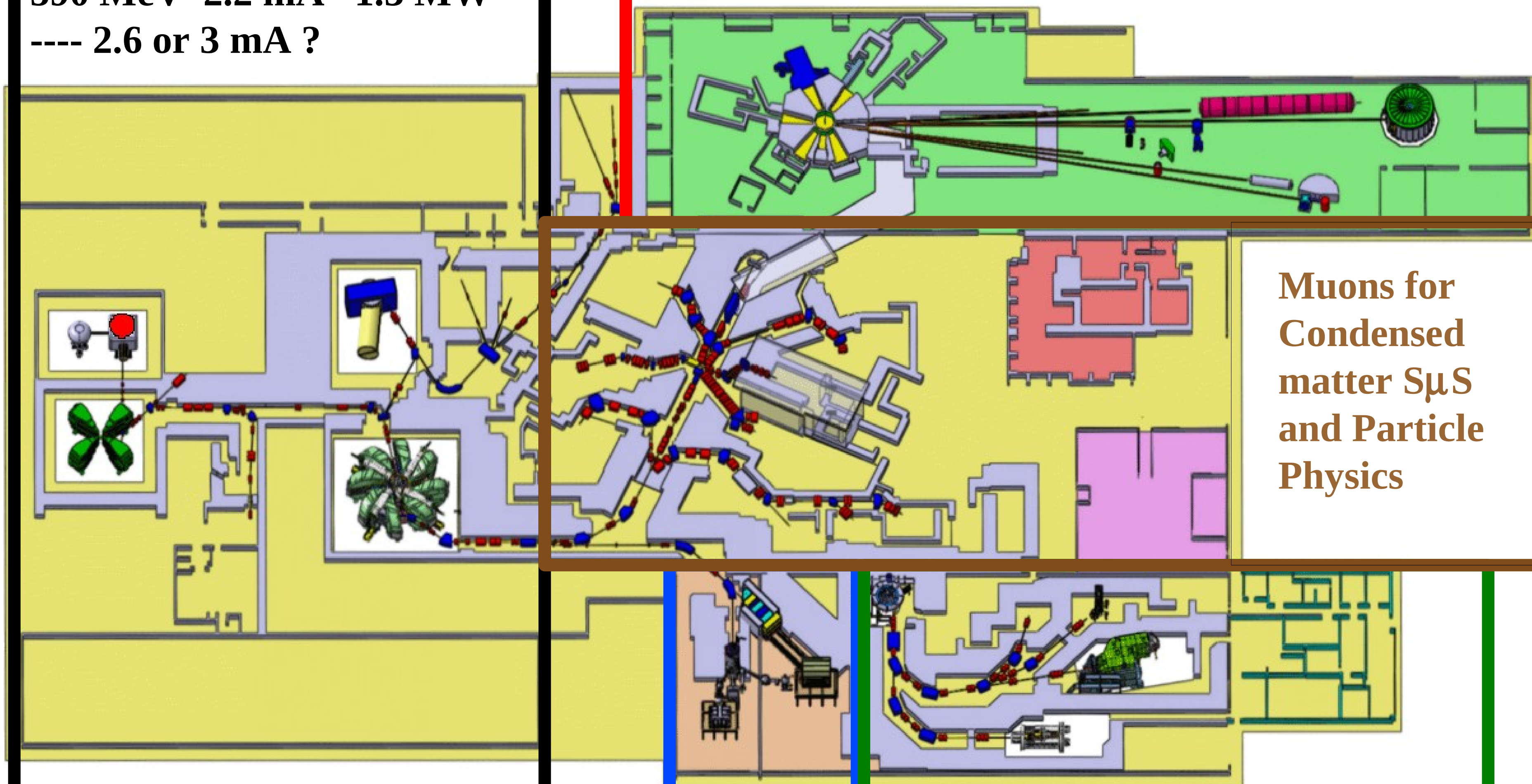
Large Hadron Collider (LHC)



Proton accelerator at PSI

Proton accelerator CW
590 MeV 2.2 mA 1.3 MW
---- 2.6 or 3 mA ?

SINQ CW Spallation neutron source 0.9 MW

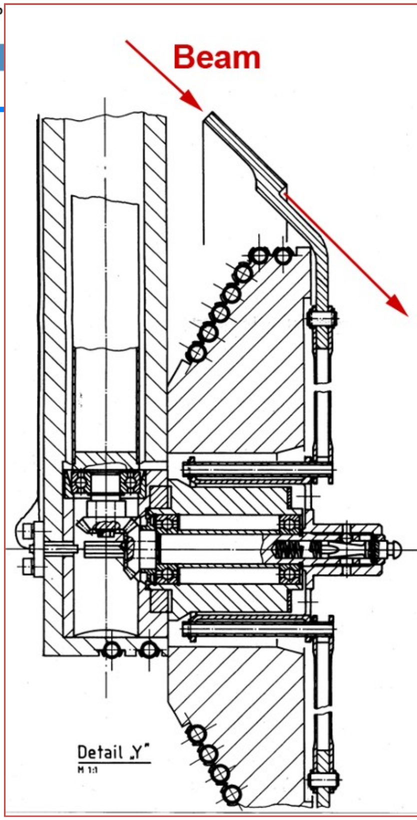


Muons for Condensed matter SμS and Particle Physics

UCN

Proton Therapy

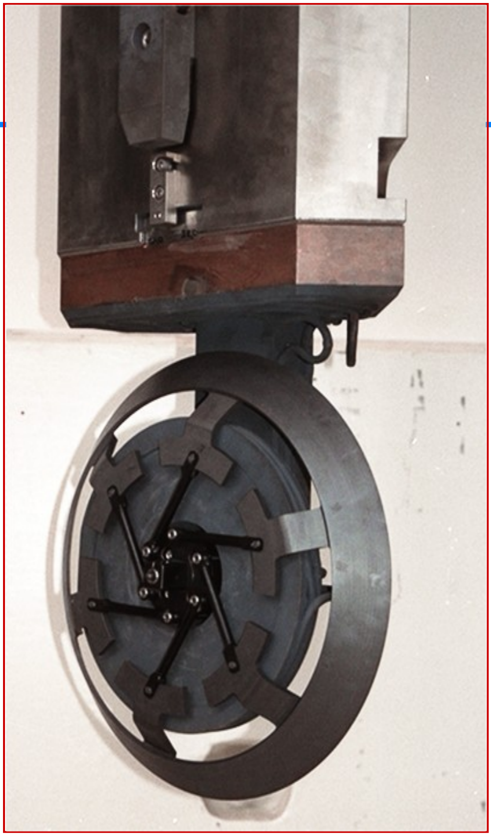
Meson production target



See Lecture 30/5
M Wohlmuther

TARGET CONE

Mean diameter:	**450 mm**
Graphite density:	1.8 g/cm^3
Operating Temp.:	**1700 K**
Rotation Speed:	**1 Turn/s**
Target thickness:	**40 mm**
Beam loss:	12 %
Power deposit.:	20 kW/mA



Charge state	π^+	π^-
Mean lifetime (s)	26x10^{-9}	26x10^{-9}
Spin	0	0
Mass (MeV)	139.57	139.57
Decay mode	$\pi^+ \rightarrow \mu^+ + \nu_\mu$	$\pi^- \rightarrow \mu^- + \overline{\nu}_\mu$

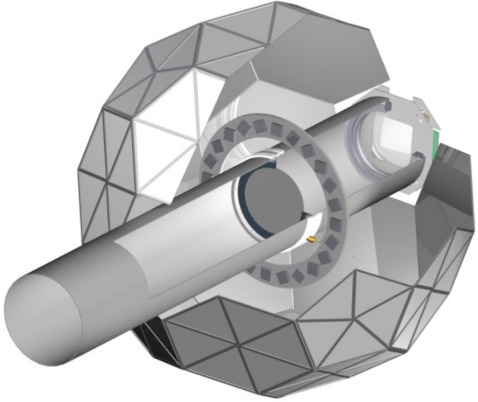
100% polarised "*surface*" positive muons (~4MeV).

Muon Rate at **μE4 at PSI**

4.6E8 μ$^+$/sec @ p=29.8 MeV/c

M Seidel, T Prokscha, PSI

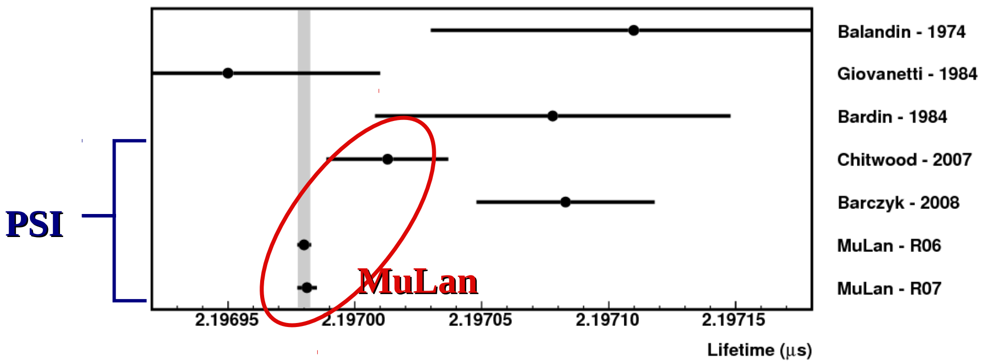
Part-per-Million Measurement of the Muon Lifetime Determination of the Fundamental Fermi Constant

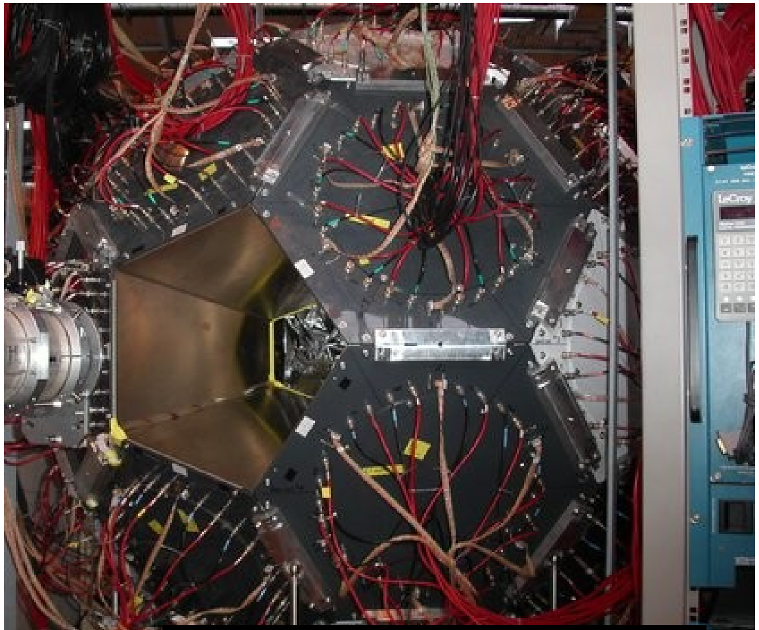


- Fermi constant: strength of the weak interaction
- Fermi constant: 1 of 3 key electroweak parameters

	G_F	α	M_Z
Now →	0.6 ppm	0.37 ppb	23 ppm

- Muon lifetime: world's most precise particle, nuclear or atomic lifetime
- PSI Beams: Only possible facility to do this research in the world
  - More than 2×10^{12} events recorded





τ(MuLan) = 2 196 980.3 ± 2.2 ps (1.0 ppm)

G_F(MuLan) = 1.166 378 8(7) x 10^{-5} GeV^{-2} (0.6 ppm)

Phys. Rev. Lett

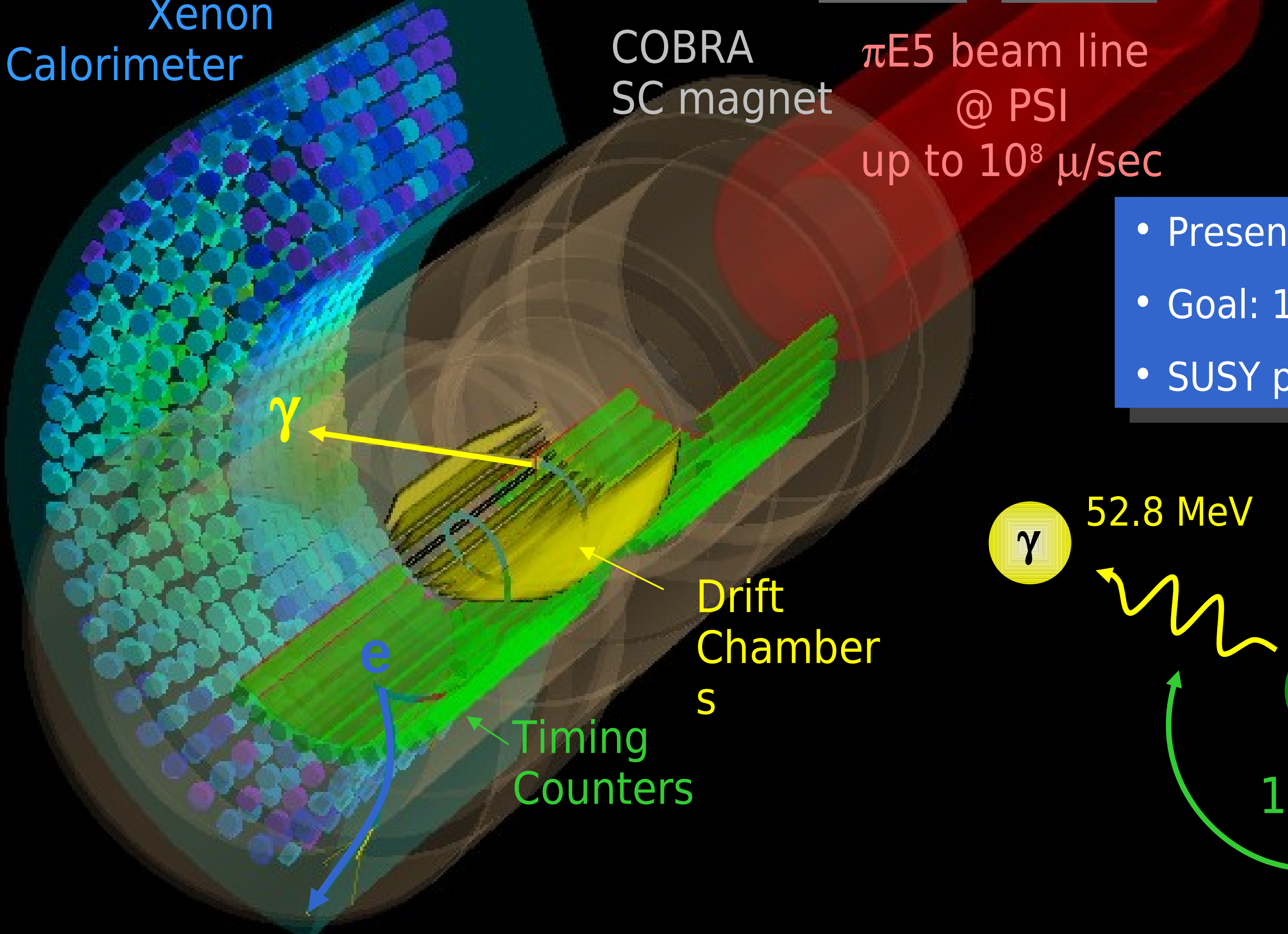
MuLan Collaboration

D. Hertzog, Univ. of Illinois

Search for μ → e γ

S. Ritt, PSI

~ 60 collaborators from



- Present limit: 1.2 x 10^{-11}
- Goal: 10^{-13}
- SUSY predictions: O(10^{-12})