Swiss Institute of Particle Physics

an Association according to Swiss law

Particle Physics Activities

Klaus Kirch, ETHZ & PSI, CHIPP

Plenary ECFA, PSI, July 19, 2012

Swiss Particle Physics Landscape in 2012

Swiss Institute of Particle Physics

an Association according to Swiss law

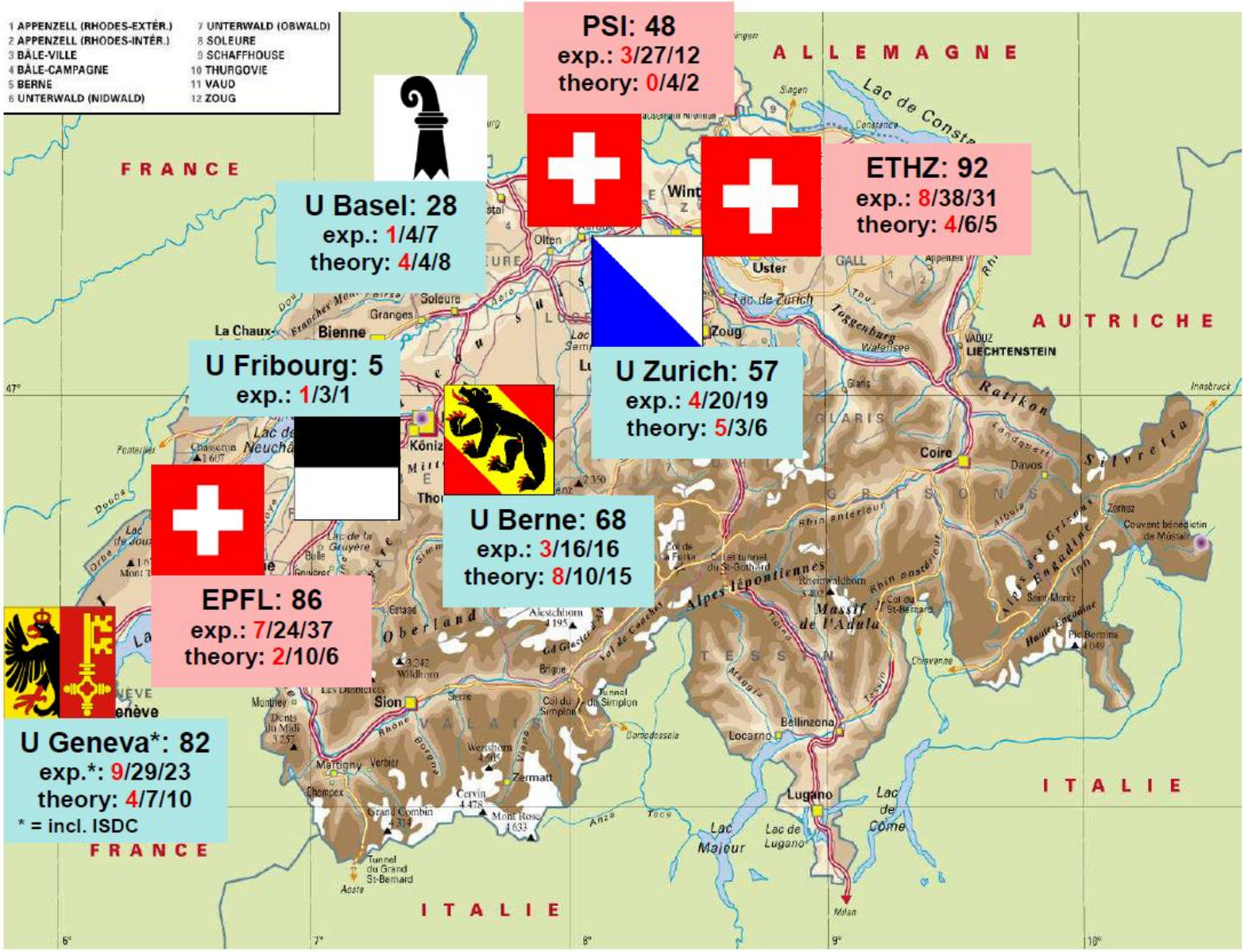
sc | nat

Member of the Swiss Academy of Sciences

Total Scientific personnel:
Total 466

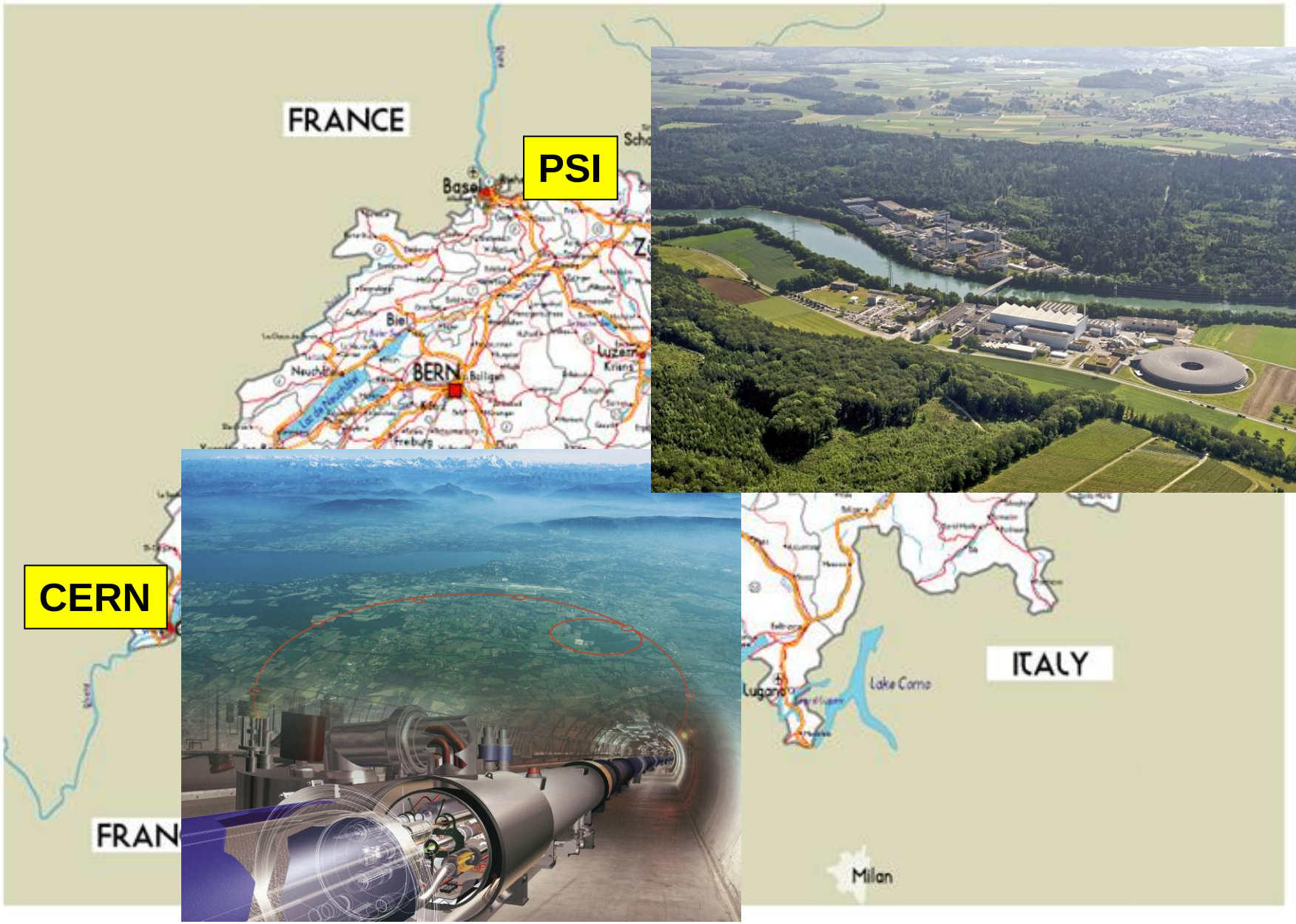
Professors / staff / PhD students
Total 63/205/198

(admin. & technical staff not included: hard to quantify)



Source: CHIPP Membership Database, 19 Jun 2012
Author: J.P. Ruder


GERMANY
FRANCE
PSI
Schaffhausen
Lake Constance
Basel
Winterthur
Sankt Gallen
Zürich
AUSTRIA
LIECHTENSTEIN
Biel
Luzern
Kriens
BERN
Lausanne
Lac Léman
CERN
Genève (Geneva)
ITALY
Lake Como
Lugano
Lake Maggiore
ITALY
FRANCE
Milan


FRANCE
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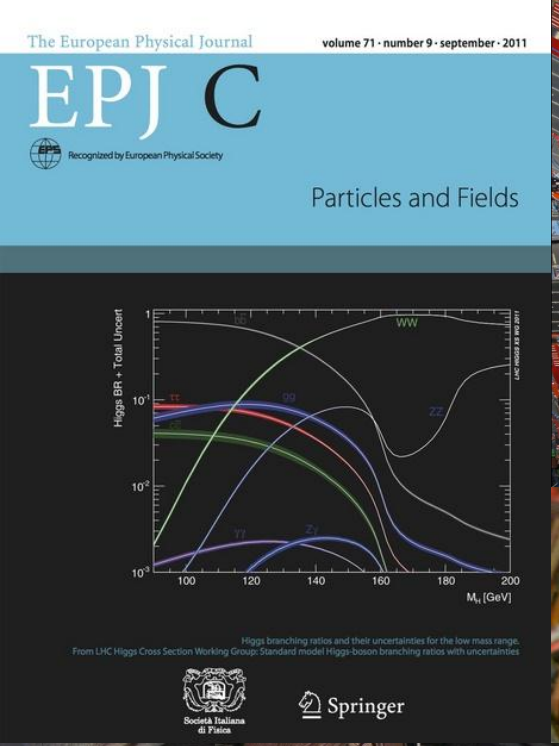
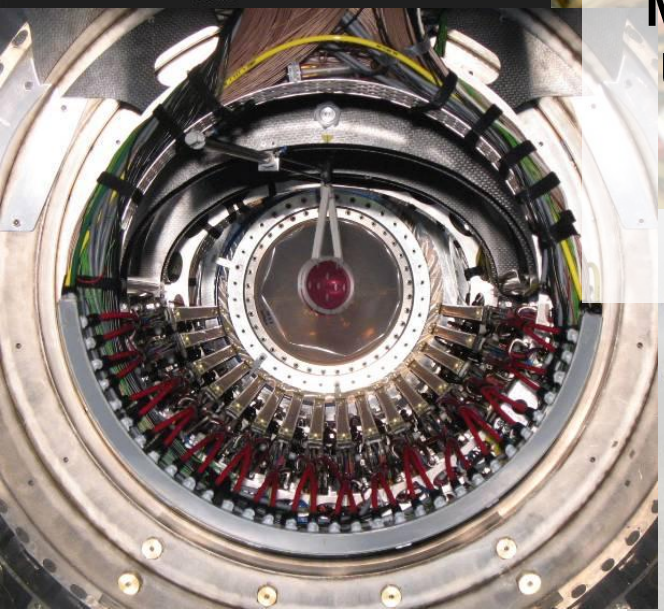
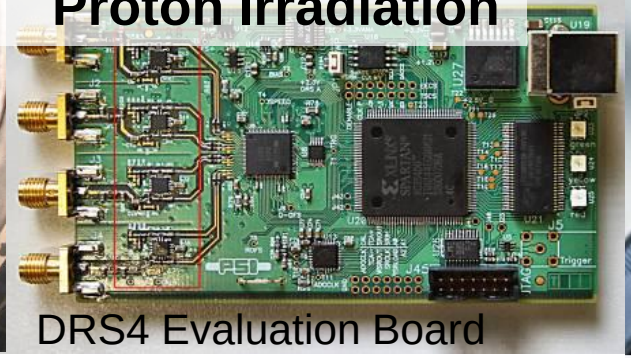


PSI Laboratory for Particle Physics:

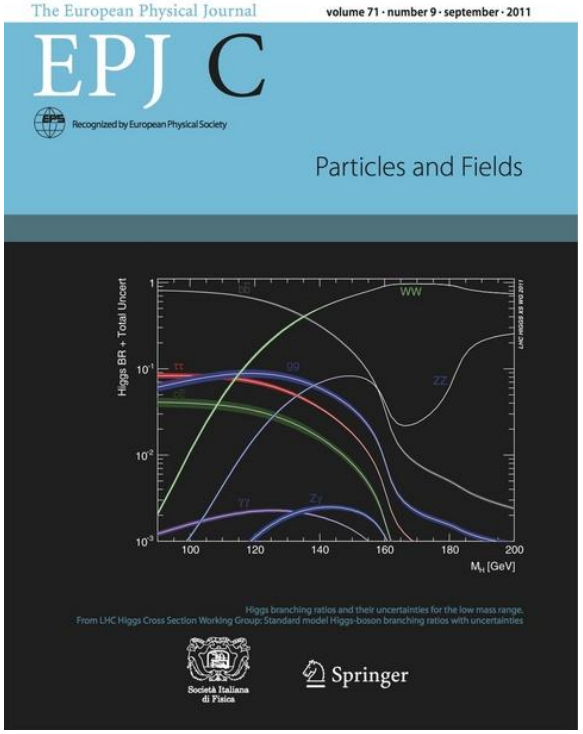
- Theory
- High Energy
- Muons
- Ultracold Neutrons
- Electronics
- Detectors
- Proton Irradiation



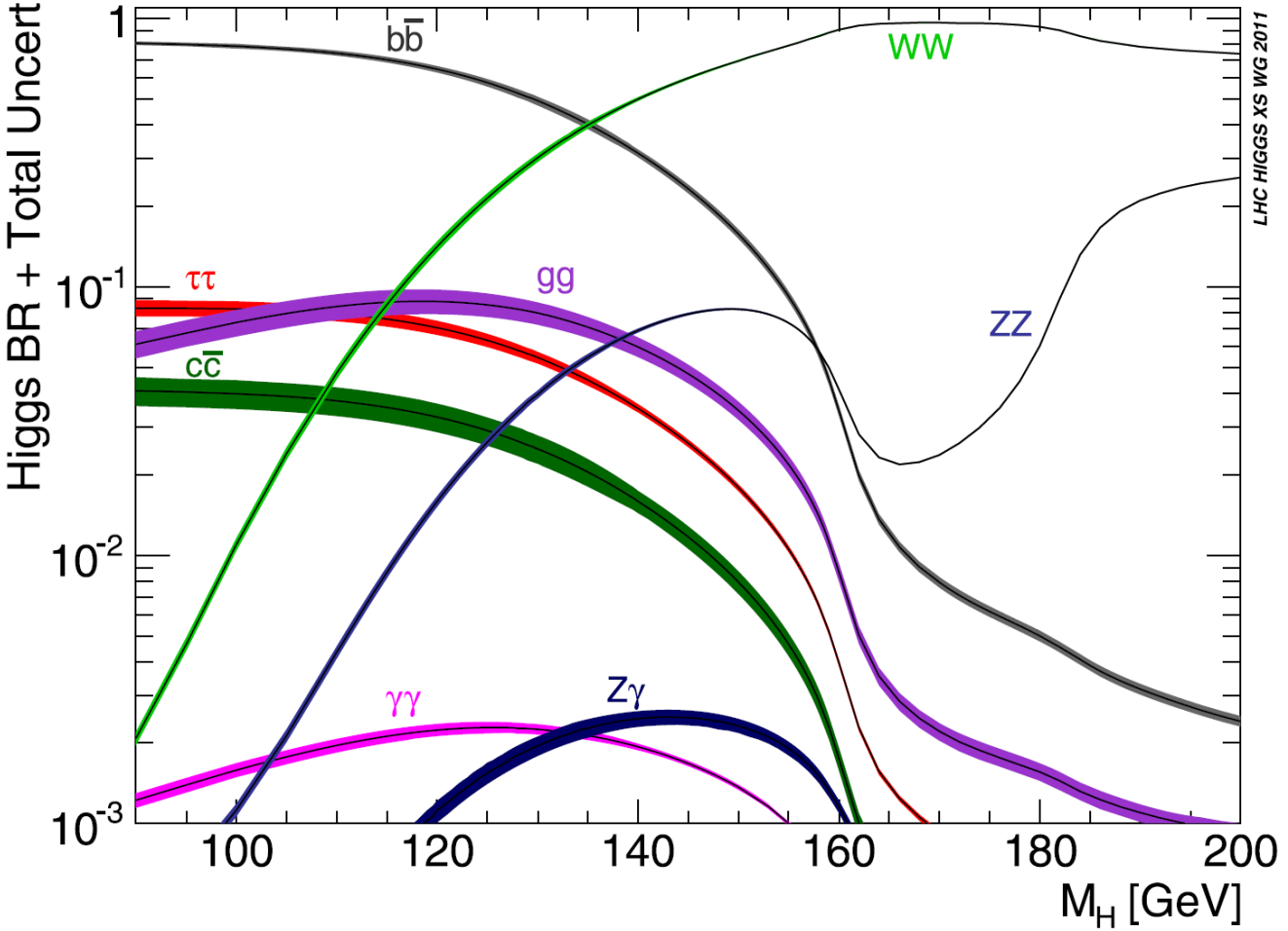


DRS4 Evaluation Board

Precision Standard Model Calculations:
One example for crucial theoretical input



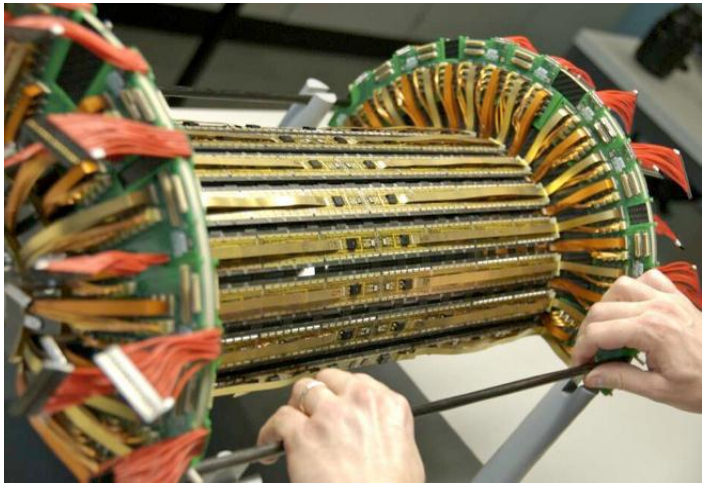
A. Denner et al., Eur. Phys. J. C71(2011)1753



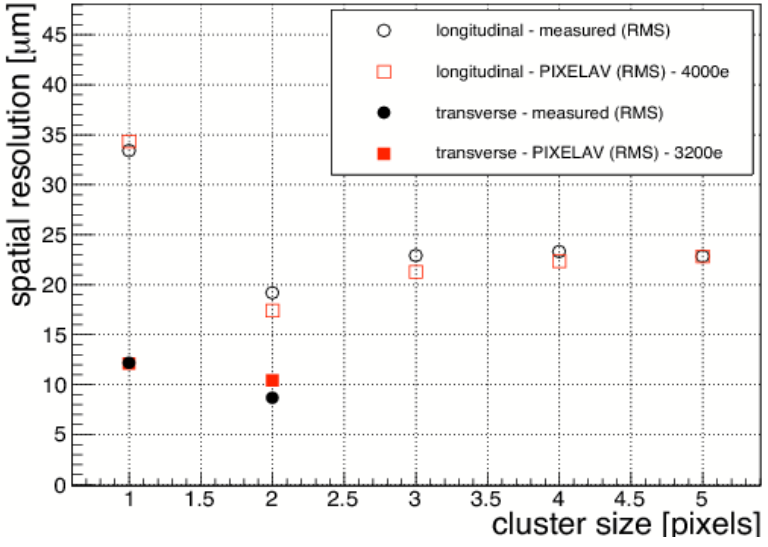
A. Denner[1,a], S. Heinemeyer[2], I. Puljak[3], D. Rebuzzi[4], M. Spira[5]

The CMS Pixel Detector at LHC/CERN

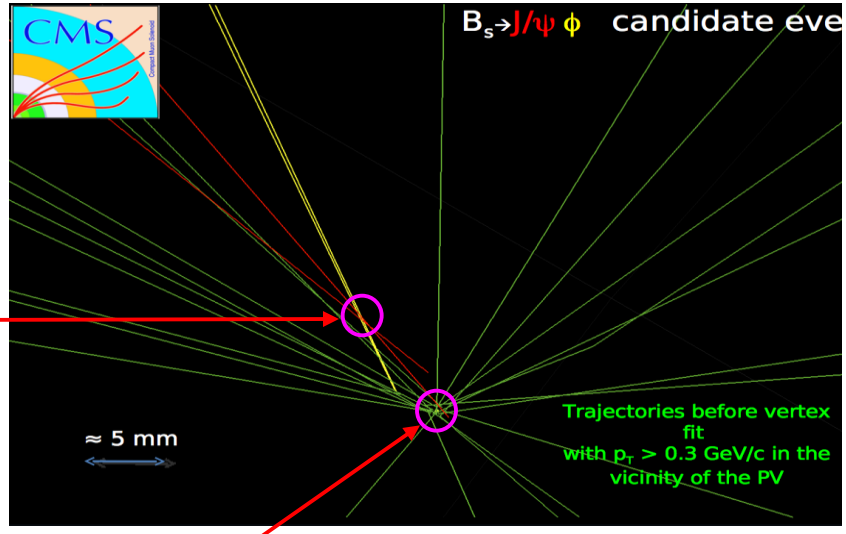
Developed and built at PSI
in collaboration with ETHZ and UZH.
48 Mpixels @ 40MHz.
Deployed in 2008.



Position resolution 10-20μm



A typical event with 2 muons (**red**) and 2 kaons (yellow) from a Bs decay. Most other particles are pions. Reconstruction based on the pixel detector.

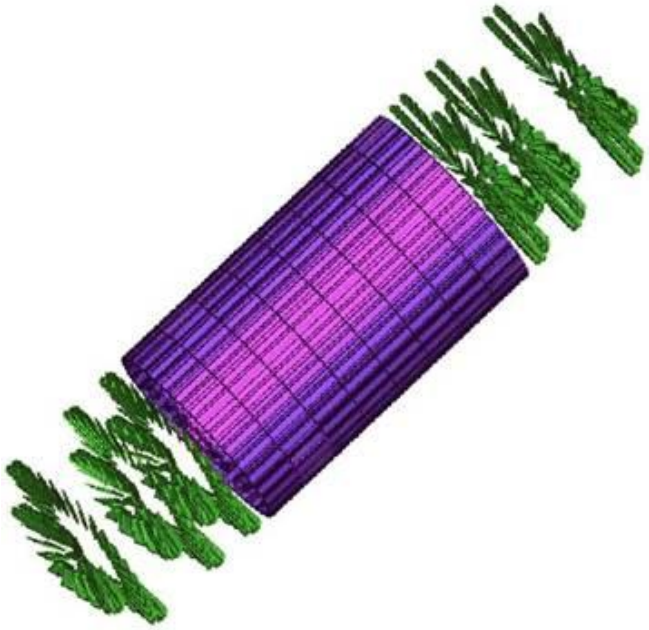


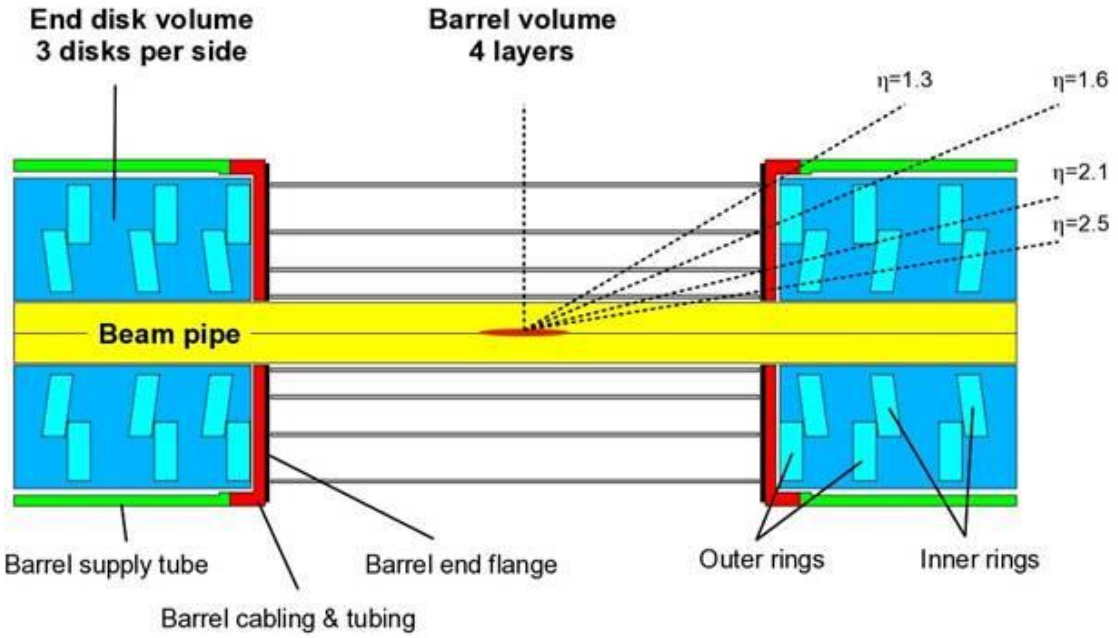
Bs decays to
2 muons and
2 kaons

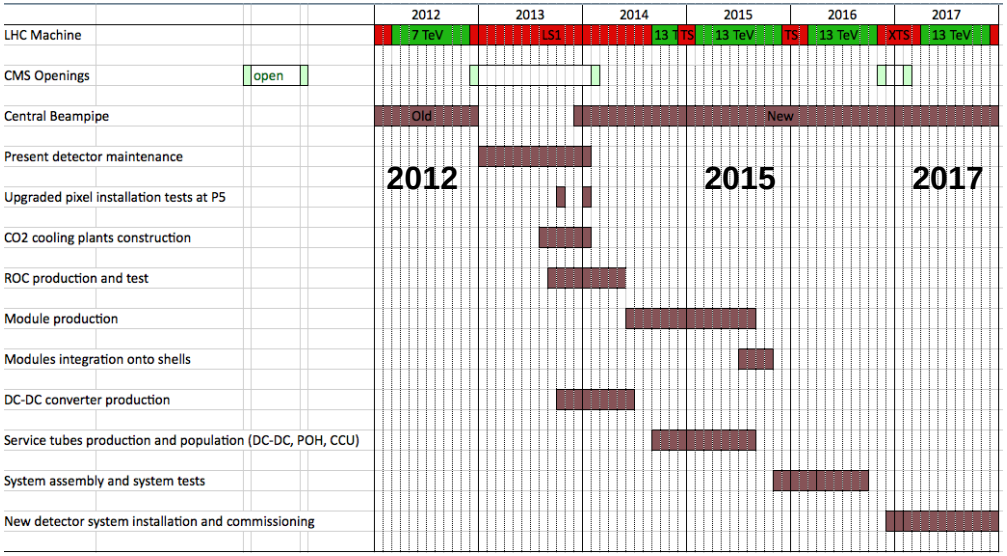
Bs production at the primary vertex

Installation of Present Pixel Detector

BPIX / FPIX Envelope Definition & Insertion into CMS







Pixel Upgrade Project under way.
4 layer barrel and 3 disks per side.
New Read Out Chip Design:
PSI46dig+ pixel rates < 600 MHz/cm²
Much reduced material budget.
CO_2 cooling.

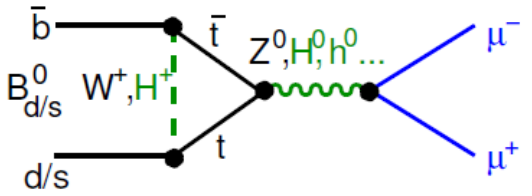
Strong Swiss consortium: PSI/ETHZ/UZH
PSI coordinated effort.

courtesy: Roland Horisberger

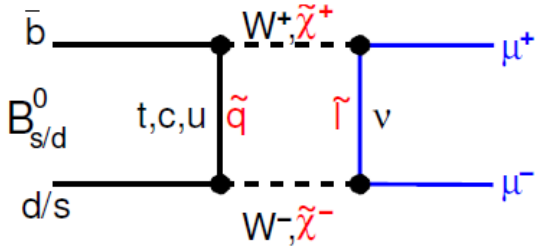
Search for $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$

- Decays highly suppressed in Standard Model (Buras 2010)
  - effective FCNC, helicity suppression
  - SM expectation:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$$



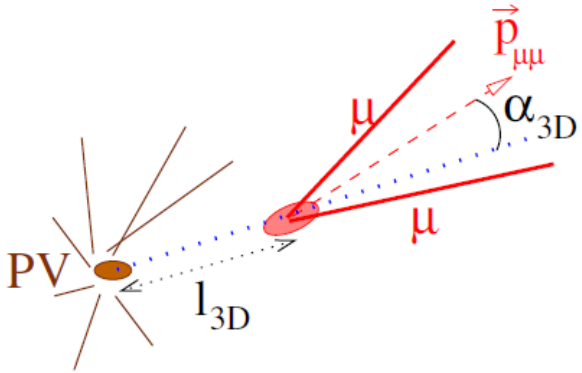
- Sensitivity to new physics
  - → extended Higgs boson sectors



- Measurement of $B_s^0 \to \mu^+\mu^-$ relative to normalization channel:

  $B^+ \to J/\psi(\to \mu^+\mu^-)K$

  (reduced systematic uncertainties)
  - Search for two muons
    with displaced, well-measured vertex
    pointing back to primary vertex
    isolated from other decay remnants



courtesy: Urs Langenegger

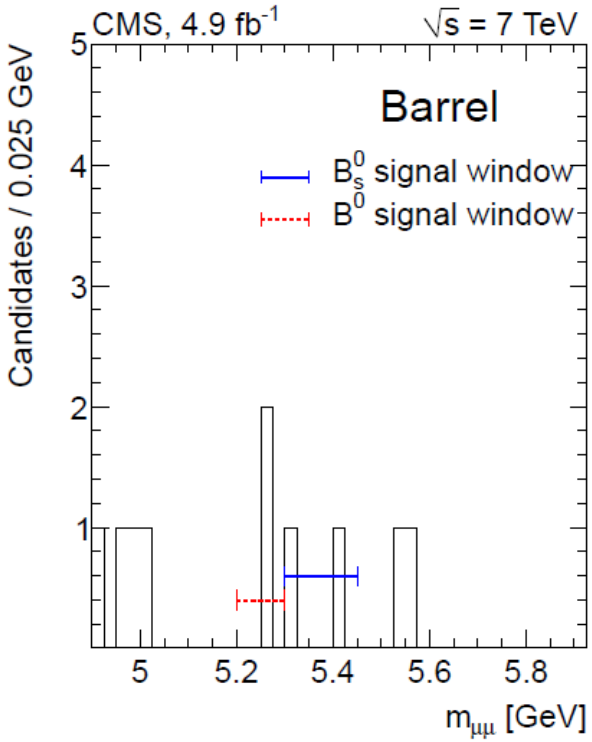
Expectations and observation

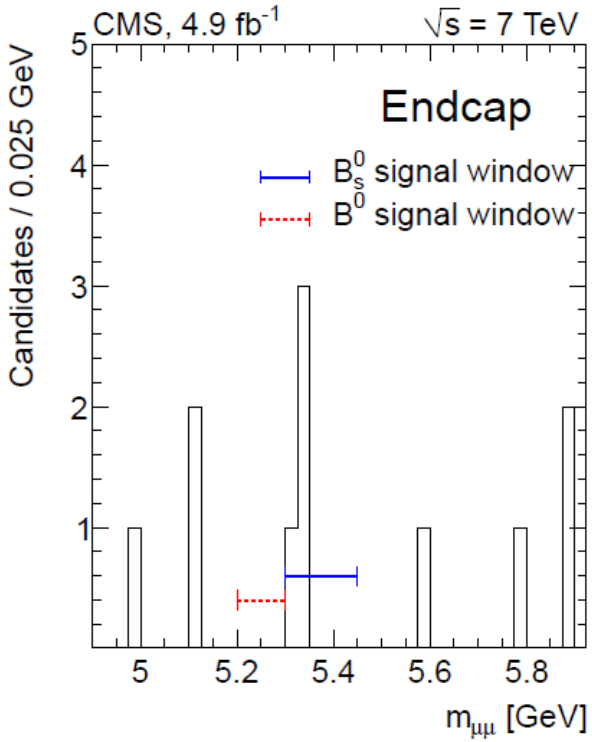
Upper limit on $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ and $\mathcal{B}(B^0 \to \mu^+\mu^-)$

upper limit (95%CL)	observed	(median) expected
$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	7.7×10^{-9}	8.4×10^{-9}
$\mathcal{B}(B^0 \to \mu^+\mu^-)$	1.8×10^{-9}	1.6×10^{-9}

SM expectation:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$$





courtesy: Urs Langenegger

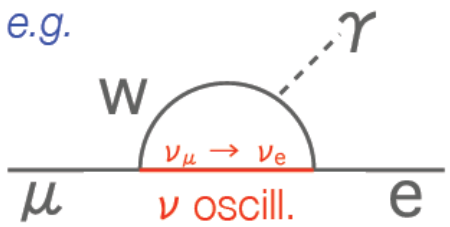
PRL 107(2011)191802, recently updated CMS with 5fb^{-1} JHEP 4(2012)33

Why charged LFV has never been observed ?

Why ? : Quark/Neutrino Flavour Mixing = ☺ / Charged LFV = ☹ ?

SM + simple ν Oscillation

- charged LFV is possible



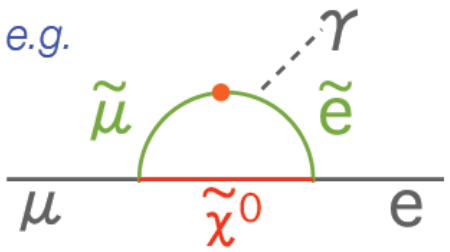
- but extremely rare

$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\sum_i \left| U^*_{\mu i} U_{ei} \frac{m^2_{\nu i}}{m^2_W} \right|^2$$

- B(μ→eγ) ≲ 10^{-57} !!!

beyond SM (SUSY-GUT *etc.*)

- charged LFV is largely enhanced



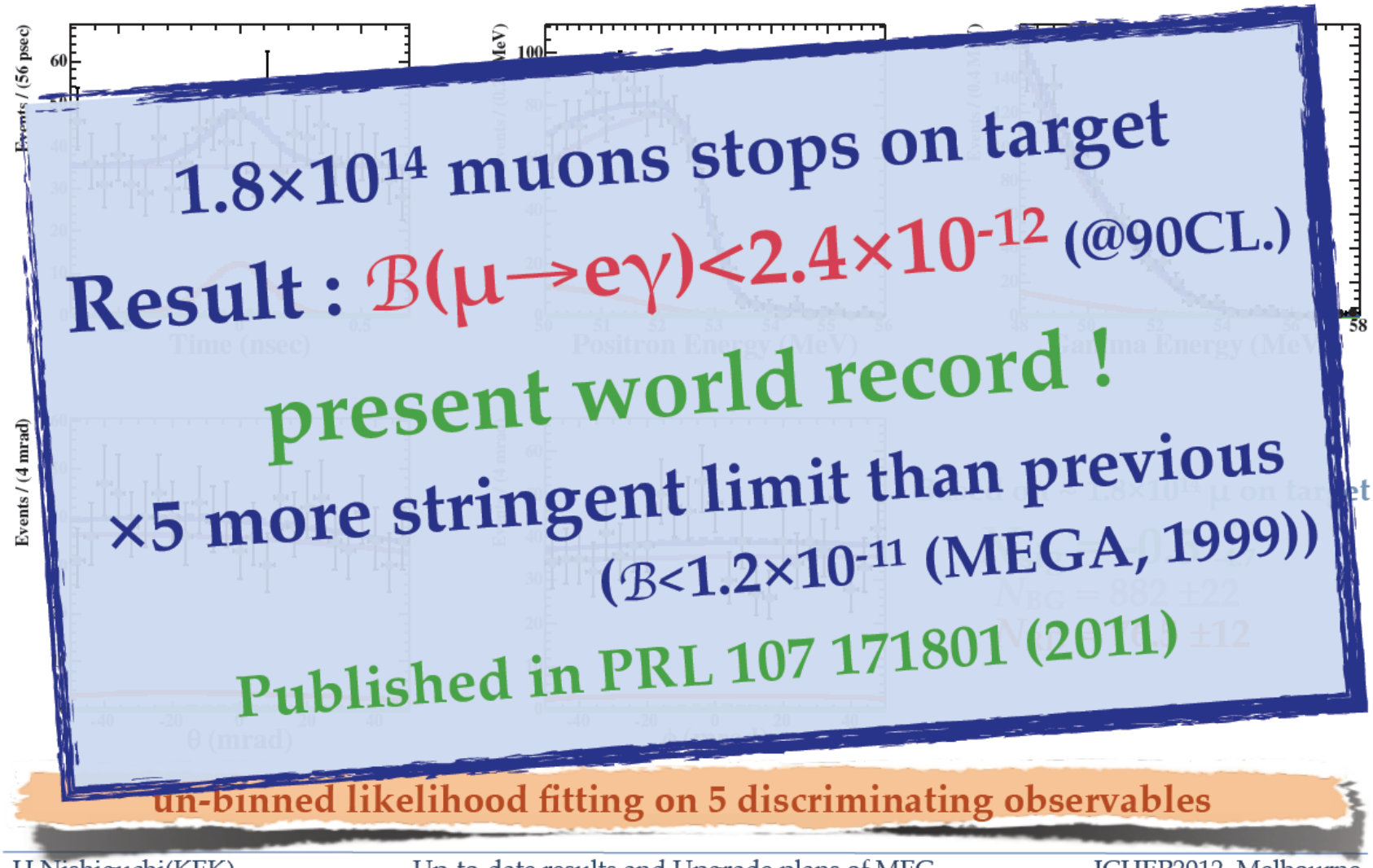
- still rare but observable level

$$\mathcal{B}(\mu \to e\gamma) \simeq \frac{\alpha^3 \pi \theta^2_{\tilde{e}\tilde{\mu}}}{G^2_F \tilde{m}^4}$$

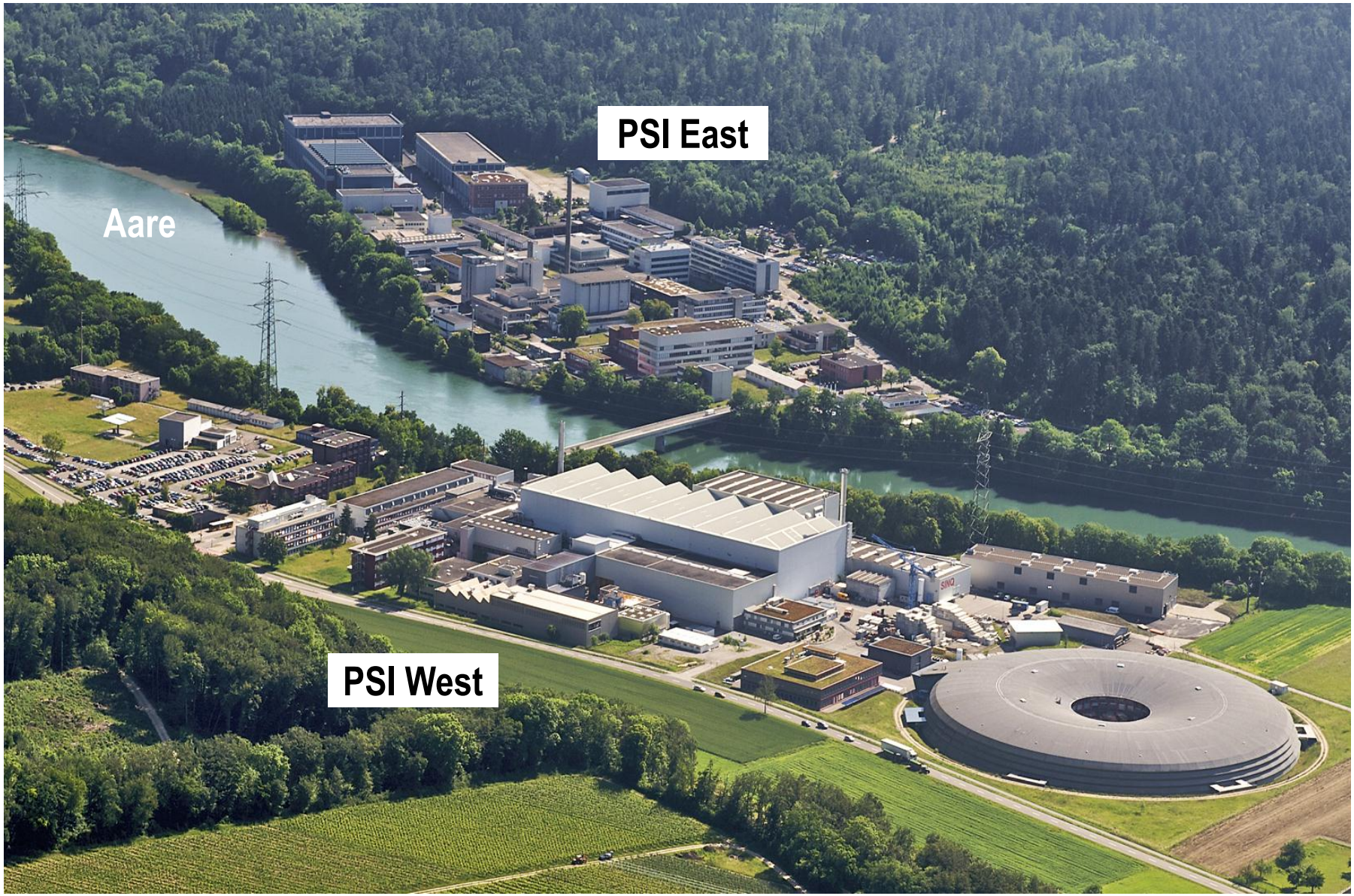
- B(μ→eγ) = 10^{-15} ~ 10^{-11} !!!

courtesy: H. Nishiguchi

Results (2009+2010)



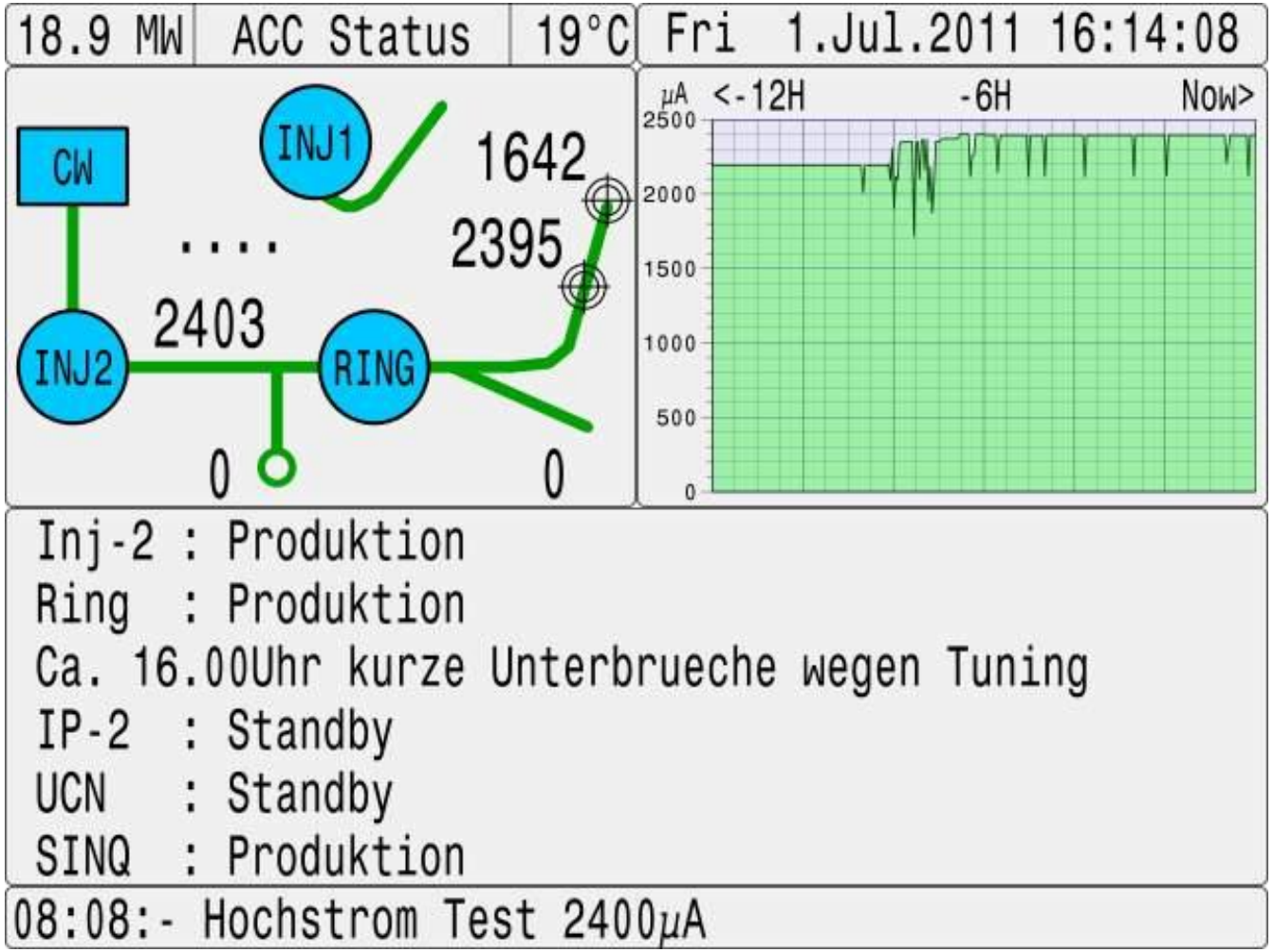
The Paul Scherrer Institut



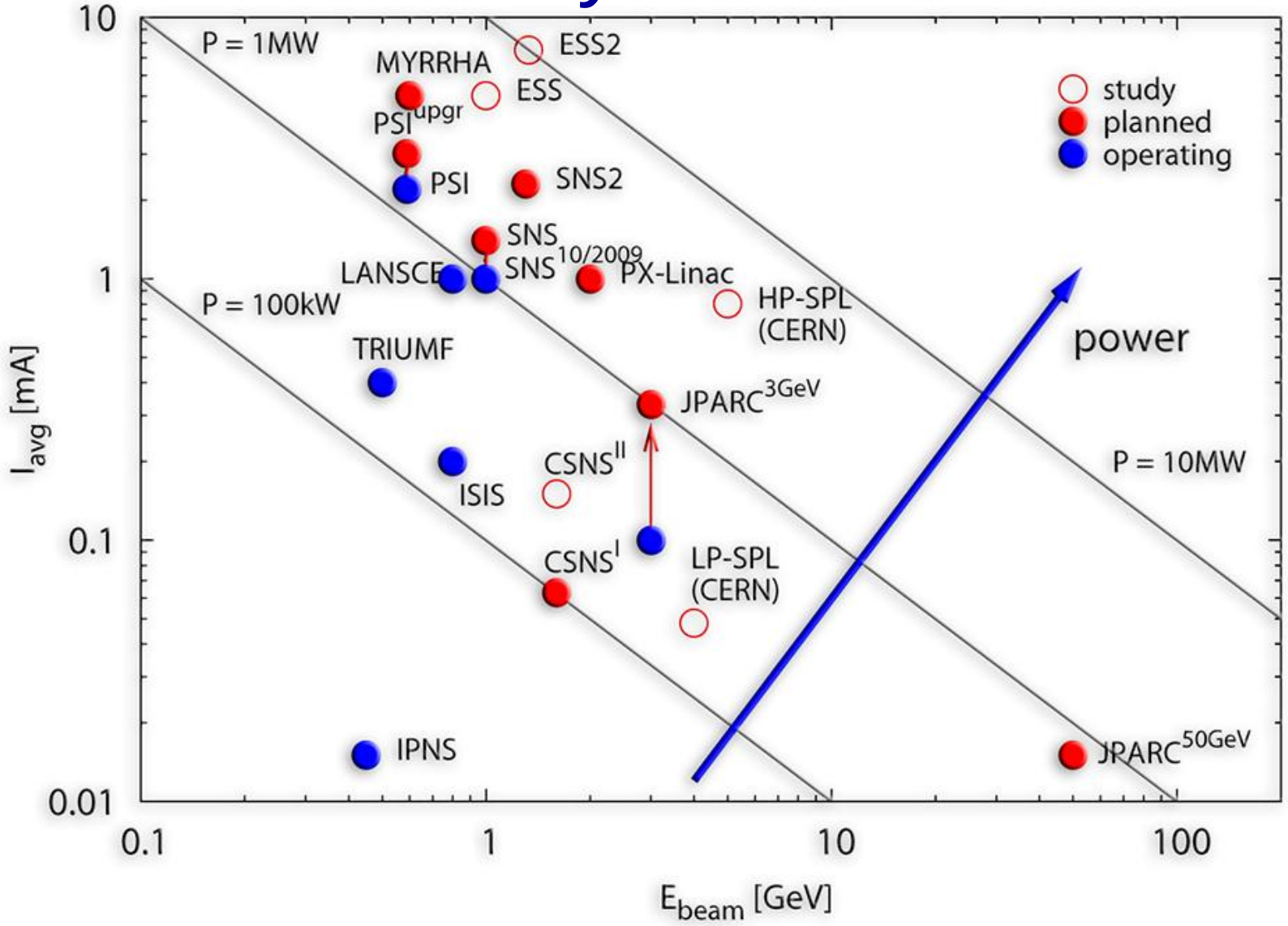
The 590 MeV Ringcyclotron at PSI

2.2 ... 2.4 mA
1.3 ... 1.4 MW

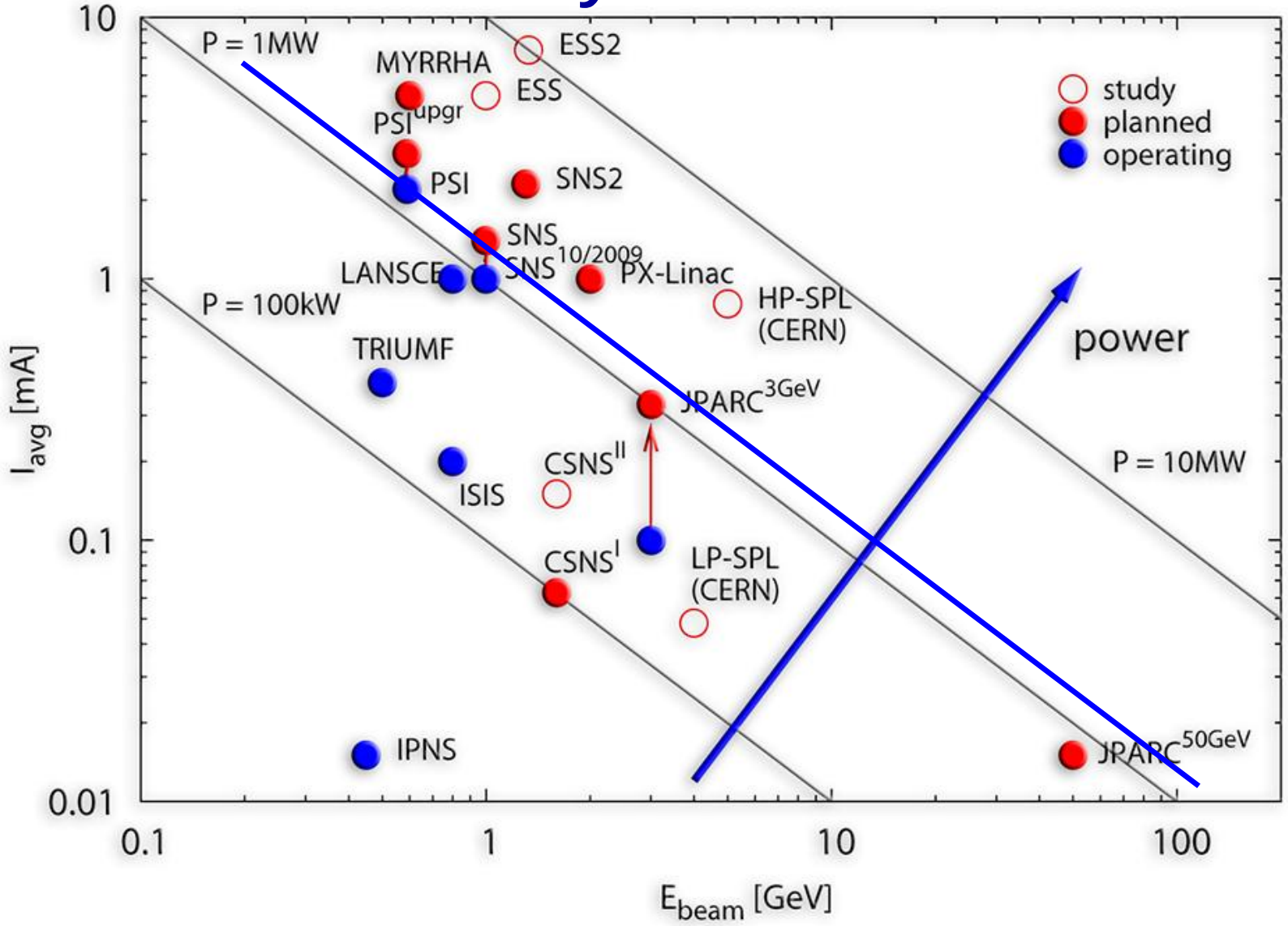
Test operation at 2.4mA
(exceeding 1.4MW)



Intensity machines



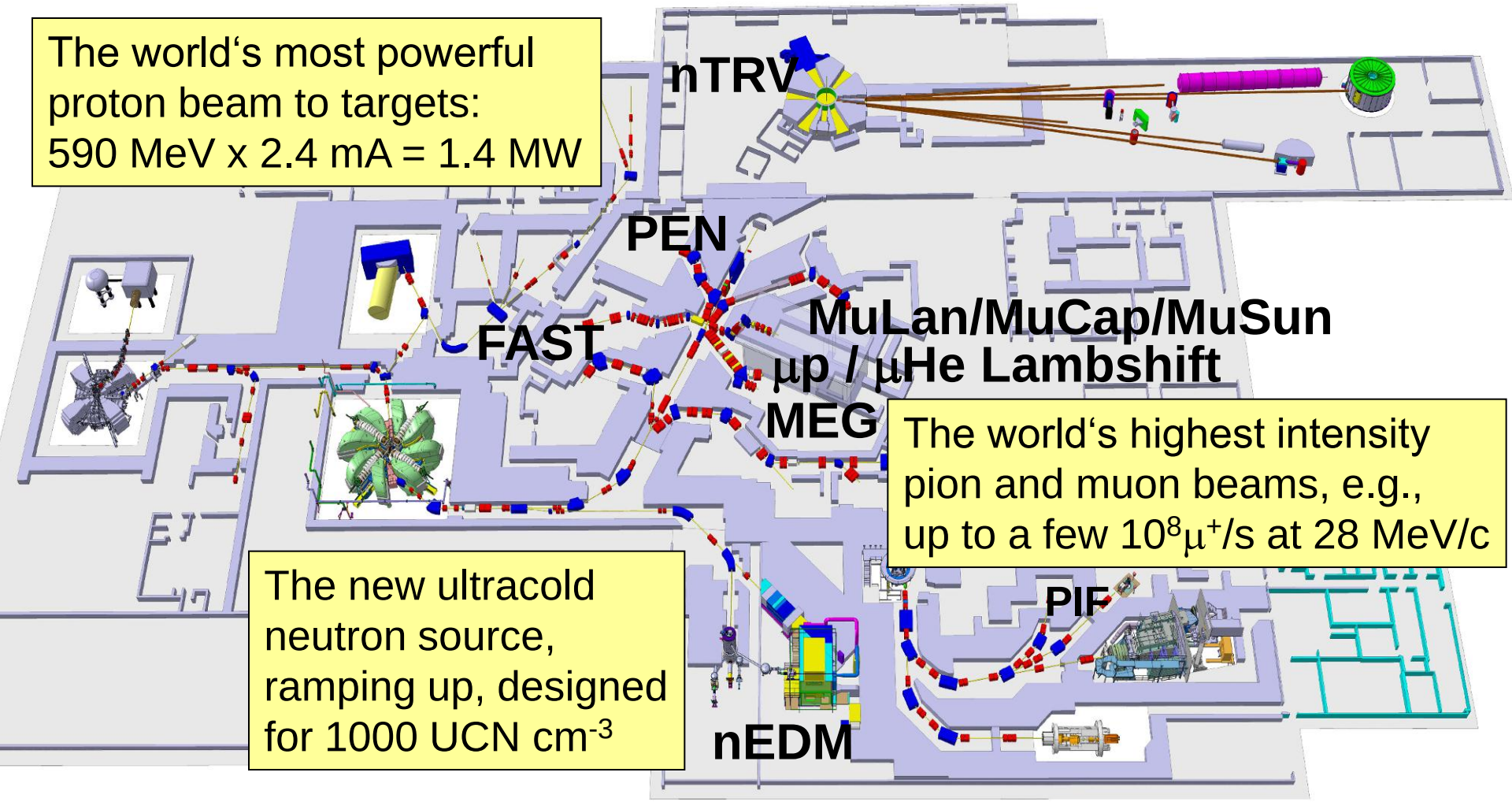
Intensity machines



The intensity frontier at PSI: π, μ, UCN

Precision experiments with **the lightest unstable particles** of their kind

The world's most powerful proton beam to targets:
590 MeV x 2.4 mA = 1.4 MW



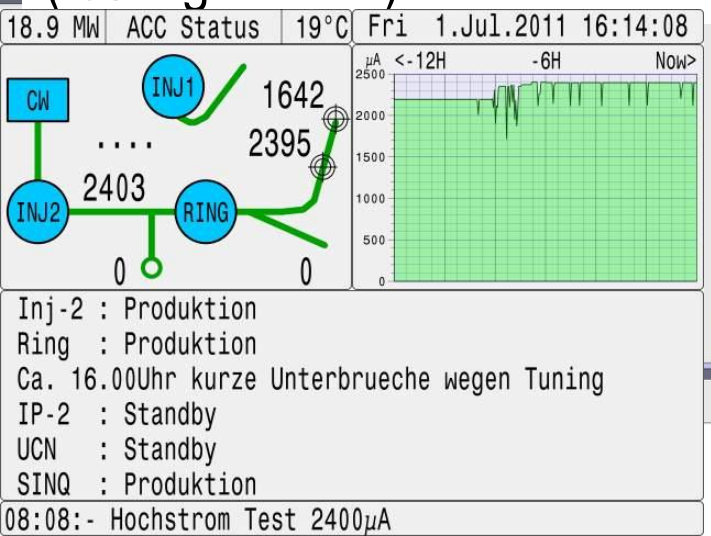
The world's highest intensity pion and muon beams, e.g., up to a few $10^8 \mu^+$/s at 28 MeV/c

The new ultracold neutron source, ramping up, designed for 1000 UCN cm^{-3}

Swiss national laboratory with strong international collaborations

High Intensity Proton accelerator & UCN Source

590 MeV Proton Cyclotron
2.2 mA Beam Current
(testing 2.4 mA)



Ultra Cold Neutron Source

Beam dump

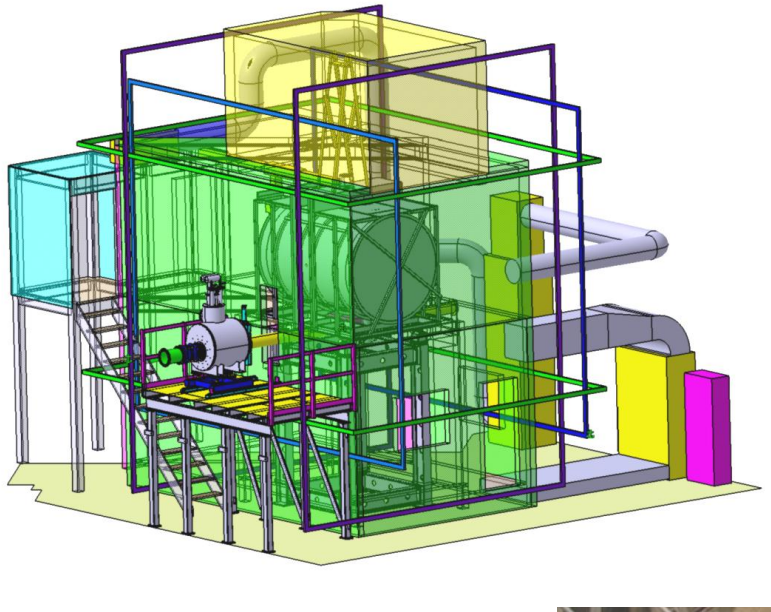
UCN-Source

Status: -1st test beam 12/2010
-Safety approval: 06/2011
-UCN delivered 08-12/2011
-Improvements in cryo-system during winter shutdown 11/12
-Optimization ongoing 03-08/2012
-Expect UCN delivery 08-12/2012

nEDM

Installing nEDM at PSI in 2009

Coming from ILL
Sussex-RAL-ILL collaboration
PRL 97 (2006) 131801



nEDM

Status: -1st test beam 12/2010
-UCN measurements 08-12/2011
-optimizing magnetic field homogeneity and stability
-optimizing Hg magnetometer performance
-optimizing Cs magnetometry
-optimizing UCN handling and measurement cycles
-expect nEDM data taking starting 08/2012

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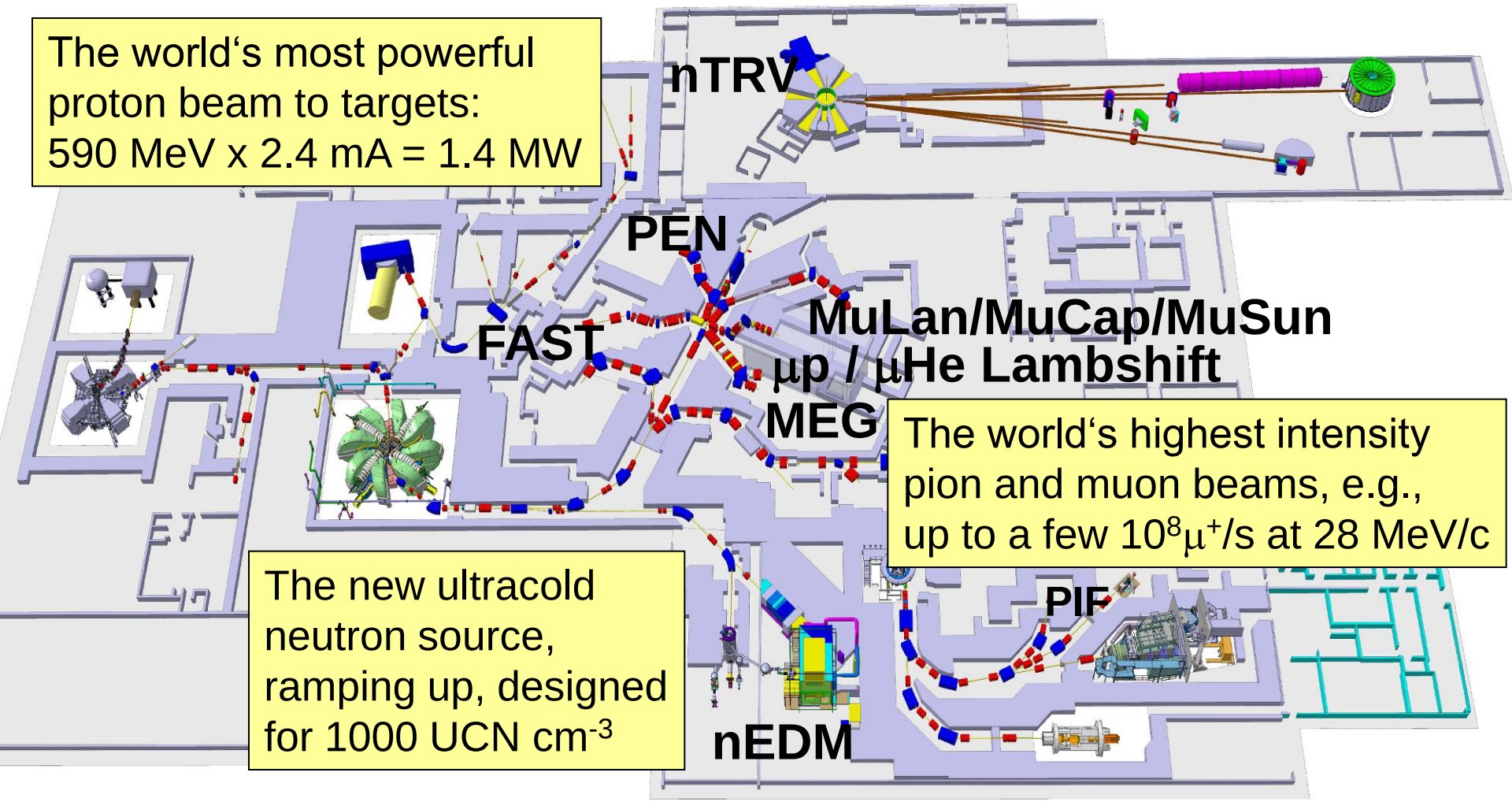
590 MeV x 2.4 mA = 1.4 MW



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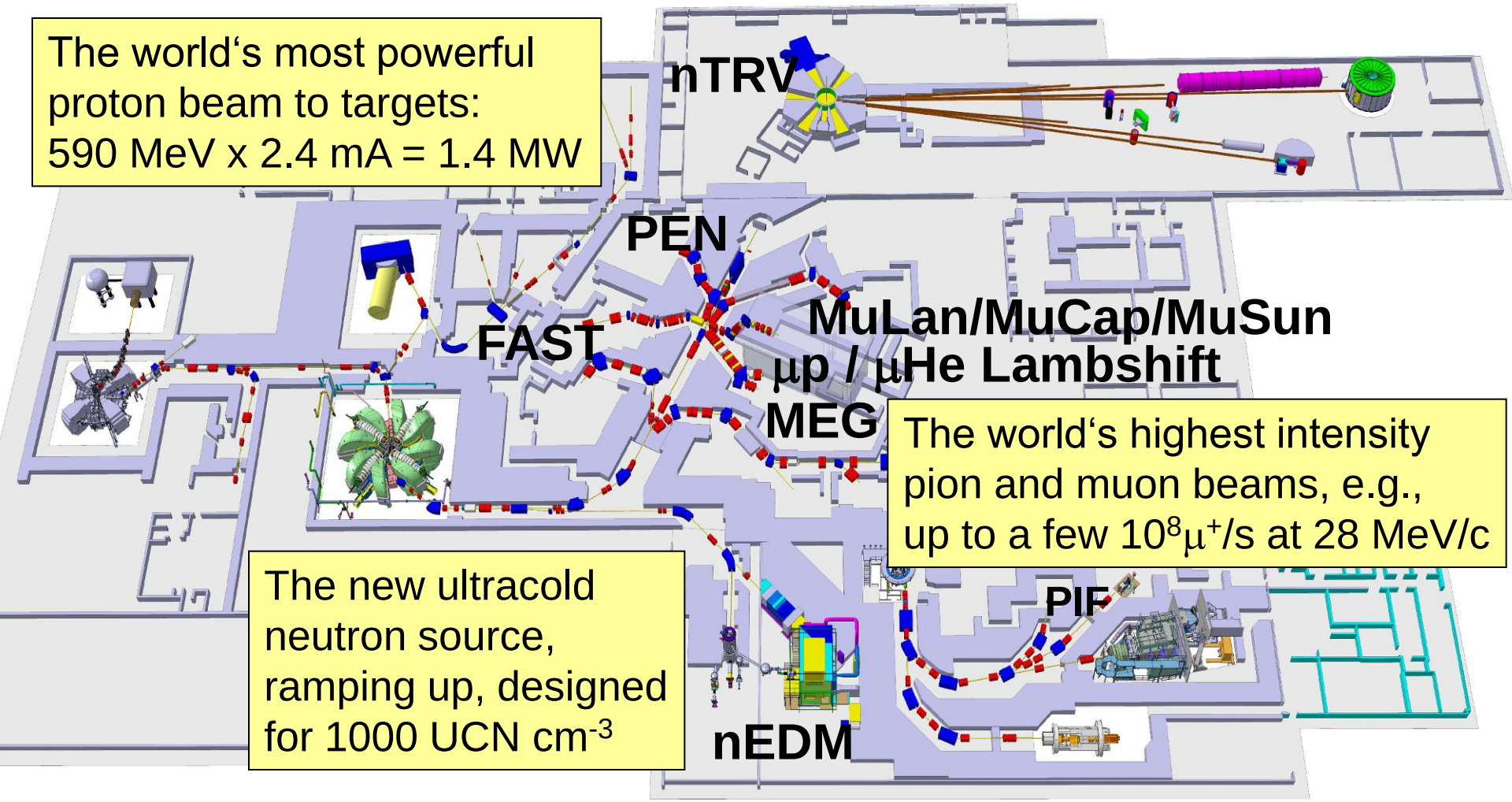

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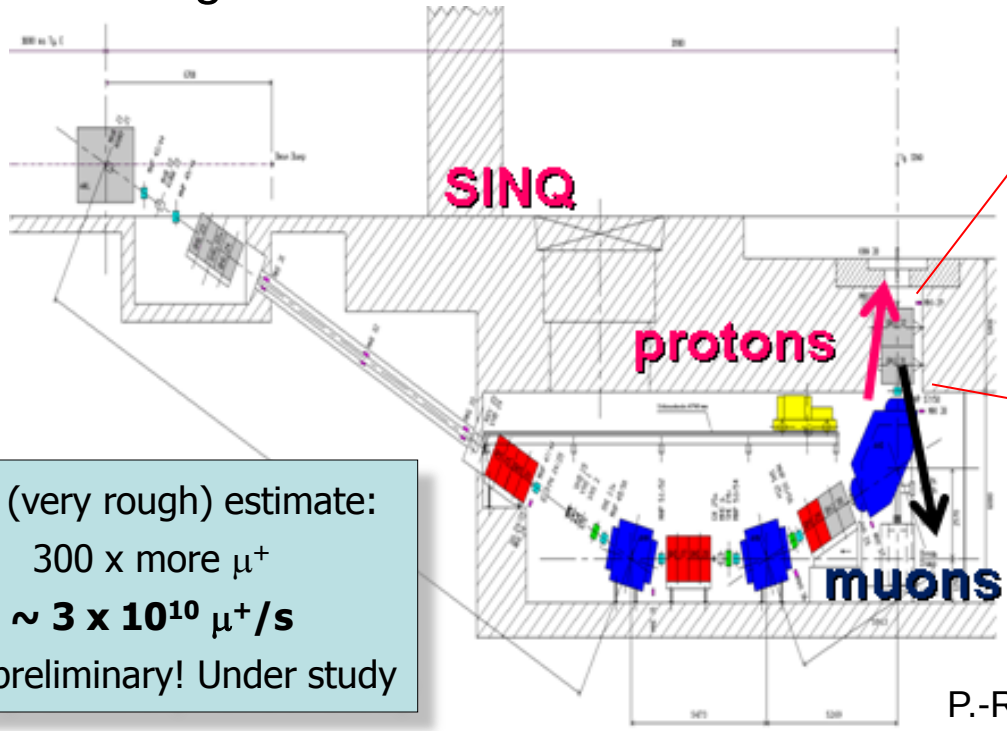
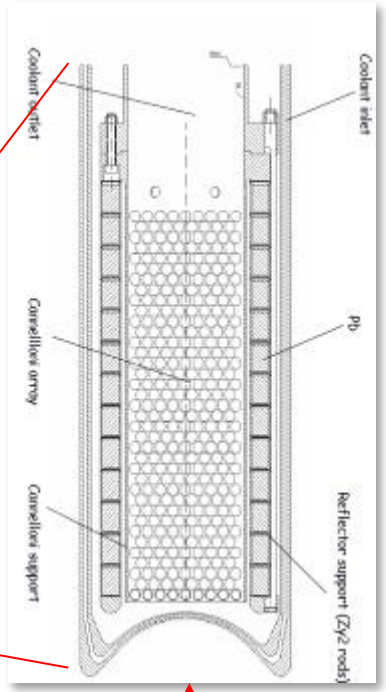
Ultra-high intensity muon beam line

- Spallation target as a muon source?
  - Larger energy range of π production exploited
  - Stopping volume substantially larger
  - Higher Z
  - Target window: surface muon source



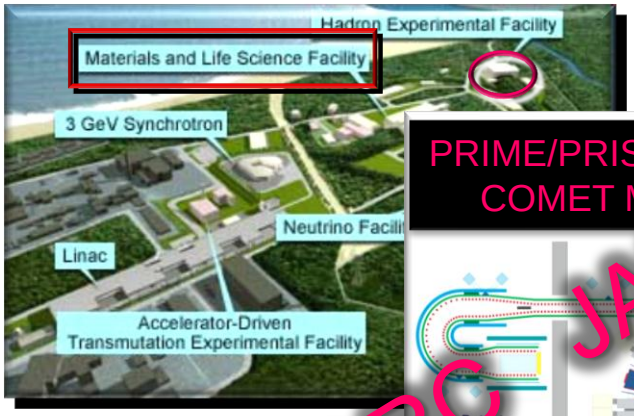


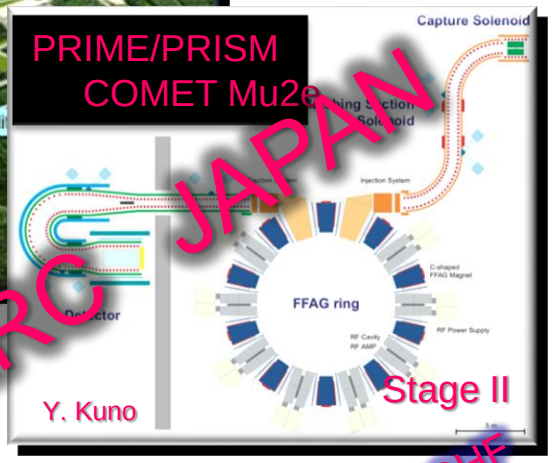
p^+

First (very rough) estimate:
300 x more μ^+
~ 3 x 10^{10} μ^+/s
Very preliminary! Under study

P.-R.Kettle, M. Wohlmuther, work in progress

Next Generation Facilities & cLFV experiments





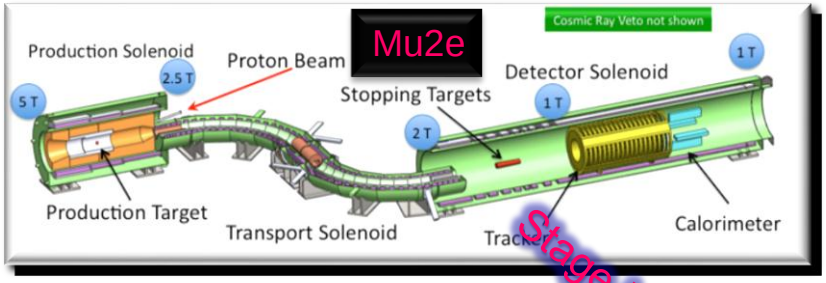
J-PARC JAPAN

Stage II

Stage I ~40MCHF

J-PARC cLFV μ→e Conversion **(Pulsed!)**
Staged Expt:
(i)COMET (2019-2020) ⇒10^{11} μ^-/s
(ii)PRIME/PRISM (>2020) $10^{11\text{-}12}$ μ^-/s

Photo c/o Fermilab and Sandbox Studio



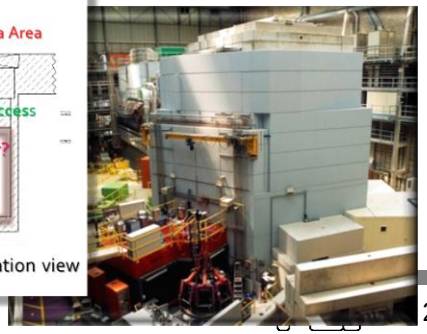
Stage I ~180 MCHF

FNAL cLFV μ→e Conversion **(Pulsed!)**
Staged Expt:
(i)Mu2e (2019-2020) ⇒$5{\cdot}10^{10}$ μ^-/s
(ii)Project X Mu2e (>2022) $2{\cdot}10^{12}$ μ^-/s

HiMB@PSI

Stage II ~10-20 MCHF

PSI CH

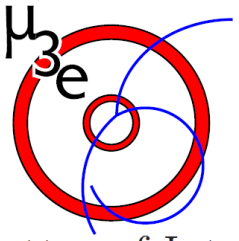


PSI cLFV μ→eγ μ→3e **(DC)**
Staged Expt:
(i)Mu3e I (2014-2017) πE5 ⇒$2{\cdot}10^{8}$ μ^+/s
(ii)Mu3e II (>2017) SINQ >10^{10} μ^+/s

courtesy: P.R. Kettle

A new search for μ→eee

- aiming in a stepwise approach at
  10^{-15} (2017) and
  10^{-16} (thereafter at HiMB)



Letter of Intent for an Experiment to Search for the Decay $\mu \to eee$

A. Blondel, A. Bravar, M. Pohl
Département de physique nucléaire et corpusculaire, Université de Genève, Genève

S. Bachmann, N. Berger, A. Schöning, D. Wiedner
Physikalisches Institut, Universität Heidelberg, Heidelberg

P. Fischer, I. Perić
Zentralinstitut für Informatik, Universität Heidelberg, Mannheim

M. Hildebrandt, P.-R. Kettle, A. Papa, S. Ritt
Paul Scherrer Institut, Villigen

G. Dissertori, Ch. Grab, R. Wallny
Eidgenössiche Technische Hochschule Zürich, Zürich

P. Robmann, U. Straumann
Universität Zürich, Zürich

We propose an experiment (*Mu3e*) to search for the lepton flavour violating (LFV) decay $\mu^+ \to e^+e^-e^+$. We aim for a sensitivity of one in 10^{16} μ-decays, four orders of magnitude better than previous searches. This sensitivity is made possible by exploiting modern tracking detectors based on monolithic active pixel sensors providing high spatial resolution and hodoscopes using scintillating fibres and tiles providing precise timing information at high particle rates.

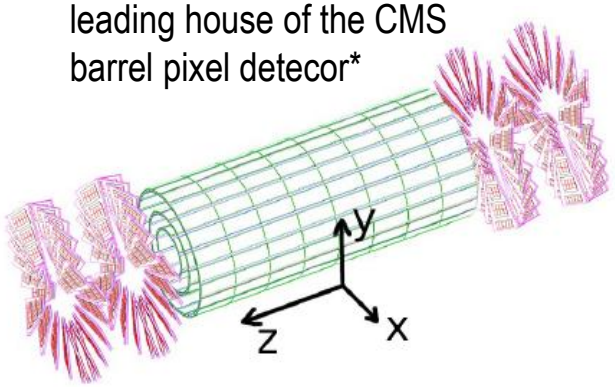
Existing beamlines available at PSI providing rates of order 10^8 muons per second would allow one to test the decay $\mu^+ \to e^+e^-e^+$ in one of 10^{15} muon decays. Upgrades to increase the intensities of the existing muon beams and the installation of a new beamline are currently under discussion at PSI. Upgrades providing muon intensities in excess of 10^9 muons per second are required to reach the aimed sensitivity of $\mathrm{B}(\mu^+ \to e^+e^-e^+) \sim 10^{-16}$.

January 23rd, 2012

The high energy frontier: PSI involved in LHC physics

Si pixel detector

- PSI High Energy Physics: leading house of the CMS barrel pixel detecor*



Pixel detector

- 3 barrel layers and 2×2 endcap disks
- $100 \times 150\,\mu$m pixel size
- analog pulse-height readout
- 66 million pixels (97% working)
- $2500\,e^-$ threshold
- $\approx 3200\,e^-$ in-time threshold

Measured resolutions in data

- impact parameter ($p_\perp > 10$ GeV)

$$\begin{aligned} \delta(r\phi) &= 25\,\mu\text{m} \\ \delta(z) &= 45\,\mu\text{m} \end{aligned}$$

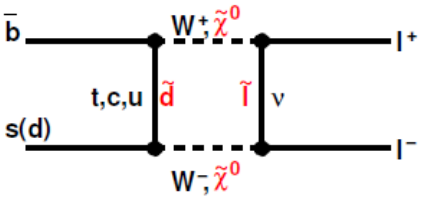
- hit resolution

$$\begin{aligned} \delta(r\phi) &= (11.2 \pm 0.1)\,\mu\text{m} \\ \delta(z) &= (26.8 \pm 0.1)\,\mu\text{m} \end{aligned}$$

Physics Analysis

- PSI lead analysis searching for the rare decay

$$B_s^0 \to \mu^+\mu^-$$



- SM expectation:

$$\begin{aligned} \mathcal{B}(B_s^0 \to \mu^+\mu^-) &= (3.2 \pm 0.2) \times 10^{-9} \\ \mathcal{B}(B^0 \to \mu^+\mu^-) &= (1.0 \pm 0.1) \times 10^{-10} \end{aligned}$$

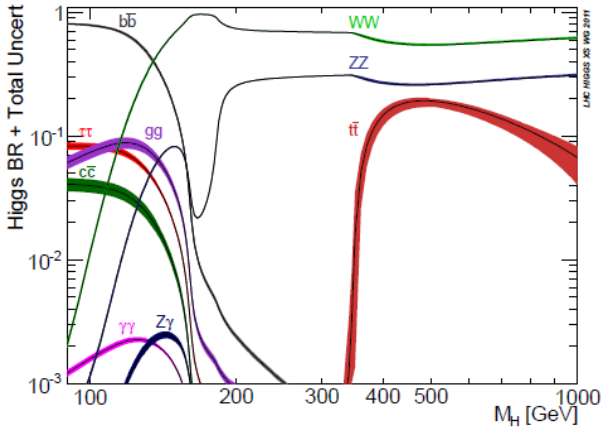
- limits at 95% CL

$$\begin{aligned} \mathcal{B}(B_s^0 \to \mu^+\mu^-) &< 7.7 \times 10^{-9} \\ \mathcal{B}(B^0 \to \mu^+\mu^-) &< 1.8 \times 10^{-9} \end{aligned}$$

PRL 107(2011)191802, recently updated CMS with 5fb^{-1} JHEP 4(2012)33

Collider phenomenology

- PSI particle theory with many established contacts to the experiments. Relevant, e.g. in recent work of the LHC Higgs Cross Section Working Group



- A. Denner, S. Heinemeyer, I. Puljak, D. Rebuzzi, and M. Spira
- Standard Model Higgs-Boson Branching Ratios with Uncertainties

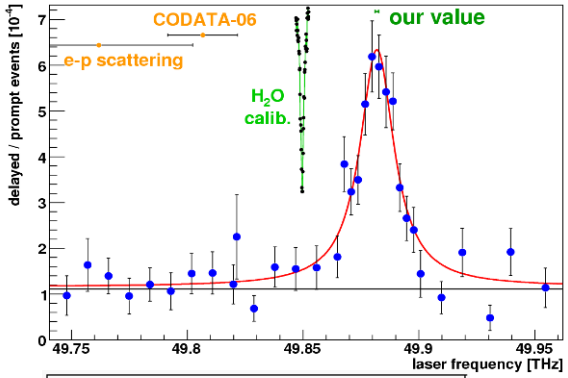
A. Denner et al., Eur. Phys. J. C71(2011)1753

* also key in CMS pixel upgrade

Recent results from particle physics at PSI

Bound state QED

The most precise value of the **proton charge radius** via a measurement of the Lambshift in muonic hydrogen



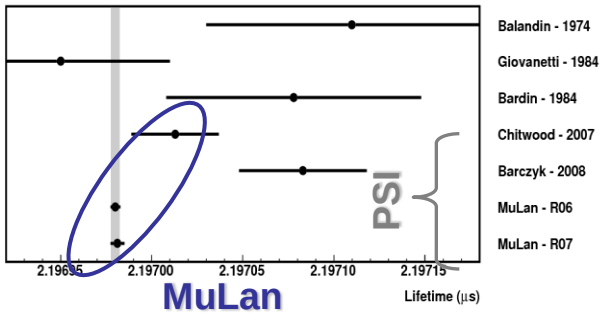
$r_p = 0.84184(67)$ fm

muhy.web.psi.ch

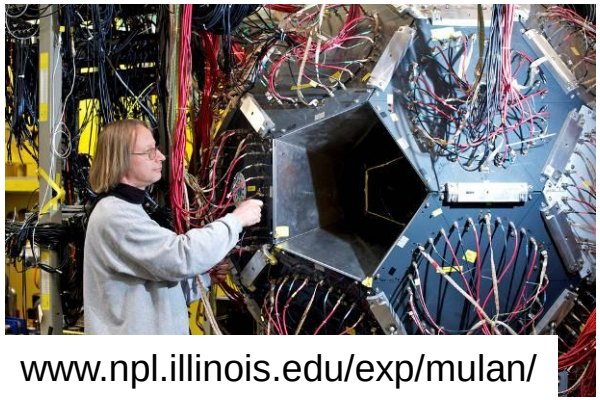
R. Pohl et al., Nature 466 (2010) 213

Weak interaction

The most precise measurement of any lifetime: the muon's and a 0.6 ppm determination of the **Fermi coupling constant**



τ = 2 196 980.3 ± 2.2 ps (1.0 ppm)

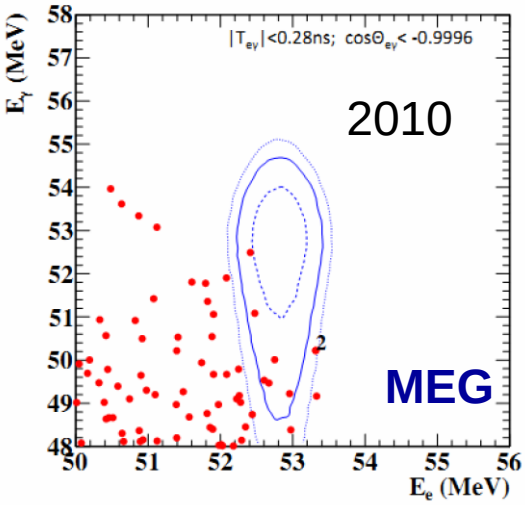


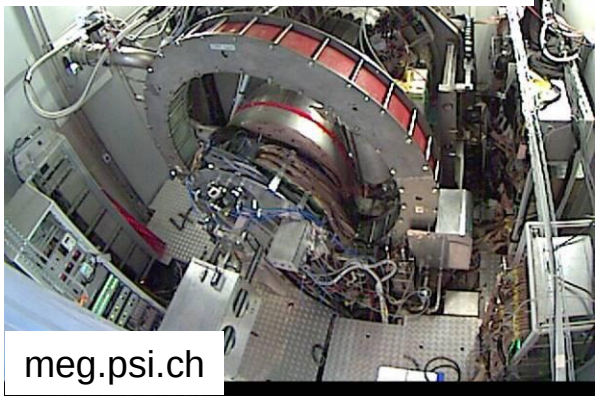
www.npl.illinois.edu/exp/mulan/

D.M. Webber et al., PRL 106(2011)041803

New physics search

The best rare decay limit:
A new **search for μ→eγ** yields a branching less than 2.4×10^{-12}





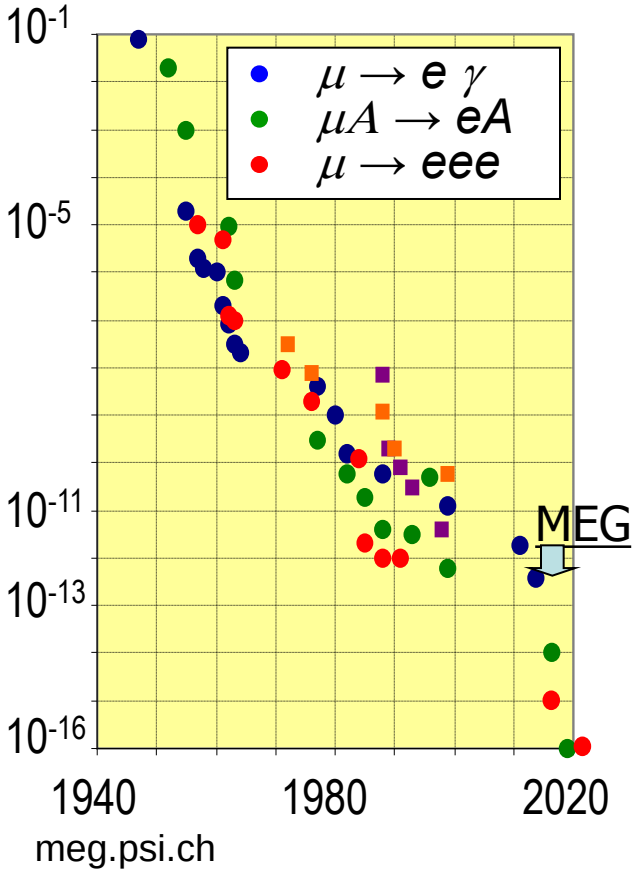
meg.psi.ch

J. Adam et al., PRL 107(2011)171801

Present flagship experiments

MEG

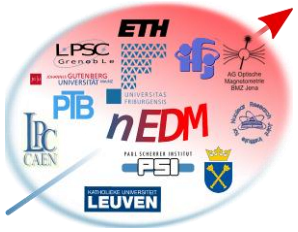
Search for μ→eg aiming at a sensitivity of a 6×10^{-13} over the next couple of years & upgrade plans thereafter

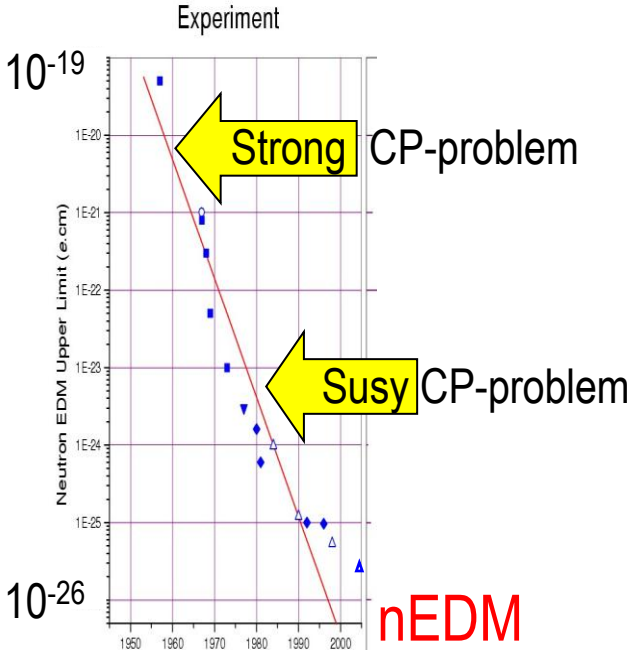


meg.psi.ch

nEDM

Aiming at a sensitivity (95%CL) of 5×10^{-27} *e*cm in 2-3 years on the **neutron electric dipole moment**





nedm.web.psi.ch

Precision measurements & New physics searches

Recently completed with final analysis:

- MuLan (muon lifetime)
- πp (pionic hydrogen spectroscopy)
- nTRV (time reversal violation in n deca

Completed, first results available:

- FAST (muon lifetime)
- MuCap (muon capture on proton)
- PEN (π→eν branching fraction)
- μp-Lambshift (proton charge radius)

Running, first results available:

- MEG (μ→eγ search)

Running, starting up, in preparation:

- nEDM (neutron electric dipole moment
- MuSun (muon capture on deuteron)
- μHe-Lambshift (helium charge radius)

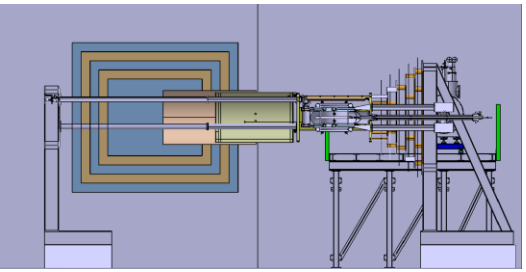
Conceptual phase or letter of intent:

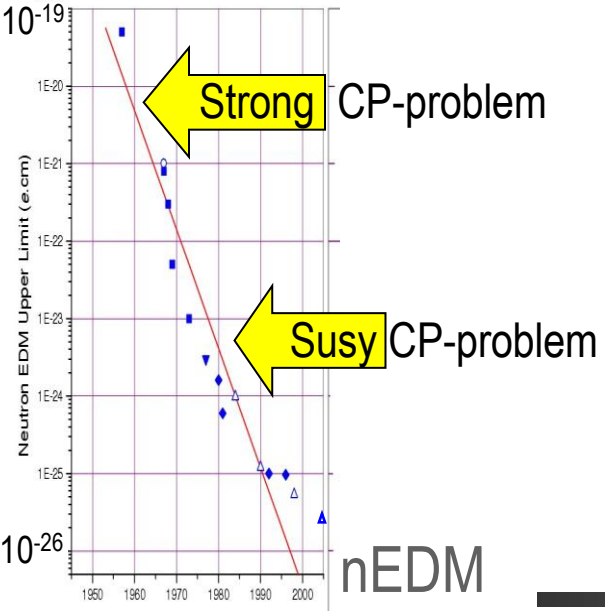
- n2EDM (neutron electric dipole momer
- μ→3e
- neutron lifetime
- Muonium spectroscopy

Projects in preparation and R&D at PSI

n2EDM

Aiming at a sensitivity (95%CL) of 5x10 $^{-28}$ ecm on the **neutron electric dipole moment**

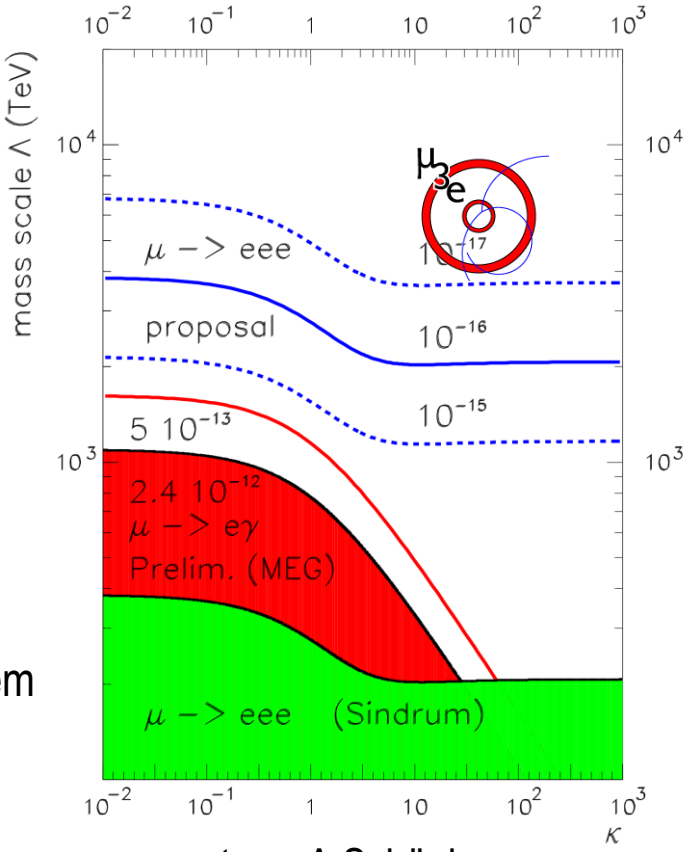




nedm.web.psi.ch

μ→eee

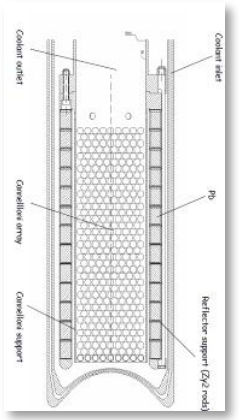
Search for μ→eee aiming at a sensitivity 10 $^{-15}$ to 10 $^{-16}$



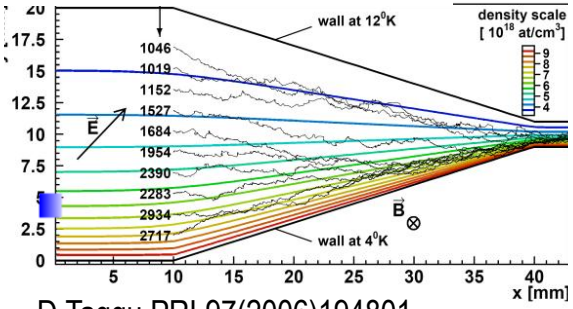
courtesy: A.Schöning

muon beam R&D

High intensity beamline exceeding 10 ^{9} μ^{+} /s e.g. SINQ spallation target window as a surface muon source? (P.R.Kettle, M.Wohlmuther, work in progress)



Brilliant μ^{+} beam with orders of magnitude improved phase space compressing stopped μ^{+}



D.Taqqu,PRL97(2006)194801

Coming up 19-25 Aug. 2012 :
The PSI Zuoz school (21!) on Particle Physics:
„Closing in on the Standard Model“

2010: „Gearing up for LHC Physics“
The 20th Zuoz school on Particle Physics

PSI2013

3rd Workshop on the

Physics of Fundamental Symmetries and Interactions

at low energies and the precision frontier

Sept. 9-12, 2013

Paul Scherrer Institute, Switzerland

psi2013.web.psi.ch

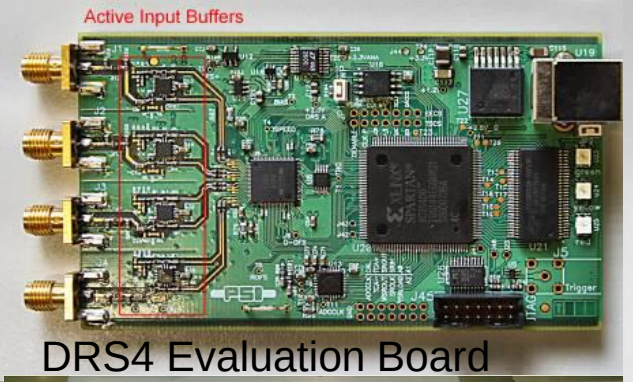
Welcome to PSI and Thank you for your attention

- I wish you a pleasant stay at PSI
- and a fruitful meeting
- Fr afternoon we offer a facility tour

Particle Physics applications and spin-offs

for PSI, for CH, and for use world wide

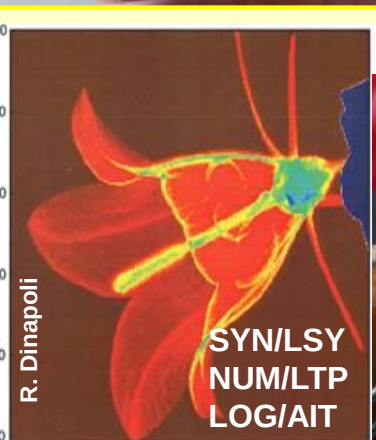
- Detector and DAQ
- xray detection, www.dectris.
- DRS-4, drs.web.psi.ch
- elog, Midas
- MSCB, SCS-2000
- thin wires, point welding
- thin foils, stretching, glueir
- thinnest foils
- carbo-copper

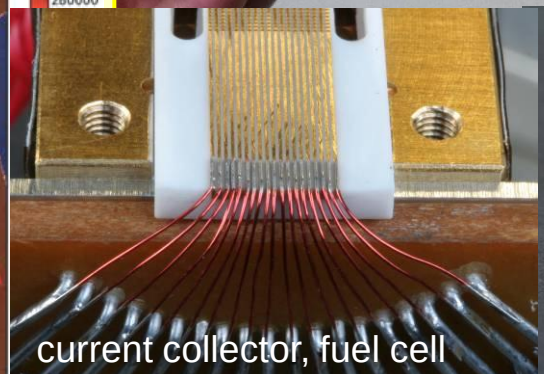


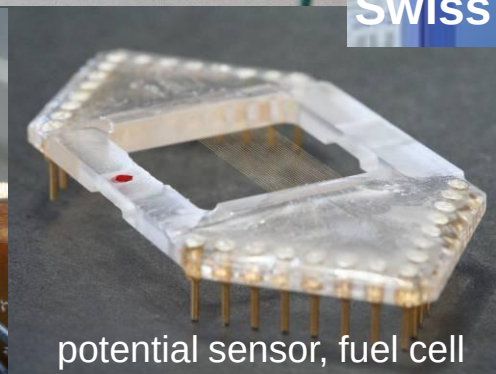
DRS4 Evaluation Board


SCS-2000

Swiss Economic Award 2010



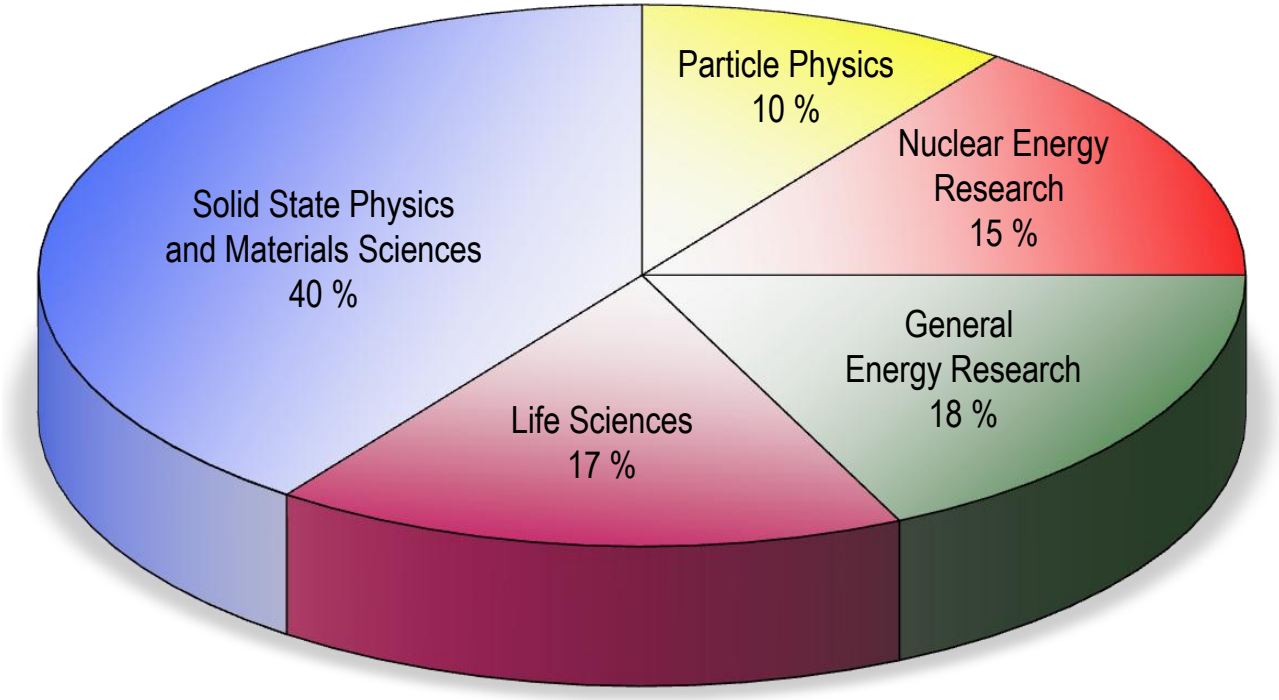

current collector, fuel cell


potential sensor, fuel cell

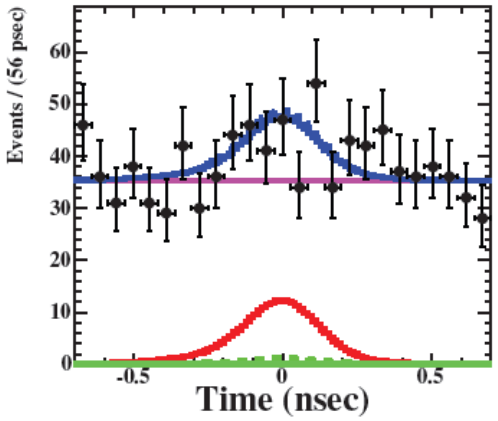

µSR UHV-cryostat

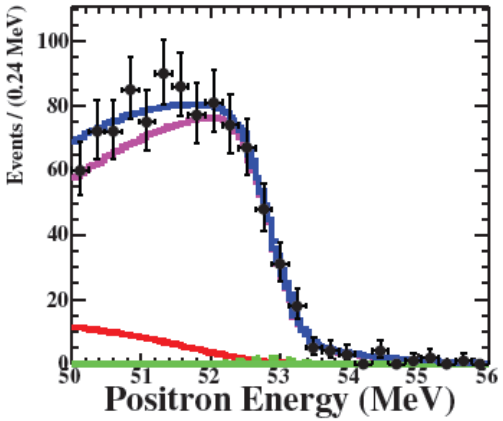
Budget 2011

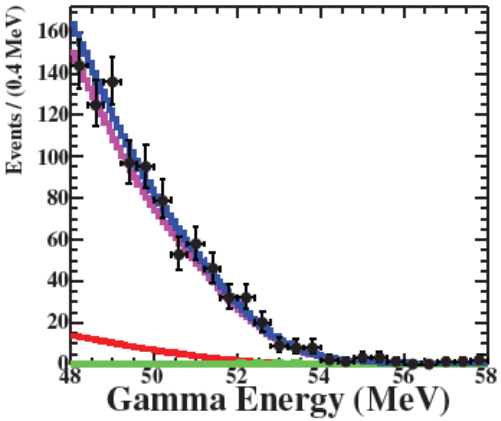
- Distribution by points of emphasis; 320 MCHF (PSI and third-party contributions)

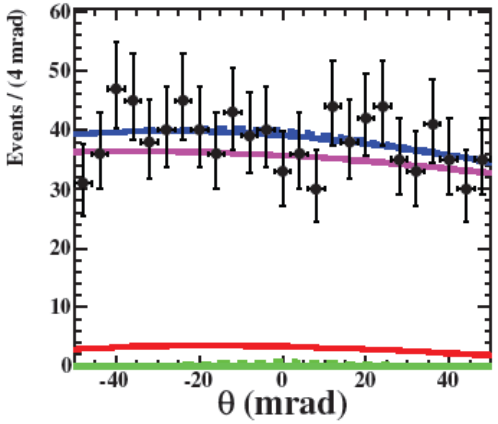


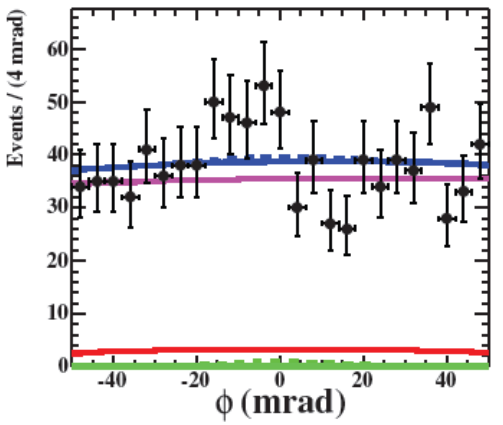
Results (2009+2010)











Based on ~ 1.8×10^{14} μ on target

$N_{sig} = -0.5\ ^{+7.9}_{-4.7}$

$N_{BG} = 882 \pm 22$

$N_{RD} = 76.5 \pm 12$

un-binned likelihood fitting on 5 discriminating observables

MEG prospects

1. Analysis

- Almost Finished
- Box will be opened in this Autumn

- Improved analysis is applied on 2009+2010, and then it will be re-processed.
- After reprocess, blind box will be opened with old data
- All combined analysis (2009+2010+2011) will be published in this autumn → $O(-13)$!!

2. Physics Run

- Will Re-Start Soon
- Long Shutdown will start in 2013

- Detector Maintenance is almost finished.
- Extra run (3 months) are planned at begin of 2013 → Enough statistics to achieve 6×10^{-13}
- Long Shutdown (~2 y) for Major Upgrade

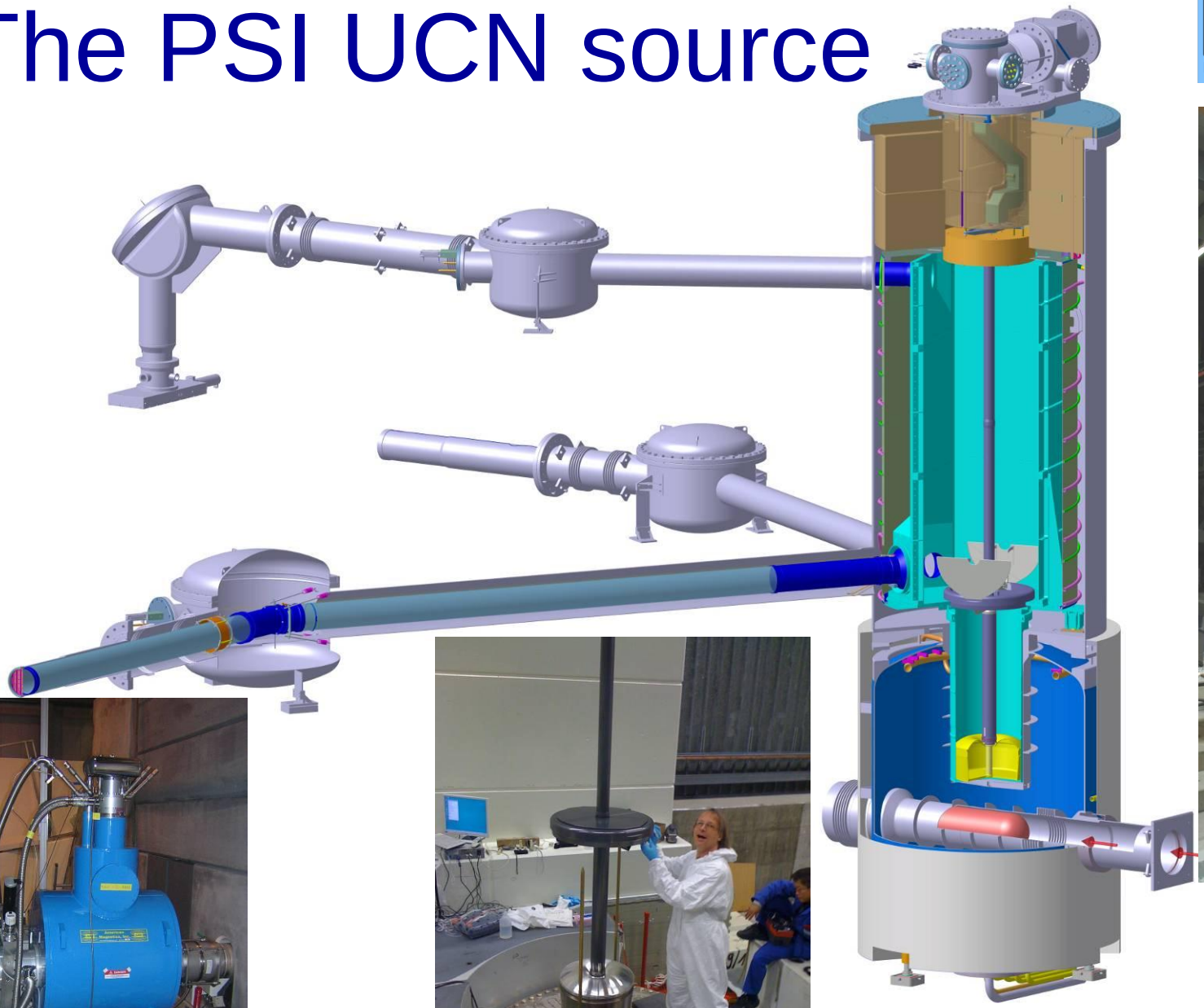
3. Upgrade

- R&D Started
- Goal : 5×10^{-14} Sensitivity

- Many Activities are ongoing for upgrade
- Proposals are under preparation for INFN (Jul.) and PSI (Dec.)
- MEG-II will start ~2015(16) and run ~3 y

The PSI UCN source

Ultra Cold Neutron Source



final assembly during 2010

First results from UCN source commissioning

Improvements Dec 22, 2010 → Aug 31, 2011: x 48