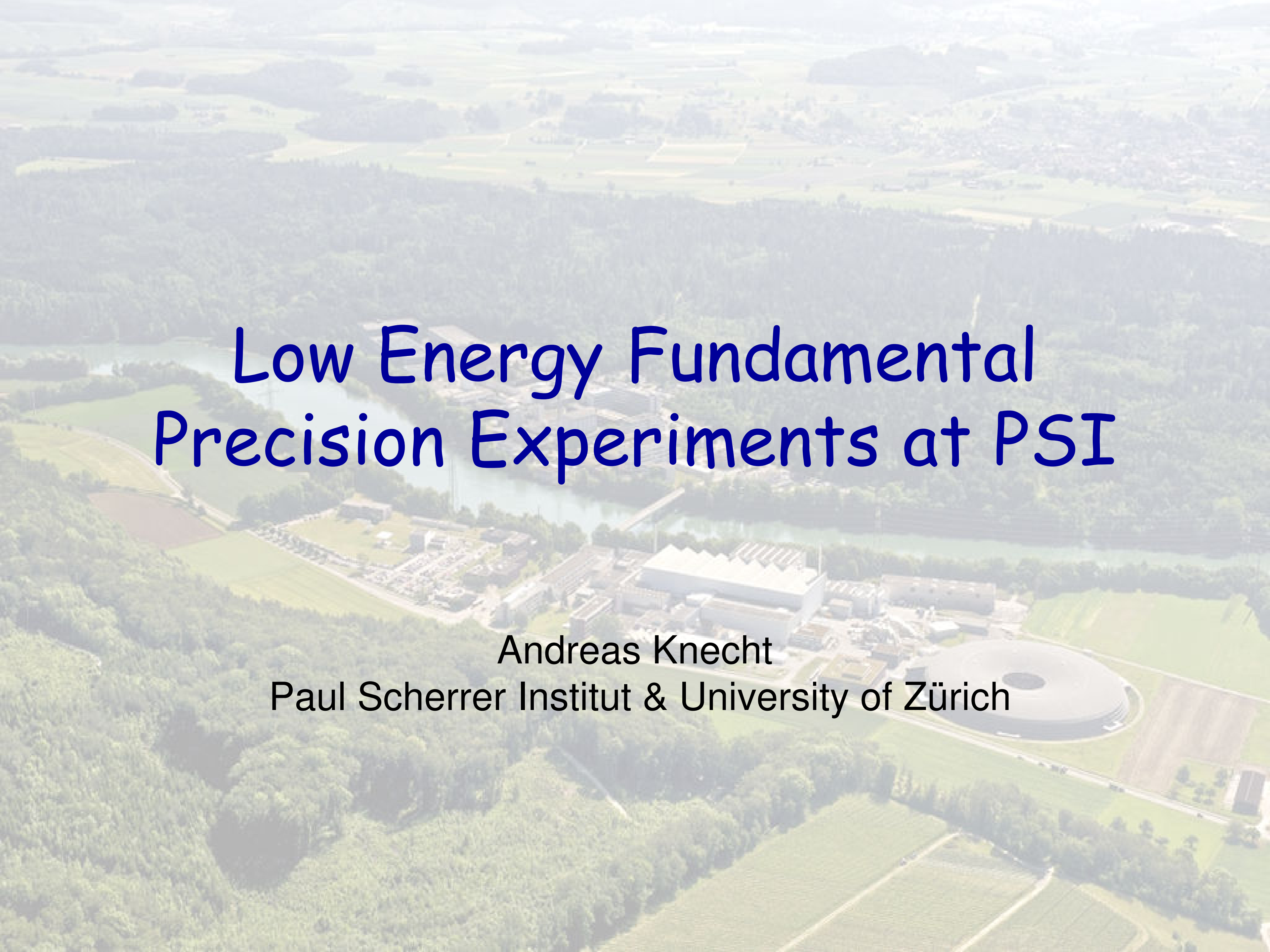
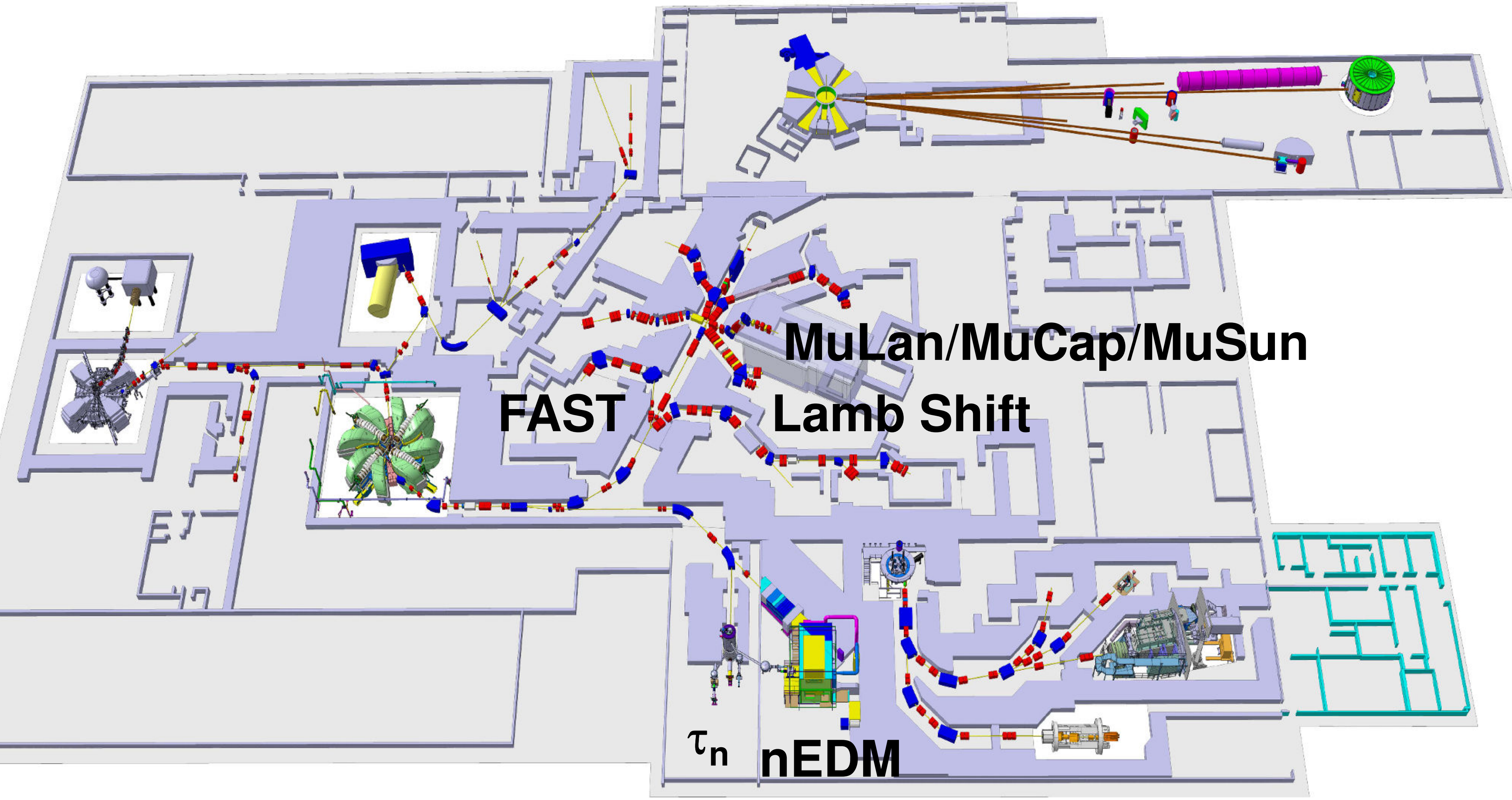


Low Energy Fundamental Precision Experiments at PSI

Andreas Knecht
Paul Scherrer Institut & University of Zürich

Proton Accelerator Facility @ PSI



Not covered: MEG, PEN, μ→eee, μEDM (see last year)

The Fermi Constant and τ_μ

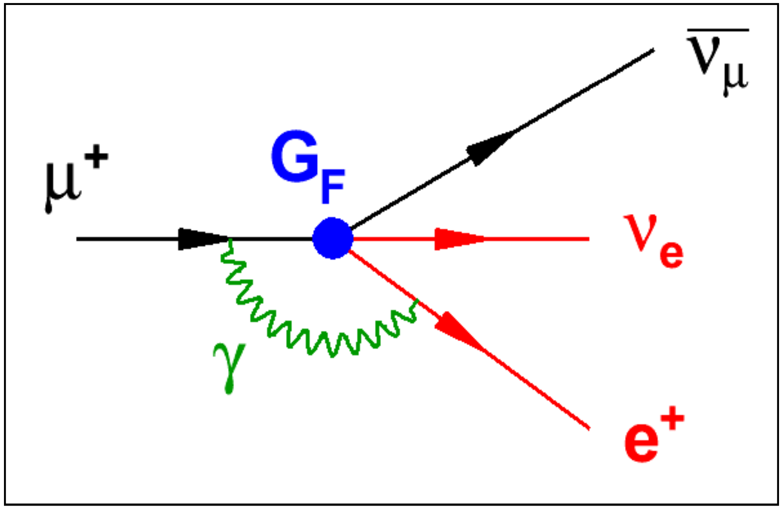
Fundamental parameters of electroweak Standard Model

	G_F	α	M_Z
Precision (2008)	**9 ppm**	**0.0004 ppm**	**23 ppm**

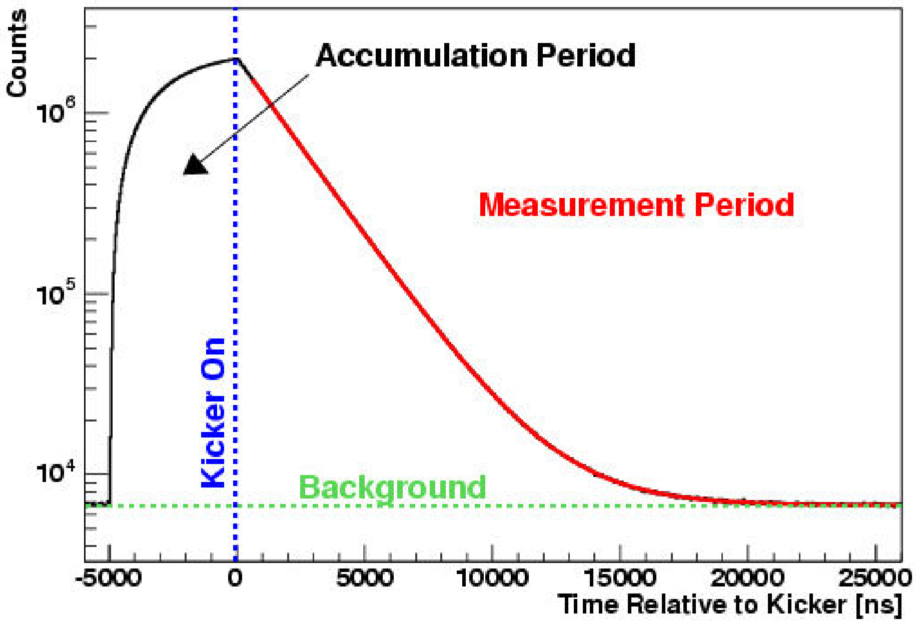
G_F contributes to all electroweak processes

$$\frac{1}{\tau_{\mu^+}} = \frac{G_F{}^2 m_\mu^5}{192\pi^3}(1+q)$$

QED corrections

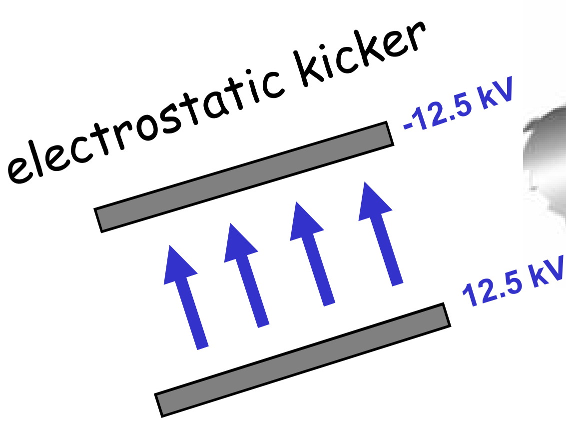


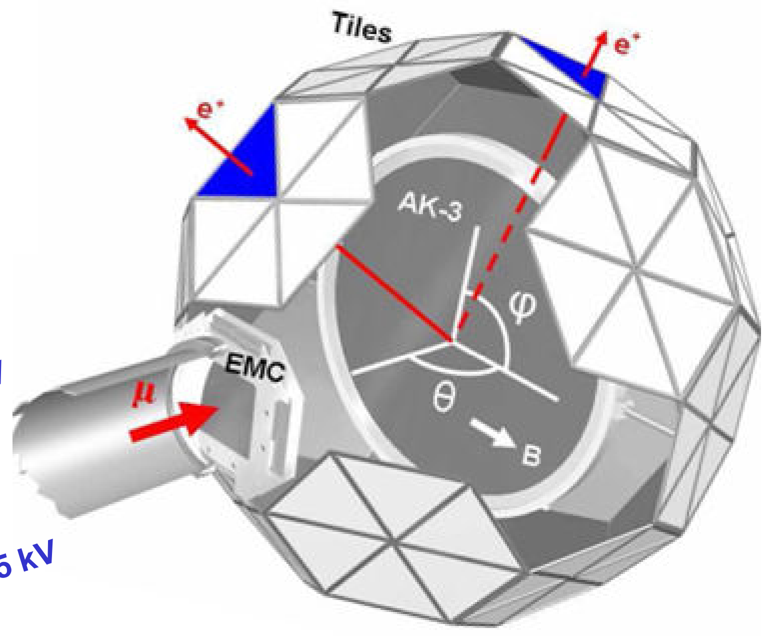
The MuLan Experiment at PSI



PSI DC proton beam with 1.7 mA
→ 10 MHz μ^+

Final analysis under way
(several 10^{12} decays)

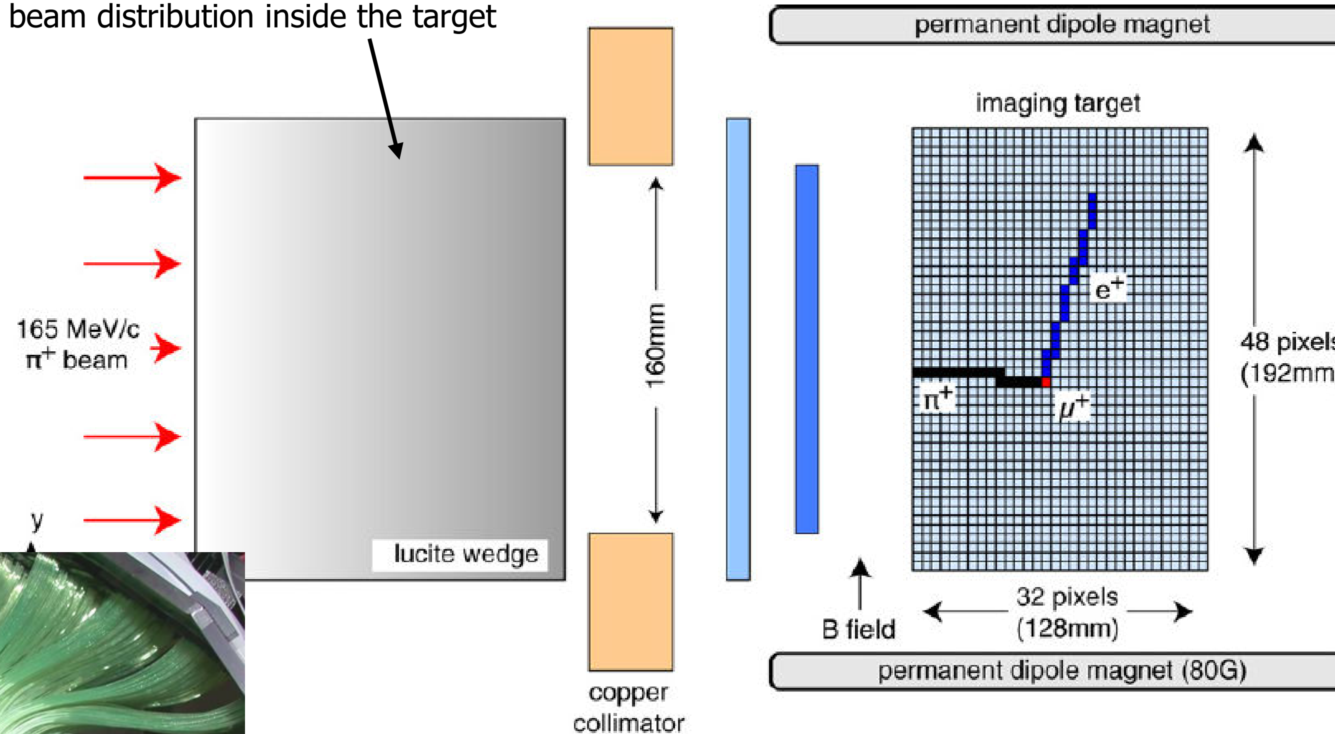


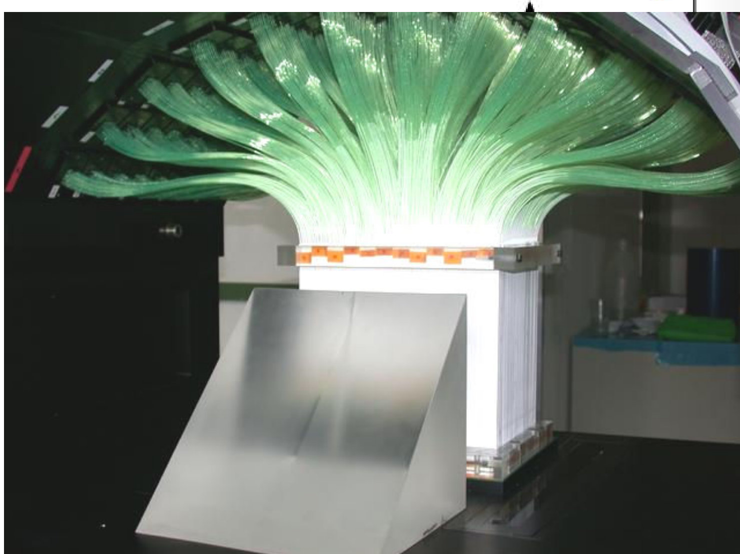


The FAST Experiment at PSI

PAUL SCHERRER INSTITUT PSI — Ultra Cold Neutron Source

Plastic wedge beam degrader
to achieve a uniform beam distribution inside the target





→ Final data taking under way (2009)
Goal: a few 10^{11} full decay events

The Fermi Constant and τ_μ

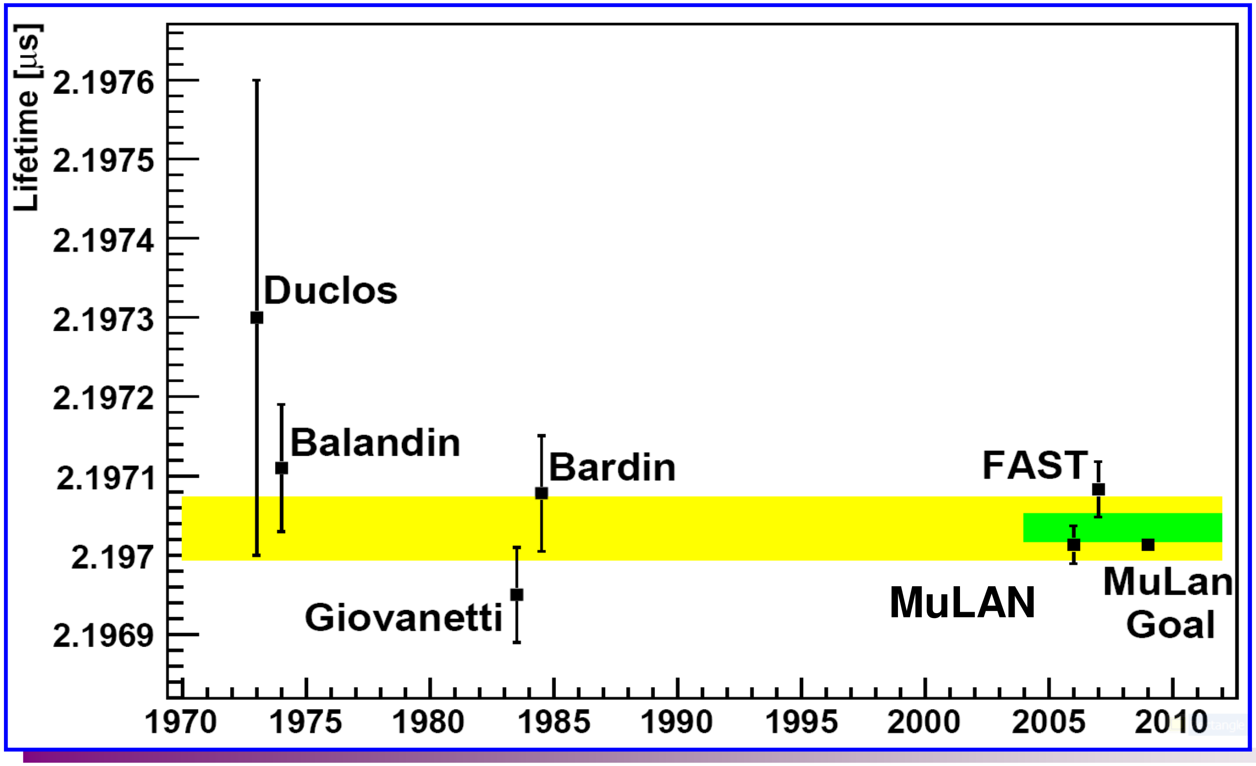
Ultra Cold Neutron Source

τ_μ(MuLan) = 2.197 013(21)(11) µs (11ppm) Phys. Rev. Lett. 99, 032001 (2007)

τ_μ(World) = 2.197 019(21) µs (9.6 ppm)

→ $G_F = 1.166\ 371(6) \times 10^{-5}\ GeV^{-2}$ (5 ppm)

τ_μ(FAST) = 2.197 083(32)(15) µs (15ppm) Phys.Lett. B 663, 172 (2008)



Precision goals:

MuLan

τ_μ= 1 ppm ~ 0.5 ppm G_F

FAST

τ_μ= 2 ppm ~ 1 ppm G_F

PAUL SCHERRER INSTITUT PSI

Muon Capture on the Proton and the Pseudoscalar Formfactor g_P

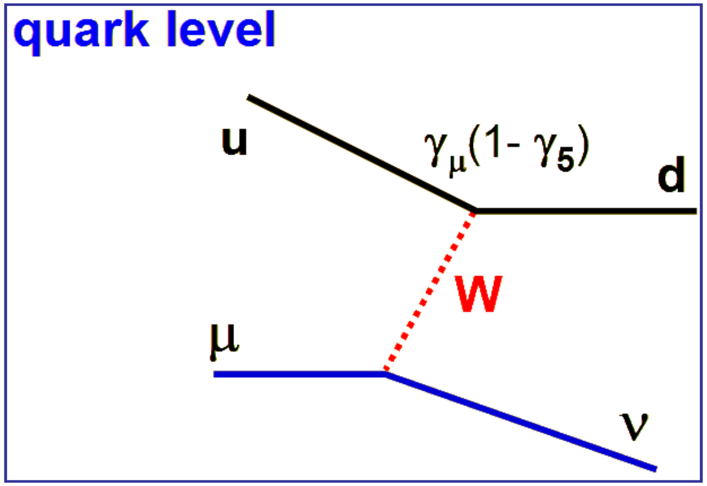
Ultra Cold Neutron Source

$$\mu^- + p \rightarrow \nu_\mu + n$$

charged current

'historically' V-A structure

$$J_N = \langle n|\, V_\alpha - A_\alpha \,|p\rangle$$



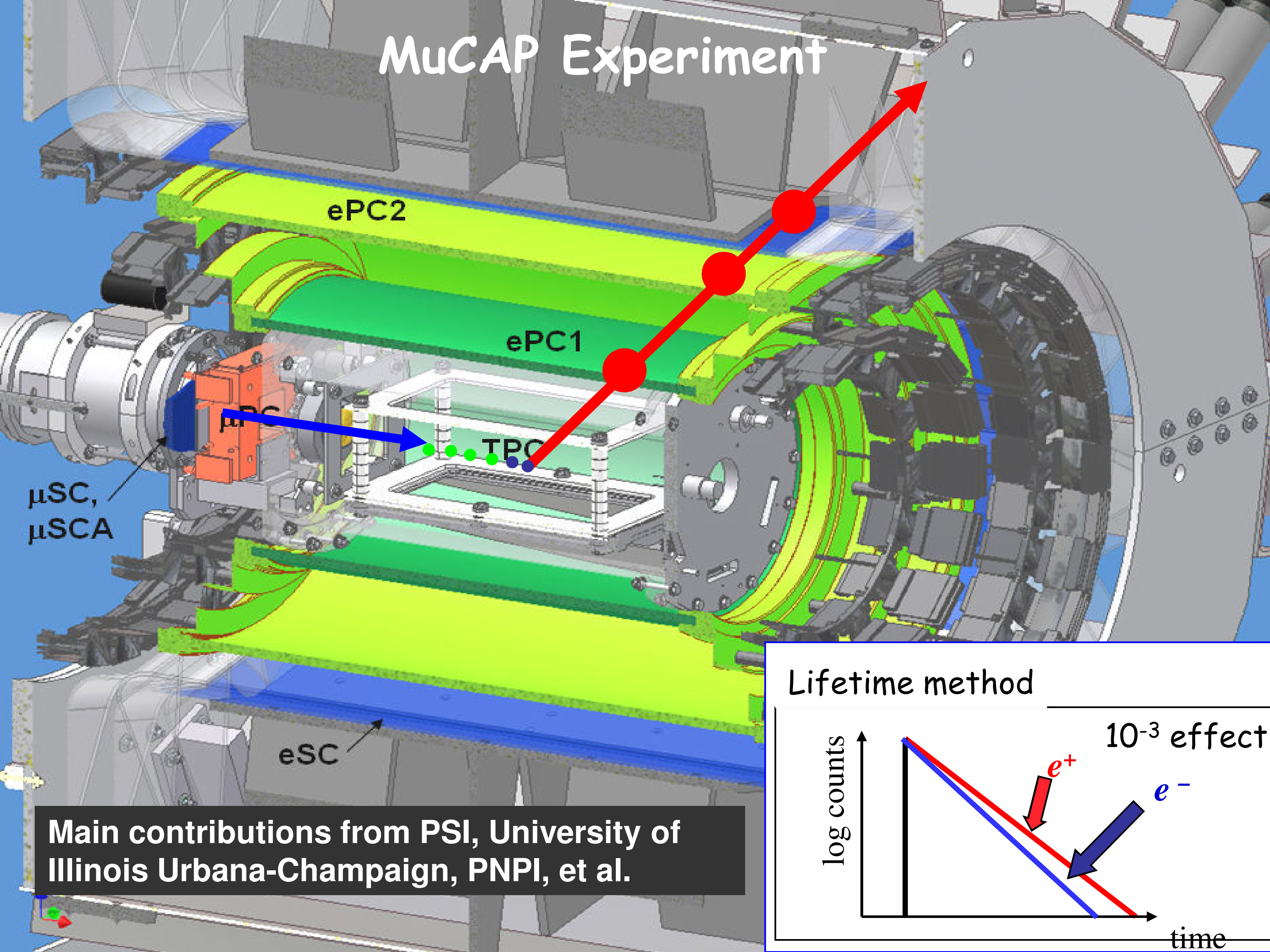
Lorentz invariance allows 6 terms and couplings in the nucleon charged current

$$V_\alpha = g_V(q^2) \quad + \; i g_M(q^2)/2M\, \sigma_{\alpha\beta}\, q^\beta \quad + \; g_S(q^2)/m\, q_\alpha$$

$$A_\alpha = g_A(q^2)\, \gamma_5 \quad + \; g_P(q^2)\, q_\alpha/m\, \gamma_5 \quad + \; i g_T(q^2)/2M\, \sigma_{\alpha\beta}\, q^\beta\, \gamma_5$$

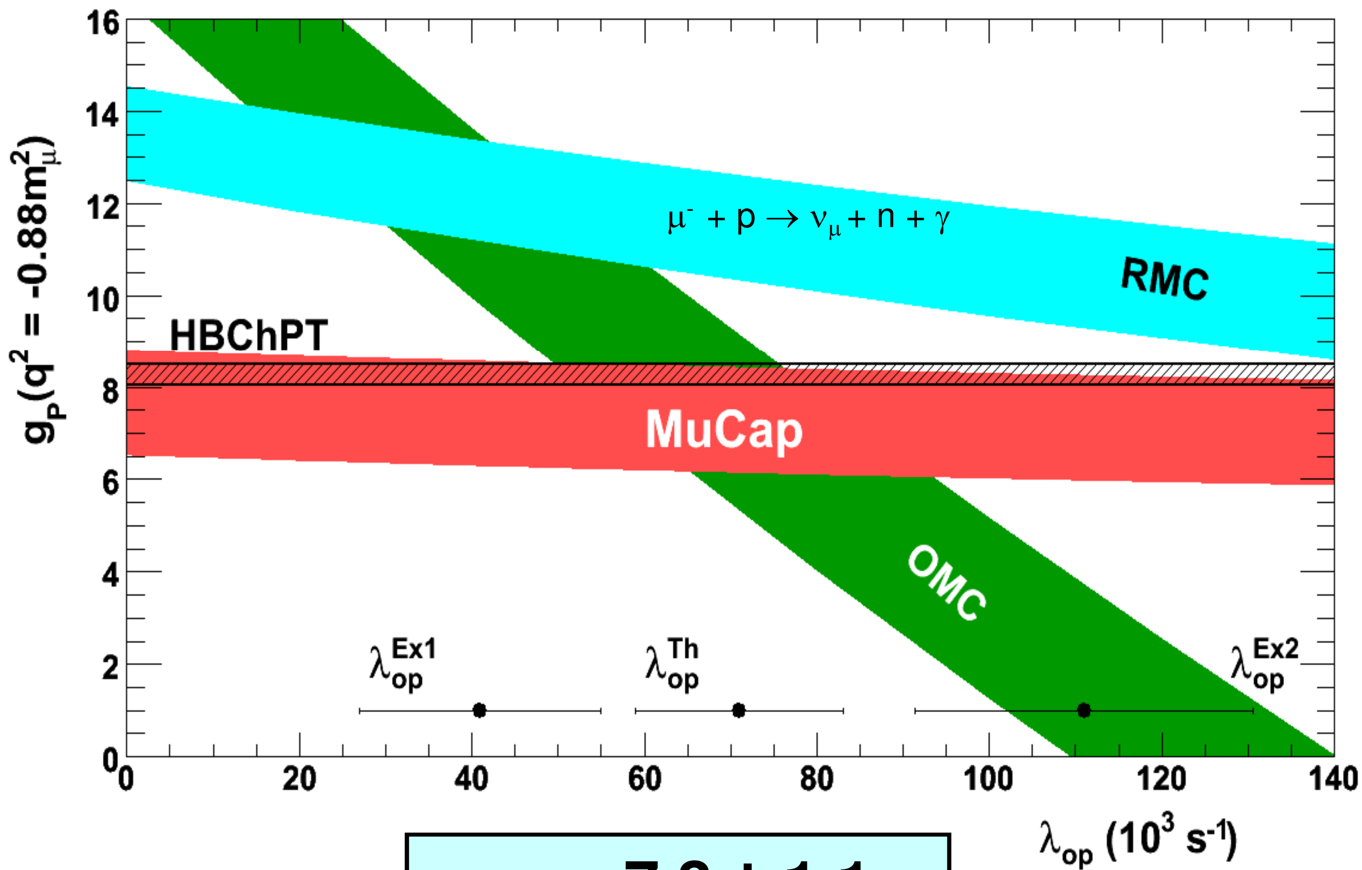
Nucleon weak form factors g_V, g_M, g_A are determined by SM symmetries and data. They contribute < 0.5% uncertainty to **capture rate**

but g_P = 8.3 ± 50% (before 2007)


MuCAP Experiment
ePC2
ePC1
μPC
TPC
μSC,
μSCA
eSC
Main contributions from PSI, University of Illinois Urbana-Champaign, PNPI, et al.
Lifetime method
10^{-3} effect
log counts
e^+
e^-
time

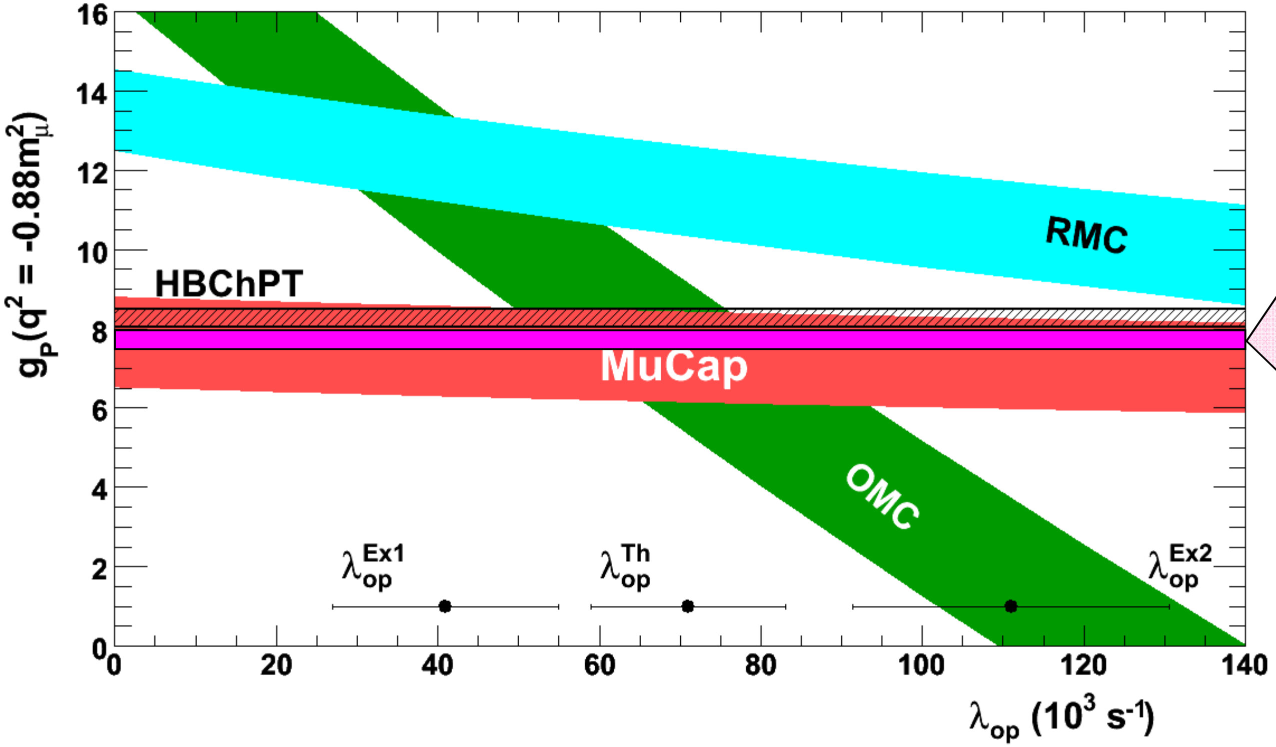
g_P after MuCAP 07 result

$\Lambda_S^{MuCap} = 725.0 \pm 13.7\ (stat) \pm 10.7\ (sys)\ s^{-1}$ MuCap, PRL **99**, 032001 (2007)	$\Lambda_S^{theory} = 710.6\ s^{-1}$ Czarnecki, Marciano, Sirlin, PRL **99**, 032003 (2007)



$g_P = 7.3 \pm 1.1$

MuCAP Goal for Final Analysis

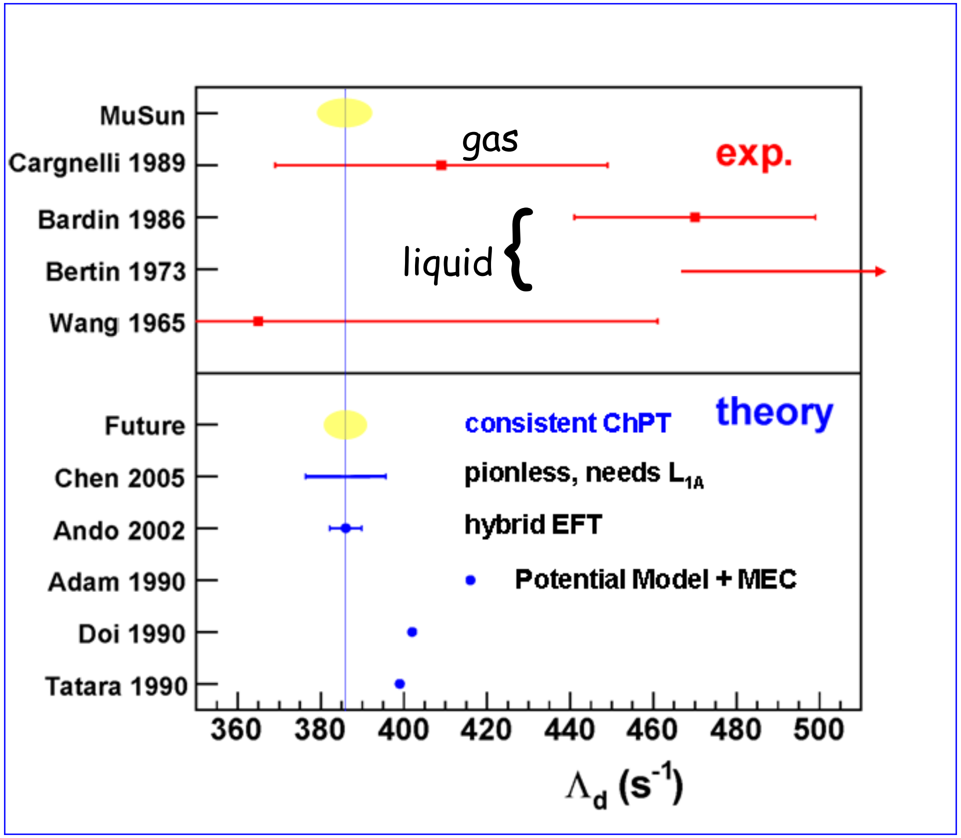


Ongoing analysis of 10^{10} mu-e events to reduce the error on Λ_S to < 1% and on g_P to < 7%

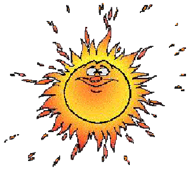
Muon Capture on the Deuteron

$$\mu^- + d \rightarrow n + n + \nu$$

(doublet capture rate Λ_d)



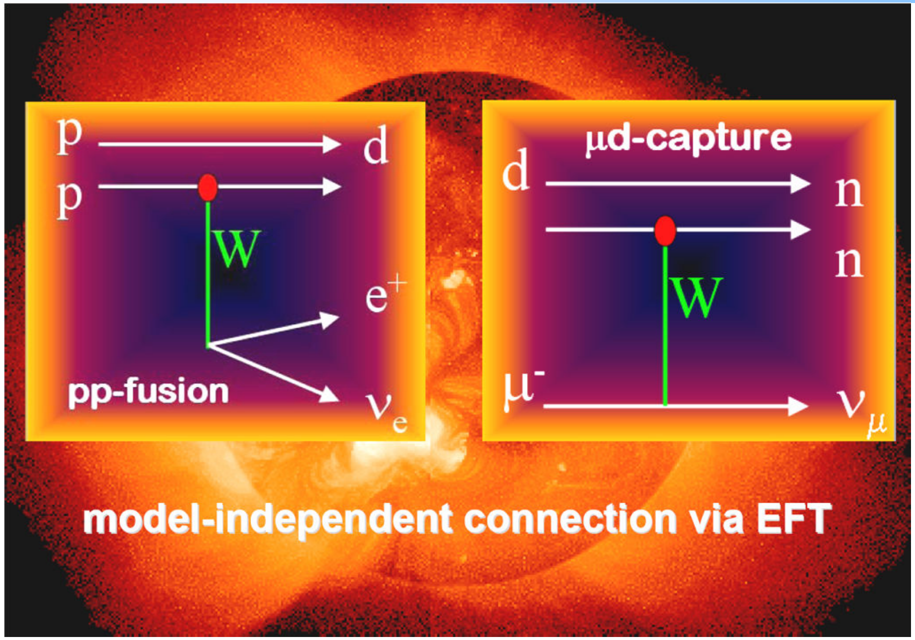
World knowledge on Λ_d is not satisfying



Goal of the MuSUN experiment at PSI is to measure muon capture rate Λ_d to < 1.5 %

MuSUN footed on experience within MuCAP and MuLAN, but needs to develop new cryo-TPC for 30 K measurement. First engineering runs completed

Connection to Neutrino/Astrophysics



EFT connection to μ+d capture via a single LowEnergy Constant L_{1A}

Basic solar fusion reaction: $p + p \rightarrow d + e^+ + \nu$

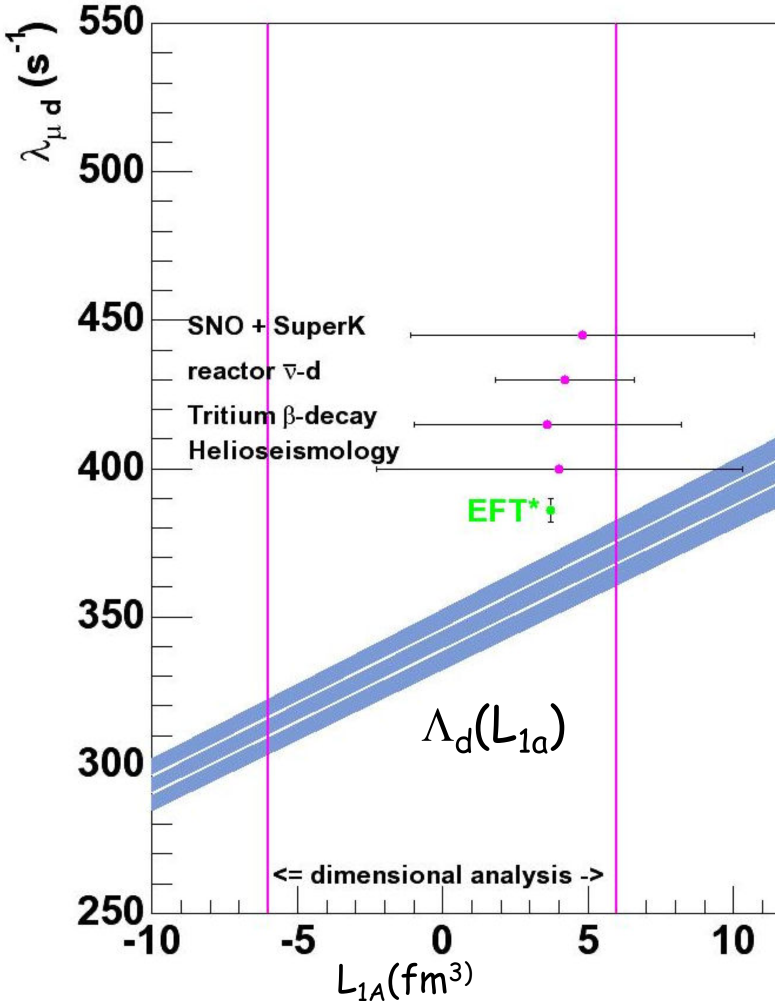
Key reactions for SNO:

$\nu_e + d \rightarrow p + p + e^-$ (CC)

$\nu_x + d \rightarrow p + n + \nu_x$ (NC)

Present Knowledge on L_{1A}

Ultra Cold Neutron Source



Goal of the MuSUN experiment at PSI is to measure muon capture rate Λ_d to < 1.5 %

Allows to extract L_{1A} to ~1.5 fm^3

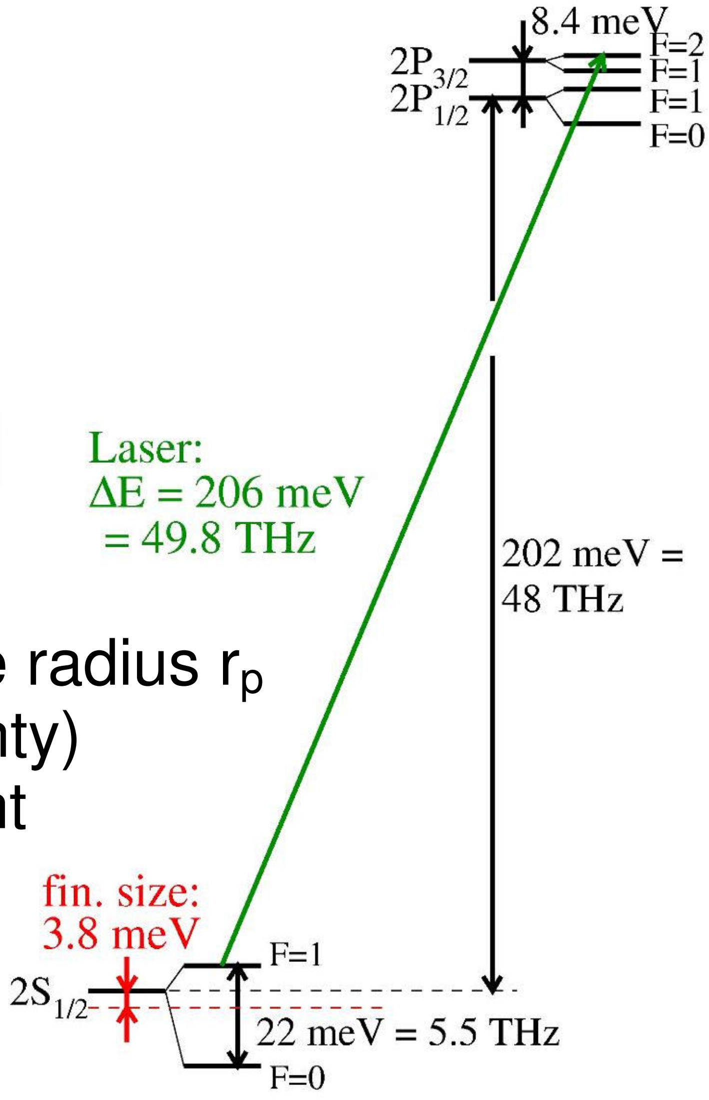
Lamb Shift in Muonic Hydrogen

Laser-spectroscopic experiment
@ PSI proton accelerator facility

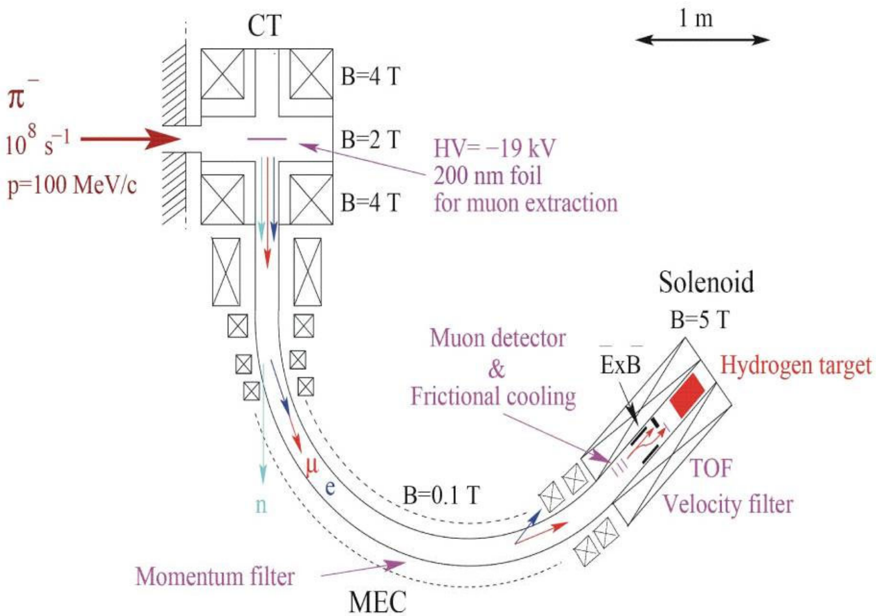
Lamb shift in μp: $\Delta E(2P^{F=2}_{3/2} - 2S^{F=1}_{1/2}) =$

$$209.968(5) - 5.2248\, r_p^2 + 0.0347\, r_p^3 \quad \text{[meV]}$$

- highly sensitive to rms proton charge radius r_p
- r_p is not well known (+/- 2% uncertainty)
- r_p is a fundamental CODATA-constant
- test bound-state QED.
- improve Rydberg constant 6-fold

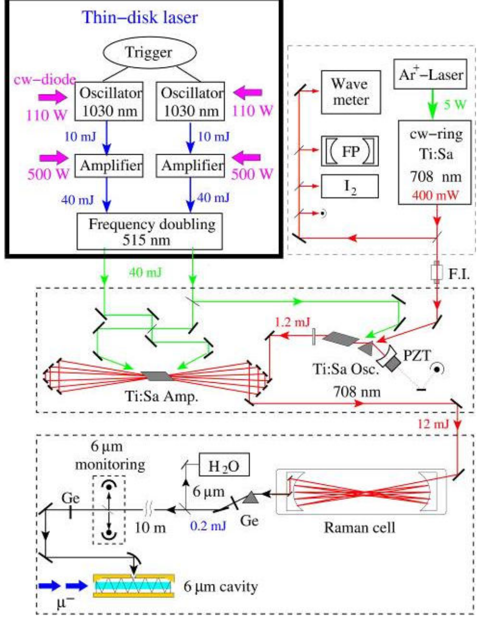


Experiment:



Unique muon beam:
~ 1000 μ^- @ 10 keV

APDs as X-ray detectors:
- mup(2P-1S) @ 1.9 keV
- time resolution 30 ns
- energy resolution 25%
- work in B = 5 Tesla



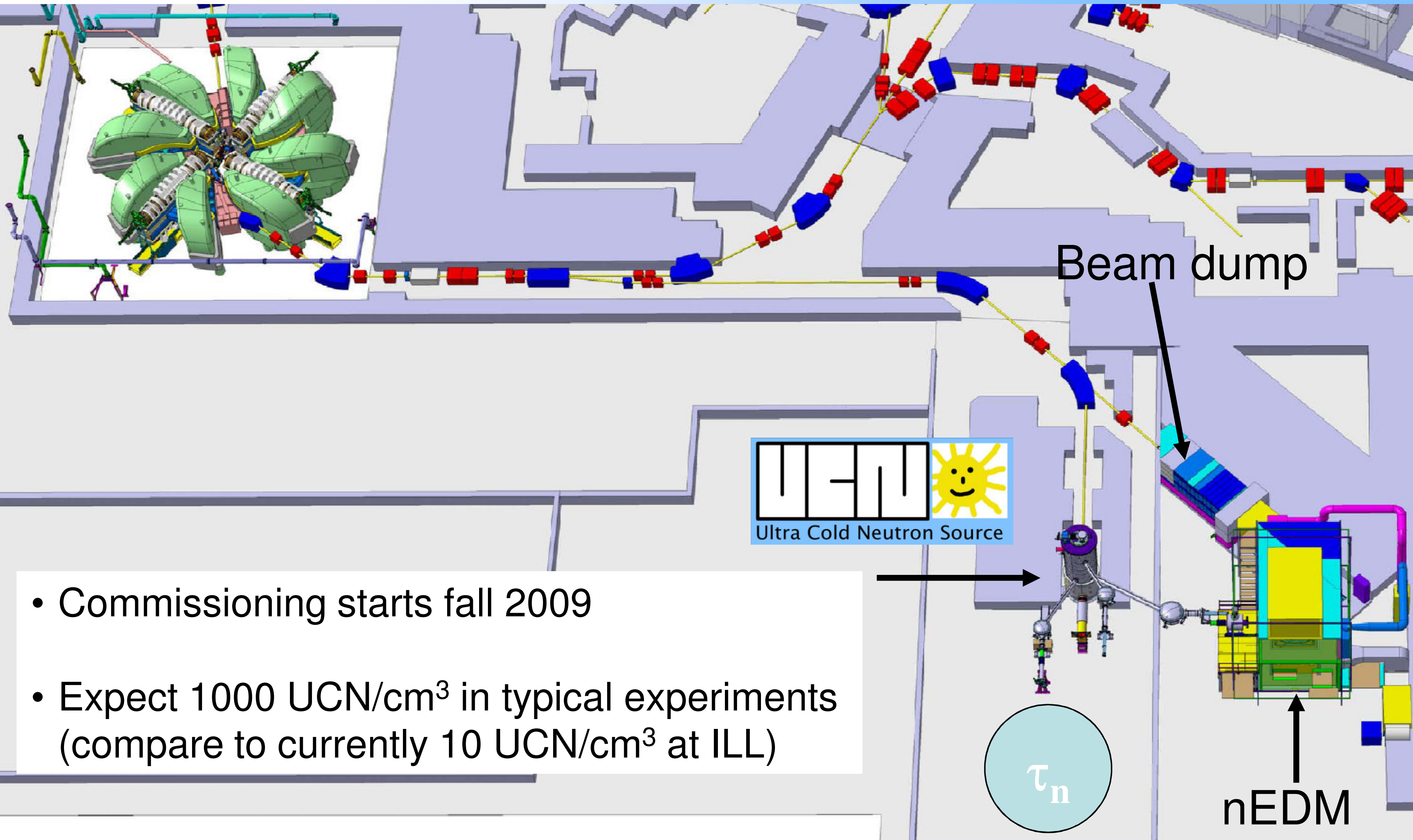
Multi-stage laser-system:
- 6 µm wavelength well
- determined
- tunable and fast
- stochastically triggerable

Beam time 2009 finished successfully.
Brand new result currently under refined analysis.
Goal for precision on r_P: 0.1%

Future:
→ µHe and µD @ PSI
→ further refinement of QED-tests with new experiments with exotic atoms

PAUL SCHERRER INSTITUT PSI | MPQ | Laboratoire Kastler Brossel — Physique quantique et applications | University of Stuttgart Germany | U C — Universidade de Coimbra

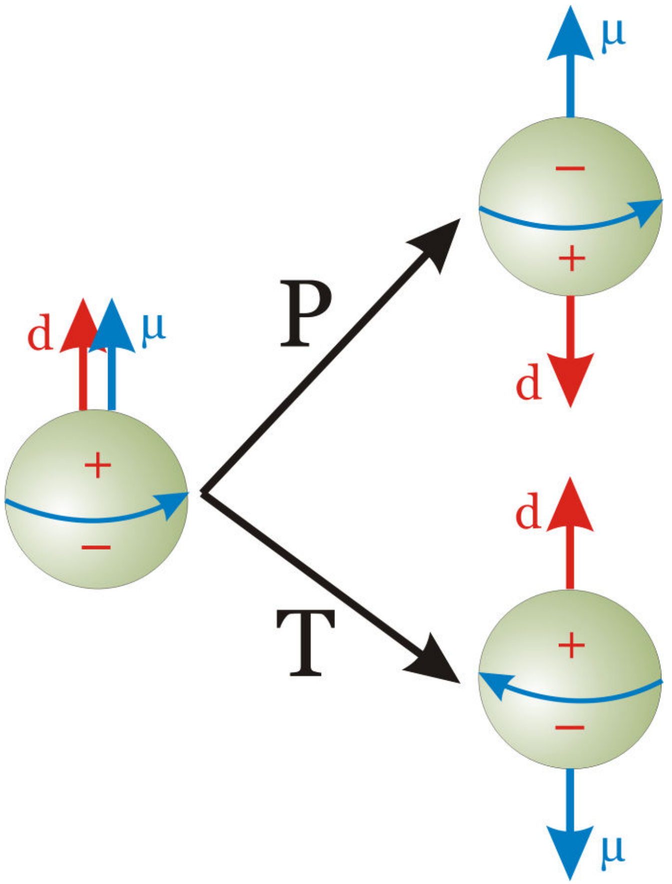
PSI UCN Source



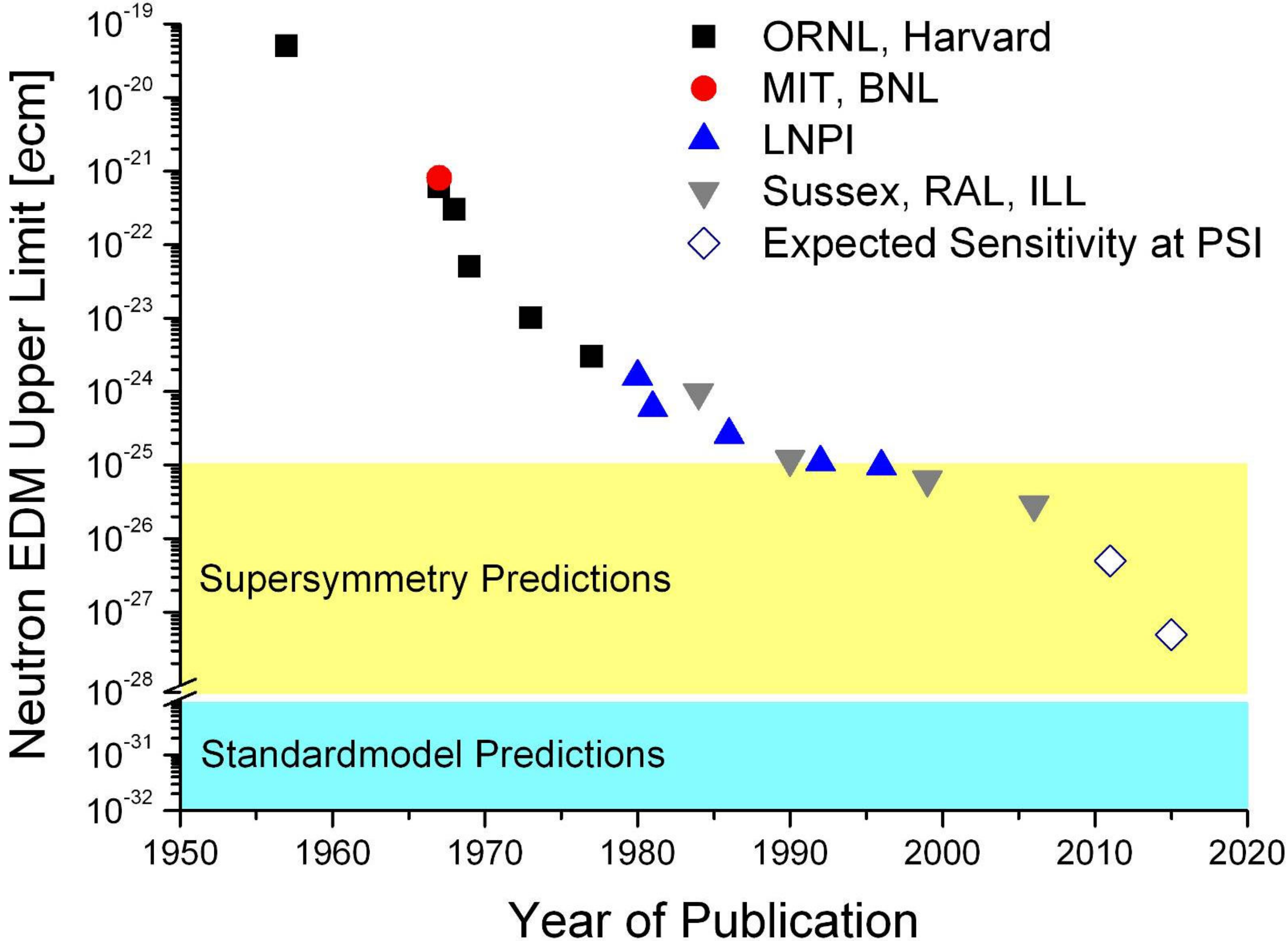
- Commissioning starts fall 2009
- Expect 1000 UCN/cm^3 in typical experiments (compare to currently 10 UCN/cm^3 at ILL)

nEDM @ PSI

- Phase I:
  - Operate and improve Sussex-RAL-ILL apparatus at ILL
  - R&D for n2EDM
  - Move to PSI March 2009
- Phase II:
  - Operate Sussex-RAL-ILL apparatus at PSI (2009-2012)
  - Sensitivity goal: 5×10^{-27} *e*cm
  - Construction and setup of n2EDM
- Phase III:
  - Operate n2EDM (2012-2015)
  - Sensitivity goal: 5×10^{-28} *e*cm



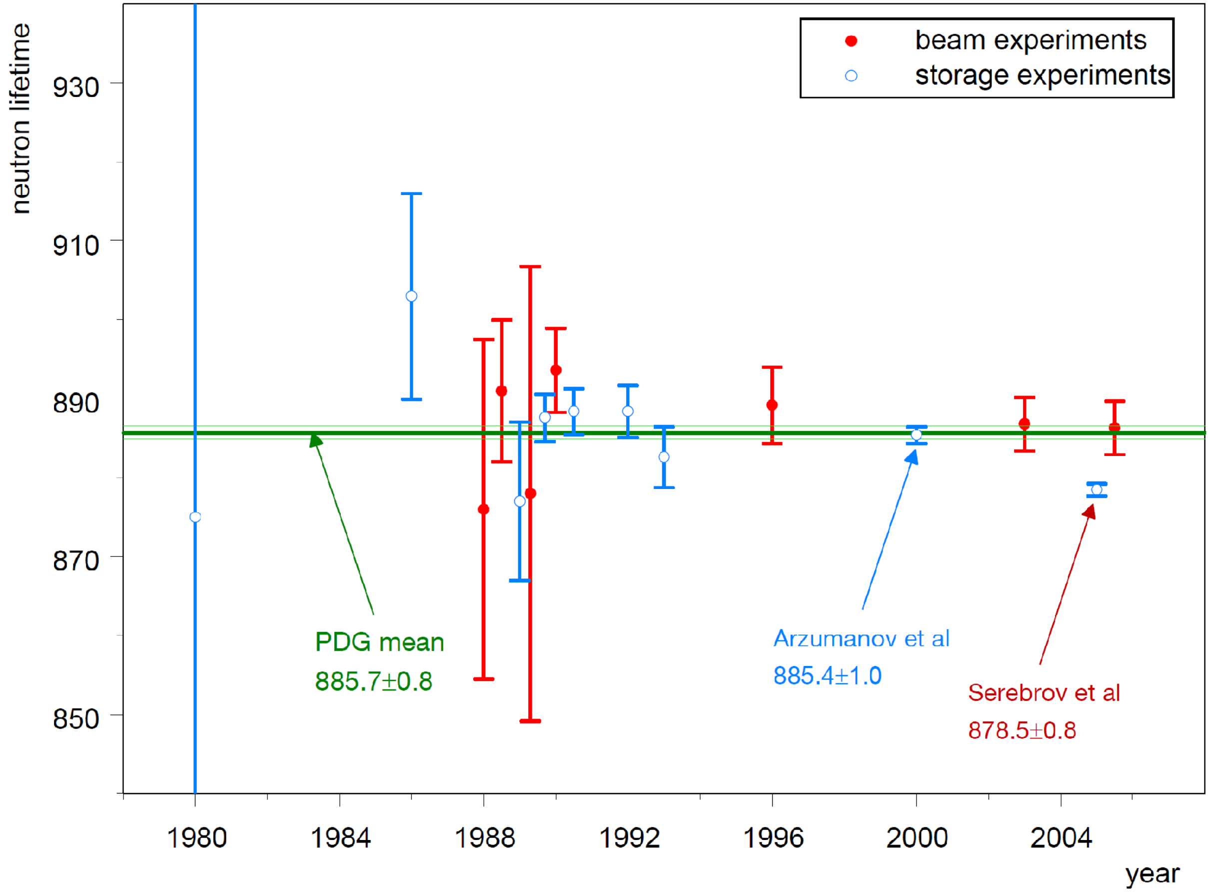
nEDM @ PSI



Neutron EDM Upper Limit [ecm]
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-31}
10^{-32}
ORNL, Harvard
MIT, BNL
LNPI
Sussex, RAL, ILL
Expected Sensitivity at PSI
Supersymmetry Predictions
Standardmodel Predictions
1950
1960
1970
1980
1990
2000
2010
2020
Year of Publication

EDM ready for UCN

Neutron Lifetime Puzzle



New improved neutron lifetime experiments of high priority:
Aim at 0.1s precision

New proposal to PSI:
PENeLOPE neutron lifetime measurement

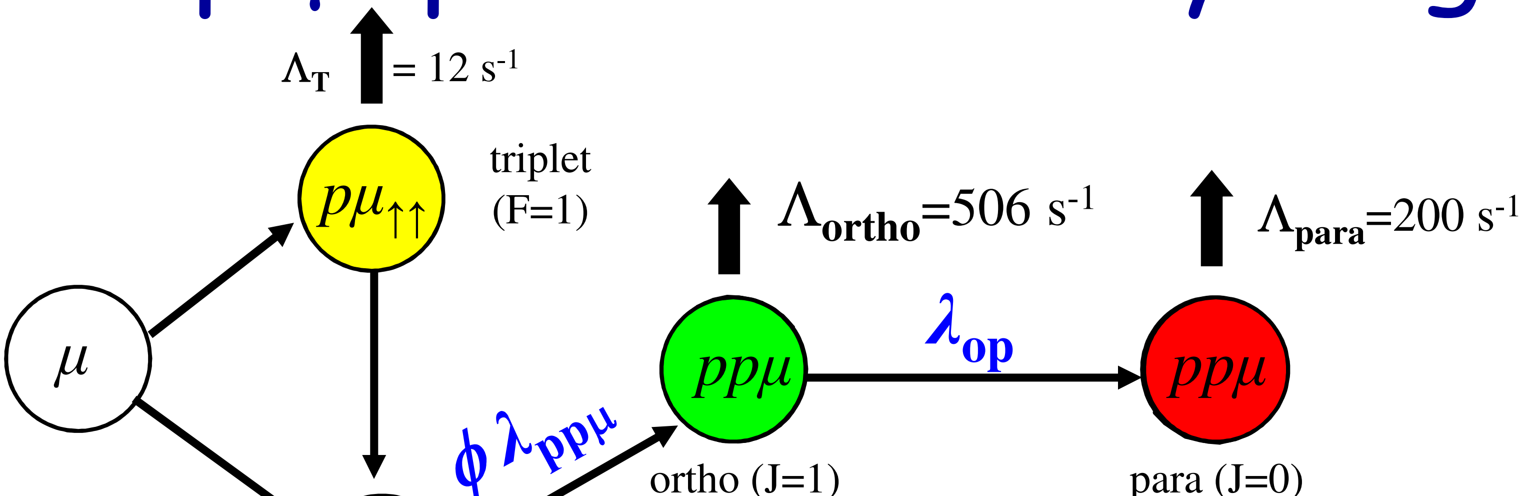
Conclusions

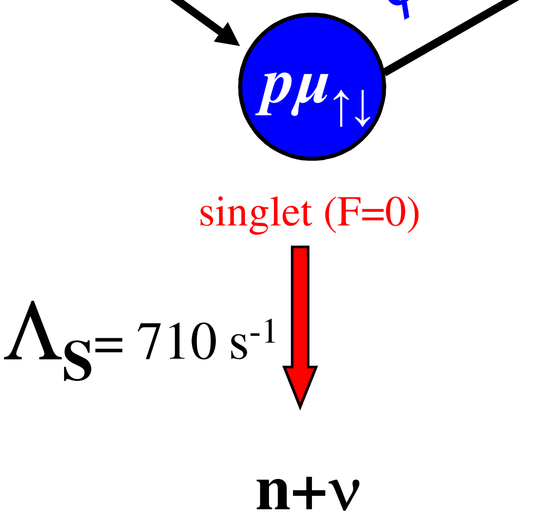
- Several experiments being performed at PSI in fundamental particle physics.
- Precision experiments at low energies complement the high energy experiments in the searches for physics beyond the SM.
- Several new and exciting results to be expected in the coming years.

Special thanks to C. Casella, K. Deiters, K. Kirch, F. Kottman, B. Lauss,T. Nebel and R. Picker for their contributions.

Backup

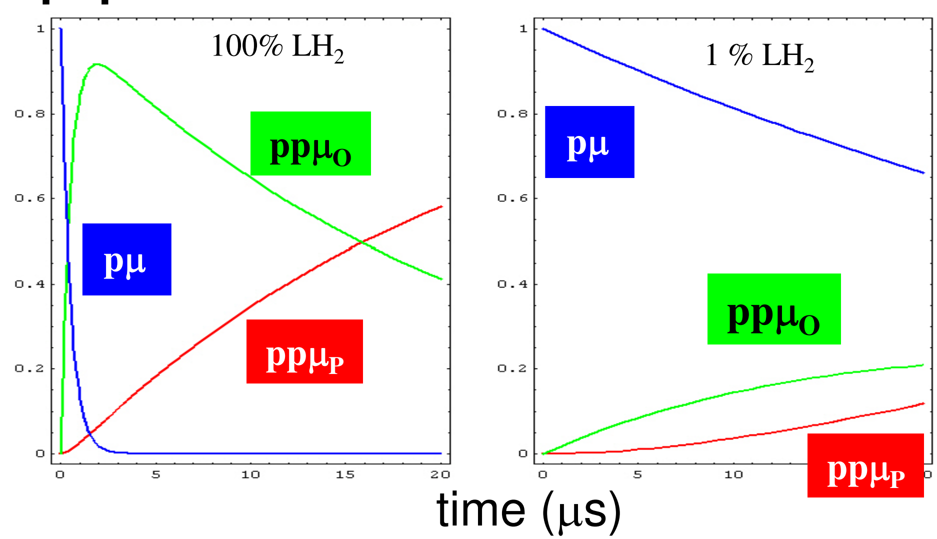
p-μ-p kinetics in hydrogen





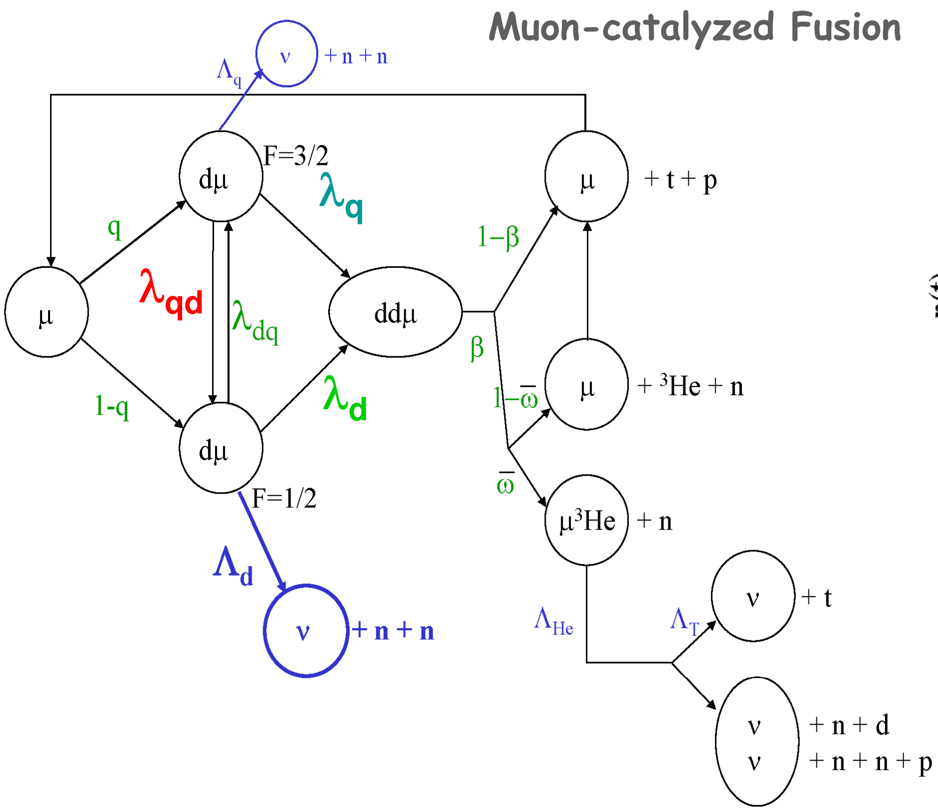
- Interpretation requires knowledge of ppμ population
- Strong dependence on hydrogen density ϕ

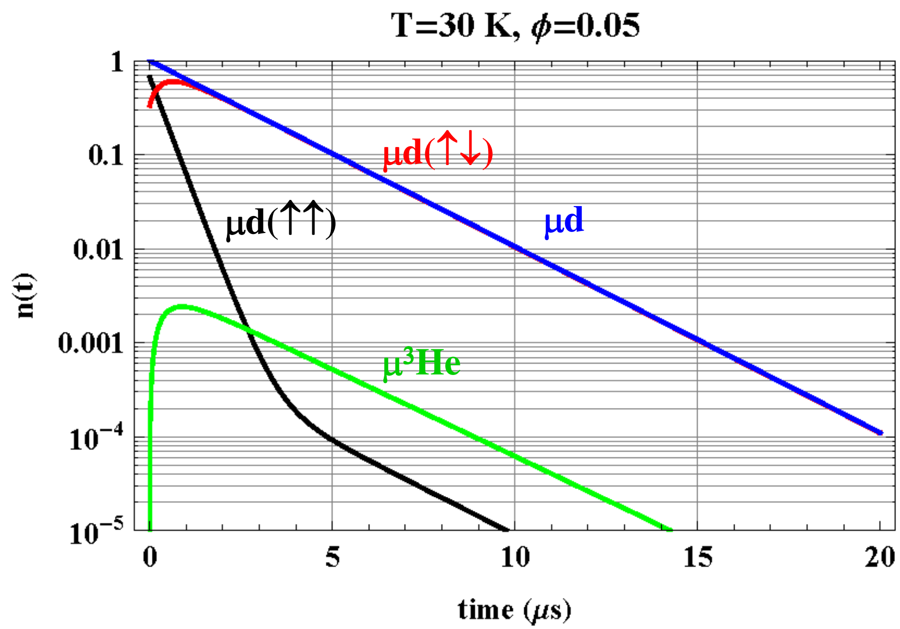
populations of states



MuCap

Muon Kinetics in deuterium





- Collisional processes density ϕ dependent, e.g.
- hfs transition rate from q to d state = $\phi\ \lambda_{qd}$
- density ϕ normalized to LH_2 density

MuSun