

μ Physics at the ν Factory

progress report of the Stopped Muons Working Group*

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phase 1:

Neutrino Factory and Muon Storage Rings at CERN

Report of the Stopped Muons Working Group:

Physics with

Low-Energy Muons at a Neutrino Factory Complex

CERN-TH/2001-231 hep-ph/0109217

- physics motivation
- present experimental limitations
- requirements to muon beams

phase 2:

- design the production targets / beam lines
- set priorities inside the program
- work out some experiments in more detail

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Physics with Low-Energy Muons at a Neutrino Factory Complex

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7 CONCLUSIONS

ecfa, october 2001

What could be reached at a Neutrino Factory Complex ?

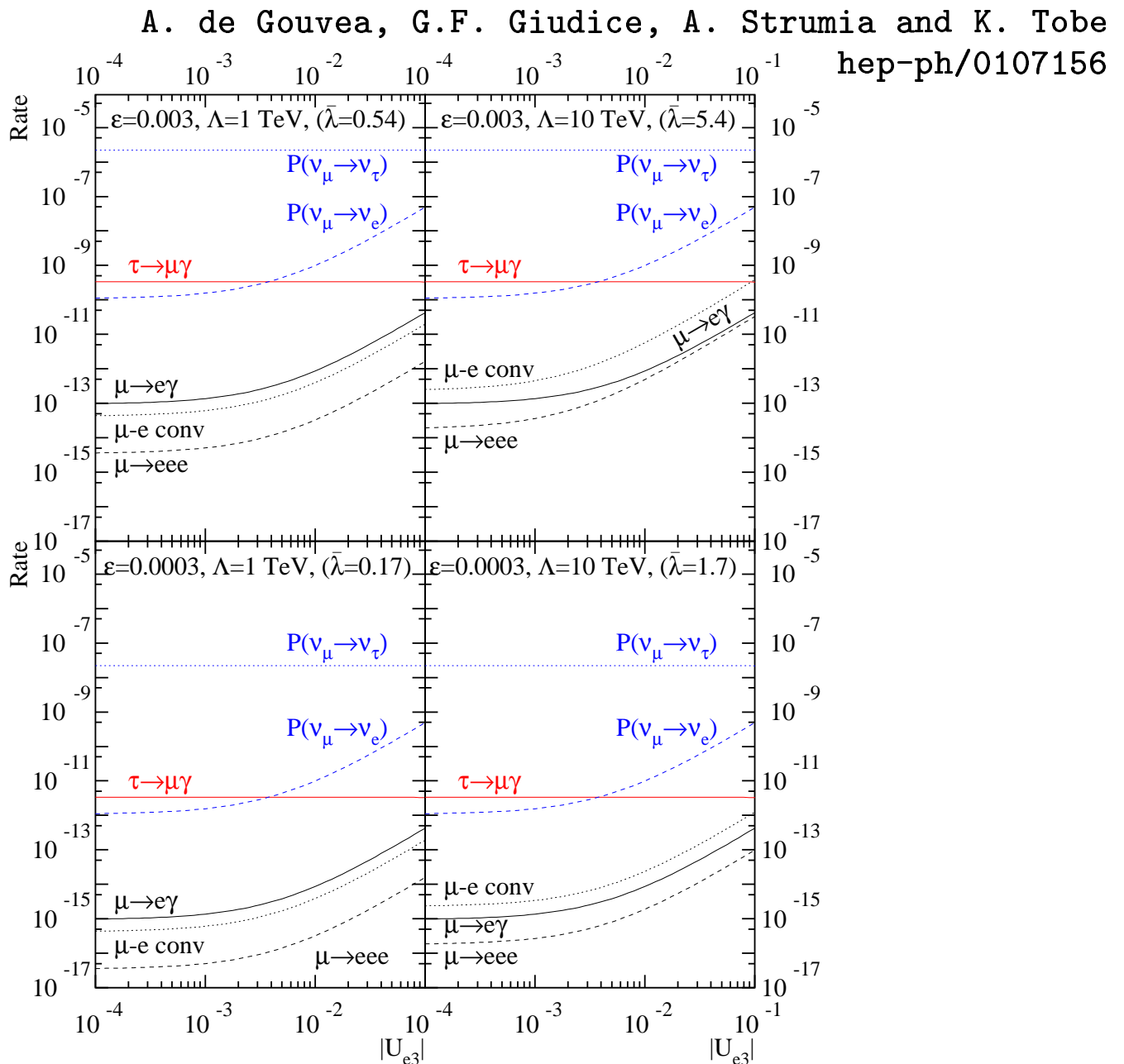
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Type of experiment	Physics Issues	Possible experiments	Previously established accuracy	Present activities (proposed accuracy)	Projected for Nufact @ CERN
'Classical' rare & forbidden decays	Lepton Number Violation; Searches for New Physics; SUSY; L-R Symmetry; R-parity violation,	$\mu^- N \rightarrow e^- N$ $\mu^- \rightarrow e \gamma$ $\mu^+ e^- \rightarrow e e e$	6.1×10^{-13} 1.2×10^{-11} 1.0×10^{-12} 8.1×10^{-11} 18×10^{-11} 2×10^{-2}	PSI, proposed completed BNL (5×10^{-17}) PSI, proposed accuracy completed PSI (2×10^{-14}) completed 1985 PSI PSI (2X) RAL (1 x 10 ⁻⁹) PSI, TRIUMF (5×10^{-3})	$< 10^{-18}$ $< 10^{-15}$ $< 10^{-16}$ $< 10^{-13}$ $< 10^{-7}$ $< 10^{-3}$
Muon decays	transy. Polariz.	$7_{\mu} e^+$		BNL (3.5×10^{-7}) proposed BNL ($10^{-24} e$ cm)	$< 5 \times 10^{-7}$ $5 \times 10^{-26} e$ cm
Muon moments	$g_{\mu} - 2$ edm_{μ}		1.3×10^{-6} $3.4 \times 10^{-19} e$ cm 12×10^{-9} 1×10^{-9} depends	completed 1999 LAMPF completed 2000 RAL PSI, possible CERN ($< 10^{-9}$ to 10^{-3}) PSI, RAL (n/a)	$< 10^{-9}$ $< 10^{-11}$ new nuclear structure high rate
Muonium spectroscopy	$M_H F_S$ $M_{1,2S}$				
Muonic atoms	μ^- atoms				
Condensed matter	surface μ SR				

Table 7 of report

Rare muon processes

in models with extra dimensions



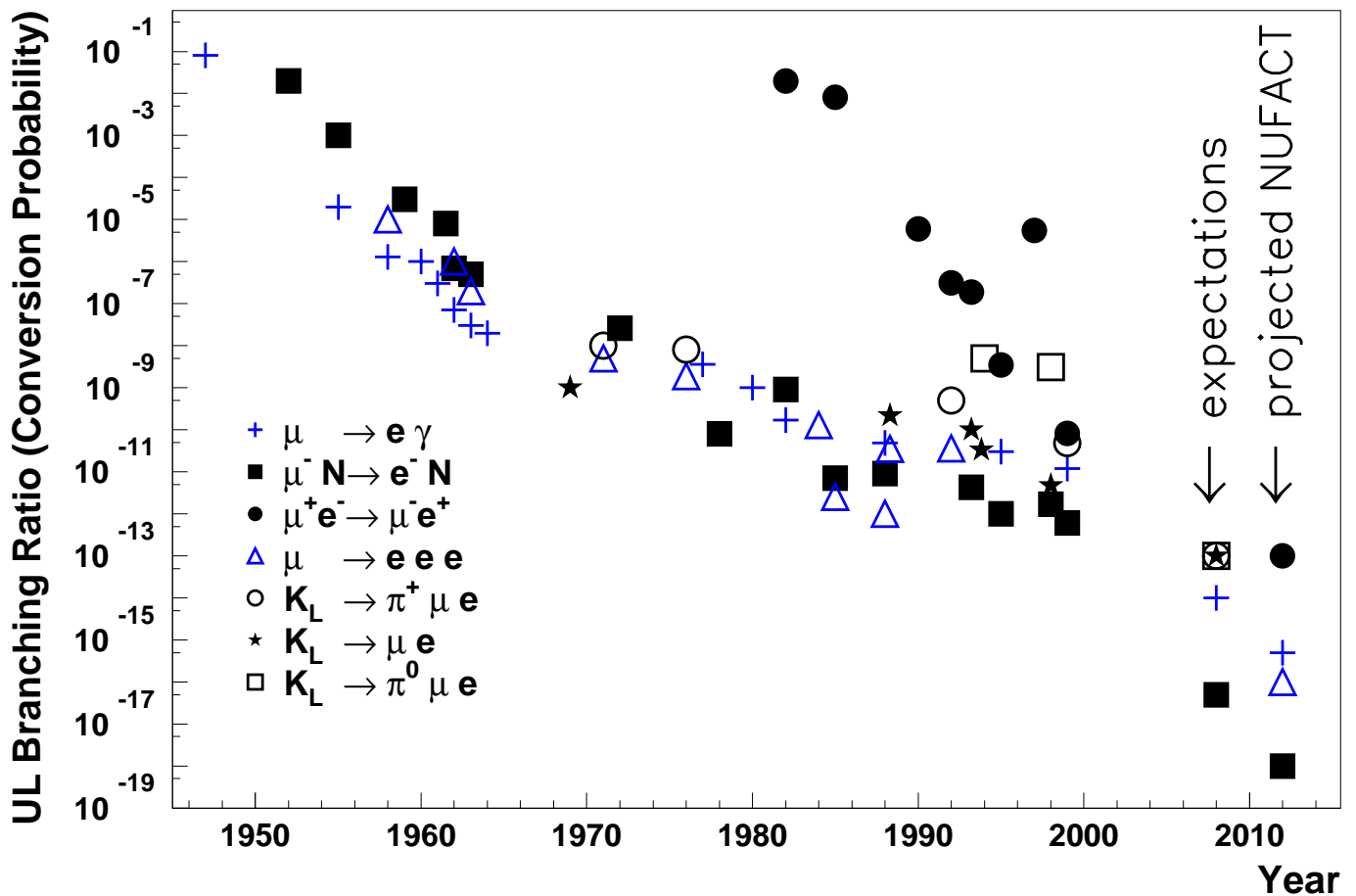
Assumptions: maximal mixing for atmospheric and LMA for solar sector, no CP-violation in ν mixing matrix and hierarchical μ masses.

Charged Lepton Flavor Violation*

historical development

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Searches for Lepton Number Violation

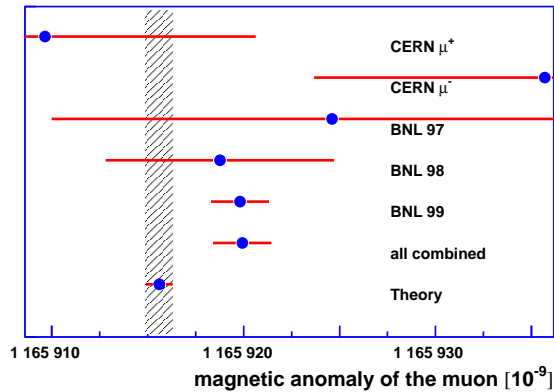


*: see presentation at October 2000 meeting

Muon $g-2$

BNL E821

H.N. Brown *et al.*, Phys.rev.Lett. **86** (2001) 2227.

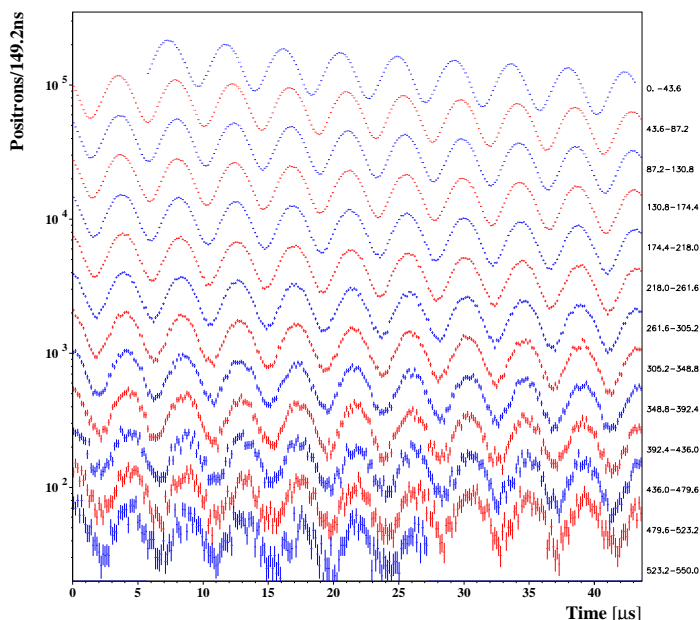


$g-2$ values from recent measurements and from the calculation by Davier and Höcker

Vernon Hughes:

1. new physics beyond the Standard Model, such as supersymmetry.
2. **small statistical probability** that the experimental and theoretical values are consistent.
3. although **unlikely**, there is always the possibility of mistakes in experiments and theories.

$E > 1.8\text{GeV}$, 70 million positrons (1999 Run)



sample of new data: no sign of background after ten dilated $64 \mu\text{s}$ lifetimes

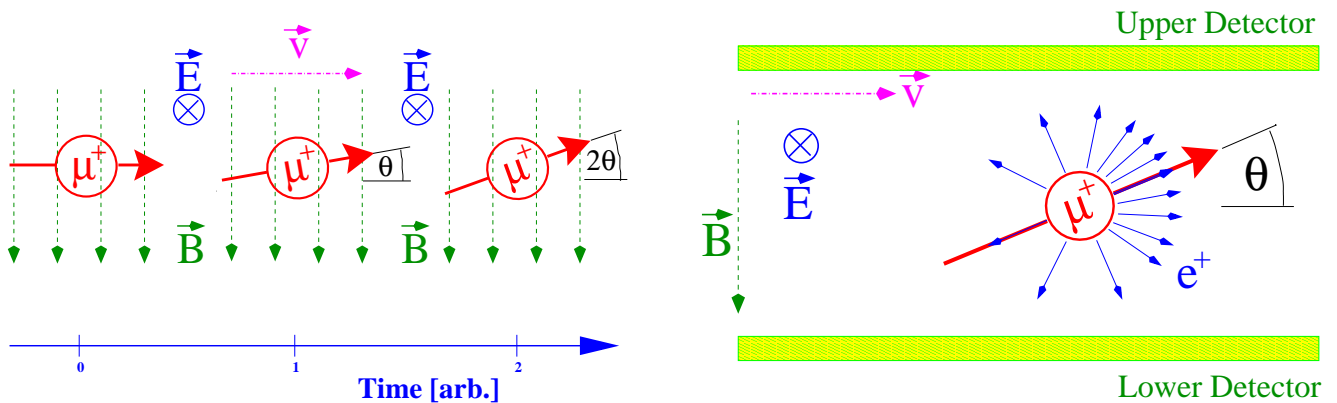
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Muon electric dipole moment

T violation

BNL g-2 collaboration

	edm (e.cm)
Standard Model:	10^{-35}
present limit:	10^{-18}
proposed sensitivity	10^{-24}
electron limit:	10^{-27}



Principle of a novel muon edm measurement.

Muons move in a magnetic storage ring with a radial E field superimposed. Θ would grow with time.

$$\vec{\omega} = -\frac{e}{m} \left\{ a \vec{B} + \left(\frac{1}{\gamma^2 - 1} - a \right) \frac{\vec{\beta} \times \vec{E}}{c} + \frac{\eta}{2} \left(\frac{\vec{E}}{c} + \vec{\beta} \times \vec{B} \right) \right\}$$

$$\text{edm}_\mu = \frac{\eta}{2} \frac{e \hbar}{2mc} \text{ e.cm}$$

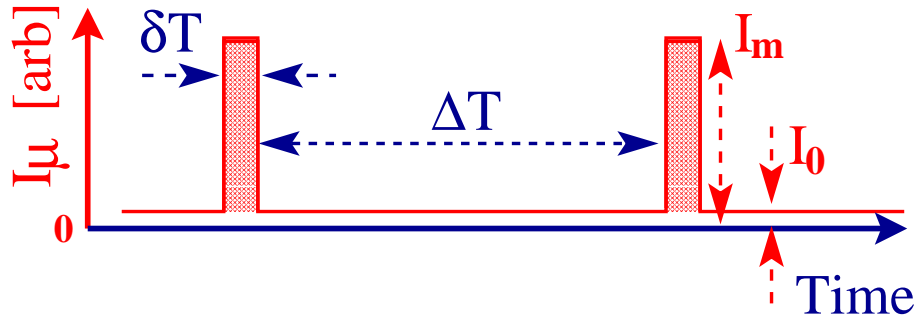
In a g-2 experiment one chooses $\frac{1}{\gamma^2 - 1} - a = 0$,
i.e. $\gamma = 29.3$

Here one chooses $a \vec{B} + \left(\frac{1}{\gamma^2 - 1} - a \right) \frac{\vec{\beta} \times \vec{E}}{c} = 0$,
i.e. $\gamma = 5$, $B = 0.24 \text{ T}$, $E = 2 \text{ MV/m}$.

Muon beam requirements

Tab.6 from report

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Experiment	q	N_μ	I_0/I_m <	δT < [ns]	ΔT > [μ s]	E_μ [MeV]	$\Delta p_\mu/p_\mu$ [%]
$\mu^- N \rightarrow e^- N^\dagger$	-	10^{21}	10^{-10}	100	1	20	< 10
$\mu^- N \rightarrow e^- N^\ddagger$	-	10^{20}	n/a	n/a	n/a	< 20	< 10
$\mu \rightarrow e\gamma$	+	10^{17}	n/a	n/a	n/a	1...4	< 10
$\mu \rightarrow eee$	+	10^{17}	n/a	n/a	n/a	1...4	< 10
$\mu^+ e^- \rightarrow \mu^- e^+$	+	10^{16}	10^{-4}	1000	20	1...4	1...2
τ_μ	+	10^{14}	10^{-4}	100	20	4	1...10
transv. pol.	+	10^{16}	10^{-4}	0.5	0.02	30-40	1...3
$g_\mu - 2$	\pm	10^{15}	10^{-7}	50	10^3	3100	10^{-2}
edm_μ	\pm	10^{16}	10^{-6}	50	10^3	1000	10^{-3}
M_{HFS}	+	10^{15}	10^{-4}	1000	20	4	1...3
M_{1s2s}	+	10^{14}	10^{-3}	500	10^3	1...4	1...2
μ^- atoms	-	10^{14}	10^{-3}	500	20	1...4	1...5
cond. matter (bio sciences)	\pm	10^{14}	10^{-3}	50	20	1...4	1...5

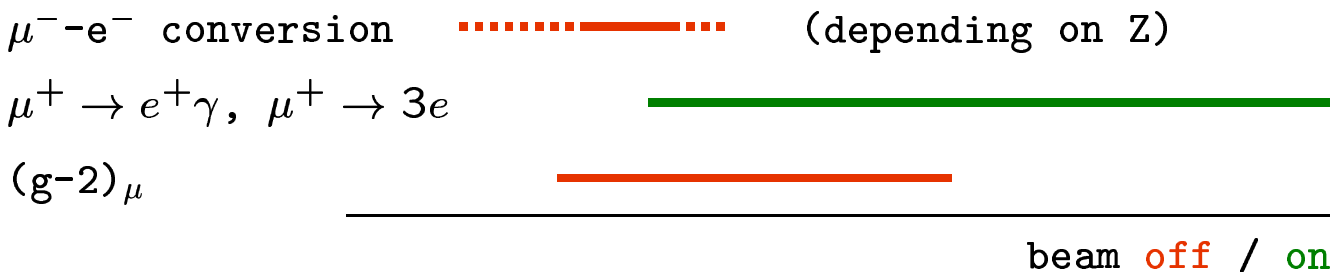
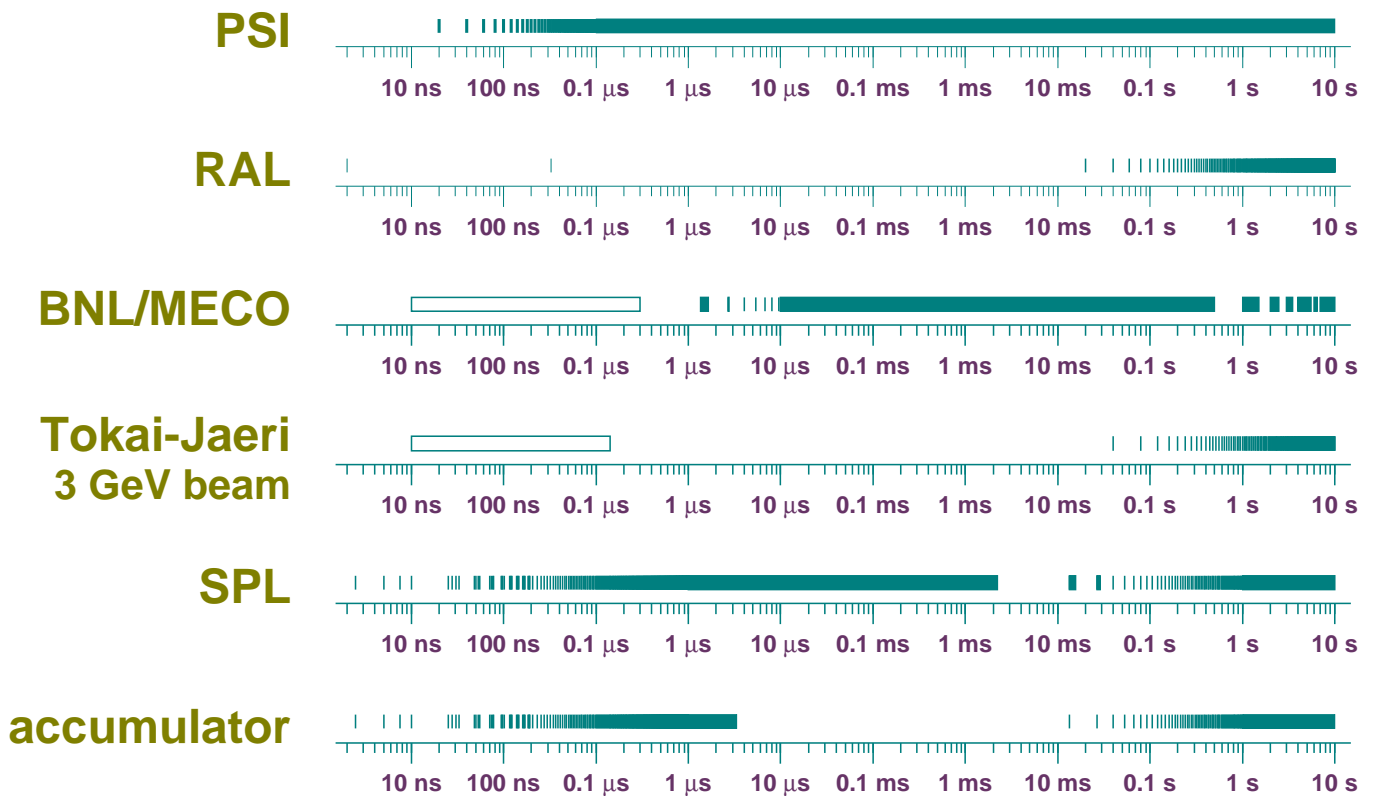
\dagger Scenario in which a pulsed beam is utilized.

\ddagger Scenario in which a continuous beam after the muon cooling stage is employed.

Proton time structure

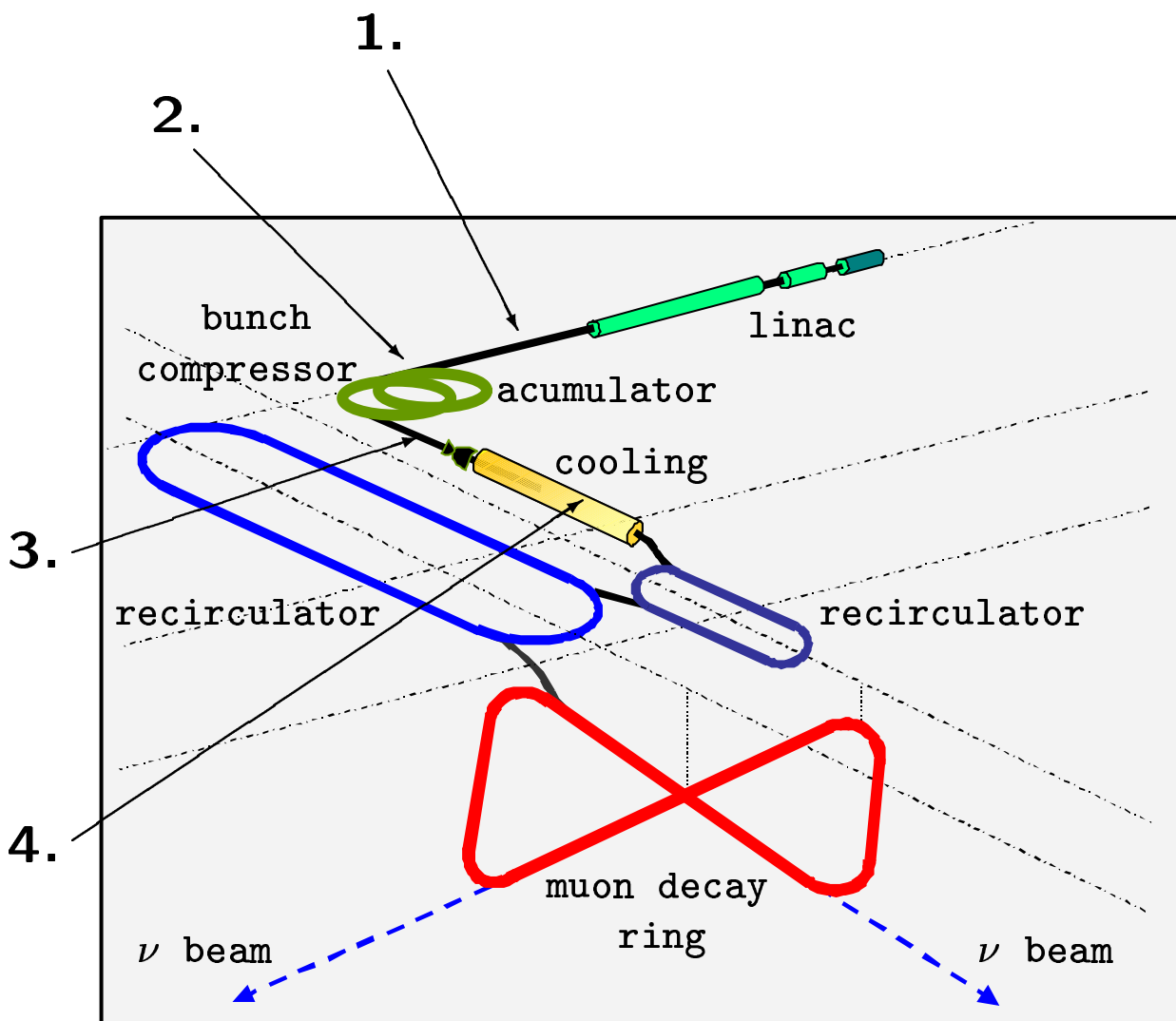
comparison with other accelerators

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Options for slow μ^\pm beams

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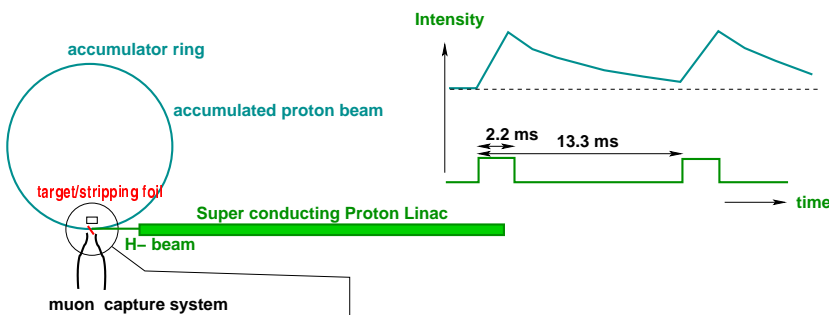
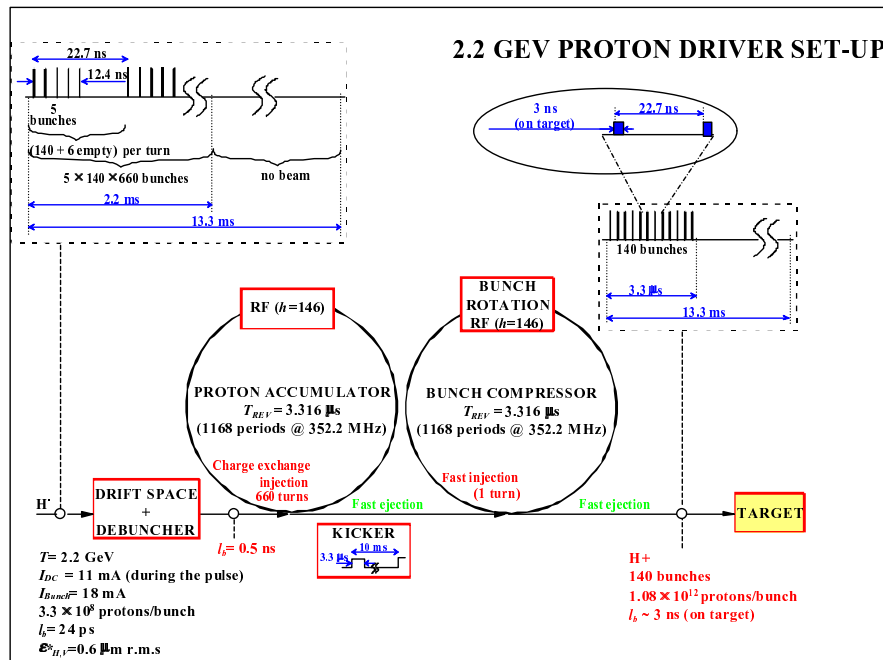


1. target for pulsed beam
2. thin target for quasi-DC beam
3. target for beam with dedicated time structure
4. target for pion-free pulsed beam

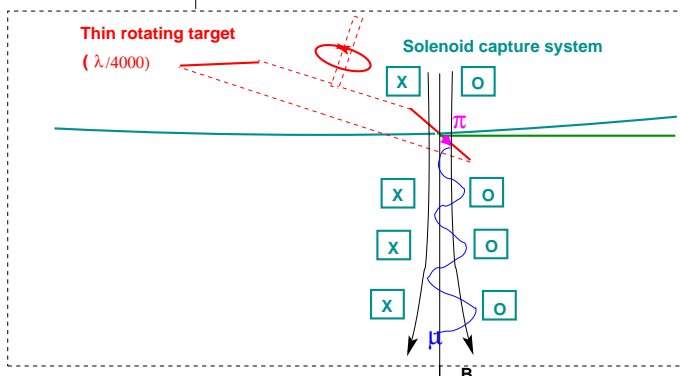
Internal target in accumulator

DC beams of surface μ^+ and cloud μ^-

Blondel, Fabre, Gilardoni, Vassilopoulos
CERN Neutrino Factory Note 6



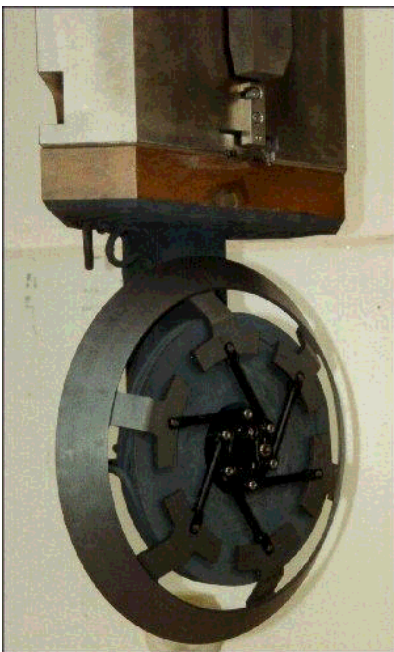
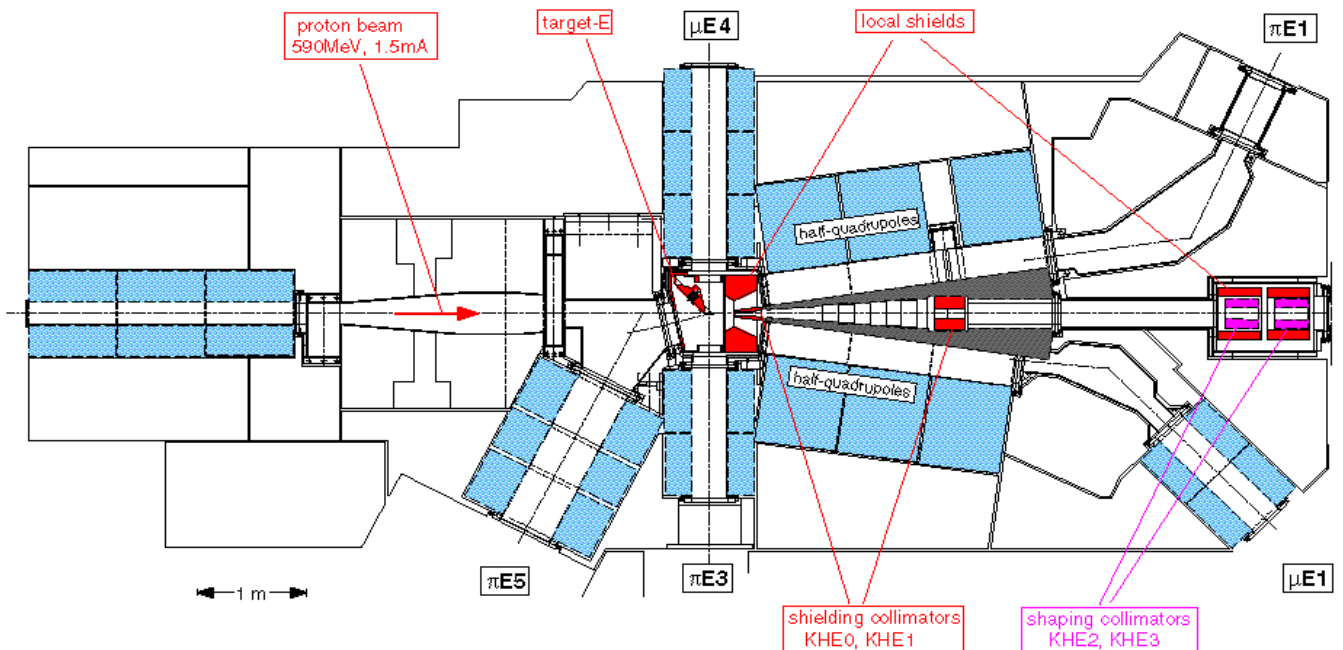
A DC beam from SPL?



A thin internal target for a quasi-continuous muon beam

PSI 6 cm production target for 1 MW proton beam

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target wheel

- 1.78 g/cm³ polycrystalline graphite
- mean diameter 45 cm
- length in beam direction 6 cm
- heating 45 kW for $I_p=1.5$ mA
- cooled by thermal radiation to 1500 K

Outlook

plans of the working group

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- low-energy muon physics contributes to many fields of basic research
- we know the beam intensities and time structures required for significant progress in most areas
- the CERN neutrino factory could deliver 10^{3-4} times more muons than available now
- work to be done:
 - set priorities in the program
 - define production targets and beam lines
 - work out most-promising experiments (μ -e conversion, g-2?)