SINDRUM II: Search for muon electron conversion in gold

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SINDRUM II collaboration

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Outline

- why search for lepton flavour violation
- muon electron conversion
- the SINDRUM experiment
- discussion of background
- results so far

Why search for LFV?

three (low-energy) lepton flavours

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix}_L \begin{pmatrix} e \end{pmatrix}_R \qquad \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}_L \begin{pmatrix} \mu \end{pmatrix}_R \qquad \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}_L \begin{pmatrix} \tau \end{pmatrix}_R$$

- Mass degeneracy of neutrinos leads to transitions *only within a flavour*
- Lepton flavour conservation is *not* based on fundamental symmetry
- Search for LFV is a search for „new physics“ beyond the SM

Many extensions to the SM suggest LFV:

- Left-right symmetric models
- Supersymmmetric models
- Superstring theories
- Theories with heavy neutral leptons

Need for some input (branching ratios) for these models to determine masses and coupling constants

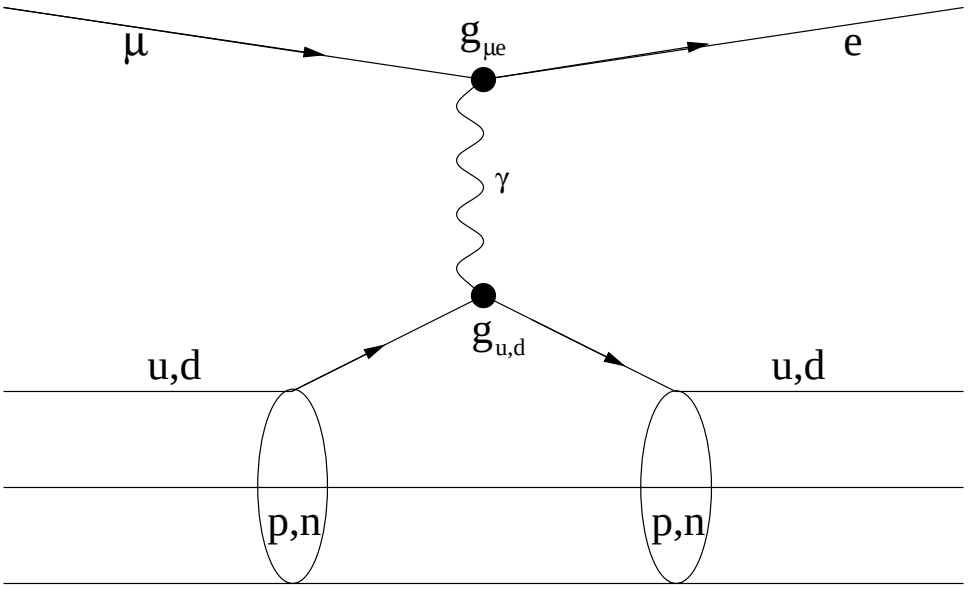
Do we have hints from neutrino oscillation experiments?

Process	Experiment	BR/upper limit
leptonic		
$\mu^+ \to e^+\gamma$	LAMPF XBox (1988)	$< 4.9 \cdot 10^{-11}$
$\mu^+ \to e^+e^-e^+$	SINDRUM (1988)	$< 1.0 \cdot 10^{-12}$
$\mu^- Ti \to e^- Ti$	SINDRUM II (1993)	$< 6.1 \cdot 10^{-13}$
$\mu^- Pb \to e^- Pb$	SINDRUM II (1996)	$< 4.6 \cdot 10^{-11}$
$\mu^- Ti \to e^+ Ca$	SINDRUM II (1997)	$< 1.7 \cdot 10^{-12}$
$\mu^- Ti \to e^+ Ca^*$	SINDRUM II (1997)	$< 3.6 \cdot 10^{-11}$ [a]
$\mu^- Au \to e^- Au$	SINDRUM II (1999)	$< 1.9 \cdot 10^{-11}$
$\mu^+ \to e^+\bar{\nu}_e\nu_\mu$	LAMPF E 645 (1993)	$< 1.2 \cdot 10^{-2}$
$\mu^+e^- \to \mu^-e^+$	PSI M$\overline{\text{M}}$ (1996)	$< 3.6 \cdot 10^{-9}$
$\tau \to \mu\gamma$	CLEO II (1997)	$< 3.0 \cdot 10^{-6}$
$\tau \to e\gamma$	CLEO II (1997)	$< 2.7 \cdot 10^{-6}$
$\tau \to \mu\mu\mu$	CLEO II (1998)	$< 1.9 \cdot 10^{-6}$
$\tau \to \mu\mu e$	CLEO II (1998)	$< 1.5 \cdot 10^{-6}$
$\tau \to \mu ee$	CLEO II (1998)	$< 1.5 \cdot 10^{-6}$
$\tau \to eee$	CLEO II (1998)	$< 2.9 \cdot 10^{-6}$
semi-leptonic		
$Z_0 \to \mu e$	OPAL (1995)	$< 1.7 \cdot 10^{-6}(95\,\%)$
$Z_0 \to \tau e$	OPAL (1995)	$< 9.8 \cdot 10^{-6}(95\,\%)$
$Z_0 \to \tau\mu$	DELPHI (1997)	$< 1.2 \cdot 10^{-5}(95\,\%)$
$K^+ \to \pi^+\mu e$	BNL E777 (1990)	$< 2.1 \cdot 10^{-10}$
$K_L^0 \to \mu e$	BNL E791 (1993)	$< 3.3 \cdot 10^{-11}$
$B^0 \to \mu e$	CLEO II (1994)	$< 5.9 \cdot 10^{-6}$
$B^0 \to \tau e$	CLEO II (1994)	$< 5.3 \cdot 10^{-4}$
$B^0 \to \tau\mu$	CLEO II (1994)	$< 8.3 \cdot 10^{-4}$
$B^0 \to K\mu e$	CLEO II (1994)	$< 1.5 \cdot 10^{-5}$

[a] für resonante Ca–Kernanregung (Breite $20\,MeV$, Anregung $20\,MeV$)

μ-e conversion

$$\mu^- + (Z, N) \longrightarrow e^- + (Z, N)$$



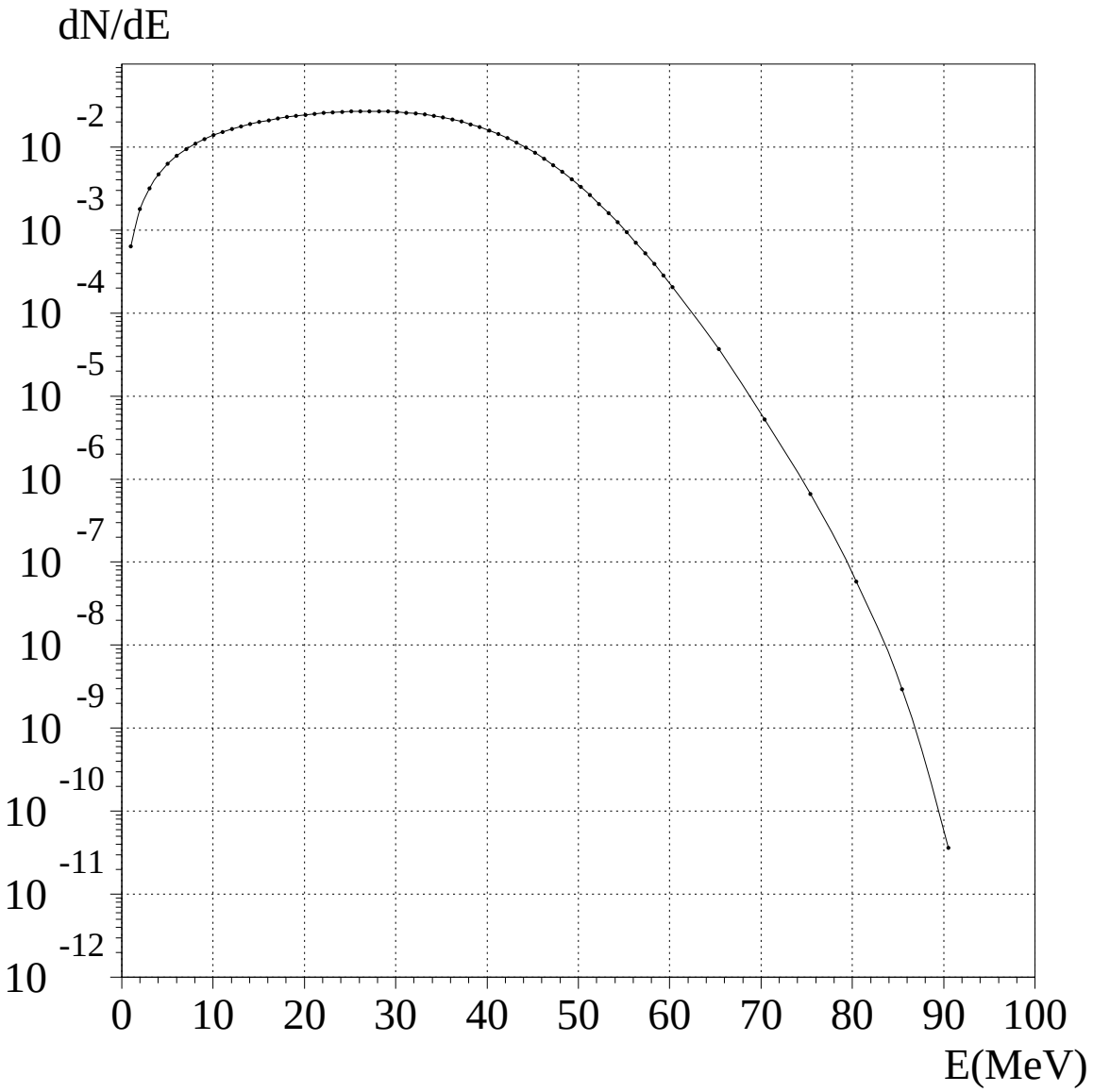
- Simple signature: electron with energy

$$E_{\mu e} = m_\mu - B_\mu - R_{\mathrm{atom}}$$

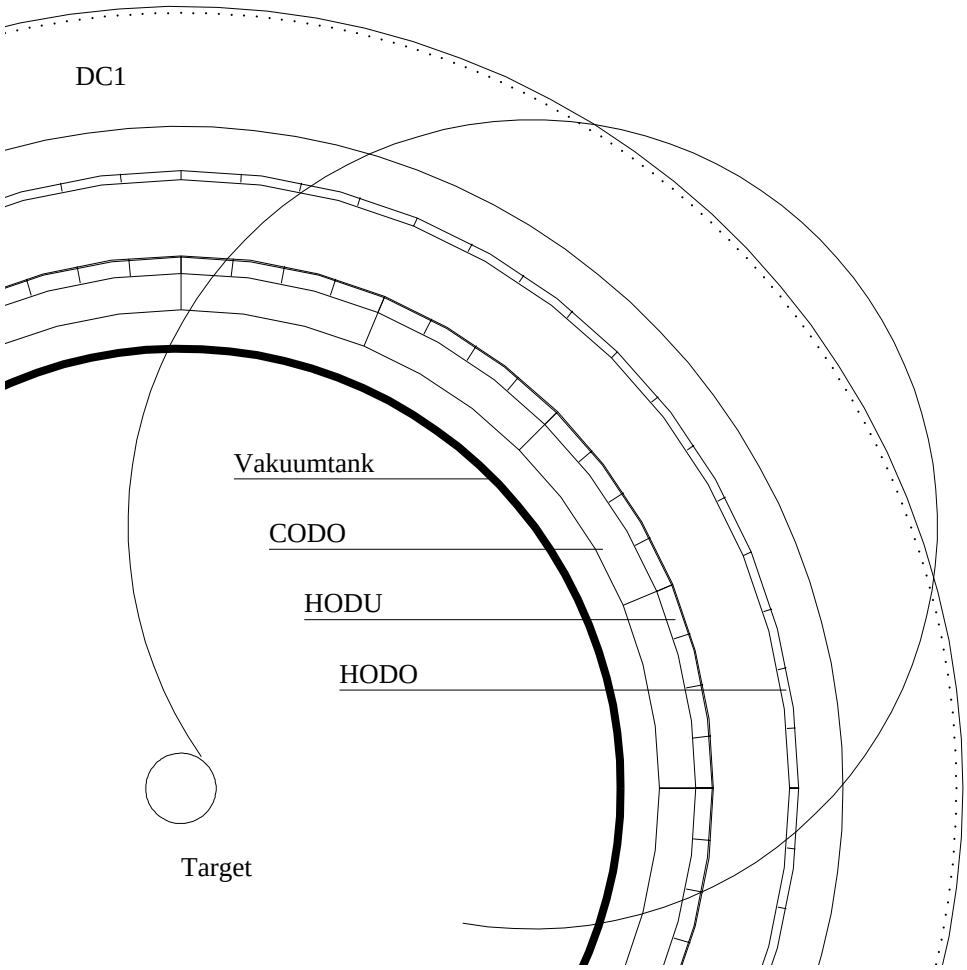
- Enhancement due to coherence effects

Intrinsic background: muon decay in orbit („MIO“)

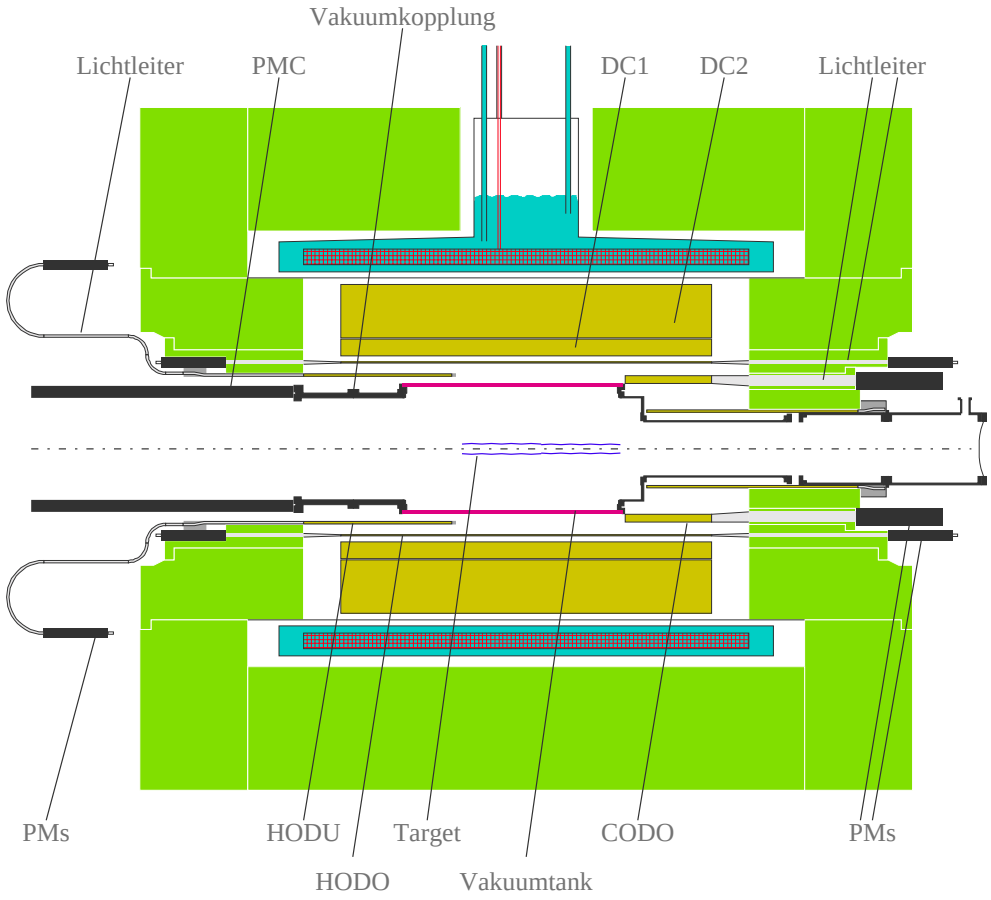
$$\mu^- + (A, Z) \longrightarrow e^- + \bar{\nu}_e + \nu_\mu + (A, Z)$$



SINDRUM II spectrometer

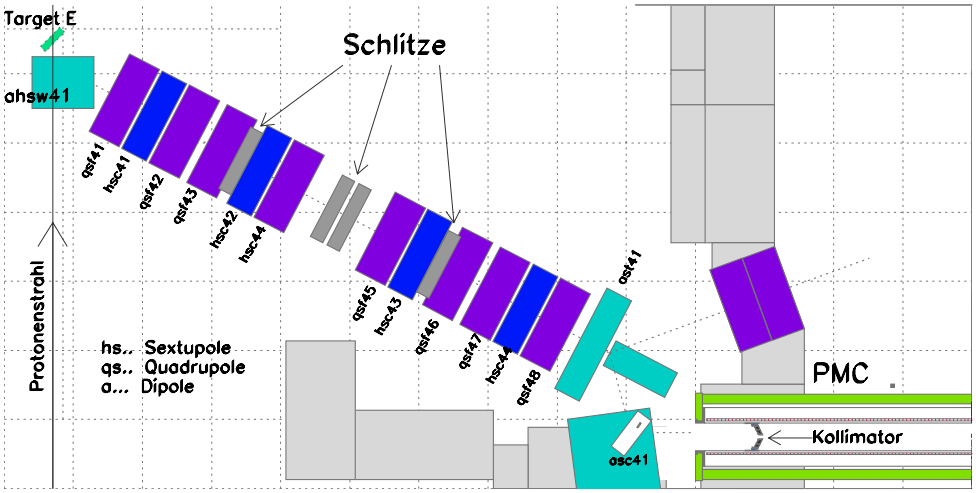


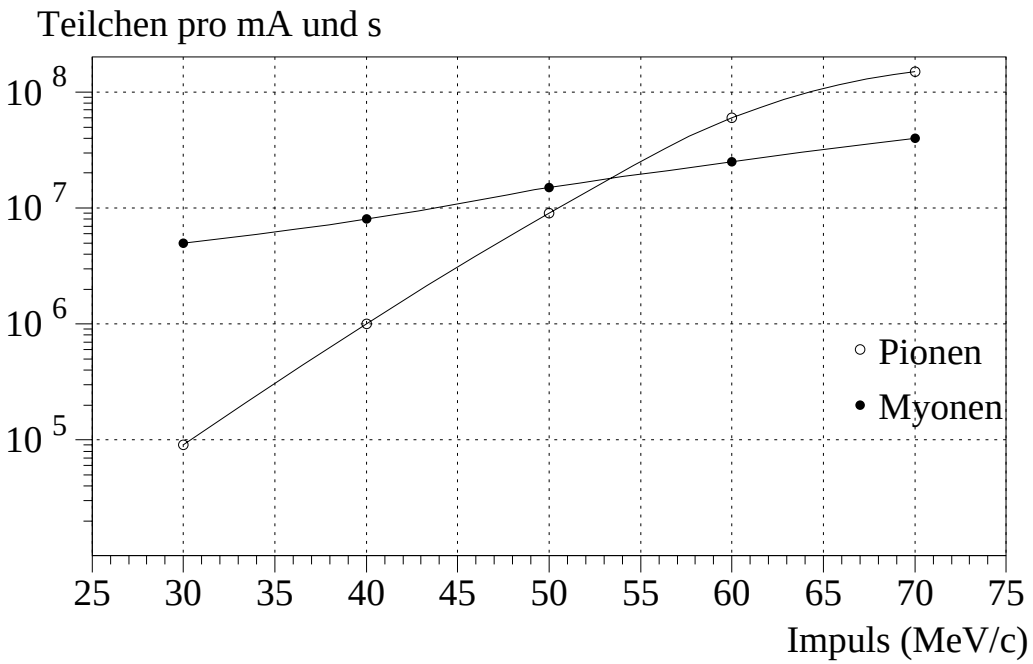
SINDRUM II spectrometer



component	radius	numb. of chan.
HODO	35.1 cm	64
HODU	30.25 cm	64
CODO	30.0 cm	32
DC1	44.07 cm	384 anodes 2x192 cathodes

Beamline

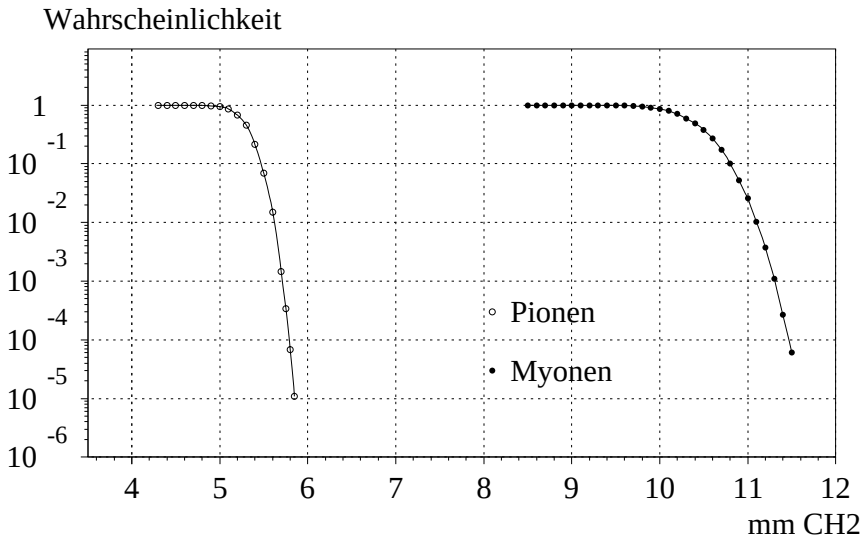

Target E
ahsw41
Schlitze
qsf41
hsc41
qsf42
qsf43
hsc42
hsc44
qsf45
hsc43
qsf46
qsf47
hsc45
qsf48
qsf41
Protonenstrahl
hs.. Sextupole
qs.. Quadrupole
a... Dipole
PMC
Kollimator
asc41

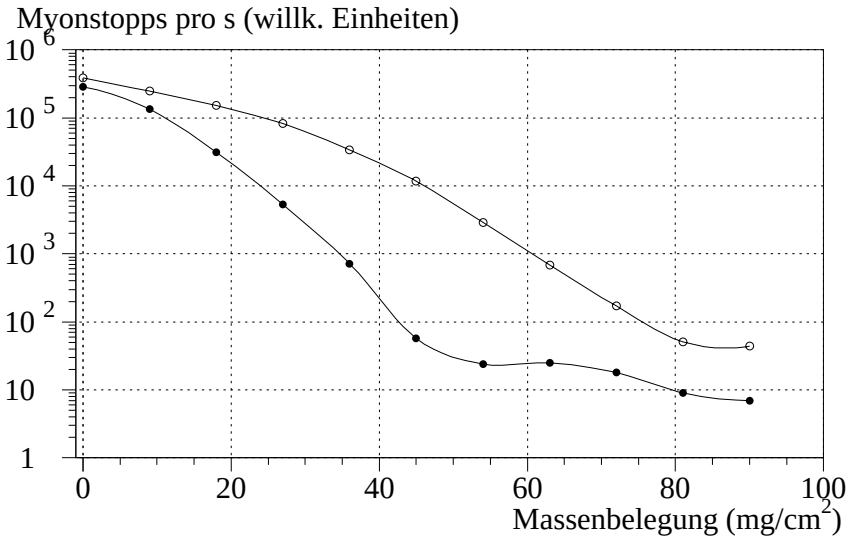

Teilchen pro mA und s
10 8
10 7
10 6
10 5
25
30
35
40
45
50
55
60
65
70
75
Impuls (MeV/c)
Pionen
Myonen

Background from radiative pion capture (RPC)

$$\pi^- + (Z, N) \longrightarrow (Z-1, N+1)^* + \gamma$$

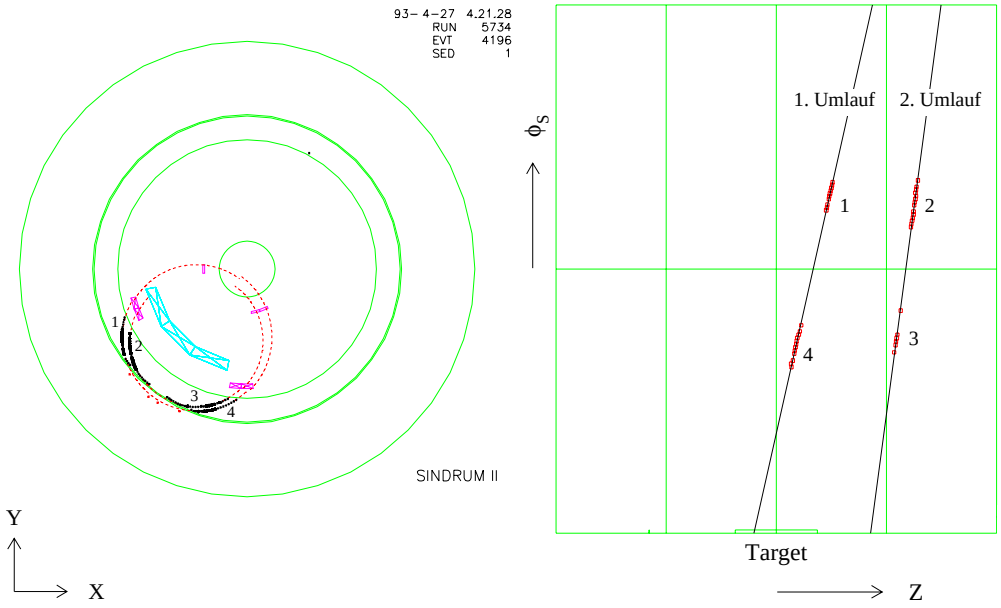
$$\gamma \longrightarrow e^+ + e^-$$



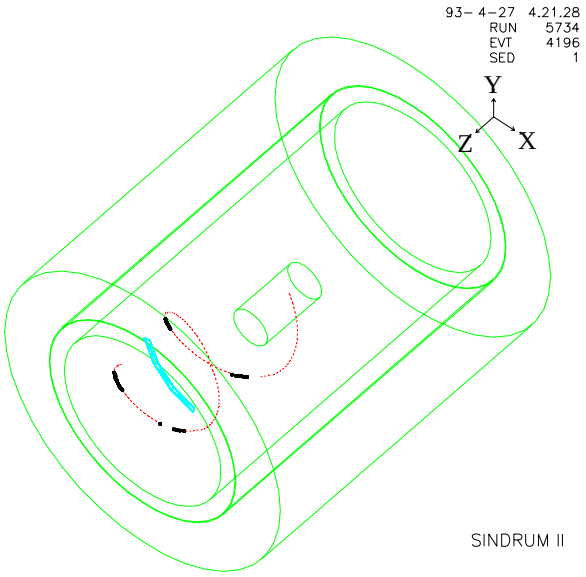


Event reconstruction

Tracks in r-ϕ-plane

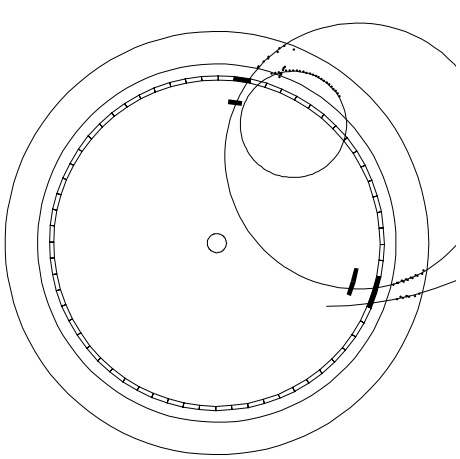


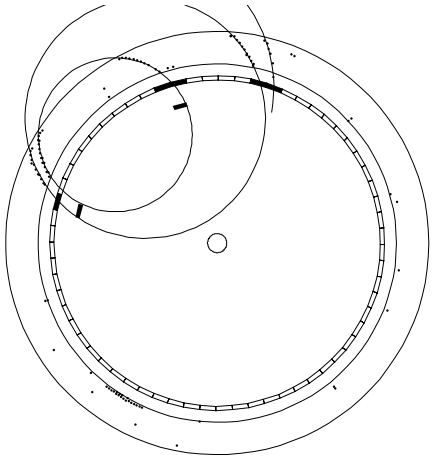
Three-dimensional tracks using cathode chains:



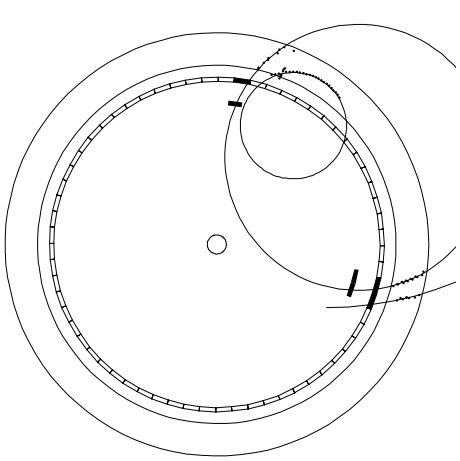
Cosmic background

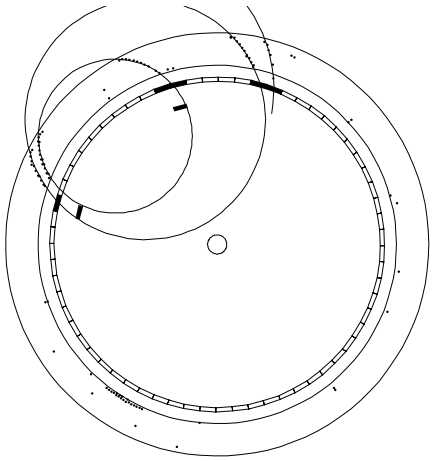
Low-energy electrons spiraling in:





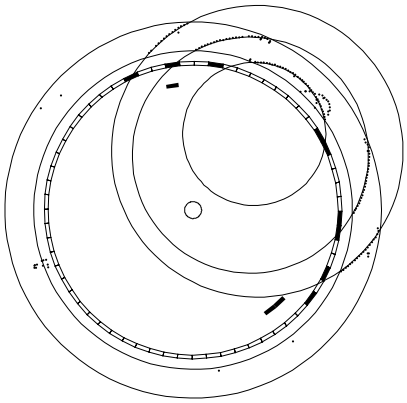
High-energy particles triggering low-energy electron:

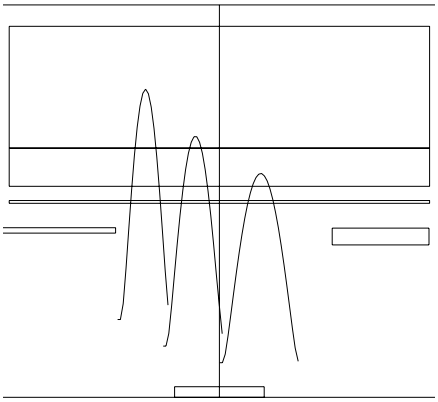


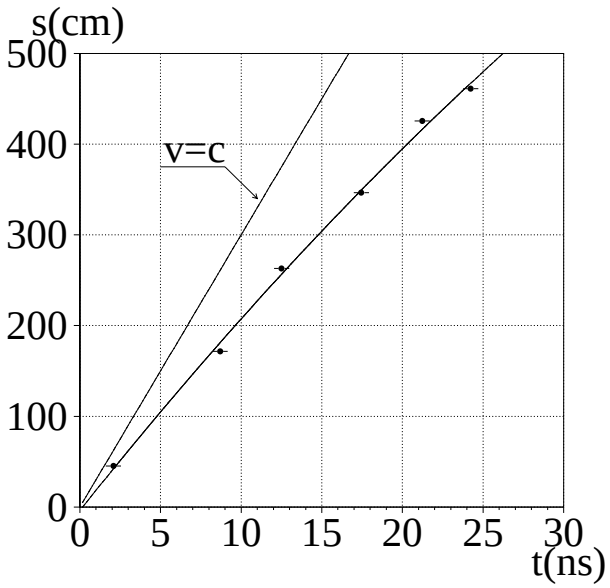


Cosmic background

Low-energy muon spiraling in:







Summary of results from earlier measurements

Branching ratio $\equiv \frac{\Gamma(\mu \to e)}{\Gamma(\text{capture})}$

μ^- Pb $\to e^-$ Pb:	4.6*10^{-11} (90%)
μ^- Ti $\to e^-$ Ti:	6.1*10^{-13} (90%)
μ^- Au $\to e^-$ Au:	1.9*10^{-11} (90%)

μ^- Ti $\to e^+$ Sc^{gs}:	1.7*10^{-12} (90%)
μ^- Ti $\to e^+$ Sc*:	3.6*10^{-11} (90%)