From Wolfgang Paul to eEDM : Why – and why in Bonn?

Wolfgang Hillert

Physics Institute of Bonn University

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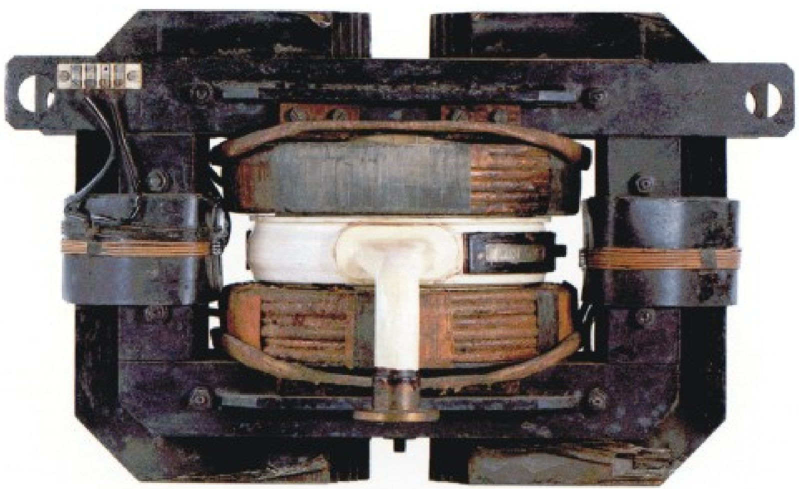
1. Acc. and Nucl. Physics in Bonn
2. Phys. Motivation of EDM Meas.
3. EDM Meas. Principle
4. Challenges of EDM Meas.
5. Possible Realisation
6. Task of JLAB-Visit

Accelerator and Nuclear Physics in Bonn

From the first AG synchrotron in Europe to ELSA

The Beginning

Wolfgang Paul



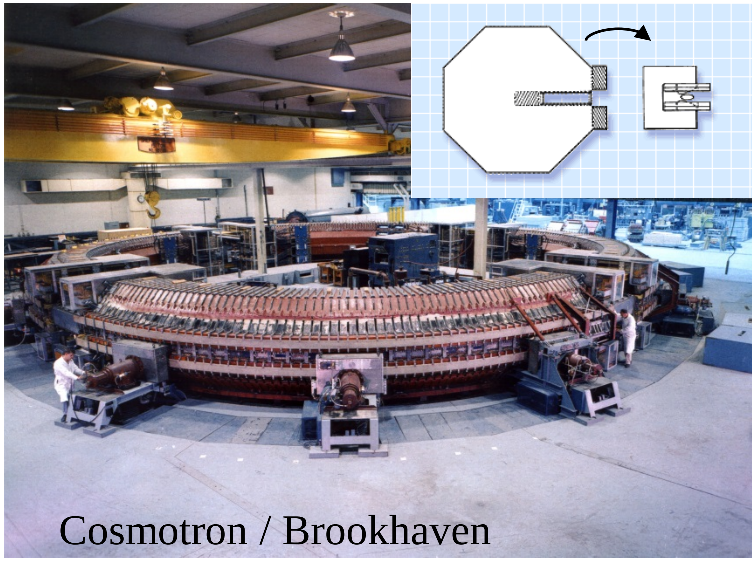
6 MeV Betatron Göttingen

1952: Göttingen → Bonn

1953: Planning of a AG synchrotron

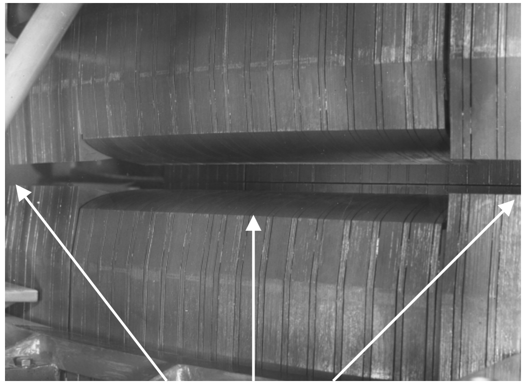
first idea: 100MeV → 500MeV

1952: AG –Focusing:
Courant, Livingston and Snyder
Phys. Rev., **88**, 1952
(Christofilos for patent already 1950 !)



Cosmotron / Brookhaven

Bending Magnets:



horizontal defocusing

½D – F – ½D

horizon

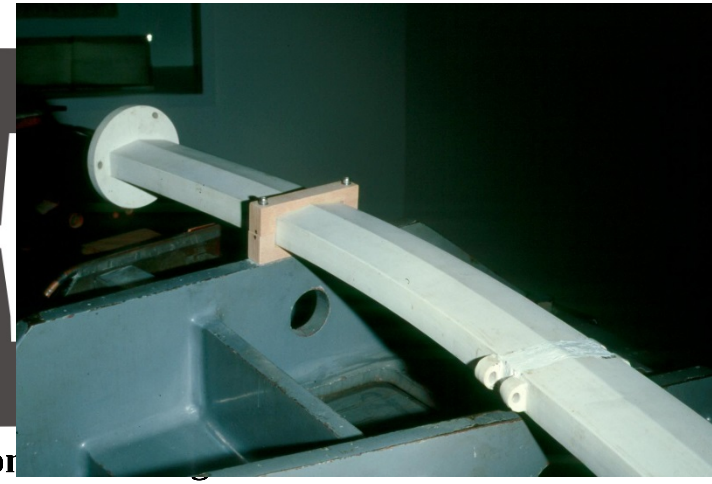
MeV

m

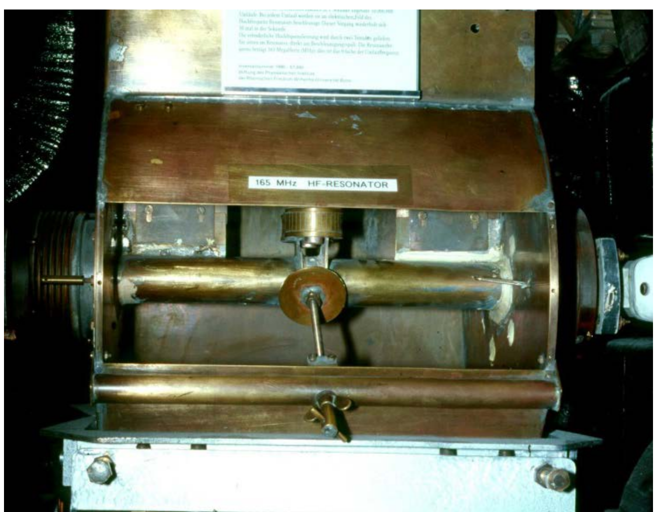
la

m

Vacuum Chamber:



6 Accelerating Cavities:



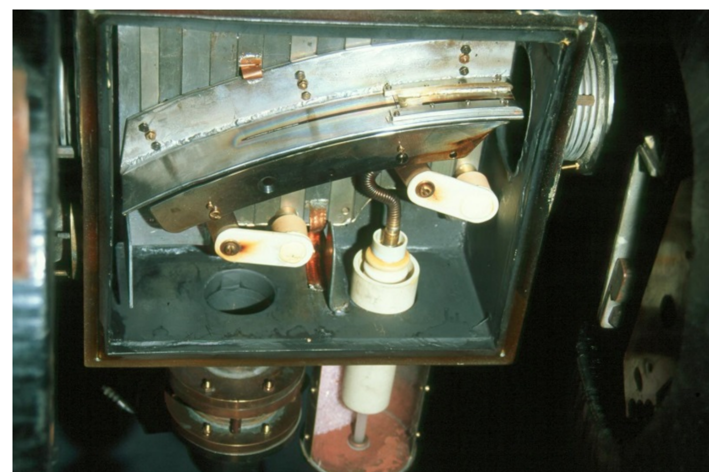
frequency:
163.1MHz ±1%

peak voltage:
2.5 kV

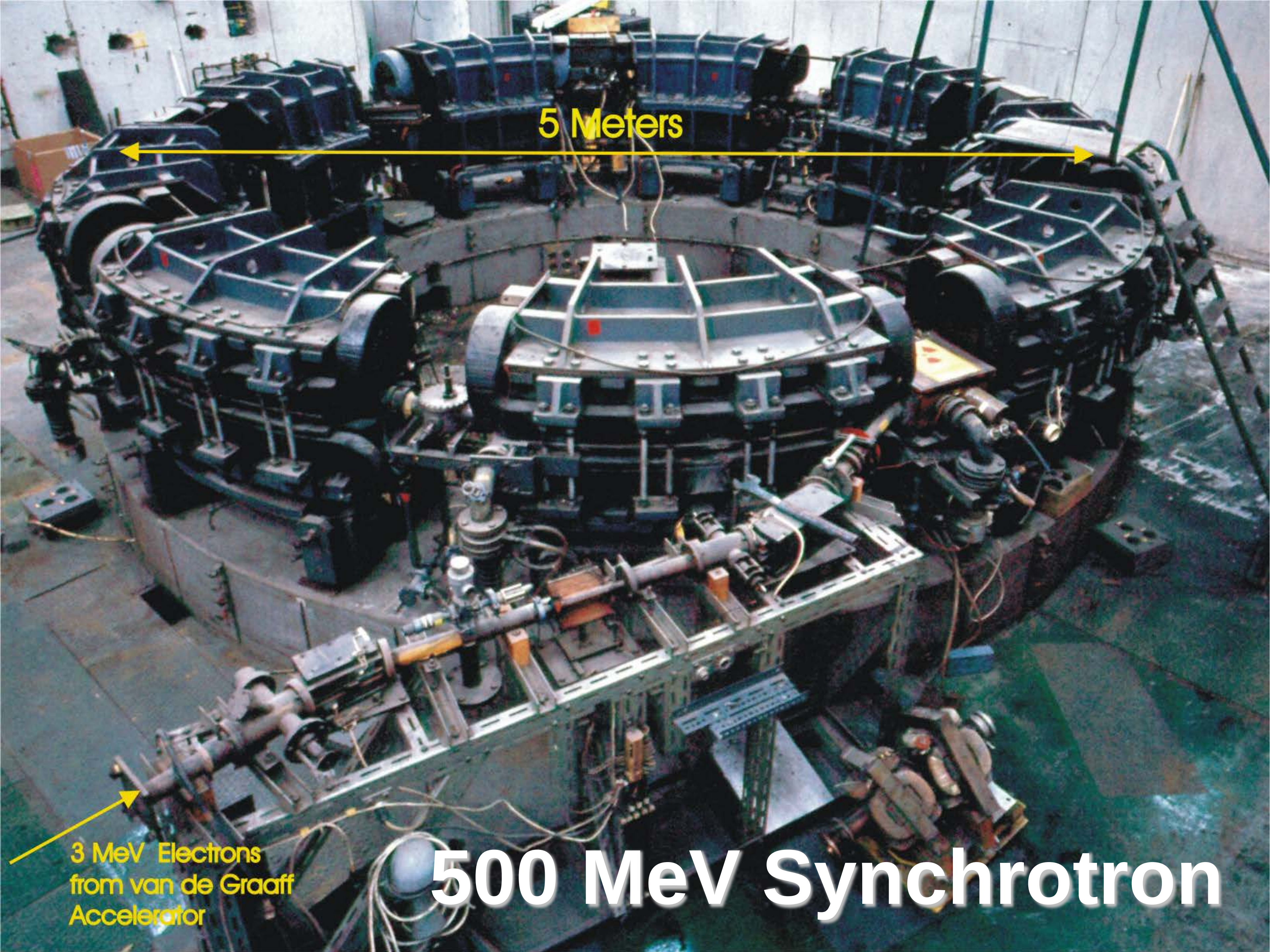
RF amplifier:
coax. tetrodes

acc. gap:
≈10 mm

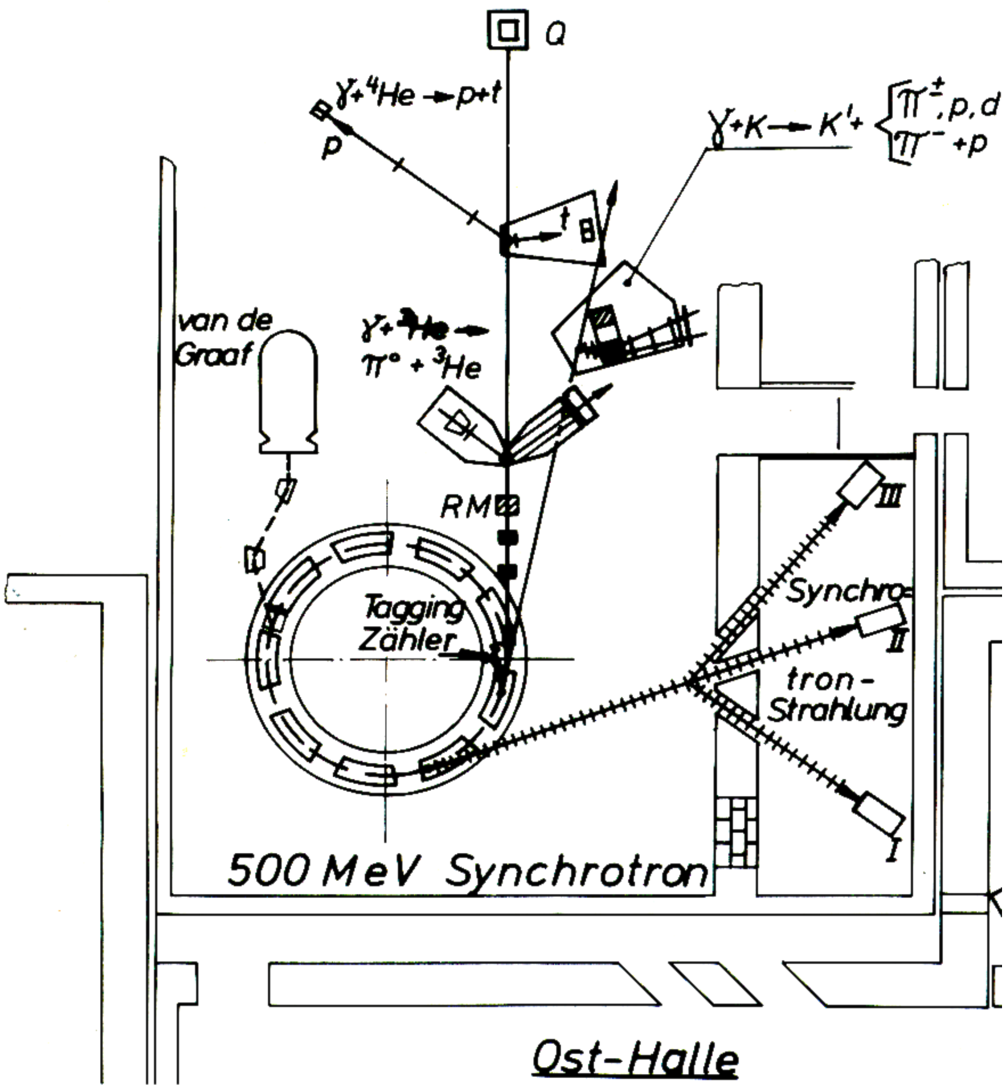
Particle Injection:



60 kV electrostatic deflector


5 Meters
3 MeV Electrons from van de Graaff Accelerator
500 MeV Synchrotron

Experiments 1958-1984:



Beam Characteristics:

I = 30mA, rep. rate = 50 Hz, DC = 5%

2 γ-beams, produced by rotating targets

Experimental Set-Up:

- magnetic spectrometer
- range telescope
- time of flight telescope
- lead glass Cerenkov counters

Photoproduction of Mesons:

$\gamma p \to \pi^+ n,\ \pi^0 p;\qquad \gamma n \to \pi^- p,\ \pi^0 n$

diff. cross sections, **recoil n-polarization**

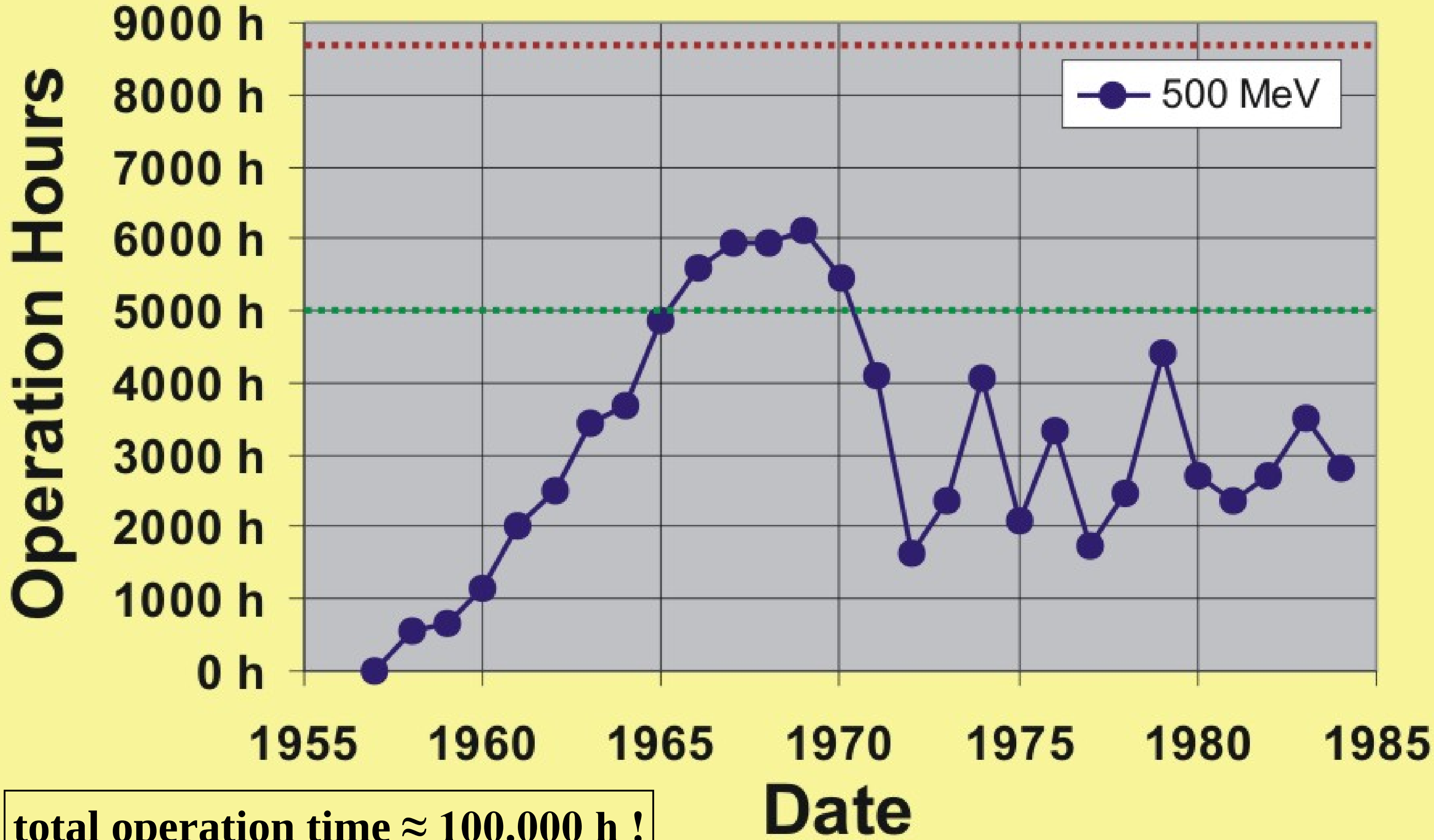
$\gamma d \to \pi^0 d,\ \pi^0 pn$ (coherent., incoherent)

Other Experiments:

2-body disintegration of ^3He / ^4He

π-production at ^3H / ^3He

Statistics:



total operation time ≈ 100.000 h !

150 diploma / doctoral theses @ 500 MeV Synchrotron

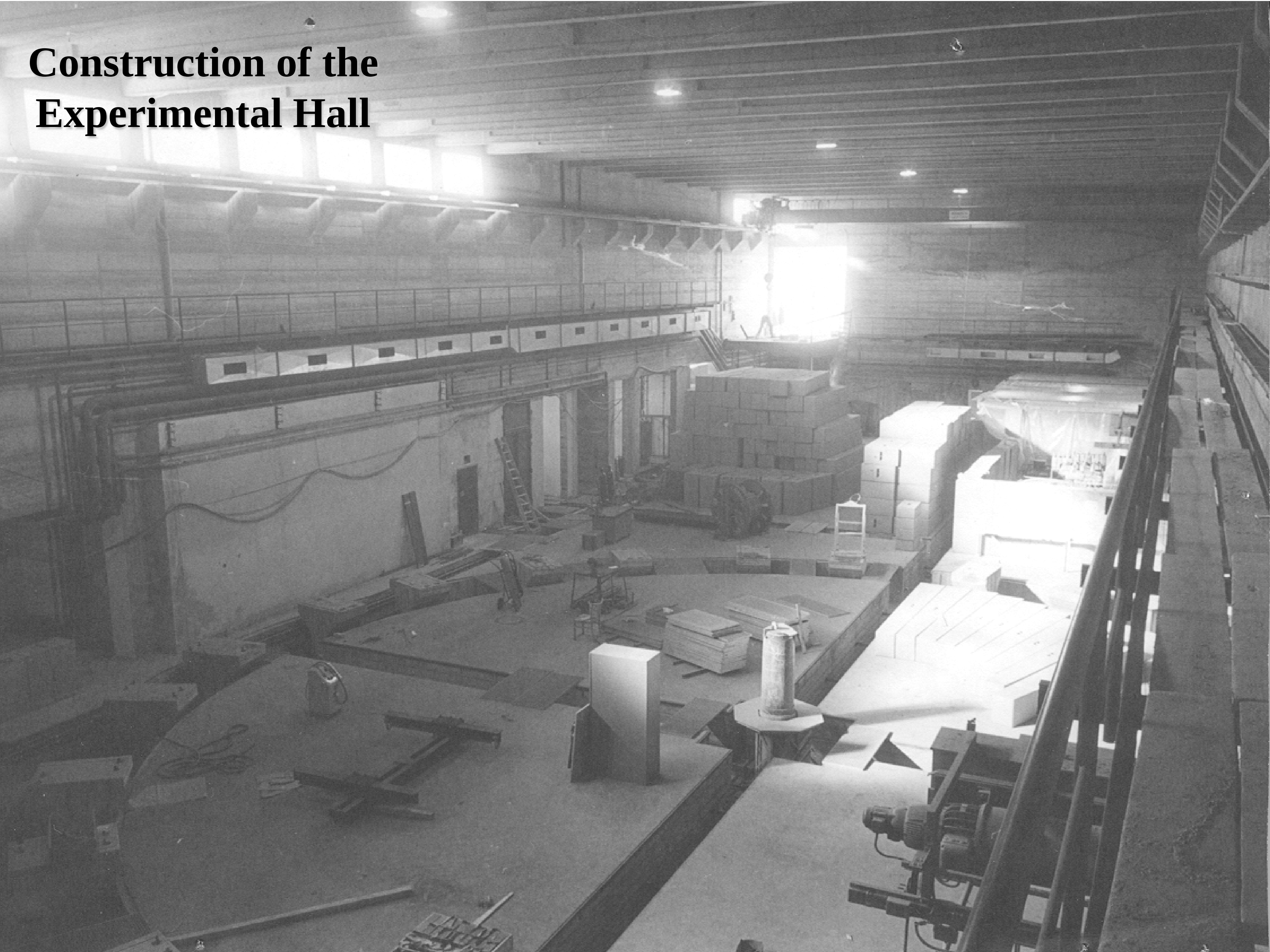
1965: Beginning of the Constructions

Investigation of higher-lying Baryon Resonances

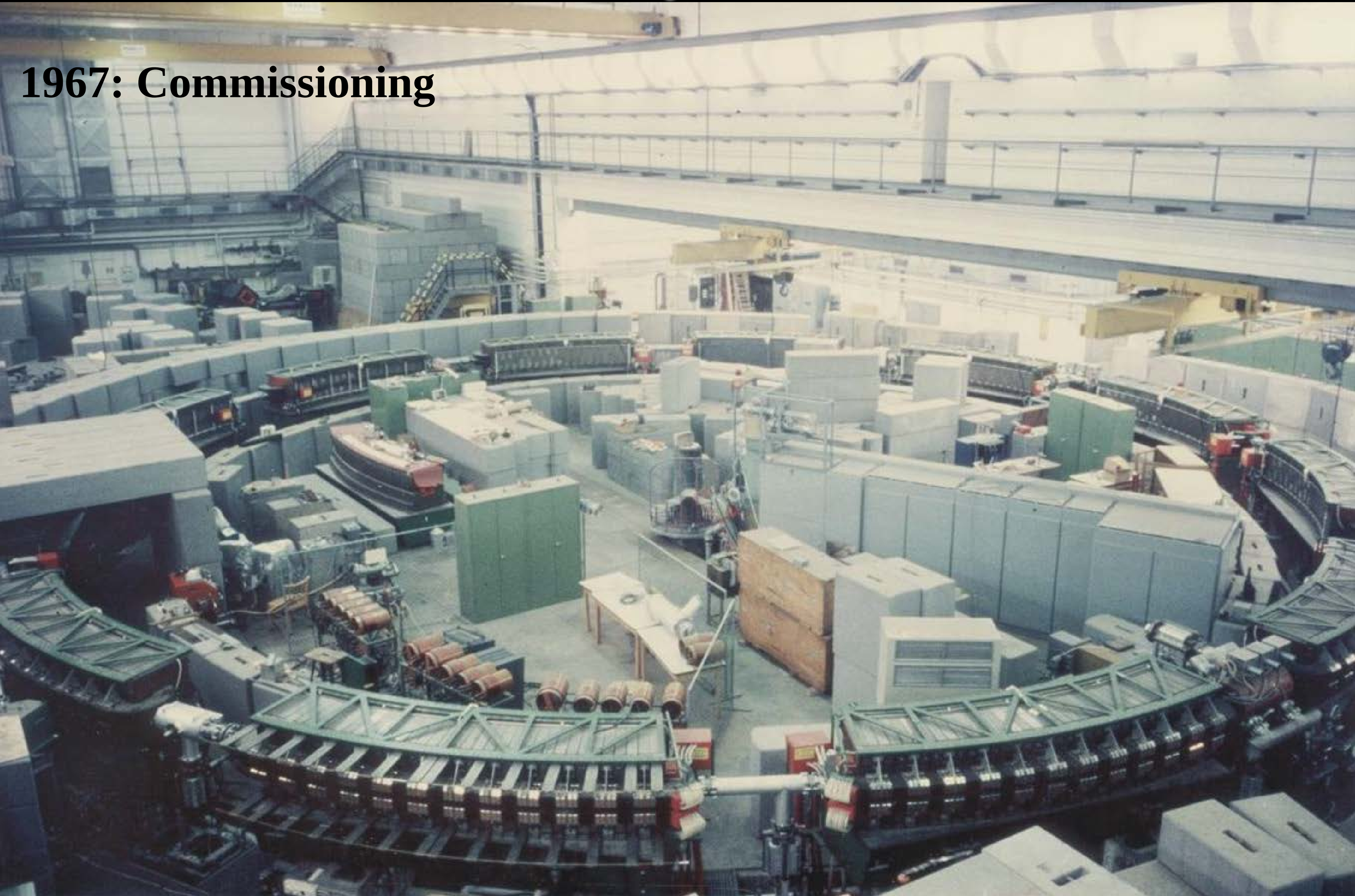
500 MeV → 2.3 GeV

1963: Design of a 2.3 GeV Synchrotron

Construction of the Experimental Hall



2.3 GeV Synchrotron



1967: Commissioning

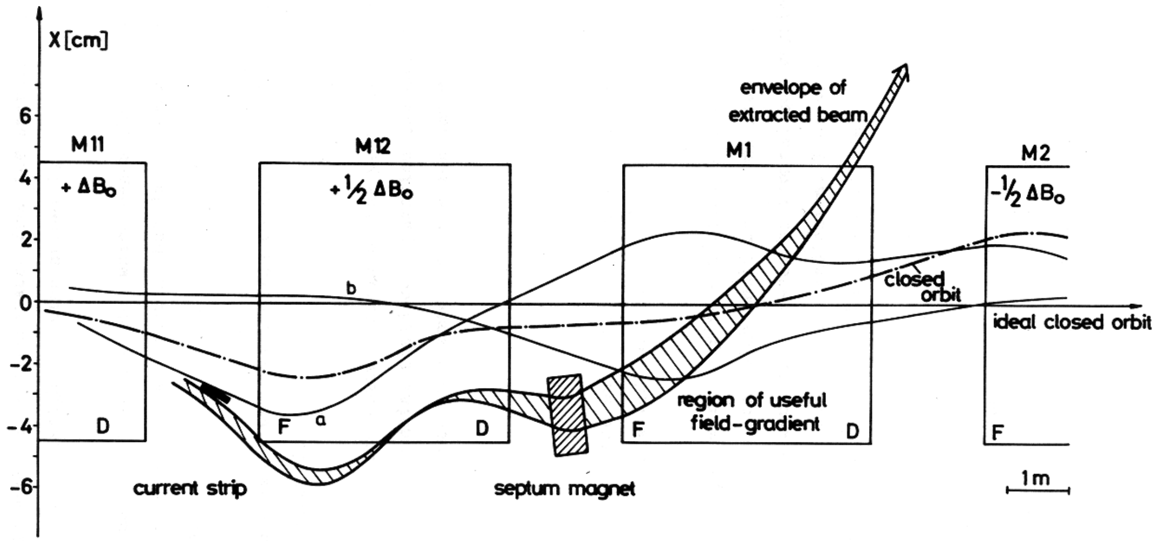
External Beams

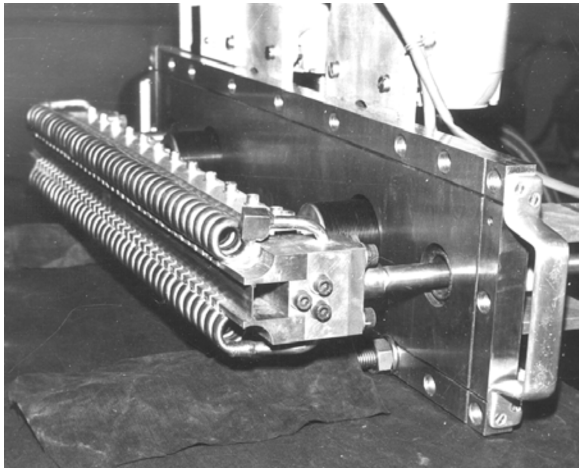
External Photon-Beams:

- produced be synchronous rotating tungsten rods
- spill time of about 1ms → duty cycle = 5%
- exit through small aluminum windows

External Electron Beam:

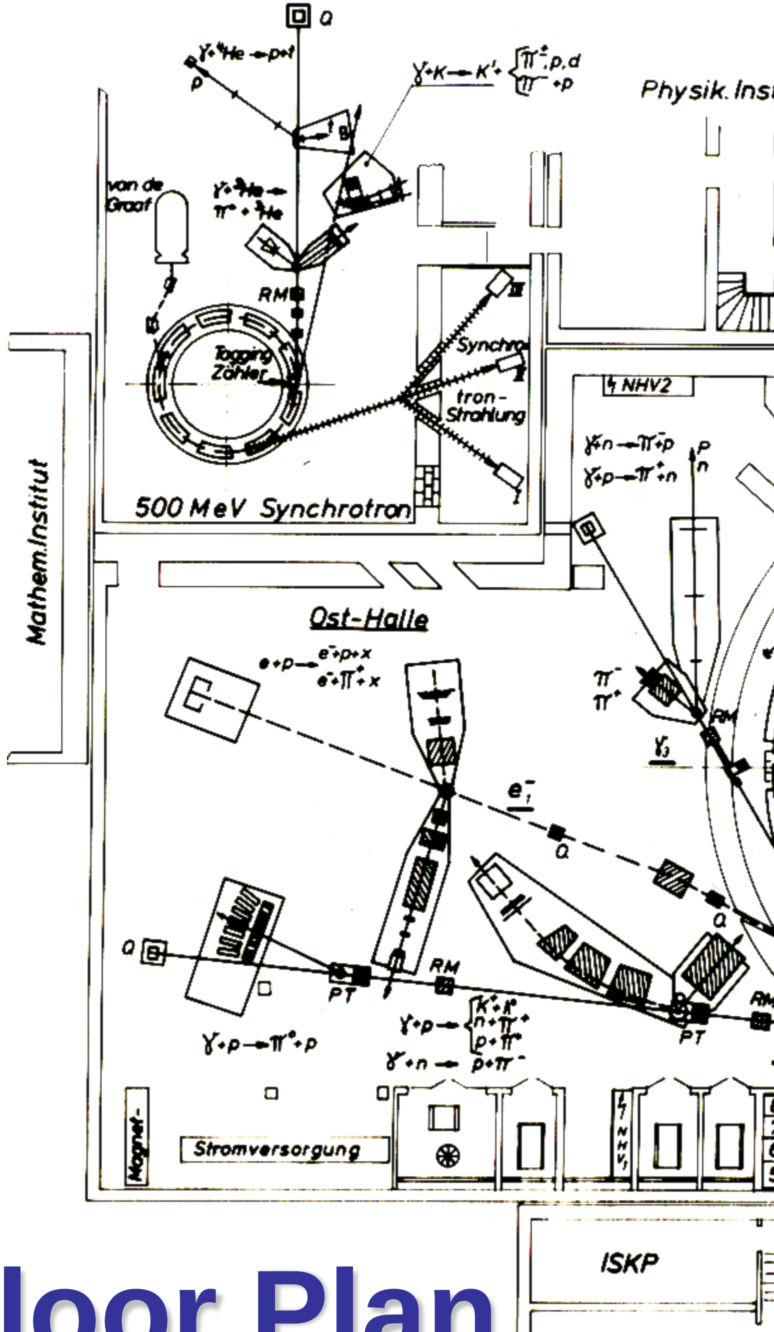
- slow extraction on a half integer resonance





Current Strip

Floor Plan



Experiments 1967–1985:

Beam Characteristics:

I = 30-60mA, rep. rate = 50 Hz, DC = 5%

5 γ-beams, 1 external electron beam

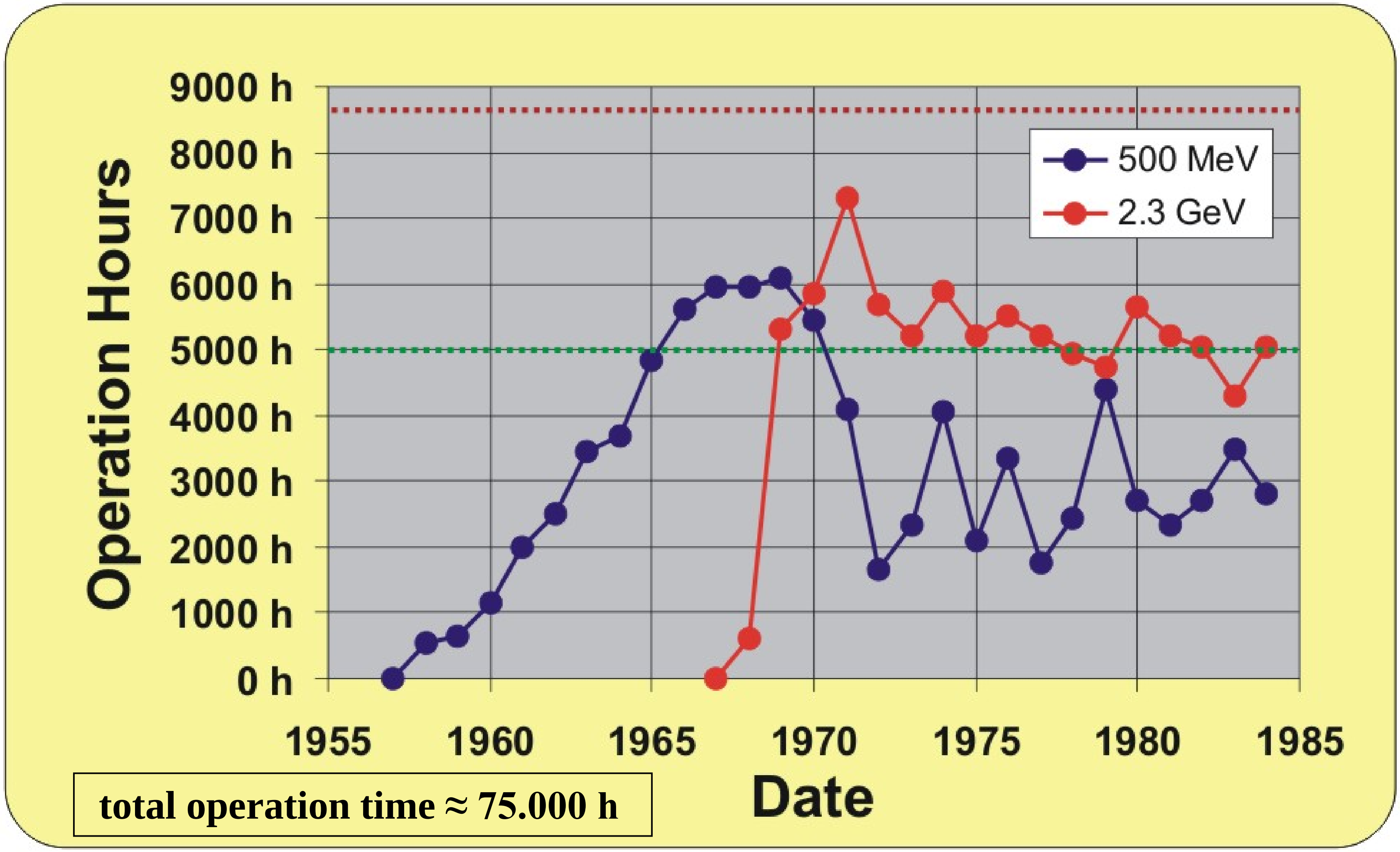
Targets:

- liquid hydrogen, liquid deuterium,
- meas. of the recoil nucleon polarization,
- **polarized $\vec{p}$, $\vec{n}$ and $\vec{d}$ targets ($\vec{p}$ since 1970)**

$\gamma p \to K^+\Lambda^0,\ K^+\Sigma^0$:	$d\sigma/d\Omega$, P_Λ, T
$\gamma p \to \pi^0 p,\ \pi^+ n$:	$d\sigma/d\Omega$
$\vec{\gamma} p \to \pi^+ n$:	Σ
$\vec{\gamma} d \to pn$:	Σ
$\gamma p \to \pi^0 \vec{p}$:	P
$\gamma \vec{p} \to \pi^0 p, \pi^+ n$:	T
$\gamma \vec{n} \to \pi^- p$:	T
$\gamma \vec{d} \to pn$:	T
$\gamma p \to \gamma p$:	$0.7 < E\gamma < 0.9$GeV

…

Statistics again

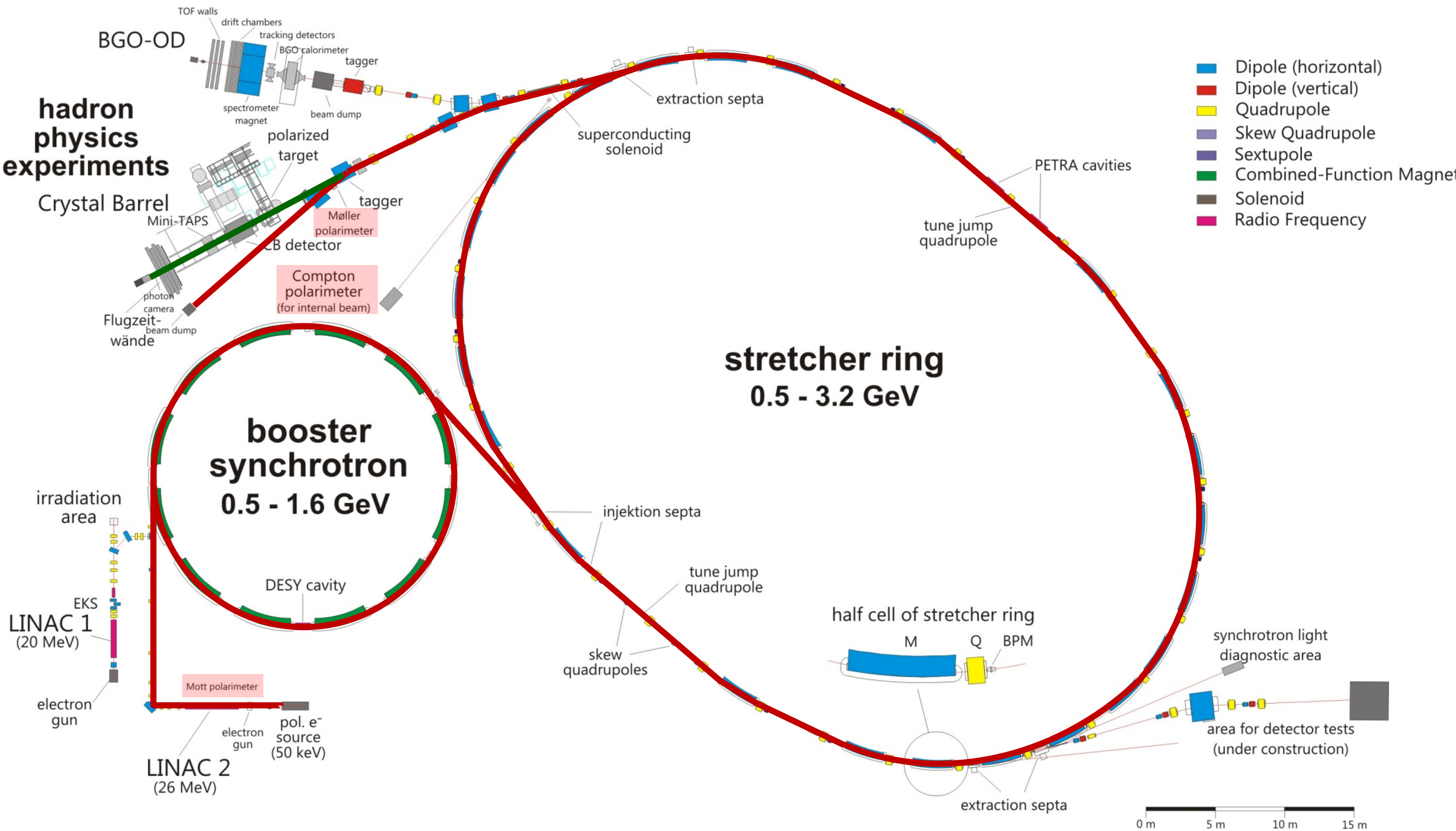


total operation time ≈ 75.000 h

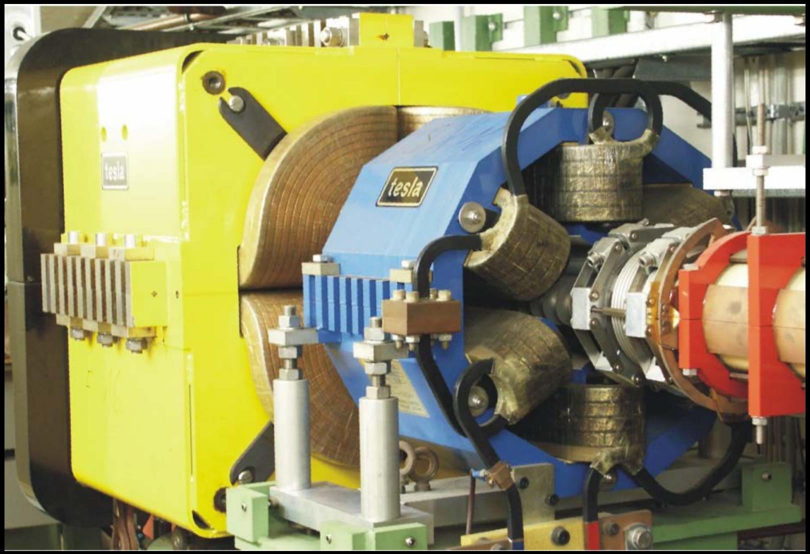
210 diploma / doctoral theses @ 2.3 GeV Synchrotron

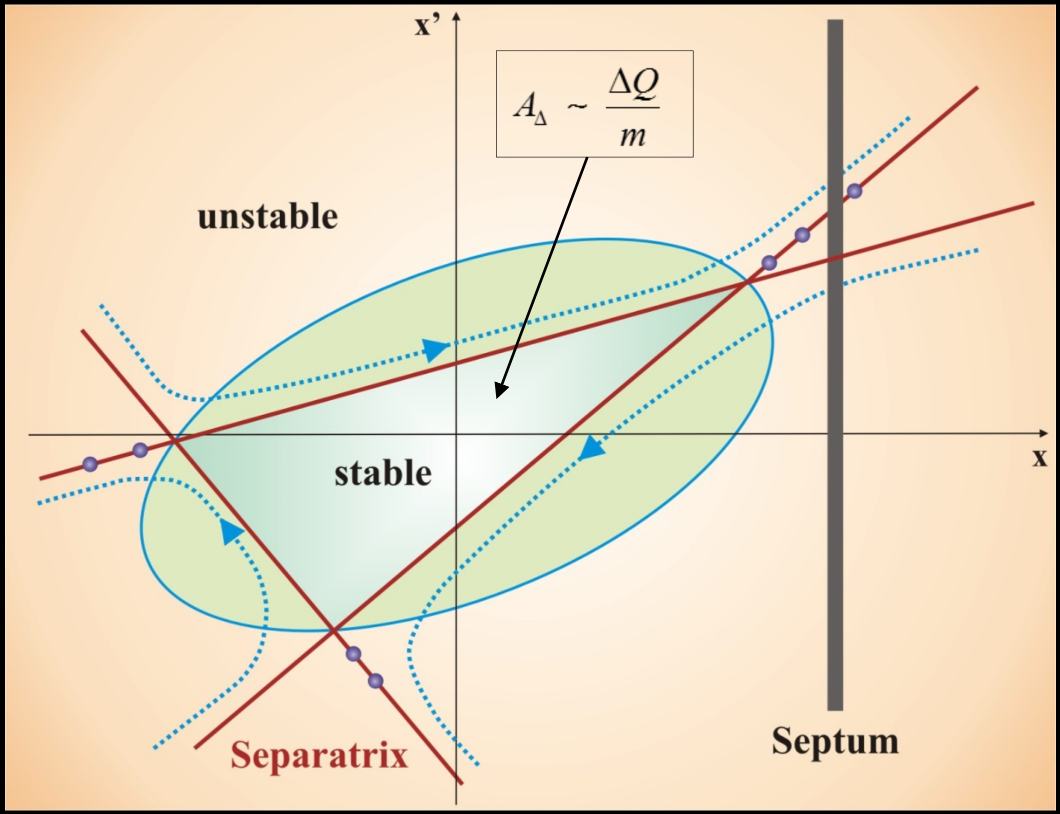
1984 - …

Electron Stretcher Accelerator (ELSA)



Slow Extraction



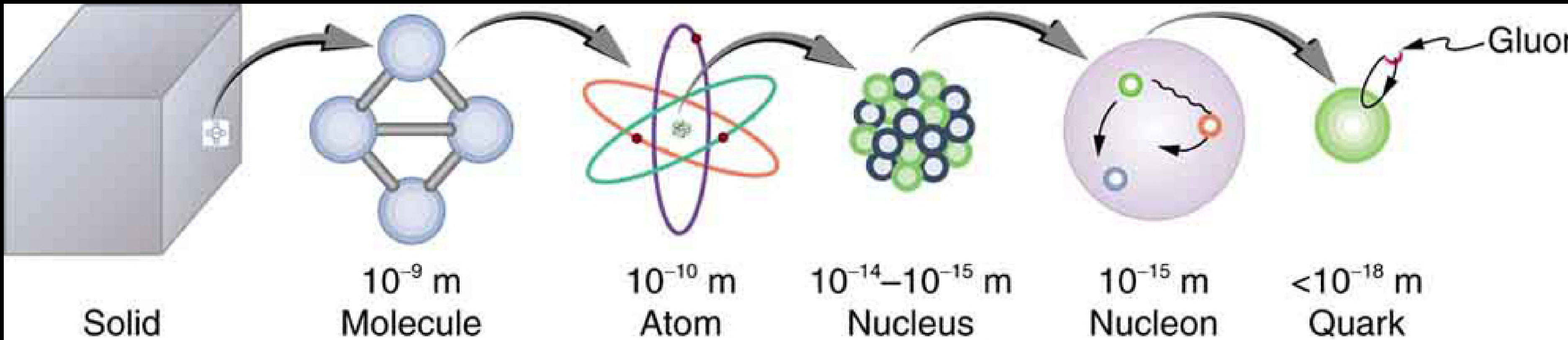


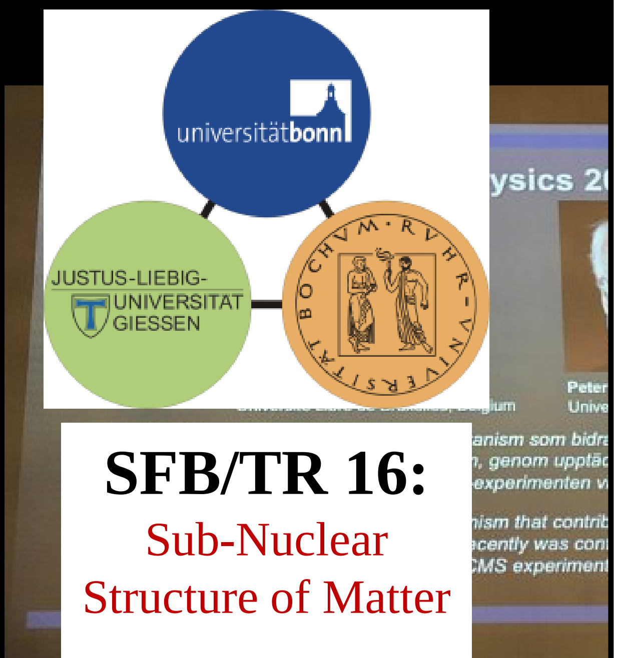
Extraction Sextupole-Magnets:
excitation of a 3rd integer resonance

Extraction Quadrupole-Magnets:
tune-shift close to a 3rd integer resonance, feedback (TAG-OR) stabilizes the external current


Science Programme
Crystal Barrel
BGO-OD
D. Elsner 200

Strong QCD in the non-perturbative regime





SFB/TR 16:

Sub-Nuclear Structure of Matter

07/2004 – 06/2016

Masses of Elementary Particles:

Leptons:

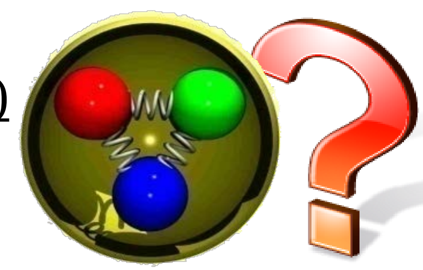
electron	e:	0.511 MeV
μ meson	μ:	105.6 MeV
τ meson	τ:	1.777 GeV
neutrino	ν:	„small“

Quarks:

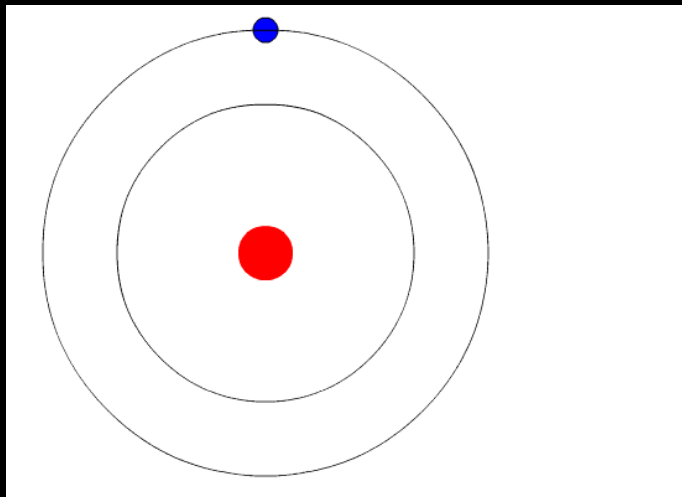
up quark	u:	3 MeV
down quark	d:	6 MeV
strange quark	s:	150 MeV
charm quark	c:	1200 MeV
bottom quark	b:	4200 MeV
top quark	t:	170 GeV

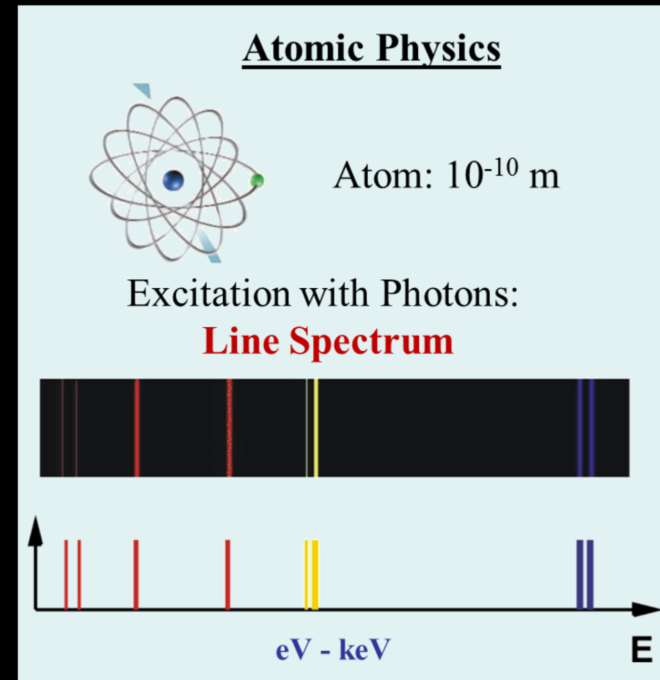
Nucleon: (“building block of matter”)

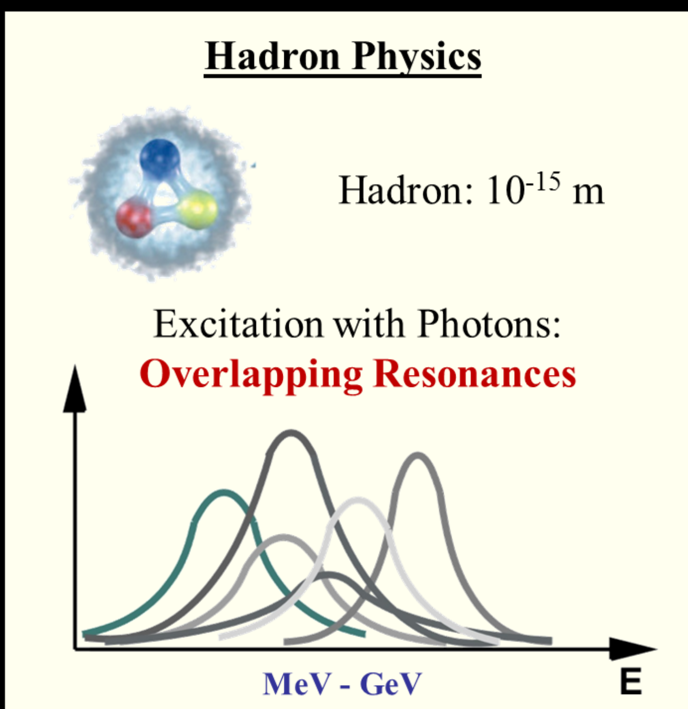
proton	p:	938.3 MeV
neutron	n:	939.6 MeV



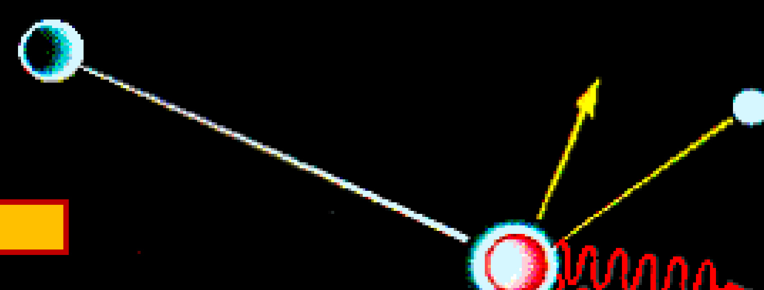
Excitations of Atoms





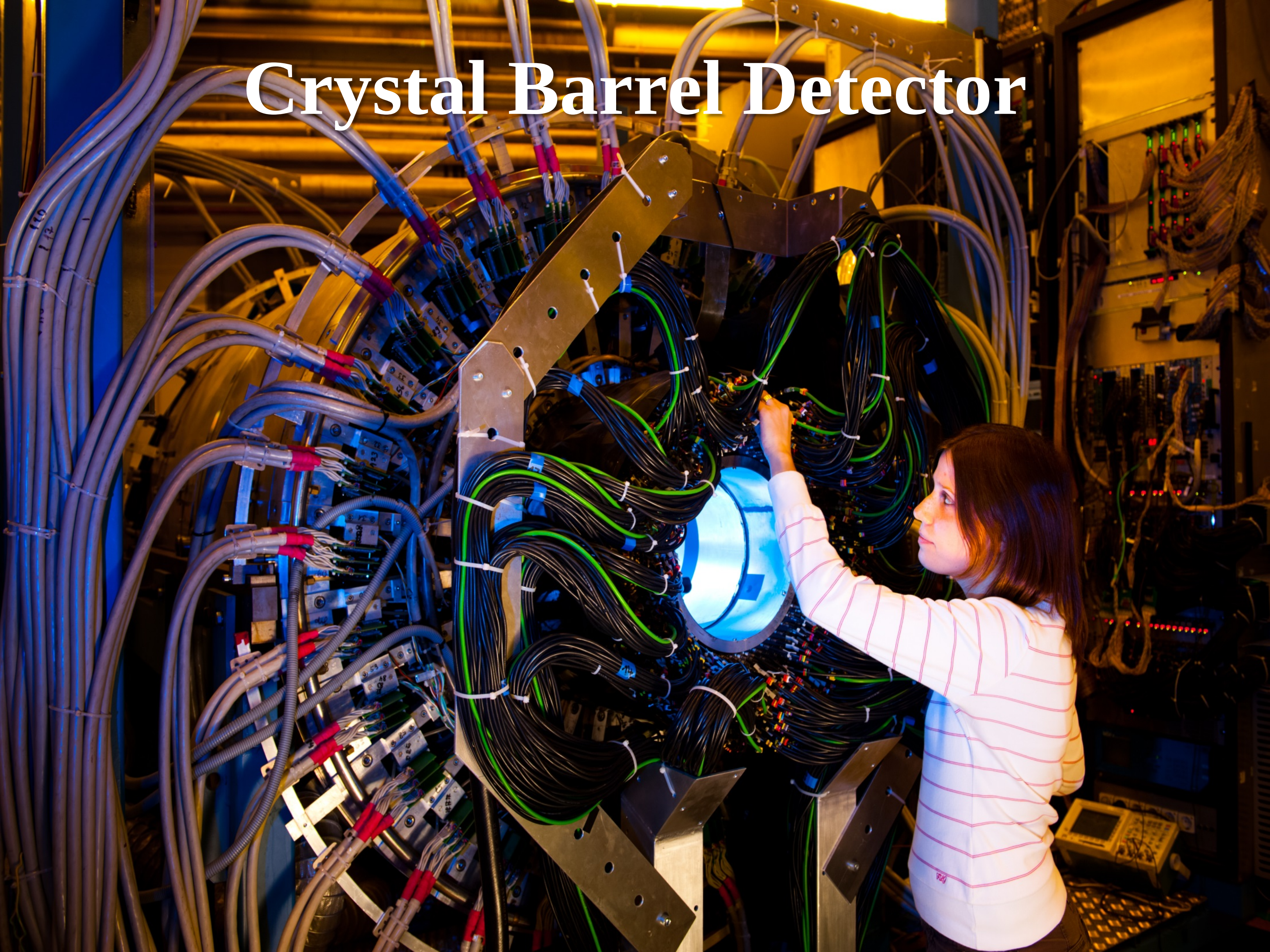


Excitations of Protons



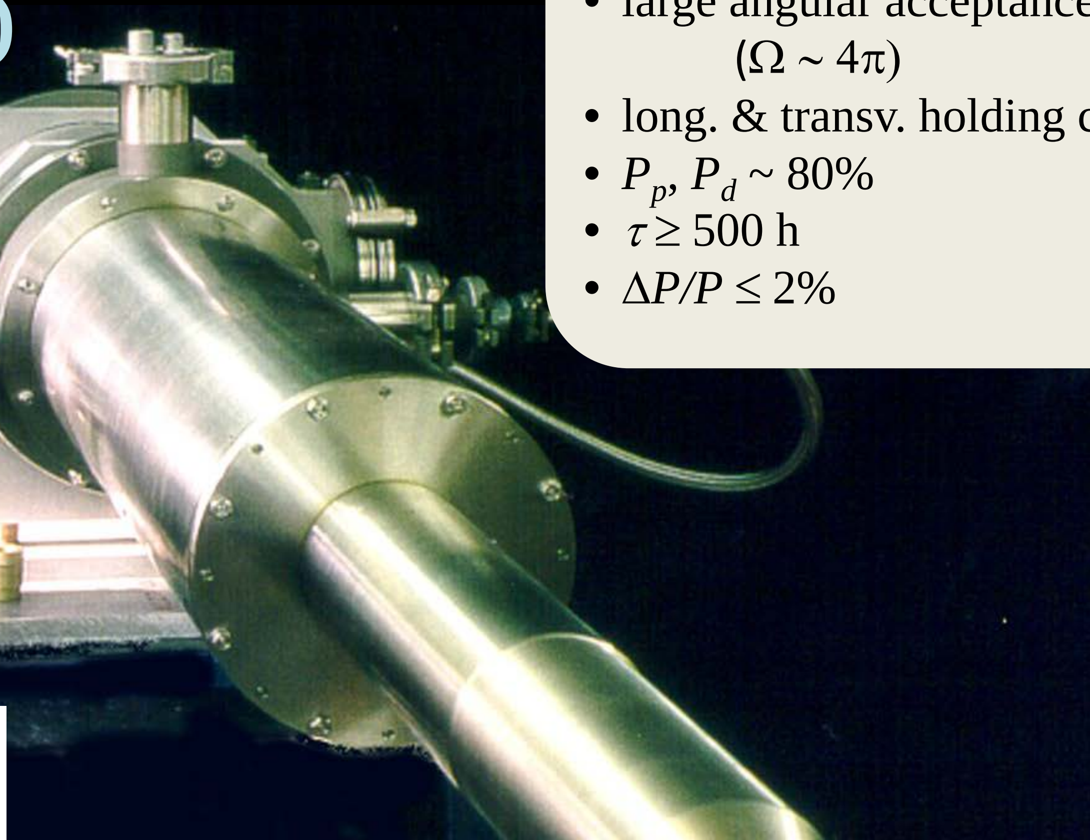
Double Polarisation Experiments!

Crystal Barrel Detector

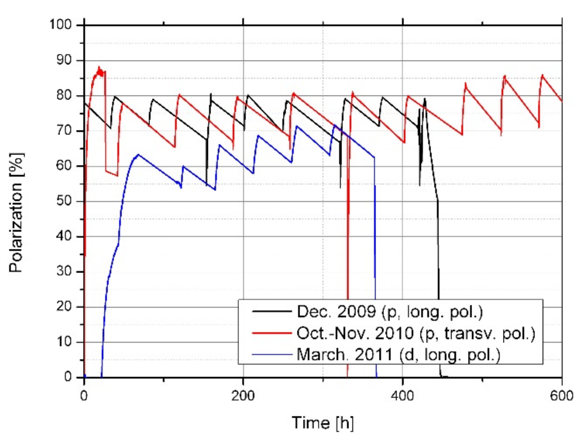


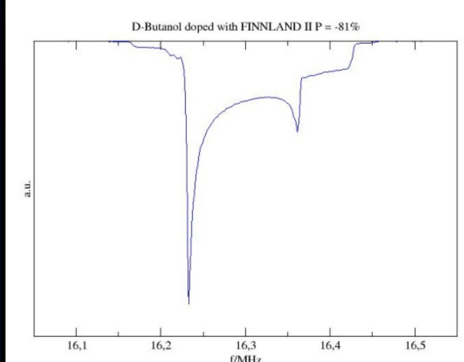
Polarized Target
(frozen spin)

Specific features:
- large angular acceptance ($\Omega \sim 4\pi$)
- long. & transv. holding coil
- P_p, $P_d \sim 80\%$
- $\tau \geq 500$ h
- $\Delta P/P \leq 2\%$

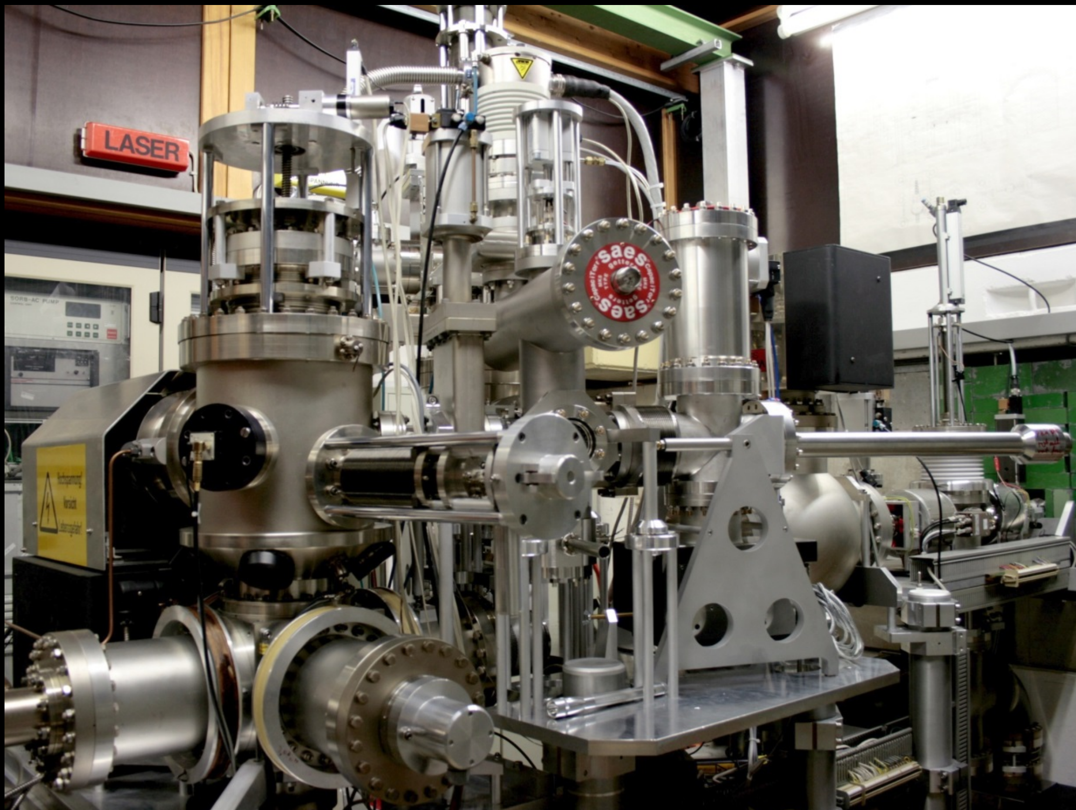


Polarization history plot (CB 2009-2011)



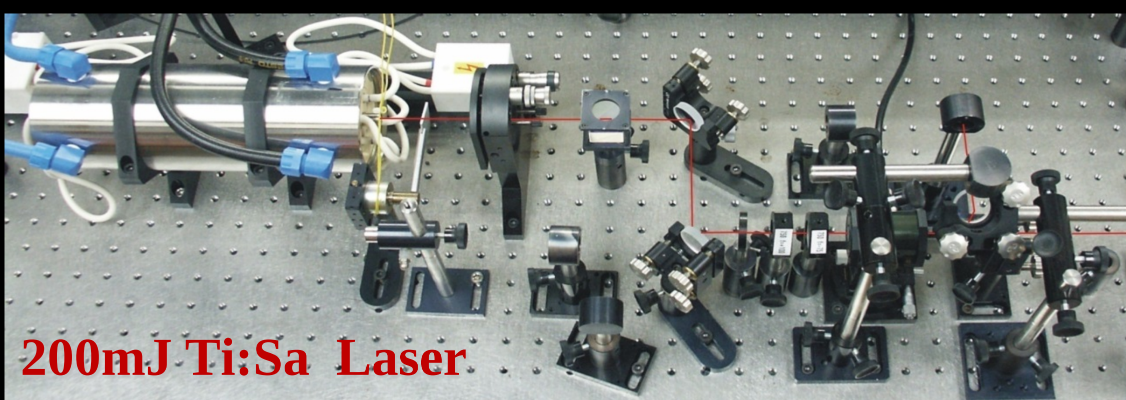


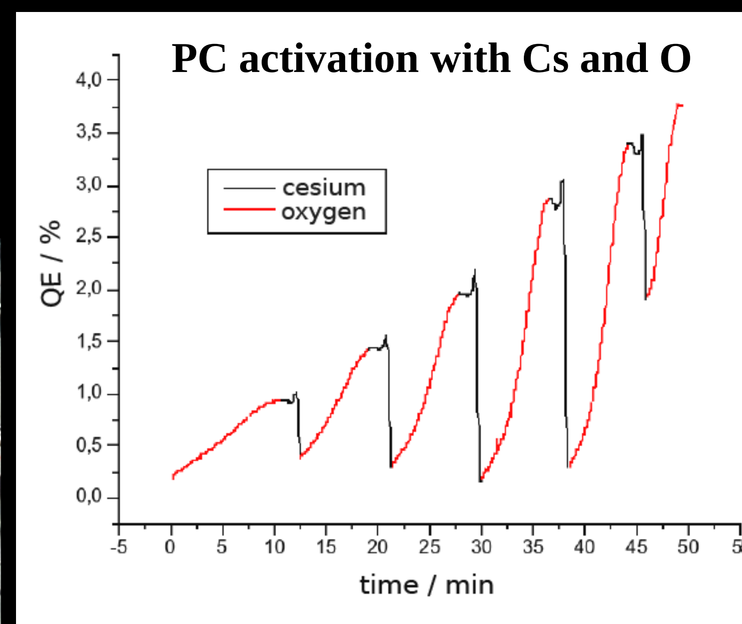
Source of Polarized Electrons



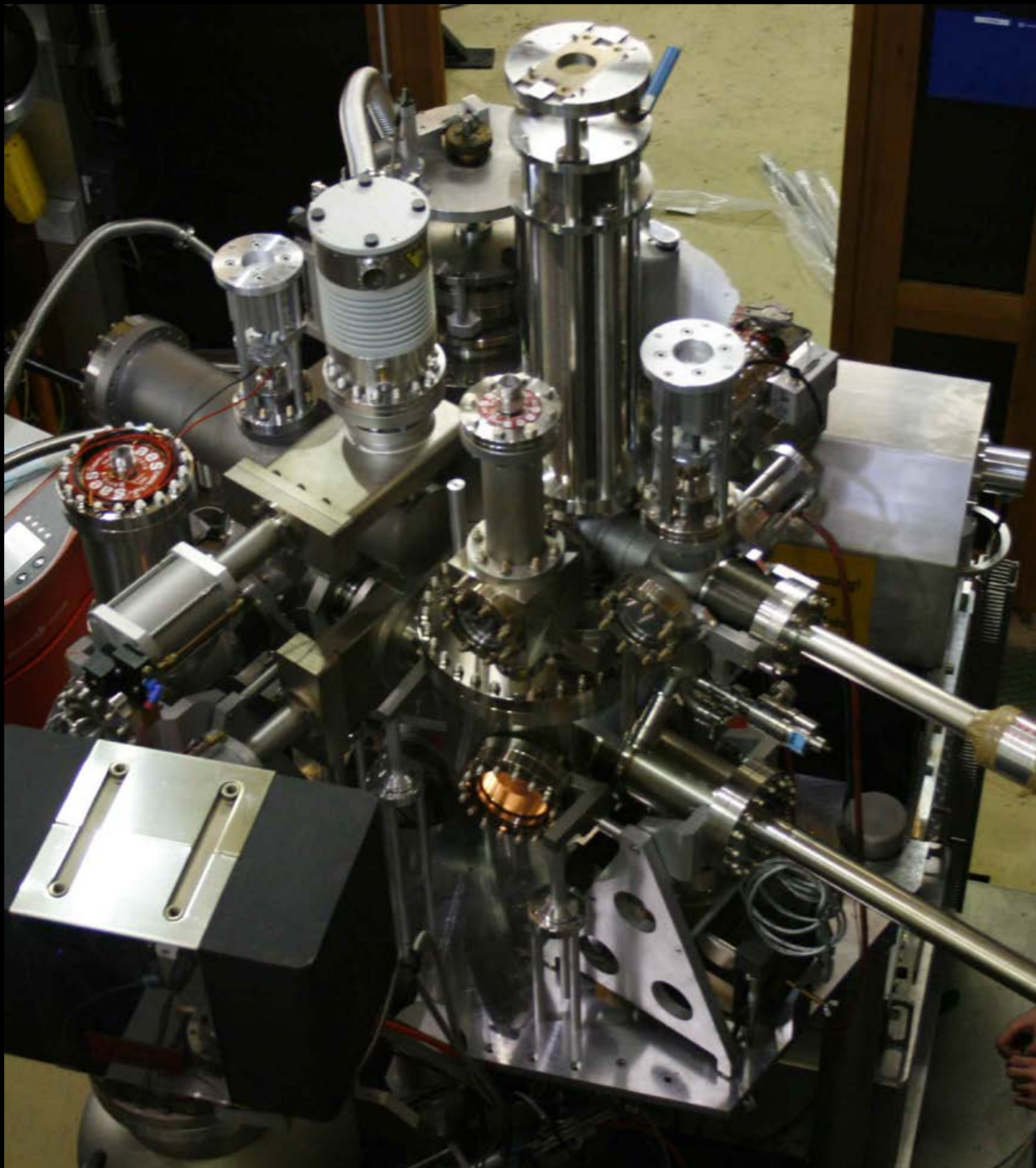
Specific features:

- inverted HV geometry
- adjustable perveance
- full load lock system
- H-cleaning
- $P > 80\%$ @ $E = 48$ keV
- $I = 200$ mA @ $\tau = 1\mu$s
- QE-lifetime > 1000 h





Source of Polarized Electrons



Specific features:

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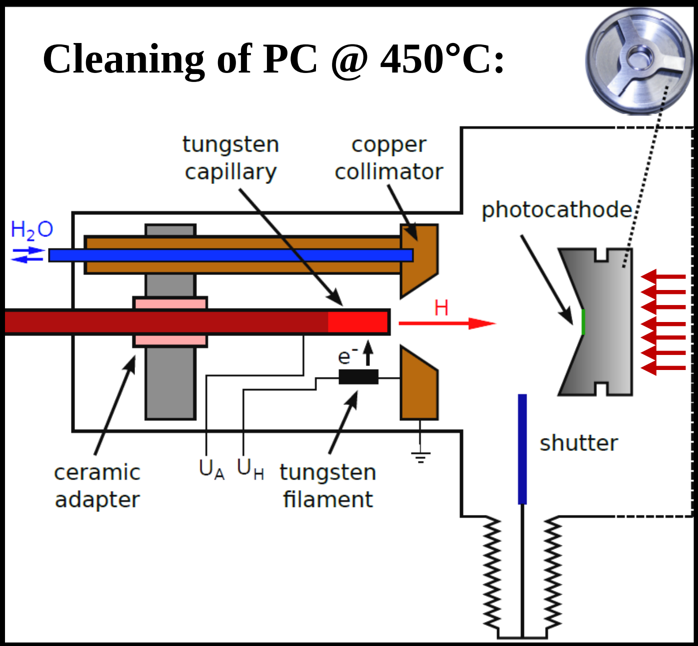
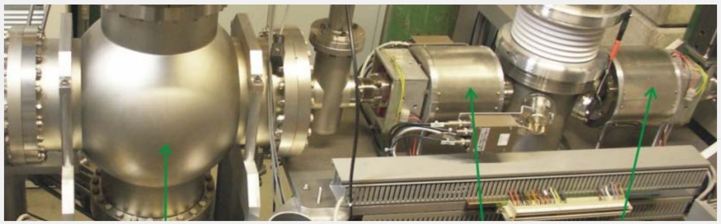
- full load lock system
- H-cleaning
- $P > 80\%$ @ $E = 48$ keV
- $I = 200$ mA @ $\tau = 1\mu s$
- QE-lifetime > 1000 h

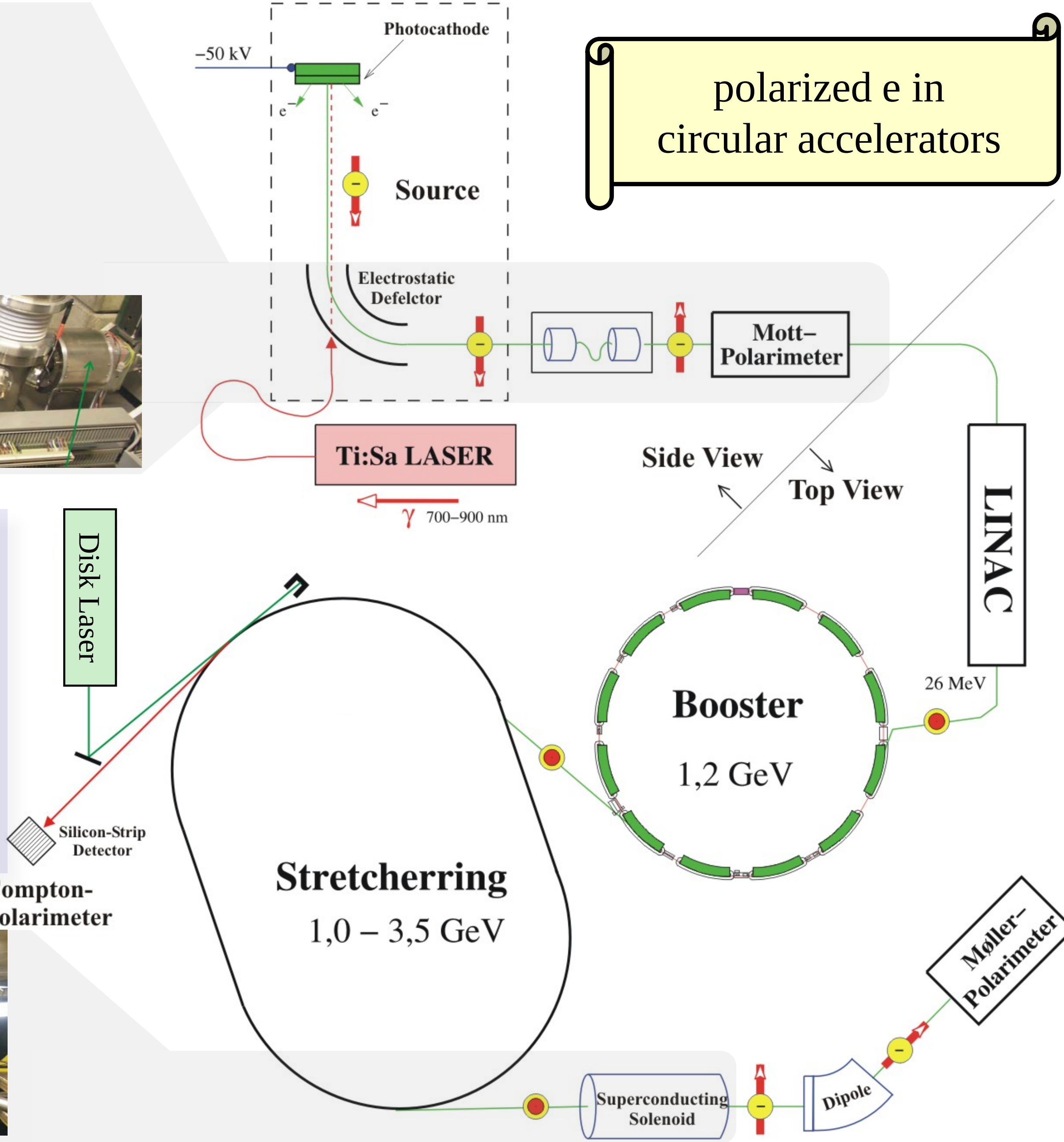
Cleaning of PC @ 450°C:



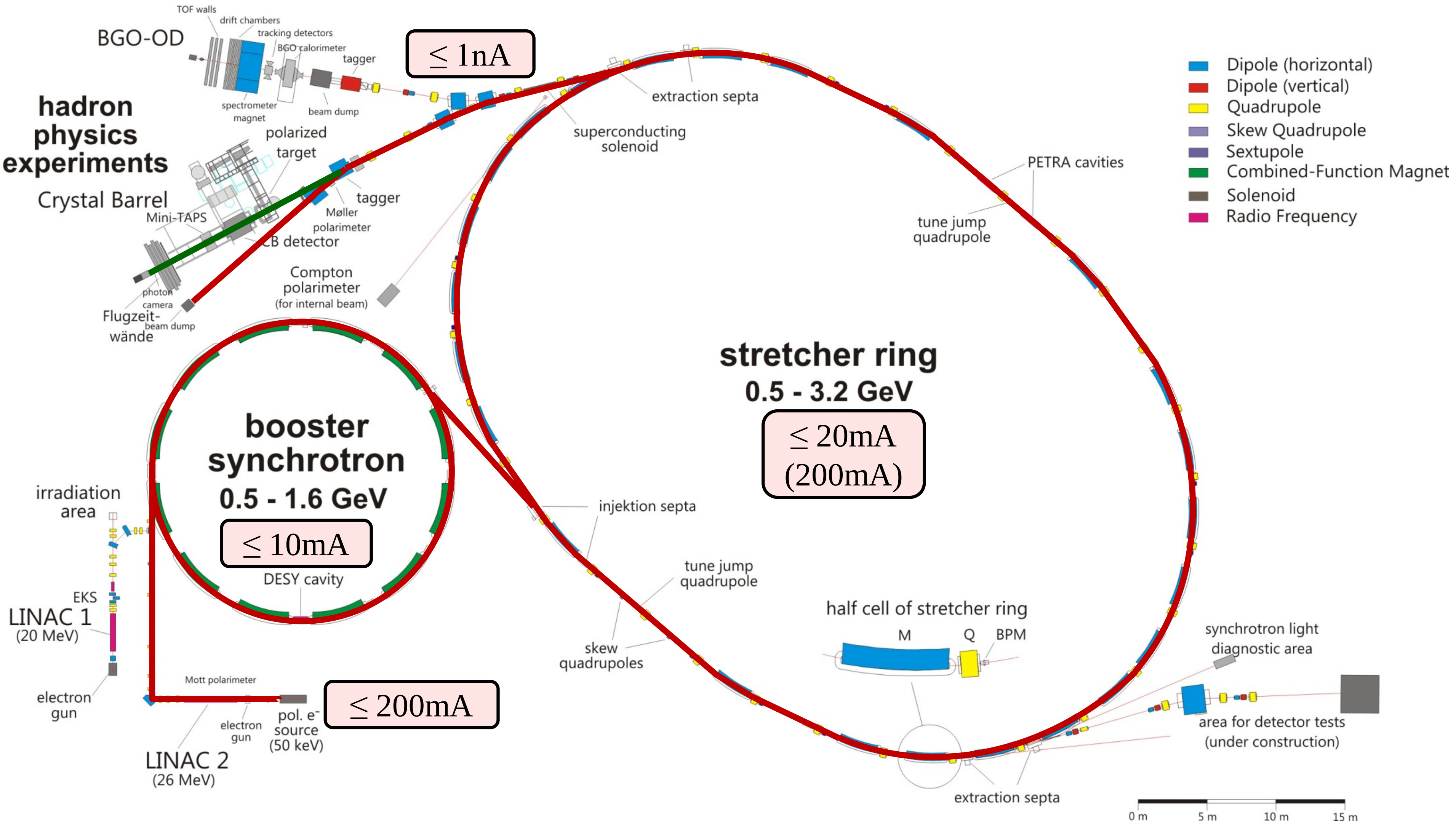
polarized e in circular accelerators

Spin Manipulation at ELSA

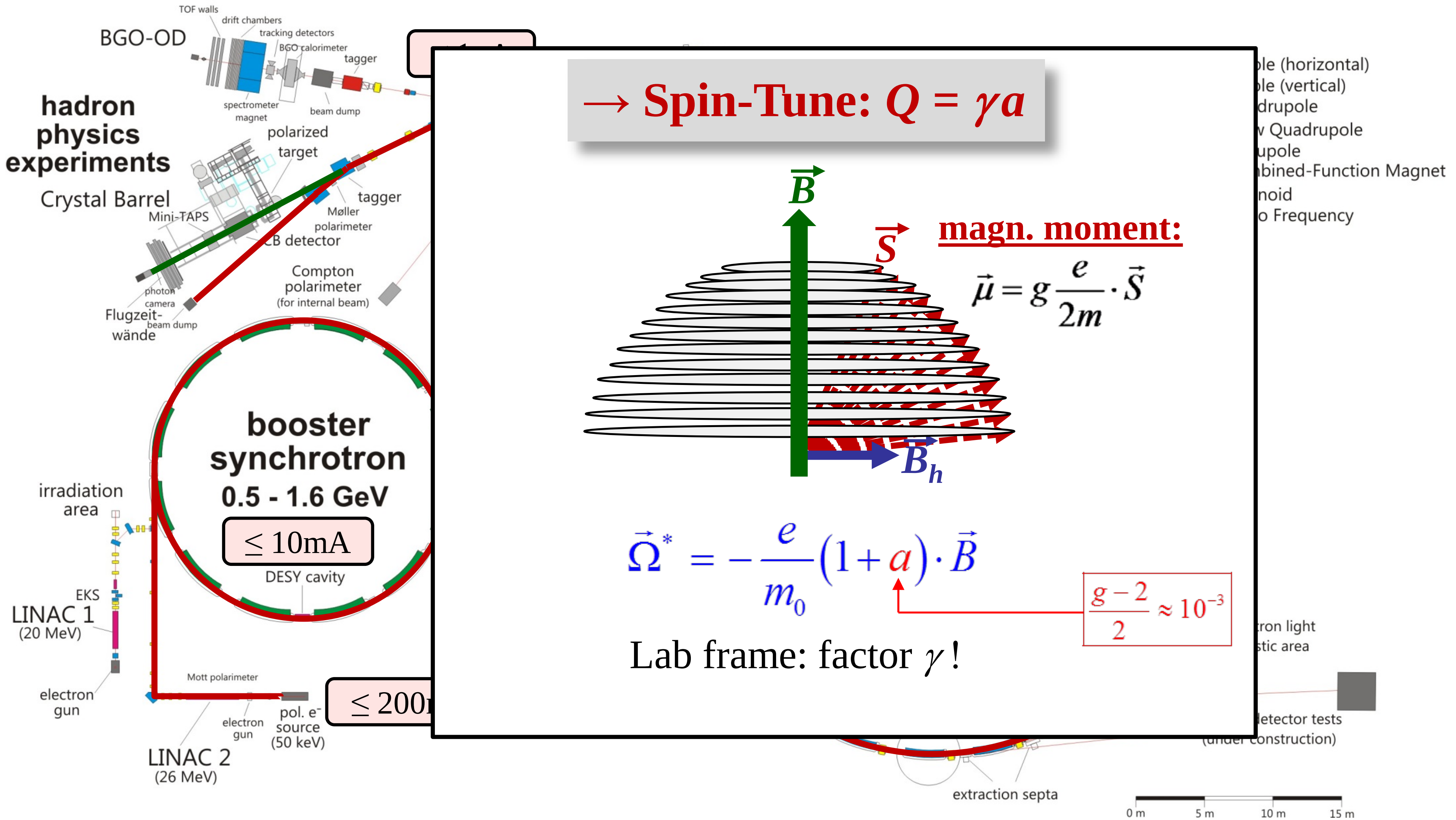




Acceleration of polarized electrons



Acceleration of polarized electrons



→ Spin-Tune: $Q = \gamma a$

$\vec{B}$, $\vec{S}$, $\vec{B}_h$

magn. moment:

$$\vec{\mu} = g\,\frac{e}{2m}\cdot\vec{S}$$

$$\vec{\Omega}^* = -\frac{e}{m_0}(1+a)\cdot\vec{B}$$

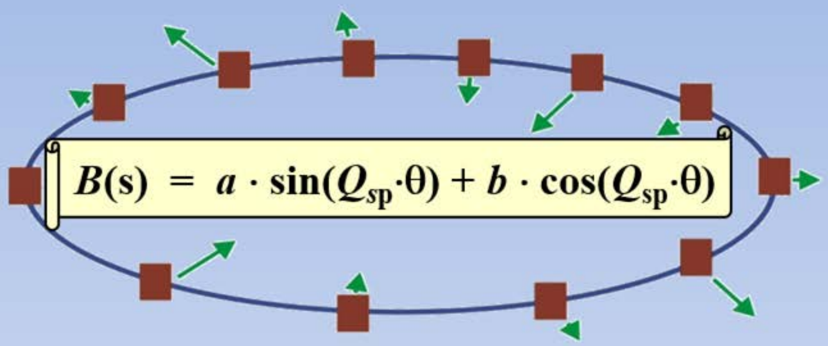
$$\boxed{\frac{g-2}{2} \approx 10^{-3}}$$

Lab frame: factor γ !

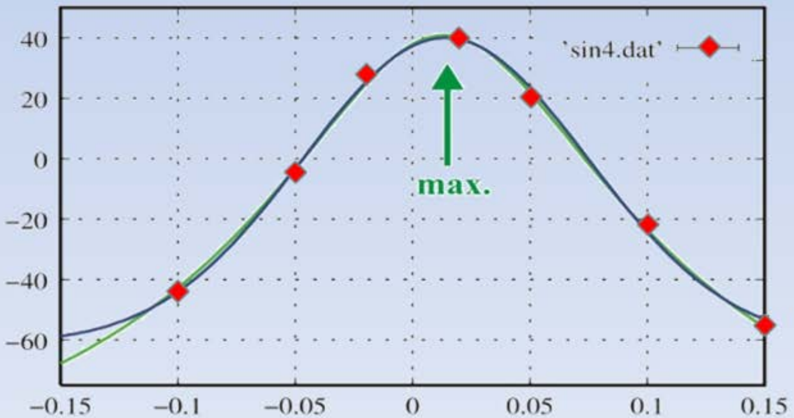
Acc. of Polarized Electrons

Integer Resonances: $\gamma a = n$

- precise CO correction (z_{rms}< 80µm)
- harmonic correction:

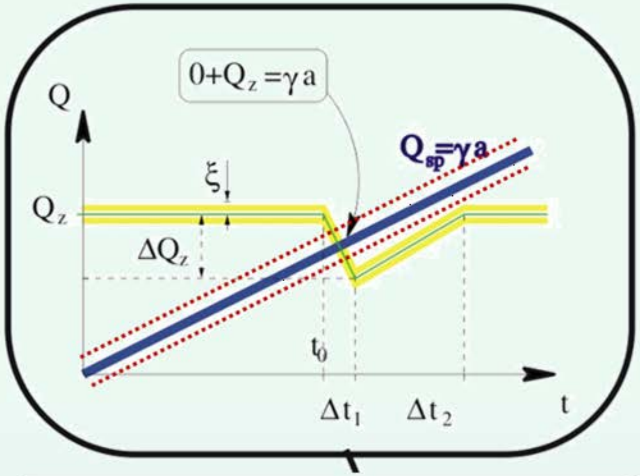


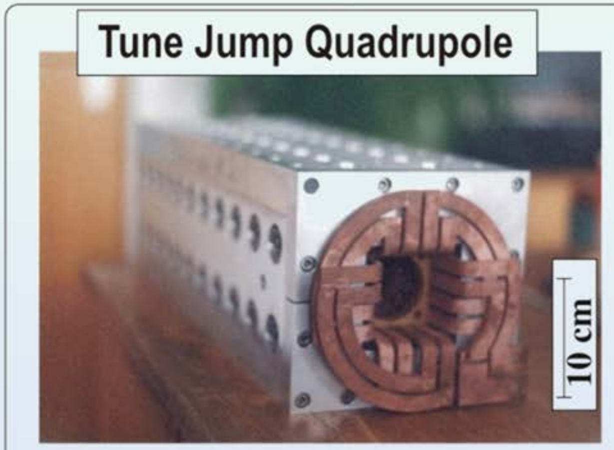
→ scan of sin amplitude:



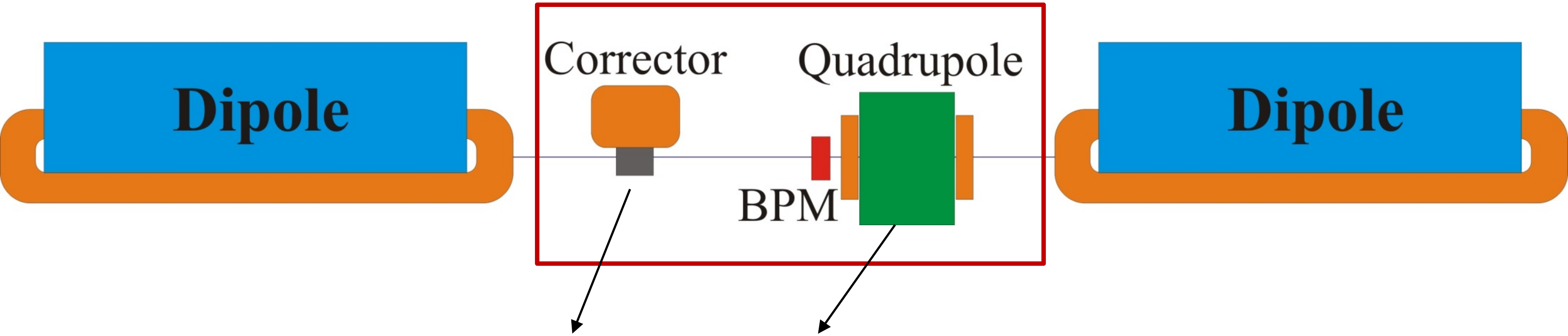
Intr. Resonances: $\gamma a = nP \pm Q_z$

- small vertical beam size
- tune jumping with pulsed quads





Spin-Orbit Response Technique

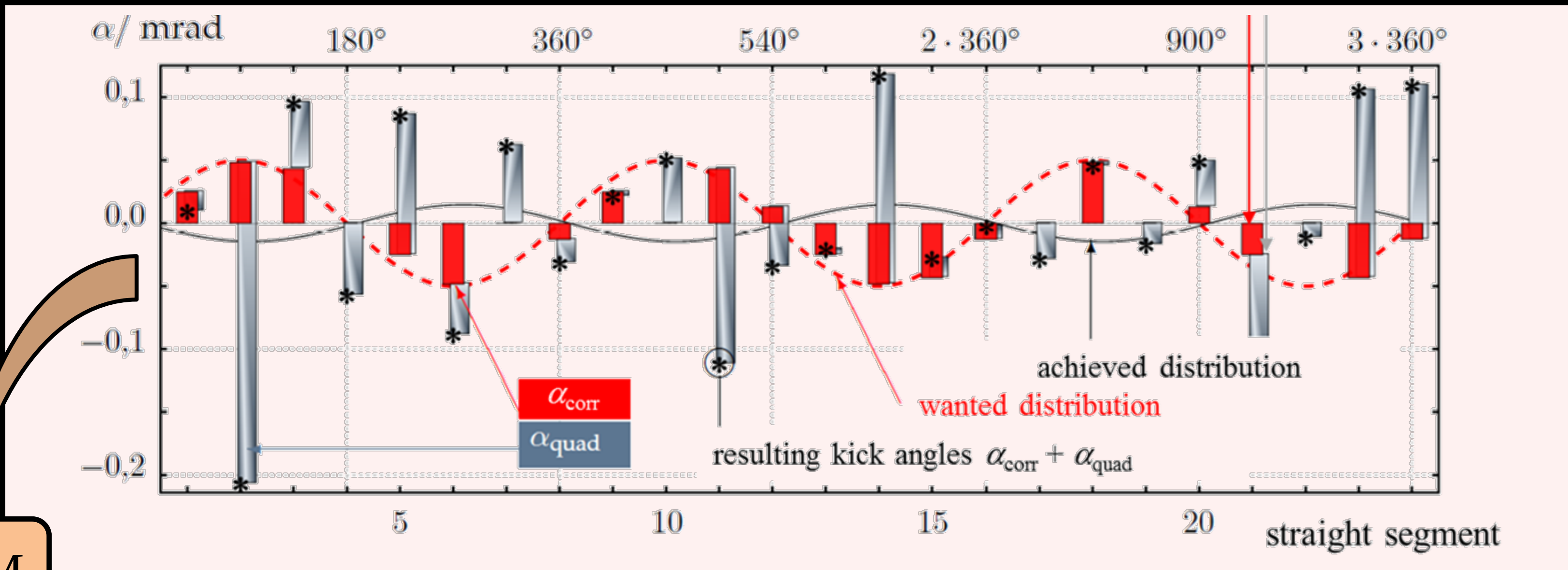


2 Contributions: $\alpha_n = \boxed{\sum_{j \in Dip_n} \alpha_{corr,j}} + \boxed{l \cdot \sum_{j \in Dip_n} k_j \cdot \Delta z_j} = \sum_{j \in Dip_n} \alpha_{corr,j} + l \cdot \sum_{j \in Dip_n} k_j \cdot \left(\mathbf{ORM} \cdot \vec{\alpha}_{corr} \right)_j$

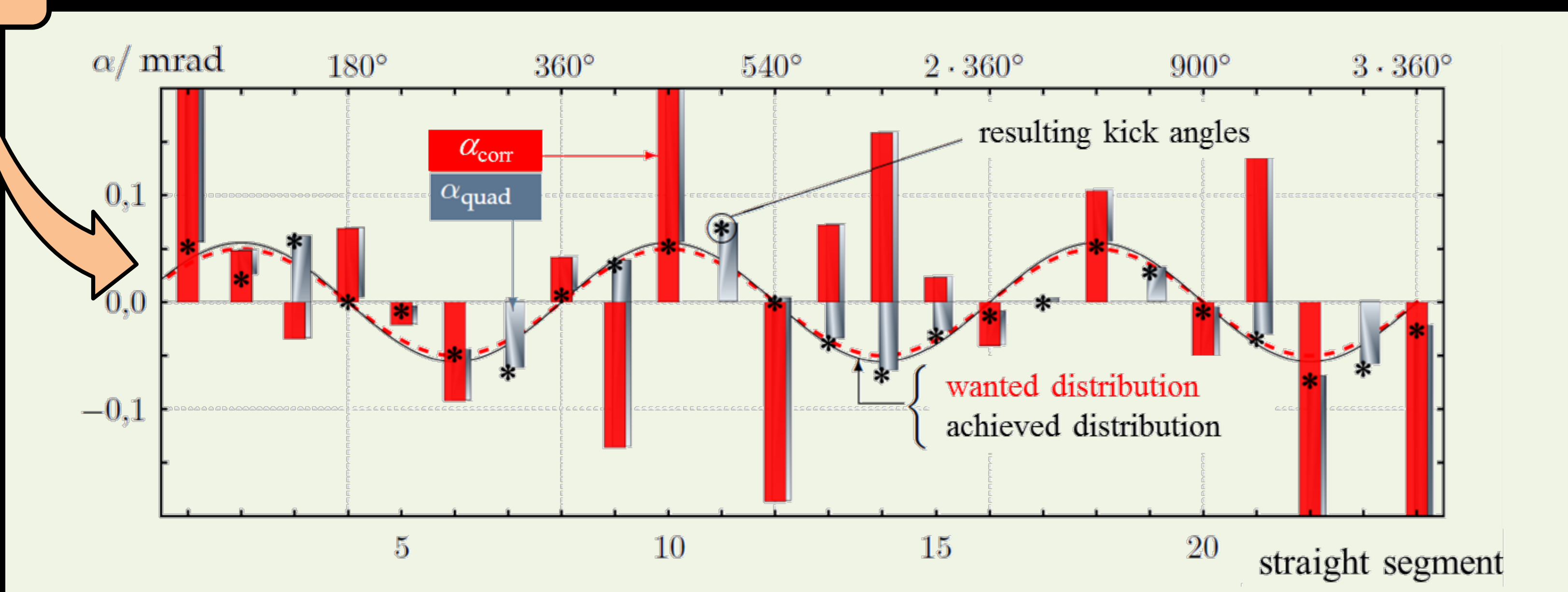
Harmonic Correction Matrix: $\vec{\alpha}_{harm} = \mathbf{HCM} \cdot \vec{\alpha}_{corr}$

$$\mathbf{HCM}_{i,k} = \delta^{\mathrm{VC}}_{i,k} + \sum_{m=1}^{32} \delta^{\mathrm{Q}}_{m,k} \cdot l_m \cdot k_m \cdot \mathbf{ORM}_{m,i}$$

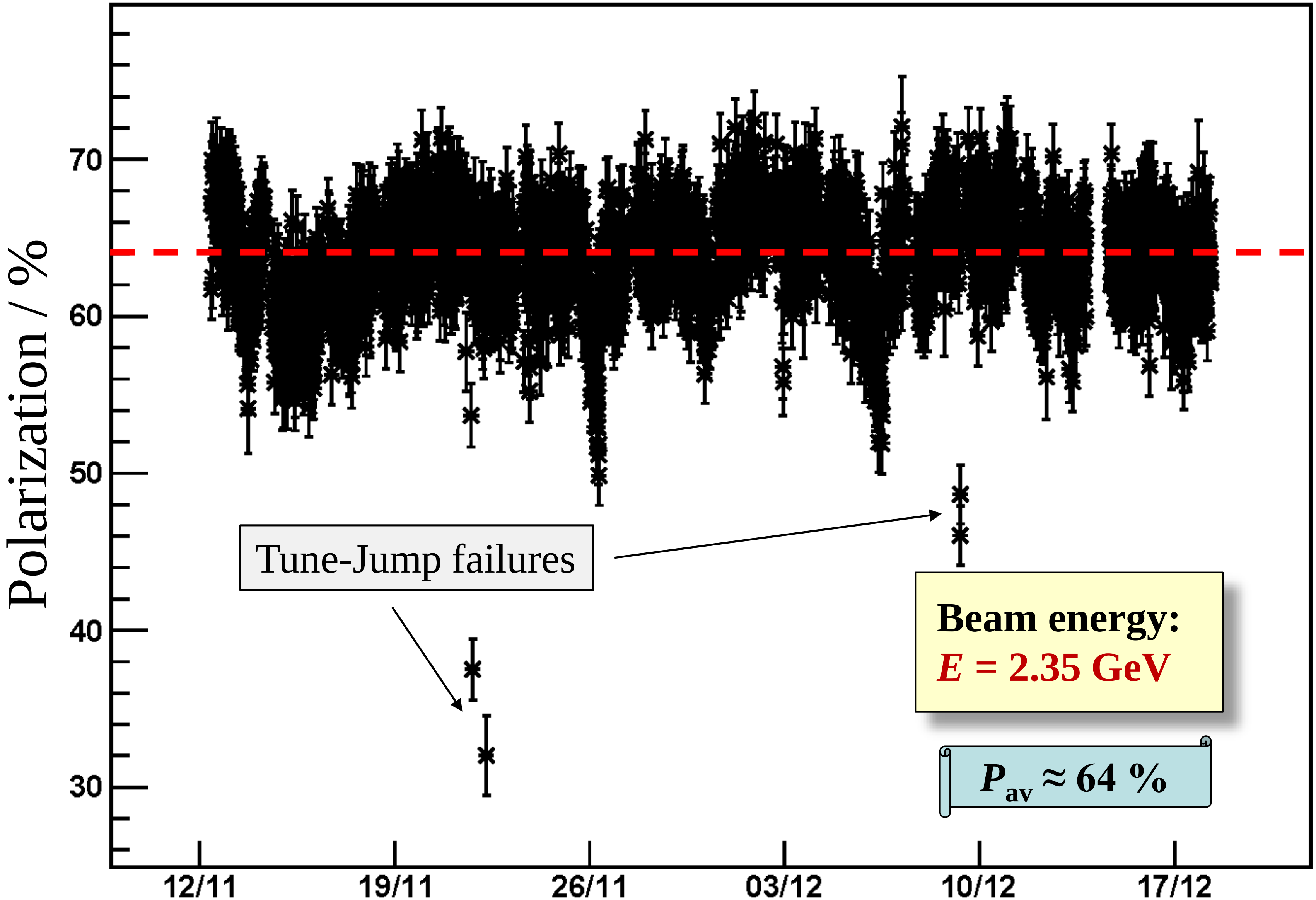
Spin-Orbit Response Technique



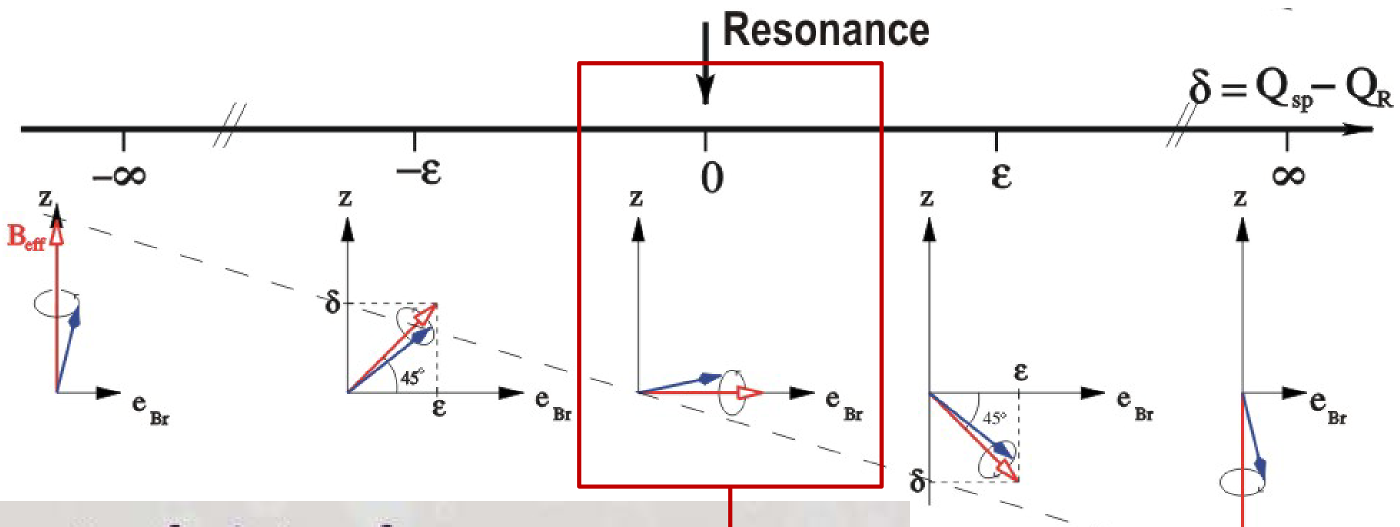
HCM

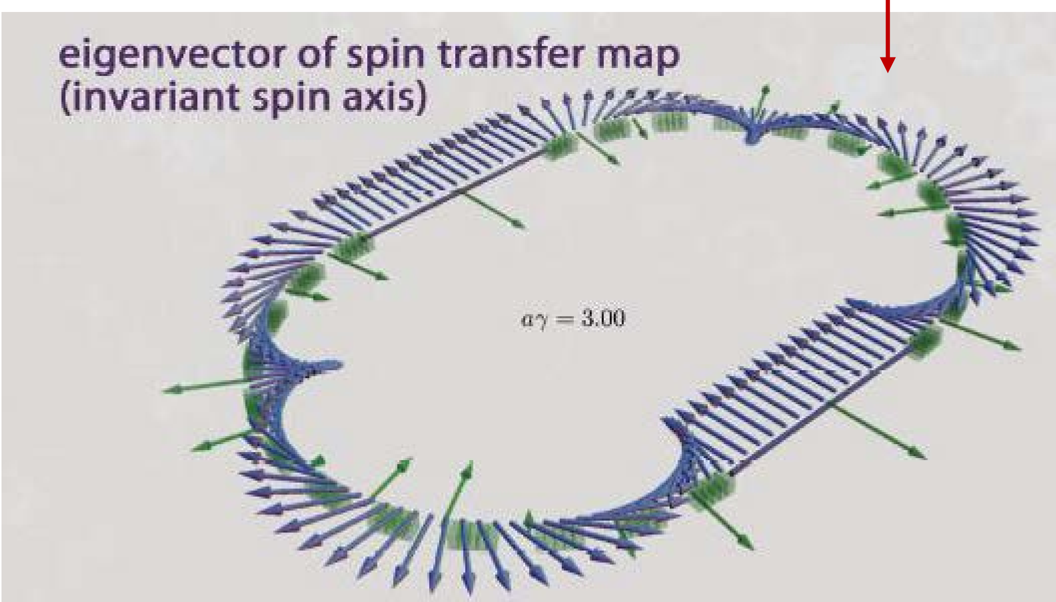


Polarization at the Experiment



Horizontal Polarization





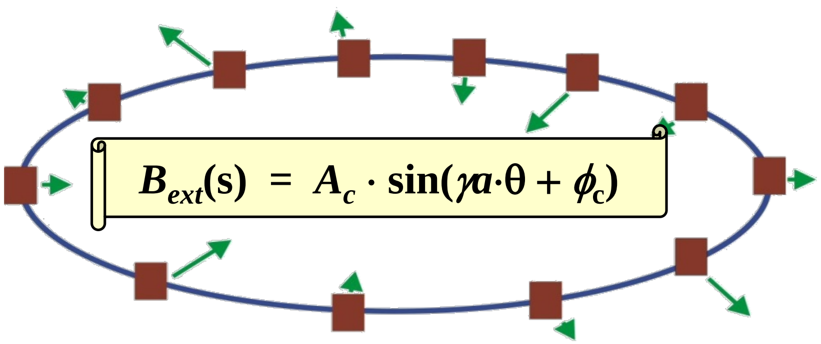
Integer Resonance $\gamma a = n$

- spin is aligned along the resonance driving B_x

$$B_x = B_{imp} + B_{ext}$$

- phase variation of the external corrector field allows change of spin orientation

Operation at $\gamma a = 3$

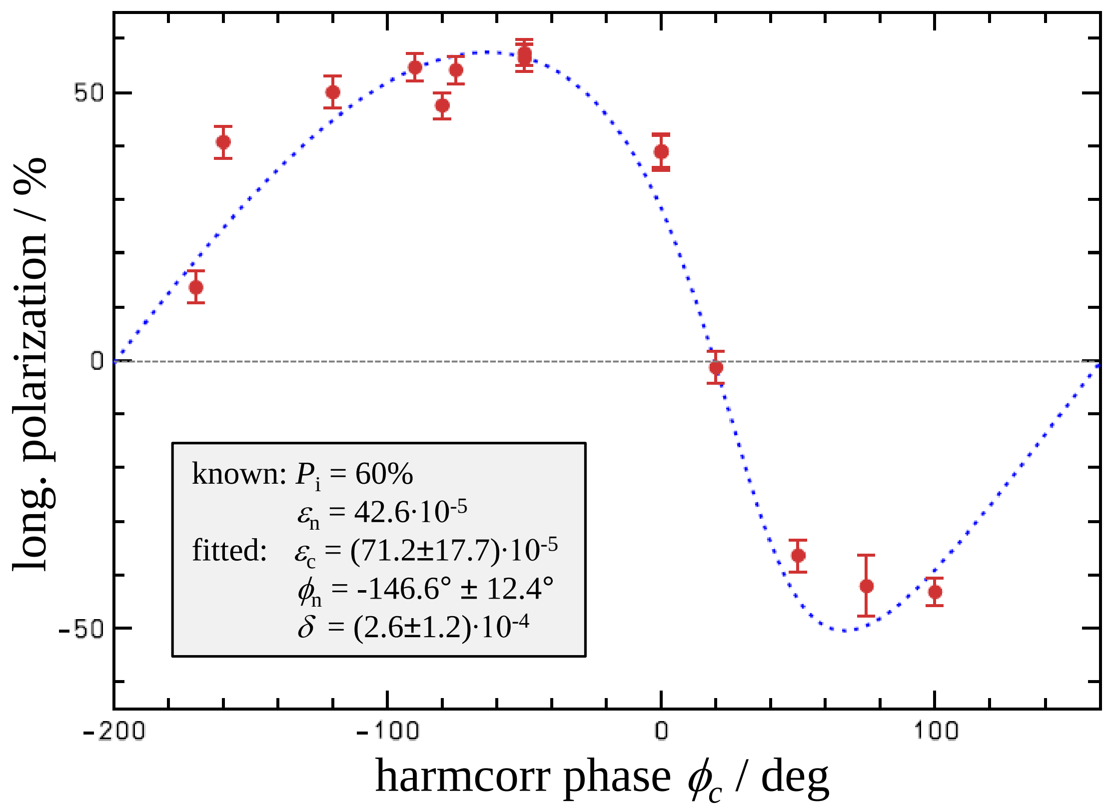


$$\vec{n}_0 = \frac{1}{\sqrt{|\varepsilon|^2 + \delta^2}} \begin{pmatrix} -\mathrm{Re}(\varepsilon) \\ \delta \\ \mathrm{Im}(\varepsilon) \end{pmatrix} \Rightarrow P_s = P_i \frac{|\varepsilon_n| \sin\phi_n + |\varepsilon_c| \sin\phi_c}{\sqrt{\left||\varepsilon_n| e^{-i\phi_n} + |\varepsilon_c| e^{-i\phi_c}\right|^2 + \delta^2}}$$

$P_{\text{long}} \sim \sin\phi_c$ expected!

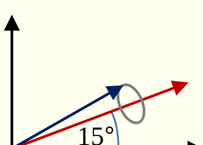
Observed distortion and offset caused by:

- superposition of $\varepsilon_n + \varepsilon_c$
- small energy shift ($\gamma a \neq 3$)



Fitted δ corresponds to:

$$\frac{\Delta E}{E_{res}} \approx 7.5 \cdot 10^{-5} \longleftrightarrow$$

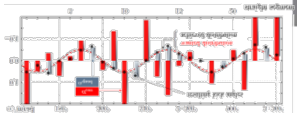
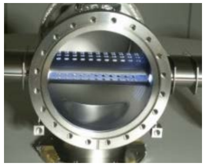


List of Research Efforts

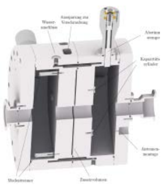
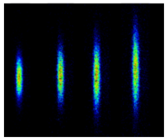
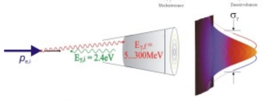
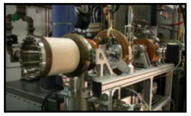
($P \rightarrow 80\%$, $I \rightarrow 200\text{mA}$)

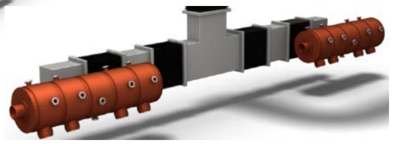
- **<u>Source of polarized electrons</u>**
- Precise and fast BPM system: $\Delta_{x,z} \approx \mu\text{m}$, 1kHz
- Fast bipolar steerer system: $\dot{B} = 2\text{T/sec}$, $B{\cdot}l \approx 0.01\,\text{T}{\cdot}\text{m}$
- **<u>Harmcorr based on spin-orbit response technique</u>**
- Low-impedance vacuum chambers
- Effective ion clearing (35 clearing electrodes)
- HOM suppression in accelerating cavities
- 3D bunch-by-bunch feedback system ($\Delta f = 250\,\text{MHz}$)
- FPGA-based LLRF control: $\Delta A/A < 3{\cdot}10^{-4}$, $\Delta\phi < 0.04°$
- 3D ps-diagnosis based on a streak camera system
- Cavity-based BPM for low intensities: $\Delta_{x,z} \approx 0.1\text{mm}$, 100pA
- Mott, Møller and Compton polarimetry
- High current single-bunch injector
- New RF station and cavities
- Numerical simulation of spin dynamics







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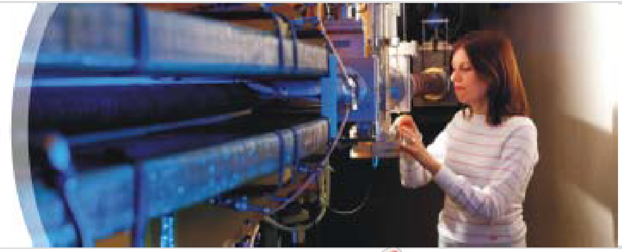
Collaborative Research Centre 16

Subnuclear Structure of Matter



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- Publications
- News

Bye, bye, SFB!!

July 2004 – June 2016

SFB/TRR 16

Subnuclear Structure of Matter

The Standard Model of the strong, electromagnetic and weak interaction is in general very well established. Until recently the Standard Model still had two open ends. On the one side it was the search for the Higgs Boson at highest energies and on the other side it is the formation and understanding of the different forms of strongly interacting matter. First evidence for the possible existence of the Higgs boson was recently reported by the LHC experiments. The Higgs mechanism is responsible for the creation of the masses of quarks and leptons. However this explains only a few percent of the mass of the nucleons and therefore the matter surrounding us. The rest of the mass is due to the strong interaction itself. The question how this happens and how one can understand the spectrum and the properties of the emerging strongly interacting particles (hadrons) is the central object of the CRC 16. The aim is to understand the strong interaction in the non-perturbative regime.

The experiments are performed at the electron accelerator ELSA at Bonn. The aim is to gain a deeper understanding of the spectrum and the properties of baryon resonances and to investigate the underlying QCD dynamics in the photoproduction of mesons. Furthermore, in-medium properties of mesons are investigated. To perform these experiments two detector systems are available, the Crystal Barrel/TAPS and the BGO-OD experiment. The polarized target and the availability of a polarized beam make e.g. the measurement of highly sensitive double polarization observables possible. Polarization

News

Students Tranining Days

In Collaboration with the Bethe Zentrum the "Students Training Days - Modern Detector Systems" will take place in Bonn from 31.3. to 11.4.

Feb 10, 2014

more ...

ELSA

POLARIZED TARGET BONN

What comes next?

Forschungs- und Technologiezentrum
Detektorphysik

3 Säulen

Forschungsbau

Money

Money

ELSA (PI)

Zyklotron (HISKP)

Future Accelerator-based Program

General Constraints:

- new ideas, no simple continuation of baryon spectroscopy
- limited operating funds due to low budget, incr. energy costs, Forschungsbau
- should be based on experience with polarized beams?
- well suited for future excellence initiatives?!

Accelerator Constraints:

- should involve further accelerator physics R&D, not only operation
- should be based on existing expertise
- "generic" accelerator R&D?!

Upcoming "New" Ideas:

- parity violating experiments (e.g. Weinberg angle in access. energy range)?
- **electron electric dipole moment in collaboration with FZJ?**

Physics Motivation of an EDM Measurement

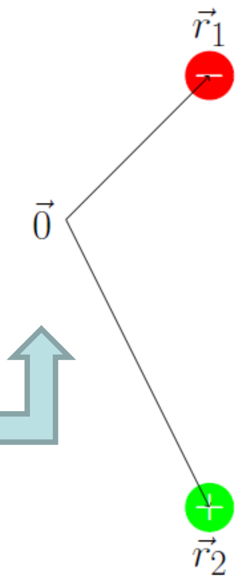
What makes neutral and charged particle EDMs interesting?

Definition and Order of Magnitude

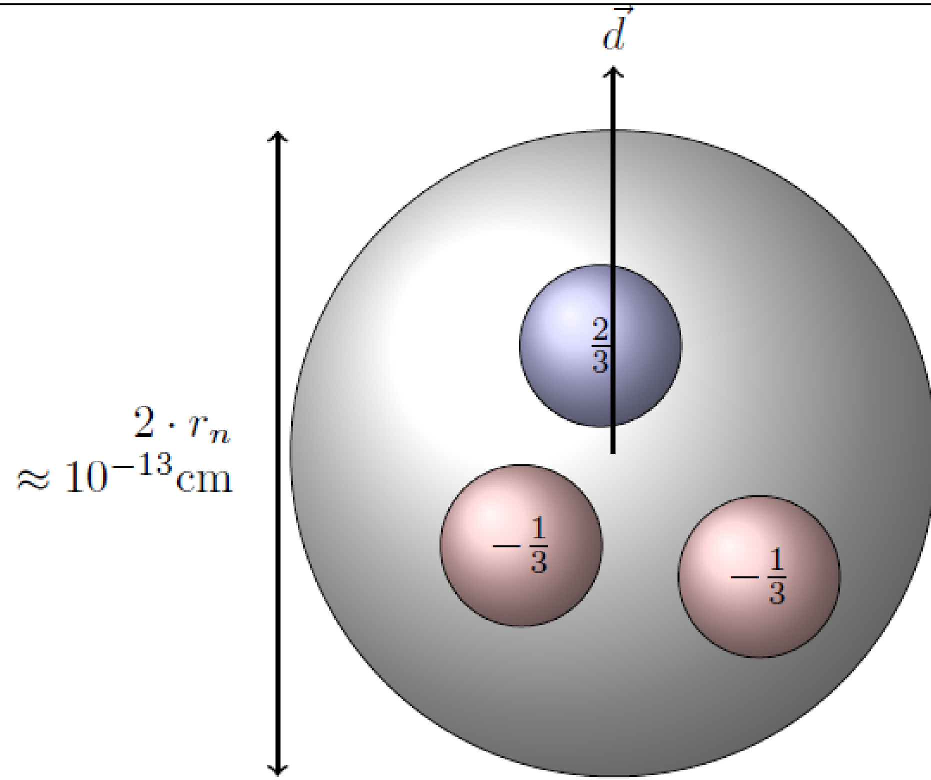
	atomic physics	hadron physics
charges	e	e
$\lvert\vec{r}_1 - \vec{r}_2\rvert$	$1\ \text{Å} = 10^{-8}\text{cm}$	$1\,\text{fm} = 10^{-13}\text{cm}$
EDM		
naive expectation	$10^{-8} e \cdot \text{cm}$	$10^{-13} e \cdot \text{cm}$
observed	water molecule	neutron
	$2 \cdot 10^{-8} e \cdot \text{cm}$	$< 3 \cdot 10^{-26} e \cdot \text{cm}$

EDM

Classical definition: $\vec{d} = \sum_i q_i \cdot \vec{r}_i$



Definition and Order of Magnitude

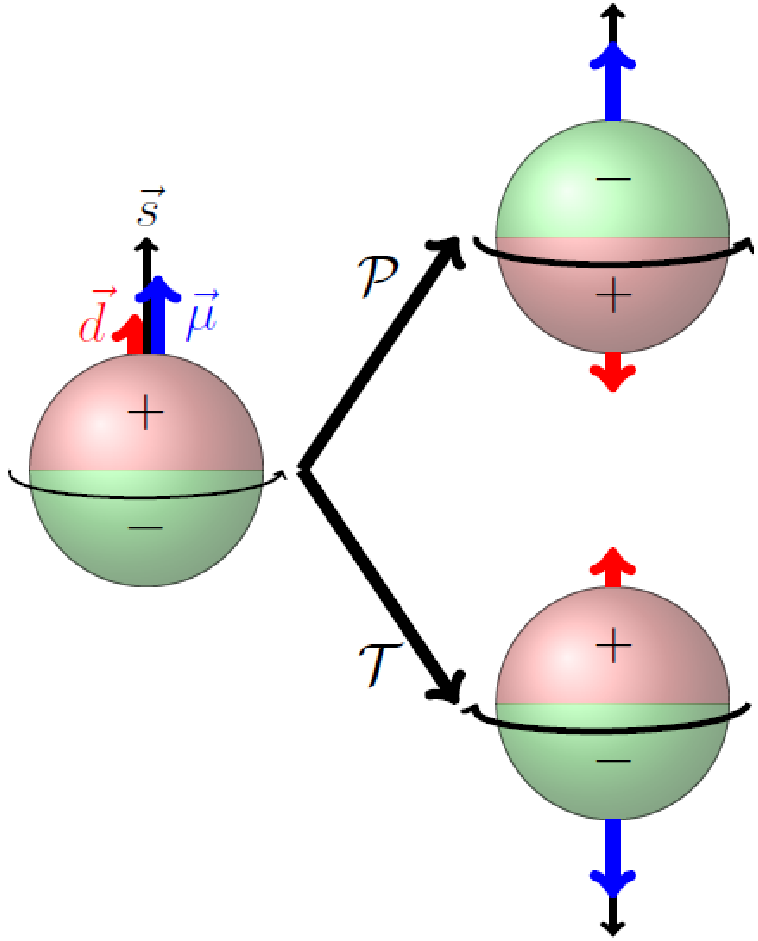


neutron EDM of $d_n = 3 \cdot 10^{-26} e{\cdot}\mathrm{cm}$ corresponds to separation of $u-$ from $d-$quarks of $\approx 5 \cdot 10^{-26}\mathrm{cm}$

$\mathcal{T}$ and $\mathcal{P}$ violation of EDM

$\vec{d}$: EDM
$\vec{\mu}$: magnetic moment
both || to spin

$$
\begin{aligned}
H &= -\mu\vec{\sigma}\cdot\vec{B} - d\vec{\sigma}\cdot\vec{E} \\
\mathcal{T}: \quad H &= -\mu\vec{\sigma}\cdot\vec{B} + d\vec{\sigma}\cdot\vec{E} \\
\mathcal{P}: \quad H &= -\mu\vec{\sigma}\cdot\vec{B} + d\vec{\sigma}\cdot\vec{E}
\end{aligned}
$$



$\Rightarrow$ EDM measurement tests violation of fundamental symmetries $\mathcal{P}$ and $\mathcal{T}(\overset{\mathcal{CPT}}{=} \mathcal{CP})$

$\mathcal{CP}$ violation

Excess of matter in the universe:

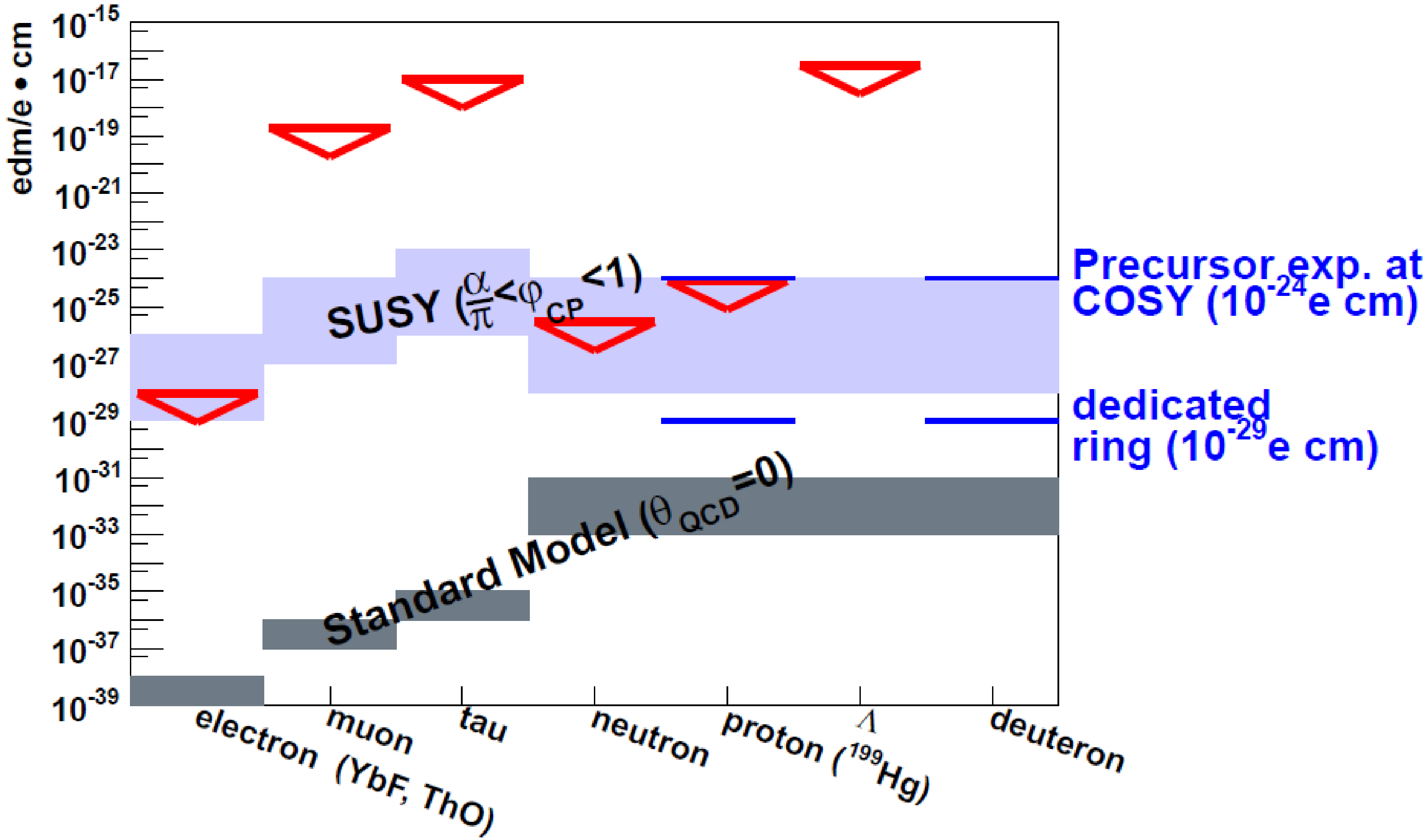
	observed	SM prediction
$\eta = \frac{n_B - n_{\bar{B}}}{n_\gamma}$	$\mathbf{6 \times 10^{-10}}$	$\mathbf{10^{-18}}$

Sakharov (1967): $\mathcal{CP}$ violation needed for baryogenesis

$\Rightarrow$ New $\mathcal{CP}$ violating sources beyond SM needed to explain this discrepancy

They could manifest in EDMs of elementary particles

EDM: Current Upper Limits



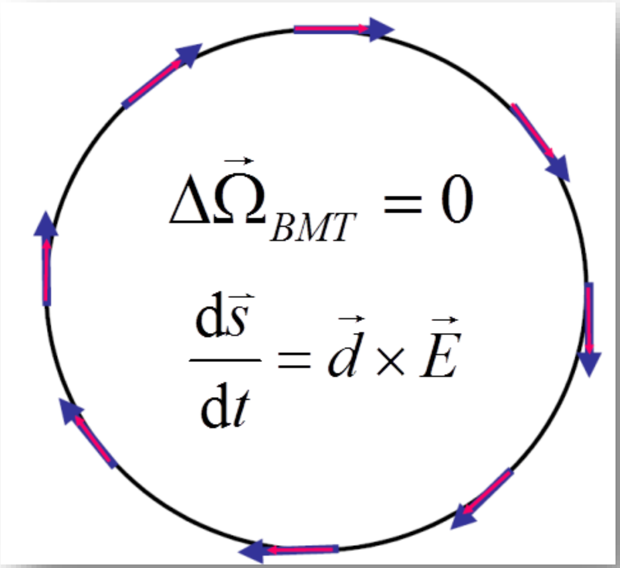
FZ Jülich: EDMs of **charged** hadrons: $p, d, {}^3$He

Measurement Principle and Challenges

From frozen spin and
magic energies

Frozen Spin

Spins aligned along particles' momentum:



$$\Delta\Omega_{BMT} = -\frac{e}{m}\left\{a \cdot \vec{B}_{\perp} + \left(\frac{1}{\gamma^2 - 1} - a\right)\frac{\vec{\beta} \times \vec{E}}{c}\right\}$$

<u>Magic Energies:</u>

- all electric ($B = 0$): $p = m/\sqrt{a}$
- combined ($E, B \neq 0$): $E_x = \frac{ac\beta\gamma^2}{1 - a\beta^2\gamma^2} B_z$

EDM would cause a development of vertical polarization!

$R \approx 30\text{m}$, *all-in-one*:

particle	p (GeV/c)	E (MV/m)	B (T)
proton	0.701	16.789	0.000
deuteron	1.000	−3.983	0.160
^{3}He	1.285	17.158	−0.051

Concept: Systematics

Magnetic fields:

- Radial field B_r mimics EDM effect when $\mu \times B_r \approx d \times E_r$
- With $d = 10^{-29}\ \mathrm{e \cdot cm}$ in a field of $E = 10\ \mathrm{MV/m}$,

$$B_r = \frac{dE_r}{\mu_n} = \frac{10^{-31} \cdot 10^{7}\,\mathrm{eV}}{3.152 \cdot 10^{-8}\ \mathrm{eV/T}} = 3.1 \cdot 10^{-17}\ \mathrm{T}$$

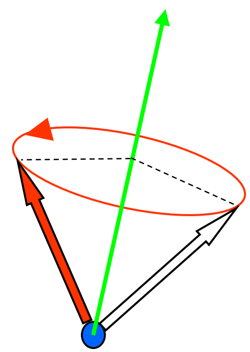
- **Solution:** Use two beams *simultanously*, clockwise (CW) and counter-clockwise (CCW), the vertical separation of the beam orbits is sensitive to B_r.

Use CW and CCW beams to tackle systematics

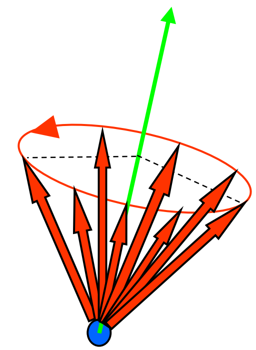
Challenge: Spin coherence time (SCT)

We usually don't worry about coherence of spins along $\hat{n}_{co}$

$$Q_{sp} = \gamma \cdot a$$



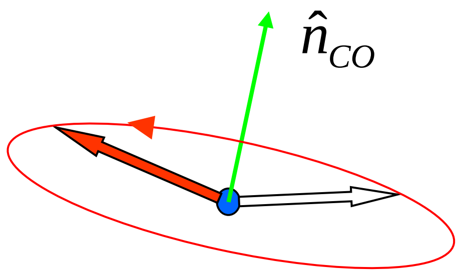
At injection all
spin vectors aligned (coherent)



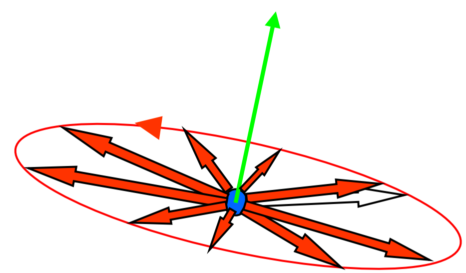
After some time, spin vectors get out of
phase and fully populate the cone

Polarization along $\hat{n}_{co}$ not affected!

Situation very different, when you deal with $\vec{S} \perp \hat{n}_{co}$ machines with frozen spin.



At injection all spin vectors aligned



Later, spin vectors are out of
phase in the horizontal plane

Longitudinal polarization vanishes!

In a machine with frozen spins the buildup time to observe a polarization $P_y(t)$ is limited by τ_{SCT}.

EDM-Measurement in Storage Rings (srEDM)

Challenges:

- Suppression of **systematic effects** (cw and ccw beams)
- High **electric field gradients** required ($E \approx 17$ MV/m)
- Long **spin coherence time** ($T_{coh} \geq 1000$ sec)
- Continuous and **precise polarimetry** ($\Delta P \approx 10^{-6}$)
- Precise **beam positioning** (10 nm)
- Sophisticated **spin tracking**

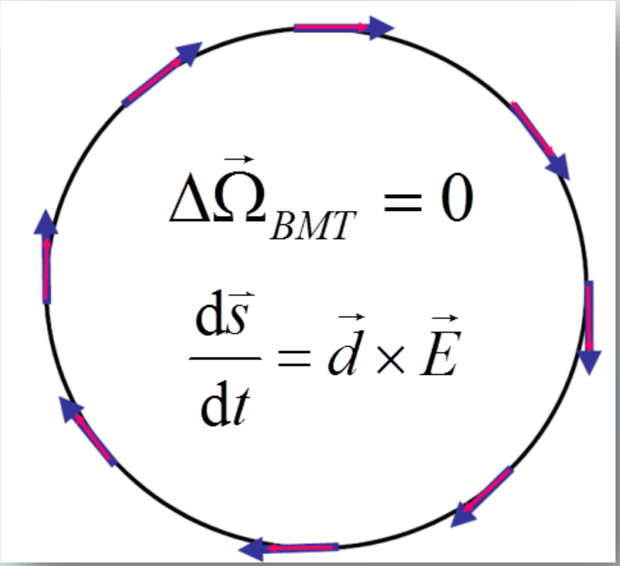
Jülich Electric Dipole moment Investigation, goal: 10^{-29} e·cm

Possible Realisation in Bonn

A closer look into the world of electron EDMs

Frozen Spin

Spins aligned along particles' momentum:



$$\Delta\Omega_{BMT} = -\frac{e}{m}\left\{a\cdot\vec{B}_{\perp} + \left(\frac{1}{\gamma^2-1}-a\right)\frac{\vec{\beta}\times\vec{E}}{c}\right\}$$

<u>Magic Energies:</u>

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- combined (E, $B \neq 0$): $E_x = \frac{ac\beta\gamma^2}{1-a\beta^2\gamma^2}B_z$

EDM would cause a development of vertical polarization!

$\rightarrow$ $p_e = 15$ MeV/c **relatively small ring, ideally suited for University group**

sre-EDM Layout

Required *E*-field:

$$m\frac{\mathrm{v}^2}{R} = \frac{p^2}{\gamma m_0 R} = e \cdot E \quad \rightarrow \quad E \simeq \beta \frac{pc}{eR} \overset{R=2\mathrm{m}}{\simeq} 7.5\frac{\mathrm{MV}}{\mathrm{m}}$$

E-bends with 3cm gap @ ± 112.5 kV: seems feasible and affordable!

Synchrotron radiation:

$$U[\mathrm{kV}] \simeq 88.5 \cdot \frac{E_e{}^4[\mathrm{GeV}]}{R[\mathrm{m}]} \quad \rightarrow \quad \Delta E_e \sim 2\,\frac{\mathrm{meV}}{\mathrm{turn}} \quad \text{but} \quad > 35\frac{\mathrm{keV}}{\mathrm{sec}}$$

→ bunched beam with $f_0 \approx 20\mathrm{MHz}$, up to 25 bunches possible @ 500MHz RF

Spin Coherence Time (SCT):

$$\tau_{sc} \simeq \frac{1}{f_0 \cdot a^2 \cdot \langle \delta\gamma^2 \rangle} \approx \frac{0.04\,\mathrm{sec}}{\langle \delta\gamma^2 \rangle} \quad \tau_{sc} = 1000\,\mathrm{sec} \leftrightarrow \delta\gamma \approx 6 \cdot 10^{-3} \quad \frac{\delta p}{p} \simeq 2 \cdot 10^{-4}\,!!!$$

Challenges

Same as for p-EDM and d-EDM:

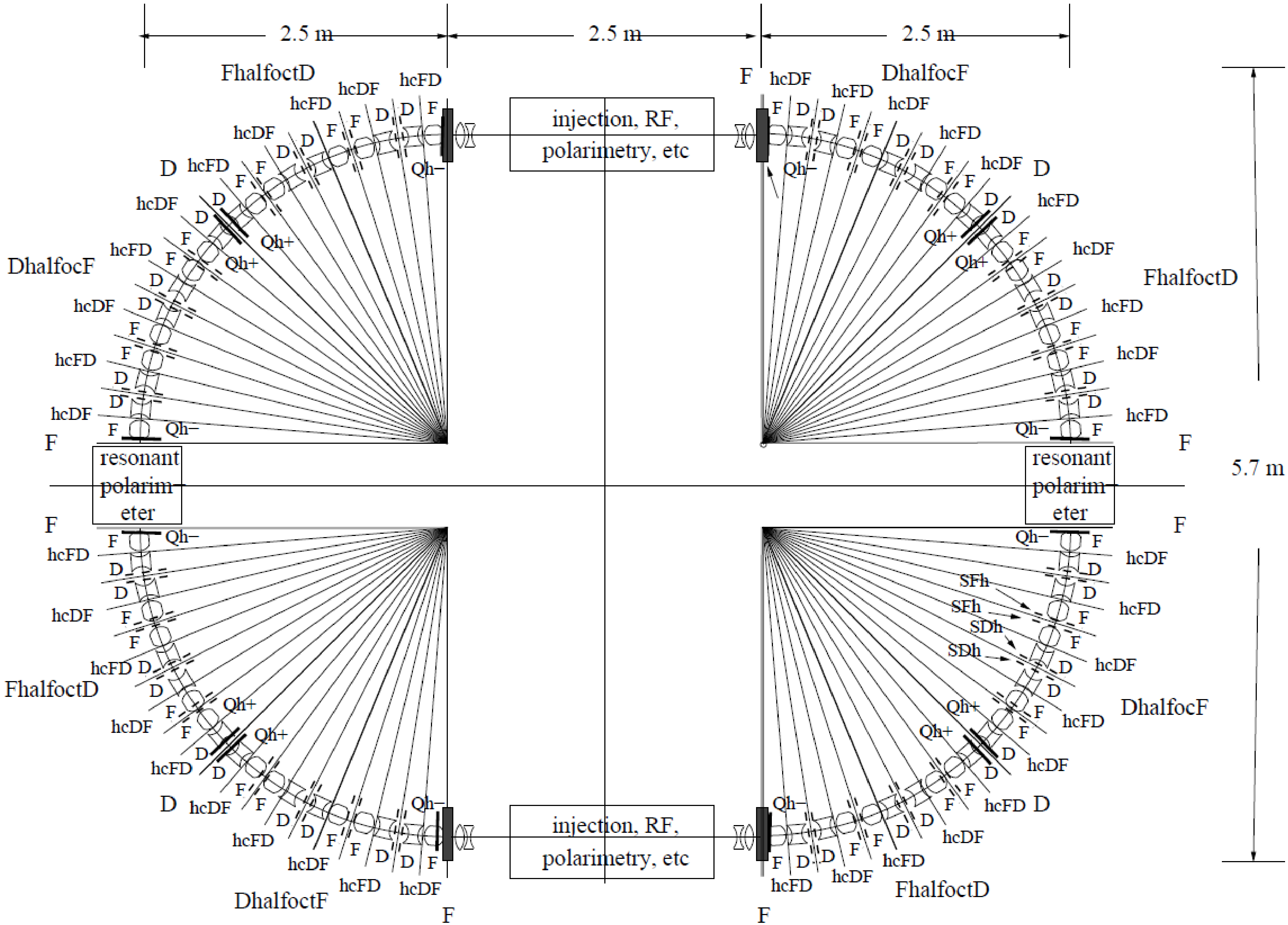
- electrostatic bends and related optics
- shielding of unwanted B-fields
- precise beam positioning and measurement
- suppression of systematic effects (cw and ccw beams)
- sophisticated spin tracking to study systematic effects

… and in particular (electrons):

- precise polarimetry!!!
- intra-beam scattering? (Touschek effect)
- add. constraints from small ring: SCT, beam injection, bpm, polarimetry, …

Could serve as a technology driver!

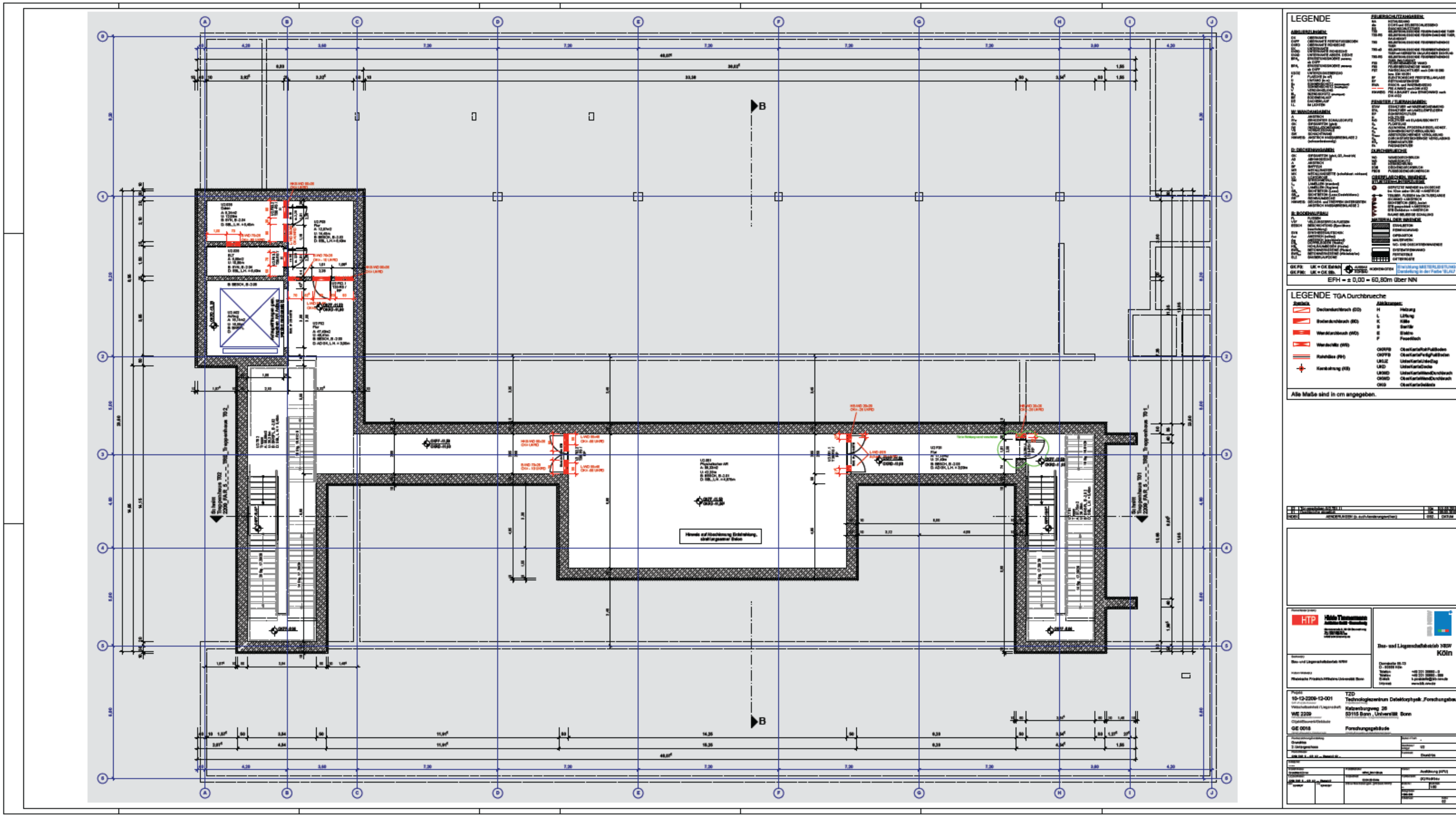
Talman (2013):


2.5 m
2.5 m
2.5 m
5.7 m
FhalfoctD
DhalfocF
DhalfocF
FhalfoctD
FhalfoctD
DhalfocF
DhalfoctF
FhalfoctD
injection, RF, polarimetry, etc
injection, RF, polarimetry, etc
resonant polarim-eter
resonant polarim-eter
hcFD
hcDF
Qh−
Qh+
SFh
SFh
SDh
SDh
F
D

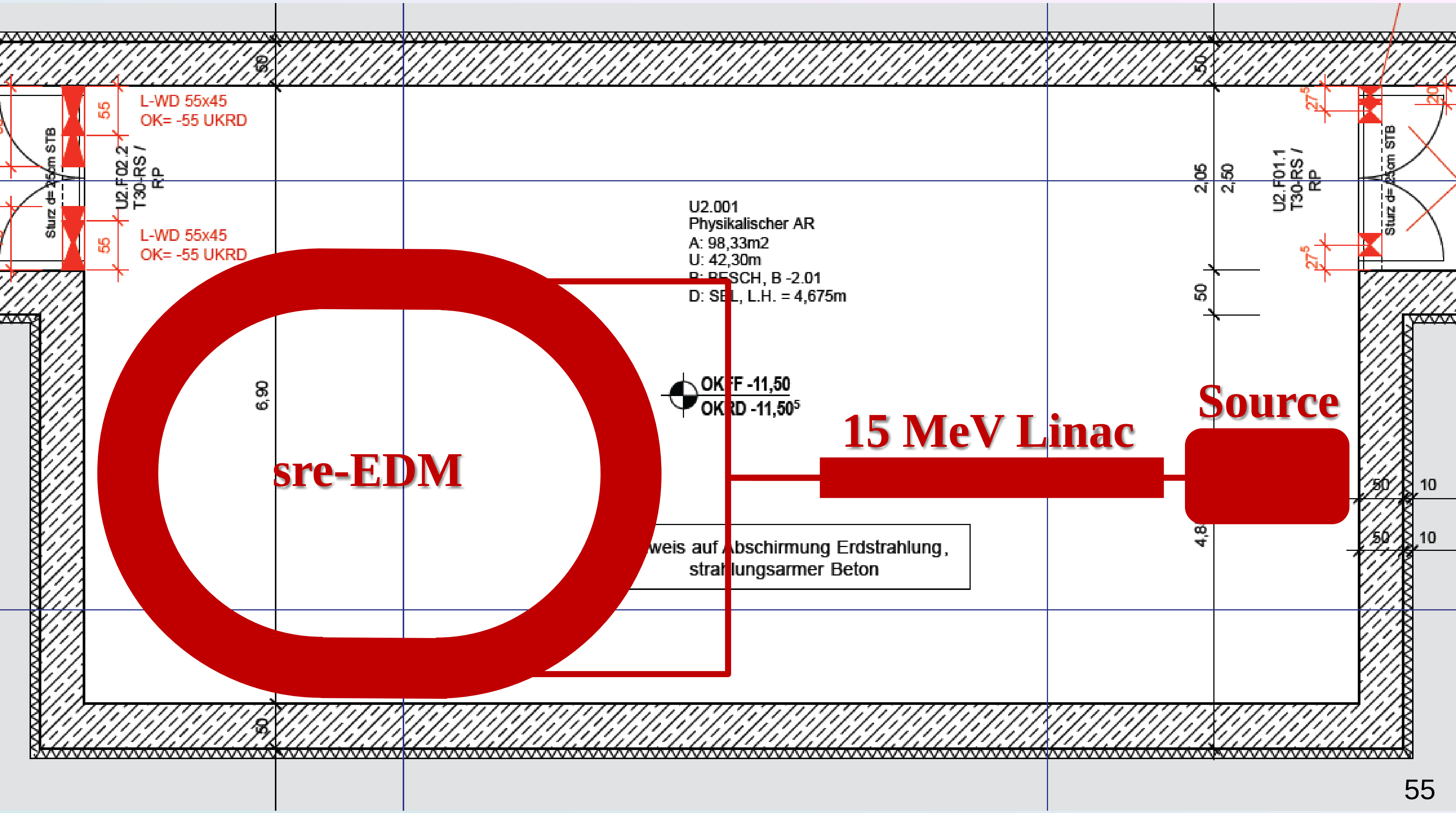
Where? One Example:

basement

Where? One Example:



Tiefenlabor Forschungsbau

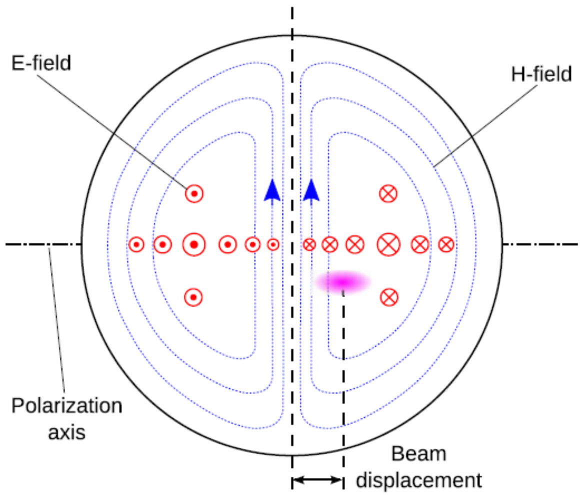


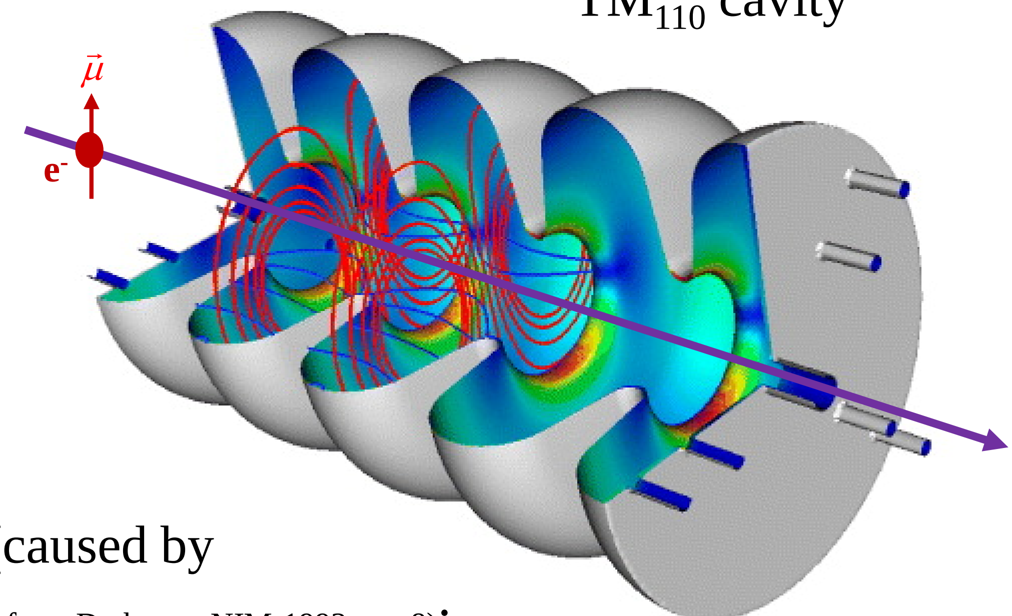
Tasks of the JLAB Visit

resonant polarimetry
combined E/B deflectors

Resonant Polarimetry

Principle Idea (Derbenev 1993):





TM$_{110}$ cavity

Coupling of the magnetic moment (caused by the spin) to the cavity's B-field (taken from Derbenev-NIM-1993, eq. 8):

$$W_C = \omega_c |a|^2 = \omega_c N^2 \left| \left\langle \frac{e}{2mc\sqrt{2\omega_c}} \left(\left(a + \frac{1}{\gamma} \right) B_\perp^c + \frac{1+a}{\gamma} B_\parallel^c \right) \vec{e} \cdot e^{ik\theta} \right\rangle \right|^2 \frac{\hbar^2 t^2}{4} P_e \sin^2 \alpha$$

Shows no γ scaling compared to Conte's γ^2 scaling?

Conte's simple Approach

Longitudinal Stern-Gerlach force:

$$F_z^{SG} = \frac{\partial}{\partial z^*}\left(\vec{\mu}^* \bullet \vec{B}^*\right) = \gamma\left(\frac{\partial}{\partial z} + \frac{\beta}{c}\frac{\partial}{\partial t}\right)\left(\vec{\mu}^* \bullet \gamma\left[\left(\vec{B} - \frac{\vec{\beta}}{c} \times \vec{E}\right) - \frac{\gamma^2}{\gamma+1}\vec{\beta}\left(\vec{\beta} \bullet \vec{B}\right)\right]\right)$$

Energy transfer to the cavity:

$$\Delta W = \int_0^d F_z^{SG} \cdot dz$$

What's wrong with this???

What’s wrong with Conte‘s Approach

Transformation of derivatives: $$\gamma\left(\frac{\partial}{\partial z}+\frac{\beta}{c}\frac{\partial}{\partial t}\right)=\gamma\frac{d}{dz}-\frac{1}{\beta\gamma c}\frac{\partial}{\partial t}$$

$$\Rightarrow F_z^{SG}=\left(\gamma^2\frac{d}{dz}-\frac{1}{\beta c}\frac{\partial}{\partial t}\right)\left(\vec{\mu}^*\bullet\left[\left(\vec{B}-\frac{\vec{\beta}}{c}\times\vec{E}\right)-\frac{\gamma}{\gamma+1}\vec{\beta}\left(\vec{\beta}\bullet\vec{B}\right)\right]\right)$$

and: $$\Delta W=\int_0^d F_z^{SG}\cdot dz=\underbrace{\gamma\vec{\mu}^*\bullet\vec{B}^*\Big|_0^d}_{=0}-\frac{\vec{\mu}^*}{\beta c}\bullet\int_0^d\frac{\partial}{\partial t}\left[\left(\vec{B}-\frac{\vec{\beta}}{c}\times\vec{E}\right)-\frac{\gamma}{\gamma+1}\vec{\beta}\left(\vec{\beta}\bullet\vec{B}\right)\right]dz$$

Improper treatment in Conte:

- Treatment of the fringe fields: $F\simeq\gamma^2\frac{\partial B_y}{\partial z}$ neglecting temporal changes
- Neglecting beam deflection and spin precession in the transverse magnetic fields in the cavity, using

$$\vec{B}^*=\gamma\left(\vec{B}_\perp-\frac{\vec{\beta}}{c}\times\vec{E}\right)+\vec{B}_{||}$$

whereas the correct transformation is given by the T-BMT term

Thank you for your attention!

Machine Development: PhD students in the ELSA control room