

The Electron Stretcher Facility ELSA

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Accelerating the Search for Disappearing Light Dark Matter – a Community Workshop

30.09.2026



Outline

- 1 History of ELSA
- 2 Accelerator Overview & Experimental Beam Lines
- 3 Resonance Extraction Characteristics
- 4 Beam Parameters and Single Electron Extraction
- 5 Polarized Electron Beam
- 6 Summary, Outlook & Availability

History of ELSA

1953 First *strong* focusing synchrotron in Europe $E = 500$ MeV

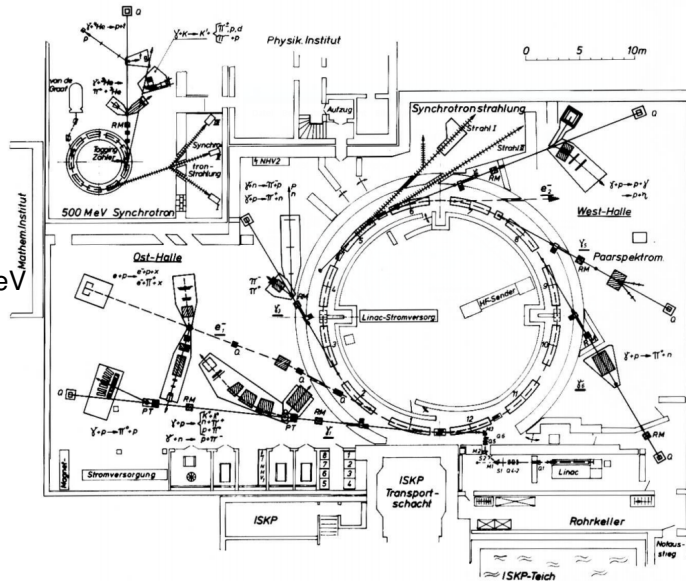
- experiments from 1958 to 1984
- decommissioned in favor of ELSA

1963 design & construction of the 2.5 GeV synchrotron started

- experiments from 1967 to 1982
- drawback: 5 % duty cycle

1982 construction of ELSA started

- first beam 1987
- start of exp. program 1988



Hall layout from 1975

Different Generations of Experiments

Hadron Physics Experiments

1988→1997 ELAN

1989→1996 PHOENICS

1991→1999 SAPHIR

2000→2002 GDH

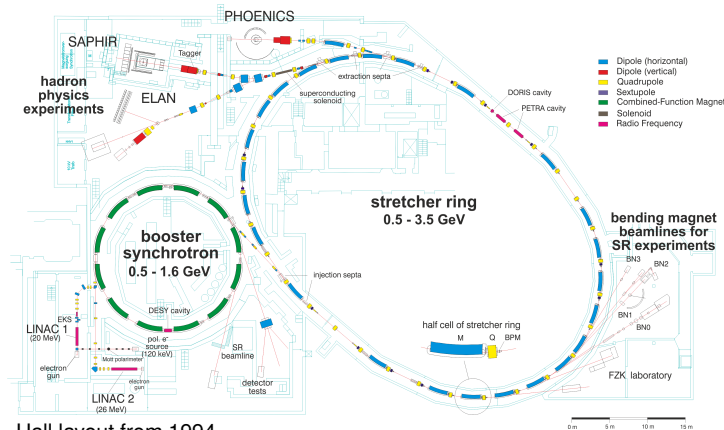
2000→now CB-ELSA

2014→2025 BGOOD

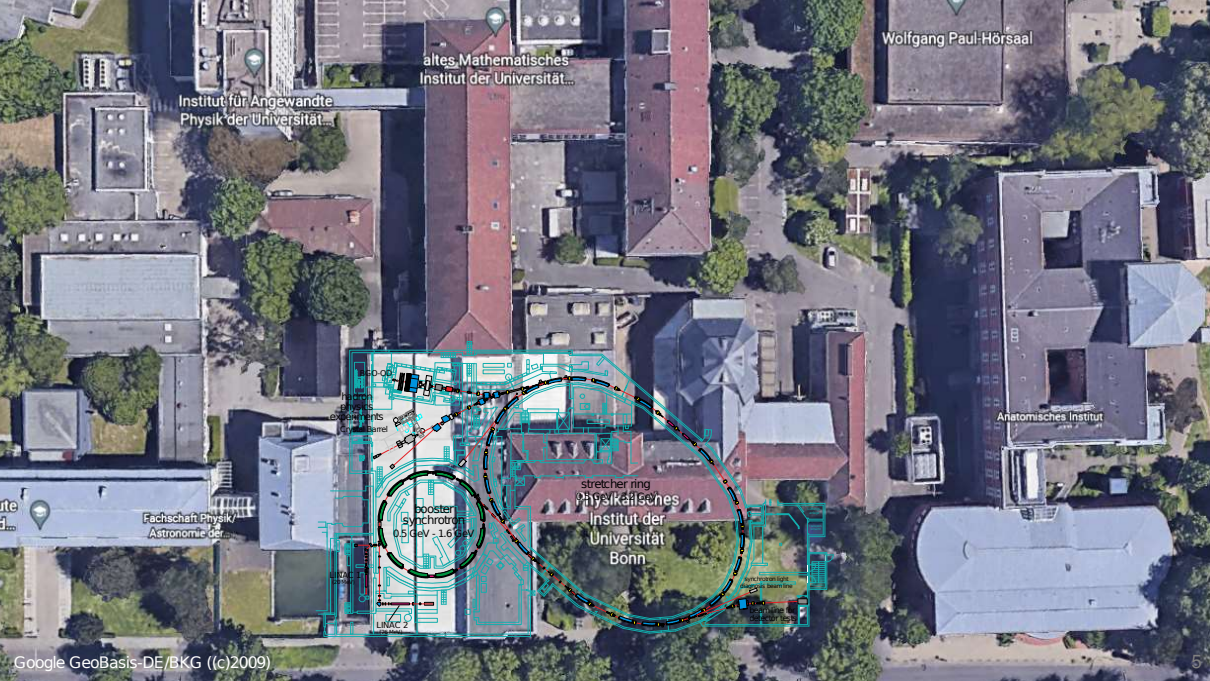
→ each generation: dedicated, purpose-built setup around the beamline

Synchrotron Radiation Experiments
(from 1990 to 2005):

- beamlines decommissioned
- since 2017: new beamline for e^-



Hall layout from 1994



Institut für Angewandte
Physik der Universität...

altes Mathematisches
Institut der Universität...

Wolfgang Paul-Hörsaal

Anatomisches Institut

Fachschaft Physik/
Astronomie der...

Physikalisches
Institut der
Universität
Bonn

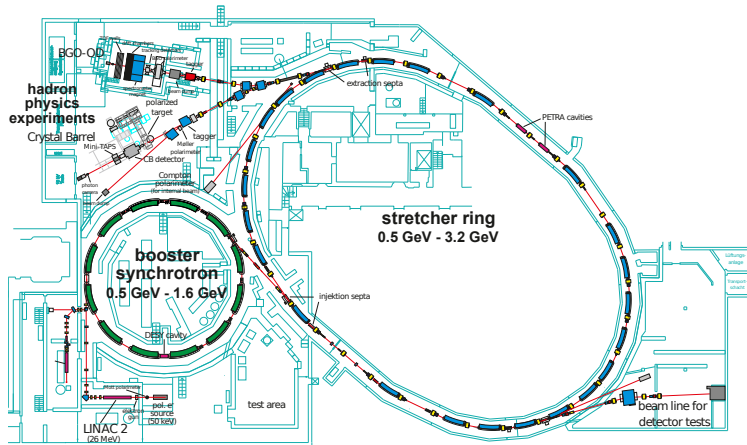
booster
synchrotron
0.5 GeV - 1.6 GeV

LINAC 2

synchrotron light
beam line

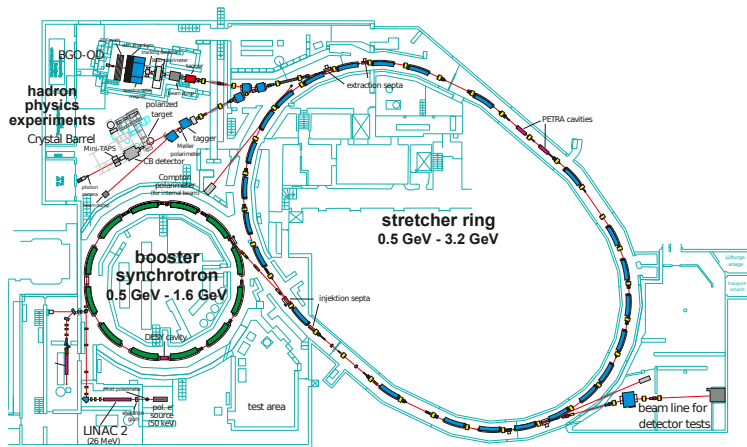
Elektronen Stretcher Anlage: ELSA

- 3.2 GeV electron synchrotron
- two electron sources
 - unpolarized
 - spin-polarized



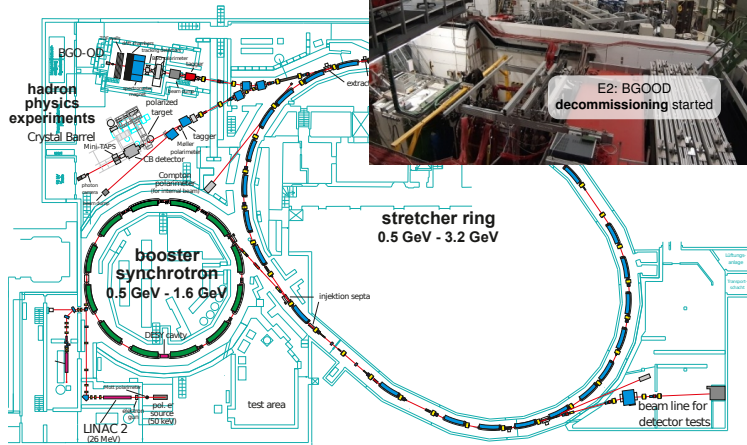
Elektronen Stretcher Anlage: ELSA

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- accelerators:
 - 26 MeV Linear Accelerator
 - 1.2 GeV Booster Synchrotron
 - 3.2 GeV Stretcher Ring



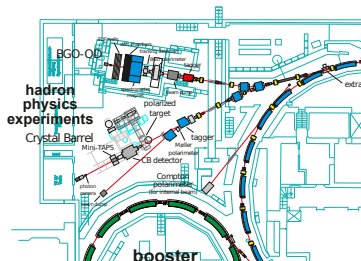
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E1/E2: permanent experiments

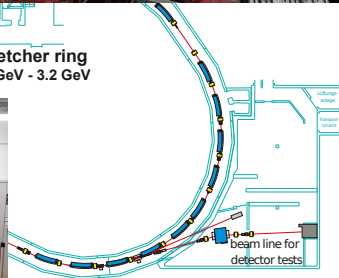
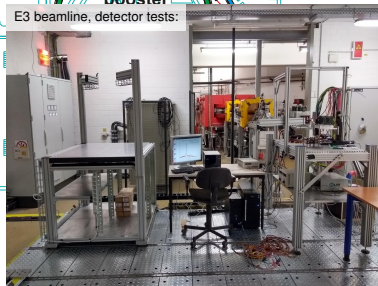


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 - E3: 4 movable tables, table-top exp.



E3 beamline, detector tests:

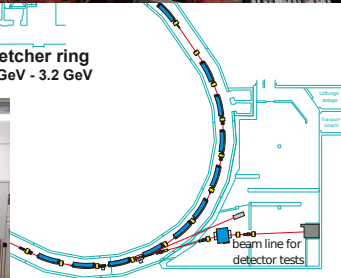
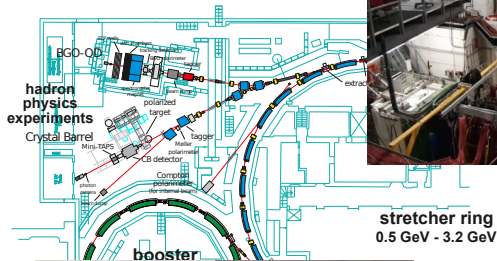


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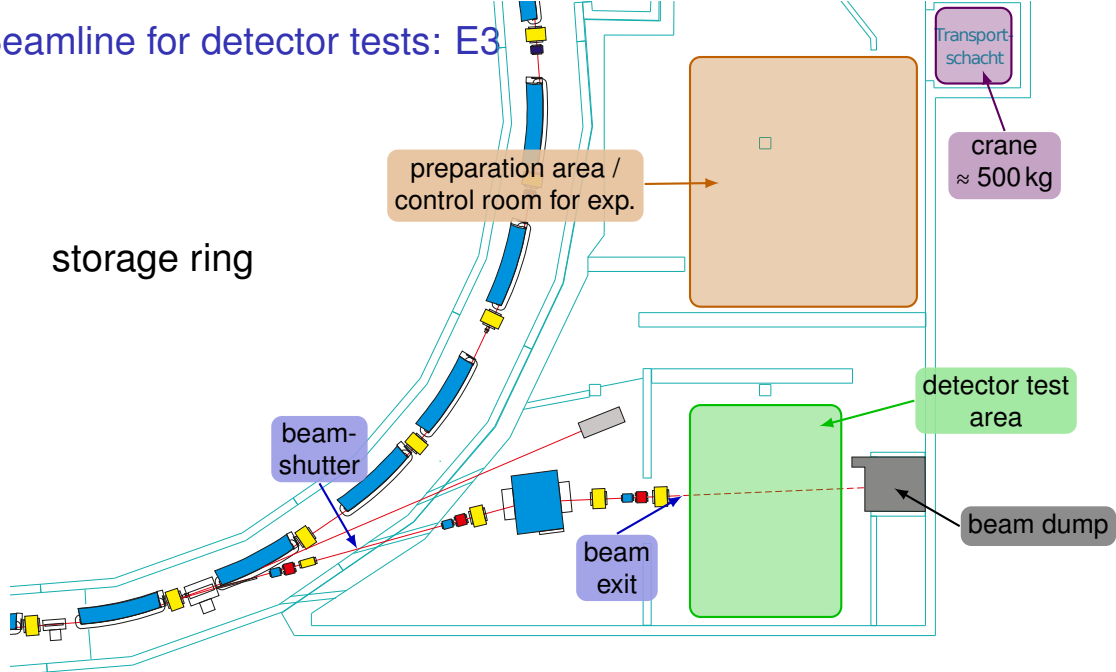
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- two experimental sites
 - E1/E2: permanent experiments
 - E3: 4 movable tables, table-top exp.
- experimental program
 - hadron physics experiments (at beamlines E1/E2)

⇒ **BGOOD just finished data taking**

 - detector tests (at beamline E3)
 - medical physics (at beamline E3)

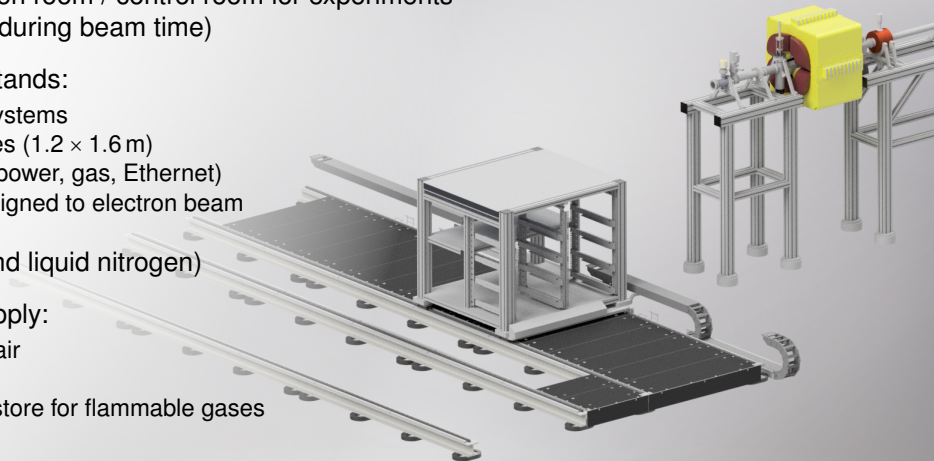


Beamline for detector tests: E3

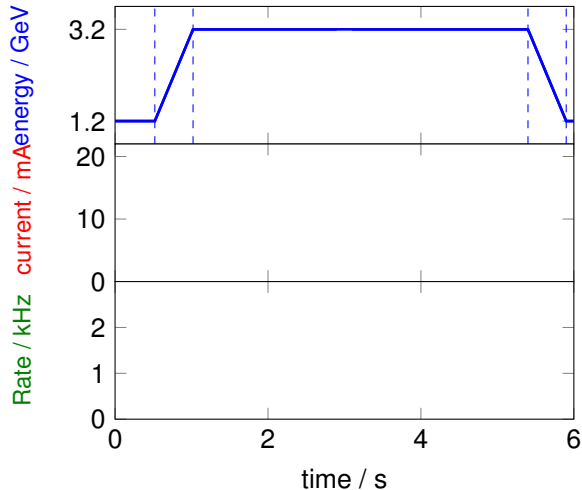


E3 Infrastructure

- 30 m² experimental area
- nearby preparation room / control room for experiments (fully accessible during beam time)
- 4 movable test stands:
 - 2 guide rail systems
 - movable tables (1.2 × 1.6 m)
 - patch panel (power, gas, Ethernet)
 - laser beam aligned to electron beam
- cooling (water and liquid nitrogen)
- available gas supply:
 - compressed air
 - dry nitrogen
 - gas cylinder store for flammable gases



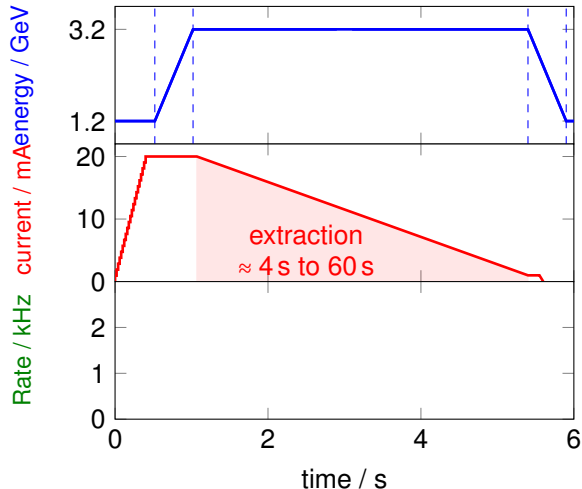
ELSA: Booster Mode



● flat top energy: 0.8 GeV to 3.2 GeV

each ~ 6 s cycle: injection → ramp to flat-top energy → slow extraction for several seconds
→ ramp to injection energy
⇒ overall duty cycle: $\approx 80\%$ to 90%

ELSA: Booster Mode

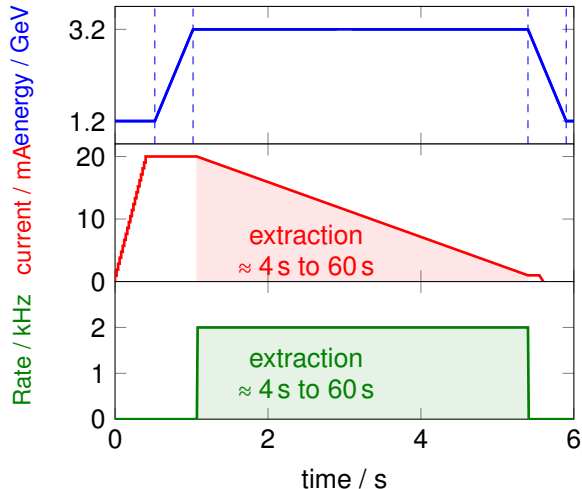


• flat top energy: 0.8 GeV to 3.2 GeV

• stored current: up to 30 mA

each ~ 6 s cycle: injection $\rightarrow$ ramp to flat-top energy $\rightarrow$ slow extraction for several seconds
 $\rightarrow$ ramp to injection energy
 $\Rightarrow$ overall duty cycle: $\approx 80\%$ to 90%

ELSA: Booster Mode



- flat top energy: 0.8 GeV to 3.2 GeV
- stored current: up to 30 mA
- extracted current: up to 1 nA (E1/E2)
- extracted rate (E1/E2): 200 Hz to 6.25 GHz
- (E3): 1 Hz to 625 MHz

each ~ 6 s cycle: injection $\rightarrow$ ramp to flat-top energy $\rightarrow$ slow extraction for several seconds
 $\rightarrow$ ramp to injection energy
 $\Rightarrow$ overall duty cycle: $\approx 80\%$ to 90%

Additional Operation Modes

Operation Modes aren't fixed...

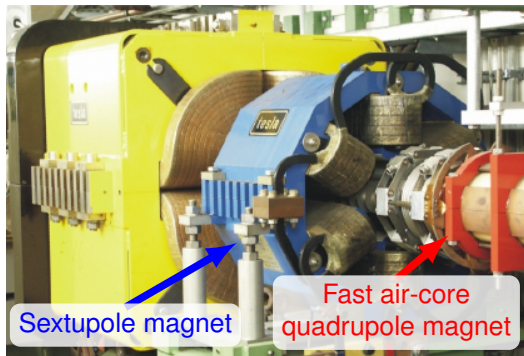
“Syli Mode” (Storage Mode)

- storage of high currents (up to 200 mA)
- energies up to 3.2 GeV (limited lifetime, limited current)
- only utilized for machine studies/development

Fast Beam Extraction Modes

- developed for FLASH radiotherapy R&D (FLASH: ultra-high dose-rate single-pulse irradiation)
- **from Booster:** part of the Stretcher ring used as beamline for direct transfer to E3 experimental area
 - single shots, 250 ns pulse duration, up to 10 nC, rep. rate ≤ 1 Hz
 - limited energy: 1.2 GeV
- ⇒ **from Stretcher:** newly developed: single turn kicker extraction from the Stretcher ring
 - supports energies up to 3.2 GeV
 - single shots, 250 ns pulse duration, up to 100 nC, rep. rate ≤ 0.1 Hz

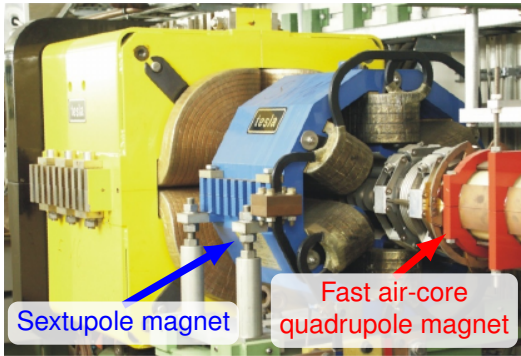
Resonance Extraction Scheme



Sextupole: drives third-integer resonance
(driving term $\propto x^2$)

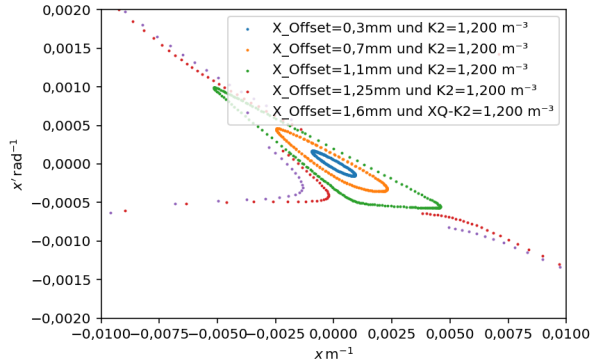
Quadrupole: shifts tune towards $Q = 4\frac{2}{3}$

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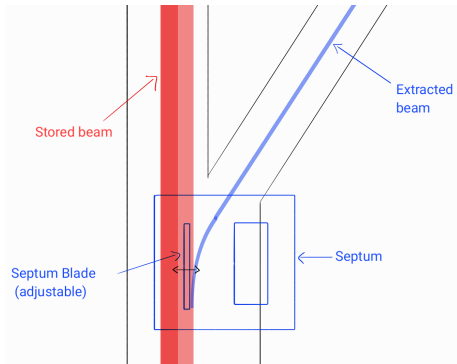
Quadrupole: shifts tune towards $Q = 4\frac{2}{3}$



- **blue:** small amplitude, essentially unperturbed
- **green:** last stable particle (on the separatrix)
- **red:** amplitude grows every turn $\rightarrow$ extracted

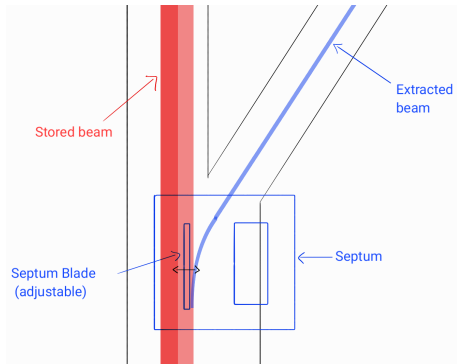
Extraction Mechanism (simplified)

- Septum magnet guides out particles with high betatron amplitude
- Extraction efficiency $\approx 50\%$

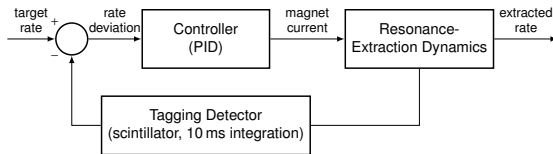


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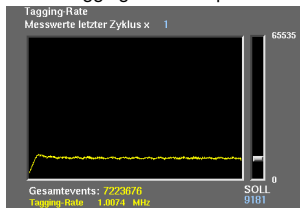


- Rate regulation by software PID controller

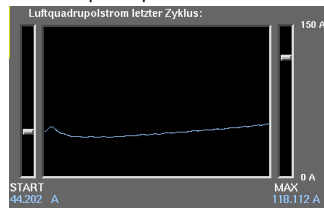


- Setpoint event / tagging rate adjustable by accelerator operator / experiment operator

Event-/tagging rate at Experiment:

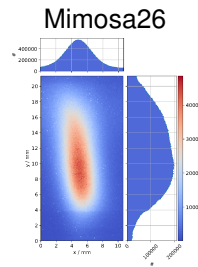
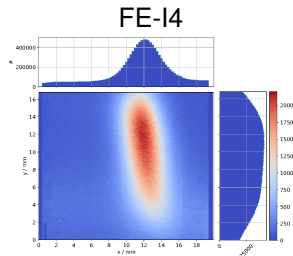


Air-core quadrupole current:



Electron Beam Properties at E3

Snapshot of a beam profile at detector test beamline:



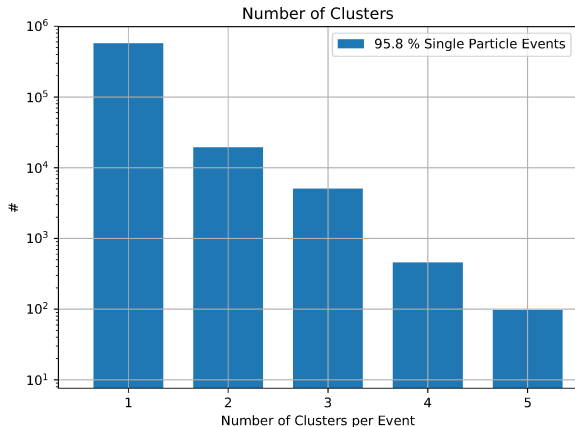
Beam properties at detector test beamline:

	energy E	$\frac{\Delta E}{E}$	width/mm	divergence/mrad	rate	current
Min	0.8 GeV	< 0.2 ‰	$\sigma_x = 1.3$ $\sigma_z = 1.0$	$\sigma'_x = 0.13$ $\sigma'_z = 0.01$	200 Hz*	≈ 0 A
Max	3.2 GeV	< 0.8 ‰	$\sigma_x = 9.0$ $\sigma_z = 6.0$	$\sigma'_x = 2.5$ $\sigma'_z = 3.0$	625 MHz	100 pA

* in controlled operation mode down to 1 Hz

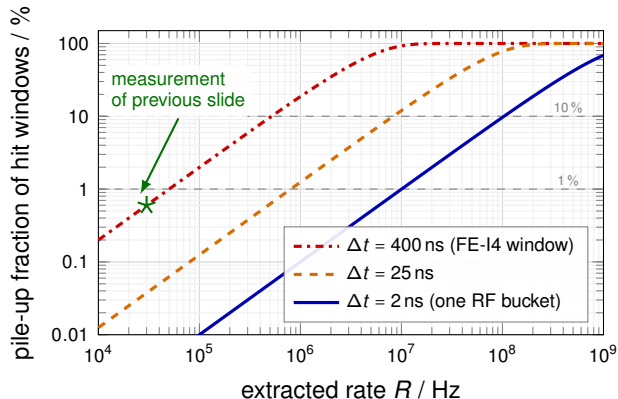
Single-Electron Purity at E3

- extraction rate: 30 kHz
- measurement using FE-I4 plane of beam telescope:
number of clusters per 400 ns time window



- > 95 % **single cluster** events
 - remaining events (< 5 %)
 - 2 (or more) electrons extracted during time window
 - secondary particles
 - purity degrades with higher rates
- ⇒ expect the same purity for E1/E2 beamlines (same extraction mechanism and septum as for E3)

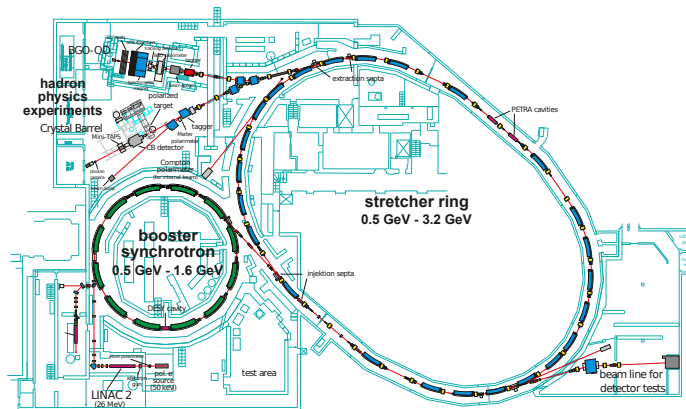
Single-Electron Purity: Scaling to Higher Rates



- extracted electrons arrive uncorrelated
 - Poisson, $\mu = R \Delta t$
 - expected pile-up at 30 kHz: only 0.6 %
 - ⇒ the remaining 5 % are secondaries, not multiple electrons per time window
- extrapolated to one RF bucket (2 ns):
 - 1 % double occupancy at $R \approx 10$ MHz
 - 10 % at $R \approx 100$ MHz
- ⇒ **single electron per bucket up to ~ 10 MHz**

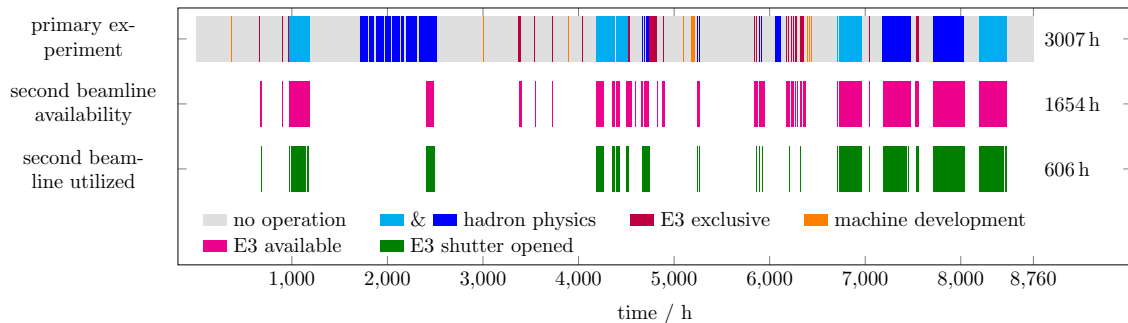
New Mode of Operation: Simultaneous Extraction E1/E2 and E3

- superperiodicity $P = 2$
 - ⇒ 2 extraction points with similar beam properties
 - MSE22/23 → E1 / E2 beamline
 - MSE6/7 → E3 beamline
- different extraction *rates*
 - E1/E2: $O(R) \approx \text{GHz}$
 - E3 : $O(R) \approx \text{kHz}$
- ⇒ no impact on beam at E1/E2 visible



⇒ in operation since beginning of 2025!

Beamtime Overview 2025



Total beamtime 2025: 3007 h

- Hadron physics experiments: **2532 hours**
- Exclusive E3 experiments: 331 hours
- Machine development: 55 hours

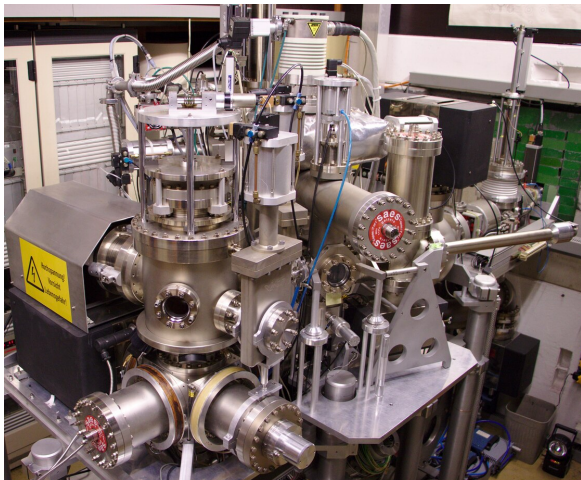
⇒

Gained 1654 hours more beam time availability by establishing the simultaneous extraction mode!

→ With 606 hours beam on!

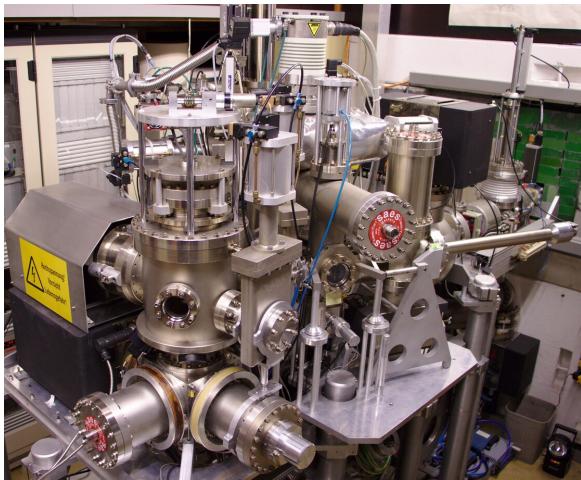
- Remaining 1048h preparation / setup time for experiments

Source for Polarized Electrons



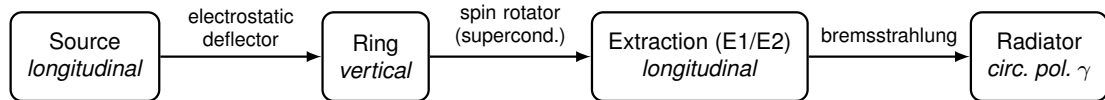
- strained-layer superlattice GaAs photocathode, inverted 50 keV electron gun
- polarization: $(82.6 \pm 0.6) \%$ (Mott polarimeter)
- lifetime: ≈ 250 h
- charge per pulse: $200 \text{ mA} \times 1 \mu\text{s} = 200 \text{ nC}$
- laser: home-built Ti:Sa system
- load-lock system (installed 2013)

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 - laser: home-built Ti:Sa system
 - load-lock system (installed 2013)
- ⇒ after 7 years of hibernation:
crystals recovered, source reactivated,
Ti:Sa laser system optimized
- **ready for regular beam time**

Polarized Beam in ELSA



→ depolarizing resonances countered by:

- harmonic orbit correction
- tune jumps

→ achieved polarization (2014):

E	polarization
at source	$(82.6 \pm 0.6) \%$
2.35 GeV	$(71 \pm 1) \%$
2.90 GeV	$(62 \pm 2) \%$
3.20 GeV	$(55 \pm 5) \%$

- combined with a polarized target

→ double-polarization observables

⇒ disentangles overlapping/interfering resonance contributions in baryon spectroscopy

A combination only a few facilities worldwide offer
in the ELSA energy regime

Availability

Availability

- up to 3000 h/year total beamtime
 - E3 runs *simultaneous* during hadron-physics beamtime
 - 1654 h available in 2025, 606 h used
 - dedicated E3 blocks schedulable in addition
 - institute renovation (next ~7 years): periodic few-month shutdowns, schedule still evolving
- annual beamtime expected to stay stable

Getting beam at ELSA

- simply **get in contact with us**
 - 4 beam time meetings per year
- each one plans the *next quarter*
- ⇒ **high flexibility due to a university-operated accelerator**

<https://www.elsa.uni-bonn.de>
proft@physik.uni-bonn.de

Summary

ELSA at a glance

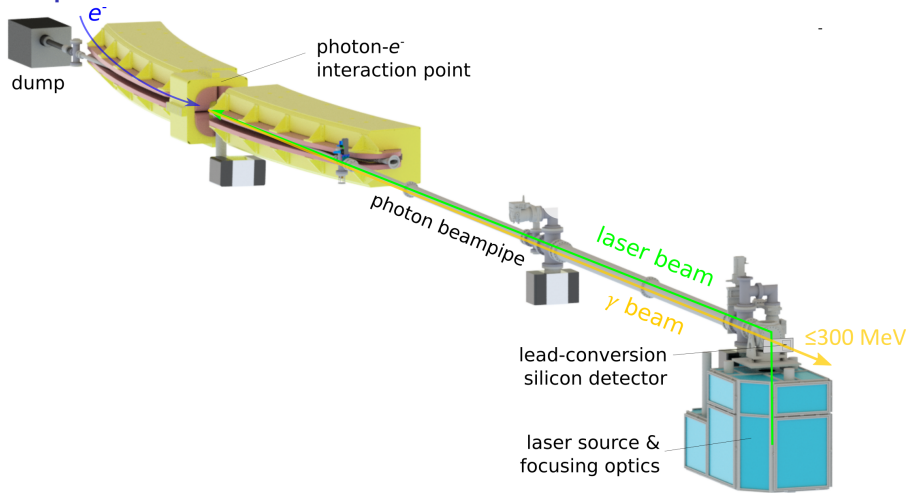
- Electron synchrotron, tunable energy: 0.8 GeV to 3.2 GeV
- Extracted rate:
 - continuously
 - PID-controlled
 - from ~ 1 Hz to 6.25 GHz
 - genuinely single-particle across almost the whole range
- Extracted current: sub-pA up to ~ 1 nA
- Single-electron purity: $> 95\%$ (measured at E3 with 30 kHz)
- Two independent, simultaneous extraction points (E1/E2 + E3); no measurable cross-talk
- Two source options:
 - unpolarized
 - or polarized up to $\sim 83\%$ at source
- up to 3000 h/year total beamtime
 - with a growing share via parasitic simultaneous extraction (+1654 h gained in 2025)

A group of 18 people, mostly men, are posing for a group photo in a large industrial facility. They are arranged in two rows, with some standing and some kneeling or sitting in the front. The background features large white modular structures, blue equipment, and industrial infrastructure like stairs and railings. A semi-transparent white banner with the text "Thank you for your attention" is overlaid on the top half of the image.

Thank you for your attention

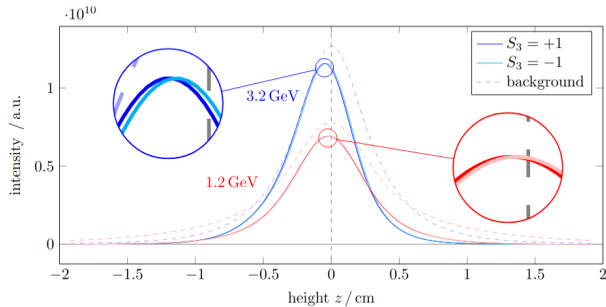
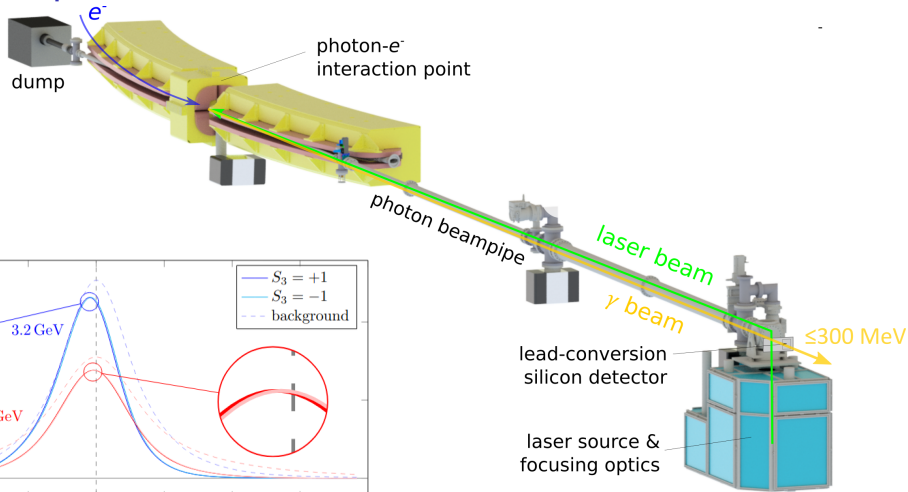
Additional Slides

Polarimetry: Compton Polarimeter



→ Recently upgraded the microstrip detector by a Timepix 3

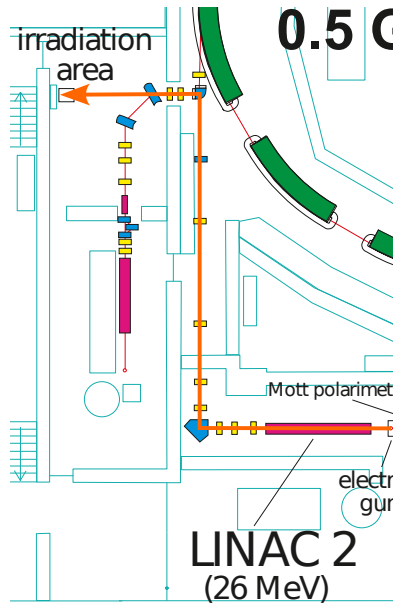
Polarimetry: Compton Polarimeter



→ Recently upgraded the microstrip detector by a Timepix 3

Experimental Area E5

- former irradiation site
 - “repurposed” from decommissioned LINAC 1
- beamline ends approx. 1 m in front of beam dump
- exit window made of thin Kapton[®] foil
- beam travels trough 2 cm of air
- enters light-tight black box



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