The Bonn
Electron Stretcher Accelerator

Project D2 / 2014

Beam and spin dynamics
in a fast ramping stretcher ring

Wolfgang Hillert

Physics Institute of Bonn University

(1. **The Challenge of High Intensities**) → last meeting…

2. **The Hunt for Highest Polarization**

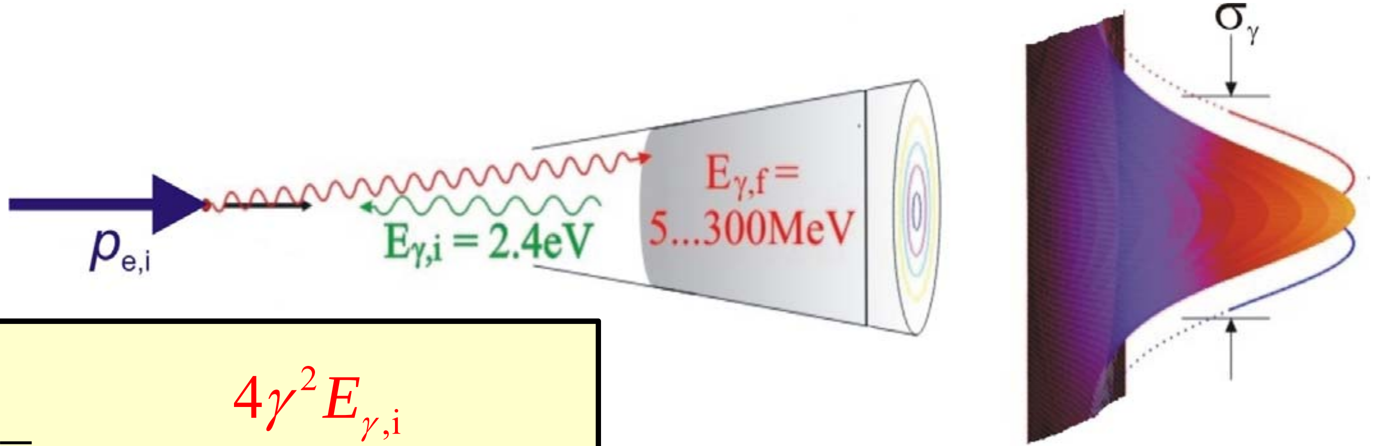
(3. The Mystery of Resonance Extraction) → next meeting…

The Hunt for Highest Polarization

Photoproduction Experiments:

- GeV photon beams with **precisely known photon energies** (tagging!)
- **Linear or circular polarization** of photon beam

Underlying basic generation principle: Compton scattering!



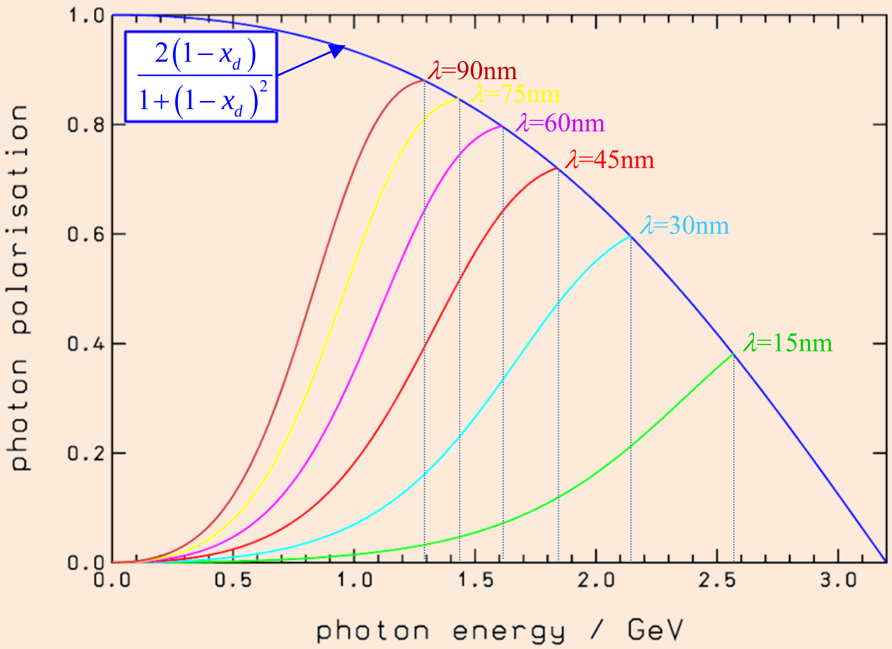
$$E_{\gamma,\mathrm{f}} = \frac{4\gamma^2 E_{\gamma,\mathrm{i}}}{1 + \underbrace{4\gamma E_\gamma / m_e c^2}_{\text{recoil}} + \gamma^2\theta^2}$$

$\rightarrow$ $E_{\gamma,\mathrm{i}} \approx 10 - 100$ eV required!

Compton scattering of polarized γ's

Beam energy: 3.2 GeV

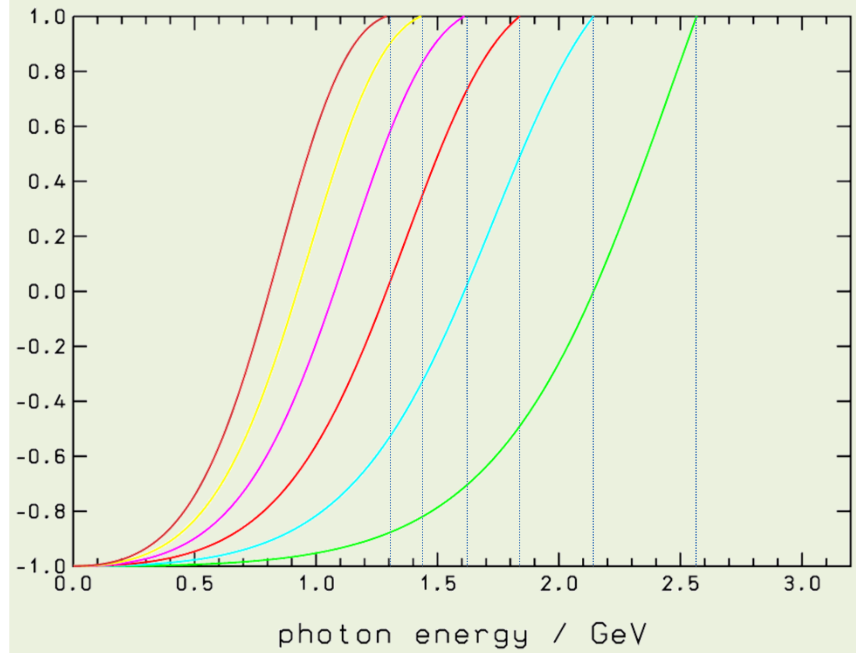
Linear polarization



$$P = \frac{2x^2Q^2}{1-x}\left\{1+(1-x)^2 - \frac{4x^2Q^2}{1-x}\left(\frac{1-x}{xQ}-1\right)\right\}^{-1}$$

Recoil limits max. polarization!!!

Circular polarization



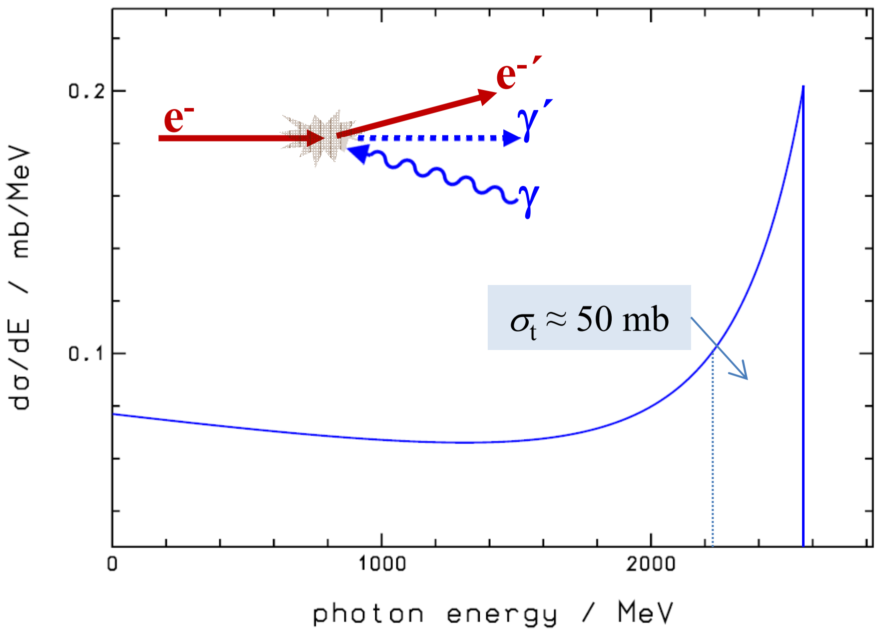
$$P = \left(1-\frac{2xQ}{1-x}\right)\left(1+(1-x)^2\right)\left\{1+(1-x)^2 - \frac{4x^2Q^2}{1-x}\left(\frac{1-x}{xQ}-1\right)\right\}^{-1}$$

with $Q = \frac{1-x_d}{x_d}$ and $x_d = \frac{E_{\gamma,\mathrm{f}}^{\max}}{E_{\mathrm{beam}}}$

Required Photon Flux

Compton Backscattering:

Beam energy: $E = 3.2$ GeV
Beam current: $I = 100$ mA
Incoming photon: $\lambda = 15$ nm (80 eV)



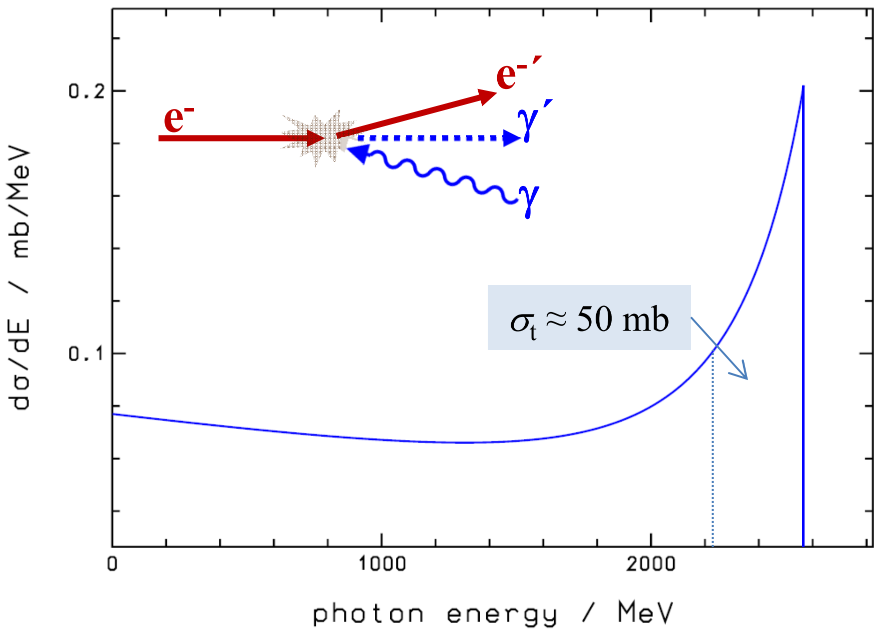
$N_\gamma > 10^{19}$ s^{-1} **required!**

P_L(15nm) > 100W!

Required Photon Flux

Compton Backscattering:

Beam energy: $E = 3.2$ GeV
Beam current: $I = 100$ mA
Incoming photon: $\lambda = 15$ nm (80 eV)

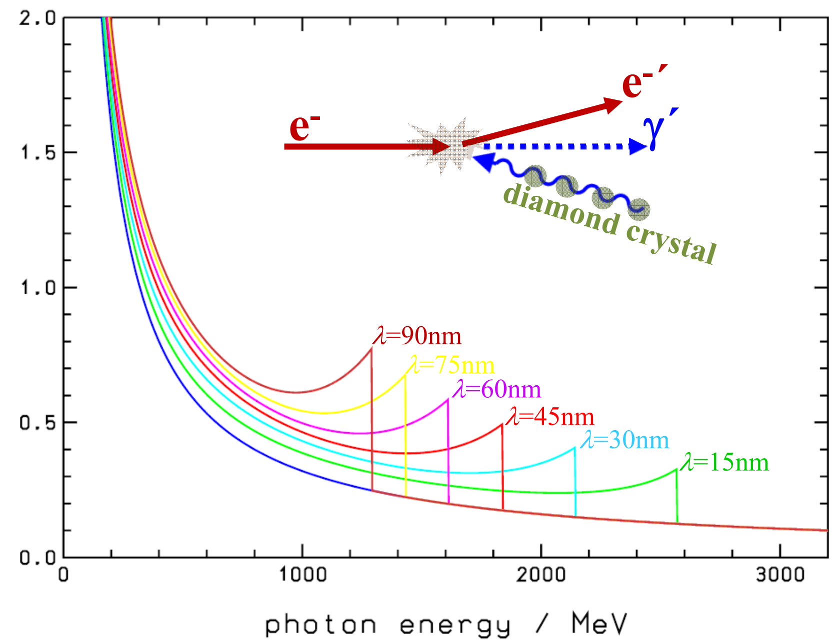


$N_\gamma > 10^{19}$ s^{-1} required!

P_L(15nm) > 100W!

Coherent Bremsstrahlung:

Beam energy: $E = 3.2$ GeV
Beam current: $I = 1$ nA
Momentum transfer to crystal radiator!

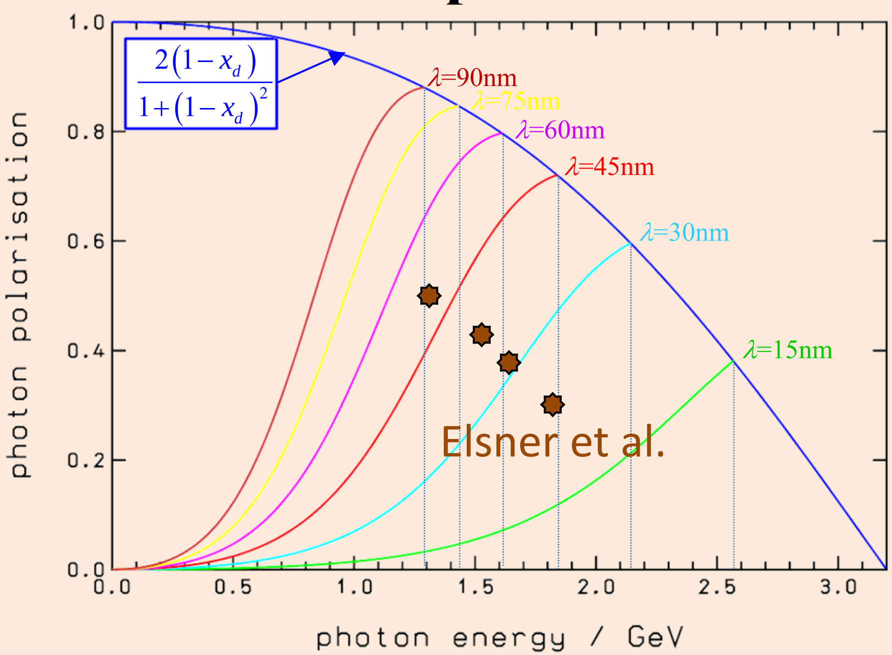


Polarization determined by orientation of the crystal!

Coherent Bremsstrahlung

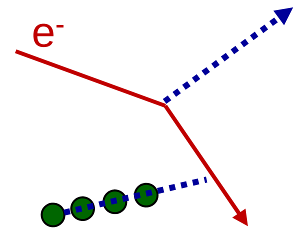
Beam energy: 3.2 GeV

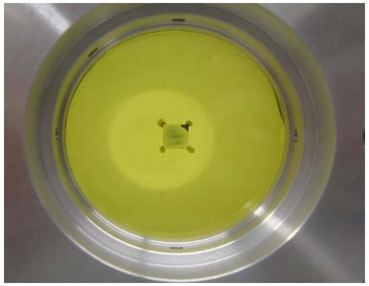
Linear polarization

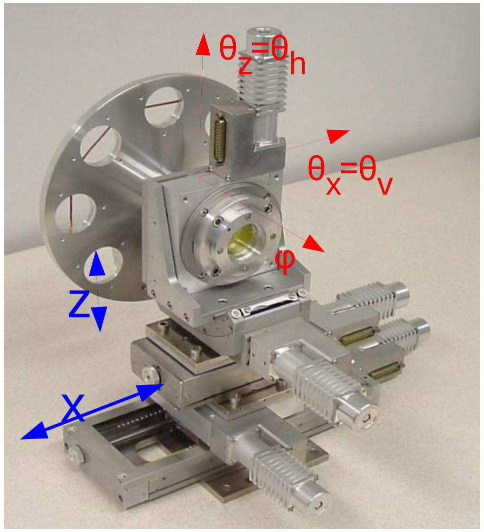


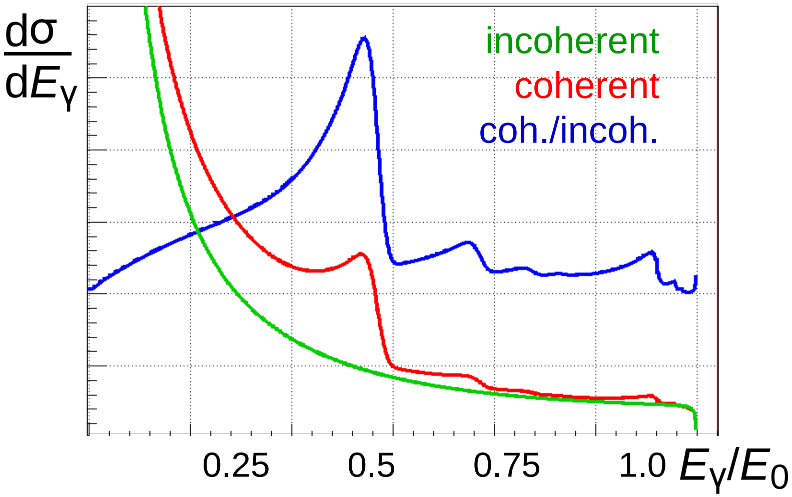
$$P = \frac{2x^2Q^2}{1-x}\left\{1+(1-x)^2 - \frac{4x^2Q^2}{1-x}\left(\frac{1-x}{xQ}-1\right)\right\}^{-1}$$

Increase of beam energy desirable!

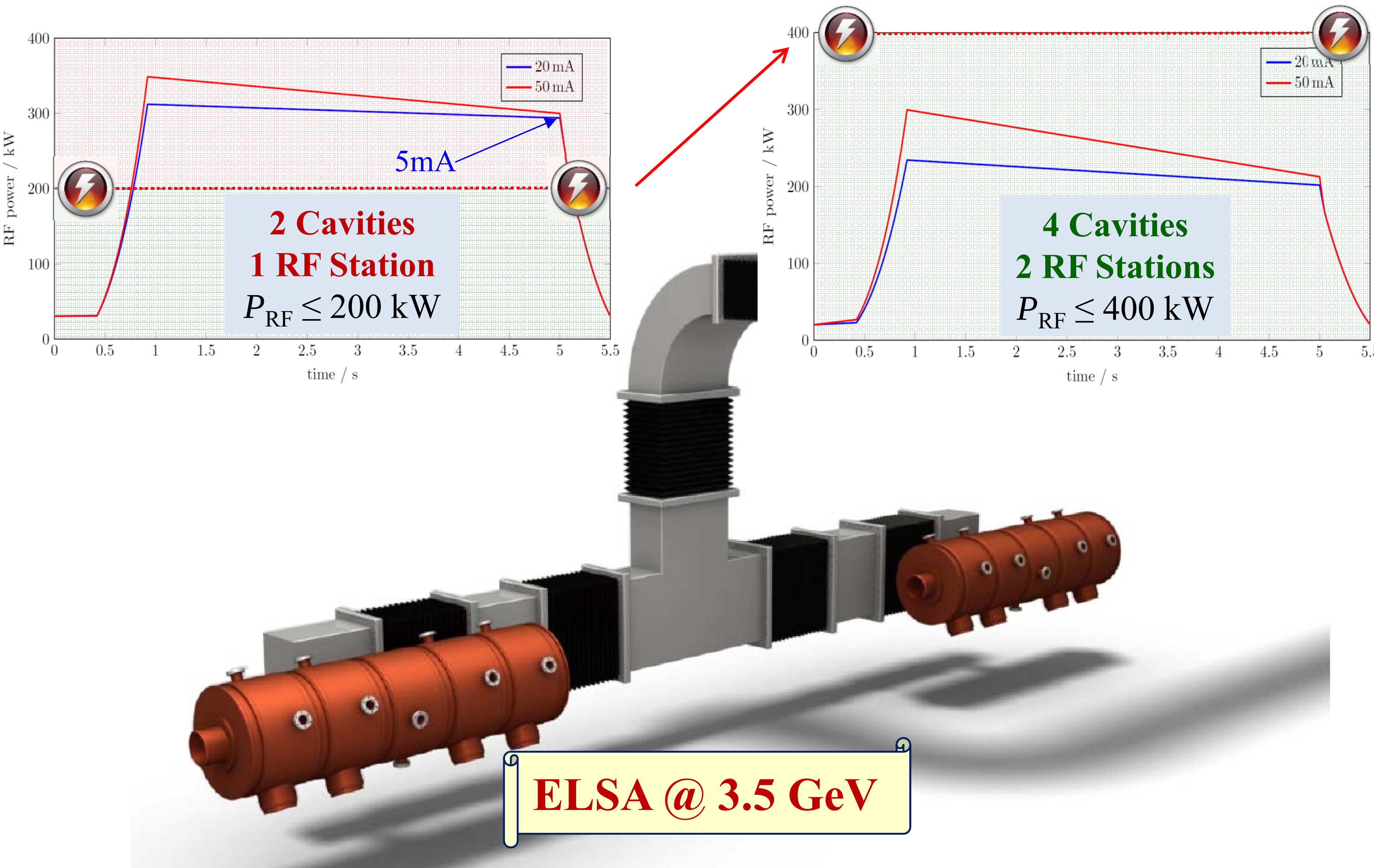




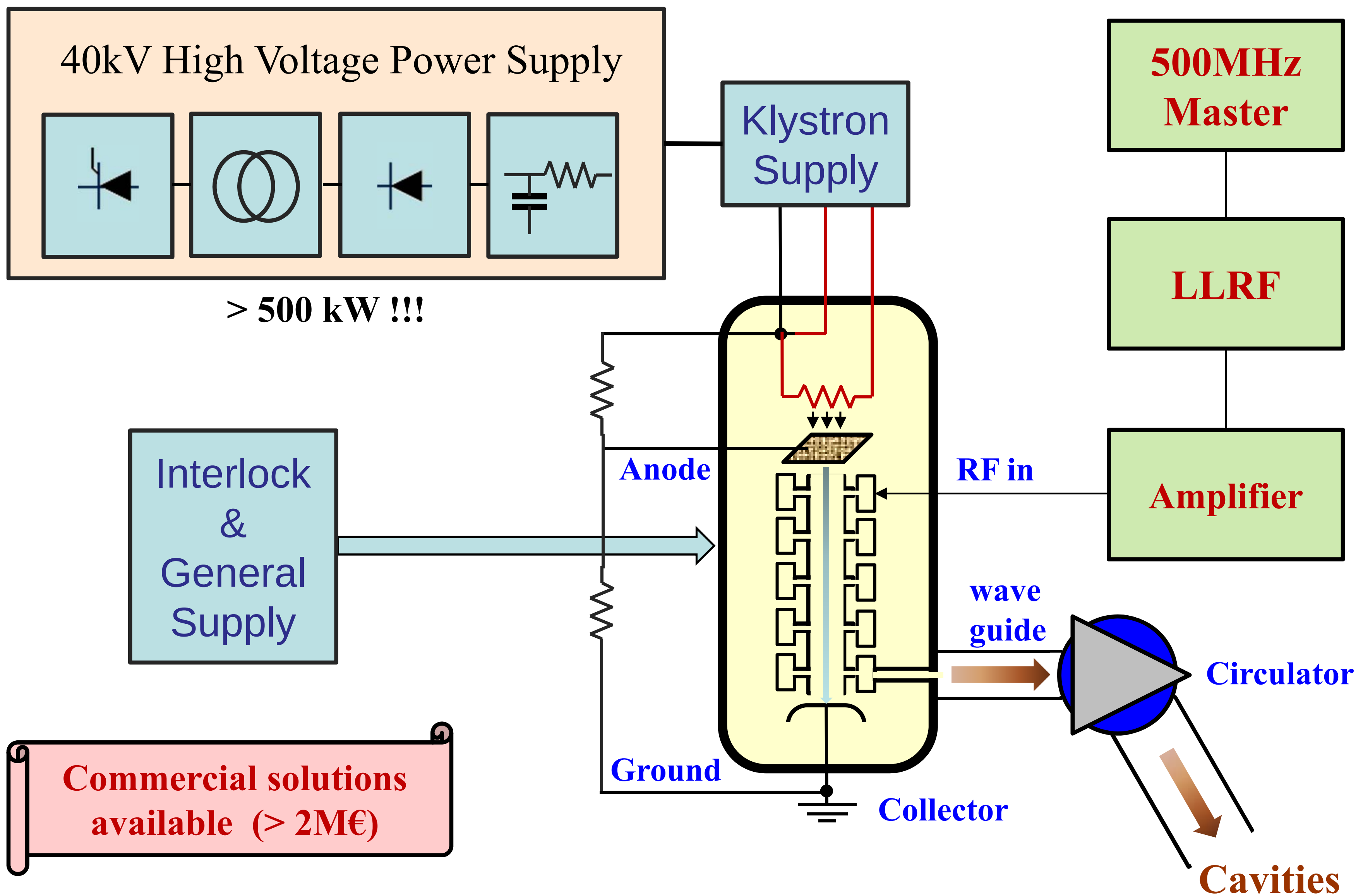




New RF System



General Set-Up

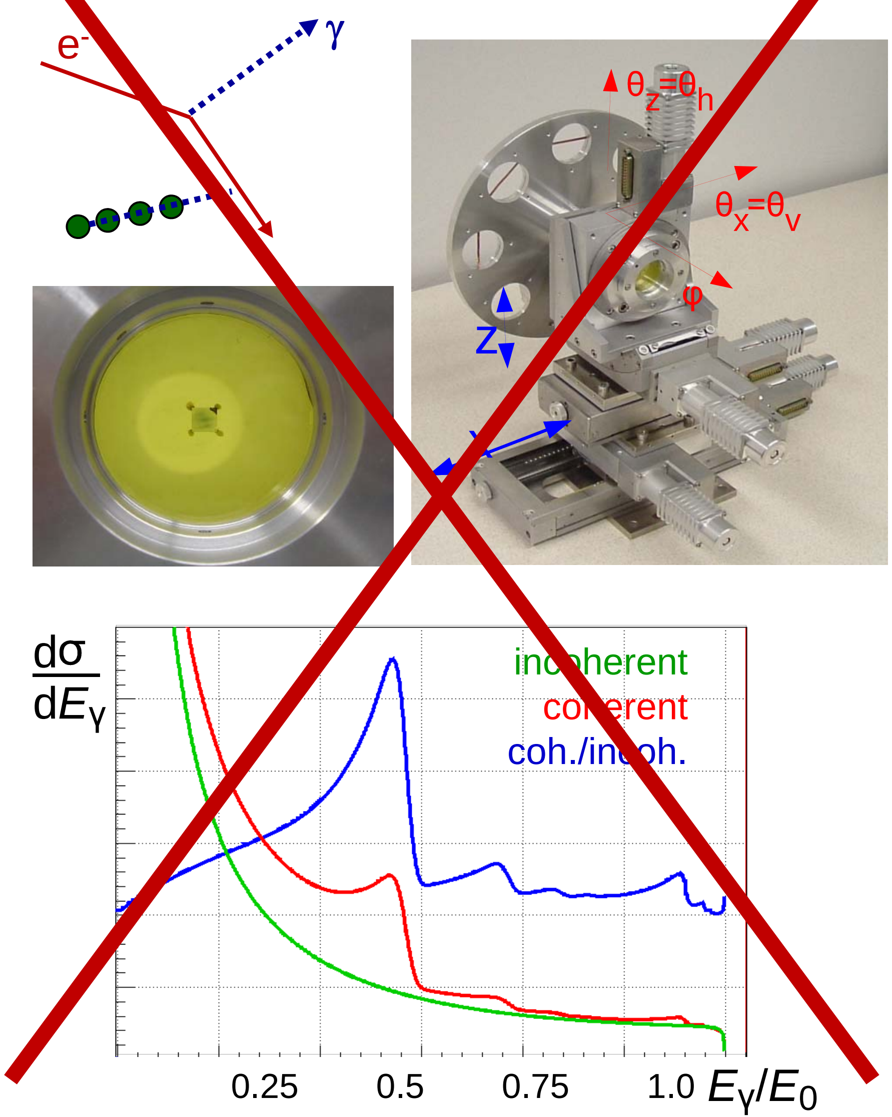


Our Approach:

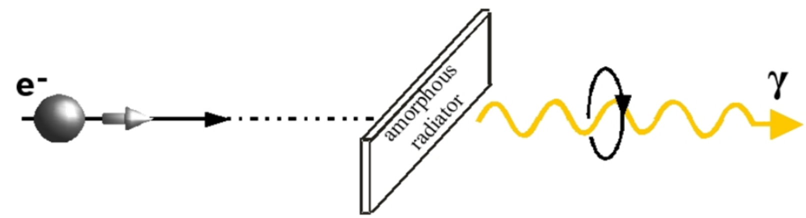
Home-made solution with RF components from DESY: < 0.1M€ !!!

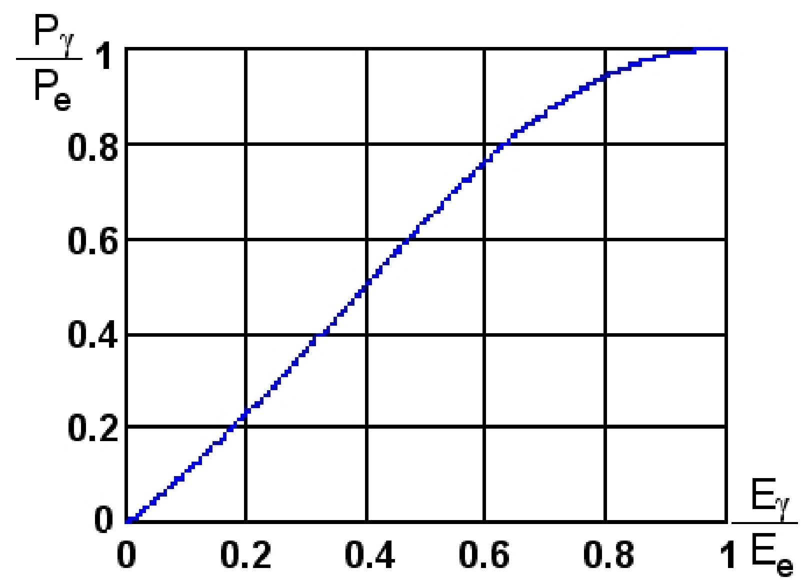
Circularly Polarized Photons

Transverse:



Longitudinal:



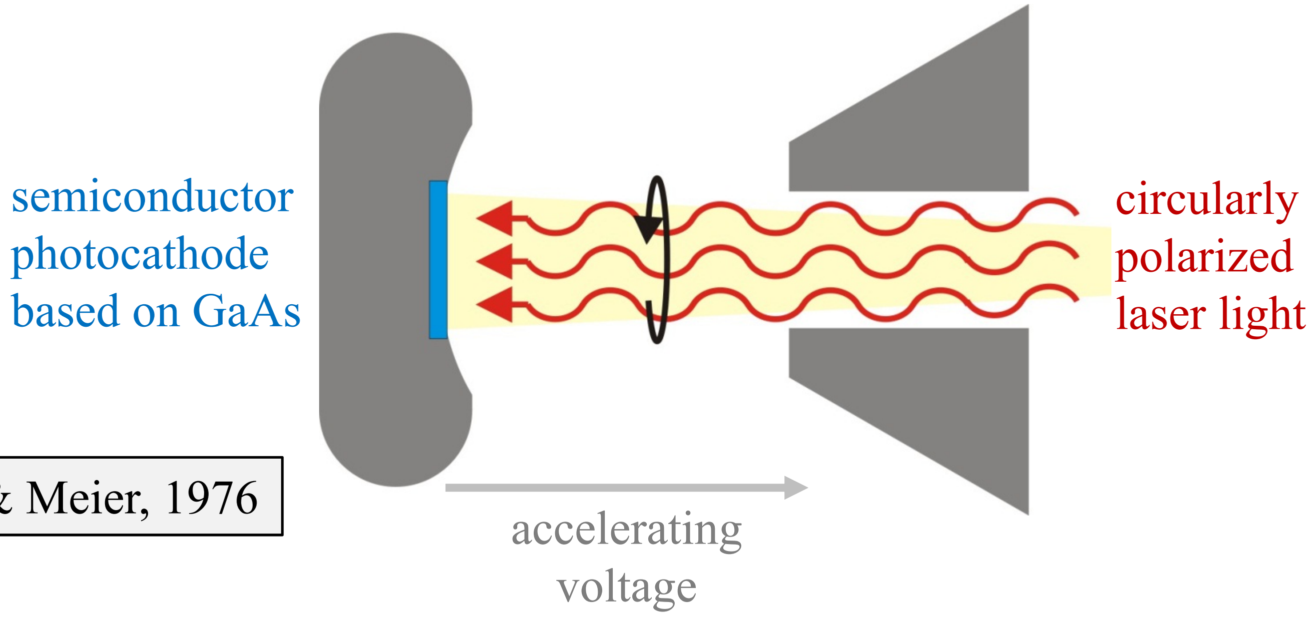


$$\frac{P_{\gamma,circ}}{P_e} = \frac{E_\gamma}{E_0}\,\frac{1 + \frac{1}{3}(1-E_\gamma/E_0)}{1 - \frac{2}{3}(1-E_\gamma/E_0) + (1-E_\gamma/E_0)^2}$$

H. Olsen & L.C. Maximon, PR 114 (1959) 887

Generation of Polarized Electrons

Functional Principle:



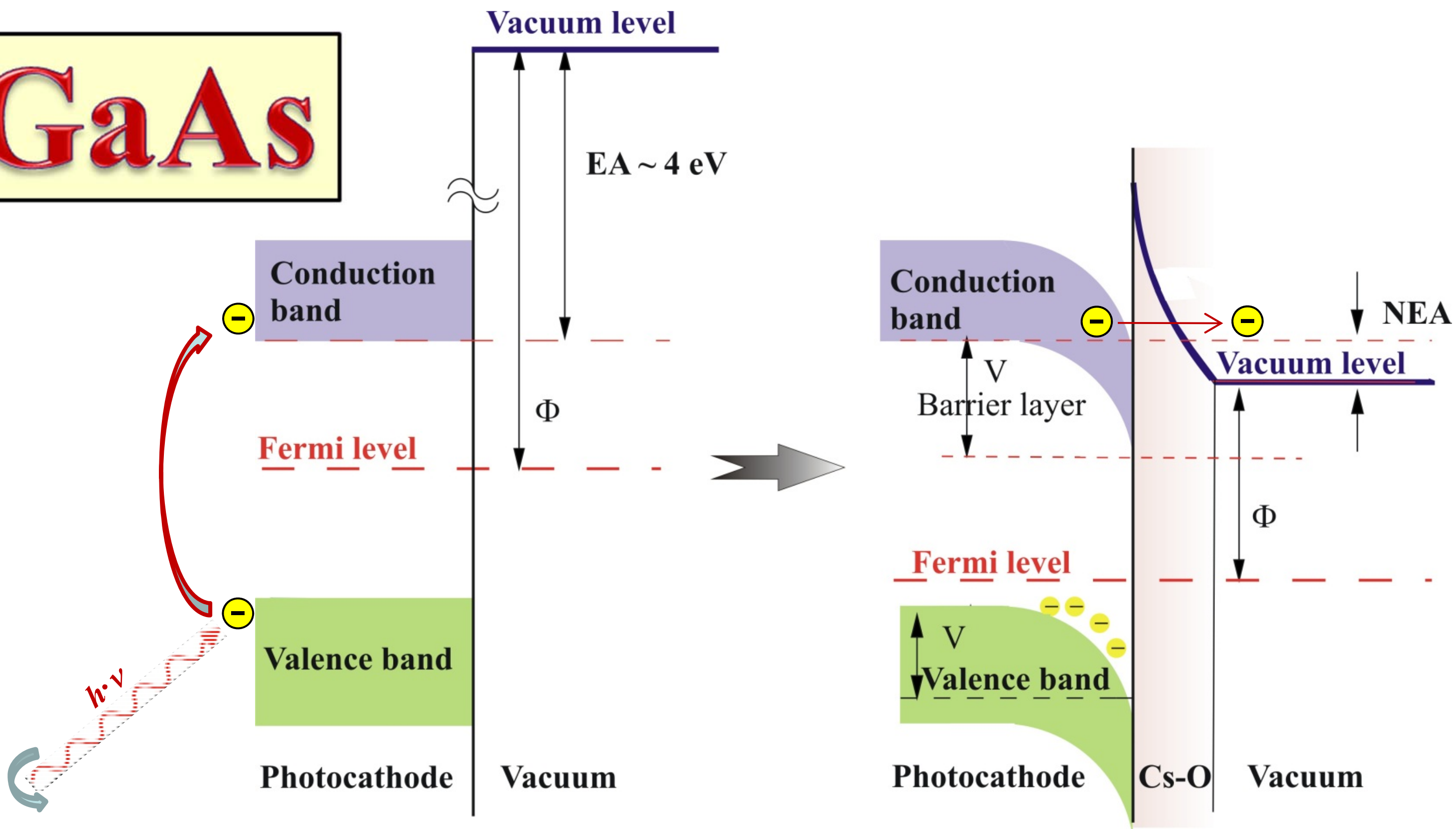
Pierce & Meier, 1976

Photoelectron emission from GaAs

polarization transfer from laser photons to emitted electrons

Generation of Polarized Electrons

GaAs



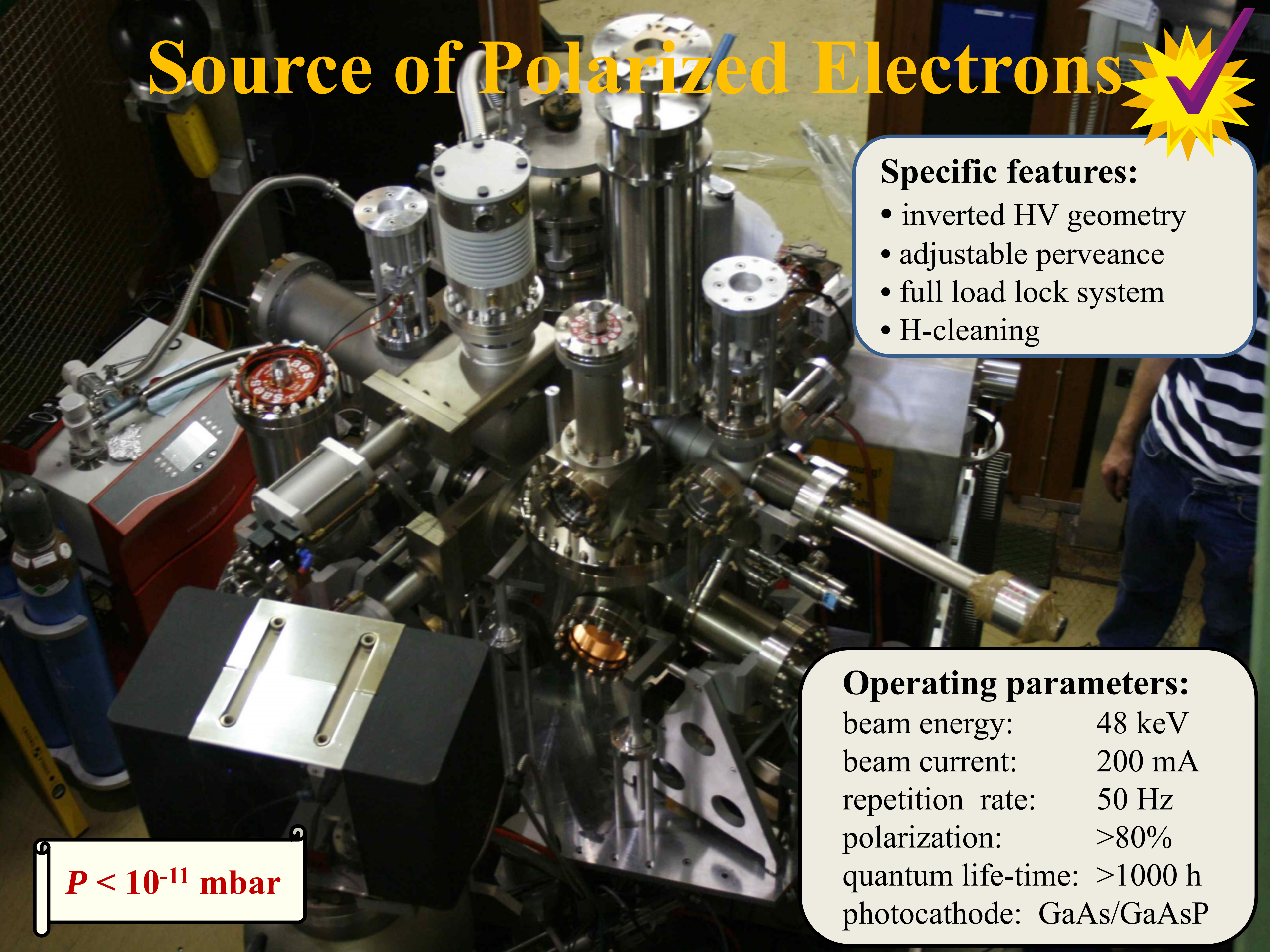
Semiconductor

p-doped Semiconductor with Cs-O layer

Operation, heat cleaning and activation in extreme UHV

Lifetime 1000 h ↔ $P\,(H_2O, CO_2) < 10^{-13}$ mbar

Source of Polarized Electrons



Specific features:

- inverted HV geometry
- adjustable perveance
- full load lock system
- H-cleaning

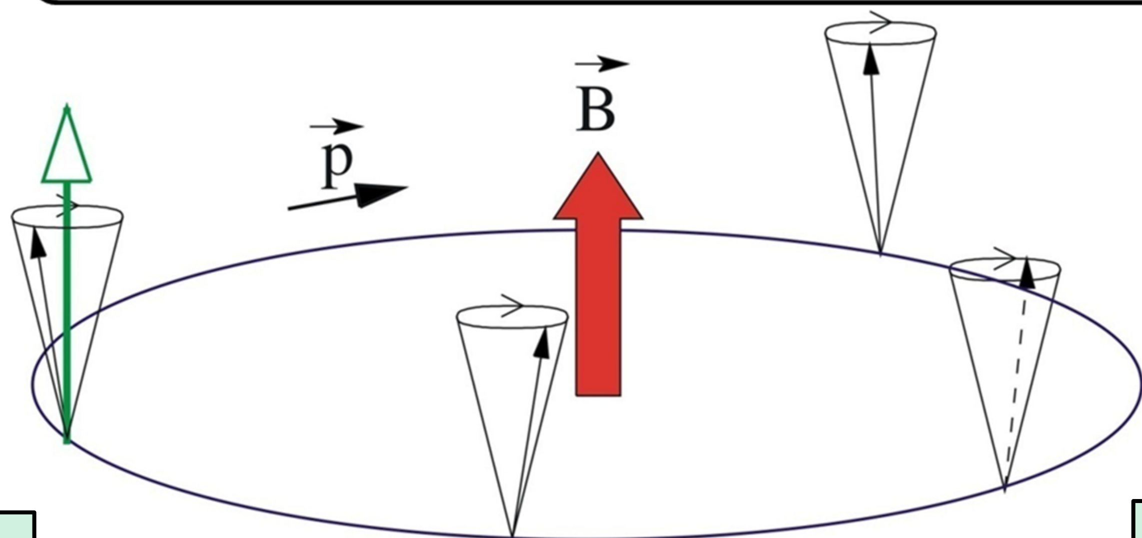
Operating parameters:

beam energy:	48 keV
beam current:	200 mA
repetition rate:	50 Hz
polarization:	>80%
quantum life-time:	>1000 h
photocathode:	GaAs/GaAsP

***P* < 10^{-11} mbar**

Spins in Magnetic Fields

Spin-Tune: $Q_{Sp} = \gamma a, \quad a = \frac{g-2}{2}$



magn. moment:

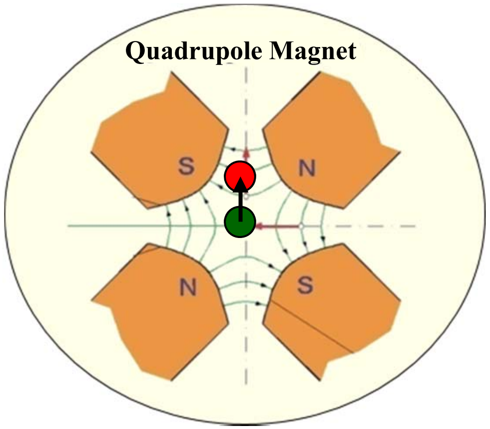
$$\vec{\mu} = g\frac{e}{2m}\cdot\vec{S}$$

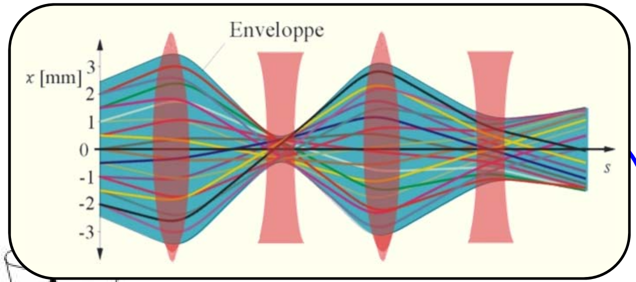
$a_{e^-} \approx 1.16\cdot 10^{-3}$

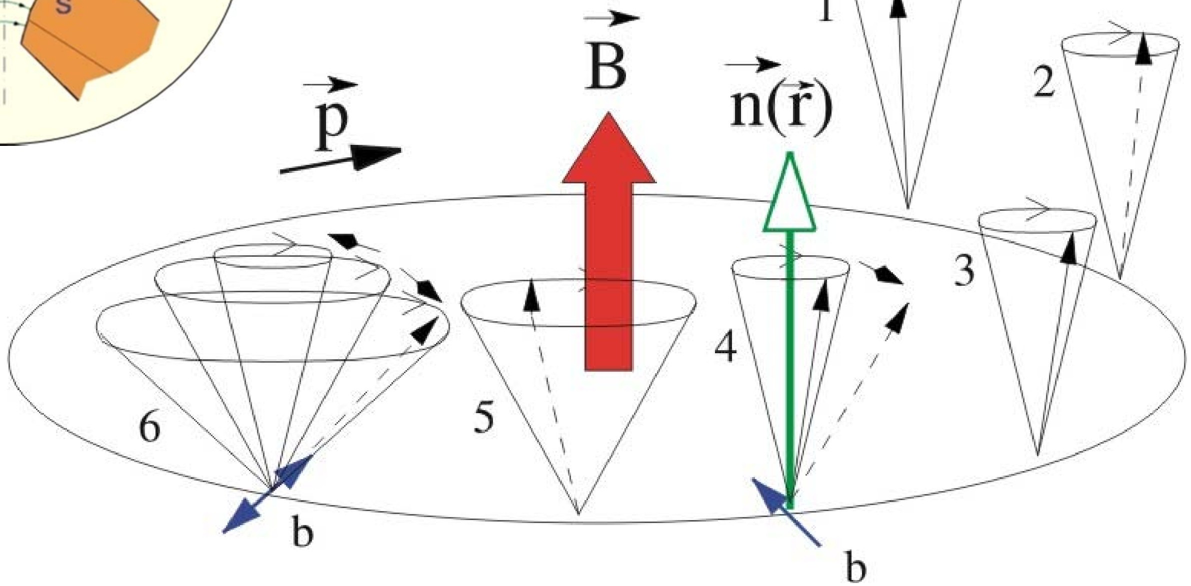
$$\frac{d\vec{S}}{dt} = \vec{\Omega}\times\vec{S} \qquad \vec{\Omega}^* = -\frac{e}{m_0}(1+a)\cdot\vec{B}$$

$$\vec{\Omega}_{BMT} = -\frac{e}{m_0\gamma}\left\{(1+a\gamma)\cdot\vec{B}_\perp + (1+a)\cdot\vec{B}_\parallel - \left(a+\frac{1}{\gamma+1}\right)\cdot\gamma\vec{\beta}\times\frac{\vec{E}}{c}\right\}$$

Depolarizing Resonances



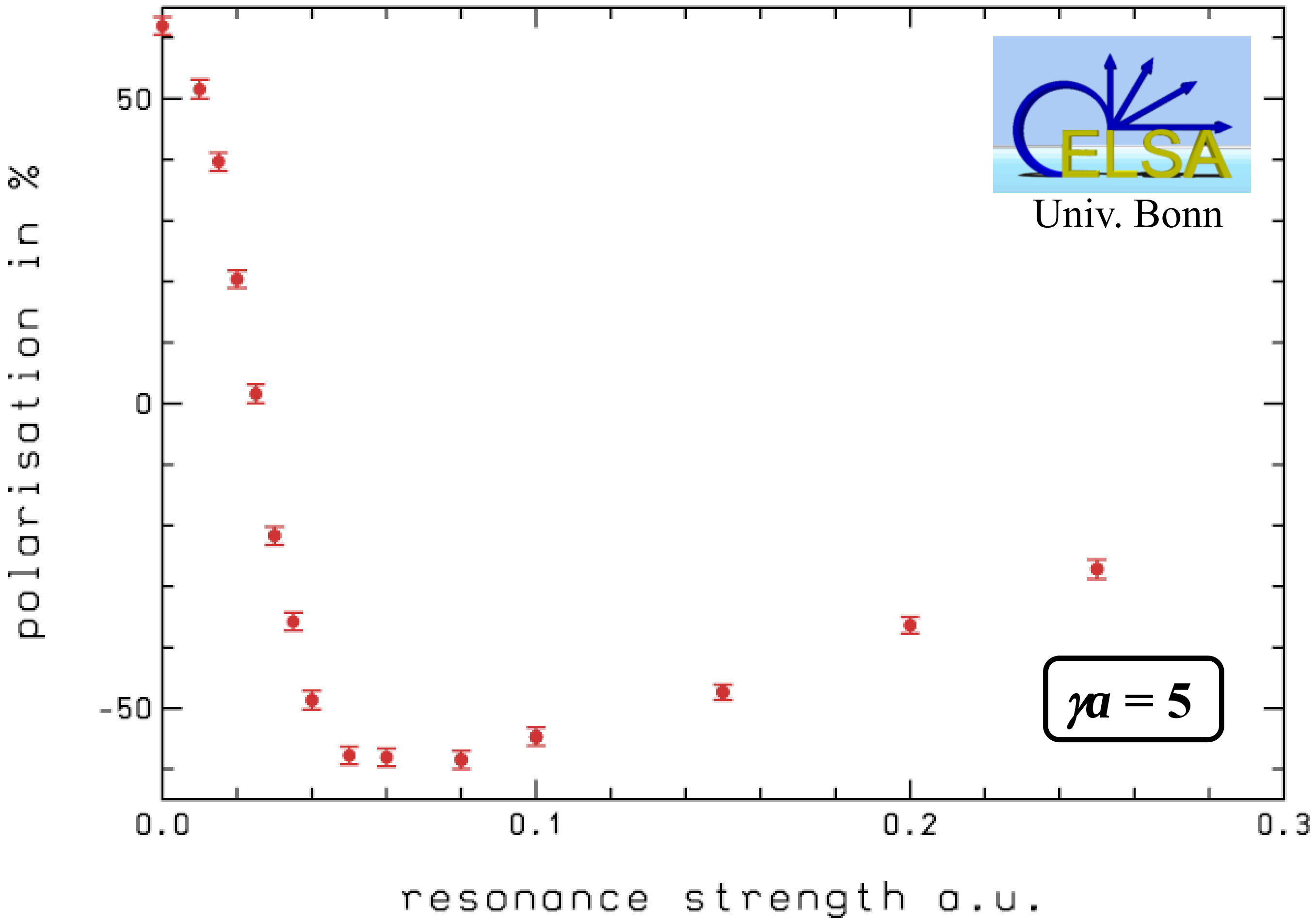




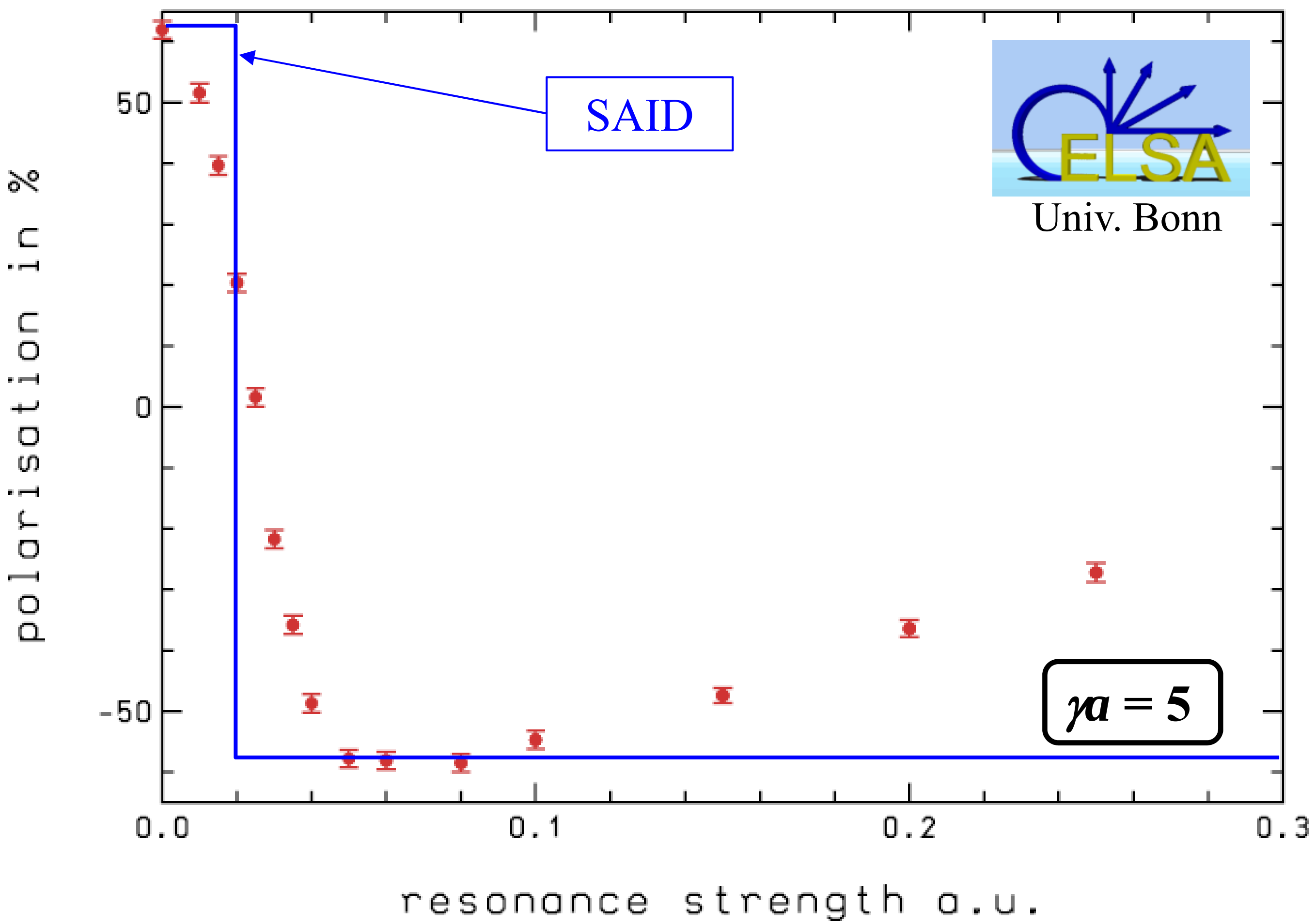
Imperfection Resonance: $\gamma \cdot a = n, \quad n \in Z$

Intrinsic Resonance: $\gamma \cdot a = n \cdot P \pm Q_z, \quad n \in Z$

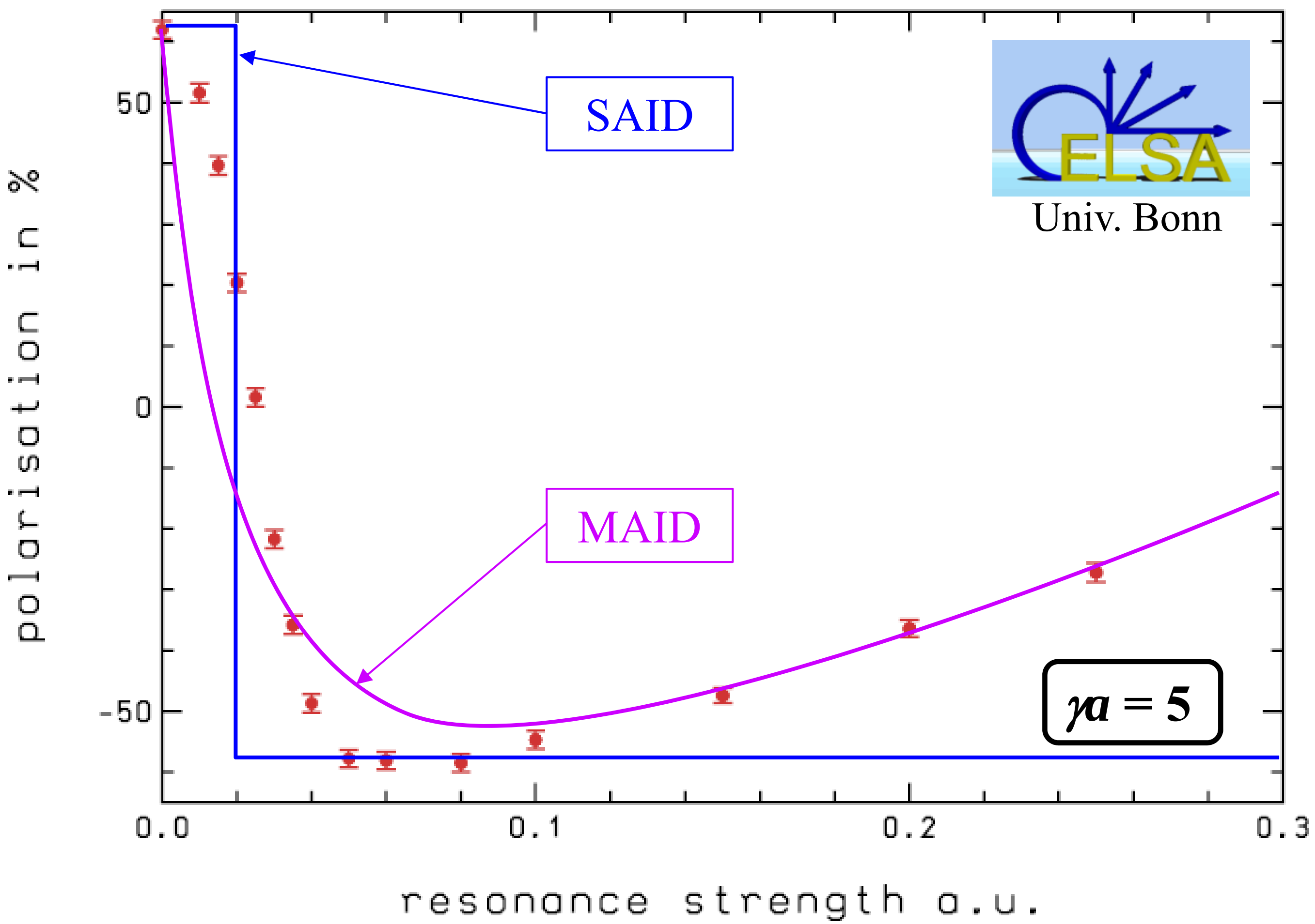
Resonance Crossing



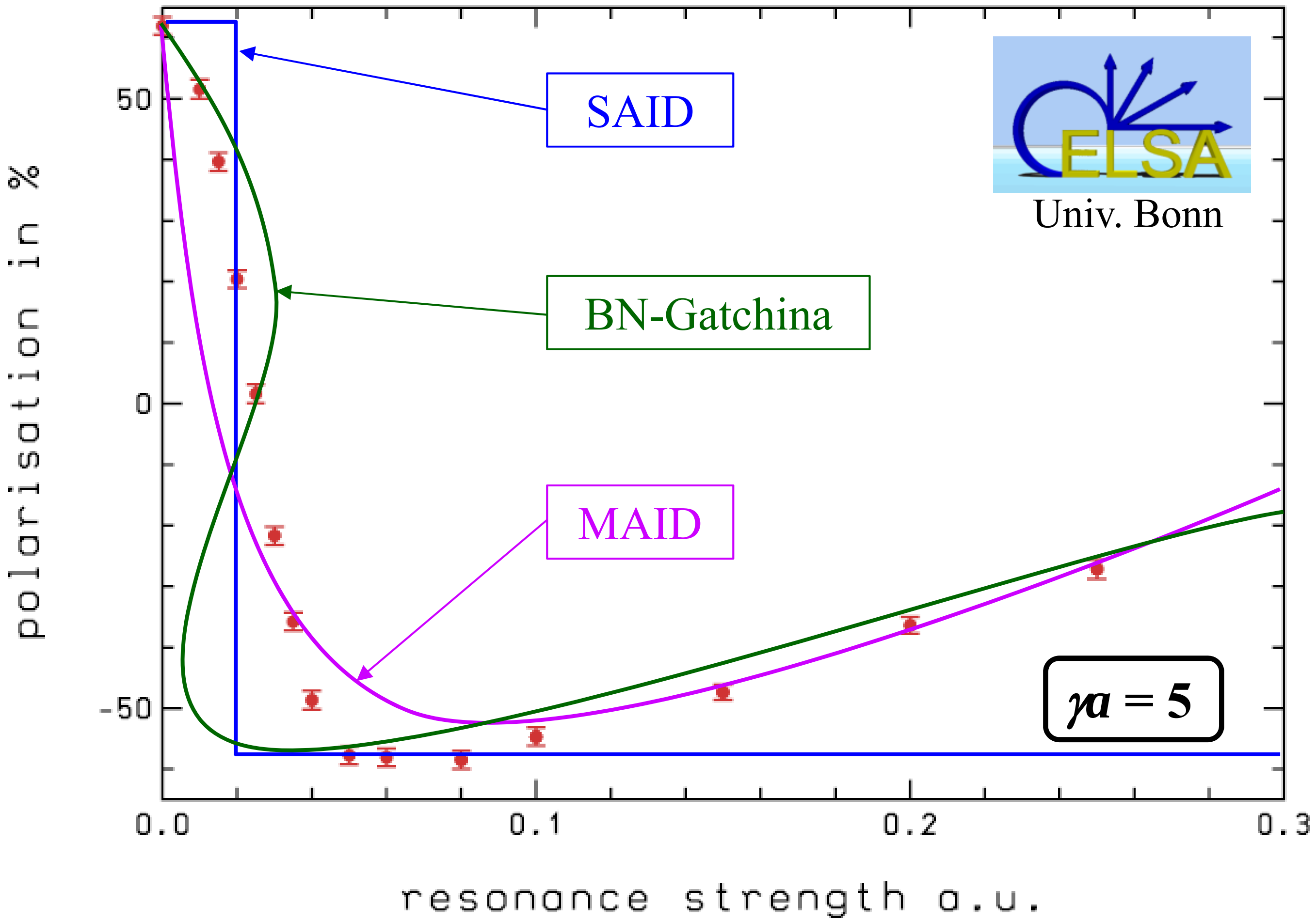
Resonance Crossing



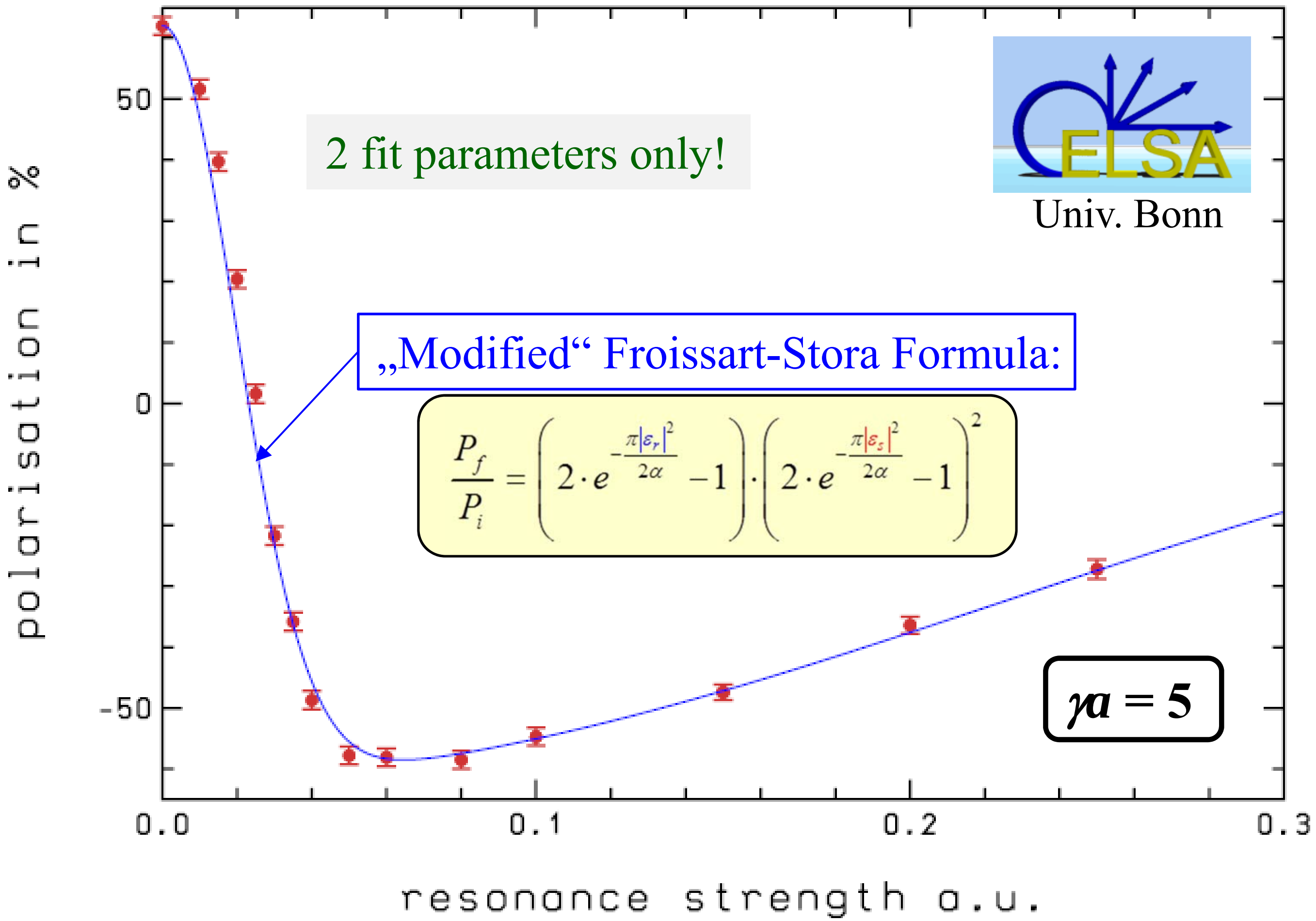
Resonance Crossing



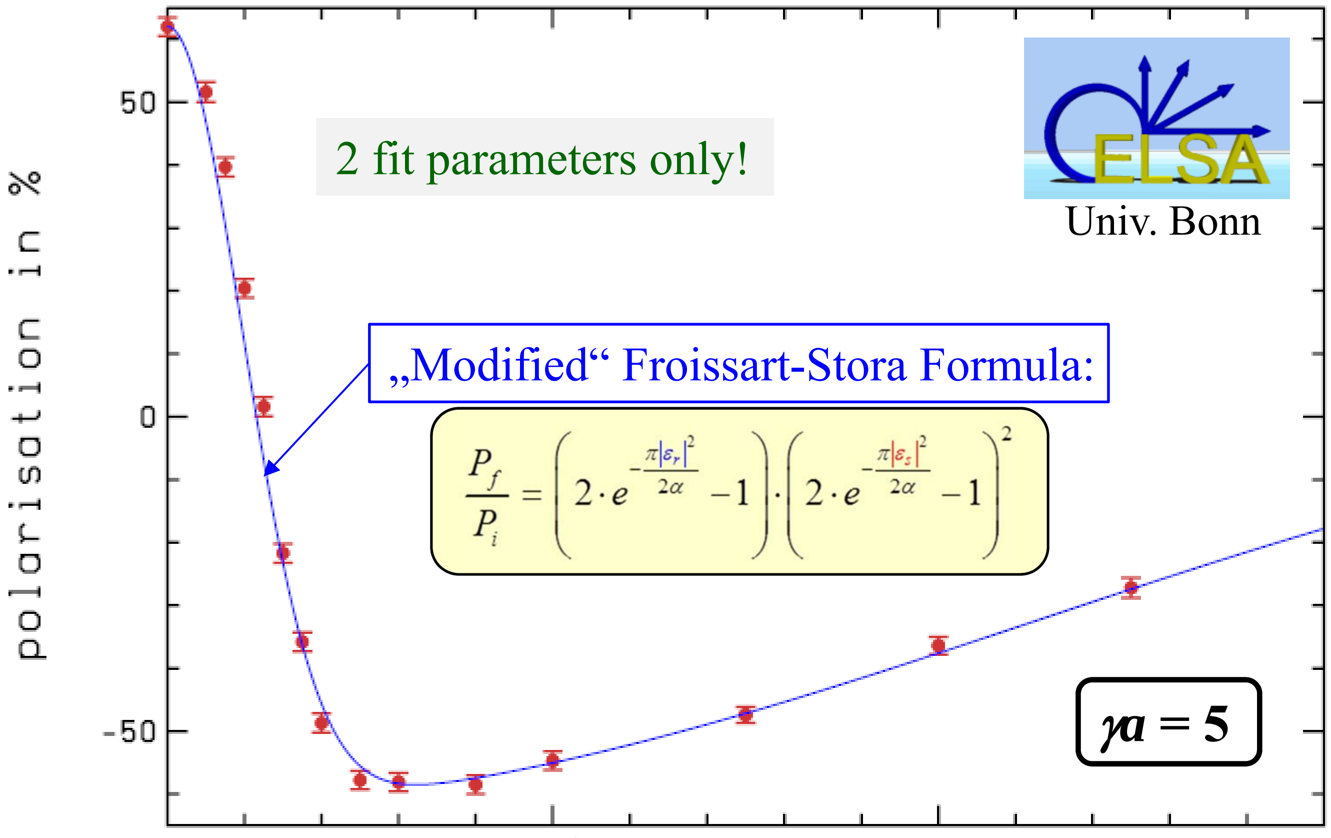
Resonance Crossing



Resonance Crossing



Resonance Crossing



$$\frac{P_f}{P_i} = \left(2 \cdot e^{-\frac{\pi|\varepsilon_r|^2}{2\alpha}} - 1\right) \cdot \left(2 \cdot e^{-\frac{\pi|\varepsilon_s|^2}{2\alpha}} - 1\right)^2$$

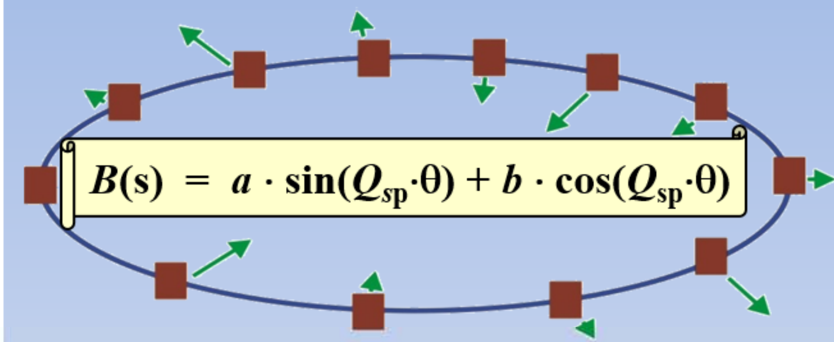
Beam excitation will only cause partial spin flip → depolarization!

- Reduce resonance strength by **proper centering in the quads**
- Compensate **resonance driving horizontal magnetic fields**

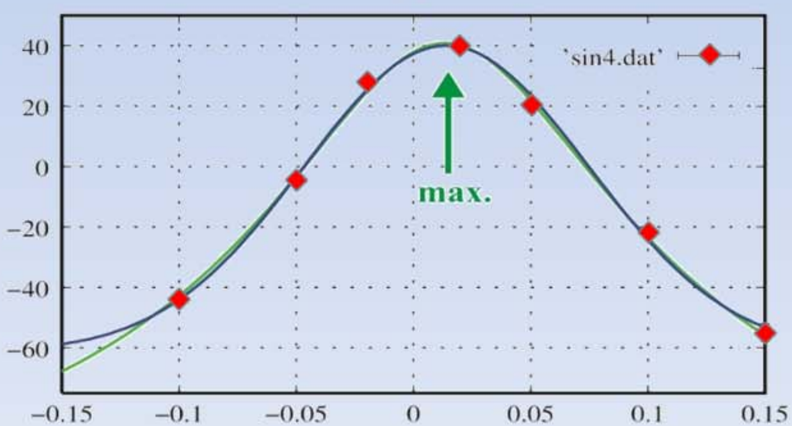
Acc. of Polarized Electrons

Integer Resonances: $\gamma a = n$

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

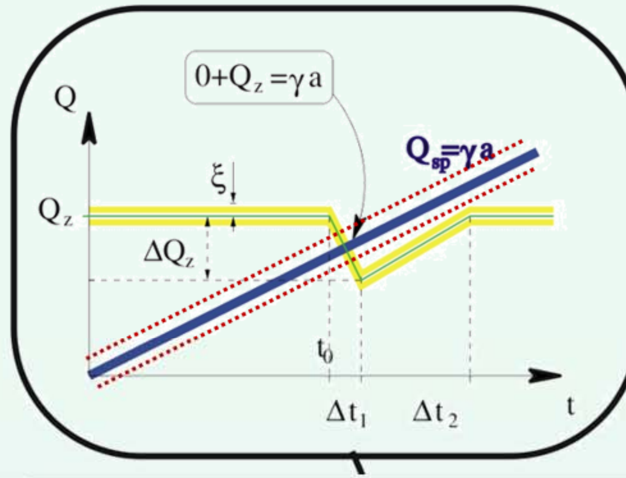


→ scan of sin amplitude:

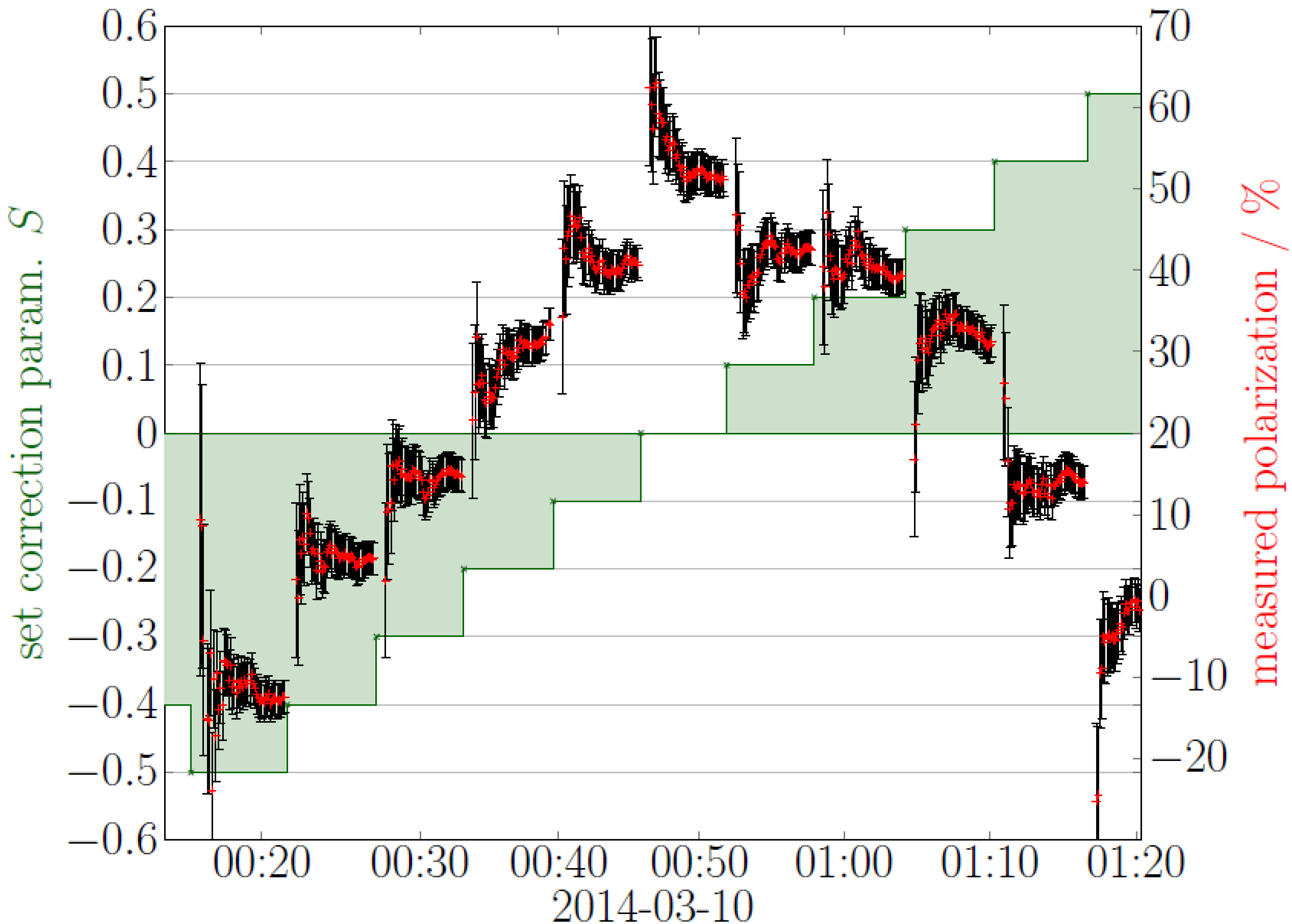


Intr. Resonances: $\gamma a = nP \pm Q_z$

- small vertical beam size
- tune jumping with pulsed quads

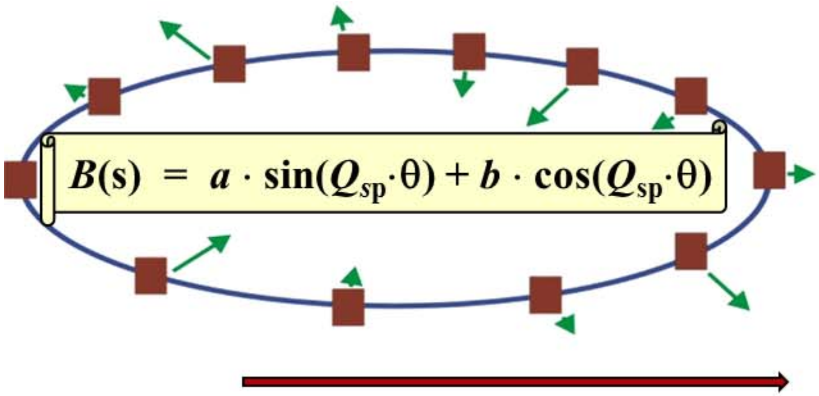


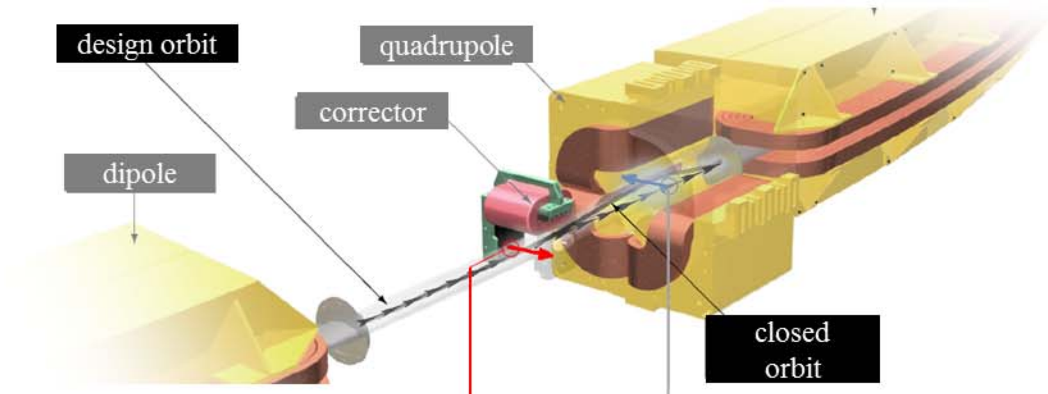
Harmcor (sine) of γa = 3

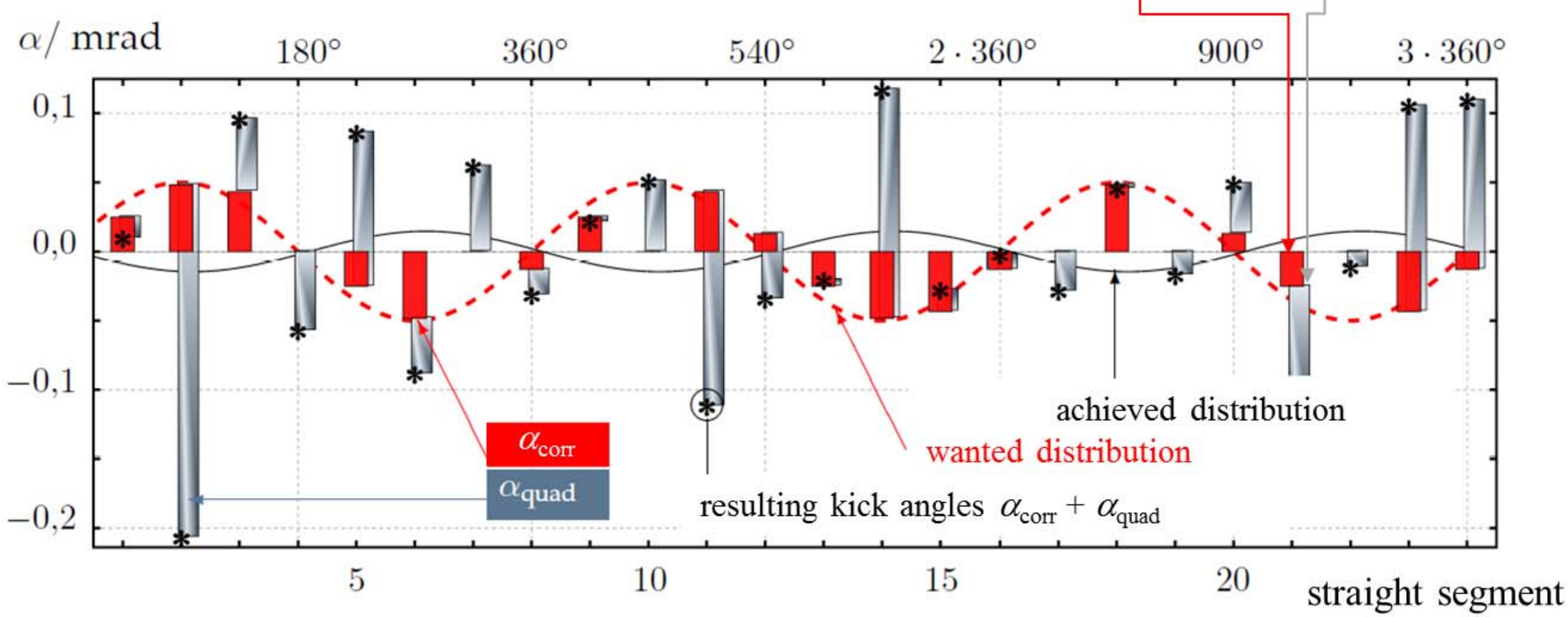


Harmonic Correction

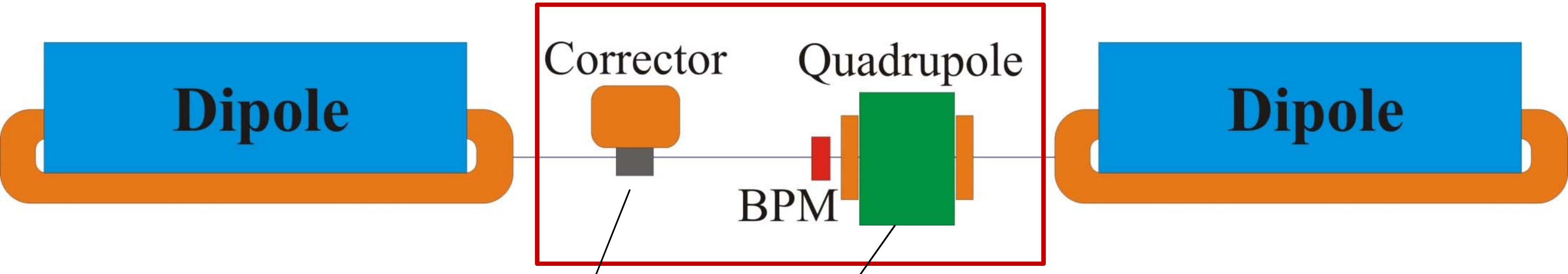
(simple approach)







Spin-Orbit Response Technique



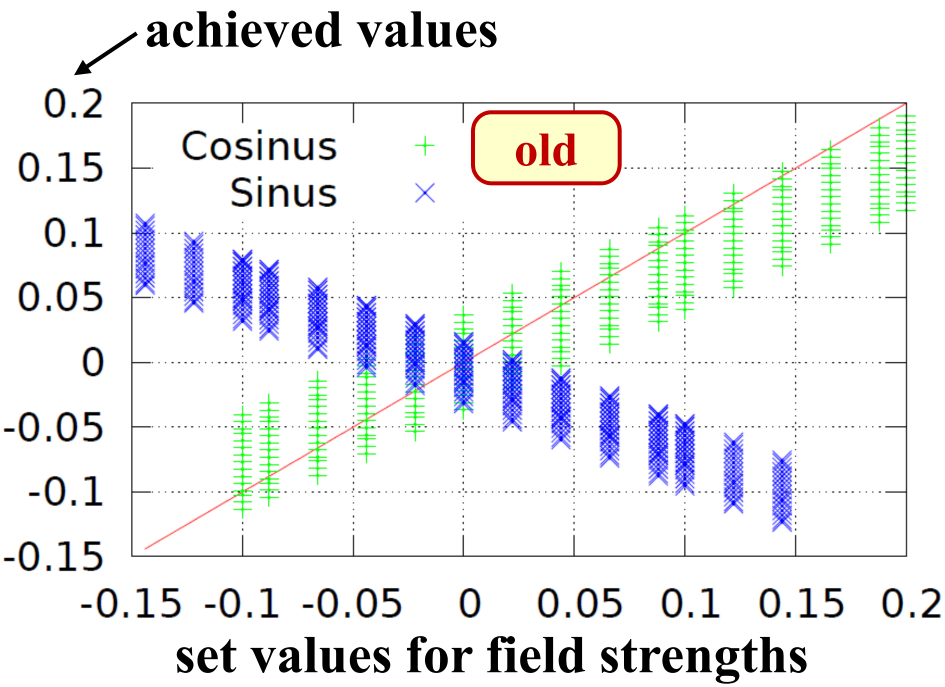
2 Contributions: $\alpha_n = \boxed{\sum_{j\in Dip_n} \alpha_{corr,j}} + \boxed{l\cdot \sum_{j\in Dip_n} k_j \cdot \Delta z_j} = \sum_{j\in Dip_n} \alpha_{corr,j} + l\cdot \sum_{j\in Dip_n} k_j \cdot \left(\mathbf{ORM}\cdot \vec{\alpha}_{corr}\right)_j$

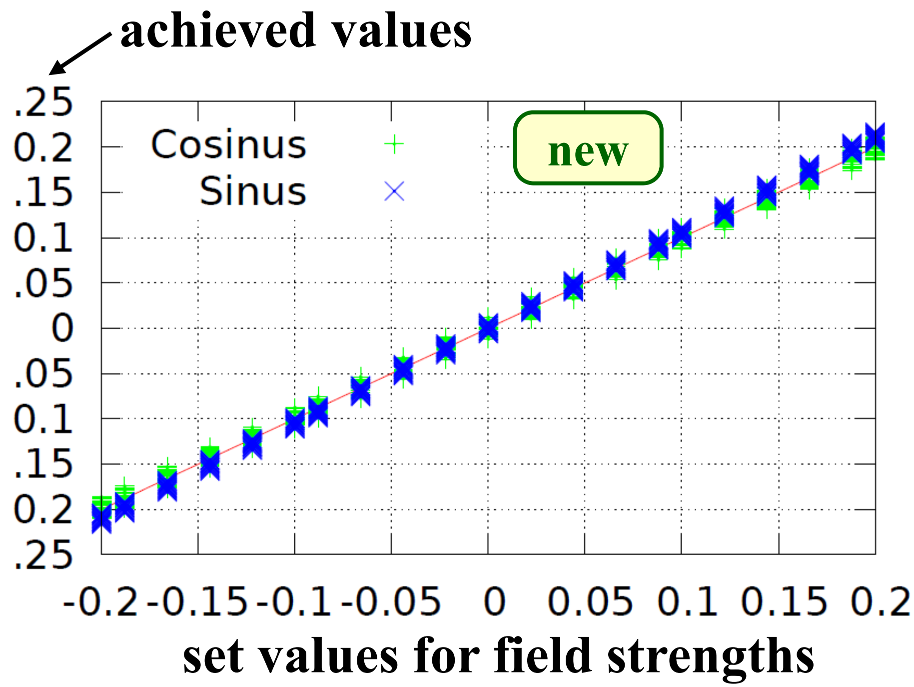
Spin-Orbit Response Matrix: $\vec{\alpha}_{harm} = \mathbf{HCM}\cdot \vec{\alpha}_{corr}$

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

Simulation of Field Compensation

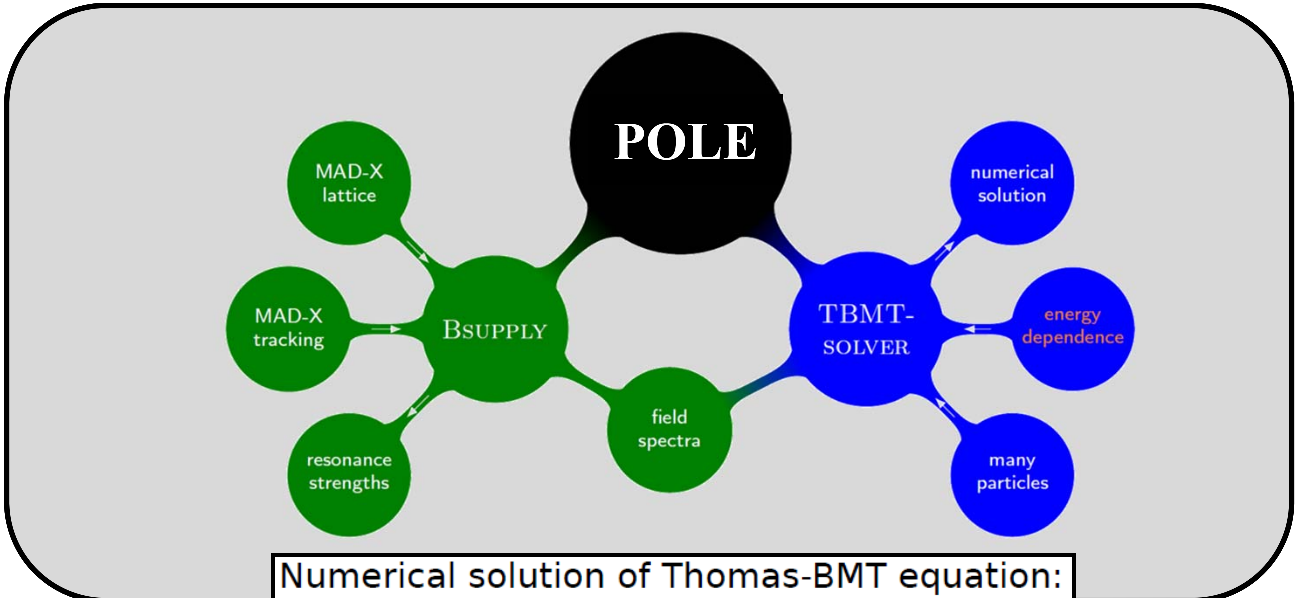
Variation of sine and cosine amplitudes for γa = 6





reliable field compensation possible!

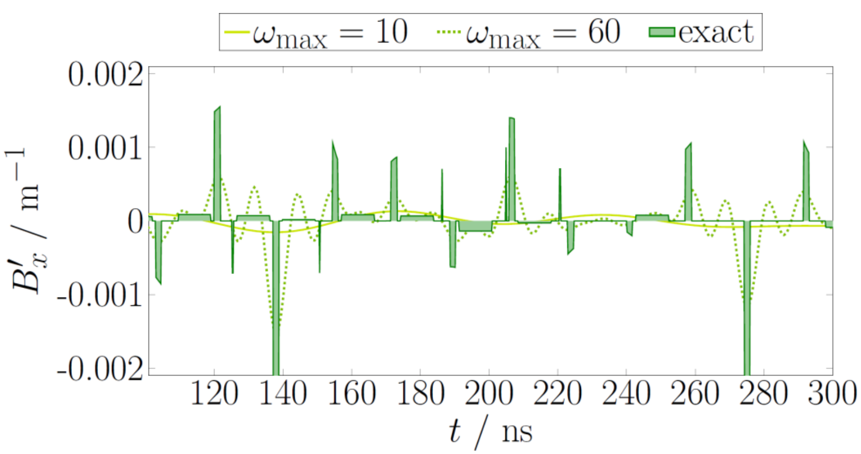
Simulation of Spin Dynamics



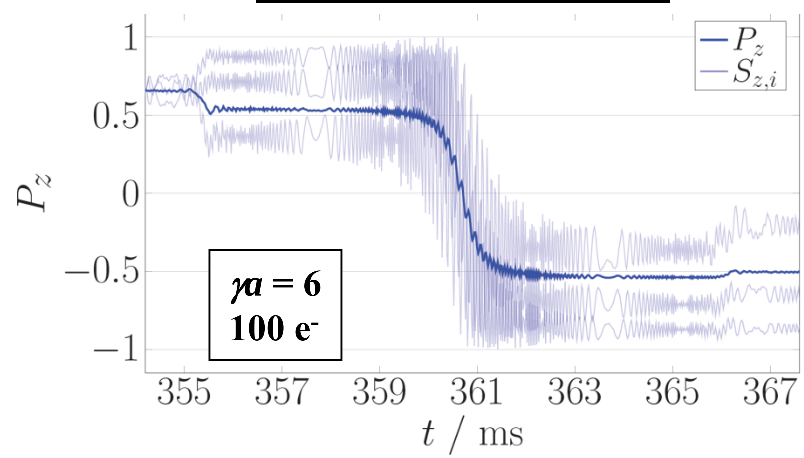
Numerical solution of Thomas-BMT equation:

$$\frac{\mathrm{d}}{\mathrm{d}t}\vec{S}(t) \approx c \cdot \vec{S}(t) \times \left[a\gamma(t)\vec{B}'_{\perp}(t) \; + \; a\vec{B}'_{\parallel}(t)\right]$$

<u>*B*-field as (filtered) Fourier series:</u>

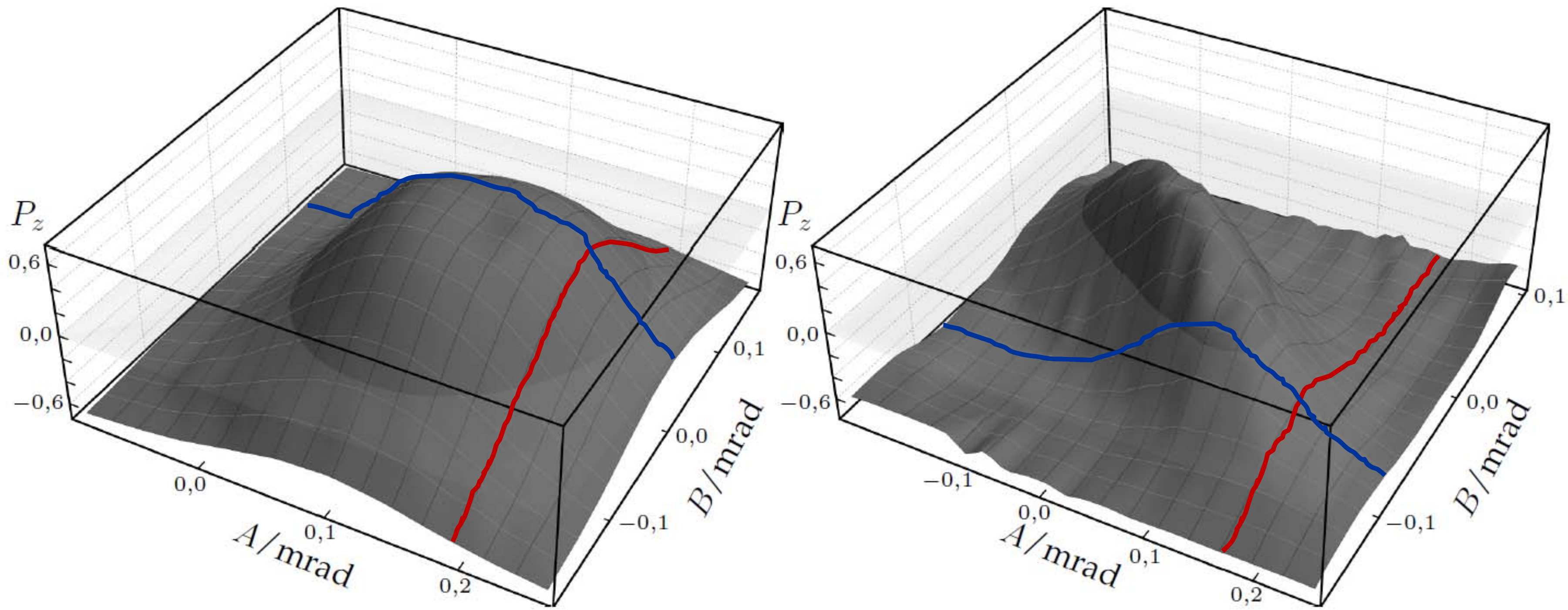


<u>Resonance crossing:</u>



POLE-Simulation of Harmcor

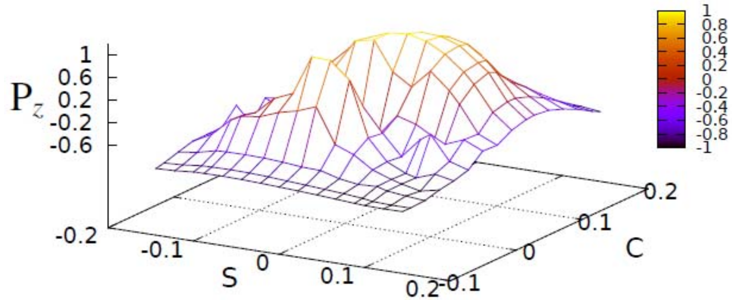
$$\alpha_{corr} = A \cdot \cos(2\pi n / 24) + B \cdot \sin(2\pi n / 24)$$

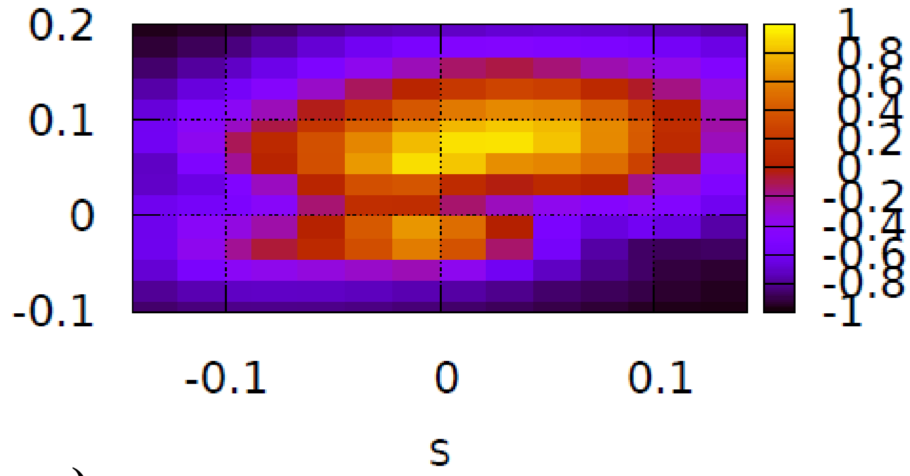


(a) Polarisationsoptimierung bei $a\gamma = 3$ **(b)** Polarisationsoptimierung bei $a\gamma = 6$

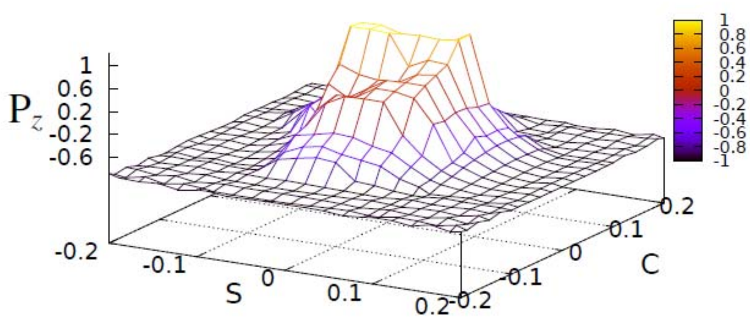
POLE-Simulation of γa = 6

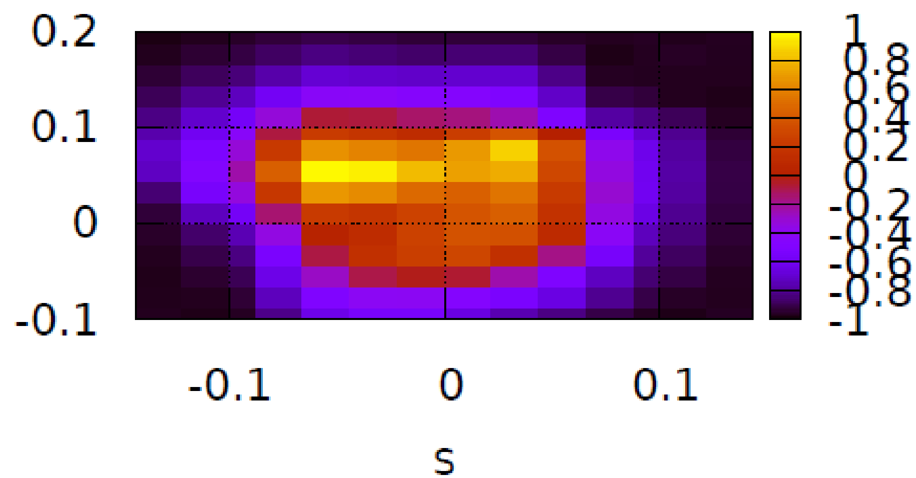
Old method (harmonic corrector fields only):





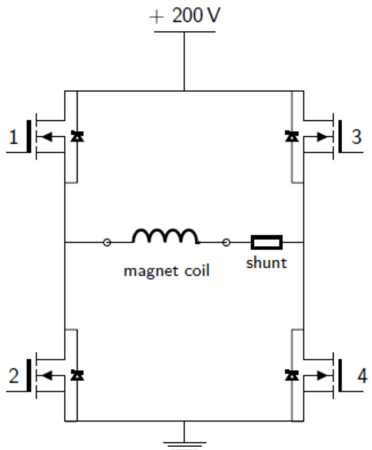
New method (orbit response technique):

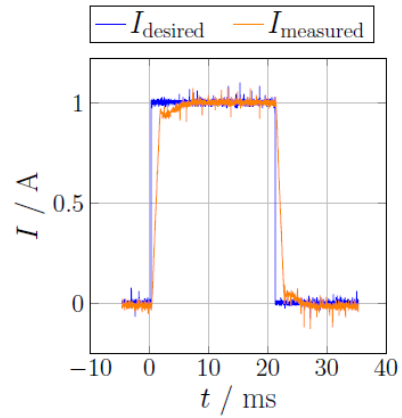




Fast Correction System

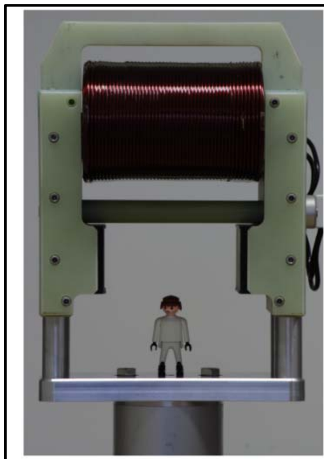
Programmable 4-Quadrant PS:





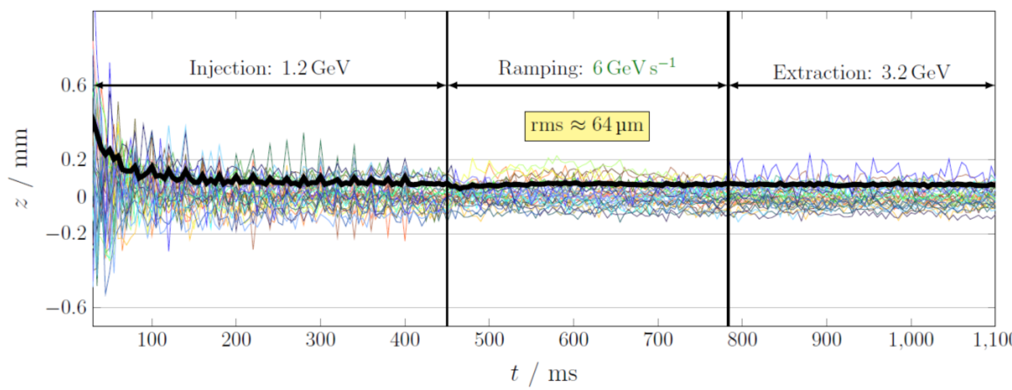
- 20 kHz pulsed H-bridge
- PI-controller
- current precision ≈ 1 ‰
- CAN-Bus module
- stored current ramps
- external trigger
- in total 54 power supplies distributed in 14 cabinets along the ELSA tunnel

Correction Coils:



	new
voltage	200 V
max. current	8.0 A
inductance	260 mH
max. field	40 mT
weight	30 kg
field integral	9.8 mT m

$\dot{I} = 400$ A/sec ↔ $\dot{B} = 2$ Tesla/sec



Highlights:

ELSA is hunting for highest polarization!

Highlights:

ELSA is hunting for highest polarization!

Linearly polarized photons:

Radiated by unpolarized electrons via coherent bremsstrahlung

→ highest possible energy (recoil!!!) and intensity (photon beam collimation!!!)

- 3D bunch by bunch feedback, HOM suppression, tapered chambers, new LLRF, …

2nd RF station serving to additional 7-cell resonators → operation @ 3.5GeV

Highlights:

ELSA is hunting for highest polarization!

Linearly polarized photons:

Radiated by unpolarized electrons via coherent bremsstrahlung

→ highest possible energy (recoil!!!) and intensity (photon beam collimation!!!)

- 3D bunch by bunch feedback, HOM suppression, tapered chambers, new LLRF, …

2nd RF station serving to additional 7-cell resonators → operation @ 3.5GeV

Circularly polarized photons:

Radiated by longitudinally polarized electrons, full polarization transfer at max. energy

→ highest possible electron polarization at desired (max?!) energy

- polarized source, spin manipulation, num. simulation, resonance compensation

new corrector system → appl. spin response harmonic correction technique

Achieved Polarization: *P* = 74±2%@2.35 GeV, *P* = 65±2%@2.92 GeV

… for our spokesperson

Milestones D.2

… and all interested people …

1. **Minimization of beam depolarization on the fast energy ramp up to maximum beam energy**
   - ✓ Spin-orbit response technique for harmcor of depolarizing resonances
   - ✓ Simulation of spin dynamics with POLE

   } ongoing

   - ❖ Horizontal polarization when operating on an integer resonance

   coming soon

2. **Reduction of beam halo and emittance of the extracted electron beam by improving the slow beam extraction**
   - ❖ Experimental and theoretical studies of the slow beam extraction

   starting next year

3. **Optimization of the high current operation with circulating beam currents up to 200mA in the stretcher ring**
   - ✓ Damping of higher order modes (HOM) in accelerating cavities
   - ✓ Tapering of vacuum chambers to reduce the total coupling impedance of the ring

   } ongoing

   - ❖ Systematic investigations of ion induced beam instabilities
   - ❖ (Construction and commissioning of a second RF system)

   in full swing

Installation and commissioning of a streak camera system!