LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

Status of target and photon collimator work for polarized e+

LCWS 2014, Belgrade, Serbia

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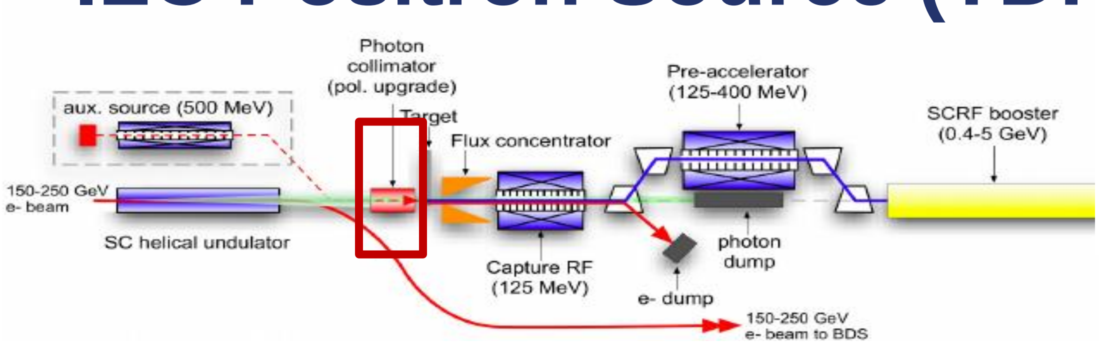
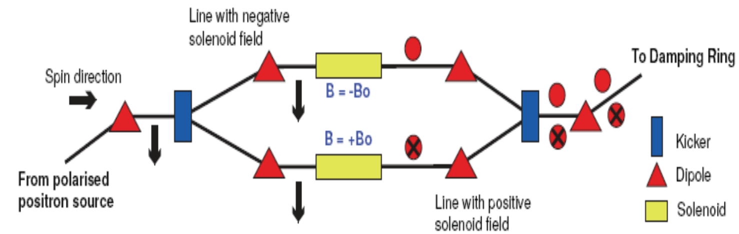
Outline

- Positron target
  - **Stability and imbalance studies**
  - **Radiation cooling**
- Photon collimator
  - **Fixed design**
  - **Alternative design options – to be studied**
- General studies and tests concerning materials
- Summary

ILC Positron Source (TDR)





Positron source is located at end of main linac, uses e- beam

- Superconducting helical undulator
  - **K=0.92, λ=1.15cm, (B=0.86T on the axis), aperture 5.85mm**
  - **Max 231m active length**
- e+ Production Target
  - **400m downstream the undulator**
  - **0.4 X0 Ti alloy**
- Positron Capture: Pulsed flux concentrator + capture RF
  - Alternative: quarter wave transformer + capture RF
- Normal-conducting pre-acceleration up to 400MeV
- e+ polarization
  - **Default: ~30%**
  - **polarization upgrade up to 60%: photon collimator**
  - **Polarization sign is determined by undulator winding → Spin Flipper**

Main problems

Energy deposition in target

- Ti alloy wheel, Ø = 1m, 2000rpm
  - **PEDD per bunch train: 67.5 J/g ⇔ ΔT_{max} = 130K**
    101.3 J/g h.lumi ⇔ ΔT_{max} = 195K
    - Energy deposition per bunch: 0.31 … 0.72J ⇔ ΔT ≈ O(1K)
    - Polarization upgrade to 50% or 60% increases E_{dep} and PEDD
  - **Fatigue limit in Ti (10^7 cycles): ΔT ~ 425K (240MPa)**

Spinning target: Rotation speed

- **Vacuum seals, bearing**
- **Mechanical instabilities**
- **cooling of spinning target**

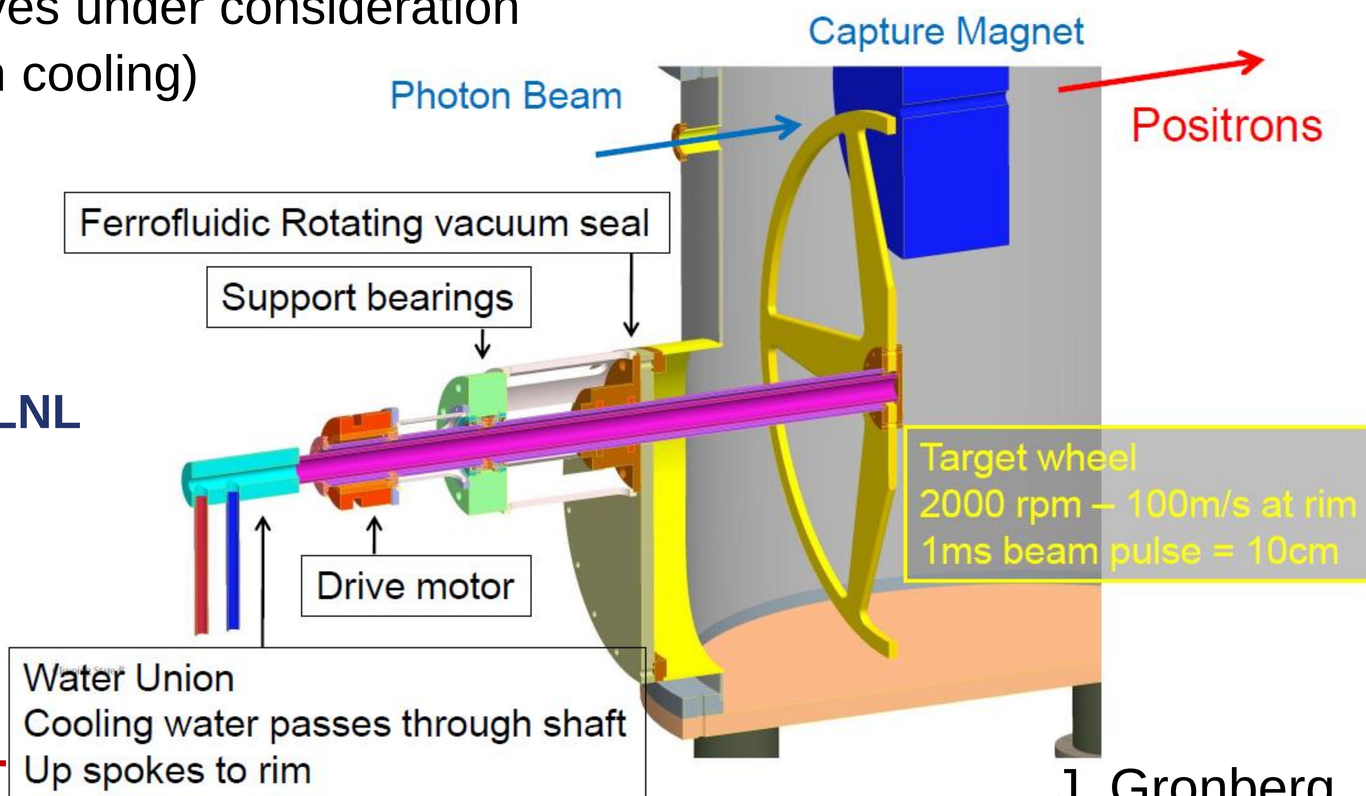
Energy deposition in photon collimator

- **Collimator is partial γ beam dump, absorbs ~50% of γ beam power**
- **Design strongly coupled to drive e- beam energy**
  - Details see Friedrich's talks at previous POSIPOL, LCWS and ECFA workshops

Positron target (undulator based source)

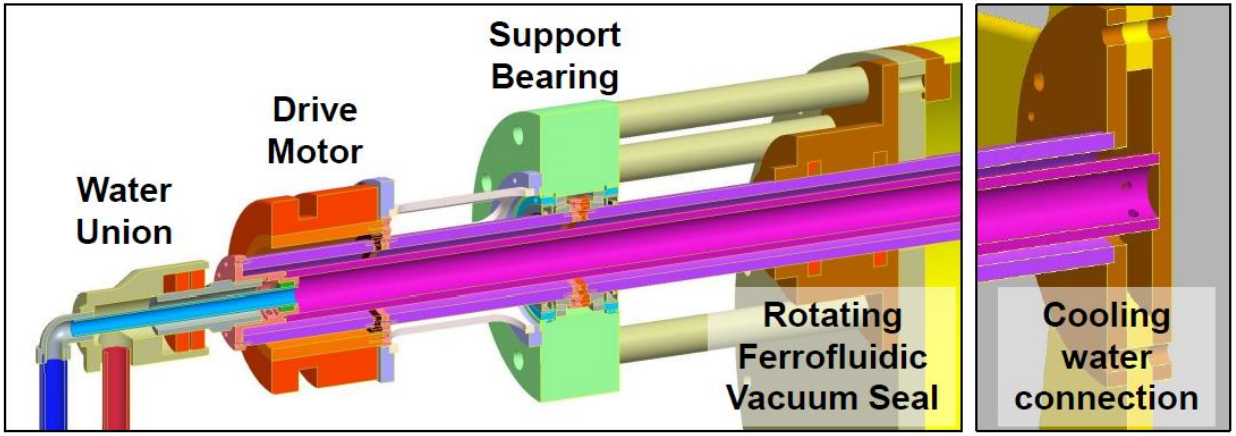
- Most important concern is the target
  - **wheel, Ti4Al6V; 1.4cm thick (0.4 X0) Ø 1m, 2000rpm (100m/s)**
    - Vacuum environment
    - Power deposition 2-7kW (PEDD in Ti: J/g)
    - Water cooling (TDR);
      alternatives under consideration
      (radiation cooling)

prototype @LLNL



J. Gronberg

ILC e+ target: Test of vacuum seals at LLNL

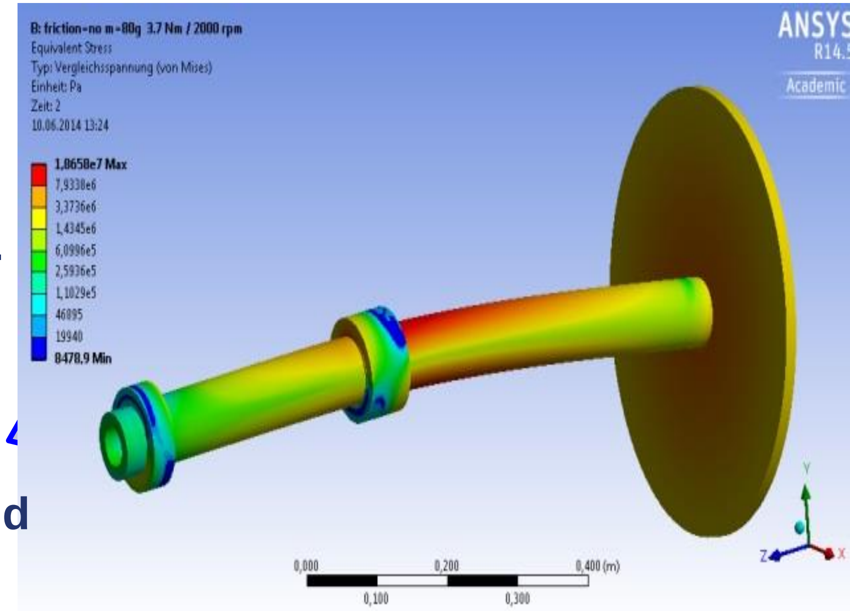


J. Gronberg

Built a full scale prototype shaft
- **Water cooling in the shaft (⇔ balancing)**
- **Ferrofluidic seals**
- **Same weight as Ti wheel but lower moment of inertia**

The ferrofluid seal didn't fail but:
- **Outgassing spikes**
  ➔ differential pumping in region near the seal would help
- **Excessive vibrations in ferrofluid seal**
- **significant heat dissipation due to rotation speed**
  ➔ need special design and improved cooling system
  ➔ magnetic bearings at the wheel to achieve more robust system

Mechanical instabilities



See Friedrich Staufenbiel at POSIPOL'14.

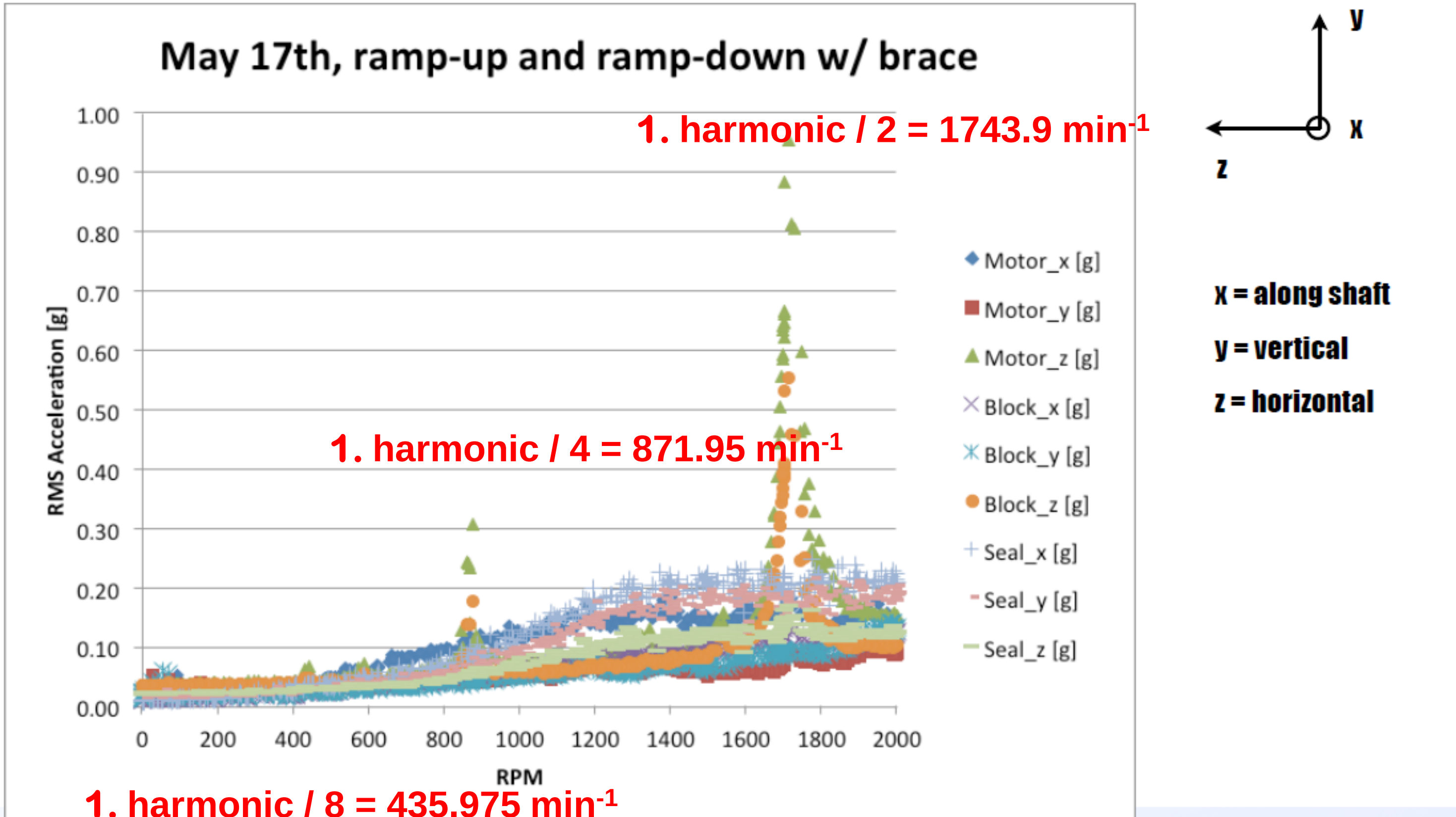
- simulation of torque and reaction force at target system/prototype
  - **comparison with results of prototype operation at LLNL**
  - **Support on both sides of wheel to avoid displacements of shaft**
  - **additional magnetic bearing will improve balance substantially;**
  - **Prototyping at LLNL → reaction forces were directed to O-rings, the ferrofluid seals were not 'the' problem**
  - **Improved layout needed**
- Eddy current induced imbalances and heat load are small
- Resonances are 'natural', running at resonance frequencies must be avoided

Vibration measurement of rotating wheel setup + ANSYS Simulation

Resonance: 3487.8 min^{-1} (1. harmonic)

J. Gronberg: Exp
F. Staufenbiel: Sim, 2000rpm

Balancing data from the FerroTec seal



Lawrence Livermore National Laboratory

Option:UCRL#

Option:Additional Information

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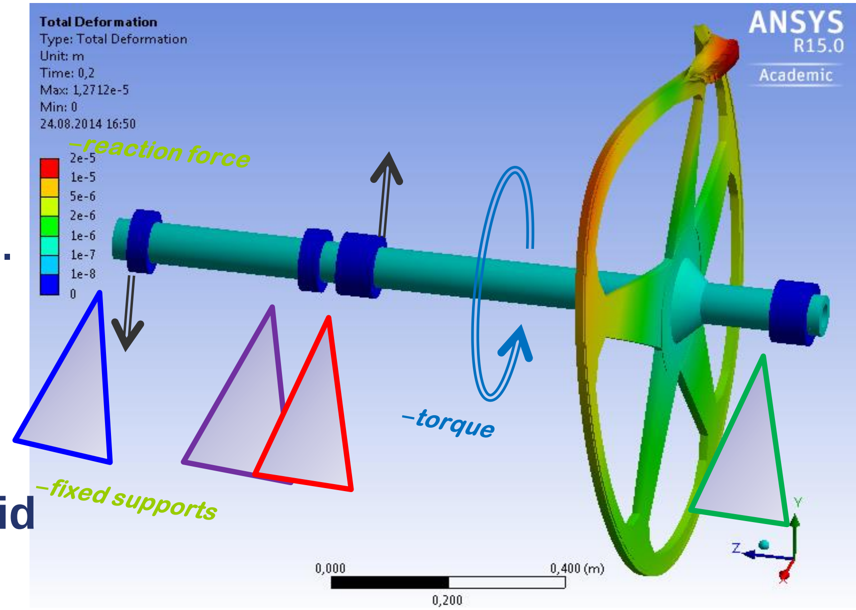
Mechanical instabilities



See Friedrich Staufenbiel at POSIPOL 14.

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  - **Improved layout needed**
- Eddy current induced imbalances and heat load are small
- Resonances are 'natural', running at resonance frequencies must be avoided
- Heat load studies for target ⇔ lower rotation speed possible
- To be done: mechanical studies & tests including cooling system

Lower rotation speed of Ti wheel?

Consider E_{cm} = 500GeV, 50% polarization (K=0.92)

- 2000rpm ⬄ about 10cm length of heated area; area at rim is hit again after ~6s
  - **2625 bunches in 1ms (bunch spacing 366ns)⬄ 'superposition' of ~55 bunches, PEDD ~65J/g (ΔT_{max} ~ 125K)**
  - **1312 bunches in 1ms (bunch spacing 554ns) ⬄ 'superposition' of ~36 bunches, PEDD ~43J/g (ΔT_{max} ~ 82K)**
- Fatigue limit: ~220 J/g (~425K) for 10^7 cycles

➔ 1500rpm ⬄ about 7.8cm length of heated area; area at rim is hit again after ~8s

- **2625 bunches in 1ms (bunch spacing 366ns)⬄ 'superposition' of 83 bunches, PEDD ~J/g (ΔT_{max} ~ 188K)**
- **1312 bunches in 1ms (bunch spacing 554ns) ⬄ 'superposition' of 54 bunches, PEDD ~99J/g (ΔT_{max} ~ 123K)**

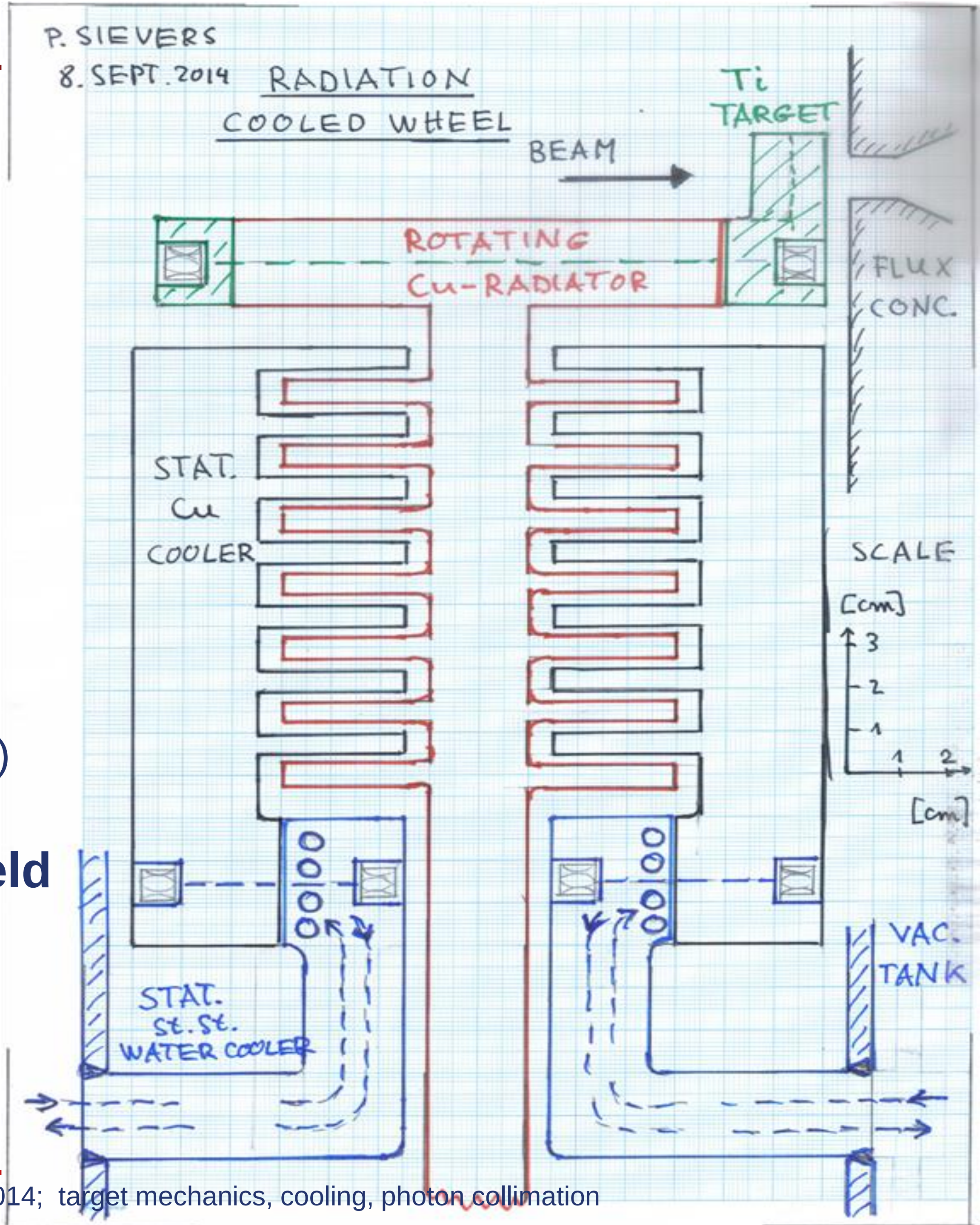
Cooling of target rim

- Power deposited in Ti target 2-7kW
- TDR: water cooling
  - **so far, not yet tested for spinning wheel in vacuum**
- Alternative solutions:
  - **cooling by radiation**
    - Need radiative surface of >1m^2
    - looks promising (see talks of Andriy Ushakov, Peter Sievers at POSIPOL’14)
    - Studies are ongoing → design (DESY, Uni H, P. Sievers)
    - Protoyping (?)
  - **friction cooling (Wei Gai @ POSIPOL’14)**

Radiation cooling

P. Sievers' revised design version

- Important:
  - **thermal contacts**
  - **thermal conductivity (Ti)** (6s ⇔ Δs ~ 1cm in Cu)
  - **Stress must not exceed fatigue yield limits**



Upgrade of positron polarization

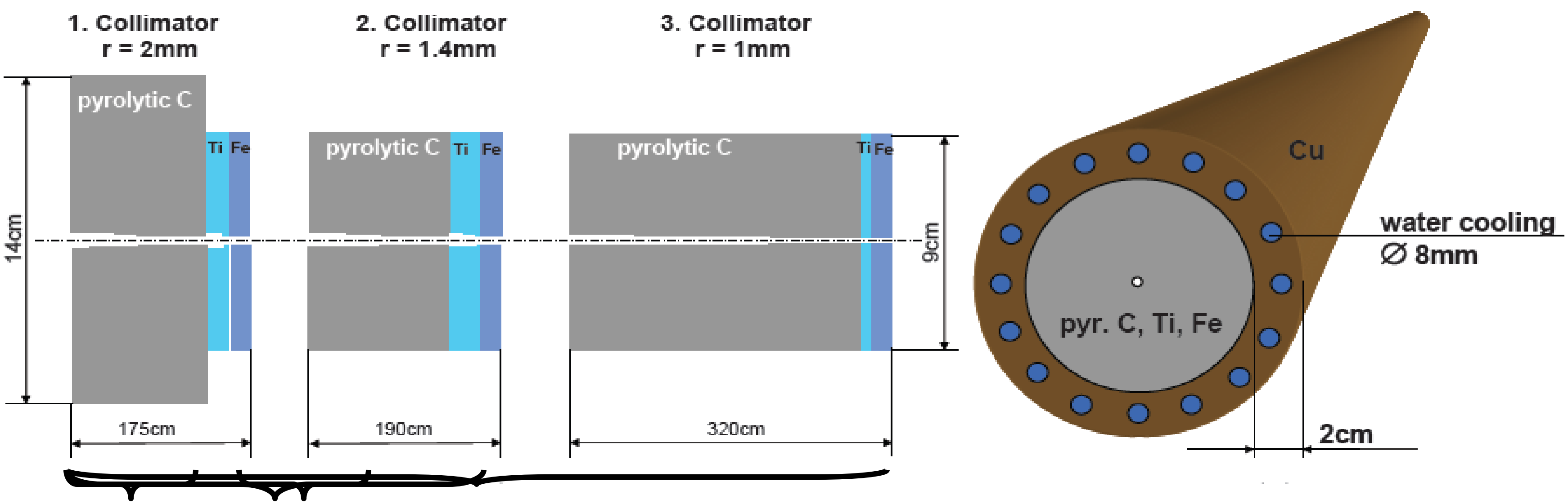
- Nominal source design allows only ~30% e+ pol
- Increase e+ pol with photon beam collimation
- Collimator aperture coupled to drive beam energy
- undulator at end of linac ⇔ small opening angle of photon beam (proportional to 1/γ)

Parameter	Unit					L upgrade
Centre-of-mass energy	GeV	200-250	350	500	500	500
Drive-electron-beam energy	GeV	150	175	250	250	250
Undulator K value				0.92		
Undulator period	cm			1.15		
Positron polarisation	%	55	59	50	59	50
Collimator-iris radius	mm	2.0	1.4	1.0	0.7	1.0
Active undulator length	m	231	196	70	144	70
Photon beam power	kW	98.5	113.8	83	173	166
Power absorbed in collimator	kW	48.1	68.7	43.4	121	86.8
Power absorbed in collimator	%	48.8	60.4	52.3	70.1	52.3

Photon beam collimation

- Stationary collimator; avoid overheating!
  - **Details see talks of Friedrich Staufenbiel (LCWS12, ECFA13)**
  - **Collimator parameters depend on energy**
  - **Use carbon/ graphite to distribute beam over large volume and absorb the beam**
  - **Stop the remaining particles → add Ti and Fe**

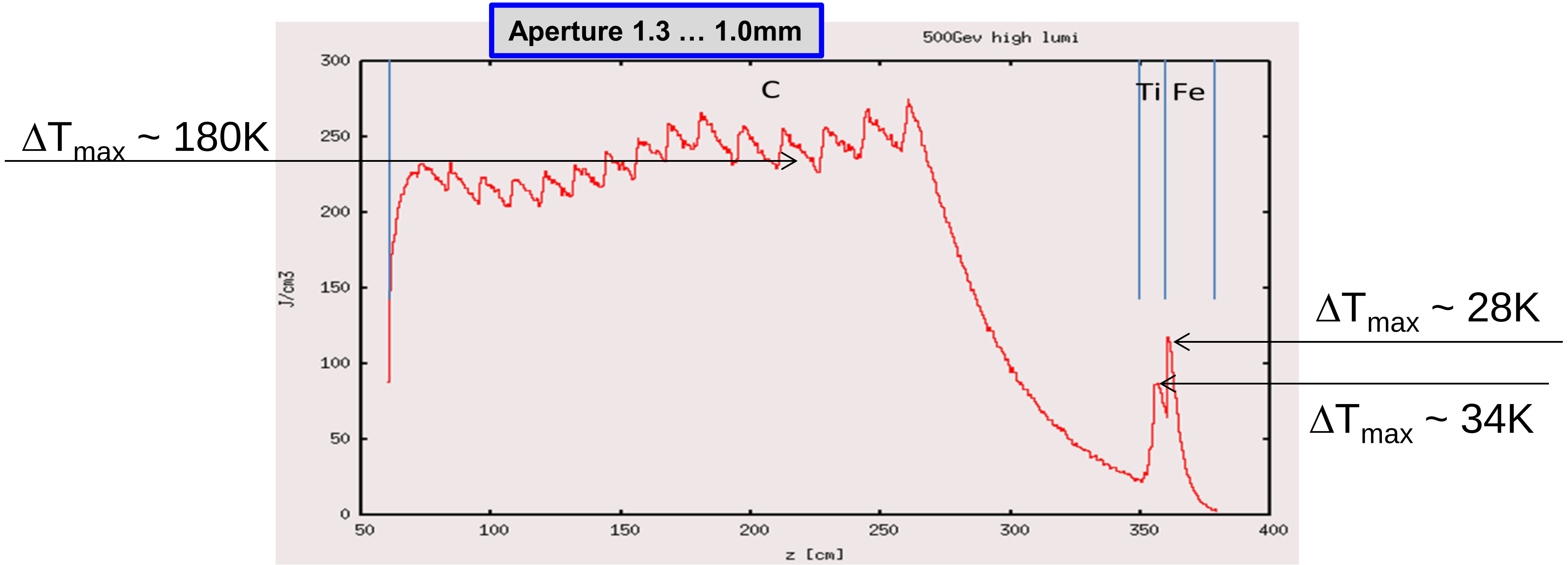
  → Multistage collimator (3 stages with each pyr. C, Ti, Fe)



E_{e-} =150 GeV E_{e-} = 175 GeV E_{e-} = 250 GeV

P_{e+} = 50% P_{e+} ≈ 60% P_{e+} ≈ 50%

- Low Z material (larger critical energy, large X0)
  - **Longer extension of shower; tapered aperture helps to reduce PEDD**
  - **FLUKA simulations (Friedrich) to find collimator parameters that avoid steep temperature rise → almost homogeneous (max) temperature along z**



- High Z material?
  - **A similar but shorter design consisting of W yields overheating due to the low critical energy (low X0, more intense shower)**

Pyrolytic graphite

- Maximum dpa values in the collimator materials

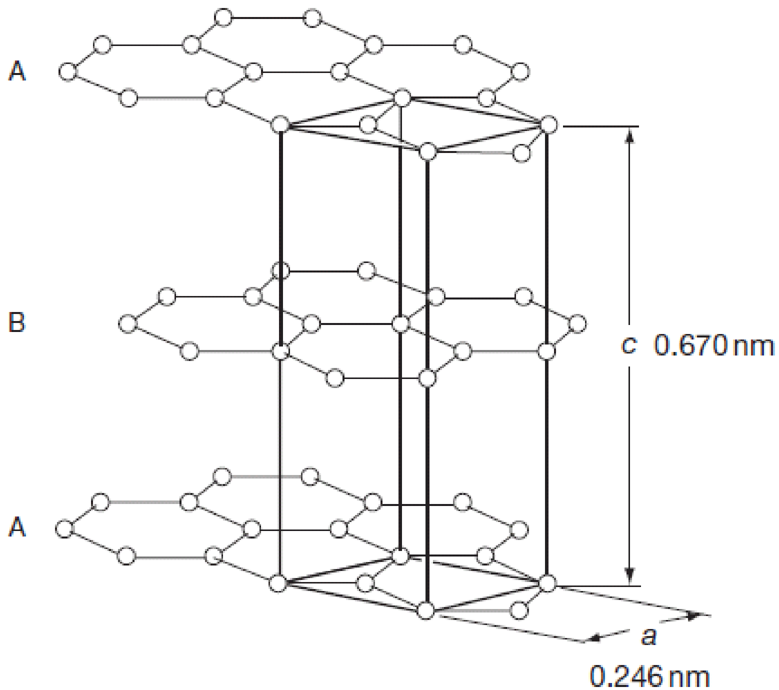
E_{cm}[GeV]	250		350	500 (h.lumi)
E_{e-} [GeV]	125	150	175	250
	1st collimator		2nd collimator	3rd collimator
Pyr. C	1.0	1.6	2.7	3.0
Ti8Mn	0.7	1.1	2.2	2.5
Iron(St-70)	0.5	0.8	1.7	1.7

these high values occur near the inner surface of the collimator

- Expect dimensional change for dpa values larger than ~0.5

Graphite: anisotropic material

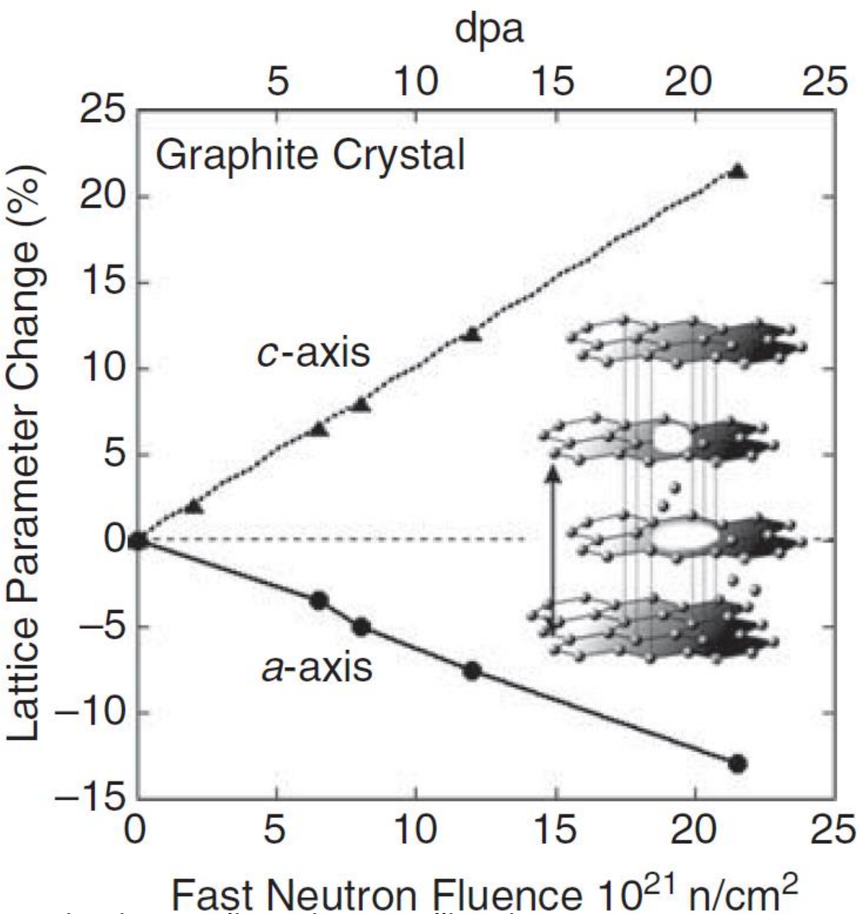
Structure of graphite



→ anisotropic material properties:

– thermal expansion coefficient,

– dimensional changes under irradiation



Bonal et al, MRS Bulletin34 (2009), p28

Kelly, Martin, Nettley.

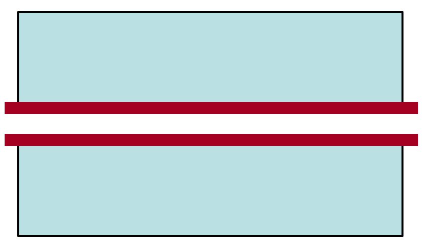
Taken from

IAEA-TECDOC-1154

Swelling

- **increases dimension along z by few %**
- **decreases dimension in x,y direction slightly**

at inner collimator surface



- **Depends on temperature**
- **Depends on radiation level**

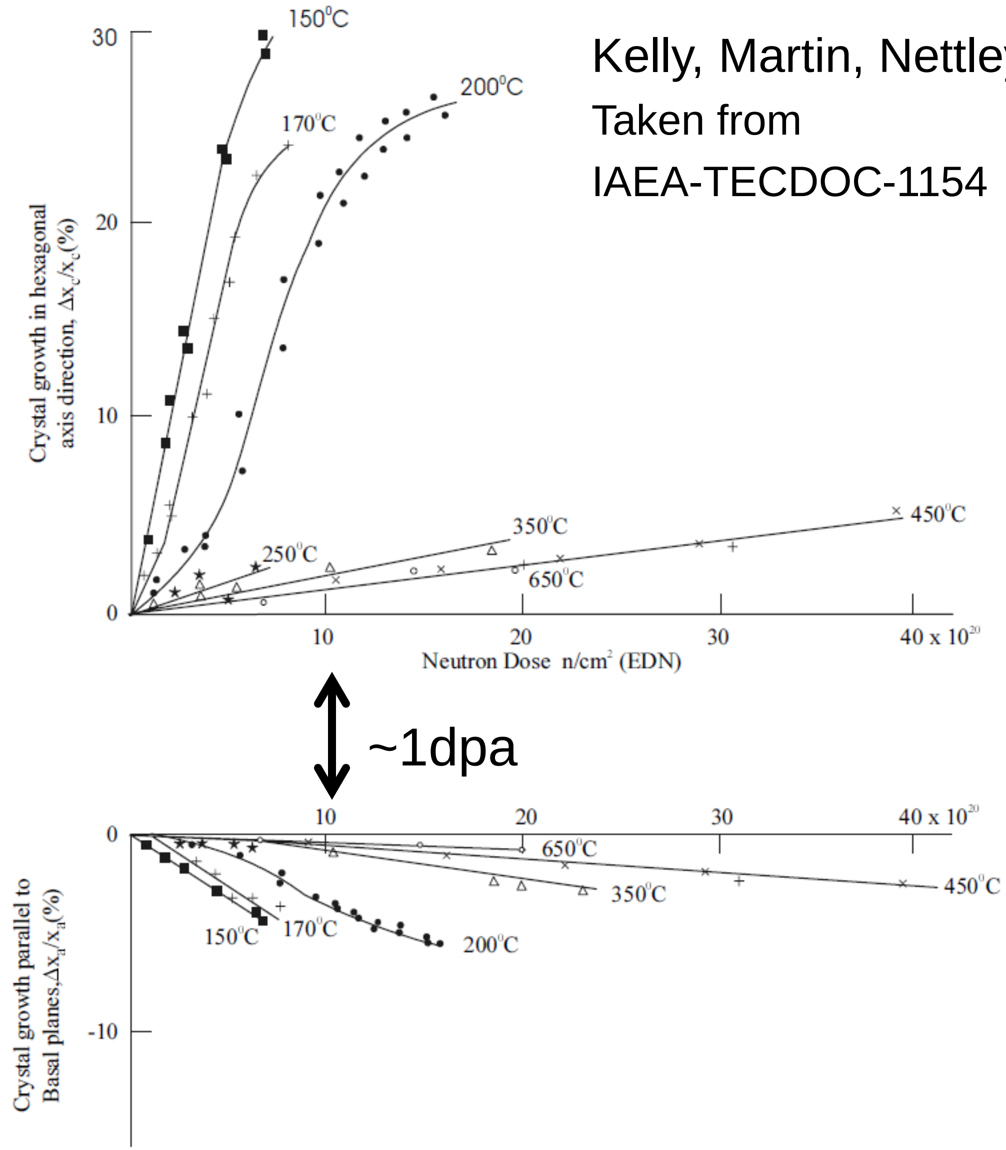


FIG. 3.5. Dimensional changes of pyrolytic graphite: Low temperature.

Some comments

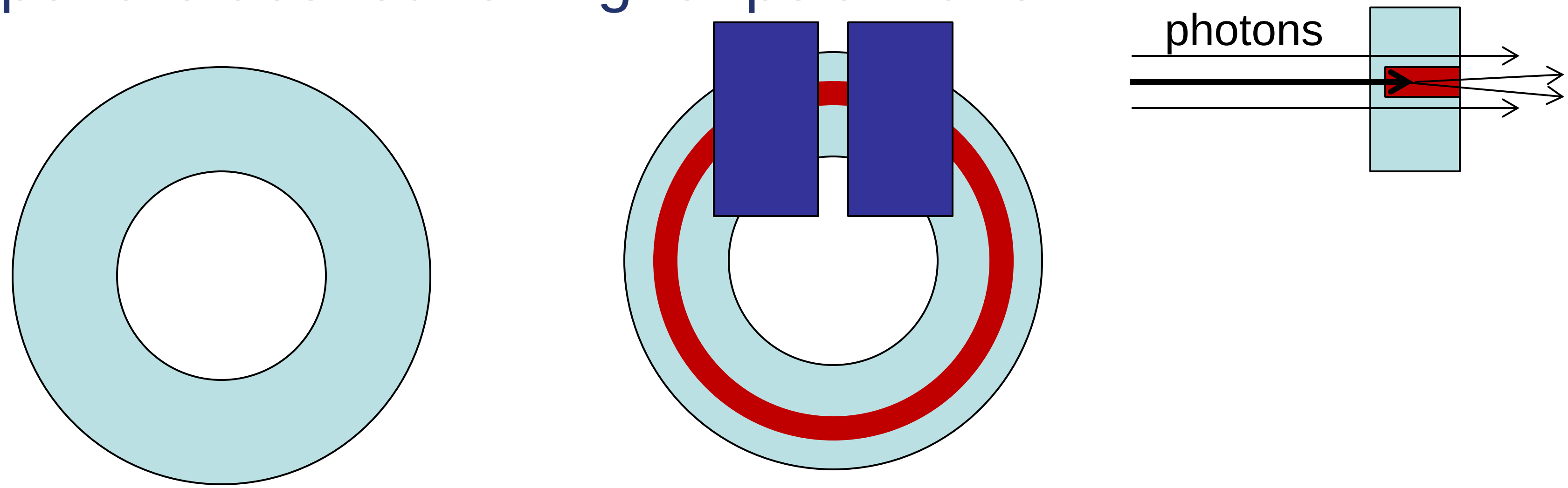
- Expect substantial dimensional in pyr graphite change for ≥0.5dpa
  - **Changes depend on irradition particle type and energy and on temperature**
- Swelling could damage the innermost layer;
  We do not know which dimensional change will be obtained
  - **Max temperature rise ΔT ~ 50-200K in pyr. graphite**
  - **only very thin layer of high dpa**
  - **Surface damage ? Lifetime?**
- For our collimator we need quite large blocks of pyr graphite, but it is available only in ~1cm thick slices
  - **difficult for construction of ~1-3m long collimator parts**
- Vacuum ⇔ pyrolytic graphite ?

The design for a stationary collimator is a first step.

Better ideas are welcome and must be studied in detail

Alternative collimator design: First idea

- Instead using a rim of target material, the target material (preferably higher Z) is embedded in a holder material with lower Z
- Height of the target corresponds to collimator aperture desired for higher polarization



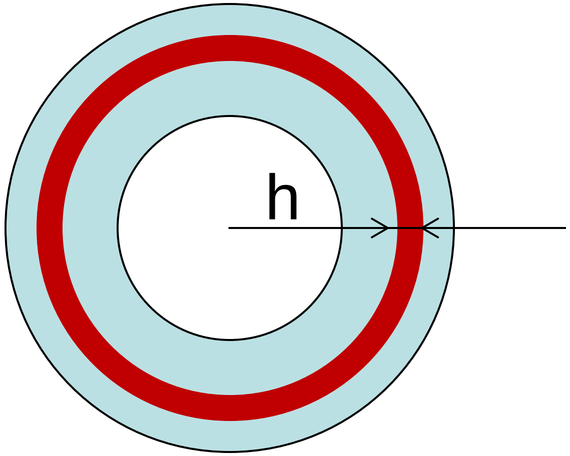
- In addition, simple collimators could further increase the e+ pol

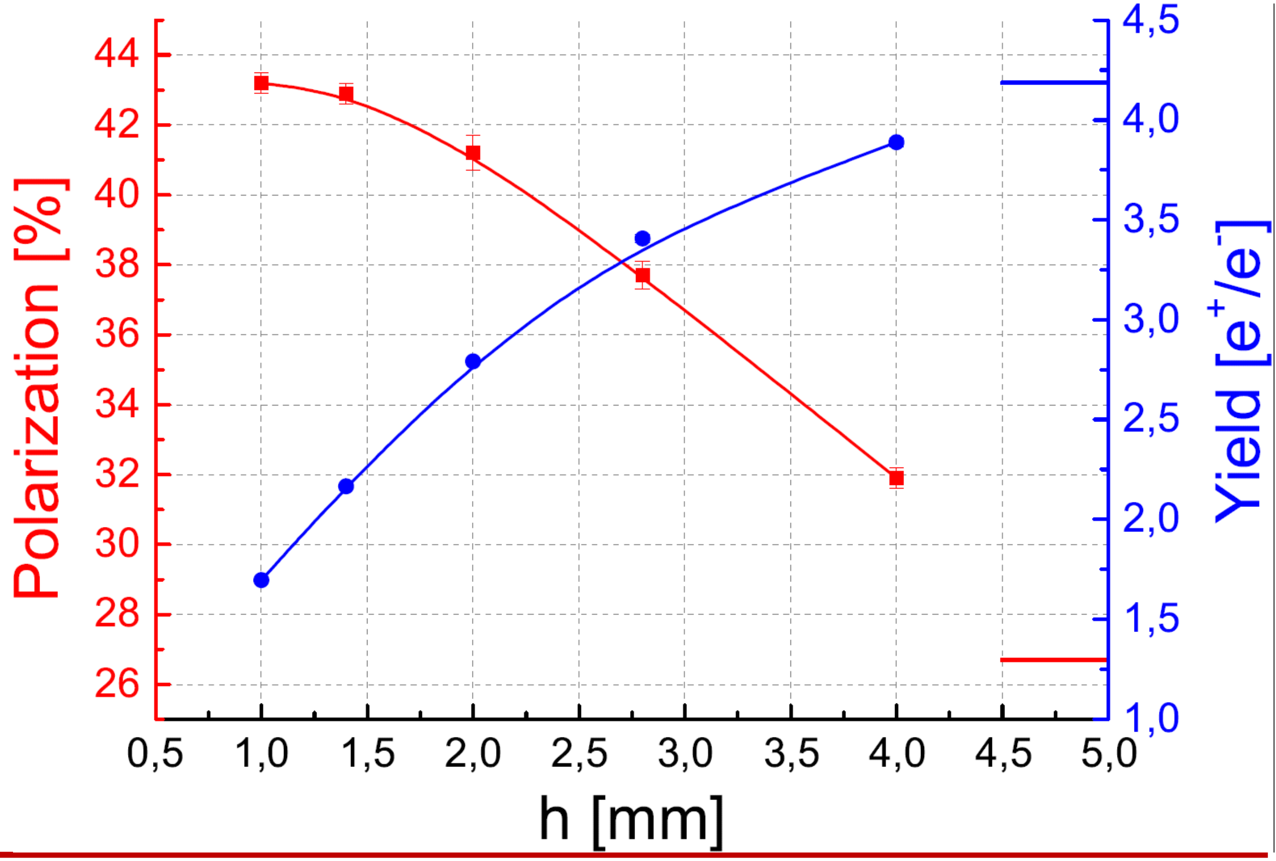
First Idea (contd)

- Which e+ pol could be reached?
- First rough estimates:

A. Ushakov

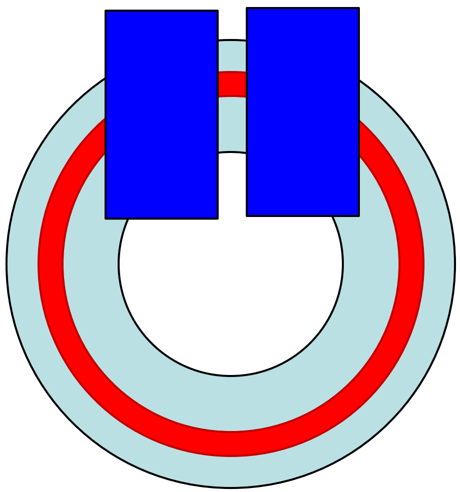
E_{cm} = 350GeV

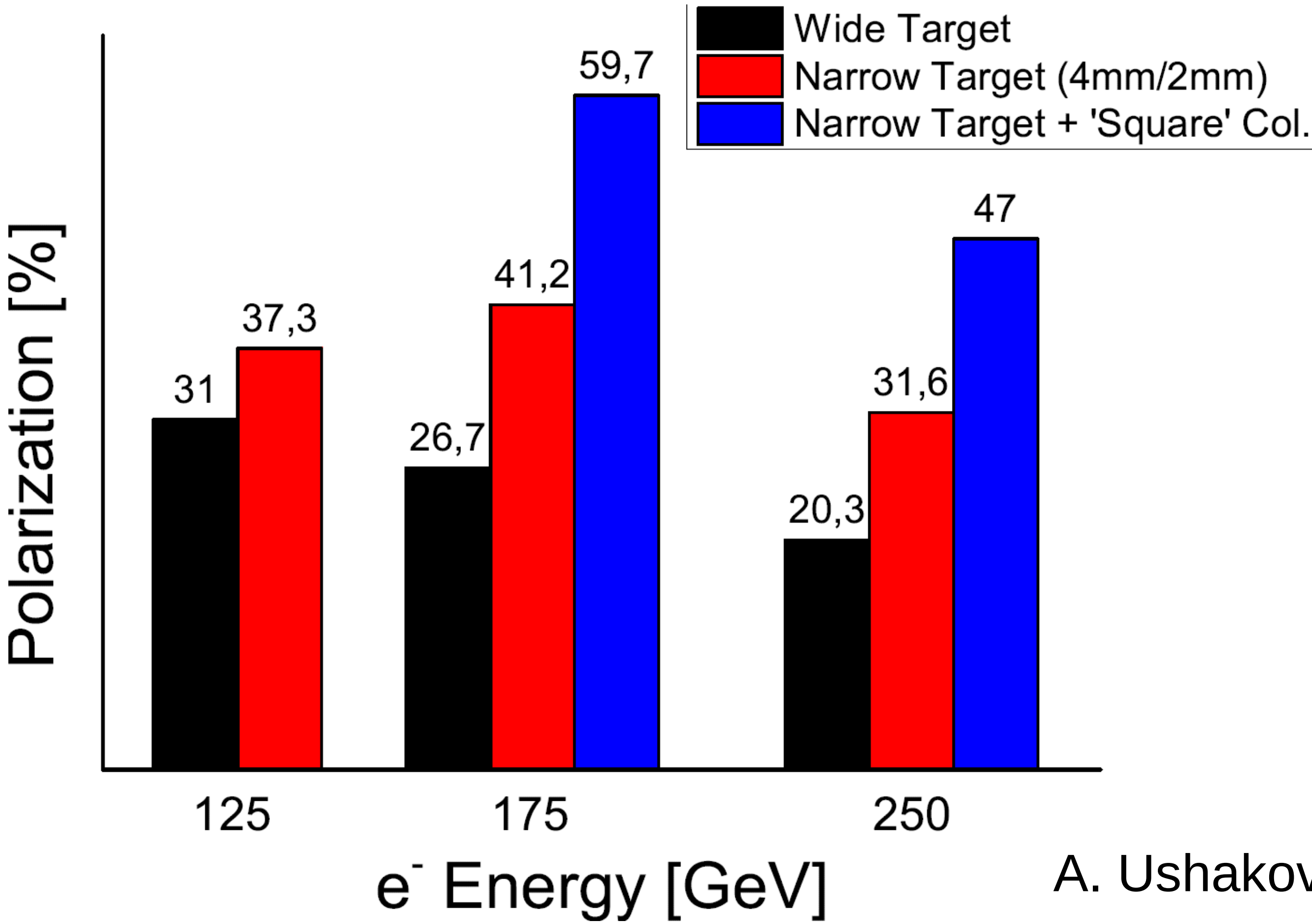




First Idea (contd)

- Which e+ pol could be reached? (K = 0.92)

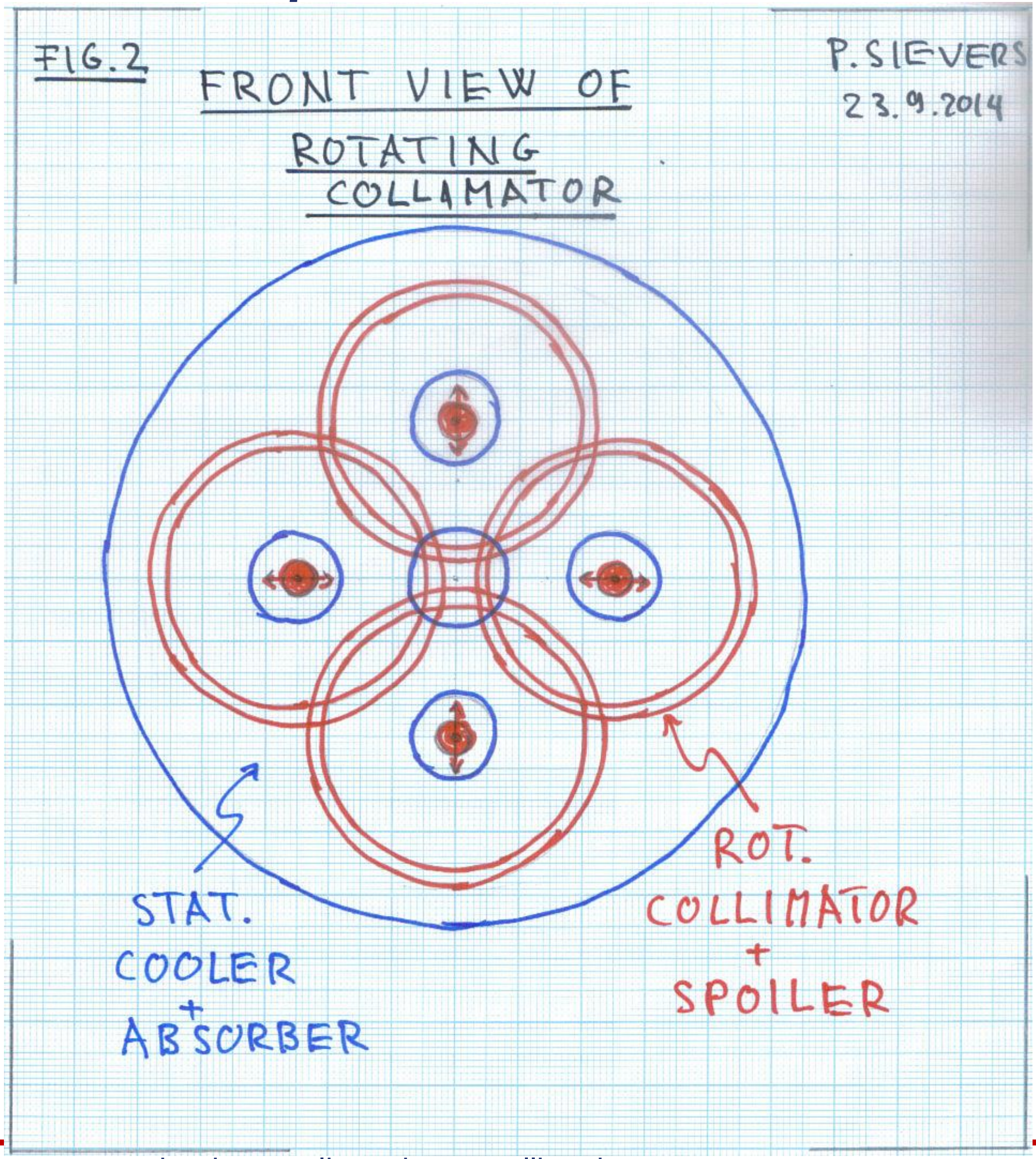




A. Ushakov

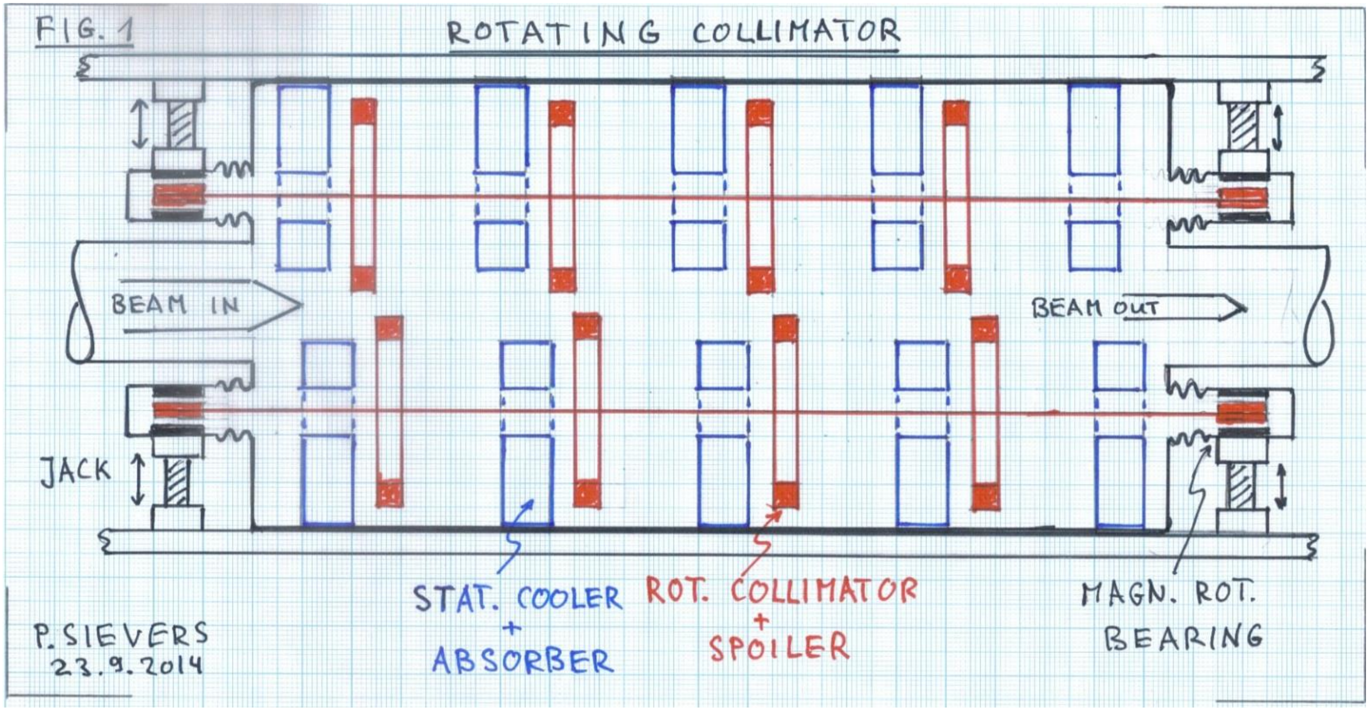
Alternative collimator design: Second idea

- Use a system of rotating spoilers + absorbers to dump the shower



Alternative collimator design: Second idea

- Use a system of rotating spoilers + stationary cooled absorbers



- Simulation studies needed
- although the rotation speed is below that of the Ti target, the solution is not easy

Summary

- Positron target of undulator based source:
  - **Rotating wheel design can be improved, in particular**
    - magnetic bearing
    - 2-side support
    - Alternative (no-water) cooling system
    - Lower rotation speed
  - **no showstopper but a R&D work remains**
  - **To be done: mechanical studies & tests including cooling system**
- Cooling options to be considered:
  - **Water cooling ⇔ prototyping**
  - **Radiation cooling (principle design exists)**
  - **Friction cooling**
- Photon collimator ⇔ polarization upgrade
  - **Principal design exists**
  - **Alternatives under study**
- Prototyping, endurance tests are necessary; fatigue load of target material?
- Resources needed

backup

LINEAR COLLIDER COLLABORATION

Concept study of heavy rotor with "Juelich" bearings

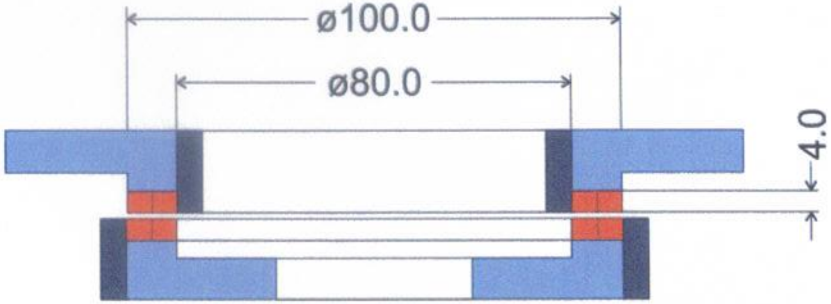
JÜLICH FORSCHUNGSZENTRUM

P. Sievers, POSIPOL2014

- 100 kg steel rotor levitated by 0.2 kg ferromagnetic material

- Support bearing with one gap / two double rings

Magnetic (double) ring dimension:
Ø 80/100 mm, height 4 mm

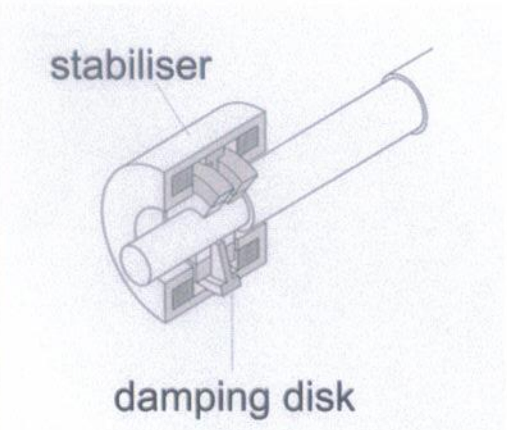


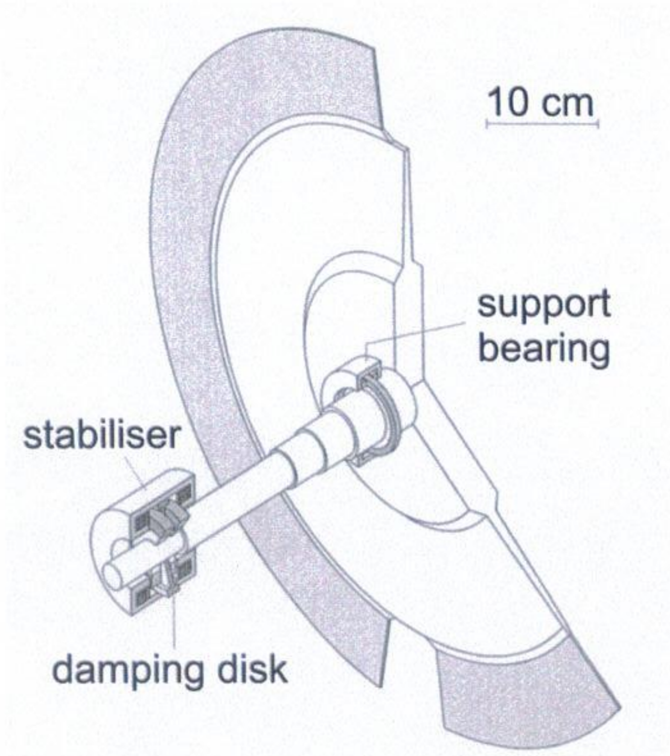
Outlook:
Design of above permanent magnetic bearings easily expandable
for much heavier rotors by using multiple stacked double ring magnets

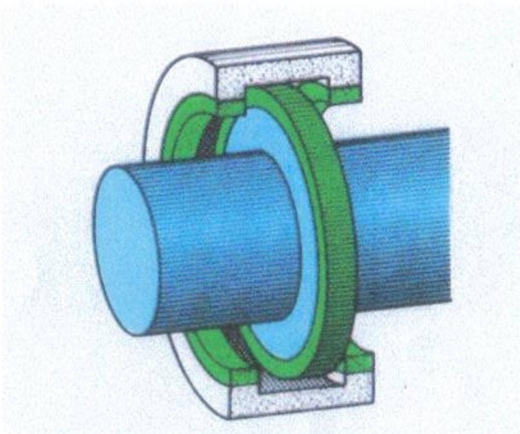
Typical design of system "Juelich" chopper bearings

JÜLICH
FORSCHUNGSZENTRUM

P. Sievers, POSIPOL2014







Stabiliser

- Two rotating permanent magnets made out of NdFeB
- Two coils
- Copper disk for damping via eddy currents
- Steel case

Support bearing

- Positioned in mass centre
- Passive bearing
- Permanent magnetic rings made out of NdFeB

Realised parameters for "Juelich" choppers

JÜLICH FORSCHUNGSZENTRUM

P. Sievers, POSIPOL2014

Disk diameter:	Up to 750 mm
Disk materials:	High strength aluminium / Titanium alloy / Carbon fibre
Rotor mass:	Up to 50 kg
Rotational speed:	Up to 1000 Hz / 60,000 RPM
Highest Phase stability:	Better than 2 ns (electronically)

More than 30 Years Experience in chopper design

Some examples:

- NEAT chopper cascade (7 disks) at HZB, former HMI, Germany
- DCS chopper cascade (7 disks) at NIST, USA
- IN5 chopper cascade (6 disks) at ILL, Grenoble
- SANS-NG3 chopper system (2 disks) at NIST, USA
- MARS chopper cascade (5 disks) at PSI, Switzerland
- NSE chopper cascade (4 disks) at SNS, USA
- HET, MAPS, MARI: Fermi choppers for ISIS, UK
- IN6 Fermi chopper for ILL, Grenoble
- BioCARS, 1 kHz X-ray chopper, Advanced Photon Source, Argonne, Illinois, USA
-

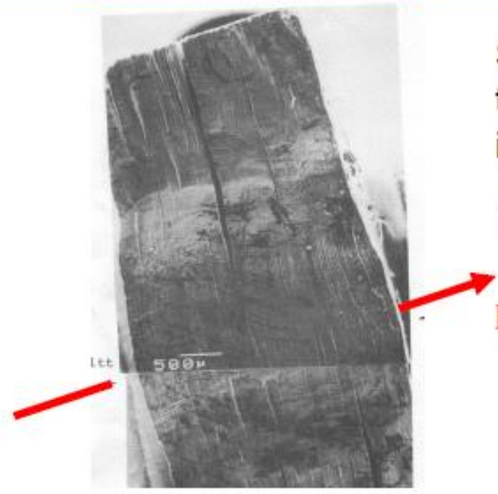
Lifetime of the pyrolitic graphite targets due to irradiation-induced dimensional changes

Operational parameters:

Proton current:	100 µA
Peak current density:	1000 µA/cm²
Peak temperature:	1800 K

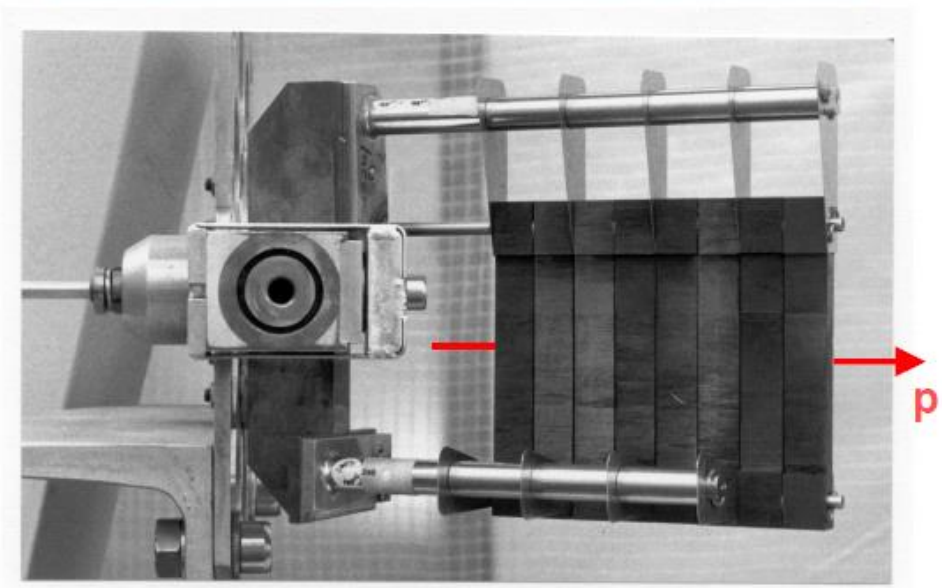
Lifetime limits:

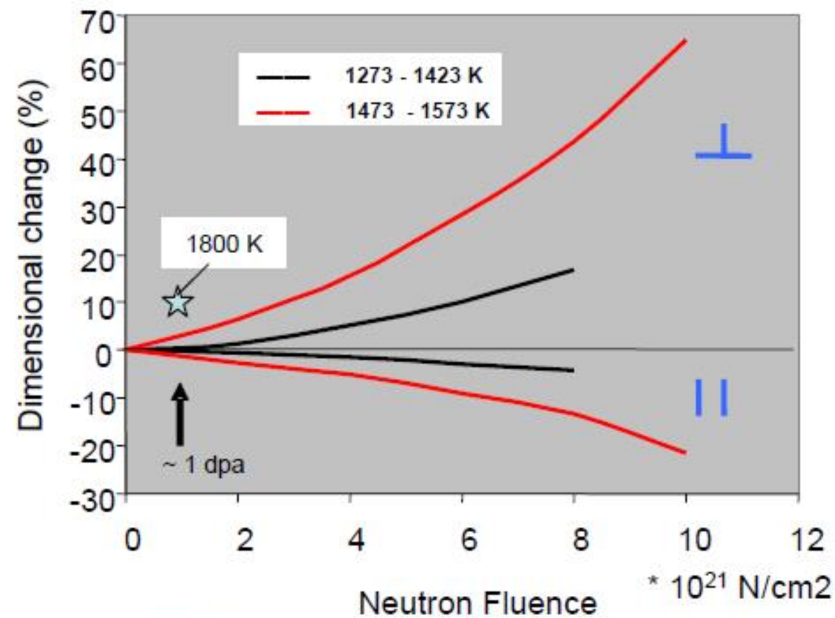
Proton fluence:	10^{22} p/cm²
Integrated beam current:	50 mAh
Irradiation-induced swelling:	~ 10 %
Irradiation damage rate:	~ 1 dpa



Swelling of the target after irradiation

10^{22} p/cm2





J. Bokros et. al, Carbon 1971,Vol. 9,p. 349

Dimensional changes in pyr graphite

Koike, http://ir.library.tohoku.ac.jp/re/bitstream/10097/46594/1/10.1557-JMR.1994.1899.pdf

(e- irradiation

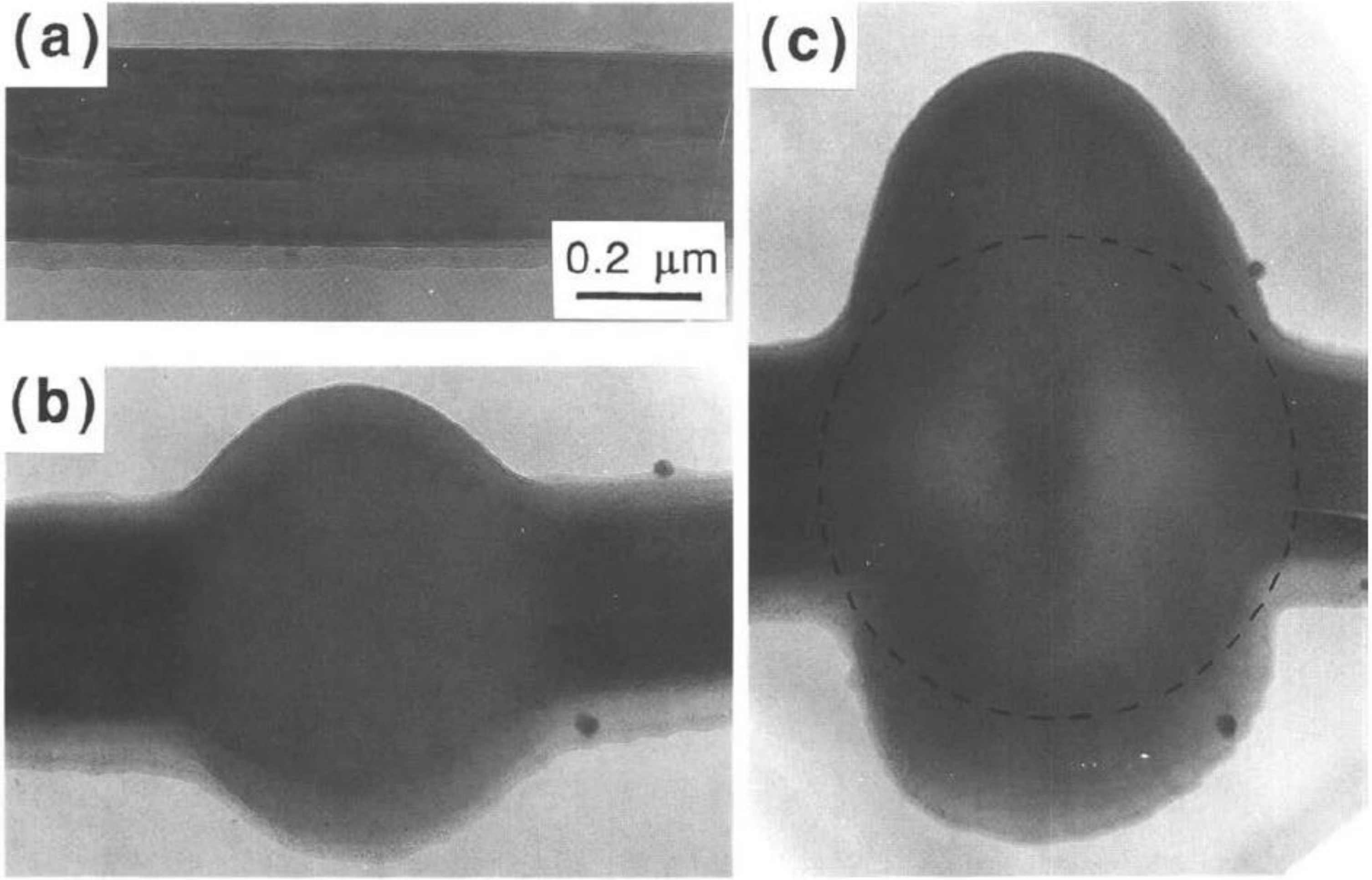
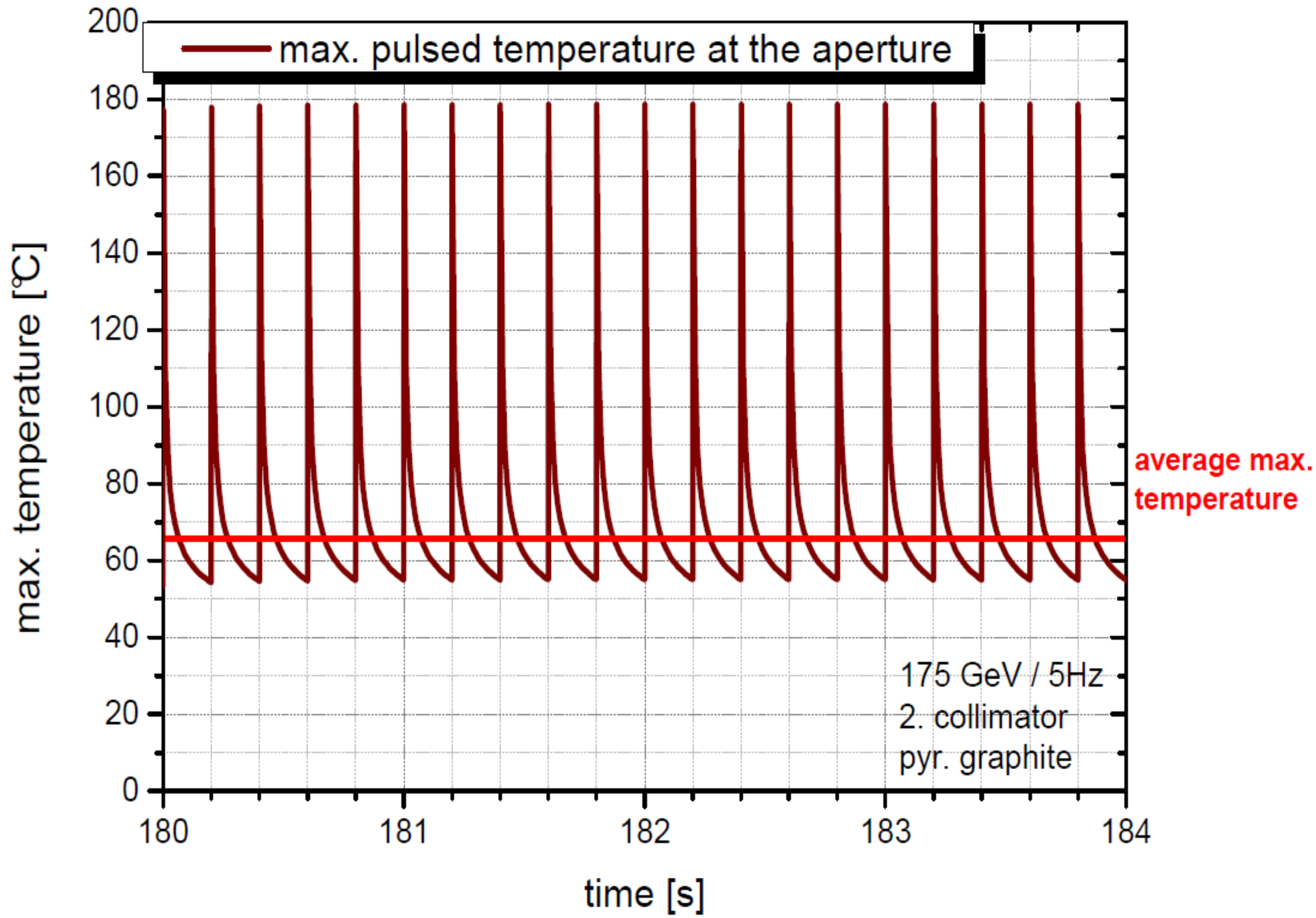
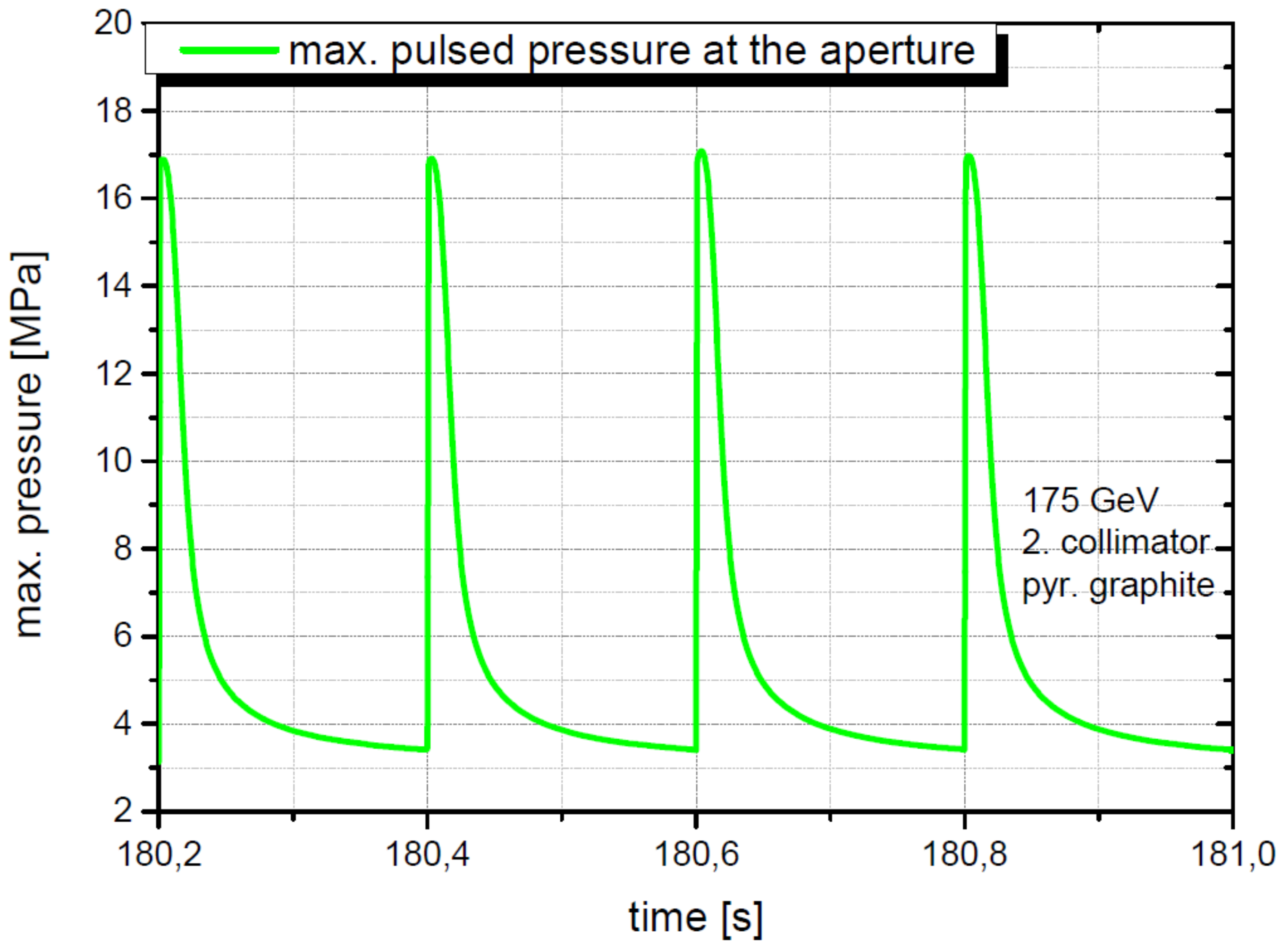


FIG. 2. Bright-field images of an HOPG strip illustrating the radical morphological changes produced by 300 keV electron irradiation at room temperature: (a) before irradiation, (b) after irradiation to 1.35 dpa, and (c) after irradiation to 5.0 dpa. The dotted circle indicates the size of the incident beam.

F. Staufenbiel





F. Staufenbiel