The ILC Positron Source

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- Overview LC
- Positron source
- Target stress
- Planned experiments
- Conclusions

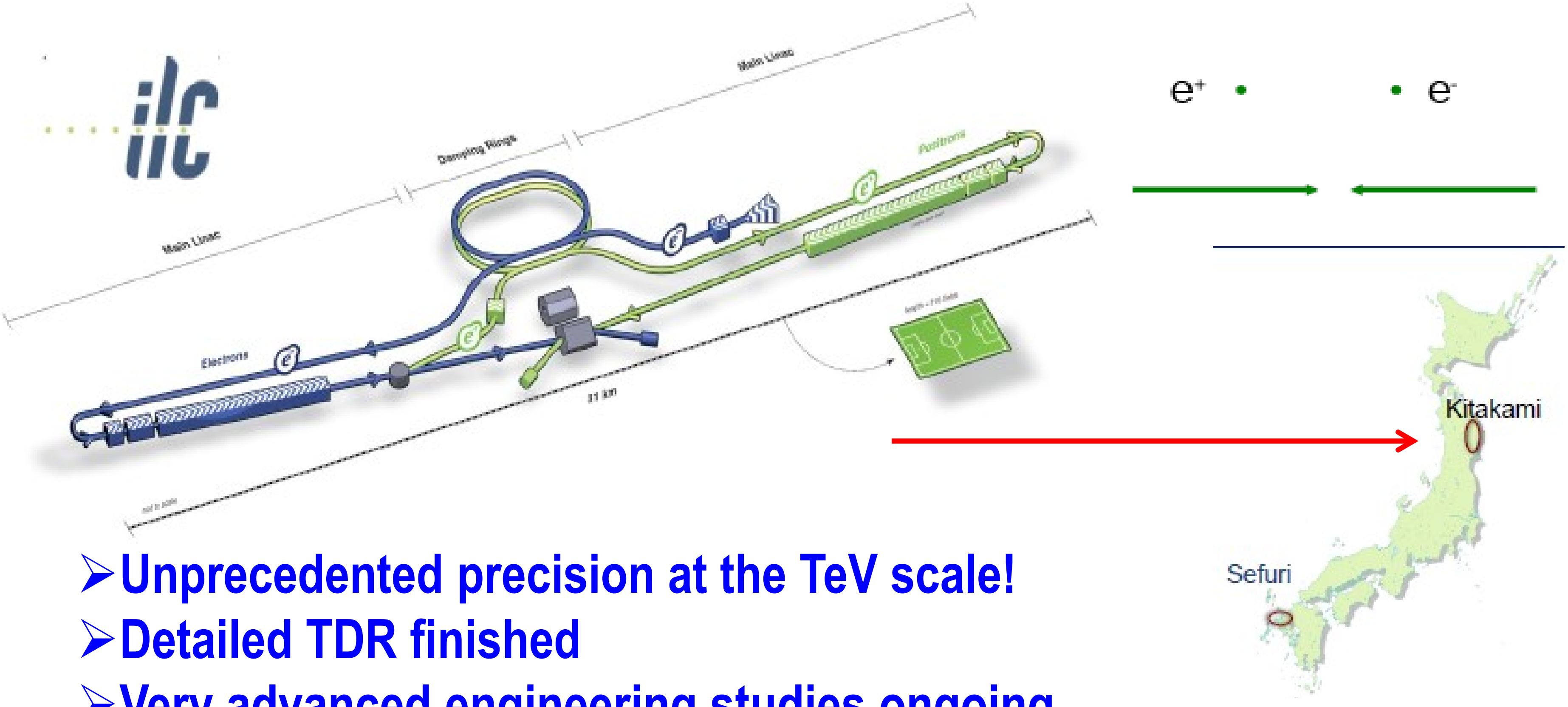
Universität Hamburg
DER FORSCHUNG I DER LEHRE I DER BILDUNG

LINEAR COLLIDER COLLABORATION

Overview

See plenary A. Seryi

- **ILC (International Linear Collider), worldwide project, electron-positron collider, energy ~1 TeV**



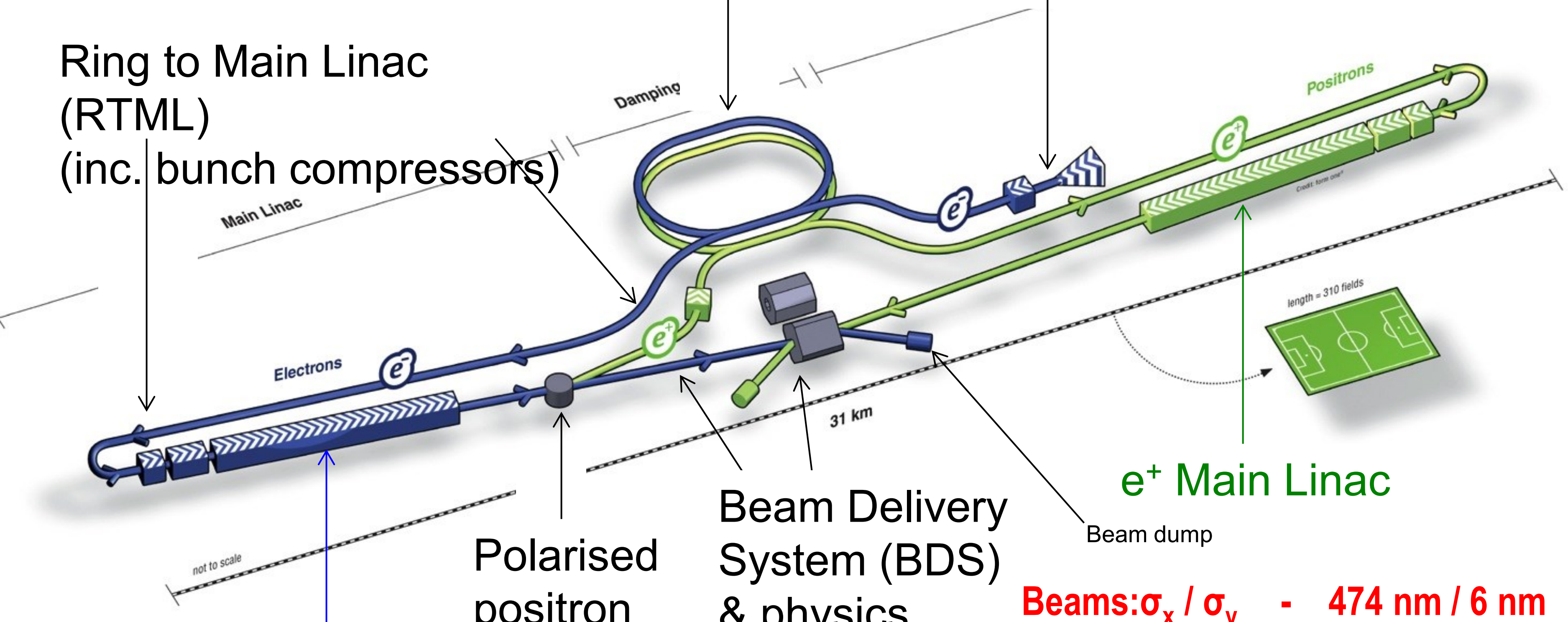
- ➢ **Unprecedented precision at the TeV scale!**
- ➢ **Detailed TDR finished**
- ➢ **Very advanced engineering studies ongoing**

The LC physics offer and challenges

- **Staged energy approach:**
  - √s~240 GeV, `Higgs frontier‘
  - √s~350 GeV, `Top threshold‘
  - √s~500 GeV, `Top Yukawa‘
  - (√s=91 GeV, `EW Precision frontier‘)
  - √s~1000 GeV, `Higgs potential‘
- **Polarized beams and threshold scans:**
  - impact on quality and quantity
  - Something ‘new’ comp. to LHC analyses
- **Highest precision: high luminosity+polarization required**

ILC Machine Overview

See plenary A. Seryi



Damping Rings

Polarised electron source

Ring to Main Linac (RTML)
(inc. bunch compressors)

e^+ Main Linac

Beam dump

Polarised positron source

Beam Delivery System (BDS) & physics detectors

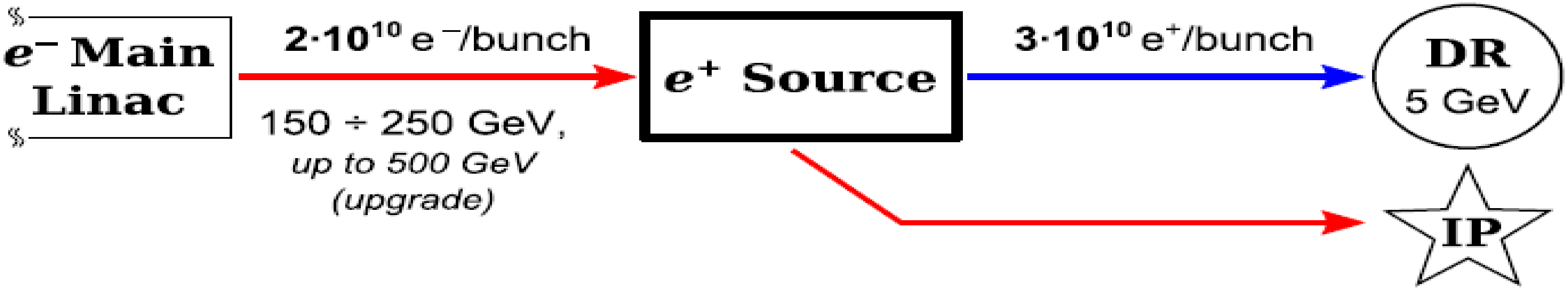
e^- Main Linac

Beams: σ_x / σ_y - 474 nm / 6 nm
$2*10^{10}$/bunch, 1312 bunch/pulse
5 Hz repitition rate
Luminosity - 2×10^{34} cm^{-2}s^{-1}
Polarisation (e-/e+) - 80% / 30(60)%

not to scale

ILC Scheme | © www.form-one.de

ILC e+ Source



e⁻ Main Linac

$2 \cdot 10^{10}$ e⁻/bunch

150 ÷ 250 GeV,
up to 500 GeV
(upgrade)

e⁺ Source

$3 \cdot 10^{10}$ e⁺/bunch

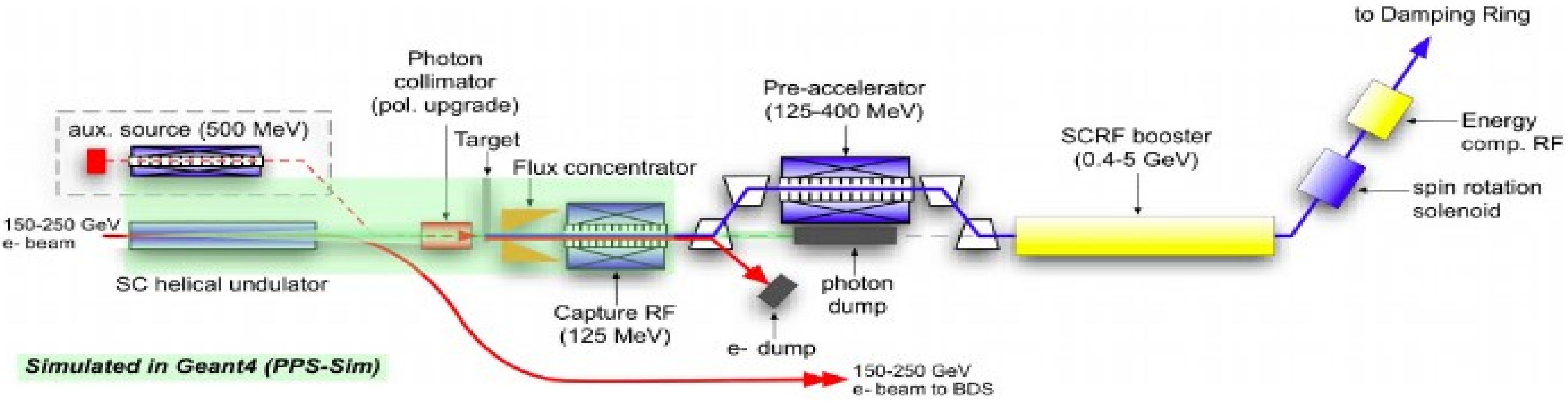
DR
5 GeV

IP

- Wide range of drive e^- energy: 150 GeV ÷ 250 GeV (design), 500 GeV (upgrade)
- **e^+ yield**: 1.5 e^+/e^- (50% safety margin)
- DR acceptance:
  - Transverse emittance: $\epsilon_{nx} + \epsilon_{ny} \leq 70$ mm rad
  - Max. energy spread: ±37.5 MeV
  - Longitudinal bunch size: ≤ 34 mm
- **e^+ polarization**: $\sim$ 30% (up to 60%, upgrade)

Schematic layout of e^+ source

- **Choice: e^+ via radiation from a helical undulator (because of higher yield, less rad. level, better DR accept., less target stress)**



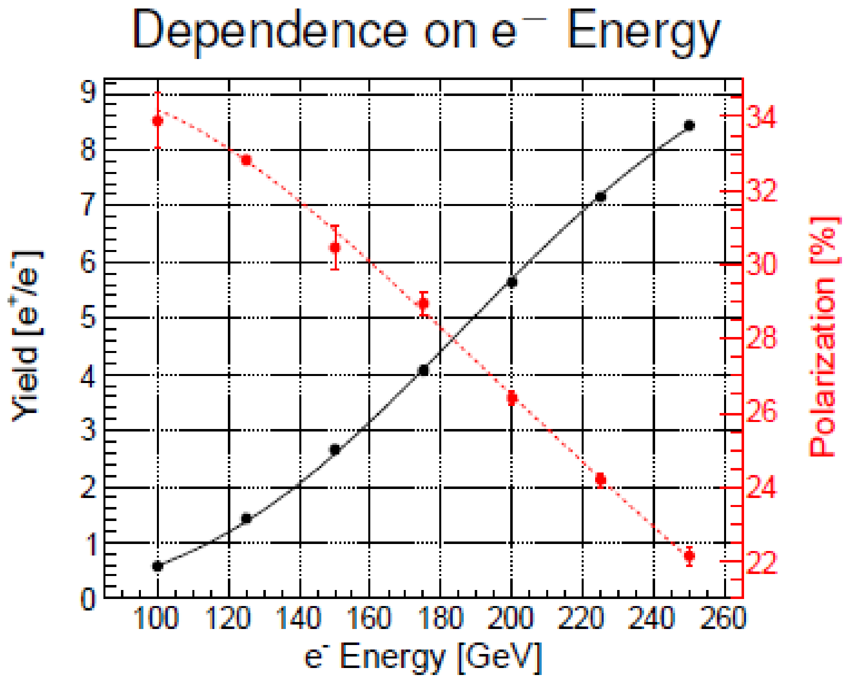
- SC Helical Undulator: 231 m length, 11.5 mm period, $K \leq 0.92$ ($B \leq 0.86$ T)
- (Optional) Photon Collimator: exist principal design (to improve polarization)
- Target: $0.4X_0$ thickness, Ti6Al4V rim rotated with 100 m/s tangential speed
- Flux Concentrator: 12 cm length, $B_{max} = 3.2$ T, $B_{end} = 0.5$ T
- NC Capture RF: 1.3 GHz, ≈ 10 m length, 14.5 MeV/m and 8.5 MeV/m

Pol(e^+):Technical facts (yield ≥1.5)

- √s=240 GeV: 120 GeV e- drive beam
  - Undulator with 231 m (K=0.92, λ=11.5 mm), collimator r=3.5 mm
  - P(e+)~ 40%
- √s=350GeV: 175 GeV e- drive beam
  - Collimator with r=1.2 mm
  - P(e+)~ 56%
- √s=500GeV: 250 GeV e- drive beam
  - Undulator with 144 m, collimator r=0.7mm
  - P(e+)~59%
- √s=1 TeV: 500 GeV e- drive beam
  - Undulator with 176 m (K=2.5), collimator r=0.9mm
  - P(e+)~54%

Yield , pol. vs e- energy (231 m undulator)

baseline design



Geant4 simulations for

- **231 m undulator, B = 0.86 T, K = 0.92**
- 0.4 X_0 Ti6Al4V target
- FC: 3.2 T to 0.5 T in 12 cm and $R_{ini} = 6$ mm
- $\approx$10 m 1.3 GHz RF structure

e^+ Polarization at 250 GeV e^-:

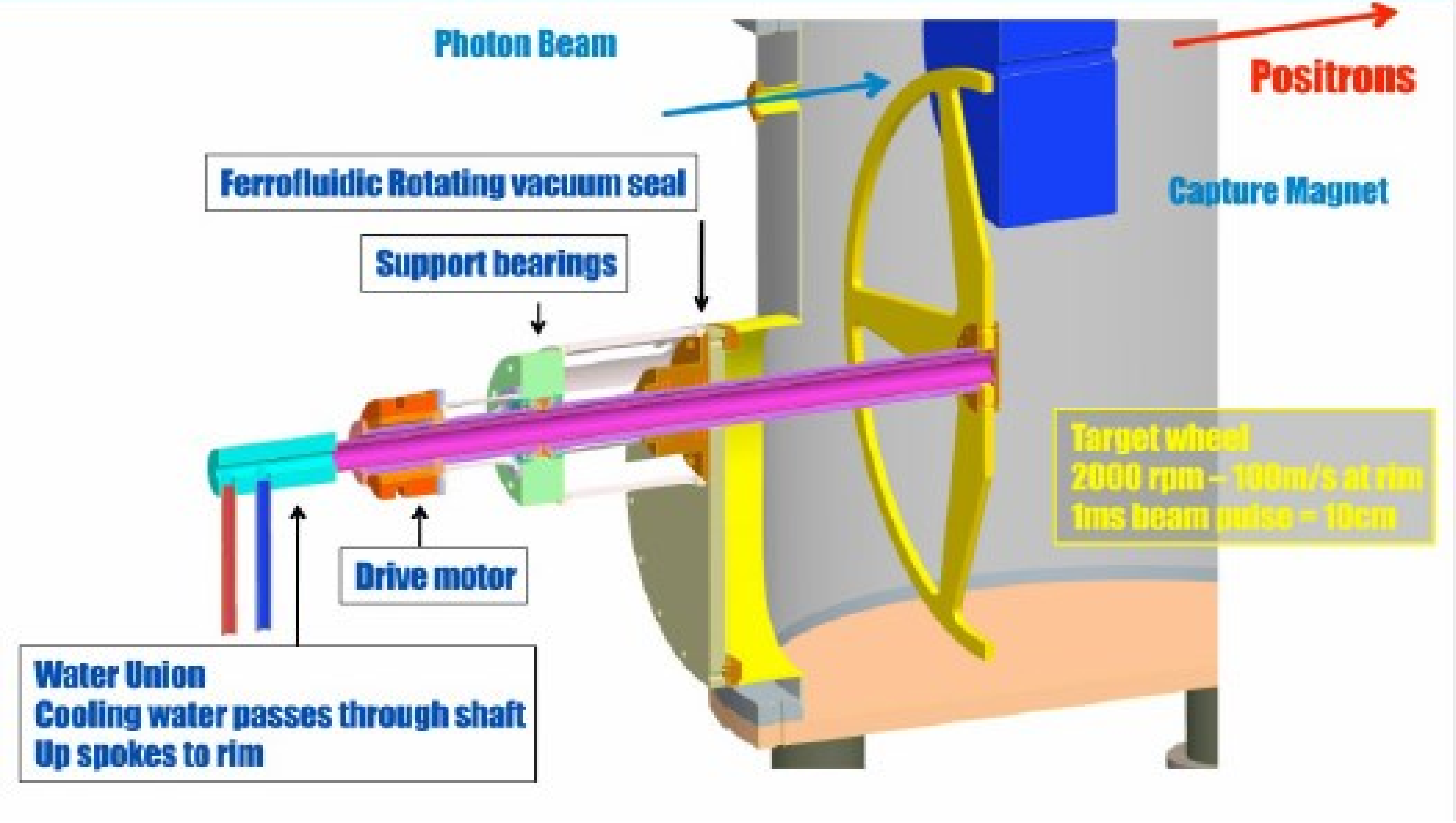
$\Rightarrow$ To increase polarization up to 30% a reduction of magnetic field of undulator is needed ($B = 0.42$ T, $K = 0.45$)

$\Rightarrow$ High energy of e^- and low field of undulator result in small photon spot size on the target and high peak energy deposited in the target

Positron source parameters baseline design

e^- Energy [GeV]	250
Number e^- per Bunch	$2 \cdot 10^{10}$
Number of Bunches per Pulse	1312
Bunch Spacing [ns]	554
Pulse Repetition Rate [Hz]	5
Undulator Field [T]	0.42
Photon Energy (1st harmonic) [MeV]	42.9
Required Undulator Length [m]	147
Average Photon Power [kW]	43
Relative Energy Deposition in Target [%]	5.3
Photon rms spot size on target [mm]	0.8
Peak Energy Deposition Density in Target [J/g]	?
Max. Thermal Stress in Target [MPa]	?

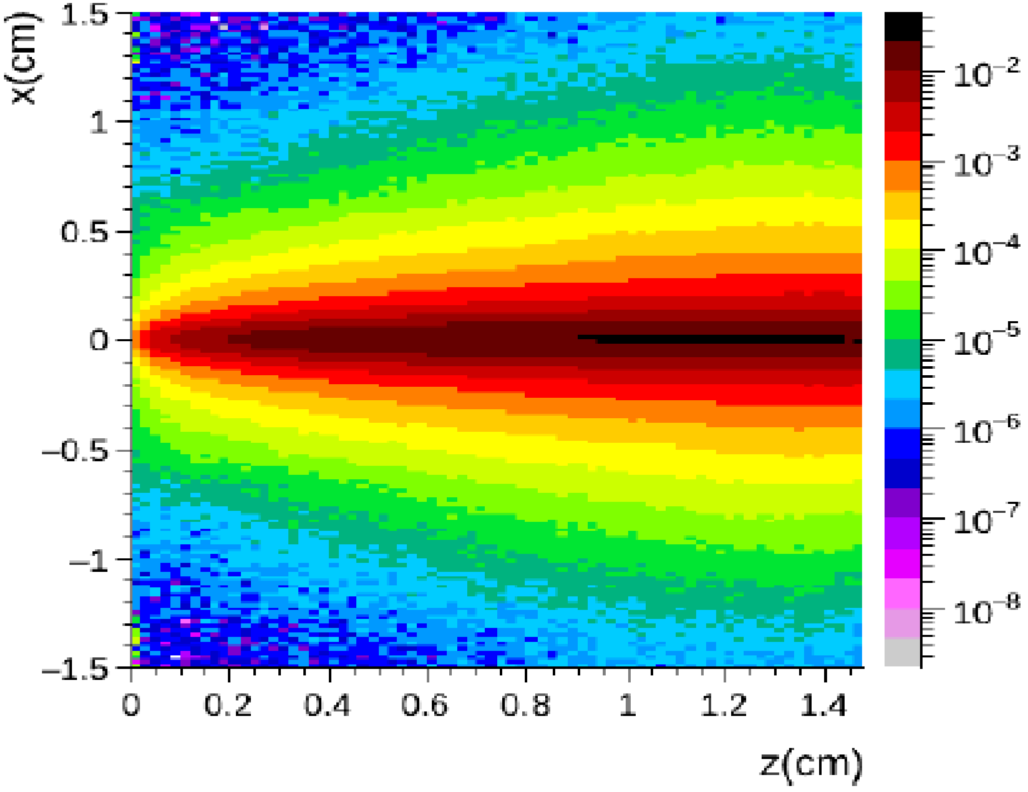
ILC baseline target wheel



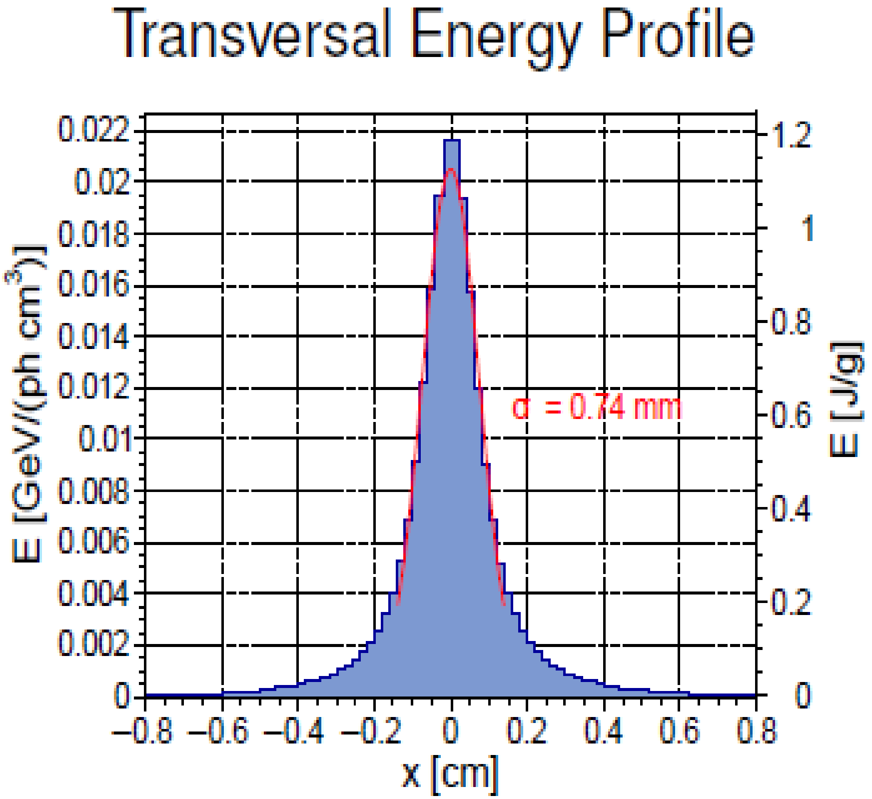
Target stress

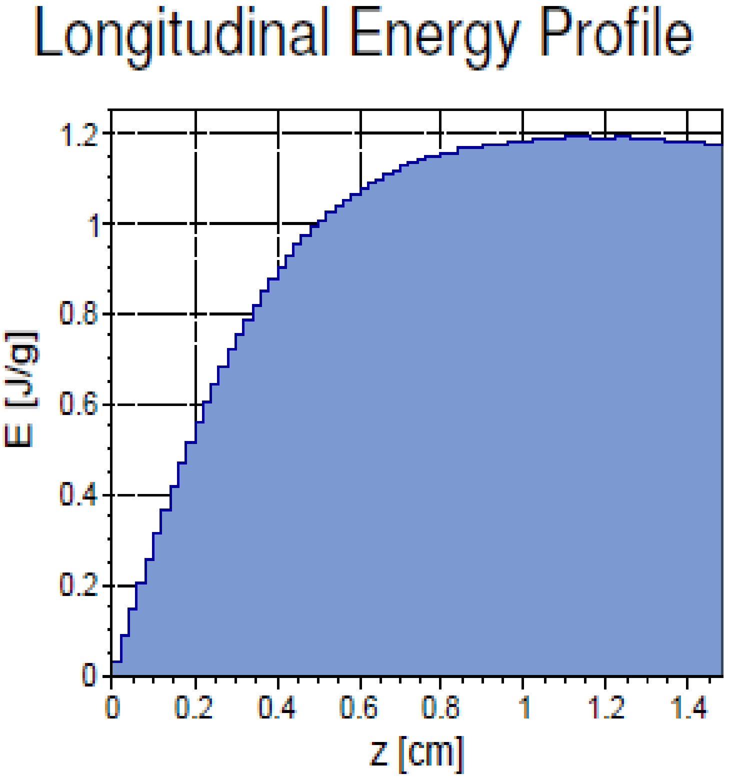
- **Energy deposition in e+ target (FLUKA)**

Distribution of Energy Density Deposited by Bunch [GeV/(ph cm^3)]

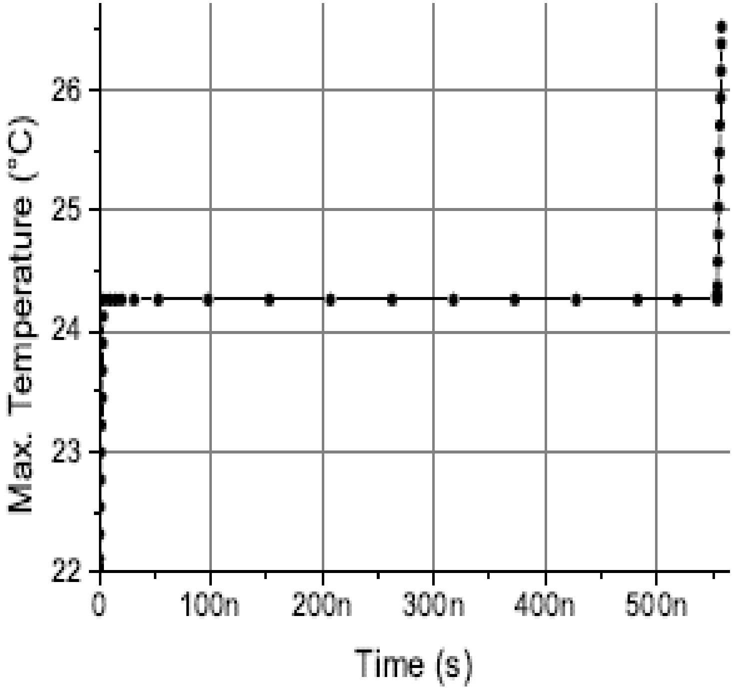


Peak energy deposition by bunch

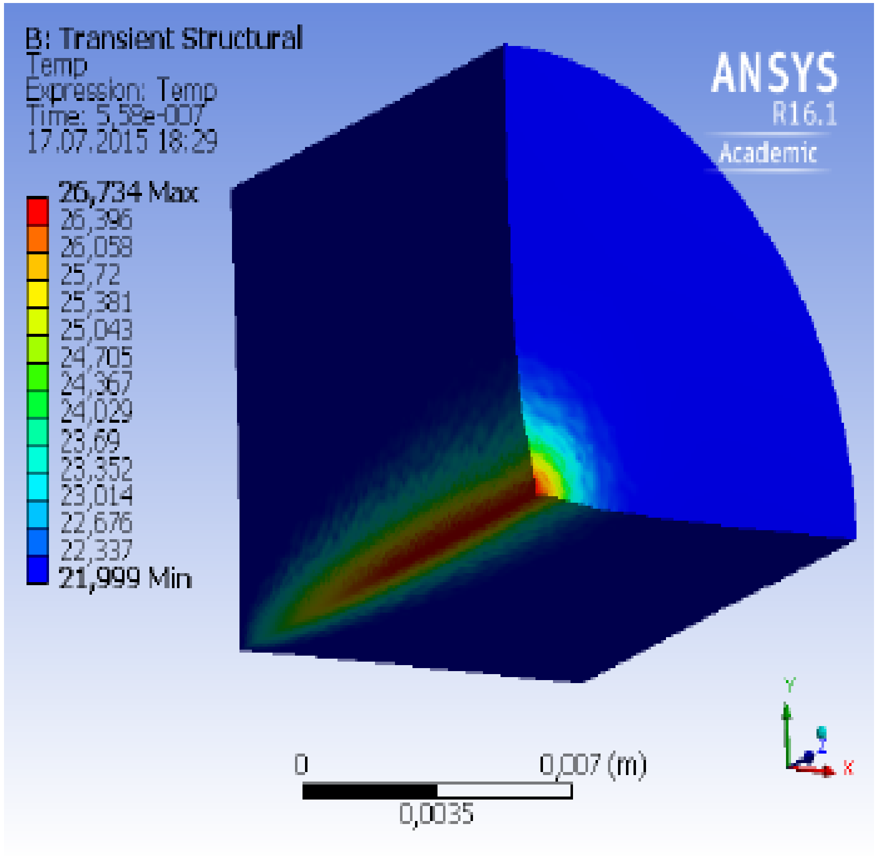




Temperature rise and distribution (ANSYS)



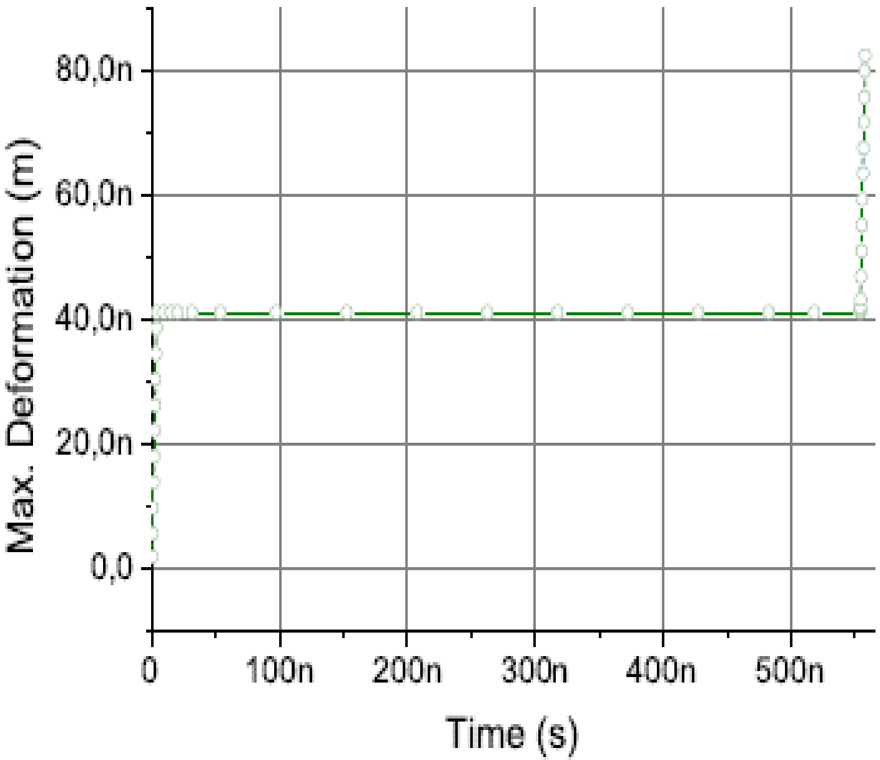
Temperature Rise Induced by First Two Bunches



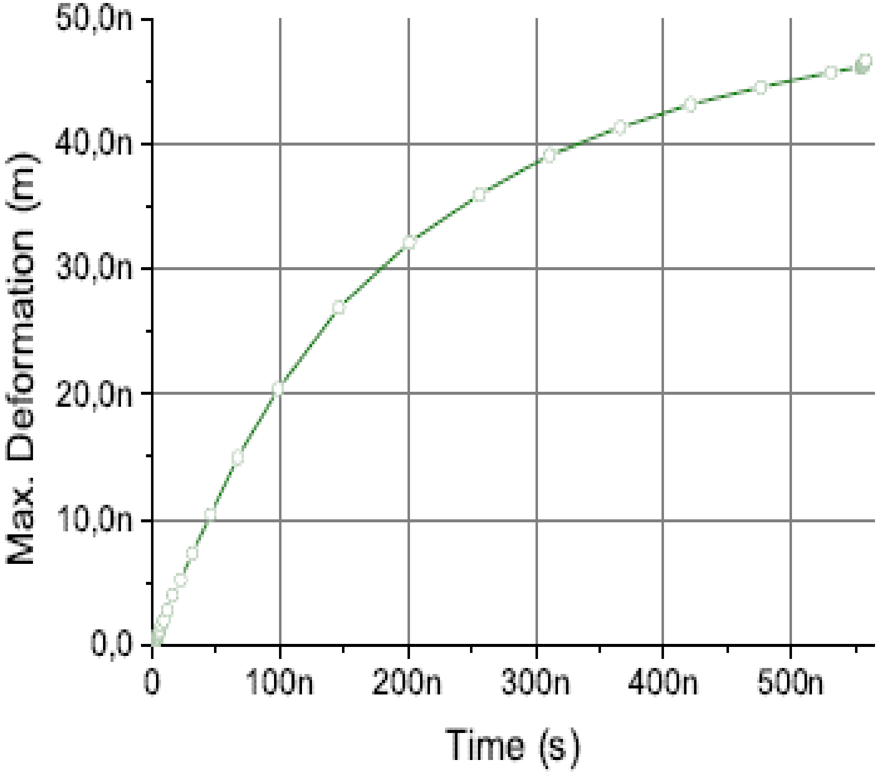
Distribution of Temperature in Target

Time evolution of 'static' and transient deformation

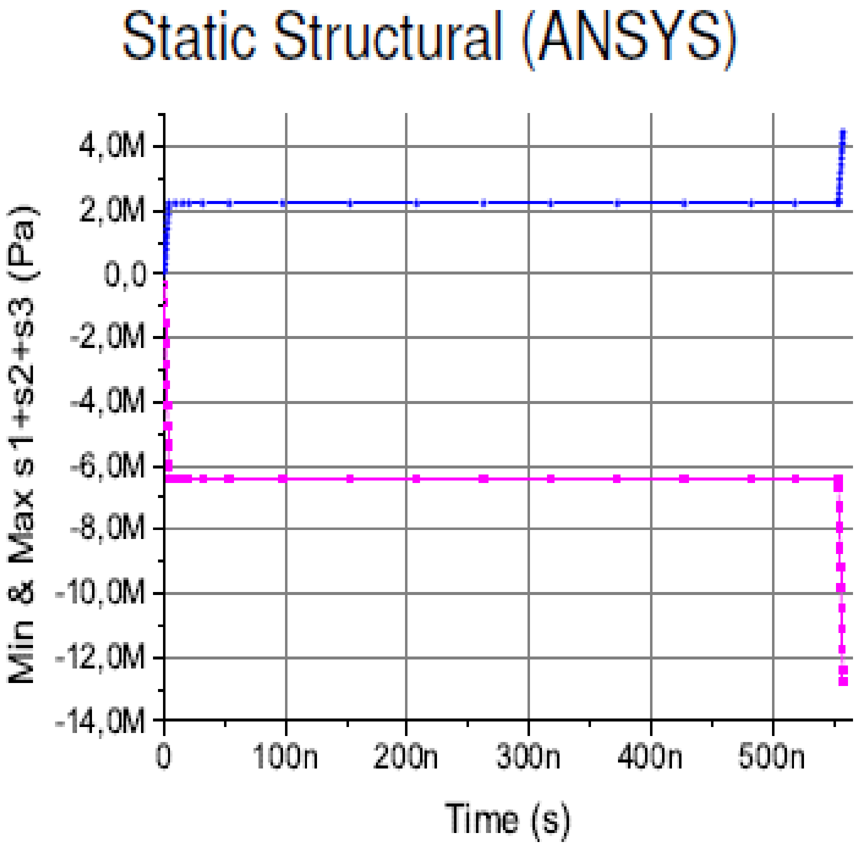
Static Structural (ANSYS)



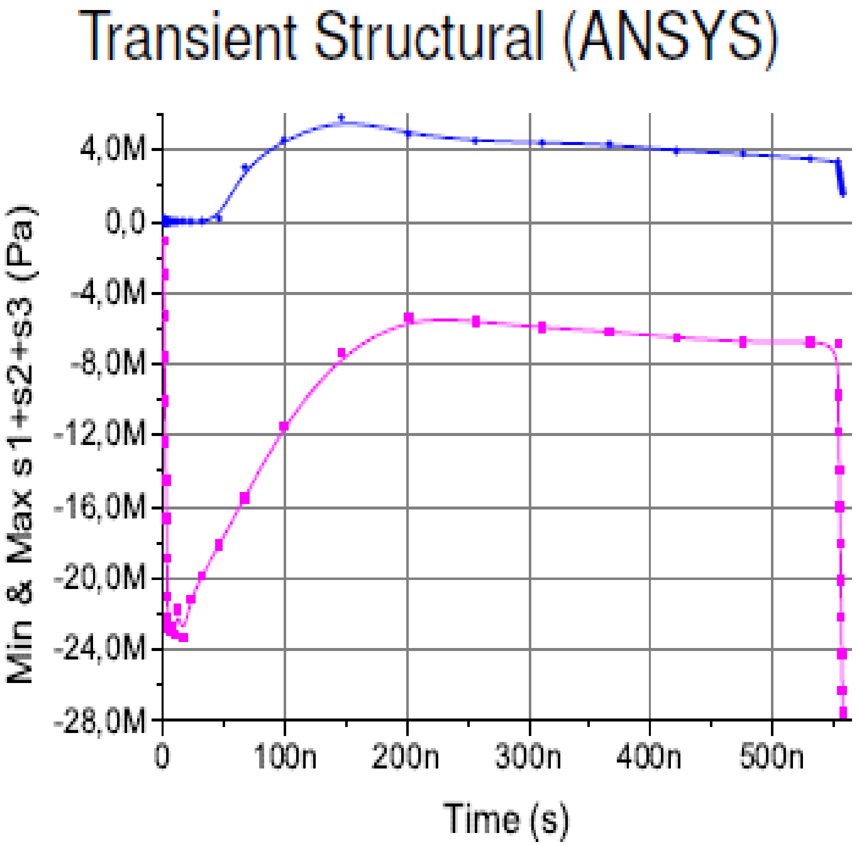
Transient Structural (ANSYS)



Time evolution of 'static' and transient normal stresses (s1+s2+s3)



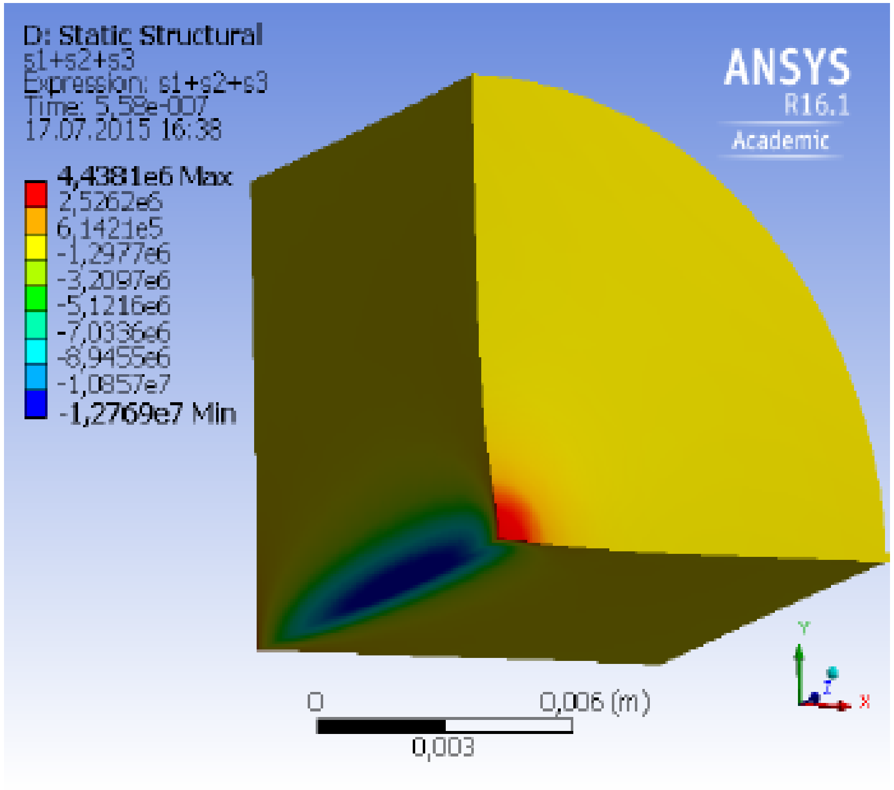
Static Structural (ANSYS)



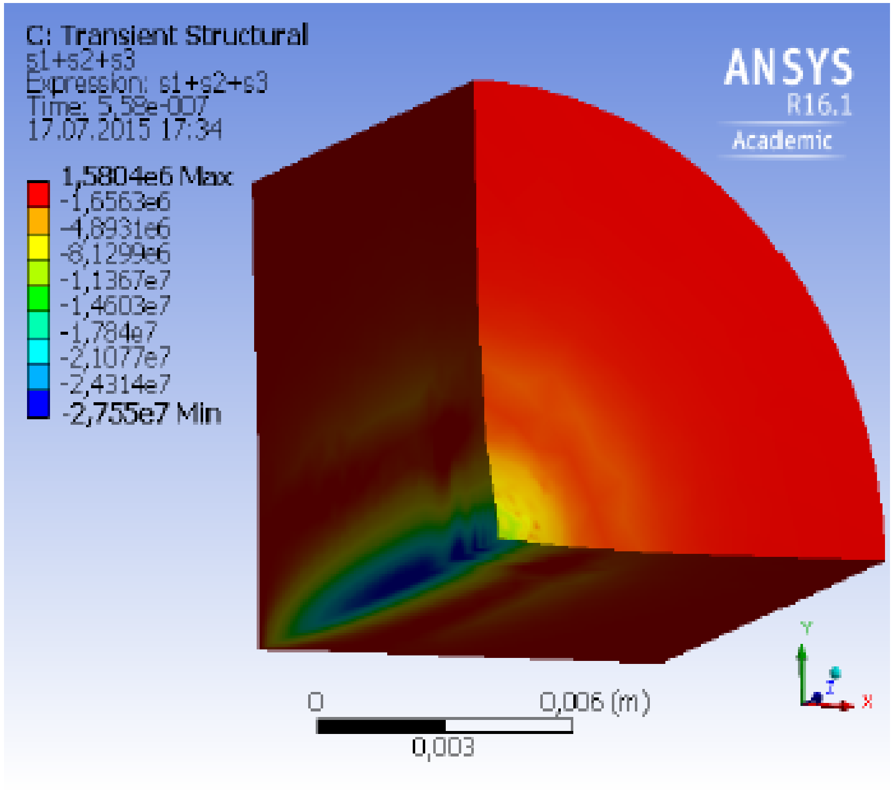
Transient Structural (ANSYS)

Static and transient normal stress after 2^{nd} bunch (s1+s2+s3)

Static Structural (ANSYS)



Transient Structural (ANSYS)

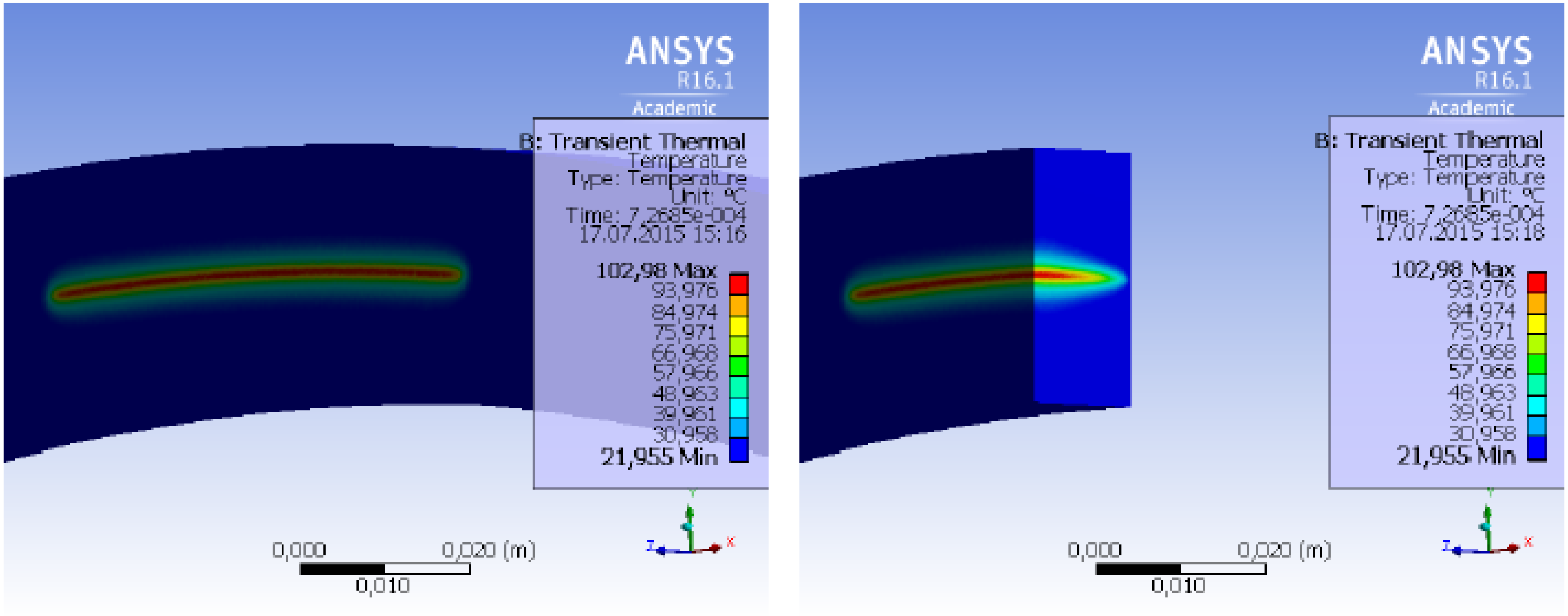


Temperature distribution in rotated target (100 m/s)

t_{pulse} = 0.727 ms; Pulse Length = 7.27 cm

Absorbed Energy = 456 J; Average during Pulse Power = 627 kW

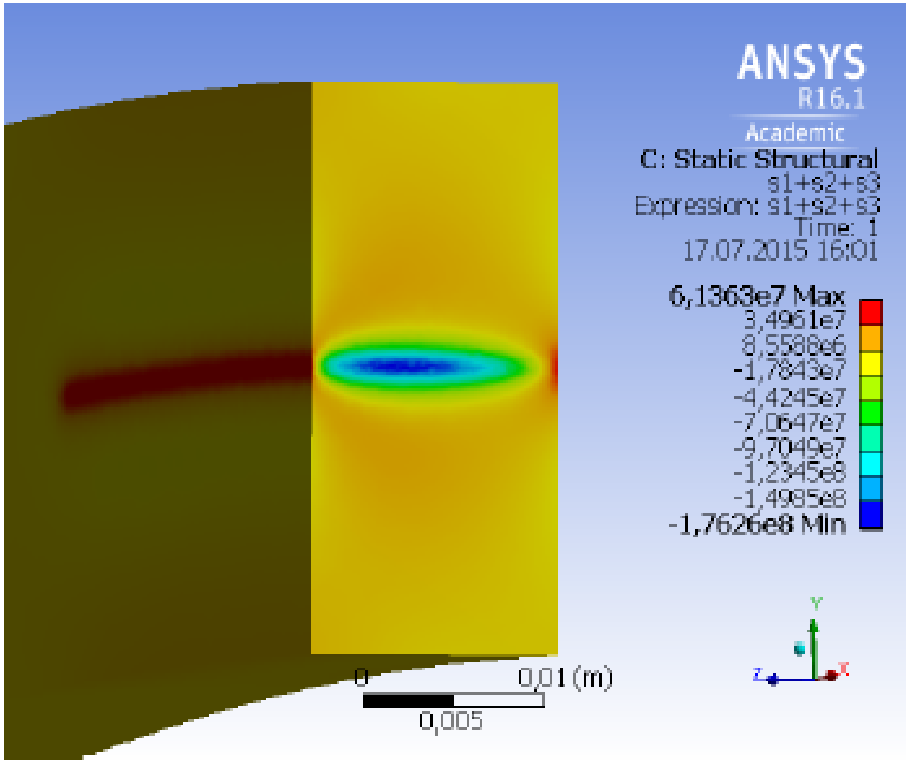
Peak Power Density = 276 kW/cm^3



$\Delta T_{max\ pulse}/\Delta T_{max\ bunch} = 37.8$; $PEDD_{pulse} = 45.3$ J/g

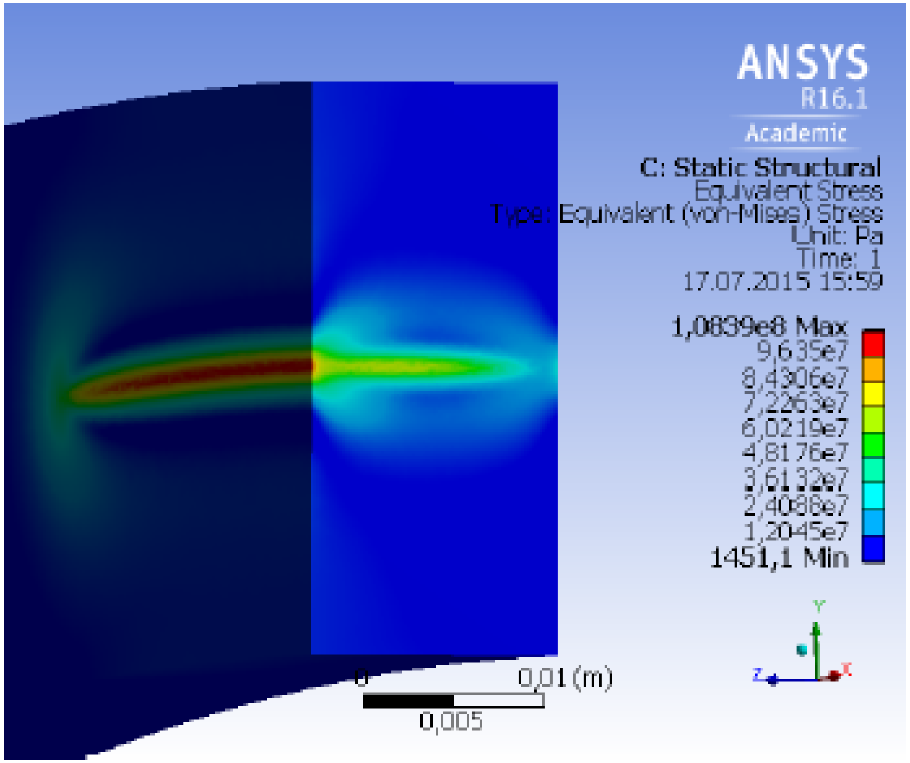
s1+s2+s3 and the equivalent von Mises stress

Sum of Normal Stresses



Maximum: -176 MPa

Equivalent von Mises Stress



Maximum: 108 MPa

- **Fatigue limit: Ti ~ 340 MPa: dynamical stress at acceptable level**

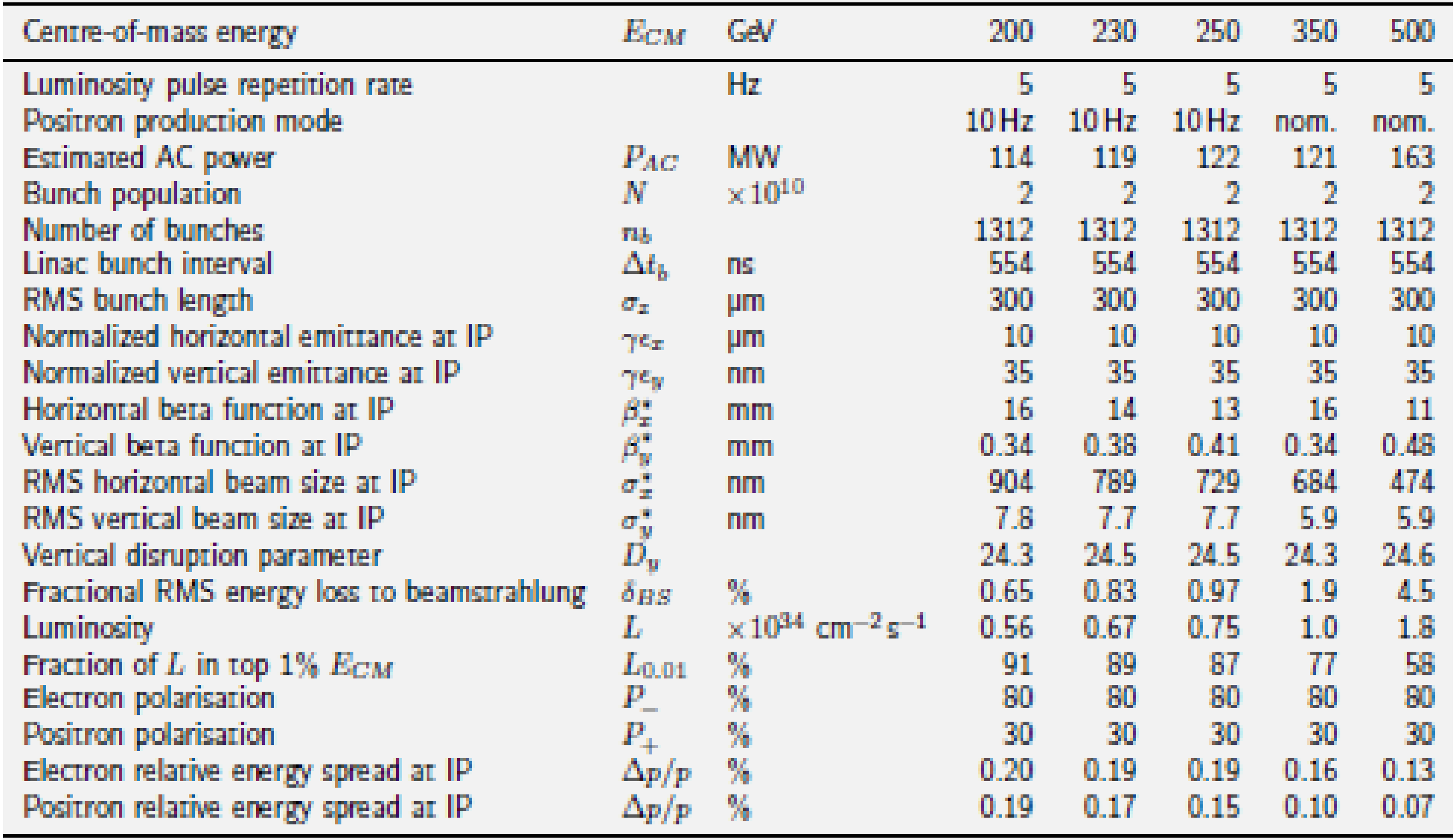
Planned experiment

- Experimental test of material fatigue limit:
  - Use e- beams with high intensity, high currents, reduce beam size and thickness until dE/dV similar to target conditions at the ILC
  - mimic the stress via long (~20µs) electron pulses
  - test different materials and geometries
  - approved at Mainz (Germany) at MAMI and MESA
- MAMI c.w. injector, kW, 1mA at 3.5 MeV
  - with a typical beam spot target-thickness scale is 1/10mm (can be reduced to 10µm)
  - due to c.w. capability -> high rep. rate -> ‘artificial aging
  - first beam time: this year
- MESA: preacc. runs with 5-8MW, 10mA at 5-14 MeV
  - Starts 2017

Conclusions

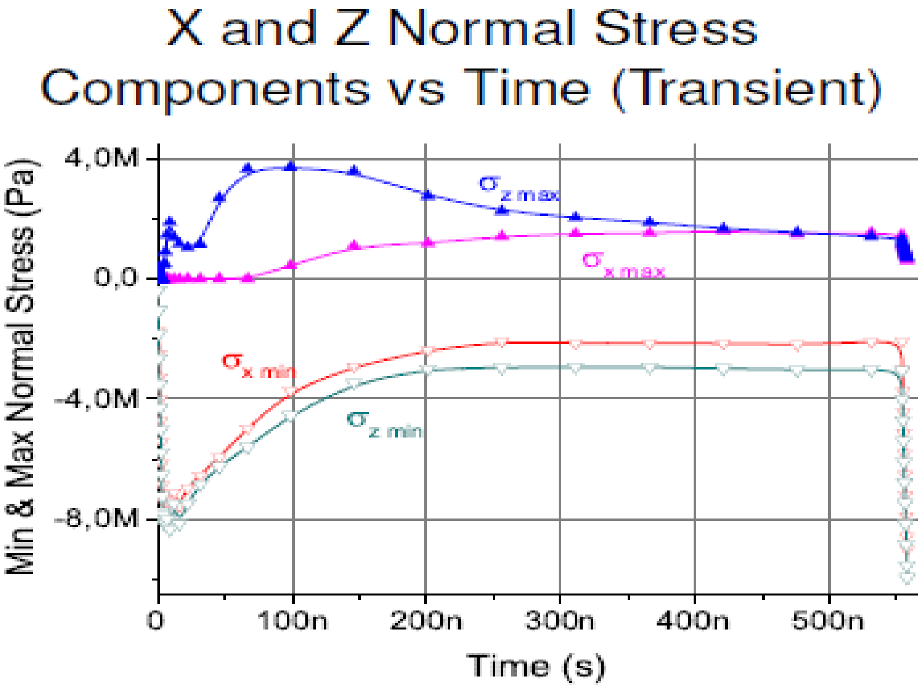
- Baseline LC Positron source well designed, mature level
  - high polarization and luminosity at all different energy stages
- Still target issues (relevant for all LC designs)
  - Bunch-by-bunch simulations of thermal stress induced by photon beam in Ti-alloy target
  - Simulations (still under work) shows that fatigue limit will not be reached
  - Real target geometry and sound wave reflections have to be included
  - Not shown here in detail: backup with analytical calculation done!
- Target tests at MAMI / MESA approved
  - Test fatigue limit of different target materials
  - Starts 2015

ILC Parameters



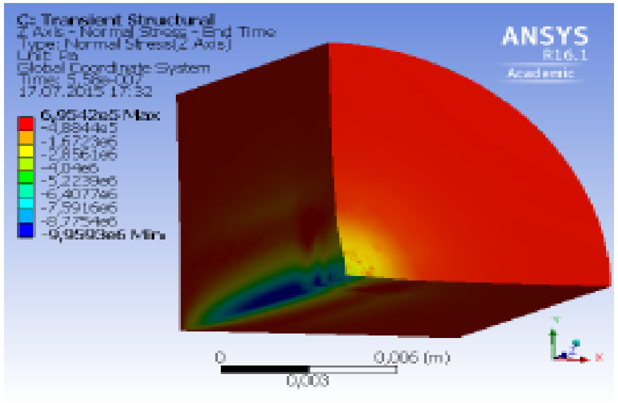
Centre-of-mass energy	E_{CM}	GeV	200	230	250	350	500
Luminosity pulse repetition rate		Hz	5	5	5	5	5
Positron production mode			10 Hz	10 Hz	10 Hz	nom.	nom.
Estimated AC power	P_{AC}	MW	114	119	122	121	163
Bunch population	N	$\times 10^{10}$	2	2	2	2	2
Number of bunches	n_b		1312	1312	1312	1312	1312
Linac bunch interval	Δt_b	ns	554	554	554	554	554
RMS bunch length	σ_z	µm	300	300	300	300	300
Normalized horizontal emittance at IP	$\gamma\epsilon_x$	µm	10	10	10	10	10
Normalized vertical emittance at IP	$\gamma\epsilon_y$	nm	35	35	35	35	35
Horizontal beta function at IP	β_x^*	mm	16	14	13	16	11
Vertical beta function at IP	β_y^*	mm	0.34	0.38	0.41	0.34	0.48
RMS horizontal beam size at IP	σ_x^*	nm	904	789	729	684	474
RMS vertical beam size at IP	σ_y^*	nm	7.8	7.7	7.7	5.9	5.9
Vertical disruption parameter	D_y		24.3	24.5	24.5	24.3	24.6
Fractional RMS energy loss to beamstrahlung	δ_{BS}	%	0.65	0.83	0.97	1.9	4.5
Luminosity	L	$\times 10^{34}$ cm^{-2}s^{-1}	0.56	0.67	0.75	1.0	1.8
Fraction of L in top 1% E_{CM}	$L_{0.01}$	%	91	89	87	77	58
Electron polarisation	P_-	%	80	80	80	80	80
Positron polarisation	P_+	%	30	30	30	30	30
Electron relative energy spread at IP	$\Delta p/p$	%	0.20	0.19	0.19	0.16	0.13
Positron relative energy spread at IP	$\Delta p/p$	%	0.19	0.17	0.15	0.10	0.07

Longitudinal σ_z and transversal σ_x stress components

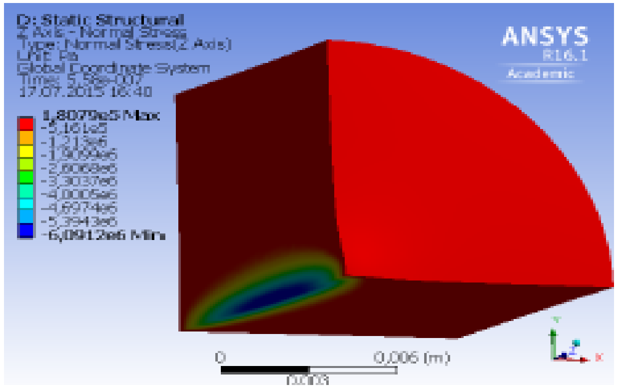


σ_Z after 2nd Bunch

Transient

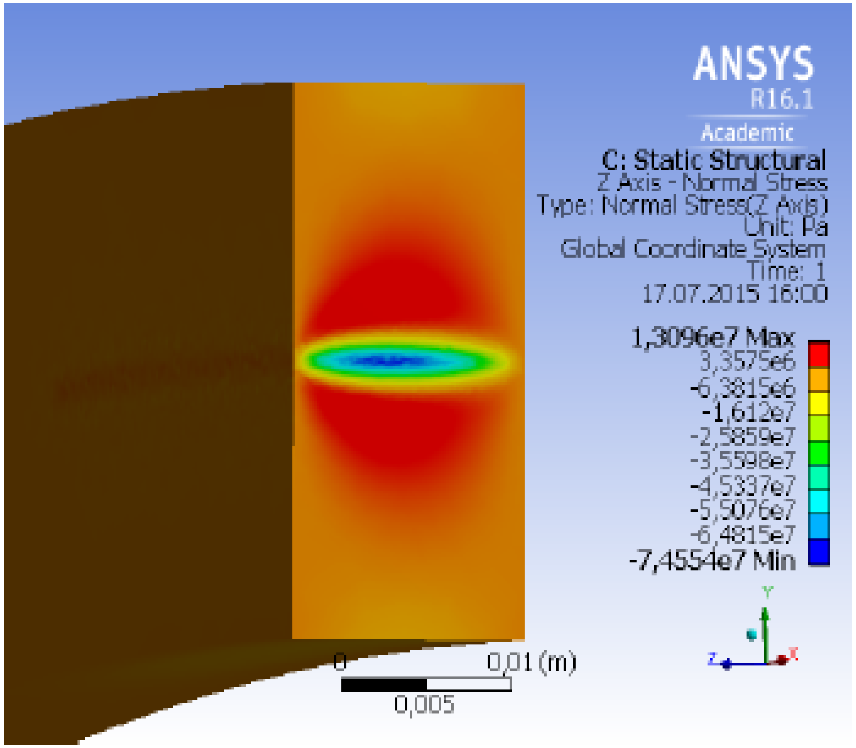


“Static”

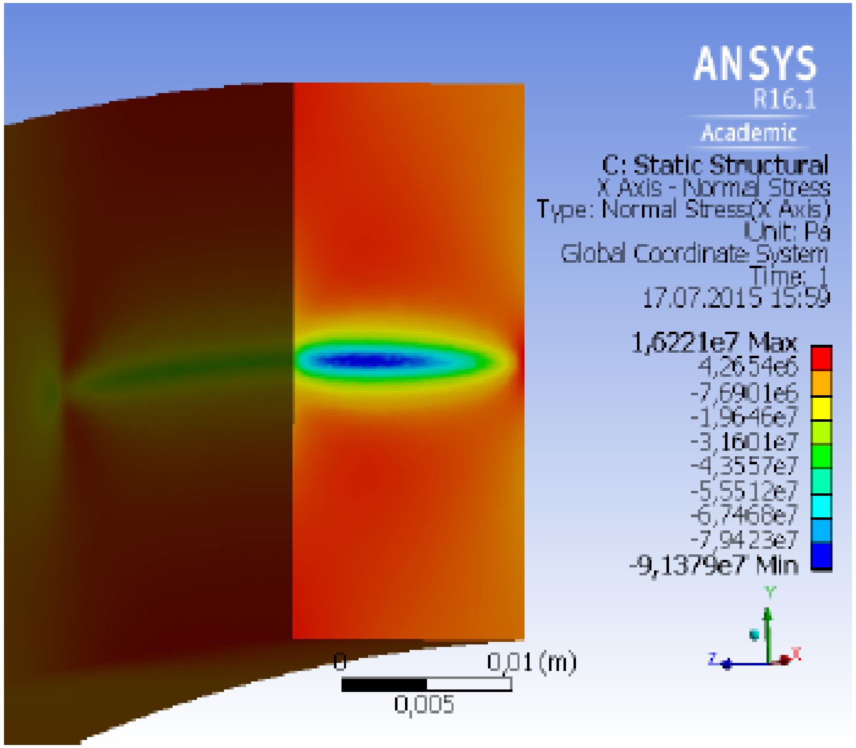


Longitudinal and transversal stress components (static)

Normal Stress Component (Z Axis)



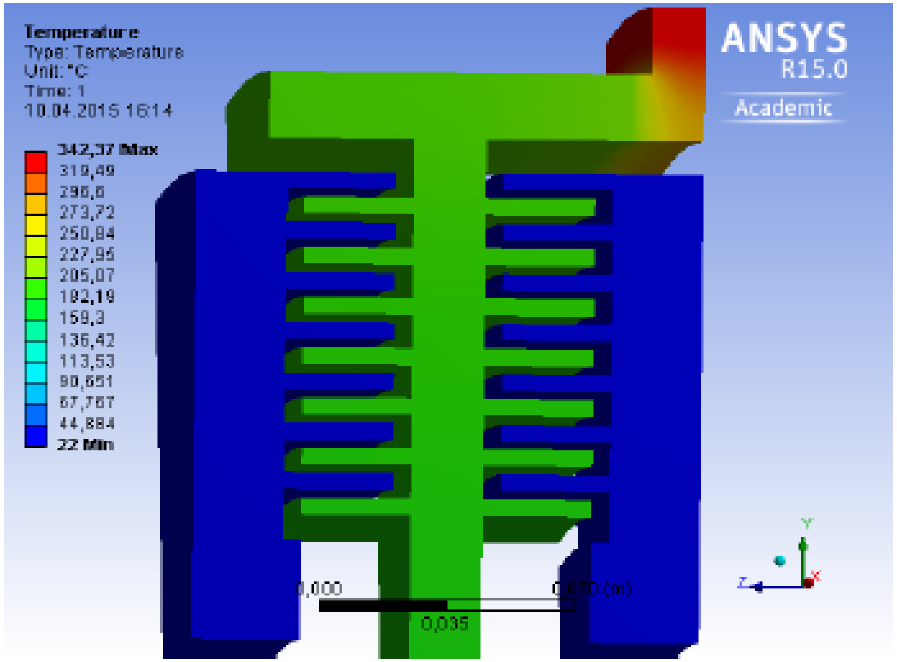
Normal Stress Component (X Axis)



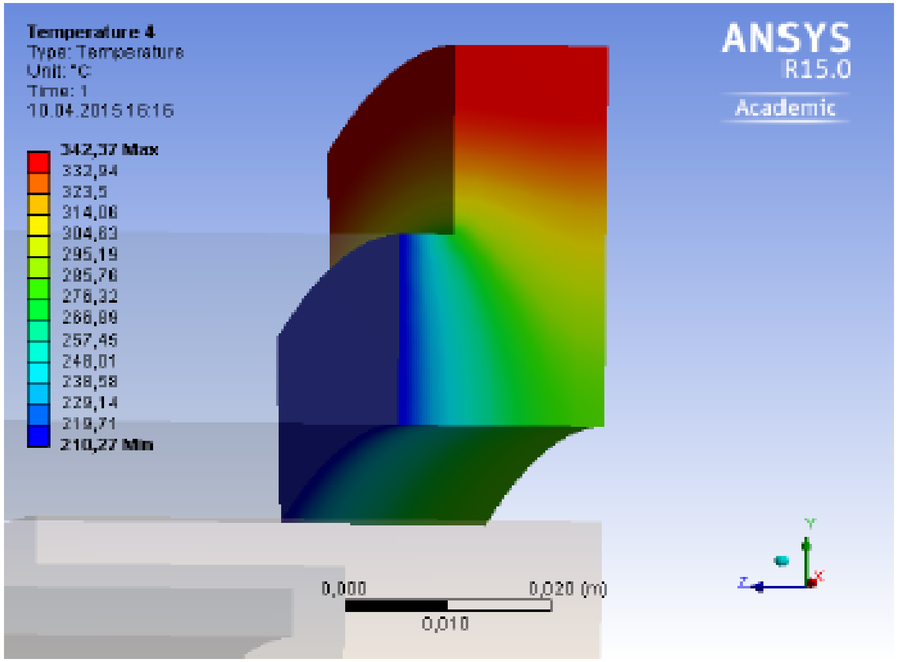
Equilibrium (background) temperature in radiative cooled target

Static (equilibrium) simulation was done for 120 GeV e^- beam and for initial target design proposed by Peter Sievers.
Currently, Felix is optimizing the design to reduce the peak temperature in Ti part.

All Parts of Target System

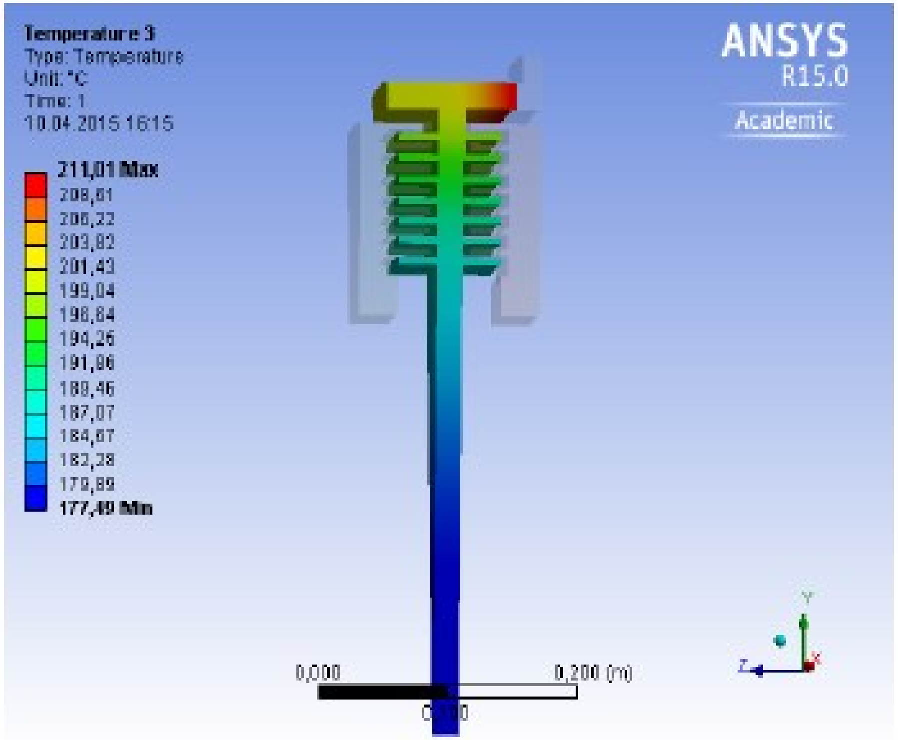


Ti Target

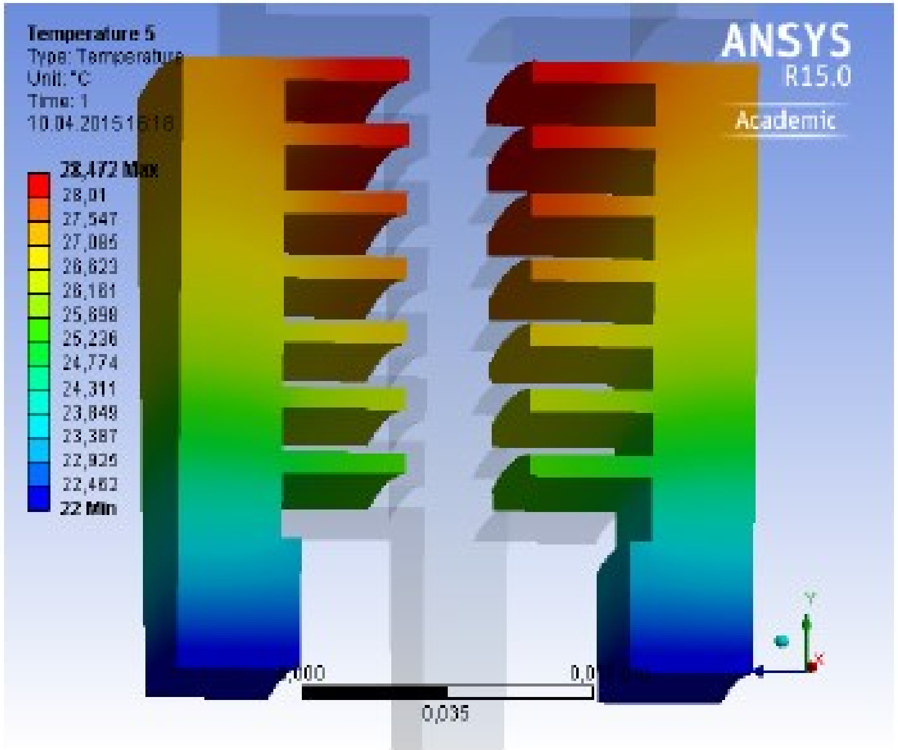


Radiative Cooling, cont.

Cu Radiator



Cu Coolers



Bottom surface of coolers have fixed temperature (22 °C) in that way water cooling has been emulated.