Report from the Positron WS (Daresbury)

Sabine Riemann, DESY

- Polarised Positrons
- Operational Aspects

Polarised Positrons

- **Why ?**

  Gudi Moortgat-Pick: Why are polarised positrons essential for physics?

- **How ?**

  Alexander Mikhailichenko: Experience gained from the pulsed undulator for E166 for the ILC

  Yuri Ivanyushenkov: Development of a superconducting helical undulator for a polarised positron source

  Klaus Moenig: A laser cavity for polarised positron production

  Fabian Zomer: High finesse Fabry-Perot cavity for a pulsed laser

- **Polarimetry**

  Peter Schueler: Polarimetry of polarised positrons

  Masao Kuriki: Polarised e+ generation and measurement at KEK

Gudi: The physics case for having both beams polarized

- **P_{e+}** ➔ only gains, independent in which direction (new) physics points
- **P_{e+}** crucial preparation for being prepared for the Unexpected
- many examples and arguments: **Polarization report**:

'POWER Write-Up'

(Polarization at Work in Energetic Reactions)

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IPPP-04-50
SHEP-05-03
SLAC-PUB-11087

Final Draft

Revealing fundamental interactions: the rôle of polarized positrons and electrons at the Linear Collider[*]

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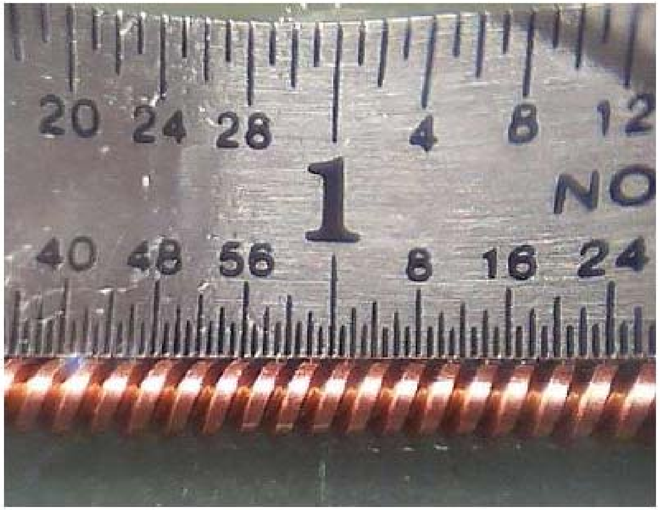
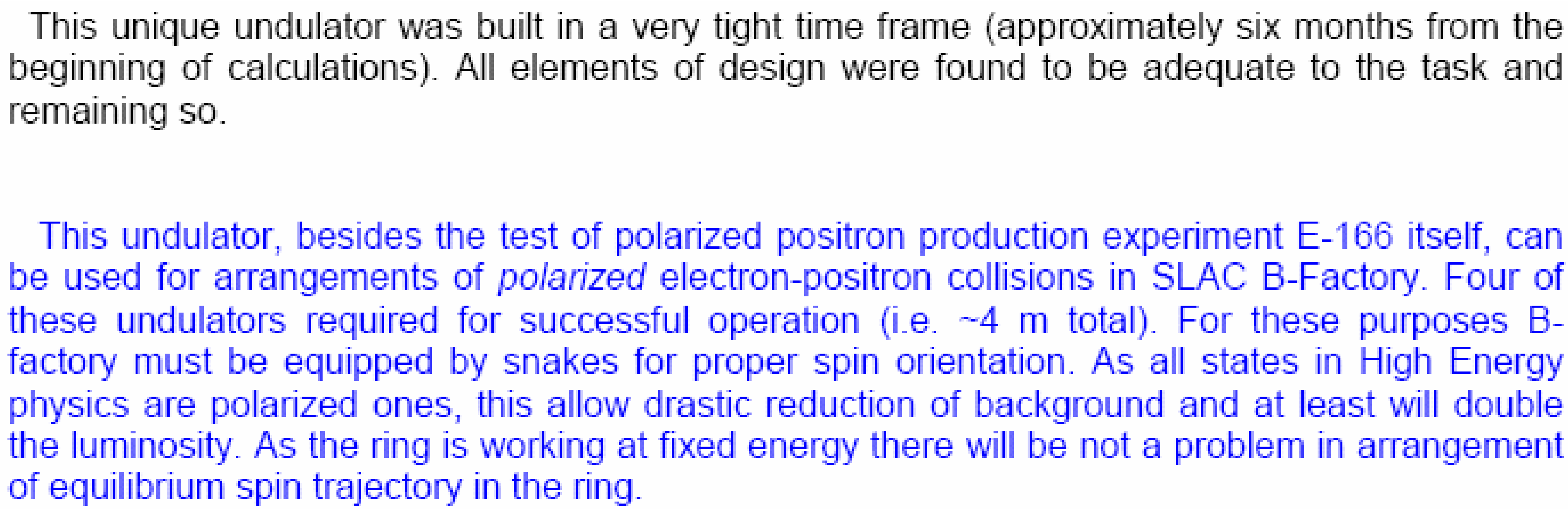
A. Mikhailichenko: Pulsed micro-undulator for E166 for the ILC

Helical undulator,
~2.5mm period

- Manufactured at Cornell for polarised e+ at SLAC
- at 2.3 kA K~0.2 is reached, operated at 30 Hz
- design, manufacturing, tests are described



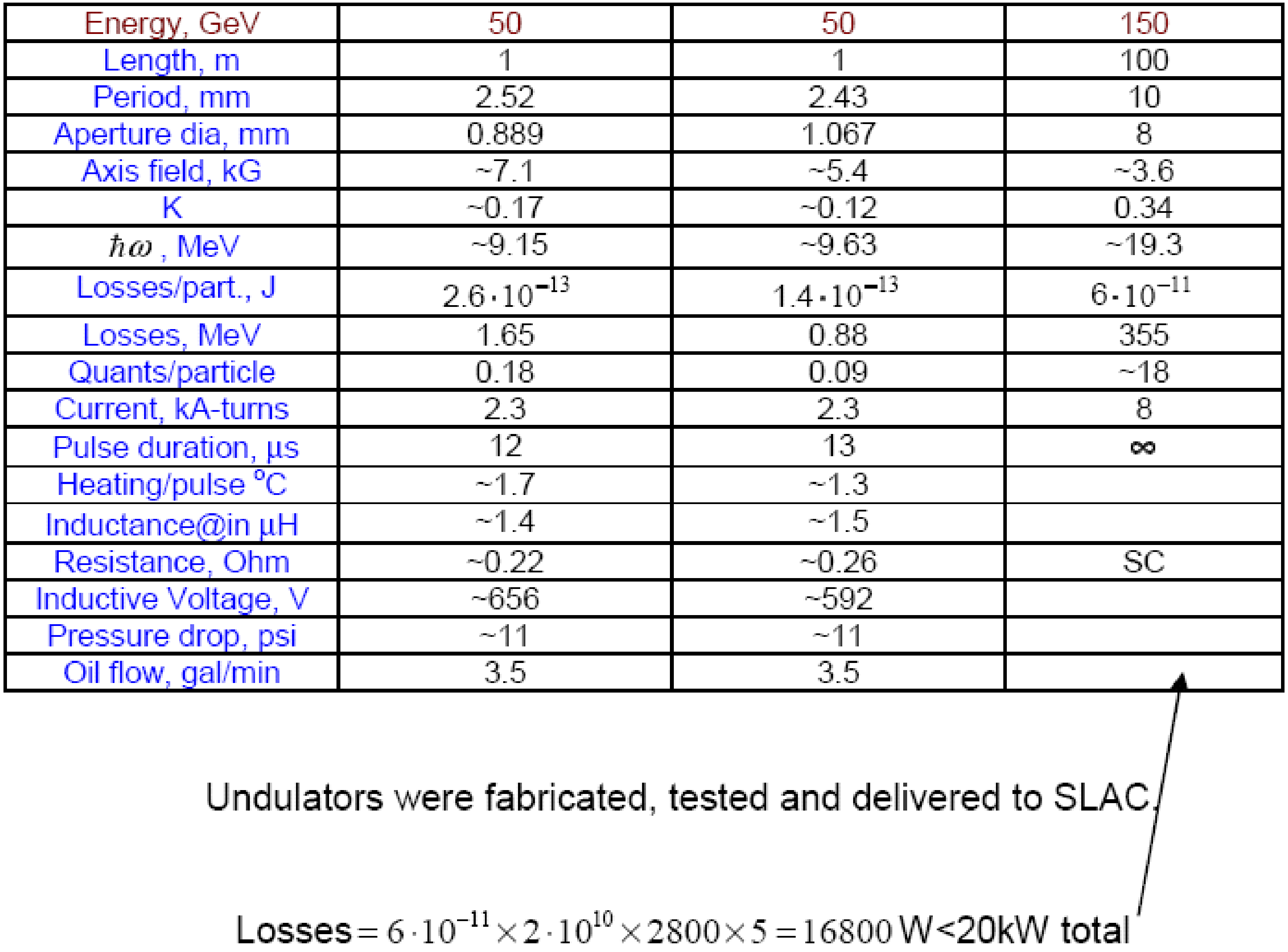
Windings enlarged. Scale in minimal division is 1/64 of an inch.



This unique undulator was built in a very tight time frame (approximately six months from the beginning of calculations). All elements of design were found to be adequate to the task and remaining so.

This undulator, besides the test of polarized positron production experiment E-166 itself, can be used for arrangements of *polarized* electron-positron collisions in SLAC B-Factory. Four of these undulators required for successful operation (i.e. ~4 m total). For these purposes B-factory must be equipped by snakes for proper spin orientation. As all states in High Energy physics are polarized ones, this allow drastic reduction of background and at least will double the luminosity. As the ring is working at fixed energy there will be not a problem in arrangement of equilibrium spin trajectory in the ring.

A. Mikhailichenko: Undulator parameter



Energy, GeV	50	50	150
Length, m	1	1	100
Period, mm	2.52	2.43	10
Aperture dia, mm	0.889	1.067	8
Axis field, kG	~7.1	~5.4	~3.6
K	~0.17	~0.12	0.34
$\hbar\omega$, MeV	~9.15	~9.63	~19.3
Losses/part., J	$2.6\cdot10^{-13}$	$1.4\cdot10^{-13}$	$6\cdot10^{-11}$
Losses, MeV	1.65	0.88	355
Quants/particle	0.18	0.09	~18
Current, kA-turns	2.3	2.3	8
Pulse duration, µs	12	13	∞
Heating/pulse °C	~1.7	~1.3	
Inductance@in µH	~1.4	~1.5	
Resistance, Ohm	~0.22	~0.26	SC
Inductive Voltage, V	~656	~592	
Pressure drop, psi	~11	~11	
Oil flow, gal/min	3.5	3.5	

Undulators were fabricated, tested and delivered to SLAC.

Losses $= 6\cdot10^{-11}\times2\cdot10^{10}\times2800\times5=16800$ W<20kW total

Yuri Ivanyushenkov: Development of a superconducting undulator for a polarised positron source

Specification:

Pitch:	14 mm
Bore:	4 mm
Field on axis:	0.85 T
Geometry:	bi-conductor helical
Technology:	superconducting
Prototype length:	20 periods

→ produce 20 MeV photons

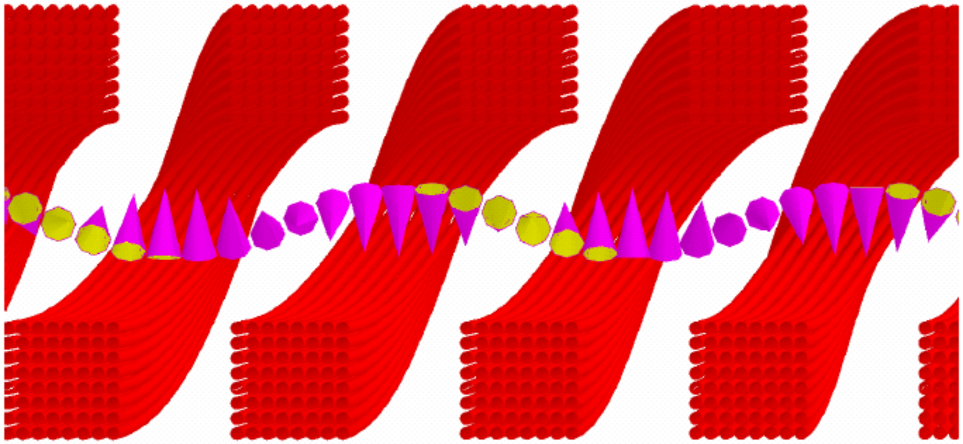
Magnetic modelling

Include iron between windings

→Field on axis increases by 40%

→Reduce winding current and sc margin for given field

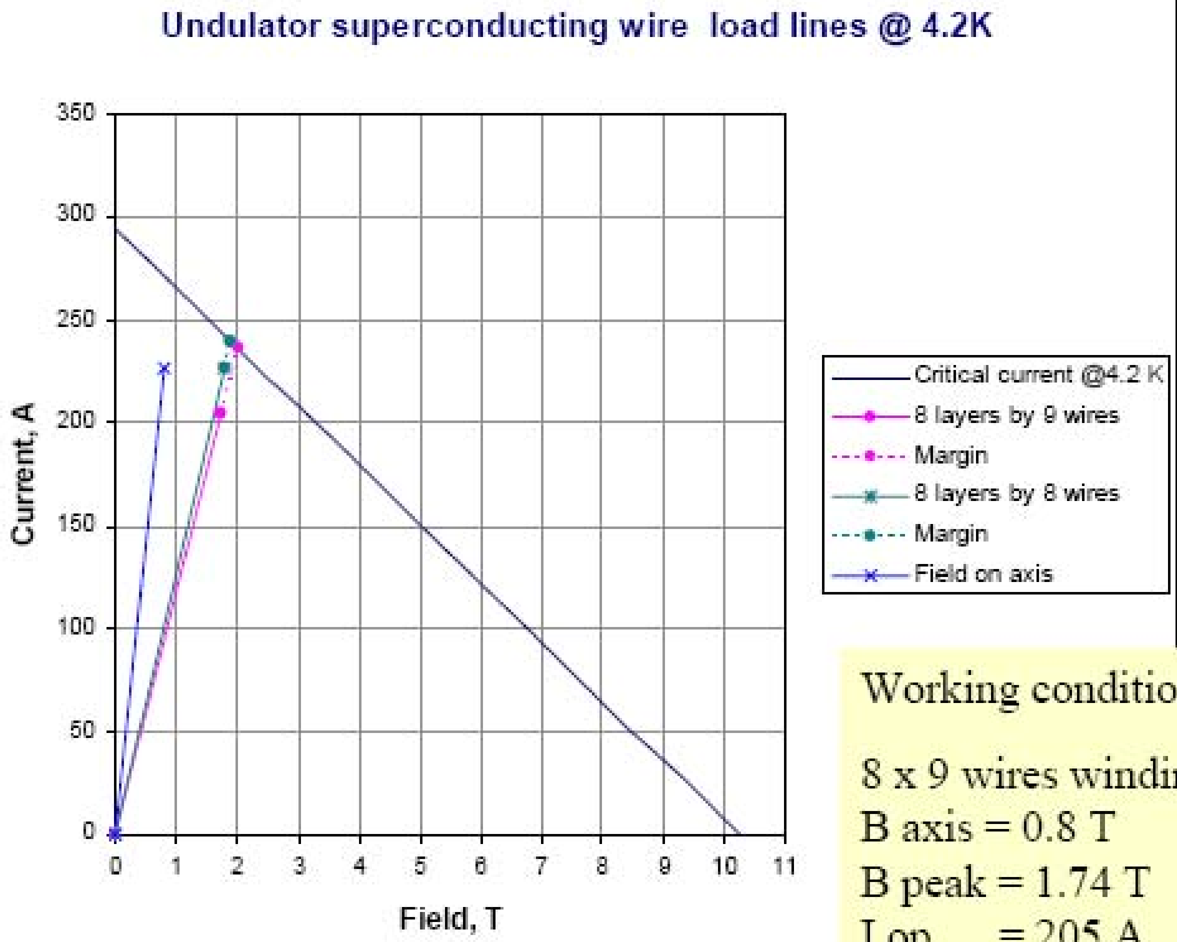
Multi-wire winding model in Opera 3d



Model parameters:
dimensions and positions of individual wires;
wire current

VECTOR FIELDS

Y. Ivanyushenkov: SC wire selection



Wire:
VACRYFLUX 5001
Type F54-1.35

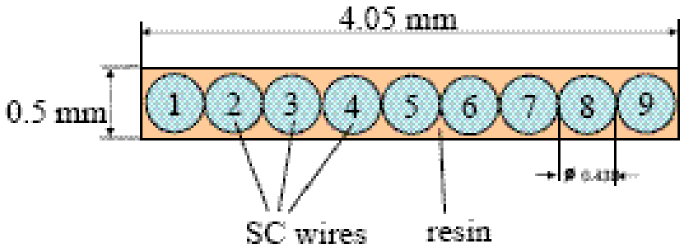
Consists of	54 NbTi filaments in Cu-matrix;
Ratio Cu:NbTi	1.35 : 1
Bare diameter	0.4 mm
Insulated diameter	0.438 mm
Critical currents	151 A @ 5T 36 A @ 9T

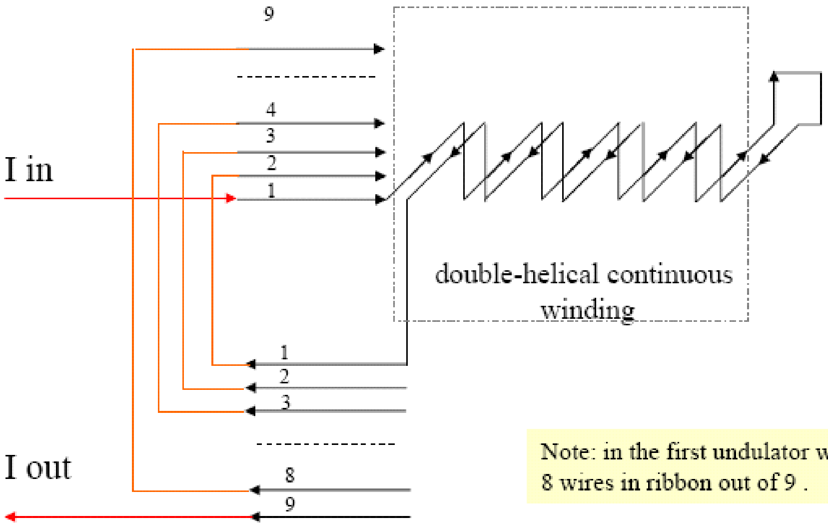
Working conditions:

8 x 9 wires winding:	8 x 8 wires winding:
B axis = 0.8 T	B axis = 0.8 T
B peak = 1.74 T	B peak = 1.8 T
I op = 205 A	I op = 226.5 A
86 % of Ic	94 % of Ic

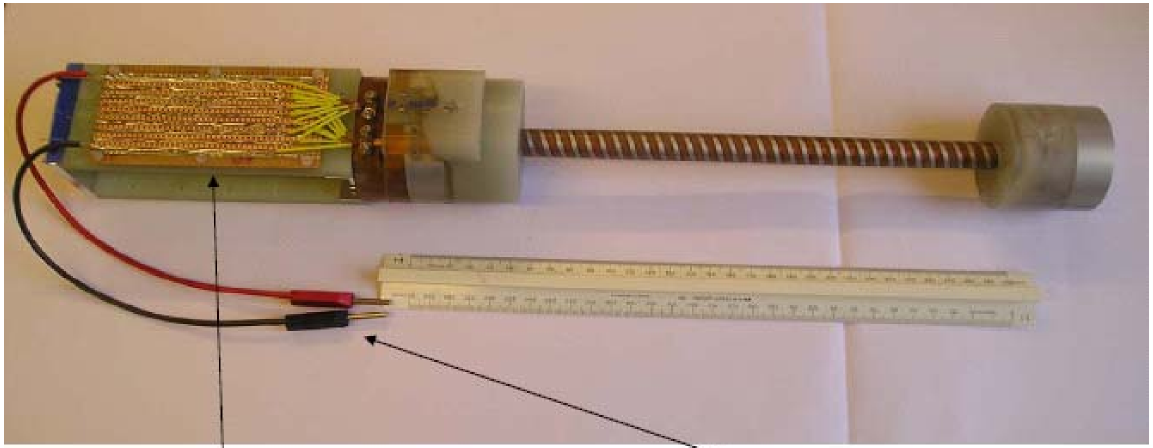
Y. Ivanyushenkov: Prototype fabrication

-> only 1 power supply with 205 A working current is required.





Note: in the first undulator we are using 8 wires in ribbon out of 9 .

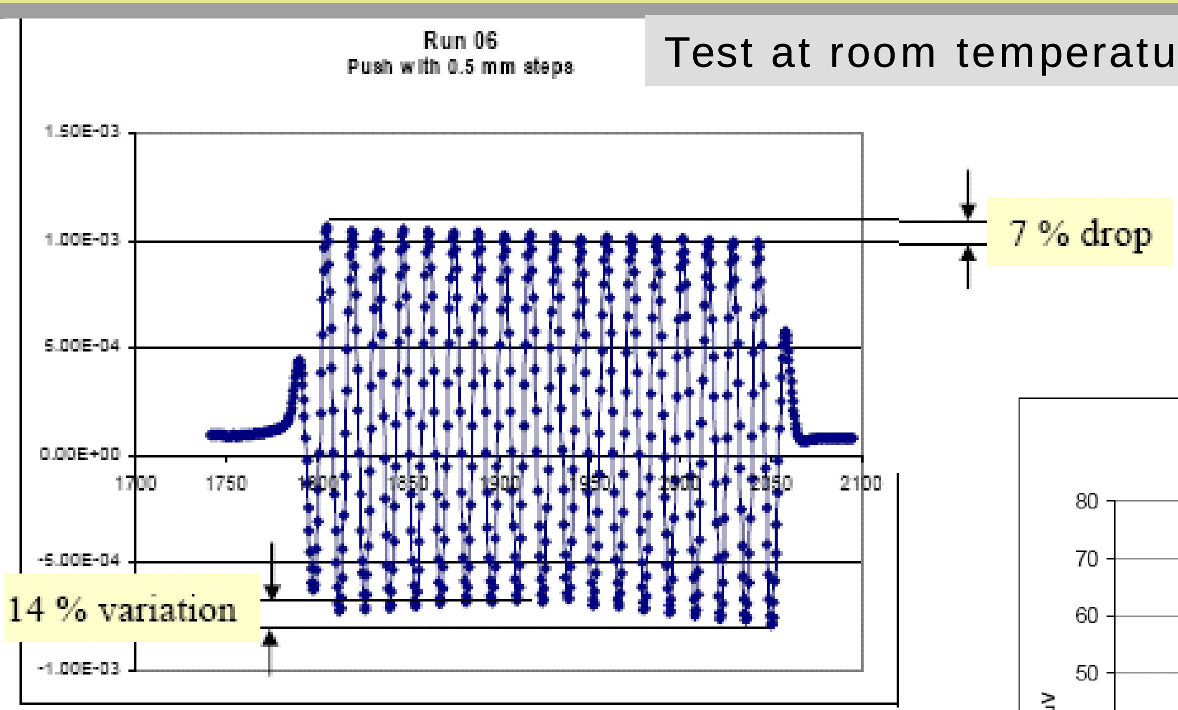


Wiring plate

Current leads for room temperature test

Y. Ivanyushenkov: Prototyp tests

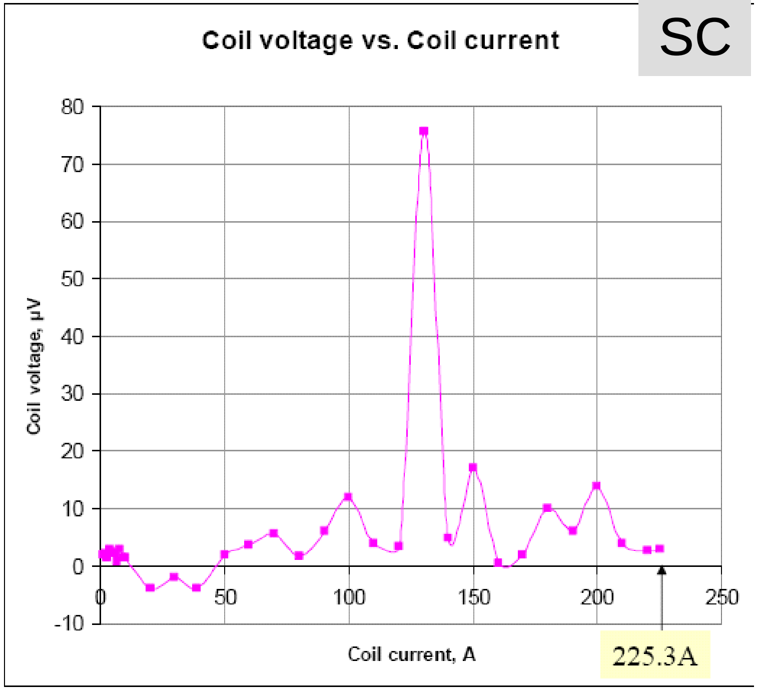
Test at room temperature



Undulator current = 0.7 A

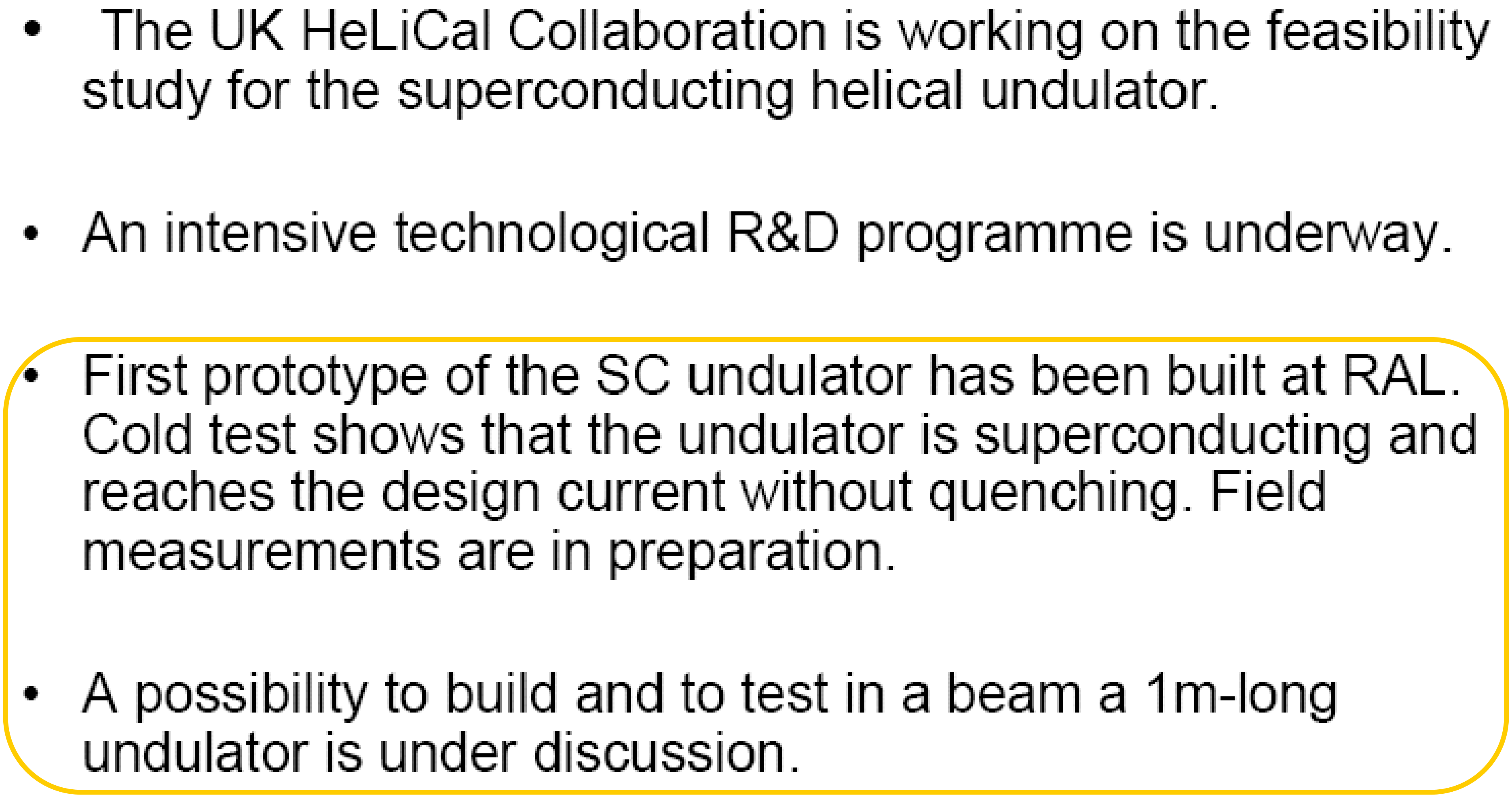
Average positive field = 27 gauss
Average negative field = 24 gauss

SC



Conclusion:
Undulator is superconducting !

Y. Ivanyushenkov: Summary



- The UK HeLiCal Collaboration is working on the feasibility study for the superconducting helical undulator.
- An intensive technological R&D programme is underway.
- First prototype of the SC undulator has been built at RAL. Cold test shows that the undulator is superconducting and reaches the design current without quenching. Field measurements are in preparation.
- A possibility to build and to test in a beam a 1m-long undulator is under discussion.

K. Moenig: A laser cavity for polarized positron production?

Up to now two ideas to produce polarised positrons

1. helical undulator in the high energy beam
2. Compton scattering of a low energy electron beam with a CO_2 laser

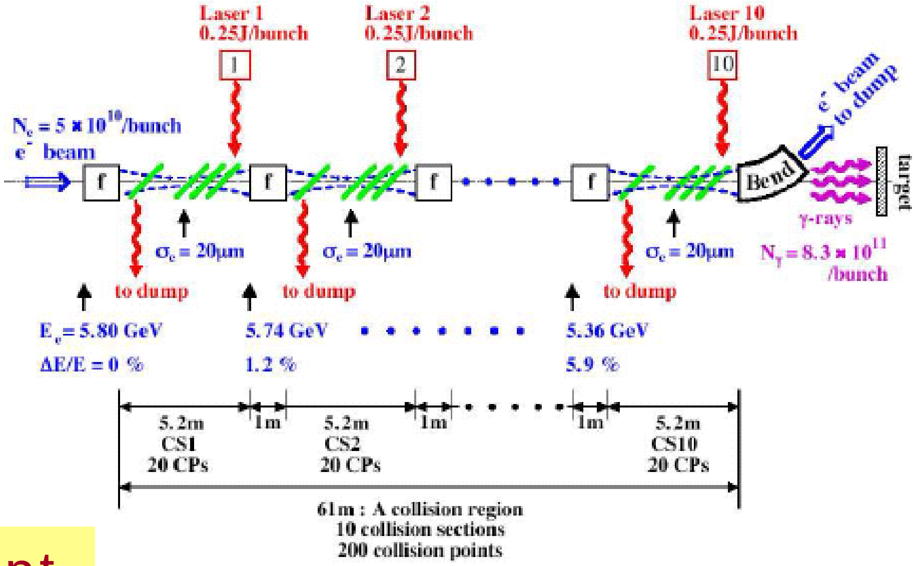
Both schemes produce polarised photons which are converted into polarised positrons in a thin target

Advantage undulator

- seems technically easier
- small power cost

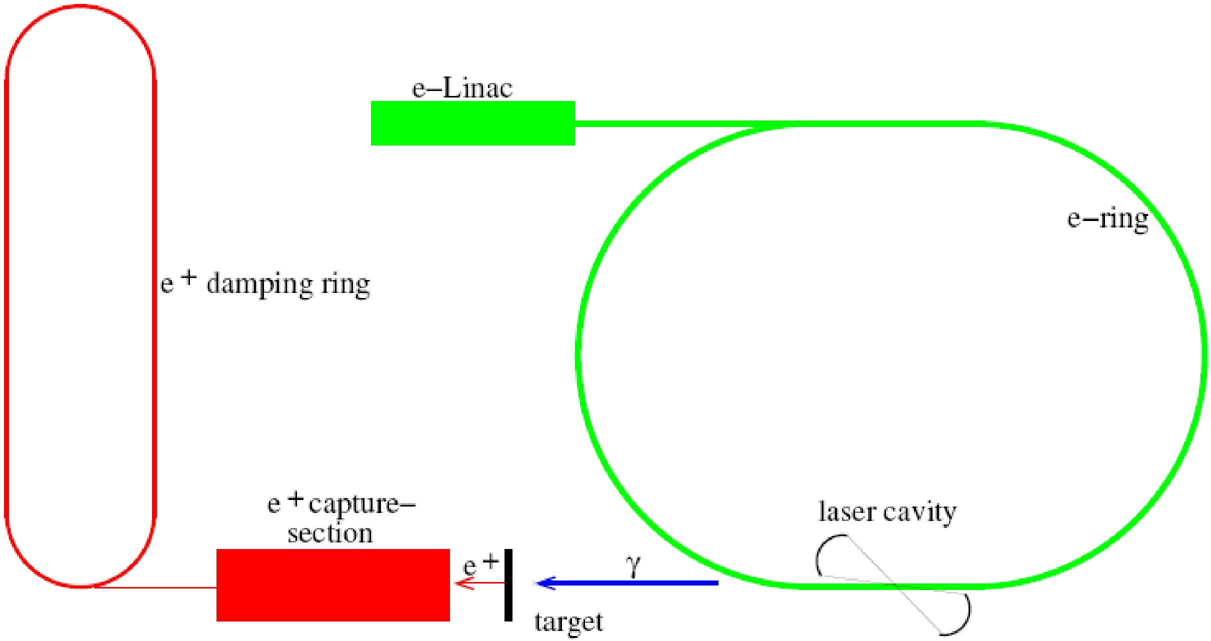
Advantage Compton scattering

- independent of electron arm
- no additional energy spread



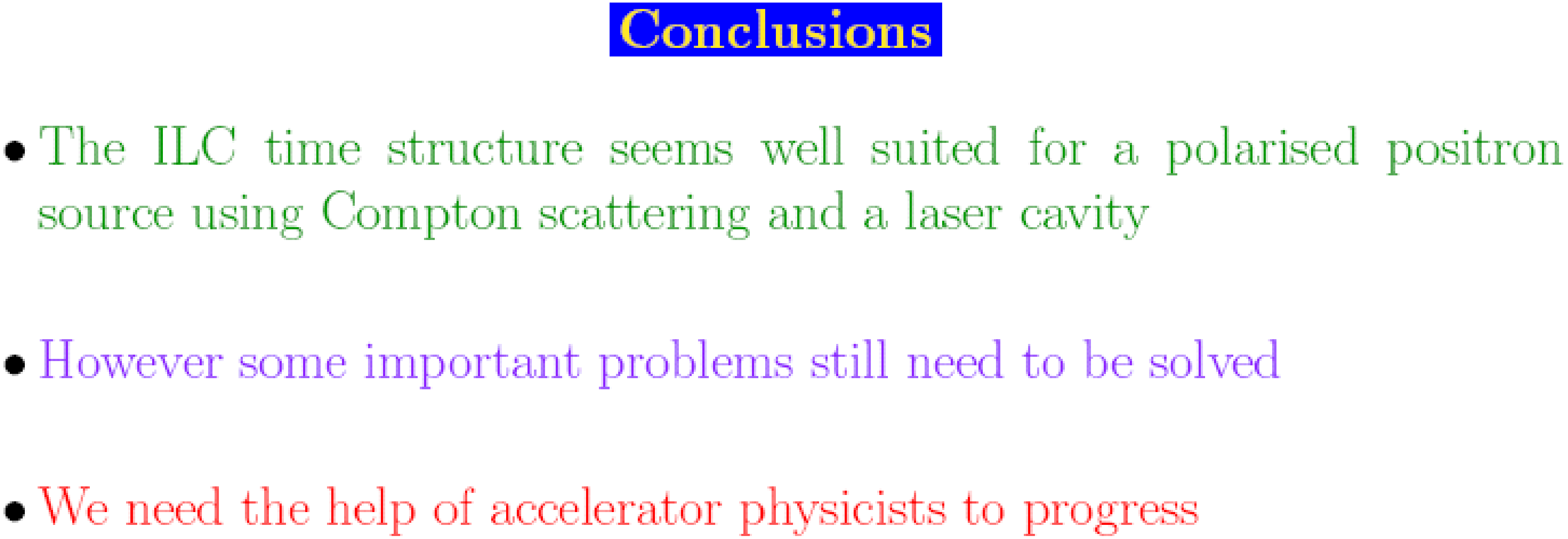
→ Improve the Compton concept

- In the damping ring the e^+ are stored with a much smaller distance than the ILC bunch spacing
  (Assume 3 ns as proposed by KEK study)
  $\Rightarrow$ can use this bunch spacing for positron production
- Propose to store the electrons in a storage ring with this bunch spacing
- Collide them in one (or few) points with a laser cavity
  - Use Nd:Yag or similar laser ($\lambda = 1.06\mu$m)
  - 10 times smaller luminosity than CO_2 laser for same parameters
  - however much easier to build a cavity and smaller spotsizes possible
  - at KEK a prototype with 5μm spotsize and 3° crossing angle will be built (J. Urakawa)



Problems with this scheme:

- How long can we keep the scattered electrons in the ring?
- Can we fill the positron damping ring in this mode?
- What about radiation damage on the mirrors?



Conclusions

- The ILC time structure seems well suited for a polarised positron source using Compton scattering and a laser cavity
- However some important problems still need to be solved
- We need the help of accelerator physicists to progress

Fabian Zomer: Fabry-Perot cavity & pulsed laser

Klaus's talk:

LASER: 1ps pulsed with

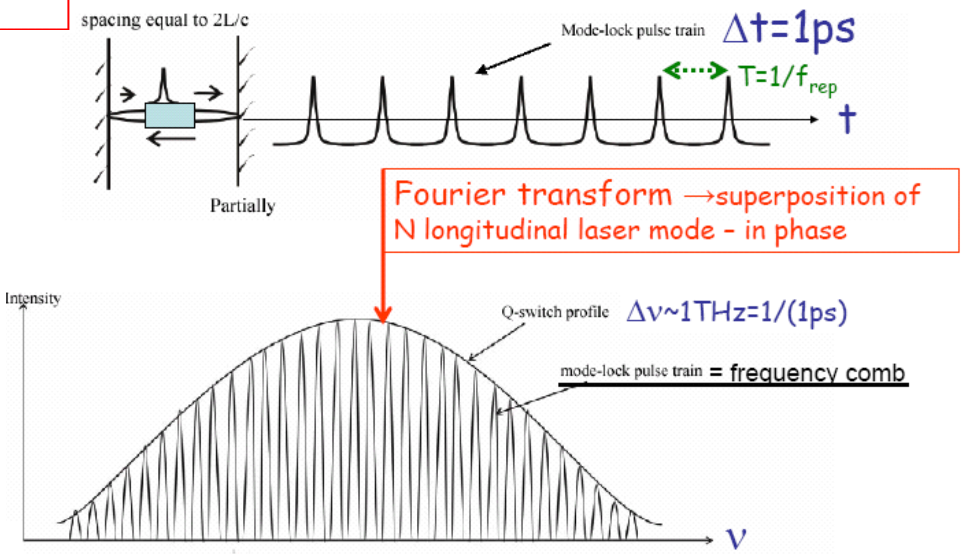
~ 0.1J/pulse @ ~300MHz

& Smallest beam waist

Solution:

Concentric Fabry-Perot resonator in pulsed regime

Mode-locked laser



Fourier transform →superposition of N longitudinal laser mode - in phase

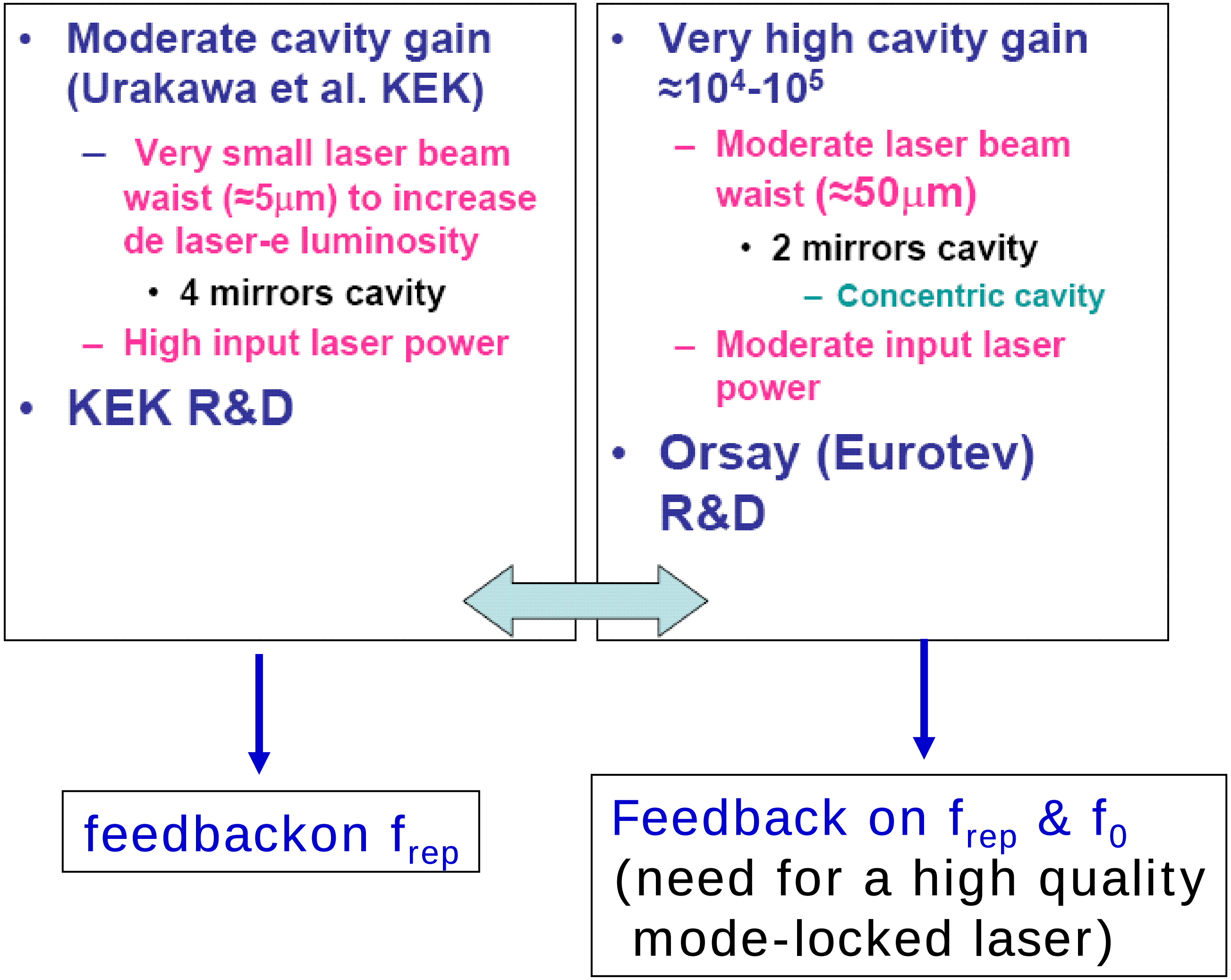
If F.P. cavity length = laser cavity length
→ all modes are also resonant modes of the FP cavity

Fill FP with mode-locked laser

Max. cavity gain in pulsed regime is limited by

- dispersion
  (pulse time width broadening)
- chromatic dependence of refl. coeff. of cavity mirror coatings

R&D to match Klaus's requirement



- Moderate cavity gain (Urakawa et al. KEK)
  - Very small laser beam waist (≈5μm) to increase de laser-e luminosity
    - 4 mirrors cavity
  - High input laser power
- KEK R&D

- Very high cavity gain ≈10^4-10^5
  - Moderate laser beam waist (≈50μm)
    - 2 mirrors cavity
      - Concentric cavity
  - Moderate input laser power
- Orsay (Eurotev) R&D

feedbackon f_{rep}

Feedback on f_{rep} & f_0 (need for a high quality mode-locked laser)

A priori feasable

Polarimetry of Polarized Positrons

K. Peter Schuler

R&D polarimetry at or near source energies (5-50 MeV)

- Low-Energy Positron Polarimetry
  - general choices and considerations
- Basics of the Transmission Method
  - for photon polarimetry
  - for positron polarimetry
- Positron Polarimetry at E166
  - photon polarimeter
  - for the positron polarimeter
- Expected Polarimeter Performance

operational polarimetry at medium energies (5 GeV)

- Bhabha & two-photon annihilation

dedicated polarimetry for physics data at ILC energies (45.6-500 GeV)

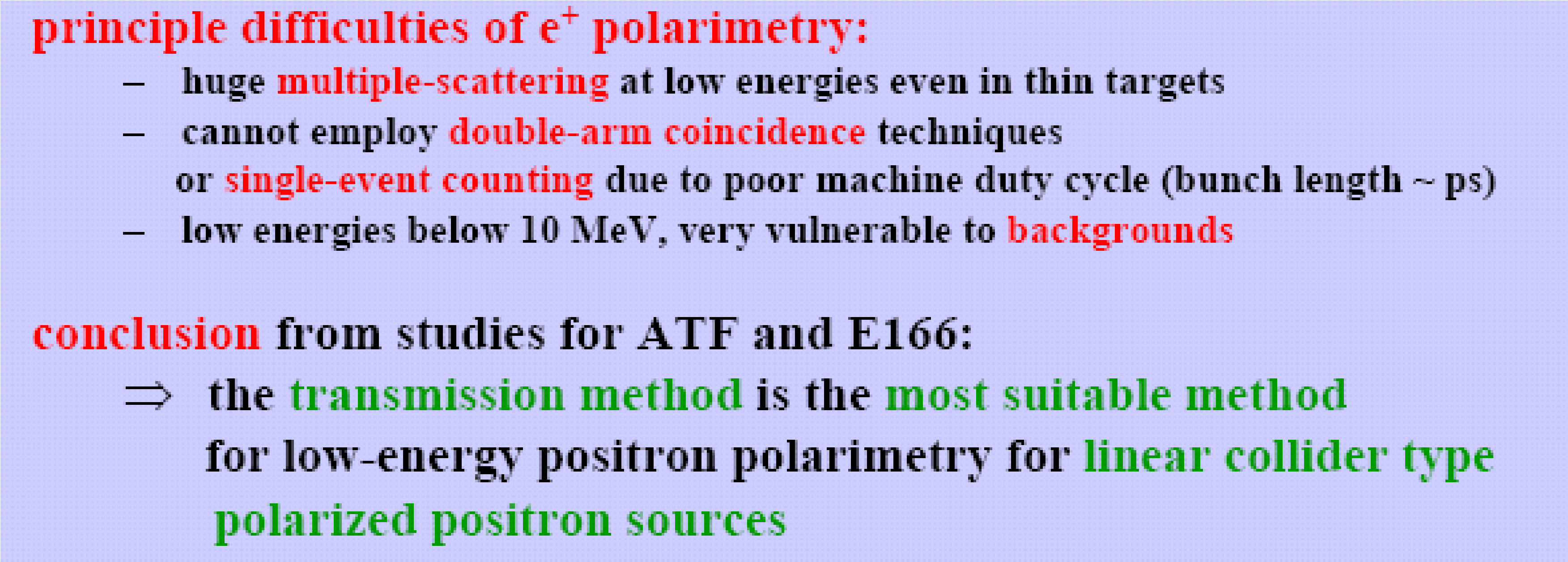
- Compton laser backscattering (upstream & downstream)

  and maybe occasional Bhabha cross checks with iron foils

collider detector based polarimetry (E_{cm} = 500-1000 GeV)

- Bhabha & two-photon annihilation
- electro-weak processes, such as single W-production

P. Schueler



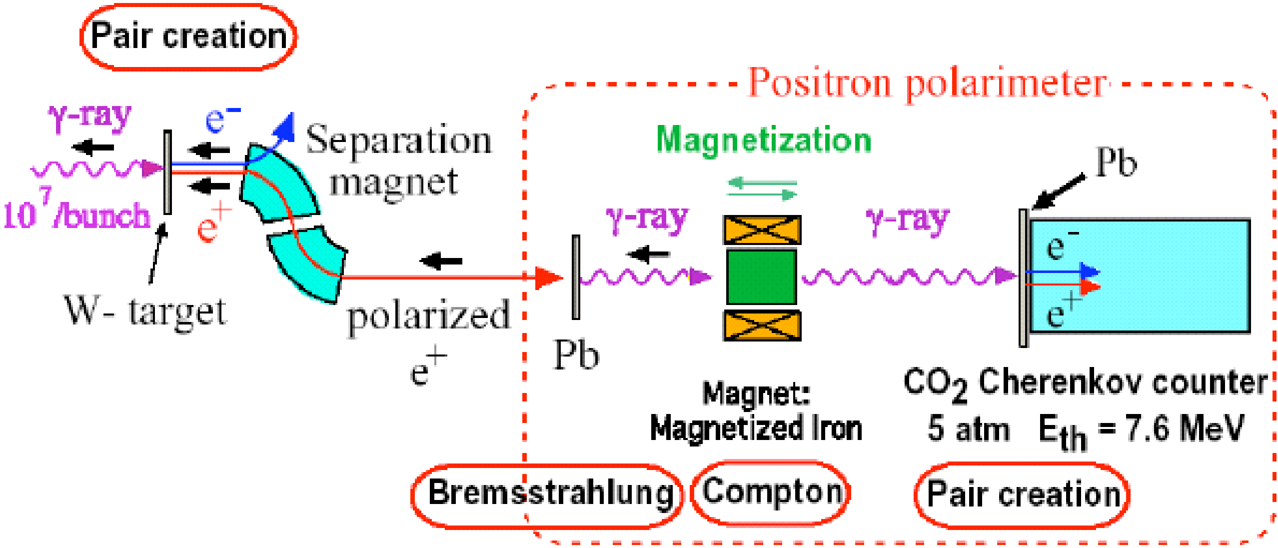
principle difficulties of e^+ polarimetry:

- huge multiple-scattering at low energies even in thin targets
- cannot employ double-arm coincidence techniques
  or single-event counting due to poor machine duty cycle (bunch length ~ ps)
- low energies below 10 MeV, very vulnerable to backgrounds

conclusion from studies for ATF and E166:

⇒ the transmission method is the most suitable method for low-energy positron polarimetry for linear collider type polarized positron sources

Masao Kuriki: Polarised e+ generation and measurement at KEK



Summary

1) We confirmed propagation of the polarization from laser photons -> γ-rays -> pair created e^+s & e^-s.

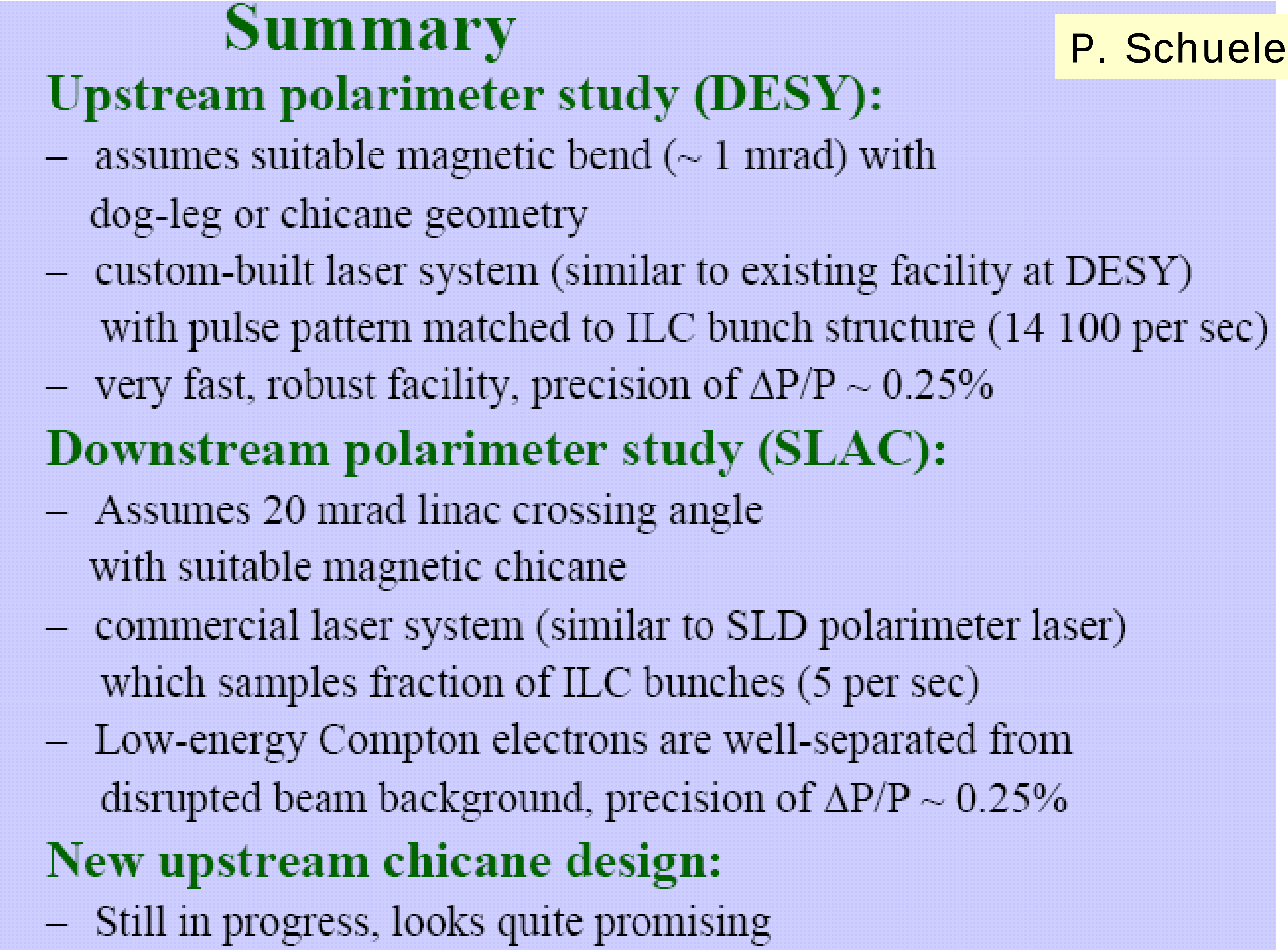
2) We established polarimetry of short pulse & high intensity γ-rays, positrons, and electrons.

3) Measured value of asymmetries agreed with expected value. (~ 0.7 %)
--> We got e^+ polarization of ~80%

ıresbury)

High-Energy Compton Polarimetry

P. Schueler



Summary

Upstream polarimeter study (DESY):

- assumes suitable magnetic bend (~ 1 mrad) with dog-leg or chicane geometry
- custom-built laser system (similar to existing facility at DESY) with pulse pattern matched to ILC bunch structure (14 100 per sec)
- very fast, robust facility, precision of ΔP/P ~ 0.25%

Downstream polarimeter study (SLAC):

- Assumes 20 mrad linac crossing angle with suitable magnetic chicane
- commercial laser system (similar to SLD polarimeter laser) which samples fraction of ILC bunches (5 per sec)
- Low-energy Compton electrons are well-separated from disrupted beam background, precision of ΔP/P ~ 0.25%

New upstream chicane design:

- Still in progress, looks quite promising

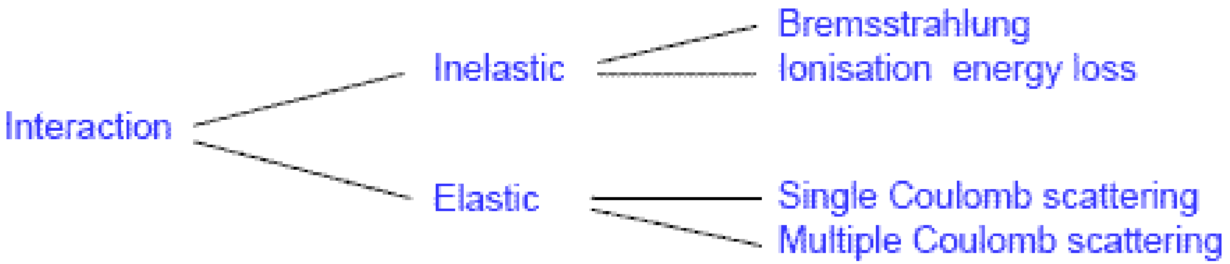
Operational Aspects

Tim Broome: Experience of remote handling of a proton beam target
Duncan Scott: GEANT4 Simulations of photon interactions with the target and vacuum vessel
Oleg Malyshev: Achieving a vacuum in a small bore helical undulator
Sabine Riemann: Radiation aspects in positron sources

Eckhard Elsen: ILC Source reliability
Nan Phinney: LC availibility simulation – An update with concentration on positron sources

Malyshev: Vacuum systems for the ILC undulator

Interaction between the Beam and Residual Gas Molecules



- Interaction
  - Inelastic
    - Bremsstrahlung
    - Ionisation energy loss
  - Elastic
    - Single Coulomb scattering
    - Multiple Coulomb scattering

Photon stimulated desorption (PSD)
= source of gas in vacuum system

Upper limit: depends on SR power loss, photon energy
Lowest limit: thermal stimulated desorption ⇔ baking

- There are no data on photo-desorption at such high photon energies, but the higher desorption the faster it reduces with an accumulated photon dose

Conclusions

- Vacuum design of the Undulator may be either very challenging or quite conventional depending on number of unknowns:
  - Desorption yield stimulated by ~0.1-1 MeV photons
  - Cryogenic or RT vacuum chamber
  - Al or stainless steel vacuum chamber
  - What column density is required!
  - Beam conditioning time
  - Photon flux dissipated in the vacuum chamber wall
  - Energy distribution of photons hitting the vacuum chamber wall
  - Compton effect
- It does not look that there are problems which we could not solve

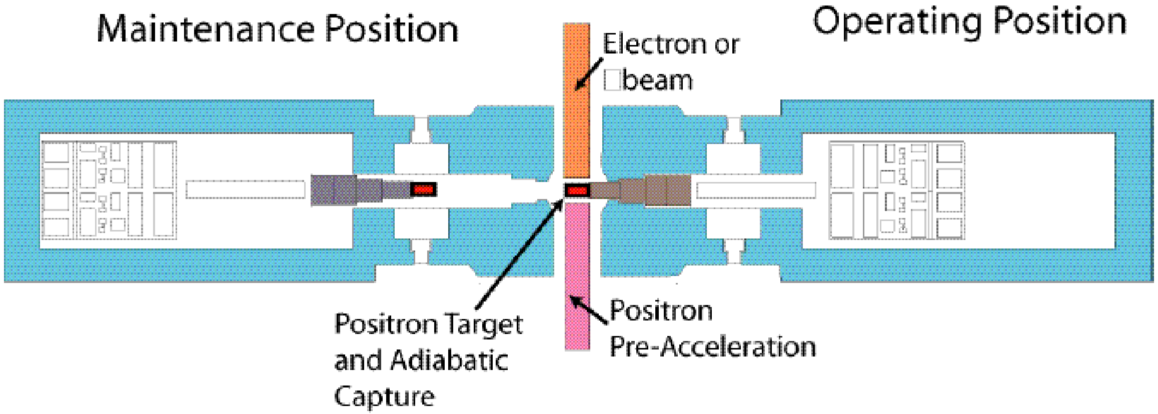
T. Broome: Experience of remote handling of a proton beam target

Guiding principle:

Components have limited lifetime & must be exchangeable in reasonable time

Consider:

- Lifetime
- Expected activation
- Complexity of geometrical arrangement
- Handling areas
- Decommissioning



→ design as simple as possible

→ remote handling (that will dominate the layout of the target area)

→ use experience (spallation sources)

Duncan Scott: GEANT4 simulations of photon interactions with the target and vacuum vessel

Create an integrated system of computer simulations in which we can parameterise and model all the key components…

- SPECTRA – Undulator spectrum code from SPRING-8
- GEANT4 – particle physics code
- Mathematica – commerical package
- Spectra
  - Calculate realistic undulator spectra
- G4
  - Model physics process in target

- Output read into Mathematica to analyse data
- In principal entire system can be modelled and parameterised
  - Effect of collimation, K, Beam Energy..
- Other effects looked at
  - Secondary Electrons

S. Riemann, K. Floettmann: Radiation aspects in Positron Sources

	rep rate	# of bunches per pulse	# of positrons per bunch	# of positrons per pulse
TESLA TDR	5 Hz	2820	$2 \cdot 10^{10}$	$5.6 \cdot 10^{13}$

Power depositions [kW] in conventional (280 kW e-) and undulator (230 kW γ) source

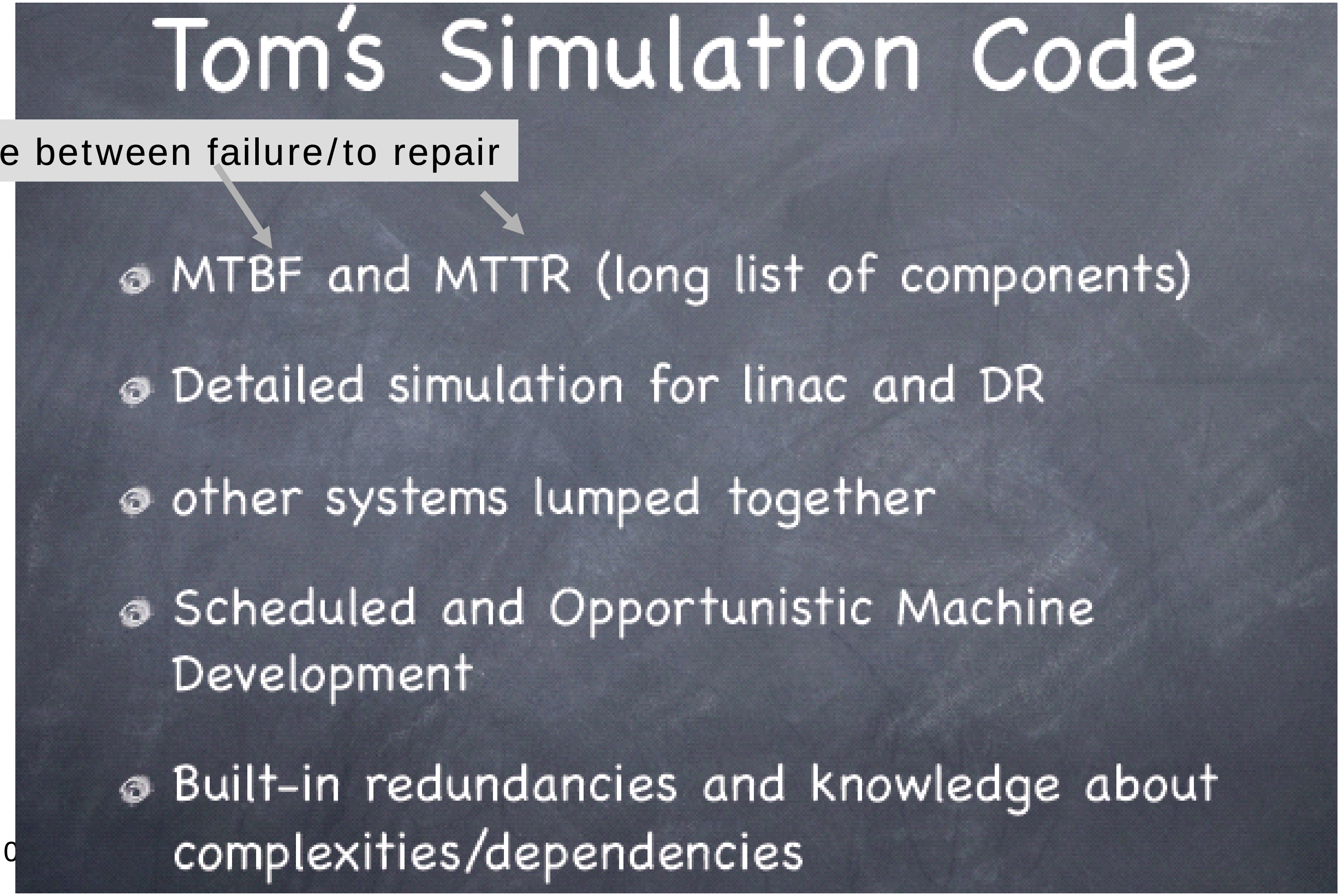
	Target		Capture section		collimator		dump	
e-	56	10.4	37	6.8			4.5	185
e+			37	10.4	2.8	9.2		
γ			≈150	8.4				11.1

➔ 10x higher n flux for conv. source → more shielding

A Undulator: 2.7 e+ per undulator e-, conv: 0.6 e+ per 1e-

Eckhard Elsen: ILC source reliability

with Sebastian Schaetzel; based on work of Tom Himel on ILC availability in USLCTOS (=US LC Technology Option Studies)

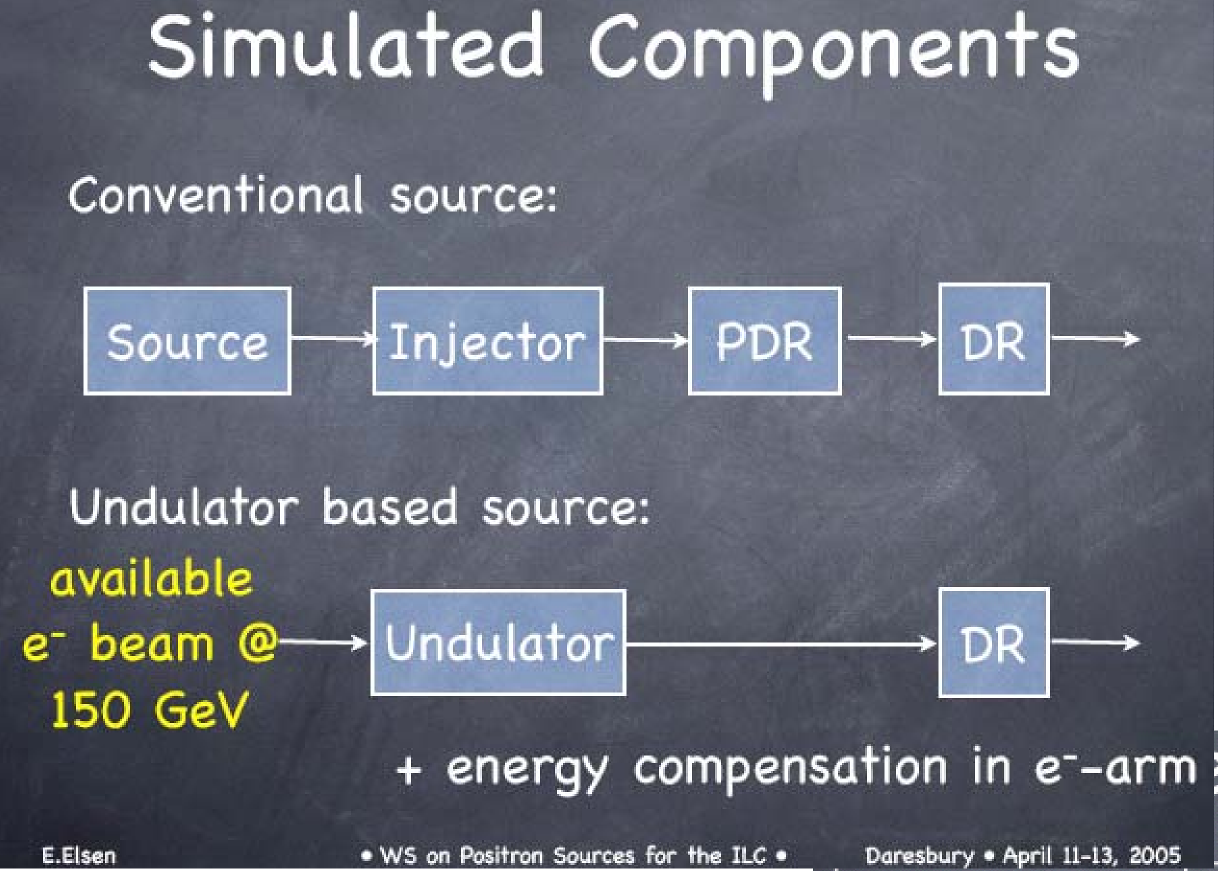


Tom's Simulation Code

Mean time between failure/to repair

- MTBF and MTTR (long list of components)
- Detailed simulation for linac and DR
- other systems lumped together
- Scheduled and Opportunistic Machine Development
- Built-in redundancies and knowledge about complexities/dependencies

E. Elsen



Simulated Components

Conventional source:

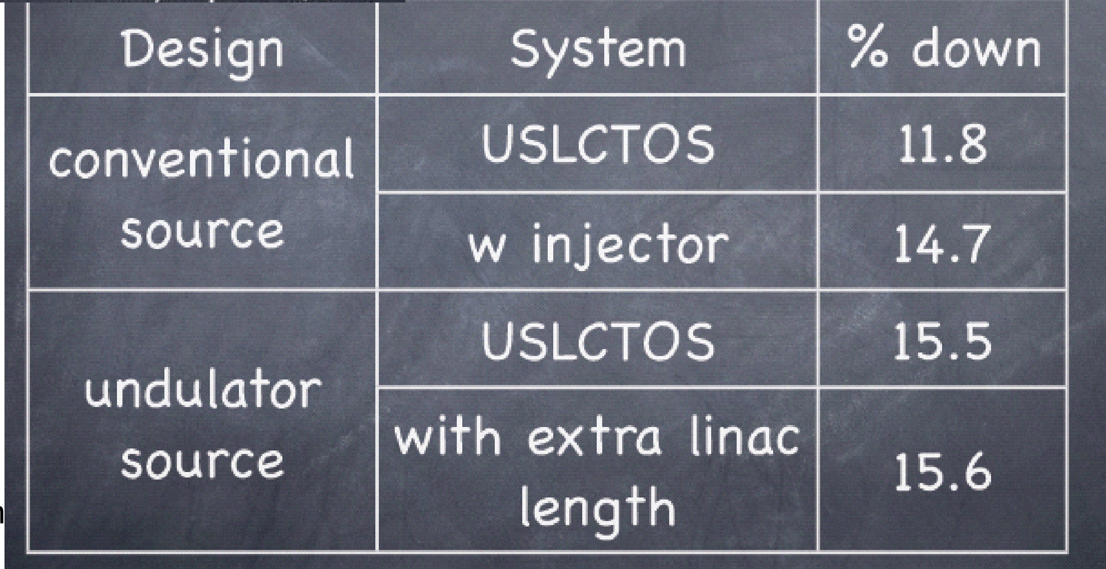
Source → Injector → PDR → DR →

Undulator based source:

available e^- beam @ 150 GeV → Undulator → DR →

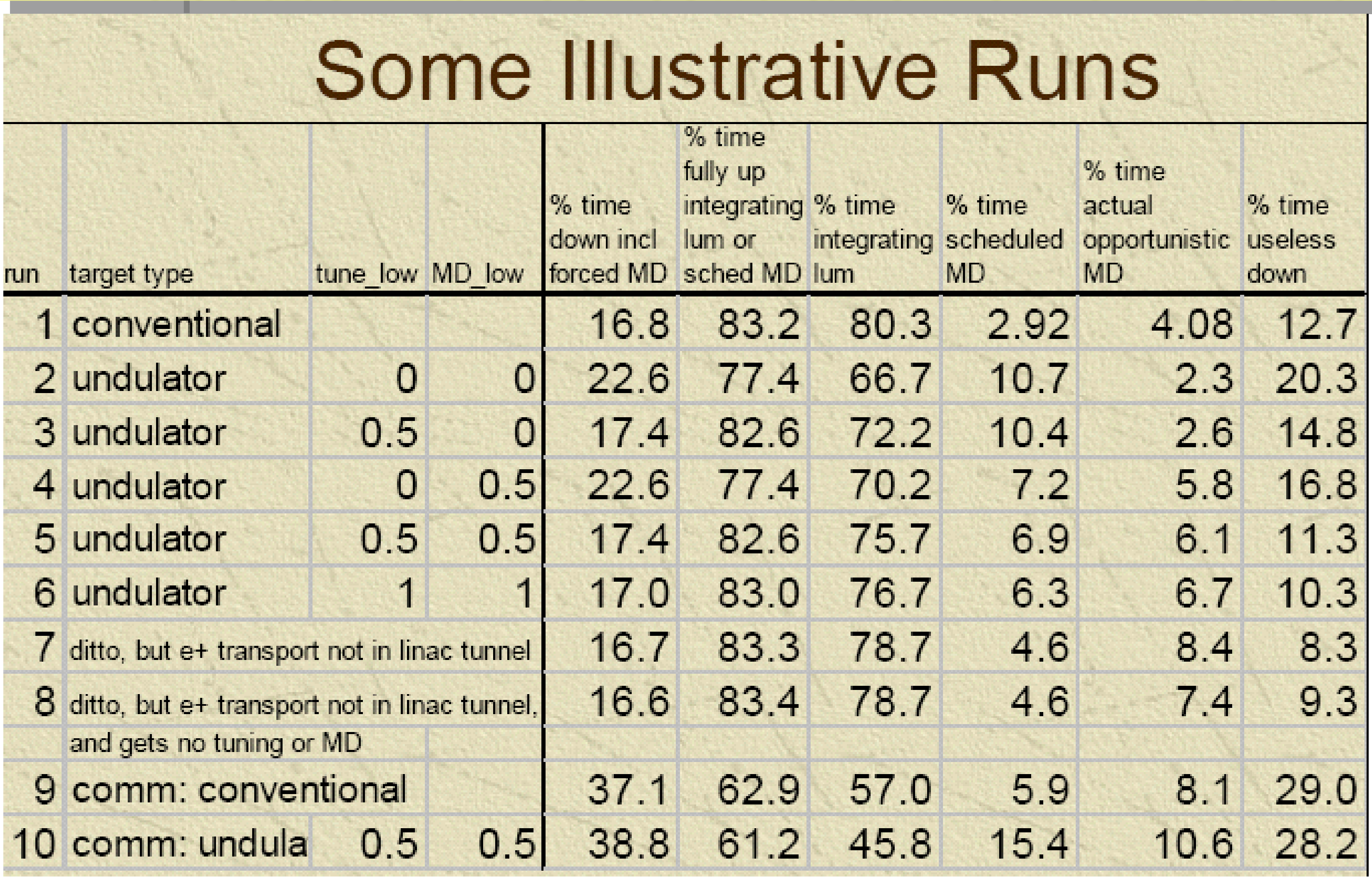
+ energy compensation in e^--arm

Comparisons



Design	System	% down
conventional source	USLCTOS	11.8
	w injector	14.7
undulator source	USLCTOS	15.5
	with extra linac length	15.6

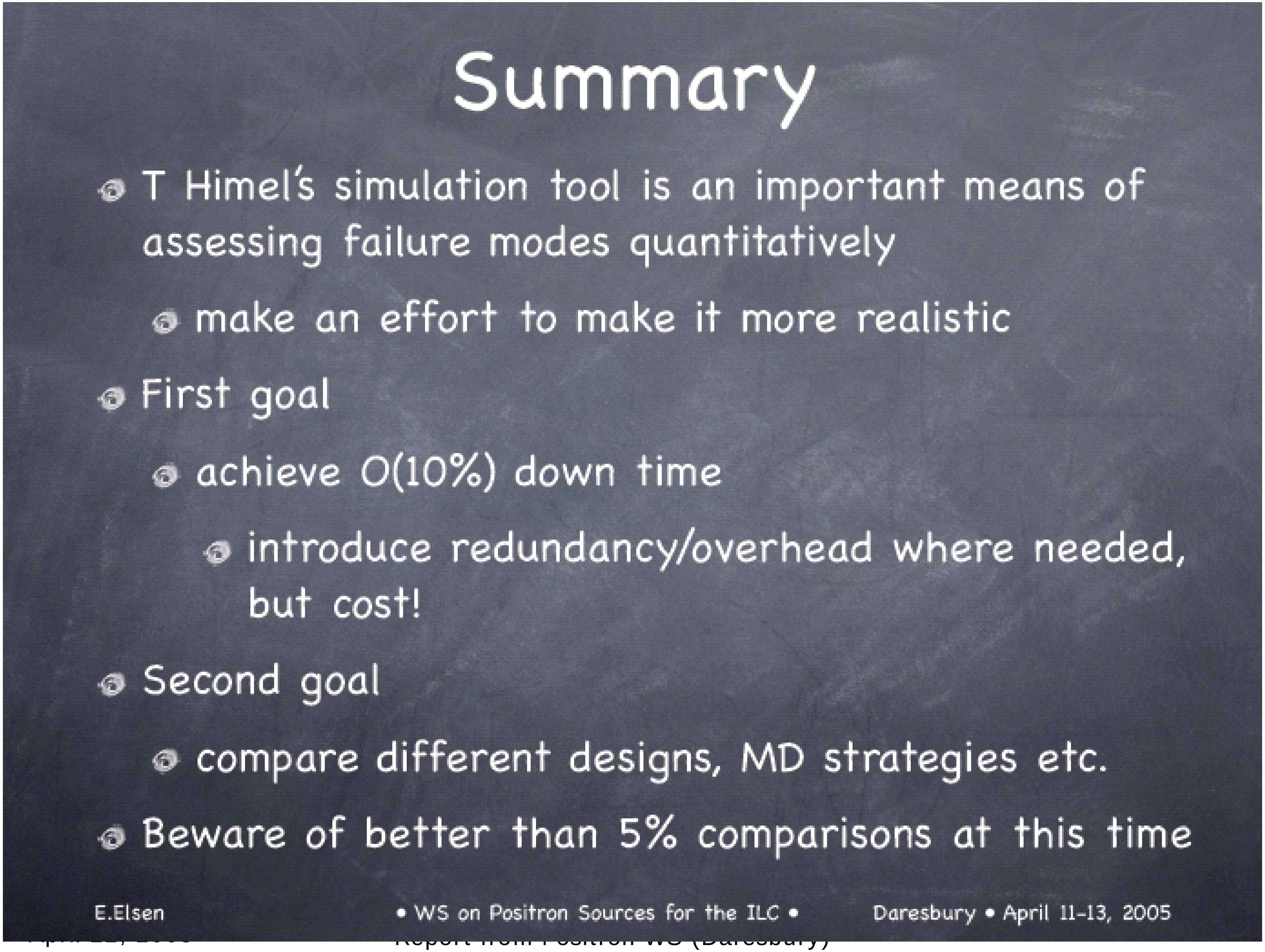
Nan Phinney: LC Availability simulations – An update with concentration on e+ sources



Some Illustrative Runs

run	target type	tune_low	MD_low	% time down incl forced MD	% time fully up integrating lum or sched MD	% time integrating lum	% time scheduled MD	% time actual opportunistic MD	% time useless down
1	conventional			16.8	83.2	80.3	2.92	4.08	12.7
2	undulator	0	0	22.6	77.4	66.7	10.7	2.3	20.3
3	undulator	0.5	0	17.4	82.6	72.2	10.4	2.6	14.8
4	undulator	0	0.5	22.6	77.4	70.2	7.2	5.8	16.8
5	undulator	0.5	0.5	17.4	82.6	75.7	6.9	6.1	11.3
6	undulator	1	1	17.0	83.0	76.7	6.3	6.7	10.3
7	ditto, but e+ transport not in linac tunnel			16.7	83.3	78.7	4.6	8.4	8.3
8	ditto, but e+ transport not in linac tunnel, and gets no tuning or MD			16.6	83.4	78.7	4.6	7.4	9.3
9	comm: conventional			37.1	62.9	57.0	5.9	8.1	29.0
10	comm: undula	0.5	0.5	38.8	61.2	45.8	15.4	10.6	28.2

Further checks needed. But undulator has higher down time or less time to collect lumi than convenventional source...



Summary

- T Himel's simulation tool is an important means of assessing failure modes quantitatively
  - make an effort to make it more realistic
- First goal
  - achieve O(10%) down time
    - introduce redundancy/overhead where needed, but cost!
- Second goal
  - compare different designs, MD strategies etc.
- Beware of better than 5% comparisons at this time

E.Elsen • WS on Positron Sources for the ILC • Daresbury • April 11-13, 2005

Jim Clarke: Workshop summary

Issues Raised

- Can we agree a baseline set of undulator parameters to make comparing results easier
  - Period, K, electron energy, length, helical, photon energy
- Agree definition of DR acceptance and value – need for Pre DR
- Multiple targets
- Undulator in positron linac
  - Feedback loop or 10Hz operation
- Can we accumulate positrons in ring over 100ms

R & D Challenges

- Targets
  - Further simulation of electron or gamma on targets
    - Consistent data sets
    - Activation calcs
    - Polarisation in G4
  - Liquid target development
  - Application of crystal targets
  - Material properties
  - Tests at KEK
  - Prototype
- Remote handling
  - Include at concept stage

Jim Clarke: Workshop summary

R & D Challenges

- Compton
  - – Alignment
  - – Laser cavity development
  - – Large scale optics setup
    - 1 laser x 20 collision points
    - Alignment
- Prototypes
  - – AMD
  - – RF structure PPA
  - – Complete capture section
- Positron source emulator
  - – Combine with capture section prototype
- Assess operational issues
  - – Reliability
  - – Ease of commissioning
  - – Integrated luminosity
- Cost estimates

Problems with this scheme

How long can we keep the scattered electrons in the ring?

- The bandwidth allows for one maximum or two “average” scatters
- How many turns do we need until the electron energy is recovered?
- Can we use dispersion effects to protect the low energy electrons?
- We need a low emittance gun to fill the electron storage ring

Can we fill the positron damping ring in this mode?

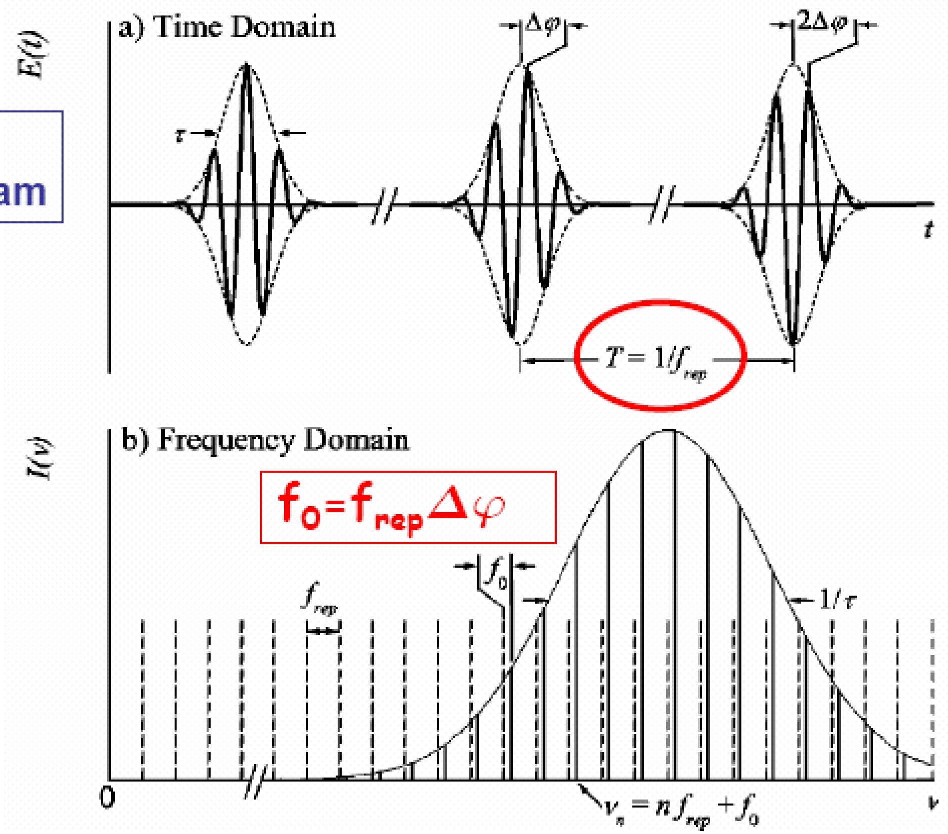
- The positron emittance at the damping ring entrance is very large
- There might not be enough phase space available to fill the positrons on top of the existing bunch
- Can we use some pre-cooling?

What about radiation damage on mirrors?

- Radiation on mirror $0.05\,\mathrm{J/cm^2}$ per pulse and per Joule pulse energy for mirror distance of $1\,\mathrm{m}$ from IP
- For a single pulse this is far below the critical value of $2.5\,\mathrm{J/cm^2}$ for $2\,\mathrm{ps}$ laser pulses
- However I don’t know about data for high repetition rates

- Feedback technique
  - Fabry-Perot cavity taken as the reference
  - f_{rep} & f_0 are changed inside the laser(s)
  - Error signals: taken at different values of $\lambda \rightarrow$ to lock the full frequency comb to the cavity

Feedback for mode-locked laser beam



$f_0 = f_{rep} \Delta\varphi$

Jitter $\Delta f_0 \approx 1$ MHz → [f_0 or $\Delta\varphi$] & f_{rep} must be controlled even for 1ps pulses if the cavity finesse is very high

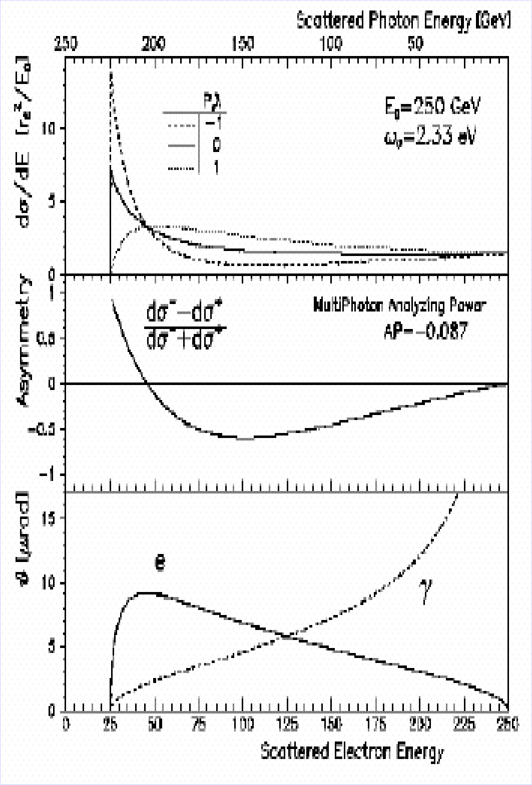
[*Femtosecond optical frequency comb technology*, Ye&Cundiff, Springer 2005]

High-Energy Compton Polarimetry

cross sections,

spin asymmetry,

scattering angles



$-1 < P < +1$

$-1 < \lambda < +1$

P. Schueler

laser choices & parameters

1. Q-switched Nd:YAG laser

pro ⇒ very high pulse energy (up to several 100 mJ),
robust commercial systems, relatively low cost

con ⇒ very low rep-rate (~5 Hz), i.e. only a small sampling fraction (1/2820)
of all ILC bunches can be measured;
inefficient due to long pulse length (ns's)

2. TESLA TTF rf-gun type Nd:YLF laser

pro ⇒ pulse pattern matched to ILC bunch & pulse structure;
100% of all ILC bunches will be measured;
high efficiency due to short pulse length (10 ps);
sufficient pulse energy (10-100 μJ) to achieve negligible stat. errors in 1 sec !

con ⇒ non-commercial system, ~ 400 k€ per laser

3. Pulsed Fabry-Perot Cavity (R&D project at Orsay)

pro ⇒ aims for similar performance as (2)

con ⇒ must operate complex laser system remotely in ILC tunnel (reliability!);
feasibility must still be demonstrated (note: HERA Fabry-Perot is not pulsed!)