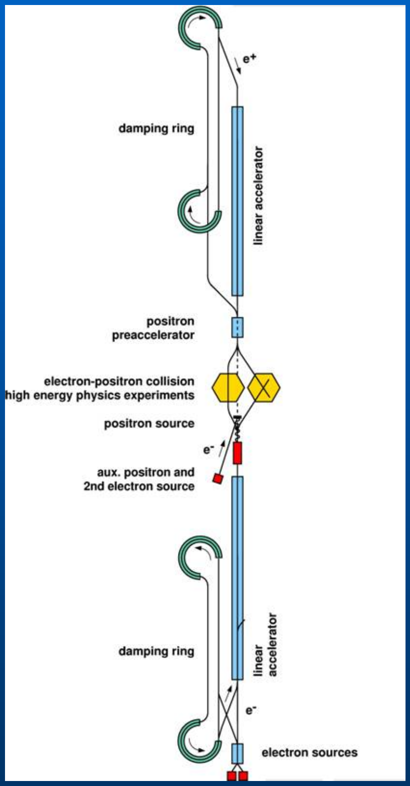
ILC Accelerator Technical Issues

Nick Walker

LCWS 2005

Stanford University 18.3.2005

Already have two ILC Possibilities

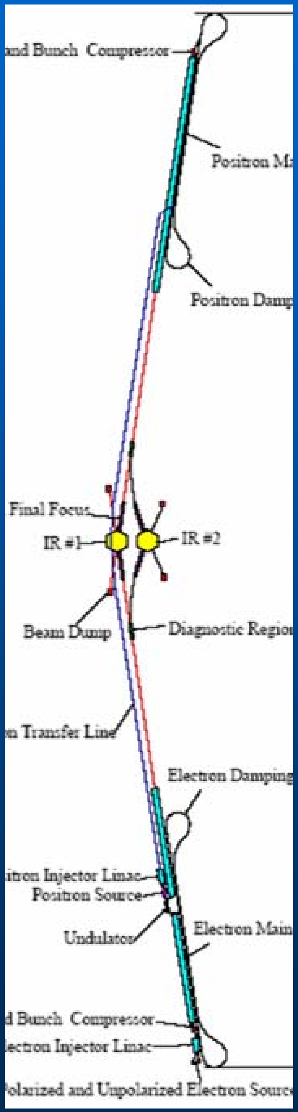


TESLA TDR
500 GeV (800 GeV)

33km

47 km

US Options Study
500 GeV (1 TeV)



ILC Design Issues

After ITRP decision: Back to Basics!

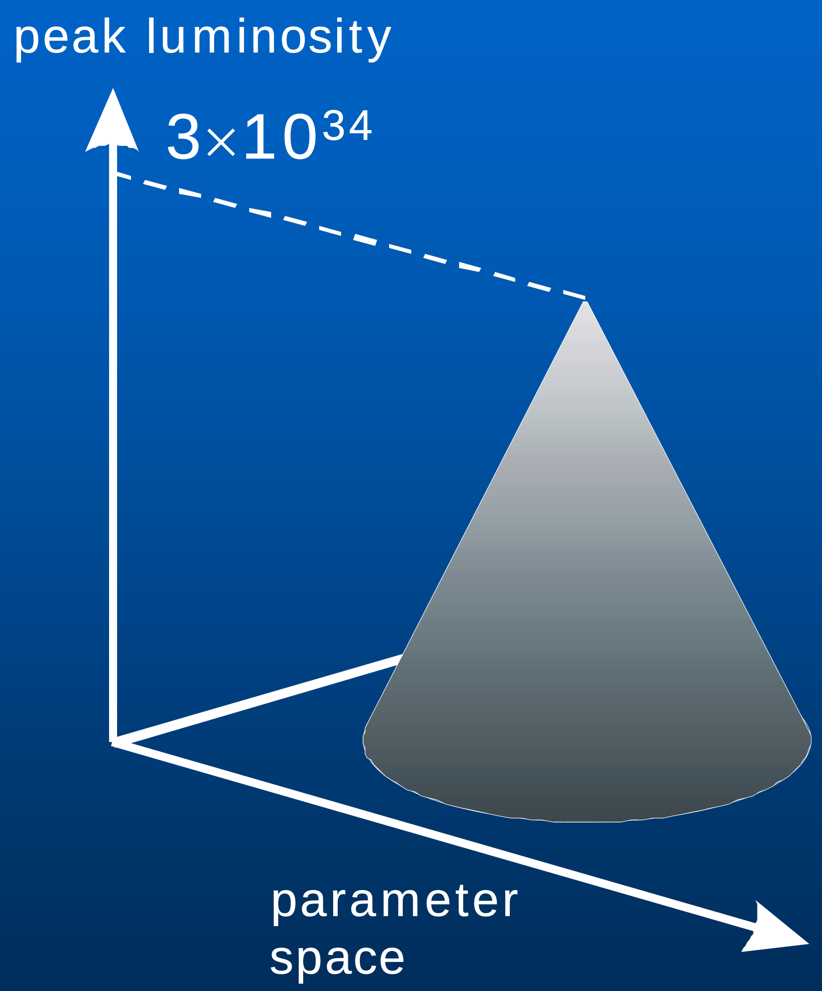
Energy Reach

$$E_{cm} = 2b_{fill} L_{linac} G_{RF}$$

Luminosity

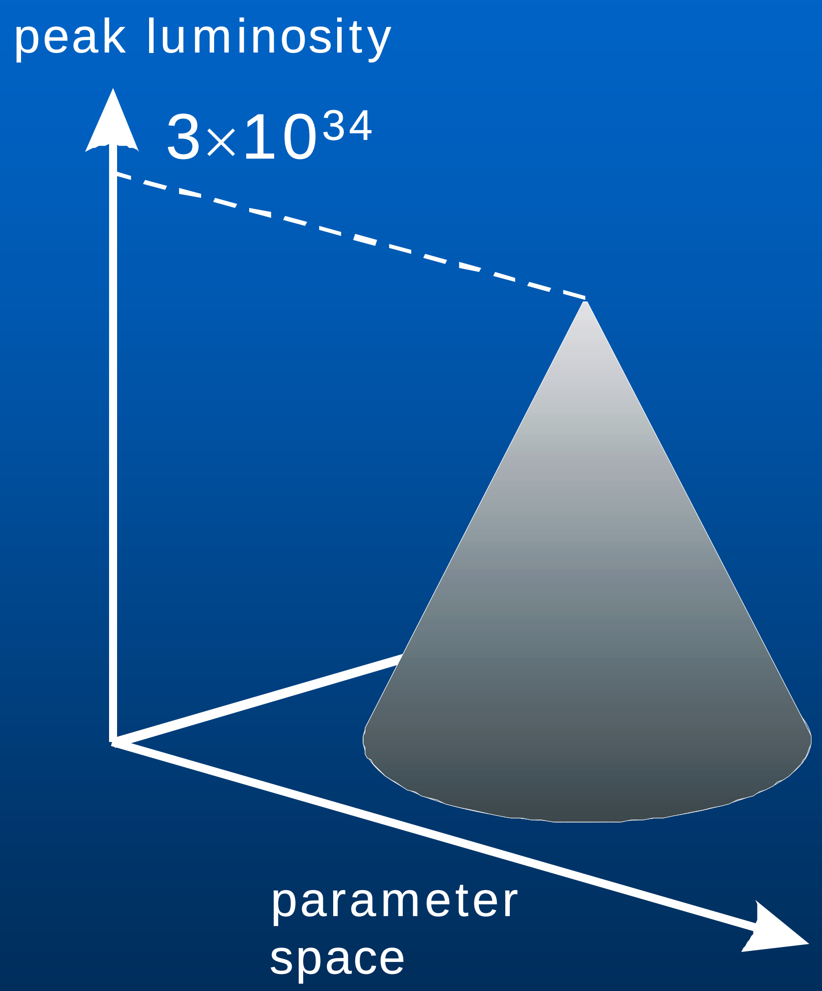
$$L \propto \frac{\eta_{RF} P_{AC}}{E_{cm}} \sqrt{\frac{\delta_{BS}}{\gamma \varepsilon_y}}$$

TESLA TDR Parameters

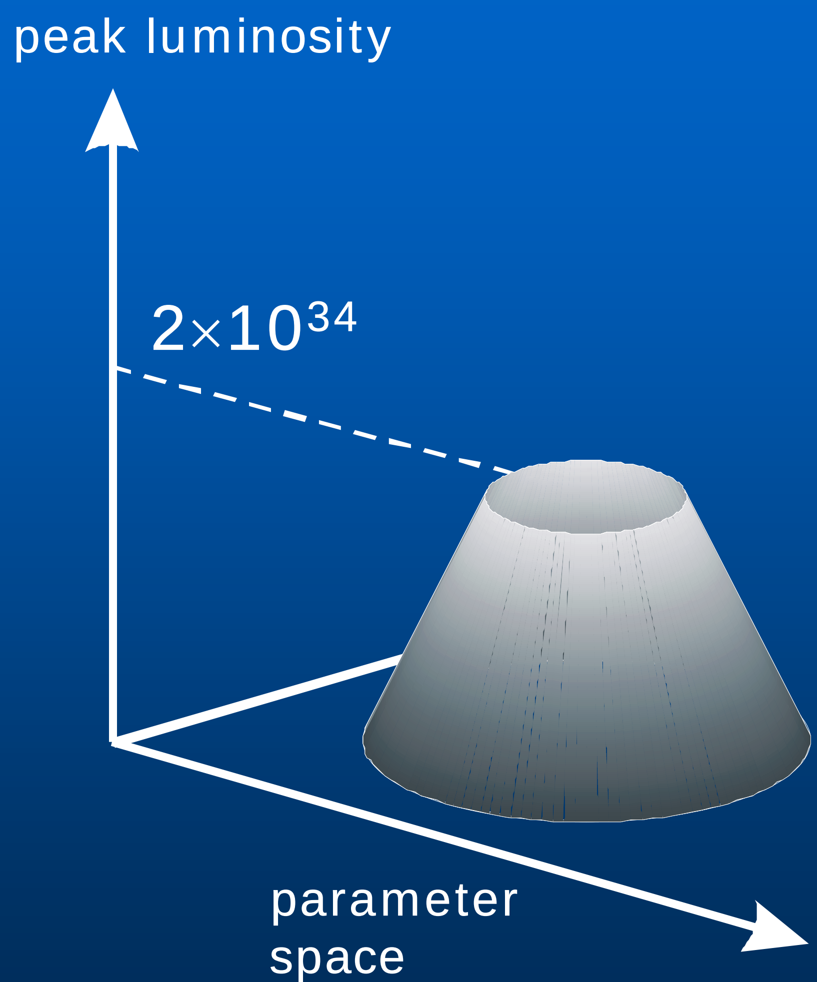


- 3×10^{34} cm^{-2}s^{-1} peak achievable
- Possible due to very high beam-beam disruption (D_y)
- Well into kink-instability regime (unstable)
- Little head room to play with

TESLA TDR Parameters



ILC Parameters



- Define baseline at relaxed goal of 2×10^{34} cm^{-2}s^{-1}
  - consistent with WWS 500fb^{-1} in first 4 years
- Now have several possible parameter sets (parameter ‘plane’)
- Operational flexibility
- Sub-system experts to evaluate trade-offs between relevant parameters

ILC Parameters

Suggested ILC Beam Parameter Range
by Tor Raubenheimer (SLAC)

available from:
http://www-project.slac.stanford.edu/ilc/
http://ilc.desy.de
http://...

parameters discussion forum:
http://www-project.slac.stanford.edu/ilc/discussion/Default.htm

This document intended to provoke your feedback and comment!

Parameter Plane

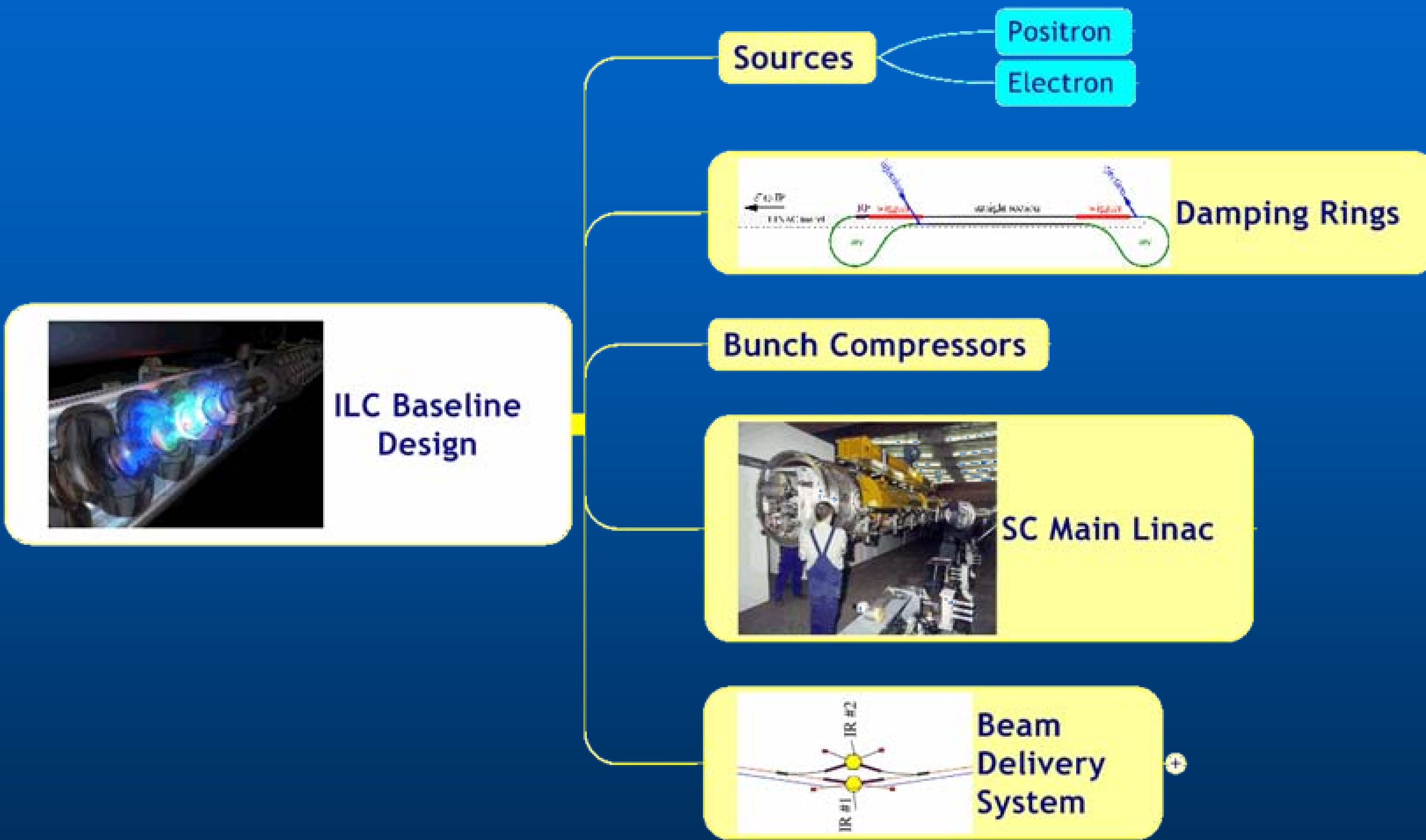
		nom	low N	lrg Y	low P
N	$\times 10^{10}$	2	1	2	2
n_b		2820	5640	2820	1330
$\varepsilon_{x,y}$	μm, nm	9.6, 40	10,30	12,80	10,35
$\beta_{x,y}$	cm, mm	2, 0.4	1.2, 0.2	1, 0.4	1, 0.2
$\sigma_{x,y}$	nm	543, 5.7	495, 3.5	495, 8	452, 3.8
D_y		18.5	10	28.6	27
δ_{BS}	%	2.2	1.8	2.4	5.7
σ_z	μm	300	150	500	200
P_{beam}	MW	11	11	11	5.3
L	$\times 10^{34}$	2	2	2	2

Range of parameters design to achieve 2×10^{34}

Pushing the Luminosity Envelope

		nom	low N	lrg Y	low P	High L
N	$\times 10^{10}$	2	1	2	2	2
n_b		2820	5640	2820	1330	2820
$\varepsilon_{x,y}$	μm, nm	9.6, 40	10,30	12,80	10,35	10,30
$\beta_{x,y}$	cm, mm	2, 0.4	1.2, 0.2	1, 0.4	1, 0.2	1, 0.2
$\sigma_{x,y}$	nm	543, 5.7	495, 3.5	495, 8	452, 3.8	452, 3.5
D_y		18.5	10	28.6	27	22
δ_{BS}	%	2.2	1.8	2.4	5.7	7
σ_z	μm	300	150	500	200	150
P_{beam}	MW	11	11	11	5.3	11
L	$\times 10^{34}$	2	2	2	2	4.9!

Towards the ILC Baseline Design



Decisions to be Made!

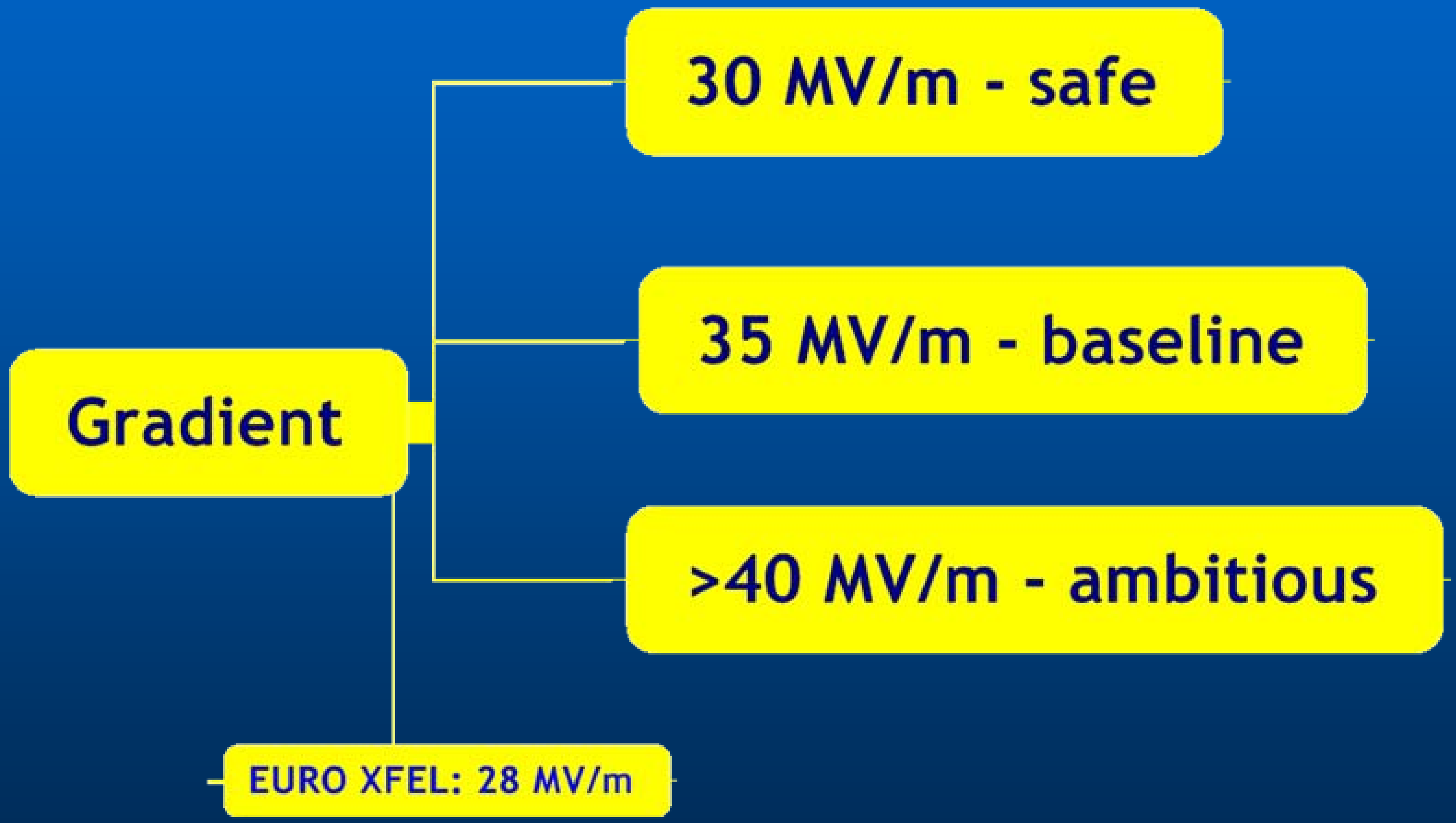
Main Linac: The Cost Driver

- Biggest single cost item
- 10 years of R&D by the TESLA Collaboration has produced a mature technology
  - But still lots to do...

Main Linac: The Cost Driver

- Primary focus of future R&D *should* be
  - successful tech. transfer to industry
  - cost reduction through industrialisation
  - need extensive effort to achieve high reliability !!!
- Euro XFEL project is already doing much of this within Europe
  - Asia and US should follow
- One important question:
  "What should the design gradient be?"

Gradient

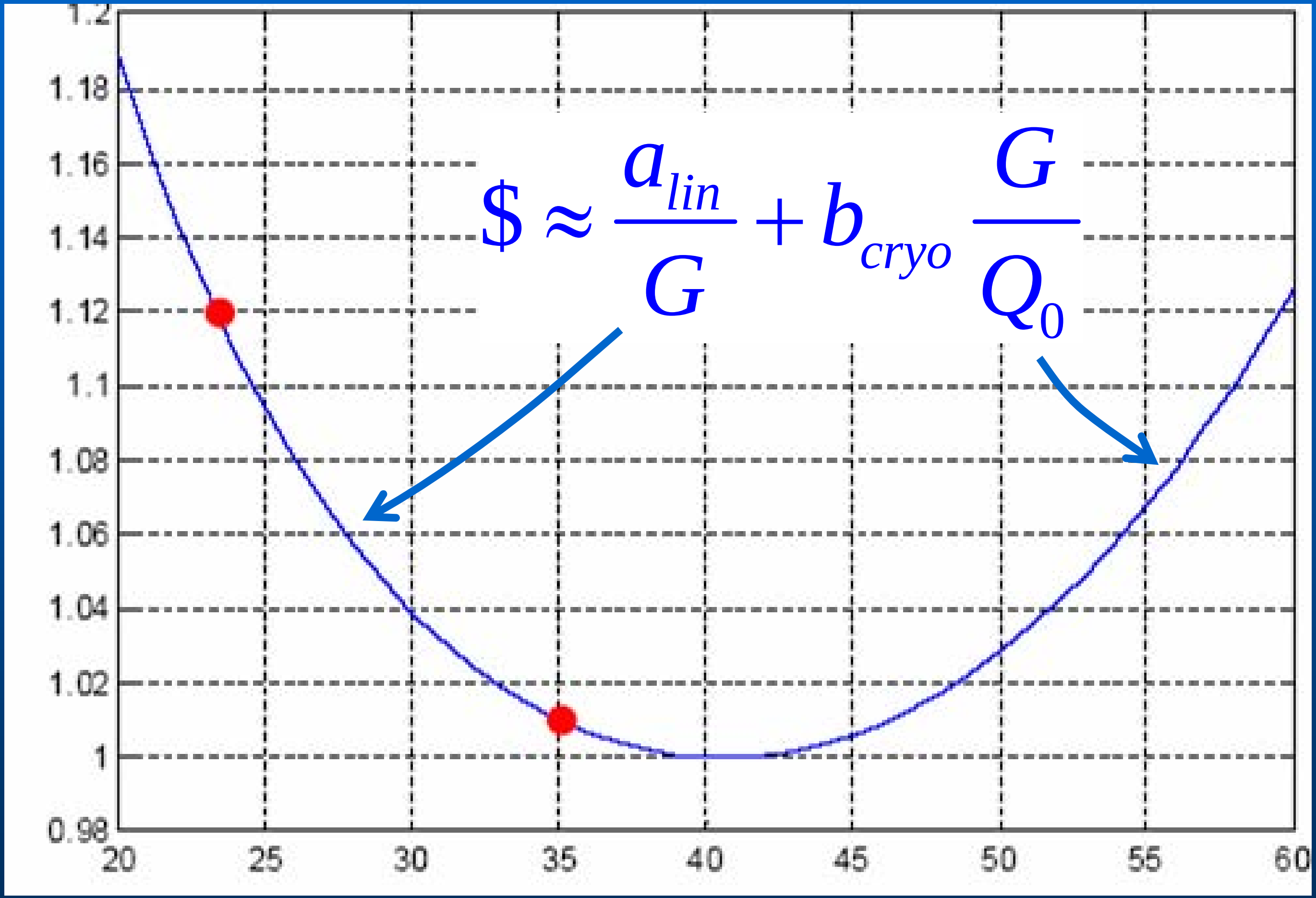

Gradient
30 MV/m - safe
35 MV/m - baseline
>40 MV/m - ambitious
EURO XFEL: 28 MV/m

Gradient versus Length

- Higher gradient gives shorter linac ☺
  - cheaper tunnel / civil engineering
  - less cavities
  - (but still need same # klystrons)

- Higher gradient needs more refrigeration ☹
  - 'cryo-power' per unit length scales as G^2/Q_0
  - cost of cryoplants goes up!

Simple Cost Scaling



$$\$ \approx \frac{a_{lin}}{G} + b_{cryo}\frac{G}{Q_0}$$

C. Adolphsen (SLAC)

Relative Cost

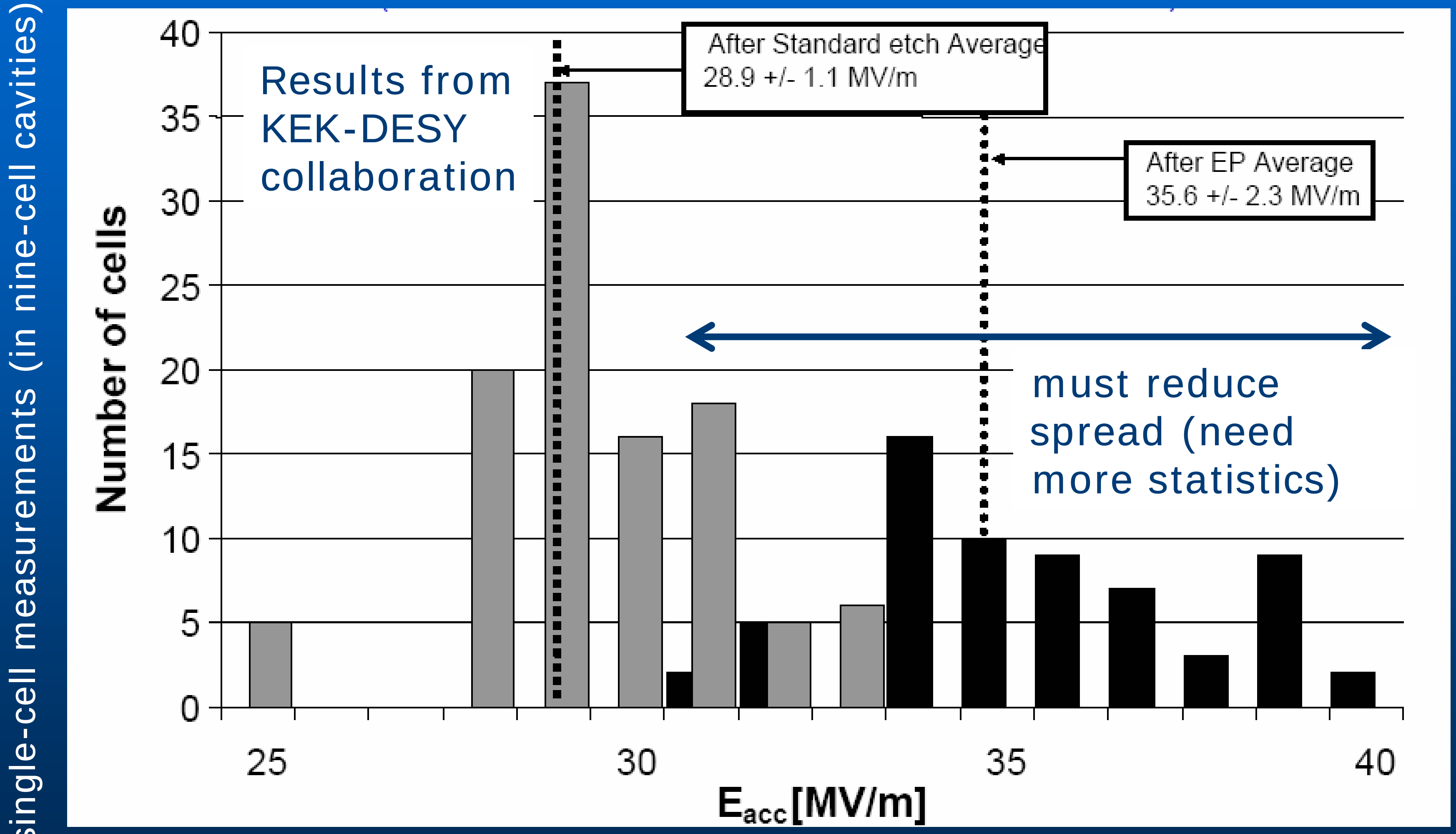
Gradient MV/m

general consensus that 35MV/m is close to optimum

However Japanese are still pushing for 40-45MV/m

30 MV/m would give safety margin

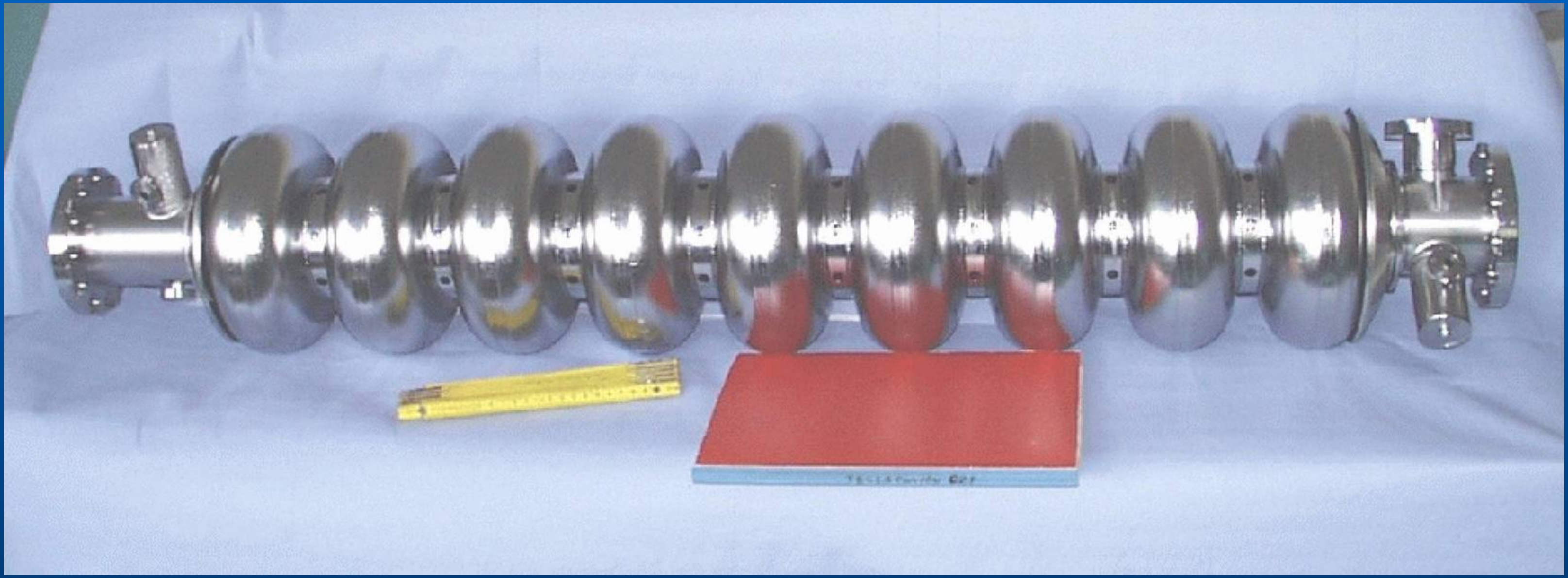
Gradient



Electropolishing the way to (reproducible) high gradients

TESLA Cavity Design

~1m



9-cell 1.3GHz Niobium Cavity

Reference design: has not been modified in 10 years

Possible Minor Enhancement

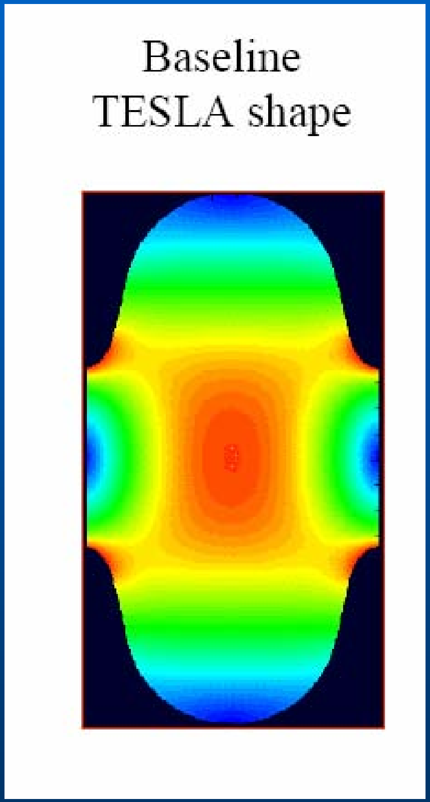
Low Loss Design

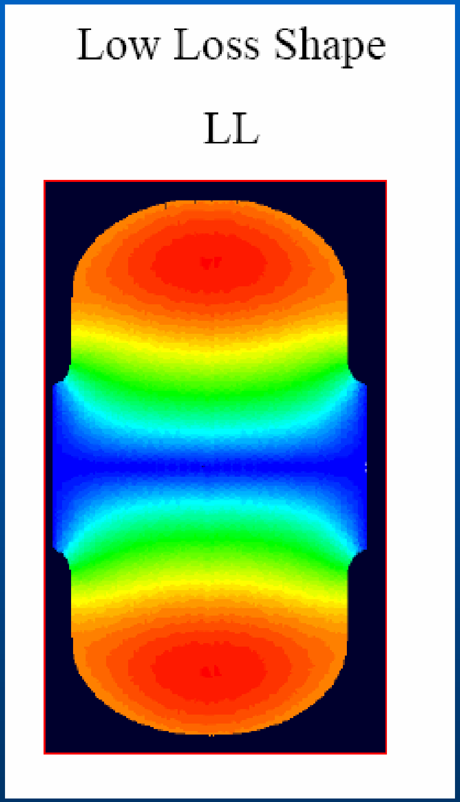
Small modification to cavity shape reduces peak B field.

Increase operation margin.

Increases peak E field ☹ (field emission)

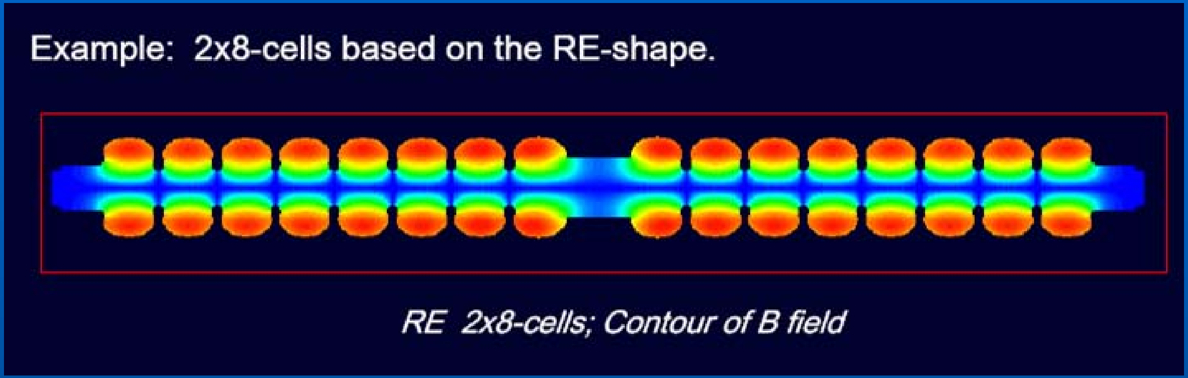
Mechanical stability ?? (Lorentz force detuning)





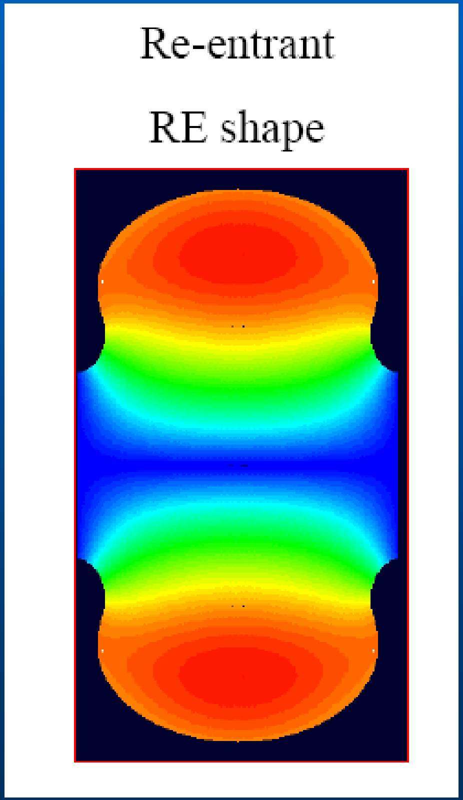
KEK currently producing prototypes

More Radical Possibilities



2×8 cell Super-structure

Re-entrant



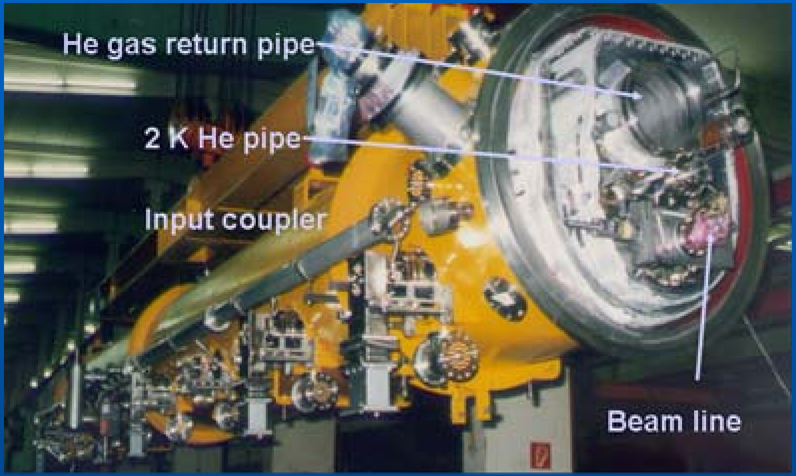
single-cell achieved 45.7 MV/m Q_0 ~10^{10} (Cornell)

More radical concepts *potentially* offer greater benefits.

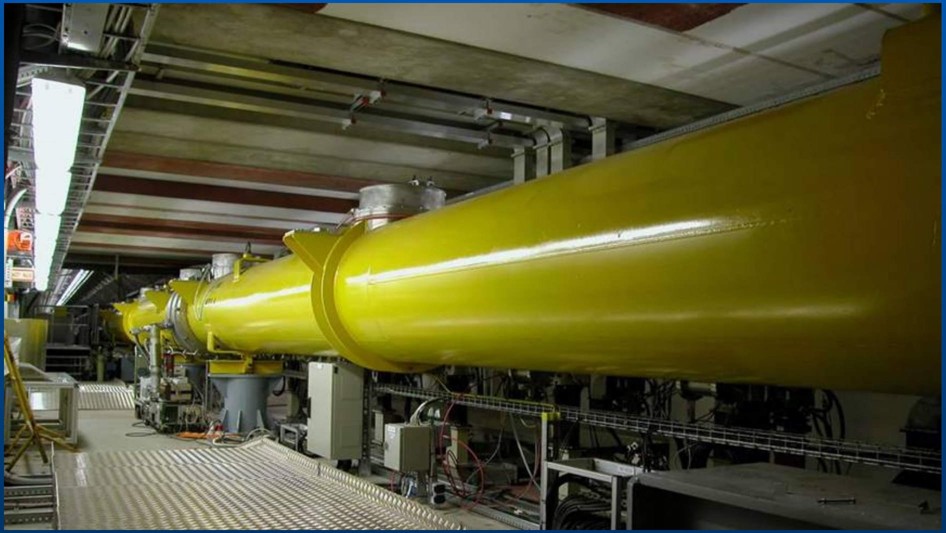
But requires major new infrastructure to develop.

Cryomodule Variants

	TTF	ILC
# cavities	8	12?
spacing	3λ/2	λ/2?
quad loc.	end	centre?



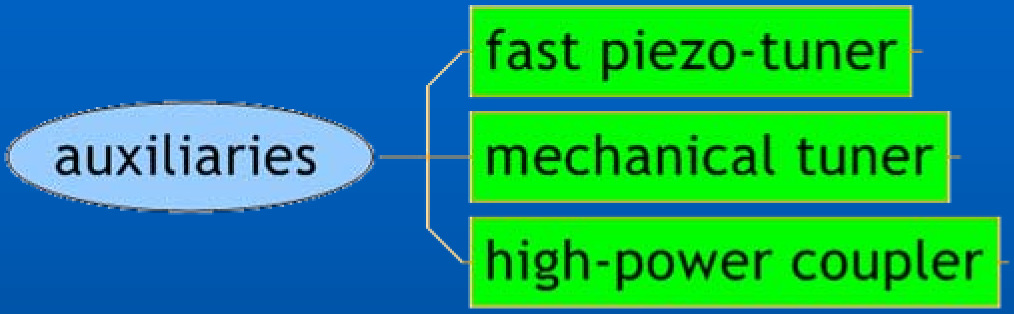
TESLA CM already
3rd generation

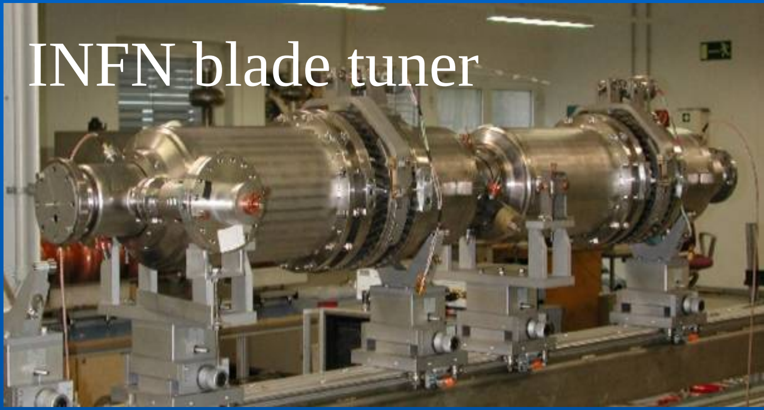


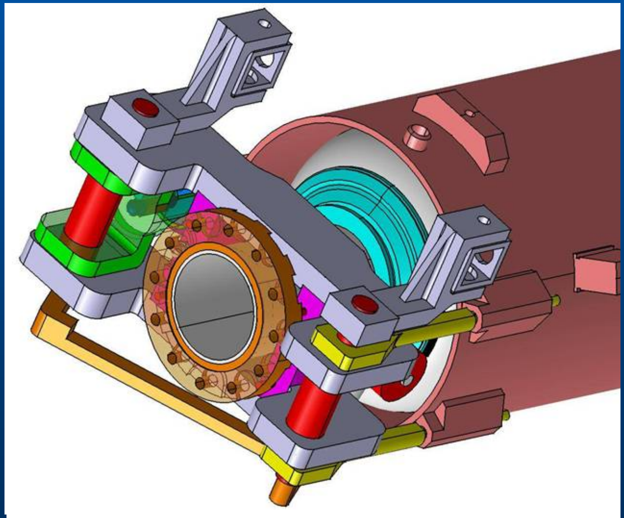
Main emphasis is on
- industrialisation
- reliability
- cost optimisation

} EURO XFEL

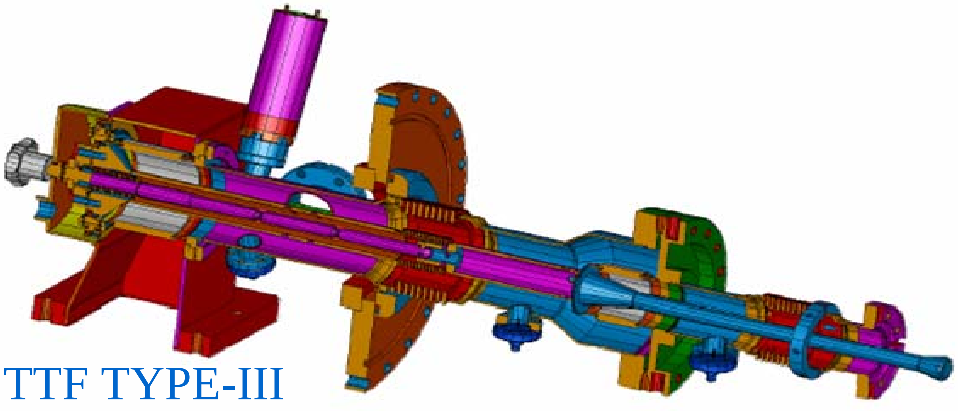
Cavity Auxiliaries







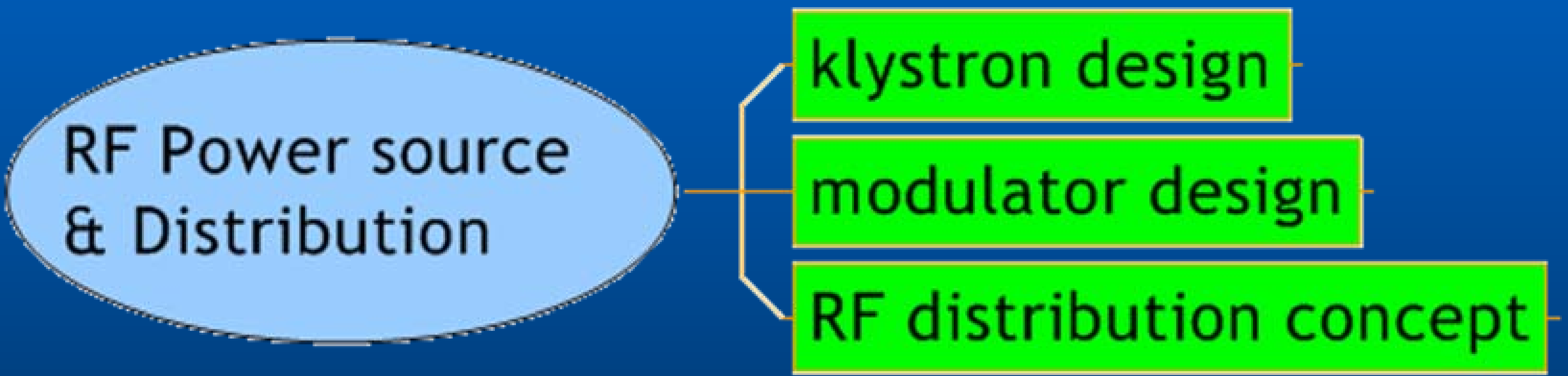
SACLAY tuner (type III)



TTF TYPE-III
HP Coupler

industrialisation – cost – reliability

RF Power source & Distribution

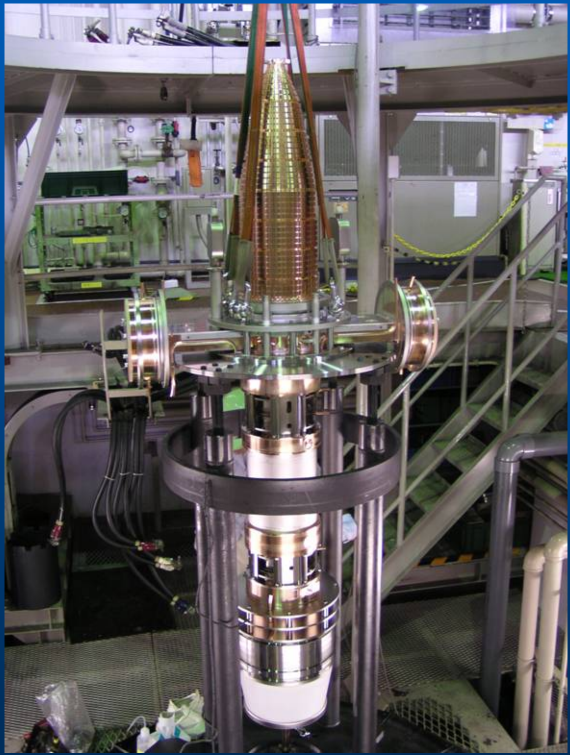


Example: Klystron Development

THALUS

CPI

TOSHIBA



10MW 1.4ms Multibeam Klystrons

~650 for 500 GeV

+650 for 1 TeV upgrade

Other ideas being considered (e.g. sheet beam klystrons)

Global SCRF Test Facilities

- **TESLA Test Facility (TTF)**
  currently unique in the world
  VUV-FEL user facility
  test-bed for both XFEL & ILC

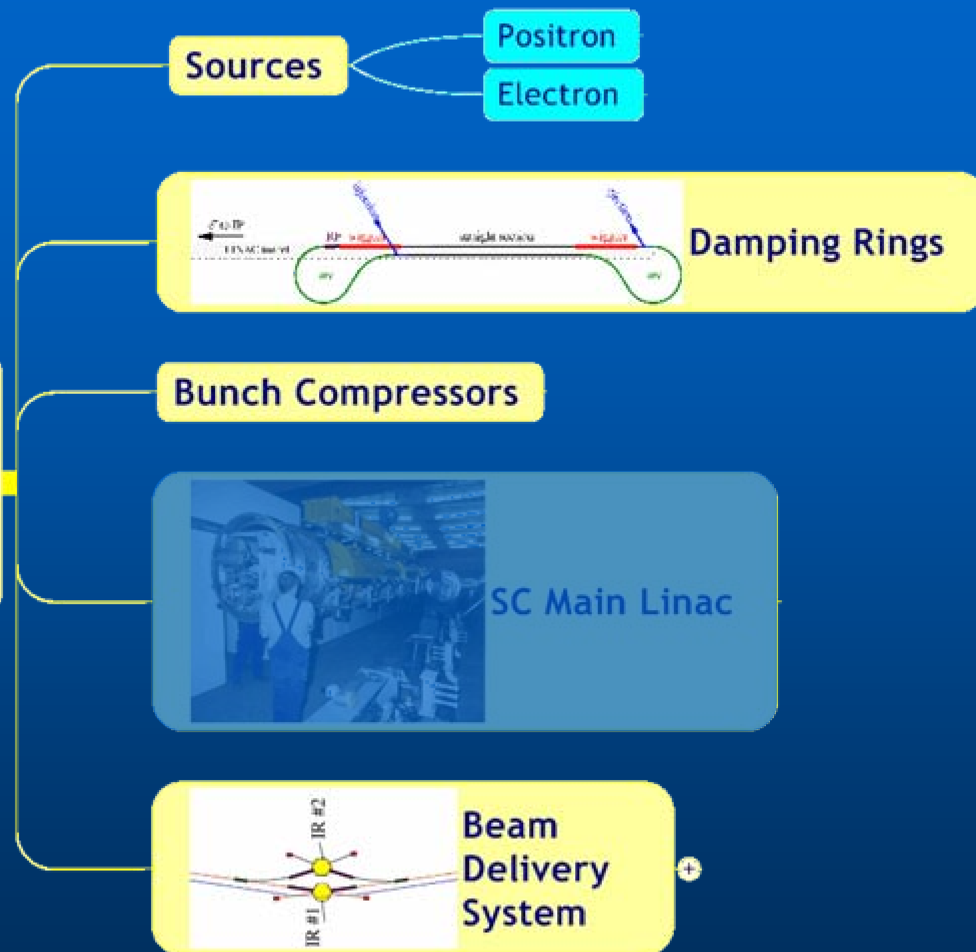
- **US proposed SMTF**
  Cornell, JLab, ANL, FNAL, LBNL, LANL, MIT, MSU, SNS, UPenn, NIU, BNL, SLAC
  currently requesting funding
  TF for ILC, Proton Driver (and more)

- **STF @ KEK**
  aggressive schedule to produce high-gradient (~45MV/m) cavities / cryomodules

Others (UK proposals?)

All facilities will be discussed at **TESLA Collaboration Meeting** 30/3-1/4 at DESY

Towards the ILC Baseline Design



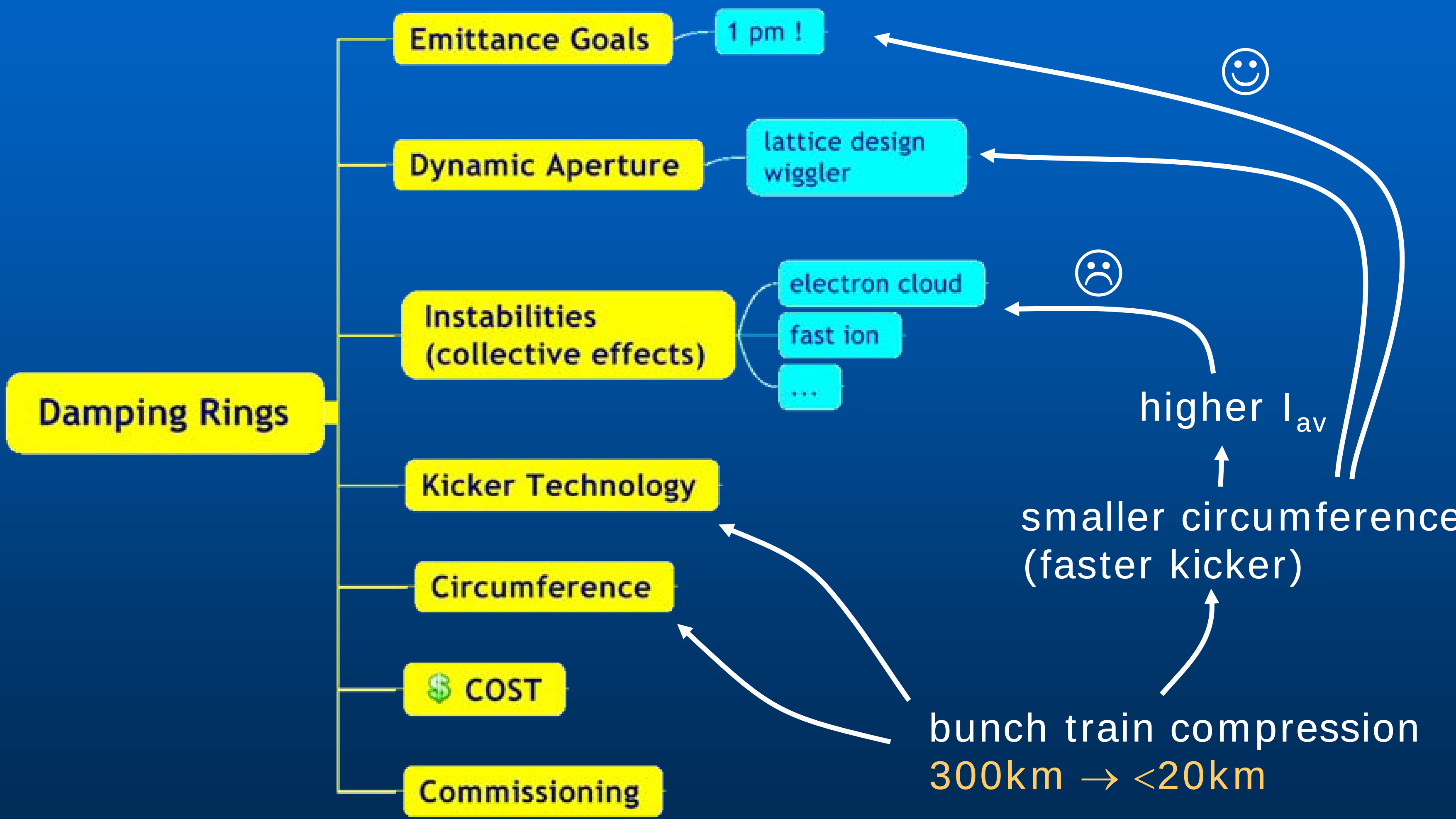
Not cost drivers

But can be L performance bottlenecks

Many challenges!

More Decisions to be Made!

Damping Rings

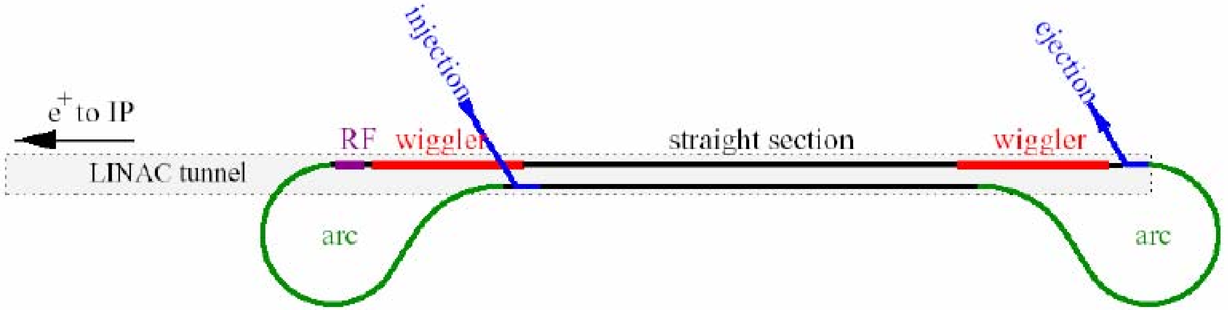


DR Design Approaches: Example #1, the TESLA TDR lattice

5 GeV, 17 km lattice (arcs 1 km each, straights 15 km total).

Bunches spaced by 20 ns, injected and extracted individually.

Positron damping ring requires 440 m of wiggler to achieve damping time of 27 ms.



Schematic of Dogbone Damping Ring from TESLA TDR

Strengths:

- Relatively small amount of extra tunnel required.
- Large circumference reduces average current, and helps mitigate some instabilities.
- Flexibility in modes of operation (e.g. could double number of bunches)

Weaknesses:

- Large space-charge tune shift needs to be corrected using coupling-bumps.
- Sensitive to stray magnetic fields.

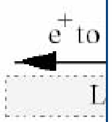
see A. Wolski's talk: http://lcdev.kek.jp/ILCWS/Talks/14wg3-10-WG3-10_DR_Wolski.pdf

DR Design Approaches: Example #1, the TESLA TDR lattice

5 GeV, 17

Bunches s

Positron d



Strengths
- Relat
- Larg
- Flexi

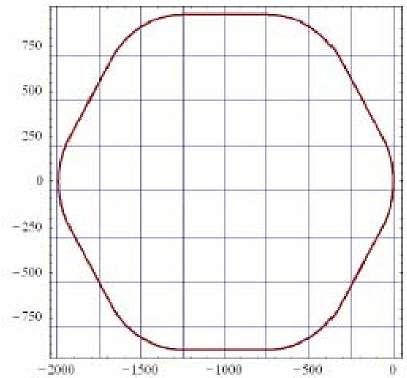
Weakness
- Larg
- Sens

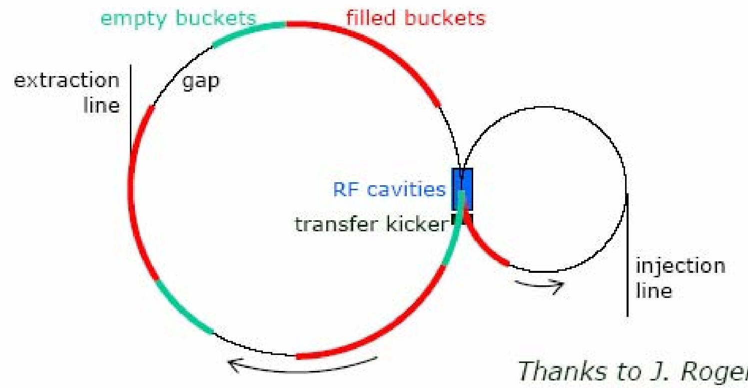
DR Design Approaches: Example #2, the FNAL 6 km lattice

5 GeV, 6 km lattice (six-fold symmetry).

Injection/extraction scheme uses 6 ns rise-time, 60 ns fall-time kicker.

Lattice documented in FERMILAB-TM-2272-AD-TD
http://www.hep.uiuc.edu/home/g-gollin/linear_collider/Fermilab_damping_ring_report.pdf





Thanks to J. Rogers and G. Dugan (Cornell)

Strengths:
- Relatively small circumference reduces space-charge effects.
- Reduced amount of wiggler needed to achieve required damping rate.
- Injection/extraction scheme allows use of slow fall-time kicker.

Weaknesses:
- Higher average current makes electron-cloud and ion effects more difficult.

see A. Wolski's talk: http://lcdev.kek.jp/ILCWS/Talks/14wg3-10-WG3-10_DR_Wolski.pdf

DR Design Approaches: Example #1, the TESLA TDR lattice

5 GeV, 17

Bunches s

Positron d

e+ to

L

Strengths

- Relat
- Larg
- Flexi

Weakness

- Larg
- Sens

DR Design Approaches: Example #2, the FNAL 6 km lattice

5 GeV, 6 k

Injection/e

Lattice doc

http://www.hep.

Strengths:

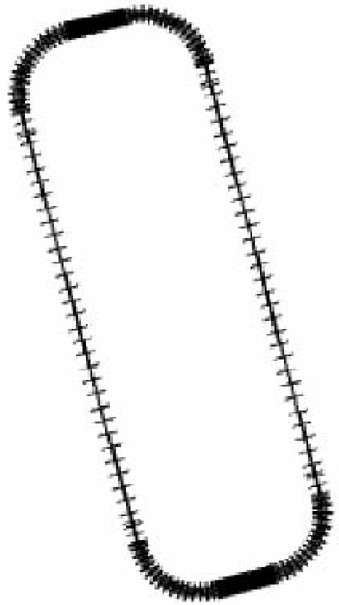
- Relati
- Reduc
- Inject

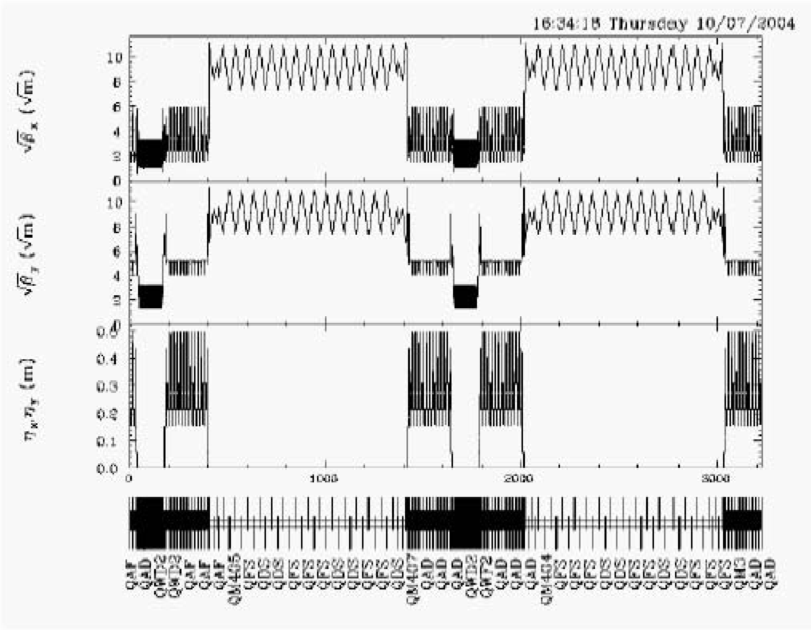
Weaknesse

- Highe

DR Design Approaches: Example #3, the KEK 3 km lattice

5 GeV, 3.2 km lattice (racetrack design).



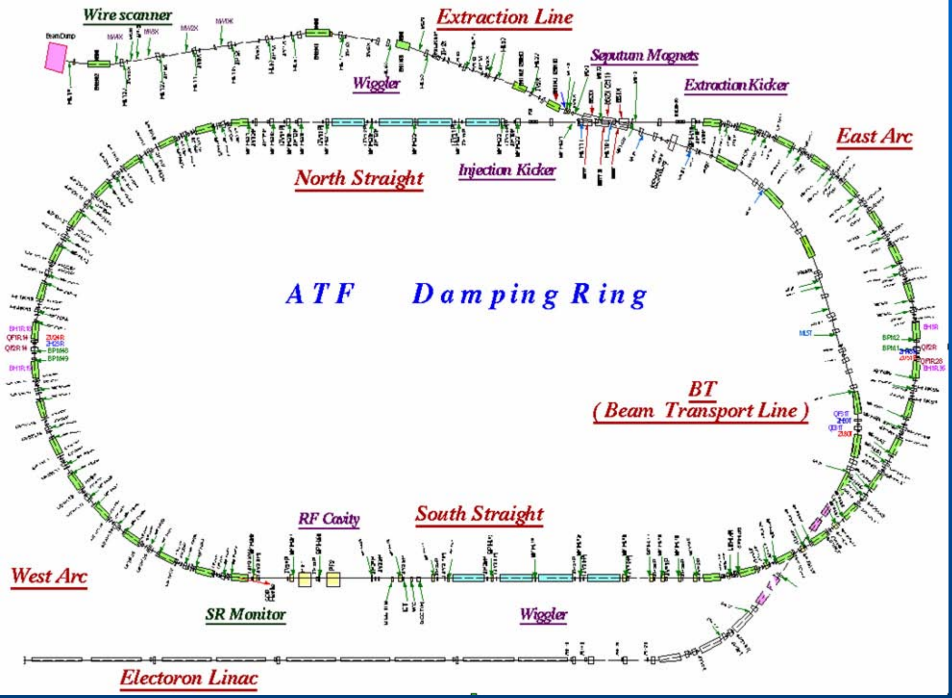


Lattice layout and optical functions in KEK 3 km damping ring.

S. Kuroda and J. Urakawa (KEK)

see A. Wolski's talk: http://lcdev.kek.jp/ILCWS/Talks/14wg3-10-WG3-10_DR_Wolski.pdf

ATF @ KEK



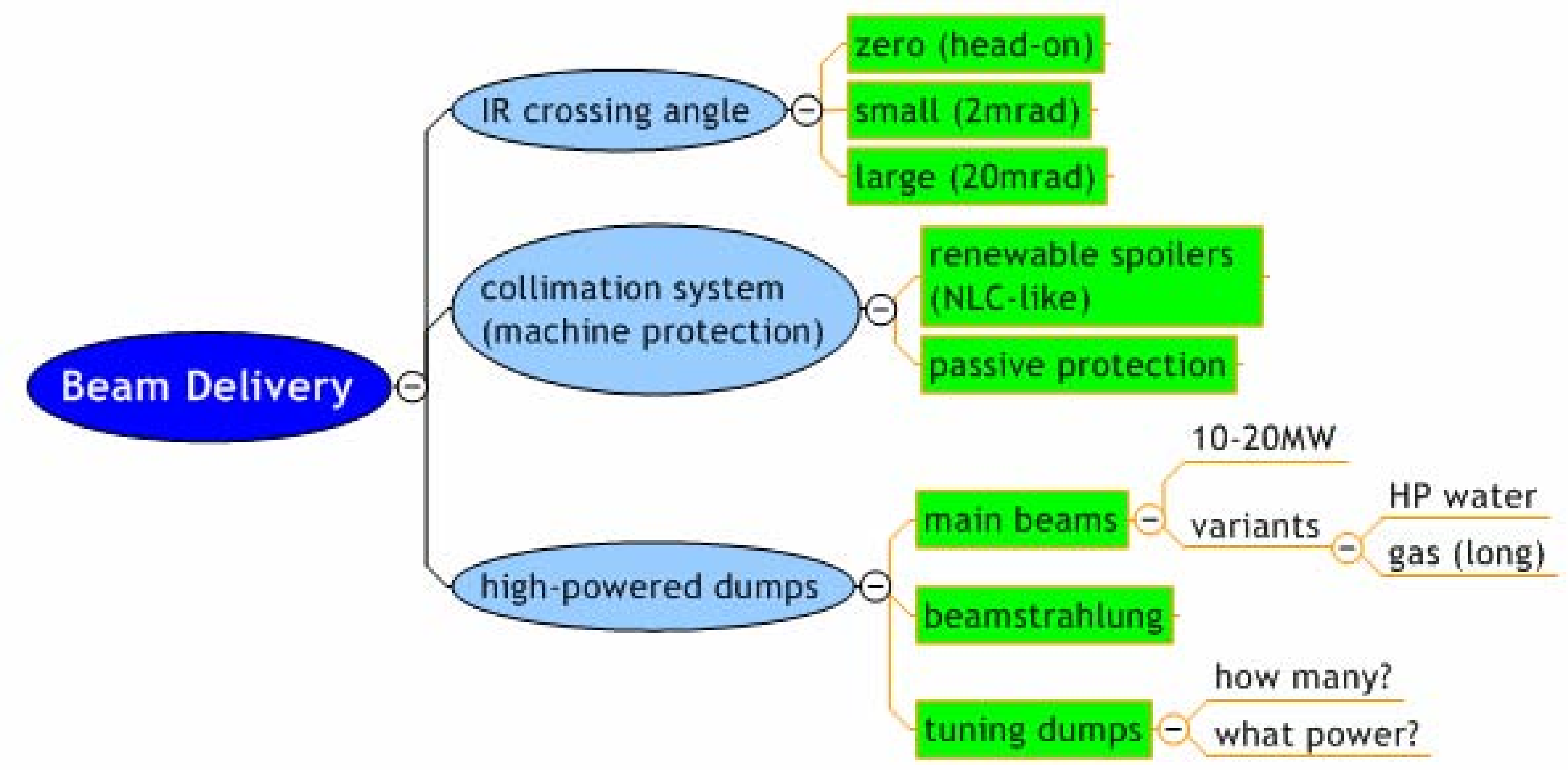
E	1.28 GeV
N	2×10^{10} e/bunch
bunches	1-20
ε x/y	1.5nm / 4pm

20 weeks/year
2 weeks/month

- emittance tuning
- wiggler dynamics
- collective effects
- multi-bunch
- fast kicker technology
- diagnostics test bed

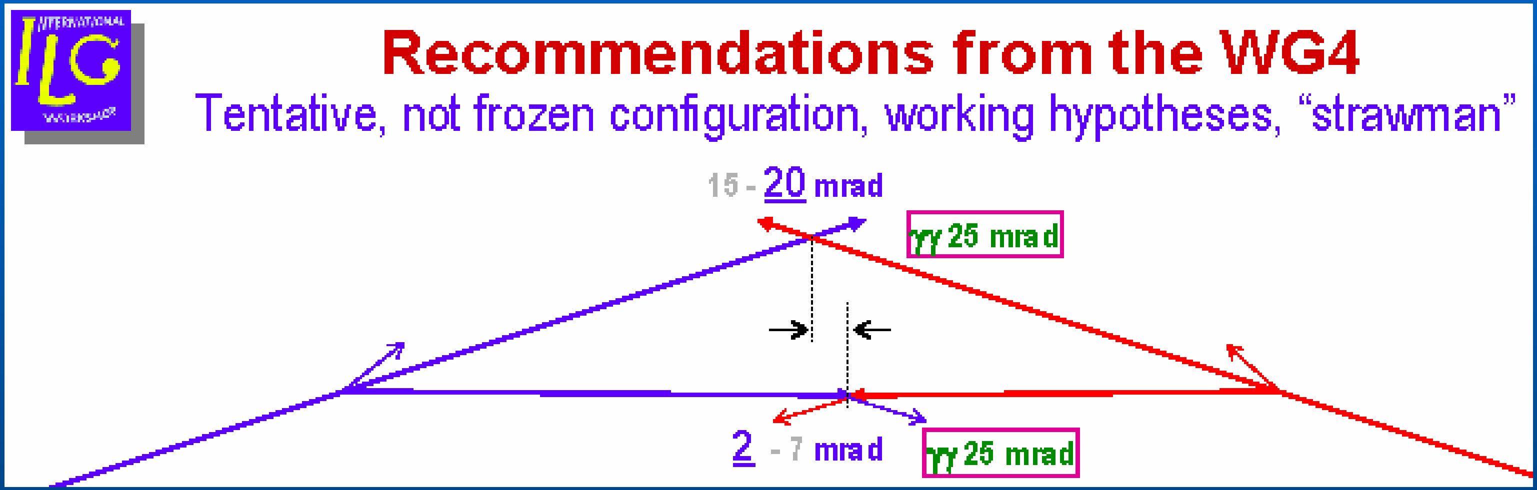

wiggler magnets

BDS Issues



very active (international) group!

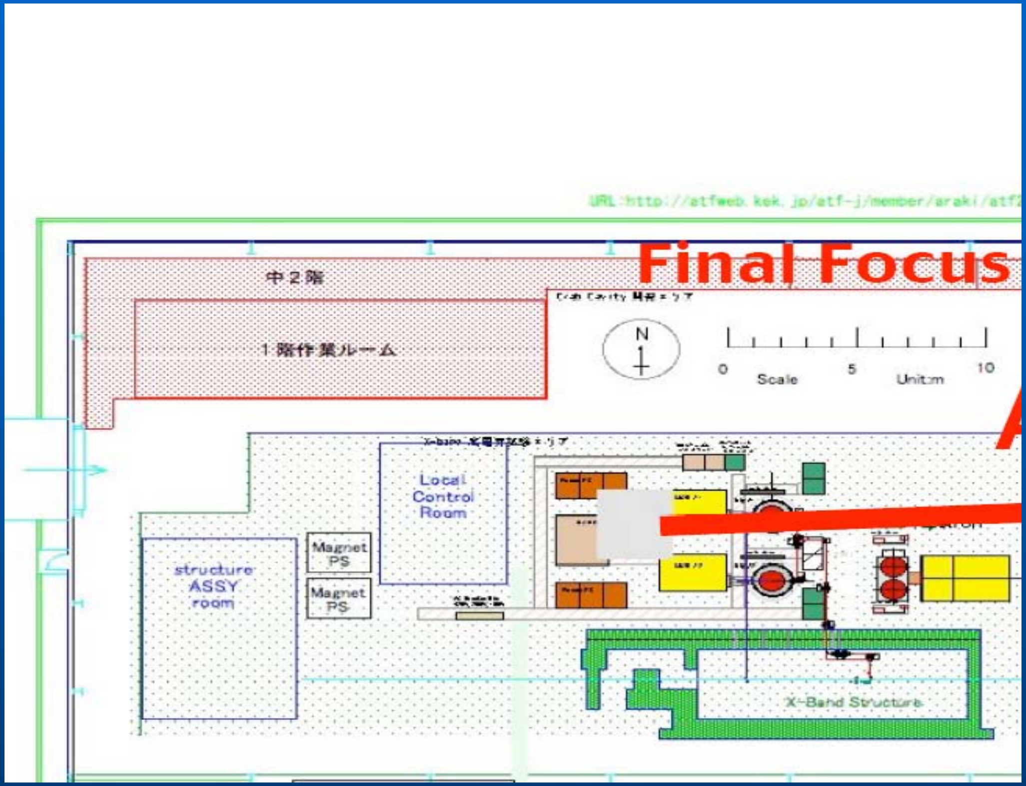
BDS Strawman Model



Discussion on angles between the Linacs:

- Multi-TeV upgradeability argument is favoured by many
- Small crossing angle is disfavoured by some

ATF-2: FFTB @ ATF



International Collaboration

(ongoing discussions)

Begin construction 8.2006

Begin operation 1.2007

- Test of local correction FF optics
- 35nm IP beam size
- Test facility for stabilisation techniques (beam-based feedback and mechanical: goal 2nm at IP)
- Long term stability studies
- …

Positron Source

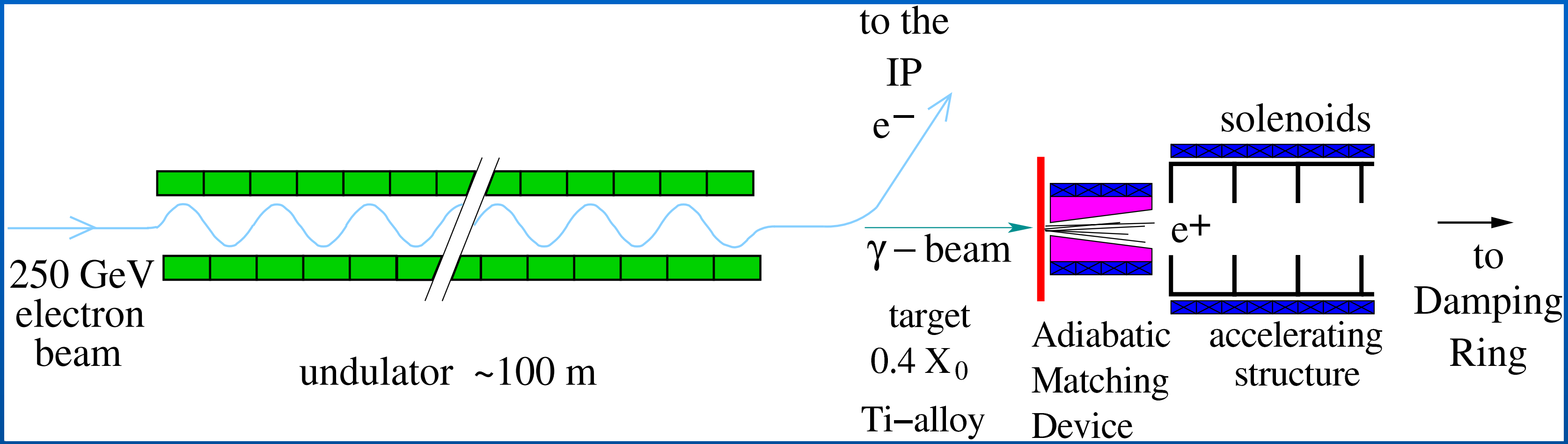
- Large amount of charge to produce
- Three concepts:
  - undulator-based (TESLA TDR baseline)
  - ‘conventional’
  - laser Compton based

Hotly debated subject.

Parameters of existing and planed positron sources

	rep rate	# of bunches per pulse	# of positrons per bunch	# of positrons per pulse
TESLA TDR	5 Hz	2820	$2 \cdot 10^{10}$	$5.6 \cdot 10^{13}$
NLC	120 Hz	192	$0.75 \cdot 10^{10}$	$1.4 \cdot 10^{12}$
SLC	120 Hz	1	$5 \cdot 10^{10}$	$5 \cdot 10^{10}$
DESY positron source	50 Hz	1	$1.5 \cdot 10^{9}$	$1.5 \cdot 10^{9}$

Undulator-Based



6D e+ emittance small enough that (probably) no pre-DR needed [shifts emphasis/challenge to DR acceptance]

Lower *n* production rates (radiation damage)

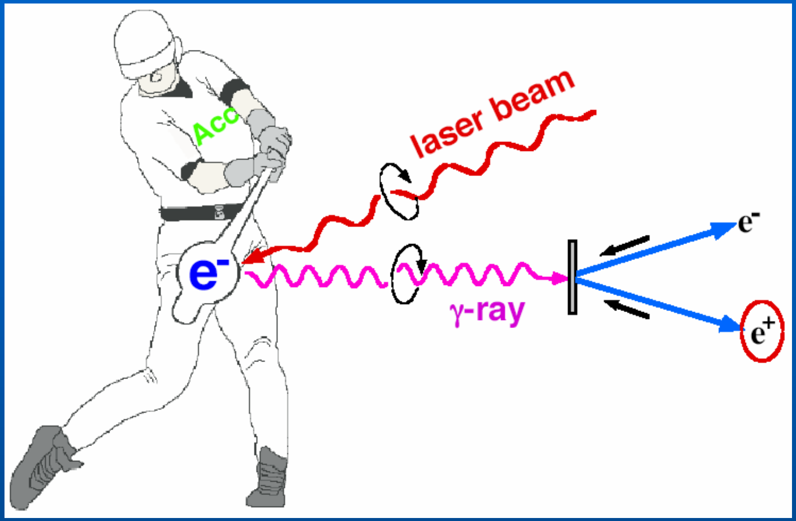
Need high-energy e- to make e+ (coupled operation) ☹
Makes commissioning more difficult

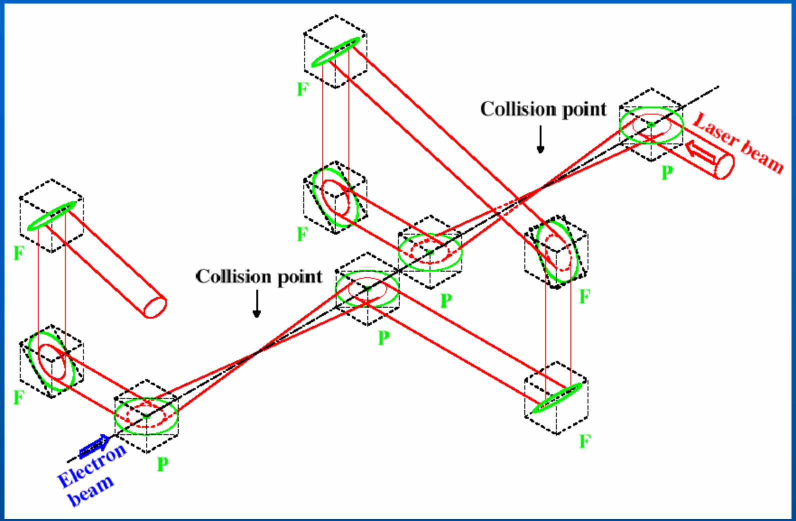
Polarised positrons (almost) for free ☺

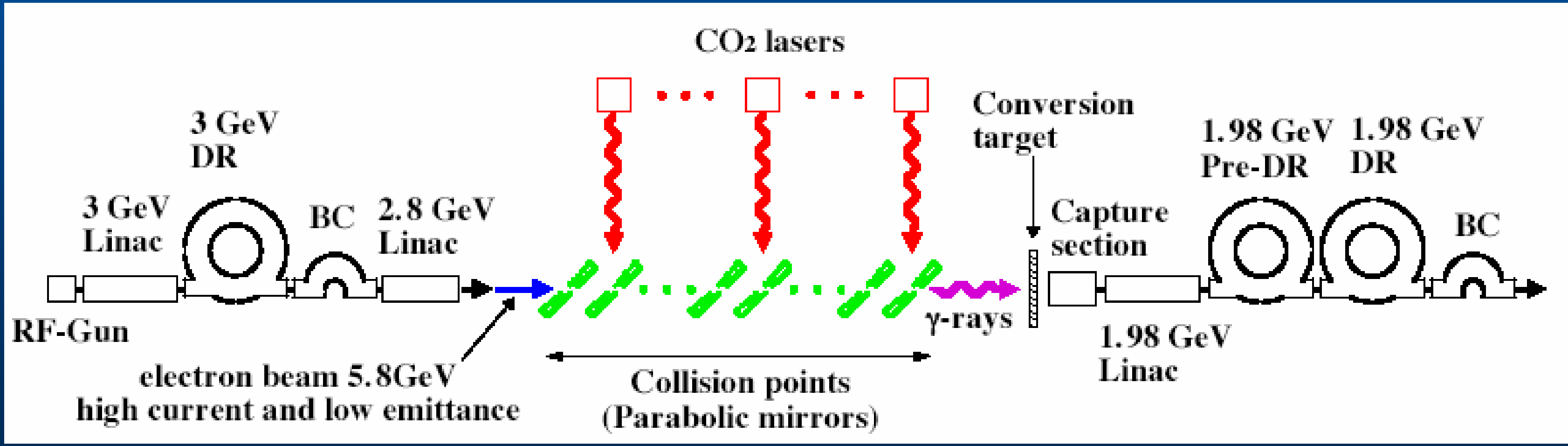
Conventional

- Extrapolation of existing methods
  - SLC e+ source
- Extremely challenging for ILC pulse structure
  - feasibility still a question
- Requires thick target(s)
  - High(er) n production – radiation damage a primary issue
  - Large e+ emittance probably means pre-DR needed.
- Completely de-couples e^+ from e^- machine ☺
  - greater flexibility ✓
  - operability ✓
  - commissioning ✓

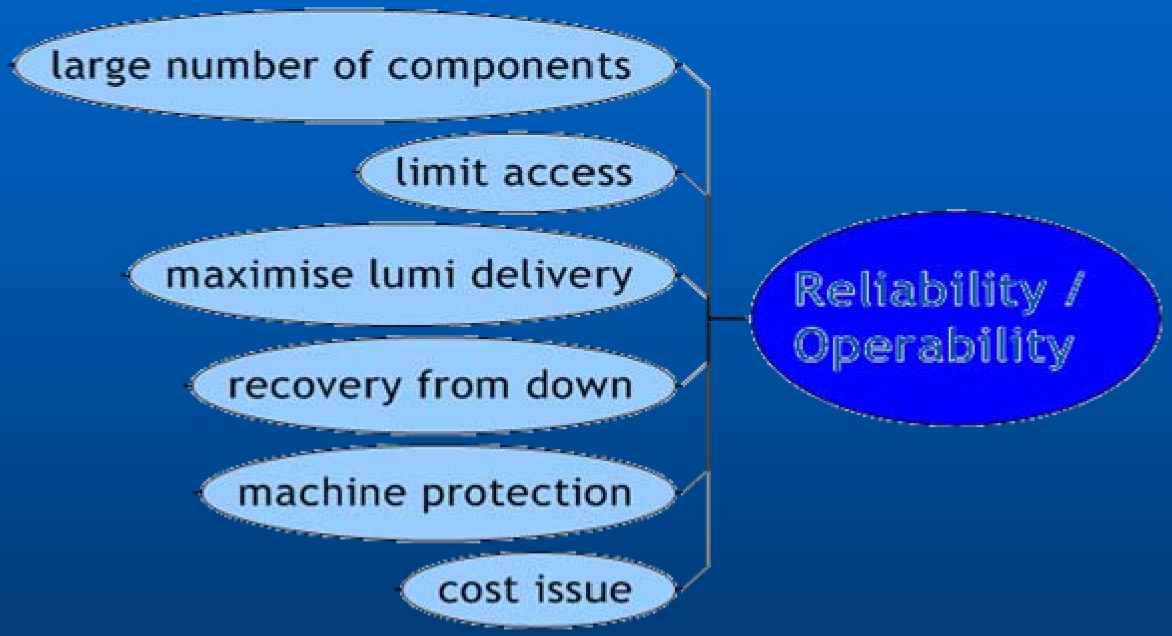
Compton Source (KEK)







Reliability / Operability



A major issue for ILC – needs much more work

Current state-of-the-art is Tom Himel study for USCWO

Summary

- The ILC is ambitious project which pushed the envelope in every subsystem:
  - Main SCRF linac — cost driver $$$
  - sources
  - damping rings
  - beam delivery

  } *L* performance bottleneck (sources, damping rings, beam delivery)

Summary

- The ILC is ambitious project which pushed the envelope in every subsystem:
  - Main SCRF linac — cost driver $$$
  - sources
  - damping rings
  - beam delivery

  (sources, damping rings, beam delivery: L performance bottleneck)

- Still many accelerator physics issues to deal with, but **reliability** and **cost issues** are probably the greater challenges
- Probably in excess of 3000 man-years already invested in design work.
  - but still plenty for you to do if you want to join us ☺