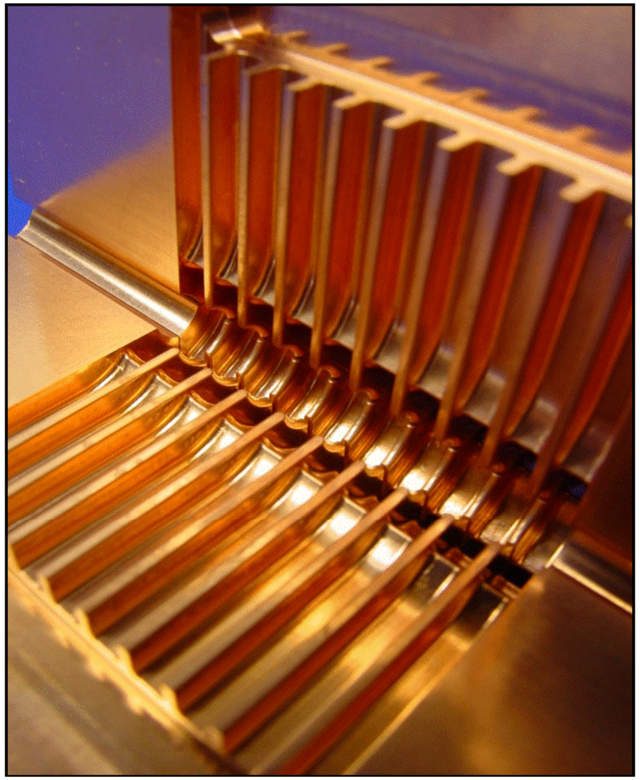
CLIC

Frank Tecker – CERN

- Introduction
- Room temperature RF cavities
- CLIC (Compact Linear Collider)
- CTF3 (CLIC Test Facility)
- Conclusion

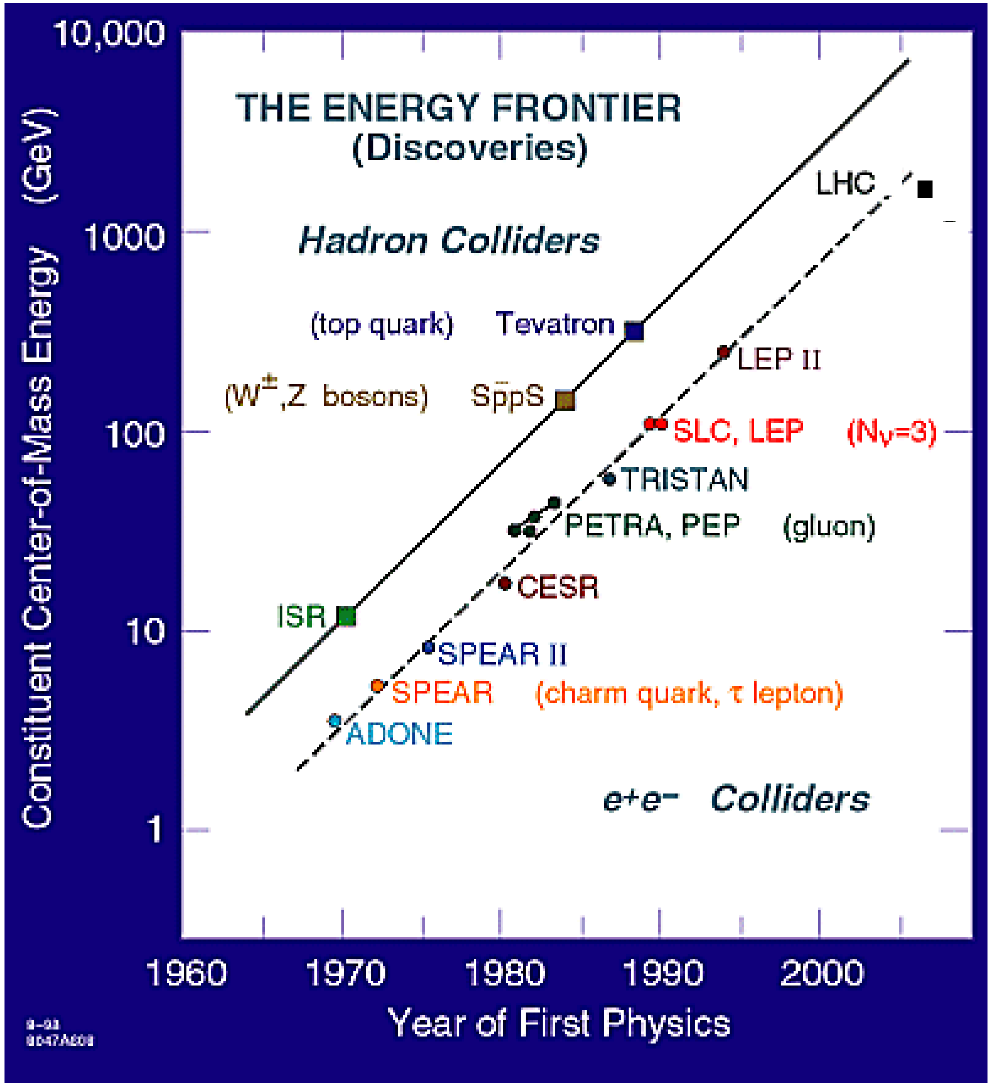


Preface

- Complex topic
- Approach:
  - Explain the fundamental effects and principles
    that leads to differences between SuperConducting (SC)
    and normal conducting (NC) technology
  - I will not go into technical details
  - Try to avoid formulae as much as possible
- Goal: You understand
  - Basic principles
  - The driving forces and limitations in NC linear collider design
  - The basic building blocks of CLIC

- Ask questions at any time!

Path to higher energy

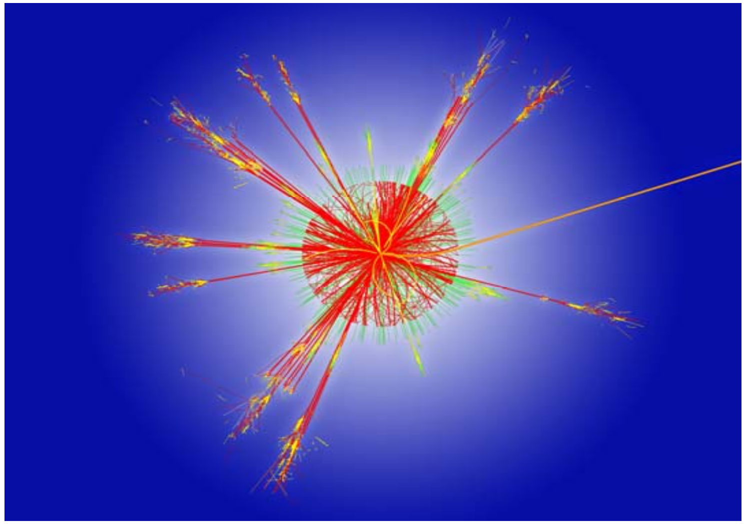


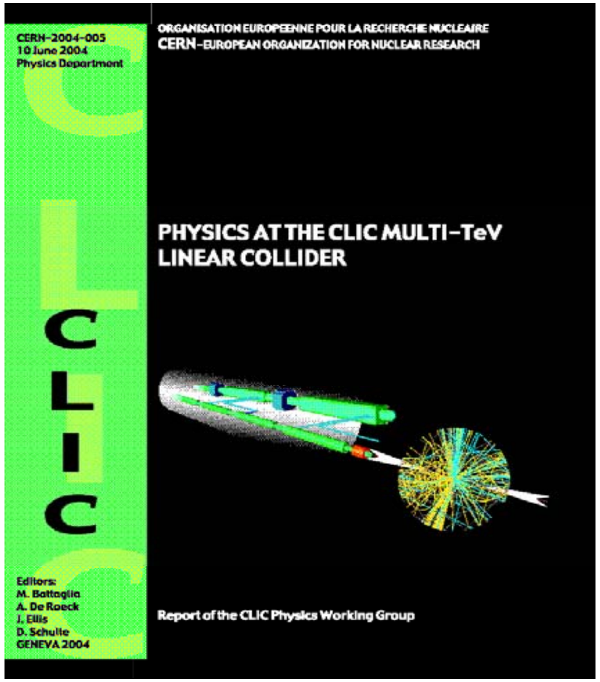
- History:
  - Energy constantly increasing with time
  - Hadron Collider at the energy frontier
  - Lepton Collider for precision physics
- LHC coming online soon
- Consensus to build Lin. Collider with E_{cm} > 500 GeV to complement LHC physics (*European strategy for particle physics* by CERN Council)

Linear Collider e+e- physics

- Higgs physics
  - Tevatron/LHC should discover Higgs (or something else)
  - LC explore its properties in detail
- Supersymmetry
  - LC will complement the LHC particle spectrum
- Extra spatial dimensions
- New strong interactions
- . . .

  => a lot of new territory to discover beyond the standard model
- Energy can be crucial for discovery!
- "Physics at the CLIC Multi-TeV Linear Collider" CERN-2004-005

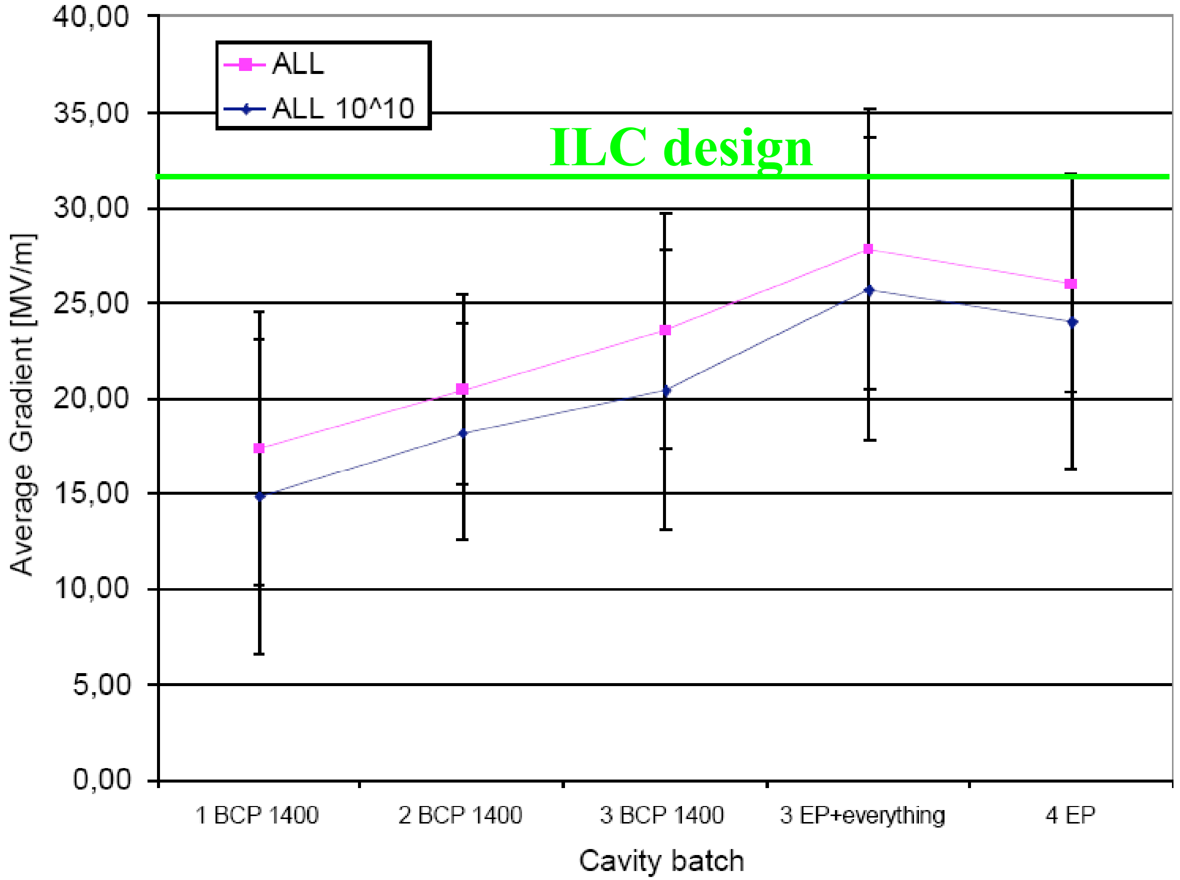


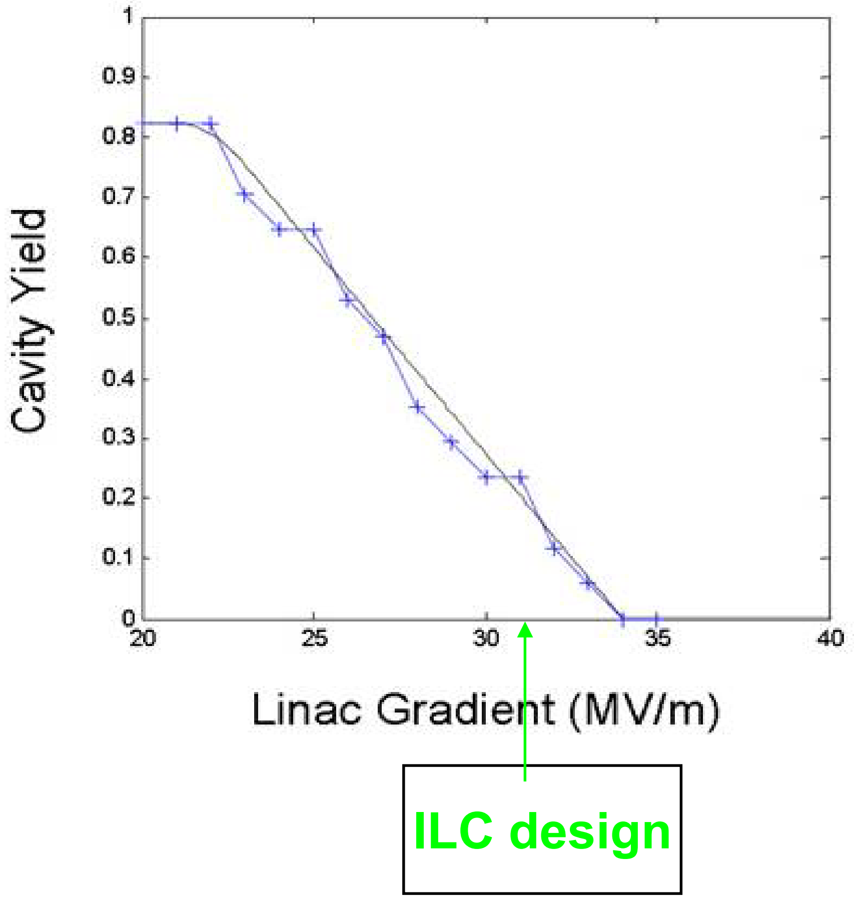


Linear Colliders - Energy

- Historical background: 2004 – ILC-TRC review
  - Evaluation of linear collider (LC) projects (NLC/JLC, TESLA and CLIC)
  - Decision for Superconducting Accelerator Technology for LC with E_{cm} = 0.5-1 TeV
- Consequences:
  - End of competition between normal conducting and SC schemes
  - Concentration of R&D on superconducting ILC scheme
- What about E_{cm} >> 0.5-1 TeV ???
  - LC size has to be kept reasonable (<50km?) gradient >100MV/m needed for E_{cm} = 5 TeV
  - SC technology excluded, fundamental limit ~60 MV/m
  - Normal conducting RF structures, but not trivial either!
  - CLIC study for multi-TeV linear collider

Achieved SC accelerating gradients





With the presently available technology **average 28 MV/m:**

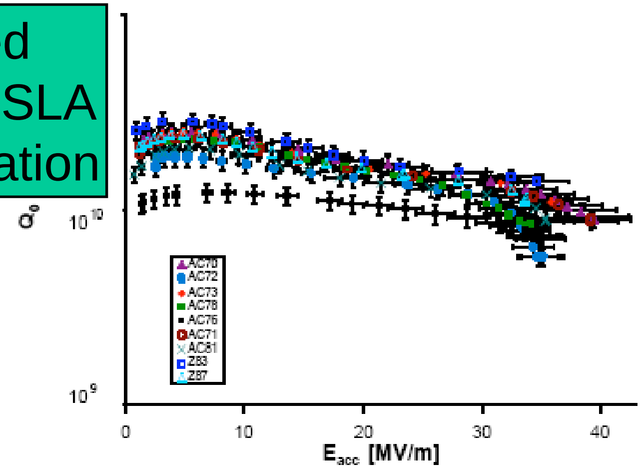
Cost increase ~7 %

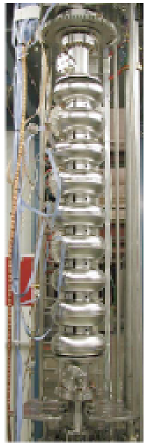
B. Foster

R&D of SC RF cavities

Derived From TESLA Collaboration

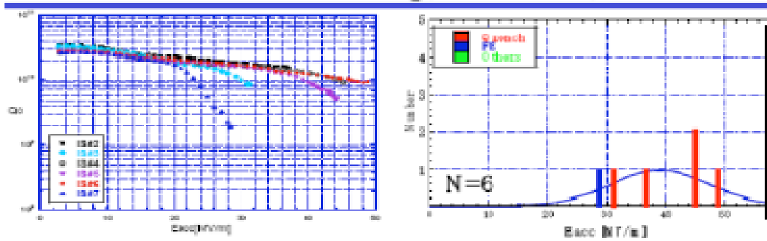
TESLA Nine-Cells: (Proof-of-Principle)
Best tests of 9 best Cavities (Vertical Test Results)





(A) CBP+CP+Anneal+EP(80μm) +HPR+Baking(120C*48hrs)

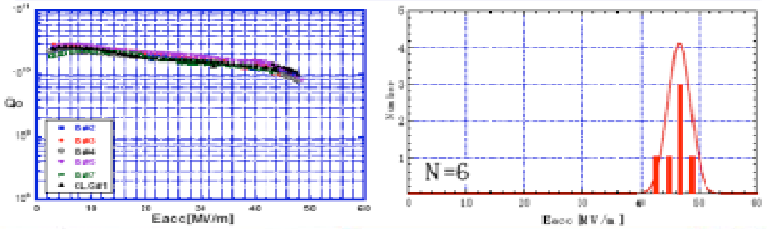
K. Saito et al.



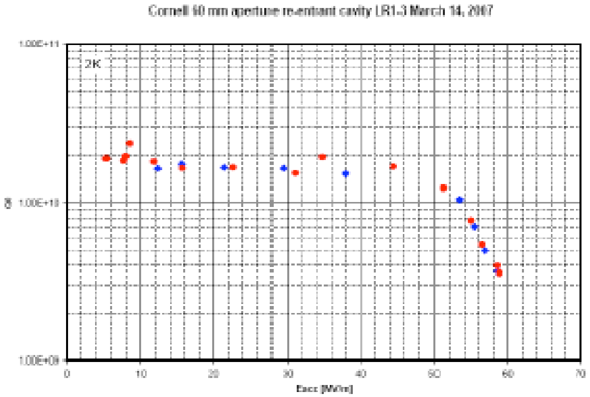
New preparation techniques

(D) +EP(20μm)+EP(3μm, fresh, closed) +HF* +HPR+Baking (120C*48hrs)

K. Saito et al.

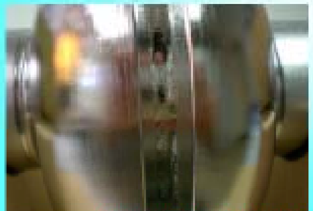


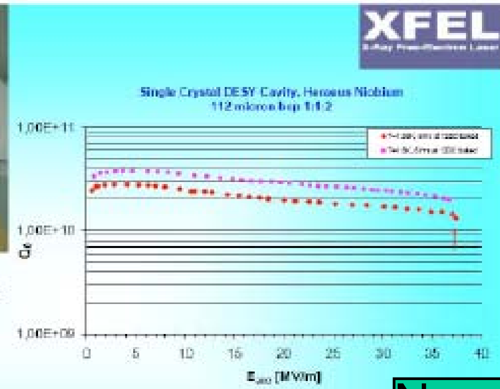
60mm-Aperture Re-Entrant Cavity, 58 MV/m!
KEK/Cornell Collaboration



New cavity shapes

DESY single crystal cavity 1AC8 build from Heraeus disc by rolling at RWTH, deep drawing and EB welding at ACCEL





Q(Eacc) curve after only 112 μ... and in situ baking 120°C for ...

Preparation and RF tests P.Kneisel, JLab

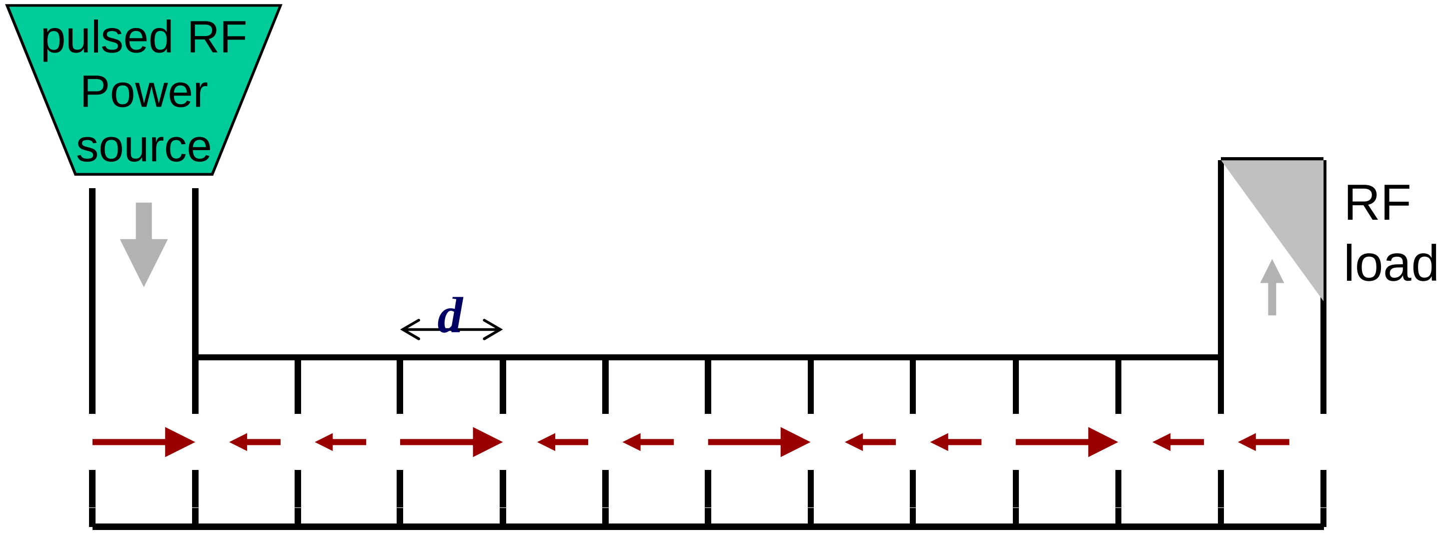
W. Singer, Single Crystal Nb Technology Workshop, CBMM, Brazil, Oct. 30-Nov. 1, 20...

New material
Large grains
Higher perf
Lower cost

Normal conducting structures

- Higher gradients reachable with normal conducting structures
- But! Compare to advantages of SC RF cavities:
  - Very low losses due to tiny surface resistance
  - High efficiency
  - Long pulse trains possible
  - Favourable for feed-backs within the pulse train
  - Standing wave cavities with low peak power requirements
  - Lower frequency => Large dimensions and lower wakefields
- => Important implications for the design of the collider

- NC standing wave structures would have high Ohmic losses
- => traveling wave structures



- RF 'flows' with group velocity v_G along the structure into a load at the structure exit
- Shorter fill time $T_{fill} = \int 1/v_G \, dz$ order <100 ns compared to ~ms for SC RF

RF efficiency: cavities

- Fields established after cavity filling time
- Steady state: power to
  beam, cavity losses, and (for TW) output coupler
- Efficiency:

$$\eta_{RF\rightarrow beam} = \underbrace{\frac{P_{beam}}{P_{beam} + P_{loss} + P_{out}}}_{\approx 1 \text{ for SC SW cavities}} \frac{T_{beam}}{T_{fill} + T_{beam}}$$

- => long pulse length favoured
- NC TW cavities have smaller filling time T_{fill}
  => Second term is higher for NC RF
- Typical values SC: $\eta = 0.6$
  NC: $\eta = 0.3$

Limitations of Gradient E_{acc}

- Surface magnetic field
  - Pulsed surface heating ⇒ material fatigue ⇒ cracks
- Field emission due to surface electric field
  - RF break downs
  - Break down rate ⇒ Operation efficiency
  - Local plasma triggered by field emission ⇒ Erosion of surface
  - Dark current capture
    ⇒ Efficiency reduction, activation, detector backgrounds
- RF power flow
  - RF power flow and/or iris aperture apparently have a strong impact on achievable E_{acc} and on surface erosion. Mechanism not fully understood

Pulsed surface heating

- Ohmic losses heat up the cavity during the RF pulse!
- Proportional to square root of pulse length
- Limits the maximum pulse length => short pulses (~few 100ns)

=> see homework

$$\Delta T = \sqrt{\frac{\mu_0}{2\pi}\frac{\omega t_P}{\sigma\,\lambda\,\rho\,c_H}}\,\hat{H}^2$$

ΔT temperature rise, σ electric conductivity

λ heat conductivity, ρ mass density

c_H specific heat, t_P pulse length

$\hat{H}$ peak magnetic field

$$\hat{H} = \frac{g_H}{377\,\Omega} E_{acc}$$

g_H geometry factor of structure design

typical value $g_H \approx 1.2$

Numerical values for copper

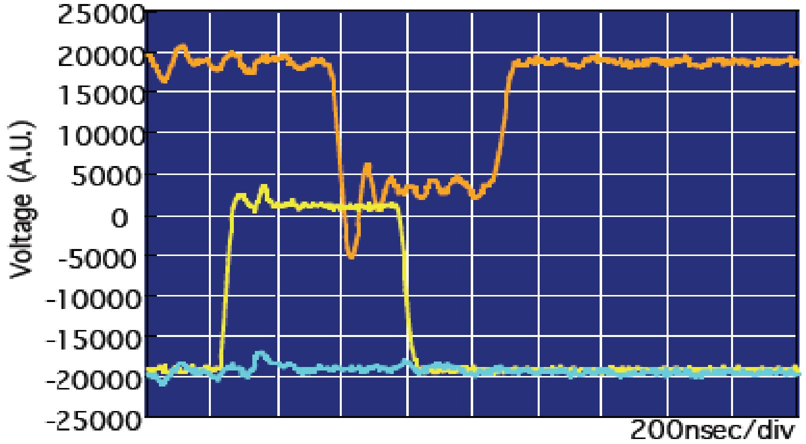
$$\Delta T \approx 4\cdot 10^{-17}\left[\frac{\mathrm{K\,m}^2}{\mathrm{V}^2}\right]\sqrt{t_P\, f}\; E_{acc}^2$$

$$\Delta T_{\max} \approx 50\ \mathrm{K}$$

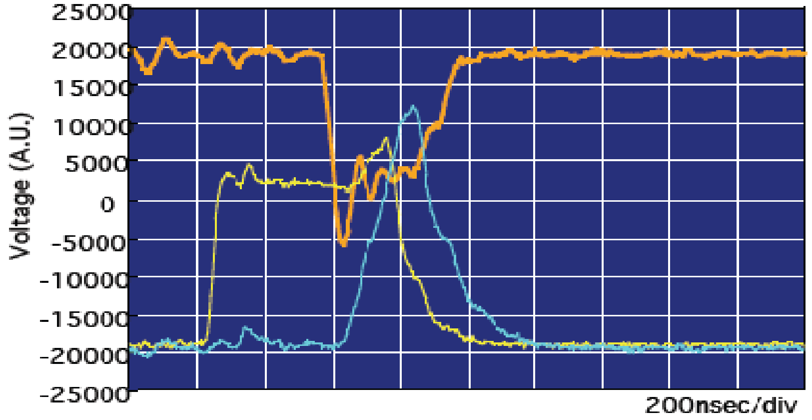
$$t_P < \left(\frac{\Delta T_{\max}}{4\cdot 10^{-17}}\right)^2 \frac{1}{f\, E_{acc}^4}$$

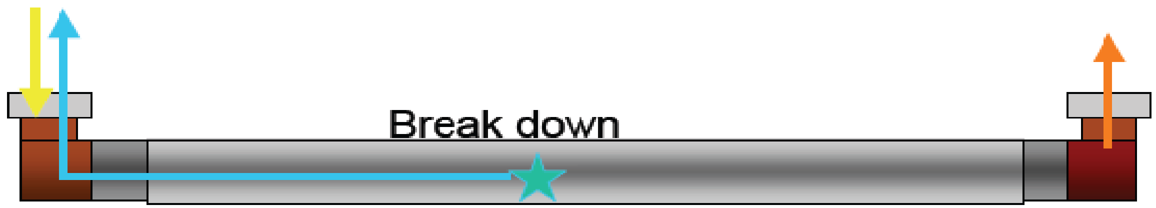
Breakdowns - RF wave form

Normal RF pulse



Break down





Incoming wave
Outgoing wave
Reflected wave

from S.Fukuda/KEK

- Pulses with breakdowns not useful for acceleration
- Low breakdown rate needed

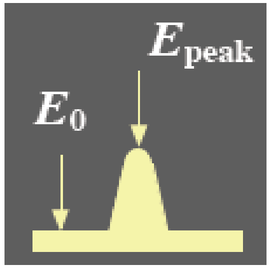
=> see homework

Phenomenology of RF breakdowns

- Breakdown events characterised by
  - always
    - disappearance of transmitted power
    - reflection of incident power
    - emission of intense bursts of fast electrons (E_{Kin}~100 keV)
    - acoustic shock wave (can be detected with accelerometer)
    - build up time ~ 20 ns
  - often
    - fast rise of gas pressure
    - emission of visible and UV light,
      light pulse longer than incident RF pulse (~ few ms)
    - emission of positive ions (E_{Kin}~few 100 eV),
      pulse longer than incident RF pulse (~ few ms)
- usually no precursor signals !

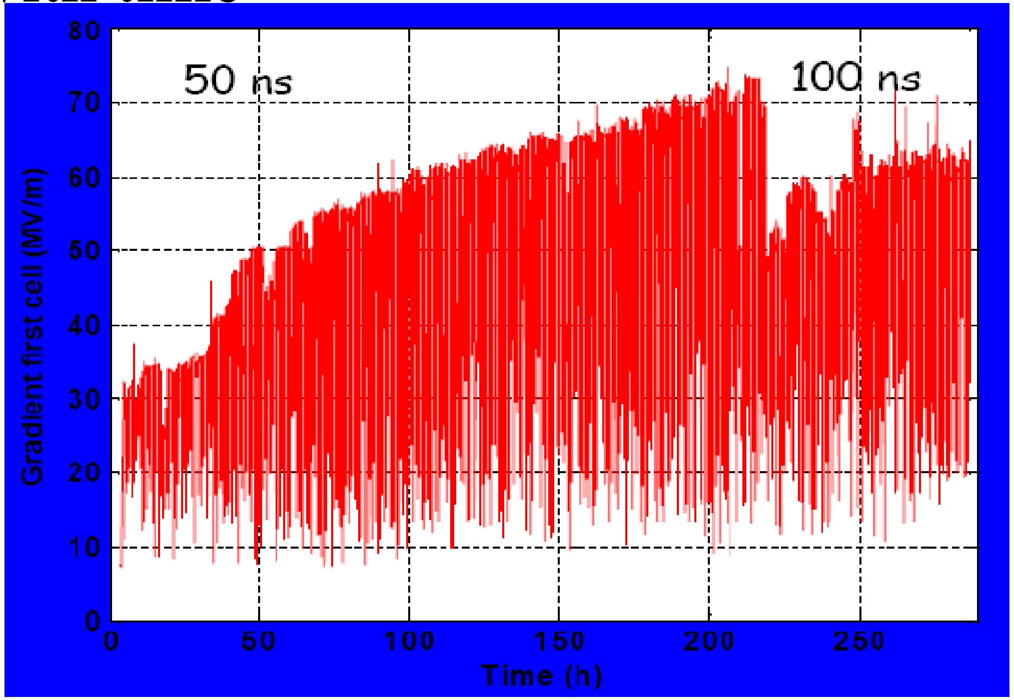
Structure conditioning

- Material surface has some intrinsic roughness (from machining)
- Leads to field enhancement $E_{\text{peak}} = \beta E_0$
  β field enhancement factor



- Need conditioning to reach ultimate gradient
  RF power gradually increased with time

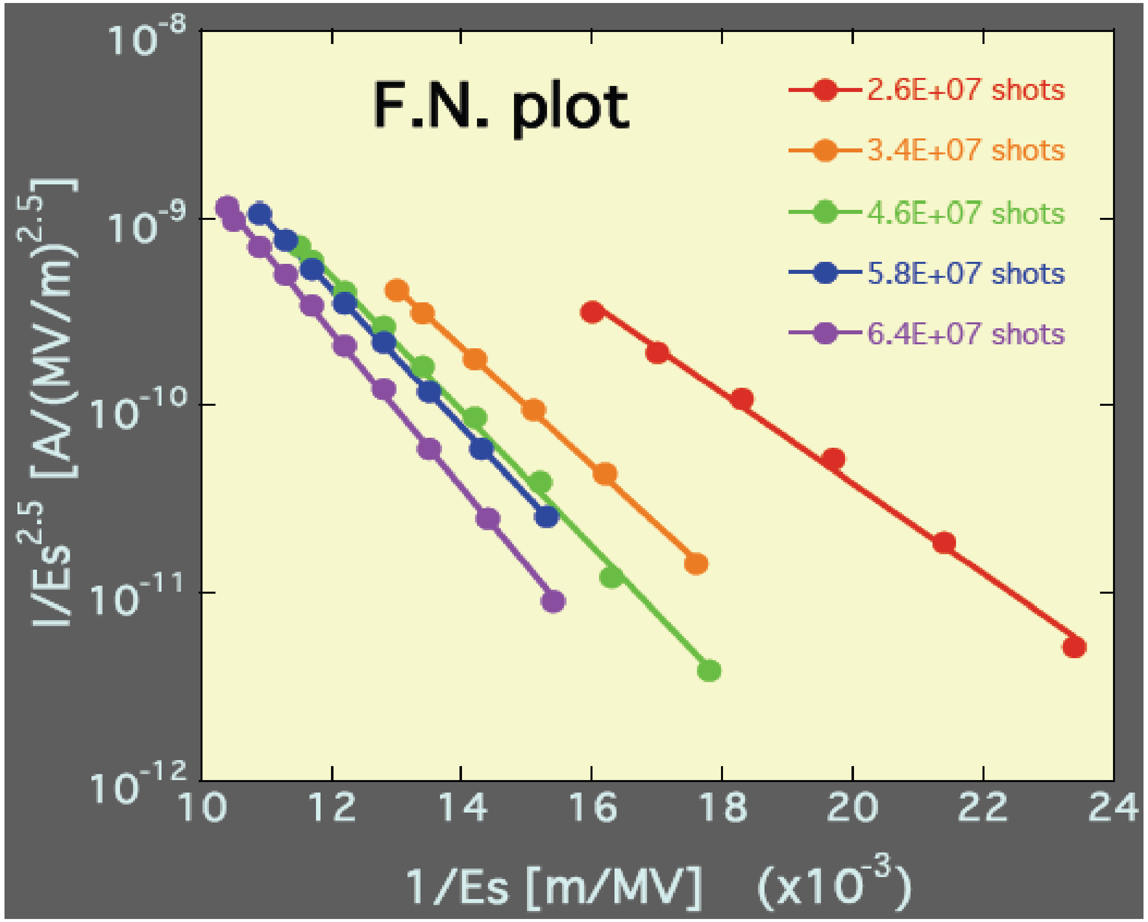
from S.Doebert



- RF processing can melt field emission points
  - Surface becomes smoother
  - field enhancement reduced
  - $\Rightarrow$ higher fields
    less breakdowns

Improvement by conditioning

higher emission



higher field

from S.Yamaguchi

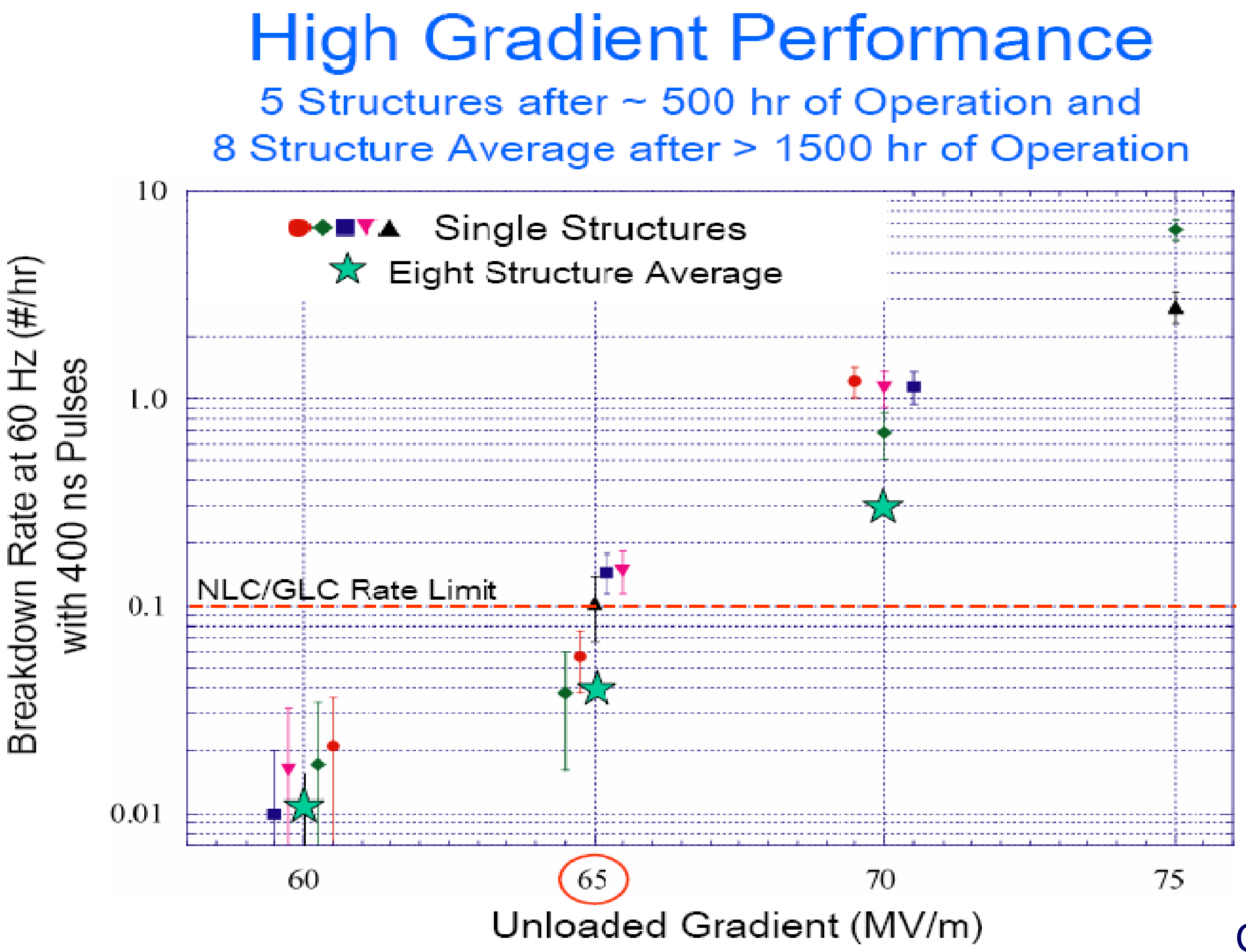
Fowler Nordheim law of field emission

$$j_{FN} \propto \frac{E_{peak}^{\ 2}}{\phi} e^{\frac{-k\phi^{1.5}}{E_{peak}}}$$

- Higher fields reachable
- Lower breakdown rate at a given field

Breakdown-rate vs gradient

- Higher breakdown rate for higher gradient



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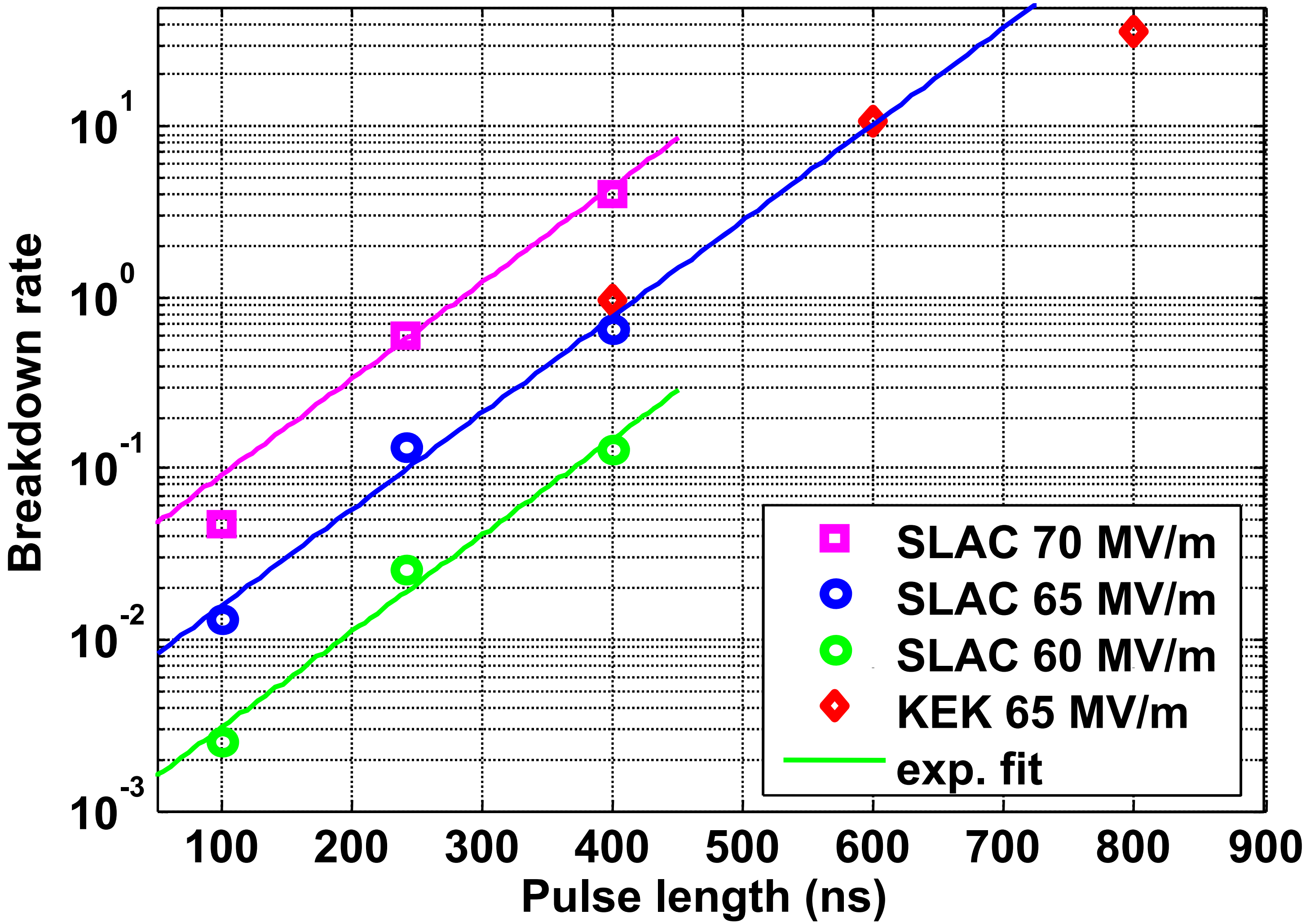
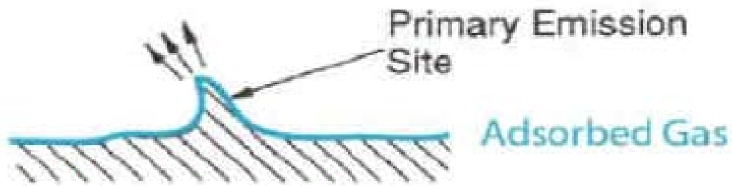
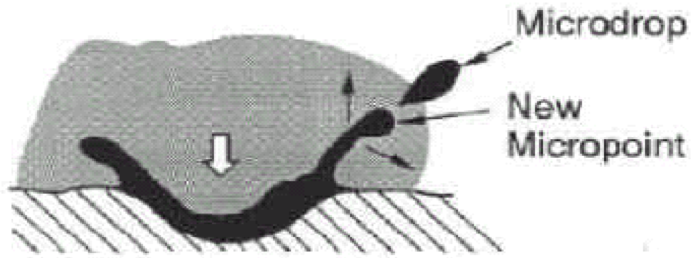
Breakdown-rate vs pulse length

- Higher breakdown rate for longer pulses

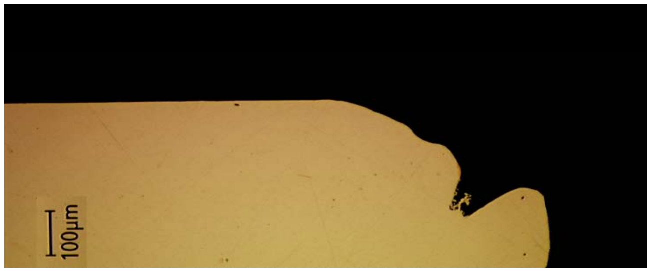


Conditioning limits

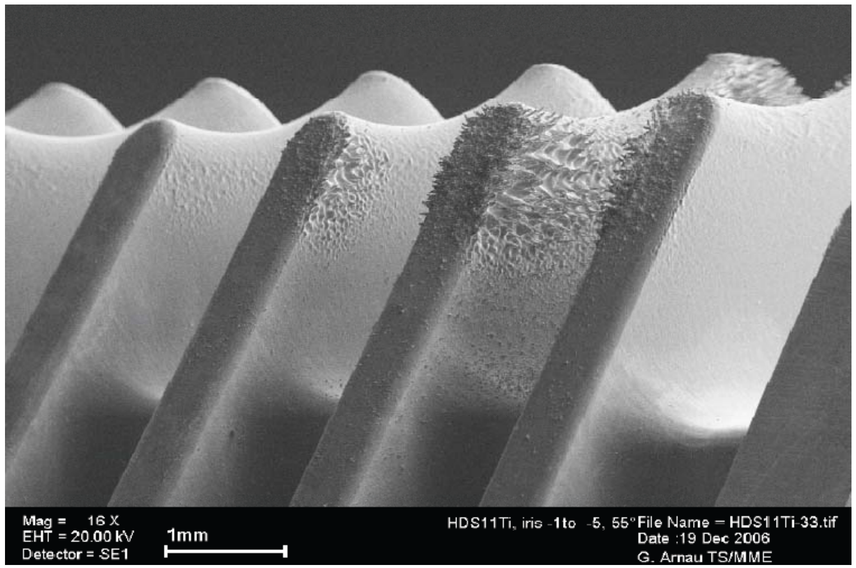




- More energy: electrons generate plasma and melt surface
- Molten surface splatters and generates new field emission points!
  ⇒ limits the achievable field
- Excessive fields can also damage the structures
- Design structures with low E_{surf}/E_{acc}
- Study new materials (Mo, W)



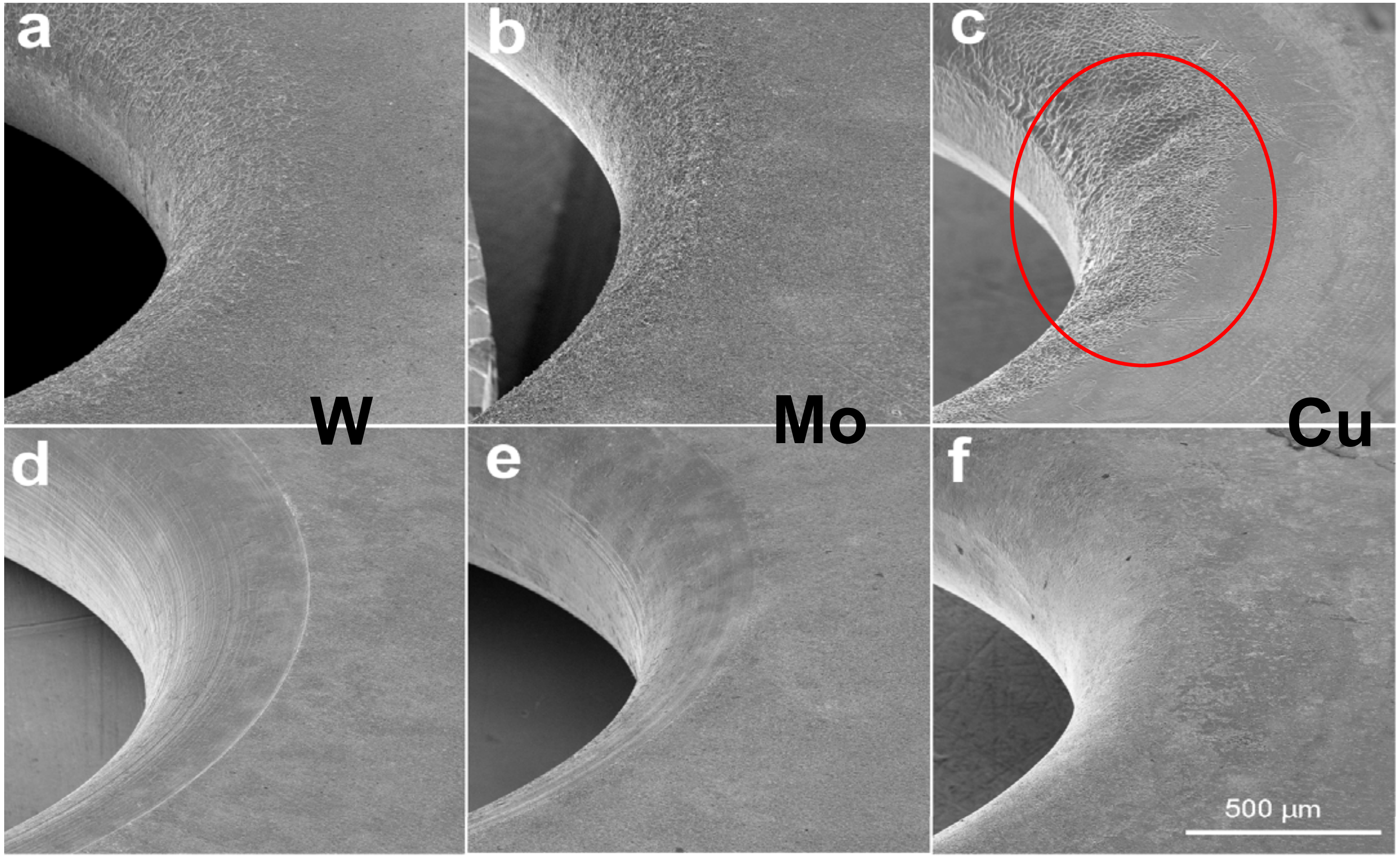
Damaged CLIC structure iris



Iris material tests in CTF2

First iris

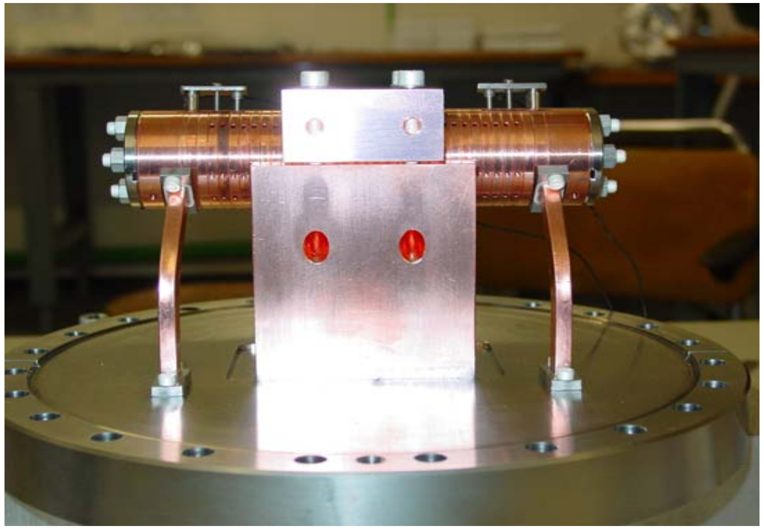
downstream iris



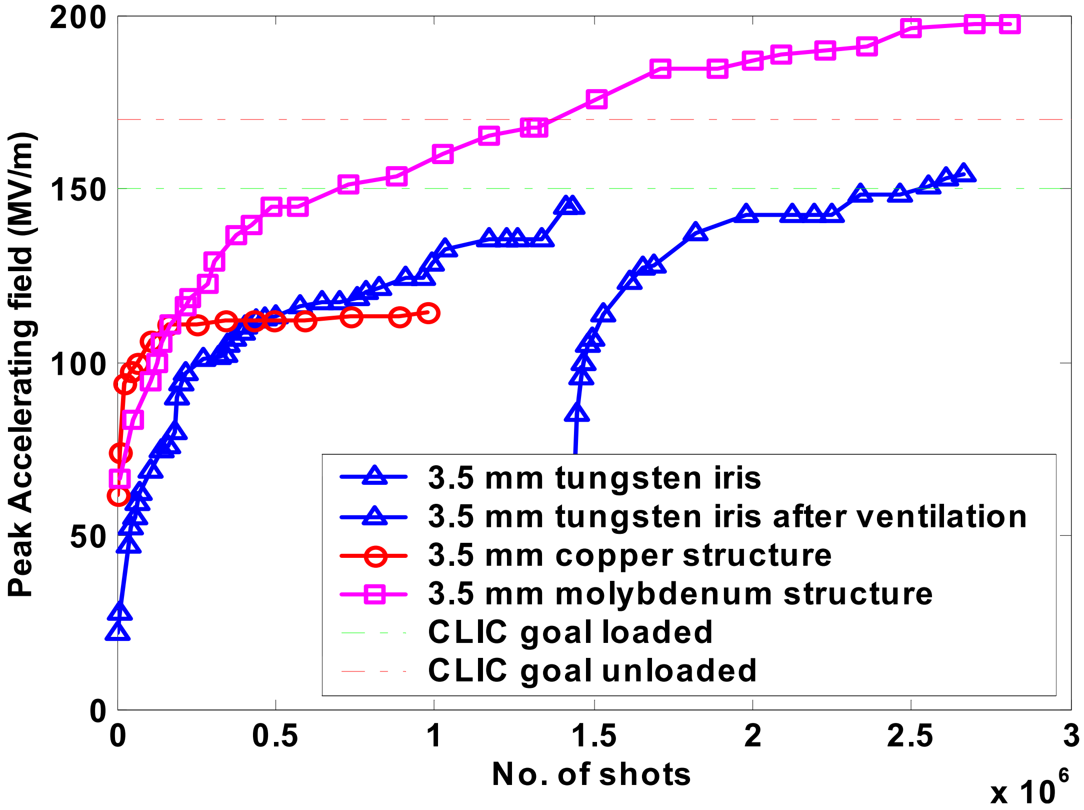
Damage on iris after runs of the 30-cell clamped structures tested in CTFII.
First (a, b and c) and generic irises (d, e and f) of W ,Mo and Cu structures respectively.

Achieved accelerating fields in CTF2

High gradient tests of new structures with molybdenum irises reached 190 MV/m peak accelerating gradient without any damage well above the nominal CLIC accelerating field of 150 MV/m but with RF pulse length of 16 ns only (nominal 200 ns)



30 cell clamped tungsten-iris structure



A world record !!!

Frequency choice for NC RF

- Shunt impedance $R_s \propto f^{1/2}$ (higher acceleration, as R_s=V^2/P)
- RF peak power $P_{rf} \propto 1/f^{1/2}$
- Stored energy $E \propto 1/f^2$
- Filling time $T_{fill} \propto 1/f^{3/2}$
- Structure dimensions $a \propto 1/f$
- Wakefields $W_\perp \propto f^3$

- The choice of frequency depends on the parameters above (cost issues!)
- Higher frequency is favourable for NC structures if you can manage the wakefield effects
- Actual frequency also depends on availability of RF power sources (high power klystrons up to ~17 GHz)

Power requirements

- Accelerating field: (transit time, field geometry)

$$E_{acc} = g\,E_0, \quad \text{with} \quad g_{Typical} \approx 0.6$$

- Stored e.m. energy:

$$W_{Linac} \approx \tfrac{\pi}{2}\varepsilon_0\, L\,\frac{E_{acc}^2}{g^2}(2.405\,\tfrac{c}{\omega})^2\, J_1(2.405)^2$$

$$\approx 140000\left[\frac{\mathrm{J\,m}}{\mathrm{V^2 s^2}}\right]\frac{L\,E_{acc}^2}{f^2} \propto \frac{V\,E_{acc}}{f^2}$$

- Peak power: (neglecting beam power)

$$P = -\frac{\omega}{Q}W \quad \text{power lost,} \quad Q \approx \frac{7\cdot 10^8}{\sqrt{f}} \quad \text{(typical value for Cu)}$$

$$\approx \frac{2\pi\, f^{-\frac{3}{2}}}{7\cdot 10^8}W \quad \approx 0.0013\left[\frac{\mathrm{J\,m}}{\mathrm{V^2 s^{3/2}}}\right]\frac{V\,E_{acc}}{\sqrt{f}}$$

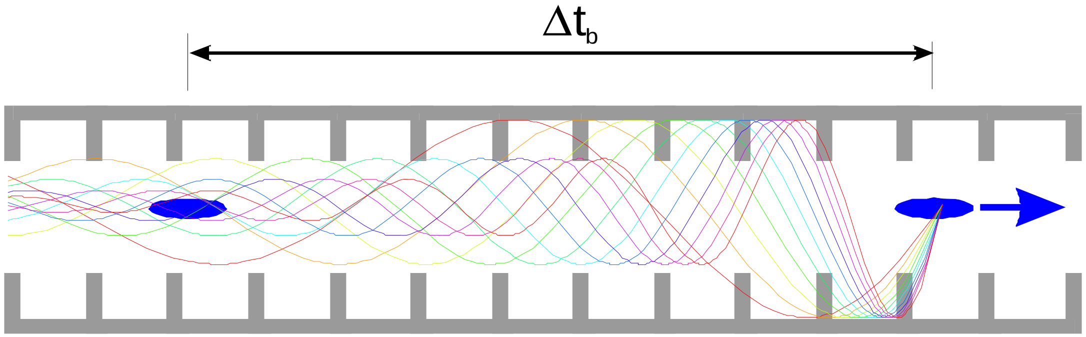
- Example:

$V = 1$ TeV $\quad E = 50$ MV/m $\quad L = 20$ km $\quad f = 3$ GHz

=> $\quad W = 0.8$ MJ $\quad P = 1.2$ TW $\quad P' = 60$ MW/m

- Would need 15000 80 MW klystrons, Not very practical!
  => higher frequency, pulse compression (NLC/JLC), drive beam (CLIC)

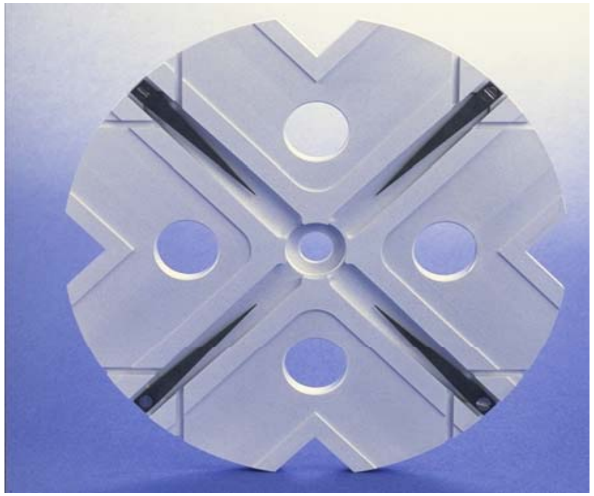
RF structures: transverse wakefields

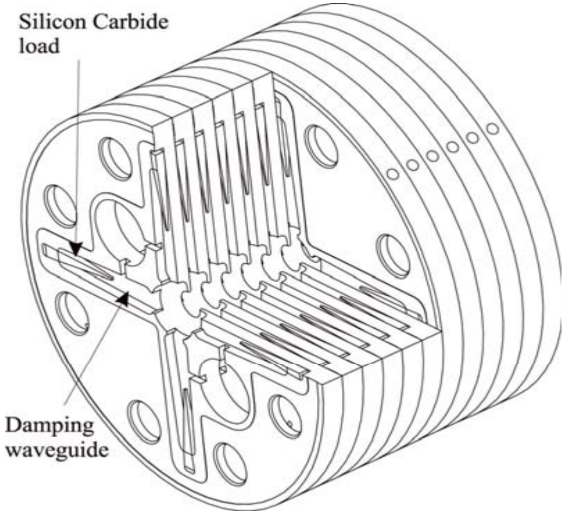


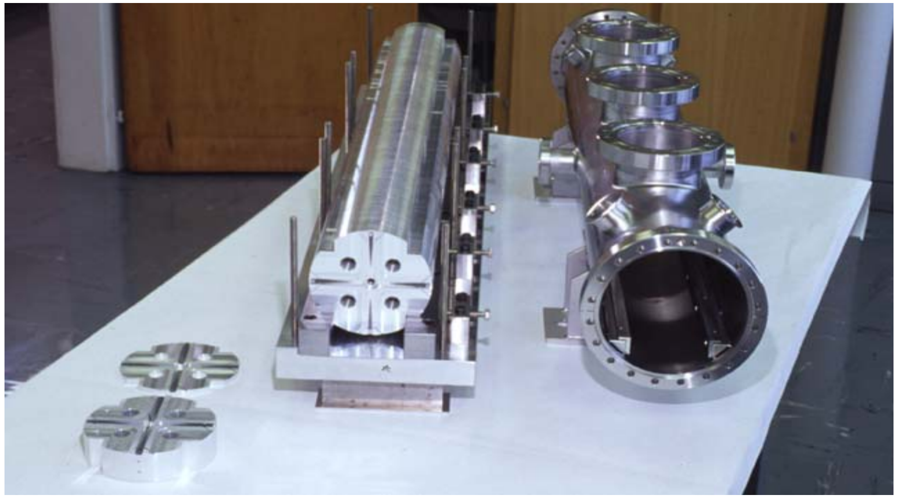
- Bunches induce wakefields in the cavities
- Later bunches are perturbed by these fields
- Can lead to emittance growth and instabilities!!!

- Effect depends on a/λ (a iris aperture) and structure design details
- transverse wakefields roughly scale as $W_\perp$ ✪ f^3
- less important for lower frequency:
  Super-Conducting (SW) cavities suffer less from wakefields
- Long-range minimised by structure design

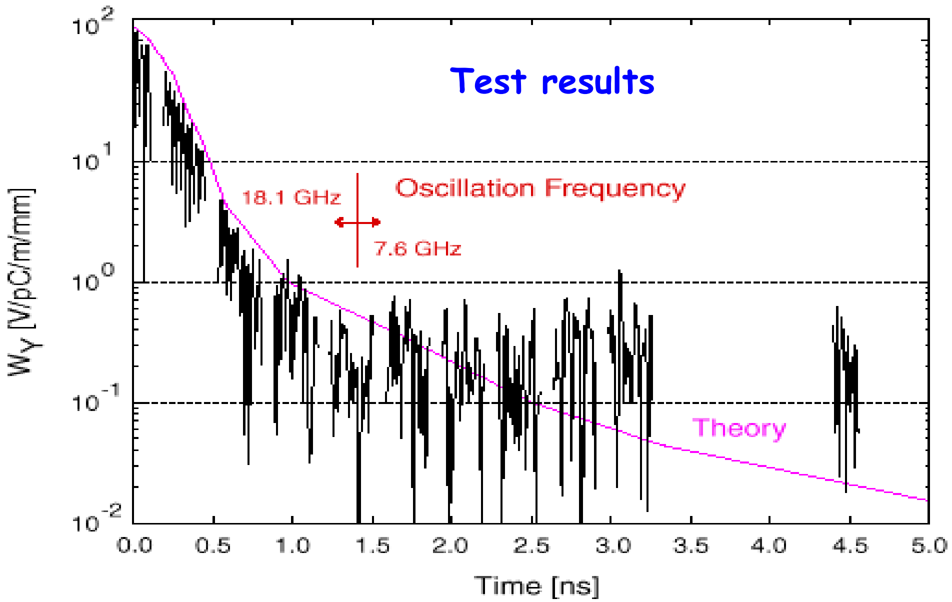
Accelerating structure developments





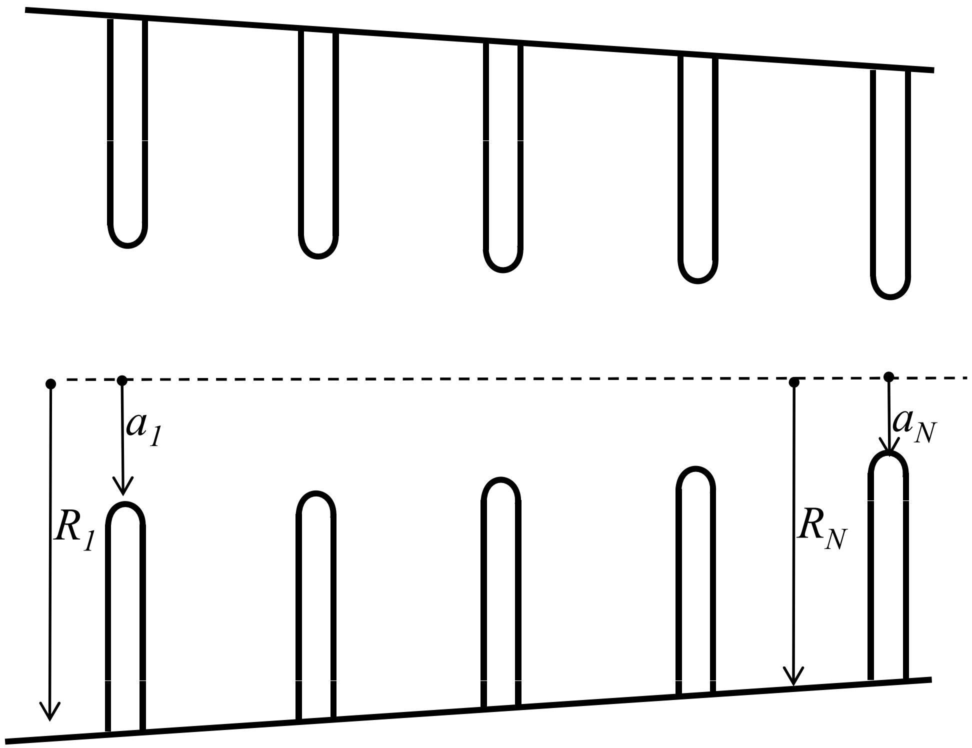


- Structures built from discs
- Each cell damped by 4 radial WGs
- terminated by SiC RF loads
- Higher order modes (HOM) enter WG
- Long-range wakefields efficiently damped

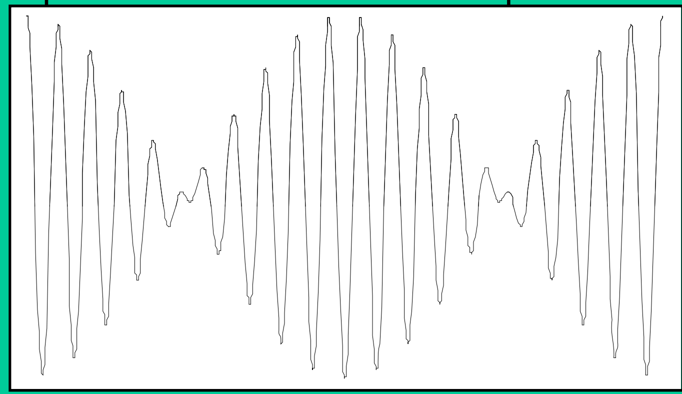


Dipole mode detuning

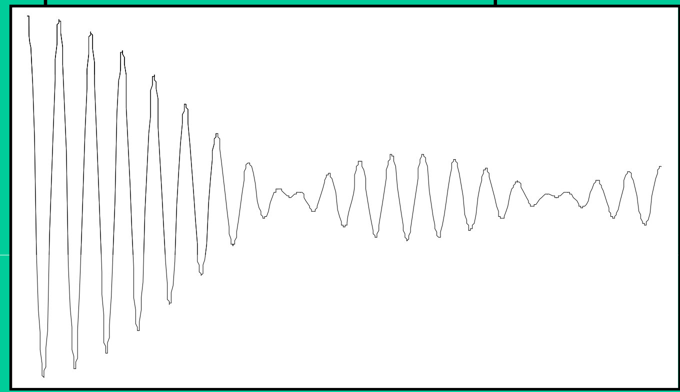
Structure parameters can be varied along structure keeping synchronous frequency for accelerating mode constant but varying synchronous frequencies of dipole modes



Long range wake of a dipole mode spread over **two** different frequencies



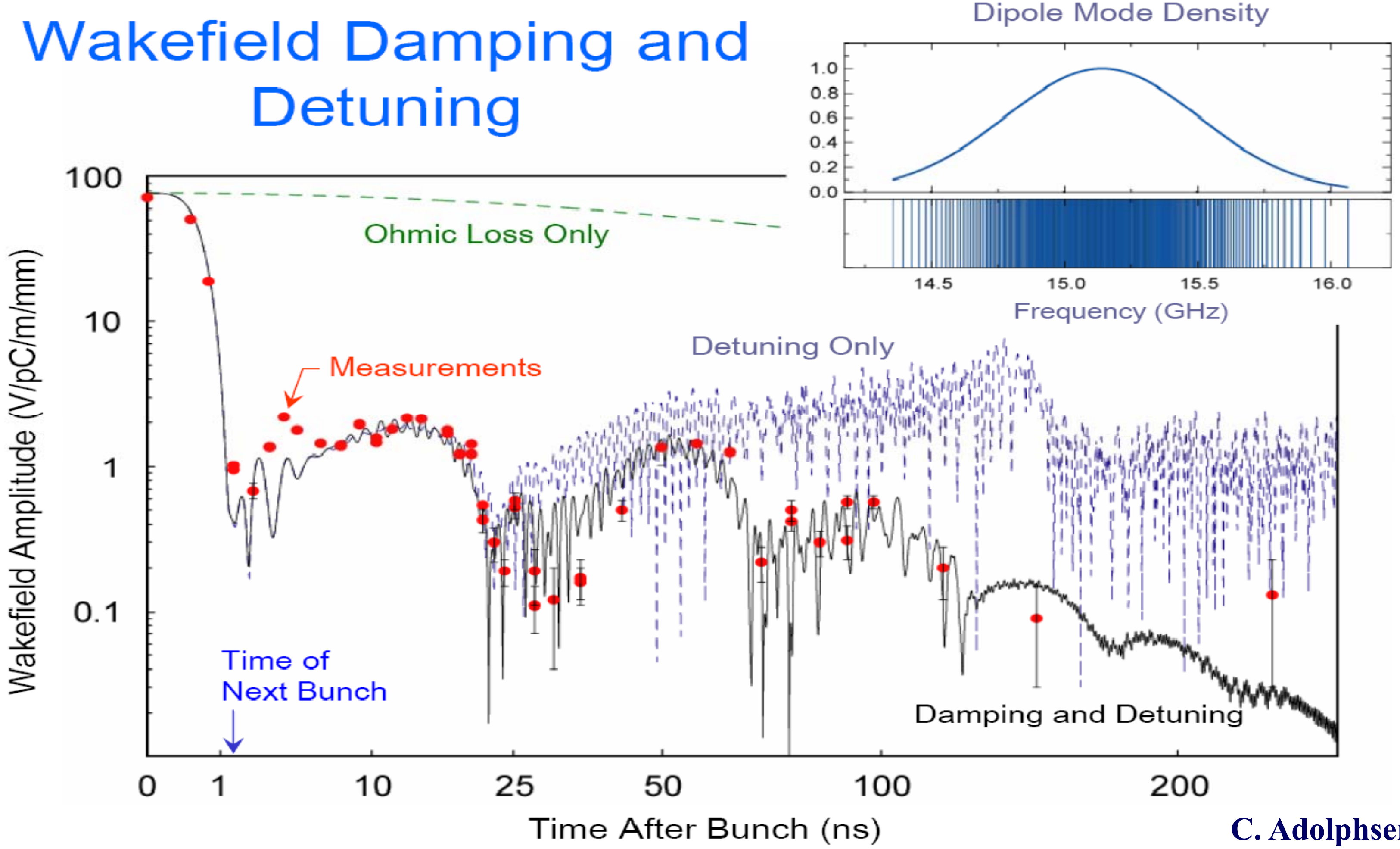
Long range wake of a dipole mode spread over **six** different frequencies



Ideal is a Gaussian weighting of frequency distribution, but finite number of cells leads always to re-coherence after some time !

Damping and detuning

- Slight random detuning between cells makes HOMs decohere quickly
- Will recohere later: need to be damped (HOM dampers)



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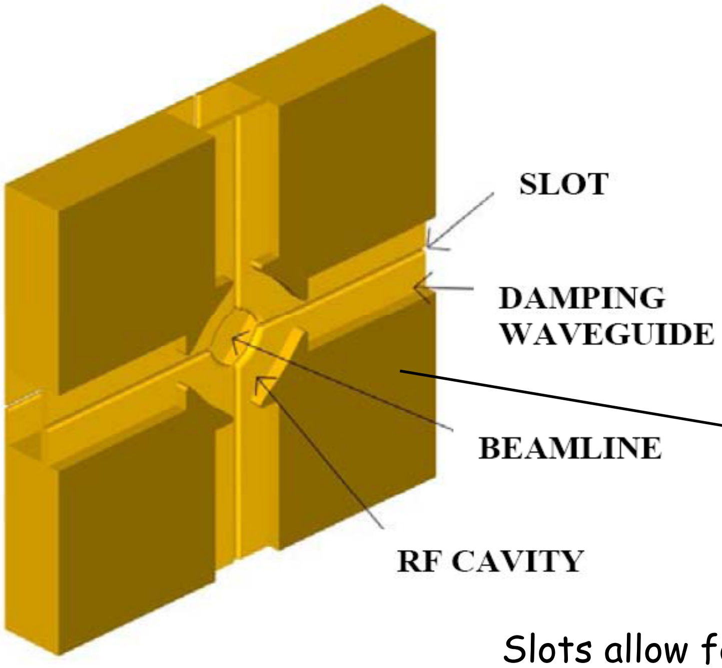
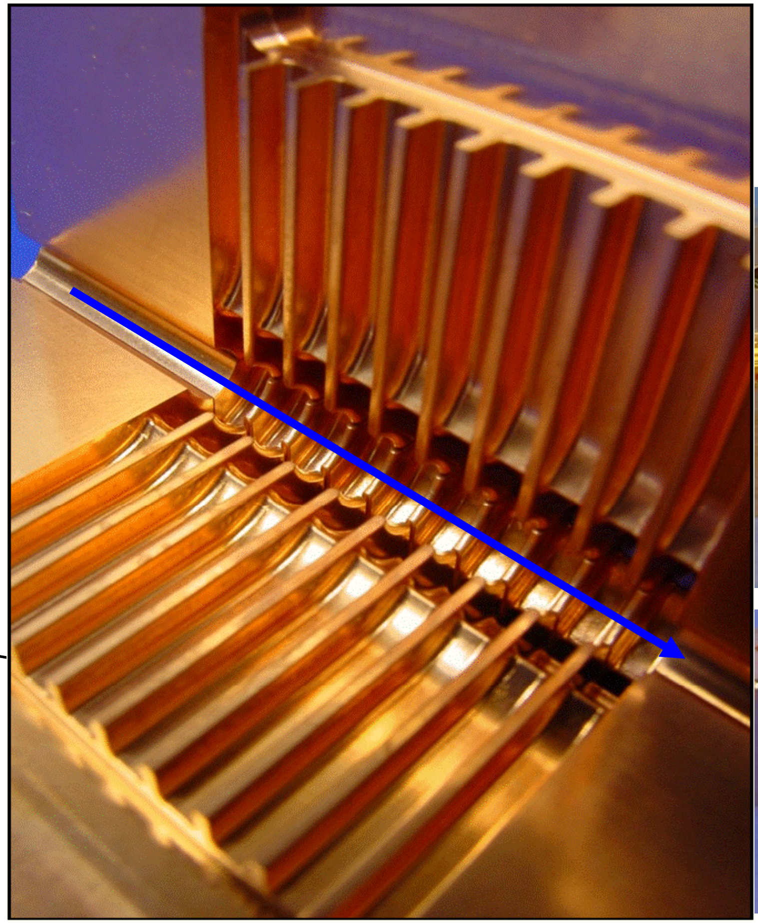
Accelerating structure development

- Recent optimization of CLIC structure for Luminosity/power including RF constraints
- New construction concept



Slots allow for a new construction method, with 4-quadrant assembly



3 quadrants assembled

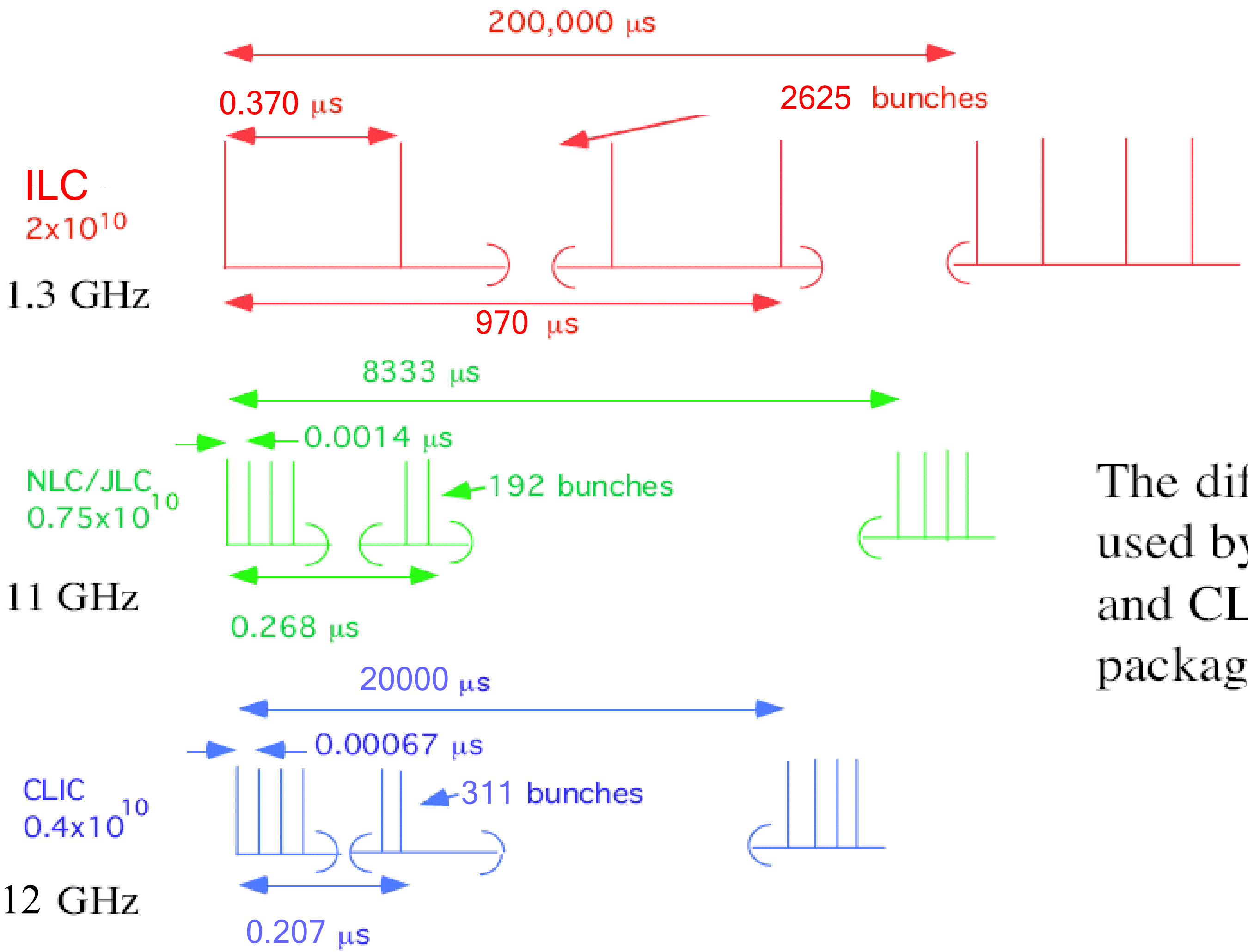
Quadrant prototype

NC RF structures - Summary

- Traveling wave structures
  - Short RF pulses (still as long as possible - for efficiency)
- Higher frequency preferred (power reasons)
  - Smaller dimensions and higher wakefields
  - Careful cavity design (damping + detuning)
  - Sophisticated mechanical + beam-based alignment
- Higher gradients achievable
  - Limited by
    - Pulsed surface heating
    - RF breakdowns
    - Structure damage

Bunch structure

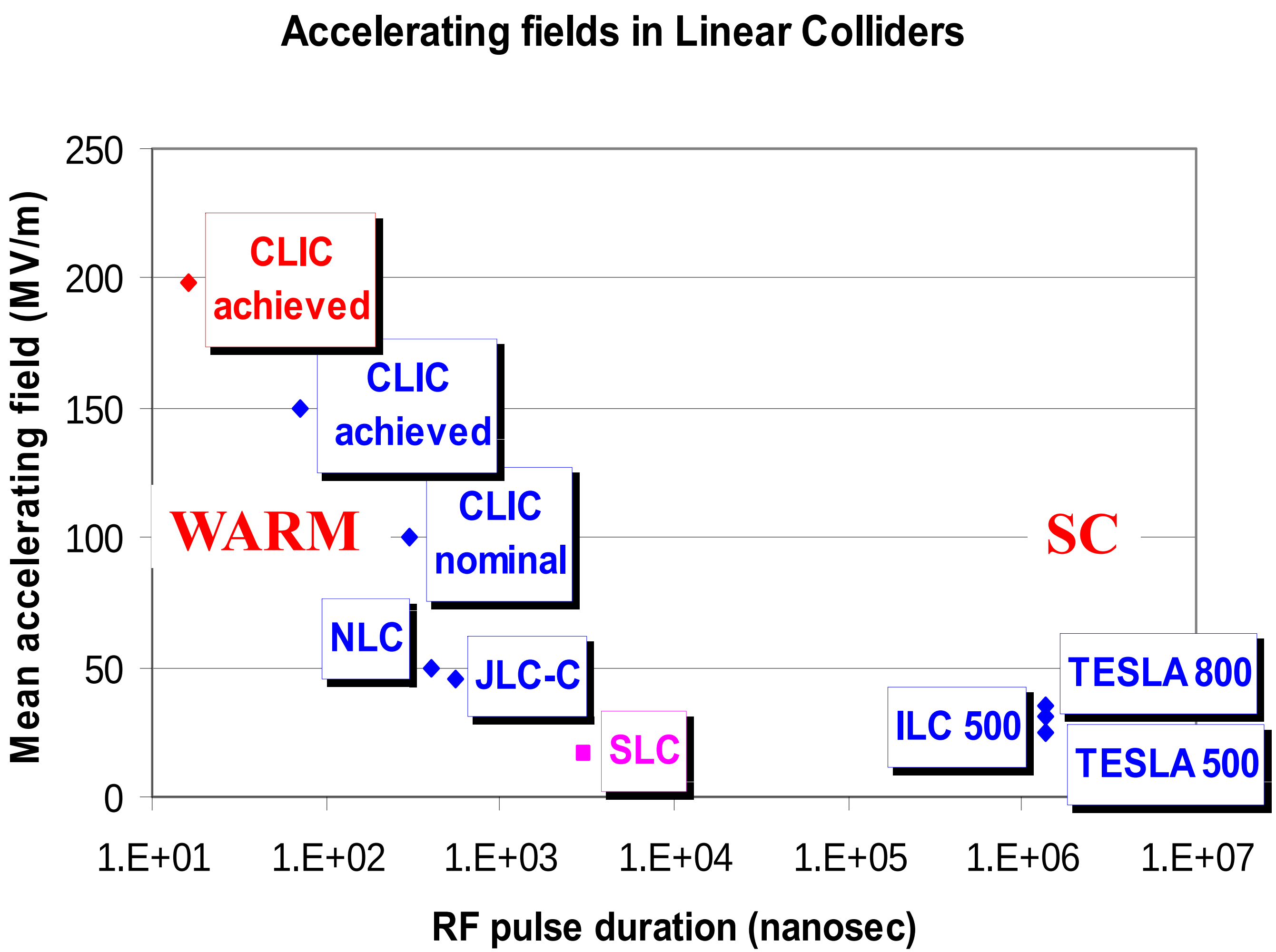
- SC allows long pulse, NC needs short pulse with smaller bunch charge



The different RF technologies used by ILC, NLC/JLC and CLIC require different packaging for the beam power

Accelerating gradient

- Superconducting cavities have lower gradient (fundamental limit) with long RF pulse
- Normal conducting cavities have higher gradient with shorter RF pulse length



Warm vs Cold RF Collider

- ## Normal Conducting
  - High gradient ⇒ short linac ☺
  - High rep. rate ⇒ GM suppression ☺
  - Small structures ⇒ strong wakefields ☹
  - Generation of high peak RF power ☹

- ## Superconducting
  - long pulse ⇒ low peak power ☺
  - large structure dimensions ⇒ low WF ☺
  - very long pulse train ⇒ feedback within train ☺
  - SC structures ⇒ high efficiency ☺
  - Gradient limited <40 MV/m ⇒ longer linac ☹
    (SC material limit ~ 55 MV/m)
  - low rep. rate ⇒ bad GM suppression
    (ε_y dilution) ☹
  - Large number of e+ per pulse ☹
  - very large DR ☹☹

Comparison ILC - CLIC

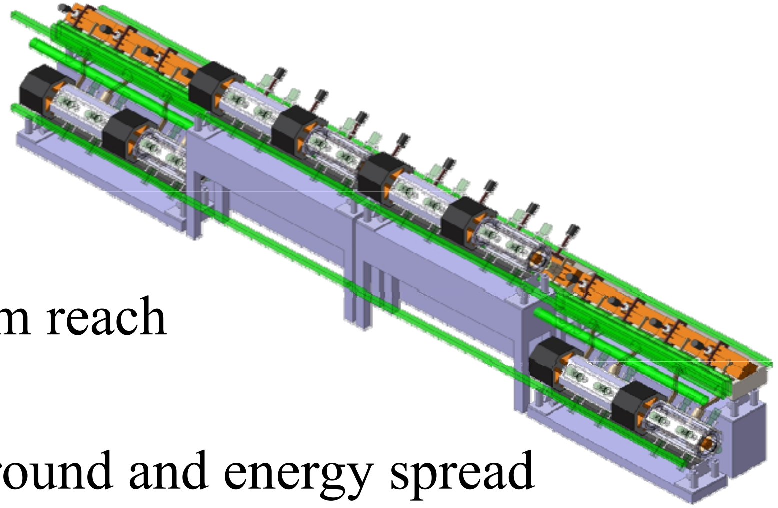
		ILC	CLIC	remarks
No. of particles / bunch	10^9	20	4	CLIC can't go higher because of short range wakefields
Bunch separation	ns	370	0.667	Short spacing essential for CLIC to get comparable RF to beam efficiency, but CLIC requirements on long range wakefield suppression much more stringent
Bunch train length	µs	970	0.207	One CLIC pulse fits easily in small damping ring, simple single turn extraction from DR. But intra train feedback very difficult.
Charge per pulse	nC	8400	200	Positron source much easier for CLIC
Linac repetition rate	Hz	5	50	Pulse to pulse feedback more efficient for CLIC (less linac movement between pulses)
$\gamma \varepsilon_x , \gamma \varepsilon_y$	nm	10000, 40	660, 20	Because of smaller bunch charge CLIC has more stringent requirements for DR equilibrium emittance and emittance preservation (partly offset by lower bunch charge and smaller DR)

Parameter comparison

	SLC	TESLA	ILC	J/NLC	CLIC
Technology	NC	Supercond.	Supercond.	NC	NC
Gradient [MeV/m]	20	25	31.5	50	100
E [GeV]	92	500-800	500-1000	500-1000	500-3000
f [GHz]	2.8	1.3	1.3	11.4	12.0
L [10^{33} $cm^{-2}s^{-1}$]	0.003	34	20	20	21
P_{beam} [MW]	0.035	11.3	10.8	6.9	5
P_{AC} [MW]		140	230	195	158
σ_z* [mm]	~1	0.3	0.3	0.11	0.04
$\gamma\varepsilon_y$ [10^{-8}m]	300	3	4	4	2
β_y* [mm]	~1.5	0.4	0.4	0.11	0.1
σ_y* [nm]	650	5	5.7	3	2
H_D	2.4	2.1	1.7	1.5	2.6

Parameters (except SLC) at 500 GeV

Multi-TeV: the CLIC Study



- Develop technology for linear e+/e- collider with the requirements:
  - E_{cm} should cover range from ILC to LHC maximum reach and beyond $\Rightarrow E_{cm} = 0.5 – 3$ TeV
  - Luminosity > few 10^{34} cm^{-2} with acceptable background and energy spread
    - E_{cm} and L to be reviewed once LHC results are available
  - Design compatible with maximum length ~ 50 km
  - Affordable
  - Total power consumption < 500 MW
- Present goal: Demonstrate all key feasibility issues and document in a CDR by 2010 (possibly TDR by 2015)

CLIC-CTF3 Collaboration

Ankara University (Turkey)
Berlin Tech. Univ. (Germany)
BINP (Russia)
CERN
CIEMAT (Spain)
DAPNIA/Saclay (France)

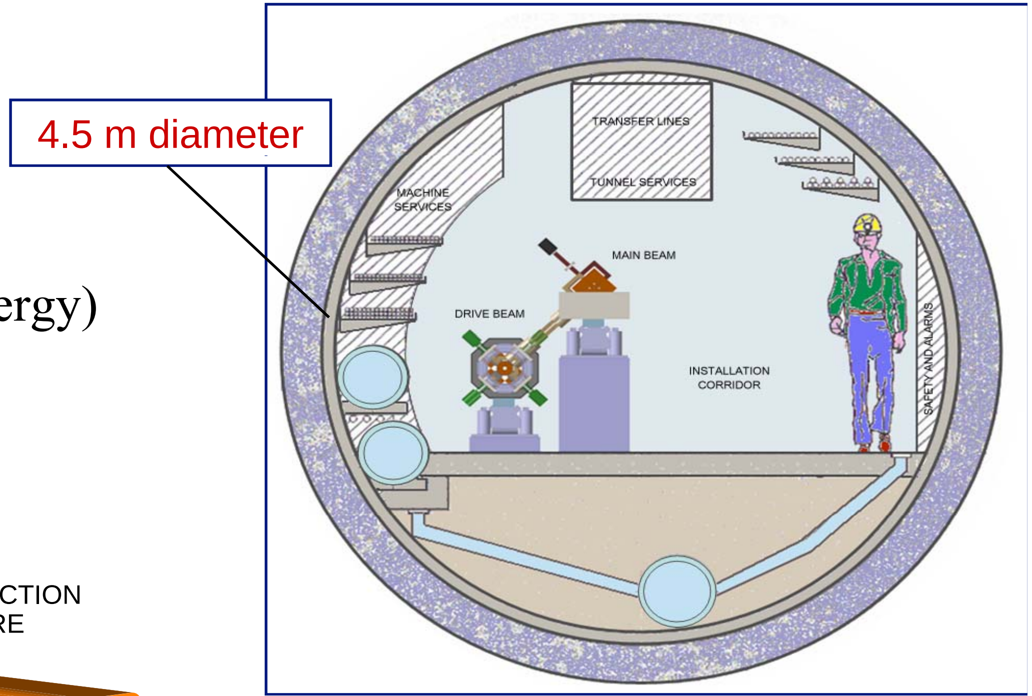
RRCAT-Indore (India)
Finnish Industry (Finland)
Gazi Universities (Turkey)
Helsinki Institute of Physics (Finland)
IAP (Russia)
Instituto de Fisica Corpuscular (Spain)
INFN / LNF (Italy)

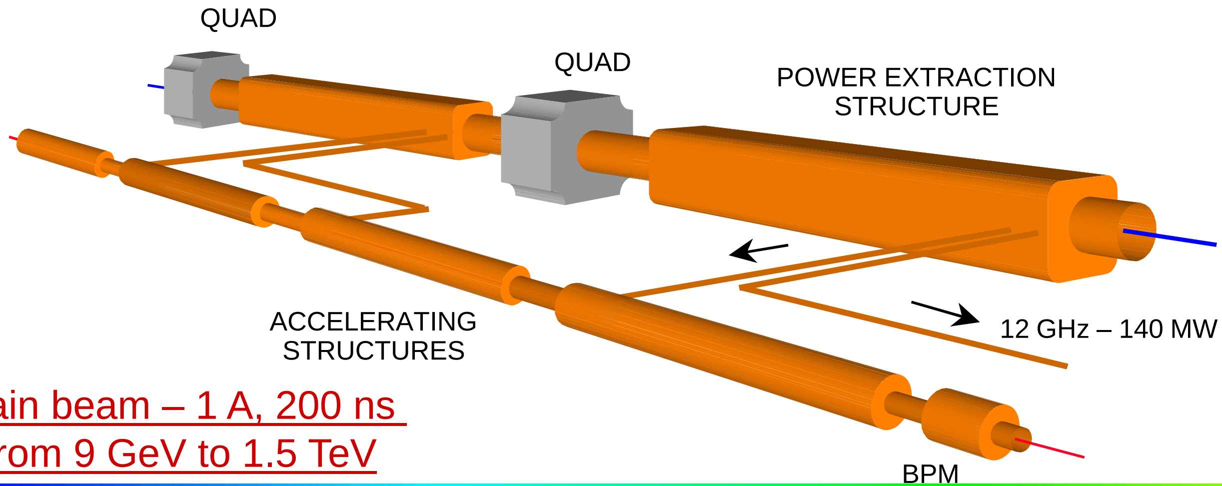
JASRI (Japan)
JINR (Russia)
KEK (Japan)
LAL/Orsay (France)
LAPP/ESIA (France)
LLBL/LBL (USA)
NCP (Pakistan)

PSI (Switzerland),
North-West. Univ. Illinois (USA)
Polytech. University of Catalonia (Spain)
John Adams Institute (England)
SLAC (USA)
Svedberg Laboratory (Sweden)
Uppsala University (Sweden)

- High acceleration gradient
  - "Compact" collider – total length < 50 km
  - Normal conducting acceleration structures
  - High acceleration frequency (12 GHz)
- Two-Beam Acceleration Scheme
  - High charge Drive Beam (low energy)
  - Low charge Main Beam (high collision energy)
  - ⇒ Simple tunnel, no active elements
  - ⇒ Modular, easy energy upgrade in stages

CLIC TUNNEL CROSS-SECTION



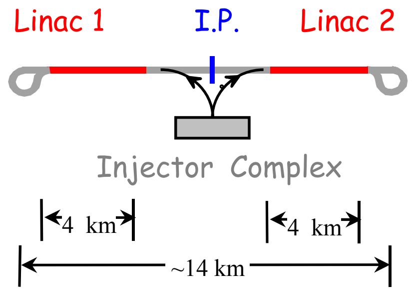


Drive beam - 95 A, 300 ns
from 2.4 GeV to 240 MeV

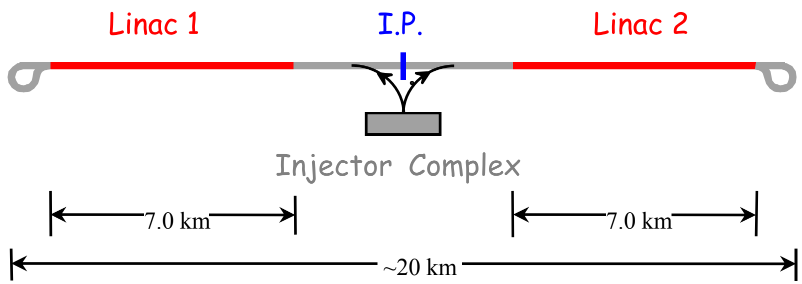
Main beam – 1 A, 200 ns
from 9 GeV to 1.5 TeV

CLIC Layout at various energies

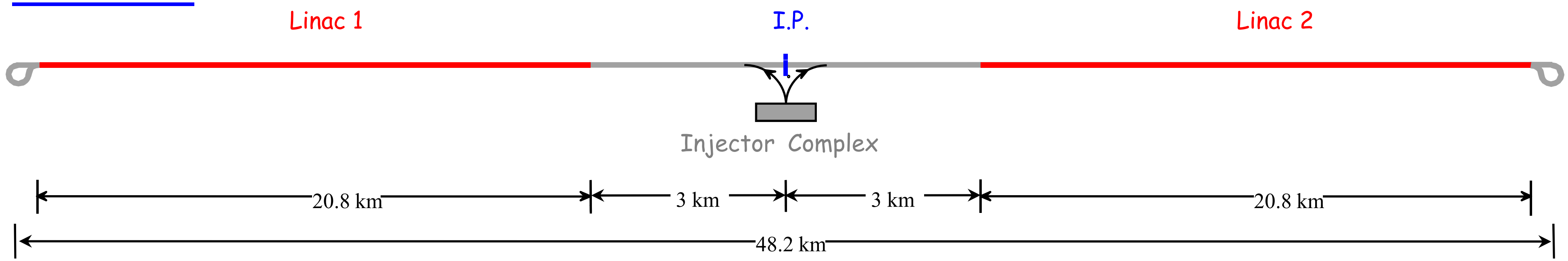
0.5 TeV Stage



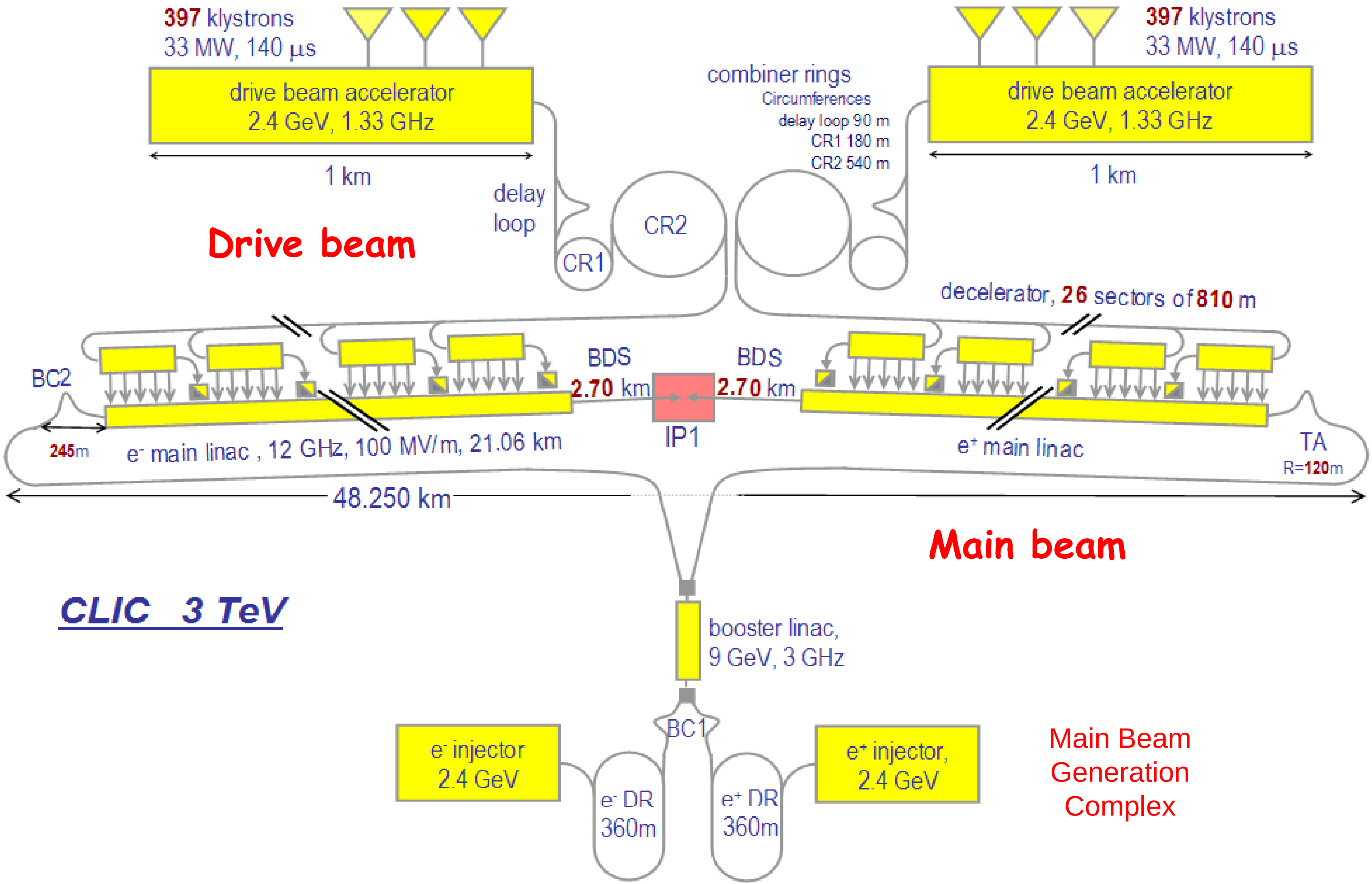
1 TeV Stage



3 TeV Stage



CLIC – overall layout



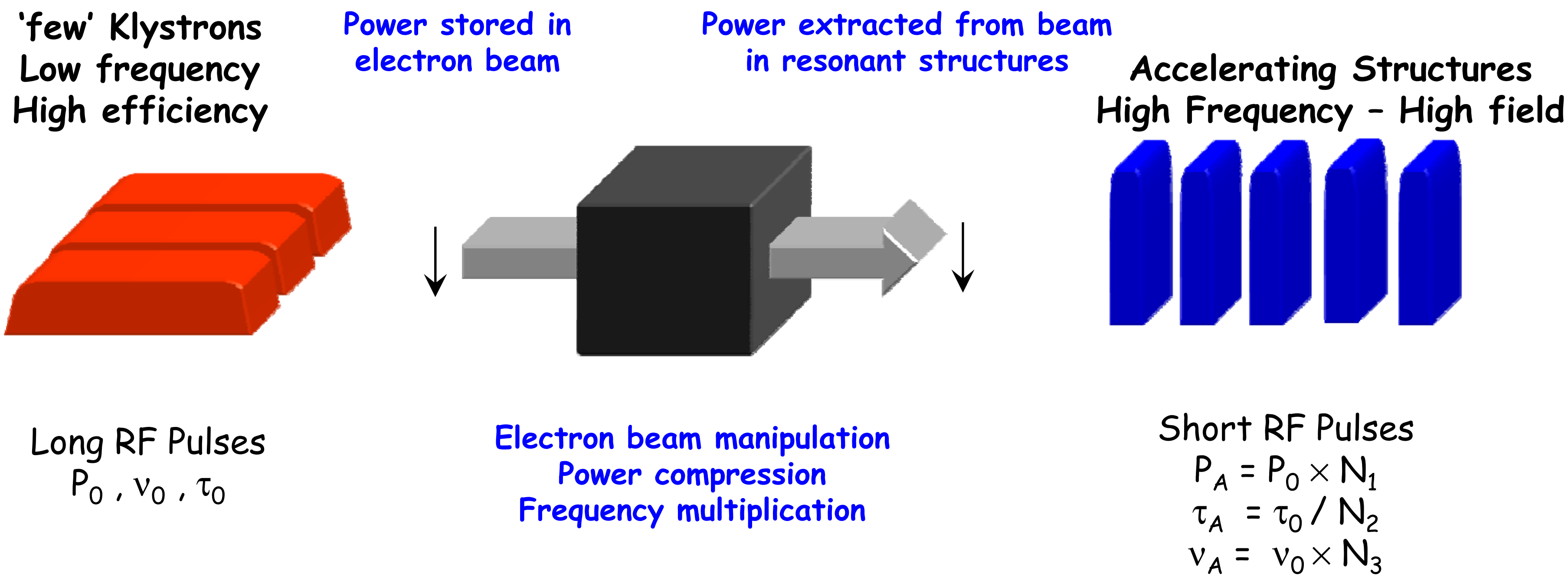
New CLIC main parameters

Center-of-mass energy	3 TeV
Peak Luminosity	$7{\cdot}10^{34}$ cm^{-2} s^{-1}
Peak luminosity (in 1% of energy)	$2{\cdot}10^{34}$ cm^{-2} s^{-1}
Repetition rate	50 Hz
Loaded accelerating gradient	100 MV/m
Main linac RF frequency	12 GHz
Overall two-linac length	41.7 km
Bunch charge	$4{\cdot}10^{9}$
Beam pulse length	200 ns
Average current in pulse	1 A
Hor./vert. normalized emittance	660 / 20 nm rad
Hor./vert. IP beam size before pinch	53 / ~1 nm
Total site length	48.25 km
Total power consumption	390 MW

Provisional values

CLIC scheme

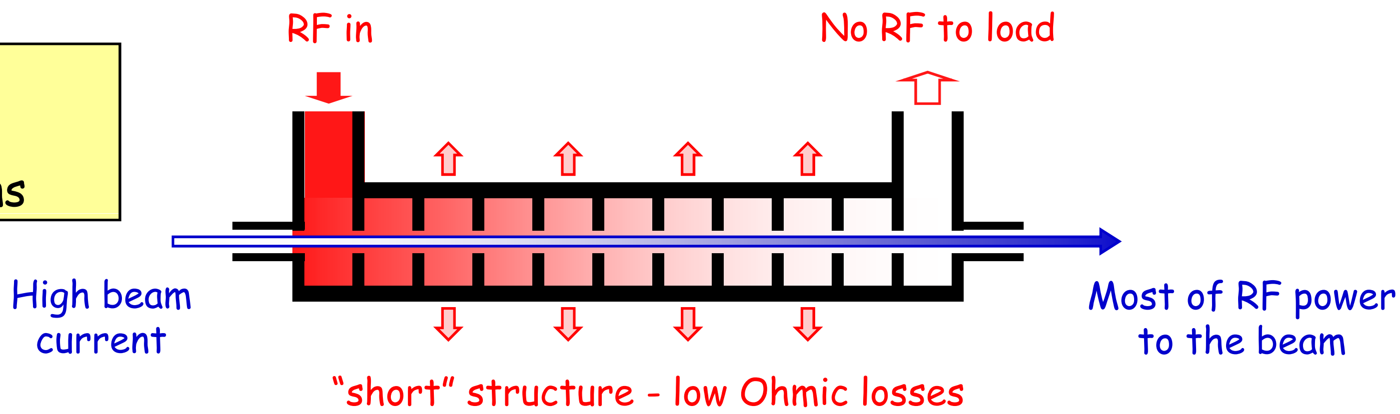
- Very high gradients possible with NC accelerating structures at high RF frequencies (30 GHz → 12 GHz)
- Extract required high RF power from an intense e- "drive beam"
- Generate efficiently long beam pulse and compress it (in power + frequency)



Drive beam generation basics

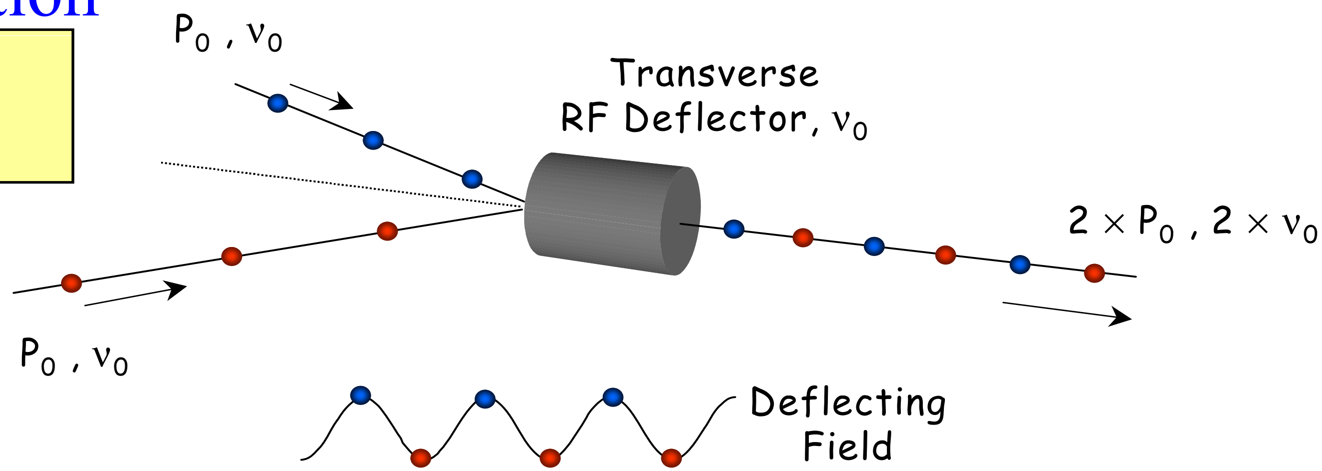
- Efficient acceleration

Full beam-loading acceleration in traveling wave sections

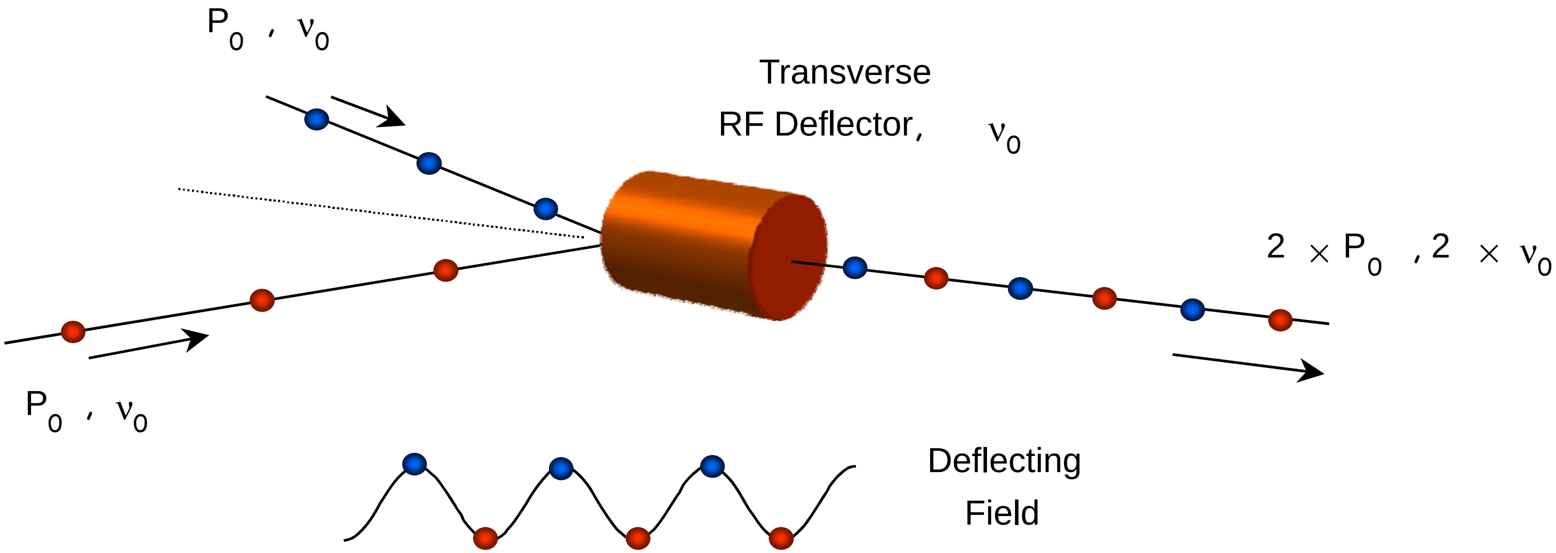


- Frequency multiplication

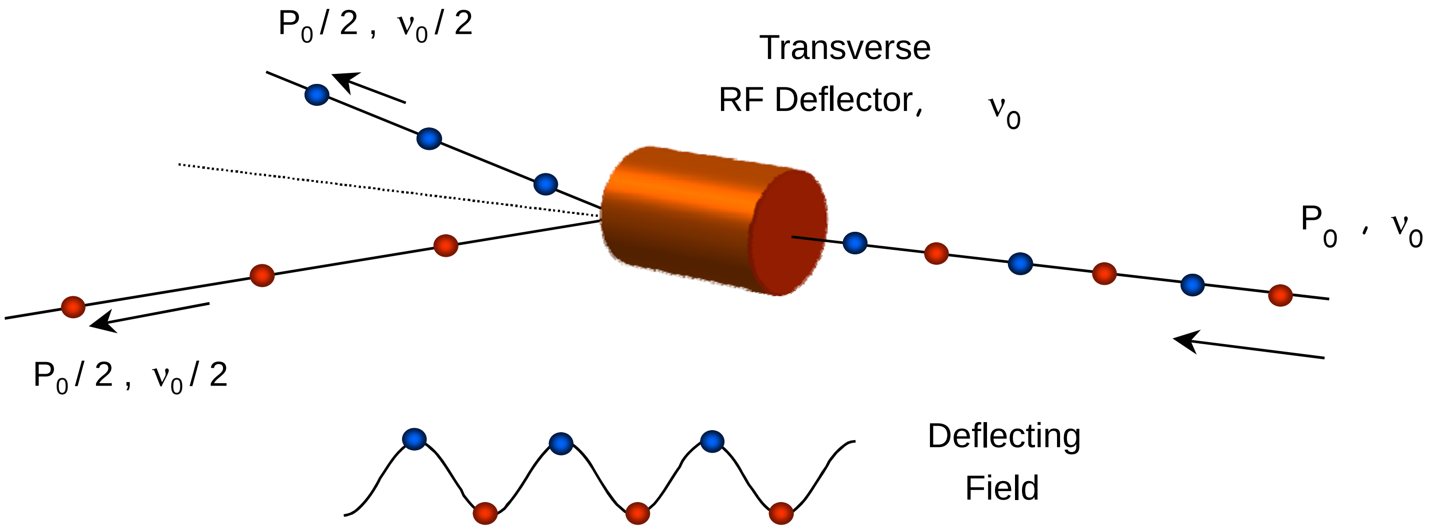
Beam combination/separation by transverse RF deflectors



Beam combination by RF deflectors

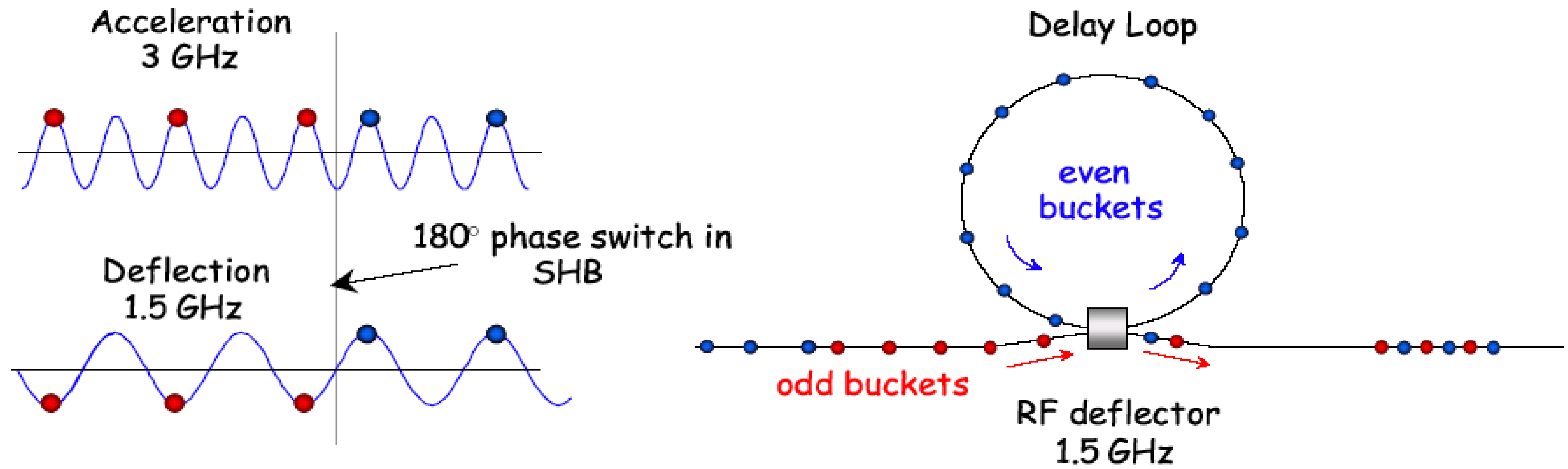


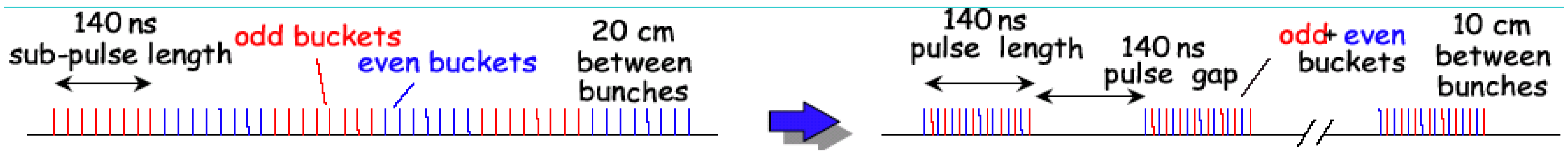
Beam separation by RF deflectors



Delay Loop Principle

- **double repetition frequency and current**
- parts of bunch train delayed in loop
- RF deflector combines the bunches (f_{defl}=bunch rep. frequency)
- Path length corresponds to beam pulse length

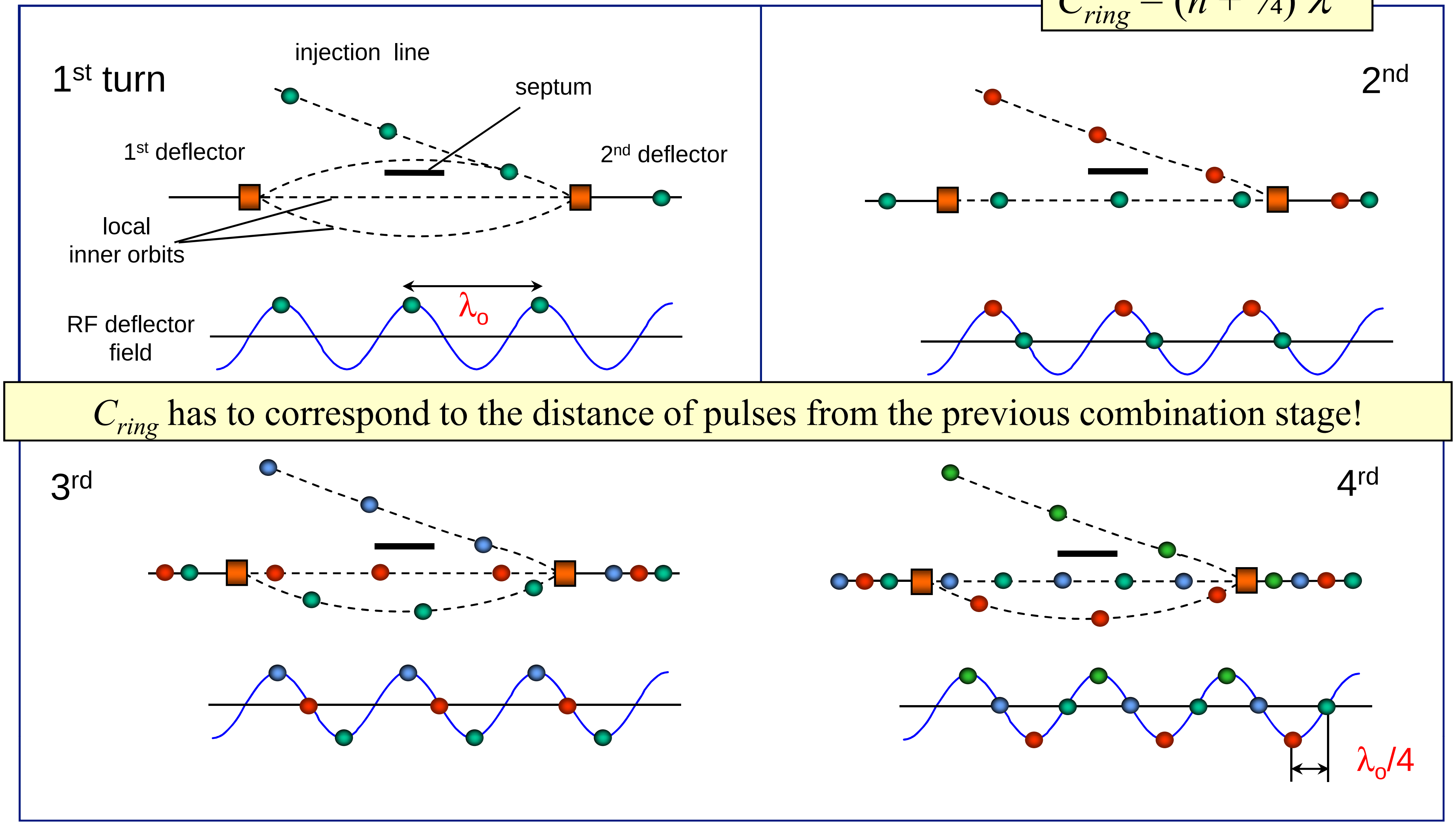




RF injection in combiner ring

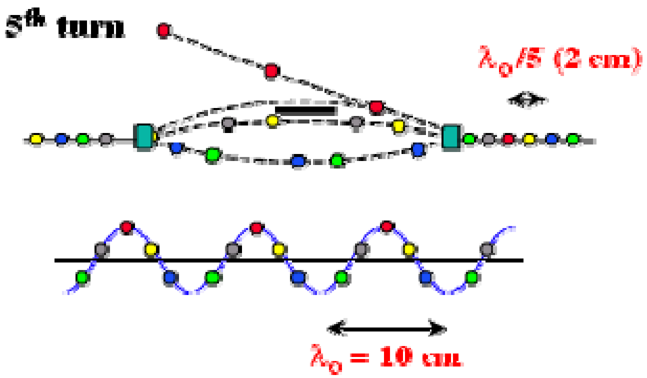
- combination factors up to 5 reachable in a ring

$C_{ring} = (n + ¼)\,\lambda$



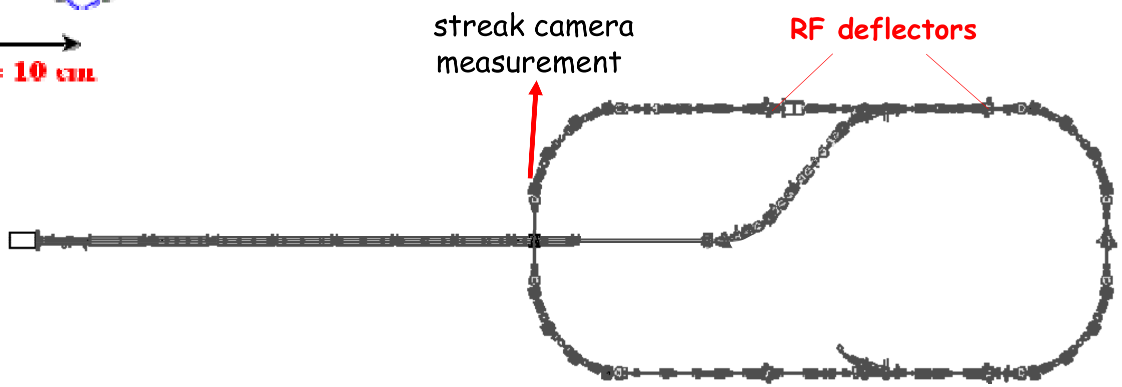
C_{ring} has to correspond to the distance of pulses from the previous combination stage!

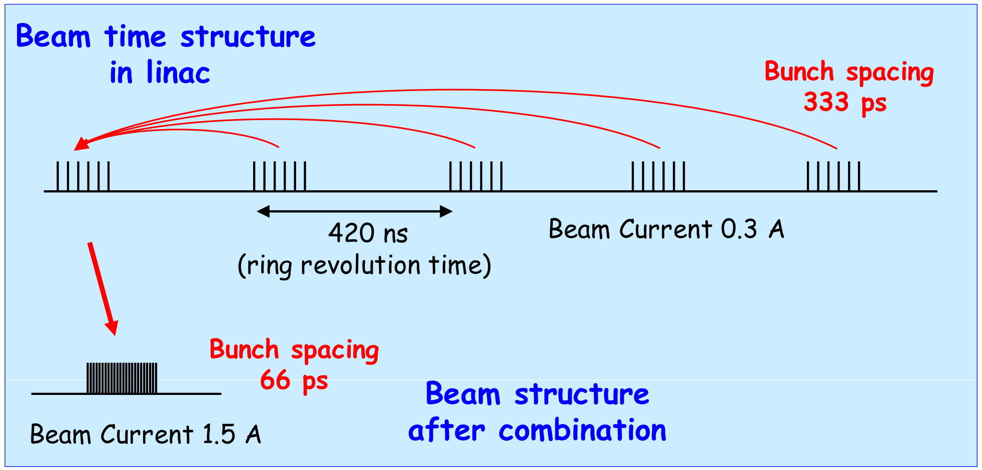
Demonstration of frequency multiplication



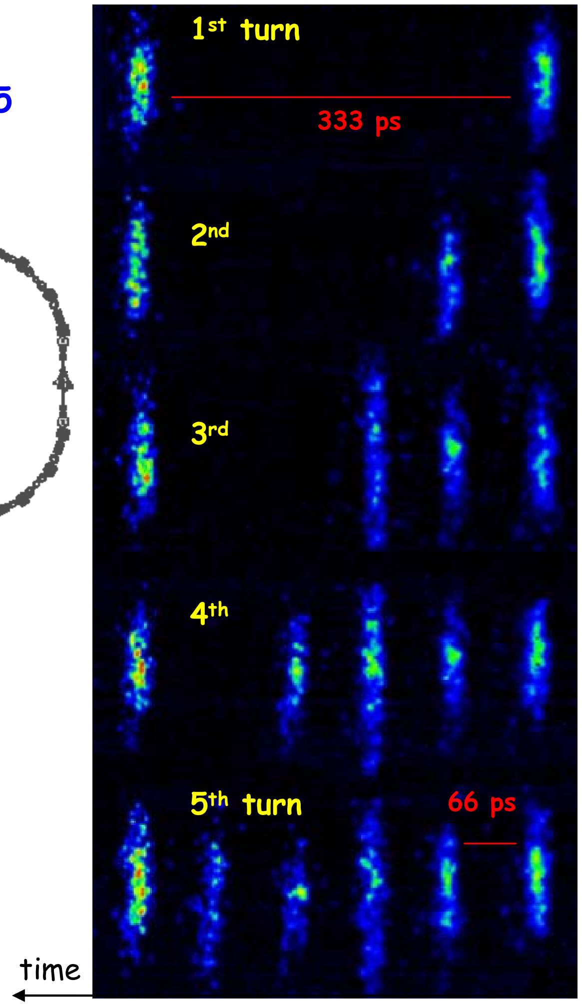
CTF3 - PRELIMINARY PHASE 2001/2002

Successful low-charge demonstration of electron pulse combination and bunch frequency multiplication by up to factor 5

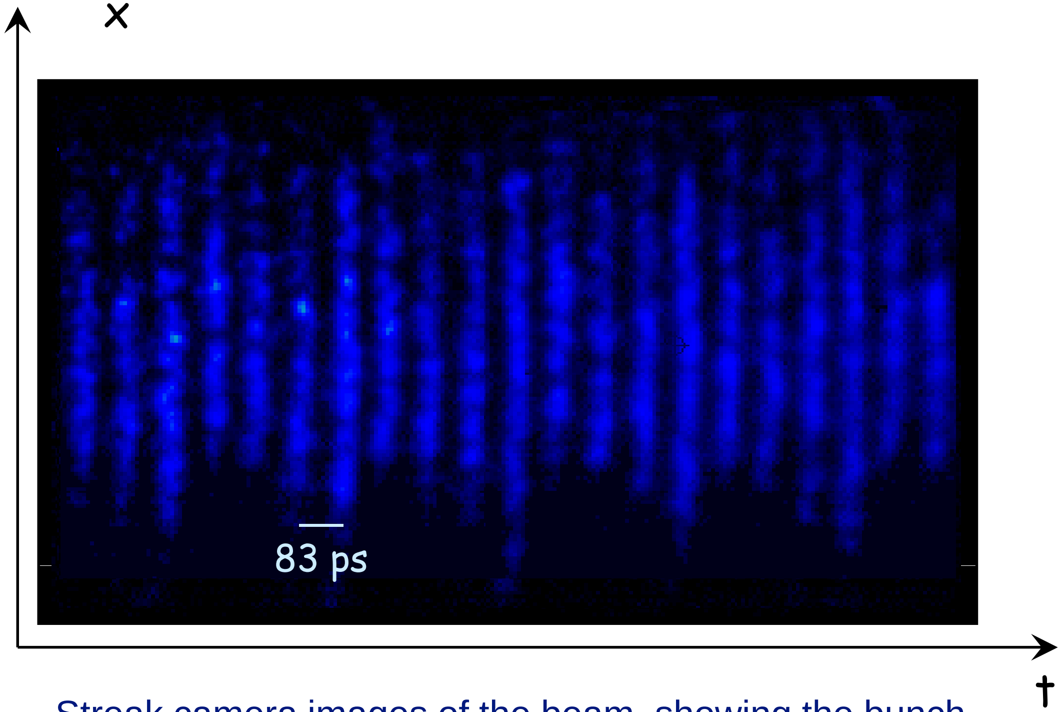




Streak camera image of beam time structure evolution



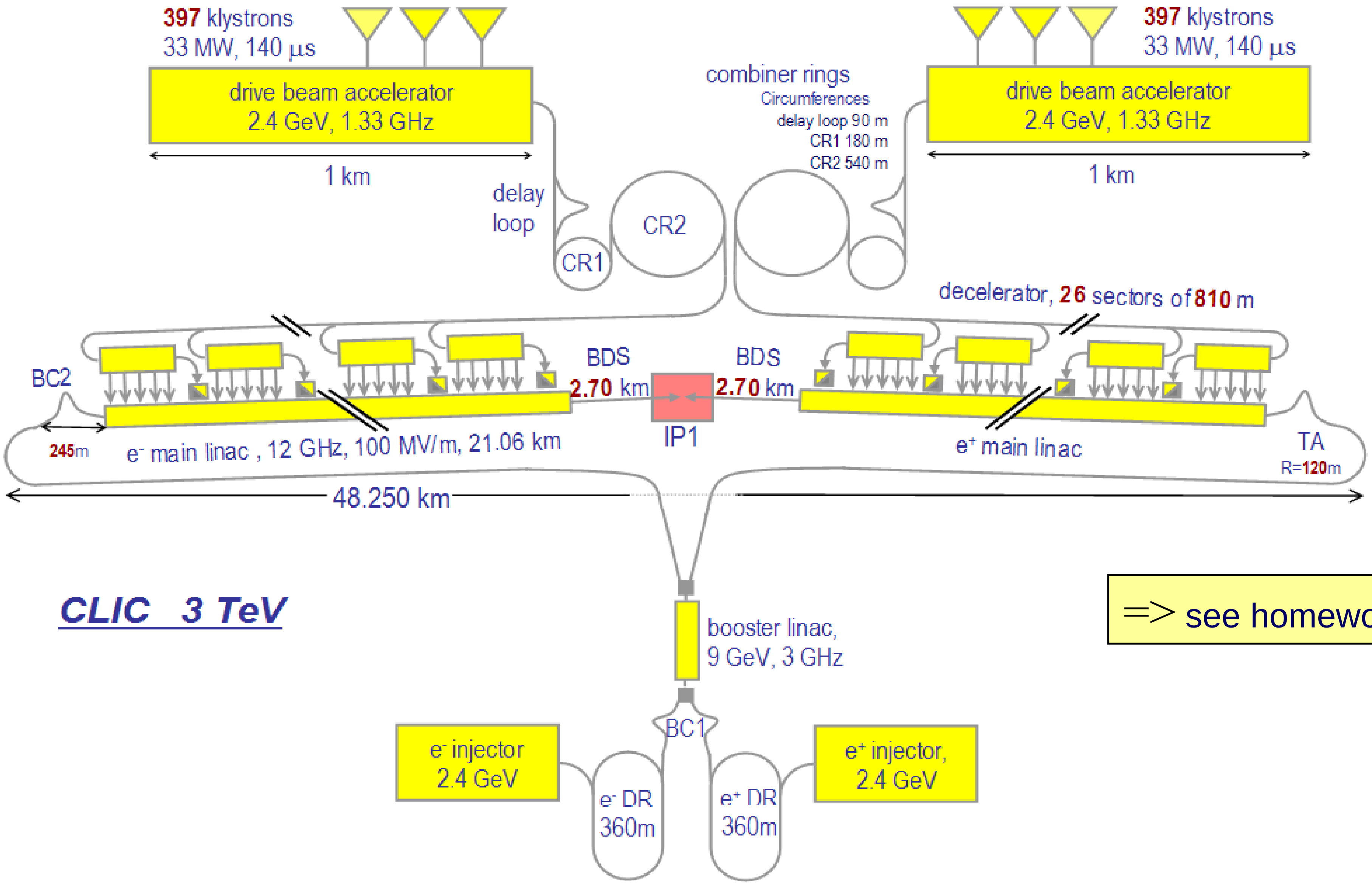
RF injection in combiner ring



Streak camera images of the beam, showing the bunch combination process

A first ring combination test was performed in 2002, *at low current and short pulse*, in the CERN Electron-Positron Accumulator (EPA), properly modified

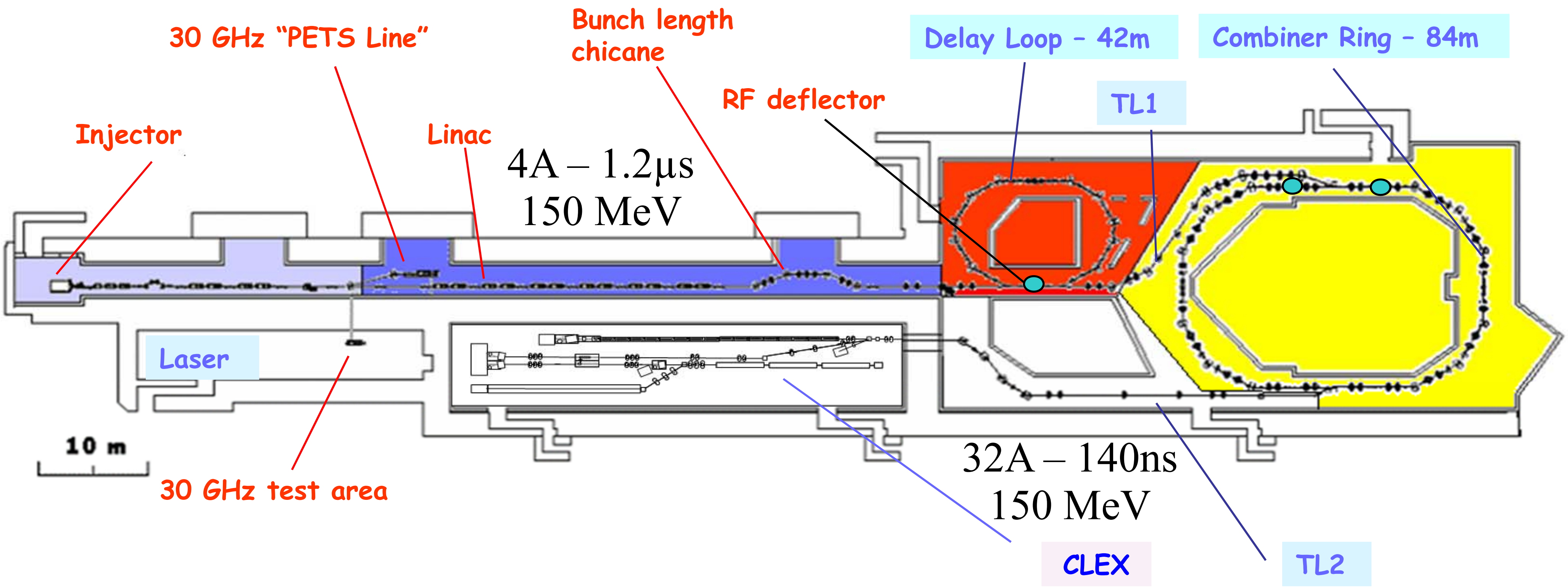
CLIC Drive Beam generation



=> see homework

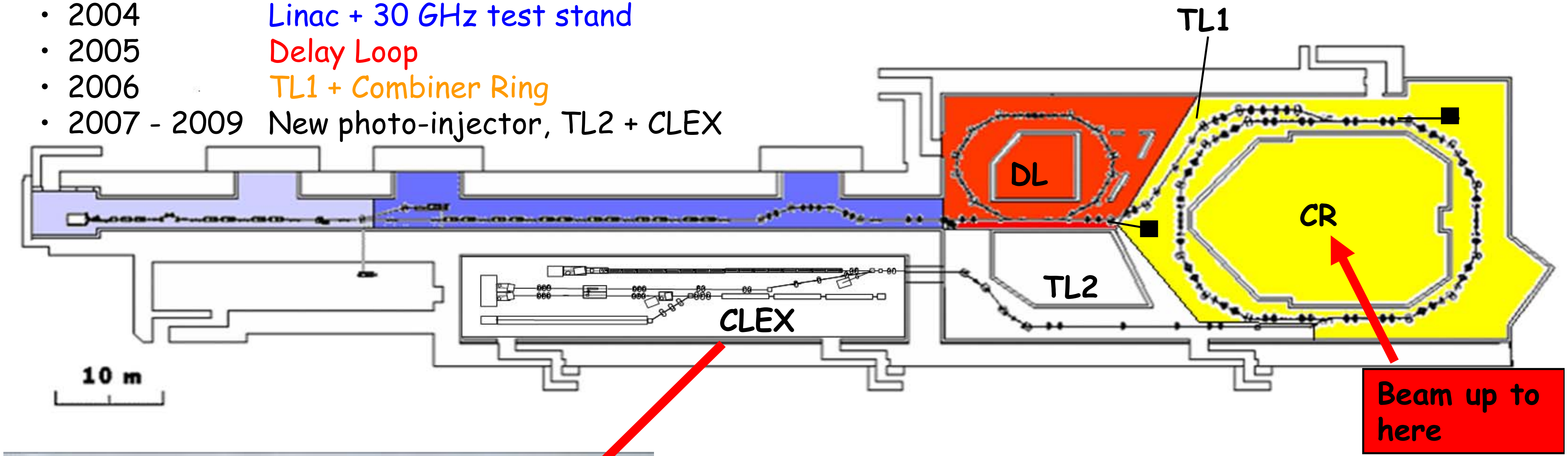
CTF 3

- demonstrate Drive Beam generation
  (fully loaded acceleration, bunch frequency multiplication 8x)
- Test CLIC accelerating structures
- Test power production structures (PETS)



CTF3 Evolution

- 2003 Injector + part of linac
- 2004 Linac + 30 GHz test stand
- 2005 Delay Loop
- 2006 TL1 + Combiner Ring
- 2007 - 2009 New photo-injector, TL2 + CLEX

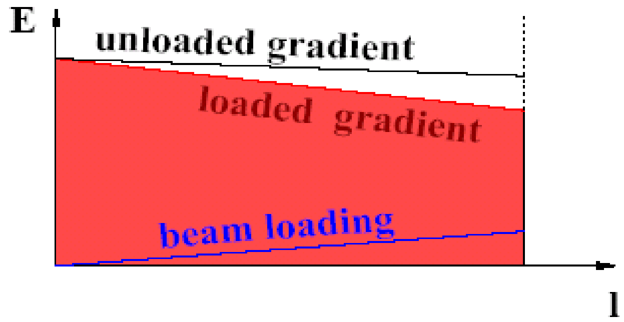


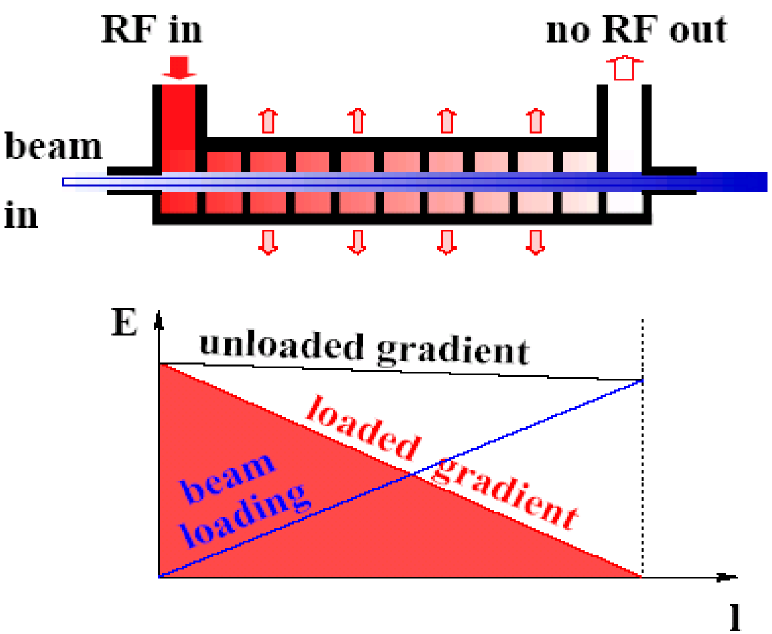
Fully loaded operation

- efficient power transfer from RF to the beam needed

"Standard" situation:

- small beam loading
- power at structure exit lost in load





"Efficient" situation:

- high beam current
- high beam loading
- no power flows into load
- $V_{ACC} \approx 1/2\ V_{unloaded}$

Fully loaded operation

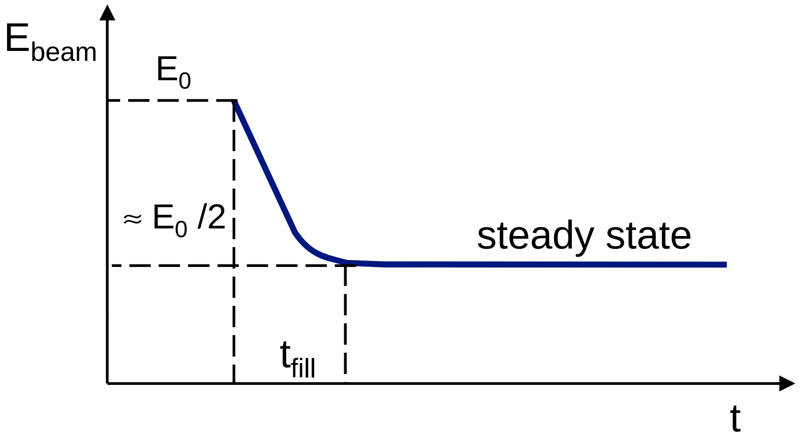
- Disadvantage: any current variation changes energy gain

$$\frac{dV/V}{dI_{beam}/I_{beam}} = -\frac{I_{beam}}{I_{opt}}$$

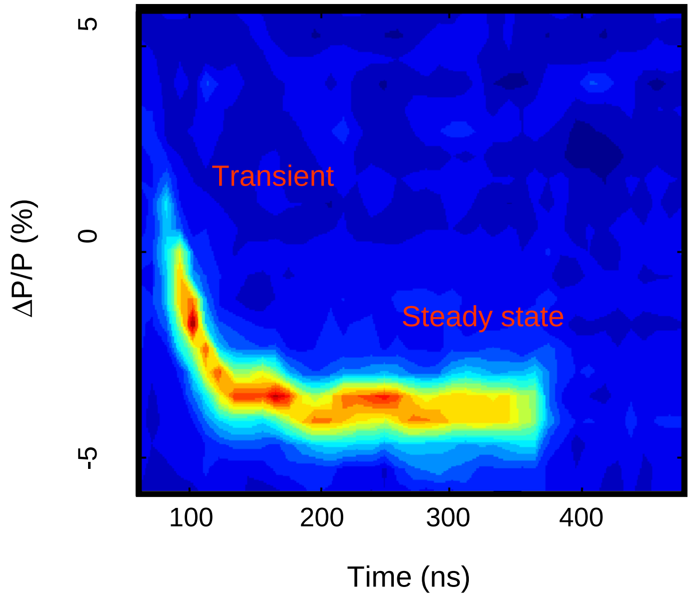
at full loading, 1% current variation = 1% voltage variation

- Requires high current stability

- Energy transient

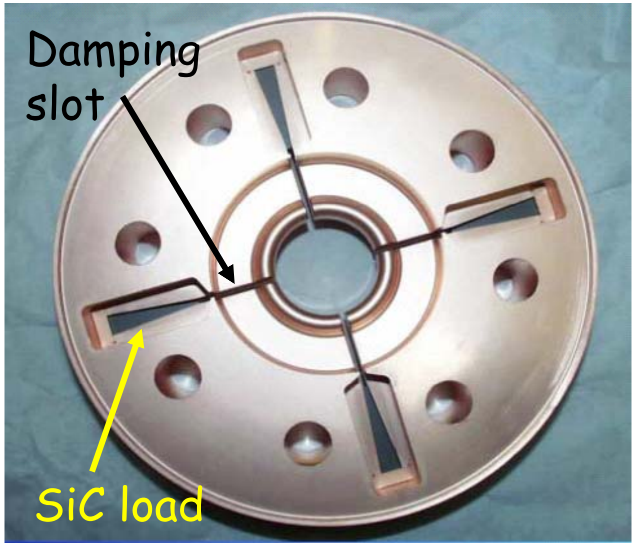


Time resolved beam energy spectrum measurement in CTF3



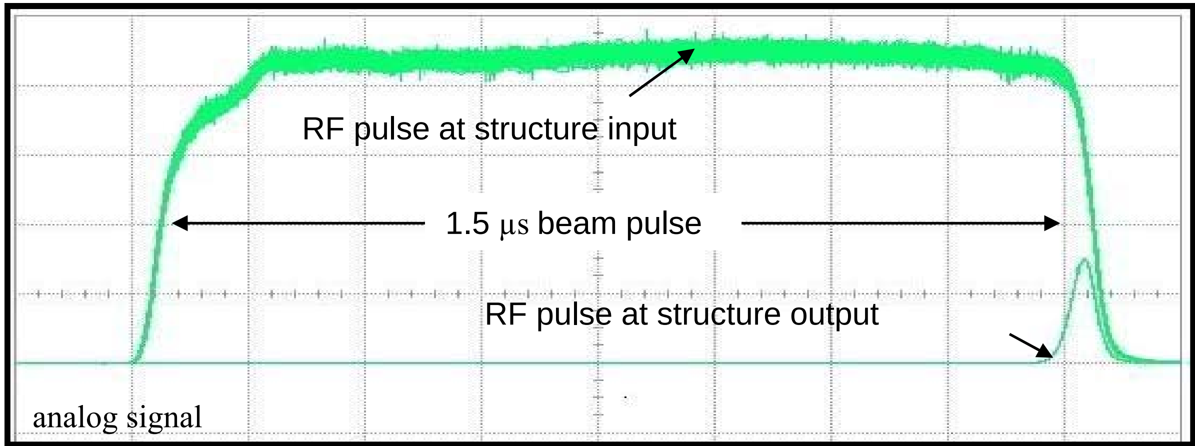
CTF3 linac acceleration structures

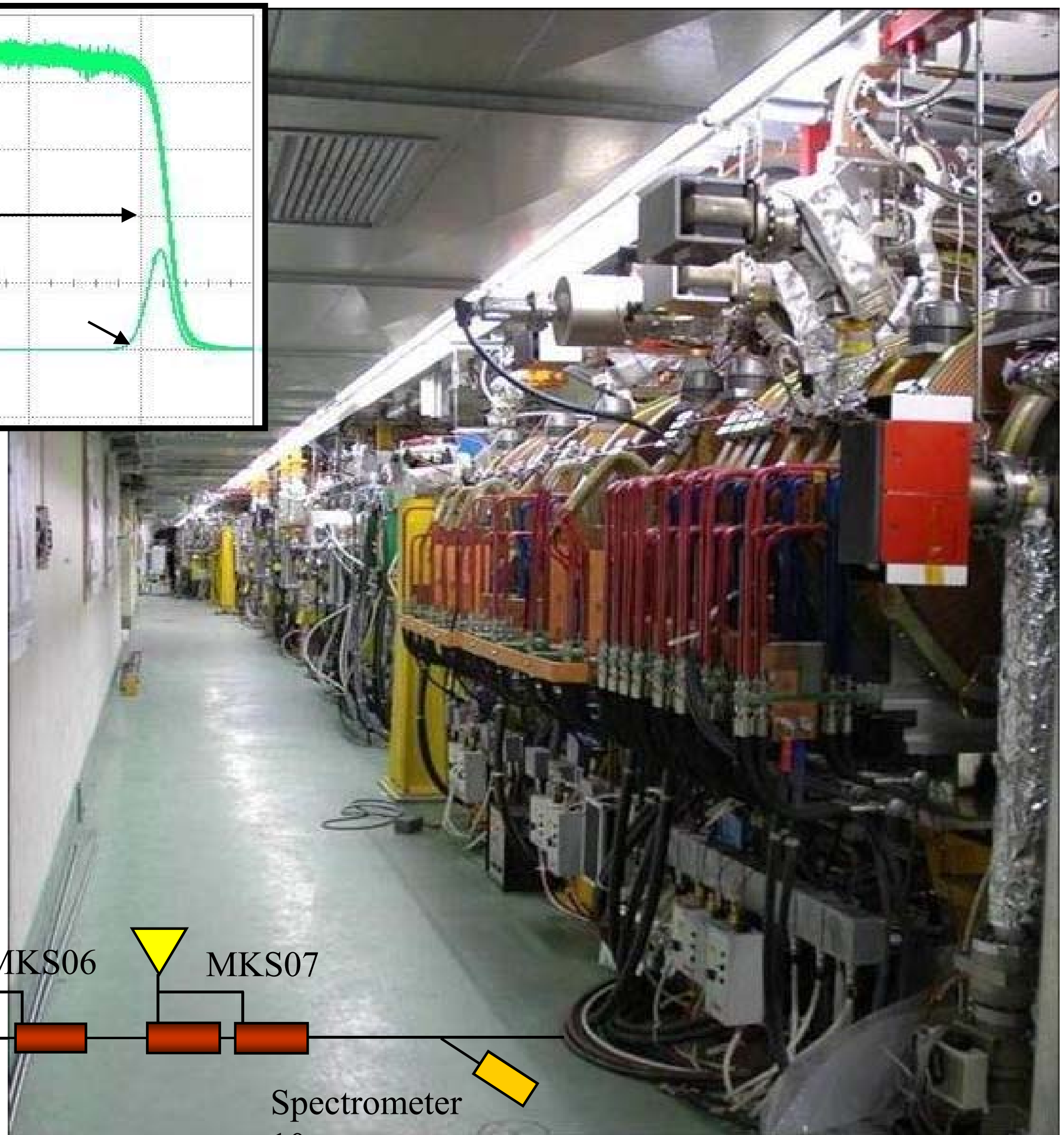
Dipole modes suppressed by slotted iris damping (first dipole's Q factor < 20) and HOM frequency detuning



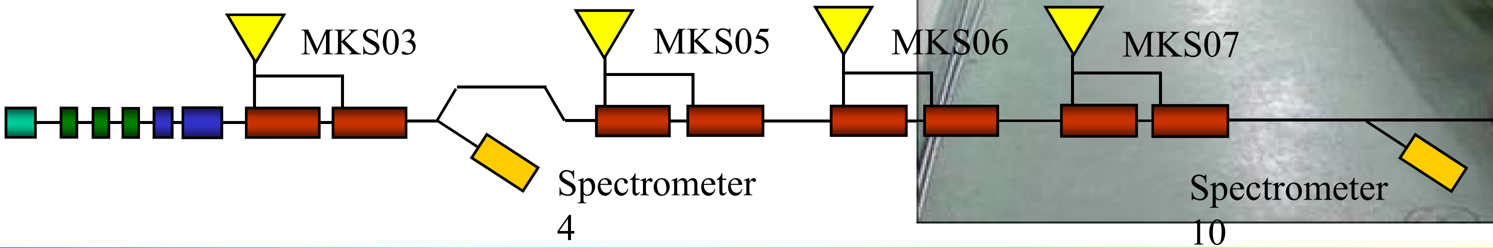
- 3 GHz $2\pi/3$ traveling wave structure
- constant aperture
- slotted-iris damping + detuning with nose cones
- up to 4 A 1.4 μs beam pulse accelerated
  no sign of beam break-up

Full beam-loading acceleration in CTF3

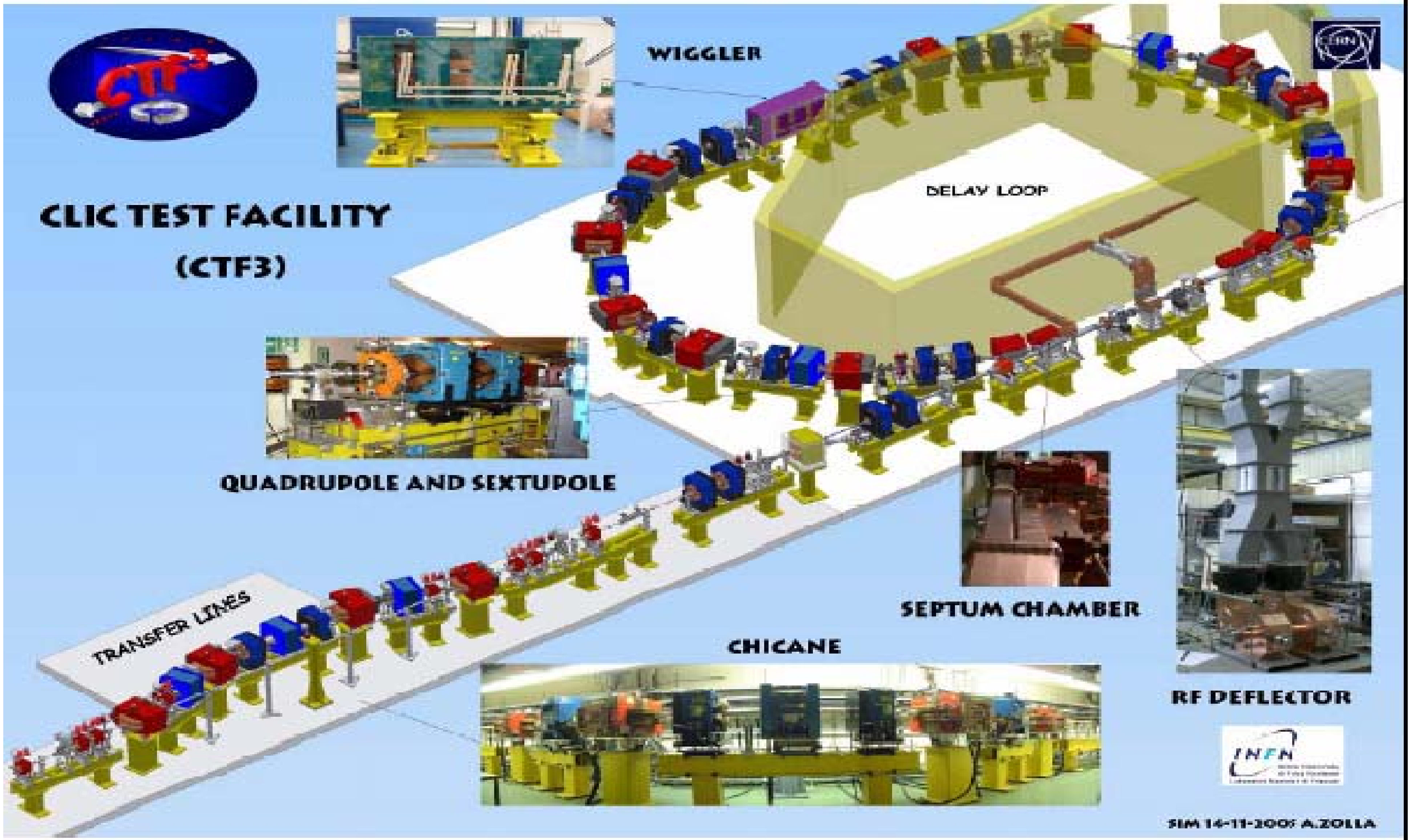




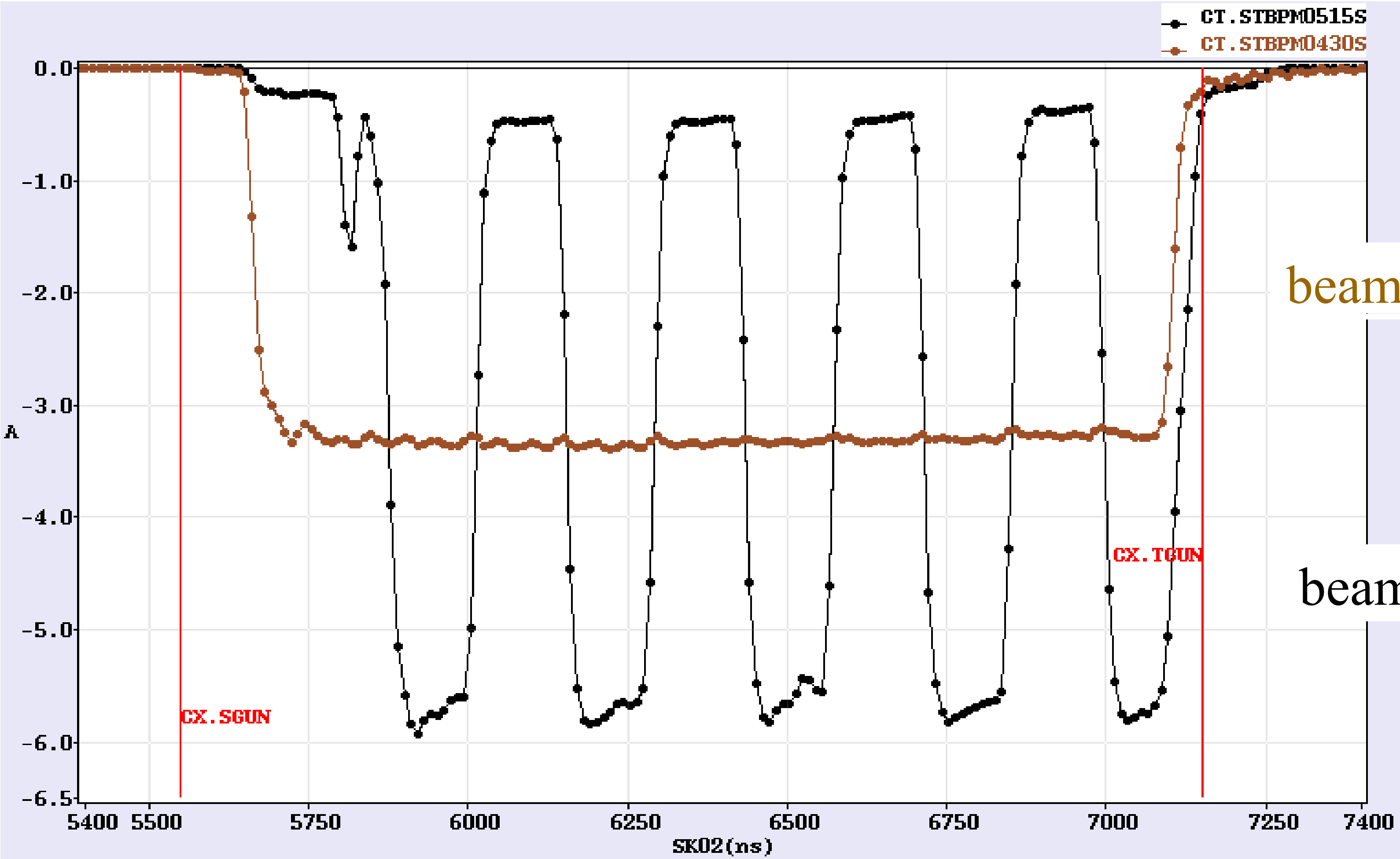
- Measured RF-to-beam efficiency 95.3%
- Theory 96%
  (~ 4 % ohmic losses)



CTF3 Delay Loop



Delay Loop – full recombination

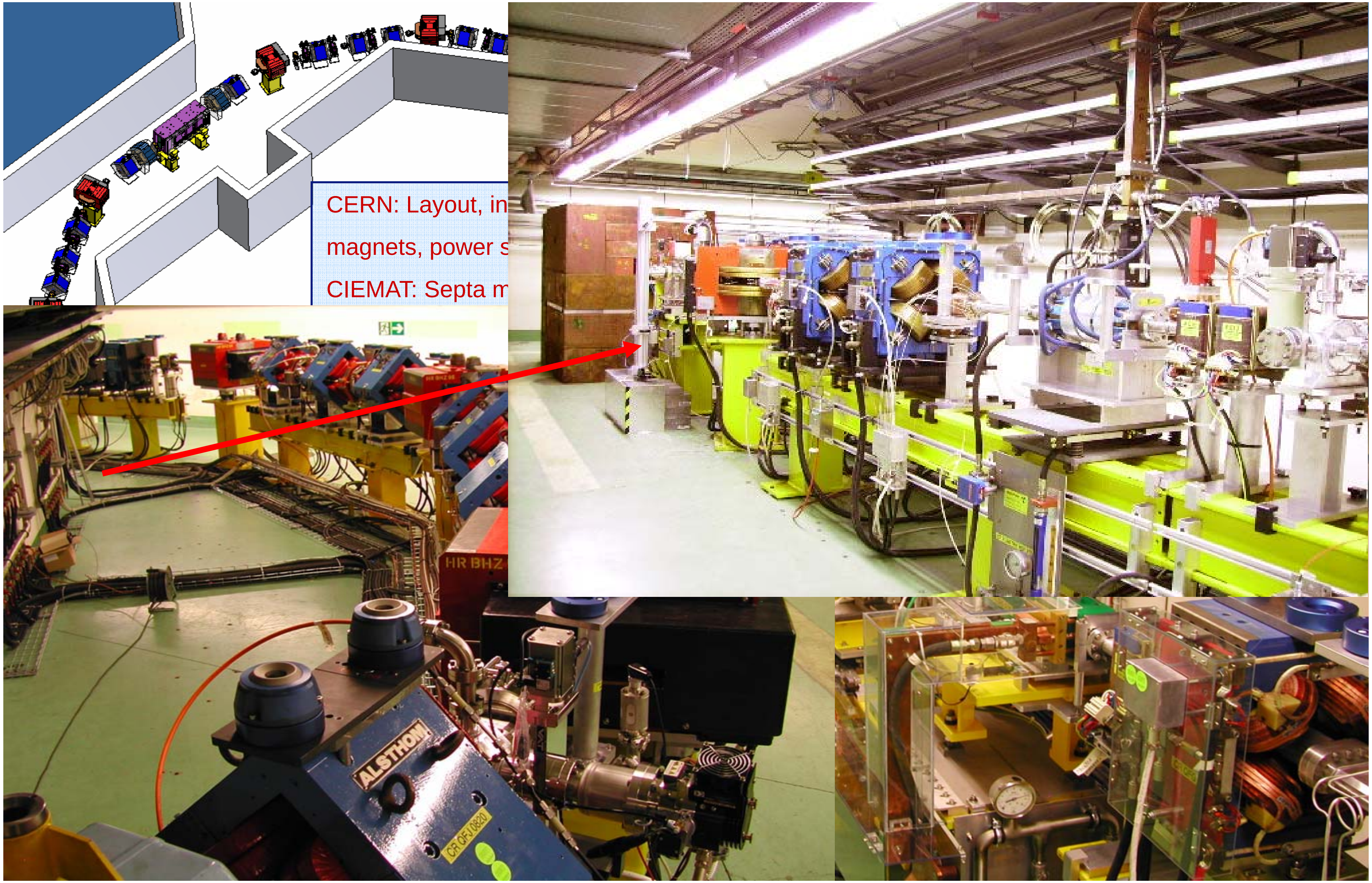


beam before the DL

beam after the DL

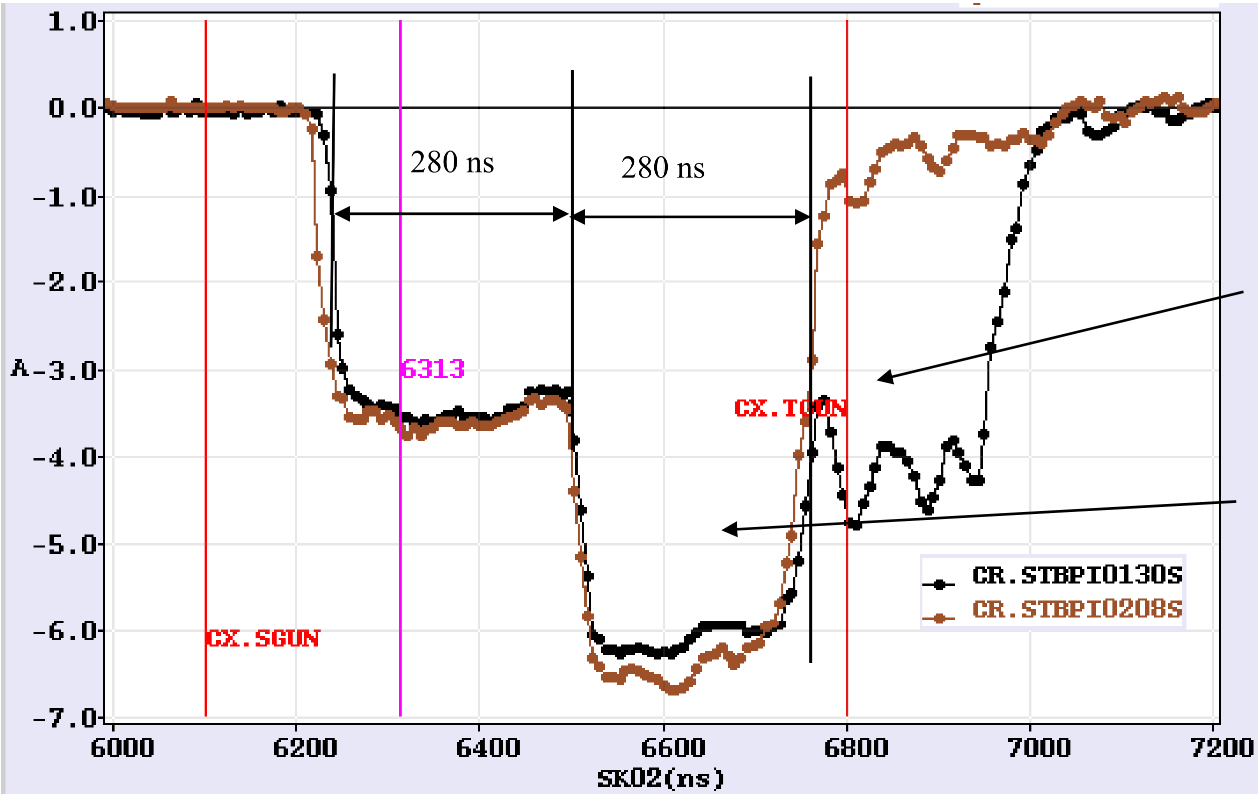
- 3.3 A after chicane => < 6 A after combination (satellites)

CTF3 combiner ring



Combiner ring - latest status

Latest results from commissioning … we recombine (factor 2)!

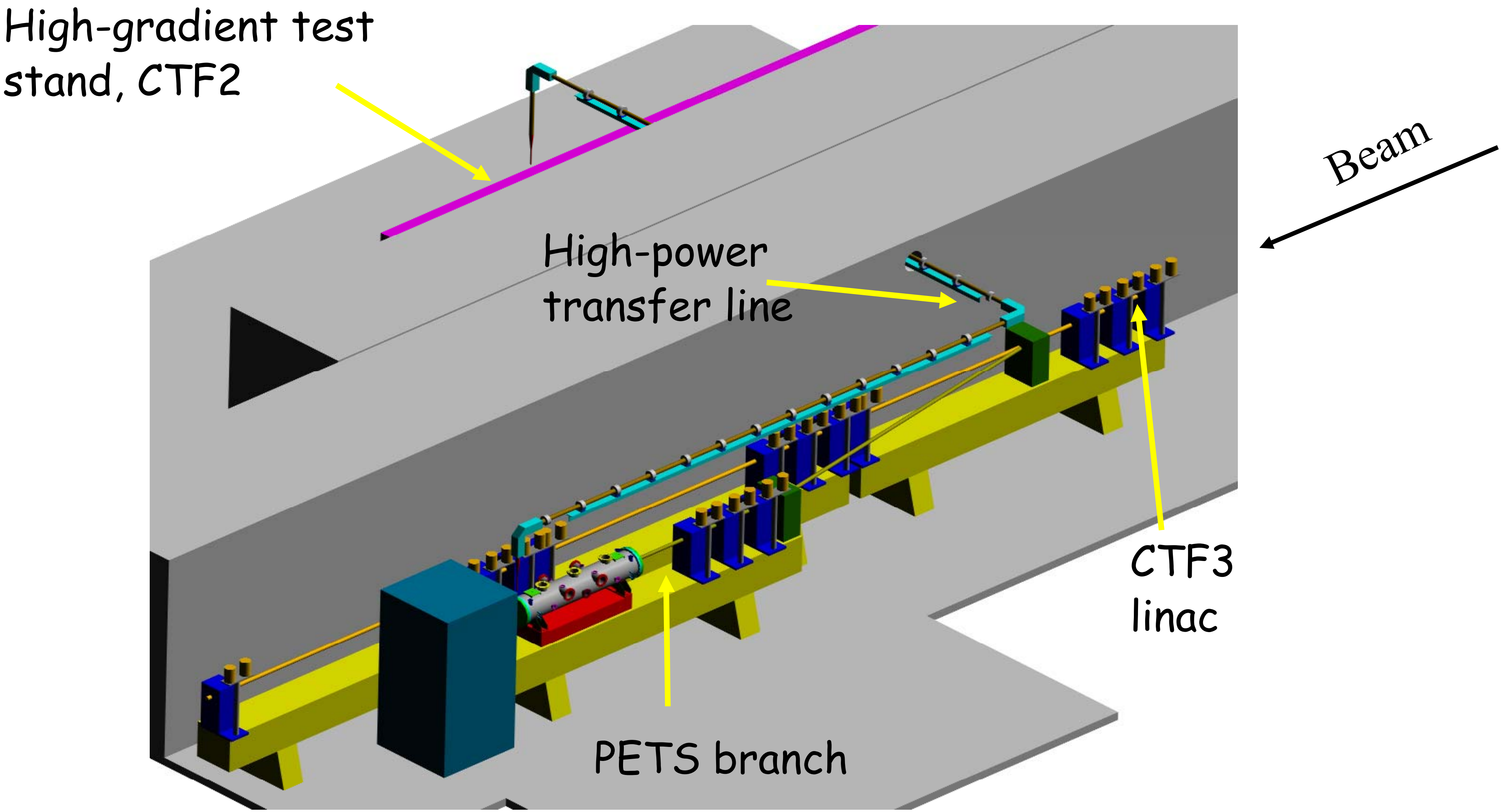


Second turn of second pulse and partly third turn of first pulse

Recombination – factor 2

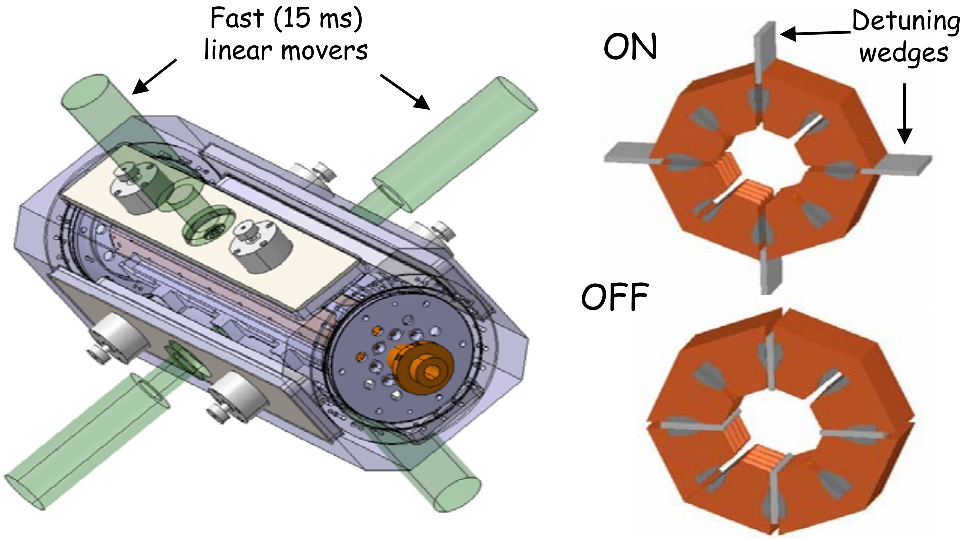
- nominal isochronous optics
- energy ~ 115 MeV
- RF injection (2nd RF deflector off – so far)
- set up of the path length in CR with wiggler

30 GHz test line

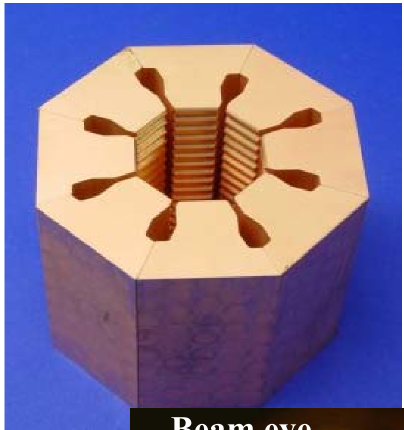


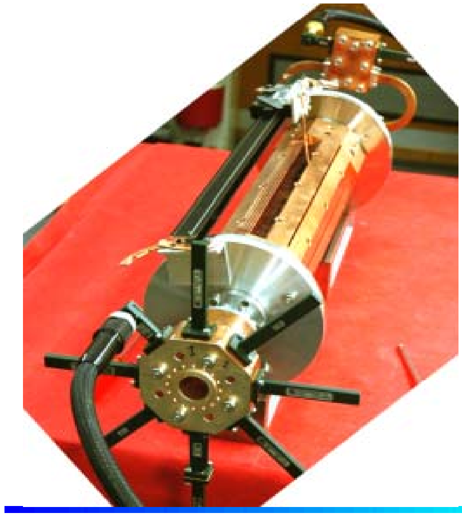
Power extraction structure PETS

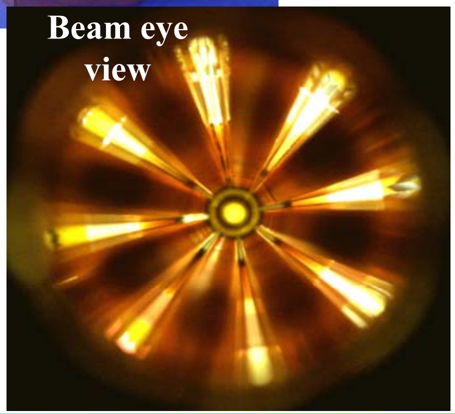
- must extract efficiently several 100 MW power from high current drive beam
- periodically corrugated structure with low impedance (big a/λ)
- ON/OFF mechanism

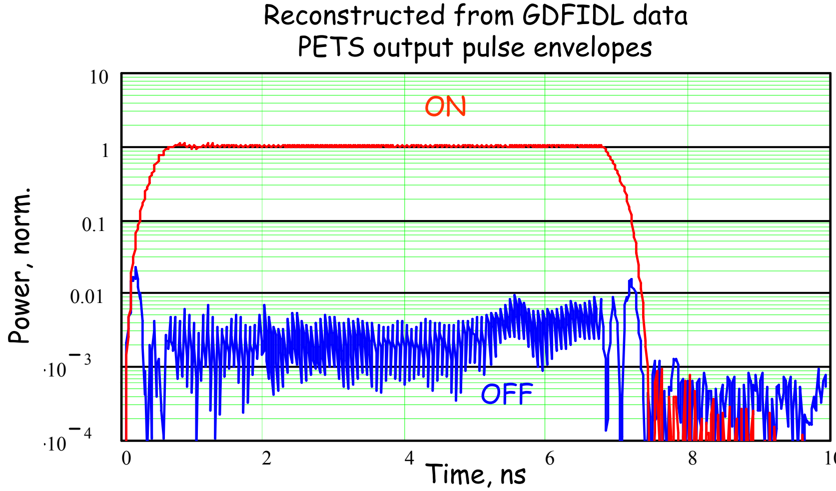


PETS ON/OFF mechanism

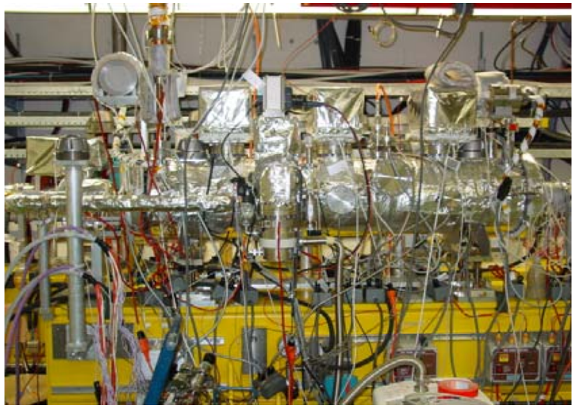








30 GHz power production (PETS)



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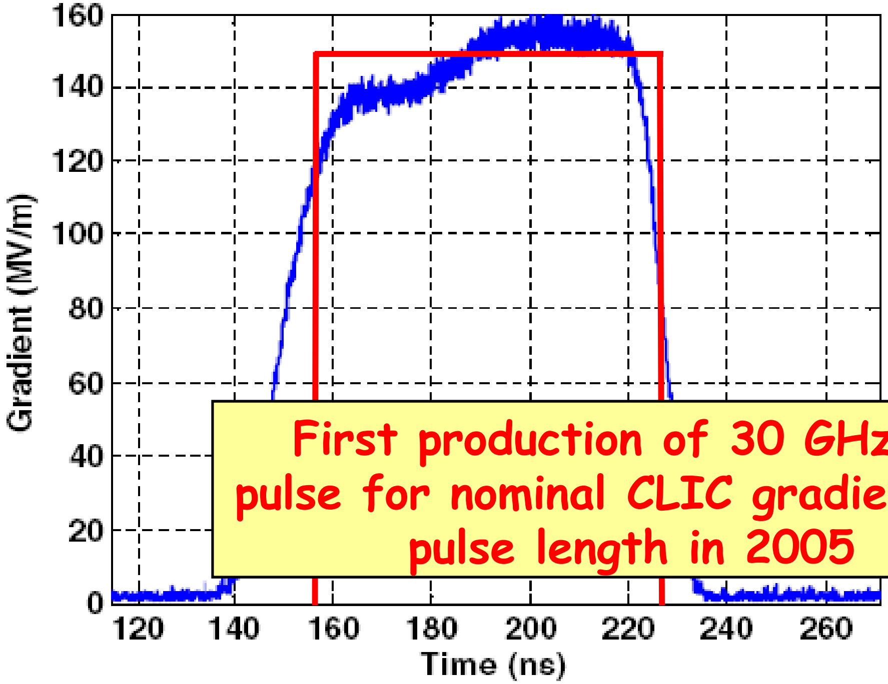
vacuum tanks containing Power Extraction Transfer Structure

17m waveguide with 5 bends but low-loss (85% transmission) (Russian collaboration)

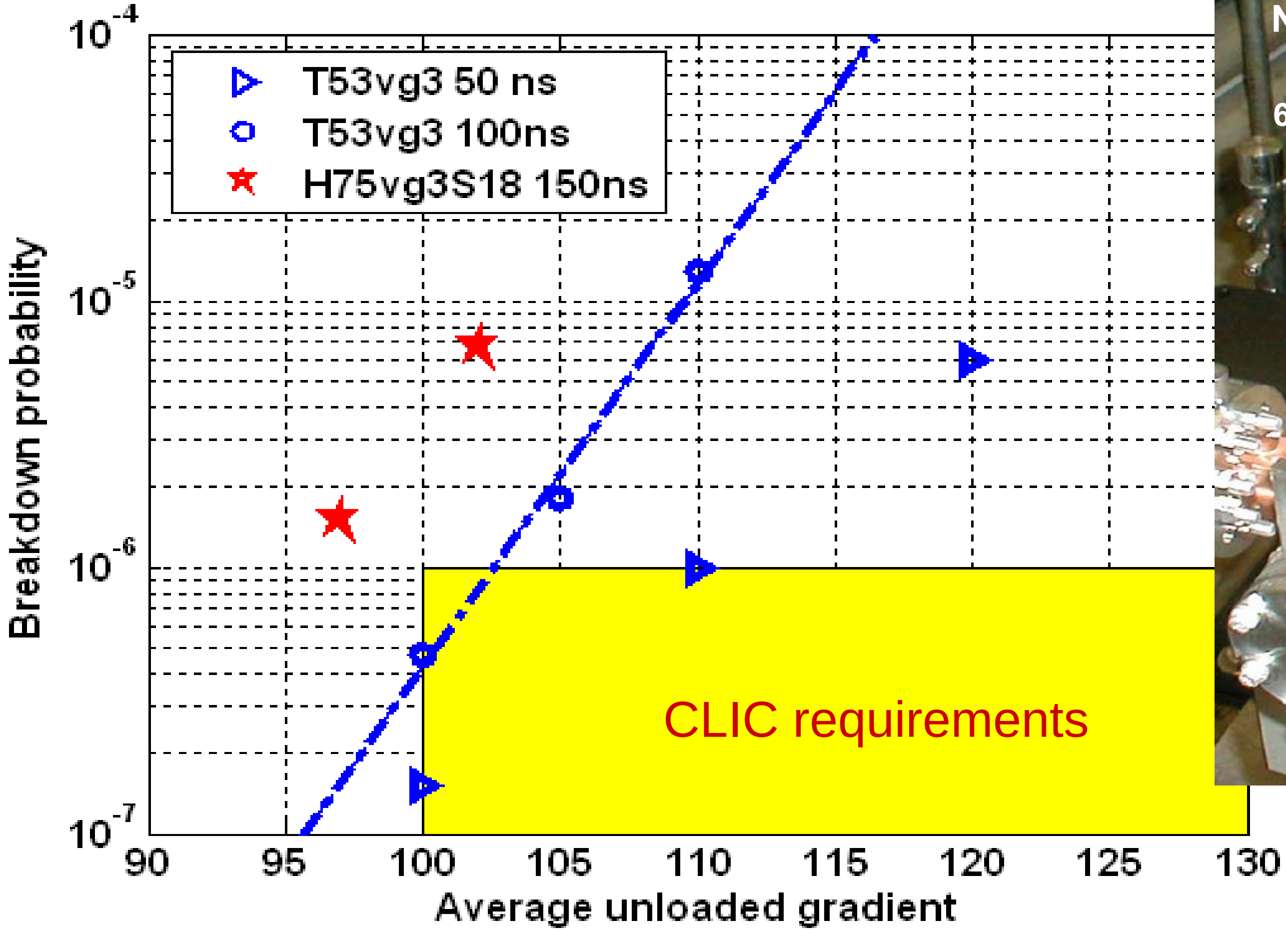


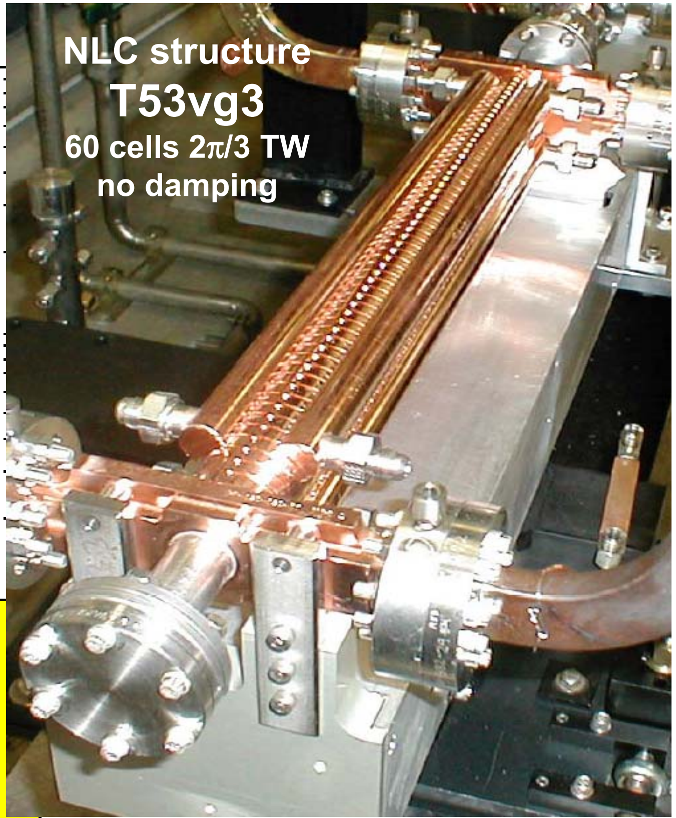
First production of 30 GHz RF pulse for nominal CLIC gradient and pulse length in 2005

high power load / accel. structure

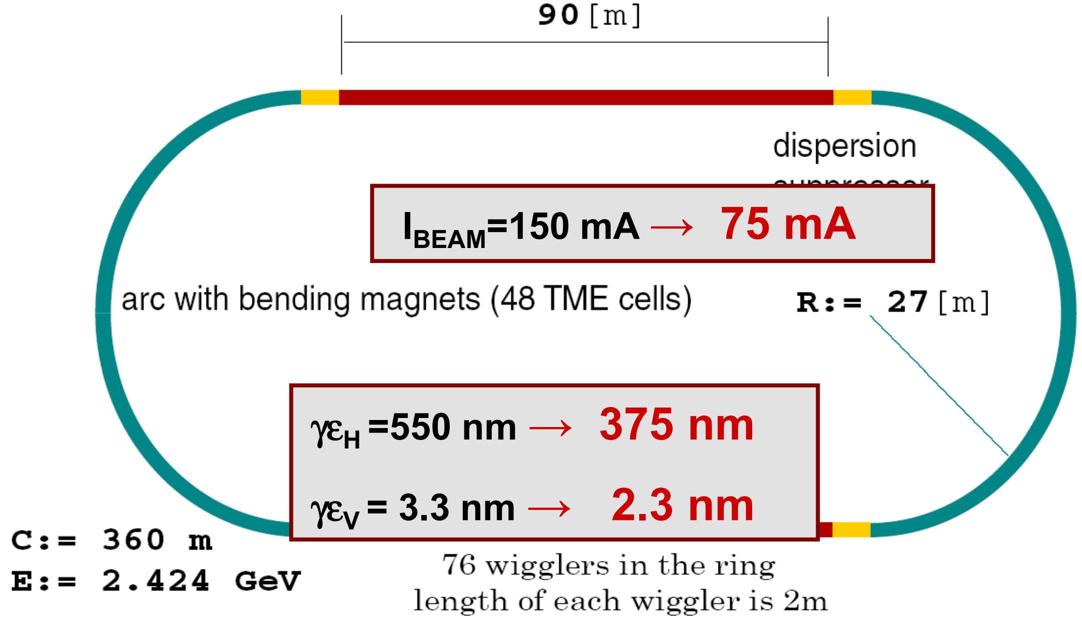
11.4 GHz High-Power test results

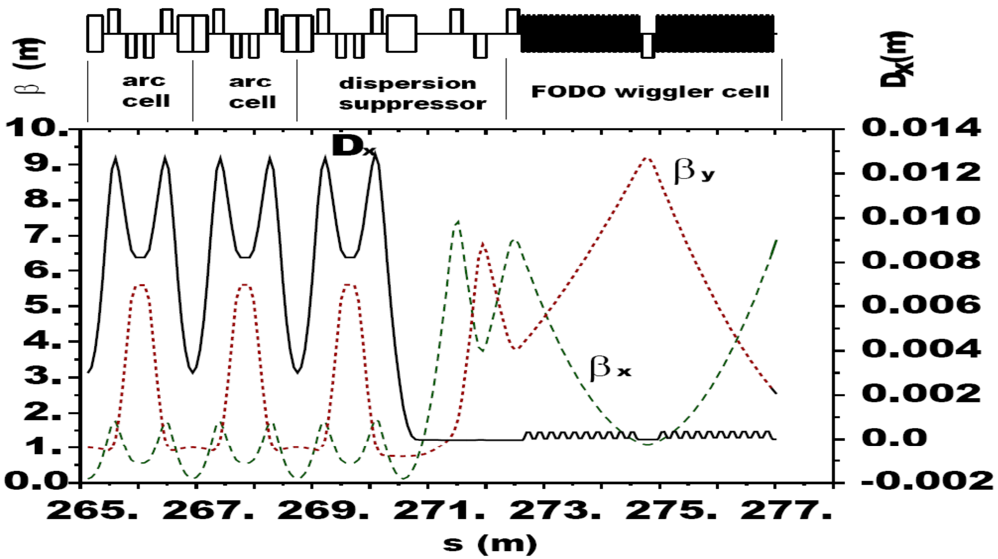
Recent SLAC High-Power test results – 11.4 GHz





CLIC damping ring





PM wiggler parameters (CLIC baseline)

CLIC damping wiggler parameters

Period:	10 cm
Gap:	12 mm
Pole width:	50 mm
Length:	2 m
Field amplitude:	1.7 T
Field quality @ ±1 cm:	10^{-3}
Total length:	160 m

SC wiggler parameters (September '05)

20 mm (pole gap) – 2x1 mm (He wall) – 2x2 mm (safety vacuum) - 2x1 mm (N wall screen) = 12 mm (beam aperture)

	λ_w (mm)	I (kA)	I/I_c (%)	H_w (T)	$H_{coil\text{-}max}$ (T)
Nb_3Sn	40	1.80	100	2.25	7.5
	40	1.67	85	2.10	7.0
	45	1.50	75	2.52	7.0
	50	1.67	85	3.05	7.0
NbTi	50	0.71	90	2.26	5.0

Transverse field quality: $\Delta B/B \sim 10^{-4}$ at ± 1 cm.

Stability Studies

Vertical spot size at IP is ~ 1 nm *(10 x size of water molecule)*

Stability requirements (> 4 Hz) for a 2% loss in luminosity

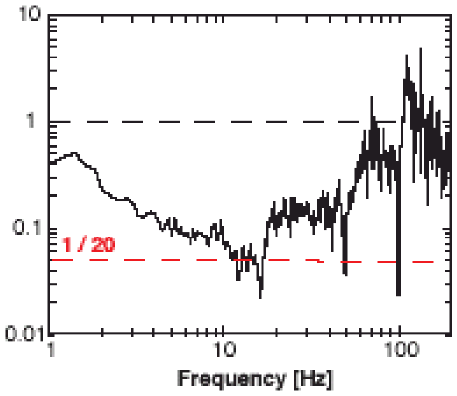
Magnet	Ix	Iy
Linac (2600 quads)	14 nm	1.3 nm
Final Focus (2 quads)	4 nm	0.2 nm

→ Need active damping of vibrations

CERN vibration test stand

Vertical stabilization of a CLIC prototype quadrupole

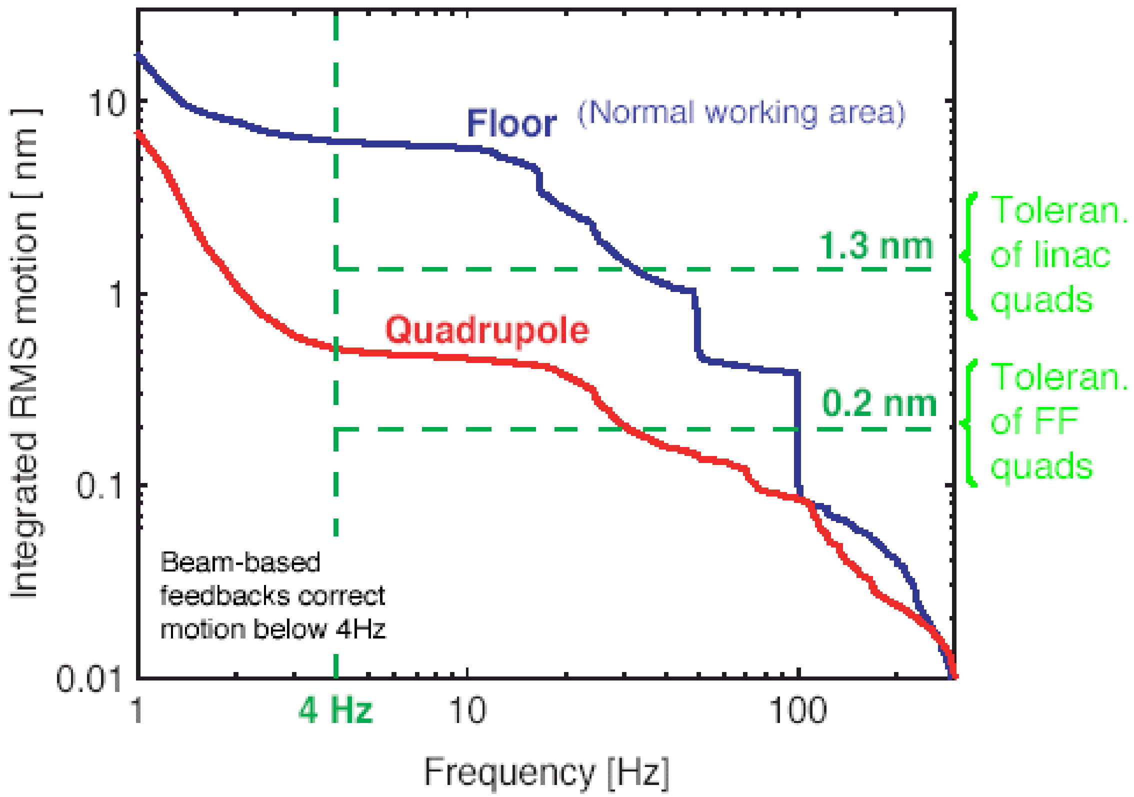
Ground-to-table transmission



RMS vibrations above 4 Hz

	Quad [nm]	Ground [nm]
Vertical	**0.43**	**6.20**
Horizontal	**0.79**	**3.04**
Longitud.	4.29	4.32

Integrated *vertical* RMS motion versus frequency



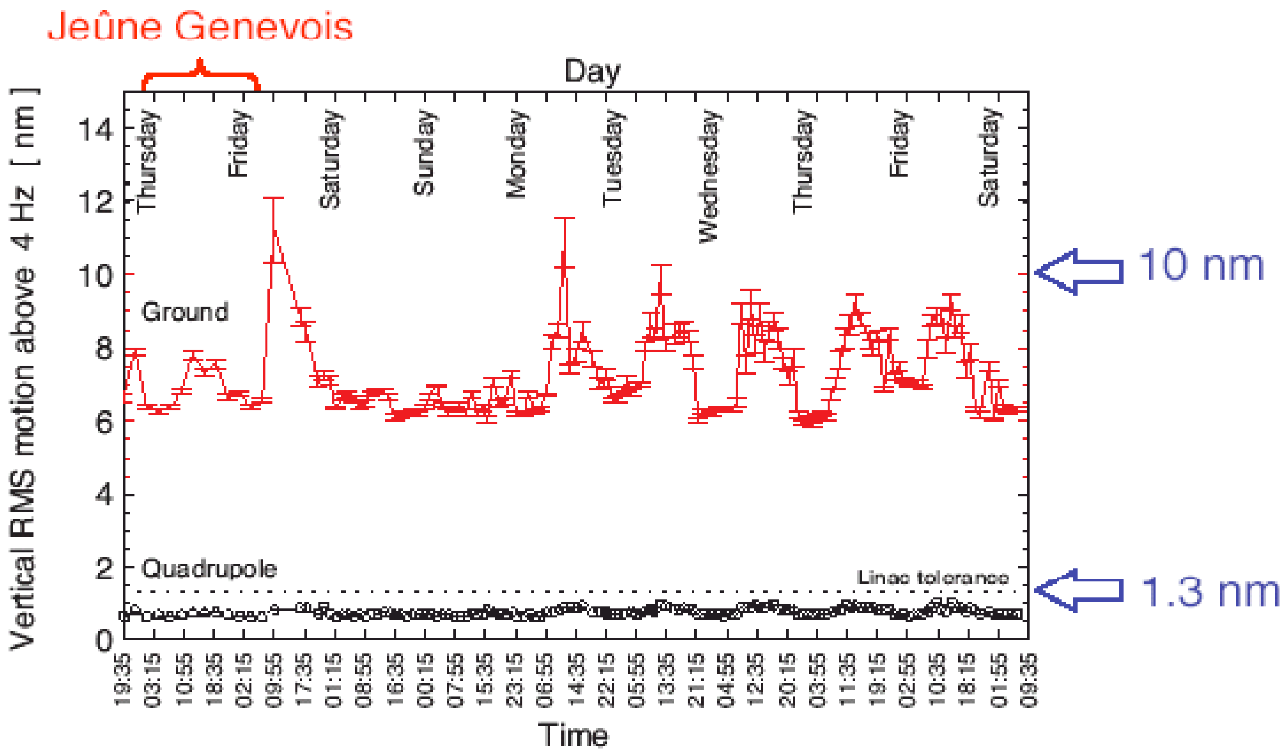
CLIC prototype magnets stabilized to the sub-nanometre level !!

Above 4 Hz: **0.43 nm** on the quadrupole instead of **6.20 nm** on the ground.

(World record in magnet stability)

Stefano Redaelli

Ok, this is good. But is it ***stable***?



Quadrupole vibrations kept below the 1 nm level
over a period of 9 consecutive days!

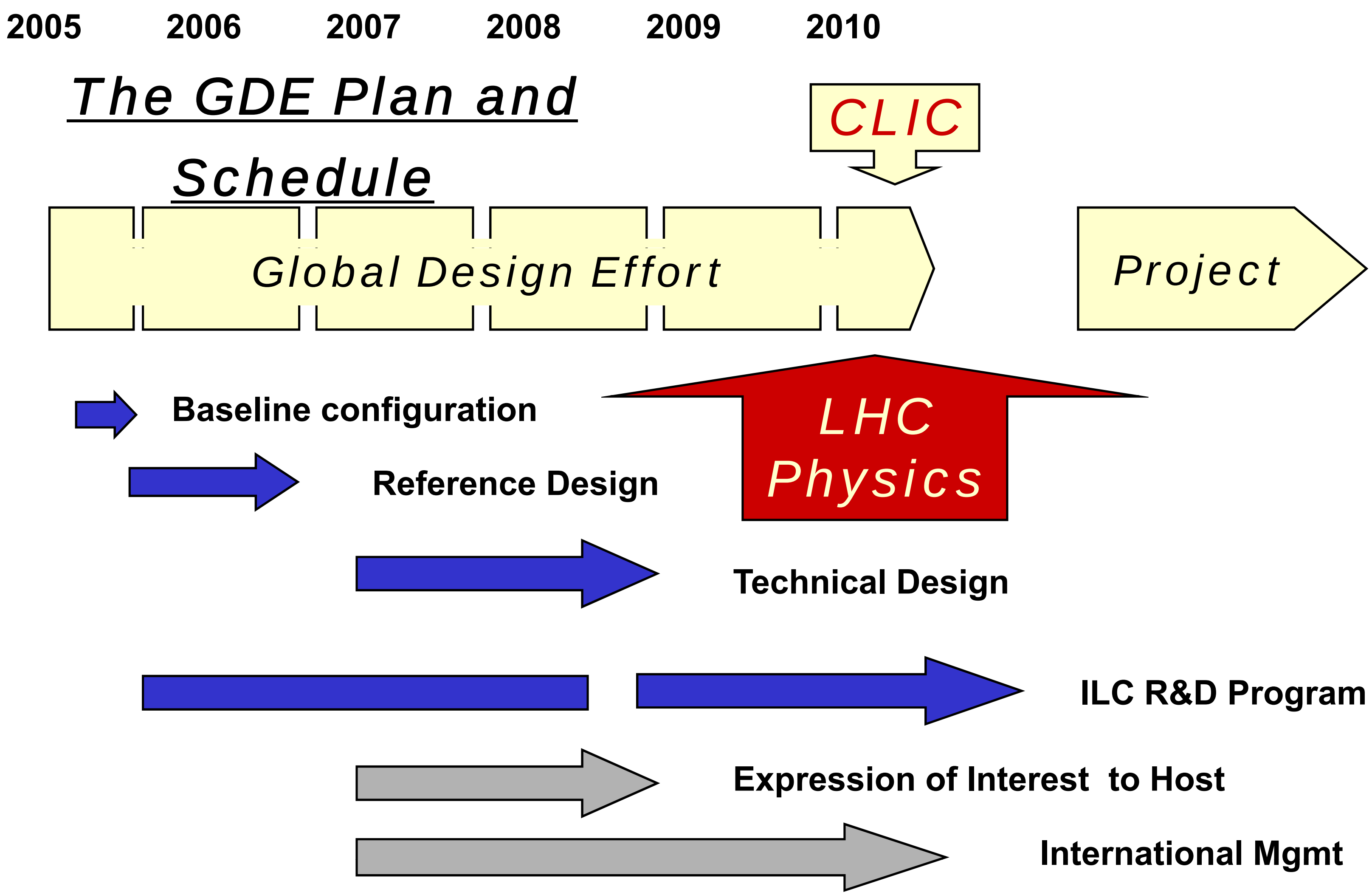
Stefano Redaelli

Other issues

- Many similar issues as ILC
  - Generation of tiny emittance in the damping rings
  - Emittance preservation
  - Collimation
  - Final focus system
  - Beam-beam effects
  - Detector background
  - Extraction of post collision beams
  - Beam instrumentation
  - Feed-backs
  - Efficiency!
  - …

CLIC and ILC timeline

From B. Barish, ILC Global Design Effort director



CONCLUSION

- World-wide Consensus for a Lepton Linear Collider as the next HEP facility to complement LHC at the energy frontier
- Energy range < 1 TeV accessible by ILC
- CLIC technology based on
  - normal conducting RF structures at high frequency
  - two-beam scheme

only possible scheme to extend collider beam energy into Multi-TeV energy range

- Very promising results but technology not mature yet, requires challenging R&D
- CLIC-related key issues addressed in CTF3 by 2010

> Aim to provide the High Energy Physics community with the feasibility of CLIC technology for Linear Collider in due time, when physics needs will be fully determined following LHC results
>
> Alternative to the SC technology in case sub-TeV energy range is not considered attractive enough for physics

http://cern.ch/clic-study