Technology Highlights of High Energy Accelerator Projects

(an almost random choice for entertainment on the last day of this course)

Hermann Schmickler, ex-CERN

The CERN Accelerator School

CERN

Copyright statement and speaker's release for video publishing

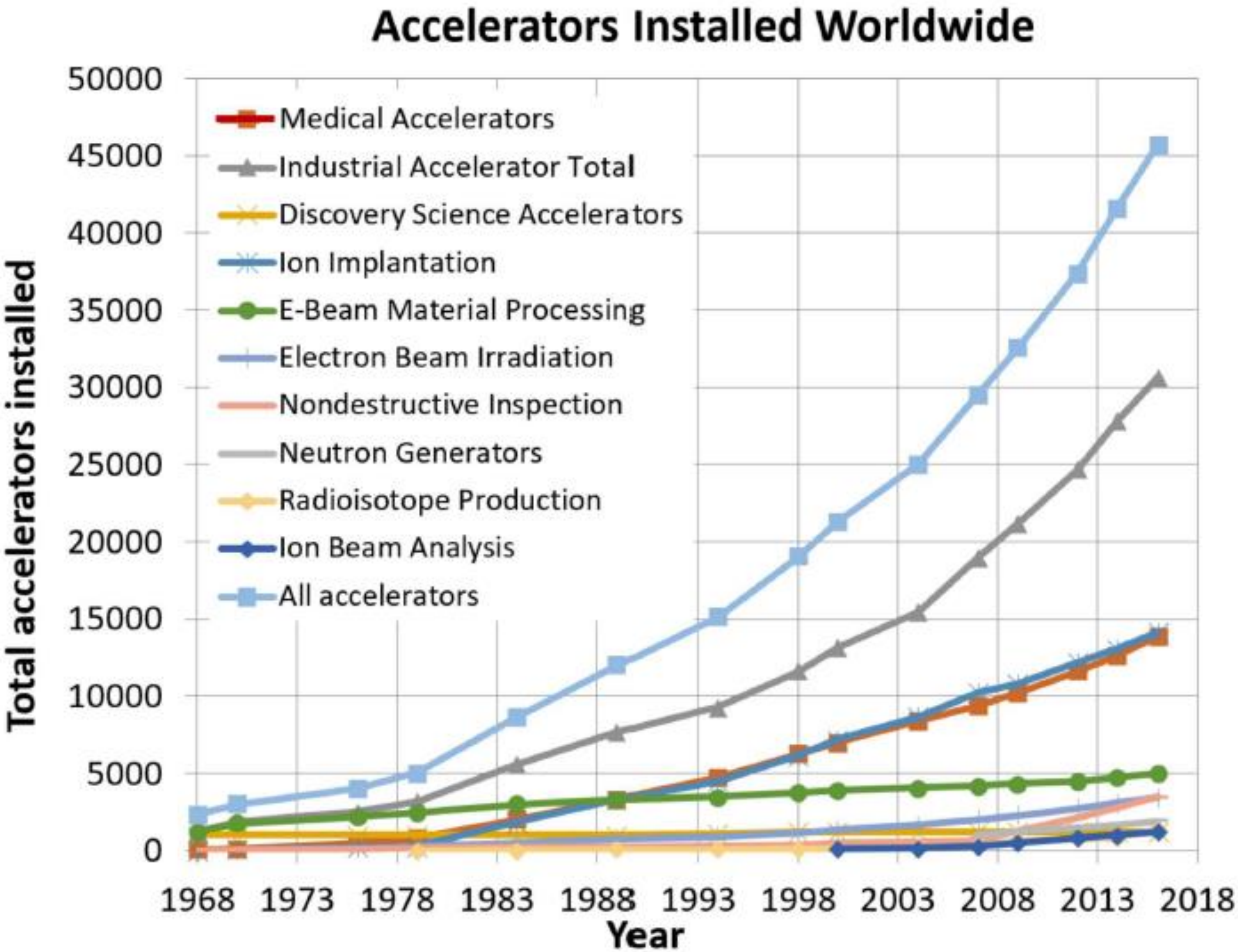
Outline

- Accelerator types
- Most important beam parameters

  - particle type → application, very different accelerator types
  - beam energy → acceleration (cavities), bending (dipoles)
  - beam intensity → shielding, losses, irradiation, **alignment**
  - beam size (emittance) → focusing
    cavities, quadrupoles, sextupoles, **alignment**

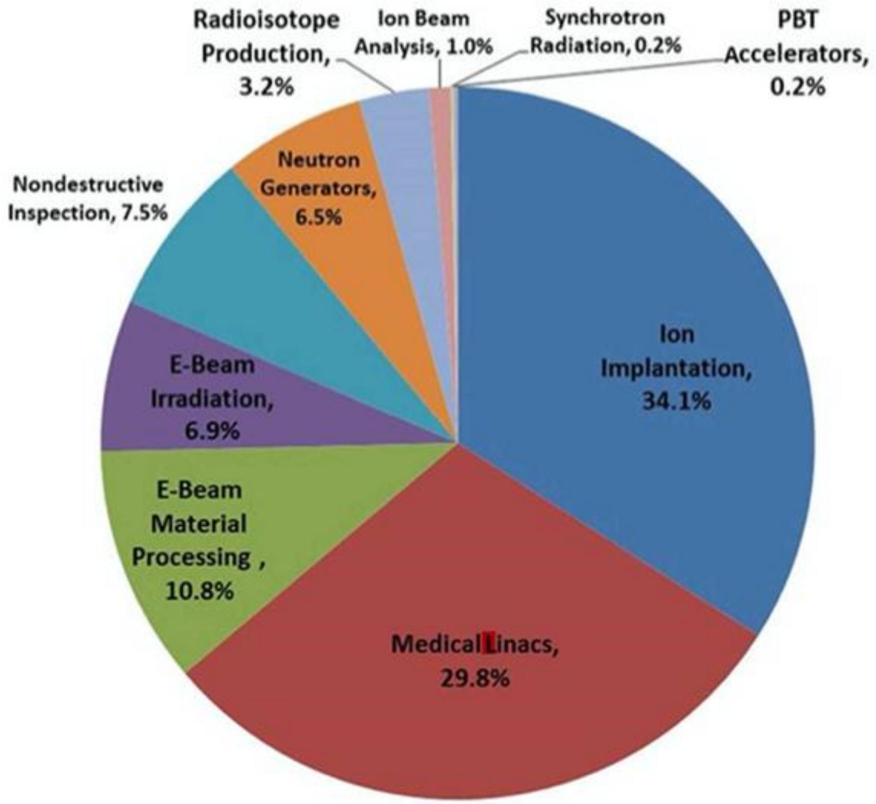
- Some mechanical engineering highlights including some beam physics background

  - hollow electron lens for beam cleaning (project Hilumi-LHC)
  - CLIC two-beam module



Doyle, McDaniel, Hamm, *The Future of Industrial Accelerators and Applications, SAND2018-5903B*

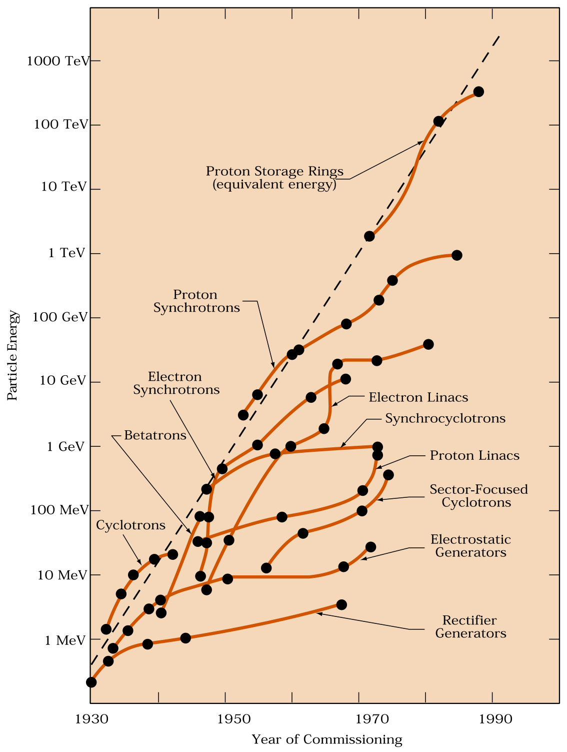
“A beam of particles is a very useful tool…”



Doyle, McDaniel, Hamm, *The Future of Industrial Accelerators and Applications, SAND2018-5903B*

Where do breakthrough technologies come from?

Many innovations emerge from interplay between curiosity driven research and societal need



https://www.symmetrymagazine.org/article/october-2009/deconstruction-livingston-plot

particle physics

vaccines, archaeology, etc…

proton therapy

radiotherapy, security

water, food, materials treatment, sterilisation

John Womersley, former CEO of STFC (UK) said:

"Particle physics is unreasonable. It makes unreasonable demands on technology. And when those technologies, those inventions, those innovations happen, they spread out into the economy, and they generate a huge impact."

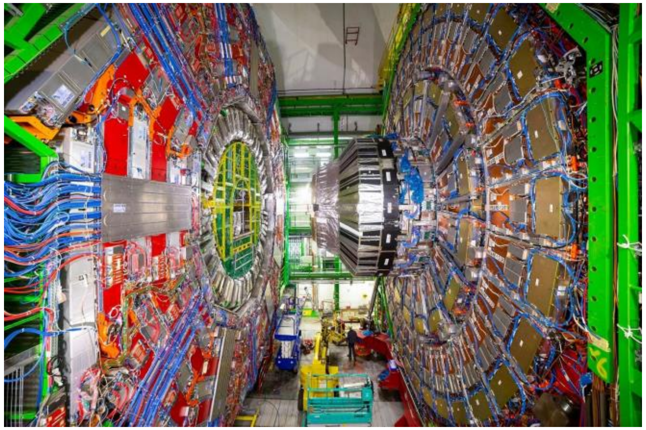


Image: CMS, CERN

This and the following 3 slides taken from: S.Sheehy, CAS Introduction to Accelerator physics

Most important beam parameters

1) Particle types

- Particles need to be charged and stable to be accelerated →

e+,e-,p, pbar, heavy ions

- Other particles created as secondary beams

x-rays, photons, neutrons…pions, muons….

- actual choice depends exclusivly on application

- High energy colliders in these days: e+,e-,p …(muons)

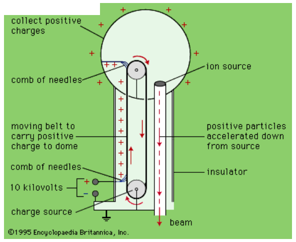
→ more in 2nd lecture about colliders

Most important beam parameters

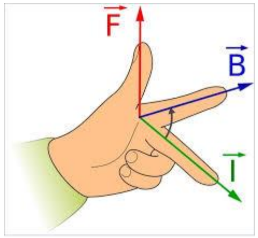
2) Beam energy….Lorentz-Force:

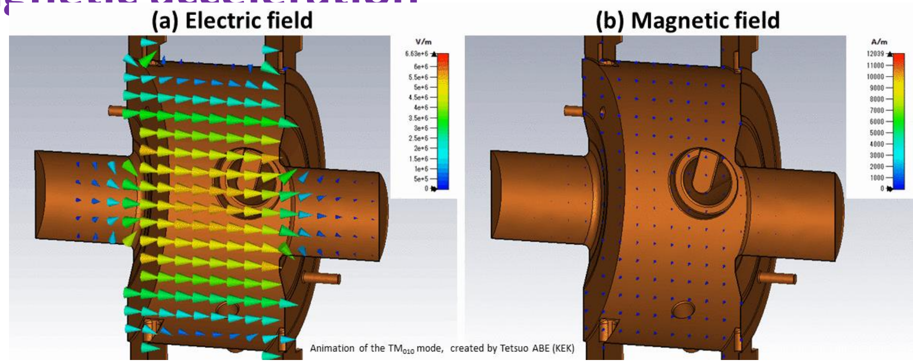
$$\vec{F} = \underbrace{q\vec{E}}_{\text{Electric force}} + \underbrace{q\vec{v} \times \vec{B}}_{\text{Magnetic force}}$$

- up to max. 10 MeV **electrostatic acceleration** possible
→ DC beam; van de Graaff accelerator type



- higher energies demand **electromagnetic acceleration** in cavities → bunched beams





- linear accelerators: **Single pass acceleration**
→need very **high acceleration gradients** (CLIC: 100 MeV/m)

- circular accelerators: **Multi pass acceleration** through few cavities
→ need (strong) **dipoles** to put beam onto a **circular orbit**

Most important beam parameters

3) beam intensity

- particles of equal charge expulse each other → maximum bunch intensity (up to 10^{13} charges/bunch)
  → more: instabilities, blow-up, losses

- stored energy of beams can become very large (kinetic energy)
  (HL-LHC up to 1 GJ stored beam energy: a 200m long TGV at 400 km/h)

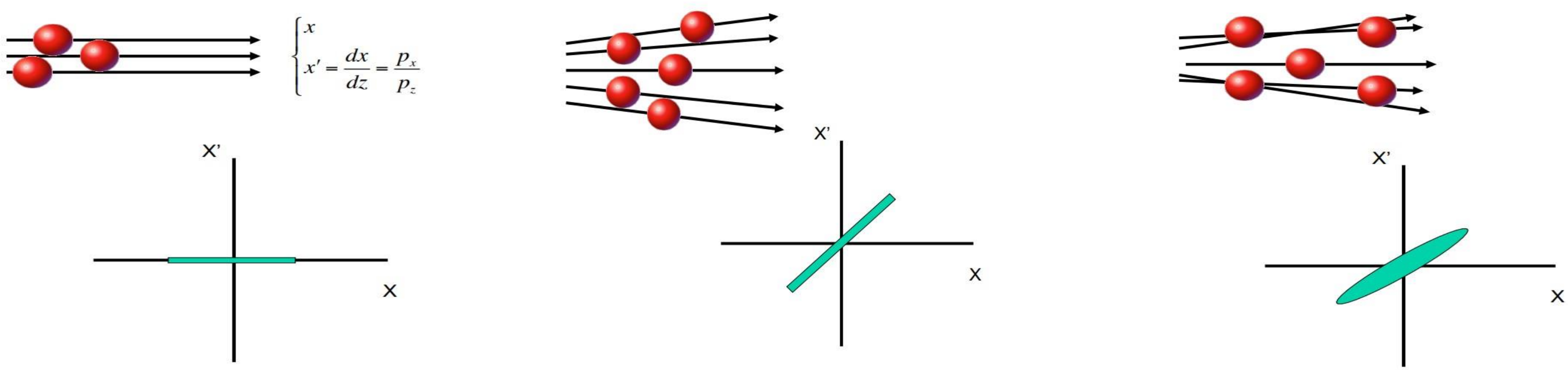
→ issues:

- sources (how to get so many particles)
- Irradiation and activation of machine components
- damage to accelerator components
- particle (performance) loss
- sophisticated access control systems
- sophisticated beam dumps (controlled extraction of particles)

Most important beam parameters

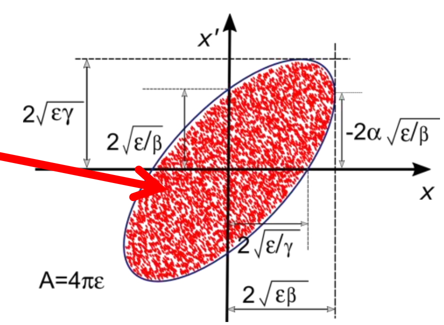
4) beam size …the most complex part!

Description of beams in **trace space**:= space – angle coordinate system



Ideal beam | laminar beam | non-laminar beam

Describe real beam by its surface in trace space:=
geometrical emittance



!! In a conservative system (energy conservation) the beam emittance is preserved !!

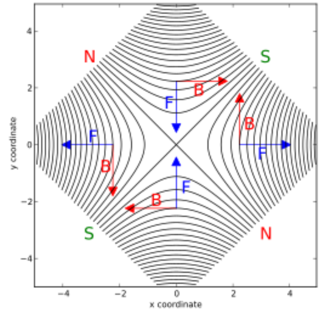
Focusing

- Without additional elements any non-laminar beam will diverge along its propagation path

transverse case:

- a single lens can focus a beam to a point, but then the beam diverges again
- need a sequence of lenses
- a « lens » for a particle beam is an element with a force towards its center, which is proportinal to the distance from the center

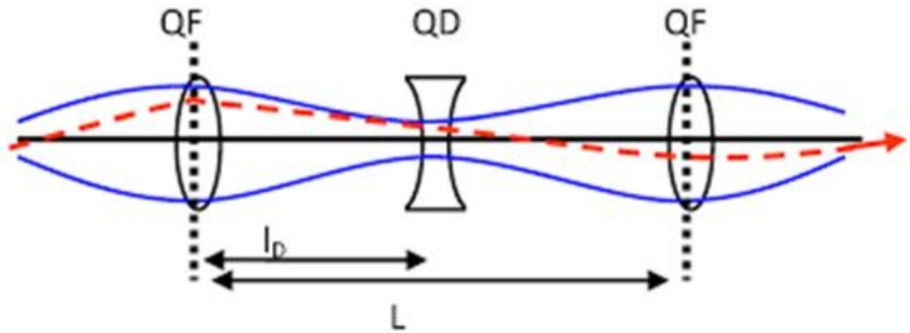
→ a quadrupole



But unlike an optical lens a magnetic lens (quadrupole)

- **A quadrupole focuses only in one plane**
- **Defocuses in the orthogonal plane**

FODO transfer Matrix in 6-D



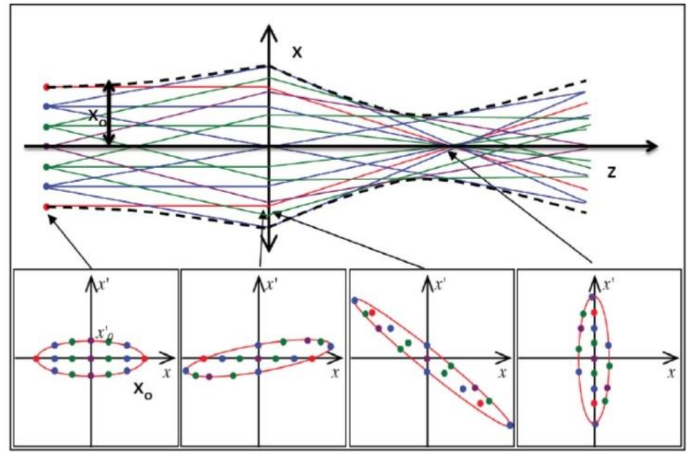
In order to calculate numbers one usually defines a FODO cell from the middle of the first F-quadrupole up to the middle of the last F-quadrupole.

Hence the resulting transfer matrix looks:

$$\begin{pmatrix} 1-\frac{L^2}{2f_0^2} & \frac{L}{f_0}(L+2f_0) & 0 & 0 & 0 & 0 \\ \frac{L}{4f_0^3}(L-2f_0) & 1-\frac{L^2}{2f_0^2} & 0 & 0 & 0 & 0 \\ 0 & 0 & 1-\frac{L^2}{2f_0^2} & -\frac{L}{f_0}(L-2f_0) & 0 & 0 \\ 0 & 0 & -\frac{L}{4f_0^3}(L+2f_0) & 1-\frac{L^2}{2f_0^2} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & \frac{2L}{\beta_0^2\gamma_0^2} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

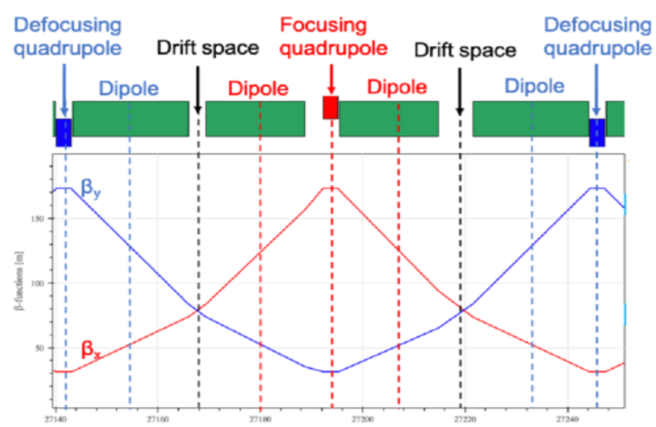
FODO lattice

- Resulting beam envelope:



"$1D\ beam\ size$": $x(s) = \sqrt{\varepsilon} \cdot \sqrt{\beta(s)} \cdot cos\{\mu(s) + \varphi\}$

$\beta(s)$ = Beta function



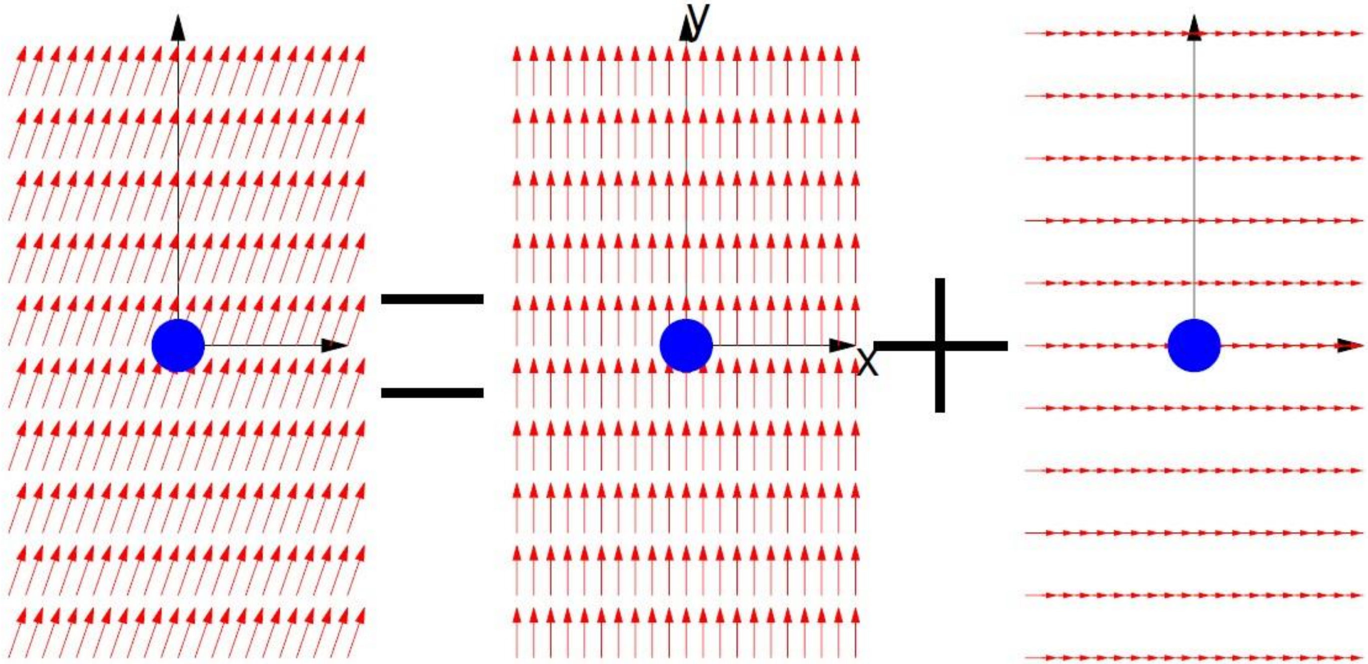
Horizontal (red) and vertical (blue) beta-functions of a FODO cell

ε = emittance [mm mrad]

In an energy conserving system the emittance of a beam is preserved; hence one has to produce the beam with a small emittance and keep it small.

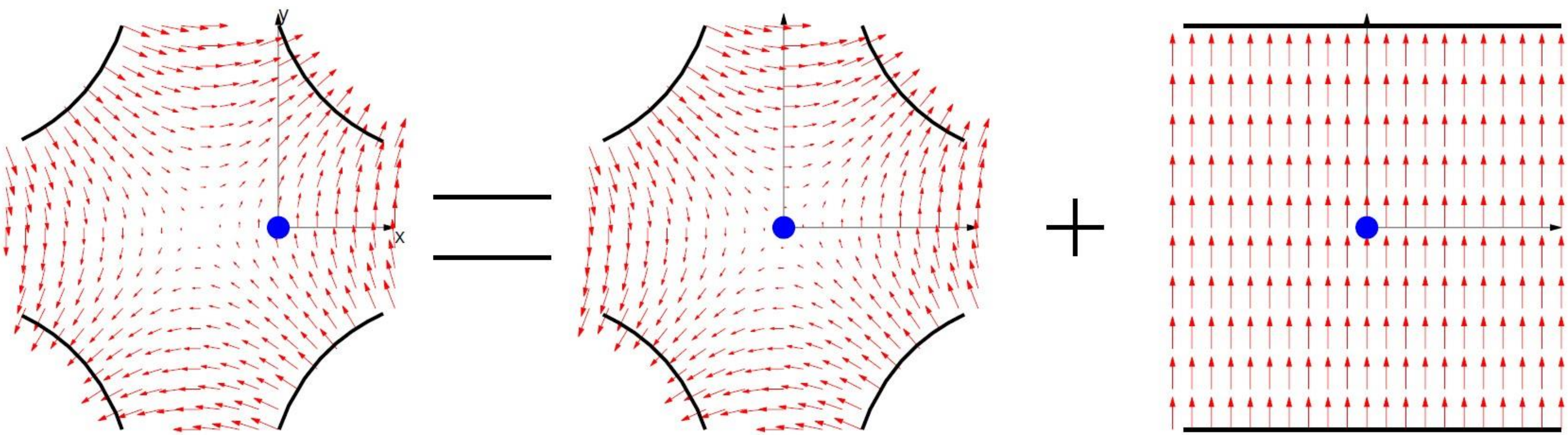
Dipole Errors

error	effect	correction
strength (k)	change in deflection	change excitation current, replace magnet
lateral shift	none	
tilt	additional vertical deflection	corrector dipole magnet



Quadrupole Errors

Error type	effect on beam	correction(s)
strength	Change in focusing, “beta-beating”	Change excitation current, Repair/Replace magnet
Lateral shift	Extra dipole kick	Excitation of a corrector dipole magnet
tilt	Coupling of the beam motion in the two planes	Excitation of a additional “skewed quadrupoles (45^0)

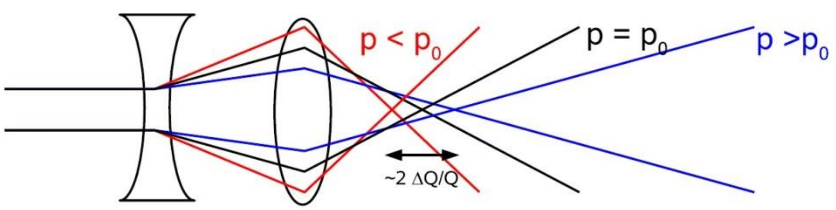


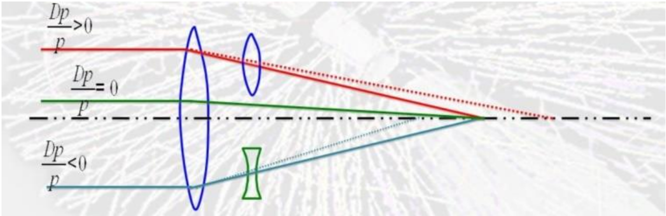
An offset quadrupole is seen as a centered quadrupole plus a dipole.

sextupoles

- For all magnetic elements in an accelerator the force on the beam depends on the magnetic field AND on the momentum of the particles.
- Particles in a bunch have always a momentum spread (spread some 10^{-3}) (→longitudinal emittance!), so each magnetic element exerts a slightly different force onto individual particles.
- In dipoles this means that particles travel on different orbits
→ bigger vacuum chambers

- The effect in the case of quadrupoles can be corrected with sextupoles (quadratic dependence of field from origin) in a dispersive region.



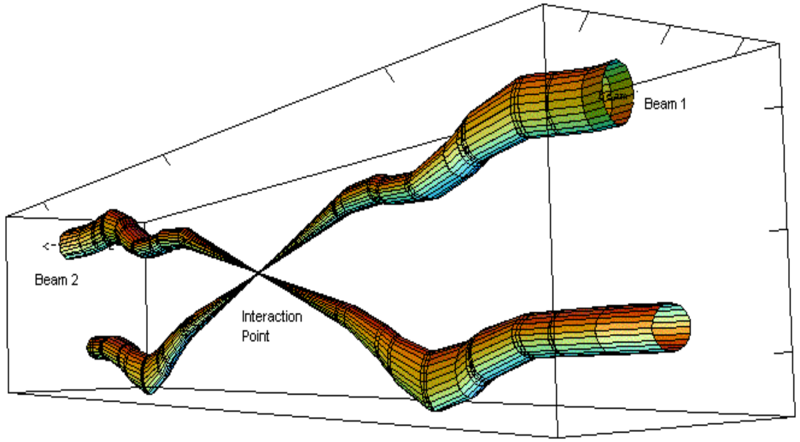


Last slide (for now) on quadrupoles

- For particle colliders (next lecture!) one of the most important parameter of performance is the so called **luminosity L**.
- The luminosity is a measure of how many particle interactions can be produced per time unit.
- It depends crucially on the beam densities at the interaction point (IP), in other words on the beam size at the IP.
- One uses very strong (SC-) quadrupoles for maximum focalization at the IP.

$$L = \frac{n_b N_{b1} N_{b2} f \gamma_r}{4 \pi \beta^* \varepsilon}$$

Low values of β^* are alone not sufficient, one must generate and preserve beams with the lowest possible **emittance**



Relative beam sizes around IP1 (Atlas) in collision

J. Jowett

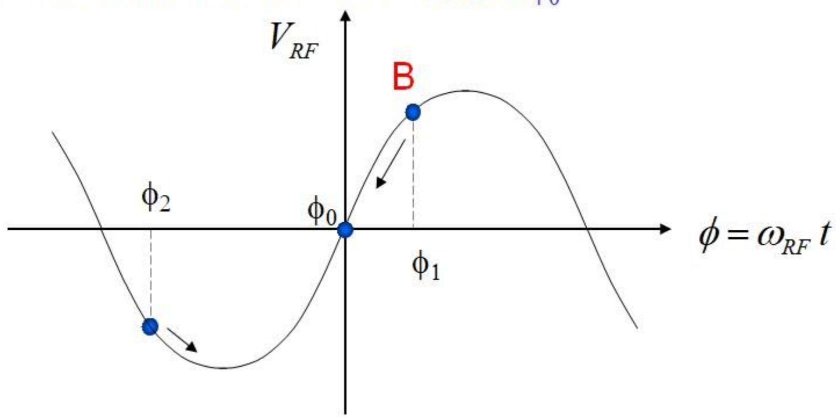
LHC
β^* = 18 → 0.55 m
ε = 3.75 μm
γ_r = 7463
$\sigma_{x,y}$ = 16.6 μm

Only one slide on longitudinal focusing

- (maybe too much) **simplified picture**
- Also in the longitudinal plane the beam has a finite emittance $(x, x') \rightarrow (z, dp_z/p_z)$
- T Simple case (no accel.): B = const., below transition $\gamma < \gamma_t$

The phase of the synchronous particle must therefore be $\phi_0 = 0$.

Φ_1 - The particle B is accelerated
- Below transition, an energy increase means an increase in revolution frequency
- The particle arrives earlier – tends toward ϕ_0

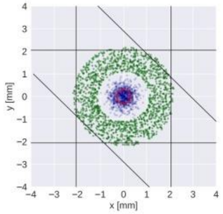


ϕ_2 - The particle is decelerated
- decrease in energy - decrease in revolution frequency
- The particle arrives later – tends toward ϕ_0

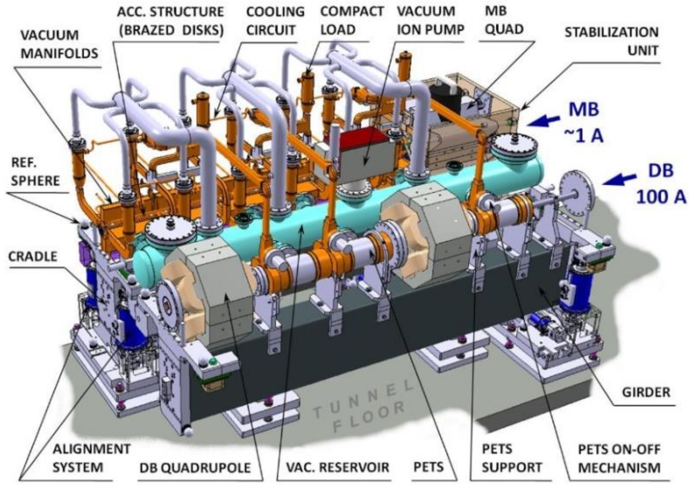
Highlights

- Just a personal choice!
- **Show two highly integrated subsystems**
- Related to the previously explained physics aspects

1. **Hollow Electron Lens** ← handling of high power beams

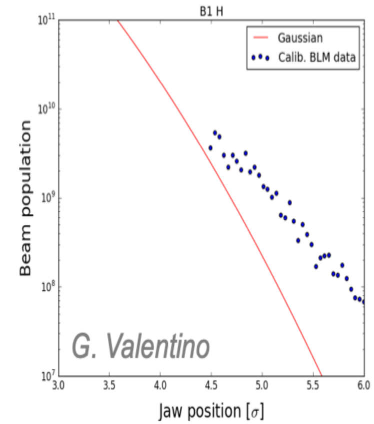


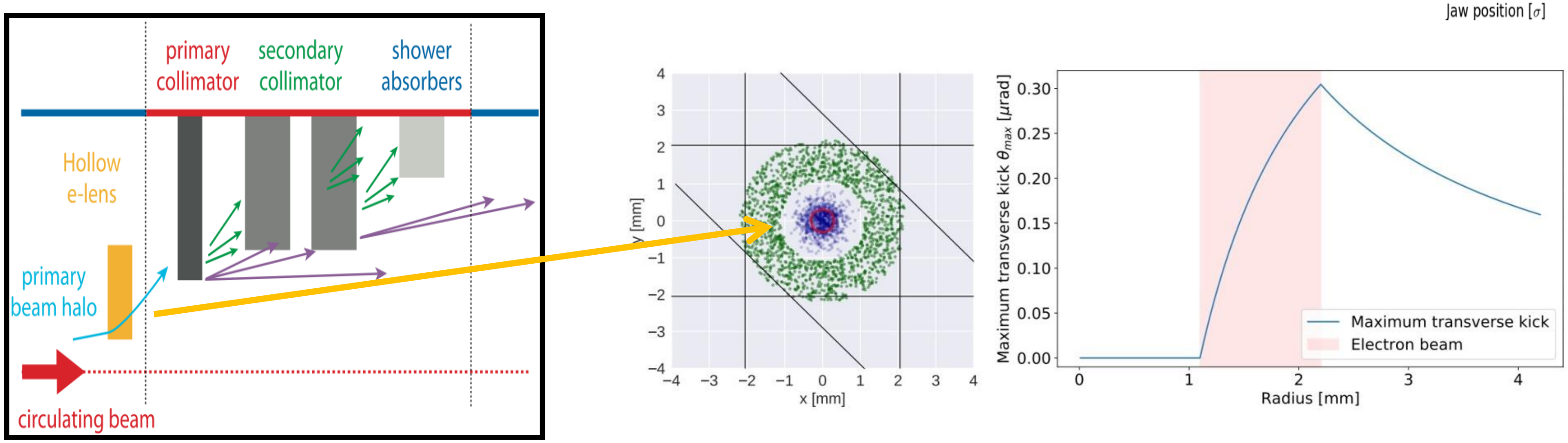
2. **CLIC Two-beam module** ← almost every aspect of accelerator technology one dreams of !



Hollow electron lens (HEL) for the HL-LHC

- Project developped at CERN for the Hi-Lumi upgrade of the LHC with the help of many CERN collaborators and many external collaborations.
- Main motivation:
  Complement to existing collimation system
  - up to 700 MJ stored beam energy
  - existing two stage collimation system needs « help »
  - beam can develop « non-gaussian tails »

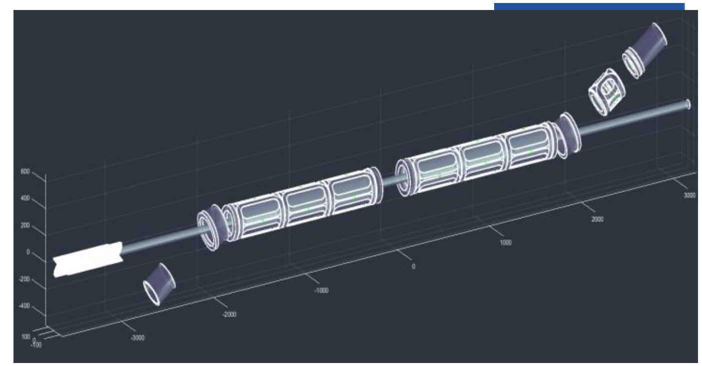


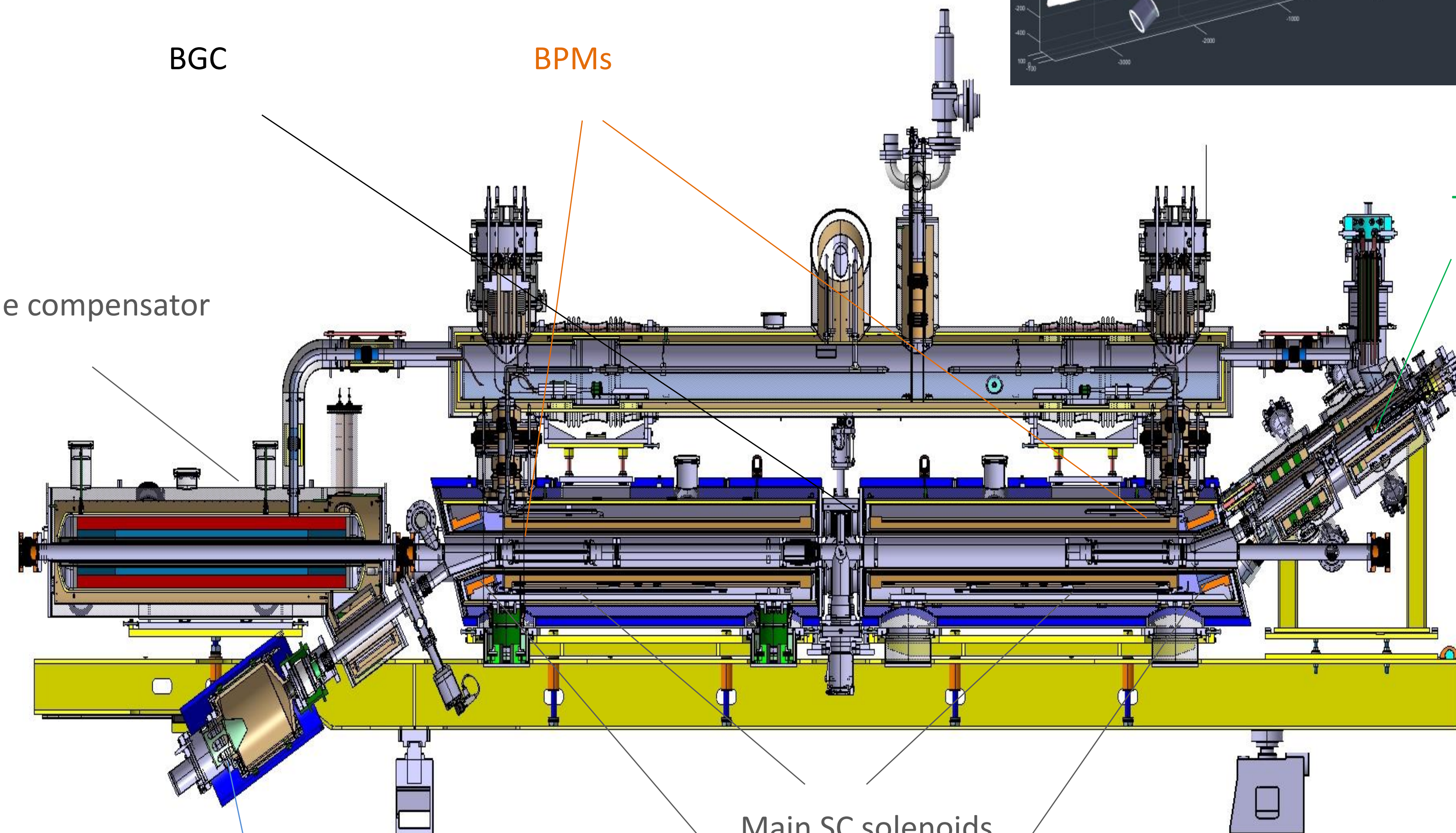


Following slides: **Adriana Rossi**, 12th HLLHC Collaboration Meeting, Uppsala (Sweden),19-22 Sept. '22

The CERN Accelerator School

HEL design





D. Nikiforov & BINP team

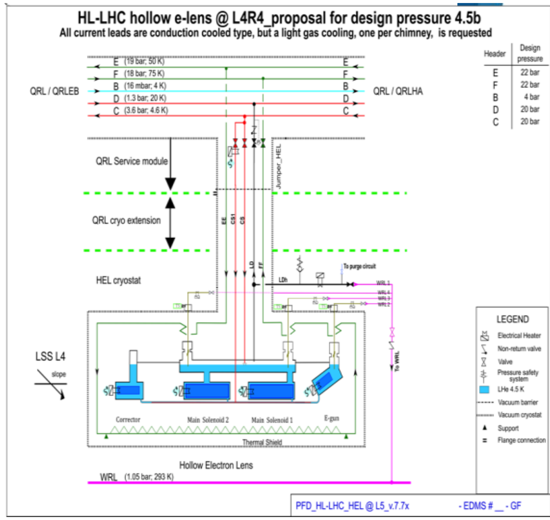
D. Perini, A. Kolehmainen

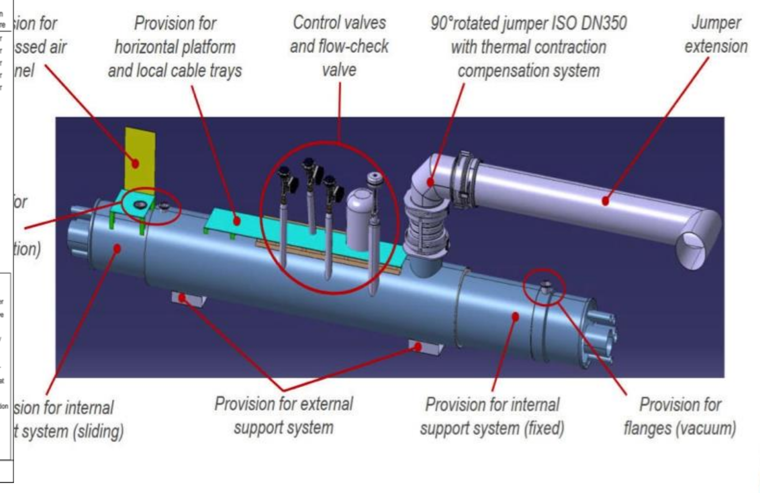
A. Foussat, A. Bragin

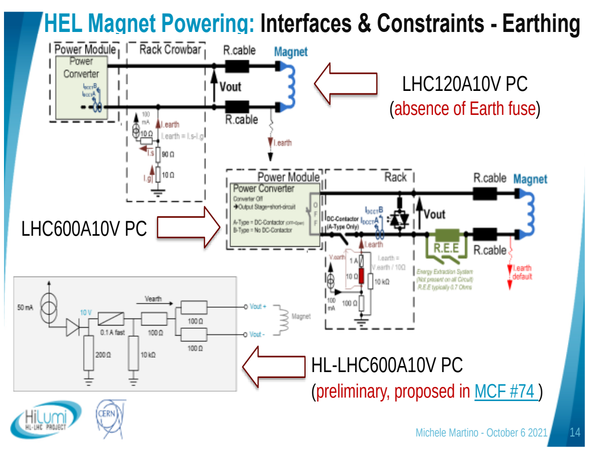
Cryogenics

- Service module designed
- Pressure analysis for magnet system complete

G. Ferlin

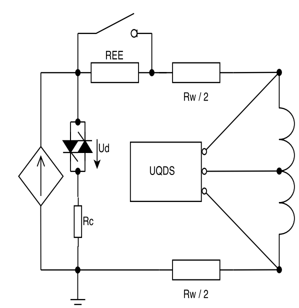






Circuits and quench protection

- Magnet circuit defined
- Quench protection system thoroughly studied
- Energy extraction required for mains only

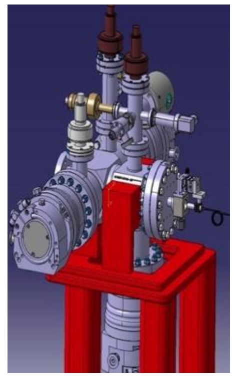


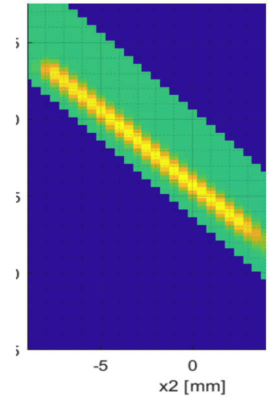
S. Yammine, M. Wozniak

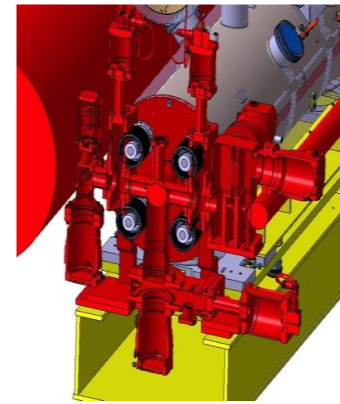
Key technology demonstration

Beam Gas Curtain (e- and hadron beams)

- Version for LHC measurements to be tested at EBTS – Q1/2 ’22, at LHC in 2023.
- Gas curtain 9x0.3mm at 10^{16} N_2/m^3
- Design to fit in tight HEL space in progress

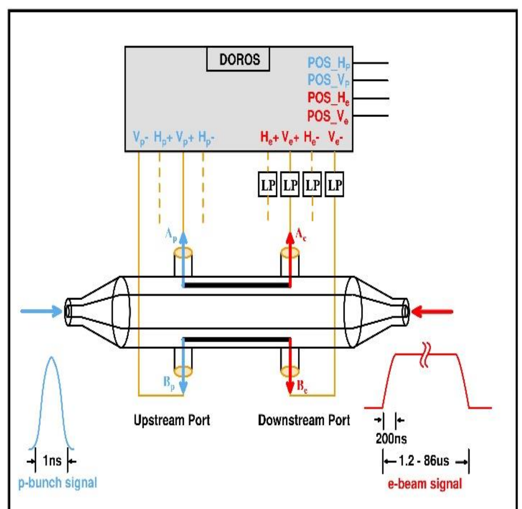


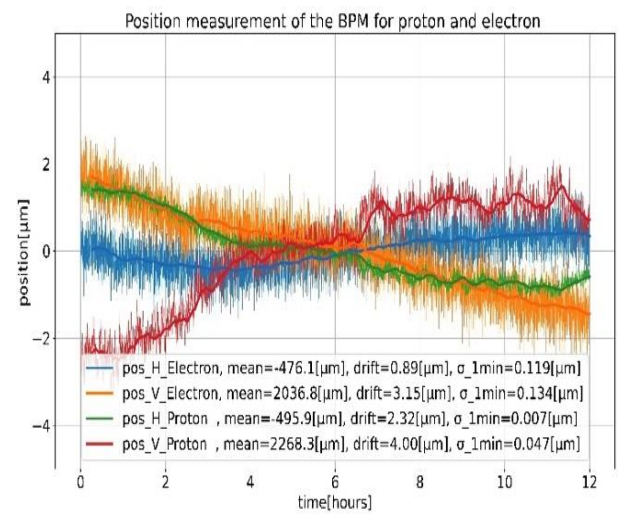




Strip-line BPM (e- and hadron beams)

- Numerical simulations and laboratory measurements demonstrate the feasibility of measuring both ~ DC e-beam and bunched LHC beam, with < 2um difference



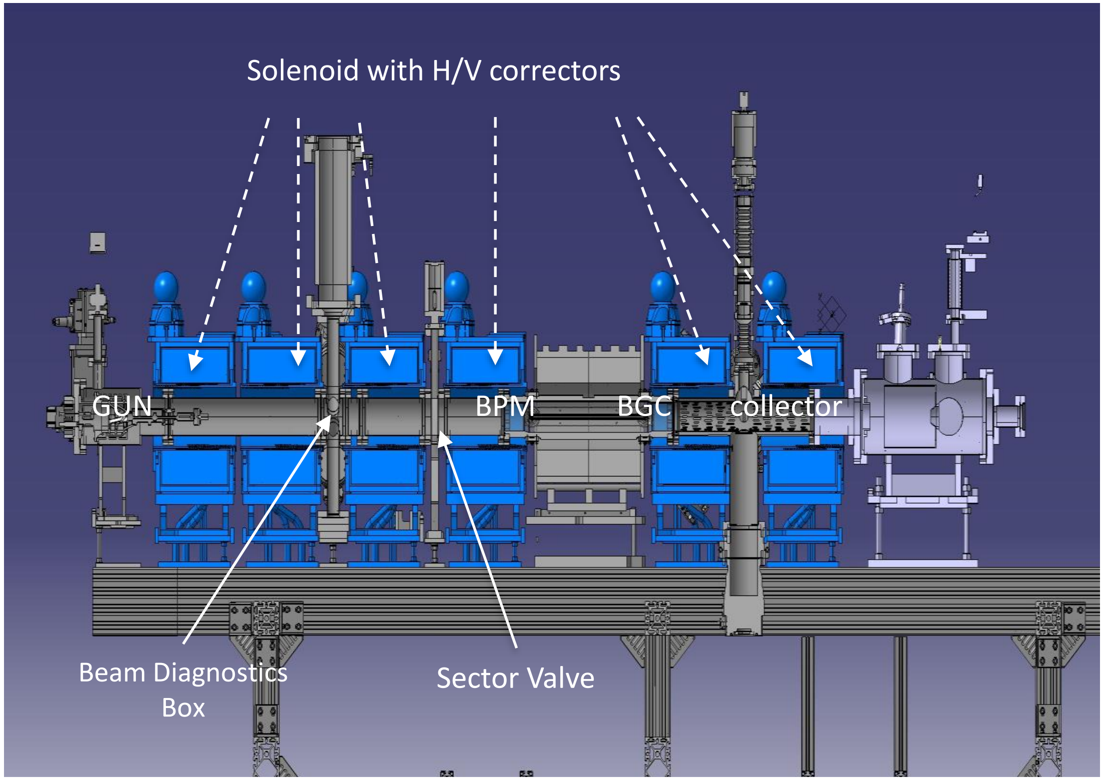


M. Wendt

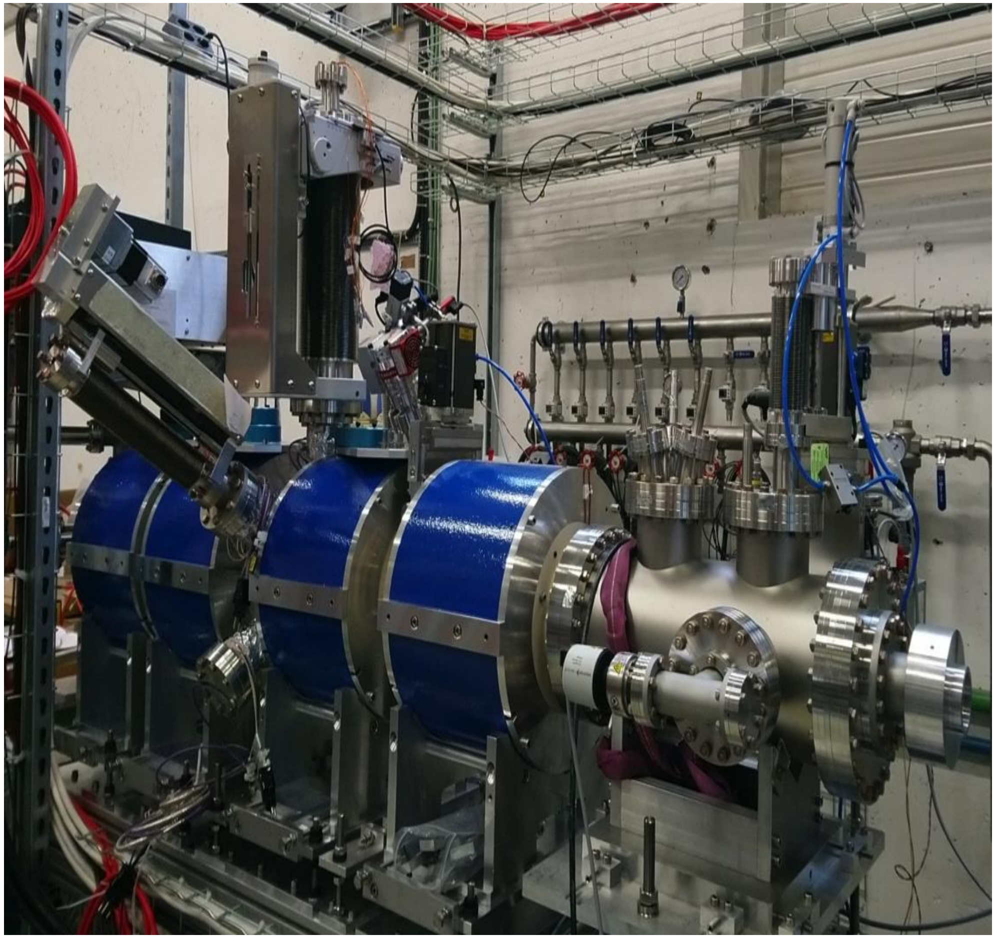
Electron Beam Test Stand

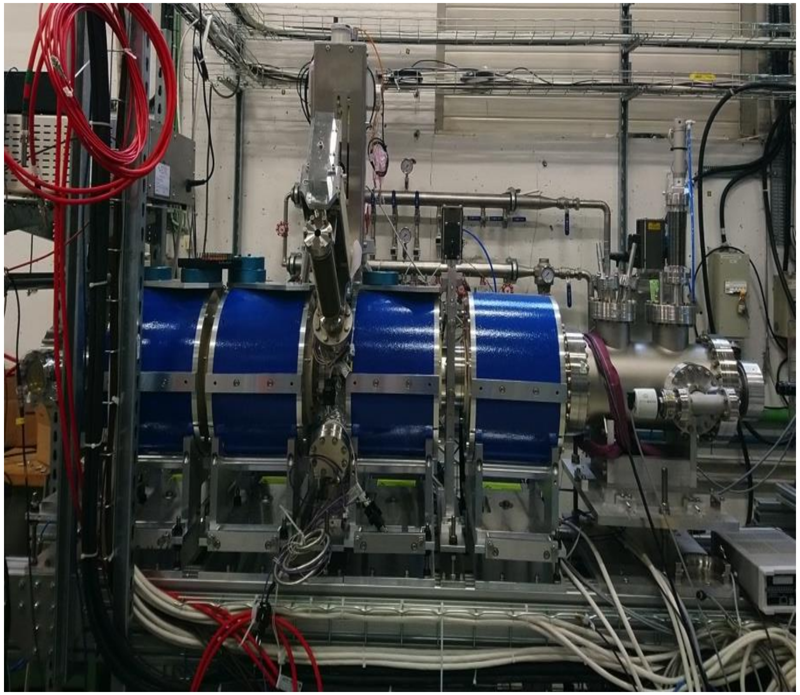
- Resistive magnets (0.4T max)
- H/V correctors
- Capability of testing:
  - E-gun
  - Collector
  - BPM, BGC
  - Modulator
  - HV power convertor
  - HV control and interlocks

S. Sadovich
SY-BI-XEI section

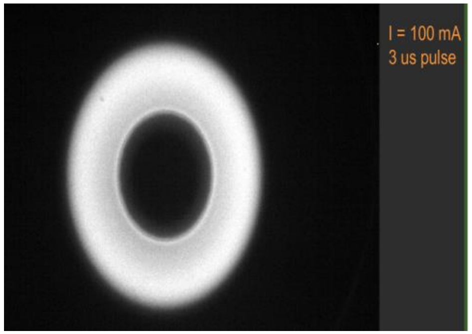


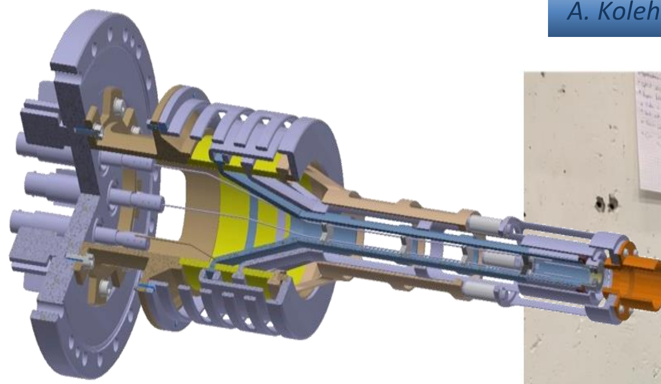
Electron Beam Test Stand



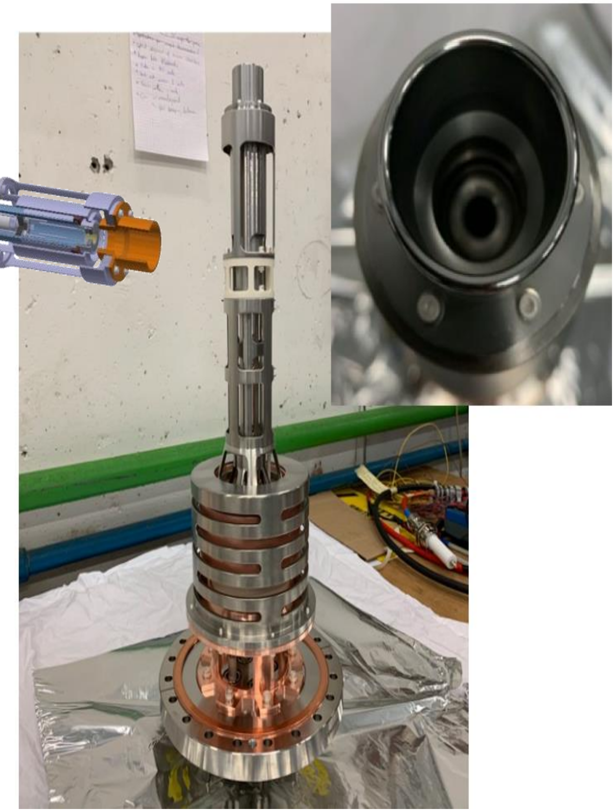


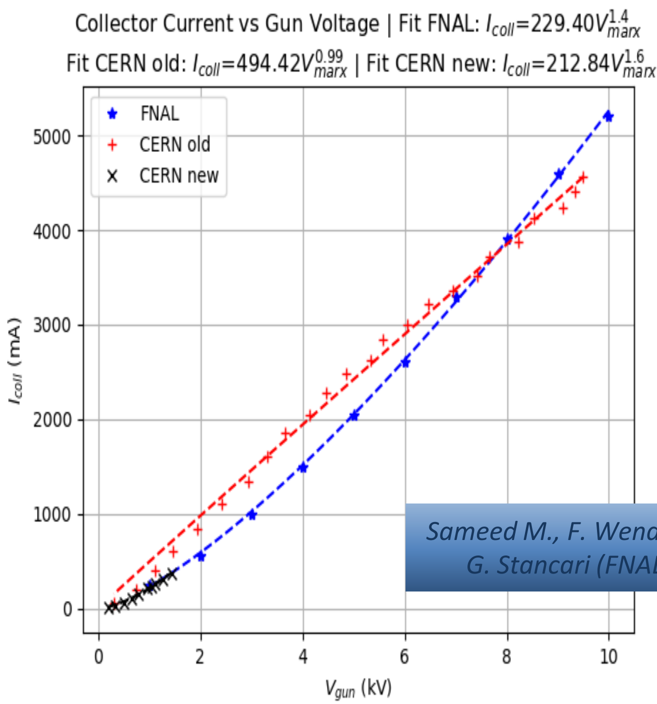
Electron gun





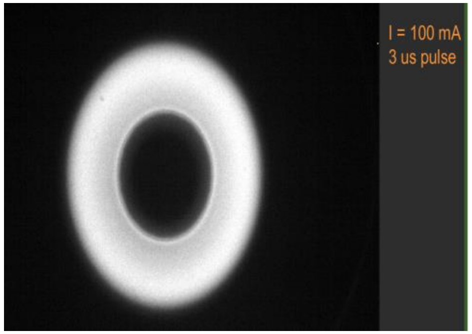
A. Kolehmainen

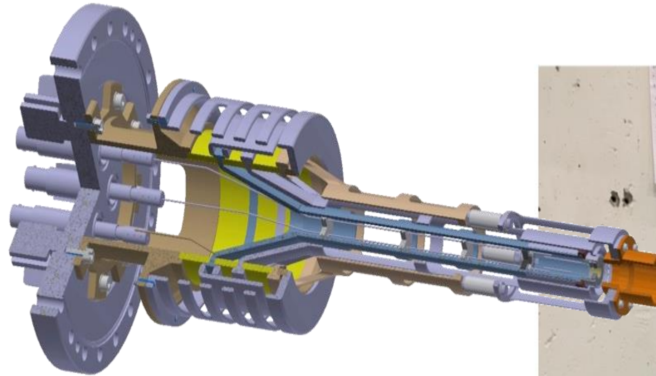


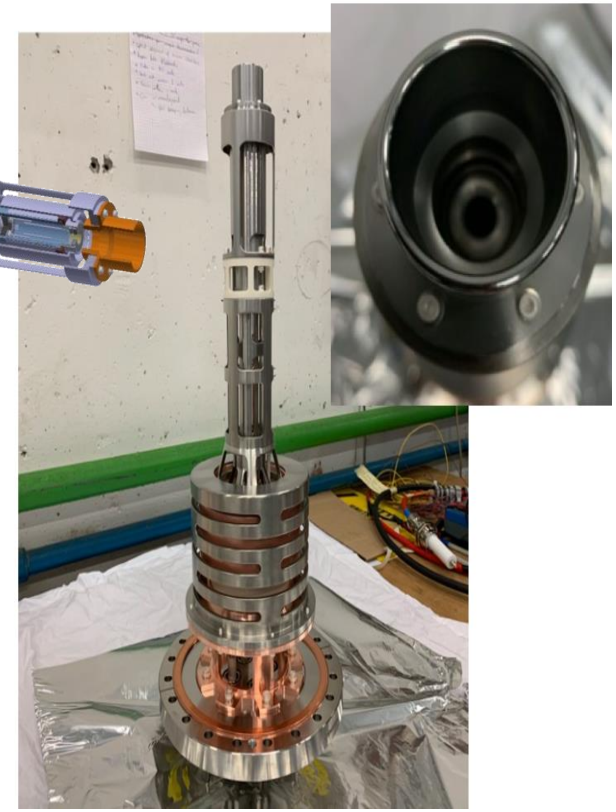


Sameed M., F. Wenander
G. Stancari (FNAL)

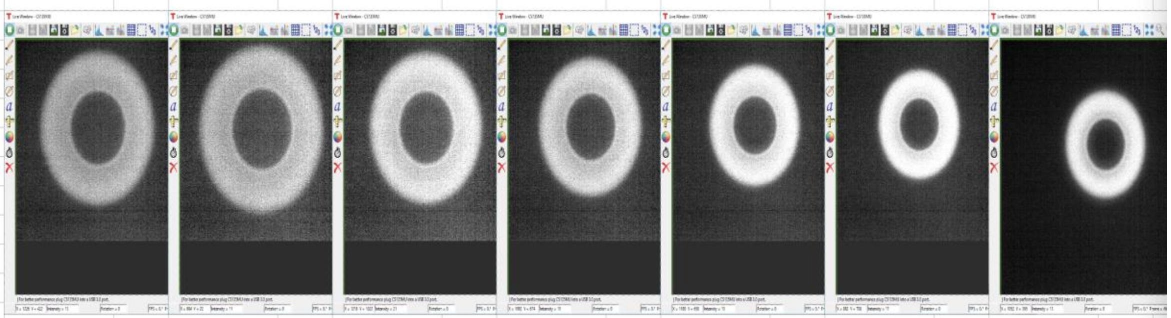
Electron gun







Gun Magnet Current (A	100	200	200	200	200	200	100
BDB Magnet Current (A	55	55	100	185	300	420	420
Gun B-Field (T)	0.045	0.091	0.091	0.091	0.091	0.091	0.046
BDB B-Field (T)	0.02	0.033	0.039	0.051	0.066	0.081	0.068
Expansion Factor	1.493	1.646	1.518	1.341	1.178	1.059	0.822
Beam Size (mm)	**24.0**	**26.5**	**24.4**	**21.6**	**19.0**	**17.1**	**13.2**



⃠ 8-16 mm cathode

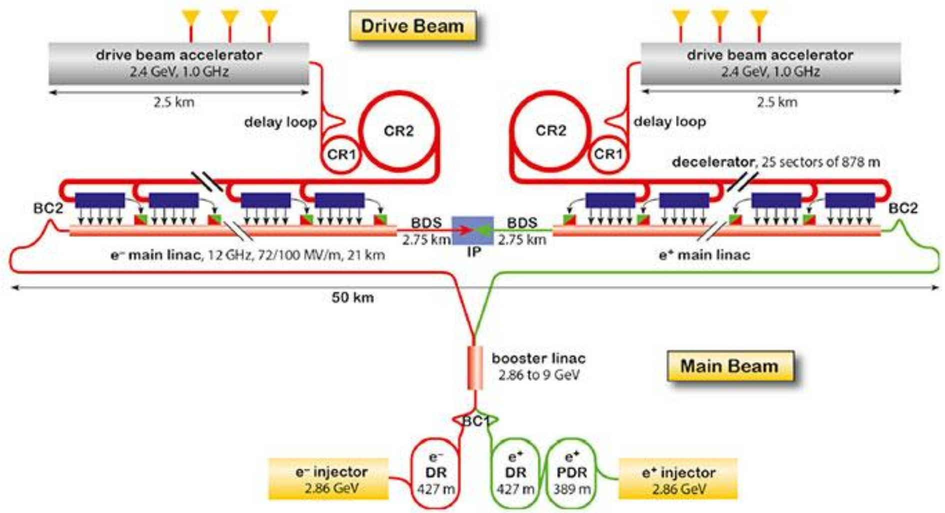
20mA x 3μs pulse

CLIC (= Compact LInear Collider) in a nutshell

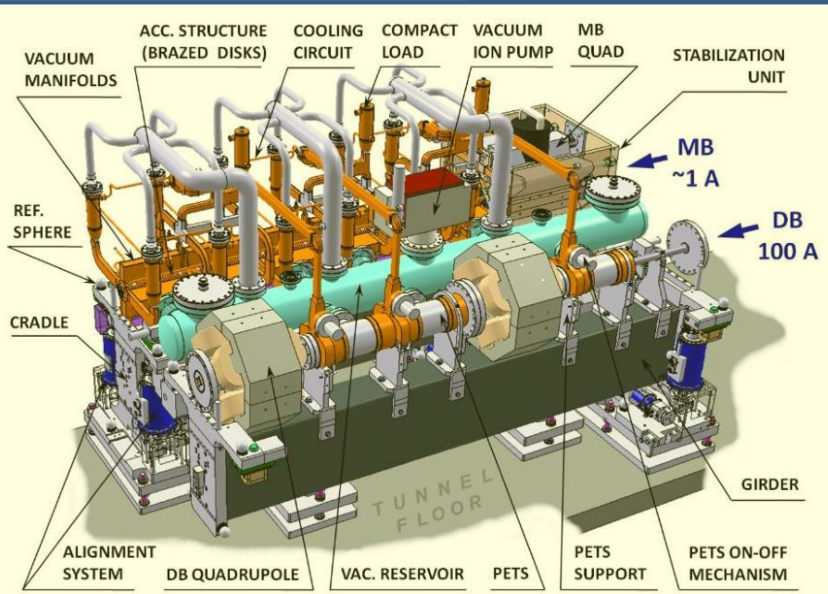
Novel two beam acceleration scheme (cost, efficiency)

e+e- collider: cms energy: 250 GeV up to 3 TeV

Very high luminosity needs 1nm vertical beam size at IP



CLIC main linac module



- 100 MV/m accelerating gradient copper cavities
- large NC quadrupoles

- 100 A electron beam to deliver power
- 1 A main beam
- 7kW/m power dissipation, watercooling

- mechanical and thermal stability on the um level
- um level pre-alignment without beam
- active stabilization against ground motion on the nm-level

Alexandre.Samochkine @ cern.ch

R F

AS shape tolerance ± 2.5 μm

MAGNET AND POWERING

DB 81.2-8.12 T/m, current density: 4.8 A/mm2, MB 200 T/m

INSTRUMENTATION

BPM resolution: MB - 50 nm, DB – 2 μm, temporal - 10 ns (MB & DB),

PRE-ALIGNMENT AND STABILIZATION

active pre-alignment ± 10 μm at 3σ, MB Q stabilization 1 nm >1Hz

SUPPORTING

Max. vertical & lateral deformation of the girders in loaded condition 10μm

VACUUM

Baseline 10^{-9} mbar

COOLING

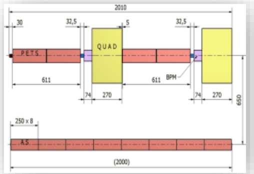
400 W per AS

ASSEMBLY, TRANSPORT, INSTALLATION

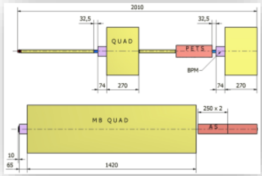
clear interconnection plane

MODULE TYPES

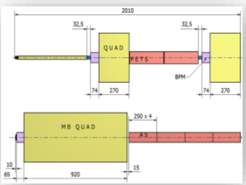
Alexandre.Samochkine @ cern.ch



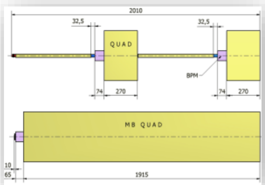
Standard Module
8374 per Linac



Module Type 3
477 per Linac



Module Type 2
634 per Linac



Module Type 4
731 per Linac

Standard Module (L=2010 mm)

DB (100 A)

4 PETS, 2 Quads with BPM

Each PETS feeds 2 AS

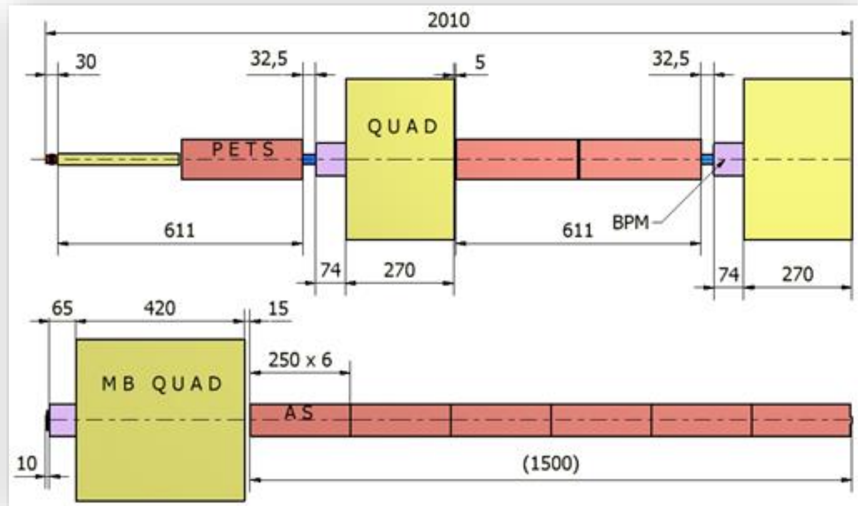
MB (1 A)

8 acc. structures

MB filling factor: 91%

CLIC Module Type1
154 per Linac

1 pair of AS replaced by MB Quadrupole



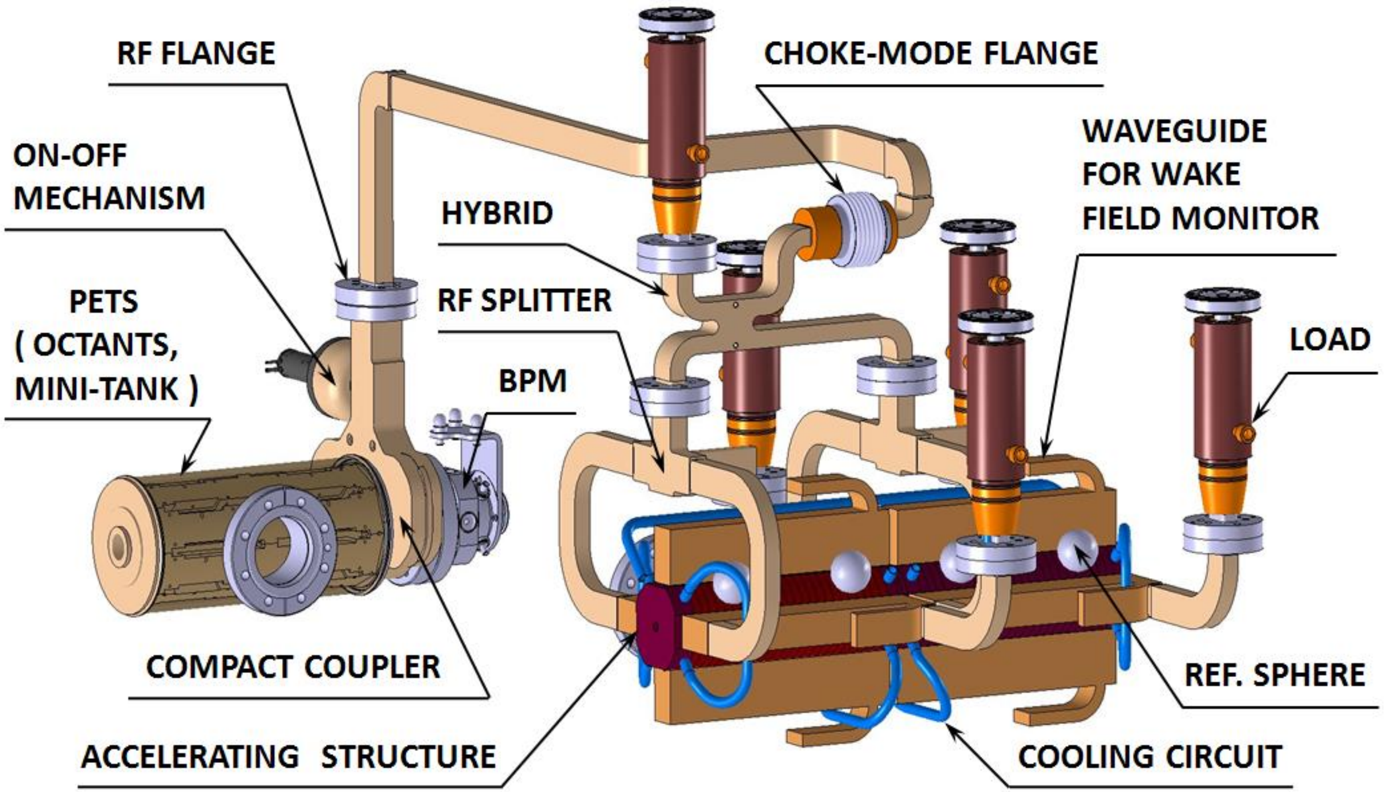
+
special modules
(damping region,
modules with instrumentation
and/or vacuum equipment)

RF SYSTEMS

RF NETWORK LAYOUT

Alexandre.Samochkine @ cern.ch

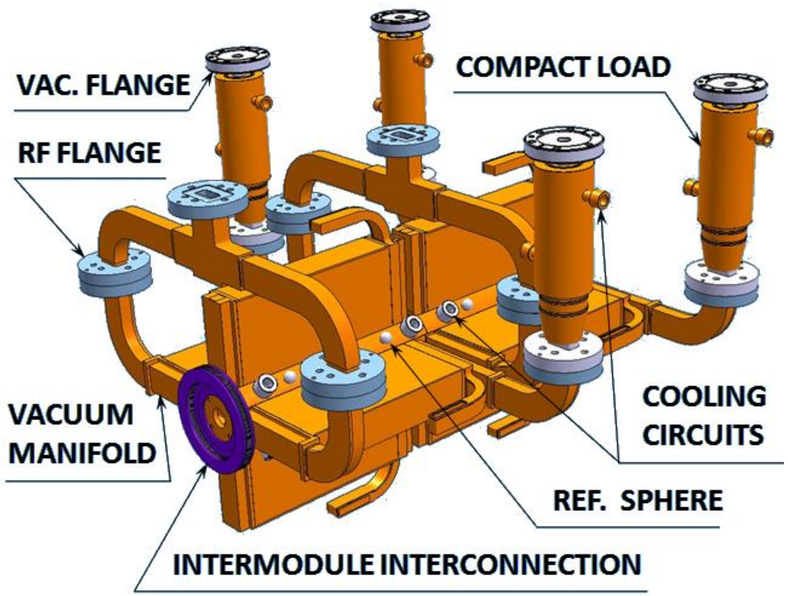
tolerance on RF phase change between DB and MB: ± 0.12 deg

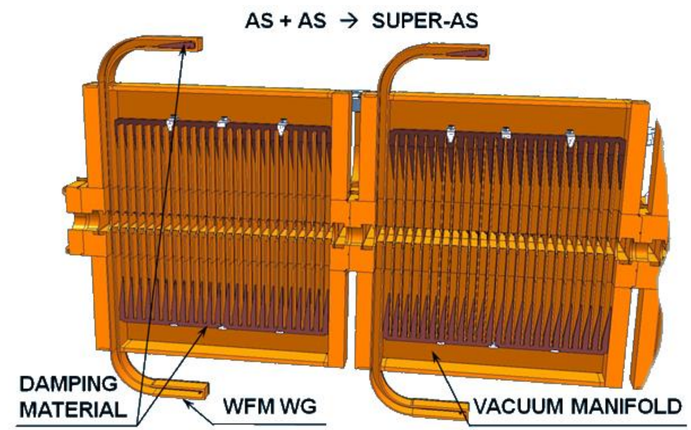


The CLIC two-beam RF network includes the standard X-band rectangular waveguides connecting PETS, AS and other supplementary devices such as choke-mode flange (CMF), Hybrid, high power load, splitter and WFM.

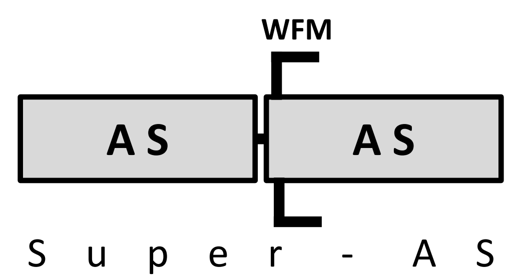
Alexandre.Samochkine@cern.ch

The design of AS is driven by extreme performance requirements. The assembly accuracy is ±5 μm. Many features of different systems, such as vacuum, cooling, wake field monitor as well as damping waveguide absorbers are incorporated into design.





Longitudinal cut of Super-AS



Schematic layout of Super-AS implemented in test module

COMPLEXITY

Brazed disks with “compact” coupler & vacuum system (10^{-9} mbar),

micro-precision assembly, cooling circuits (400 W per AS)

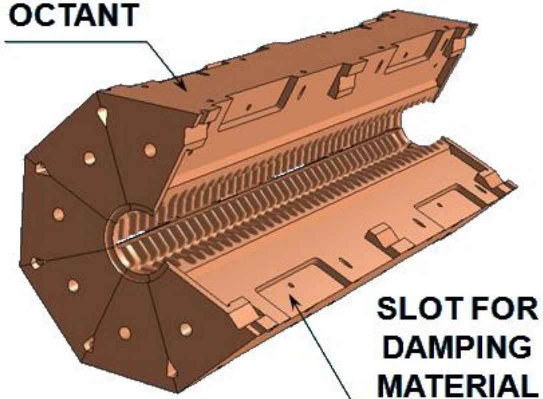
wakefield monitor (1 WFM per SAS), interconnection to MB Q (stabilization!)

structure support (alignment), output WG with RF components (e.g. loads)

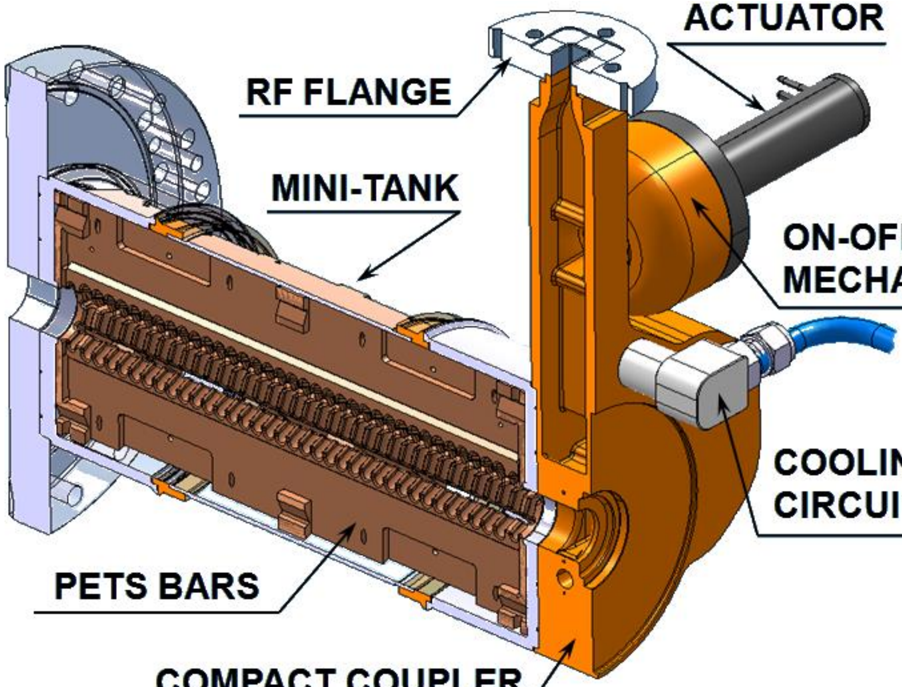
RF distribution (WGs & splitters)

Detailed design under way

Alexandre.Samochkine @ cern.ch

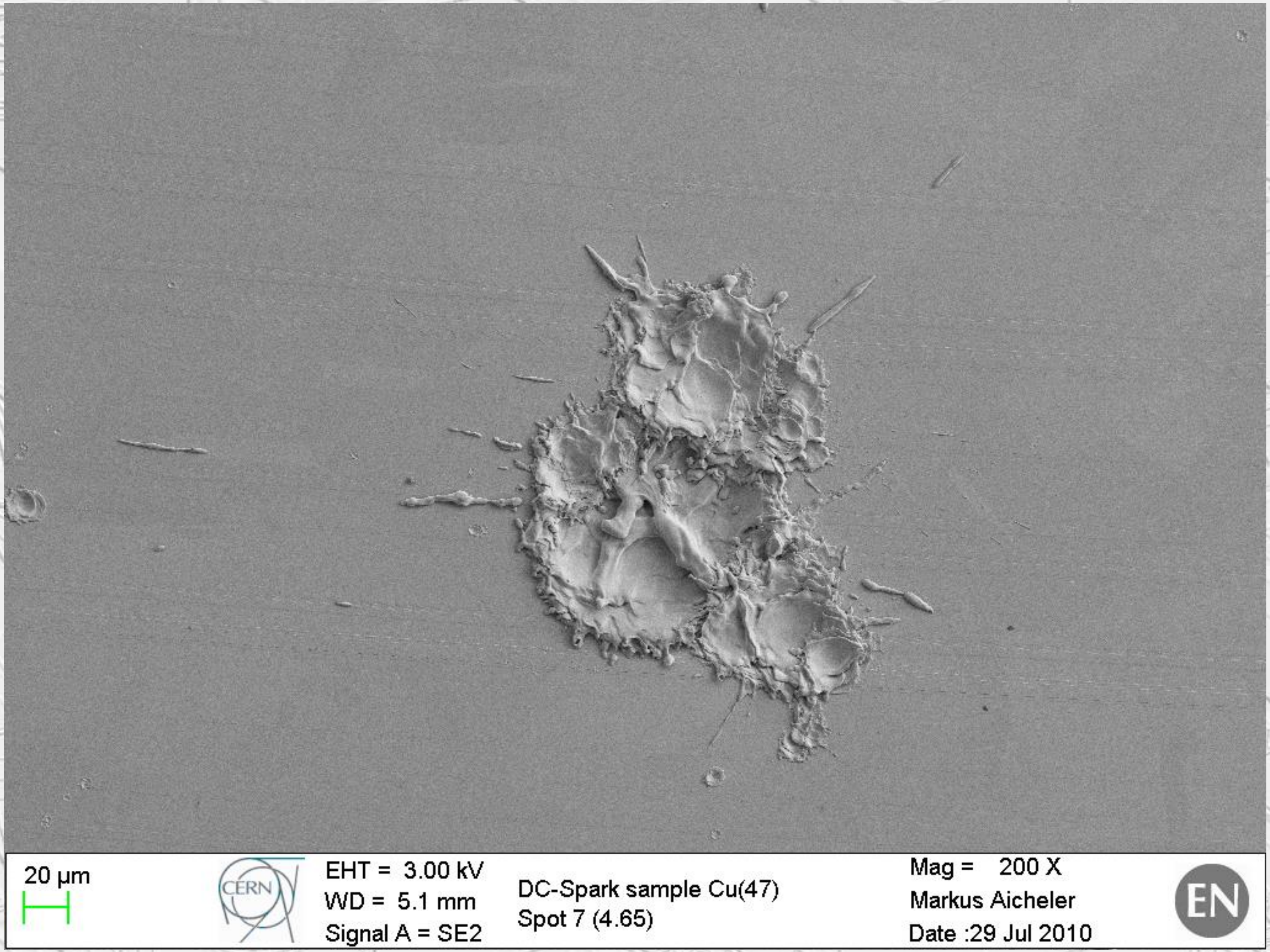


The PETS are composed of eight bars milled with 0.015 mm shape accuracy. The octants assembly, mini-tank, “ON-OFF” mechanism combined with compact coupler, vacuum system, cooling circuits and interconnection are the subject for integration study.

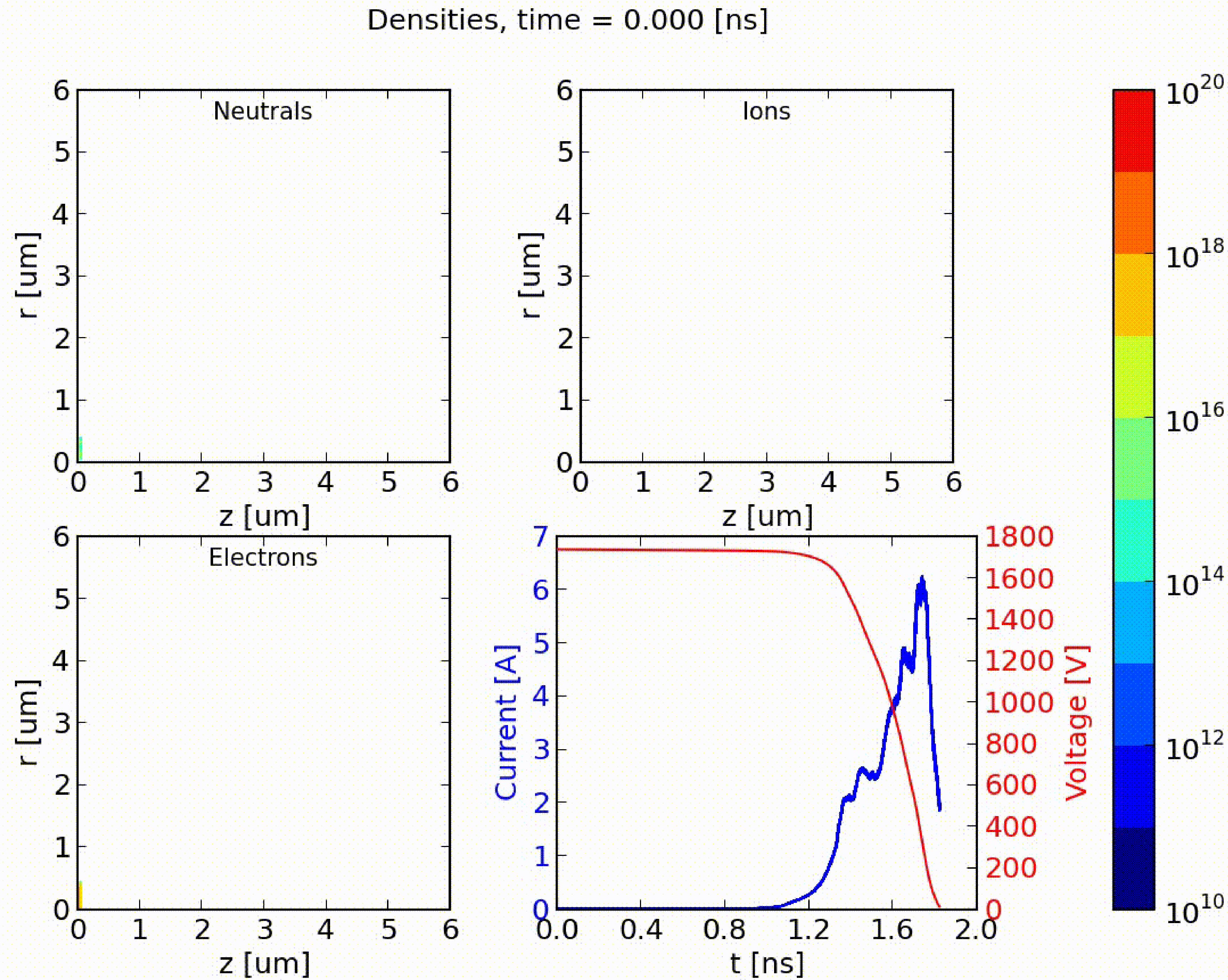


A closer look at the dynamics of Breakdown!

Alexandre.Samochkine @ cern.ch



From pA to kA and from Angstroms to 100s of μm to mms.

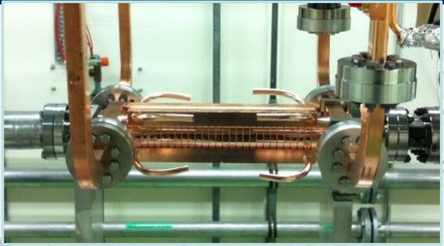


Densities, time = 0.000 [ns]
Neutrals
Ions
Electrons
r [um]
z [um]
0
1
2
3
4
5
6
Current [A]
Voltage [V]
t [ns]
0.0
0.4
0.8
1.2
1.6
2.0
7
0
200
400
600
800
1000
1200
1400
1600
1800
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
10^{20}

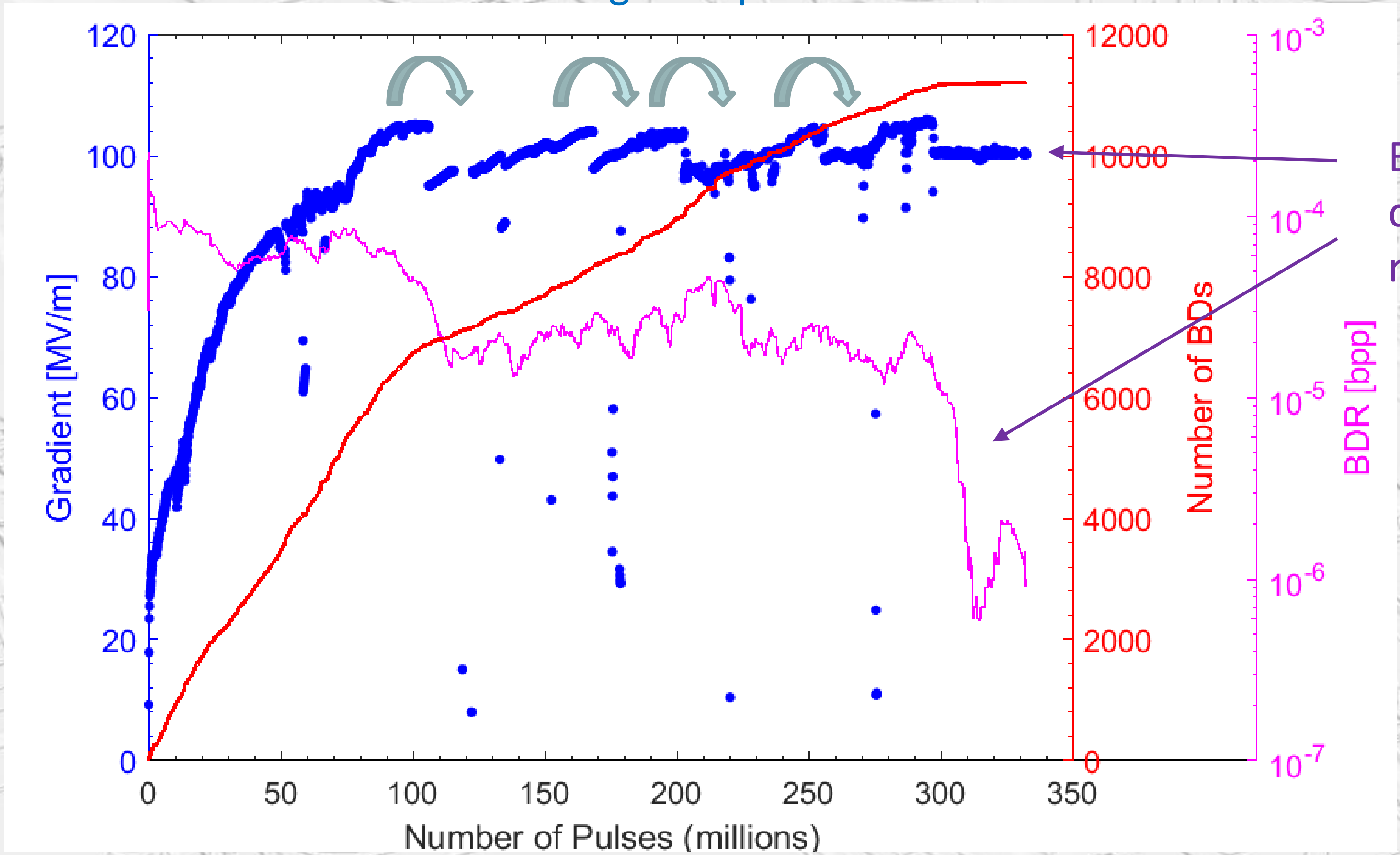
Conditioning

Alexandre.Samochkine @ cern.ch

Accelerating structures do not run right away at full specification – pulse length and gradient need to be gradually increased while pulsing. Typical behaviour looks like this:



Pulse length steps



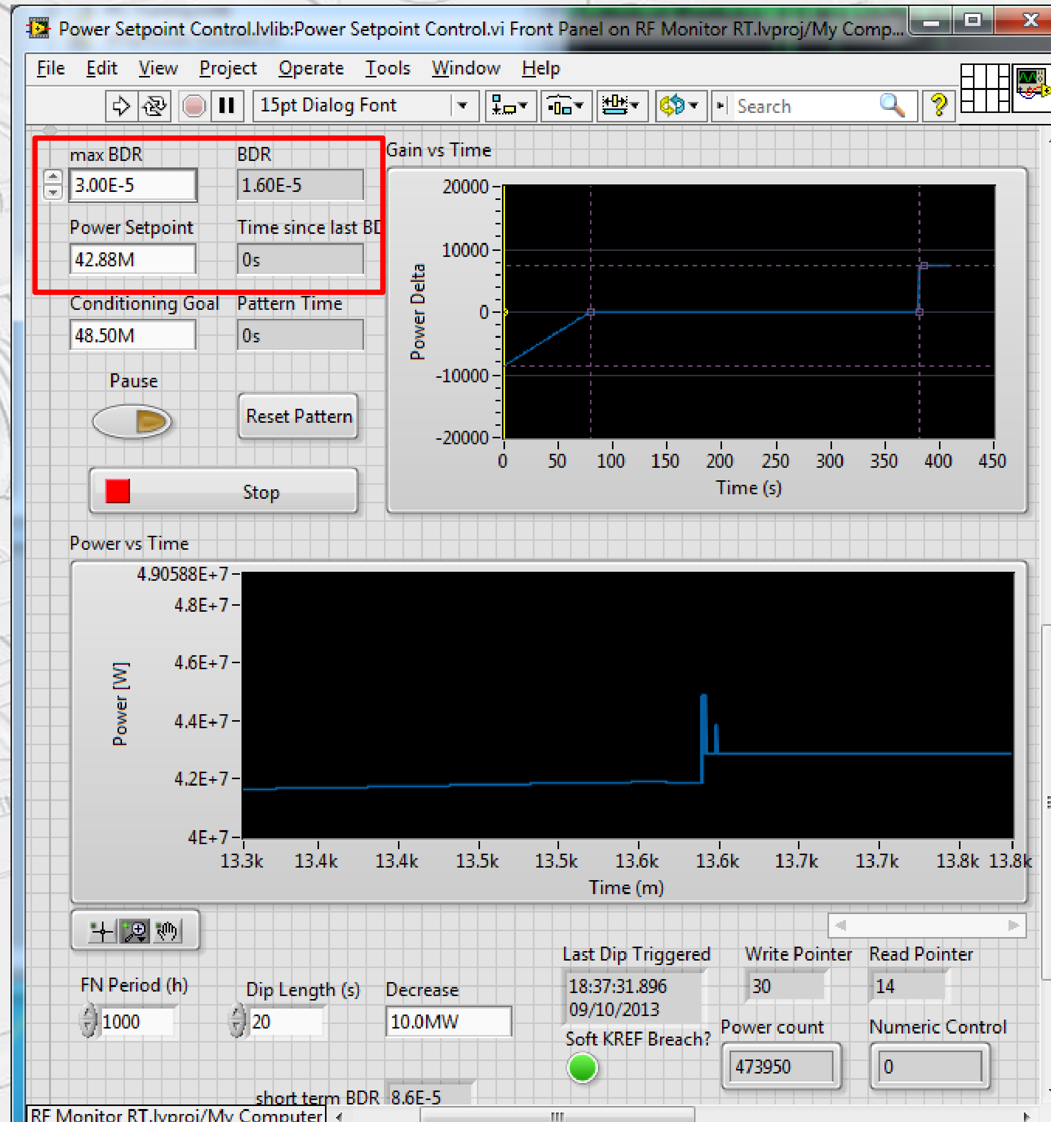
BDR falls during flat E run

4 million pulses per day at 50 Hz

Cavity Conditioning Algorithm

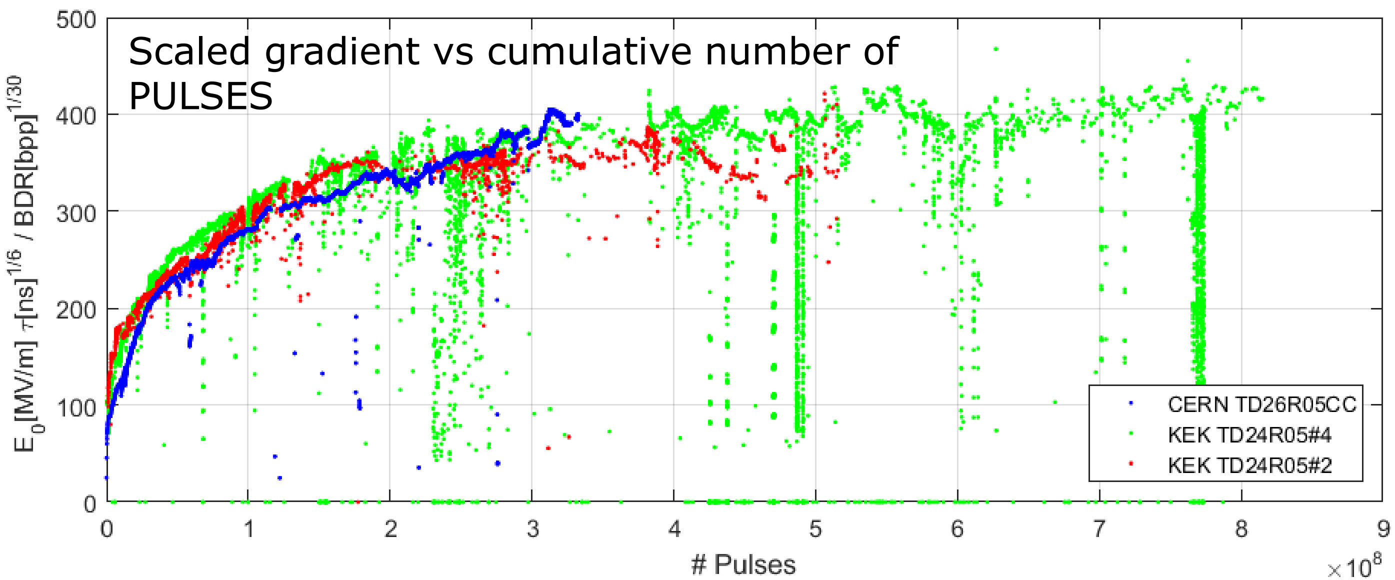
Alexandre.Samochkine @ cern.ch

- Automatically controls incident power to structure.
- Short term: +10kW steps every 6 min and -10kW per BD event.
- **Long Term**: Measures BDR (1MPulse moving avg.) and will stop power increase if BDR too high.



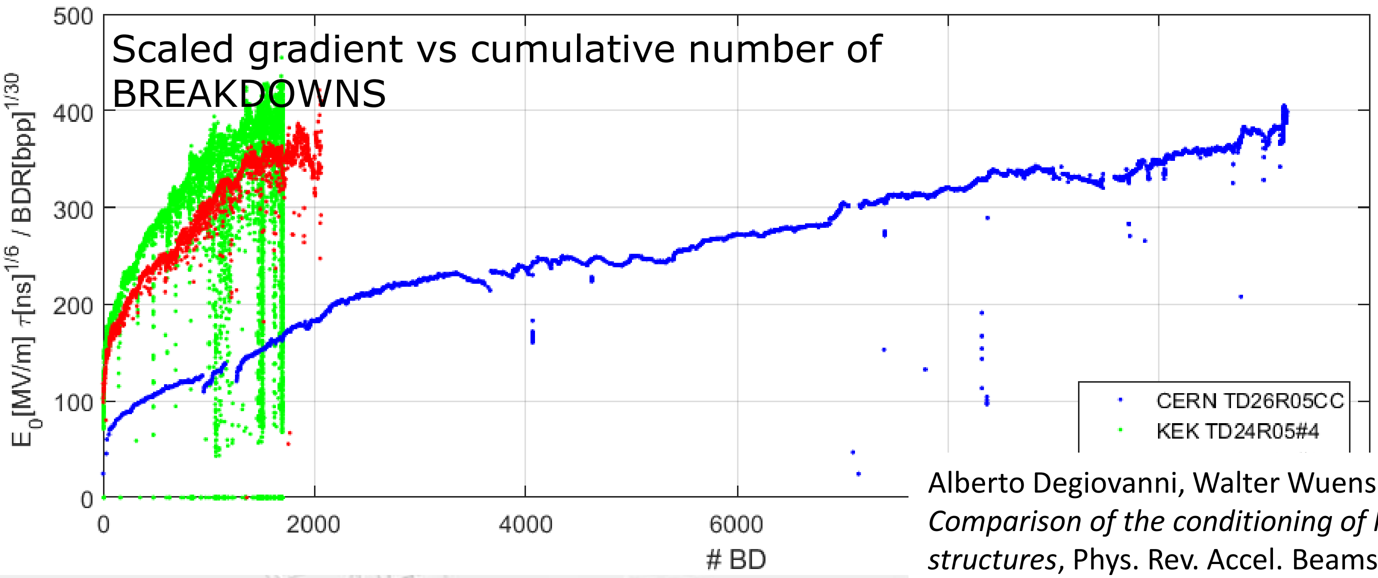
Comparing conditioning

Alexandre.Samochkine @ cern.ch



Pulses

$$BDR \propto E^{30}\tau^{5}$$



Breakdowns

Alberto Degiovanni, Walter Wuensch, and Jorge Giner Navarro, *Comparison of the conditioning of high gradient accelerating structures*, Phys. Rev. Accel. Beams 19, 032001 (2016) - Published 4 March 2016

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **14**, 041001 (2011)

Experimental study of rf pulsed heating

Lisa Laurent,* Sami Tantawi, Valery Dolgashev, and Christopher Nantista
SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, California 94025, USA

Yasuo Higashi
KEK, High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Markus Aicheler, Samuli Heikkinen, and Walter Wuensch
CERN, European Organization for Nuclear Research, 1211 Geneva 23, Switzerland
(Received 9 September 2010; published 7 April 2011)

Pulsed surface heating.

Fatigue process driven by pulsed resistive wall losses

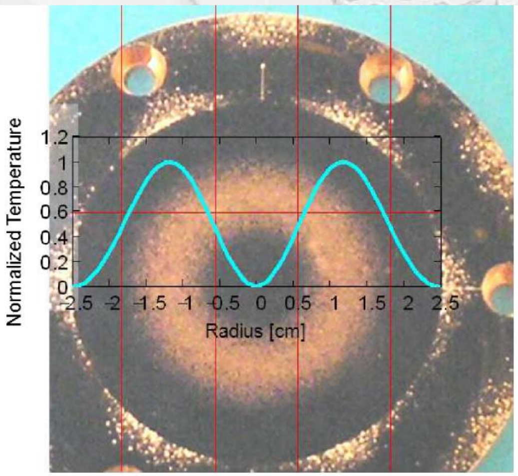


FIG. 6. Normalized pulsed heating temperature calculations superimposed on a copper pulsed heating sample.

depth limit, which is valid for small skin depths in comparison with the thermal diffusion length. In the samples we have tested, the skin depth is typically on the order of 0.65 μm, and the thermal diffusion length is greater than 10 μm. The simplified temperature rise function in this case is

$$T(t, z) = \frac{R_s}{2(\sqrt{\pi \alpha} \rho c_\epsilon)} \int_0^t \frac{H^2(t', r) e^{-(z^2/4\alpha(t-t'))}}{\sqrt{t-t'}} dt'; \quad (3)$$

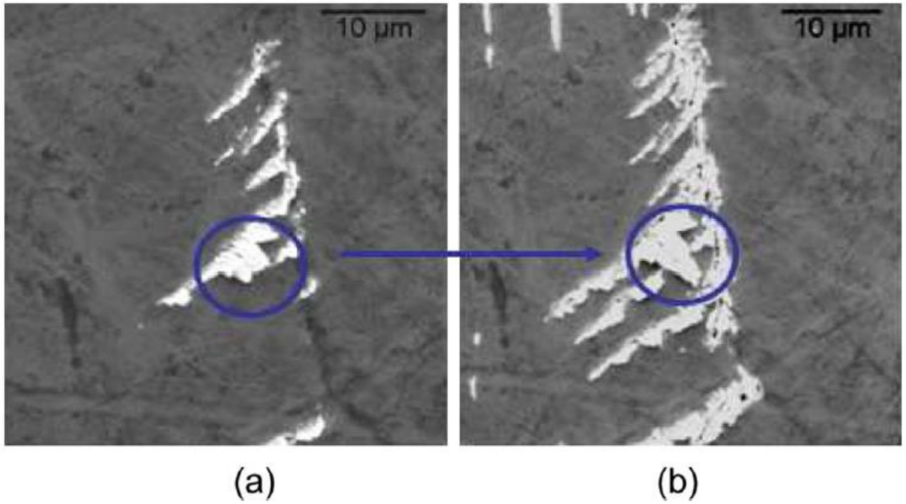


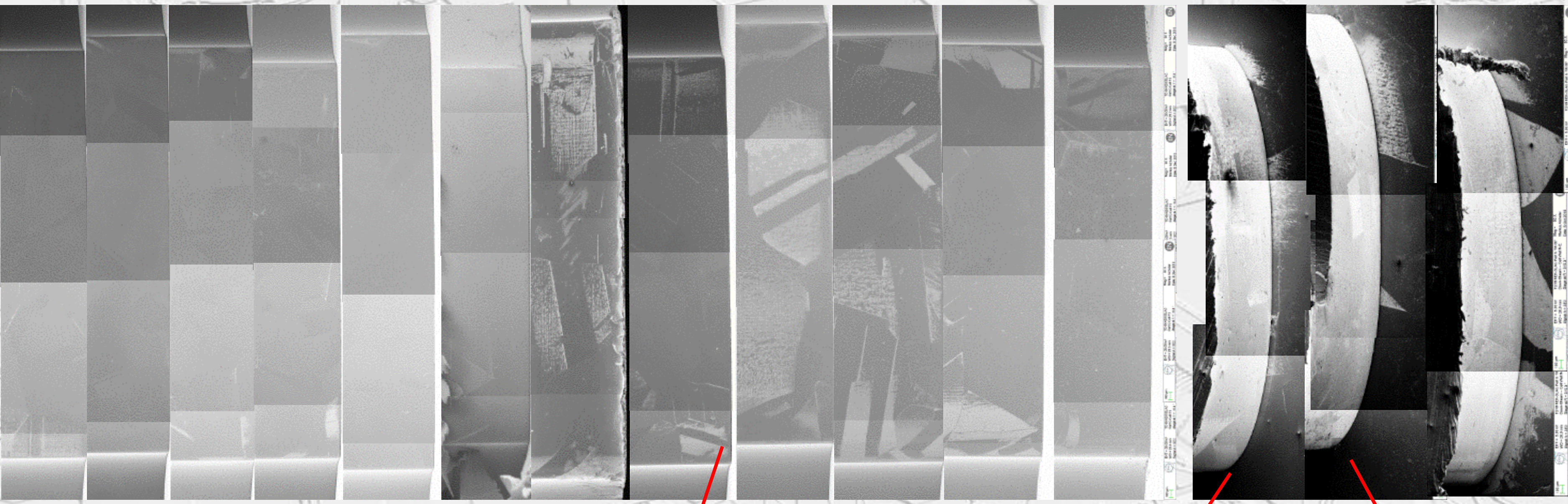
FIG. 12. SEM image after (a) first 70°C run and after (b) second 70°C run. Surface extrusions were more severe after extending the rf processing time.

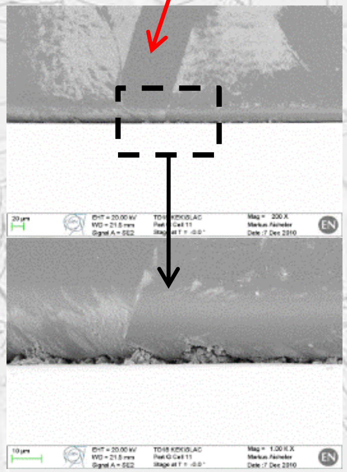
Pulsed surface heating limit

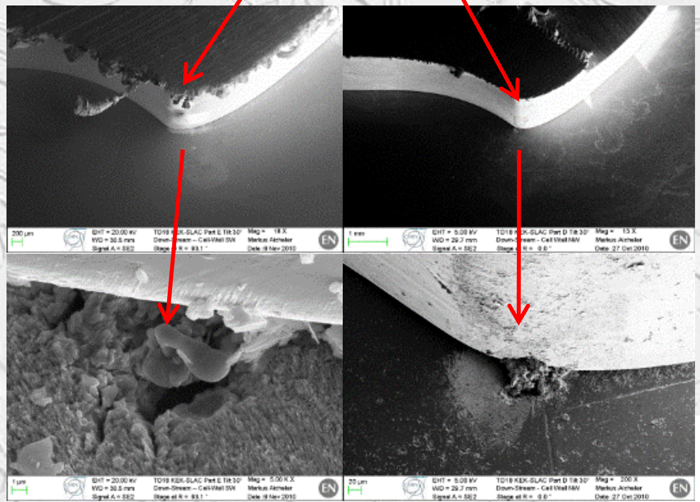
Alexandre.Samochkine @cern.ch

Cell # (cell #1 is a input matching cell):

4 5 6 7 8 9 10 11 12 13 14 15 ?16? 17 18 Last regular cell: 19







It seems that cell #10 (regular cell #9 ~ **middle cell**) exhibits the level of damage which could be considered as **a limit**.

A. Grudiev

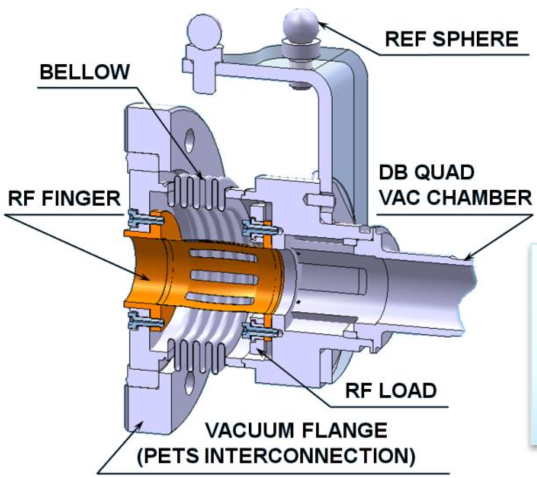
Images courtesy of M. Aicheler: http://indico.cern.ch/getFile.py/access?contribId=0&resId=1&materialId=slides&confId=106251

Alexandre.Samochkine @ cern.ch

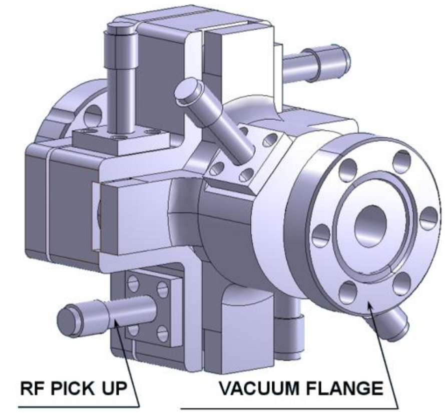
INSTRUMENTATION

Alexandre.Samochkine @ cern.ch

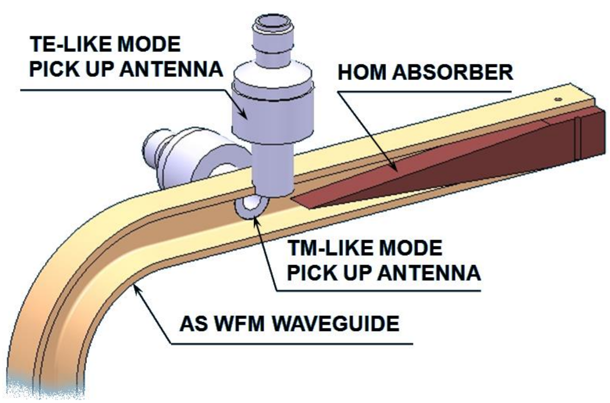
Limited space for BPM integration and interconnection, 1 BPM per Quad, 1 WFM per SAS (RMS position error 5 µm)
Qty: DB: ~47000; MB: ~151000 units



DB BPM
resolution requirement: 2 µm, 10 ns
design: RF - S. Smith (SLAC),
mechanical - D. Gudkov (JINR)

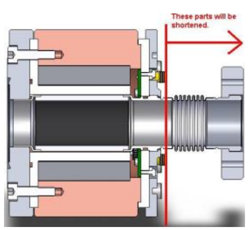


MB BPM
resolution requirement: 2 µm, 10 ns
choke type, mech. design of prototype is done. Optimization for CLIC module layout is under way.



WFM
Design:
RF - F. Peauger (CEA-Saclay),
Mechanical - A. Solodko (JINR)

AS with WFM → end of 2010
Validation in CLEX (2011)



alternative: DB BPS (IFIC)

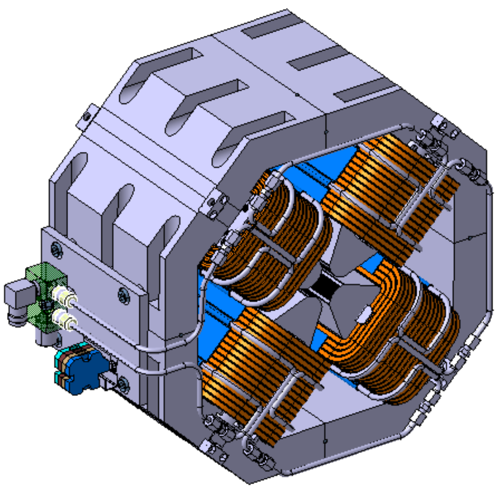
MAGNET SYSTEM

Alexandre.Samochkine @ cern.ch

Baseline: classical electro-magnetic design

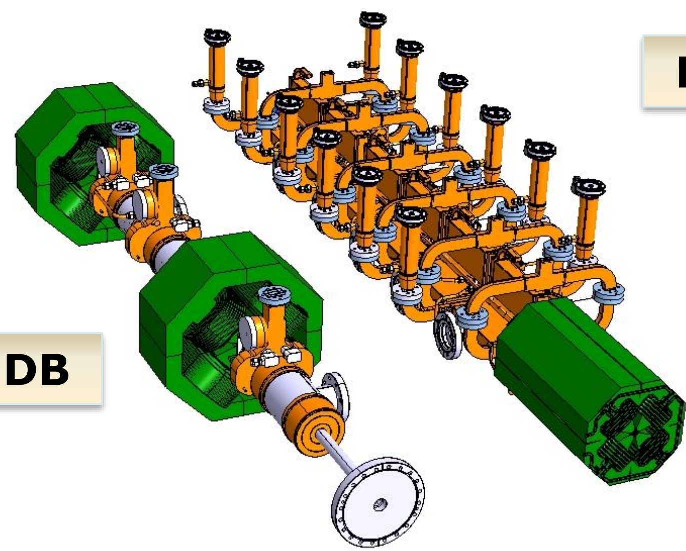
MB: The magnets are needed in four different magnetic lengths (350, 850, 1350 & 1850mm).
- the beam pipe is attached to the magnet and must be aligned to the magnetic centre of the Quad with an accuracy better than 30 µm; transverse tolerance for pre-alignment 17 µm at 1σ; stabilization: 1nm >1Hz in vertical & 5nm >1Hz in horizontal direction at 1σ.

DB: The active length specified is 150 mm. The total number of quads required for both linacs is ~42000. In current module design the DB Quad vertical size drives the beam height.

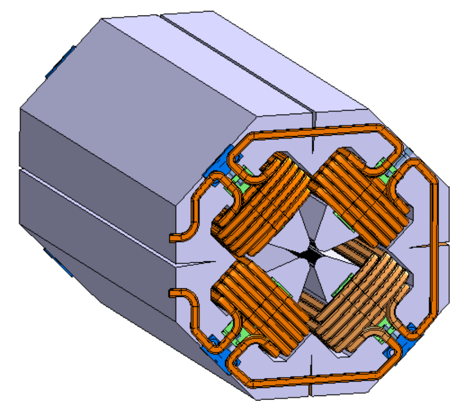


Drive Beam Quadrupole
working gradient: 81.2-8.12 T/m,
current density: 4.8 A/mm^2
magnet aperture: Ø23mm

DB



MB



Main Beam Quadrupole
Nominal Gradient: 200 T/m
Magnet aperture: Ø10 mm

alternative: DB tuneable permanent magnet solution is under investigation (Cockcroft Institute)

Details → talk of M. Modena

Magnets for CLIC Two-Beam Module Test Program

First 10 Coils (for 2 magnets + spares) at CERN acceptance

Quadrants (for 2 magnets + spares) delivered at CERN Metrology Lab

b) Optional Tunable Permanent Magnet Design

*(refer to presentation of **J. Clarke** in WG 6 Session of Wednesday 20 Oct. morning)*

Advantages:

-Very limited electrical requirements (moving actuators)

- no cooling needs

Disadvantages (or specific difficulties):

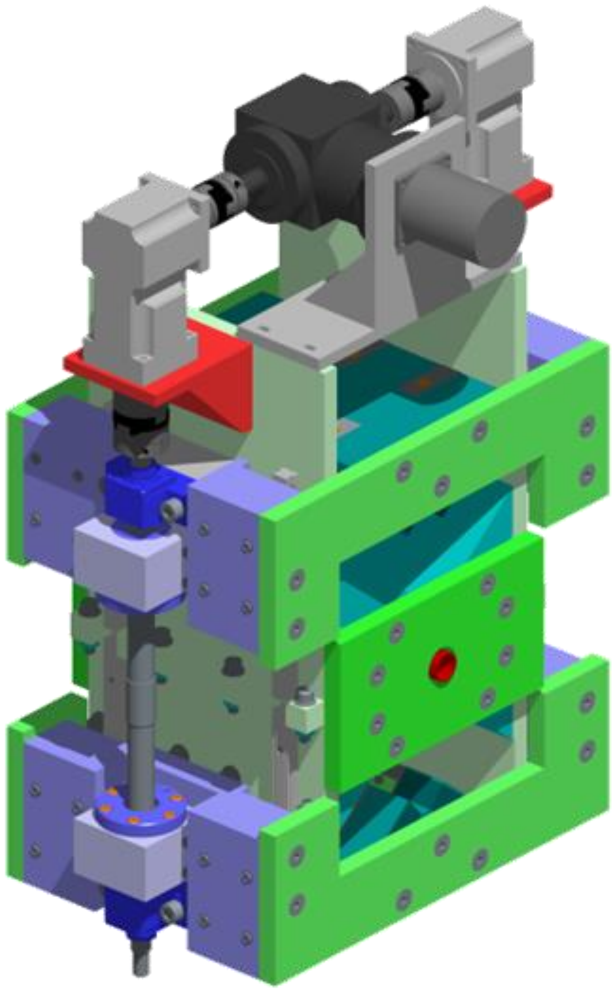
-Complexity (moving parts)

-Reliability (tuning is individual)

-Stability of the PM blocks versus: time/temperature/radiation

***Cost** :*

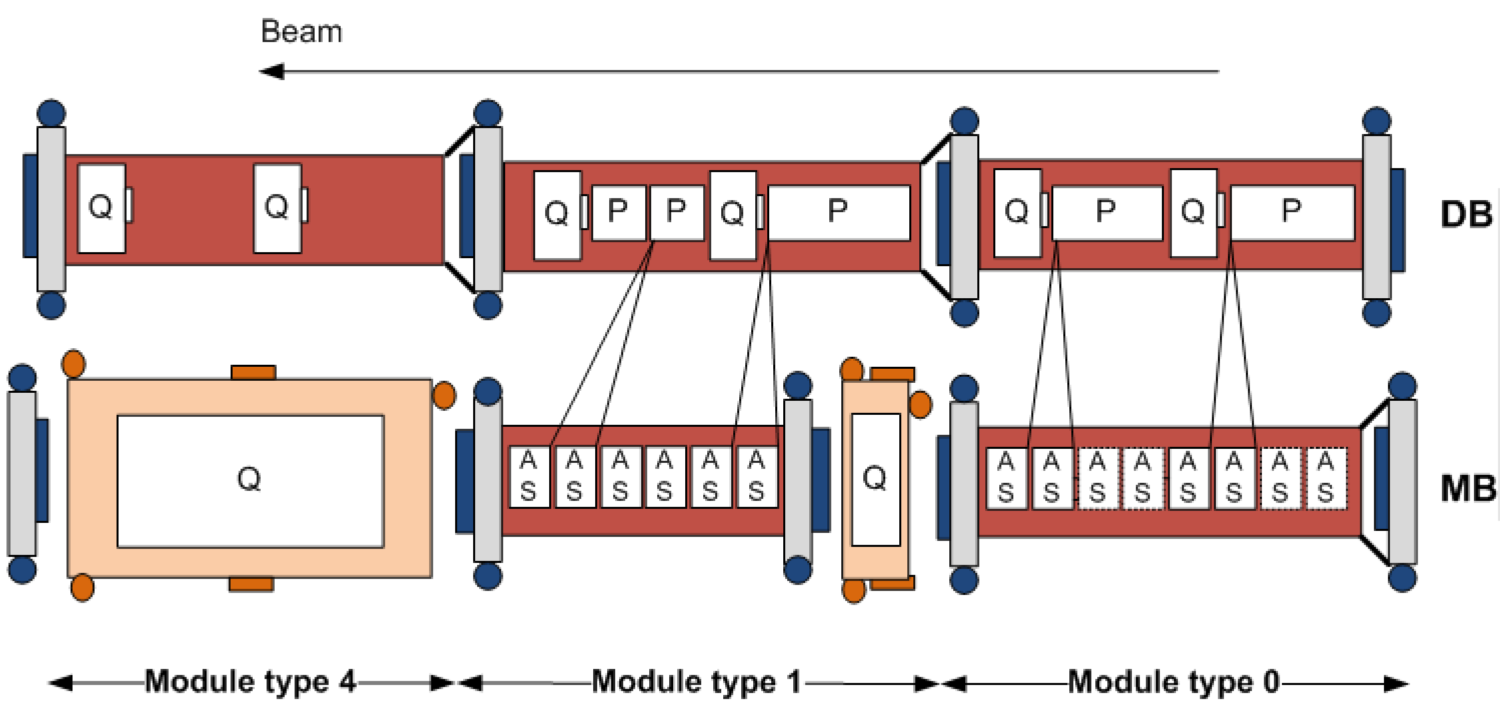
Limit the production cost for a so impressive series (> 40000 units), is a challenging aspect (but this for both solutions).



SUPPORTING SYSTEM

Alexandre.Samochkine @ cern.ch

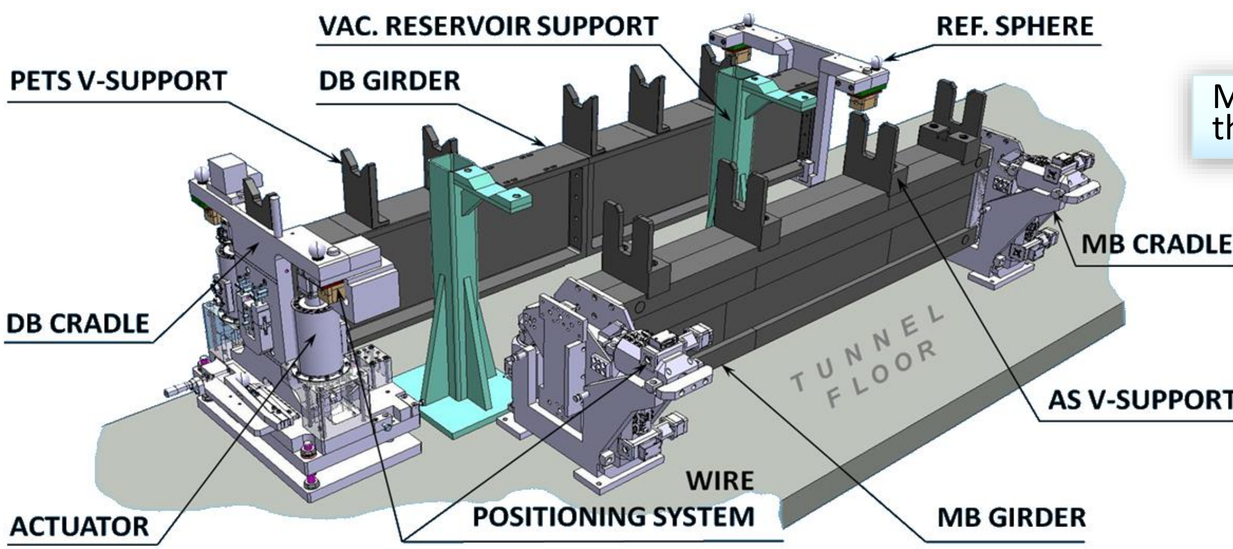
BASELINE:
- interconnected girders form a “snake system”
- MB girders are not of the same length
- MB Q support interrupts the MB girder
- MB Q beam pipe and AS are connected by bellows



CLIC MODULE SUPPORTING SYSTEM

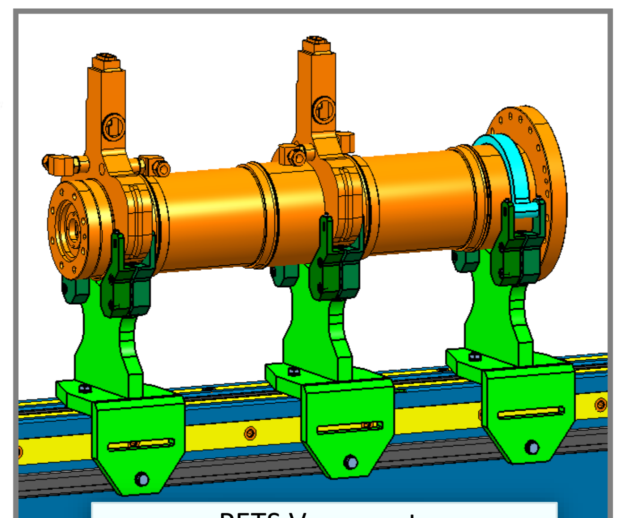
Alexandre.Samochkine @ cern.ch

The main components of both beams are supported on rectangular shaped girders linked to one chain all along the linac. The MB focusing magnet is an exception due to stringent position requirements. It has its own support and stabilization unit, which will be integrated in a later phase.
The sensors of Wire Positioning System (WPS) are reading the transversal and vertical distances to one of the wires stretched between two beams for forming a straight reference line all along the linac.



Max. vertical & lateral deformation of the girders in loaded condition - 10µm

requirement : yellow reference surfaces precision - 2 µm

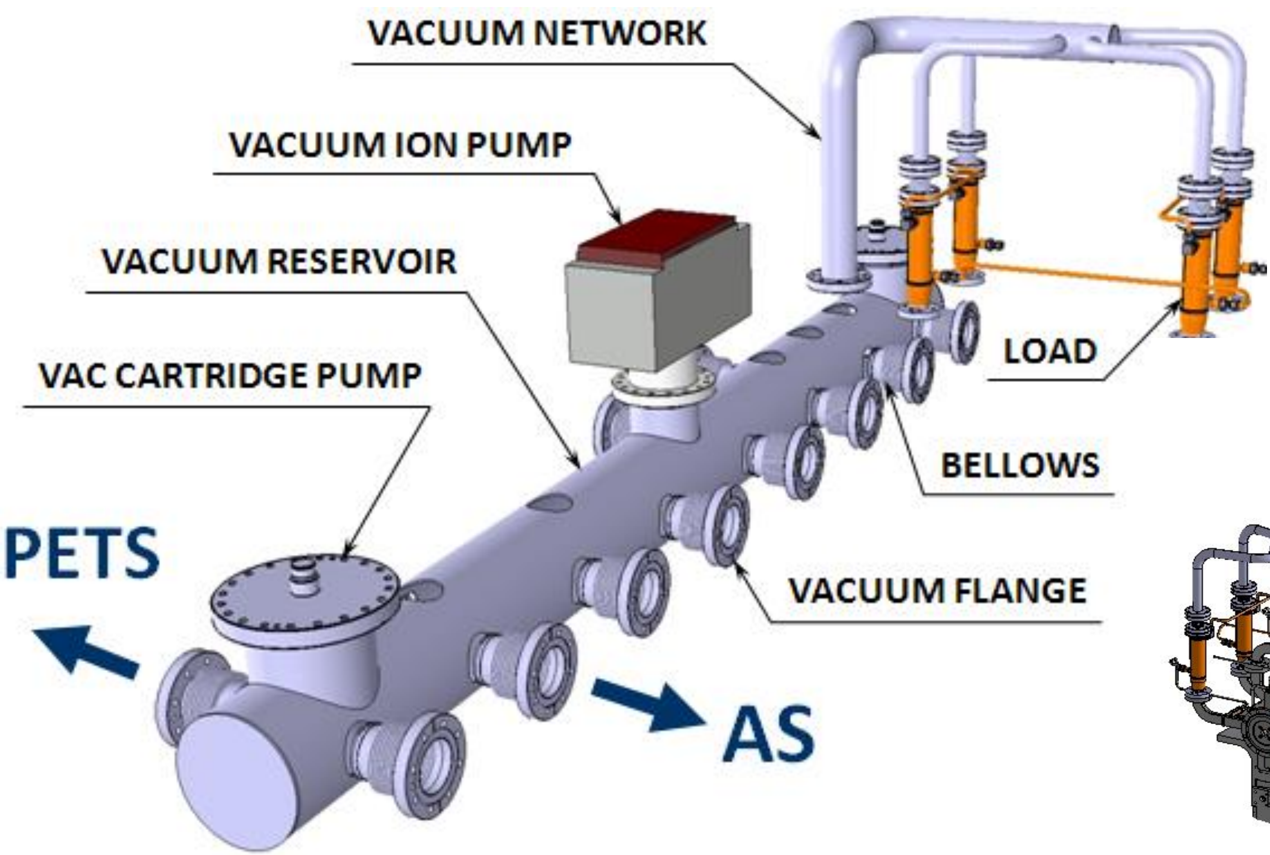


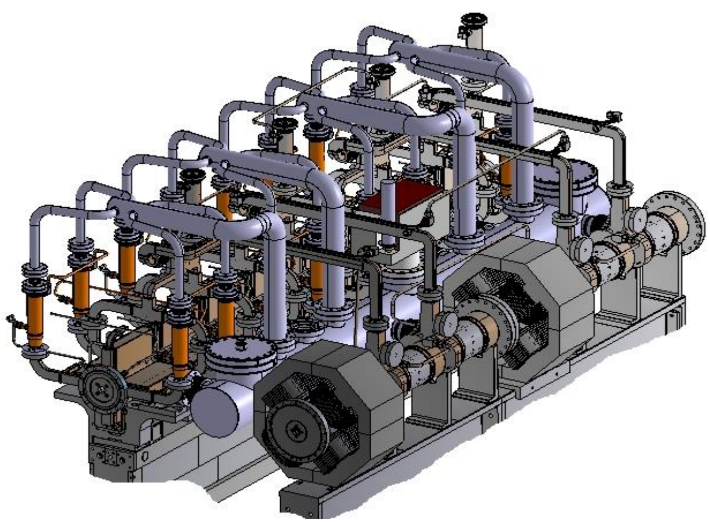
PETS V-supports
mech. design – J. Huopana (HIP)

VACUUM SYSTEM

Alexandre.Samochkine @ cern.ch

A low pressure level (10^{-9} mbar) is needed for keeping the good beam quality. The interconnections between main components should sustain the vacuum forces, provide an adequate electrical continuity with low impedance and remain flexible not to restrict the alignment.





VACUUM INTERCONNECTIONS

Alexandre.Samochkine @ cern.ch

The MB and DB vacuum coupled via the common manifold and WG

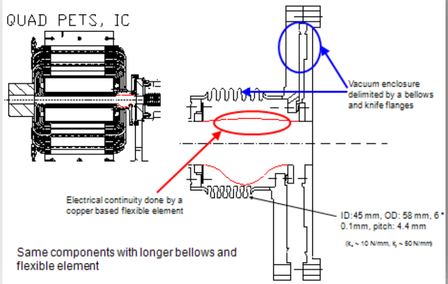
<u>The vacuum interconnections (intra-/inter-module):</u>

MB: non-contacting interconnects acceptable. Short range wake-fields essentially equal to an iris. Long range wake-fields need damping.

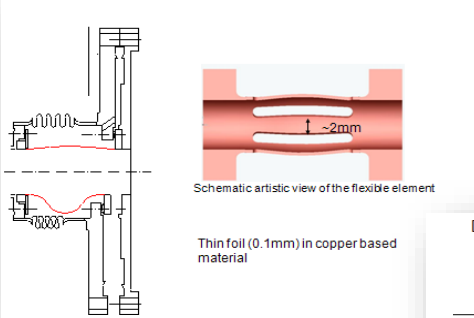
DB: good contact is necessary due to high current.

BASELINE:
10^{-9} mbar

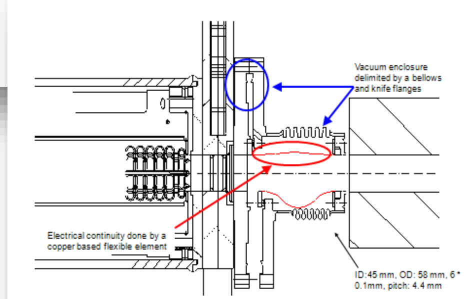
Drive beam – QUAD/PETS intermodule interconnections



Drive beam – QUAD/PETS intramodule interconnections

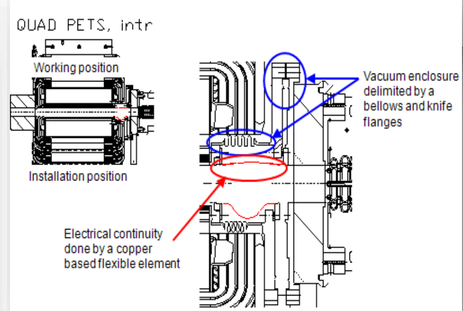


Drive beam –PETS/BPM intramodule interconnections

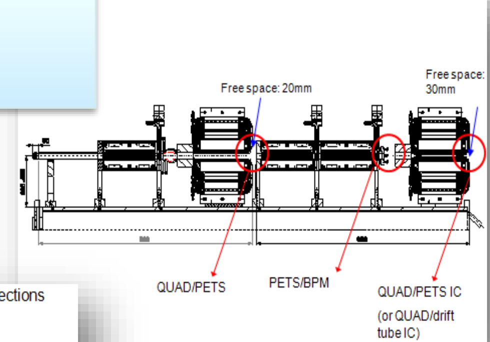


Same components as QUAD/PETS intermodule interconnections except flange on PETS side

Drive beam – QUAD/PETS intramodule interconnections



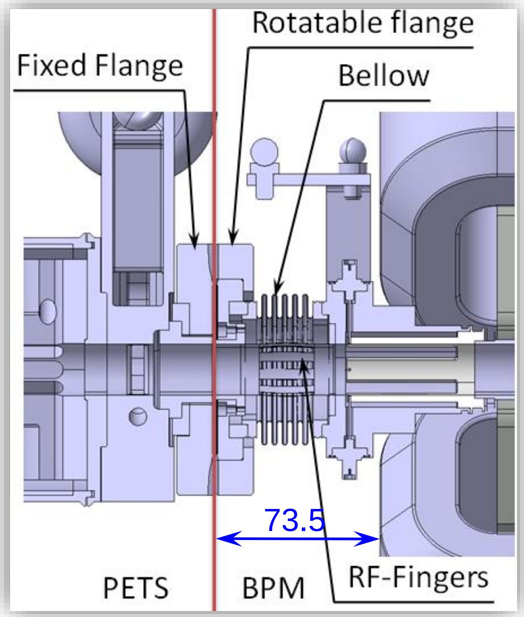
Interconnections - Drive beam

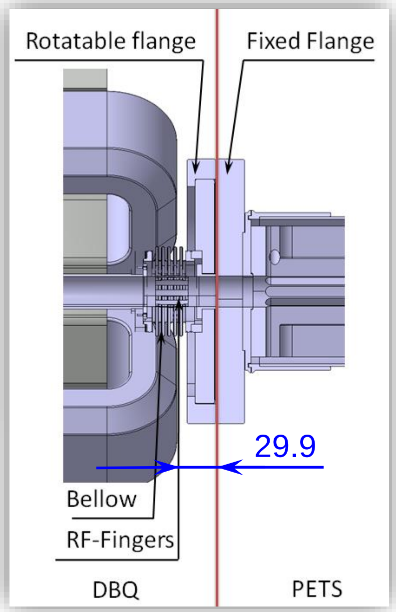


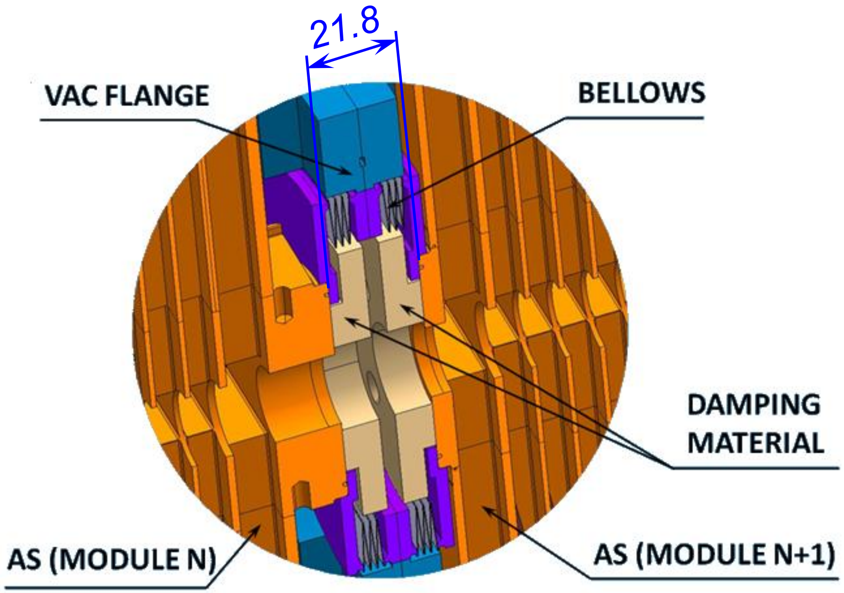
Design by C. Garion

VACUUM INTERCONNECTIONS

Alexandre.Samochkine @ cern.ch







MB AS-AS interconnections

DB Quad vacuum chamber – PETS interconnections
(mech. design D. Gudkov, JINR)

Details → talk of C. Garion

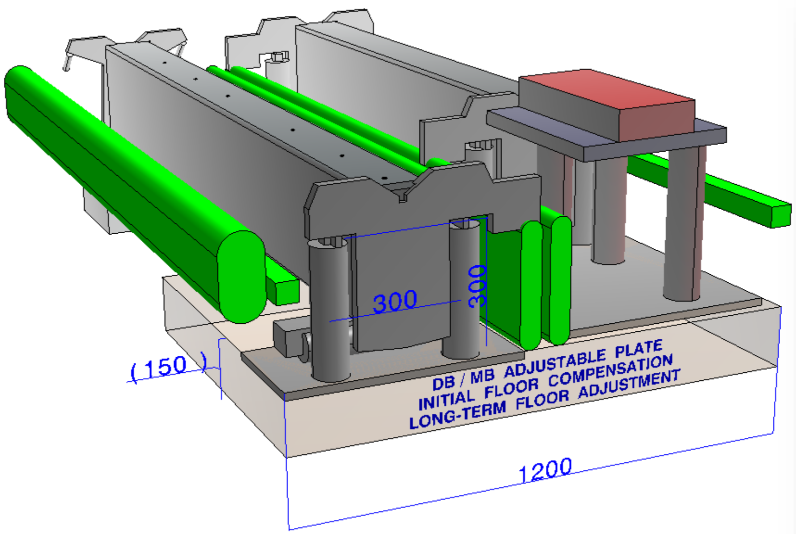
Alexandre.Samochkine @ cern.ch

PRE - ALIGNMENT & STABILIZATION SYSTEM

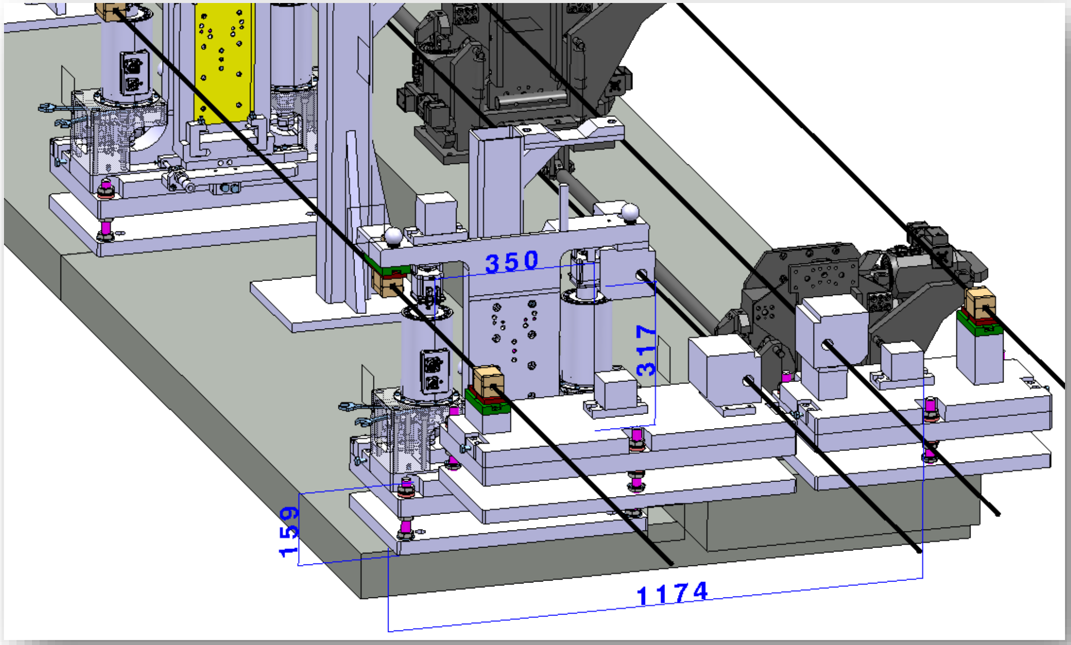
Alexandre.Samochkine@cern.ch

Mechanical pre-alignment within ±0.1 mm (1σ) → active pre-alignment: within ± 10 µm (3σ)

Concept: «snake system», straight alignment reference over 20 km based on overlapping stretched wires, AS and PETS pre-aligned on independent girders, MB Quad pre-aligned independently.



Space reservation for the alignment equipment



3D model of the WPS

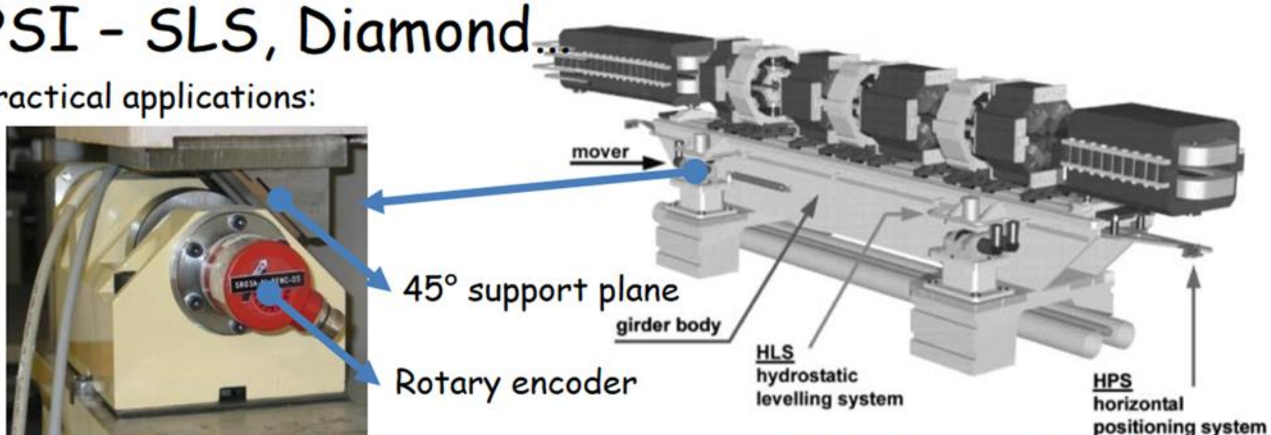
The CLIC study – micrometric pre-alignment 1

F.Lackner, CERN

Development of micrometric girder alignment based on cam shaft movers:

PSI - SLS, Diamond...

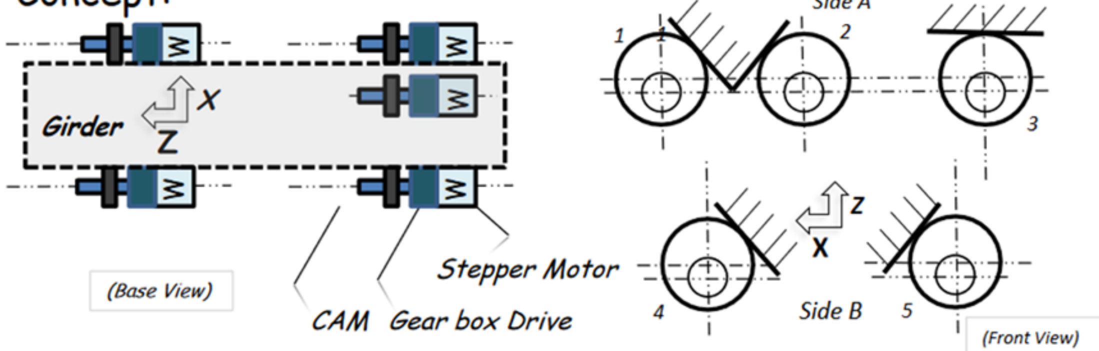
Practical applications:

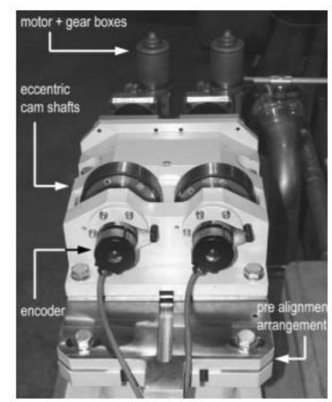


SLS Girder, active alignment

A mechanically determined system by choosing the correct amount of degrees of freedom:

Concept:





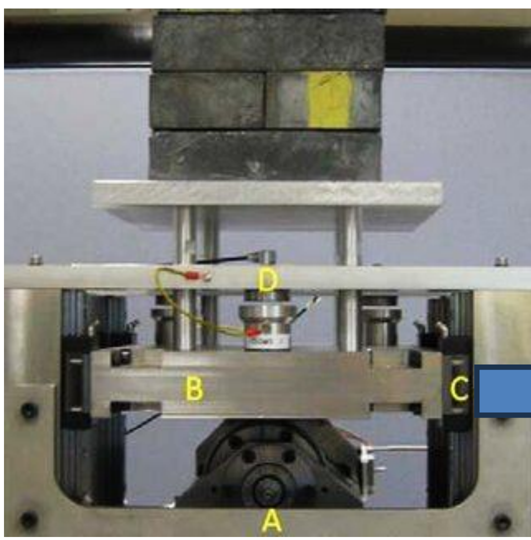
2-CAM support (SLS)

The CLIC study – micrometric pre-alignment 2

Alignment accuracy studied in 1 DOF -> minimization of relative micro displacements (parasitic alignment errors):

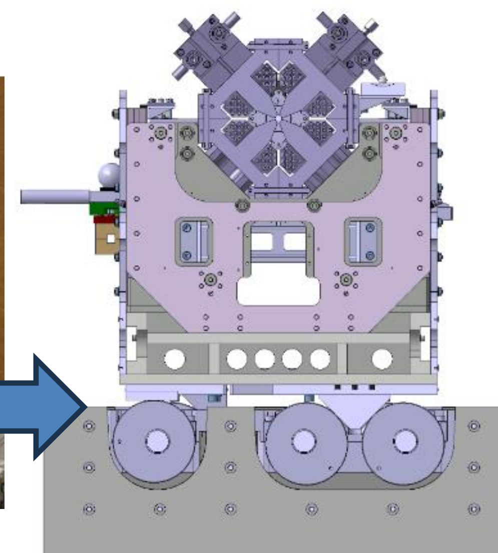
- Sine wave response, repeatability in short and long range alignment
- Modal behaviour as function of load mass
- Verification of heat dissipation during continuous operation
- Material fatigue behaviour studies (Wear, jamming)
- Modular assembly in order to study CAM optimization based on the
- Hertzian theory, interchangeable CAM

After optimization integration on girder object in 5 DOF



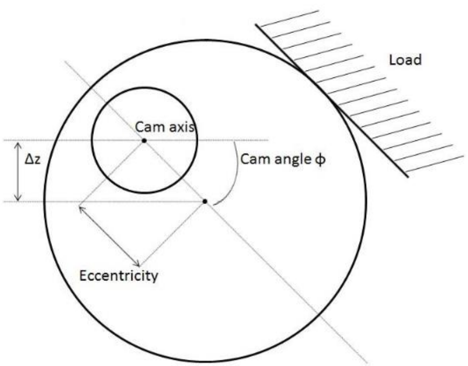
1 DOF

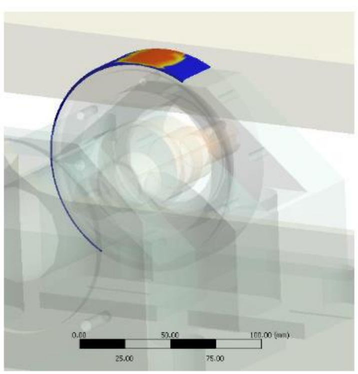
5 DOF



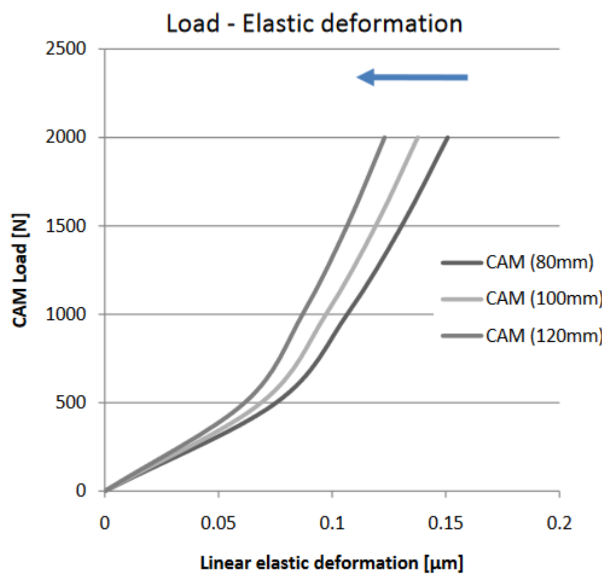
Final integration

The CLIC study – micrometric pre-alignment 3



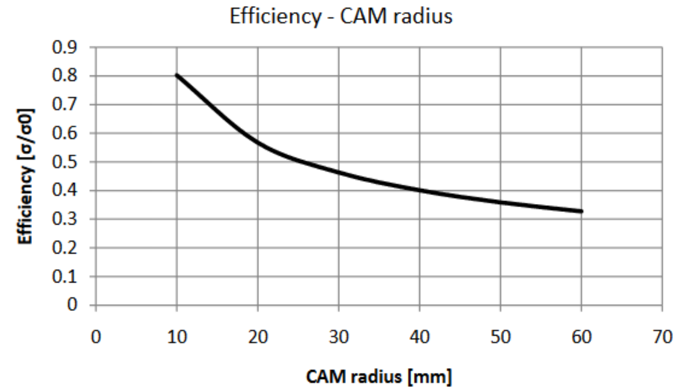


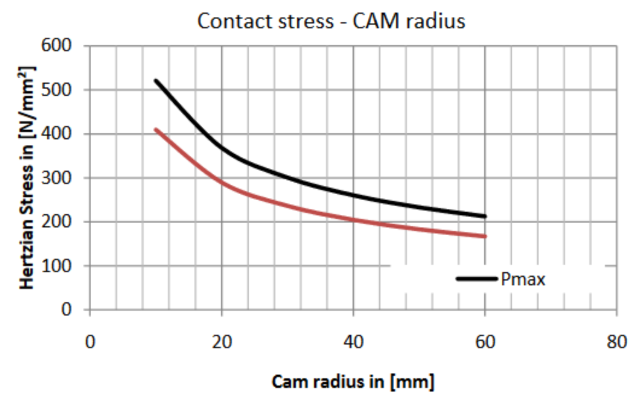
$$p_{max} = \frac{1}{\xi \cdot \eta} \cdot \sqrt[3]{\frac{3F \cdot E^2 \cdot (\sum k)^2}{8\pi^3(1-\nu^2)^2}}$$



$$\Delta N = k_c \Delta d$$

Optimization of cam diameter in order to increase the Hertz contact region.





Stabilization Requirements

K. Artoos, CERN

3992 CLIC Main Beam Quadrupoles:

Four types :

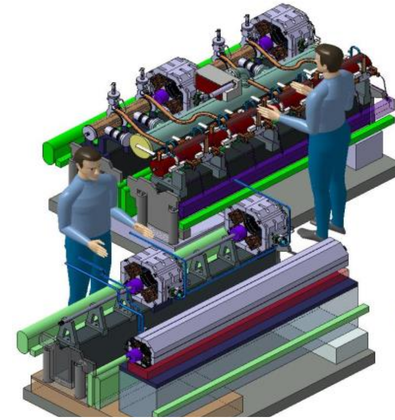
Mass: ~ 100 to 400 kg

Length: 500 to 2000 mm

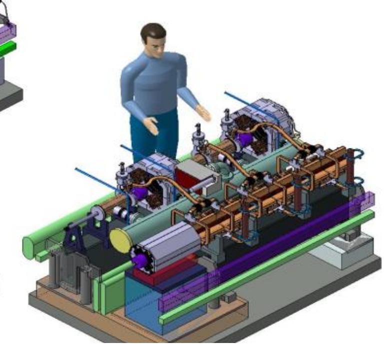
Stability (magnetic axis):

$$\sigma_x(f) = \sqrt{\int_f^{\infty} \Phi_x(\nu)d\nu}$$

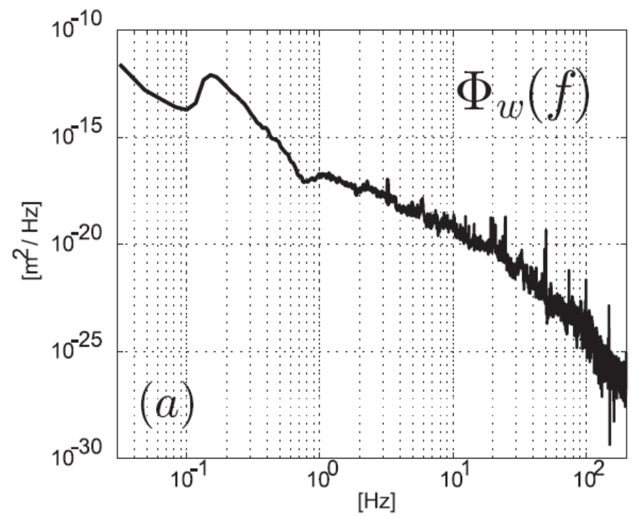
	Main beam quadrupoles
Vertical	**1.5 nm > 1 Hz** *(1 nm)*
Lateral	**5 nm > 1 Hz**

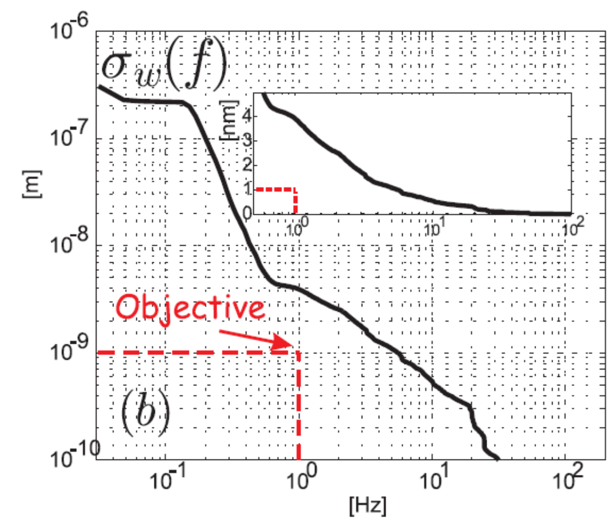


Type 4: 2m, 400 kg



Type 1: 0.5 m, 100 kg



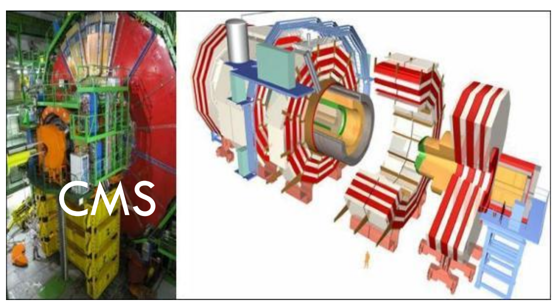


Characterisation vibration sources

Measurements LAPP, DESY, SLAC

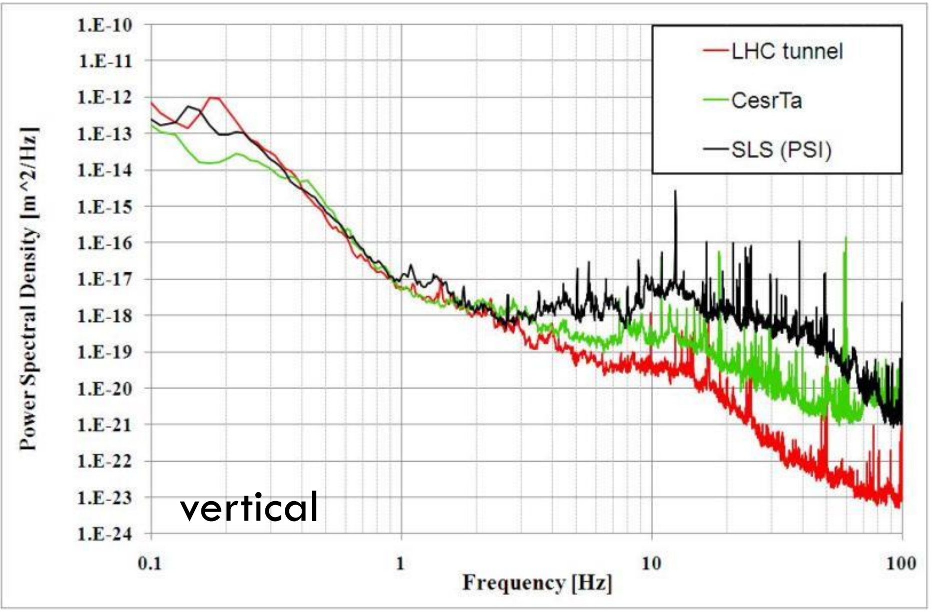
Broadband seismometers characterisation

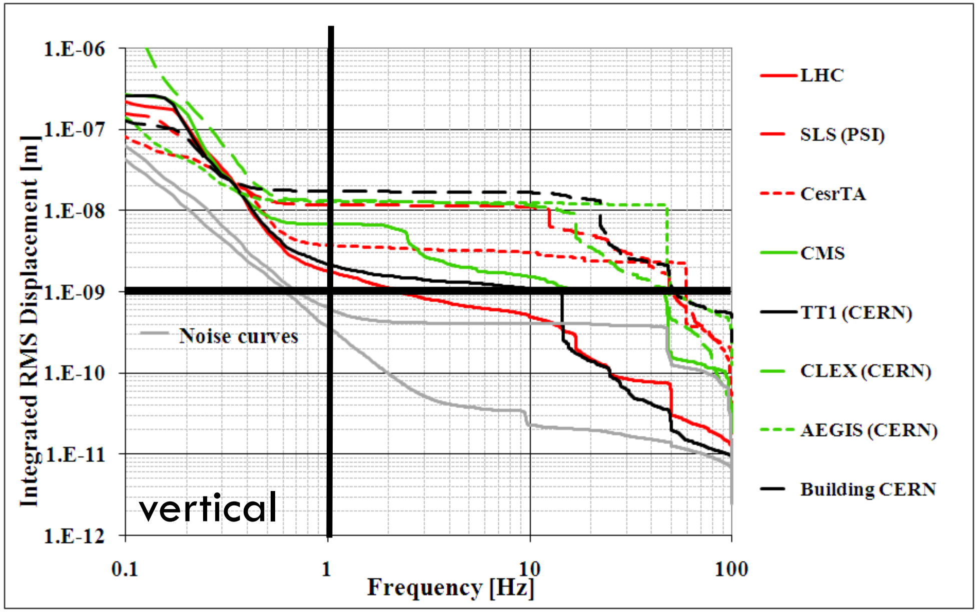
More measurements by CERN in accelerator environments



M. Sylte, M. Guinchard, A. Kuzmin, A. Slaathaug

Characterisation vibration sources





- Running accelerator in deep tunnel comparable to LHC:
- **between 2 and 5 nm** ground vertical integrated R.M.S. displacement
- Amplitude to be reduced by a **factor 4-5** in frequency range **1-20 Hz**
- **Above 20 Hz** contribution to integrated RMS is **small**
- Updated ground motion model with technical noise

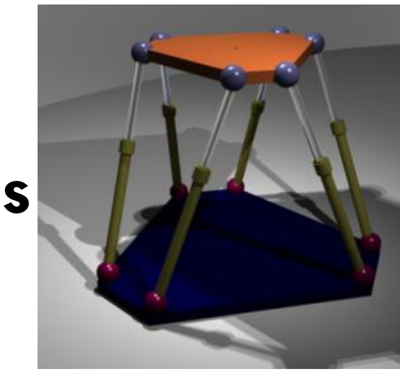
Strategy Support

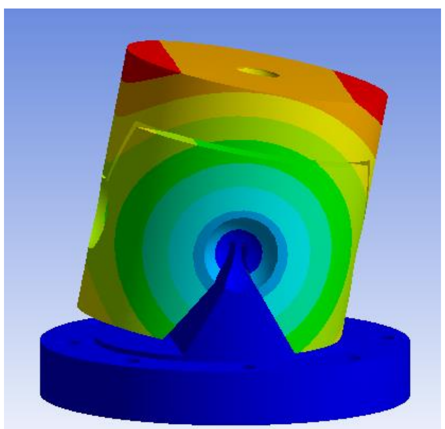
- Stiff structure
- At least four d.o.f.
- Precise motion
- Repeatability
- 0.1 nm resolution vertically

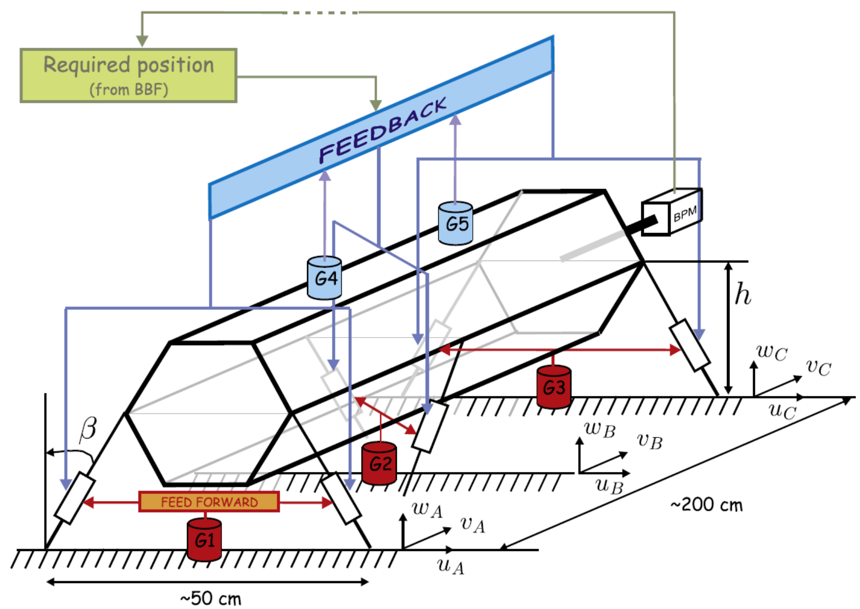
Parallel structure

Stiff piezo actuators

Flexural hinges



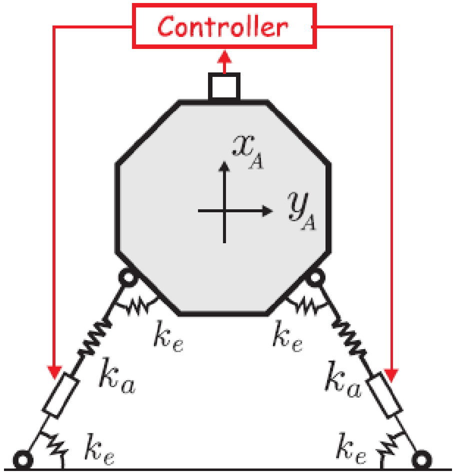




Sensors : Seismometers "to get started"

Strategy Support

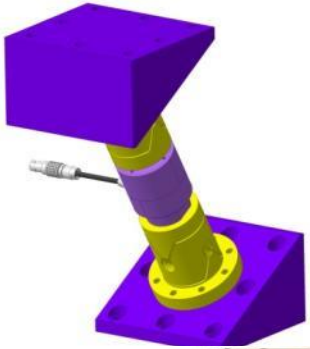
Structural stiffness	⟷	Induced stresses in piezo
Inclination	⟷	Resolution, structure stiffness, forces
Number	⟷	# D.O.F. , COST Resonant frequency Solution 4 types

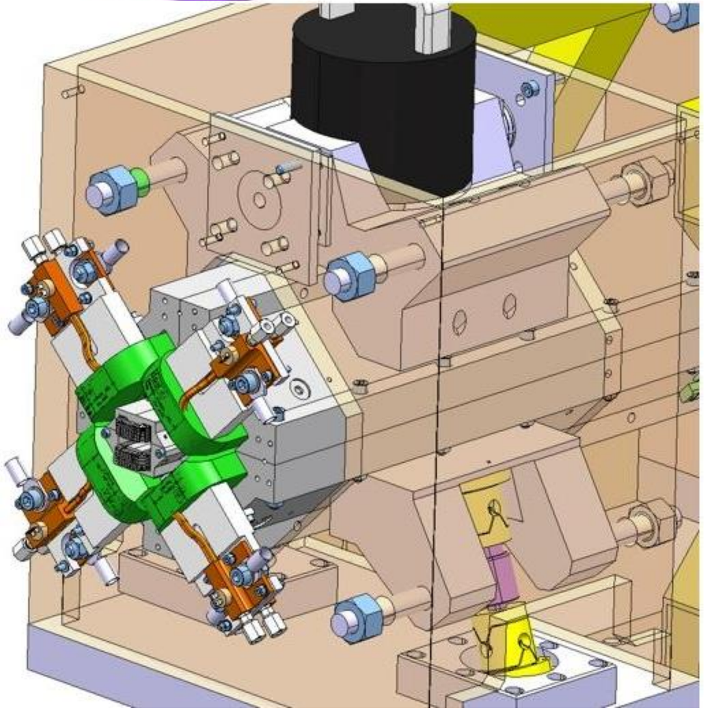


↓

Block longitudinal
Block roll

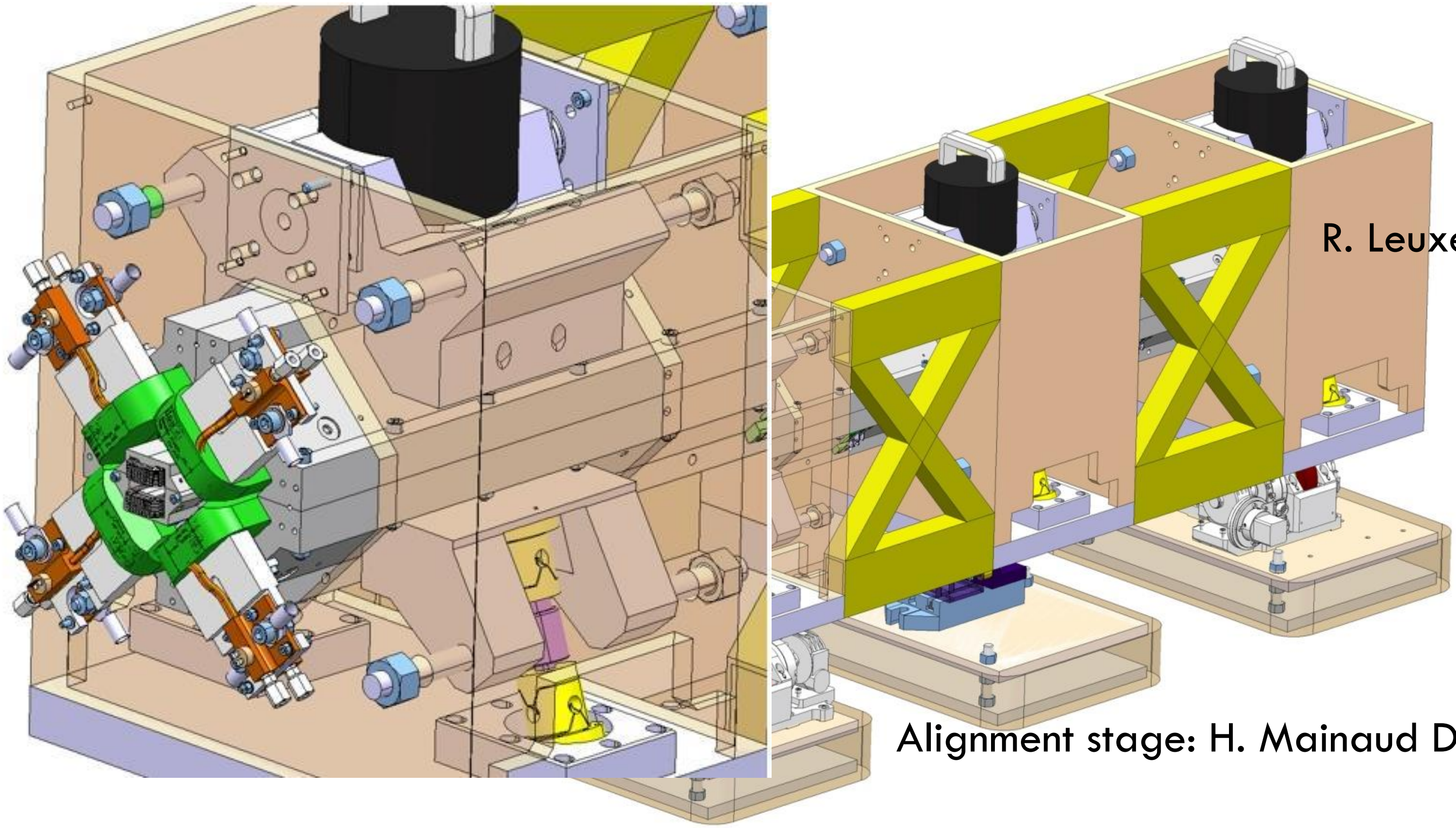
X-Y flexural guide





Concept drawing

Type 4



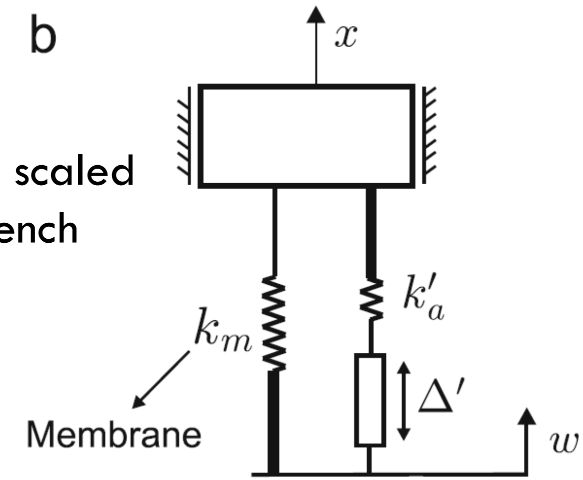
Stiff intermediate girder between alignment and stabilisation

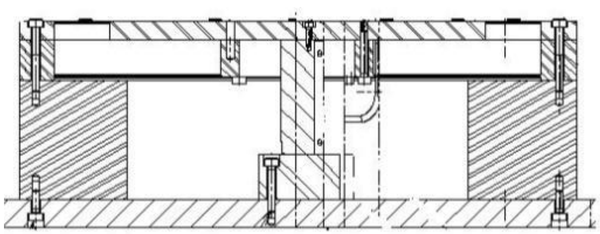
Lockable in longitudinal direction (transport)

Step 1: One d.o.f. scaled set-up

1d.o.f scaled test bench

b

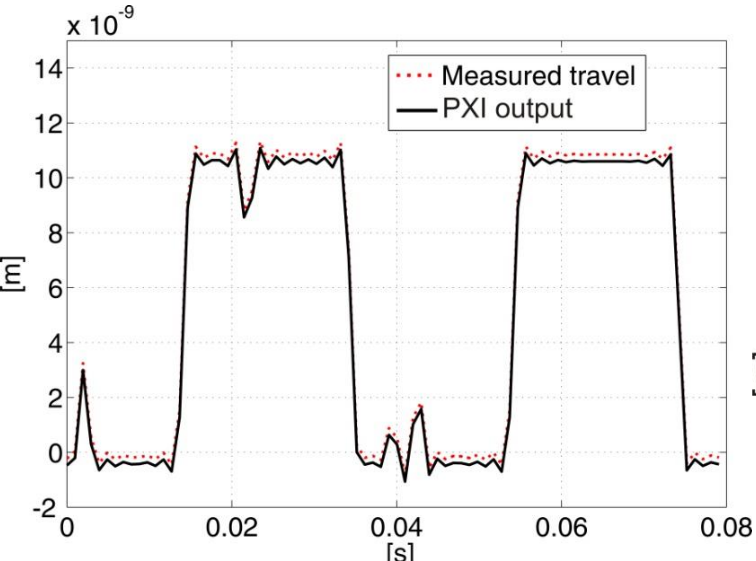




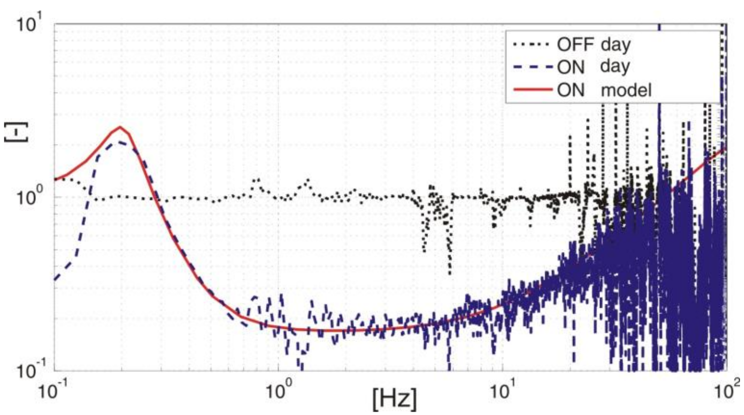
$$\frac{k}{m} = \frac{k'}{m'}$$

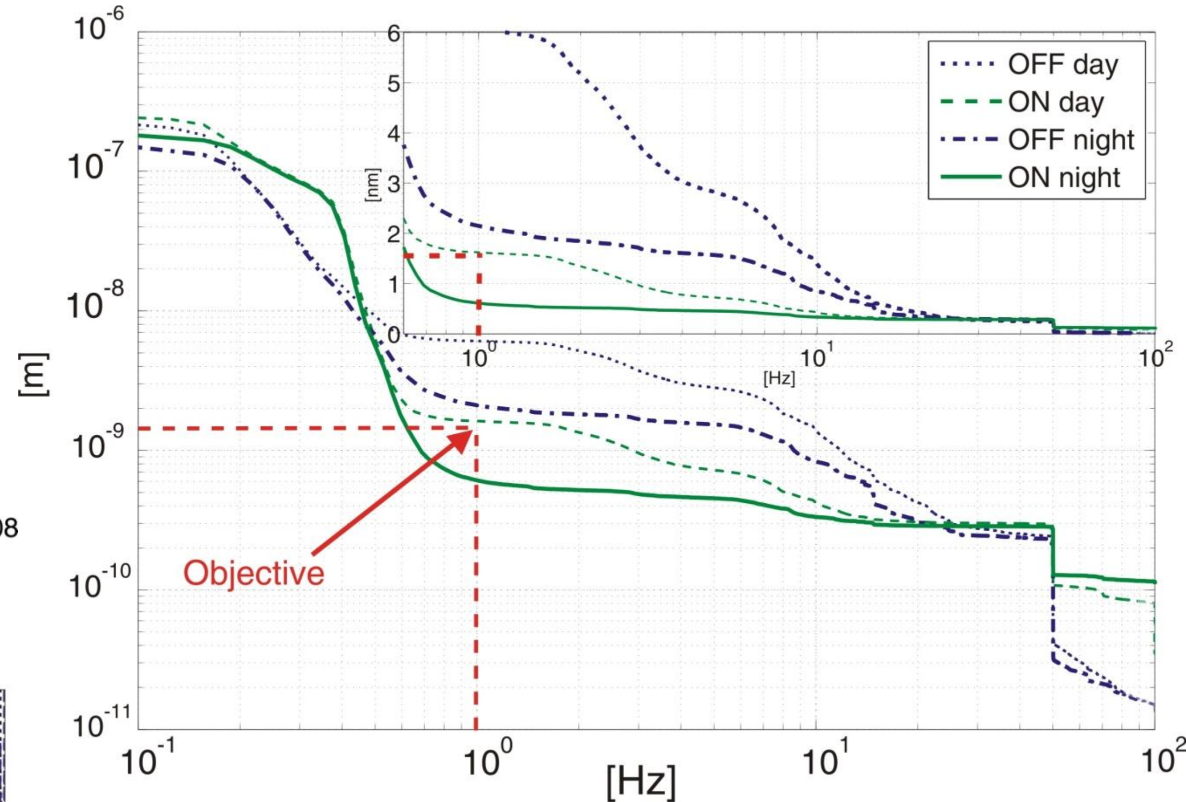
COLLETTE C., ARTOOS K., KUZMIN A., SYLTE M., GUINCHARD M. and HAUVILLER C., Active quadrupole stabilization for future linear particle colliders, *Nuclear instruments and methods in physics research section A*, vol.621 (1-3) pp.71-78 (2010).

Experimental results



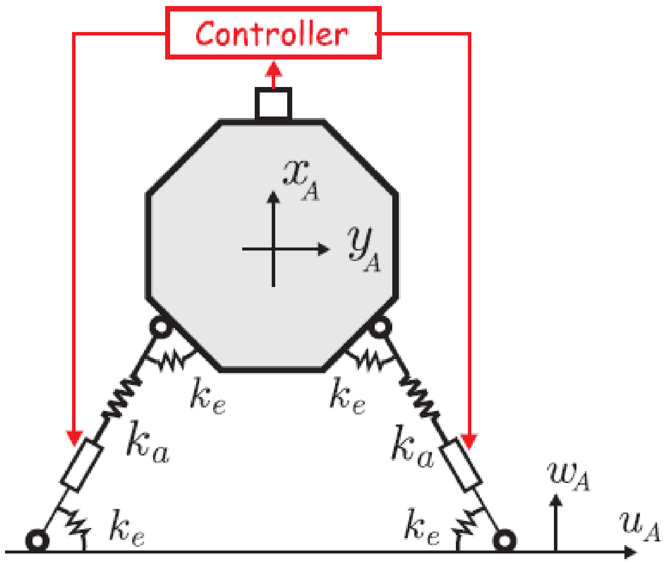
Objectives reached

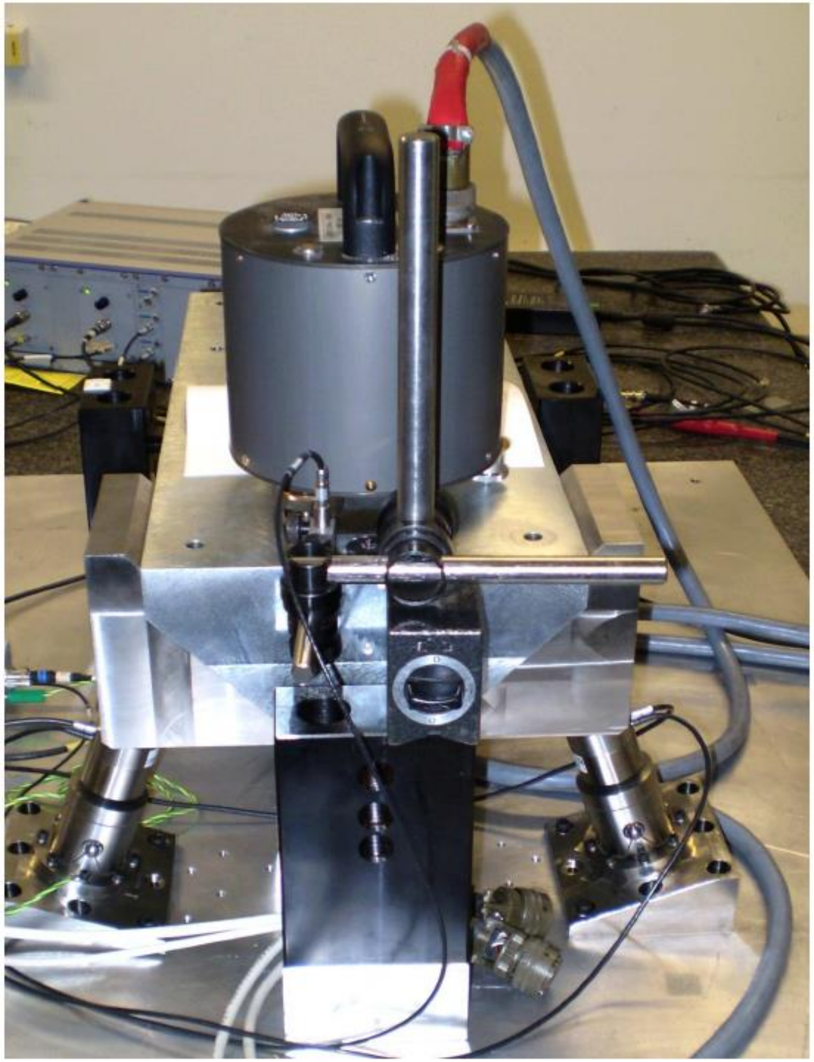




Result: 0.6 nm at 1 Hz from 2.2 nm
day: 1.6 nm from 6.4 nm
0.44 nm at 4 Hz

Step 3: 2 d.o.f. with type 1 mass

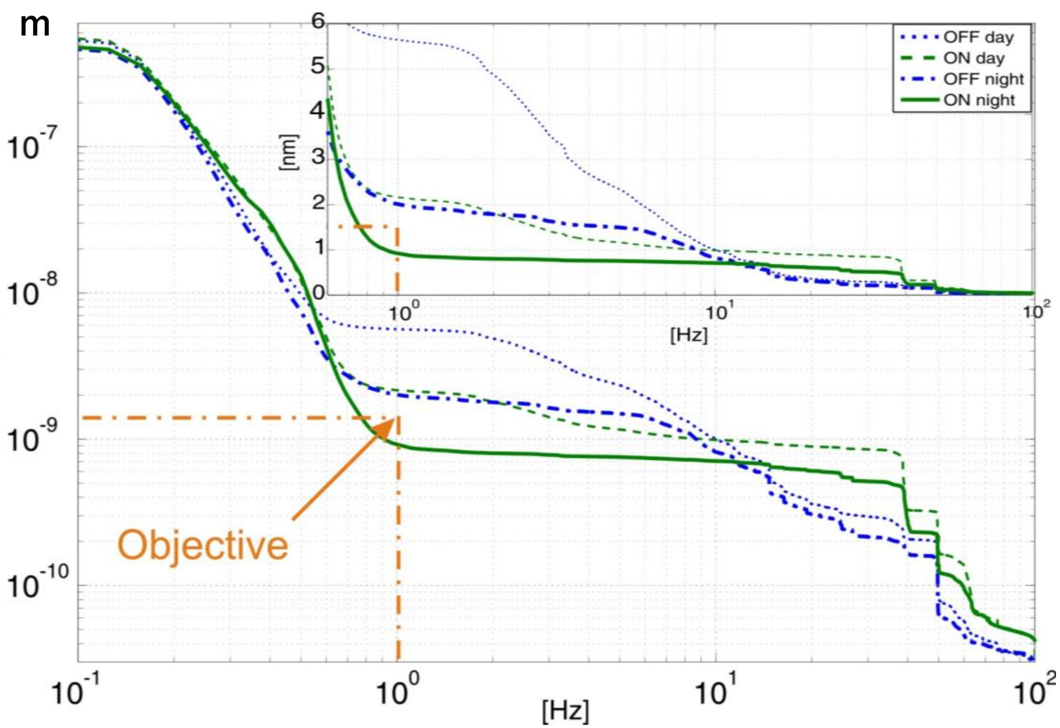


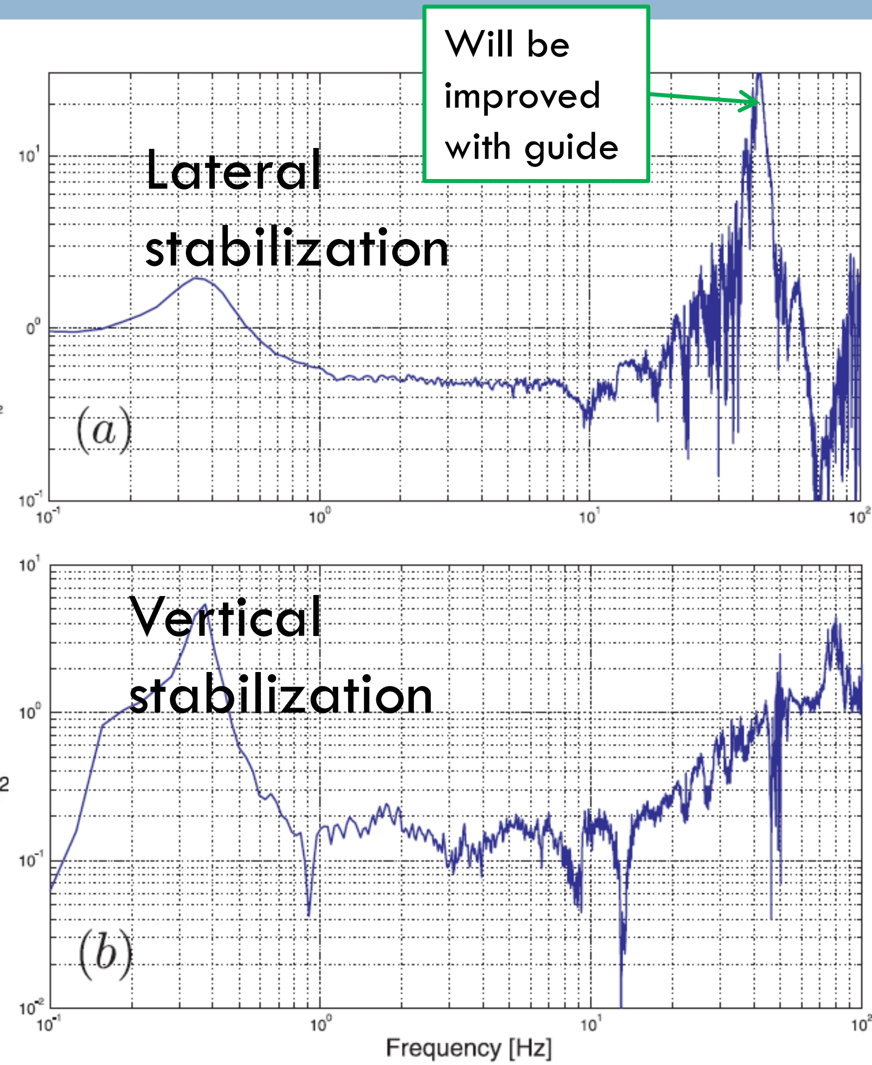


Objectives:

- Validate the strategy and controller in 2 d.o.f.
- Validate flexural hinge design
- Validate Mounting and assembly issues
- Validate nano positioning in 2 d.o.f.

Stabilization in 2 d.o.f.

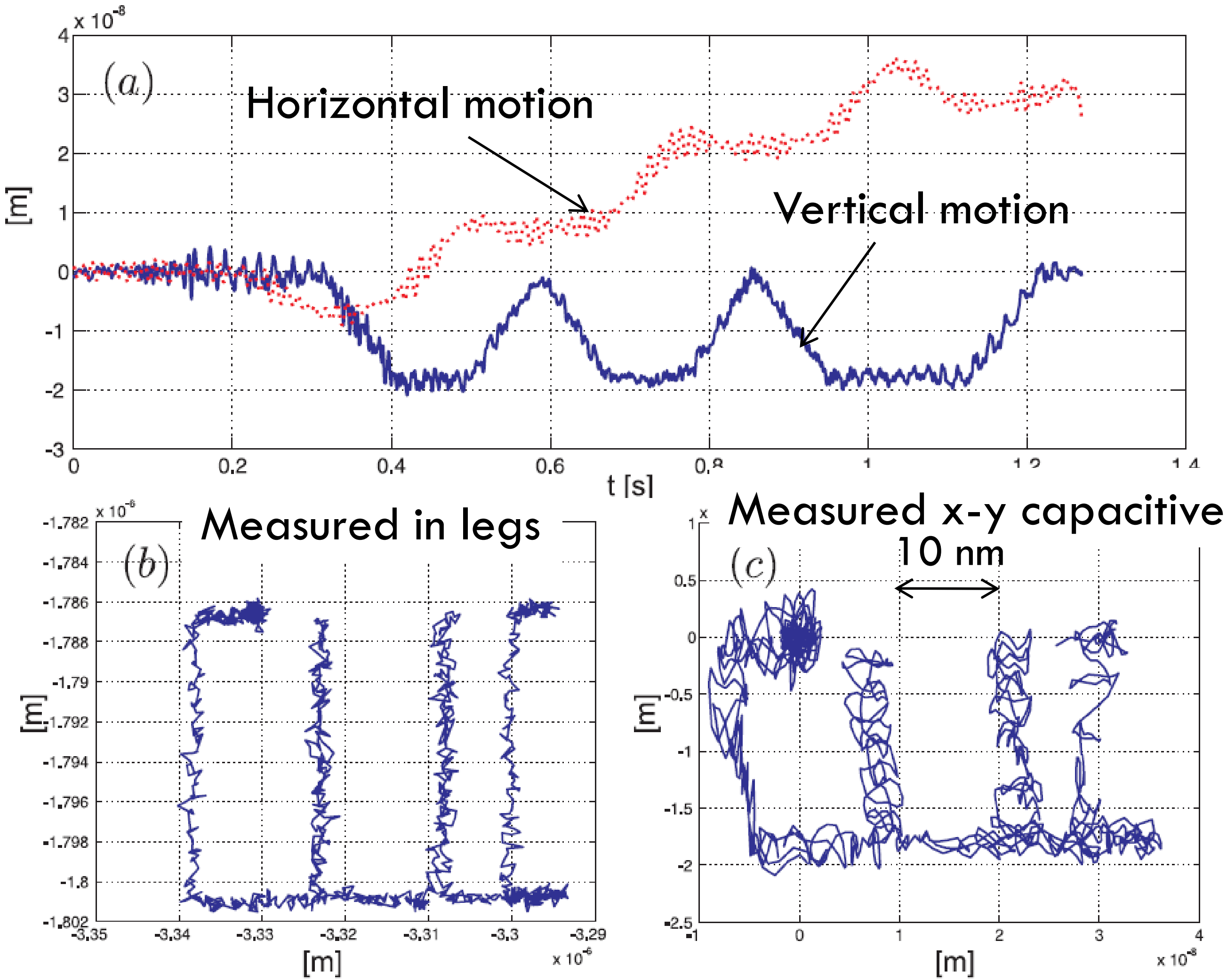




0.9 nm at 1 Hz

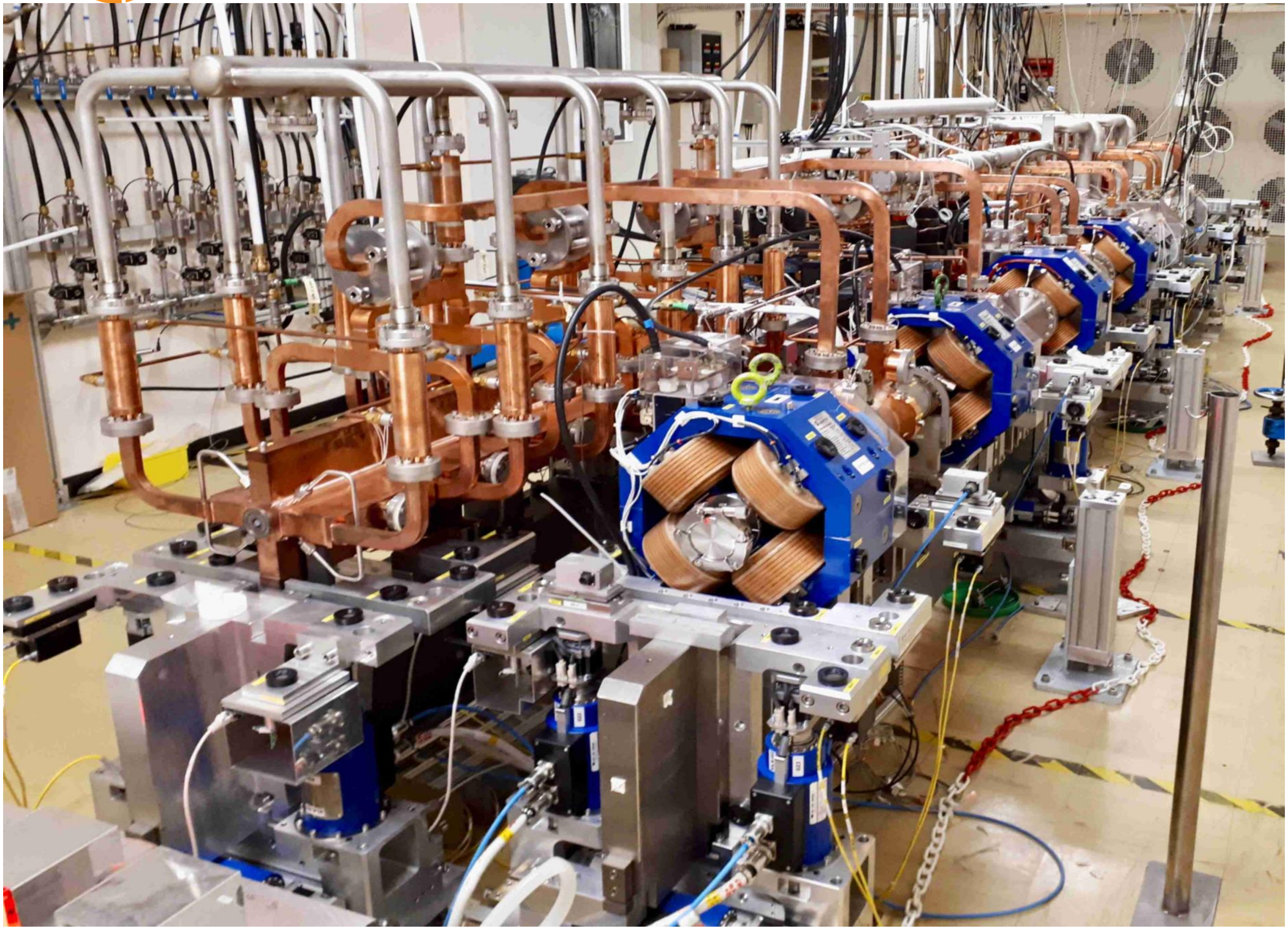
Can be improved still.

Positioning in 2 d.o.f.



Integration test at CERN

Two-beam module string



Summary

- 1000's of examples of splendid ME examples in accelerators
- Only two shown
- At todays level of complexity and pushed requirements for new projects one should:
  - **Increase the knowledge of (mechanical) engineers on beam physics**
  - **Increase the knowledge of accelerator physicists on technologies and feasibilities**

  ...leading to a better dialog for optimized designs
- New role for CAS