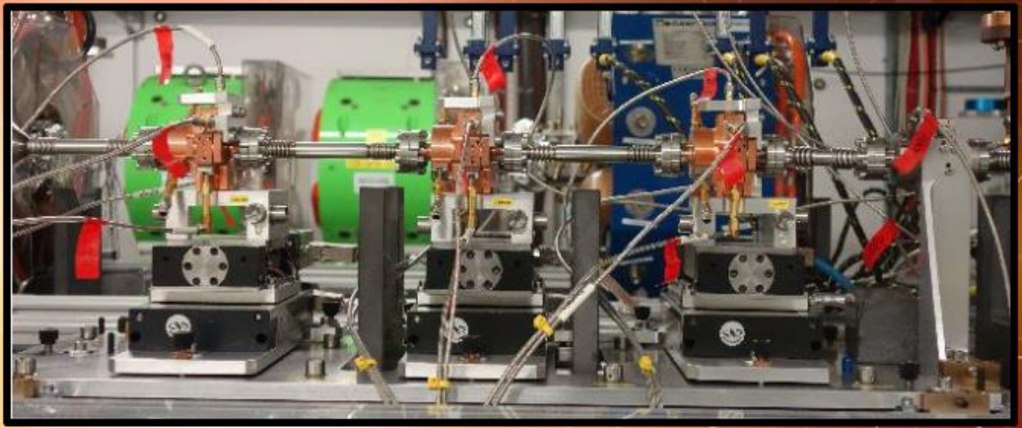
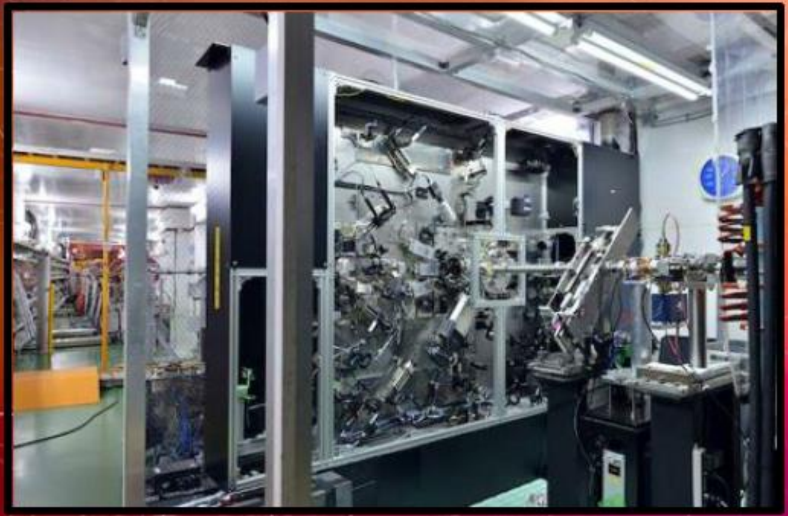
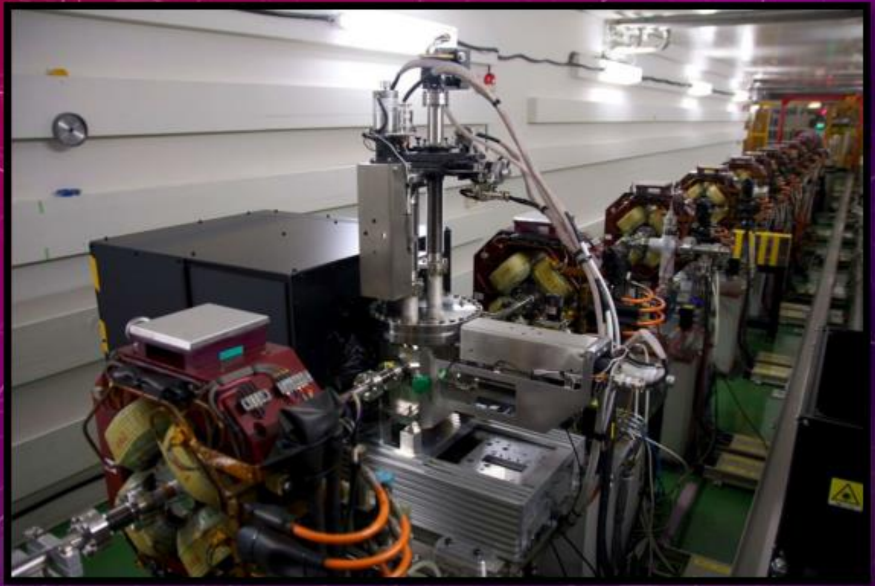




# Nanobeam Technologies

1 FEBRUARY- 3 FEBRUARY

https://indico.cern.ch/event/980103



# Motivation

*In the coming years "nanobeams" will be a priority area – for CLIC and many other existing and future projects*

*… more from other Higgs factories, and other accelerators with similar challenges, other technologies*

*We hope the workshop will be a success – and will consider to make it annual*

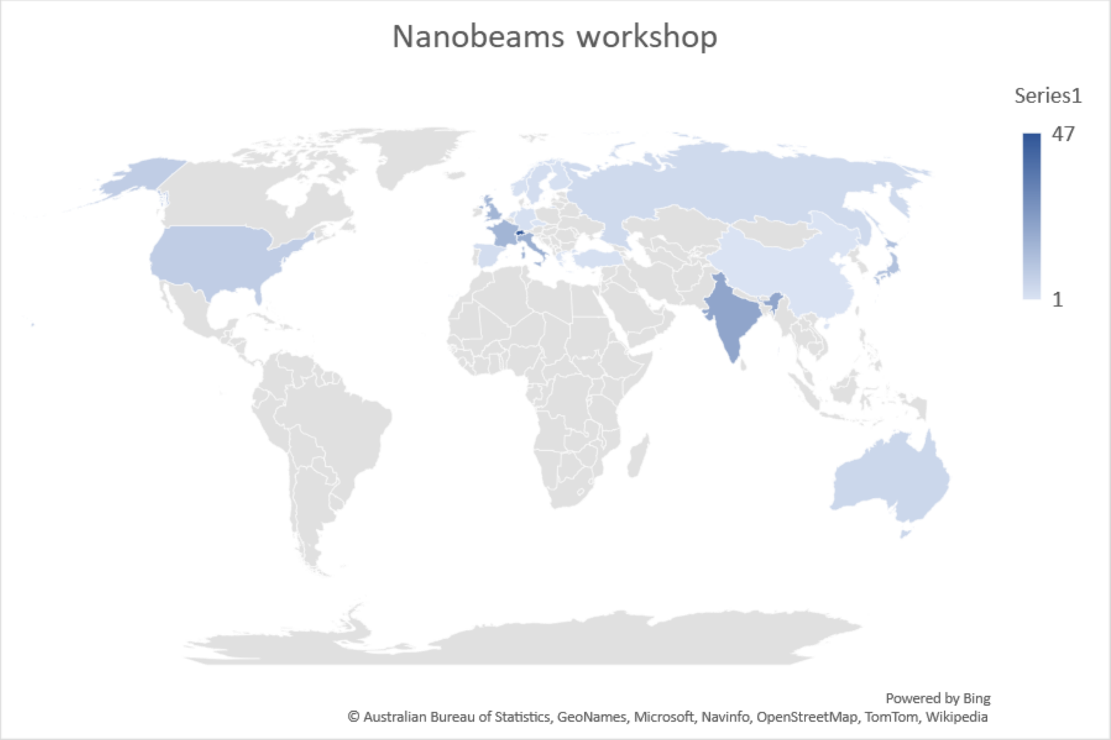
*We also hope it will increase knowledge exchange and foster further collaboration in this area*

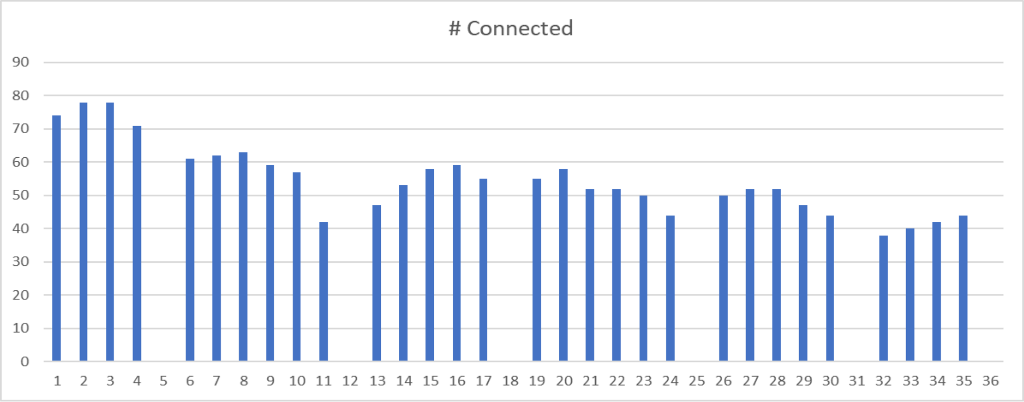
*S. Stapnes*

| Parameter | Symbol | Unit | Stage 1 | Stage 2 | Stage 3 |
|---|---|---|---|---|---|
| Centre-of-mass energy | $\sqrt{s}$ | GeV | 380 | 1500 | 3000 |
| Repetition frequency | $f_{\rm rep}$ | Hz | 50 | 50 | 50 |
| Number of bunches per train | $n_b$ | | 352 | 312 | 312 |
| Bunch separation | $\Delta t$ | ns | 0.5 | 0.5 | 0.5 |
| Pulse length | $\tau_{\rm RF}$ | ns | 244 | 244 | 244 |
| Accelerating gradient | $G$ | MV/m | 72 | 72/100 | 72/100 |
| Total luminosity | $\mathscr{L}$ | $10^{34}$ cm$^{-2}$ s$^{-1}$ | 1.5 | 3.7 | 5.9 |
| Luminosity above 99% of $\sqrt{s}$ | $\mathscr{L}_{0.01}$ | $10^{34}$ cm$^{-2}$ s$^{-1}$ | 0.9 | 1.4 | 2 |
| Total integrated luminosity per year | $\mathscr{L}_{\rm int}$ | fb$^{-1}$ | 180 | 444 | 708 |
| Main linac tunnel length | | km | 11.4 | 29.0 | 50.1 |
| Number of particles per bunch | $N$ | $10^9$ | 5.2 | 3.7 | 3.7 |
| Bunch length | $\sigma_z$ | μm | 70 | 44 | 44 |
| IP beam size | $\sigma_x/\sigma_y$ | nm | 149/2.9 | ~ 60/1.5 | ~ 40/1 |
| Normalised emittance (end of linac) | $\epsilon_x/\epsilon_y$ | nm | 900/20 | 660/20 | 660/20 |
| Final RMS energy spread | | % | 0.35 | 0.35 | 0.35 |
| Crossing angle (at IP) | | mrad | 16.5 | 20 | 20 |

# Participants

- 168 registered participants from 47 Institutions
- 31 talks for around 10 hours..
- Apologies to you and the speakers for flying over the slides…



# Program and organization team

- Nuria Catalan-Lasheras
- Angeles Faus-Golfe
- Thibaut Lefevre
- Helene Mainaud-Durand
- Yannis Papaphilippou
- Nobuhiro Terunuma

- Alexia Augier
- Grace Fern Jackson

**Tuesday 2 February 2021**

| | | |
|---|---|---|
| RF/Injection/Extraction (Chair: T. Lefevre) | RF design for High-frequency systems for rings (including lov | Themis Mastoridis |
| | Injection systems and methods for ultra-low emittance rings | Masamitsu Aiba |
| | Power systems for low emmittance rings | Erk Jensen |
| | Wake-field monitors and wakefield mitigation. | Kyrre Ness Sjobaek |
| | Kicker design with tight kick tolerances and Pulsers with ultr | Mike Barnes |
| Break | | |
| Instrumentation (Chair: H. Mainaud-Durand) | Overview on profile measurements of nano-beams. | Thibaut Lefevre |
| | Measuring nanometer beam size at final focus. | Toshiyuki Okugi |
| | High resolution cavity BPMS. From prototype to larger produ | Alexej Lyapin |
| | Non-invasive beam measurement using polarisation radiatio | Pavel Karataev |
| | X -band transverse deflection structure with variable polariz | Barbara Marchetti |
| | Measuring femtosecond bunches using Electro-optical techn | Serge Bielawski |

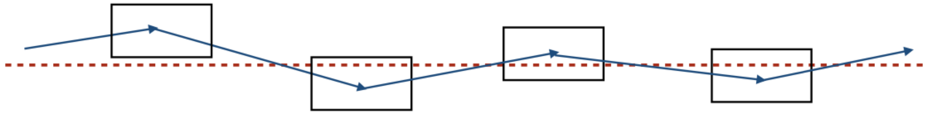
| | | |
|---|---|---|
| Beam dynamics (Chair: N. Catalan-Lasheras) | Welcome and introduction | Steinar Stapnes |
| | Beam dynamics tolerances for Rings. | Yannis Papaphilippou |
| | Beam dynamics tolerances for FELs and Linear colliders. | Andrea Latina |
| | Jitter control and Feedback (IP, DB). | Philippe Burrows |
| Break | | |
| Magnets (Chair: A. Faus-Golfe) | Permanent adjustable Magnets | Ben Shepard |
| | SC Low-beta magnets | Brett Parker |
| | High-field undulators/wigglers HTS | Daniel Schoerling |
| | Special magnets (ATF octupoles, skew sextupoles) | M. Modena |
| | High-field longitudinal gradient dipoles. | Manuel Dominguez |
| | Crab cavities | S. Verdu |

| | | |
|---|---|---|
| Alignment and stability (Chair: Terunuma) | The PACMAN project results. | Helene Mainaud-Durand |
| | Structured laser beam for alignment. | Jean-Christoph Gayde |
| | Status MDI alignment. | Leonard Watrelot |
| | Development of low-cost alignment systems. | Mateusz Sosin |
| | Girder stability LAPP | Gael Balik |
| Break | | |
| Vacuum and wrap-up (Chair: Y. Papaphilippou) | "Very thin" Non-Evaporable Getter coatings for particle acce | Pedro Costa Pinto |
| | Development of thin-walled copper electroformed vacuum c | Lucia Lain Amador |
| | Measuring conductivity of coated surfaces at high frequency. | Andrea Pasarelli |
| | Beam dynamics tolerances for next generation of accelerator | Daniel Schulte |
| | Workshop wrap-up | Nuria Catalan-Lasheras |

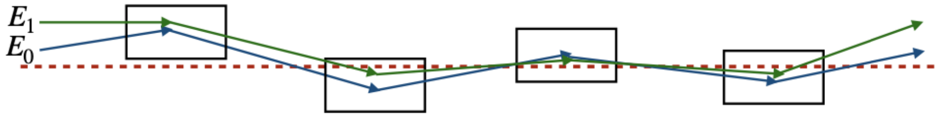
**Damping rings, radio-frequency, magnets, alignment, stabilization, Injection/extraction, vacuum and impedance, instrumentation**

# “Beam dynamics tolerances for Linear Colliders and FELs”, A. Latina

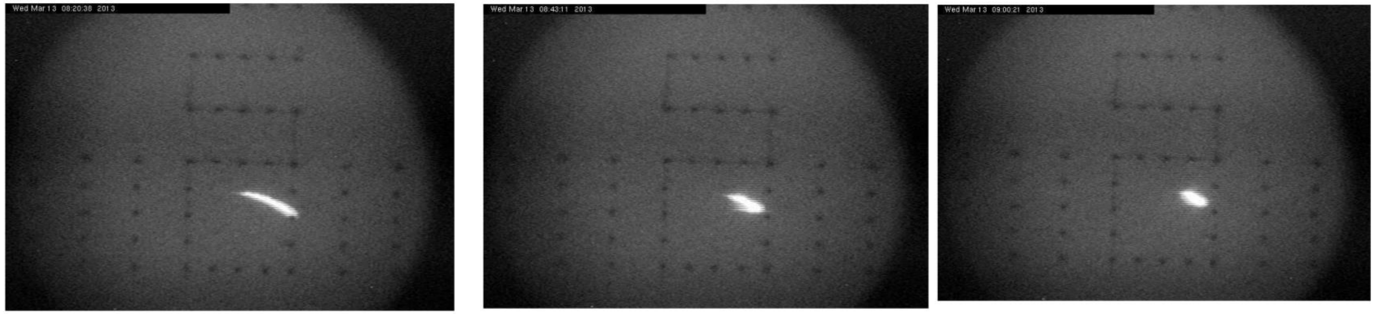
1. Orbit correction



2. Dispersion-free / wakefield-free steering

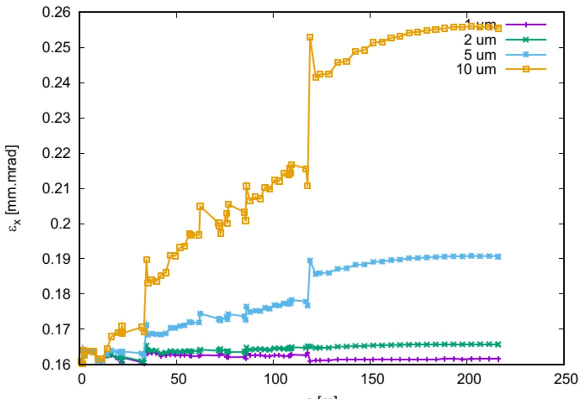



3. RF alignment
4. Sextupoles

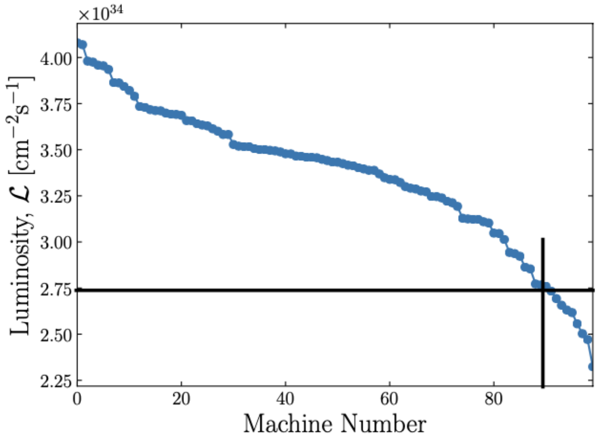


Beam-based alignment tests at FACET@SLAC

[ Gohil, Burrows, Blaskovic, Latina, Ögren, Schulte, D.. (2020). Luminosity Performance of the Compact Linear Collider at 380 GeV with Static and Dynamic Imperfections. Phys. Rev. Accel. Beams 23, 101001 ]



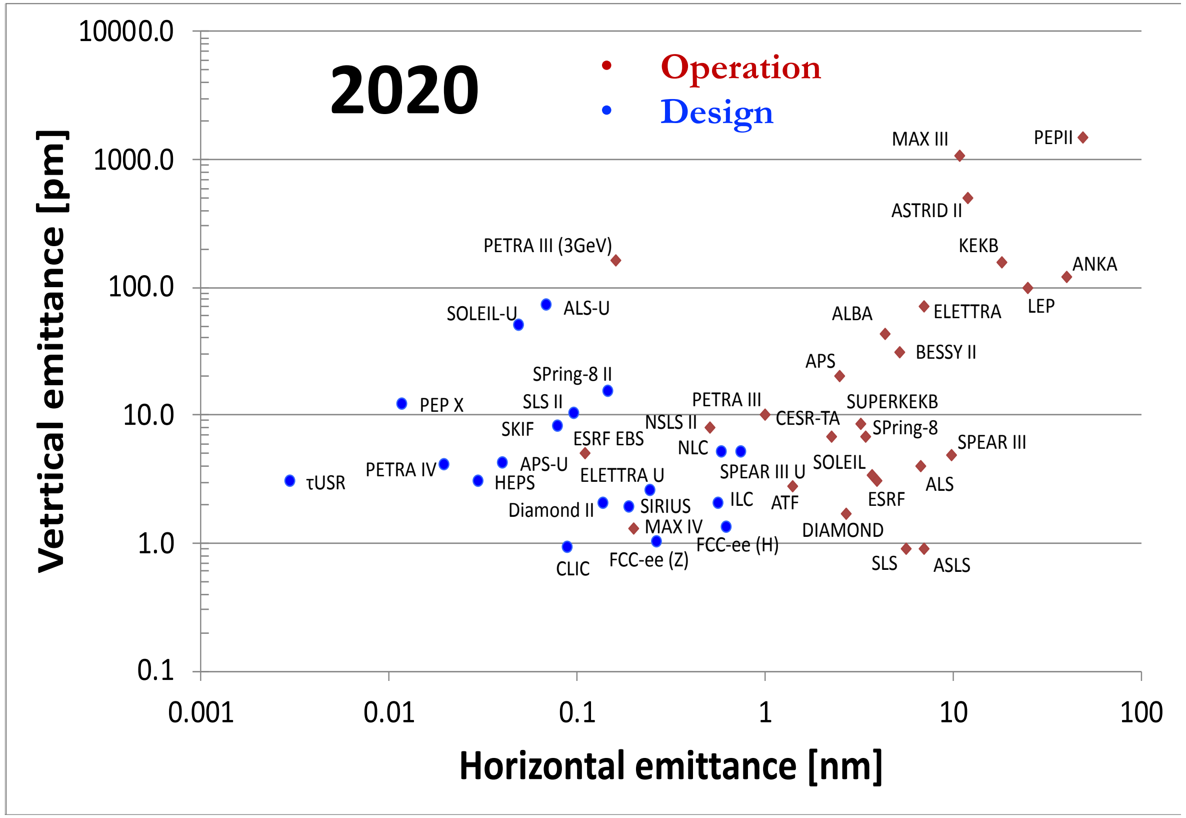

| Imperfection | Value |
|---|---|
| **Ring to Main Linac** | |
| Magnet and BPM offset | 30 µm |
| Magnet and BPM roll | 100 µrad |
| CA and TAL quadrupole strength errors | 0.01% |
| All other magnet strength errors | 0.1% |
| BPM resolution | 1 µm |
| **Main Linac** | |
| Magnet and BPM offset | 14 µm |
| Magnet and BPM roll | 100 µrad |
| Magnet strength error | 0.1% |
| BPM resolution | 0.1 µm |
| Girder end point with respect to reference wire | 12 µm |
| Girder end point with respect to articulation point | 5 µm |
| Cavity offset | 14 µm |
| Cavity tilt | 141 µrad |
| Wakefield monitor offset | 3.5 µm |
| **Beam Delivery System** | |
| Magnet and BPM offset | 10 µm |
| Magnet and BPM roll | 100 µrad |
| Magnet strength errors | 0.01% |
| BPM resolution | 20 nm |




Expected luminosity:

- Target:
  **L = 2.3 x $10^{34}$ cm$^{-2}$s$^{-1}$**
- Average (simulation):
  **L = 3.4 x $10^{34}$ cm$^{-2}$s$^{-1}$**
- 90% has luminosity above:
  **L = 2.7 x $10^{34}$ cm$^{-2}$s$^{-1}$**

# "Beam dynamics tolerances for (Low Emittance) Rings", Y. Papaphilippou

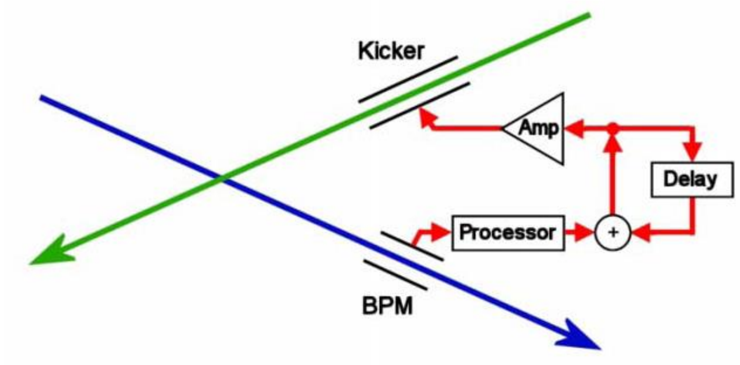


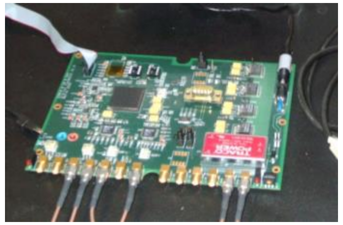

(8) Low emittance rings workshops

- High-bunch brightness in all three dimensions
  - **Intra-beam Scattering** effect reduced by choice of ring energy, lattice design, wiggler technology, alignment tolerances
  - **Electron cloud** in $e^+$ rings mitigated by chamber coatings and efficient photon absorption
  - **Fast Ion Instability** in the $e^-$ rings reduced by low vacuum pressure and train gaps
  - **Space charge vertical tune-shift** limited by energy choice, reduced circumference, bunch length increase
  - Other **collective instabilities** controlled by low –impedance requirements on machine components
- Repetition rate and bunch structure
  - Fast damping times achieved with SC wigglers
  - RF frequency reduction @ 1GHz considered due to many challenges @ 2GHz (power source, high peak and average current, transient beam loading)
- Output emittance stability
  - Tight jitter tolerance driving kicker technology
- Positron beam dimensions from source
  - Pre-damping ring challenges (energy acceptance, dynamic aperture) solved with lattice design

# “Beam Fast Jitter Control and Feedback”, Ph. Burrows

## Feedback On Nanosecond Timescales O(10-100ns)



Low latency ~150 ns

- IP FB and ground motion FF in ATF
- Phase FF in CTF3
- Wake-field effect reduction in ATF
- Simulations for CLIC 3TeV

FONT performance in ATF

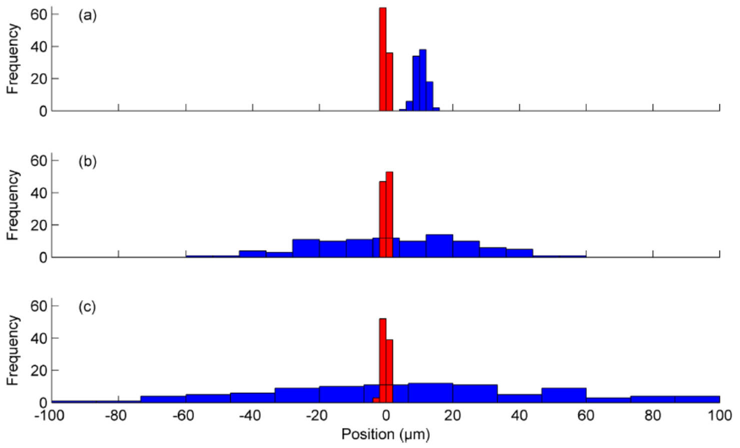
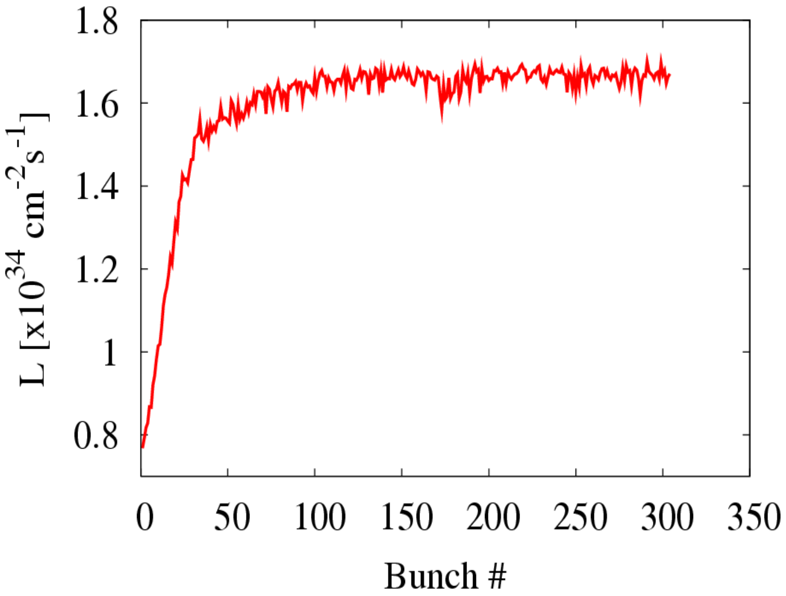
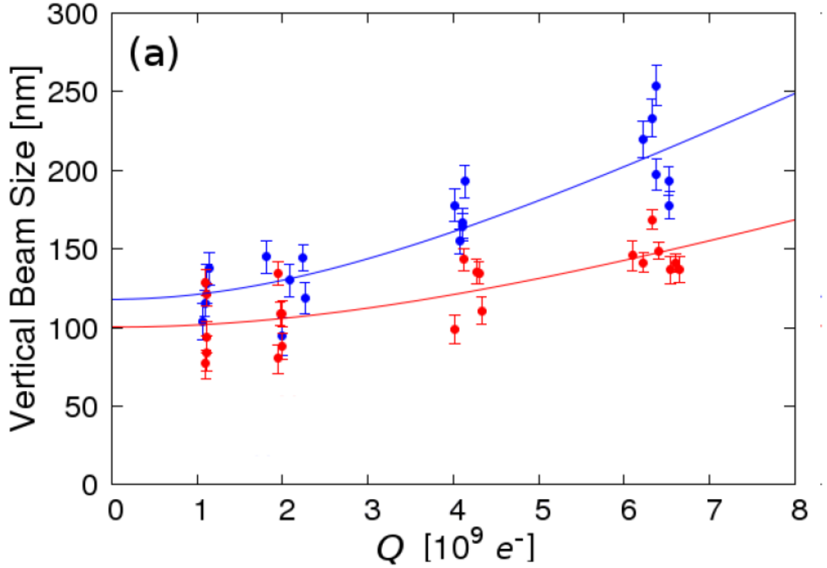



FIG. 19. Distributions of positions with feedback off (blue) and feedback on (red) for bunch 2 at P3 with incoming, uncorrected position jitters of (a) ~2 μm, (b) ~22 μm, and (c) ~45 μm.

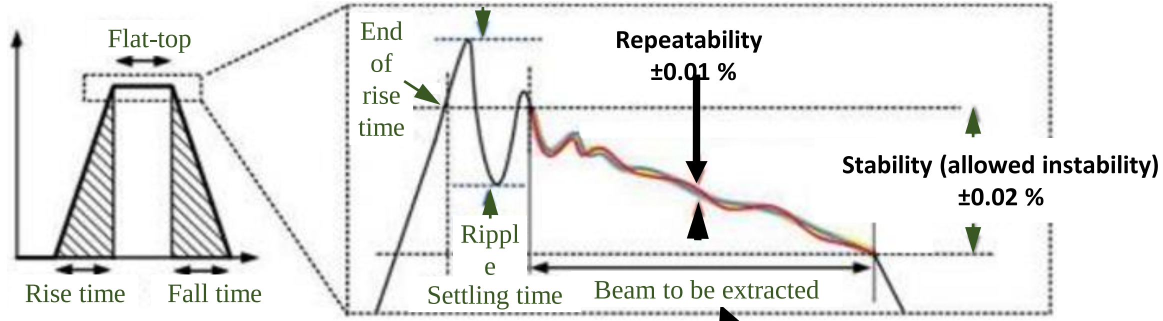
Simulated ILC IP FB performance (500 GeV)




Trajectory control of wakefield effects

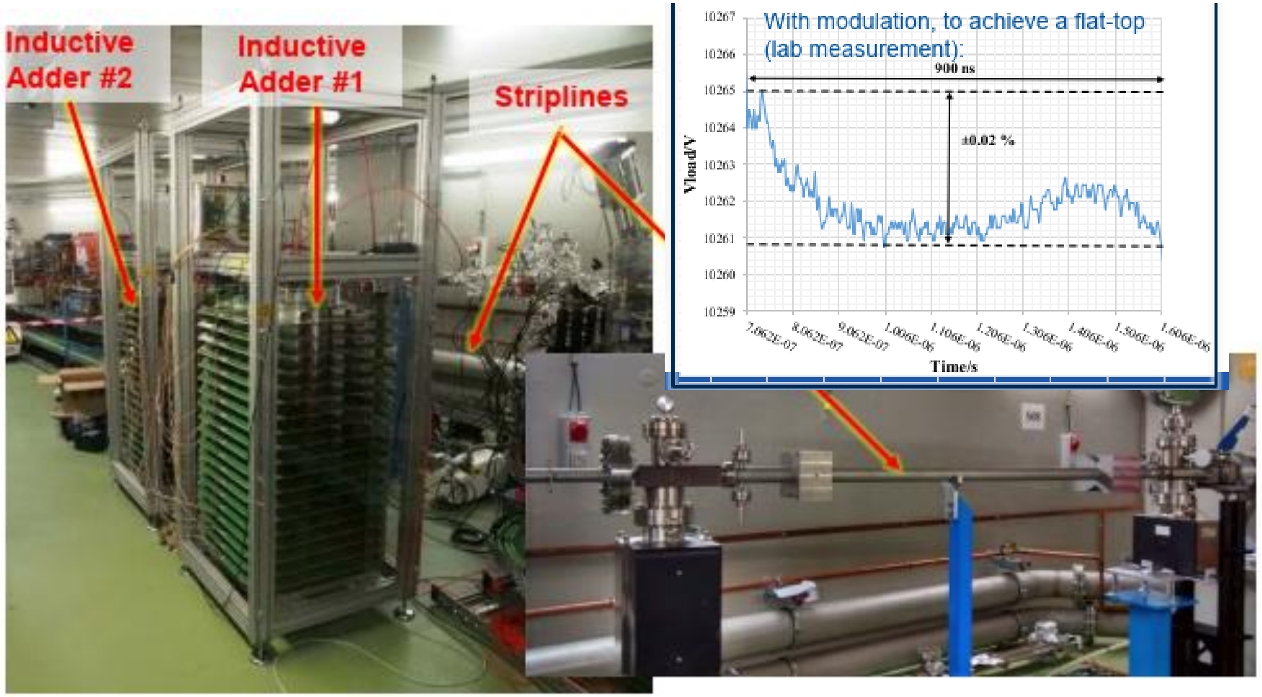


## “Kicker design with tight kick tolerances and Pulser with ultra-fast rise-time”, M. Barnes

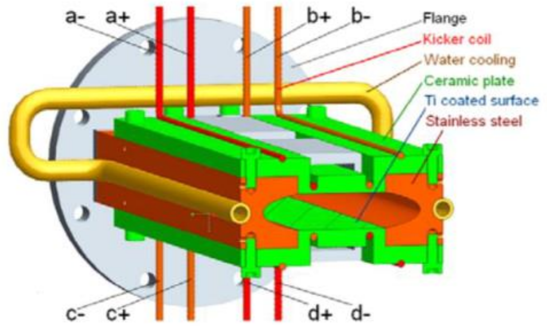


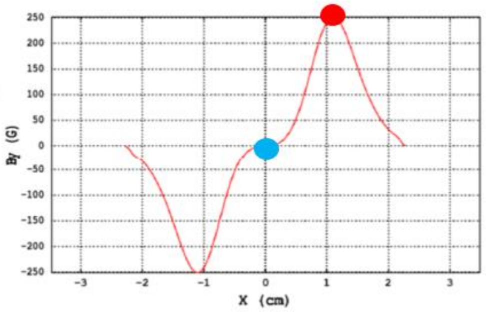

**Rise/Fall time ~100 ns**

**Flat-top duration 160 | 900 ns**




## “Injection/extraction systems and methods for ultra-low emittance rings ”, M. Aiba

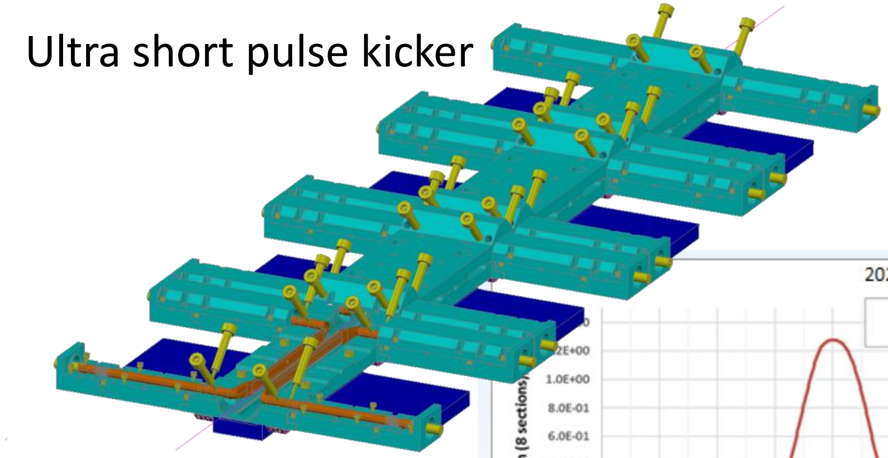


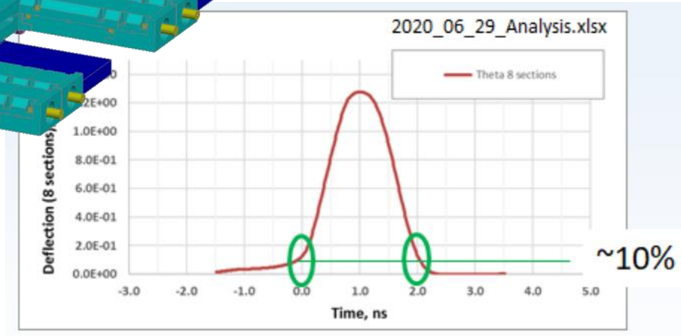




THPO024 Proceedings of IPAC2011, San Sebastián, Spain

**DEVELOPMENT OF A NON-LINEAR KICKER SYSTEM TO FACILITATE A NEW INJECTION SCHEME FOR THE BESSY II STORAGE RING**

Ultra short pulse kicker

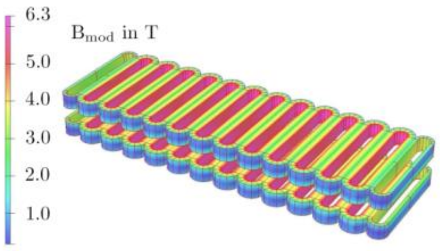





Expected deflection from 8 sections*

## "The HTS undulator and wiggler development", D. Schoerling

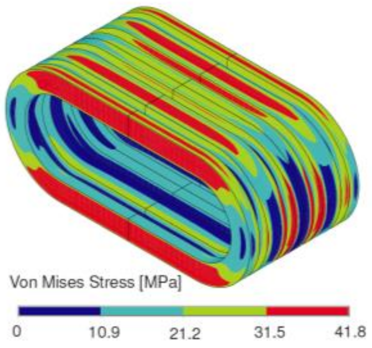
- NbTi Wiggler design ad built. Under operation in ANKA/KARA

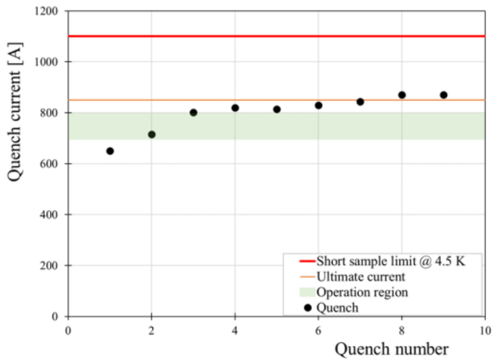


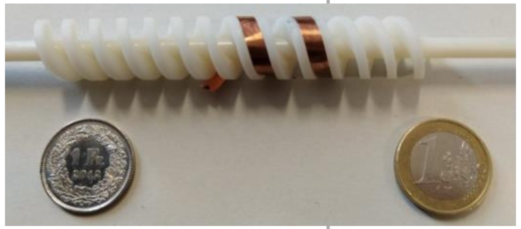


- The presence of non-allowed harmonics, measured with beam, indicates an asymmetry of the wiggler. For a future CLIC damping ring, the manufacturing and assembly tolerances shall be revisited

- Nb3Ti Wiggler prototype, manufactured and tested

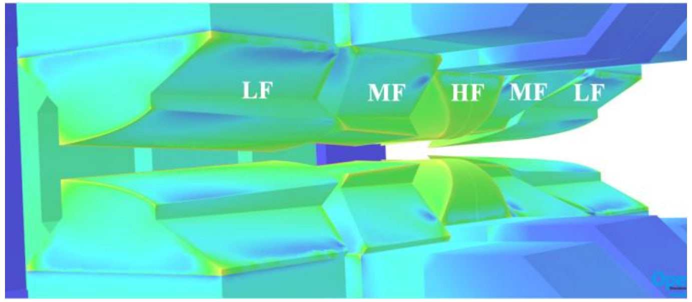


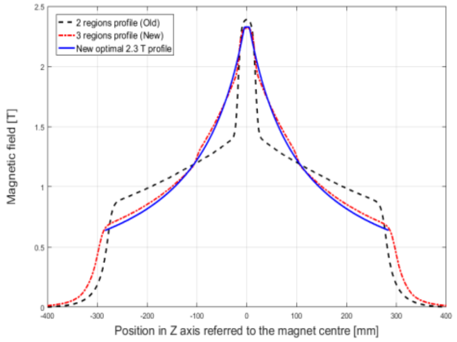



- New ideas, HTS development, helical, planar undulators…

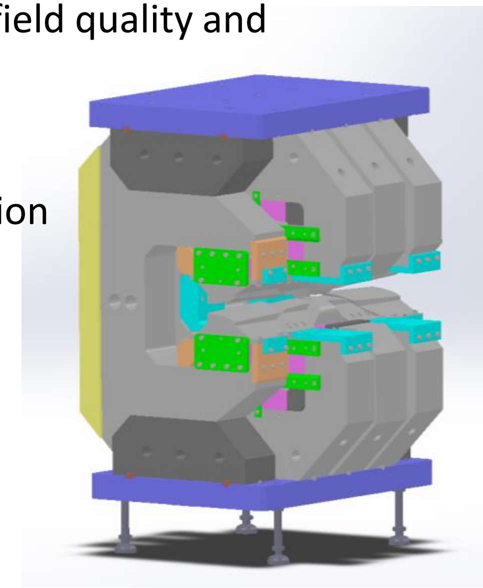
- Combined function magnets: dipolar and quadrupolar field. Hyperbolic pole tip profiles



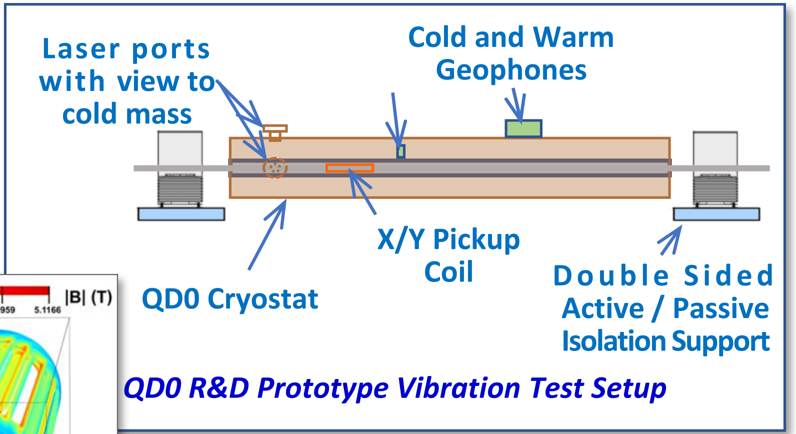

- Multiple backup solutions and adjustments implemented to achieve the desired field quality and specifications
- 98% of the pieces produced
- Remaining 2% already under production

A new version of these magnets will be used in the Elettra new upgrade!

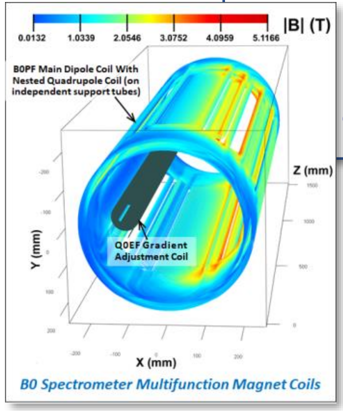


## "Development of a high-field longitudinal gradient dipole at CIEMAT", M. Dominguez

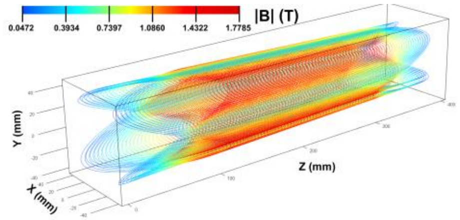
## "Developments in Superconducting Final Focus Technology", B. Parker

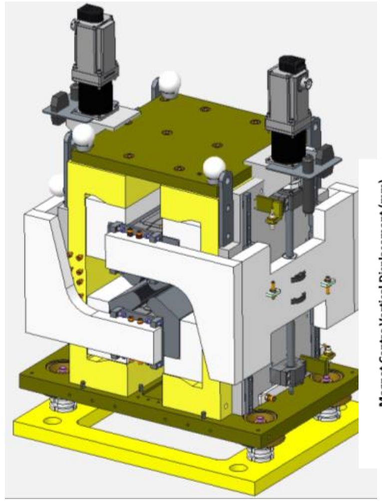

*QD0 R&D Prototype Vibration Test Setup*

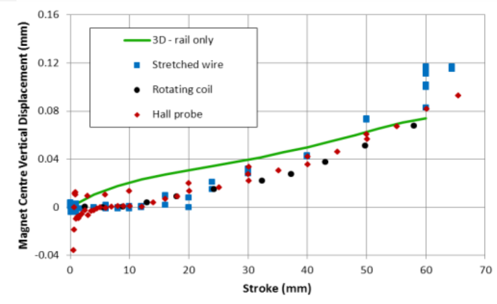


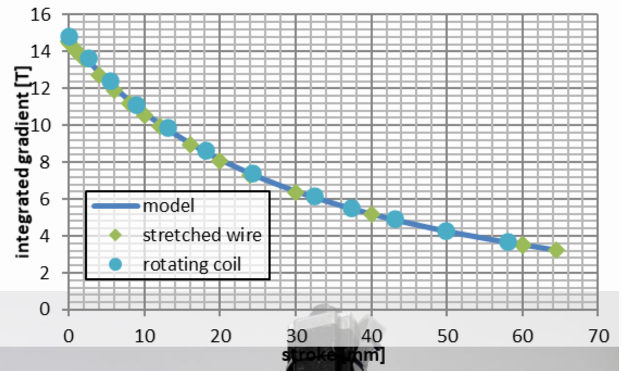

*B0 Spectrometer Multifunction Magnet Coils*

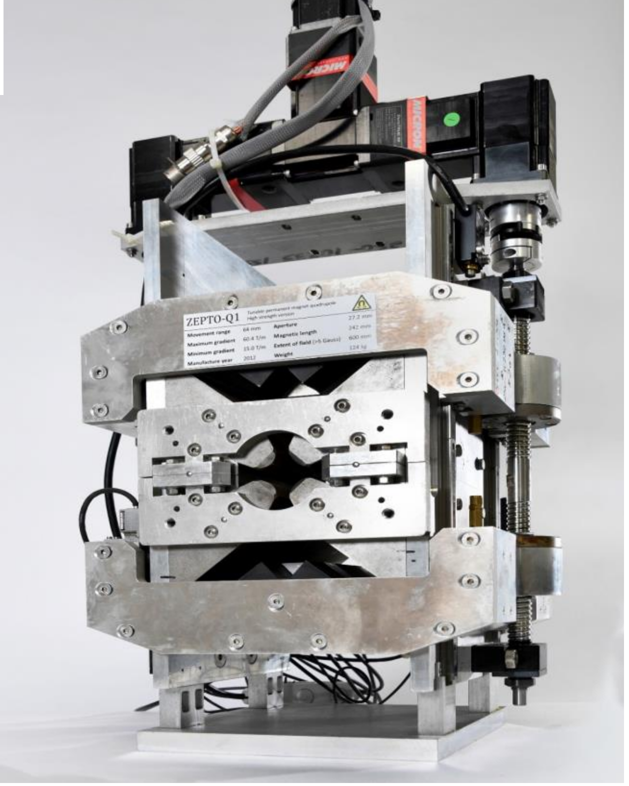



## "Adjustable permanent magnets", B. Shepherd

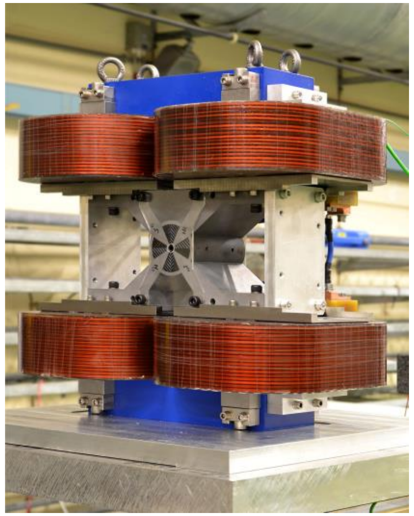


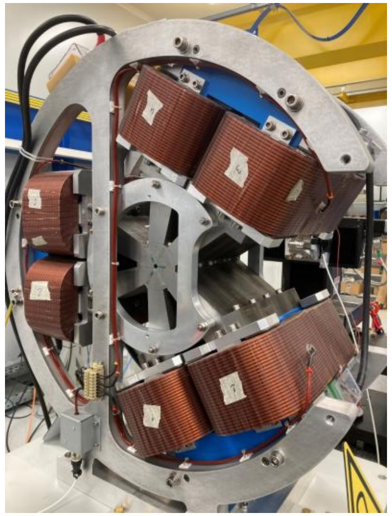


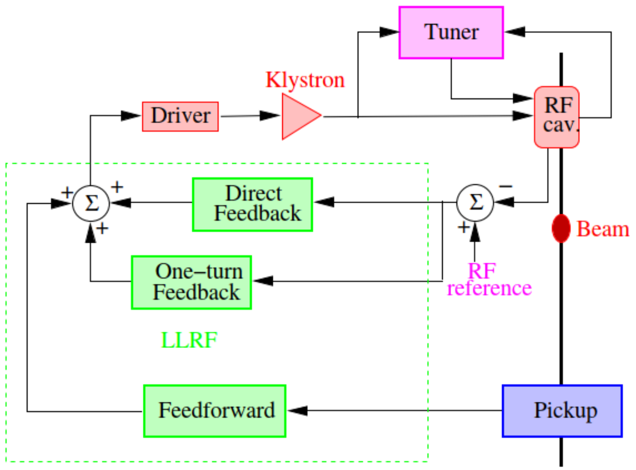



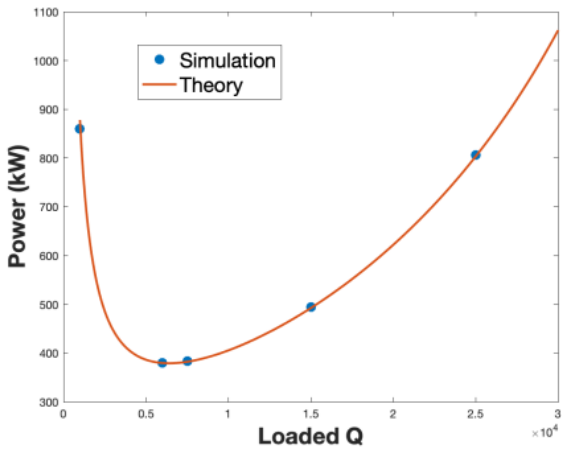

## "Special magnets", M. Modena





“Beam specifications impact on RF and LLRF design
The CLIC Damping Rings LLRF”,
T. Mastoridis

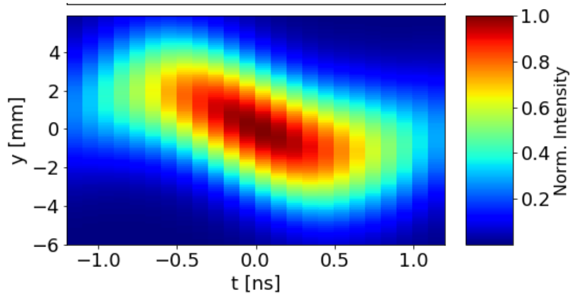


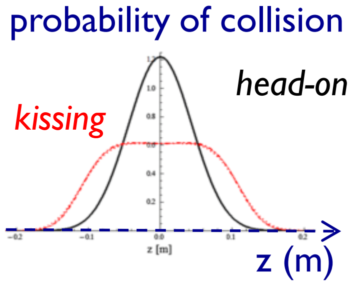



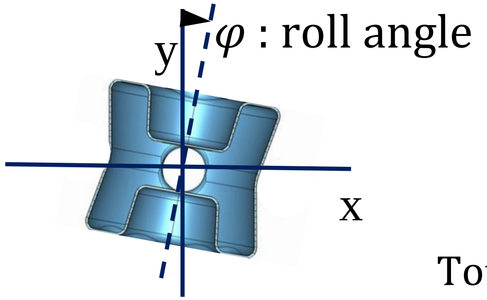

- The system performance will greatly depend on the klystron frequency response and to a lesser extent on the measurement noise from the beam pickup and on the accurate and precise feedforward gain setting.

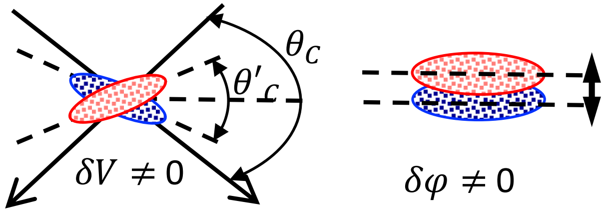
- The peak power requirements are strongly related to the instantaneous beam power, which is rather demanding and dominates the size and cost of the Damping Rings RF system.

“Power RF systems for low emittance rings“, E. Jensen



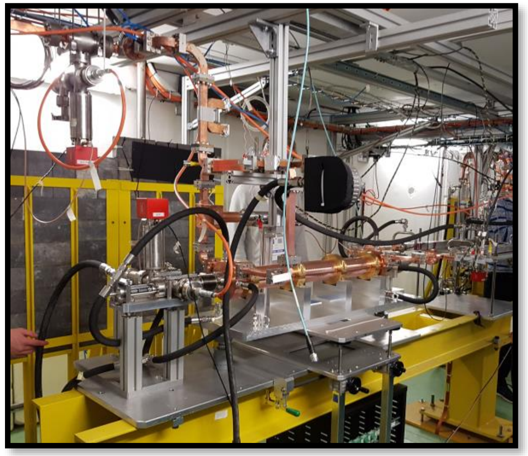

$$\text{Total } V_{cc} = \frac{c\boldsymbol{E_s}\tan(\boldsymbol{\theta_c}/2)}{q\boldsymbol{\omega_{RF}}\sqrt{\boldsymbol{\beta^*\beta_{cc}}}\sin(\mu)}$$

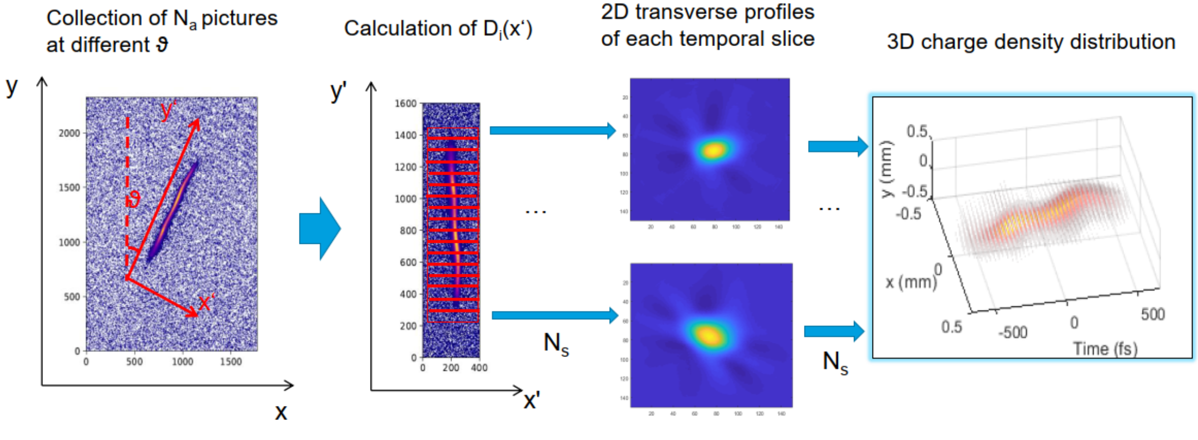
- Crab crossing with **NANOBEAMS** in colliders requires careful study of:
  - Implications on required kick voltage (via $\beta$), frequency choice
  - HOM power, impedances (esp. short bunches)
  - Effects of detector solenoid
  - Demanding installation tolerances, RF noise control
  - Consider crab kissing, crab waist scheme

“Crab cavities for colliders.” S. Verdú-Andrés

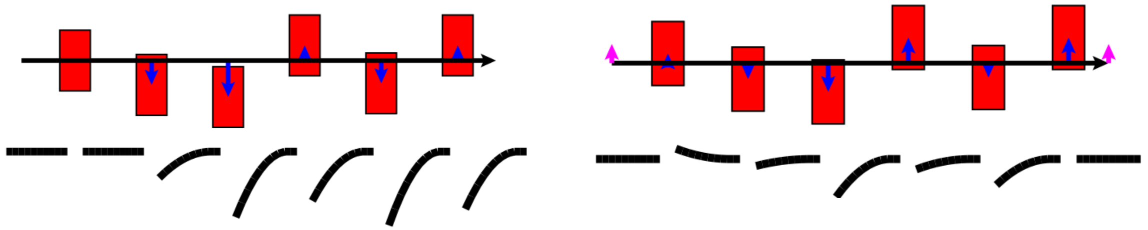
## “X-band transverse deflection structure with variable polarisation“, B. Marchetti

Collaboration between PSI, CERN and DESY on X-band technology



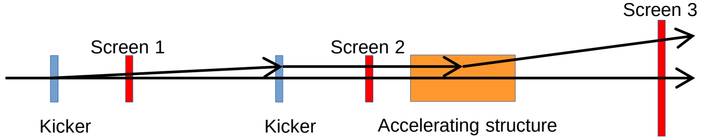


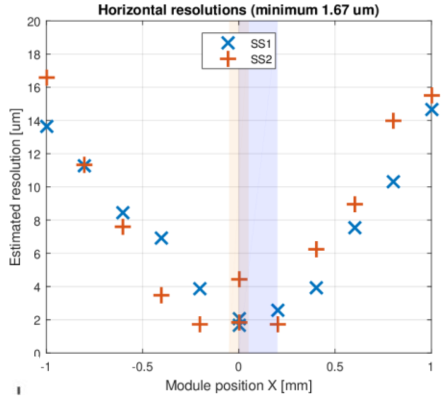

## “Wakefield Monitors and Wakefield Mitigation“, K. Sjobak

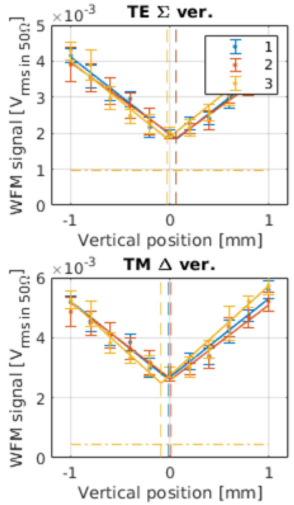


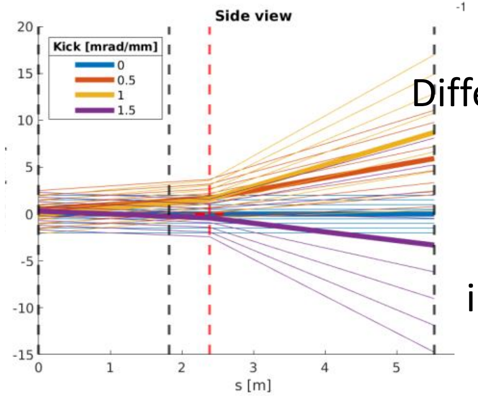
- Alignment of RF structures according to WFM measurements
- For CLIC luminosity target: Need <u>accuracy better than 3.5 μm</u>

Resolution of the WFM at micron level



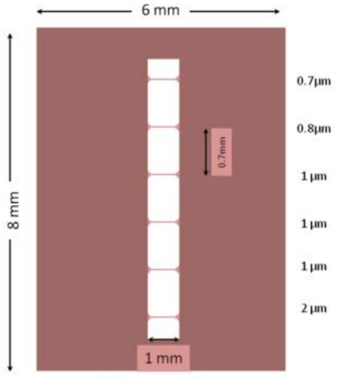




Different center location In TM and TE mode

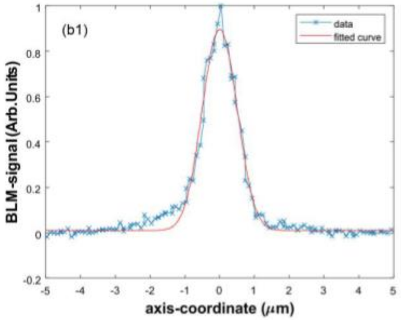
Look simultaneously into position and kick

# "Overview of profile measurements for nanobeams ", T. Lefevre

sub-micrometer resolution wire scanner




gold nanowires

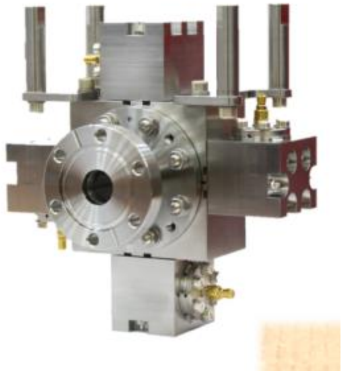



G. L. Orlandi et *al.*, *PRAB* ***23*** *(2020) 042802*

# "High resolution cavity BPMs: From prototype to production", A. Lyapin

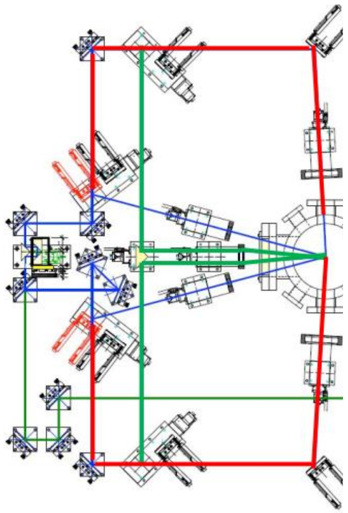
- X-band LCLS-1 (36)
- 200nm precision

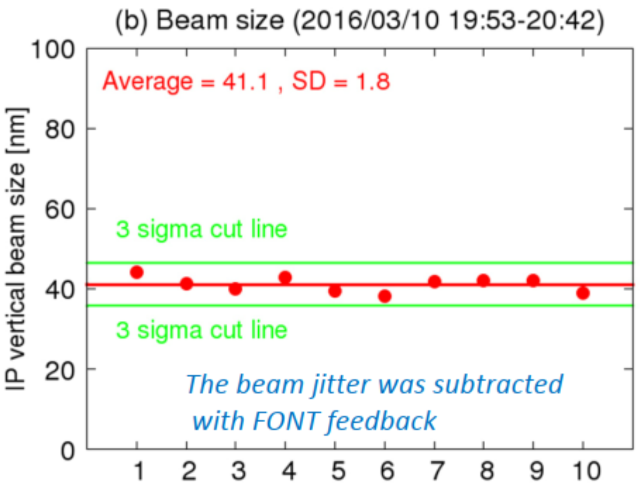
- C-band commercial
- RHUL- FMB Oxford
- Digital electronics

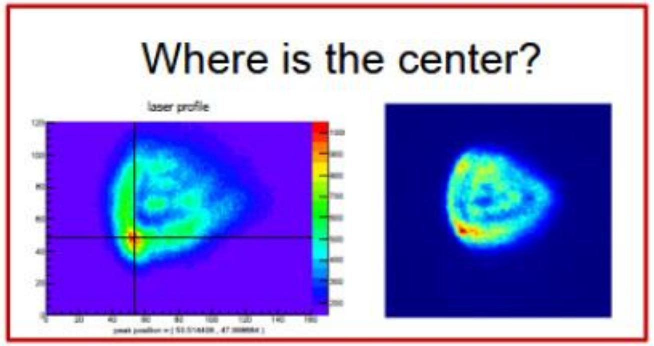


TOMSK POLYTECHNIC UNIVERSITY

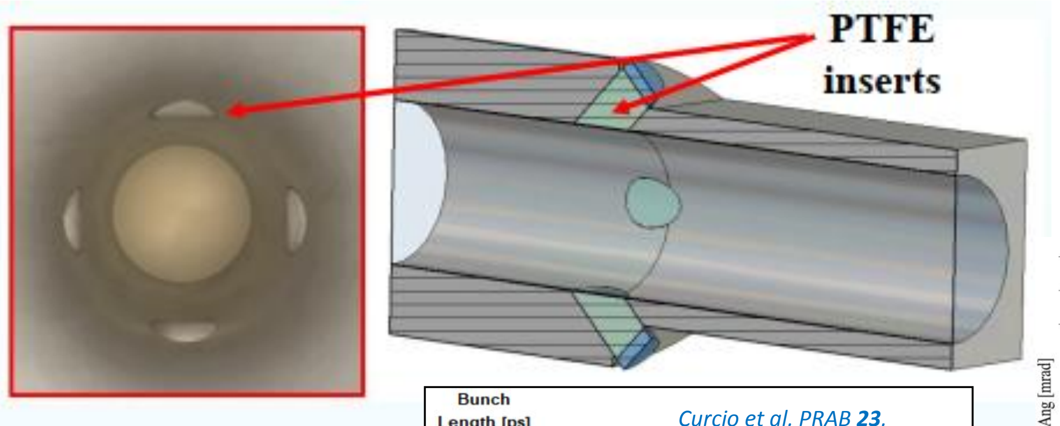
# "Measuring nanometer beam size at final focus", T. Okugi



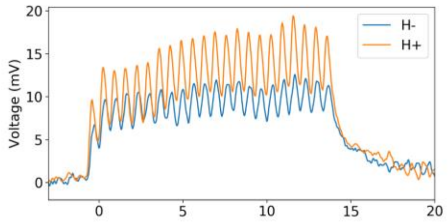


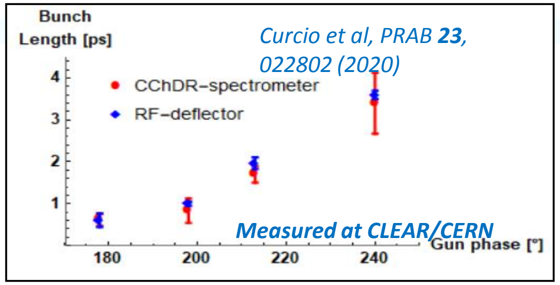



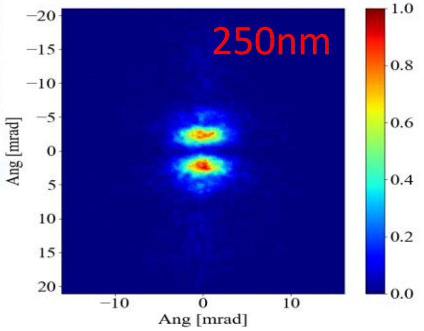

Compton scattering with a 532nm
Considering an upgrade for ATF3
New laser and new crossing angle

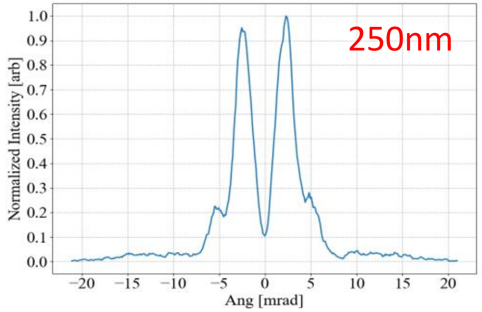


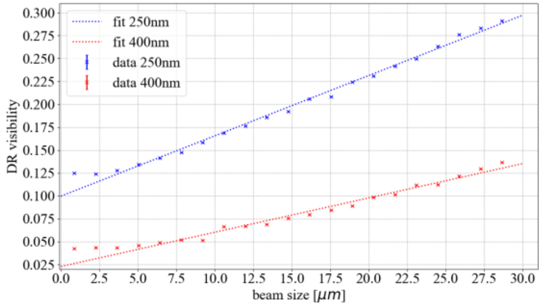

"Non-invasive beam measurement using polarization radiation", P. Karataev



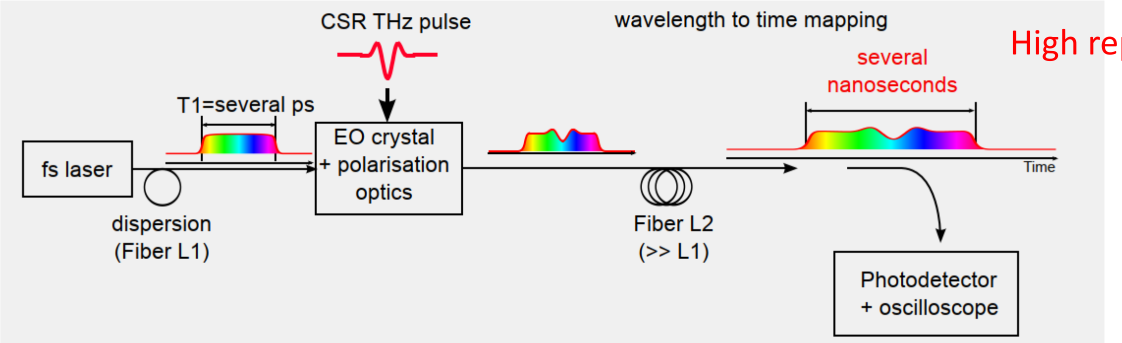



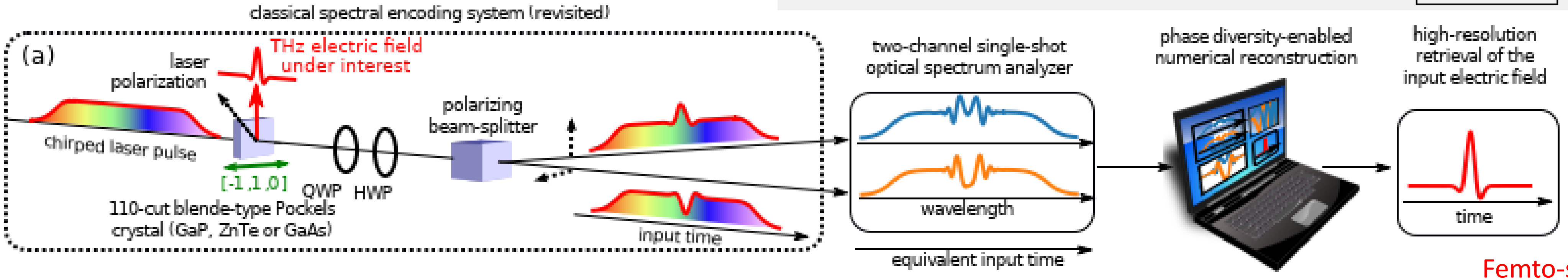




"Measuring femtosecond bunches using electro-optical techniques", S . Bielawski

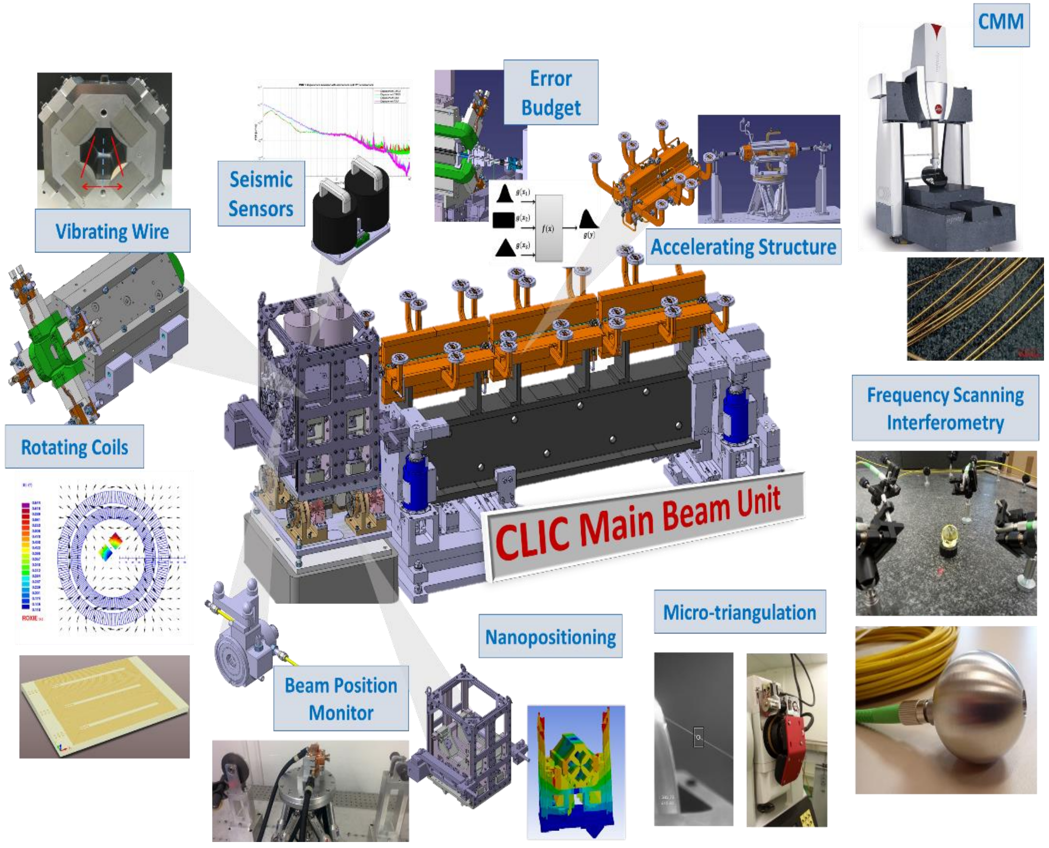


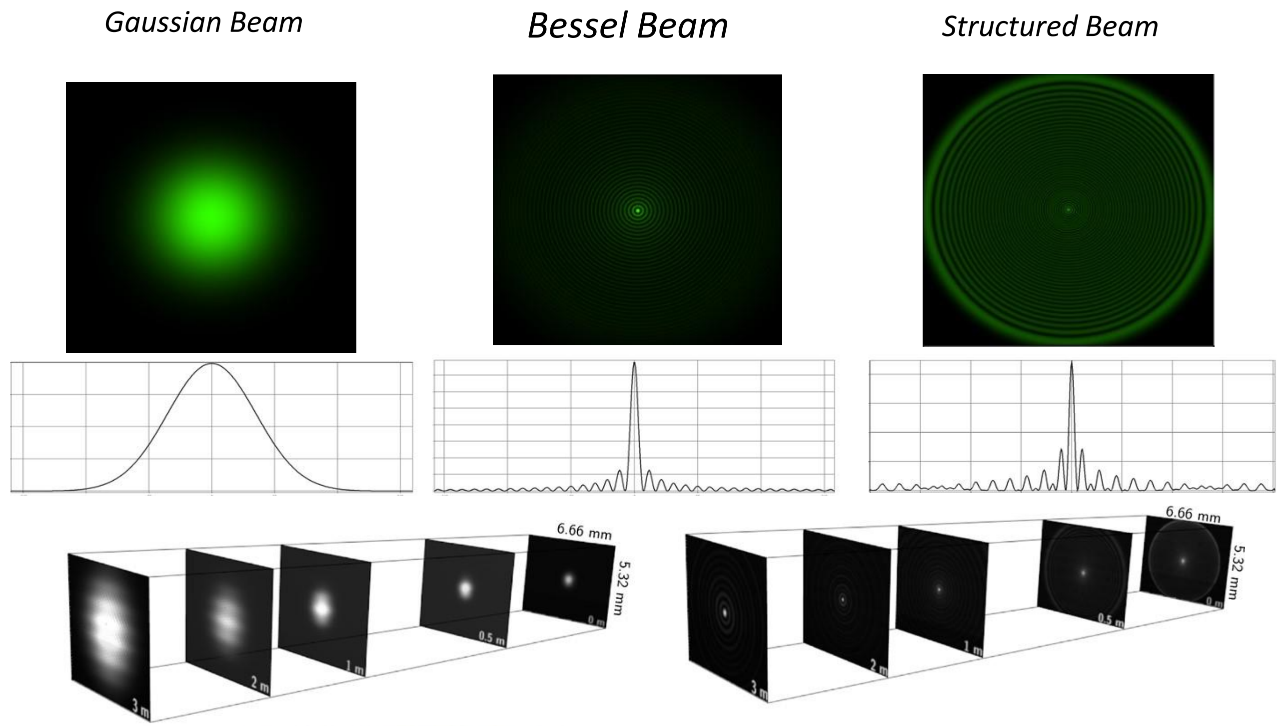

High repetition rate

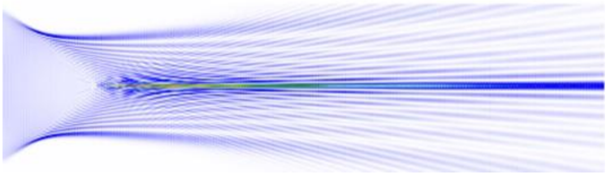



Femto-second resolution

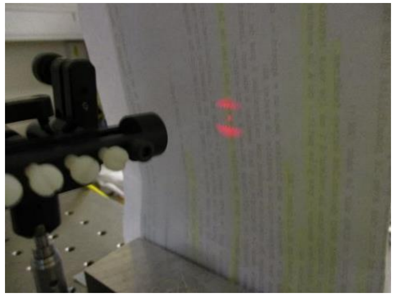
# "Structured Laser Beam… towards an alignment system", J-C. Gayde

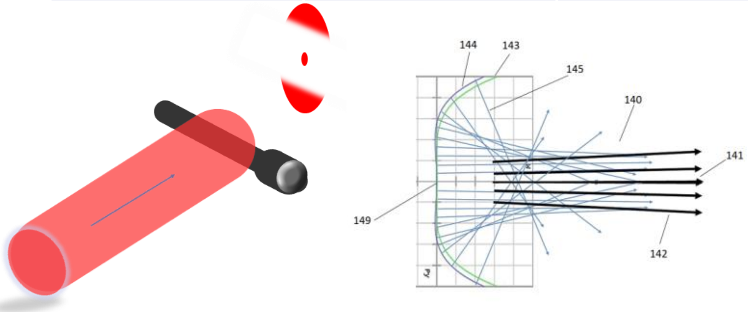


| Beam diameter | 3 m distance | 100 m distance |
|---|---|---|
| Gaussian Beam | 0.8 mm | 240 mm |
| Structured Beam | 0.01 mm | 1.4 mm |

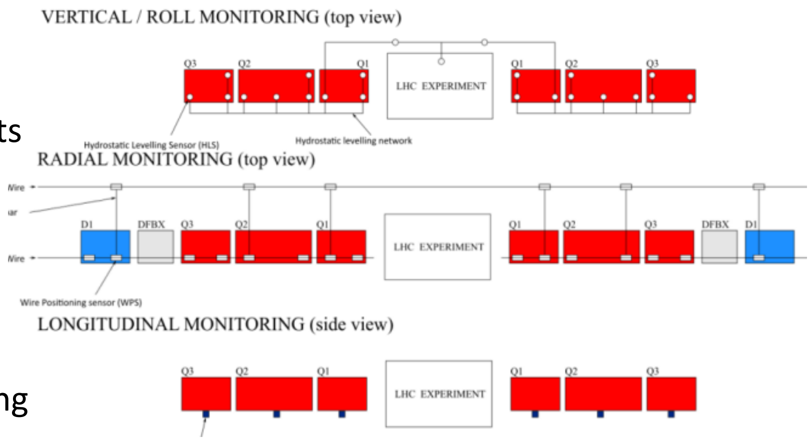





"The PACMAN project results",
H. Mainaud-Durand.

## “Machine detector interface alignment techniques for nanobeams machines“, L. Watrelot

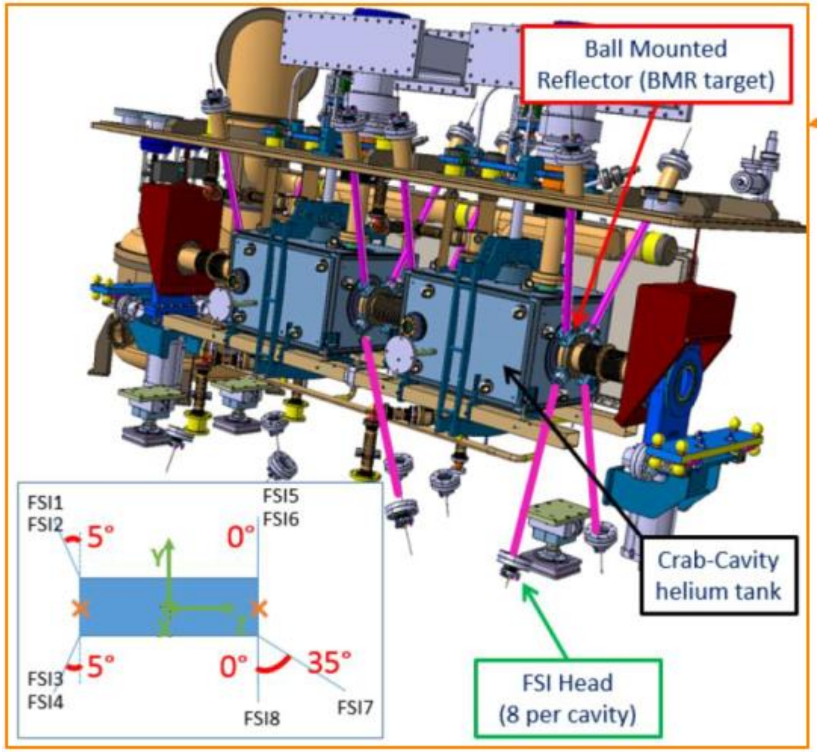
MDI alignment systems involving:
- Hydrostatic levelling systems
- Wire positioning sensors
- Distance offset measurements
- Remote CAM movers

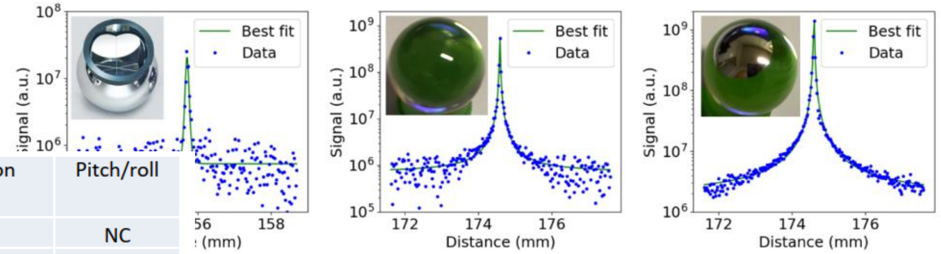



HL-LHC:
- External and internal monitoring
- Using FSI
- Inclinometers
- Improved network

<u>However, no solution for LC or FCC-ee</u>

## “Development of low-cost alignment systems“, M. Sosin



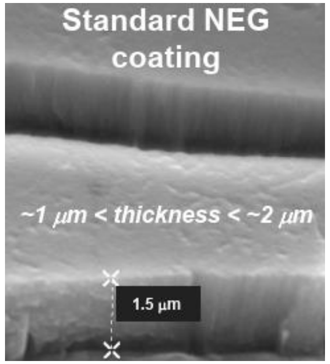

## “Girder Stability“, G. Balik

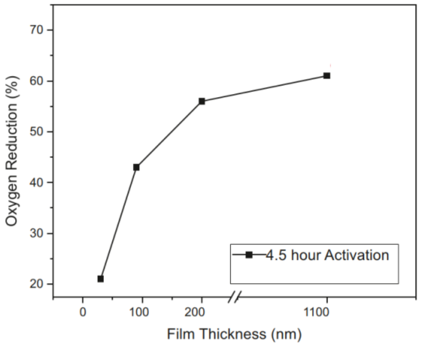
| | Technology | | | | | | | Positioning type | | Range | Resolution | Pitch/roll |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nano system | Jacks | Cam mover | HLS | HPS | LVDT | WPS | Girder | Magnet | | | |
| ESRF | ☐ | ☑ | ☐ | ☑ | ☐ | ☐ | ☐ | ☑ | ☐ | 5 mm | 5 µm | NC |
| SLS | ☐ | ☐ | ☑ | ☑ | ☑ | ☐ | ☐ | ☑ | ☐ | 2,5 mm | 2 µm | NC |
| ATF2 | ☐ | ☐ | ☑ | ☐ | ☐ | ☑ | ☐ | ☐ | ☑ | 1,5 mm | 2 µm | 3-5 µrad |
| CLIC | ☑ | ☐ | ☑ | ☐ | ☐ | ☐ | ☑ | ☐ | ☑ | 10mm/10 µm * | 0,5 µm/0,45 nm* | 1,3 µrad |
| FCC-ee | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ??? | ??? | ??? |

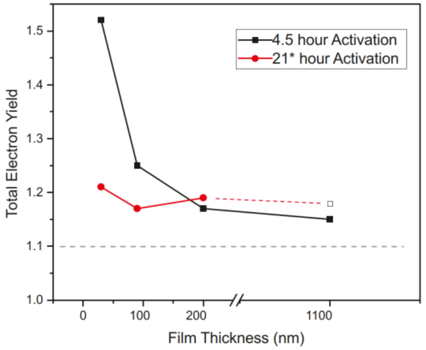
* Static/dynamic

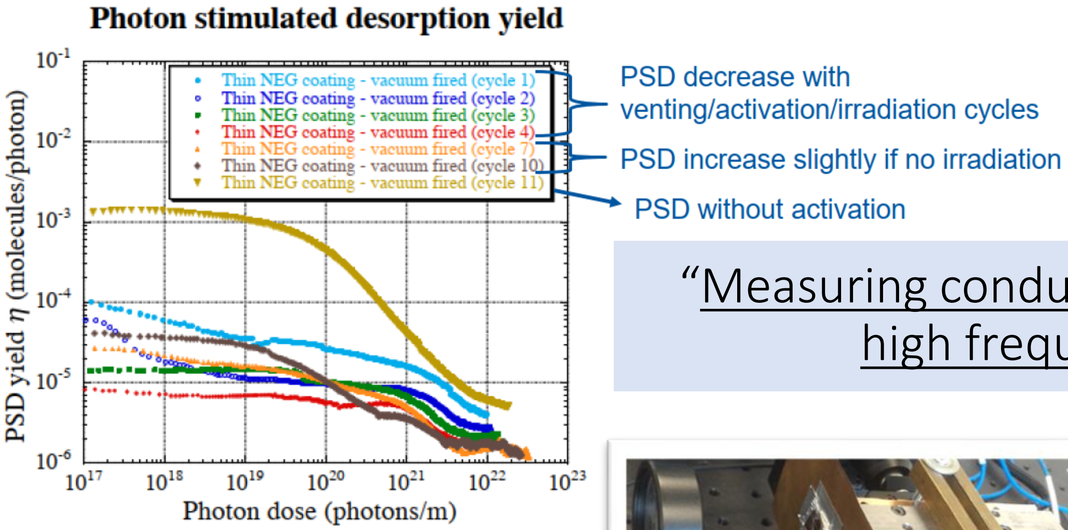
# “Very thin Non-Evaporable Getter coatings for particle accelerators“, P. Costa-Pinto

How thin can it be and still withstand 4 venting / activation cycles?

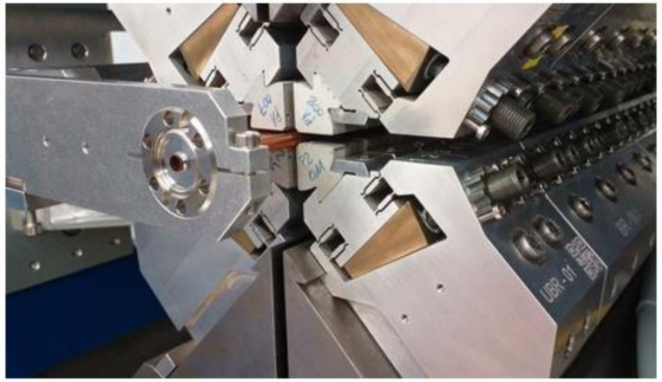


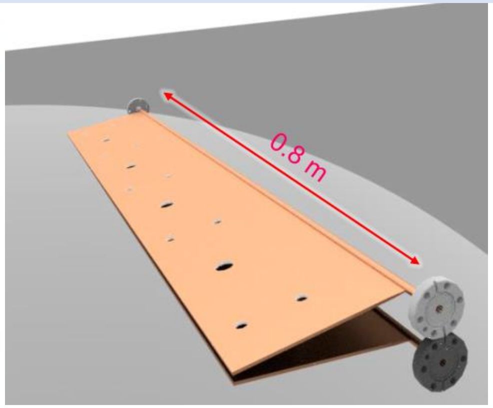



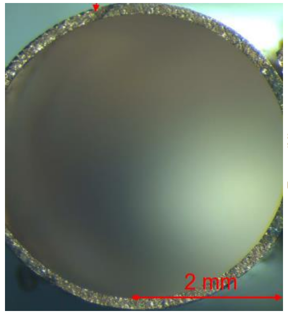



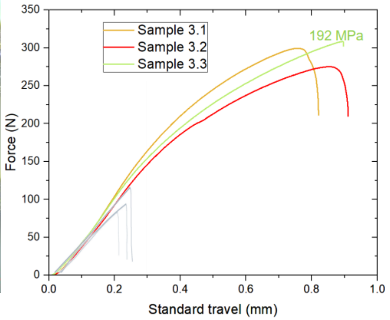

# “Development of thin-walled copper electroformed vacuum chambers for undulators“, L. Lain Amador

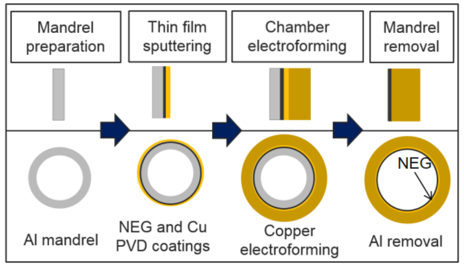


UE38 Undulator[1]

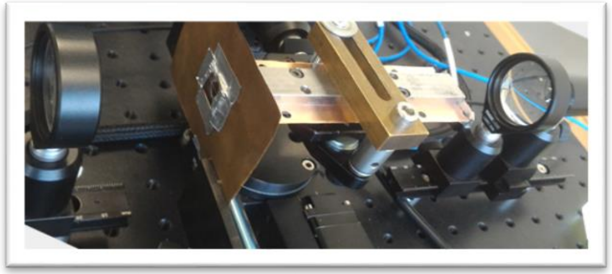


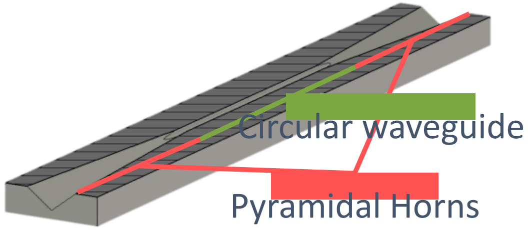



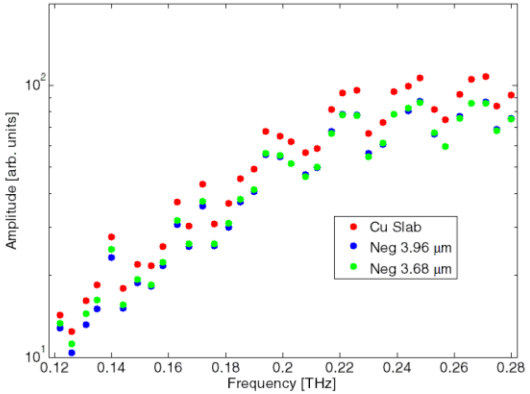




# “Measuring conductivity of coated surfaces at high frequency“, A. Passarelli

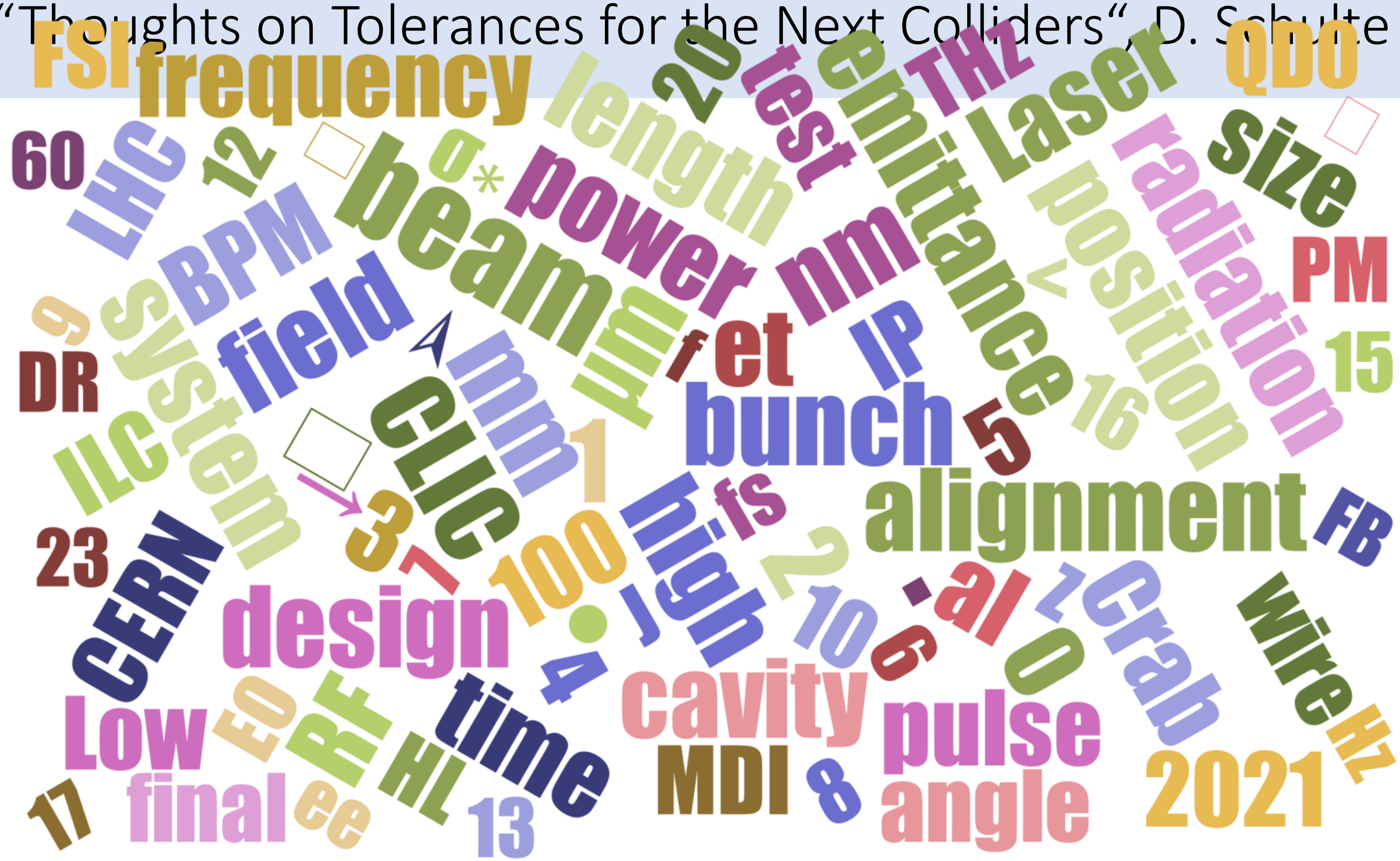




“Thoughts on Tolerances for the Next Colliders“, D. Schulte

“Thoughts on Tolerances for the Next Colliders“, D. Schulte




Thank you all!!