

# Highlights from CAS, Slangerup 2019

CERN Accelerator School course in Advanced Accelerator Physics

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PITZ Physics Seminar  
Zeuthen, 27.06.2019



# Quick facts

- Course in Advanced Accelerator Physics
  - Once every two years
  - General and broad set of topics
  - Different location (CERN member state)
  - About two weeks duration
    - 50% lectures, 50% hands-on exercise
    - 2 seminars, movie night, **excursion**
- This year
  - Metalskolen (Slangerup, Denmark)
- Other courses
  - Introduction to Accelerator Physics – every year
  - Specialized topics: RF, beam dynamics, DAQ, DSP...



# Lecture topics

## Week 1

- Introduction to: RF, Beam instrumentation, Optics
- Optics, Lattice cells, Insertion and dispersion suppression
- Longitudinal beam dynamics
- Space charge
- Beam loading, RF feedback
- Wakefields and impedances, WFA
- Beam instabilities, Electron cloud effects
- Low emittance lattices
- Timing and synchronization

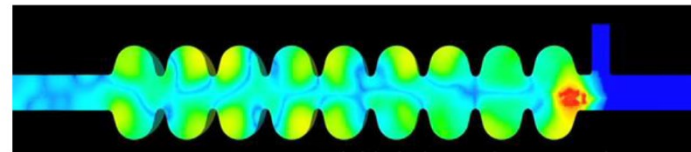
### Example: 400 MHz cavities in LHC

- Reduce beam loading in RF cavities
- Shunt impedance,  $R$ , low for small R/Q with normal conducting cavities → superconducting cavities in LHC

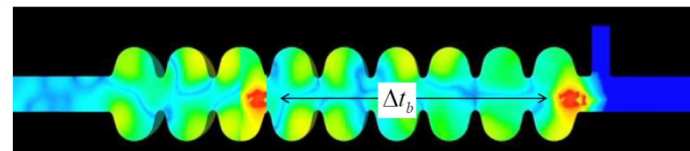


Bell shape:  $R/Q \sim 44 \Omega$ , 400 MHz

Short Range Wake Fields Effects → head tail effects

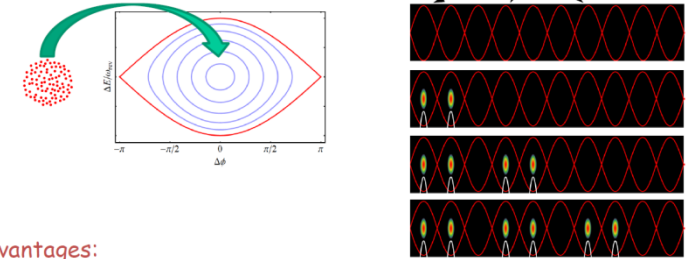


Long Range Wake Fields Effects → multibunch instabilities



### Bunch-to-bucket transfer

- Bunch from sending accelerator into the bucket of receiving

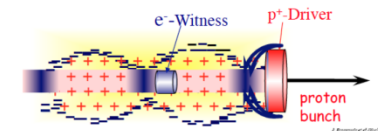


#### Advantages:

- Particles always subject to longitudinal focusing
- No need for RF capture of de-bunched beam in receiving accelerator
- No particles at unstable fixed point
- Time structure of beam preserved during transfer



### WHY p<sup>+</sup>-DRIVEN PWFA?



- ◇ ILC, 0.5TeV bunch with  $2 \times 10^{10} e^-$  ~1.6kJ
- ◇ SLAC, 20GeV bunch with  $2 \times 10^{10} e^-$  ~60J
- ◇ SLAC-like driver for staging (FACET= 1 stage, collider 10<sup>+</sup> stages)
- ◇ SPS, 400GeV bunch with  $10^{11} p^+$  ~6.4kJ
- ◇ LHC, 7TeV bunch with  $10^{11} p^+$  ~112kJ
- ◇ A single SPS or LHC bunch could produce an ILC bunch in a single PWFA stage!
- ◇ Large average gradient! ( $\geq 1 \text{ GeV/m}$ , 100's m)

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P. Muggli, 06/04/2013, EAC 2103



# Lecture topics

## Week 2

- Beam cooling, Stochastic cooling, Landau damping
- Polarisation (spin), Beam-beam effects
- Non-linear dynamics, Truncated power series algebra
- High brightness and longitudinal beam diagnostics

### X-ray pinhole cameras

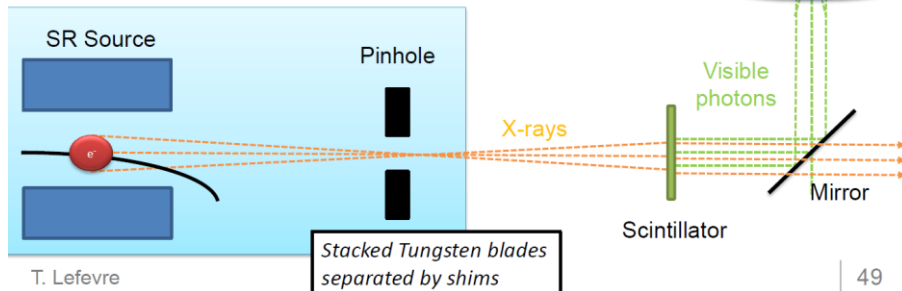
**Point Spread Function** (Gaussian approx.)  
contribution to beam size measurement :

$$\sigma_{PSF}^2 = \sigma_{Pinhole}^2 + \sigma_{Camera}^2 > 0$$

where

$$\sigma_{Pinhole}^2 = \sigma_{Diffraction}^2 + \sigma_{Aperture}^2$$

$$\sigma_{Camera}^2 = \sigma_{Screen}^2 + \sigma_{Lens}^2 + \sigma_{Sensor}^2$$



T. Lefevre

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### Differential Algebra

■ The basic idea is the **automatic differentiation** of results produced by a tracking code to provide the **coefficients** of a Taylor series

■ Consider a pair of real numbers  $(q_0, q_1)$  and define **operations** on a pair like

$$(q_0, q_1) + (r_0, r_1) = (q_0 + r_0, q_1 + r_1)$$

$$c \cdot (q_0, q_1) = (c \cdot q_0, c \cdot q_1)$$

$$(q_0, q_1) \cdot (r_0, r_1) = (q_0 \cdot r_0, q_0 \cdot r_1 + q_1 \cdot r_0)$$

and some ordering

$$(q_0, q_1) < (r_0, r_1) \text{ if } q_0 < r_0 \text{ or } (q_0 = r_0 \text{ and } q_1 < r_1)$$

$$(q_0, q_1) > (r_0, r_1) \text{ if } q_0 > r_0 \text{ or } (q_0 = r_0 \text{ and } q_1 > r_1)$$

implying strange relations of the form

$$(0, 0) < (0, 1) < (r, 0), \quad \forall r > 0$$

$$(0, 1) \cdot (0, 1) = (0, 0) \rightarrow (0, 1) = \sqrt{(0, 0)}$$

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### EXAMPLE: a thick quadrupole I

One can derive the transfer matrix of a thick quadrupole of length  $L$  by and normalized gradient  $K_1$  by considering the following limit

$$\lim_n \left[ \begin{pmatrix} 1 & 0 \\ -\frac{K_1 L}{n} & 1 \end{pmatrix} \begin{pmatrix} 1 & \frac{L}{n} \\ 0 & 1 \end{pmatrix} \right]^n = \begin{pmatrix} \cos(\sqrt{K_1 L}) & \frac{\sin(\sqrt{K_1 L})}{\sqrt{K_1}} \\ -\sqrt{K_1} \sin(\sqrt{K_1 L}) & \cos(\sqrt{K_1 L}) \end{pmatrix}$$

Therefore we now have a correspondence between elements along our machine (drift, bending, quadrupoles, solenoids, ...) and symplectic matrices.

G. Sterbini Introduction to Optics Design

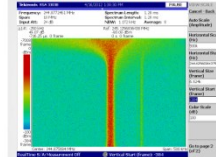
### Comparison of Longitudinal Cooling Methods

Ar<sup>18+</sup> 400 MeV/u

longitudinal momentum distribution versus time

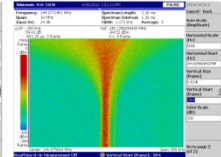
measured at the ESR heavy ion storage ring Schottky signal observed at 245 MHz (h=124)

Palmer cooling



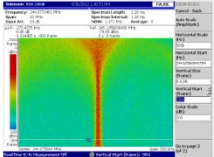
large momentum capture range  
fast cooling  
good final momentum spread  
drawback: horizontal heating needs to be compensated by horizontal cooling

Time-of-Flight cooling



large momentum capture range  
slower cooling  
moderate final momentum spread  
simple set-up  
no special lattice requirement

Notch filter cooling



reduced momentum capture range  
good cooling rate  
smallest final momentum spread  
most elaborate rf hardware  
issue of notch filter stability

### Example: Single Sextupole

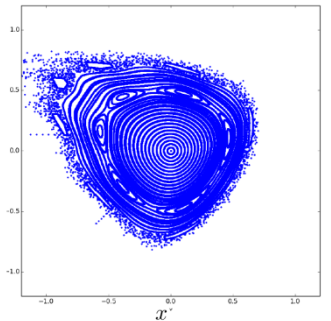
■ Appearance of 3<sup>rd</sup> order resonance for certain phase advance

■ ... but also 4<sup>th</sup> order resonance

■ ... and 5<sup>th</sup> order resonance

■ ... and 6<sup>th</sup> order and 7<sup>th</sup> order and several higher orders...

$$\mu_x = 0.18$$

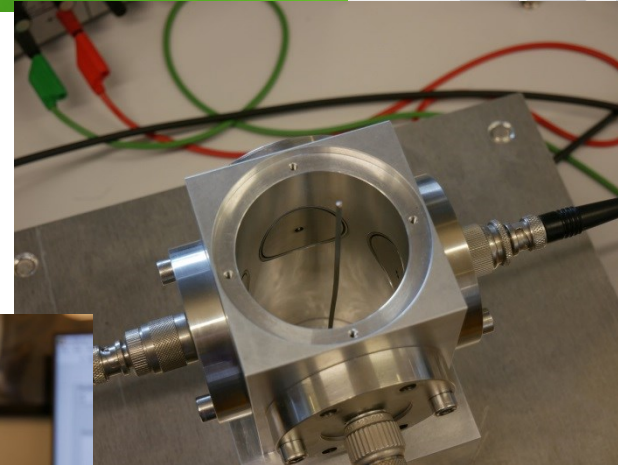
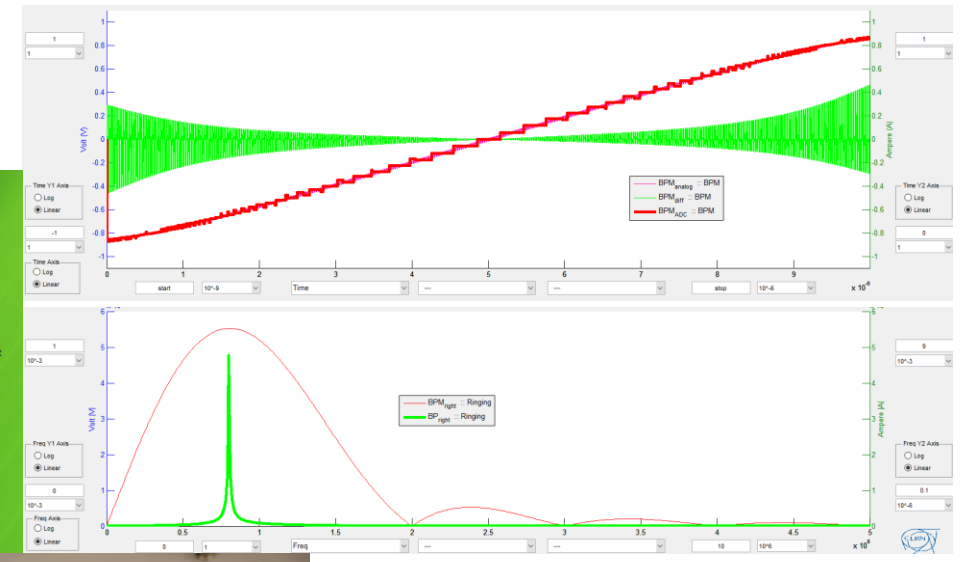
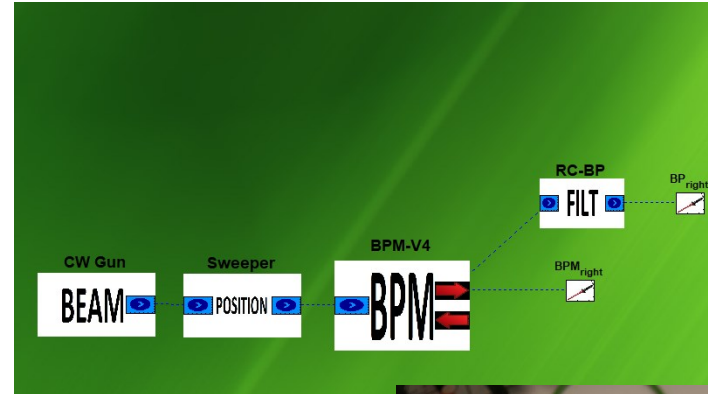


techniques, CERN Accelerator School, June 2019

# Afternoon exercises

## Beam instrumentation and diagnostics

- Design of a BPM electronics
  - Drag and drop style
  - LTspice
- BPM laboratory exercises
  - Button BPM
  - RF BPM
- Beam size and emittance measurements
  - Laser beam
  - Pinhole, scraper, pepper-pot, quad scan, multiple screens
  - Electro-optic modulator

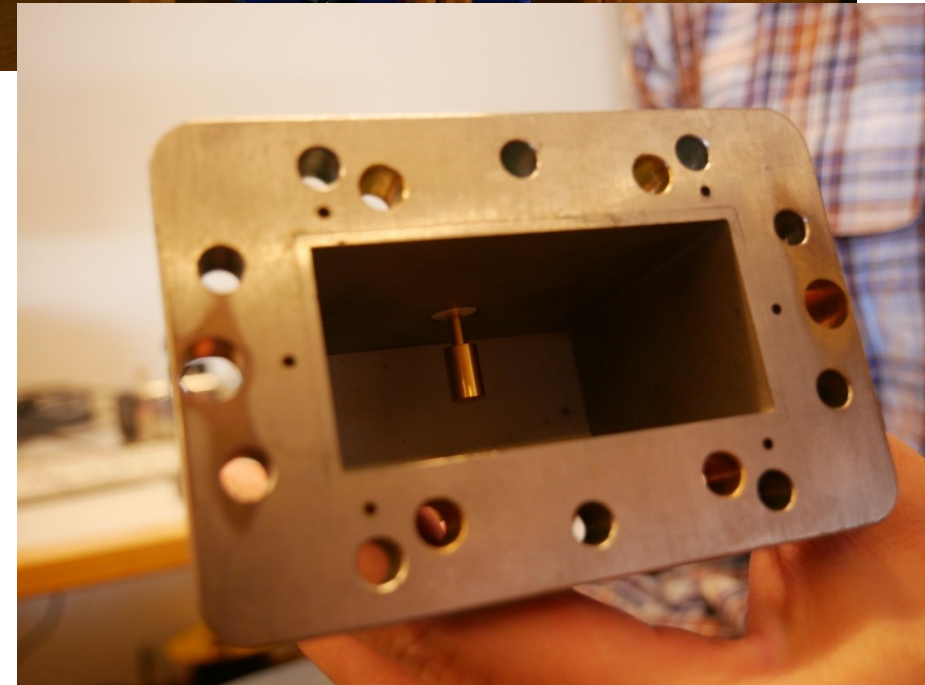




# Afternoon exercises

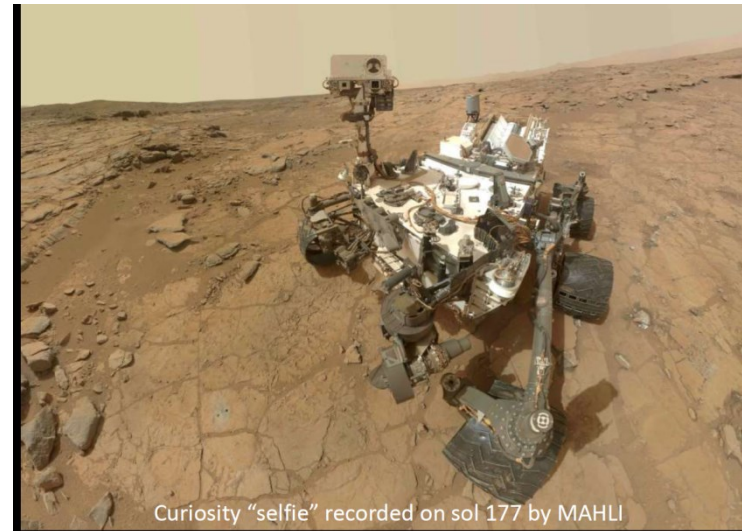
## RF lab and optics

- RF lab
  - Vector network analyzer
  - AM/FM modulation, Coupling impedance
  - RF characteristics, Pill-box cavity
  - Coupling impedance
  - CST simulations
- Optical design
  - MAD-X, Python
  - Lattices
  - ???

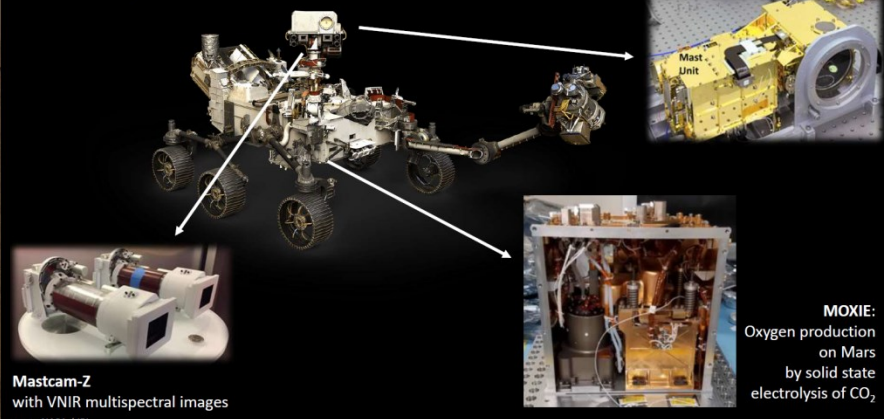


# Seminars

- Non-accelerator scientific topics
- Exploration of Mars
  - Landers
  - Search for evidence of water
  - Measurement instruments
  - Human voyage to Mars
- Deep Greenland ice core and climate
  - Deep ice elemental contents
  - Evidence of past global warming
  - Ice flow in Greenland and dating
  - North vs south ice caps
  - Sea level rise by source



University of Copenhagen has a formal association with three experiments on NASA's Mars 2020 Rover:



**SuperCam** with LIBS, "remote microscopy", VNIR- and Raman-spectroscopy

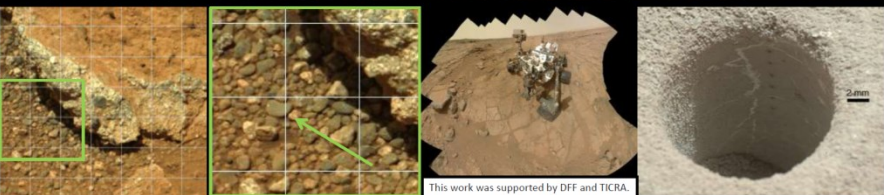
**Mastcam-Z** with VNIR multispectral images  
source: NASA / JPL

**MOXIE:** Oxygen production on Mars by solid state electrolysis of CO<sub>2</sub>

NASA's MSL Curiosity Rover, Gale Crater

Pebbles rounded by streaming water: Rivers once flowed here ... Old lake sediments of neutral pH and chlorobenzene Intermittent lakes throughout early history of Gale crater

Mars once DID have an environment conducive for Life!



This work was supported by DFF and TICRA

Images: NASA/JPL, Caltech, Malin Space Science Systems.



# Evenings





# Excursion

Secret underground military base





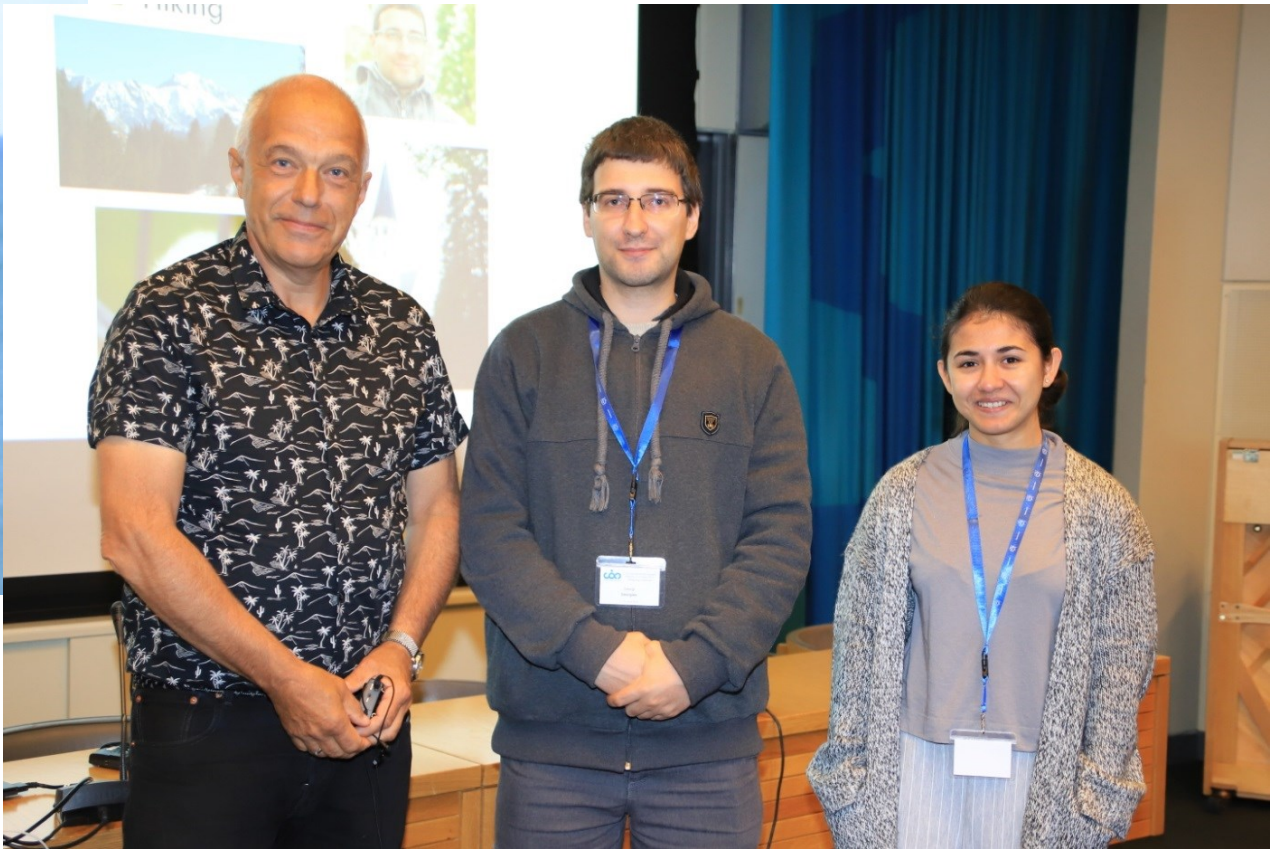
# Excursion

## Viking ships and 50 My old fossils





# Thank you!





# Backup slide

Sorry, if someone did not have lunch yet!

