This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

For peace
and freedom

Solidarity
with Ukraine

ARIES Network ADA on Beam Diagnostics

WP8: Advanced Diagnostics at Accelerators

5th ARIES Annual Meeting, May 2nd to 3rd, 2022

Work-package leader: Peter Forck GSI

Task 2: Diagnostics at hadron LINACs → Peter Forck GSI

Task 3: Diagnostics at hadron synchrotrons → Rhodri Jones CERN

Task 4: Diagnostics at circular light sources → Ubaldo Iriso ALBA-CELLS

Task 5: Diagnostics at linear light sources → Kay Wittenburg DESY

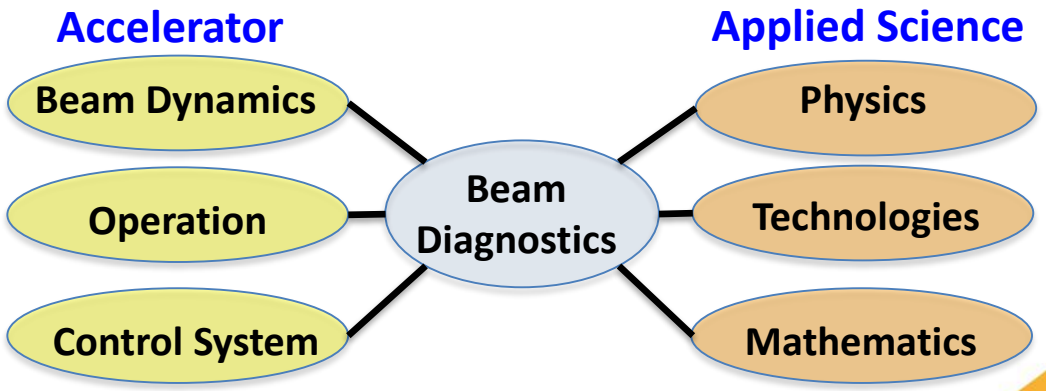
ARIES-ADA Network

ADA = Advanced Diagnostics for Accelerators was one Network Activity

- **Goal:** Initialize and strengthen knowledge transfer & collaboration between experts on various fields
- **Methodology:** Topic workshops on **one dedicated subject** & exchange of personnel
- **Task structure:** Hadron LINAC (GSI), Hadron synchrotrons (CERN)
  Electron circular light source (ALBA), linear light source (DESY)
- **Budget:** 160 k€ plus administrative overhead shared by ALBA, CERN, DESY & GSI
- **Covid-19:** Interruption for face-to-face meetings & continuation as remote events; ended mid 2021

Requirements for beam diagnostics at novel accelerators:

- Design of adequate diagnostics for existing & novel accelerators
- Instruments are based on different physics and techniques



Workshop goal based on:

- Physicists, engineers, technicians from acc. labs, universities & industry
- Expertise from experts on other fields
- Documentation of state-of-the-art knowledge

ARIES-ADA Workshops

#	Date	Org. & location red: exclusive event	Title of workshop	# Part.	Task
1	22-24 May 2017	**GSI Darmstadt**	Simulation, Design & Operation of Ionization Profile Monitors	33	2 & 3
2	29-30 Jan. 2018	**ALBA & DESY Barcelona**	Emittance Measurements for Light Sources and FELs	37	4 & 5
3	14-16 May 2018	**CERN & GSI Geneva**	Extracting information from electro-magnetic monitors in Hadron Accelerators	32	3 & 4
4	25-27 June 2018	DESY & PSI Hamburg	Longitudinal Diagnostics at FELs (co-sponsoring)	45	5
5 & 6	12-14 Nov. 2018	**ALBA & GSI Barcelona**	Next Generation Beam Position Acquisition and Feedback Systems Two in one event: hadron & electron acc.	84	3 & 4
7	1-3 April 2019	**GSI & SOLARIS Krakow**	Scintillation Screens and Optical Technology for transverse Profile Measurements	49	2, 4 & 5
8	3-5 June 2019	ALBA & ESRF Grenoble	Diagnostics Experts of European Light Sources (DEELS 19) (co-sponsoring)	33	4
9	25-29 Jan. 2021	**CIEMAT & GSI Online**	Experiences during Hadron LINAC Commissioning	239	2
10	21-23 June 2021	**CERN & GSI Online**	Materials and Engineering for Particle Accelerator Beam Diagnostic Instruments	205	2, 3, 4 & 5
11	7-8 July 2021	ALBA & SESAME Online	Diagnostics Experts of European Light Sources (DEELS 21) (co-sponsoring)	49	4

red: organized **only** due to ARIES-ADA

Documentation at https://aries.web.cern.ch/wp8

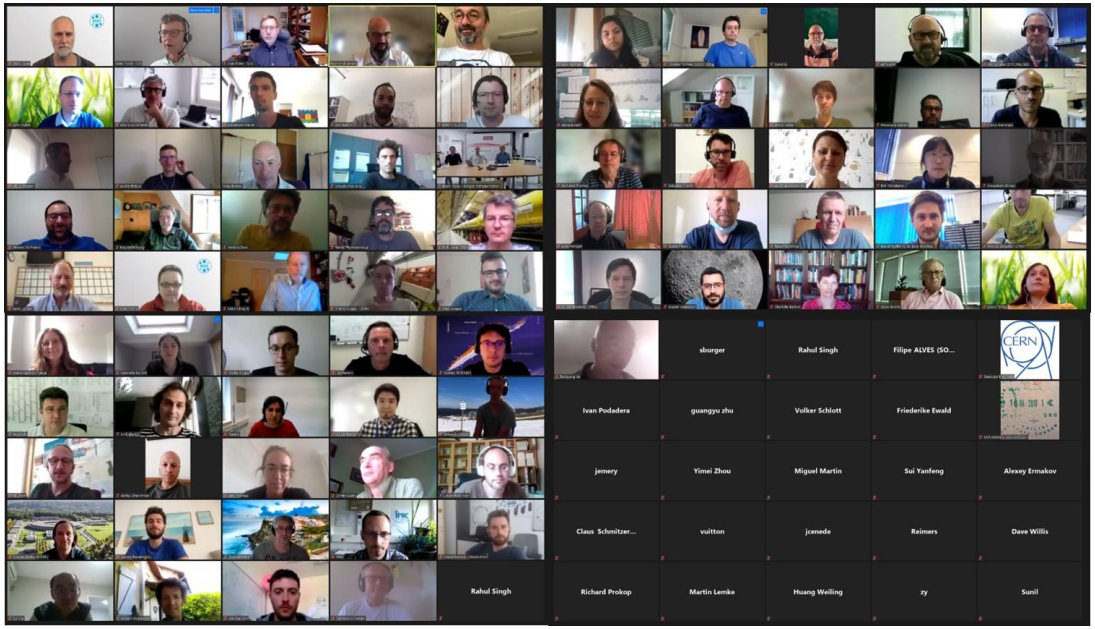
Workshop on Materials and Engineering Technologies

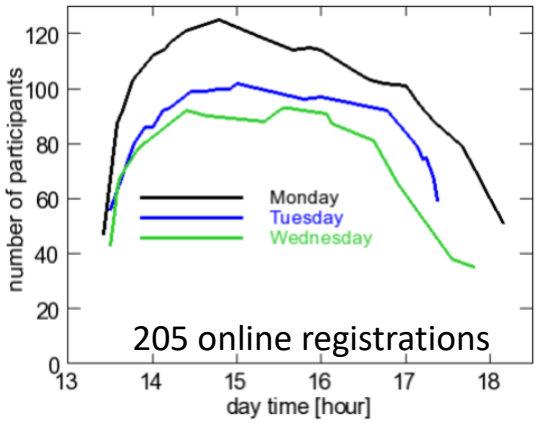
Title: 'Materials and Engineering Technologies for Particle Accelerator Beam Instruments'

Originally planned in Oxford for March 2020,
3 days with 50 attendees and 32 talks

Execution of remote workshop:

- Date: June 21st to 23rd, 2021
- 205 registered participants
  15 Americans, 20 Asian, 170 Europeans
- ≈ 100 simultaneous attendees
- 3 half days at afternoon in Europe
- In total 22 talks, 25 min each
- No pre-recordings
  to keep lively atmosphere
- Break-out rooms for discussion
- Documentation at
  https://indico.cern.ch/event/1031708/





Summary talk by P. Forck at IBIC 2021

Workshop on Materials and Engineering Technologies

Title: 'Materials and Engineering Technologies for Particle Accelerator Beam Instruments'

→ Novel applications for accelerator beam instrumentation

The aims of the Workshop are to review:

- Novel materials and application
- Innovative production methods
- Improved vacuum components
- Information concerning experiences
- Intensify collaborations institutes and industry

Participation of **engineers** (normally not attending conferences) and companies

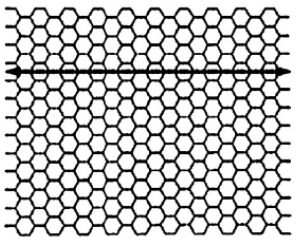
Carbon Nanotubes for fast rotating Wire Scanner

Talk by William Andreazza and Alexandre Mariet on behalf of CERN

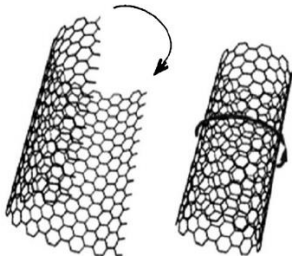
Requirements: High speed 20 m/s & acc. 15000 rad/s^2
⇒ mechanical stiffness
⇒ light (low-Z) material
⇒ high temperature tolerance

New techniques for wire: Carbon nanotube wires

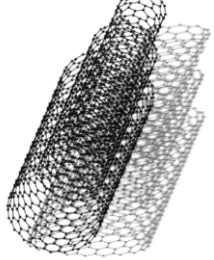
Result: CNT wires successfully tested



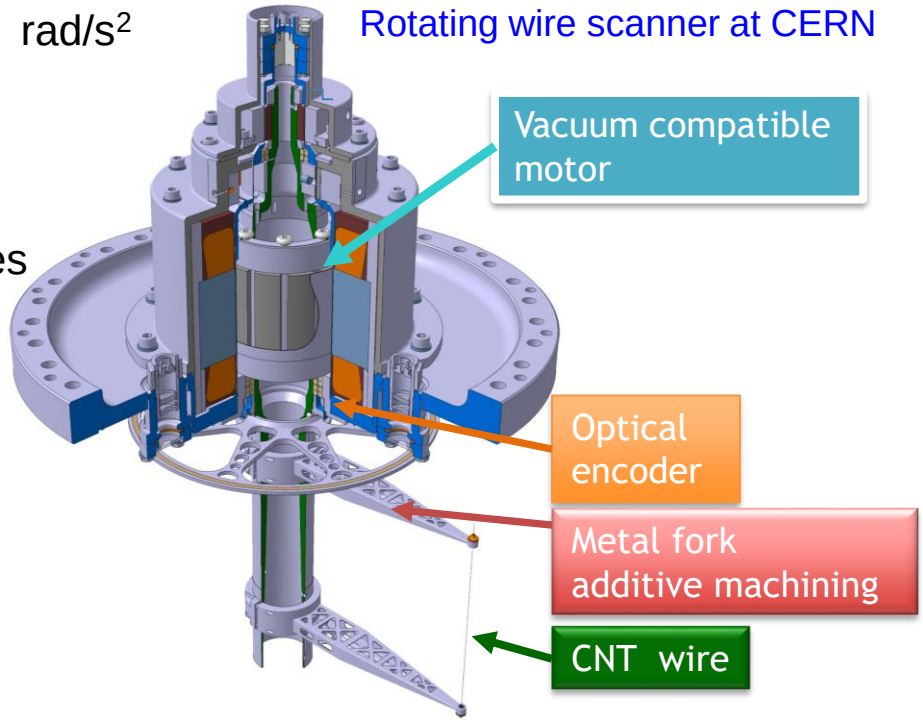
Single wall nanotubes



Multi wall nanotubes



Rotating wire scanner at CERN



Mechanical properties of carbon materials

Material	ρ [g.cm^{-3}] Density	σ_{max} [GPa] Tensile strength	E [GPa] Young modulus
CNT (SWNT)[1]	0,02 - 4	up to 150	up to 1e3
Carbon fiber [2]	1,7 - 2,5	0.6 - 4.5	60 - 500
CNT wire [3]	1.1 - 2.1	0.2 - 3.3	20 - 100

‘Ashby Diagram’: Quantitative Selection Method for Wire Scanner

Talk by John Huber behalf of Engineering Dep. University Oxford and CERN

Requirements: High speed 20 m/s & acc. 15000 rad/s^2

$\Rightarrow$ mechanical stiffness

$\Rightarrow$ light (low-Z) material

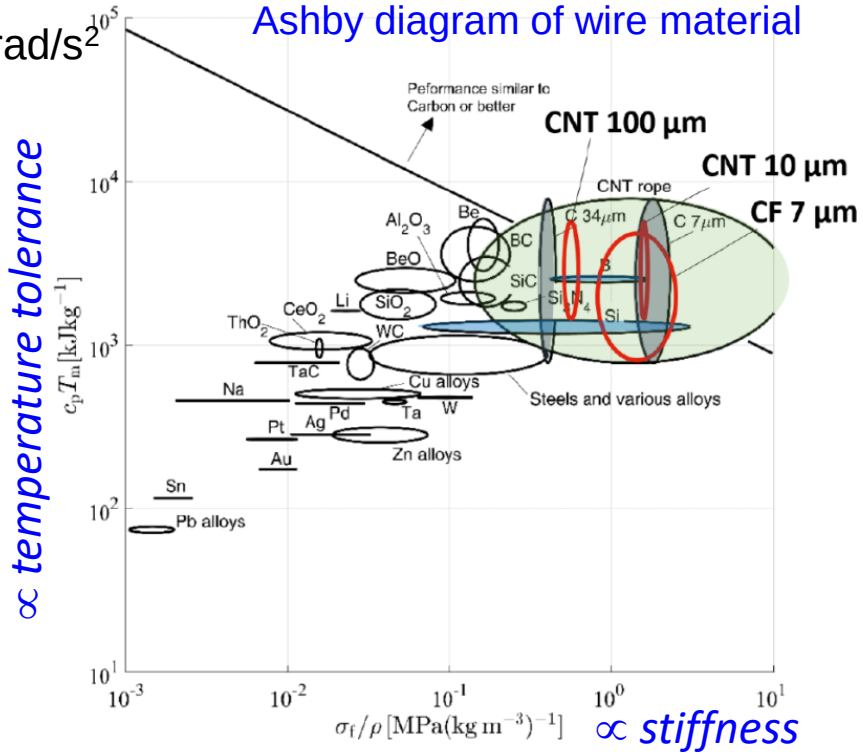
$\Rightarrow$ high temperature tolerance

Quantitative selection method: Ashby diagram

Result:

- Clear selection criteria
- CNT robes have superior performance
- Test of open topics performed
  e.g. stat. variation of breaking strength

Ashby diagram of wire material



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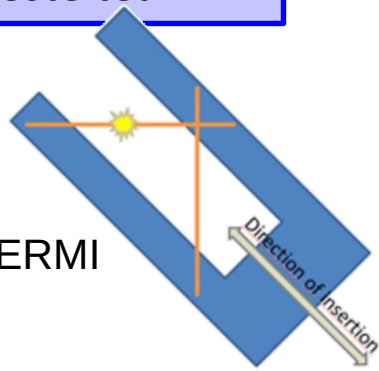
Ultra-thin Wire for linear Wire Scanner

Talk by Gian Luca Orlandi on behalf of PSI, Elettra and IOM-CNR Trieste team



Requirements: Spatial resolution of below 1µm ↔ thinner wire below ∅ 1 µm

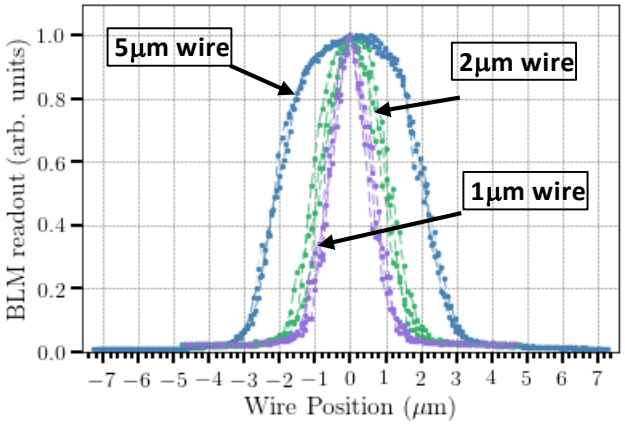
New techniques: Fabrication via Nano-lithography
with integration wire+fork in a unique structure

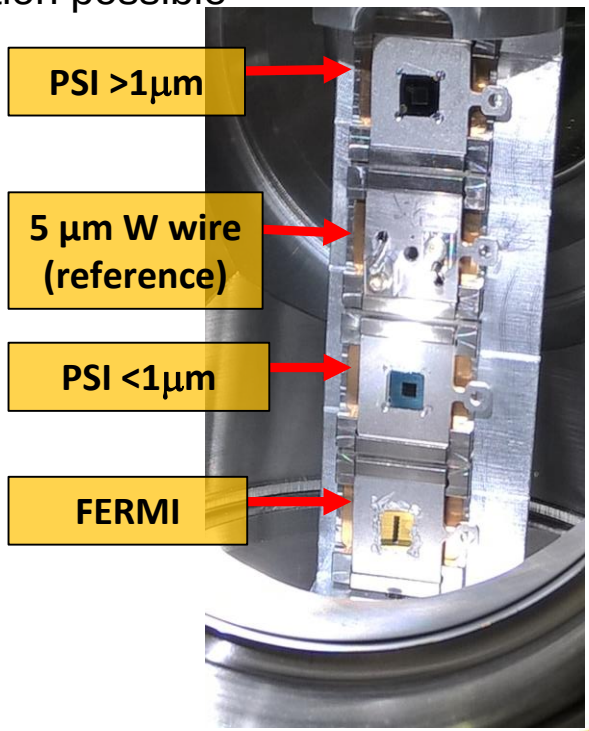
Present status: **Free-standing** WS independently nano-fabricated at PSI & FERMI

Result: Sub-µm spatial resolution ~250 nm, beam clearance ~ 2 mm
Tomography for quadrupole variation possible

Future plans: Beam clearance ~**10 mm**

Test at SwissFEL PSI





Adaptive Manufacturing: Example of fast Wire Scanner

Talk by Ana Miarnau on behalf of CERN

Adaptive Manufacturing: Manufacturing parts by adding layer upon layer of material

Examples of methods for metals: DED & EBM

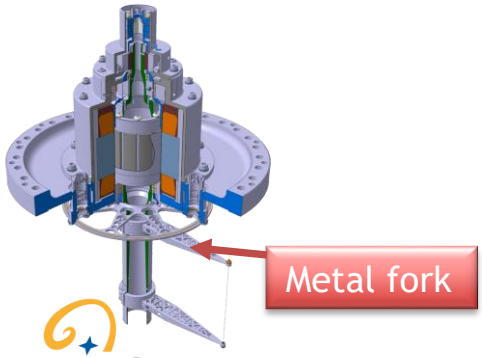
Design of wire scanner fork:

- High stiffness in two planes and
- Low inertia
- Titanium alloy Ti-6Al-4V chosen

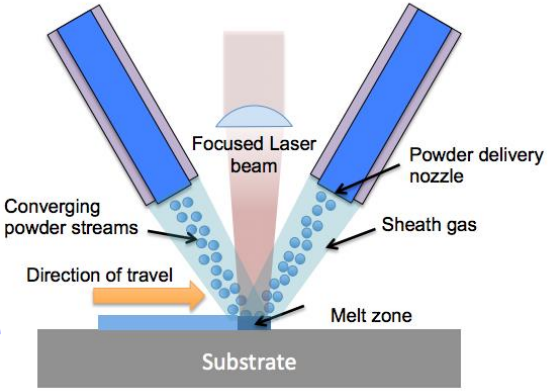
Series of 56 forks produced in 3 batches

Results:

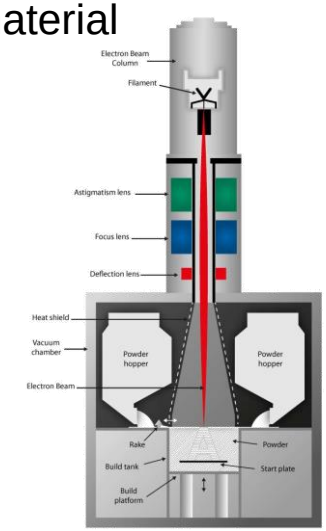
- Fully functional
- Vacuum outgassing comparable to traditional production



Example: Fork for wire scanner at CERN



Powder fed:
Direct
Energy **D**eposition



Powder bed:
Electron **B**eam
Melting

Carbon Nanotubes for Stray Light suppression by black Coating

Talk by Ben Jensen on behalf of company NanoSystem in collaboration with CERN

Requirement: In-vacuum suppression of stray light for optical monitors

Method: Spray coating of carbon nanotubes
Post processing by backing

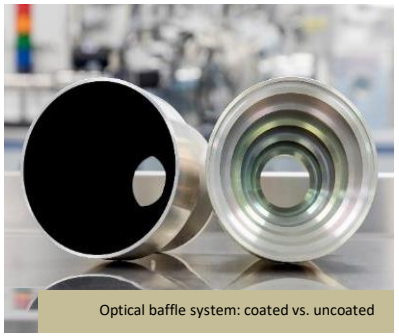
Product: 'Vantablack', several types available

Results:

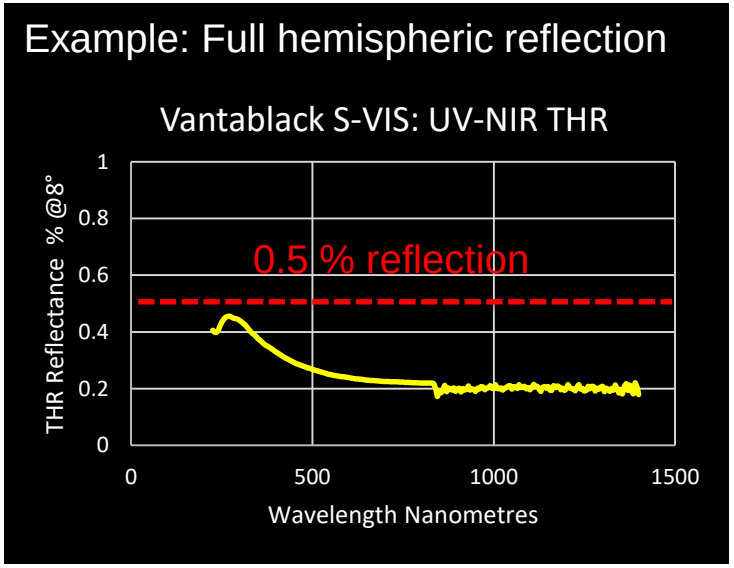
- Broadband (UV to NIR) reflection below 0.5 %
- Acceptable mechanical properties
- Low vacuum outgassing
- Radiation hard

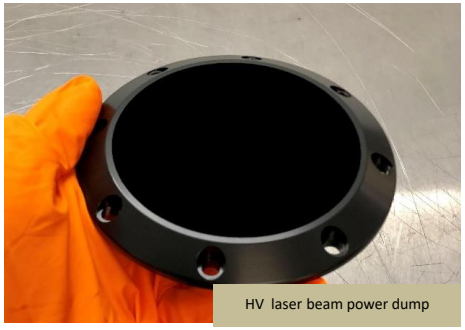
Tests at CERN performed

Production examples


Optical baffle system: coated vs. uncoated


UHV Instrument module coated with S-VIS




HV laser beam power dump

Company background
in space technology

Remote Workshop: Diagnostics Experts of Euro. Light Sources (DEELS) 2021

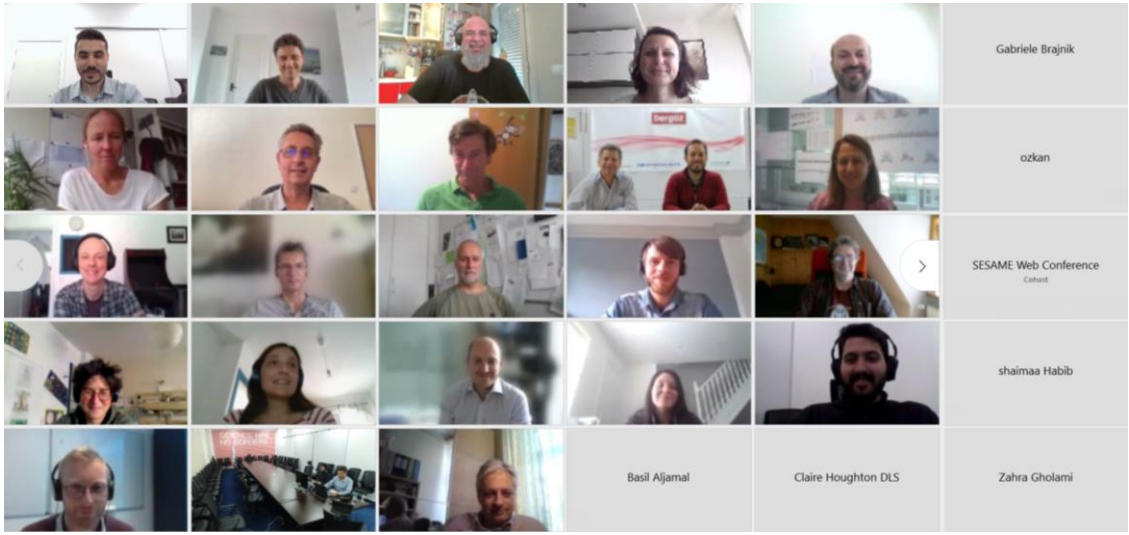
Practical details and statistics:

Organized by SESAME, Jordan including virtual tour

- **Meeting time:** 7th July, 2021, 10:00 to 17:00
- **Registrations**: total 49, most connected

  Europa: 31 = 63 % | America: 2 = 5 % | Asia & Middle East: 15 = 31 % (SESAME member states)

9 talks followed by 10 min discussion



Topics:

- **Overview on SESAME**
- Synchrotron radiation monitors e.g. at EBS-ESRF for transverse & longitudinal beam characterization
- X-ray BPMs for beam stabilization
- Machine Learning for image reconstruction

SESAME

ALBA

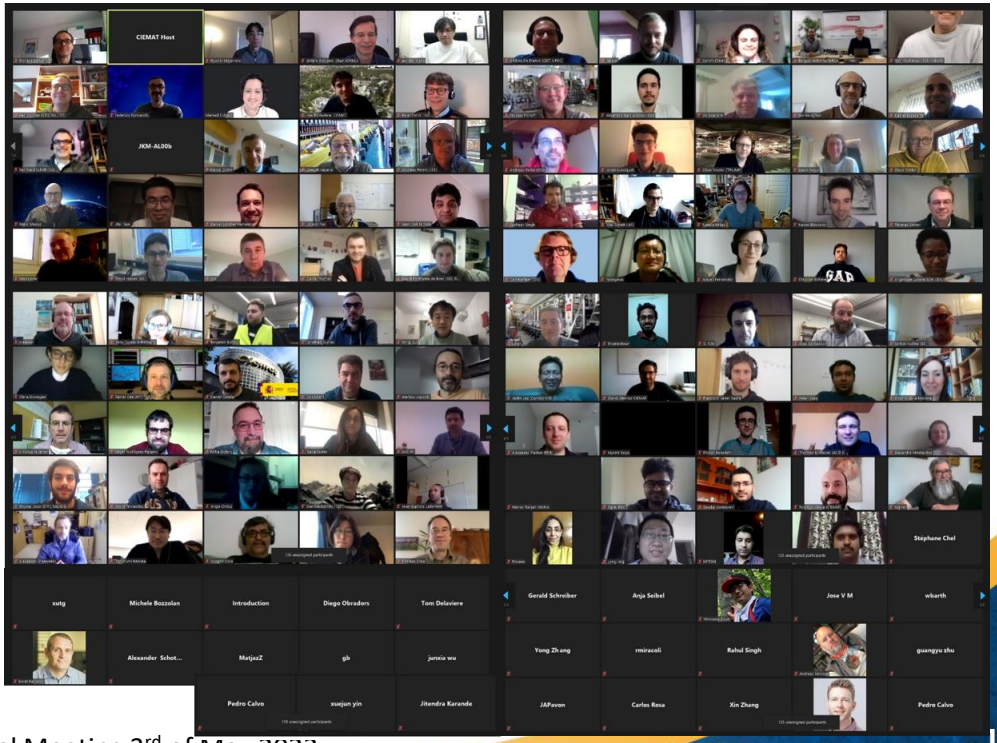
Remote Workshop on ‘Experiences during Hadron LINAC Commissioning’

Workshop from 25th to 29th of January 2021 organized by CIEMAT (Madrid) and GSI

Planned for June 2020 as in-person event; however, postponed as remote with the aims:

- Common efforts by experts on **instrumentation**, beam **dynamics** and **operation**
- Review experiences from commissioning to early operation
- Review initially formulated requirements and final usage of instrumentation
- Explore the balance between detailed measurements on a test bench and fast commissioning

Many proton and ion LINACs are presently realized worldwide



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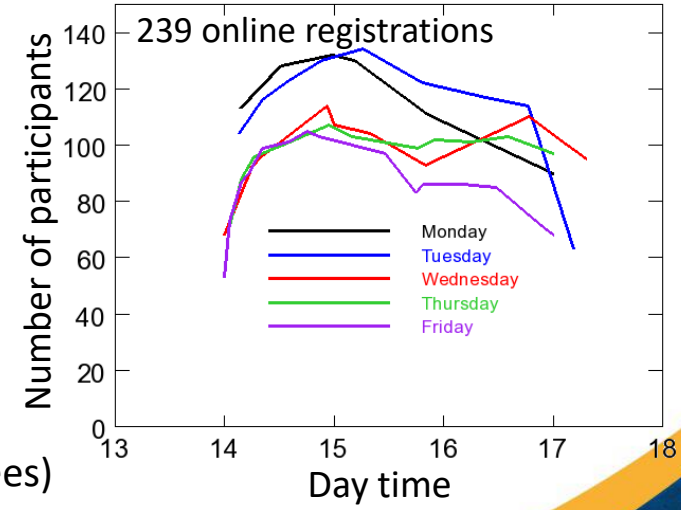
Many proton and ion LINACs are presently realized worldwide

Practical details and statistics:

- **Registrations**: total 239
  Europa: 154 = 70 % | Asia: 47 = 21 % | America: 19 = 9%
  Industry: 36 participants = 15 %
- Meeting time: Monday to Friday from 14:00 to 17:15 CET
  2 x 3 talks + discussion per day
- **Talks:**
  Europa: 18 = 60 % | Asia: 5 = 17 % | America: 7 = 23%
- About 100 people connected in parallel,
  many contribution to discussion (even on Friday 90 attendees)
- No pre-recorded talks to keep life atmosphere



Scintillation Screens and Optical Technology for transverse Profile Measurements

Workshop on 1st to 3rd of April 2019 in Krakow

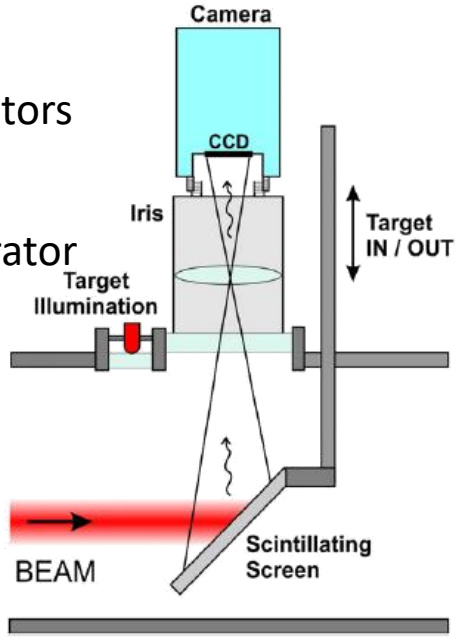
see indico.cern.ch/event/765975/

49 participants (more applications but restriction de to venue)

incl. material research, laser acceleration, industry

- Physics and production techniques of scintillators
- Optics and cameras
- Experiences at hadron accelerators
  → mainly radiation hardness
- Experiences at electron accelerator
  → mainly resolution limits
- 29 talks incl. 3 talks by industry

Screens: Simple set-up, but non-trivial physics



Summary by B. Walasek-Höhne (GSI) as invited talk IBIC conference in September 2019

Workshop Scintillation Screens: Profile Measurement versus Detector Appl.

Difference to traditional applications in high energy physics, medical imaging & security:

Parameter	Physics, Medical	Hadron acc.	Electron acc.
Application	Secondary part.	Primary beam transverse profile	
Particle rate	Low	High	Very high
Energy	Up to 10 GeV	10 keV...100 GeV	100 keV...10 GeV
Spot size	10...100 mm	1...50 mm	0.01...1 mm
Spatial resolution	1 mm	100 µm	3 µm
Deposited dose	Low	Very high	Medium
Saturation	None	Expected	Possible
Radiation damage	Low	Very high	High

Accelerators:

- Some time same material used e.g. YAG:Ce for electron beams
- Different requirements e.g. ceramic Al_2O_3:Cr (‘Chromox ‘)
- Challenge for electron accelerators: resolution down to 1 µm
- Challenge for hadron accelerators: Radiation damage
- Both types: Prevention of possible saturation and quenching for correct beam image

→ **Discussion on experiences with experts in material science**

Workshop on 'Next Generation Beam Position Acquisition and Feedback Systems'

Workshop on 12th to 14th of November 2018 in Barcelona see indico.cern.ch/event/743699/
Common event for hadron and electron synchrotron

84 participants

(strong Chinese participation)

Hadron community:

- Analog electronics
- Realization & trends for digital electronics

Common hadron & electron:

- Closed orbit feedback

Electron community:

- Fast feedback for instability cure
- Accuracy requirements for BPMs for ultra-low emittance circular light sources (e.g. 'pilot tone')
- Two talks by industry

Common session with hadron & electron accelerators well acknowledged

Remark: Discussion between engineers who seldom participate at conferences!

Workshop on 'Longitudinal Diagnostics for Free Electron Lasers'

Workshop on 25th - 27th of June 2018 at DESY see https://indico.cern.ch/event/702602/

45 participants

Meeting with experts in

- Detector development
- Optics
- Electronics

Topics:

- Compression monitors & THz detectors
- Electro-Optical diagnostics
- THz Streak of the primary electron beam
- Laser heater operation and diagnostics
- KALYPSO and fast digitization electronics

Working procedure:

1st day: Working group to five subjects → information about status, collaborations &experiments

2nd and 3rd day: Report by working group coordinator, discussion and poster presentations

ARIES-Workshop ‘Extracting Information from electro-magnetic Monitors’

Workshop on 14th - 16th of May 2018 at CERN

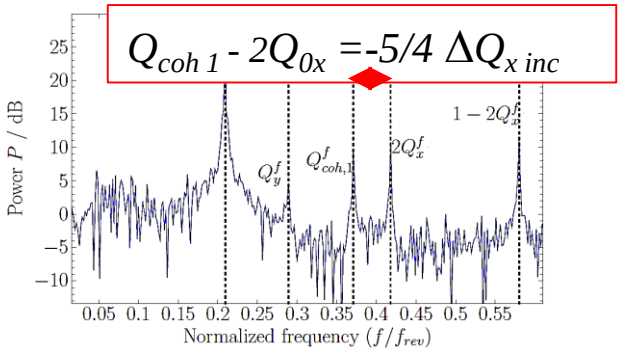
see https://indico.cern.ch/event/705430

32 participants from CERN, France, Germany, Japan, Switzerland, Russia, USA

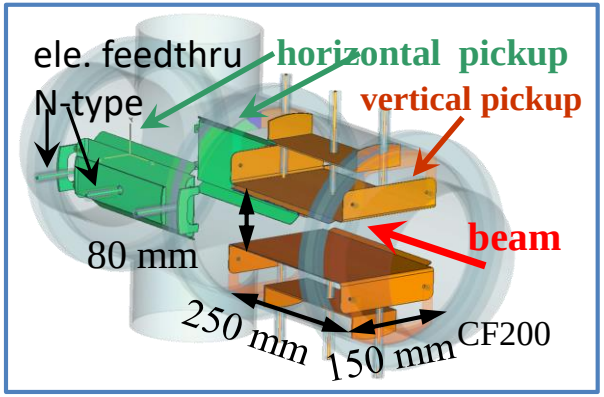
- Measurements of machine optics
  e.g. tune and beta-beating
- Beam parameter measurements
  e.g. quadrupolar oscillation → tune spread
- Schottky signal analysis

→ **‘beam dynamics meets diagnostics’**

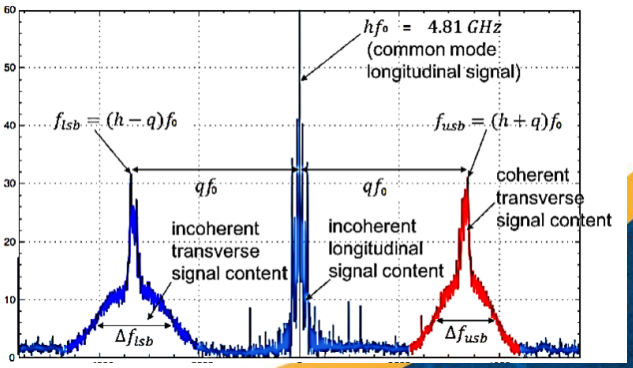
Tune & quadrupole oscil.



BPM



Schottky spectrum

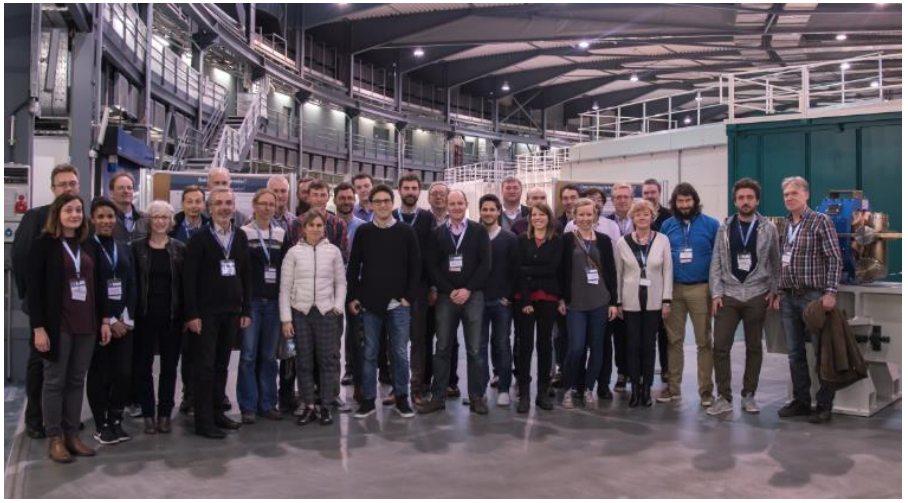


ARIES-Workshop on 'Emittance Measurements for Light Sources and FELs'

Workshop on 29th - 30th of Jan. 2018 at ALBA

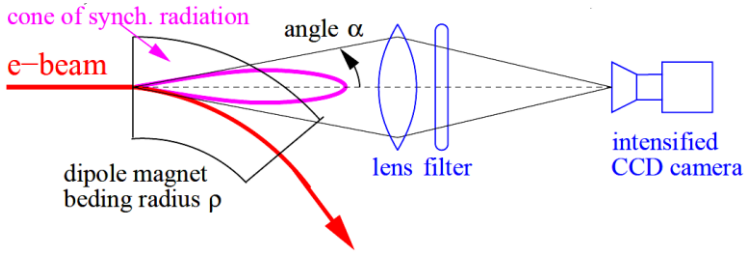
see https://indico.cells.es/indico/event/128/

37 participants from CERN, France, Germany, India, Italy, Japan, Poland, Sweden, Spain, Switzerland, Russia, UK, USA

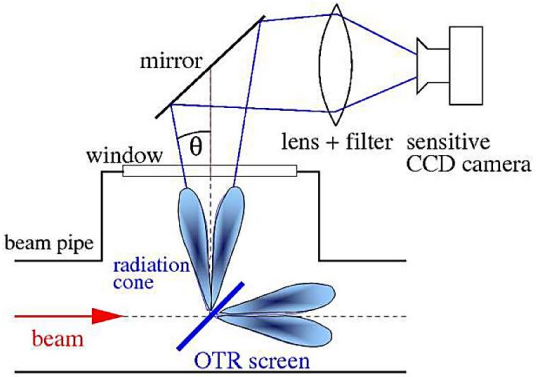


- Resolution challenges at light sources
- Direct images technique
- Measurements from light coherence analysis
- FEL challenges and OTR & ODR techniques
- Wire and laser scanner techniques

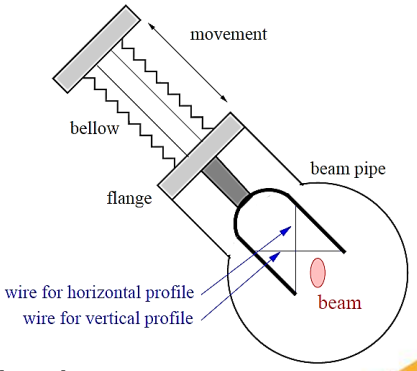
Synch. light monitor visible x-ray



OTR screen & ODR



Wire & laser scanner



Unique result: Table with detailed comparison of resolution of all methods

Invited Talk at IBIC 2018 by Ubaldo Iriso (ALBA), Shanghai September 2018

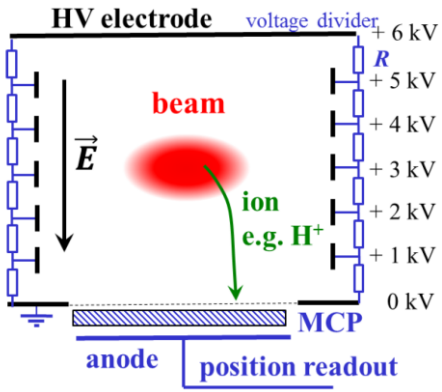
ARIES-Workshop on 'Simulation, Design & Operation of Ionization Profile Monitors'

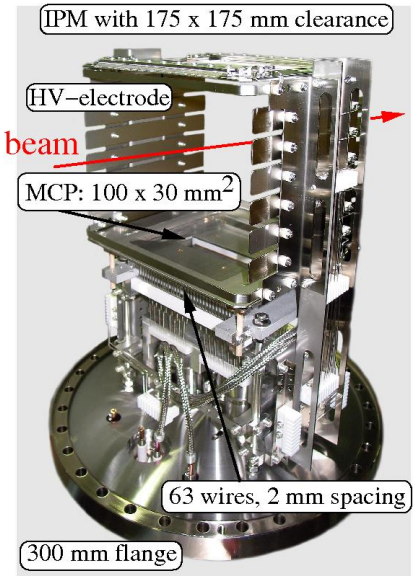
Workshop on 22nd - 24th of May 2017 at GSI
see http://indico.gsi.de/event/5366/

33 participants from Austria, CERN, China, France, Germany, Japan, Russia, UK, USA

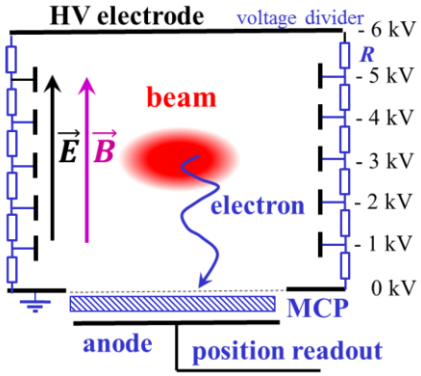
- General compilation on IPM realization at LINACs and synchrotrons
- Exchange of novel ideas
- Common code development for image reconstruction

Ion detection mode:





Electron detection mode:



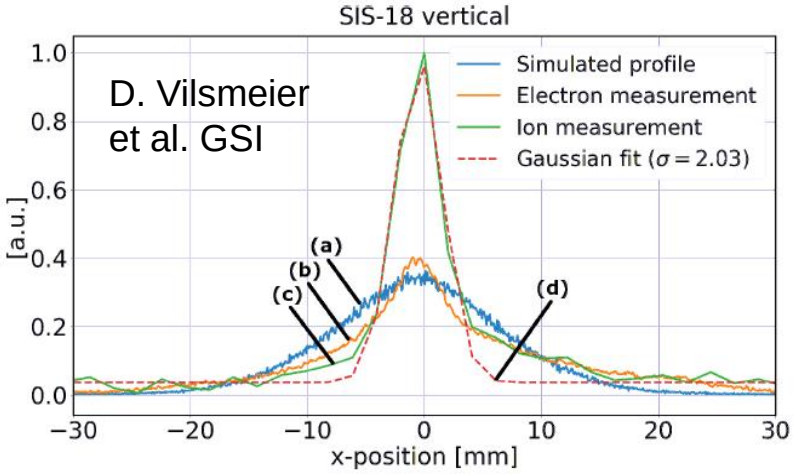
Topic 4: Code for space charge broadening by beam's space charge

Each laboratory has its own code with special application & restriction

⇒ Discussion underlying physics & software, validation as initialized by m. Sapinski GSI

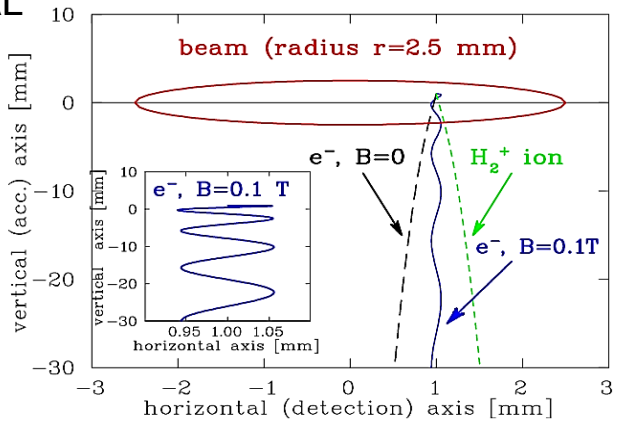
Code includes:

- Application for **LINACs**
  i.e. short bunches, non-relativistic
- Application for **synchrotrons**
  i.e. long bunches, relativistic ⇒ 2d calc.
- Homogeneous $\vec{E}$ & $\vec{B}$ fields ***or*** input CST maps
- Realistic e⁻ generation: $\frac{d^2\sigma}{dE \cdot d\theta}$ and tracking
- Meaningful GUI
- twiki.cern.ch/twiki/bin/view/IPMSim/



Present participants: CEA, CERN, ESS, FNAL, GSI, J-PARC, RAL

→ **Developed towards 'standard' code for simulation & related machine-learning corrections**



Assessment for ARIES-ADA

Mission accomplished for ARIES-ADA in 2017 to 2021:

- Workshops related to **one** special subject acts as an addition to conferences
- Inclusion of engineers & PhD-students is a central pillar for tech. realization & knowledge transfer
- Focused talks on achievement & failures (you can gain for others: '…don't do a mistake twice…')
- Large interest within the community:
- Well appreciated by the beam diagnostics community: 4 summary talks at IBIC conference
- Durable documentation of state-of-the-art beam instrumentation and diagnostics

Experience and organizational view to ARIES-ADA:

- There are many things to learn from other labs' experiences ⇒ very valuable workshops
- Must be an **actual** topic ⇒ interest by many people to achieve 'critical mass'
- Pleasure atmosphere & small talks (e.g. **one** hotel to keep people together) are essential for collaborations
- Advantage: **Financial budget** (in total 160 k€) to cover part of the travel costs
- In-person meeting are required to **establish** collaborations

Conclusion: ARIES-ADA contributed significantly to accelerator R&D

The support by EU-Project ARIES is greatly acknowledged!
Thank you very much to ARIES team at CERN!
Thank you for your attention!

ARIES-Workshop on 'Emittance Measurements for Light Sources and FELs'

Comparison of different methods of synchrotron light monitors (visible or x-ray)

⇒ **Different techniques for circular SLS compared, technical realization discussed,**

Method for circular accelerator	smallest σ [µm] (measured)	Workshop Talk
Scintillator (reference)	**1.5**	G. Kube (DESY)
X-ray Pinhole	7	L. Bobb (DLS)/ F. Ewald (ESRF)
Comp. Refractive Lenses	10	F. Ewald (ESRF)/ A. Snigirev (Kalin.)
Vis. Light Interf.	3.9	T. Mitsuhashi (KEK)
Vis. Light Inter. (mask)	2 (sim)	L. Torino (ESRF)
p-polarization (vis)	3.7	A. Andersson (MAXLab)
Coded Aperture	5	J. Flanagan (KEK)
In-air X-ray Det.	9	F. Ewald (ESRF)
X-ray Diffraction	4.8	A. Snigirev (Kaliningrad)
X-ray (multi/lens) Inter.	4.8	A. Snigirev (Kaliningrad)
HNFS (near-field speckles)	≈ 10 (development)	M. Siano (Milan)

ARIES-Workshop on 'Emittance Measurements for Light Sources and FELs'

Comparison of different methods (invasive optical methods, wire & laser scanner)
⇒ Different techniques for linear FELs compared, technical realization discussed

Method for linear accelerator	smallest σ [µm] (measured)	Workshop Talk
Scintillator (reference)	**1.5**	G. Kube (DESY)
OTR Techniques	1.5	L. Sukhikh (Tomsk)
ODRI Techniques	??	E. Chiadroni (INFN)
COTR Techniques	3.8	A. Potylitsyn (Tomsk)
Wire Scanner Technique	0.490	K. Wittenburg (DESY) / S. Borrelli (PSI)
Laser Wire Technique	0.070	P. Karataev (RHUL)
Multi-Slit Mask Technique	200	M. Kraskilnikov (DESY)

Recent improvements for Au-wires (strips from membrane) down to ∅ 1 µm