SINBAD

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Leading Scientist, DESY

LAOLA Collaboration Meeting, Wismar

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Reminder: Helmholtz Roadmap

➢ The latest Helmholtz-roadmap for research infrastructure was published in 2011.

➢ This roadmap calls for a Distributed ARD Test Facility.

➢ This would be a joined proposal in 2016 by several Helmholtz centers for infrastructures at these labs.

➢ Total construction cost as listed: 40 M€.
Daten und Zahlen

Zeitplan:
• Einrichtung und Weiterentwicklung: 2015–2019
• Betrieb: ab 2015/16

Geschätzte Kosten:
• Vorbereitungs-/Planungskosten: im Rahmen der Grundfinanzierung des ARD-Programms
• Baukosten: 40 Mio. €
• Betriebskosten: 3 Mio. € p.a., z. T. im Rahmen ARD zu finanzieren
• Rückbaukosten: noch nicht zu spezifizieren
Why a Distributed ARD Test Facility?

- German accelerator tradition is very strong and in several aspects world-leading → join up forces in ARD, as together we are stronger!

- Avoid duplication of critical R&D in Helmholtz centers, institutes and partners.

- Profit from and exchange technical developments in other places (e.g. UHV techniques with plasmas, instrumentation, simulation, …).

- Open up expensive accelerator test facilities for usage by our fellow research partners.

- Words are nice, but how to best achieve this?
  A common, distributed research infrastructure for accelerator R&D → Distributed ARD test facility.

  - Work on a common proposal will support technical exchange and build common long-term strategy.
  - A common distributed facility costs additional budget (additional test stands) and can only be implemented with the funding mentioned in the Helmholtz roadmap.
SINBAD – A Dedicated DESY Facility for Accelerator R&D

**SINBAD** = **S**hort **IN**novative **B**unches and **A**ccelerators at **D**oris

> Turning good ideas into useful technology requires:

- Resources
- Dedicated R&D facility for beam tests and prototyping (see example of TTF → FLASH)

> SINBAD is the proposal to set up such a facility in DORIS.

- 10 year horizon: either build a useable plasma accelerator or show why not
- Sufficient space and beam time in SINBAD to achieve this goal
SINBAD (Short Innovative Bunches and Accelerators at Doris): Phase 1

- **S Band Injector (100 MEV)**
- **X Band Injector**
- **RF Infrastructure** (Modulators, Klystrons, ...)
- **X band RF** (Modulators, Klystrons, ...)
- **Matching, Diagnostics**
- **Compression and Matching Study Line**
- **Experiment 1a & 1b** (LAOLA at REGAE cont, staging, dielectric)
- **Experiment 2**
- **Laser Lab**
  - Sufficient up to 1 PW or 3 times 200 TW
  - Area: 200 m²
  - Area: 9 m x 22 m
  - Several levels possible

**DESY Laser Laboratory**
“Conventional” 1 GeV Electrons in DORIS?

Excellent integration into DESY accelerator park!

1 GeV allows FEL studies, seeding, … in DORIS, outside of user’s operation.

Shows enormous potential of DORIS für accelerator R&D!

PIA allows positrons → needed for collider applications (HEP)!

Must address RP aspects in transfer tunnel below building 30.
Generating bunches with length < 1 fs, into the atto-second regime:

- Conventional photo-injectors with velocity bunching, space charge field, ...
  (see also Holger Schlarb, FLUTE, ...)
- Atto-second proposal
- Compact light sources

Prototyping a 1 GeV plasma accelerator unit with industrial quality:

- **External Injection of 100 MeV beam into laser-driven plasma**, staging, ...
  (next phase of LAOLA@REGAE type experiment)
- Best plasma cell technology: different types, UHV compatibility, ...
- Plasma unit with internal injection (replacing 100 MeV linac)
- Plasma unit with resonant beam-driven wakefields (10 b. low E → 1 b. high E)

Prototyping applications for plasma accelerators:

- Ultra-compact VUV FEL’s
- Demonstration of plasma linear collider at very low energy
LAOLA Collaboration: Related Projects and Schedule

<table>
<thead>
<tr>
<th>Year</th>
<th>LUX: LWFA driven undulator &amp; FEL</th>
<th>REGAE: low energy injection</th>
<th>SINBAD: ARD distributed facility at DESY</th>
<th>FLASHForward: high energy injection, Trojan horse</th>
<th>PIZT: self-modulation &amp; high transformer ratio</th>
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<tbody>
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SINBAD Scenario: Building a 1 GeV Plasma Stage

A. Plasma density $\approx 10^{14}$ cm$^{-3}$ – plasma length $\approx 0.1$ m

1) Match a well characterized beam into plasma with $\approx 1$ cm beta
2) Energy gain $\leq 100$ MeV, match plasma at exit $\approx 1.4$ cm beta, measure E spread
3) Demonstrate injection tolerance of 10 $\mu$m (non-diluted case): transport over 60 $\pi$ phase advance, minimize betatron oscillation out of plasma, measure emittance
4) Requires about two $\pi/2$ FODO cells before and after plasma, eventually plus matching, diagnostic integrated in FODO cells

B. Increase plasma density in steps...

C. ...up to final of $\approx 10^{17}$ cm$^{-3}$ – plasma length $\approx 0.1$ m:

1) Match a well characterized beam into plasma with $\approx 0.4$ mm beta
2) Energy gain $\approx 1$ GeV, match plasma at exit with $\approx 1.3$ mm beta
3) Demonstrate injection tolerance of 2 $\mu$m (fully diluted case): transport over 2000 $\pi$ phase advance, minimize betatron osc. out of plasma, measure emittance

NOTE: SINBAD is not aimed at new accelerating records but at producing a useable, high quality beam from a plasma accelerator!
Space Budget SINBAD

The following components are required and listed with estimated length of beamline space:

- Conventional 100 MeV photo-injector: 15 m
- $2 \pi/2$ FODO cells before plasma ($\beta_{av} = L_{FODO}$): 20 m
- Matching into plasma: 5 m
- Plasma accelerator + transitions: 2 m
- Spectrometer magnet for up to 3 GeV + matching: 10 m
- $2 \pi/2$ FODO cells after plasma ($\beta_{av} = L_{FODO}$): 20 m
- Beam dump: 2 m

Total: 74 m

This fits into a straight section of DORIS with some usage of the neighboring arcs. Alternative would be a HERA straight section.

As work proceeds, length will be reduced (less complete diagnostics).

Final goal: 1 GeV in 20 m (10 times shorter than FLASH)

2 GeV in 25 m
## SINBAD Parameters (Draft)

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<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>REGAE</th>
<th>FLUTE I</th>
<th>FLUTE II</th>
<th>SINBAD I</th>
<th>SINBAD II</th>
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<td>Maximum length</td>
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<td>15</td>
<td>15</td>
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## Short INovative Bunches and Accelerators at DORIS (SINBAD)

A Proposal to the DESY Directorate

**Abstract**

The Helmholtz Association has set up an ARD (“Accelerator Research & Development”) program across its accelerator subdivisions in Germany. This program opposes a focus on accelerator research at DESY, a DORIS-based setup with multiple experimental areas is described that would allow putting DESY and University Hamburg at the forefront of research on short bunches and ultra-comment accelerators. Such a facility would only have on existing DESY infrastructure. It would provide a future-proof basis to the ARD effort at DESY while providing enough room for developing the setup into a leg of the distributed ARD test facility, as foreseen in the Helmholtz roadmap for large infrastructures. The required investments would therefore be leveraged by third-party funding as obtained with possible proposals to Helmholtz, EU and other agencies.

**Authors**

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- University Hamburg, Hamburg, Germany
- SST, Karlsruhe, Germany

Hamburg, 26 Feb 13

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<td>Pulse duration</td>
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<td>Repetition rate</td>
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<td>Beam pointing stability</td>
<td>3 μrad</td>
<td>rms over 500 shots</td>
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<tr>
<td>Diameter beam profile (1/e)</td>
<td>76 mm</td>
<td>super-Gaussian to power of 8</td>
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SINBAD Planning

SINBAD must take into account work for existing projects and the availability of DESY resources:

- Until end 2015: Team Accelerator R&D DESY and university Hamburg.
  
  Design and preparational studies for SINBAD.
  Experiments in LAOLA@REGAE and LAOLA@PITZ.
  AXSIS studies. Experiments at FLUTE at KIT.
  Experiments at SPARC in Frascati, SLAC, ...
  **Final project decision.**

- **2016:** Clean up DORIS.

- **2017:** Construction of Phase 1 and removal of LAOLA@REGAE to SINBAD.
  
  Start of first plasma and beam studies in SINBAD.

- **2020:** Complete construction of full SINBAD.
  
  Four independent experimental zones.
  Laser-Upgrade to 1 PW.

Financing of Phase 1 with ARD regular budget and non-strategic PoF3 investment funds.

- **SINBAD as attractor for third-party funding (e.g. ARD distributed test facility).**
Conclusion

➢ The distributed ARD test facility is a great opportunity for the Helmholtz centers, institutes and partners:

- Build a common, distributed accelerator research infrastructure in Germany with a strategic vision.
- Improve our competitive position as one of the world leaders in accelerators.
- Develop together new applications for accelerators.

➢ SINBAD would be the DESY part of such a distributed ARD test facility:

- The DORIS infrastructure provides unique possibilities for a powerful R&D facility in the very successful DESY tradition of TTF (now FLASH).
- Science case of ultra-short, intense electron bunches, compact radiation sources and novel plasma accelerators.
- Plasma accelerator modules with industrial quality.
- Prototype new solutions for photon science (table-top FEL) and particle physics (ultra-high gradient plasma linear colliders).

➢ It fits very well into the long-term LAOLA strategy, plans for short bunches and proposal in photon science (THz-driven sources).
Thank you for your attention…
Determining SINBAD Parameters: Plasma Wavelength

Plasma wavelength [mm] vs. Plasma density [cm\(^{-3}\)]

Length of SINBAD plasma: 0.1 – 3 mm

Plasma wavelength [mm] range: 0.01 – 100

Plasma density [cm\(^{-3}\)] range: \(10^{12}\) – \(10^{20}\)
Electron Velocity and Plasma Wave Group Velocity

- Plasma has a refraction index and modifies group velocity of plasma wave.
- The plasma wave can be faster or slower than an injected beam.
- Figure compares the $\beta = v/c$ of the plasma wave versus various injected beam.
Difference in velocity is converted into slippage in plasma bucket.

A maximum length of the plasma can be calculated for the different cases and a fixed tolerance.

Tolerance assumed here:

±1% slippage in bucket
(± 3.6°)

100 MeV injector $\rightarrow$ **10 cm plasma length**
up to $10^{17}$ cm$^{-3}$ plasma density OK
Optical Beta Function and Matched Beam Size

> The focusing channel can be characterized by its beta function.

> This is a very small beta function (plasma lenses)!

> Correspondingly, a matched beam size is calculated from the beta function and the emittance of the injected beam.
Injection Tolerance

> A tolerance for doubling of the initial emittance is calculated.

> Assumptions:
  - $\delta = 0.1\%$
  - Full dilution

> Injection tolerances for the considered SINBAD case (100 MeV):

$10 \, \mu m \rightarrow 1 \, \mu m$
Dilution and Divergence

- For the assumed energy spread (0.1%) the length required for full dilution can be calculated.
- For the SINBAD case at low densities, oscillations would not dilute.
- A **1 sigma beam oscillation would lead to outgoing beam angles between 0 and 5 mrad**, depending on the integrated phase advance in the plasma cell.
- Must be taken into account…