LESSONS LEARNED AND PERSPECTIVES FOR A MORE EFFECTIVE EXPLOITATION OF THE INDUSTRIAL POTENITAL IN ACCELERATOR MAGNET PROJECTS

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BILFINGER

Content

01

INTRODUCTION

Accelerator Magnets
@ Bilfinger Nuclear & Energy Transition

Bilfinger Nuclear & Energy Transition GmbH

BILFINGER

Bilfinger Noell
+
Bilfinger Energy &Technology

Bilfinger Nuclear & Energy Transition

2 Bilfinger companies merged to operate under the same name

→ Offer more services from one source

- Relationships will be continued as usual by existing contacts under the umrella of the new company:
  - Meet the same people
  - Contact us with same coordinates (email, phone)
  - Find us at the same site.

BILFINGER CORE COMPETENCES

Engineering

Multi-physics approach towards complex engineering tasks for custom design solutions

Vacuum technology

Extensive experience in the design and manufacture of complex UHV components and vacuum vessels

Cryogenics

Highly efficient design of both helium and conduction-cooled systems down to 2 K

Series production

Optimization of complex manufacturing processes from small-scale to series production

Testing capabilities

Trained personnel and specialized equipment for cryogenic and vacuum testing in-house

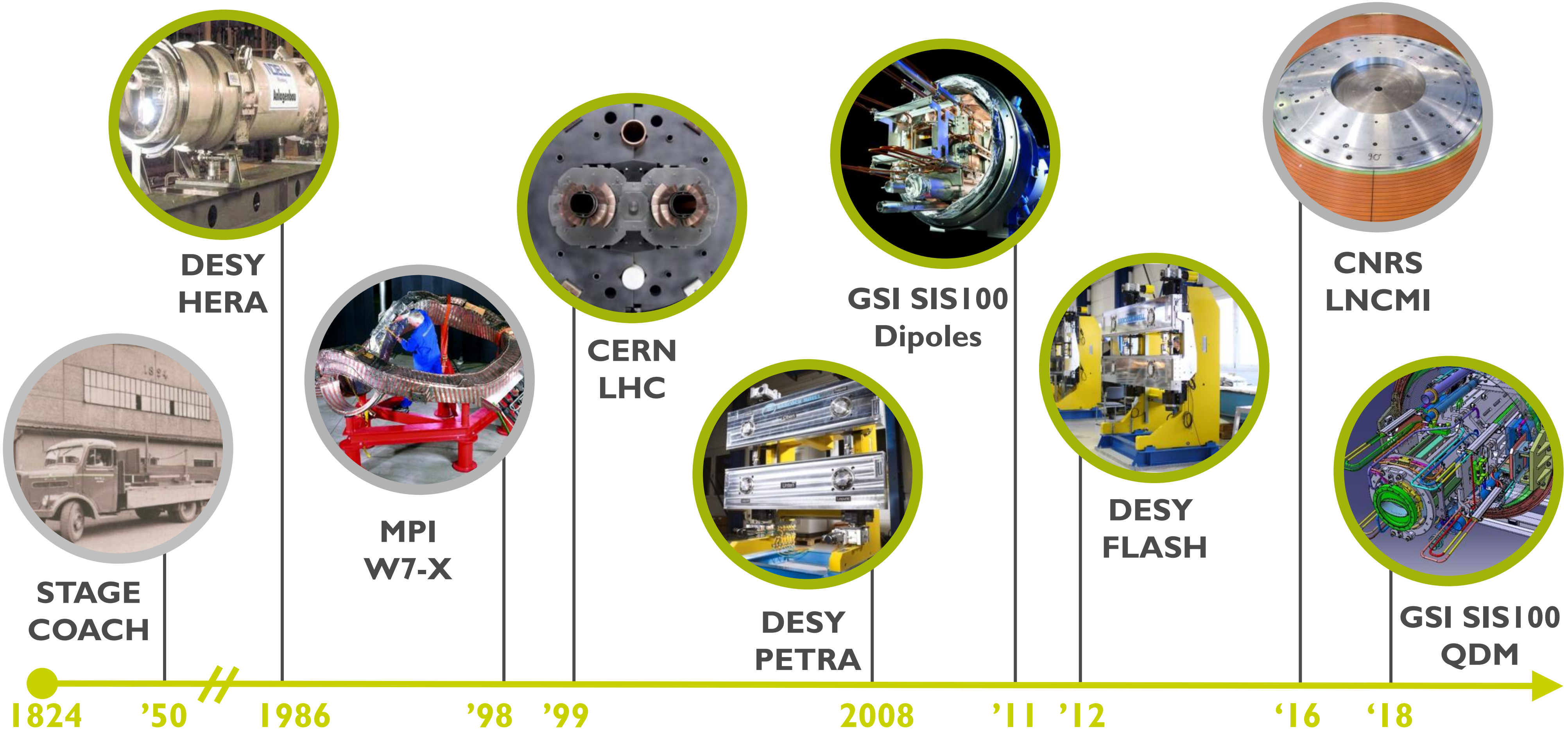
Magnet technology

Wide range of experience in superconducting (LTS and HTS) as well as resistive and permanent magnets

Specialized hardware

Special tooling and equipment including winding and cabling machines and furnaces for impregnation

SERIES production at BILFINGER
A history of performance



Series Production Example: Main Dipole Magnets for the LHC

Development Phase (Paid learning)

- 1990: 10 m Prototype Cold Masses
- 1995: 10 m All Kapton Collared Coil
- 1999: Preparation for Series Production

Series Production

- 1999: 30 Cold Masses
- 2002 - 2006: 386 Cold Masses

16 years from first R&D contract until completion of series

Next Generation Nb3Sn Dipoles

2014 - 2017: Onsite industrial development @ CERN

Series Production Example: FAIR SIS 100 Dipoles

2004 – 07: **EU-FP6 Task:**

GSI with partners from institutes and industries

2007 – 08: **First straight prototype**

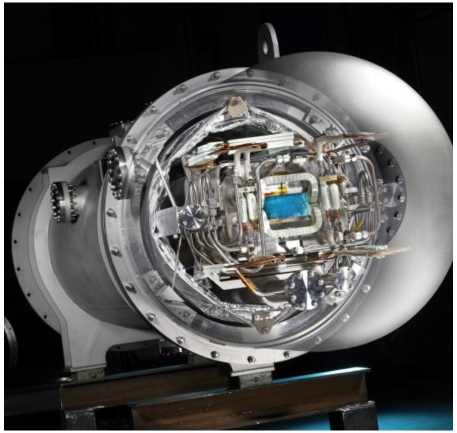
2012 – 13: **First of series - FOS**

- Industrial manufacturing of the SC cable
- Qualification for the industrial series production

2016 – 20: **Series production**

- Cable production & Manufacturing of 110 dipoles

16 years from first contract until completion of series



Series Production Example: FAIR SIS 100 Quadrupole Dublett Modules

<u>Integration of QDM Modules:</u>

2018: Start of project

2019: Delivery of First of series - FOS

2020: Start of series production

13 QDM manufactured until Stop of Unit deliveries

2023: Production on hold due to Ukraine crisis

2024: Re-start of series production of remaining 70 QDM this summer, new units expected

2027: Completion of series production planned

02

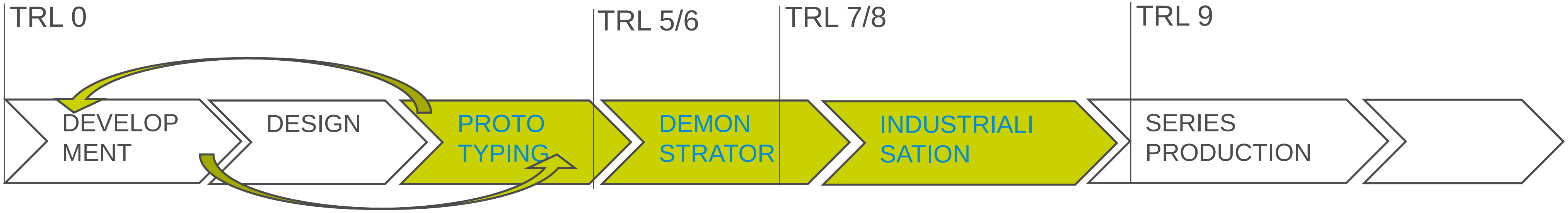
MAGNETS FOR BIG SCIENCE PROJECTS

Interaction: Labs – Industry in Stages
Requirements from Industry
Lessons Learned

Classical Project Oriented Collaboration

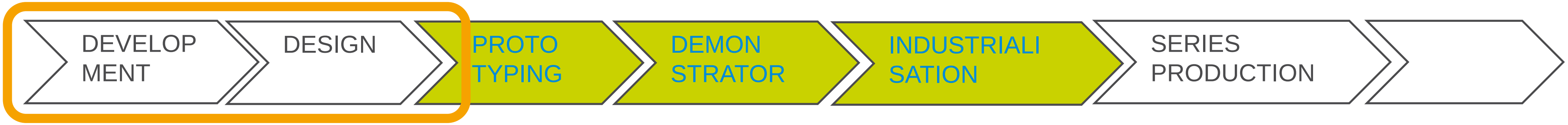
General setup of successful large scale magnet projects always similar:

e.g. LHC Dipoles, FAIR SIS100 Dipols + QDM but also e.g. W7-X coils …



Collaboration between research labs and industry over many years and multiple contracts essential.

Development & Design Phase



Main work-load at Labs

Industrial input valuable:

- Industrial feedback from previous projects
- Input to cost, risk, industrial feasibility
- Early industrial input to the design

Typical industrial contributions:

- Analysis of cost, production schedule, industrial feasibility
- Participation in design process:
    - validate manufacturing concept incl. tooling concept
    - Introduce proven and robust industrial solutions based on manufacturing experience

Development & Design Phase - Examples

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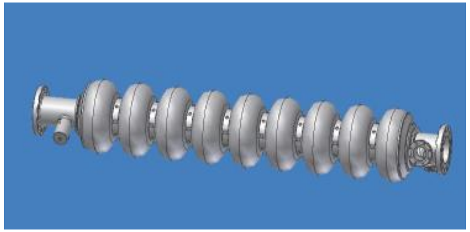
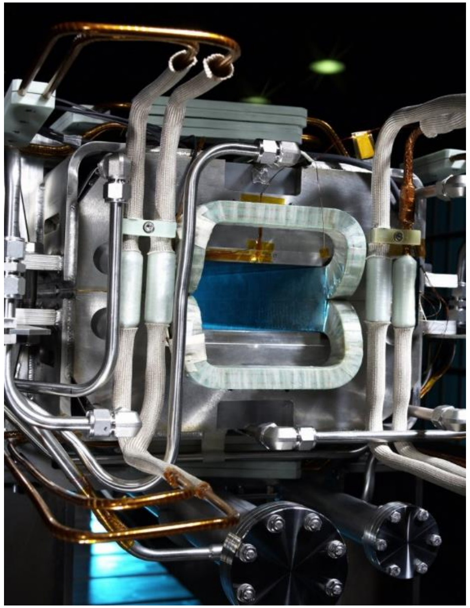
TESLA / XFEL:

- Industrial analysis of production process
- Heat treatment of cavities identified as expensive bottleneck in the production
- Following DESY R&D work eliminated the bottleneck

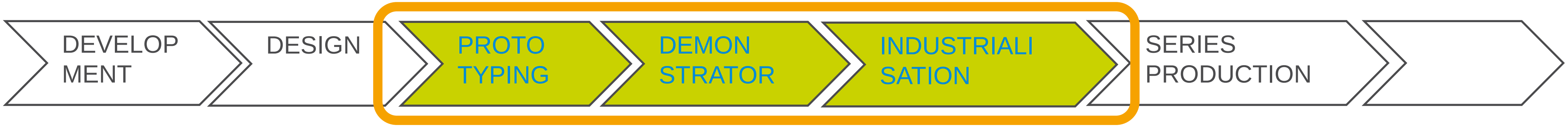


FAIR SIS100:

- Collaboration of lab and industry on magnet design in FP6 project
- Industry identified Aluminumoxide structure as cost driver and manufacturing risk
- GSI eliminated the component from the design



Prototyping and Industrialization



Shared work between labs and industry

Prototyping → important step towards hardware!

Importance of industrial prototyping:

- Transfer of know-how and experience from labs to industry preferably at industry workshop
- Input from industry on robust manufacturing concepts and processes based on series experience
- Input from industry on tooling concepts for efficient series production with consistent quality
- Mutual design optimization to
    - Improve consistent magnet quality
    - Make production process robust and repeatable
- Develop quality criteria for series (specify only what’s needed and not more, give margin to work with)

Prototyping Phase - Examples

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LHC Main Dipoles:

- Development of tooling & qualification with industustrial prototypes (e.g winding machine)

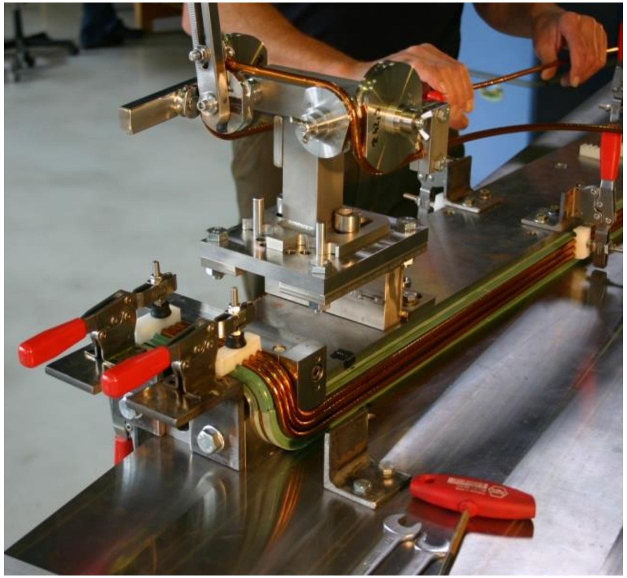
XFEL Undulators:

- Manufacturing of industrial prototypes with 316LN and Aluminum beams to qualifiy both technologies

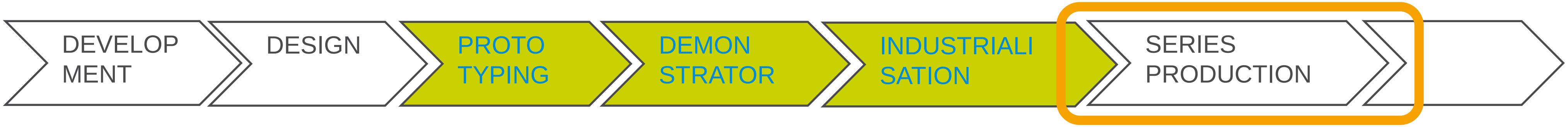
FAIR SIS100:

- Industrial prototype to qualify e.g. Kapton as cable insulation (instead of Prepreg) and the use of machined G11 structures to position the windings

- Robust series production: store-able cable and consistent coil geometry



Series Production



Work load highest at industry.

Important factors for a successful series production

- Design freeze prior to series manufacturing
- Robust and realistic planning incl. risk mitigation measures by industry, labs and probably sub-contractors including contingencies (schedule, supplies)
- Problem solving mechanisms and awareness that small problems can have big effects in a series
- Open collaboration and trust

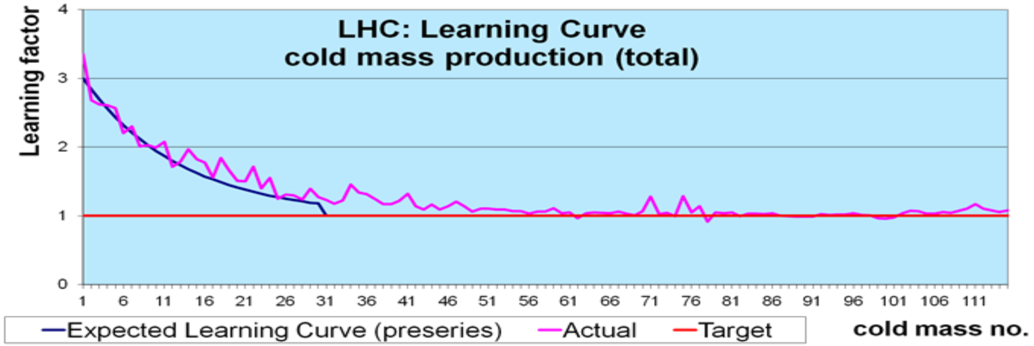
Series Production – Example

LHC:

- Largest series production of high field accelerator magnets
- Very good and consistant quality produced by industry
- Huge bubble project business managed by companies
- Industry had freedom to produce at their site with their tooling concepts
- Labs assured consistency with test procedures, equipment and monitoring test results.

For Industry:

- Spin-off for other industry products is limited
- Business itself is interesting project business
- Projects are important as experience and reference for other large scale research projects



FAIR SIS100 Dipoles: Experience of GSI and Bilfinger

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- 2004-2007: Development with Industry cable insulation, coil structure — ← Early involvement of industry -> more robust design
- 2007-2008: Prototype Dipole 2-layer straight magnet — ← Industrial prototype -> verification in industry

  ← 4-years gap: people left, 1 company out of business…
- 2012-2013: First of Series (FoS) Dipole 1-layer curved magnet — ← Major design change at late stage
- 2013-2016: Cold test and yoke modification — ← Lead to additional development and qualification
- 11/2016: Start of SIS100 Dipole series production — Successful series production in good collaboration between GSI and Bilfinger Noell results in high quality magnets
- 09/2017: First series dipole has been delivered
- 12/2020: Last series dipole delivered

Requirements from Industry

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Basic condition: industry must earn money and must not go bankrupt fullfilling is obligations.

→ Fair sharing of risks and chances is essential! Make risks manageable for companies:

- Limit contractual risks to acceptable values
- Split technical risks into foreseeable portions using appropriate contractual concepts:
  - Split contract into stages where only first stage is binding
  - Cost + fee concept makes sense when quantitative risk is high
- Talk and negotiate risks with industry. Use negotiated procedures not submission for calls for tender
- Utilize existing EU concepts for collaboration e.g. “innovation partnership”

Labs will benefit:

Support Industry

EU: industrial suppliers can manage large scale high-tech magnet projects.
Know-how, experience and infrastructure available at the companies.

→This asset should be fostered by EU labs with:

Continuous basic work load for industry to keep and extend industrial know-how.

→This requires a long term strategy and roadmap incl. collaboration of research and industry.

- Existing involvement of industry in planning and strategy for big science projects is very welcome by industry.
- Perspectives on the future projects (scope, timeline, in-kind situation) are necessary to promote projects in industrial landscape.

→ Continuous information of and collaboration with industry enables industry to be ready for the next big series production of superconducting magnets

03

PRODUCTS

TR-Level: Labs & Industry Requirements from Industry Lessons Learned

Types of Collaboration by TRL Level

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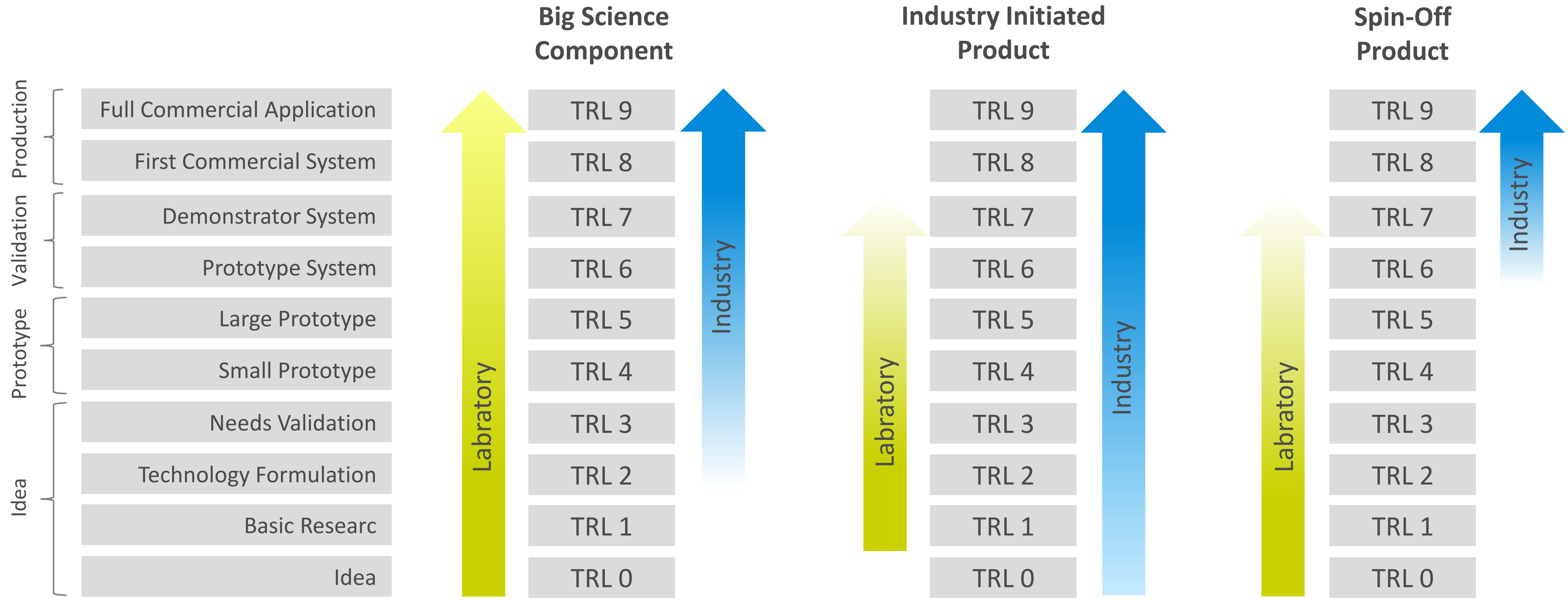

Types of Collaboration by Examples

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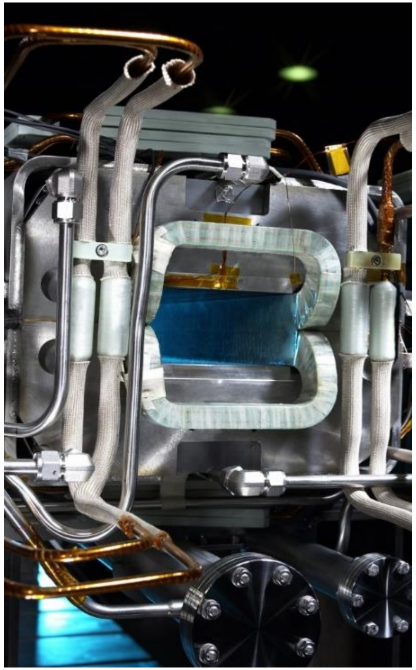
Big Science Component

Labratory



Industry

FAIR SIS100 Dipoles

Industry Initiated Product

Labratory

Industry

Flywheel Storage

Spin-Off Product

Labratory

Industry

PINE Cloud Chamber

Spin-Off Product – PINE Cloud Chamber

- KIT‘s Institute of Meteorology and Climate Research Atmospheric Aerosol Research developed and validated a working protoype
- Bilfinger industrialzed the design (thermal, etc.)

- KIT has active interest in wide spread use of PINE to do research
- Bilfinger is selling the device successfully
- Partners actively working on continuation and development of PINE

Lessons Learned:

- Win-win match between partners with clear interfaces (validated prototype), but match happened by coincidence
- Short time-to-market and calculable risks → attractive for industry
- World-wide spread of KIT technology standard and industrial third party funds → attractive for laboratory

Industry Initiaded Product – Flywheel Energy Storage

UPS

Power Quality

- Development of 2 flywheels with superconducting bearing for
  - UPS (250 kVA, 2.5 kWh, high availability): in-house
  - Power Quality (500 kVA, 5 kWh, high cycle life): 2 BMWi projects with Uni and DLR Braunschweig and with KIT and NHF

- Feasibility demonstrated. Effort to bring novel product to market still high.
- Project stopped due to degraded market expectations.

Lessons Learned:

- Development of target market over years → high commercial risk
- Expertise & infrastructure of laboratories → help mitigate technological risk
- Continuous financial and technical project review important

Industry Product – Superconducting Insertion Device

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- Kicked off as a supply contract for a SCU, developed into a cooperation agreement KIT with Bilfinger.
- KIT active on further development of insertion devices and equipment to meassure and test the devices
- Bilfinger is selling superconducting insertion devices as product platform for undulators and wigglers worldwide

Lessons Learned:

- Win-win match between partners with clear interfaces, but project not identified as high risk multiple year product development by both partners from the start
- In retrospective: development program in steps with overseeable, shared risks more appropriate

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04

SUMMARY & CONCLUSIONS

Conclusions & Lessons Learned – Big Science Projects

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High field accelerator magnets are a bubble project business with potentially high risk also for industry.

- Fair sharing of risks is important:
  - Be transparent on risks, negotiate: negotiated procedure
  - Limit contractual risks (liability ≤ 100%, total penalties ≤ 10%)
  - Split risks (staged contract, cost + fee)

- European industry is an asset that should be fostered:
  - Provide continuous workload by involving industry at all project stages
  - Industry provides special know-how and experience also at early stage and should be compensated for that
  - Reliable and clear project planning helps (schedule, basic technical solutions, in-kind situation)

Conclusions & Lessons Learned – Science vs. Products

Clear distinction between different cases is important:

- Science initiated development e.g. for Big Science Projects
- Spin-off product from Lab development
- Supply contract (no significant development character)
- Industry initiated product development

Each case has different boundary conditions and requires different tools for collaboration

Thank you for your attention.