Knowledge Exchange through Collaborations with Industry Partners: A Perspective from a University Group

Georg Steinbrück, Hamburg University

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Knowledge Exchange

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- Detectors in experimental physics are custom made devices
- They are developed by the research groups who later use them for their experiments
- The production of such detectors requires industrial processes
- Mutual understanding of our experimental needs and the technologies offered by the companies is critical
- Adaptations of the processes might be required
- **Open collaborations with industry partners are essential for the field of instrumentation for experimental physics**

- We will give four examples of knowledge exchange with companies and explain how knowledge exchange boosts technology advancements

Example 1: Fine Pitch Bump Bonding

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Project: Hybridisation of pixel modules for the CMS Inner Tracker

The challenge:

- Fine pitch bump bonding of pixel sensors to readout ASICs
- 6000 Inner Tracker modules, 580 k bumps per module with < permille failure rate, 50x50 μm^2 bump bond pitch, 150 µm thick sensors and FE ASICs, 300 mm FE wafers
- Yield of individual process steps > 90 %: Sensors and FE chips are expensive and downstream losses have to be minimized

The process:

- Step 1: identify vendors capable of fulfilling our specifications
- Step 2: vendor qualification - Knowledge exchange between industry and academia
- Step 3: tender, contract and production

Example hybridization CMS

- Step 1: O(10) companies identified
- Step 2: Dedicated R&D for vendor qualification with a subset → qualification →tendering

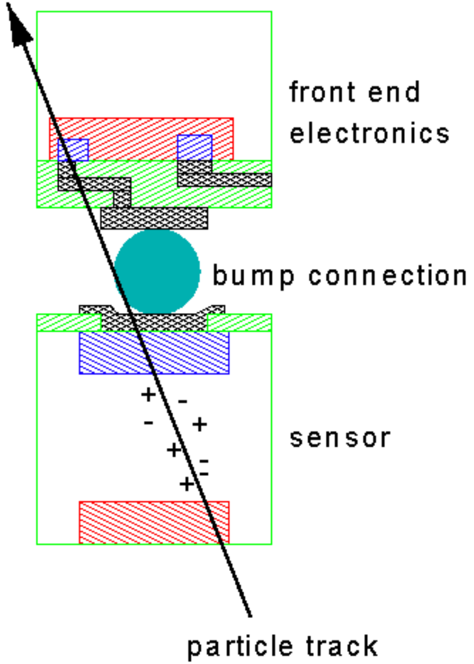
Example 1: Fine Pitch Bump Bonding

Fraunhofer society of Germany

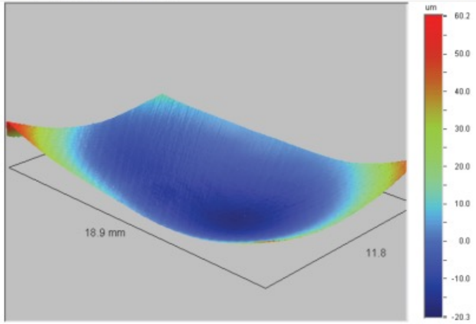
- Leading applied research organization, 76 institutes and research units throughout Germany, 30,000 employees, annual budget of 3.0 billion €, of which 2.6 billion € are contract research

IZM Fraunhofer (Institute for Reliability and Microintegration) Berlin

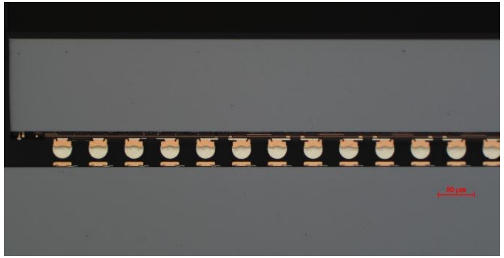
- Long standing partner for CMS (and ATLAS) bump bonding since 2003 for CMS (ATLAS since 2000)
- R&D for Phase 2 Upgrade started in 2016
- Projects in research institutes often rather long term compared to industry, relatively low volume, small investments over a long time
- IZM developed special process for thin (150 µm) FE wafers with glass carrier
- Special need: Many different FE chips and sensor types during R&D phase, requiring different work flows



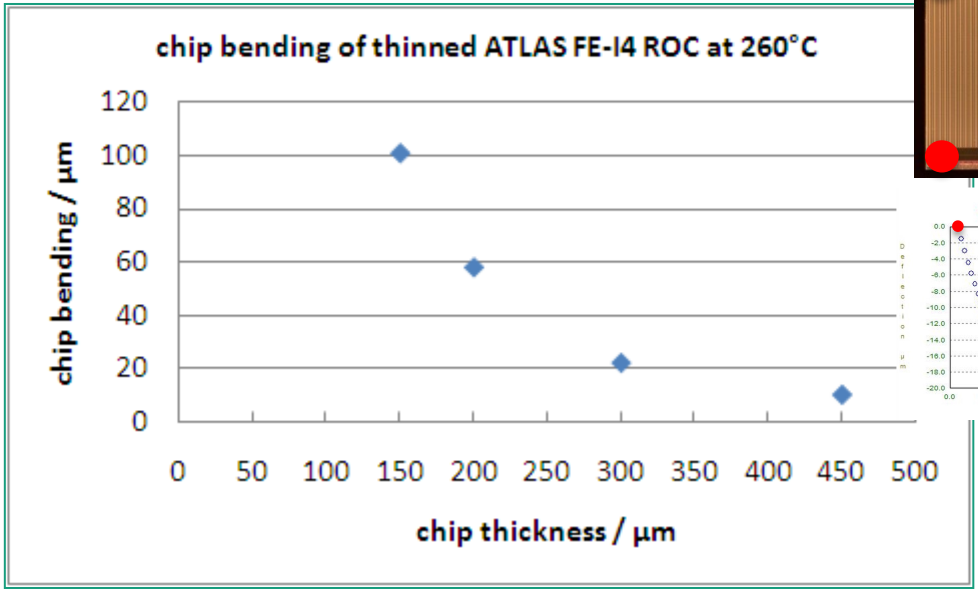
Problem: Warpage of Thinnend Chips

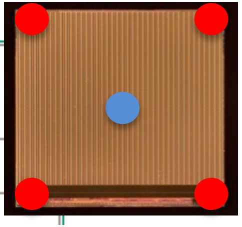


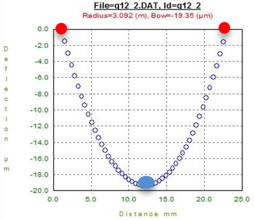
TDCPix chip with thickness 50µm warpage at room temperature



Open bump connection due to chip warpage at bonding temperature



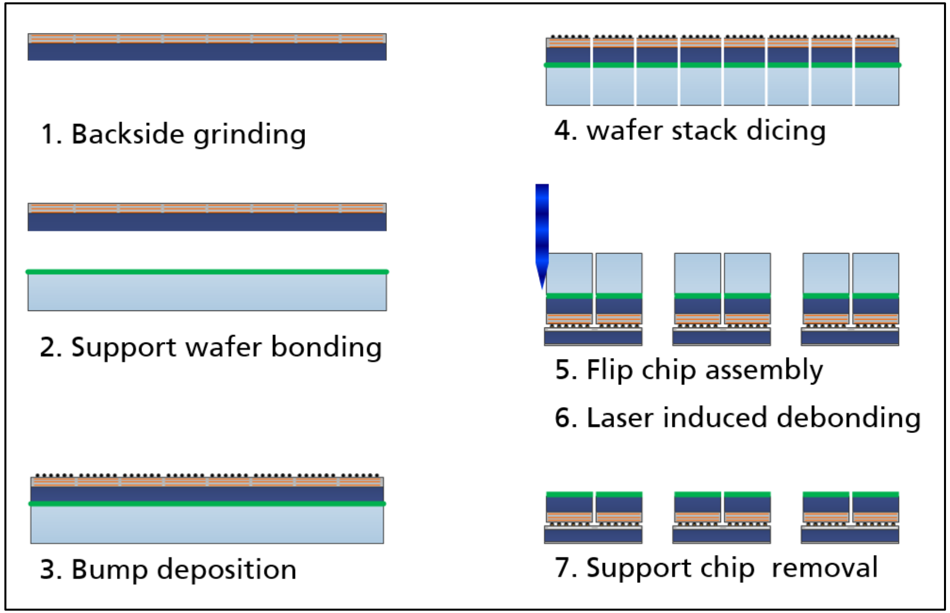


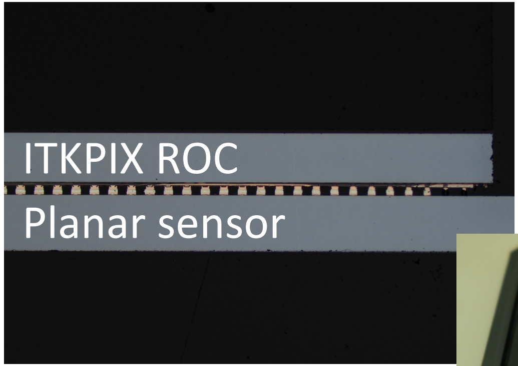


Chip bending measured on FE-I4 ROCs

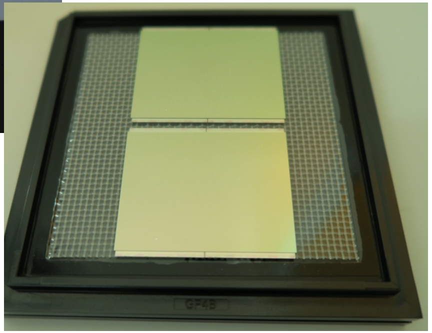
Single chips thinned to several thicknesses

IZM Technology Development: Bump Bonding with Temporary Carrier





all bumps well connected



CROC 2x2 quad chip module, planar sensor side up

General process flow:
Bump bonding with temporary carrier
Process available for 8” and 12” wafer size

Custom work flow

Cross section of assembled hybrid module and 4-chip module using the temporary carrier process
readout chip: size approx. 2x2 cm², thickness 150µm

Example 2: Silicon Sensors

Project: Radiation hard silicon sensors for Extreme Fluences beyond 10^{15} cm^{-2} 1 MeV n_{eq}

The challenge:

- To operate Silicon in extreme radiation environments
- Minimize increase of leakage current, signal reduction, power consumption, noise, ….
- Understanding of radiation induces defects in the Silicon bandgap

The Process:

- Dedicated R&D production of silicon structures
- Test special materials not used in mass production
- Open exchange of process parameters as input for process simulation

Example 2: Silicon Sensors

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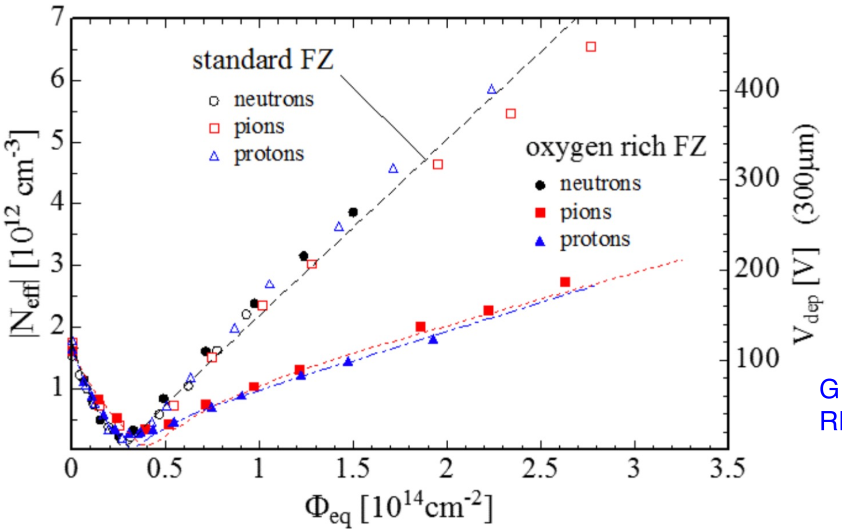
CiS Erfurt

- CiS Research Institute for Micro Sensors https://www.cismst.de/en/welcome/
- Long standing partner for CMS: first and current CMS pixel detectors use CiS sensors
- R&D with Hamburg Uni within CERN RD48/RD50 collaboration started 1995, with CiS in 2000
- Early results (Lindström et al., Hamburg model) led to the knowledge that oxygen rich Si is beneficial



Reduced depletion voltage in [O]-rich Si

G. Lindström et al., Radiation hard silicon detectors - developments by the RD48 (ROSE) collaboration, NIM A 466 (2001) 308–326

Example 2: Silicon Sensors

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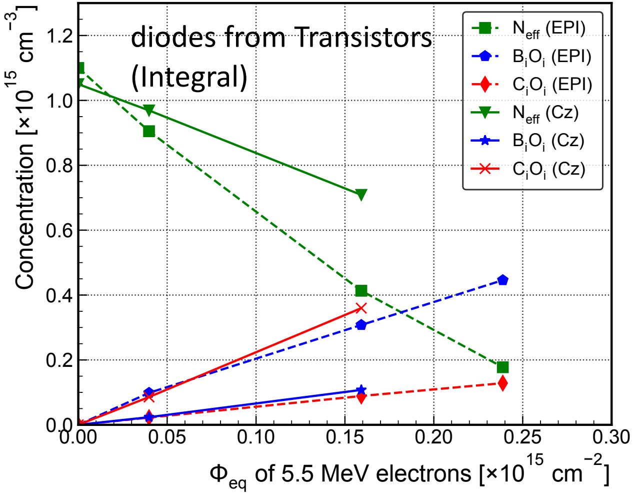
- Long standing partner for CMS: first and current CMS pixel detectors use CiS sensors
- R&D with Hamburg Uni within CERN RD48/RD50 collaboration started 1995, with CiS in 2000
- **Latest R&D: Carbon enriched Si to reduce Boron removal,**
- Step1: Comparison of EPI and Cz, **Step 2: Intentional Carbon co-implantation: CiS project started**



Small investments over a long time

Carbon enriched Si: [C] larger for Cz than EPI
→Boron removal reduced

Investigation of the Boron removal effect induced by 5.5MeV electrons on highly doped EPI- and Cz-silicon, C. Liao et al., accepted by NIM A

Example 3: Single Photon Detection in Radiation Environment

Project: Radiation Hard Silicon Photomultipliers

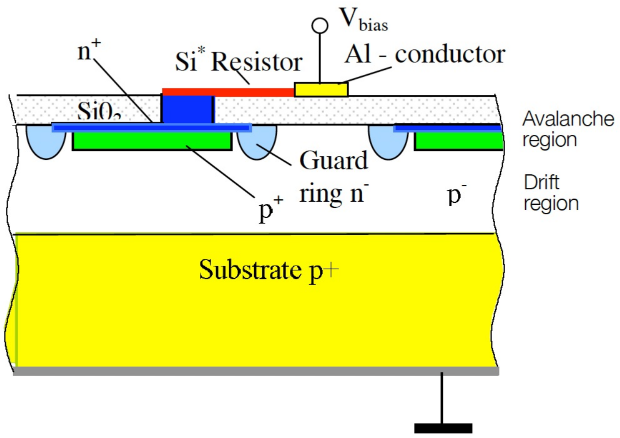
The challenge:

- To operate Silicon Photomultipliers in high radiation environments
- Minimize increase of leakage current (dark count rate), noise
- Understanding of damage mechanisms in SiPMs

The Process

- Dedicated R&D production of silicon structures with gain
- Novel implant designs
- Open exchange of layout parameters as input for device simulation

- **SiPMs: planar devices operated in Geiger mode**



[P. Buzhan et al., ICFA Inst. Bull. 23 (2001) 28]

Example 3: Si Photomultiplyers in Radiation Environment

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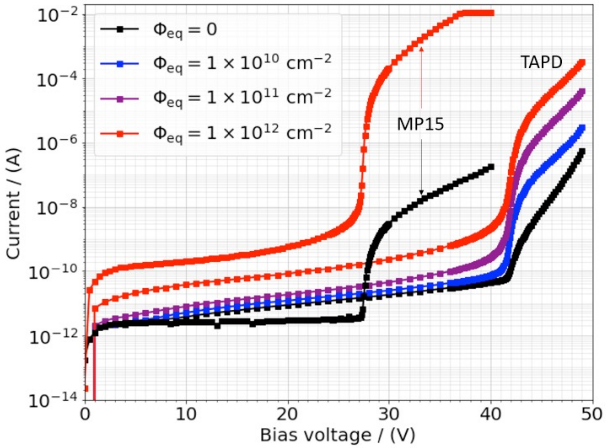
Ketek (https://www.ketek.net)

- Research oriented company based in Munich specialized in Si drift detectors and photonics
- R&D with Hamburg Uni and DESY since 2010 on High granular Calorimeters (Calice HCAL)
- Specialized in R&D and less in mass production
  → SiPM branch of KETEK acquired by Broadcom (https://www.broadcom.com)

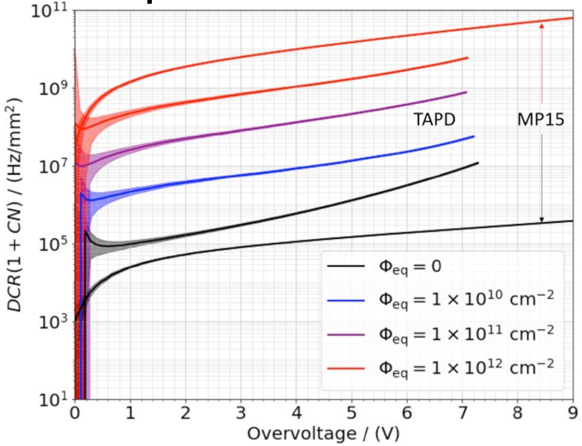
Example 3: Si Photomultiplyers in Radiation Environment

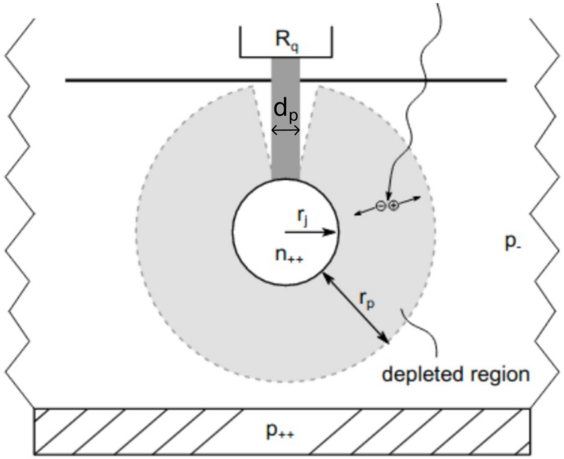
Sample results

- Novel device: spherical implant developed for extension of sensitivity to red light (→Lidar*), potentially improving radiation hardness
- Synergy: Development for industry →useful for HEP research in a different context →feedback to company



Improved dark count rate





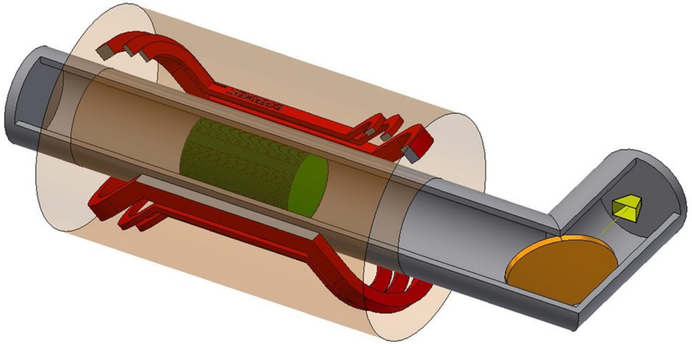
tip avalanche photo-diode (TAPD)

Make use of commercial development: Synergy

* Lidar: Light Detection and Ranging: used for navigation of autonomous cars

Example 4: Piezo Actuators

Project: Piezo actuators for the MADMAX booster system for positioning of dielectric discs



The challenge:

- Axion dark matter
- Actuators that work in vacuum, magnetic field up to 10 T, at 4 K, with long stroke (up to a meter), and with high precision (better than 10 µm)

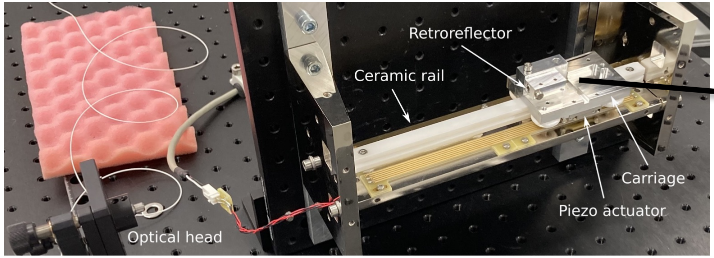
The Process

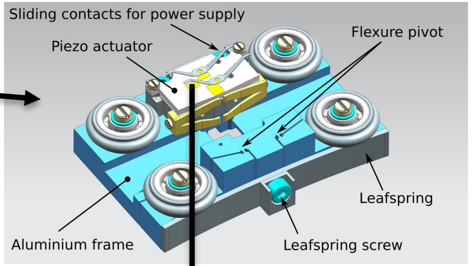
- Market survey: Object does not exist
- **J**anssen **P**recision **E**ngineering: Company with experience in cryogenic piezo actuators (www.jpe-innovations.com)
- The company could not test under our conditions: high magnetic field, actuator itself at 4 K
- They now have a product that meets the qualification that can be used in other applications

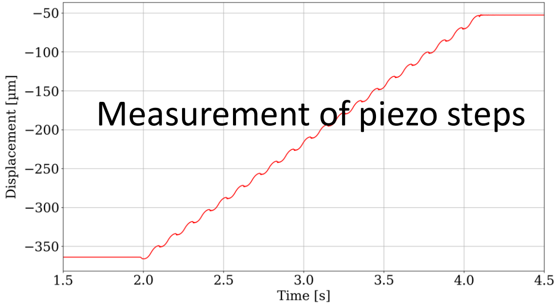
Example 4: Piezo Actuators

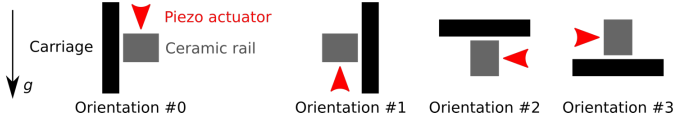
Qualification Process:

- Demonstrator delivered by JPE
- Tested at RT at UHH, at 4 K at MPP and inside 5.3 T (and 5 K) at DESY (ALPS-II test magnet)

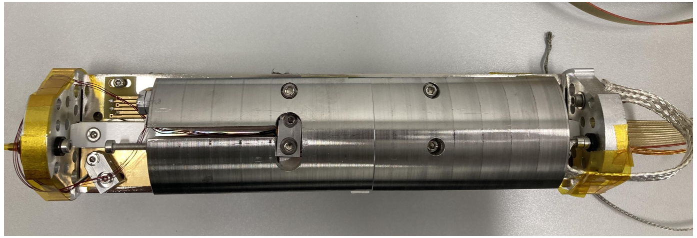


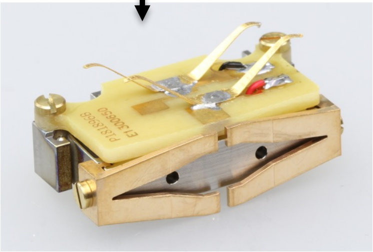


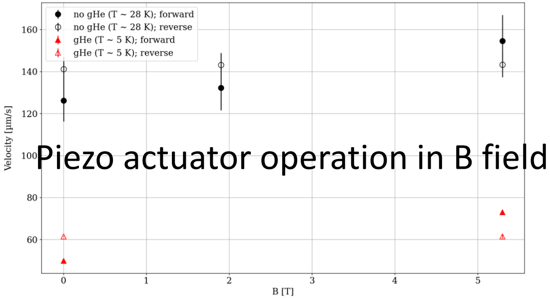




Demonstrator modified for ALPS-II test magnet







E. Garutti *et al* 2023 *JINST* **18** P08011
https://arxiv.org/abs/2305.12808

Lessons learned from knowledge exchange

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Research Institutes	Companies	How to overcome
Long timescales from ideas to final product →15 years	Interested in faster turnaround	Work with R&D SME or break into well defined blocks
Open source policy	Patents, company specific processes	Sign NDAs, define clear boundaries for publication of information
Niche applications and smallish productions	Mass application/ productions	Become active in identifying spinoffs, import existing solutions where possible
Fundamental understanding of underlying science	Often application of existing knowledge	Knowledge exchange via secondments, industry-academia events
Education driven	Market driven	“