HEPHY Vienna
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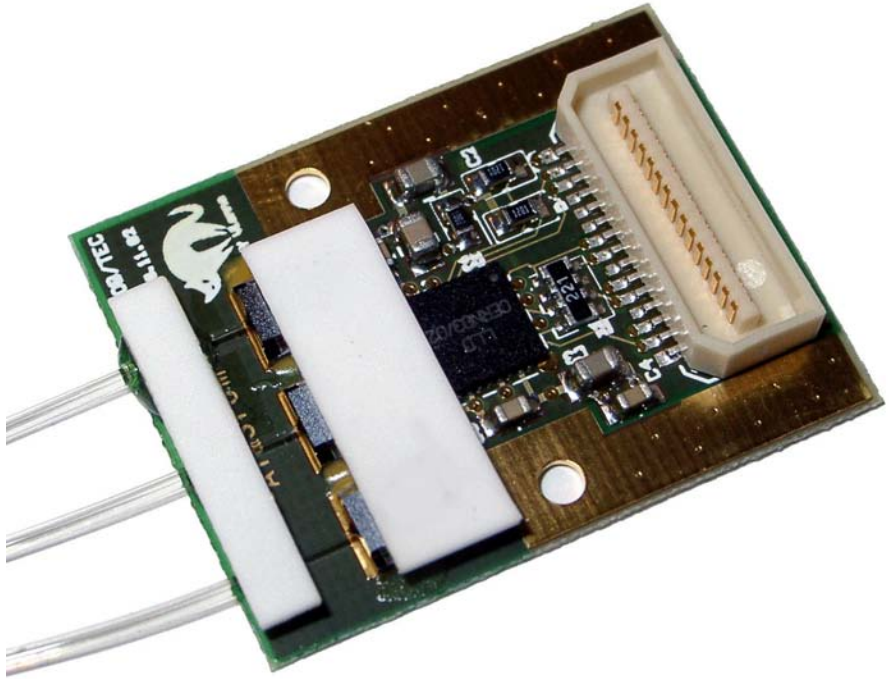
Experience with Large-Scale Industrial Production Considering the CMS Tracker Analog Optohybrids

M. Friedl, M. Pernicka (HEPHY Vienna)

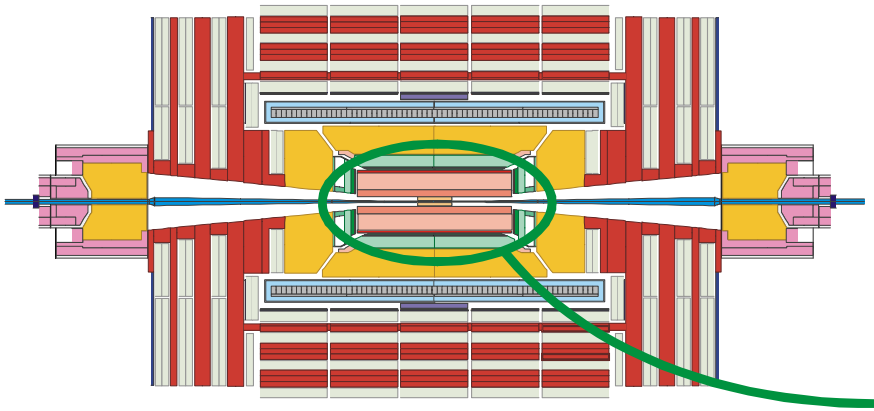


Outline

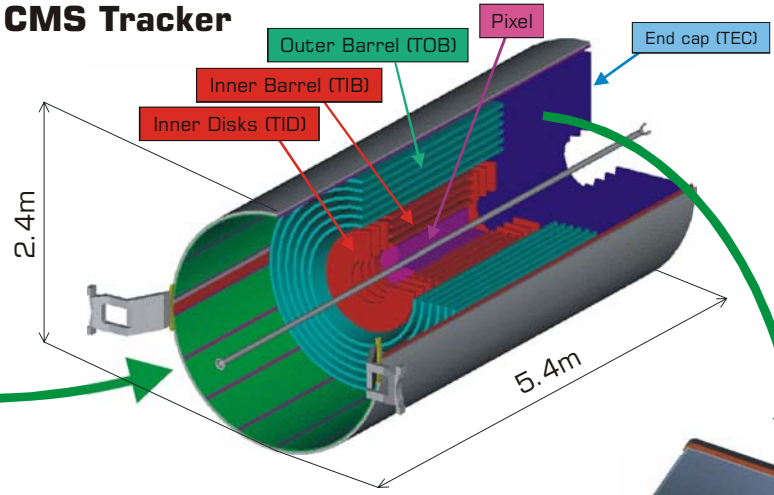
- CMS Tracker Readout
- Devices
- Procedures
- Quality
- Summary

Web http://aoh.hephy.at

CMS Tracker Readout / Overview



CMS Detector



Silicon Detector Module

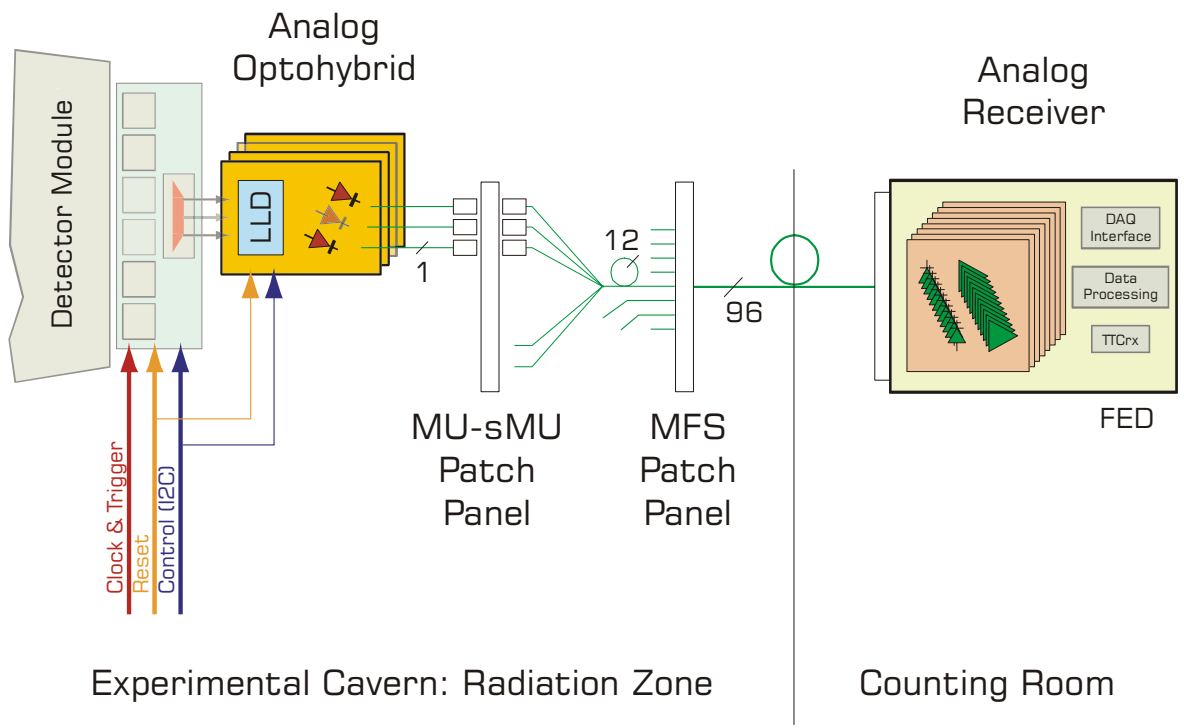
Magnetic field: 4T
Operating temperature: -10°C
10^{15} cm^{-2} particles / 10 years (@ 7 cm)
9.3 million readout strips
206 m^2 sensitive silicon area

Readout

Analog optical readout @ 40MS/s (time-multiplexed strip data)

36k optical fibers, 60…100m long

CMS Tracker Readout / Readout Path



Detector Module	APV25 readout chips + APVMUX multiplexer
Analog Optohybrid	LLD (Linear Laser Driver) + pigtailed laser diodes
Receiver	12-way pin diode array on FED (Front End Driver)

Devices / Choice of Optical Components

Laser

Edge-emitting Fabry-Perot InGaAsP laser diode | VCSEL

- Considered more reliable/matured
- Good linearity

Wavelength

850 | **1310** | 1550 nm

- Little radiation damage in fiber
- Relatively safe for human eye

Fiber type

Single-mode 9μm core | Multi-mode 50μm or 62.5μm core

- "Straight" signal propagation
- Low noise and dispersion

Overall

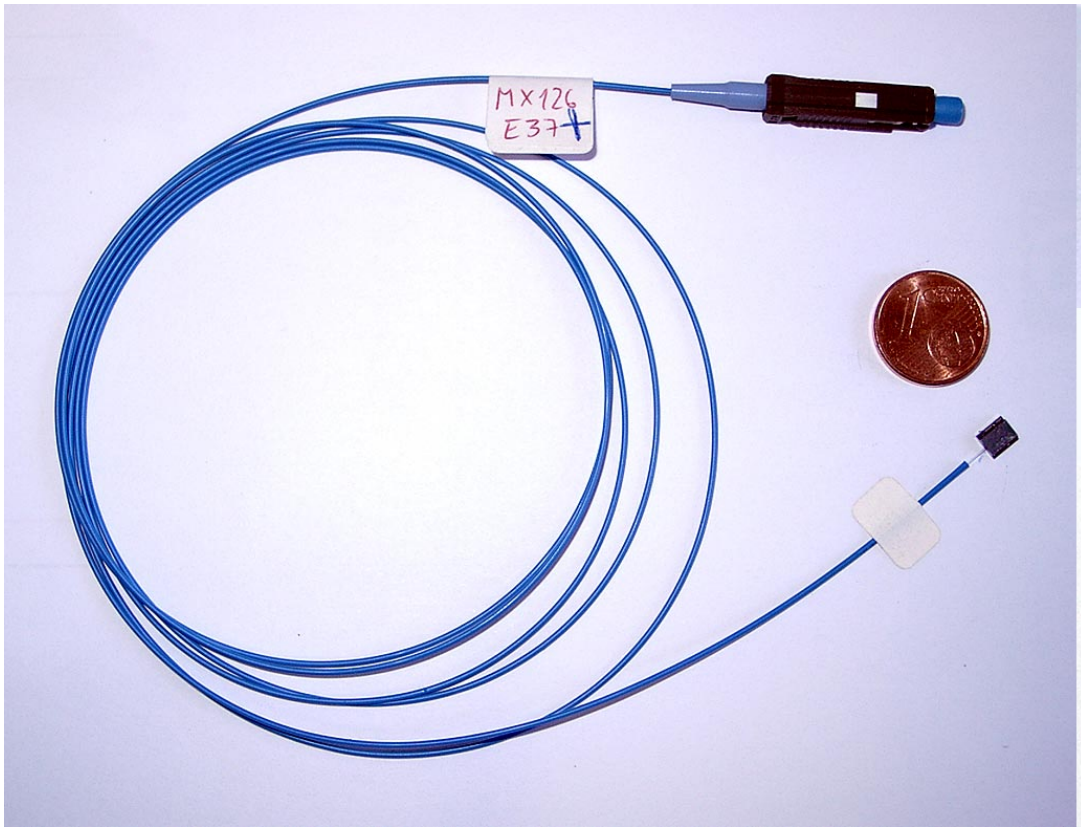
Following long-distance telecom standards; partly COTS

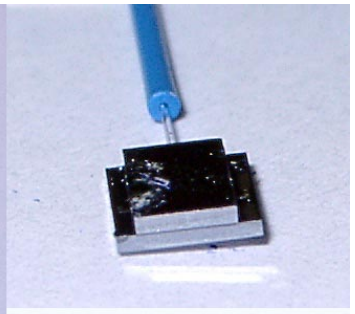
Usage in CMS

Tracker analog readout, ECAL digital readout

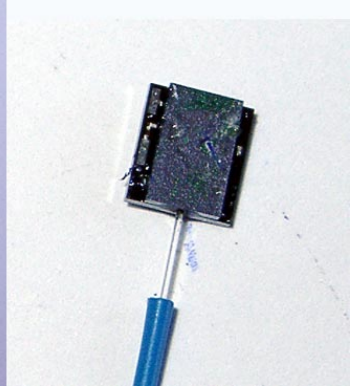
Tracker & ECAL digital control (bi-directional)

Devices / Laser diode



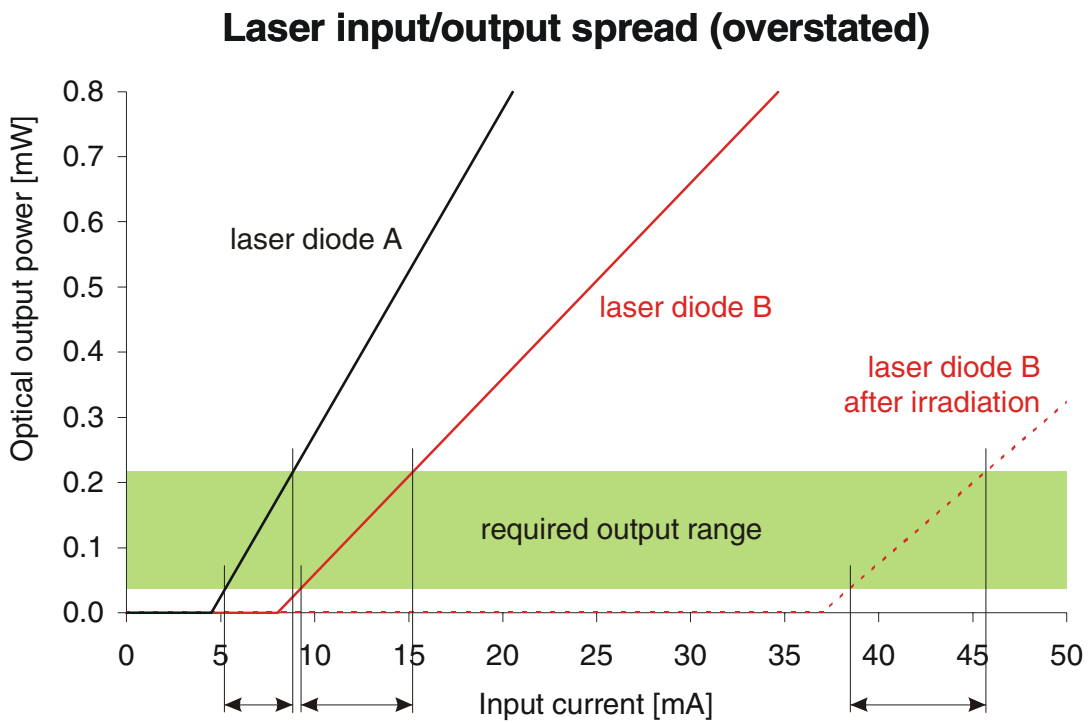


Outer laser dimensions (excluding fiber pigtail): 4 x 4.5 x 1.35 mm^3



Type	Pigtailed single-laser pill (no suitable COTS arrays available)
Connections	Electrical: wire-bonding; Optical: MU connector

Devices / Laser diode

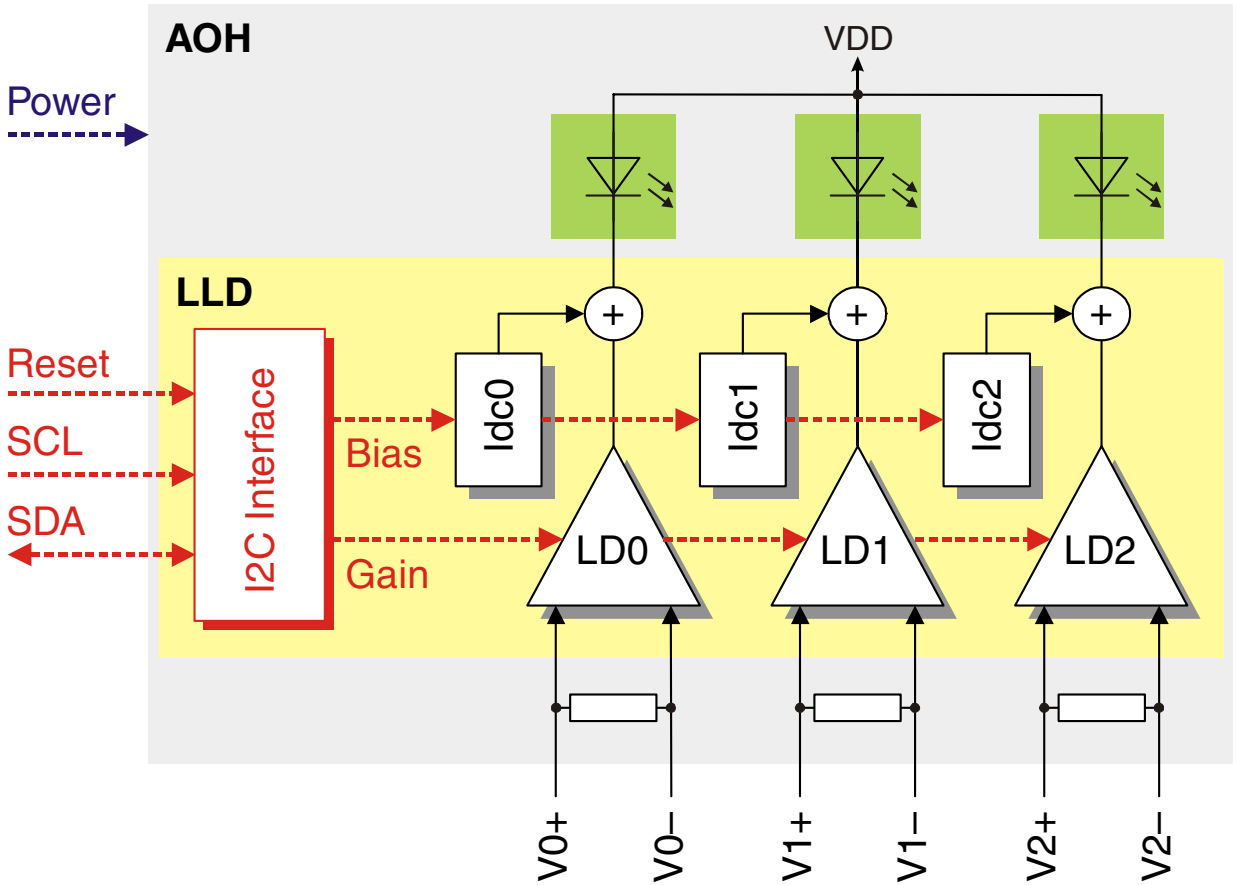


Spread — In threshold and slope efficiency

Radiation — Increases threshold

Solution — Driver with adjustable gain and pre-bias

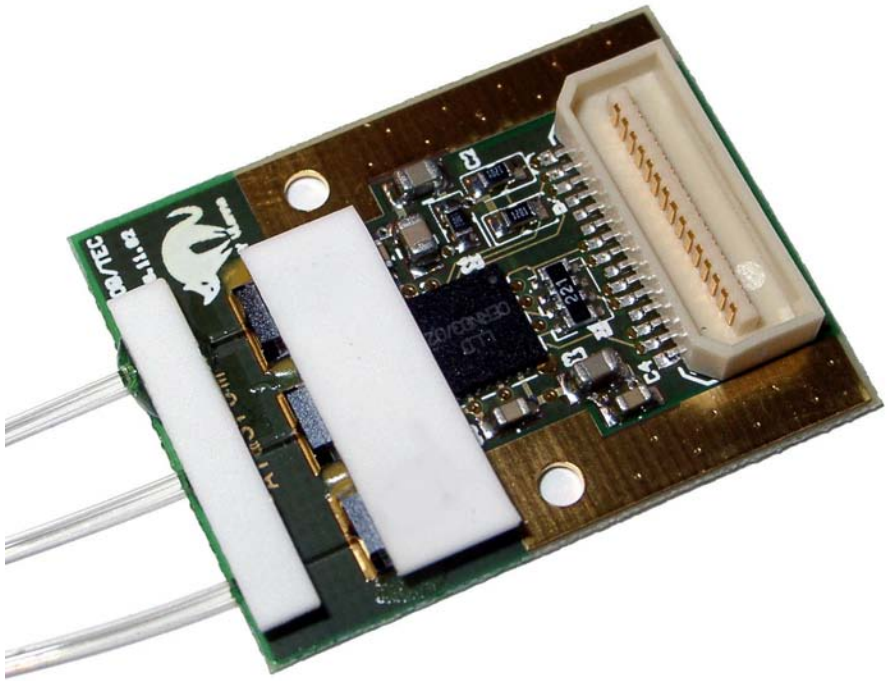
Devices / Analog Optohybrid (AOH)



Contents

Linear Laser Driver (LLD) and 2 or 3 laser diodes

Procedures / Analog Optohybrid (AOH)



Assembly procedure:

1. Fully automatic SMD assembly (without laser diodes)
2. Automatic electrical test
3. Manual laser gluing
4. Manual wire bonding
5. Manual cover gluing
6. Automatic electro-optical test

Steps 3-5 completely done by hand!

Steps 2 and 6 require manual insertion

Overall

Non-standard components and procedures
→ Significant amount of manual work (~10 min) for laser assembly

No issue for laboratory prototypes, but important for series production

Procedures / Costs

Material	1 Laser diode: € 65 (contains ~50...60% of labor)
	Linear Laser Driver ASIC: € 3; PCB: € 1
	SMD components, connector, label: € 2
SMD assembly	€ 2 (automatic)
Labor	€ 16 (mainly laser assembly)
Conclusion	Overall material : labor costs ~ 40 : 60 %
Comparison	Typical industrial electronics production: 80 : 20 %
Why?	Small quantities and special components due to special requirements
	→ High level of automation is not cost-effective

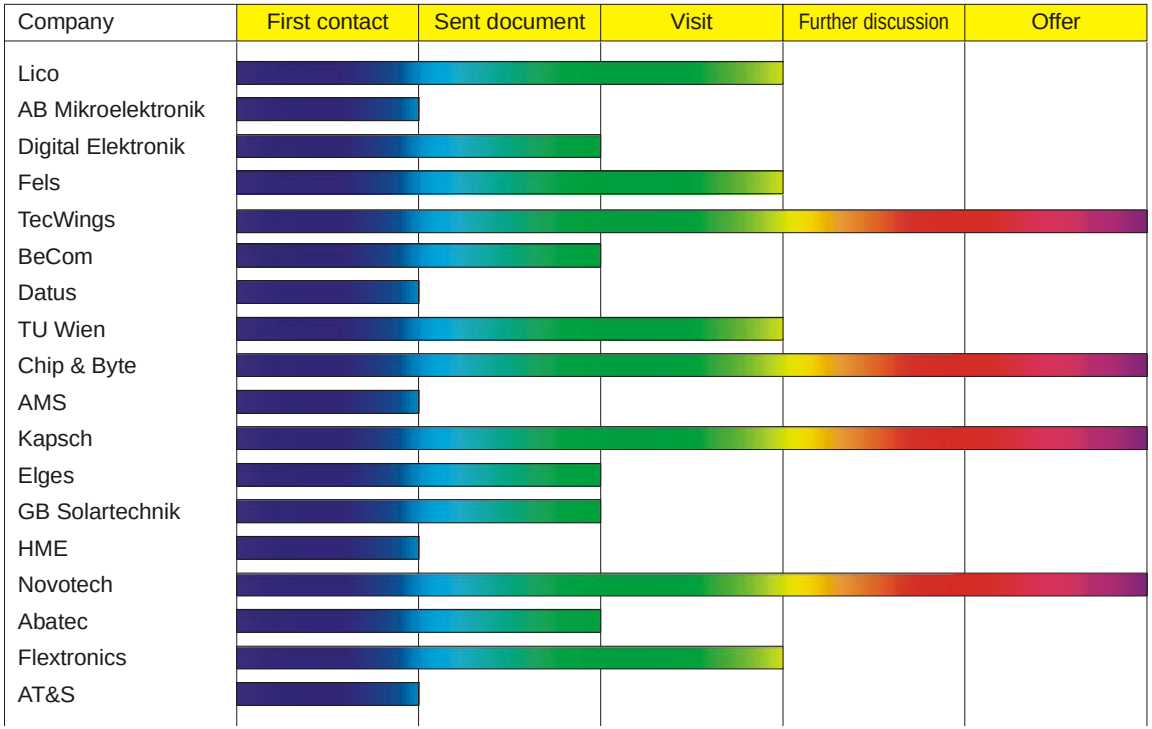
Procedures / Uneconomic Issues

Variants	Total of 22 variants (2 substrates, 2 or 3 lasers, 8 pigtail lengths)
Components	Delivered in several batches with delays
User requests	Small numbers of each variant in parallel
Feedback	Slow feedback from users due to other delays
Logistics	Complicated…
Hypothesis	Profit is not the aim of science, thus scientists do not (primarily) think in economic terms
Conclusion	→ Inevitable paradigmatic differences to industry

Procedures / Company Selection

Requirements

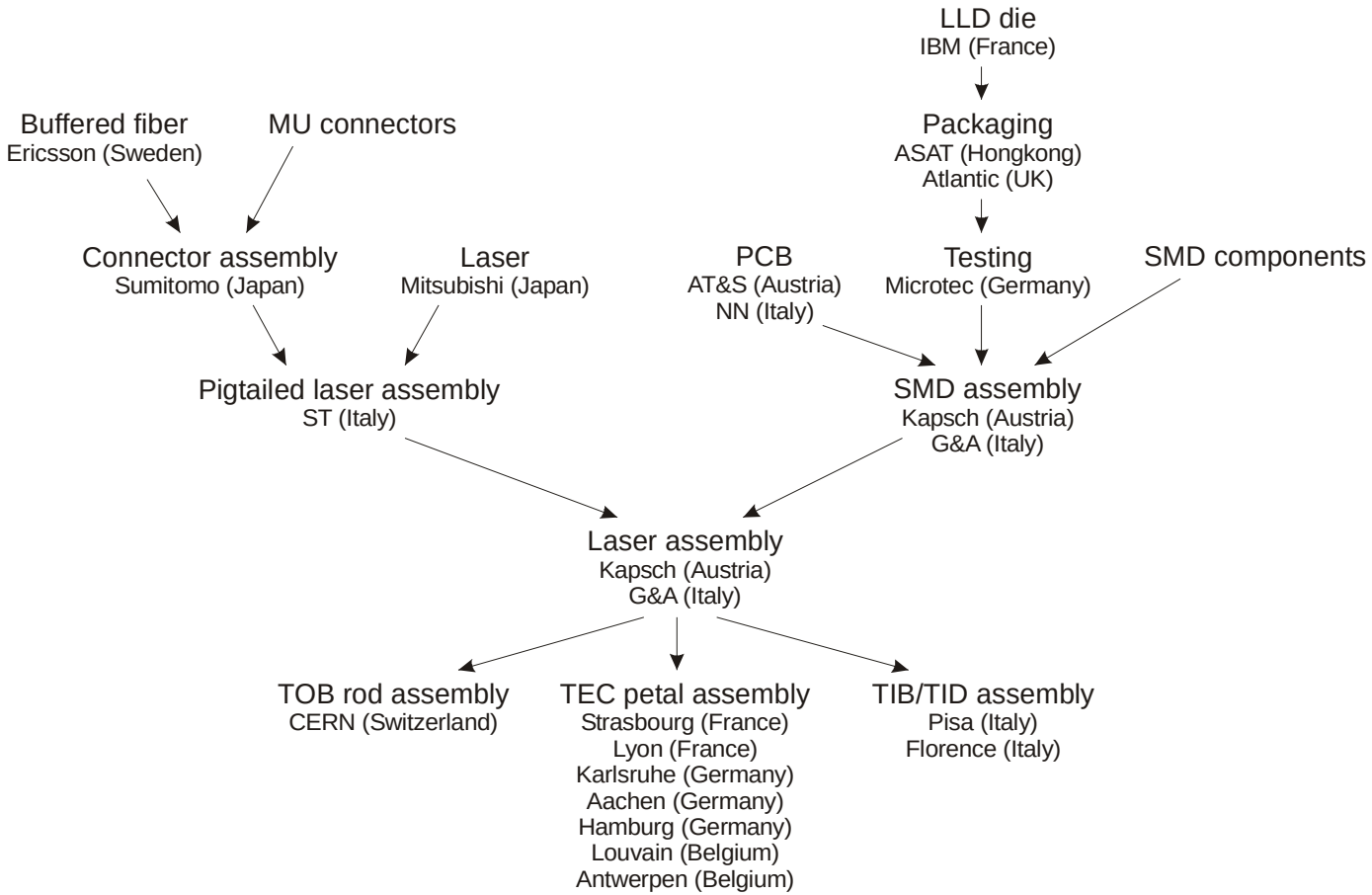
- Special equipment (wire bonding, x-ray inspection, vibration tests, ...)
- Ability to perform large fraction of manual work
- Stable production over ~2 years @ throughput of up to 100 devices/day



- 18 Austrian companies contacted
- Offers from 4 companies
- Prototype production with 2 companies

- Kapsch selected mainly for good experience, proximity and size
- Later got similar contracts for DOH, GOH

Procedures / Logistics



Many possibilities for delays

Procedures / Distribution

Status

Current distribution (8 Sept 2004) of TOB/TEC types

Center	B_2_35	B_2_56	B_2_70	B_2_88	B_3_35	B_3_56	B_3_70	B_3_88	B_3_100	C_2_35	C_2_56	C_2_70	C_2_80	C_2_88	C_2_100	C_3_56	C_3_70	C_3_80	C_3_88	C_3_100	C_3_110	C_3_120	Sum
AACHEN-1	0	0	0	0	0	0	0	0	0	4	2	5	6	5	28	1	2	1	2	2	5	16	79
AACHEN-3B	0	0	0	0	0	0	0	0	0	3	3	5	4	2	0	1	2	1	2	2	3	0	28
CERN	696	724	321	137	127	366	201	285	10	0	2	0	11	6	0	1	10	4	2	2	6	9	2924
COURIER	9	9	36	0	0	13	0	6	0	8	3	8	0	0	0	0	0	0	11	3	0	0	106
HAMBURG	0	0	0	0	0	0	0	0	0	133	101	304	323	135	0	52	87	121	92	41	92	2	1483
LONDON	0	7	0	0	0	0	0	0	61	0	0	0	0	0	0	0	0	0	0	0	0	0	69
KARLSRUHE	0	0	0	0	0	0	0	0	0	6	5	11	8	6	3	3	5	3	5	5	7	4	71
LYON	0	0	0	0	0	0	0	0	0	4	4	7	5	5	16	3	4	3	4	4	5	14	78
SANTA-BARBARA	2	3	2	4	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
STRASBOURG	0	0	0	0	0	0	0	0	0	2	2	5	3	3	0	1	2	1	2	2	3	1	27
VIENNA	76	6	185	243	488	101	6	3	3	195	21	248	0	287	152	143	104	2	1	1	12	61	2340
Sum	783	749	544	384	617	482	209	296	74	355	143	593	360	449	199	205	216	136	121	62	133	107	7224

Distribution

Shipped to several institutes for installation in bigger structures

Similar analog optohybrids for TIB/TID (responsibility INFN Perugia)

Totals

Analog Optohybrid (TOB/TEC: 13k; Kapsch)
Analog Optohybrid (TIB/TID: 4k; G&A)

Similar objects

Digital Optohybrid (Tracker, ECAL: 2k; Kapsch)

Gigabit Optohybrid (ECAL: 11k; Kapsch)

Quality / Qualification

Requirements

Non-standard conditions for devices in CMS Tracker:

- Magnetic field 4 T
- Operating temperature -10°C
- Radiation $3 \cdot 10^{14}$ hadrons/cm^2, 15 MRad gamma dose

Testing

All components were tested and qualified for those criteria

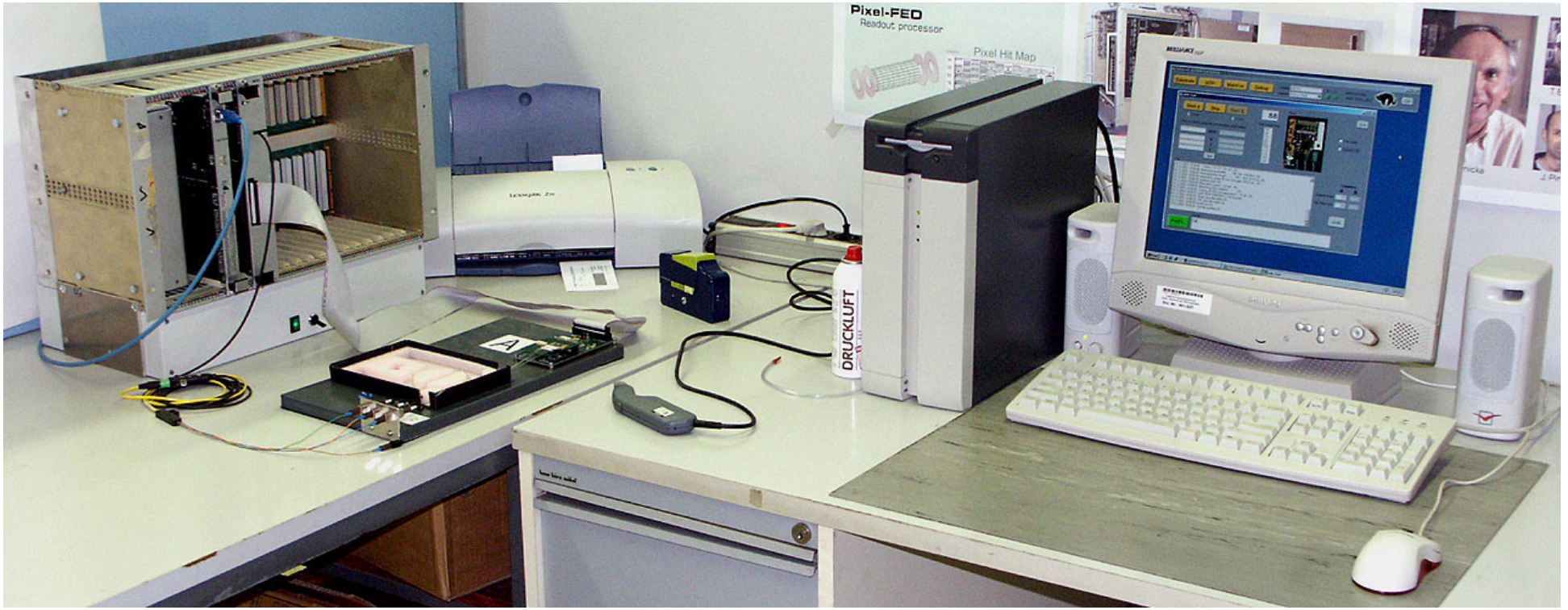
Specific brands/types of SMD capacitors and glues were specified after competitive radiation tests

Industry

Is not familiar with such requirements

Qualification tests performed by institutes and CERN

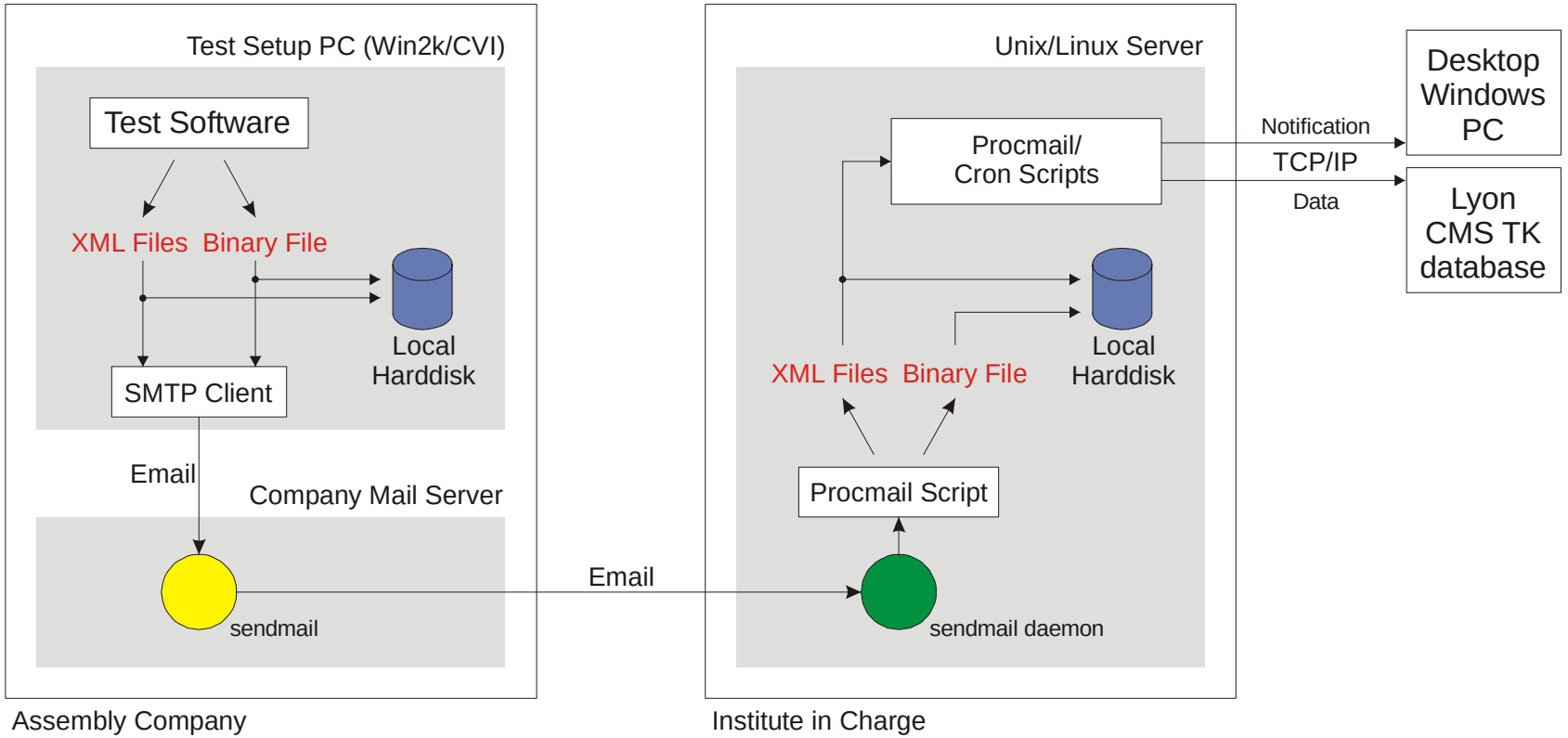
Quality / Testing



System

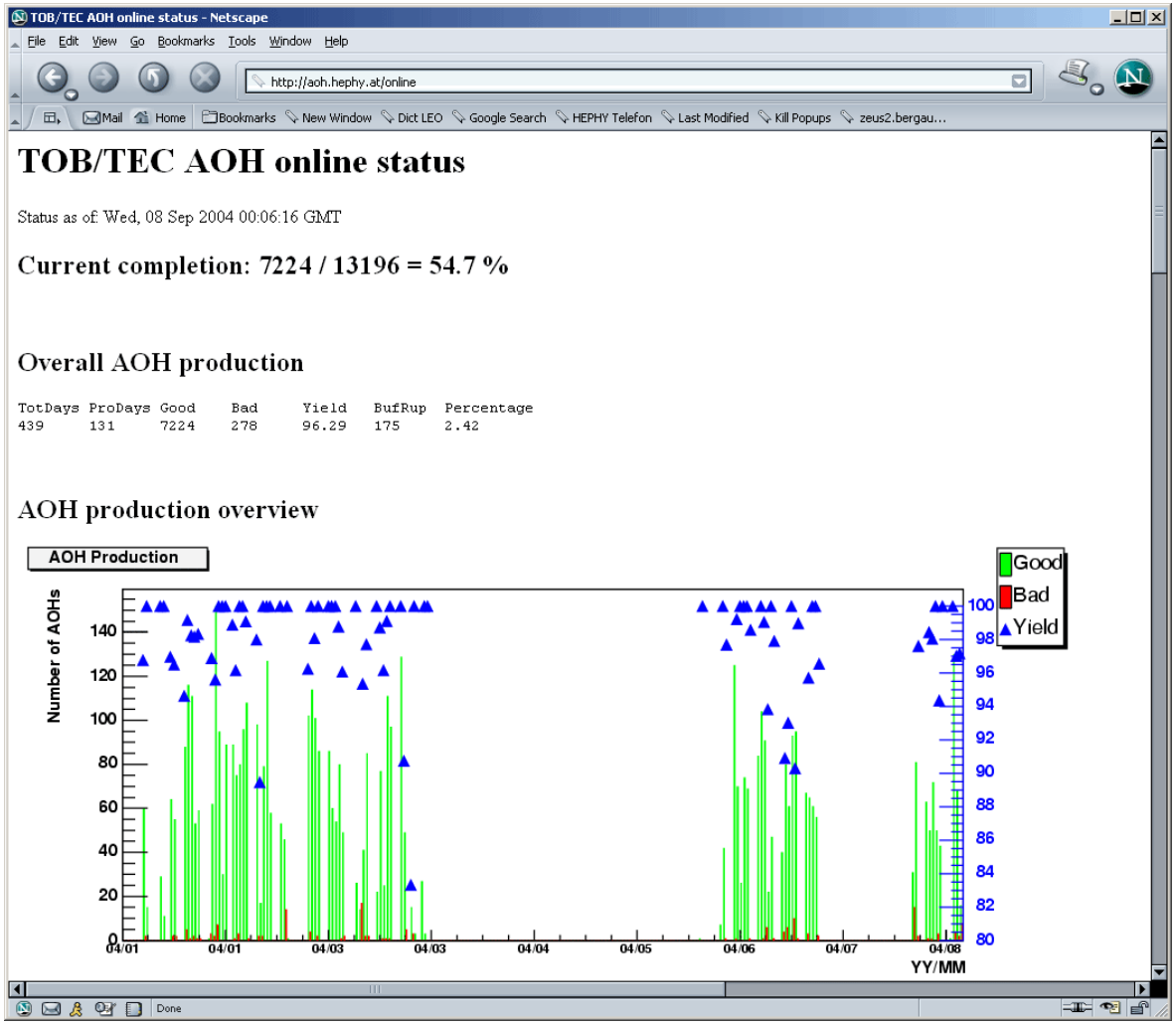
- Automatic Test Setup (hardware and software by HEPHY Vienna)
- 4 Systems for Kapsch, G&A, HEPHY Vienna and INFN Perugia
- Every AOH is measured at companies, sample tests at institutes

Quality / Test Data Flow



System	Fully automatic & realtime transmission to database
Monitoring	Online production monitoring → invaluable for immediate feedback/interaction with company

Quality / Online Status



http://aoh.hephy.at/online

Automatically updated every night

Plots and tables

Learning curve: Yield initially (mid-2003) only ~50%, now 96% overall

Throughput up to 150 AOHs/day

Custom software with database connectivity also for

- shipping
- laser rejection

Quality / Problem handling

Initially	Iterative improvements and optimizations (transition from laboratory prototyping to industrial series production)
Unexpected problem	After ~40% of completion, Kapsch admitted they used wrong (non-qualified) capacitors
	Production stalled and caps re-qualified → (luckily) turned out OK
	(luckily) turned out OK; otherwise terrible logistics and laborious work
Conclusion	Problems appear where humans work despite of ISO 9k/14k certifications!
Key points	How does the company react in case of problems? → Corporate culture
	Contact to person(s) in charge at the company
	Geographical distance: local company allows effortless interaction
Result	Kapsch handled this case very well

Quality / Paradigms

Statement: Different paradigms inevitably lead to misunderstandings and problems

Production…	Scientific world	Industrial world
Quantities	low	high
Variants	many	few
Automation	low	high
Duration	long	short
Requirements	specific	standard

Problem: Many of the scientific items are inherent and can hardly be industrialized

Remedies:
- Design trade-off (e.g. number of variants)
- Careful company selection (experience beyond bid and certifications)
- Extensive communication → close contact to company
- Close production & quality monitoring → fast feedback

Summary

CMS Tracker	Analog optical readout over 37k optical fibers, 40MS/s, 60...100m
Technology	Edge-emitting semiconductor lasers, 1310nm, single-mode fiber
	Special requirements → special components: Laser, Linear Laser Driver
Assembly	Largely manual, since automation is not cost-effective
Company	Selection based on experience, proximity, size etc. ("soft" parameters)
	ISO certification and price are less important
Logistics	Complicated both on component input and product distribution
	Prone to propagating delays
Quality	Industry not familiar with scientific requirements (different paradigms)
	Online monitoring system turned out invaluable
	Human errors are inevitable