How to create successful open hardware projects

about White Rabbits and open fields

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CERN, Geneva, Switzerland

Topical Workshop on Electronics for Particle Physics
TWEPP-13
Perugia, Italy

Outline

Outline

CERN Beams Controls group - BE/CO

Responsible for

- Controls infrastructure for all CERN accelerators, transfer lines and experimental areas.
- General services such as machine and beam synchronous timing and signal observation.

Supports

- Beam instrumentation, cryogenics, power converters, etc.

Software

- Linux device drivers, C/C++ libraries, test programs.

Beams Controls standard kit

Hardware kit

- Analog and digital I/O
- Level converters, repeaters
- Serial links, timing modules

Currently, September 2013

- We support about 120 module types.
- Most are custom designed: only 1 in 4 is commercial.

Why we use Open Hardware

Get a design just the way we want it

- We specify fully the design.

Peer review

- Get your design reviewed by experts all around the world.

Healthier relationship with companies

- No vendor-locked situations. Companies selected solely on the basis of technical excellence, good support and price.

Spend money where you or your funding agencies want

- Makes life easier for public institutions.
- Opens the door to smaller companies with good local support.

Why we use Open Hardware

Design re-use

- When it's Open, people are more likely to re-use it.

Dissemination of knowledge

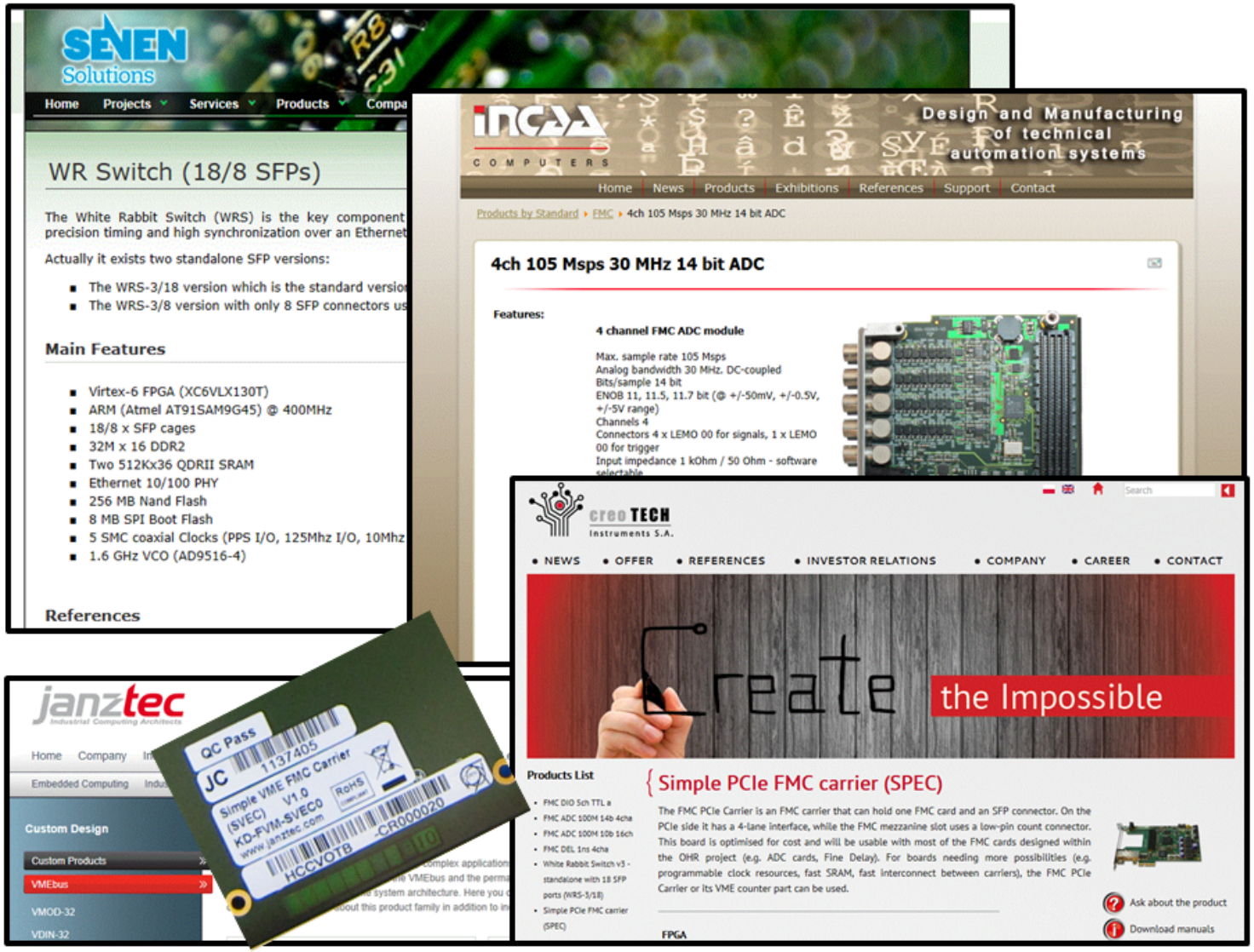
- One of CERN's key missions!

Dispelling the commercial vs open myth

	Commercial	Non-commercial
Open	**Winning combination. Best of both worlds.**	Whole support burden falls on developers. Not scalable.
Proprietary	Vendor lock-in.	Dedicated non-reusable projects.

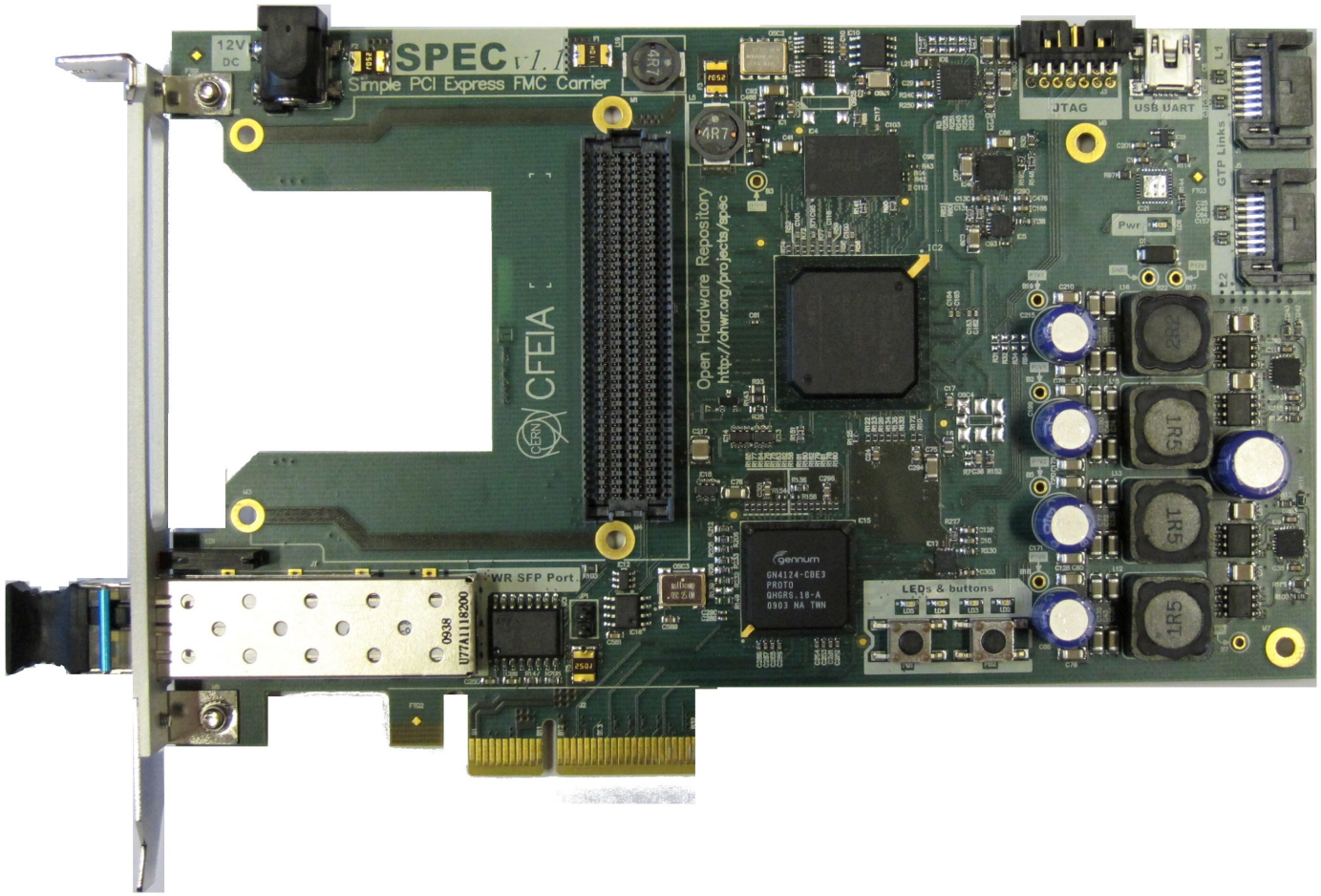
Outline

Open products are real products™



SPEC: Simple PCI Express FMC carrier

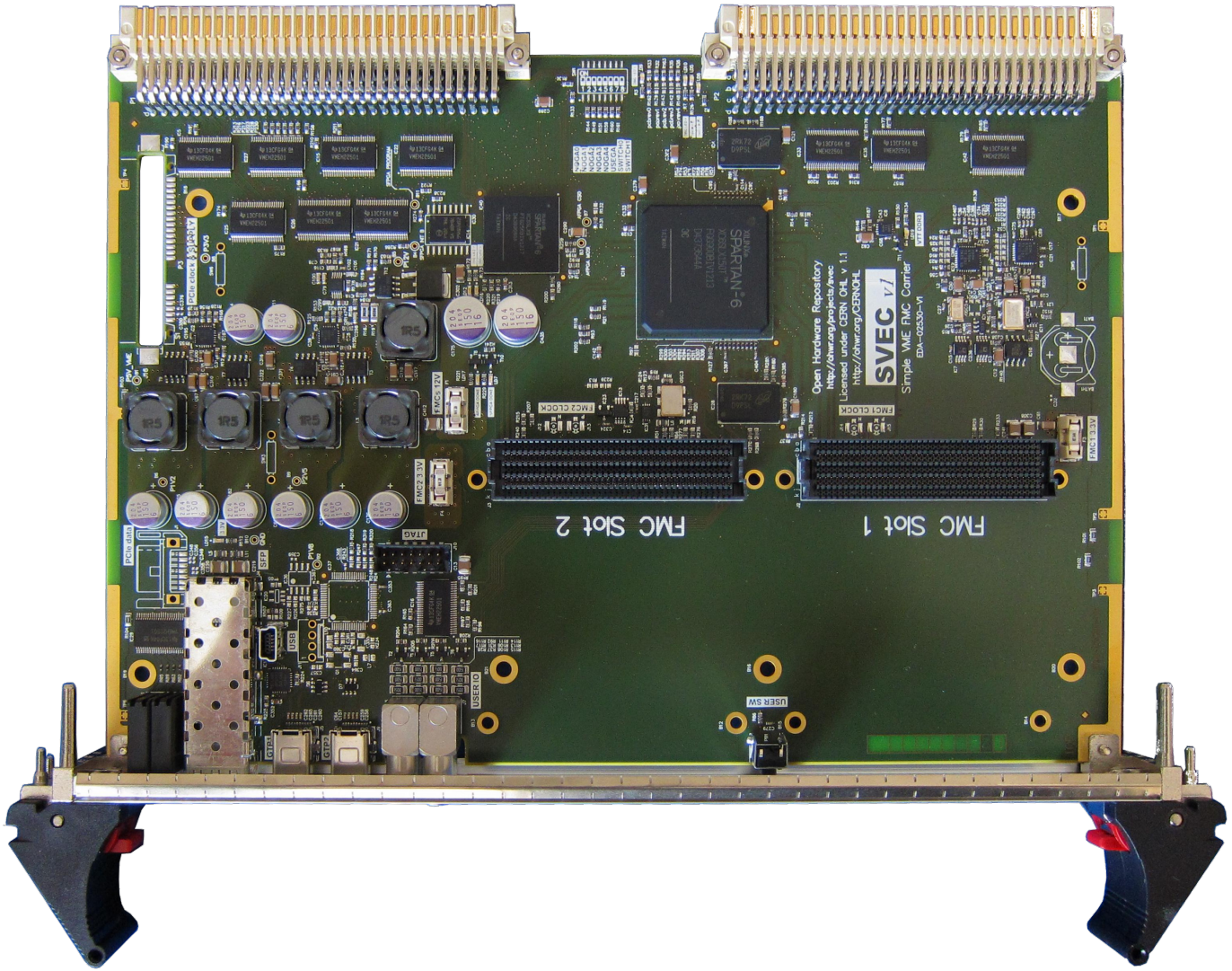
Made in Spain, The Netherlands & Poland



PCB with only 6-layers

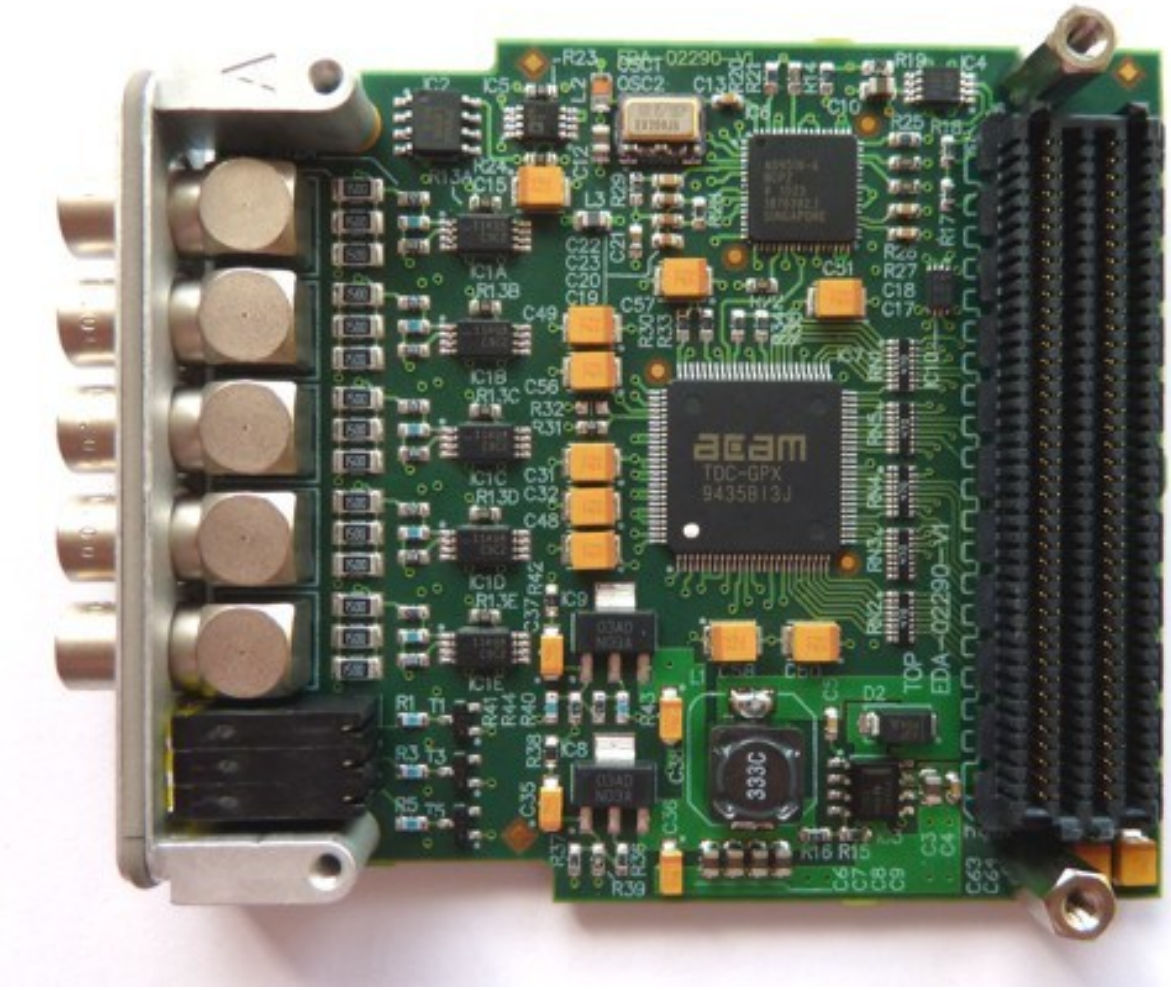
SVEC - Simple VME FMC Carrier

Made in Germany



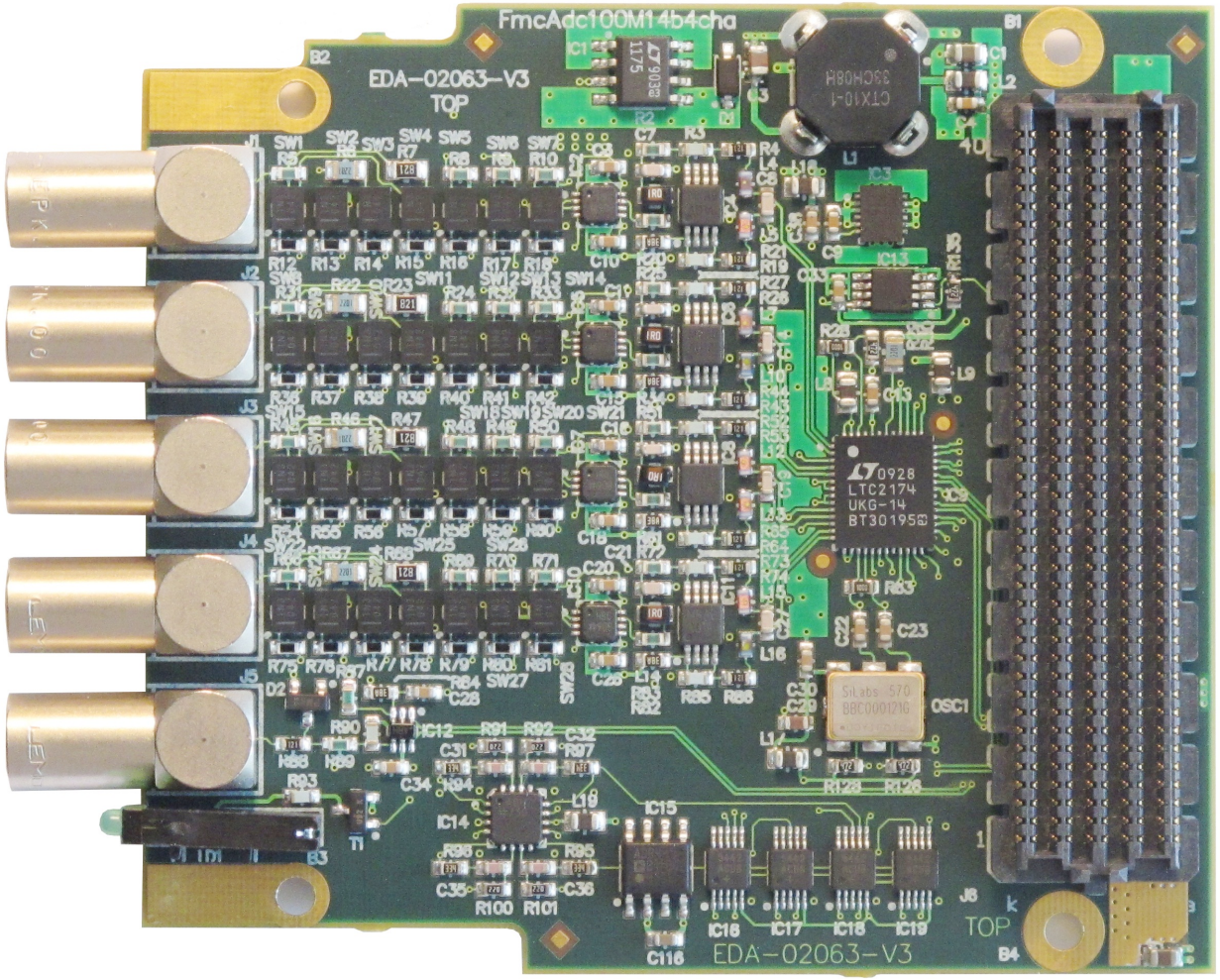
FMC mezzanine: 5-channel 1ns TDC

Joint development by TE/ABT, TE/CRG & BE/CO. Made in Spain.



FMC mezzanine: 100 MSPS 14-bit 4-channel ADC

Made in The Netherlands & Poland



Commercially available CERN OH designs

September 2013

Project	Producers	Users	Produced
SPEC carrier - PCIe	3	41	300
SVEC carrier - VME	2	4	105
SPEXI carrier - PXIe	1	2	(proto) 3
ADC 100M 14b 4ch	2	11	70
TDC 1ns 5cha	1	3	70
FMC DEL 1ns 4cha	3	4	108
FMC DIO 5ch	3	10	92
WR switch 18 ports	1	11	77

Table: eight CERN OH designs found producers and users

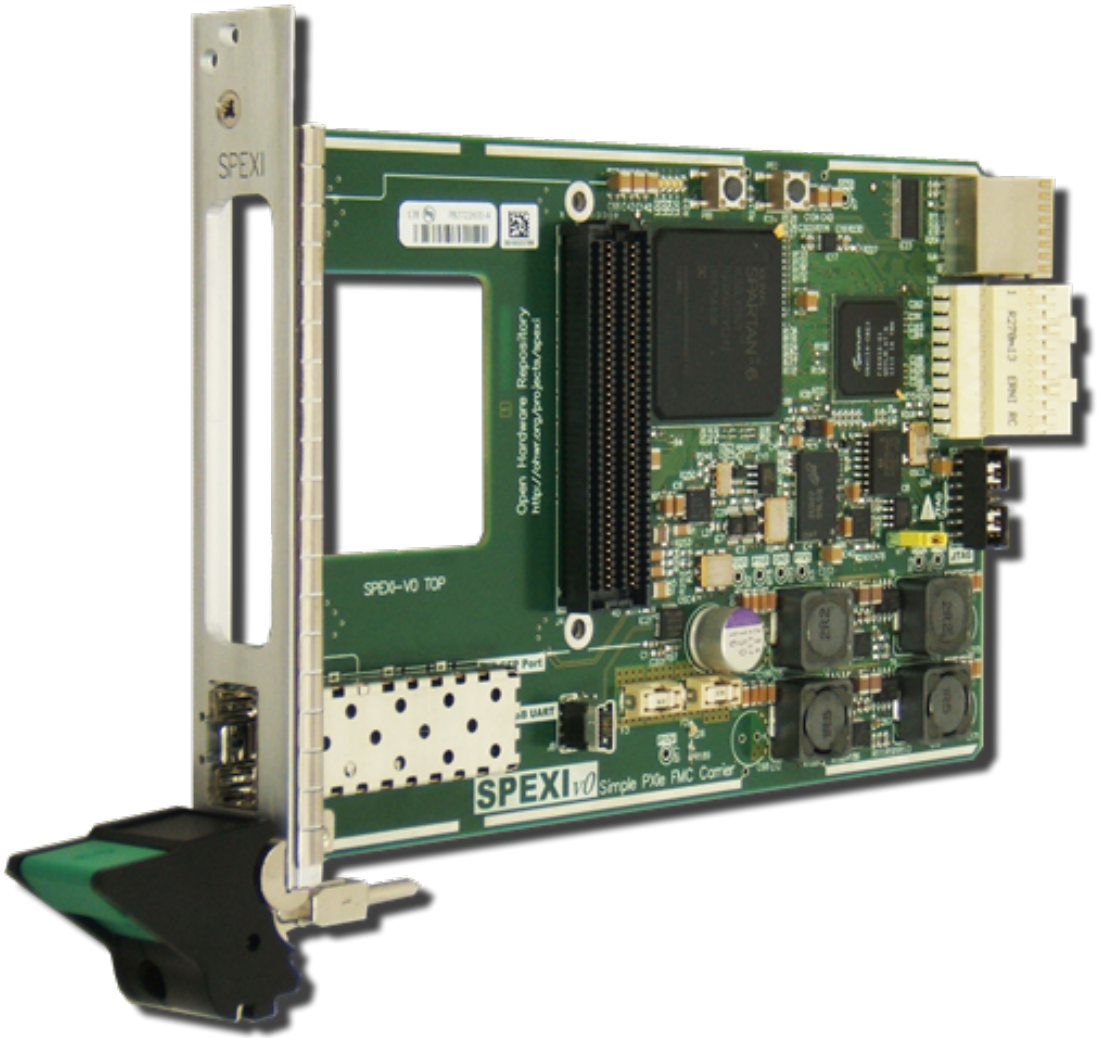
Re-use of work

Examples of re-use of work

- Two companies modified the SPEC carrier design.
  - larger FPGA (for software radio)
  - AMC and PXIe bus versions
- A company modified the ADC100M design.
  - other input filter
  - high-voltage front-end
- A company re-used nanoFIP code for renovating trains.

SPEXI board: a modified SPEC board

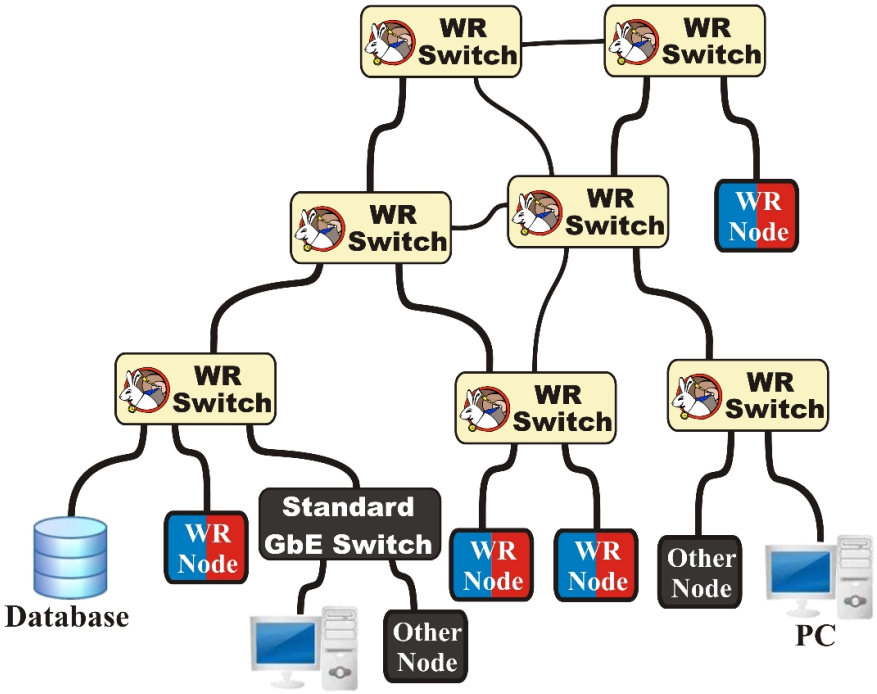
uses the PXI Express bus instead of PCIe



Outline

White Rabbit – is Ethernet...

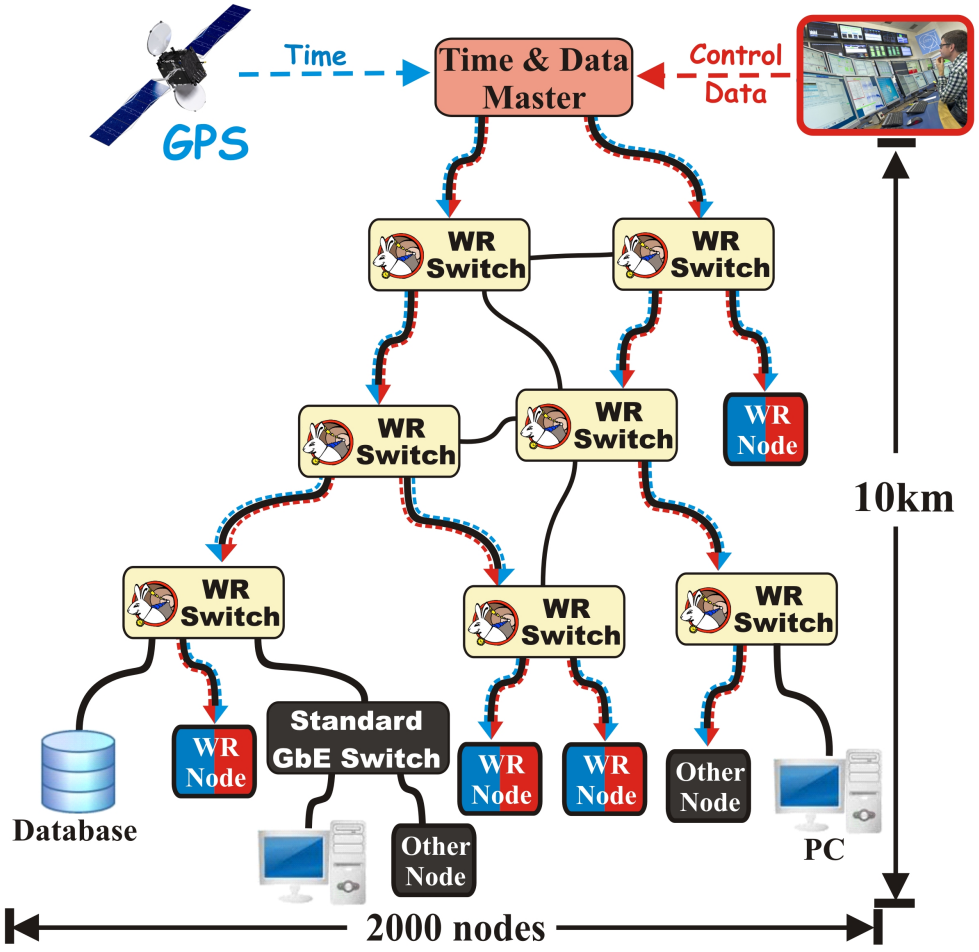
- Bandwidth: 1 Gbps
- Single fiber medium
- Up to 10 km links
- WR Switch: 18 ports
- Allows non-WR Devices
- Ethernet features (VLAN) & protocols (SNMP)



White Rabbit – is enhanced Ethernet!

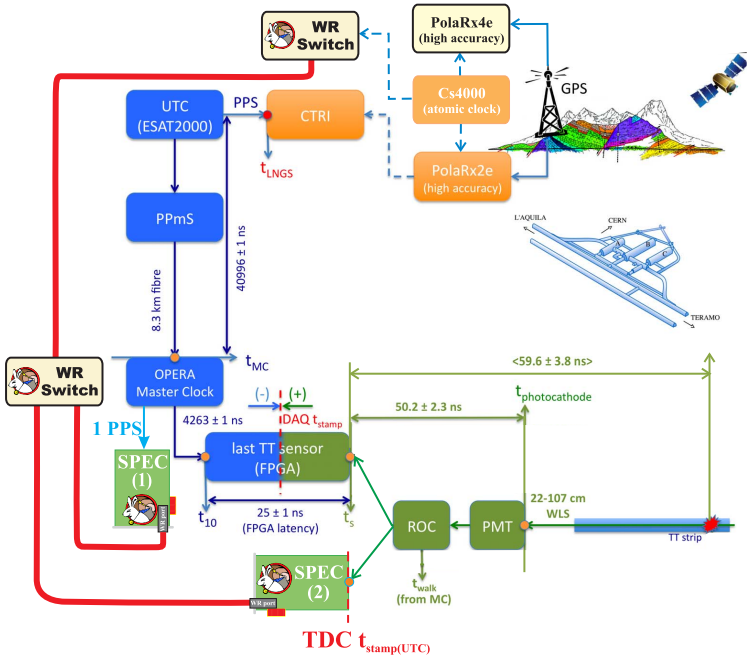
Two separate services (enhancements to Ethernet) provided by WR:

1. Synchronization:
   - accuracy better than 1 ns
   - precision (tens of ps sdev skew max)
2. Deterministic, reliable and low-latency Control Data delivery



White Rabbit applications

- Existing applications:
  - **CERN Neutrinos to Gran Sasso**



White Rabbit applications

- Existing applications:
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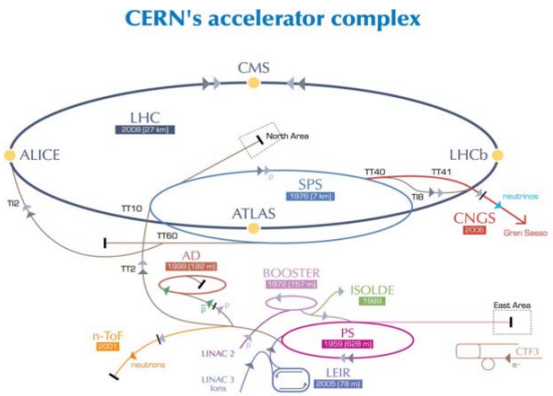
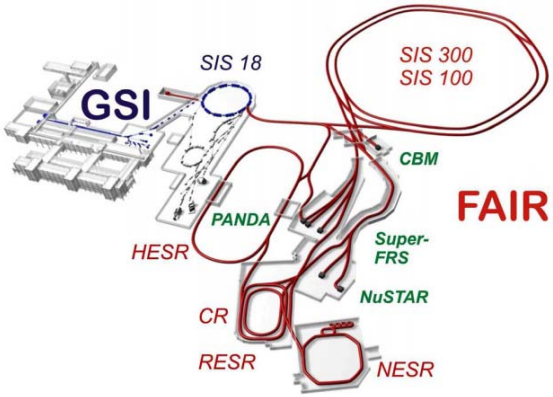
- Future applications:
  - **CERN and GSI**





White Rabbit applications

- Existing applications:
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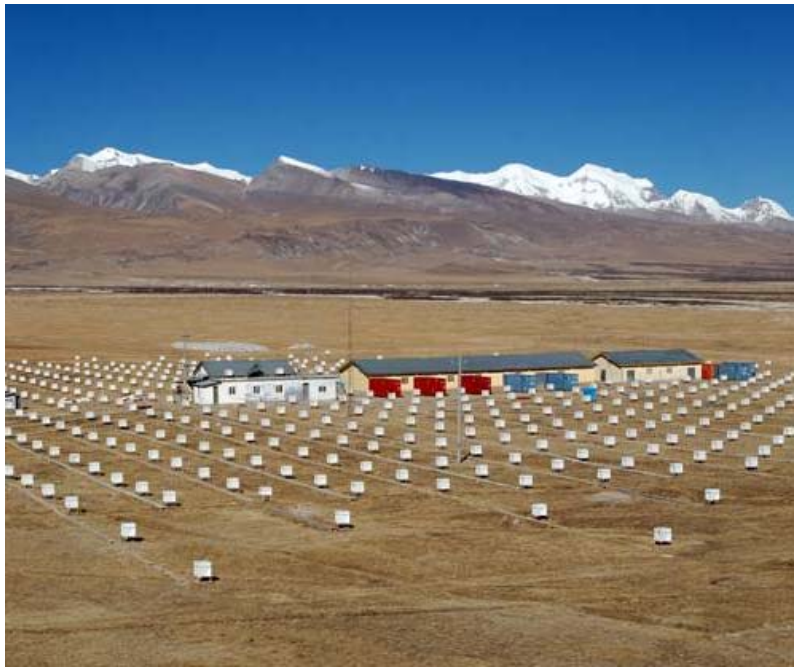
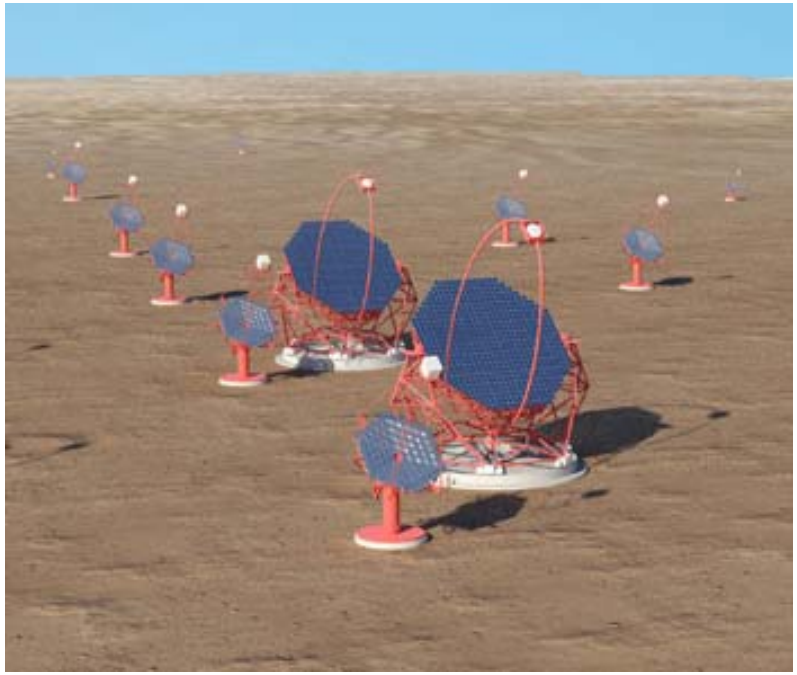
- Future applications:
  - CERN and GSI
  - **The Large High Altitude Air Shower Observatory (China)**



White Rabbit applications

- Existing applications:
  - CERN Neutrinos to Gran Sasso
- Future applications:
  - CERN and GSI
  - The Large High Altitude Air Shower Observatory (China)
- Potential applications:
  - **Cherenkov Telescope Array**



White Rabbit applications

- Existing applications:
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- Future applications:
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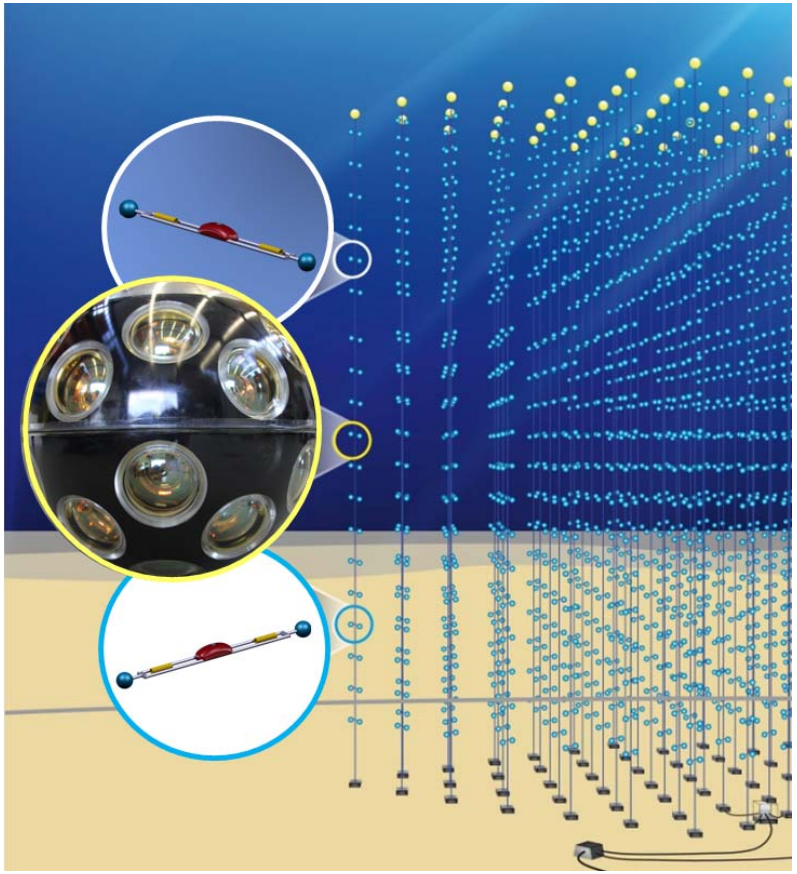
  - The Large High Altitude Air Shower Observatory (China)
- Potential applications:
  - Cherenkov Telescope Array
  - **European deep-sea research infrastructure (KM3NET)**
  - Long distance Time Transfer

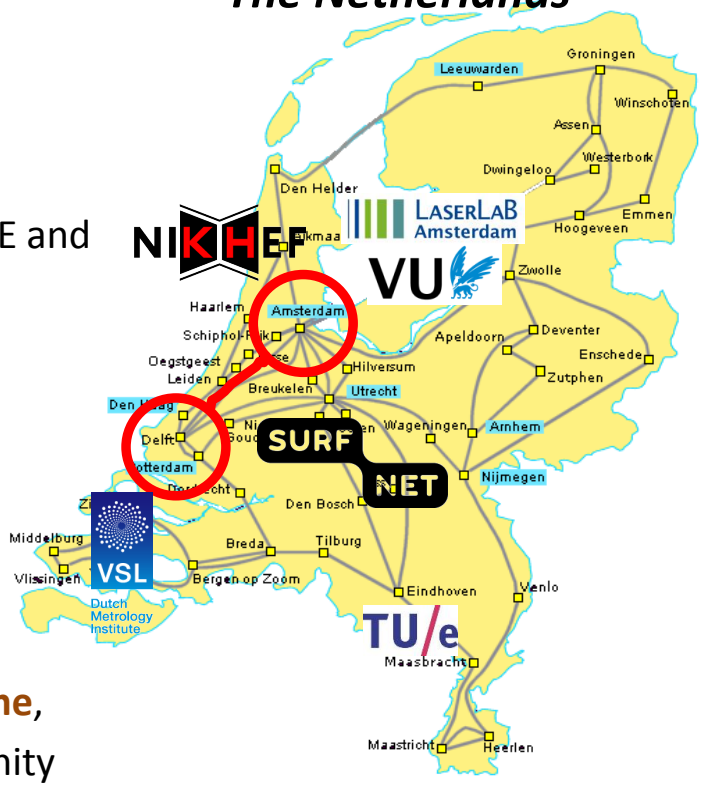


NL: Time Distribution over 120 km with amplifiers

Netherlands: 120 km installed fiber link

- Collaboration* **VU University/SURFnet/ VSL Delft/TU Eindhoven/ NIKHEF**
- Field trial: long-haul T&F transfer using WRE and bi-di amplifiers through SURFnet network
- Transfer Cs clock signals from **VSL Delft** to **Amsterdam** (120 km)
- Provide optical traceability to SI units of **time**, **frequency** and **length** to academic community

The Netherlands

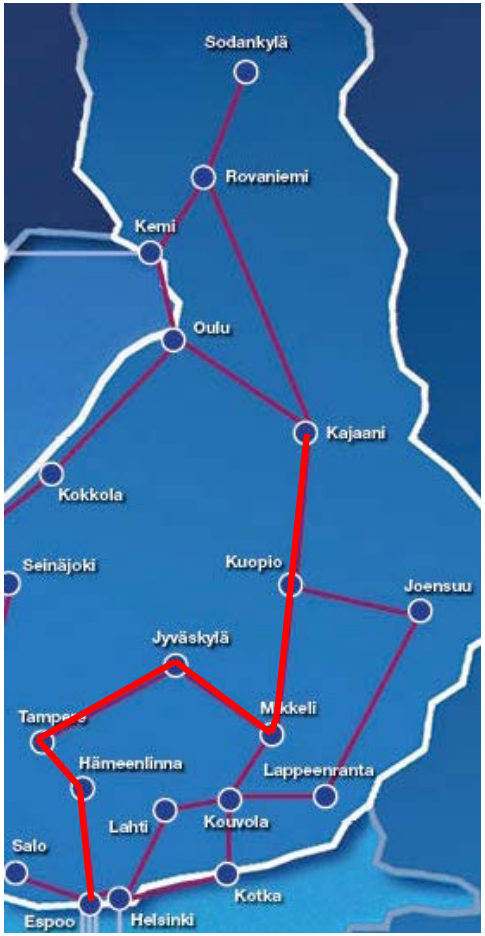


*J.C.J. Koelemeij *et al.*

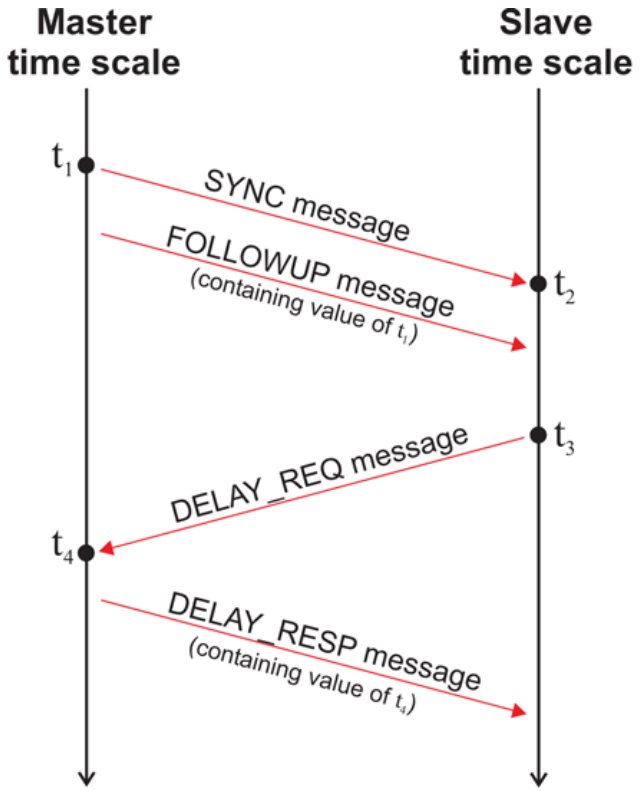
FI: Time Distribution over 900 km with amplifiers

White Rabbit time-transfer experiment between Espoo and Kajaani in Finland

- Status:
  - White Rabbit link between MIKES and CSC sites in Espoo is operational and under evaluation (1PPS transfer).
  - Grandmaster clock is synchronized to UTC(MIKE) and feeds a WR-switch at the CSC Espoo site. All other links will be connected to this switch.
  - Alien wave link (all-optical underground link) has been established between MIKES sites at Espoo and Kajaani (fibre length ~900 km, with a number of unidirectional amplifiers).
  - GPS-PPP time transfer link is being set-up between MIKES sites at Espoo and Kajaani to evaluate the link performance.
  - Once proper operation of the link is verified, a 5071A Cs-clock will be transferred to Kajaani to aid in link evaluation.



Precision Time Protocol (IEEE 1588)

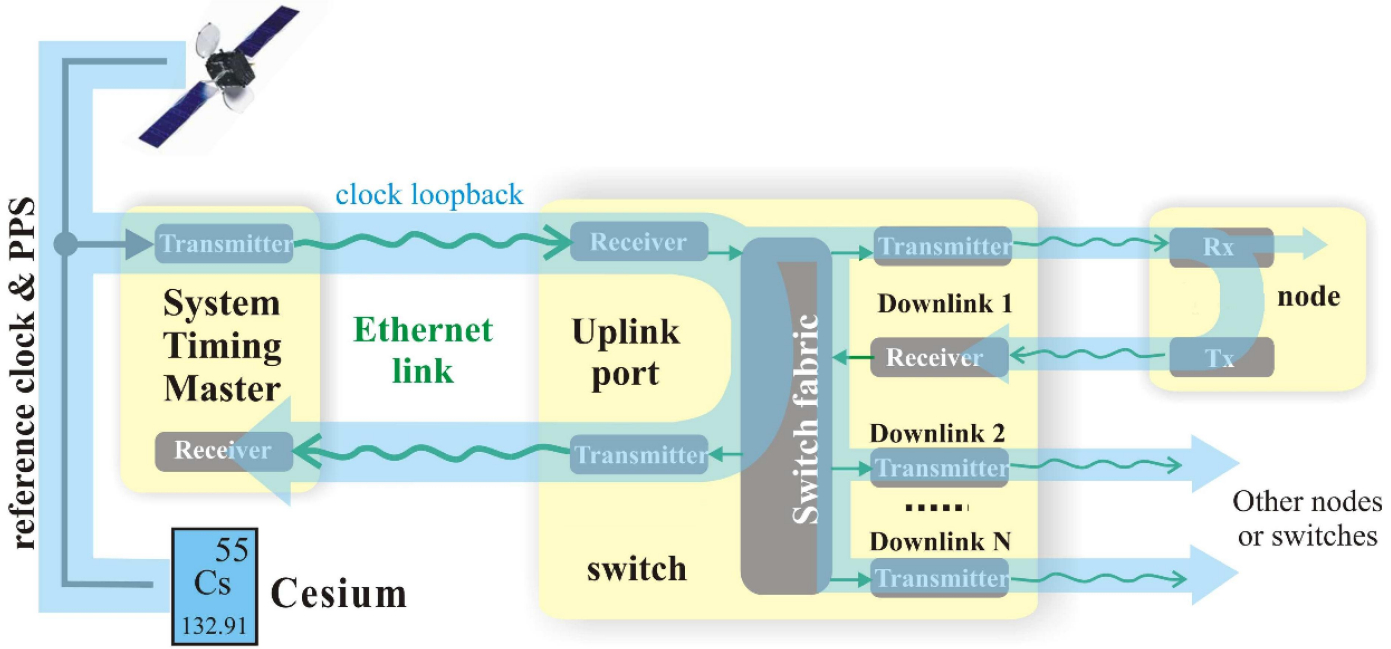


- Packet-based synchronization protocol.
- Synchronizes local clock with the master clock.
- Link delay evaluated by measuring and exchanging packets tx/rx timestamps.

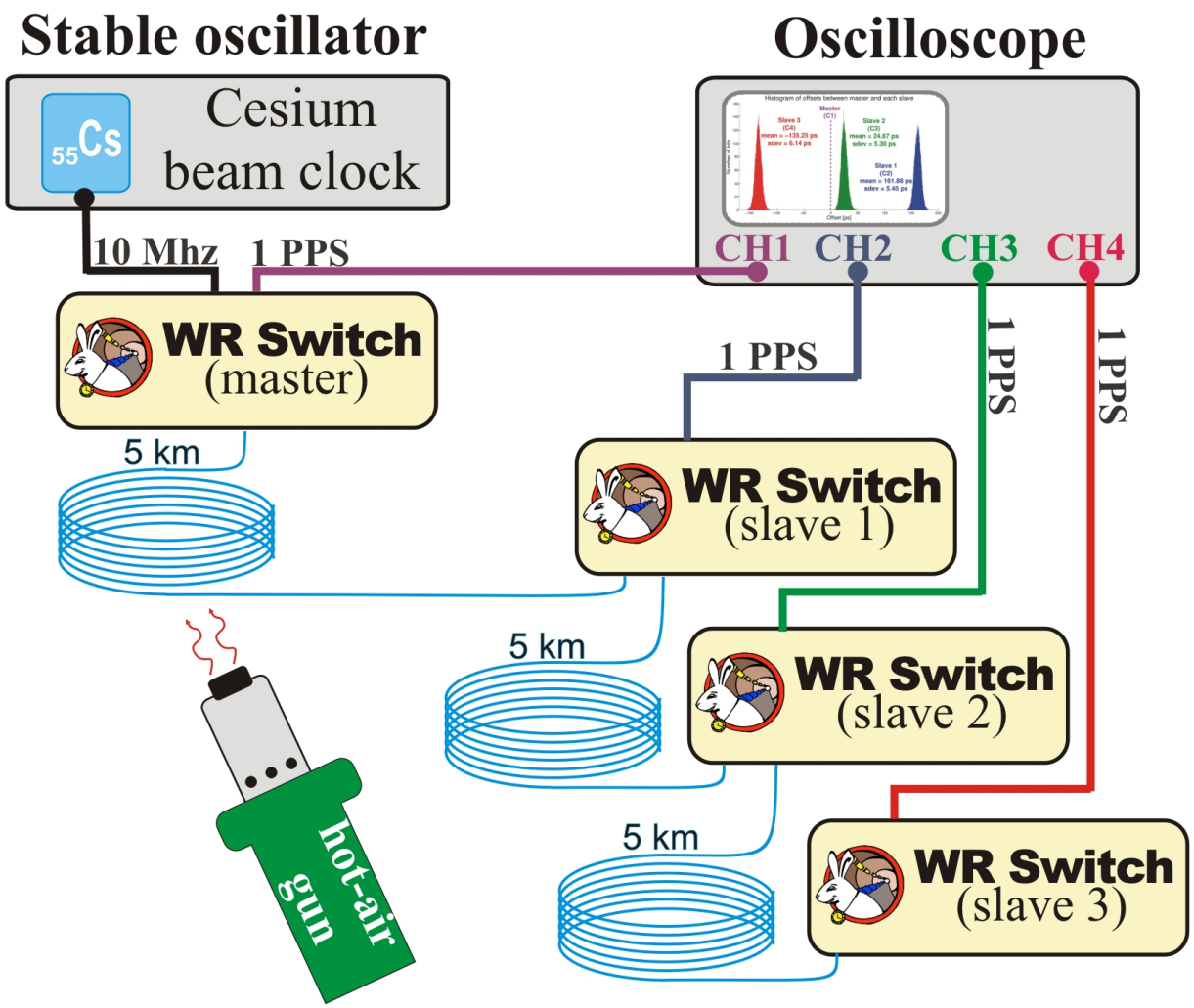
Layer 1 Syntonization

Common clock for the entire network

- All network devices use the same physical layer clock.
- Clock is encoded in the Ethernet carrier and recovered by the receiver chip.
- Phase detection allows sub-ns delay measurement.



WR time transfer performance: lab tests



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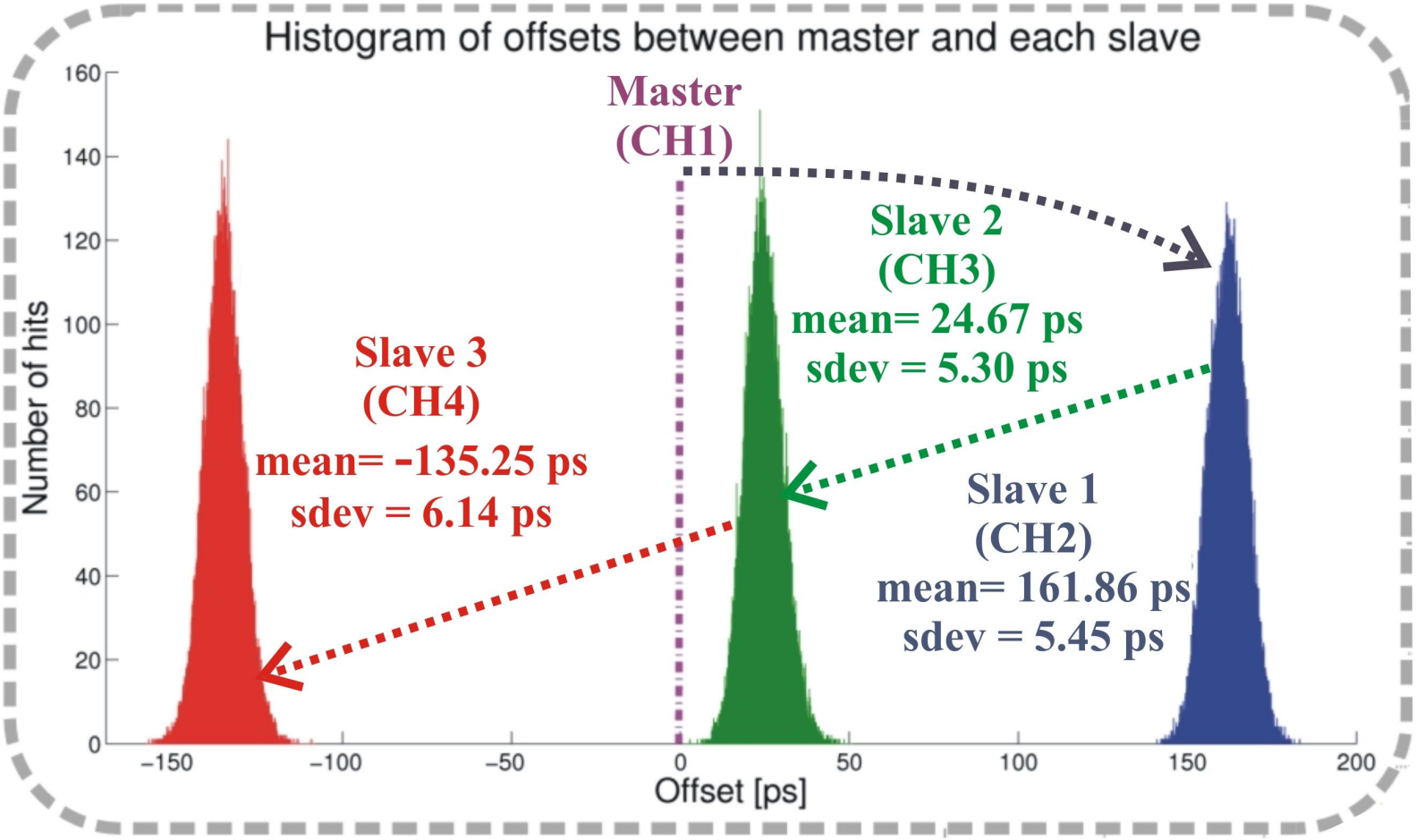
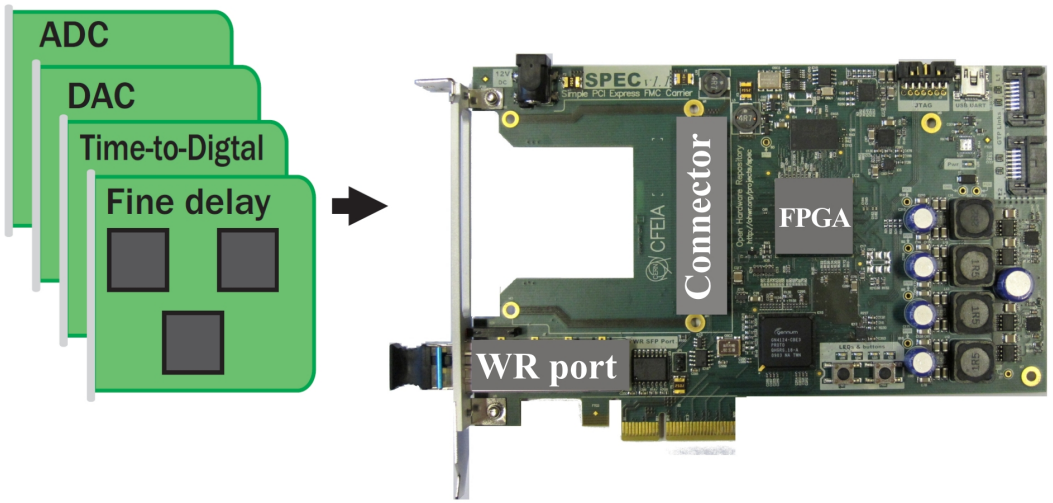


White Rabbit Switch

- Central element of WR network
- Original design optimized for timing, designed from scratch
- 18 1000BASE-BX10 ports
- Open design (H/W and S/W)
- Commercially available

WR Node: SPEC board



FMC-based Hardware Kit

- All carrier cards are equipped with a White Rabbit port.
- Mezzanines can use the accurate clock and TAI time (synchronous sampling clock, trigger time tag, ...).

Outline

Be Open - Open Hardware Repository – ohwr.org

A web-based collaborative tool for electronics designers

- Wiki, News
- File repository
- Issues management
- Mailing list

Fully open access

- All information readable by everyone, without registration.

Example of an OHR project

HOME PROJECTS LICENSES COMPANIES SIGN IN REGISTER

FMC PROJECTS » SIMPLE PCIE FMC CARRIER (SPEC)

OVERVIEW | WIKI | ACTIVITY | MAILING LIST | ROADMAP | ISSUES | NEWS | DOCUMENTS | FILES | REPOSITORY

OVERVIEW

A simple 4-lane PCIe carrier for a low pin count FPGA Mezzanine Card (VITA 57). It has memory and clocking resources and supports the White Rabbit timing and control network. Commercially available.
More info at the Wiki page

- Subprojects: **Software support for the SPEC board**
- Status: Release

Latest news

License

CERN OHL v1.1

Be Open

Use OHR to the fullest

- Document everything on OHR: schematics, status.
- Discuss over mailing list.
- Document design review results.
- Track Issues and detected bugs.

Don't be afraid to show mistakes!

- E.g. SPEC: 73 Issues documented, 28 still 'Open'.
- Issues may help others when adapting a design.
- OHR becomes a teaching tool.

CERN Open Hardware License – ohwr.org/cernohl

Provides a solid legal basis

- Developed by Knowledge and Technology Transfer Group at CERN .
- Open Software licences not usable (GNU, GPL, . . .).

Practical: makes it easier to work with others

- Upfront clear: anything you give is available to everyone.
- Everyone can use it for free.

CERN Open Hardware License – ohwr.org/cernohl

Same principles as Open Software

- Anyone can see the source (design documentation).
- Anyone is free to study, modify and share.
- Any modification and distribution under same licence.
- Persistence makes everyone profit from improvements.

Hardware production

- When produce: licensee is invited to inform the licensor.

Make design general enough

General functions find more users

- General purpose carrier boards
- Analog to digital converters, Digital I/O
- Time to digital converter, Fine Delay
- White Rabbit timing and control network

Tips

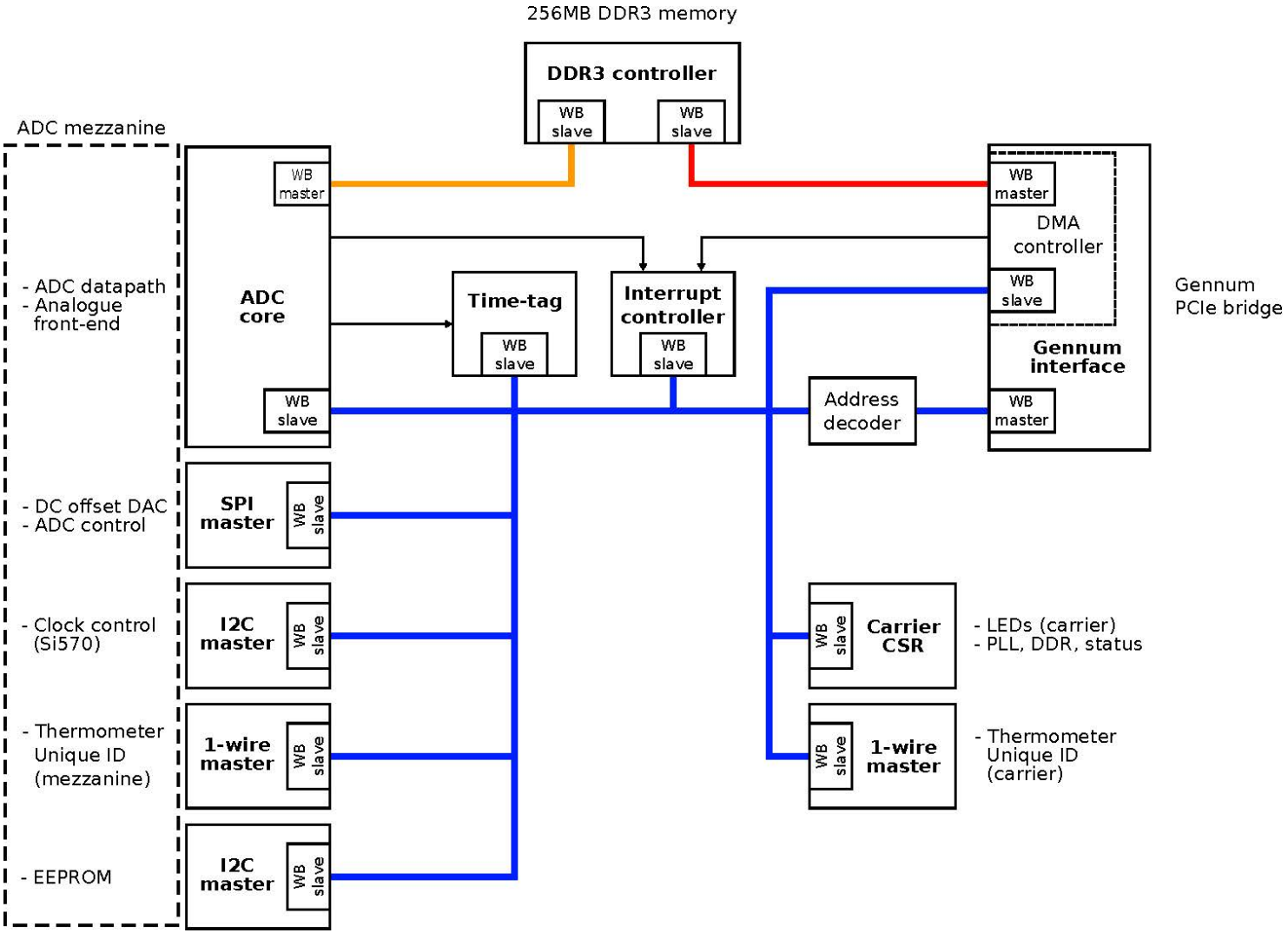
- Some functions are more generic than you think
  e.g. White Rabbit network and WorldFIP interface.
- Keep as simple as possible and do not use specific CERN functions. Stay cheap.
- People can modify or extend the design later if needed.

Use standards

Standards stimulate re-use and fit in systems

- Bus standards: VME, PCI express, PXI express
- FMC Mezzanine card (VITA 57.1)
- Wishbone internal bus, OpenCores IP, Plain VHDL
- Linux drivers

Wishbone-based System-on-Chip architecture (ADC)



If a standard does not exist, contribute to one

Contributions to standards

- White Rabbit: will be in **IEEE 1588** High Accuracy profile.
- WB pipelined mode: in **Wishbone spec** Rev.B4 (2010).
- Linux driver structure called FMC bus: in **Linux v3.11**.
- ZIO Linux framework for DAQ and CTL hardware: **RFC** made **to Linux** Kernel list.

Be complete: from design to production test and driver

It's not only about schematics and PCB

- Quality - design reviews; reduced BOM; DFM
- Professional production documentation, incl. quality norms
- Production test system (tests solder connections)
- Firmware and its documentation
- Linux drivers

Save yourself time

- Reuse a lot: document templates, IP cores, HW designs.
  - allows engineers to help each other.
- Make Design Tools.
  - hdlmake: generates makefiles for FPGA projects.
  - wbgen: wishbone register and documentation generator.
  - ZIO, SDB and FMC bus tools for driver development.

Work intensively with industry

Types of work we've outsourced

- Hardware: development, production.
- Software: VHDL firmware, drivers.
- Usually small projects (<2 months work).
- Speeds up projects.
- Gets in specialist knowledge.
- Small companies can play a large role.
- Production: follows CERN purchasing rules (competition).

Via OHR and companies the products find their own way

- The fun starts here: more users, more feedback.

Work intensively with industry

Industry and the OH concept

- Open Hardware is new and not always understood.
- Need to explain companies the opportunities and risks.
- Companies think they compete with *assembly companies*. We ask only *engineering companies* that can also give support (guarantee, repair, improve)!
- Needs time from us and guts from companies.

Outline

Is it for you?

Some 'personal' prerequisites

- You believe that collaborating helps to find bugs.
- You're ready to document and publish everything.
- You think technology transfer is important.
- You like to stimulate industry with innovative products.
- You love to help people outside your environment.

Is it for you?

Be prepared for surprises

- Support may take more time than you want.
- Others *will* find bugs.
- Learn about new uses of your design.
- You may get interesting new contacts.

Outline

Future work

Consolidate our designs

- Consolidate firmware and Linux drivers. Make Releases.
- Consolidate documentation (manuals, FAQs, ...).
- Help companies to provide support.

Improve re-usability with free electronics design tools

- Tools are expensive and do not interoperate.
- Existing free tools are not usable to make complex designs.
- Therefore we stimulate the development of free tools:
  - VHDL simulator (extension of **Icarus** Verilog simulator)
  - Schematics & PCB editor (catalysing **KiCAD** development)

Conclusions

- Open Hardware has many advantages.
  - Anyone can help in developments and make improvements.
  - Allows to work differently with industry (design work, smaller companies).
  - Not tied to a single company for production and support.
- Many things must be done right:
  - Be Open
  - Make design general enough
  - Use standards - cool features help: White Rabbit
  - Be complete: from design to production test and drivers
  - Work intensively with industry
- Likely not for everyone or all designs.
- OHR site is practical for engineers and is stimulating.
- Eight CERN designs are already commercialized.
- Four years of experience show it works!

Open products are real products™