Diagnosis & Instrumentation Issues for NUSTAR and SuperFRS

H.Simon, C. Nociforo, J. Winfield,
J. Gerl, S. Pietri, H. Schaffner, N. Kurz, ...

AIMS: detector system used for

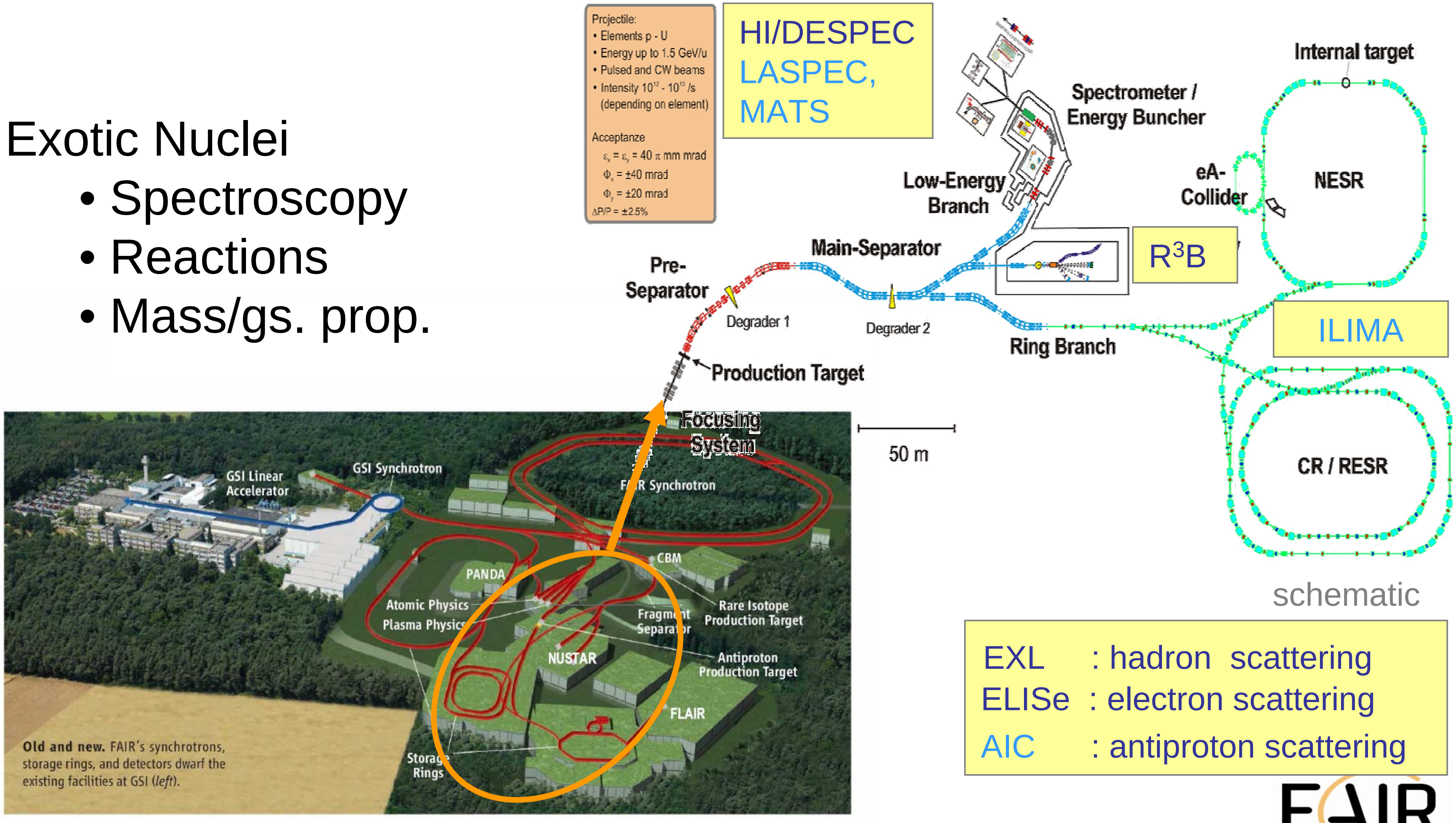
1. initial beam steering → ACS/FESA
   → simple, reliable, slow control interface
2. machine safety → ACS/FESA
   → slow control interface, interlocks
3. part of the experiments → MBS/DABC/EPICS
   → interface to DAQ system

NUSTAR Experiments

(**NU**clear **ST**ructure **A**strophysics and **R**eactions)

Exotic Nuclei

- Spectroscopy
- Reactions
- Mass/gs. prop.



Projectile:
- Elements p - U
- Energy up to 1.5 GeV/u
- Pulsed and CW beams
- Intensity 10^{12} - 10^{13} /s (depending on element)

Acceptanze

$\varepsilon_x = \varepsilon_y = 40\,\pi$ mm mrad

$\Phi_x = \pm 40$ mrad

$\Phi_y = \pm 20$ mrad

$\Delta P/P = \pm 2.5\%$

HI/DESPEC
LASPEC,
MATS

R^{3}B

ILIMA

Old and new. FAIR's synchrotrons, storage rings, and detectors dwarf the existing facilities at GSI (*left*).

2 NOVEMBER 2007 VOL 318 **SCIENCE** www.sciencemag.org

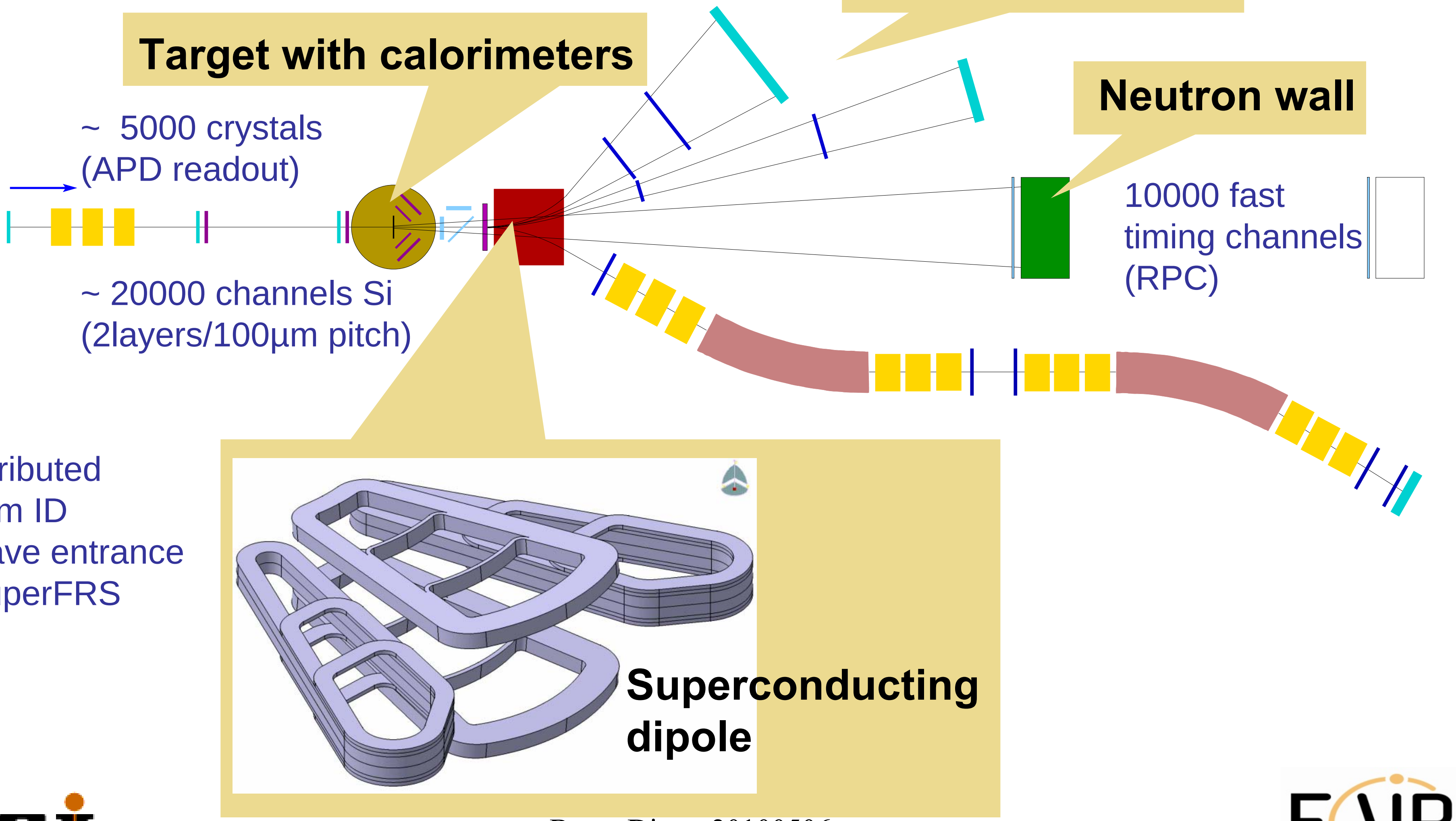
schematic

EXL : hadron scattering
ELISe : electron scattering
AIC : antiproton scattering

FAIR

R^{3}B

Reactions with Relativistic Radioactive Beams



Distributed
beam ID
* Cave entrance
* SuperFRS

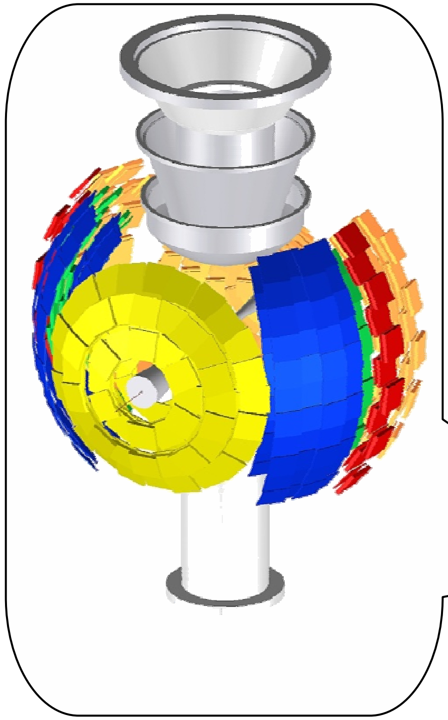
Triggered vs. non triggered readout

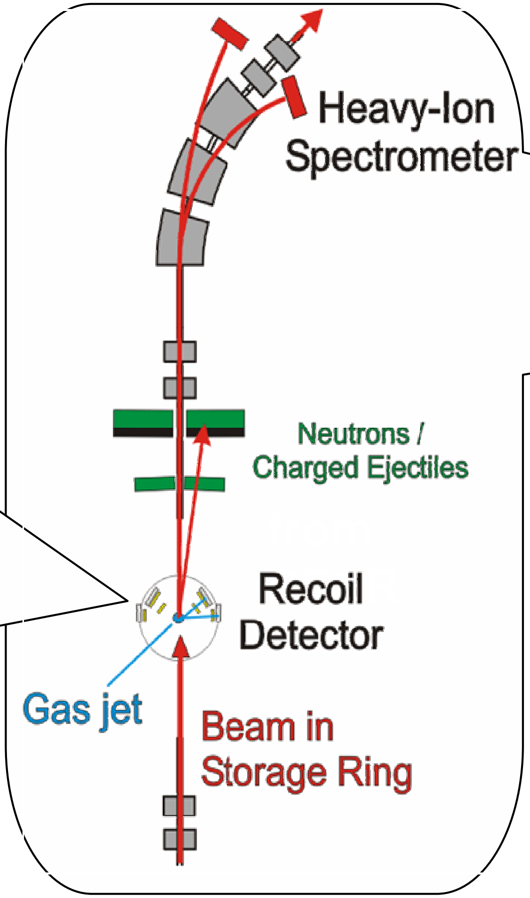
- smooth transition from existing systems
- triggered systems will be replaced whenever they cause excessive dead time or
- … are difficult to handle

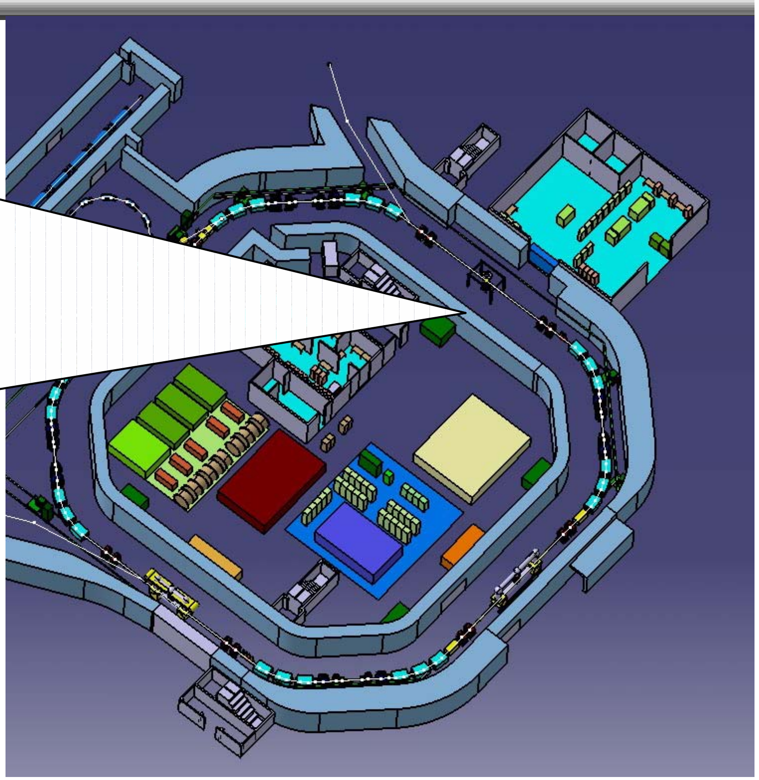
Examples: (1) incoming tracker (deadtime)
(2) calorimeter (several 1’000-100’000 channels)
(3) delayed coincidences

… so don’t forcefully leave out trigger capabilities
and don’t force triggers to be there

EXL







- distributed setup
- 300’000 ch Si (DSSD), Si(Li), CsI shell

Integration, Interoperability, and Modularity

System design:

- data-transfer
  - → DABC/MBS, NARVAL (Agata)
- slow-control
  - → EPICS, others ...
- time-synchronization
  - → BuTiS@FAIR/White Rabbit + local time distrib.

Readout using MBS

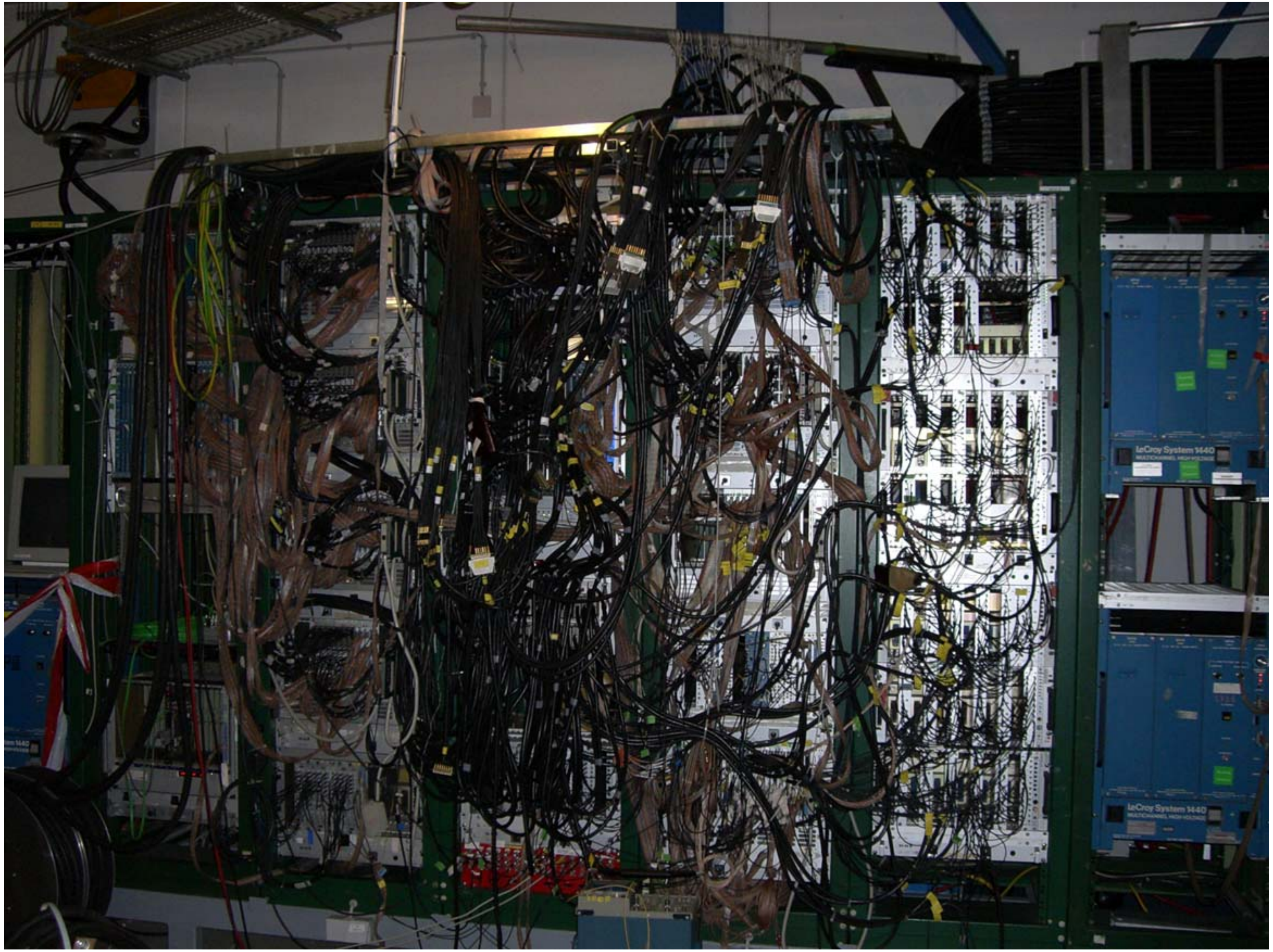
N.Kurz, J. Hoffmann, K.Koch, W.Ott (GSI)

- Basic system (http://daq.gsi.de)
  - Trigger module + VME processor
    Modules (CAMAC, VME)
- Integrates foreign DAQ Systems
  (via Time Stamps)
- various FEE integrated

  via GTB/SAM (Bus / DSP&FPGA VME board)

lightweight, scalable, N x M, full VME speed
allows for staged transition !!!
SuperFRS, R^3B, PRESPEC(High/Despec)

Integrated Electronics Needed !



New design

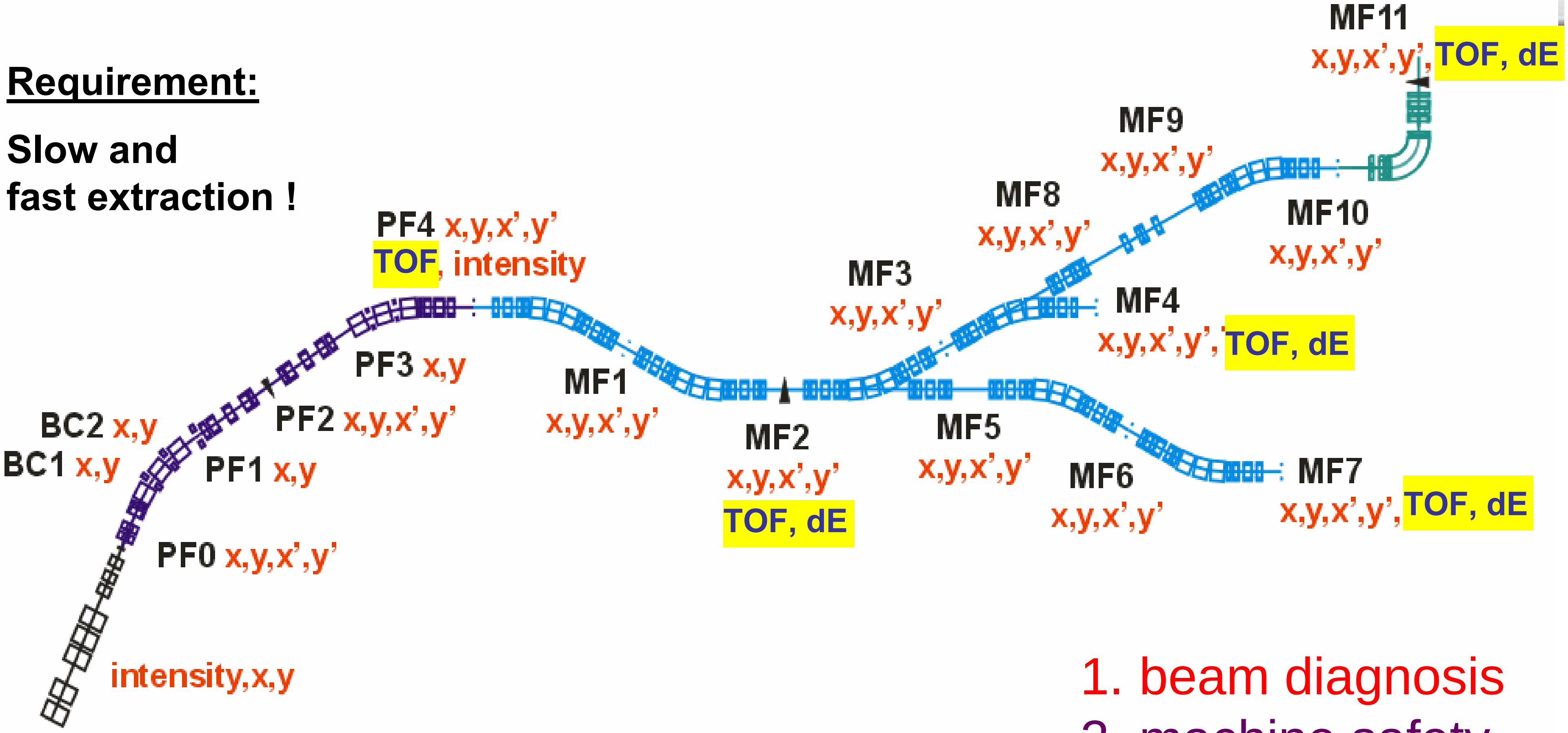
= 30 Tacquila cards with LAND FEE + 2 VME helper modules + 1 VME CPU
+ 10 VME QDCs
+ 3 HV bins

Boils down to
$1 + \varepsilon$ crates !

Detector Instrumentation of the SuperFRS

Requirement:

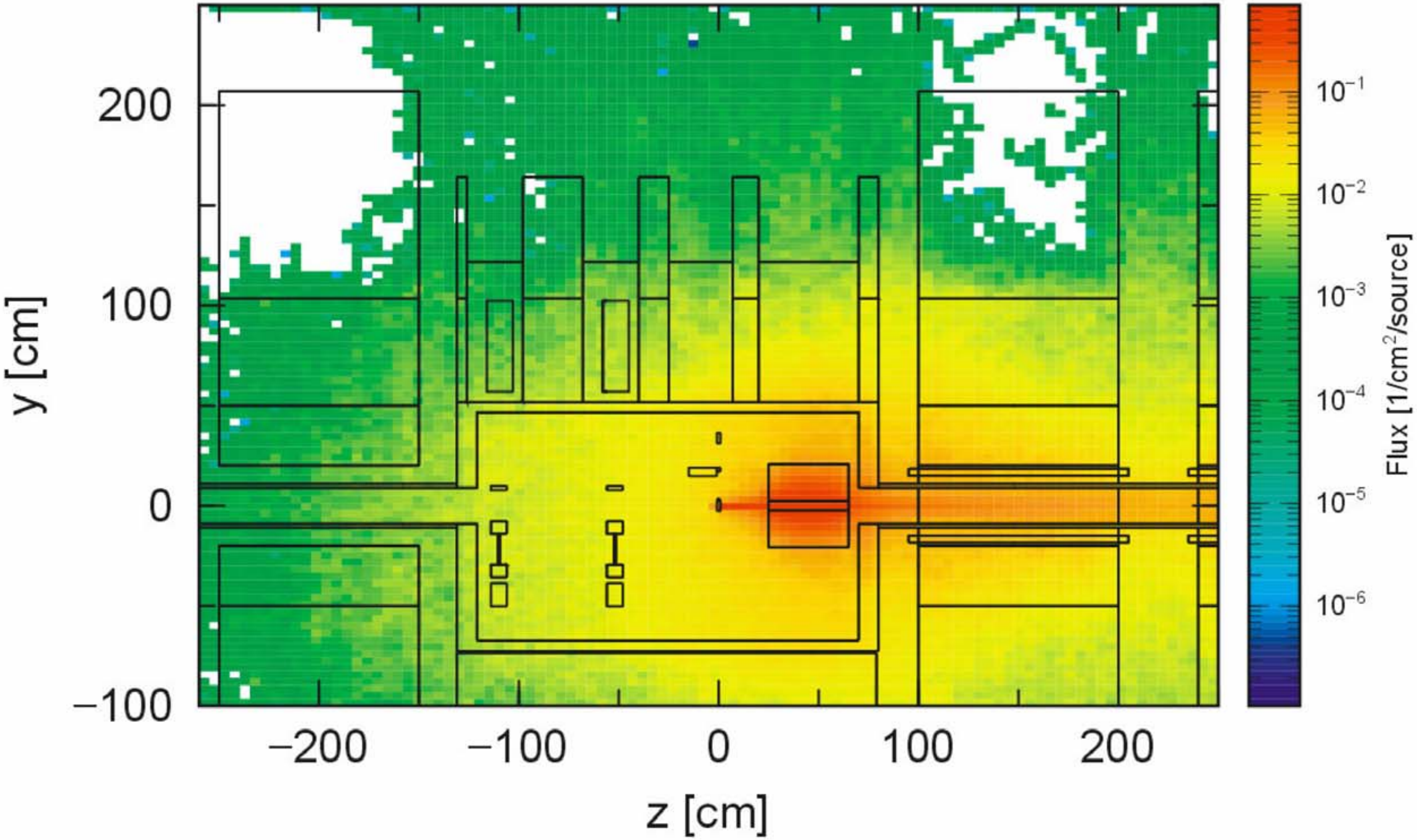
Slow and
fast extraction !



1. beam diagnosis
2. machine safety
3. experiments

10^{12} /s   <10^{10} /s   <10^{9} /s   <10^{7} /s   <10^{5} /s

Radiation environment target area



Detector Scheme for Super-FRS target area

available/possible systems

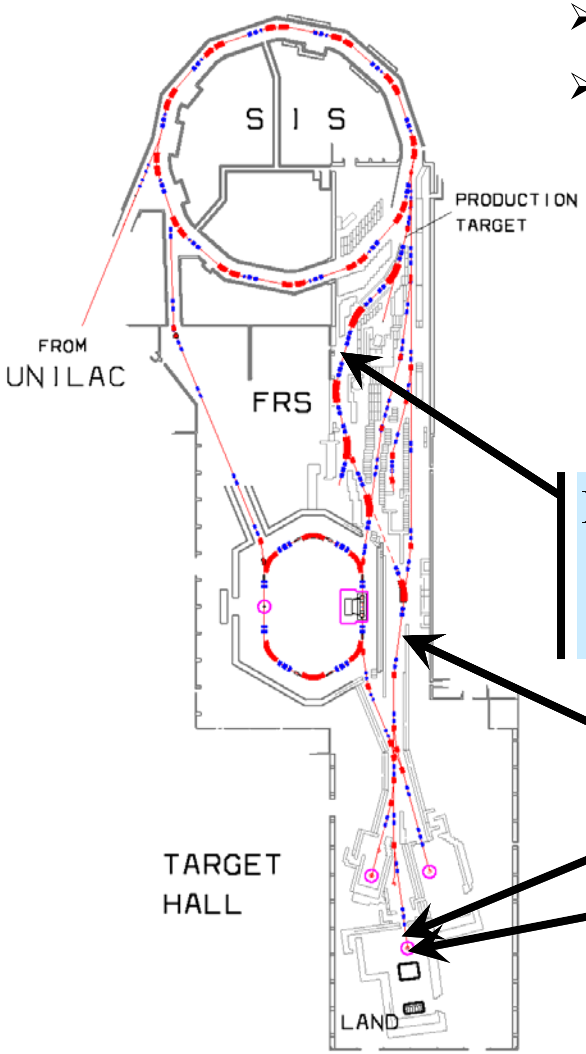
Fast extraction		**Slow extraction**
	Intensity	
Resonance Transformer Diamond (single crystal, current readout)		Cryogenic Current Comparator (SQUID) SEETRAM Diamond (poly crystal & particle)
	Position	
Pickups		
	Profile	
Beam induced fluorescence(BIF) Rest Gas Monitor (RGM) Current Grids		BIF RGM Current Grids/Wire chambers
	Monitoring	
Camera on target (IR)		Camera on target (IR)

full intensity | *reduced intensity (< about 1 nA)*

Continous beam ID is integral part of experiments

Example: ^{132}Sn PDR studies

- Primary: $3 \cdot 10^{8}$ ^{238}U/spill @550Mev/u
- Secondary (mixed): 50 ions ^{132}Sn/spill

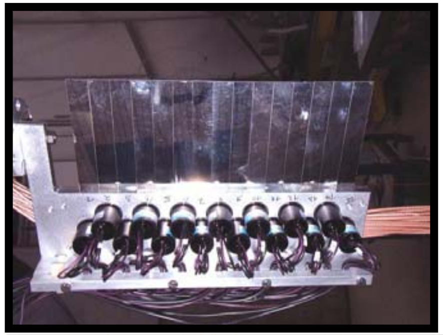


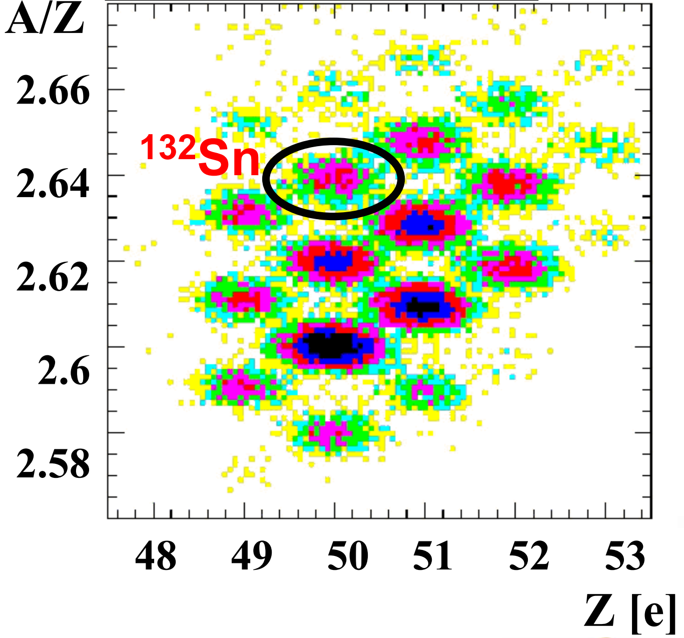
$$\frac{A}{Z} = \frac{m_u c}{e} \frac{B\rho}{\beta\gamma}$$

Bρ – from position at middle focal plane of the FRS

β – from TOF

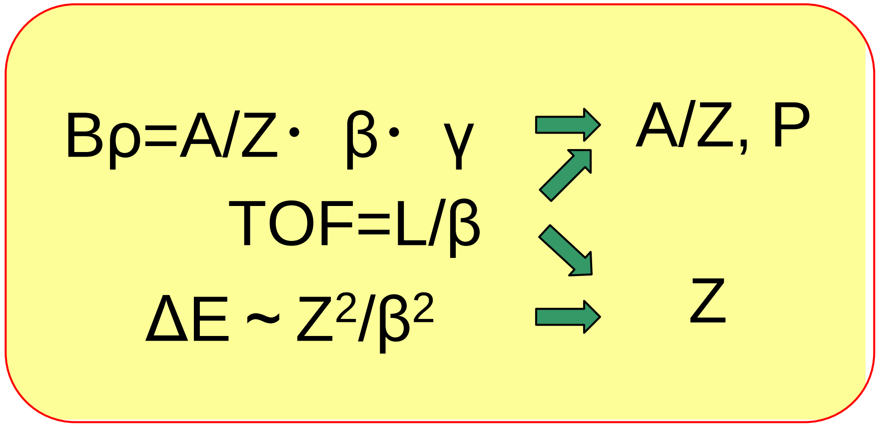
Z – from ΔE





NO CHARGE STATES !

Bρ-ΔE-TOF method: Requirements



$B\rho = A/Z \cdot \beta \cdot \gamma$ → A/Z, P

$TOF = L/\beta$

$\Delta E \sim Z^2/\beta^2$ → Z

Pos res.	$\sigma \leq 1$ mm
Timing res.	σ: 50 ps
ΔE resolution	σ: 1-2 %

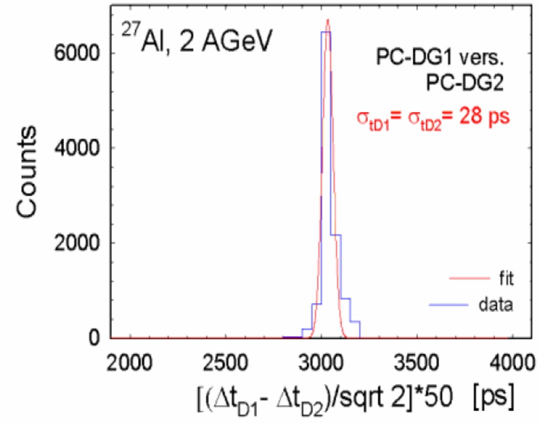
- Position: Wirechambers (single event readout)/Diamond
- ΔE: MUSIC/TEGIC
- TOF: Plastic/Diamond

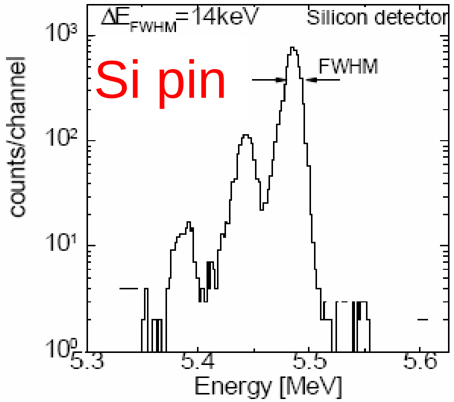
Standard detectors at the FRS

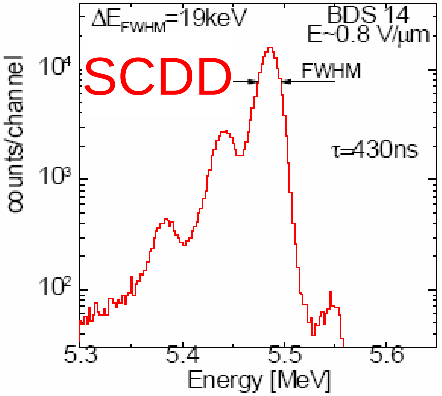
- Beam diagnostics : Current Grid (CG)
- Intensity : Secondary Electron Emission Transmission Monitor (SEETRAM)
- x,y : Multi Wire Proportional Chamber (MWPC)
  ΔE : Multi Sampling Ionization Chamber (MUSIC)
  Tof : Scintillators

Throughout the separator:
Diamond Detectors ?

- current readout for single crystal (a few mm²)
- cheaper polycrystaline diamonds (a few cm²)
- very good homogenity and radiation hardness
- price from a few 100 €/cm² to 1000 €/cm²
- expertise inhouse



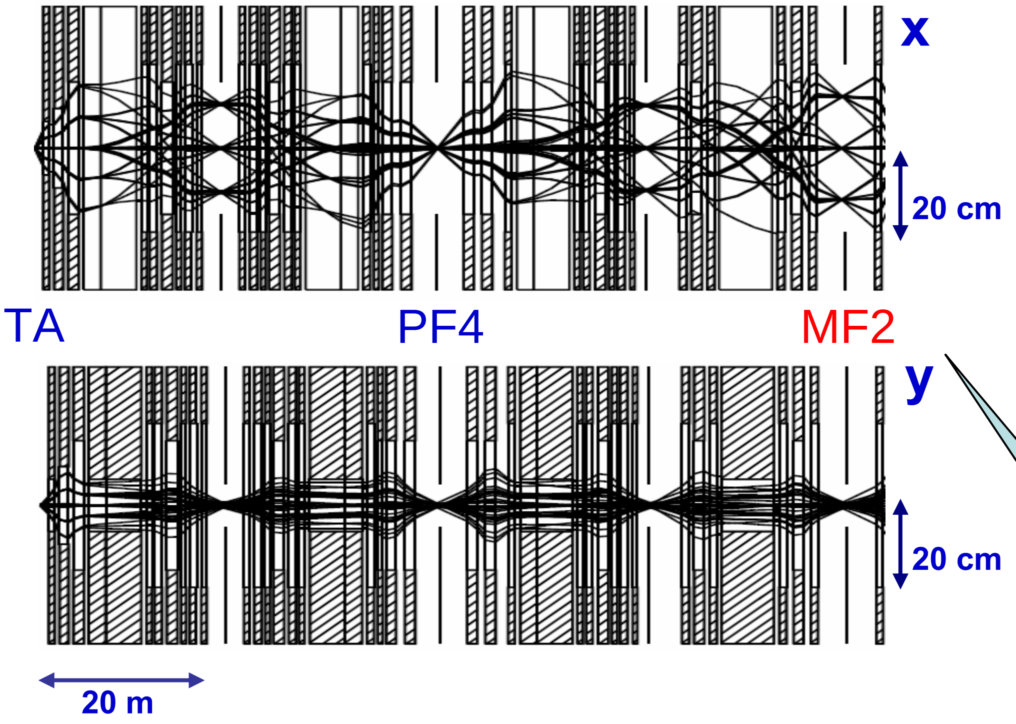




M. Pomorski,
E. Berdermann
et al. Nordhia, RD42

Detector sizes: Super-FRS

→ dipole gaps 140mm



TA
- $(6x12)mm^2$ slow extr.
- $(12x72)mm^2$ fast extr.

PF4
- $(30x30)mm^2$ slow extr.
- $(60x60)mm^2$ fast extr.

MF2
- Dispersive/full appert.
- $(380x140)mm^2$ slow/fast extr.

MF4
- $(90x30)mm^2$ slow extr.

MF7
- $(120x30)mm^2$ fast extr.

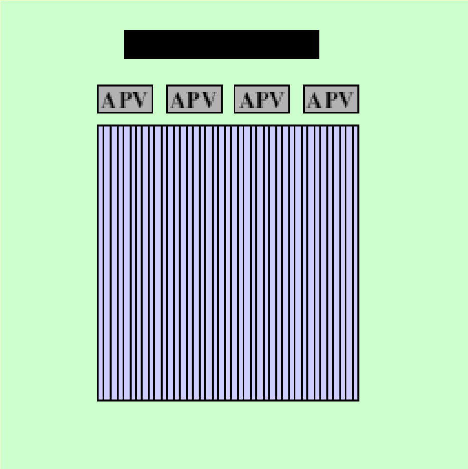
MF9
- $(90x30)mm^2$ slow extr.

R^3B diamond detector layout:

→ MF2 SuperFRS: × 8(h)

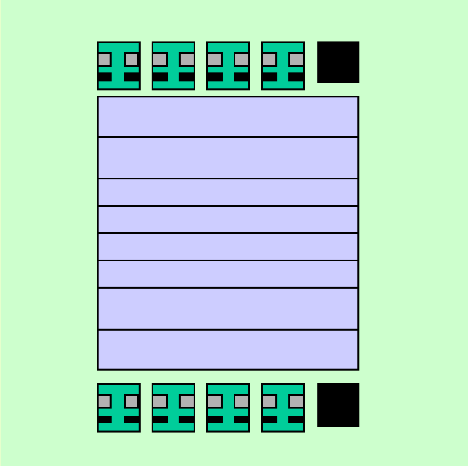
Test exp. 04/08

R. Gernhäuser (TU-München)



tracking layer:

- 50 x 50 mm, d = 100 μm, PC-CVDD
- 140 μm pitch (125μm strips, 15 μm gap)
- only digital position information
- multiplexed readout in vacuum



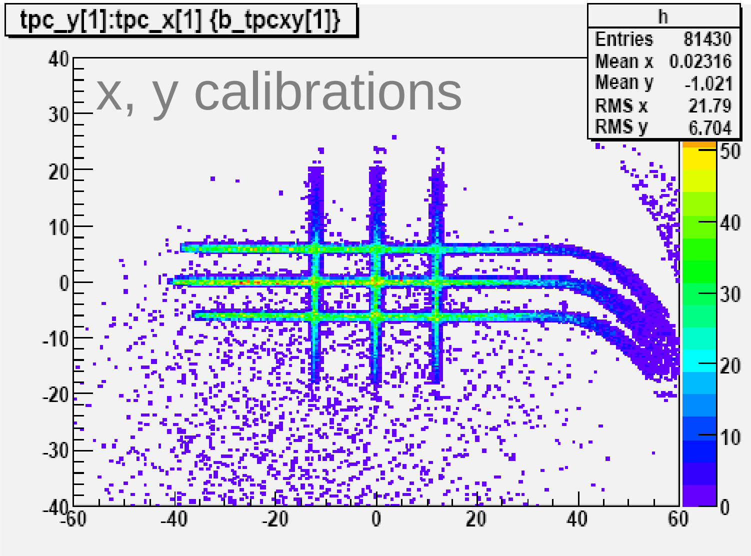
timing layer:

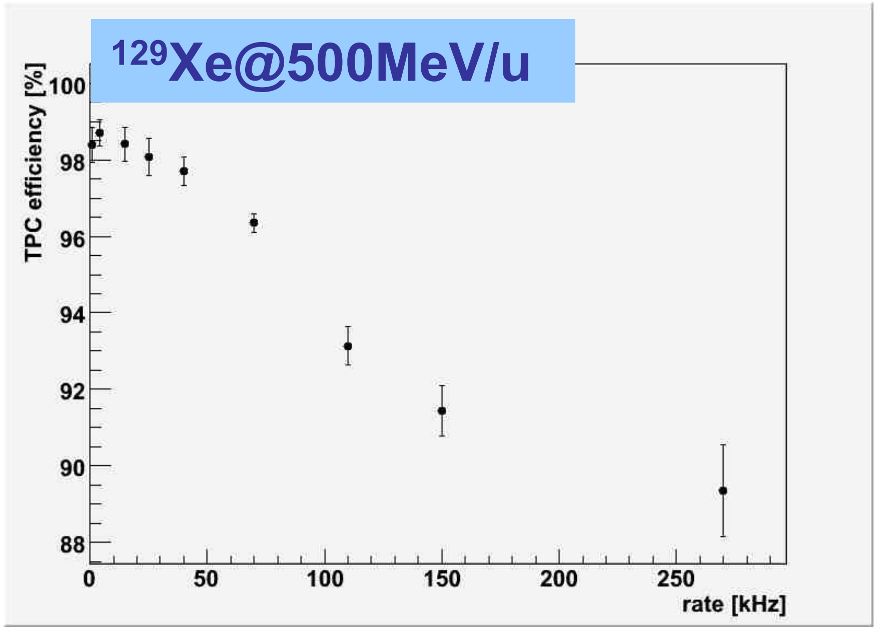
- 50 x 50 mm, d = 100 μm, PC-CVDD
- 8 rate matched strips, y information, trigger
- analog preamplification in vacuum
- discriminator @ 5 m distance

Time Projection Chamber

- CUB Bratislava

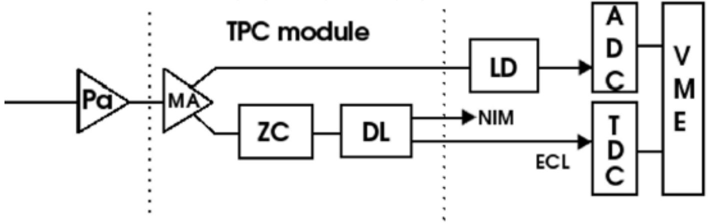
- (240x100) mm^2 active area
- Gas P10 at 1 atm
- Integrated delay lines (2x-pos, 4y-pos)
- σ_x ~ 0.1 mm, σ_y~ 0.05 mm





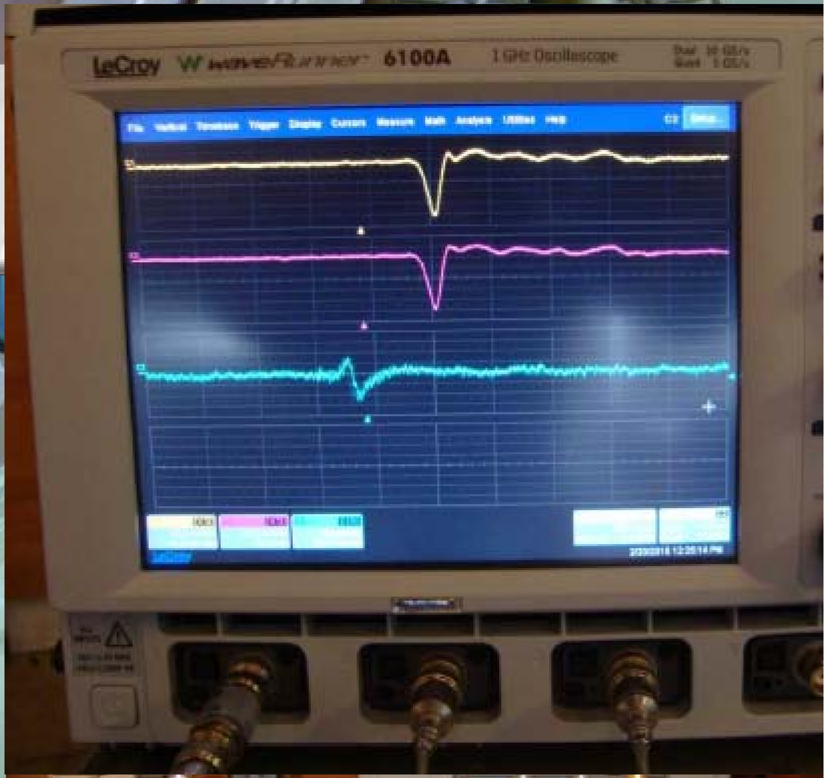
- VME standard electronics
- 90% efficency at ~100kHz

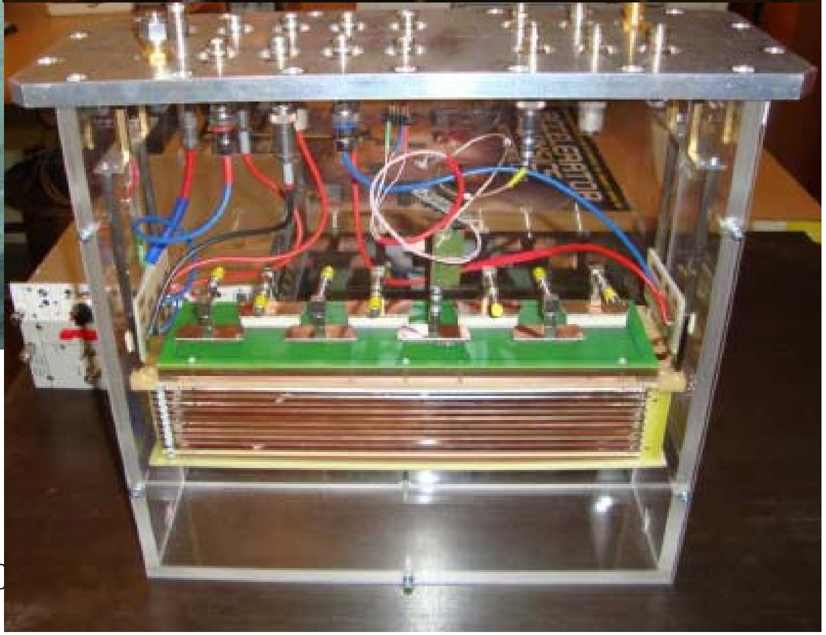
Electronics



New idea: GEM readout
(TOTEM/CERN)


Comenius Univ. Bratislava
& Univ. Helsinki





Readout still missing ➔
NXYTER/GSI

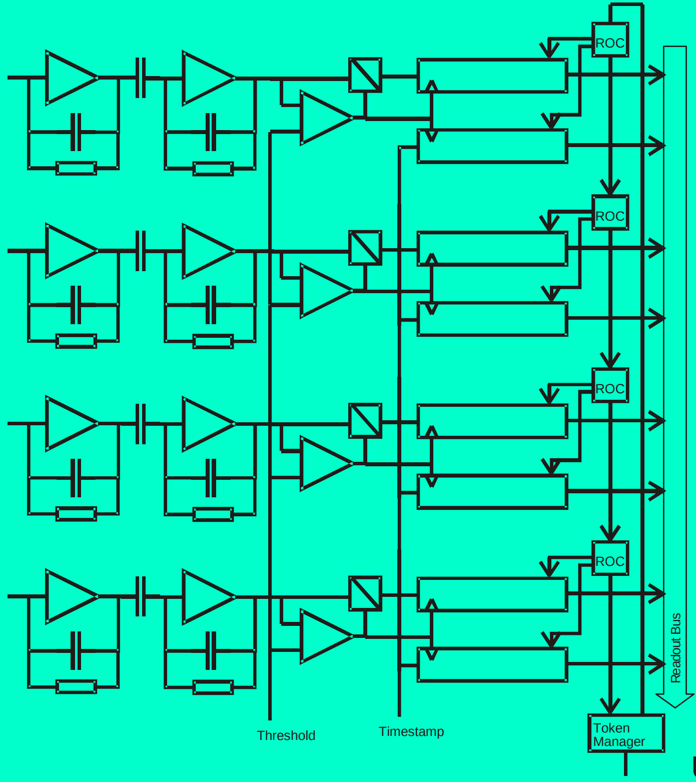
Token Ring Scheme (NXYTER)

➔ "deadtime free"/no trigger out

Ch. Schmidt (GSI)

ASIC Labor Heidelberg

Sparse & derandomized readout

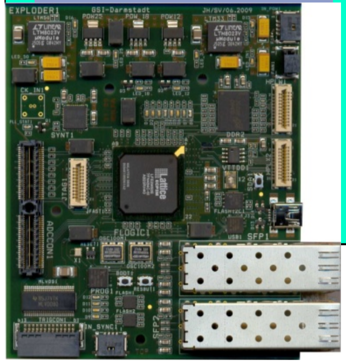


Ulrich Trunk
Physikalisches Institut der Universität Heidelberg

- Periodic readout at 20MHz
- Token asynchronously passes from channel to channel in search of data
- Within one readout cycle token could pass through all channels
- If token encounters occupied channels, data readout is initiated.
- After readout the token passes to the next channel.

→20 MHz/128 Ch ≈ 160 kHz

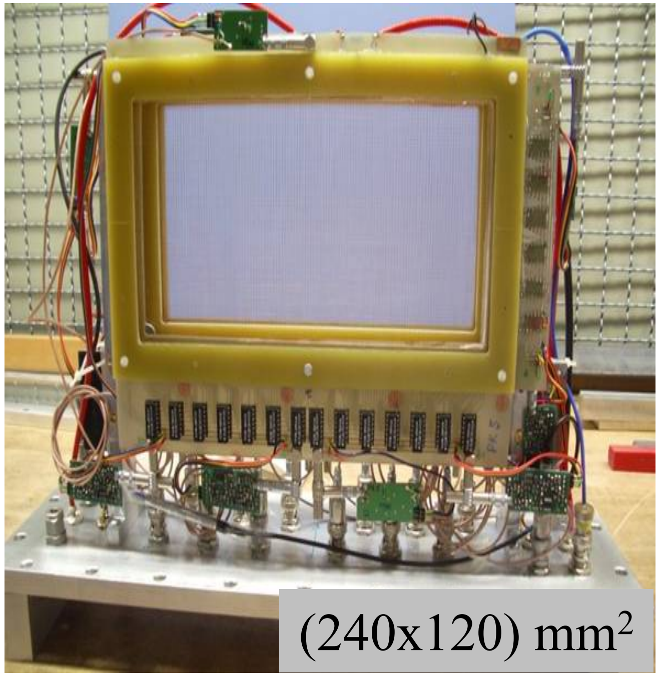
ENOB 10.4



Beam Profile Detector - CUB Bratislava

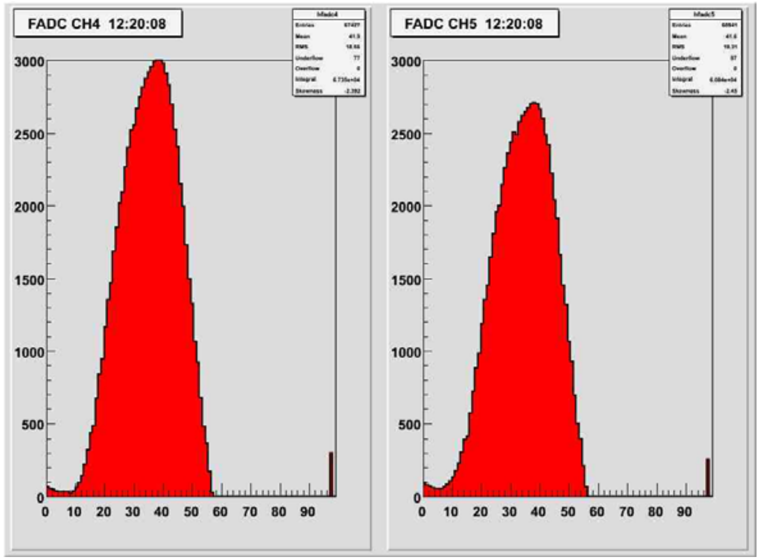
for intense fast extracted and slow extracted beams

- Basic module (120x120) mm^2
- 5mbar < gas $\mathrm{Ar+(10\%)CO_2}$ < 1bar
- Wires 2mm pitch directly connected to delay lines



(240x120) mm^2

Beam profile



^{12}C@200-400 MeV/u

10^4- $1.6 \cdot 10^9$ ions/spill

Spill length: 300 ns

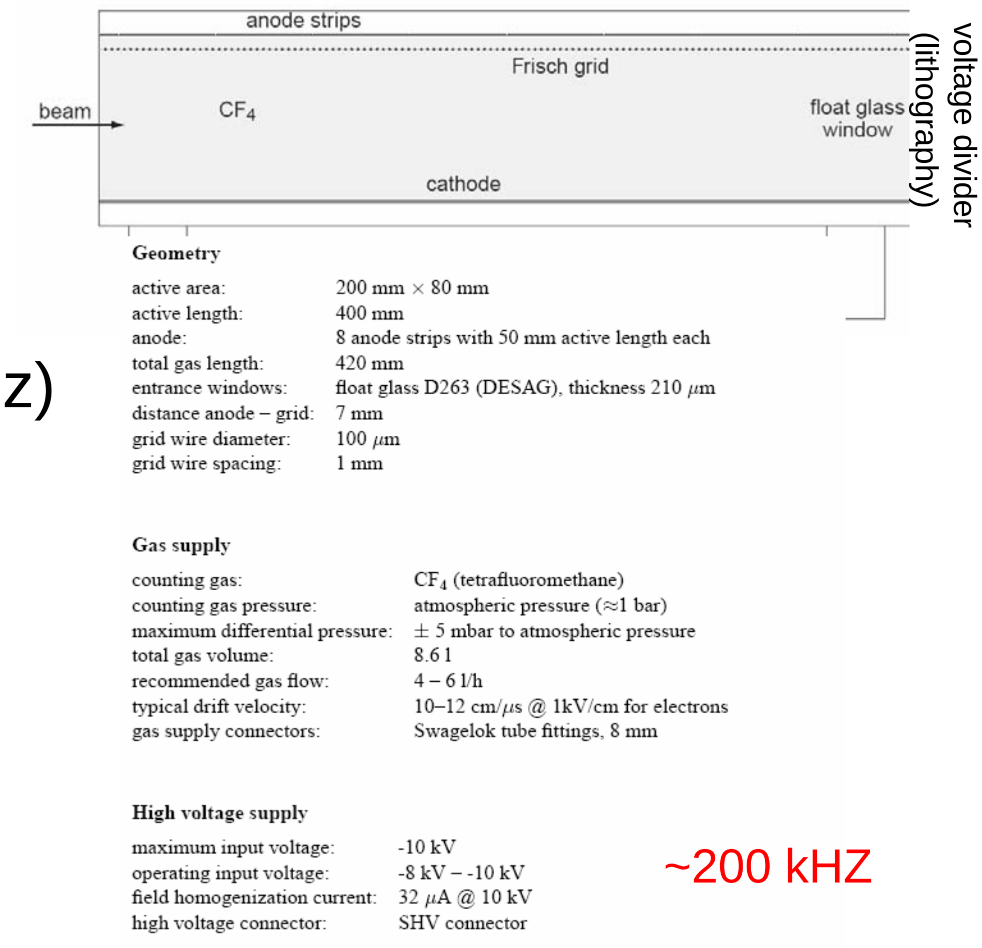
FADC SIS3301(100MHz)

A. Procházka, C. Nociforo *et al.*

Missing items:

FRS MUSIC

- Fast ΔE counter
  100 kHz – 1MHz, res. 1-2%,
  <u>large</u> dynamic range
  (no MIPS Z → ~100)
  - TEGIC (RIKEN, ca 1MHz)
  - Silicon stacks ?
  - sc-CVDD ?



Geometry

active area:	200 mm × 80 mm
active length:	400 mm
anode:	8 anode strips with 50 mm active length each
total gas length:	420 mm
entrance windows:	float glass D263 (DESAG), thickness 210 μm
distance anode – grid:	7 mm
grid wire diameter:	100 μm
grid wire spacing:	1 mm

Gas supply

counting gas:	CF$_4$ (tetrafluoromethane)
counting gas pressure:	atmospheric pressure (≈1 bar)
maximum differential pressure:	± 5 mbar to atmospheric pressure
total gas volume:	8.6 l
recommended gas flow:	4 – 6 l/h
typical drift velocity:	10–12 cm/μs @ 1kV/cm for electrons
gas supply connectors:	Swagelok tube fittings, 8 mm

High voltage supply

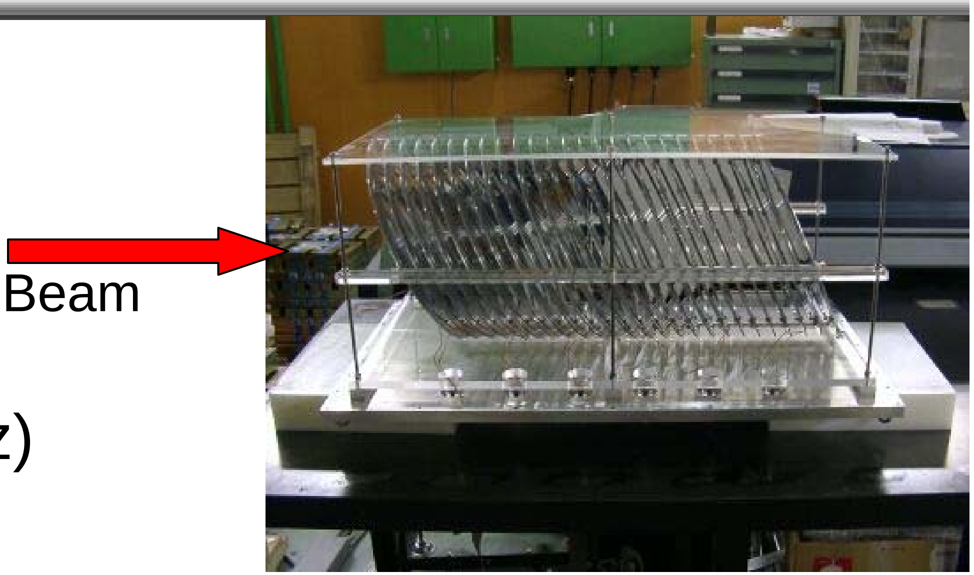
maximum input voltage:	-10 kV
operating input voltage:	-8 kV – -10 kV
field homogenization current:	32 μA @ 10 kV
high voltage connector:	SHV connector

~200 kHZ

Missing items:

TEGIC

- Fast ΔE counter
  100 kHz – 1MHz, res. 1-2%,
  large dynamic range
  (no MIPS Z → ~100)
  - TEGIC (RIKEN, ca 1MHz)
  - Silicon stacks ?
  - sc-CVDD ?



K. Kimura et al., Nucl. Instr. and Meth. A538(2005)608

P10 425mm normal pressure
Electrodes(anode/cathode) 4μm×25 Mylar
$14\ \mathrm{mg/cm^2}$
Distance(anode-cathode) 2cm
Detector Window 150μm Kapton

~1 MHZ

What do we (the DAQ&Controls people) require for fast incoming tracking systems:

- high rate capability → limit by detectors
  →avoid common dead time

- compliance with existing setups (easiest/fastest integration if system operates also in a triggered environment)

- feedback to accelerator controls
  (work in progress; interface difficult)
  (high demands on physicists → models)

- interesting separation
  - ‘slow’ control
  - (fast) feedback loops
  - interlocks ! machine & detector safety

First Steps: ADC coupled to Hades TRB2 at KVI

Peter Schakel / Pim Lubberdink

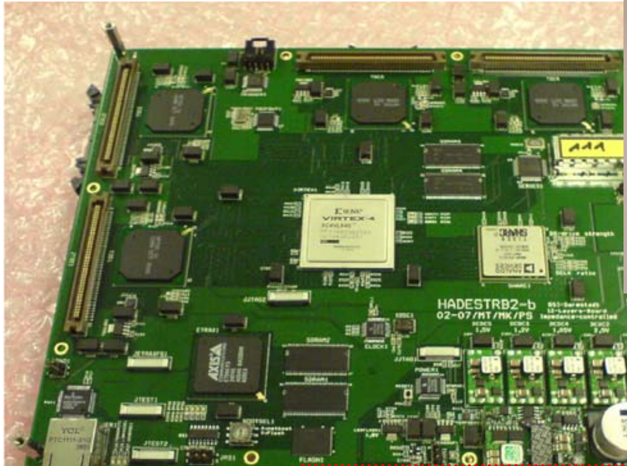
- Prototype hard/software environment:

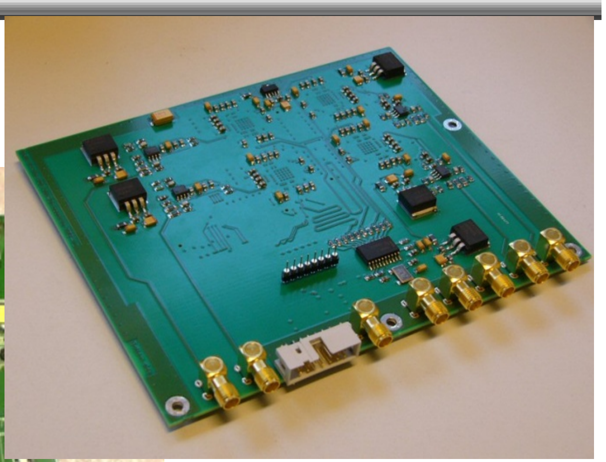
  (1) ADC Piggy back / KVI
  100MS/14Bit
  50MHZ BW

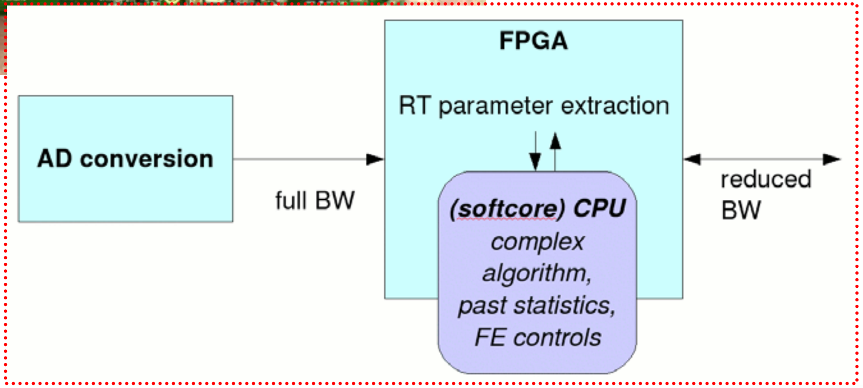
  (2) Xilinx based board
  HADES TRB2

  (3) Base line follower/
  kσ trigger
  (J. Jungmann / M. Vencelj)

  Labview based readout system







AD conversion

full BW

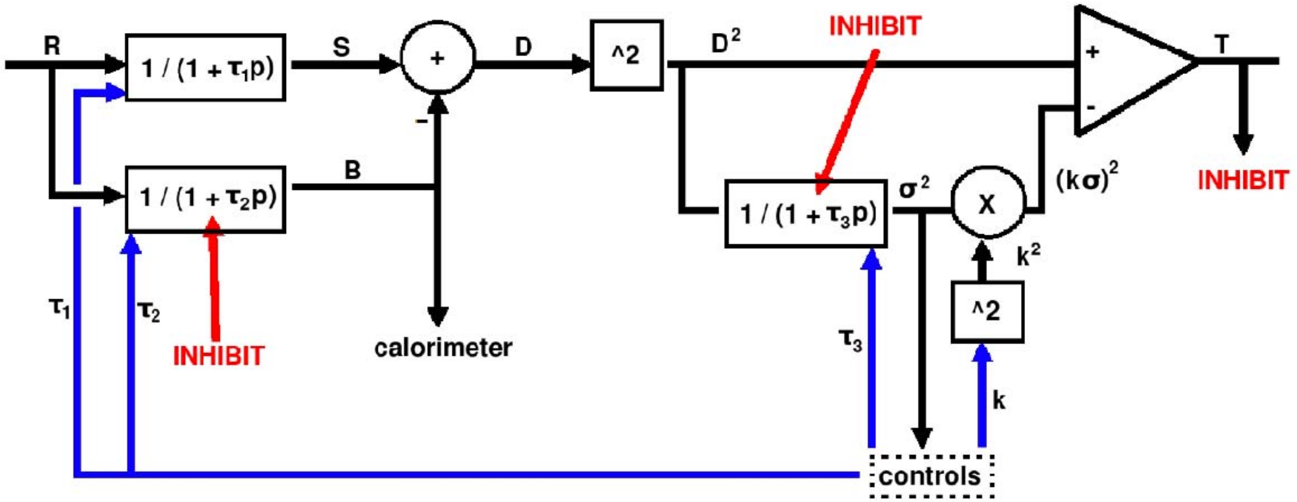
FPGA

RT parameter extraction

(softcore) CPU

complex algorithm, past statistics, FE controls

reduced BW



Baseline follower based on 3 fold low-pass filter

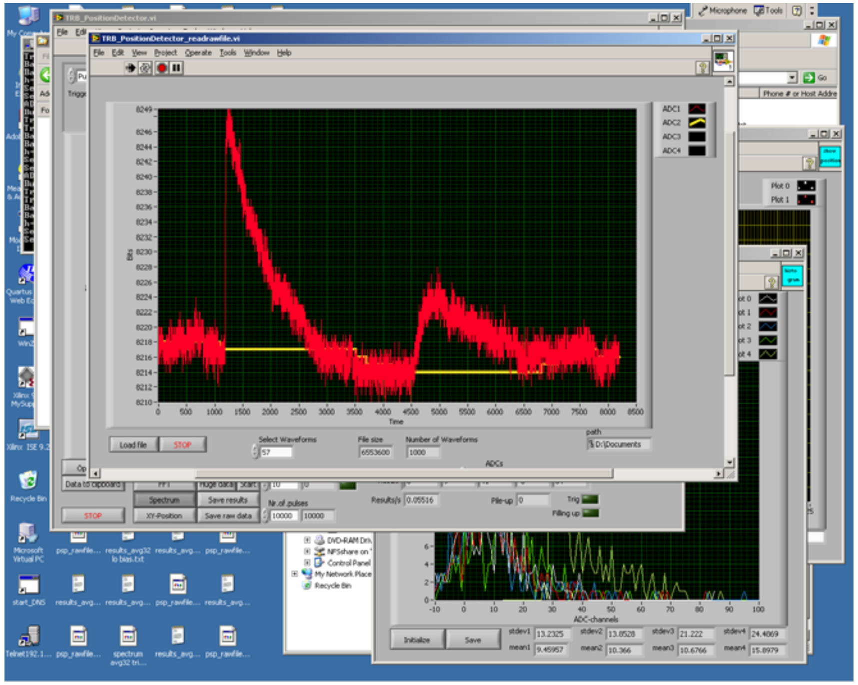
- **R**aw, **S**ignal, **B**aseline → **D**ifference → **D²** (Energy)
- **calorimeter, σ^2** → histograming ➔ controls
- Inhibit → **Bimodal** filter

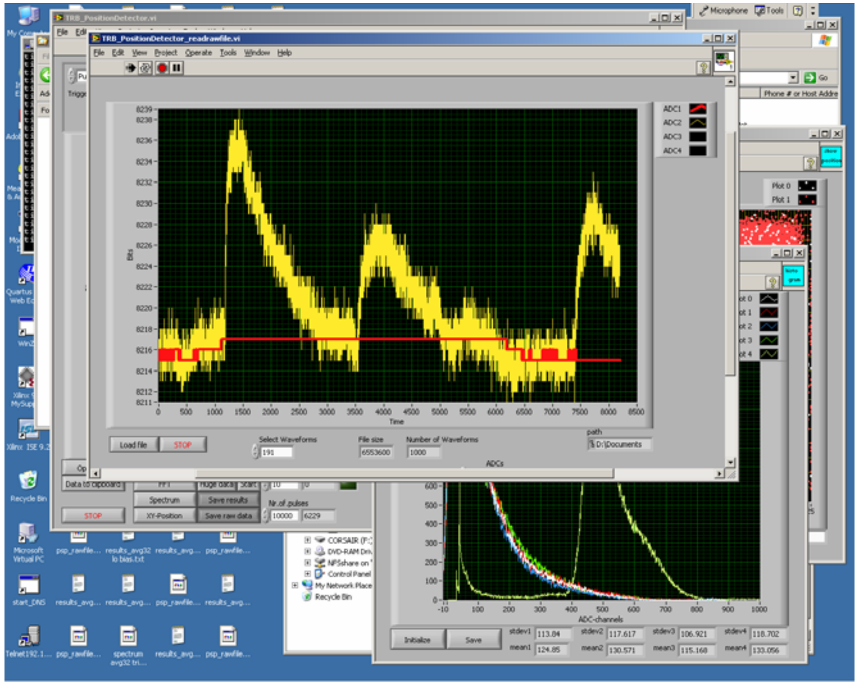
- controls ➔ filter parameters

Benefit: kσ Trigger i.e. most precise & "quantitative" treshold

➔ Potential problem: Spikes

Results: Baseline

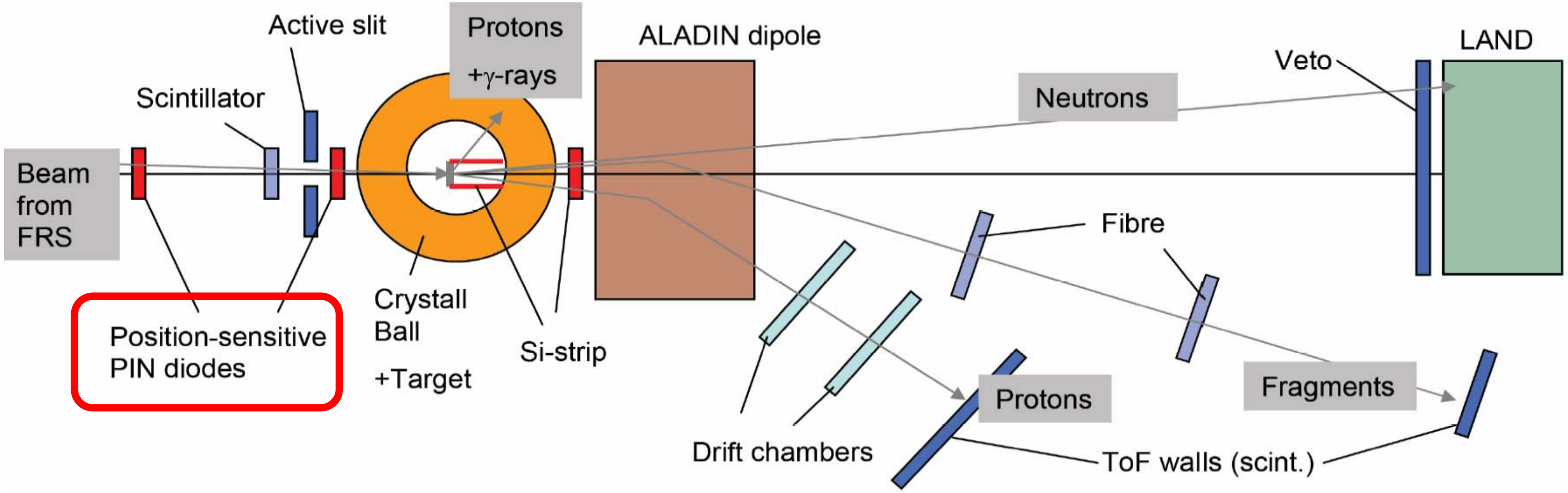




Baseline follower works !
(Bimodal Filter)

Treatment of double hits !

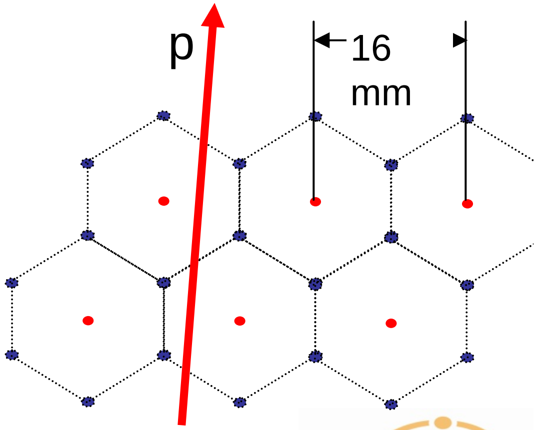
Prologue: Extended experimental Setup at Cave C



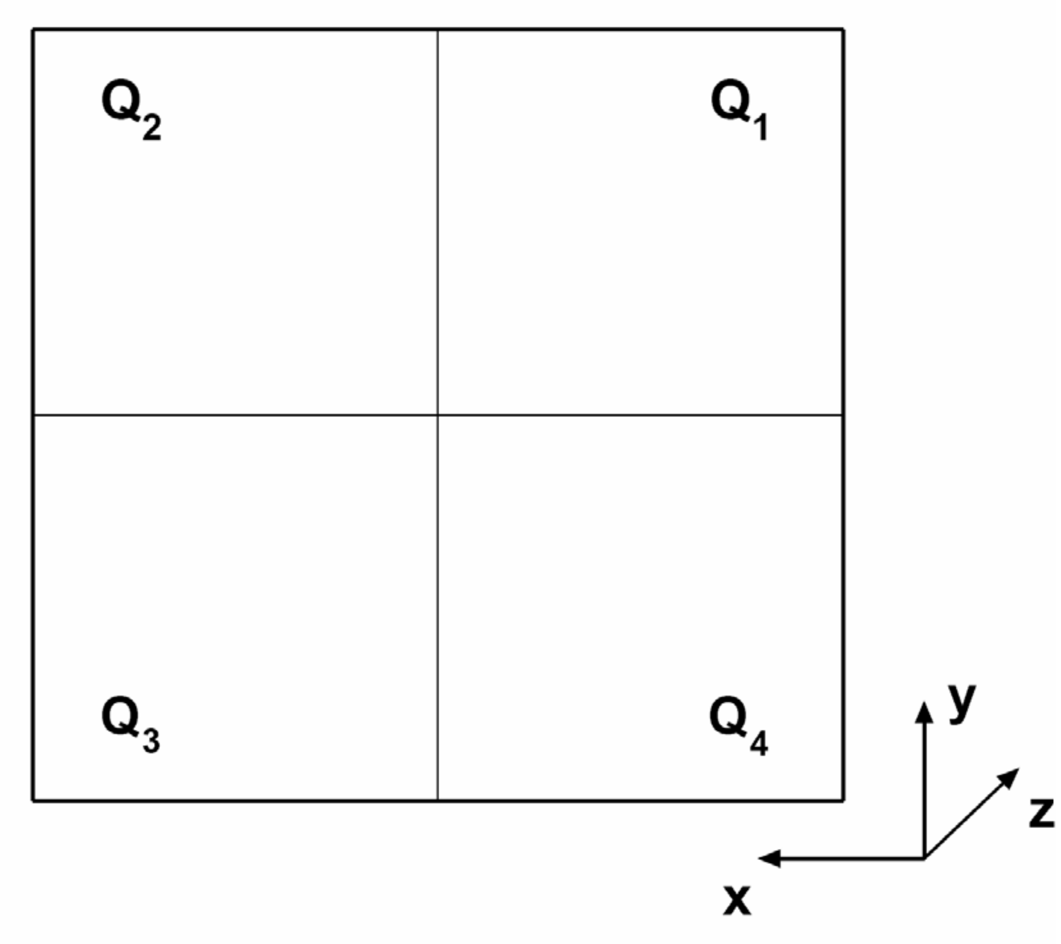
300 µm high n-type Si

4,5 x 4,5 cm²

B doped → p-side



PSP



- Cathode : Sum energy
- 4 Anodes → position

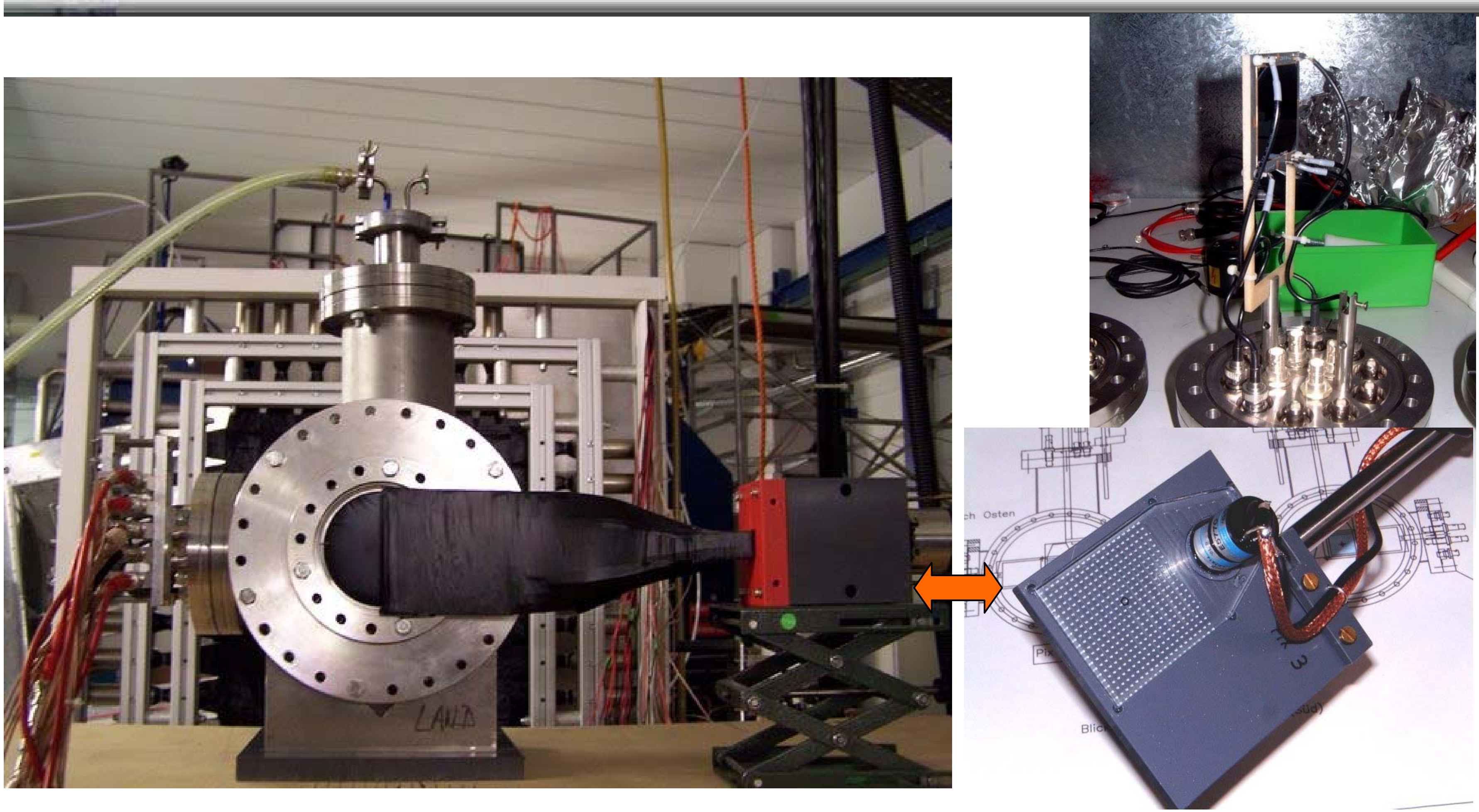
$$u = (Q2 + Q3) - (Q1 + Q4) / Q$$
$$v = (Q1 + Q2) - (Q3 + Q4) / Q$$

$$Q = Q1+Q2+Q3+Q4$$

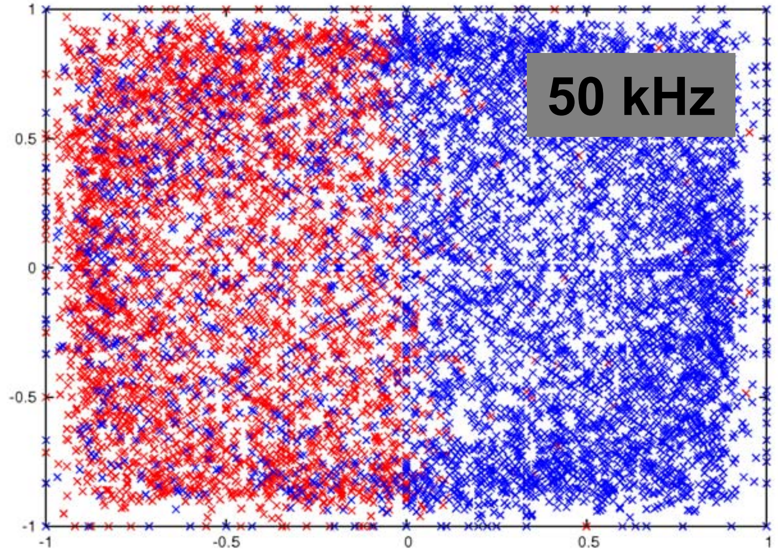
→ x(u,v) ; y (u,v)

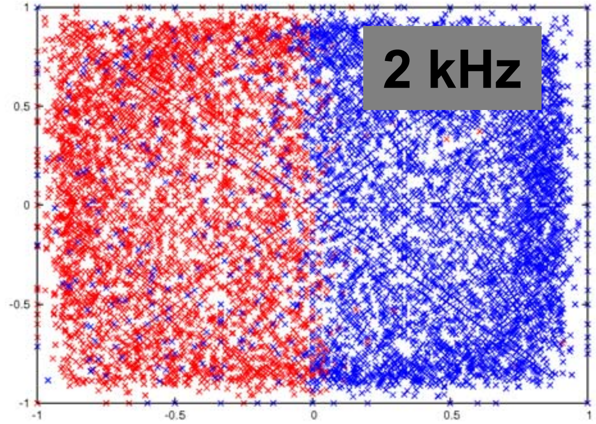
Test experiment S327 (16.-18.4.2008)

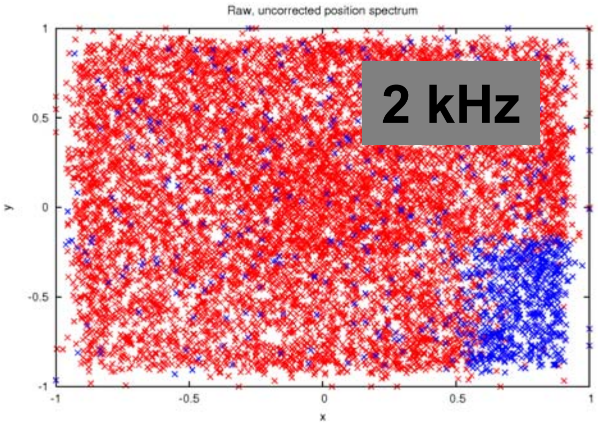
^{12}C: 550-700 MeV/u ; 2-50 kEv/s



Online Position and amplitude reconstruction







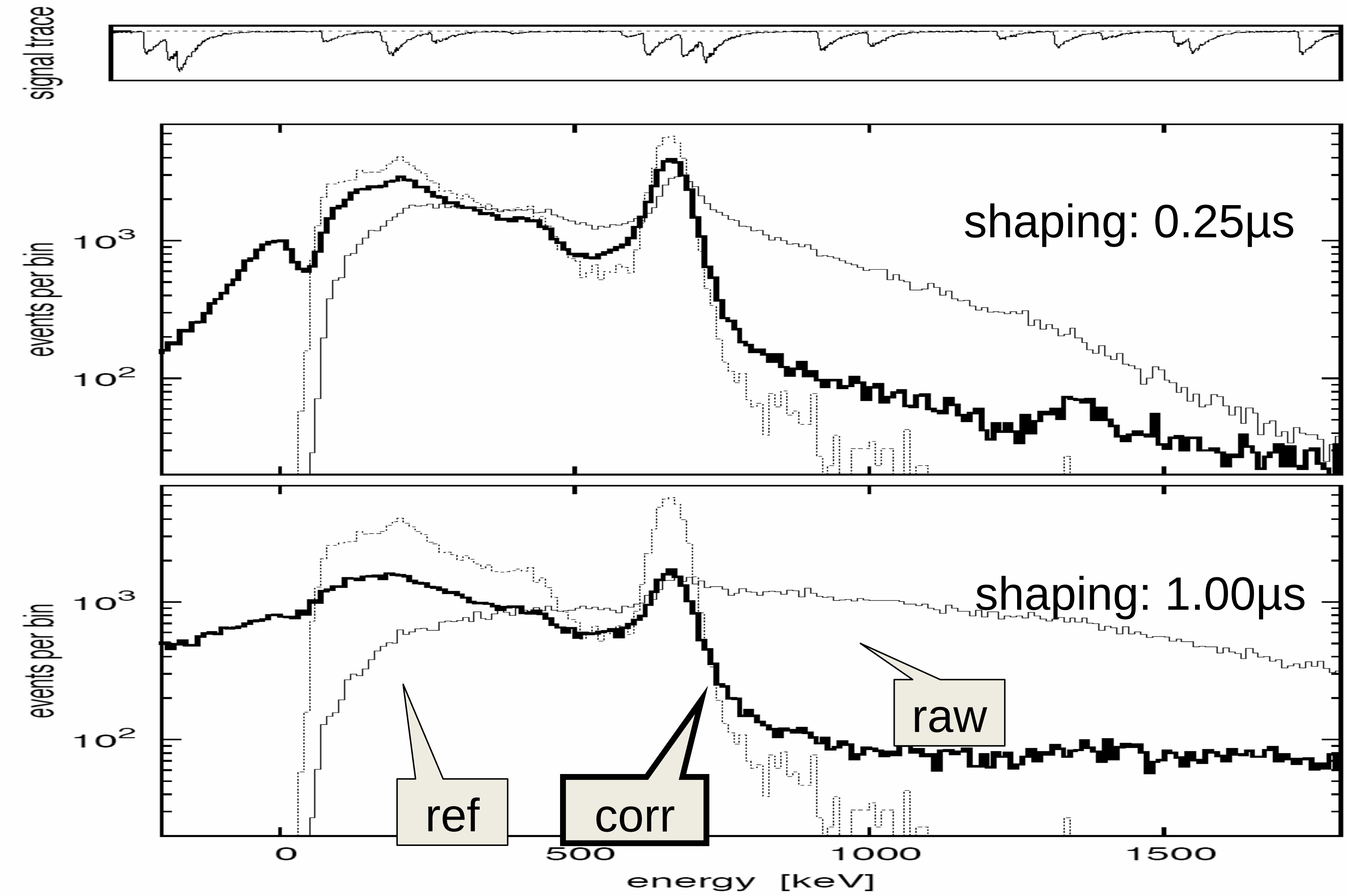
minimal
distortions

Computation in FPGA:

i. @ full rate (i.e. 50+ kHz, theoretical limit: ADC speed !)
ii. no correction yet

→ development of a “slow process”

High rates: On line Pile up correction

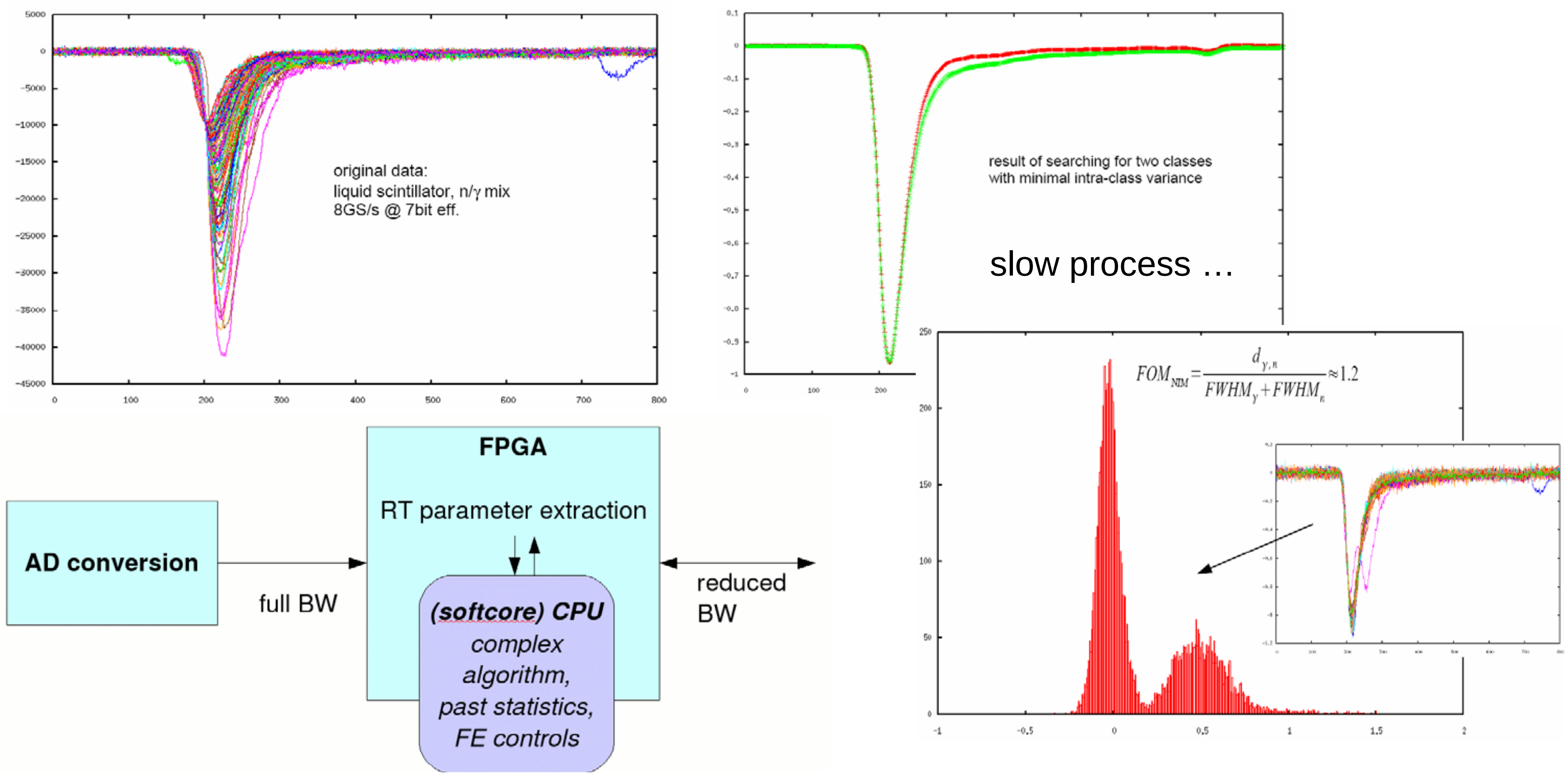


2’x2’ NaI, ^{137}Cs, ca. 1MBq

M. Vencelj – GSI/JSI/KVI/INCAS³

Digital Signal Processing (PULSE SHAPE)

M. Vencelj et al. (JSI)



$$FOM_{NIM} = \frac{d_{\gamma,n}}{FWHM_{\gamma} + FWHM_{n}} \approx 1.2$$

AD conversion

full BW

FPGA

RT parameter extraction

(softcore) CPU

complex algorithm,
past statistics,
FE controls

reduced BW

similar: energy loss/position

→ fast pos. sens. PIN tracker project (P. Lubberdink, H. Wörtche, H. Simon)

Commercial VME module implementation

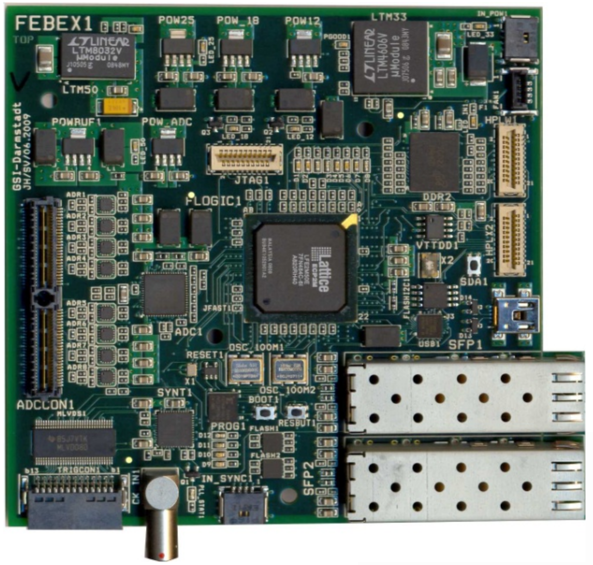
- Open Firmware

→ Agreement 20090507

KVI/GSI/Struck (P.Schakel/V.Stoica)

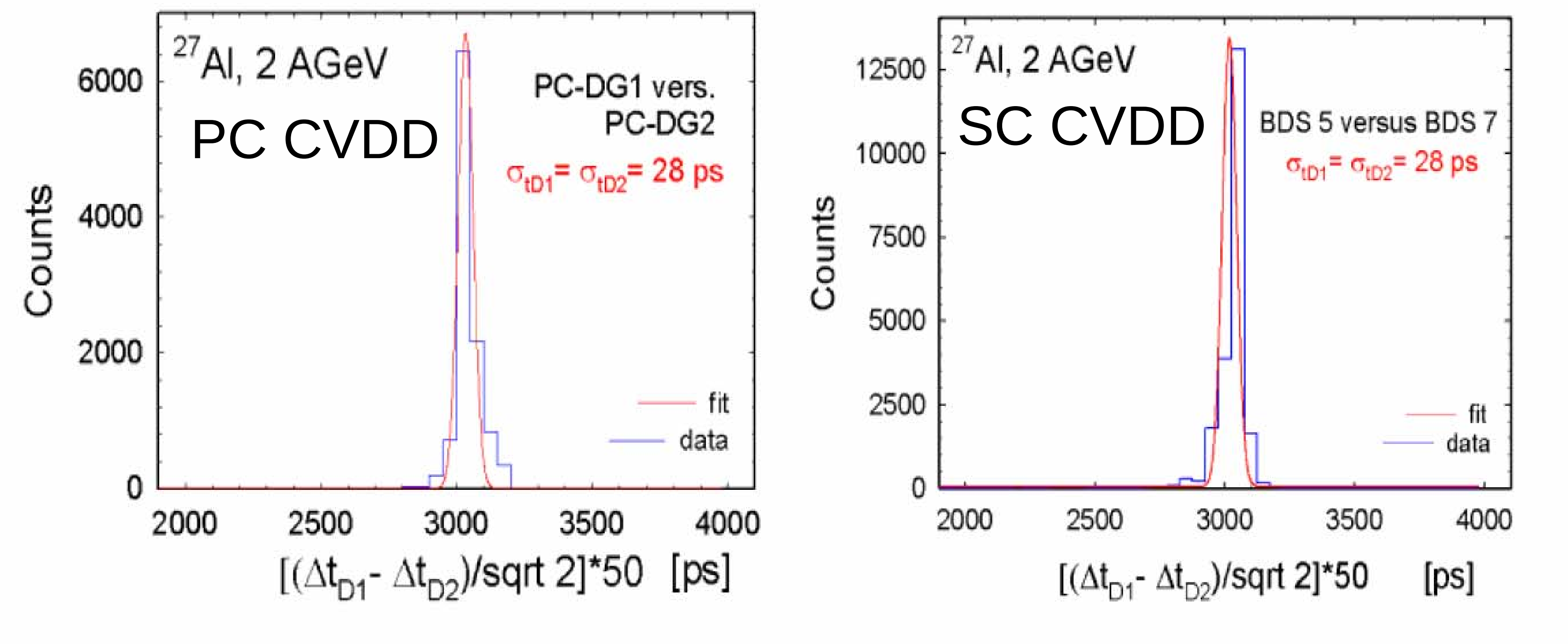
- MBS integration (N.Kurz)

- Limited FPGA resources
- Next implementation
FEBEX (larger FPGA)
- Baseline + pileup corr.



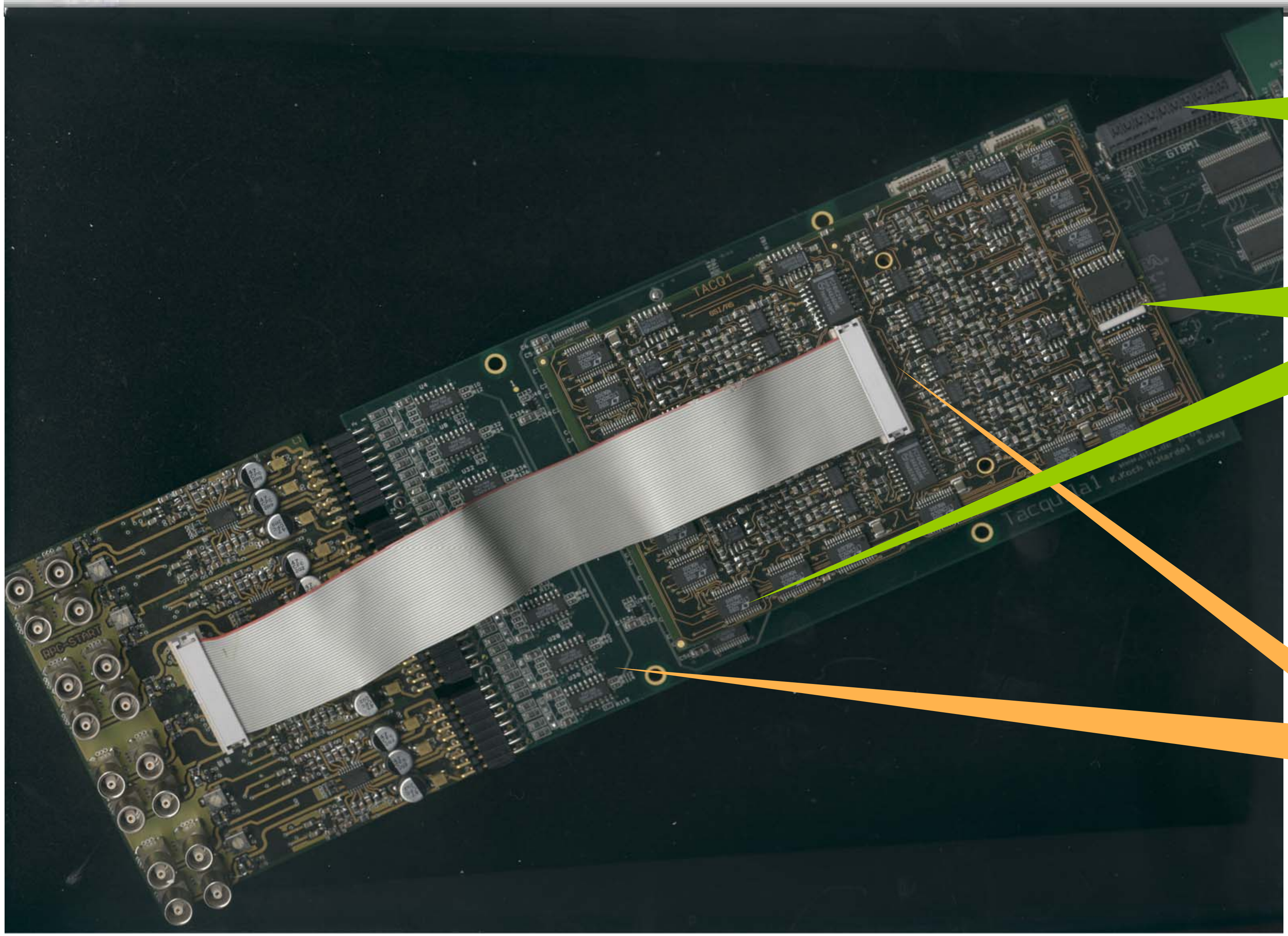
Diamond Detectors

TOF



- good timing (eg. R3B req. σ_t~50ps)
- R&D: detector geometry strips or pxl / readout electronics (in about 1m distance)

Field test: Precision timing system Tacquila (R^3B: FE prototype) - FOPI/GSI



GTB interface

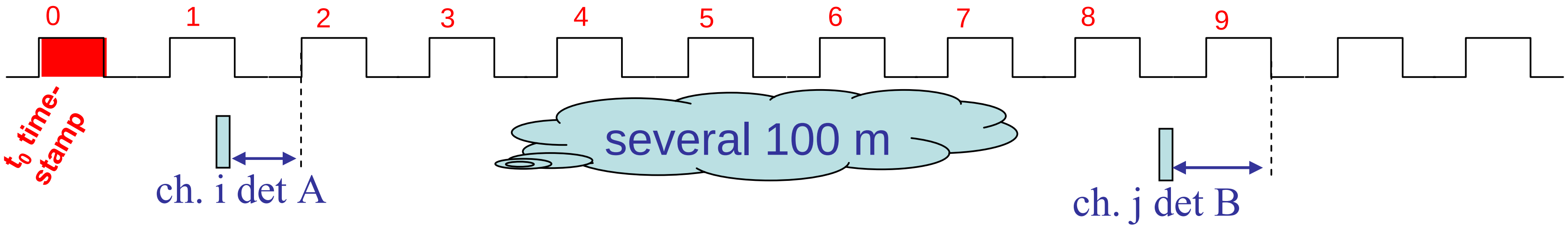
12 Bit ADCs

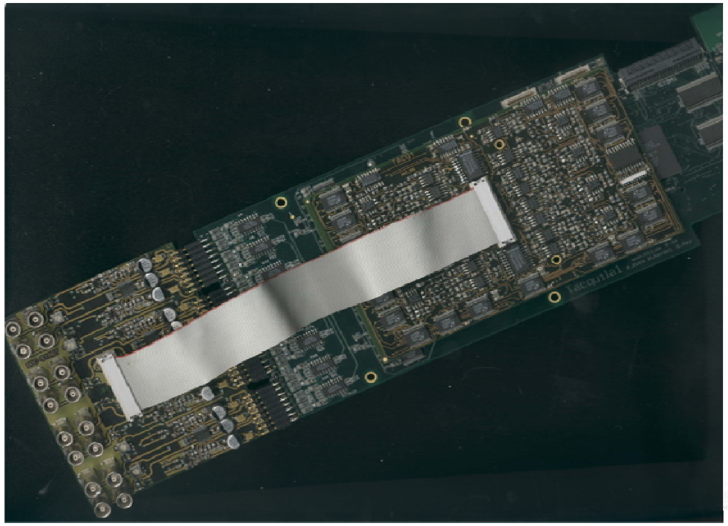
10 Bit read ...

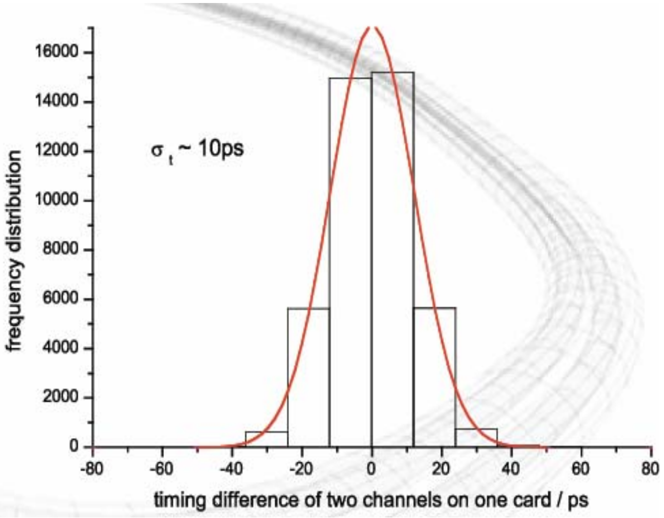
TAC Q uila

Precision timing (<50ps) vs. Campus Clock

FOPI collaboration/Tacquila – K. Koch







Timing FEEs:

Tacquila system (ASIC FhG/GSI) all existing chips in house

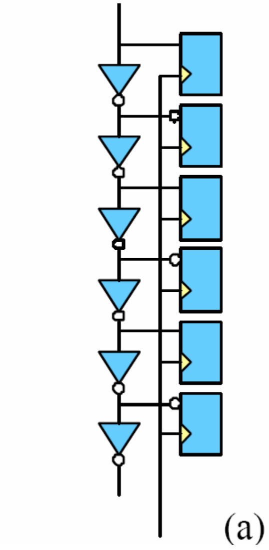
New systems (ASIC dev. GSI FPGA based TDC)

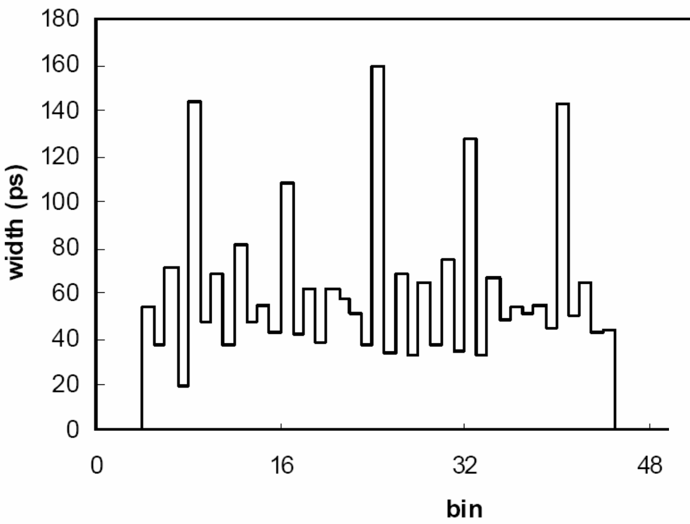
FPGA TDC

The 10-ps Wave Union TDC:
Improving FPGA TDC Resolution beyond Its Cell Delay

Jinyuan Wu and Zonghan Shi

IEEE Nuclear Science Symposium Conference Record, 2008. NSS '08.





Project at GSI:
M. Traxler / N. Kurz

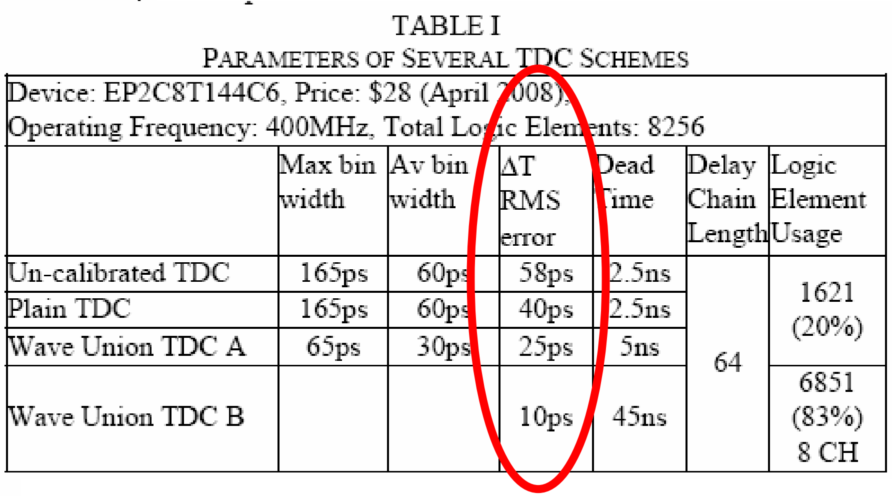


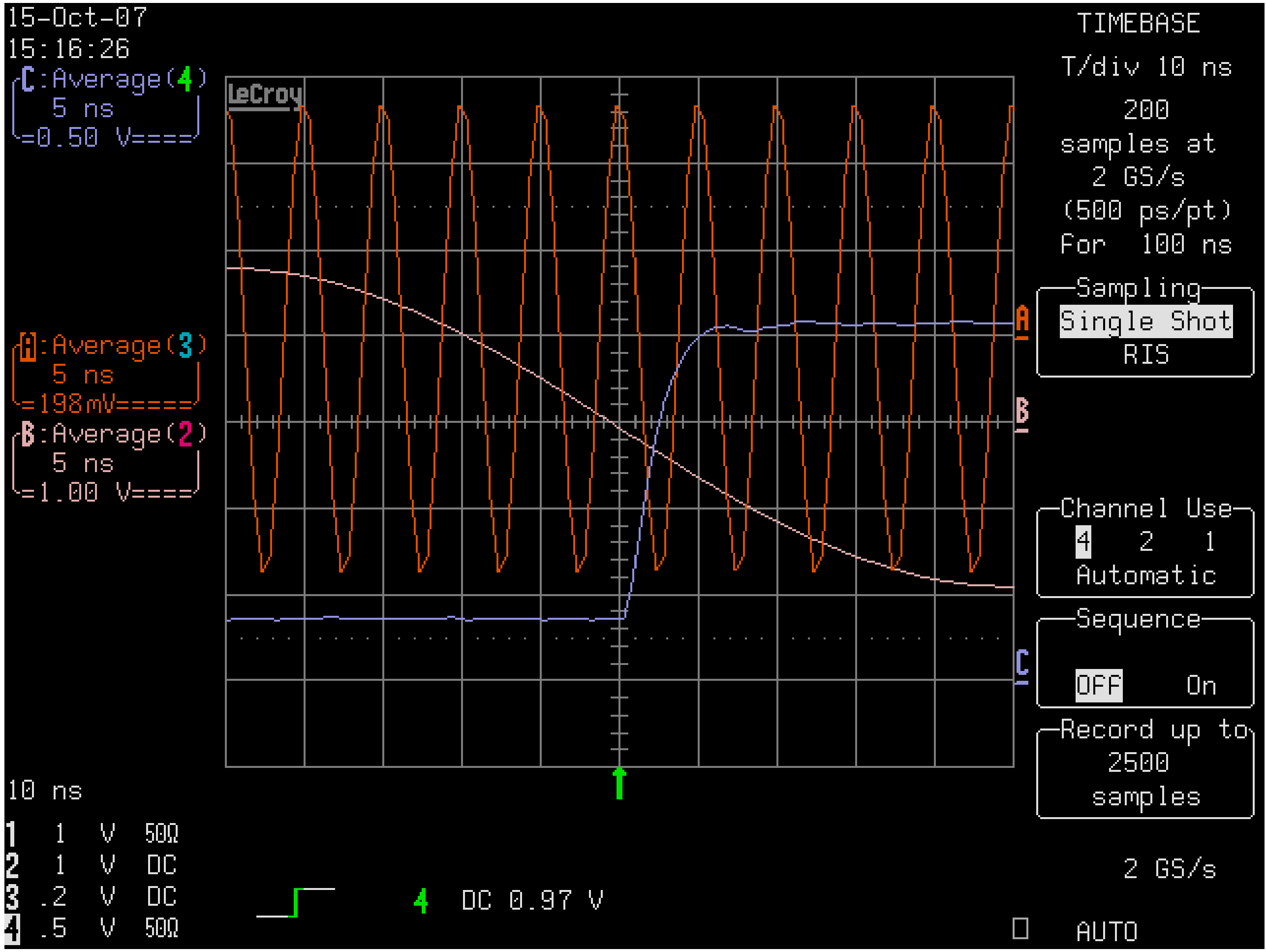
TABLE I
PARAMETERS OF SEVERAL TDC SCHEMES

Device: EP2C8T144C6, Price: $28 (April 2008), Operating Frequency: 400MHz, Total Logic Elements: 8256						
	Max bin width	Av bin width	ΔT RMS error	Dead Time	Delay Chain Length	Logic Element Usage
Un-calibrated TDC	165ps	60ps	58ps	2.5ns	64	1621 (20%)
Plain TDC	165ps	60ps	40ps	2.5ns		
Wave Union TDC A	65ps	30ps	25ps	5ns		
Wave Union TDC B			10ps	45ns		6851 (83%) 8 CH

Altera Cyclone II device (EP2C8T144C6)

BuTiS at work (20071015)

P.Moritz/GSI

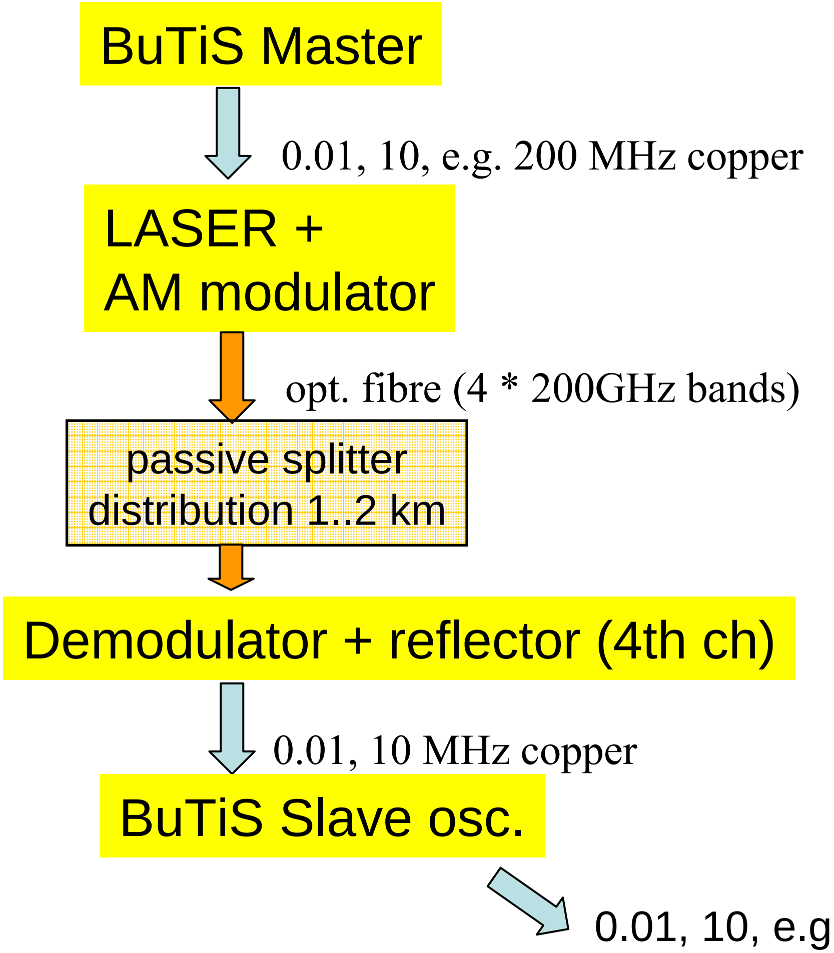


- 10, 200 MHz sine waves (adj. phase)
- T0 pulse for sync. every 100µs
- very good phase stability
- BuTiS oscillator can run standalone
- about 10k€/system

➔Test of BuTiS generators BNC coupled

BuTiS fibre distribution test bench (09/2009 succesful test of 4th channel < 100ps/km)

P. Moritz



BuTiS Master

0.01, 10, e.g. 200 MHz copper

LASER + AM modulator

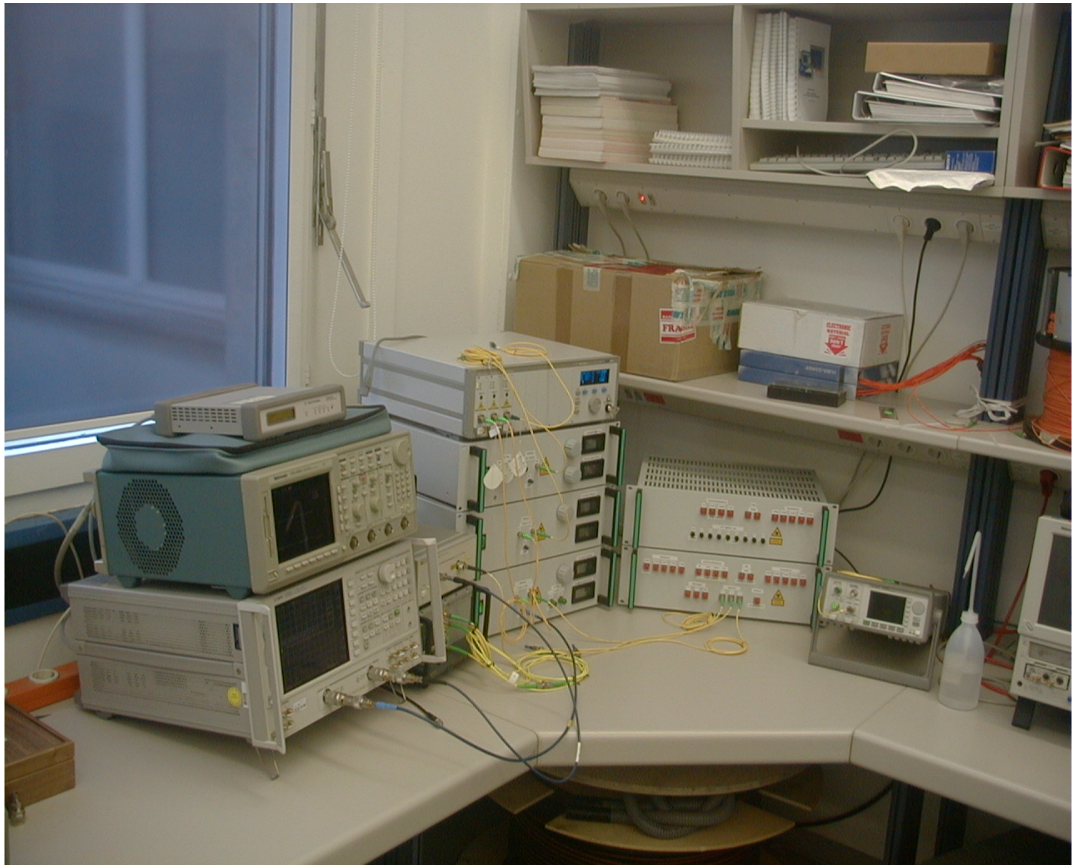
opt. fibre (4 * 200GHz bands)

passive splitter distribution 1..2 km

Demodulator + reflector (4th ch)

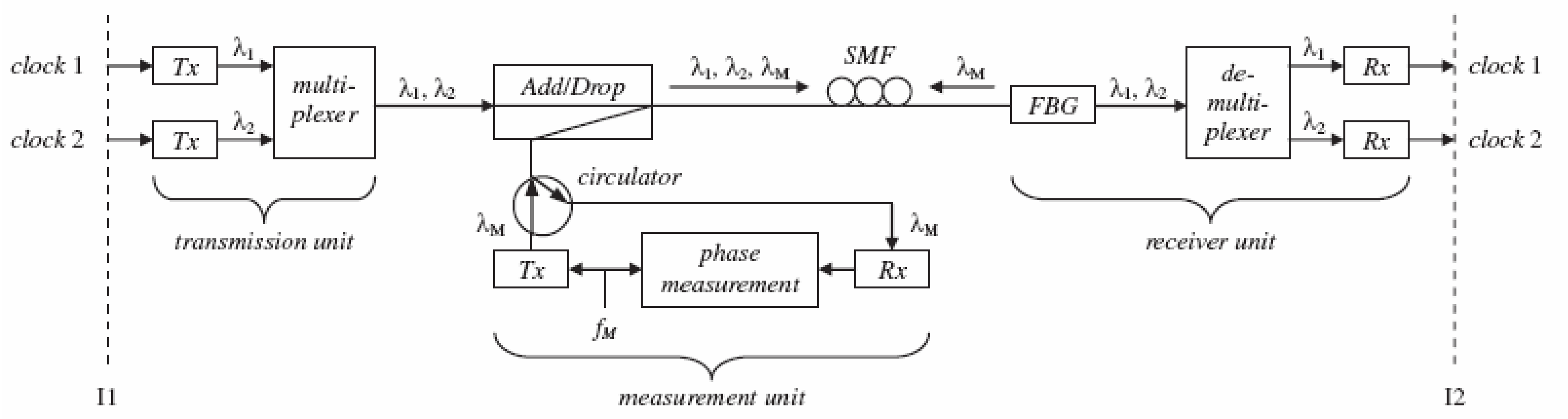
0.01, 10 MHz copper

BuTiS Slave osc.



0.01, 10, e.g. 200 MHz copper ➔ **(local TDS) ?**

Detailed view on the LASER distribution system



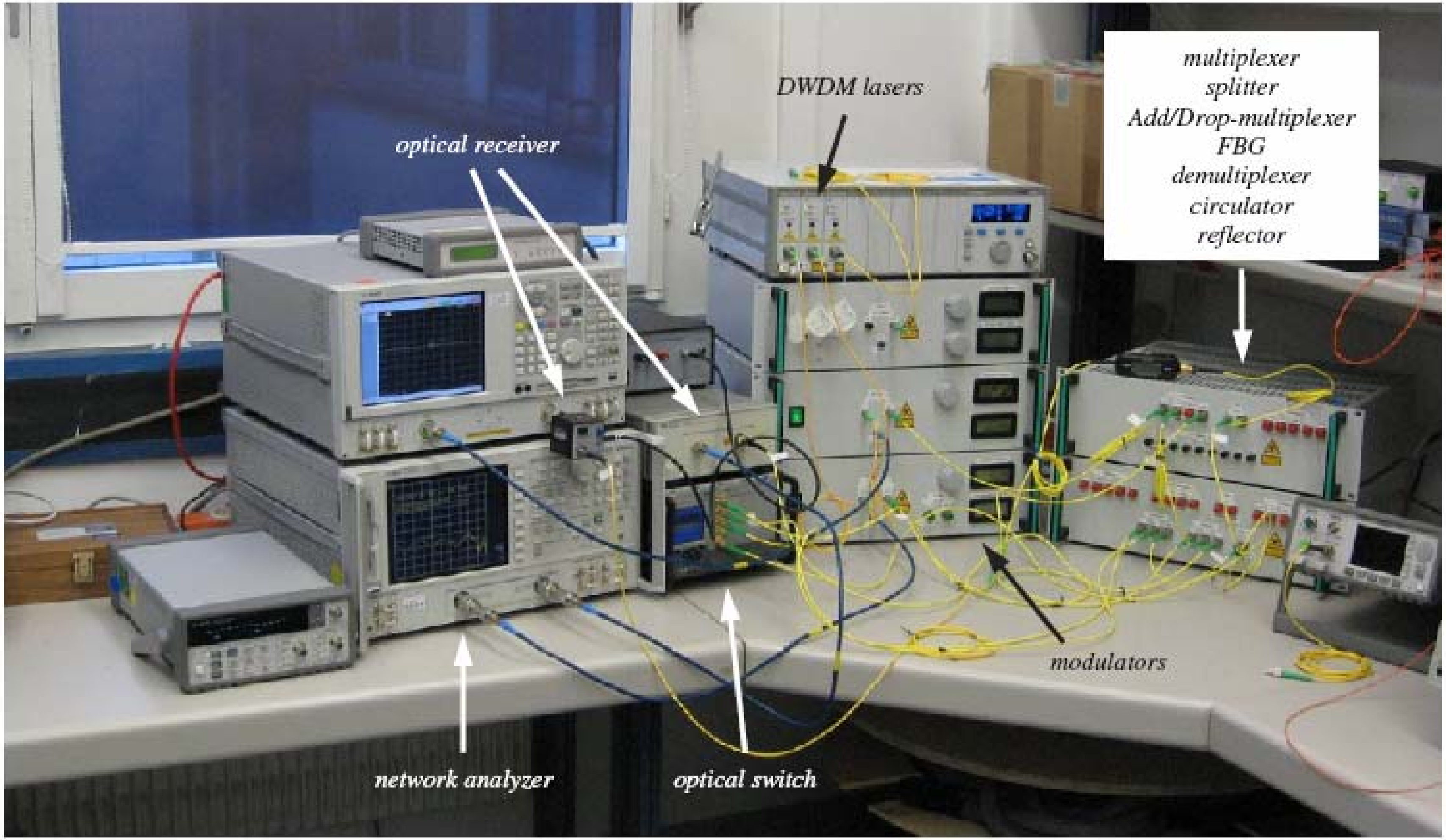
Dense wavelength division multiplex
Standard single mode fibres

- Passive splitter
- Erbium-doped fiber amplifier

	Channel (ITU norm)	Optical frequency ν [THz]	Optical wavelength λ [nm]
λ_1	32	193.2	1551.721
λ_2	34	193.4	1550.116
λ_M	36	193.6	1548.515

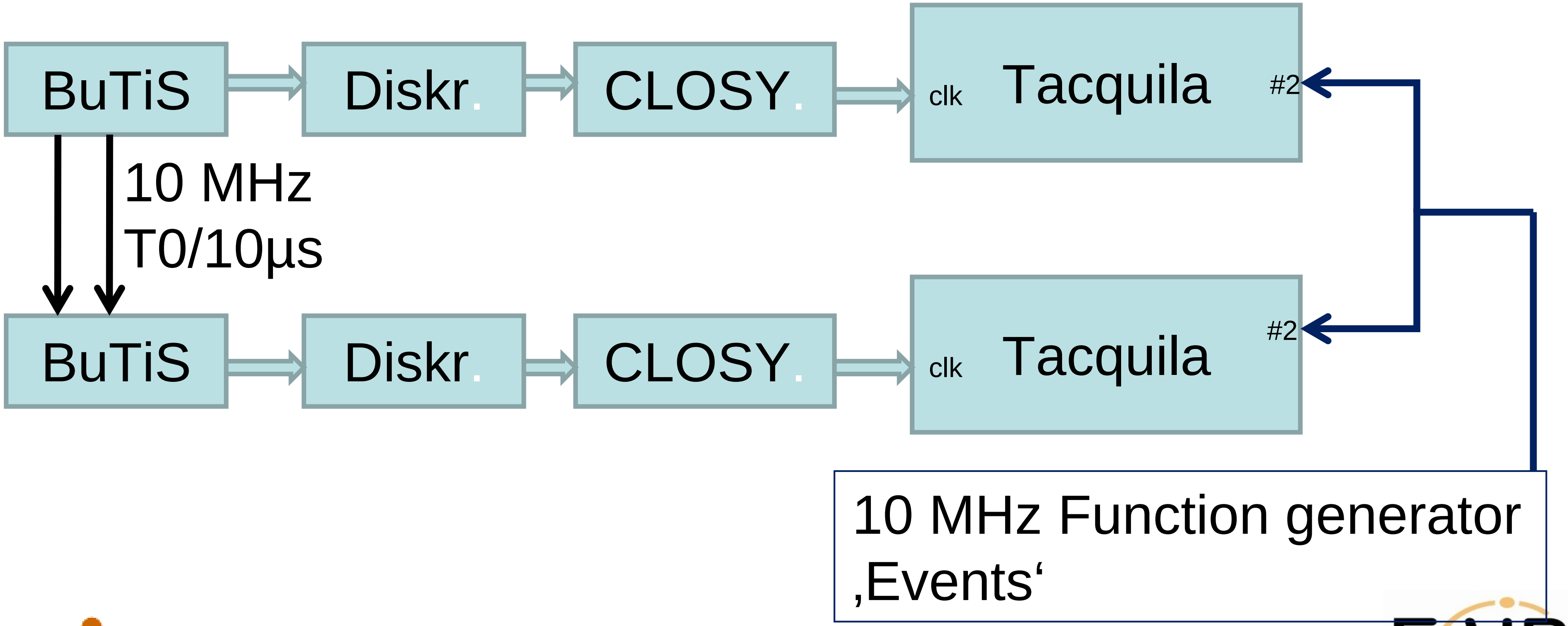
As seen in the laboratory

PR Spec. Top. Acc. Beams 12, 042801 (2009)



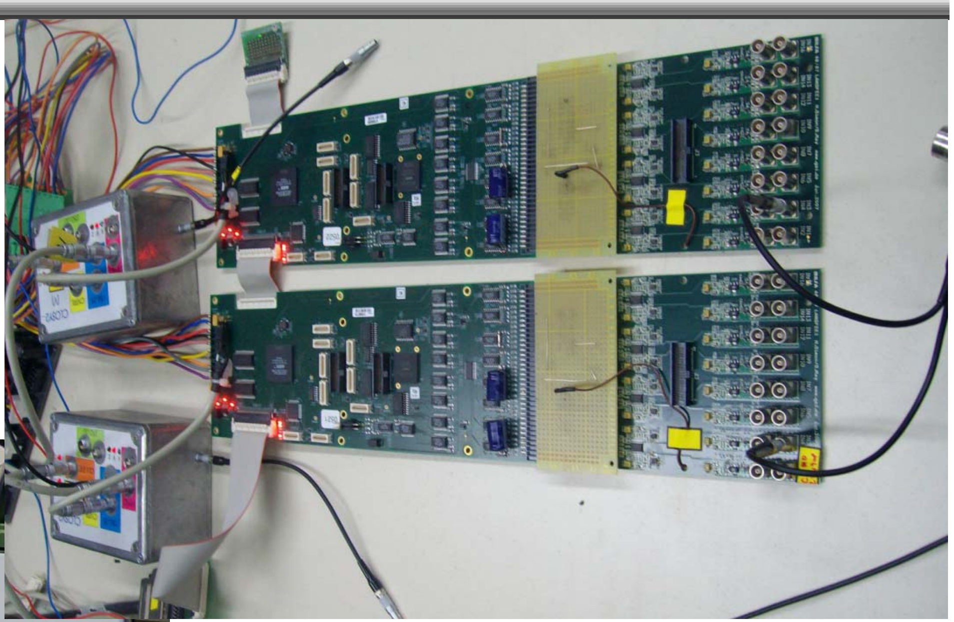
Test Bench 20091208 (schematic)

- Demonstration of BuTiS capabilities
- Two Tacquila systems at two coupled BuTiS generators
- Schematic View:



Less schematic

2 * CLOSY and Tacquila



2 BuTiS generators
master & slave

CLOSY
(modified CBM prototype)

- PLL based clock divider
- input range limited

➔ CPLD stage

- Butis: division/5

➔ 200 MHz to 40 MHz for Tacquila

Discriminator:

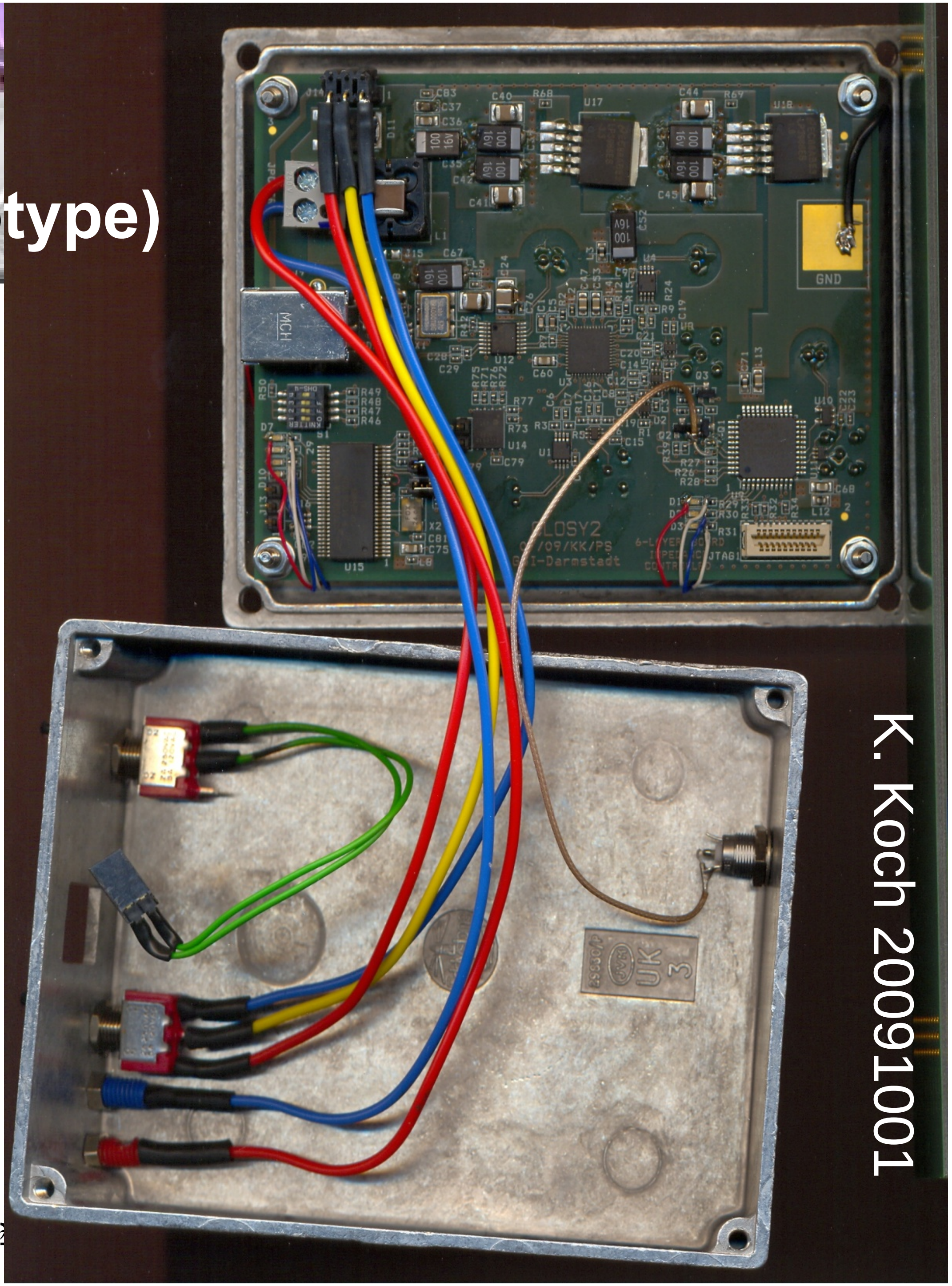
NB4N316M

3.3 V AnyLevel™ Receiver to CML Driver/Translator with Input Hysteresis

2.0 GHz Clock / 2.5 Gb/s Data

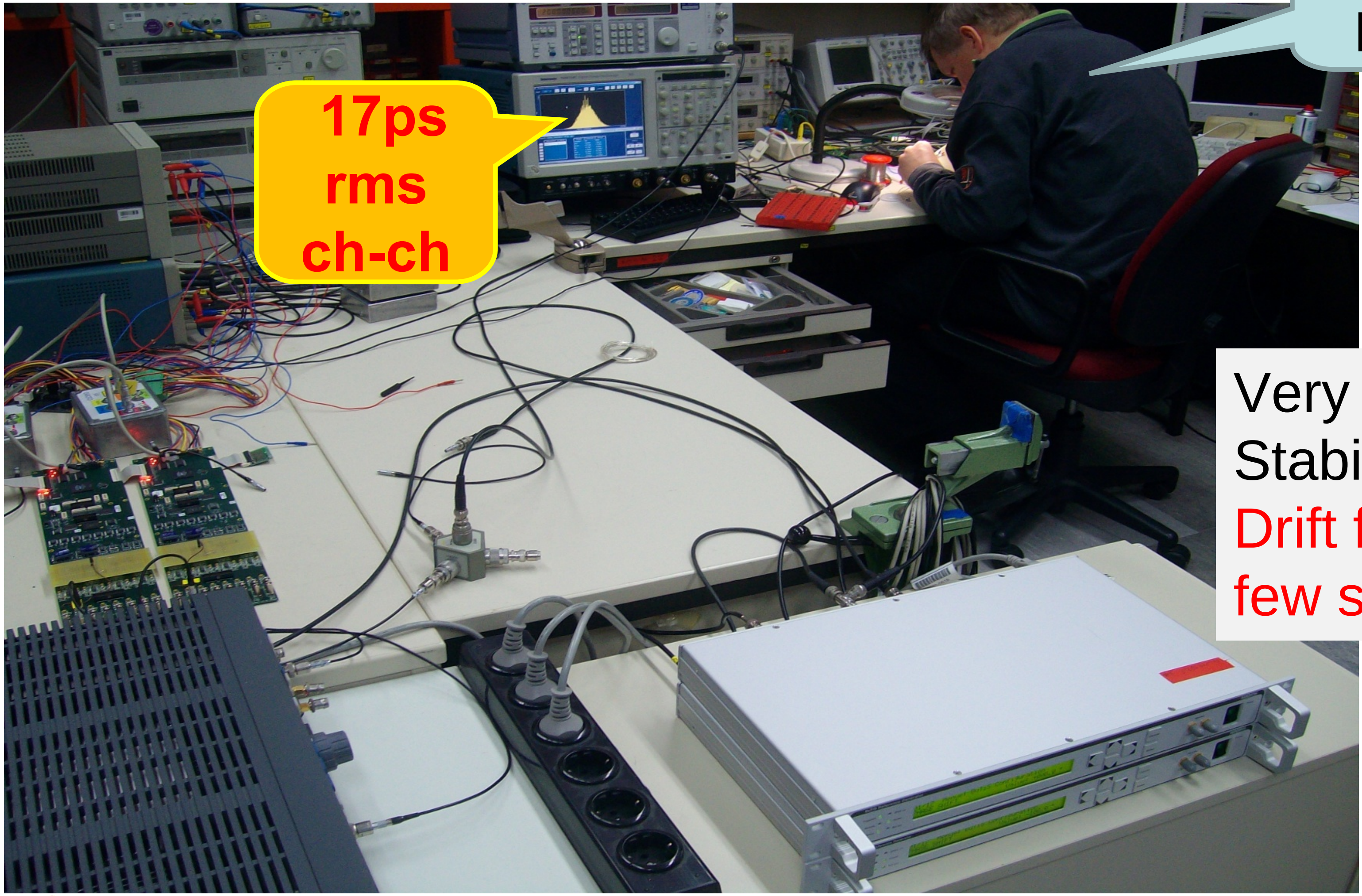
ON Semiconductor®

http://onsemi.com



K. Koch 20091001

Result: Test Bench 20091208



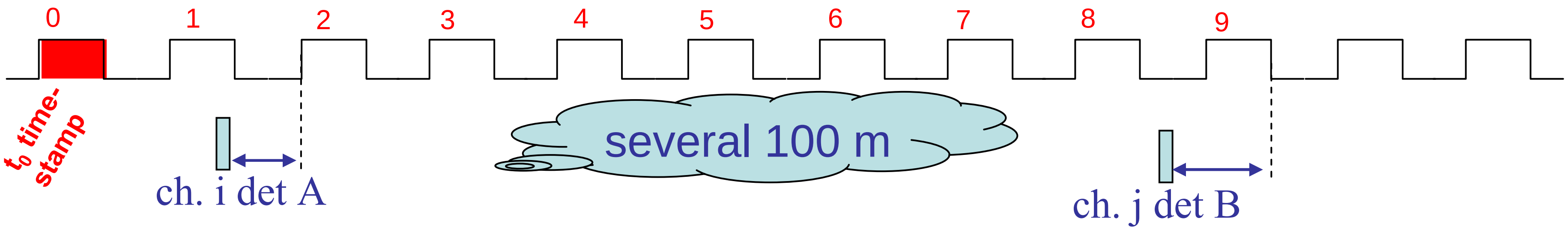
17ps rms ch-ch

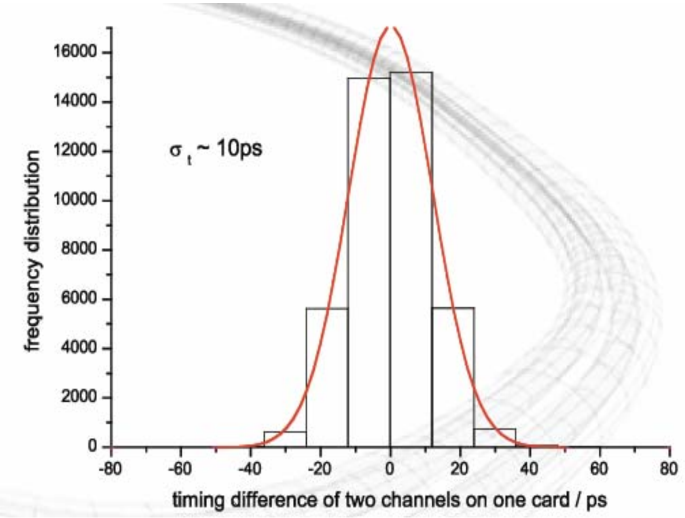
Karsten Koch

Very good Stability !

Drift few ps/ few seconds

Precision timing (<50ps) vs. Campus Clock II



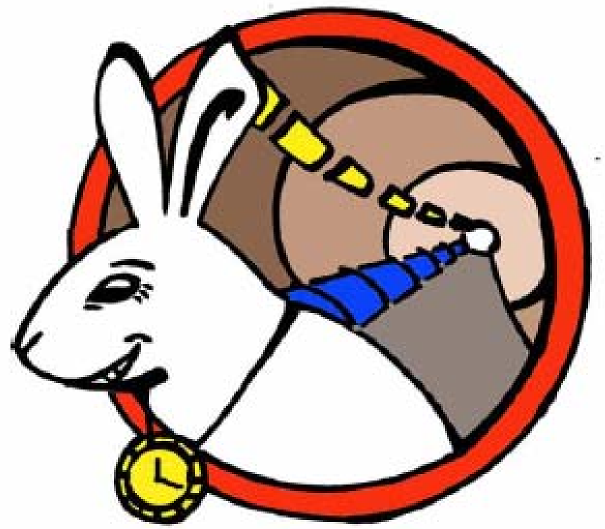


1. T0 pulse needs time stamping
2. Reset of internal 200MHz counters
3. Unambiguous assignment

➔ White rabbit

What is White Rabbit ?

T. Włostowski/CERN



- An extension to Ethernet providing

1. A common clock via synchronous ethernet + compensation from PHY clock (PTPv2@125MHz IEEE1588 + compensation) 10MHz with ~1ns precision and
   ~100ps accuracy

2. A real time Protocol with guaranted latency

Who is behind ?

- **Main Partners**

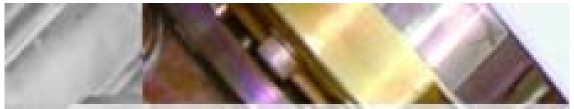
CERN, GSI/FAIR, AAS, IN2P3, Cosylab, Elettra, ...

- **Possible participation**

NUSTAR, ITER, medAustron, ...

List of logos …

T.Fleck, M. Kreider,
C. Prados, GSI



Where does it reside ?

The **WR protocol** defines **standard** and **high priority** frames Ethertypes:

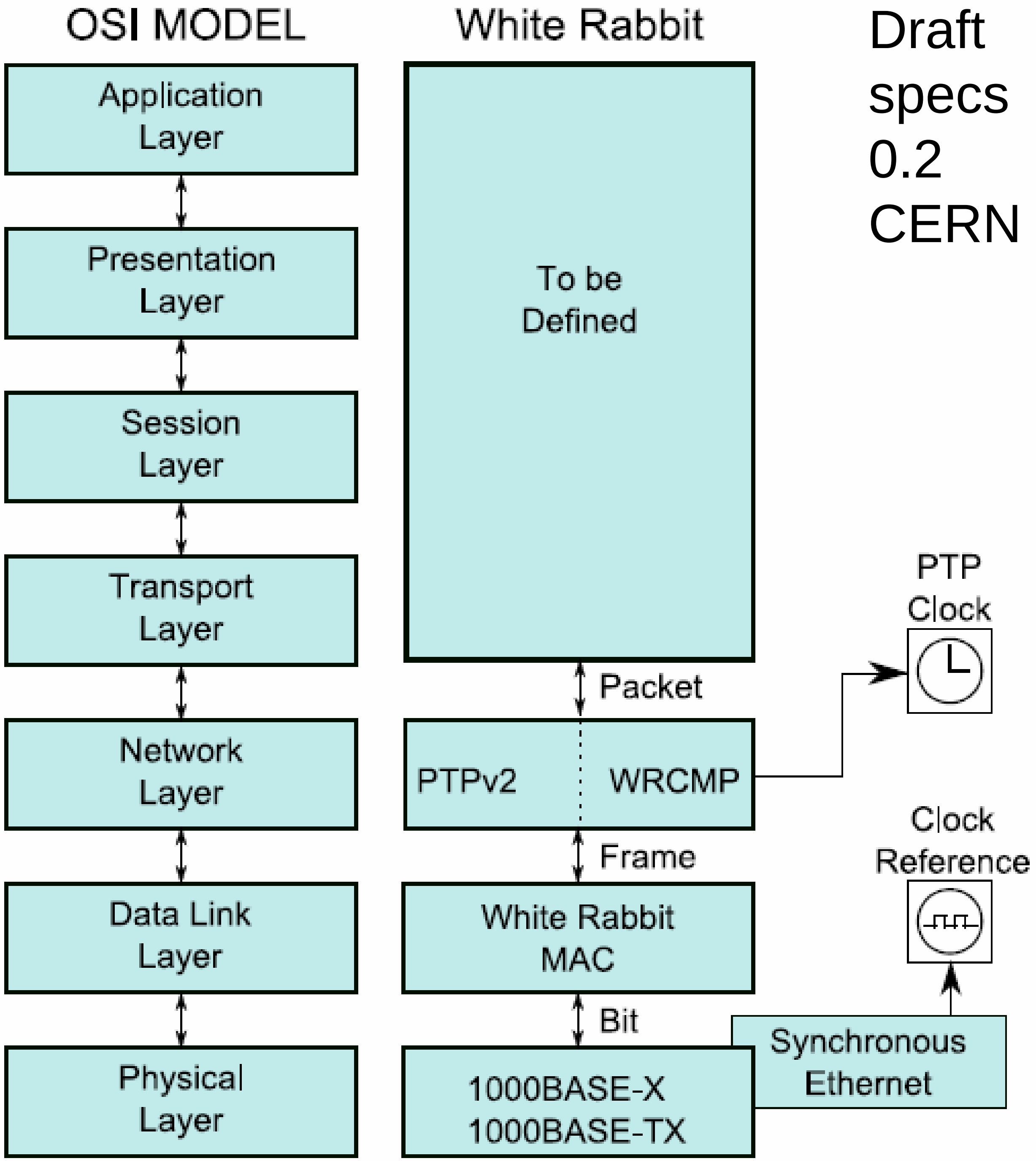
0xa0a0

0xa0a1

with

1500 byte payloac

Draft specs 0.2 CERN



Topology

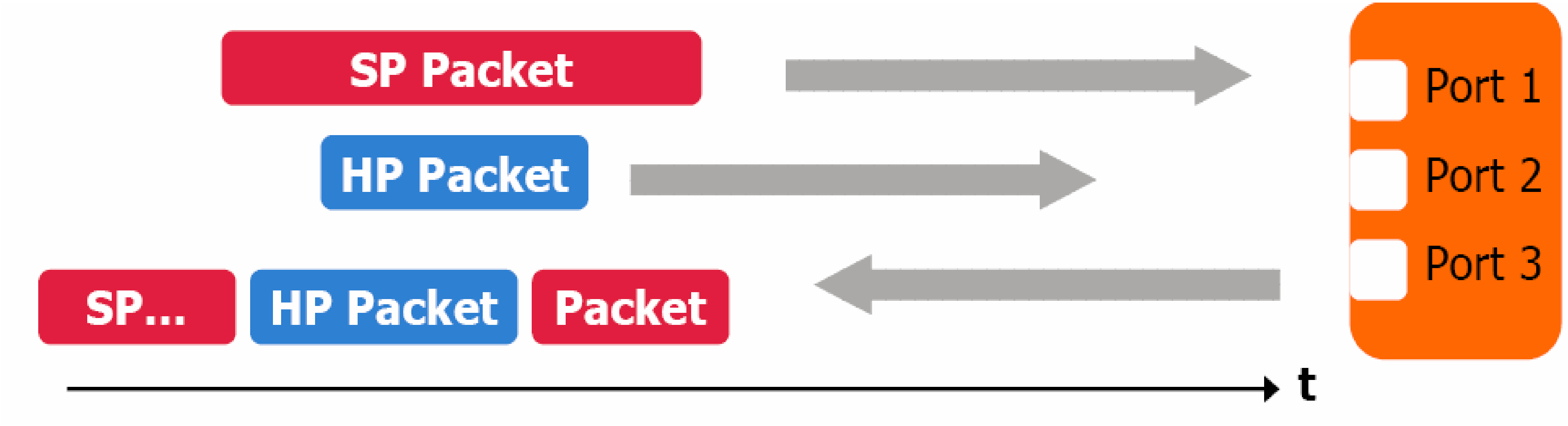
- Timing tree: e.g. CERN GPS/cesium reference clock mastered WR master switch

➔WR slave switches and nodes
(up to 2000 nodes, 10km fibres)

… is separated from data routes, managed with the spanning tree protocol

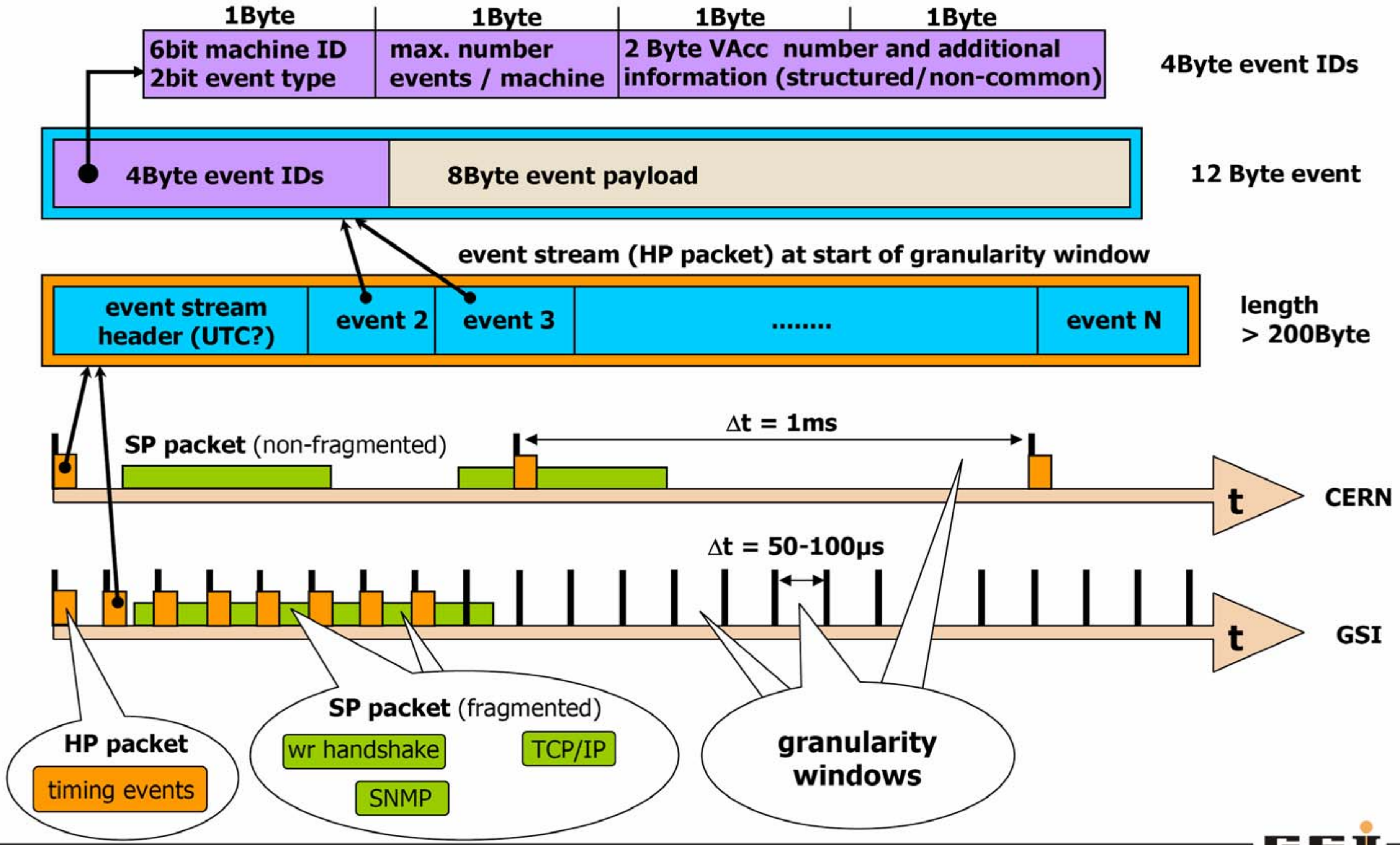
Mechanism

- Functionality of the White Rabbit switch



SP packets are fragmented in the switch if they collide with HP packets

timing event messages / content granularity windows



1Byte	1Byte	1Byte	1Byte
6bit machine ID 2bit event type	max. number events / machine	2 Byte VAcc number and additional information (structured/non-common)	

4Byte event IDs

4Byte event IDs	8Byte event payload

12 Byte event

event stream (HP packet) at start of granularity window

event stream header (UTC?)	event 2	event 3	……..	event N

length
> 200Byte

SP packet (non-fragmented)

Δt = 1ms

CERN

Δt = 50-100μs

GSI

HP packet

timing events

SP packet (fragmented)

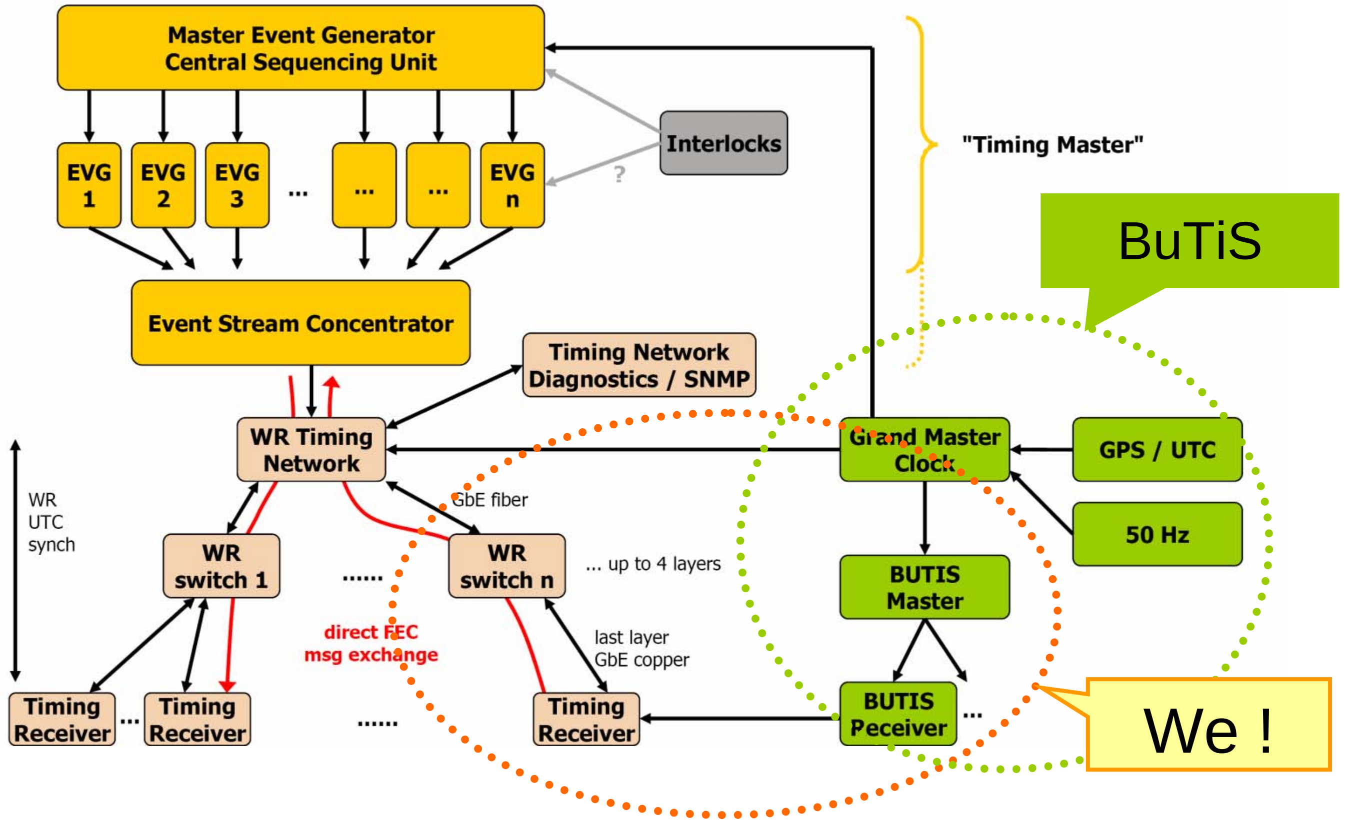
wr handshake

TCP/IP

SNMP

granularity windows

- BuTiS & White Rabbit System



Perspective

- **AMC card design for WR switch planned for early 2010 at CERN**
- **Timing receiver board development in 2010**
  various form factors
- **FAIR Timing Master prototype in 2010**
- **Complete functional specs in 2010**

µTCA based switch protoptype exists at CERN

Reported October/09 ISPCS/Brescia ´09
P. Moreira, J. Serrano, T. Wlostowski,
P. Lochschmidt, G. Gaderer

Applications

- White rabbit receiver can replace time stamping modules
  … or be e.g. used as piggy back with moderate cost
- provides additional status information (e.g. accelerator timing)
- can be used for real time messages

- does not provide any trigger functionality

Summary

- Specific detector developments by collaborating institutes
- Diamonds …
- Integration in-house !
- BuTiS/White Rabbit

- We need to talk about ‘experimental detectors’ within ACS/FESA

Collaborators

- CU Bratislava - B. Sitar et al. (MWs)
- TU Munich - R. Gernhäuser et al. (Diamond)
- JSI Ljubljana - M. Vencelj et al. (PSA)
- KVI Groningen - H. Wörtche et al. (FE-Controls)
- HIP Helsinki - E. Tuominen, F. Garcia (GTPC/Si)

Additional @ GSI

- Detector Laboratory - Ch. Schmidt et al.
- Experimental Electronics - E. Badura et al.
- Accelerator Group - R. Bär, P. Forck, et al.

Collaboration

KVI
H. Wörtche, J. Jungmann,
P. Lubberdink, P. Schakel,
V. Stoica

TU Darmstadt
D. Savran, B. Löher

JSI Ljubljana
M. Vencelj

GSI
H. Simon, T. Aumann, Y. Aksyutina,
K. Boretzky, O. Ershova, M. Heil, A. Klimkiewicz,
T. Le Bleis, A. Kelic, R. Plag, R. Reifarth,
D. Rossi, K. Sümmerer, F. Wamers

FIN