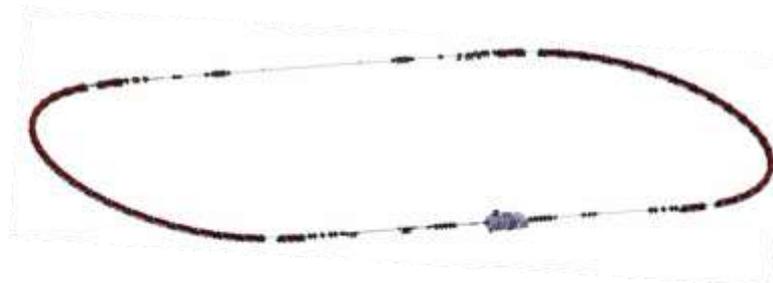
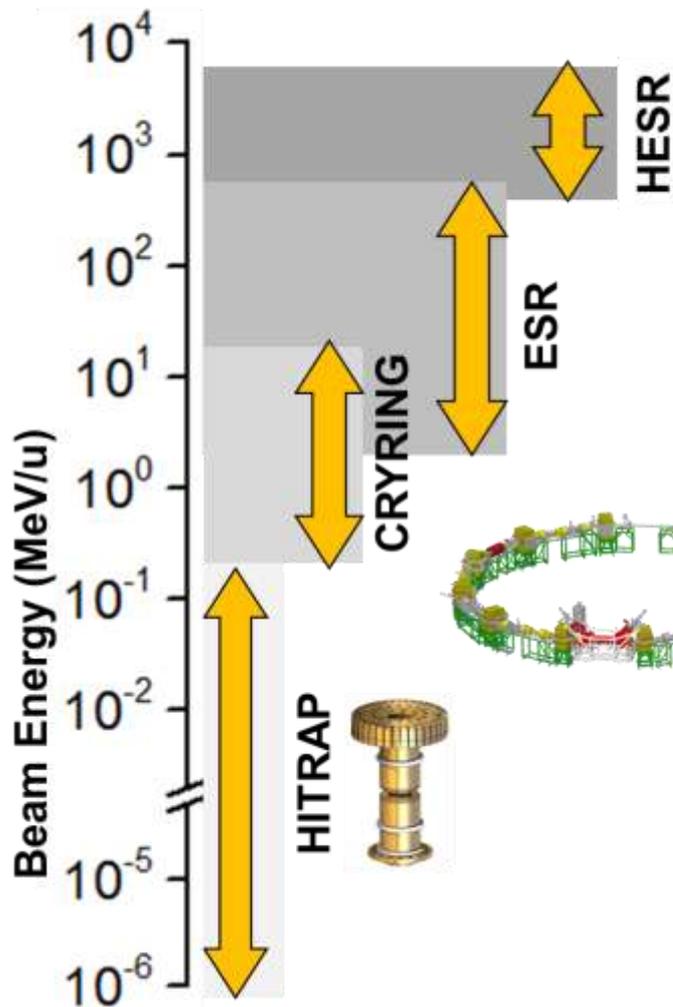


# Instrumentation Atomic Physics

Uwe Spillmann, AP  
for the **SPARC** Collaboration

# SPARC@FAIR: Storage and Trapping



Observables
x-rays
electrons
ions
visible light, IR, UV, XUV

# Sophisticated & Versatile Instrumentation

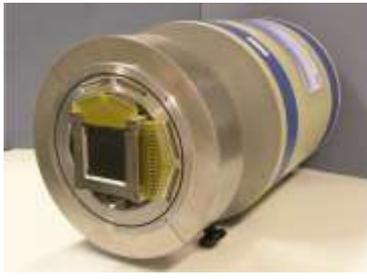
**Observables:** Photons, electrons, positrons, ions



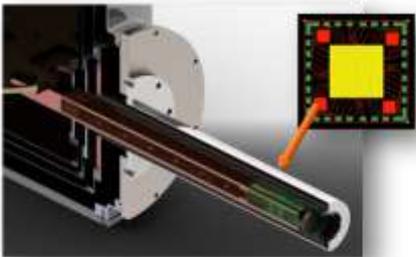
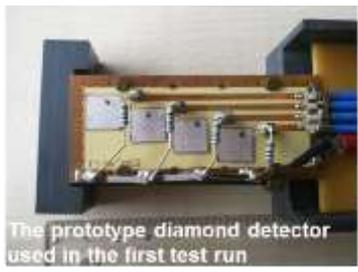
Targets



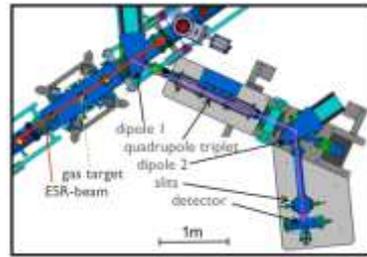
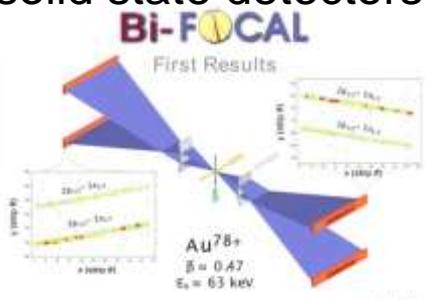
Position sensitive solid state detectors



Particle detectors



High resolution x-ray spectrometers



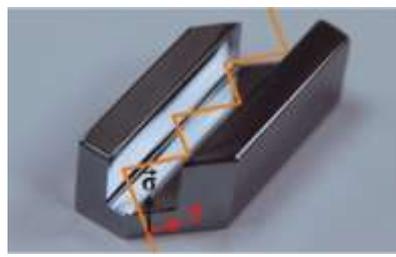
Electron spectrometer



Traps



X-ray optics, channel cut crystals



Laser systems

# SPARC Working Groups

TOPIC	Group/Leaders
High Energy Single Pass Experiments	Alexandre Gumberidze / Angela Bräuning-Demian
Ring Physics and Performance	Michael Lestinsky / Yuri Litvinov
Laser Spectroscopy	Wilfried Nörtershäuser / Rodolfo Sanchez
Laser Cooling	Michael Bussmann / Danyal Winters
Electron Targets/Cooler	Carsten Brandau / Stephan Schippers
Target Developments	Robert Grisenti / Alfons Khoukaz
Electron and Electron/Positron Spectrometers	Xinwen Ma / Siegbert Hagmann
Photon and X-ray Spectrometers	Martino Trassinelli / Heinrich Beyer
Photon Detector Development	Günter Weber / Andreas Fleischmann
Intense Laser/Ion Interaction (intense laser)	Vincent Bagnoud / Thomas Kühl
Reaction Microscope	Daniel Fischer / Siegbert Hagmann
Slow Ion/ Surface-Experiments	Ronie Hoeckstra / Angela Bräuning-Demian
HITRAP/Traps	Frank Herfurth / Wolfgang Quint
Theory: Atomic Structure/Collision Dynamic	Stephan Fritzsche / Andrey Surzhykov
<b>Technical Support for:</b>	
Data Analysis and Simulations	Harald Bräuning
SPARC DAQ/Slow Controls	Harald Bräuning, Uwe Spillmann
SPARC Infrastructure	Angela Bräuning-Demian

[http://www.gsi.de/en/start/fair/fair\\_experimente\\_und\\_kollaborationen/sparc/working\\_groups.htm](http://www.gsi.de/en/start/fair/fair_experimente_und_kollaborationen/sparc/working_groups.htm)

# X-RAYS

## **2D- Si(Li) and 2D-Ge(i) detector systems**

- **high resolution crystal spectrometer: FOCAL**
- **Compton polarimetry**

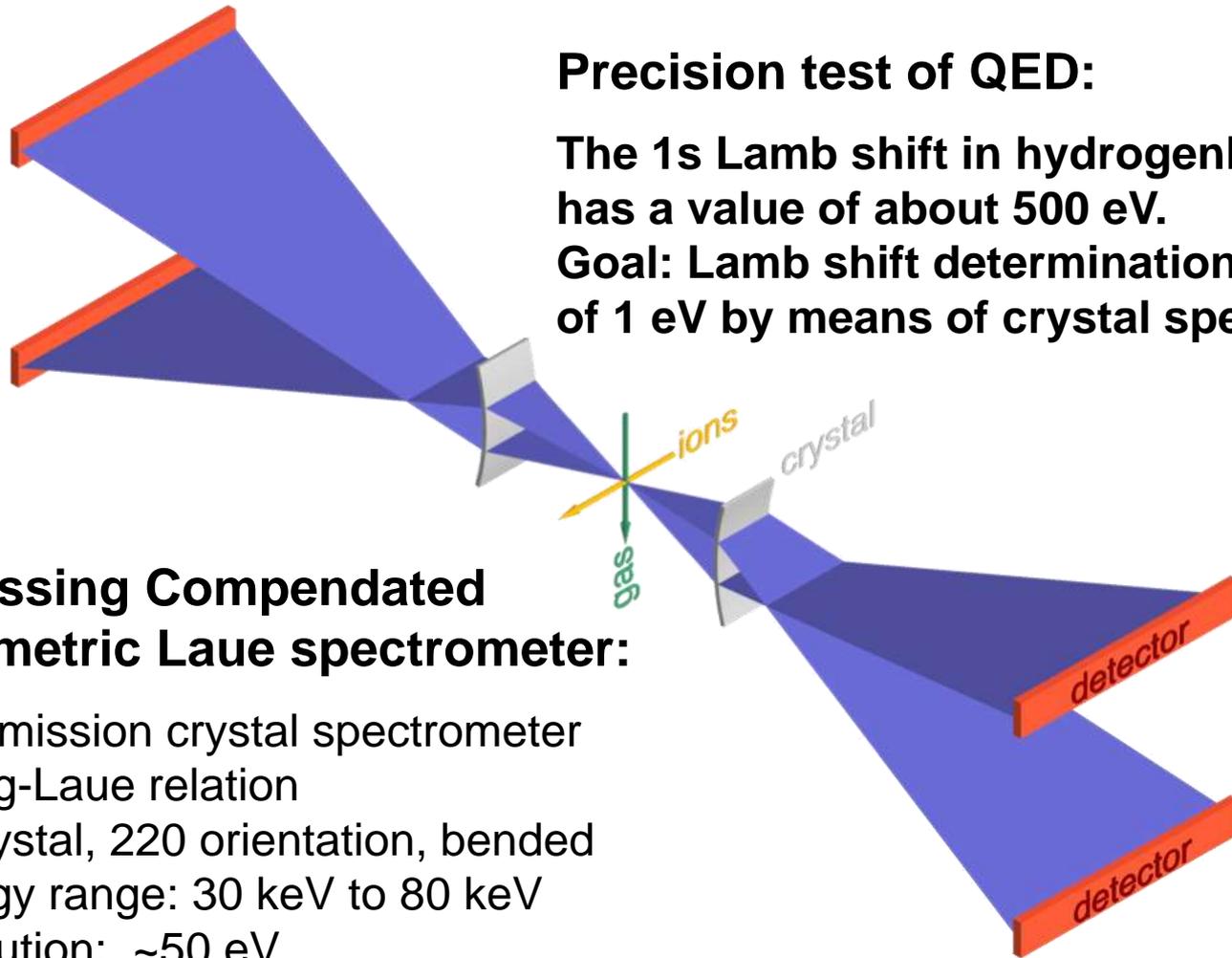
## **Metallic magnetic calorimeter maXs**

# FOCAL

## Precision test of QED:

The 1s Lamb shift in hydrogenlike Uranium ( $U^{91+}$ ) has a value of about 500 eV.

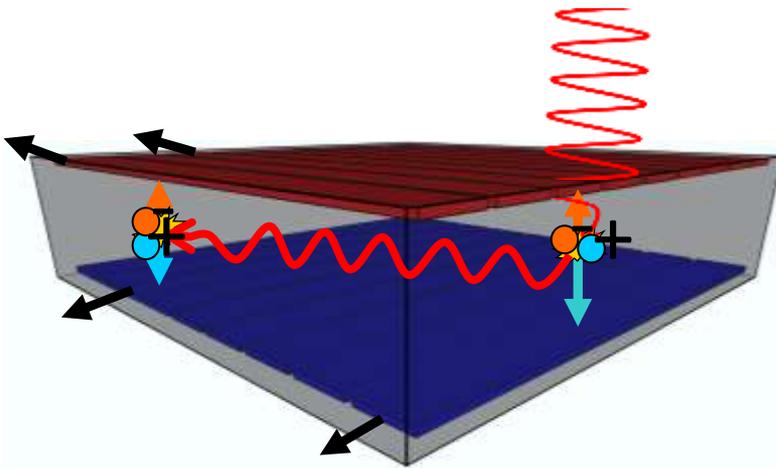
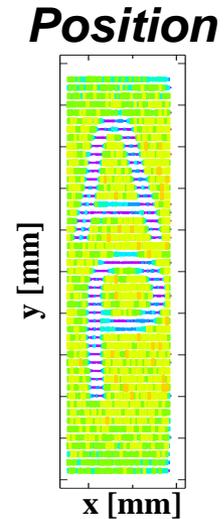
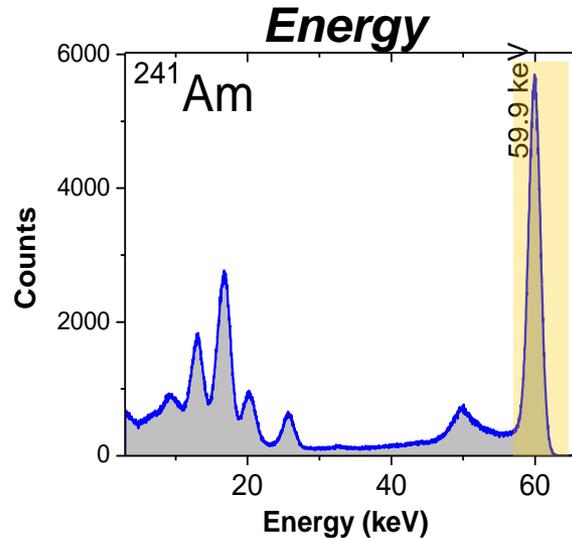
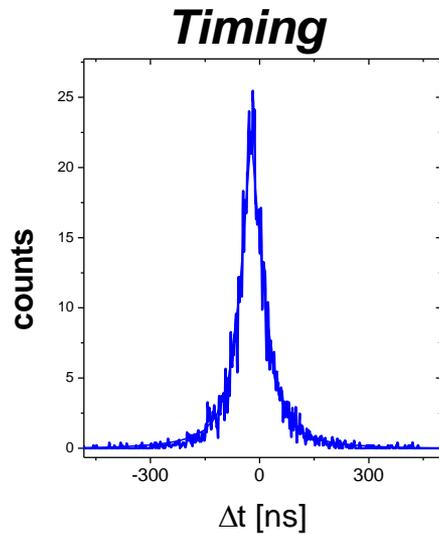
Goal: Lamb shift determination with a precision of 1 eV by means of crystal spectroscopy.



## Focusing Compensated Asymmetric Laue spectrometer:

- transmission crystal spectrometer
- Bragg-Laue relation
- Si-crystal, 220 orientation, bended
- energy range: 30 keV to 80 keV
- resolution: ~50 eV
- $\epsilon \approx 10^{-8}$
- ⇒ 3-4 counts/h in the line of interest

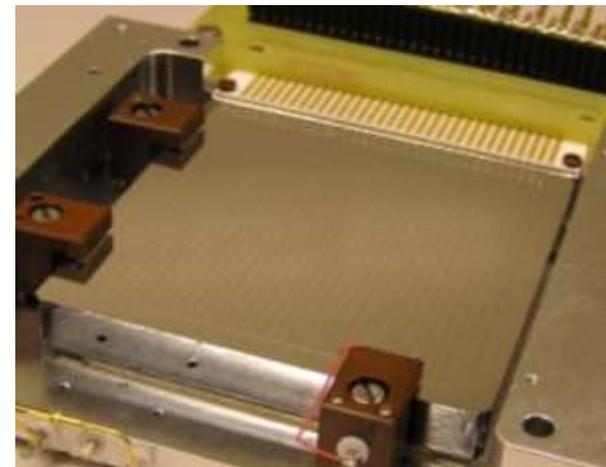
# Planar structured semiconductor detectors



X,Y: strip contacts

Z: drift time

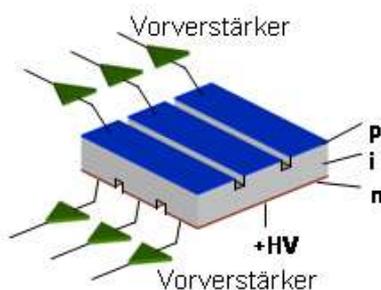
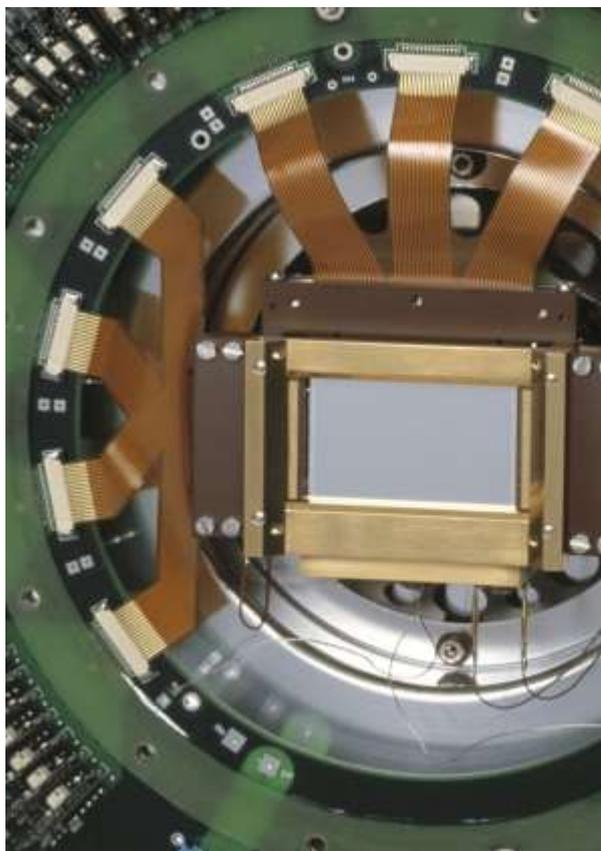
x-ray interacts with the detector bulk



Si(Li)-strip-detector in a test holder

# Planar structured semiconductor detectors

## 2D Ge(i)- $\mu$ -strip-detector



### Crystal size (sensitive area)

height: 32 mm

width: 56 mm

thickness: 11 mm

absorption (photons): **~100% for 60 keV**

**~80% for 122 keV**

front: 128 strips, 250 $\mu$ m pitch

back: 48 strips, 1167 $\mu$ m pitch

=> **6144 Pseudopixel**

resolution: **~2.1 keV @ 60 keV**

weight: ca 50 kg

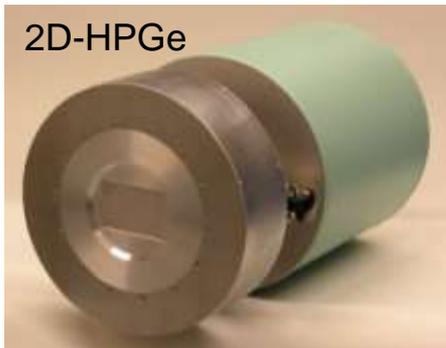
LN2 – consumption: 2 kg per day

crystal-temperature: -160°C

Detector Lab of th IKP FZ Jülich,  
now Semikon GmbH

***Energy, Timing, Position***

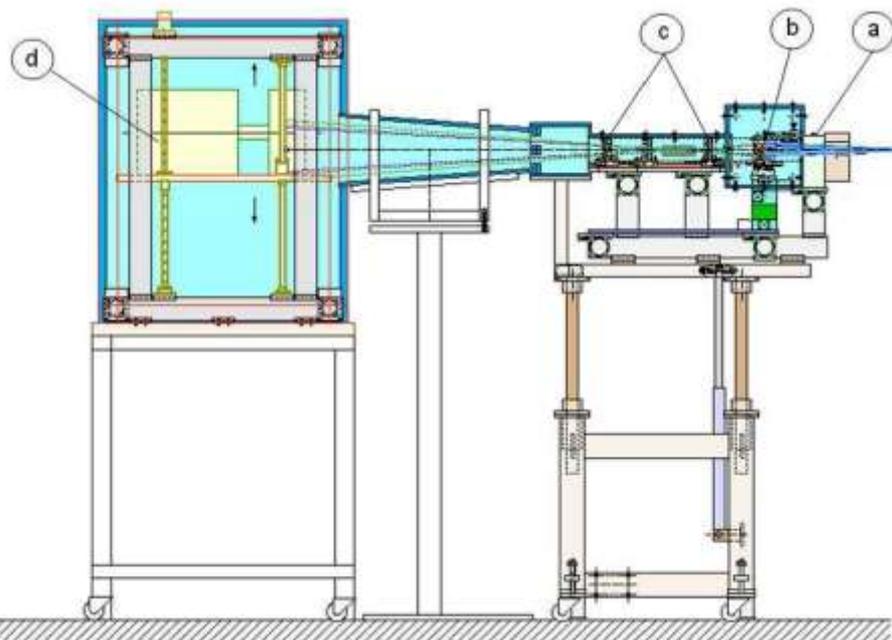
# FOCAL



2D-HPGe



crystal holder

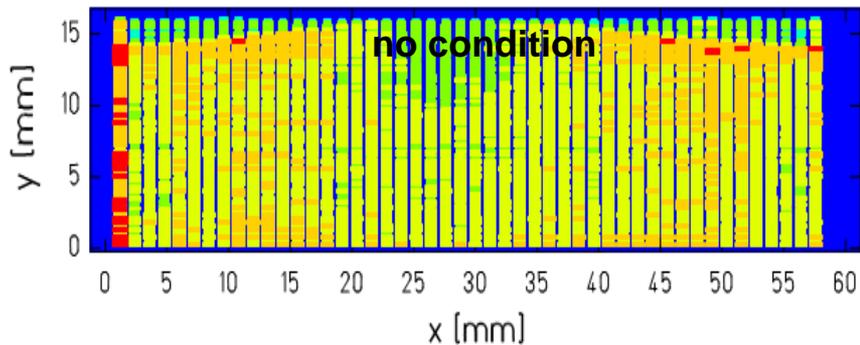


a: calibration source holder, b: crystal holder,  
c: slit system, d: 2d-HpGe-detector

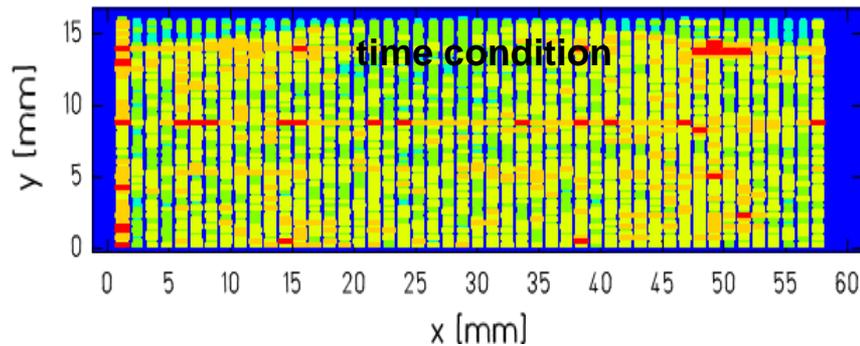


FOCAL@ESR

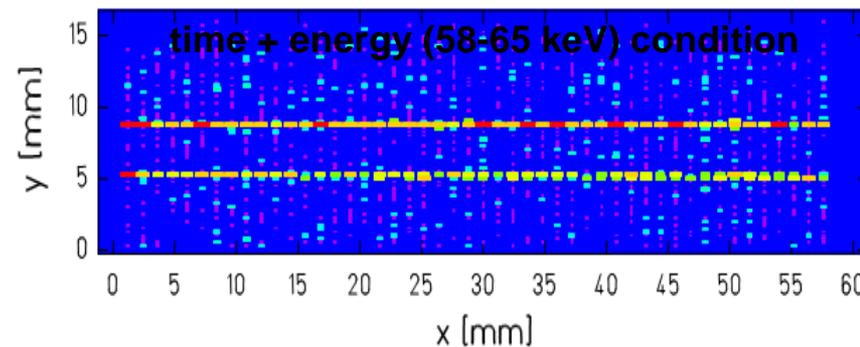
# Test experiment with $\text{Pb}^{81+}$ at ESR



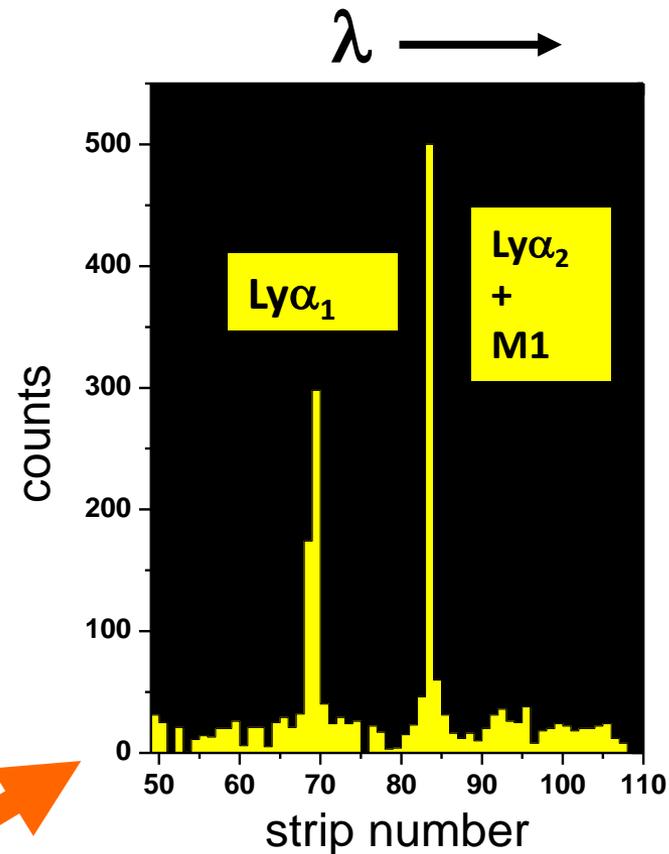
- 1379
- 1264
- 1149
- 1034
- 919
- 804



- 145
- 133
- 121
- 109
- 96.7
- 84.6

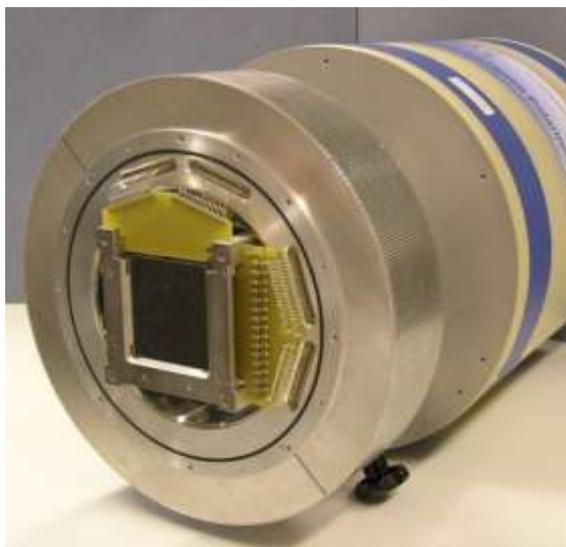
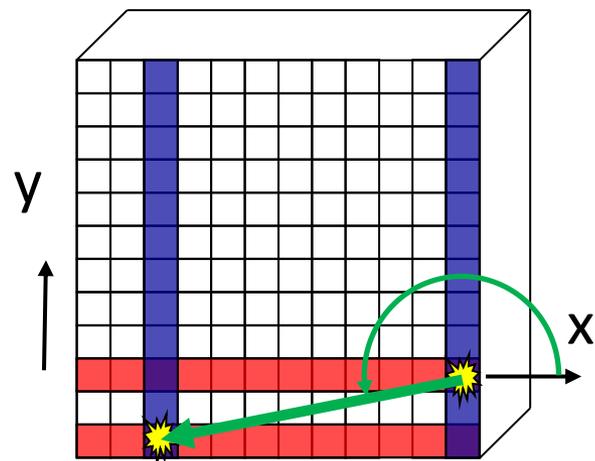
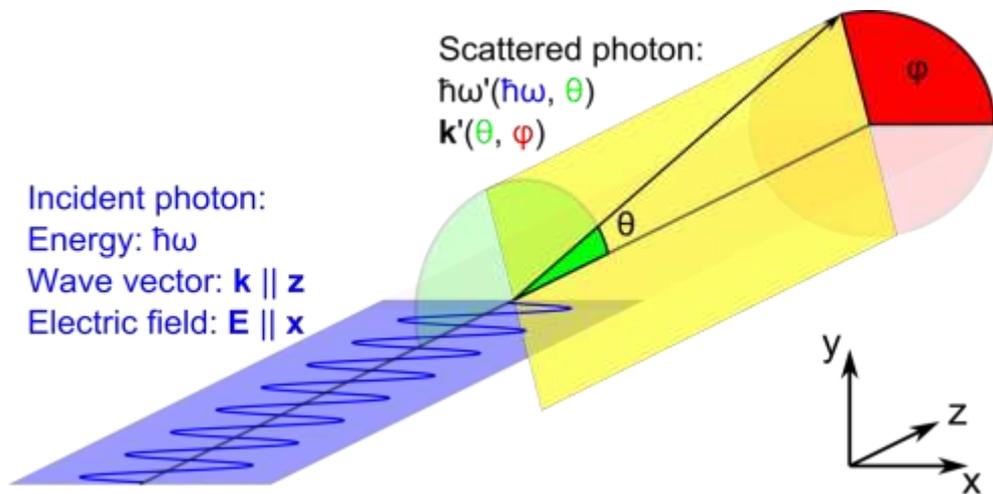


- 20
- 15
- 1
- 8.7
- 6.5
- 4.9



Clear identification of both  $\text{Ly}\alpha$  lines.

# Compton Polarimetry



## Planar Si(Li) Detector

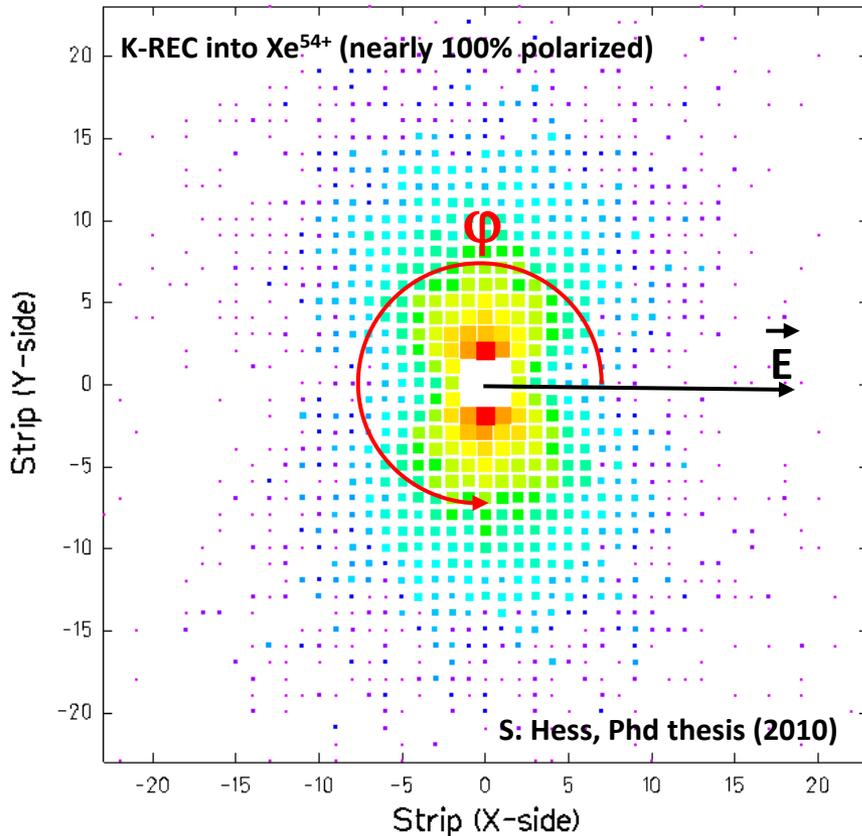
32 strips per contact  
 pitch 2 mm  
 detector thickness 7 mm  
 $\Rightarrow$  1024 stripsel  
 active area: 4100 mm<sup>2</sup>

**Compton Event reconstruction for  
 recoil electron and scattered  
 photon**

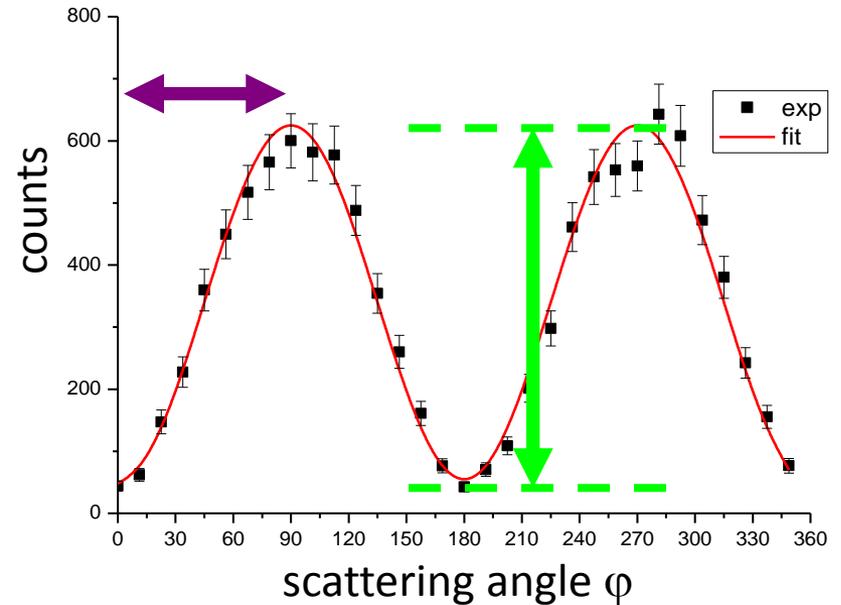
**XY Position - Energy - Time**

# Compton Polarimetry

Compton scattered photon  
xy-distribution

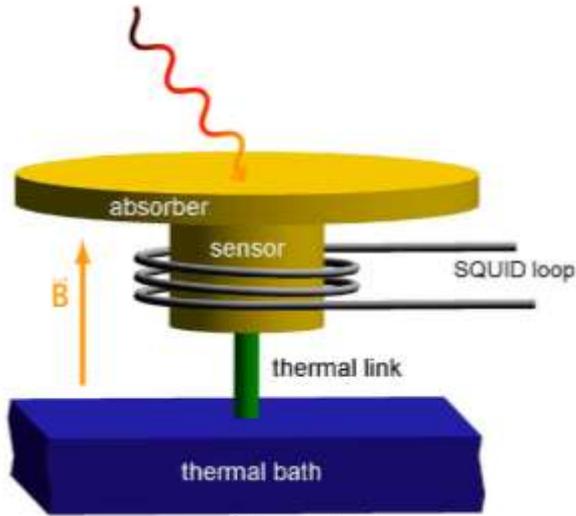


Projection on the  $\varphi$  angle

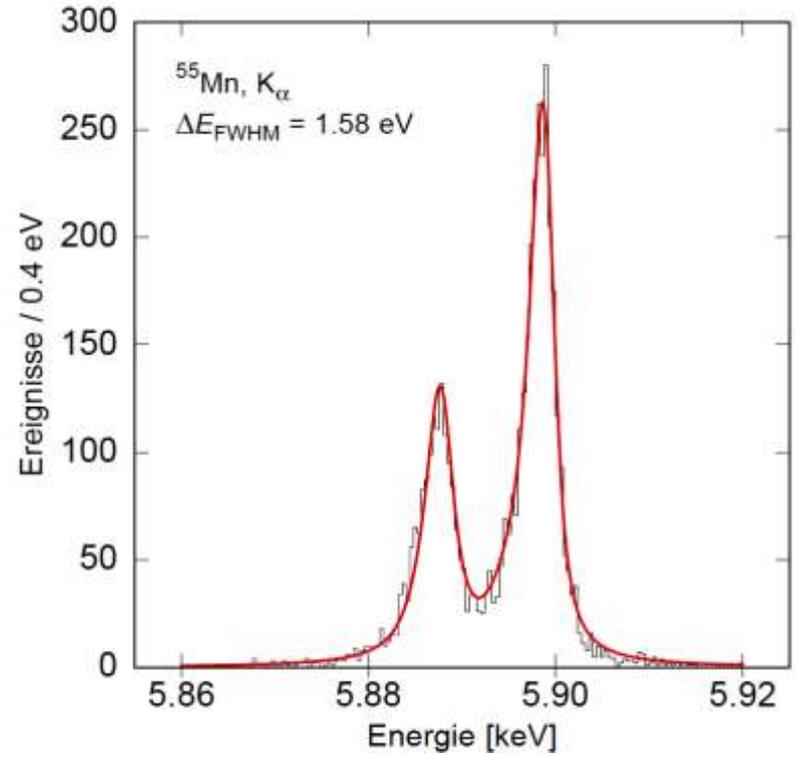


- Modulation  $\sim$  Degree of linear polarization  $P_L$
- Horizontal shift  $\sim$  direction of electric field vector  $\chi$

# Metallic Magnetic Calorimeter maXs



C. Enss, A. Fleischmann, et.al



$\Delta E_{\text{FWHM}} = 1.6 \text{ eV @ } 6 \text{ keV}$

World record together with TES-sensors of NASA-GSFC!

maXs @ ESR (2014)



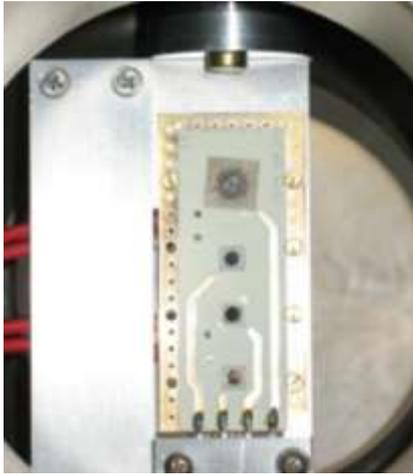
# IONs

**Diamond Detectors**

**Schottky - Resonator**

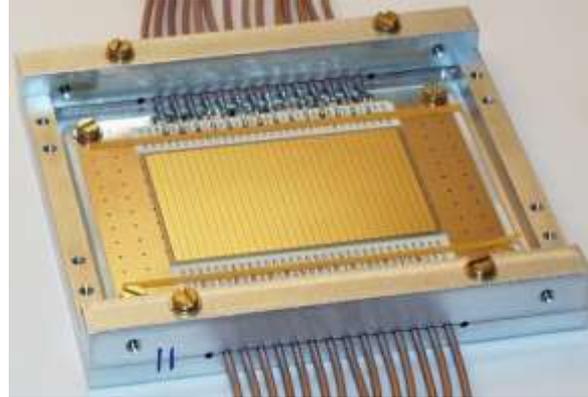
**Cryogenic Current Comparator**

# Diamond Detectors



**Single crystal**

- Transmission detector
- Absorption/Stop detector
- Excelent timing (sub-ns)
- Energy resolution comparable to silicon at room temperature
  - Only small areas



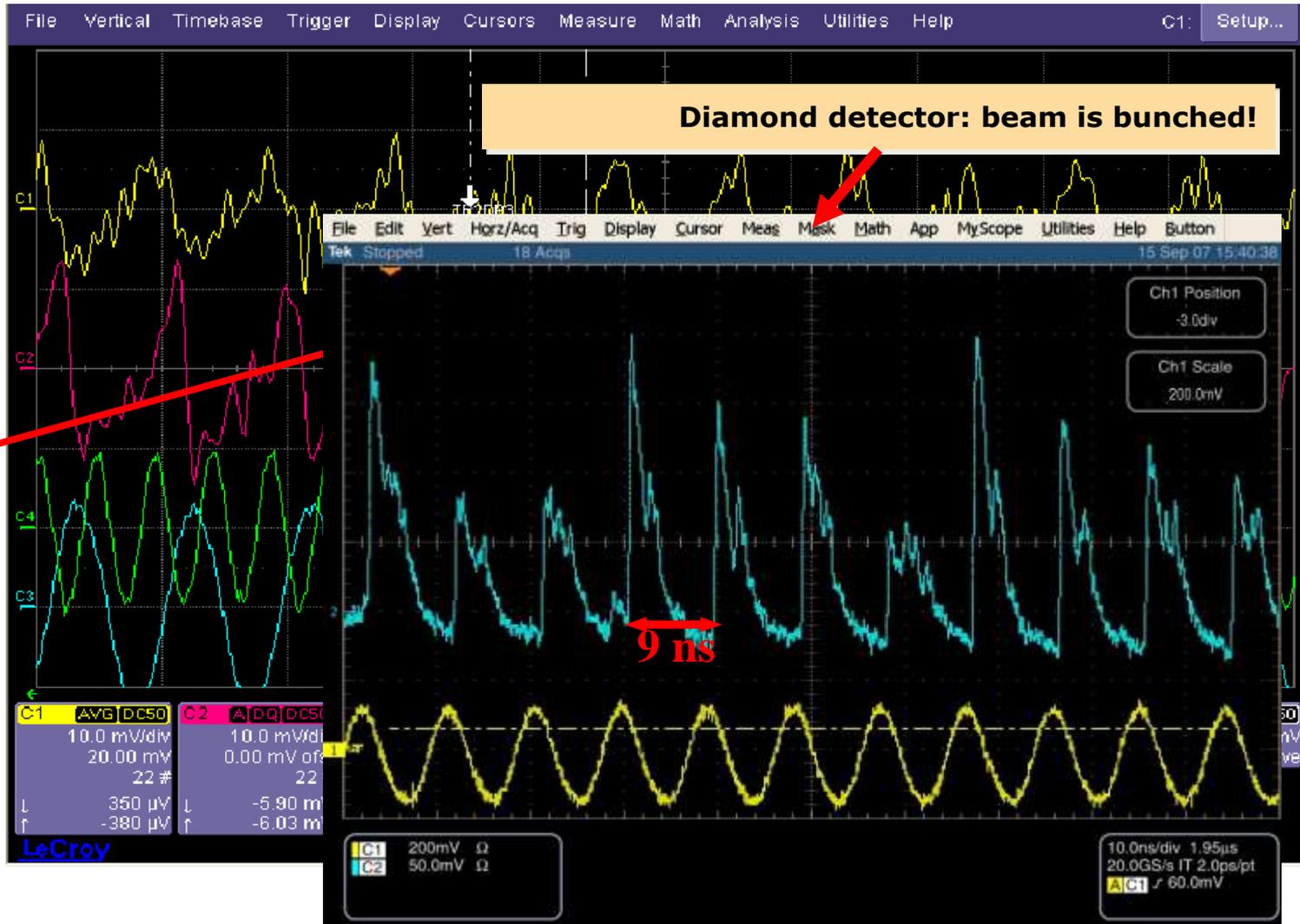
**Poly crystal**

- Transmission detector
- Excellent timing (sub-ns)
- Several cm<sup>2</sup> size



# Diamond in beam: bunch probe at HITRAP

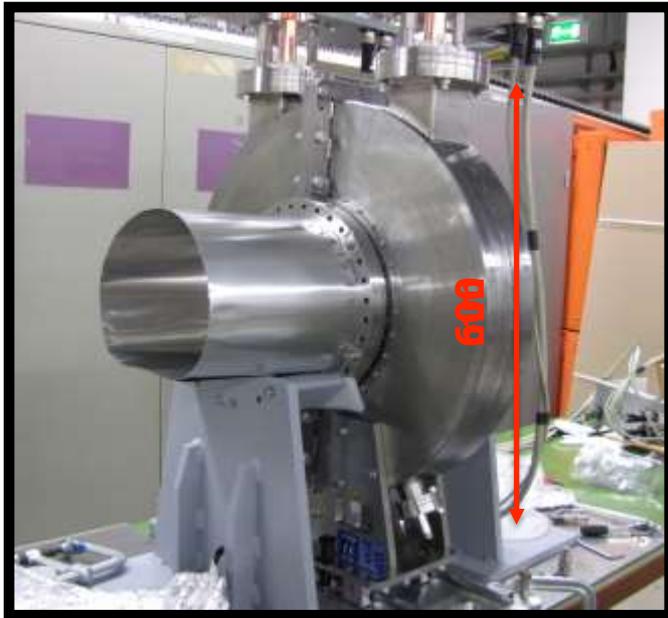
Bunched beam detected with phase probe in front of IH-structure



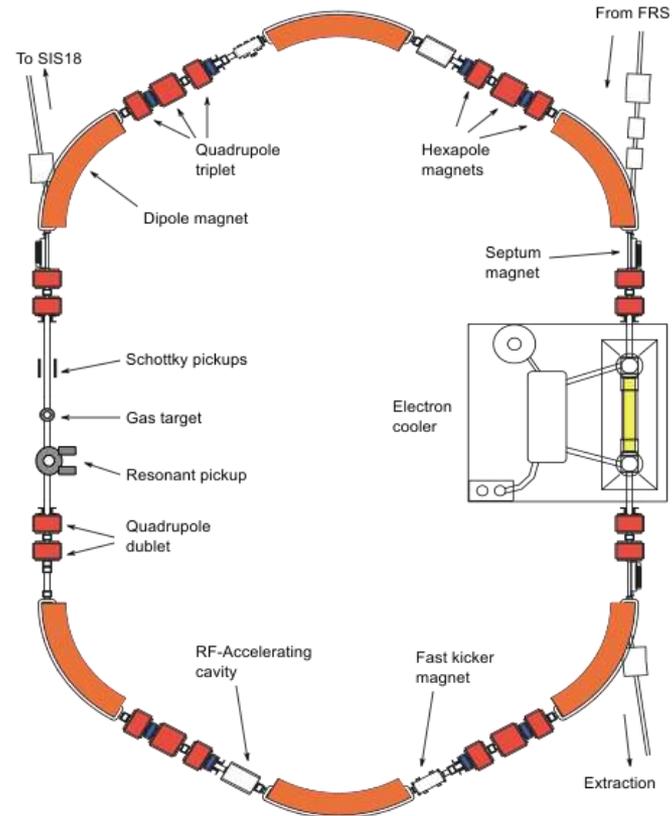
# Non-Destructive In-Ring Particle Detection

## Resonant Schottky Pickups

Foto: P. Petri 2009



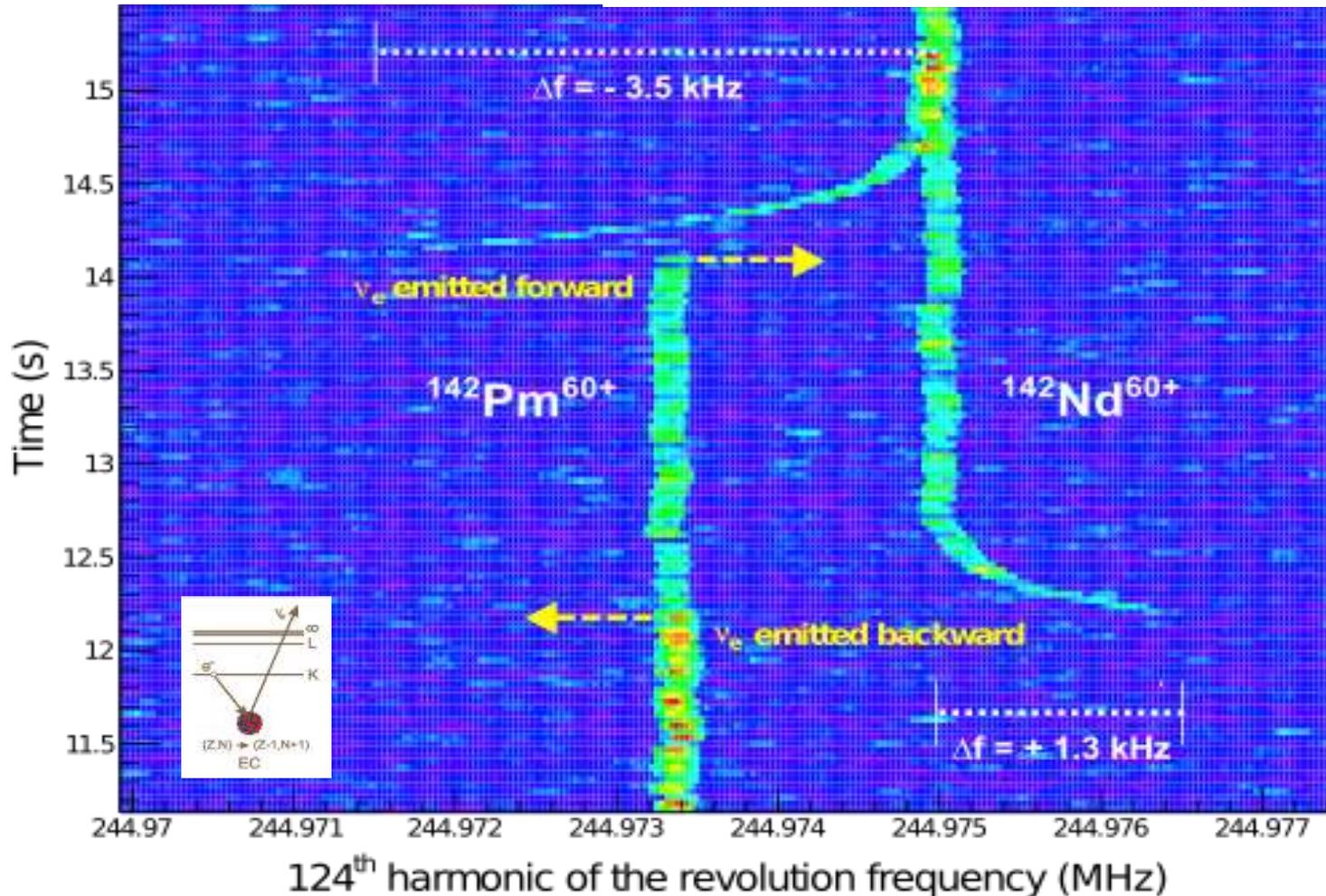
The ESR resonant pickup  
 $R/Q \sim 42 \Omega @ 245 \text{ MHz}$   
 $Q_l \sim 500$



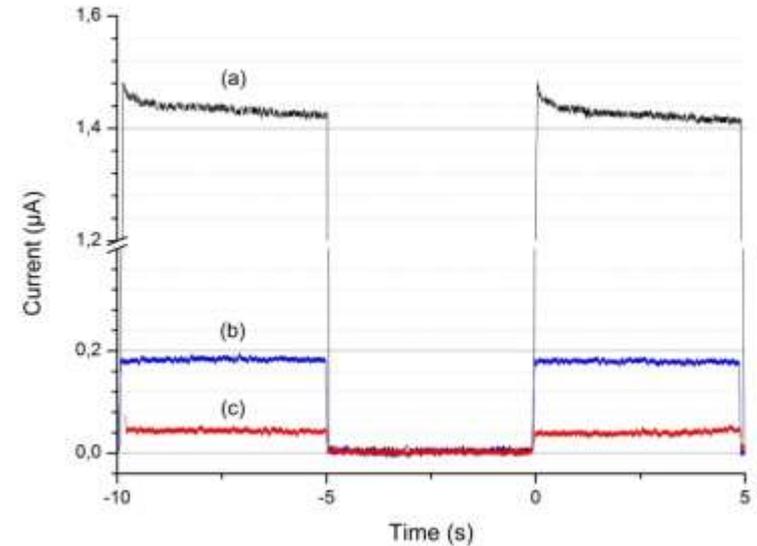
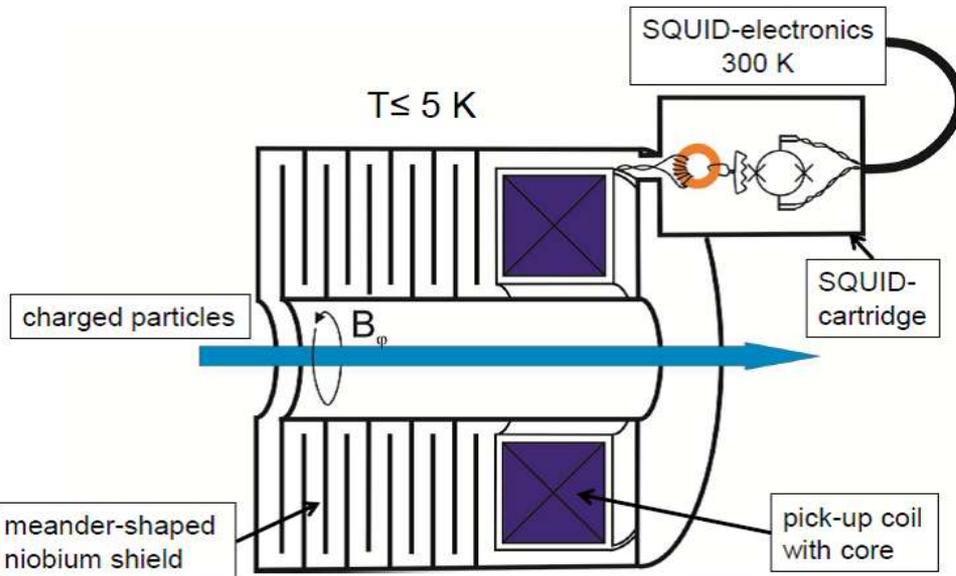
# Non-Destructive In-Ring Particle Detection

Two-body decay spectroscopy with single ion sensitivity using time resolved frequency analysis

P. Kienle, F. Bosch, et al. PLB, V. 726, No. 4-5, Nov 2013, pp.



# Cryogenic Current Comparator



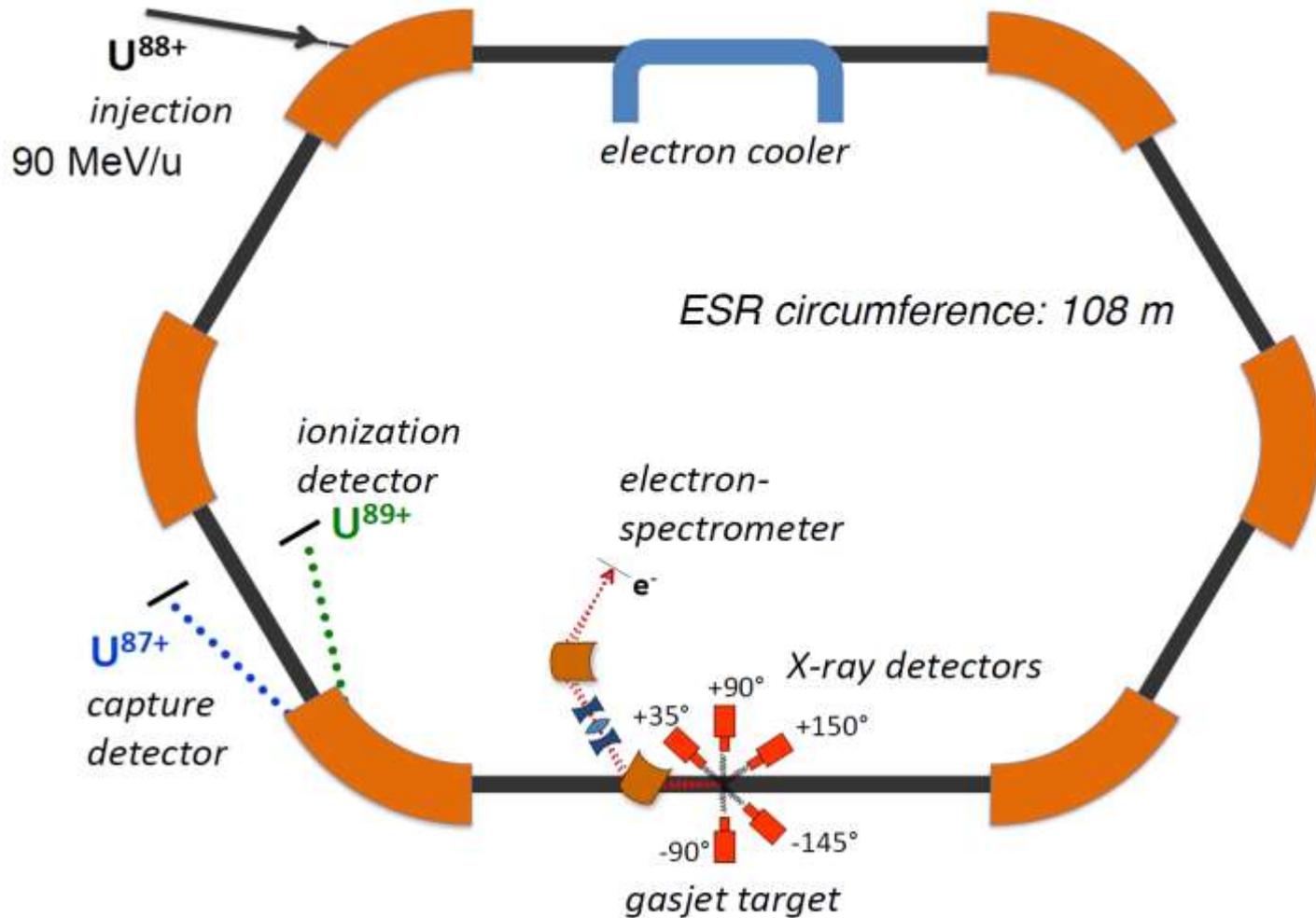
Smoothed response of the FAIR-CCC to a rectangular current signal of 1.438  $\mu\text{A}$  (black), 185 nA (blue), and 42.5 nA (red).



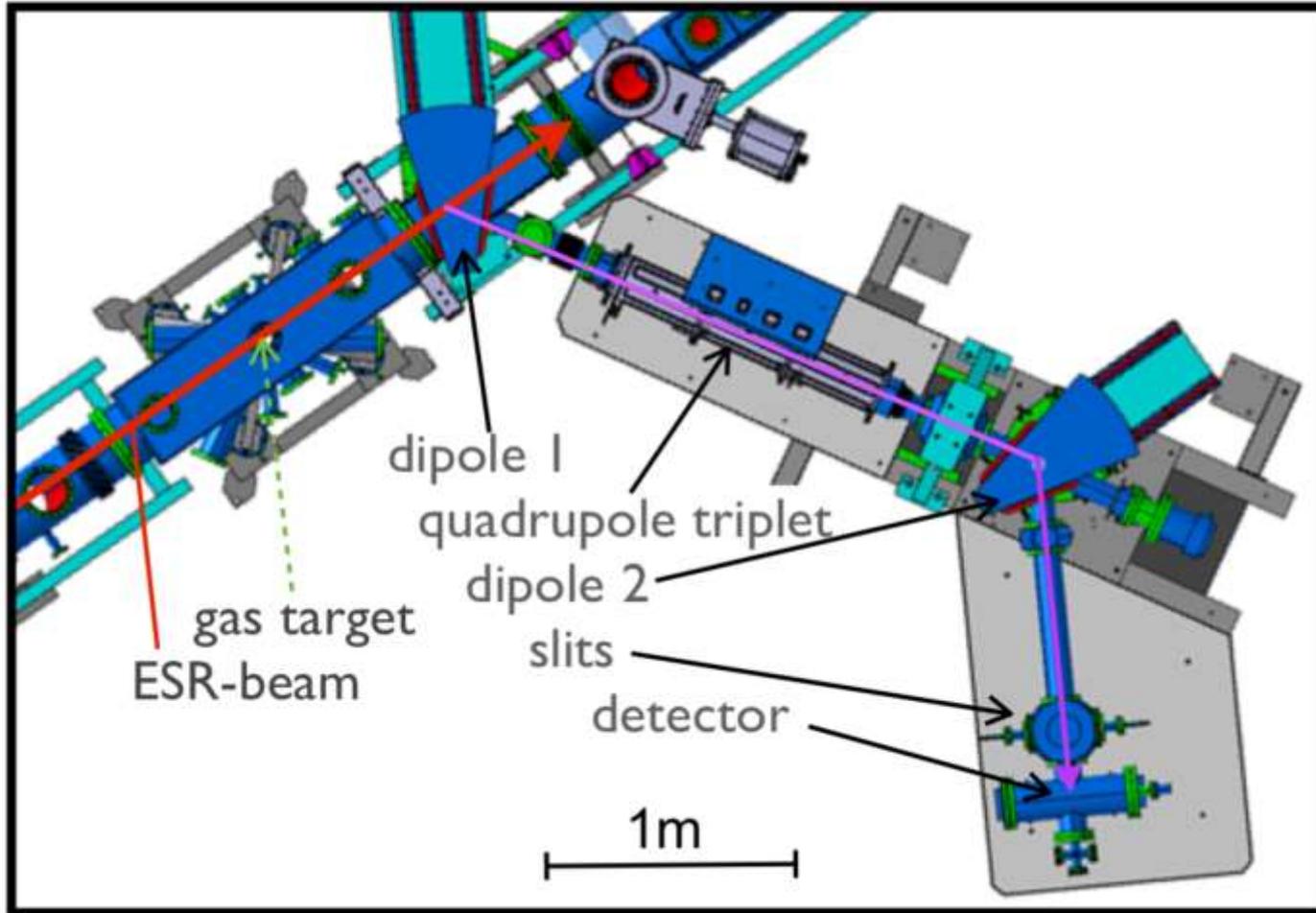
Determination of the absolute current value

# Electron spectrometer

## Experimental Storage Ring ESR at GSI



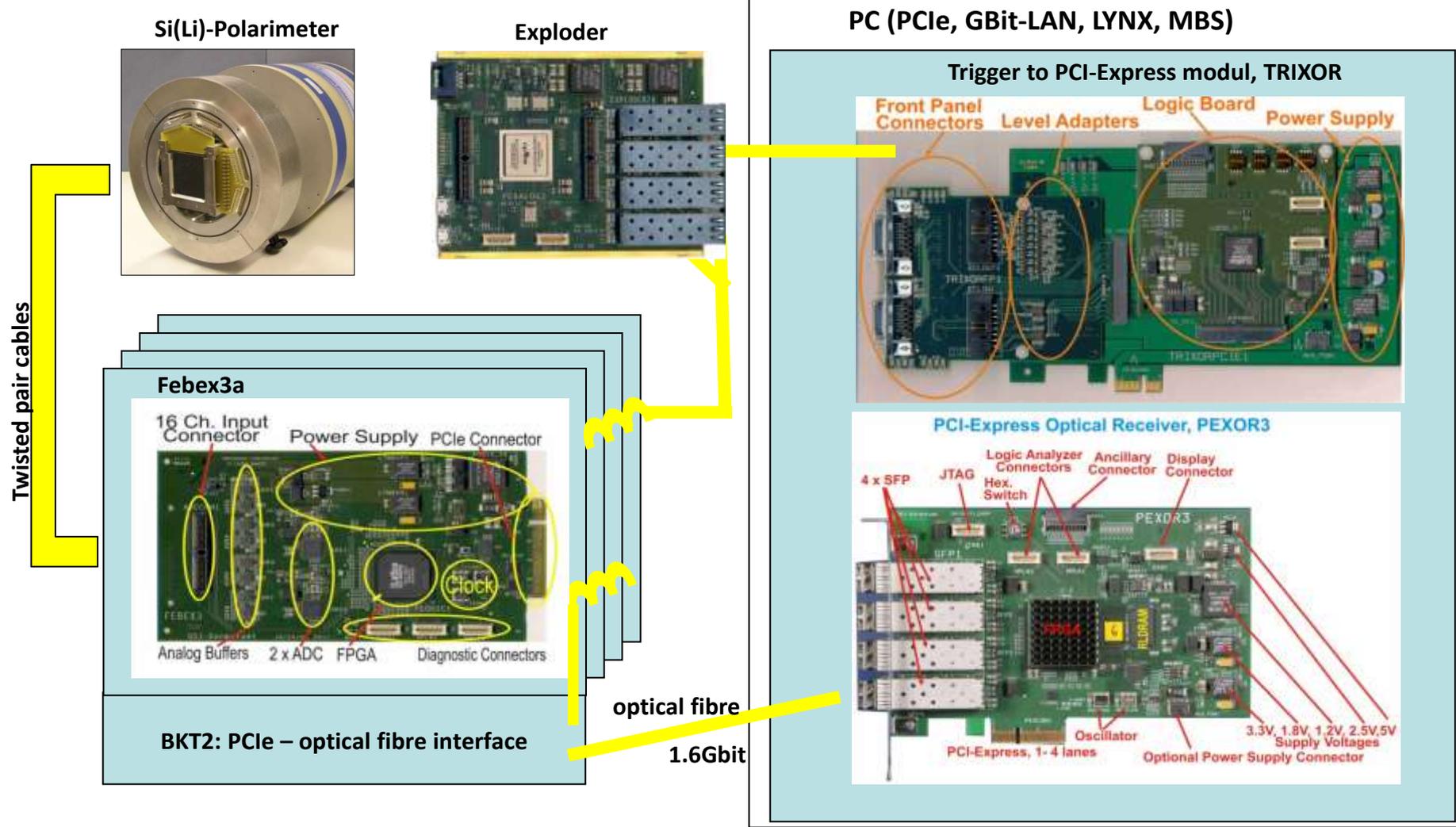
# Electron spectrometer



ESR:  
E up to 800 keV  
electrons

HESR:  
E up to 5 MeV  
electrons and  
positrons

# DAQ for Strip-Detectors: VME to Febex3a-based reduction in size and costs by factors, higher event rates



# Laser systems and optical detection



# Summary

**SPARC@FAIR:** atomic physics experiments  
from eV/u to GeV/u beam energies

**Observables:** x-rays, ions (projectiles/recoils),  
electrons and light (IR to VUV)

x-rays	high resolution spectroscopy Compton polarimetry
ions	diamond detectors Schottky resonator Cryogenic Current Comparator
electrons	electron spectrometer

# The SPARC collaboration

AUSTRIA  
Vienna University of Technology  
CANADA  
University of Manitoba  
York University  
CHINA  
China Institute of Atomic Energy, Beijing  
Institute of Applied Physics and Computational Mathematics, Beijing  
Institute of Modern Physics, Fudan University, Shanghai  
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou  
Institute of Atomic and Molecular Physics, Jilin University, Jilin  
Lanzhou University, Lanzhou  
University of Science and Technology of China, Hefei  
Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences  
Physics Department, West Normal University  
Department of Physics and Astronomy, University of Aarhus  
DENMARK  
Department of Physics and Astronomy, University of Aarhus  
EGYPT  
Physics Department, Beni-Suef Faculty of Science  
FRANCE  
CIRIL Ganil  
Ecole Normale Supérieure – Lyon  
Institut de Physique Nucléaire de Lyon

>340 participants from over 20 countries

Vaish College, Rohtak  
Nuclear Science Centre, New Delhi  
Bhabha Atomic Research Centre  
ITALY  
Inst. Naz. Fisica Nucleare, Dip. di Fisica, Catania  
JAPAN  
University of Tokyo & Atomic Physics Laboratory RIKEN, Wako  
JORDAN  
Hashemite University  
POLAND  
Institute of Physics, Swietokrzyska Academy  
Institute of Physics, Jagiellonian University  
Institute of Theoretical Physics, Warsaw University  
Institute of Nuclear Physics of Polish Academy of Sciences  
The Stefan Institute For Nuclear Studies  
ROMANIA  
NIPNE National Institute for Physics and Nuclear Engineering  
RUSSIA  
Lebedev Physical Institute, Moscow  
Institute of Physics, St. Petersburg State University  
Institute of Metrology for Time and Space at VNIIFTRI  
Institute of Spectroscopy of the RAS  
V.G.Khlopov Radium Institute, St.Petersburg  
SERBIA AND MONTENEGRO  
Institute of Physics, Belgrade

Many, many more activities going on!  
Personally biased selection of a few examples !

Max-Planck-Institut für Kernphysik, Heidelberg  
Institut für Theoretische Physik, TU Dresden  
Tübingen University  
IKF, J.W.v.Goethe Universität Frankfurt am Main  
Institut für Physik, Universität Mainz  
Institut für Physik, Universität Kassel  
Institut für Theoretische Physik, TU Clausthal  
Kirchhoff-Institut für Physik, Universität Heidelberg  
TU Darmstadt  
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Mathematics Institute, University of Munich, 80333 Munich  
HUNGARY  
Inst. of Nuclear Research (ATOMKI), Debrecen  
INDIA  
Tata Institute of Fundamental Research

Institut für Physik, Universität Basel  
UNITED KINGDOM  
Department of Physics, The University of Durham  
Queen's University, Belfast  
UNITED STATES  
Lawrence Berkeley National Laboratory  
Georgia State University  
University of Missouri Rolla  
Oak Ridge National Laboratory  
Western Michigan University  
Harvard-Smithsonian Center for Astrophysics  
Brown University, Physics Department  
University of Texas at Austin  
Kansas State University  
Columbia Astrophysics Laboratory, Columbia University