32nd RD50 Worskhop, Hamburg, 4-6. June 2018

Symposium in Honor of Dr.Eckhart Fretwurst

A brief history of the RD50 Collaboration

… in perspective of RD50 Hamburg team ..

Michael Moll

CERN, Geneva, Switzerland

….how it all started!

- **… out of my perspective (198x - 1999)**

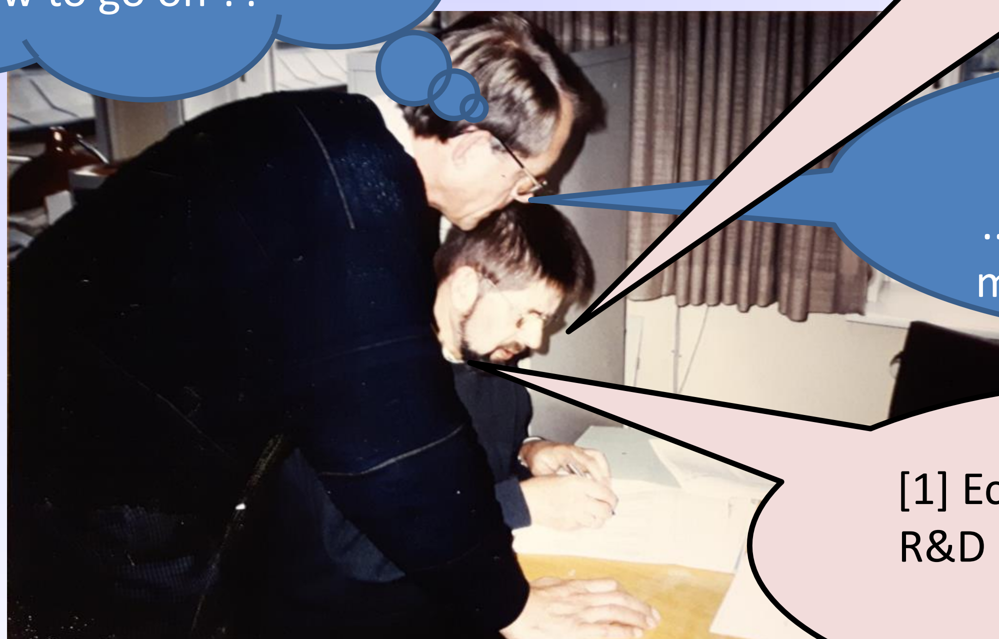
  - …remember,

I was still a young student in Hamburg

so, from the outside things might have looked different

How did it all start?

- **Potentially like this: Jungiusstrasse, Hamburg, maybe rainy afternoon, around198x.**



[1] Eckhart, we need to start R&D on radiation damage in silicon detectors.

[2] Good idea! Let’s get started. ..but who will do all the measurements Gunnar?

[3] Eckhart, don’t worry! We will build a team with lots of students.

[4] Hmm, I wonder who will teach and supervise all those students, help them if they don’t know how to go on ??

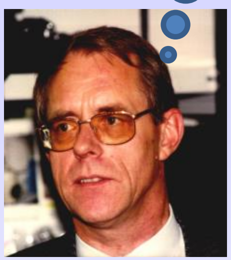
[Foto: R.Wunstorf ca.1988]

… and then ?

- ..and the next step potentially like this: equipping the lab.

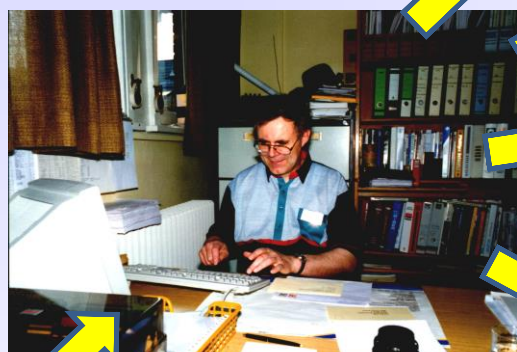
How to get the data?

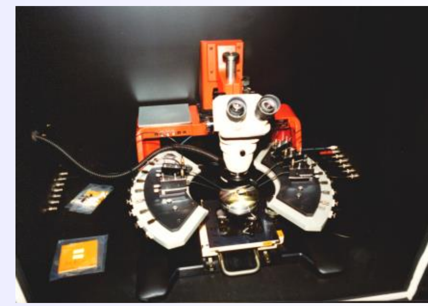
How to equip the lab?

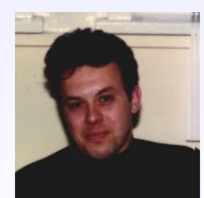


Uuuweeeee

Kein Problem!



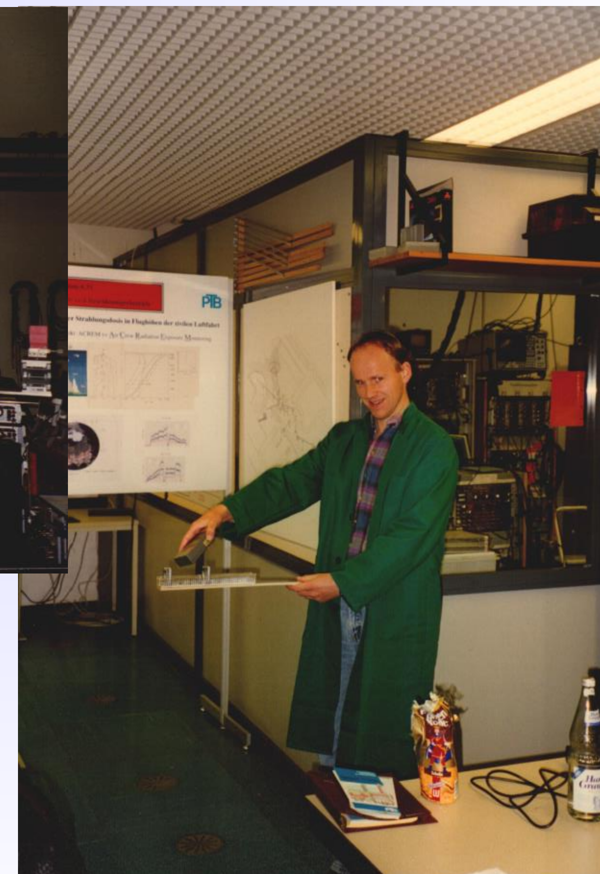




…let's do irradiation tests

1997 Neutron irradiations at the PTB Braunschweig

"….lets switch off the radiation monitors, they make too much noise…"



Portable freezer

… liquid nitrogen all around

.. open transport in the trunk of our car

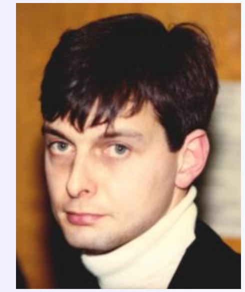
Generations of PhD students in Hamburg

- …working on the "Hamburg Model" 1987 - 2001

Systematische Untersuchungen zur
Strahlenresistenz von Silizium-Detektoren
für die Verwendung in
Hochenergiephysik-Experimenten

Renate Wunstorf 1992

Investigation on the Long Term Behaviour
of Damage Effects and Corresponding
Defects in Detector Grade Silicon
after Neutron Irradiation



Torsten Schulz 1992

Radiation Tolerance of Silicon Particle
Detectors for High-Energy Physics
Experiments

Henning Feick 1997

Radiation Damage in
Silicon Particle Detectors
– microscopic defects and macroscopic properties –

Look at that smile, I certainly had a good time!

Michael Moll 1999

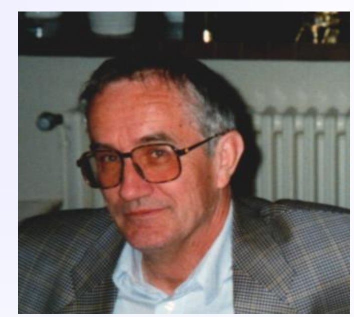
Microscopic Investigations
on various Silicon Materials
Irradiated with different Particles
with the DLTS Method

Martin Kuhnke 2001

… and many, many diploma students.

Nukleare Messtechnik

- Thank you Eckhart, thank you Gunnar
  and all the Nukleare Messtechnik team
  for the great years in Hamburg!



1999 ..inspiring visitors

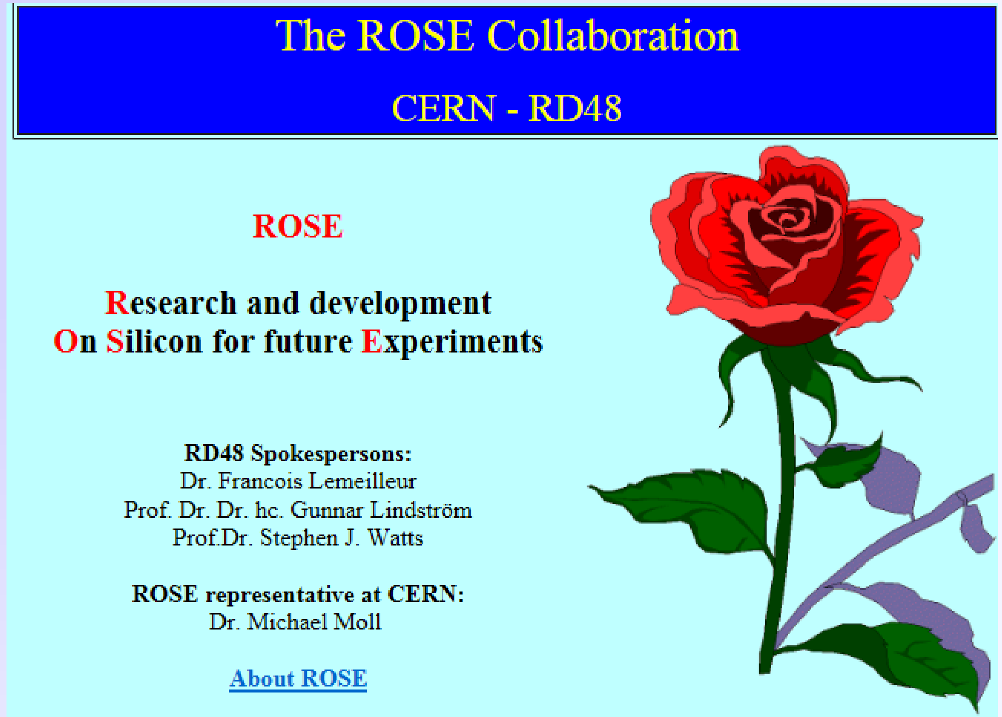
..we deserve a break now.

- “Karin is not around,
  let’s have a cigarette before we continue.”

- …o.k. lets try again from another perspective:
  How did RD50 start?

R&D on radiation damage before RD50

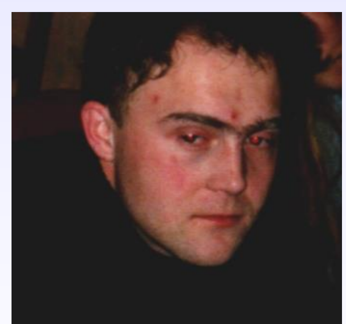
- **R&D on radiation damage**
- **RD2 – formed 1990**
- **RD48 – The ROSE Collaboration (1995-2000)**
  - **23-24.10.2000 6th ROSE Workshop**
    - Last RD48 Workshop, discussions how to continue are starting…..



http://rd48.web.cern.ch/RD48/





2001/2002: The RD50 story begins

- 28-31 November 2001 “1st Workshop on Radiation hard semiconductor devices for very high luminosity colliders” [100 participants]
- 15 February 2002: Proposal submitted to the LHCC
  [proposal drivers & editors: C. Da Via, M.Moll, C.Joram,]
- 25 February 2002: Formation of the Collaboration
  47 members: 45 Institutes and 2 Industrial Partners
  - **….and the first official role within the collaboration goes to:**
    - Collaboration Board Chair: **Dr.Eckhart Fretwurst**
  - **Spokespersons: Mara Bruzzi (Florence) and Claude Leroy (Montreal)**
- 14/15 March 2002: Discussion of Proposal in LHCC closed session
- 15/16 May 2002: Proposal presented to the LHCC (open session)
- 30 May 2002: Proposal approved by Research Board and project defined as RD50

LHCC 2002-003 / P6 – 1/36

LHCC 2002-003
LHCC P6
15 February 2002

R&D Proposal

DEVELOPMENT OF RADIATION HARD SEMICONDUCTOR DEVICES FOR VERY HIGH LUMINOSITY COLLIDERS

Institute for Experimental Physics, University of Hamburg, Germany
E. Fretwurst, G. Lindström, J. Stahl, D. Contarato, P. Buhmann, U. Pein, I.Pintilie

Formation of the Collaboration
“Radiation hard semiconductor devices for very high luminosity colliders”

Minutes of the meeting held at CERN on 25 February 2002
(recorded by M.Moll, until topic 6., and G.Casse starting from topic 7.)

Approval and Baptism

- **30 May 2002 : Research Board approves the proposal**
  - ..following the recommendation of the LHCC (Large Hadron Collider Committee)

MINUTES OF THE 159th MEETING OF THE RESEARCH BOARD
HELD ON THURSDAY, 30 May 2002

3. REPORTS AND MATTERS ARISING FROM THE LHCC MEETING OF 15-16 MAY 2002

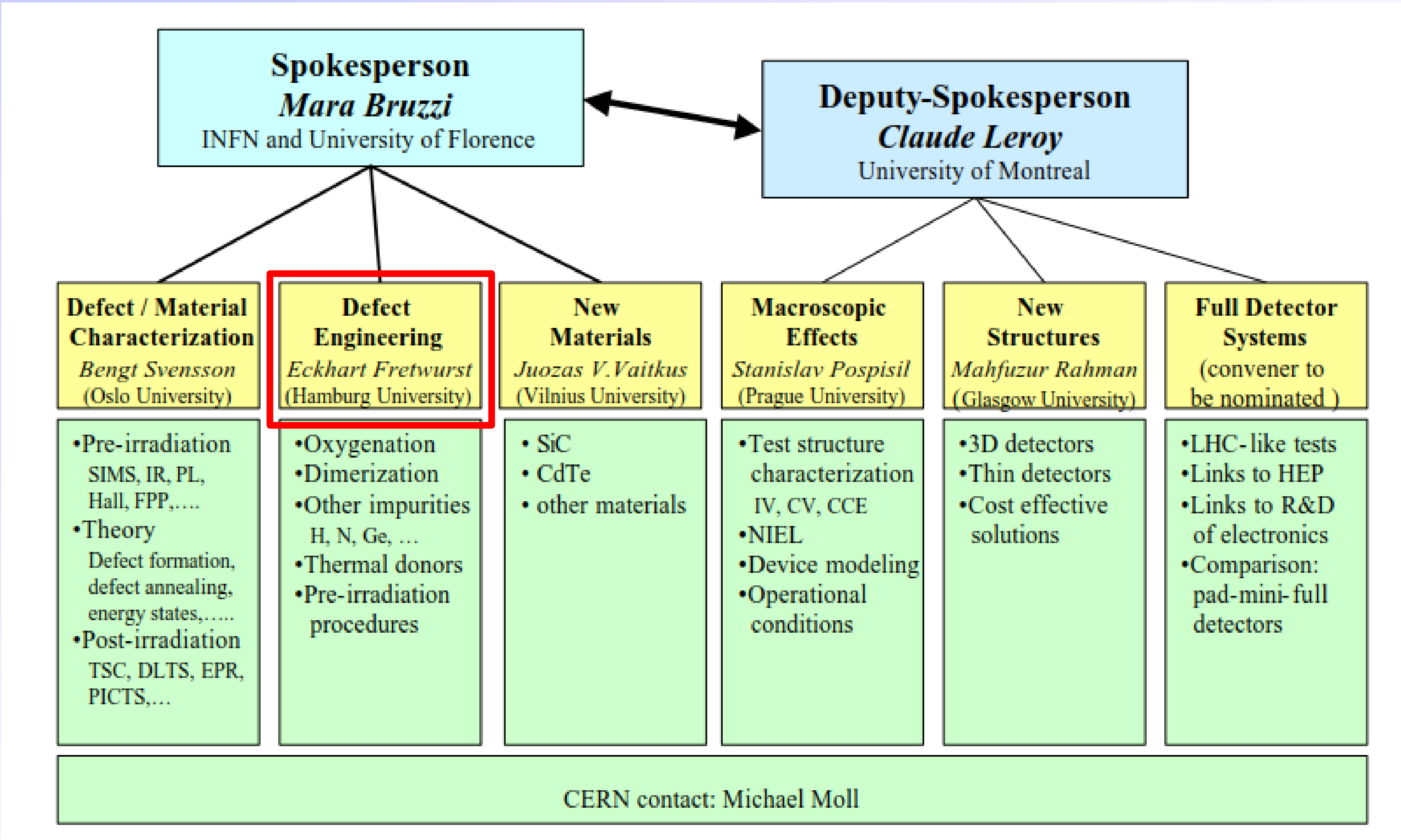
M. Calvetti reported on the 58th meeting of the LHCC.

He also described a new R&D proposal [10] that intends to develop semiconductor devices that could operate at hadron collider luminosities as high as 10^{35} cm^{-2} s^{-1}. The LHCC estimated that the proposed programme of research is sound and therefore recommended approval of this proposal with the proviso that the collaboration presents a clearer organizational structure. The Research Board **concurred** with this recommendation. The new R&D project will be known as **RD50**.

In the ensuing discussion on semiconductor R&D Schlatter pointed out that, whereas CERN resources was wished for, these were not available.

Born in times of strong funding concerns for the LHC construction; guideline at CERN : *"O.k, you can spend some time on R&D, but don't ask for resources and don't take any visible role in an R&D collaboration"*

The first RD50 Organigram



LHCC presentation: May 2002

RD50 Organigram 2018

Co-Spokespersons

Gianluigi Casse and *Michael Moll*

(Liverpool University, UK & FBK-CMM, Trento, Italy) (CERN EP-DT)

Defect / Material Characterization
Ioana Pintilie
(NIMP Bucharest)

- Characterization of microscopic properties of standard-, defect engineered and new materials pre- and post-irradiation
- DLTS, TSC, ….
- SIMS, SR, …
- NIEL (calculations)
- Cluster and Point defects
- Boron related defects

Detector Characterization
Eckhart Fretwurst
(Hamburg University)

- Characterization of test structures (IV, CV, CCE, TCT,.)
- Development and testing of defect engineered devices
- EPI, MCZ and other materials
- NIEL (experimental)
- Device modeling
- Operational conditions
- Common irradiations

- Wafer procurement (M.Moll)
- Acceptor removal (Kramberger)
- TCAD simulations

New Structures
Giulio Pellegrini
(CNM Barcelona)

- 3D detectors
- Thin detectors
- Cost effective solutions
- Other new structures
- Detectors with internal gain
- LGAD: Low Gain Avalanche Det.
- Deep depleted Avalanche Det.
- Slim Edges
- HVCMOS

- LGAD (S.Hidalgo)
- HVCMOS (E. Vilella)
- Slim Edges (V.Fadeyev)

Full Detector Systems
Gregor Kramberger
(Ljubljana University)

- LHC-like tests
- Links to HEP(LHC upgrade, FCC)
- Links electronics R&D
- Low rho strips
- Sensor readout (Alibava)
- Comparison:
  - pad-mini-full detectors
  - different producers
- Radiation Damage in HEP detectors
- Timing detectors
- Test beams (M.Bomben & G.Casse)

Collaboration Board Chair & Deputy: G.Kramberger (Ljubljana) & J.Vaitkus (Vilnius), Conference committee: U.Parzefall (Freiburg)
CERN contact: M.Moll (EP-DT), Secretary: V.Wedlake (EP-DT), Budget holder & GLIMOS: M.Moll & M.Glaser (EP-DT)

LHCC presentation: May 2018

RD50 success stories: p-type silicon

- **2002: n-in-p segmented sensors: not mentioned in proposal**
- **2004: First "very encouraging" results on p-type strip sensors presented**

RD50 n-in-p microstrip detectors — LHCC 2005

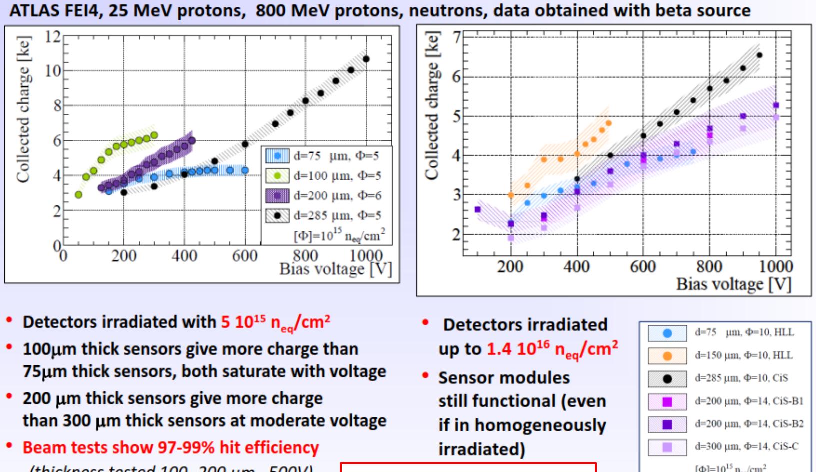
RD50 n-in-p microstrip detector — LHCC 2006

n-in-p: - no type inversion, high electric field stays on structured side
- collection of electrons

- n-in-p microstrip detectors on p-type FZ (280μm thick, 80μm pitch, 18μm implant)
- Detectors read-out with 40MHz

RD50 Thin p-type pixel sensors

- **Thin FZ p-type pixel sensors: 75 to 300 μm with 450 μm edge** (MPI/CIS/VTT)
- **ATLAS FEI4, 25 MeV protons, 800 MeV protons, neutrons, data obtained with beta source**



- Detectors irradiated with $5\ 10^{15}\ n_{eq}/cm^2$
- 100μm thick sensors give more charge than 75μm thick sensors, both saturate with voltage
- 200 μm thick sensors give more charge than 300 μm thick sensors at moderate voltage
- Beam tests show 97-99% hit efficiency (thickness tested 100 -200 μm, 500V)

- Detectors irradiated up to $1.4\ 10^{16}\ n_{eq}/cm^2$
- Sensor modules still functional (even if in homogeneously irradiated)

S. Terzo, 24th RD50 Workshop June 2014 ... hen, 25th RD50 Workshop Nov. 2014

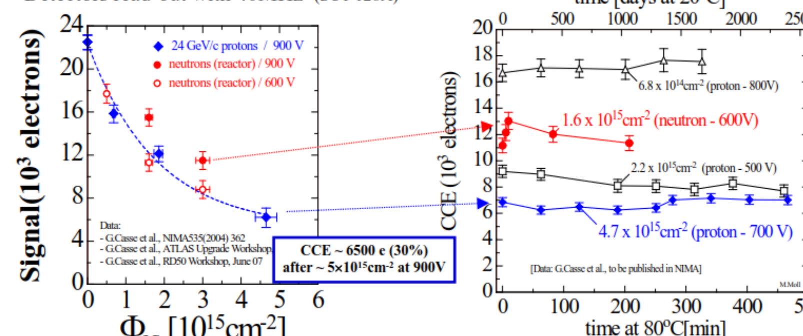
LHCC 2015 ...ll, RD50 Status Report, June 2015 -14-

RD50 Annealing of p-type sensors — LHCC 2005

RD50 n-in-p microstrip detectors — LHCC 2007

n-in-p: - no type inversion, high electric field stays on structured side
- collection of electrons

- n-in-p microstrip p-type FZ detectors (Micron, 280 or 300μm thick, 80μm pitch, 18μm implant)
- Detectors read-out with 40MHz (SCT 128A)



- **no reverse annealing visible in CCE measurements !** for neutron and proton irradiated detectors

- n-in-p sensors are now strongly considered for ATLAS upgrade (previously p-in-n was used)

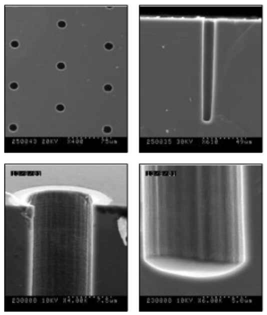
Mara Bruzzi and Michael Moll on behalf of the RD50 CERN Collaboration – LHCC, November 21, 2007 -9-

Today: For HL-LHC upgrades the trackers and the pixel will be based on n-on-p technology!

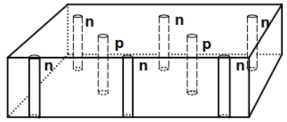
RD50 success stories: 3D detectors

Device Engineering: 3D detectors

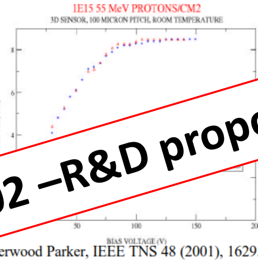
p^+ and n^+ polysilicon electrodes in narrow columns along the detector thickness.
Depletion depth develops laterally - Typical electrode distances: 50-100 µm.
Very fast collection times, low full depletion voltages (~10V), full charge collection over the 300µm detector active thickness



Size up to ~1cm²



First radiation hardness tests after 10^{15} cm^{-2} 55MeV protons (measured with IR LED)



R. Bates, 1st Workshop on Radiation hard semiconductor devices for high luminosity colliders, CERN, November 2001.

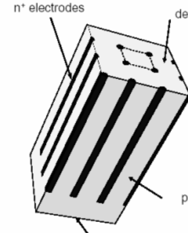
Sherwood Parker, IEEE TNS 48 (2001), 1629.

LHCC 15 May 2002 M. Bruzzi 16

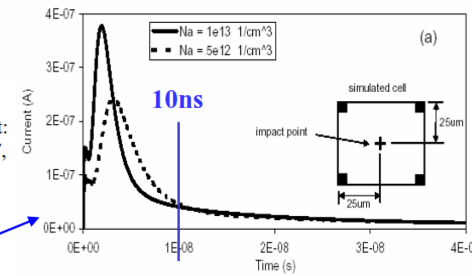
2002 –R&D proposal

RD50 3D Detectors: New Architecture

2004 – first RD50 results



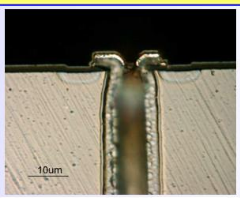
- **Simplified 3D architecture**
  - n^+ columns in p-type
  - operation similar to standa...
- **Simplified process**
  - hole etching and doping only done once
  - no wafer bonding technology needed
- **Fabrication planned for 2005**
  - INFN/Trento funded project: collaboration between IRST, Trento and CNM Barcelona
- **Simulation**
  - CCE within < 10 ns
  - worst case shown (hit in middle of cell)



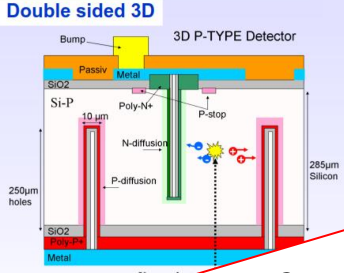
C. Piemonte et al. Presented at STD05, June 04, Hiroshima, in press on Nucl. Instrum. Meth A. -14-

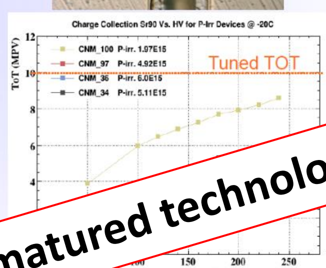
RD50 New structures: 3D sensors

- **3D sensors: Mastering the technology (CNM-Barcelona, FBK-Trento)**
  - Reproducible, reliable results before and after irradiation



Double sided 3D





...arb (IFAE Barcelona), 19th RD50 Workshop, Nov. 2011]

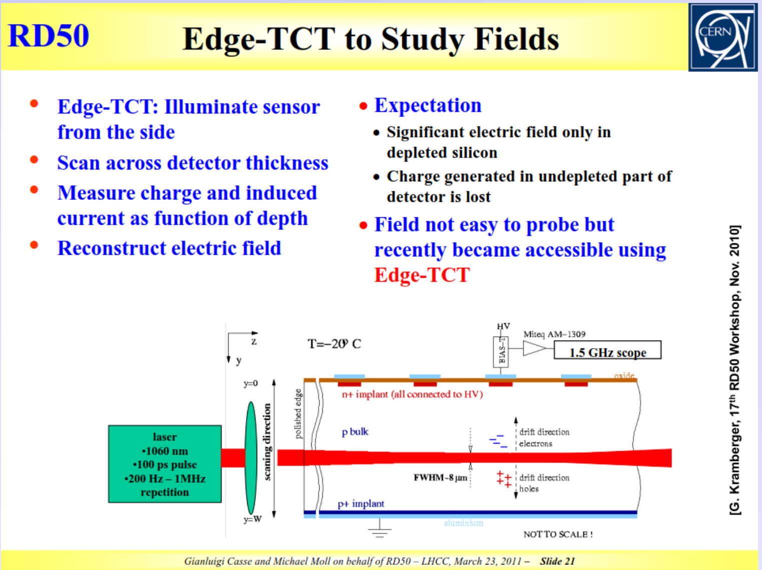
G.Casse and M.Moll, RD50 Status Report, June 2012 -16-

LHCC 2012 – matured technology

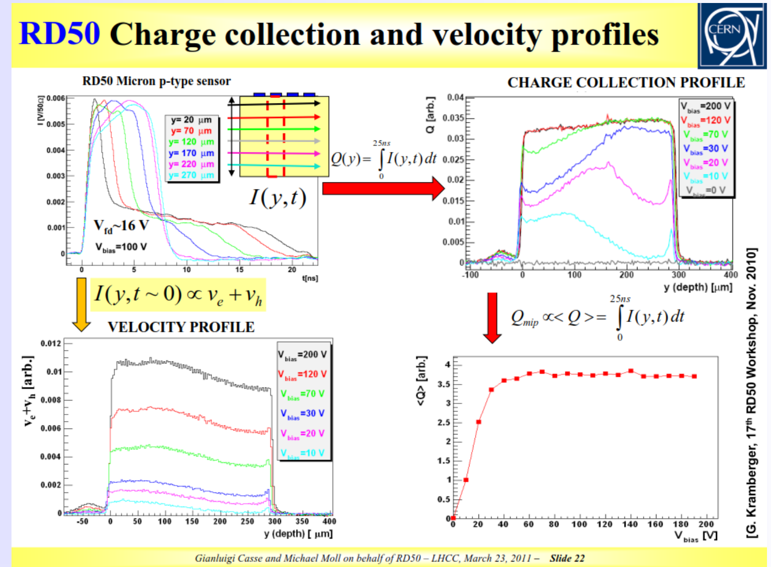
May 2014 – ATLAS IBL installed
…3D detectors are operating in the LHC

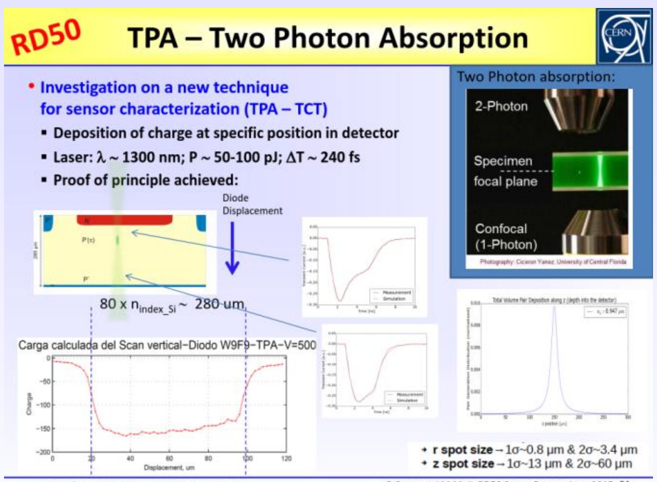
Success stories: Characterization tools

- Many tools and characterization techniques developed by RD50 … examples



LHCC 2011 : edge-TCT



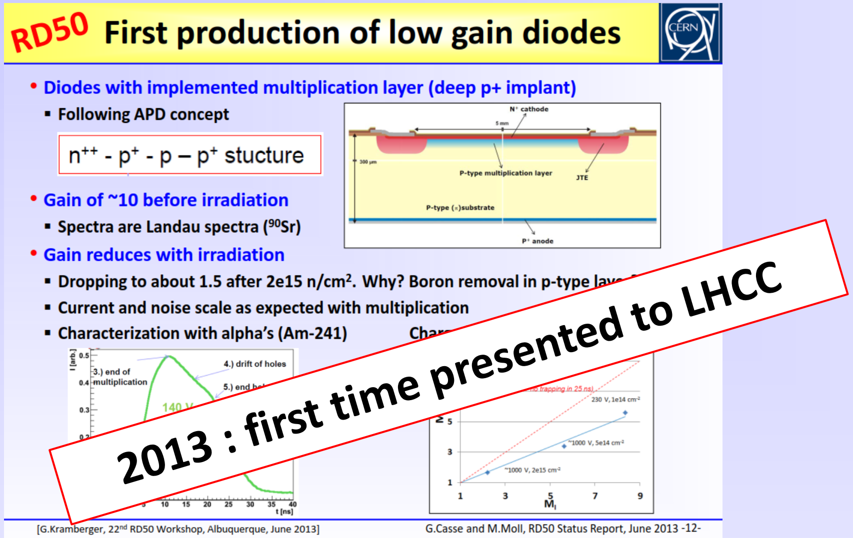


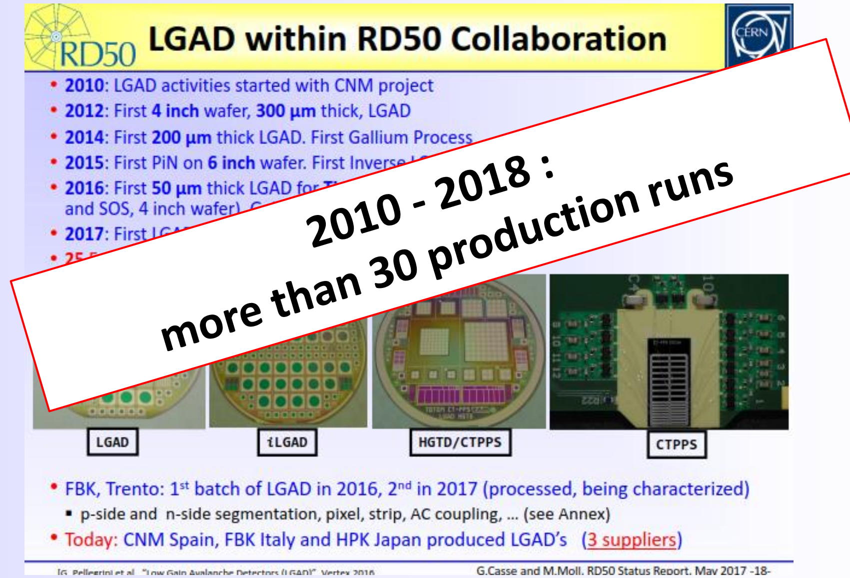
LHCC 2015 : TPA-TCT

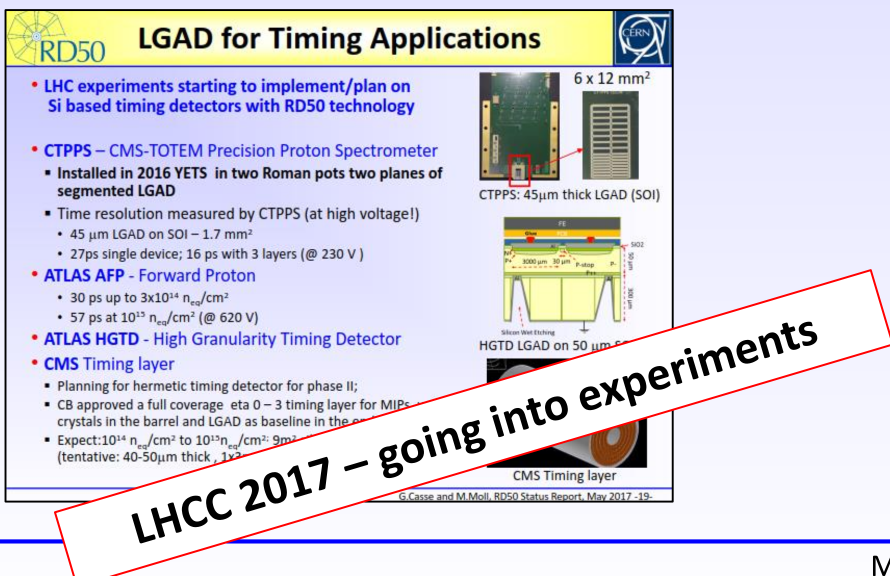
..spin offs

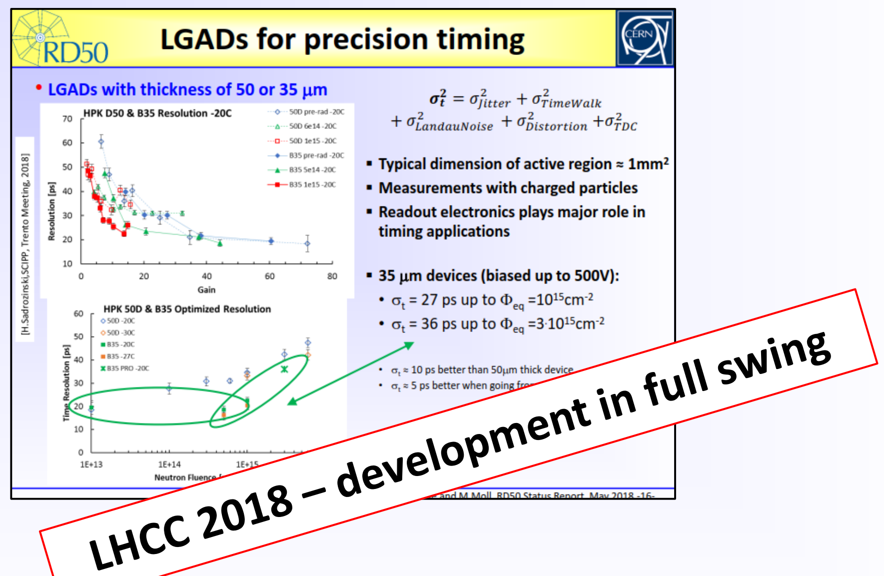
Success stories: LGAD sensors

- Born out of RD50 “charge multiplication studies”





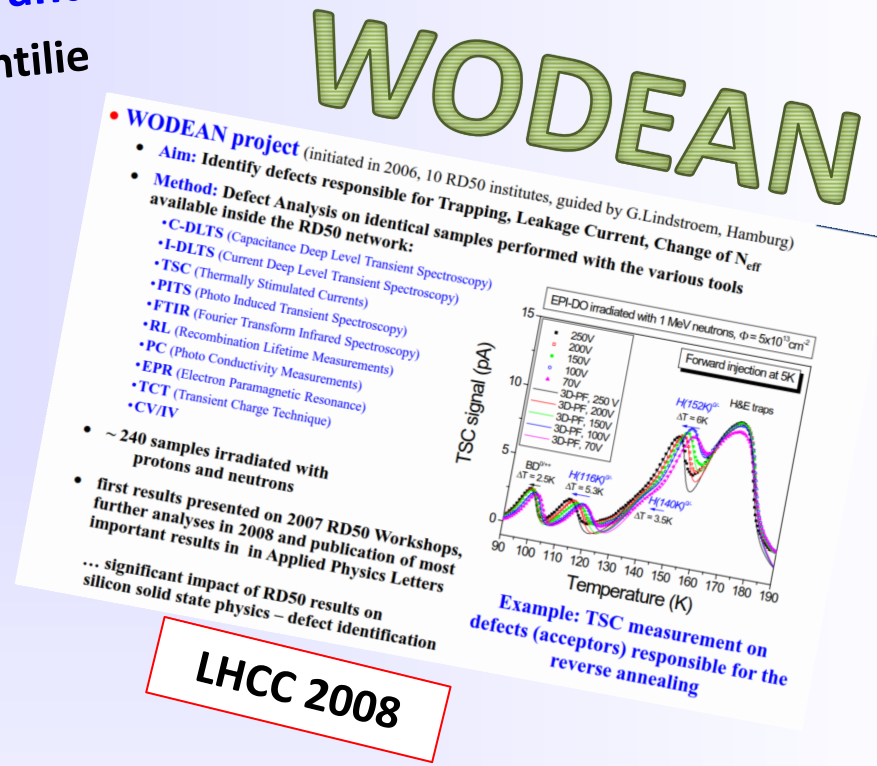




Success stories: Defect Characterization

- Very strong impact from the Hamburg and Bucharest teams
  - .. see following presentation of Ioana Pintilie

1999



- …. and many more success stories …. (simulations, models, sensor designs,….)
  … sorry, for not being able to show them all

RD50 so far… Main Achievements

- Development of the p-type silicon strip and pixel technology
- Double column 3D detectors and first industrialization at CNM and FBK
- Convincing demonstration of the performance of planar segmented sensors to the maximum fluences anticipated for the HL-LHC ($3x10^{16}$ n_{eq} cm^{-2})
- Extensive evaluation of defect engineered Silicon and other semiconductor materials
- Observation and explanation of charge multiplication in highly irradiated sensors operated at high voltage
- Design and production of LGAD (Low Gain Avalanche Detectors) for 4D tracking
- Development of several unique characterization methods and systems for sensor and material analyses: Transient Current Technique (TCT), Edge-TCT, Two Photon Absorption (TPA)-TCT, Alivaba readout system and standardized measurement and analyses procedures, partly now marketed through spin-off companies
- Defect characterization: identification of defects responsible for the degradation of various detectors parameters defining the state of the art in the corresponding solid state community
- Data collection and development of damage parameters/models essential for sensor design (TCAD parameters) and for planning the running scenarios of LHC experiments and their upgrades (evolution of leakage current, CCE, power consumption, noise,….)
- **Close links to the LHC experiments (upgrades** and operation**)**

....producing publications (e.g. 2005)

- **RD50 produced long articles:** Eckhart consumed 3 pages for the title and abstract

Recent advancements in the development of radiation hard semiconductor detectors for ~~S-LHC~~

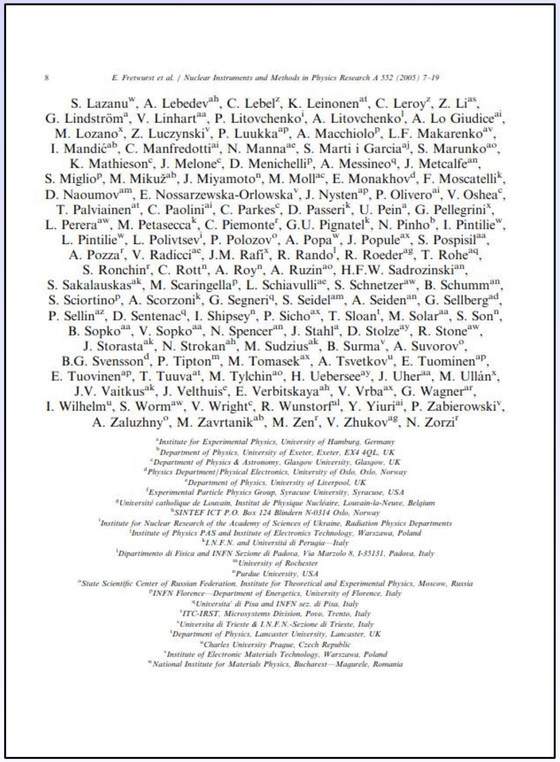
E. Fretwurst[a,*], J. Adey[b], A. Al-Ajili[c], G. Alfieri[d], P.P. Allport[e], M. Artuso[f], S. Assouak[g], B.S. Avset[h], L. Barabash[i], A. Barcz[j], R. Bates[c], S.F. Biagi[e], G.M. Bilei[k], D. Bisello[l], A. Blue[c], A. Blumenau[b], V. Boisvert[m], G. Bolla[n],

- **...plus typo:**

  S-LHC (Super – LHC)

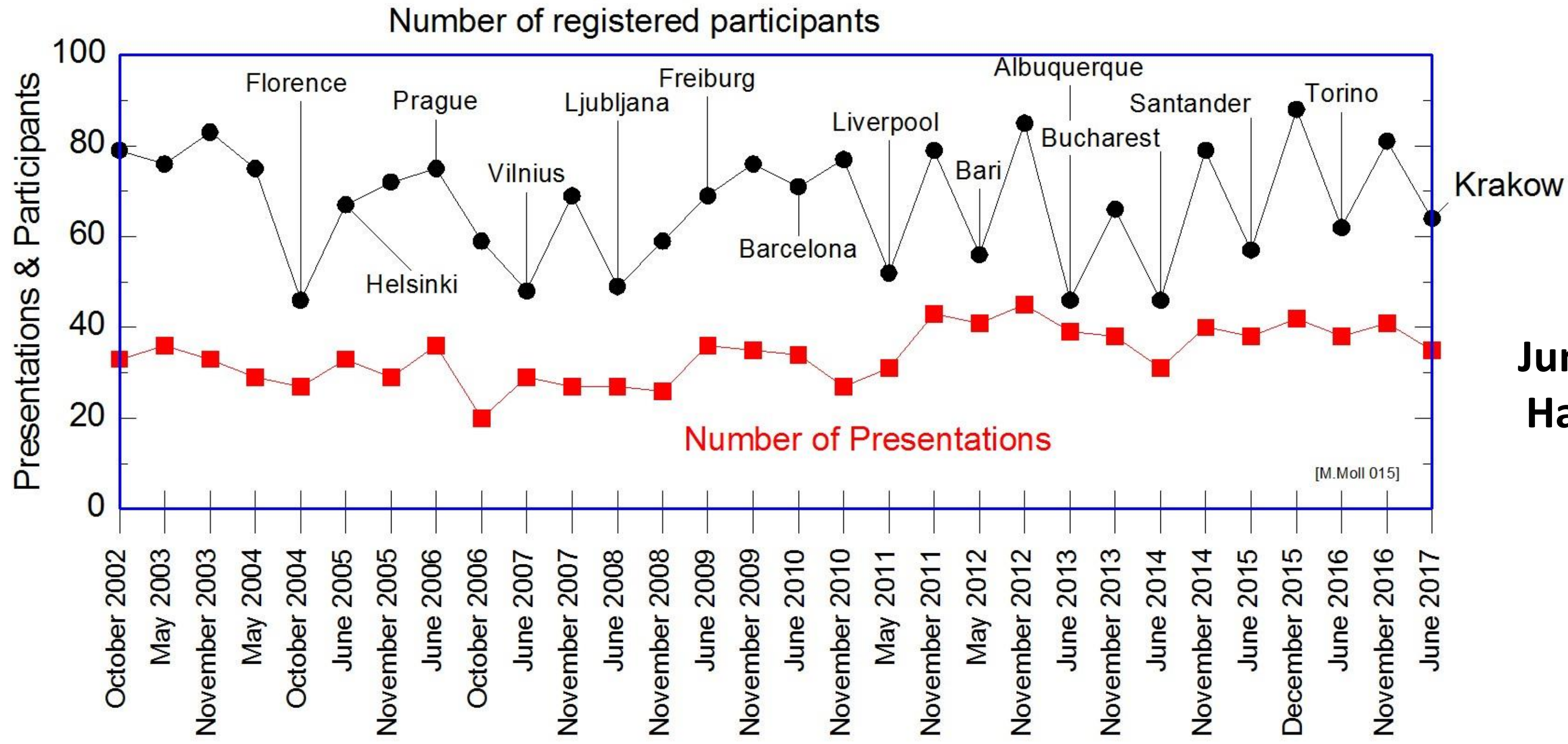
  ....became

  HL-LHC (High Lumi – LHC)



32 Workshops

- 2 Workshops per year: One at CERN in November and one outside in summer
- The R&D highlights of the year ☺ ..and a lot of fun.

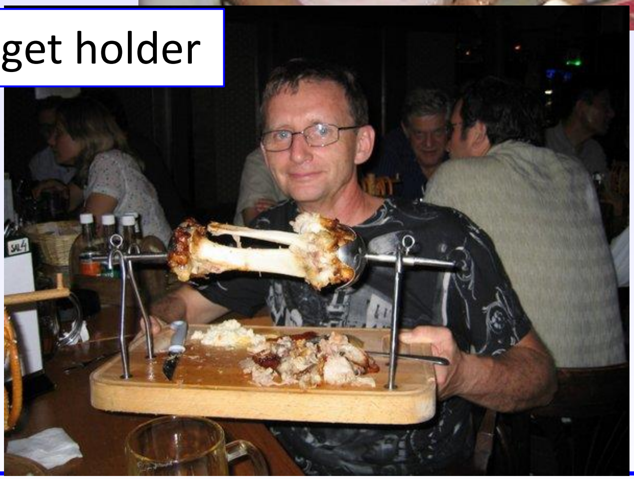


June 2018 Hamburg

RD50 - May 2004 - Geneva

RD50 - Prague - 2006

.. RD50 budget holder



RD50 - Vilnius - 2007

.. with cake and press conference at the Center of Europe

RD50 - Ljubljana - 2008

RD50 - Freiburg - 2009

RD50 - Barcelona - 2010

The RD50 Collaboration

- **RD50: 59 *institutes and 345 members…***

… forming a COLLABORATION!

The RD50 community brings together:
solid state physicists; device physicists;
experts of radiation-matter interactions;
high energy physicists; electronics system designers;
ASICs designers; sensor foundries.

This community has learned to work towards common goals developing methods, tools and standards that are world reference for the domain.

This vast expertise is an unsurpassed basis for continuing research towards sensor solution for future challenges.

RD50 Tomorrow

- **5 year work plan submitted to LHCC on 31.May 2018**
  - ….just in time for the 1.6.2018 (…a special day, Eckhart's Birthday, see next slide).


RD50 Prolongation Request: May 2018

CERN, 31 May 2018

RD50

RD50 Prolongation Request

– May 2018 –

The RD50 Collaboration

Abstract

With this document, we request the prolongation of the CERN RD50 research program for 5 years. A very brief historical review of the RD50 research program since the RD50 project approval by the Research Board in the year 2002 is presented and the biggest RD50 achievements are highlighted. The present composition of the collaboration, its organizational structure, and the research methodology are described. The role of RD50 in the present various upgrade and research programs of the LHC Experiments community is given and the overall work plan explained. Finally, a detailed 5-years work program with precise milestones and deliverables for the various research activities is presented. We conclude with our prolongation request towards the LHCC.

CERN-LHCC-2018-017 / LHCC-SR-007
31/05/2018

https://cds.cern.ch/record/2320882/files/LHCC-SR-007.pdf

Dr. Eckhart Fretwurst

80 years
Happy Birthday Eckhart
and
many thanks for your
outstanding contribution to RD50
… in science and in management

P.S.: We count on your contribution for the future …..