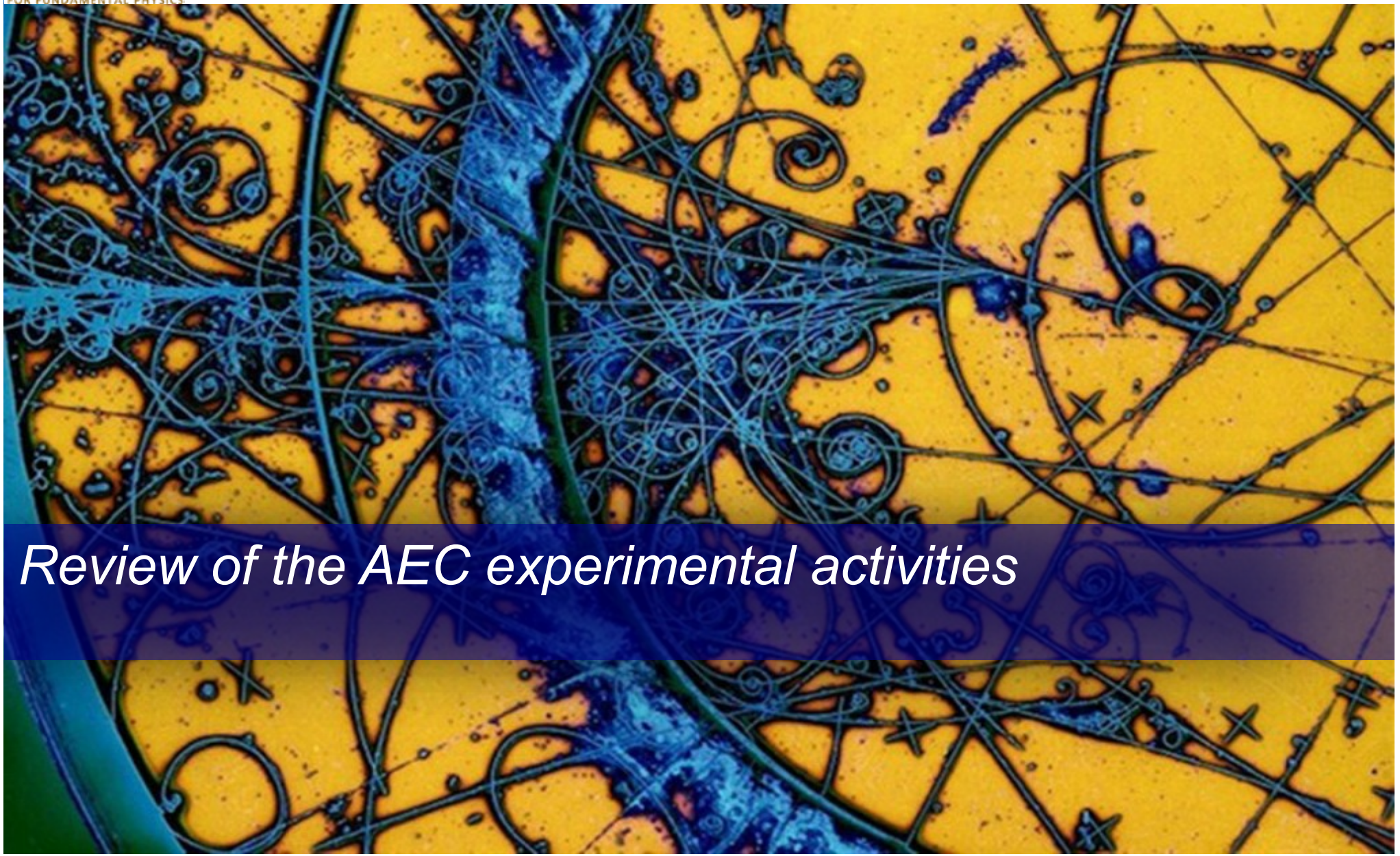
UNIVERSITÄT BERN

AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS

Antonio Ereditato

AEC Plenary Meeting – Bern, 3 September 2019

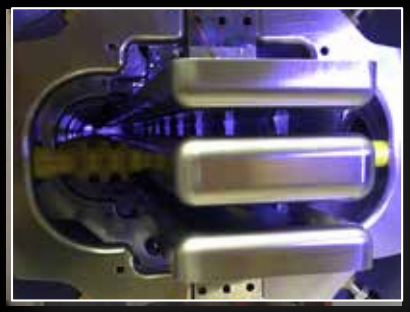


Review of the AEC experimental activities

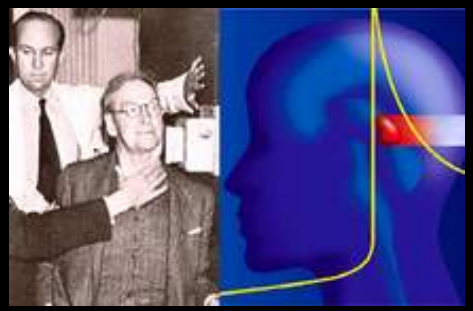
In line with LHEP long standing tradition

High-energy physics

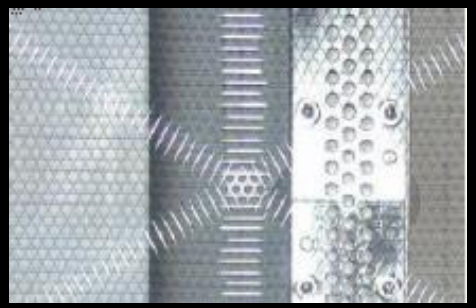
Neutrino oscillation physics



Precision & astroparticle physics



Medical applications of particle physics



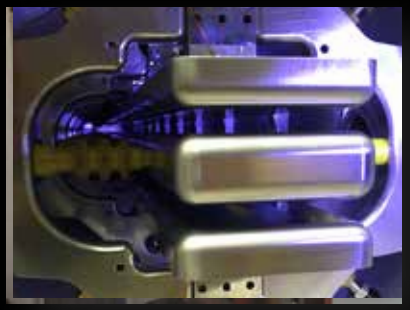
Development of novel particle detectors

Interdisciplinary & various projects

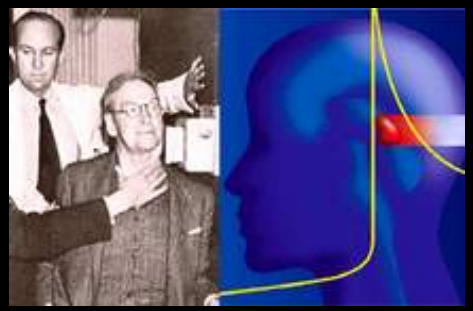
Today's situation

ATLAS (CERN)

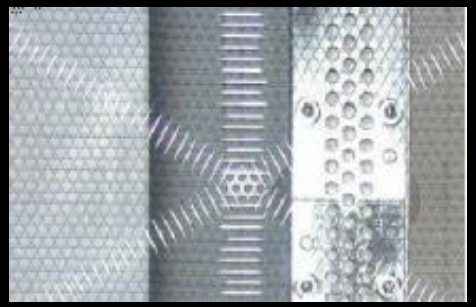
OPERA (Gran Sasso)
T2K (Japan)
MicroBooNE (USA)
SBND (USA)
DUNE (USA)



EXO (USA)
Xenon (Gran Sasso)
nEDM n2EDM (PSI)
Pulsed CNB (Bern)



INSELSPITAL cyclotron
Novel radioisotopes
Neutron beams
Beam instrumentation
Irradiation studies
Imaging and diagnostics



Liquid Argon TPCs
Nuclear emulsions
Scintillators
TT-PET

AEgIS (CERN)
QPLAS
Muon radiography (Alps)
FASER (CERN)
DsTAU (CERN)

The AEC Computing Center

Gianfranco Sciacca

- Very large computing center at UNIBE: 5000 CPU cores, 1 petabyte storage
- ATLAS TIER2: in the first half of 2019, 1.5 million jobs with 8 million of CPUs used
- Serving neutrino experiments, as well

Mechanical and Electronics Workshops

Roger Hänni

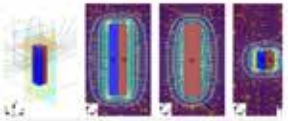
Pascal Lutz

Secretariat and Administration office

Marcella Esposito

Ursula Witschi

Long list of scientific achievements



Visualizaton of magnetic fields with neutrons

A new quantitative method for measuring magnetic fields using polarized neutrons has been developed ...

Swiss LHC computing Tier-2 moves to HPC

The ATLAS computing group of LHEP has pioneered the integration of High Performance Computing (HPC) systems with the ATLAS ...

Elementary particles reveal the landscape of Switzerland

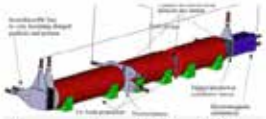
Muon radiography is a method to inspect internal structure of large objects by means of cosmic muons ...

Demonstration of antimatter wave interferometry

Wave-particle duality of single positrons in a double-slit like experiment has been demonstrated by the QUPLAS collaboration ...

DUNE RRB and PIP-II groundbreaking

With a ceremony held on March 15th 2019, the Fermi National Accelerator Laboratory officially broke ground on a major new particle accelerator ...



New experiment at the LHC, FASER, was approved

On March 5th 2019, CERN approved the FASER experiment, which will search for new particles ...

Bern students visit Fermilab

A group of bachelor students of this semester course of particle physics of the University of Bern visited Fermilab ...

29.04.19

National Future Day

On this year's National Future Day (Zukunftstag) several kids visited the laboratories of LHEP ...

18.03.19

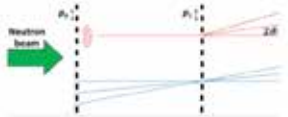
Prototype of the Resistive Shell LAr TPC

LHEP has realized and commissioned a first prototype of the so-called Resistive Shell LAr TPC ...

First particle tracks in ProtoDUNE

The largest liquid-argon neutrino detector in the world has just recorded its first particle tracks ...

18.09.18



Novel neutron interferometry concept published and funded

A new method to measure the neutron charge using interferometry has been published ...

05.11.18

Neutron beam time at PSI completed

The Fundamental Neutron Physics Group of LHEP has just completed a four-weeks-long beam time ...

26.10.18

PixLAr beam test completed

The collaboration between LHEP/AEC and Fermilab led to another new result ...

OPERA collaboration presents its final result

In May 2018, the OPERA collaboration presented its final result on the muon-neutrino to tau-neutrino oscillation experiment ...

EU RISE grant for neutrino research

The group working on the Fermilab neutrino program has been awarded an EU RISE grant ...

11.07.18

A boon for physicists: new MicroBooNE results at Neutrino 2018

The MicroBooNE collaboration produced their first collection of science results and presented them at the Neutrino 2018 conference Heidelberg ...

ARGONCUBE module becomes reality

In January 2018, the assembly of the first ARGONCUBE module ...

Results on ArCLight sensor published

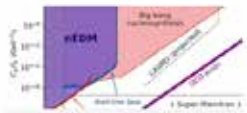
The ArCLight photon counting device combines advantages of two well-known photon detectors ...

A study in Tau

The DsTau project is a newly launched project, aiming to study tau neutrino production in proton interactions ...

19.02.18

11.06.18



Axion Dark Matter Search

The nEDM collaboration has published new results on a laboratory-based search for axion dark matter ...

Successful neutron beam time at PSI

The members of the Neutron Physics Group of LHEP have just completed their first beam time of four weeks at the Paul Scherrer Institute ...

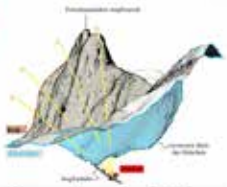
First SBND neutrino data with Cosmic Ray Tagger from Bern

On the morning of June 22, a first subdetector of the Short Baseline Near Detector began taking data at Fermilab ...

Particle Physics at "Nacht der Forschung"

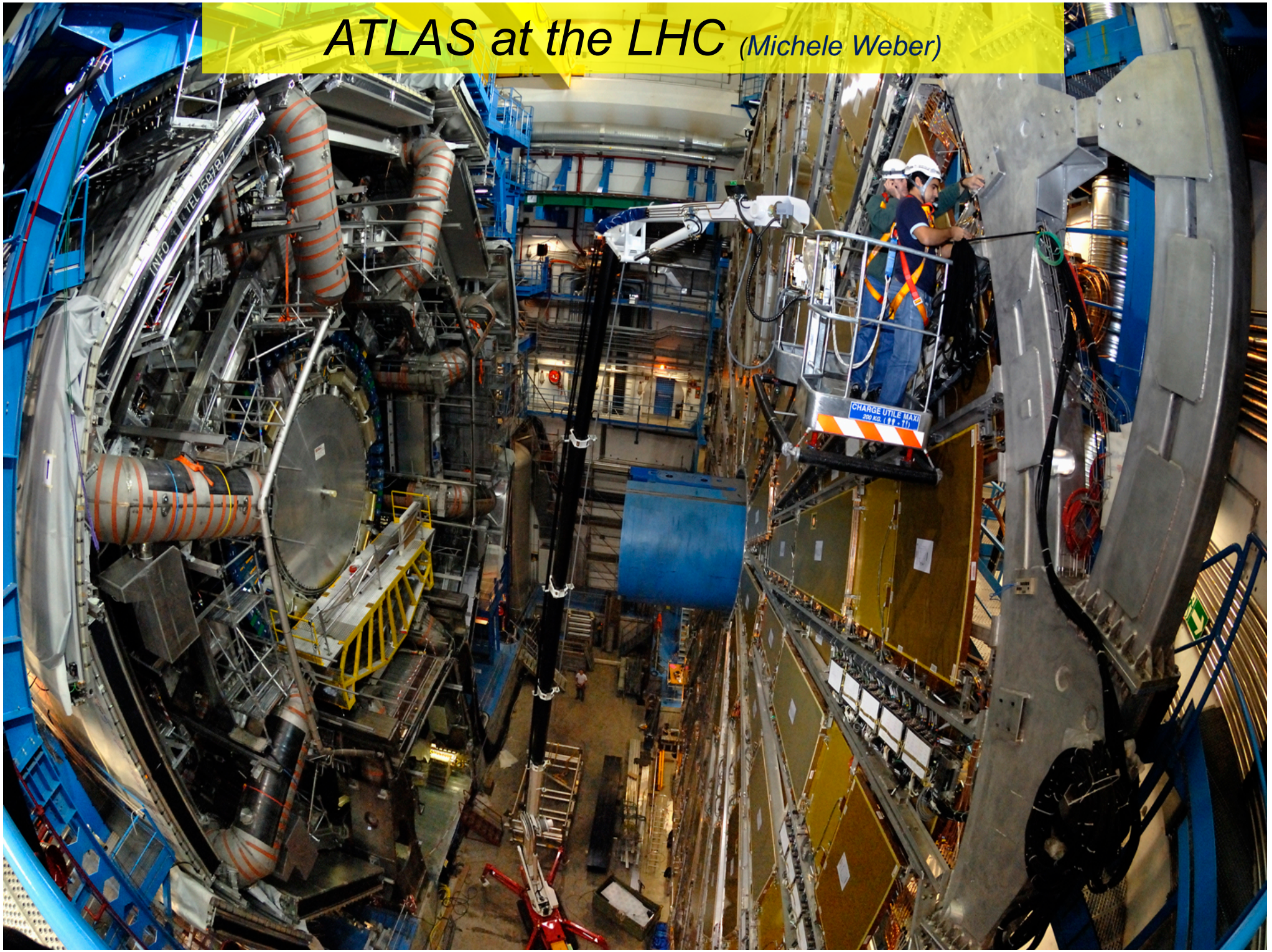
Members of LHEP coorganized the "Nacht der Forschung" at the University of Bern ...

24.10.17

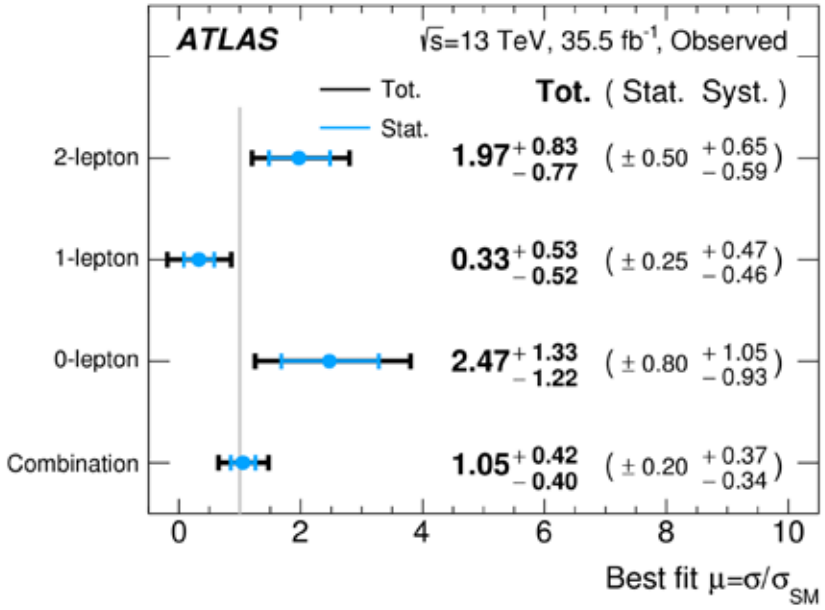


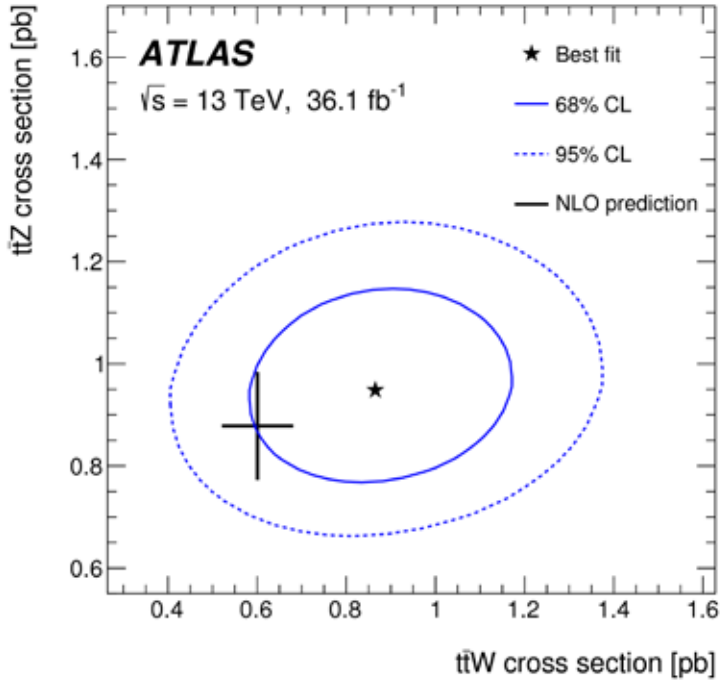
Muon radiography of Alpine glaciers

ATLAS at the LHC *(Michele Weber)*



ATLAS: recent scientific results





Standard Model physics

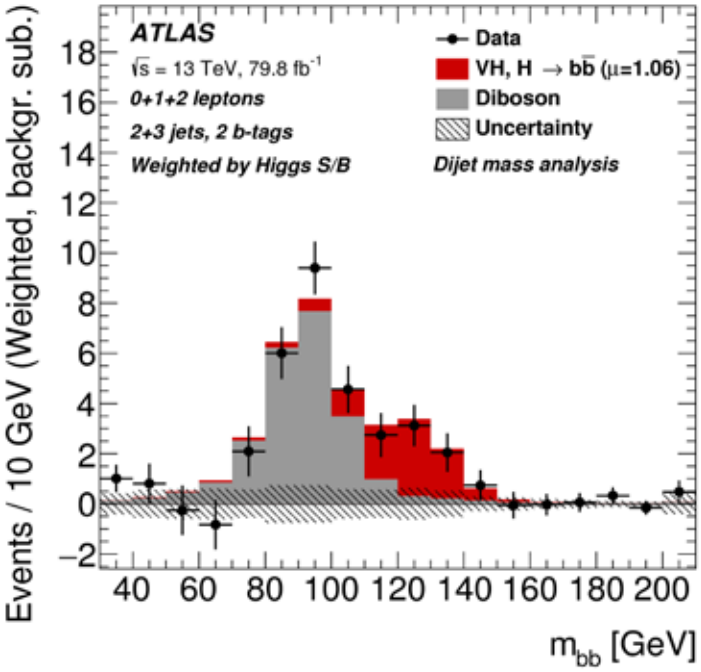
Hints for diboson production

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2017-20/

Top quark physics

Measurement of ttV (Z,W) cross sections

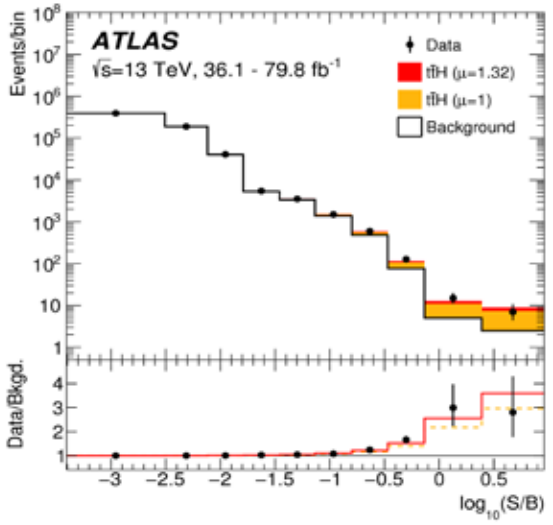
Phys. Rev. D 99 (2019) 072009

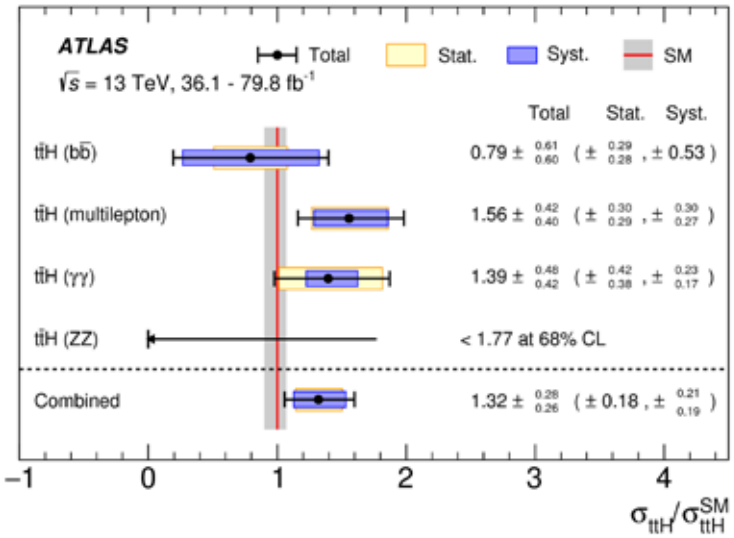


Higgs physics

Observation of H→bb

Phys. Lett. B 786 (2018) 59



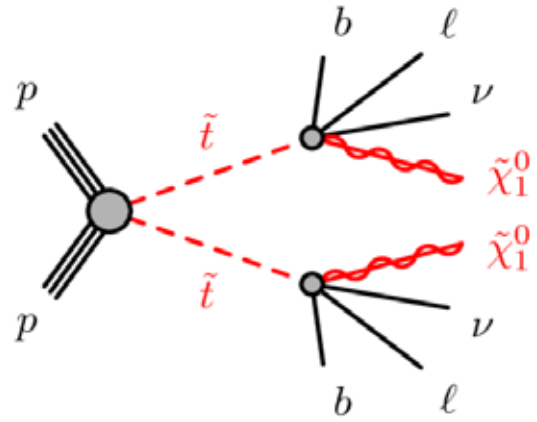


Higgs physics

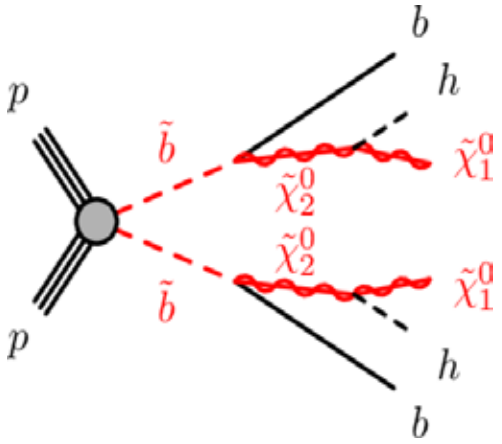
Observation of ttH production

Phys. Rev. D 99 (2019) 072009

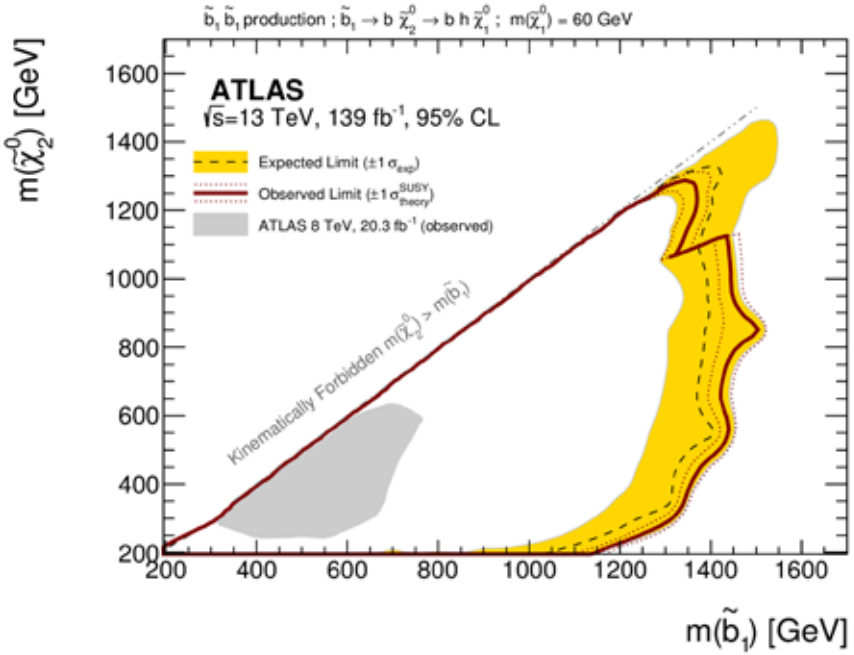
Bern group highlights: SUSY searches



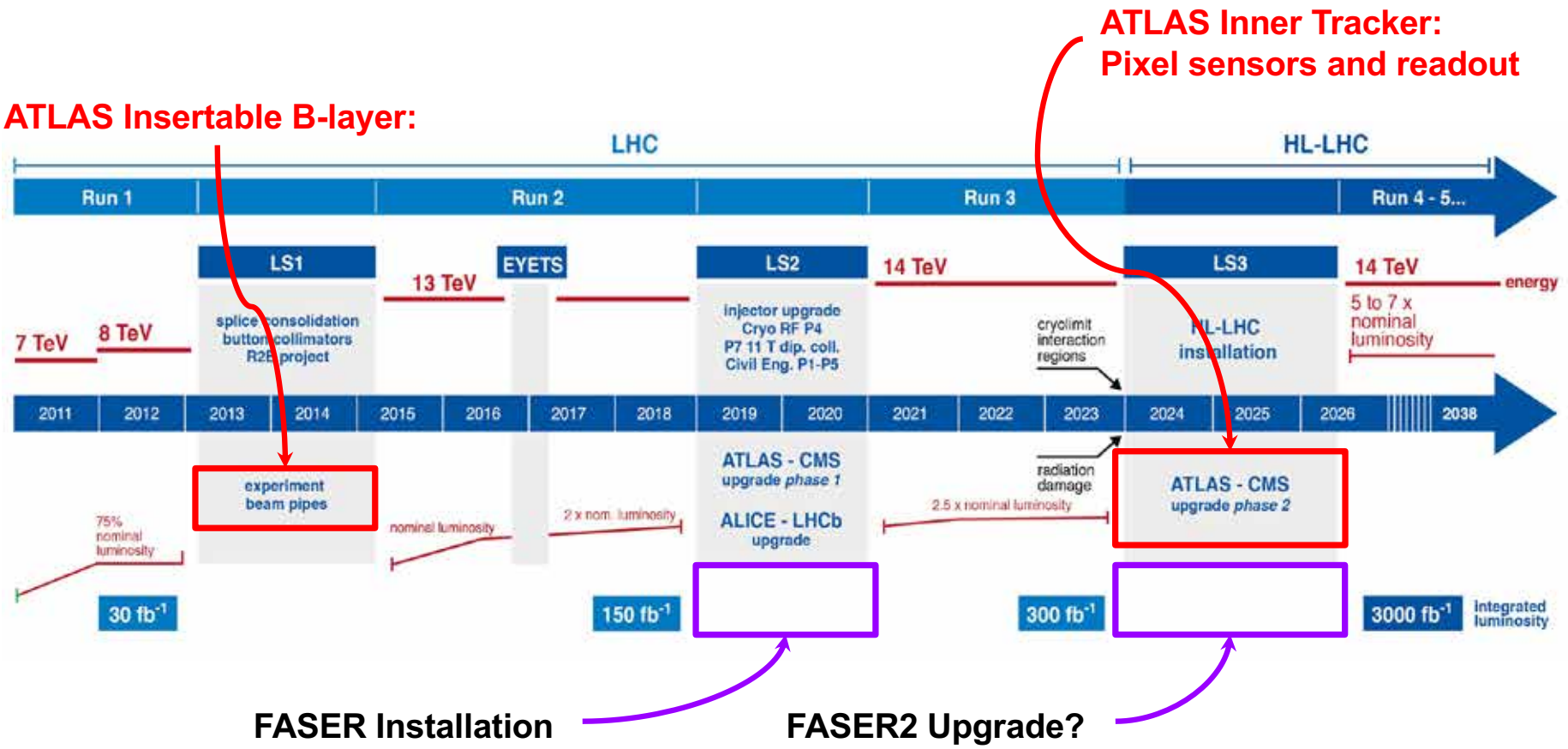
Direct *stop* pair with leptons and b-jets



***sbottom* pair with H (and b-jets)**



LHC upgrades and Bern involvement



Current Bern group hardware developments

Optoboard V0 prototype

Working on testing the complete readout chain in-house

03.05.2019 | News | Press release | CHIPP

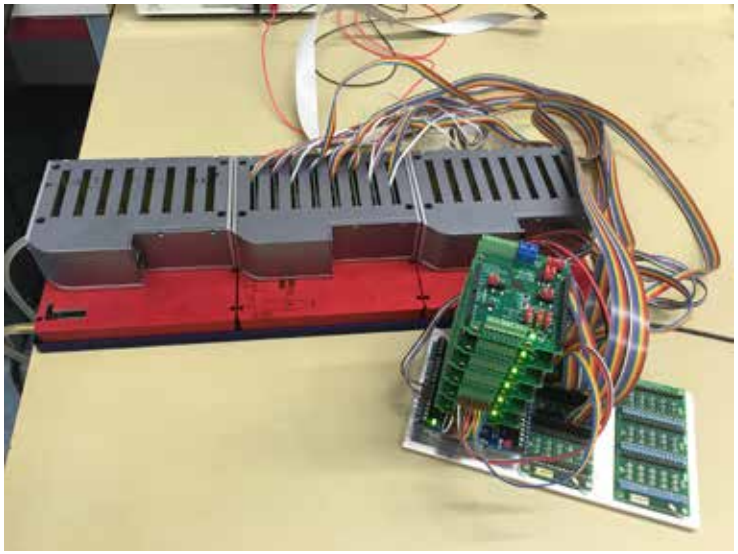
Every second fifty terabits of data

Junior Researcher Armin Fehr is working at the University of Bern on the upgrade of a large CERN experiment

Image: B. Vogel, CHIPP, Switzerland

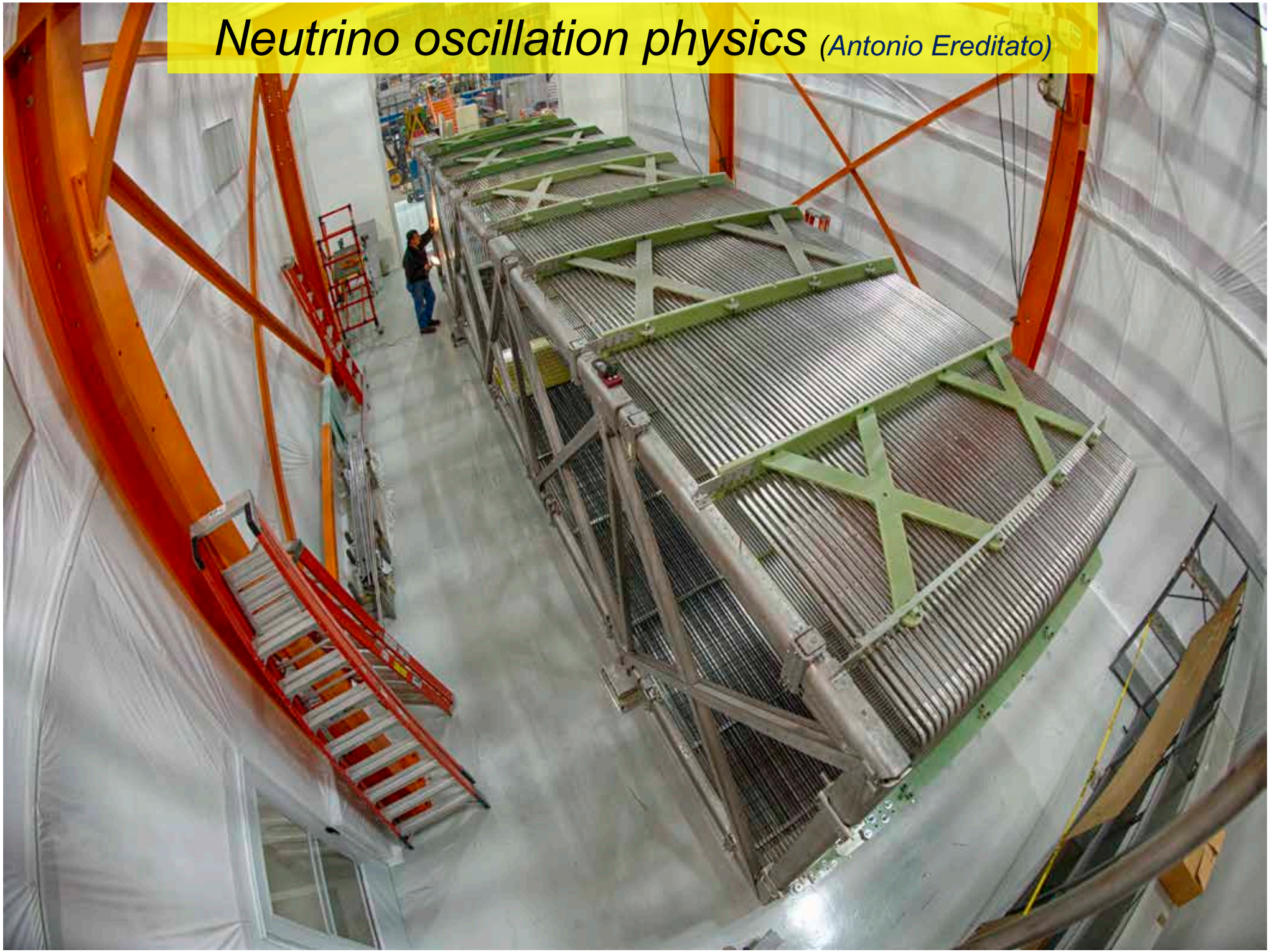
From 2026, the performance of the large-scale experiments at the European particle physics laboratory, CERN, in Geneva will be significantly increased. The preliminary work for the upgrade of the large particle accelerator LHC and the associated detectors is currently in full swing. An important contribution is made by the University of Bern, where doctoral student Armin Fehr (26) and his colleagues are working on a component for the ATLAS detector. This component will enable the read-out of the greatly increased data rates from 2026 onwards.

In the media: Articles on naturalsciences.ch and in Uniaktuell



Optobox prototype

Neutrino oscillation physics *(Antonio Ereditato)*



A look at past achievements

Featured in Physics | Editors' Suggestion

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Discovery of τ Neutrino Appearance in the CNGS Neutrino Beam with the OPERA Experiment

N. Agafonova *et al.* (OPERA Collaboration)
Phys. Rev. Lett. **115**, 121802 – Published 17 September 2015

Physics See Synopsis: OPERA Bags Fifth Tau Neutrino

18

More

ELSEVIER

Nuclear Physics B
Volume 908, July 2016, Pages 116-129

The discovery of the appearance of $\nu_\mu - \nu_\tau$ oscillations

Antonio Ereditato

Show more

https://doi.org/10.1016/j.nuclphysb.2016.03.014

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Featured in Physics | Editors' Suggestion

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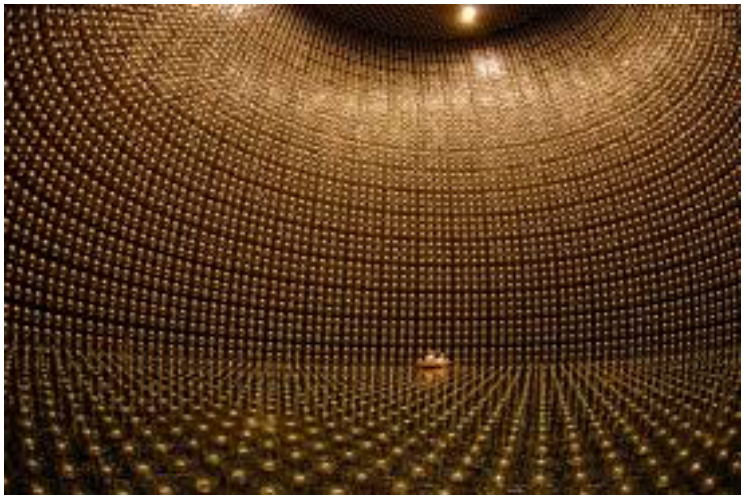
Observation of Electron Neutrino Appearance in a Muon Neutrino Beam

K. Abe *et al.* (T2K Collaboration)
Phys. Rev. Lett. **112**, 061802 – Published 10 February 2014

Physics See Viewpoint: Neutrino Experiments Come Closer to Seeing *CP* Violation

59

More



2016 Breakthrough prize in fundamental physics

“For the fundamental discovery and exploration of neutrino oscillations, revealing a new frontier beyond, and possibly far beyond, the standard model of particle physics”

The online magazine of the University of Bern

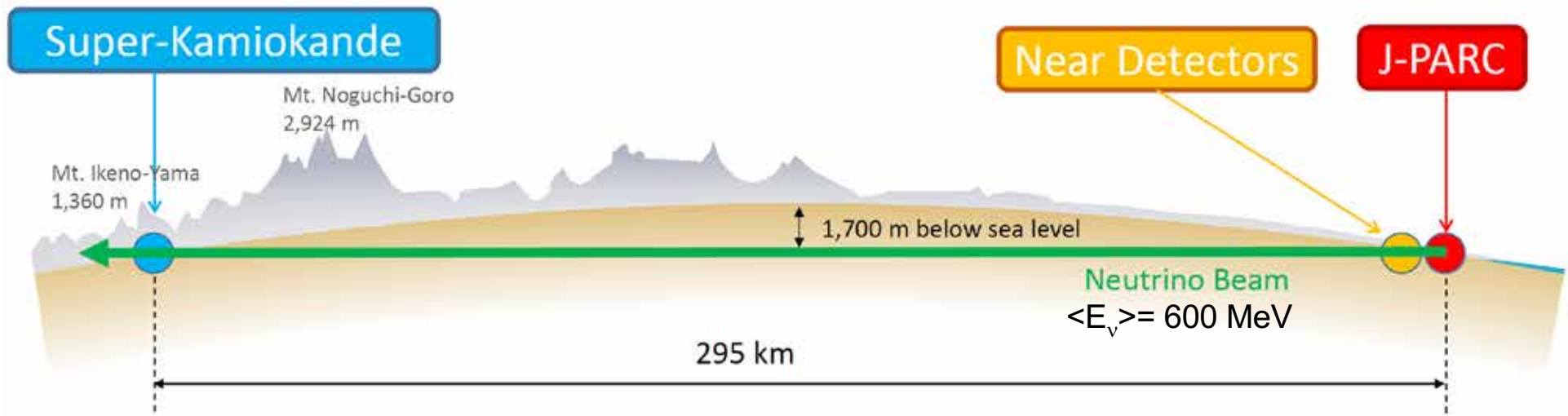
Colophon Tips

2017/12/01 | Tips | Environment & Matter

An Evening with Nobel Prize Winner Takaaki Kajita: The Mysteries of the Neutrino

On the occasion of the Dies academicus of the University of Bern on December 2, 2017, Takaaki Kajita will receive an honorary doctorate by the Faculty of Science. The night before the Dies academicus, Antonio Ereditato, Director of the Laboratory of High Energy Physics (LHEP) of the University of Bern, will talk with the Nobel Prize Winner Takaaki Kajita about the most fascinating among all elementary particles: the neutrino. The public event will take place on Friday, December 1, at 6 p.m. in the Aula of the Main Building at Hochschulstrasse 4.

The T2K experiment



Long-baseline accelerator neutrino oscillation experiment

Near detectors:

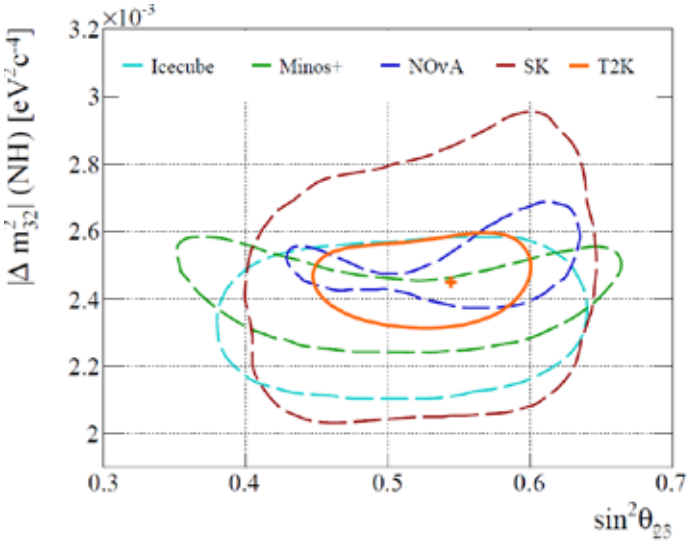
Constrain flux and cross-section model before oscillation

Cross-section measurements in unoscillated beam (Bern highlight)

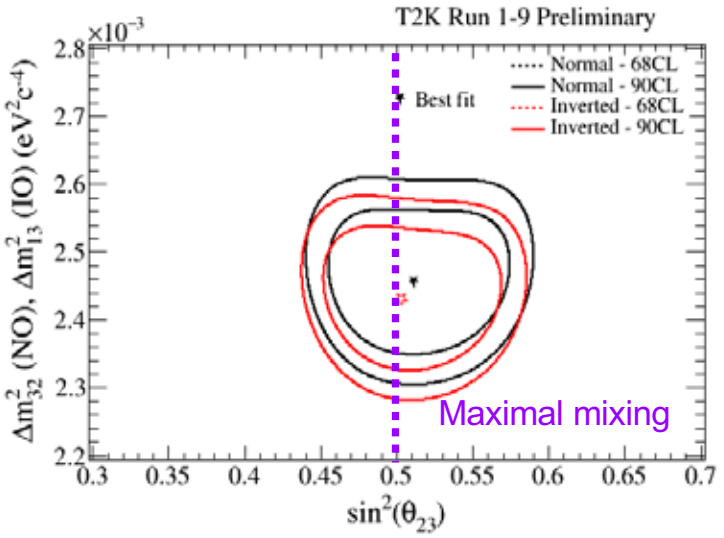
Far detector:

Oscillation analyses

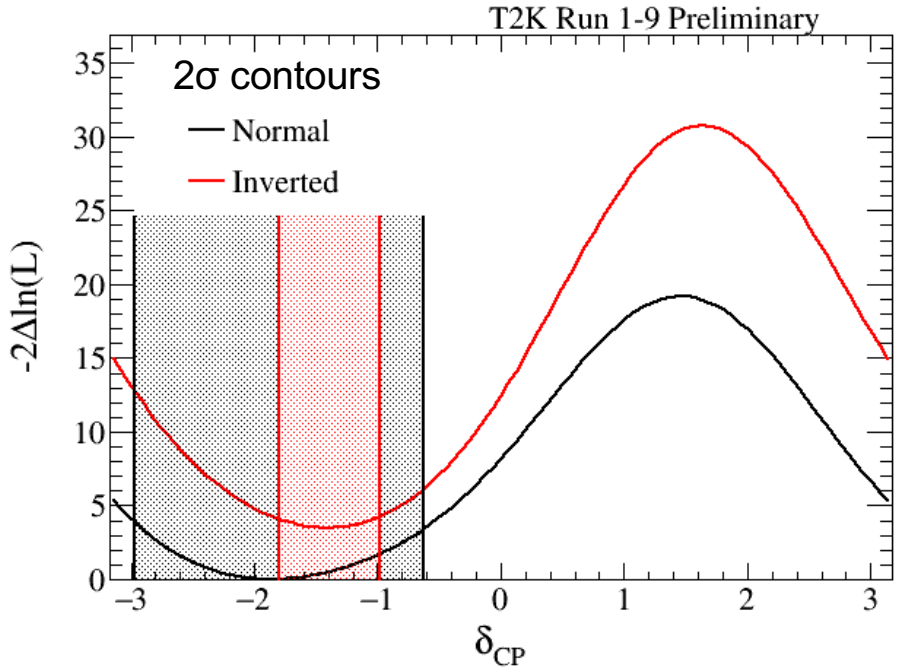
Latest T2K results



World leading θ_{23} measurement…

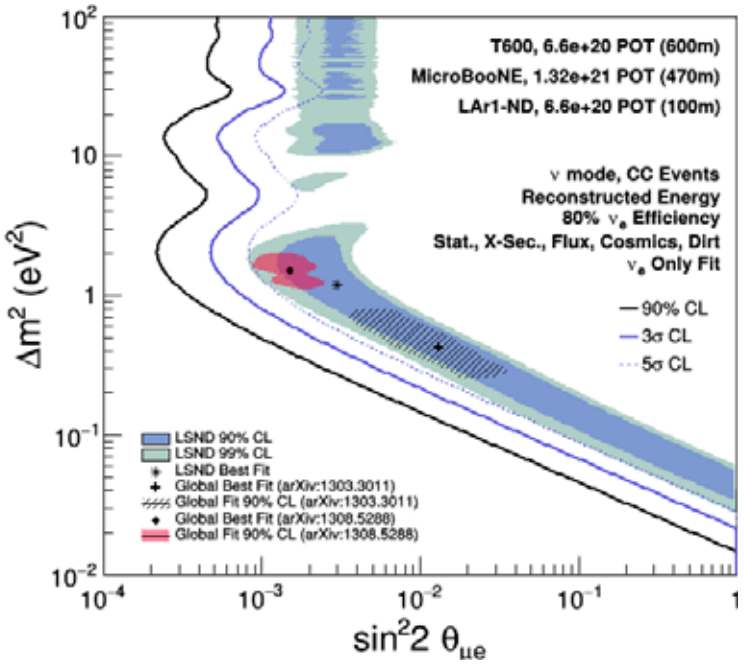


…consistent with maximal mixing



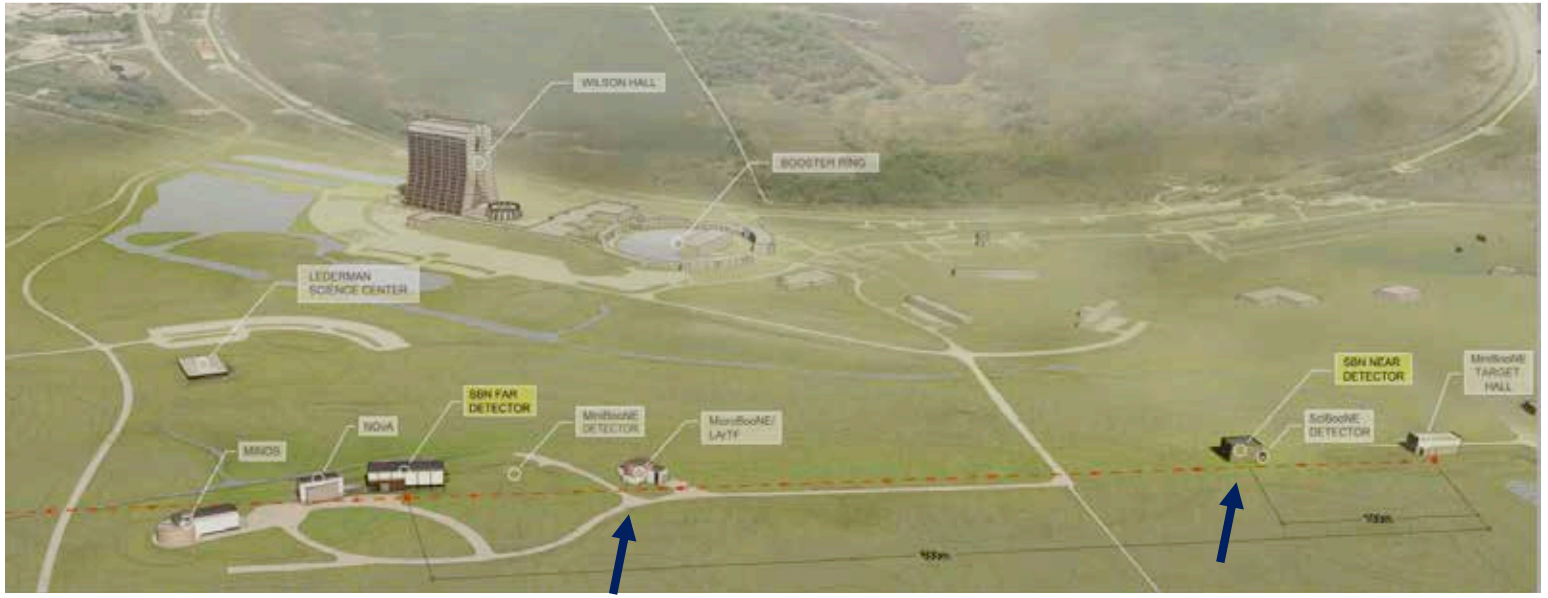
Increasingly strong exclusion of CP conservation (δ_{CP} = 0,π)

The MicroBooNE and SBND experiments



- Sterile neutrino puzzle
- Assess background/signal nature of the events (MicroBooNE) + detailed study of the potential signal (SBND)
- Large 170 ton mass liquid argon TPC in the Booster neutrino beam

- Recognition of Bern expertise with LAr TPCs
- Management and coordination roles + visible contributions



MicroBooNE

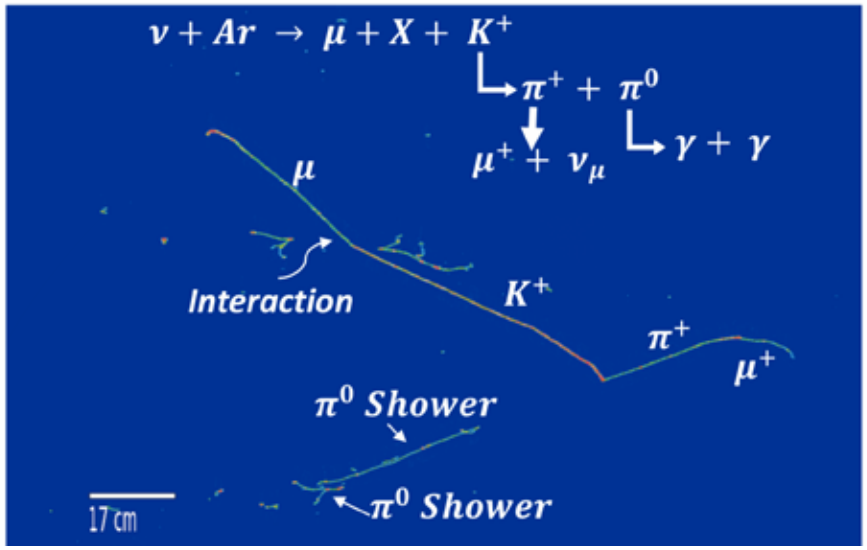
SBND

MicroBooNE

- Large statistics since (2015 first run): 13.4 x 10^{20} pot (already twice as many w.r.t design)
- Blind oscillation analysis: “opening the box” tuned to NEUTRINO20 Conference in Chicago
- Scientific record:

~ 20 physics publications + 20 technology papers, 15 PhD theses + as many in progress.

- 180 scientists from 31 international institutions

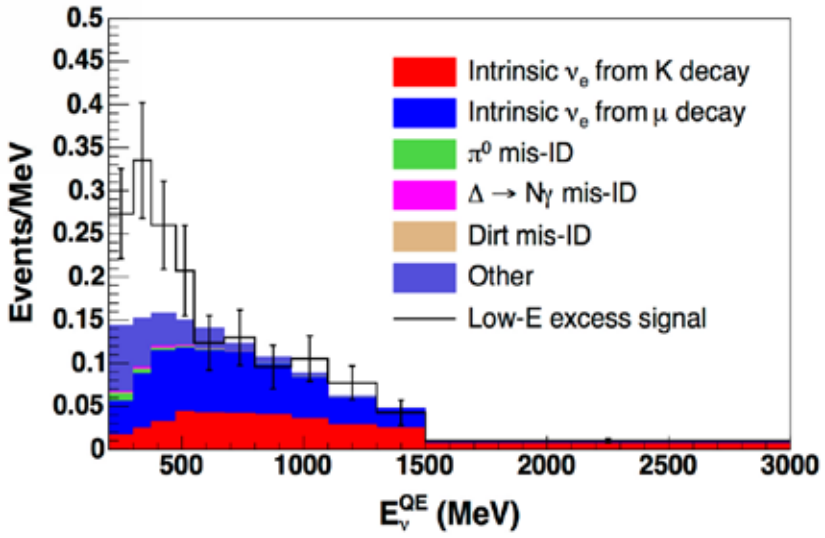


$\nu_\mu + Ar \rightarrow \mu^- + K^+\Lambda^0$

$K^+ \rightarrow \pi^+ \pi^0$
$\Lambda^0 \rightarrow n \pi^0$

Example of the imaging features of the detector for exclusive channels

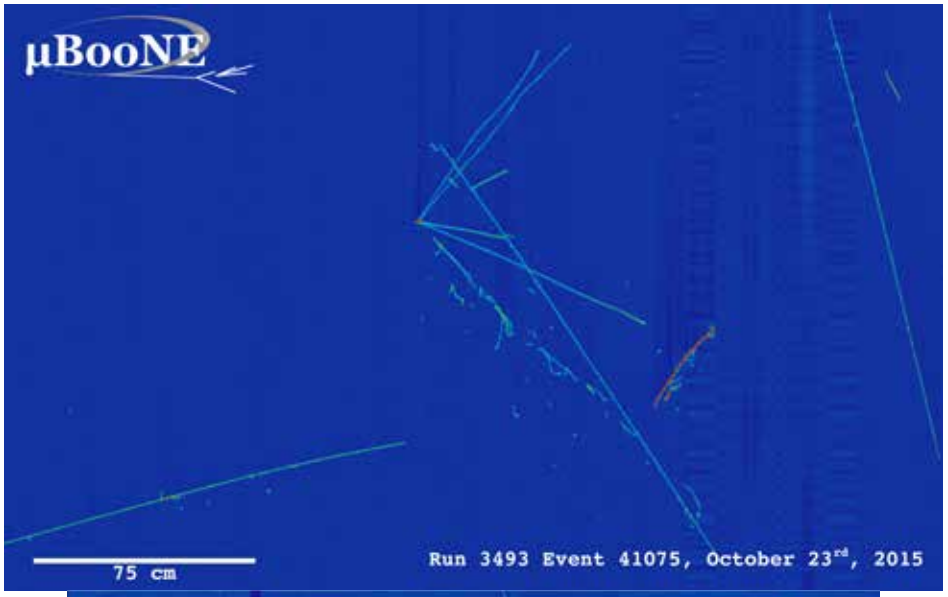
Sensitivity

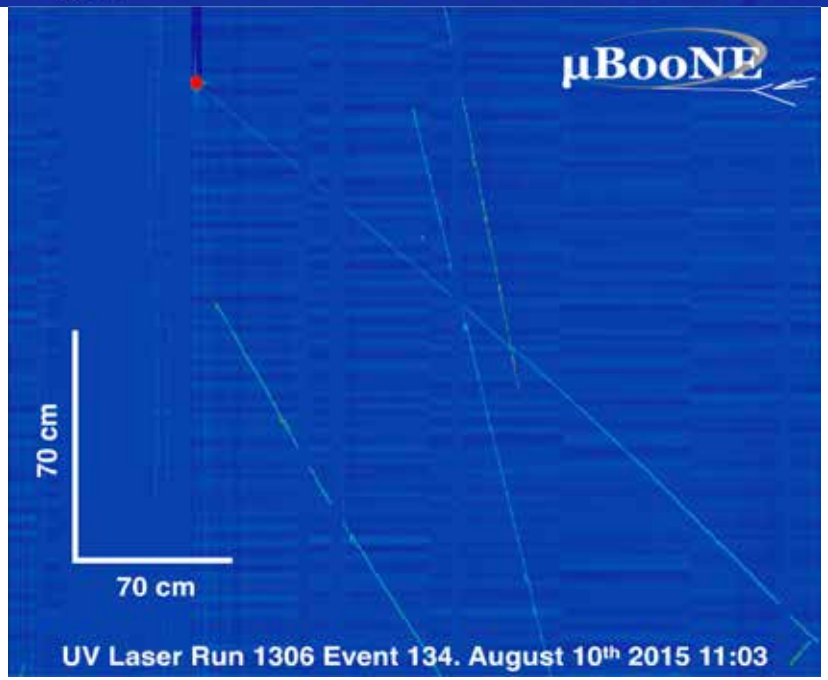


MicroBooNE: Bern hardware highlights

Cosmic-ray tagger (CRT) system ~200 m^2

Both systems, designed, funded and built (in house) by the Bern group

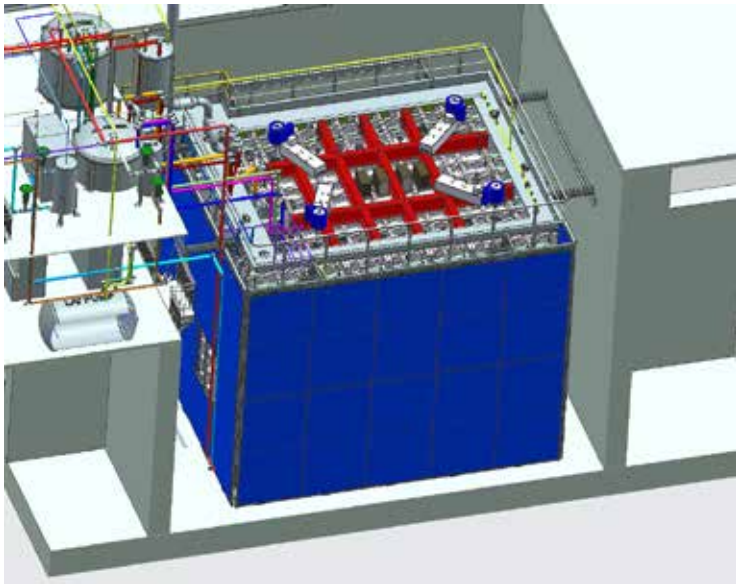




UV-laser system

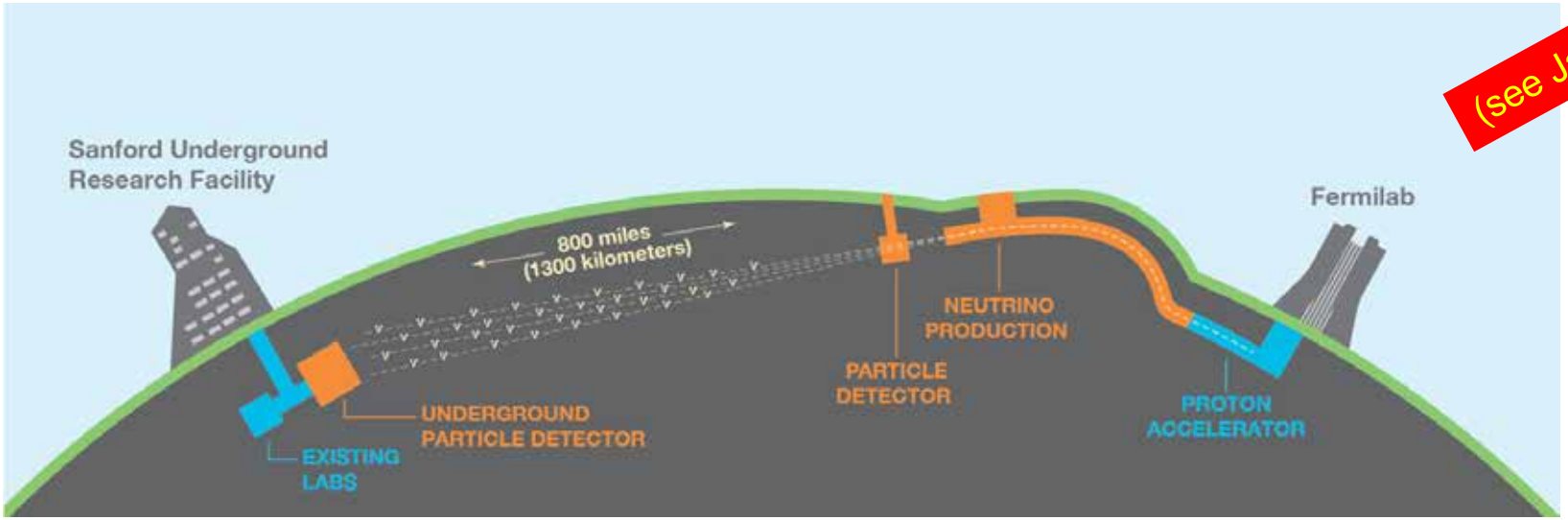
SBND

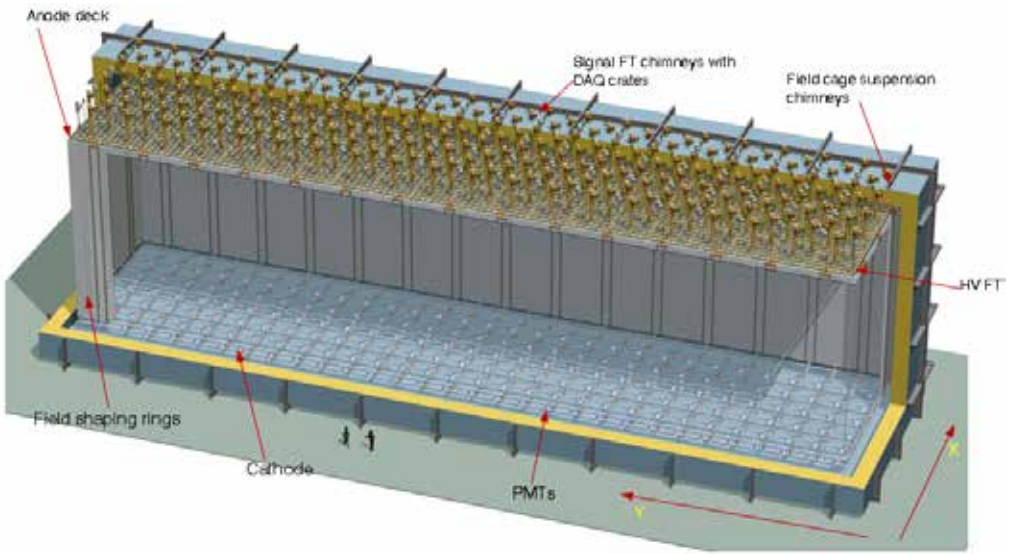
- Measure unoscillated ν flux + high-statistics cross sections
- Large LAr TPC: 112 tons active volume
- 37 international institutions; start data taking 2020
- Bern contributions, as for MicroBooNE: 450 m^2 *CRT's* and 4 advanced UV-laser systems



The LBNF/DUNE project

(see James Sinclair's talk)





Deep Underground Neutrino Experiment (DUNE):

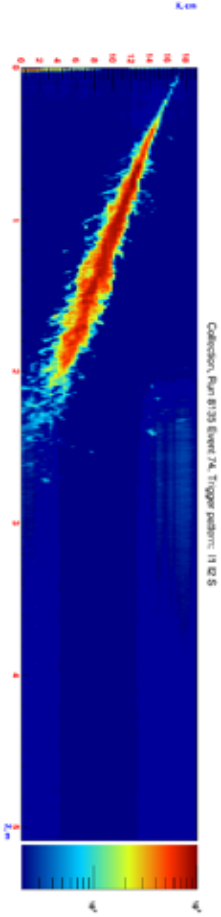
- Ultimate neutrino observatory for neutrino, astroparticle and matter stability physics.
- Large international project: > $2B, >1000 people, 180 institutions from 30 countries. Data taking by 2027.
- Two neutrino detectors placed in the world's most intense neutrino beam: near detector at Fermilab, far detector (40 kton LAr TPCs) at the underground Sanford Underground Research Laboratory in Lead, South Dakota — 1300 kilometers from the source.
- Groundbreaking for the LBNF excavation and construction at Sanford Lab occurred on July 21, 2017.

DUNE: Bern highlights

- Seminal role in 2014: Interim International Executive Board
- Visible and recognized role of the Bern group
- Original scientific initiative for the near detector LAr TPC

From the ArgonTube…

2006

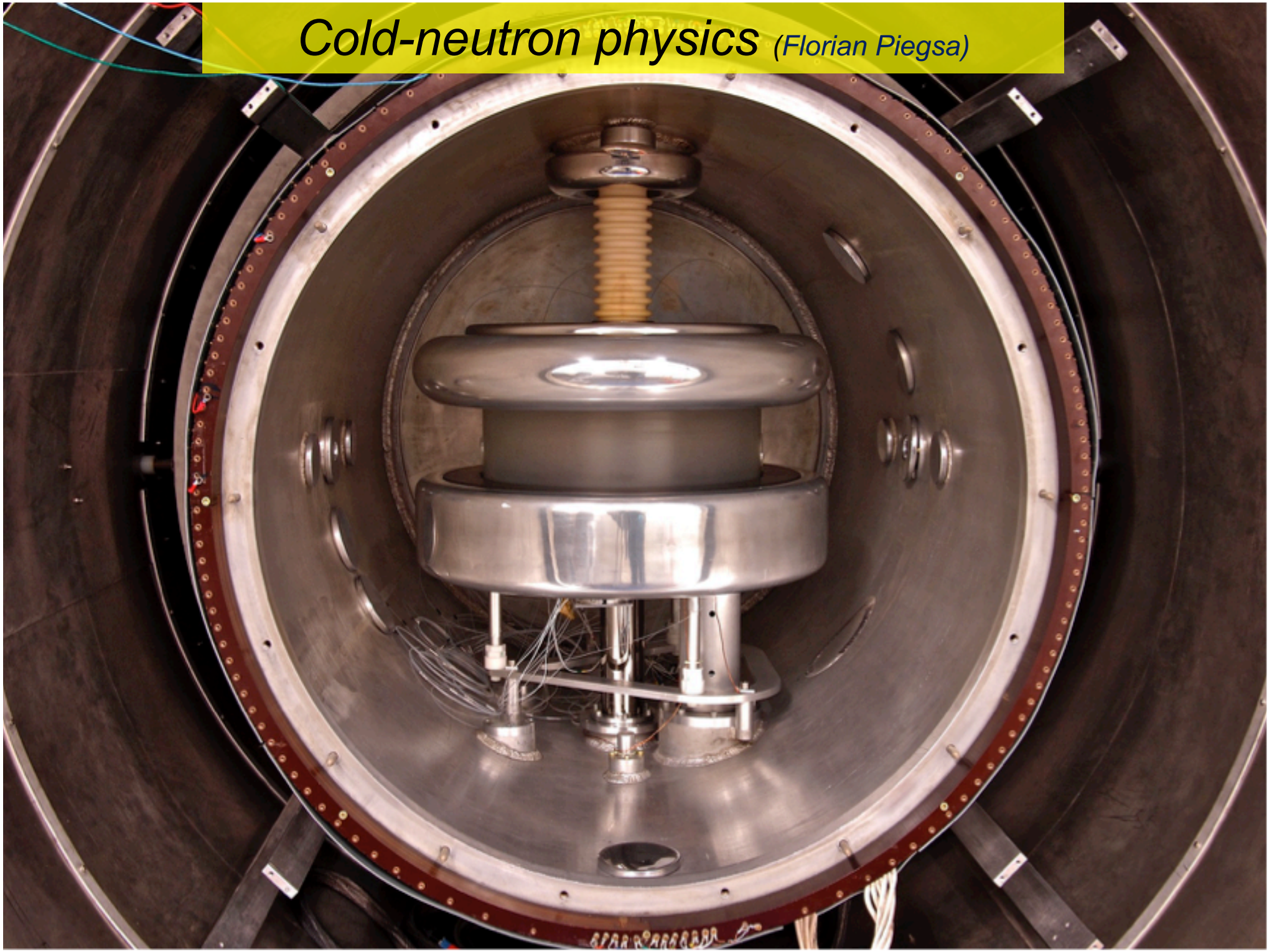


2016

To the ArgonCube…

Bern, Grosslabor, 2019

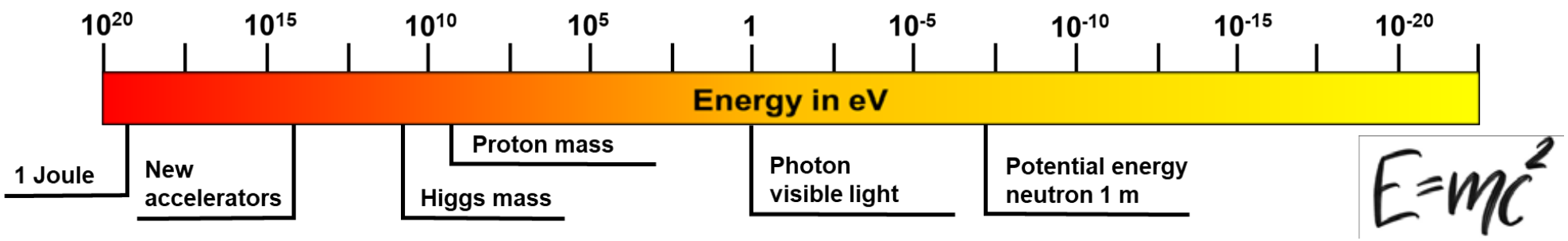
Cold-neutron physics *(Florian Piegsa)*



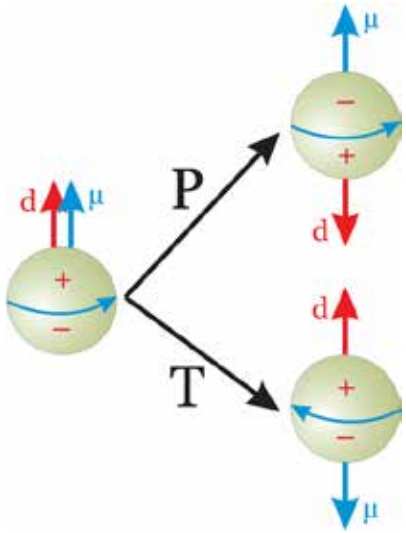
nEDM experiments

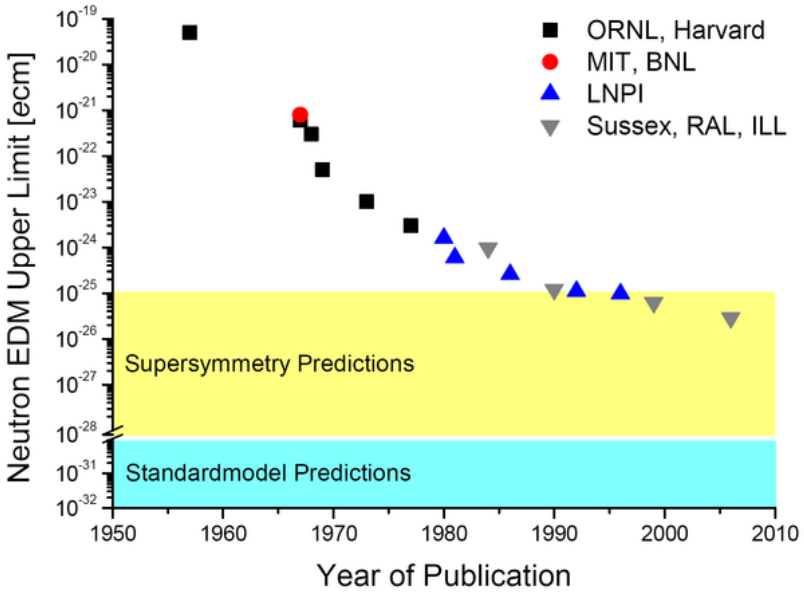
(see Ivo Schulthess' talk)

High Energy Physics	Low Energy Physics
Direct production of new particles via collisions at high energy	Precision searches for anomalies at low energies



The electric dipole moment of the neutron as a probe for new physics





Experimental method:

measure Larmor precession of neutron spins

Current upper limit 3 × 10^{-26} e cm

Bern activities

- Ultracold neutrons @ PSI: complete nEDM and start n2EDM experiments
- Pulsed cold neutron beam @ Bern (new idea) meant for the European Spallation Source

Related research

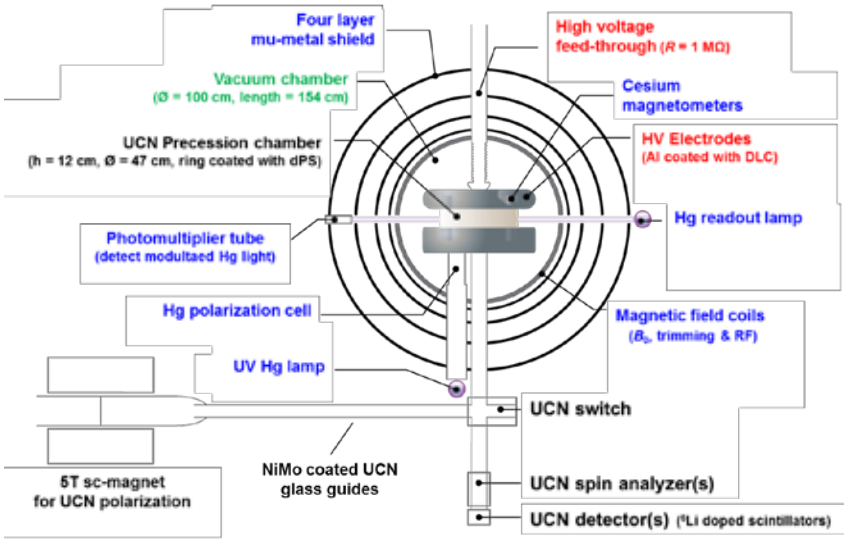
- Q-neutron: measurement of the neutron charge

nEDM

Final results end 2019
(sensitivity at the 10^{-26} level)

n2EDM

Commissioning 2020
(x10 sensitivity increase)



New approach: pulsed cold neutron beam
(Piegsa, PRC 88, 045502, 2013)

FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

erc
European Research Council
Established by the European Commission

- The new concept is ideal for pulsed neutron spallation sources, e.g. at the European Spallation Source – proposed ANNI beam line
- Start with proof-of-principle experiments at PSI and Institute Laue-Langevin
- Aim at higher sensitivities (10^{-27})

Side project carried out at the polarized cold neutron beamline BOA (Beamline for neutron Optics and other Applications), at the Swiss Spallation Neutron Source (SINQ) at the PSI

Micrometric space resolution in imaging B fields and gradients

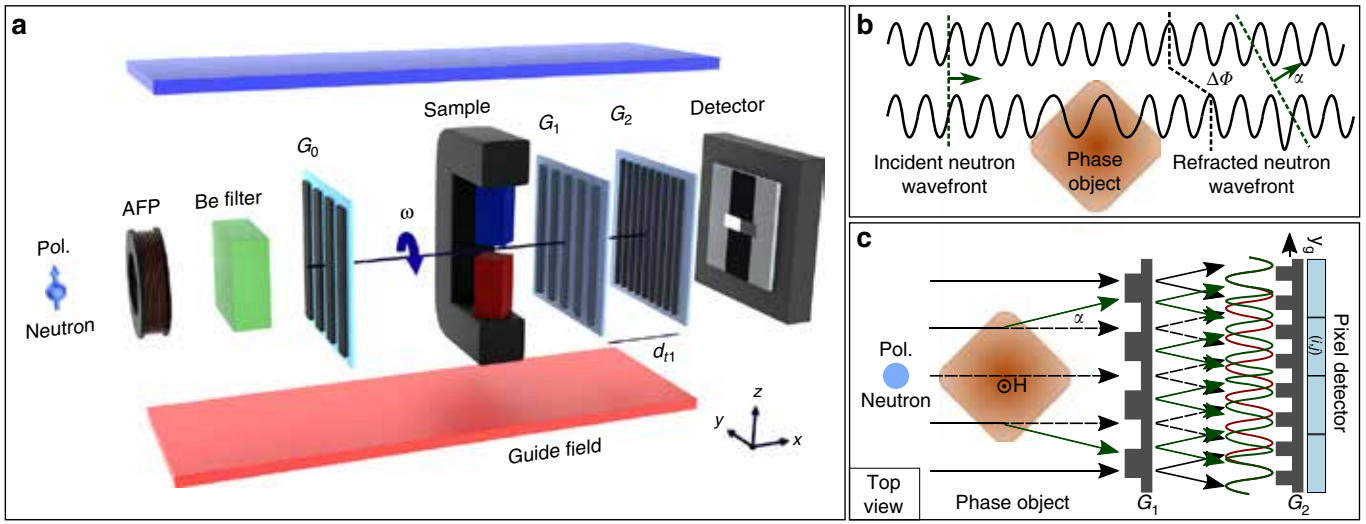
nature COMMUNICATIONS

ARTICLE

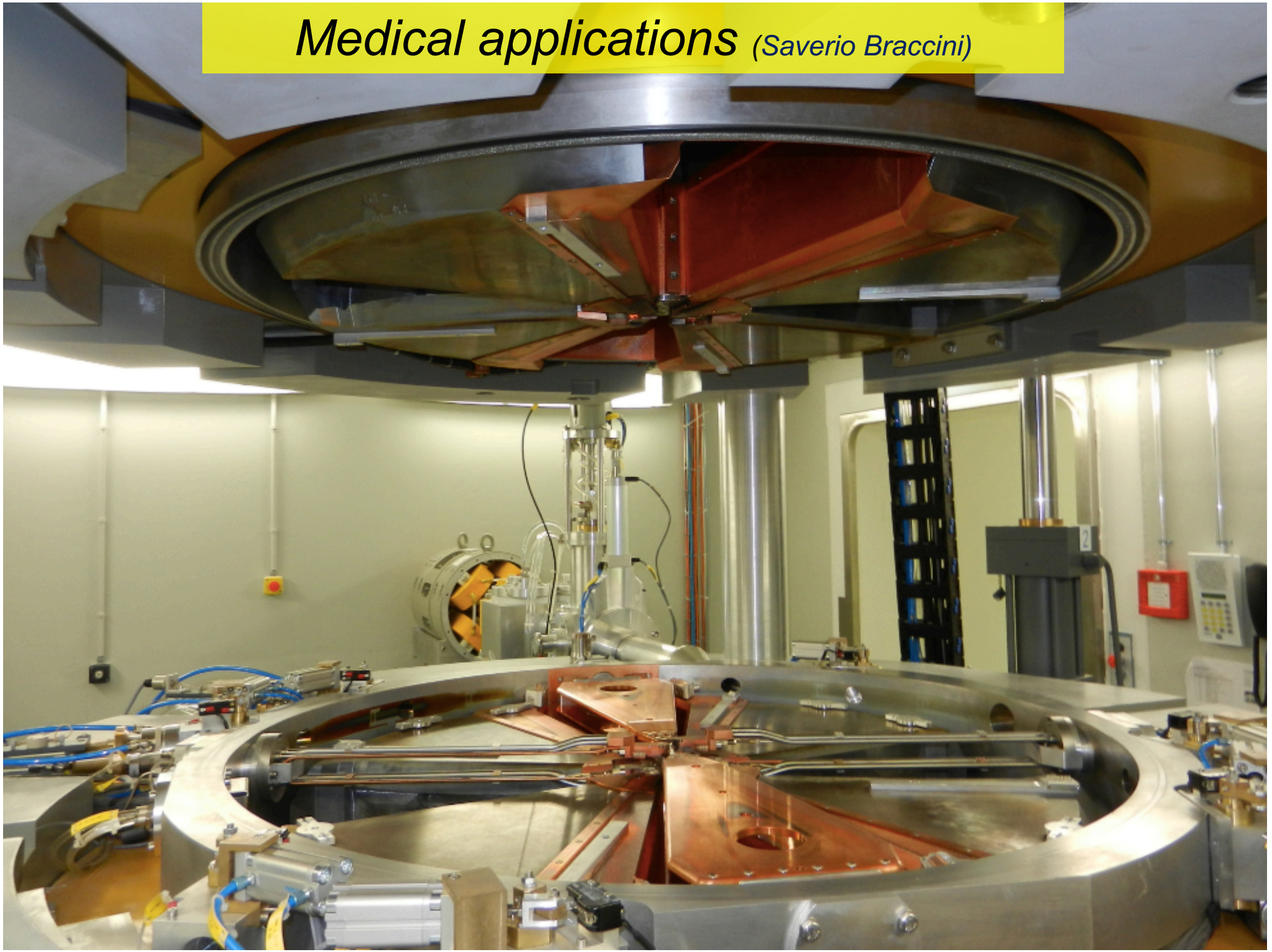
https://doi.org/10.1038/s41467-019-11590-2 OPEN

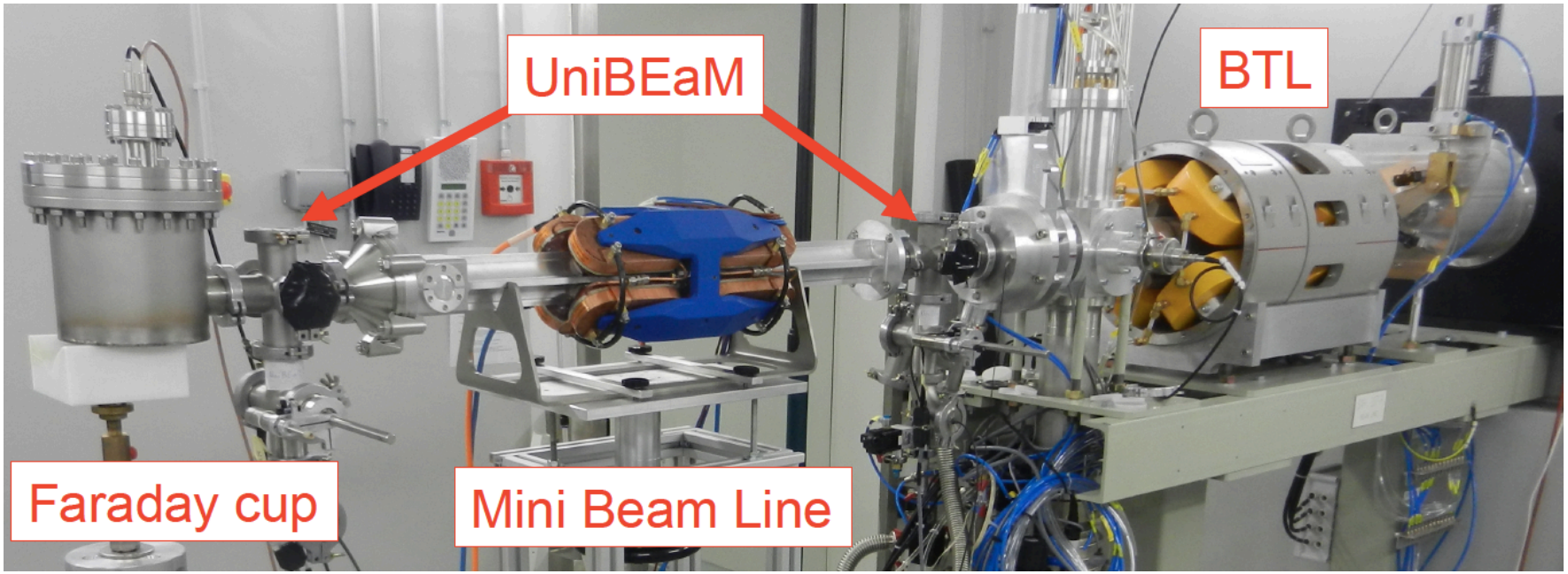
Visualization and quantification of inhomogeneous and anisotropic magnetic fields by polarized neutron grating interferometry

Jacopo Valsecchi[1,2], Ralph P. Harti[1,2], Marc Raventós[1,2], Muriel D. Siegwart[1,3], Manuel Morgano[1], Pierre Boillat[1,3], Markus Strobl[1,4], Patrick Hautle[5], Lothar Holitzner[5], Uwe Filges[5], Wolfgang Treimer[6], Florian M. Piegsa[7] & Christian Grünzweig[1]



Medical applications *(Saverio Braccini)*

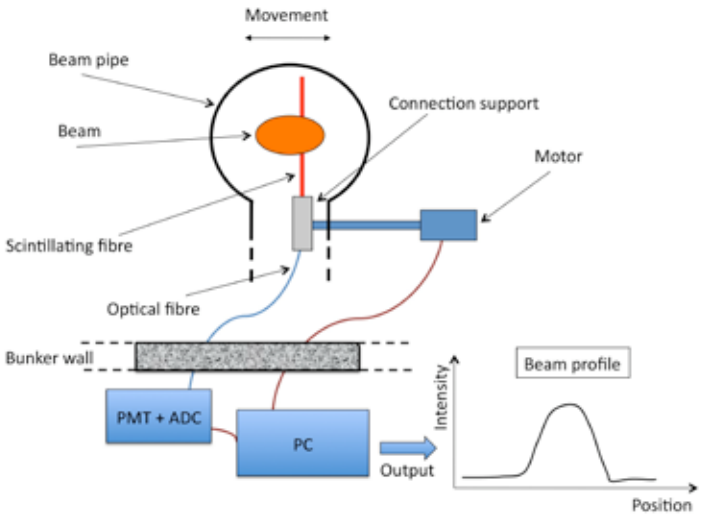




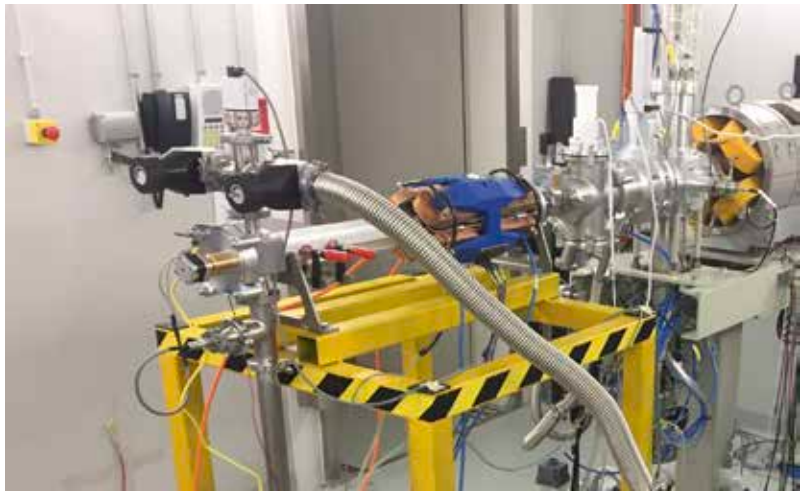
- The medical application activities are centred on the University Hospital Cyclotron: IBA 18 MeV “twin” (two H^- ion sources) high current (150 μA)
- Beam line + separate bunker for production and research
- Irradiation facility for ATLAS and other clients
- > 10 years experience, almost unique in Europe, lots of scientific, technological and educational results

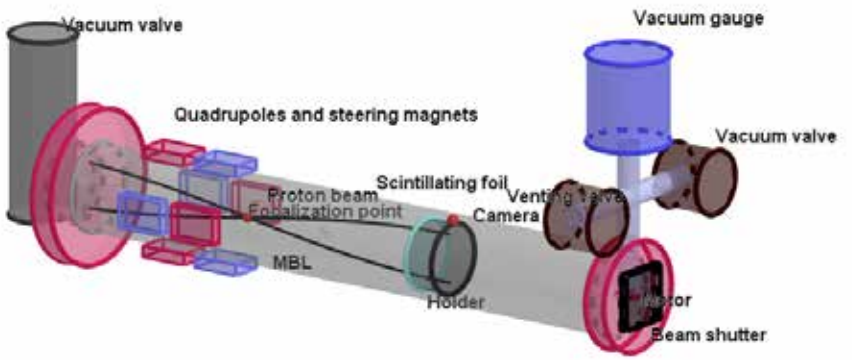
A few examples

UniBEaM



First 3D monitoring detector



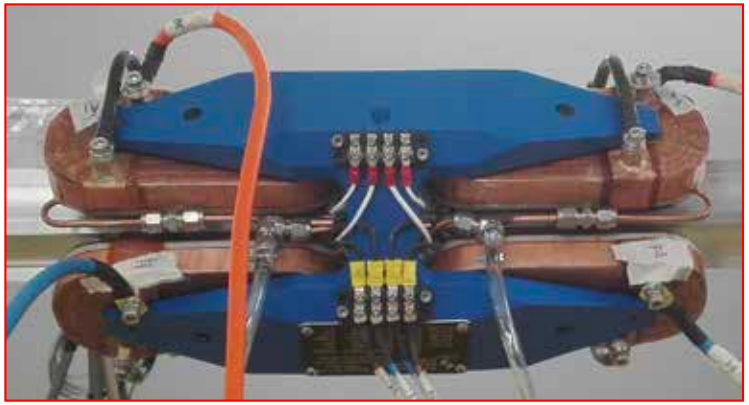


Radioisotopes for theranostics (in collaboration with PSI)

Isotope	Reaction	Target material	Current [μA]	Time [h]	A_{EOB} [GBq]
^{44}Sc	(p,n)	^{enr}CaO pellet	5	5	~15
^{64}Cu	(p,n)	^{enr}Ni electrodeposition	15	10	~20
^{68}Ga	(p,n)	^{enr}Zn pellet	5	0.5	~15
^{48}V	(p,n)	Ti metal disc	10	1	~0.15
^{165}Er	(p,n)	Ho metal disc	10	10	~1.5

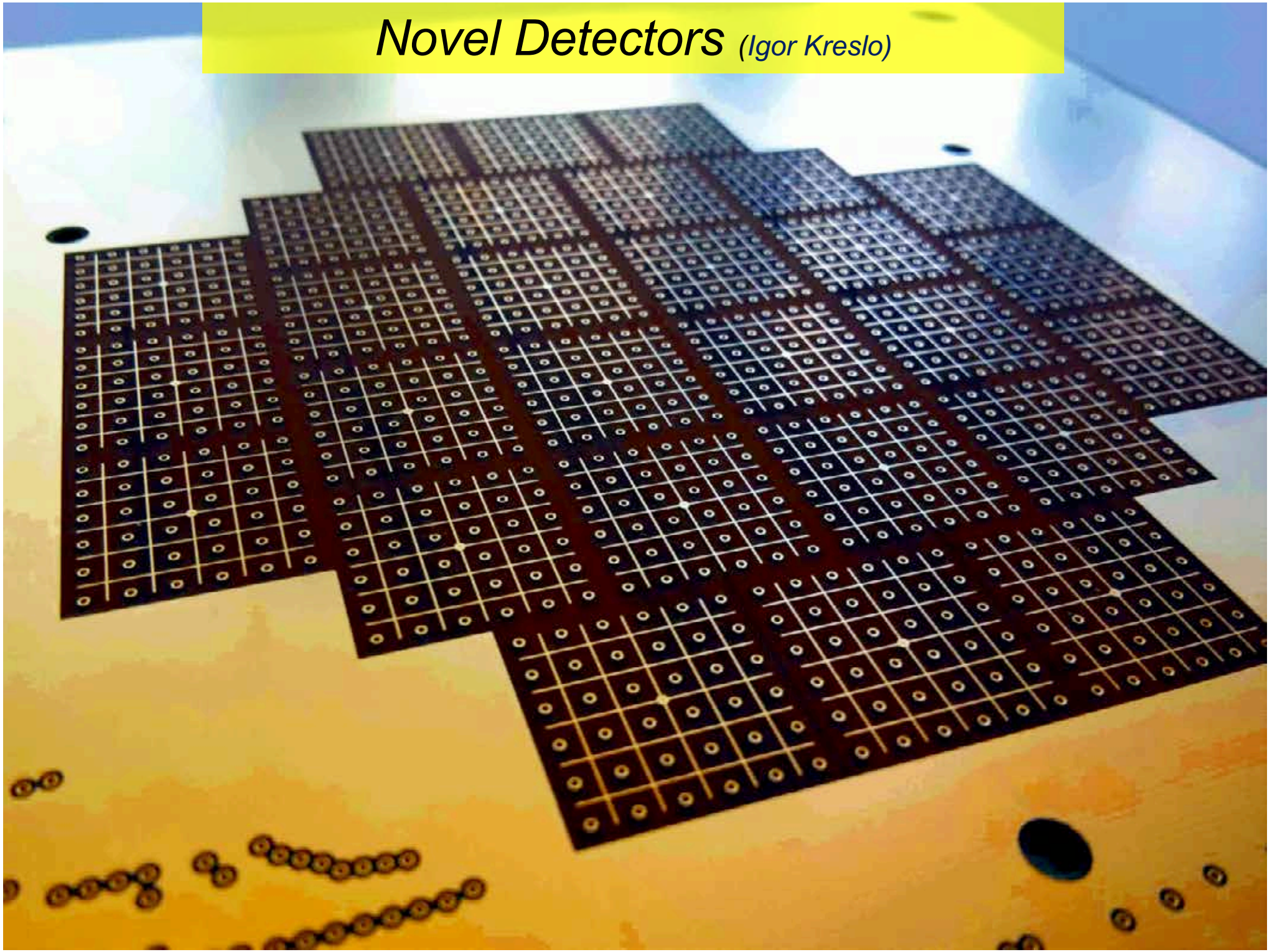
Example: ^{44}Sc: ~15 GBq in 5 hours (world record)

Further development



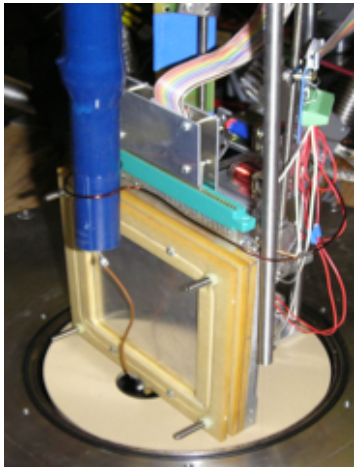
- Compact 40 cm long, 54 kg) MiniBeamLine (D-Pace, Canada)
- Quad doublet + XY steering in a single magnet
- active irradiation system to enhance performance of solid targets

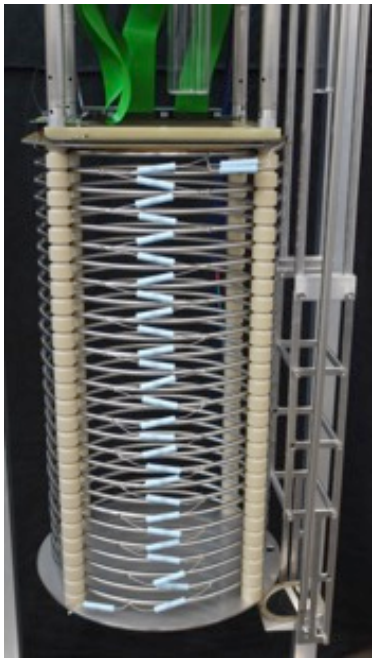
Novel Detectors *(Igor Kreslo)*



Cryogenic TPCs

Long standing research, which followed a graded strategy over >10 years:





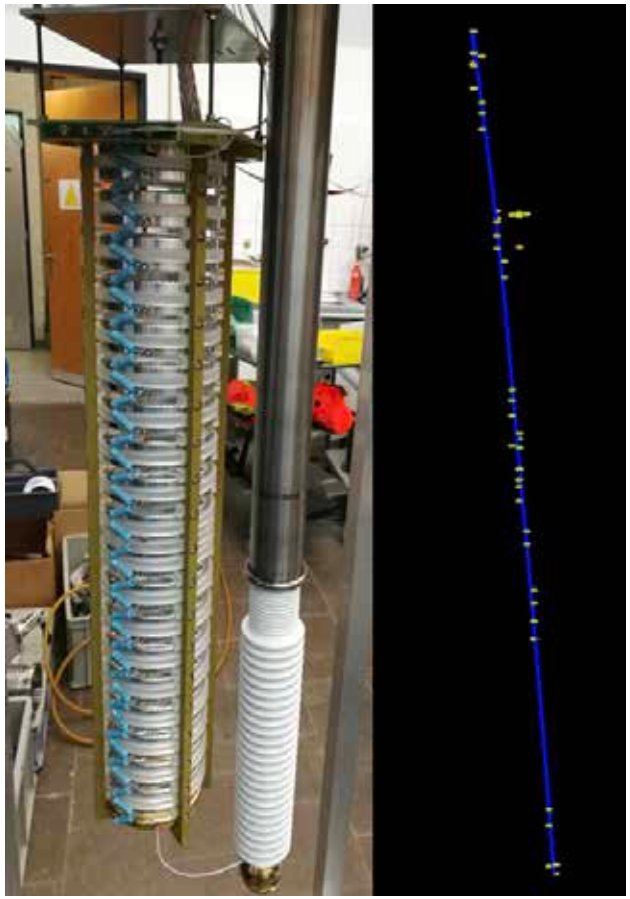
…and now, finalizing R&D effort to DUNE

novel idea of the Bern group:

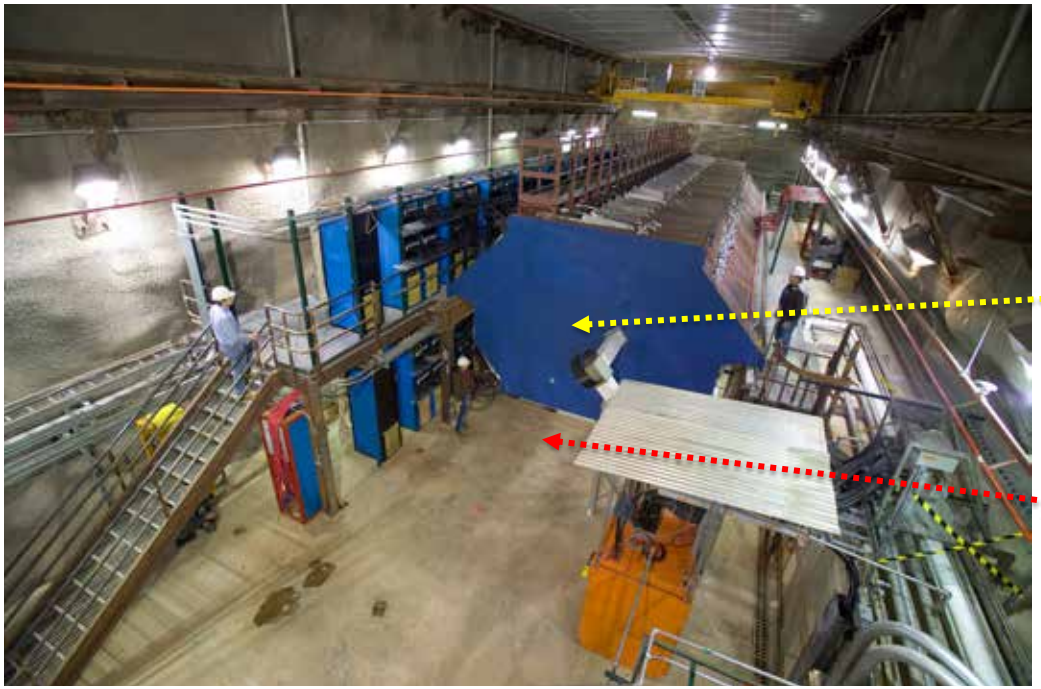
replace wires by printed board pixels

for charge readout

ArgonCube technique for the DUNE ND

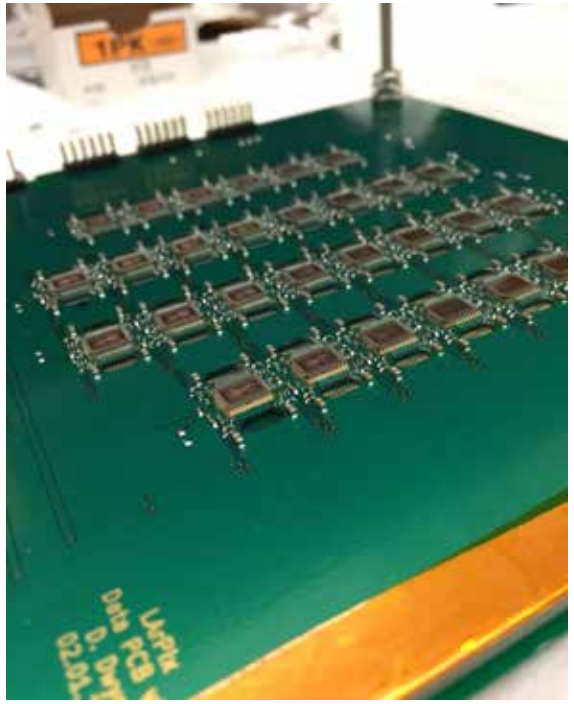


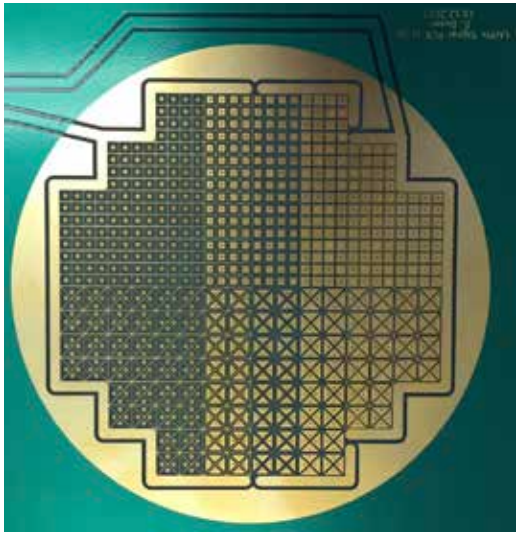
→ 2020: install the ArgonCube 2x2 demonstrator on the Fermilab NuMI beam



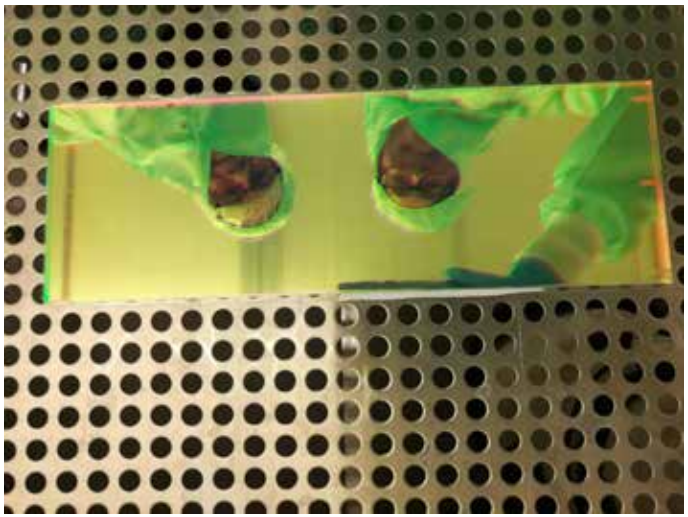
Related R&D

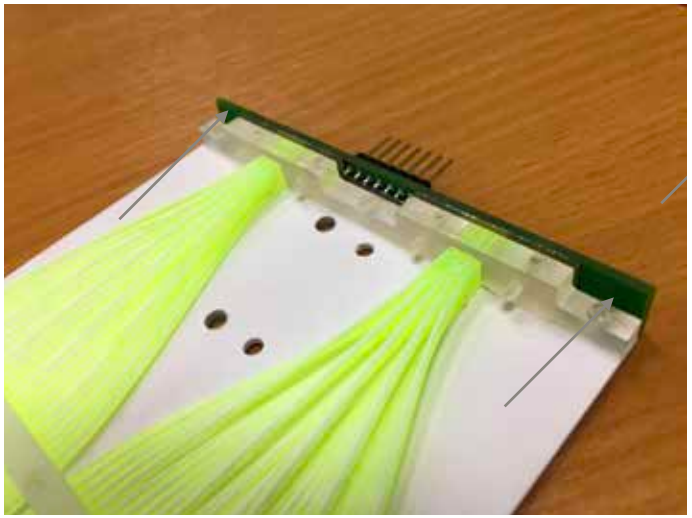
Pixel readout electronics





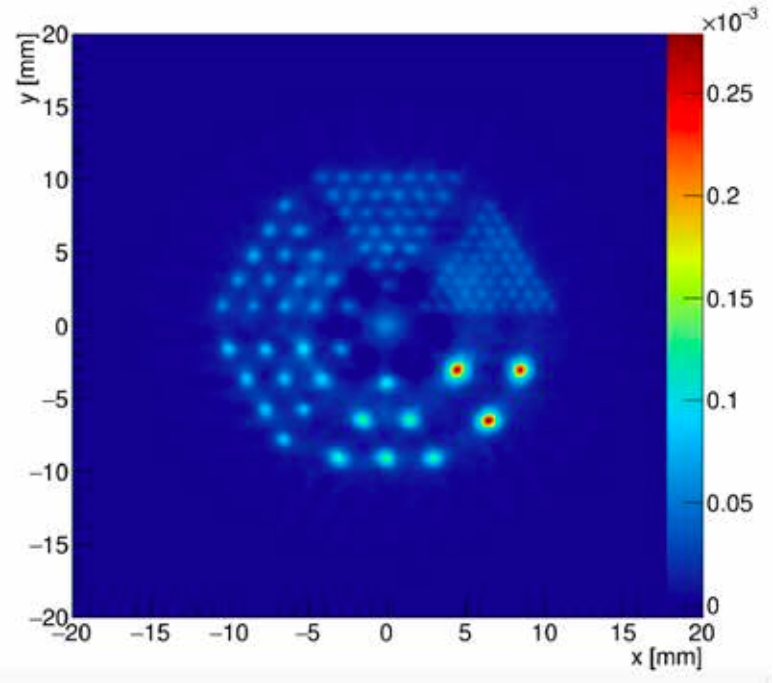
Novel LAr scintillation light readout schemes

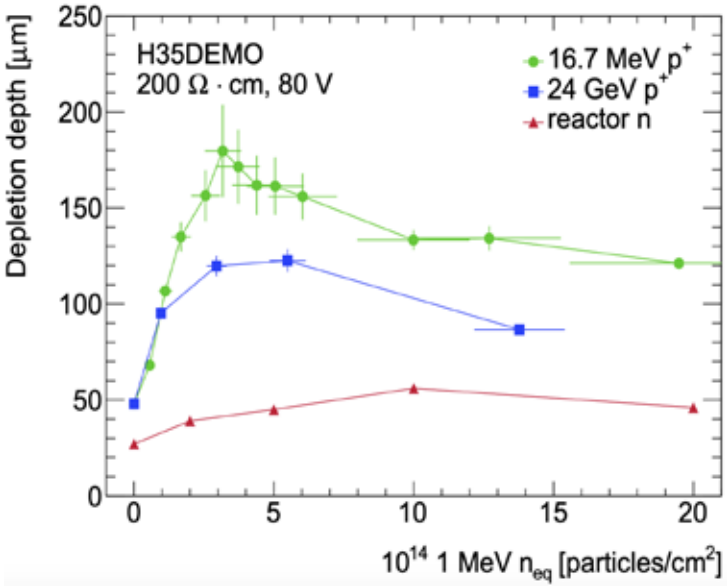




TT PET

- ATLAS spinoff
- Proof of concept for a small animal PET scanner, integrated in MRI, that uses ToF technology (goal 30 ps time resolution).
- Bern: readout development, data collection (^{90}Sr source and cyclotron with ^{18}F, test beam with pions) and data analysis.



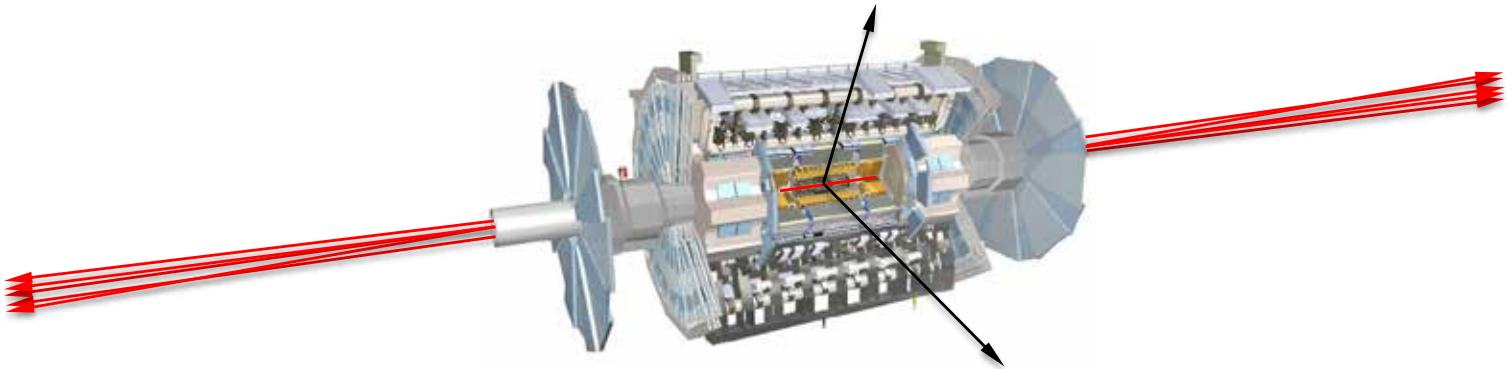


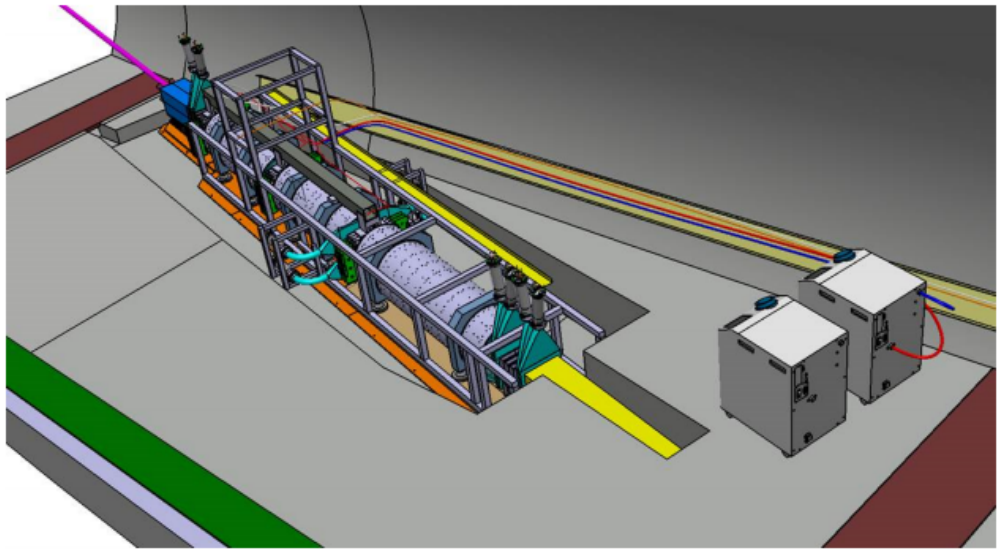
J. Anders *et al* 2018 *JINST* **13** P10004

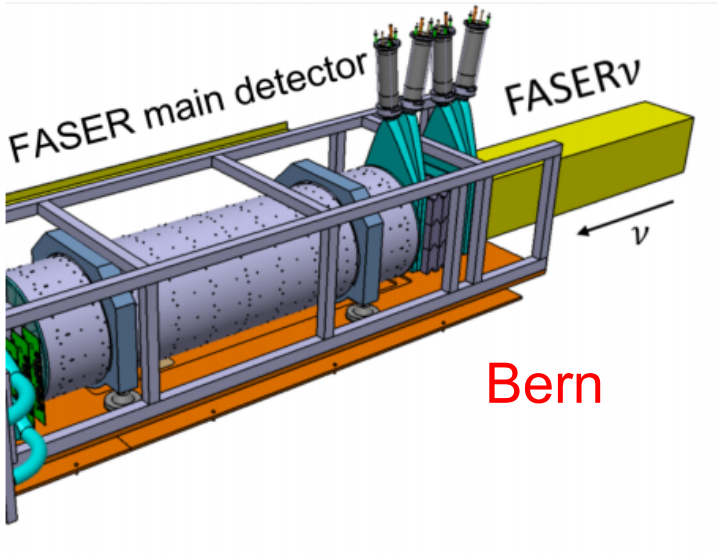
Interdisciplinary & various projects

FASER experiment at CERN

- Search for very forward particles at the CERN LHC
- Long-lived exotics: e.g. dark photons; known physics: first neutrino detection at the LHC
- Approved March 2019. First beam 2021.
- FASERν (Bern interest) https://arxiv.org/abs/1908.02310

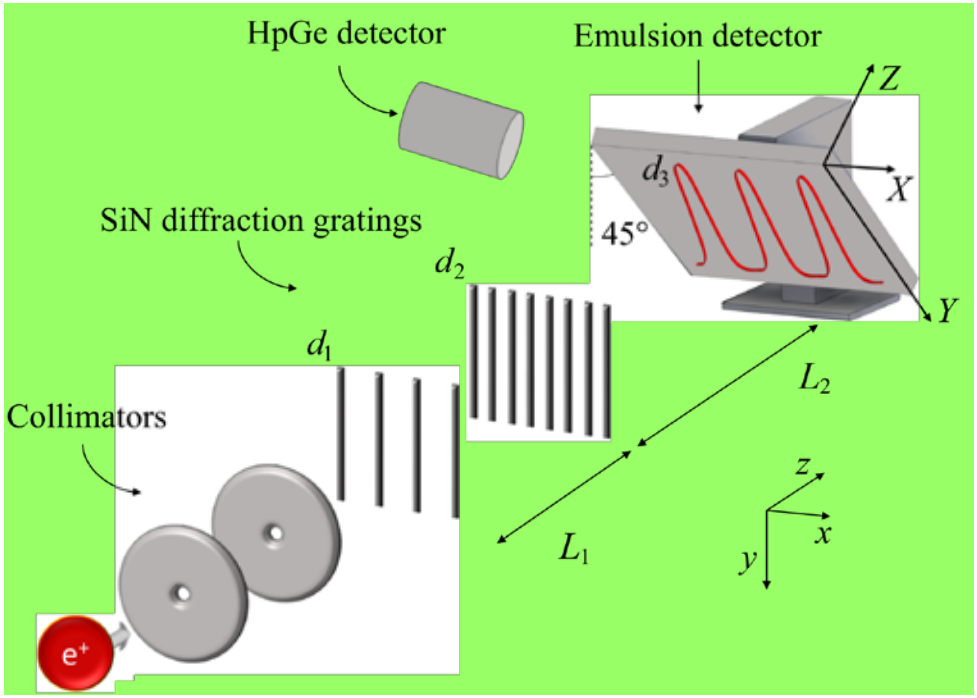


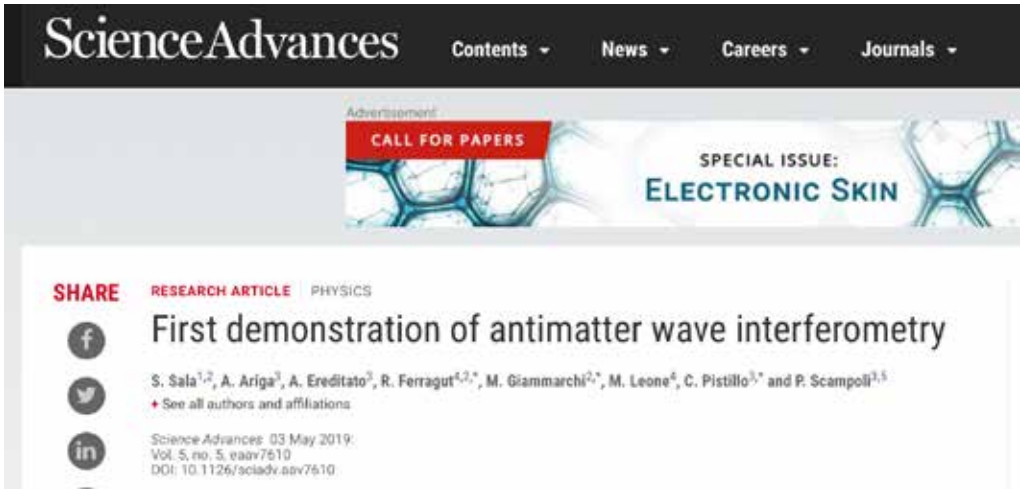




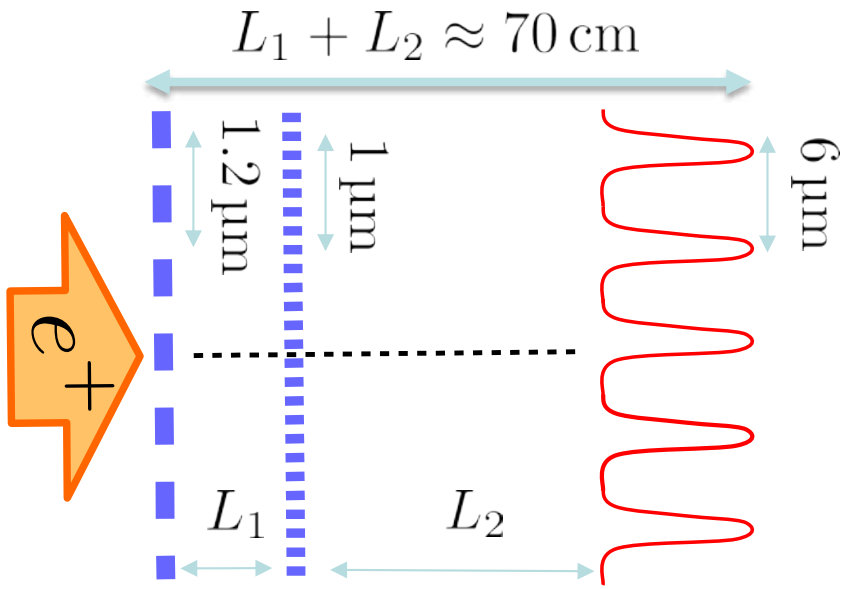
QUPLAS: antimatter interferometry

- First evidence for antimatter quantum interferometry
- Crucial: Talbot Laue + custom emulsion films (Bern responsibility)
- 8-16 keV single positron beam: 10 ms average time between consecutive positrons, time through the interferometer
- Bern funding exclusively from AEC



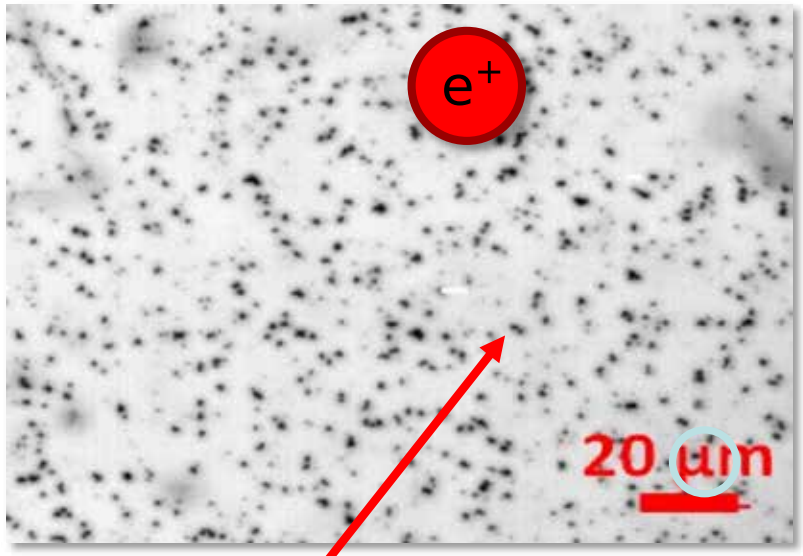


The experimental method



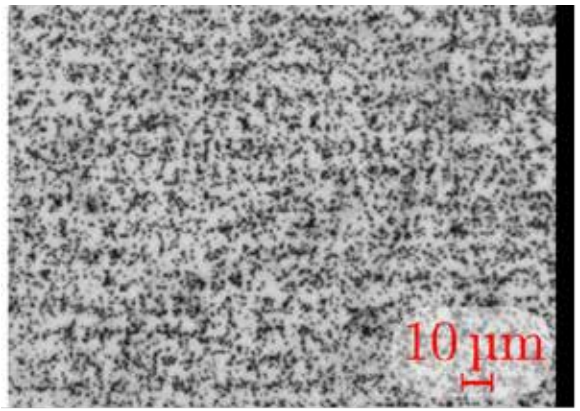
«Asymmetric», period-magnifying Talbot- Lau interferometer

Sub-μm resolution

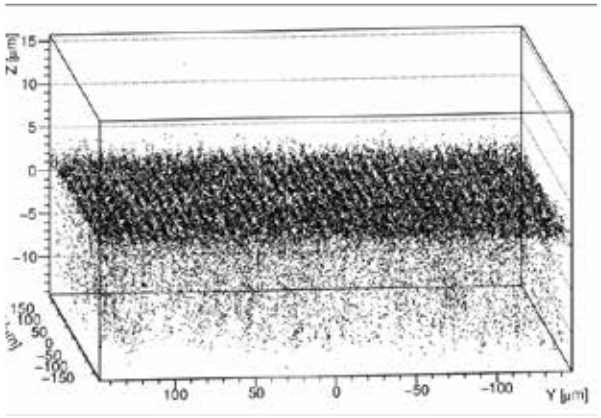


Individual positrons

The results



(a)



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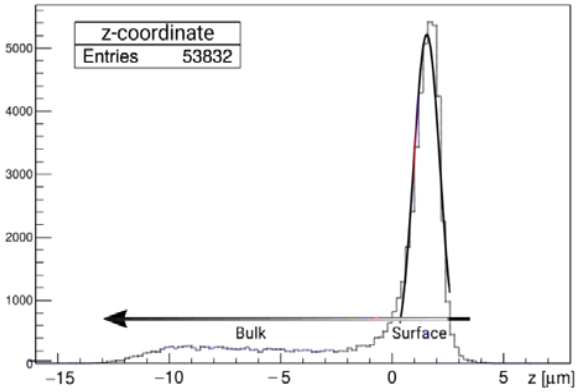
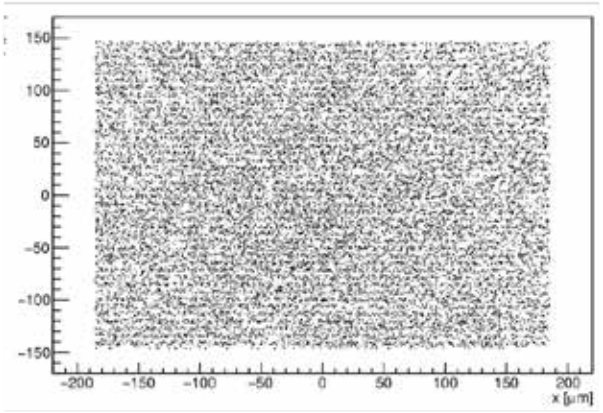




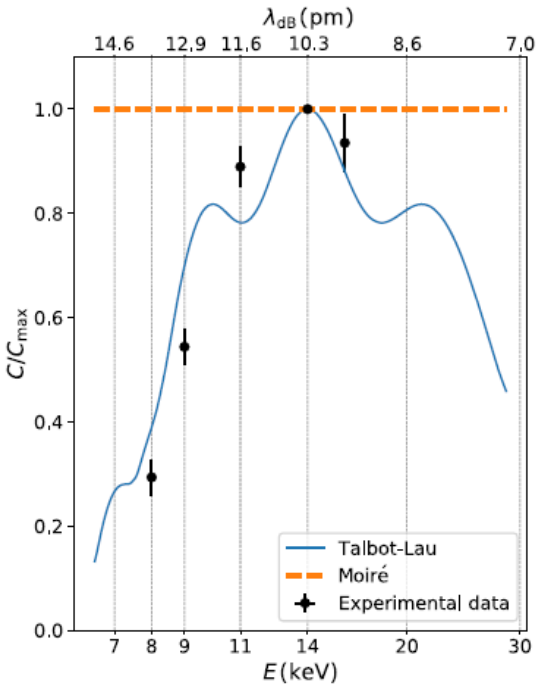
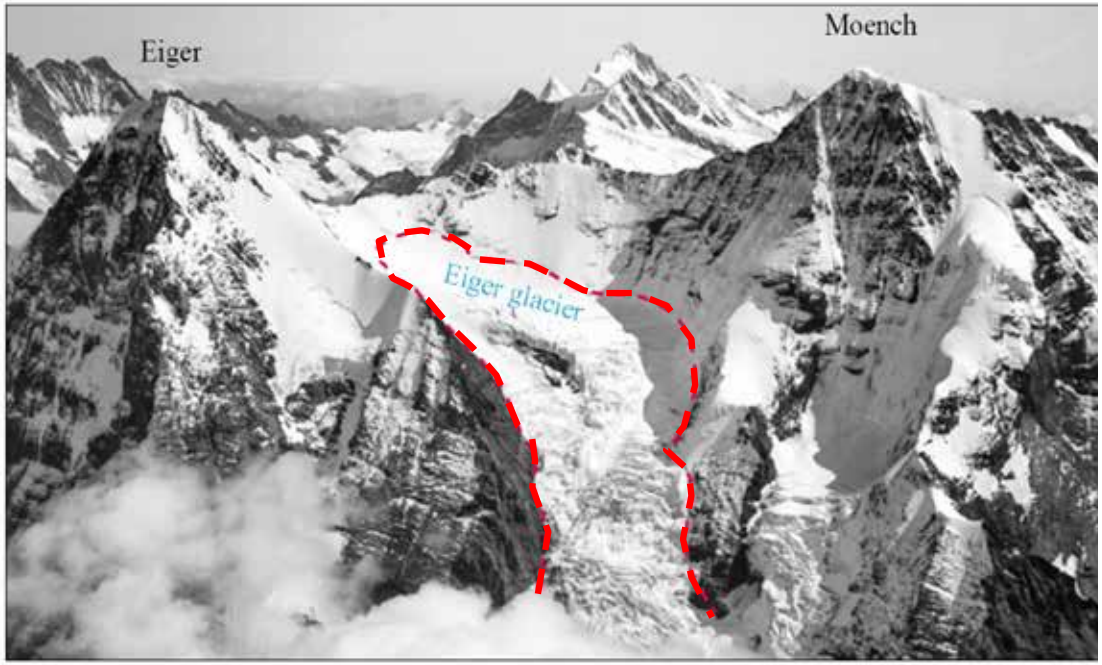
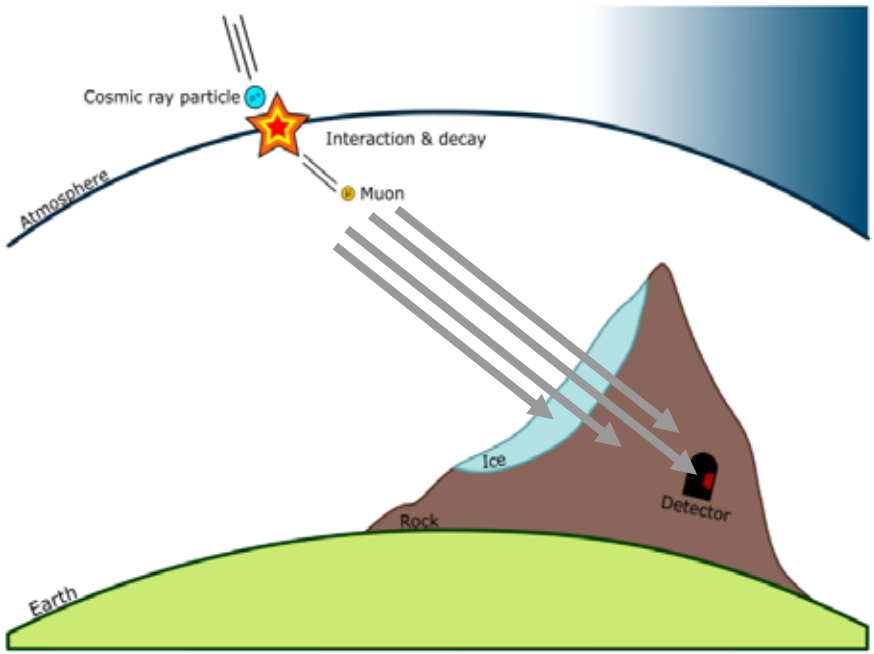


Fig. 5. Contrast as a function of energy. Measured contrast normalized to the resonance value, defined as $C/C_{max}(E)$. The 68% confidence interval uncertainties are obtained by standard error propagation. The solid line is the quantum-mechanical prediction, while the classical prediction is indicated by the dashed line.

Glacier muon radiography

- Interdisciplinary project: particle physics detectors (emulsion films) & geology of alpine glaciers→ imaging of glacier bedrock
- Cosmic muon radiography: exploit experience of the Bern group with nuclear emulsions (OPERA)
- Eiger glacier: exploit the Jungfraubahn tunnel



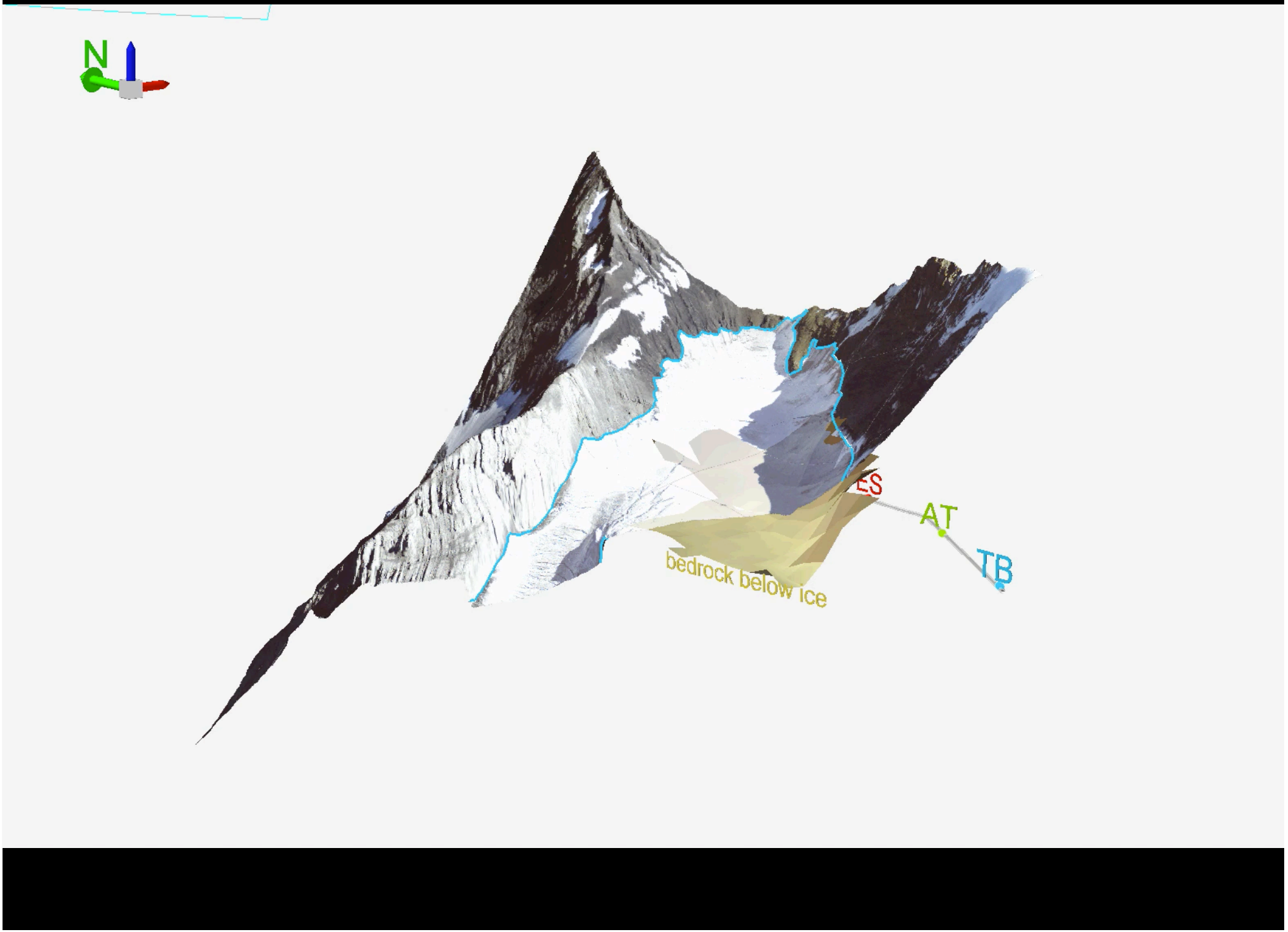


Dissemination of the results

NATURE S.R. : order of 1000 downloads

Berner Zeitung: order of 20,000 readers

RAI1 SuperQuark: order of 2,000,000 televiewers


N
ES
AT
TB
bedrock below ice

Thank you for the attention!

…and a special thank to the experimentalist colleagues: