The ALICE Programme

Raimond Snellings

Nikhef/UU Group: 6 staff, 3 postdocs, 10 PhD’s
Publications: 303
Theses: 26
University Partner: Utrecht University
Investment Phase 1&2: 6.3 M
Personal Grants: 8.1 M

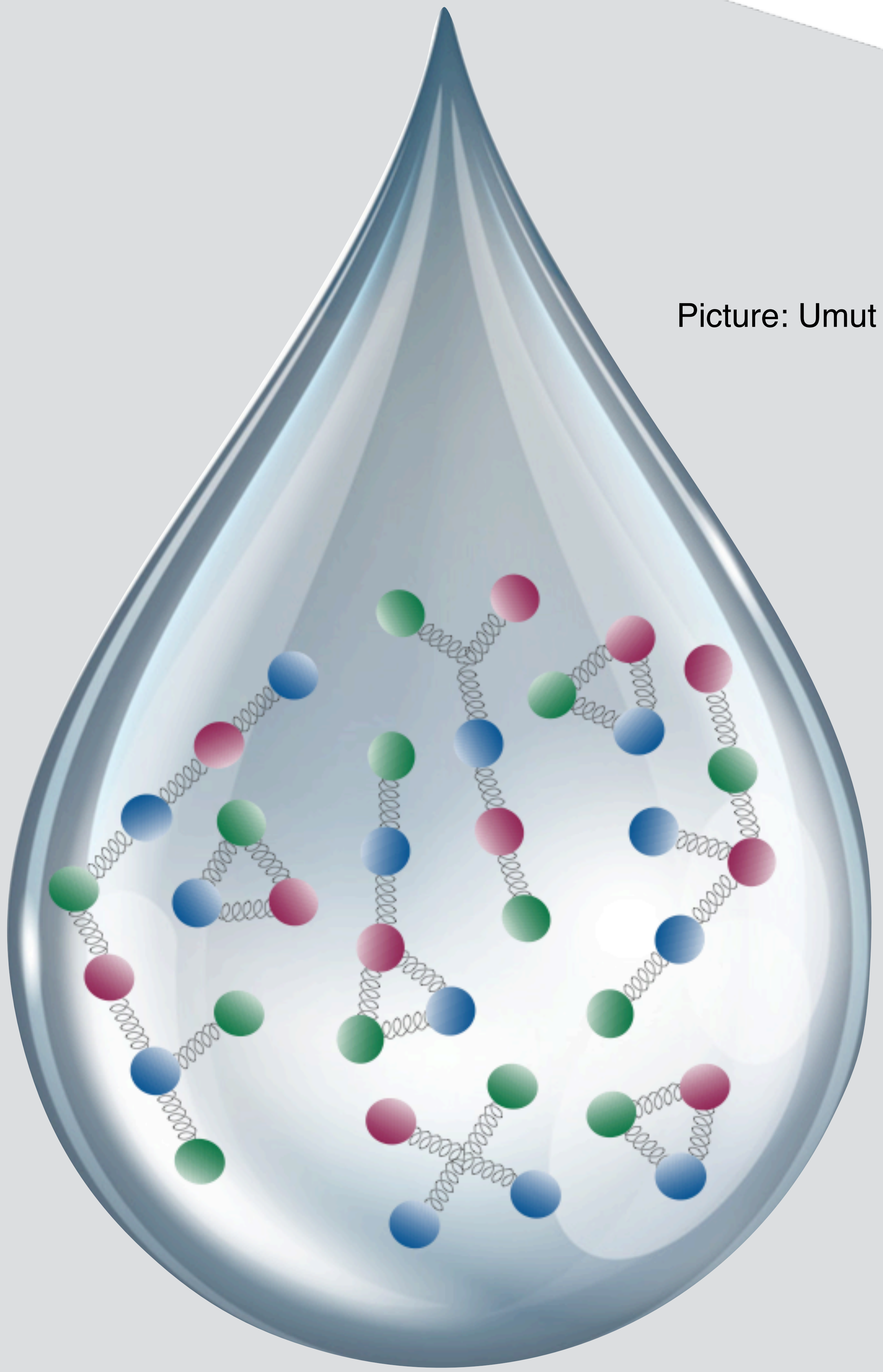
The ALICE Programme

- **What happens to matter when you heat and compress it to extreme magnitudes which existed in the primordial universe?**
  - Phase transition to a **quark-gluon-plasma**
    - **QCD in the regime of extreme matter with emergent phenomena**

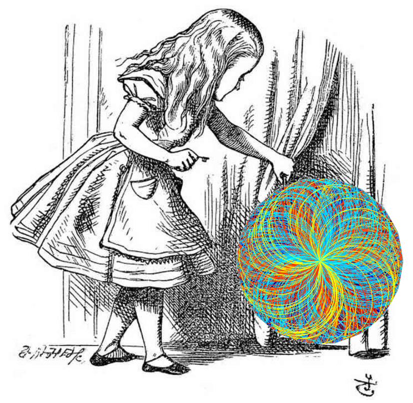
    ➡ Unique conditions to study QCD
      - Temperature ≈ 10^{12} K – 10^{5} times larger than the core of the sun
      - Magnetic fields ≈ 10^{18} G – 10^{10} times larger than in the lab
      - Initial angular momentum of order $J = 10^{7}$, of which a fraction is transferred to the interaction region
  - Properties of the quark-gluon-plasma are still not well understood

    ➡ Theoretically complicated (lQCD, AdS/CFT, pQCD, Hydro, ..)
  - Experimentally studied with high-energy nuclear collisions at the LHC: **the ALICE experiment**

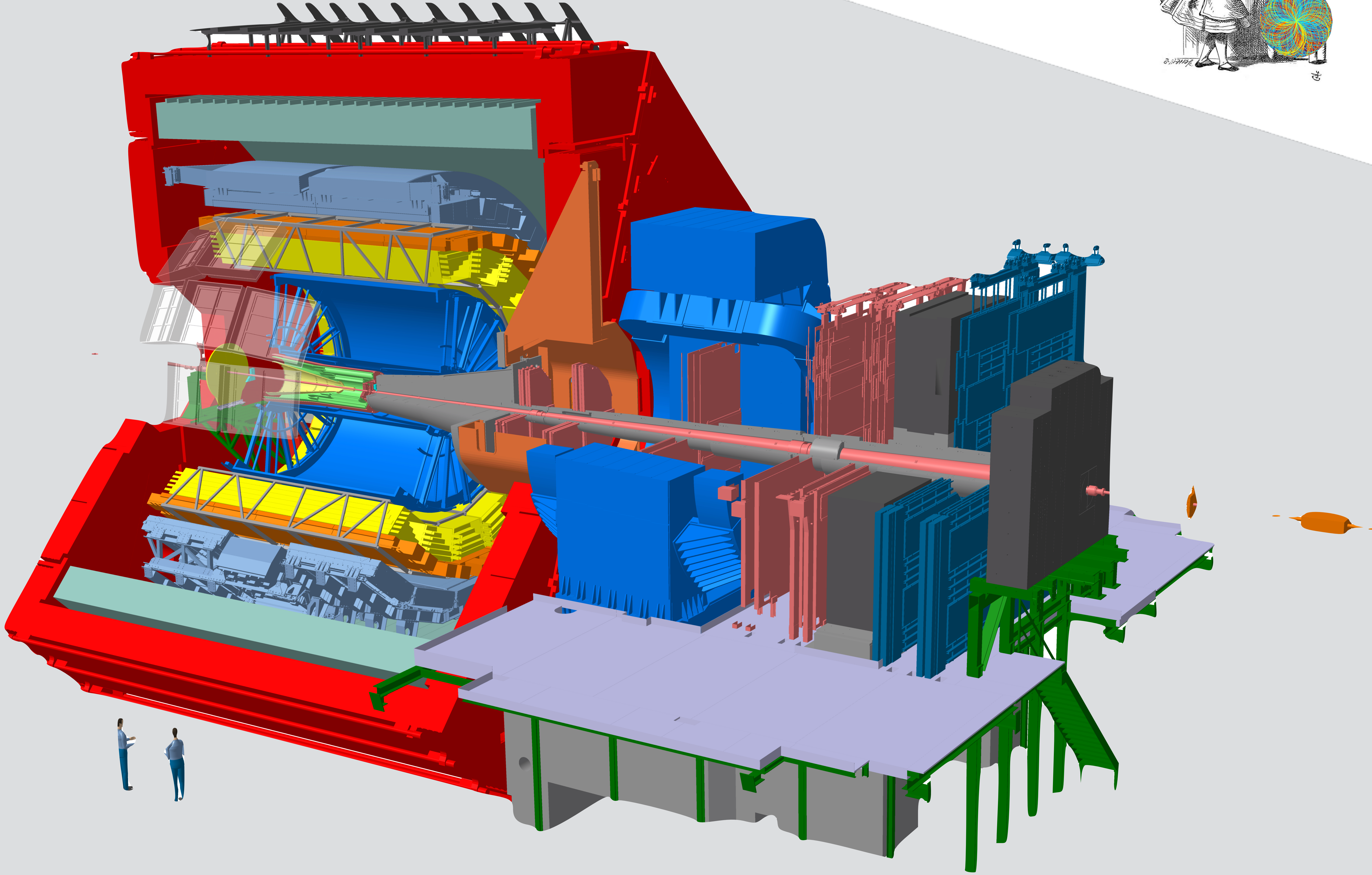
Picture: Umut Gursoy



The ALICE Programme

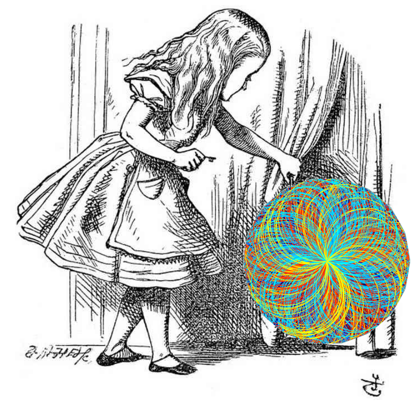


- **Dutch ALICE group (Nikhef+UU) is participating in the ALICE experiment at the LHC as a leading group**
  - ➡ Leading positions in ALICE
  - ➡ Very productive in data analysis using different probes of the quark-gluon plasma:
    - our group produced the most cited publications
  - ➡ Significant and visible contribution to the detector hardware

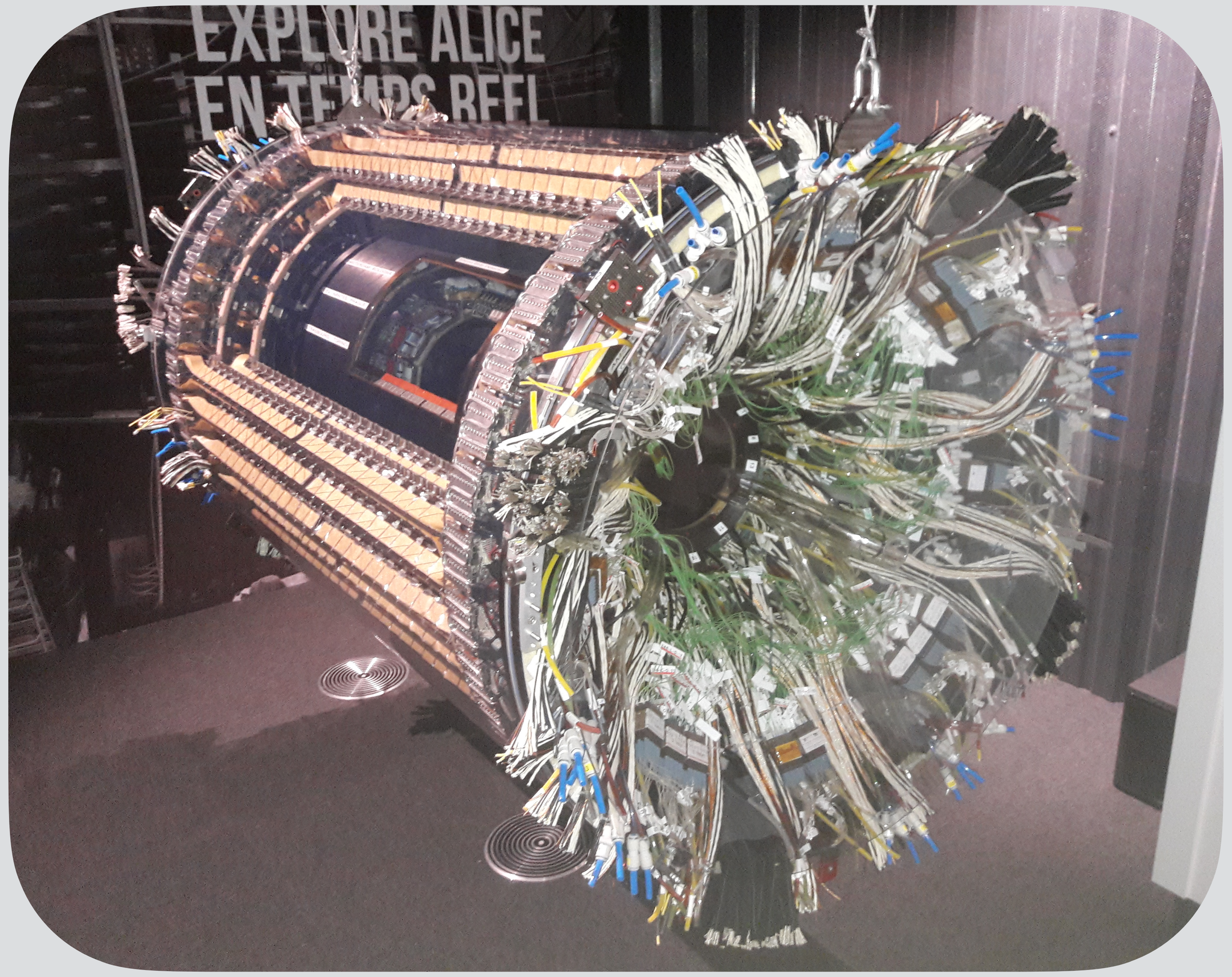


The ALICE Collaboration: 41 countries, 176 institutes, ~1800 members

ITS 1 (2010-2018)



- The ITS 1 consisted of 6 layer of silicon detectors
  - ➡ Nikhef led the construction of the outer two layer of the ITS (silicon strip detectors) and assembled half of the ITS
  - ➡ This detector worked almost perfectly for the last decade, due to Nikhef's continuous support for its operation
  - ➡ Important for almost every physics analysis in ALICE



Now a museum piece

ITS 2 (MAPS ALPIDE, 2021-2030)

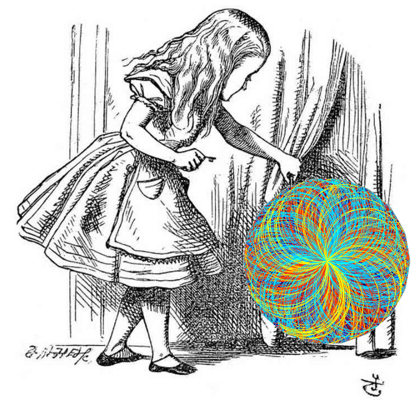
Change of technology: new tracker based on monolithic CMOS sensors!

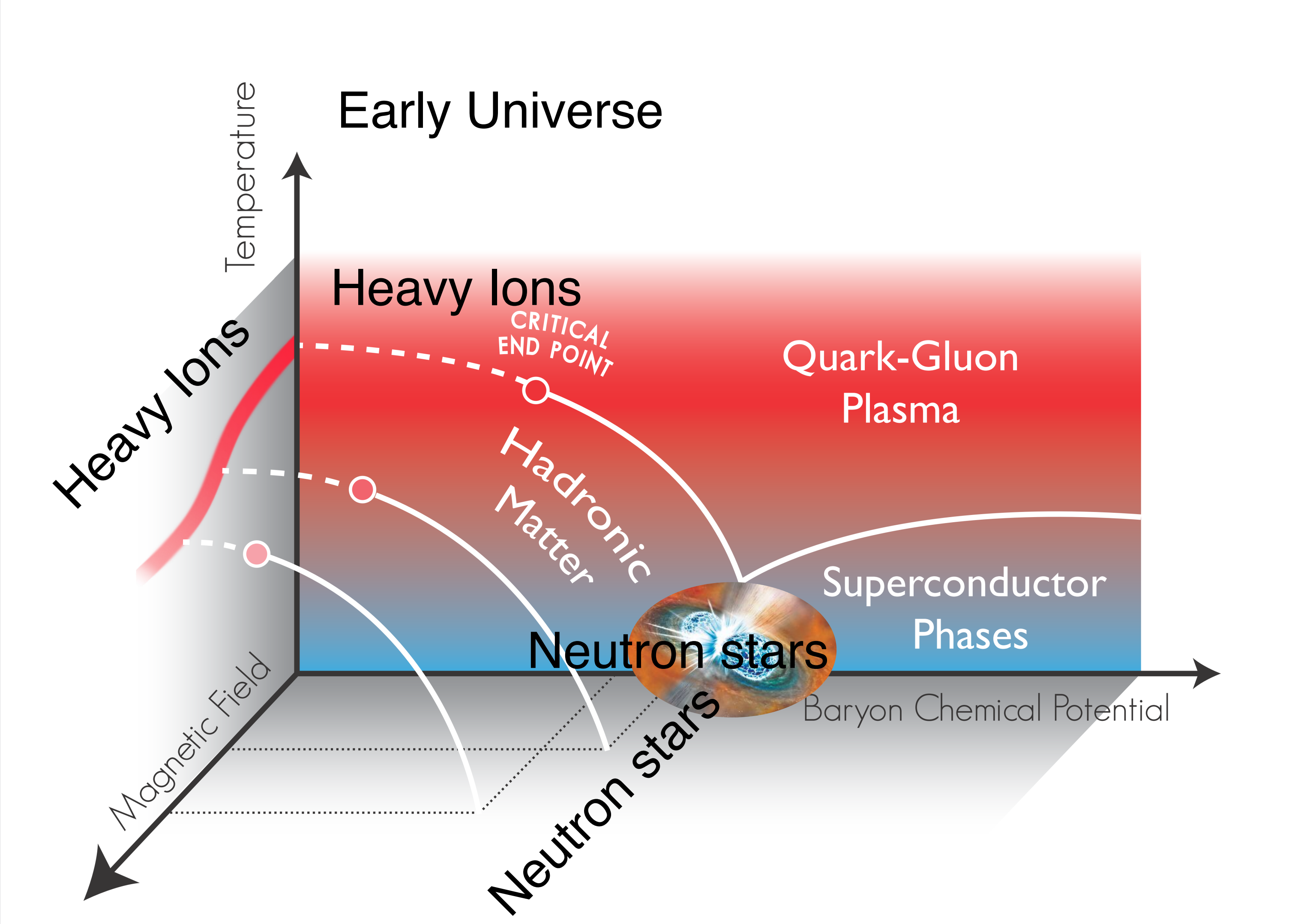
- Thin sensor with on-chip digital readout (~10m^2)

- Improve impact parameter resolution by a factor of 3
  - ➡ Get closer to the IP: first layer 39 -> 22 mm
  - ➡ Reduce material budget: 1.14% -> 0.3% X_0 per layer or better
  - ➡ Increase pixel density 50 x 425 µm -> 20 x 20 µm
- High standalone tracking efficiency and p_t resolution
  - ➡ Increase granularity 6 -> 7 layers with reduced pixel size
  - ➡ Larger radial extent 39-430 mm -> 22-430 mm
- Fast PbPb (and pp) readout
  - ➡ Instantaneous luminosity: 6x10^{27} cm^{-2}s^{-1} gives hadronic interaction rate of 50kHz
  - ➡ ITS 1 slow, maximal readout at 1 kHz
  - ➡ In new setup Pb-Pb collisions are readout at > 50 kHz and pp at > 2 MHz

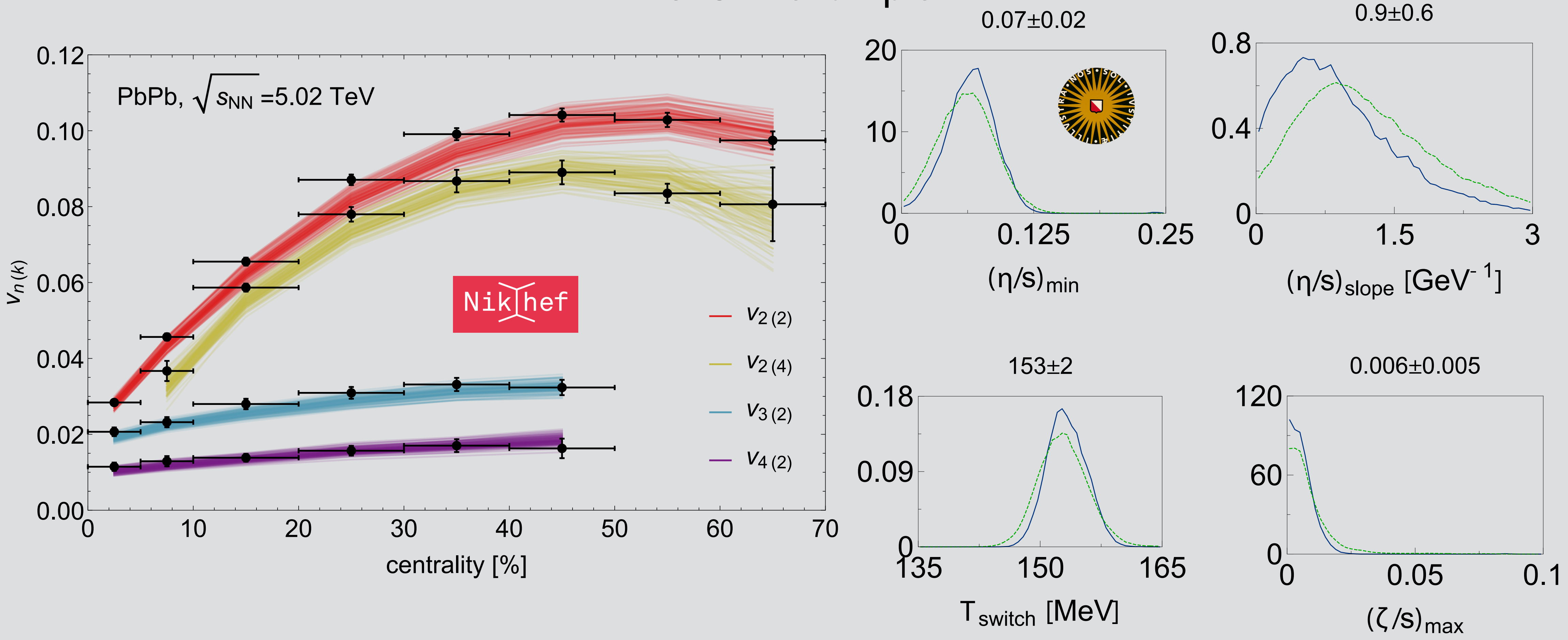
Currently being tested at CERN, installation in Point 2 02-2021

The ALICE Programme 2010-2020





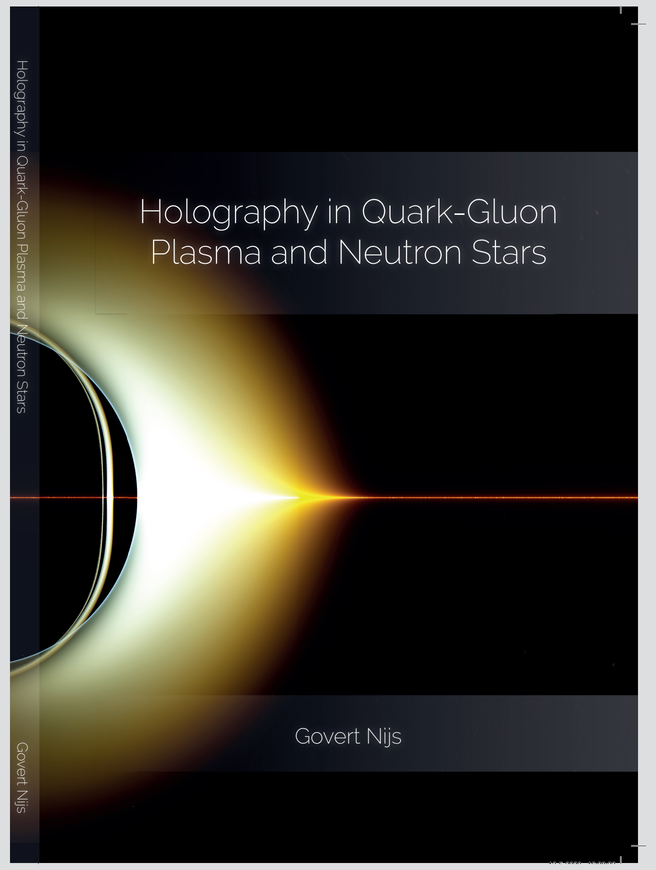
Just 1 example!



Govert Nijs, Wilke van der Schee, Umut Gursoy and RS

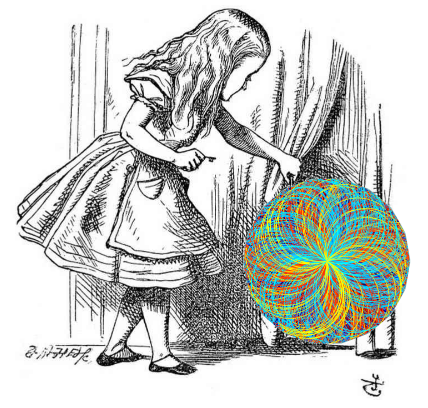
- ➡ Strong Nikhef contribution to many of the key ALICE measurements
- ➡ Global Bayesian theoretical analysis to extract QCD properties
    - ➡ Dutch theoretical contributions (AdS/CFT, LQCD, relativistic viscous hydrodynamics, transport theory, …)
- ➡ Theoretical work connecting quark gluon plasma properties at LHC and properties merging neutron stars (GRASP and ITF)

Recent PhD thesis: Govert Nijs, Holography in quark gluon plasma and neutron stars (UU, 2020)



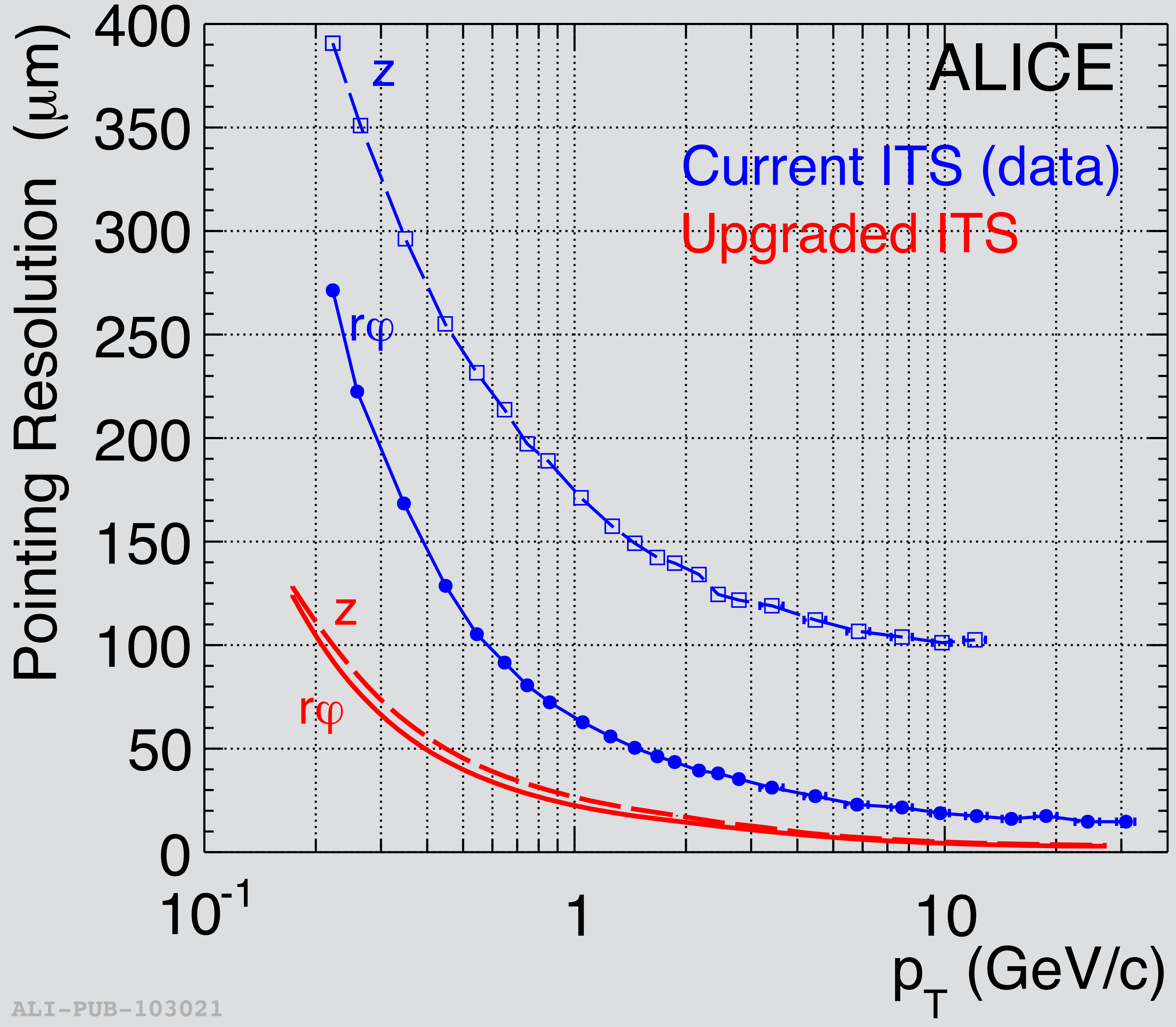
- ➡ New developments to measure and describe EM and spin transport properties of the QGP (experiment and theory)

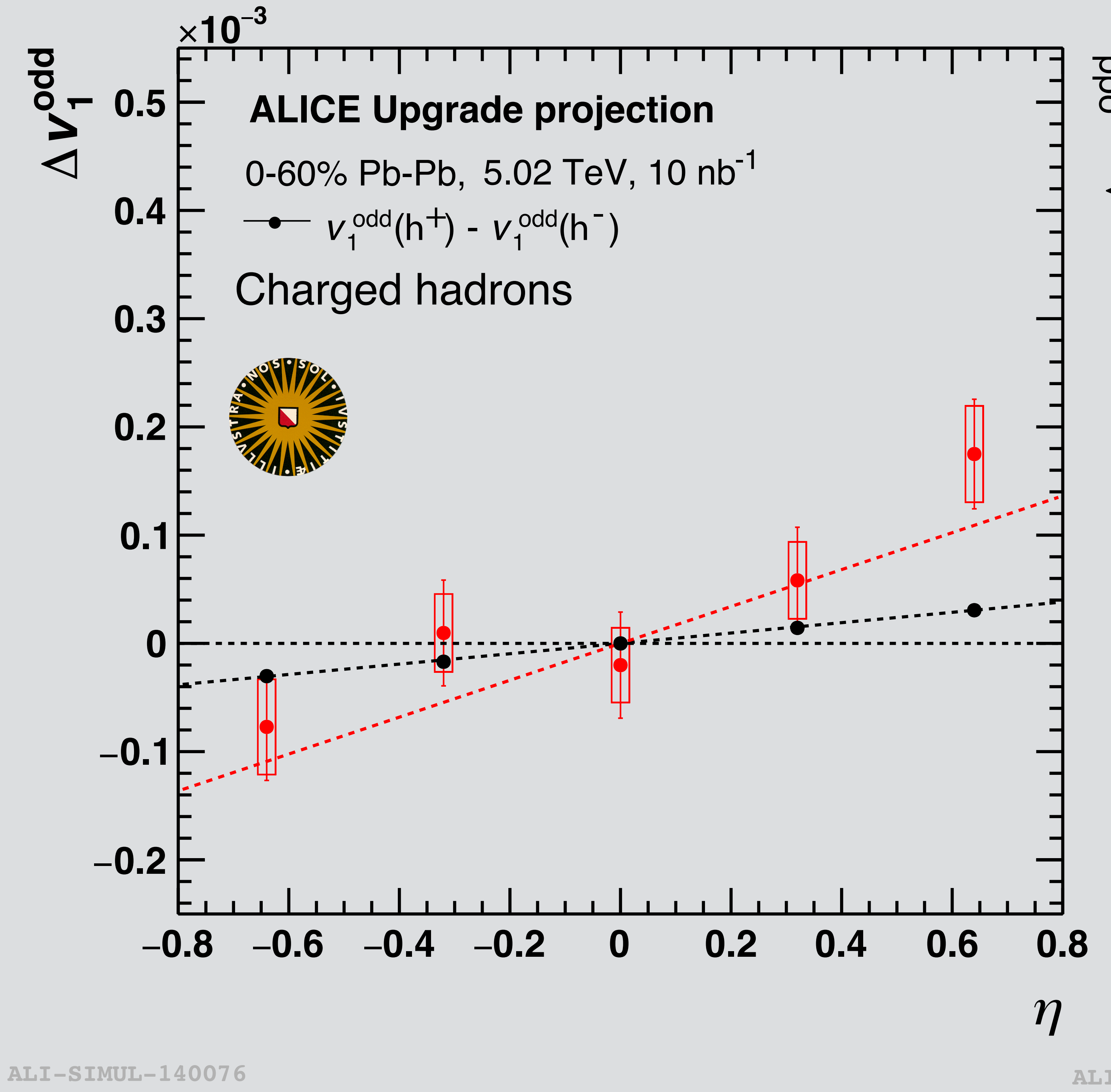
The ALICE Programme 2020-2025

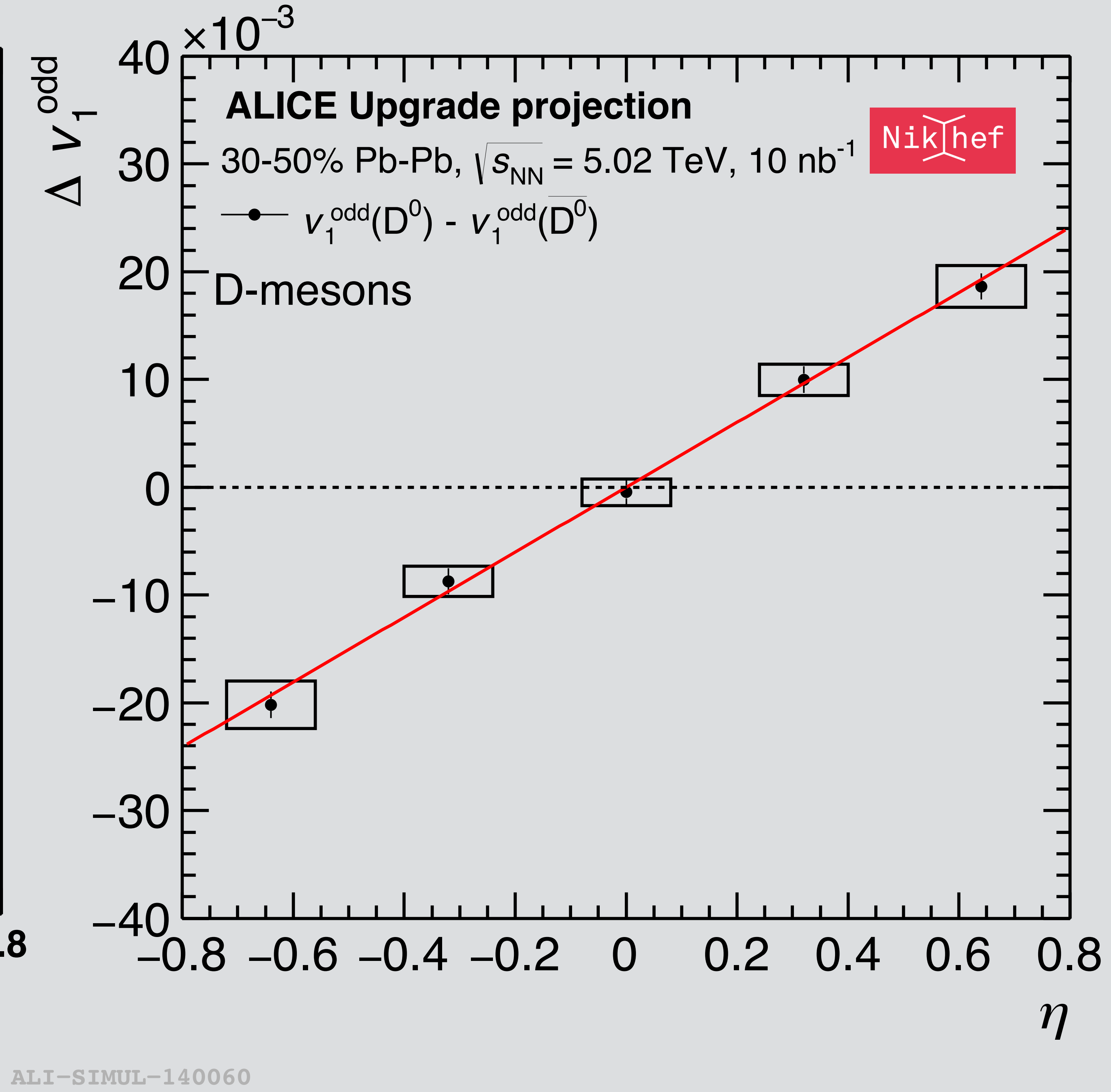


Improved spatial resolution

Charge dependence of directed flow (magnetic field effect)







Upgraded ITS 2, in fully upgraded ALICE detector, allows us to collect 100x more data with higher precision

Physics: e.g. determine the EM properties of the QGP

@Nikhef: R&D on 4D-tracking

- Currently there are exciting developments for new Silicon detectors
  - ➡ Large surface area (affordable)
  - ➡ Extremely thin
  - ➡ Radiation hard
  - ➡ *Fast timing*
- CERN is strongly invested in strategic R&D programme for future experiments (started January 2020)
  - ➡ R&D carried out with external groups from universities and national labs
- Nikhef currently involved in work package 1.2
  - ➡ ALICE, ATLAS, LHCb and Nikhef R&D
    - ➡ ALICE for ITS 3 (2025) and interested in ALICE 3 (2030)
    - ➡ LHCb interested in “ChronoPix” vertex detector, prototype (2025) and full detector (2030)
    - ➡ ATLAS interested in High Granularity Timing Detector and possible MAPS inner tracker (2030- 2035)

WORK PACKAGES

1.1 Hybrid Pixel Detectors

Hybrid pixel sensors with advanced features to be combined with high performance readout ASICs. These developments target small pixels, high-resolution timing and high-rate applications and comprise...

Read more 5

1.2 Monolithic Pixel Detectors Nikhef

Development of monolithic CMOS sensors for the innermost radii for maximum performance, and for the outer-layers as cost effective pixel trackers with high granularity and low material budget...

Read more 20

1.3 Module Development

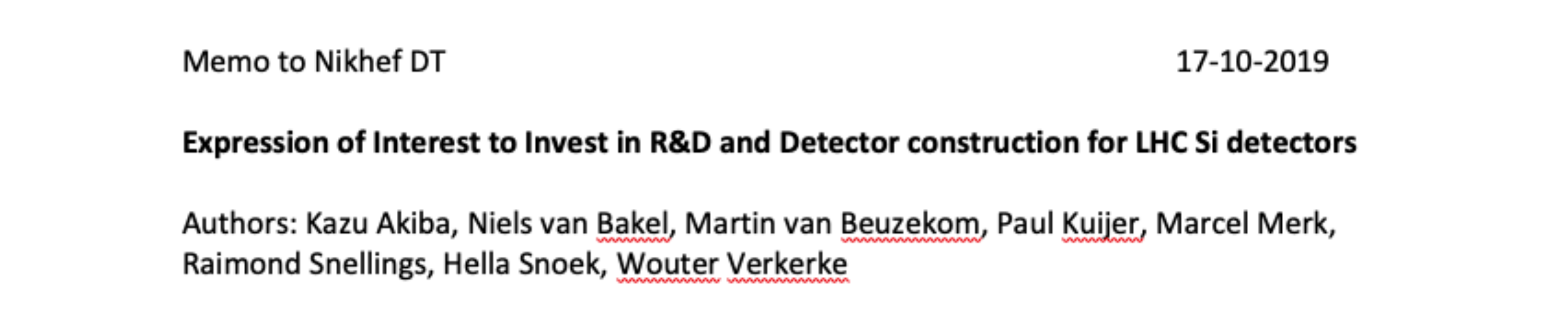
Within the EP R&D the module work package (WP 1.3) focusses on the study and development of new module concepts for hybrid and CMOS pixel detectors and their integration for future applications...

Read more 3

1.4 Simulation and Characterization

Detector simulations and modelling of radiation damage, as well as the development of dedicated characterization setups and flexible data-acquisition systems for testing purposes. Mailing List...

Read more 4



Memo to Nikhef DT 17-10-2019

Expression of Interest to Invest in R&D and Detector construction for LHC Si detectors

Authors: Kazu Akiba, Niels van Bakel, Martin van Beuzekom, Paul Kuijer, Marcel Merk, Raimond Snellings, Hella Snoek, Wouter Verkerke

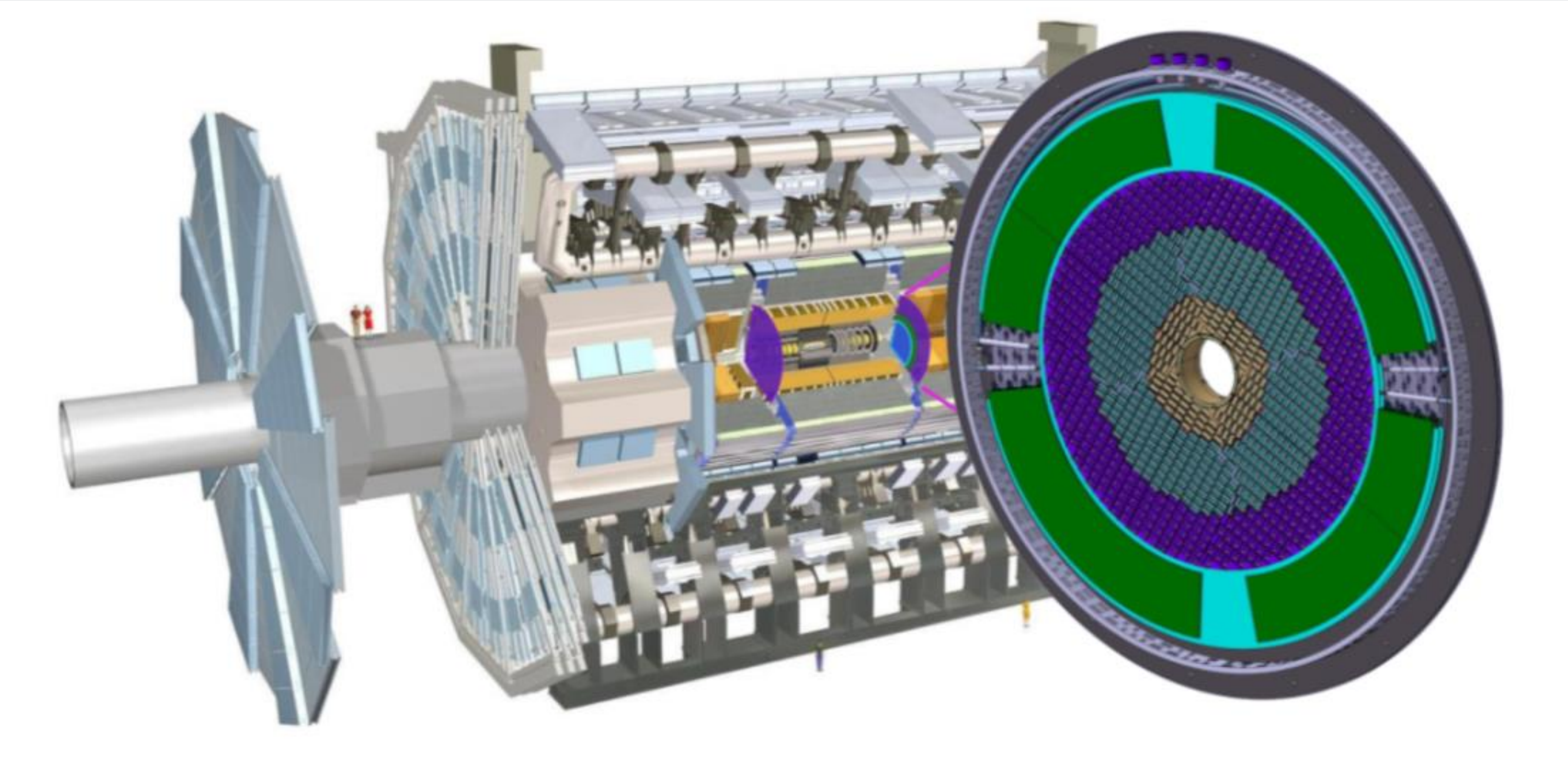
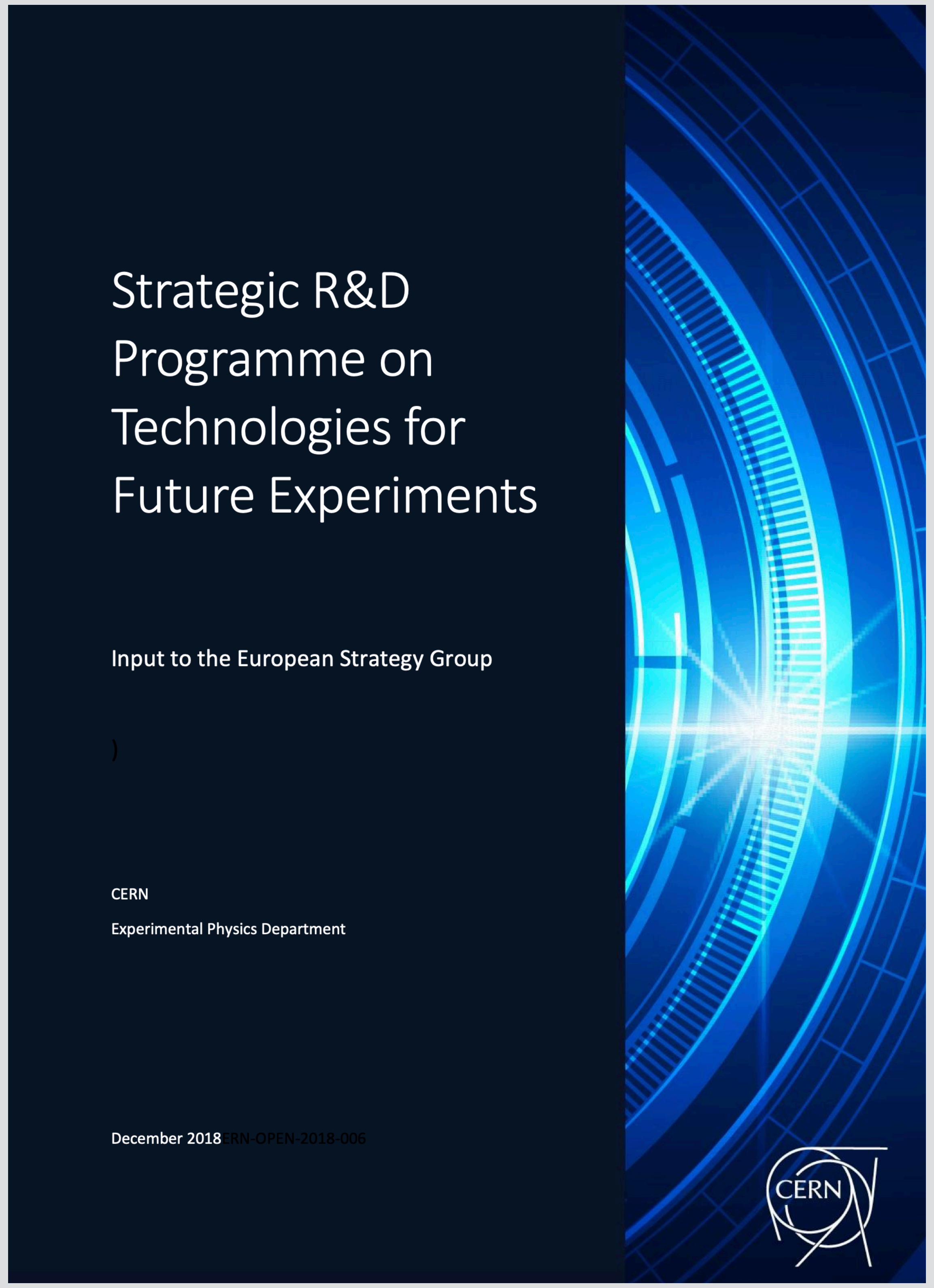


Figure 5: Position of the HGTD within the ATLAS Detector. The HGTD acceptance is defined as the surface covered by the HGTD between a radius of 120 mm and 640 mm at a position of z = ± 3.5 *m along the beamline*



ITS 3 (MAPS, 2025-2030)

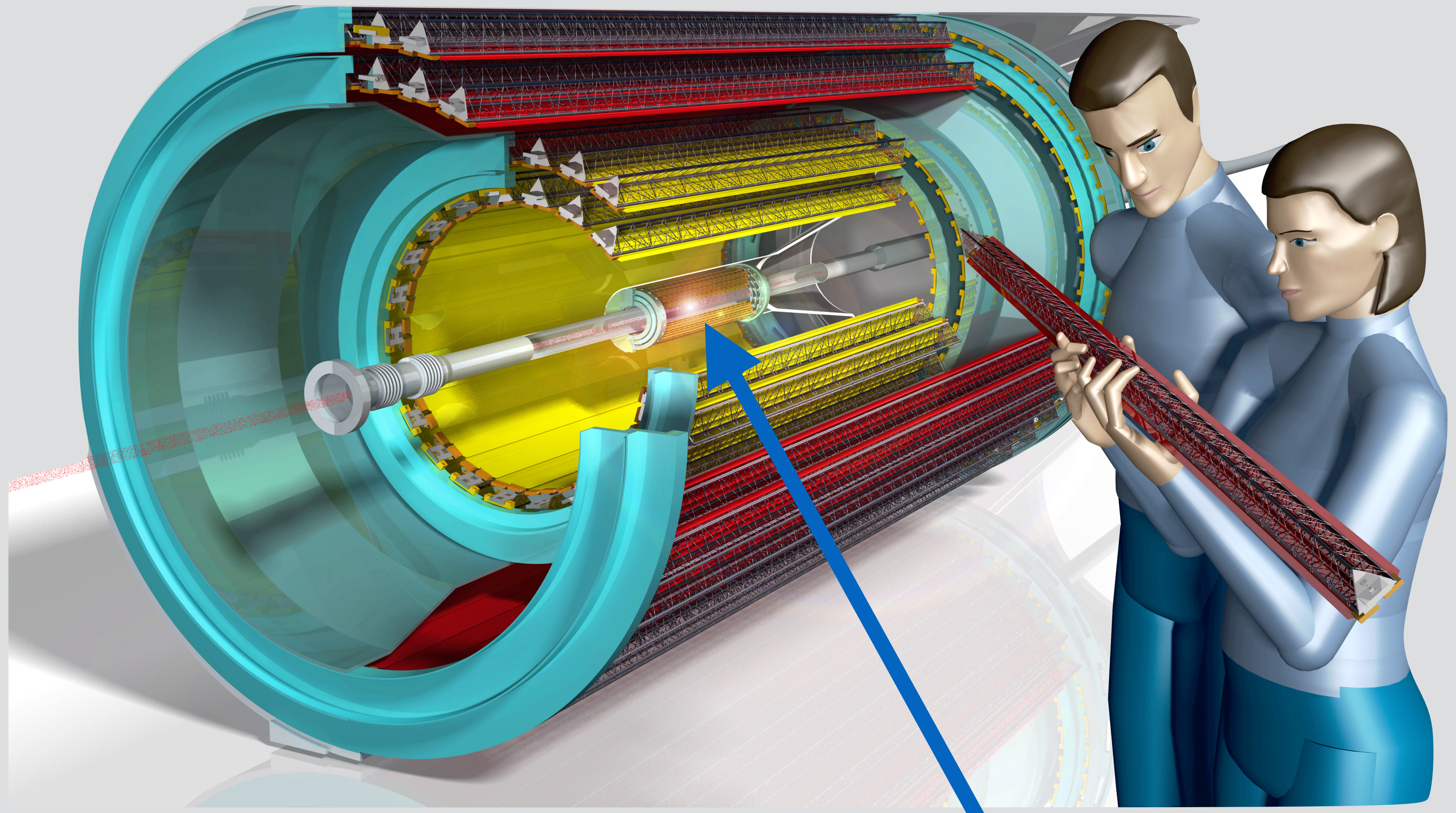
Chip size is traditionally limited by CMOS manufacturing

- New option: stitching and bending

- Can we get thinner?
  - ➡ Reduce material budget: 0.3% -> 0.05% X_0 per layer

- Can we get closer?
  - ➡ From 22 -> 18 mm

replace innermost 3 layers ITS 2

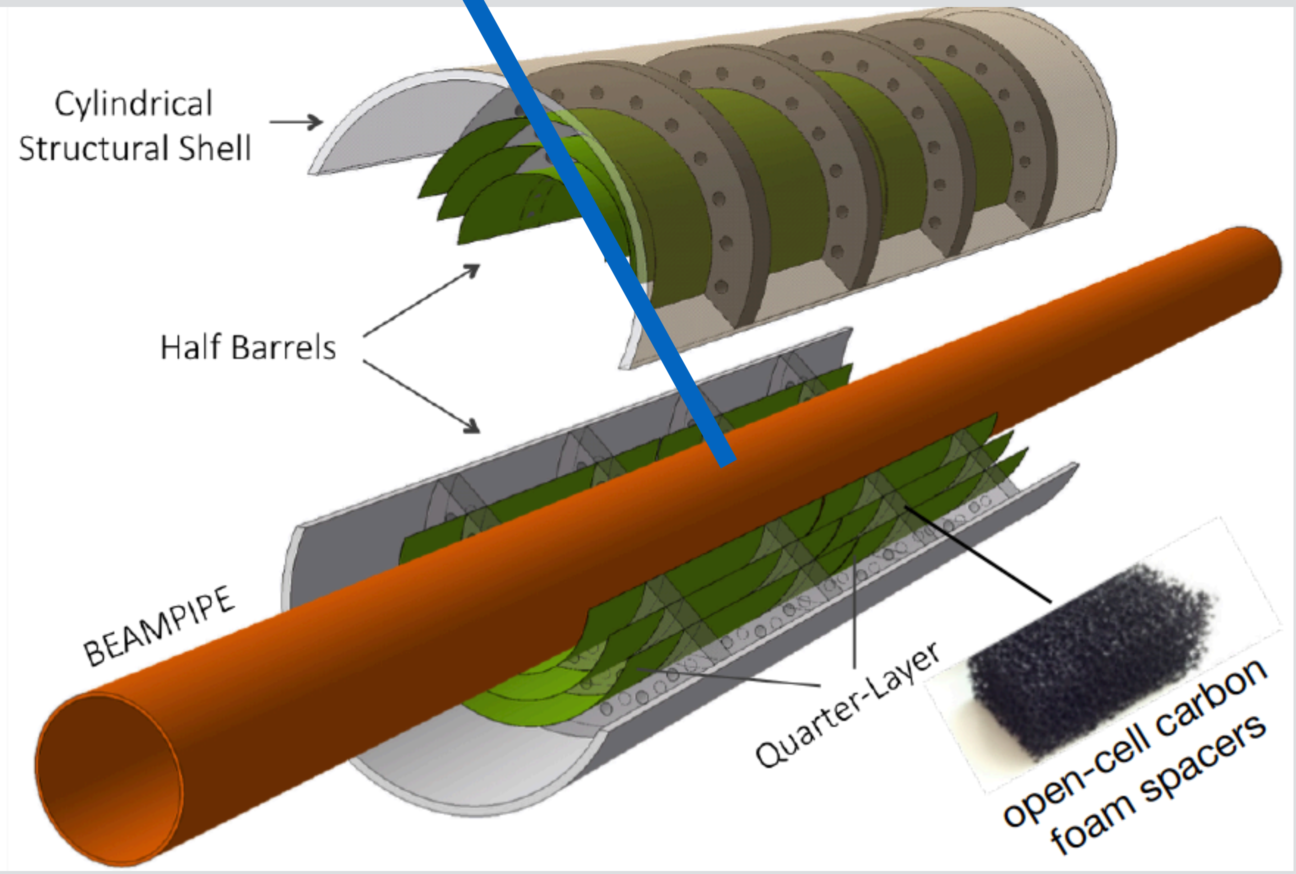


- Contribute to analog and digital design Nikhef
  - ➡ Our design is at Tower Semiconductor currently
- Contribute to data transmission Nikhef
- Contribute to mechanical design Nikhef

Technical Design Report 2022

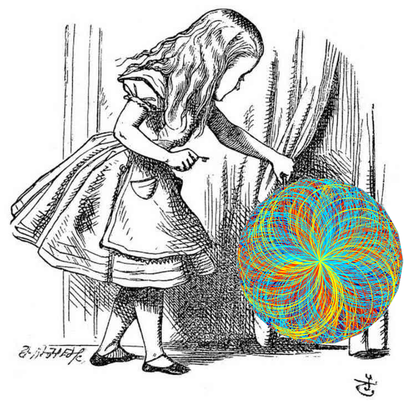
Construction 2024-2025

Installation during LS3

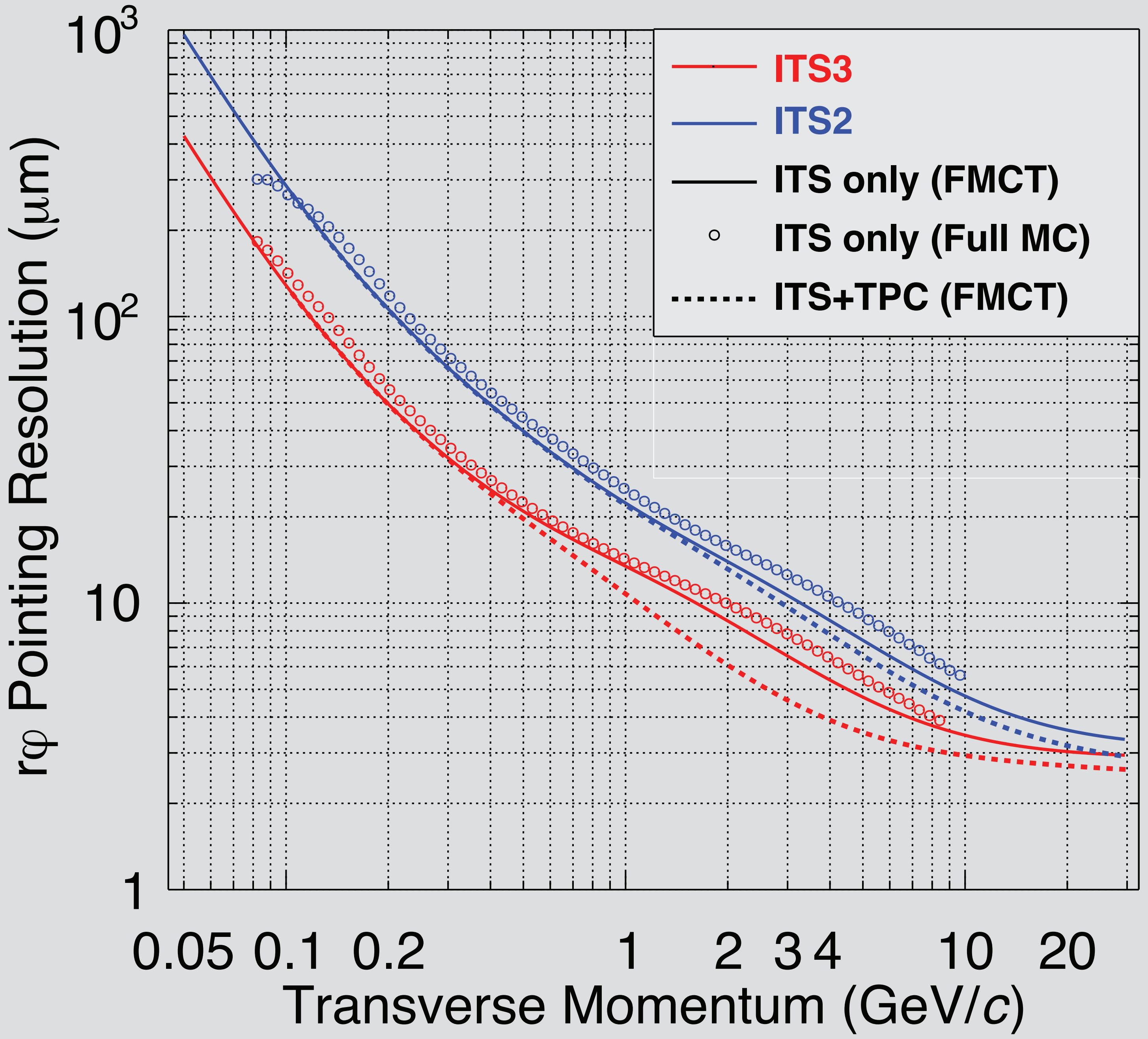


- 2020-2022 prototyping chips
- 2022-2023 full-scale prototype + final chip

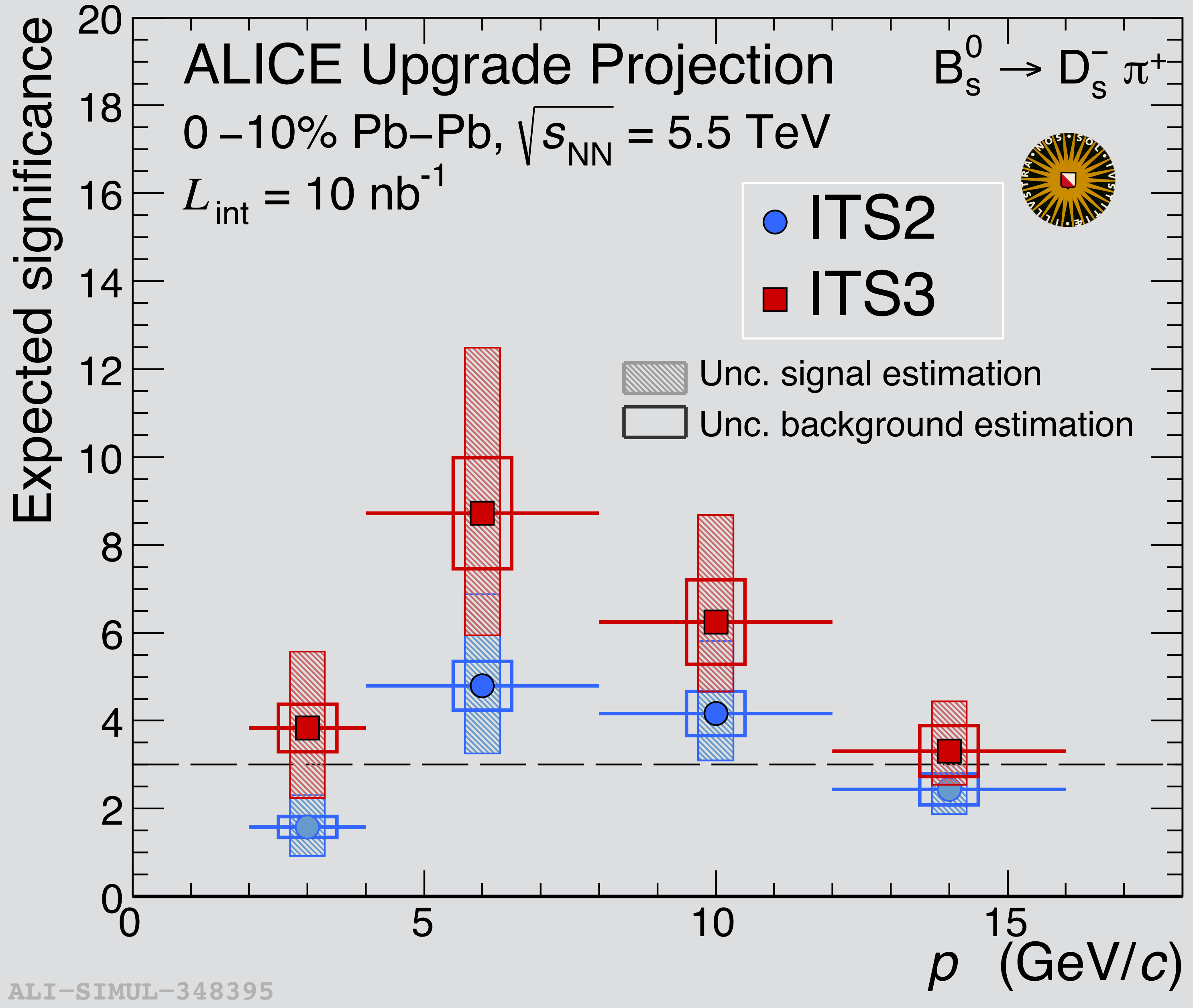
The ALICE Programme 2025-2030



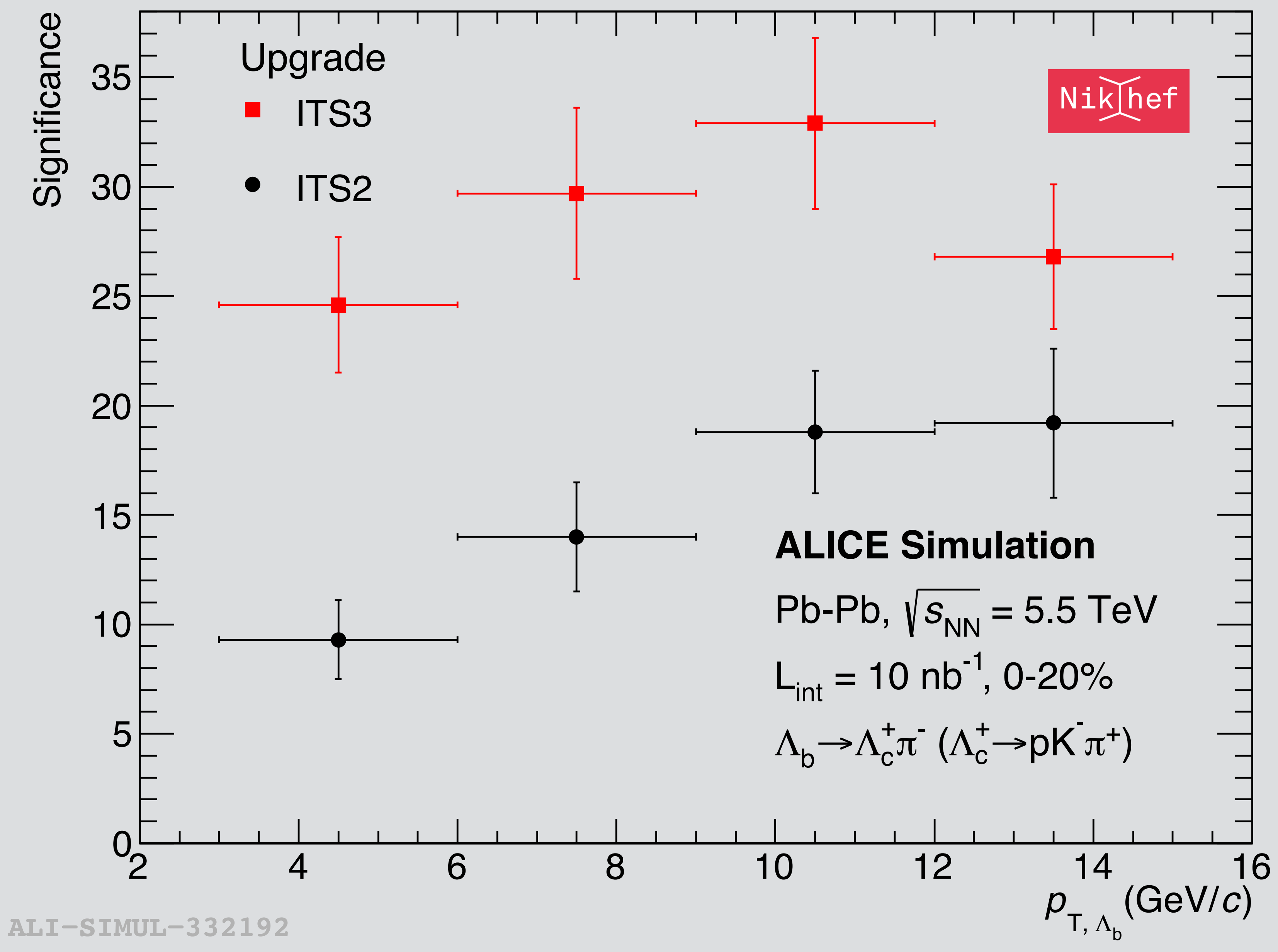
Improved spatial resolution



$B_s^0 \to D_s^- \pi^+$ significance



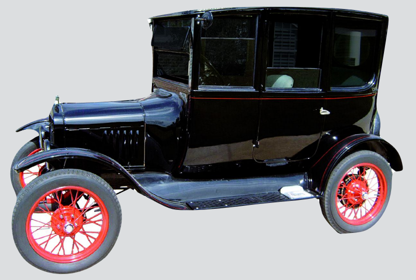
$\Lambda_b \to \Lambda_c^+ \pi^- (\Lambda_c^+ \to p K^- \pi^+)$ significance

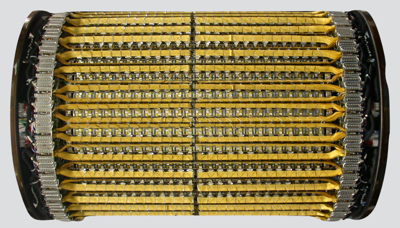


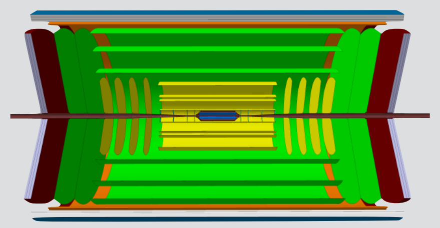
Upgraded ITS 3, in fully upgraded ALICE detector, allows us collect 100x more data with even higher precision
Physics: e.g. determine the in-medium hadronization properties and energy loss mechanisms

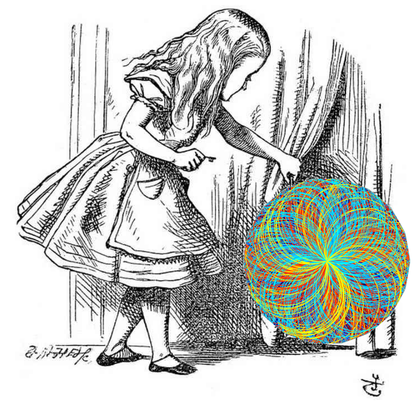
ALICE 3 (2030-)

From Werner Riegler

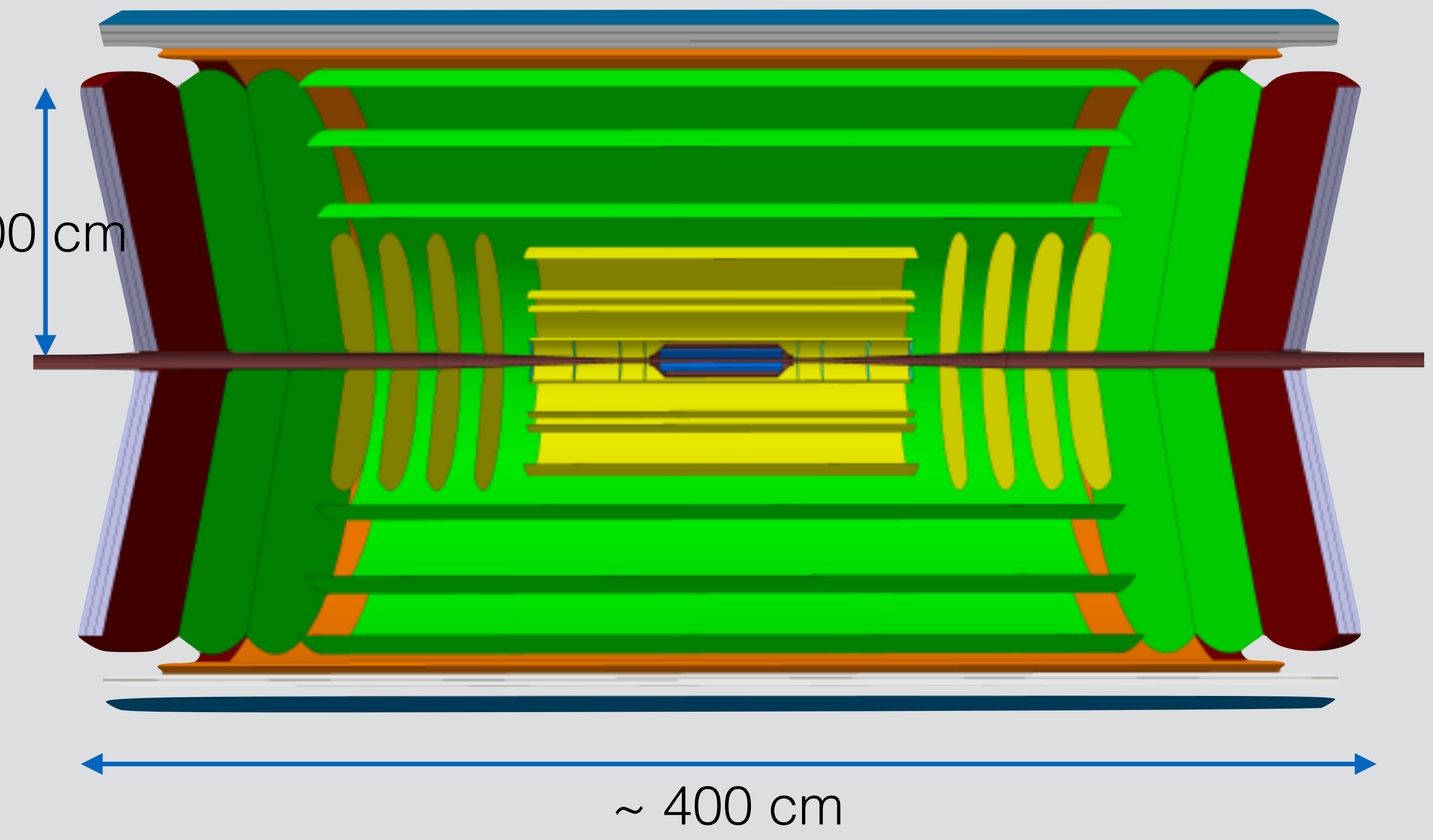








- Completely new experiment
  - ➡ Material budget: 0.05% X_0 per layer (~10 CMOS layers)
  - ➡ Magnetic Field: 0.2 and 0.5 T
  - ➡ Rapidity coverage: up to 8 rapidity units
  - ➡ Trying to get as close to the beam as possible
    - ➡ Improved Velo like and new solutions
  - ➡ Time measurements: outer layer ~ 20 ps
    - ➡ More timing layers and different silicon pixel technologies considered Nikhef



Version 2

arXiv:1902.01211v2 [physics.ins-det] 2 May 2019

A next-generation LHC heavy-ion experiment

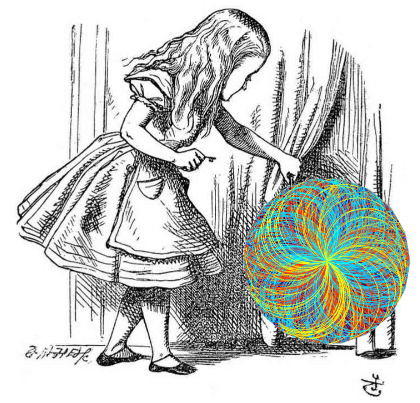
List of authors in appendix

Abstract

The present document discusses plans for a compact, next-generation multi-purpose detector at the LHC as a follow-up to the present ALICE experiment. The aim is to build a nearly massless barrel detector consisting of truly cylindrical layers based on curved wafer-scale ultra-thin silicon sensors with MAPS technology, featuring an unprecedented low material budget of 0.05% X_0 per layer, with the innermost layers possibly positioned inside the beam pipe. In addition to superior tracking and vertexing capabilities over a wide momentum range down to a few tens of MeV/c, the detector will provide particle identification via time-of-flight determination with about 20 ps resolution. In addition, electron and photon identification will be performed in a separate shower detector. The proposed detector is conceived for studies of pp, pA and AA collisions at luminosities a factor of 20 to 50 times higher than possible with the upgraded ALICE detector, enabling a rich physics program ranging from measurements with electromagnetic probes at ultra-low transverse momenta to precision physics in the charm and beauty sector.

Geneva, Switzerland
2 May 2019

ALICE in the LHC Wonderland



- The Nikhef ALICE group is very productive and has a large impact on the ALICE programme
  - Connected to the Nikhef and Utrecht Theory department, joint effort on heavy-ions and gravitational waves
  - Connected to GW as well in GRASP
- Current ITS 2 installation well on track

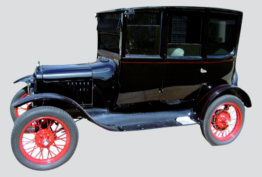
- Strong future programme and ambitions!
  - ➡ Started with R&D for ITS 3 and ALICE 3
  - ➡ Joint Nikhef R&D programme for 4D-tracking with the detector R&D and other LHC groups
  - ➡ Funding required for 4D tracking R&D, Physics analysis and building ALICE 3, initially ~0.5-1 M for ITS 3 and ALICE 3 R&D, ~~~~4-5 M for ALICE 3

Increase in luminosity
10x more data

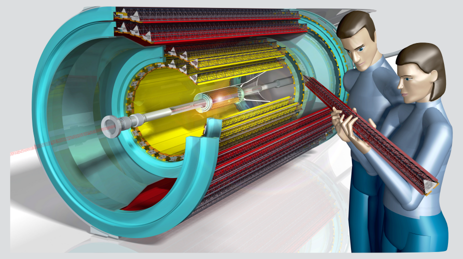
high luminosity LHC
100x more data

different systems

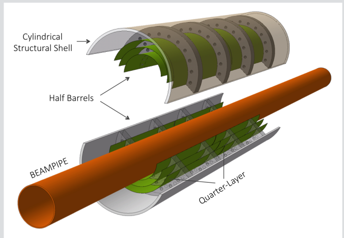
LS1
2014



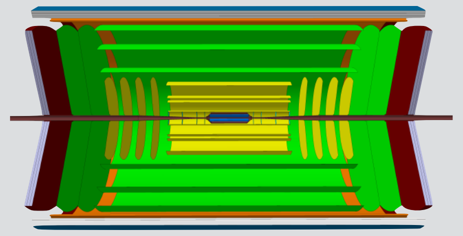
LS2
2019-2021



LS3
2025-2027

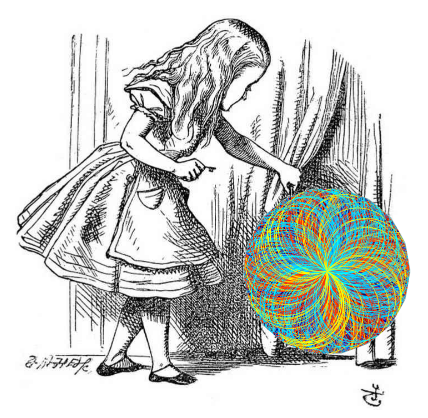


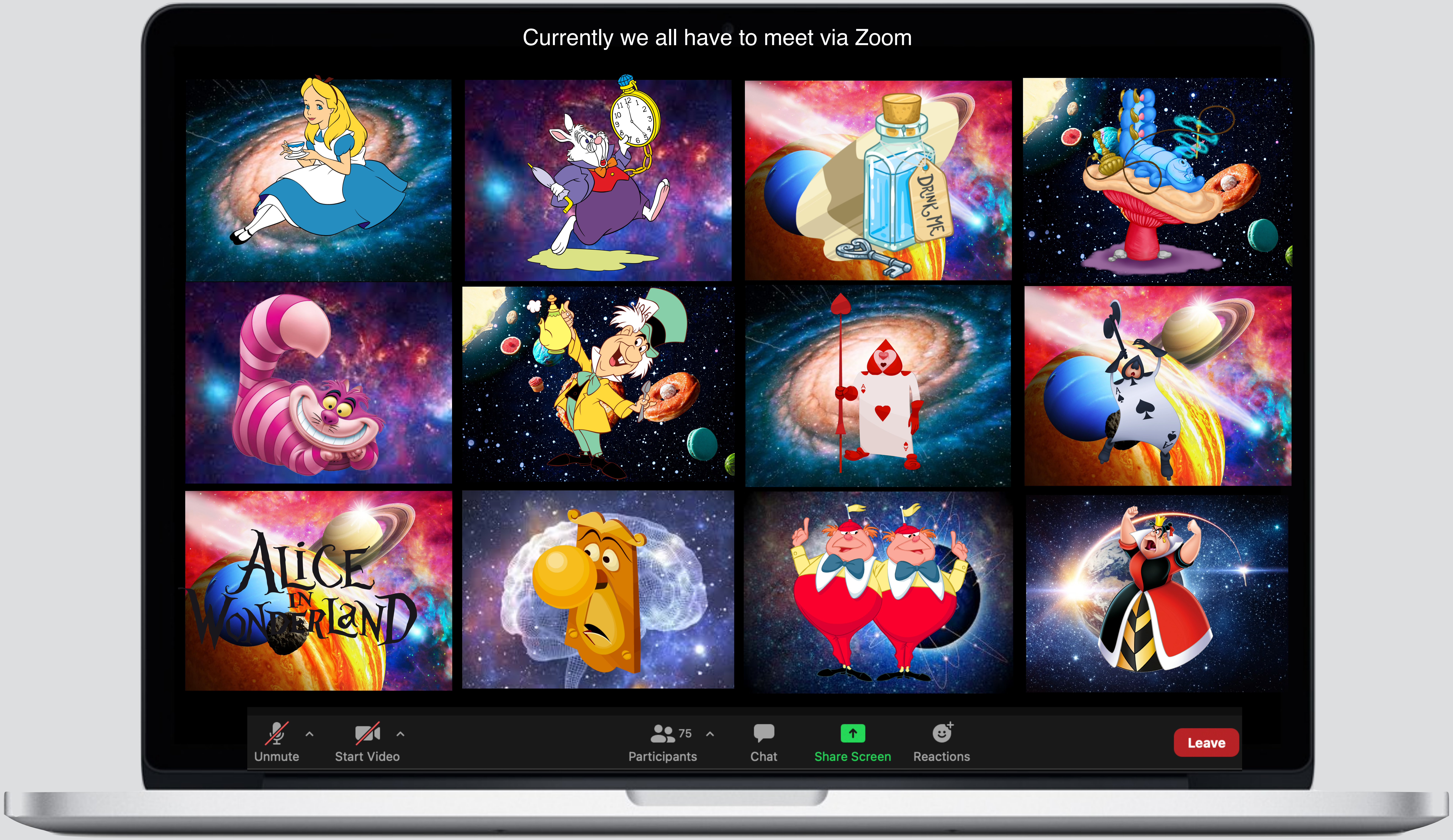
LS4
2031-2032



LS5
2035-2036

ALICE group Zoom meeting





ALICE group Zoom meeting