The ALICE Programme

Raimond Snellings

Programme Leadership: Prof. Raimond Snellings
7 staff, 4 Postdocs, 18 PhD
Publications: 224
Theses: 20
University Partner: Utrecht University
Investment Phase 1&2: 6.3 M
Personal Grants: 4.23M

Nikhef

The ALICE Programme

- **Scientific Question: 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**
    - State of the universe in the first 10 μs
    - 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
  - Properties of the quark-gluon-plasma are still not well understood
    - Theoretically extremely complicated
    - **QCD in the regime of extreme matter with emergent phenomena**
      - Extremely dense, opaque system, which looks thermalized
      - Ideal fluid – viscosity over entropy ratio close to zero
  - Experimentally studied with high-energy nuclear collisions at the LHC at CERN: **the ALICE experiment**

Independent quarks and gluons?

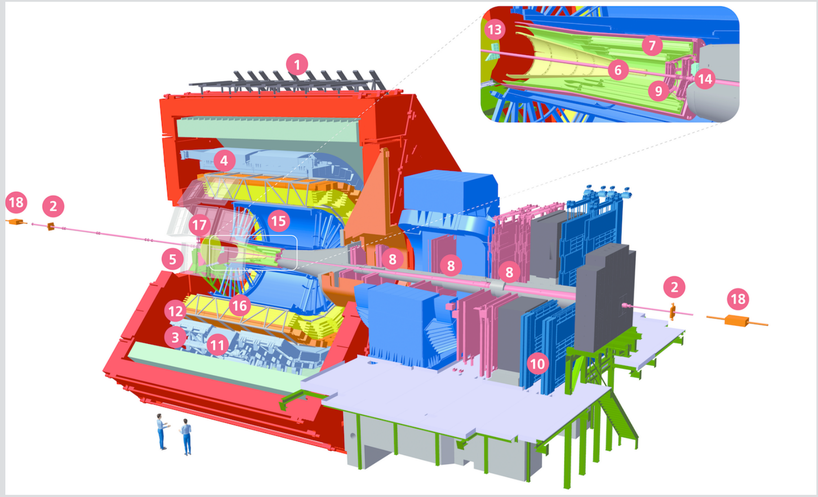
Or new collective degrees of freedom?

The ALICE Programme

- **Dutch ALICE group (Nikhef+UU) is participating in the ALICE experiment at LHC as a leading group**
  - Leading positions in ALICE
  - Well respected for hardware contribution
  - Very productive in data analysis using different probes of the quark-gluon plasma:
    - heavy quarks, elliptic flow & correlations, jets & photons

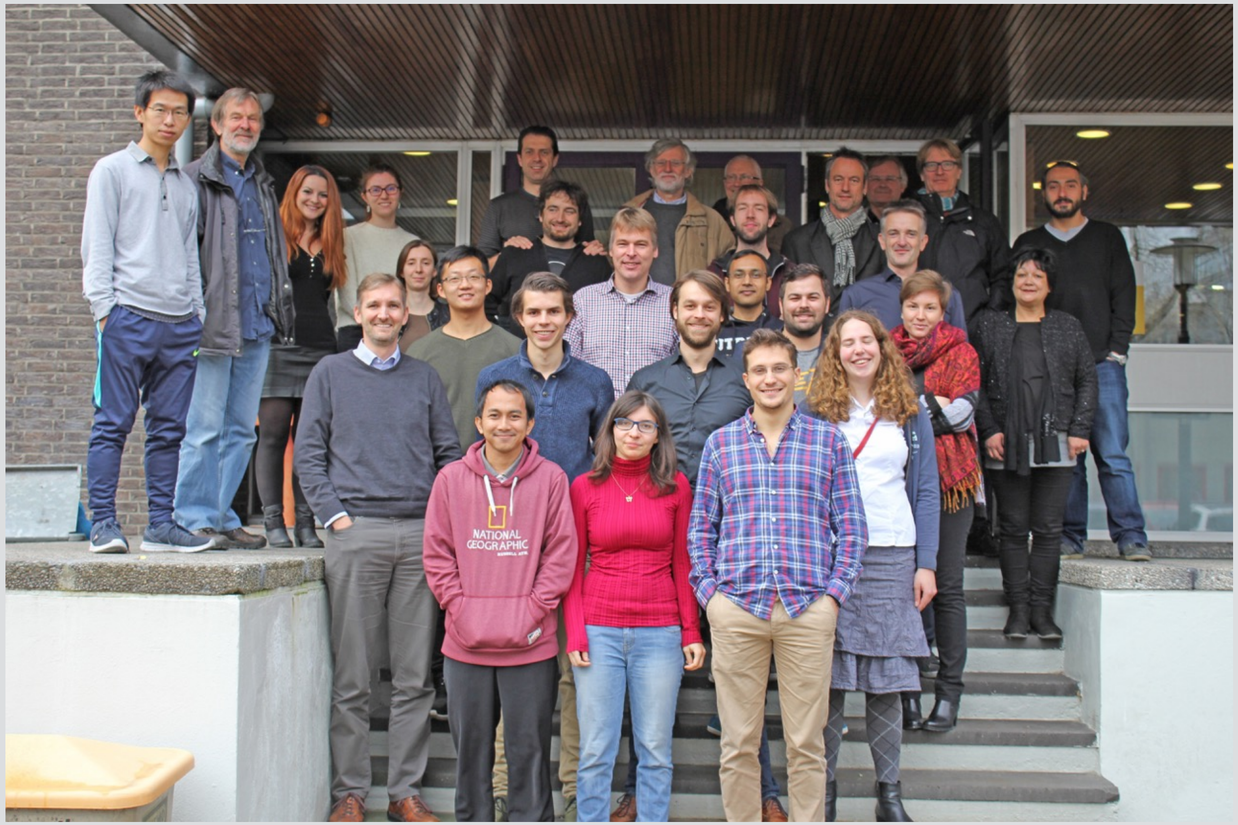
- **Large impact for relatively small group**
  - Impact: among 50 top-cited publications (WoS) from LHC, 15 from ALICE (CMS:15, ATLAS: 12.5, LHCb 7.5)
  - Possible through combination of contributions in hardware (detector technology) and physics analysis.

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

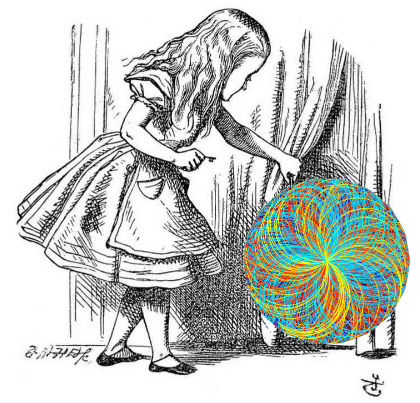


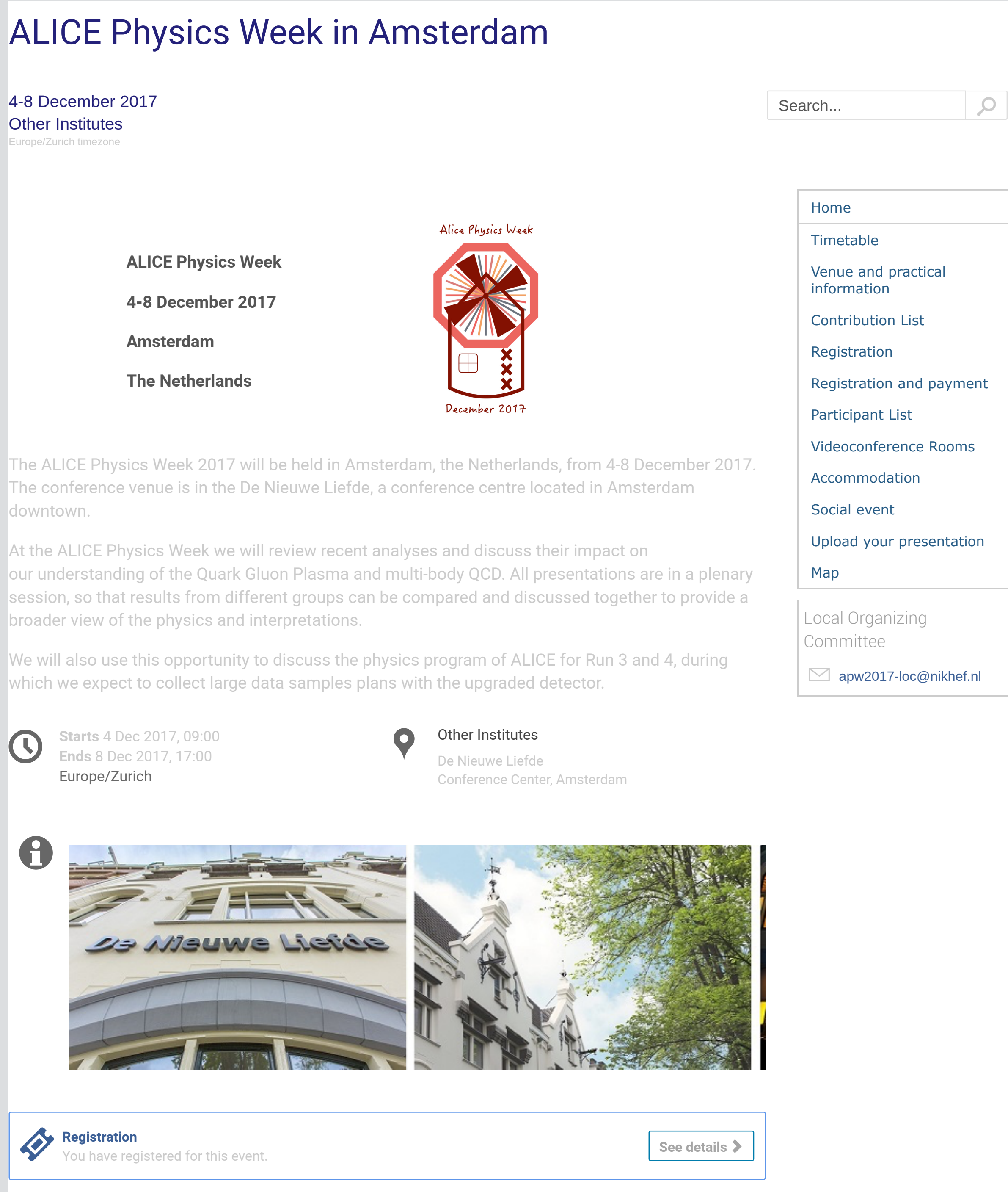
The Nikhef ALICE Group

- The Dutch ALICE team is analysis-wise one of the most productive teams in ALICE
  - Our group produced the most cited ALICE publications, second to the Higgs publications, the most cited LHC publications
- Deputy spokesperson, Physics Coordinator, Upgrade Coordinator, Editorial Board, Conference Committee, Physics Working Group and Physics Analysis Group coordinators
- QM2018: 1 summary talk, 5 talks (one selected as best experimental talk), 4 posters (one selected as flash talk as one of the best posters)



Meetings in the Netherlands

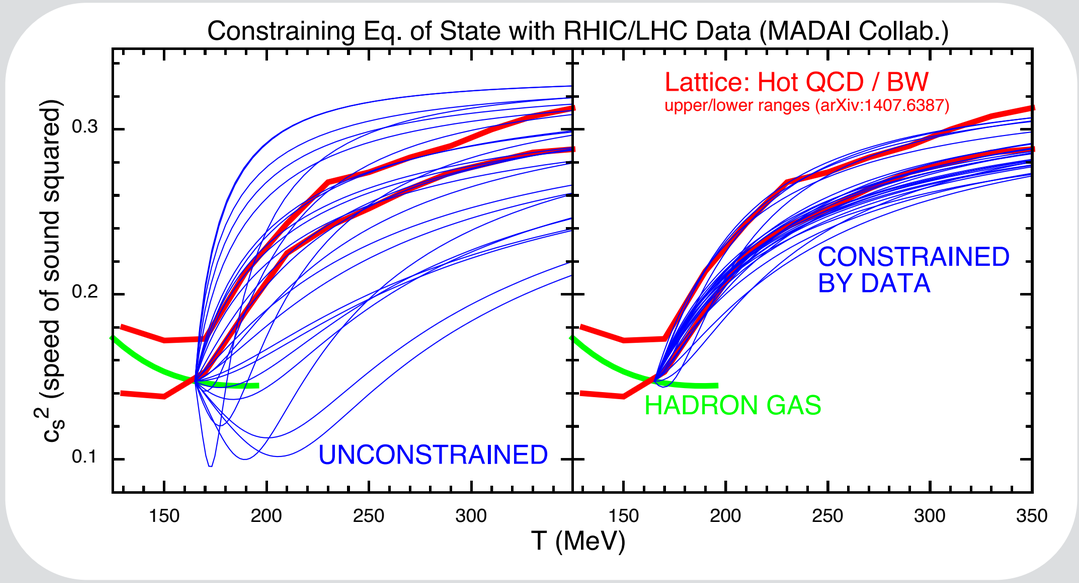


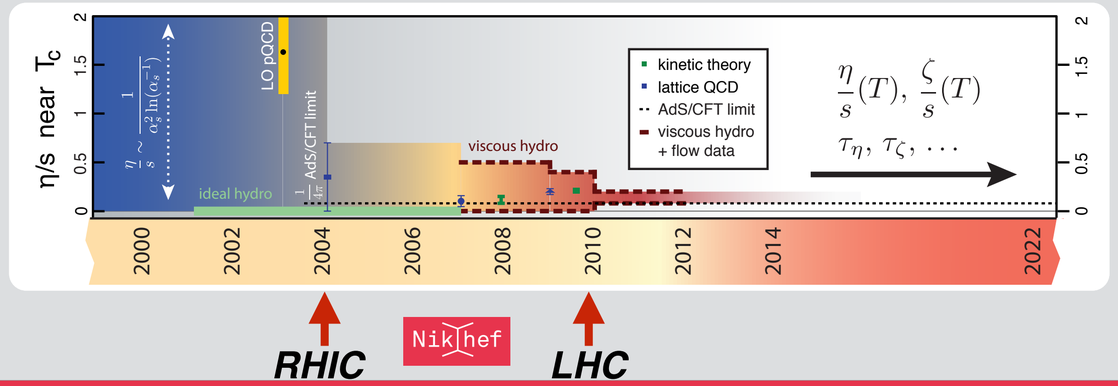


We organized many big meetings in the Netherlands

Some Open Questions:

- Collective Flow
  - already strong constraints on shear viscosity, open questions initial state, hadronization, …
- Hard and EM Probes
  - Medium modification of the jet structure, medium properties, thermalisation, degrees of freedom, …
- Heavy Flavor
  - special role as it is a well calibrated probe and could contribute to better understanding of collective flow and jet-medium interactions
- Angular Correlations
  - Understanding the magnetic field in these collisions and the strong cp violation as well as role of conservation laws in particle production





The ALICE Upgrade in LS2

- We would like to characterize this complex almost perfect liquid (EoS, transport parameters) and understand how it emerges from multi-body QCD

Rare probes: jets, heavy flavor, electromagnetic probes

Nikhef Nikhef Nikhef

Nikhef is leading these Physics Working Groups in ALICE

- Improve statistics: new faster ITS
- Improve S/B: new ITS; smaller pixel size inner layers, less material budget and optimized number of layers

Upgrade to full energy

Increase in luminosity
10x more data

high luminosity LHC
100x more data

LS1
2014

LS2
2019-2020

New ITS
Nikhef

LS3
2024-2026

FoCal?
Nikhef

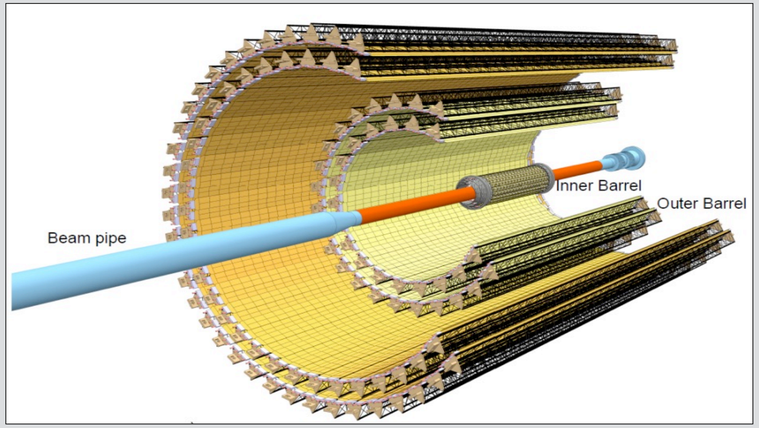
Current program (upgrade and people) funded to 2021
ALICE programme approved to 2029

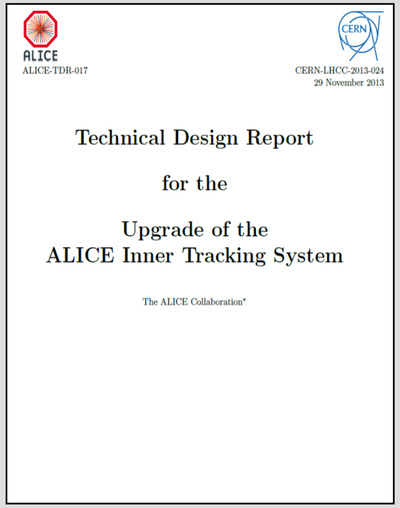
The ALICE Inner Tracker

- The current ITS consists of 6 layers of silicon detectors
  - Nikhef led the construction of the outer two layers of the silicon strip detector
  - This detector worked almost perfectly for the last decade, due to our continuous support for its operation
  - Important for almost every physics analysis in ALICE

The ALICE Inner Tracker Upgrade

- **Improve impact parameter resolution by a factor of 3**
  - Get closer to the IP: first layer 39mm -> 22 mm
  - Reduce material budget: 1.14% -> 0.3% X_0 per layer or better
  - Increase pixel density 50μm 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 extension 39-430 mm -> 22-430mm
- **Fast PbPb (and pp) readout**
  - Instantaneous luminosity: $6x10^{27}$ $cm^{-2}s^{-1}$ gives hadronic interaction rate of 50kHz
  - Current ITS slow, maximal readout at 1 kHz
  - In new setup Pb-Pb collisions are readout at > 50 kHz and pp at > 2 MHz




ALICE
ALICE-TDR-017

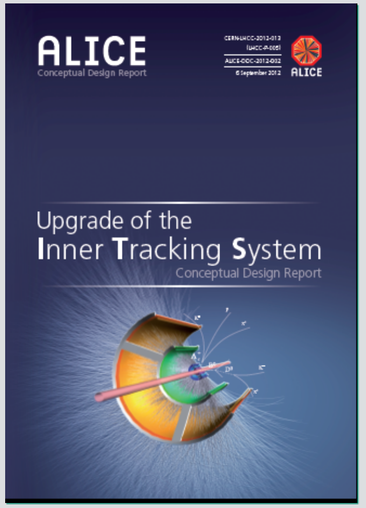
CERN-LHCC-2013-024
29 November 2013

Technical Design Report

for the

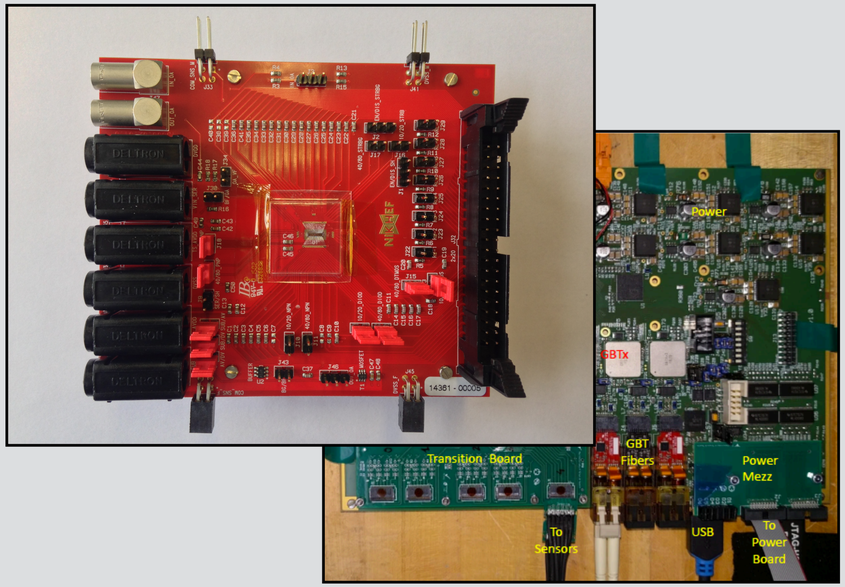
Upgrade of the
ALICE Inner Tracking System

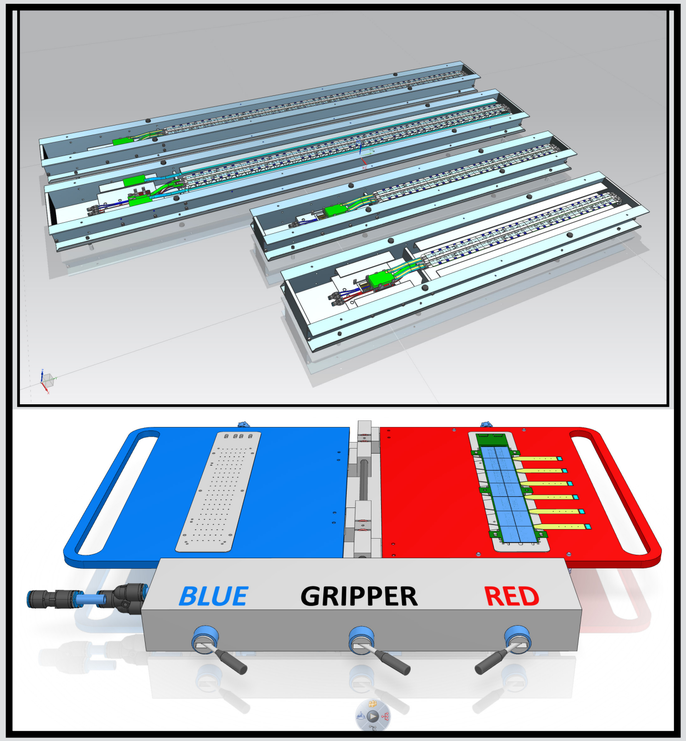
The ALICE Collaboration*



The ALICE Inner Tracker Upgrade

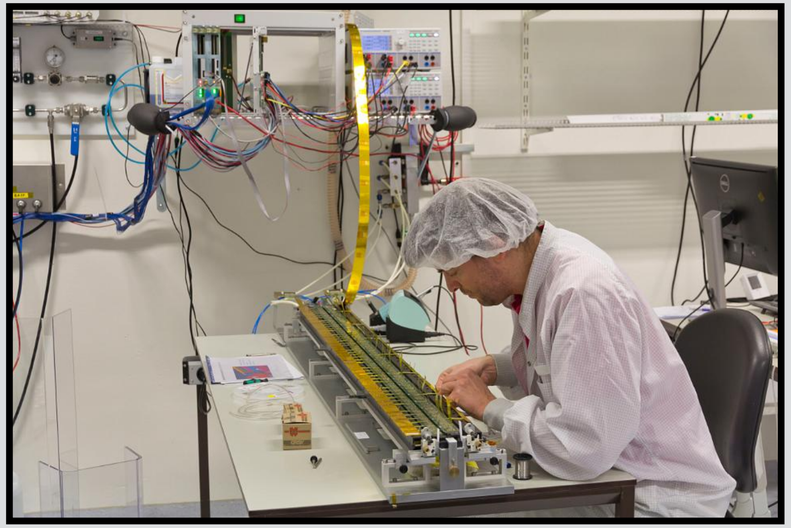
Electronics





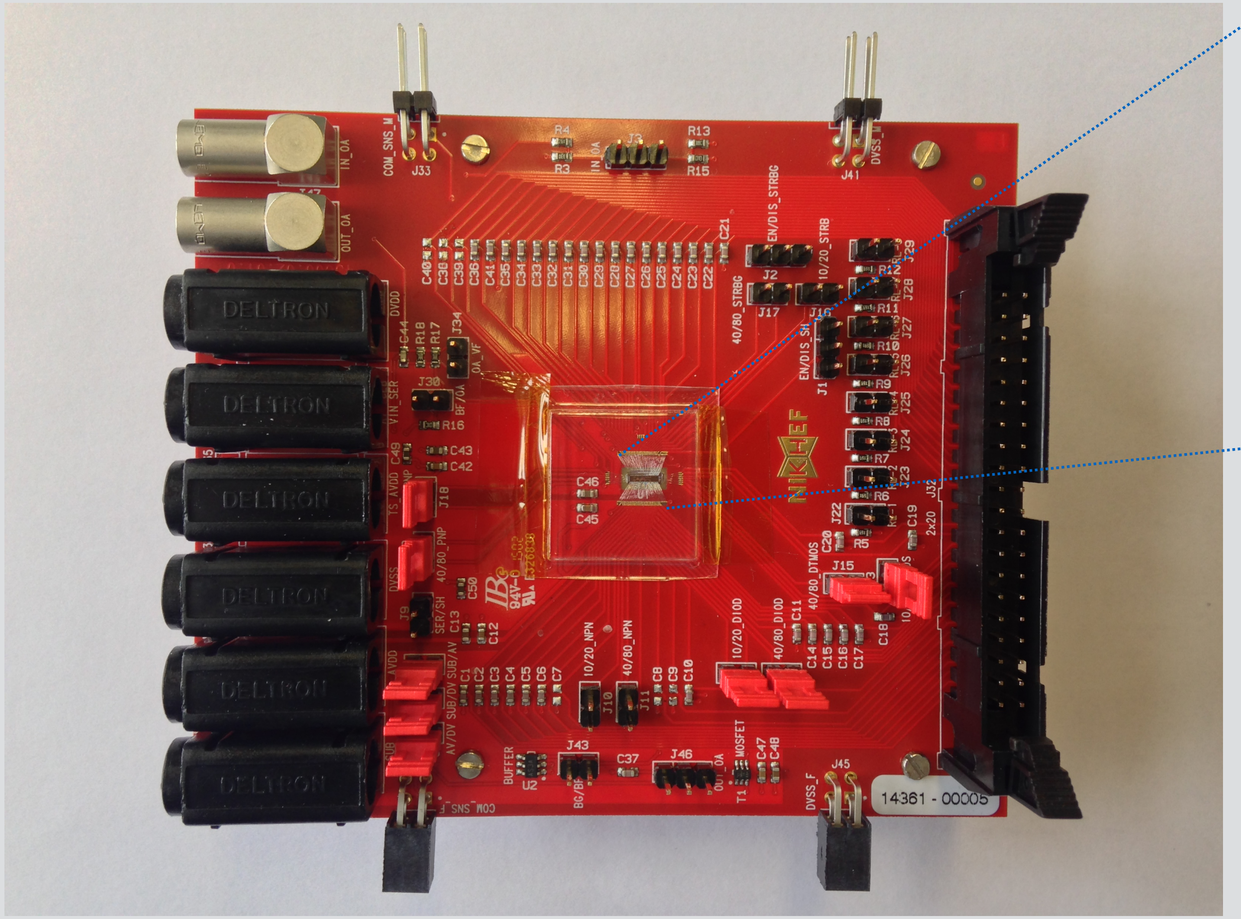
Tooling/Hardware

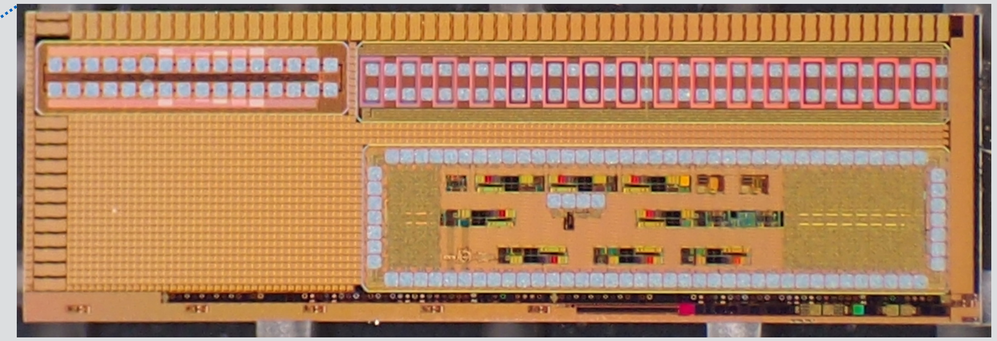
Stave assembly



The ALICE Inner Tracker Upgrade

Produced and tested variants of band-gap and temperature sensor





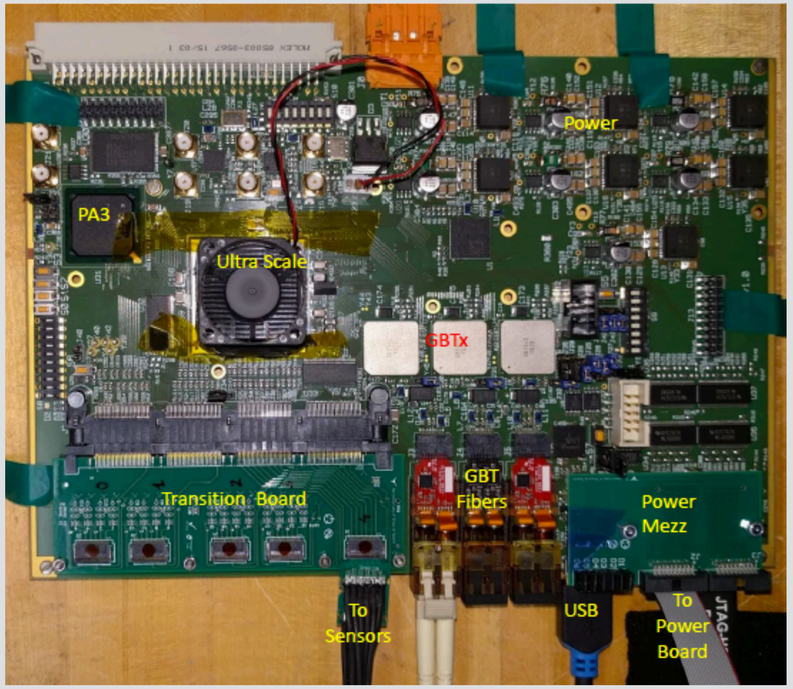
Both circuits behave exactly as designed and simulated
Both are integrated in ALPIDE

Deepak Gajanana
German Henao

Nikhef

The ALICE Inner Tracker Upgrade

- Nikhef/UU is responsible for the integration of the read-out unit (between pixel modules and DAQ)
  - Interface to local power supplies (Berkeley)
  - Interface to pixel modules (CERN)
  - GBT link to DAQ
- Cabling
  - UU+Nikhef test data transport across (firefly) cables and between modules
- Design and prototyping complete
  - Tender completed
  - UU will do test pre-series (25 boards)
  - Nikhef does acceptance test for full series (200 boards)



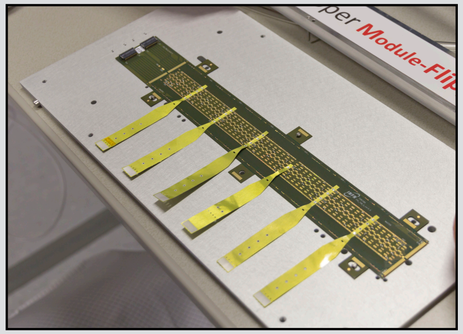
Marcel Rossewij
Jan-David Schipper

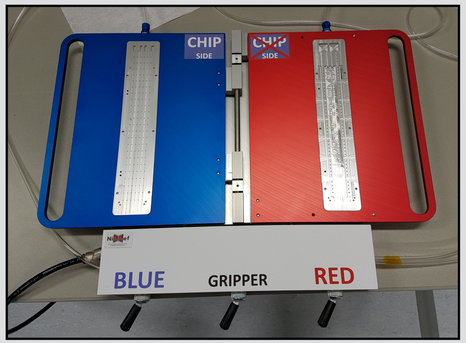
Nikhef

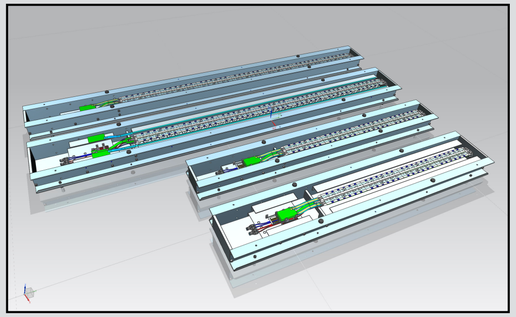
Universiteit Utrecht

The ALICE Inner Tracker Upgrade

- Reception of material
- Acceptance testing (QA)
  - Powering
  - FIFO
  - Memory tests
  - Resistance/connections
- Flipping
- 10 μm precision cutting
- Post-cut testing
- Storage/ assembly/shipping

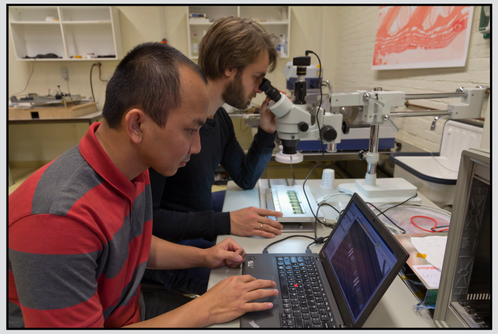


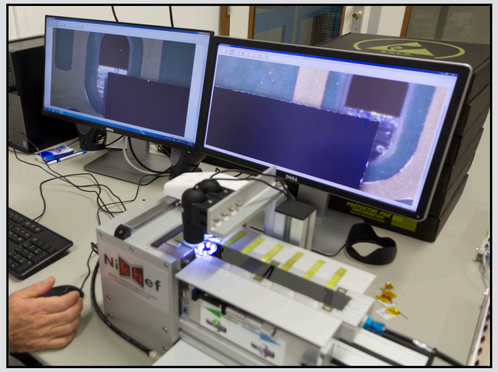




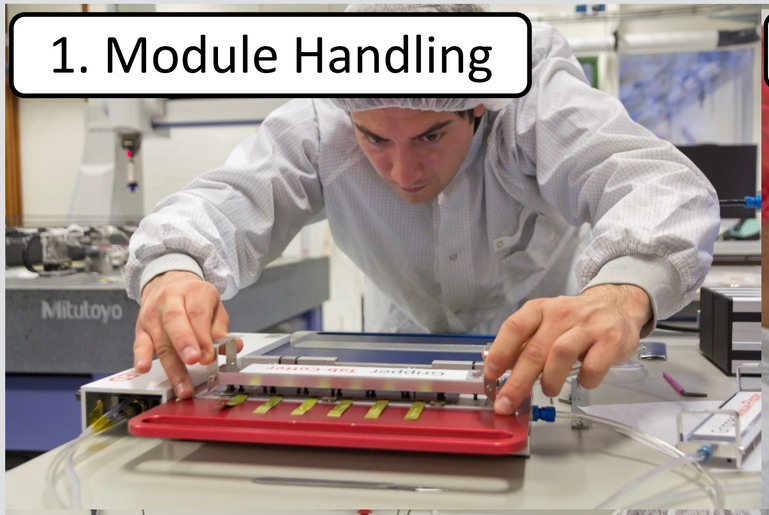
Nikhef

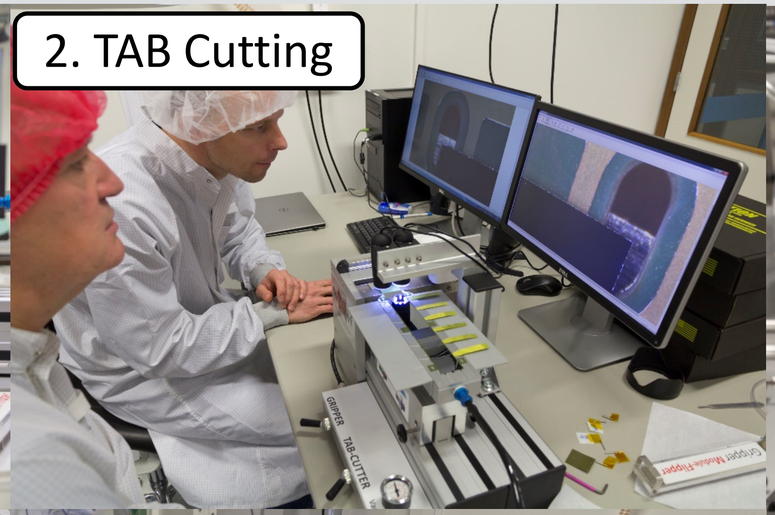
Large student involvement

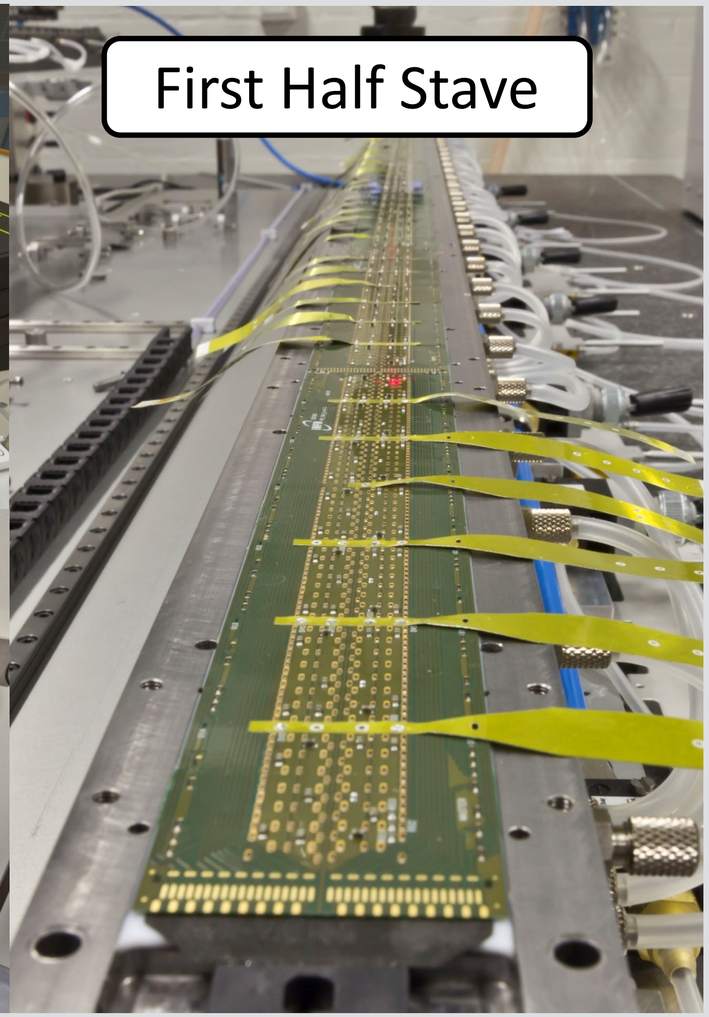


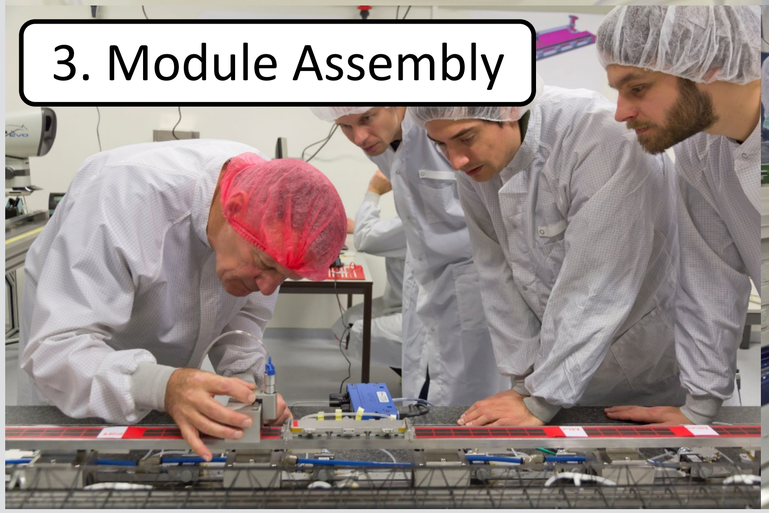


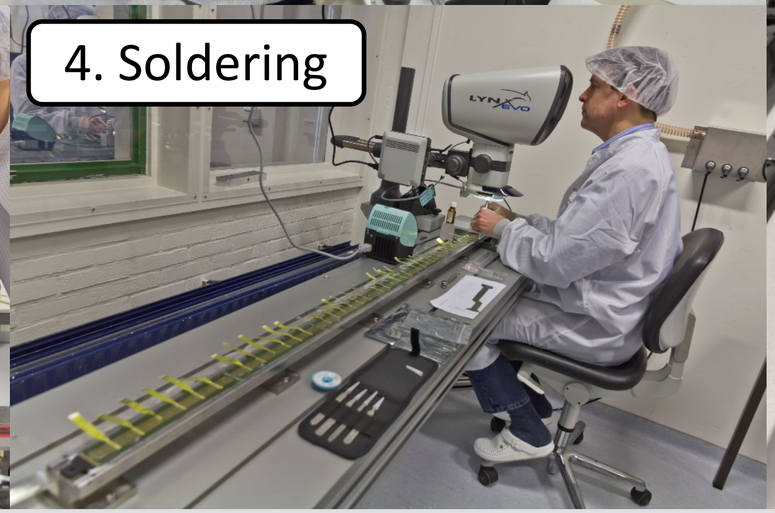
The ALICE Inner Tracker Upgrade







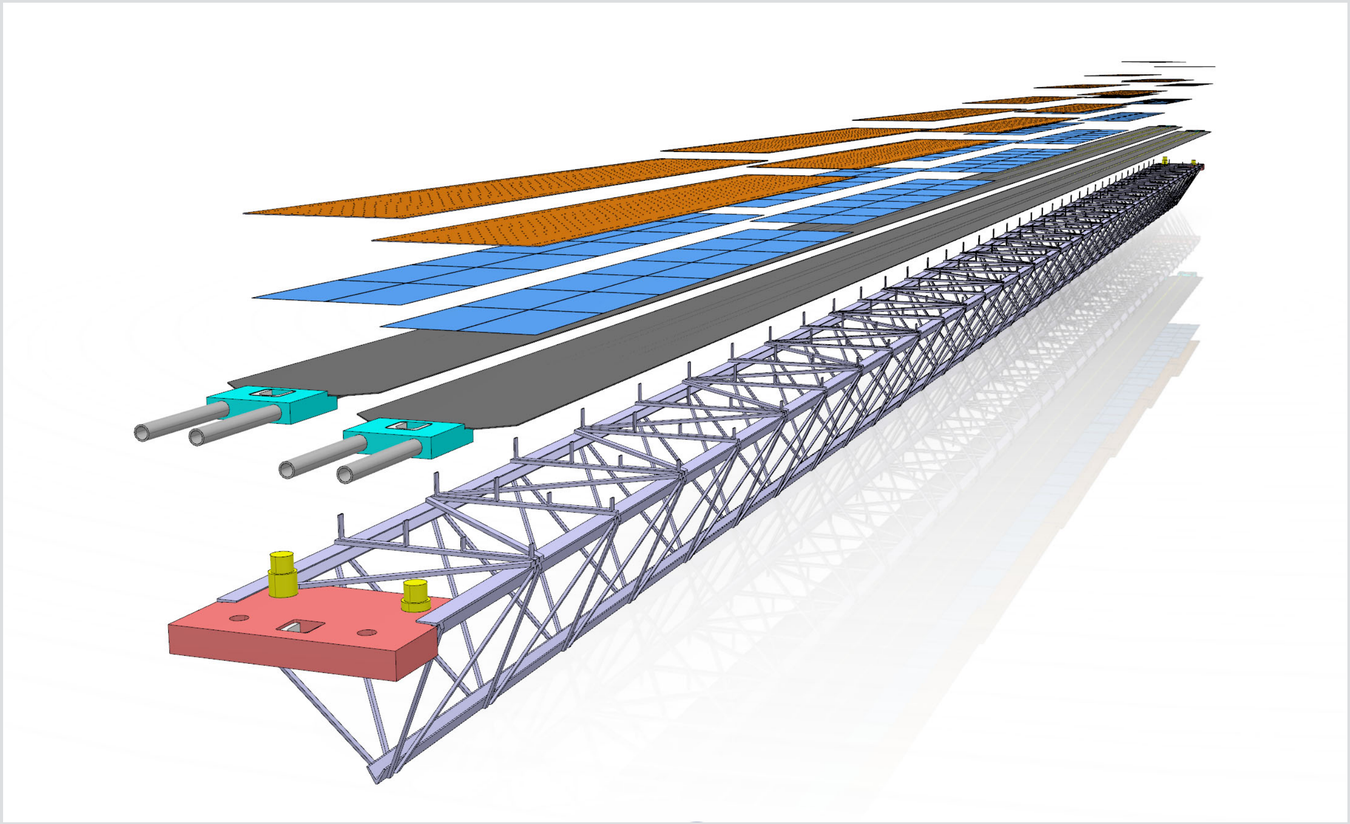




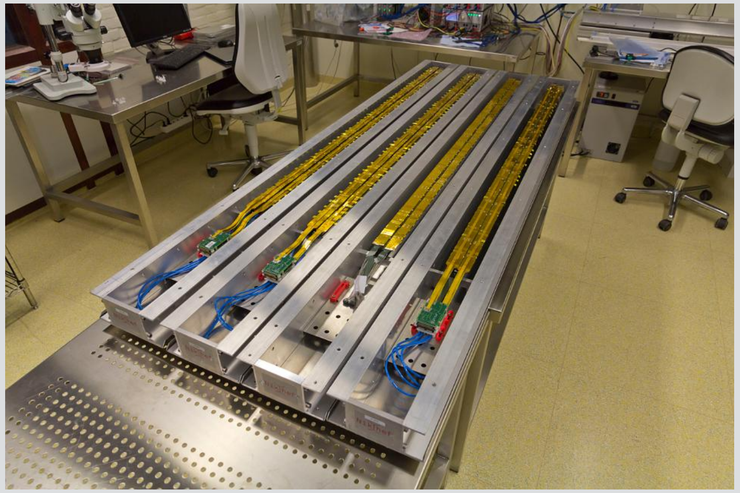
The ALICE Inner Tracker Upgrade

Universiteit Utrecht

Nikhef

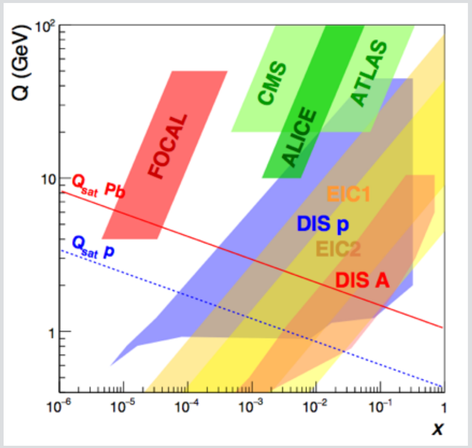


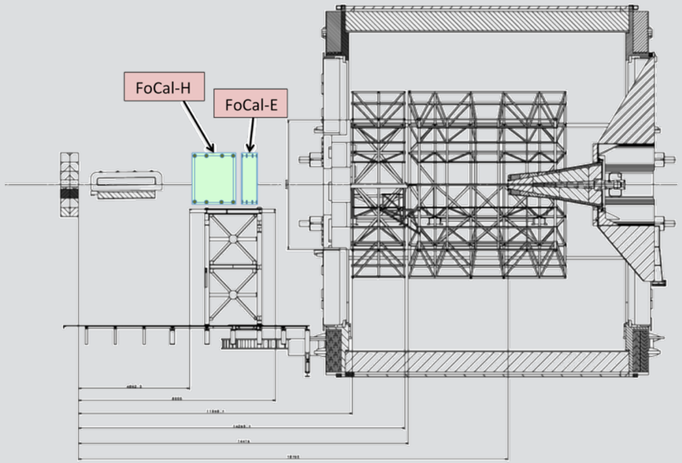
- Nikhef will produce 25% of the OB staves
- Commissioning and assembly started, 4 full staves ready so far
- Expected production rate > 25 staves per year
- Final delivery to CERN in July 2019 is on track



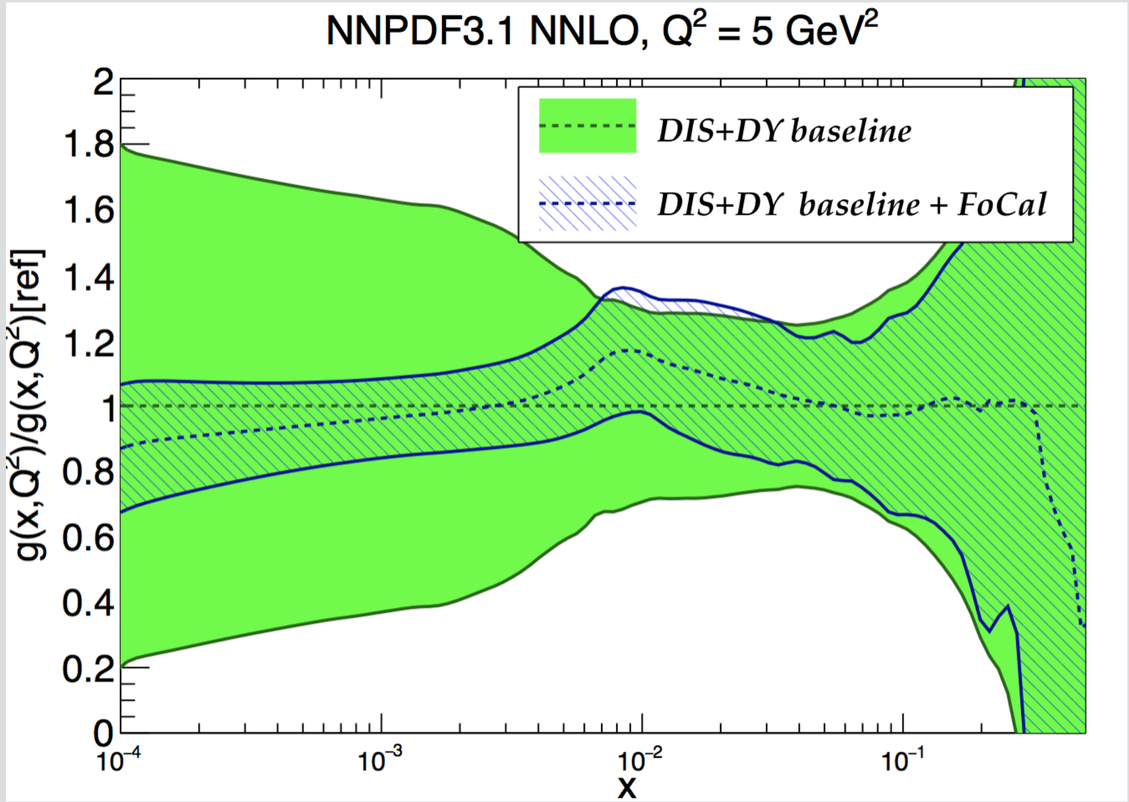
FoCal Upgrade

- Proposal to measure forward direct photons to study low-x gluon distributions (under discussion for installation in ALICE during LS3)
  - EM probes provide best sensitivity to initial state distributions
  - In ALICE the region $3.5 < \eta < 5.3$ can be used
  - Main challenge is to separate γ/π^0 at high energy
    - π^0 at forward rapidity $p_t = 10$ GeV has d = 2mm
  - Need small Moliere radius and high granularity read-out for EM calorimeter

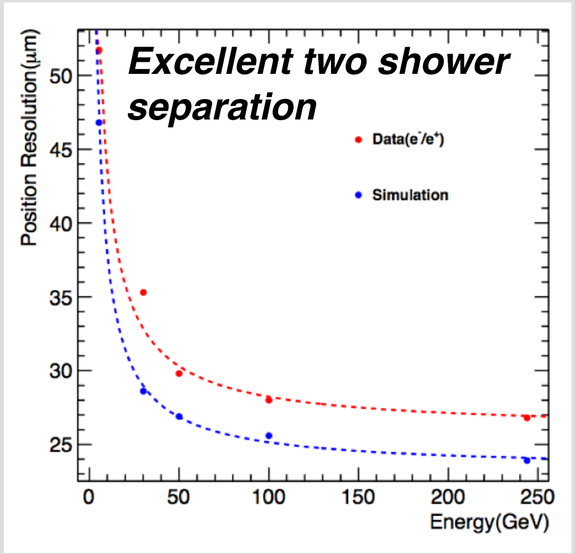


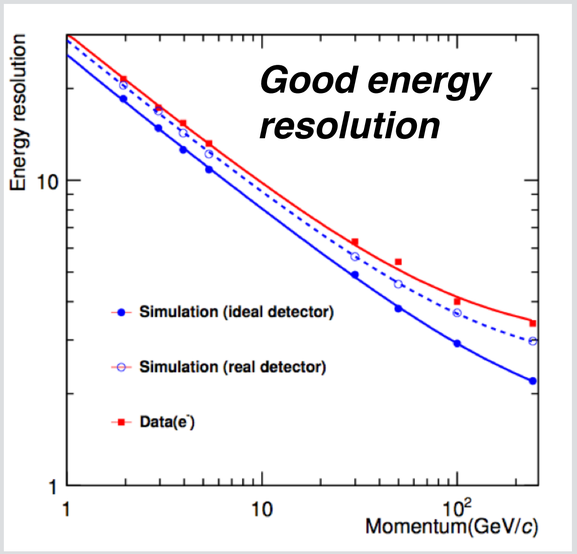


Juan Rojo (VU and Nikhef)



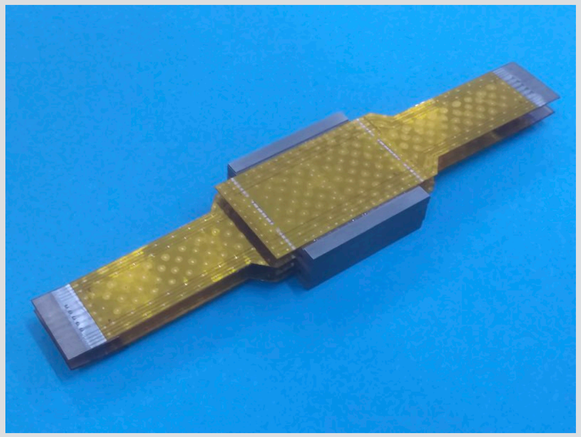
FoCal Upgrade





$$\frac{\sigma_E}{E} = a \oplus \frac{b}{\sqrt{E/\mathrm{GeV}}} \oplus \frac{c}{E/\mathrm{GeV}}$$

$$a = (2.95 \pm 1.65)\%$$
$$b = (28.5 \pm 3.8)\%$$
$$c = 6.3\%$$



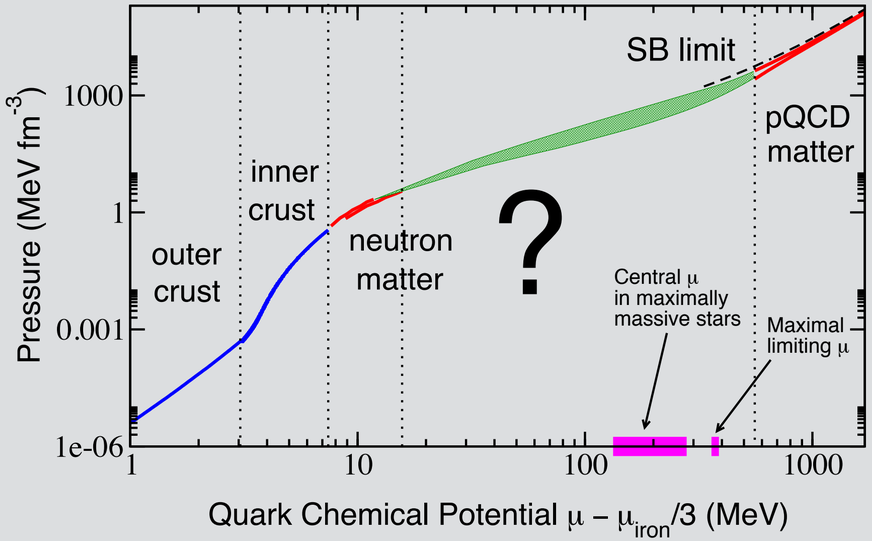
Next prototype (tungsten+two Alpides per layer and cables)

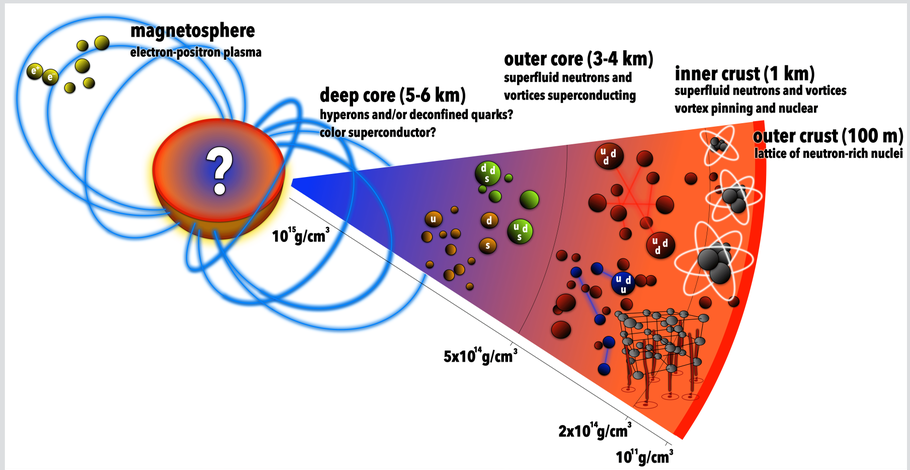
mini-FoCal (pad-only) currently in ALICE cavern for tests

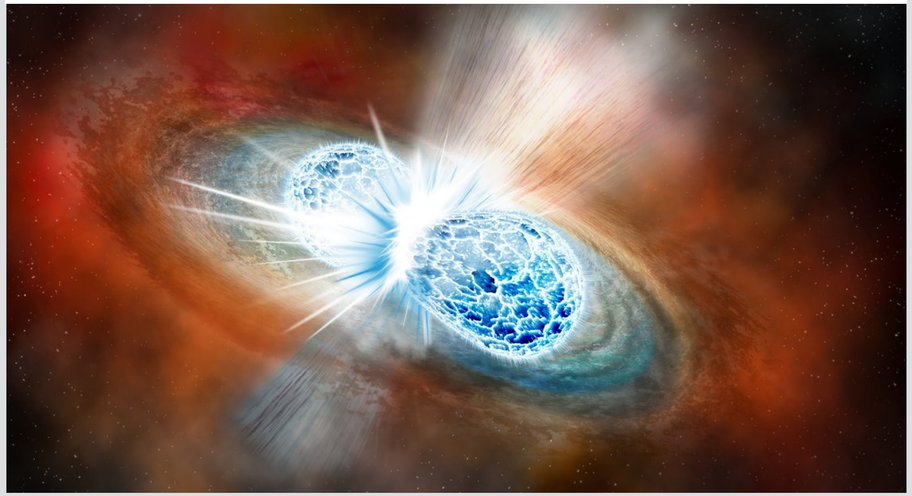
- R&D at Nikhef+UU on high granularity layers for FoCal upgrade proposal
  - Successful proof of principle of digital calorimetry
  - Enables unique measurement in ALICE
  - goal to get internal ALICE approval this year
  - LHCC and TDR 2019?

QGP in Neutron Stars?

- Densest objects in nature
- The balance of gravity and QCD
  - A neutron star is a macroscopic laboratory of QCD!
    - Deep core of some neutron stars could be a QGP



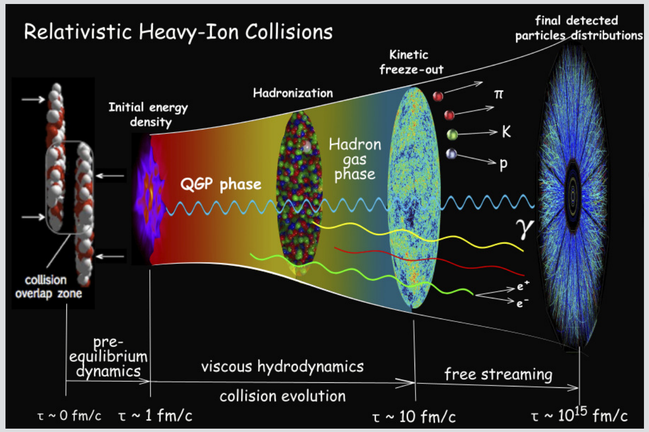


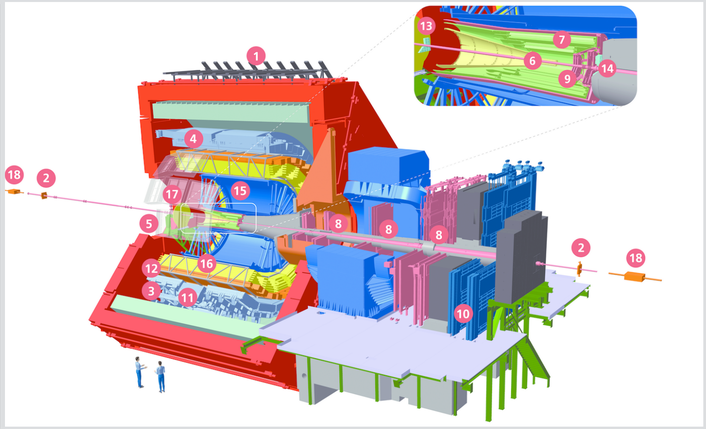


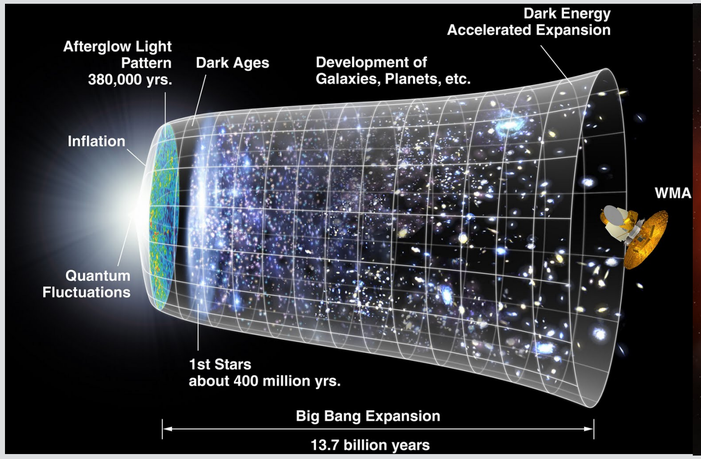
- First neutron star merger observed in Virgo/Ligo
  - Already providing constraints on the EoS
- Detailed understanding of the dynamics is required to understand the properties of the neutron star interior
  - EoS, transport parameters, ..
  - Strong overlap with the physics of heavy-ion collisions

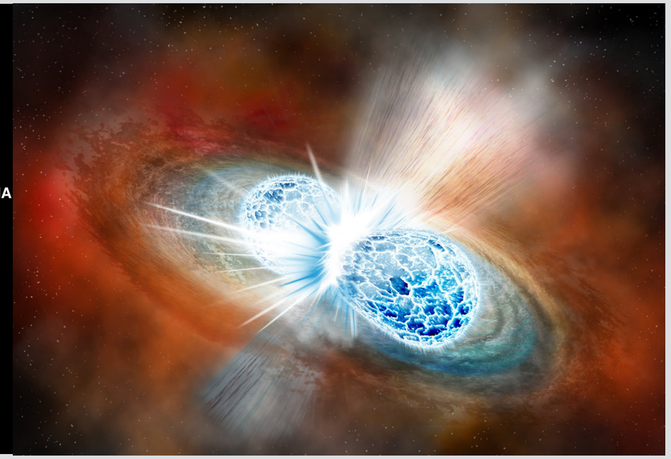
At Utrecht University ambition to form new Institute for Subatomic and *Gravitational* Physics

Our Ambitions









- ALICE programme to 2029
  - Need to secure funding
- Possible extensions (FoCal?)
- Gravitational Waves (Virgo, ET)
  - Funding requests via NWO Physics, Zwaartekracht proposal, Sectorplan

Study QCD in the regime of extreme matter with emergent properties

ALICE in the LHC Wonderland

- Colliding heavy-ions at the LHC allows us to create and study a new state of matter
- Its emergent properties are surprising and completely different than predicted, now they can be measured and modeled for the first time
  - Still many important open questions
- The Nikhef ALICE group is one of the most productive groups with strong contributions to the collaboration
- ITS upgrade well on track
- Strong future programme and ambitions!