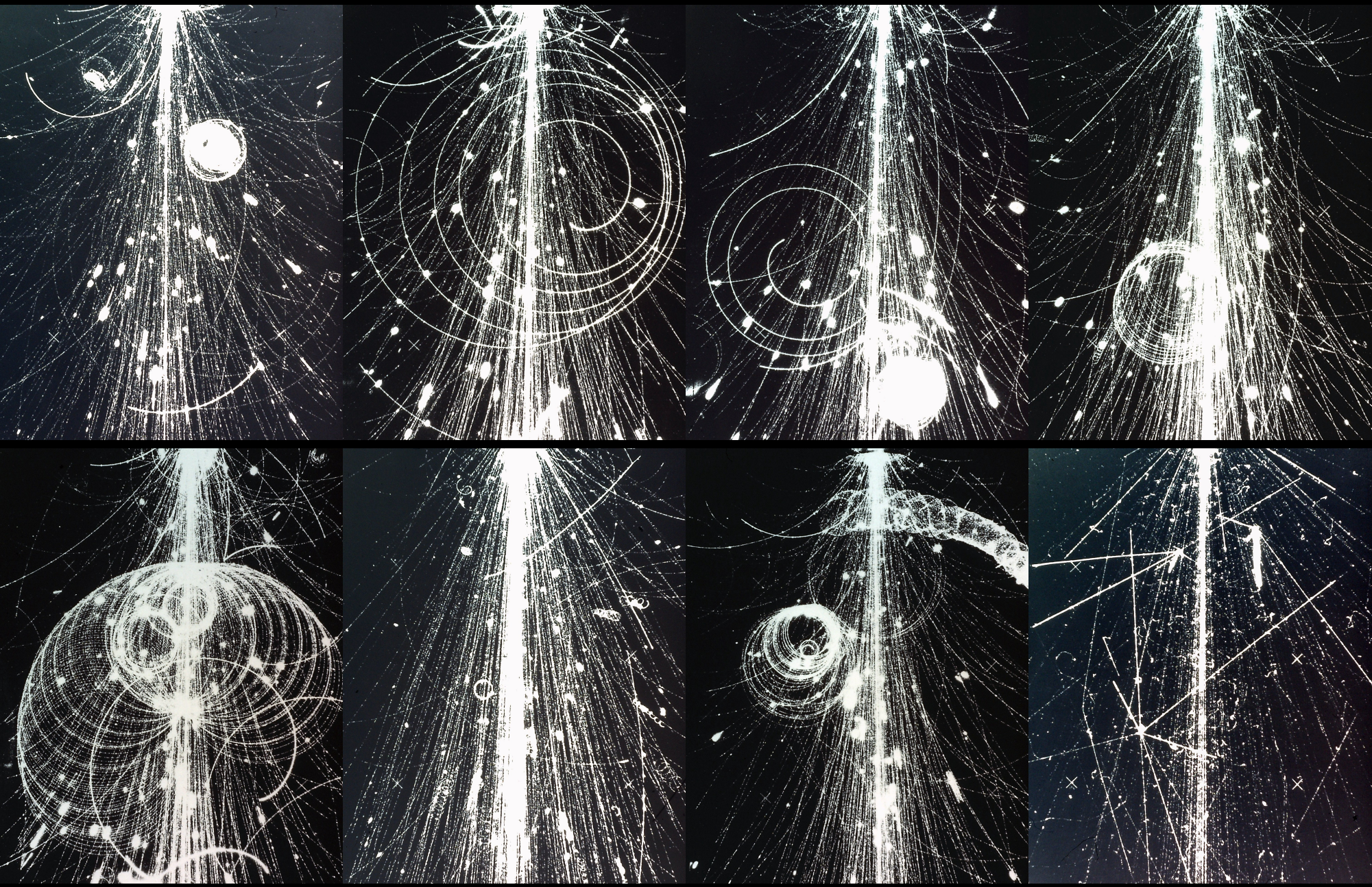
The Cosmic-Ray Program of the NA61/SHINE Facility at the CERN SPS

M. Unger (KIT) for the NA61/SHINE Collaboration



NA35 3.2 TeV O+Pb interactions

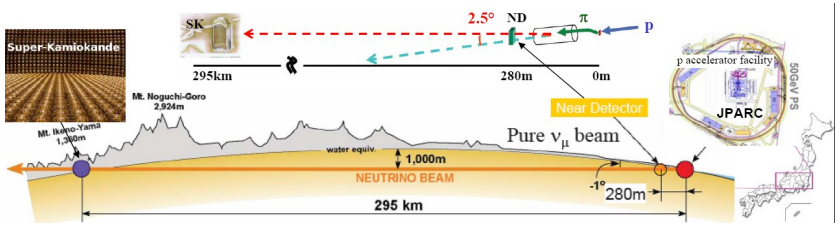
INFN Brainstorming Session 2022

NA61/SHINE

≈ 140 physicists from 14 countries and 28 institutions

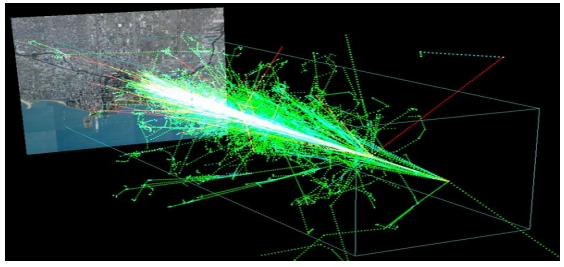
Strong interactions physics

- search for the critical point of strongly interacting matter
- study of the properties of the onset of deconfinement
- heavy quarks: direct measurement of open charm at SPS energies



Neutrino and cosmic ray physics

- hadron measurements for the J-PARC neutrino program
- hadron measurements for the Fermilab neutrino program
- measurements for cosmic ray physics (Pierre-Auger and KASCADE experiments) for improving air shower simulations
- measurements of nuclear fragmentation cross sections of intermediate mass nuclei needed to understand the propagation of cosmic rays in our Galaxy



CR groups: KIT (Germany), Uni. Hawaii (USA), Uni. Silesia (Poland)

The Super Proton Synchrotron (SPS) at CERN

LHC

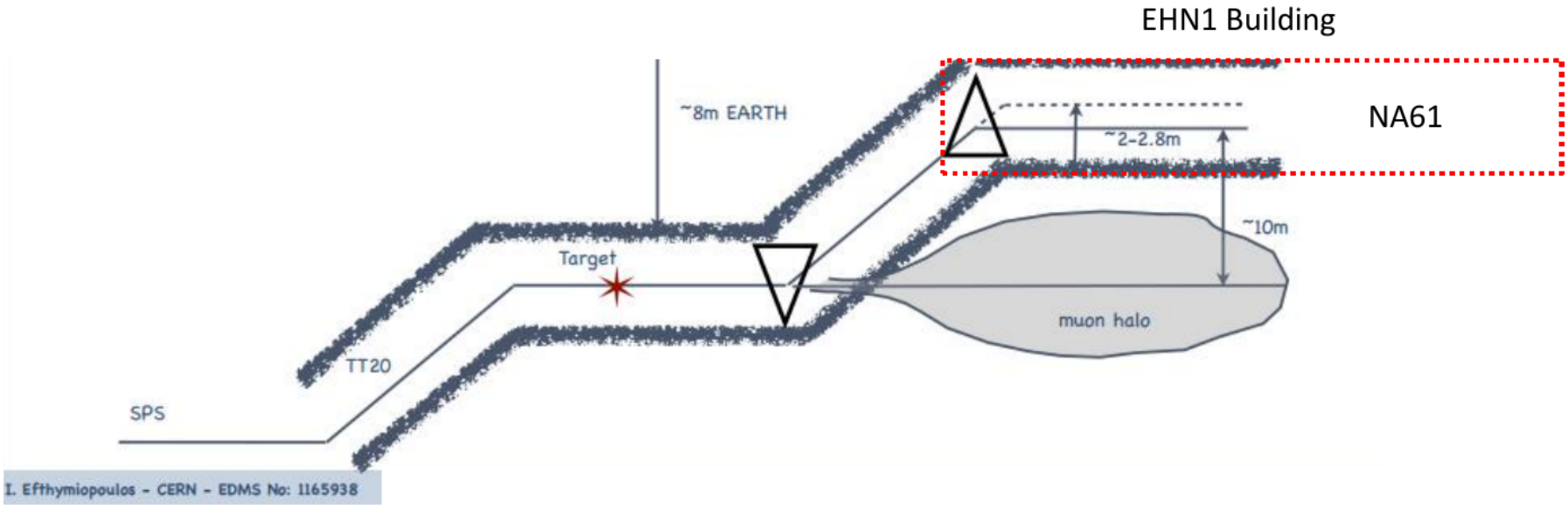
SPS

Maximum Beam Momentum: Z× 450 GeV/c, accelerates p, $\bar{p}$, O, S, Ar, Pb...

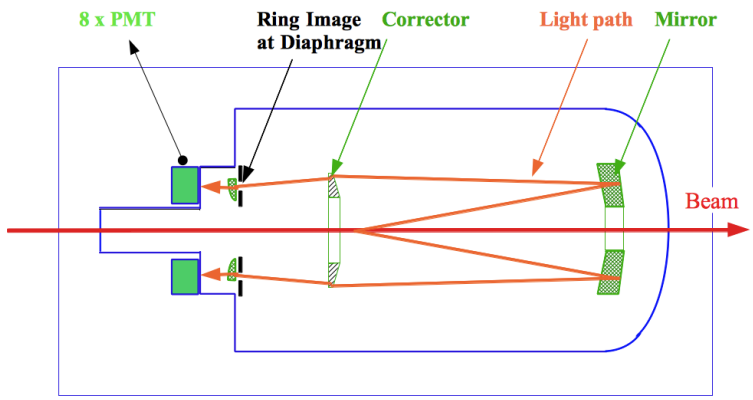
H2 Beam Line: Primary Beam, fragments, $\pi^{\pm}$, $K^{\pm}$...

H2

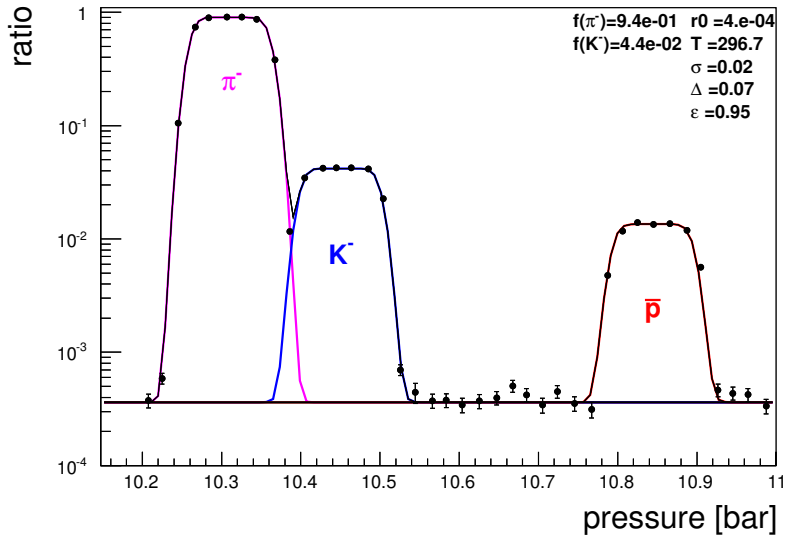
A **precise** (2% dp/p acceptance), robust, flexible **magnetic spectrometer**



Beam Particle Id (Mass via Cherenkov Angle)



CEDAR (CErenkov Differential counters with Achromatic Ring focus)



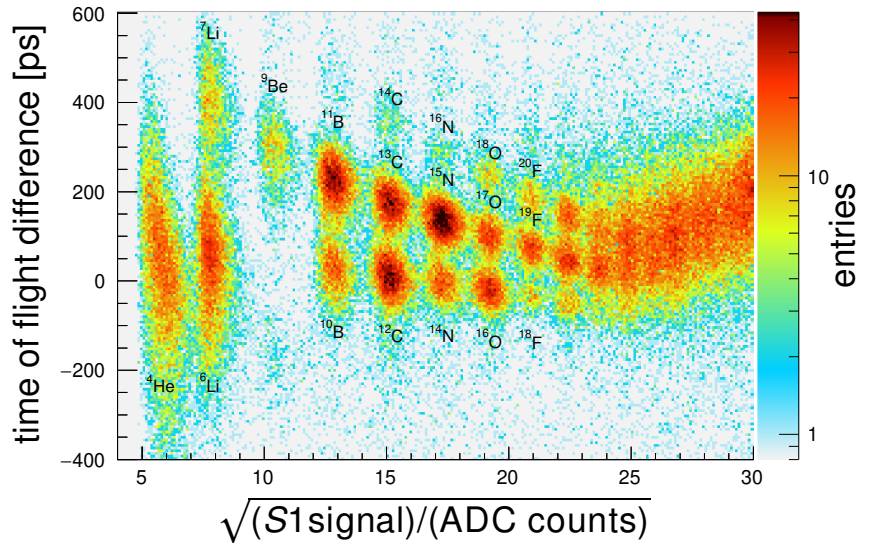
pressure scan

H2

SPS

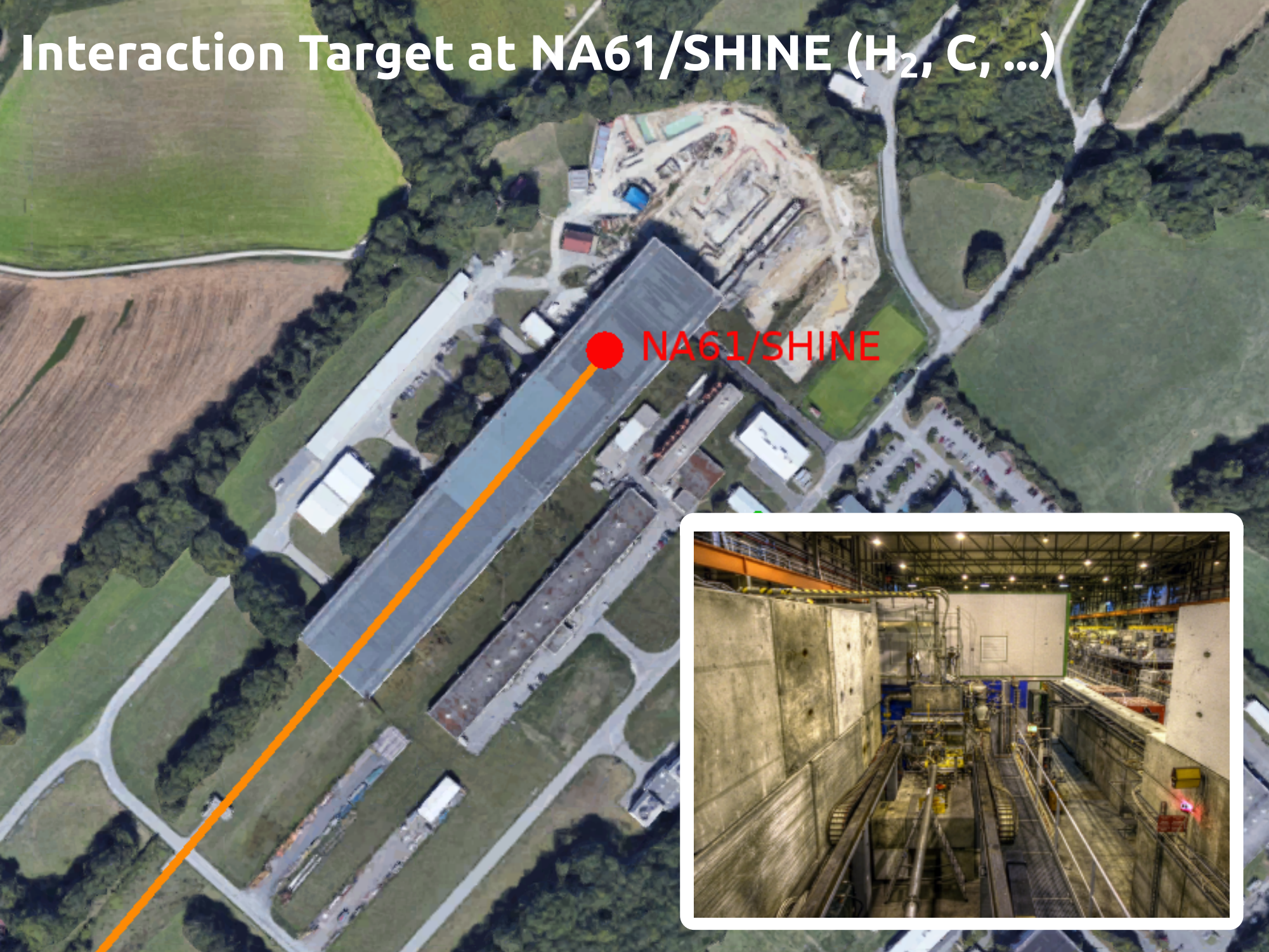
Beam Particle Id (A and Z with ToF, dE/dX, Č)

installation of ToF cable along H2 beam line, Feb 2018

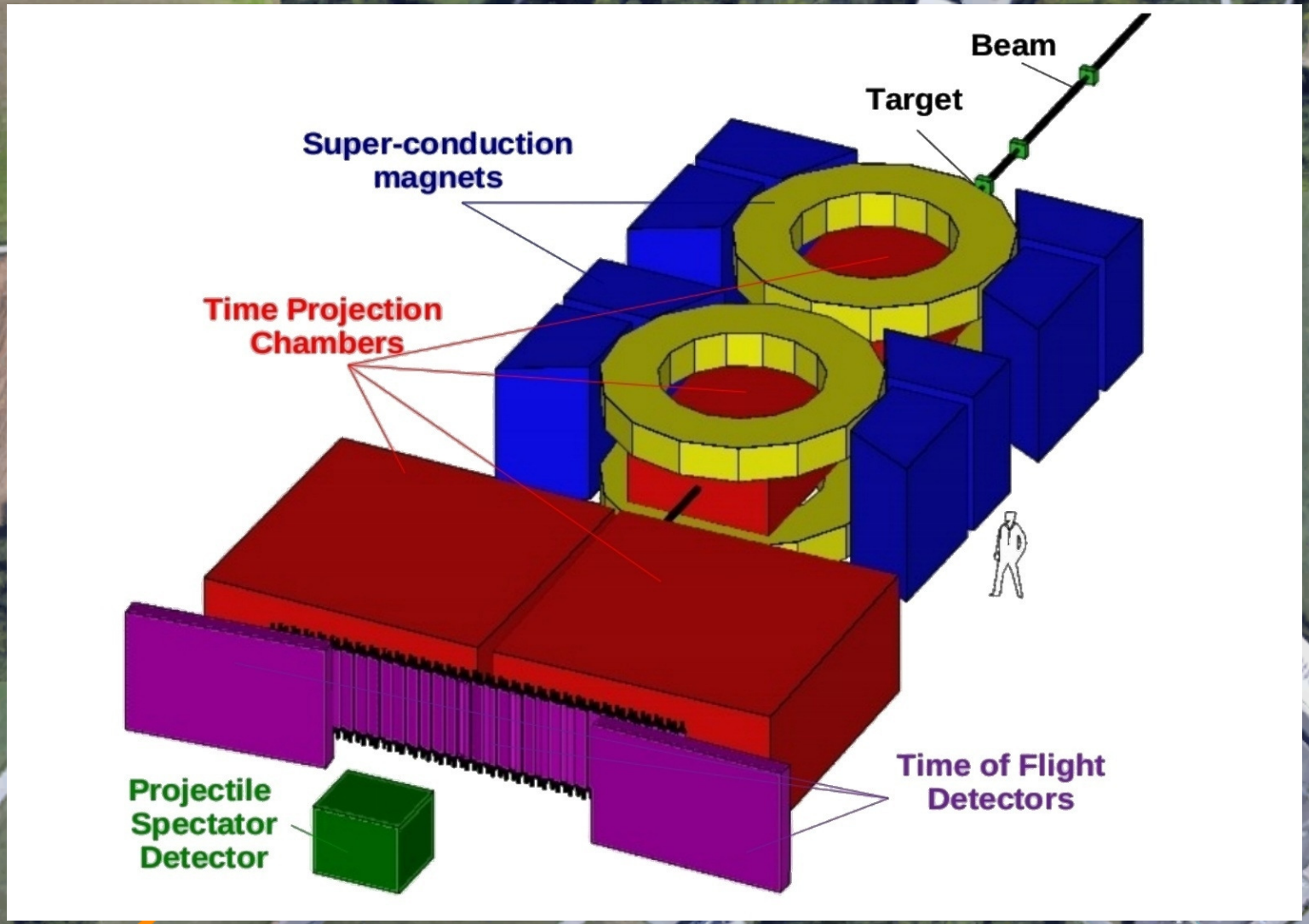


ToF and dE/dx, Fragmentation run Dec 2018

Interaction Target at NA61/SHINE (H_2, C, ...)



Particle Production Measurement at NA61/SHINE



- large acceptance $\approx 50\%$ at $p_T \leqslant 2.5$ GeV/c
- momentum resolution: $\sigma(p)/p^2 \approx 10^{-4}(\text{GeV/c})^{-1}$
- tracking efficiency: $> 95\%$, pid with dE/dx and ToF

Cosmic Ray Related Measurements with NA61/SHINE

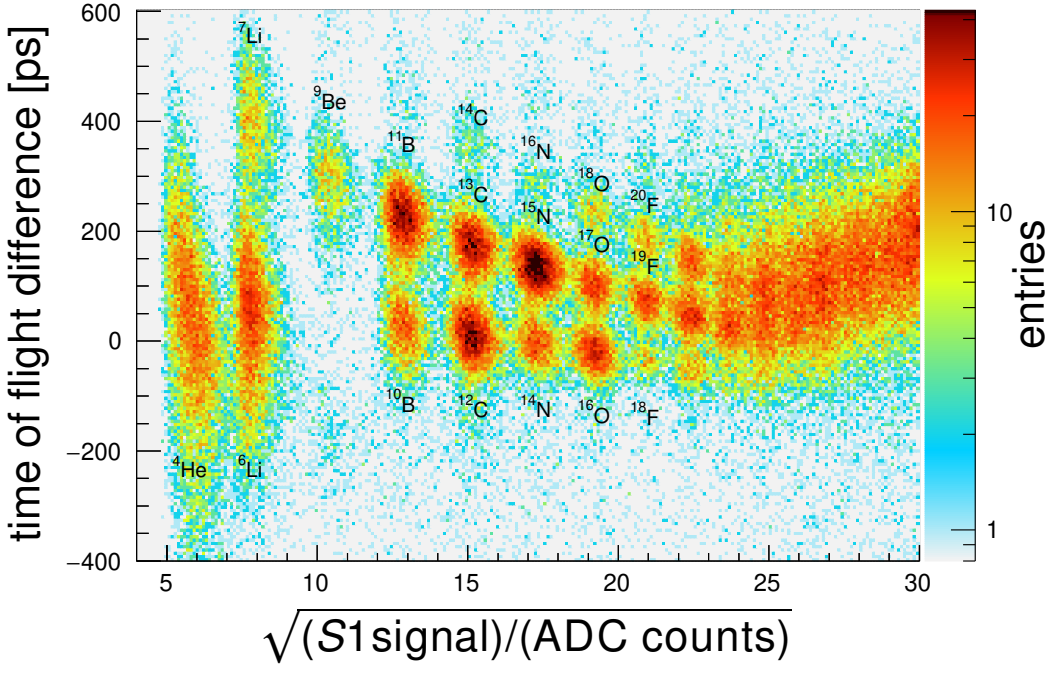
- Particle Production in Air Showers
  - p+C Interactions
    (31, 60, 90, 120 GeV/c)
  - π+C Interactions
    (60, 158, 350 GeV/c)

- Galactic Cosmic Rays
  - d, $\bar{d}$ and $\bar{p}$ Production
    (p+p at 20, 31, 40, 80, 158, 400 GeV/c)
  - Nuclear Fragmentation
    (C+C, C+CH_2 at 13.5 AGeV/c)

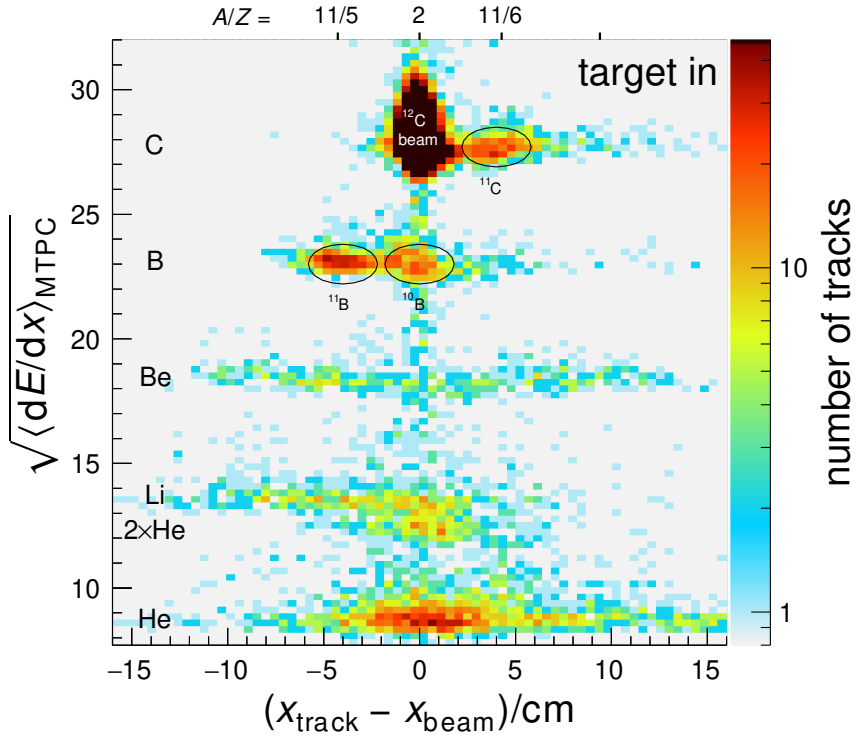
PRC **84** (2011) 034604, PRC **85** (2012) 035210, PRC **89** (2014) 025205, EPJ **C74** (2014) 2794, EPJ **C76** (2016) 84, EPJ **C76** (2016) 198, EPJ **C77** (2017) 671
EPJ **C77** (2017) 626, PRD **98** (2018) 052001, arXiv:2209.10561

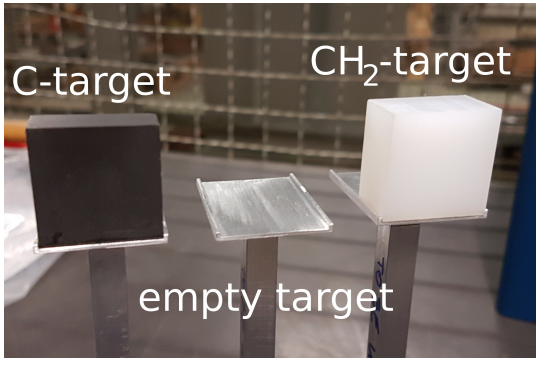
NA61/SHINE Pilot Run on Fragmentation, Dec 2018

SPS beam-fragment identification



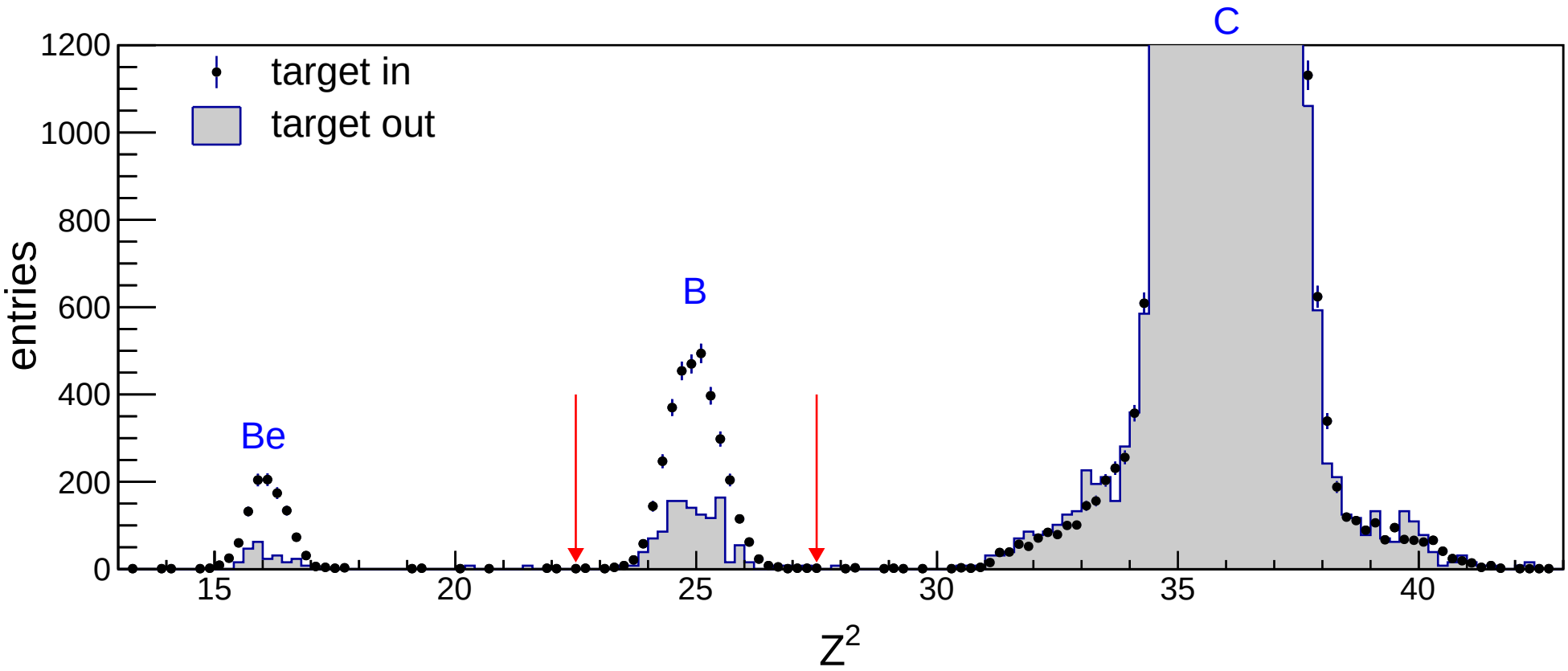
reaction-fragment identification





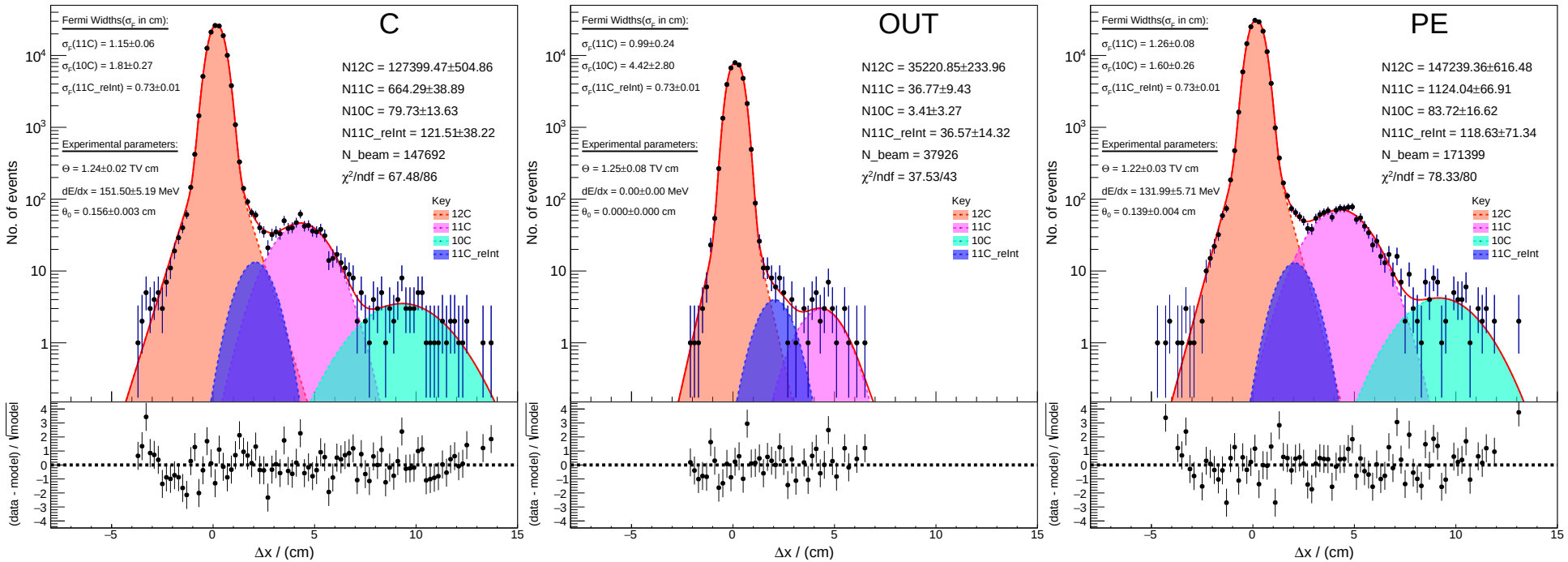
- 2.5 days data taking at 13.5 AGeV/c
- events after upstream ^{12}C selection:
  - 1.7×10^5 CH_2-target
  - 1.5×10^5 C-target
  - 0.4×10^5 empty-target

Particle Id in TPC: a) Z^2 via dE/dx



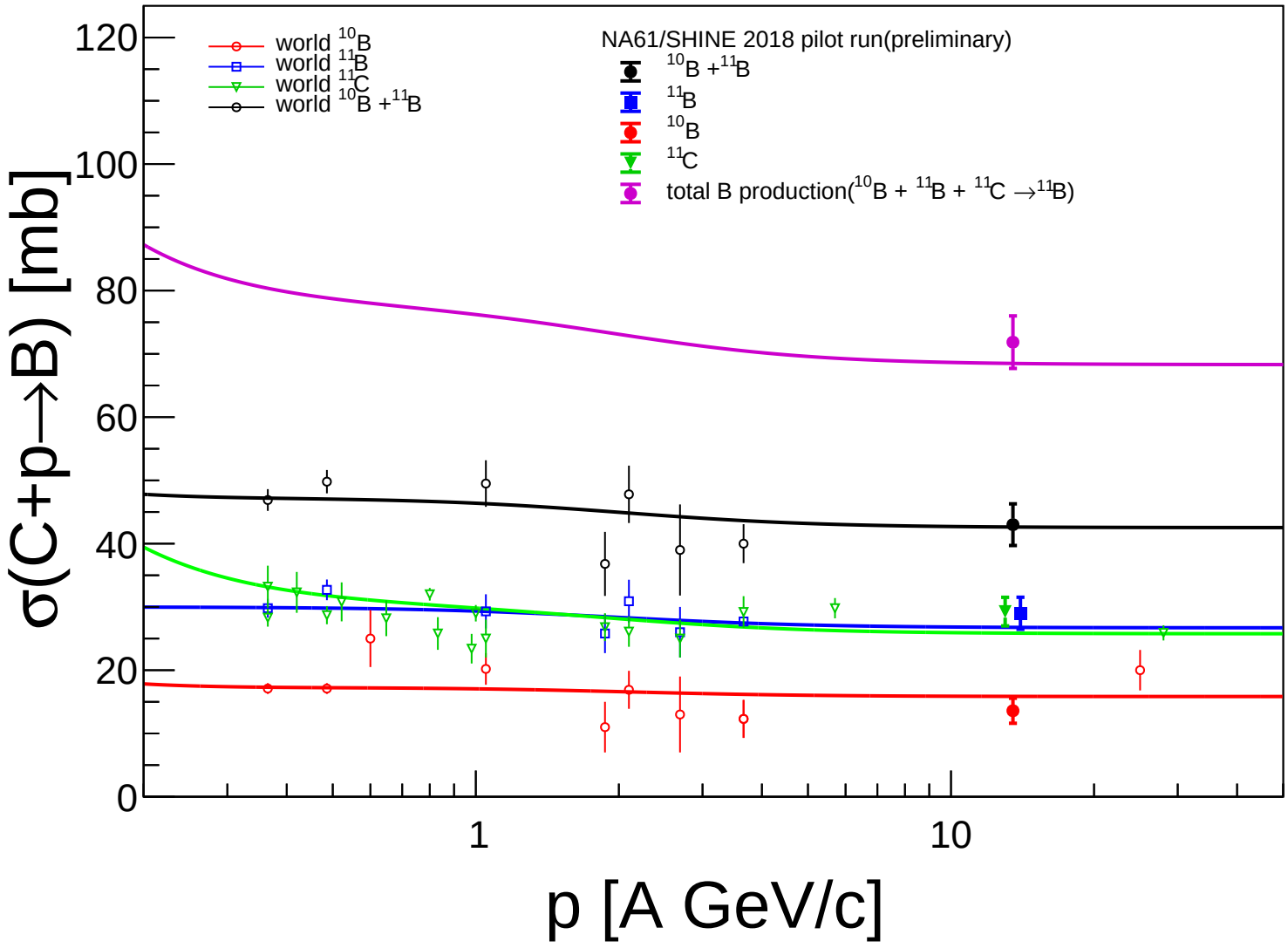
NA61/SHINE@ICRC19, arXiv:1909.07136

Particle Id in TPC: b) A/Z via in deflection in B-field



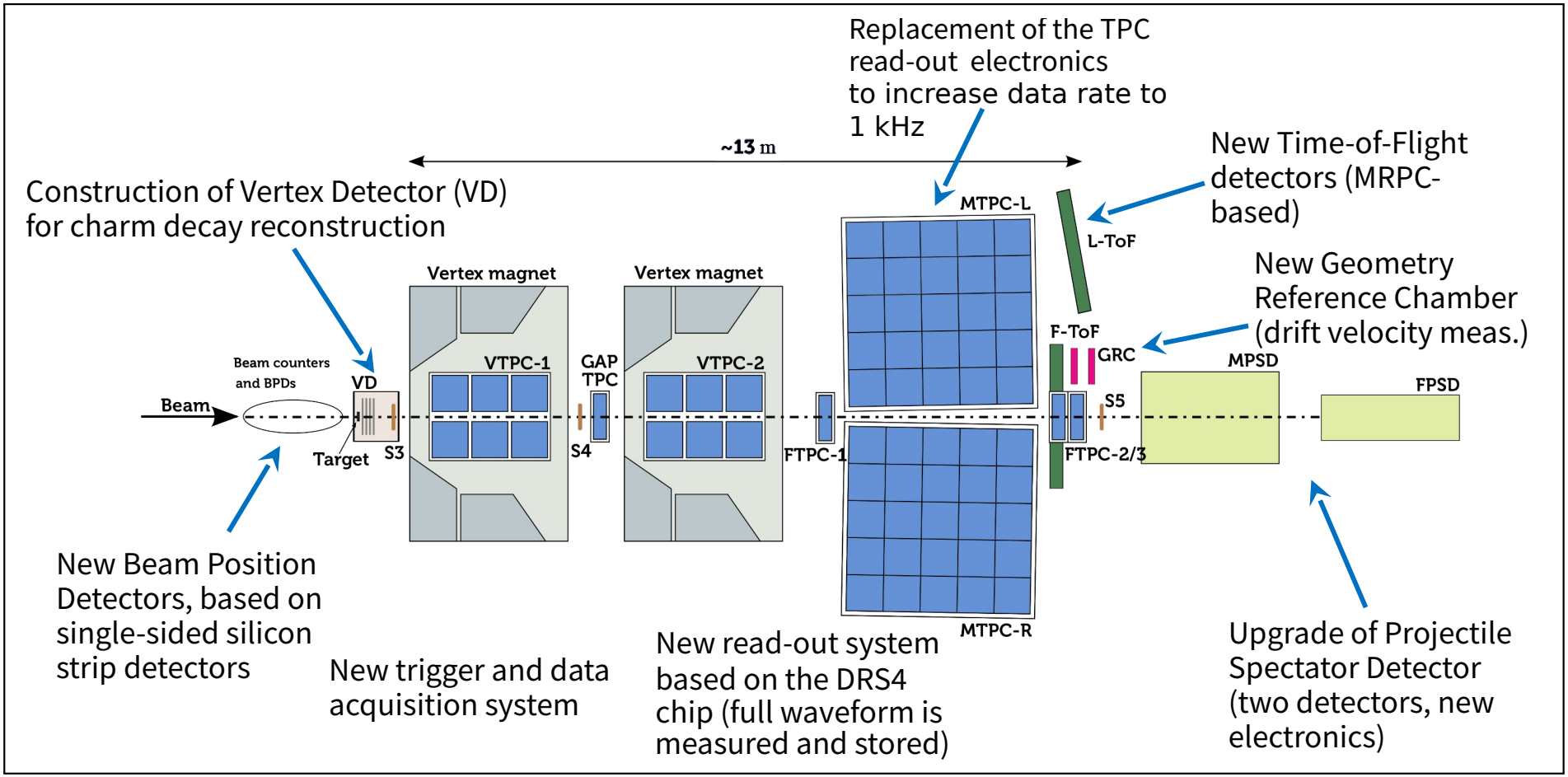
NA61/SHINE@ICRC21, arXiv:2107.12275

Results from Pilot Run on Boron Production (preliminary)



NA61/SHINE Status Report 2022, lines from C.Evoli, R.Aloisio, P.Blasi PRD 2019

Recent Detector Upgrades



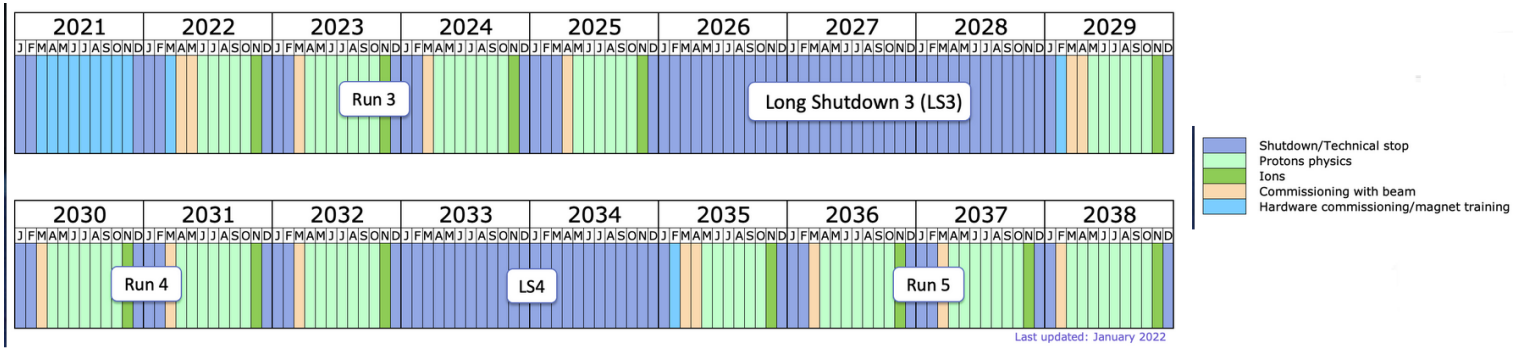
Upcoming Cosmic-Ray Related Data (Beam Requests)

Goal: Measure isotopic production cross sections relevant to astrophysics of light cosmic rays: Li, Be, B, C, and N

Genolini et al, PRC **98** (2018) 034611

- **September 2023** one week of a secondary (fragmented) light-ion beam at 13A GeV/c for nuclear fragmentation cross-section measurements for cosmic-ray physics
- **2024** 12, 8 and 8 days of primary and fragmented oxygen beams at 13A GeV/c, 30A GeV/c and 150A GeV/c, respectively. These data are needed for the onset of fireball studies and nuclear fragmentation cross-section measurements for cosmic-ray physics or
- or **2024:** optional (in case the oxygen beam is not available) one week of a secondary light-ion beam at 13A GeV/c for nuclear fragmentation cross-section measurements for cosmic-ray physics.

Post LS3 Measurements https://indico.cern.ch/event/1174830/



Post LS3 Measurements

CR-related measurements under discussion:

- high-mass fragments?
- helium target?
- anti-particle production in high-statistics p+p ($\bar{d}$, $^{3}\overline{\text{He}}$)?
- ... ?

New Collaborators Welcome! https://indico.cern.ch/event/350633/

How to join the NA61/SHINE Collaboration

Monday 3 Nov 2014, 08:00 → 18:00 Europe/Berlin

CERN

08:00 → 08:20 **How to join the NA61/SHINE Collaboration**

Speaker: Marek Gazdzicki (Johann-Wolfgang-Goethe Univ. (DE))

How.to.join.NA61.d... How.to.join.NA61.pdf

08:20 → 08:40 **Memorandum of Understanding for Collaboration in the NA61/SHINE Experiment between CERN and Collaborating Institutions**

document

08:40 → 09:00 **NA61/SHINE Bylaws**

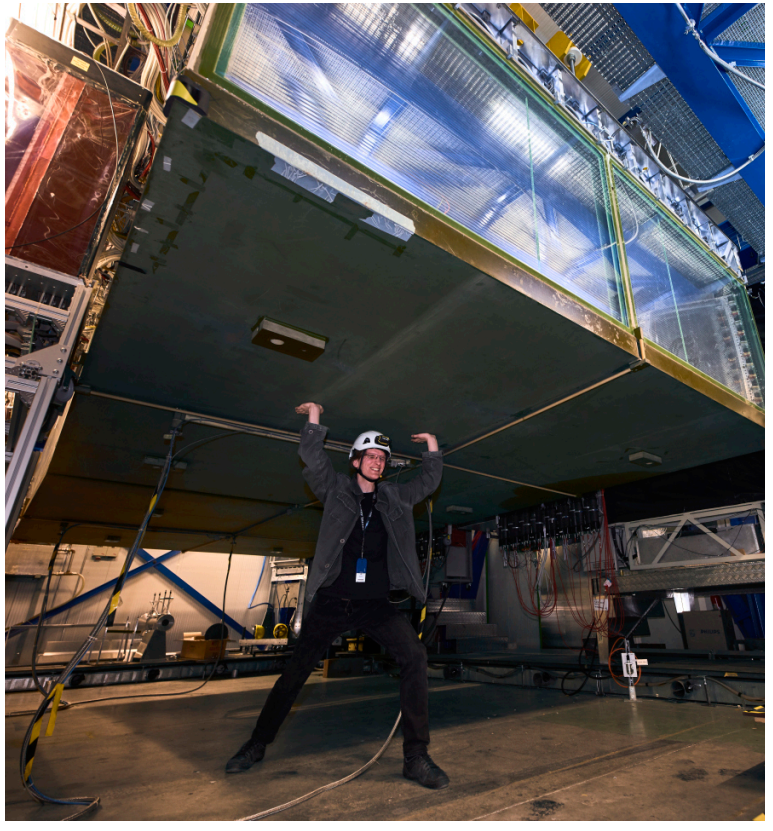
Bylaws_20180404.p...

09:00 → 09:20 **Template of Collaboration Agreement - full membership**

document

09:20 → 09:40 **Template of Collaboration Agreement - limited membership**

ca.limited.docx ca.limited.pdf



inside NA61 (Julien Ordan/CERN)