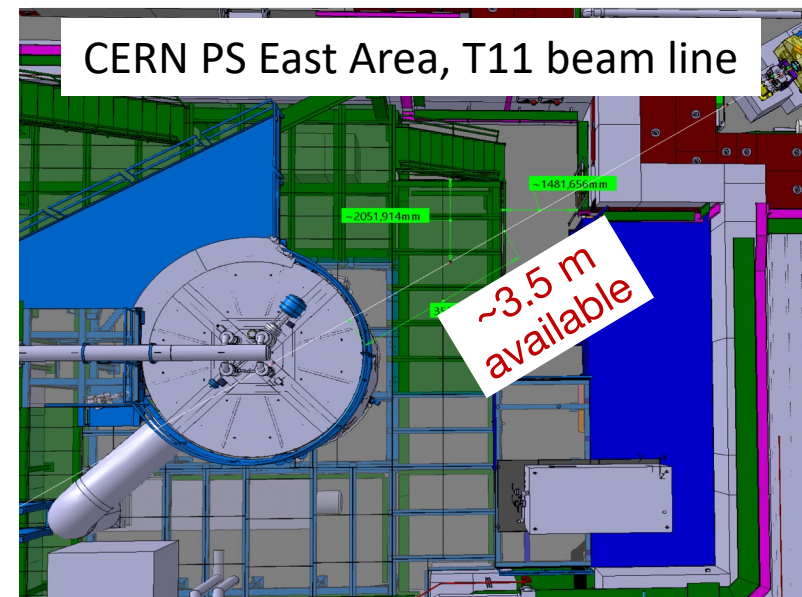


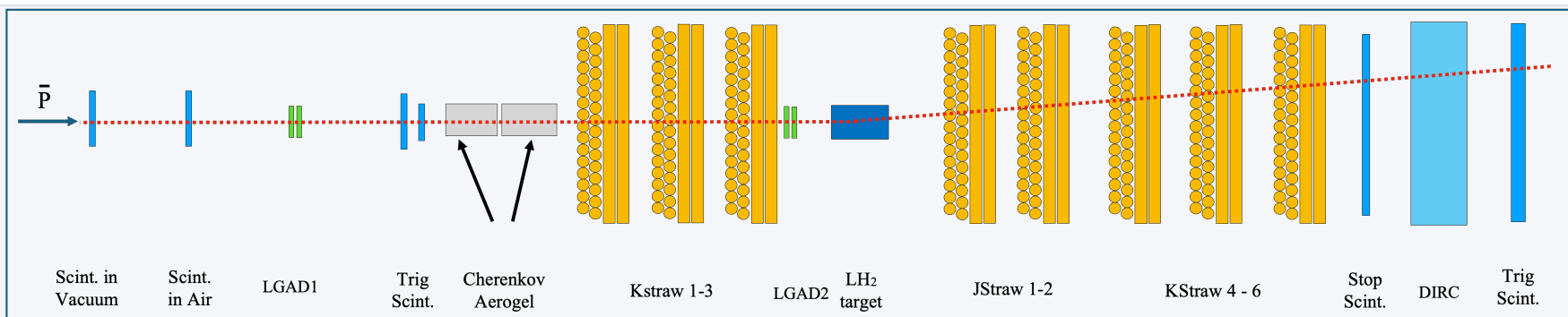
Are antiprotons polarized when they are produced?

From experimental design to data analysis
in the CERN P371 experiment

Huagen Xu



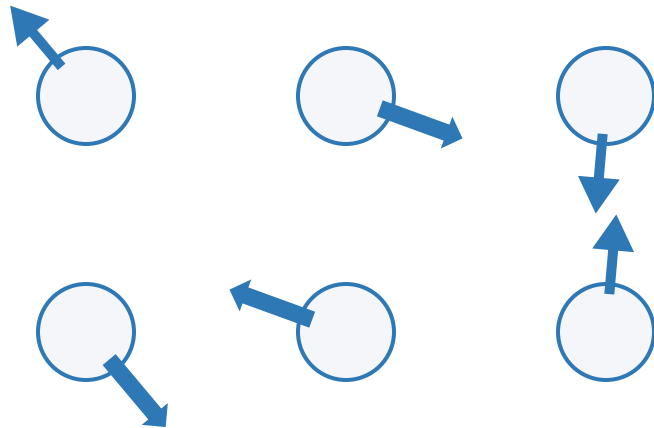
P371 DETECTOR • CERN PS EAST AREA, T11



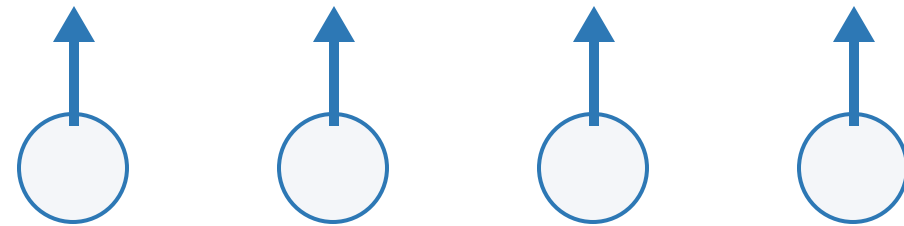
Can the production process polarize antiprotons?

Polarization means that the spins prefer one direction instead of pointing randomly.

UNPOLARIZED



POLARIZED

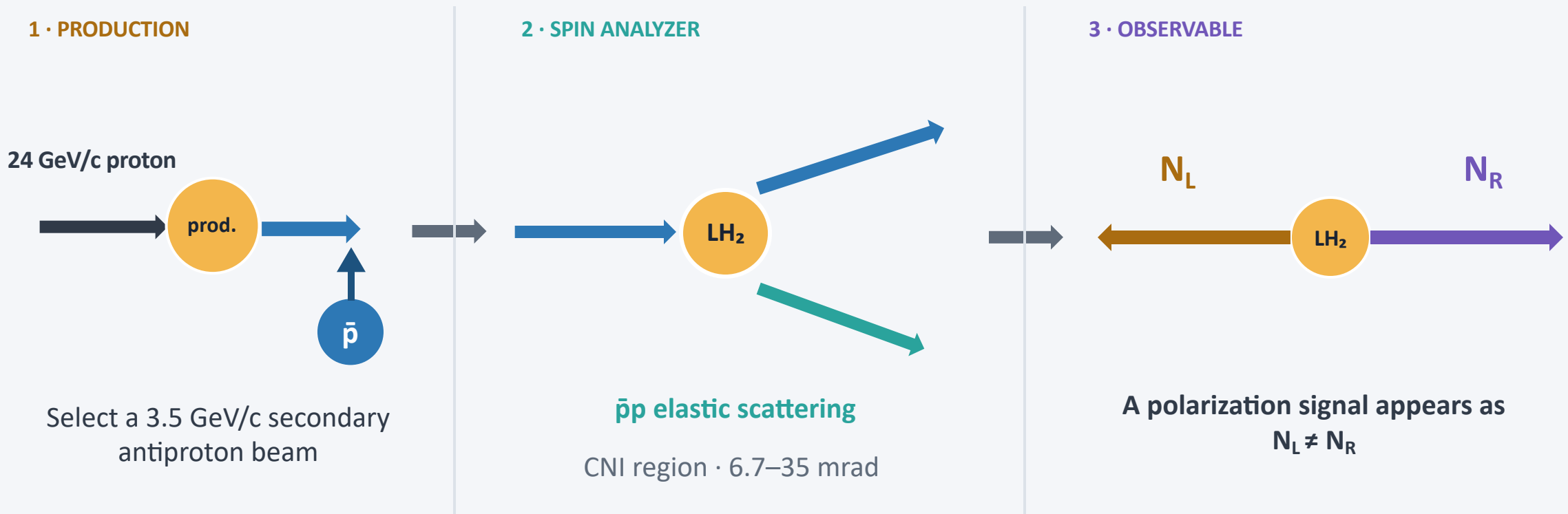


P371 asks whether produced antiprotons carry a measurable preferred spin direction.

To measure spin, convert it into a left–right scattering asymmetry.

Elastic $\bar{p}p$ scattering reveals polarization

The experiment converts an invisible spin preference into a countable left–right difference.



The analyzing power A_y tells us how strongly polarization produces a left–right difference.

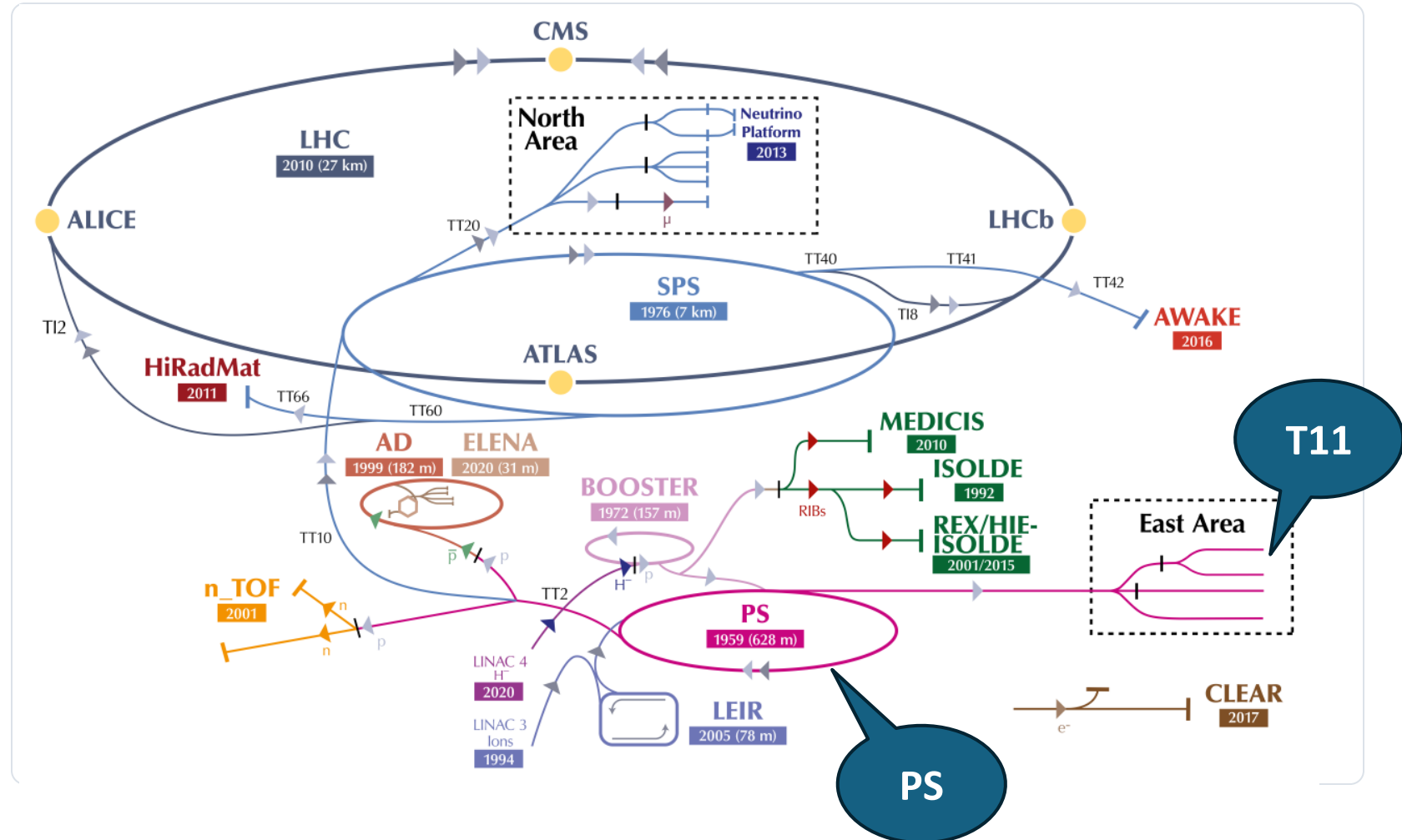
CERN provides the beam conditions P371 needs

CERN PS · T11

Why this beamline?

- 3.5 GeV/c secondary beam
- Antiprotons: ≈ 1 in 400 particles
- 2 spills per ≈ 1 -minute supercycle

Beam conditions drive detector design, DAQ, and run time.



Simulation turns physics into detector design

The best setup maximizes polarization sensitivity—not simply event count.

1

PHYSICS INPUTS

elastic angular
distribution
analyzing power $A_y(\theta)$
beam momentum +
composition

2

DETECTOR MODEL

target + tracker
geometry
detector resolution
trigger + PID efficiency

3

OPTIMIZE THE DESIGN

dimensions + positions
acceptance: 6.7–35
mrad
 $FOM \propto N_{el} \cdot A_y^2$

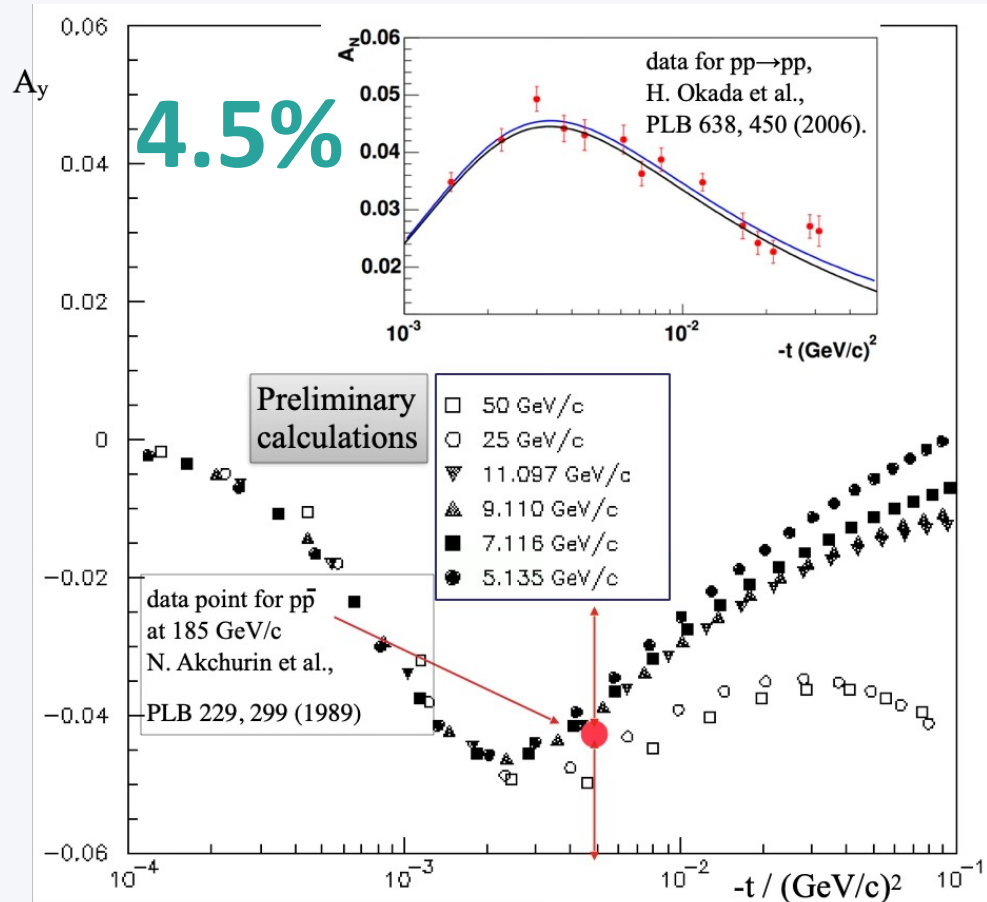
4

PREDICT OUTCOMES

selected elastic yield
polarization sensitivity
required beam time

Geometry → acceptance → statistics → polarization sensitivity

A small analyzing power demands a long run



Desired statistics: of order 10^6 elastic events

Estimate based on simulation

- **1.18 nb⁻¹** integrated luminosity
- **≈ 8 weeks** 2×400 ms spills per ≈1-minute supercycle
- **12% at 5σ** distinguishable from zero
- **7% at 3σ** distinguishable from zero

Simulation for $6.7 < \vartheta < 35$ mrad

Ref. Eur. Phys. J. C 86, 390 (2026)

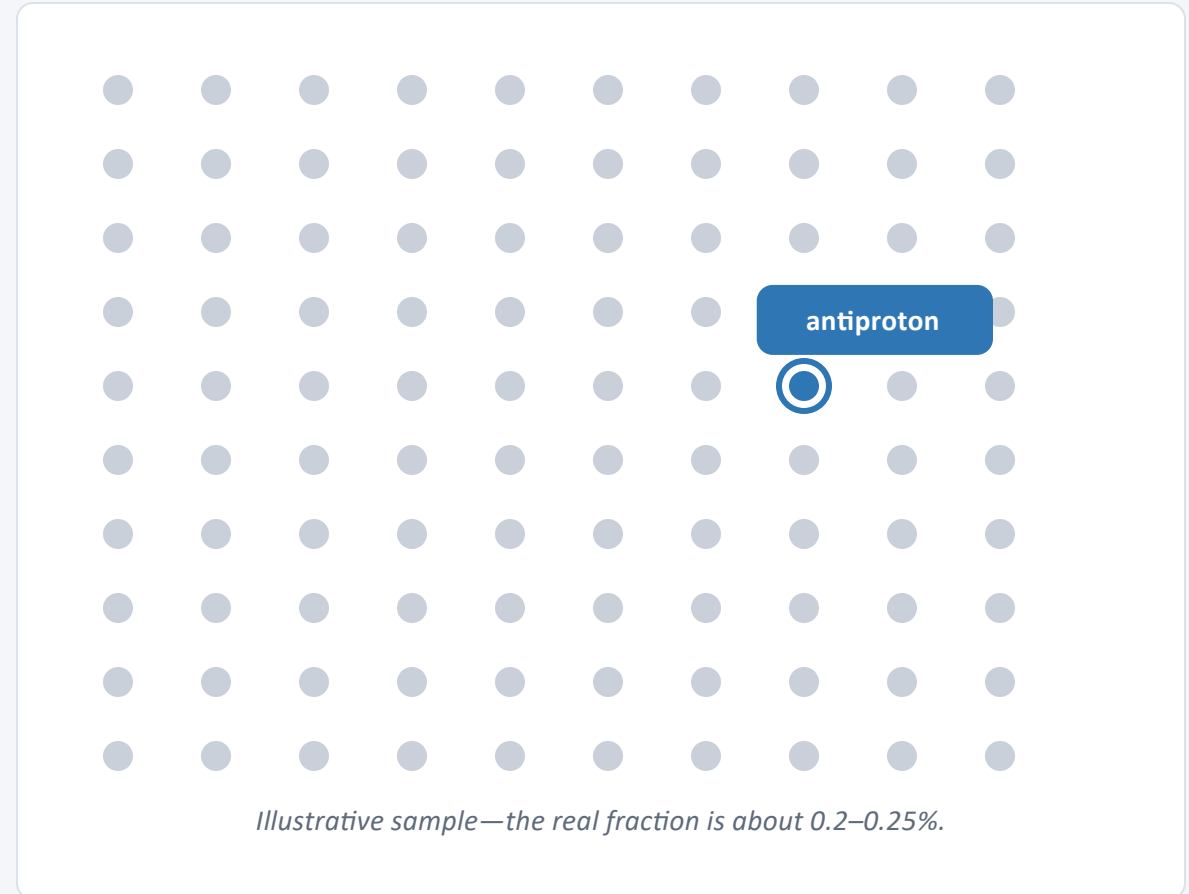
The first challenge: find a rare antiproton

Only

1 in ~400

beam particles is an antiproton

The mixed negative beam is dominated by pions.
That makes particle identification part of the
physics—not an afterthought.



P371: from particle identification to polarization

The detector details support four experimental decisions.

1

Identify the antiproton

ToF and DIRC distinguish rare antiprotons from the pion background.

2

Select elastic events

Tracking, the LH₂ target and two-body kinematics isolate $\bar{p}p$ scattering.

3

Compare left and right

Count the selected events on both sides after correcting acceptance.

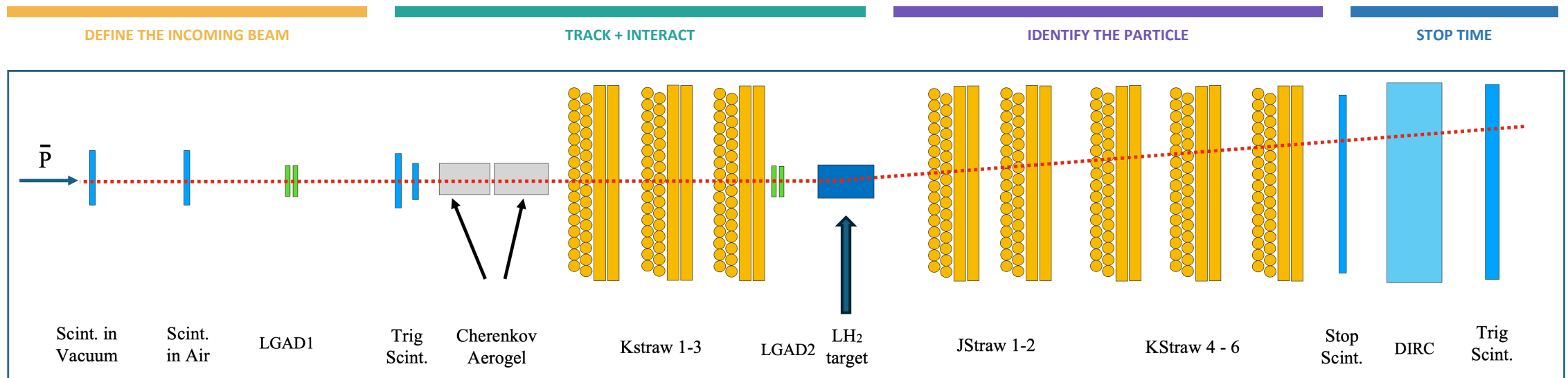
4

Determine polarization

A corrected left–right asymmetry is the observable sensitive to spin.

Particle identification is the gatekeeper—not the final measurement.

One particle crosses the complete P371 setup



The apparatus is one coordinated measurement: trajectory + timing + particle-ID response.

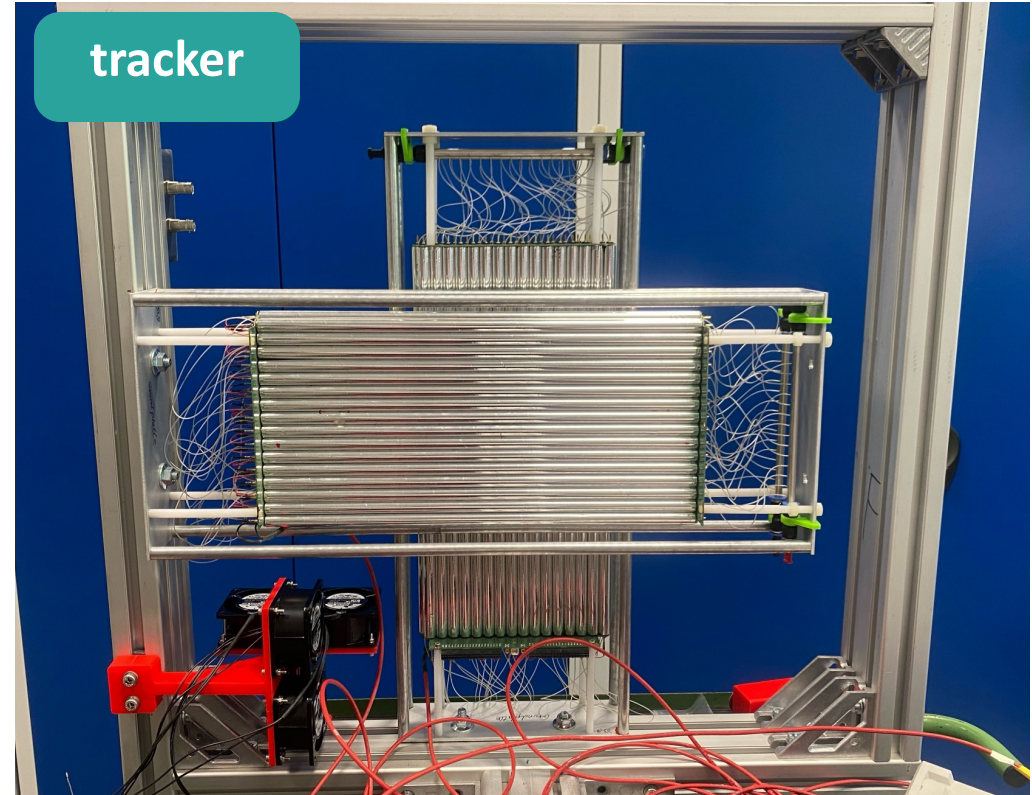
Target and trackers define the elastic event

target



LIQUID-HYDROGEN TARGET · interaction point

tracker



STRAW-TUBE TRACKER · incoming and outgoing trajectories

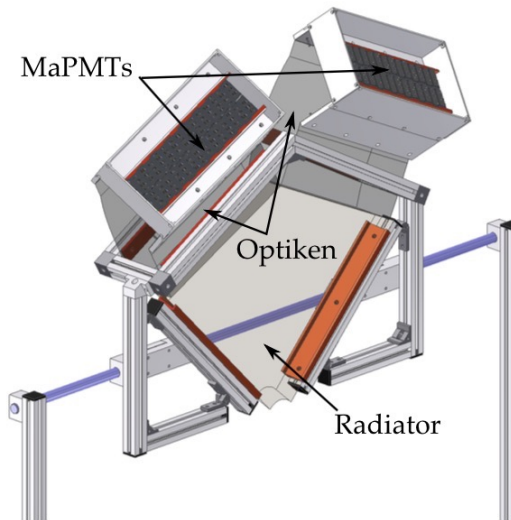
Tracks connect the beam particle, interaction vertex and scattered particle.

Three detector types provide trigger and PID



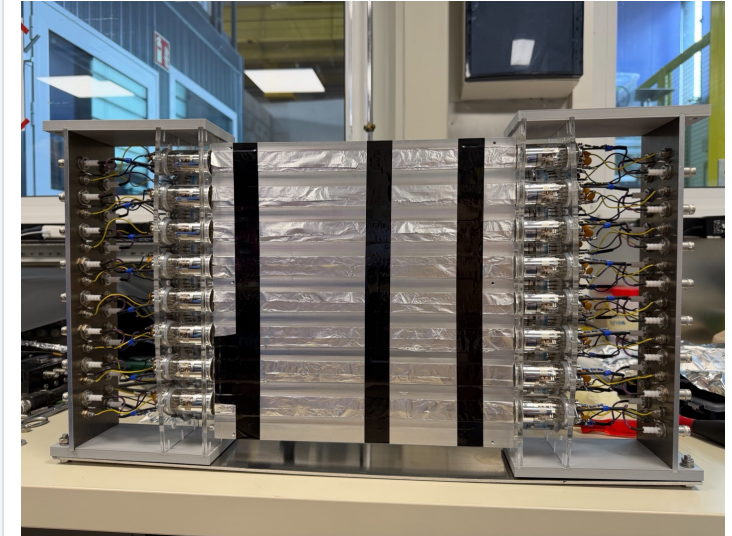
AEROGEL

Fast Cherenkov response for trigger and veto logic ($n=1.03$)



DIRC

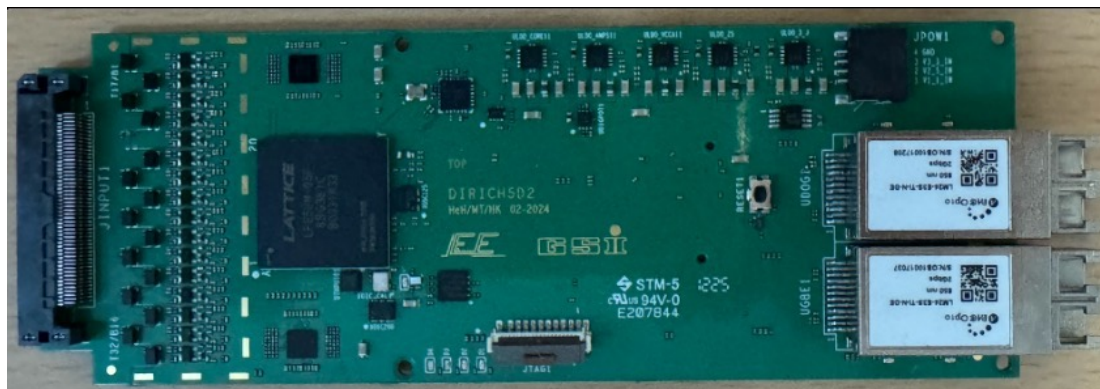
Cherenkov-light pattern for particle identification



SCINTILLATORS

Start/stop timing for the time-of-flight measurement as well as triggers

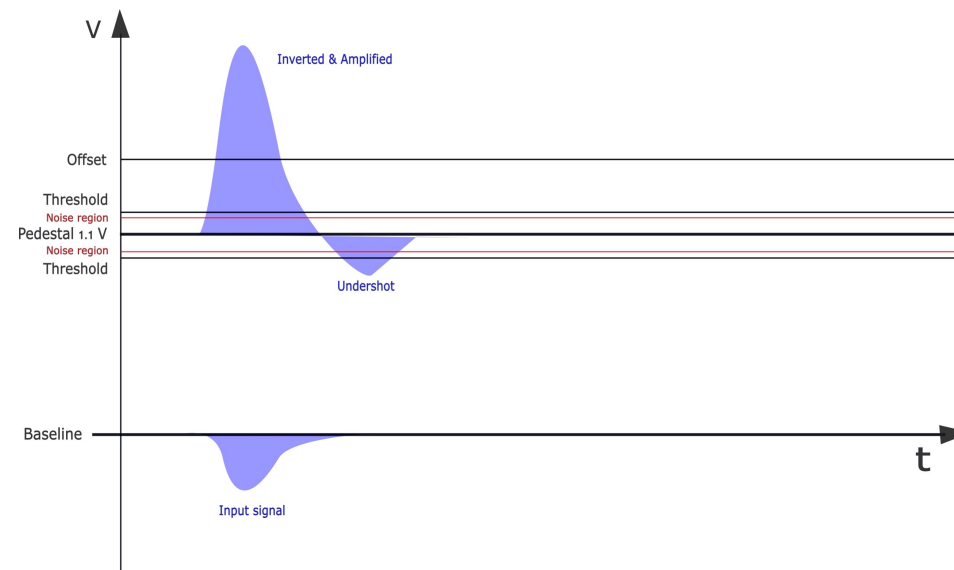
DOGMA turns detector pulses into precise timestamps



DOGMA / DiRICH board

32 channels on a 10 × 4 cm board

- Both signal polarities
- Gain: 30
- Adjustable threshold
- Optical connection



edge → time

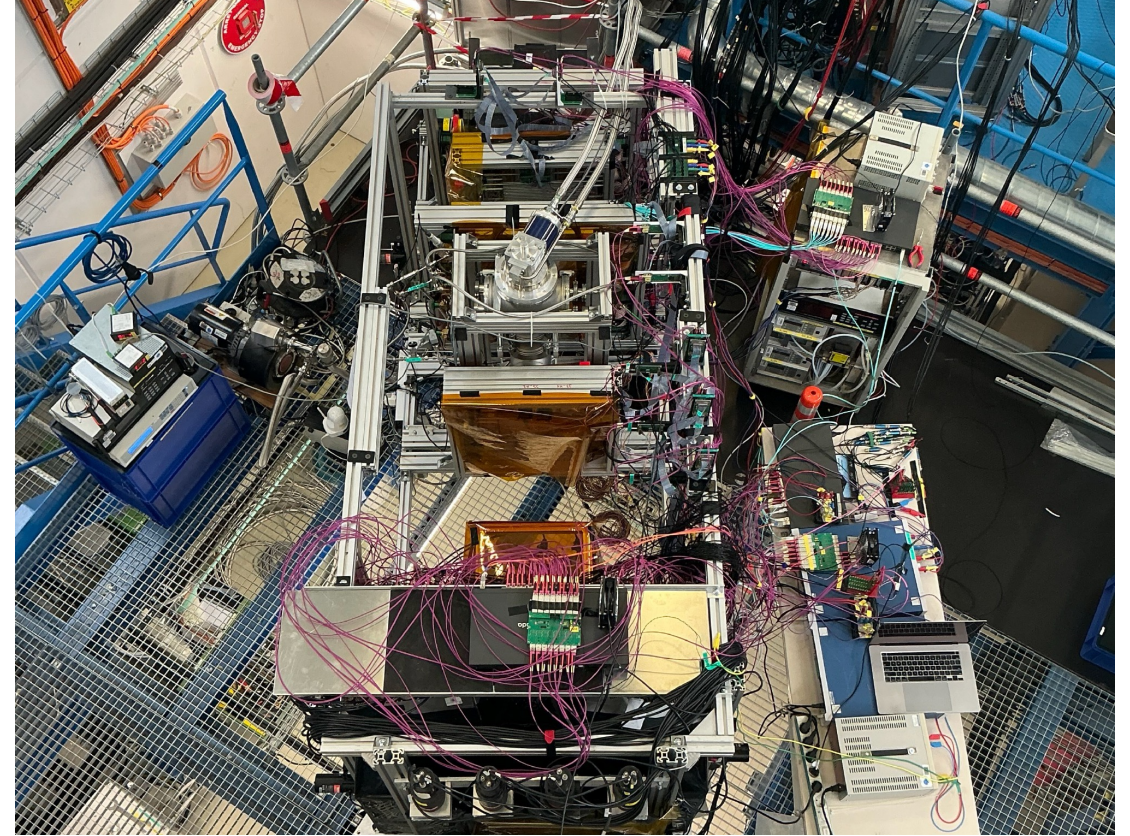
width → ToT

TDC digitization: ≈ 12 ps RMS

A compact experiment with a lot happening at once



Side view: detectors, services and readout

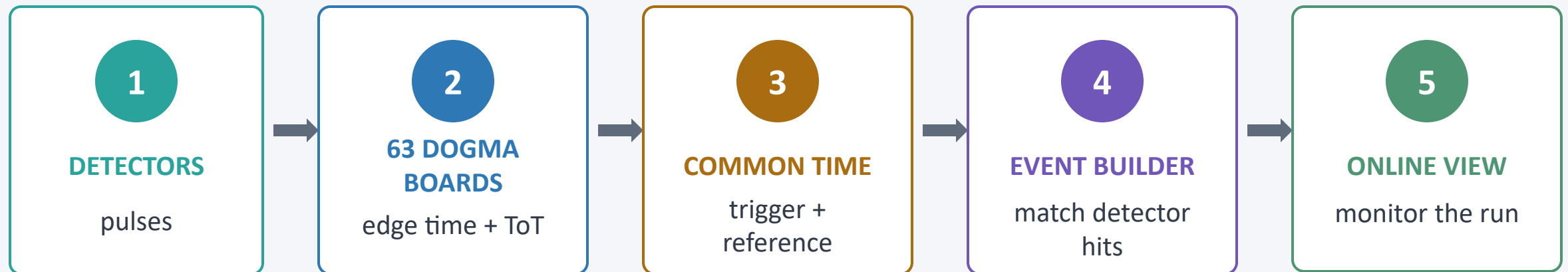


Top view: the full instrumented beam path

The engineering looks complex; the measurement logic remains simple.

63 DOGMA boards build one event

A common trigger and time reference connect detector hits.



**DOGMA does not determine polarization by itself.
It ensures that every detector hit belongs to the same event.**

Commissioning makes the data trustworthy

01

Channel mapping

Connect each cable and channel to the correct detector element.

02

Detector tuning

Find optimal working conditions for each detector

03

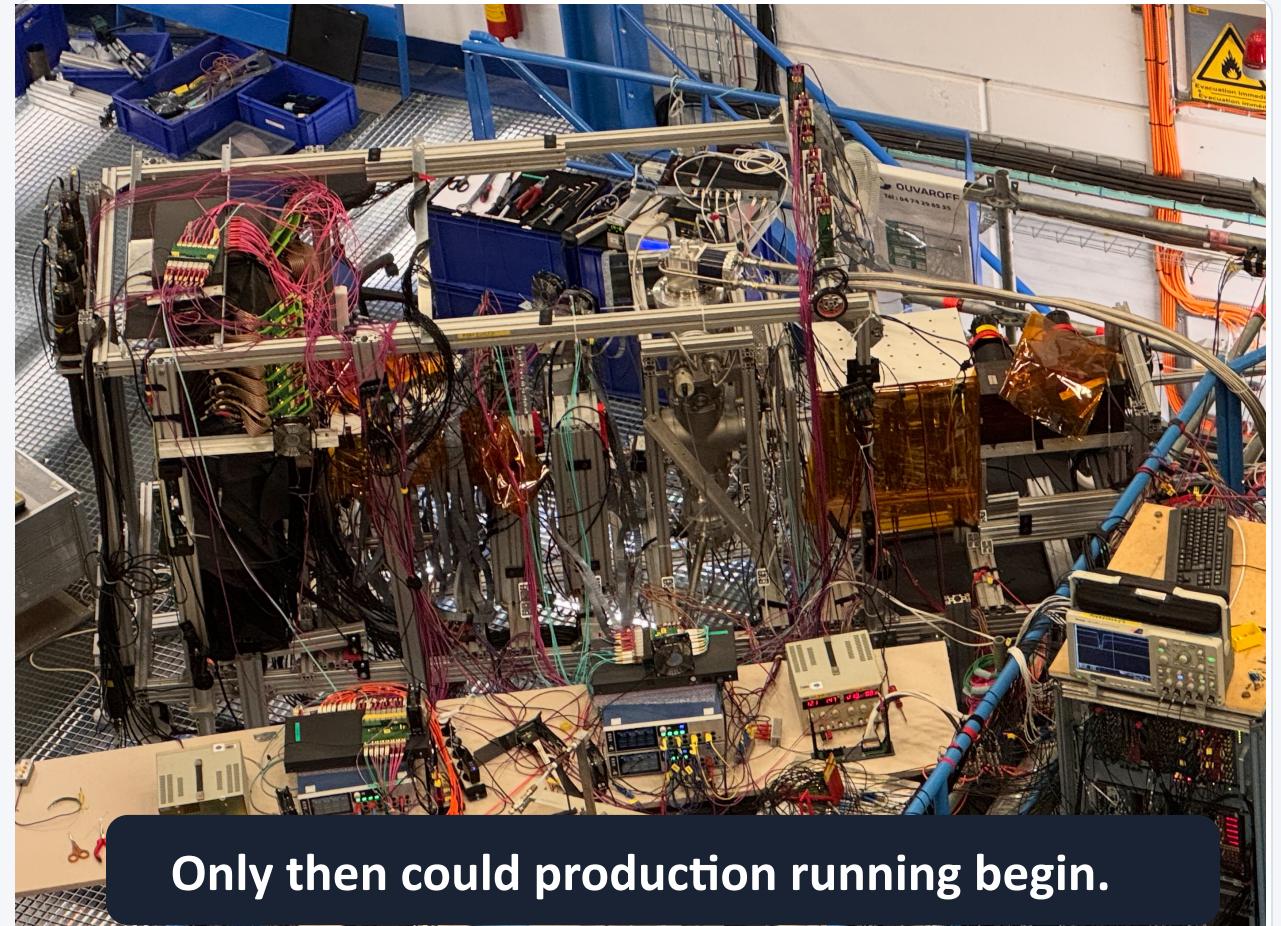
Beam alignment

Adjust the detector center to the beam axis

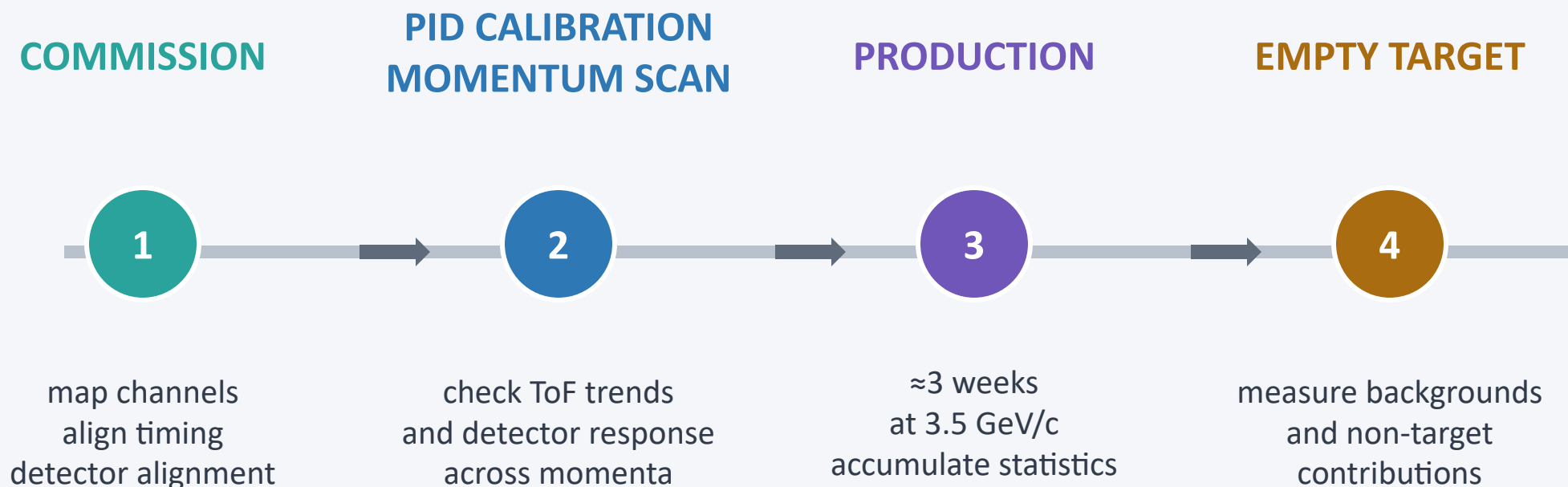
04

Online monitoring

Monitor detector, beam and DAQ status



The run moved from commissioning to control data



Three 400 ms spills per approximately one-minute supercycle including one additional spill

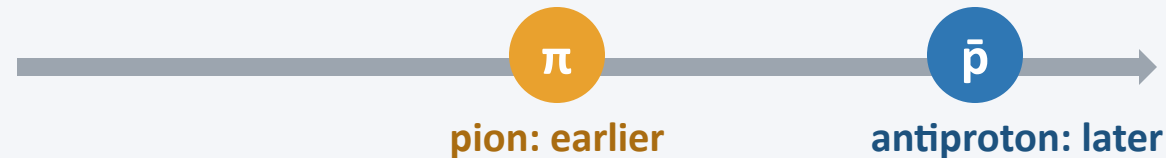
Time of flight is simply a time difference

Two scintillators record the same particle at the start and end of an approximately 8.5 m path.



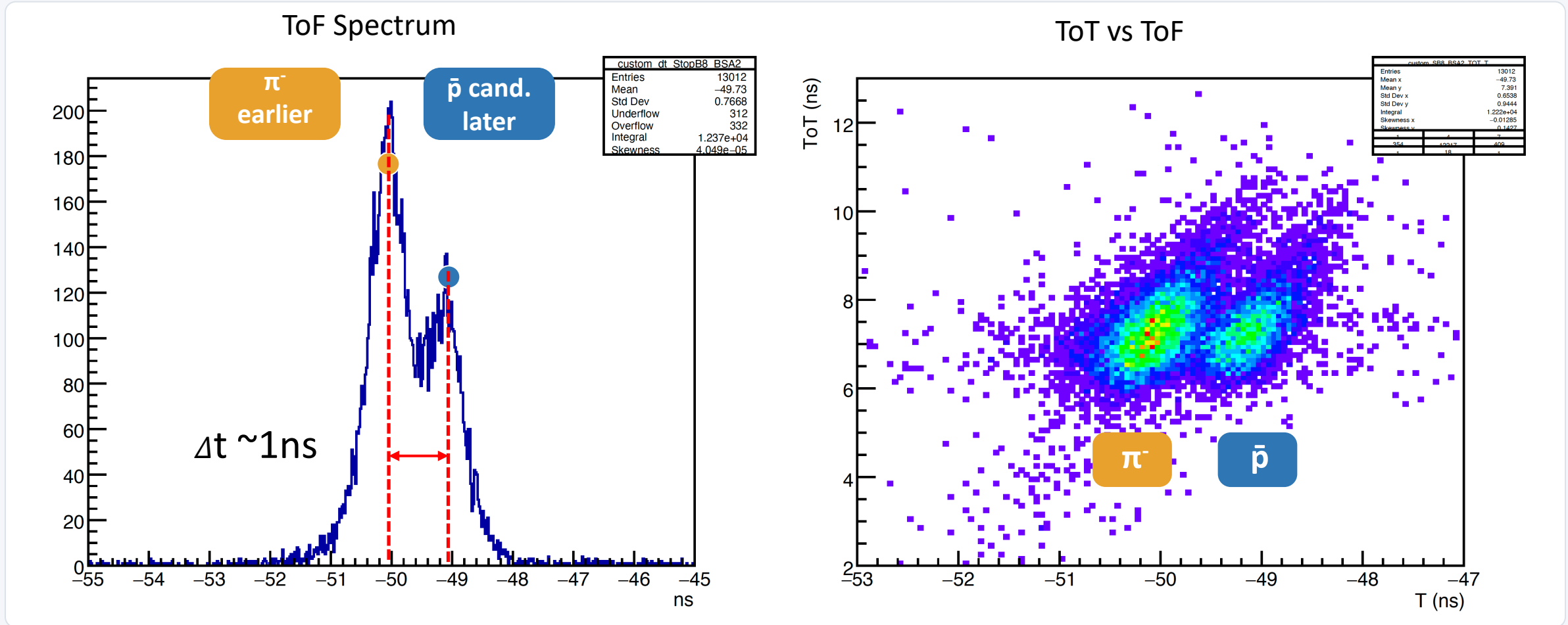
$$t = L/(\beta c)$$

same selected momentum





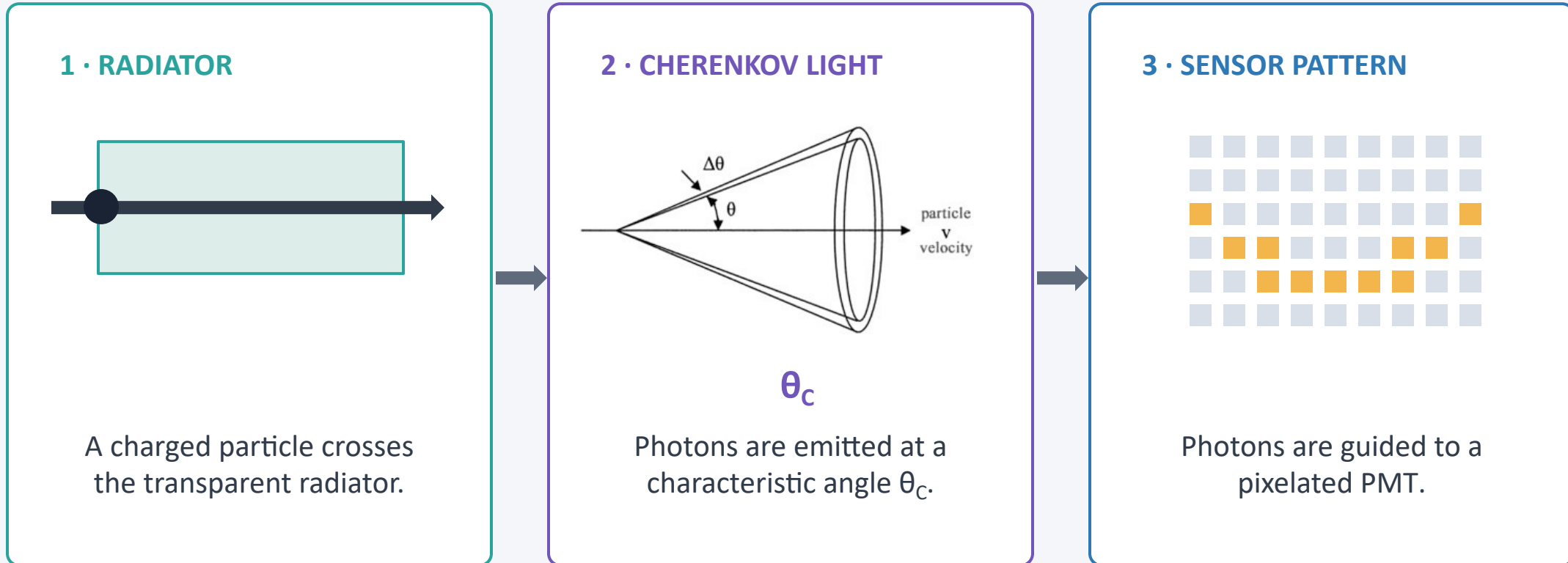
Two ToF populations at 3.5 GeV/c



PRELIMINARY · pion-suppressed trigger selection

DIRC turns Cherenkov light into a particle-ID pattern

The angle and pattern depend on the particle velocity.



DIRC is independent of ToF, so agreement between them is especially valuable.

DIRC response: a photon arc

The visible photon arc is encouraging; the result remains preliminary.

At beam momentum
 $p = 3.5 \text{ GeV}/c$

Expected Cherenkov
angles:

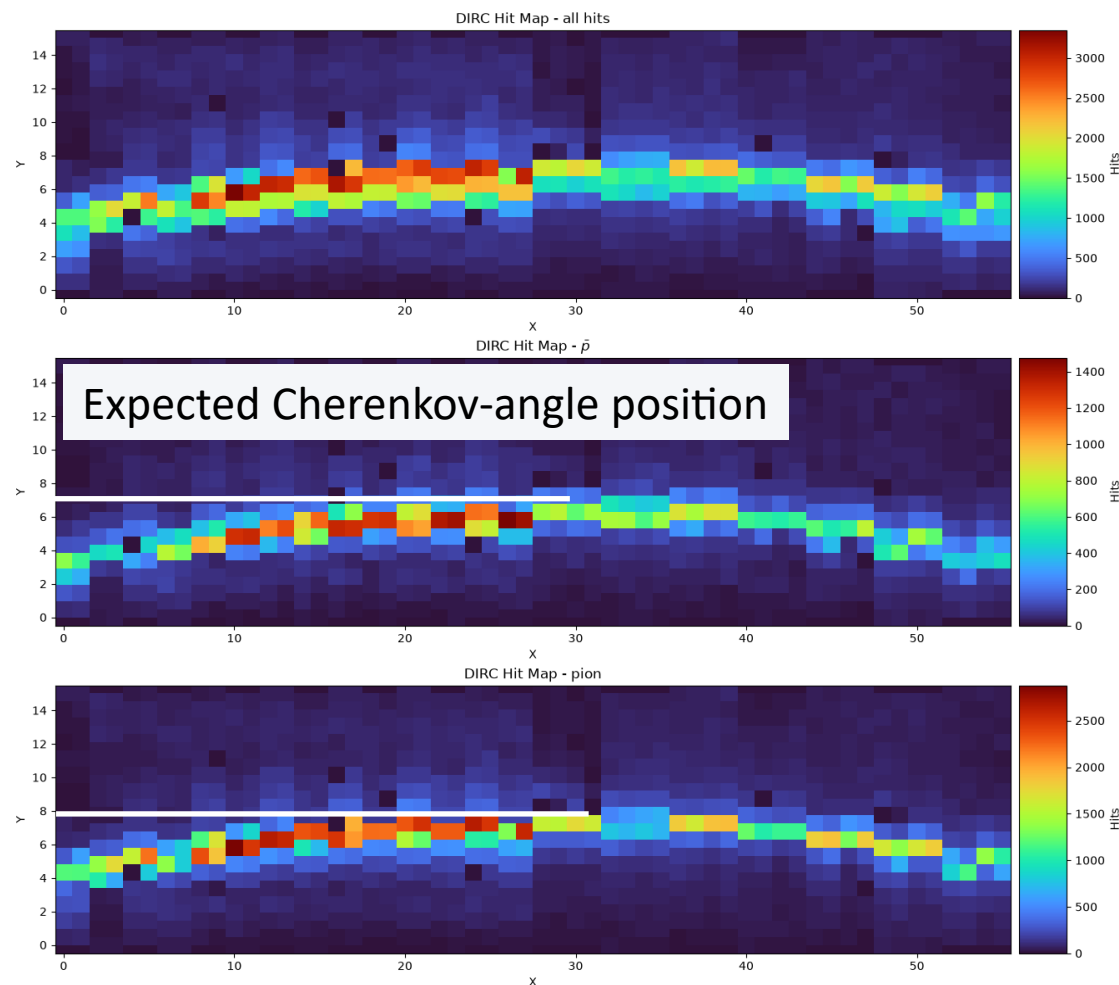
$$\theta_c(\bar{p}) = 45.99^\circ$$

$$\theta_c(\pi^-) = 47.80^\circ$$

All hits

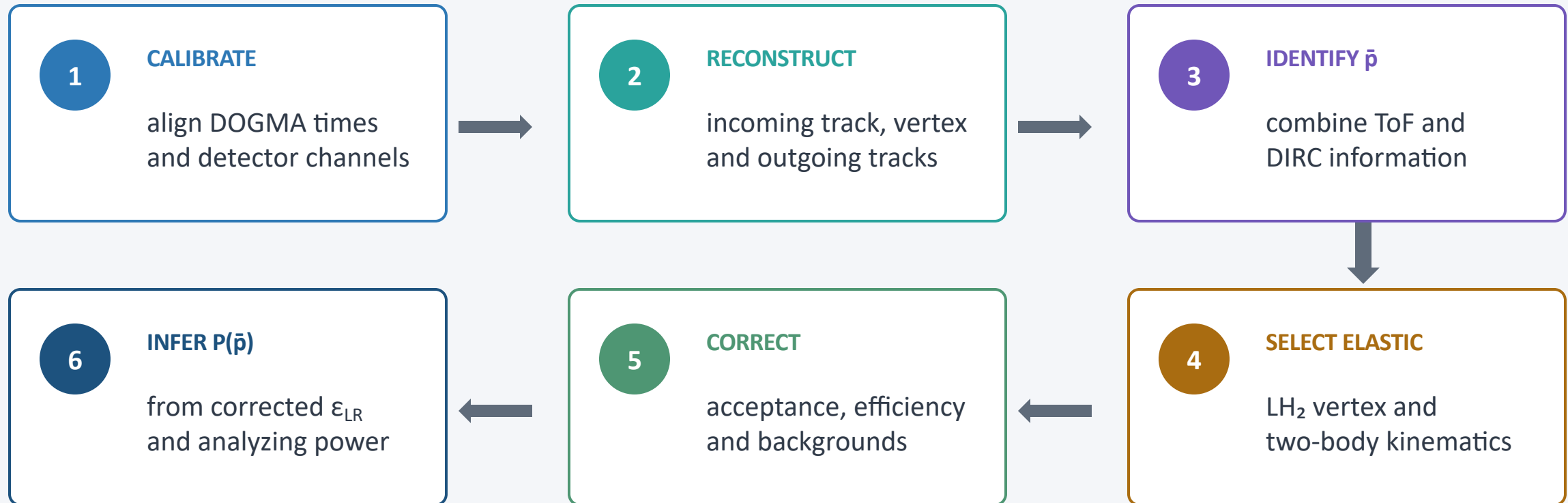
ToF-tagged
 $\bar{p}$ candidates

ToF-tagged
pions



Planned analysis chain

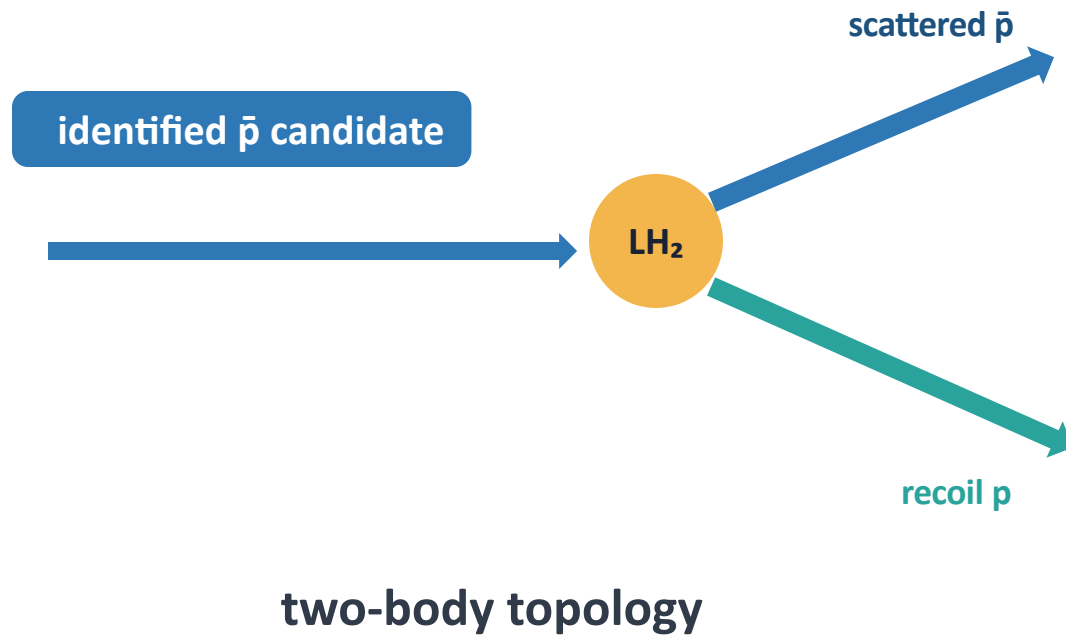
The sample becomes smaller—but more reliable—at every analysis stage.



Each cut reduces yield; each correction protects the result from a false left–right effect.

Select clean $\bar{p}p$ elastic events

CONCEPTUAL TOP VIEW



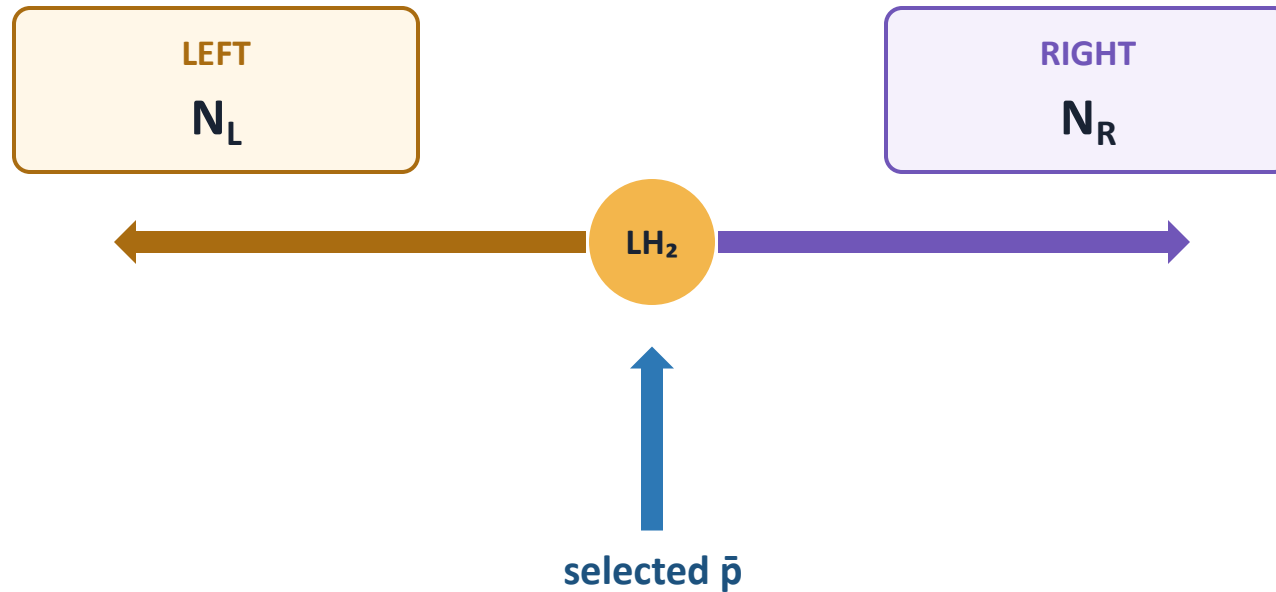
KEEP THE EVENT WHEN...

- 1 the incoming particle is identified as $\bar{p}$
- 2 the interaction vertex is inside the LH₂ target
- 3 the outgoing tracks are reconstructed
- 4 the geometry and kinematics match elastic scattering

PID asks 'what particle?'; elastic selection asks 'what interaction?'

Test polarization with a left–right asymmetry

TOP VIEW AROUND THE TARGET



LEFT–RIGHT ASYMMETRY

$$\epsilon_{LR} = \frac{N_L - N_R}{N_L + N_R}$$

after acceptance corrections

$$\epsilon_{LR} \approx P(\bar{p}) \cdot A_y$$

asymmetry $\approx$ polarization $\times$ analyzing power

A_y links the measured imbalance to polarization.

A statistically significant, acceptance-corrected asymmetry would be evidence for polarization.

P371: the complete measurement chain

- **1 · QUESTION** can the production process polarize antiprotons?
- **2 · DESIGN** use CNI elastic $\bar{p}p$ scattering as the spin analyzer
- **3 · SIMULATE** optimize geometry + acceptance; predict statistics + beam time
- **4 · BUILD** target + tracking + particle ID + DAQ
- **5 · IMPLEMENT** install, connect and commission the complete setup at T11
- **6 · TAKE DATA** production running, momentum scans and empty-target controls

7 · ANALYZE identify $\bar{p} \rightarrow$ elastic $\bar{p}p \rightarrow$ left/right asymmetry $\rightarrow$ polarization

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Thanks for your
attention!

Backup

A small analyzing power demands a long run

WHY SO MANY EVENTS?

$$\underset{\text{polarization}}{10\%} \times \underset{\text{maximum } A_y}{4.5\%} = \underset{\text{asymmetry}}{0.45\%}$$

A difference of only about 45 events
per 10,000 selected elastic events

Desired statistics: of order 10^6 elastic events

Estimate based on simulation

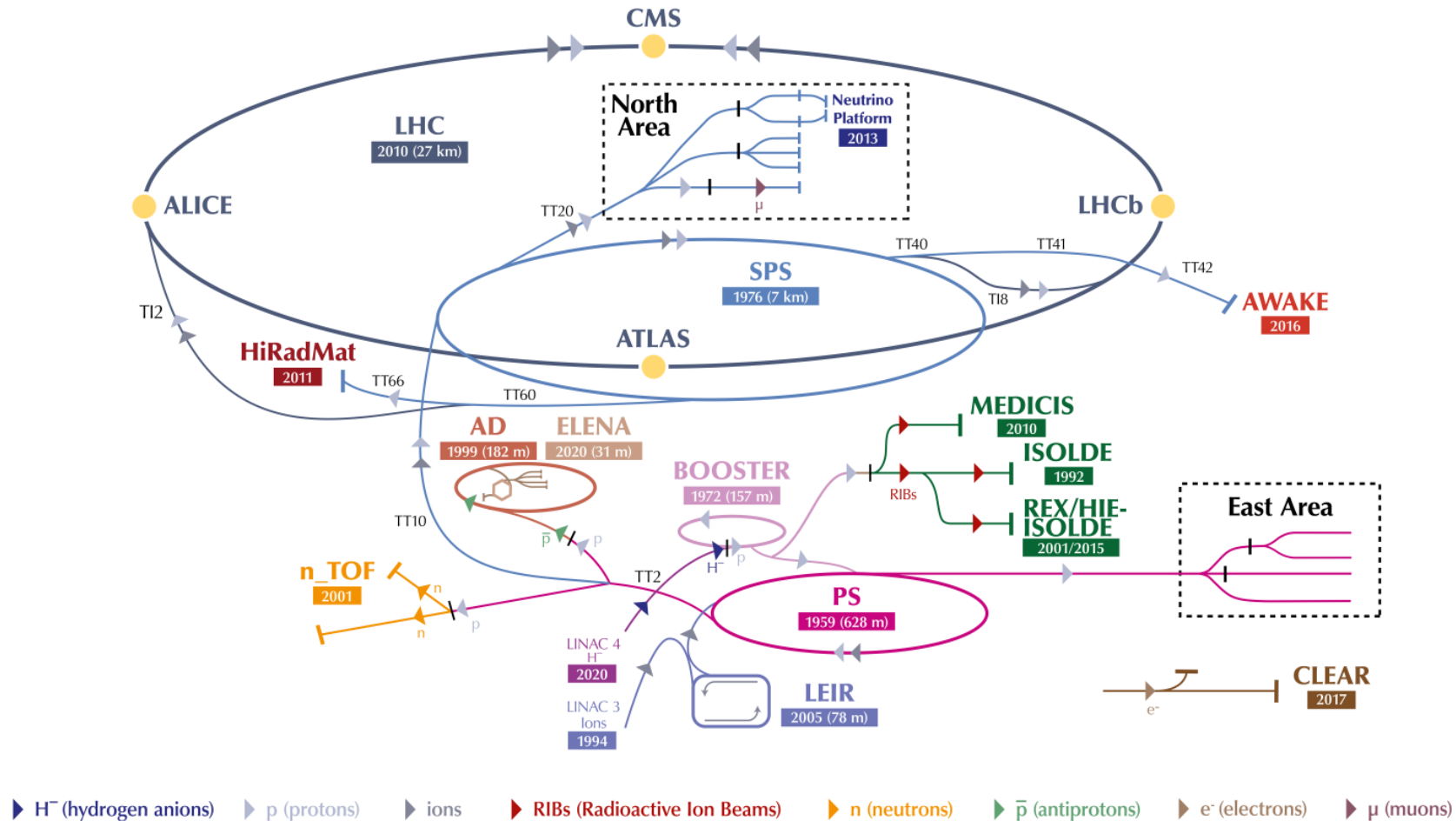
- **1.18 nb^{-1}** integrated luminosity
- **$\approx 8 \text{ weeks}$** $2 \times 400 \text{ ms}$ spills per $\approx 1\text{-minute}$ supercycle
- **$12\% \text{ at } 5\sigma$** distinguishable from zero
- **$7\% \text{ at } 3\sigma$** distinguishable from zero

Simulation for $6.7 < \vartheta < 35 \text{ mrad}$

Ref. Eur. Phys. J. C 86, 390 (2026)

The CERN accelerator complex

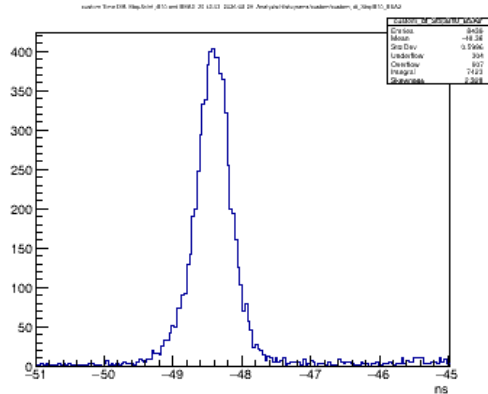
Complexe des accélérateurs du CERN



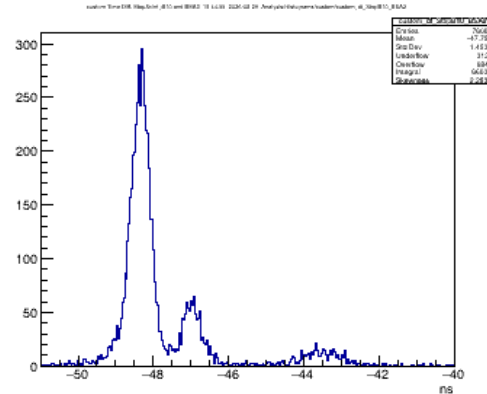
LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKEfield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive Experiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform

The separation changes with beam momentum

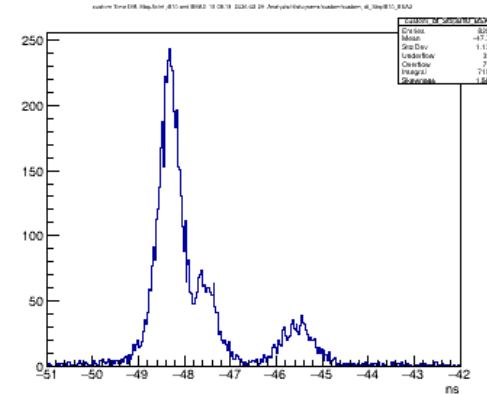
–1.0 GeV/c



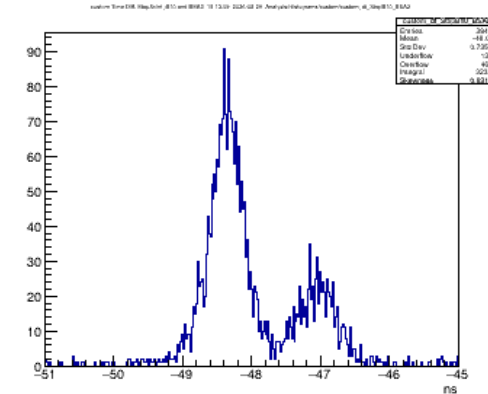
–1.5 GeV/c



–2.0 GeV/c



–3.0 GeV/c

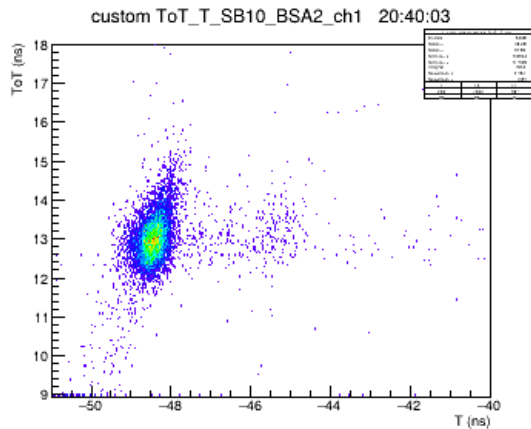


The momentum scan checks that the second peak behaves like a massive particle—not a fixed electronics artifact.

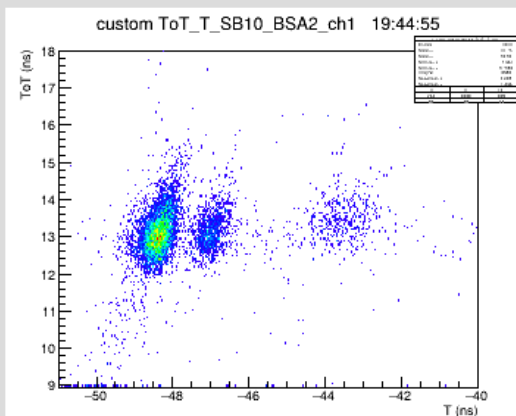
The separation changes with beam momentum

At lower momentum the heavier antiproton falls further behind; the peaks move closer as momentum increases.

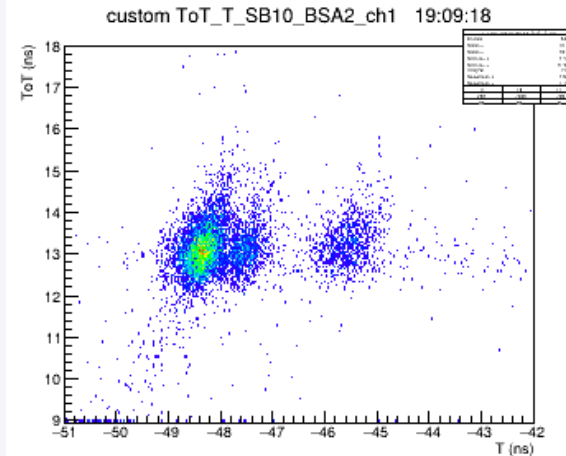
–1.0 GeV/c



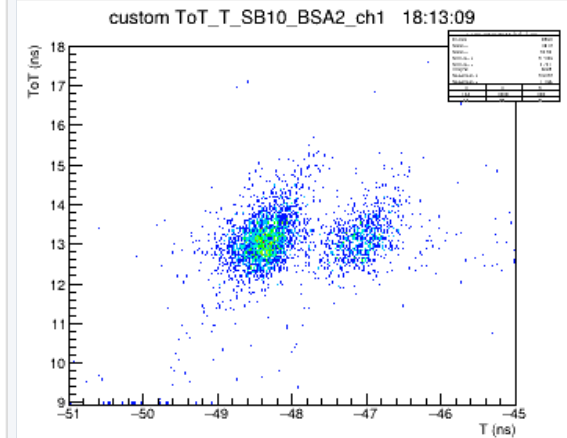
–1.5 GeV/c



–2.0 GeV/c

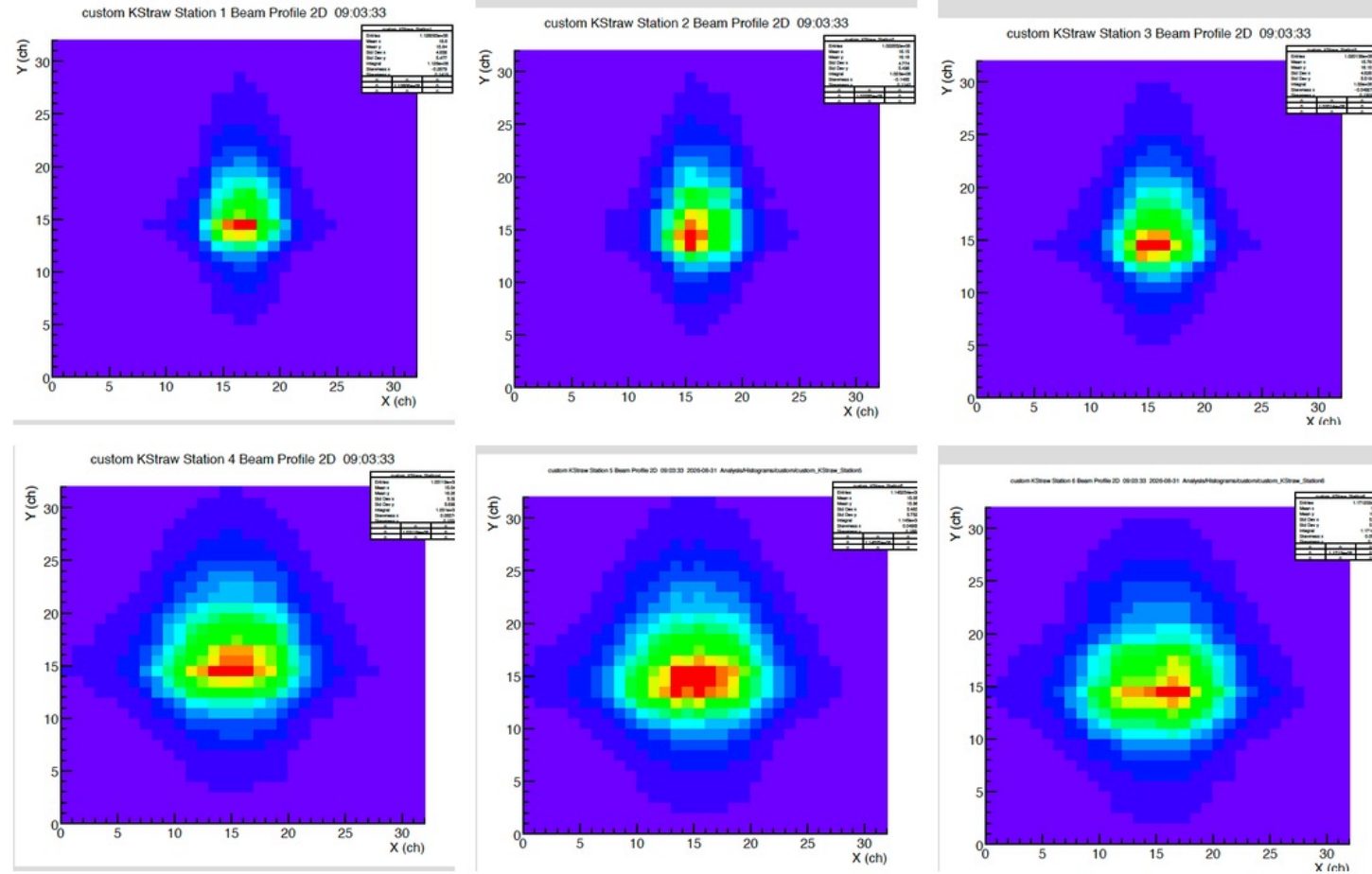


–3.0 GeV/c



The momentum scan checks that the second peak behaves like a massive particle—not a fixed electronics artifact.

Beam profiles across six straw stations

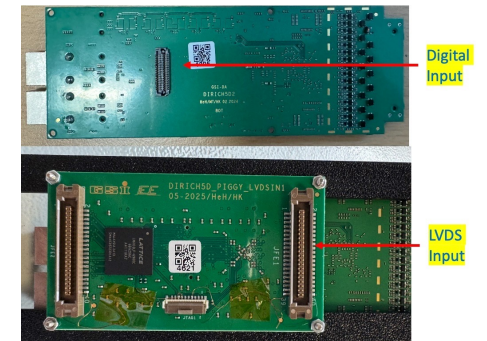
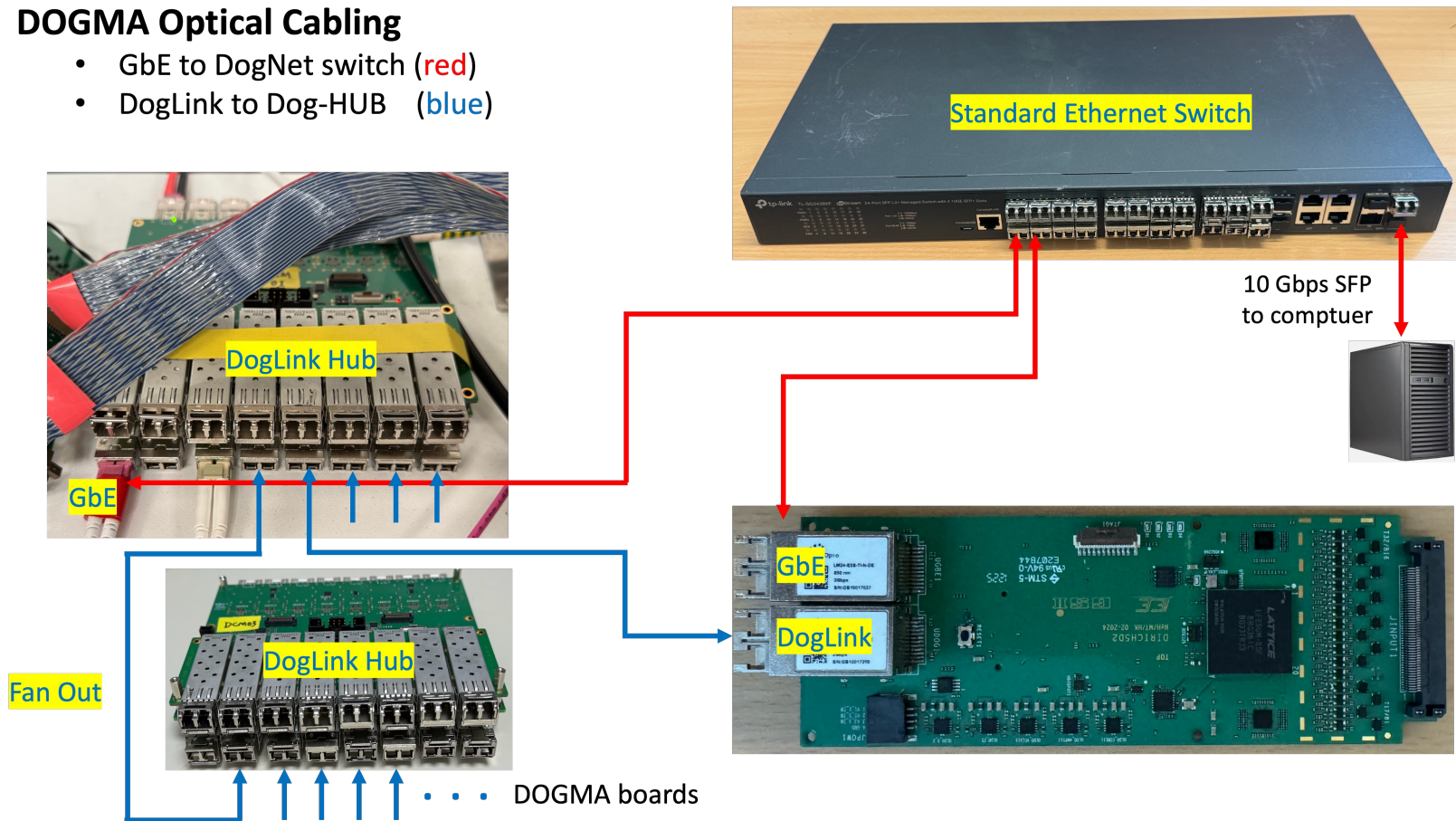


The beam spot is followed station by station to verify alignment and acceptance.

Detailed DOGMA optical readout topology

DOGMA Optical Cabling

- GbE to DogNet switch (red)
- DogLink to Dog-HUB (blue)



Interfaces adapt detector signals to the common DOGMA readout.