# Physics at the CERN secondary lines

**N. Charitonidis**, D. Banerjee, J. Bernhard, L.Gatignon, L. Nevay, M. Van Dijk

Acknowledgements: A. Gerbershagen

15 February 2024

# Outline – Contents

- **I will attempt to go through the basic design & operation principles of secondary particle beams**
- **Describe the available facilities of the PS and SPS experimental areas**
  - Not discussing AD experiments nor primary beam facilities (like HiRadMat or AWAKE)
- **Give some highlights of the physics experiments that take place in these facilities and their corresponding beamlines**
- **Hoping to motivate you to visit and participate some experiments or perform a new one .... ☺**

# Particle beams – What are they ?

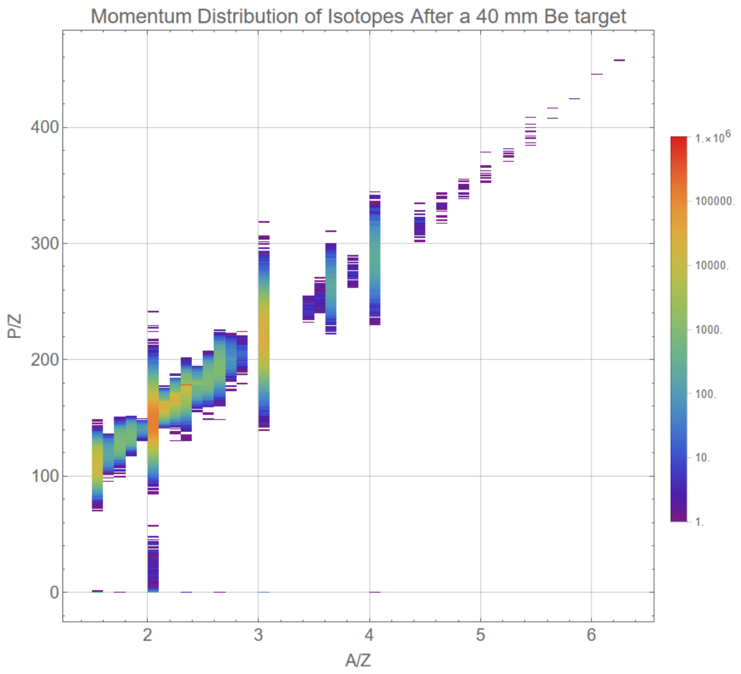
- **The term refers to secondary or tertiary beams, i.e beams produced from primary beams, typically via the interaction on a target material or particle decay.**

$$\mathbf{p} + A \rightarrow \quad p, \bar{p}, \pi^{\pm}, K^{\pm}, \mu^{\pm}$$
$$\pi^{\pm}, K^{\pm} \rightarrow \mu^{\pm}, \nu_{\mu}(\overline{\nu_{\mu}}), \nu_{e}(\overline{\nu_{e}})$$

$$\mathbf{p} + A \rightarrow \begin{cases} \Lambda^0(\overline{\Lambda^0}) \rightarrow p, \pi^- \; (\bar{p}, \pi^+) \\ K^0(\overline{K^0}) \rightarrow \pi^{\pm}, \pi^{\mp} \\ K^0_S \, K^0_L \end{cases}$$

$$\mathbf{p} + A \rightarrow \quad e^{\pm}, \gamma$$
$$e^{\pm} + A \rightarrow \gamma$$
$$\gamma + A \rightarrow e^{\pm}$$

**Ion** +$A$ → Fragments



# Motivation for particle beams

## 1. Exciting physics opportunities with particles that can mainly be produced via hadronic interactions or particle decays

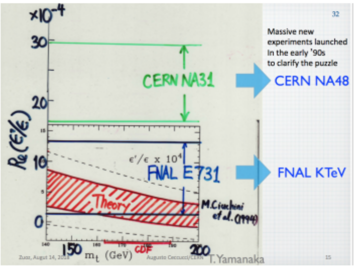
- **Kaon physics** : A prominent example

My own interest in K particles started in 1952-53 while I was at Columbia working with Jim Rainwater on μ--mesonic atoms. At that time the strange behavior of the particles newly discovered in cosmic rays(1) was a major topic of conversation in the corridors and over coffee. By strange behavior I am referring to the copious production but slow decay. Protons bombarded by pions would

Standing alone among the particles with positive strangeness were the $K^+$ and $K^0$ mesons, and I idly thought that if the situation was ever to be understood these objects might be the key. Most often experiments in physics are long and difficult. It takes some special tweaking of interest to make the commitment to a new area of research. The original motivation is, in the

Val. L. Fitch et al. – Nobel Prize 1980

Indirect ($\varepsilon$) and Direct ($\varepsilon'$) CP-Violation




Phenomenology: Wu and Yang, (1964)

$$\eta_{\pm} = \varepsilon + \varepsilon'$$

$$\eta_{00} = \varepsilon - 2\varepsilon'$$

$$\eta_{\pm} = \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} \qquad \eta_{00} = \frac{A(K_L \to \pi^0\pi^0)}{A(K_S \to \pi^0\pi^0)}$$

$$R = \frac{\Gamma(K_L \to \pi^0\pi^0)/\Gamma(K_S \to \pi^0\pi^0)}{\Gamma(K_L \to \pi^+\pi^-)/\Gamma(K_S \to \pi^+\pi^-)} \simeq 1 - 6\,\varepsilon'/\varepsilon.$$

Courtesy: A.Buras

...Still many open questions hiding with kaons
But where do we find the **kaons** ?

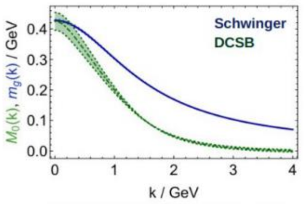
# Motivation for particle beams

## 1. Exciting physics opportunities with particles that can only be produced via hadronic interactions or particle decays

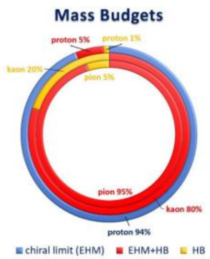
- **Muon physics** : Measuring fundamental properties of matter

Courtesy: C. Quintans

### Emergence of Hadron Mass and Structure



Gluon and quark *running masses*




In QCD, via Dynamic Chiral Symmetry Breaking

Understand how hadrons acquire the observable masses, out of "nothing":

Higgs mechanism contributes only a small part
In the proton: 1%

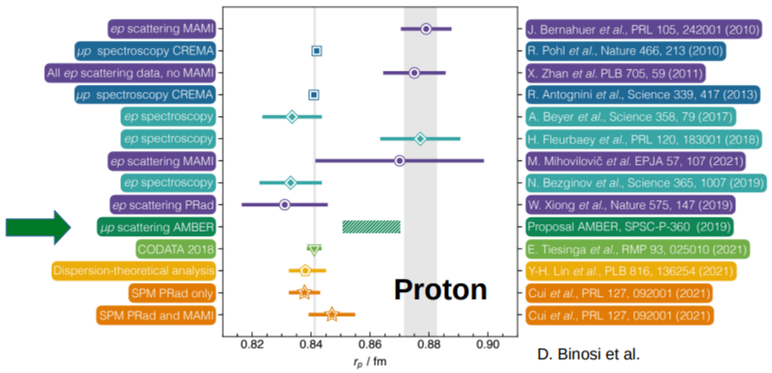
EHM mechanism (i.e. quarks and gluons dynamics) significant contribution
In the proton: ~94%

Also the interference between HB and EHM plays a role
In the kaon: ~80%. In the pion: ~95%

Measurements of meson structure are crucial to confirm it! 4

### Proton charge radius measurement: physics motivation

Hadron radii are an expression of the link between EHM and QCD confinement



D. Binosi et al.

Two types of measurements:
**lepton-proton scattering** and **hydrogen spectroscopy,** leading to discrepant results

Courtesy: O. Denisov

We need intense **muon** beams to understand more....
Main source of muons: **pion decays**.

# Motivation for particle beams

## 1. Exciting physics opportunities with particles that can only be produced via hadronic interactions or particle decays

- **Dark Matter** : It is there, but can we measure it ?

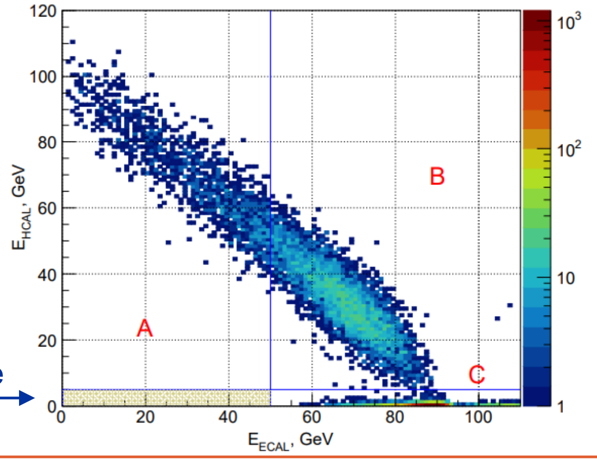
Courtesy: S. Gninenko et al.

> The idea that in addition to gravity a new force between the dark and visible matter transmitted by a vector boson, $A'$ , called dark photon, might exist is quite exciting [1–4]. The $A'$ can have a mass in the sub-GeV mass range, and couple to the standard model (SM) via kinetic mixing with the ordinary photon, described by the term $\frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu}$ and parametrized by the mixing strength

> Another method, discussed in this work and proposed in Refs. [43, 44], is based on the detection of the missing energy, carried away by the hard bremsstrahlung $A'$ produced in the process $e^-Z \to e^-ZA'; A' \to invisible$ of high-energy electrons scattering in the active beam dump target. The advantage of this type of experiment compared to the beam dump ones is that its sensitivity is proportional to $\epsilon^2$, associated with the $A'$ production

**Overwhelming evidence of existence of dark matter**, but we have no clue what does it mean on the particle level.

A' signal should be in here



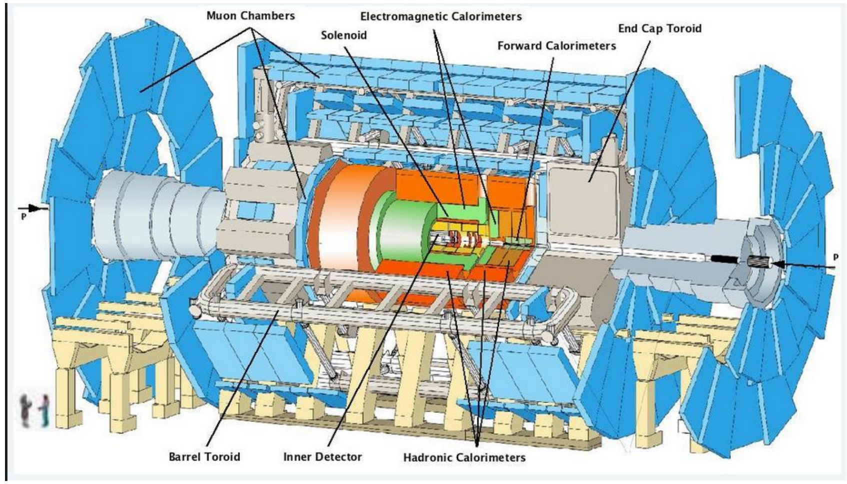

Courtesy: NA64

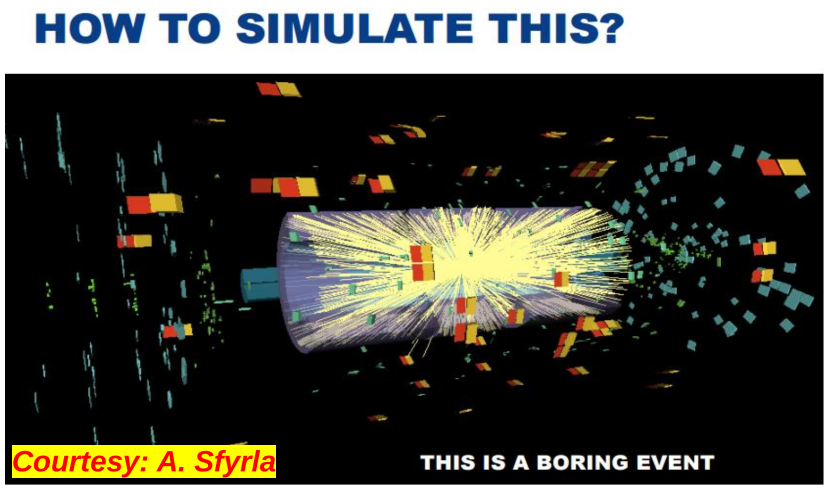
We need **intense** and **pure electron** beams to understand more...
High energy electrons (O(10(GeV)) can currently **only** be produced via the **$\pi^0$ → γγ → $e^+e^-$ channel**

# Motivation for particle beams

- **2. Detector development and R&D**
  - The design of the big LHC experiments and the future accelerators & machines needs a lot of research in order to understand and choose the correct and expensive components.

  - Simulations are certainly valuable – However ...



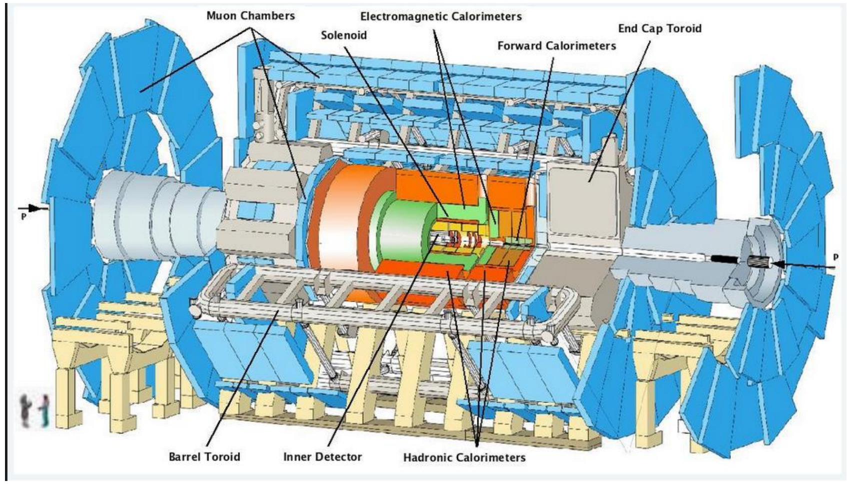



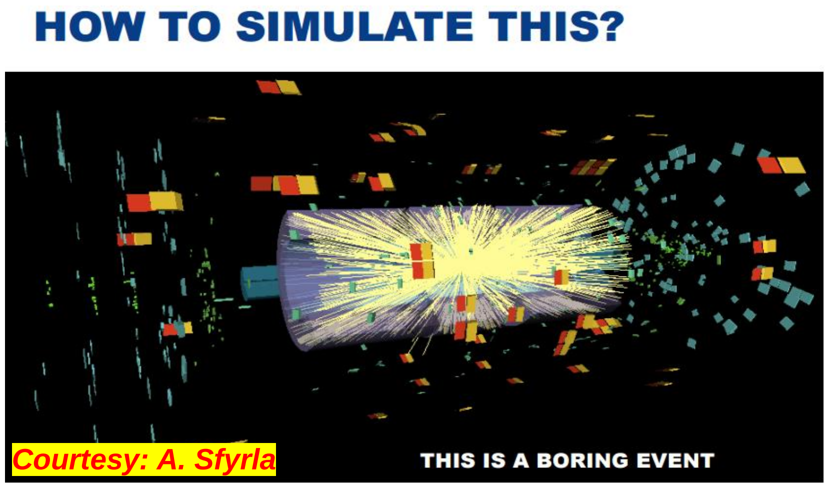

(Simulation material by Z. Marshal) 57

The only way **is to test these new components**, starting from their "development" phase many years before

# Motivation for particle beams

- **2. Detector development and R&D**
  - The design of the big LHC experiments and the future accelerators & machines needs a lot of research in order to understand and choose the correct and expensive components.
  - Simulations are certainly valuable – However ...

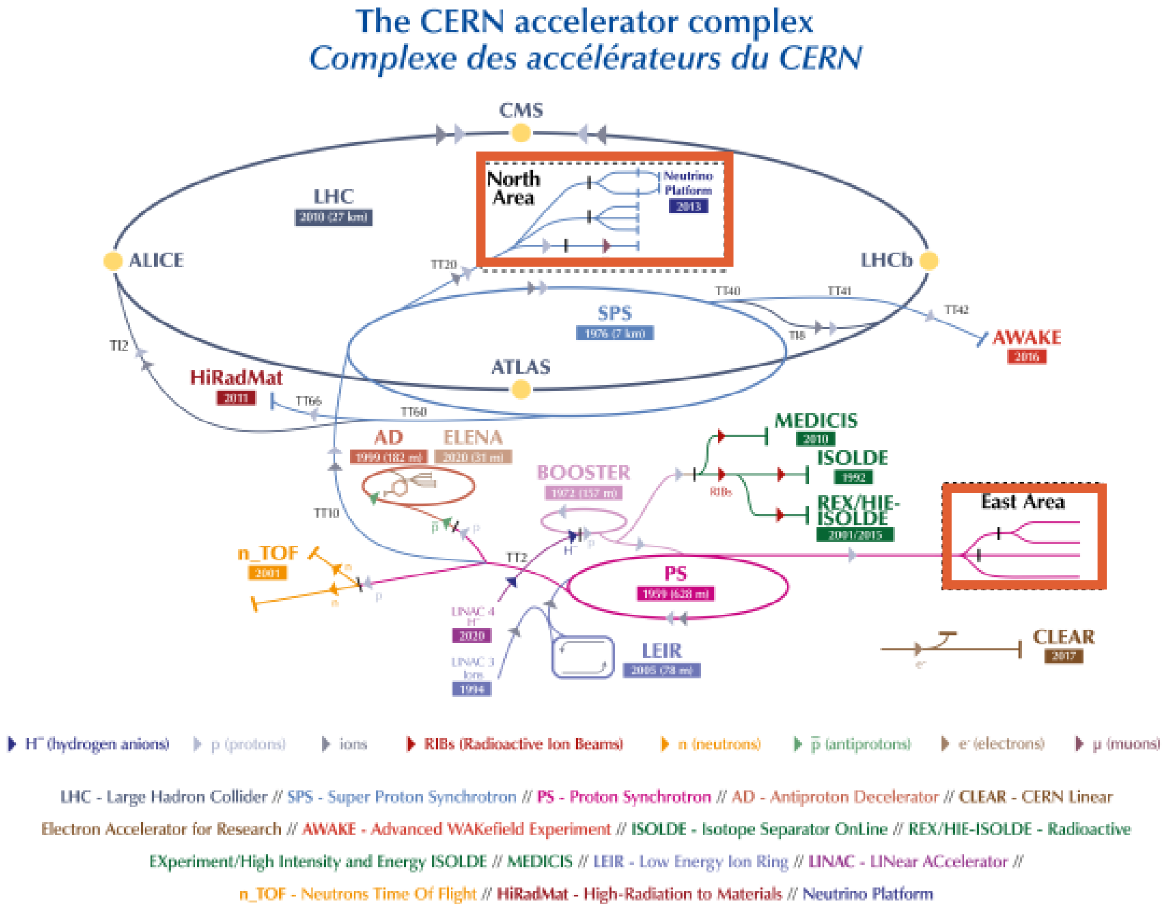



(Simulation material by Z. Marshal) 57

- TEST BEAMS
  - Controlled and easily accessible environment (and lots of space !)
  - Low intensities ($10^5$ – $10^6$ pps) of high quality beams
  - Many different particles and energies
  - Possibility of long-term housing of big and complex installations

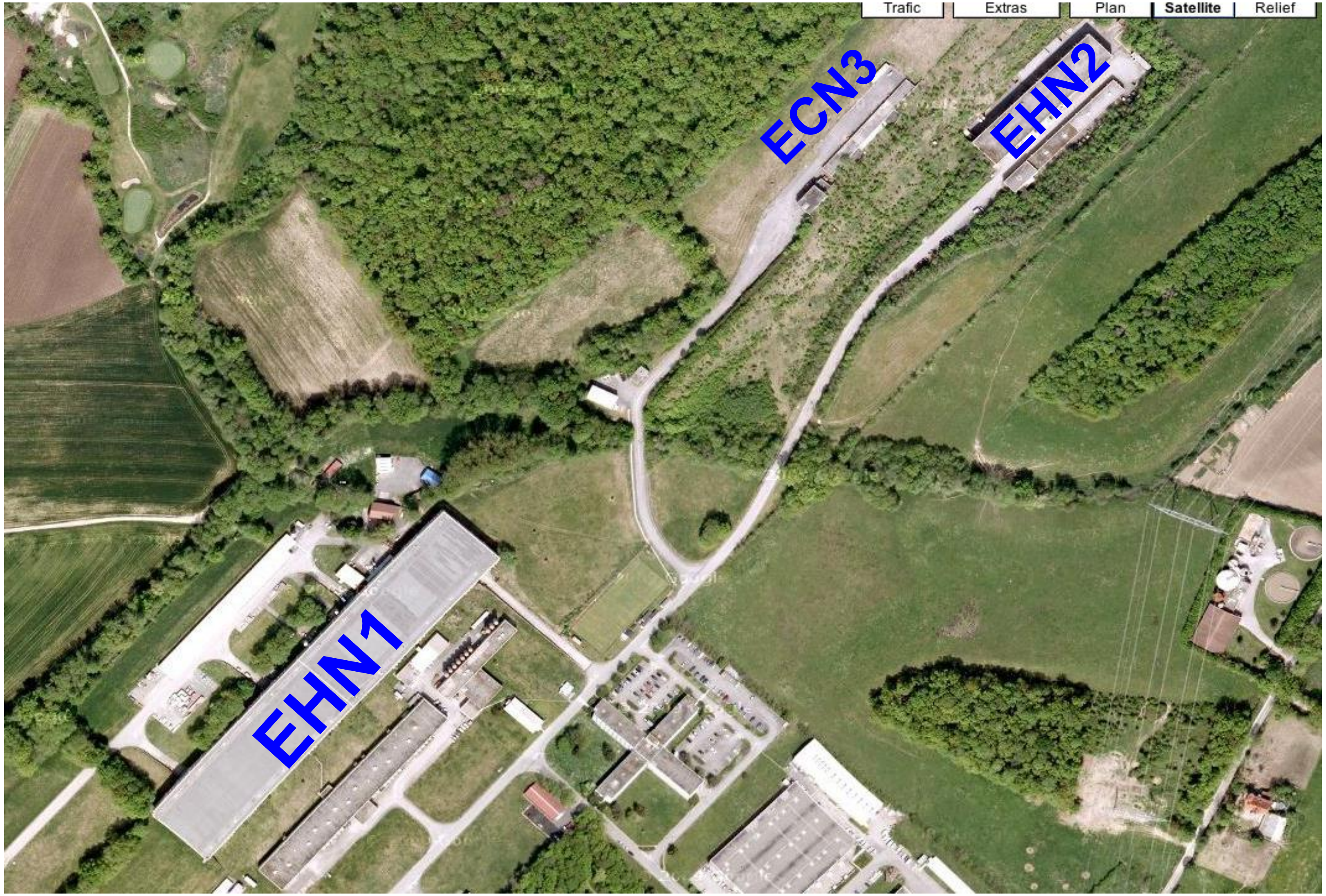
# The CERN secondary lines




Essentially, the only place world-wide that such a large variety of high energy **secondary particles** & **momenta can be produced, transported and delivered to various experiments.**

SPS : protons/ions @ 400 GeV/c/Z
PS: protons /ions @ 24 GeV/c/Z

# Focus on North Area



# Commissioned in 1978 as the flagship CERN project

SPS NORTH EXPERIMENTAL AREA

General Layout

G. Brianti

1. INTRODUCTION

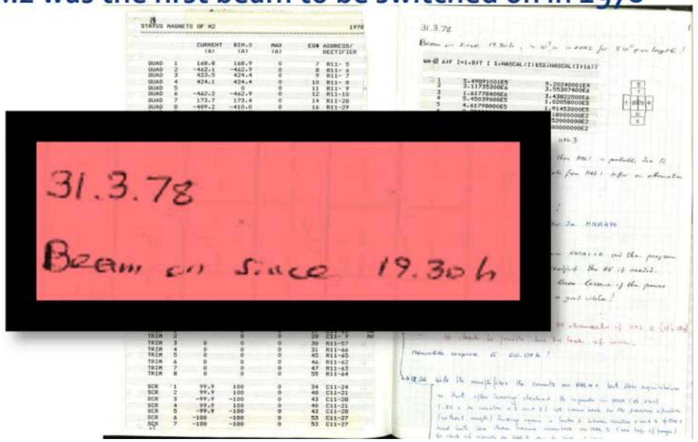
At its sixth meeting on June 27, 1973, the SPSC approved the basic features of the general layout as outlined in CERN/SPSC/T 73-3, namely :

i) three targets in one common enclosure,

ii) the types of target stations for the various facilities,

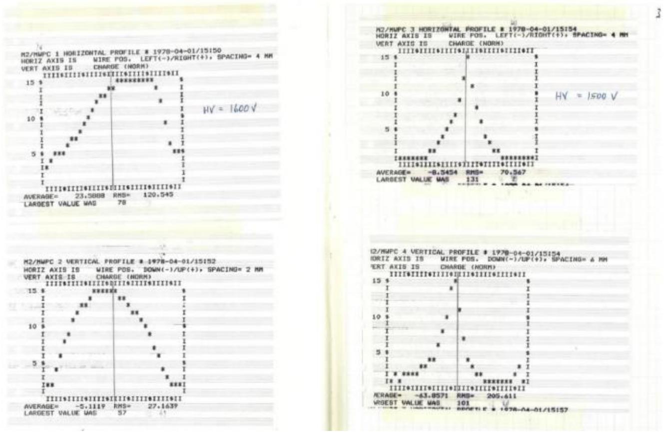
iii) two experimental zones.

M2 was the first beam to be switched on in 1978

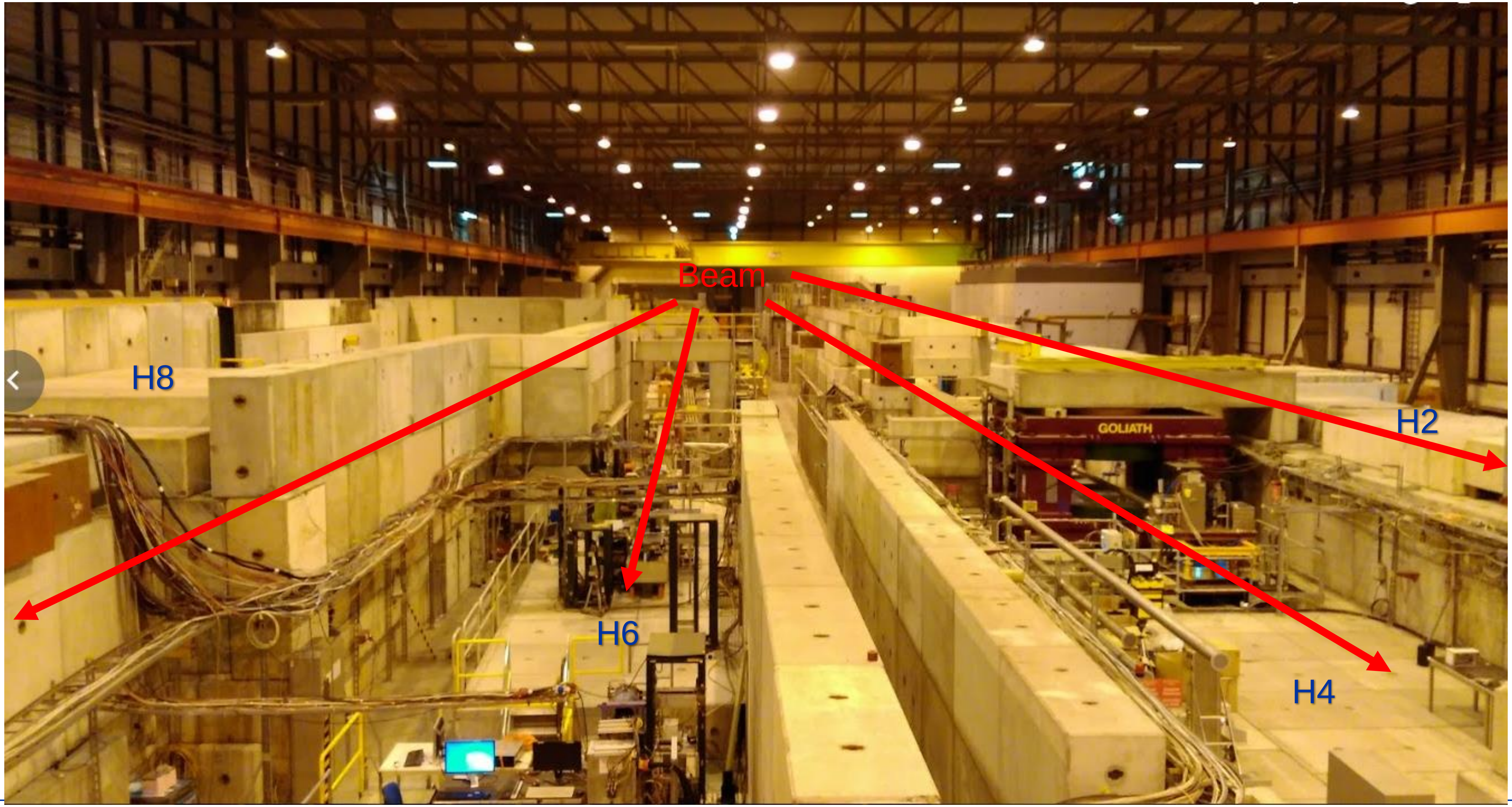



Courtesy: N. Doble

First Beam Profiles

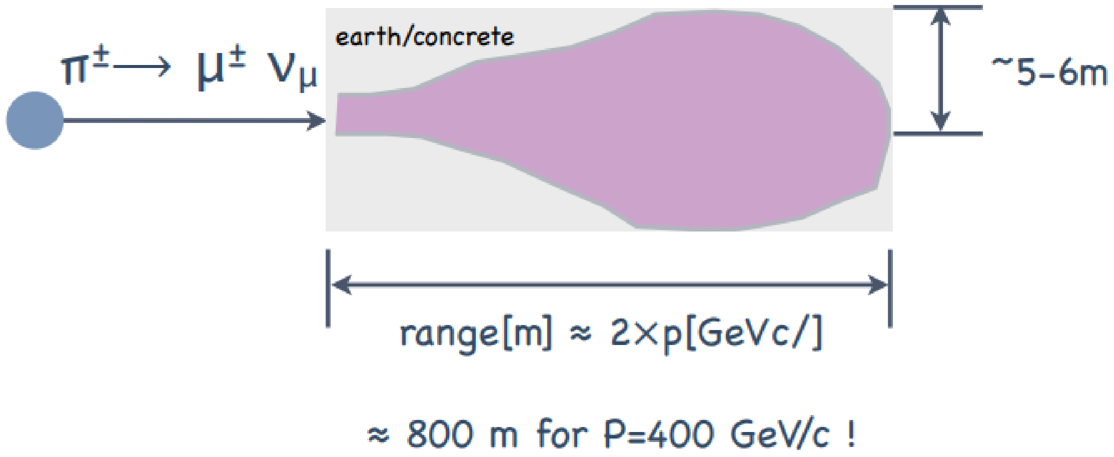


# North Area : EHN1 building

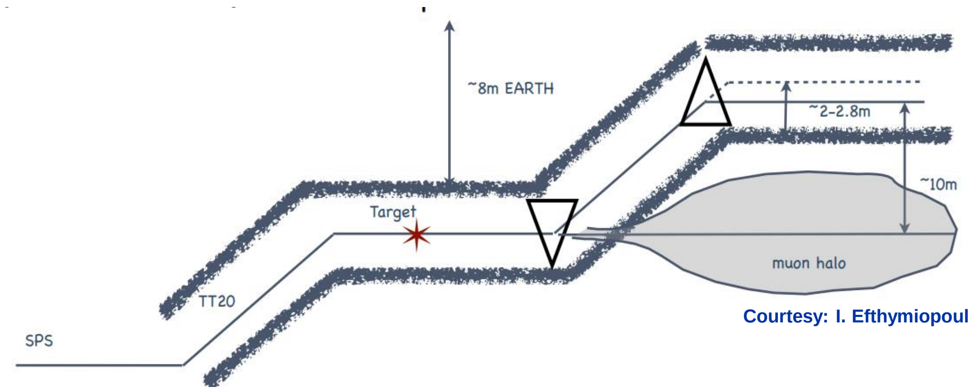


# Layout considerations

- **Typically, the accelerators are located underground ;**
  - Radiation, lower cost (land owning), safety ...
- **Not very practical for experimental halls though:**
  - Accompanying infrastructure, electrical installations, cryogenics
  - Lower intensities – Lower radiation environment
  - **Background is important to be minimal !**
- **For this reason: NA designed with two experimental halls & one underground cavern**
- **In all cases: Momentum selection necessary.**



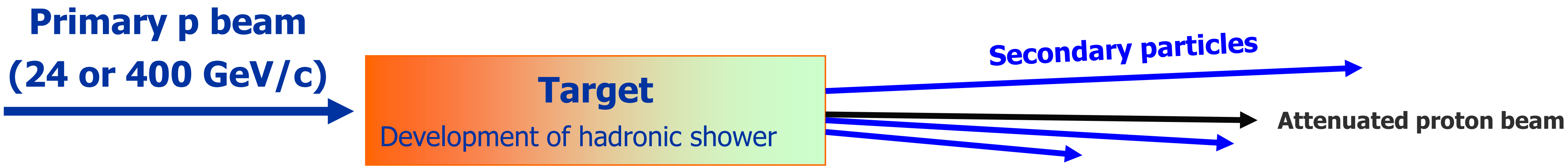

Schematic NA beam design



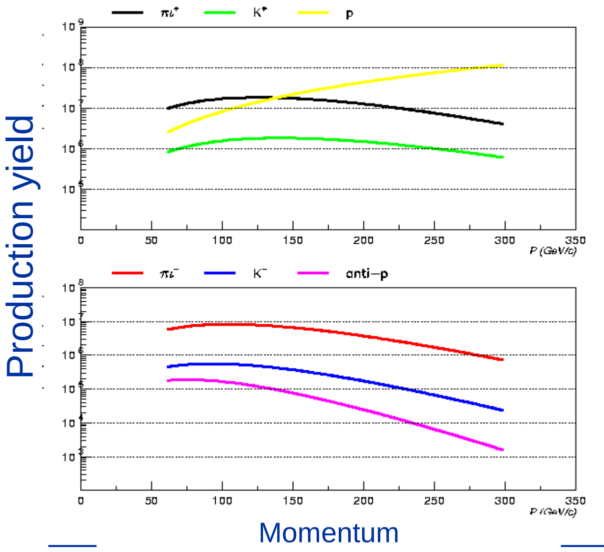

Courtesy: I. Efthymiopoulos

# Particle production

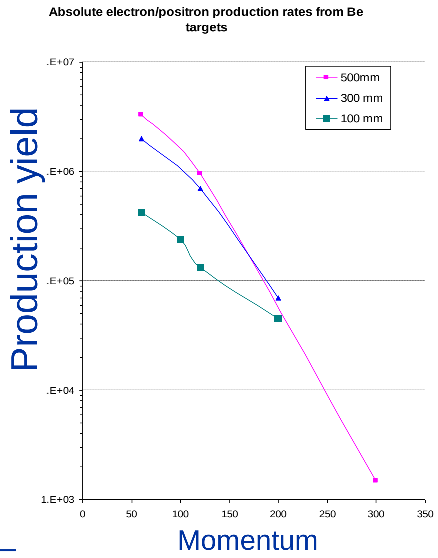
- The high energy, high intensity proton beam from PS or SPS is extracted on a target material.

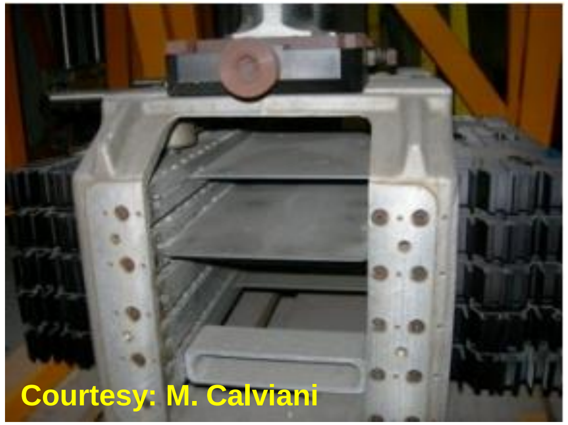


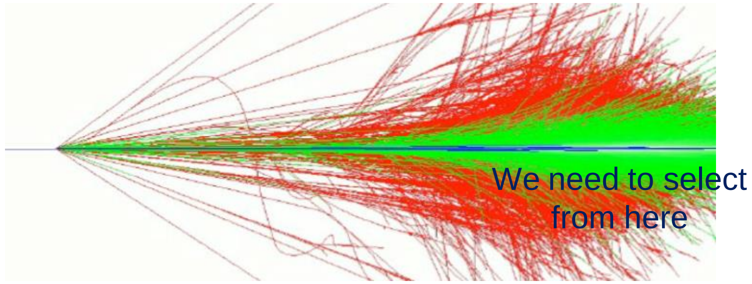

**Hadron beams**



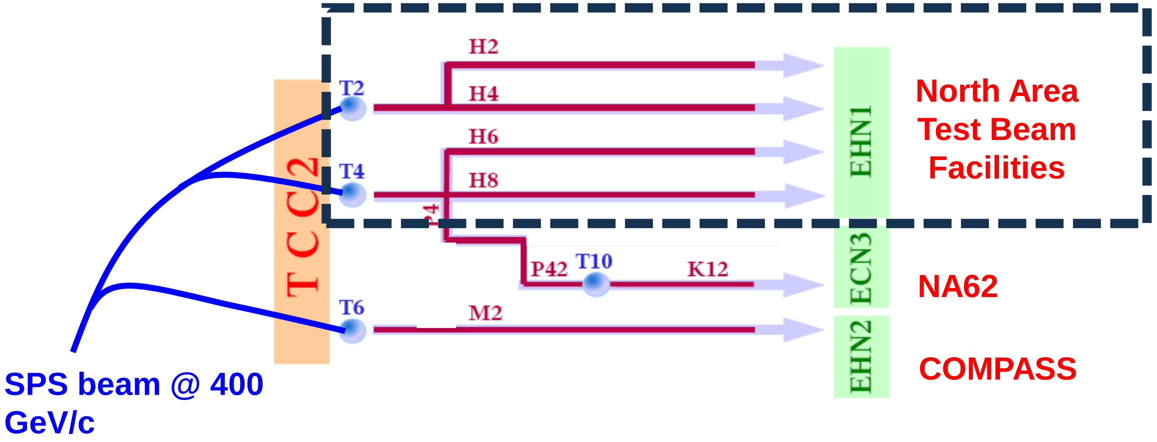

**Electron beams**



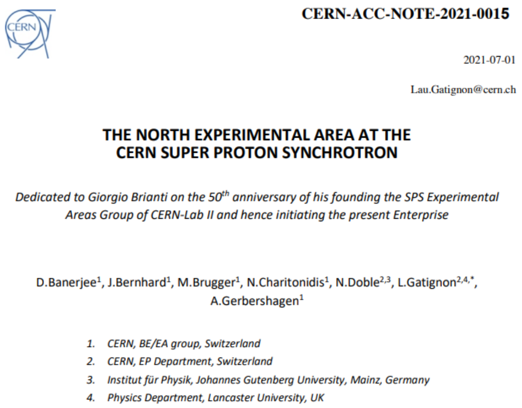



# The North Area Target Stations




Detailed information:

https://cds.cern.ch/record/2774716/files/CERN-ACC-NOTE-2021-0015-NA.pdf


CERN-ACC-NOTE-2021-0015

2021-07-01

Lau.Gatignon@cern.ch

THE NORTH EXPERIMENTAL AREA AT THE CERN SUPER PROTON SYNCHROTRON

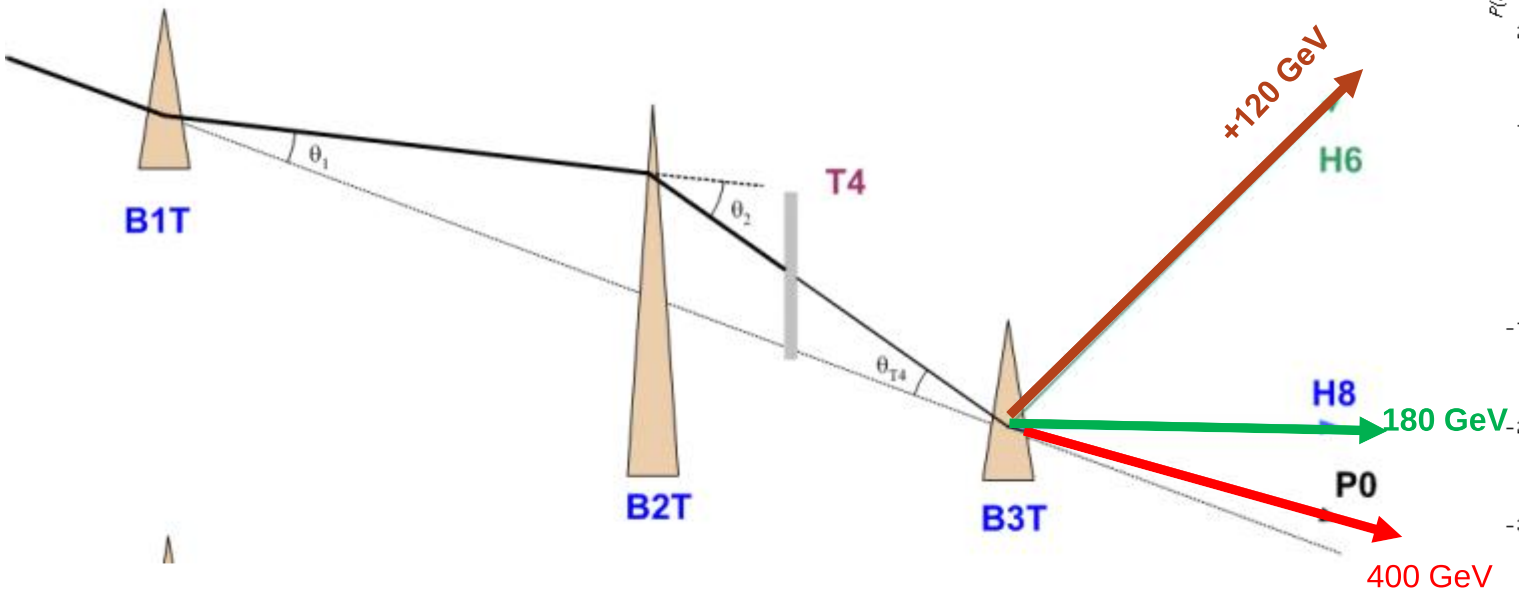
*Dedicated to Giorgio Brianti on the 50th anniversary of his founding the SPS Experimental Areas Group of CERN-Lab II and hence initiating the present Enterprise*

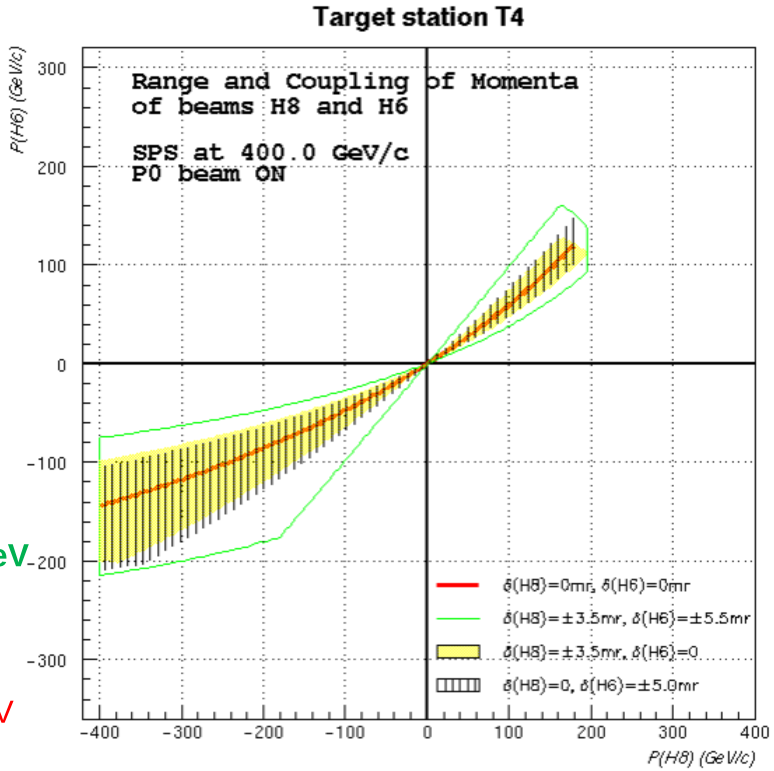
D.Banerjee[1], J.Bernhard[1], M.Brugger[1], N.Charitonidis[1], N.Doble[2,3], L.Gatignon[2,4,*], A.Gerbershagen[1]

1. CERN, BE/EA group, Switzerland
2. CERN, EP Department, Switzerland
3. Institut für Physik, Johannes Gutenberg University, Mainz, Germany
4. Physics Department, Lancaster University, UK

# The North Area Target Stations -- Wobbling

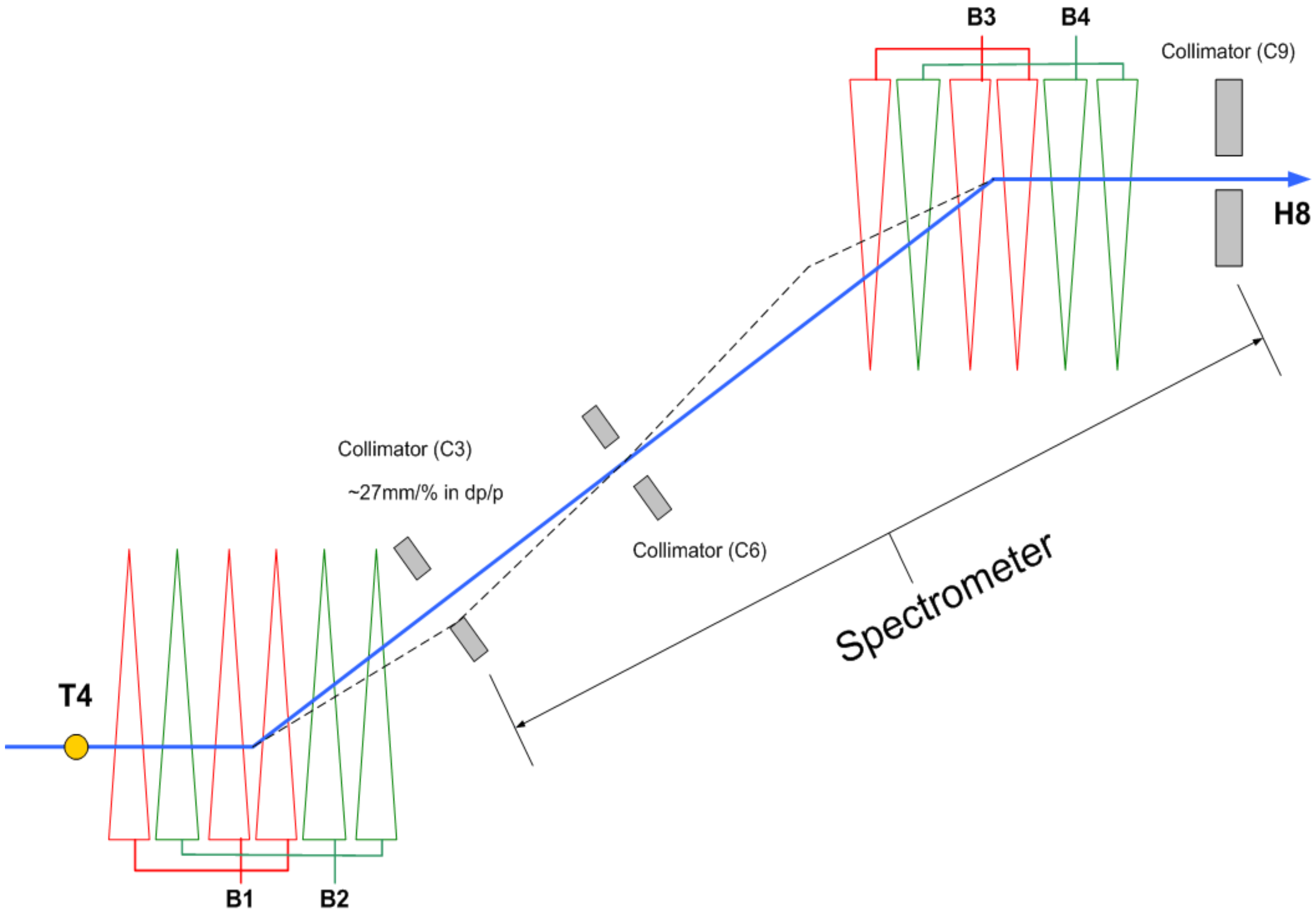
- "Wobbling" of the beam before and after the target allows for different production angles in the different beamlines allowing for many different configurations serving various experiments



# Momentum selection

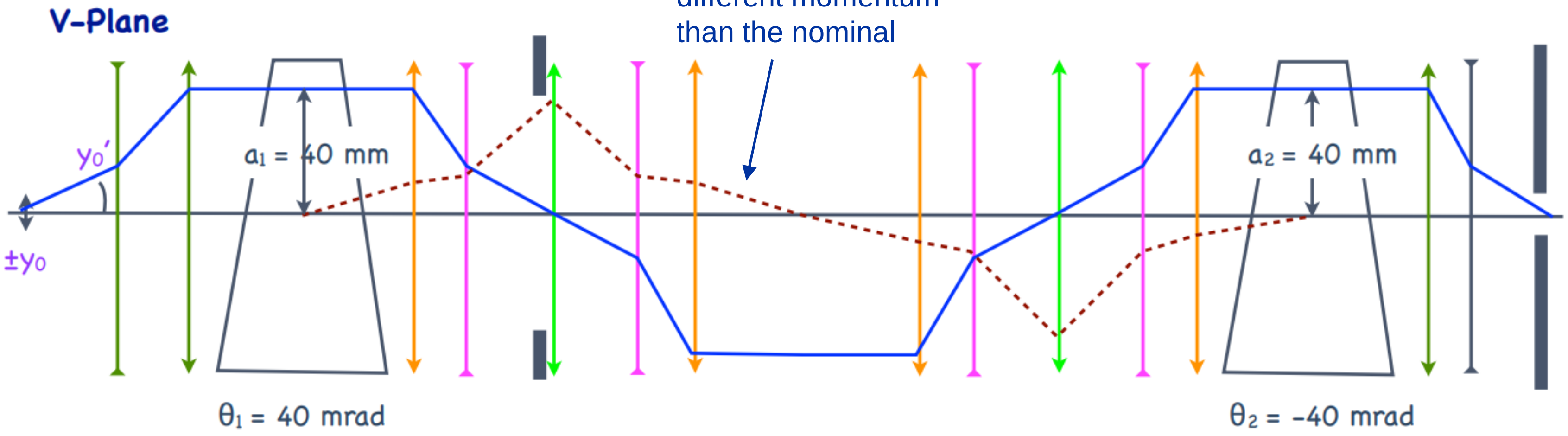
**The momentum selection is done in the vertical plane with specially designed collimators.**




*View of the H8 and H6 beam lines in TT82 tunnel.*

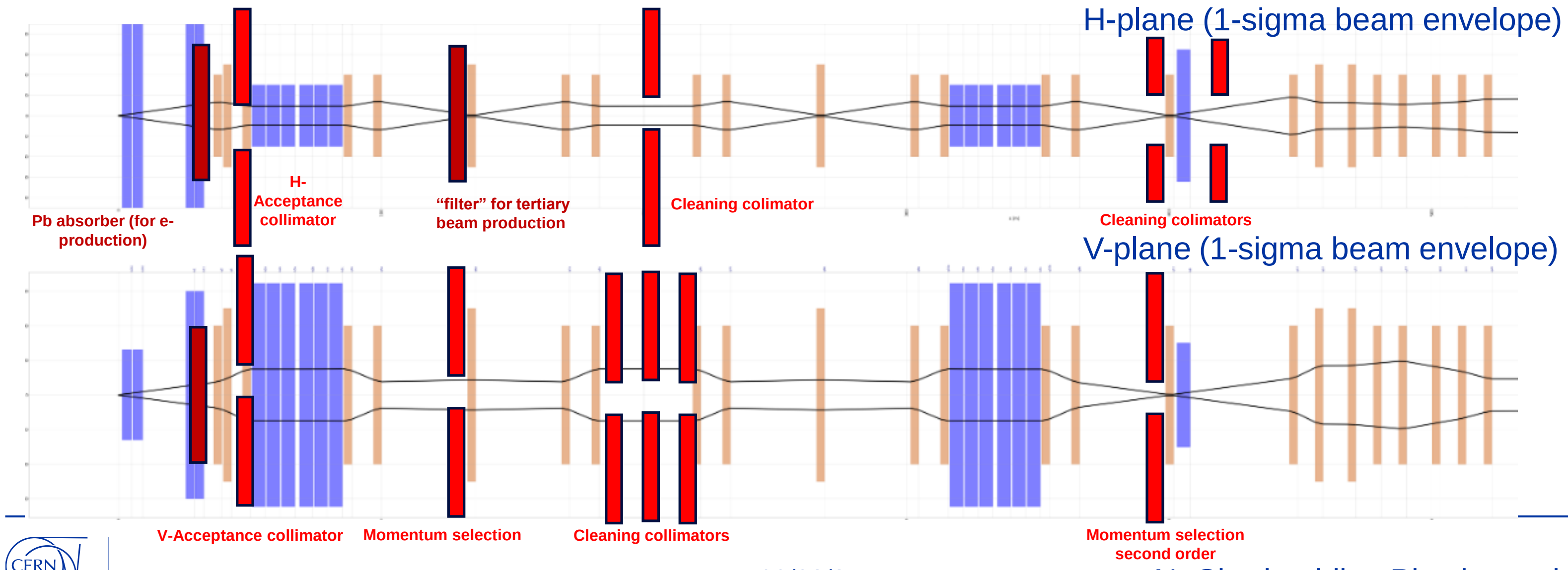
# Optics

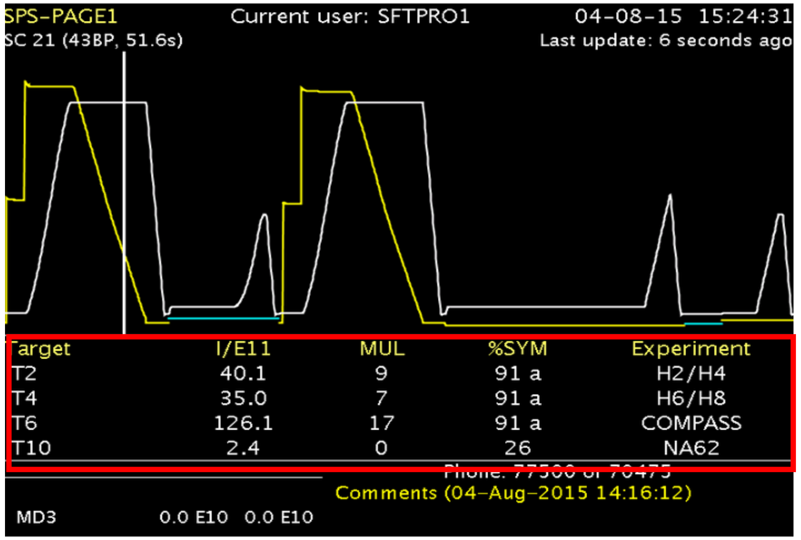
Particle with a different momentum than the nominal




- Spill duration approx. **5 seconds**
- Usually: 2 cycles / SPS supercycle for NA

~600m length



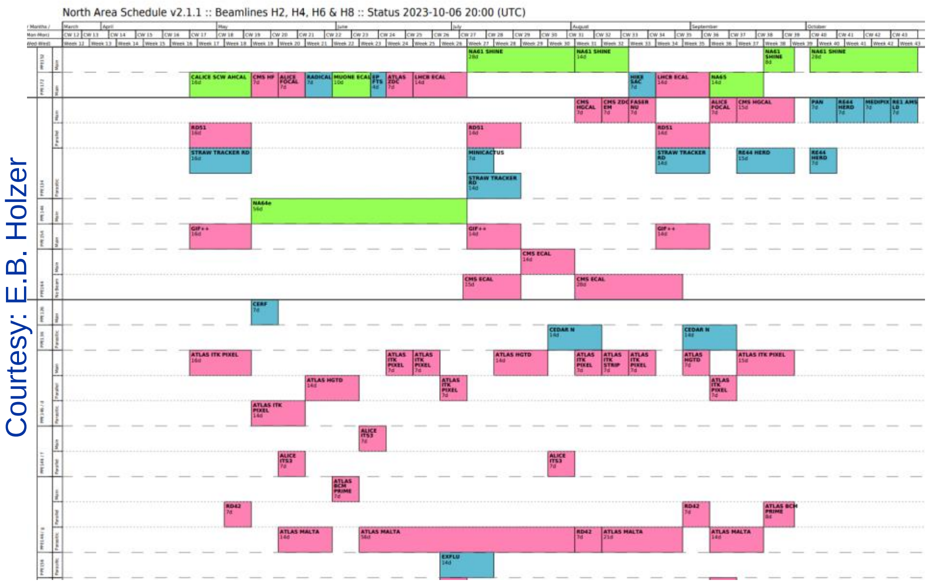
# North Area EHN1 Beamline Characteristics

| Parameters | Target T2 | | Target T4 | |
|---|---|---|---|---|
| Beam Line | H2 | H4 | H6 | H8 |
| Maximum Momentum [GeV/c] | 400 / 350 | 400 /330 | - / 205 | 400 / 350 |
| Maximum Acceptance [uSr] | 1.5 | 1.5 | 2 | 2.5 |
| Maximum Δp/p [%] | ± 2.0% | ± 1.4 % | ±1.5% | ±1.5% |
| Maximum Intensity / spill * (Hadrons / Electrons) | $10^7/10^5$ | $10^7/10^6$ | $10^7$ **/$10^5$ | $10^7$ **/$10^5$ |
| Available Particle Types | Primary protons/ions*** OR pure electrons OR mixed hadrons (pions, protons,kaons) | | | |

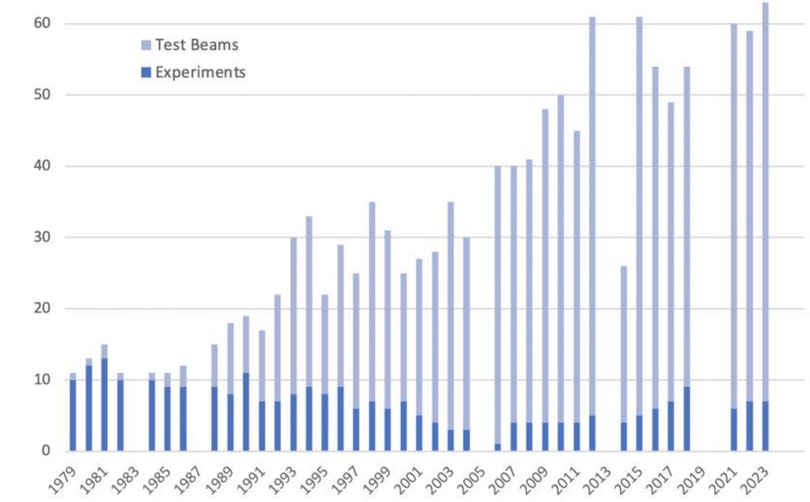
* Imposed by Radio Protection, and not available to every zone
** In some zones can be elevated up to $10^8$ subject to certain restrictions
*** Not available in H6

# Experiments / test-beams in the SBA

Courtesy: E.B. Holzer




Courtesy: L. Gatignon




- Estimate similar levels of overbooking as in 2024 (not yet accounting for the reduction in the available number of spills per week)

| p beam period EHN1 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NA61 proton period | 6 | 6 | | | 6 | 6 | 6 | 6 | 6 | | | | | | | | | | H2 |
| NP02 | | 6 | | | possibly | possibly | possibly | | | | | | | | | | | | H2 |
| NP04 | 6 | | LS3 | | possibly | possibly | possibly | | | LS4 | | | | | | LS5 | | | H4 |
| NA64e | 10 | 10 | | | 9 | 9 | 9 | 8 | 8 | | 8 | 8 | 8 | 8 | 8 | | | | H4 |
| NA64e+ | | | | | 2 | 2 | 2 | 3 | 3 | | 3 | 3 | 3 | 3 | 3 | | | | H4 |
| GIF++ | 6 | 6 | 0 | 0 | 8 | 8 | 8 | 8 | 8 | 0 | 8 | 8 | 8 | 8 | 8 | 0 | 8 | 8 | H4 |
| NA60+ p beam | | | | | 2 | 3 | 3 | 3 | 3 | | 3 | 3 | 3 | 3 | 3 | | | | H8 |
| SUM experiments H4 (without GIF++ and test beams) | 22 | 22 | 0 | 0 | 17 | 17 | 17 | 17 | 17 | 0 | 11 | 11 | 11 | 11 | 11 | 0 | 0 | 0 | |
| SUM EHN1 (without GIF++ and test beams) | 22 | 22 | 0 | 0 | 19 | 20 | 20 | 20 | 20 | 0 | 14 | 14 | 14 | 14 | 14 | 0 | 0 | 0 | |

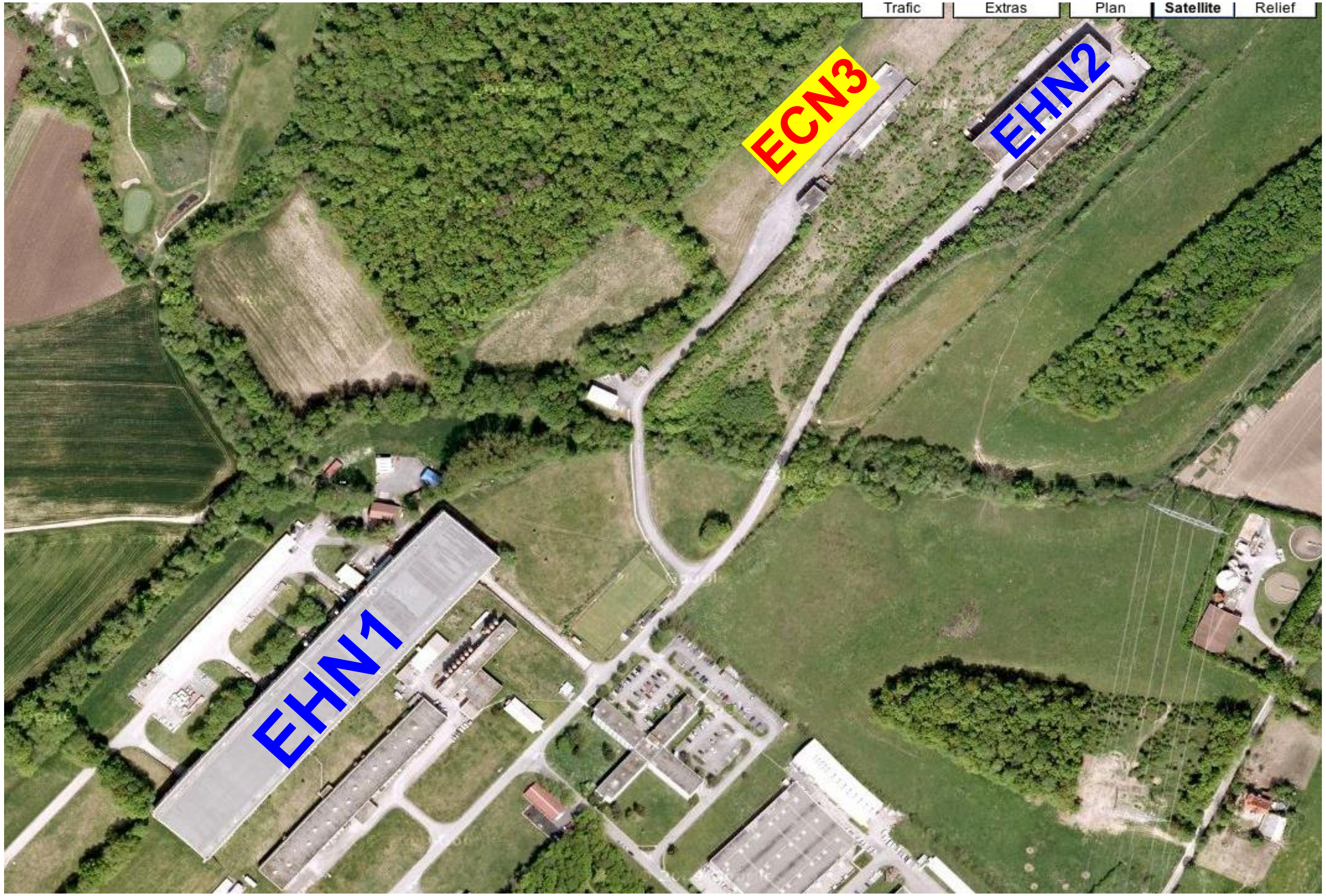
## 2023 and 2024 Multi-User Lines PS EA and SPS NA Beam Time Requests

Weeks requested as main user during proton beam period

| 2023 | SPSC related user | LHC experiments R&D | other users (CERN and external) | Requested (main) | | Weeks available | Requested including parasitic | |
|---|---|---|---|---|---|---|---|---|
| PS T9 & T10 | 8 | 22 | 19 | 49 | 85% | 58 | | |
| SPS H2, H4 | 28 | 28 | 13 | 69 | 157% | 44 | 77 | 175% |
| SPS H6, H8 | 0 | 64 | 24 | 88 | 200% | 44 | 128 | 291% |

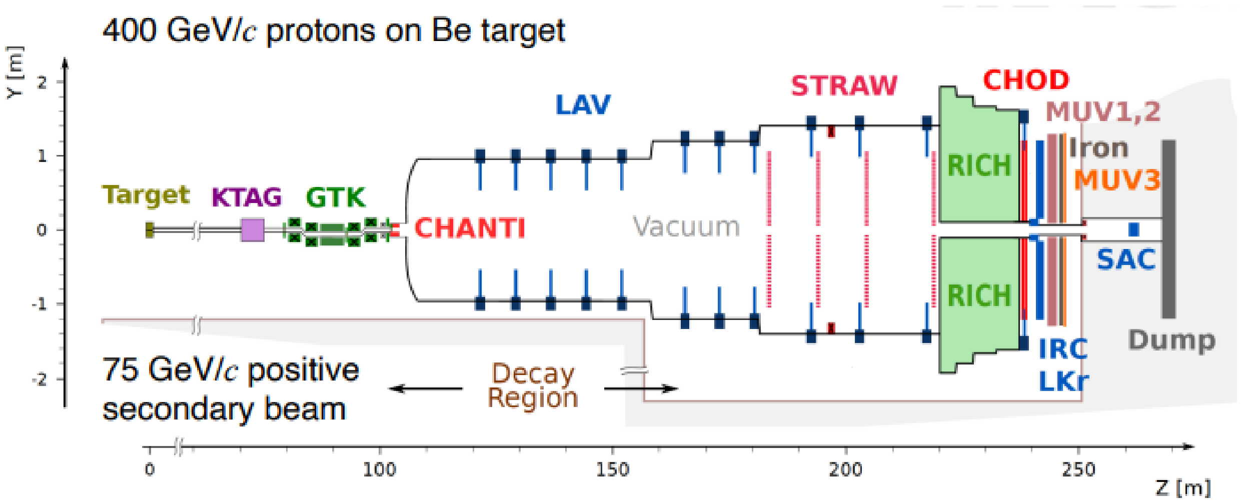
| 2024 | SPSC related user | LHC experiments R&D | other users (CERN and external) | Requested (main) | | Weeks available | Requested including parasitic | |
|---|---|---|---|---|---|---|---|---|
| PS T9 & T10 | 27 | 24.5 | 30 | 81.5 | 132% | 62 | | |
| SPS H2, H4 | 24 | 30 | 11 | 65 | 135% | 48 | 75 | 156% |
| SPS H6, H8 | 0 | 55 | 28 | 83 | 173% | 48 | 155 | 323% |

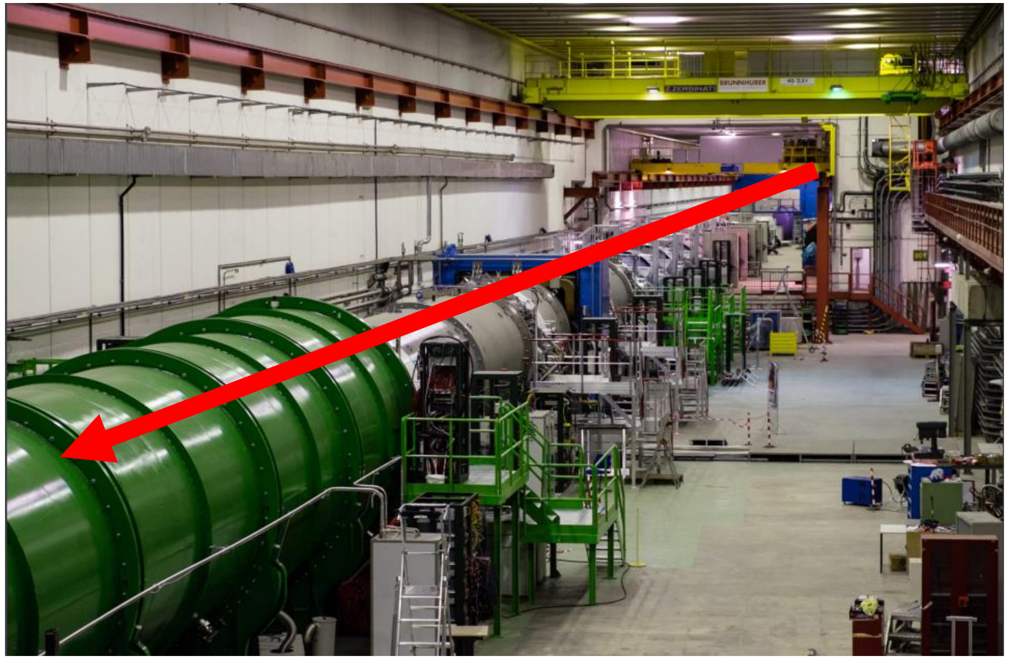
# Just a few highlights of experiments ....



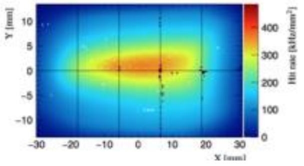
# The NA62 experiment

Courtesy: G. Ruggiero (NA62)



- **SPS Beam:**
  - 400 GeV/c protons
  - $2.10^{12}$ protons/spill
  - 5s spill [3s eff.] / ~16 s



Courtesy: A. Cecucci

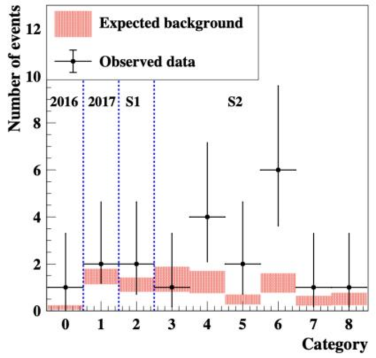
- **Secondary positive Beam:**
  - 75 GeV/c momentum, 1 % bite
  - 100 μrad divergence (RMS)
  - 60x30 mm$^2$ transverse size
  - $K^+$(6%)/$\pi^+$(70%)/p(24%)
  - For $33 \times 10^{11}$ ppp on T10
  - → 750 MHz at GTK3

- **Decay Region:**
  - 60 m long fiducial region
  - ~ 5 MHz $K^+$ decay rate
  - Vacuum ~ O($10^{-6}$) mbar

Detector and Performances: arXiv:1703.08501

NA62 Combined Result (2016,2017 and 2018)

JHEP 06 (2021) 093 arXiv:2103.15389 [hep-ex]



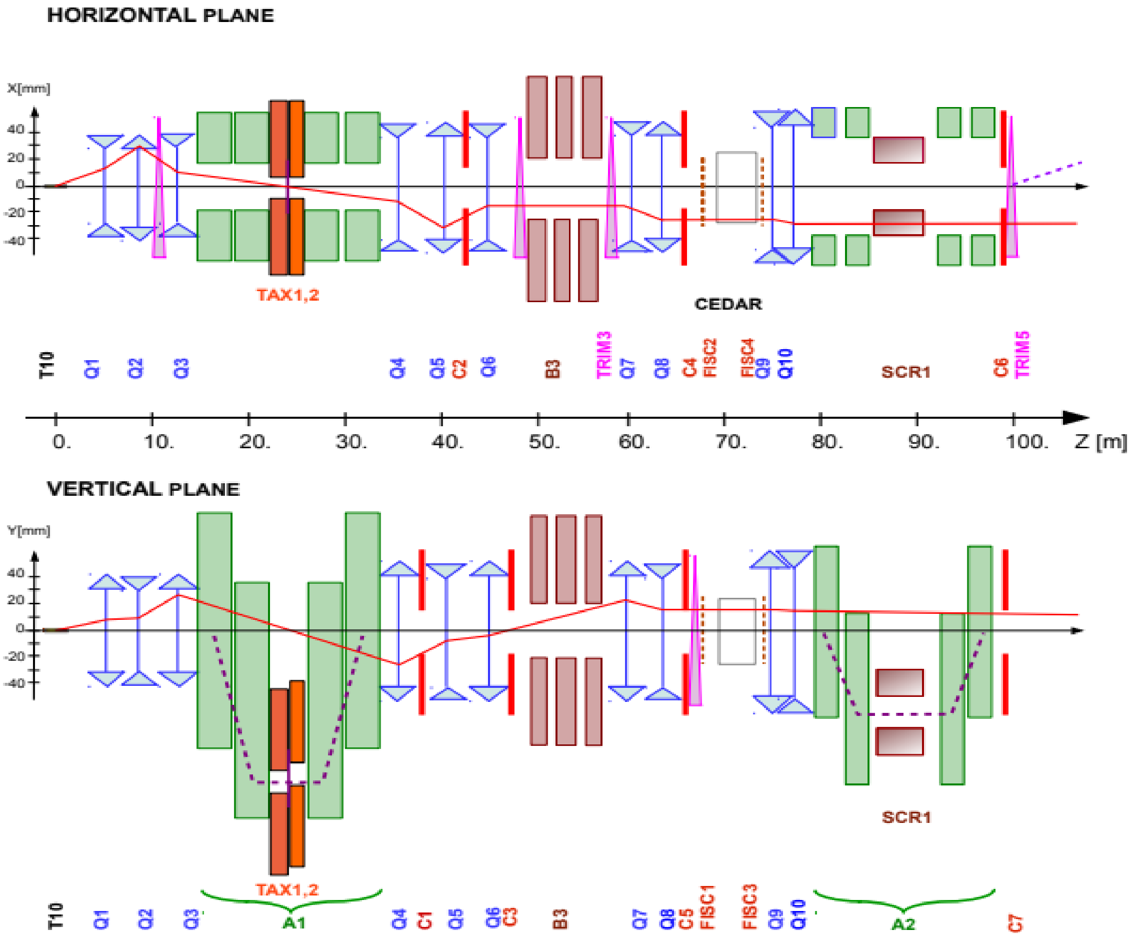

$SES = (0.839 \pm 0.053_{syst}) \times 10^{-11}$,
$N^{exp}_{\pi\nu\bar{\nu}} = 10.01 \pm 0.42_{syst} \pm 1.19_{ext}$,
$N^{exp}_{background} = 7.03^{+1.05}_{-0.82}$.

$$B(K^+ \to \pi^+ \nu\bar{\nu}) = (10.6^{+4.0}_{-3.4}\ (stat) \pm 0.9\ (syst)) \times 10^{-11}$$

20 Candidates  3.4 $\sigma$ significance,  $P(back.only)\ 3.4 \cdot 10^{-4}$

Courtesy: A. Cecucci

# The K12 beamline




## CEDAR - H

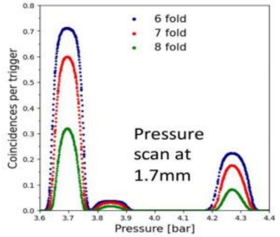
Reduction of material budget in the beamline: $\mathbf{N_2}$ $\mathbf{3.9\%}$ $\mathbf{X_0}$ vs $\mathbf{H_2}$ $\mathbf{0.7\%}$ $\mathbf{X_0}$

Expected 15% reduction rate at L0, Lower occupancy of detectors (to be quantified)

New optics

Exhaust Tested in H6 (fall 2022)


Isolation of motor controls within ATEX zone



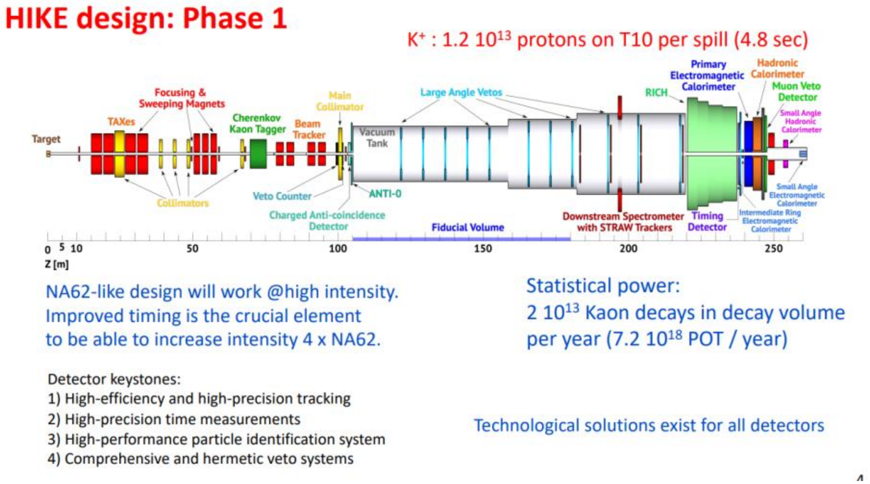

Photon yield $\langle N_\gamma \rangle \approx \mathbf{18-19}$

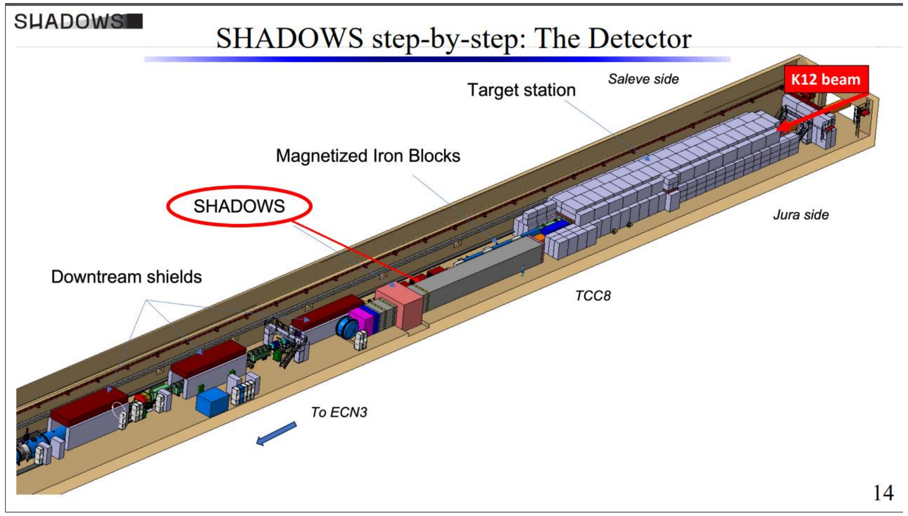
$K - \pi$ separation $\pi^+$ $ID < 10^{-4}$

Time resolution $\sigma_t^{KTAG} \approx \mathbf{65\ ps}$

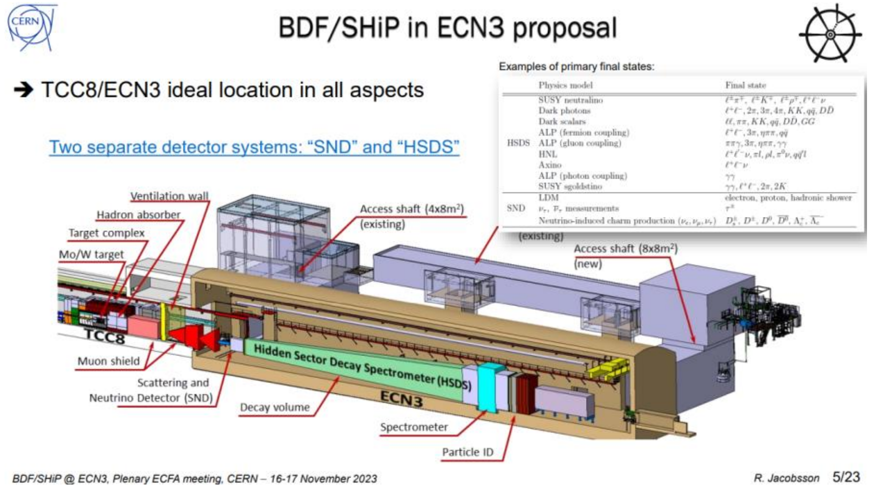
# ...And exciting proposals on the table for the future of ECN3 with higher intensities

Courtesy: C. Lazzeroni

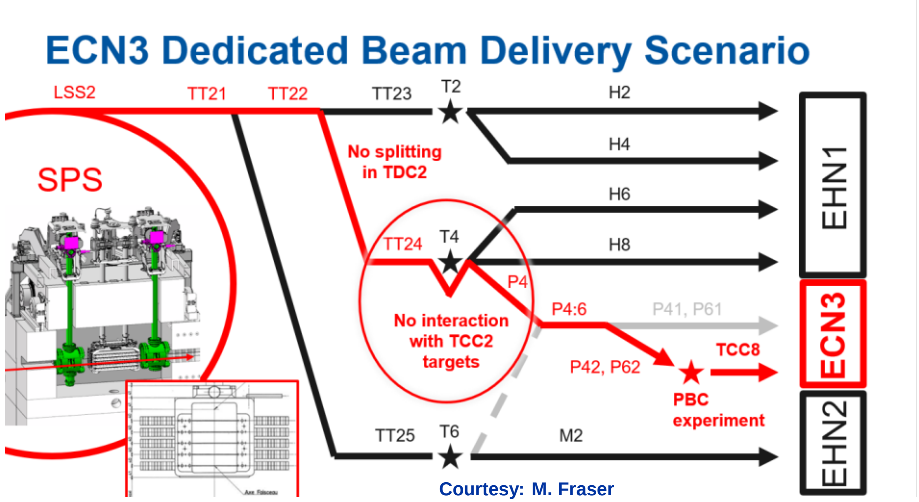



Courtesy: G. Gianfranchi

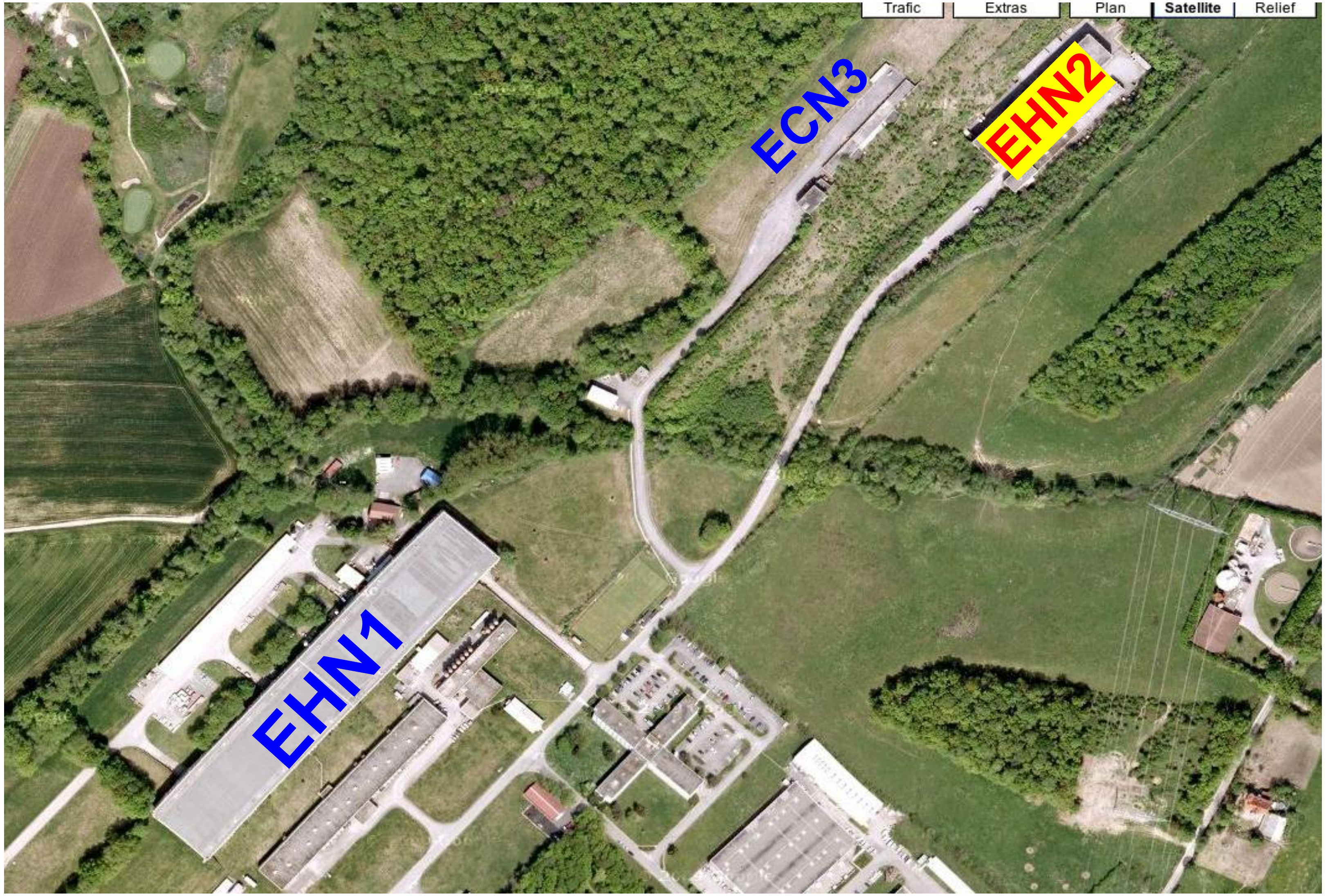



Courtesy: R. Jacobsson




Courtesy: M. Fraser

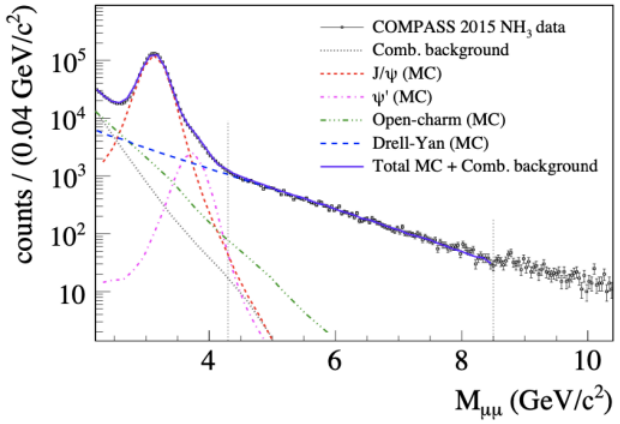
# Just a few highlights of experiments ....



# AMBER: Uncovering the mysteries of muon/hadron structures and spectroscopy

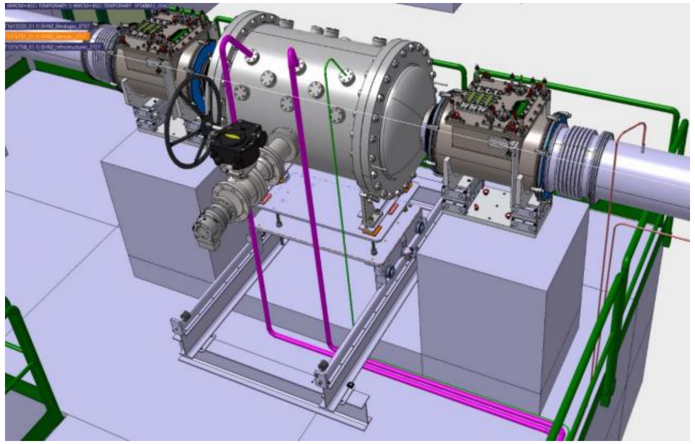

Courtesy: A. Cecucci

Drell-Yan cross-section measurements to study meson structure




- The high-energy, high-intensity M2 hadron beams allow to measure Drell-Yan pairs, cleanest in the range 4.3 to 8.5 GeV

New TPC to be employed and will offer unprecedented precision in the Proton Radius Measurement program

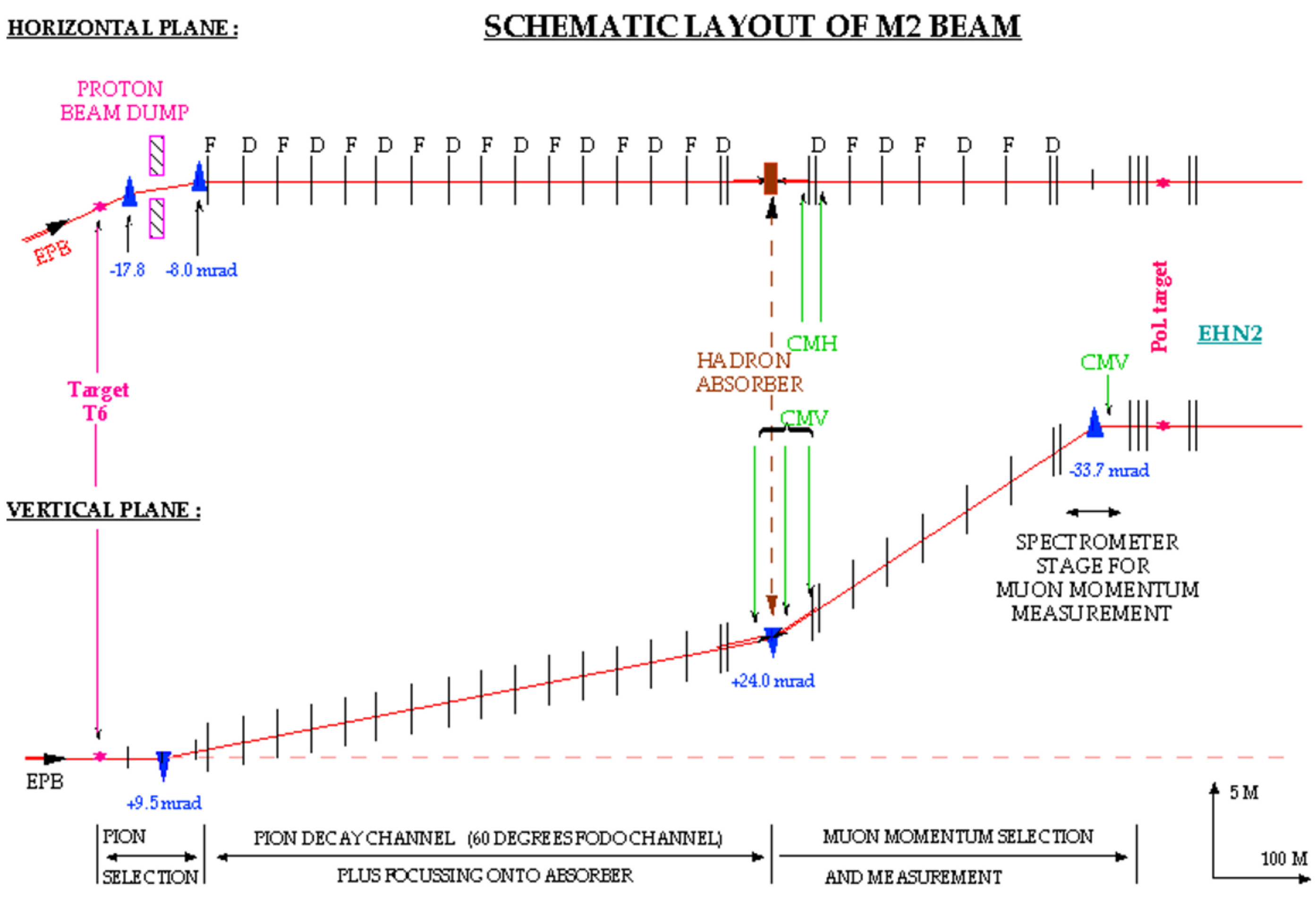


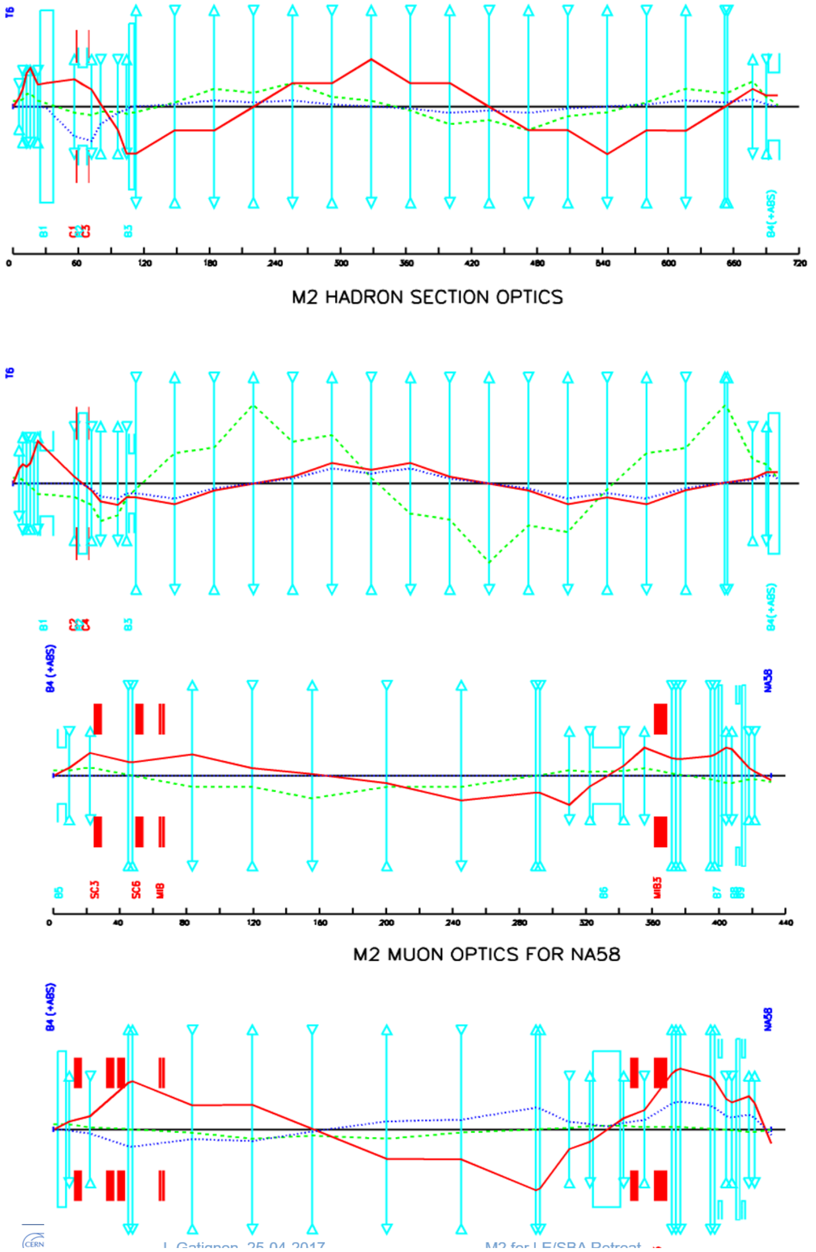
In M2 line, up to 2x10$^8$ muons/spill @ 190 GeV/c

*"The most intense polarized muon beam in the world"*

Hadrons of high intensity also available for D-Y measurements.

# The M2 beamline



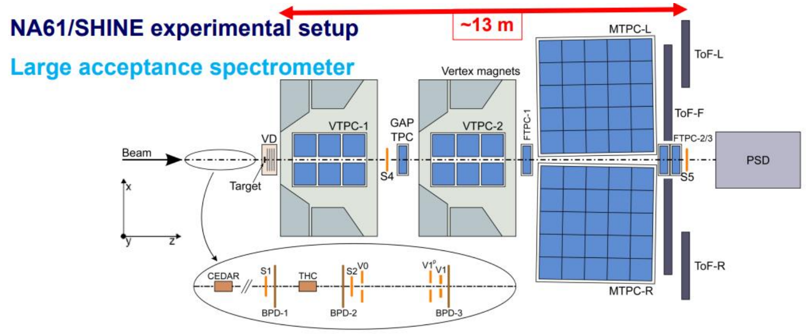
# Just a few highlights of experiments ....

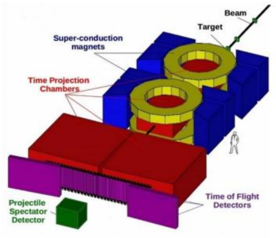
# NA61: Understanding hadronization

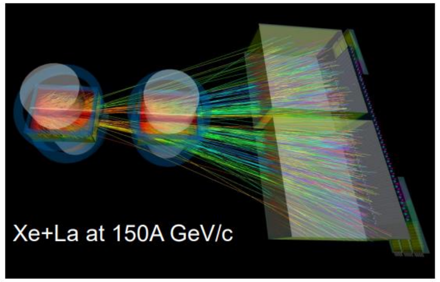
- **Strong interaction physics**
  - Focus: Understanding the properties of the ‘onset of deconfinement’
  - Direct measurement of open charm mesons

- **Neutrino and cosmic ray physics**
  - Service measurements for JPARC,FNAL and other laboratories
  - Nuclear fragmentation cross sections for intermediate mass nuclei.

- **Measurements using hadrons of very broad energy range (30 – 120 GeV/c).**
  - With a unique TPC + spectrometer of large acceptance

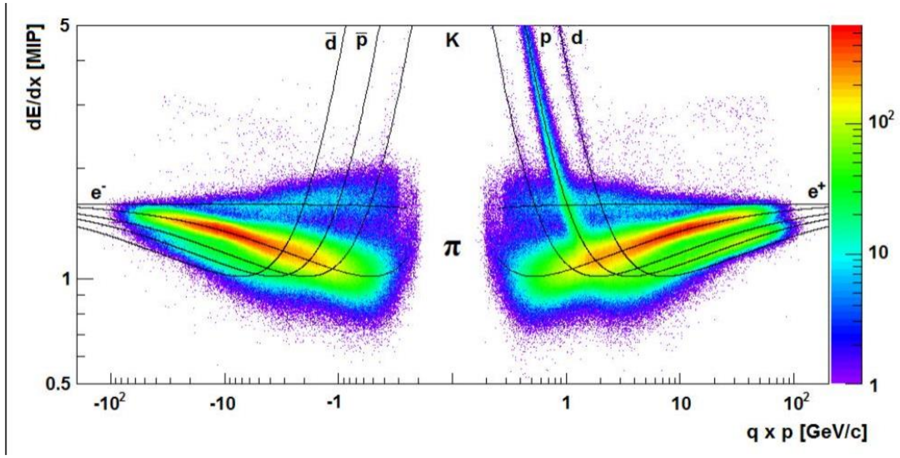



3

Courtesy: NA61



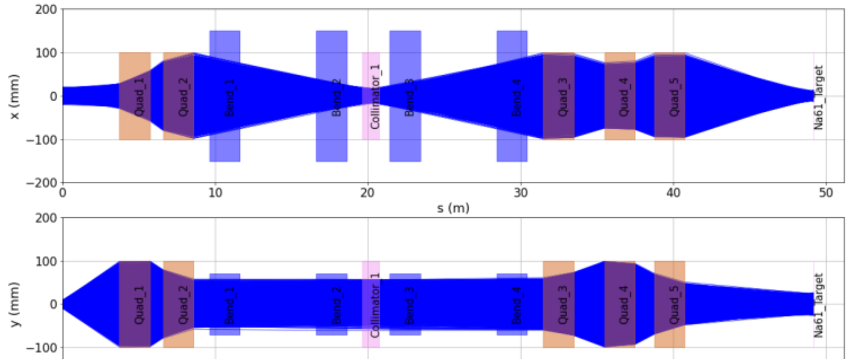
# NA61 Low-Energy – A DOCT thesis from Univ. Oxford & CERN

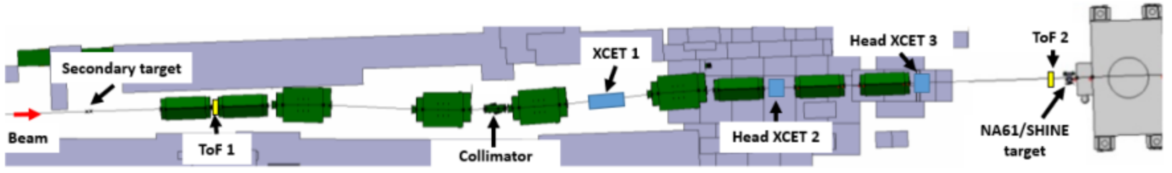
- **NA61 in need of measurements in the “Very-Low” momentum range of 1 – 10 GeV/c. The beamline serving NA61 is optimized for momenta > 30 GeV/c.**

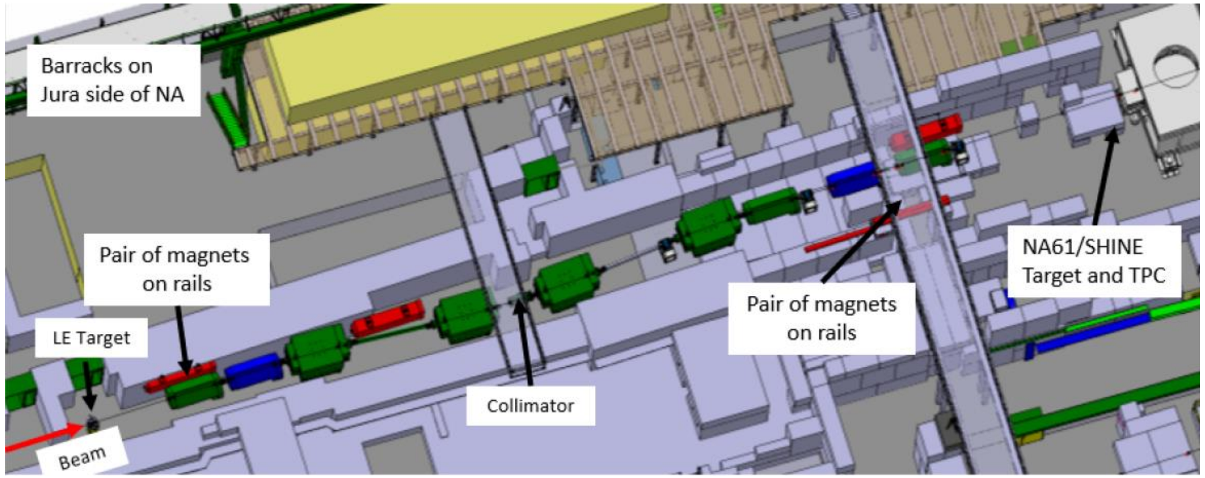
- **A new, short, high-acceptance beamline was designed in front of NA61 that could deliver particles in this very low energy range.**

- **Led to the PhD thesis of C. Mussolini (Univ. Oxford, 2023)**

- **Proposal under consideration by the CERN committees.**



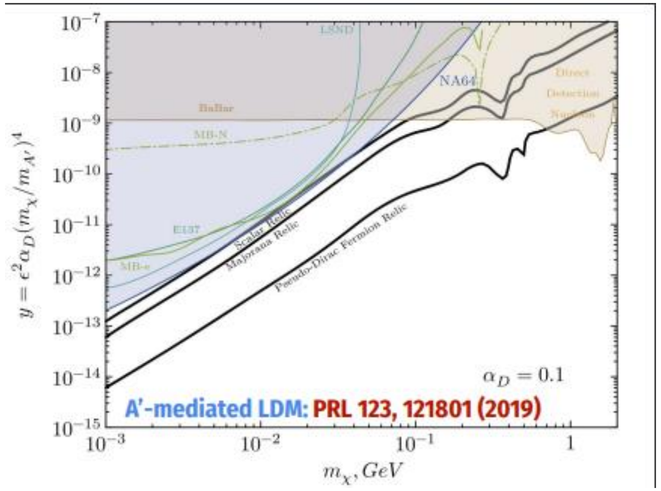



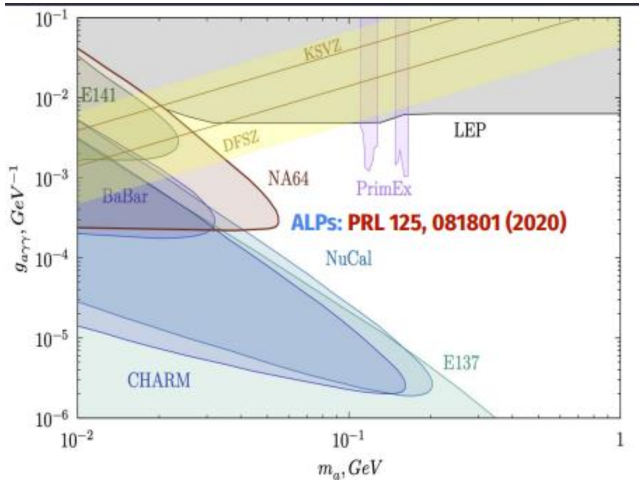



# NA64: Looking for dark matter and FIPs

- Comprehensive search for new physics with feebly interacting particles

Courtesy: A. Celentano (NA64)

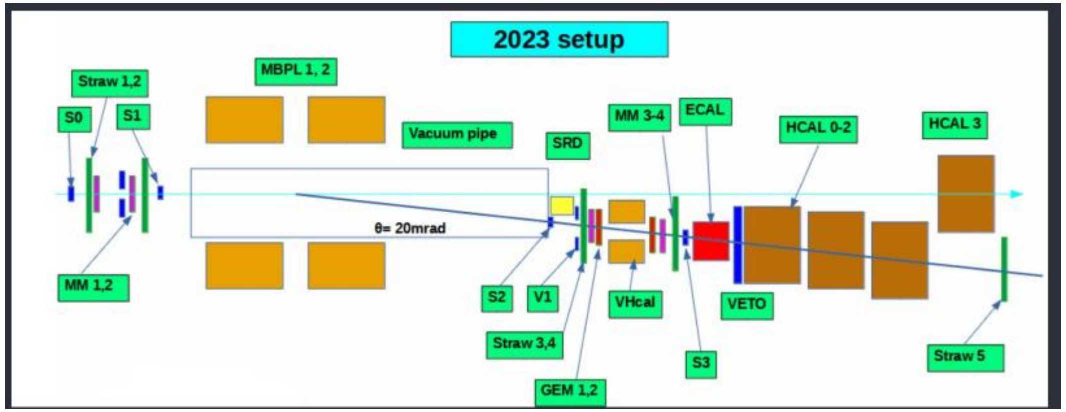


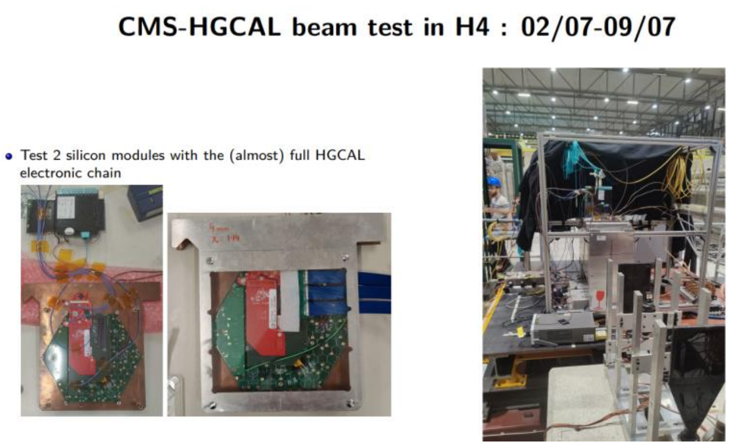

Courtesy: A. Celentano (NA64)

- 100 GeV/c pure e$^-$ beam from H4 offers unique conditions to measure missing energy observables with the stricter limits in the world

- Part of their physics program in M2

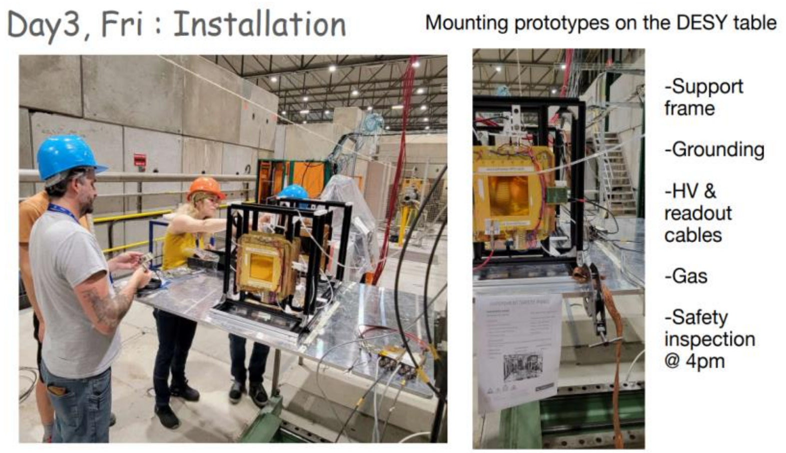


# Test beams for LHC experiments (and not only)

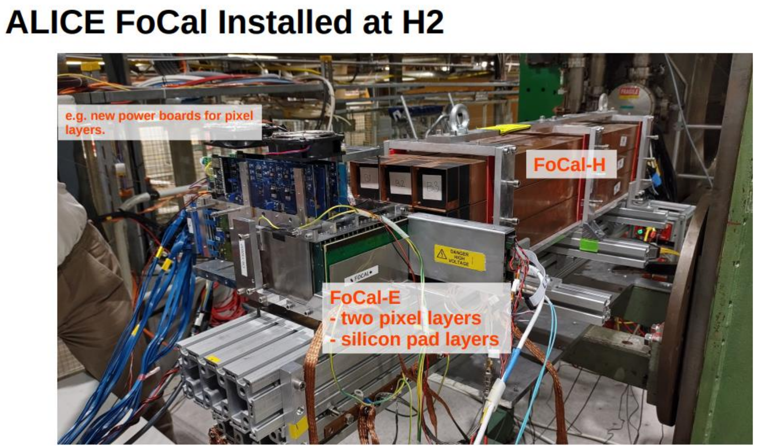



CMS: Electrons 20-250 GeV/c @ H4

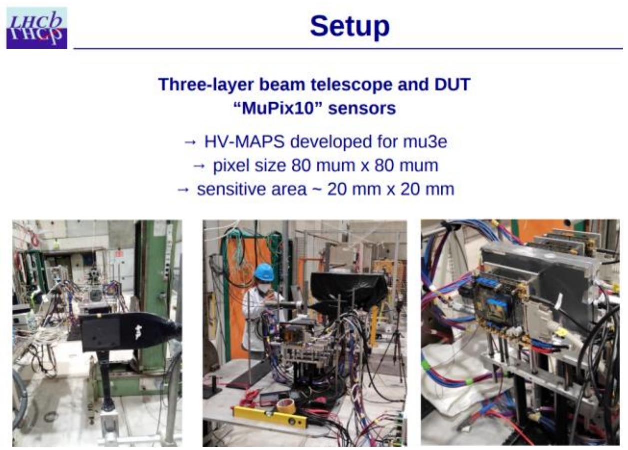

ATLAS: Hadrons / Electrons 20-180 GeV/c @ H8




MPGD: Hadrons 120 GeV/c @ H6



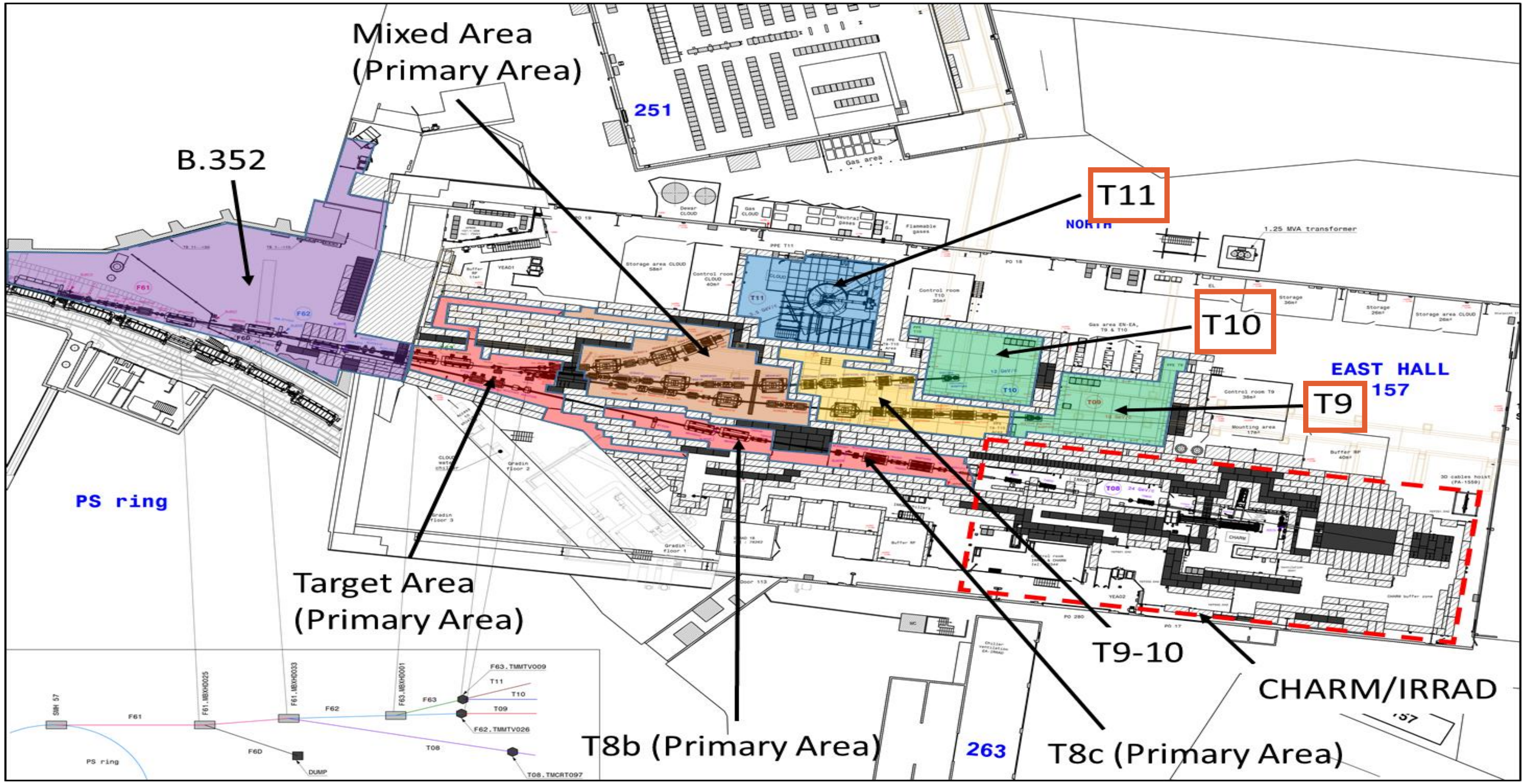

ALICE: Electrons / Hadrons 20-250 GeV/c @ H2




LHCb: Hadrons 180 GeV/c @ H8

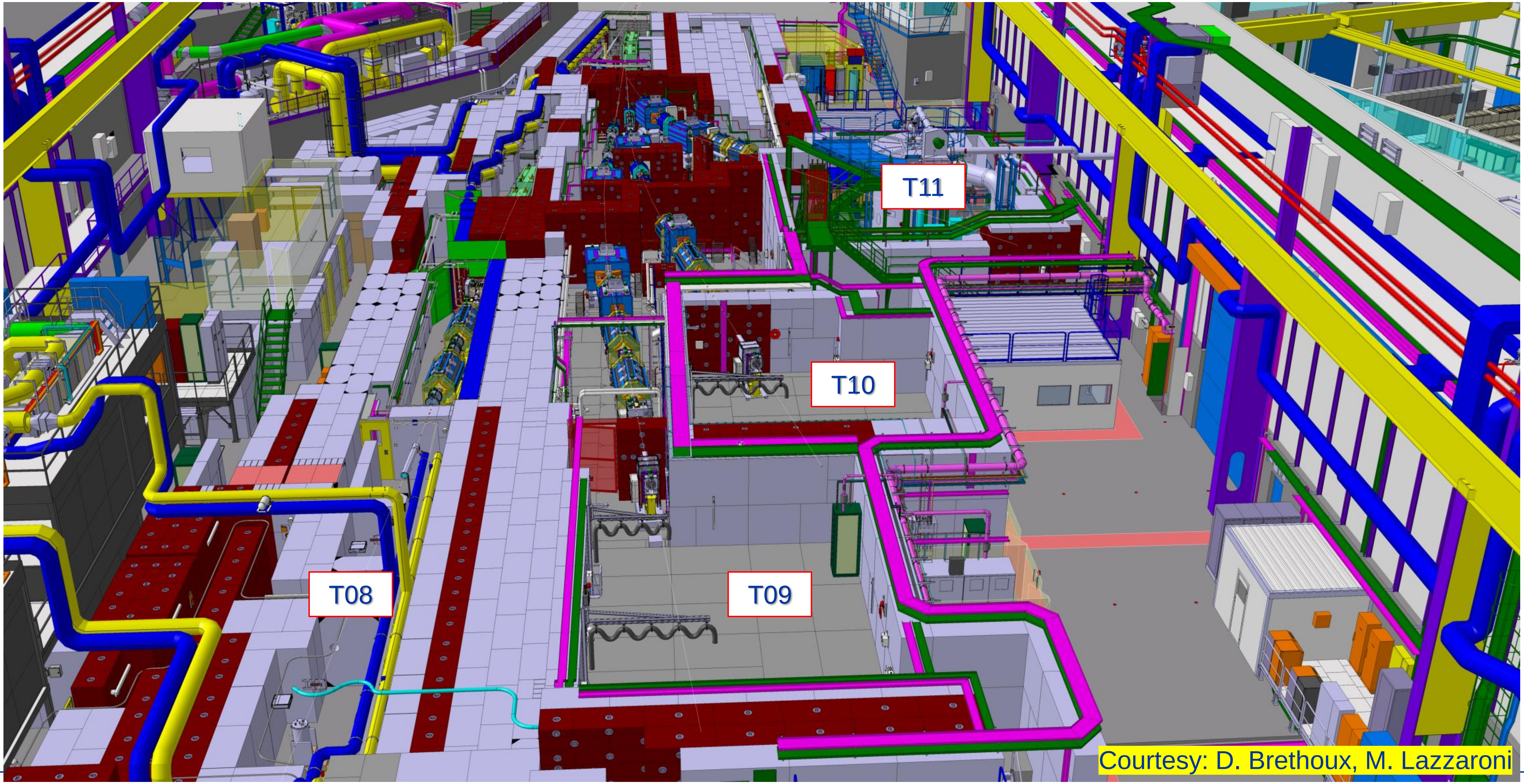

POKER: Hadrons/Electrons @ 20-180 GeV/c @ H8

# (Quick) Focus on the East Area




Recently (2021) renovated and commissioned : Improved energy consumption (11GWh /y → 0.6 GWh/y)

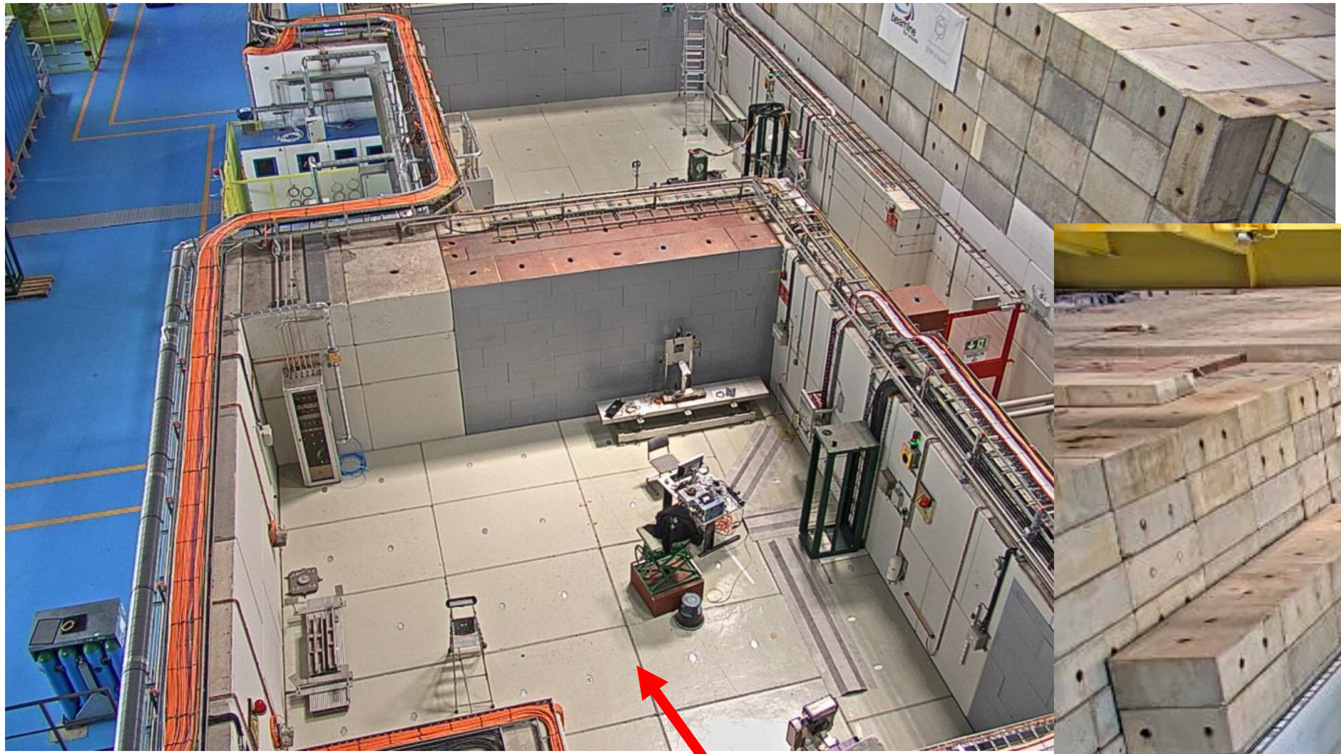
# East Area beamlines




Courtesy: D. Brethoux, M. Lazzaroni

# East Area Lines : T9/T10

Beam

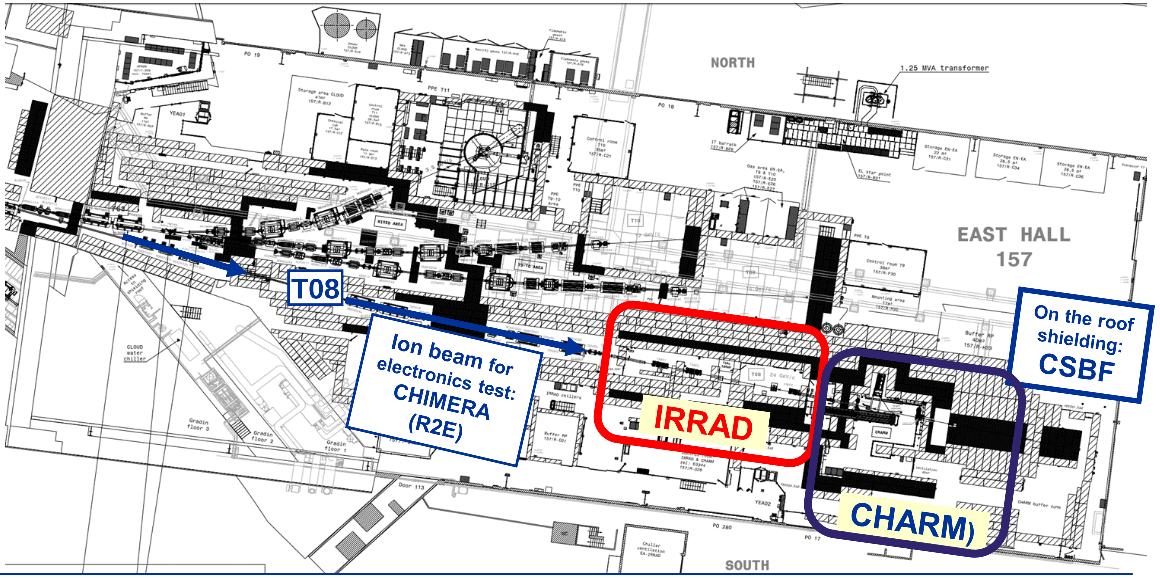



Beam

# East Area Beamline Characteristics

| Parameter | T09 Target | T10/T11 Target | |
|---|---|---|---|
| Beam Line | T09 | T10 | T11 |
| Secondary beam Max Momentum (GeV/c) | 15 | 11.5 | 3.5 |
| $\Delta p/p$ (%) | $\pm$0.7 to $\pm$15.0 | $\pm$0.7 to $\pm$15.0 | $\pm$0.7 to $\pm$15.0 |
| Maximum intensity/spill (hadrons/electrons) | ~few x $10^6$ | ~few x $10^6$ | ~few x $10^6$ |
| Available particle types | Pure electrons (T09) or mixed/pure hadrons or pure muons | | |

..and a dedicated primary line – T08, delivering the PS protons of 24 GeV/c to various irradiation facilities



# East Area Experiments

- **T11: CLOUD experiment**
  - Study of aerosol particles influence on climate
  - Simulation of a CLOUD in a dedicated chamber using the 3 GeV/c hadron beam from PS

CLOUD16 run (25Sep-3Dec23)


## CLOUD advances in atmospheric aerosol 2011-23

| | Year (cites.) | |
|---|---|---|
| nature | 2011 (912) | LETTER – Role of sulphuric acid, ammonia and galactic cosmic rays in atmospheric aerosol nucleation |
| nature | 2013 (658) | LETTER – Molecular understanding of sulphuric acid–amine particle nucleation in the atmosphere |
| Science | 2014 (370) | Oxidation Products of Biogenic Emissions Contribute to Nucleation of Atmospheric Particles |
| nature | 2016 (349) | LETTER – Ion-induced nucleation of pure biogenic particles |
| nature | 2016 (454) | LETTER – The role of low-volatility organic compounds in initial particle growth in the atmosphere |
| Science | 2016 (238) | RESEARCH ARTICLE – Global atmospheric particle formation from CERN CLOUD measurements |
| nature | 2020 (98) | Article – Rapid growth of new atmospheric particles by nitric acid and ammonia condensation |
| Science | 2021 (66) | RESEARCH ARTICLE – Role of iodine oxoacids in atmospheric aerosol nucleation |
| nature | 2022 (13) | Article – Synergistic $HNO_3$–$H_2SO_4$–$NH_3$ upper tropospheric particle formation |

8

- CLOUD publications total around 75, including:
  - 6 in Nature
  - X 4 in Science
  - 1 in Nature Geosc.
  - 1 in Nature Chem.
  - 4 in Proc. Natl. Acad. Sci. USA
  - 2 in Nature Com.
  - 4 in Science Adv.

Science 2023 (embargoed) He et al

# Summary

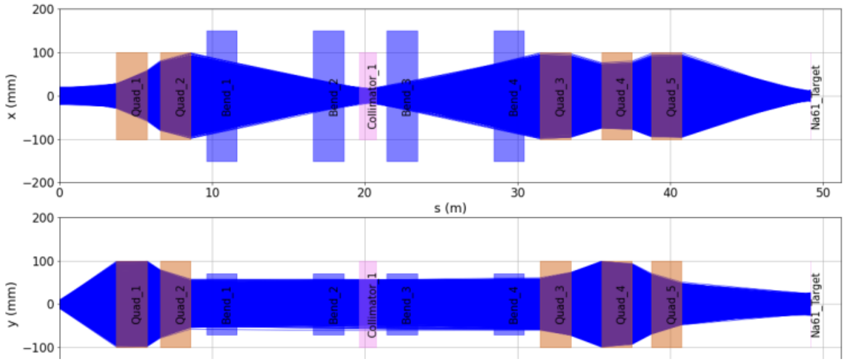
- **I hope that I have given a summary of the existing facilities in the CERN secondary areas**

- **There are exciting physics opportunities in these unique areas, and as well a long standing collaboration with JAI and Univ. Oxford.**

- **Looking forward to see you at CERN !**
    - Contact sba-operation@cern.ch

CERN

# NA61 Low-Energy – A DOCT thesis from Univ. Oxford & CERN

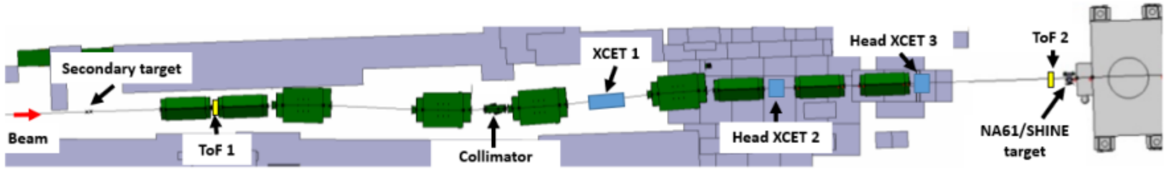


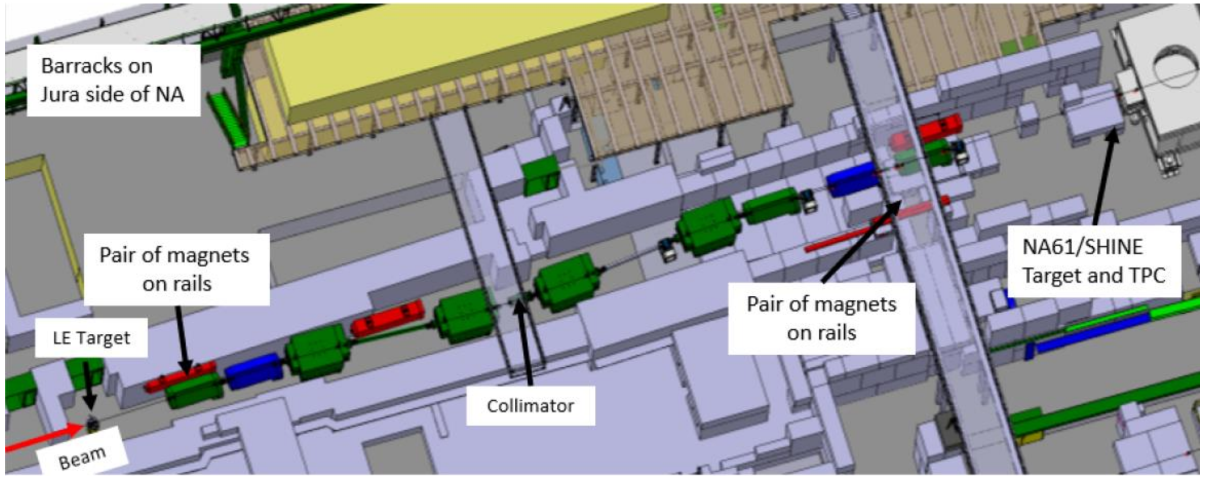

- NA61 in need of measurements in the "Very-Low" momentum range of 1 – 10 GeV/c. The beamline serving NA61 is optimized for momenta > 30 GeV/c.

- A new, short, high-acceptance beamline was designed in front of NA61 that could deliver particles in this very low energy range.

- Led to the PhD thesis of C. Mussolini (2023)

- Proposal under consideration by the CERN committees.



# East Area testbeams

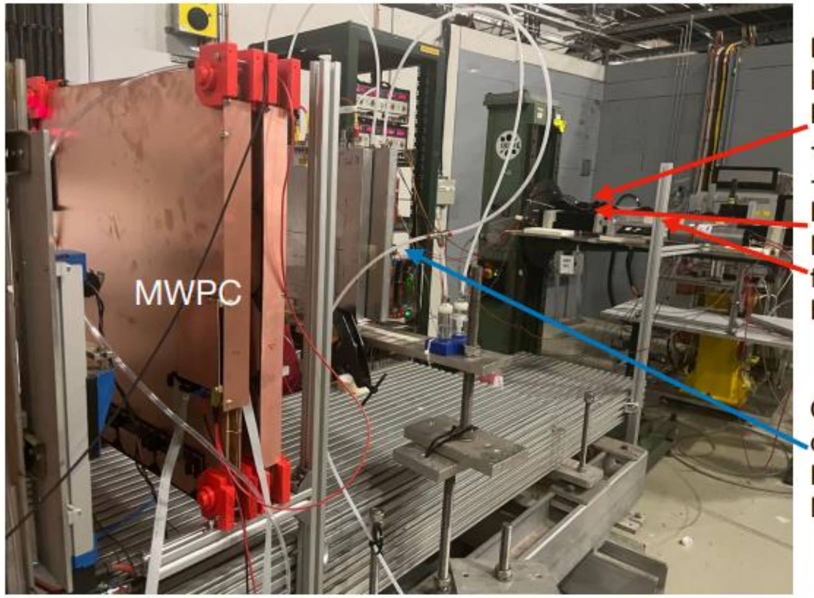
## T9: IDEA DRC (Team Korea)

- **Thank you very much for the stable and high quality em and hadron beams.**
- **We are grateful to Dipanwita, James, Alex, RP measurement people, and CCC for their kind and essential help.**
- **Thanks to nice people and the excellent beam facility, we had a successful test beam!!!**

## T10: ALICE MUON ID

### Test beam program

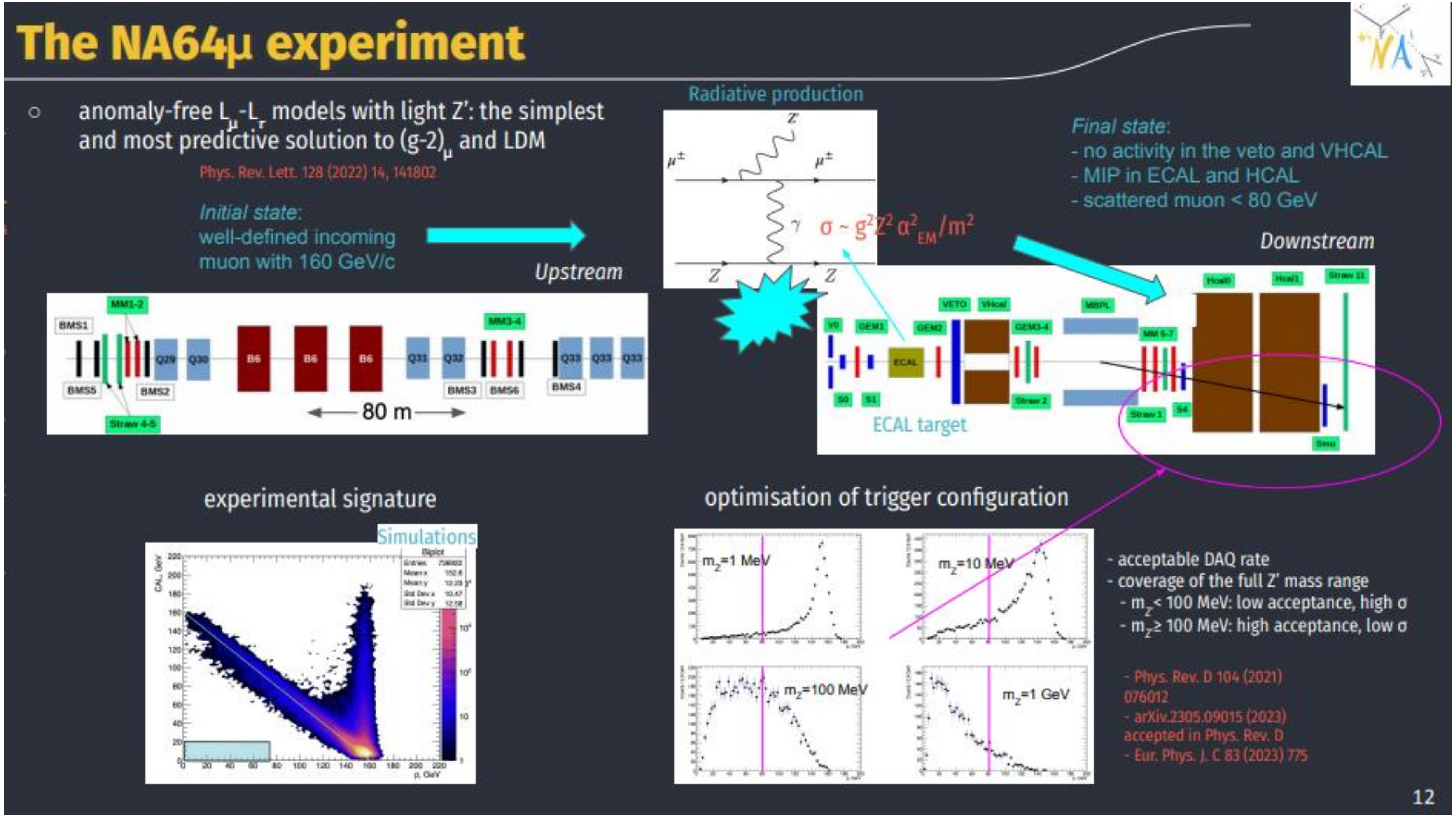
ALICE




Different plastic scintillators (1m length) were tested:
Fermilab (with WLS fiber)
-> REFERENCE OPTION FOR MID
-> LOW COST
Ellen (w/o WLS fiber)
Mexican scintillator (w and w/o WLS fiber)
Bricron (w/o WLS fiber)

Other technologies were tested (also considered for MID):
RPC
MWPC

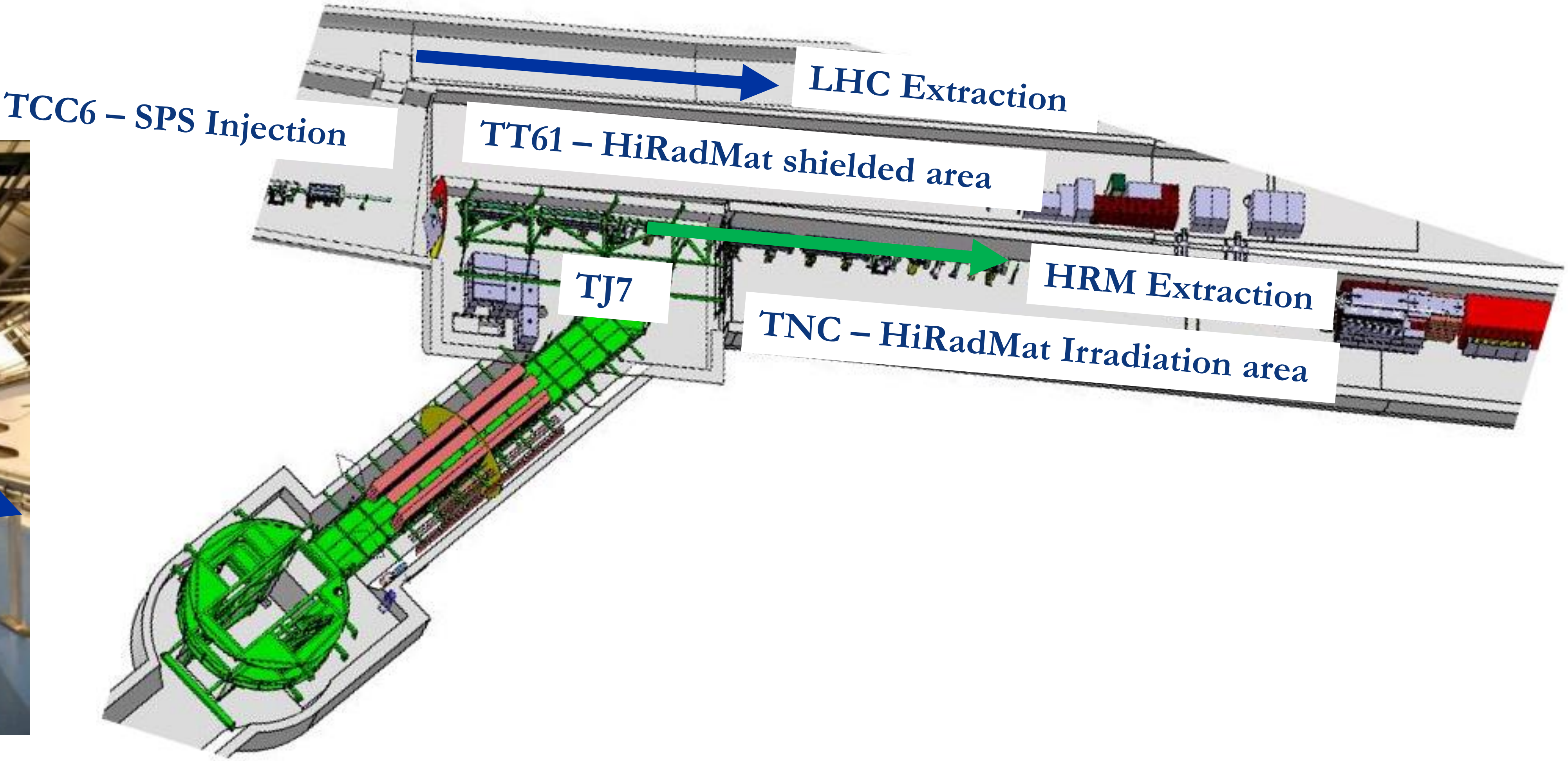
# NA64 mu



The NA64μ experiment
anomaly-free Lμ-Lτ models with light Z′: the simplest and most predictive solution to (g-2)μ and LDM
Phys. Rev. Lett. 128 (2022) 14, 141802
Initial state: well-defined incoming muon with 160 GeV/c
Upstream
Radiative production
σ ~ g²Z² α²EM/m²
Final state:
- no activity in the veto and VHCAL
- MIP in ECAL and HCAL
- scattered muon < 80 GeV
Downstream
80 m
ECAL target
experimental signature
Simulations
optimisation of trigger configuration
mZ=1 MeV
mZ=10 MeV
mZ=100 MeV
mZ=1 GeV
- acceptable DAQ rate
- coverage of the full Z′ mass range
- mZ< 100 MeV: low acceptance, high σ
- mZ≥ 100 MeV: high acceptance, low σ
- Phys. Rev. D 104 (2021) 076012
- arXiv.2305.09015 (2023) accepted in Phys. Rev. D
- Eur. Phys. J. C 83 (2023) 775
12

# HiRadMat

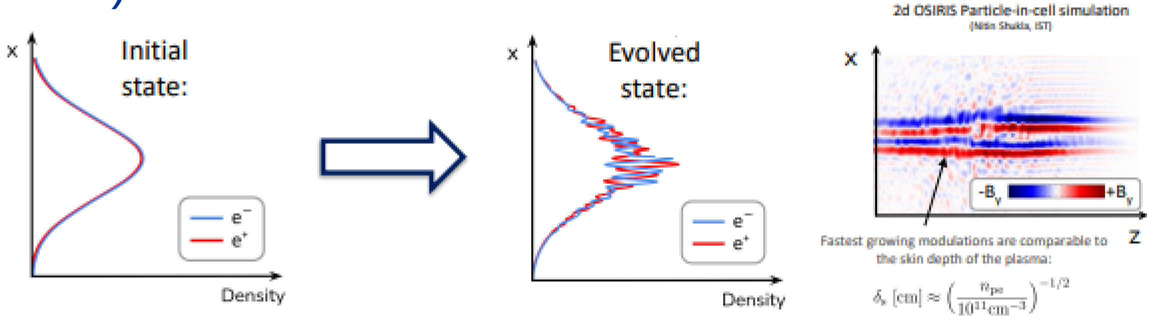

LHC
HiRadMat


TCC6 – SPS Injection
LHC Extraction
TT61 – HiRadMat shielded area
TJ7
HRM Extraction
TNC – HiRadMat Irradiation area

# HRMT64 FIREBALL-2 – Oxford Univ.

Courtesy of Charles Arrowsmith (and the FIREBALL collaboration)

- **Motivation:** Produce a laboratory analogue to an electron-positron enriched astrophysical jet




- **Improve layout and diagnostic equipment**
- **Larger beam size**
  - $\sigma_r$ ~ 1 mm → 2/3 mm

Introduce:
- an additional target
- a magnetic lens (permanent quadrupoles)

To enhance:
- spatial structure in the proton beam
- Collimate the electron-positron beam

- **Beam parameters**
  - 3e11 ppp
  - $4\sigma_t$ ~ 1 ns
  - $\sigma_r$ ~2-4 mm
- **Integrated fluence will not exceed 1x10$^{14}$ protons**