# Possibilities for (Very) Low Energy Beams at CERN North Area

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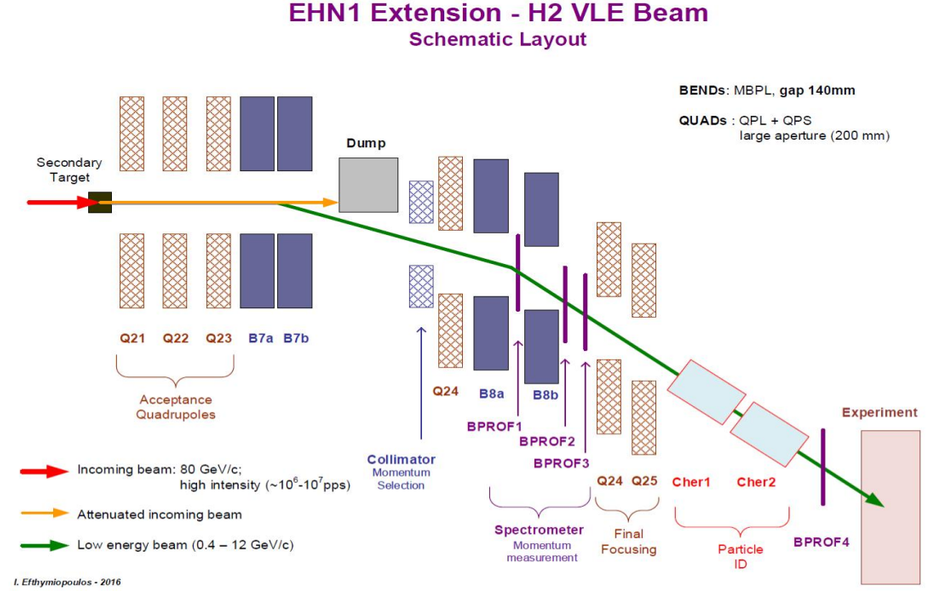
Acknowledgements: L. Gatignon, M. Rosenthal, Y. Chatzidaki, S. Girod, V. Clerc

# Presentation outline

- Introduction – CERN North Area Beam Facility

- Lower energy beam lines

  ØH2-VLE (for NP-02) and H4-VLE (for NP-04)

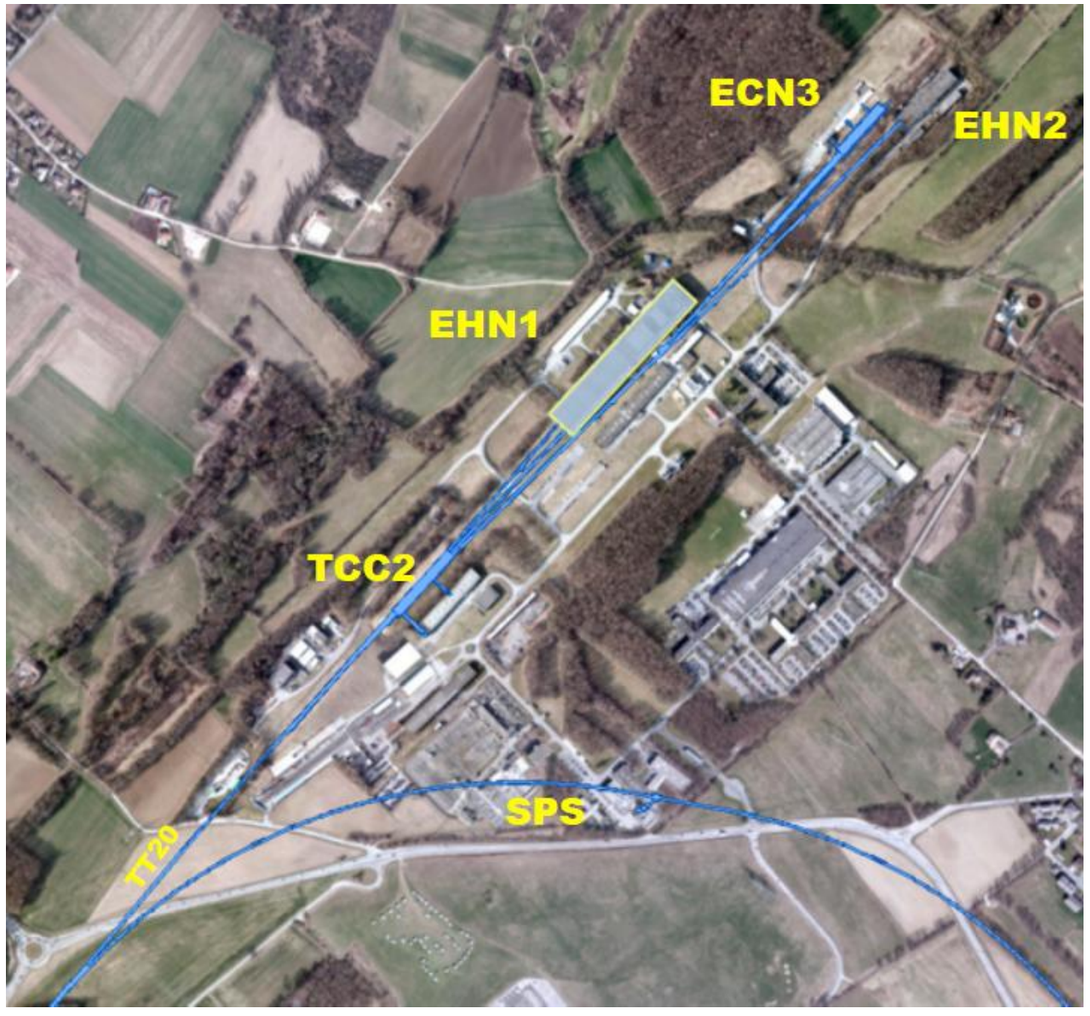
- Outlook in their performance and characteristics

  ØInstrumentation

- Summary / Conclusions

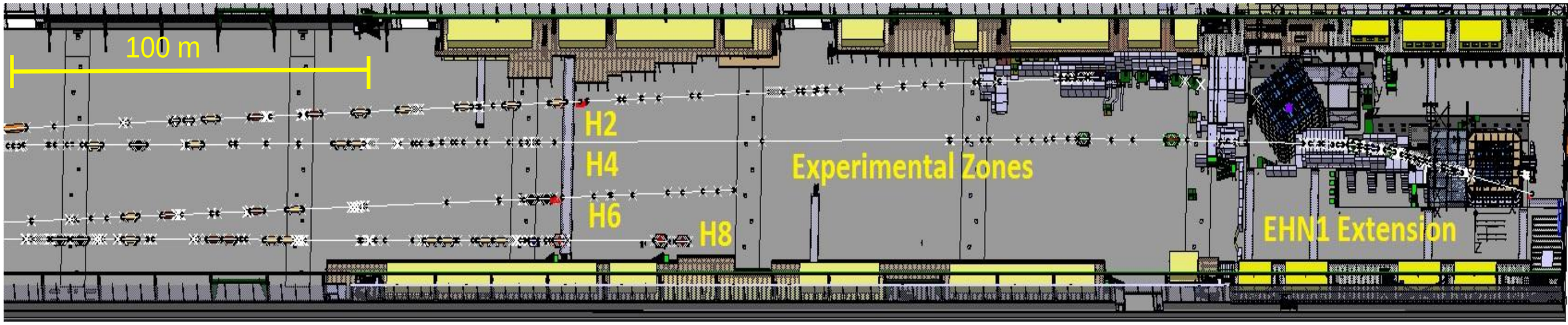
# The Experimental Hall North 1 – EHN1

- Part of the SPS North Area complex in the CERN prevessin site




- ~330 m long, ~50 m wide industrial type building (recently extended by ~70 m)
- Houses 4 beam lines (H2/H4/H6/H8)
- General purpose building, modular infrastructure, easy to adapt to the needs of the experiments

# The Experimental Hall North 1 – EHN1
# …and the EHN1-extension



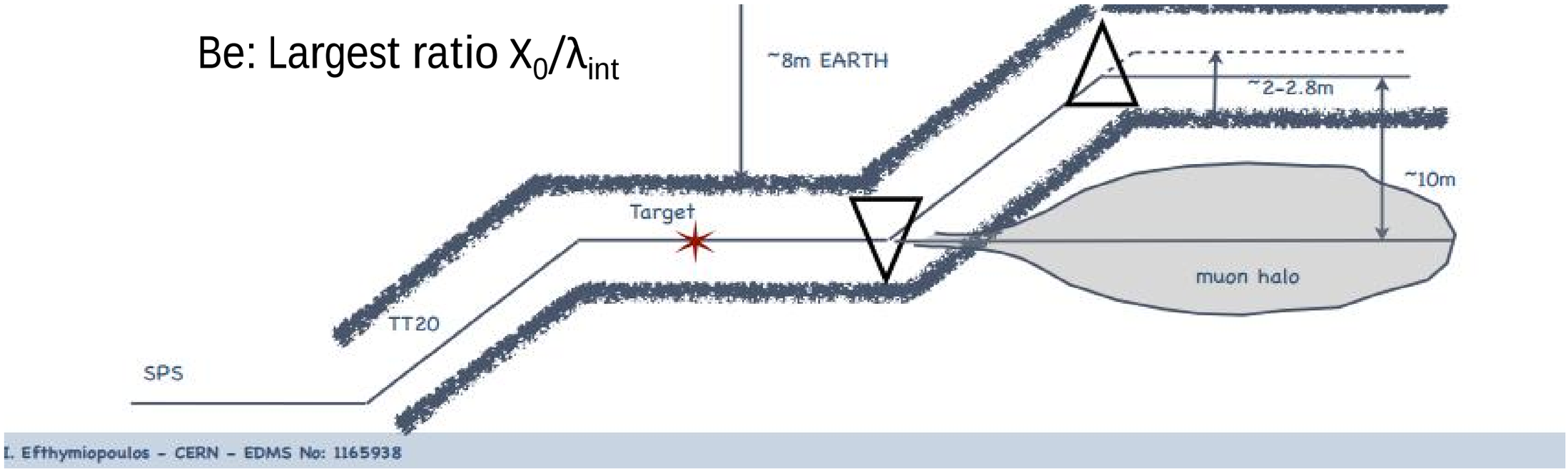

Hosts permanent fixed target experiments and quasi permanent test beams of large LHC experiments, as well as many non-permanent test beams for detector R&D

à A dynamic building that adapts to the user needs

# The North Area Beam Lines – Design Principle

Precise (< 2% dp/p acceptance, 0.1% intrinsic resolution), robust, flexible magnetic spectrometers

Be: Largest ratio $X_0/\lambda_{int}$




"Wobbling" of the beam *before* and *after* the target allows for flexibility on the particles selected and transported to the experimental areas.

# H2 / H4 Magnetic Spectrometer Magnets

# North Area Beam line characteristics

- Very large momentum range from approx. 10 GeV/c à 400 GeV/c (primary beam)
  - Mixed hadron or pure electron secondary (or tertiary) beams
  - Muon beams also available with controllable intensity and energy spread
- High intensity ( mostly limited by the radiation protection rules in the halls)
  - ~ 1E7 particles / spill (~4.8s)

à However : Designed for high energies (>300 GeV/c).

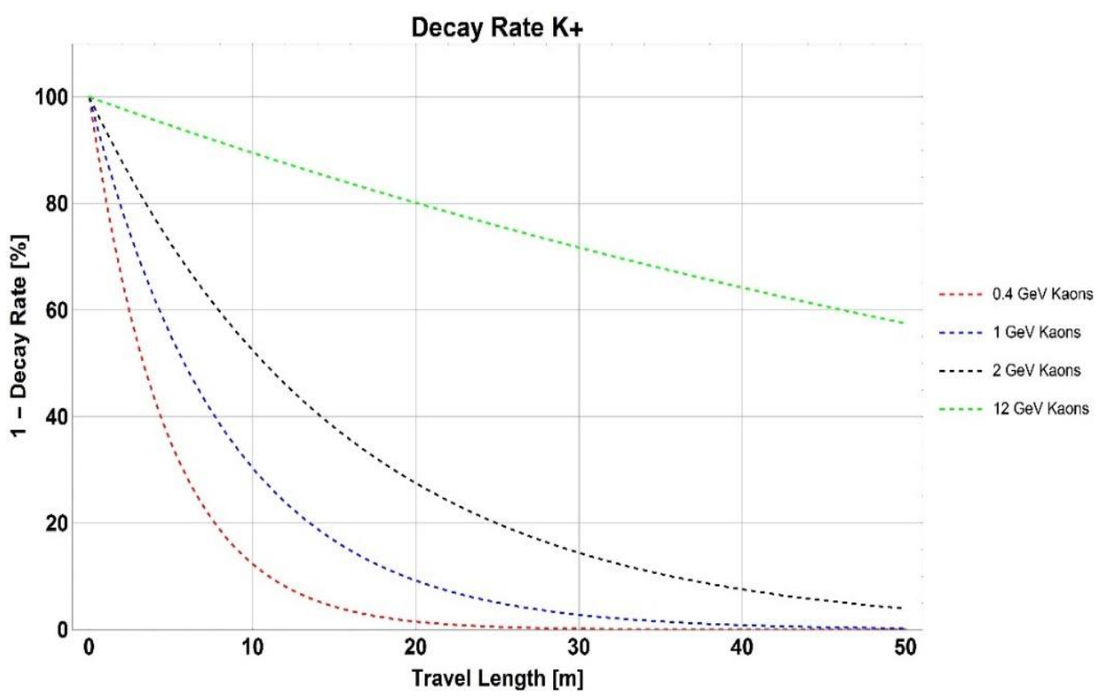
§ Total length : ~ 600 m – For low energy particles becomes critical

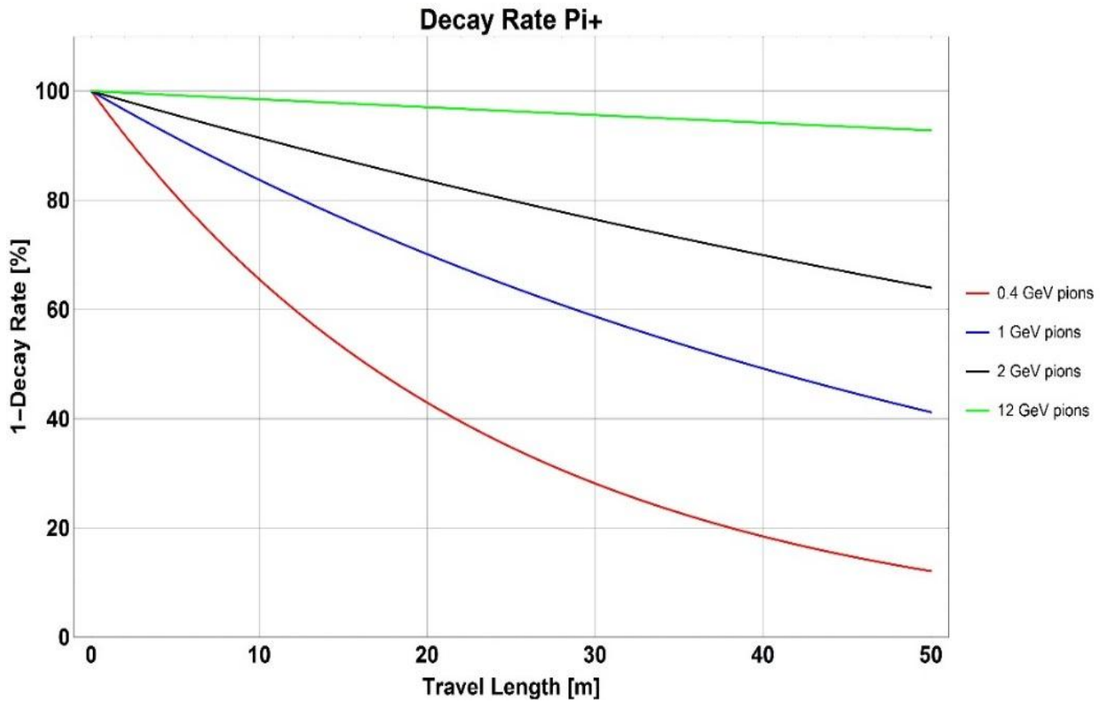
§ Power supplies of bends and quads not very stable when operating in very low currents (for 10 GeV à 31A, setting error 0.2A à 0.6% momentum or ~50% acceptance!)

§ Most of the available instrumentation is tuned for high intensities > $10^5$ p/spill

# Low momenta ( < 10 GeV/c)

- Design Challenges :
  - à Short length of the beam line necessary for momenta
  - à Minimizing the muon/charged particle background (important for slow read-out detectors, like LAr TPC's.... or in any other detector)
  - à Momentum selection within a few %
  - à Sufficient acceptance à Rate to the experiment



# Example: NP-02 and NP-04 (“ProtoDUNEs”)

## Scope

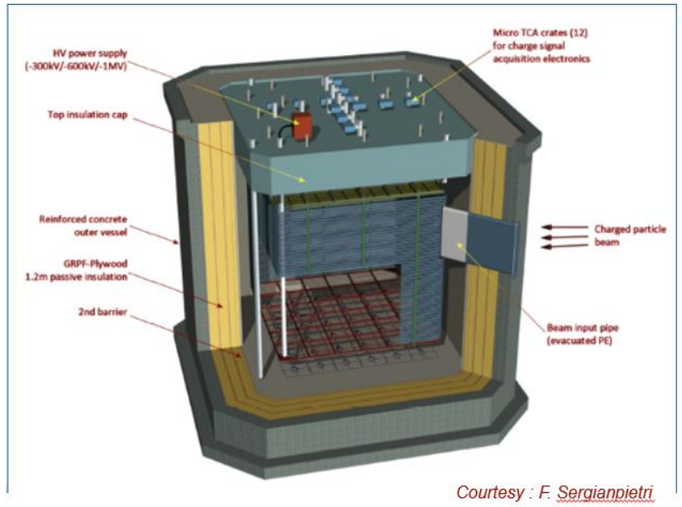
- Design, installation and operation of **V**ery **L**ow **E**nergy (VLE) extensions and new experimental areas of H2 / H4 beam lines of North Area
  - ➢In the framework of CERN Neutrino Platform Project → Generic R&D on ν-detectors
- New test-beam infrastructure where large-volume ν-detector prototypes can be **tested** and **calibrated** using charged particle beams
  - ➢NP-02/NP-04: 6x6x6 $m^3$ Liquid Argon detectors
  - ➢Outside structure: 11x11x11 $m^3$ (~300 tons LAr)
- Low momentum charged particle beams needed
  - ➢Hadrons/electrons with momentum 1-12 GeV/c
  - ➢NP-02 TDR: CERN-SPSC-2014-013 ; SPSC-TDR-004
  - ➢NP-04 proposal: CERN-SPSC-2015-020 ; SPSC-P-351

| Parameter | Requirements |
|---|---|
| Particle Types | $e^{\pm}, \mu^{\pm}, \pi^{\pm}, K, p$ |
| Momentum Range | 0.2 - 10 GeV/c |
| Momentum Spread | $\Delta p/p$ <5 % (limited by the aperture of the magnets) |
| Transverse Beam Size | RMS(x,y) ≈ 10 cm (At the entrance face of the LAr cryostat) |
| Beam Divergence | tbd |
| Beam Angle (horizontal plane) | ≈10° (w.r.t. the long axis of the cryostat) |
| Beam Dip Angle (vertical plane) | ≈6° (downward from horizontal) |
| Beam Entrance Position | Multiple beam windows |
| Rates | 200 Hz (maximum) |

Table 4: Particle beam requirements.



## Example: NP-02 detector




Courtesy : F. Sergianpietri

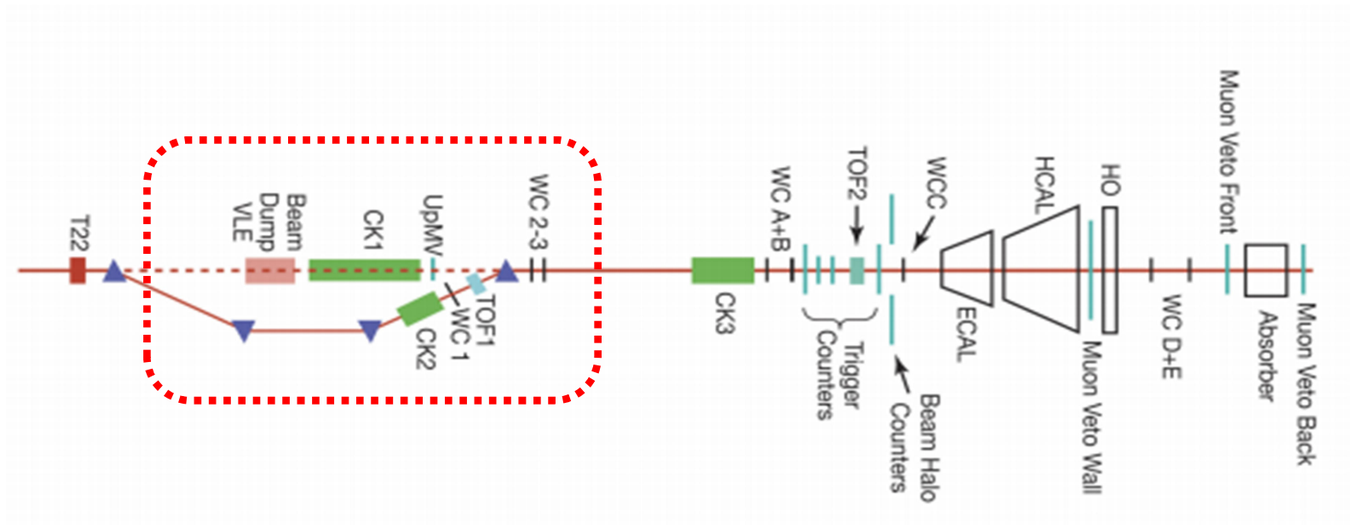
| | | |
|---|---|---|
| Liquid argon density | $T/m^3$ | 1.38 |
| Liquid argon volume height | m | 7.6 |
| Active liquid argon height | m | 5.99 |
| Hydrostatic pressure at the bottom | bar | 1.03 |
| Inner vessel size (WxLxH) | $m^3$ | 8.3 × 8.3 × 8.1 |
| Inner vessel base surface | $m^2$ | 67.6 |
| Total liquid argon volume | $m^3$ | 509.6 |
| Total liquid argon mass | t | 705 |
| Active LAr area | $m^2$ | 36 |
| Charge readout module (0.5 x0.5 $m^2$) | | 36 |
| N of signal feedthrough | | 12 |
| N of readout channels | | 7680 |
| N of PMT | | 36 |

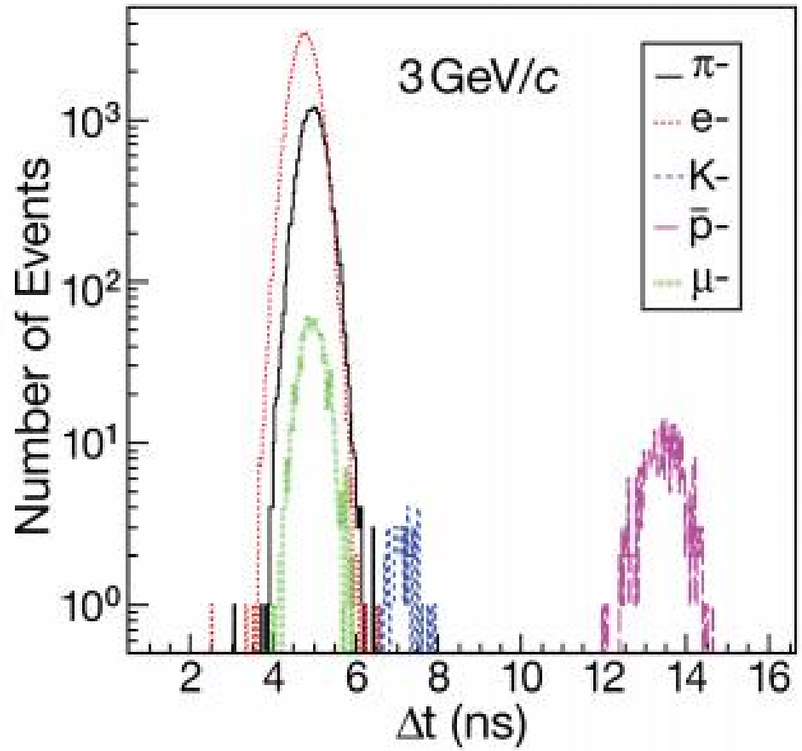
TABLE I: Main parameters of the LBNO prototype.

## How to satisfy these experimental requirements ?

# V-L-E Extensions of the secondary beam lines

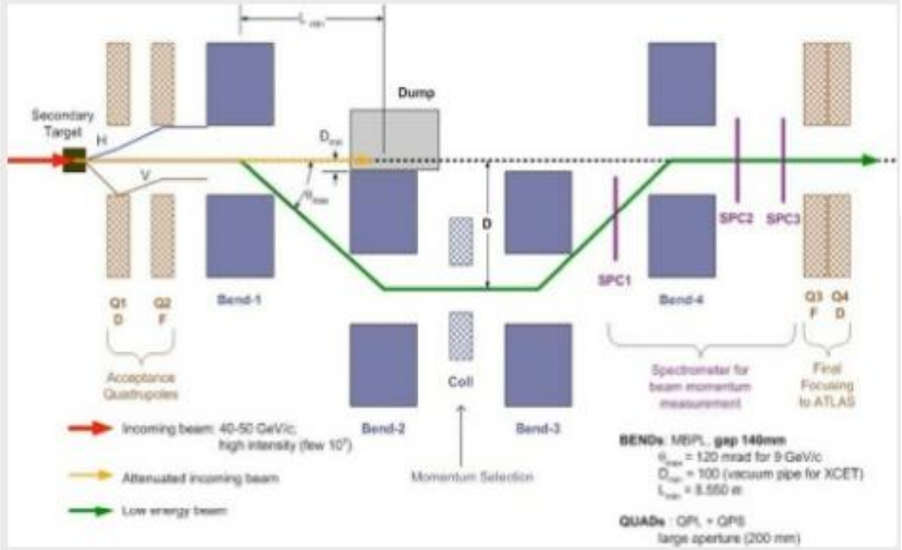
- A “tertiary” beam line – and a second magnetic spectrometer, with the low-energy particles being created and selected *close* to the experiment
- Not a “new” idea – Successful implementations in the past in H8 (for ATLAS) and H2 (for CMS)
  - https://arxiv.org/ftp/arxiv/papers/1206/1206.2184.pdf
  - CMS NOTE-2008/034



# H2-VLE (2003)

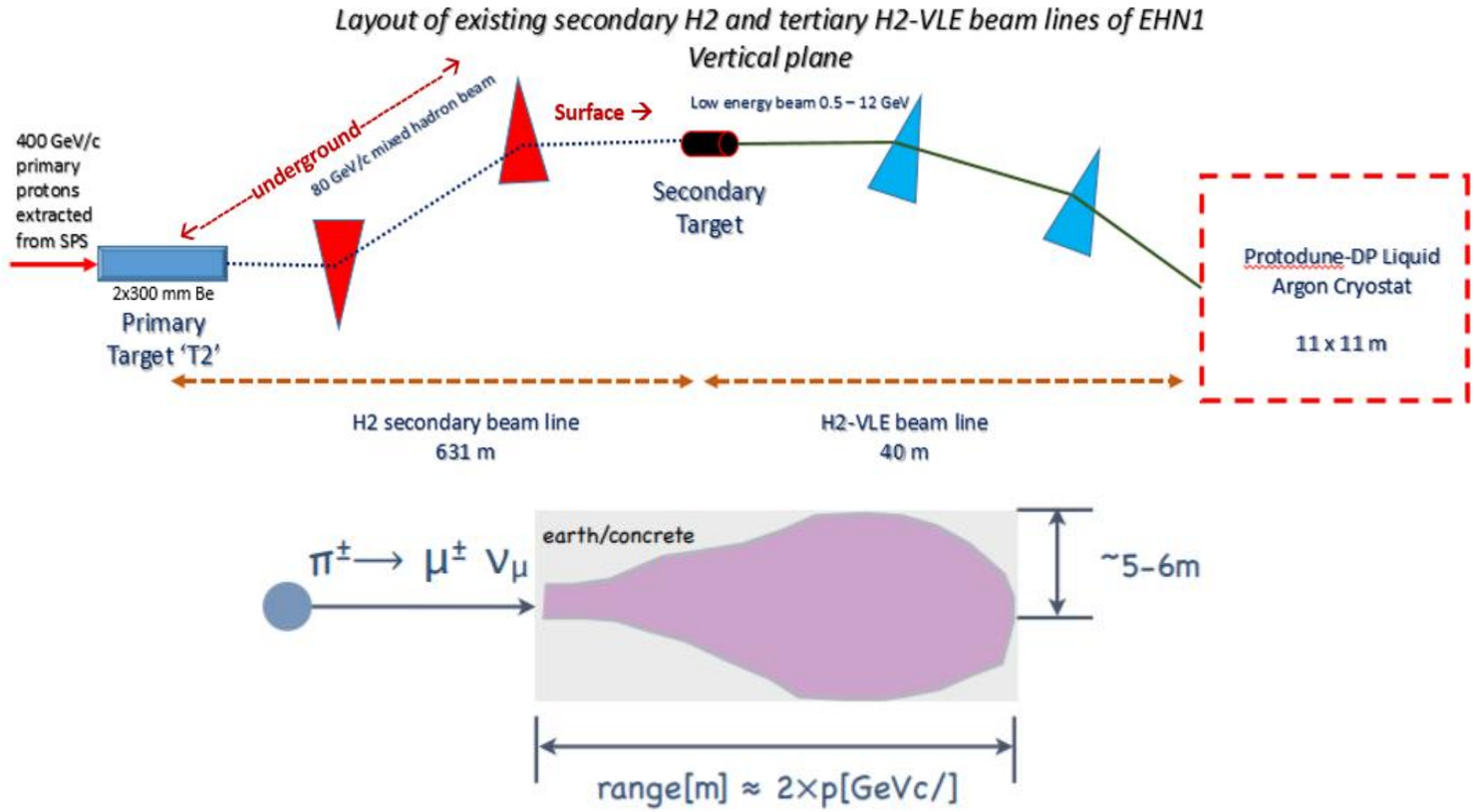
- **Four-bends layout**
  - Available magnets: **MBPL 120mrad for 1-9 GeV beams**




- design used for the ATLAS(H8) &CMS(H2) calorimeters in the past
- suffers from large background from the direct secondary beam

Courtesy: I. Efthymiopoulos

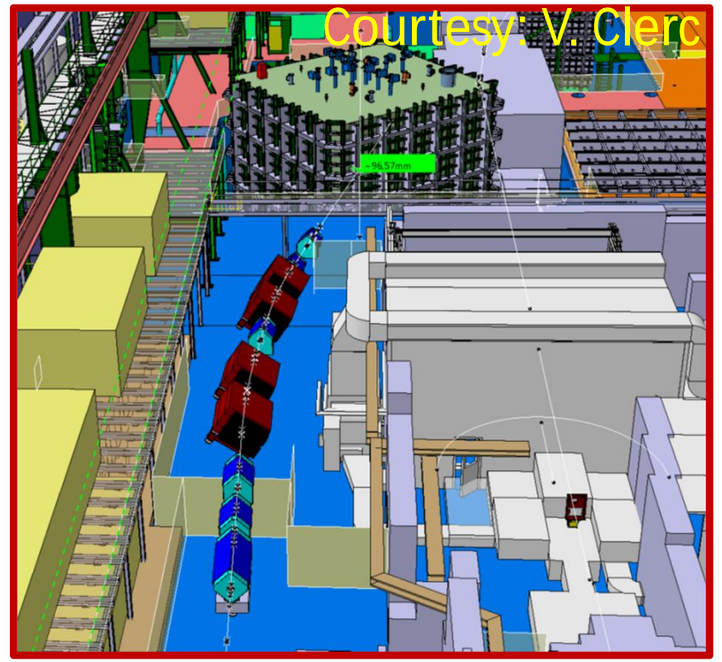
# H2-VLE (2018)

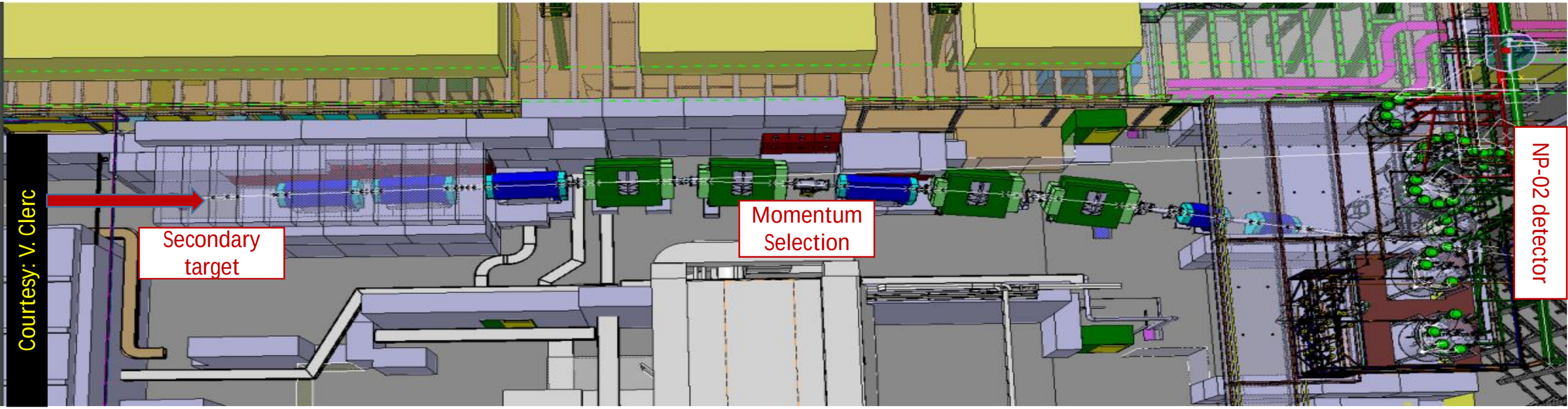



à Large angles and off-axis placement of the detector wrt the secondary beam reduces the background to the experiment from the beam and ground shields (mostly) the one from the target.

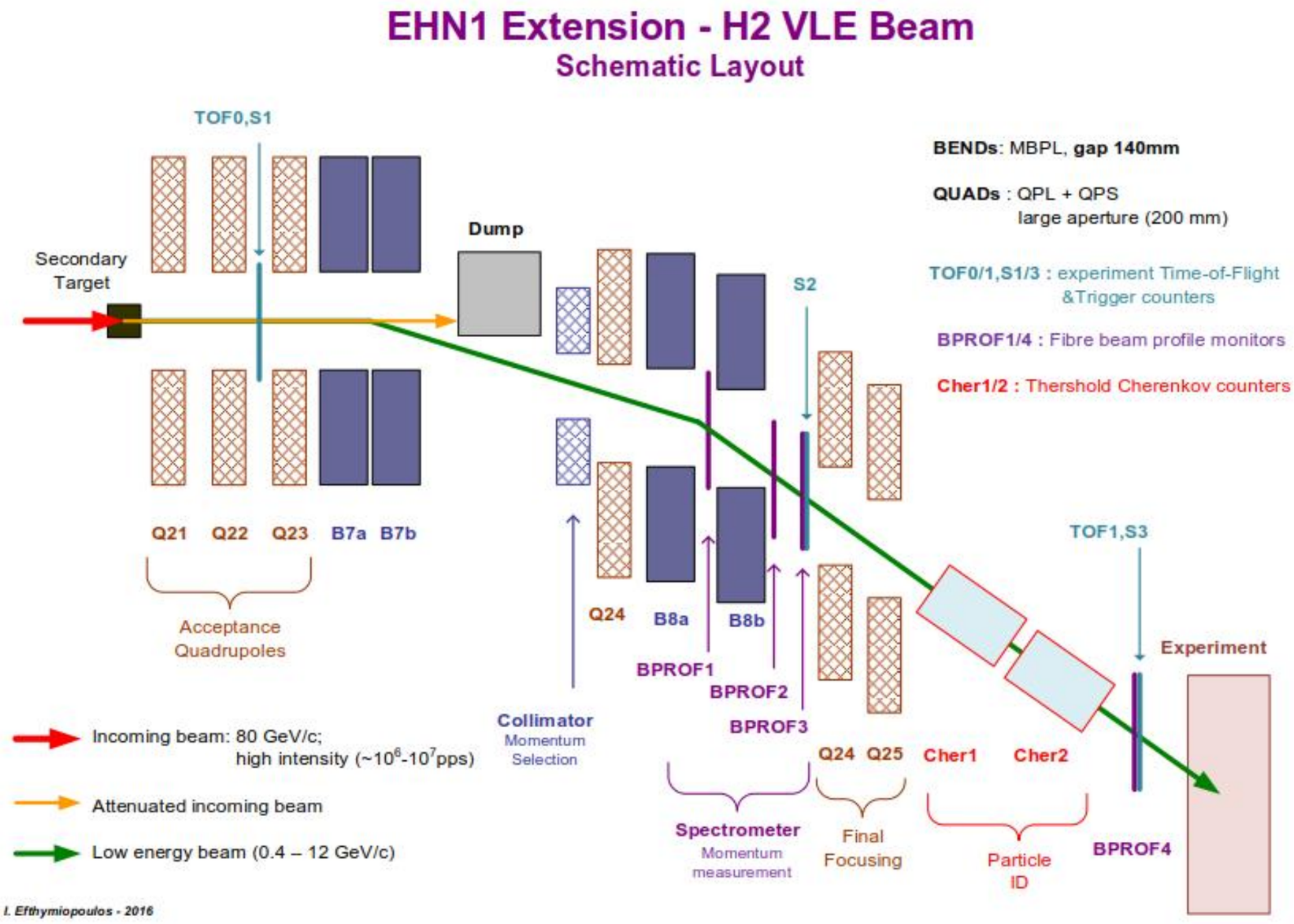
# Beam Layout - H2-VLE

- Tilted dipoles & quadrupoles
  - Ø 34.9 degrees with respect to x-plane
  - Ø Total bend angle : 234.8 mrad in the bending plane
- Momentum selection collimator available
  - Ø Full acceptance δp/p: 5%



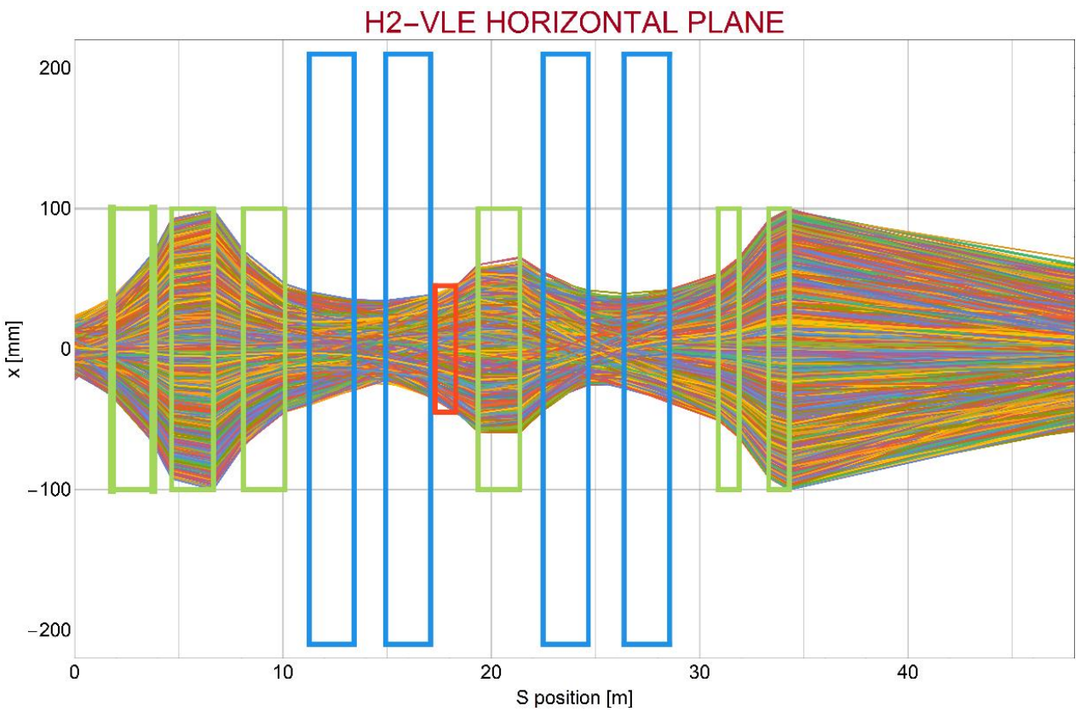



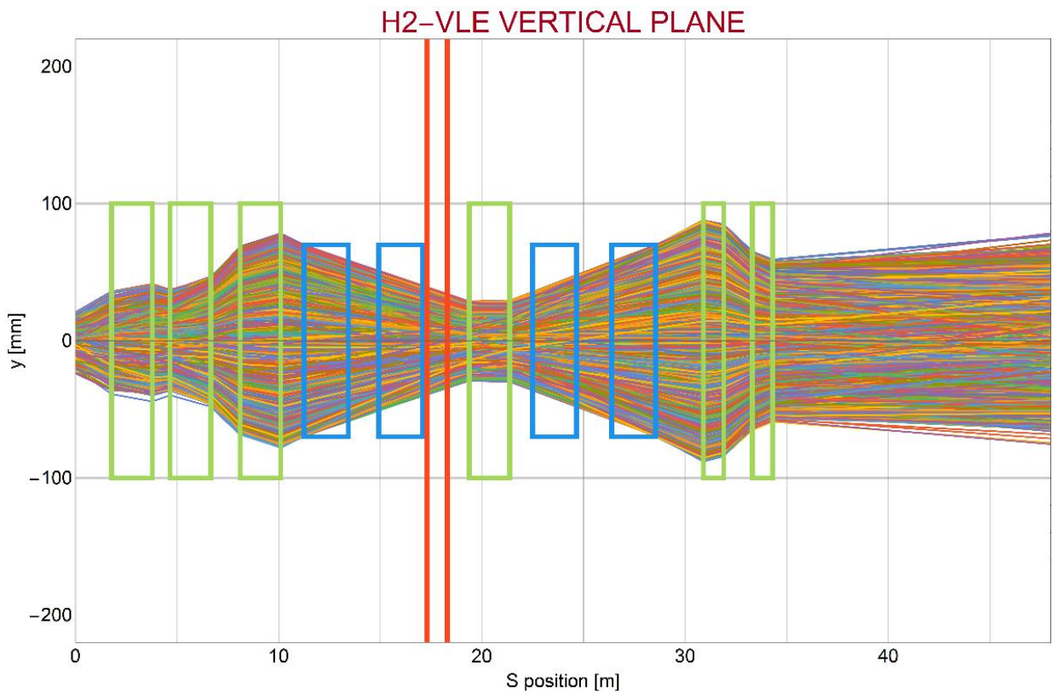
# Conceptual Design H2/H4 – VLE



# Beam optics optimization

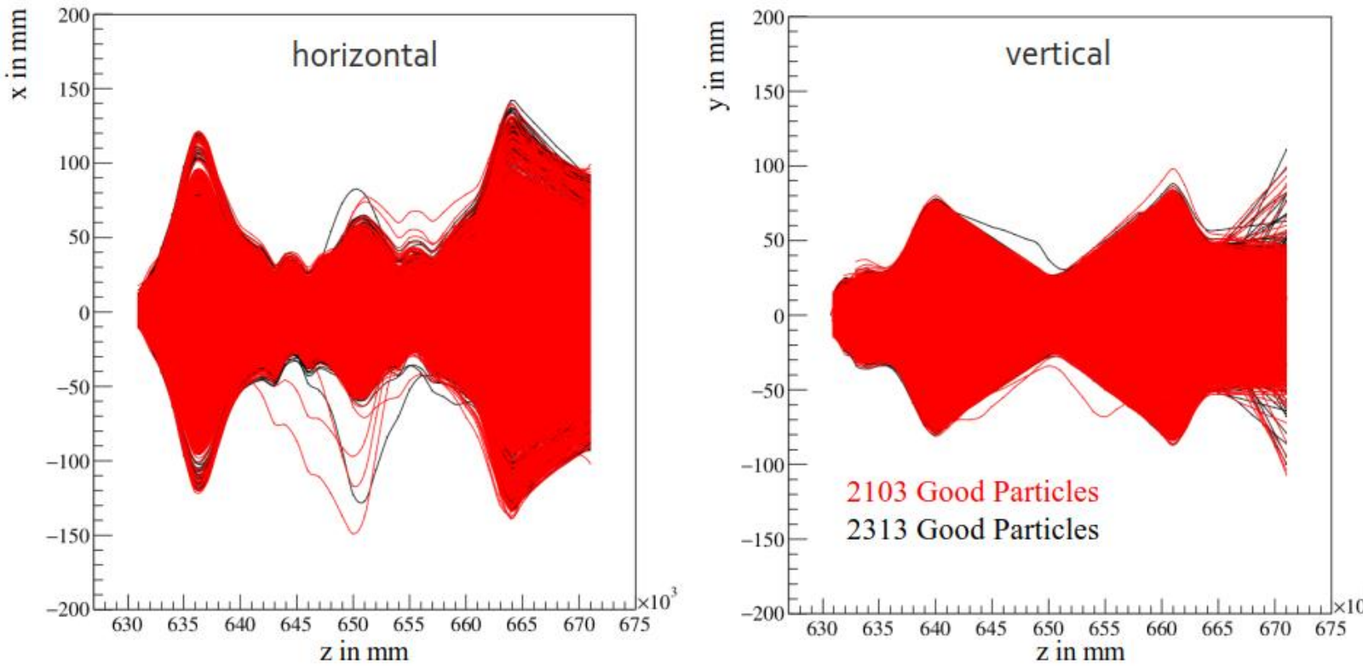
- Optics / tracking calculations with MAD-X & TRANSPORT




Optics optimization by Y. Chatzidaki [CERN & NTU Athens]

# And validation with a Full Monte – Carlo

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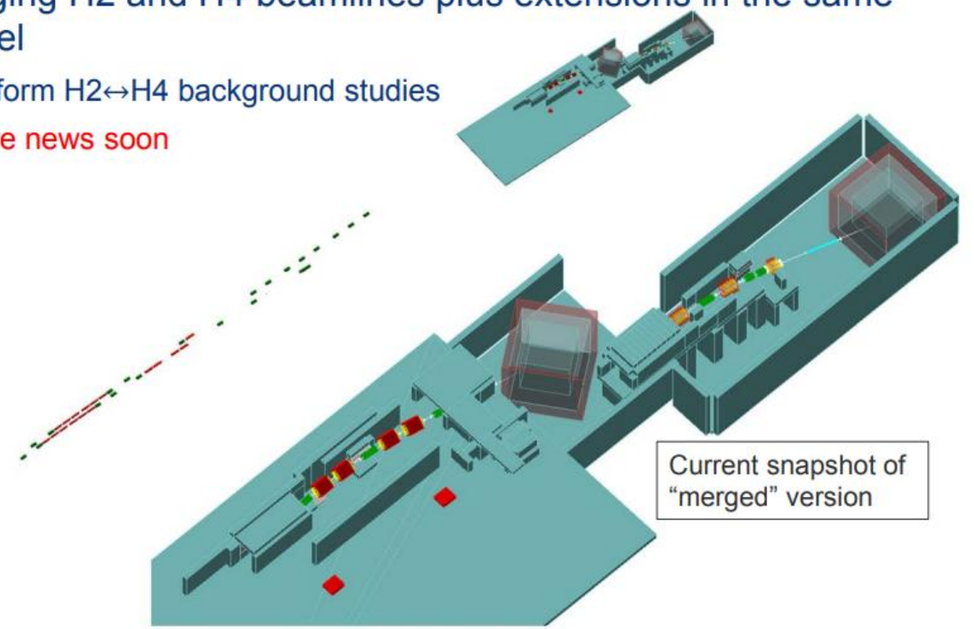
- Merging H2 and H4 beamlines plus extensions in the same model
  - Perform H2↔H4 background studies
  - More news soon

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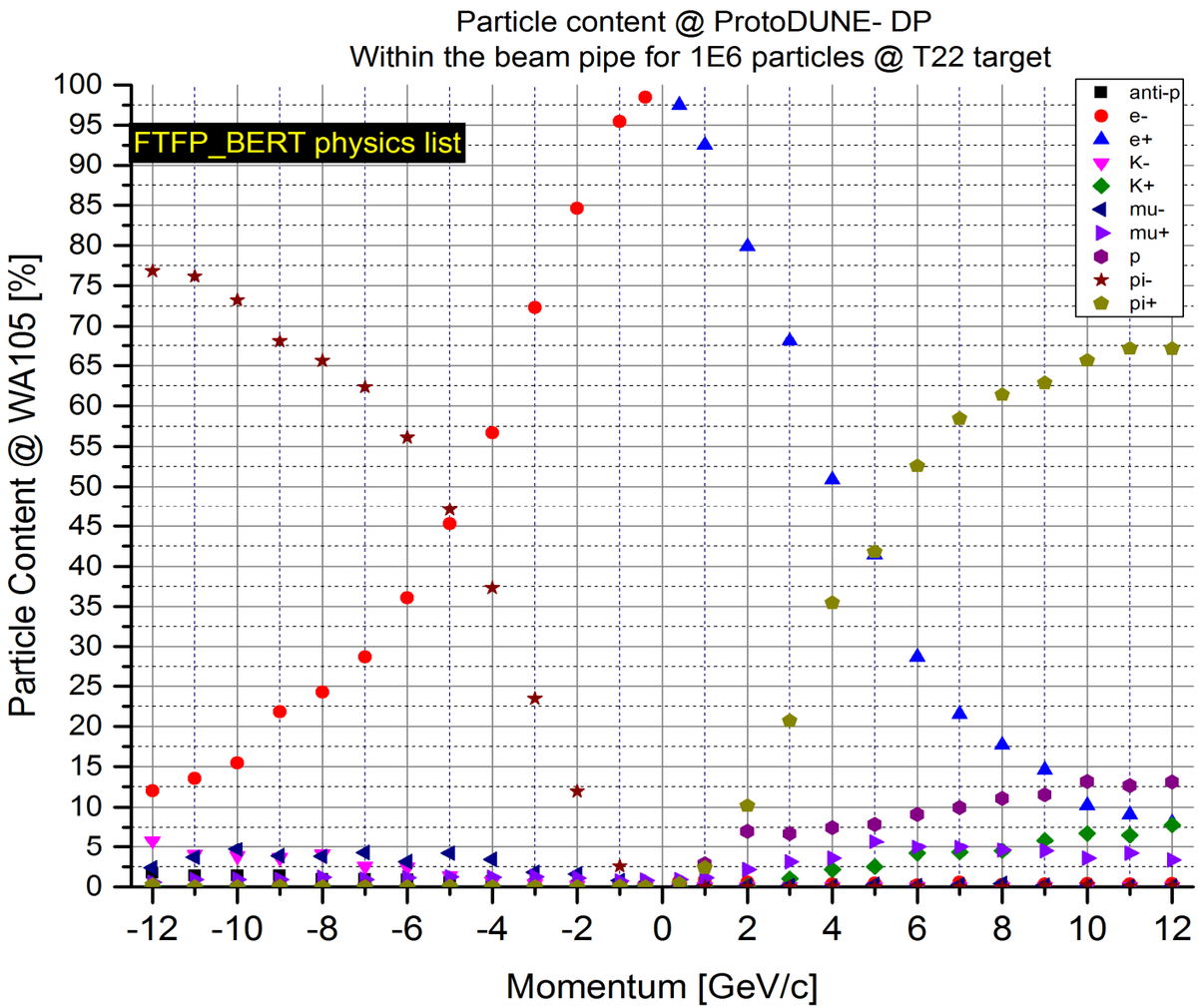
Simulations by M. Rosenthal [CERN]

# Beam Composition

References :

CERN-ACC-NOTE-2016-0052

CERN-ACC-NOTE-2016-0059



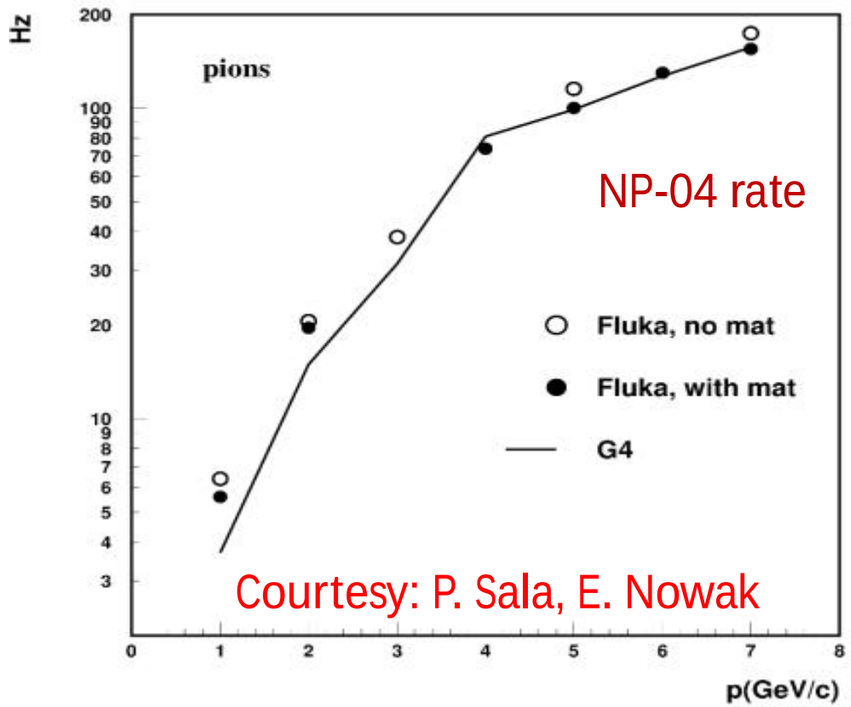

Assuming ~$10^6$ particles / spill on the secondary target

NP-02 rate

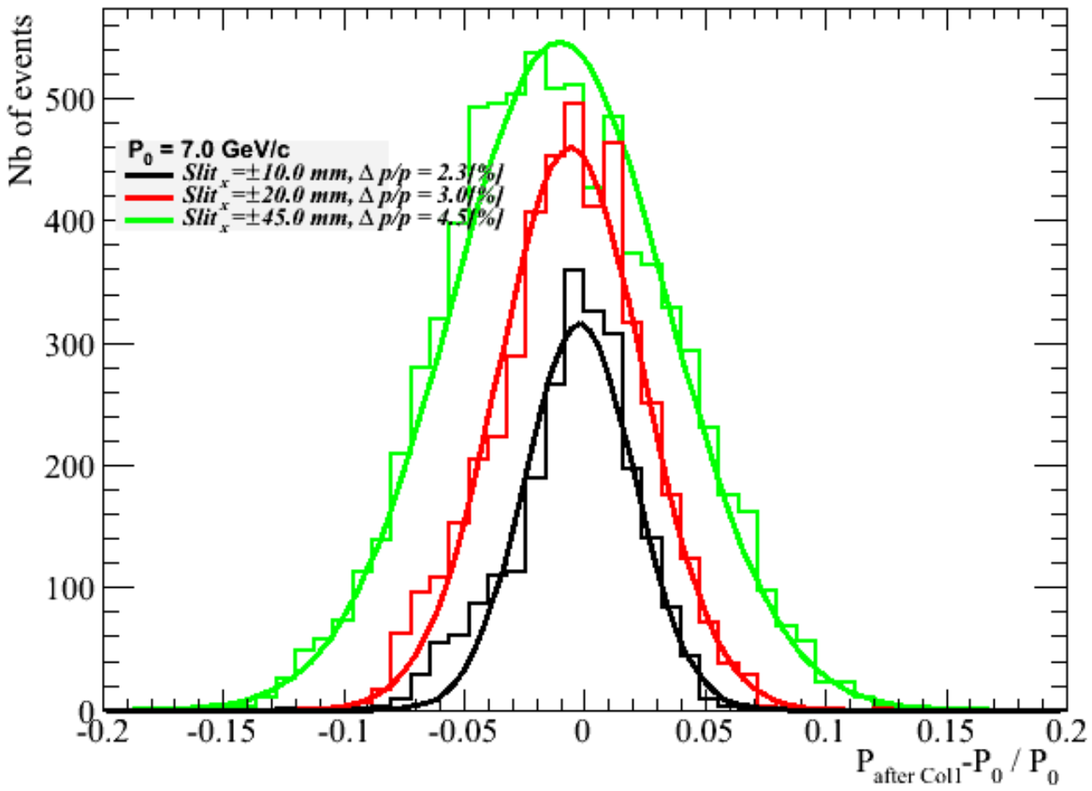
| Momentum | e+ | K+ | mu+ | p | pi+ | Trigger rate [Hz] |
|---|---|---|---|---|---|---|
| 0.4 | 7 | 0 | 0 | 0 | 0 | 7 |
| 1 | 21 | 0 | 0 | 4 | 3 | 28 |
| 2 | 17 | 0 | 0 | 7 | 12 | 36 |
| 3 | 14 | 1 | 1 | 10 | 30 | 56 |

| Momentum | e+ | K+ | mu+ | p | pi+ | Trigger rate [Hz] |
|---|---|---|---|---|---|---|
| 3 | 145 | 1 | 1 | 16 | 49 | 213 |
| 4 | 117 | 3 | 1 | 16 | 80 | 218 |
| 5 | 94 | 5 | 2 | 20 | 100 | 222 |
| 6 | 77 | 9 | 2 | 25 | 133 | 247 |
| 7 | 69 | 11 | 2 | 28 | 169 | 279 |
| 8 | 59 | 16 | 3 | 35 | 193 | 305 |
| 9 | 51 | 19 | 3 | 37 | 227 | 337 |
| 10 | 46 | 22 | 3 | 45 | 254 | 370 |
| 11 | 41 | 27 | 3 | 53 | 268 | 393 |
| 12 | 38 | 29 | 3 | 60 | 292 | 422 |

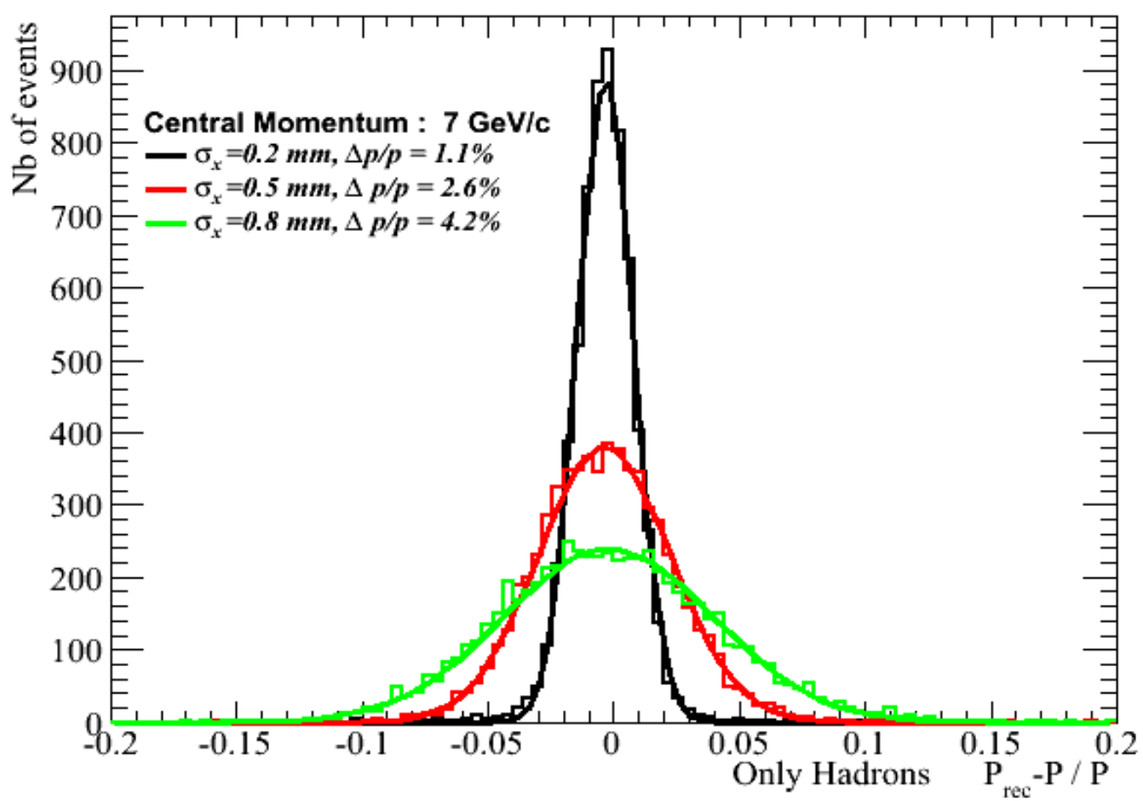
Table 2: Trigger rate for a Cu (0.4 – 3 GeV/c) target and a W (4-12 GeV/c) target.



# Momentum Resolution




Beam lines equipped with a momentum selection station which can offer a dp/p down to 2% at an expense of the rate

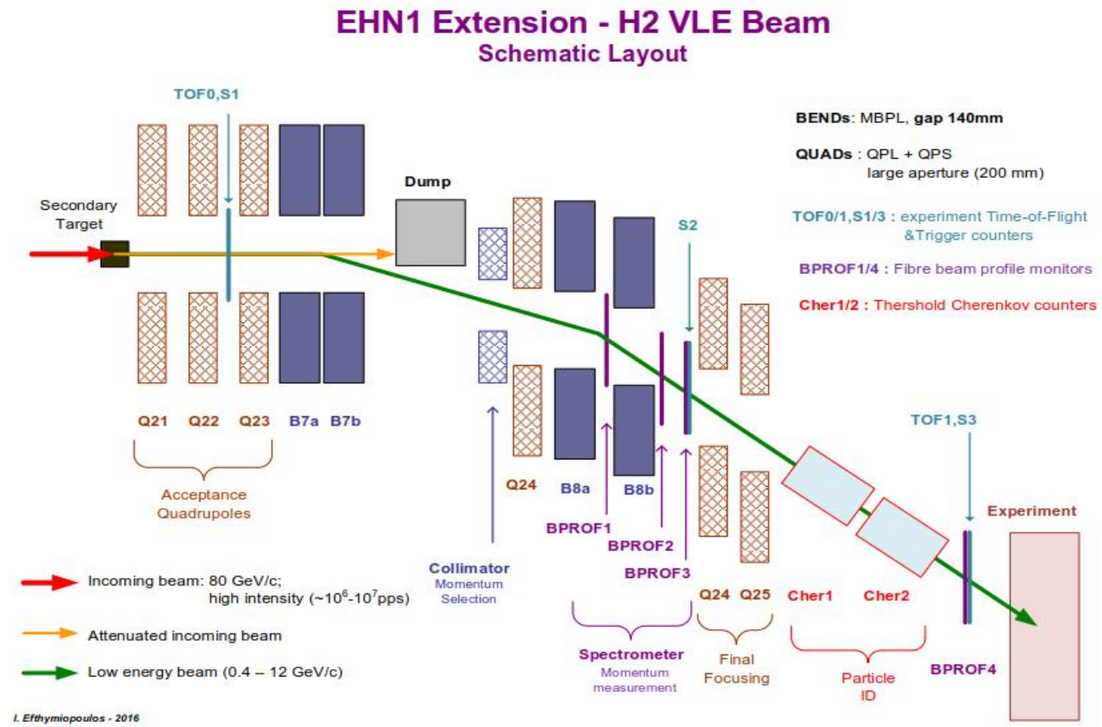



Spectrometer (using 3 profile monitors) around a bending magnet – momentum measurement without expense on the rate

References : CERN-ACC-NOTE-2016-0052, CERN-ACC-NOTE-2016-0059

# Instrumentation under consideration

- Profile/Intensity monitors
  - ØNecessary for beam tuning
- Beam momentum spectrometer
  - Ø3 profile monitors around a bending magnet
- 2 Gas Cherenkov Detectors per beam line
  - Ø R134a & CO2 gases (1 high and 1 low pressure)
  - Øp±/K±/π± separation from >2 GeV/c
  - Øe- tagging




- ToF using scintillating fiber detectors or ionization detectors
  - Øp±/π± separation <2 GeV/c

à All of the above combined with the triggers of the experiment !

  - à A challenging exercise !

# Challenges for (new) VLE Beams

- Infrastructure related
  - Magnets and power supplies availability
  - Space availability – with minimal disturbance to the downstream experiments and the ‘normal’ operation of the beam line
  - Acceptance ß à rate defined by the line geometry
- Composition, background to the experiment & instrumentation
  - Low proton content in tertiary beams ( ~5-10%)
  - Rate does not exceed ~a few hundred of Hz
  - Muons/background from the secondary beam – can they be vetoed ?

# Conclusions

- VLE (Very Low Energy) beam lines have been designed, implemented and operated in the past in EHN1 with success
  - Two new VLE extensions will be operational in 2018 to serve NP-02 and NP-04 experiments, in the framework of Neutrino Platform project.
- They are able to provide mixed hadrons and/or pure electrons, in a short length and with a maximum momentum bite of 5%
- The spot size expected in such beams is large ~10x10 $cm^2$ – tunable depending on the exact line configuration
- A possibility for implementing such a configuration in EHN1 for future users/experiments can be studied.

# Questions ?

Thank you for your attention !