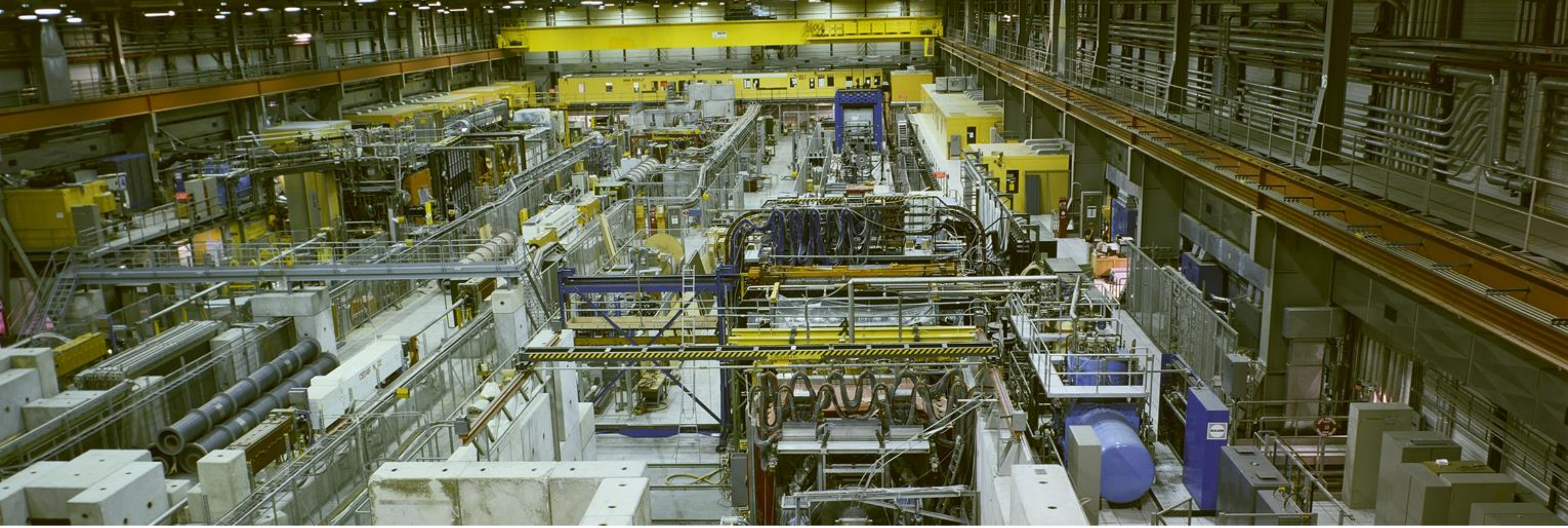
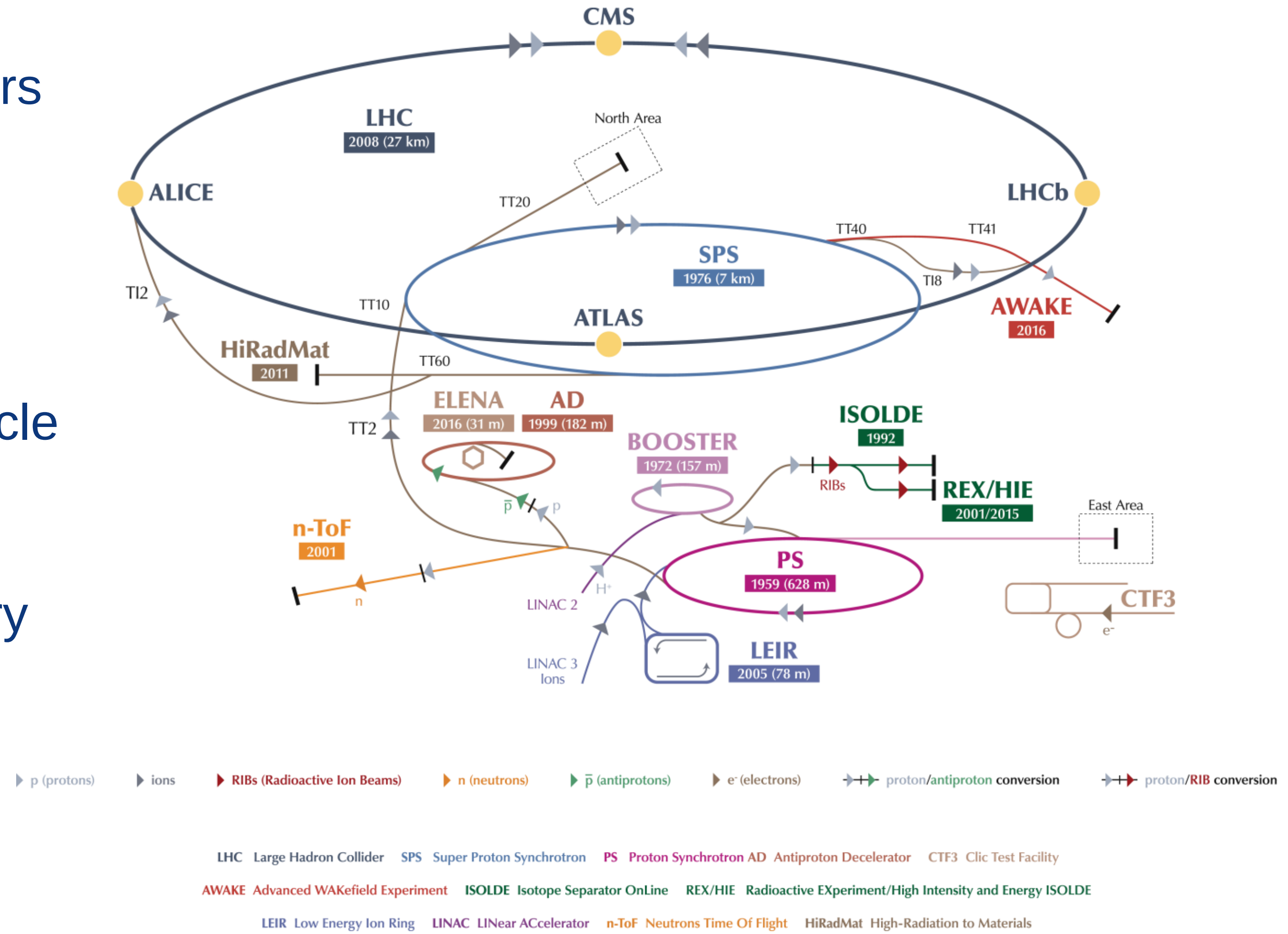


Beam Generation for Test Beams

Alexander Gerbershagen

Overview

- Introduction: Purpose and users
- Examples of test beam facilities
- Targets and particle production
- Secondary/tertiary beam lines



Introduction: Purpose and Users

Purpose and Users

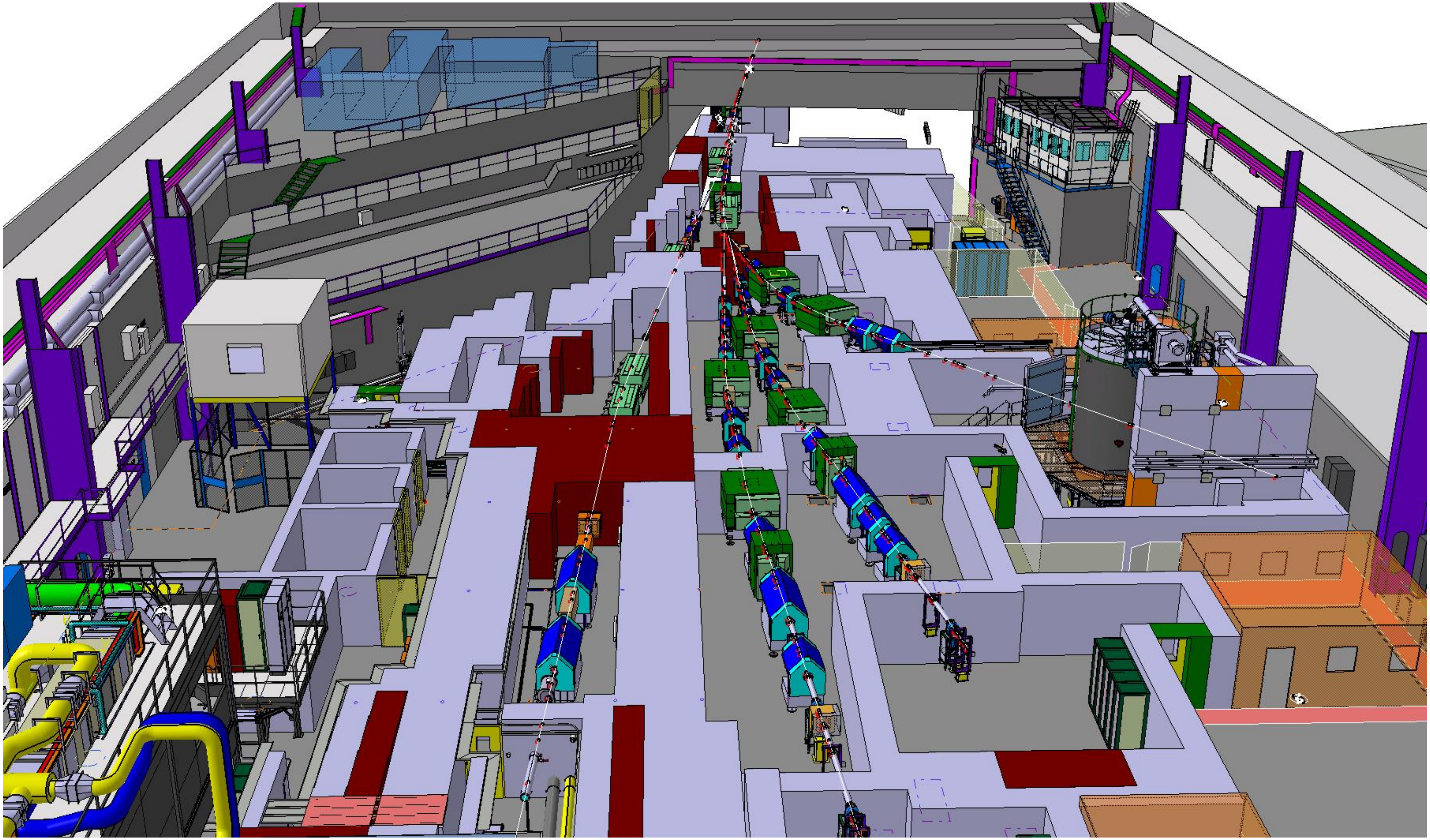
Secondary Beam Areas (SBA) are hosting:

- **FT experiments**: COMPASS,NA61, NA62, NA63, NA64, CLOUD, …
  - Precision studies (QCD, standard model, BSM physics)
  - Stable beam conditions for weeks and weeks
- **Radiation facilities**: PARTREC, HiRadMat, Charm, Irrad, GIF++
- **Test beams:**
  - Detector prototype tests
  - Detector calibration

    e.g. for LHC, linear colliders, space & balloon experiments
  - Outreach
  - Usually require a large spectrum of beam conditions within few days

Examples of test beam facilities

East Area – after renovation



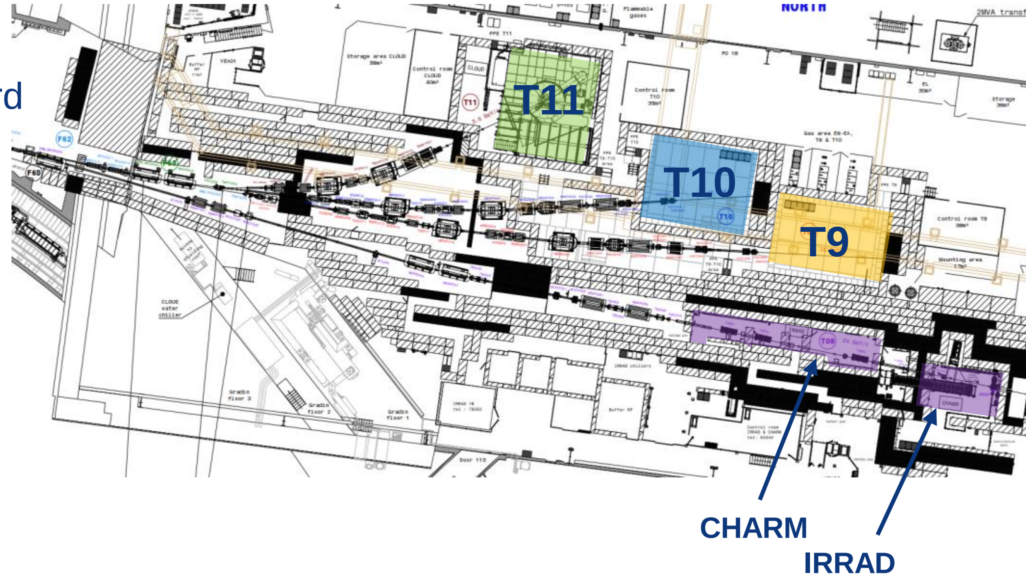
East Area

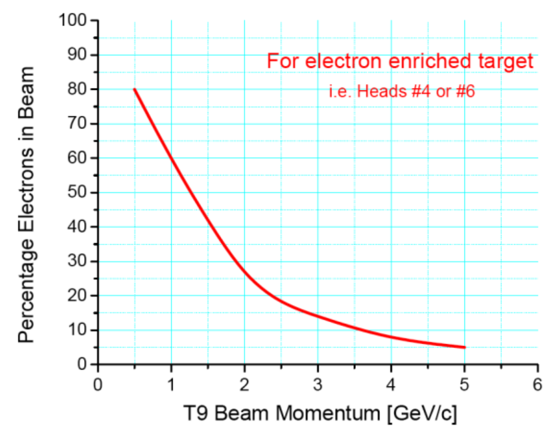
Area under renovation

-> See presentation by E. Montbarbon/J. Bernhard

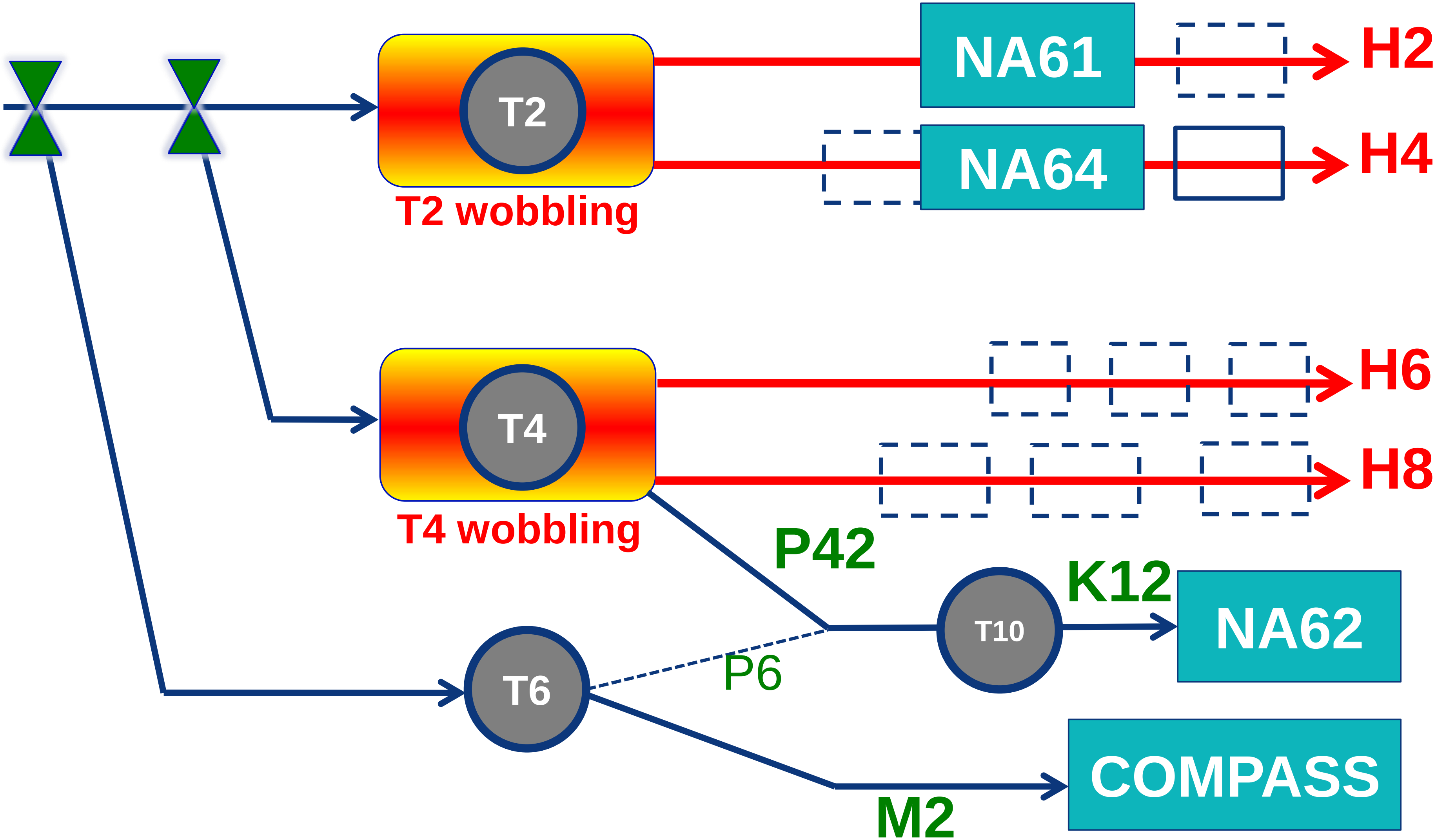
Test Beams after LS2

- Secondary beams:
  - T9: < 0.5 GeV/c – 15 GeV/c
  - T10: < 0.5 GeV/c – 12 GeV/c
  - Horizontal momentum selection
- Particle types and intensity
  - Pure electrons, hadrons, muons
  - Max. ~$5 \cdot 10^6$ particles per spill
- Spill structure from PS
  - 400ms spill length
  - Typically 1 spill every 18s (15bp), more on request
- AIDA2020 telescope AZALEA in T10
- Quick access from control room to experimental area (< 1 minute)
- Short cables





CERN North Area Beamlines



North Area beamlines characteristics

Primary mode   Secondary mode

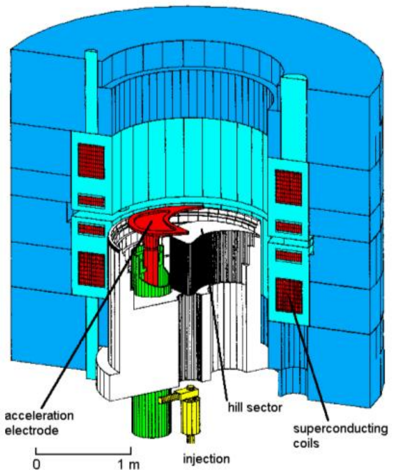
Parameters	T2		T4	
Beam Line	H2	H4	H6	H8
Maximum Momentum [GeV/c]	400 / 360	400 / 330	- / 205	400 / 360
Maximum Acceptance [µSr]	1.5	1.5	2	2.5
Maximum Δp/p [%]	± 2.0%	± 1.4 %	±1.5%	±1.5%
Maximum Intensity / spill * (Hadrons / Electrons)	$10^7/10^5$	$10^7/10^6$	10^7 **/10^5	10^7 **/10^5
Available Particle Types	Primary protons*** OR pure electrons OR mixed hadrons (pions, protons,kaons)			
Other / Special requests	sba-physicists@cern.ch & sps.coordinator@cern.ch			

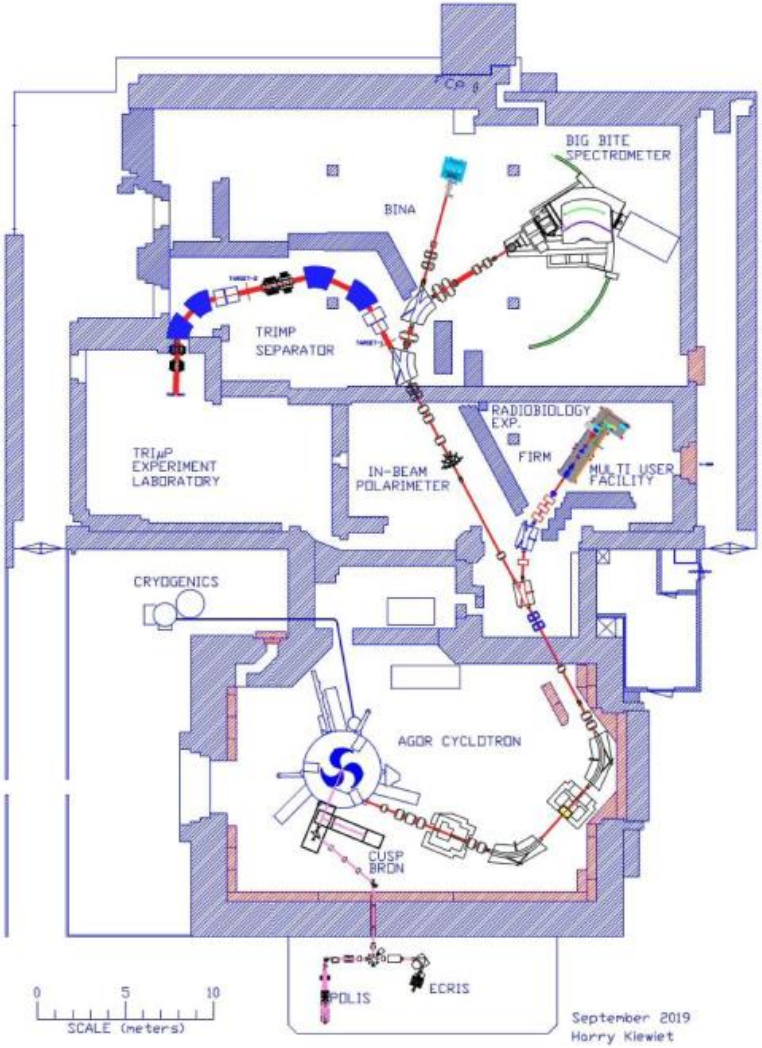
* Imposed by Radio Protection, and not available to every zone
** In some zones can be elevated up to 10^8 subject to certain restrictions
*** Not available in H6

Nota Bene : The particle momenta in H2/H4 and in H6/H8 are coupled. Send your beam request and discuss in advance with the SPS coordinator and the responsible liaison physicists.

PARTREC – Accelerator and Facility

- Superconducting AGOR cyclotron is a multi-particle, variable energy AVF-cyclotron
- Operational since 1996
- 3 halfwave RF cavities, 24 - 62 MHz; h = 2, 3 or 4
- Three external ion sources (two ECR sources for heavy ions, multi-cusp source for light ions) are axially injected
- Extraction
  - 300 - 500 turns depending on harmonic mode
  - extraction radius 870 - 890 mm depending on E/A
  - turn separation at extraction 2 - 3 mm ~ beamwidth

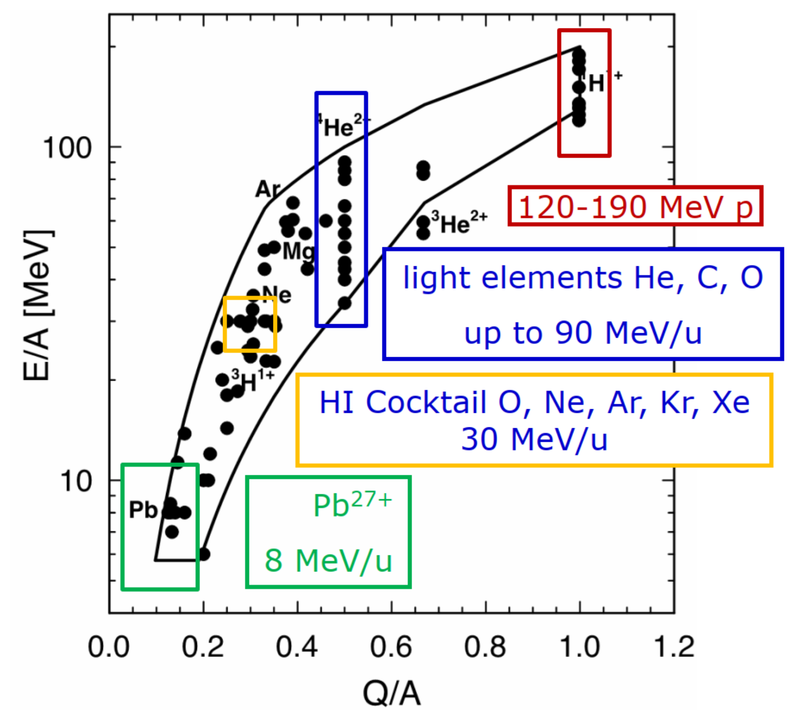


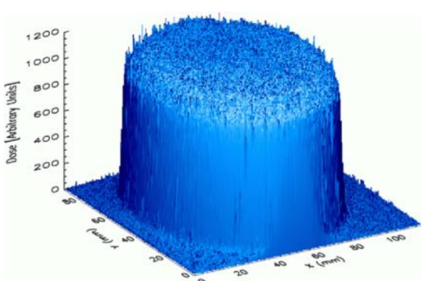


PARTREC – Beam Delivery

	Protons	Ions
Kinetic energy (MeV/amu)	≤ 190	≤ 90 for C and O ≤ 30 for all up to Xe
Attainable flux (particles per s)	> 10^{13}	≤ 10^{13} for Ne ≤ 10^{11} for heavier ions
Field size (cm²)	≤ 10 x 10 (scanned beam) ≤ 8 x 8 (scattered beam)	≤ 7 x 7 for light ions (scanned beam) ≤ 3 x 3 for heavy ions (scanned beam)
Field homogeneity	± 2 % (scattered beam) ± 1 % (scanned beam)	± 2 % (scattered beam) ± 1 % (scanned beam)

AGOR can deliver beams of all elements up to Xe



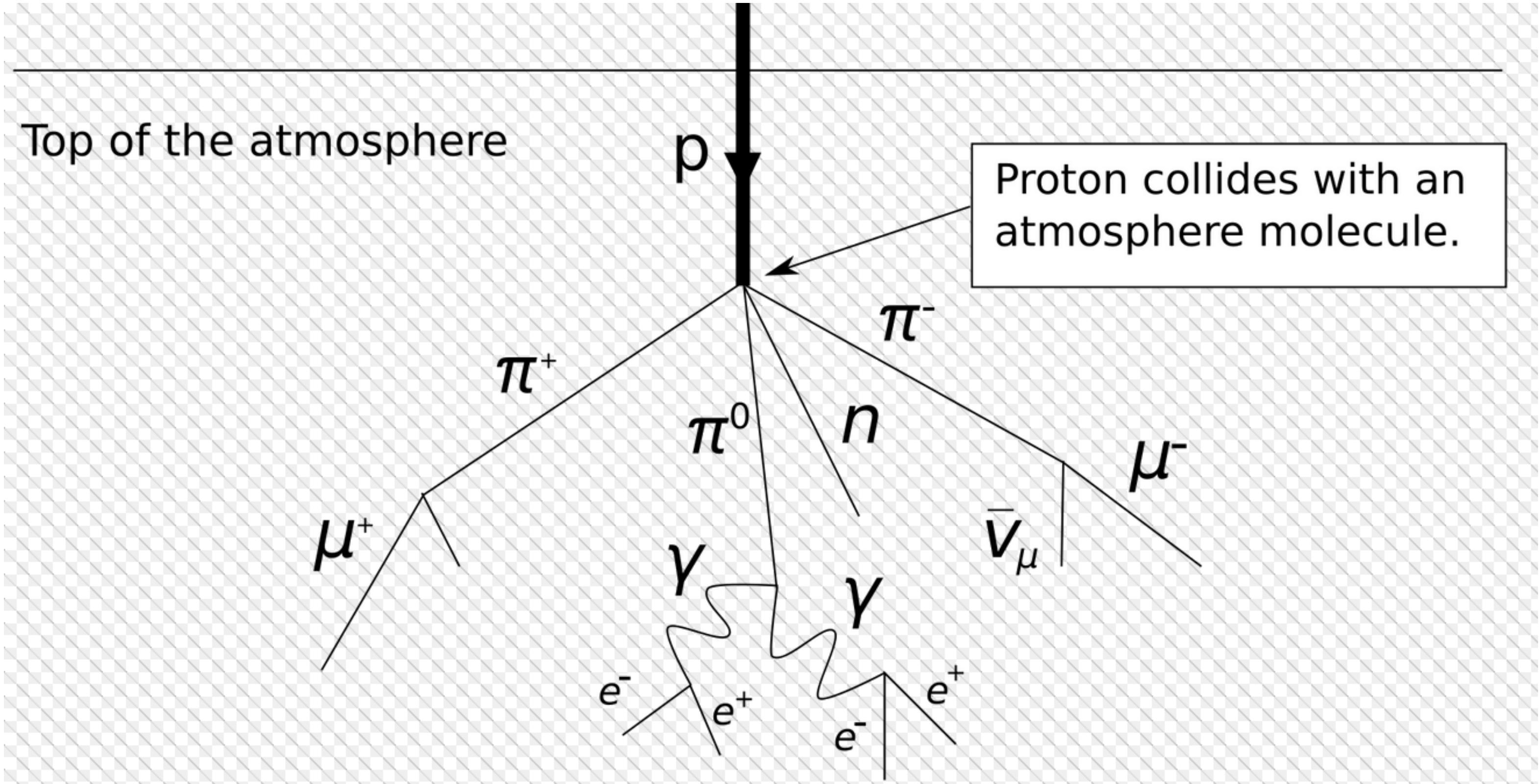


Beam requests:
irradiations.partrec@umcg.nl

Targets and particle production

Targets and particle production

- Principle taken from cosmic radiation
  - Primary proton beam initiating hadronic cascade
  - Always followed by an electro-magnetic cascade



Targets and particle production

- Principle taken from cosmic radiation
- Particles are produced in a large momentum range

SPS beam

Target length and production rates

- Beryllium has
  - radiation length X_0 = 35.3 cm,
  - nuclear interaction length λ_I = 42.1 cm,

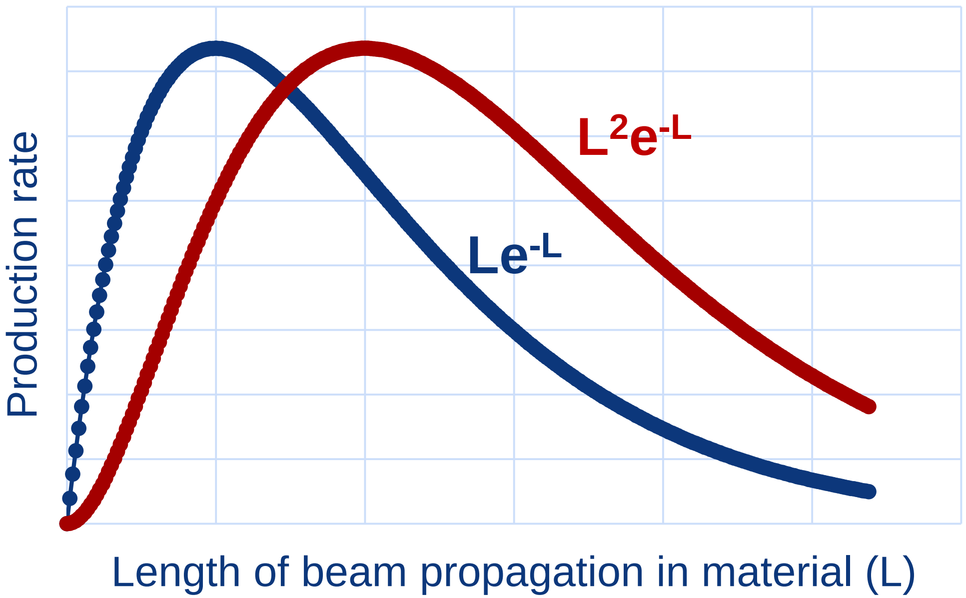
    => high X_0/λ_I ratio
  - low density (1.848 g/cm^3)
  - high melting point (1560 K)

Position	Material	Length (mm)	Height (mm)	Width (mm)
0	*Air/OUT*	-	-	-
1	Be	500	2	160
2	Be	300	2	160
3	Be	180	2	160
4	Be	100	2	160
5	Be	40	2	160
5x plates, 40 mm inter-plate distance				

- The e/π ratio increases approx. linearly with the target length
- Hadrons
  - are produced via p + N -> hadron (rate ~ L)
  - reabsorbed (rate ~ e^{-L})

  => Overall rate ~ Le^{-L} (maximum at $L \approx \lambda_I$)
- Electrons are mainly produced via
  - p + N -> π^0 -> γ γ (rate ~ L)
  - γ converts to $e^+ + e^-$ (rate also ~ L)
  - reabsorbed (rate ~ e^{-L})

  => Overall rate ~ $L^2 e^{-L}$ (maximum at $L \approx 2\lambda_I$)



Targets and hadron production

Atherton parameterisation (CERN 80-07):

$$\frac{d^2N}{dp\,d\Omega} = A\left[\frac{B}{p_0}\,e^{-Bp/p_0}\right]\left[\frac{2Cp^2}{2\pi}\,e^{-C(p\theta)^2}\right]$$

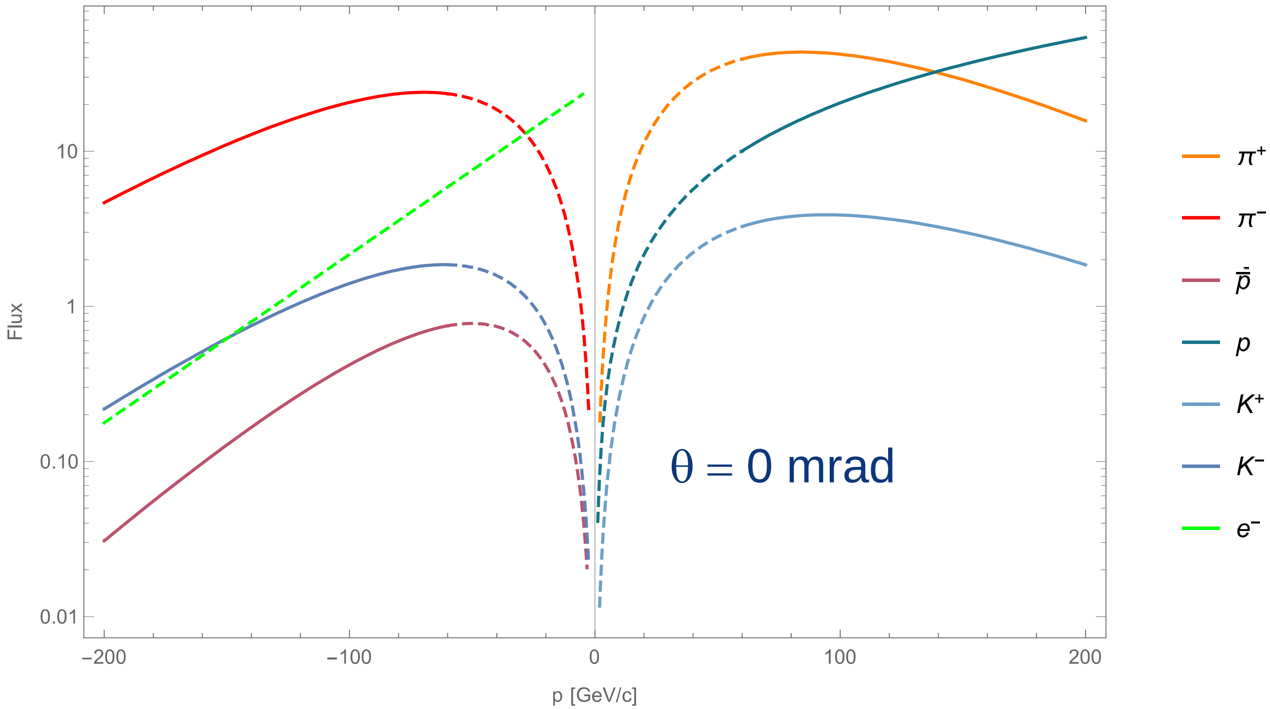
$$\frac{d^2N}{dp\,d\Omega} = A\left[\frac{(B+1)}{p_0}\left(\frac{p}{p_0}\right)^B\right]\left[\frac{2Cp^2}{2\pi}\,e^{-C(p\theta)^2}\right]$$

with primary momentum p_0 and production angle θ

Flux per solid angle [steradian], per interacting proton, and per dp [GeV/c]

	A	B	C
p	0.8	-0.6	3.5

	A	B	C
π^+	1.2	9.5	5.0
π^-	0.8	11.5	5.0
K^+	0.16	8.5	3.0
K^-	0.10	13.0	3.5
$\bar{p}$	0.06	16.0	3.0



Note: Valid for primary interactions only! Extrapolation for momenta below 60 GeV/c

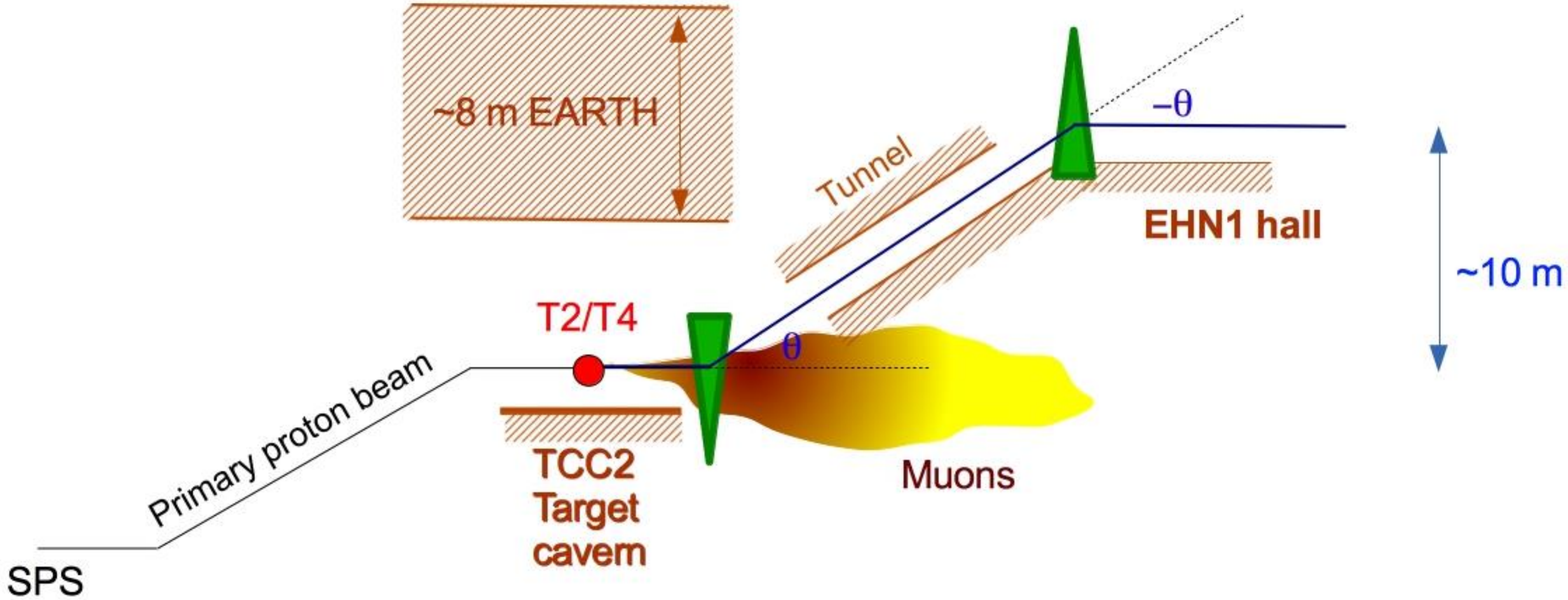
Secondary / tertiary beam lines

Beamlines

- Experiments and test beams require "clean" beams with high purity (one particle type) and small momentum spread
- Beam lines design ("optics")
  1. Collect produced particles from target
  2. Select momentum
  3. Select particle type
  4. Transport beam to experiment
  5. Select beam spot size for experiment

NA beamline design considerations

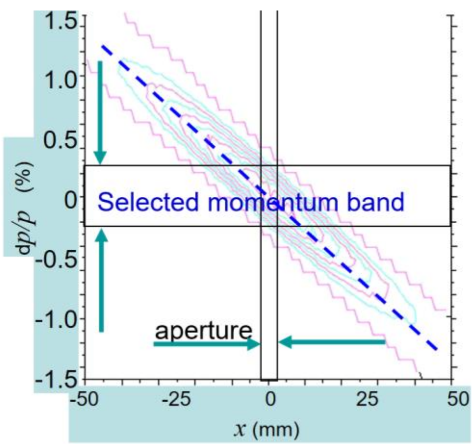
- NA beams were originally (end of 1970's) designed for the fixed target experiments. Design considerations were
  - Muon range (absorb underground)
  - Charged pion lifetime
  - Momentum selection ($2 \cdot 10^{-4}$)

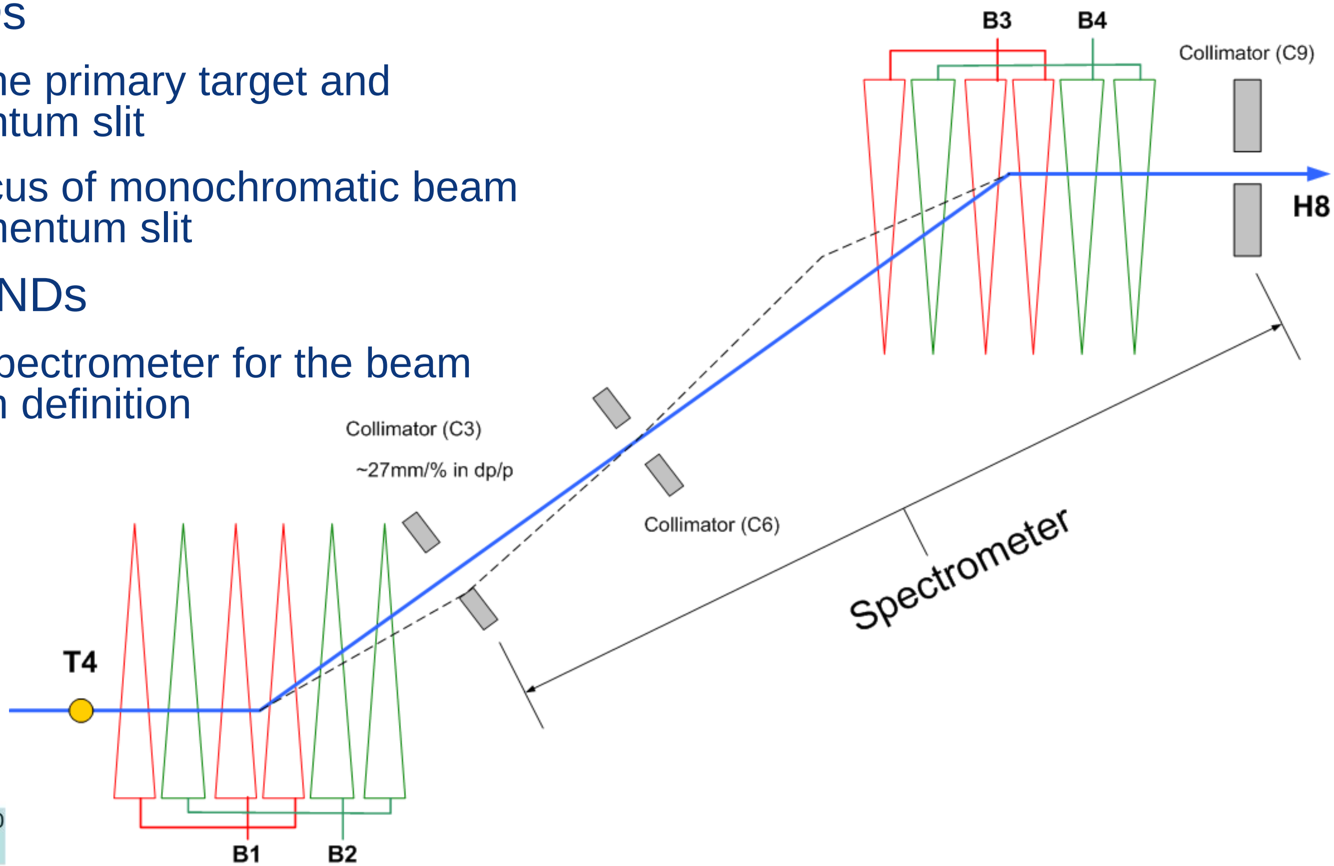


NA secondary beamline - layout

Basic beam design

- momentum selection in the vertical plane
- two sets of bending magnets
  - Upstream BENDs
    - Between the primary target and the momentum slit
    - Vertical focus of monochromatic beam at the momentum slit
  - Downstream BENDs
    - the main spectrometer for the beam momentum definition

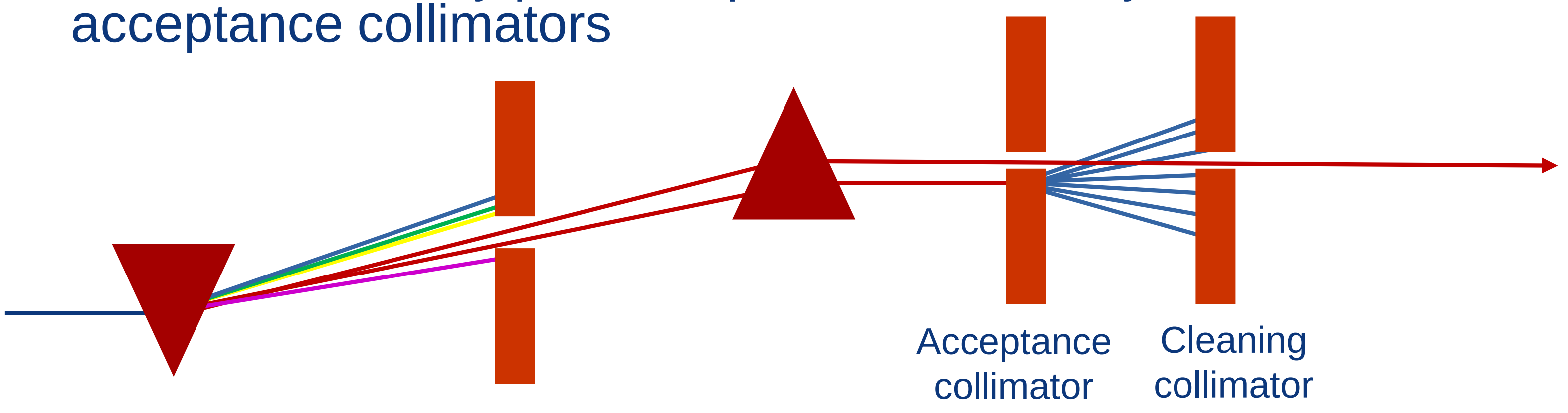




Secondary beamline - collimators

- TAX (Target attenuator)
  - Define initial acceptance of the beam line

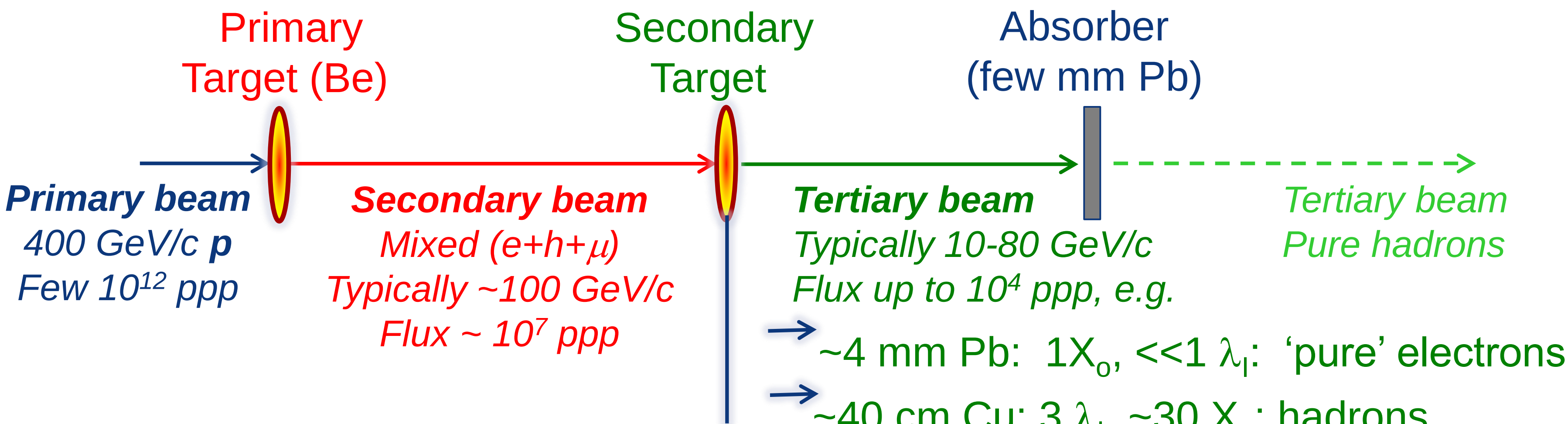
- Acceptance collimators
- Cleaning collimators
  - Absorb secondary particles produced on the jaws of acceptance collimators



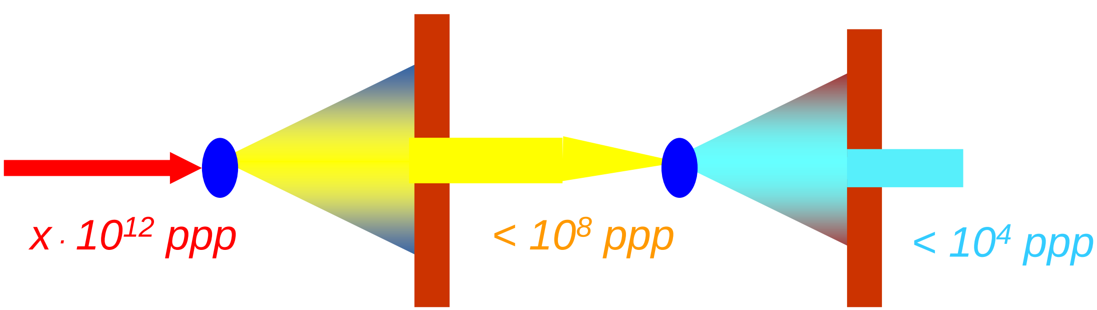
Secondary beamline - intensities

Basic beam design

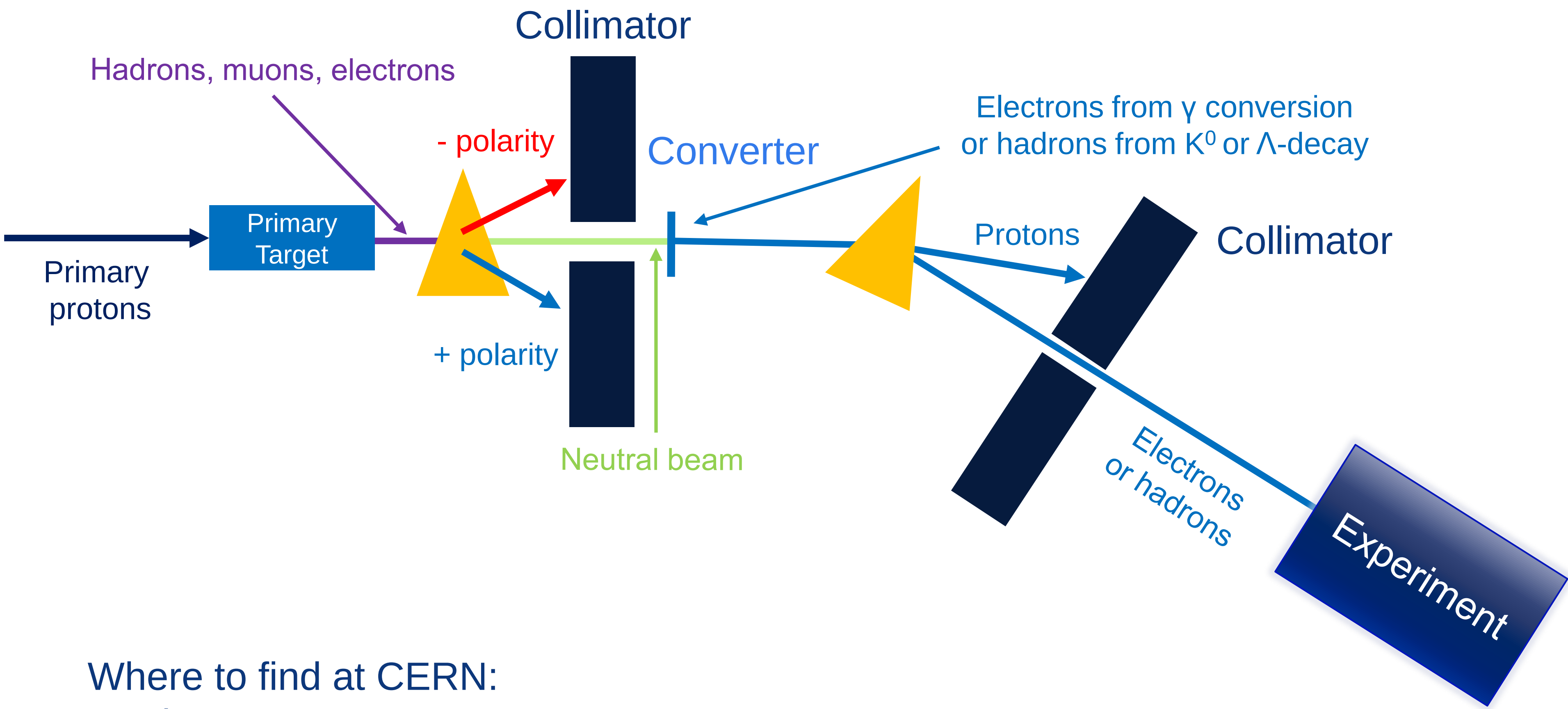
- Selection of particle types



- Intensities

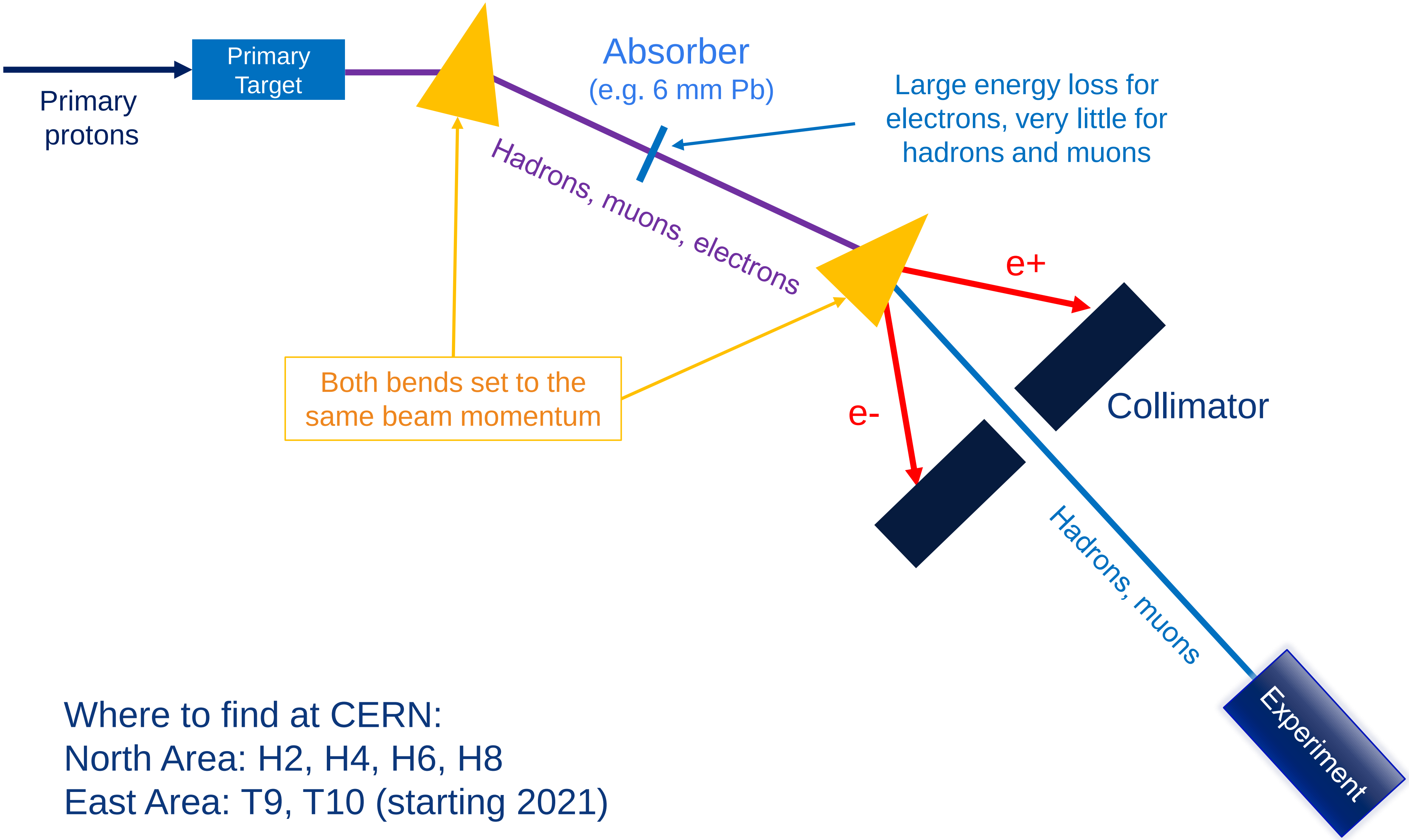


Selection of particle type - Converter



Where to find at CERN:
North Area: H2, H4
East Area: T9 (starting 2021)

Selection of particle type - Absorber



Where to find at CERN:
North Area: H2, H4, H6, H8
East Area: T9, T10 (starting 2021)

Selection of particle type - Filter

Differential absorption:

- Beam through filter 
- Enrichment = single particle attenuation a_i over total beam attenuation

$$a'_i = \frac{a_i \, e^{-L/\lambda_i}}{\sum_i a_i \, e^{-L/\lambda_i}}$$

Example: +300 GeV/c beam filtered with 3m polyethylene

- Initial flux $5 \cdot 10^8$ particles

Particles	% initial beam	% filtered beam	Flux
Protons	92.5	73.4	$7.9\ 10^6$
Pions	5.8	19.1	$2.1\ 10^6$
Kaons	1.7	7.5	$8\ 10^5$

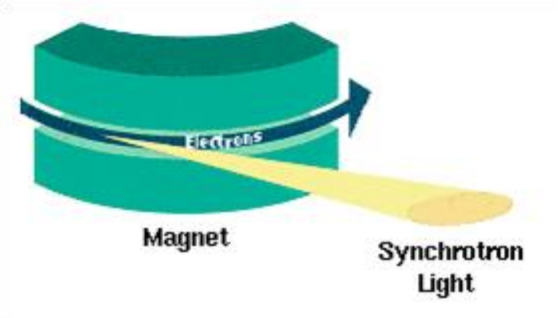
- Drawbacks:
    - Small suppression factor for unwanted particles
    - Big losses with low efficiency

High-energy electron beams

- Synchrotron radiation

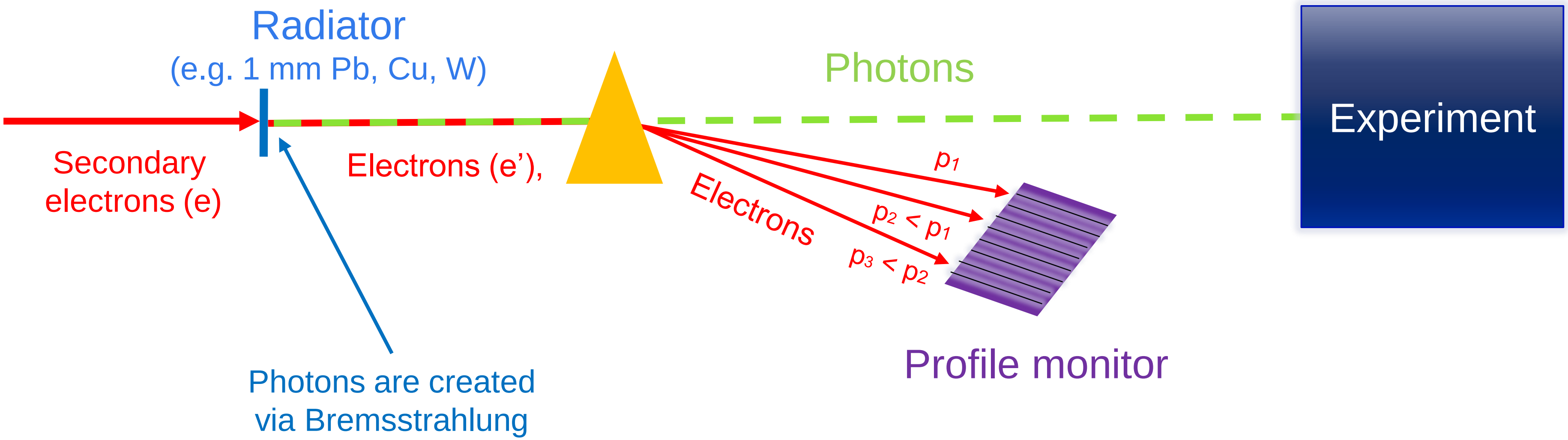
(for one full revolution)

$$P_s = \frac{e^2 c}{6\pi\varepsilon_0 (m_0 c^2)^4} \frac{E^4}{\rho^2}$$



- E.g. $e^{\pm}$ at 200 GeV lose in 1° bending magnet of 1 T field 590 MeV
  - => With beamline momentum acceptance of $\Delta p/p < 0.3$ % it is possible to separate them from (heavier) hadrons and muons. So set up the following bends either
    - at the constant energy to select heavier particles or
    - scale it with energy loss of electrons.
    - Works only for $p_e > 120$-150 GeV/c

Selection of particle type - Radiator



- Time resolution - electron by electron
- Transverse position gives information on e- momentum
- $p_\gamma = p_e - p_{e'}$
- Result : tagged photon beam

Where to find at CERN:

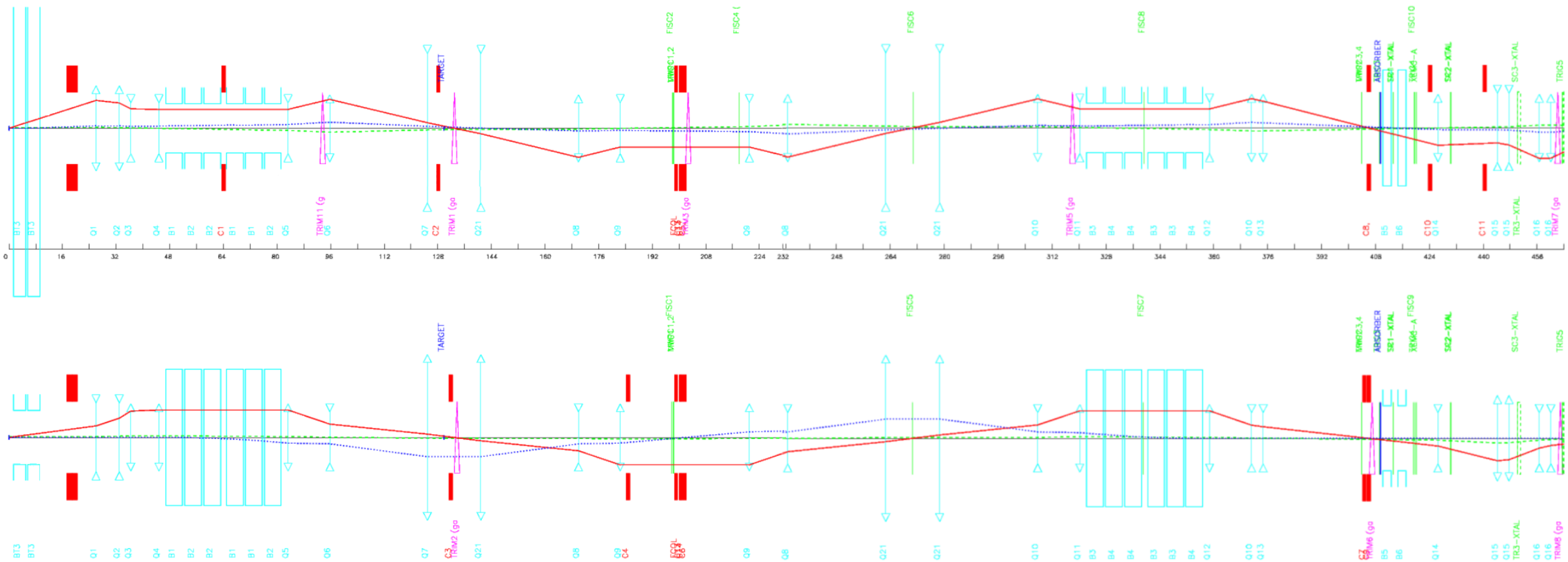
(Ad hoc installation, but usually used at)

North Area: H2, H4

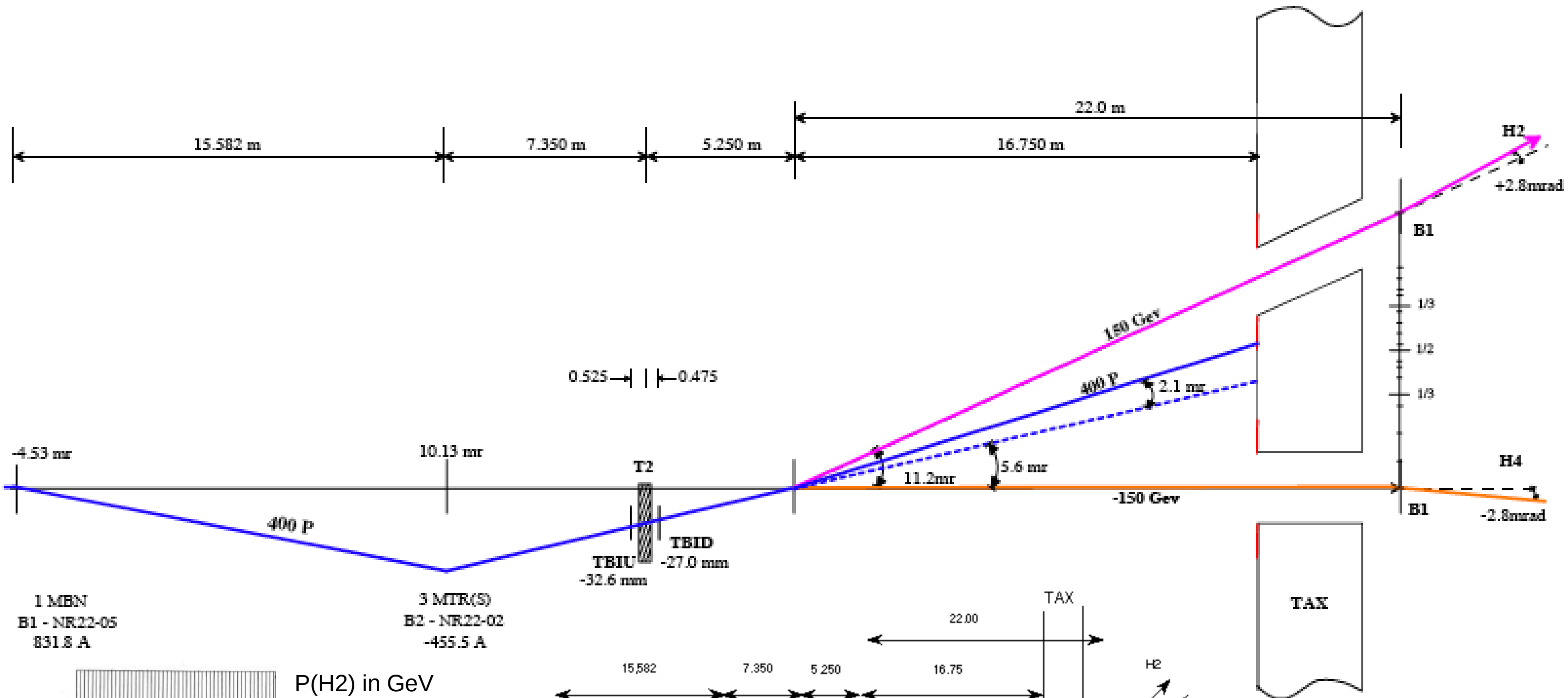
East Area: T9

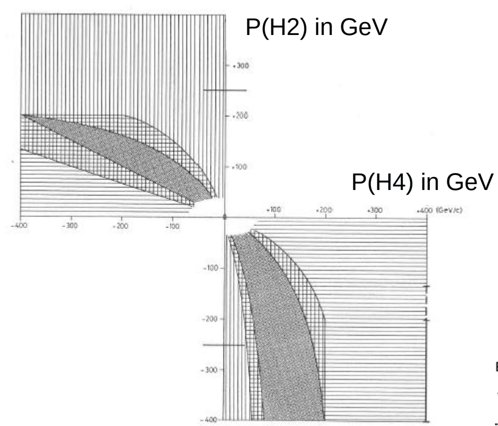
Secondary beamline – beam optics

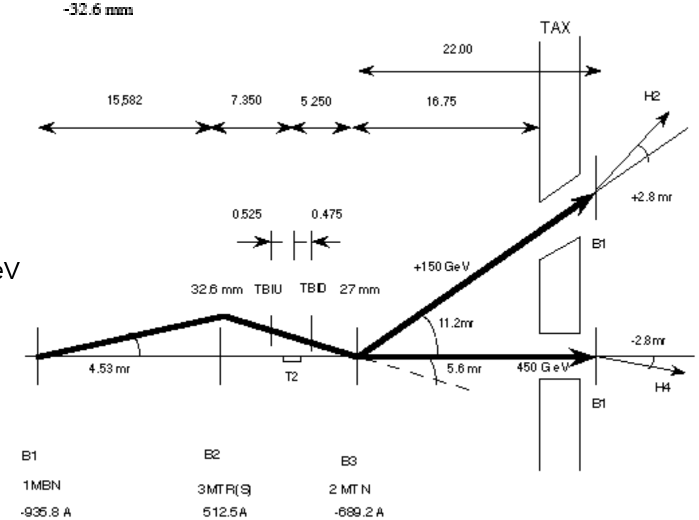
Optics of a beam line (H8)



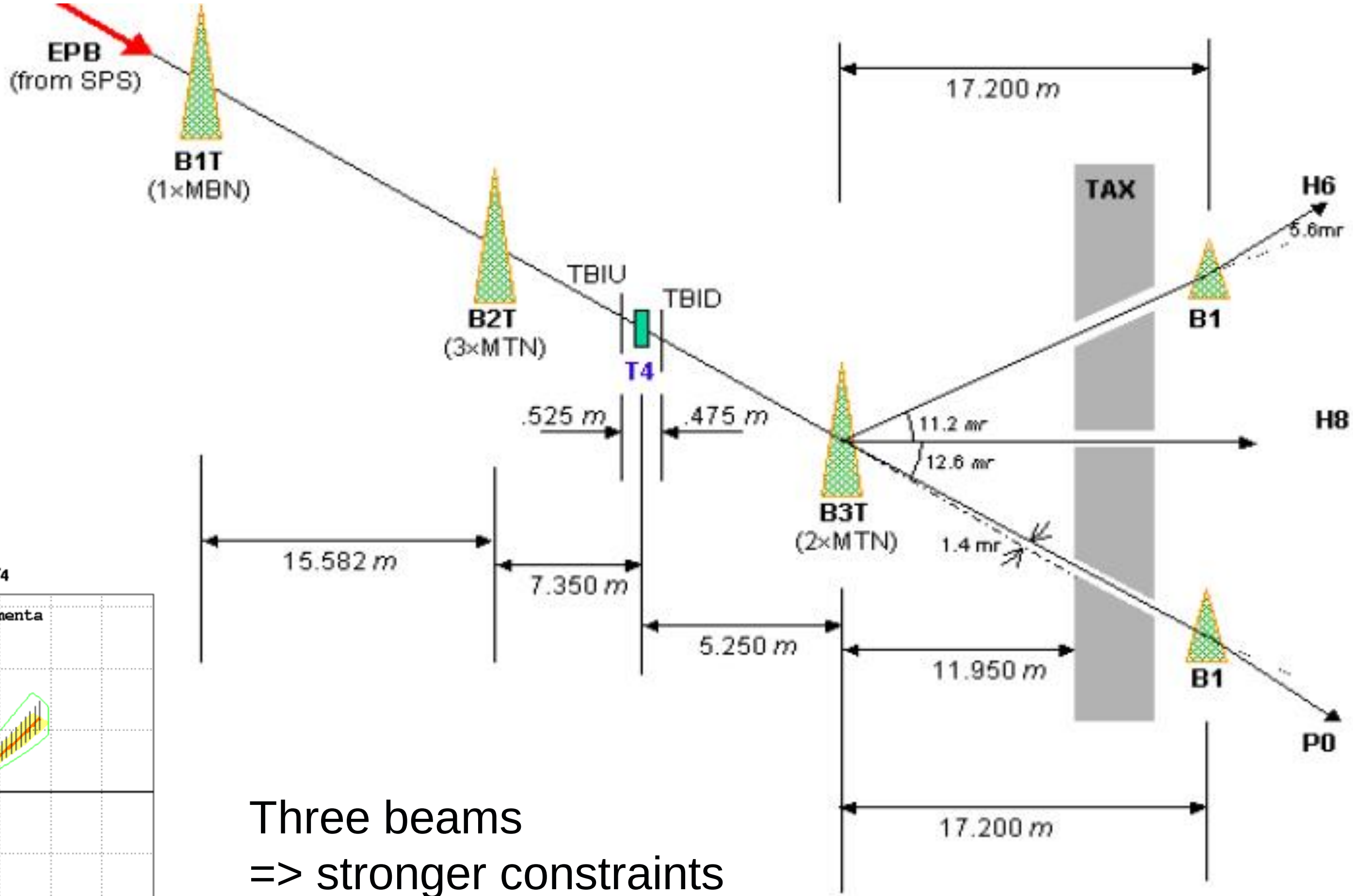
H2-H4 coupling via wobbling in T2 target

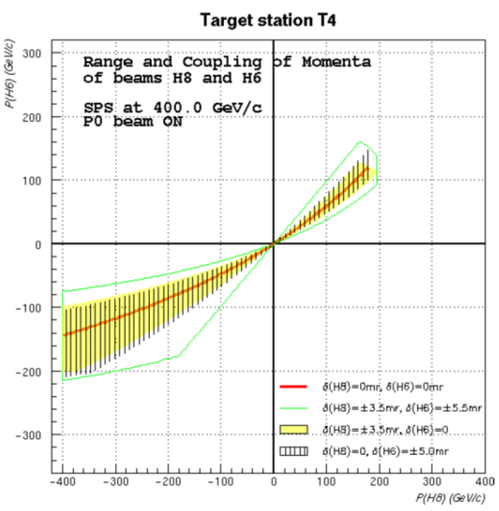






Wobbling in T4 target

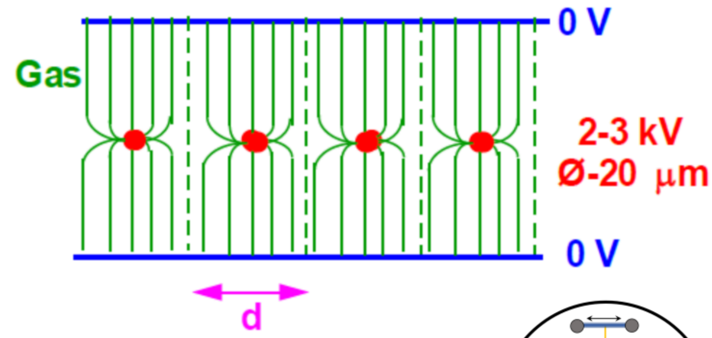


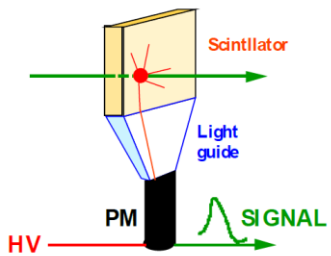


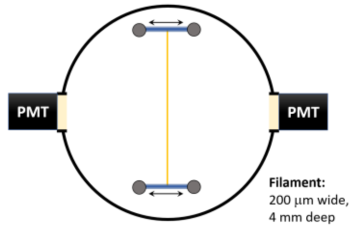
Three beams
=> stronger constraints

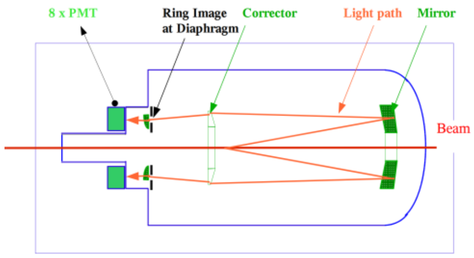
North Area – beam instrumentation

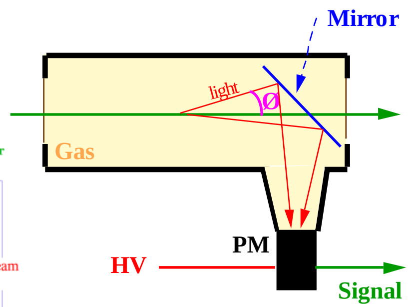
- Profile monitors
  - XWCA(M) for higher fluxes (> 10^4 per spill)
  - XDWC for lower fluxes (< 10^4 per spill)
- Fiscs
- Intensity counters
  - Scintillators for lower fluxes (< 10^7 per spill)
  - XION for higher fluxes (> 10^6 per spill)
- Cherenkov detectors
  - XCET (Threshold counter)
  - CEDAR
- SEM counters at the target
  - BSI for beam intensity
  - BSP split foil for beam symmetry
  - BSM and SEM grid for angle set up
  - BBS (fisc like)





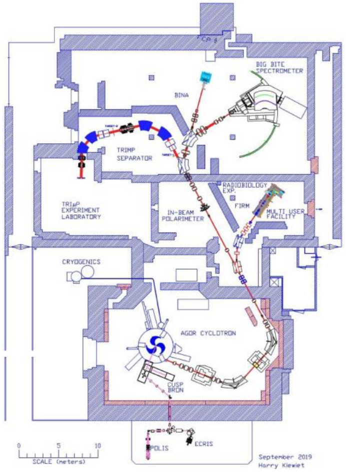


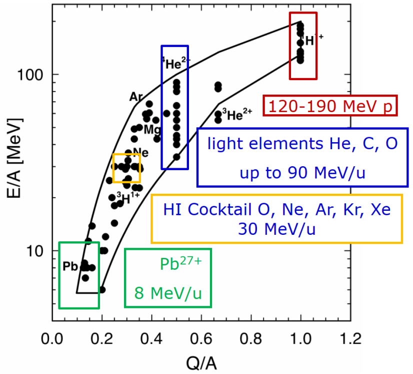


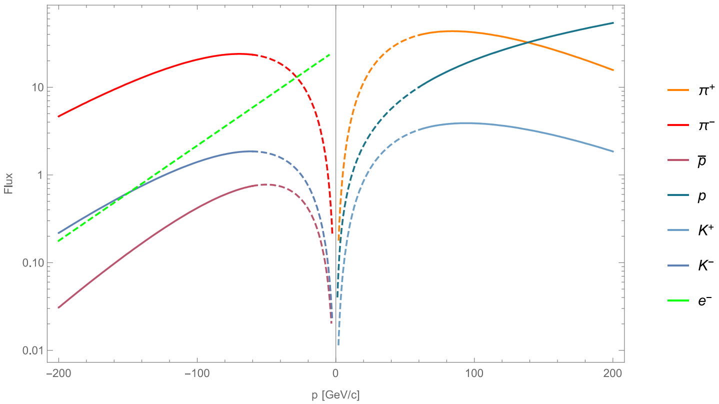


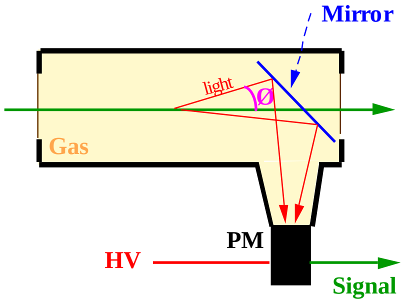
Summary

- PARTREC has a high-intensity test beam complex with primary proton and ion beams
- CERN has a test beam complex
  - East Area
    - Momentum : 0.5 GeV/c – 15 GeV/c
  - North Area
    - Momentum: 10 GeV/c – 400 GeV/c
  - Capable to provide
    - Protons
    - Electrons
    - Hadrons
    - Pure pions
    - Muons
    - Tagged photons
  - Diverse instrumentation for various purposes









Questions?