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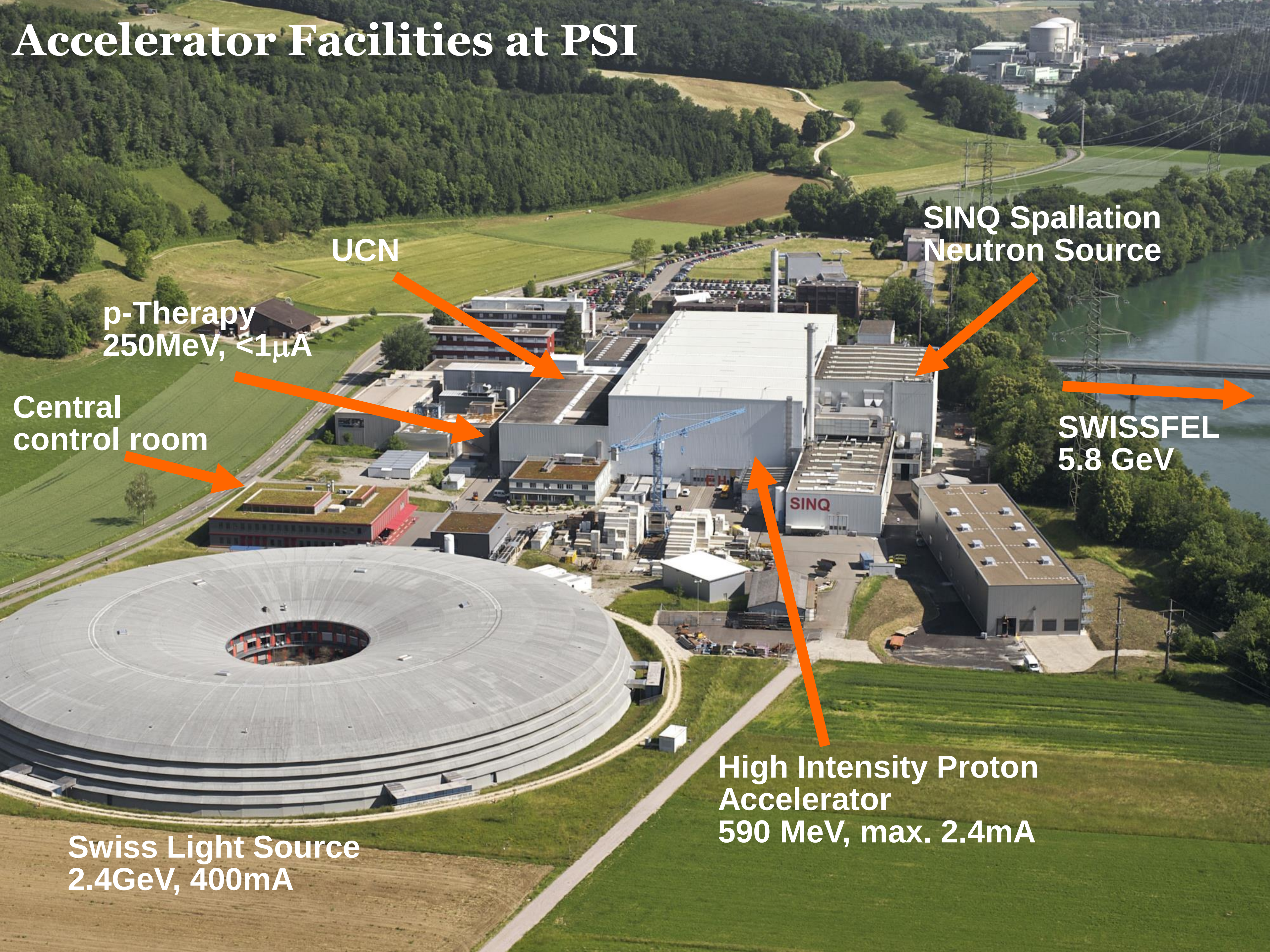
Daniela Kiselev :: ASA/GFA :: Paul Scherrer Institut

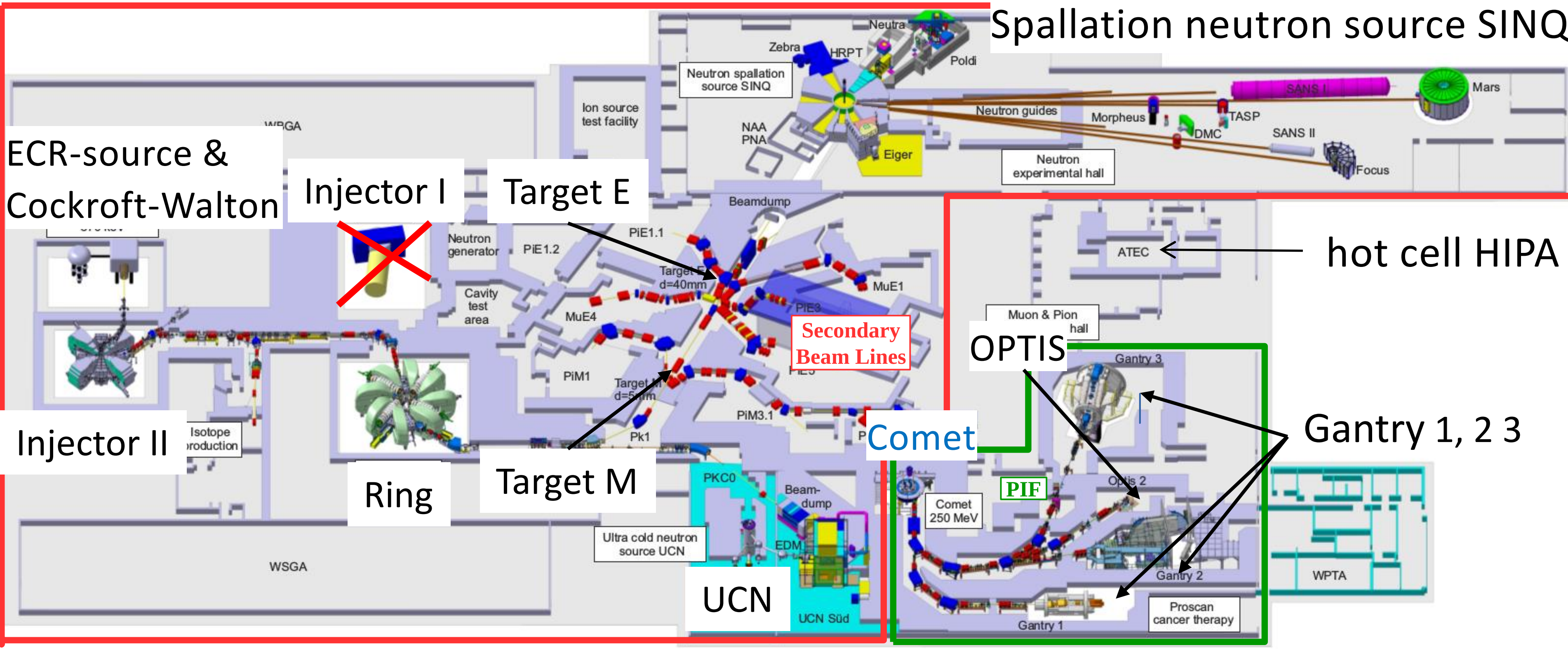
PSI Muon Facilities

Workshop on Muon Collider test opportunities, 24.3.2021

Accelerator Facilities at PSI



The PSI Proton Accelerator Facilities



HIPA (High Intensity Proton Accelerator)

- CW (50.63 MHz), 590 MeV,
- up to 2.4 mA(1.44 MW)
- 2 meson production targets
- 7 secondary beam lines
- SINQ and UCN spallation source

PROSCAN (Proton therapy): since 2007

Comet: superconducting cyclotron

CW, 250 MeV, up to 1 μA protons

medical treatment:

3 Gantries, 1 Eye Cancer Treatment Station

Irradiation Station: PIF

Challenges for meson production targets

- Power deposition:

  at 2.4 mA, 590 MeV protons ~ 50 kW on Target E
  → cooling
  → high temperature resistant material
  → thermal stress

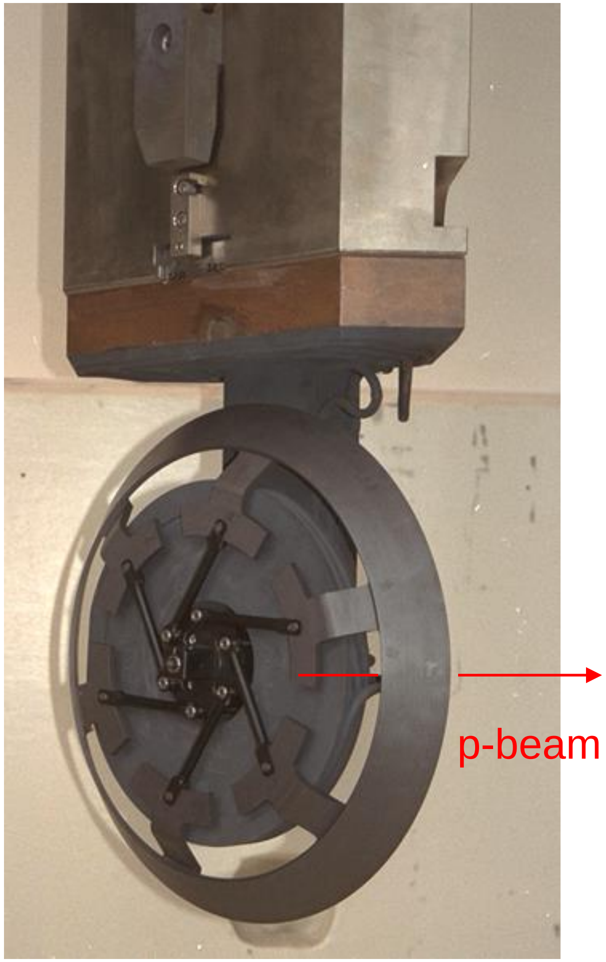
- Radiation damage:

  → embrittlement
  → deformation (also due to heating)
  → loss of conductivity

Approach:

- <u>distribute power:</u>
  rotating wheel with 1 Hz → needs bearings
- <u>cooling by radiation:</u>
  - independent of conductivity
  - local shielding (Cu) is cooled by water

Target E

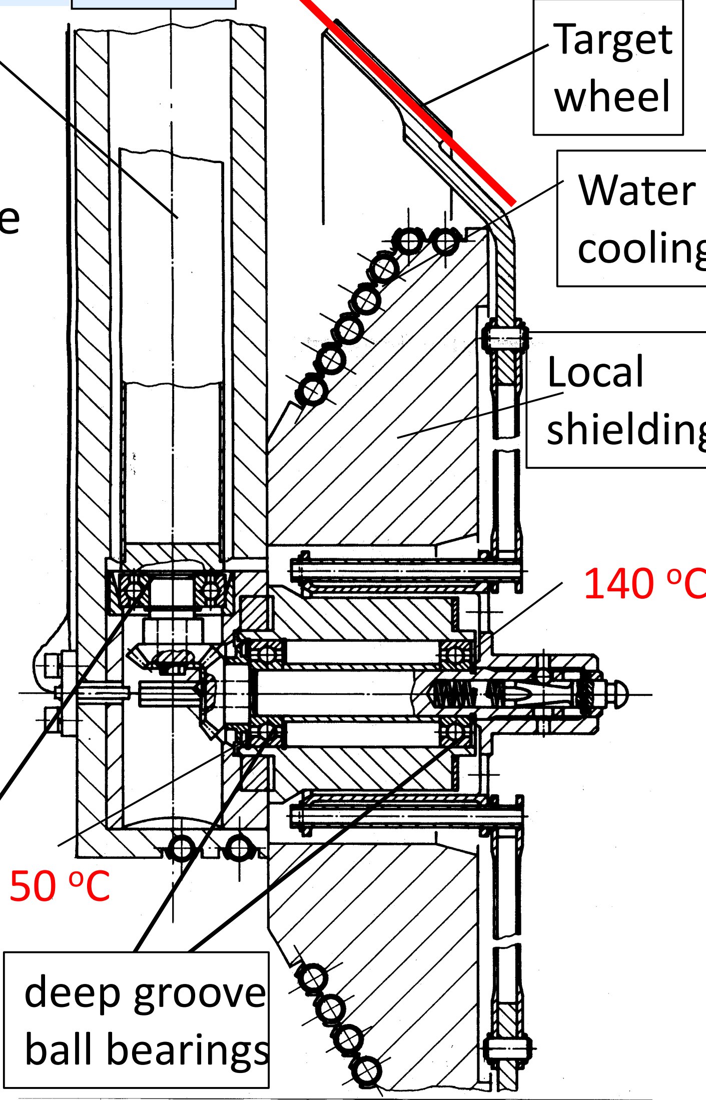


Challenges for meson production targets

- Wheel deformation reduced by
  - polycrystalline graphite → isotropic properties
  - slits in wheel rim für thermal expansion
  - spokes: allows thermal expansion of target cone hollow to avoid high temperature at bearing

1700 K

12 segments with 1 mm slit



- Motor:

2.5 m above the beam line

→Functioning is not affected by irradiation

→ life time ~ 5 – 8 years

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Critical components: Bearings

- Ball bearings:

No grease as lubrication! → brittle due to hard irradiation
so called radiation hard grease does not help → proofed

in use:

Balls Si_3N_4, GMN, Germany
Coating: MoS_2, Ag for ring & cage
1 -2 x exchange/year
←→ Graphite wheel lasts much longer: ~ 4Years
(39 Ah record)

in test:

Shun Makimura (JPARC)

Balls stainless steel + WS_2 blocks
Koyo, Japan
Test (without radiation): > 420 days
<u>Test in beam at PSI planned this year</u>

Exchange of the high-activated components

Exchange flask:

- 45 t, shielded with 40 cm steel
- remotely operated

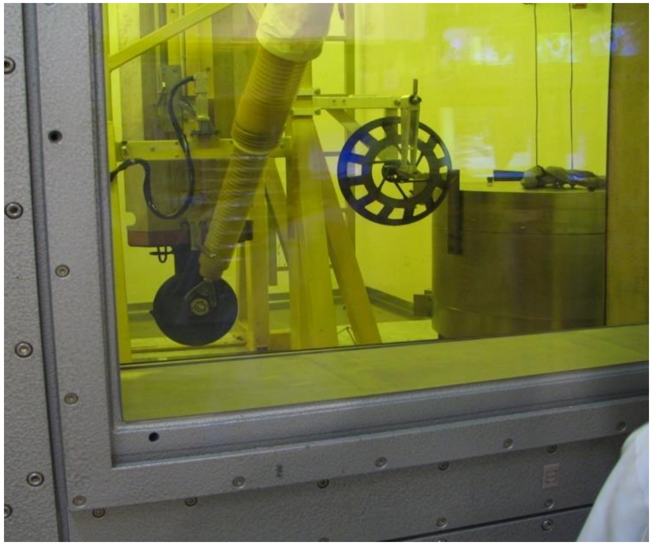
"Bridge":

- contains contamination protection
- door to close lifting hole
- sticks for positioning of the flask

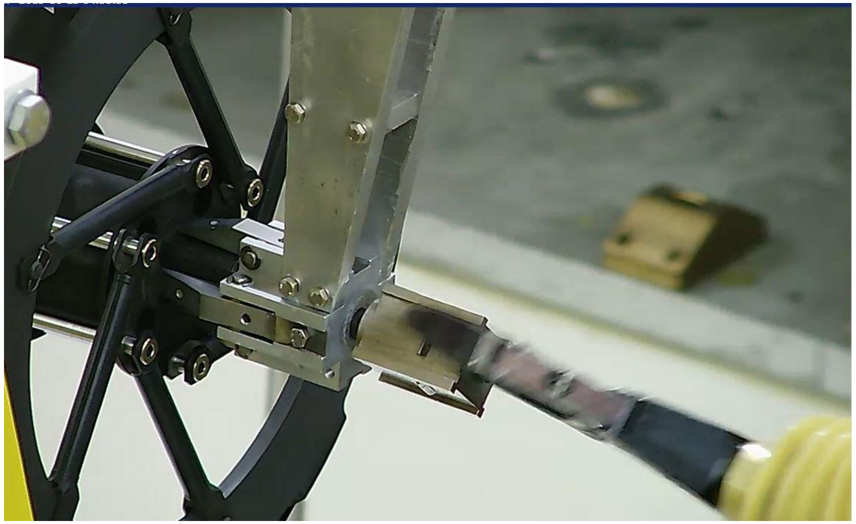
Working platform:

- ~ 2m above beamline, shielded with steel
- Accessible after removing 3 – 4 m of concrete

Transport to hotcell PSI West (ATEC)



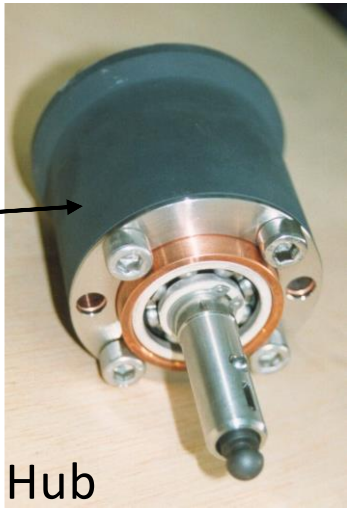
View into hotcell of ATEC



Exchange of bearings with manipulator

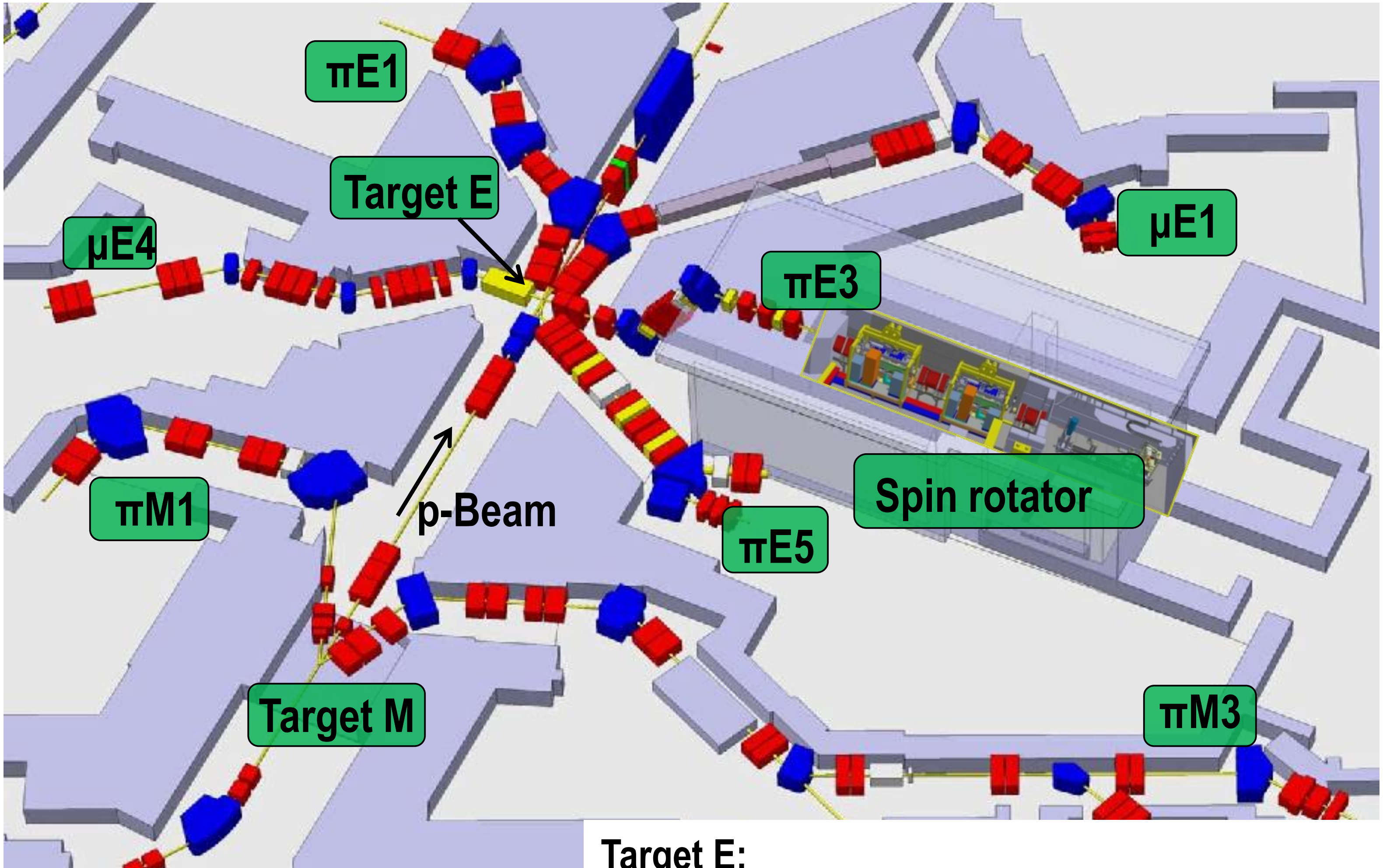
- Remote handling necessary: up to 3 Sv/h
- Handing over from flask to hotcell via sluice

Usually only the hub needs to be exchanged
→ not much radioactive waste (up to 200 mSv/h)



Hub

μ/π Secondary Beam Lines



Target M:

πM1: 100-500 MeV/c Pions

πM3: 28 MeV/c Surface Muons

Target E:

πE1: 10 - 500 MeV/c High Intensity Pions und Muons

μE1: Polarized Muon Beam

πE3: 28MeV/c Surface polarized Muons

μE4: 30 - 100 MeV/c High Intensity Polarized Muons

πE5: 10 - 120 MeV/c High Intensity Muons

Overview of Secondary Beam Lines

	PiM1	PiE5	PiE1	PiE3	PiM3	MuE4	MuE1
Target	M	E	E	E	M	E	E
Particle Type	π/e/μ/p	μ/π	π/μ/p	μ, π	μ	μ	μ (cloud)
Momentum Range	10-500 MeV/c (max 300 MeV/c for positive particles)	20-120 MeV/c	10-500 MeV/c ustream ASK 10-120 MeV/c downstream ASK	μ:10-40 MeV/c π: 50 – 250 MeV/c	10-40 MeV/c	10-40 MeV/c	60-120 MeV/c
Typical Momentum	15-300 MeV/c	28-85 MeV/c	PP: 10-50 MeV/c μSR: 28 MeV/c Irrad: 300 MeV/c	28 MeV/c	28 MeV/c	28 MeV/c	60-125 MeV/c
Max Rate [mA^{-1} s^{-1}]	@ 350 MeV/c π+:2x10^{8}	@120MeV/c π^{+}:2x10^{10} μ^{+}:5x10^{8}	@ 300 MeV/c π^{+}:4x10^{9}	μ^{+}:3x10^{7} π^{+} :2x10^{9} @ 170 MeV/c	μ^{+}:3x10^{6}	μ^{+}:4x10^{8}	@ 300 MeV/c μ^{-}:6x10^{7}
Typical Use	Particle Physics Test Experiments, Detector/Material Irradiation	Particle Physics Experiments	μSR Dolly Particle Physics Experiment, Detector Irrad.	μSR HAL 9500 (High Field)	μSR GPS and LTF	μSR LEM Facility	μSR GPD Facility

Particle physics: (**CHRISP facility**)

μSR (Muon Spin Rotation), SμS (Swiss Muon Source)

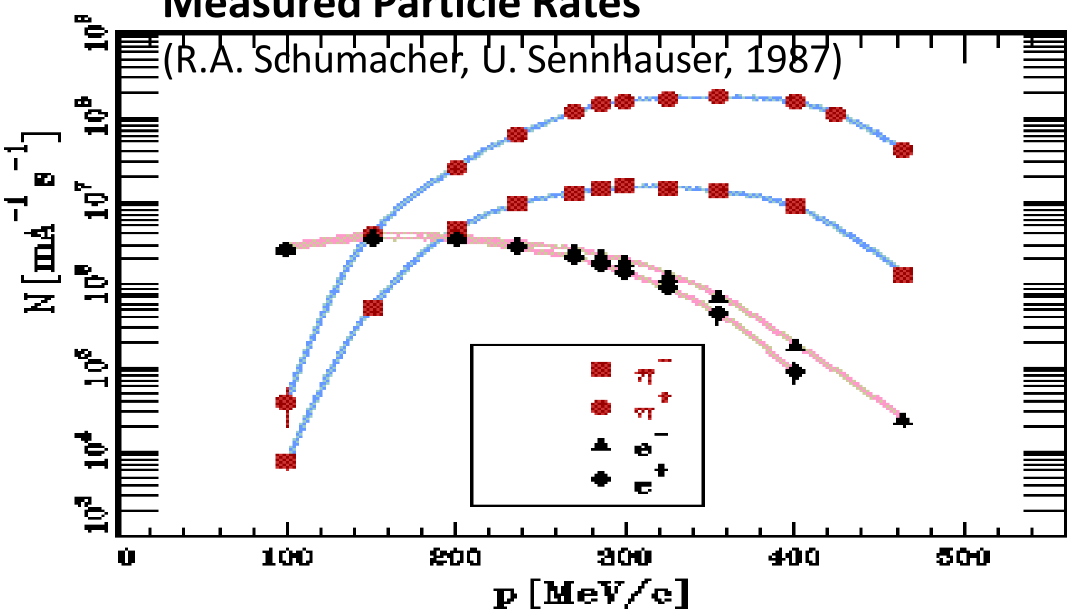
PiM1 Beamline

- Often used as Test Beam line at PSI
- e/μ/π/p momentum range 20 – 500 MeV/c
- Particle separation by energy loss in material & momentum selection
- Momentum < 115 MeV/c: dominated by e
- 115 - 280 MeV/c Beam dominated by μ/π
- > 280 MeV/c Beam dominated by π/p

Beam scanner

Measured Particle Rates

(R.A. Schumacher, U. Sennhauser, 1987)



p- acceptance: 2.9 %

p-resolution: 0.1 %

Size at Target: hor: 15 mm,
vert: 10 mm

Divergence : hor: 35 mrad
vert: 75 mrad

PiE1 Beamline

- High intensity µ/π beam line at TE

< 120 MeV/c: Beam dominated by e/µ

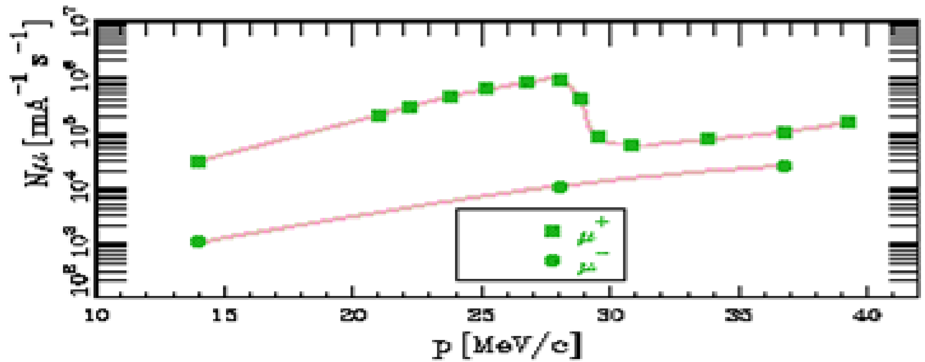
120 - 280 MeV/c Beam dominated by µ/π

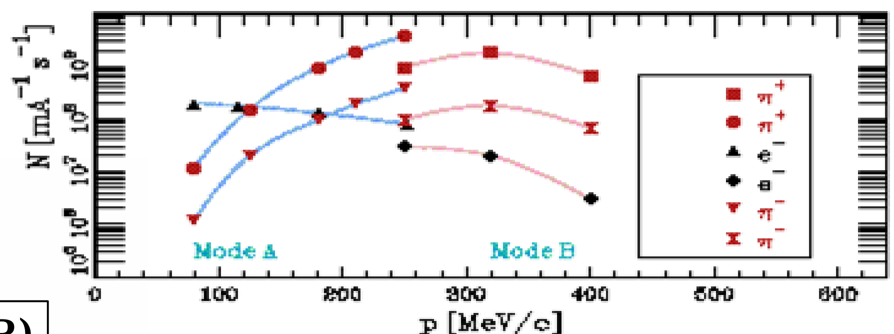
> 280 MeV/c Beam dominated by π/p

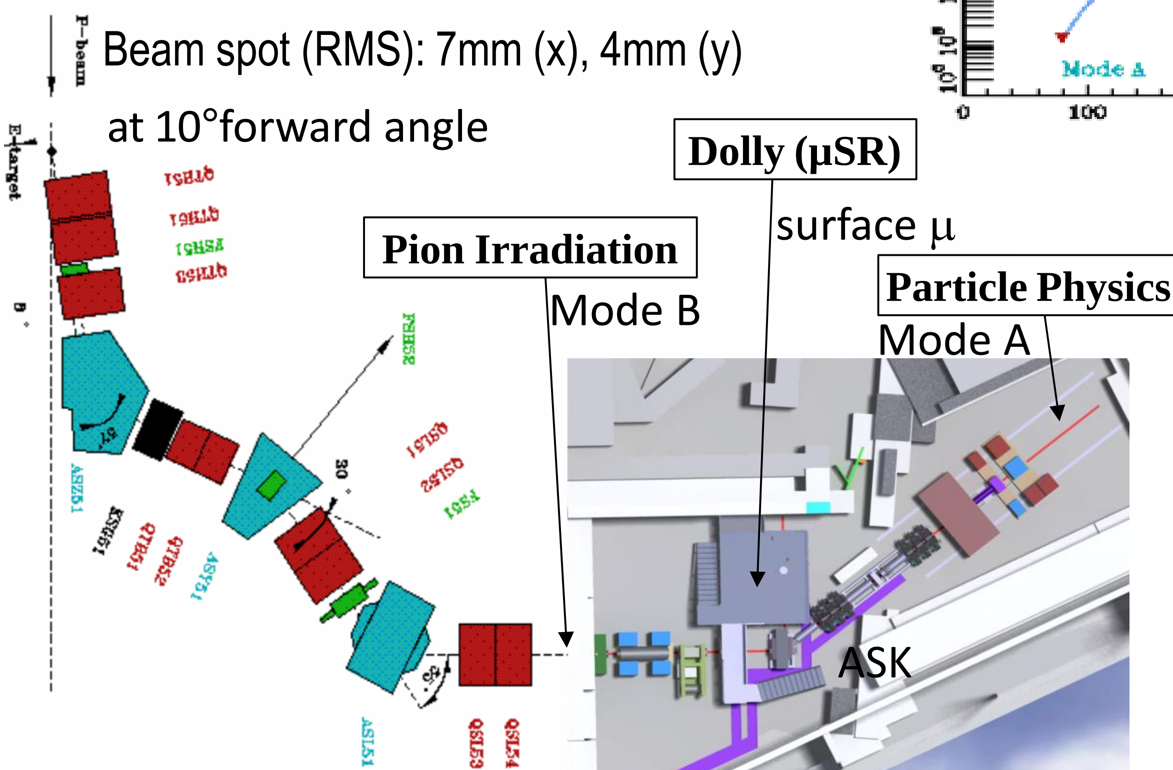
- Momentum acceptance (1σ): 4%
- Max. particle flux: $4 \times 10^9\ \pi^+$ @ 300 MeV/c

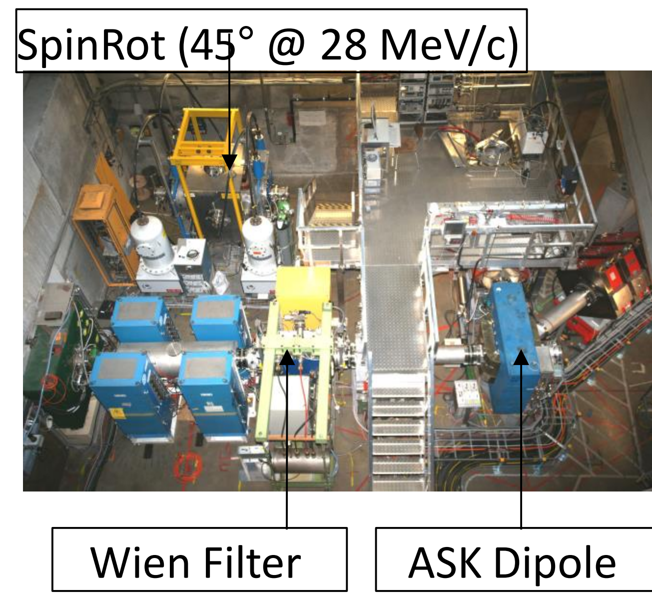
Beam spot (RMS): 7mm (x), 4mm (y)

at 10°forward angle



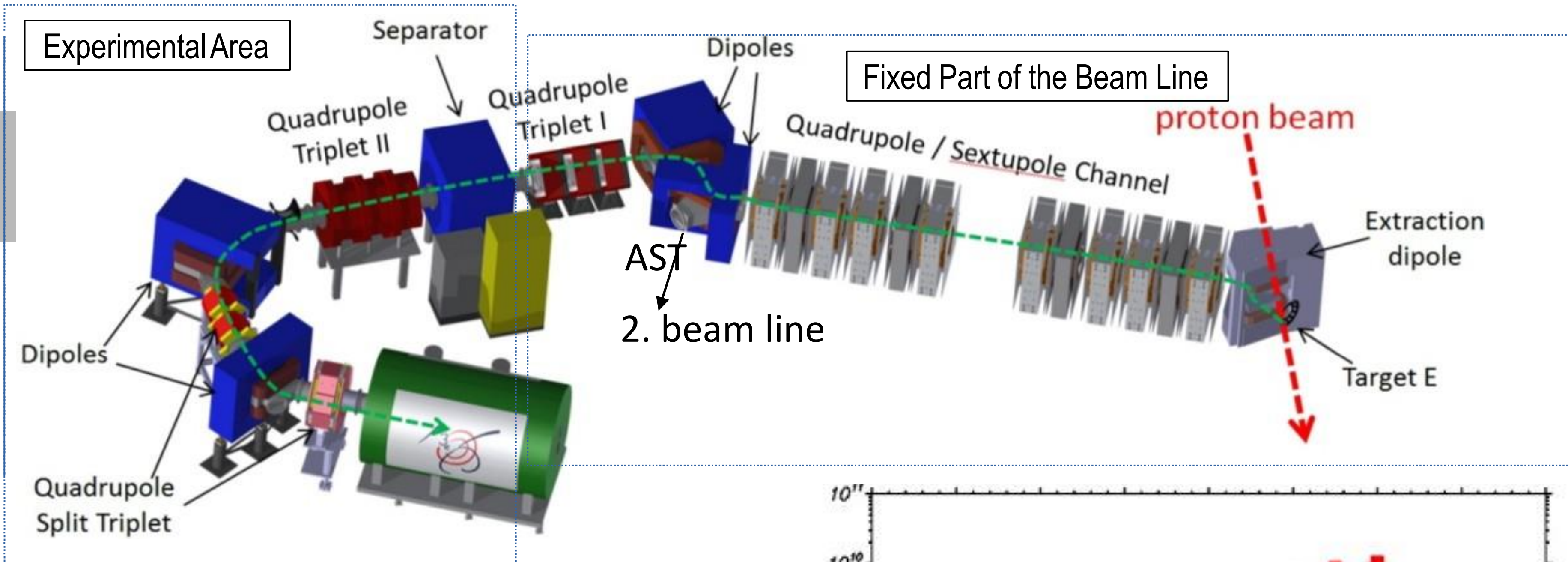




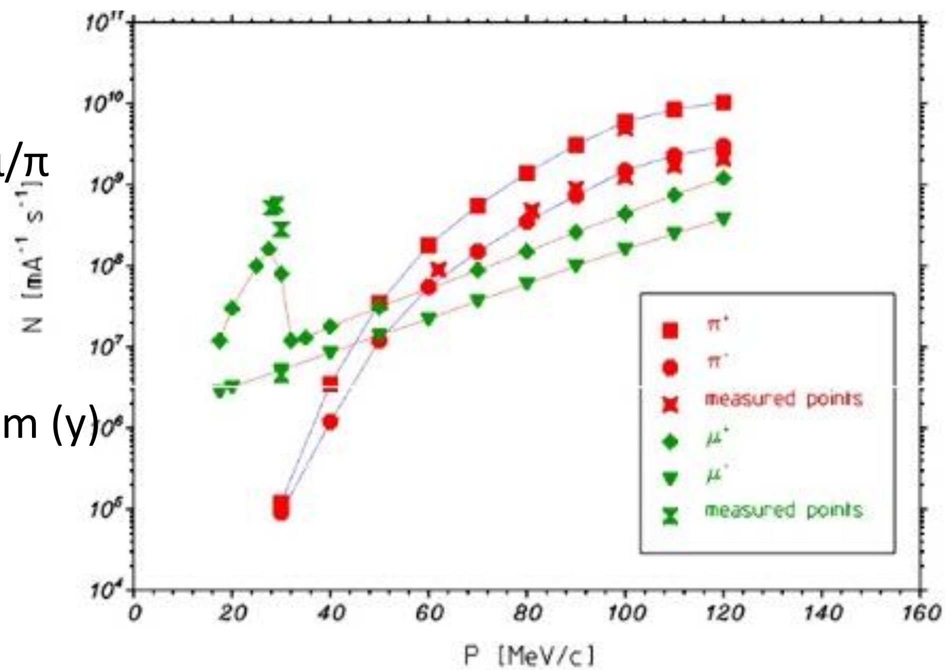


PAUL SCHERRER INSTITUT PSI

PiE5 Overview



- Low energy (10-120 MeV/c), high intensity μ/π beam line at TE (175° backward angle)
- Momentum acceptance (1σ): 5%
- Max. particle flux: $6x10^9$ π+ @ 120 MeV/c
- Spot size after triplet I (RMS): 8mm (x), 10mm (y)
- High neutron background (150 n/mA/s/cm^2
- Wien Filter (or Muon Spin Rotator)
- XY Beam Scanner

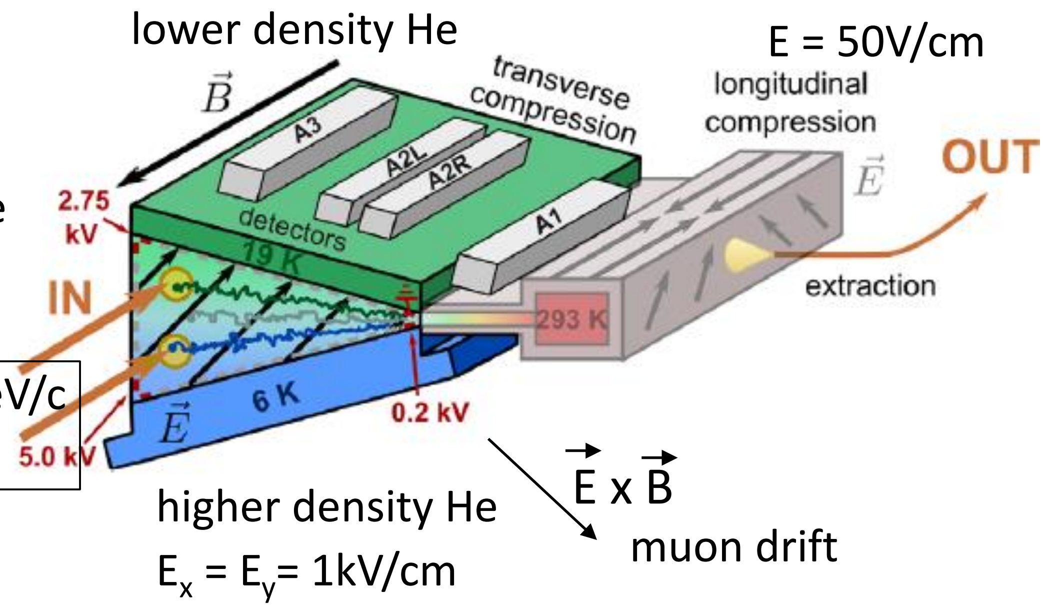


mucool: compression of μ phase space

Aim: to improve the quality of the μ beam

- ~5 mbar He
- 5 T magnetic field
- Due to He density gradient m collide with He less on the top than on the bottom.
- Energy loss compensated by electric field
- predominately drift in ExB direction

12.5 MeV/c muons



Transverse compression:
vertically 14 mm was reduced to a 0.25 mm size (rms) within 3.5 μs.

A. Antognini et al (muCool Collaboration), Phys. Rev. Lett. 125, 164802 (2020)

Longitudinal compression:
20 cm long muon stop distribution reduced to a sub-mm extent within 2 μs

Belosevic et al, (muCool Collaboration), Eur. Phys. J. C 79, 430 (2019)

Longitudinal and transverse phase space reduction of a μ^+ beam by a factor of 10^{10} with 10^{-3} efficiency.

Contacts: A. Antognini, K. Kirch, A. Knecht, A. Papa

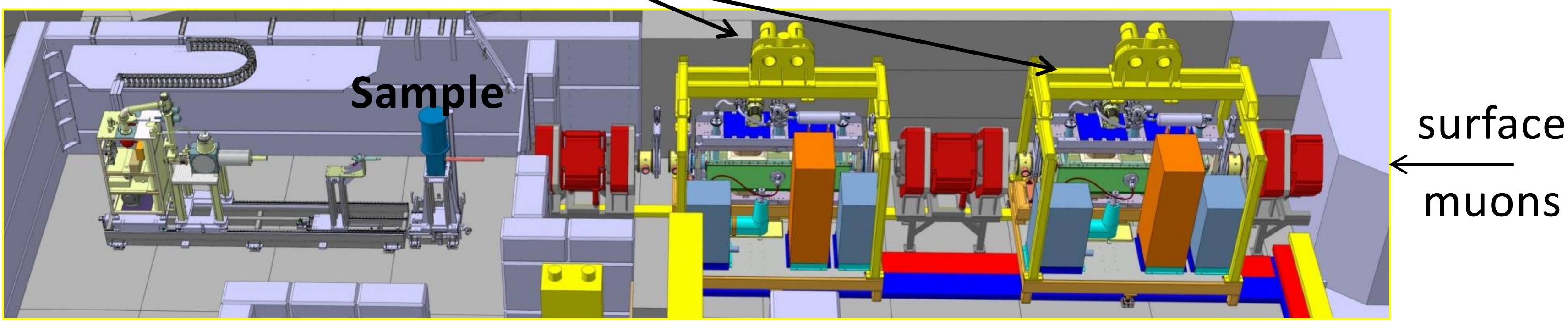
High Field μSR (Muon Spin Rotation/Relaxation/Resonance)

- Worldwide unique **9.5T External Field**
- Sample extremely small
- Material T range: **0.02 K - 320K**
- **Transverse beam polarization at the sample material:**

→ **2 Spin rotators required!**

Beam Line

- Beam size at sample: $\sigma_{x,y} \approx 15mm$
- Large beam transmission
- Momentum Bite at sample: **Δp/p ≈ 2%**



Possibilities for testing at PSI

- Detector tests
  - convenient in PM1 (test area)
  - beam scanner available

- Test of diagnostics

- mucool: a cooling method at low energy

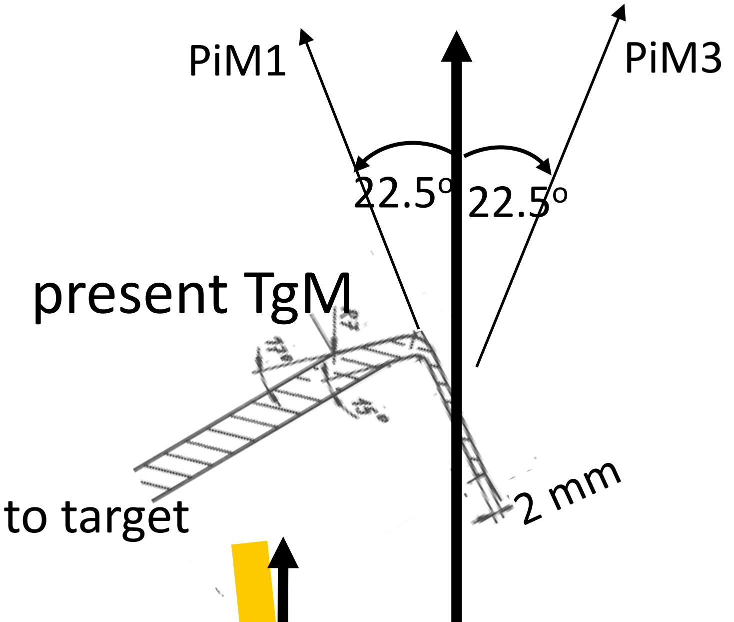
No possibility of testing the target with high intense proton beam

2027: Likely no beam because of HIMB (High Intense Muon Beam)
→ Redesign of PiM1
→ Use for particle physics program

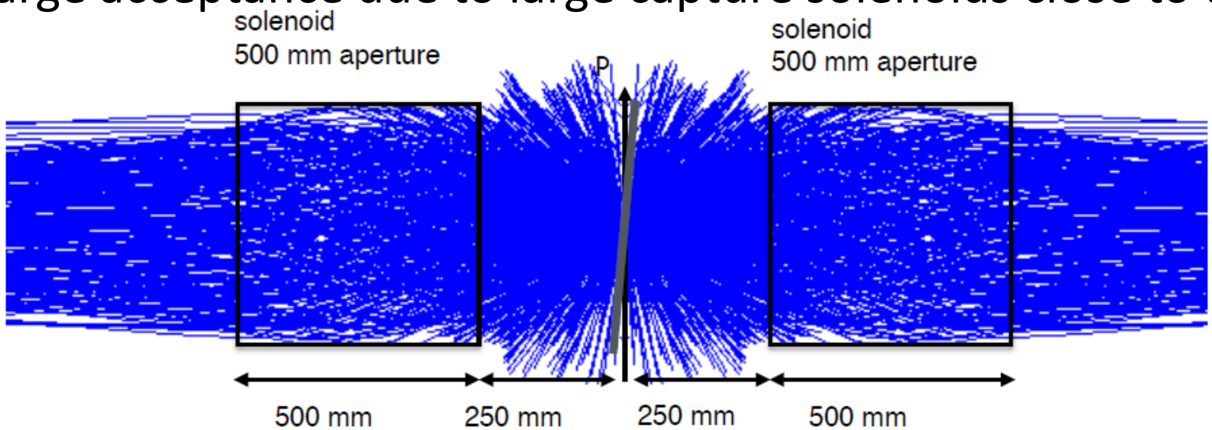
HIMB in short

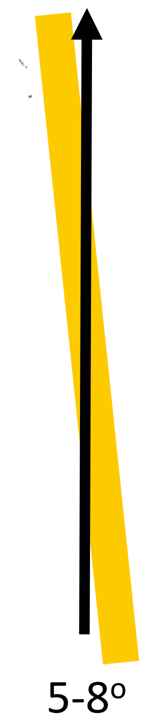
TgM (5 mm) → TgM* (20 mm)

Old type → Slanted type



Large acceptance due to large capture solenoids close to target



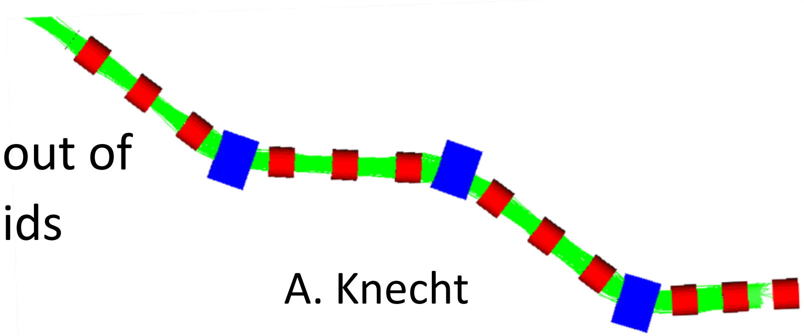


Slanted target type

→ Tested successfully at Target E

- Central field of solenoids ~0.35 T
- Field at target ~0.1 T

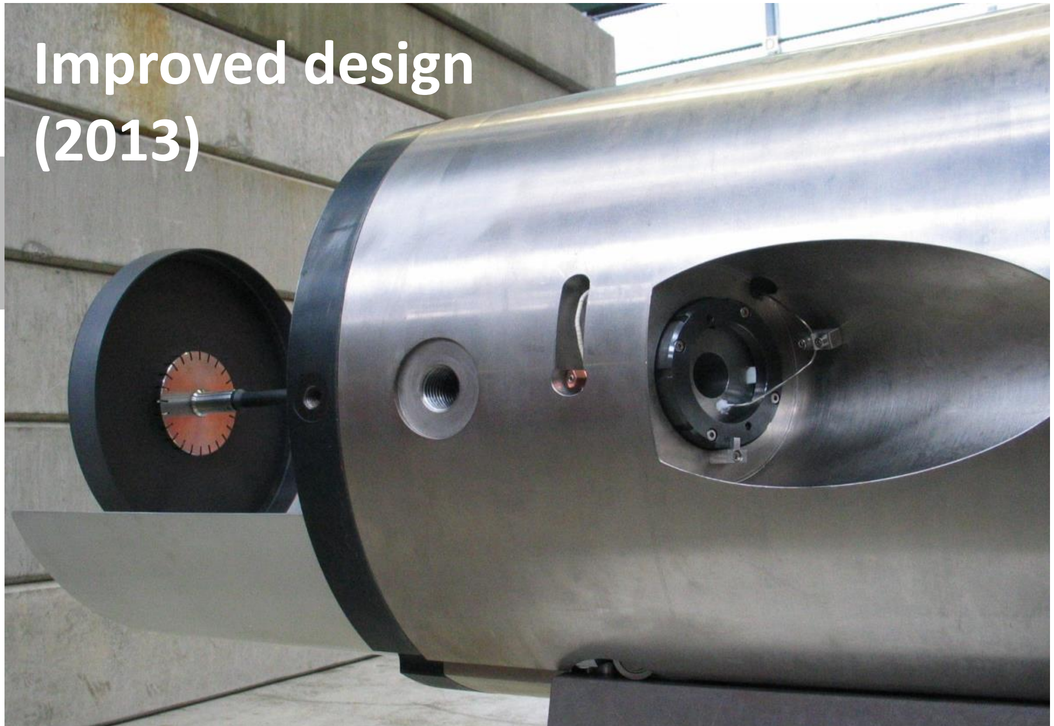
Muon/pion beamline out of large diameter solenoids



A. Knecht

Factor ~100 more Surface muons

Present Target-M



<u>Target M:</u>

Mean diameter: 320 mm

Target thickness: 5.2 mm

Target width: 20 mm

Graphite density: 1.8 g/cm^3

Beam loss: 1.6 %

Power deposition: 2.4 kW/mA

Temperature: 1100 K

Irradiation damage: 0.1 dpa/Ah

Rotational Speed: 1 Hz

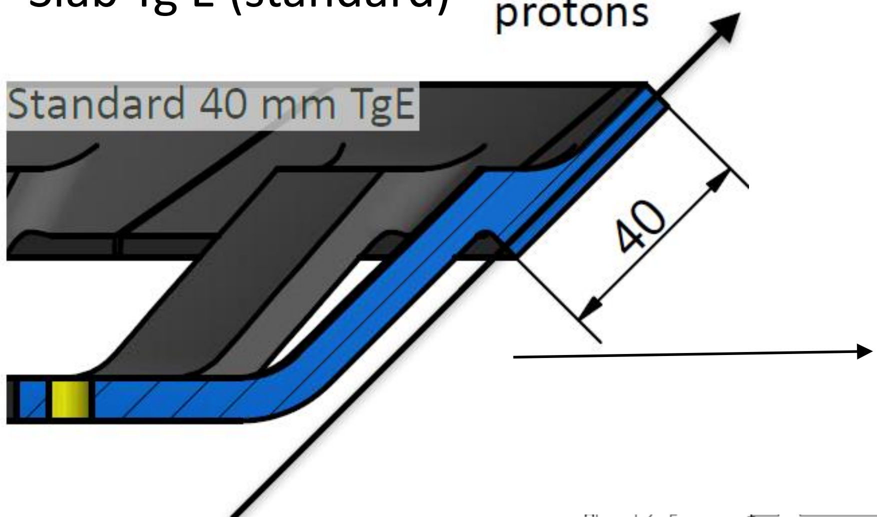
Current limit: 5 mA

Life time: up to several years

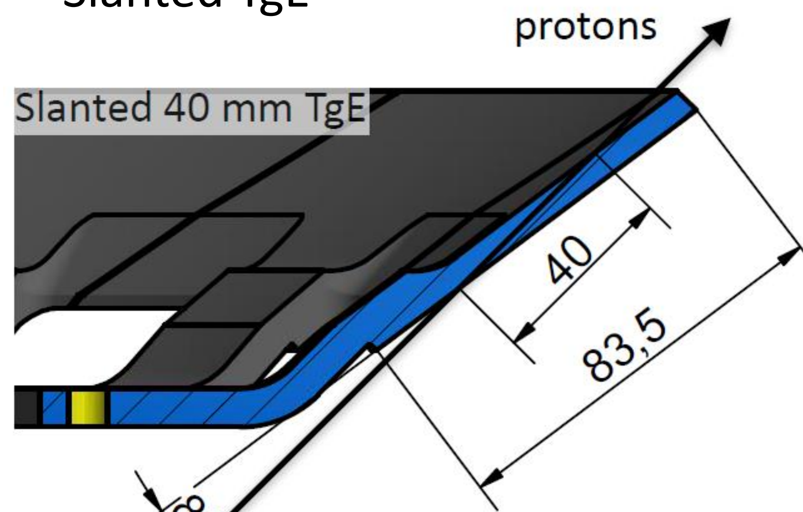
up to ~ 60 Ah ~ 6 DPA

Slanted/Standard (for TargetE 40 mm)

Slab Tg E (standard)

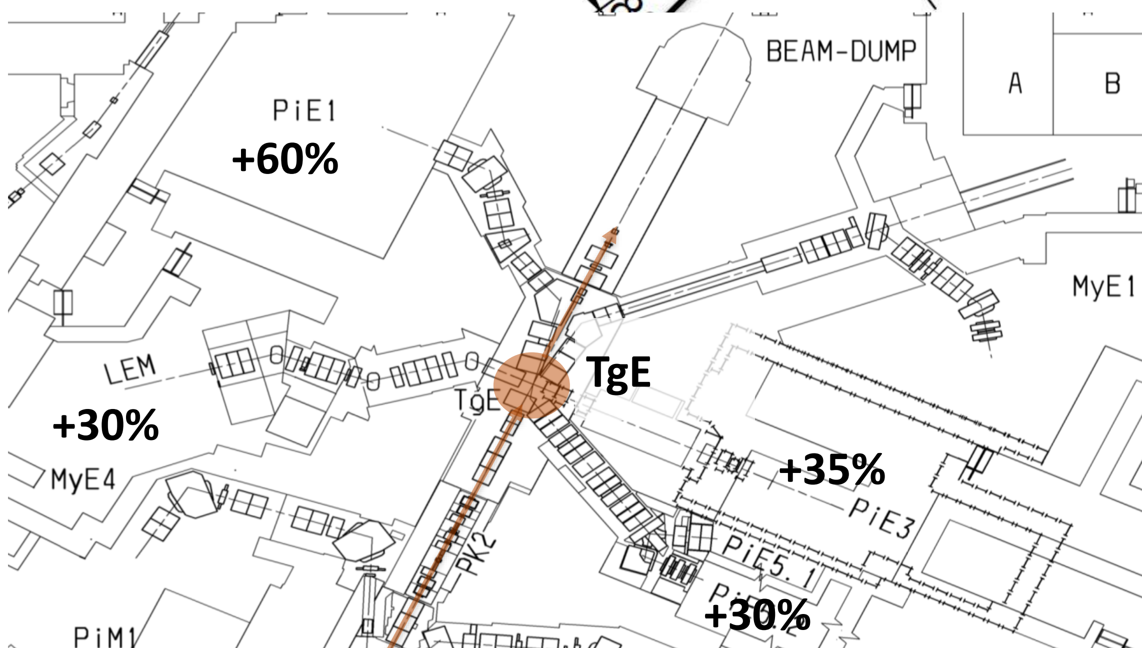


Slanted TgE



Significant increase of surface muon rate

Simulation confirmed by measurement (2019): 40 – 50 % increase



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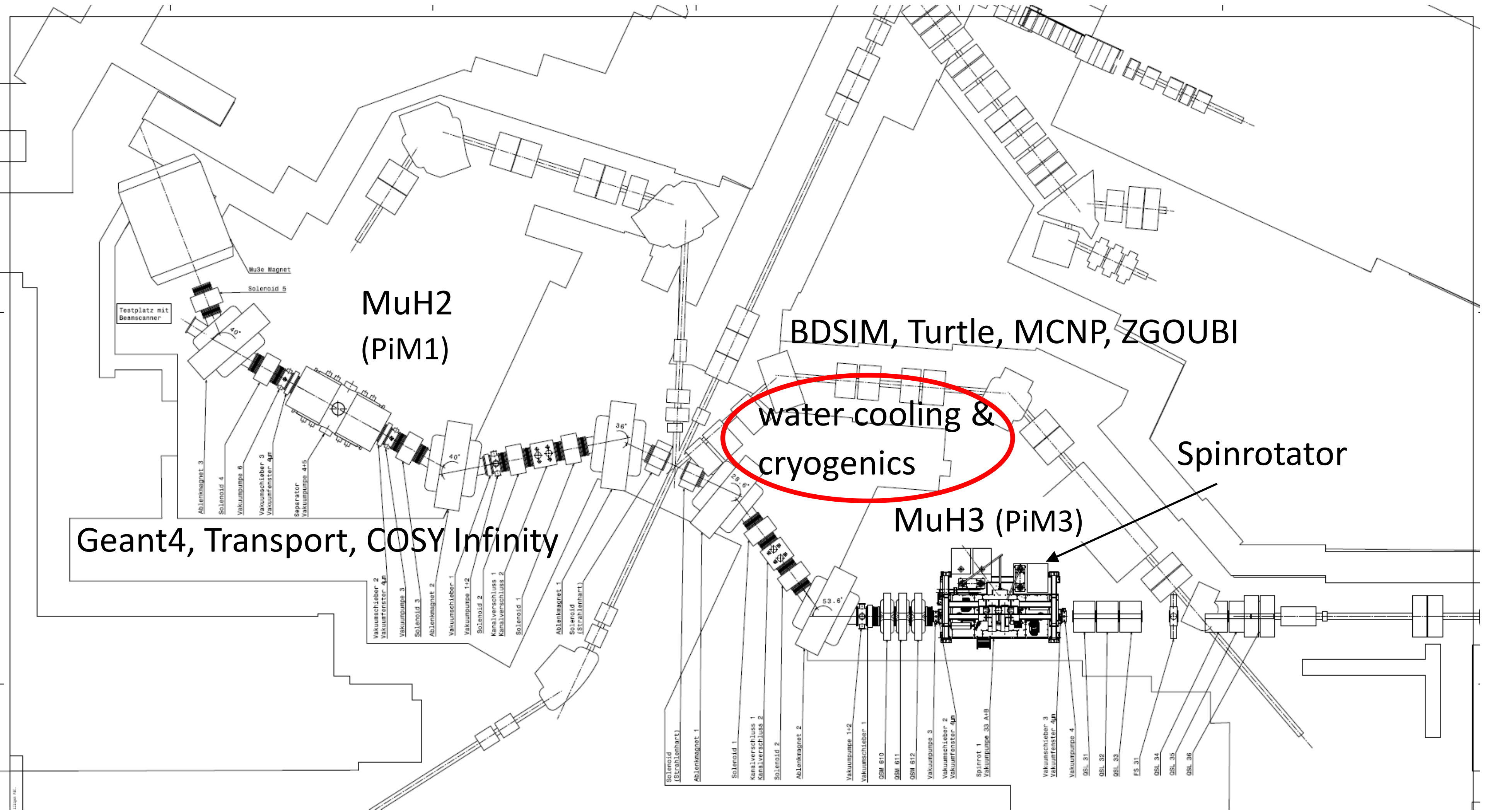
Preliminary layout

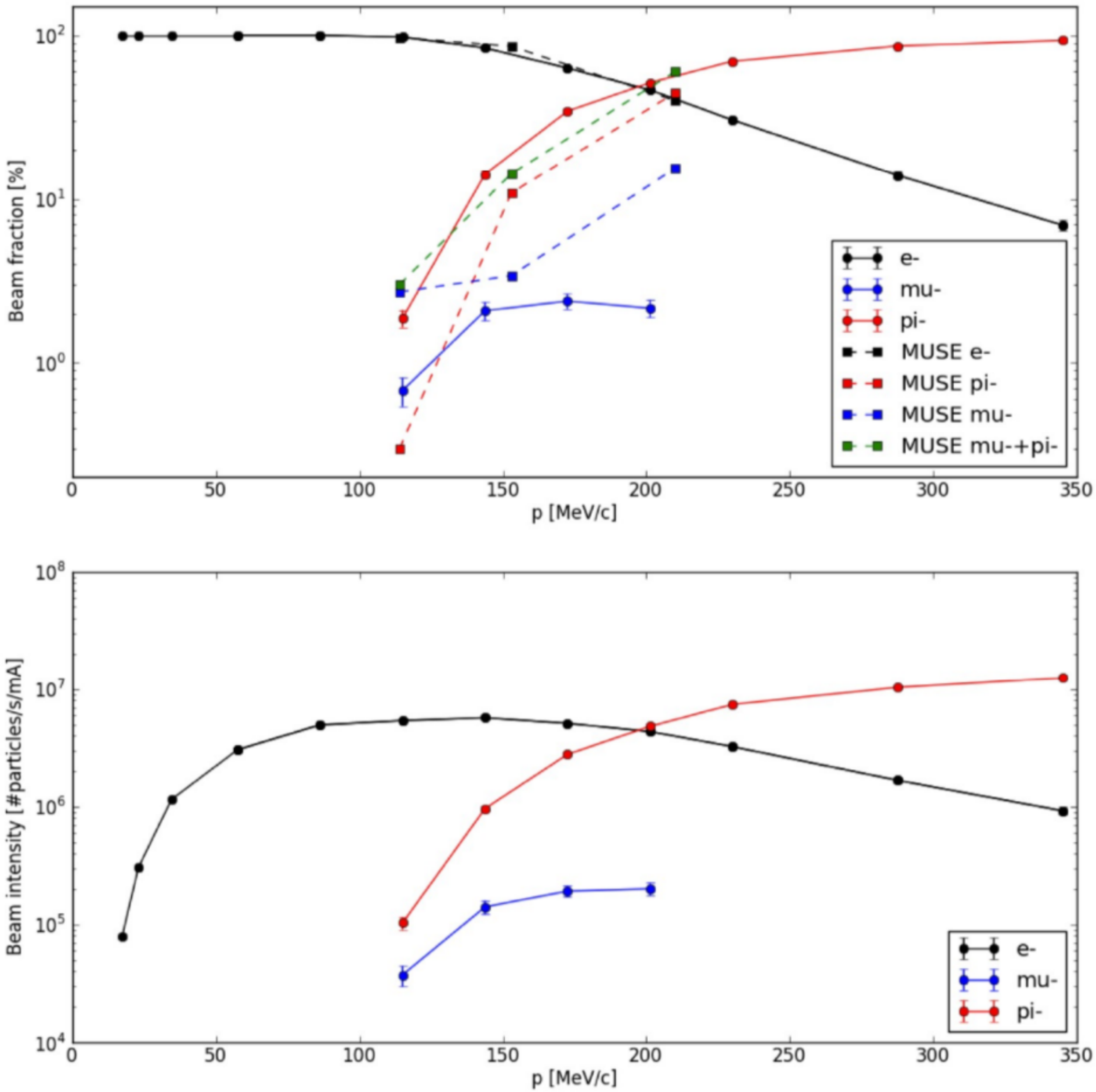


Water cooling cycle and liquid He filling platform have to be removed.

Summary

- Challenges for the muon target at 50 kW:
  - Cooling, Deformation, Bearings still need to be improved!
- Some test opportunities at PiM1: pions,muons, electrons, (protons)
- Feasibility study HIMB for Swiss Roadmap
  100 x more surface muons

PiM1 beam fractions



HiMB Slanted Target Tests

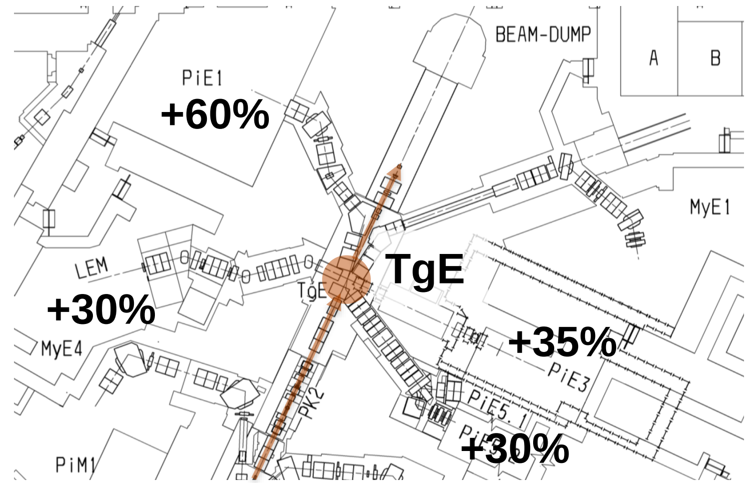
- HiMB 40 mm slanted target installed on November 25

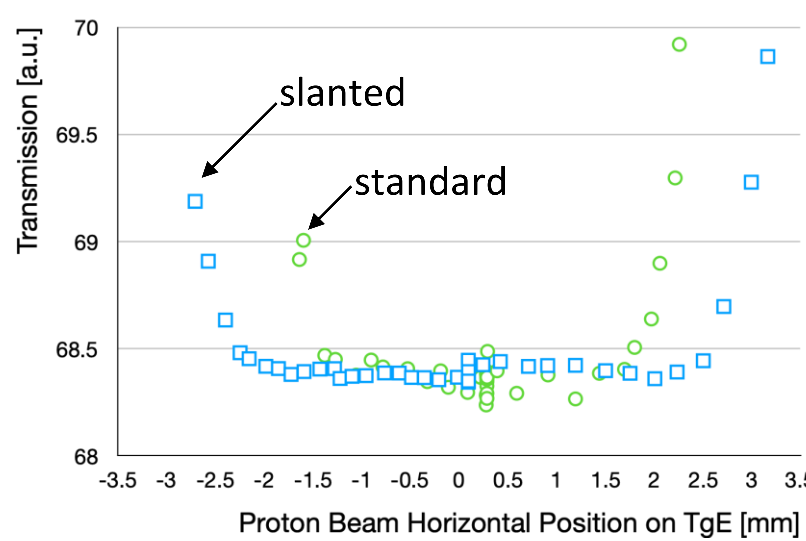
Muon beam rates:
- 30-60% increase in surface muon rate expected
- First measurements confirm this increase for μE4, πE5, πE3 and πE1 (μE1 not affected as it relies on pion collection)

   40 mm slanted target as good as 60 mm standard target!

Proton beam impact:
- Setup of proton beam well under control
- Increased safety margins confirmed

Future:
- To be seen: Impact of higher thermal stress on long term stability of target wheel
- We are looking forward to continue this work within the recently CROSS-funded HiMB study to increase surface muon rates by almost two orders to 10^{10} μ^+/s!



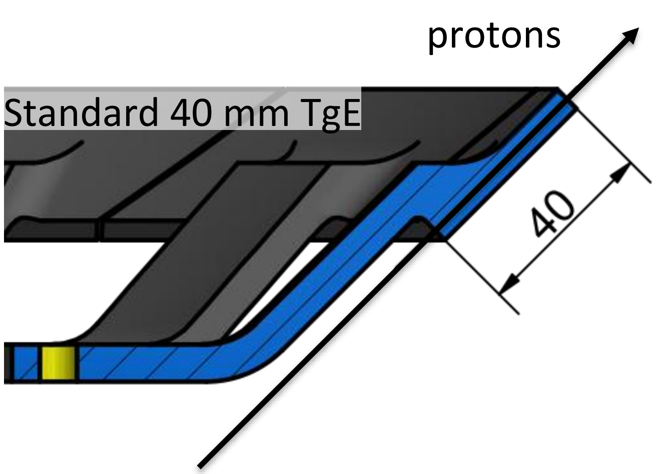


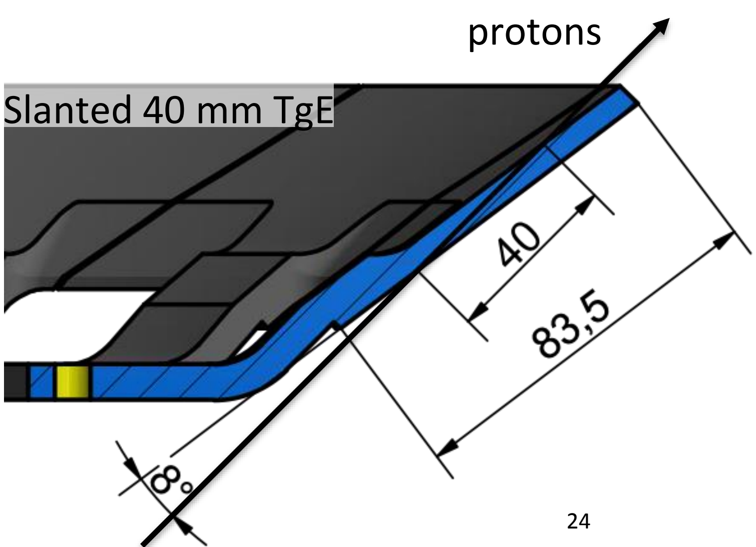
HiMB Slanted Target Design

Involved people:
NUM: P.-R. Kettle, A. Knecht, A. Papa, T. Rostomyan, P. Schwendimann
GFA: P. Baumann, S. Joray, D. Kiselev, D. Laube, R. Sobbia, D. Reggiani

Goals:

- Change of geometry of TgE to increase surface muon rates for all connected beam lines
- Increase safety margin for “missing” TgE with the proton beam





Transport of 2. target insert to beamline

sluice to hotcell

parking lot

open

closed

Exchange flask on parking lot

To save time:

Spare Target E insert is taken out from the parking lot

At the same time:

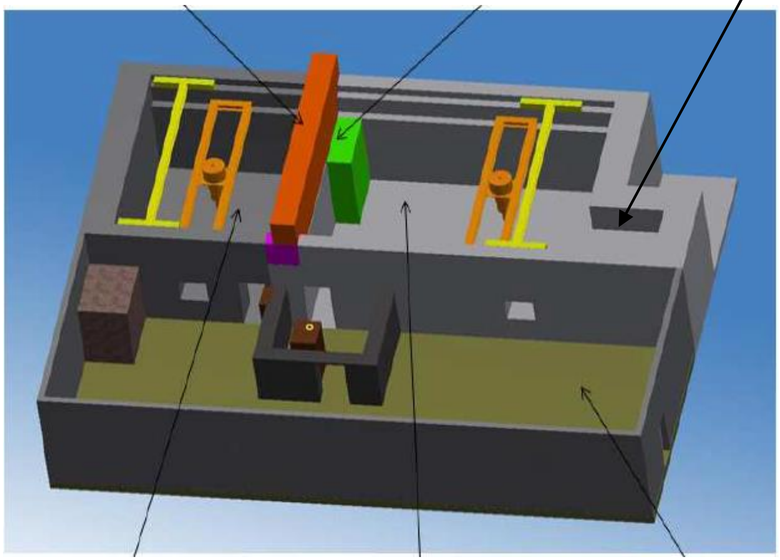
Reparing of the insert from beamline in hotcell

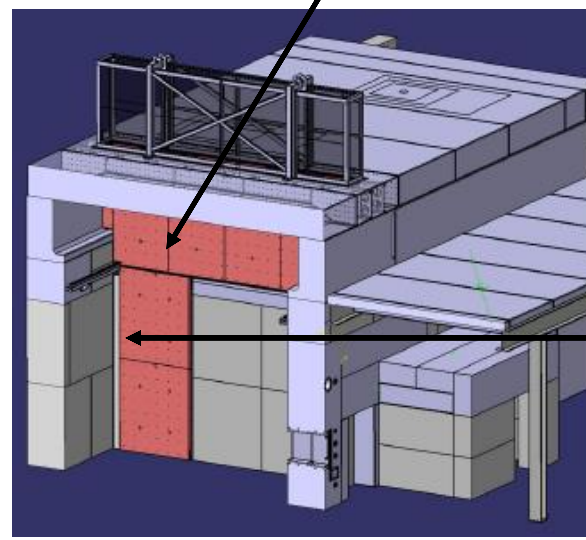
Design of the hotcell ATEC

ATEC: **2.** service cell in 2019

– wall in between can be opened vertically

Sluice in between
Sluice for Target E
Sluice pulled up by external crane





Moved by ATEC crane

2. Service cell
1. Service cell
Room for personal

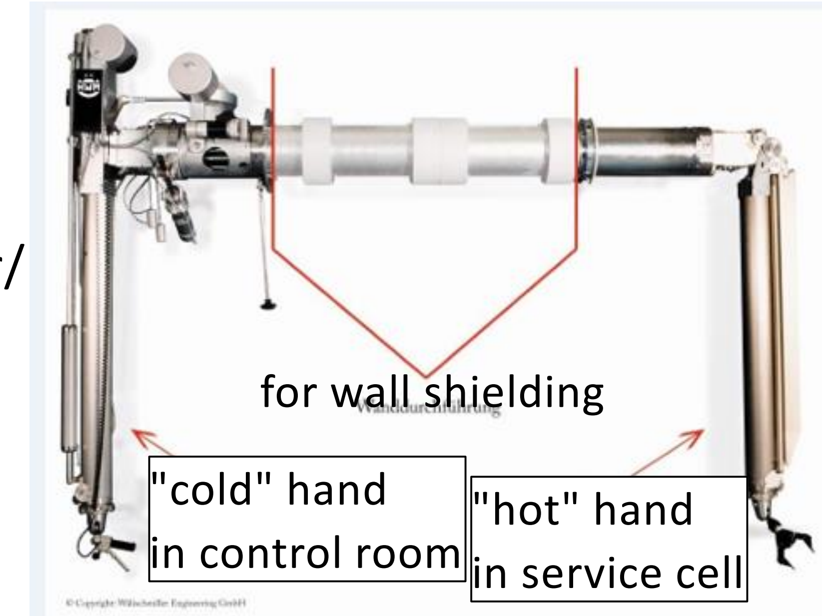
Advantage:

– in case of unavoidable access to one service cell (in case of failure), radioactive components are moved to the other service cell.

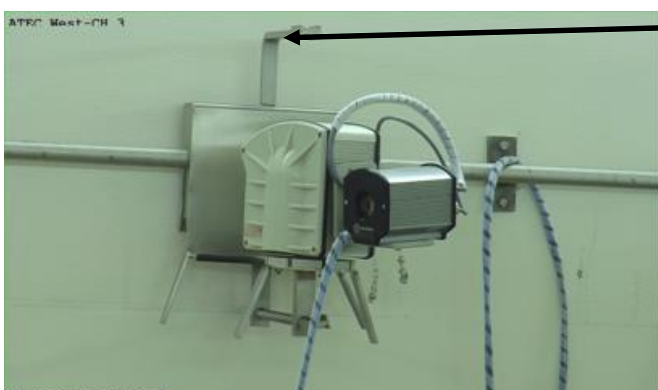
– less personal dose rate during cleaning: drums with rad. waste can be moved temporarily to the other service cell.

Standard equipment of hotcell ATEC

1 power manipulator/
service cell



6 high-resolution cameras/service cell

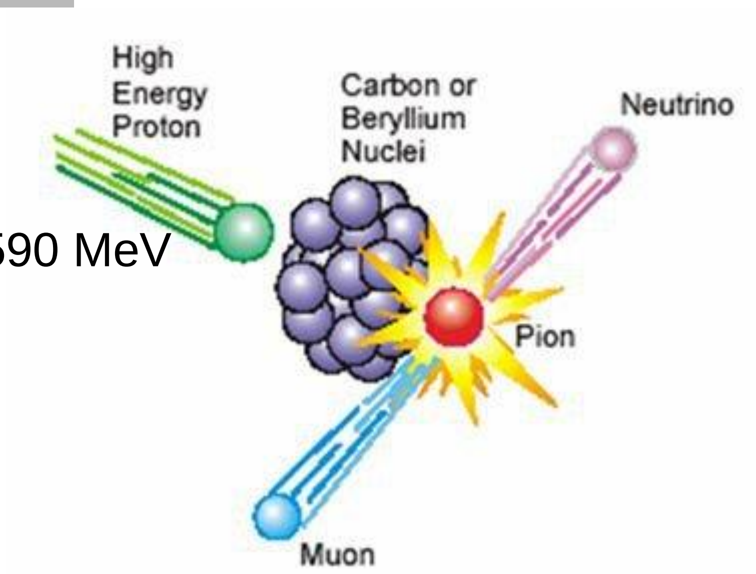


Grip
for camera

+ 1 leadglass window
+ 1 dosimeter
+ a trolley to move things around
  (up to 60 t)
+ 1 crane/cell
movable over 2 service cells
(important, if 1 crane fails)

Meson production targets: Target E and Target M

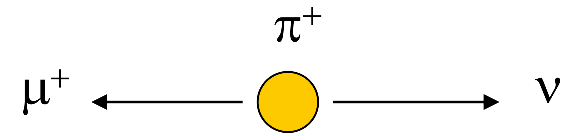
Production of muons:



590 MeV

- Surface muons:

produced from pion decay at rest at the ***surface*** of the target (d < 1 mm)



- almost monochromatic:
  max. at 28 MeV/c (= 3.7 MeV)

- 100% polarized
  (spin in opposite direction to momentum)
  in reality: 90 – 95 % polarization due to pion decays in flight

World's highest intensity surface muon beams > 10^8 μ/s

- Cloud muons: decay of pions in flight
- Low energy muons (LEM): 0.5 -30 keV
  moderated by a cryogenic target

Besides this, there are pions, positrons (and sometimes protons)