LEMMA
(Low EMittance Muon Accelerator)
2017 CERN test beam results

Lorenzo Sestini
University of Padova and INFN

On behalf of the LEMMA test beam team

6th Beam Telescopes and Test Beams workshop, 16-01-2018

Muon based colliders

Which future for colliders Physics?

- Hadronic machines, like FCC-hh, to investigate up to 100 TeV.
- Lepton machines (linear like CLIC/ILC or circular), to precisely study the Higgs and to investigate up to the highest possible energies.

If Physics beyond the Standard Model won't be found in the next years, it will be necessary to go up to 100 TeV.

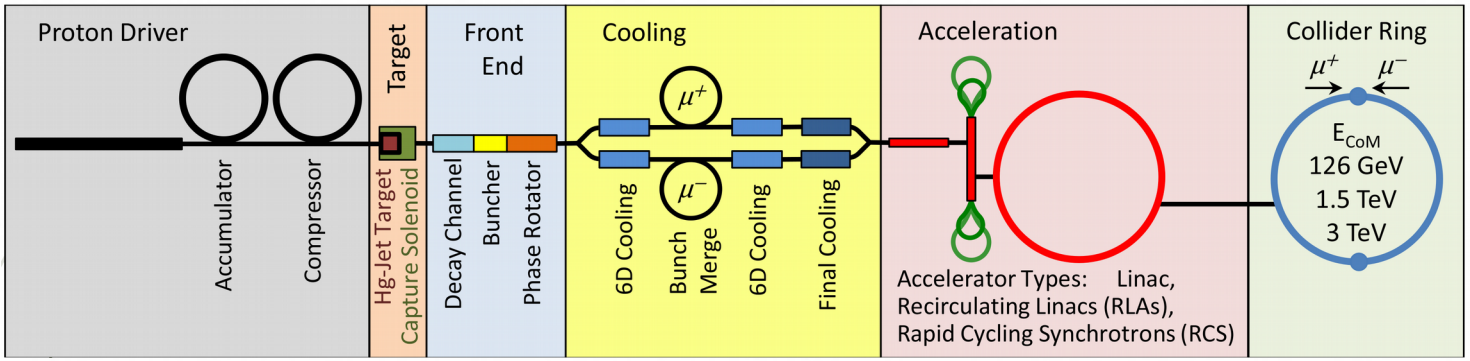
A $\mu^+\mu^-$ collider offers an ideal technology to extend the lepton energy in the multi-TeV regime:

- No synchrotron radiation.
- But muon lifetime is 2.2 μs at rest.

Classic proposal →

$p+h \rightarrow \mu^+\mu^-$

Muons cooling needed



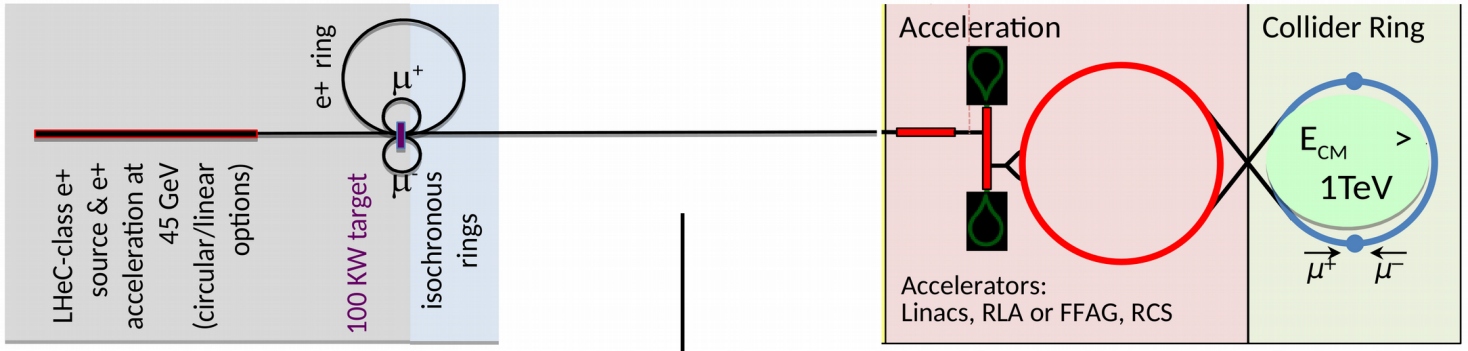
Low emittance muon source

Exploit $e^+e^- \rightarrow \mu^+\mu^-$ at $\sqrt{s}$ around the $\mu^+\mu^-$ threshold (0.212 GeV) in asymmetric collisions to generate beams of μ^+ and μ^-

- Low emittance, tunable with $\sqrt{s}$.
- Small muon energy spread at threshold, it gets larger as $\sqrt{s}$ increases.
- Low background: muons can be produced with high boost in asymmetric collisions, reducing losses from decays.
- **But low rate:** $\sigma(e^+e^- \rightarrow \mu^+\mu^-) \sim 1\mu b$ at most, to be compared with $\sigma(p+h \rightarrow \mu^+\mu^-) \sim mb$

LEMMA idea

NIM A 807 101-107 (2016)

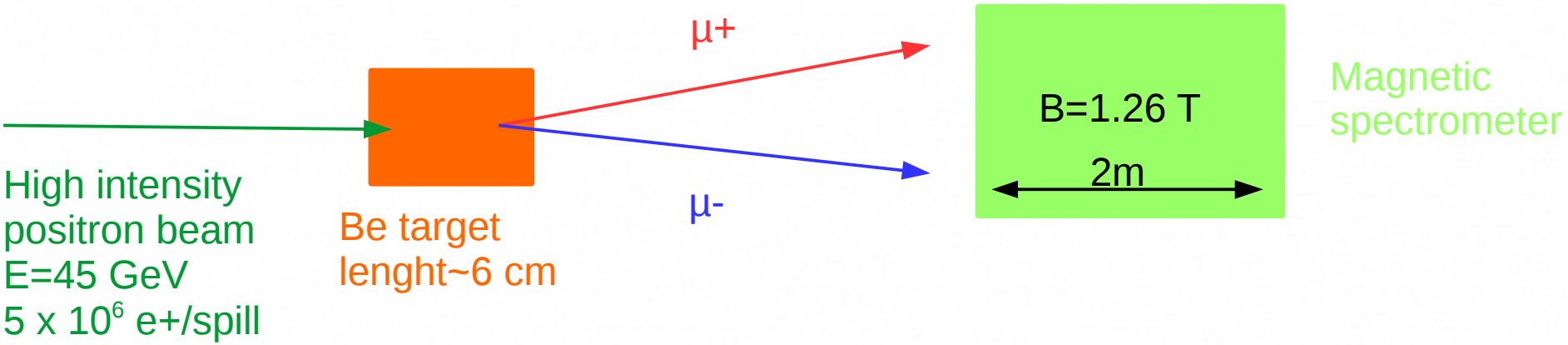


Muons cooling not needed!

Simple design

LEMMA testbeam

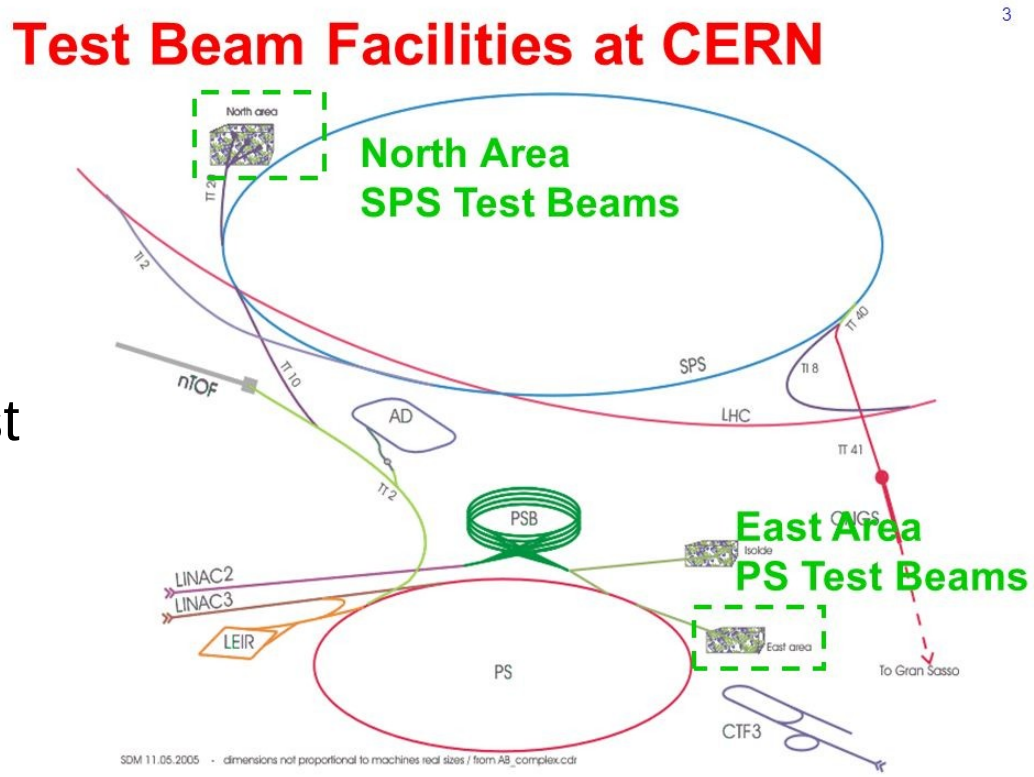
- Goal: study the properties of muons production using a positron beam and a **Berillium target**.
- First experimental verification of positron induced low emittance muon beam.



- Measurements:
  - $\frac{\sigma(\mu\mu)}{\sigma(ee)}$ μμ production cross section normalized to Bhabha cross section
  - μ+/μ- emittance: area in the muon phase space
- The measurements can be used as inputs to the LEMMA source simulations.

LEMMA testbeam operations

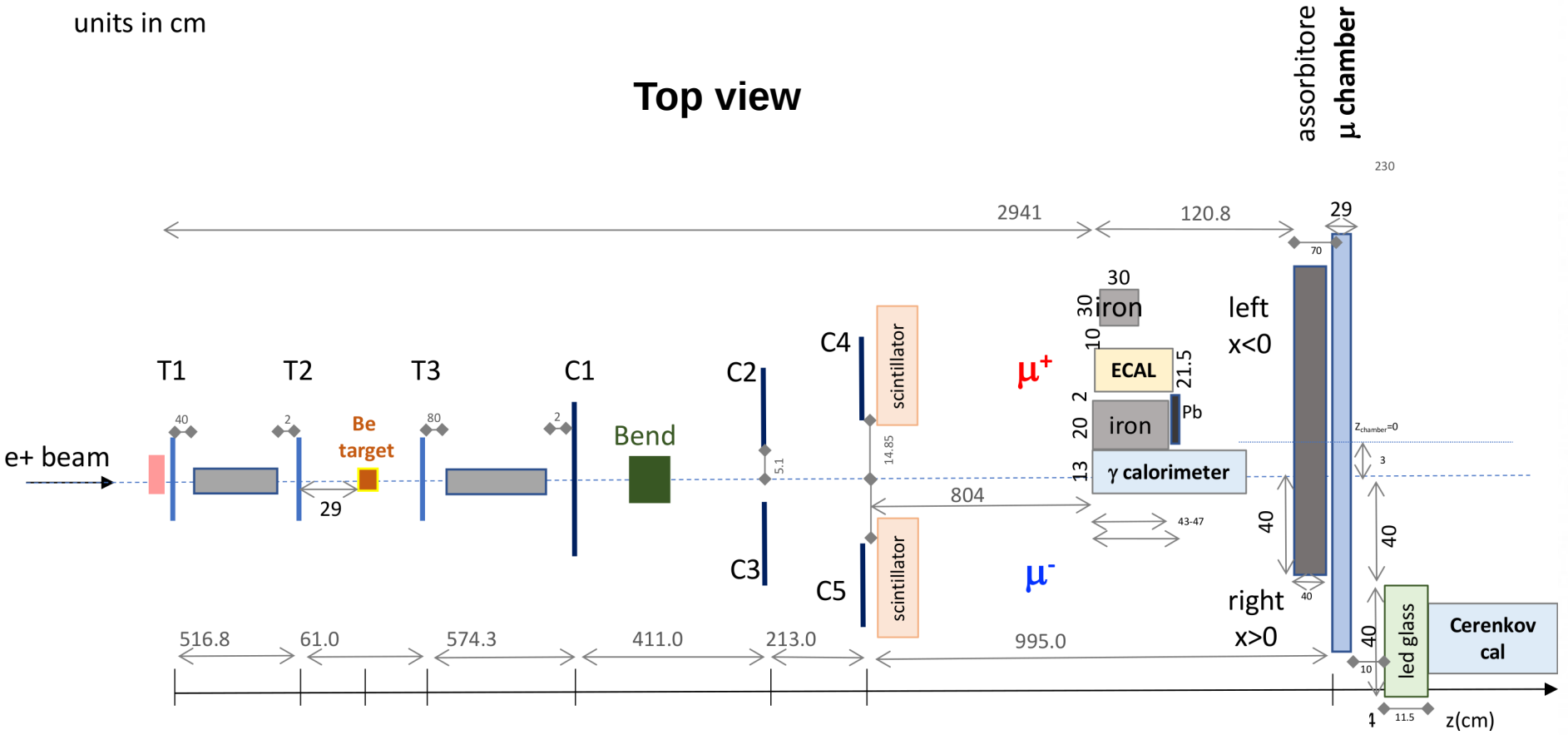
- **Location**: CERN North Area, SPS beam line
- **Period**: 26 July 2017 – 2 August 2017, ~1 week

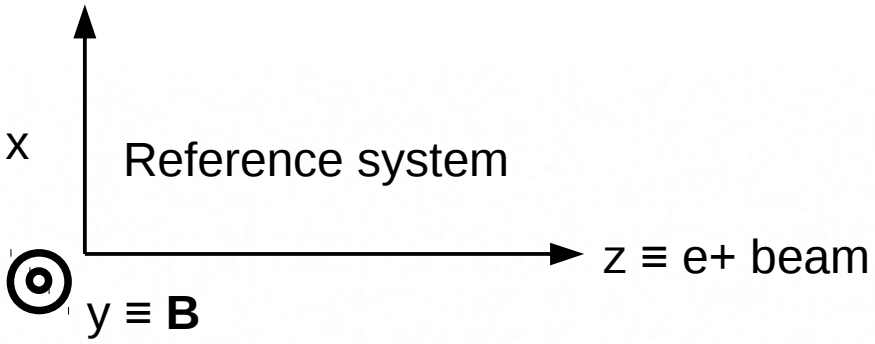


- **Calibration runs**: positron beams at 18, 22 and 26 GeV, no target
- **Data taking runs**: high intensity positron beam at 45 GeV, with Be target

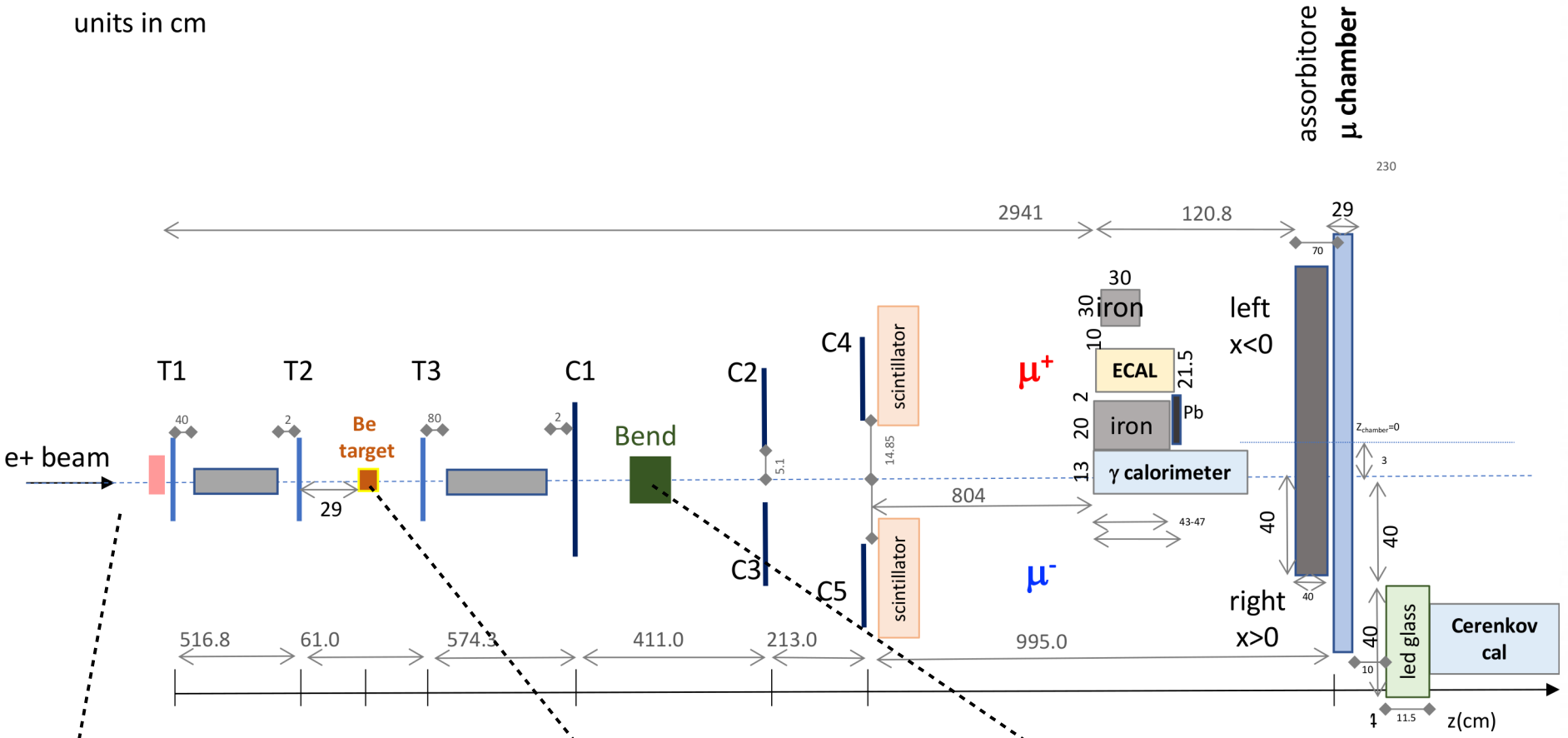
Testbeam setup

units in cm





Testbeam setup



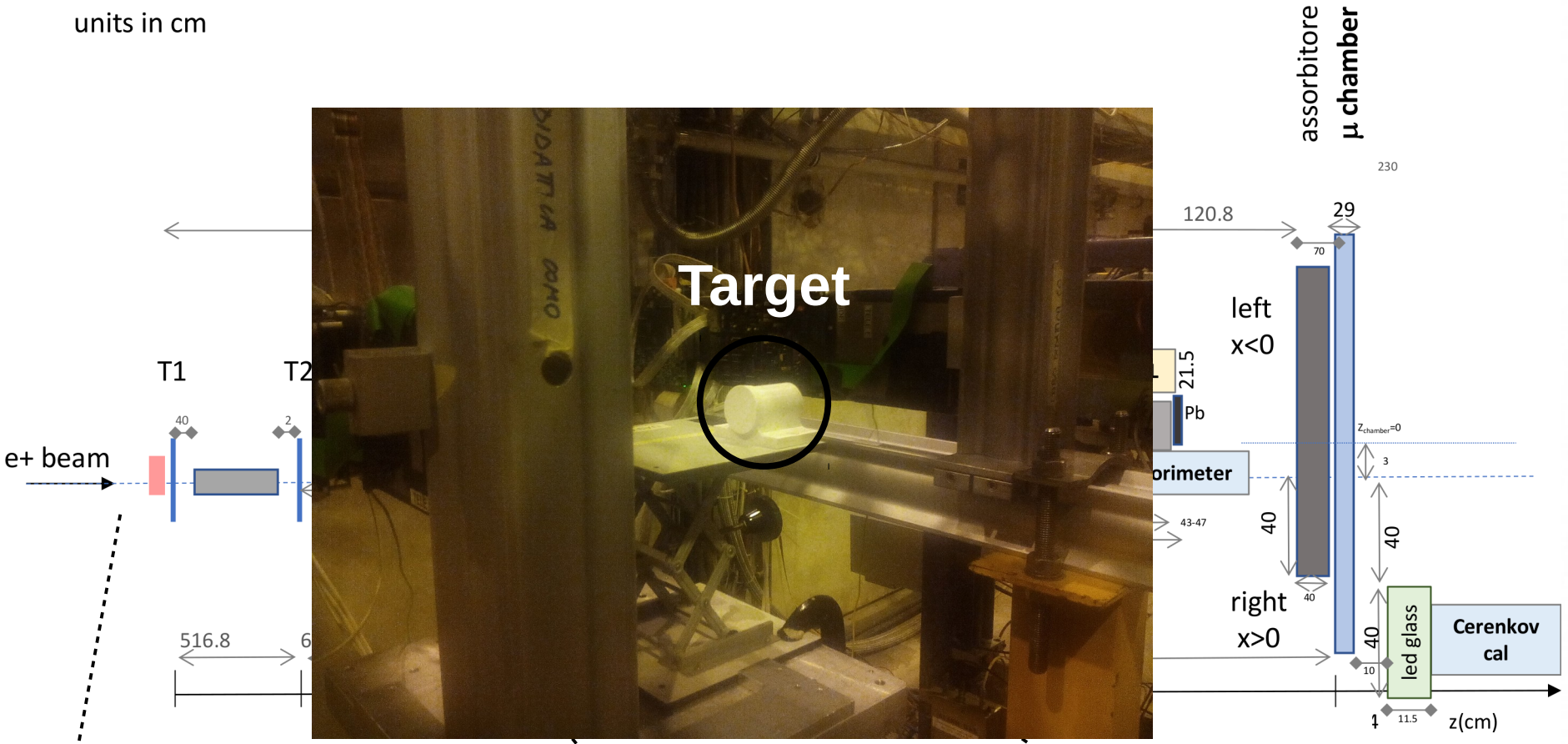
High intensity positron beam at 45 GeV ~5 x 10^6 e^+/spill

Berillium target ~6 cm lenght

Bending magnet 1.26 T x 2 m

34 mrad for 22 GeV muons

Testbeam setup



High intensity positron beam at 45 GeV
~5 x 10^6 e^+/spill

Berillium target
~6 cm lenght

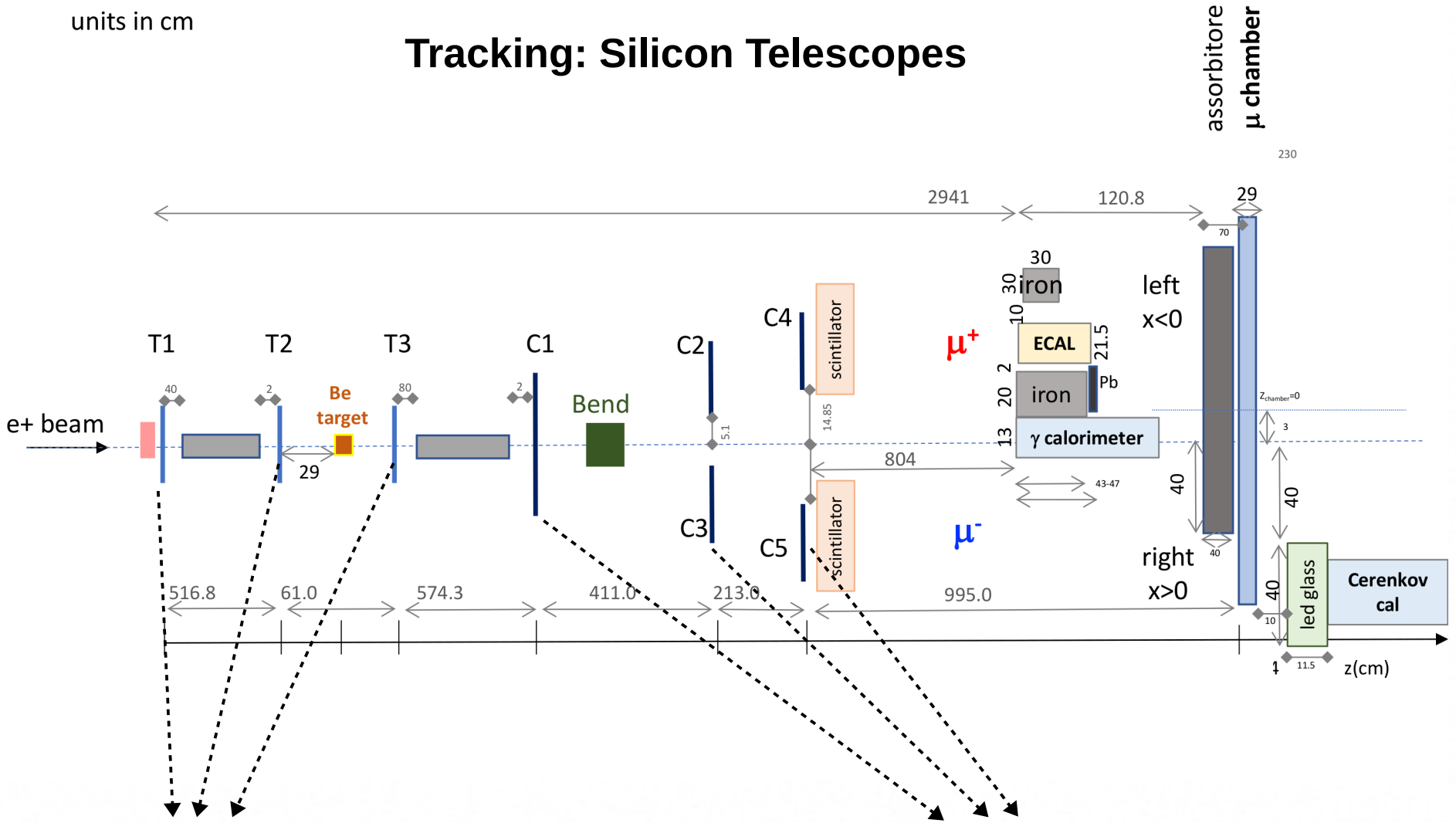
Bending magnet
1.26 T x 2 m

34 mrad for 22 GeV muons

Testbeam setup

units in cm

Tracking: Silicon Telescopes



2 cm x 2 cm silicon microstrip stations

$\sigma_x \sim 5$ μm

$\sigma_y \sim 15$ μm

10 cm x 10 cm silicon microstrip stations

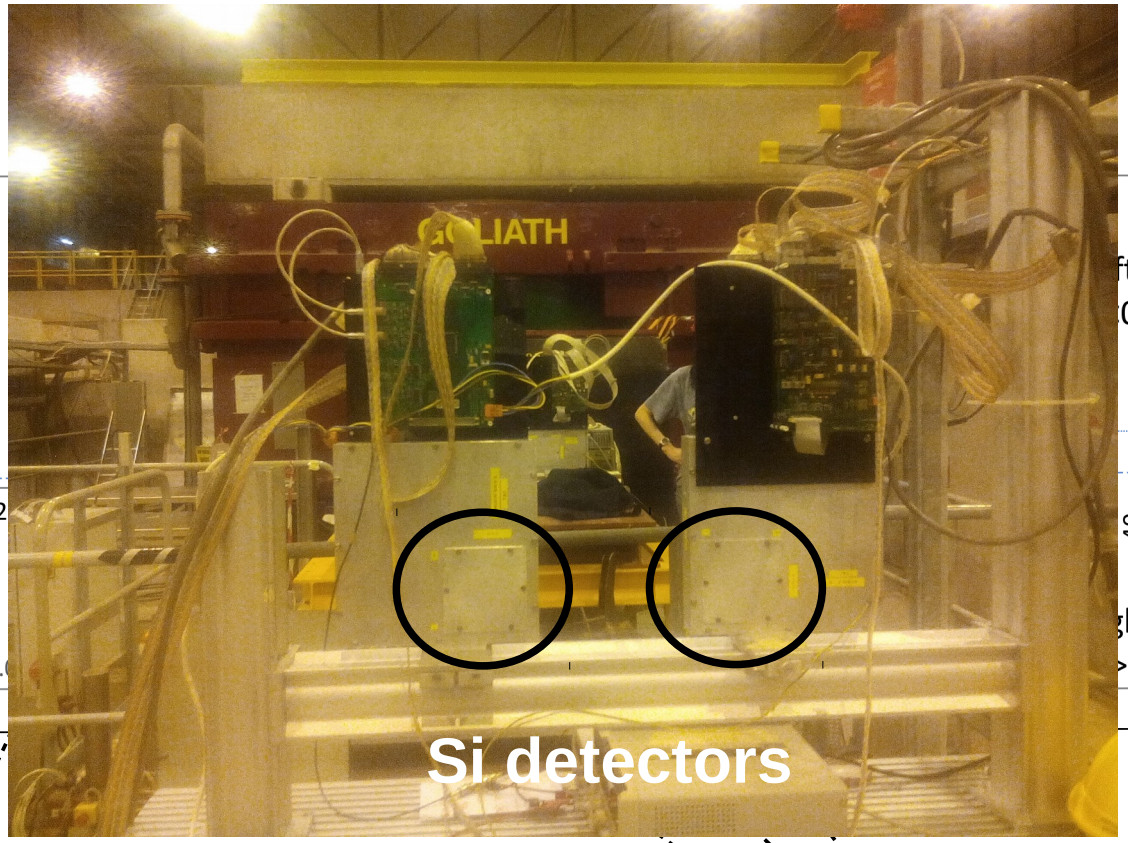
$\sigma_x \sim 30$ μm

$\sigma_y \sim 30$ μm

Testbeam setup

units in cm

Tracking: Silicon Telescopes



2 cm x 2 cm silicon microstrip stations

$\sigma_x \sim 5$ µm

$\sigma_y \sim 15$ µm

10 cm x 10 cm silicon microstrip stations

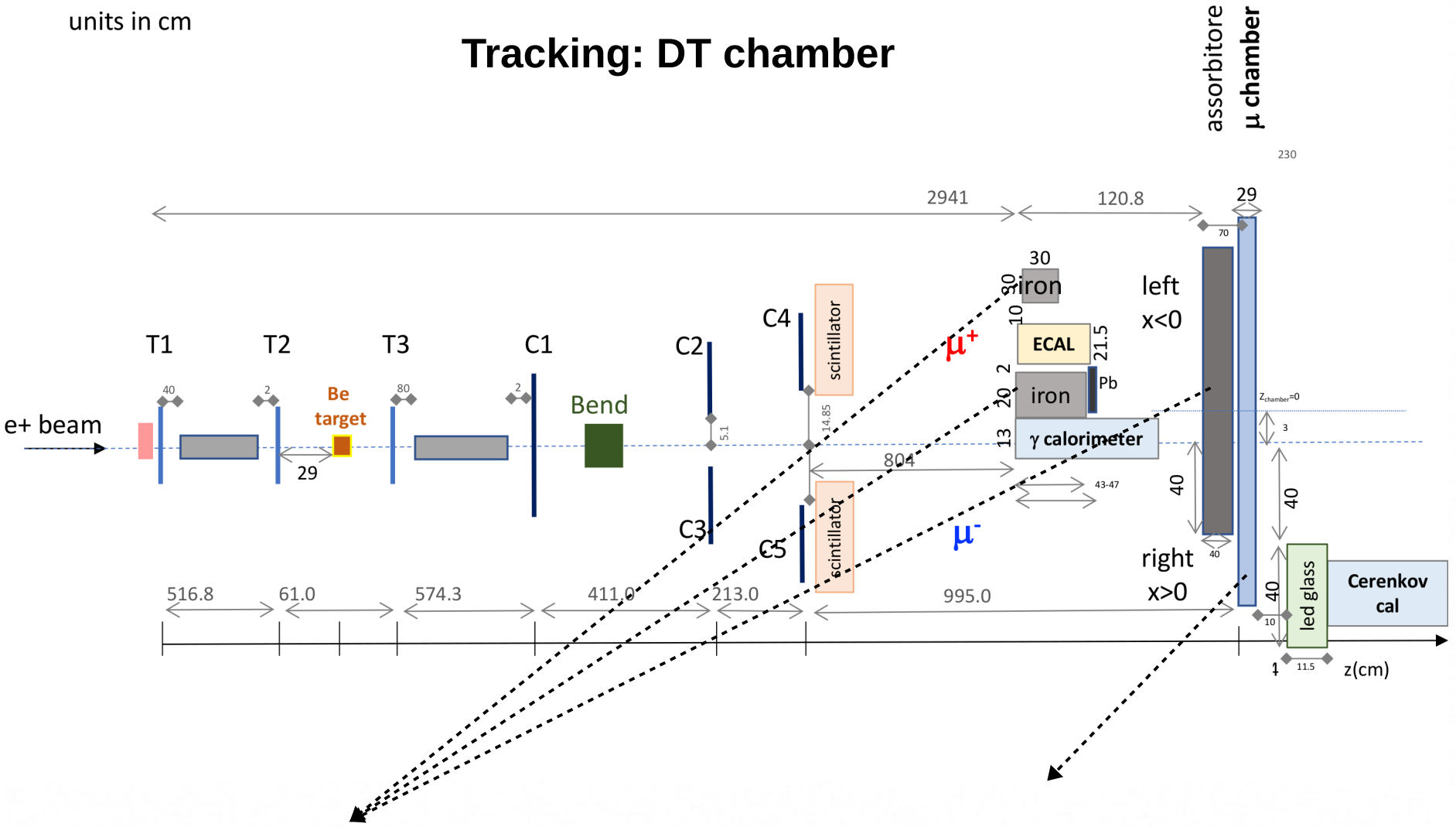
$\sigma_x \sim 30$ µm

$\sigma_y \sim 30$ µm

Testbeam setup

units in cm

Tracking: DT chamber



Iron absorbers: placed in the μ+ line to absorb e+

↘ **It reduces noise in the DT chamber**

CMS Drift Tubes chamber

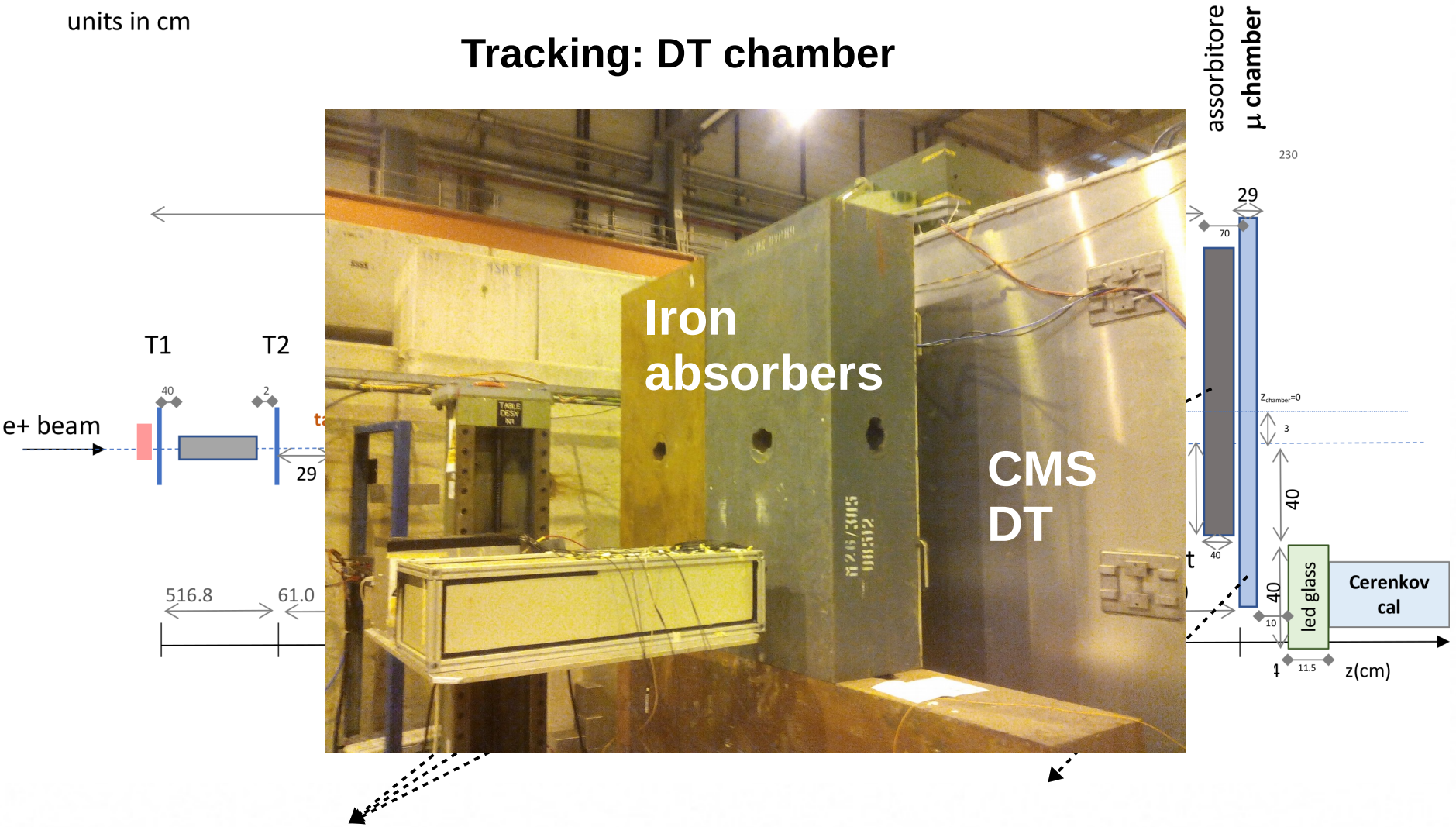
8 x layers: σ_x ~ 150 μm

4 y layers: σ_y ~ 200 μm

Testbeam setup

units in cm

Tracking: DT chamber



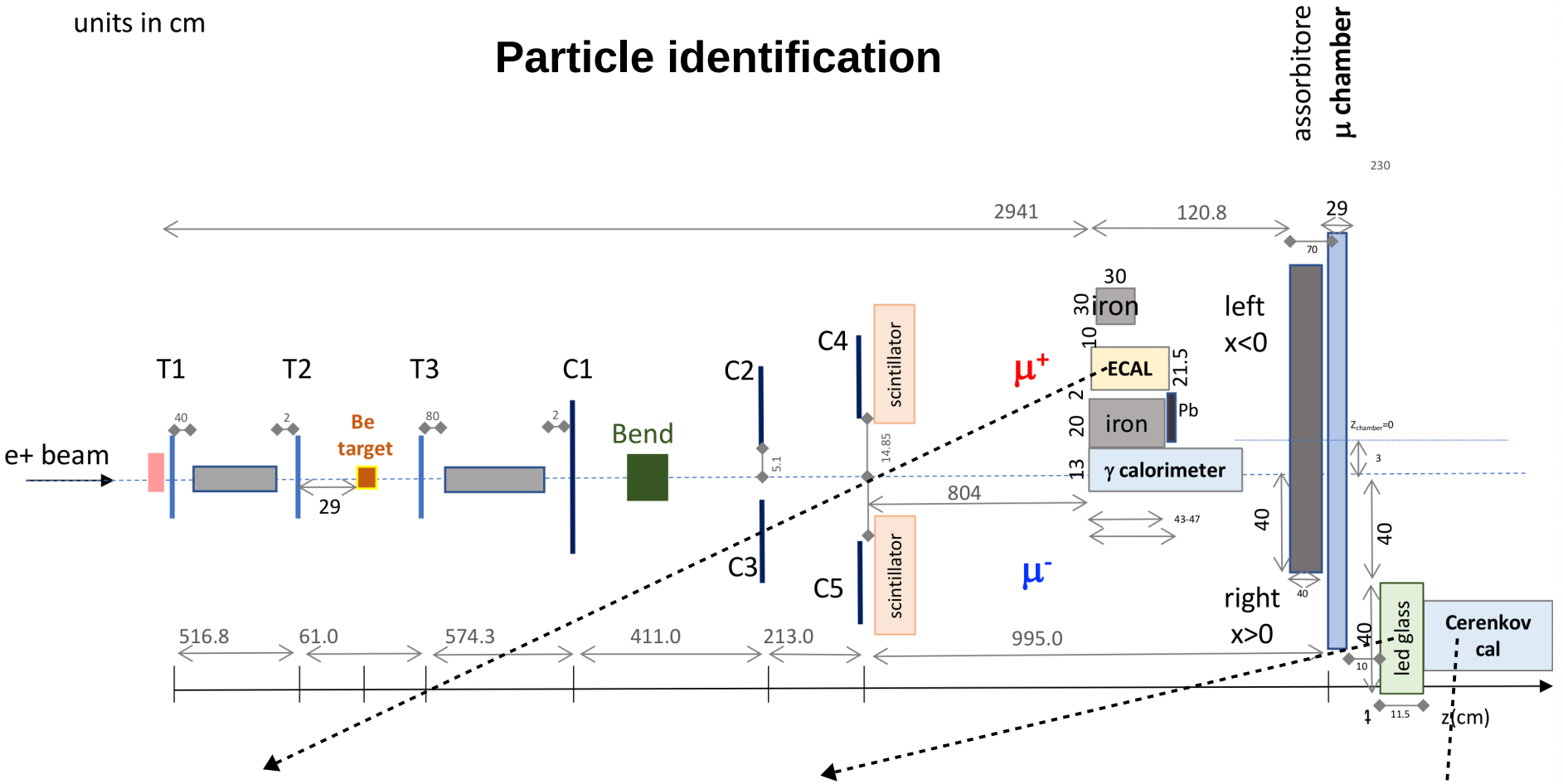
Iron absorbers: placed in the µ+ line to absorb e+

CMS Drift Tubes chamber
8 x layers: σ_x ~ 150 µm
4 y layers: σ_y ~ 200 µm

Testbeam setup

units in cm

Particle identification



Electromagnetic calorimeter for e^+/μ^+ discrimination (DEVA)

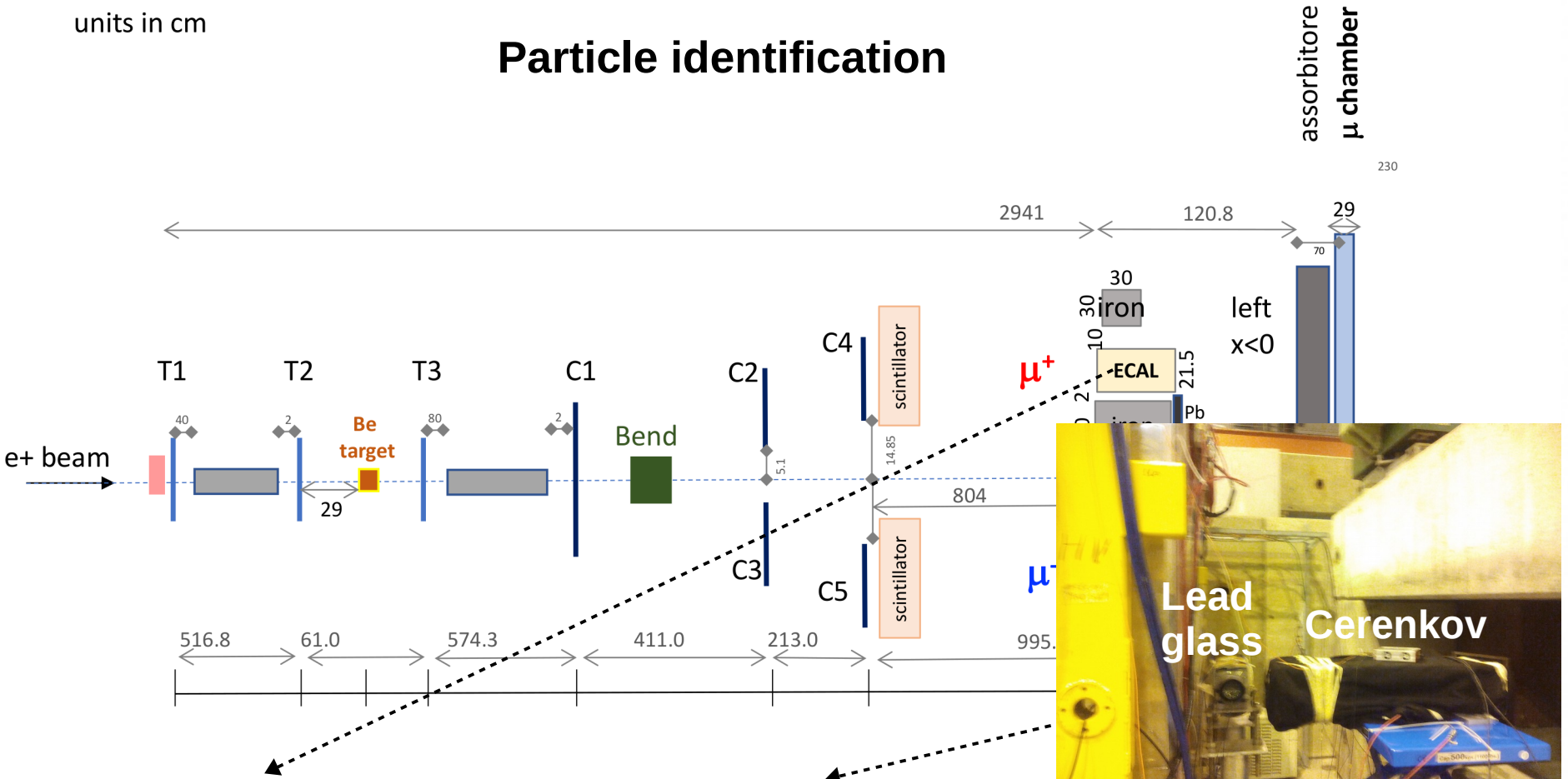
Lead glass + PMT readout (OPAL)

Cerenkov calorimeter for e^-/μ^- discrimination

Testbeam setup

units in cm

Particle identification



Electromagnetic calorimeter for e^+/μ^+ discrimination (DEVA)

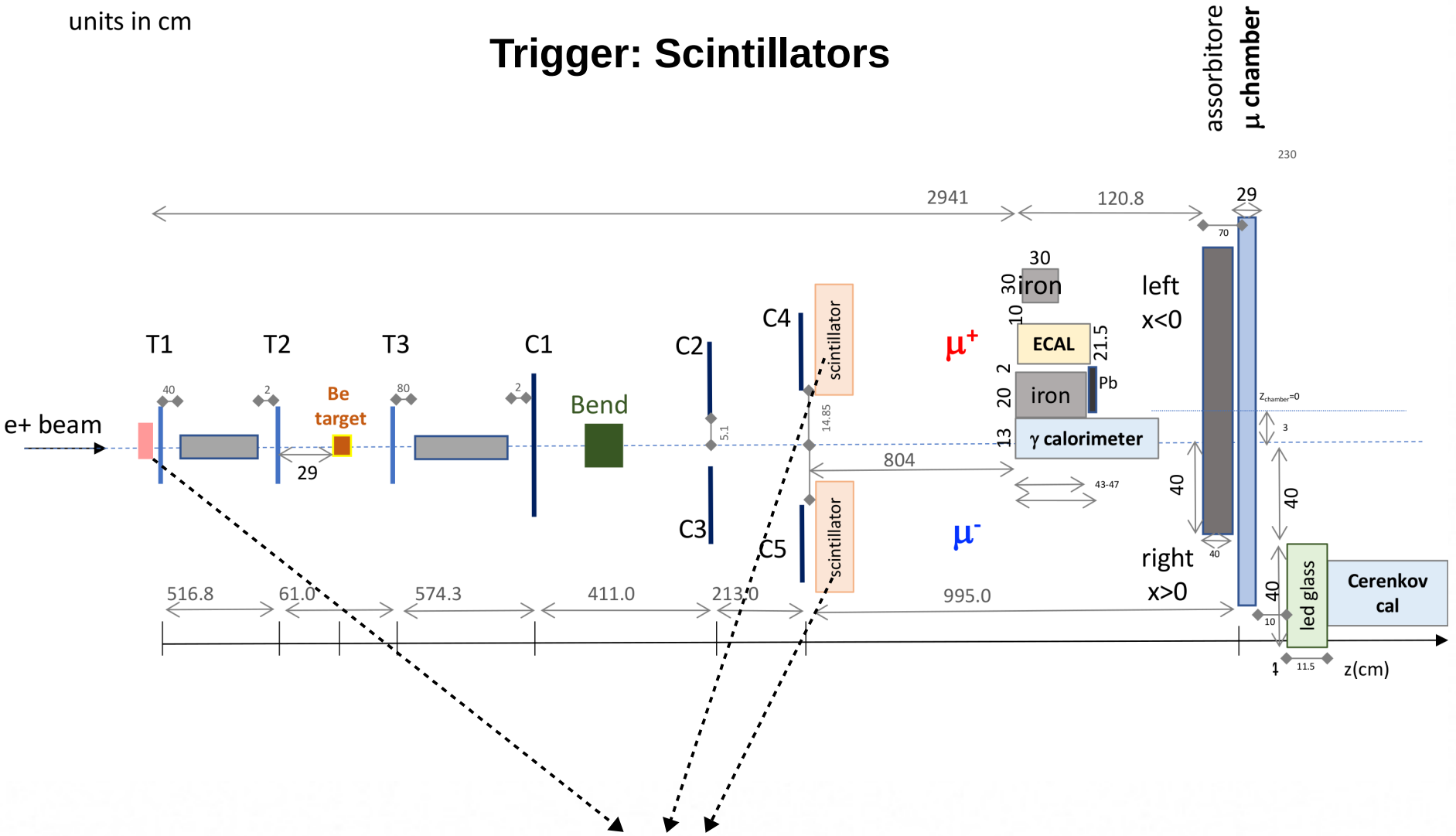
Lead glass + PMT readout (OPAL)

Cerenkov calorimeter for e^-/μ^- discrimination

Testbeam setup

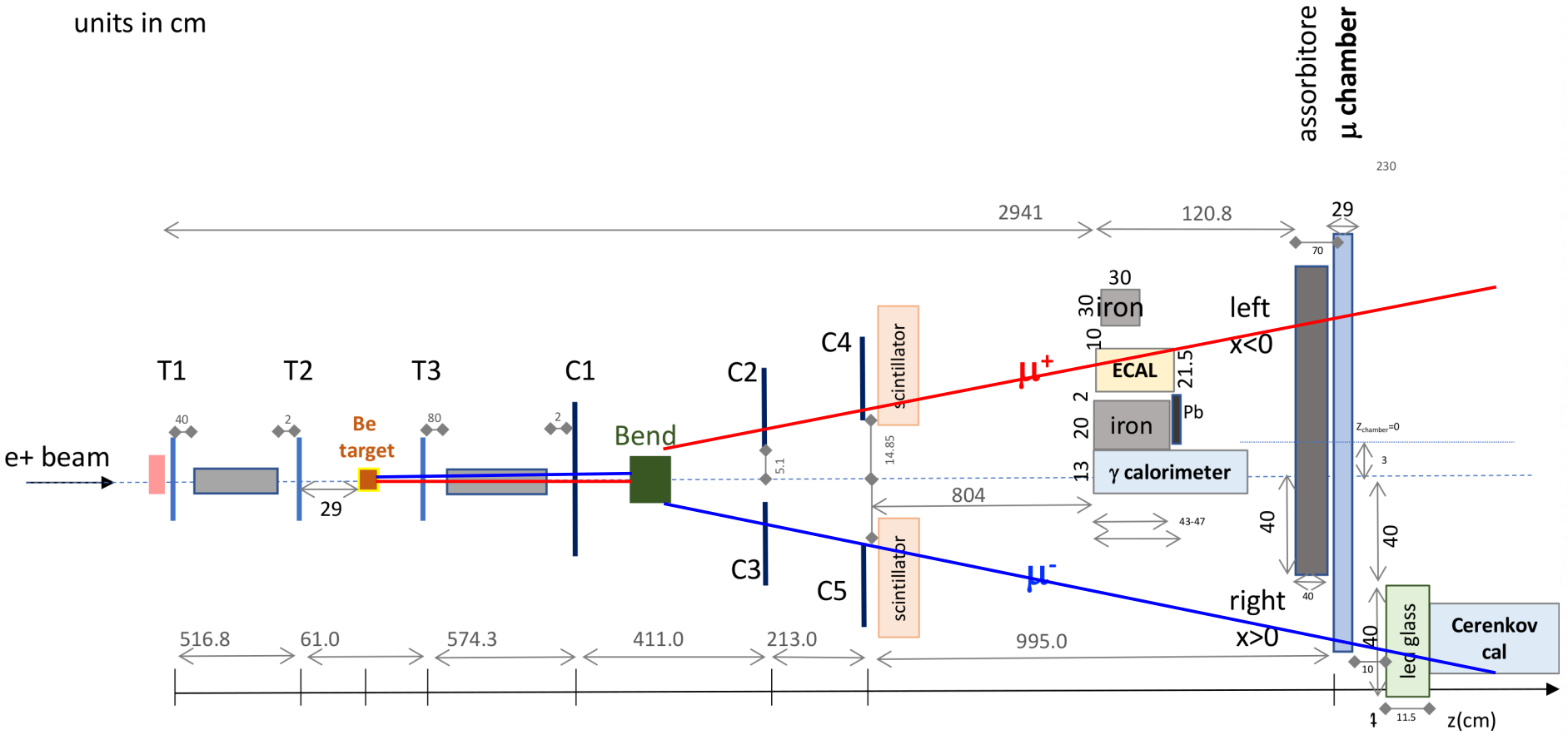
units in cm

Trigger: Scintillators



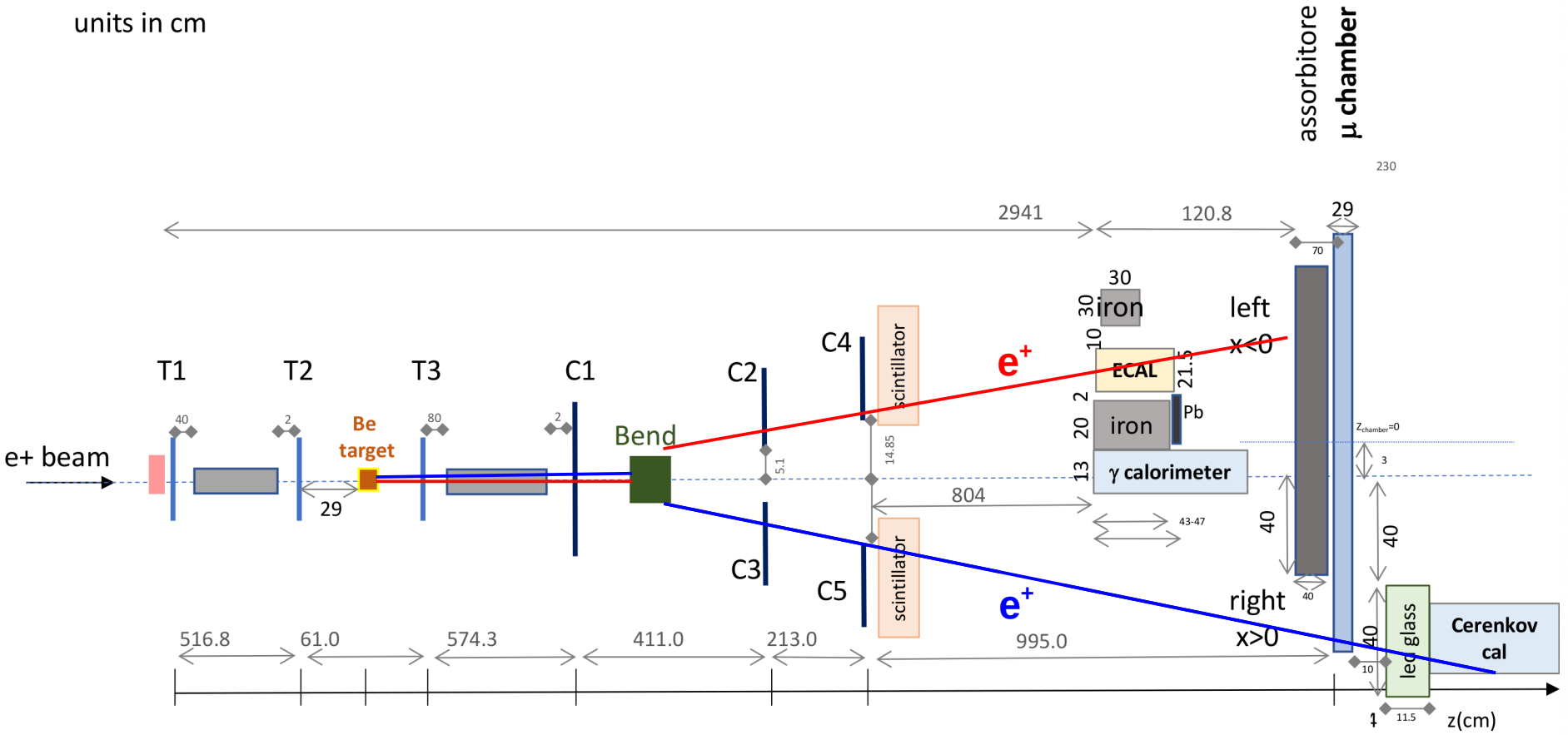
Trigger given by the coincidence of three scintillators in the μ^+/μ^- lines

Signal event topology



- **Two tracks in with hits Silicon tracker and muon chamber**
- **MIP signal in the calorimeters**

e^+e^- (Bhabha) event topology

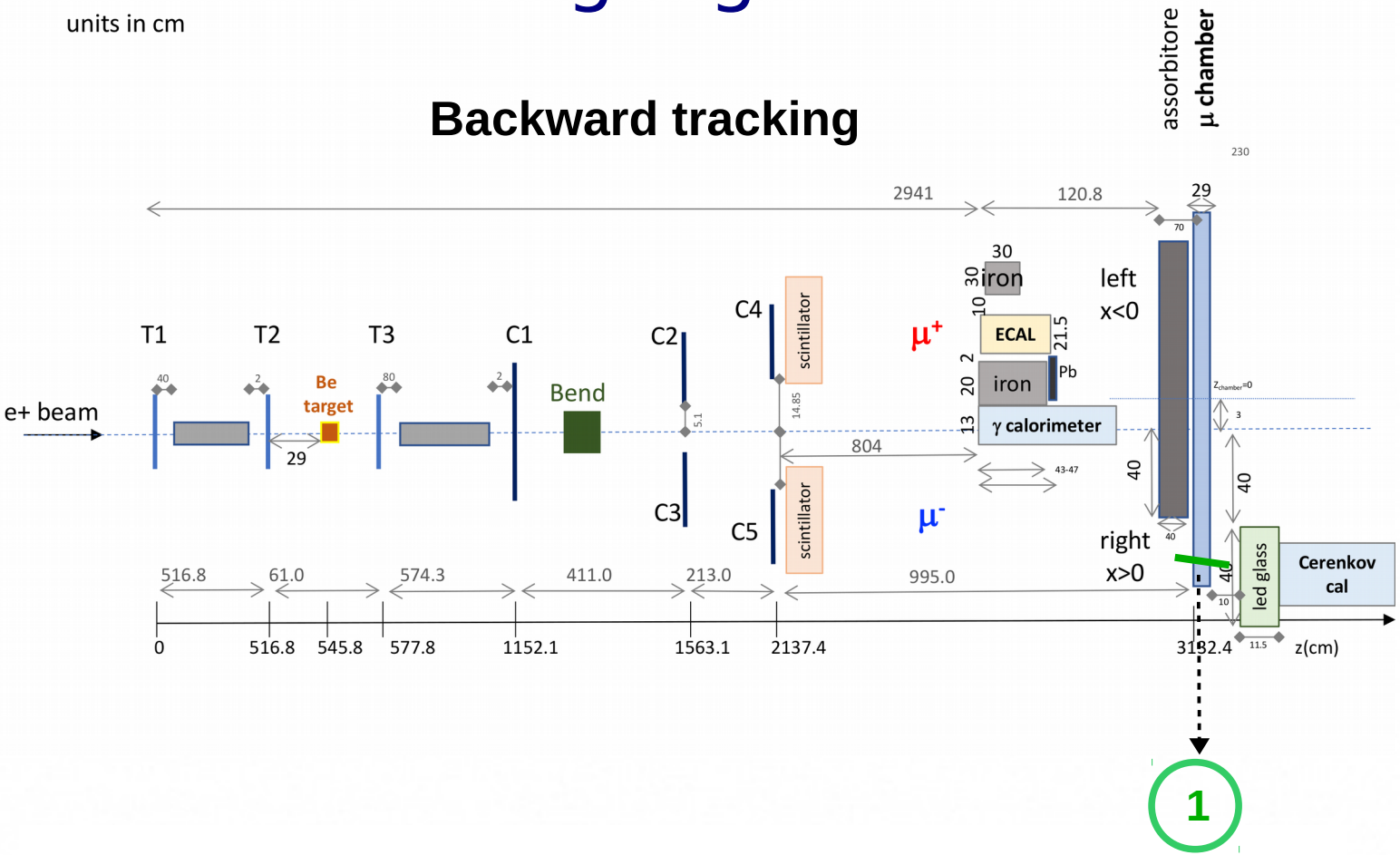


- Two tracks with hits in Silicon tracker
- One track with hits in muon chamber
- Electron signal in the calorimeters

Tracking algorithm

units in cm

Backward tracking

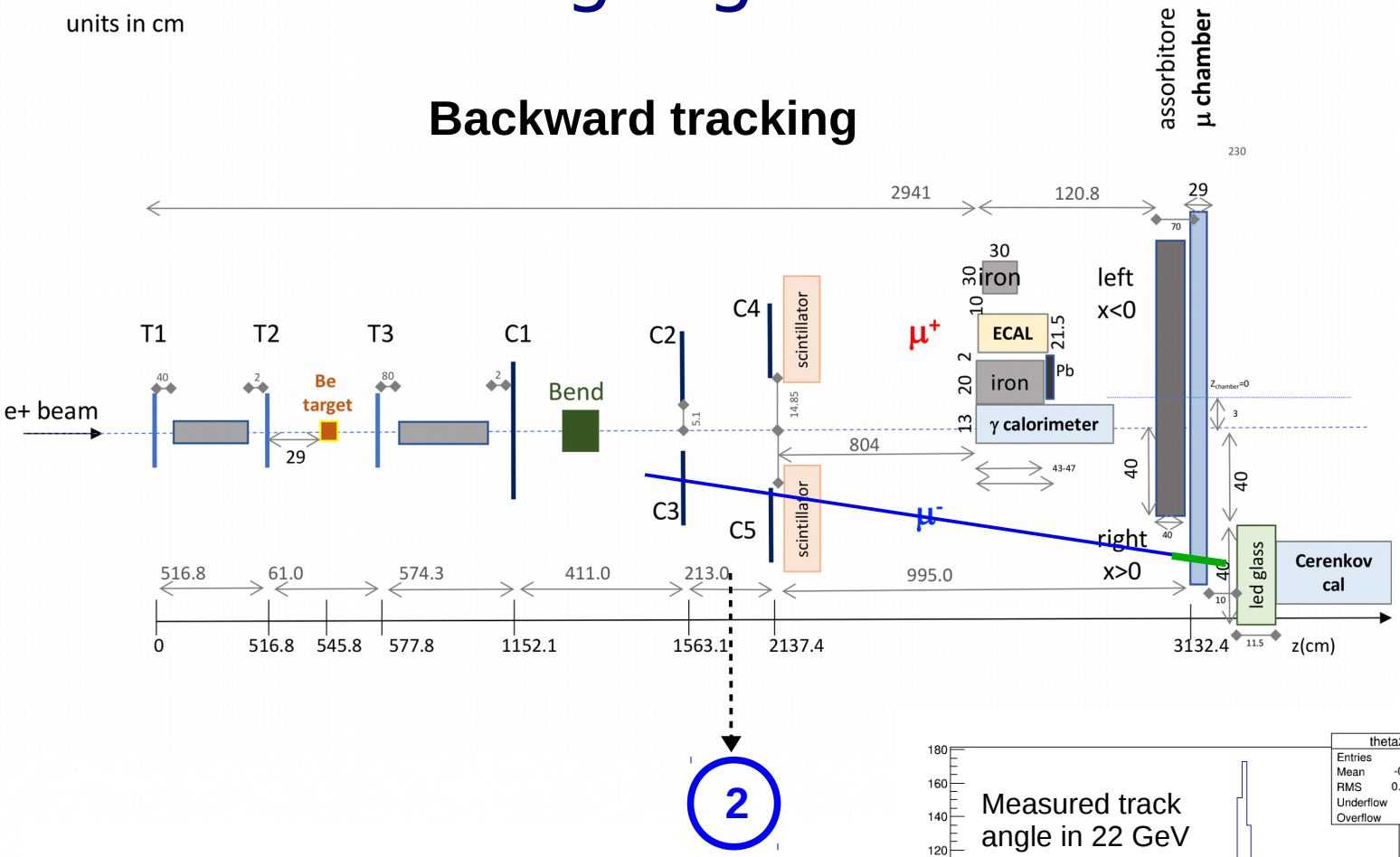


The algorithm starts from a DT track

Tracking algorithm

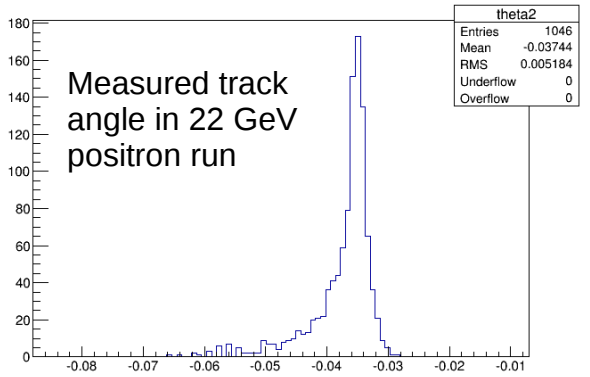
units in cm

Backward tracking



2

Hits in silicon detectors after the magnet are added to the DT track with linear fits

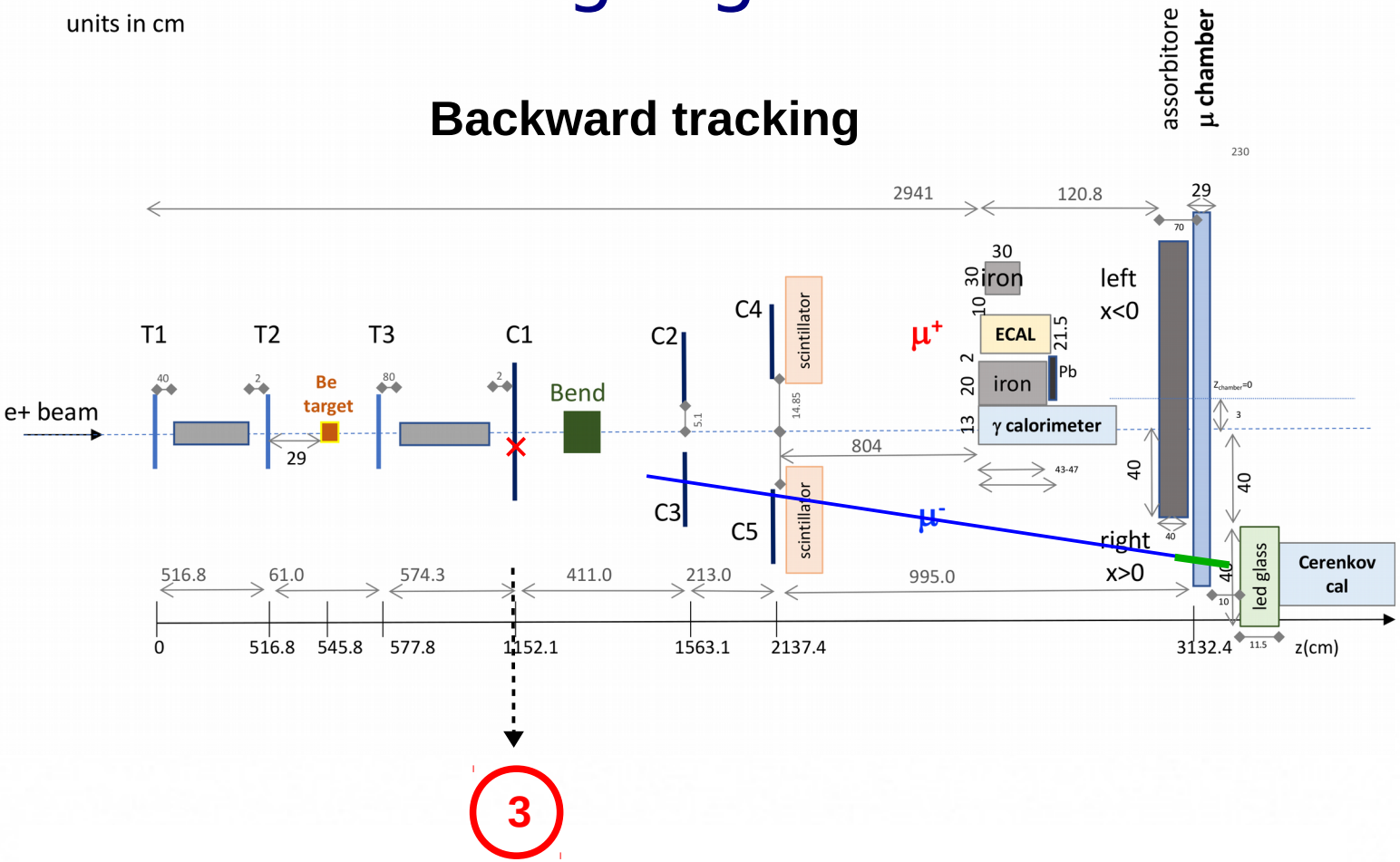


ΔΘ/Θ = 13%

Tracking algorithm

units in cm

Backward tracking



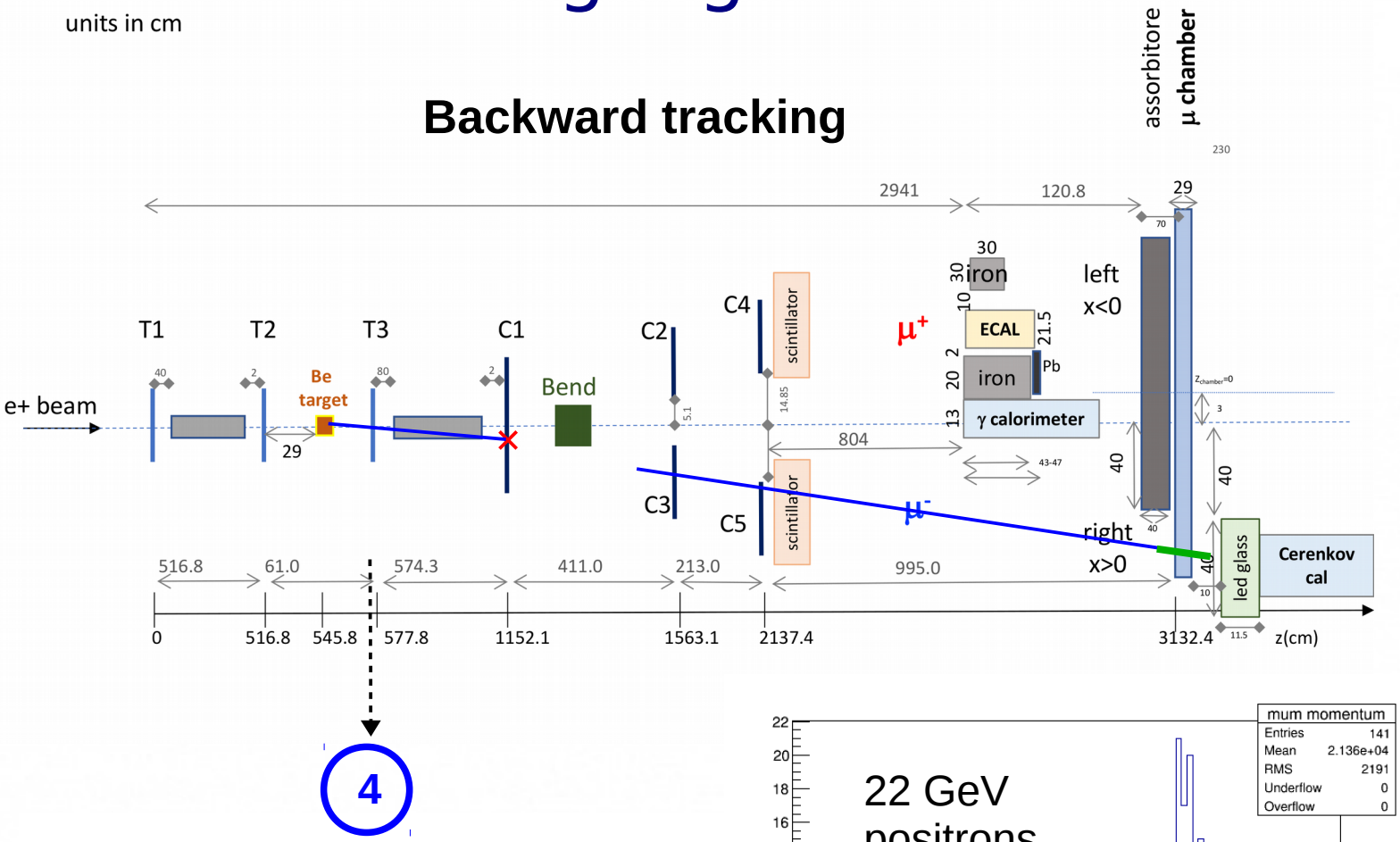
By using a rough estimation of the momentum (depending on the hits in the DT) the track is extrapolated to the detector before the magnet

The hit nearest to the extrapolation is added to the track

Tracking algorithm

units in cm

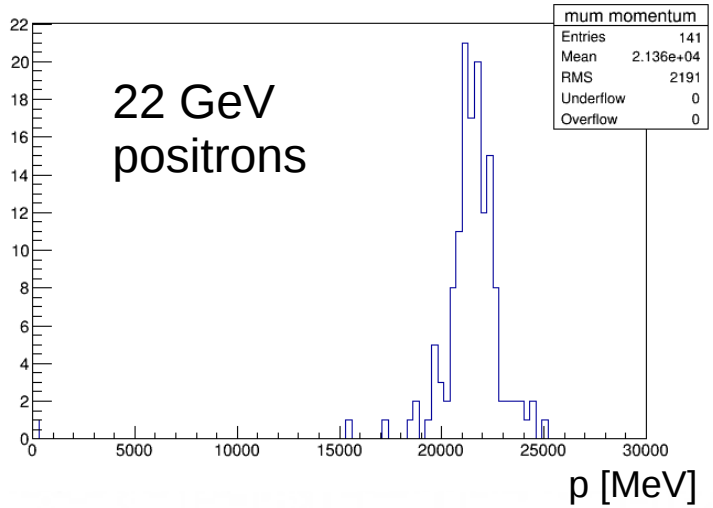
Backward tracking



4

The hit in the detector after the target is added with fits to the track

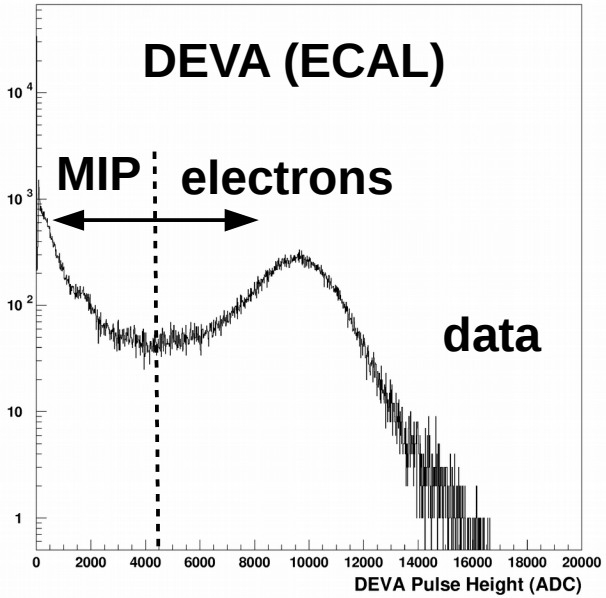
The complete track is refitted to measure the momentum



Δp/p ≈ 10% at 22 Gev

Particle identification

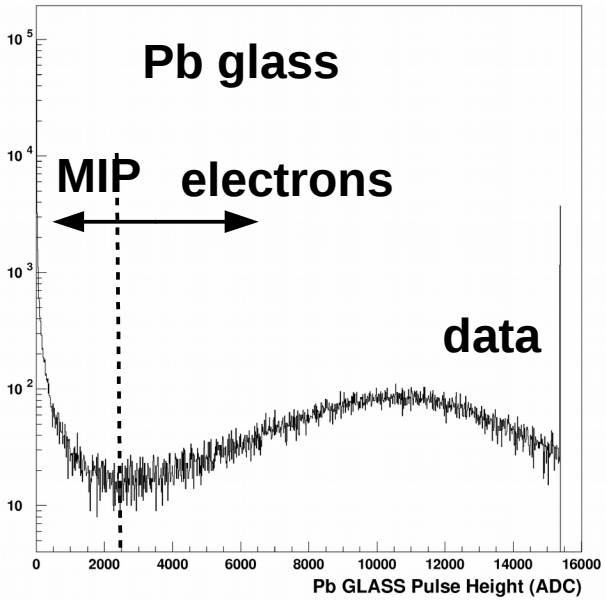
μ^+/e^+ line

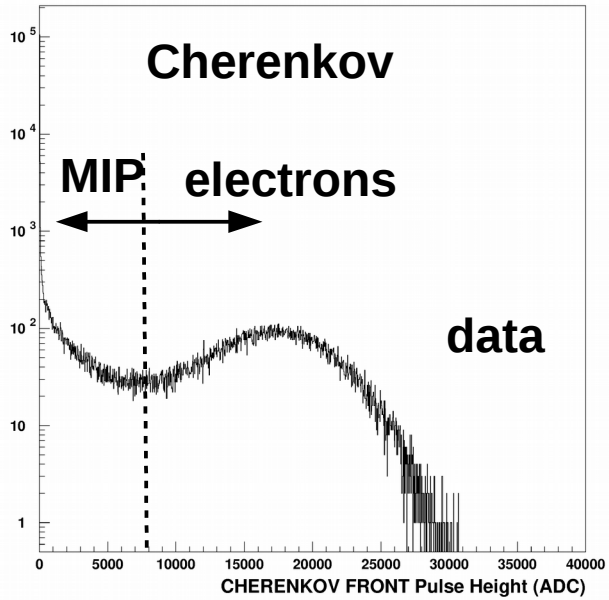


Work is ongoing to define criteria for MIP/electrons identification

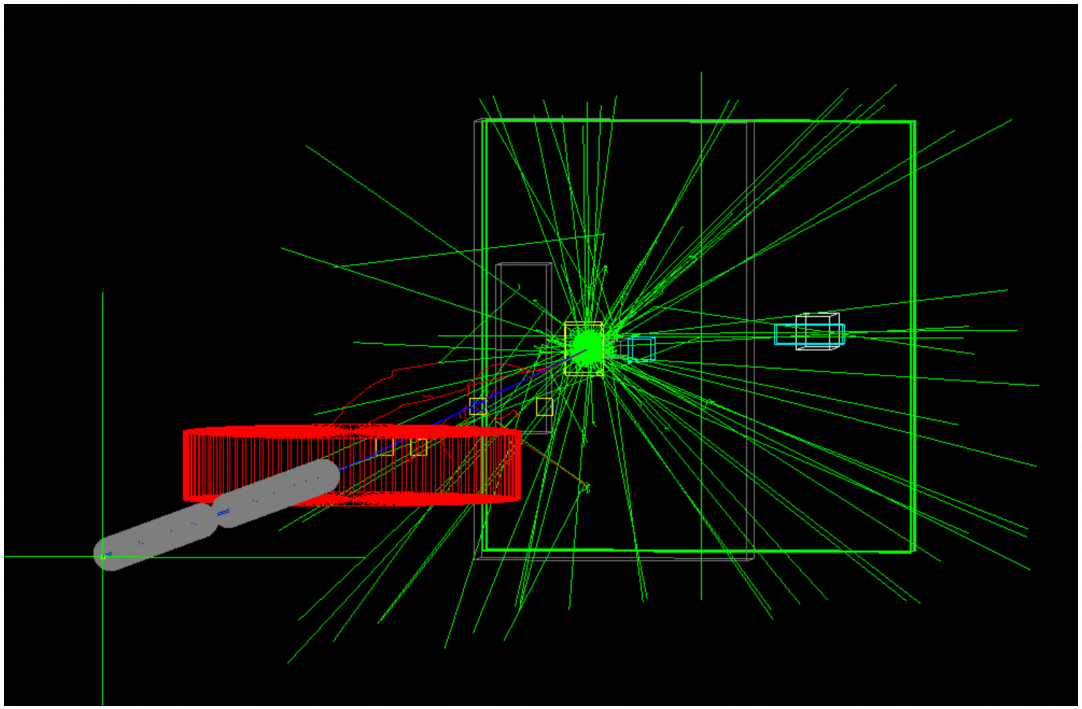
Not used in the current reconstruction

μ^-/e^- line

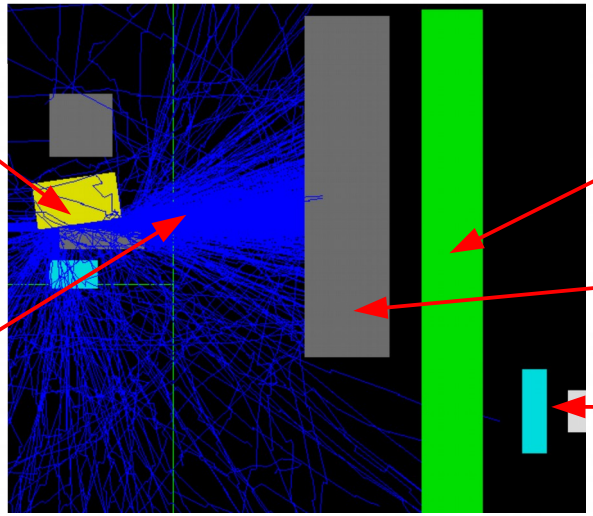




Simulation

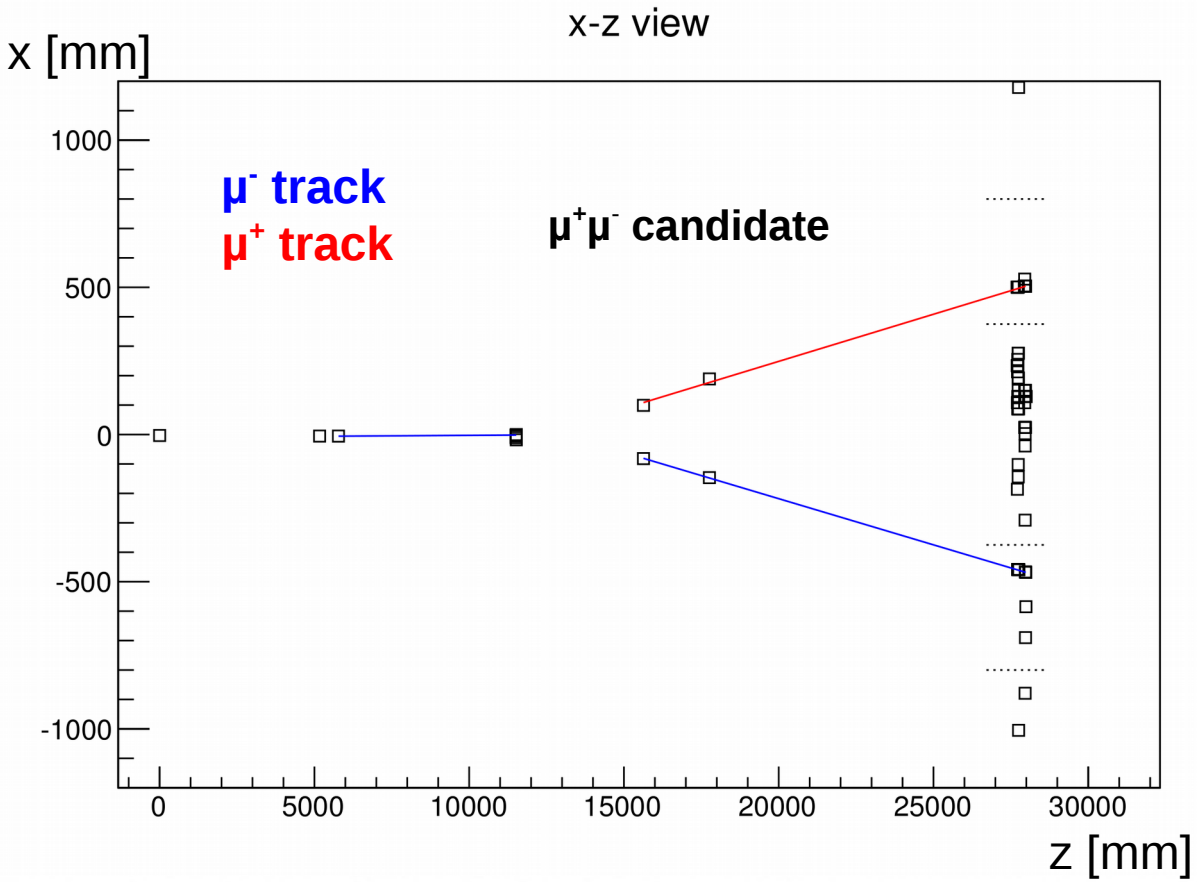


- Performed with Geant4.
- Important to validate the reconstruction and identification techniques.
- Necessary to estimate the muons/electrons acceptances and selection efficiencies.
- Work is on-going to provide the final simulation version with an accurate geometry description.



First results

- We analyzed the runs with the final trigger configuration, ~2 days of data taking
- Among 620K collected events **56 μ+μ- candidates are selected**



Candidates selection based on tracking

μ- :

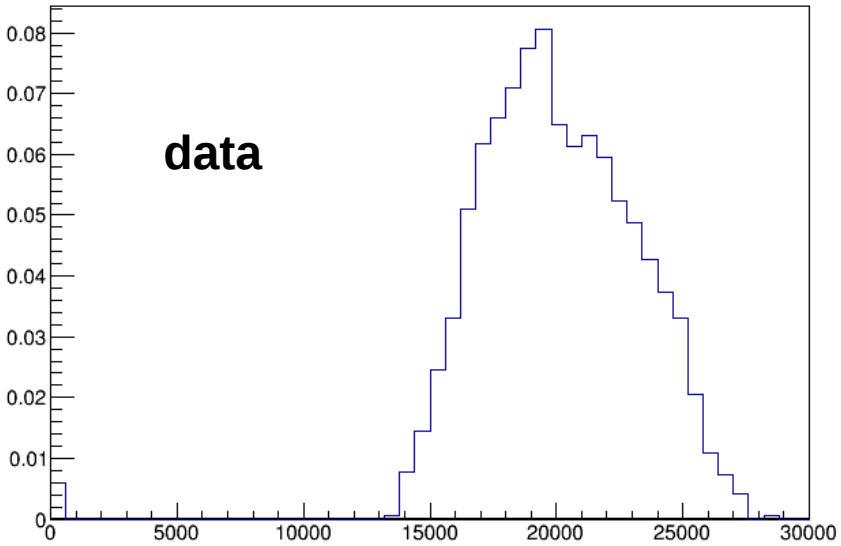
- one track with hits in the DT chamber
- at least one hit in Si detectors before the magnet
- at least one hit in Si detectors after the magnet

μ+ :

- one track with hits in the DT chamber
- at least one hit in Si detectors after the magnet

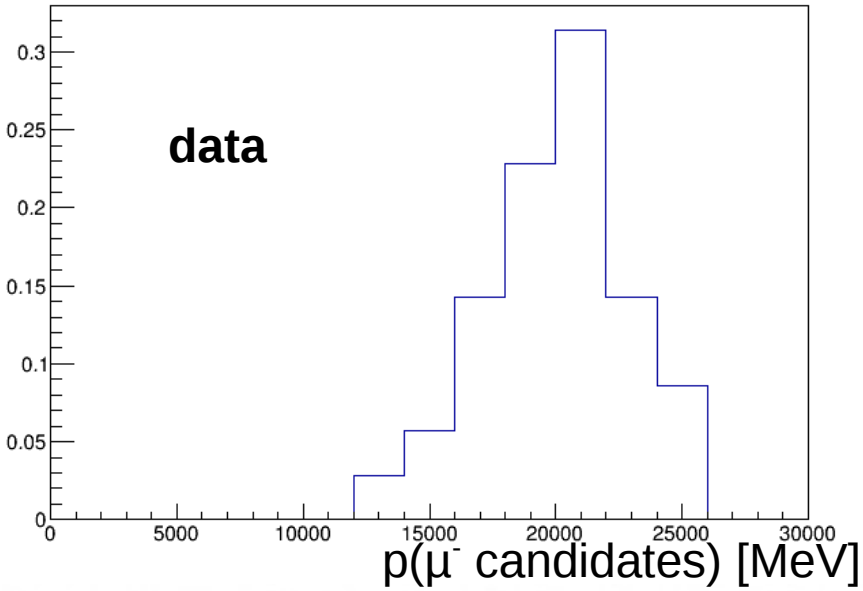
"good" signal candidates: low probability for a e+ to produce a track in the DT chamber after the iron absorber

Momentum distribution



Momentum distribution of e-/μ- candidates (μ+ track not required)

Momentum distribution of μ- candidates (μ+ track required)



Analysis perspectives

Cross section

$$\frac{\sigma(\mu^+\mu^-)}{\sigma(e^+e^-)} = \frac{N(\mu^+\mu^-)\epsilon(\mu^+)\epsilon(\mu^-)}{N(e^+e^-)\epsilon(e^+)\epsilon(e^-)}$$

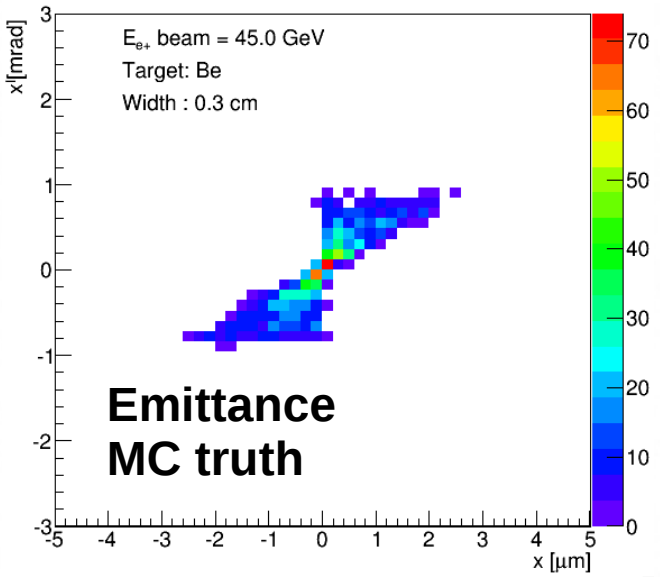
Efficiencies have to be evaluated with the final simulation version

Muons/Bhabha identification have to be improved with precise calorimeter calibration

Expected statistical error below 13% (6% precision needed to probe SSS Coulomb corrections)

Emittance

- We are working on a global μ+μ- kinematic fit to improve the resolution.
- With current tracking algorithm **we expect an uncertainty of 5 μm on the measurement of x(μ-) at target out** (evaluated from calibration runs)
- With current tracking algorithm **we expect an uncertainty of 1.2 x 10^{-6} on the measurement of dx/dz(μ-) at target out** (evaluated from calibration runs)



Conclusions and 2018 plans

- **Final results from 2017 testbeam are expected soon.**
- With the current algorithms we identified of about 50 μ+μ- candidates:
  - Measurements possible with limited accuracy.
  - Work is on-going on reconstruction algorithms to improve the efficiency.
  - But enough to probe the testbeam feasibility.
- **The plan is to repeat the testbeam in 2018, the request to the SPS committee has already been submitted.**
- One more week of data taking is planned.
- We are going to run with an **upgraded setup**:
  - Optimized testbeam layout.
  - Two separated muon chambers for μ+ and μ- lines.
- **In the next testbeams we want to test also the positron beam degradation with thin targets and crystal channeling.**