Workshop on Muon Precision Physics

7-9 November 2022

LEVERHULME TRUST

ACTIVITY ON MUONE IN PISA

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(University and INFN Pisa)

INTRODUCTION

- Target and Tracker support system
  - Mechanical stability
  - Temperature stability
  - Slow controls
- Calorimeter laser calibration system
- Simulation Study for MUonE Tracker station
- Template fit of signal and nuisances with Combine

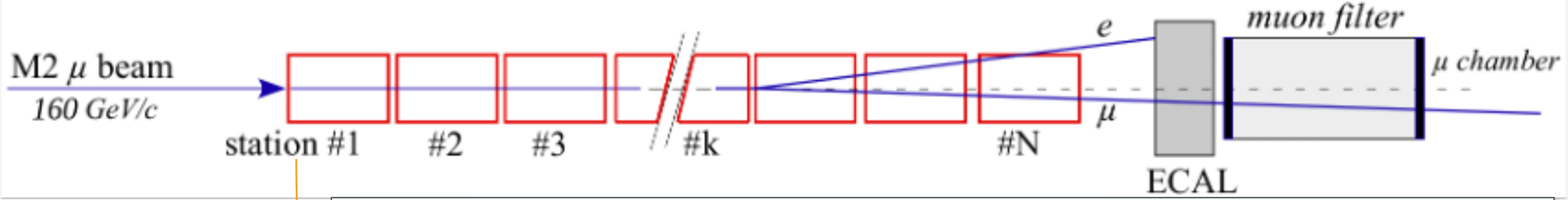
Hardware

Software
Simulation & Analysis

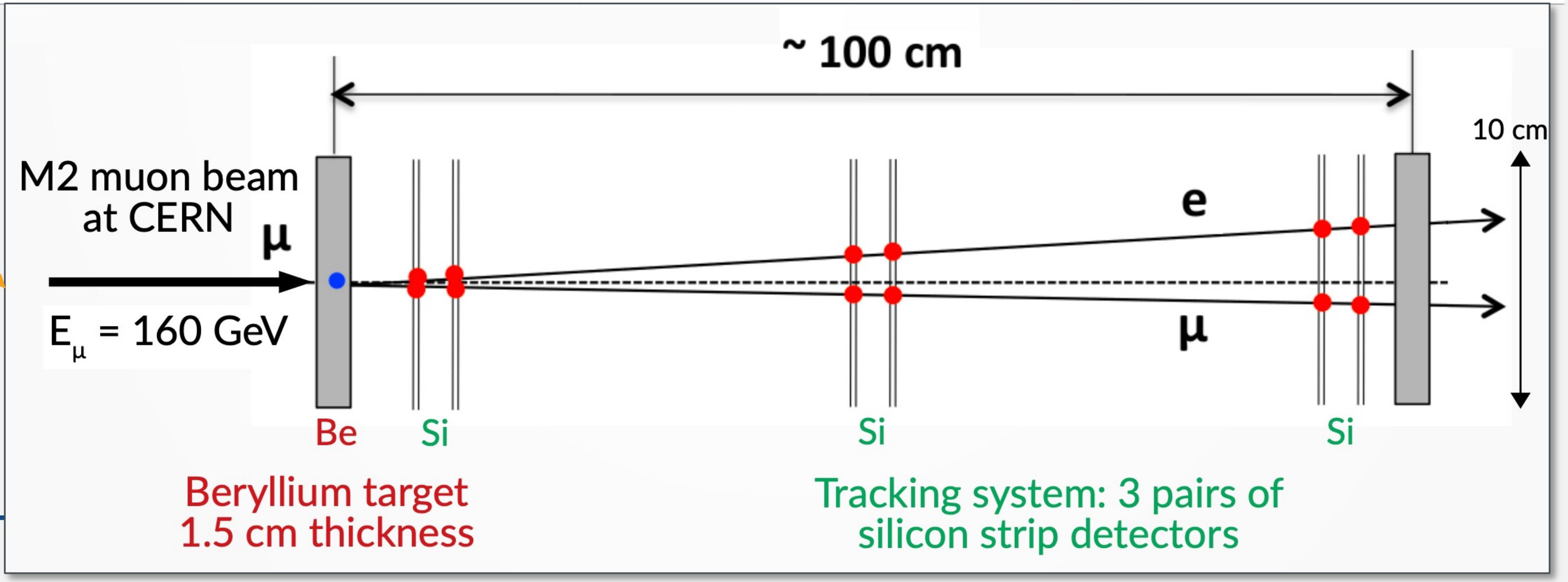
- **MUonE Pisa group**: C. Ferrari, M. Incagli, M. Massa, A. Moggi, G. Venanzoni, F. Ligabue, L. Bianchini, R.N. Pilato, A. Driutti.

MUONE DETECTOR

- MUonE Goal: ~0.3% statistical accurancy on a_μ^{HLO} to be competitive with theory
- 40 stations + 3 years of data taking with beam intensity of $10^7 \mu^+/s$

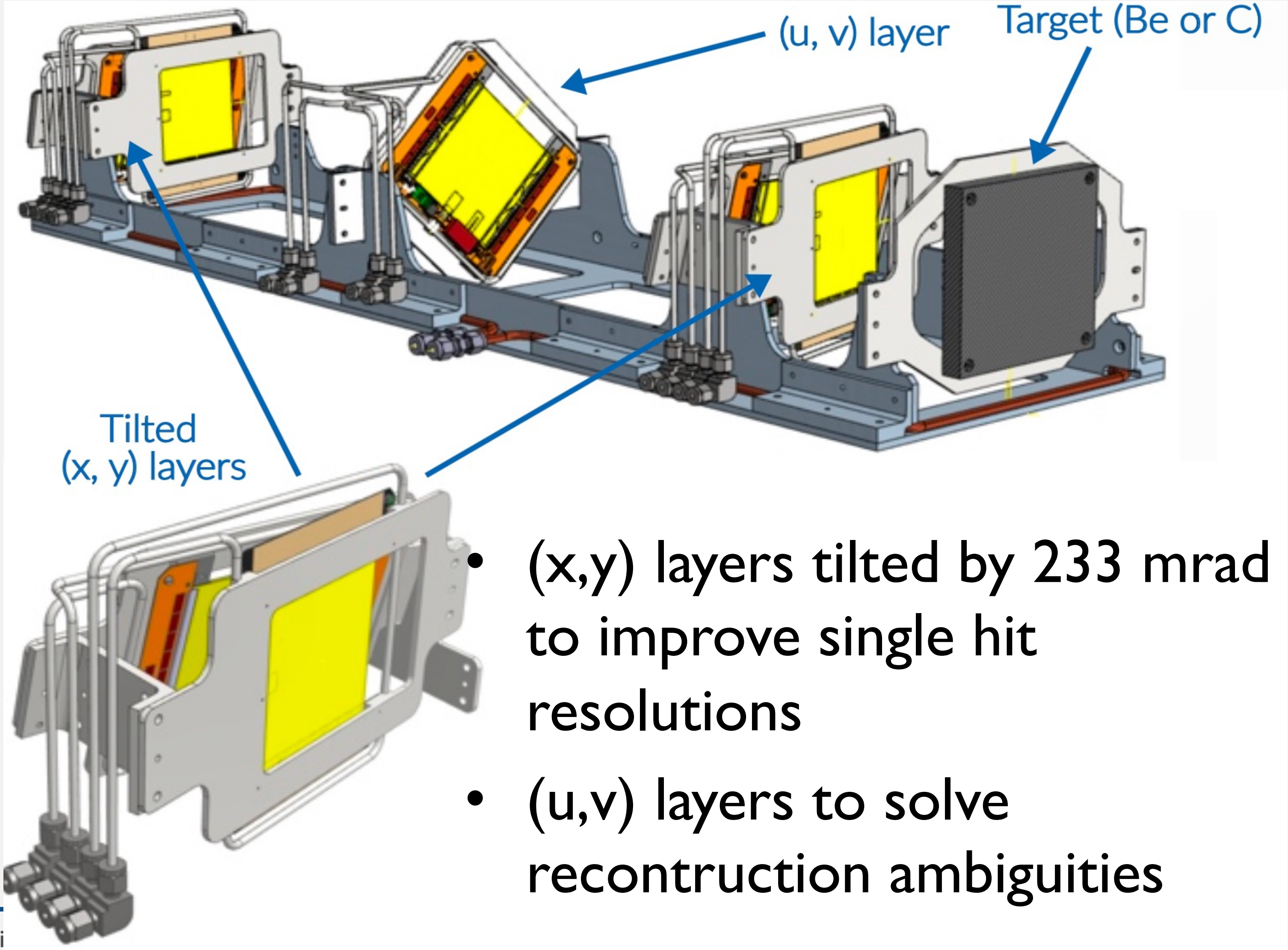


- **Each station**:



SINGLE TRACKING STATION

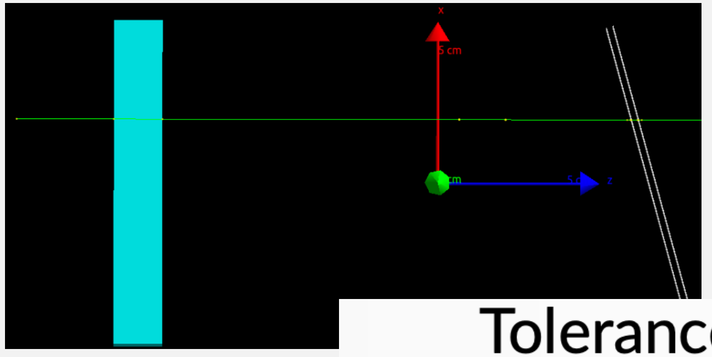
- Stringent request (within a station) : **relative position stability ~ 10 μm** (10ppm)
  - ➢ Structure material with low coefficient of thermal expansion (CTE)
  - ➢ Controlled Temperature
  - ➢ Laser Holographic system to monitor stability (Trieste Group)

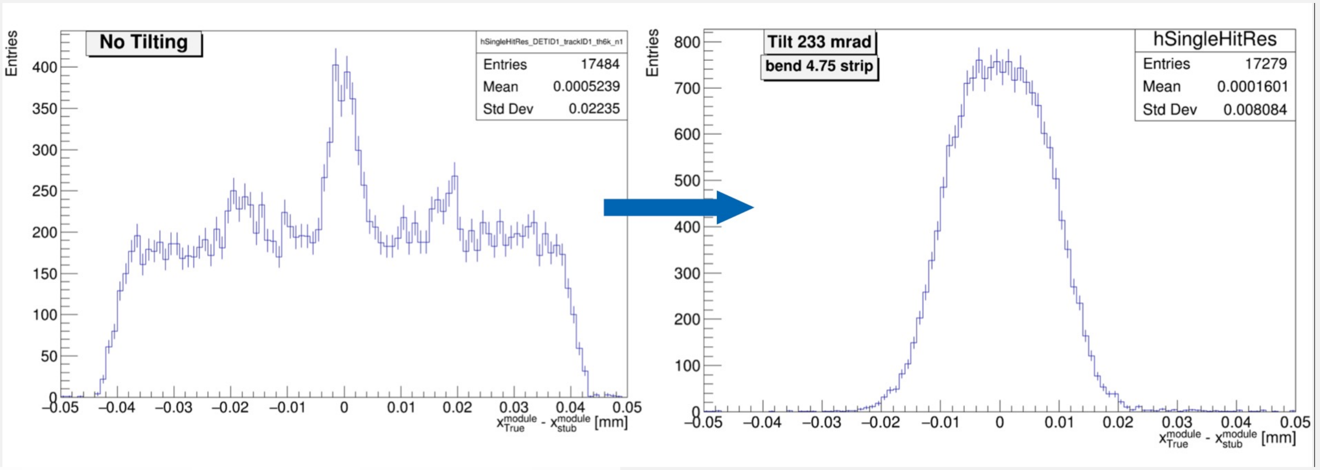


- (x,y) layers tilted by 233 mrad to improve single hit resolutions
- (u,v) layers to solve recontruction ambiguities

TILT FROM SIMULATION STUDIES

- Tilt angle from a scan as a function of tilt angle and digitization threshold using simulation:





Tolerance in the mechanical structure:
233 ± 6 mrad

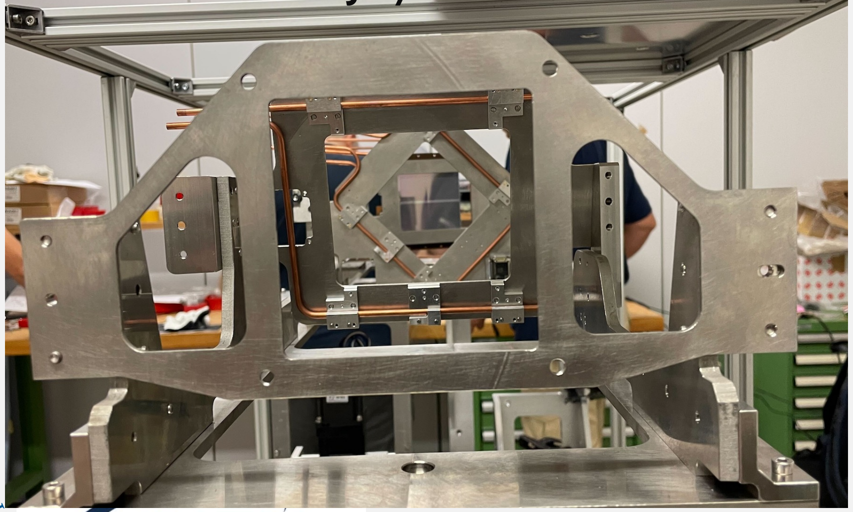
Tilt angle [mrad]	<bend> [strips]	threshold [σ]	resolution [μm]
210	4.25	5	7.8
221	4.5	5.5	11.5
233	4.75	6	8.0
245	5	6.5	11.2
257	5.25	7	8.7
268	5.5	7.5	11.0

Expected resolution will be 8 – 11 µm

TRACKER STRUCTURE

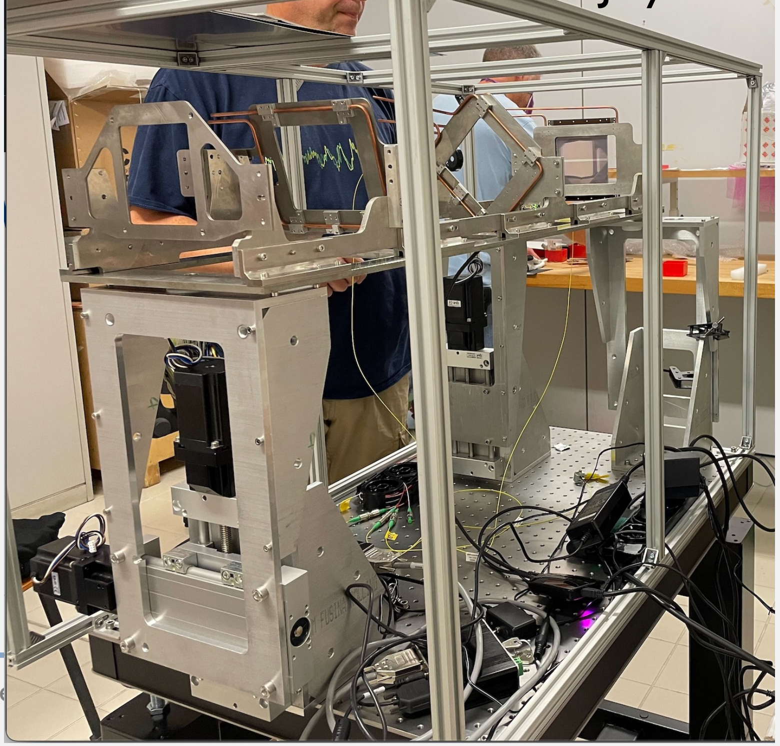
- build in **INVAR**
  - alloy of Iron and Nickel 64:36
  - Very low CTE ~ $1.2 \times 10^{-6} K^{-1}$
  - But quite expensive, hard to procure and to machine

MUonE Lab Pisa July 2022



- mounted on aluminum supports equipped with motors for alignment

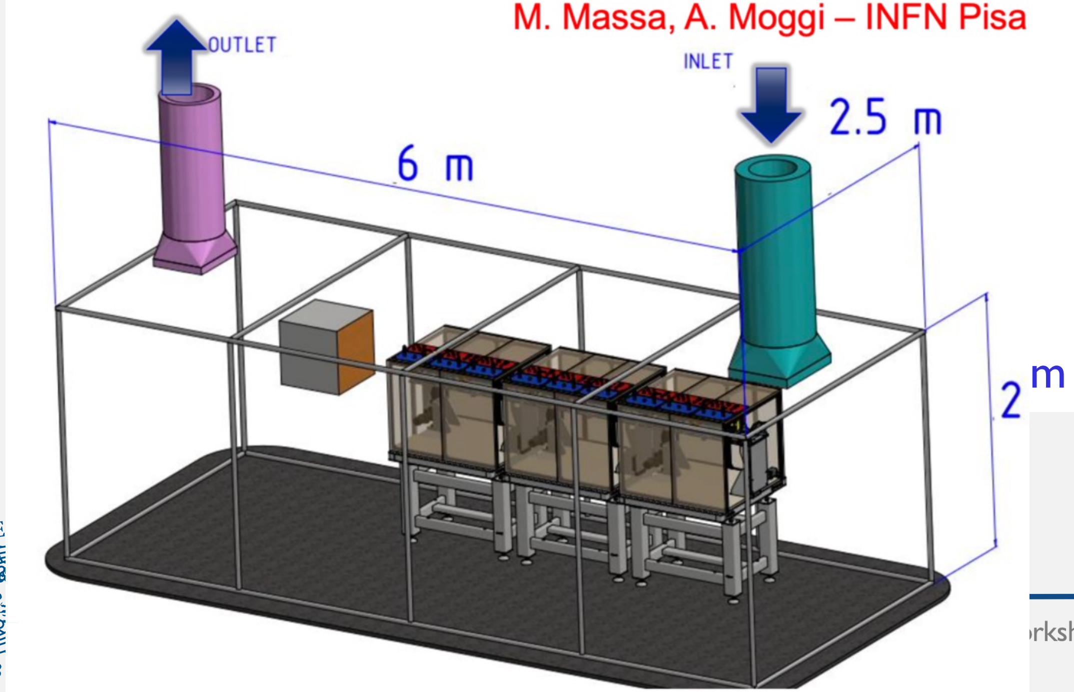
MUonE Lab Pisa - July 2022



THERMAL STABILITY

- Temperature is expected to be stable at $\pm 0.5°C$
- two levels of stability:
  - **enclosure:** cooling tubes and dry air flow
  - **tent:** surrening structure cooled by air flow

M. Massa, A. Moggi – INFN Pisa



2cm thick insulating foam

6mm cooling tubes (structure)

Patch panels for electric and hydraulic connectors

4mm cooling tubes (sensors)

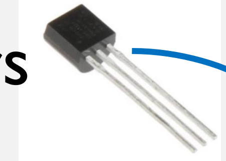
Thermal bridges (Trieste Group)

SLOW & MOTORS CONTROLS

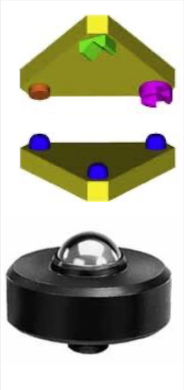
Beam test 2022

- Relative humidity
  - mod. SHT25: RH% + temperature

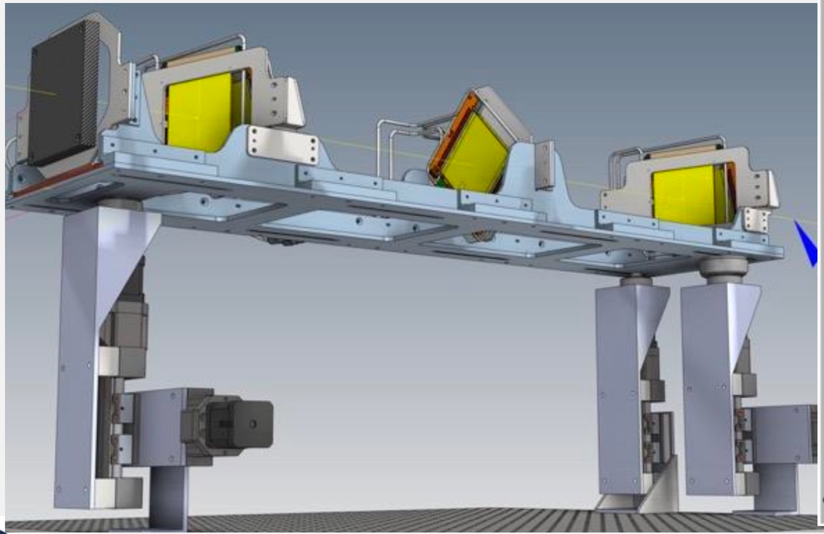
- Temperature Sensors
  - DS18B20

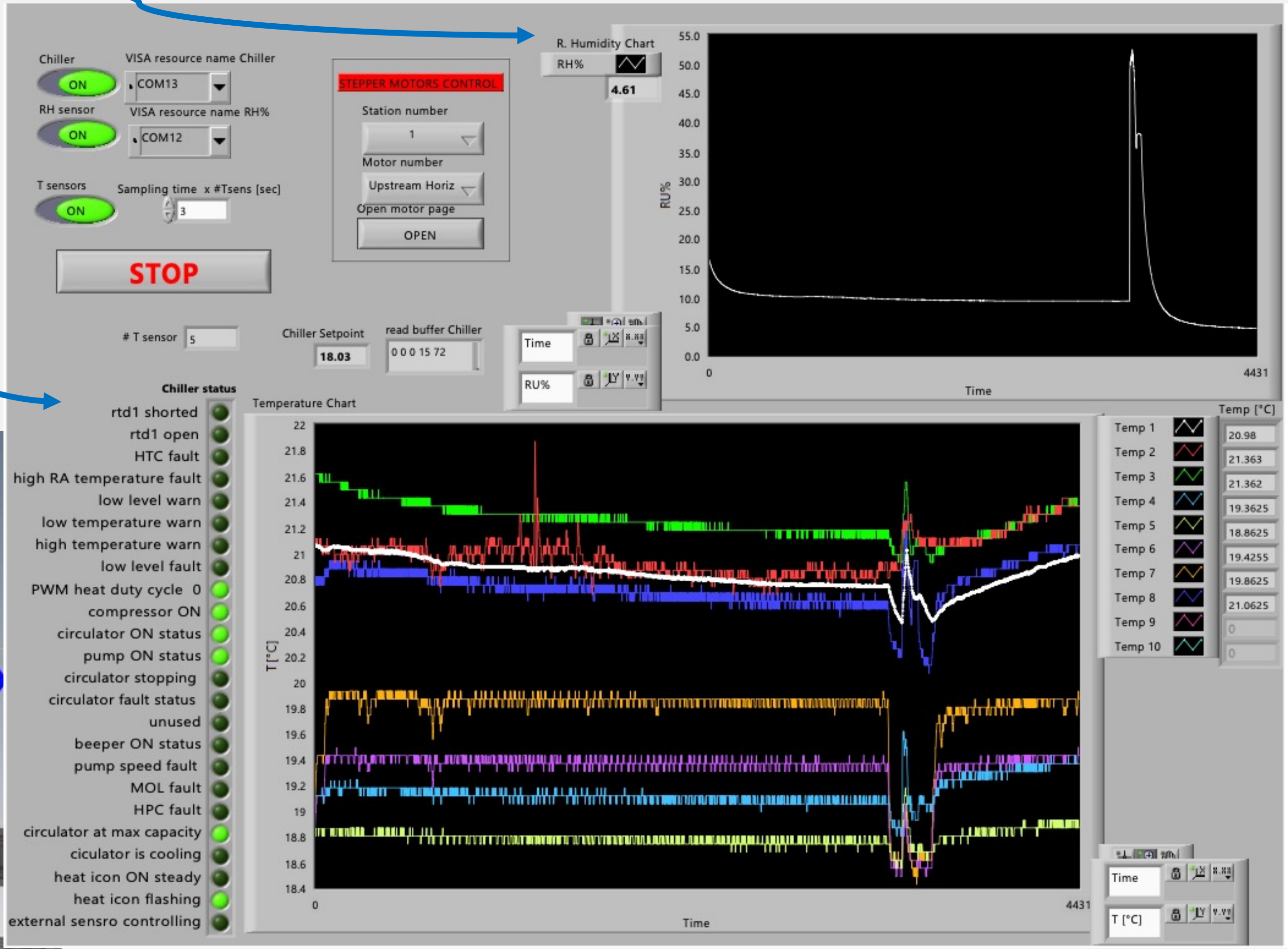


- Stepper Motors
  - Igus



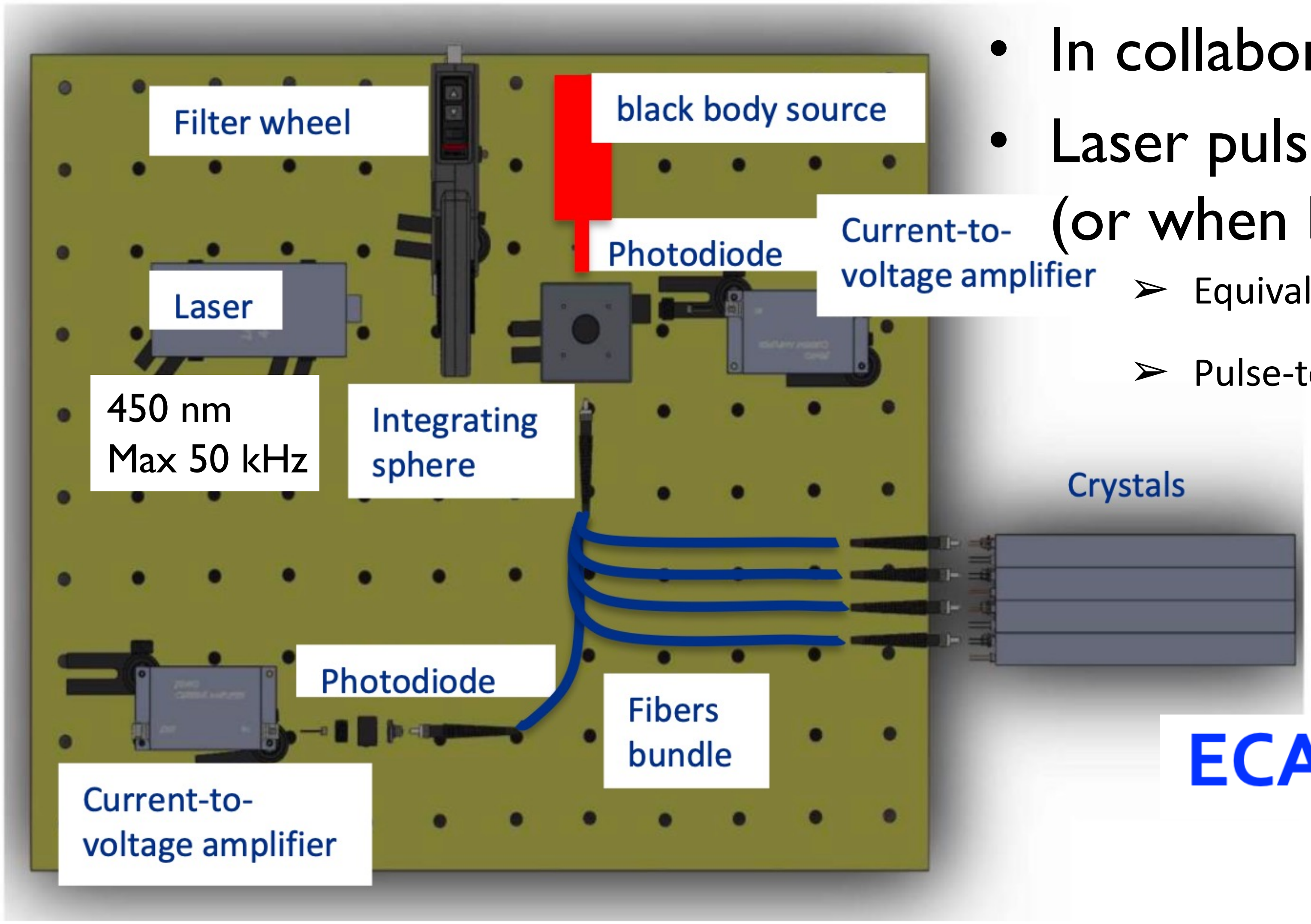
Spherical joint





CALORIMETER LASER CALIBRATION SYSTEM

- In collaboration with Trieste Group
- Laser pulsing during beam-OFF periods (or when beam-ON for special studies)
  - ➢ Equivalent deposition of 100 GeV in a crystal (9 pJ)
  - ➢ Pulse-to-pulse stability: ± 3% (tracked by monitor system)

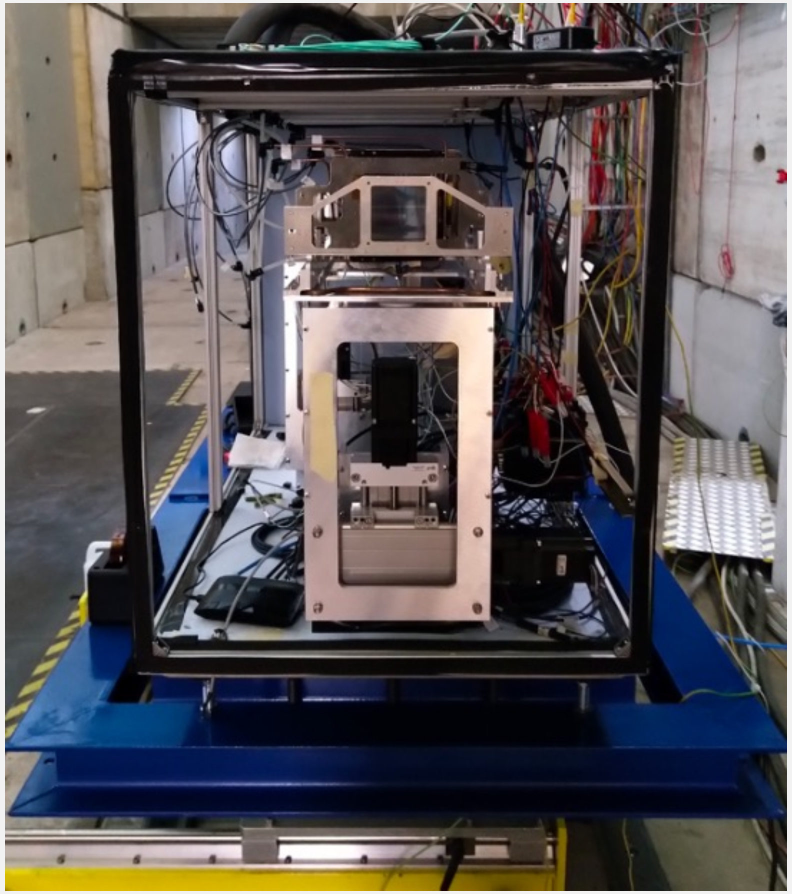


ECAL

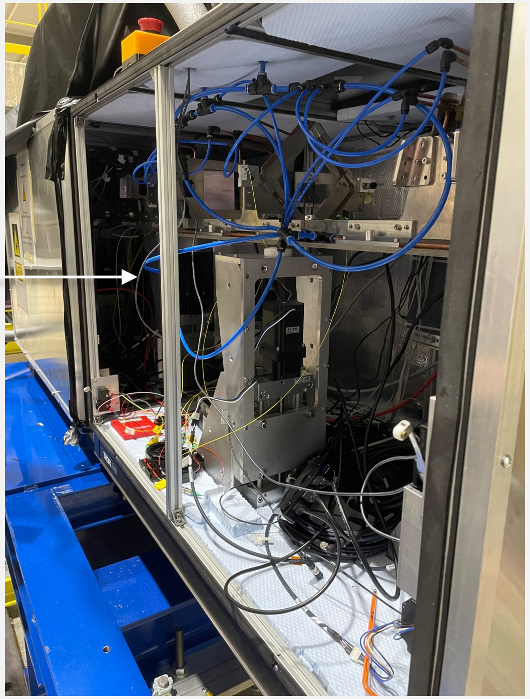
- 5x5 $PbWO_4$ crystals (CMS ECAL).
  - 2.85x2.85 cm2.
  - Length: 22cm (~25 Xo).
  - Total area: ~14x14 cm2.
- Readout: APD sensors, 10x10mm^2 photosensitive area.

BEAM TEST 2022

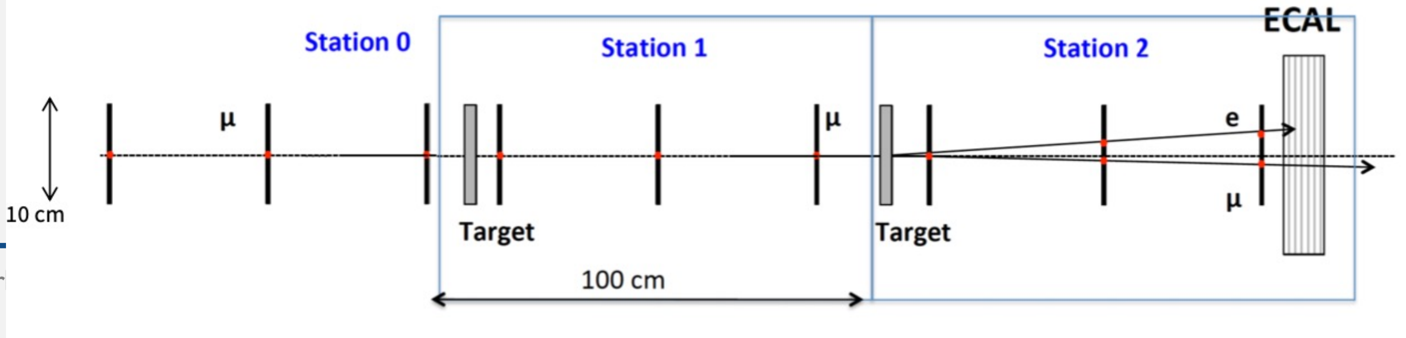
Beam Test: June 2022 with 1 station (Aluminum)



Beam Test Nov 2022 with 2 station (1 Aluminum + 1 INVAR)



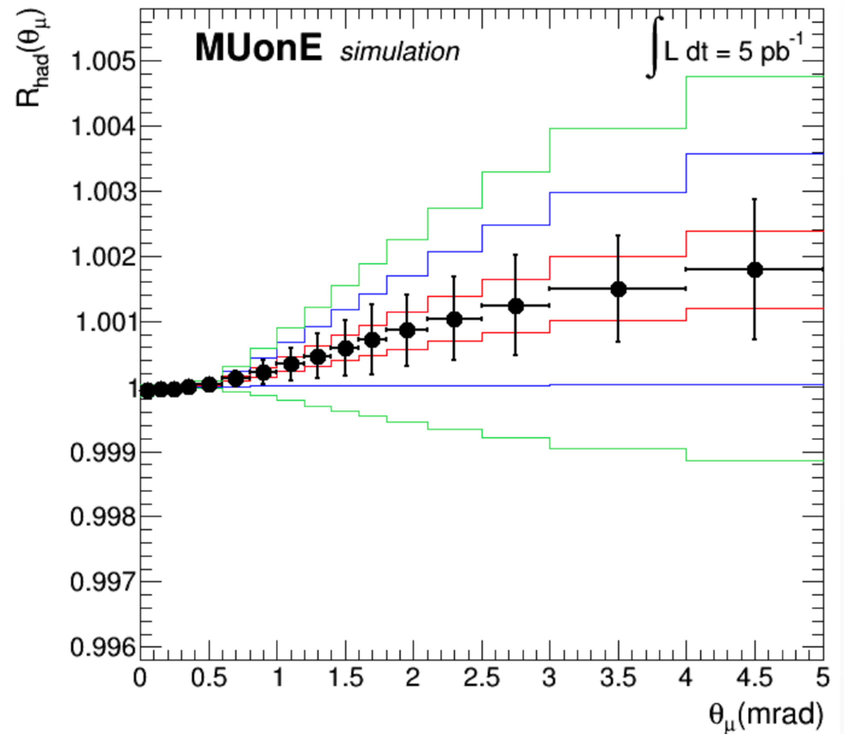
Milestone 2023: Test Run with 3 stations



TEST RUN: SENSITIVITY ON $\Delta\alpha_{had}(t)$

Expected luminosity for the Test Run: L_{TR} = 5 pb^{-1} ⟷ ~10^9 events with E_e > 1 GeV (θ_e < 32 mrad)

$$R_{\text{had}} = \frac{d\sigma_{\text{data}}(\Delta\alpha_{\text{had}})}{d\sigma_{\text{MC}}(\Delta\alpha_{\text{had}} = 0)} \sim 1 + 2\Delta\alpha_{\text{had}}(t)$$



We will be sensitive to the leptonic running ($\Delta\alpha_{lep}(t)$ < 10^{-2})

Low sensitivity to the hadronic running ($\Delta\alpha_{had}(t)$ < 10^{-3})

$$\Delta\alpha_{had}(t) \simeq -\frac{1}{15}Kt$$

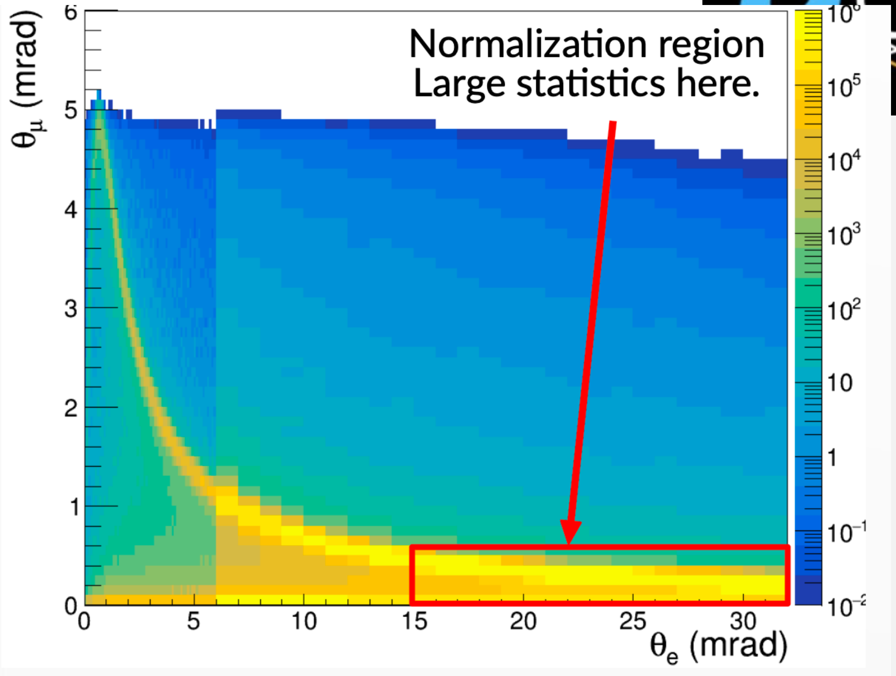
K = 0.136 ± 0.026
(20% stat error)

Template fit with just one fit parameter K= k/M in the $\Delta\alpha_{had}$ parameterization.
The other parameter is fixed at its expected value: M = 0.0525 GeV^2

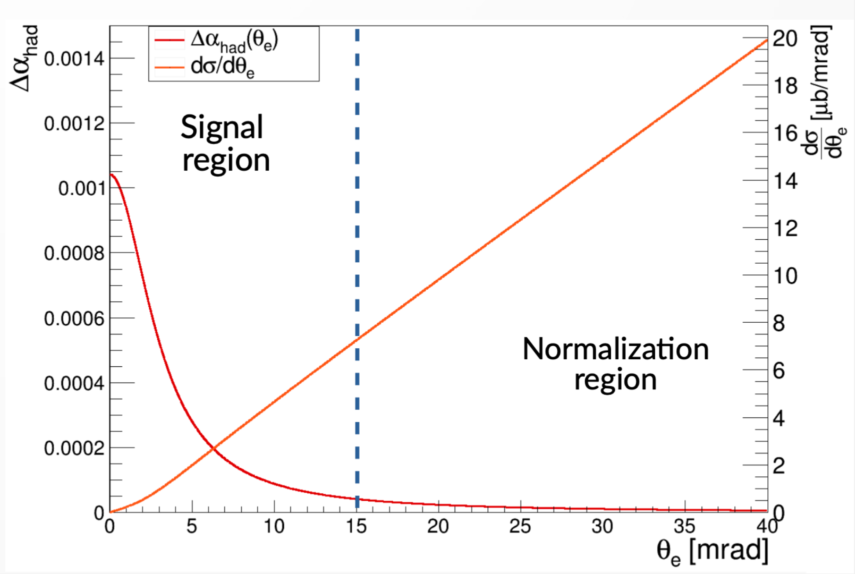
Slide from R.N. Pilato – ICHEP 2022

SYSTEMATIC EFFECTS

- Three main sources of systematic errors:
  - ✓ Multiple Scattering (MS)
  - ✓ Intrinsic angular resolution (Intr)
  - ✓ Miscalibration of energy beam (E_{beam})



- With large effects in the normalization region where there is no sensitivity to $\Delta\alpha_{had}$

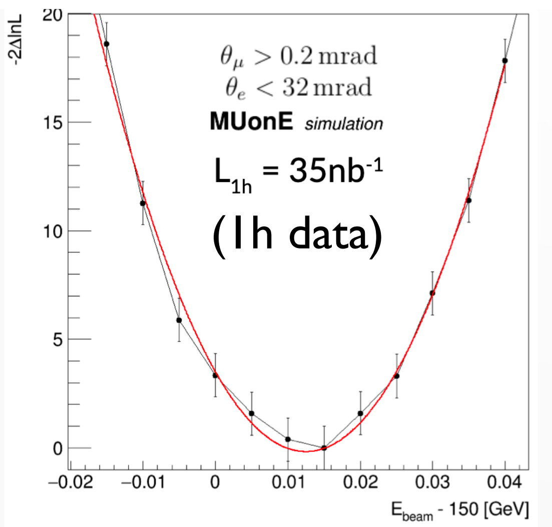


Slide from R.N. Pilato – SIF 2022

STRATEGY FOR THE SYSTEMATIC EFFECTS

- 2 steps workflow:
  1. Use normalization region to calibrate the larger syst. effects
  2. Include the residual syst. as nuisance parameters in a combine fit with signal

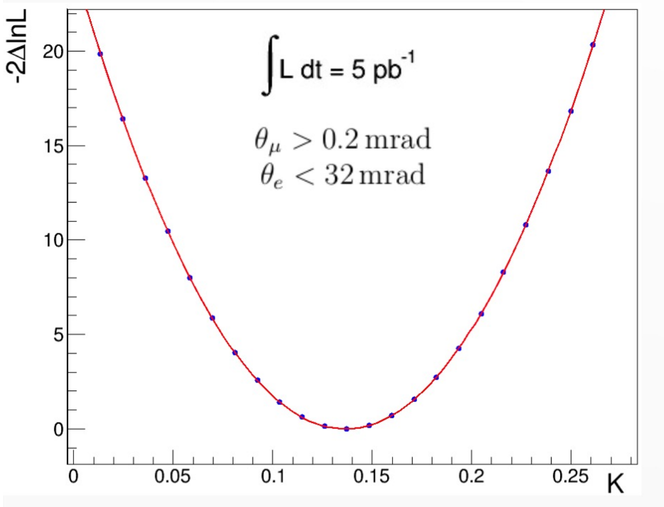
- Tools:
  - MESMER MC + fast detector simulation to generate template distributions
  - Combine analysis tool to perform the combined likelihood fit to the signal + systematics



Pseudo-data sample:
- E_{beam} = 150.012 GeV
- $\sigma_{Intr} \rightarrow$ + 5%

Fit results
$E_{Beam} = (150.012 \pm 0.007)$ GeV $\mu_{Intr} = (5.2 \pm 0.1)\%$

Expected precision on the multiple scattering model: ± 1%
G. Abbiendi et al JINST (2020) 15 P01017



Pseudo-data sample:
- $E_{beam} \rightarrow$ + 6 MeV
- $\sigma_{Intr} \rightarrow$ + 5%
- $\sigma_{MS} \rightarrow$ + 0.5%

Fit results
$K = 0.135 \pm 0.026$ $\mu_{E_{Beam}} = (5.9 \pm 0.5)$ MeV $\mu_{Intr} = (4.99 \pm 0.02)\%$ $\mu_{MS} = (0.51 \pm 0.03)\%$

Slide from R.N. Pilato – SIF 2022

THANK YOU!