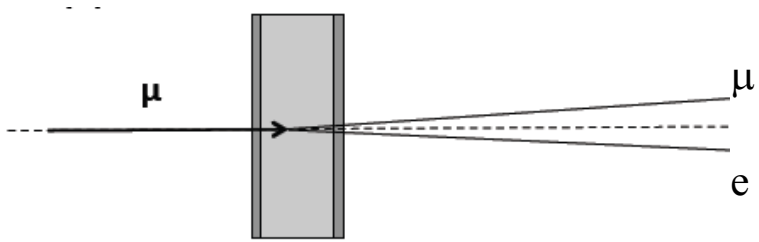
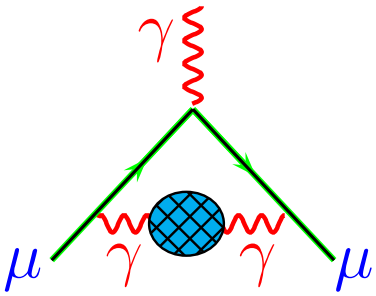
# The MUonE experiment

## a high precision measurement of $a_\mu^{HLO}$ with a 150 GeV $\mu$ beam on $e^-$ target at CERN

G. Venanzoni
INFN-Pisa





ICHEP2018 7 July 2018

# Reference papers

## A new approach to evaluate the leading hadronic corrections to the muon $g$-2 ☆

C. M. Carloni Calame[a], M. Passera[b], L. Trentadue[c], G. Venanzoni[d]

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[d] *INFN, Laboratori Nazionali di Frascati, Frascati, Italy*

Phys. Lett. B 746 (2015) 325

## Measuring the leading hadronic contribution to the muon $g$-2 via $\mu e$ scattering

G. Abbiendi[1], C. M. Carloni Calame[2], U. Marconi[1], C. Matteuzzi[3], G. Montagna[4,2], O. Nicrosini[2], M. Passera[5], F. Piccinini[2], R. Tenchini[6], L. Trentadue[7,3], and G. Venanzoni[8]

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[7] *Dipartimento di Fisica e Scienze della Terra "M. Melloni", Università di Parma, Parma, Italy*
[8] *INFN, Laboratori Nazionali di Frascati, Frascati, Italy*

Eur. Phys. J. C (2017) 77: 139.

# Muon g-2: summary of the present status

- E821 experiment at BNL has generated enormous interest:

$$a_m^{E821} = 11659208.9(6.3)\,´\,10^{-10} \quad \text{(0.54 ppm)}$$

- Tantalizing ~3σ deviation with SM (persistent since >10 years):

$$a_m^{SM} = 11659182.3(4.3)\,´\,10^{-10}$$

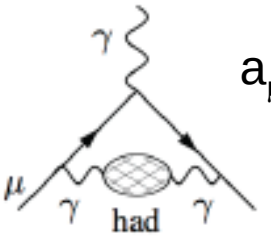
M. Davier, A. Hoecker, B. Malaescu and Z. Zhang, Eur. Phys. J. C77 (2017)

$$\boxed{a_m^{E821} - a_m^{SM} \sim (26.8 \pm 7.6)\,´\,10^{-10} (3.5s)}$$

- Current discrepancy limited by:
  - Experimental uncertainty→ New experiments at FNAL and J-PARC **x4** accuracy
  - Theoretical uncertanty→ limited by hadronic effects

$$a_m^{SM} = a_m^{QED} + \boxed{a_m^{HAD}} + a_m^{Weak}$$

Hadronic Vacuum polarization (HLO)




$a_\mu^{HLO} = (693.1 \pm 3.4)10^{-10}$

$\delta a_\mu / a_\mu \sim 0.5\% \rightarrow 0.2\%$

G. Venanzoni, ICHEP 2018 Seoul, 7 July 2018

# $a_\mu^{HLO}$ calculation, traditional way: time-like data

[C. Bouchiat, L. Michel,'61; N. Cabibbo, R. Gatto 61;
L. Durand '62-'63; M. Gourdin, E. De Rafael, ' 69;
S. Eidelman F. Jegerlehner ' 95,. . . .]

- Optical theorem and analyticity:

$$\sigma(s)_{(e^+e^-\to had)} = \frac{4\pi}{s}\,\mathrm{Im}\,\Pi_{hadron}(s)$$

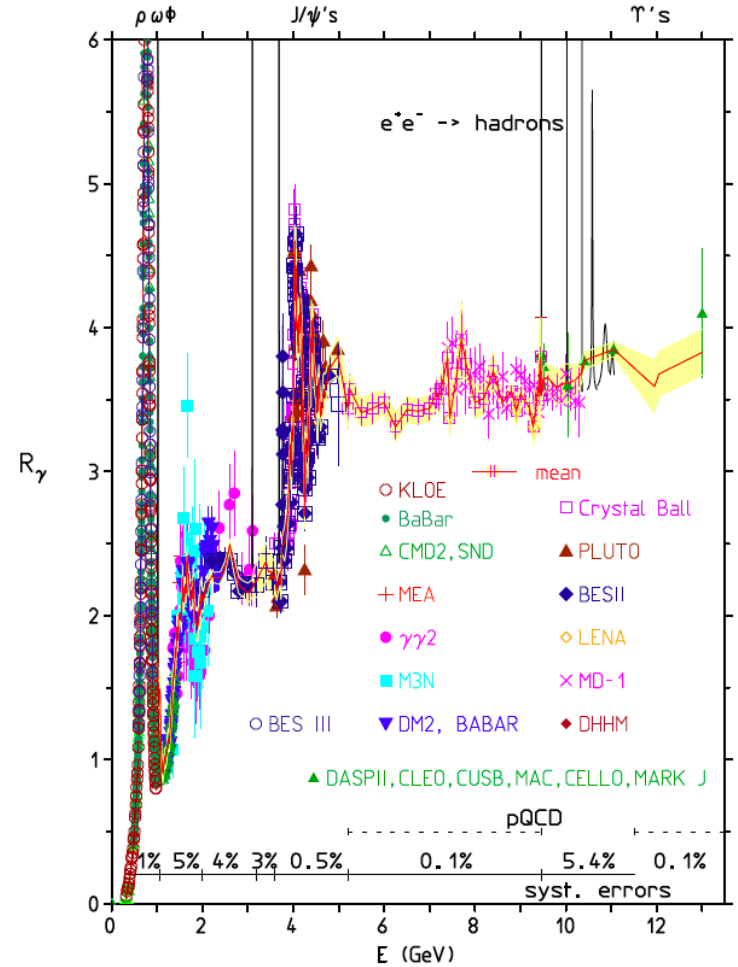
$$a_\mu^{HLO} = \frac{1}{4\pi^3}\int_{4m_\pi^2}^{\infty} ds\, K(s)\cdot\sigma(s)_{(e^+e^-\to had)}$$

- The main contribution is in the highly fluctuating low energy

$$K(s) = \int_0^1 dx\,\frac{x^2(1-x)}{x^2+(1-x)(s/m^2)} \sim \frac{1}{s}$$

The enhancement at low energy implies that the $\rho \to \pi^+\pi^-$ resonance is dominating the dispersion integral (~ 75 %). Current precision at 0.6%→ need to be reduced by a factor **~2**

**Collection of many experimental results**



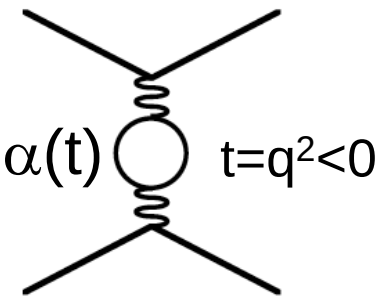

The high-energy tail of the integral is calculated using pQCD

$\Delta^{SM-BNL}$~ 4% of $a_\mu^{HLO}$

# Alternative approach: $a_\mu^{HLO}$ from space-like region

[C.M. C. Calame et al, Phys. Lett. B 746 (2015) 325]

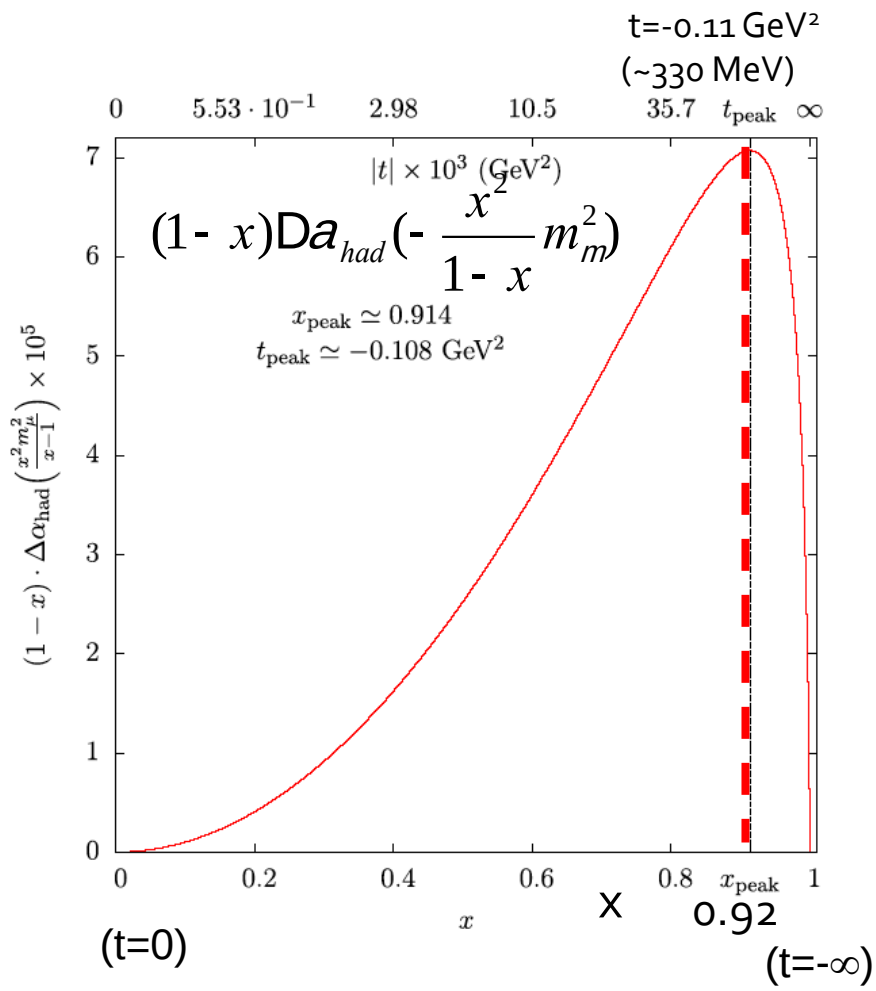
$$a_\mu^{HLO} = \frac{\alpha}{\pi}\int_0^1 dx\,(1-x)\cdot\Delta\alpha_{had}\left(-\frac{x^2 m_\mu^2}{1-x}\right)$$




$$t = \frac{x^2 m_m^2}{x - 1} \qquad 0 \text{ £ } - t < +¥$$

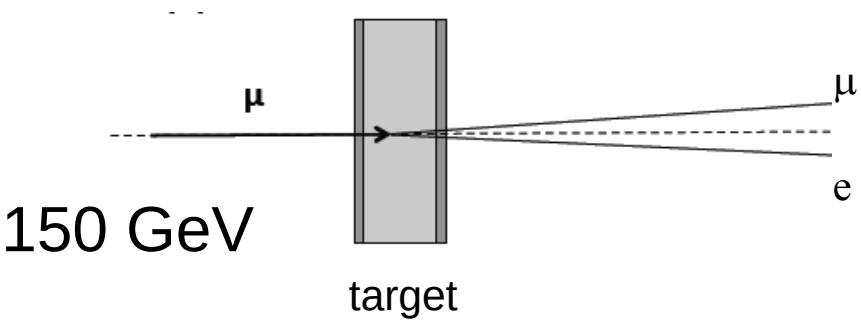
$$x = \frac{t}{2m_m^2}\left(1 - \sqrt{1 - \frac{4m_m^2}{t}}\right); \qquad 0 \text{ £ } x < 1;$$

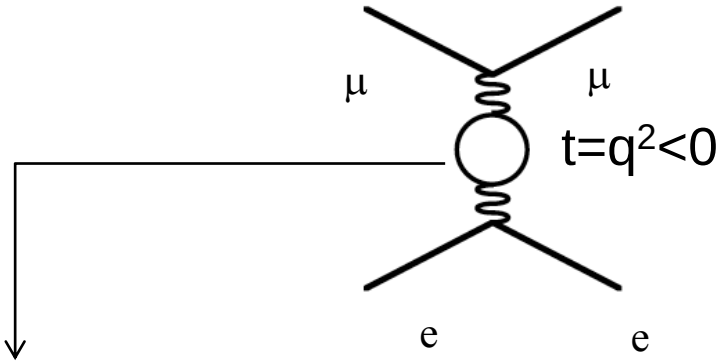
- **$a_\mu^{HLO}$ is given by the integral of the curve** (smooth behaviour)
- **It requires a measurement of** the hadronic contribution to the effective electromagnetic coupling in the space-like region **$\Delta\alpha_{had}$(t) (t=q²<o)**
- **It enhances** the contribution from **low** q² region (below 0.11 GeV²)
- **Its precision** is determined by the **uncertainty** on $\Delta\alpha_{had}$ (t) in this region



# Experimental approach:

**Use of a 150 GeV μ beam on Be target at CERN** (elastic scattering μe →μ e) to get $\Delta\alpha_{had}(t<0)$




$$\left|\frac{a(t)}{a_0}\right|^2 = \left|\frac{1}{1-\mathrm{D}a(t)}\right|^2$$

**Measuring the leading hadronic contribution to the muon g-2 via** μe **scattering,** G. Abbiendi *et al*, Eur.Phys.J. C77 (2017) no.3, 139

# Why measuring $\Delta\alpha_{had}(t)$ with a 150 GeV μ beam on $e^-$ target ?

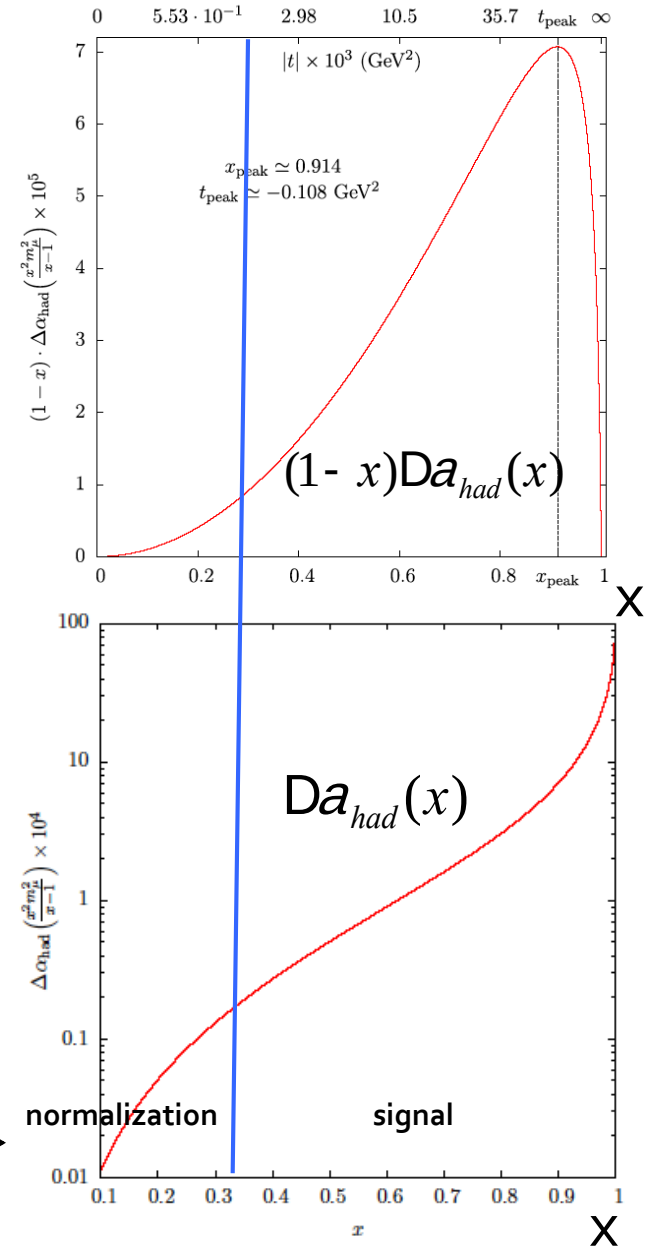
It looks an ideal process!

- $\mu\, e \rightarrow \mu\, e$ is pure t-channel (at LO)
- It gives $0<-t<0.161$ GeV² ($0<x<0.93$)
- The kinematics is very simple: $t=-2m_eE_e$
- High boosted system gives access to all angles (t) in the cms region

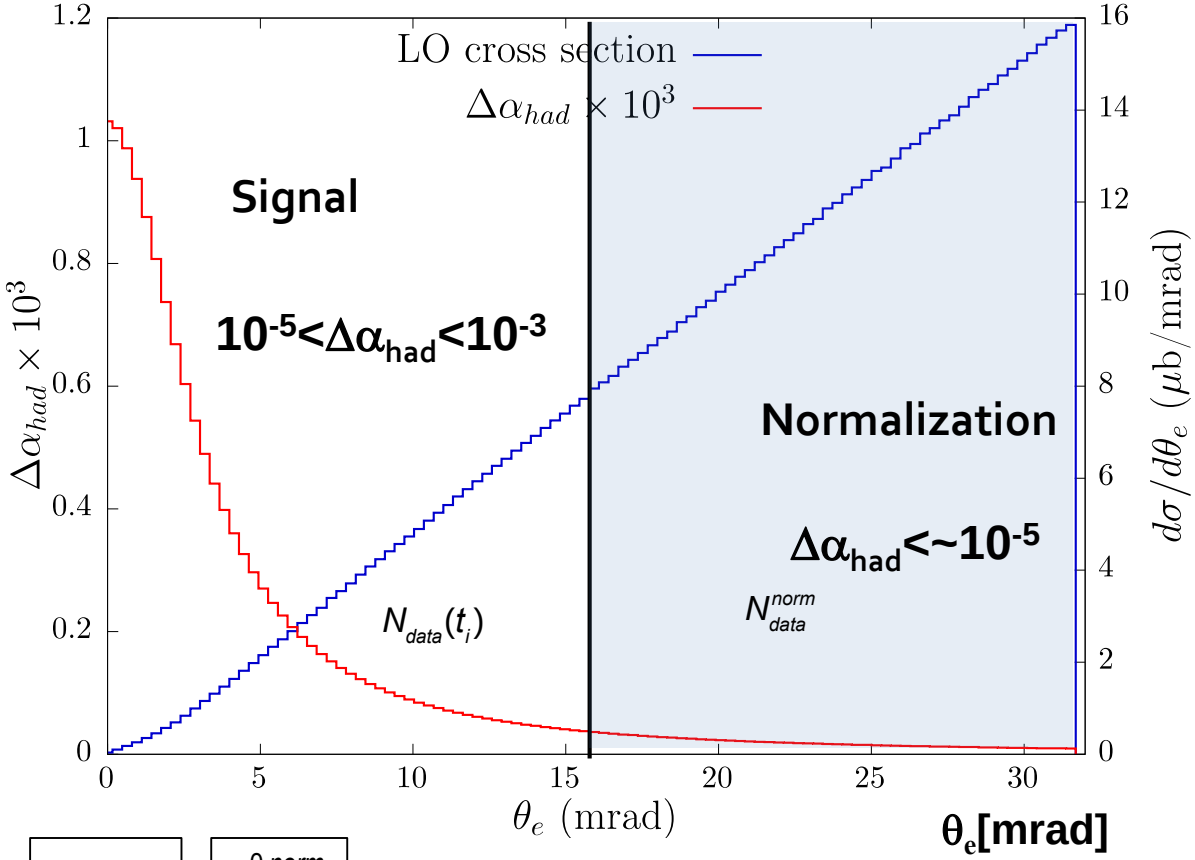
  $\theta_e^{LAB}$<32 mrad ($E_e$>1 GeV)
  $\theta_\mu^{LAB}$<5 mrad

- It allows using the same detector for signal and normalization
- Events at $x \lesssim 0.3$ ($t \sim -10^{-3}$ GeV²) can be used as normalization ($\Delta\alpha_{had}(t) \lesssim 10^{-5}$)

$t_{max}$=-0.11GeV²



# MUonE : signal/normalization region




$$\frac{N_{data}(t_i)}{N^0_{MC}(t_i)} = \frac{N_{data}(t_i)}{N^{norm}_{data}} \times \frac{s^{0,norm}_{MC}}{s^0_{MC}(t_i)} \sim 1 - 2(\Delta a_{lep}(t_i) + \Delta a_{had}(t_i))$$

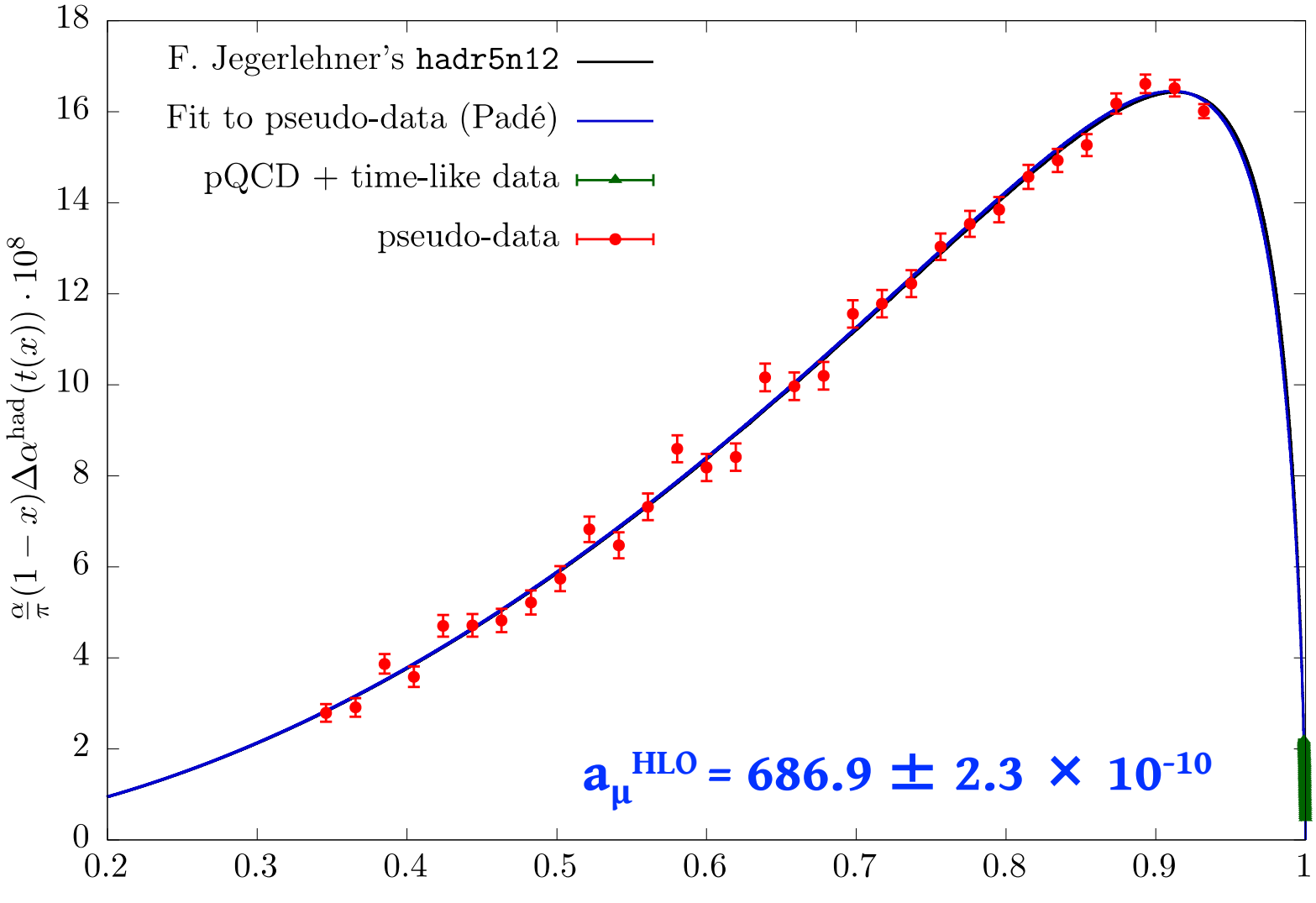
Ratio of the theoretical cross section (with no VP)

Ratio of data $N_{signal}(t)/N_{normalization}$

$a_\mu^{HLO}$ at 0.3% → These two ratios should be known at $10^{-5}$

# Statistical reach of MUonE on $a_\mu^{HLO}$

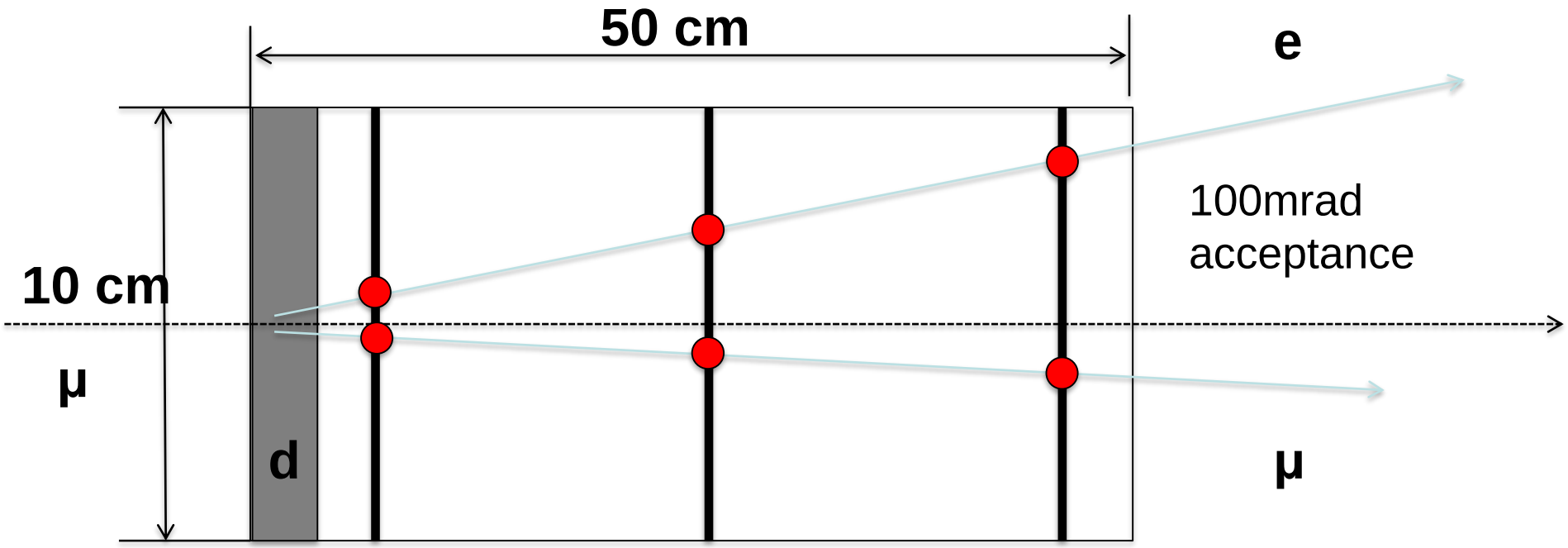
## (2 years of data taking at 1.3 x10$^7$μ/s)




A **0.3%** stat error can be achieved on $a_\mu^{HLO}$ in 2 years of data taking with ~10$^7$ μ/s (4x10$^{14}$μ total)

# Measuring e- and muon angle:

## Repetition (x50) of this single module




~1cm
Be Target

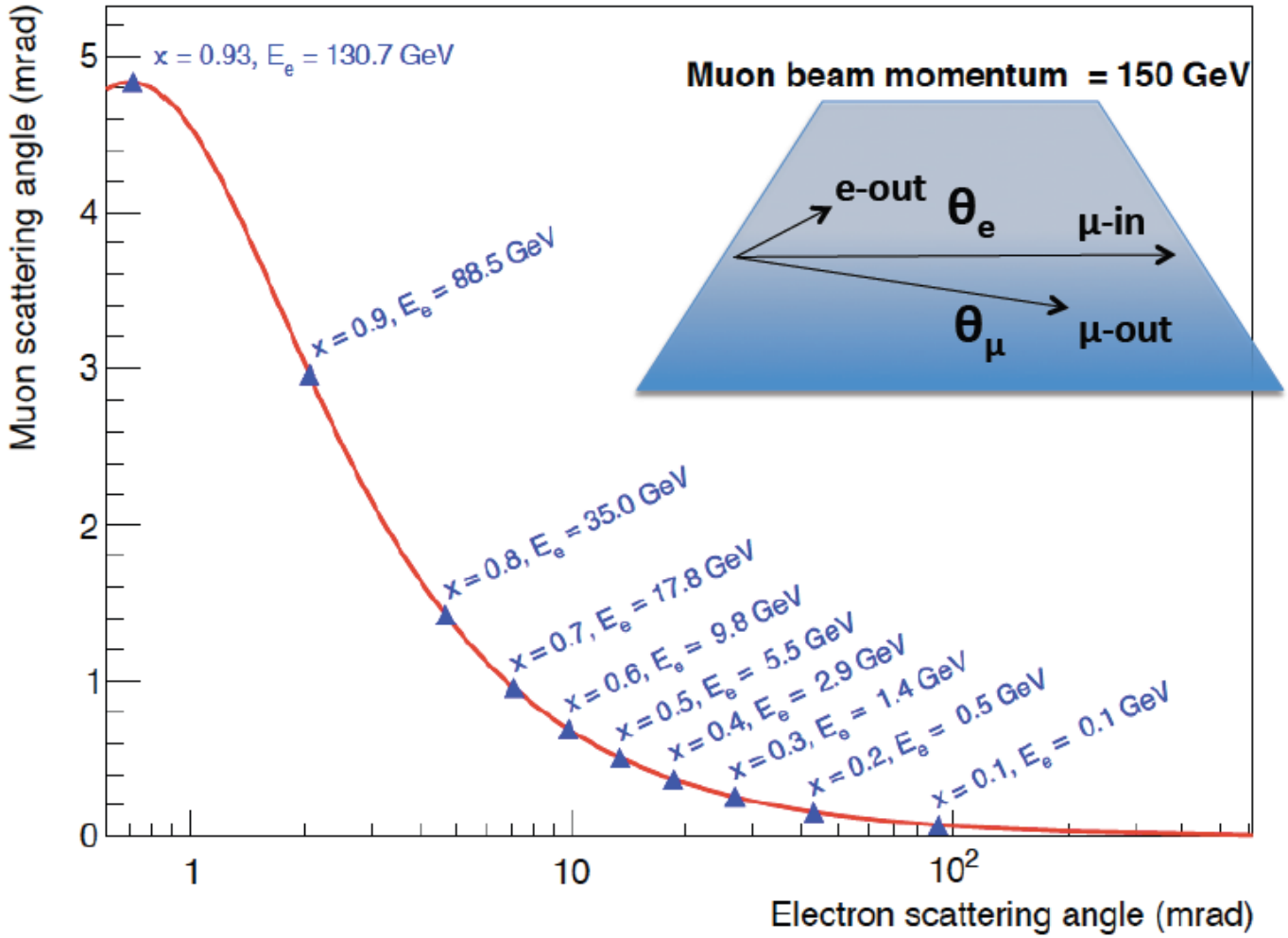
State-of-art Silicon detectors

hit resolution ~10 μm

expected angular resolution ~ 10 μm / 0.5 m = 0.02 mrad

# Elastic scattering in the ($\theta_e$ , $\theta_\mu$) plane

Coplanarity of the momentum vectors and angular kinematical constraint



# Systematics

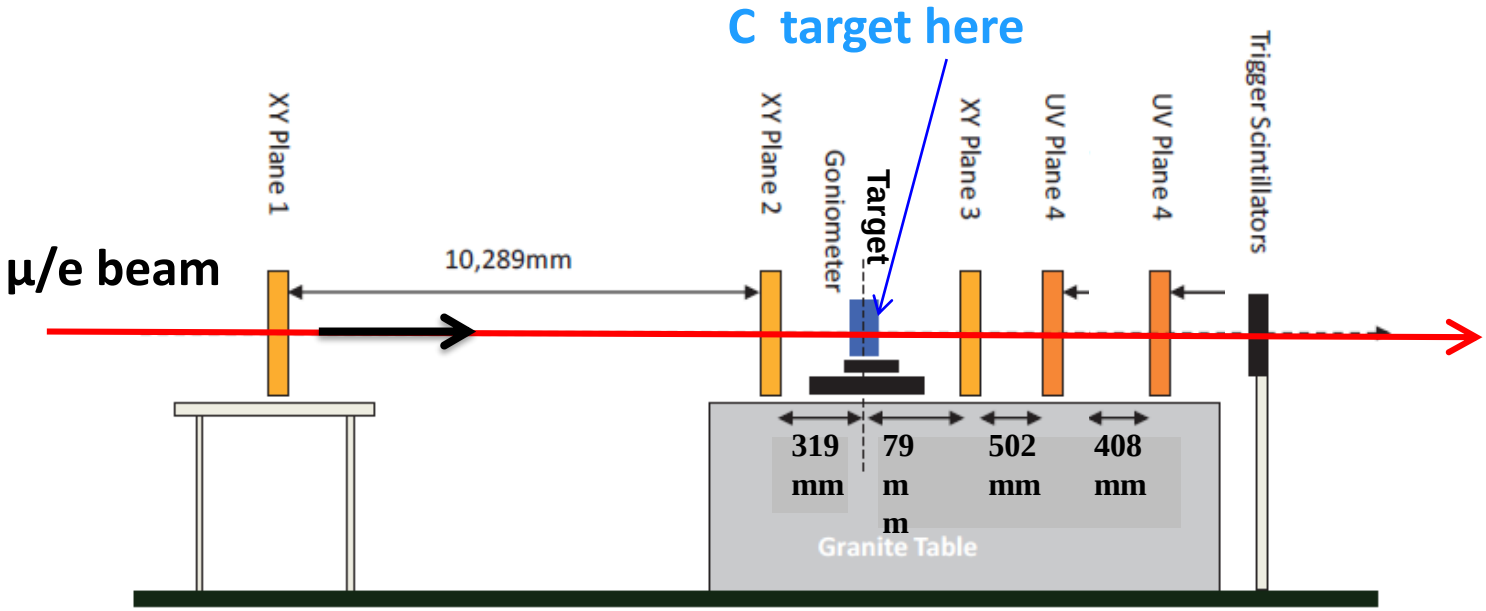
1. Multiple scattering
2. Tracking (alignment & misreconstruction)
3. PID
4. Knowledge of muon momentum distribution
5. Background
6. Theoretical uncertainty on the mu-e cross section (see later)
7. …

**All the systematic effects must be known to ensure an error on the cross section < 10ppm**

# Multiple Scattering studies: Results from Test Beam 2017

## Check GEANT MSC prediction and populate the 2D ($\theta_e$ , $\theta_\mu$) scattering plane

- 27 Sep-3 October 2017 at CERN "H8 Beam Line"
- Adapted UA9 Apparatus
- Beam energy: e- of 12/20 GeV; $\mu$ of 160 GeV
- $10^7$ events with C targets of different thickness (2,4,8,-20mm)

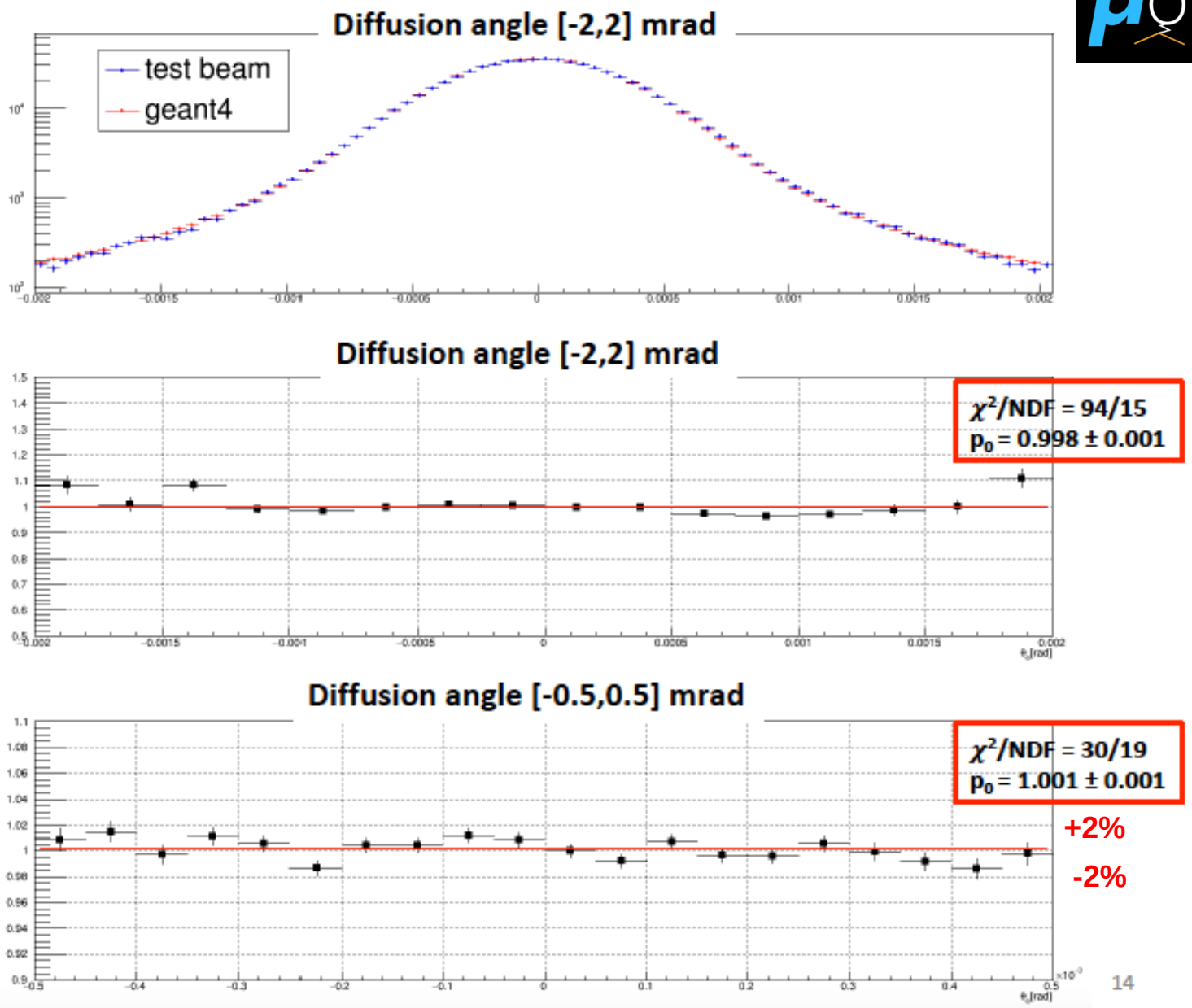



Adapted UA9 apparatus

5 Si planes: 2 before and 3 after the target, 3.8x3.8 cm2 intrinsic resolution ~**100**μrad

# MS studies with e-

20mm, 12 GeV






G. Venanzoni, ICHEP 2018 Seoul, 7 July 2018

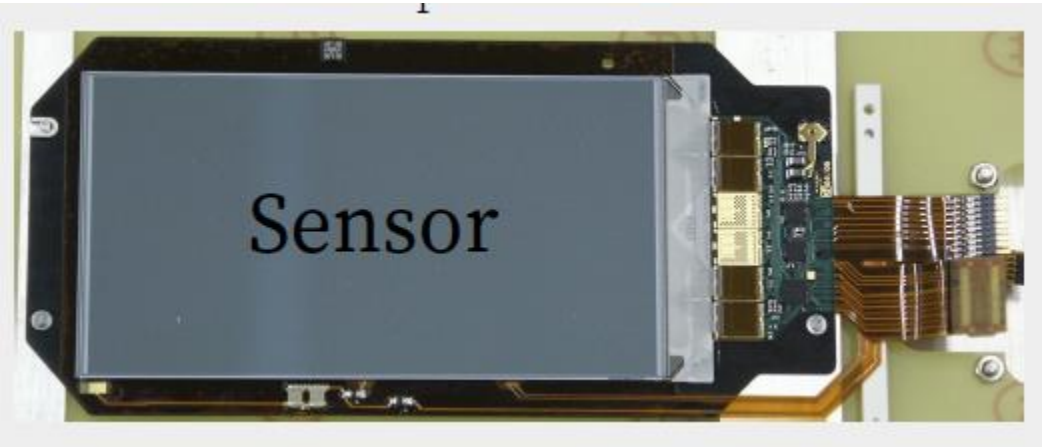
# Detector optimization

- Target thickness (10mm Be default)
- Silicon sensors (type, material)
- Number of tracking stations per unit (3-4)
- Dimension of apparatus
- Calorimetry/PID
- Trigger/DAQ
- …

# Silicon detectors survey

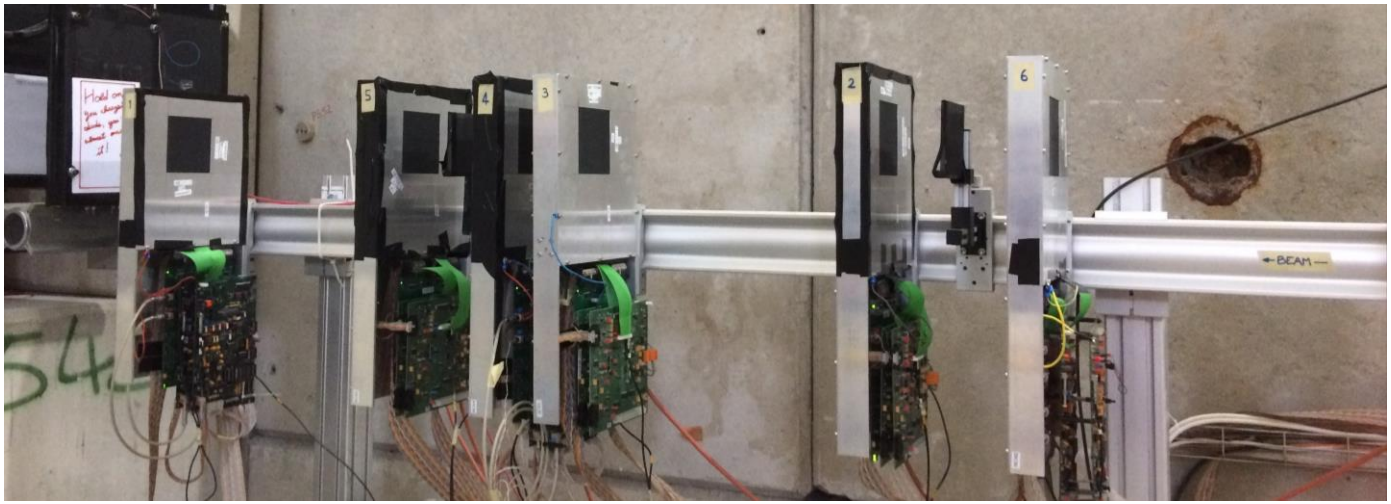
*Stefano Mersi - MUonE Mainz Workshop 2018*

| | **ALICE** Upg Inner | **ALICE** Upg Outer | **CMS** Upg 2S | 2×**CMS** Upg 2S | **CMS** Upg PS | **CMS** Upg Pixel | 2×**CMS** Current | **Mimosa26** | **LHCb** VELO-pix |
|---|---|---|---|---|---|---|---|---|---|
| Technology | MAPS | MAPS | Hybrid strip | Hybrid strip | Hybrid strip/px | Hybrid pixel | Hybrid strip | MAPS | Hybrid pixel |
| active x [cm] | 27 | 21 | 10 | 10 | 10 | 33 | 10 | 1.06 | 4.246 |
| active y [cm] | 1.5 | 3 | 10 | 10 | 5 | 44.2 | 10 | 2.12 | 1.408 |
| pixel size x [μm] | 30 | 30 | 90 | 90 | 100 | 50 | 90 | 18.4 | 55 |
| pixel size y [μm] | 30 | 30 | 50000 | 90 | 1400 | 50 | 50000 | 18.4 | 55 |
| σx [μm] | 2 | 2 | 26 | 26 | 29 | 7 | 18 | 3.2 | 12 |
| σy [μm] | 2 | 2 | 14434 | 26 | 404 | 7 | 18 | 3.2 | 12 |
| Material [$x/X_0$] | 0.3% | 0.8% | 2.3% | 4.5% | 3.8% | 2.0% | 4.5% | 0.10% | 0.94% |
| Sensor mat. [$x/X_0$] | 0.3% | 0.8% | 0.3% | 0.6% | 3.8% | 2.0% | 0.6% | 0.10% | 0.94% |



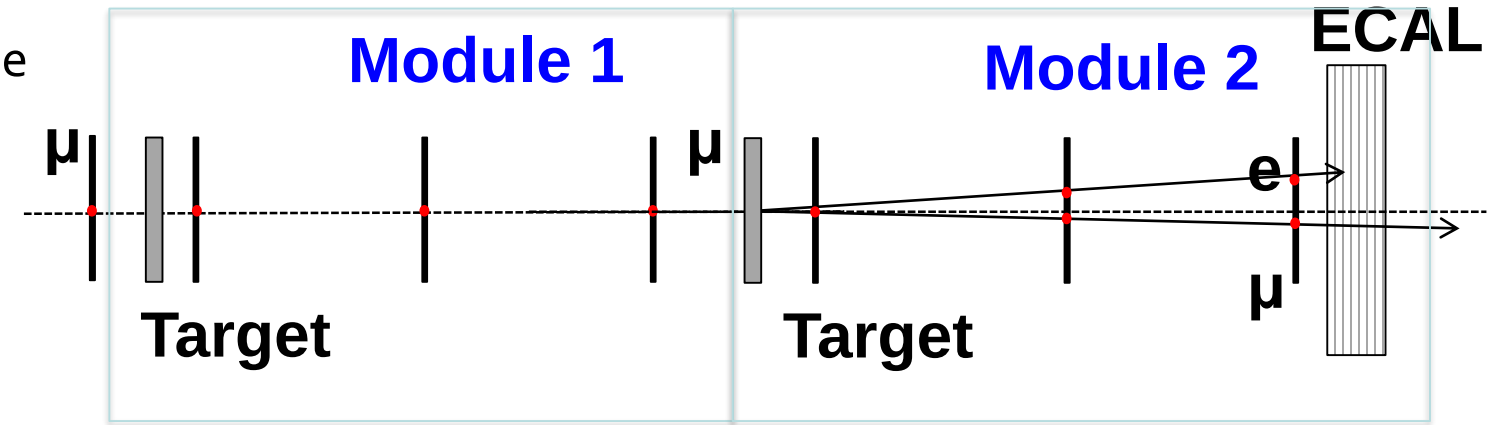
# 2018 Test run:
# Full scale prototype (2 modules) on M2 muon beam at CERN behind Compass

- Study of the detector performance: signal/background; tracking efficiency; understand the systematics



- It takes data since April 9

- 300M events already collected



# Theory

- QED NLO MC generator with full mass dependence has been developed and is currently under use (Pavia group)
- Results obtained for the NNLO box diagrams contributing to mu-e scattering in QED (Padova group)

**Master integrals for the NNLO virtual corrections to $\mu e$ scattering in QED: the planar graphs**

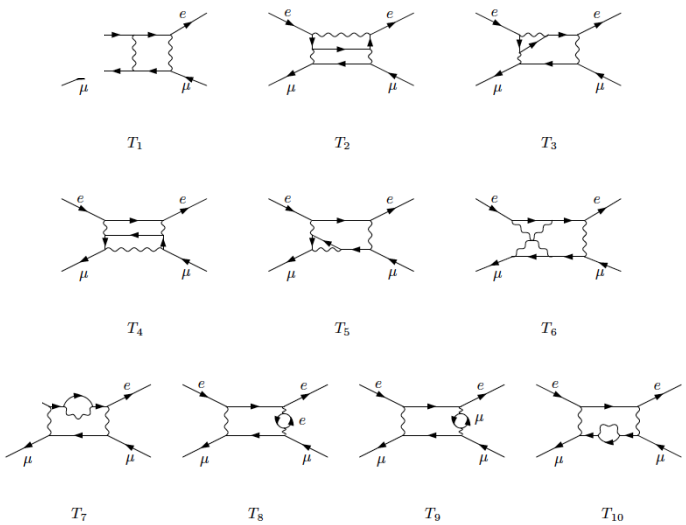
JHEP1711(2017)198

Pierpaolo Mastrolia,[a,b] Massimo Passera,[b] Amedeo Primo,[a,b] Ulrich Schubert[c]

**Master integrals for the NNLO virtual corrections to $\mu e$ scattering in QED: the non-planar graphs**

Stefano Di Vita,[a] Stefano Laporta,[b,c] Pierpaolo Mastrolia,[b,c] Amedeo Primo,[d] Ulrich Schubert[e]

1806.08241




- An unprecedented precision challenge for theory: a full NNLO MC generator for μ-e scattering ($10^{-5}$ accuracy)

# Theory: international community!

- 2017: Sept 4-5: A kick-off theory meeting in Padova: https://agenda.infn.it/internalPage.py?pageId=0&confId=13774 .


- 2018, Feb 19-23: A Topical workshop at MIPT, Mainz https://indico.mitp.uni-mainz.de/event/128/

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

mitp Mainz Institute for Theoretical Physics

The Evaluation of the Leading Hadronic Contribution to the Muon Anomalous Magnetic Moment

- 2019, Feb 4-7: Workshop on "Theory for muon-electron scattering @ 10ppm" in Zurich

# Status of the Collaboration and plans

- Collaboration is growing and interest from International groups from CERN, Poland, Russia (Novosibirsk), UK, USA (Virginia) has been expressed.

- Results so far encouraging; we are part of "Physics Beyond Collider" process at CERN (http://pbc.web.cern.ch/); we had a very good PBC review on March 2018.

- We aim to write a LoI in 2019; to construct and install the detector (funding allowing) in 2020-2021, and to start data taking in 2021/22 for 2 years (with a pilot run first)

# Conclusion

- Exciting times for the muon g-2!
- Alternative/competitive determinations of $a_\mu^{HLO}$ are essential:
  - Time-like (dispersive) approach
  - Lattice
  - Space-like approach (MUonE)

- Progress on **MUonE**:
  - Analysis of MS 2017 TB data
  - Detector optimization
  - Silicon detector procurement
  - Progress on the Theory side
  - Test run in 2018; planned tests for 2019
  - Growing interest from both experiment and theory community
  - LoI planned for 2019; if approved/funded start of data taking in 2021/22 for 2 years (with a pilot run first)

# MUonE Collaboration (in progress)

G. Abbiendi, M. Alacevich, M. Bonomi, C. Brizzolari, A. Broggio, C.M.Carloni Calame, E. Conti, D. Galli, M. Fael, A. Ferroglia, F.V. Ignatov, M. Incagli, A. Keshavarzi, F. Ligabue, U. Marconi, M.K. Marinković, V. Mascagna, P. Mastrolia, C. Matteuzzi, S. Mersi, G. Montagna, O. Nicrosini, G. Ossola, L. Pagani, M. Passera, P. Paradisi, C. Patrignani, F. Piccinini, F. Pisani, M. Prest, A. Primo, A. Principe, M. Rocco, U. Schubert, F. Simonetto, R. Stroili, L. Tranchedi, R. Tenchini, W. Torres-Bodabilla, L. Trentadue, E. Vallazza, G. Venanzoni,...

THE END

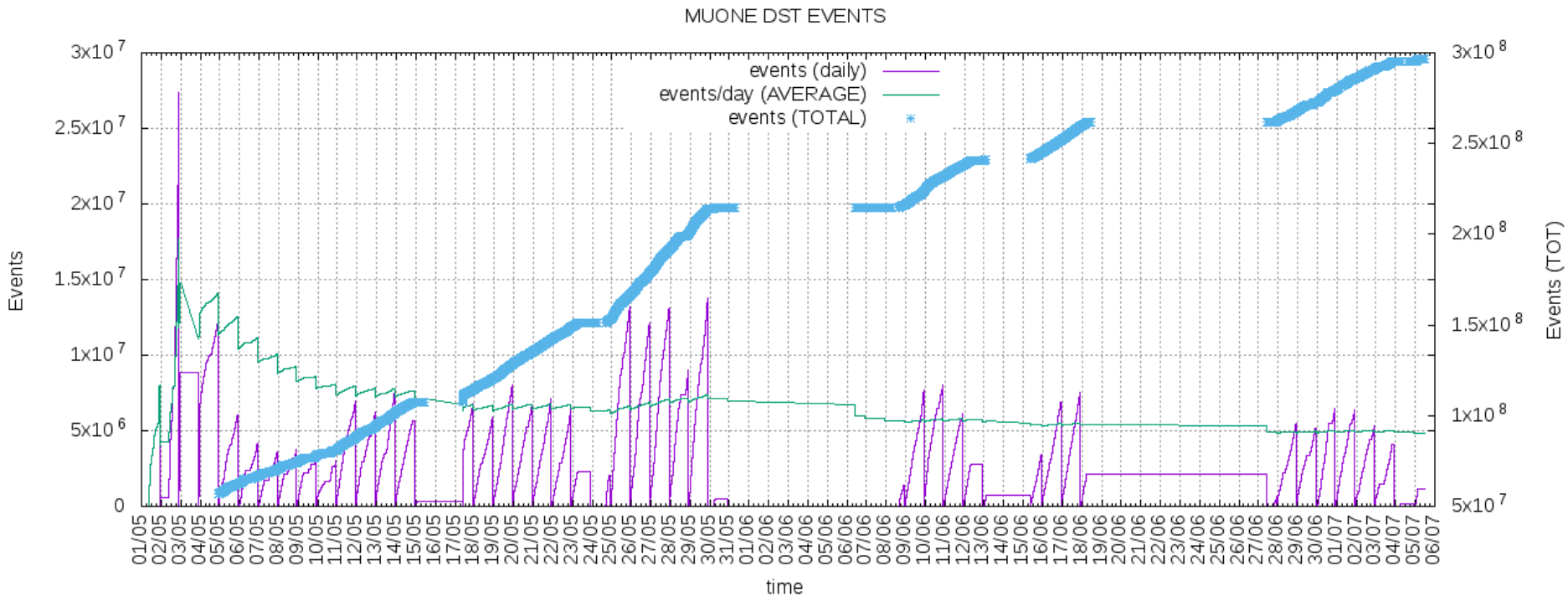
# SPARE

# EXPERIMENTAL SETUP

Picture taken on 4/8/18

# Test Beam 2018

- Setup mounted in April 3-9;
- It take data since April 9
- 300M events already collected (>1TB);
- Rate: 5Mev/day (20GB/day)

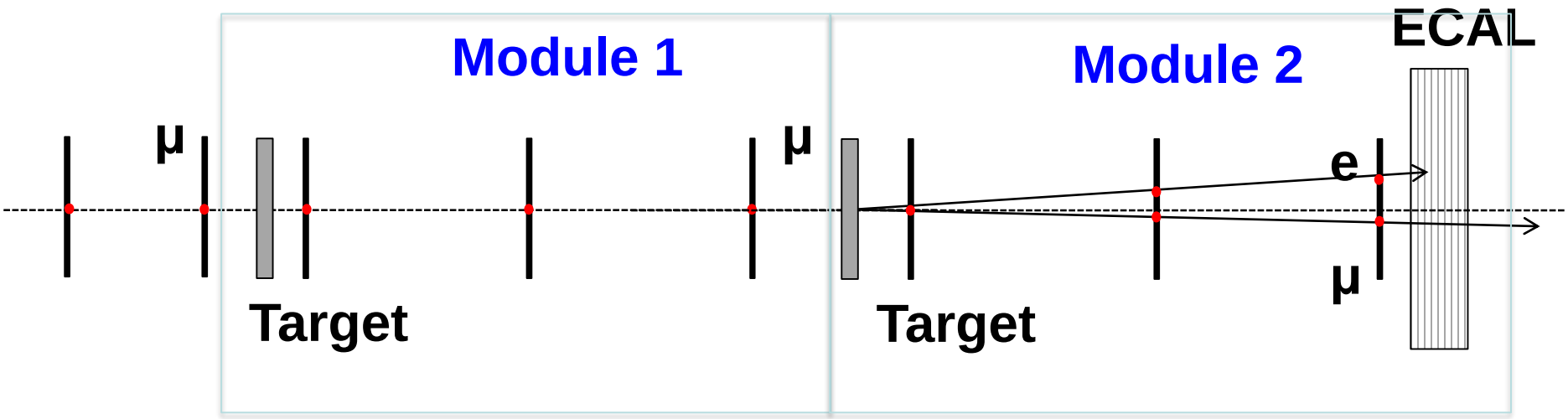


# Outline

- Muon g-2: summary of the present status
- The MUonE proposal: a novel approach to compute $a_\mu^{HLO}$ in the space-like region with $\mu e \rightarrow \mu e$ at CERN
- Some recent progress
- Plans & conclusions

# Plans for 2018

**Build up and test a full scale prototype (2 modules).**




- Run of a 2 full scale modules on a muon beam on M2 (behind COMPASS) from April/May
- Study of the detector performance: signal/background; tracking efficiency; understand the systematics
- Data taking is going on!

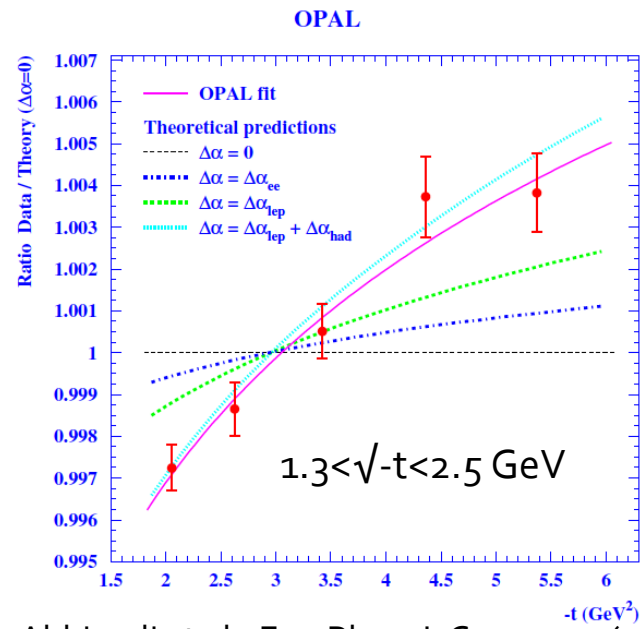
# Measurement of $\Delta\alpha_{had}(t)$ spacelike at LEP

- $\Delta\alpha_{had}$ (t) (t<0) has been measured at LEP using small angle Bhabha scattering

$$f(t) = \frac{N_{\rm data}(t)}{N^0_{\rm MC}(t)} \propto \left(\frac{1}{1-\Delta\alpha(t)}\right)^2 .$$

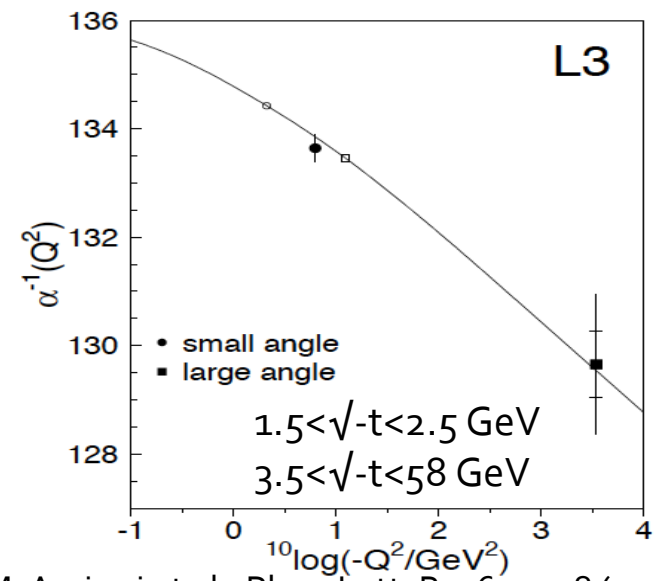
Accuracy at per mill level was achieved!

[see also A. Arbuzov et al. **Eur.Phys.J. C34 (2004) 267-275]**



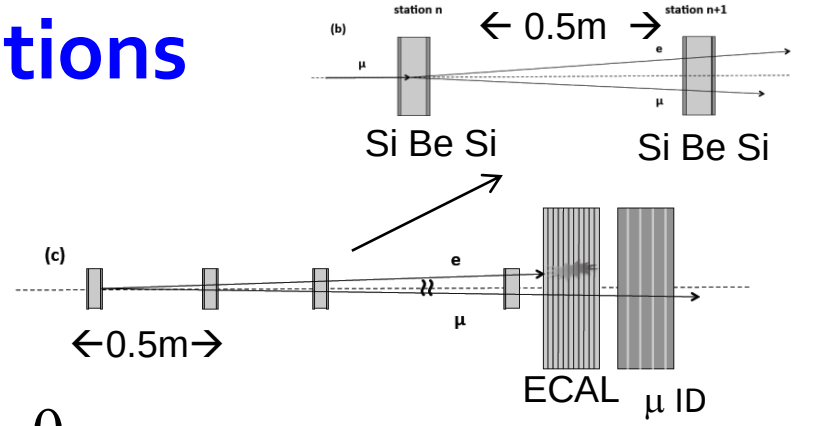

G. Abbiendi et al., Eur. Phys. J. C 45, 1–21 (2006)

- For low t values (≤0.11 GeV²) and higher precision (~$10^{-5}$) as in our case a different approach is needed!




M. Acciarri et al., Phys. Lett. B476 40-48 (2000)

# Detector considerations



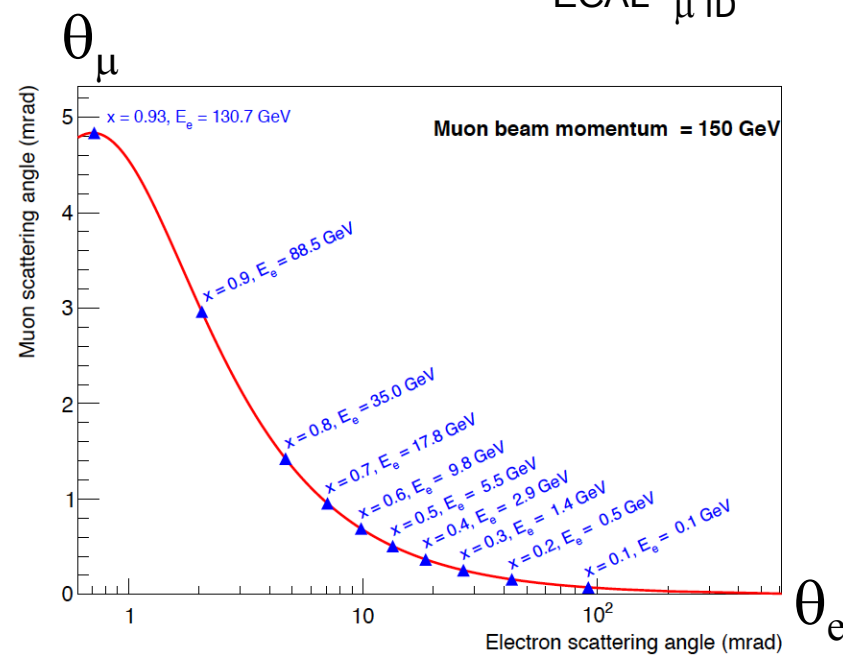

- Modular apparatus: 60 layers of ~1 cm Be (target), each coupled to ~0.5 m distant Si (0.3 mm) planes. It provides a 0.02 mrad resolution on the scattering angle

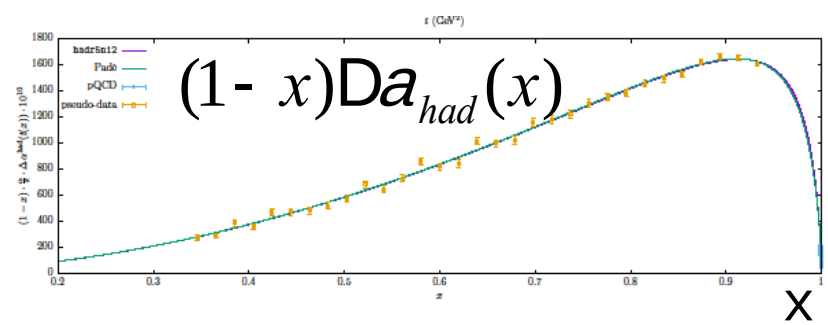
- The $t=q^2<0$ of the interaction is determined by the electron (or muon) scattering angle (a` la NA7)

- ECAL and μ Detector located downstream to solve PID ambiguity below 5 mrad. Above that, angular measurement gives correct PID

- It provides uniform full acceptance, with the potential to keep the systematic errors at $10^{-5}$ (main effect is the multiple scattering for normalization which can be studied by data)

- Statistical considerations show that a **0.3%** error can be achieved on $a_\mu^{HLO}$ in 2 years of data taking with ~$10^7$ μ/s ($4\times10^{14}$μ total)



# Muon beam M2 at CERN

"Forty years ago, on 7 May 1977, CERN inaugurated the world's largest accelerator at the time – the Super Proton Synchrotron".

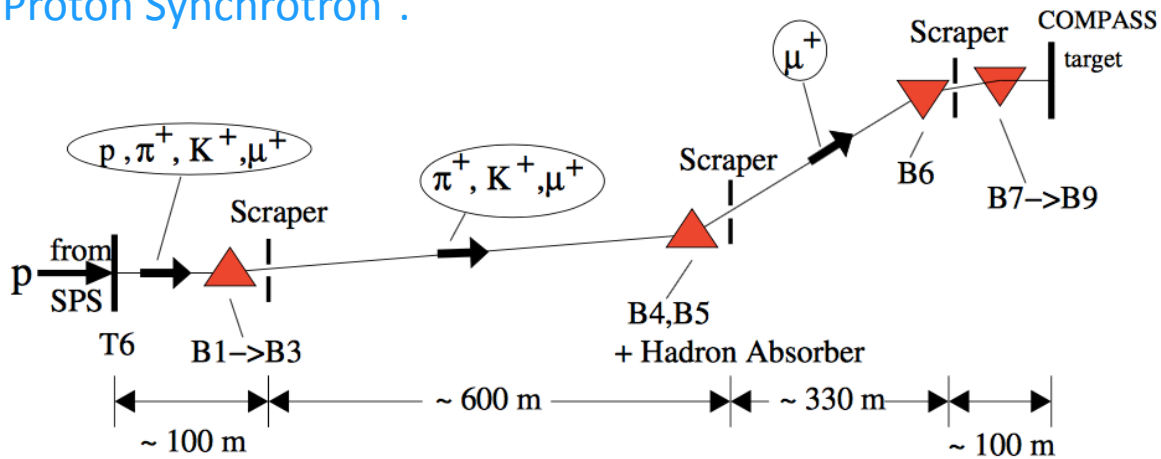


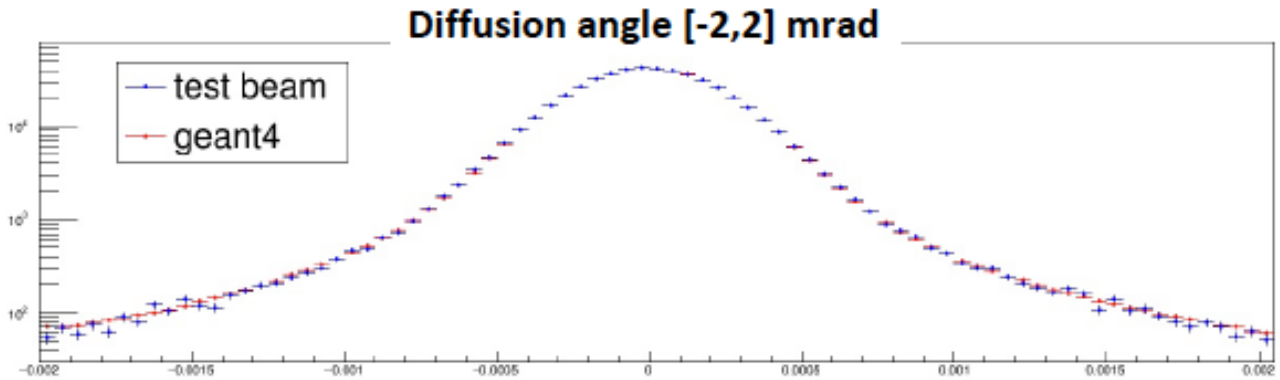

Table 3
Parameters and performance of the 160 GeV/$c$ muon beam.

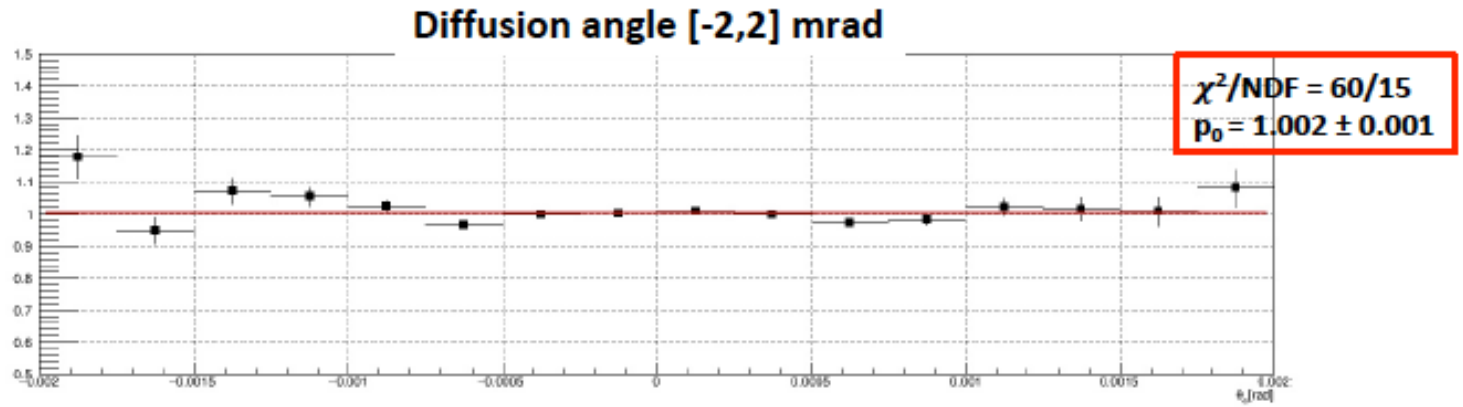
| **Beam parameters** | **Measured** |
|---|---|
| Beam momentum $(p_\mu)/(p_\pi)$ | $(160\,\mathrm{GeV}/c)/(172\,\mathrm{GeV}/c)$ |
| Proton flux on T6 per SPS cycle | $1.2 \cdot 10^{13}$ |
| Focussed muon flux per SPS cycle | $2 \cdot 10^{8}$ |
| Beam polarisation | $(-80 \pm 4)\%$ |
| Spot size at COMPASS target $(\sigma_x \times \sigma_y)$ | $8 \times 8\,\mathrm{mm}^2$ |
| Divergence at COMPASS target $(\sigma_x \times \sigma_y)$ | $0.4 \times 0.8\,\mathrm{mrad}$ |
| Muon halo within 15 cm from beam axis | 16% |
| Halo in experiment $(3.2 \times 2.5\,\mathrm{m}^2)$ at $\lvert x, y\rvert > 15\,\mathrm{cm}$ | 7% |

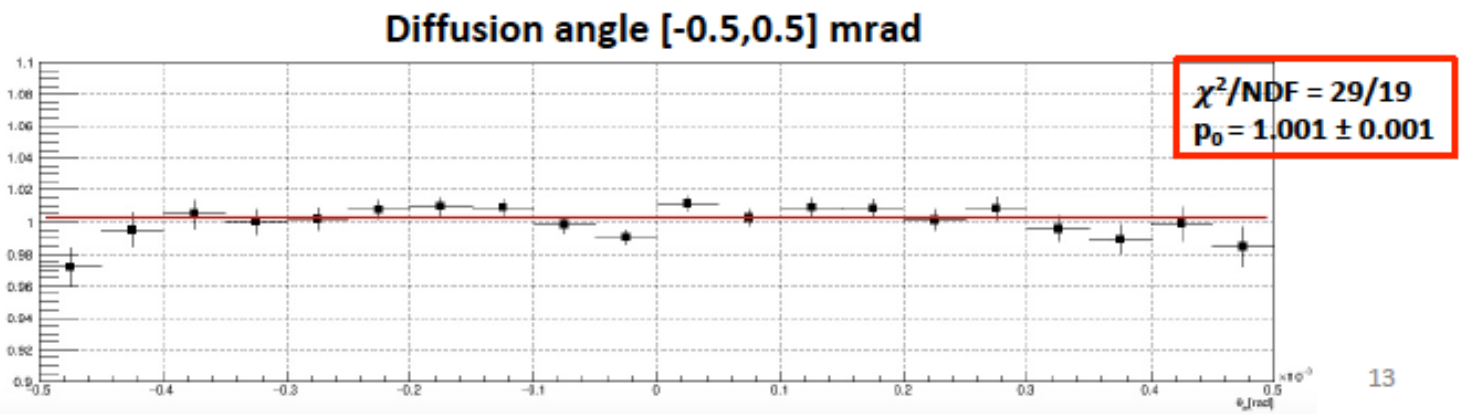
**$I_{beam} > 10^7$ muon/s, $E_\mu$ = 150 GeV**

https://arxiv.org/pdf/hep-ex/0703049.pdf

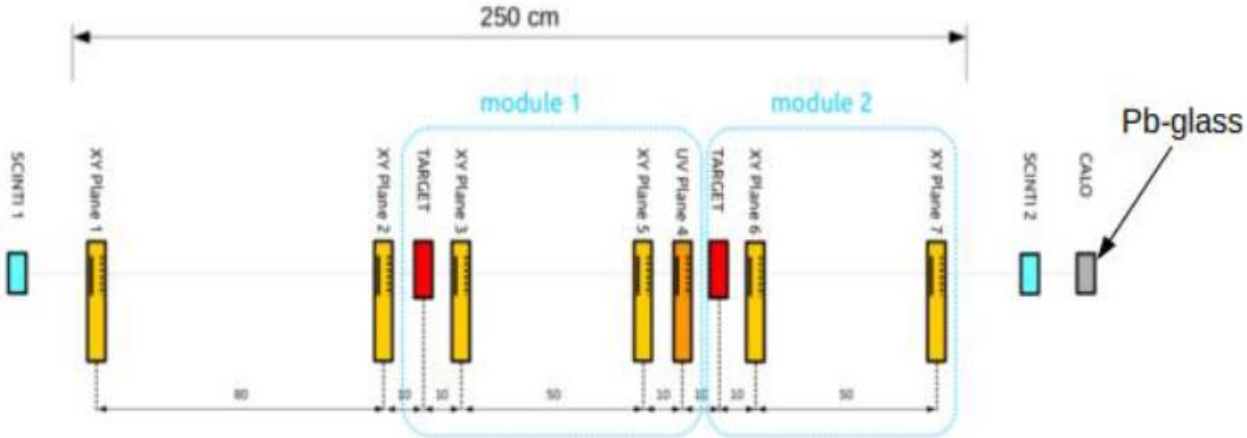
# 8mm, 12 GeV


Diffusion angle [-2,2] mrad
test beam
geant4


Diffusion angle [-2,2] mrad
$\chi^2$/NDF = 60/15
$p_0$ = 1.002 ± 0.001


Diffusion angle [-0.5,0.5] mrad
$\chi^2$/NDF = 29/19
$p_0$ = 1.001 ± 0.001

# Report of A. Magnon (MUonE referee in PBC) 2 March 2018

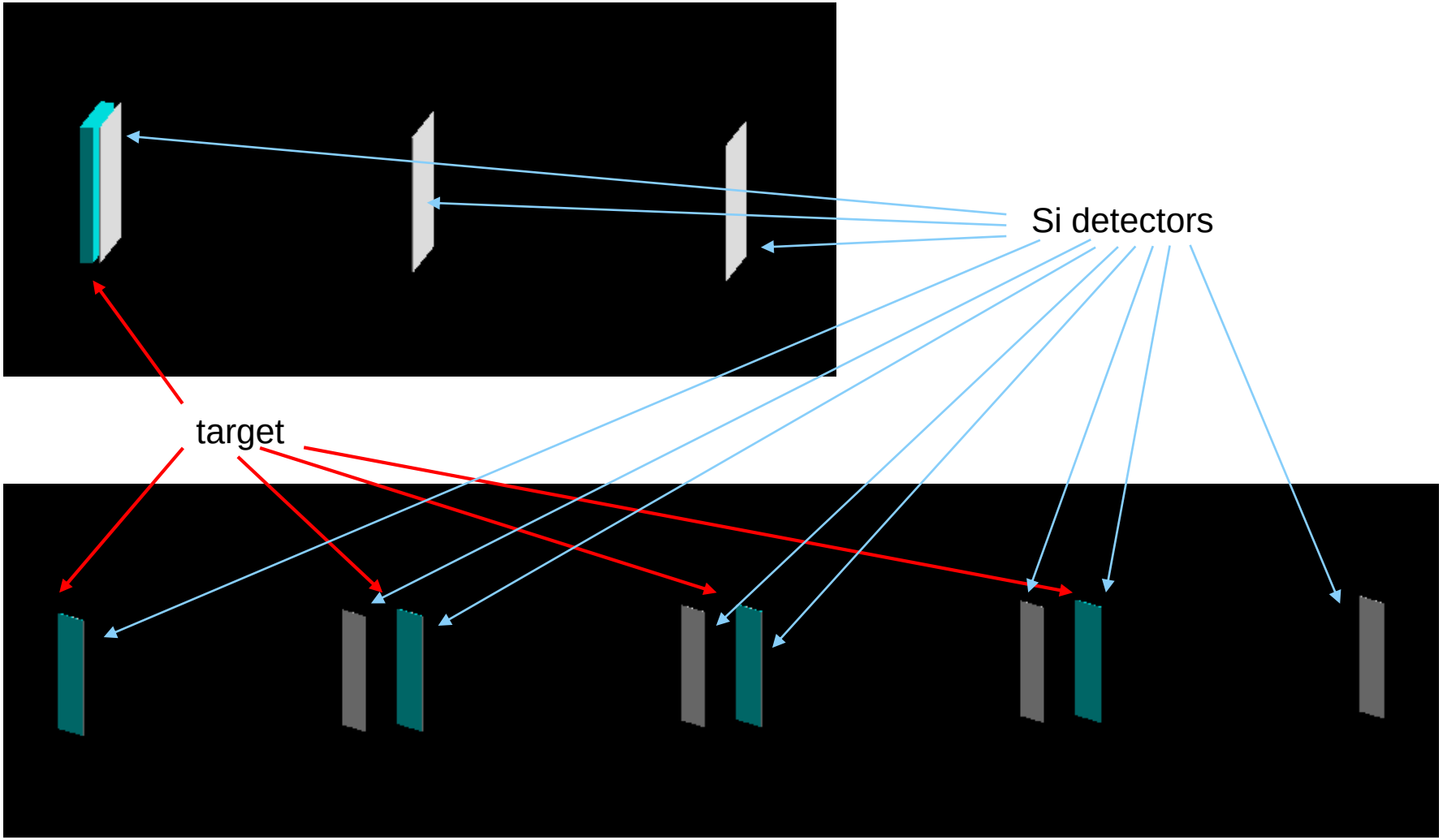




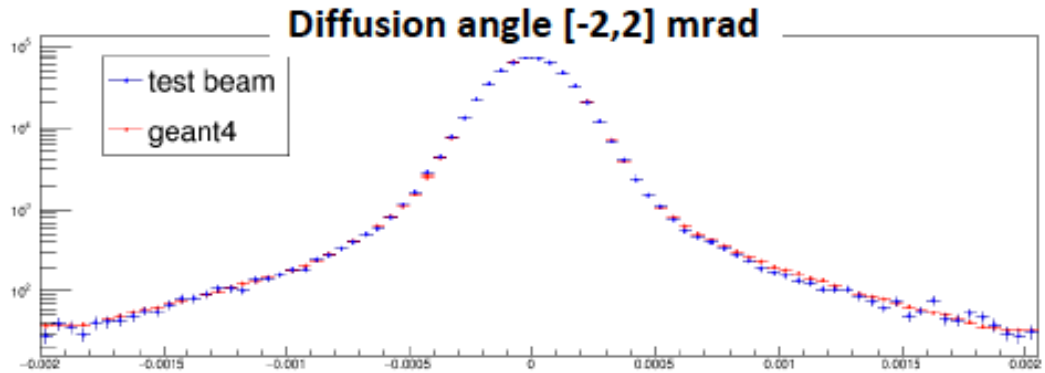
- Expect a lot of physics Input from these tests
  Hope we can run at (close) to nominal μ Flux

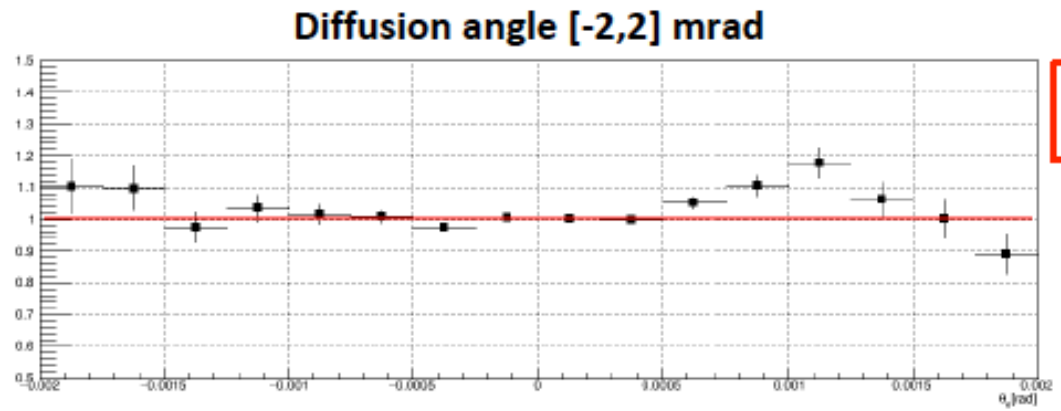
- Concerning the final project for High precision measurement of $a_\mu^{HLO}$
  Certainly very challenging
  I (Alain Magnon) DO NOT SEE a priori showstopper(s)

# Detector optimization

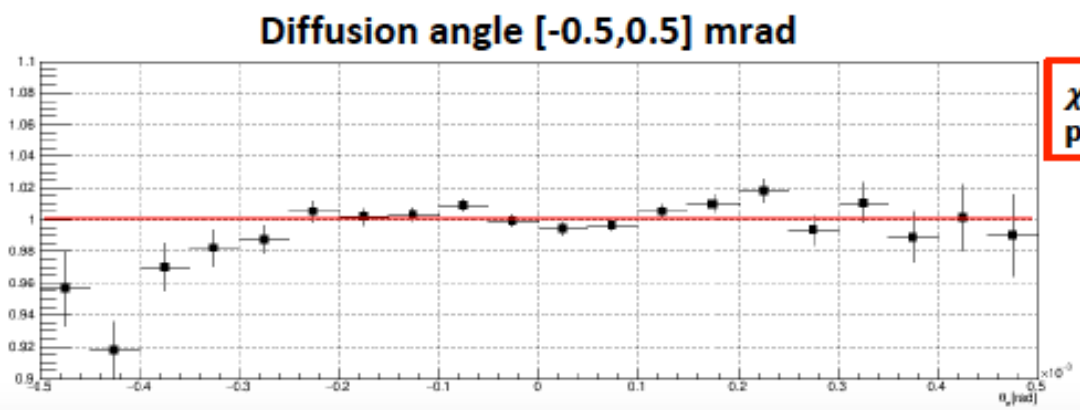


# 8mm, 20 GeV



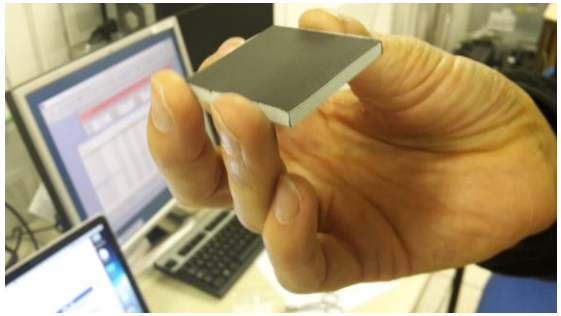

$\chi^2$/NDF = 62/15
$p_0$ = 1.001 ± 0.001

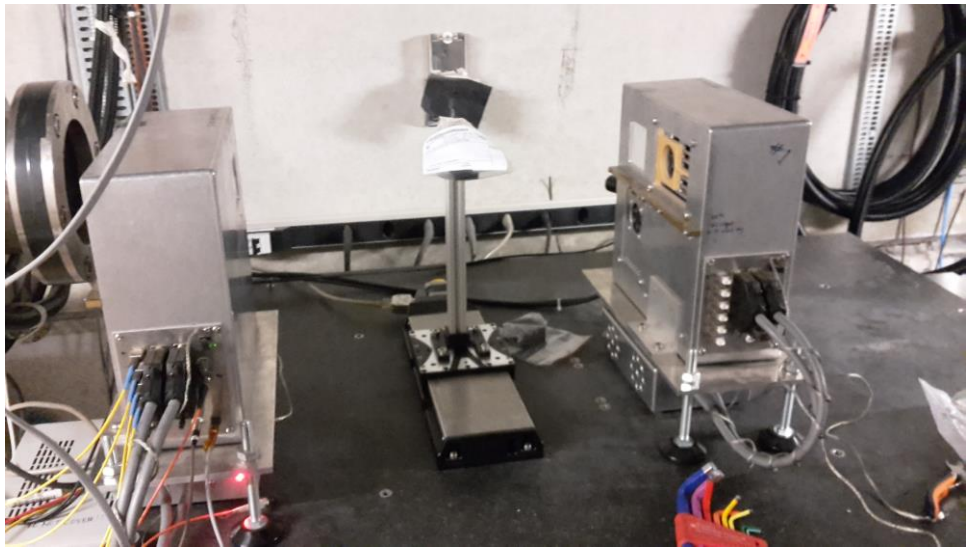



$\chi^2$/NDF = 55/19
$p_0$ = 1.001 ± 0.001

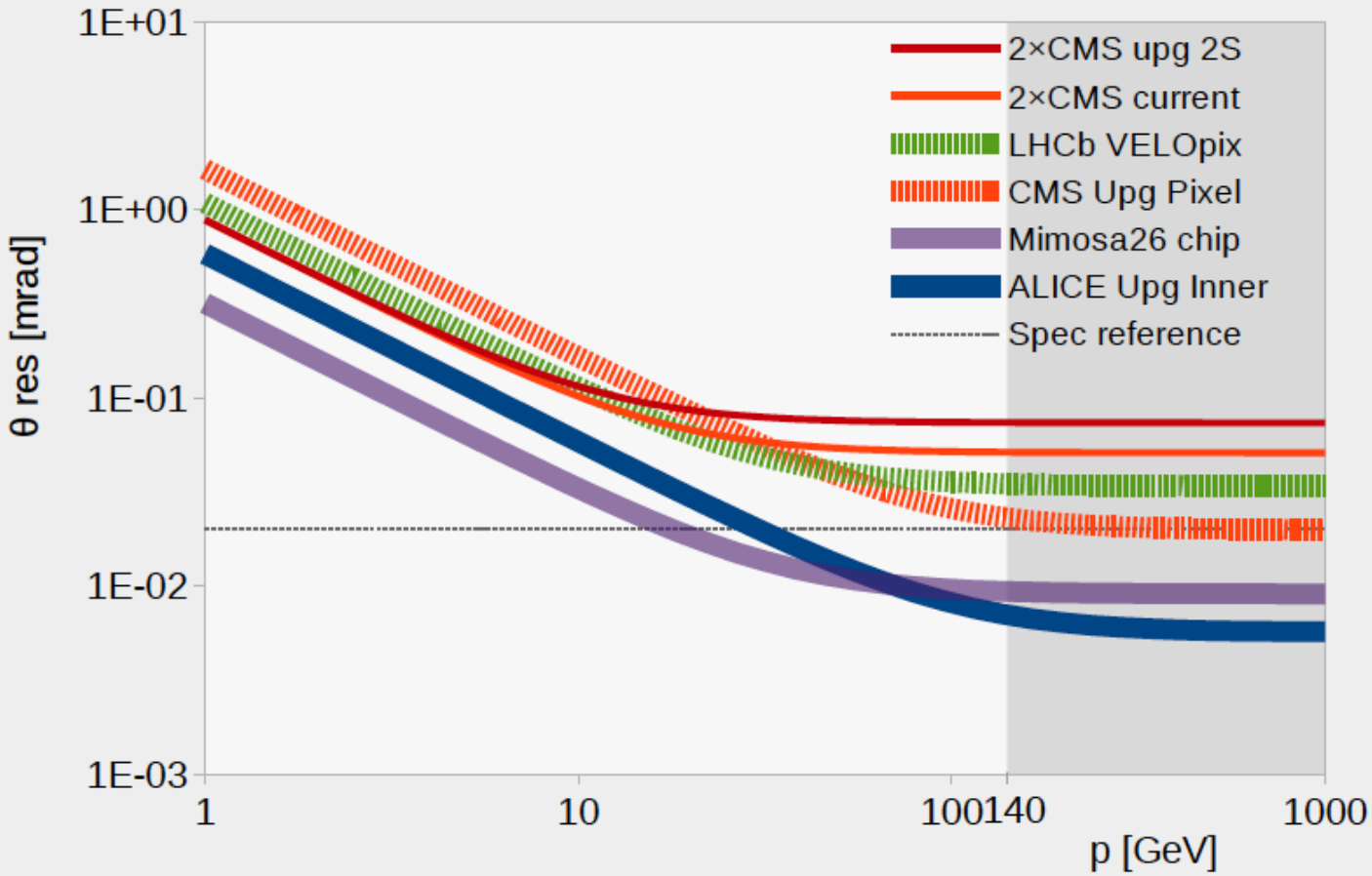
# Test Beam setup and target

Thanks to the UA9 Collaboration (particularly M. Garattini, R. Iaconageli, M. Pesaresi), J. Bernhard





# Resolution dominated by MS up to 10~100 GeV/c




Angle resolution:

$$\Delta\theta^2 = \Delta\theta_I^2 + \Delta\theta_{MS}^2$$

Angle intrinsic resolution:

$$\Delta\theta_I = \frac{\Delta x \sqrt{2}}{0.5\,\mathrm{m}}$$

MS angle:

$$\Delta\theta_{MS} = \frac{13.6}{p/\mathrm{MeV}} \sqrt{m} \times (1 + 0.038 \ln m)$$

**Scattering material: first layer only**

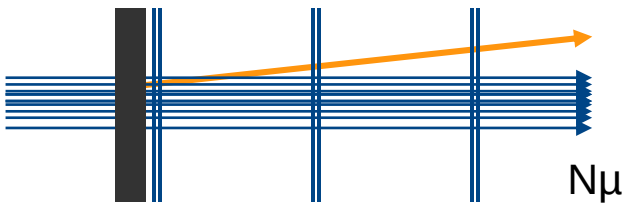
$$m = \left(\frac{x}{X_0}\right)_{\mathrm{det}}$$

- Resolution on scattering angle assumptions:
- 2 measurement plane 0.5 m apart
- Scattering on:
  - No plane (ideal resolution)
  - First detector plane (pure tracker resolution)
  - First plane + ½ Be target (includes “average” MS in target)
- Core of MS only considered (no tails)

# Detector integration time

- Hybrid pixels & strips for (HL-)LHC: 25 ns
- ALPIDE: 1 µs
- Mimosa26: 112 µs

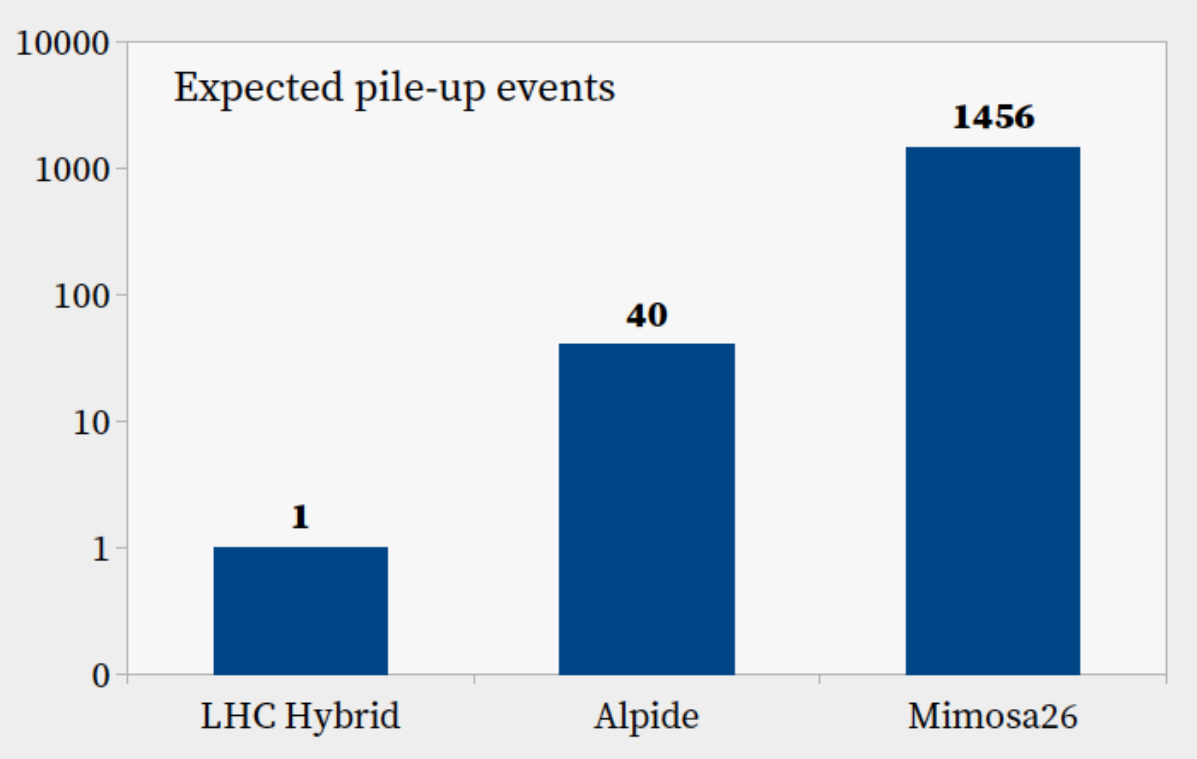
Expected pile-up events
(per 40MHz)




$N\mu = r \times \tau$

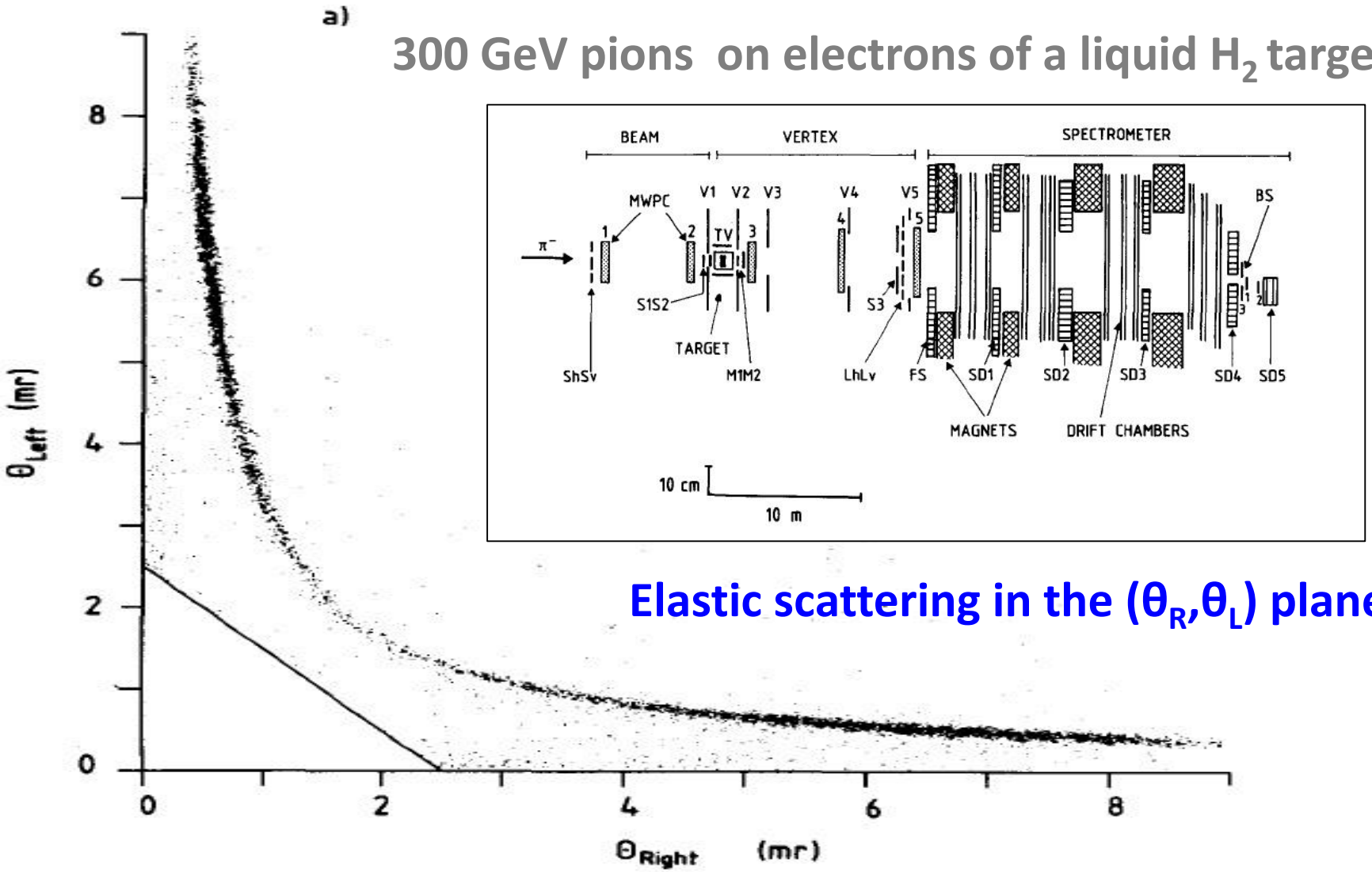
e.g. $N\mu = 40\ \text{MHz} \times 25\ \text{ns} = 1$

e.g. $N\mu = 40\ \text{MHz} \times 1\ \mu\text{s} = 40$



# NA7 experiment

## 300 GeV pions on electrons of a liquid $H_2$ target




**Elastic scattering in the $(\theta_R,\theta_L)$ plane**

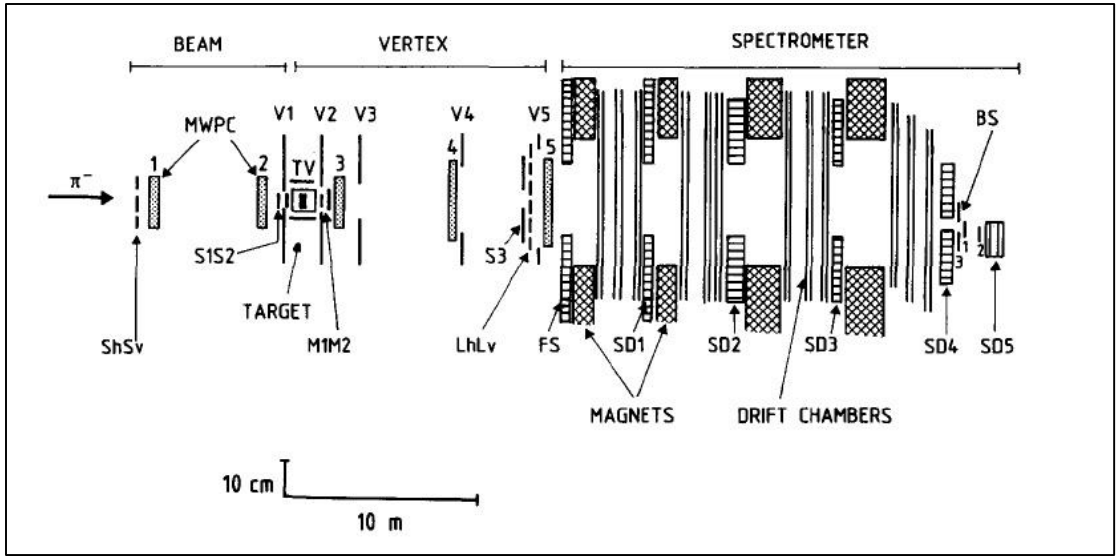
Nuclear Physics B277 (1986) 168-196

"The scatter distribution of the measured polar angles of the right and left-going particles $(\theta_R,\theta_L)$. Our estimate of $q^2$ was made from the point on the theoretical kinematic curve nearest to these angle coordinates".

# NA7 experiment

**A MEASUREMENT OF THE SPACE-LIKE PION ELECTROMAGNETIC FORM FACTOR,**

"The pion form factor has been measured in the space-like $q^2$ region 0.014 to 0.26 $(GeV/c)^2$ by **scattering 300 GeV pions from the electrons of a liquid hydrogen target**".




**Target: 28 cm liquid Hydrogen**
**$X_0$ (liquid $H_2$) = 890.5 cm**

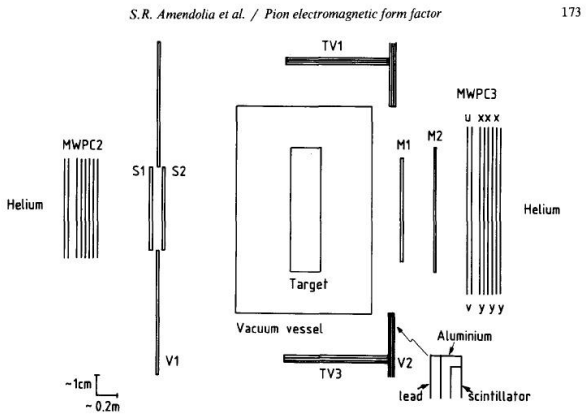


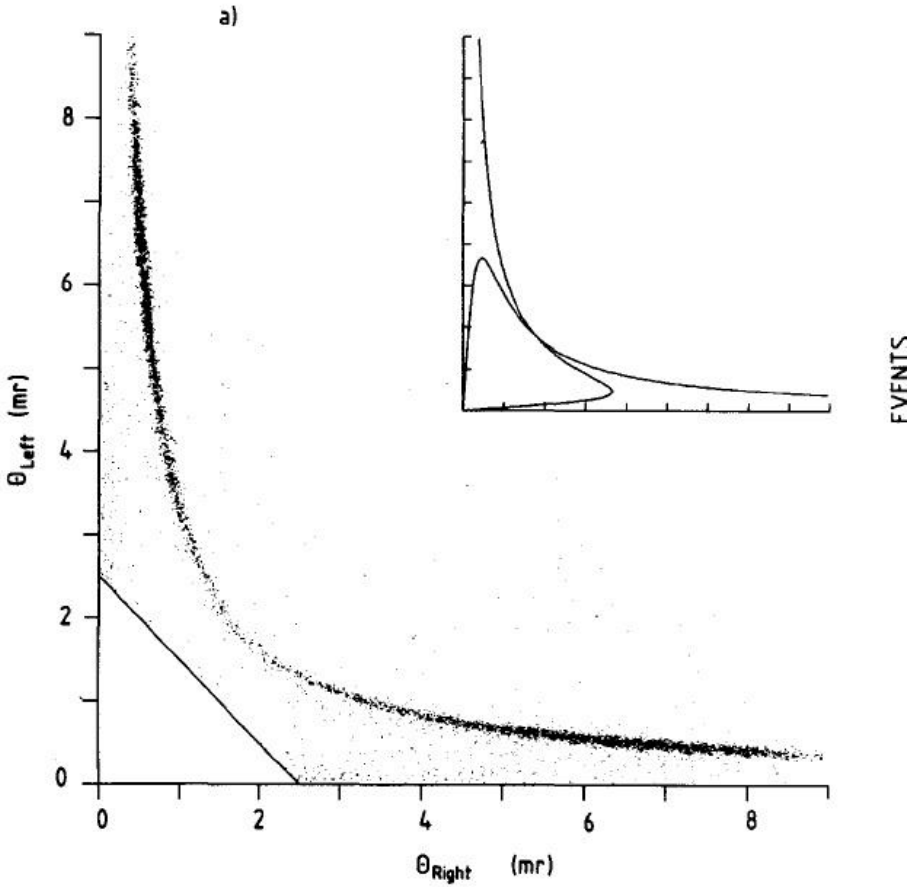

Fig. 4. Apparatus surrounding the target.

Nuclear Physics B277 (1986) 168-196

"**The $q^2$ variable for the final sample was determined from the angles alone**, up to the kinematic ambiguity which was resolved using the shower detectors. In this procedure the only rejection criterion involving the momenta was a cut against electrons of less than 1 GeV/c".

# NA7 experiment

## Elastic scattering in the ($\theta_R$,$\theta_L$) plane




"The scatter distribution of the measured polar angles of the right and left-going particles ($\theta_R$,$\theta_L$). Our estimate of $q^2$ was made from the point on the theoretical kinematic curve nearest to these angle coordinates".

## Coplanarity

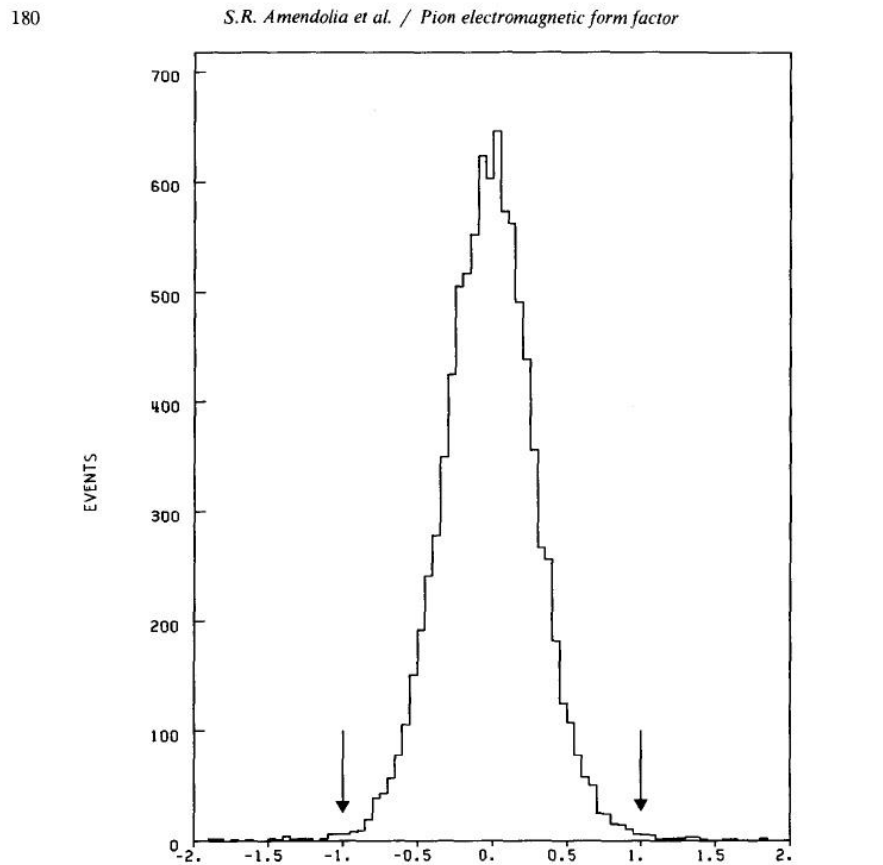
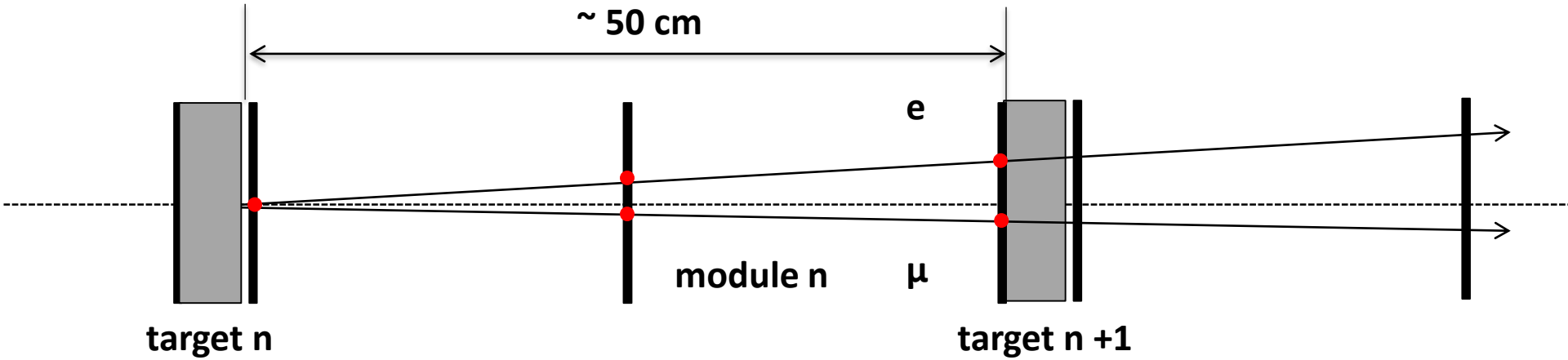




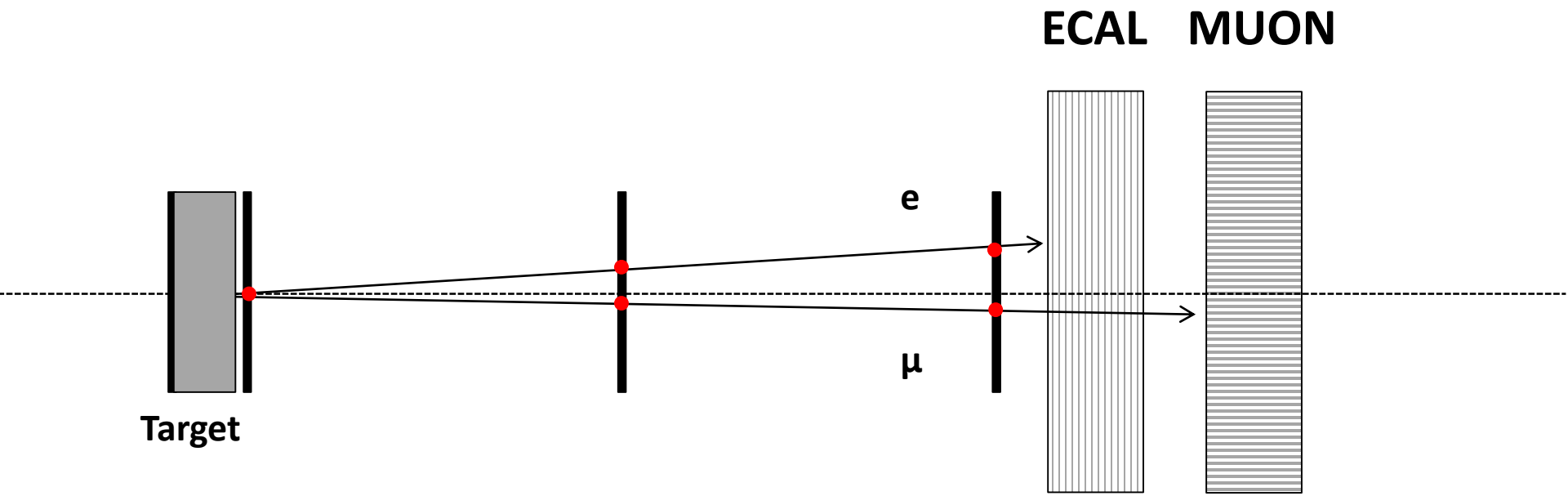


Fig. 8. The distribution of the triple scalar product of unit vectors along the incident and scattered tracks, in units of the applied cut. This varied smoothly with decreasing opening angle from $1.1 \times 10^{-6}$ to $0.6 \times 10^{-6}$.

"A fraction of the hadronic background was rejected by requiring coplanarity of the incident and scattered tracks"

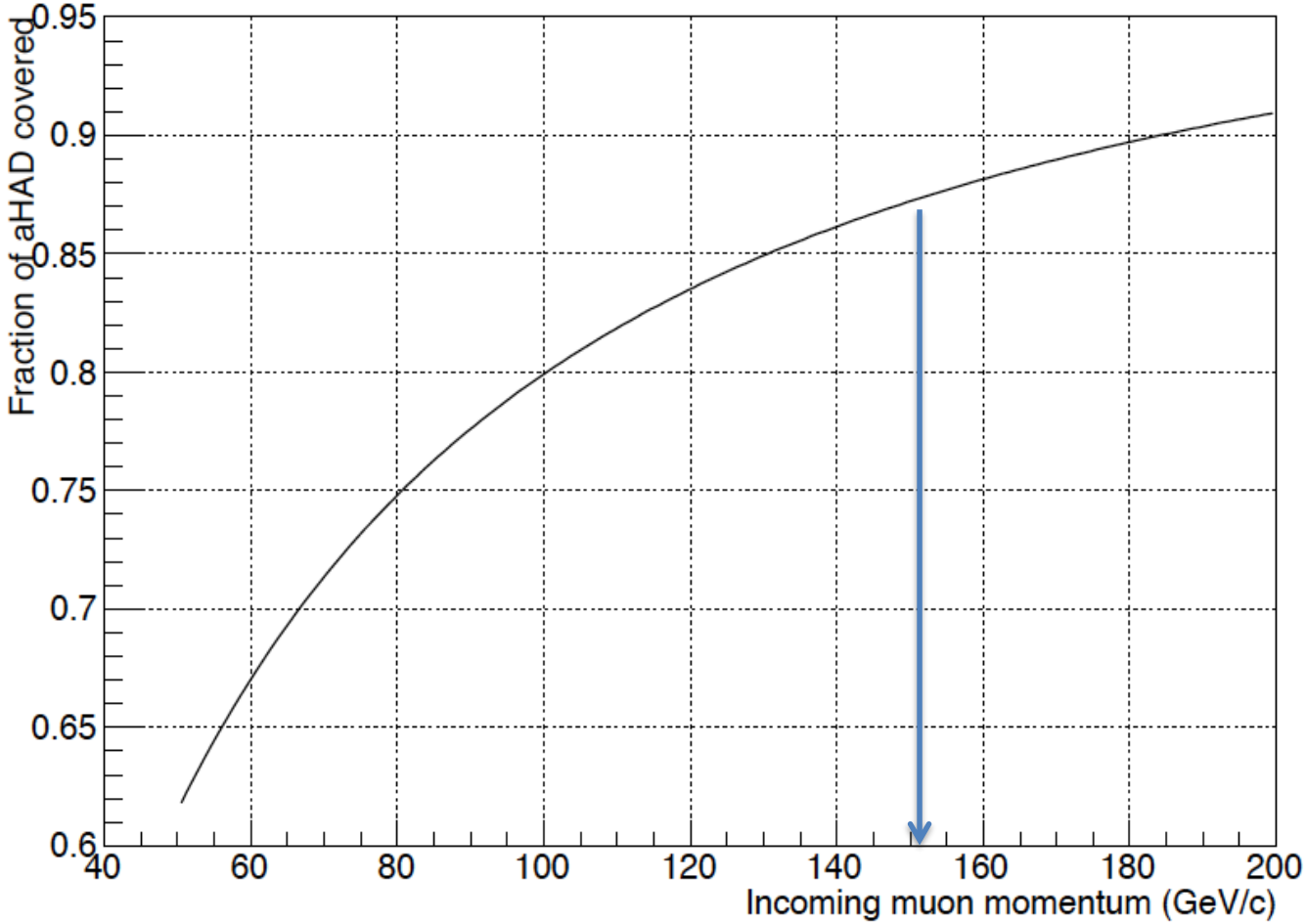



# Last module of the detector



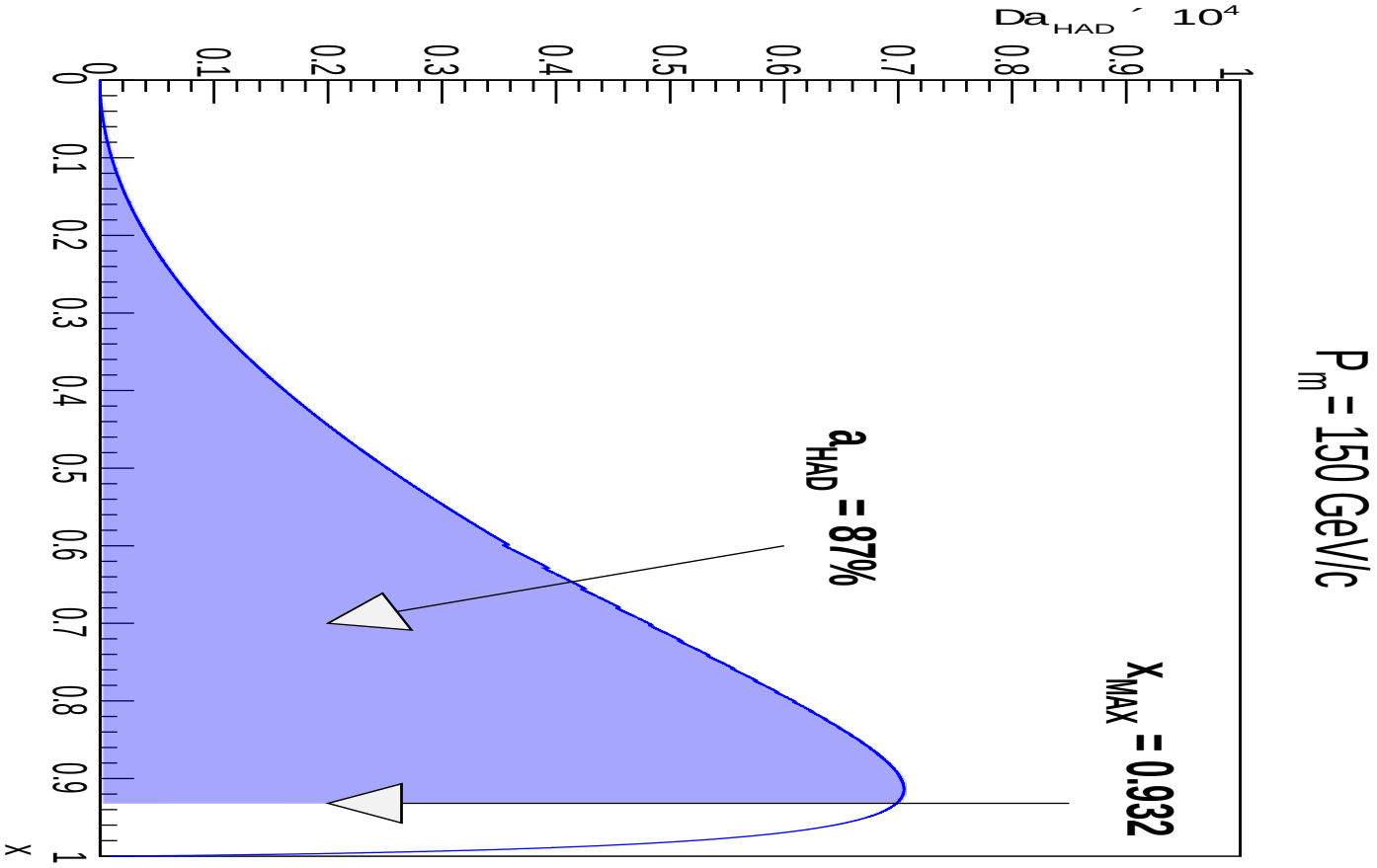

Measure both the electron angle and $E_e$ to define the reference, calibration curve. Detailed check of GEANT predictions.

# Fraction of $a_\mu^{HLO}$ covered




87% of $a_\mu^{HLO}$ covered with $P\mu$=150 GeV

# Fraction of $a_\mu^{HLO}$ covered




87% of $a_\mu^{HLO}$ covered with $P\mu$=150 GeV

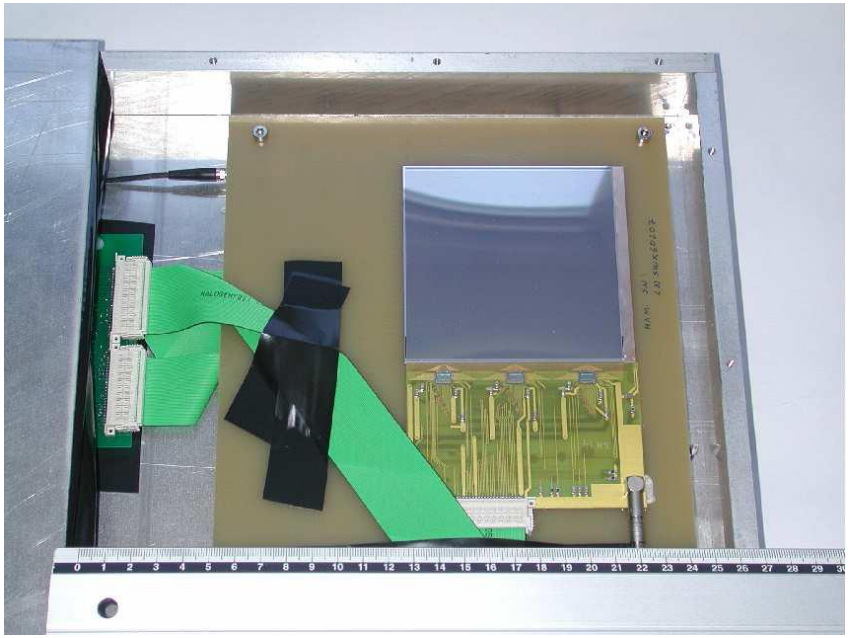
(courtesy of M. Incagli)

# The silicon detectors

## Sensors developed for AGILE, being used by LEMMA

Table 1
Main features of the AGILE silicon detector

| Item | Value |
|---|---|
| Dimension ($cm^2$) | $9.5 \times 9.5$ |
| Thickness (μm) | 410 |
| Readout strips | 384 |
| Readout pitch (μm) | 242 |
| Physical pitch (μm) | 121 |
| Bias resistor (MΩ) | 40 |
| AC coupling Al resistance (Ω/cm) | 4.5 |
| Coupling capacitance (pF) | 527 |
| Leakage current ($nA/cm^2$) | 1.5 |



M. Prest et al., NIM A, 501:280–287, 2003

**Daniela Lietti, PhD thesis. VISION: a Versatile and Innovative SIlicON tracking system**

**http://insulab.dfm.uninsubria.it/images/download_files/thesis_phd_lietti.pdf**

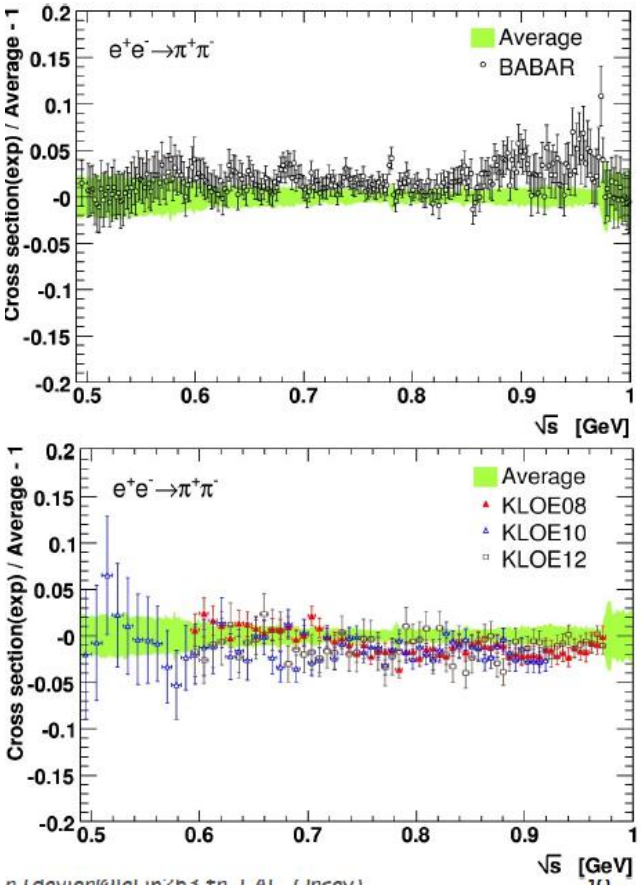
# Experimental setup location



Site inspection in COMPASS on 11/10/2017
Counting room quite far from experimental site: DAQ PC near setup → "short" optical fiber from crate VME to DAQ PC, then ethernet cable from DAQ PC to counting room

# Timelike data aiming at 0.2% on $a_\mu^{HLO}$?

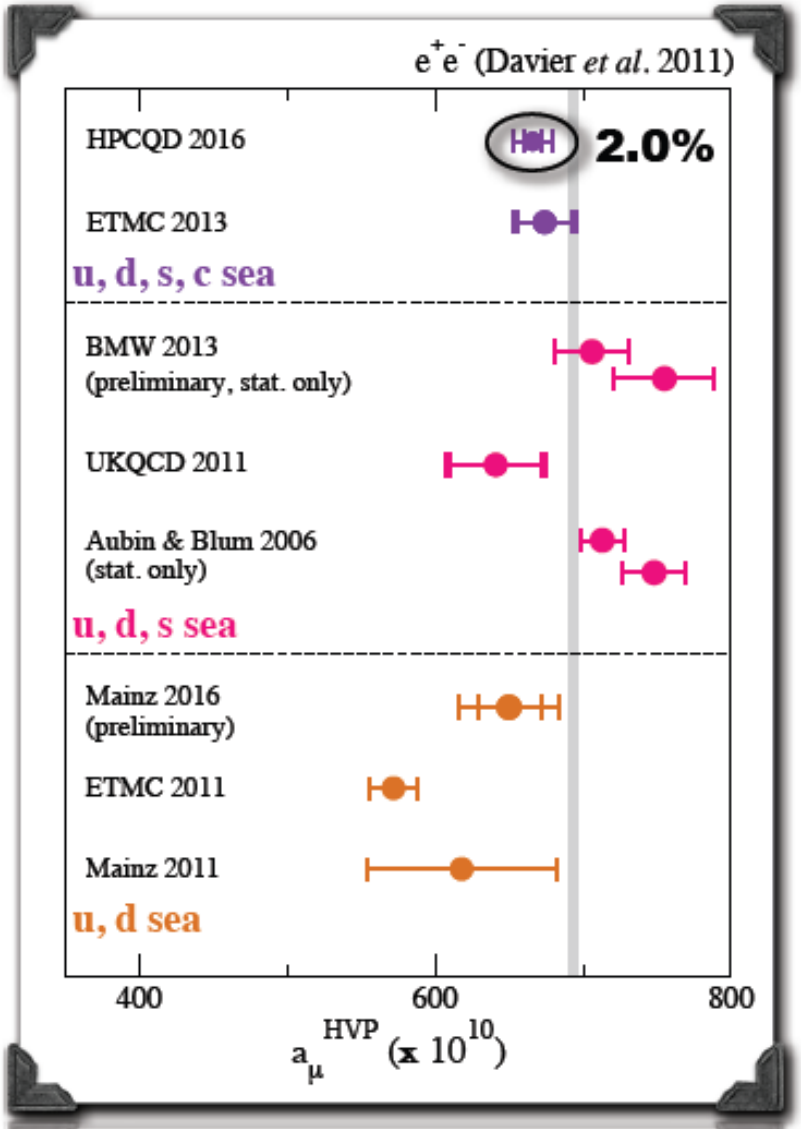
- Not an easy task!
  - >30 channels to keep under control (at (sub)percent level)
  - local discrepancies in main channels ($2\pi$ (KLOE/Babar), $K^+K^-$ CMD2/Babar)
  - Isospin corrections for not measured channels
  - Treatment of narrow resonances? (See F. Jegerlehner, ArXiv:1511.04473)




M. Davier, TAU16 WS

An independent/complementary approach is highly desirable!

# Lattice-QCD progress on $a_\mu^{HVP}$




- Can calculate nonperturbative vacuum polarization function $\Pi(Q^2)$ directly in lattice QCD from simple 2-point correlation function of EM quark current [Blum, PRL 91 (2003) 052001]
- Several ongoing lattice efforts yielding new results since ICHEP 2014 including:

(1) First calculation of quark-disconnected contribution [RBC/UKQCD, PRL116, 232002 (2016)]

(2) Second complete calculation of leading-order $a_\mu^{HVP}$ [HPQCD, arXiv:1601.03071]

- First to reach precision needed to observe significant deviation from experiment

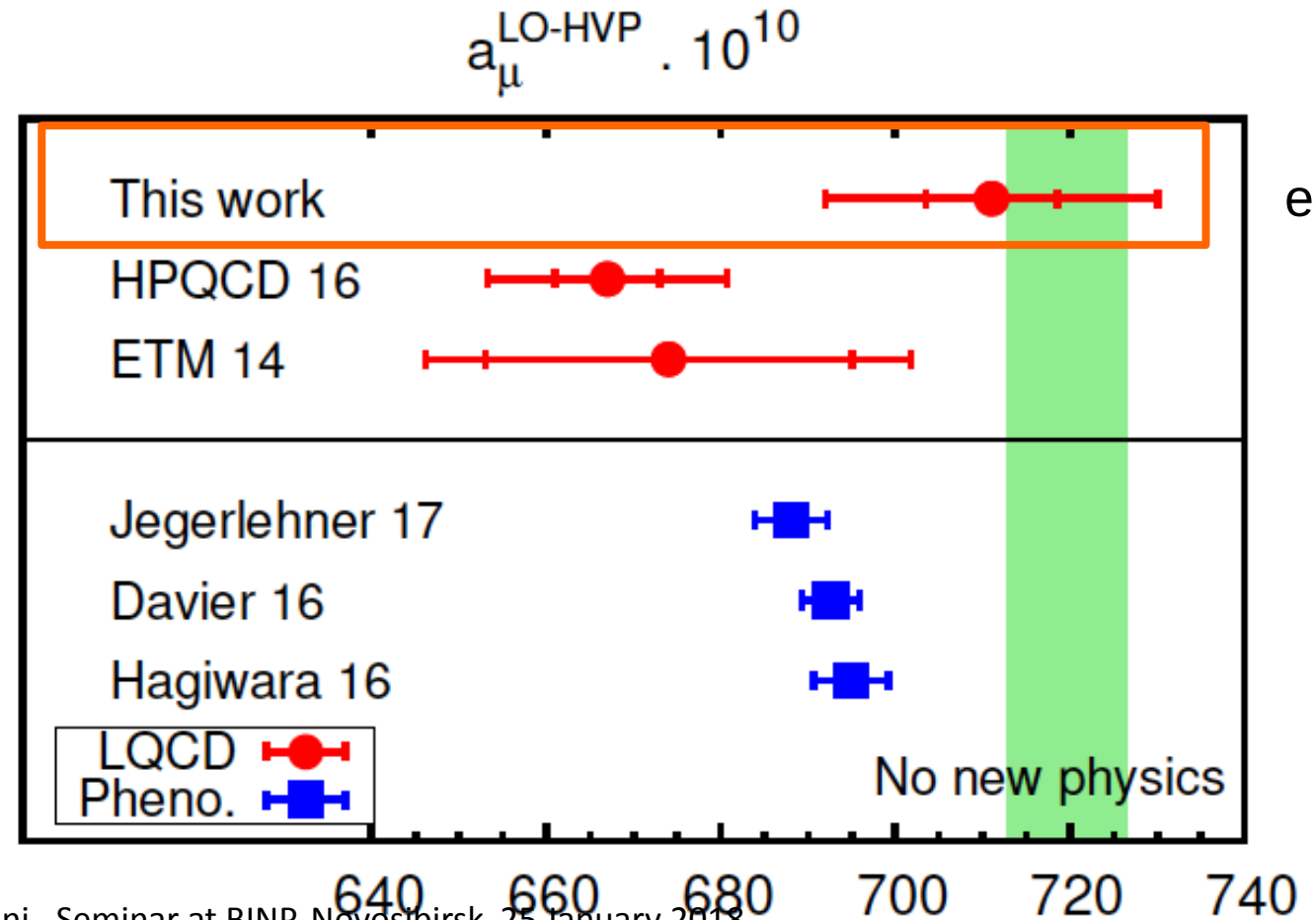
- ~1% total uncertainty by 2018 possible
- Sub-percent precision will require inclusion of isospin breaking & QED, and hence take longer

# *However*: Recent Lattice evaluation

**Hadronic vacuum polarization contribution to the anomalous magnetic moments of leptons from first principles**

Sz. Borsanyi,[1] Z. Fodor,[1,2,3] C. Hoelbling,[1] T. Kawanai,[3] S. Krieg,[1,3]
L. Lellouch,[4] R. Malak,[4,5] K. Miura,[4] K.K. Szabo,[1,3] C. Torrero,[4] and B.C. Toth[1]
(Budapest-Marseille-Wuppertal collaboration)

arXiv:1711.04980v1 [hep-lat]
14 Nov




error~2.7%

$$a_\mu^{\text{LO-HVP}} = 711.0(7.5)(17.3) \times 10^{-10}$$

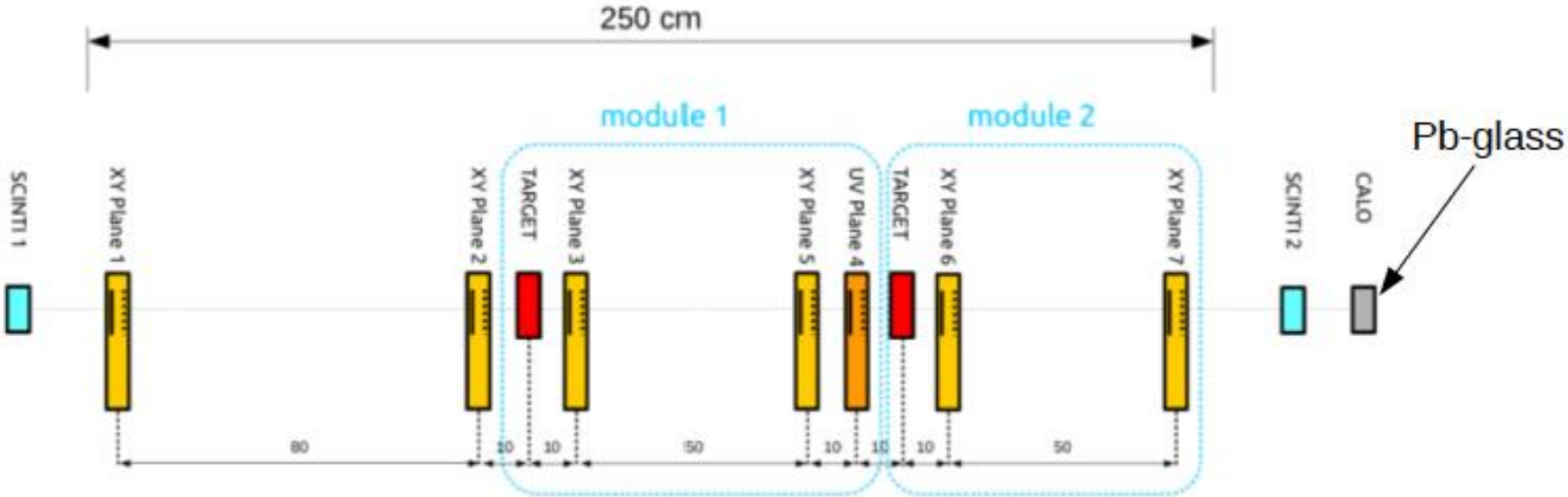
stat syst

2.7%

(NP). Using the SM contributions summarized in [8], we find $a_{\mu,\text{noNP}}^{\text{LO-HVP}} = (720.0 \pm 6.8) \times 10^{-10}$. The errors on the lattice results, which are in the range of 2.0 to 4.1% are substantially larger than those of the phenomenological approach. Our result for $a_\mu^{\text{LO-HVP}}$ is larger than those of the other lattice calculations and in slight tension with the one from HPQCD [33] which is $1.9\,\sigma$ away. A more detailed flavor-by-flavor comparison is given in [45]. However, our result is consistent with those from phenomenology within about one standard deviation, as well as with $a_{\mu,\text{noNP}}^{\text{LO-HVP}}$. Thus, one will have to wait for the next generation of lattice QCD calculations to confirm or infirm the larger than $3\,\sigma$ deviation between the measurement of $a_\mu$ and the prediction of the SM based on phenomenology.

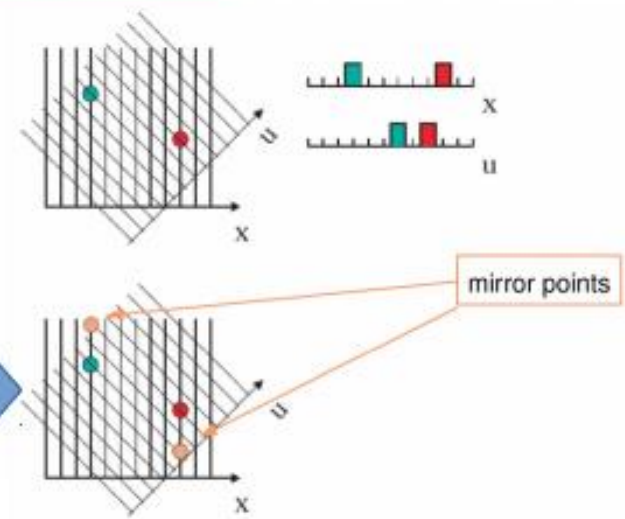
arXiv:1711.04980v1 [hep-lat]
14 Nov

# Experimental Setup




Scintillators: 2 100 x 100 mm$^2$

Silicon detectors: 12 XY planes
2 UV plane ±45°



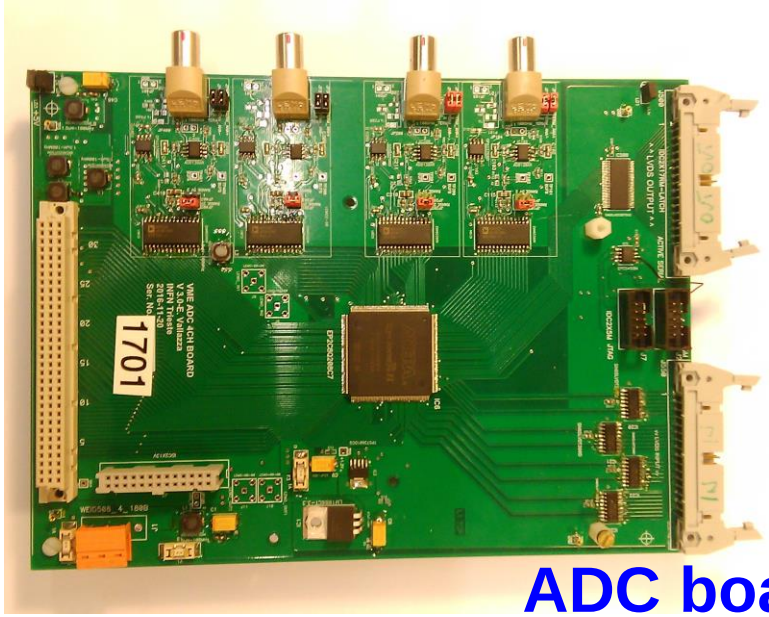

Need 3 stereo views to resolve ambiguities

# Il readout

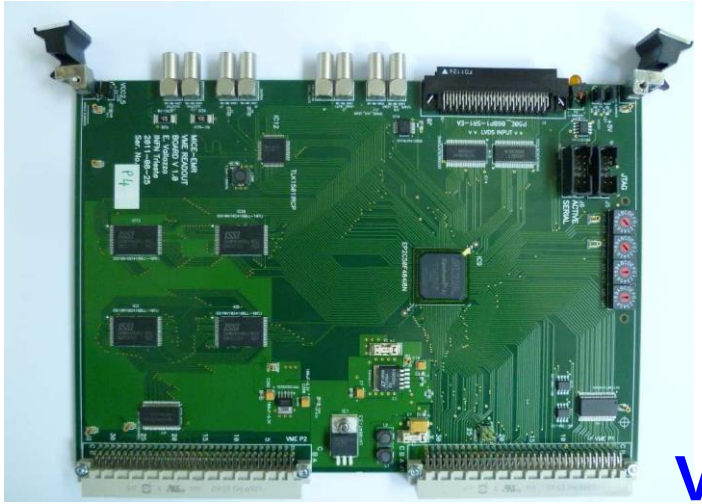
## Readout electronics

- Zero suppression mode
- 1 ADC board per 4 moduli single side
- 1 VME Readout Board per leggere gli ADC e immagazzinare i dati durante la spill
- Readout speed → 6 kHz → questo numero può salire a 15 kHz se ognuno dei 3 ASIC che leggono una vista è letto in modo indipendente (e non in una daisy chain a 3 come succede adesso) → è possibile solo costruendo moduli nuovi

**Abbiamo materiale per costruire ulteriori 10 viste x-y**




ADC board

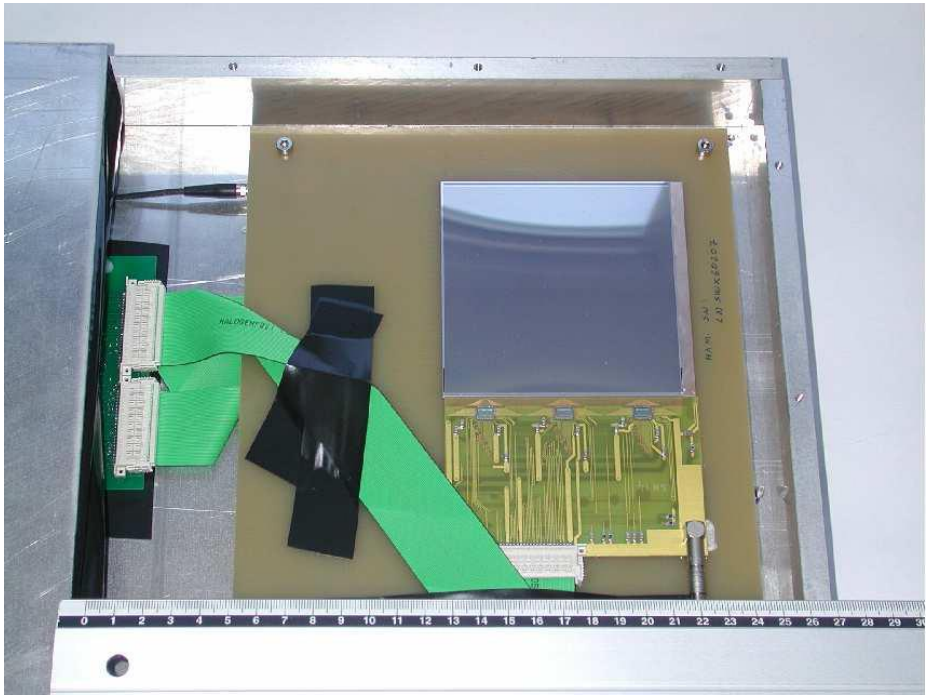


VRB

# Prospect for 2018 run

**Silicon beam chambers:**

- 4 moduli X-Y con i rivelatori single side di AGILE → 9.5x9.5 $cm^2$ con strip a passo 242 μm – 1 strip floating → risoluzione spaziale di 30 μm
- 4 moduli X-Y richiedibili a INFN Bari (gruppo Fermi) → rivelatori single side di 8.75x8.75 $cm^2$ con strip a passo 228 μm
- In costruzione: 5 moduli X-Y per LEMMA con i rivelatori single side di AGILE



M. Prest et al., Nucl. Instr. and Meth. in Phys. Res. A, 501:280–287, 2003

Daniela Lietti, PhD thesis. VISION: a Versatile and Innovative SIlicON tracking system

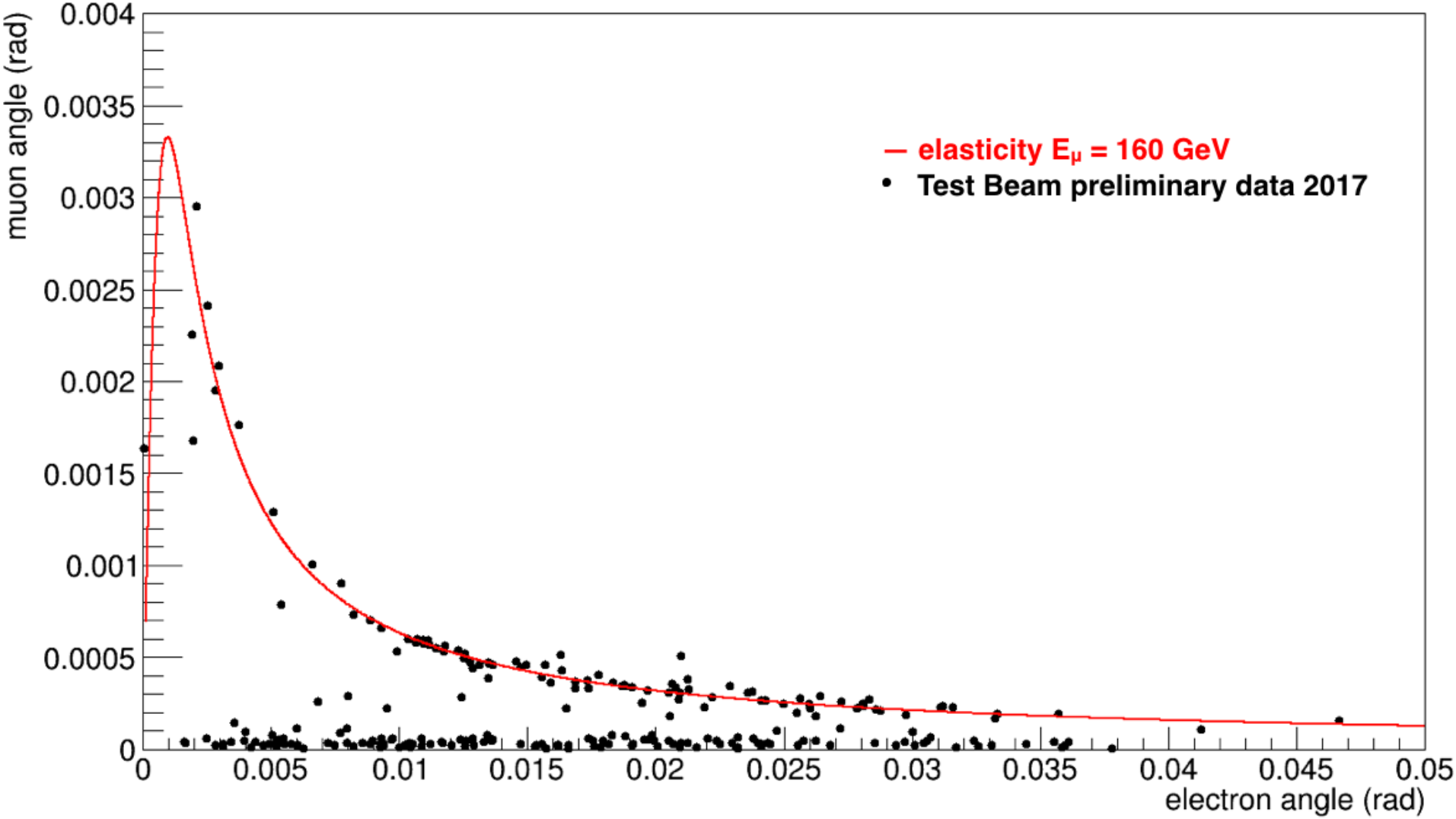
http://insulab.dfm.uninsubria.it/images/download_files/thesis_phd_lietti.pdf

# Some numbers:

- 60 cm total Be target ($2X_0$) segmented in 60 stations with 1 cm target ($0.03\ X_0$)
- ~30 m total detector length
- 10x10 $cm^2$ silicon detectors
- Resolve each μ,e track with uniform efficiency
- Best possible resolution on θμ (<5mrad),θe (<50 mrad)
- μ rate: ~60 MHz (peak) → 15 MHz (averaged)
- μ separation: 17 ns (peak) → 68 ns (averaged)
- Collect $4x10^{12}$ events with $E_e$>1GeV in ~2 years
- Scattering probability ($E_e$>1GeV): $1.7x10^{-4}$/cm
- Scattering event rate ($E_e$>1GeV): ~10 kHz per station (peak); 2.5 (avg)
- Scattering separation ($E_e$>1GeV): 100 μs per station

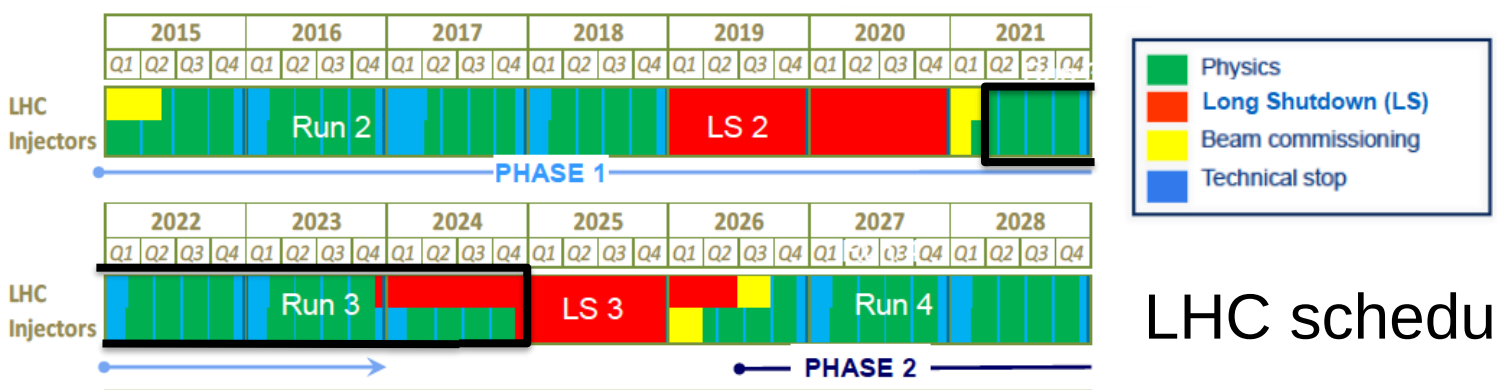
# (Preliminary) Analysis of Test Beam data

First μ-e elastic events!



# Plans

- **2018-2019**
  - Detector optimization studies: simulation; Test Run at CERN (2018); Mainz with 1GeV e- (2019); Fermilab with 60 GeV μ (2019)
  - Theoretical studies
  - Set up a collaboration
  - Letter of Intent to the SPSC
- **2020-2021**
  - Detector construction and installation (a staged version of the detector may be)
- **2022–2024**
  - Data taking: staged detector for a first (pilot) run +2 years with full detector




LHC schedule