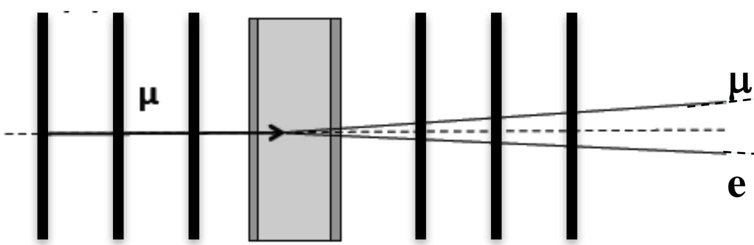
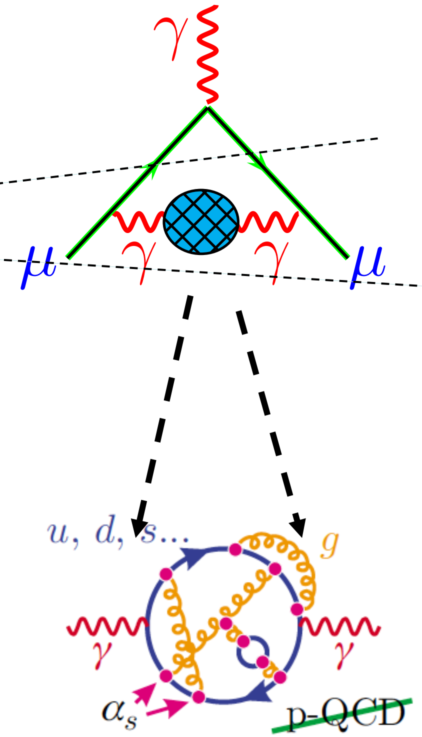
High precision measurement of a_μ^{HLO} with a 150 GeV μ beam on Be target at CERN (through the elastic scattering μe →μ e)

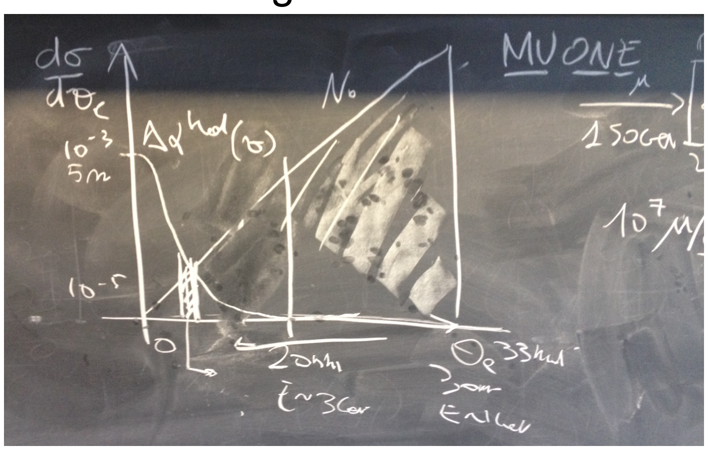
G. Venanzoni
INFN-Pisa

150 GeV 0.03X_0



target





"The closer you look the more there is to see"

Pisa 5 June 2018

Outline

- Reminder on MUonE proposal
- Some Recent progress
- Plans
- Conclusions

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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Phys. Lett. B 746 (2015) 325

Measuring the leading hadronic contribution to the muon g-2 via μe 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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Eur. Phys. J. C (2017) 77: 139.

a_μ^{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:

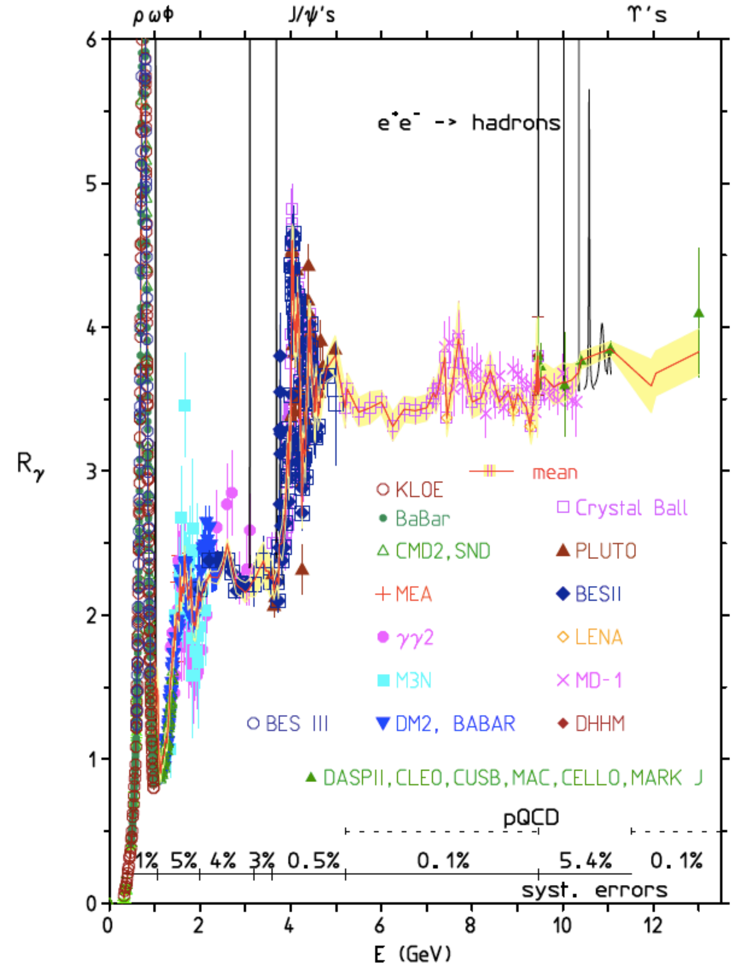
$$\sigma(s)_{(e^+e^-\to had)} = \frac{4\pi}{s}\,\mathrm{Im}\,\Pi_{hadron}(s)$$

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

- The main contribution is in the highly fluctuating low energy

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

Collection of many experimental results



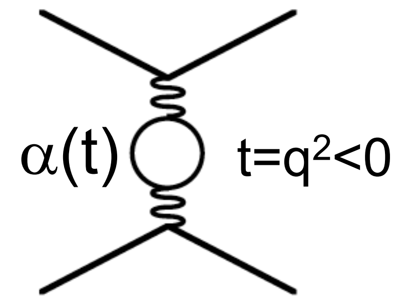
The enhancement at low energy implies that the $\rho \to \pi^+\pi^-$ resonance is dominating the dispersion integral (~ 75 %). Current precision at 0.6%→ need to be reduced by a factor **~2**

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

$\Delta^{SM\text{-}BNL} \sim 3\%\ a_\mu^{HLO}$

Alternative approach: a_μ^{HLO} from space-like region

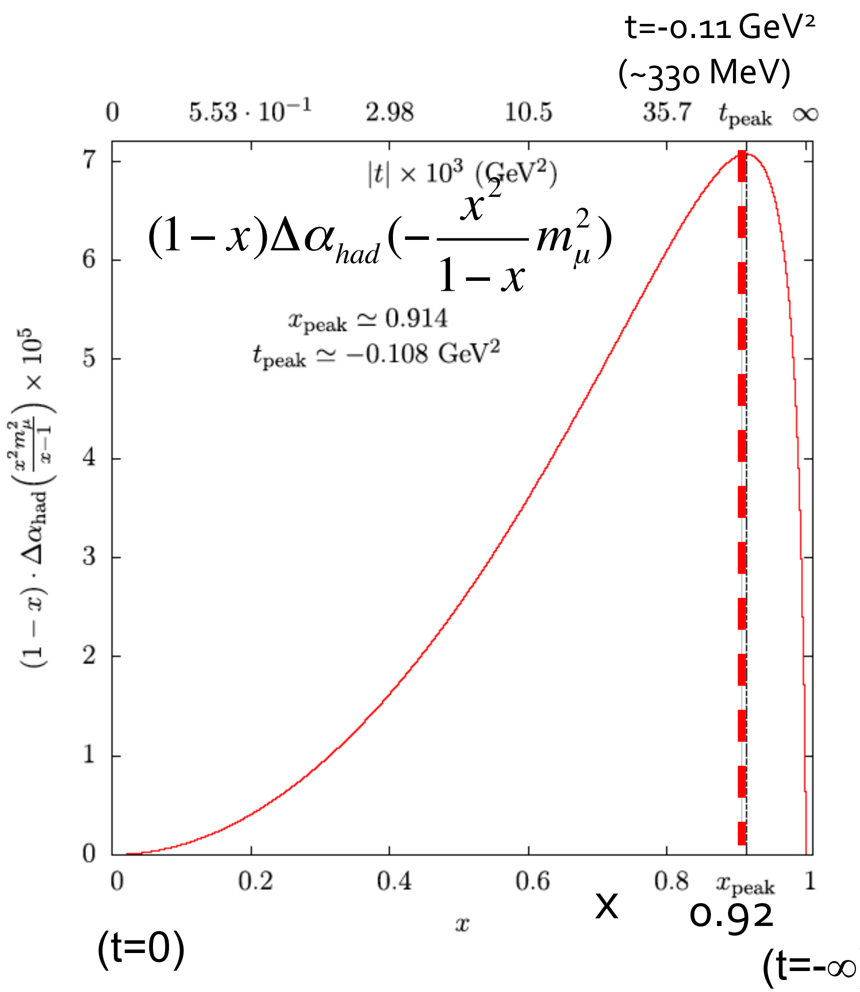
$$a_\mu^{HLO} = \frac{\alpha}{\pi}\int_0^1 dx\,(1-x)\cdot\Delta\alpha_{had}\left(-\frac{x^2 m_\mu^2}{1-x}\right)$$



$$t = \frac{x^2 m_\mu^2}{x-1} \quad 0 \le -t < +\infty$$

$$x = \frac{t}{2m_\mu^2}\left(1-\sqrt{1-\frac{4m_\mu^2}{t}}\right); \quad 0 \le x < 1;$$

- **a_μ^{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 **$\Delta\alpha_{had}(t)$ ($t=q^2<0$)**
- **It enhances** the contribution from **low** q^2 region (below 0.11 GeV²)
- **Its precision** is determined by the **uncertainty** on $\Delta\alpha_{had}$ (t) in this region

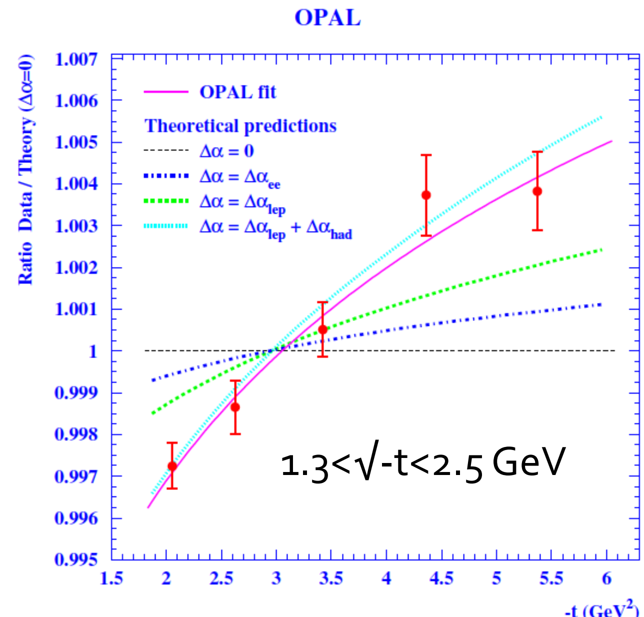


Measurement of $\Delta\alpha_{had}(t)$ spacelike at LEP

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

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

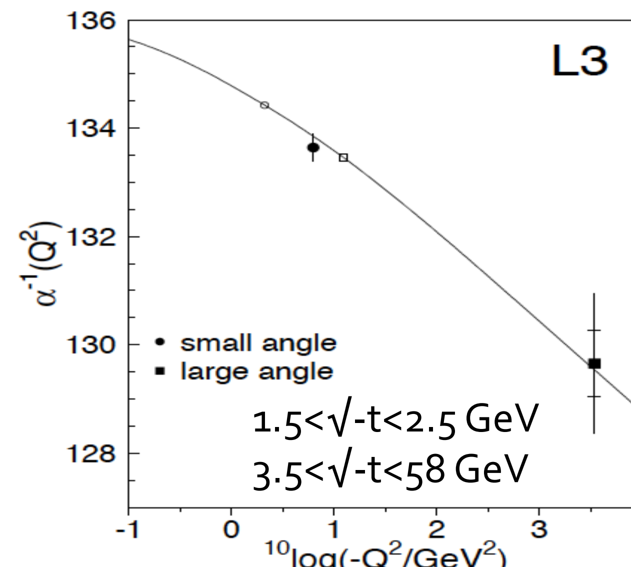
Accuracy at per mill level was achieved!



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

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

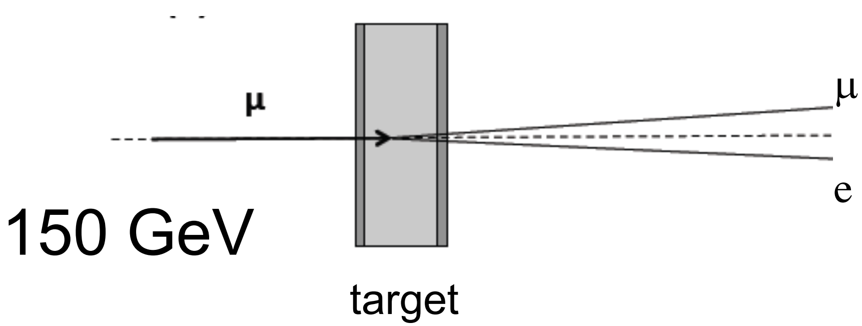
- For low t values (≤0.11 GeV²) and higher precision (~10⁻⁵) as in our case a different approach is needed!

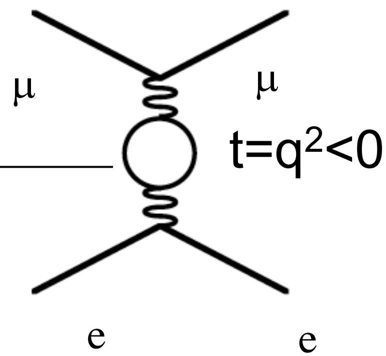


M. Acciarri et al., Phys. Lett. B476 40-48 (2000)

Experimental approach:

Use of a 150 GeV μ beam on Be target at CERN (elastic scattering μe →μ e)





$$\left|\frac{\alpha(t)}{\alpha_0}\right|^2 = \left|\frac{1}{1-\Delta\alpha(t)}\right|^2$$

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

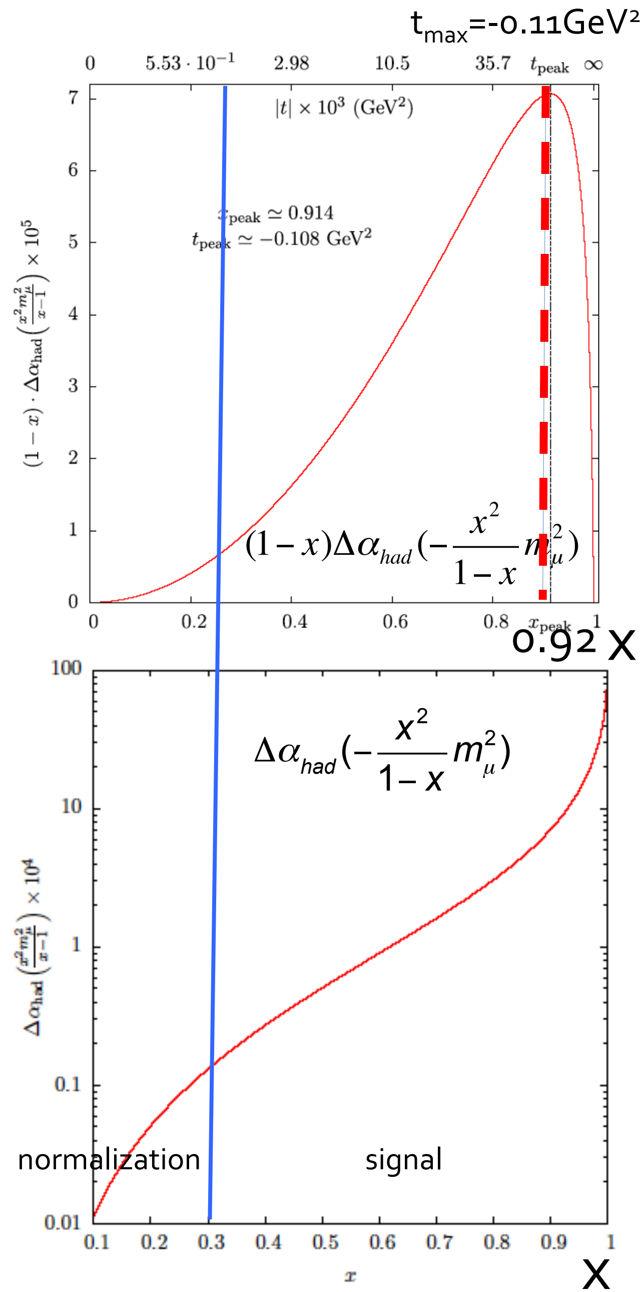
It looks an ideal process!

- $\mu\, e \rightarrow \mu\, e$ is pure t-channel (at LO)

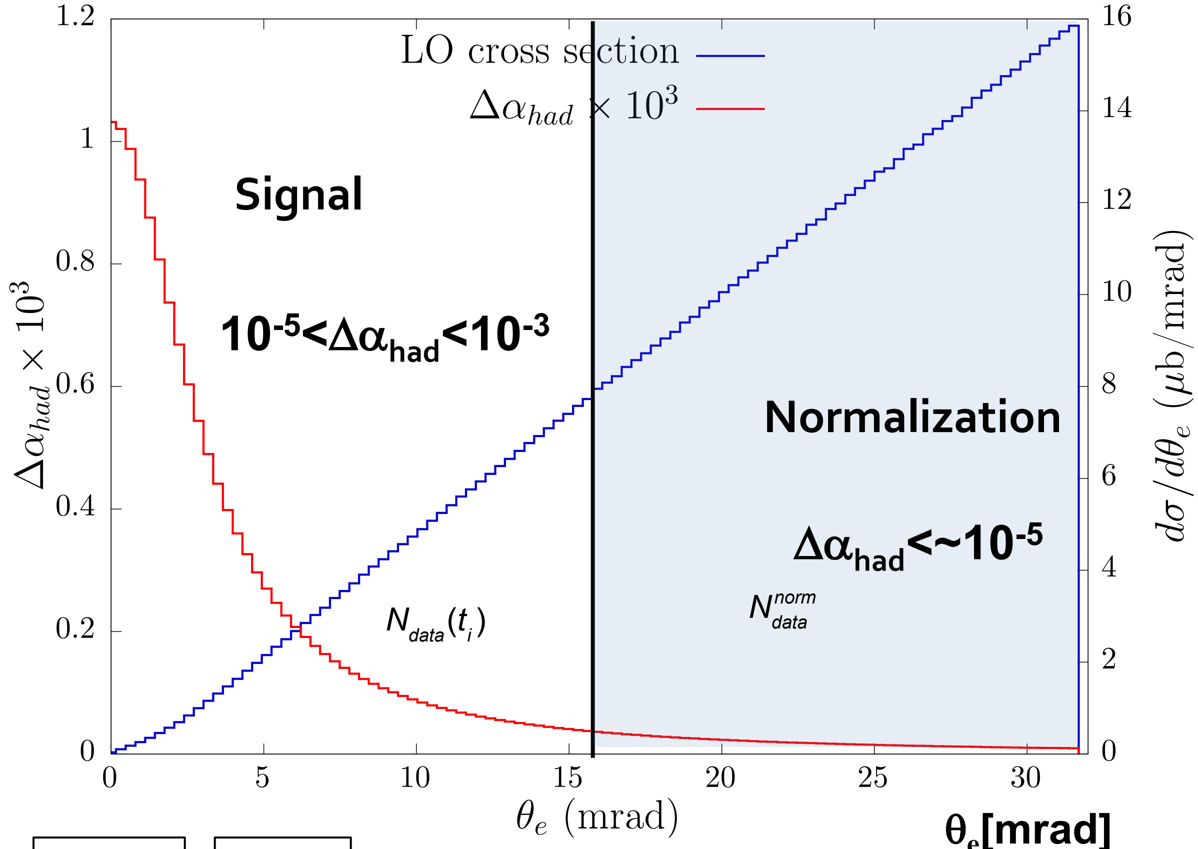
- **Simple** kinematics (2 body process, $t=-2m_eE_e<0$) allows to span the region **$0<-t<0.143$** GeV² (**$0<x<0.93$**); 87% of total a_μ^{HLO} (the rest can be computed by pQCD/time-like data)

- Angular measurement: high boosted system gives access to all angles (t) in the cms region θ_e^{LAB}<32 mrad (E_e>1 GeV) θ_μ^{LAB}<5 mrad

- It allows using the same detector for signal and normalization (**$x<0.3$, $\Delta\alpha_{had}(t)$ <10^{-5}**) → cancellation of detector effects at first order



MUonE : signal/normalization region



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

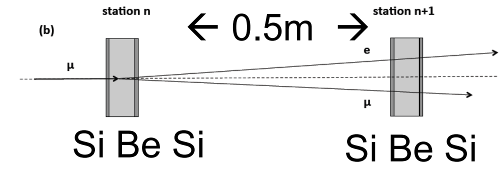
Ratio of the theoretical cross section (with no VP)

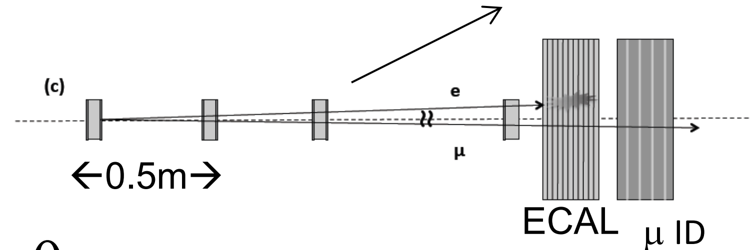
Ratio of data $N_{signal}(t)/N_{normalization}$

a_μ^{HLO} at 0.3% → These two ratios should be known at 10^{-5}

G. Venanzoni, Pisa, 5 June 2018

Detector considerations





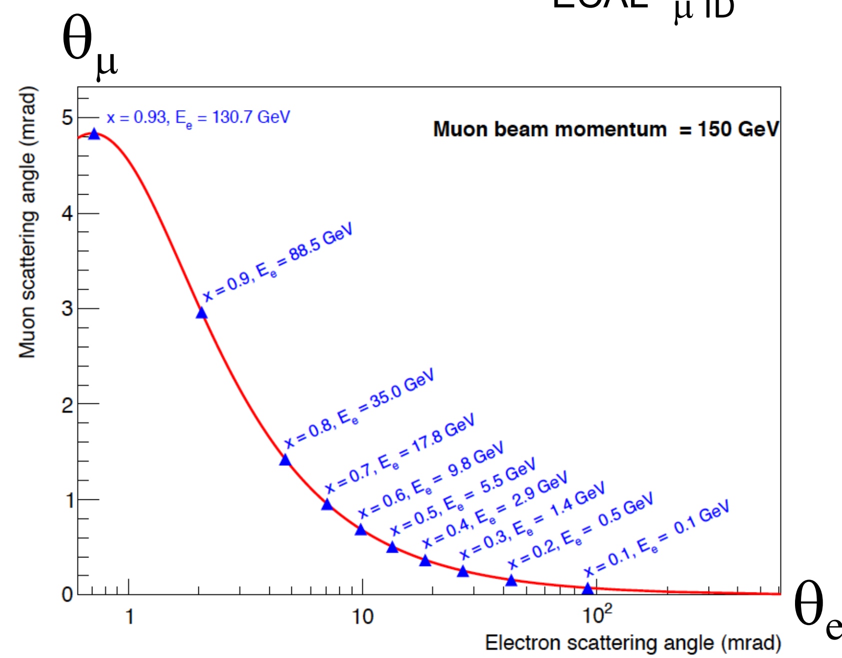
- Modular apparatus: 60 layers of ~1 cm Be (target), each coupled to ~0.5 m distant Si (0.3 mm) planes. It provides a 0.02 mrad resolution on the scattering angle

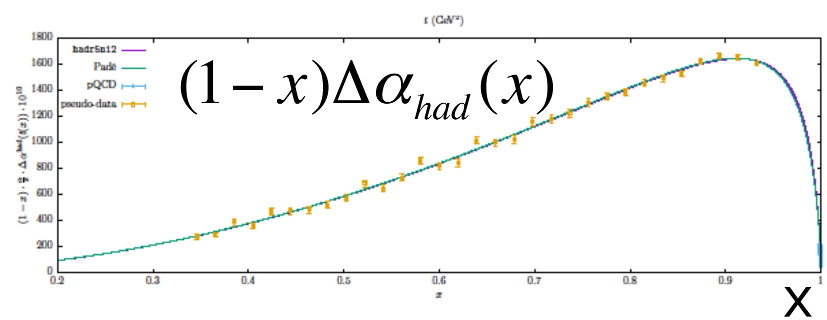
- The $t=q^2<0$ of the interaction is determined by the electron (or muon) scattering angle (a` la NA7)

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

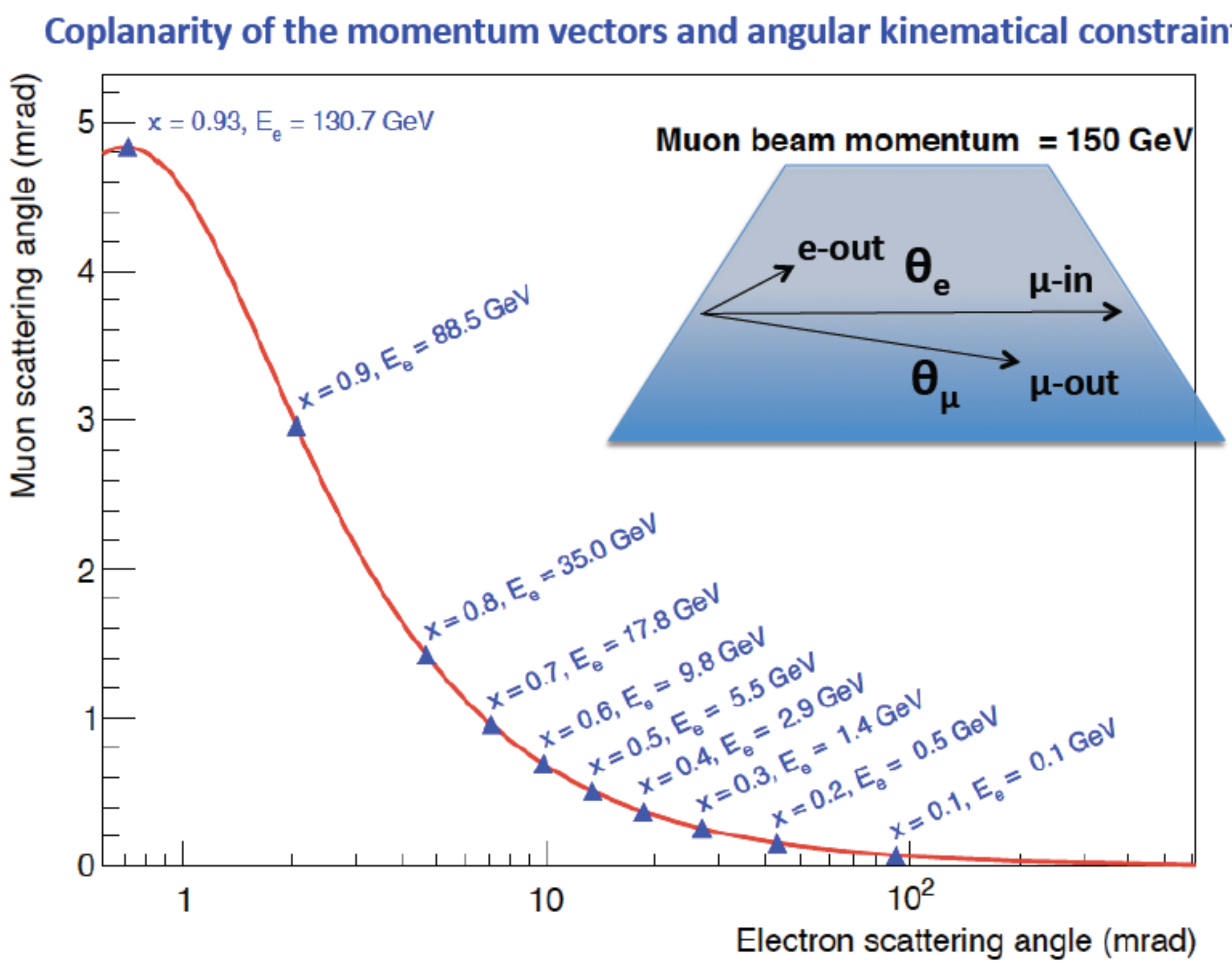
- It provides uniform full acceptance, with the potential to keep the systematic errors at 10^{-5} (main effect is the multiple scattering for normalization which can be studied by data)

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



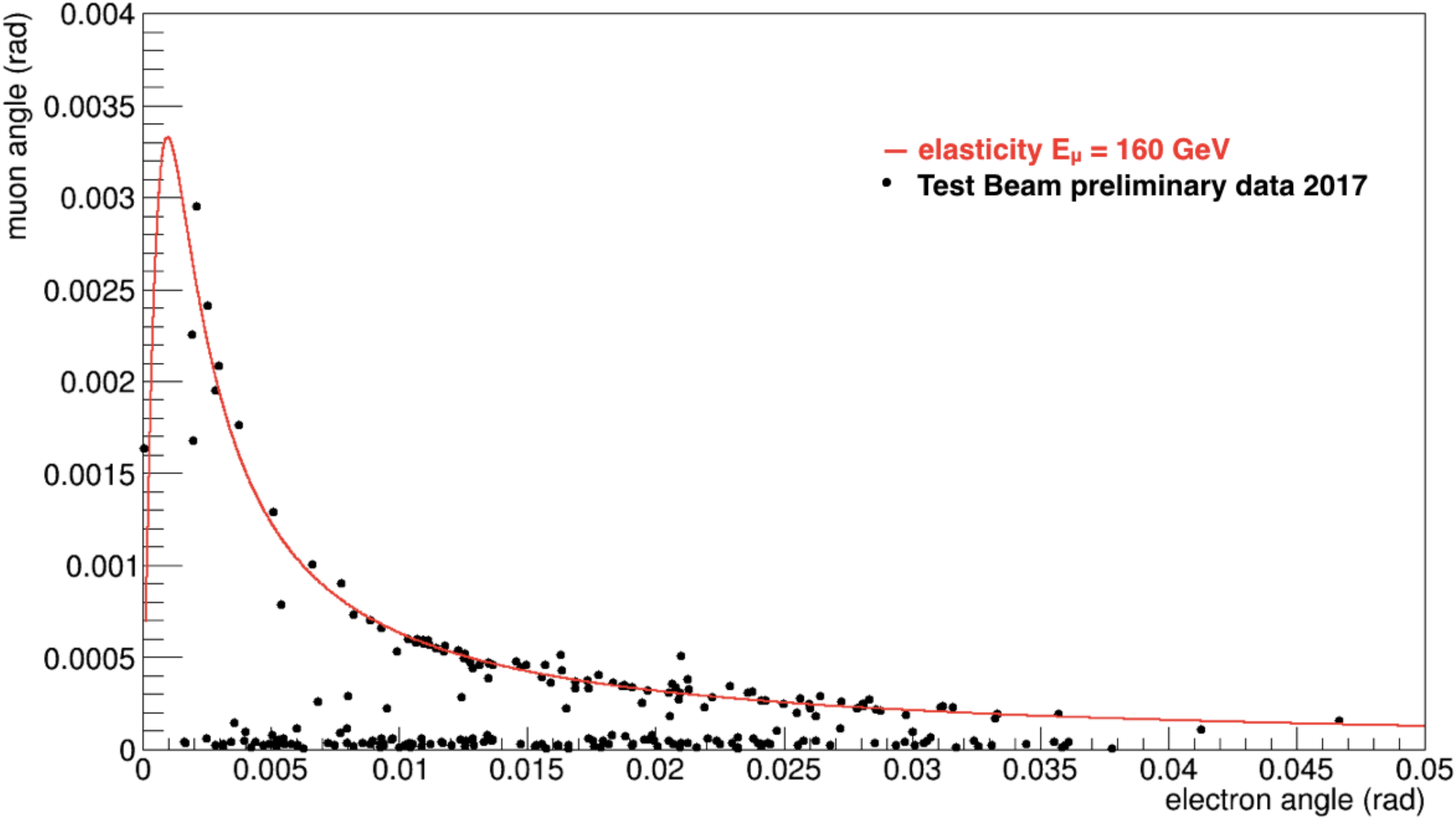


Elastic scattering in the (θ_e , θ_μ) plane



(Preliminary) Analysis of Test Beam data

First μ-e elastic events!



G. Venanzoni, Pisa, 5 June 2018

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".

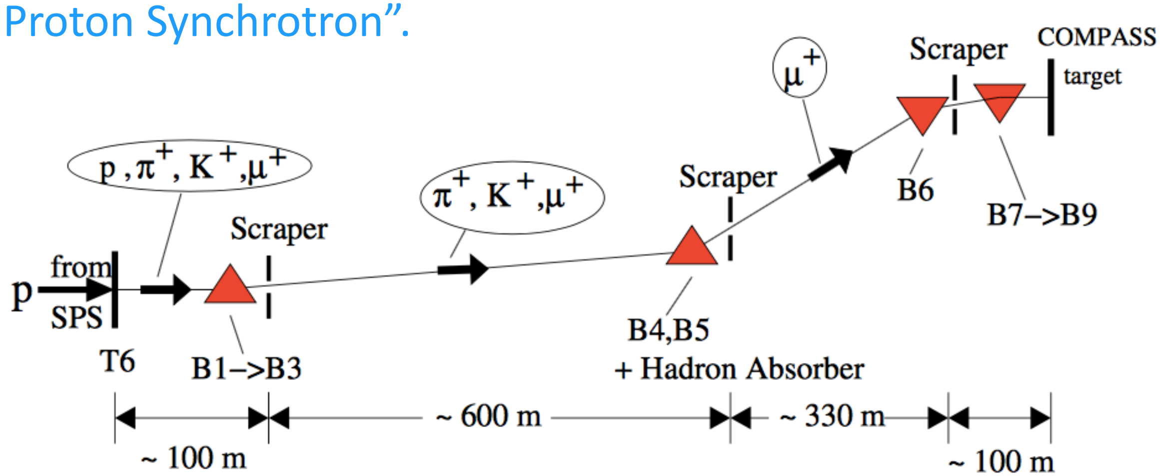


Table 3
Parameters and performance of the 160 GeV/c muon beam.

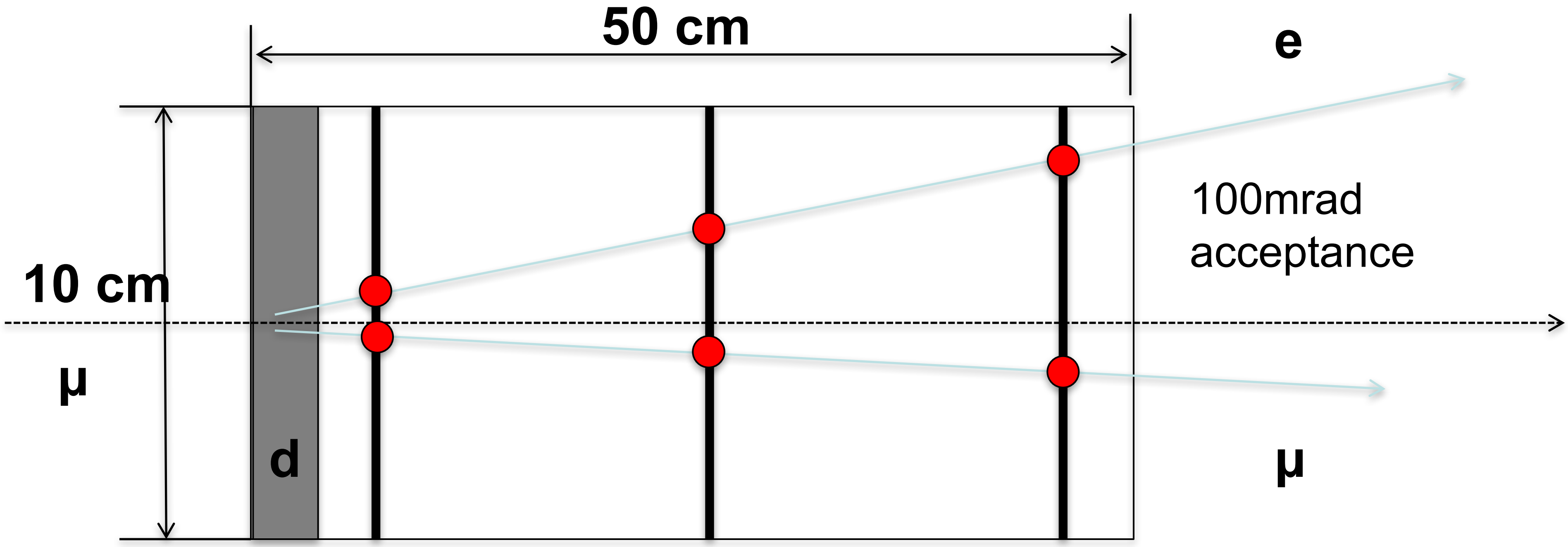
Beam parameters	Measured
Beam momentum $(p_\mu)/(p_\pi)$	$(160\,\mathrm{GeV}/c)/(172\,\mathrm{GeV}/c)$
Proton flux on T6 per SPS cycle	$1.2 \cdot 10^{13}$
Focussed muon flux per SPS cycle	$2 \cdot 10^{8}$
Beam polarisation	$(-80 \pm 4)\%$
Spot size at COMPASS target $(\sigma_x \times \sigma_y)$	$8 \times 8\,\mathrm{mm}^2$
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%

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

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

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

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. …

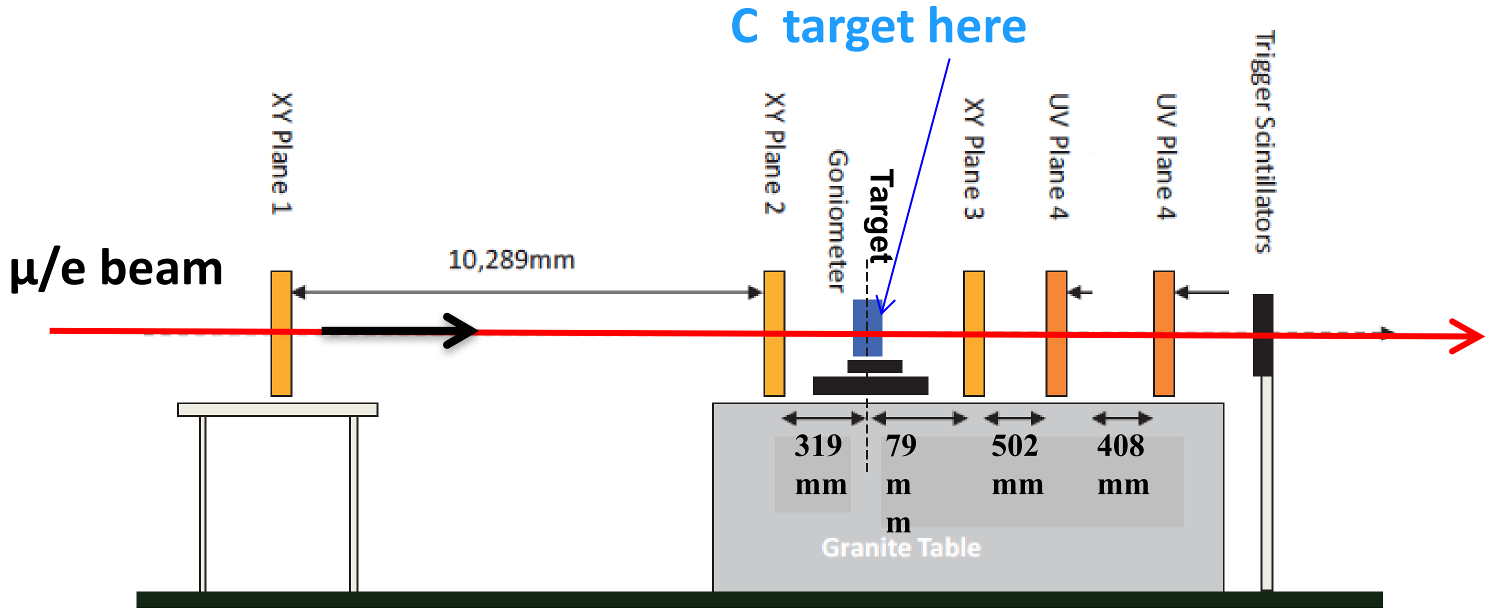
All the systematic effects must be known to ensure an error on the cross section < 10ppm

Multiple Scattering studies: Results from Test Beam

μONe

Check GEANT MSC prediction and populate the 2D (θ_e , θ_μ) scattering plane

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

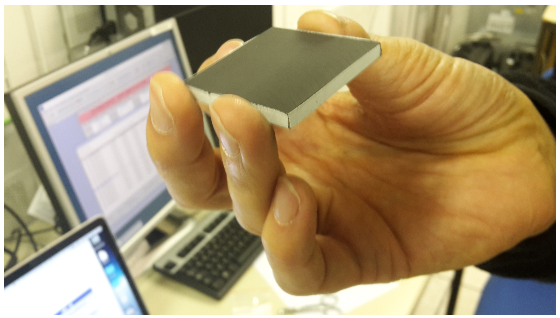


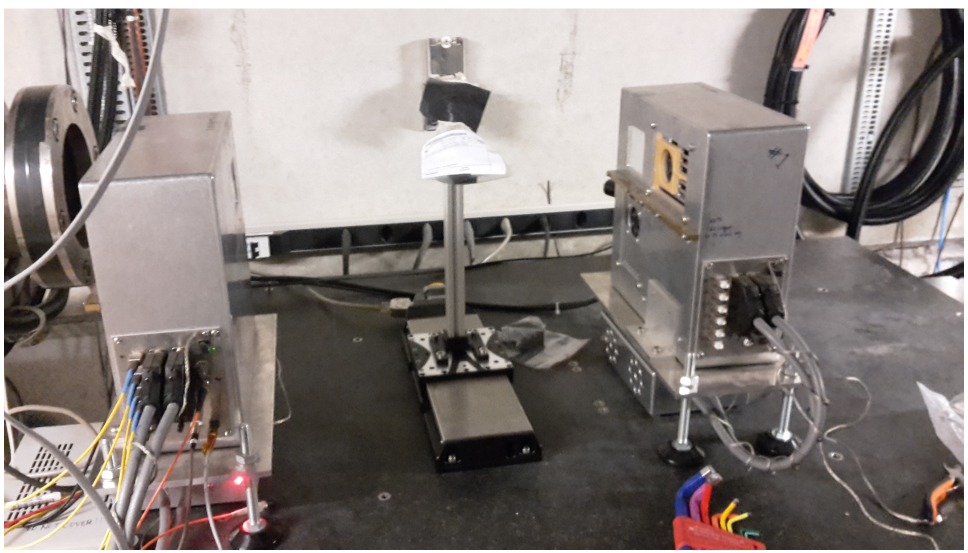
Adapted UA9 apparatus

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

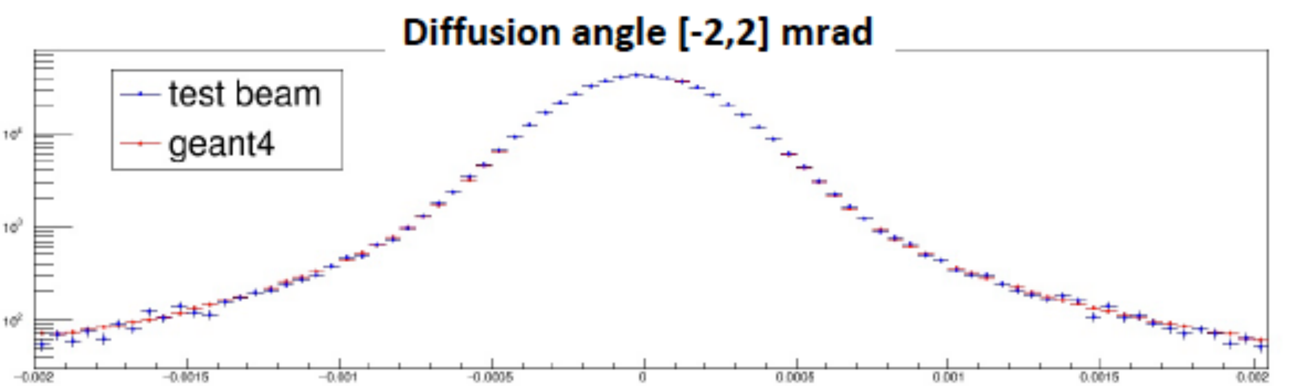
Test Beam setup and target

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

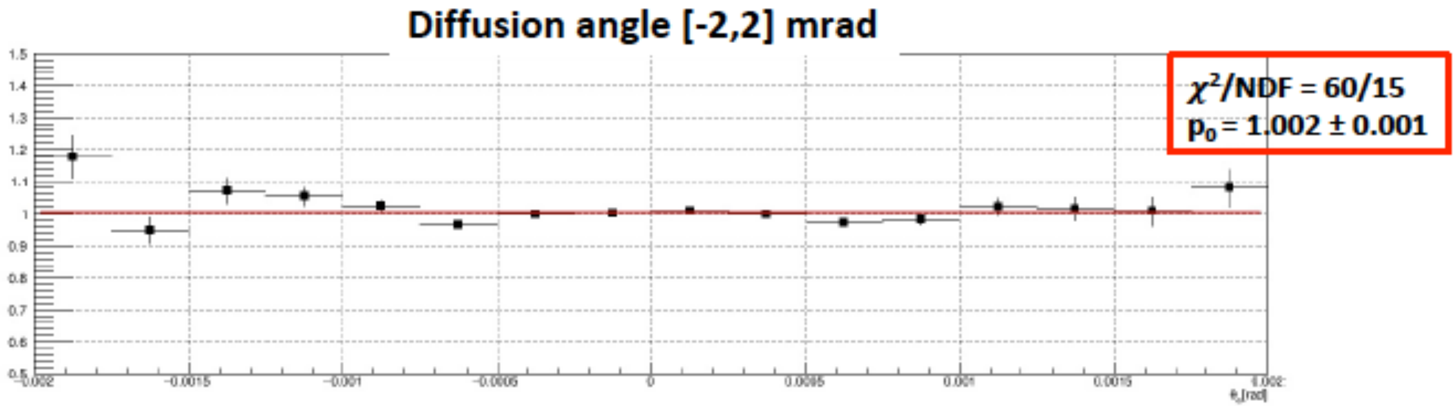




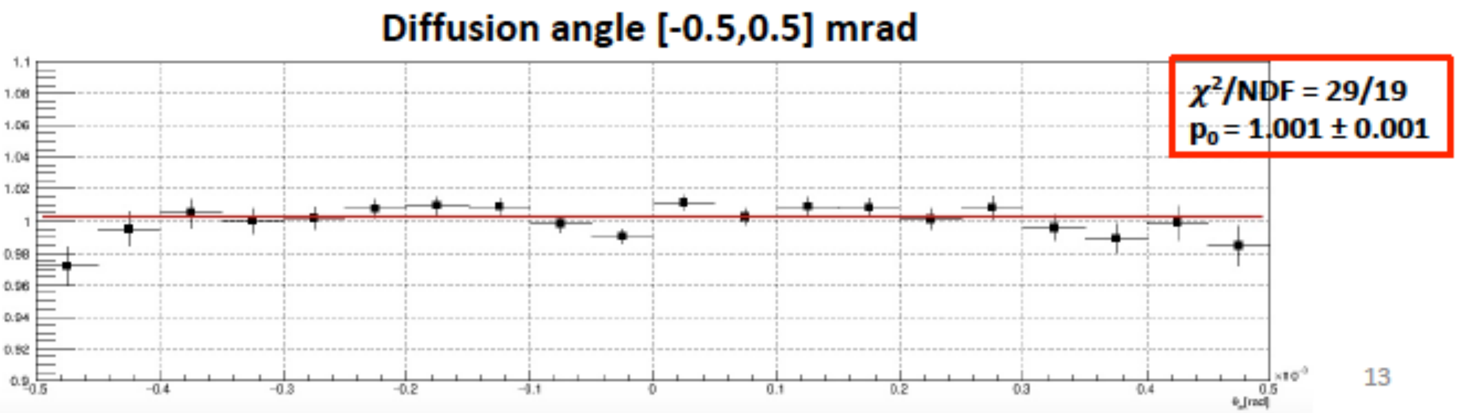
8mm, 12 GeV



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

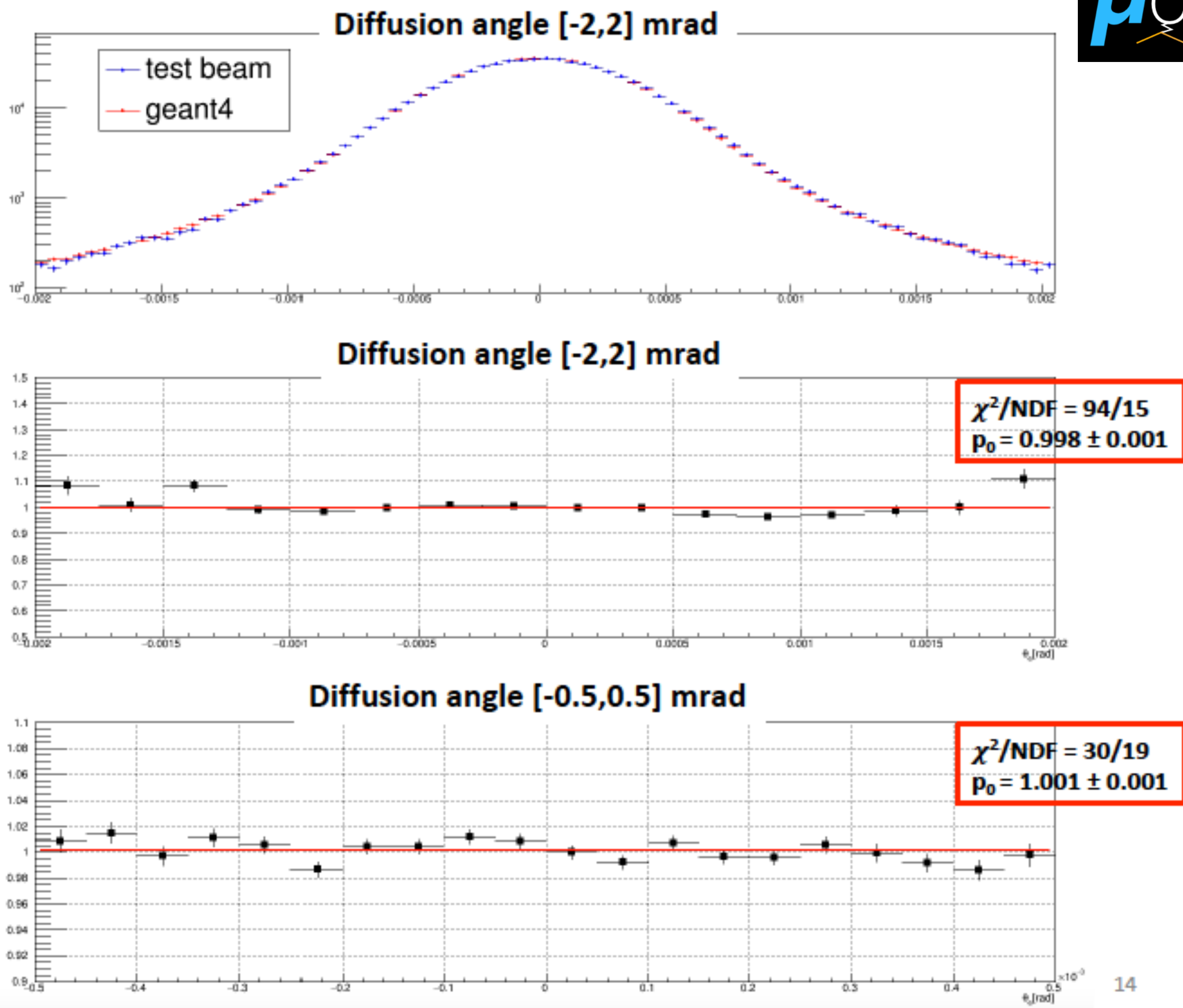


Diffusion angle [-2,2] mrad
χ^2/NDF = 60/15
p_0 = 1.002 ± 0.001



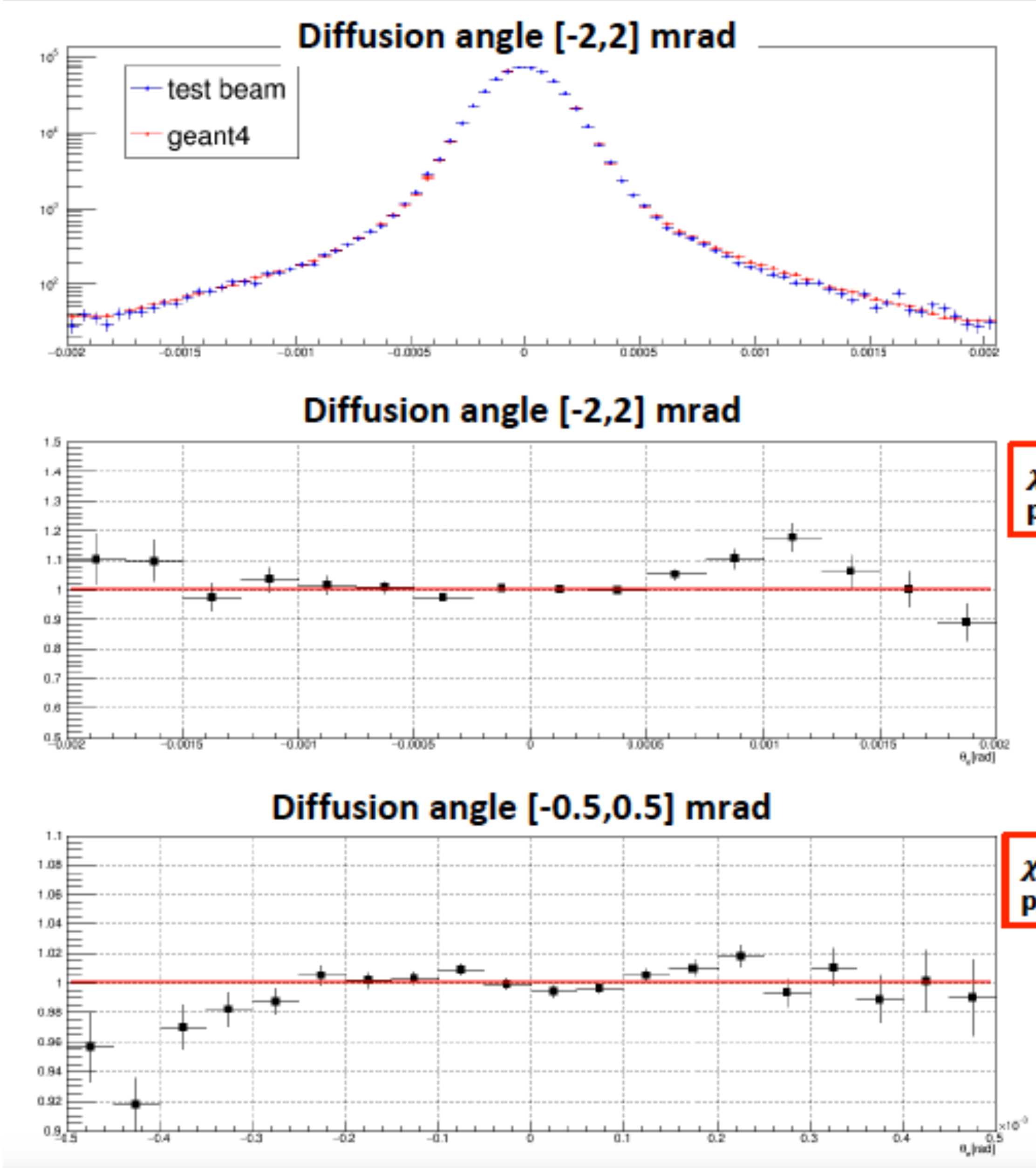
Diffusion angle [-0.5,0.5] mrad
χ^2/NDF = 29/19
p_0 = 1.001 ± 0.001

20mm, 12 GeV



Diffusion angle [-2,2] mrad
test beam
geant4
Diffusion angle [-2,2] mrad
χ^2/NDF = 94/15
p_0 = 0.998 ± 0.001
Diffusion angle [-0.5,0.5] mrad
χ^2/NDF = 30/19
p_0 = 1.001 ± 0.001

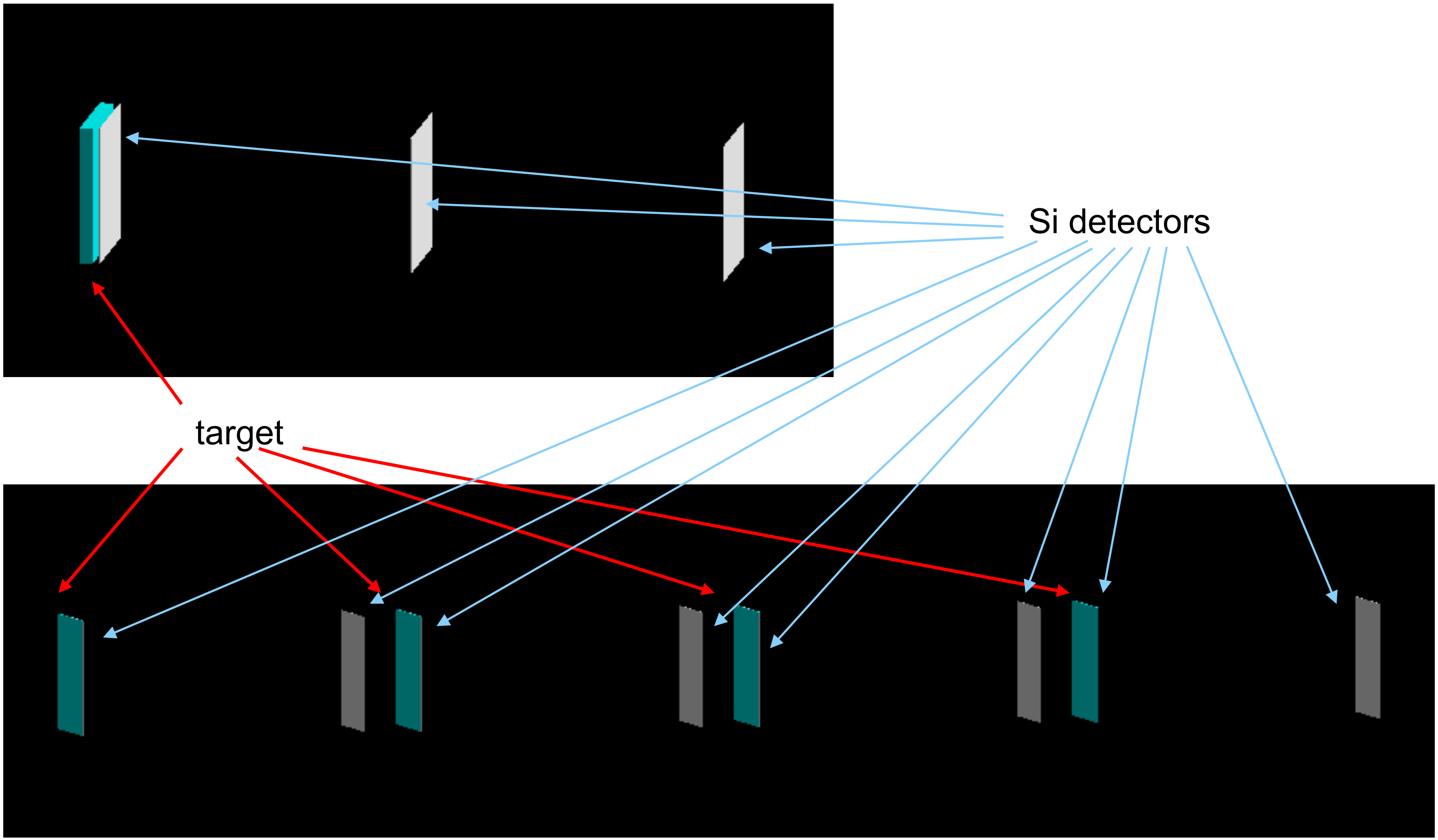
8mm, 20 GeV



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

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

Detector optimization



Detector optimization

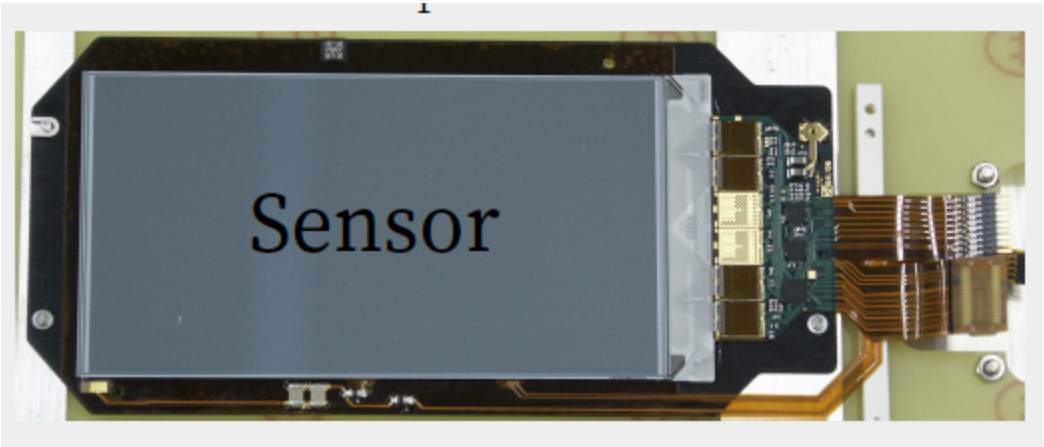
- Target thickness (10mm Be default)
- Silicon sensors (type, material)
- Number of tracking stations per unit (3-4)
- Dimension of apparatus
- Calorimetry/PID
- Trigger/DAQ
- …

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
- $10 \times 10\ cm^2$ silicon detectors
- Resolve each μ,e track with uniform efficiency
- Best possible resolution on θμ (<5mrad),θe (<50 mrad)
- μ rate: ~60 MHz (peak) → 13 MHz (averaged)
- μ separation: 17 ns (peak) → 77 ns (averaged)
- Collect 4×10^{12} events with E_e>1GeV in ~2 years
- Scattering probability (E_e>1GeV): 1.2×10^{-4}/cm
- Scattering event rate (E_e>1GeV): 7 kHz per station
- Scattering separation (E_e>1GeV): 140 μs per station

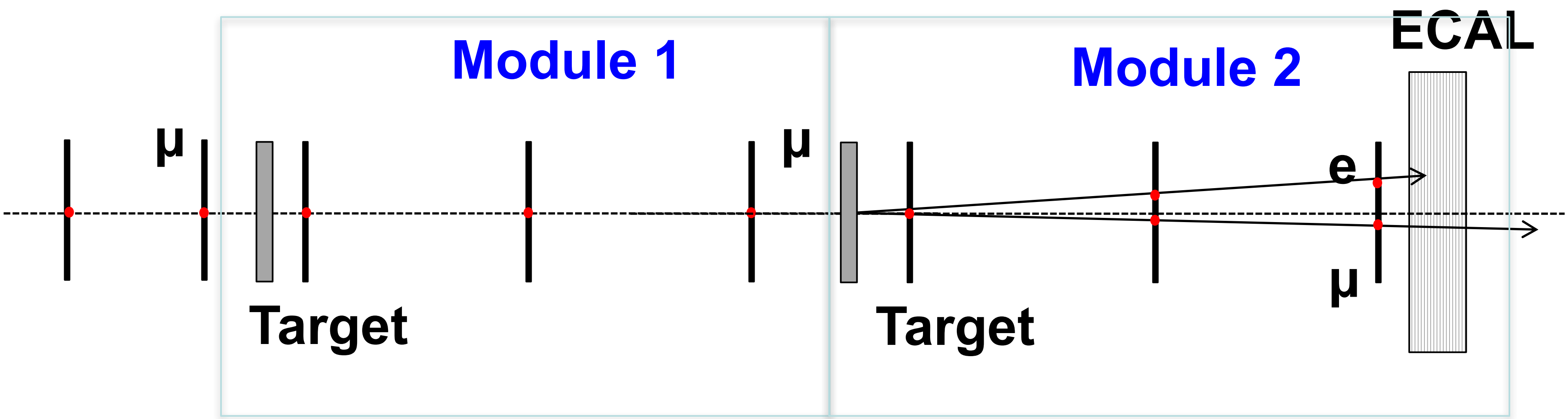
Silicon detectors survey

	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%



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!

EXPERIMENTAL SETUP

Picture taken on 4/8/18

Theory

- QED NLO MC generator with full mass dependence has been developed and is currently under use (Pavia group)

- First results obtained for the NNLO box diagrams contributing to mu-e scattering in QED (Padova group)

1709.07435

Master integrals for the NNLO virtual corrections to μe scattering in QED: the planar graphs

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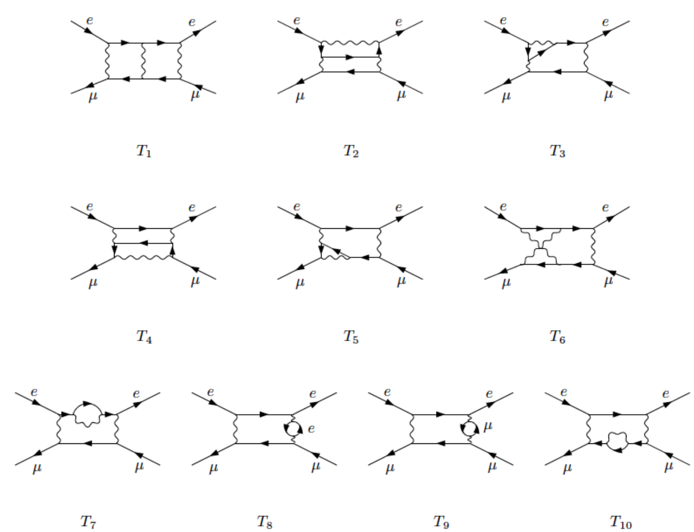


- An unprecedented precision challenge for theory: a full NNLO MC generator for μ-e scattering (10^{-5} accuracy)

Theory: international community!

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

Muon-electron scattering:
Theory kickoff workshop

4-5 September 2017
Padova

Europe/Rome timezone

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

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Mainz Institute for Theoretical Physics

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

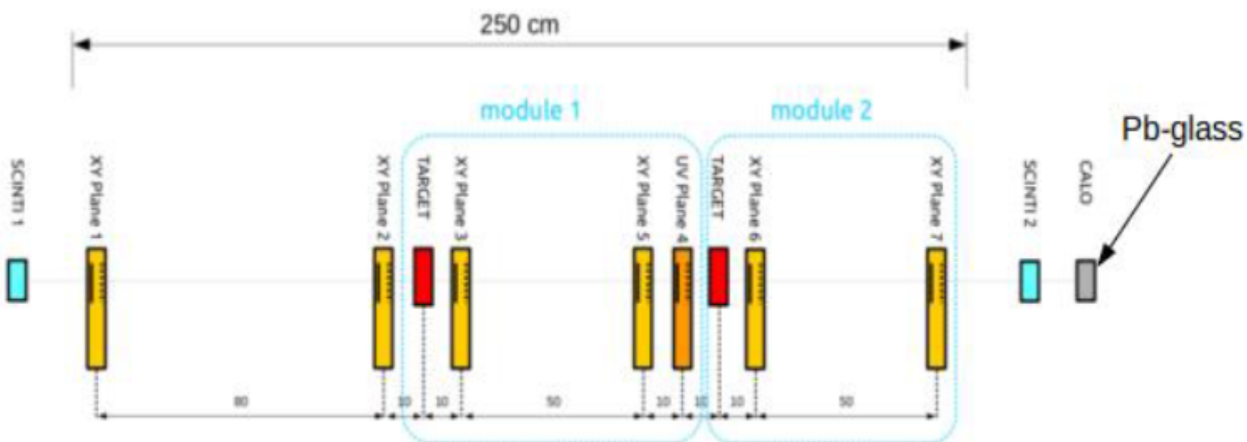
- 2019, Feb 4-7: Workshop on "Theory for muon-electron scattering @ 10ppm" in Zurich

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 are working hard toward a formal LoI (2019).

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

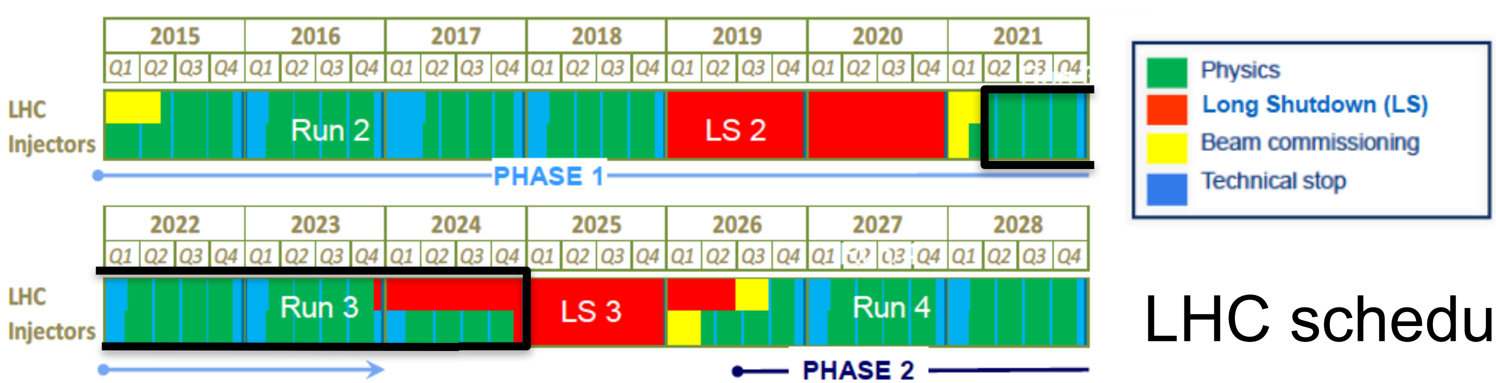
- Concerning the final project for High precision measurement of a_μ^{HLO}

  Certainly very challenging

  I (Alain Magnon) DO NOT SEE a priori showstopper(s)

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**
  - Start the data taking after LS2 to measure $\mathbf{a}_\mu^{HLO}$ (not necessarily the ultimate precision)



LHC schedule

Conclusion

- Exciting times for the muon g-2!
- Alternative/competitive determinations of a_μ^{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

Very challenging experiment: If you are interested you are very welcome!!

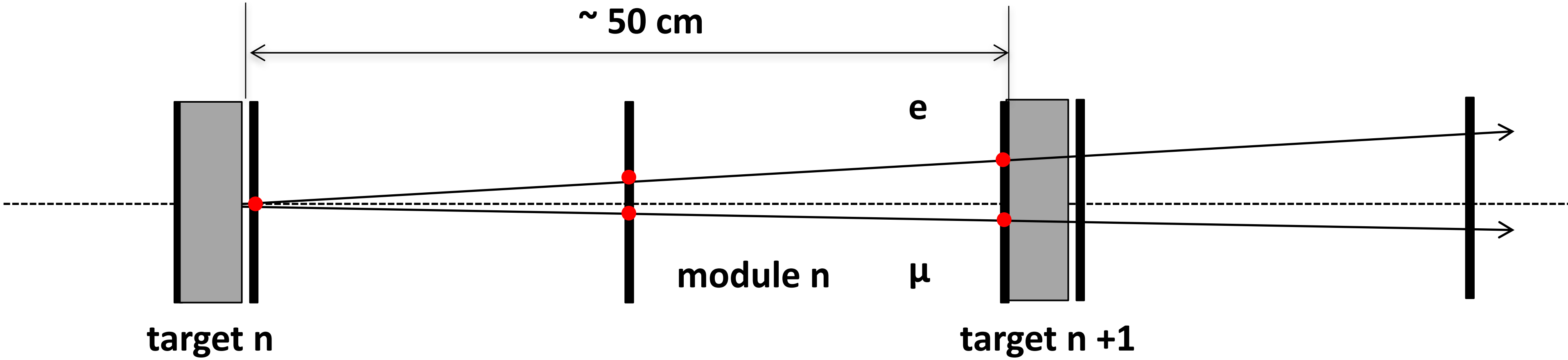
"*Fatti non foste a viver come bruti, ma per seguir virtute e canoscenza* "
(Dante Alighieri, Divina Commedia, Inferno, XXXVI)

[We were not born to live like brutes but to follow virtue and knowledge]

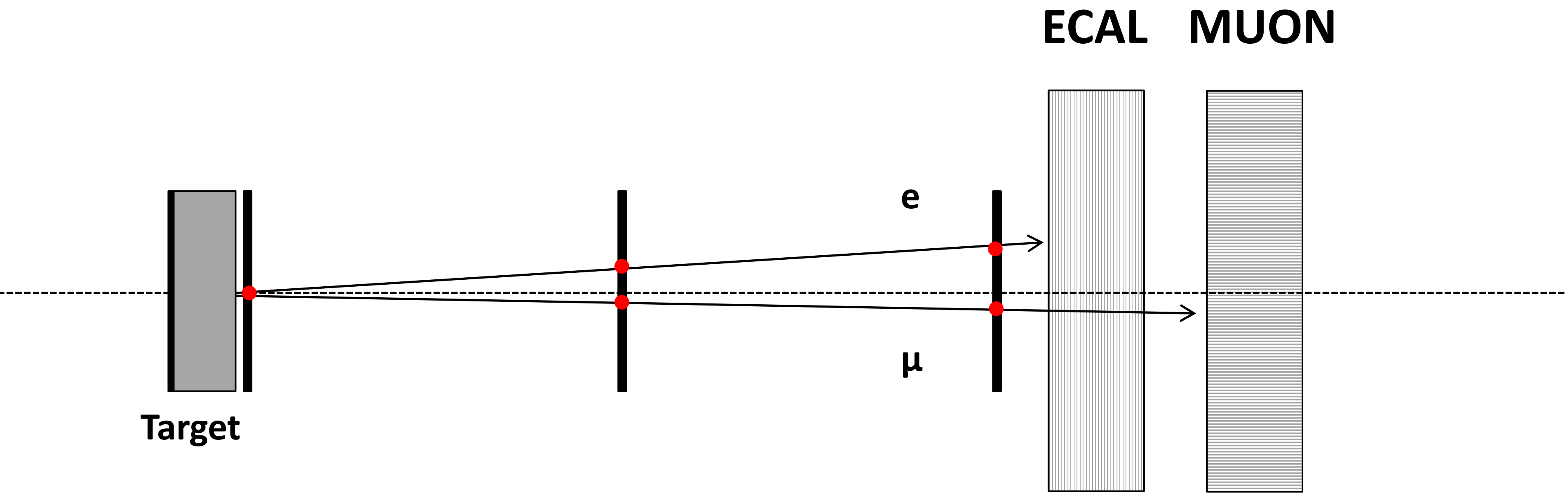
Thanks!

THE END

SPARE

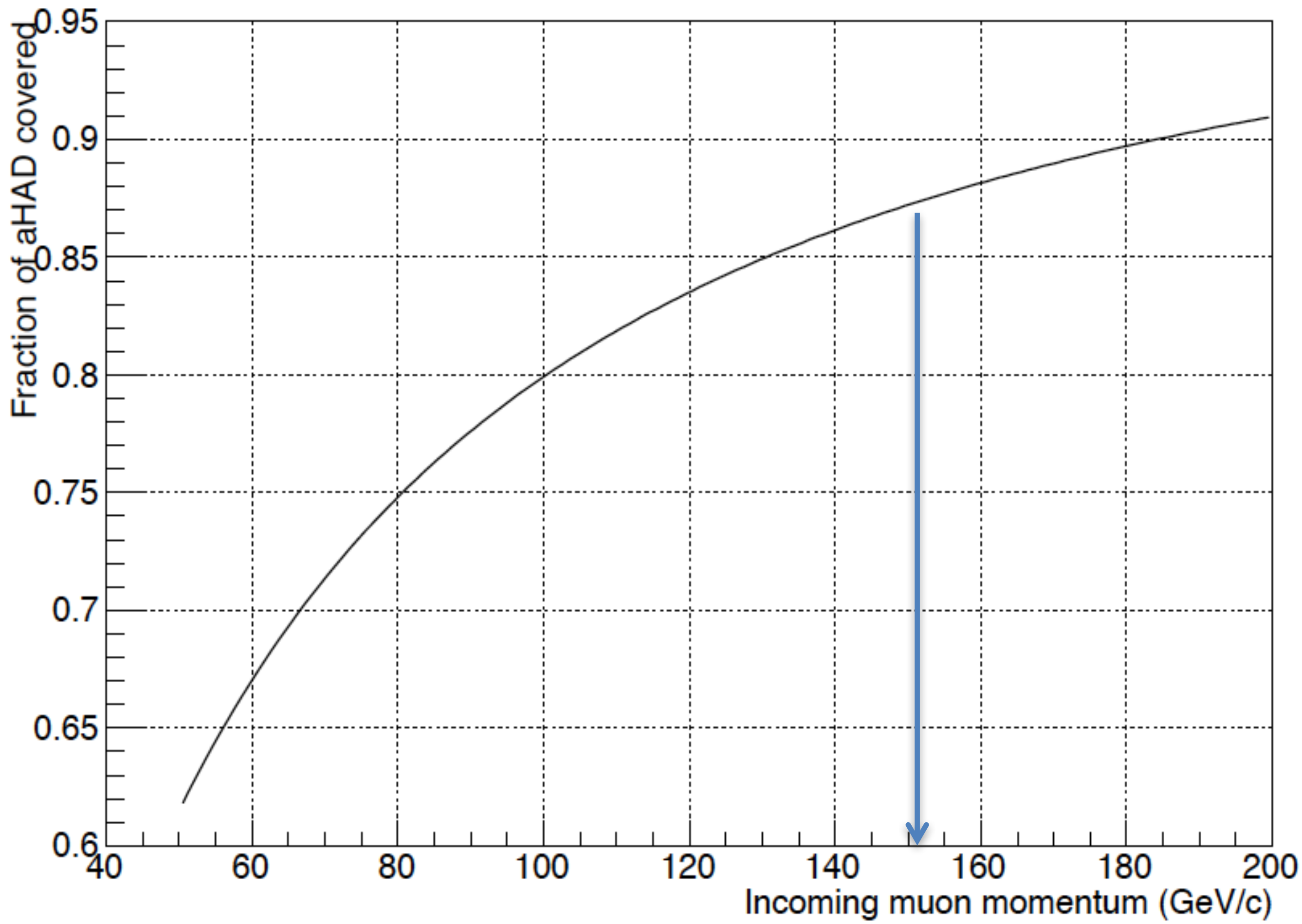


Last module of the detector



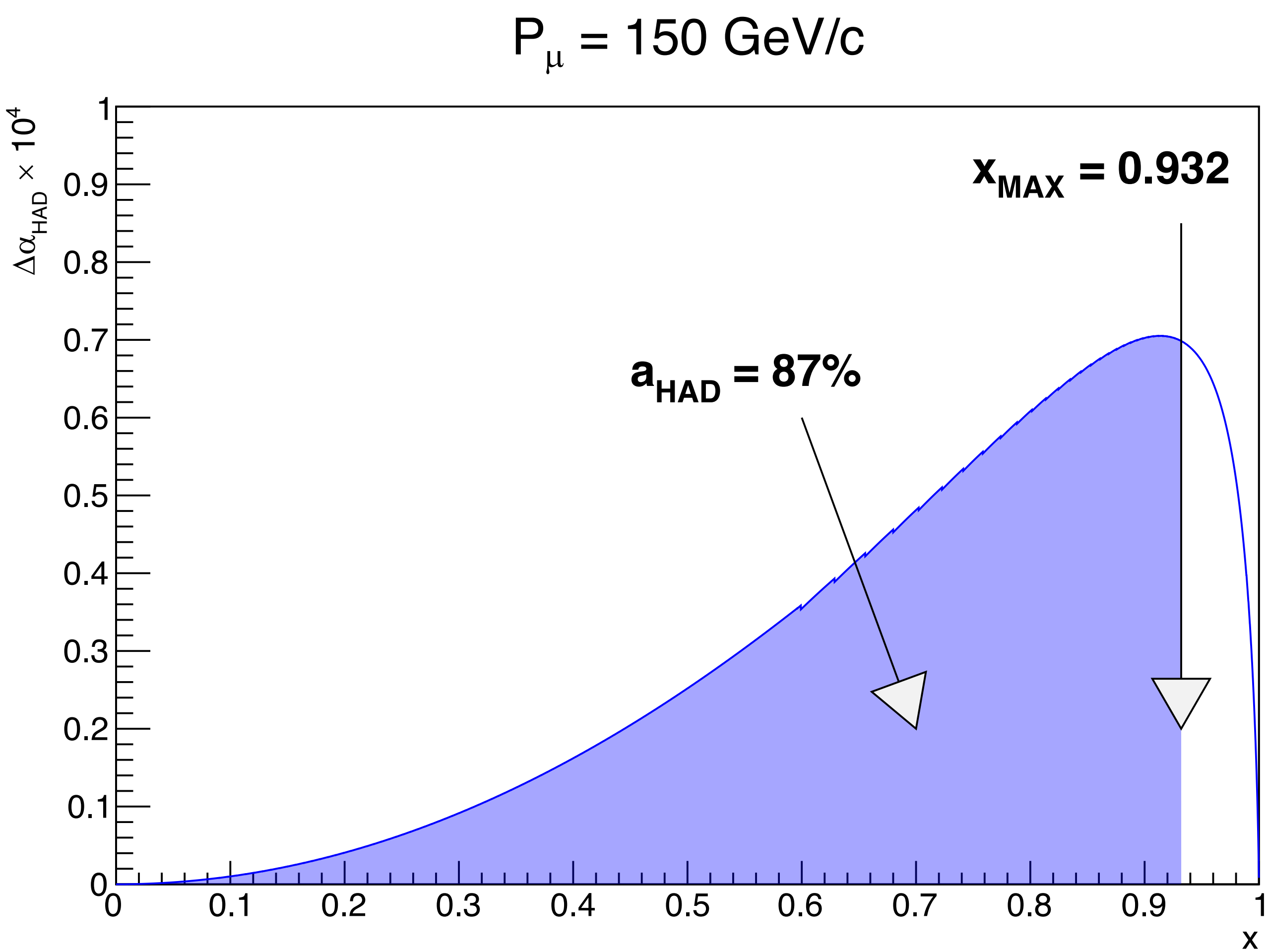
Measure both the electron angle and E_e to define the reference, calibration curve. Detailed check of GEANT predictions.

Fraction of a_μ^{HLO} covered



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

Fraction of a_μ^{HLO} covered



87% of a_μ^{HLO} covered with Pμ=150 GeV

(courtesy of M. Incagli)

Muon g-2: summary of the present status

- E821 experiment at BNL has generated enormous interest:

$$a_\mu^{E821} = 11659208.9(6.3)\times 10^{-10} \quad \text{(0.54 ppm)}$$

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

$$a_\mu^{SM} = 11659180.2(4.9)\times 10^{-10} (DHMZ)$$

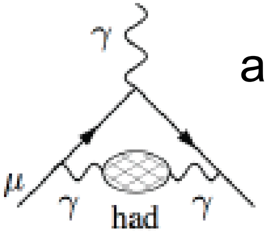
M. Davier, A. Hoecker, B. Malaescu and Z. Zhang, Eur. Phys. J. C71 (2011)

$$a_\mu^{E821} - a_\mu^{SM} \sim (28 \pm 8)\times 10^{-10}$$

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

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

Hadronic Vacuum polarization (HLO)



$a_\mu^{HLO} = (692.3 \pm 4.2)10^{-10}$

$\delta a_\mu^{HLO}/a_\mu^{HLO} \sim 0.6\%$

MUonE

A high precision measurement of a_μ^{HLO} with a 150 GeV μ beam on e^- target at CERN

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,...

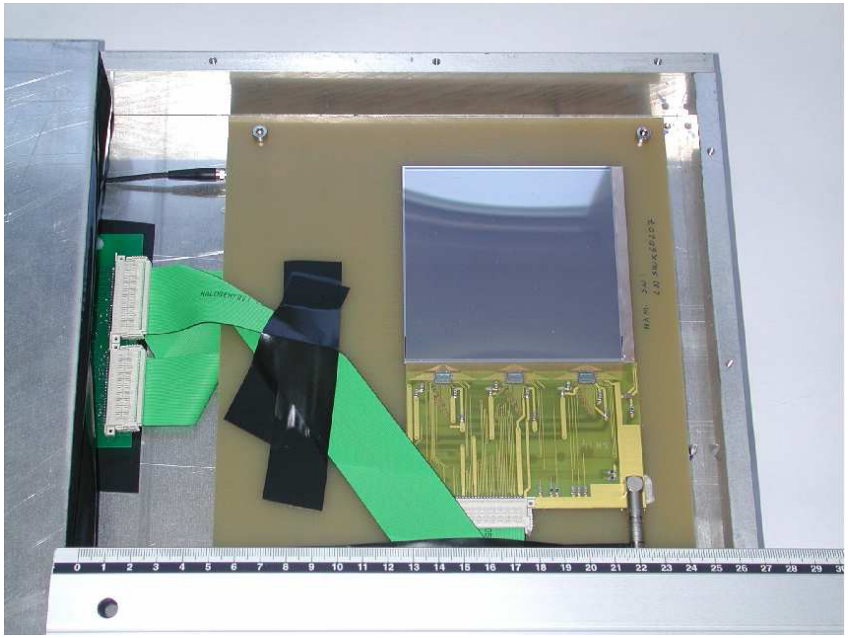
Pisa, 5 Giugno 2018

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 × 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

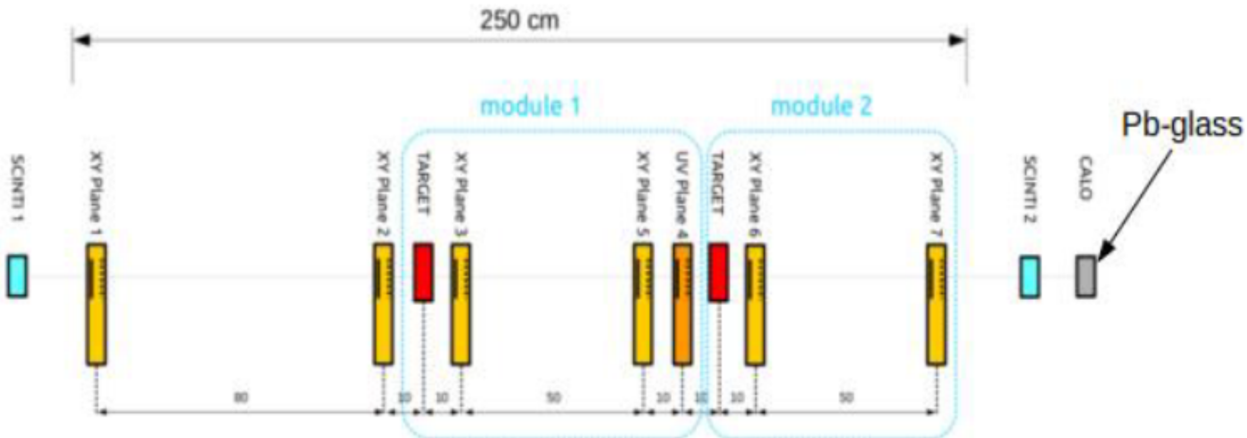


M. Prest et al., NIM A, 501:280–287, 2003

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

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

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

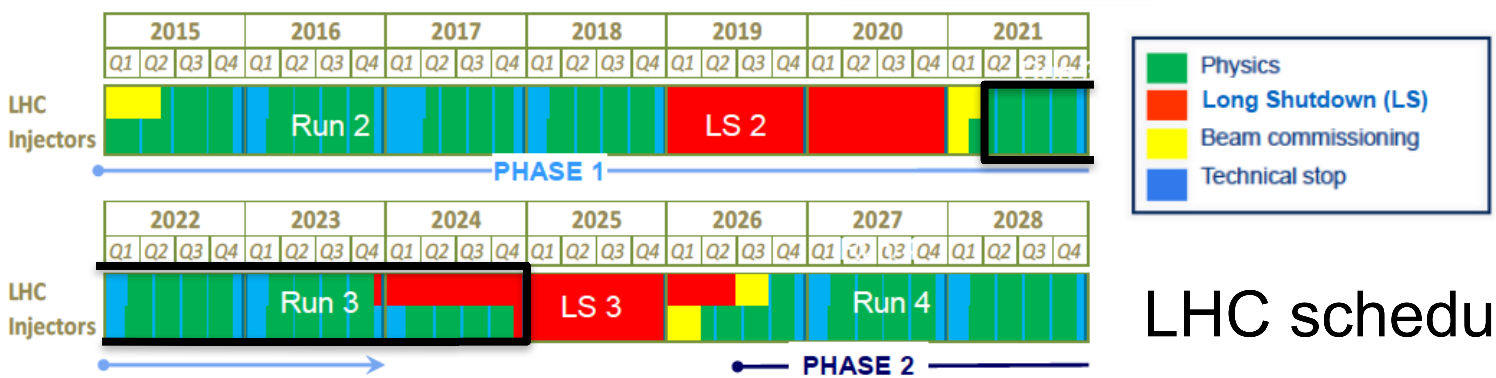
- Concerning the final project for High precision measurement of a_{μ}^{HLO}

  Certainly very challenging

  I (Alain Magnon) DO NOT SEE a priori showstopper(s)

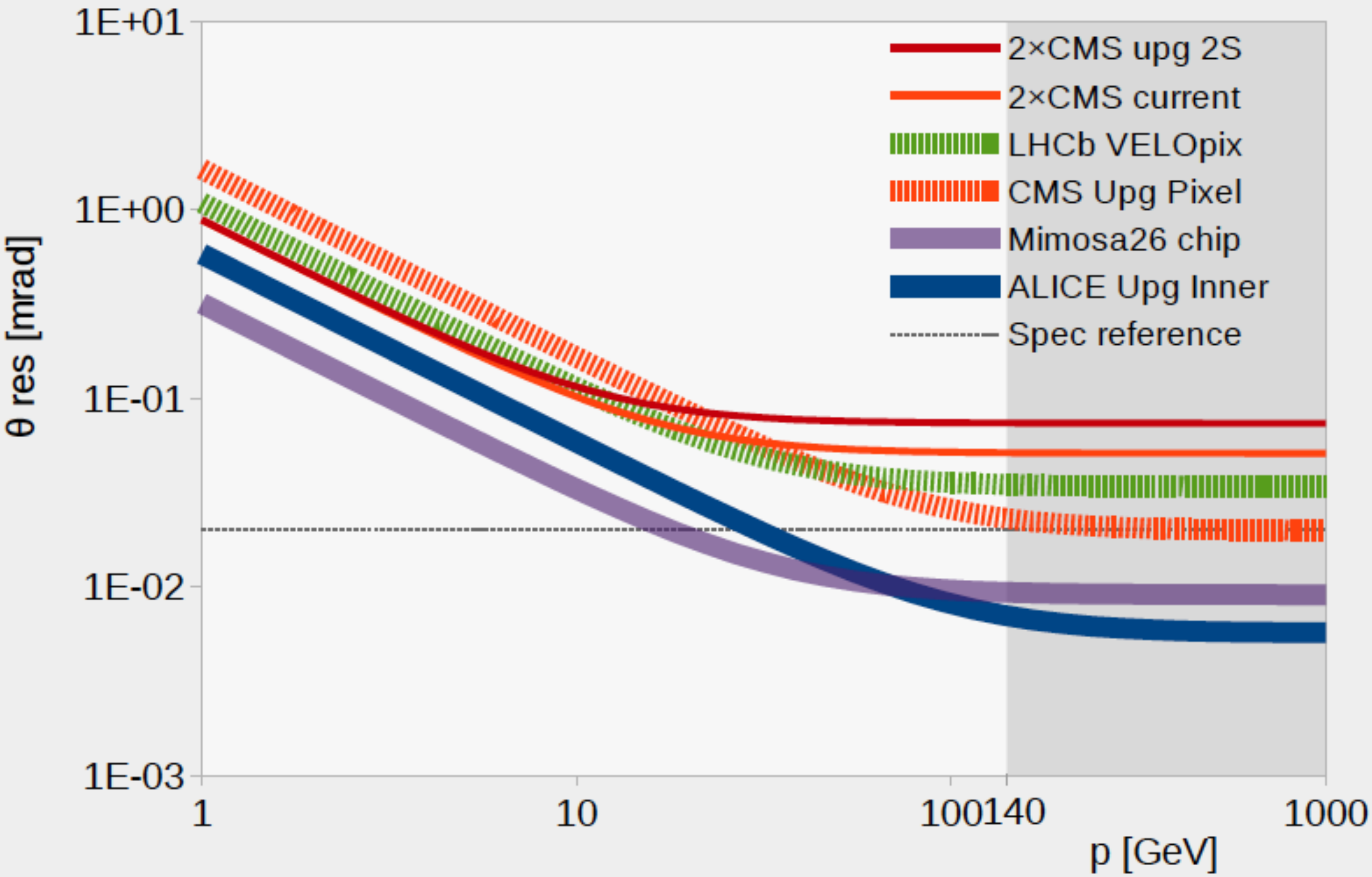
Plans

- **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**
  - Start the data taking after LS2 to measure $\mathbf{a}_\mu^{HLO}$ (not necessarily the ultimate precision)



LHC schedule

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

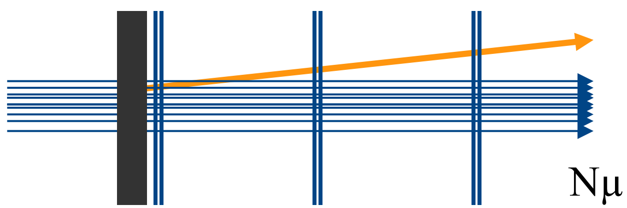
$$m = \left(\frac{x}{X_0}\right)_{\det}$$

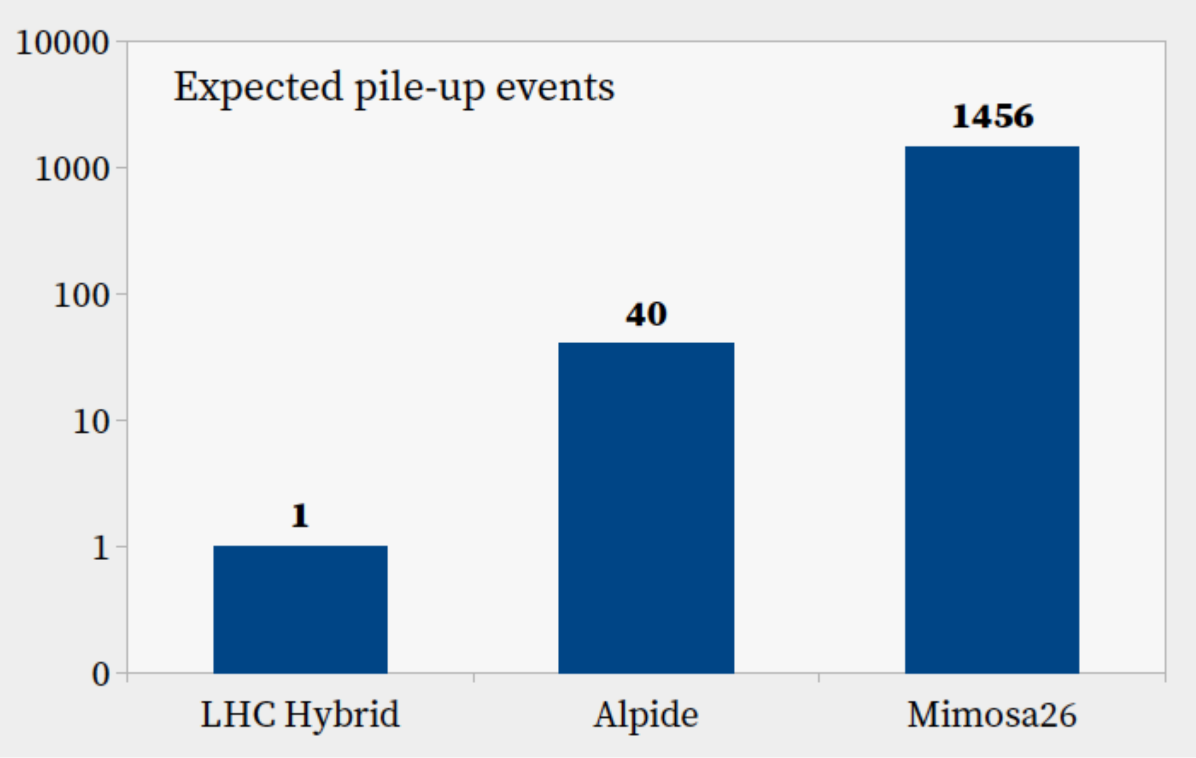
- Resolution on scattering angle assumptions:
- 2 measurement plane 0.5 m apart
- Scattering on:
  - No plane (ideal resolution)
  - First detector plane (pure tracker resolution)
  - First plane + ½ Be target (includes “average” MS in target)
- Core of MS only considered (no tails)

Detector integration time

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

Expected pile-up events





$N\mu = r \times \tau$

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

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

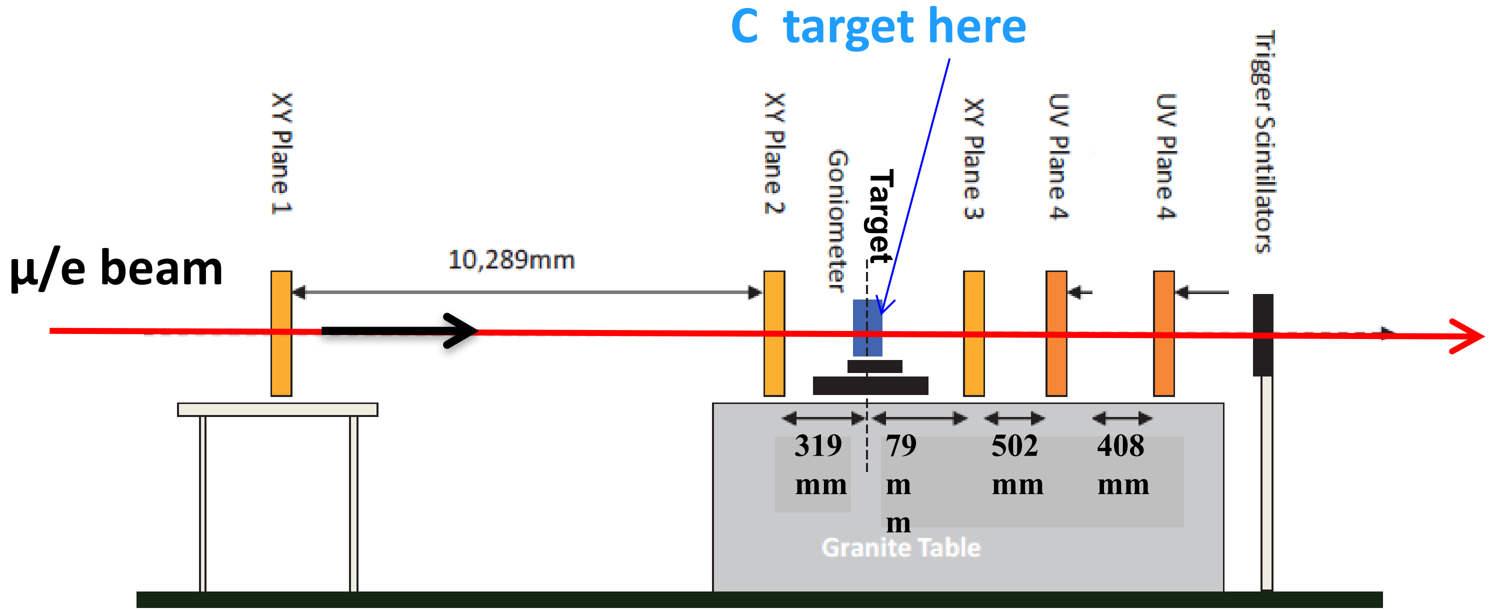
Experimental setup location

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

Multiple Scattering studies: Results from Test Beam

Check GEANT MSC prediction and populate the 2D (θ_e , θ_μ) scattering plane

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

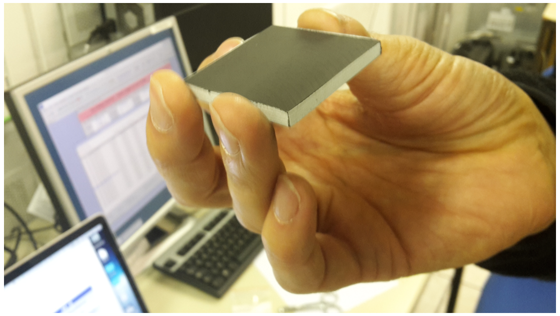


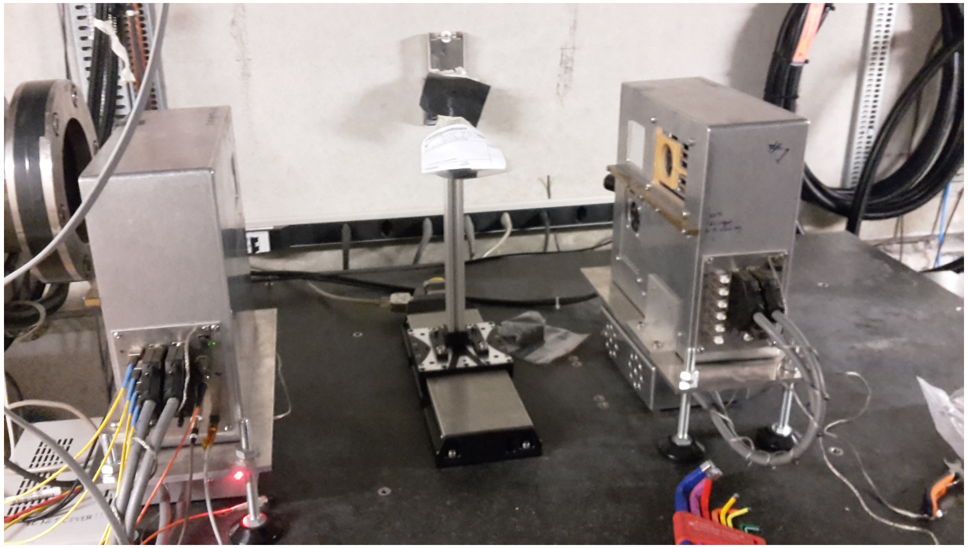
Adapted UA9 apparatus

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

Test Beam setup and target

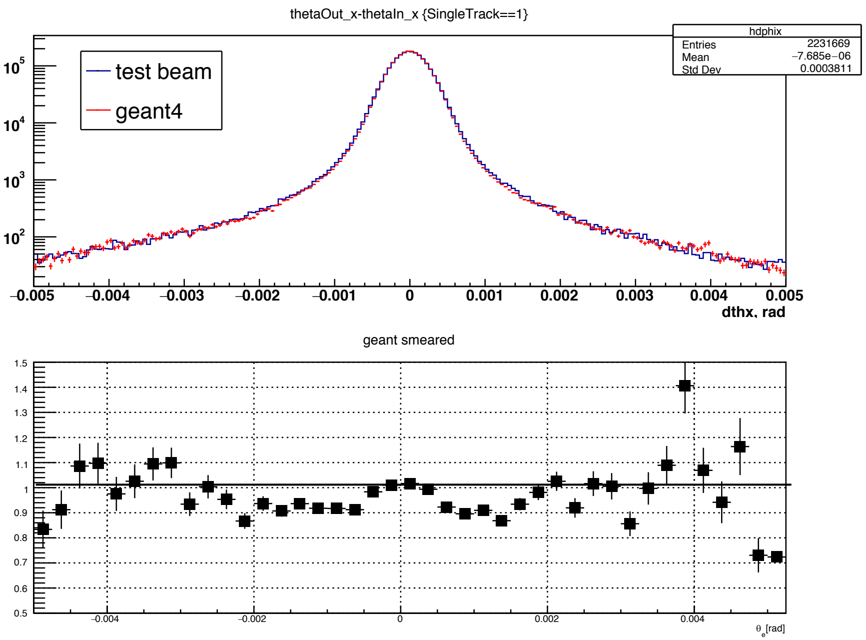
Thanks to the UA9 Collaboration (particularly M. Garattini, R. Iaconageli, M. Pesaresi), J. Bernhard



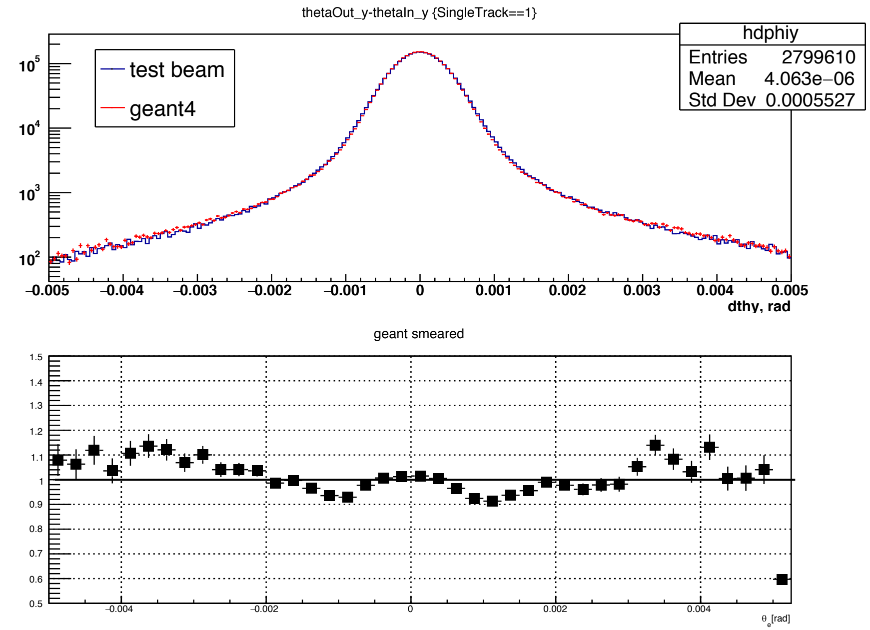


(Preliminary) Analysis of Test Beam data

12 GeV e^- 8mm C

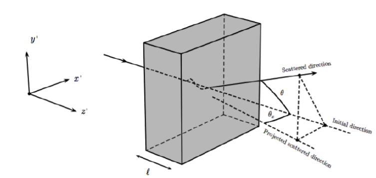


12 GeV e^- 20mm C



-5mrad +5mrad -5mrad +5mrad

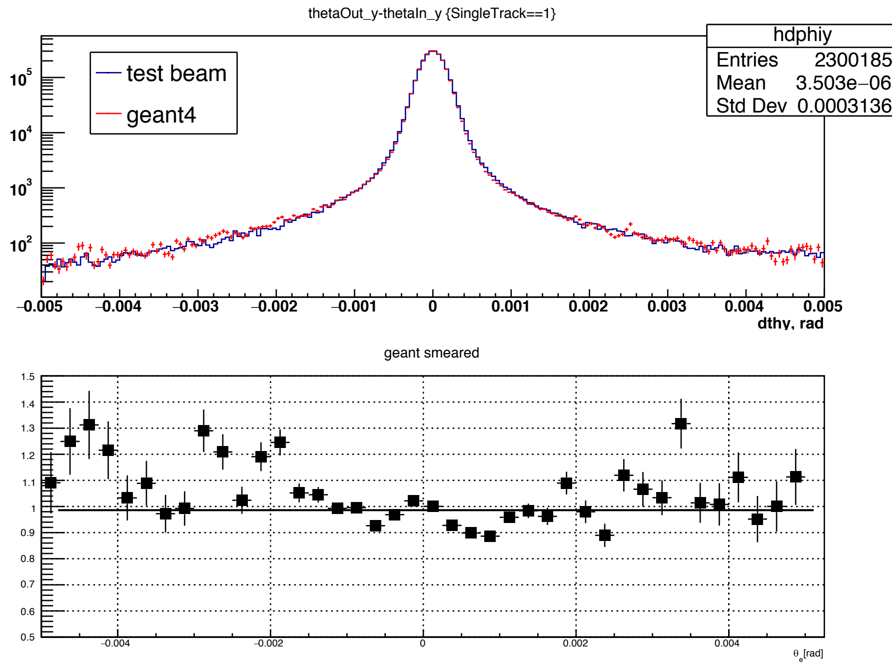
Output angle[mrad]



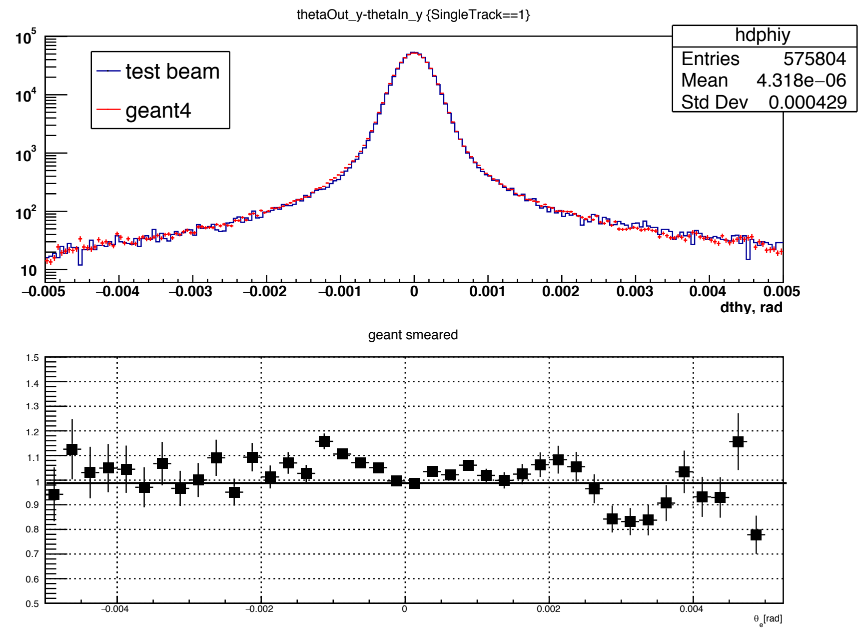
- data-MC agree on σ(core) at ~2%
- data-MC agree on σ(tail) at ~5%
- (Possible) improvement due to better alignment and track fit
- Discussion with GEANT expert (V. Ivantchenko) ongoing

(Preliminary) Analysis of Test Beam data

20 GeV e^- 8mm C



20 GeV e^+ 20mm C



-5mrad +5mrad -5mrad +5mrad

- data-MC agree on σ(core) at ~2%
- data-MC agree on σ(tail) at ~5%
- (Possible) improvement due to better alignment and track fit
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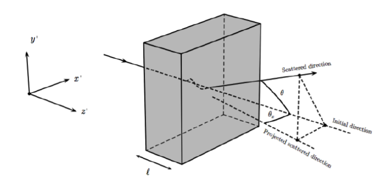
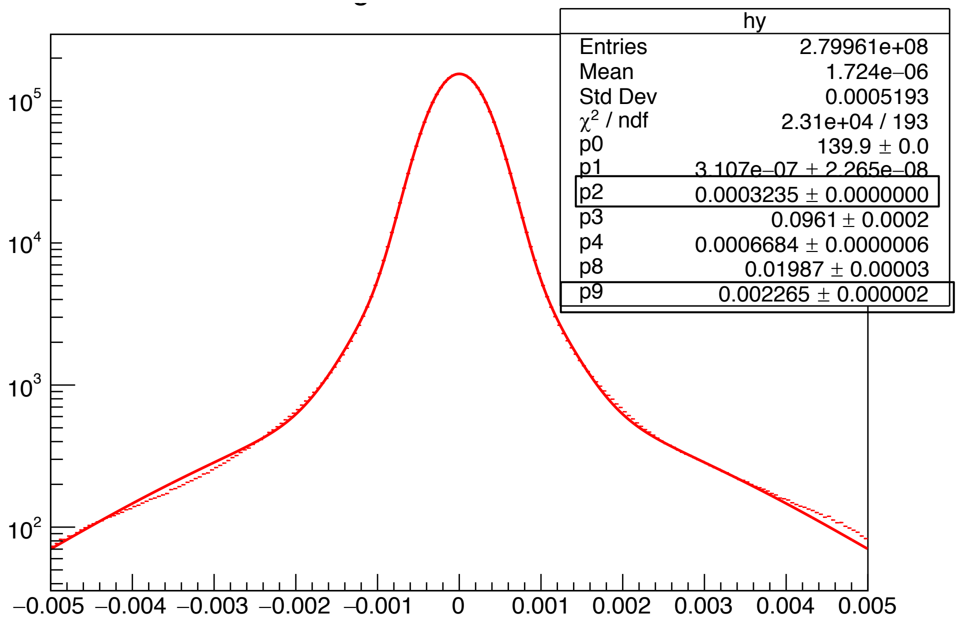
Output angle[mrad]

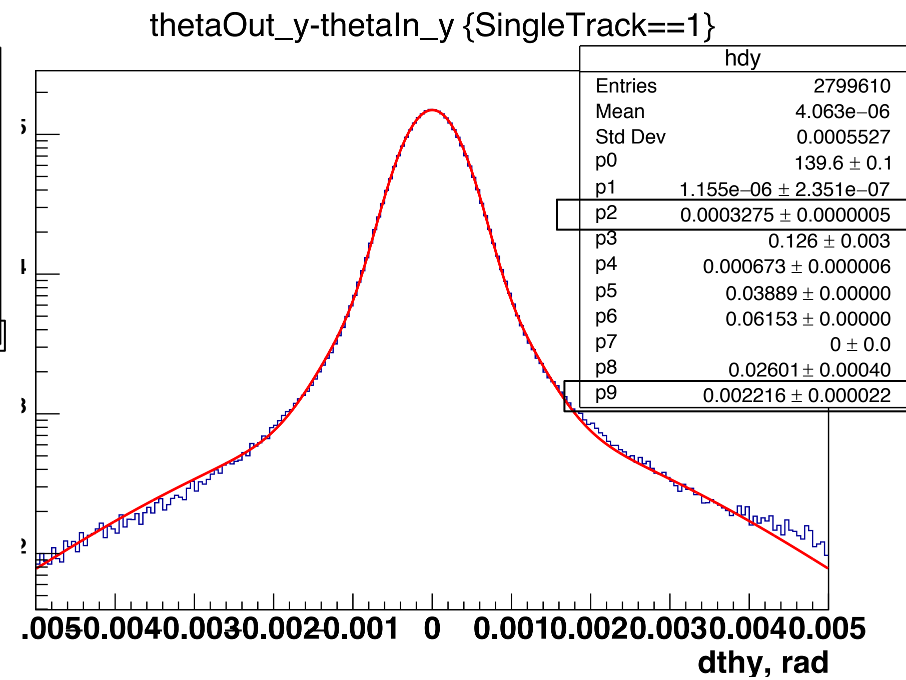


(Preliminary) Analysis of Test Beam data

20 GeV e$^-$ 20mm C
GEANT



20 GeV e$^-$ 20mm C
DATA



Output angle[mrad]

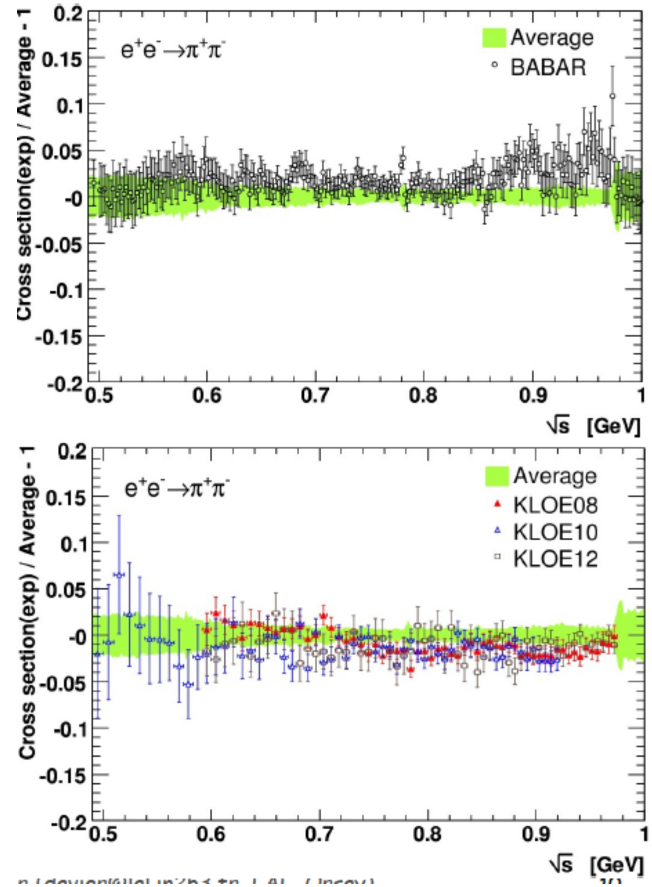
- p2: σ(core)$_{MC}$=3.24x10^{-1} mrad σ(core)$_{DATA}$=3.27x10^{-1} mrad
- p9: σ(tail)$_{MC}$=2.27 mrad σ(core)$_{DATA}$=2.22 mrad

Fractional difference: <1% on σ(core); ~3% on σ(tail)

G. Venanzoni, g-2 Coll Meeting 22 March 2018

Timelike data aiming at 0.2% on a_μ^{HLO}?

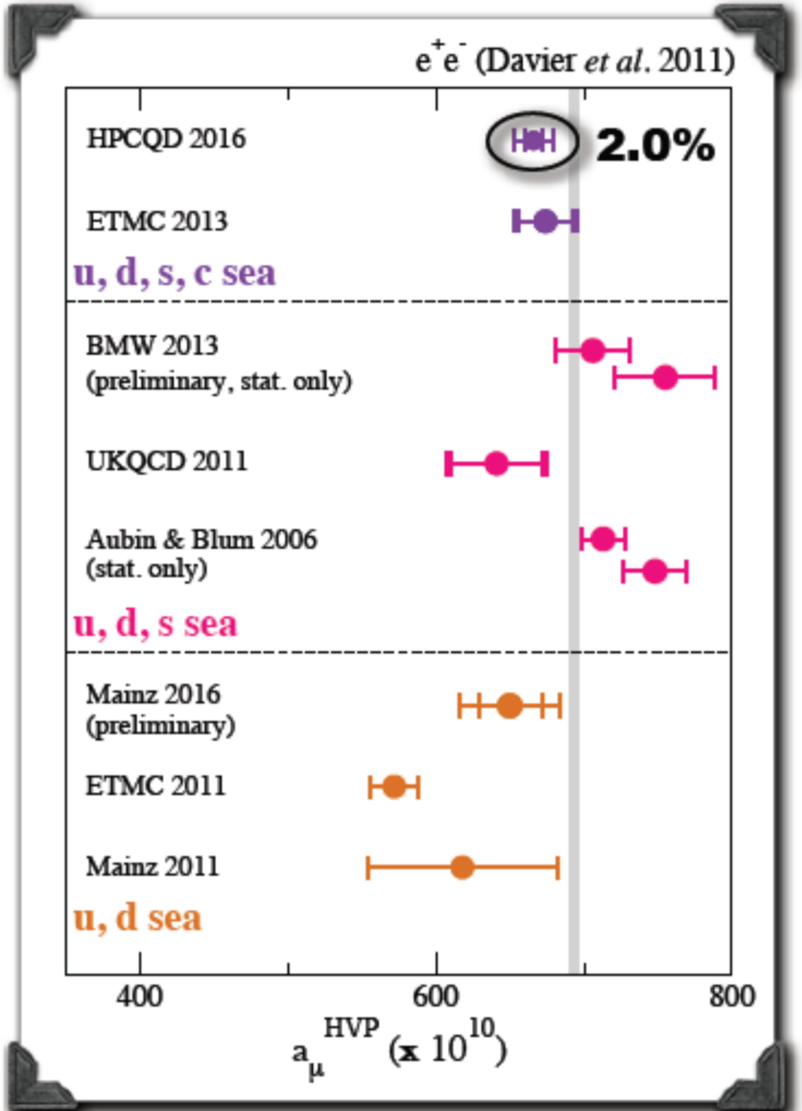
- Not an easy task!
  - >30 channels to keep under control (at (sub)percent level)
  - local discrepancies in main channels (2π (KLOE/Babar), K^+K^- CMD2/Babar)
  - Isospin corrections for not measured channels
  - Treatment of narrow resonances? (See F. Jegerlehner, ArXiv:1511.04473)



M. Davier, TAU16 WS

An independent/complementary approach is highly desirable!

Lattice-QCD progress on a_μ^{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_μ^{HVP} [HPQCD, arXiv:1601.03071]

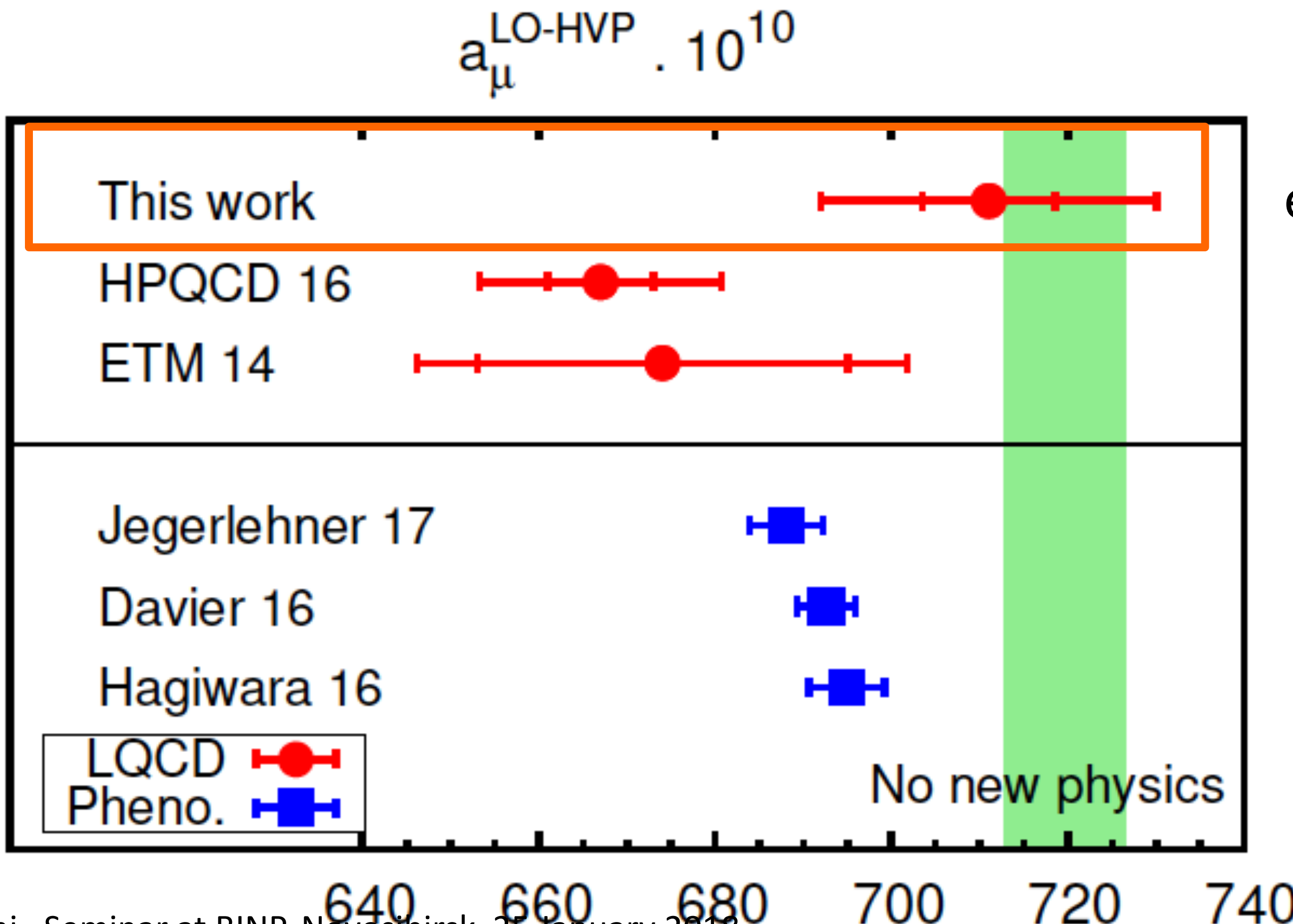
- First to reach precision needed to observe significant deviation from experiment

- ~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)



error~2.7%

arXiv:1711.04980v1 [hep-lat] 14 Nov

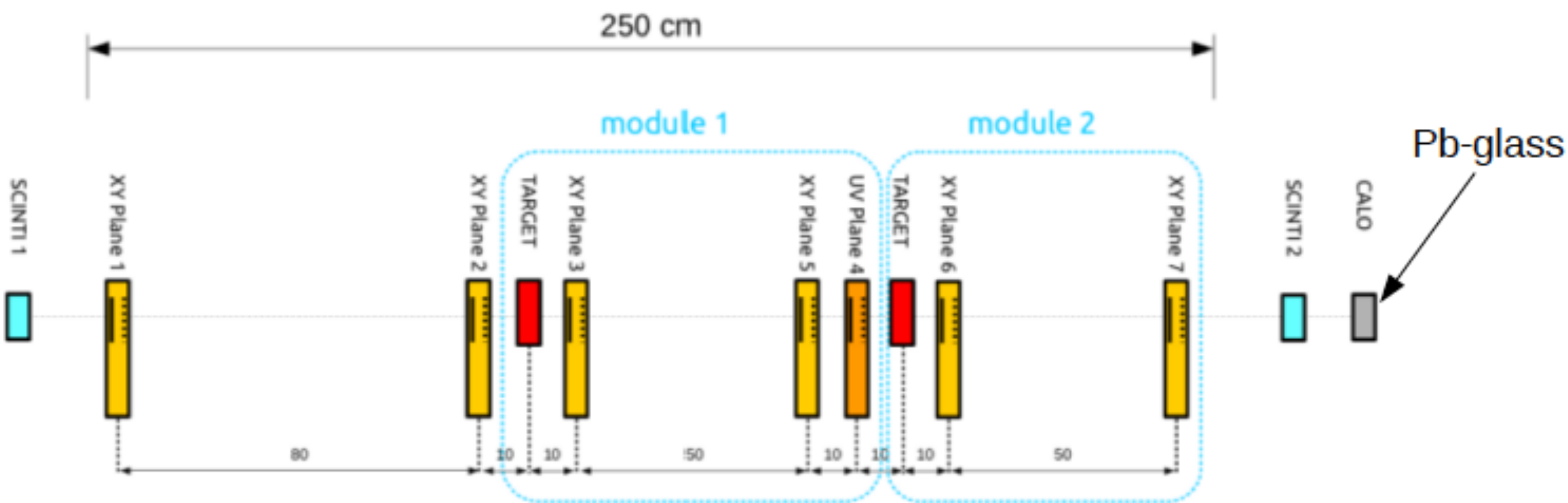
$$a_\mu^{\text{LO-HVP}} = 711.0(7.5)(17.3) \times 10^{-10}$$

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_μ and the prediction of the SM based on phenomenology.

arXiv:1711.04980v1 [hep-lat] 14 Nov

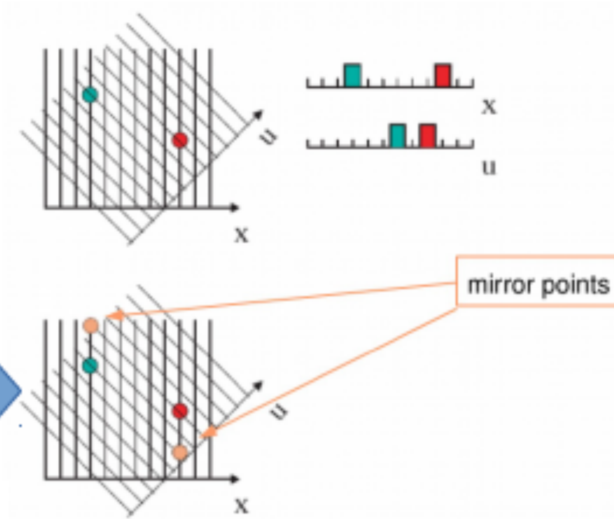
Experimental Setup



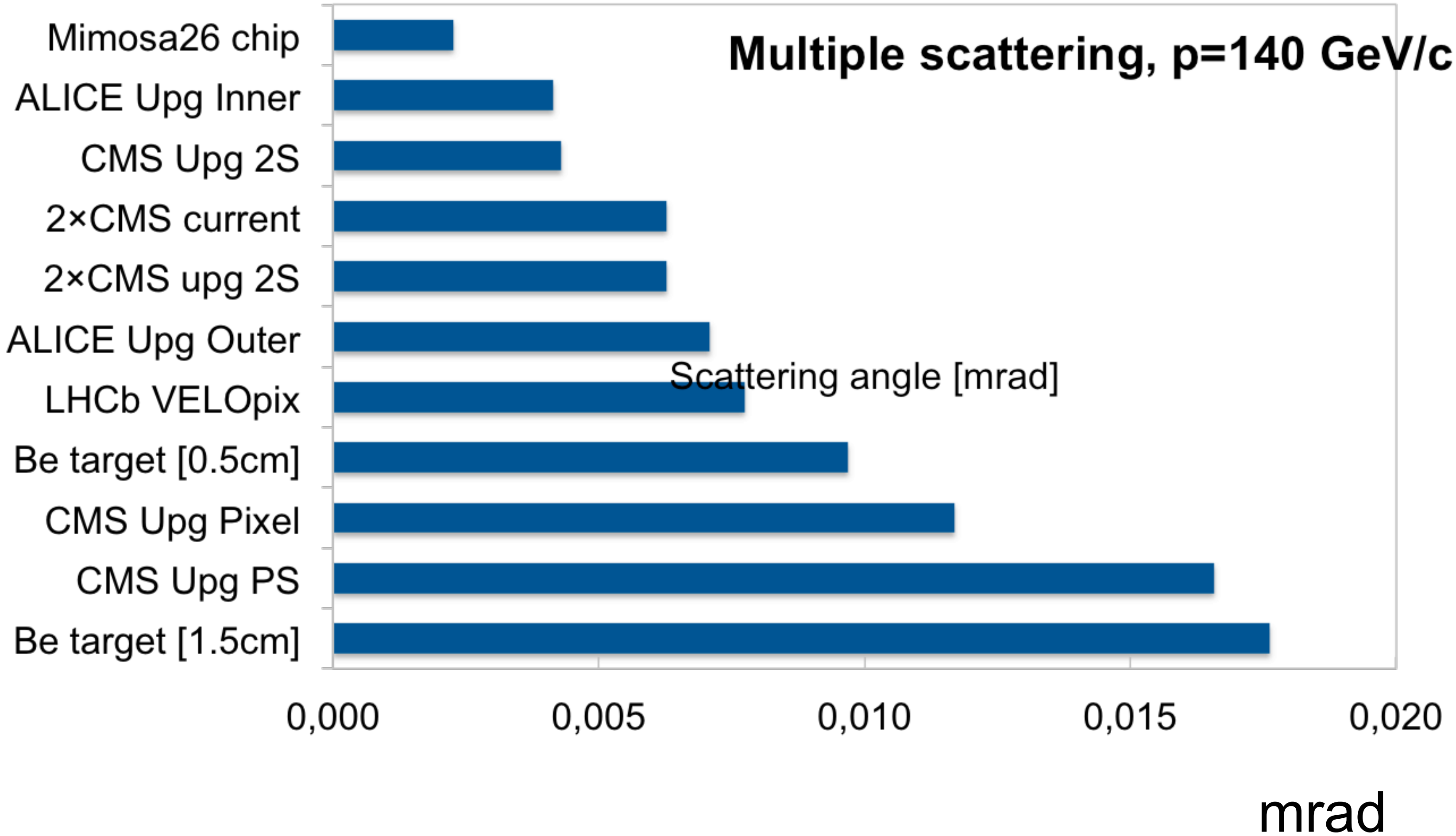
Scintillators: 2 100 x 100 mm^2

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

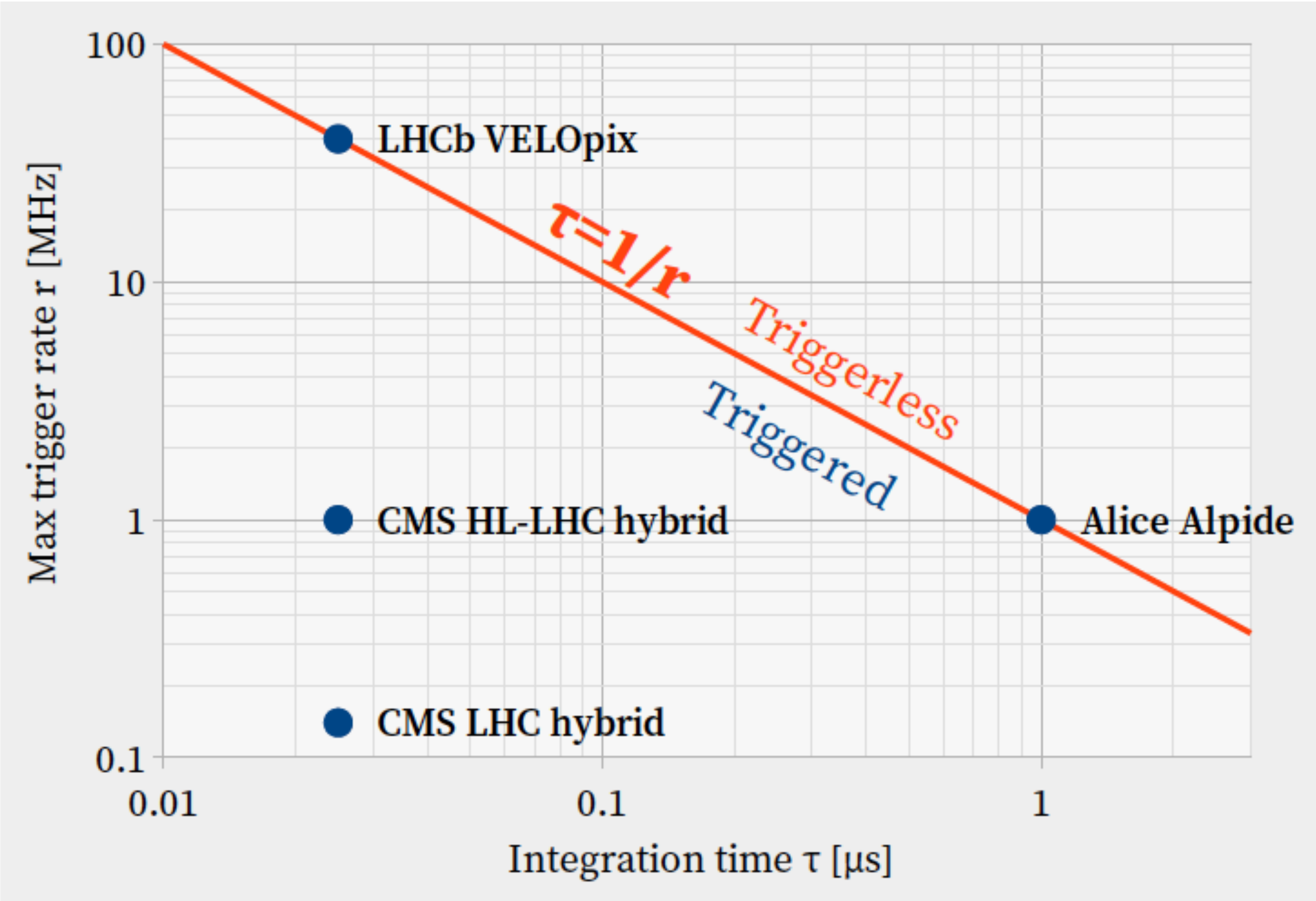
Need 3 stereo views to resolve ambiguities



Multiple scattering angle

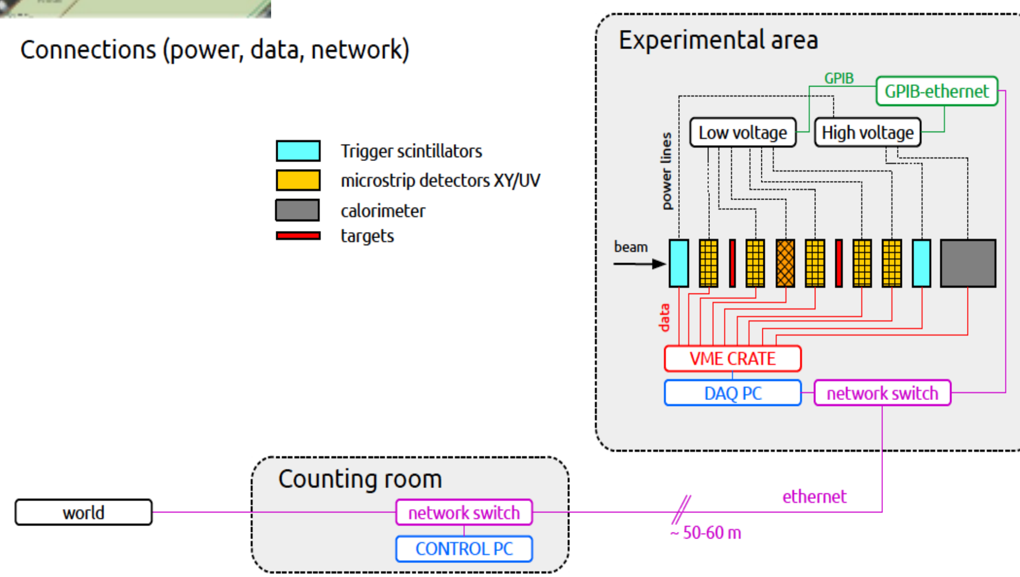


τ and trigger rate define operation mode

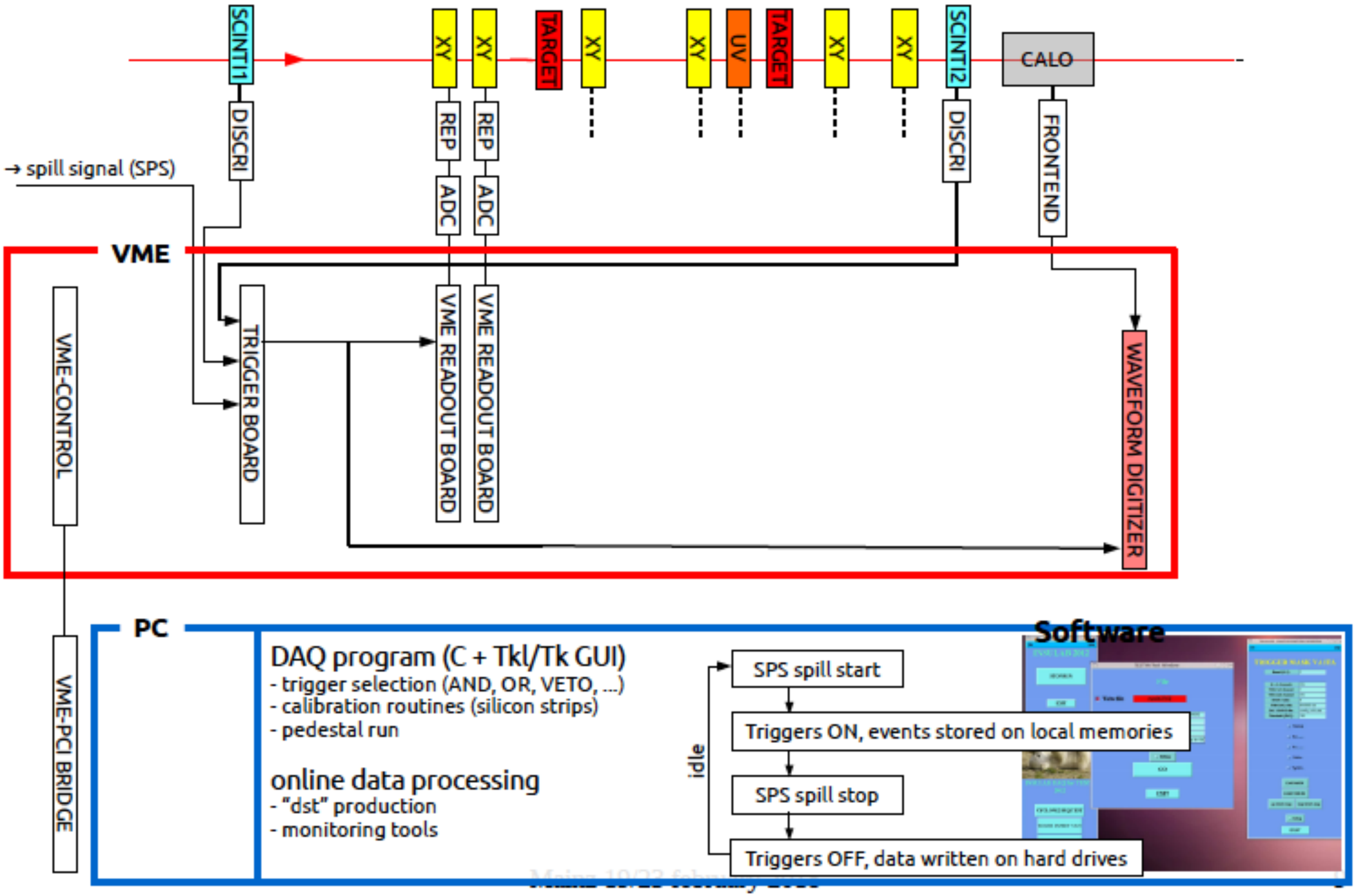


G. Venanzoni, PBC QCD-WG Meeting 2 March 2018

Connections (power, data, network)

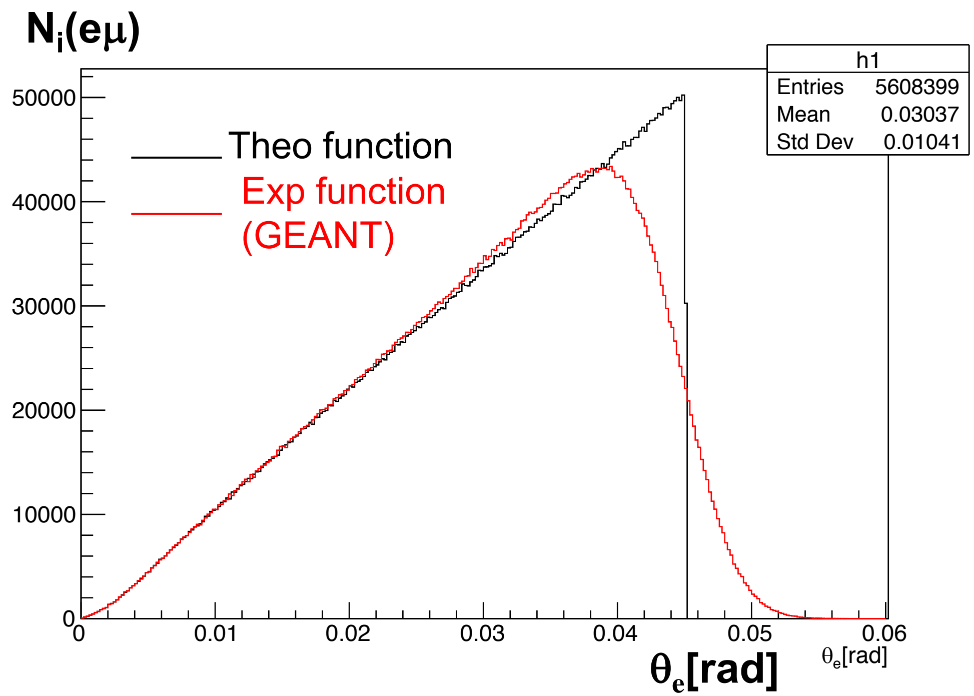


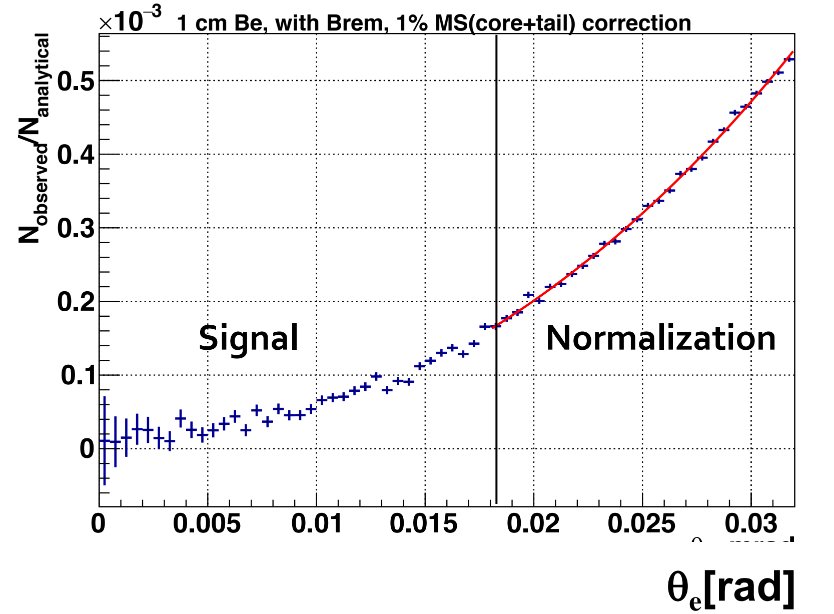
DAQ

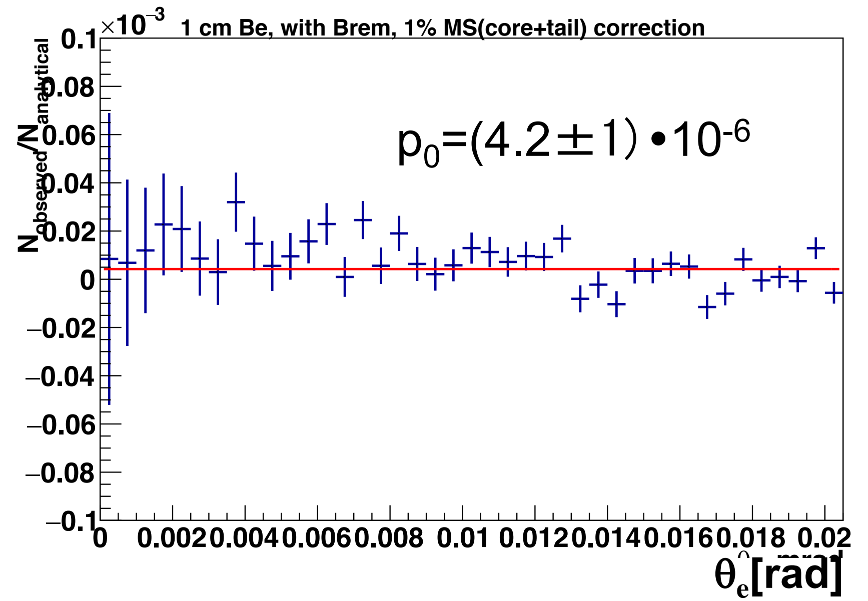

SCINTI1
XY
XY
TARGET
XY
XY
UV
TARGET
XY
XY
SCINTI2
CALO
DISCRI
REP
REP
DISCRI
FRONTEND
ADC
ADC
→ spill signal (SPS)
VME
VME-CONTROL
TRIGGER BOARD
VME READOUT BOARD
VME READOUT BOARD
WAVEFORM DIGITIZER
PC
VME-PCI BRIDGE
DAQ program (C + Tkl/Tk GUI)
- trigger selection (AND, OR, VETO, ...)
- calibration routines (silicon strips)
- pedestal run
online data processing
- "dst" production
- monitoring tools
idle
SPS spill start
Triggers ON, events stored on local memories
SPS spill stop
Triggers OFF, data written on hard drives
Software

Multiple Scattering resolution:

a worst-case scenario

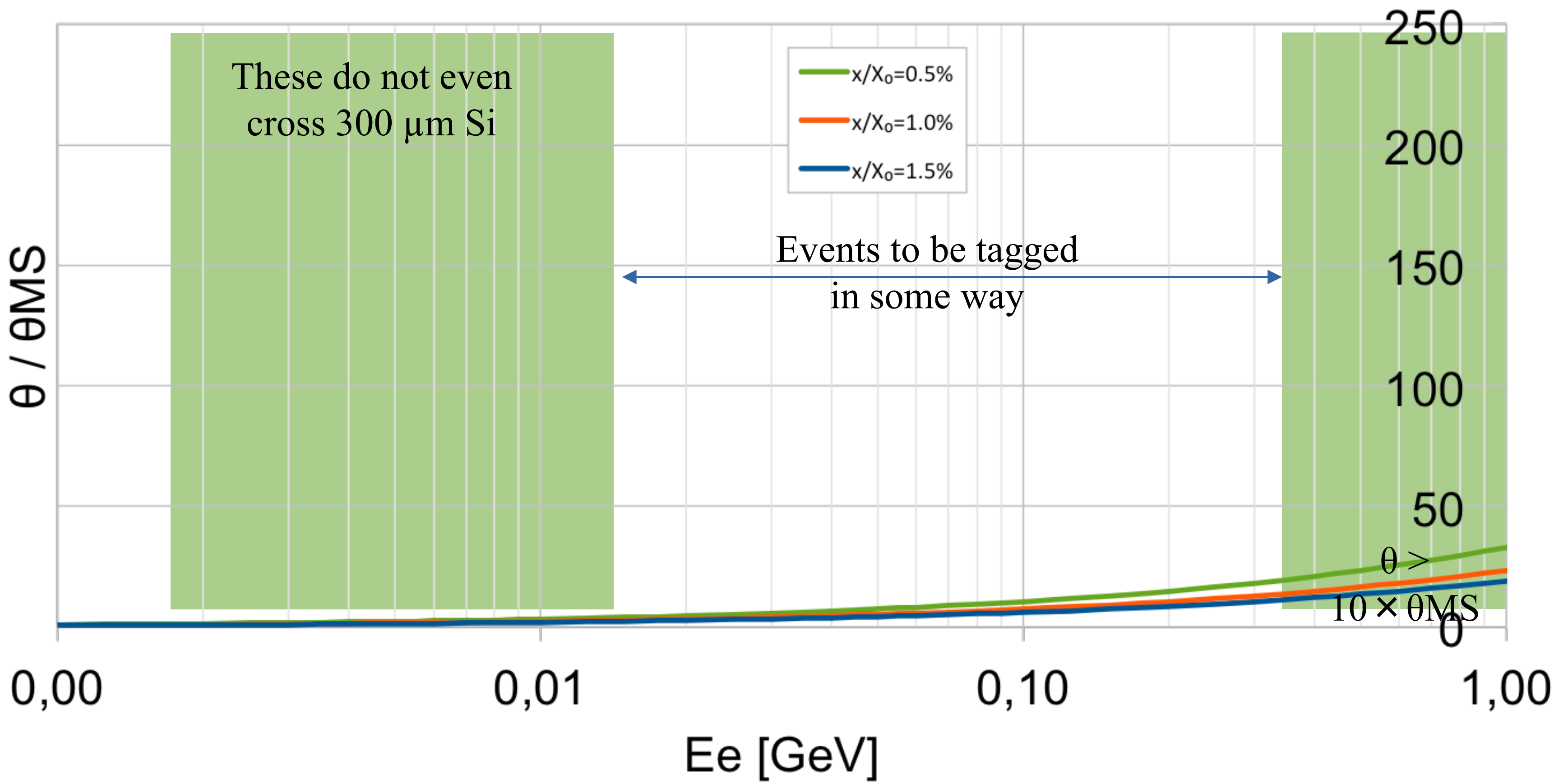






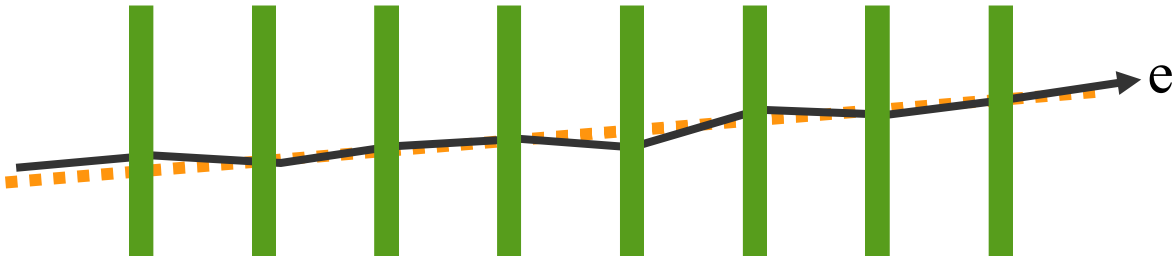
- The detector effects (mostly MS in the target) modify the theoretical spectrum ($N(\theta_e)$)
- We assume a 1% miscalibration on the GEANT model for $\sigma_{\theta e}$ MS (N_{mis})
- N_{mis} quadratically in θ_e respect to NO bias (N_i)
- By correcting N_{mis}/N_i in the normalization region → residual effects <10^{-5} in the signal region

Low energy electrons should be tagged

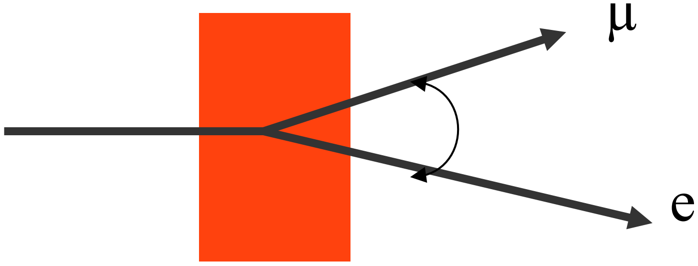


Not only the track angle

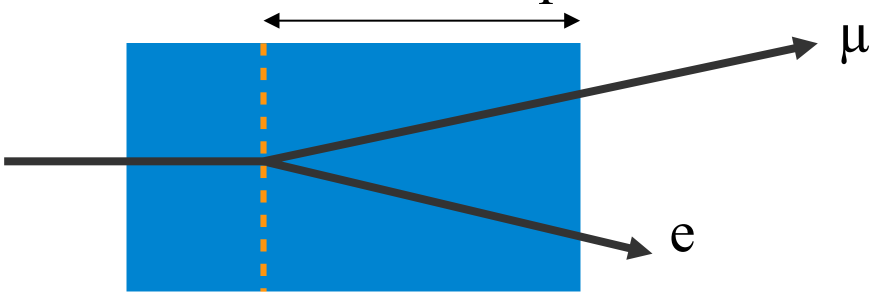
Multiple scattering



Co-planarity



Interaction depth

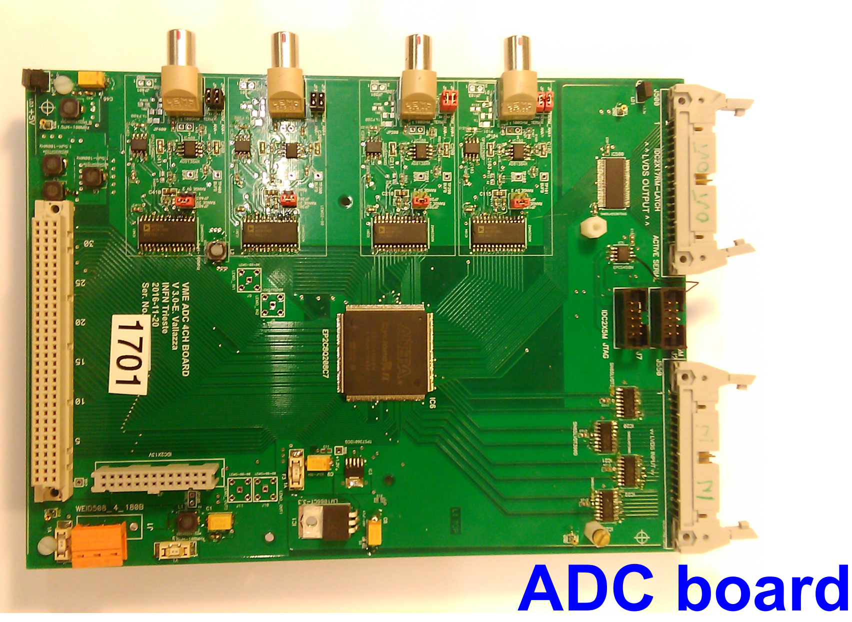


Il readout

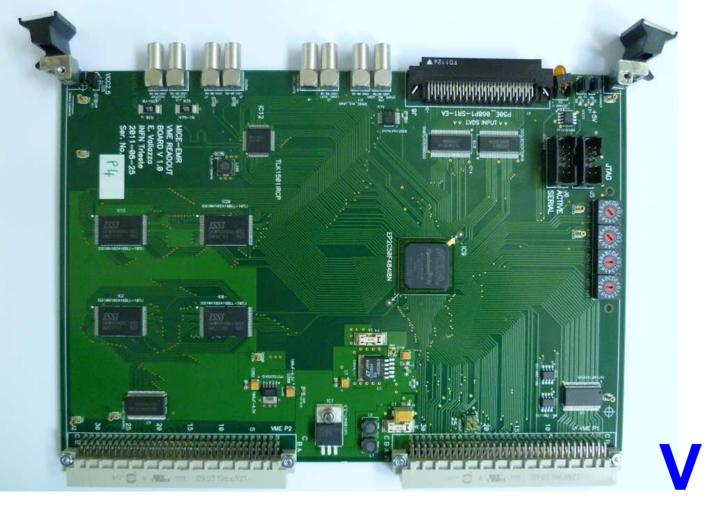
Readout electronics

- 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

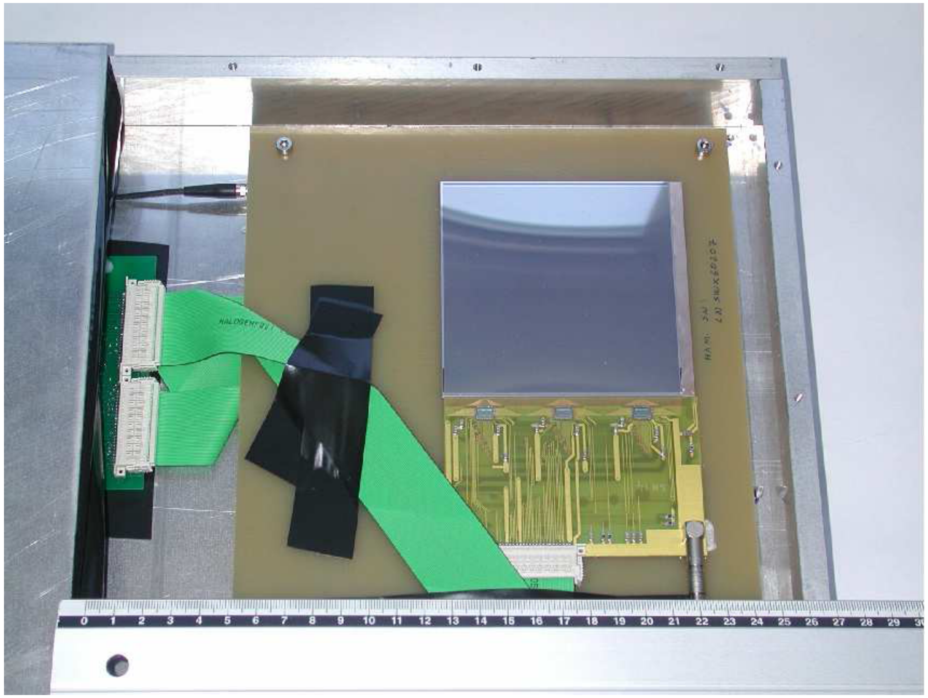


VRB

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

MuONe software status

- created a gitlab area for MuONe
- created a project for the Geant4 based simulation inside the area
  - already some wiki pages available as documentation
  - in the future also the test beam reconstruction/analysis software will be hosted in the gitlab area
- simulation has implemented two different geometries with the possibility to change parameters at runtime
- it should be easy enough to put in the test beam detectors