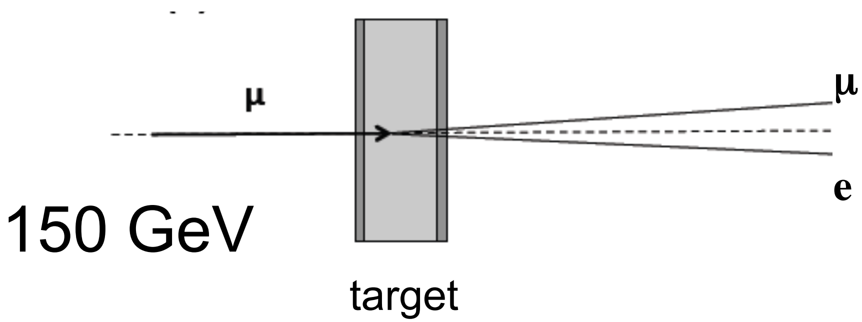
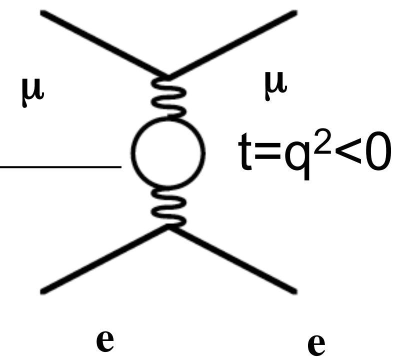
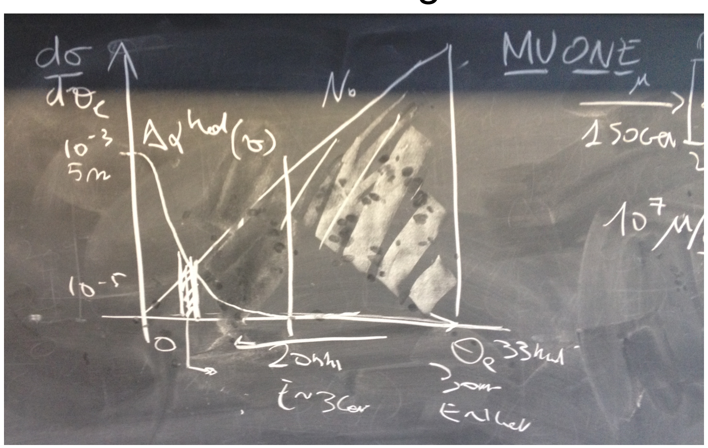
New(!) Experimental approach:

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)







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

Statistical accuracy on a_μ^{HLO}: 0.3%!

G. Venanzoni, Seminar at CERN, 5 October 2017

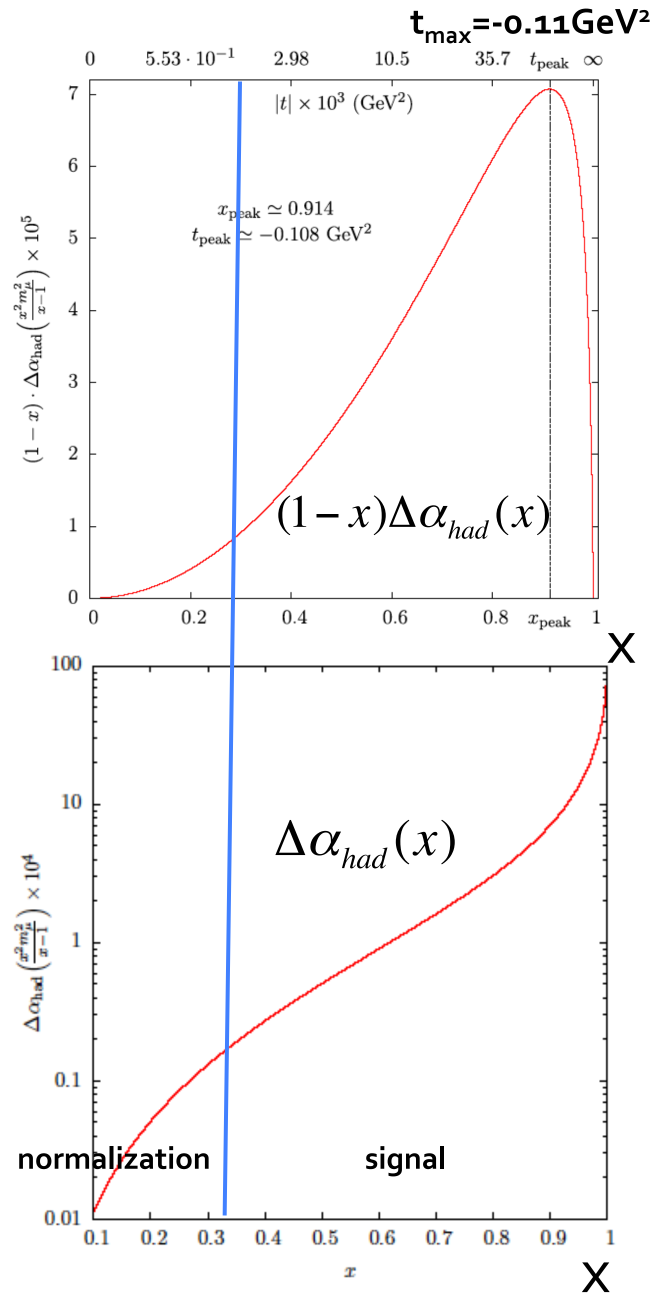
Why measuring $\Delta\alpha_{had}(t)$ with a 150 GeV μ beam on e^- target ?

It looks an ideal process!

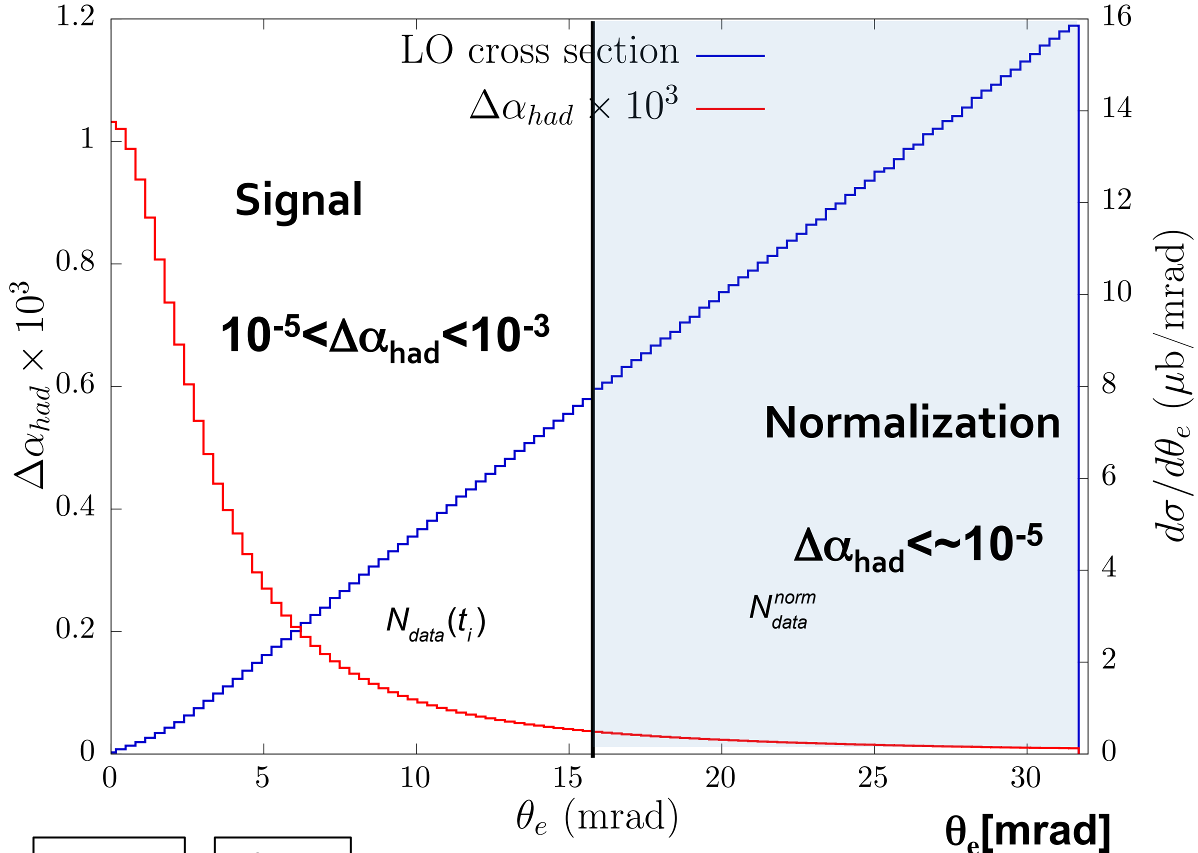
- $\mu\, e \rightarrow \mu\, e$ is pure t-channel (at LO)
- It gives $0<-t<0.161$ GeV^2 ($0<x<0.93$) →
- The kinematics is very simple: $t=-2m_eE_e$
- High boosted system gives access to all angles (t) in the cms region

  θ_e^{LAB}<32 mrad (E_e>1 GeV)
  θ_μ^{LAB}<5 mrad

- It allows using the same detector for signal and normalization
- Events at $x\sim0.3$ ($t\sim-10^{-3}$ GeV^2) can be used as normalization ($\Delta\alpha_{had}(t)<10^{-5}$) →



MUonE : signal/normalization region



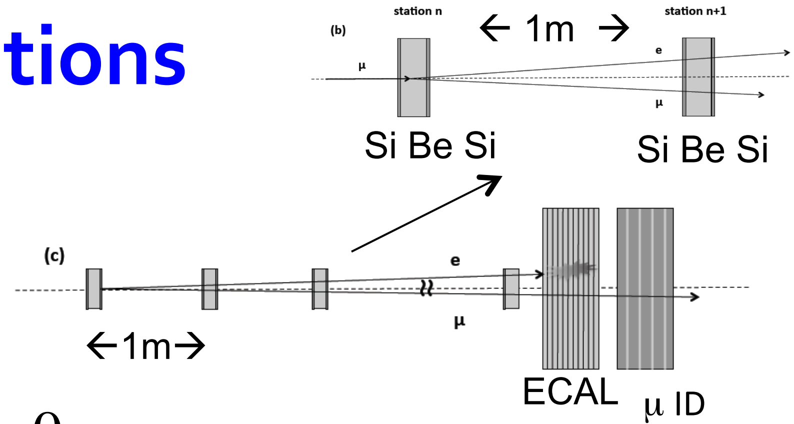
$$\frac{N_{data}(t_i)}{N_{MC}^{0}(t_i)} = \boxed{\frac{N_{data}(t_i)}{N_{data}^{norm}}} \times \boxed{\frac{\sigma_{MC}^{0,norm}}{\sigma_{MC}^{0}(t_i)}} \sim 1 - 2(\Delta\alpha_{lep}(t_i) + \Delta\alpha_{had}(t_i))$$

Ratio of the theoretical cross section (with no VP)

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

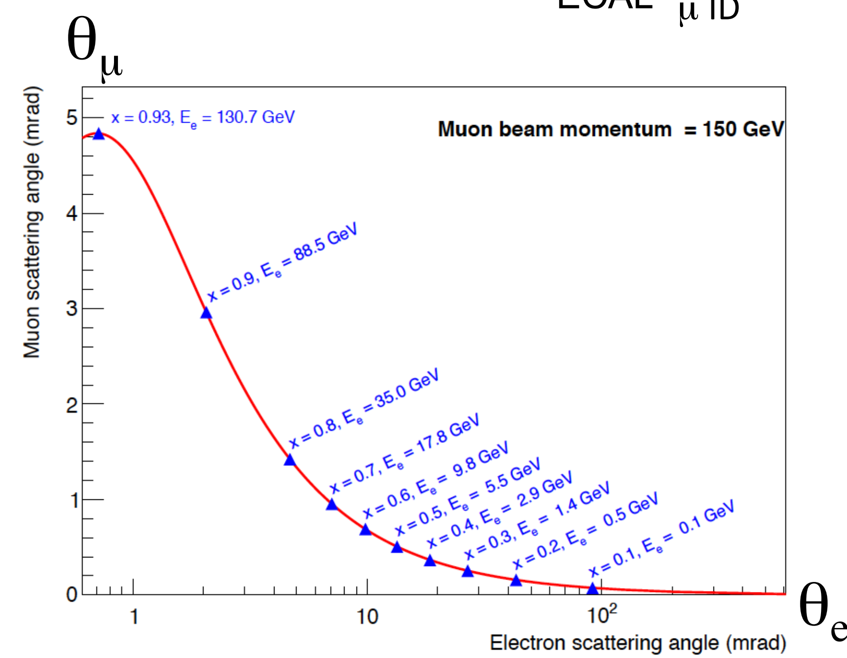
a_μ^{HLO} at 0.3% → These two ratios should be known at 10^{-5}

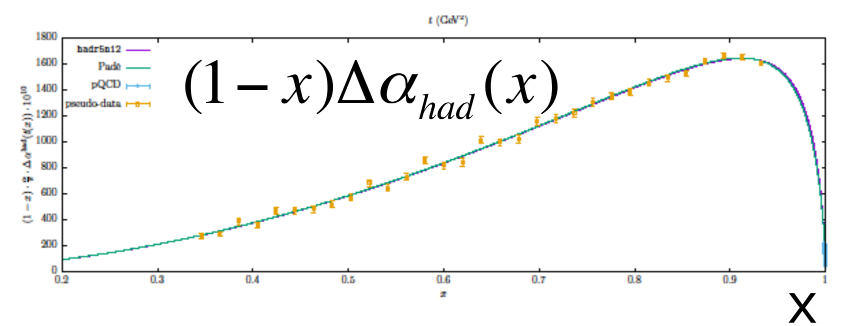
Detector considerations



- Modular apparatus: 20 layers of ~1 cm Be (target), each coupled to 1(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

  [see Ignatov's talk]
- 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 2×10^7 μ/s





Muon beam M2 at CERN

[see Bernhard's talk]

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

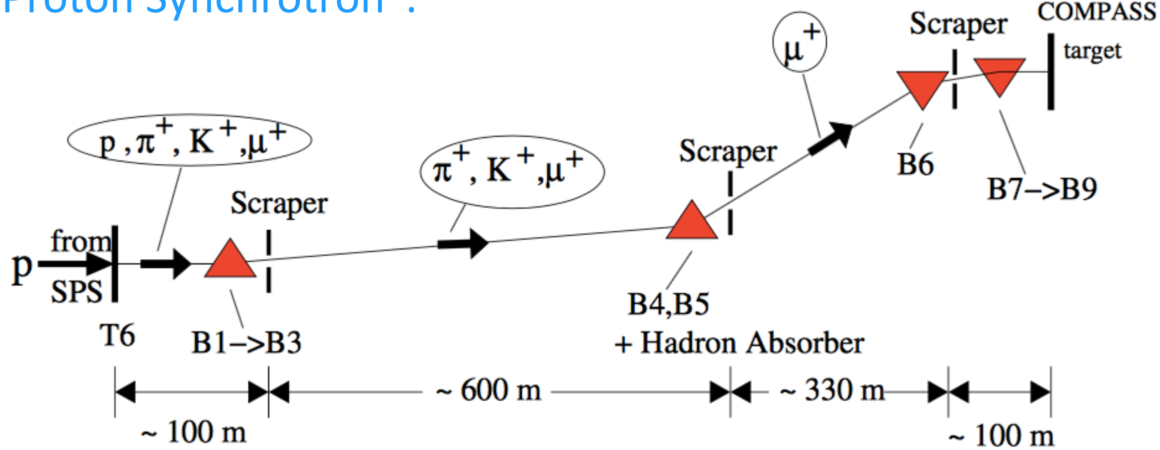


Table 3
Parameters and performance of the 160 GeV/c muon beam.

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%

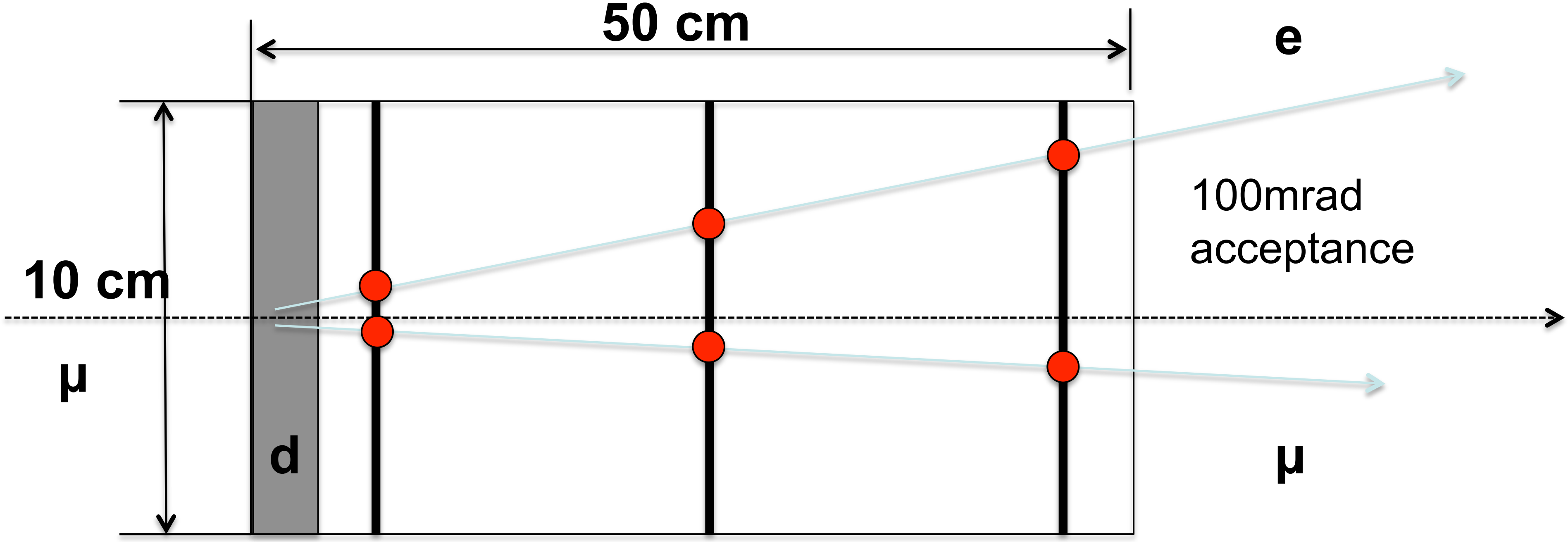
https://arxiv.org/pdf/hep-ex/0703049.pdf

I_{beam}> 10^7 muon/s, E_μ = 150 GeV

Measuring e- and muon angle:

Repetition (x50) of this single module

[see Marconi's talk]



Target State-of-art Silicon strip detectors

hit resolution ~10 μm

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

[see Mersi' talk]

Systematics

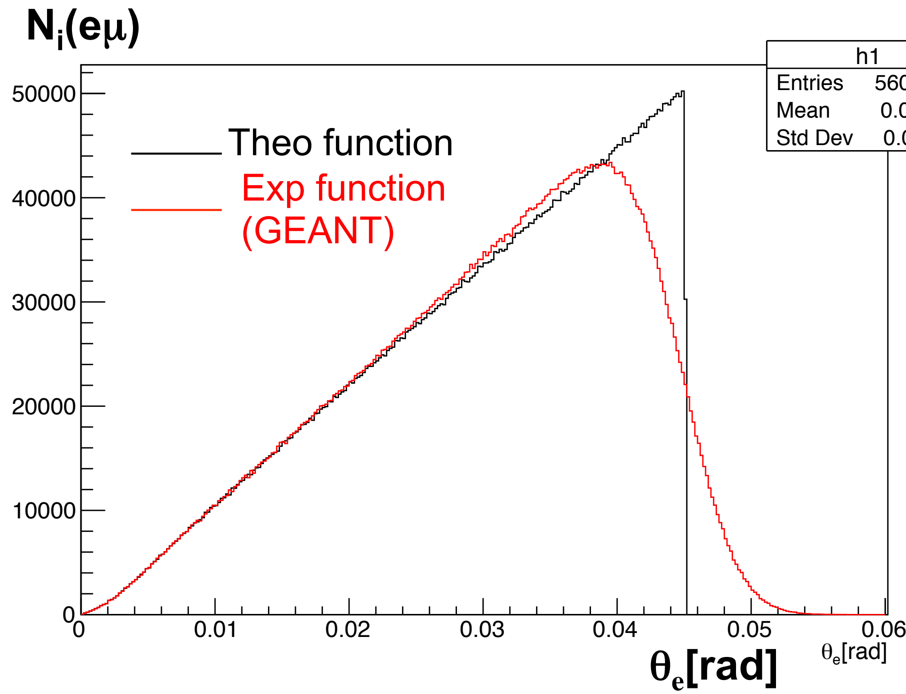
[see Marconi's talk]

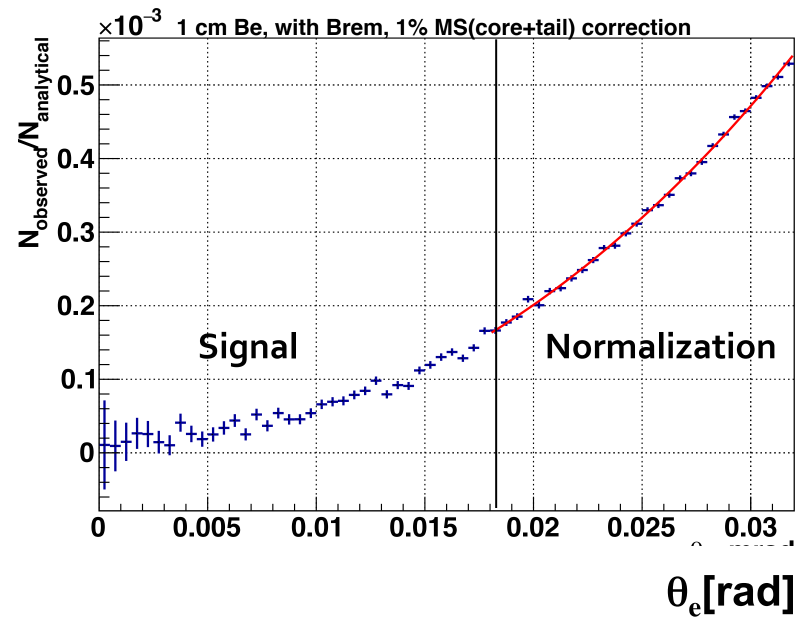
1. Acceptance
2. Tracking
3. Trigger
4. PID
5. Knwoledge of muon momentum
6. Effects of E_e energy cut
7. Signal/Background:
   It requires a dedicated event generator.
8. Uncertainty in the location of interaction vertices: Segmented/ active target to resolve the vertex position
9. Uncertainty in the muon beam momentum:
   Scattering kinematics to determine the beam momentum
10. Effects of Multiple Scattering (must be known at $\leq 1\%$):
    It requires dedicated work on simulation and measurements (test beam).
11. Theoretical uncertainty on the mu-e cross section (see later)

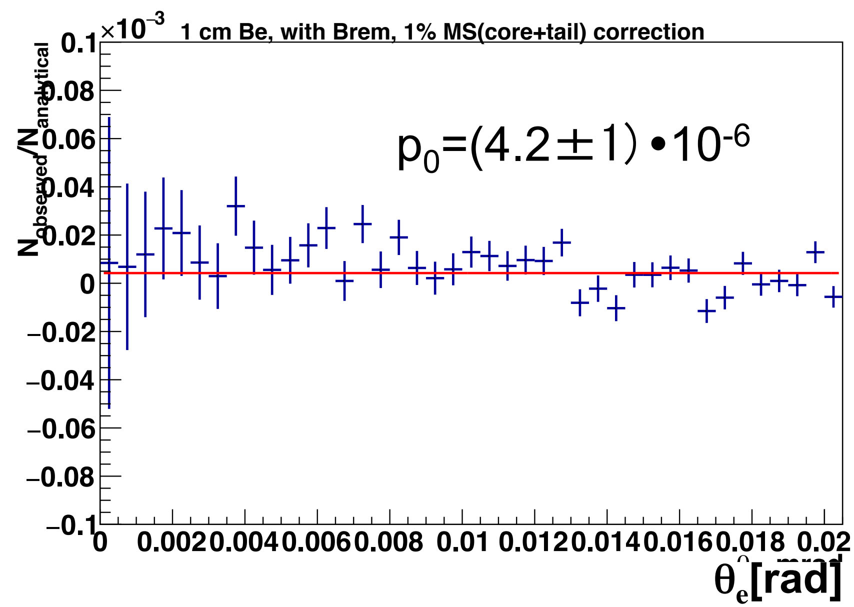
Full simulation needed

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

Multiple Scattering resolution:
a worst-case scenario







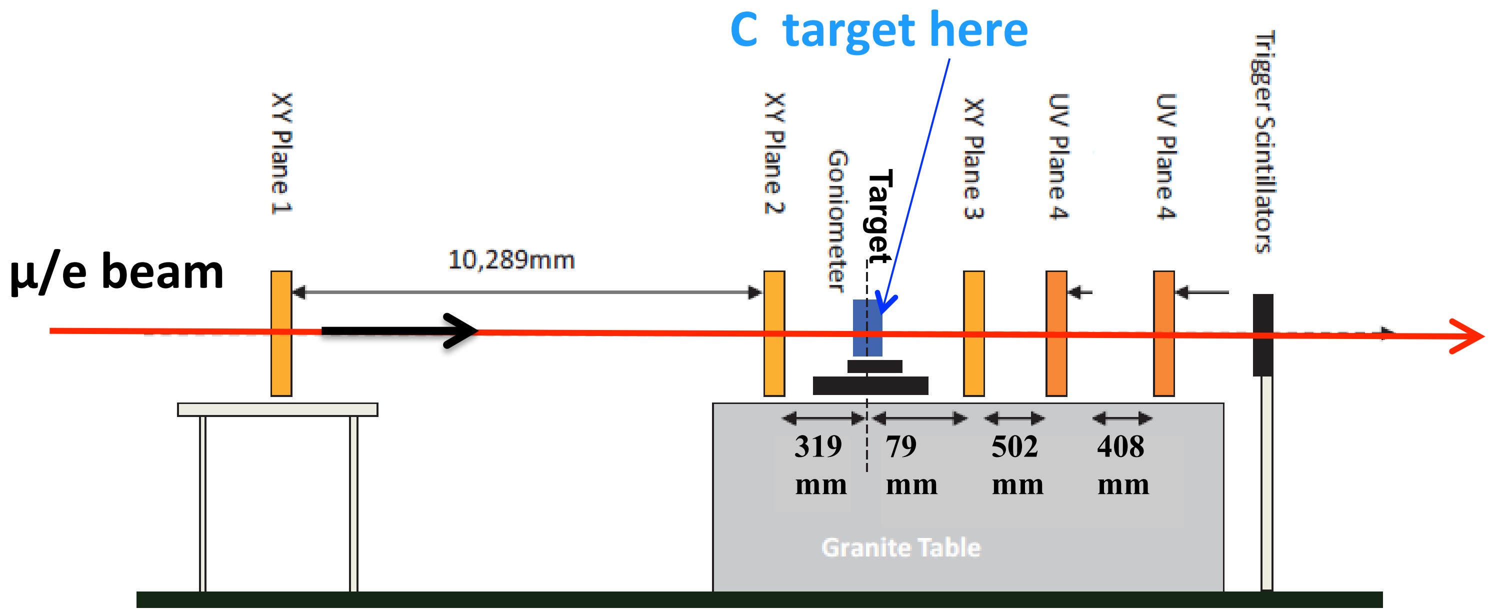
- The detector effects (mostly MS in the target) modify the theoretical spectrum ($N(\theta_e)$)
- We assume a 1% miscalibration on the GEANT model for $\sigma_{\theta e}$ MS (N_{mis})
- N_{mis} quadratically in θ_e respect to NO bias (N_i)
- By correcting N_{mis}/N_i in the normalization region → residual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

Results from Test Beam

[see Principe's talk]

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)

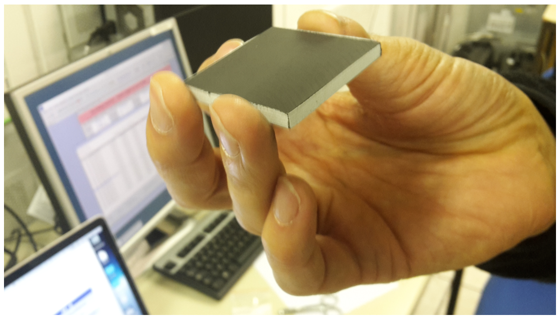


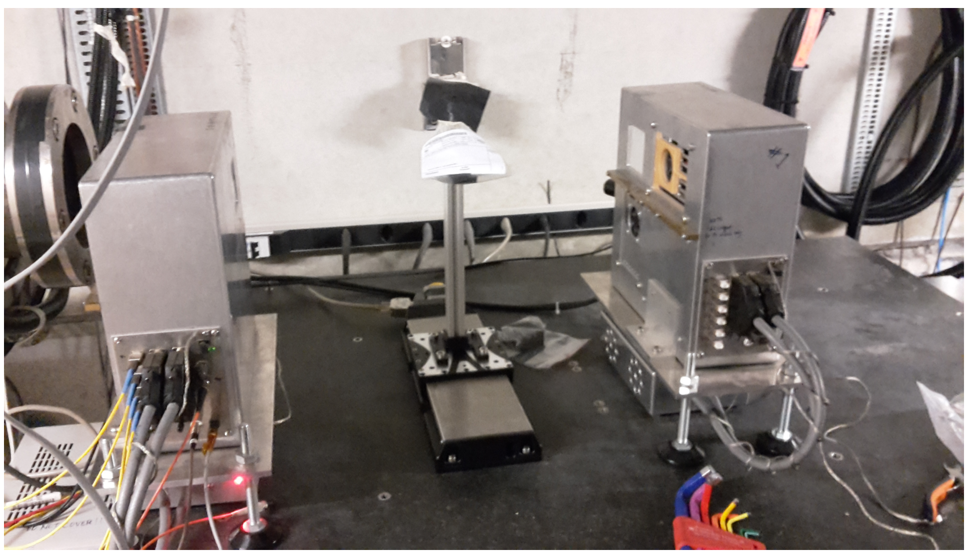
Adapted UA9 apparatus

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

Test Beam setup and target

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

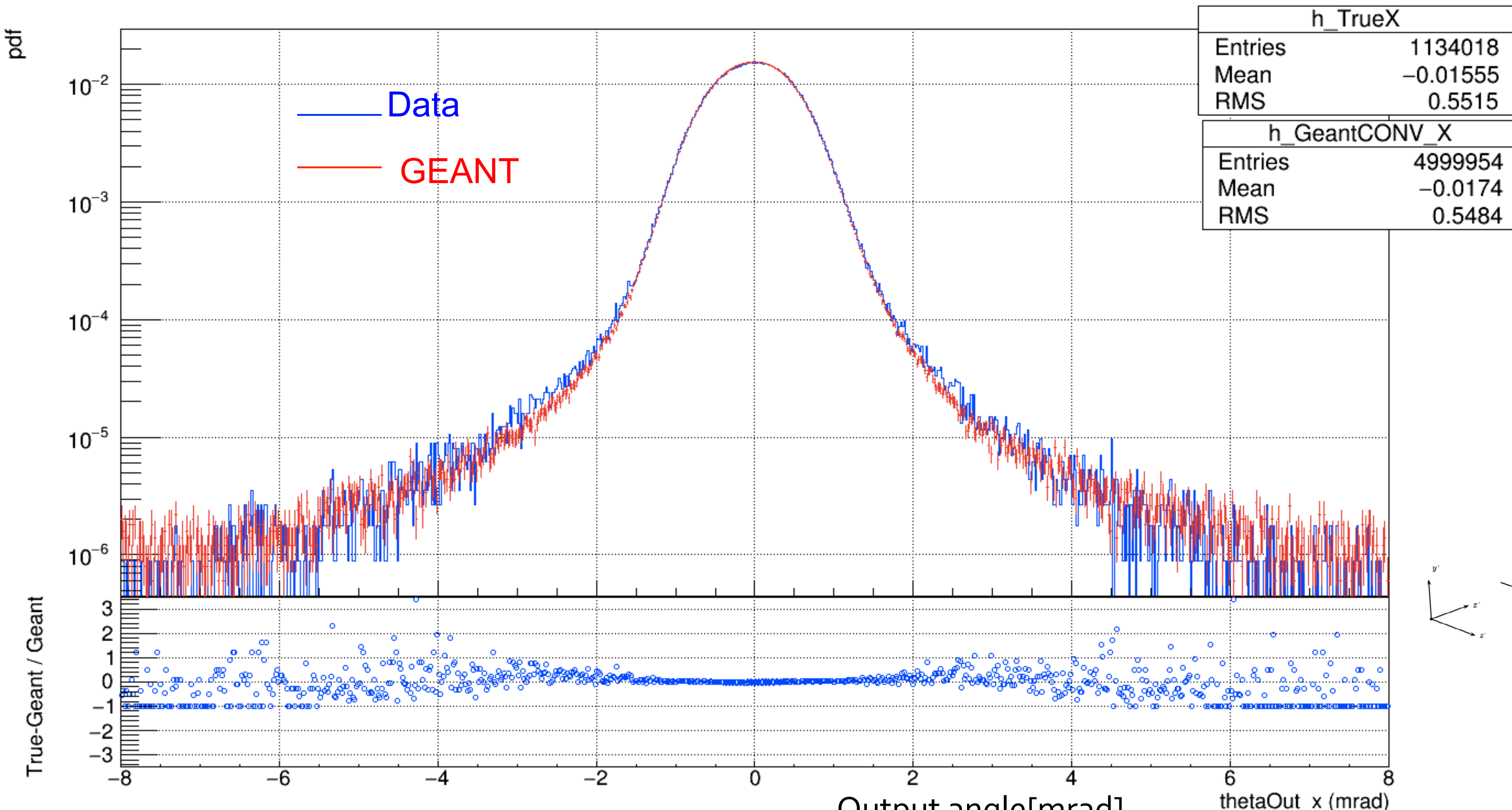


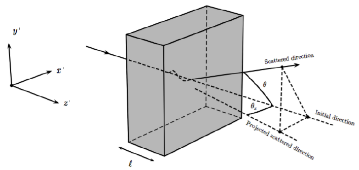


(Preliminary) Analysis of Test Beam data

[see Principe's talk]

12 GeV e⁻ 8mm C



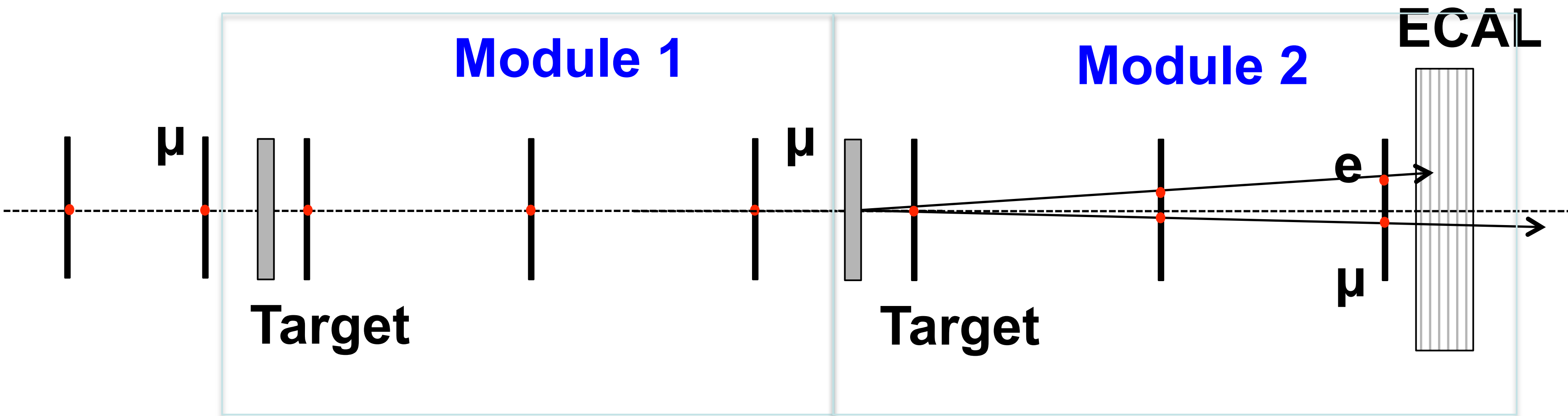


- With a preliminary analysis: data-MC agree on σ(core) at 2%
- Improvement expected due to better alignment and track fit
- Analysis of tails in progress

Plans for 2018

[see Matteuzzi's talk]

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



- Run of a 2 full scale modules on a muon beam in North area or on M2 (behind COMPASS)
- Study of the detector performance: signal/background; trigger; understand the systematics
- Try a first measurement (at 10-20% error) of a_μ^{HLO}

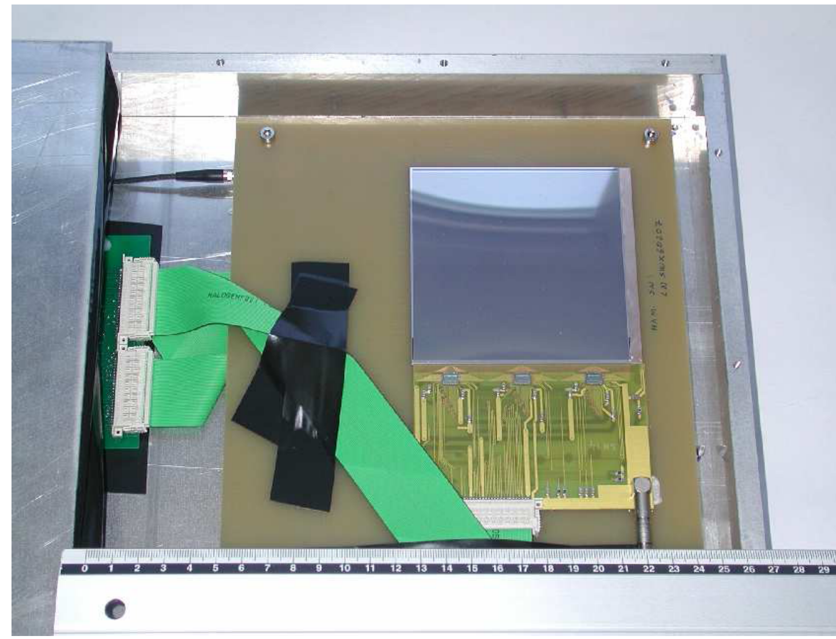
[see Brizzolari's talk]

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

Status of the Collaboration and plans

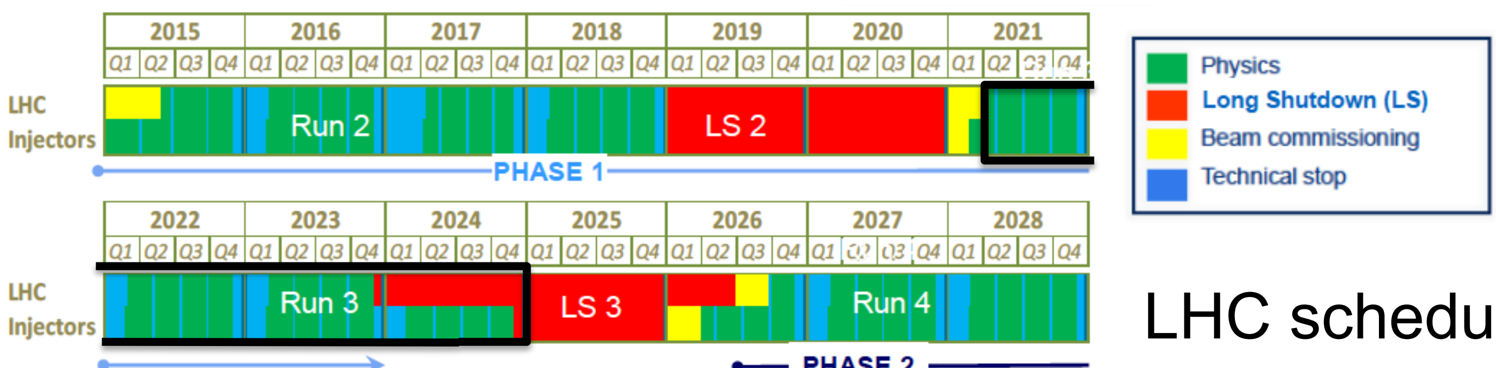
- The proposal has been presented in September at the National Scientific Committee 1 (CSN1) of INFN. Funds have been allocated to contribute effectively to a full-scale test of detector prototype in 2018.

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

- Results so far encouraging; we are working hard toward a formal LoI.

Plans

- **2018-2019**
  - Detector optimization studies: Simulation and Test Beam
  - 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)
- MUonE: a new project aiming at an "unprecedented" accuracy both in experiment and in theory!
- → Many progresses in the last year
  - Detector optimization; Test beam
  - Theory
  - Clear plan for 2018
  - Growing interest from both experiment and theory community
- A lot of work ahead us (with a very tight schedule)
- → Let's discuss it at this workshop!

Thanks MITP for supporting us!

G. Abbiendi, M. Alacevich, M. Bonomi, A. Broggio, C. Carloni Calame, E. Conti, D. Galli, M. Fael, A. Ferroglia, F.V. Ignatov, M. Incagli, U. Marconi, M.K. Marinković, P. Mastrolia, C. Matteuzzi, 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. Pruna, M. Rocco, U. Schubert, L. Tancredi, R. Tenchini, L. Trentadue, E. Vallazza, G. Venanzoni, A. Vicini, E. Del Nobile…

JOIN US!

Experimental Session

Today

15:00	**Results from Test Beam**	*Antonio PRINCIPE et al.*	*02.430, Mainz Institute for Theoretical Physics, Johannes Gutenberg University*	14:45 - 15:30
16:00	**Simulation of Multiple Scattering in GEANT4**	*Vladimir IVANTCHENKO*	*02.430, Mainz Institute for Theoretical Physics, Johannes Gutenberg University*	15:30 - 16:15

Wednesday

11:00	**Review of M2 Beam at CERN**	*Johannes BERNHARD*	*02.430, Mainz Institute for Theoretical Physics, Johannes Gutenberg University*	11:00 - 11:45
12:00	**Review of the experimental apparatus & systematic errors**	*Umberto MARCONI*	*02.430, Mainz Institute for Theoretical Physics, Johannes Gutenberg University*	11:45 - 12:30
13:00	**Lunch**		*02.430, Mainz Institute for Theoretical Physics, Johannes Gutenberg University*	12:30 - 14:00
14:00	**PID at MUonE**	*Dr. Fedor IGNATOV*	*02.430, Mainz Institute for Theoretical Physics, Johannes Gutenberg University*	14:00 - 14:45
15:00	**Silicon sensors: state of the art and possible options for MUonE**	*Stefano MERSI*	*02.430, Mainz Institute for Theoretical Physics, Johannes Gutenberg University*	14:45 - 15:30
	Coffee break		*02.430, Mainz Institute for Theoretical Physics, Johannes Gutenberg University*	15:30 - 16:00
16:00	**Tracking setup preparation for test beam 2018**	*Claudia BRIZZOLARI*	*02.430, Mainz Institute for Theoretical Physics, Johannes Gutenberg University*	16:00 - 16:45
17:00	**Work plan for 2018**	*Clara MATTEUZZI*	*02.430, Mainz Institute for Theoretical Physics, Johannes Gutenberg University*	16:45 - 17:30

Thursday

09:00 10:00	**Conclusion & outlook of the experimental session**	*Graziano VENANZONI*	*02.430, Mainz Institute for Theoretical Physics, Johannes Gutenberg University*	09:00 - 10:45

Very interesting talks!

Spare

Experimental considerations

From last talk in 2016!

Using Bhabha at small angle (to emphasize t-channel contribution) to extract $\Delta\alpha$:

$$\left(\frac{\alpha(t)}{\alpha(0)}\right)^2 \sim \frac{d\sigma_{ee\to ee}(t)}{d\sigma^0_{MC}(t)}$$

Where $d\sigma^0_{MC}$ is the MC prediction for Bhabha process with α(t)=α(0), and there are corrections due to RC…

$$\Delta\alpha_{had}(t) = 1 - \left(\frac{\alpha(t)}{\alpha(0)}\right)^{-1} - \Delta\alpha_{lept}(t)$$

$\Delta\alpha_{lep}(t)$ theoretically well known!

Which experimental accuracy we are aiming at?
$\delta\Delta\alpha_{had}$~1/2 fractional accuracy on $d\sigma(t)/d\sigma^0_{MC}(t)$.

If we assume to measure $\delta\Delta\alpha_{had}$ at 5% at the peak of the integrand ($\Delta\alpha_{had}$ ~10^{-3} at x=0.92) → fractional accuracy on $d\sigma(t)/d\sigma^0_{MC}(t)$ ~ 10^{-4} !

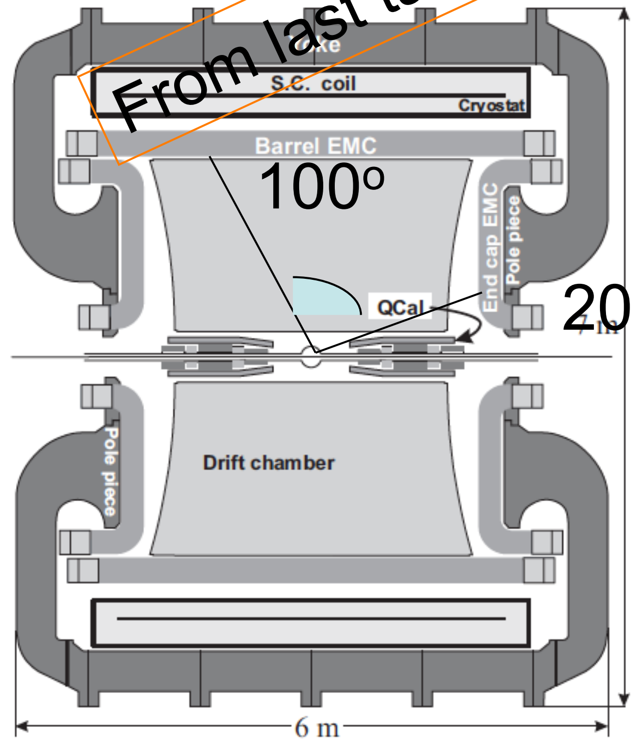
Very challenging measurement (one order of magnitude improvement respect to date) for systematic error

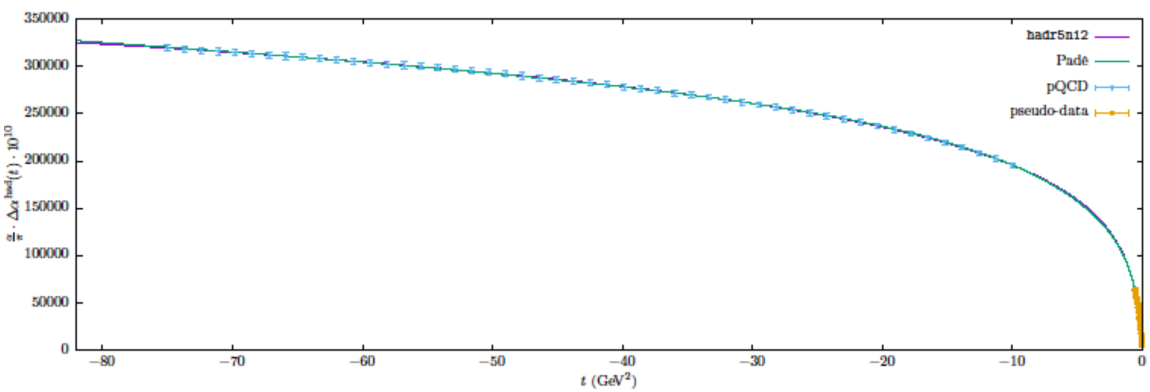
What can be done a KLOE/KLOE2?

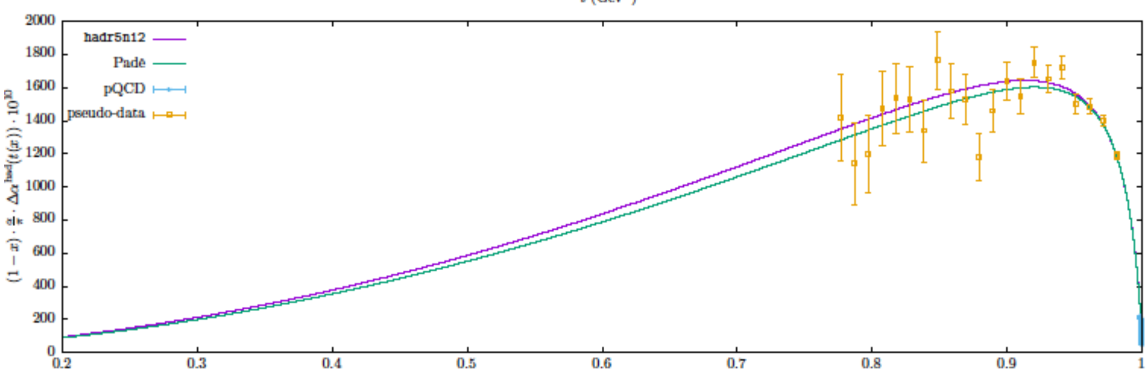
From last talk in 2016!

We did the following simulation:

- 20 points between $20^o < \theta < 100^o$ ($0.03 < -t < 0.59$ GeV^2; $0.78 < x < 0.98$) @ $\sqrt{s}=1$ GeV
- For each point $\delta\sigma_{e+e-}/\sigma_{e+e-} \sim 10^{-4}$ (stat and syst)
- We fit $\Delta\alpha_{had}(t)$ using our points+ pQCD for $-t>10$ GeV^2 with a polinomial function (like lattice)







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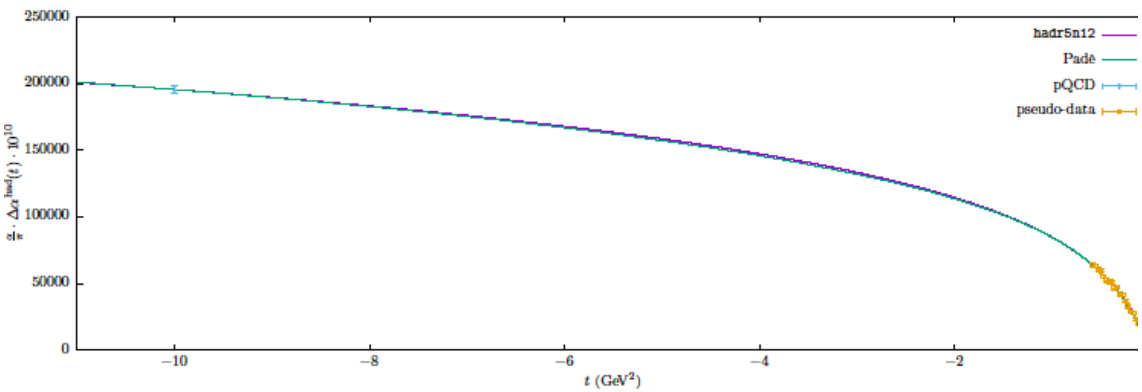

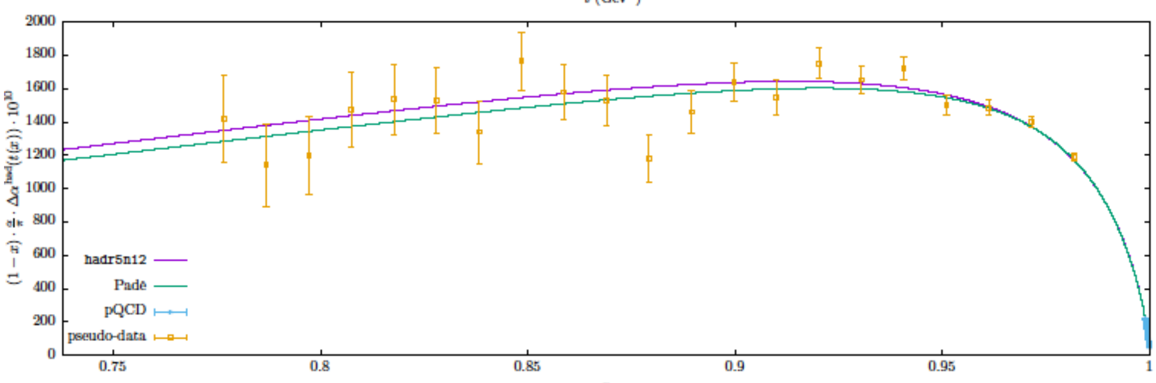

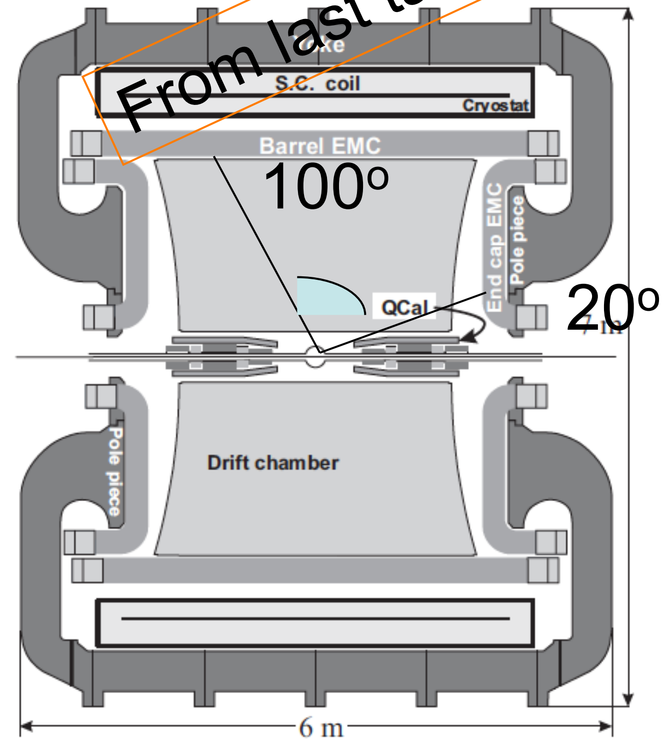

δa_μ^{HLO}~$3\%_{stat}\oplus 7\%_{syst}$

(preliminary)

Measurement at Novosibirsk ($\sqrt{s}$=2 GeV)?

- The region $0.2<x<0.98$ can be explored at $\sqrt{s}$=2 GeV with $2^o<\theta<45^o$ (for $x>0.98$ pQCD could be used)
- Normalization can be provided by Bhabha at very small angle ($2^o<\theta<5^o$) where $\Delta\alpha^{had}<10^{-5}$ (1% of the $\Delta\alpha^{had}(x=0.92)$)
- $L=10^{32}$ would allow to do a measurement of $a_\mu^{HLO}<1\%$ within 1 year (statistically)

From last talk in 2016!