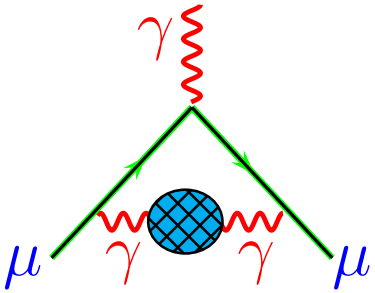
MUonE

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

G. Venanzoni,
INFN-Pisa
on behalf of the proponents



"The closer you look the more there is to see" (F. Jegerlehner)

PBC Workshop, CERN 16 Janurary 2019

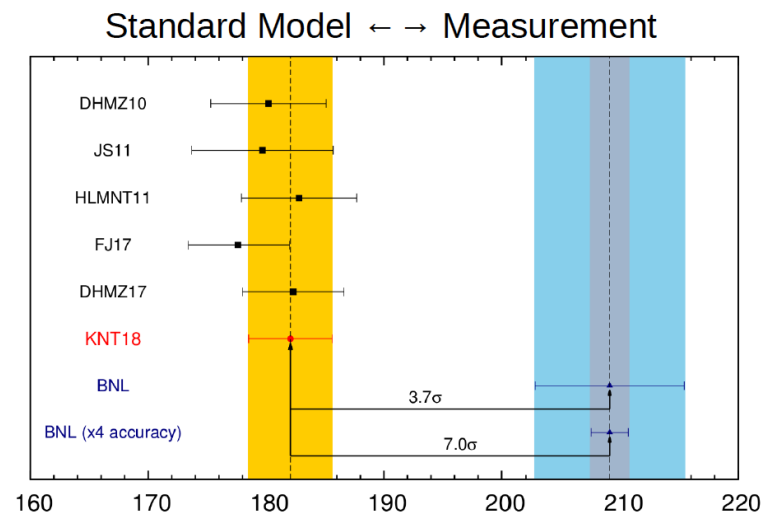
Outline

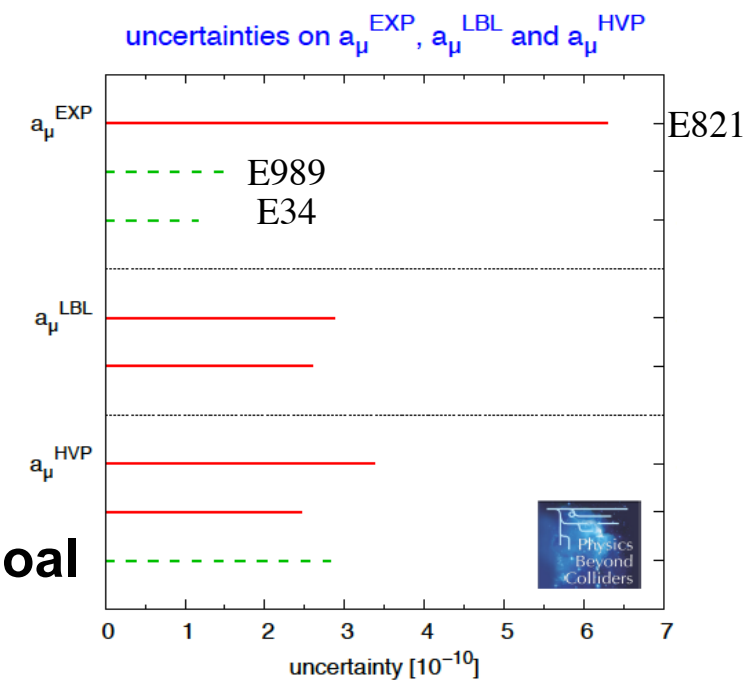
- A (brief) Reminder on MUonE proposal
- Some recent progress
- Plans
- Conclusions

Muon g-2: summary of the present status

- ~3.5σ discrepancy between a_μ^{E821} and a_μ^{SM}
- New $(g-2)_\mu$ experiments at Fermilab (E989) and JPARC (E34) → First result from E989 expected in 2019
- If E989 confirms E821 (with full stat) → $a_\mu^{EXP} - a_\mu^{SM} \sim 7\sigma$ → New Physics?
- Discrepancy limited by the uncertainty on the theory side (hadronic effects)

→ Different methods to control the theory very important !





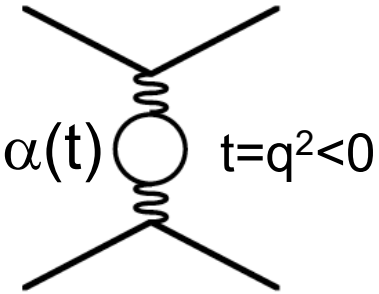
MUonE Goal

MUonE proposal: a_μ^{HLO} from space-like region

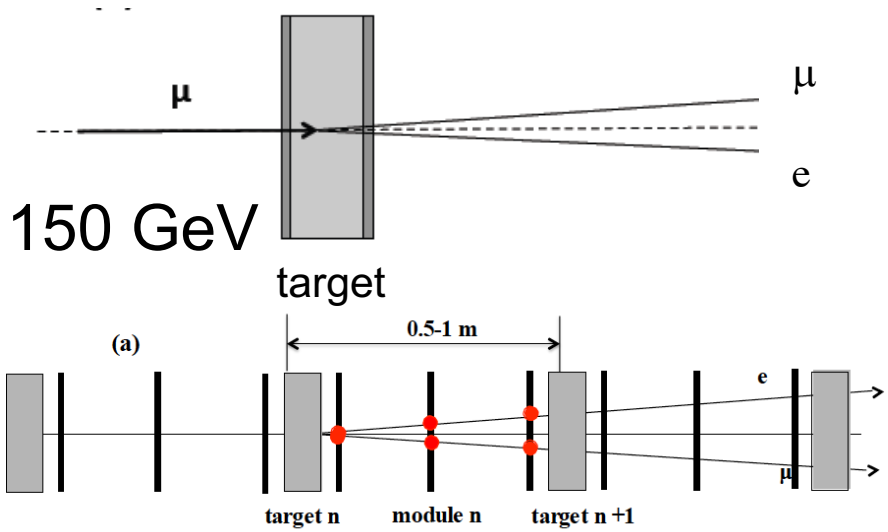
[C.M. C. Calame et al, Phys. Lett. B 746 (2015) 325,
G. Abbiendi et al., Eur. Phys. J. C77 (2017) 139]

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

$$t = \frac{x^2 m_\mu^2}{x-1}$$

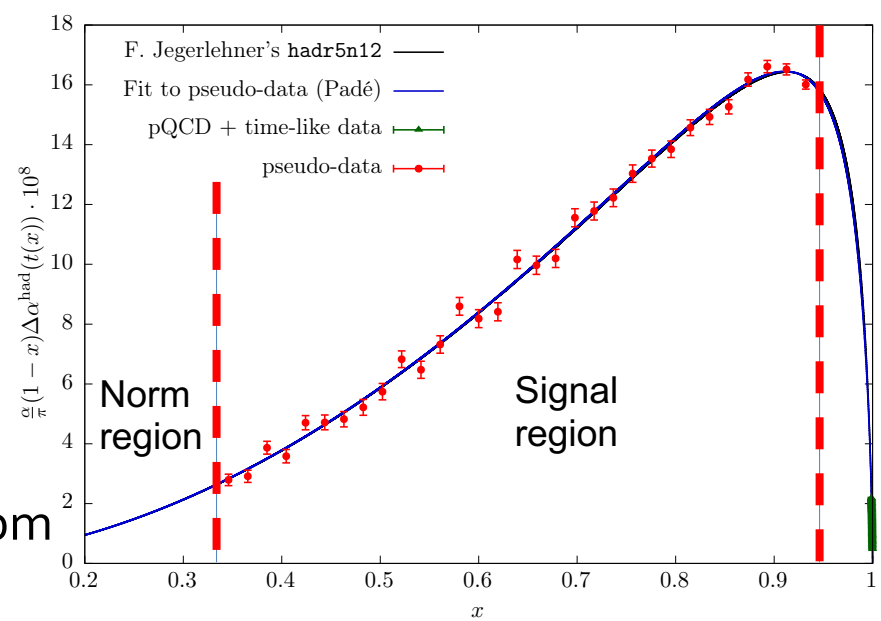


Use of a 150 GeV μ beam on Be target at CERN (elastic scattering μe → μ e) to get $\Delta\alpha_{had}(t<0)$



MUonE stat. accuracy: $\delta a_\mu^{HLO} \sim 0.3\%$

a_μ^{HLO} is given by the integral of the curve



Angular measurement $t=f(\theta_e;\,\theta_\mu)$

$\Delta\alpha_{had}(t<0)$ from $N^{\mu e}_{signal}(t)\,/\,N^{\mu e}_{norm}$ at 10ppm

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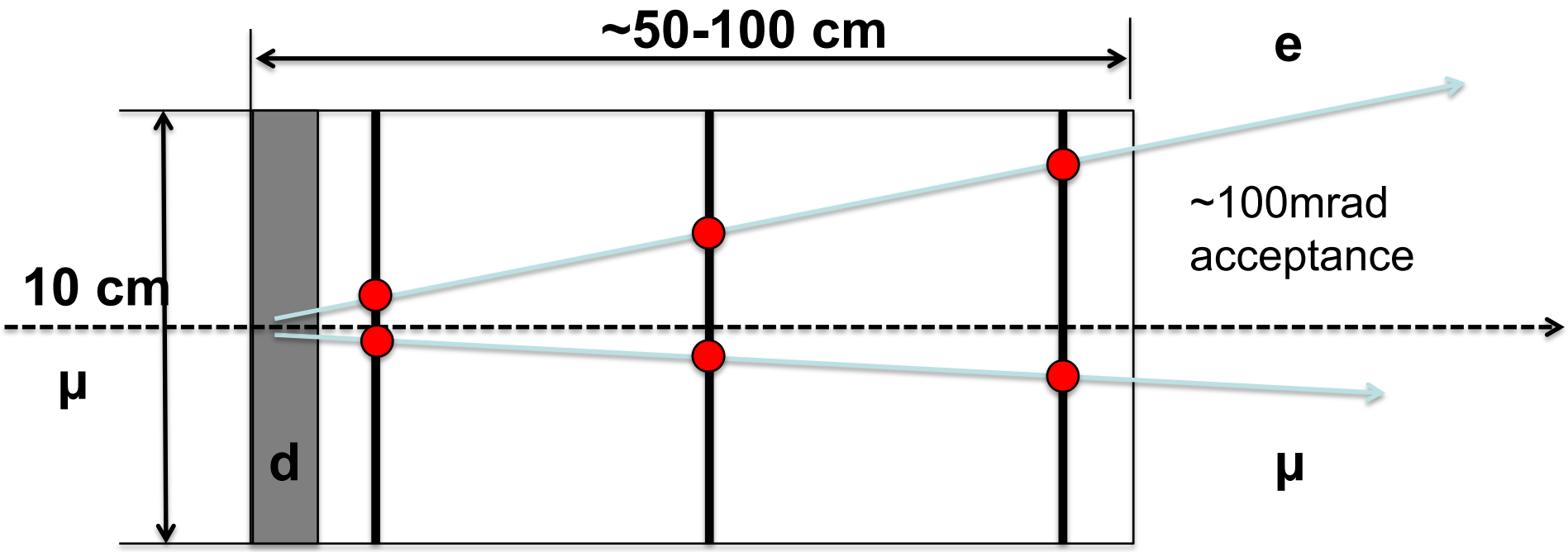
Detector concept

Repetition (x60) of this single module

(~ 40-60 m total length)



~1cm
Be Target

State-of-art Silicon detectors

hit resolution ~20 μm

Expected angular resolution ~ 20 μm / 1m = 0.02 μrad

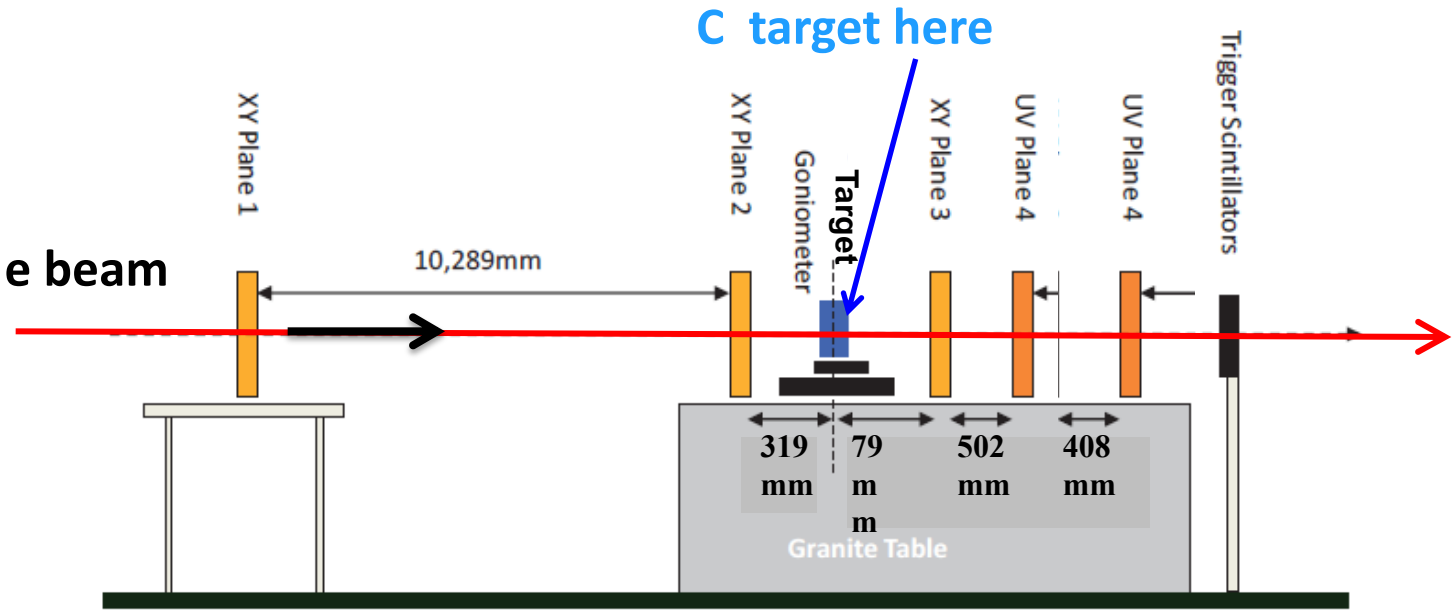
At the end ECAL and Muon Filter for PID

Last 2 years progress

1. Multiple scattering studies (TB 2017)
2. Test beam at M2 in 2018
3. Baseline Si detector defined (CMS)
4. LO and NLO Studies
5. Location at EHN2
6. Theory progress

Test Beam 2017at H8: the setup

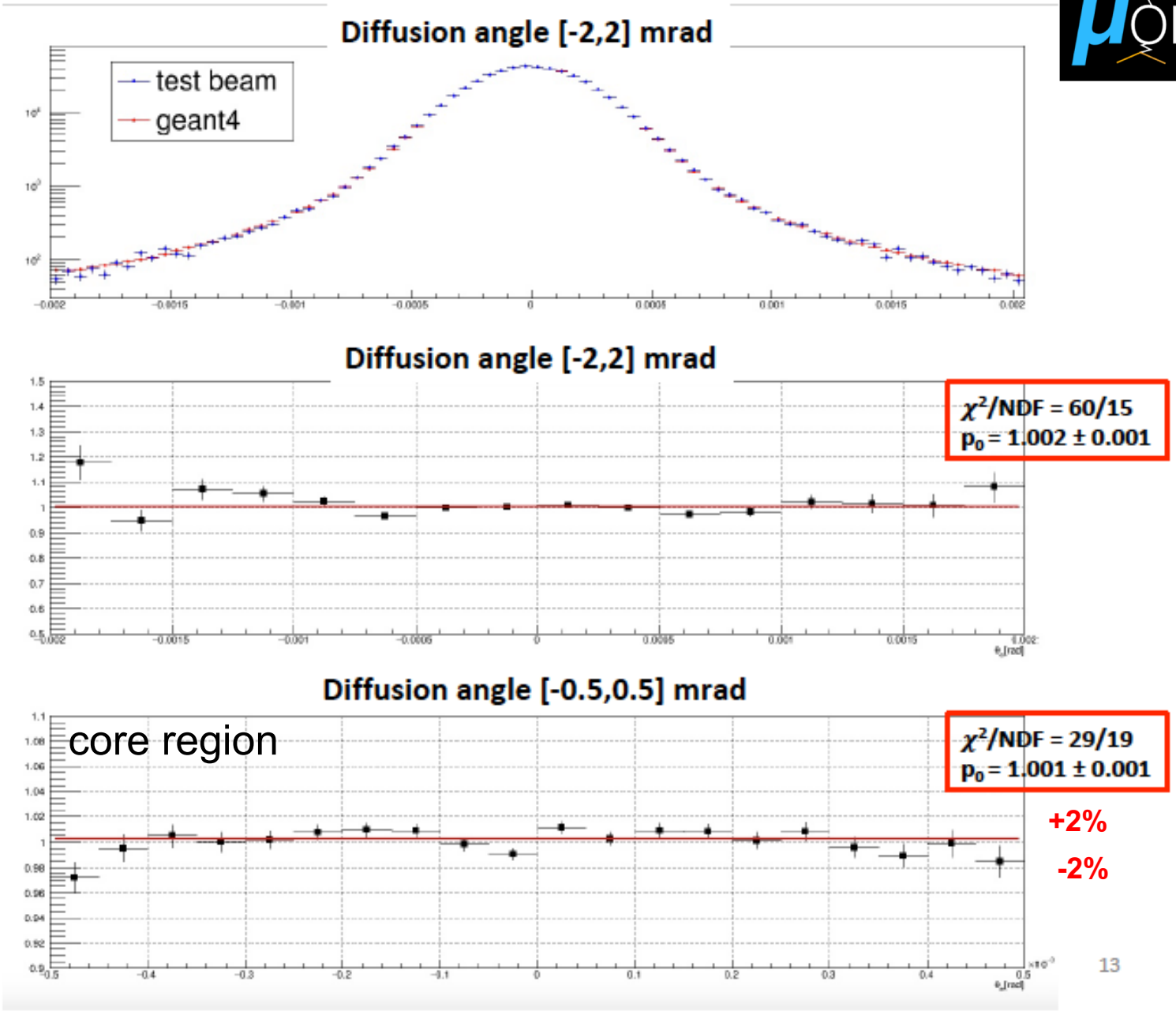
- We used the UA9 tracking system to record scattering data
- Alignment, tracking, pattern recognition, comparison with Geant4 simulation.
- **The goal**: reach **~1%** in the **core** of the MS distributions and **few per cent on the tails**



Adapted UA9 apparatus

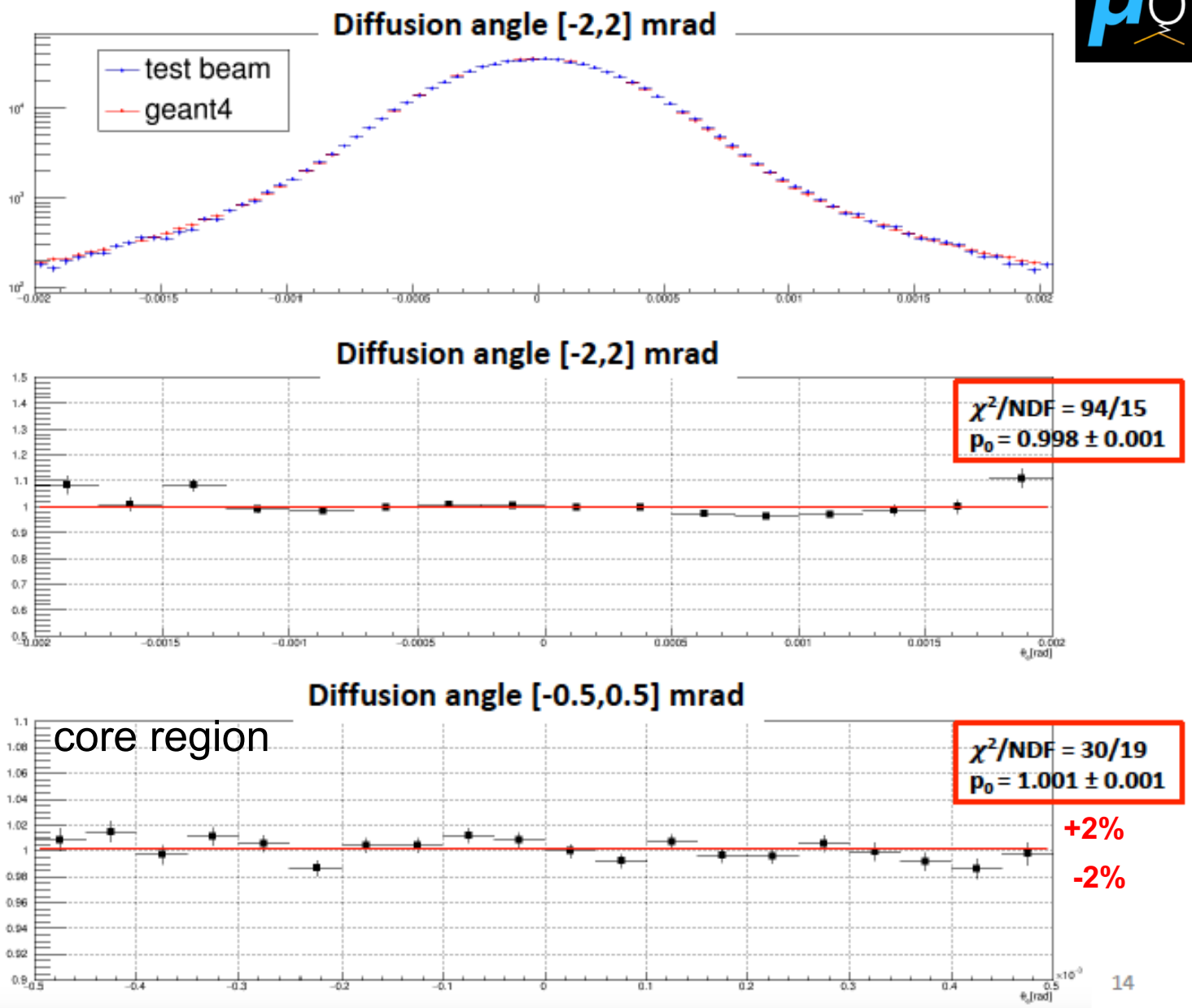
5 Si planes: 2 before and 3 after the target, 3.8x3.8 cm2 intrinsic angle resolution ~**100**μrad

8mm, 12 GeV



Agreement in the core region (90% of events) ~ 1%; outside few %

20mm, 12 GeV



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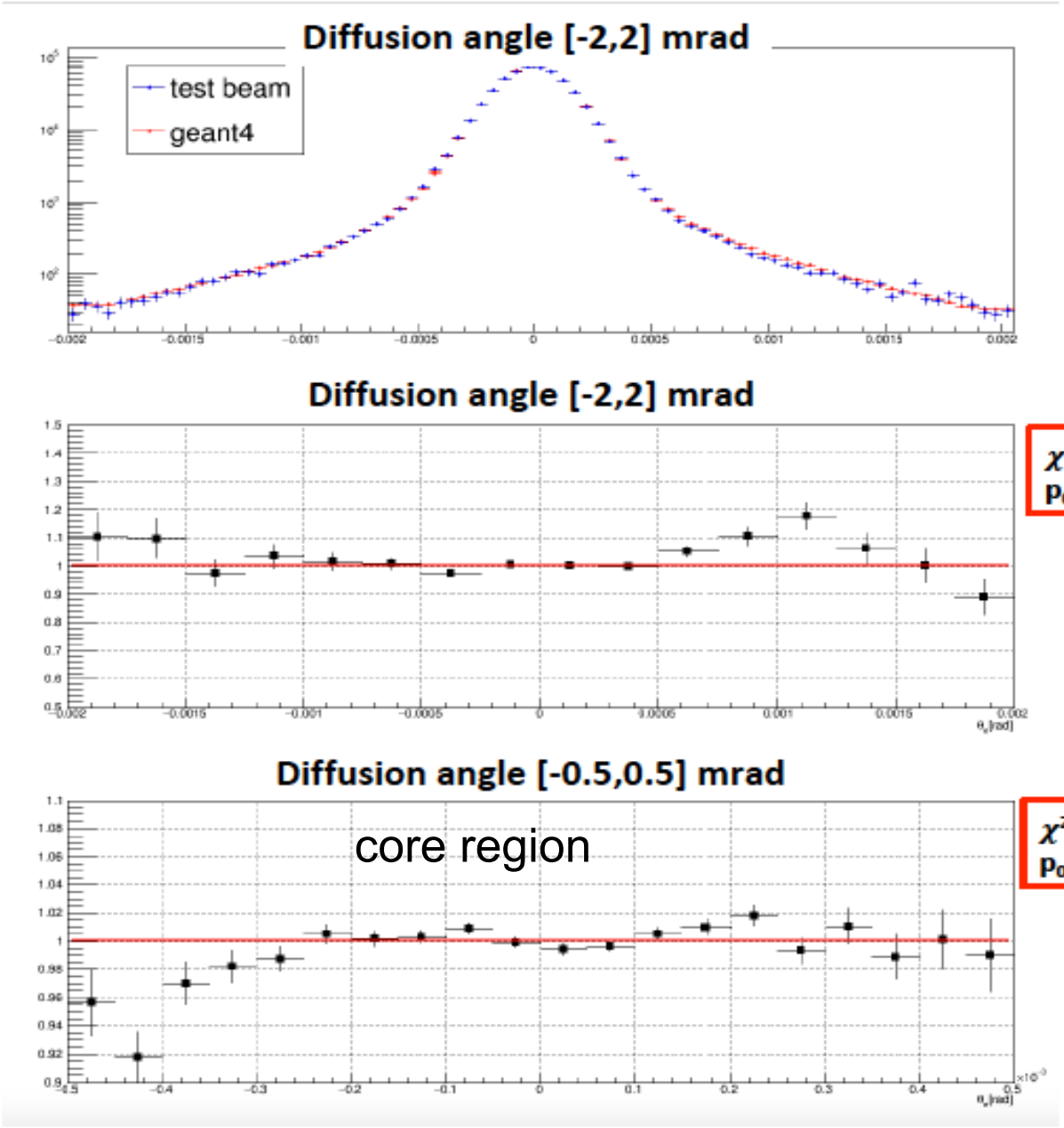
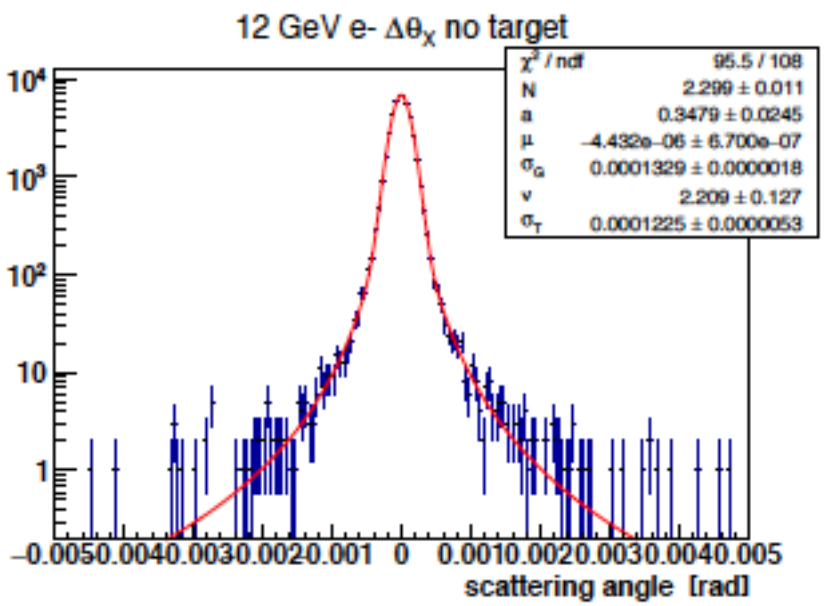


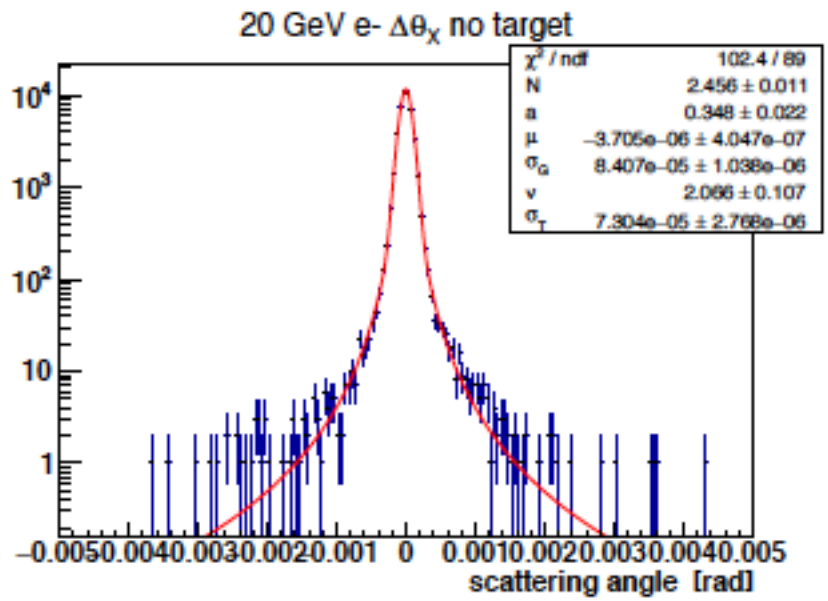
Agreement in the core region (90% of events) ~ 1%; outside few %

Parametrization of the deflection angle: telescope

$$f_{\text{telescope}}(\theta) = N\left((1-a)\frac{1}{\sqrt{2\pi}\sigma_G}e^{-\frac{(\theta-\mu)^2}{2\sigma_G^2}} + a\frac{\Gamma(\frac{\nu+1}{2})}{\sqrt{\nu\pi}\sigma\Gamma(\frac{\nu}{2})}\left(1+\frac{(\theta-\mu)^2}{\nu\sigma^2}\right)^{-\frac{\nu+1}{2}}\right)$$

[N. Berger *et al.* JINST 9 (2014) P07007]





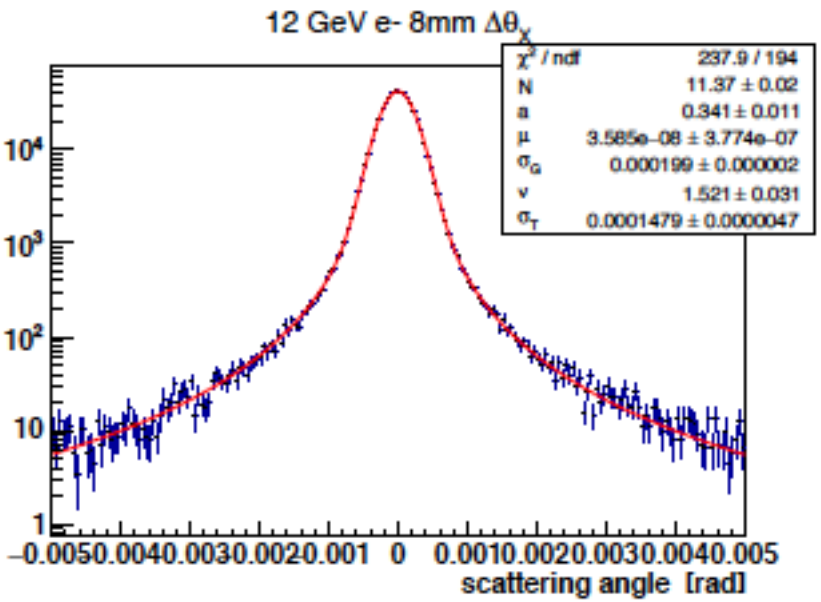
Similar results for y-view

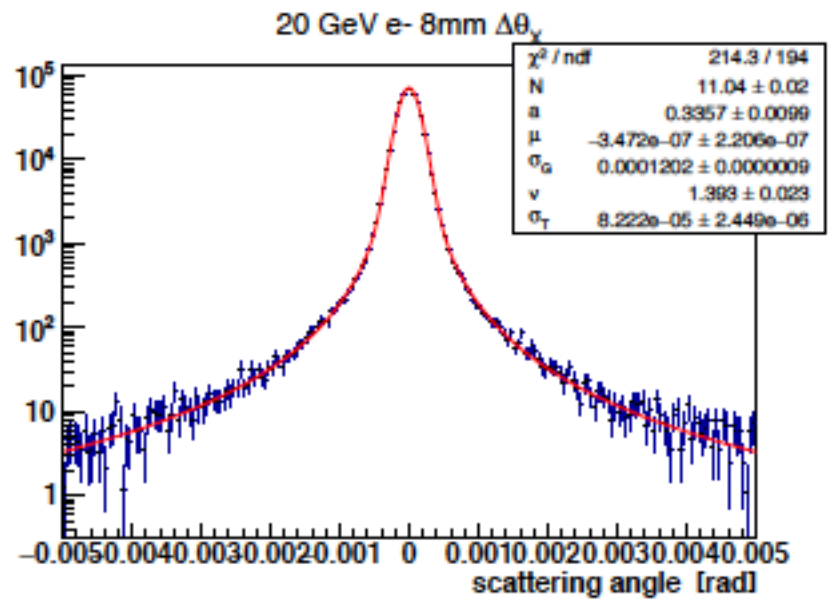
Parametrization of the deflection angle: telescope+target

$$f(\theta) = \int f_{\text{telescope}}(\theta - \theta') f_{\text{target}}(\theta') d\theta'$$

Parameters fixed to alignment data

Same parametrization as $f_{telescope}$





Parametrization of the deflection angle: telescope+target

Results of the fit

Angle	E GeV	d mm	Data σ_G 0.1 mrad	Data ν	Data σ_T 0.1 mrad	MC σ_G 0.1 mrad	MC ν	MC σ_T 0.1 mrad
θ_X	12	8	1.99 ± 0.02	1.52 ± 0.03	1.48 ± 0.05	1.938 ± 0.002	1.330 ± 0.004	1.55 ± 0.01
θ_Y	12	8	1.99 ± 0.02	1.45 ± 0.03	1.43 ± 0.05	1.923 ± 0.003	1.378 ± 0.004	1.61 ± 0.01
θ_X	12	20	3.21 ± 0.02	1.57 ± 0.03	2.95 ± 0.06	3.145 ± 0.003	1.426 ± 0.004	3.09 ± 0.01
θ_Y	12	20	3.21 ± 0.02	1.55 ± 0.03	2.92 ± 0.06	3.150 ± 0.003	1.441 ± 0.004	3.07 ± 0.01
θ_X	20	8	1.20 ± 0.01	1.39 ± 0.02	0.82 ± 0.02	1.171 ± 0.001	1.274 ± 0.003	0.899 ± 0.006
θ_Y	20	8	1.18 ± 0.01	1.41 ± 0.02	0.88 ± 0.03	1.182 ± 0.001	1.236 ± 0.004	0.862 ± 0.006

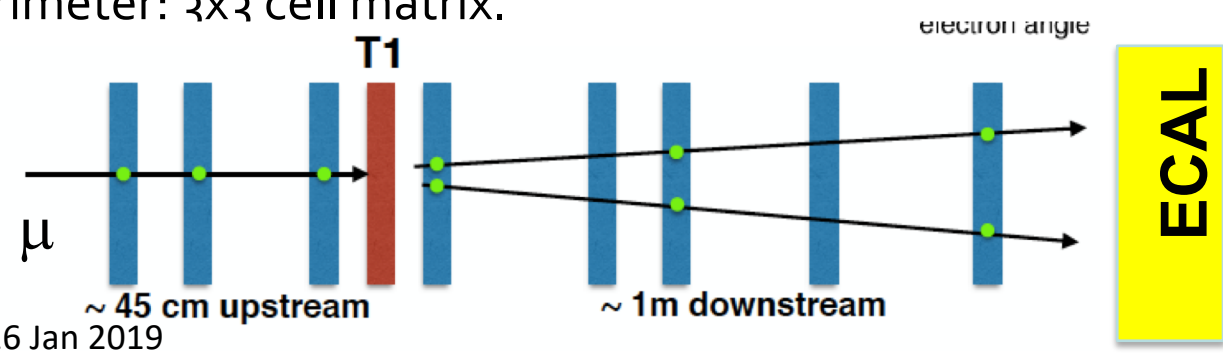
Data-MC difference ~1-2% for σ_G; ~5-10% for σ_T (systematic errors of ~1-2% not included)

Paper is in progress

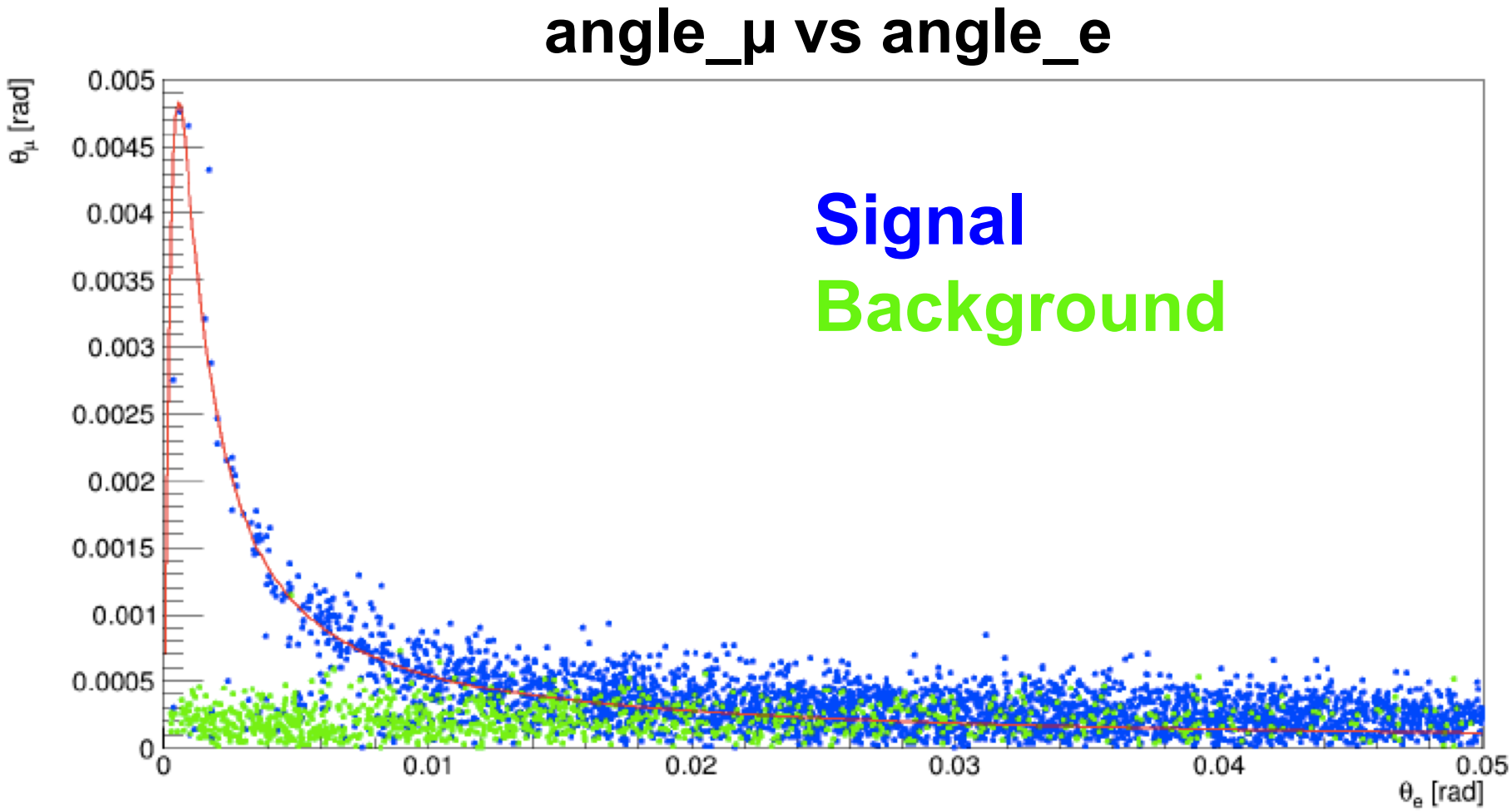
Test beam 2018

- A full scale prototype has been located downstream COMPASS, behind the Tungsten hadrons filter.
- Aim of the measurement campaign: muon – electron elastic scattering with high statistics
  - Using muons from pions decays (hadron beam) with an estimated beam momentum p = (187±7) GeV
  - To measure the correlation between the scattering angles: muon angle vs the electron angle; use of the e- Energy
- The detector consists of:
  - Tracking system: AGILE silicon strip sensors: 400 μm thick, single sided, about 40 μm intrinsic hit resolution.
  - Electromagnetic calorimeter: 3x3 cell matrix.

Data analysis in progress



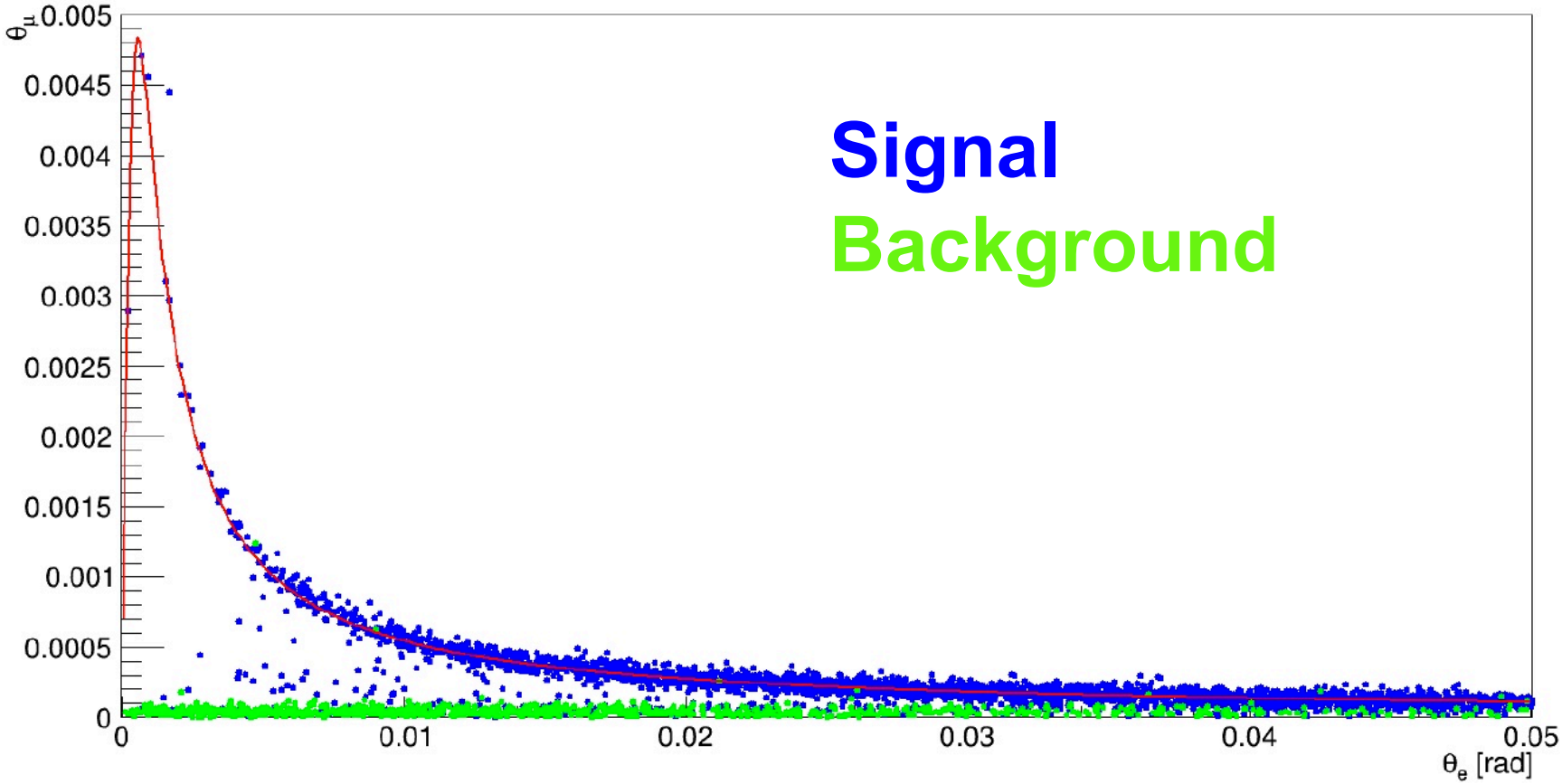
Effect of the resolution: GEANT4 (40μm hit resolution)



Pair production

Effect of the resolution: GEANT4 (10μm hit resolution)

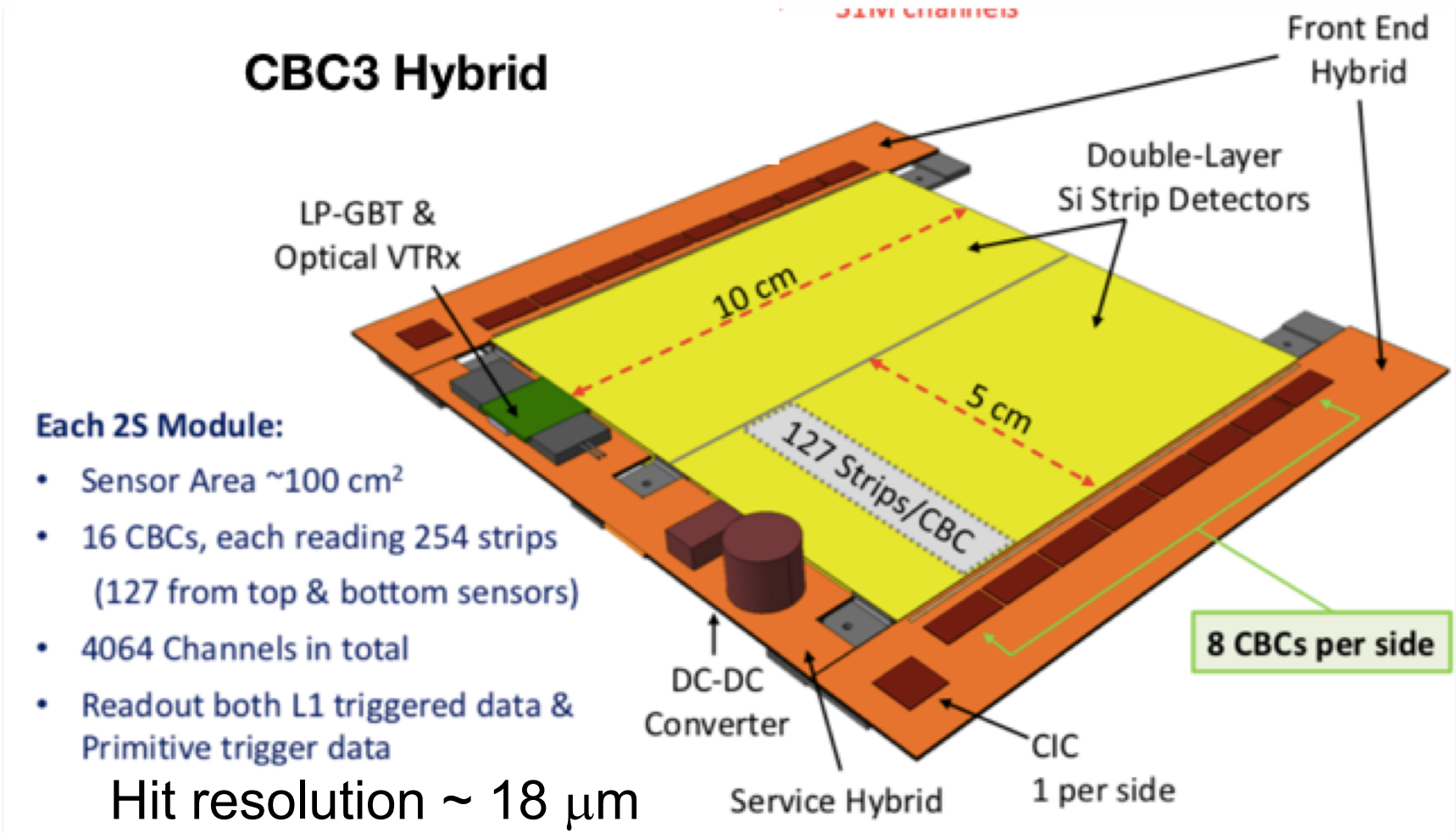
angle_μ vs angle_e



Pair production

Baseline design

CBC3 based CMS detector



Each 2S Module:

- Sensor Area ~100 cm^2
- 16 CBCs, each reading 254 strips (127 from top & bottom sensors)
- 4064 Channels in total
- Readout both L1 triggered data & Primitive trigger data

Hit resolution ~ 18 μm

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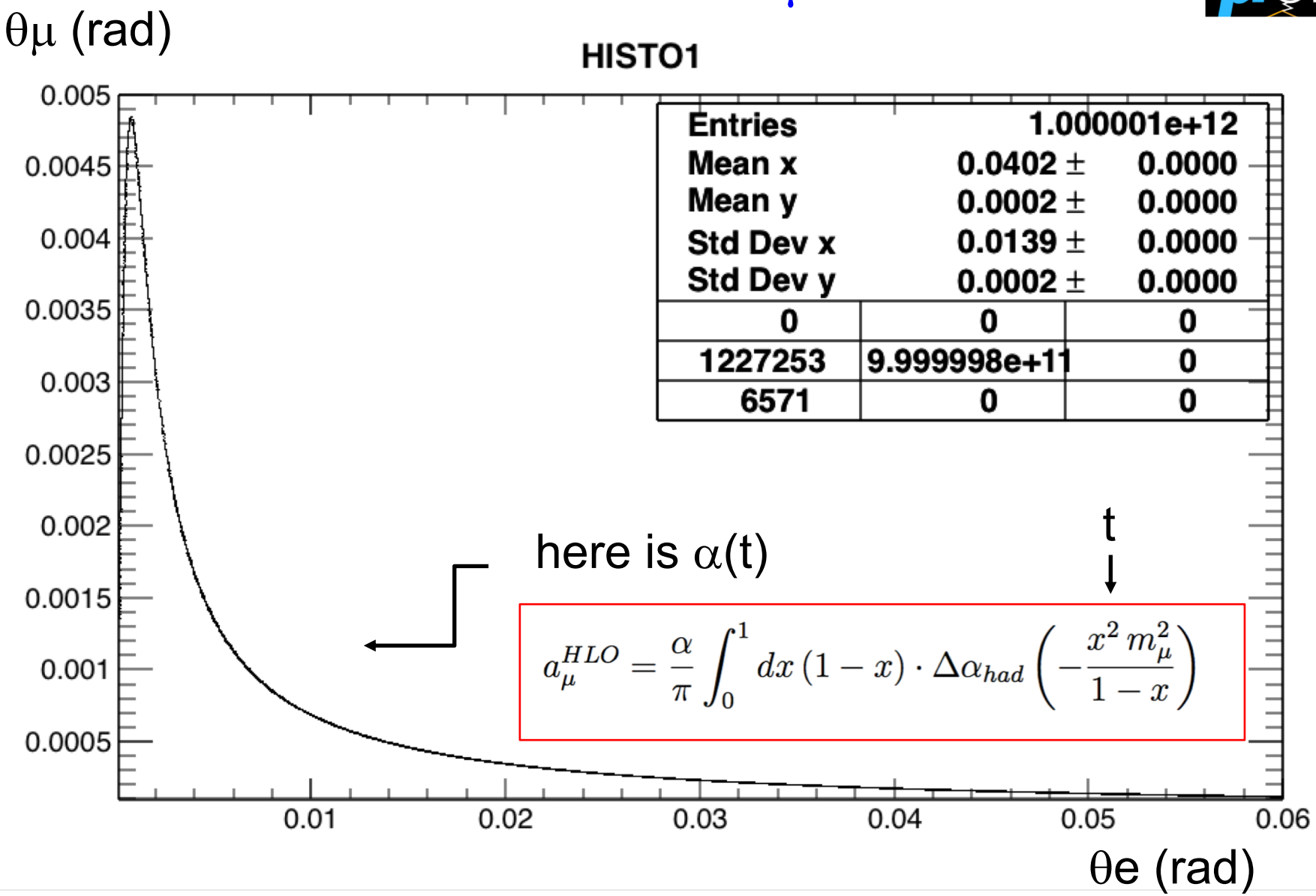
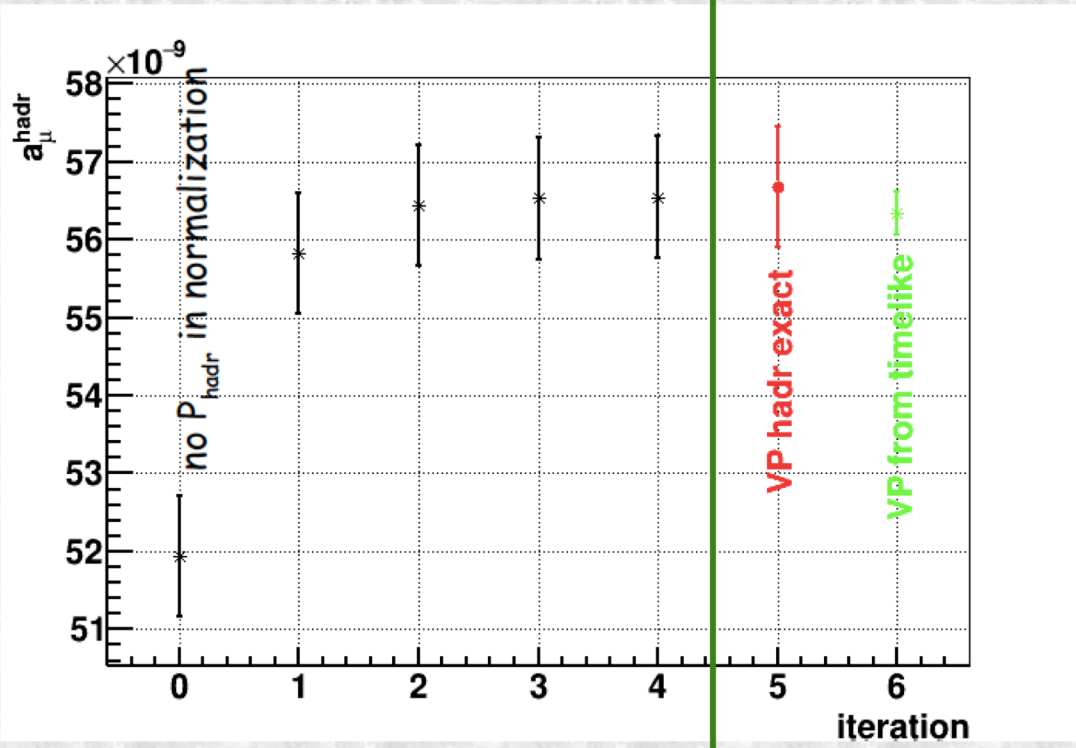
«Blind» Extraction of a_μ^{HLO} (LO)



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

«Blind» Extraction of a_μ^{HLO} (LO)



X= 0.377952 - 0.931984

From timelike data:
$\Delta a_\mu^{LO} = 563.4 +- 2.8 \times 10^{-10}$

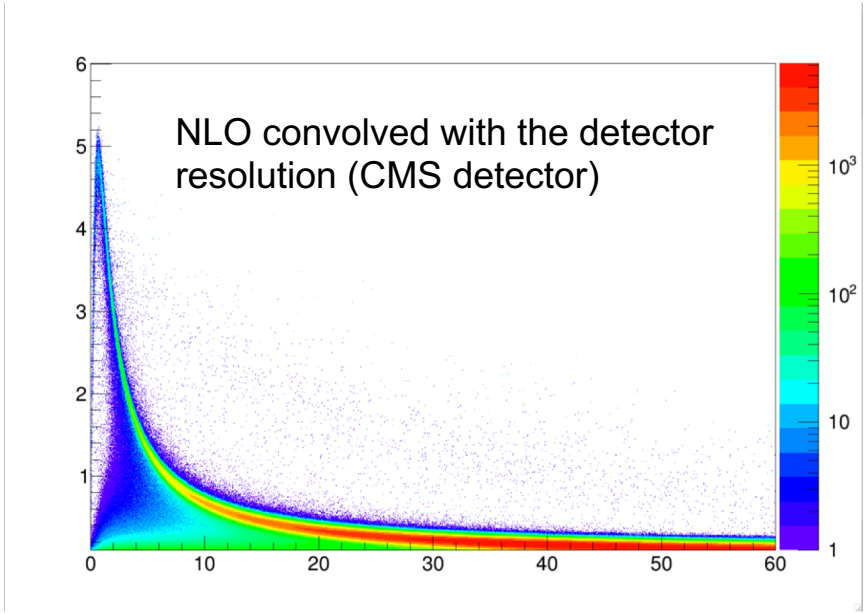
Integral After last iteration:
$565.5 +- 7.8 \times 10^{-10}$

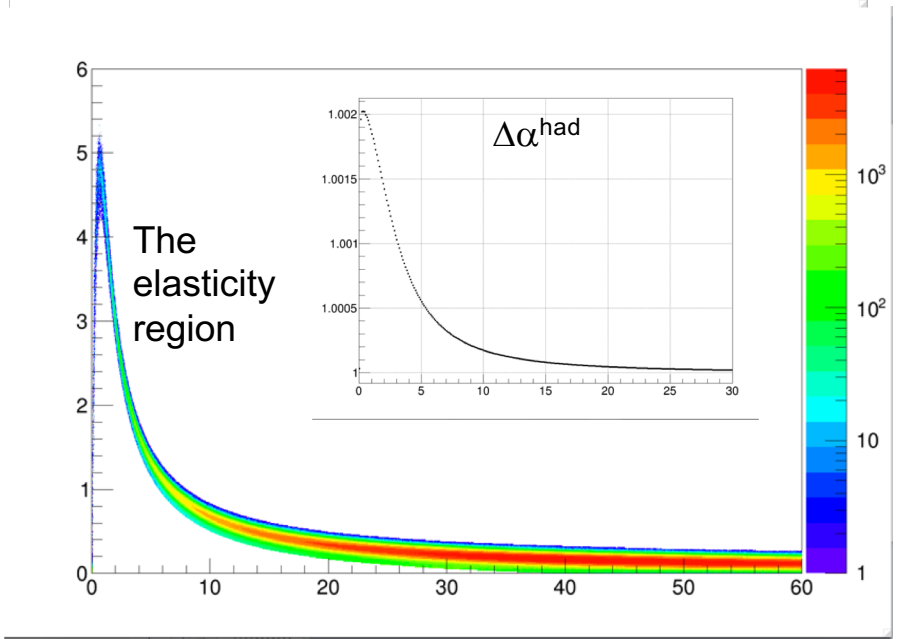
Precision 1.37%
Compatible with 0.4%

Last iteration consistent (at 0.3σ) with the input value for a_μ^{HLO}

NLO Studies

- MC NLO available (Pavia Theory group)
- An elasticity region can be defined (containing 95% of the events).
- Sensitivity to the hadronic contribution to the running of α(t) is the expected one.
- The total selection efficiency will depends on additional cuts (coplanarity, energy threshold, etc) needed





Possible location at CERN M2

- Between BSM and COMPASS

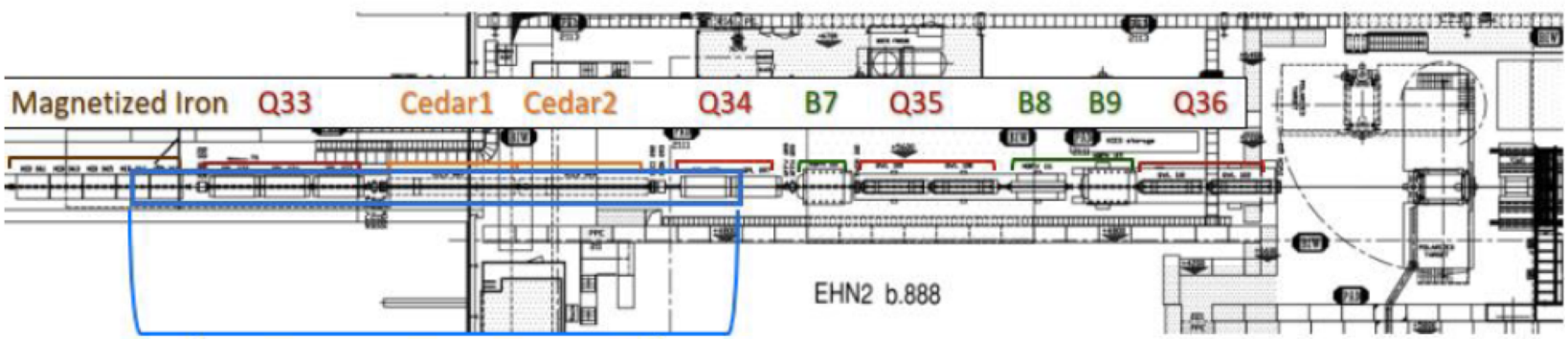
1/ μ-e setup upstream of present COMPASS experiment, i.e. within M2 beam-line

- More upstream of Entrance Area of EHN2 (Proposed by Johannes B. & Dipanwita B.)

- Pro: Could allow running μ-e/μ-p_{Radius} in parallel.

- Questions: will require displacements (also removal) of some M2 components.

- Beam(s) compatibility for μ-e & μ-p_{Radius} : Optic's wise looks OK (see Add. Sl.14 from D.B.)



μ-e Upstream (under-study) ~ 30 m

Σ length required (updated): 35 m targets + trackers + 0.8 m Ecals + 3 m (μ-Filter) ~ 39 m

10

Beam Synergy/sharing at M2 under study (thanks to A. Magnon)

Theory

- QED NLO MC generator with full mass dependence has been developed and is currently under use (Pavia group) : M. Alacevich, *et al* **arXiv:1811.06743**.

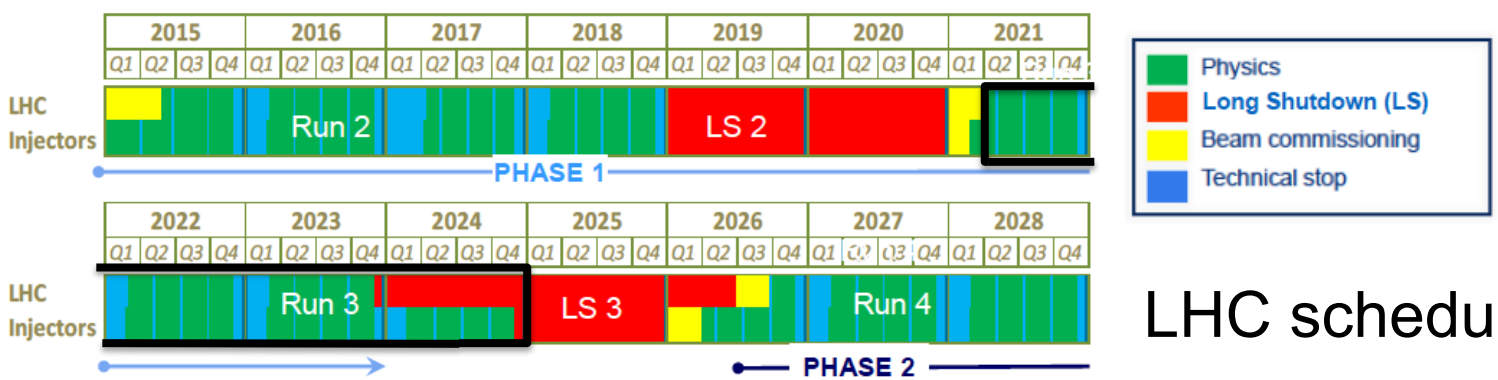
- First results obtained for the NNLO box diagrams contributing to μ-e scattering in QED (Padova group): P. Mastrolia, *et al*, **JHEP 1711 (2017) 198**; S. Di Vita, *et al.* **JHEP 1809 (2018) 016**; M. Fael, **arXiv:1808.08233**; M. Fael , M. Passera **arXiv:1901.03106**

- Next Theory workshop: Feb 4-7 2019: "Theory for muon-electron scattering @ 10ppm" in Zurich (orgs: A. Signer and Y. Ulrich)

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

Plans

- **2019**
  - Detector optimization /test beam/full MC simulation
  - Letter of Intent to the SPSC
- **2020-2021**
  - Detector construction and installation
    (request a pilot run in 2021 in the time window not yet allocated)
- **2022–2024**
  - data taking to measure a_μ^{HLO} at few per mill error
    first run with scaled detector and reduced accuracy (~1%?)



LHC schedule

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Conclusion

- Exciting times for the muon g-2. New result from the E989 experiment at Fermilab expected soon
- Very important: theory "under control" (especially strong interaction)

- Progress on **MUonE**:
  - Analysis of Multiple Scattering TB data. Paper is almost ready
  - Analysis of 2018 Test Run @M2 in progress
  - Baseline design: Silicon detector: CMS
  - Progress on NLO
  - Location of MUonE at EHN2
  - Progress on Theory side
  - LoI planned for 2019

THE END

(Thanks to J. Berhnard, L. Gatignon and A. Magnon for many useful discussions and work)

MUonE Collaboration (in progress)

G. Abbiendi, M. Alacevich, M. Baszczyk, M. Bonanomi, T. Bowcock, C. Brizzolari, A. Broggio, G. Cantatore, C.M.Carloni Calame, E. Conti, S. Eidelman, M. Fael, A. Ferroglia, D. Galli, F.V. Ignatov, M. Incagli, A. Keshavarzi, M. Kucharczyk, M. Lancaster, F. Ligabue, I. Logashenko, 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, P. Pdorosz, F. Piccinini, F. Pisani, D. Pokanic, M. Prest, A. Primo, A. Principe, M. Rocco, U. Schubert, F. Simonetto, M. Soldani, R. Stroili, L. Trancredi, R. Tenchini, W. Torres-Bodabilla, L. Trentadue, E. Vallazza, G. Venanzoni, M. Witek

Suitable sensors and ASICs

- **Requirements:**
  - **Dimensions: 10 cm × 10 cm**
  - **Single hit resolution: r ≤ 10 μm**
  - **Fast timing (25 ns).**
  - **Minimal thickness: d ≤ 300 μm**
- **Possible implementation:**
  - **strip pitch p ≤ 50μm and floating electrodes charge sharing to get a resolution better than the geometrical σ=p/sqrt(12), depending on S/N**
  - **1028 channel hybrid per sensor single sided**