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

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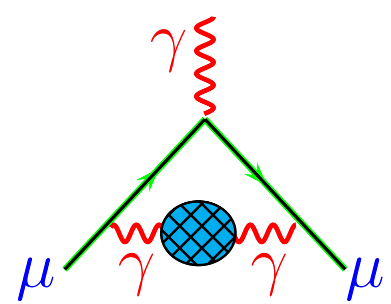


CERN, 1 March 2017

Outline

- Muon g-2: summary of the present status
- Proposal to compute a_μ^{HLO} in the space-like region with $\mu e \rightarrow \mu e$ at CERN
- Progress from September
- Next 2 years plan

Muon g-2: summary of the present status

- E821 experiment at BNL has generated enormous interest:

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

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

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

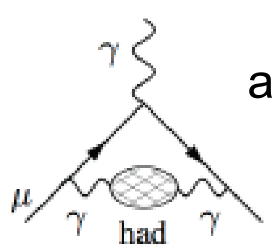
M. Davier, A. Hoecker, B. Malaescu and Z. Zhang, Eur. Phys. J. C71 (2011)

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

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

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

Hadronic Vacuum polarization (HLO)

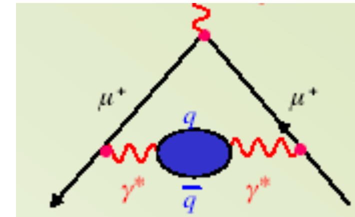


$a_\mu^{HLO} = (692.3 \pm 4.2)10^{-10}$

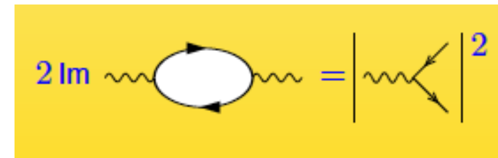
$\delta a_\mu^{HLO}/a_\mu^{HLO} \sim 0.6\%$

a_μ^{HLO} calculation, traditional way: time-like data

a_μ=(g-2)/2



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

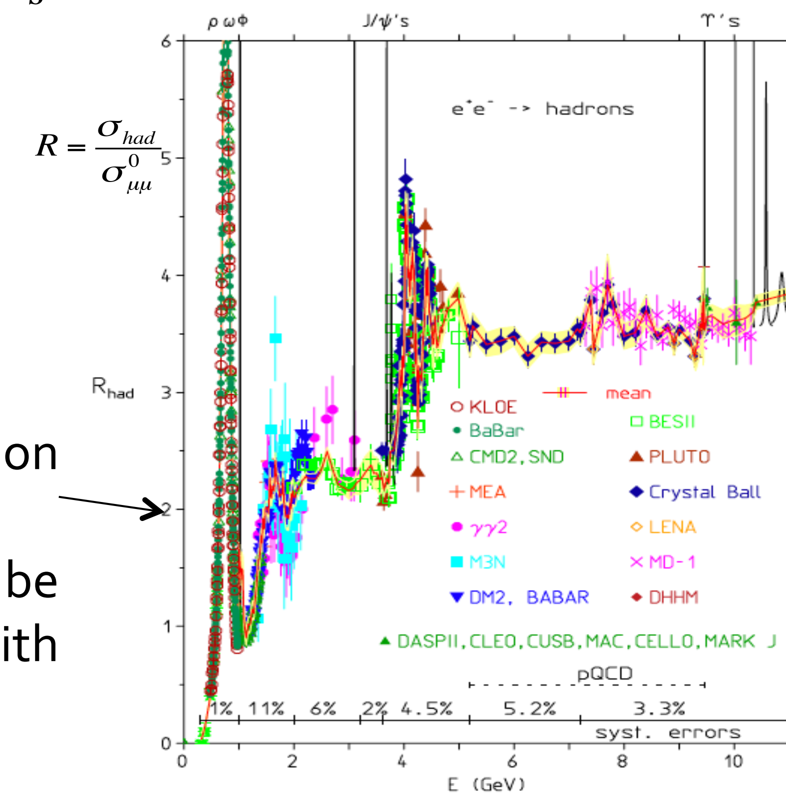


$$K(s) = \int_0^1 dx \frac{x^2(1-x)}{x^2+(1-x)(s/m^2)} \sim \frac{1}{s} \qquad \sigma_{e^+e^-\to hadr}(s) = \frac{4\pi}{s}\mathrm{Im}\,\Pi_{had}(s)$$

Traditional way: based on precise experimental (time-like) data:

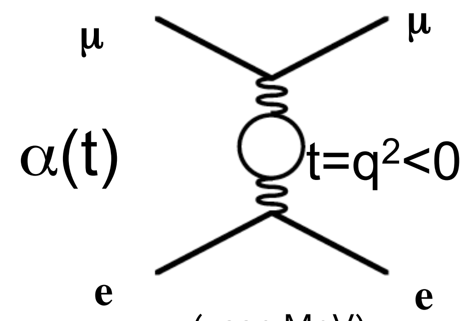
a_μ^{HLO} = (692.3±4.2)10^{-10} (DHMZ)

- Main contribution in the low energy region (**highly fluctuating!**)
- Current precision at 0.6% → needs to be reduced by a factor **~2** to be competitive with the new **g-2** experiments



Alternative (space-like) approach: a_μ^{HLO} from a 150 GeV μ beam on e⁻ target at CERN

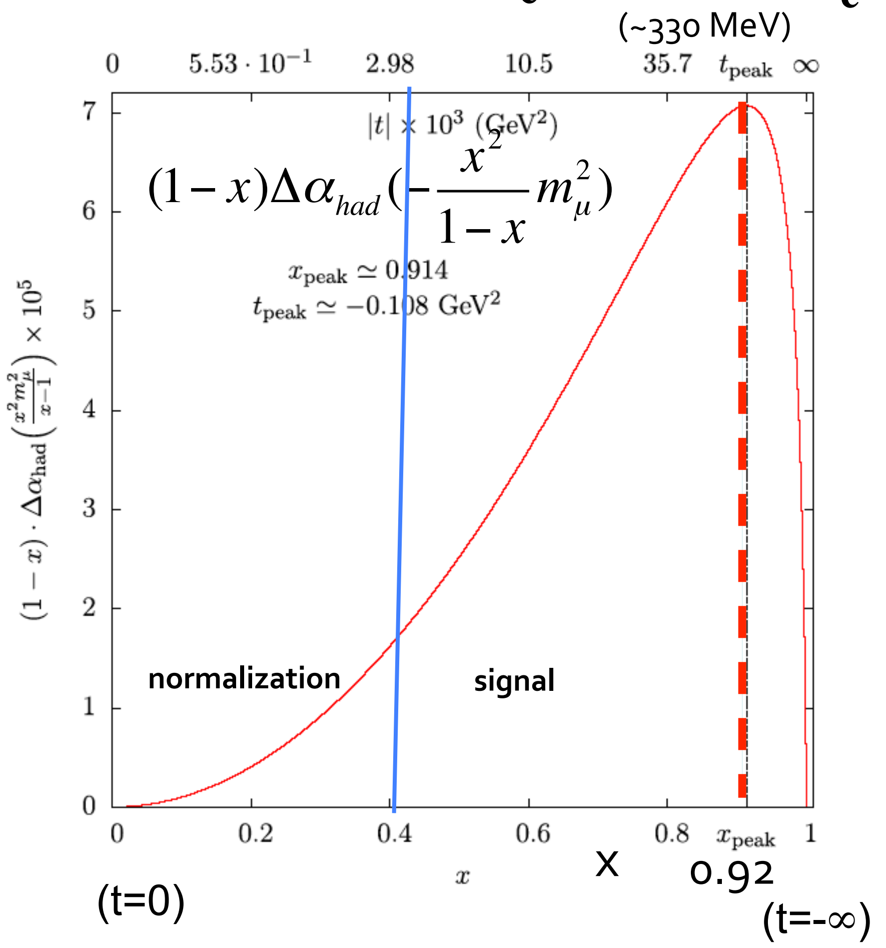
$$a_\mu^{HLO} = \frac{\alpha}{\pi}\int_0^1 (1-x)\Delta\alpha_{had}\left(-\frac{x^2}{1-x}m_\mu^2\right)dx$$



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

t=0 **t=-∞**

- Measure $\Delta\alpha_{had}(t)$ through the elastic scattering μe → μ e; $t=q^2=-2m_eE_e<0$
- Simple kinematics (2 body process) 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)
- $t=q^2$ from angular measurement of e/μ
- Highly boosted system gives access to all angles (t) in the cms region
- Same detector for signal and normalization → cancellation of detector effects at first order



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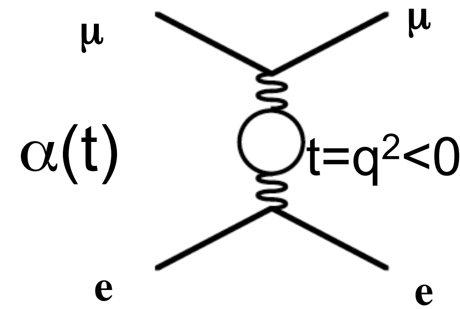

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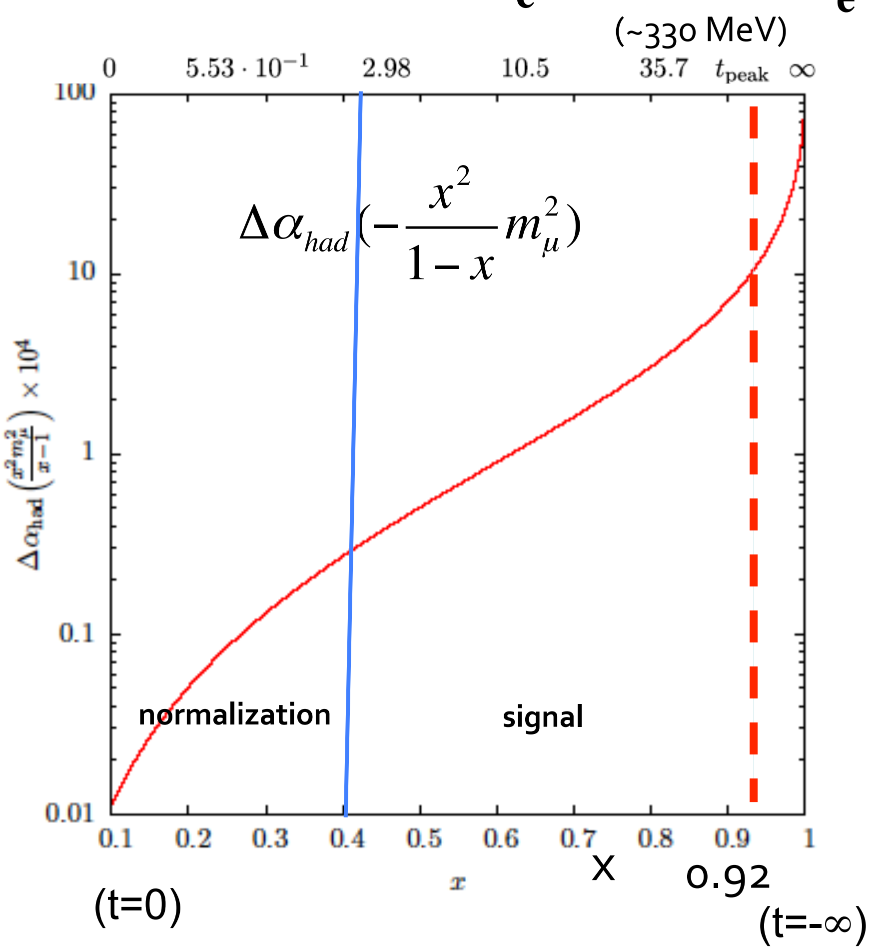
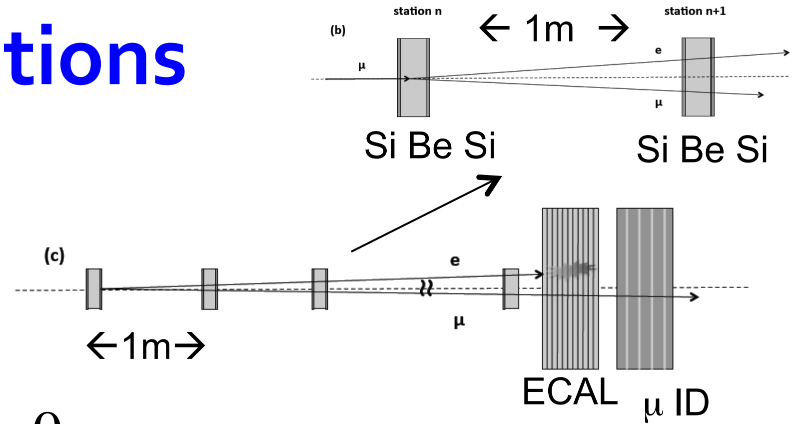
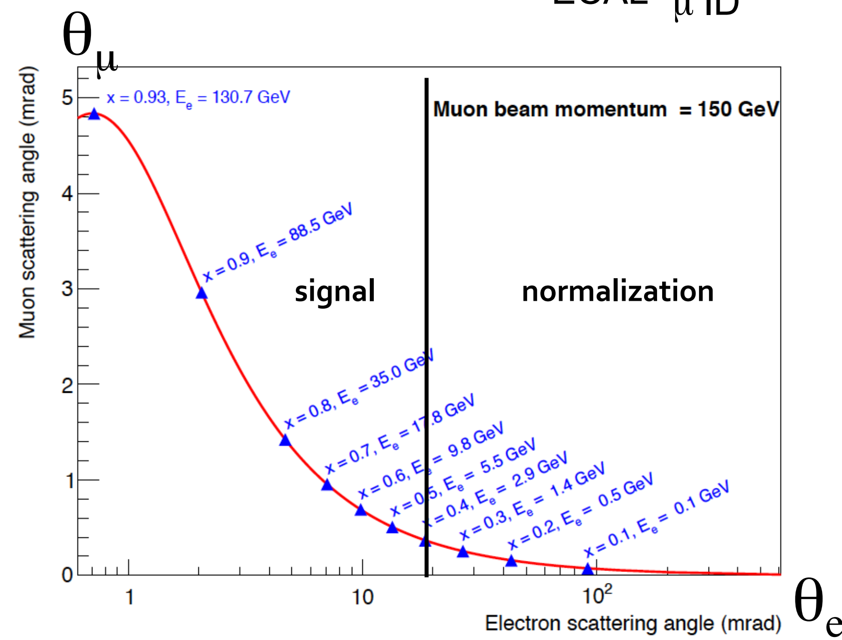


Detector considerations



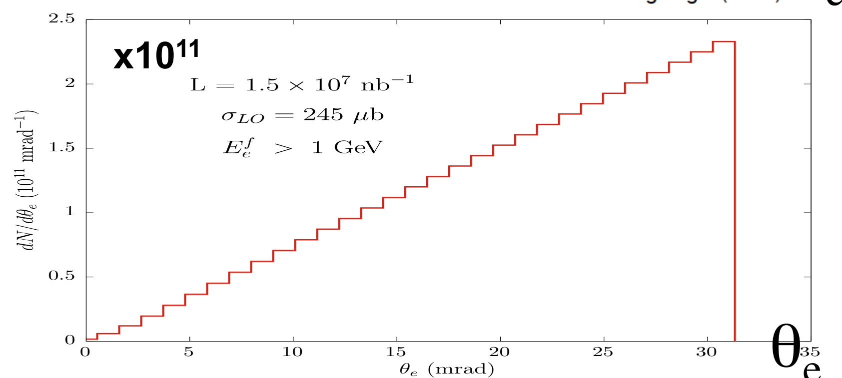
- Modular apparatus: 20 layers of 3 cm Be (target), each coupled to 1 m distant Si (0.3 mm) planes. It provides a 0.02 mrad resolution on the scattering angle

- Angular measurement: signal region ($10^{-5}<\Delta\alpha_{had}(t)<10^{-3}$) θ_e<20mrad; normalization region ($\Delta\alpha_{had}(t)<10^{-5}$) θ_e>20mrad



- Needs to keep the systematic errors at 10^{-5} (main effect is the multiple scattering, see later)

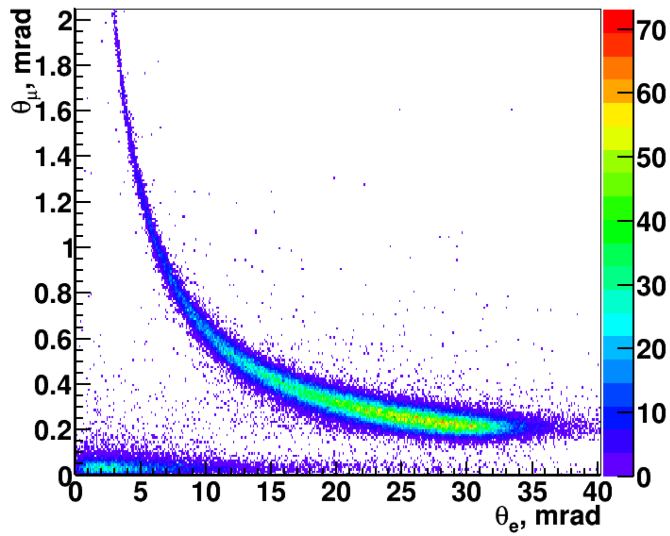
- Possible necessity of a ECAL and μ Detector located downstream to solve PID ambiguity below 5 mrad. Above that, angular measurement gives correct PID



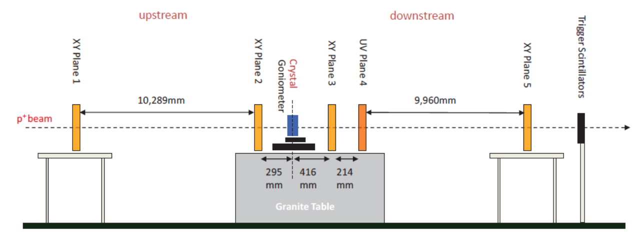
- **0.3% stat error can be achieved on a_{μ}^{HLO} in 2 years of data taking with <I>~1.3×10^{7} μ/s**
  → 2×10^{12} signal events/year

Progress from September

- Focus on Multiple Scattering (MSC) (first studies):
    - effects due to 1% uncertainty MSC (gaussian) model
    - Understanding non-gaussian tails by GEANT



- Test Beam at CERN (27 Sep-3 Oct 2017)



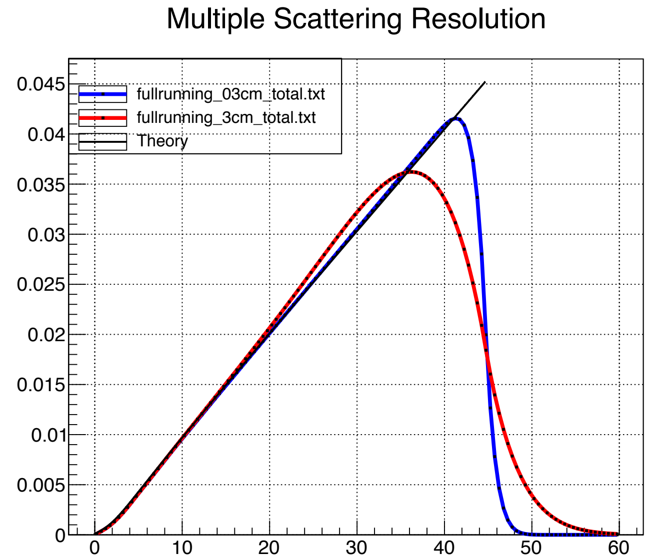
- Theoretical activity:
    - Understanding the present limitations and necessary steps towards the goal of 10ppm
    - Proposed workshop at MAINZ (2018)

- Paper "**Measuring the leading hadronic contribution to the muon g-2 via μe scattering**" G. Abbiendi et al., arXiv:1609.08987**,** accepted for publ. *EPJC* ***(DOI :10.1140/epjc/s10052-017-4633-z)***

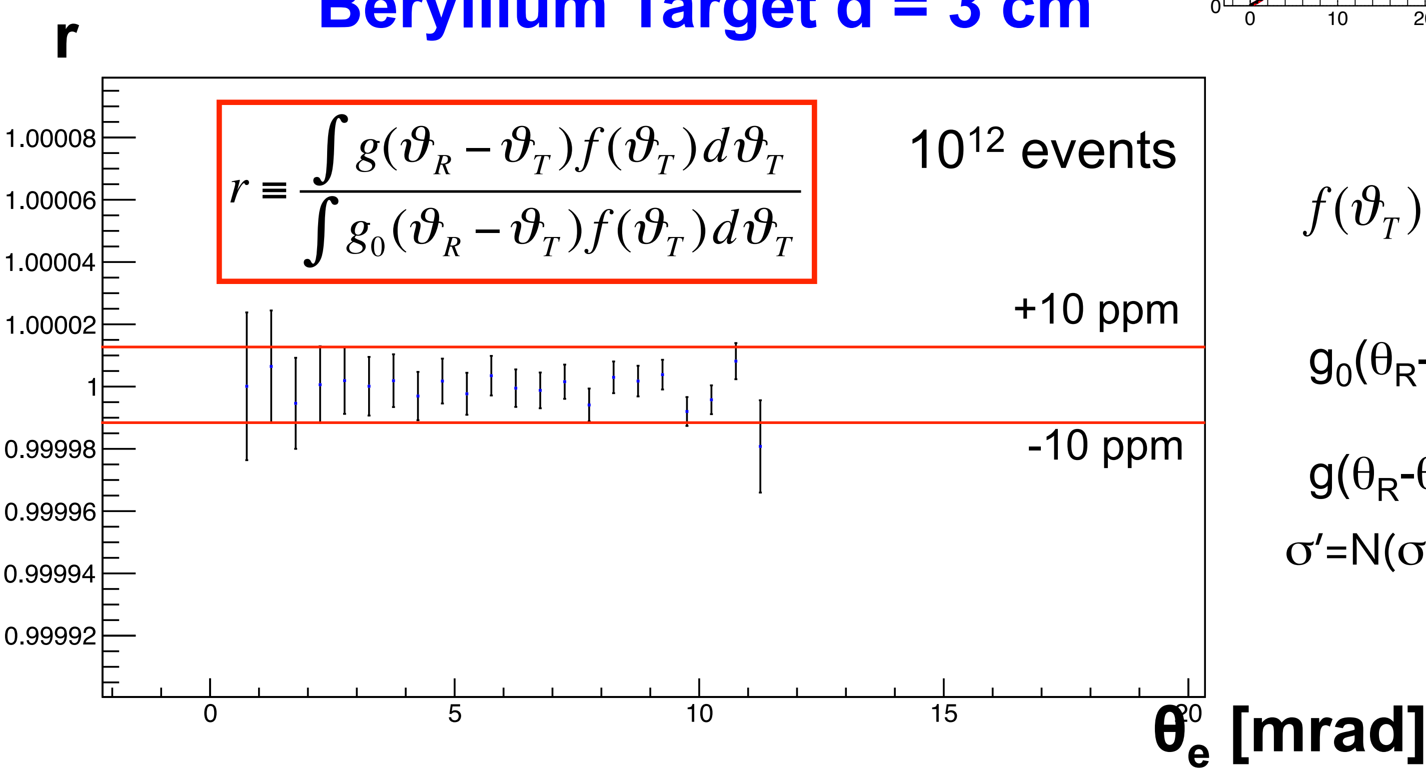
MSC studies: Gaussian model with 1% uncertainty

$$g_0(\theta_R - \theta_T) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{(\theta_R-\theta_T)^2}{2\sigma^2}\right]$$

$$\sigma = \frac{13.6}{\beta pc} z \sqrt{\frac{d}{X_0}}\left[1+0.038\ln\left(\frac{d}{X_0}\right)\right]$$



Beryllium Target d = 3 cm



$$f(\vartheta_T) = \frac{dN(e\mu \to e\mu)}{d\vartheta_T}$$

$g_0(\theta_R-\theta_T) \sim N(\theta_T,\sigma)$

$g(\theta_R-\theta_T) \sim N(\theta_T,\sigma')$

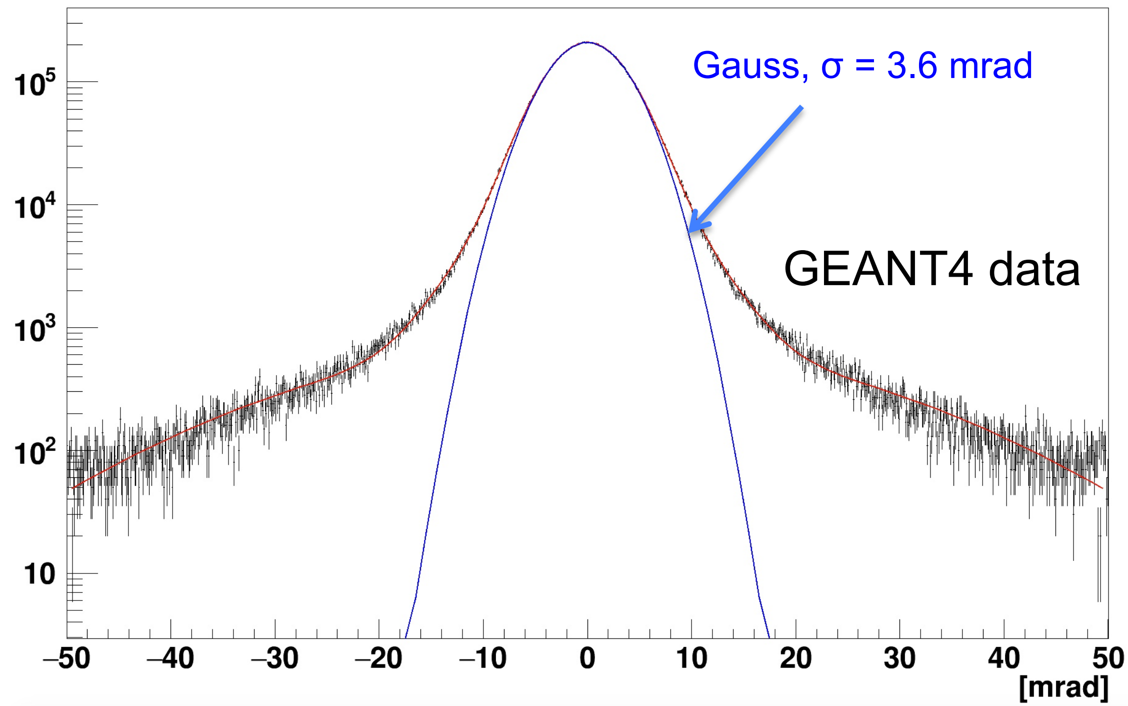
$\sigma' = N(\sigma, 0.01\sigma)$

Non gaussian tail effects

- First studies with GEANT: Non gaussian tails ~3%:
  - 1 GeV electron tails: 3 cm Multiple Scattering:
    - computed theta0 (Highland formula) = **3.593 mrad**
    - central part defined as +- **10.78 mrad (3σ)**;

Tail ratio = 3.002 %

Work in progress to study tail effects on the angular distribution

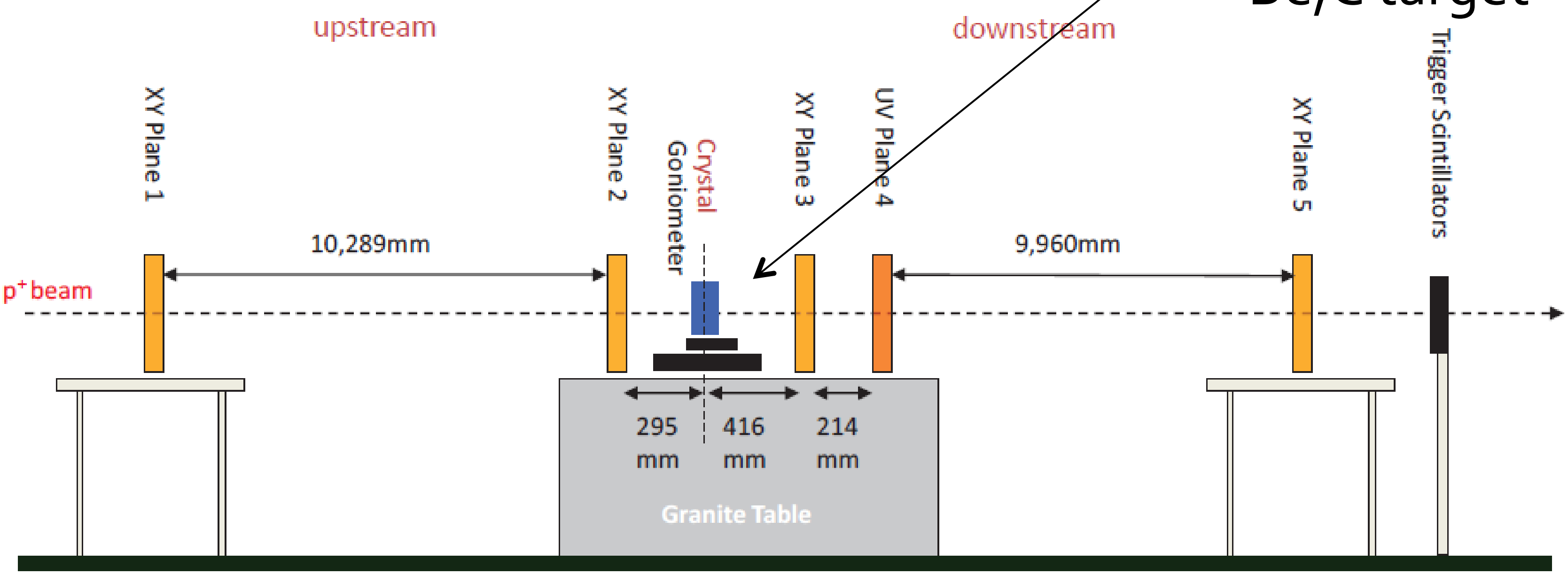


Test Beam

27 Sep-3 October 2017
Plan to use existing UA9 setup in H8

max rate ≈ 10 kHz
p beam ≈ 57%-100% of 180 GeV

Replacing crystal with thin Be,C target



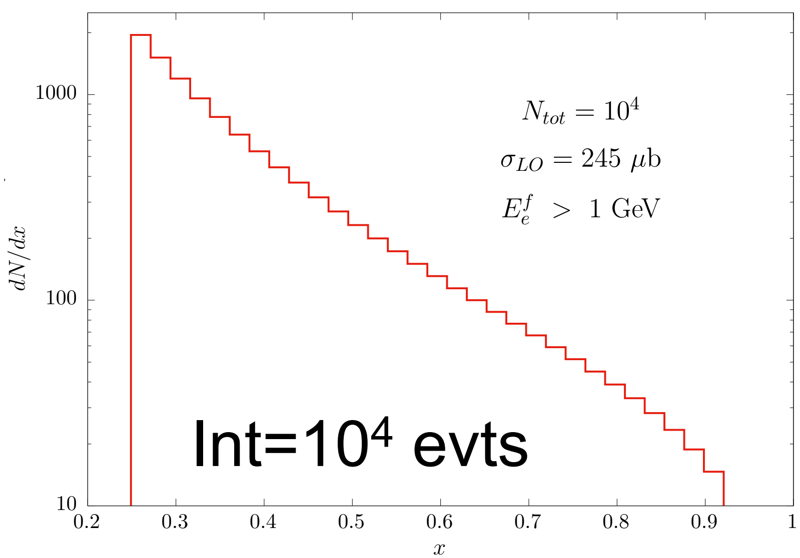
Basic setup from IC :

5 Si planes, 2 before and 3 after the target, 3.8x3.8 cm2
as is it the setup achieves 5.2 μrad, limited by the MS in the Si

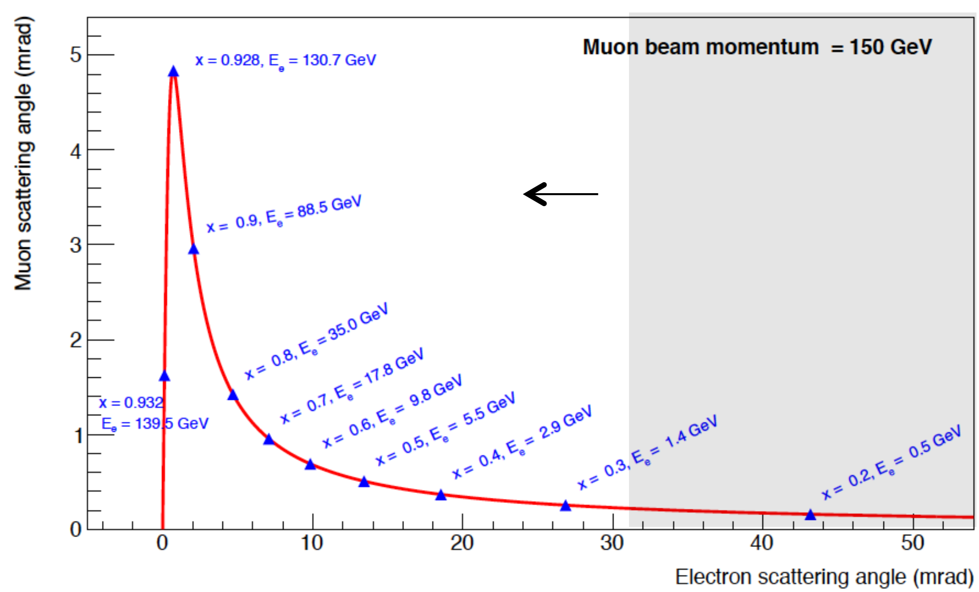
Goal of the TB

- Measure the angle of e- and muons
- Isolate the signal (elastic scattering) events
- plot 2D θ_μ vs θ_e (in the allowed region)
- Compare with simulation

Preliminary: $O(10^4)$ μe evts expected within $\theta<30$ mrad assuming 10kHz μ



30mrad 1mrad



Activity on the theory side

1. QED NLO corrections. Easy.

2. Resummation of dominant corrections up to all orders, matched with NLO corrections. Non-trivial issue: mass effects in this case are important

3. NNLO corrections: some classes of NNLO re-usable from existing Bhabha calculations, some new due to different mass scales ($\mathbf{m}_\mu$ and $\mathbf{m}_e$). In any case, NNLO must be matched with 1. and 2. [references: Eur. Phys. J. C 66 (2010) 585 and references therein]

4. Development of dedicated MC tools including all the above ingredients

5. Detailed study of all the mentioned corrections, comparison among independent calculations, estimate of further-missing higher-order corrections

6. Planned theory workshop this year in Padova (and one proposed next year in Mainz)

Plans (next 2 years) and Conclusion

- Focus on Multiple Scattering (MSC) effects:
  - How non gaussian tails affects our measurement and can be monitored/ controlled (2D plots and acoplanarity)
- Background subtraction and modeling in GEANT
- Optimization of target/detector and full detail simulation
- Test beam(s) and proto-experiment with a realistic module
- NNLO MC generation of μe process
- Design possible implementation in M2
- Consolidate the collaboration and write a TDR

Spare