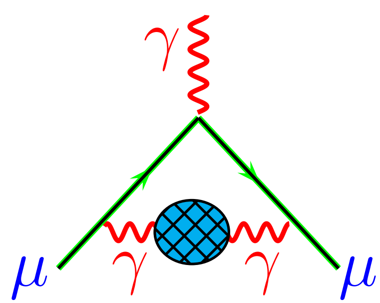
Status of MUonE and RadioMonteCarLow (+ Strong2020) activities

G. Venanzoni,
INFN-Pisa
on behalf of many colleagues



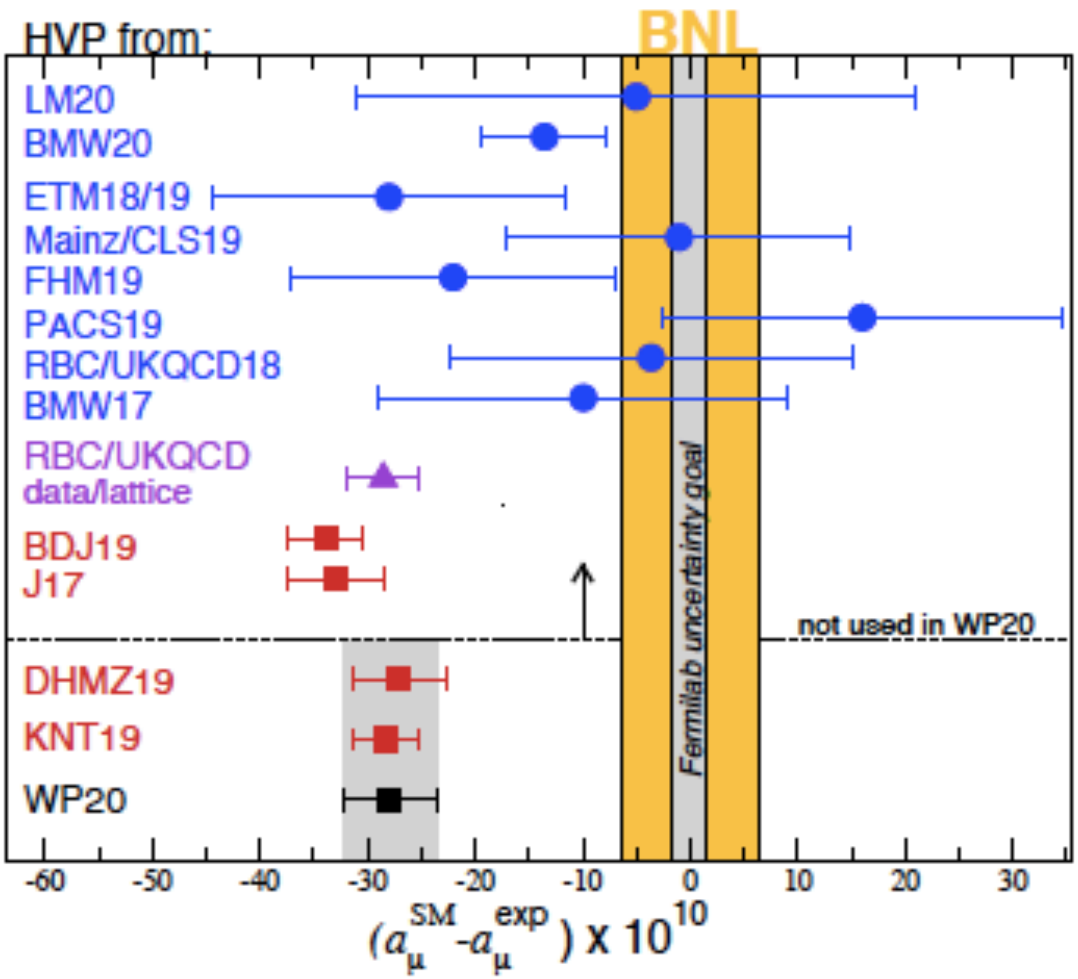
"The closer you look the more there is to see" (F. Jegerlehner)

TI –KEK 29/6/2021

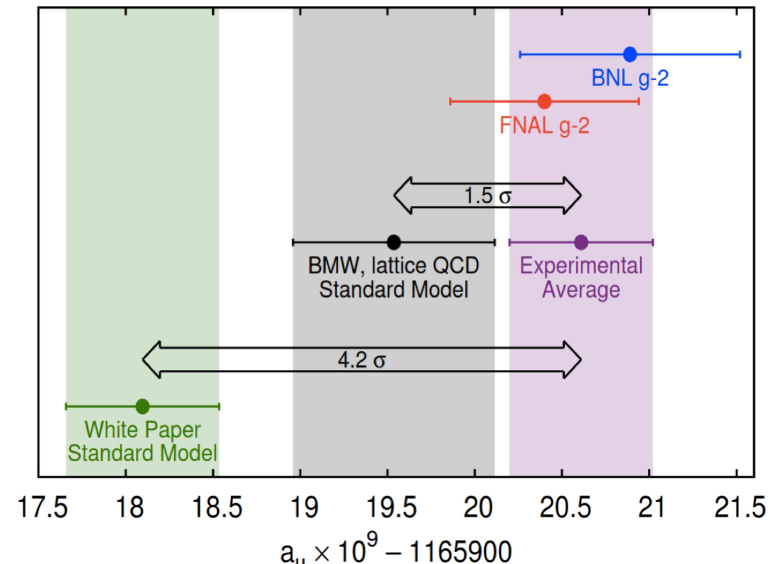
Simon

We will deeply miss him

Muon g-2: present status



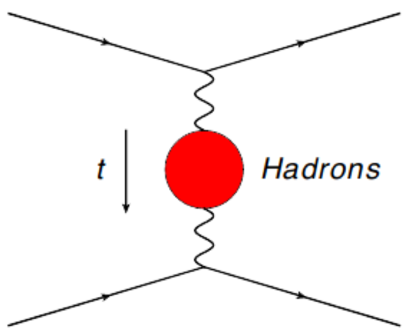
- HVP is the main limitation to the improvement in precision to the SM evaluation a_μ
- Recent evaluation(s) of HVP from lattice (BMW20) in tension with the e^+e^- evaluation (WP20)



A «Third way»: MUonE at CERN
(a space-like approach of a_μ^{HLO})

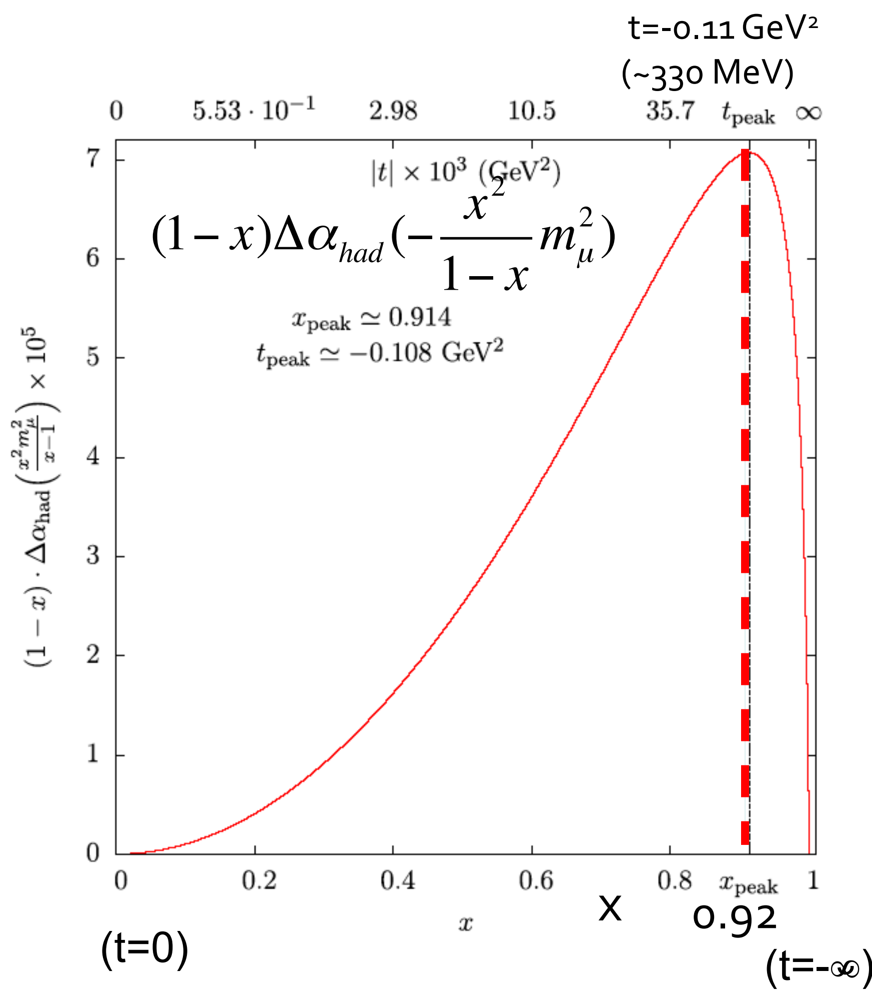
$$a_\mu^{HLO} = \frac{\alpha_0}{\pi} \int_0^1 dx(1-x)\Delta\alpha_{had}[t(x)]$$

$$t(x) = \frac{x^2 m_\mu^2}{x-1} < 0$$



Measurement of $\Delta\alpha_{had}(t)$: hadronic contribution to the running of the electromagnetic coupling constant.

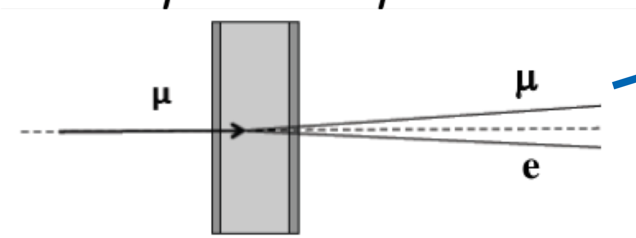
-C. M. Carloni Calame et al PLB 746 (2015) 325
-G. Abbiendi et al Eur.Phys.J.C 77 (2017) 3, 139



The MUonE experiment

Extraction of $\Delta\alpha_{had}(t)$ from the «shape» of the $\mu^+ e^- \rightarrow \mu^+ e^-$ elastic differential cross section

$$\mu\ e \rightarrow \mu\ e$$

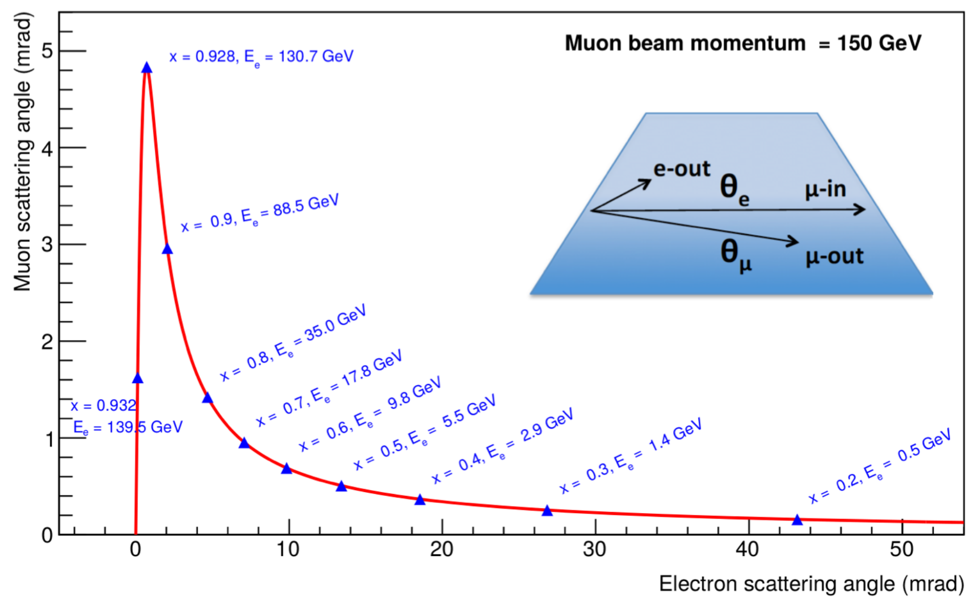


$$\frac{d\sigma_{data}/dt}{d\sigma_{MC}^{\text{no VP}}/dt} = \frac{1}{|1 - \Delta\alpha_{lep}(t) - \Delta\alpha_{had}(t)|^2}$$

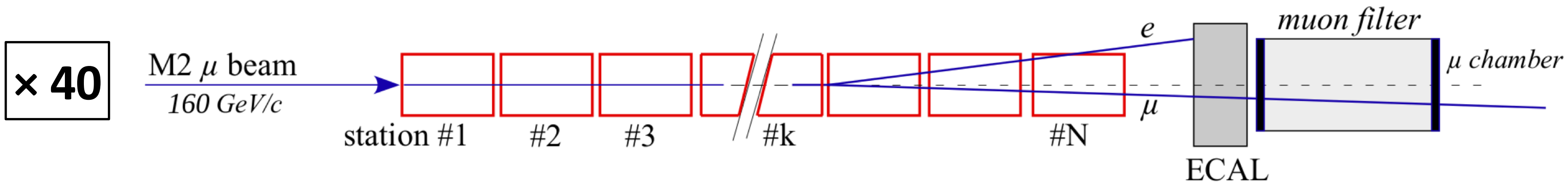
From theoretical calculation

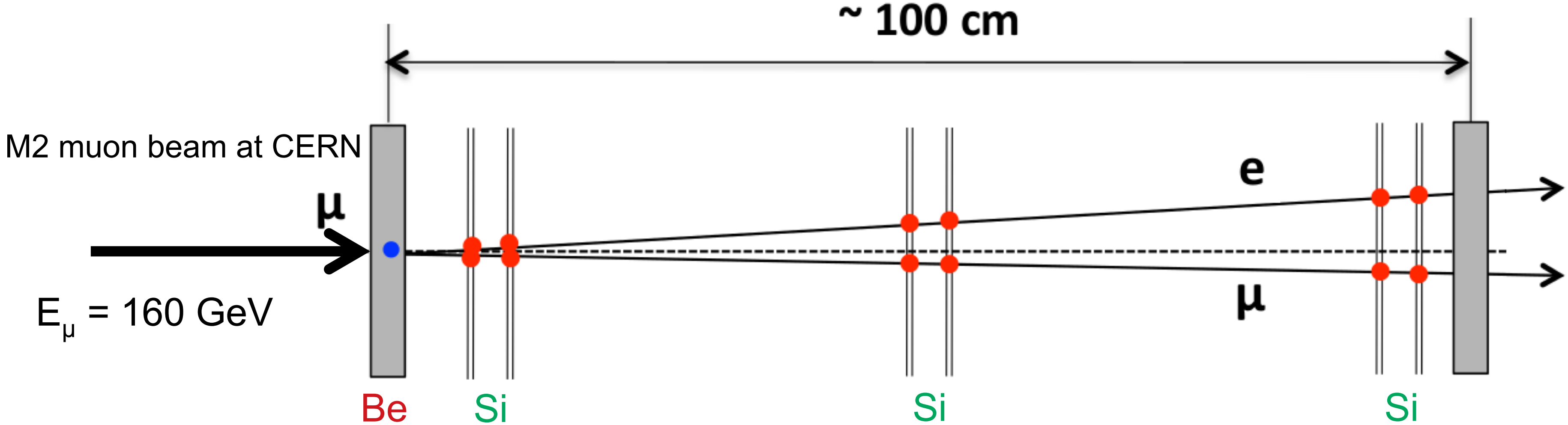
To be measured

- A beam of 160 GeV muons allows to cover the whole a_μ^{HLO}.
- Correlation between muon and electron angles allows to select elastic events and reject background (e^+e^- pair production).
- Boosted kinematics: $\theta_\mu < 5$ mrad, $\theta_e < 32$ mrad.



The experimental apparatus





Beryllium target 1.5 cm thickness

Tracking system: 3 pairs of silicon strip detectors

Achievable accuracy

40 stations + 3 years of data taking ($I_\mu \sim 10^7$ μ/s)

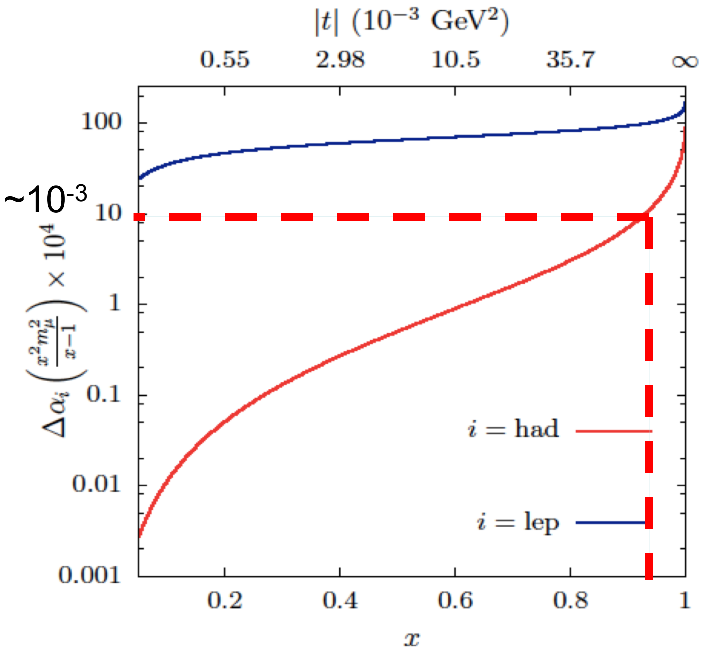
0.3% statistical accuracy on a_μ^{HLO}

Competitive with the time-like accuracy.

The big challenge of the experiment is to reach a comparable systematic accuracy

Systematic uncertainty of 10 ppm at the peak of the integrand function

- Longitudinal alignment (~10 µm)
- Knowledge of the beam energy (few MeV)
- Multiple scattering (~1%)



Last years progress

1. Multiple scattering studies (TB 2017)
2. Test beam at μ beamline (M2) at CERN in 2018
3. Baseline choice of Si detectors (CMS)
4. MC NLO studies
5. LoI at SPSC
6. Test RUN approved for 2021 (→2022)
7. Theory progress towards NNLO MC

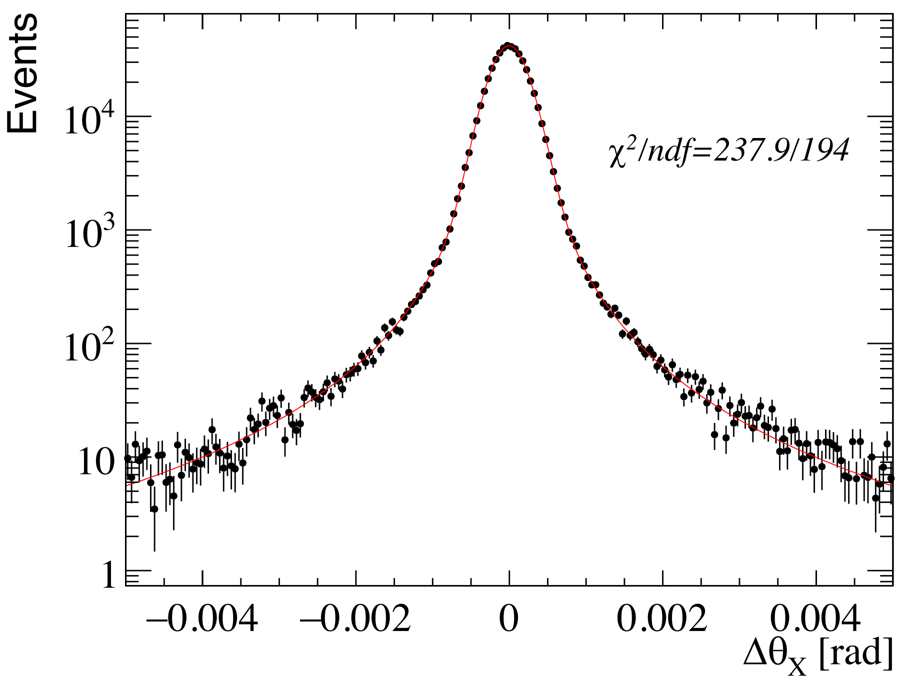
-LoI https://cds.cern.ch/record/2677471/files/SPSC-I-252.pdf arXiv:1905.11677

Results on Multiple Coulomb Scattering from 12 and 20 GeV electrons on Carbon targets (8, 20 mm)

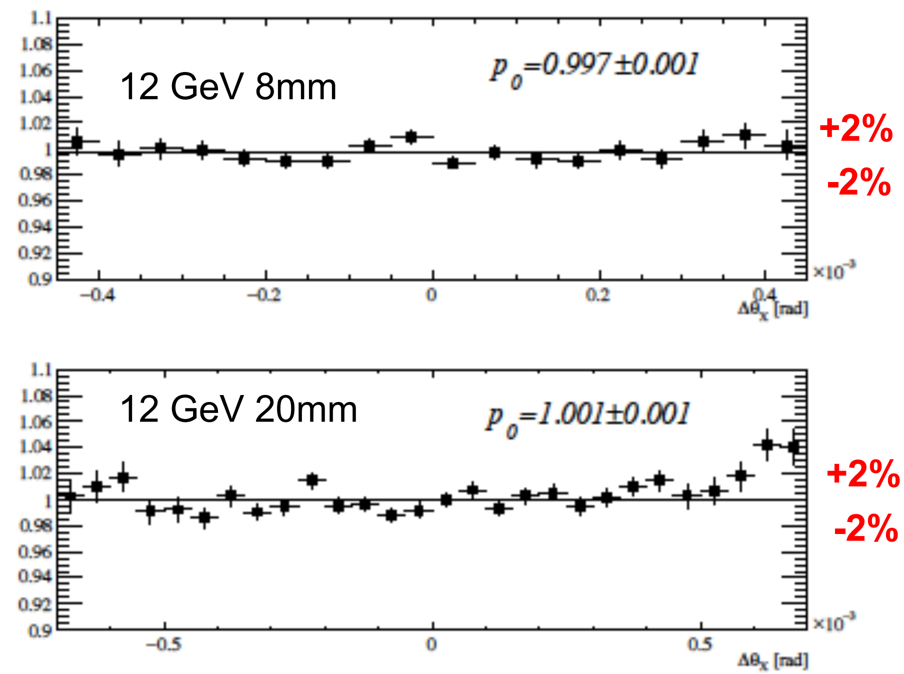
JINST 15 (2020) 01, 01

G. Abbiendi[a], J. Bernhard[b], F. Betti[a,c], M. Bonanomi[d], C. M. Carloni Calame[e], M. Garattini[b,g], Y. Gavrikov[f], G. Hall[g], F. Iacoangeli[h], F. Ignatov[i], M. Incagli[j], V. Ivanchenko[b,k], F. Ligabue[j,l], T. O. James[g], U. Marconi[a], C. Matteuzzi[d], M. Passera[m], M. Pesaresi[g], F. Piccinini[e], R. N. Pilato[j,n], F. Pisani[a,b,c], A. Principe[a,c], W. Scandale[b], R. Tenchini[j], and G. Venanzoni[j,1]

12 GeV 8mm



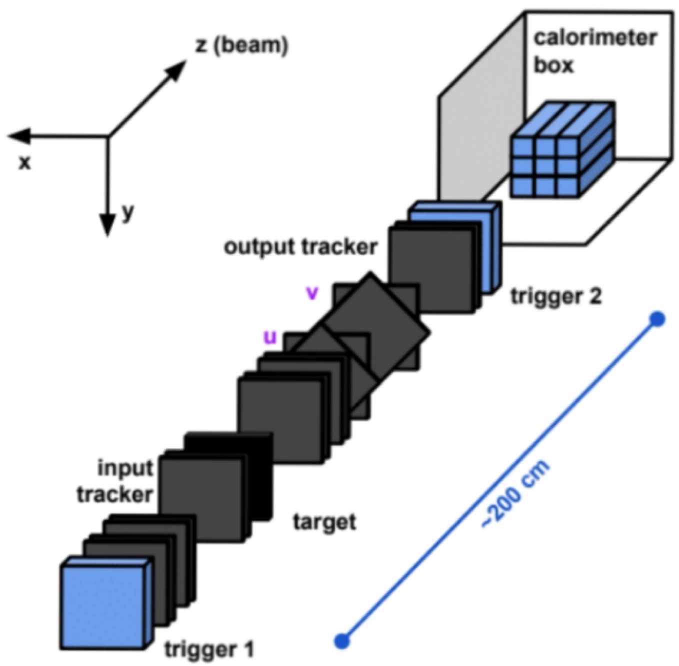
data/MC

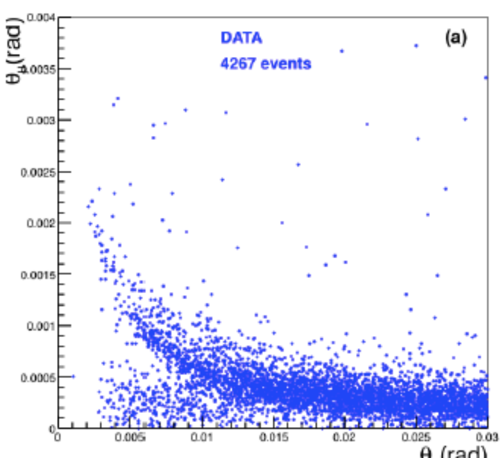


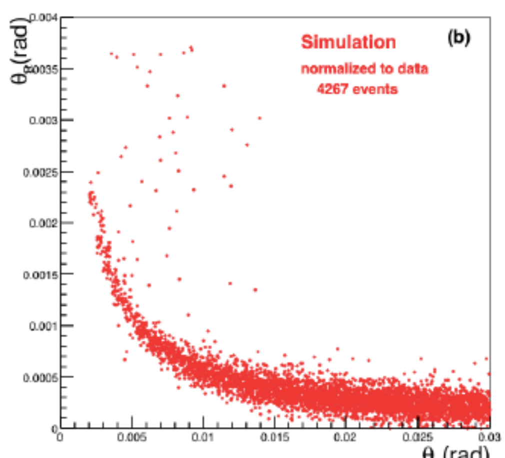
arXiv:2102.11111

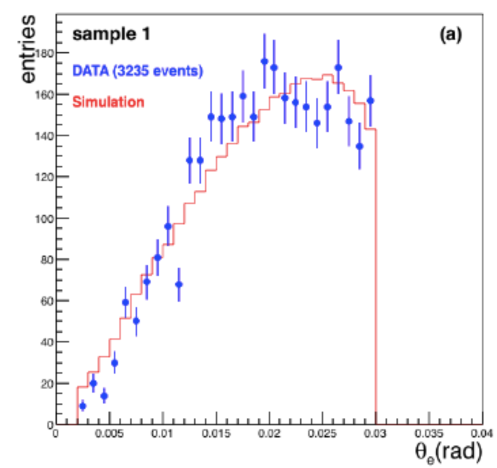
Test beam at M2 in 2018

G. Abbiendi et al JINST 16 (2021) 06, P06005





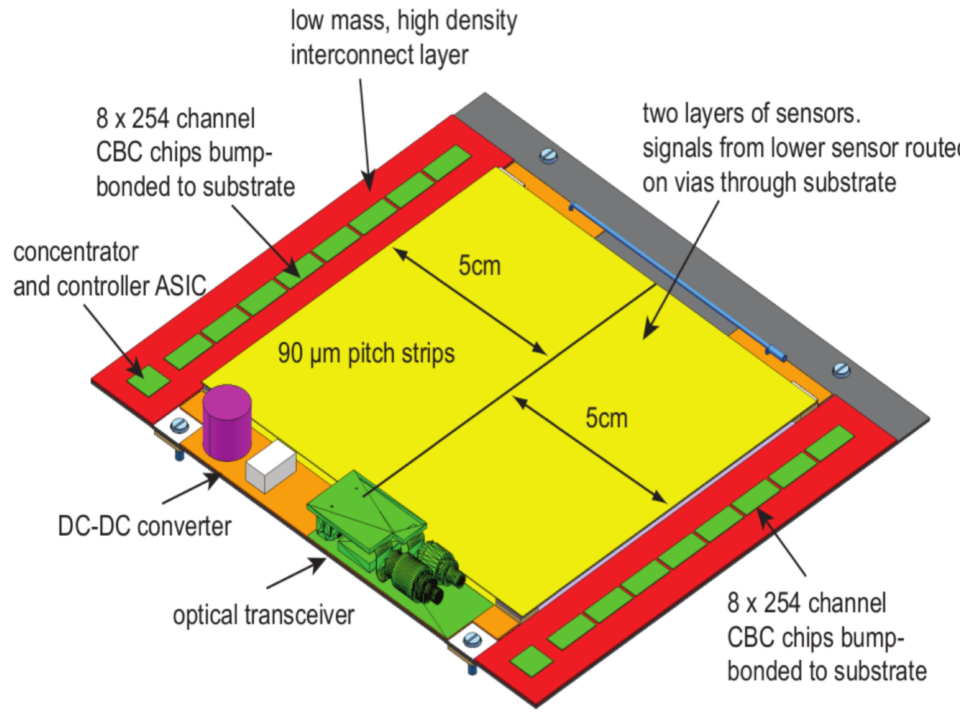




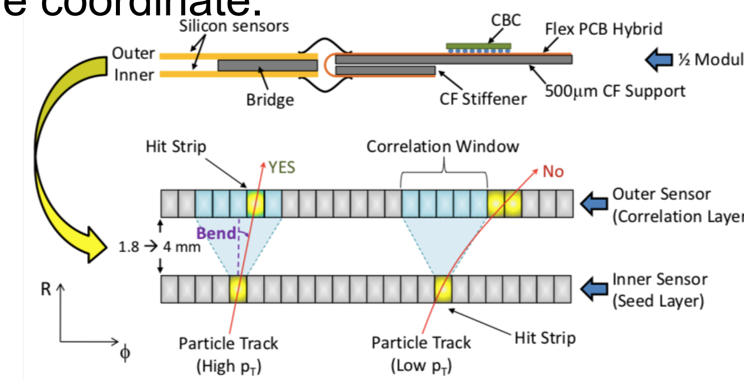
Tracking system: CMS 2S Module (baseline choice)

Requirements:
- Good resolution (~ 20 μm)
- High uniformity ($\varepsilon \gtrsim$ 99.99%)
- Capable to sustain high rate (50 MHz)
- Available technology (test run 2021)

Achievement: CMS 2S Module
- Thickness : 2 × 320 μm
- Pitch: 90 μm → σ_x = 26 μm
- Angular resolution: σ_θ ~ 30 μrad
- Readout rate: 40 MHz
- Area: 10 cm × 10 cm
- Efficiency= 99.988 ± 0.008



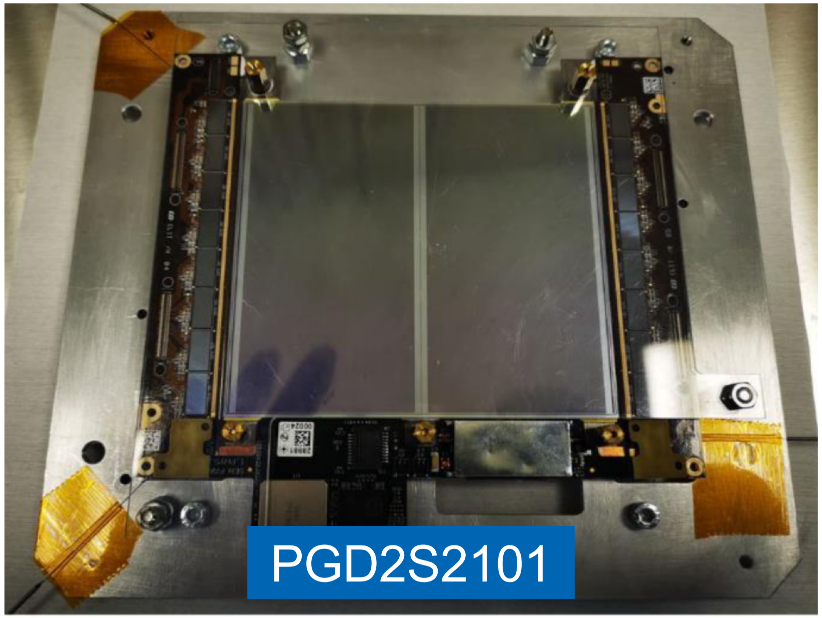
Stub: Two close-by strip sensors reading the same coordinate.



Provide complete and uniform angular acceptance, background suppression from single-sensor hits and rejection of large angle tracks.

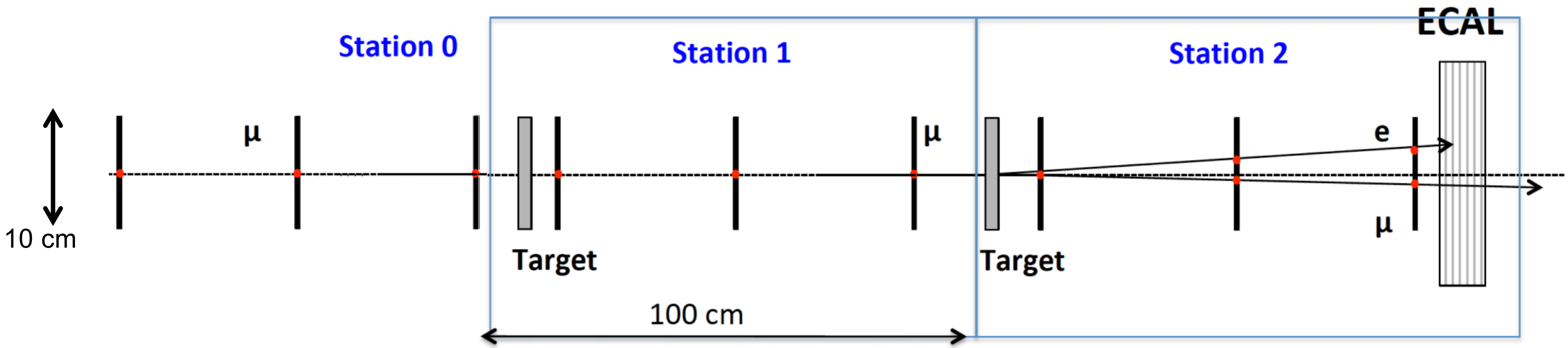
Tracker: CMS 2S modules readiness

- Two dummy 2S modules have been assembled in Perugia.
- Assembly procedure is well defined, metrology measurements meet the CMS quality requirements.
- Ready to build functional 2S modules, as soon as components will be made available by CMS.



Test Run 2021 setup

A Test Run with a reduced detector has been approved by SPSC, to validate our proposal.



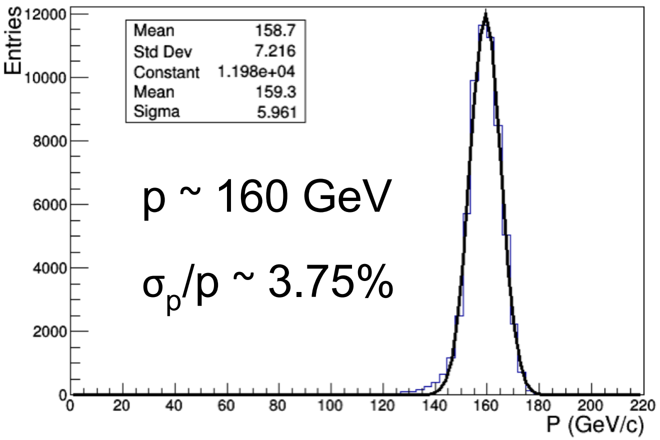
- Pretracker +
- 2 MUonE stations +
- ECAL

Main goals:

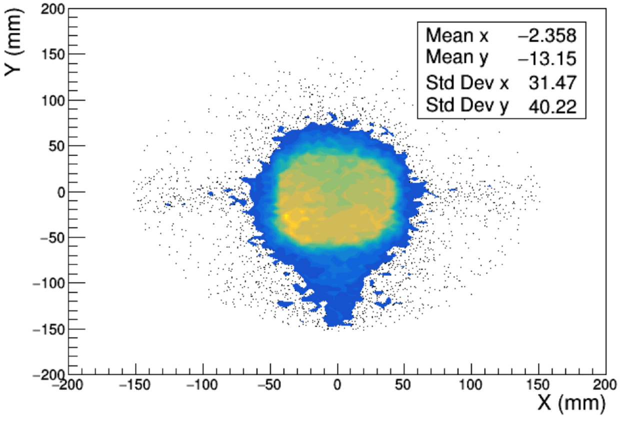
- Confirm the system engineering.
- Monitor mechanical and thermal stability.
- Check the DAQ system.
- Extract $\Delta\alpha_{lep}(t)$.

Location: M2 beam line at CERN

Beam momentum

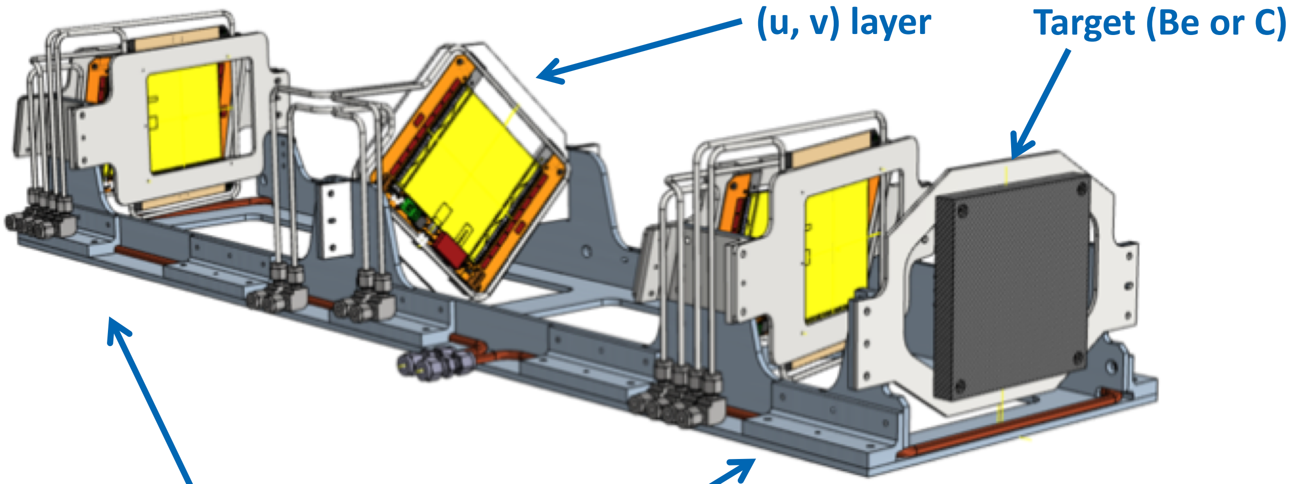


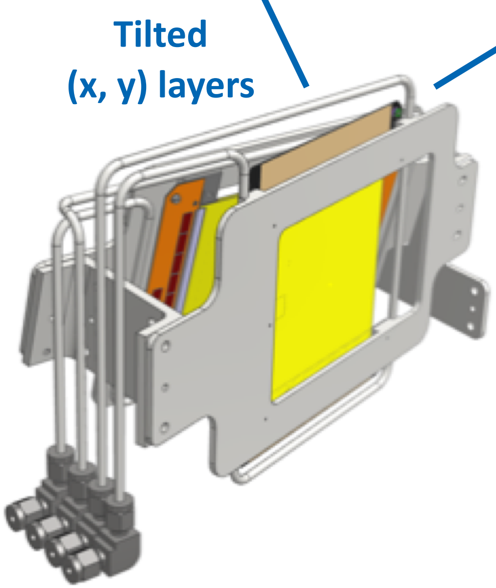
Beam spot: $\sigma_x \sim \sigma_y \sim 2.7$ cm



- Location: upstream the COMPASS detector (CERN North Area).
- Low divergence muon beam: $\sigma_{x'} \sim \sigma_{y'} \sim 0.3$ mrad.
- Spill duration ~ 5 s. Duty cycle ~ 25%.
- Maximum rate: 50 MHz (~ $3\text{x}10^8$ μ^+/spill).

Tracking station





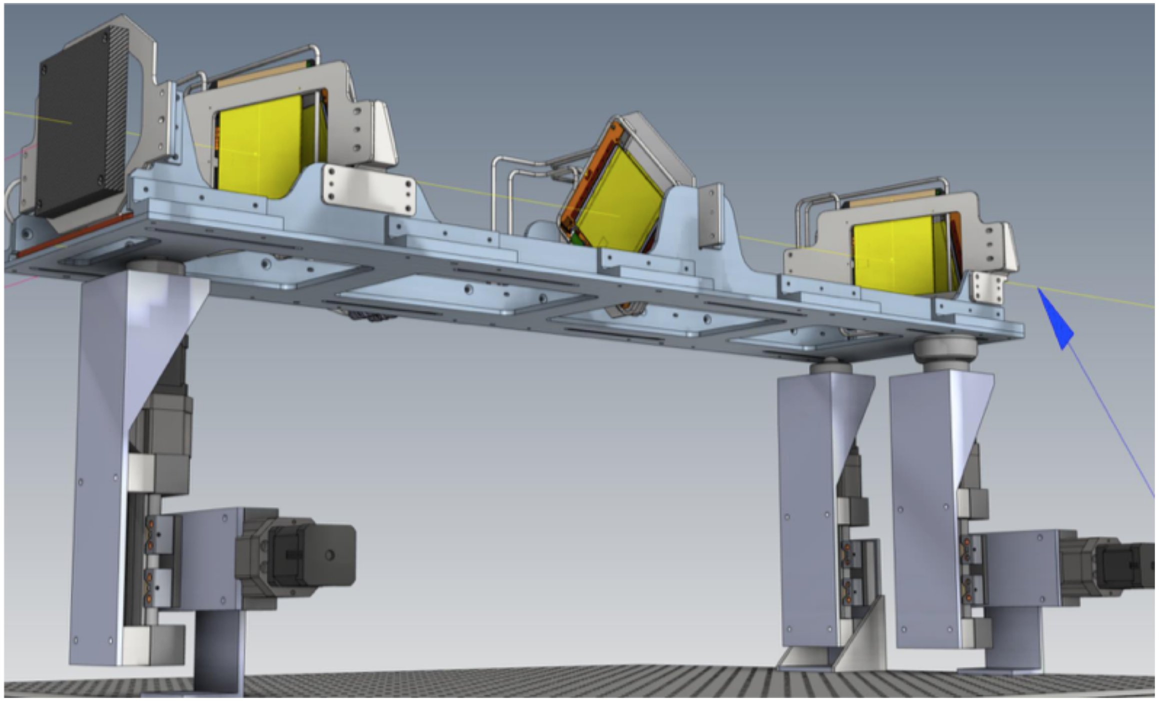
Relative position within a station must be stable at 10 μm.

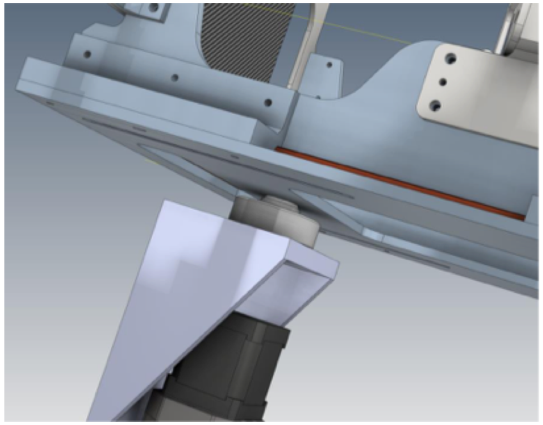
↓

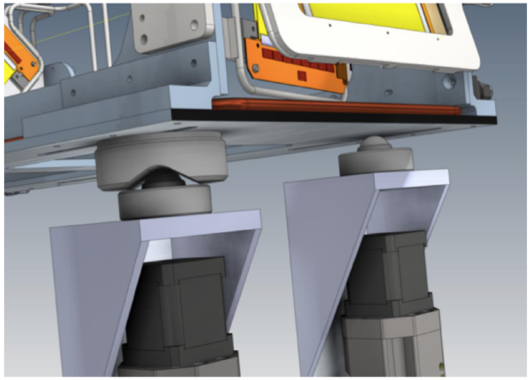
Low CTE mechanical structure: INVAR (alloy of 65%Fe, 35%Ni).

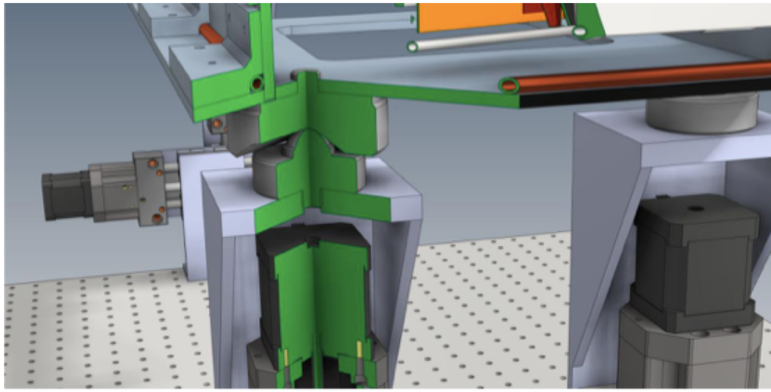
- (x, y) layers tilted by 233 mrad, to improve single hit resolution.
  - Simulation studies show a resolution of ~10 μm.
- (u, v) layers to solve reconstruction ambiguities.

Tracking station







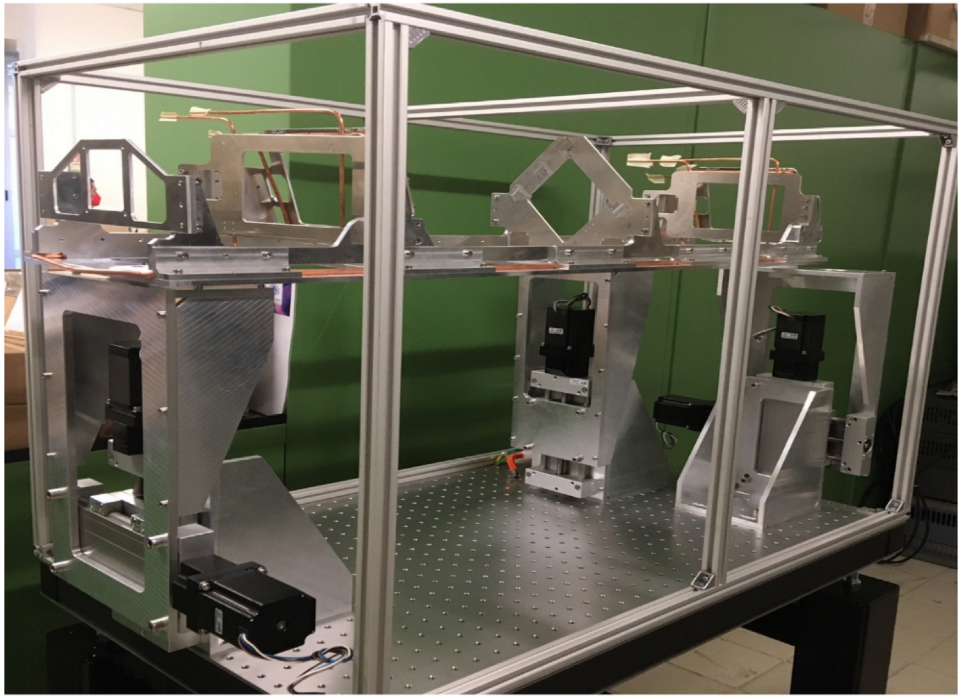


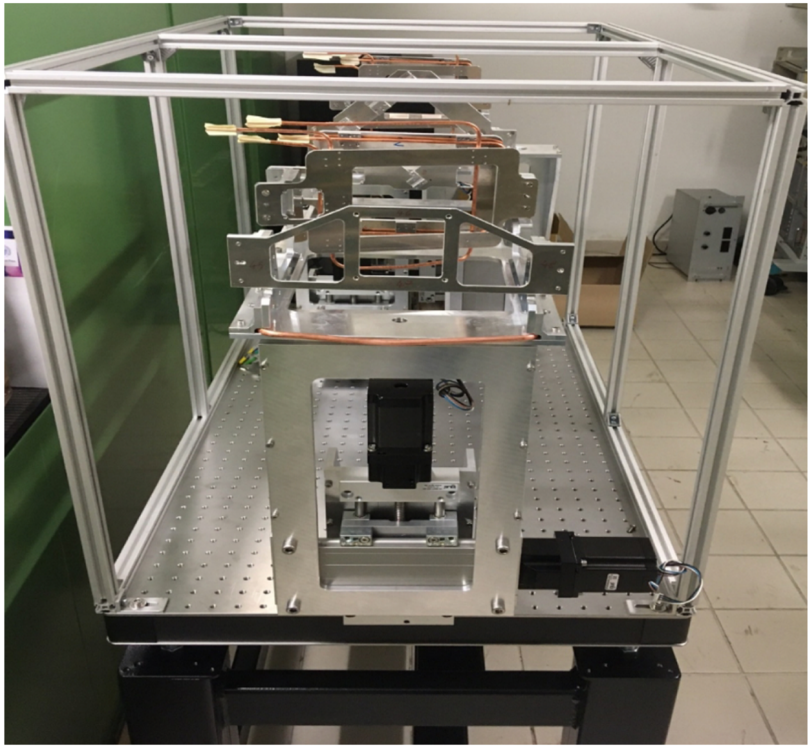
Tracking station

Aluminum mockup ready.

Stepper motors will be used to align the station to the beam.

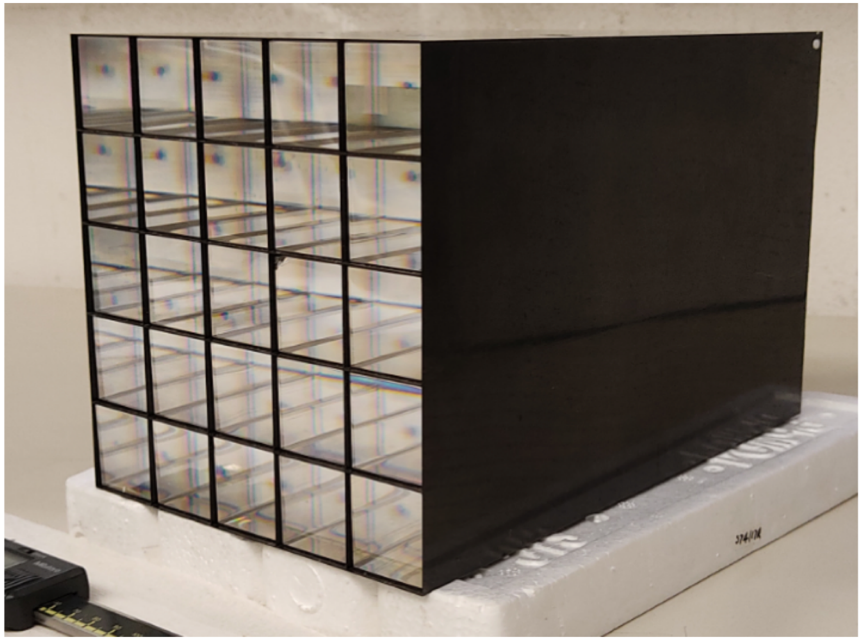
They have been installed and successfully tested in Pisa.





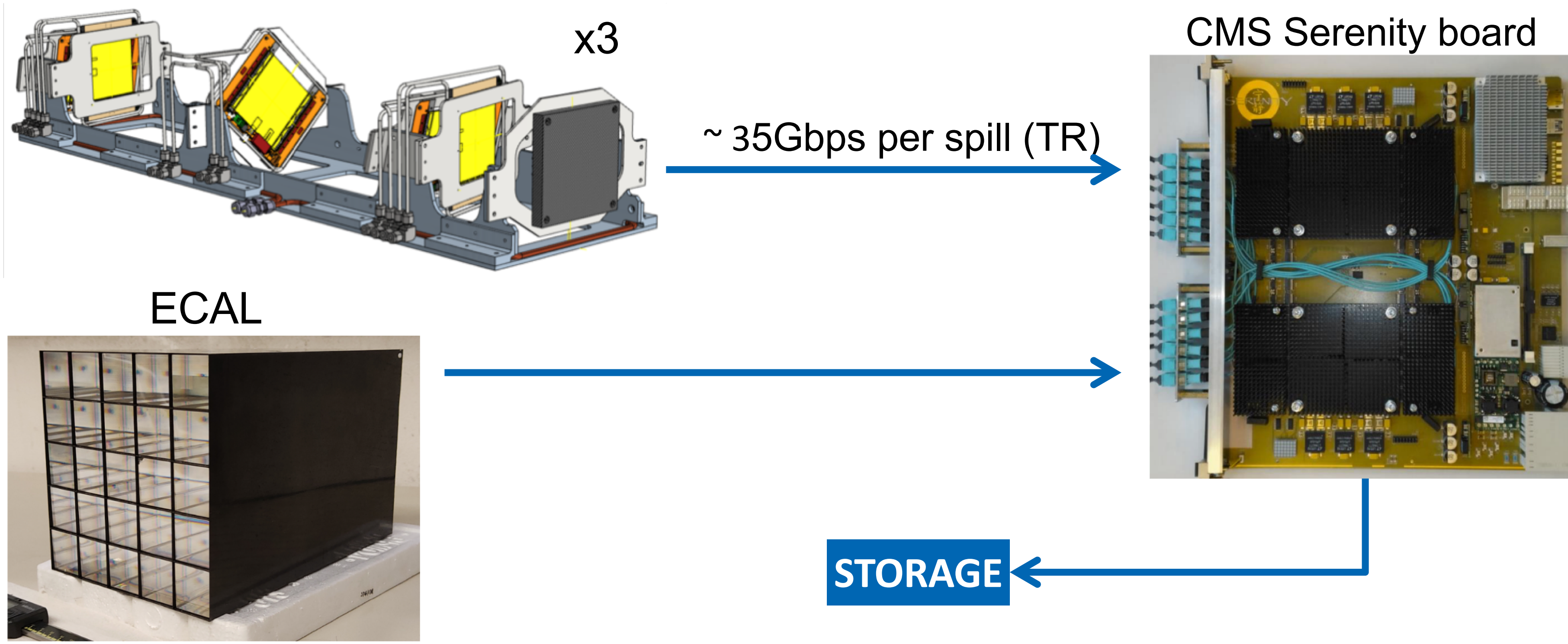
ECAL

- 5x5 $PbWO_4$ crystals (CMS ECAL).
  - 2.85x2.85 cm^2.
  - Length: 22cm (~25 X_0).
- Total area: ~14x14 cm^2.
- Readout: APD sensors, 10x10mm^2 photosensitive area.



Mechanics and crystal tests currently ongoing in Padova.

DAQ system



- Test Run: read all data with no event selection.
- Information will be used to determine online selection algorithms to be used in the Full Run.

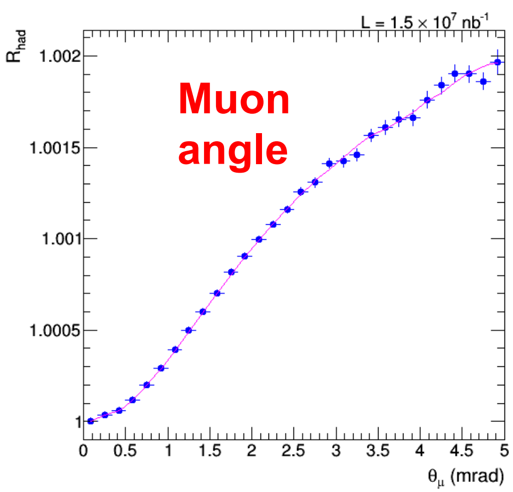
Extraction of a_μ^{HLO}

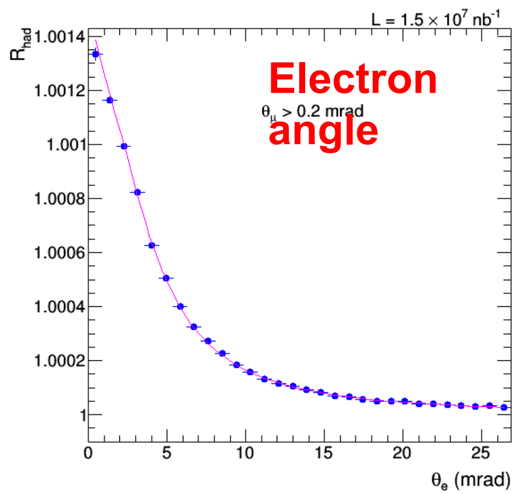
$\Delta\alpha_{had}(t)$ parameterised according to the "Lepton-Like" form.

$$\Delta\alpha_{had}(t) = KM\left\{-\frac{5}{9} - \frac{4}{3}\frac{M}{t} + \left(\frac{4}{3}\frac{M^2}{t^2} + \frac{M}{3t} - \frac{1}{6}\right)\frac{2}{\sqrt{1-\frac{4M}{t}}}\ln\left|\frac{1-\sqrt{1-\frac{4M}{t}}}{1+\sqrt{1-\frac{4M}{t}}}\right|\right\}$$

2-parameters function (K, M)

Template fit to the 2D (θ_e, θ_μ) angular distribution from NLO MC generator with parameterised detector resolution → $\Delta\alpha_{had}(t)$ best fit





$$a_\mu^{HLO} = \frac{\alpha_0}{\pi}\int_0^1 dx(1-x)\Delta\alpha_{had}[t(x)]$$

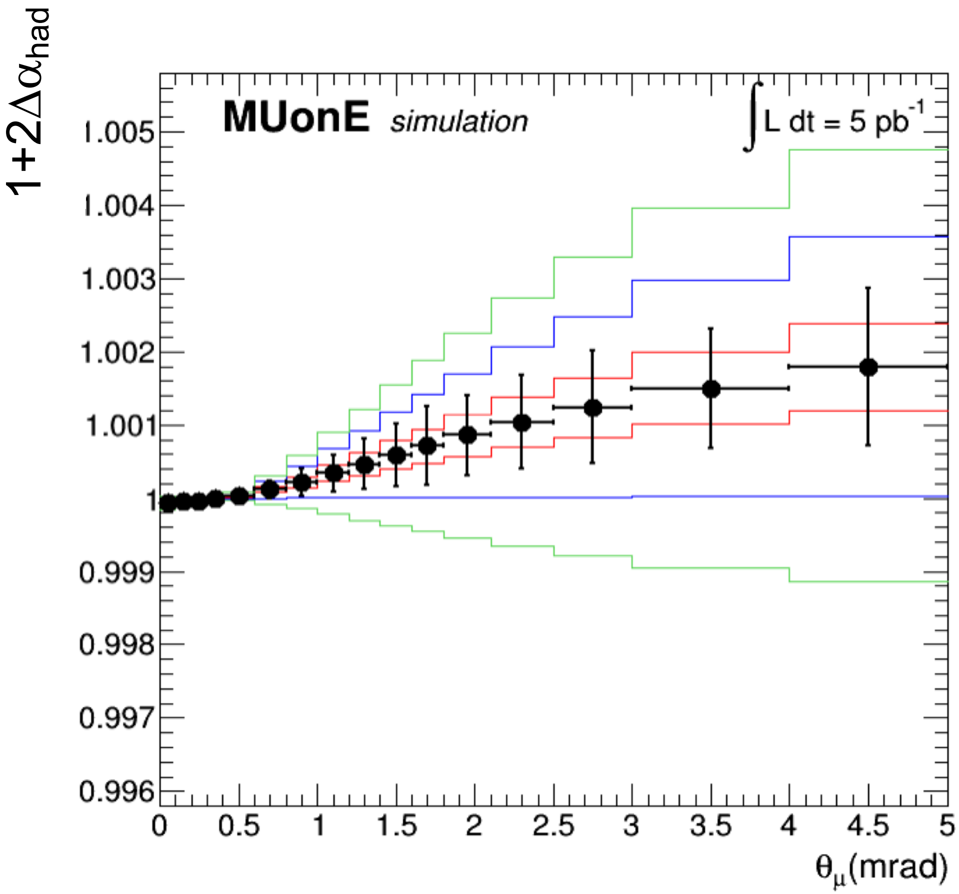
From $\Delta\alpha_{had}(t)$ best fit → **a_μ^{HLO} in the whole range**

a_μ^{HLO} (MUonE) = (688.8 ± 2.4) × 10^{-10} vs 688.6 x10^{-10} (input value)

[full statistics, 1.5 x10^4 pb^{-1} (4x10^{12} evts with E_e>1 GeV)]

Sensitivity to $\Delta\alpha_{had}(t)$ Test RUN

Expected luminosity for the Test Run: L = 5 pb^{-1} ~10^9 events with E_e > 1 GeV (θ_e < 30 mrad)



We will be able to extract the leptonic running ($\Delta\alpha_{lep}$ ~ 10^{-2})

Marginal sensitivity also to the hadronic running ($\Delta\alpha_{had}$ ~ 10^{-3})

$$K = 0.137 \pm 0.027$$

$$\Delta\alpha_{had}(t) \simeq -\frac{1}{15}Kt$$

Template fit with just one fit parameter K= k/M in the $\Delta\alpha_{had}$ parameterization. The other parameter fixed at its expected value: M = 0.0525 GeV^2

Theory

- QED NLO MC generator with full mass dependence has been developed and is currently under use (Pavia group)
- MC with approximate NNLO: MESMER (Pavia) and MCMule (PSI)
- **Huge theoretical activity (***"Theory for muon-electron scattering @ 10ppm",* P.Banerjee et al, Eur.Phys.J.C80(2020)591**):**
- P. Mastrolia, M. Passera, A. Primo, U. Schubert, JHEP 1711 (2017) 198
  S. Di Vita, S. Laporta, P. Mastrolia, A. Primo, U. Schubert, JHEP 1809 (2018) 016
  M. Alacevich et al, JHEP 02 (2019) 155
  M. Fael, JHEP 1902 (2019) 027
  M. Fael, M. Passera, PRL 122 (2019) 192001
  A. Masiero, P. Paradisi, M. Passera, PRD 102 (2020) 075013
  P. Banerjee et al, EPJC 80 (2020) 591C
  M. Carloni Calame, et al, JHEP 11 (2020) 028
  P. Banerjee, T. Engel, A. Signer, Y. Ulrich, SciPost Phys 9 (2020) 02
  R. Bonciani et al, arXiv:2106.13179

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

being formed, still growing up

CERN
Exp

INFN +Univ. (Bologna, Milano-Bicocca, Padova, Pavia, Perugia, Pisa, Trieste)
Exp-Th

Imperial College (London), Liverpool U.
Exp-Th

Krakow IFJ Pan
Exp

Northwestern U., Virginia U.
Exp

Budker Inst. (Novosibirsk)
Exp

The MUonE Collaboration

Demokritos INPP (Athens)
Exp

Shanghai Jiao Tong U.
Exp

PSI (Villigen), ETH and U.Zürich
Th

+ other involved theorists from: U.Valencia (E), KIT/Karlsruhe (D), New York City Tech (USA)

Conclusions (MUonE)

- The new method proposed by MUonE to determine a_μ^{HLO} is independent and competitive (~0.3% stat error) with the latest evaluations.

- A Test Run of 3 weeks is foreseen at CERN in Fall 2021-early 2022. The aim of the Test Run will be to verify the detector design and evaluate the analysis strategy.

- If the Test Run will confirm the goodness of our proposal, a Run with the full detector is envisaged in 2022-24.

https://web.infn.it/MUonE/

Working Group on Rad. Corrections and MC Generators for Low Energies

- Meetings with theorists and experimentalists sitting together.
- An informal room and a valuable platform to exchange ideas, enriched of new subjects (and people) during the years
- First meeting in Oct 2006. 20 meetings since then. More than 60 participants from more than 10 different countries
- 2 WG coordinators (H. Czyz, G. Venanzoni)
- 7 Subgroups
- A first report in 2010. Maybe an update is needed?

Web page: http://www.lnf.infn.it/wg/sighad/

www.lnf.infn.it/wg/sighad/

Working Group on Rad. Corrections and MC Generators for Low Energies

Home

Report

Working List

NEW Meetings

Monte Carlo Codes

Comparisons between Generators and num. Codes

Participants

Links

Working Group on Rad. Corrections and MC Generators for Low Energies

The aim of this Working Group is to bring together theorists and experimentalists in order to discuss the current status of radiative corrections and Monte Carlo generators at low energies. These radiative corrections and MC generators are crucial for the measurement of the R-ratio (both with ISR and energy scan), as well as the determination of luminosity.

The twentieth meeting took place at the Budker Institute of Nuclear Physics in Novosibirsk on Saturday March 2 2019 as satellite of the PHIPSI19 Workshop.

The nineteenth meeting took place in Mainz in the Institute for Nuclear Physics of Mainz on Friday 30 June 2017 as satellite of the PHIPSI17 Workshop.

The eighteenth meeting took place in Frascati, on May 19/20 2016.

The seventeenth meeting took place in Frascati, on April 20/21 2015.

The sixteenth meeting took place in Frascati, on November 18/19 2014.

The fifteenth meeting took place in Mainz, on April 11 2014.

The fourteenth meeting took place in Frascati, on September 13 2013, as a satellite meeting of the PHIPSI13 conference in Rome.

Radio MonteCarlow WG page: www.lnf.infn.it/wg/sighad

The Subjects covered:

- Monte Carlo generators for Luminosity
- Monte Carlo generators for e+e- into hadrons and leptons
- Monte Carlo generators for e+e- into hadrons and leptons plus photon (ISR)
- Monte Carlo generators for τ production and decays
- Hadronic Vacuum Polarization, $\Delta\alpha_{em}(Z0)$ and $(g-2)_{\mu}$
- Gamma-gamma physics
- FSR models and Transition Form Factors

Each of them has 2 convenors

People involved

RADIO MONTECARLOW

Not updated list

Aachen: Actis, Czakon
Beijing: Shen, Wang, Yuan, Zhang
Berlin: Jegerlehner
Bologna: Caffo, Remiddi
CERN: Beltrame, Mastrolia
Cracov: Grzelińska, Jadach, Przedzinski, Wąs
Dubna: Arbuzov, Kuraev
Edmonton: Penin
Frascati: Isidori, Pacetti, Pancheri, Shekhovtsova,Venanzoni
Freiburg: van der Bij
Karlsruhe: Kluge, Kühn,
Katowice: Czyż, Gluza, Kołodziej
Kharkov: Korchin
Mainz: Denig, Ferroglia, Hafner, Mueller
Moscow: Pakhlova
Novosibirsk: Cherepanov, Eidelman, Fedotovich, Sibidanov, Solodov
Palaiseau: Kalinowski
Padova: Passera
Parma: Trentadue
Pavia: Montagna, Nicrosini, Piccinini
Rome: Baldini, Bini, Greco, Nguyen
Southampton: Carloni-Calame
Valencia: Rodrigo, Roig
Wuppertal: Worek
Zeuthen: Riemann

Experiments involved

RADIO MONTECARLOW

Not exaustive list

BaBar

BELLE

BES-III

CMD2

KLOE

SND

MC generators

RADIO MONTECARLOW

Not exaustive list

BABAYAGA

KKMC

MCGPJ

PHOKHARA

PHOTOS

TAUOLA

EKHARA

Radiative Corrections for ISR

Radiator-Function $H(s,s_p)$ (ISR):

- ISR-Process calculated at NLO-level

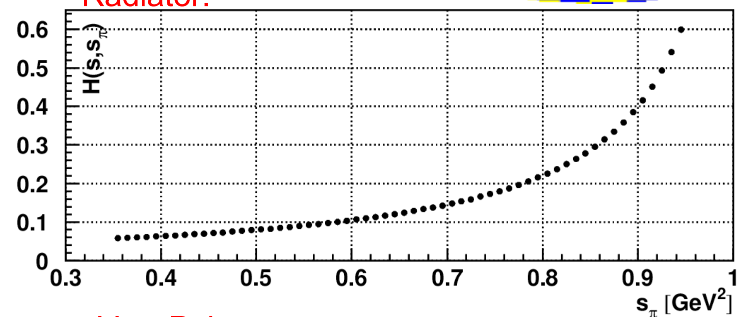
PHOKHARA generator

(H.Czyż, A.Grzelińska, J.H.Kühn, G.Rodrigo, EPJC27,2003)

Precision: *0.5%*

$$s \cdot \frac{d\sigma_{\pi\pi\gamma}}{ds_\pi} = \sigma_{\pi\pi}(s_\pi) \times H(s,s_\pi)$$

Radiator:



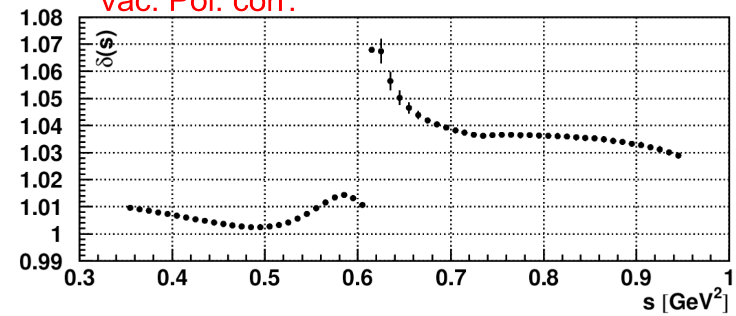
Radiative Corrections:

i) Bare Cross Section

divide by Vacuum Polarisation $d(s)=(a(s)/a(0))^2$

➔ from F. Jegerlehner

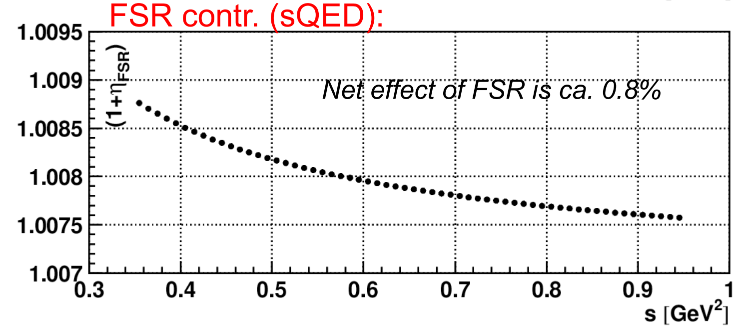
Vac. Pol. corr:



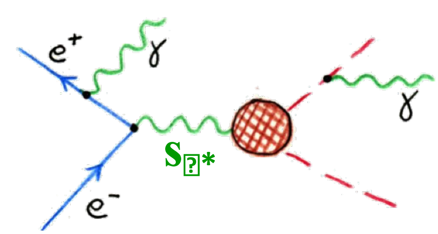
ii) FSR

Cross section s_{pp} must be incl. for FSR for use in the dispersion integral of a_m

FSR contr. (sQED):



FSR corrections have to be taken into account in the efficiency eval. (Acceptance, M_{Trk}) and in the mapping $s_\pi \rightarrow s_{\gamma*}$



$s_{?*} > s_p$

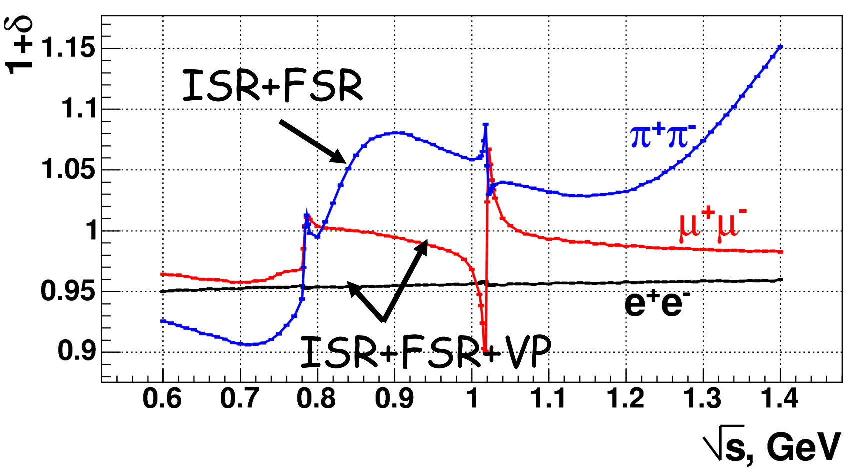
(H.Czyż, A.Grzelińska, J.H.Kühn, G.Rodrigo, EPJC33,2004)

Radiative corrections for **energy scan**:

All modes except 2π

$$\sigma\left(e^+e^- \to H\right) = \frac{N_H - N_{bg}}{L \cdot \varepsilon \cdot (1+\delta)}$$

- Luminosity L is measured using Bhabha scattering at large angles
- Efficiency ε is calculated via Monte Carlo + corrections for imperfect detector
- Radiative correction δ accounts for ISR effects only



2π

$$\left|F_\pi\right|^2 = \frac{N_{2\pi}}{N_{ee}} \cdot \frac{\sigma_{ee} \cdot (1+\delta_{ee})}{\sigma_{2\pi}(\text{point-like } \pi) \cdot (1+\delta_{2\pi})}$$

- Ratio N(2π)/N(ee) is measured directly ⇒ detector inefficiencies are cancelled out
- Virtually no background
- Analysis does not rely on simulation
- Radiative corrections account for ISR and FSR effects
- Formfactor is measured to better precision than L

Report from RMCWG: a common effort for RC and Monte Carlo tools

RADIO MONTECARLOW

Eur. Phys. J. C (2010) 66: 585–686
DOI 10.1140/epjc/s10052-010-1251-4

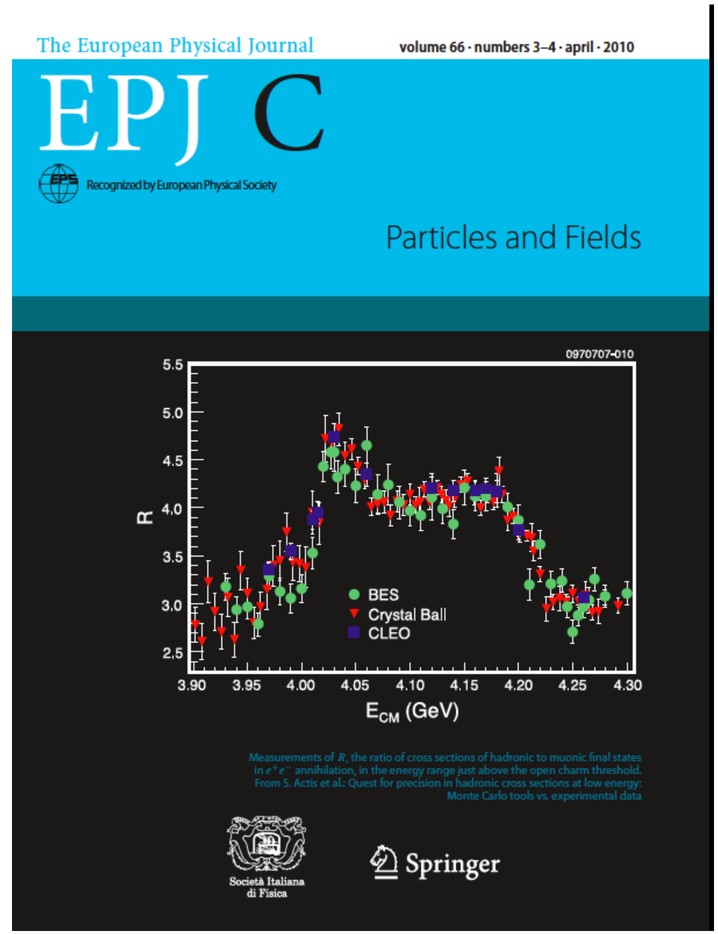
THE EUROPEAN PHYSICAL JOURNAL C

Review

Quest for precision in hadronic cross sections at low energy: Monte Carlo tools vs. experimental data

Working Group on Radiative Corrections and Monte Carlo Generators for Low Energies

S. Actis[38], A. Arbuzov[9,e], G. Balossini[32,33], P. Beltrame[13], C. Bignamini[32,33], R. Bonciani[15], C.M. Carloni Calame[35], V. Cherepanov[25,26], M. Czakon[1], H. Czyż[19,a,f,i], A. Denig[22], S. Eidelman[25,26,g], G.V. Fedotovich[25,26,e], A. Ferroglia[23], J. Gluza[19], A. Grzelińska[8], M. Gunia[19], A. Hafner[22], F. Ignatov[25], S. Jadach[8], F. Jegerlehner[3,19,41], A. Kalinowski[29], W. Kluge[17], A. Korchin[20], J.H. Kühn[18], E.A. Kuraev[9], P. Lukin[25], P. Mastrolia[14], G. Montagna[32,33,b,d], S.E. Müller[22,f], F. Nguyen[34,d], O. Nicrosini[33], D. Nomura[36,h], G. Pakhlova[24], G. Pancheri[11], M. Passera[28], A. Penin[10], F. Piccinini[33], W. Płaczek[7], T. Przedzinski[6], E. Remiddi[4,5], T. Riemann[41], G. Rodrigo[37], P. Roig[27], O. Shekhovtsova[11], C.P. Shen[16], A.L. Sibidanov[25], T. Teubner[21,h], L. Trentadue[30,31], G. Venanzoni[11,c,i], J.J. van der Bij[12], P. Wang[2], B.F.L. Ward[39], Z. Was[8,g], M. Worek[40,19], C.Z. Yuan[2]



Eur. Phys. J. C. Volume 66, Issue 3 (2010), Page 585

RMCWG Report

RADIO MONTECARLOW

Received: 3 December 2009 / Published online: 23 February 2010
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Abstract We present the achievements of the last years of the experimental and theoretical groups working on hadronic cross section measurements at the low-energy e^+e^- colliders in Beijing, Frascati, Ithaca, Novosibirsk, Stanford and Tsukuba and on τ decays. We sketch the prospects in these fields for the years to come. We emphasise the status and the precision of the Monte Carlo generators used to analyse the hadronic cross section measurements obtained as well with energy scans as with radiative return, to determine luminosities and τ decays. The radiative corrections fully or approximately implemented in the various codes and the contribution of the vacuum polarisation are discussed.

Contents

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[d] Section 2 conveners.
[e] Section 3 conveners.
[f] Section 4 conveners.
[g] Section 5 conveners.
[h] Section 6 conveners.
[i] Working group conveners.

1 Introduction

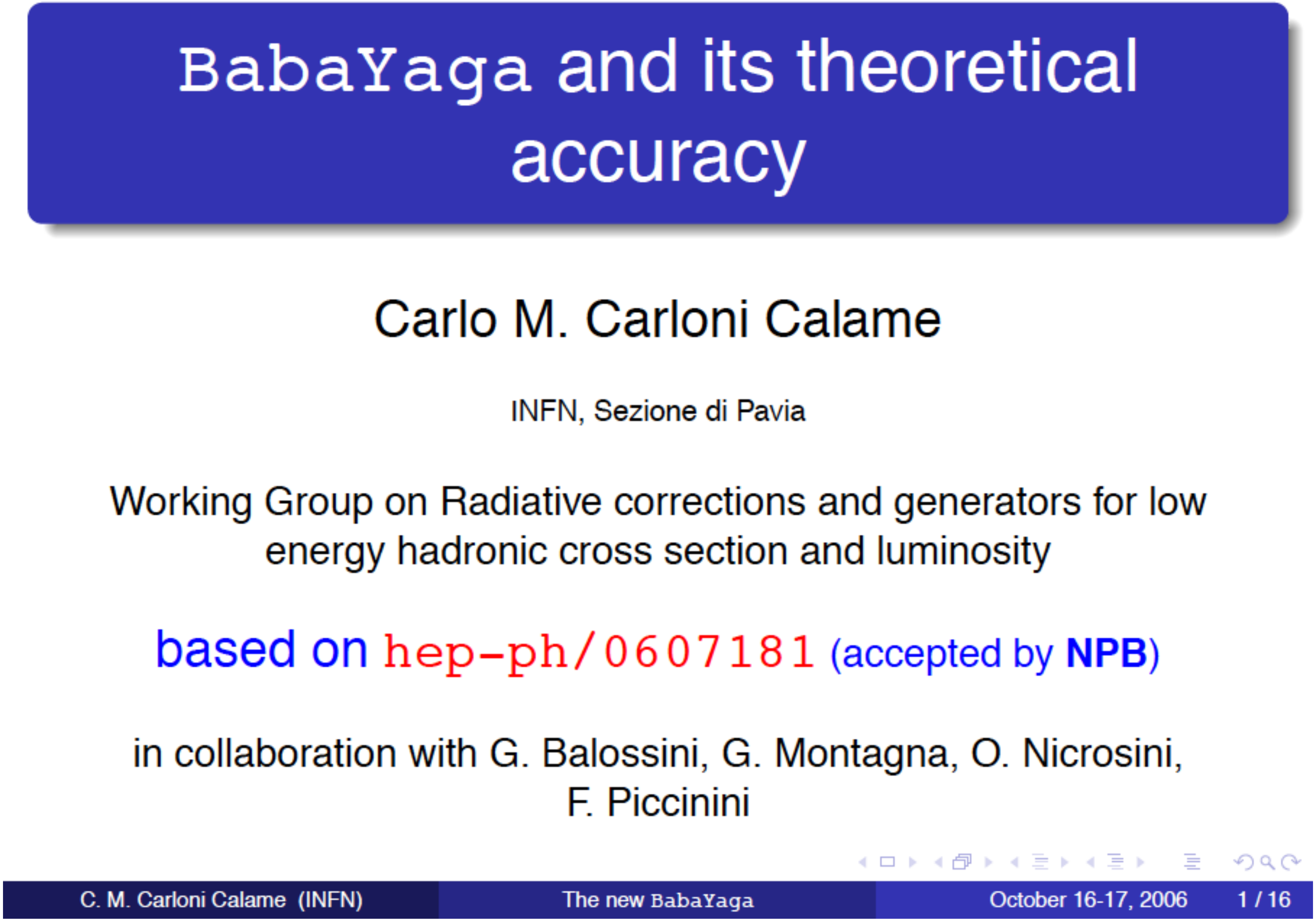
The systematic comparison of Standard Model (SM) predictions with precise experimental data served in the last decades as an invaluable tool to test the theory at the quantum level. It has also provided stringent constraints on "new physics" scenarios. The (so far) remarkable agreement between the measurements of the electroweak observables and their SM predictions is a striking experimental confirmation of the theory, even if there are a few observables where the agreement is not so satisfactory. On the other hand, the Higgs boson has not yet been observed, and there are clear phenomenological facts (dark matter, matter-antimatter asymmetry in the universe) as well as strong theoretical arguments hinting at the presence of physics beyond

Eur. Phys. J. C. Vol. 66, Issue 3 (2010), Page 585

"Tuned" comparisons are essential!

Theoretical accuracies of these generators were estimated, whenever possible, by evaluating missing higher-order contributions. From this point of view, the great progress in the calculation of two-loop corrections to the Bhabha scattering cross section was essential to establish the high theoretical accuracy of the existing generators for the luminosity measurement. However, usually only analytical or semi-analytical estimates of missing terms exist which don't take into account realistic experimental cuts. In addition, MC event generators include different parameterisations for the VP which affect the prediction (and the precision) of the cross sections and also the RC are usually implemented differently.

Example:


BabaYaga and its theoretical accuracy
Carlo M. Carloni Calame
INFN, Sezione di Pavia
Working Group on Radiative corrections and generators for low energy hadronic cross section and luminosity
based on hep-ph/0607181 (accepted by NPB)
in collaboration with G. Balossini, G. Montagna, O. Nicrosini, F. Piccinini
C. M. Carloni Calame (INFN)
The new BabaYaga
October 16-17, 2006
1 / 16

Estimate of the theoretical accuracy

- switching off VP, tuned comparisons with independent calculations/approaches (Labspv, Bhwide)
  - ⋆ $\Delta\sigma/\sigma < 0.03\%$ on cross sections
  - ⋆ up-to-0.5% differences between BabaYaga and Bhwide in distribution tails
- comparison with existing perturbative 2-loop calculations
  - ⋆ currently available
    1. Penin: complete virtual 2-loop photonic corrections (for $Q^2 \gg m_e^2$) plus real radiation in the soft limit
    2. Bonciani et al.: virtual $N_F = 1$ [only electron in the loops] fermionic contributions plus real radiation in the soft limit
  - ⋆ the photonic and $N_F = 1$ $\mathcal{O}(\alpha^2)$ content of the S+V part in the BabaYaga matched formula can be easily extracted. The terms to be directely compared to 1. and 2. can be read out!
  - ⋆ the impact of the missing $\mathcal{O}(\alpha^2)$ S+V corrections can be quantified within realistic setup

Higher order QED radiative corrections to Bhabha scattering

Andrej Arbuzov

Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna, Russia

Talk at the Radio MontecarLow workshop, Frascati, 6–7th April 2009

Studies on accuracy of the contributions from pair production in Babayaga generator - a status report

Michal Gunia

Working Group 'Radio Monte CarLow', Frascati

28 March 2011

Table of contents

Cuts dependence study for different experiments

1.Φ factories KLOE/DAΦNE (Frascati)

(a) $\sqrt{s} = 1.02$ GeV
(b) $E_{min} = 0.4$ GeV
(c) For $\theta\pm$ two selections have to be checked
i. tighter selection $55^{\circ} < \theta\pm < 125^{\circ}$
ii. wider selection $20^{\circ} < \theta\pm < 160^{\circ}$
(d) ζ_{max}=4,5,6,7,8,...,14°, with reference value ζ_{max}=9°

2. B-factories BABAR/PEP-II (SLAC) & BELLE/KEKB (KEK)

(a) $\sqrt{s} = 10.56$ GeV
(b) $|\vec{p}_{+}|/E_{beam} > 0.75$ and $|\vec{p}_{-}|/E_{beam} > 0.50$
or $|\vec{p}_{-}|/E_{beam} > 0.75$ and $|\vec{p}_{+}|/E_{beam} > 0.50$
(c) For $|cos(\theta\pm)|$ the following selections have to be checked
i. $|cos(\theta\pm)| < 0.65$ and $|cos(\theta+)| < 0.60$ or $|cos(\theta-)| < 0.60$
ii. $|cos(\theta\pm)| < 0.70$ and $|cos(\theta+)| < 0.65$ or $|cos(\theta-)| < 0.65$
iii. $|cos(\theta\pm)| < 0.60$ and $|cos(\theta+)| < 0.55$ or $|cos(\theta-)| < 0.55$
(d) ζ^{3d}_{max}= 20,22,24,...,40°, with reference value ζ^{3d}_{max}=30°

Issues to be discussed here

Comparison of results with vacuum polarization obtained using :VPHLMNT (T.Teubner et all.) and hadr5n09 (F. Jegerlehner) (all results from BabaYaga) - all results in nb

KLOE: $55^\circ < \theta\pm < 125\ ^\circ$, $\zeta_{max}=4^\circ$
σ_{BY} **=436.85(5)**

vacpol	σ_h	σ_{v+s}	sum:
VPHLMNT(2009)	1.4346(5)	-1.126(2)	0.309(2)
hadr5n09	1.6264(6)	-1.405(2)	0.221(2)
relative difference: $\left\lvert\frac{\sigma^{NNLO}_{VPHLMNT}-\sigma^{NNLO}_{hadr5n09}}{\sigma_{BY}}\right\rvert$			0.201(6)‰

BES: $\sqrt{s} = 3.650$ GeV, $|\cos\theta| < 0.8$
σ_{BY} **= 116.41(2) nb**

vacpol	σ_h	σ_{v+s}	sum:
VPHLMNT2.0(2010)	1.6613(3)	-1.7860(2)	-0.1247(4)
hadr5n09	1.6471(7)	-1.7686(2)	-0.1215(7)
relative difference: $\left\lvert\frac{\sigma^{NNLO}_{VPHLMNT}-\sigma^{NNLO}_{hadr5n09}}{\sigma_{BY}}\right\rvert$			0.0275‰

Issues to be discussed here

BES: $\sqrt{s} = 3.686$ GeV, $|\cos\theta| < 0.8$
σ_{BY} **= 114.27(2) nb**

vacpol	σ_h	σ_{v+s}	sum:
VPHLMNT2.0(2010)	10.006(4)	-16.80(1)	-6.79(1)
hadr5n09	9.60(1)	-16.28(2)	-6.68(3)
relative difference: $\left\|\frac{\sigma^{NNLO}_{VPHLMNT} - \sigma^{NNLO}_{hadr5n09}}{\sigma_{BY}}\right\|$			0.96‰

BES: $\sqrt{s} = 3.097$ GeV, $|\cos\theta| < 0.9$
σ_{BY} **= 378.48(5) nb**

vacpol	σ_h	σ_{v+s}	sum:
VPHLMNT2.0(2010)	-116.50(6)	287.7(3)	171.2(3)
hadr5n09	-119.1(2)	291.9(3)	172.8(4)
relative difference: $\left\|\frac{\sigma^{NNLO}_{VPHLMNT} - \sigma^{NNLO}_{hadr5n09}}{\sigma_{BY}}\right\|$			4.227‰

Systematic treatment of second order NLO QED radiative corrections to exclusive observables

Andrej Arbuzov

Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna, Russia

Talk at the Radio MontecarLow workshop, Frascati, 11th April 2008

MCGPJ: A. Arbuzov

Outlook

- The ansatz for the treatment of $\mathcal{O}\left(\alpha^2 L^1\right)$ QED radiative corrections to exclusive observables is described
- The ansatz is suited for MC simulations
- Many processes can be treated in this way
- $\mathcal{O}\left(\alpha^2 L^0\right)$ contributions can be put into the same structure
- MCGPJ can be upgraded
- MC integrator and generator for Bhabha scattering is under development (upgrade of SAMBHA MC)

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Status of MC generators for radiative return

H. CZYŻ, IF, UŚ, Katowice FRASCATI 2006

Motivation - what is the radiative return

What do we have on the market

Tests - comparisons, which were performed

My wish list

KKMC

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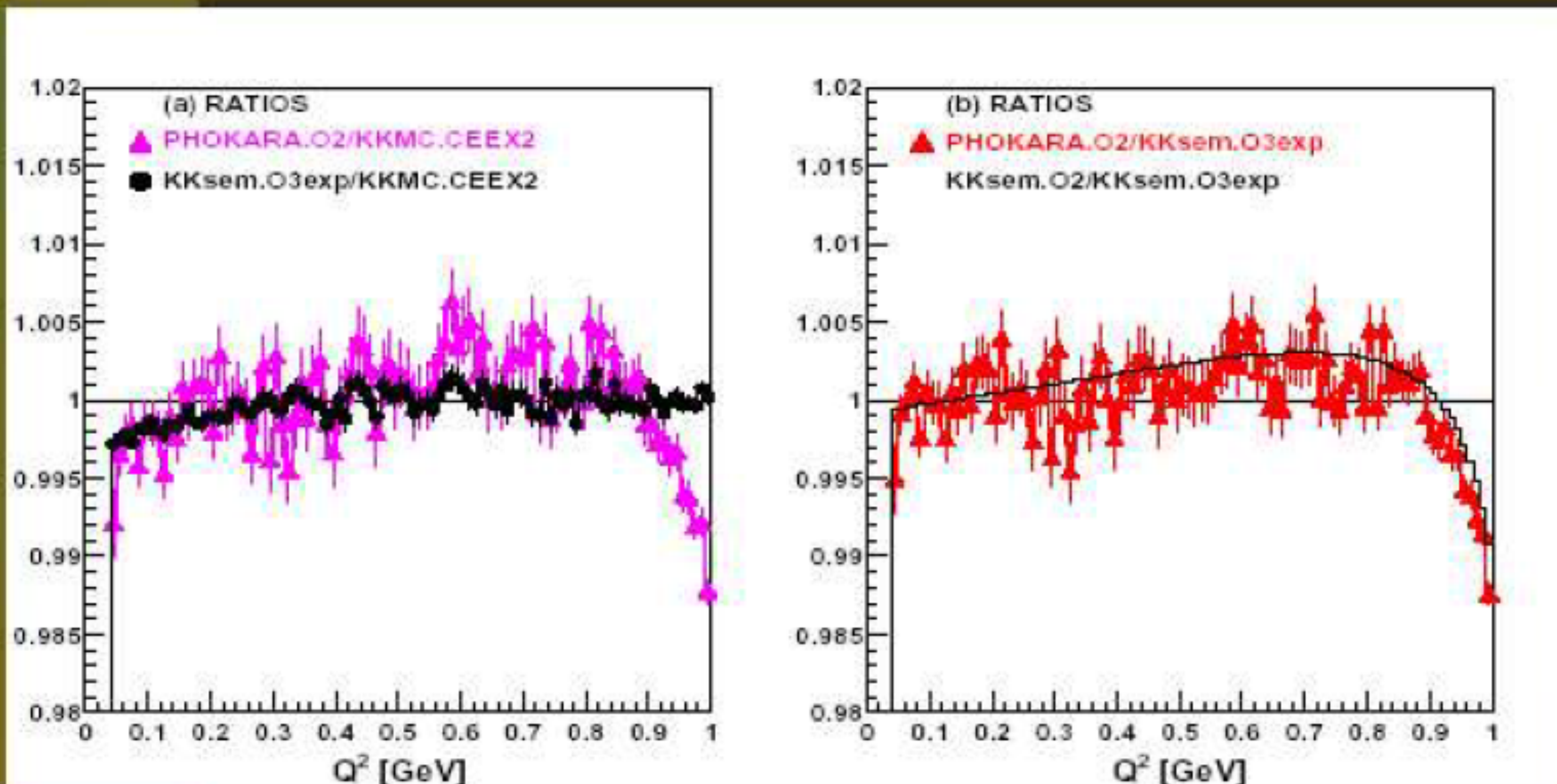
S. Jadach, B. F. L. Ward and Z. Wąs

- YFS exponentation
- high accuracy only for muon pairs
- can we hope for: upgrades ???
  broader collaboration ???

PHOKHARA included in the game, μ-pairs again



PHOKHARA agrees to within 0.3% with KKMC and KKsem.

Discrepancy at high Q^2 reflects lack of exponentiation in PHOKHARA

From H. Czyz (2006):

My wish list

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- benchmark for ISR NLO
  separately (?) for virtual and real corrections

- benchmark for ISR NNLO ???
  What accuracy do we need ?

- beyond ISR for muon and pion pairs:
  testing the codes and FSR models

- collect the results of separate code tests
  and comparisons

FSR studies

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"Non-Born"

$$M^{\mu\nu}_{NB}(Q,k,r) = -ie^2(\tau_1^{\mu\nu} f_1^{NB} + \tau_2^{\mu\nu} f_2^{NB} + \tau_3^{\mu\nu} f_3^{NB}),$$

- explicit form of $f_{1,2,3}^{NB}$ is model-dependent

We now work with

- SU(2) and SU(3) Chiral Perturbation Theory
- KLOE model as implemented in PHOKHARA 6.1 and FASTERD by Olga Shekhovtsova [Shekhovtsova, Venanzoni, Pancheri, arXiv:0901.4440 [hep-ph] (2009)]

These models give "predictions" for FSR:

parameters are fixed independently

Using realistic cuts:

FSR studies

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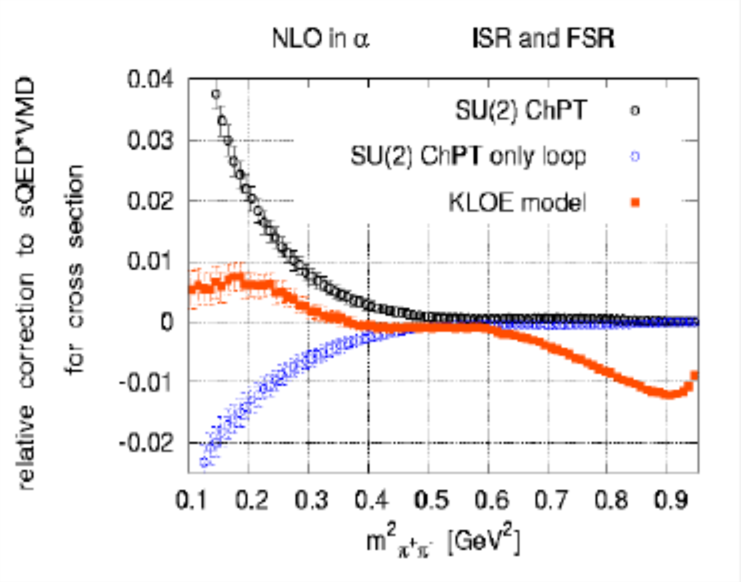
Role of "non-Born" correction



$e^+e^- \to \pi^+\pi^-\gamma$

$\sqrt{s} = 1$ GeV

$50^o < \theta_\gamma < 130^o$

- model dependence is small
- at KLOE statistics the ChPT-corrections are not visible
- effect is enhanced at low $m_{\pi\pi}$

Going forward: Strong2020

- European project (http://www.strong-2020.eu)
- WP21 — JRA3 PrecisionSM: "*Hadron Physics for Precision Tests of the Standard Model*"
- Goal: combine theory and experiment for precision tests SM & BSM
- **Task 2: Hadronic Effects in Precision Tests of the electromagnetic sector of the Standard Model: Muon g-2:**
  - 2.1 Hadronic Vacuum Polarization from spacelike and timelike processes
  - 2.2 Hadronic Light-by-Light Scattering Contribution to $(g-2)\mu$
- Deliverable for Task 2.1:
  - database for low-energy hadronic cross sections in e+e- collisions.

- Collaboration:
  - 35 participants (from main e+e- experiments)
- 3 Meetings (from June 2020)
- Next meeting (online):
  "Workshop on Timelike vs Spacelike HVP" 24-25-26 November 3-6pm CET

If you are interested please send a mail to gvenanzo(at)gmail.com and/or to Andrzej.Kupsc(at)physics.uu.se

1st Meeting on database on hadronic cross sections

Wednesday 3 Jun 2020, 10:00 → 12:00 Europe/Rome

STRONG 2020

10:00 → 10:10 **Introduction PrecisionSM/STRONG2020** 10m

Speaker: Andrzej Kupsc (Uppsala University)

Intro.pdf

10:10 → 10:30 **DataBase project goal** 20m

Speaker: Graziano Venanzoni (PI)

gv_s2020_030620....

10:30 → 10:50 **DataBase project status/options** 20m

Speakers: Alberto Lusiani (Scuola Normale Superiore and INFN, Pisa) , Dr Alberto Lusiani (Scuola Normale Superiore and INFN, sezione di Pisa)

lusiani-PrecisionSM...

10:50 → 11:10 **HEPData** 20m

Speaker: Graeme Watt (Durham University)

watt_hepdata_jun2...

11:10 → 11:20 **Example from KLOE** 10m

Speaker: Stefan Mueller

smueller_Precision...

11:20 → 11:30 **Contact with experiments** 10m

Speaker: Simon Eidelman (Budker Institute of Nuclear Physics)

eidelman.pdf

11:30 → 11:50 **Discussion/conclusions/next steps ...** 20m

2nd Meeting on database on hadronic cross sections

Friday 18 Dec 2020, 10:00 → 12:15 Europe/Rome

STRONG 2020

10:00 → 10:20 **Introduction to the meeting** 20m

Speakers: Andrzej Kupsc (Uppsala University) , Graziano Venanzoni (PI)

gv_s2020_181220....

10:20 → 10:50 **DataBase web page status** 30m

Speakers: Dr Alberto Lusiani (Scuola Normale Superiore and INFN, sezione di Pisa) , Alberto Lusiani (Scuola Normale Superiore and INFN, Pisa)

lusiani-precision-s...

10:50 → 11:20 **HEPData submission tutorial** 30m

Speaker: Stefan Mueller

smueller_Precision...

11:20 → 11:50 **List of channels to be inserted/contact persons for each experiment** 30m

11:50 → 12:00 **AoB** 10m

2nd Meeting on database on hadronic cross sections

Friday 18 Dec 2020, 10:00 → 12:15 Europe/Rome

STRONG 2020

10:00 → 10:20 **Introduction to the meeting** 20m

Speakers: Andrzej Kupsc (Uppsala University) , Graziano Venanzoni (PI)

3rd Meeting on database on hadronic cross sections

Wednesday 26 May 2021, 10:00 → 12:35 Europe/Rome

10:00 → 10:10 **Introduction to the meeting** 10m

Speakers: Andrzej Kupsc (Uppsala University) , Graziano Venanzoni (PI)

gv_s2020_260521....

10:10 → 10:30 **DataBase web page status** 20m

Speaker: Dr Alberto Lusiani (Scuola Normale Superiore and INFN, sezione di Pisa)

lusiani-precision-s...

10:30 → 11:30 **Report on pi+pi- channels in HEPDATA from various experiments** 1h

Speakers: Achim Denig (Karlsruhe / Mainz) , Bogdan Malaescu, Christoph Florian Redmer (Institute for Nuclear Physics, Johannes Gutenberg - University Mainz) , Dr Fedor Ignatov (Budker Institute of Nuclear Physics) , Graziano Venanzoni (PI) , Mikail Achasov, Stefan Mueller

BABARinputsHEPD... | BES3_2pi_HepData... | gv_s2020_260521_... | pipi_in_hepdata.pdf | smueller_Precision...

11:30 → 11:50 **Report at Theory Initiative meeting in June and future work** 20m

11:50 → 12:00 **AoB** 10m

- **Procedure:**
  - Precision SM web page (https://precision-sm.github.io/)
  - Input data (from HEPData)
  - Check of «consistency» of input data
  - Responsive Plots
  - (Possible) Production of useful quantities (VP, alpha_EM, Adler Function…)
  - Maintenance of the web page and polling to HEPData

PrecisionSM collaborative web site

https://precision-sm.github.io/

PrecisionSM Posts About RSS feed

Search

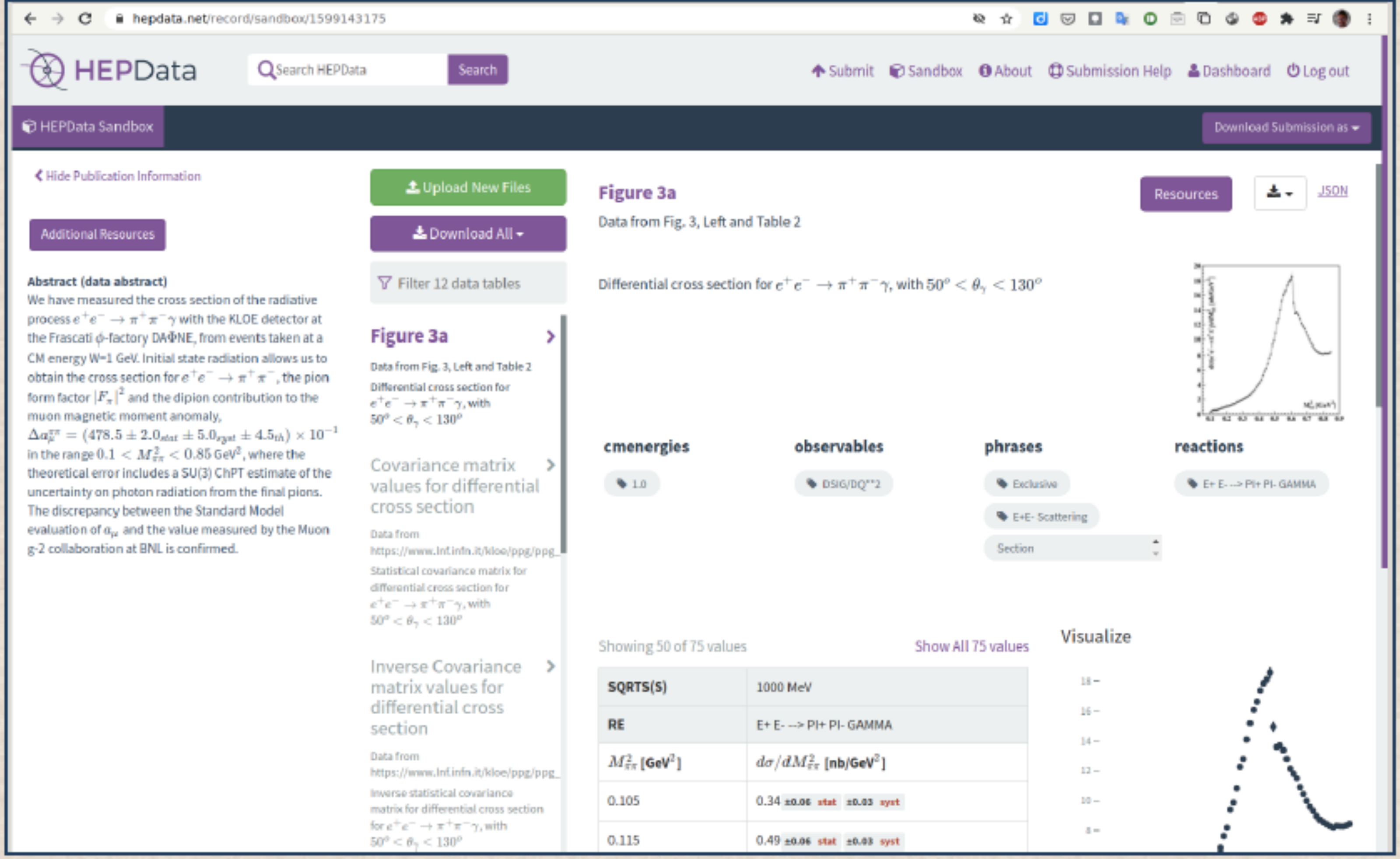
Draft PrecisionSM web site

- Example code to create a responsive plot using results stored in HEPData.net
- Example of responsive plot integrated in this website
- Example notebook
- Fedor Ignatov responsive plots

Contents © 2020 PrecisionSM Group - Powered by Nikola

HEPData.net provisional submission of KLOE10 $e^+e^- \to \pi^+\pi^-(\gamma)$

https://www.hepdata.net/record/sandbox/1599143175



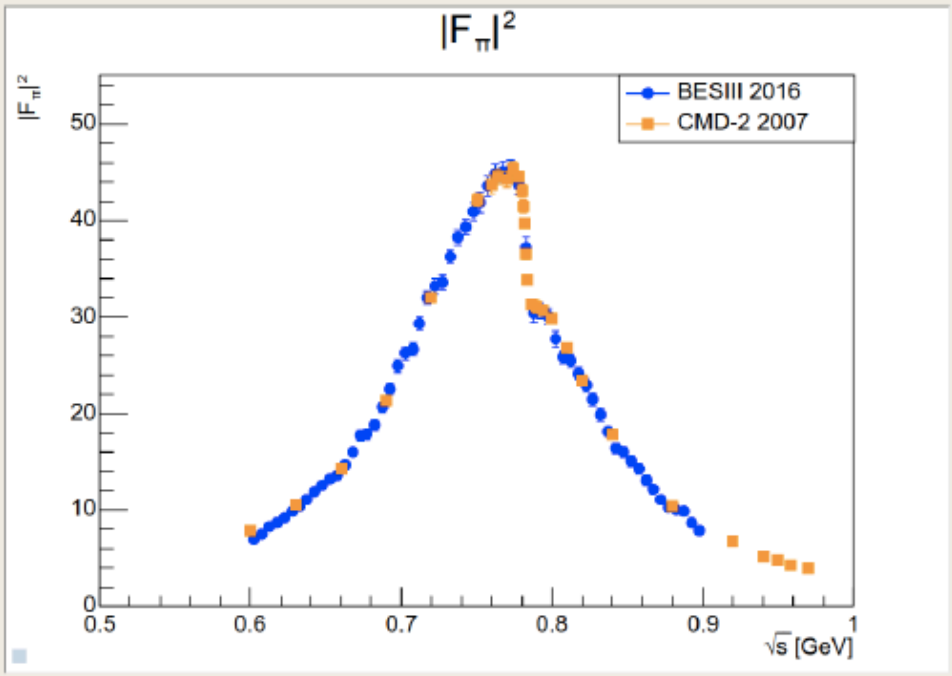
Web site, example of responsive plot

PrecisionSM Posts About RSS feed Search

PrecisionSM Group — 2020-09-06 14:36

Example responsive plot

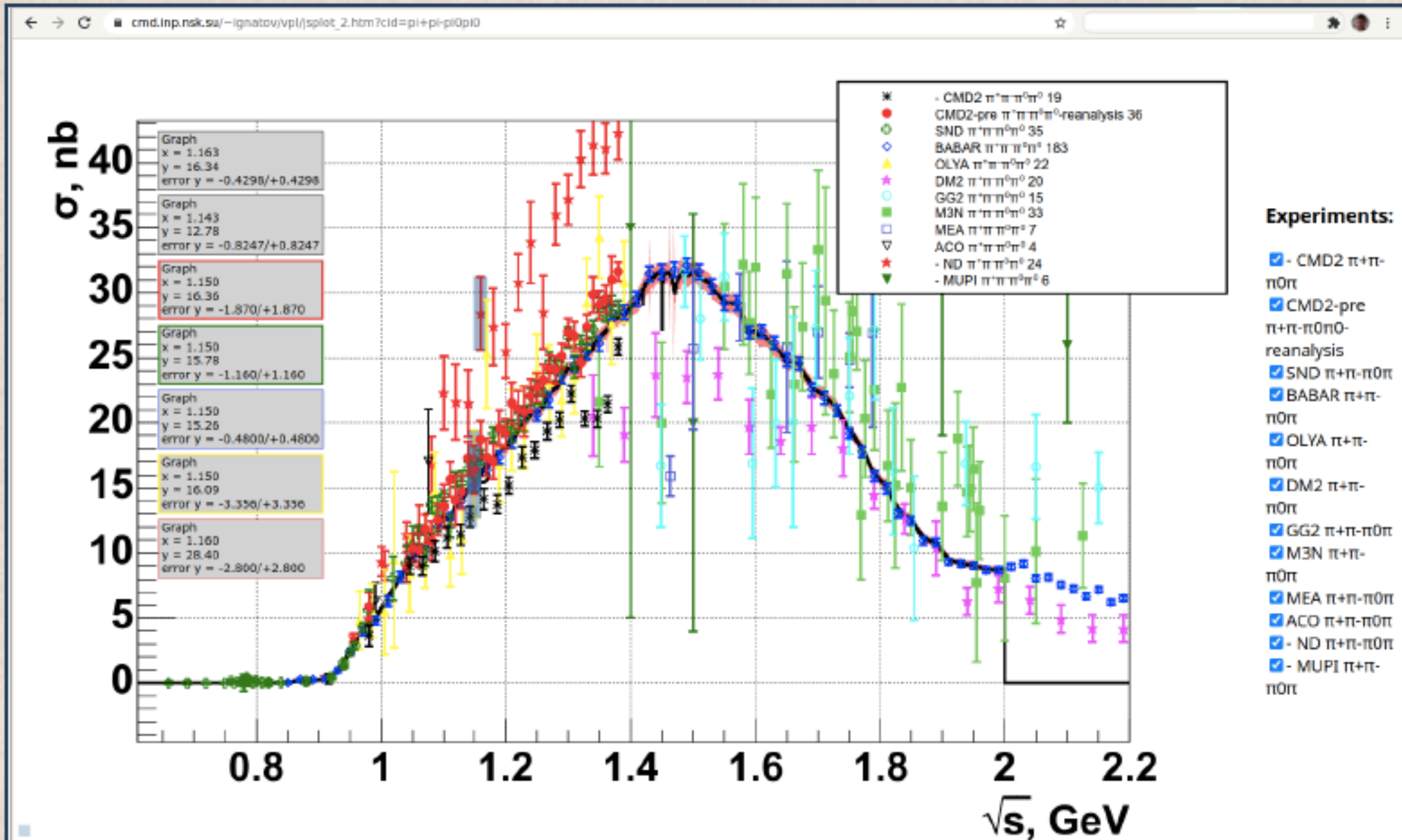
Hovering the cursor above the points reveals the respective x and y values.



Previous post Next post

Web site, Fedor Ignatov responsive plot

- re-using (with his collaboration) techniques used by F. Ignatov in https://cmd.inp.nsk.su/~ignatov/vpl/



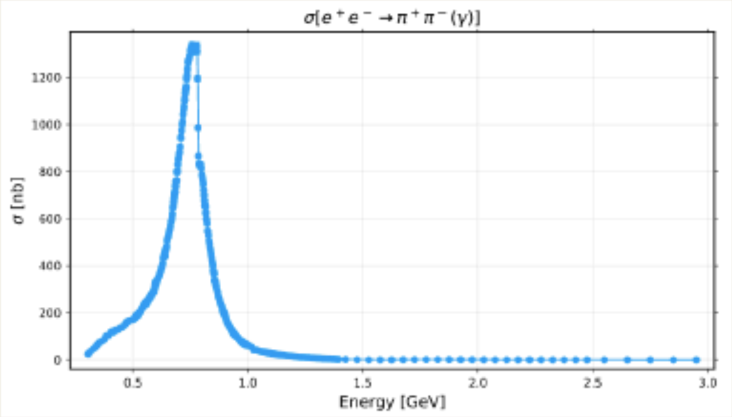
Web site, read BaBar $e^+e^- \to \pi^+\pi^-(\gamma)$ and make plots

cross-section

In [56]:

```
##
## plot cross-section vs. energy (stat. unc. only)
##
curpl = @df sigma_df plot(
  :E,
  :sigma_val,
  yerror = :sigma_unc,
  title = L"$\sigma[e^+e^- \rightarrow \pi^+\pi^-(\gamma)]$",
  xlabel = "Energy [GeV]",
  ylabel = L"$\sigma$ [nb]",
  markerstrokecolor = :auto,
  legend = false
)
## mysavefig(curpl, "curpl.pdf")
## display(curpl)
```

Out[56]:

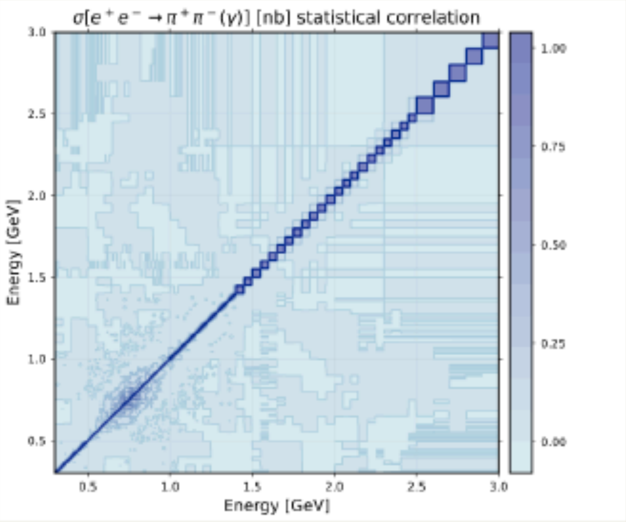


correlation

In [65]:

```
##
## plot statistical correlation contour plot
##
curpl = @df sigma_df contourf(
  range(extrema(vcat(:E_l, :E_h))..., length=500),
  range(extrema(vcat(:E_l, :E_h))..., length=500),
  sigma_stat_corr,
  ## clims = sigma_stat_corr_clims,
  color = :blues,
  title=L"$\sigma[e^+e^- \rightarrow \pi^+\pi^-(\gamma)]$ [nb] statistical correlation",
  xlabel="Energy [GeV]",
  ylabel="Energy [GeV]",
  size=(600, 500)
)
```

Out[65]:



Web site collaborative framework

- source web site files on Github repository
- Nikola static web generator generates website (= HTML, CSS and javascript)
- simple procedure to publish on Github Pages at https://precision-sm.github.io/
  - generated web site can be published anywhere else if more convenient
- web pages are edited in simplified markup languages like Markdown
  - but HTML, CSS and Javascript can be used if desired
- collaborators can be added as editors of Github repository
- written, tested and documented procedure to convert data into responsive jsRoot plots (https://precision-sm.github.io/posts/mk-hepdata-plot/)

Next steps

- responsive plot feature of channel selection (know how to do it, just matter of available time)
- collect list of measurements to be uploaded to HEPData.net
- organize and collaborate with experiments to upload the measurements' data
- produce responsive plots from data uploaded on HEPData.net (semi-automatic)
- document measurements in web site
  - link to HEPData.net, inspirehep, brief description, plots
- organize measurements in categories
- publish example code pieces: data downloading, elaborations

Thanks for your attention!

Conclusions

- A lot of effort to refine/improve HVP determination:
  - MUone at CERN (spacelike approach)
  - RadioMonteCarLow activity for RC's on e+e- (timelike) data
  - STRONG2020 database activity of e+e- (timelike) data

If you are interested to contribute you are welcome!

Introduction

goals (my view)

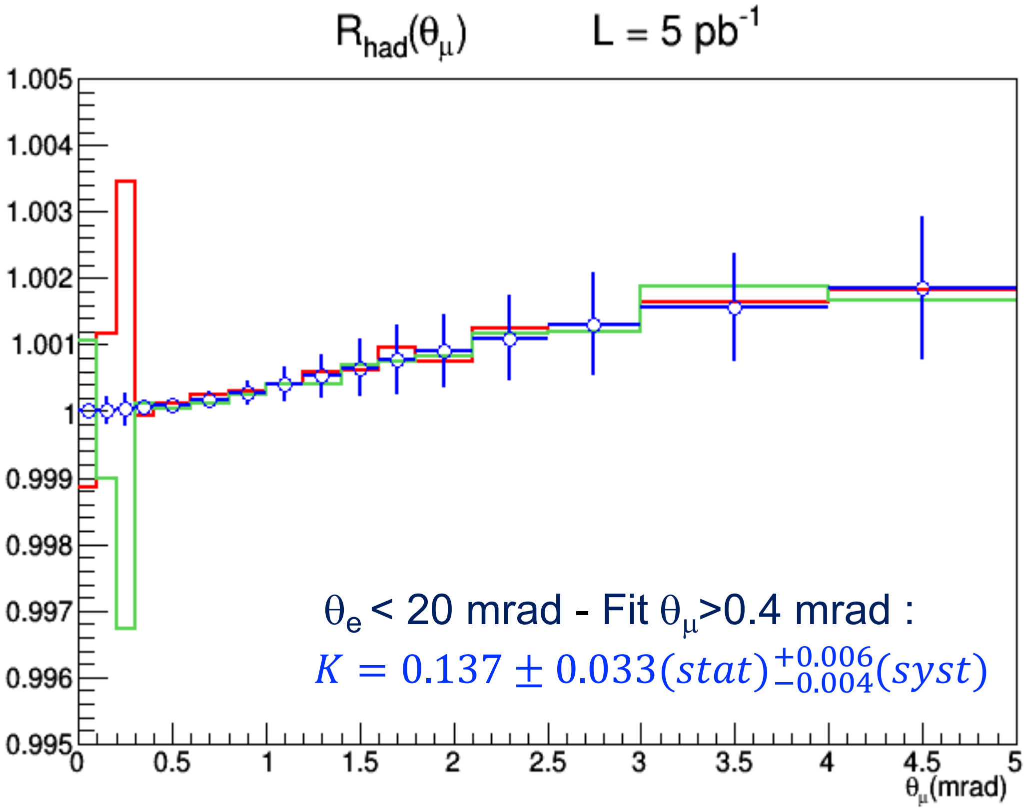
- build repository of low-energy precision measurements data
  - in a format and with instructions and examples to be readily usable
- provide instances of elaborations of the data, e.g. calculation of (part of) muon g-2 HVP contribution

on-going work

- focus on measurements of $\sigma(e^+e^- \to \text{hadrons})$ to compute HVP & LBL contributions to muon $g-2$
- rely on HEPData.net as measurements repository
  - check existing data, promote / organize data submissions
- setup collaborative web site that links to measurement data on HEPData.net and organizes the content
- provide code examples that download and elaborate data of precision measurements
- git repository used to store web site content with versioning
- eventually, additional git repositorie(s) will store more complex code examples

Systematic Effects: Multiple Coulomb Scattering

Effect of a flat error of 1% on the core width of multiple scattering



Systematic Effects: Beam Energy scale

- M2 beam average energy scale known at ~1%
- Beam muon momentum measured by the COMPASS BMS spectrometer with ~0.8% resolution
- Absolute energy scale has to be controlled by a physics process:
  - ❖ Inverse kinematic method on elastic μe events
  - ❖ Fit of the average angle distribution
- Can reach <3 MeV uncertainty in a single station in less than one week

Effect of a syst shift of the average beam energy on the θ_μ distribution: 1h run / 1 station