Workshop `High-precision QCD at low energy', Benasque, Spain 4th August 2015

Hadronic Vacuum Polarisation in $(g\text{-}2)_\mu$

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- Introduction
- Radiative corrections; VP and FSR
- Data combination, fits, models
- Ongoing puzzles, new data and new results
- Outlook, discussion

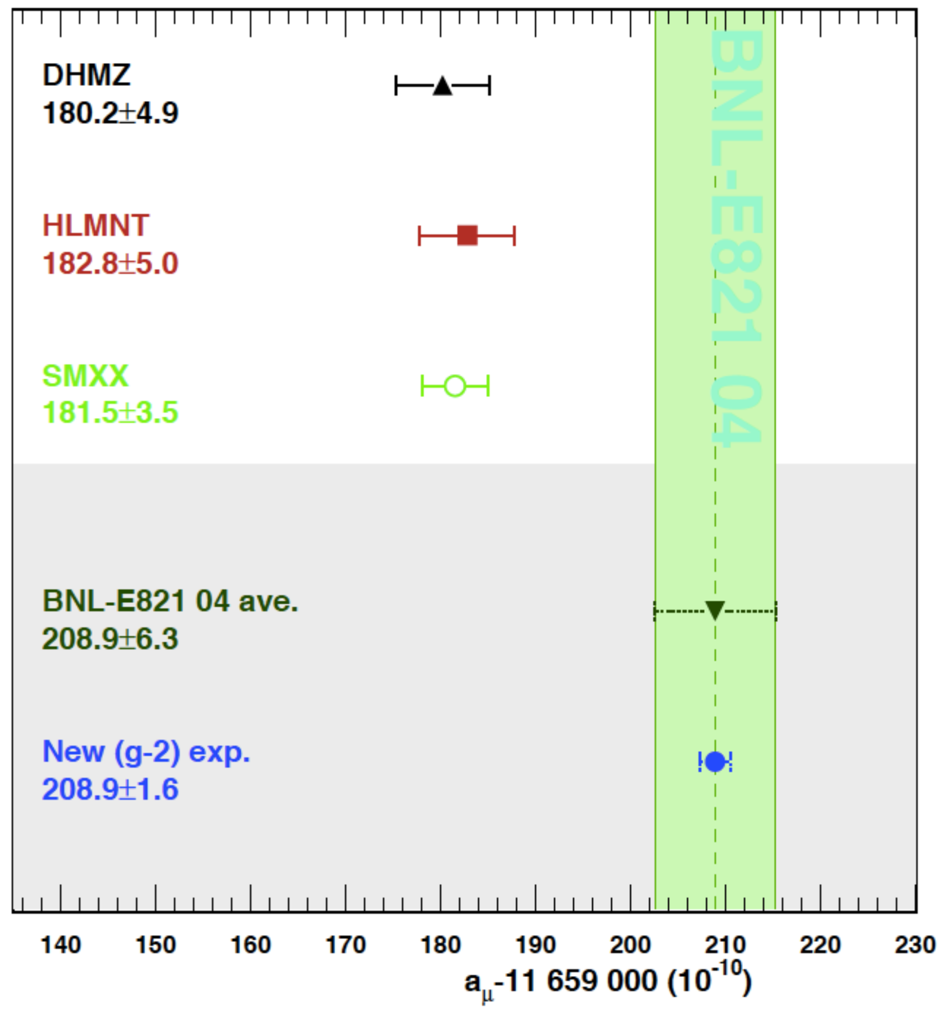
a_μ: Status and future projection → charge for TH

E989: 1st results ~ end 2017, 1-2x BNL stats early 2019…

- if mean values stay and with no a_μ^{SM} improvement: 5σ discrepancy

- if also EXP+TH can improve a_μ^{SM} \`as expected' (consolidation of L-by-L on level of Glasgow consensus, about factor 2 for HVP): NP at 7-8σ

- or, if mean values get closer, very strong exclusion limits on many NP models (extra dims, new dark sector, xxxSSSM)…



a_μ^{SM}: overview, numbers

- Several groups have produced hadronic compilations over the years.
- Here: Hagiwara+Liao+Martin+Nomura+T, numerics (~3.x σ) still valid
- Many more precise data in the meantime and more expected for near future
- At present HVP still dominates the SM error:

QED contribution	$11\,658\,471.808\,(0.015)\times10^{-10}$	Kinoshita & Nio, Aoyama et al
EW contribution	$15.4\,(0.2)\times10^{-10}$	Czarnecki et al
Hadronic contribution		
LO hadronic	$\mathbf{694.9\,(4.3)}\times10^{-10}$	HLMNT11
NLO hadronic	$-9.8\,(0.1)\times10^{-10}$	HLMNT11
light-by-light	$10.5\,(2.6)\times10^{-10}$	Prades, de Rafael & Vainshtein
Theory TOTAL	$\mathbf{11\,659\,182.8\,(4.9)}\times10^{-10}$	
Experiment	$\mathbf{11\,659\,208.9\,(6.3)}\times10^{-10}$	world avg
Exp − Theory	$\mathbf{26.1\,(8.0)}\times10^{-10}$	**3.3 σ discrepancy**

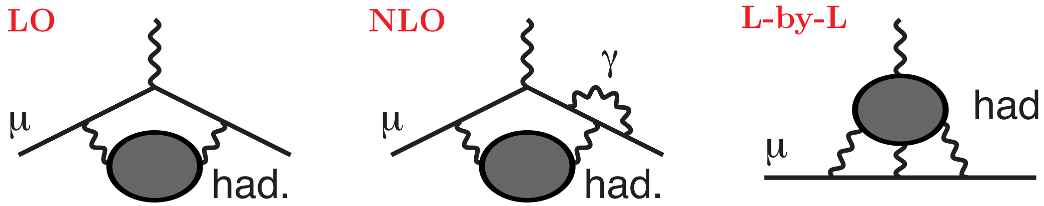
(Numbers taken from HLMNT11, arXiv:1105.3149)

$a_\mu^{\text{had, VP}}$: Hadronic Vacuum Polarisation

$$a_\mu = a_\mu^{\text{QED}} + a_\mu^{\text{EW}} + a_\mu^{\text{hadronic}} + a_\mu^{\text{NP?}}$$

- QED: ✓
- EW: ✓
- Hadronic: the limiting factor of the SM prediction ✗

$$a_\mu^{\text{had}} = a_\mu^{\text{had,VP LO}} + a_\mu^{\text{had,VP NLO}} + a_\mu^{\text{had,Light-by-Light}}$$



HVP: - most precise prediction by using e^+e^- hadronic cross section (+ tau) data and a dispersion integral

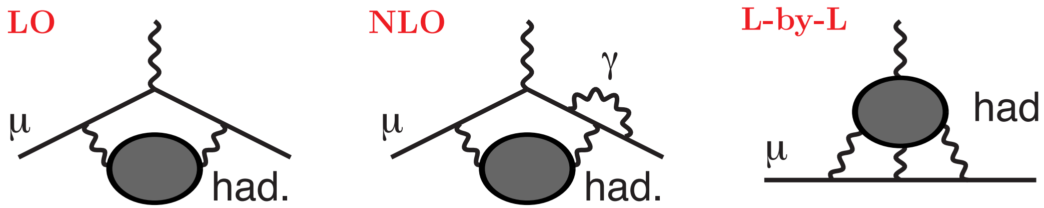
- done at LO and NLO (see graphs)
- now even at NNLO [Steinhauser et al., PLB734(2014)144] ➔

- alternative: lattice QCD, but also need QED corrections; systematics <1% ?

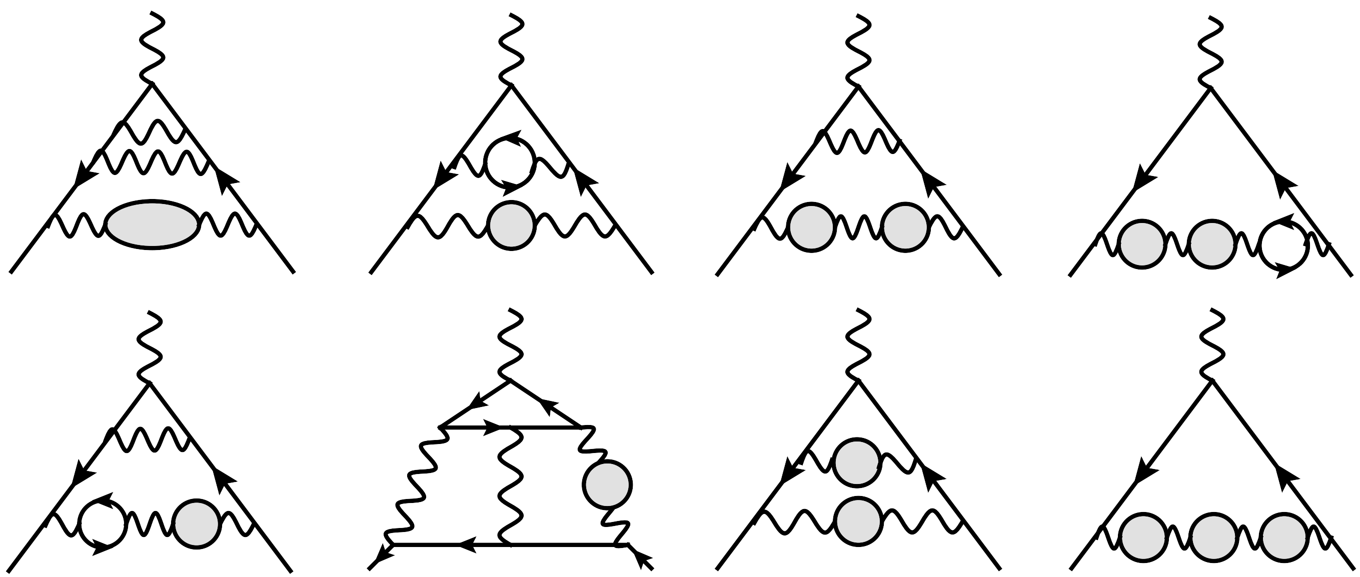
$a_\mu^{\text{had, VP}}$: Hadronic Vacuum Polarisation

- HVP: still the largest error in the SM prediction ✗

$$a_\mu^{\text{had}} = a_\mu^{\text{had,VP LO}} + a_\mu^{\text{had,VP NLO}} + a_\mu^{\text{had,Light−by−Light}}$$

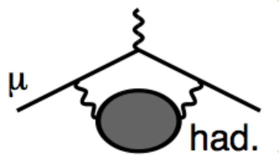


HVP at NNLO by Steinhauser et al.: $a_\mu^{\text{HVP, NNLO}} = +\,1.24 \times 10^{-10}$

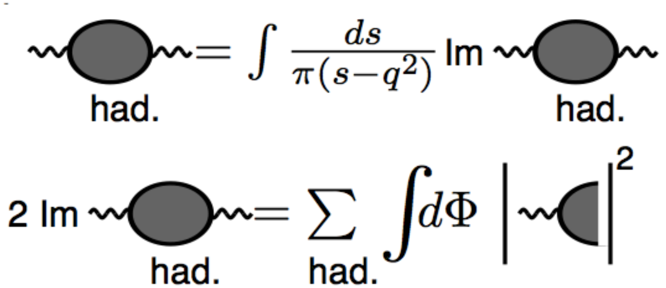


Hadronic Vacuum Polarisation, essentials:

Use of data compilation for HVP:



pQCD not useful. Use the dispersion relation and the optical theorem.



$$a_\mu^{\text{had,LO}} = \frac{m_\mu^2}{12\pi^3} \int_{s_{\text{th}}}^{\infty} ds \, \frac{1}{s} \hat{K}(s) \sigma_{\text{had}}(s)$$

- Weight function $\hat{K}(s)/s = \mathcal{O}(1)/s$

$\Longrightarrow$ Lower energies more important

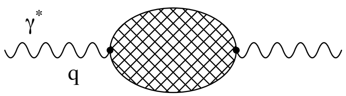
$\Longrightarrow$ $\pi^+\pi^-$ channel: 73% of total $a_\mu^{\text{had,LO}}$

How to get the most precise σ^0_{had}? e^+e^- data:

- Low energies: sum ~ 25 exclusive channels, 2π, 3π, 4π, 5π, 6π, KK, KKπ, KKππ, ηπ, …, use iso-spin relations for missing channels
- Above ~1.8 GeV: can start to use pQCD (away from flavour thresholds), supplemented by narrow resonances (J/Ψ, Υ)
- Challenge of data combination (locally in √s): from many experiments, in different energy bins, errors from different sources, correlations; must avoid inconsistencies/bias
- traditional `direct scan' (tunable $e^+e^-$ beams) vs. `Radiative Return' [+ τ spectral functions]
- σ^0_{had} means `bare' σ, but WITH FSR: RadCorrs [HLMNT: $\delta a_\mu^{\text{had, RadCor VP+FSR}} = 2 \times 10^{-10}$!]

Radiative Corrections: HVP for running $\alpha(q^2)$

- Dyson summation of Real part of one-particle irreducible blobs $\mathbf{\Pi}$ into the effective, real running coupling $\boldsymbol{\alpha}_{\mathbf{QED}}$:

$\Pi \; =$ 

Full photon propagator $\sim \; 1 \, + \, \Pi \, + \, \Pi \cdot \Pi \, + \, \Pi \cdot \Pi \cdot \Pi \, + \, \ldots$

$$\rightsquigarrow \qquad \alpha(q^2) \; = \; \frac{\alpha}{1 - \mathrm{Re}\Pi(q^2)} \; = \; \alpha \,/\, \big(1 - \Delta\alpha_{\mathrm{lep}}(q^2) - \Delta\alpha_{\mathrm{had}}(q^2)\big)$$

- The Real part of the VP, $\mathrm{Re}\Pi$, is obtained from the Imaginary part, which via the *Optical Theorem* is directly related to the cross section, $\mathrm{Im}\Pi \sim \sigma(e^+e^- \to hadrons)$:

$$\Delta\alpha^{(5)}_{\mathrm{had}}(q^2) \; = \; -\frac{q^2}{4\pi^2\alpha} \, \mathrm{P} \int_{m_\pi^2}^{\infty} \frac{\sigma^0_{\mathrm{had}}(s) \, \mathrm{d}s}{s - q^2} \; , \qquad \sigma_{\mathrm{had}}(s) = \frac{\sigma^0_{\mathrm{had}}(s)}{|1 - \Pi|^2}$$

[$\to \sigma^0$ requires 'undressing', e.g. via $\cdot(\alpha/\alpha(s))^2$ $\rightsquigarrow$ iteration needed]

- Observable cross sections σ_{had} contain the |full photon propagator|^2, i.e. |infinite sum|^2.
  $\to$ To include the subleading Imaginary part, use dressing factor $\frac{1}{|1-\Pi|^2}$.

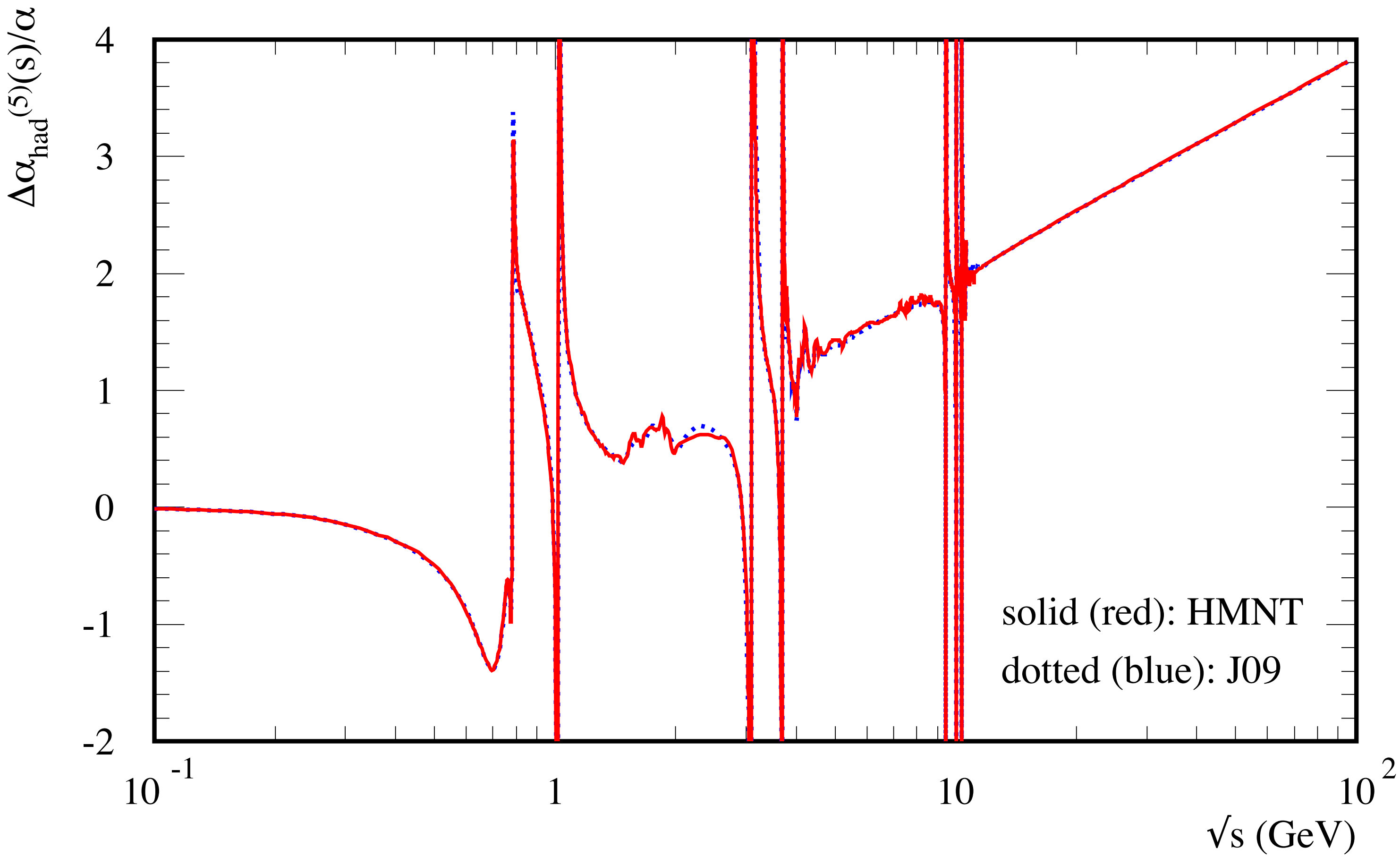
Radiative Corrections: HVP for running $\alpha(q^2)$

Parametrisations/routines based on `global' data compilations available from a few groups:

- Novosibirsk: http://cmd.inp.nsk.su/~ignatov/vpl/ tabulation with ROOT package
- Davier et al: HVPTools (status of distribution? still in preparation?)
- Fred Jegerlehner's package: http://www-com.physik.hu-berlin.de/~fjeger/software.html
  - set of routines with analytic codes and tabulations
  - uses rhad from Harlander+Steinhauser for Im part
  - regular updates (last 5.4.2012)
- HLMNT routine
  - provided upon request by authors (Daisuke Nomura or TT)
  - standalone Fortran, partly analytic, partly tabulation
  - current version is VP_HLMNT_v2_2 (20.5.2015, based mainly on HLMNT11 status)
  - flag to control if narrow resonances included or not, but Φ and higher Υ always included through direct data integration

Radiative Corrections: HVP for running $\alpha(q^2)$

- $\Delta\alpha(q^2)$ in the time-like: HLMNT compared to Fred Jegerlehner's new routines



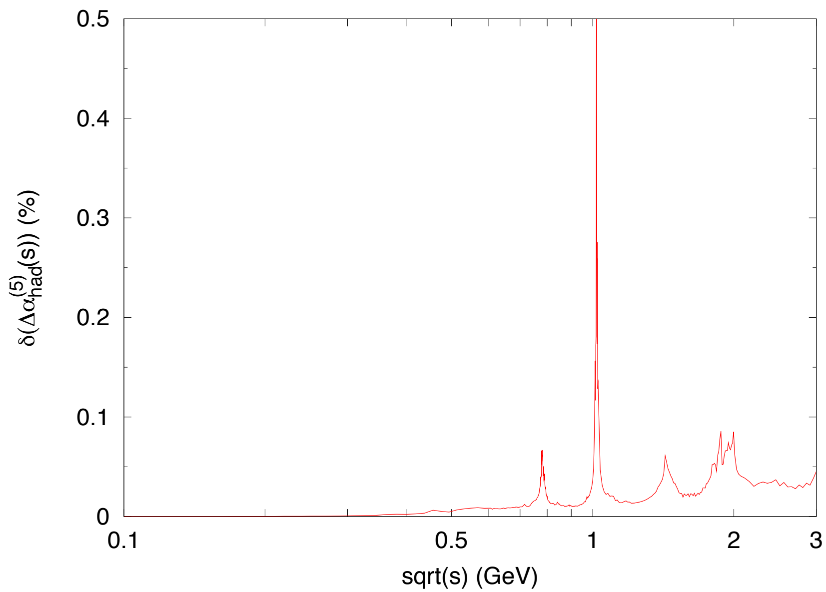
$\longrightarrow$ with new version big differences (with 2003 version) gone

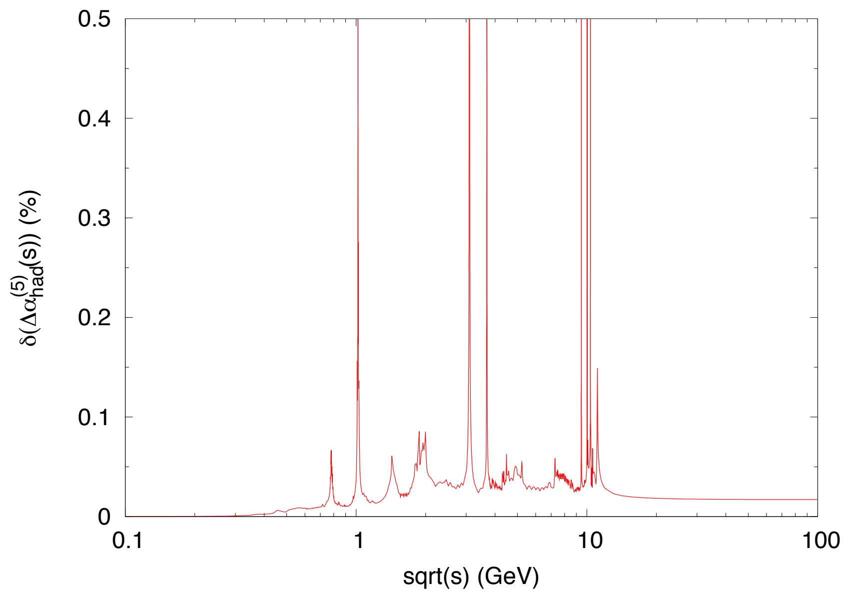
– smaller differences remain and reflect different choices, smoothing etc.

Radiative Corrections: HVP for running $\alpha(q^2)$

- Typical accuracy $\delta\left(\Delta\alpha_{\rm had}^{(5)}(s)\right)$

Error of VP in the timelike regime at low and higher energies (HLMNT compilation):





$\longrightarrow$ Below one per-mille (and typically $\sim 5 \cdot 10^{-4}$), apart from Narrow Resonances where the bubble summation is not well justified.

Enough in the long term? Need for more work in resonance regions.

Radiative Corrections: Final State Radiation

- Real+virtual; must be included in dispersion integral, but some events with real radiation will have been cut-off by experimental analyses.
  (No problem if γ just missed but event counted! Possible problem of mis-identifies)

- Experiments (now) account for this and add some FSR back;
  - based on MC and sQED for pions (checked to work well),
  - including some uncertainties in their systematics

- Note: at low energies, hard radiation limited by phase space

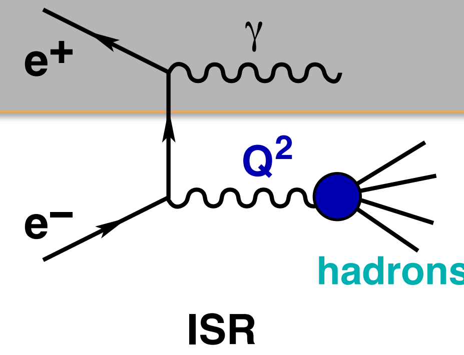
- HMNT (and other groups) include large, conservative Rad. Corr. error, i.e.
  HLMNT11: $\delta a_\mu^{\text{had, RadCor VP+FSR}} = 2 \times 10^{-10}$

- Work in progress: this error estimate is too conservative (especially in K^+K^-), and

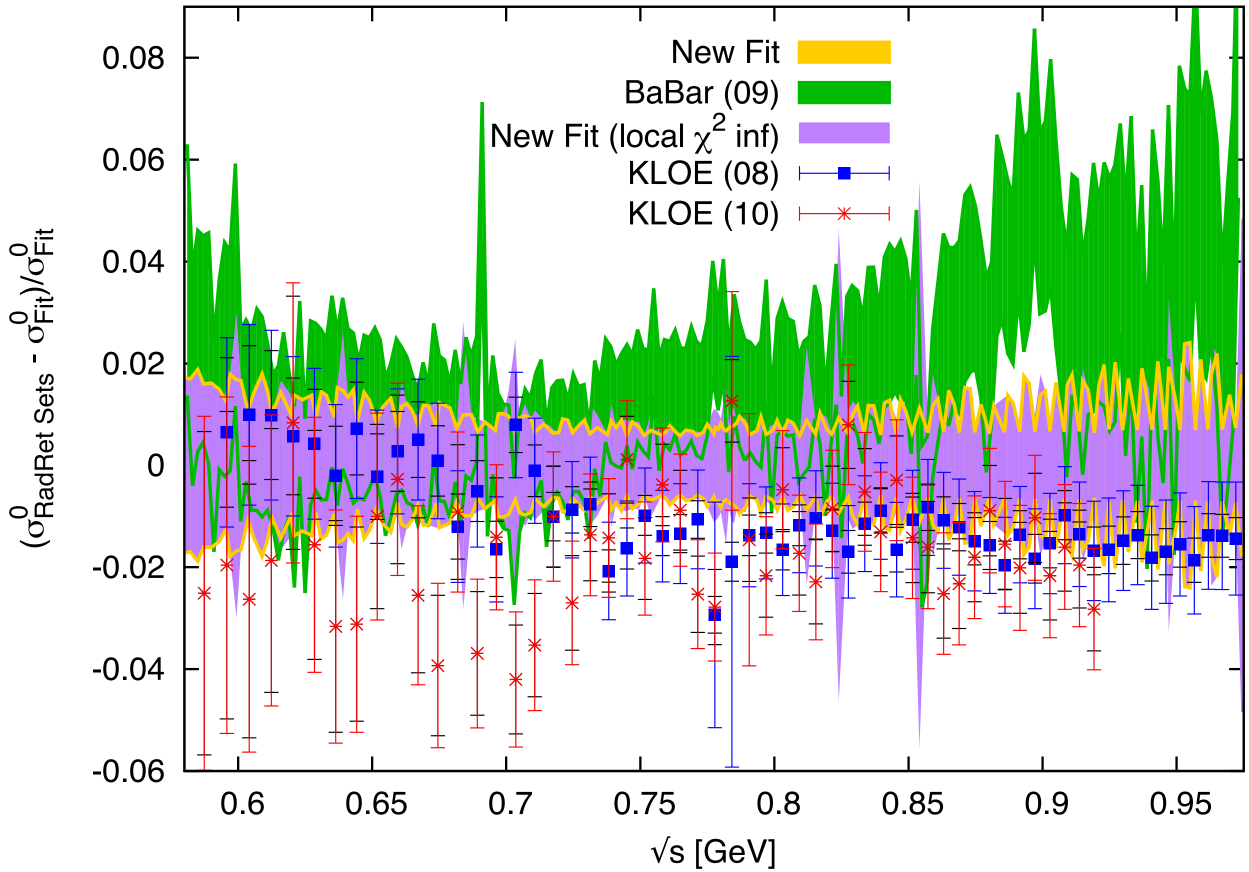
- use of more modern data sets, where FSR has been part of the analysis, will bring this down.

- However: More scrutiny needed for Rad. Ret. EXPs where this is part of the `LO'.

Data `puzzle' in the $\pi^+\pi^-$ channel



Radiative Return data in the combined fit of HLMNT 11



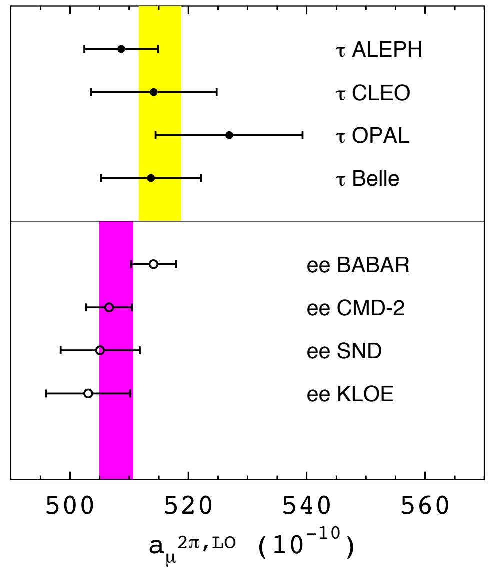
- ➔ 2π fit: overall χ^2_{min}/d.o.f. ~ 1.5 needs error inflation, limited gain in error
- ➔ Latest KLOE12 data confirm this tension, see below for new fits also including latest BESIII data

Note: $a_\mu^{\pi\pi,\ \text{w/out Rad Ret}} = 498.7 \pm 3.3$ BUT $a_\mu^{\pi\pi,\ \text{with Rad Ret}} = 504.2 \pm 3.0$

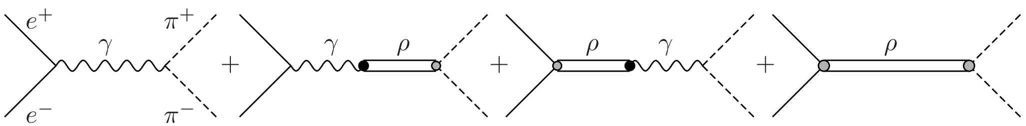
➔ i.e. a shift of +5.5 in HLMNT [DHMZ: $a_\mu^{\pi\pi}$ even higher by 2.1 units]

Another `puzzle': Use of tau spectral function data?

- Use CVC (iso-spin symmetry) to connect $\tau^- \to \pi^0\pi^-\nu_\tau$ spectral functions to $e^+e^- \to \omega, \rho \to \pi^+\pi^-$ but have to apply iso-spin corrections
- Early calculations by Alemany, Davier, Hoecker: use of τ data complementing e^+e^- data originally resulted in an improvement w.r.t. use of e^+e^- data alone; discrepancy smaller with tau data; later increased tension between e^+e^- and τ
- Recent compilation by Davier et al (Fig. from PRD86, 032013):



- Jegerlehner+Szafron: crucial role of γ-ρ mixing:



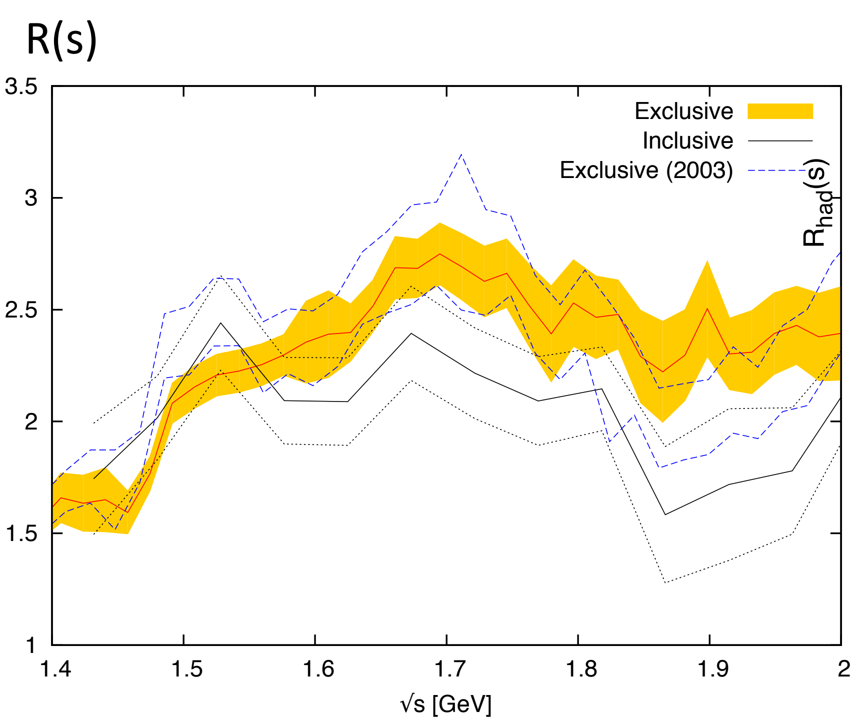
- They found discrepancy gone but τ data improves e^+e^- analysis only marginally
- Analyses by Benayoun et al: combined fit of e^+e^- and τ based on Hidden Local Symmetry (HLS): no big tension betw. e^+e^- and τ, but w. BaBar, hence not used; increased Δa_μ: of >≈ 4.5σ
- Davier+Malaescu refute criticism, claim fair agreement betw. BaBar and their τ comp.
- HLMNT: stick to e^+e^- (and do not use τ data). With e^+e^- (incl. BaBar) discrepancy of 3-3.5σ

σ_{had} at higher energies

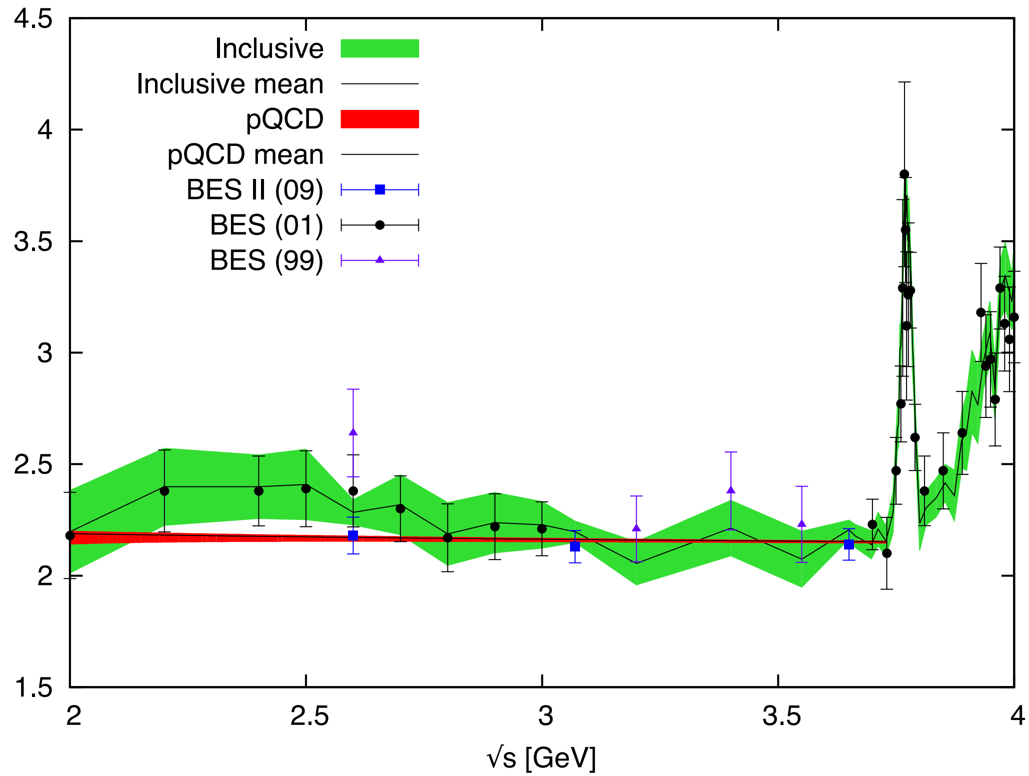
2011 status to be improved; BESIII

Inclusive vs. $\Sigma_{exclusive}$ + \`missing'

More from SND, CMD3, Belle, BaBar, BESIII



Inclusive data or perturbative QCD



More from BESIII

- Exclusive data recently improved mainly due to many Radiative Return data from BaBar
- BESII data (blue markers) in perfect agreement w. pQCD; data-based $a_\mu^{incl} > a_\mu^{pQCD}$
- Different data and data vs. pQCD choices give slightly different a_μ (within errors)

$a_\mu^{HVP, LO}$ different comps. a_μ^{SM} status: Recent history

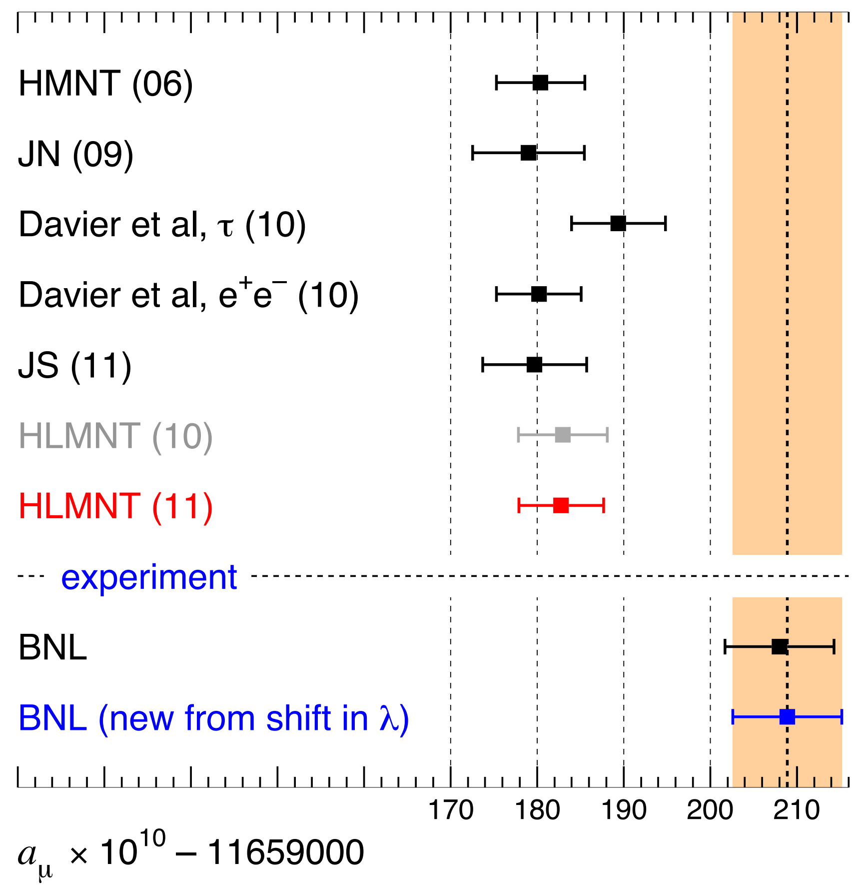
- Fair agreement between different e^+e^- analyses, including recent updates: (all numbers in 10^{-10})

HLMNT (11): 694.9 ± 3.7 (exp) ± 2.1 (rad)
Jegerlehner (11): 690.8 ± 4.7
Davier et al (11): 692.3 ± 4.2

- The `extremes' (both with τ data):

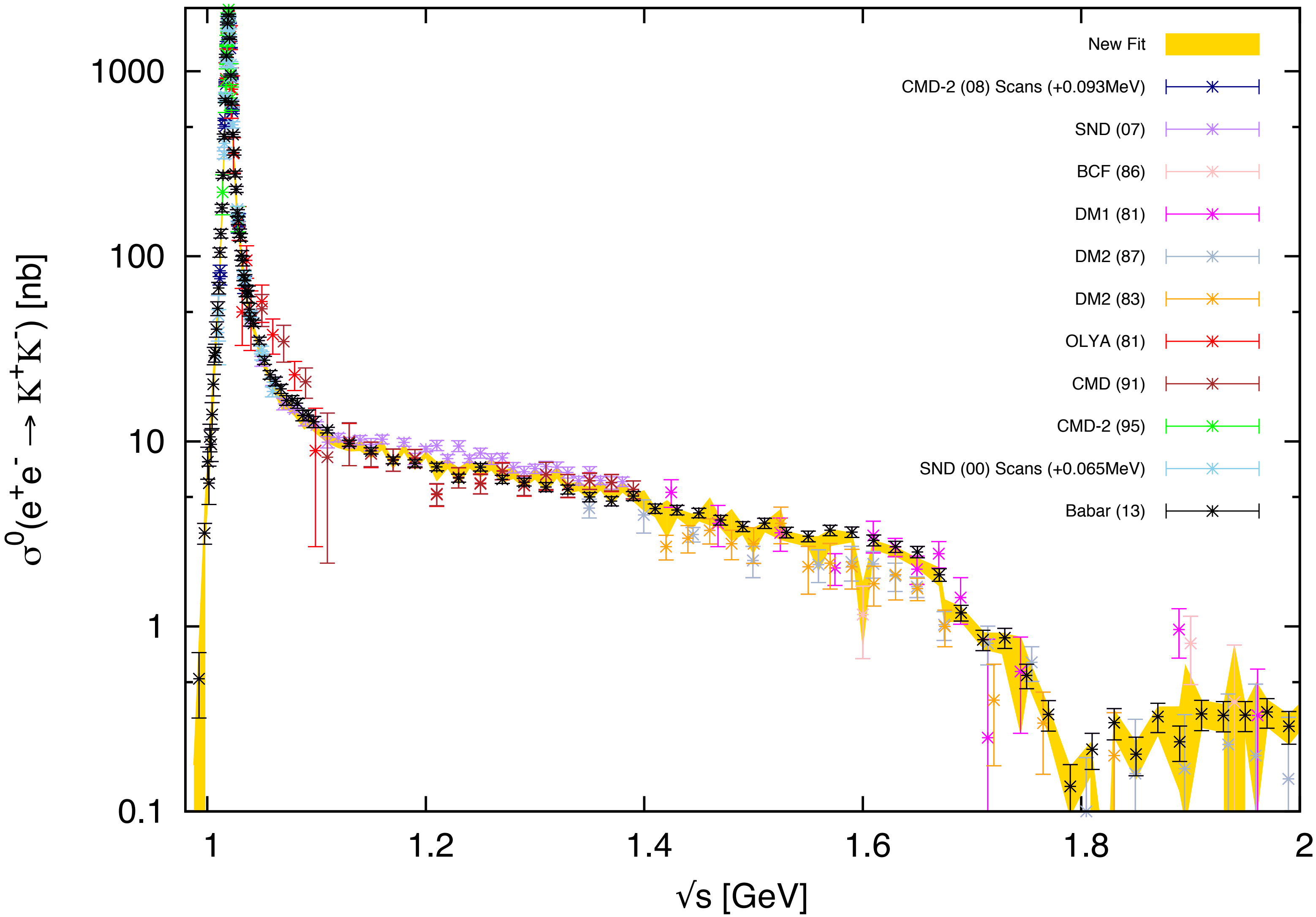
Davier et al (11): 701.5 ± 4.7 (+ ~ 1.5 shift from 2013 τ re-analysis EPJC74,3,2803)
Benayoun et al (12): 681.2 ± 4.5

- New data available already do not shift the mean value strongly, but are incrementally improving the determination of a_μ^{HVP}



σ_{had}: recent data: $K^+K^-(\gamma)$ from BaBar [PRD 88(2013)3,032013]

Work on new combination with A. Keshavarzi: PRELIMINARY results



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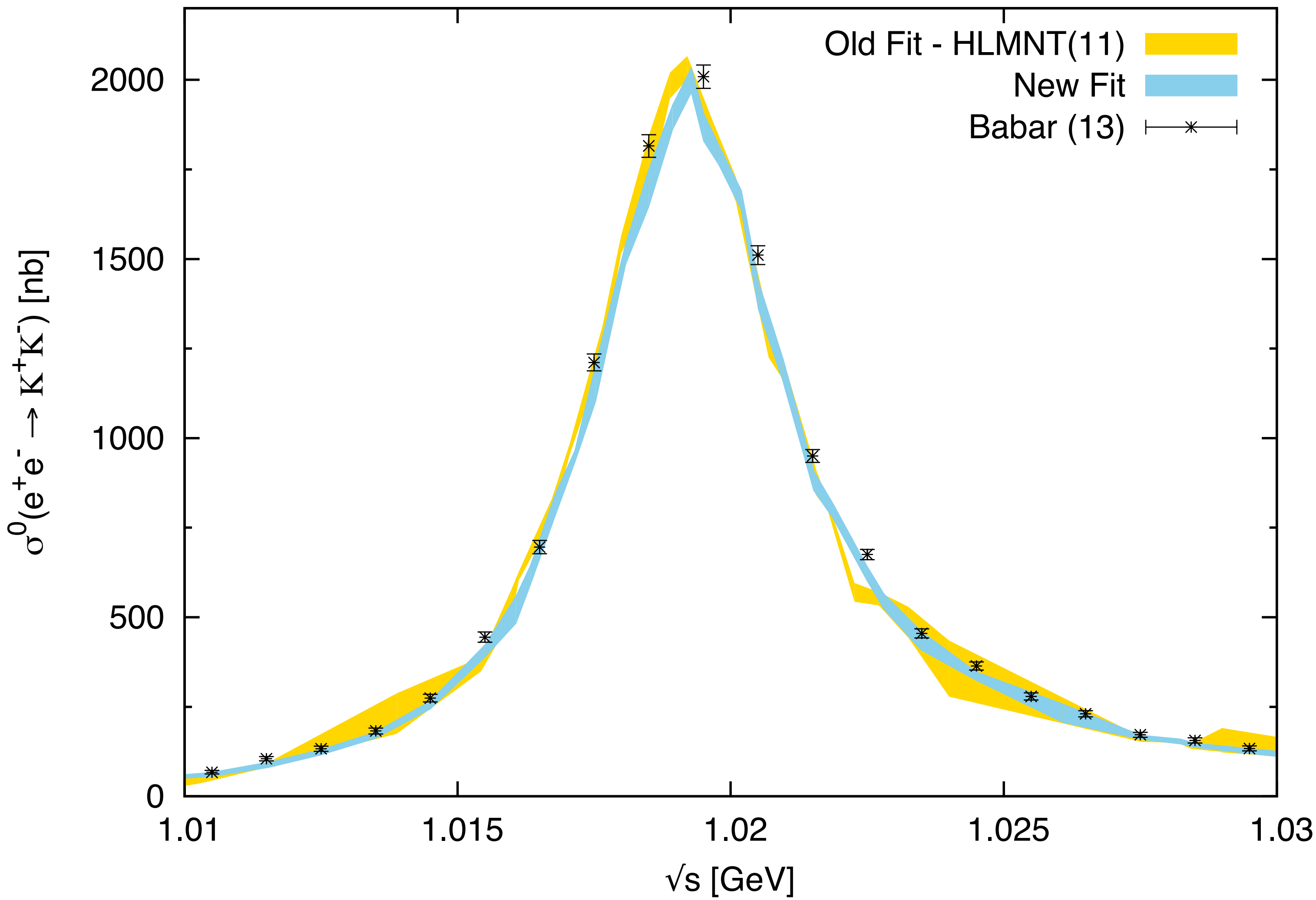
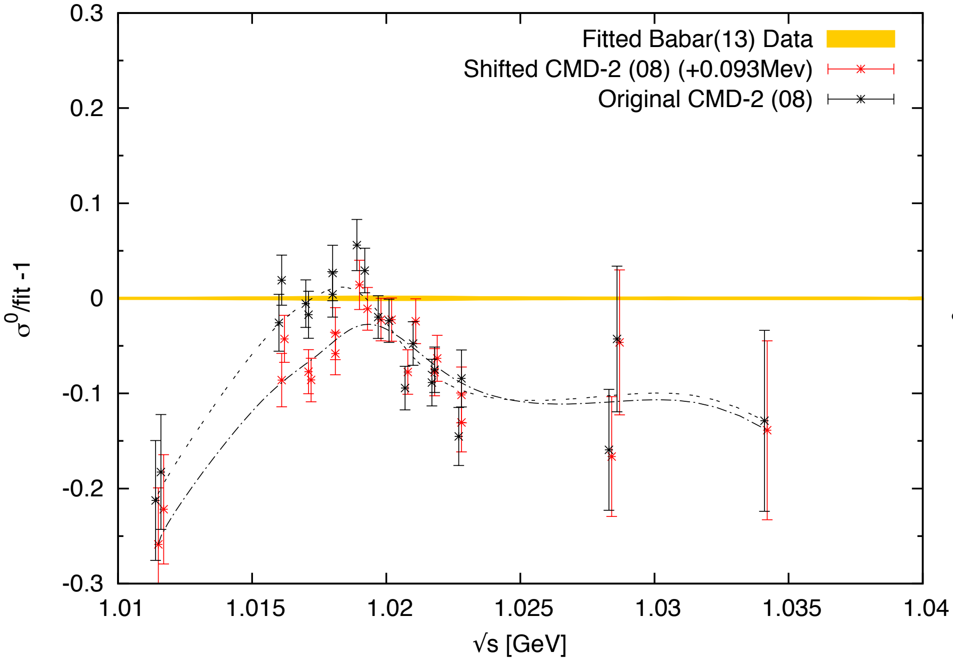
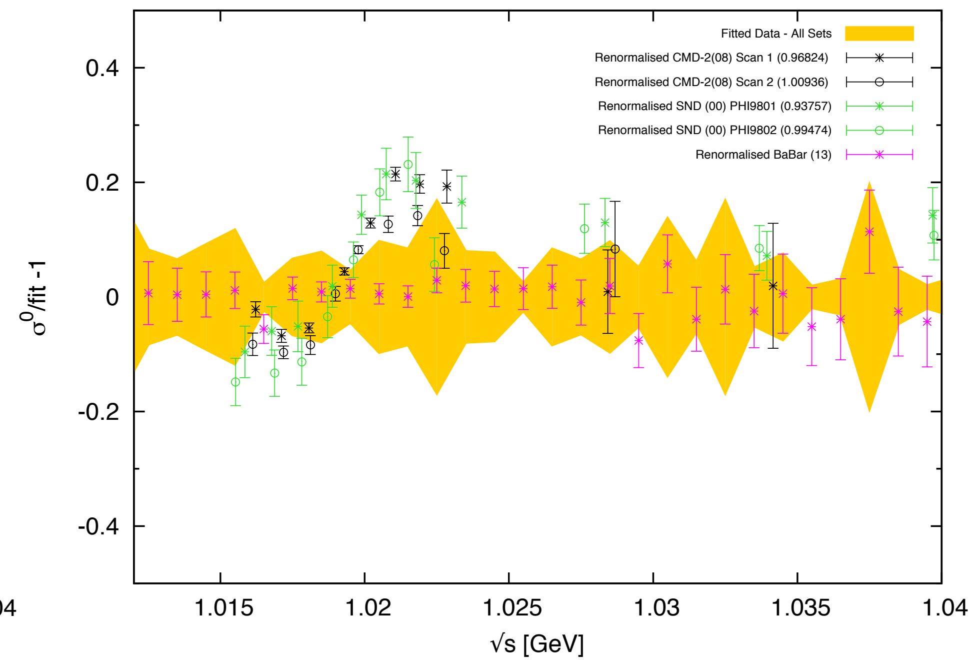


σ_{had}: recent data: $K^+K^-(\gamma)$ from BaBar [PRD 88(2013)3,032013]

Problem of data combination between BaBar and older sets: another puzzle?

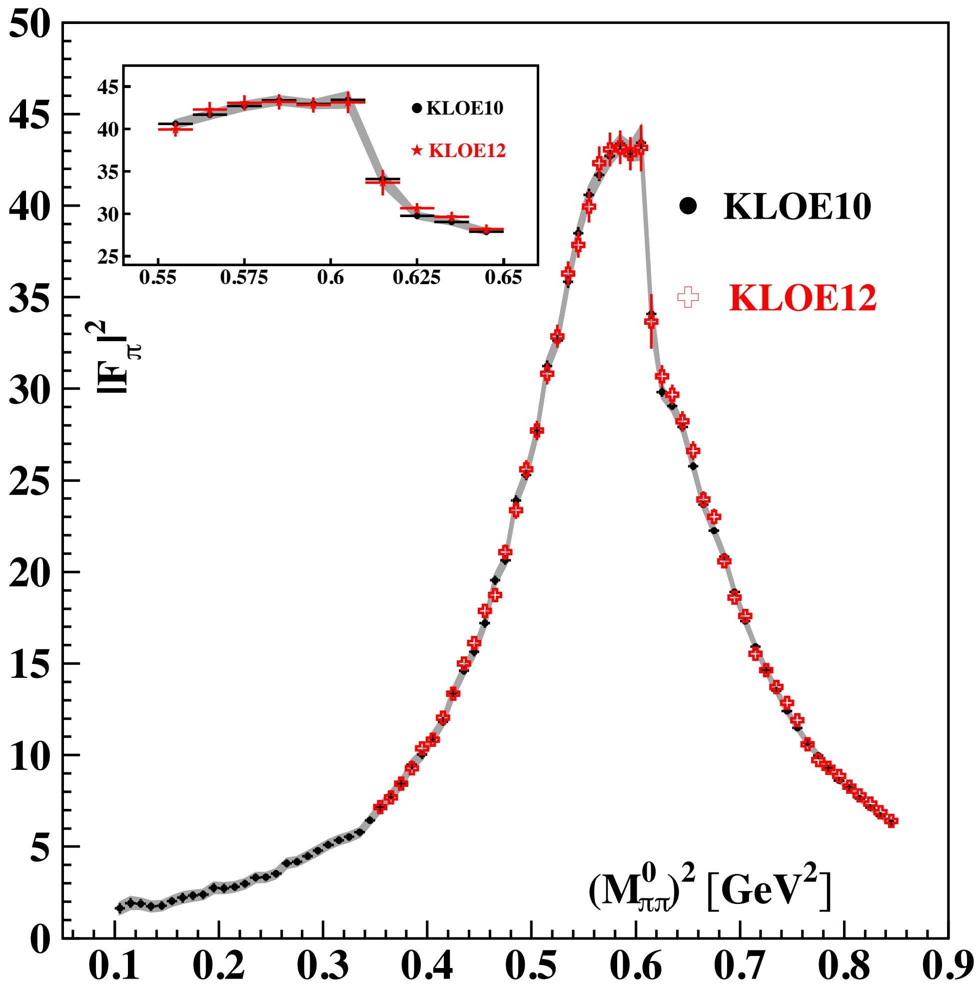




- Energy dependent difference; fitted Φ mass is different betw. BaBar and CMD-2, SND
- study to combine including energy (and normalisation) shifts
- χ^2_{min}/dof improved through energy shifts, but still not very good;
  (locally) inflated error Δa_μ^{KK} only marginally improved when BaBar data are included, and worse for all sets combined compared to BaBar only (-> χ^2_{min} inflation of error)
- In total we get a_μ^{K+K-} = 21.74 ± 0.45 (HLMNT11) → 21.69 ± 0.36 (preliminary!)

$\pi^+\pi^-$: recent data from KLOE

KLOE with $\sigma_{\mu\mu}$ normalisation [PLB720(2013)336]:



- confirm previous KLOE measurements
- do not decrease tension with BaBar, slightly increase KLOE's significance
- Open question: Why are BaBar's data so different from KLOE's?

Are there any issues with the MCs or analysis techniques used?

- Soon more from Novosibirsk, already now from BESIII:

$\pi^+\pi^-$: new data from BESIII (from BESIII conf. talk thanks to Achim Denig)

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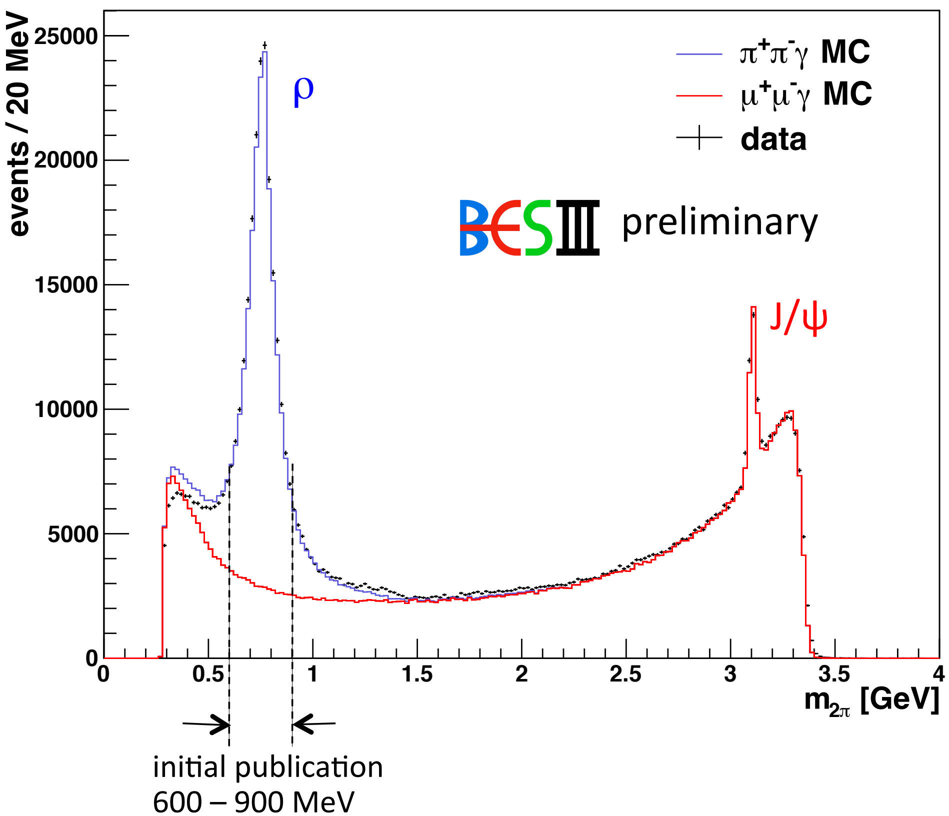
Flagship Analysis: $e^+e^- \rightarrow \pi^+\pi^-\gamma_{ISR}$

Event yield after basic event selection (acceptance only!)

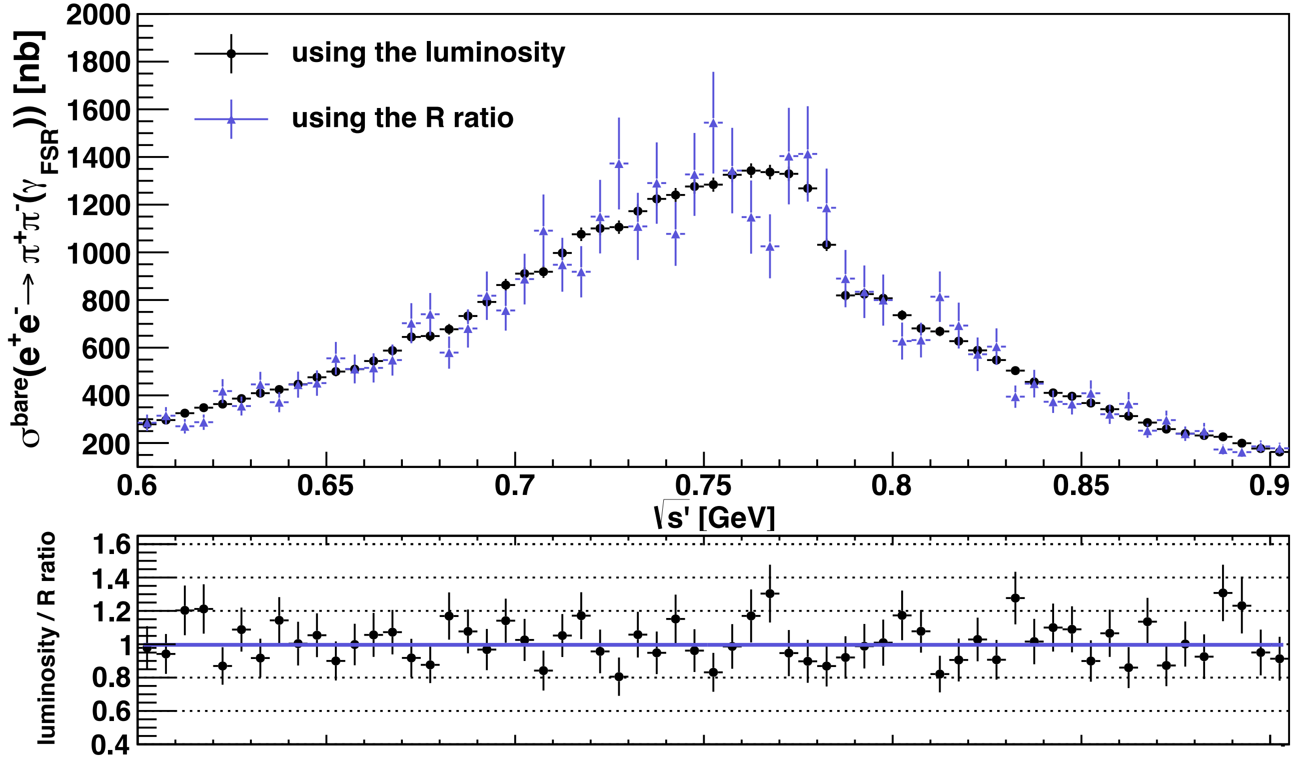


Features:

- ψ(3770) data only (2.9 fb^{-1})
- no background subtraction
- PHOKHARA event generator
- tagged ISR photon

→ large statistics of $\pi\pi\gamma$ events
→ background dominated by $\mu\mu\gamma$
→ data – MC differences observed

$\pi^+\pi^-$: new data from BESIII; arXiv:1507.08188

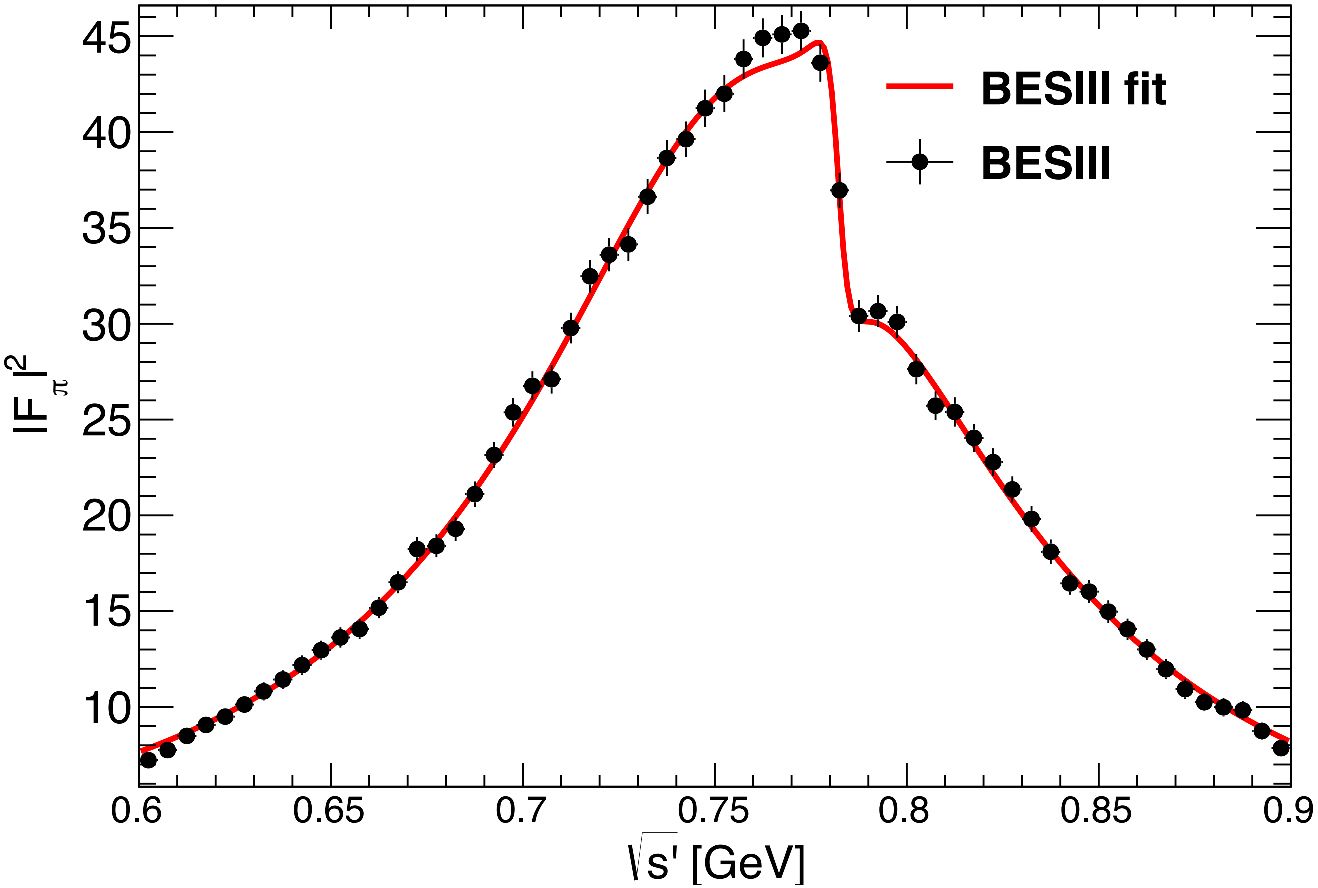


Two methods used for the normalisation:

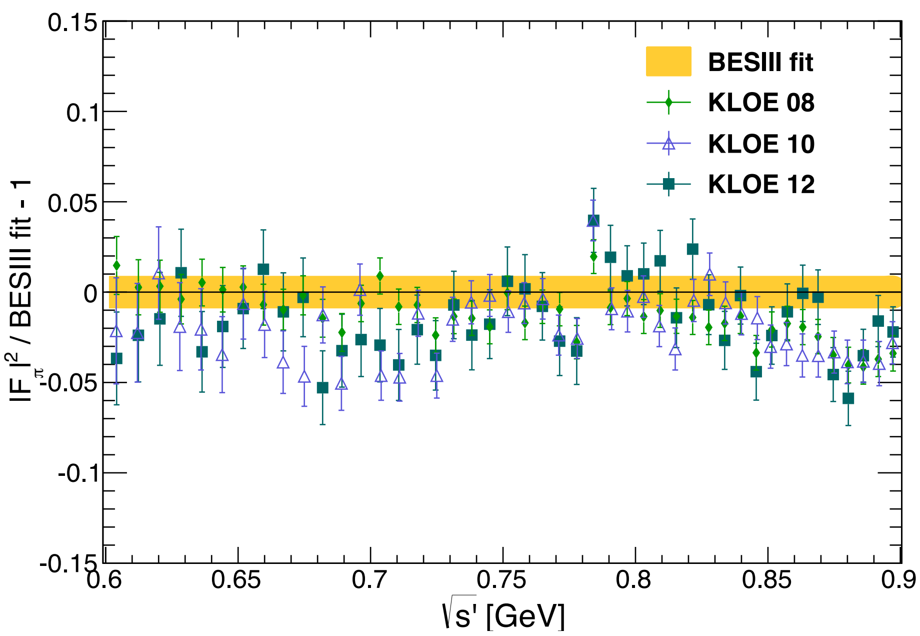
- Bhabha for the luminosity vs. $\mu^+\mu^-(\gamma)$, where the luminosity, the radiator function and the VP corrections are cancelling out.
- Much higher stats for Bhabha, but $\mu^+\mu^-(\gamma)$ important consistency check.

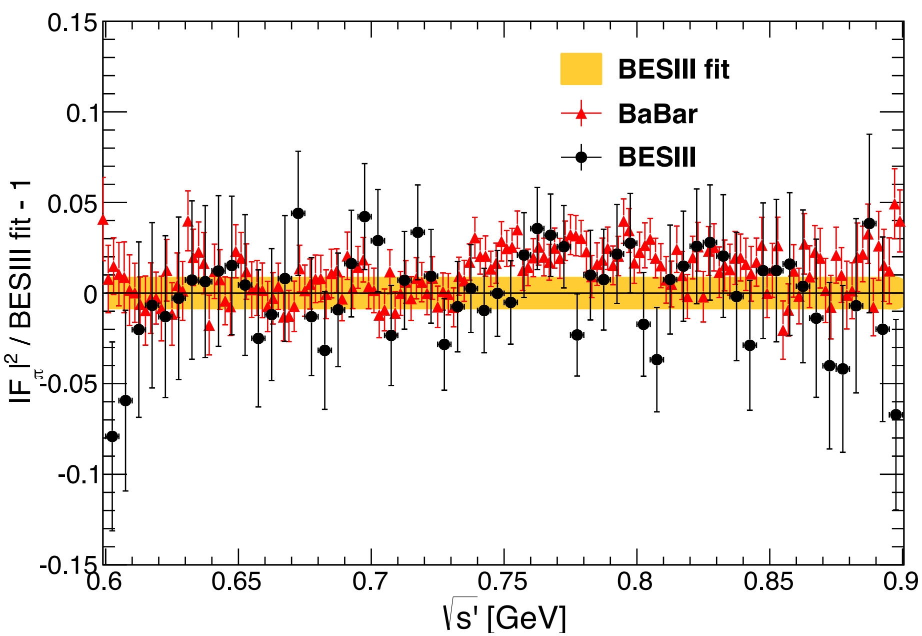
$\pi^+\pi^-$: new data from BESIII; arXiv:1507.08188

Form Factor plot with fit result:



$\pi^+\pi^-$: new data from BESIII; arXiv:1507.08188

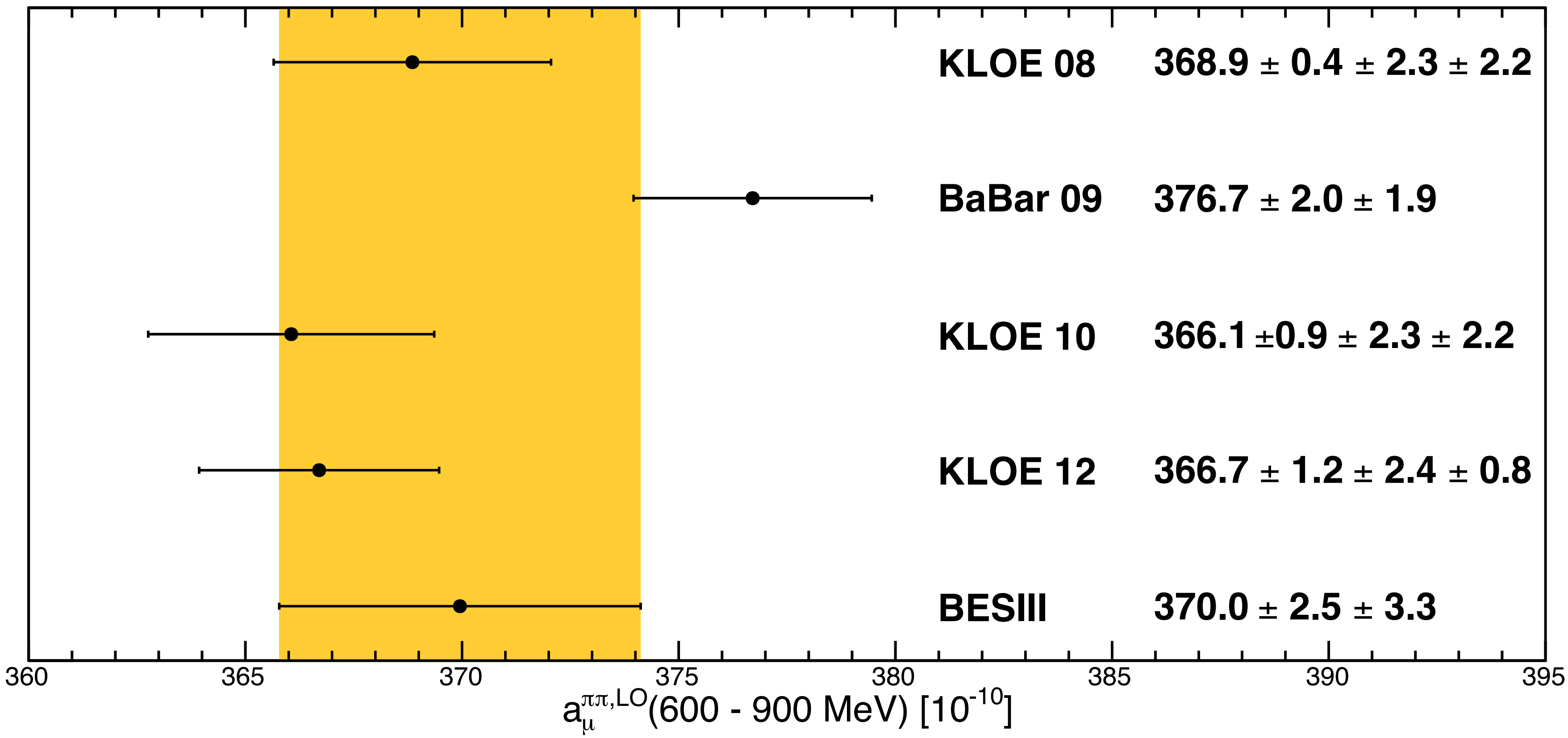




Good agreement with previous KLOE results, marginally consistent with BaBar;

BESIII `interpolates' between the two:

$\pi^+\pi^-$: new data from BESIII; arXiv:1507.08188v2

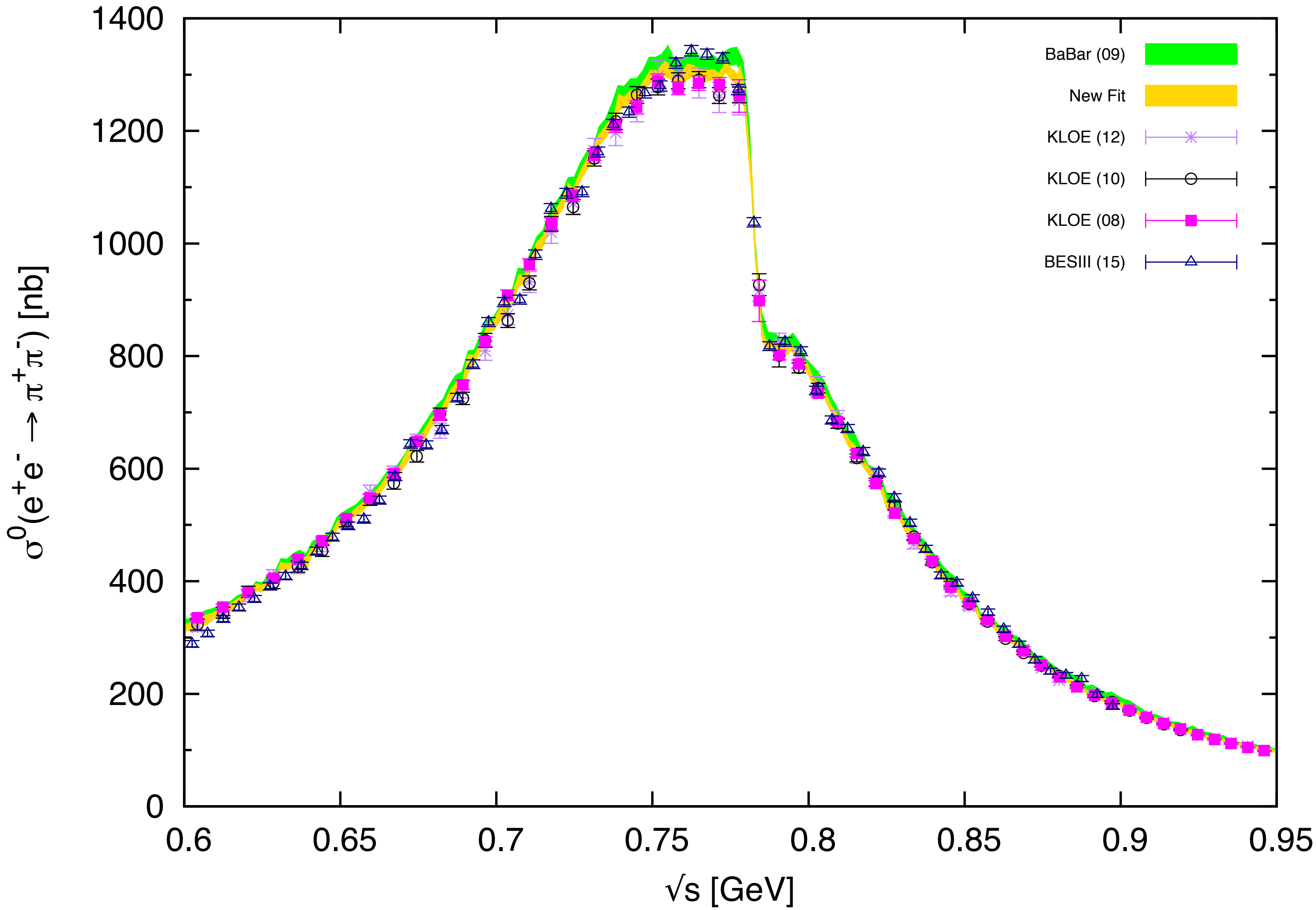


[g-2 integral and plot corrected in v2 after us finding a value different from the one of v1]

$\pi^+\pi^-$: Effect of KLOE12 + BESIII data in `global' 2π fit

Very preliminary first results (this Monday) from my PhD student Alex Kheshavarzi:

ISR data comparison in ρ peak region and new fit band:



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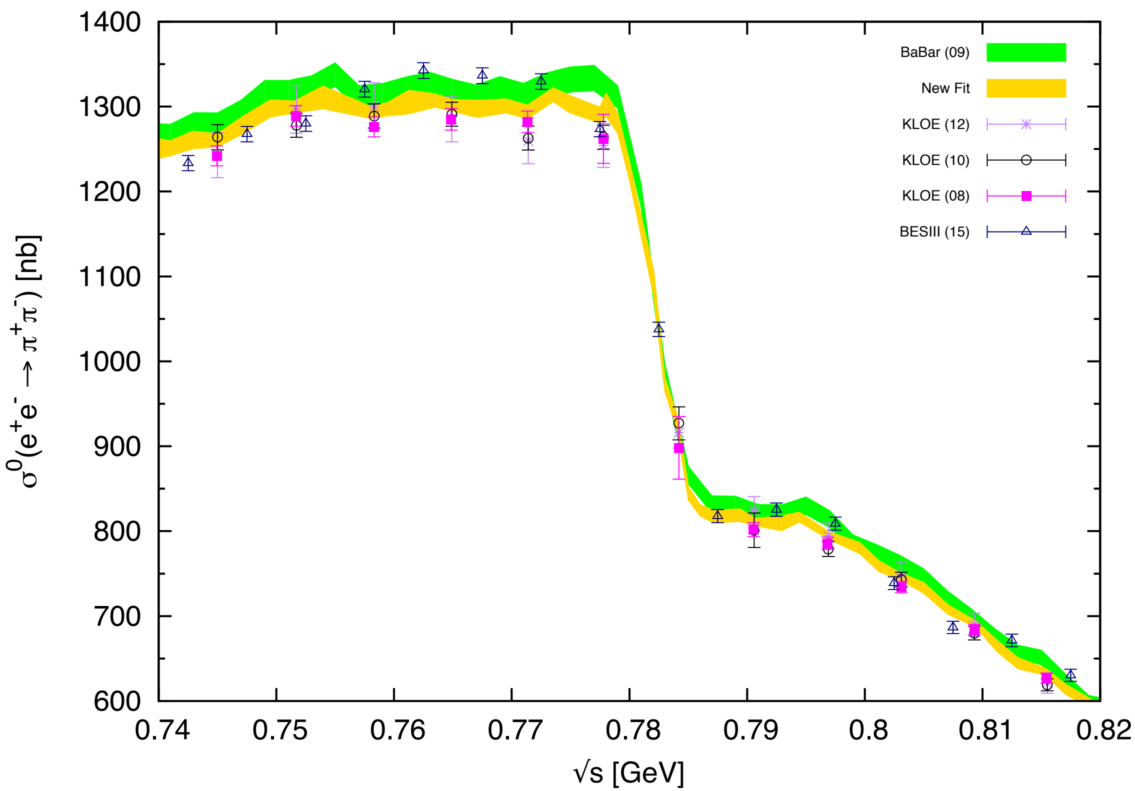
Zoom into the ρ-ω interference region:



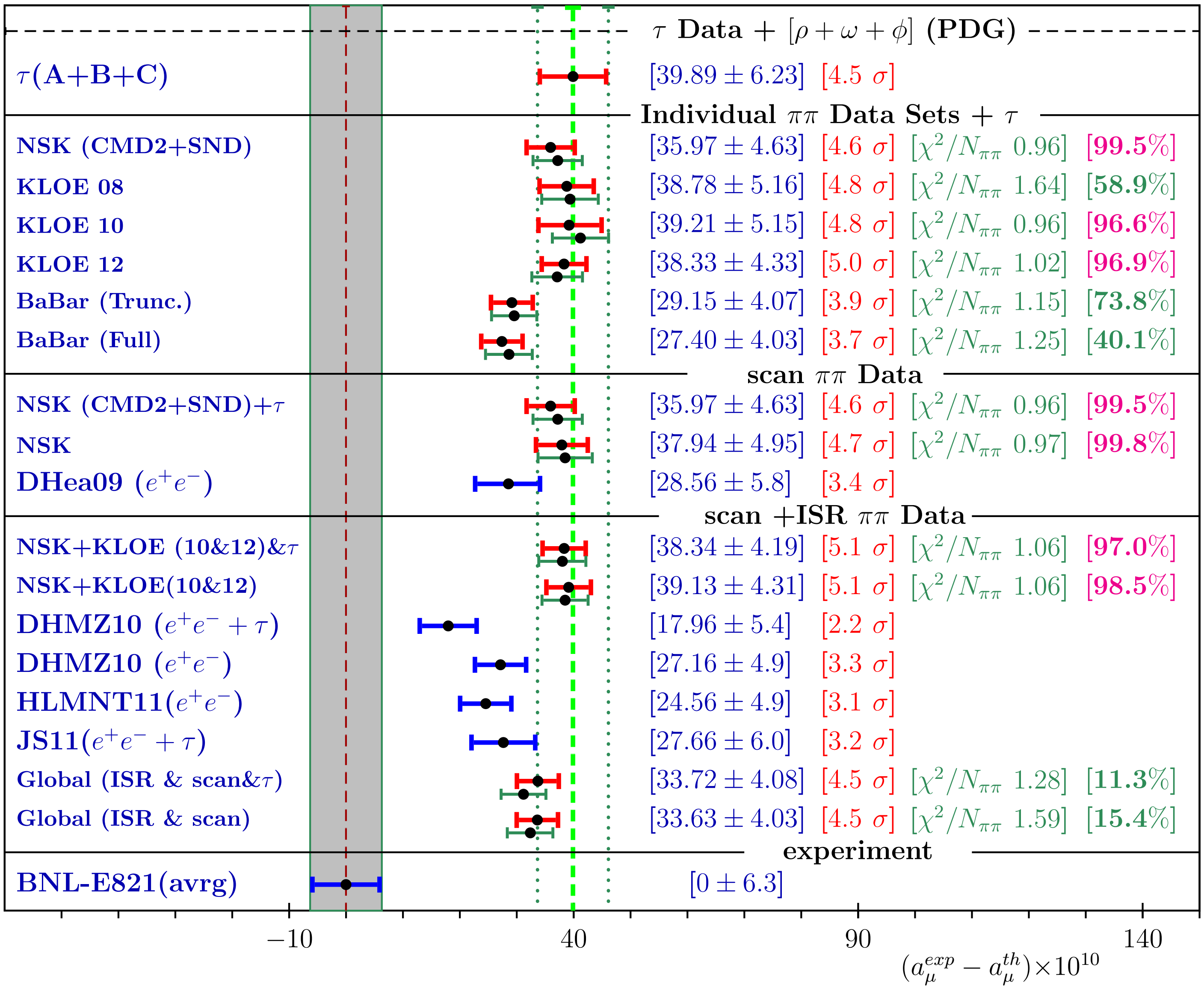
Very prel. numbers, for indication only:

(range 0.305 … 2 GeV, units of 10^{-10})

- all sets and fit as in HLMNT11:
  505.8 ± 3.1
- including now also KLOE12 and the new BESIII data:
  504.3 ± 2.6

-> improvement in error, but numbers will still change.

Hot from the arXiv: Benayoun et al., 1507.02943



Updated anal. (now with fitted normal. factors) in global fit based on HLS model:

🡐 `preferred' has 5σ already, from both aggressive errors and shifts due to the HLS model (and the fit?)

Hot from the arXiv: Benayoun et al., 1507.02943

Table 4 from their paper showing shifts and error improvements:

Channel	$A = m$	$A = M_0$	$A = M(\vec{a})$ (variable)	Exp. Value
$\pi^+\pi^-$	494.57 ± 1.48	494.01 ± 1.11	493.80 ± 1.00	496.38 ± 3.13
$\pi^0\gamma$	4.53 ± 0.04	4.54 ± 0.04	4.54 ± 0.04	3.67 ± 0.11
$\eta\gamma$	0.64 ± 0.01	0.64 ± 0.01	0.64 ± 0.01	0.56 ± 0.02
$\pi^+\pi^-\pi^0$	40.83 ± 0.58	40.85 ± 0.58	40.87 ± 0.57	43.54 ± 1.29
$K_L K_S$	11.56 ± 0.08	11.56 ± 0.08	11.56 ± 0.08	12.21 ± 0.33
K^+K^-	16.78 ± 0.20	16.77 ± 0.21	16.77 ± 0.20	17.72 ± 0.52
Total	569.19 ± 1.60	568.37 ± 1.27	568.17 ± 1.17	574.08 ± 3.45

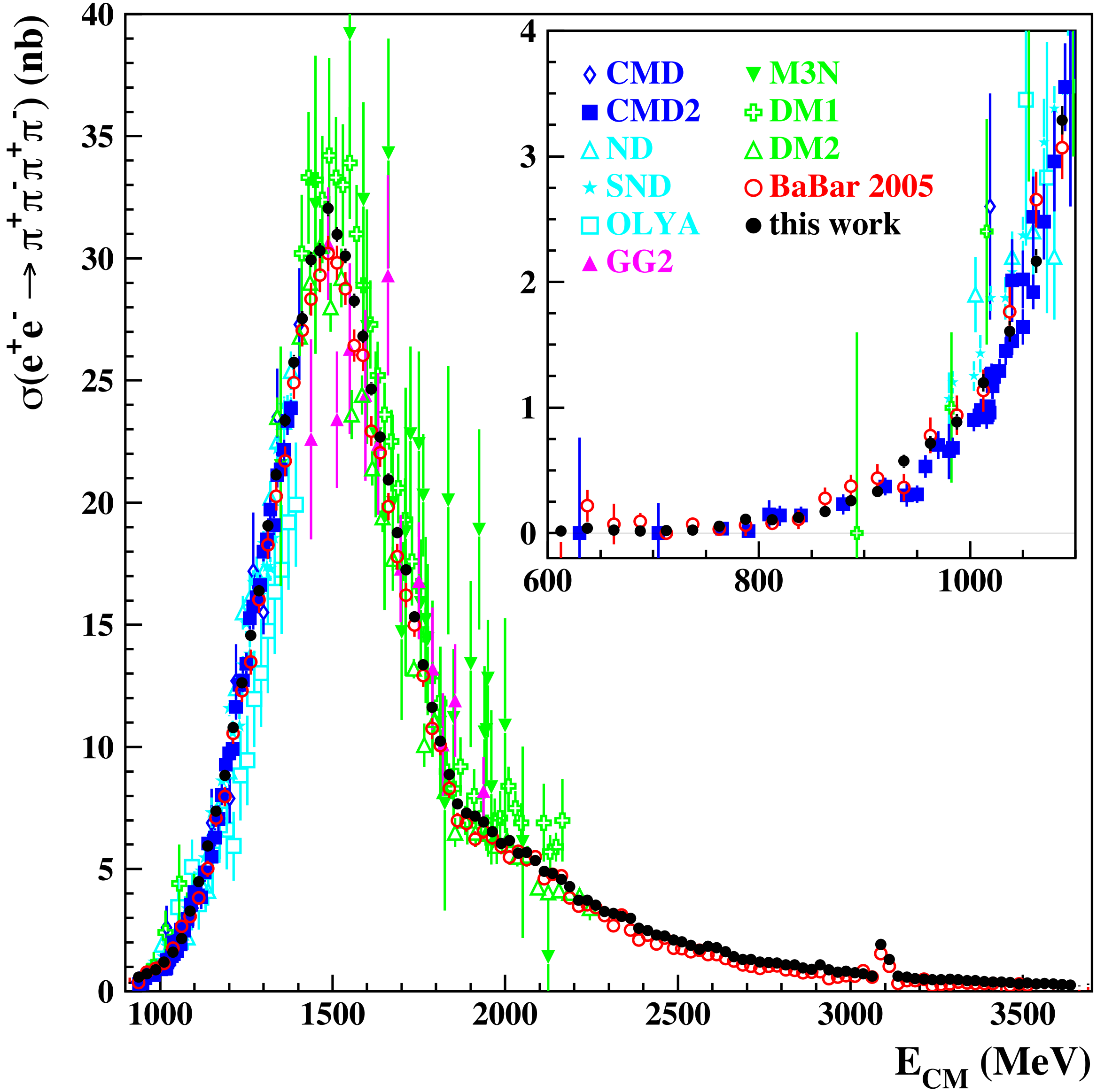
Table 4: The contributions to the muon LO–HVP from the various channels covered by BHLS from their respective thresholds to 1.05 GeV in units of 10^{-10} at start and after iteration. The last column displays the direct numerical integration of the various spectra used within BHLS. The $\pi^+\pi^-$ data samples considered are those flagged by "Combination 2" in Table 2.

➔ 2π data choices lead to very different results;
if BaBar is used (untruncated) then their fit is worse (incompatibilities mainly between BaBar and other data), their mean and error are larger and the discrepancy goes to 3.7σ.

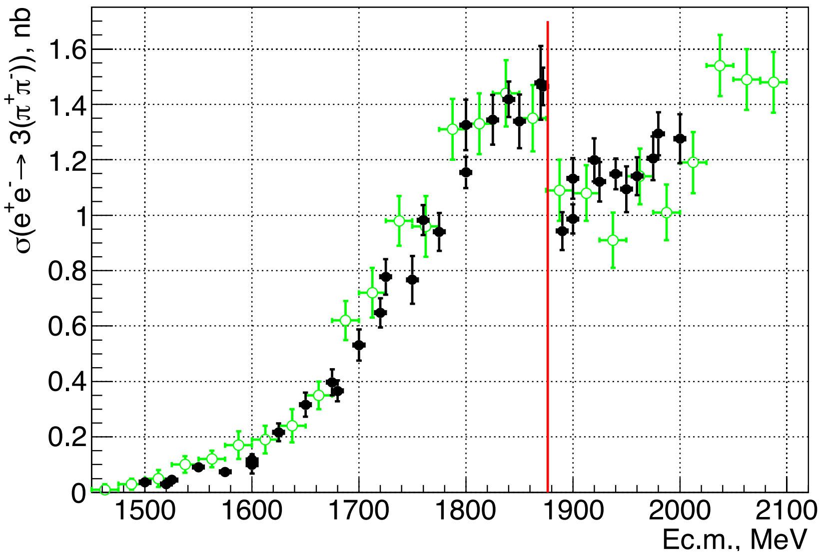
σ_{had}: recent new data: $2\pi^+2\pi^-(\gamma)$ from BaBar

PRD85(2012)112009

- shift of $+0.3 \times 10^{-10}$ for a_μ
- error down to a third
- combination?

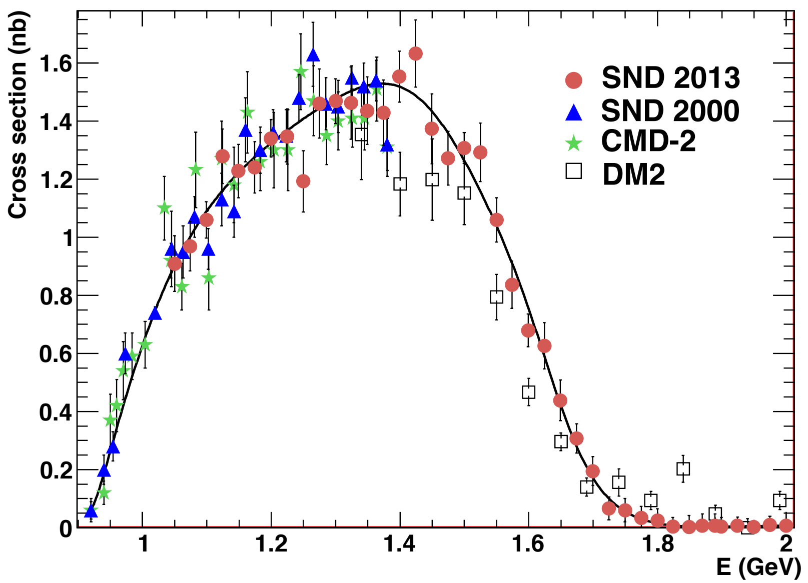


σ_{had}: recent new data from Novosibirsk



CMD-3 6π charged, PLB723(2013)82

- solid black: CMD-3, open green: BaBar
- full analysis will include $2(\pi^+\pi^-\pi^0)$



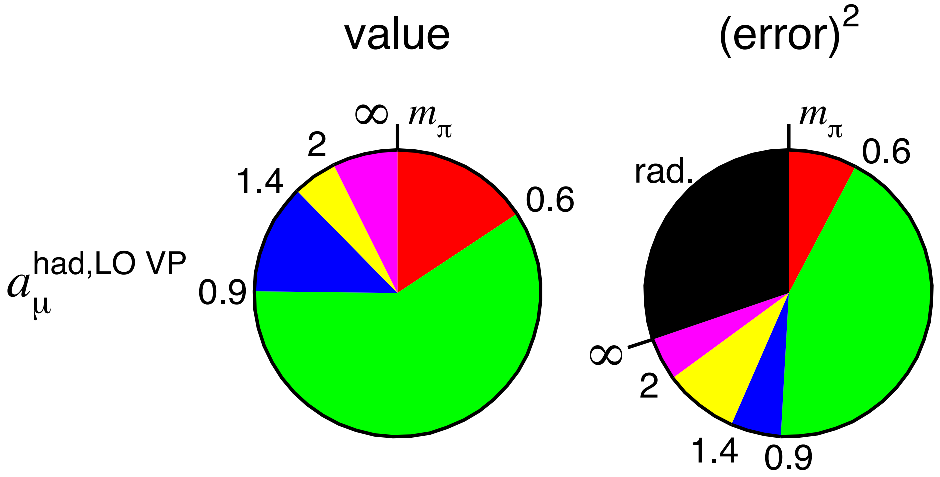
SND $\omega\pi^0$, PRD88(2013)054013

- many more analyses reported with preliminary results, incl. 3π, 4π(2n)
- looking forward to rich harvest from SND and CMD-3

Outlook: Future improvements for a_μ^{HVP}

- Most important 2π:
  - close to threshold important; possible info also from space-like
  - more data already now and more expected well before new g-2 EXPs
  - understand discrepancy between sets, especially `BaBar puzzle'?!
  - possibility of direct scan & ISR in the same experiment? Lattice?!
- $\sqrt{s} > 1.4$ GeV: higher energies will improve with input from SND, CMD-3, BESIII, BaBar
- With channels more complete, test/ replace iso-spin corrections
- Very good prospects to significantly squeeze the dominant HLO error!

Pie diagrams from HLMNT 11:



3-5 year plan:

- 2π: error down by about 30-50%
- subleading channels: by factor 2-3
- $\sqrt{s} > 2$ GeV: by about a factor 2

→ I believe we can half the HVP error in time for the new g-2 EXPs.

Conclusions:

- All sectors of the Standard Model prediction of g-2 have been scrutinised a lot in recent years
- No major changes recently, but discrepancy > 3σ consolidated
- With the next round of hadronic data it should be possible to push the error down significantly, hopefully halfing Δa_μ^{HVP}
- For this much more work will be needed (solve some puzzles)
- though Benayoun et al. already claim 5σ now
- But where is the NP?

Extras

Channels with biggest errors. PQCD at 2 GeV?

Importance of various 'channels' [Numbers from HLMNT, 'local error infl.', $\cdot 10^{-10}$]

- Errors contributions to a_μ from leading and subleading channels (ordered) up to 2 GeV

Purely from data:

channel	error
$\pi^+\pi^-$	3.09
$\pi^+\pi^-\pi^0\pi^0$	1.26
3π	0.99
$2\pi^+2\pi^-$	0.47
K^+K^-	0.46
$2\pi^+2\pi^-2\pi^0$	0.24
$K_S^0K_L^0$	0.16

'Higher multiplicity' region from 1.4 to 2 GeV with use of isospin relations for some channels: [Use of old inclusive data disfavoured.]

Channel	contr. $\pm$ error
$K\bar{K}2\pi$	3.31 ± 0.58
$\pi^+\pi^-4\pi^0$	0.28 ± 0.28
$\eta\pi^+\pi^-$	0.98 ± 0.24
$K\bar{K}\pi$	2.77 ± 0.15
$2\pi^+2\pi^-\pi^0$	1.20 ± 0.10

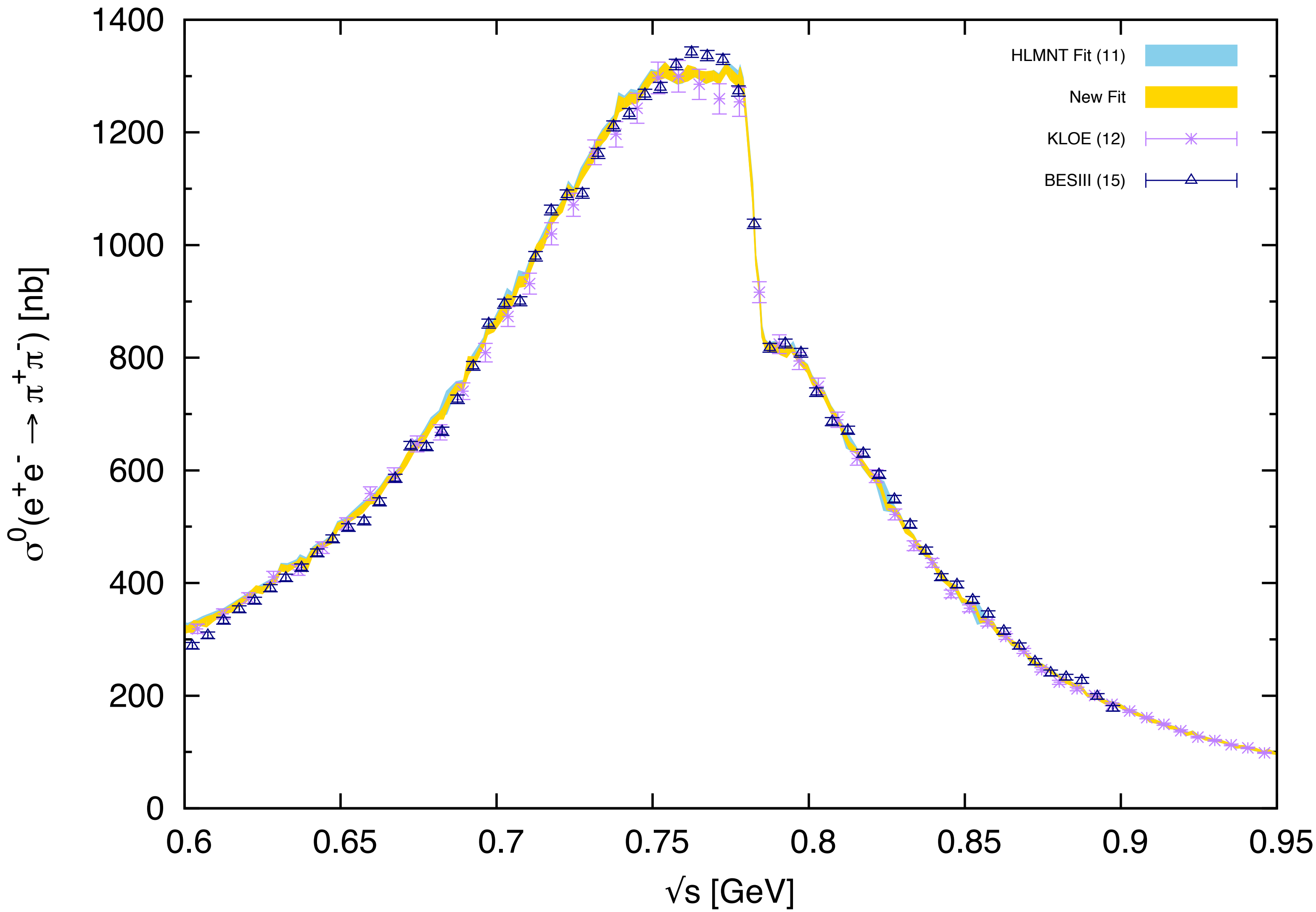
- 'Inclusive' region from 2 to ~ 11 GeV: $\mathbf{41.19 \pm 0.82}$

Can be 'squeezed' by using pQCD (done by DHMZ from 1.8 GeV);

region from 2 to 2.6 GeV: $\mathbf{15.69 \pm 0.63} \;\rightarrow\; \mathbf{14.49 \pm 0.13}$, only small changes for higher energies.

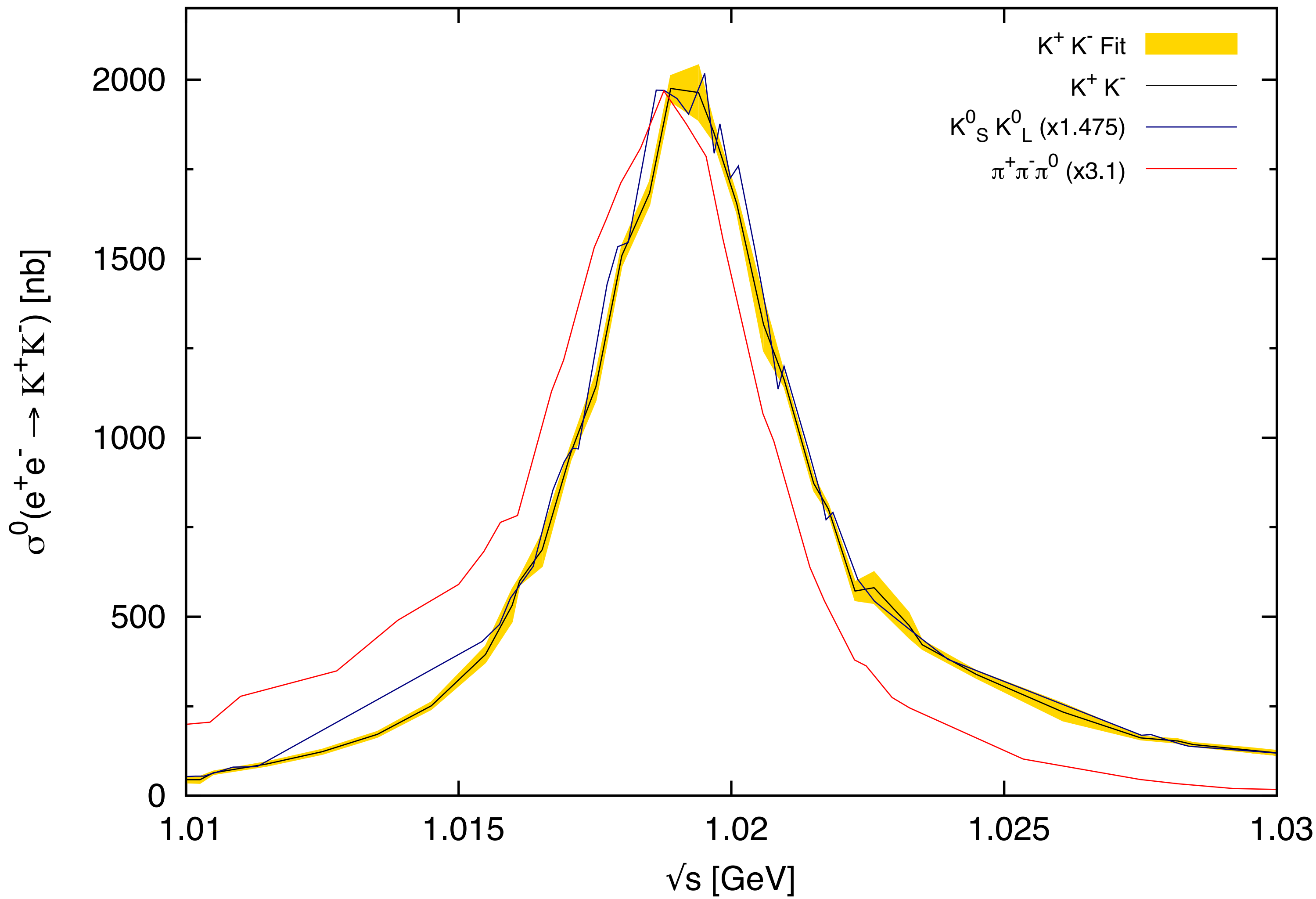
$\pi^+\pi^-$: Effect of KLOE12 + BESIII data in `global' 2π fit

Comparison old vs. new fit, with new ISR data:



σ_{had}: Φ in different final states K^+K^-, $K_s^0K_L^0$, $\pi^+\pi^-\pi^0$

Why we prefer to integrate data directly, or: How to not fit a resonance



HLMNT fit strategy:

Fitting The Data

Use a non-linear non-linear χ^2-function [HLMNT, 2012]

$$\chi^2(R_m, f_k) = \sum_{k=1}^{N_{exp}} \left(\frac{1-f_k}{df_k}\right)^2 + \left\{\sum_{m=1}^{N_{clu}} \sum_{i=1}^{N^{(k,m)}} \left(\frac{R_i^{(k,m)} - f_k R_m}{d\tilde{R}_i^{(k,m)}}\right)^2\right\}_{\text{w/o cov. mat}}$$

$$+ \left\{\sum_{m=1}^{N_{clu}} \sum_{i=1}^{N^{(k,m)}} \sum_{j=1}^{N^{(k,n)}} (R_i^{(k,m)} - f_k R_m) C^{-1}(m_i, n_j) (R_j^{(k,n)} - f_k R_n)\right\}$$

where N_{clu}, N_{exp} are total number of clusters,experiments.

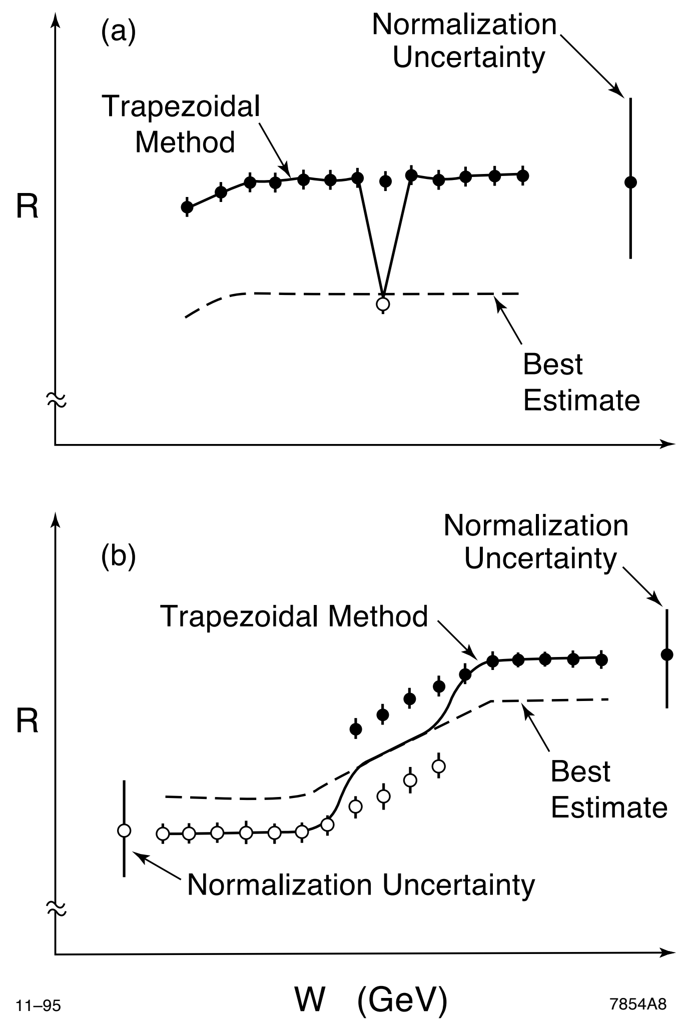
- Treat the statistical/systematic errors according to experimental data.
- Input covariance matrices where provided (last term!).

HLMNT fit strategy:

Processing the hadronic data: Clustering

- Need: combination of data from different experiments (for the same channel) with very different stat.+sys. errors and different energy ranges.
- Aims:
  - $\longrightarrow$ Make maximal use of (normalization of) precise data.
  - $\longrightarrow$ Don't suppress shape info. of older data.
  - $\longrightarrow$ Have as few theor. constraints on R as possible (like pQCD, BW resonance shapes, fit by polynomials...).
- Solution: 'A fit that's not a fit' $\leadsto$

Figure from M.L. Swartz:



HLMNT fit strategy:

- Our fit-model: piecewise constant R within a *Cluster* of a given (min.) size.
- Realization: Non-linear (numerical, iterative) χ^2-minimalization of:

$$\chi^2(\bar{R}_m, f_k) = \sum_{k=1}^{\#Exp} \left[(1 - f_k)/\mathrm{d}f_k\right]^2 + \sum_{m=1}^{\#Cl} \sum_{i=1}^{N_{\{k,m\}}} \left[\left(R_i^{\{k,m\}} - f_k \bar{R}_m\right)/\mathrm{d}R_i^{\{k,m\}}\right]^2$$

Given a binning of all R data $R_i^{\{k,m\}} \pm \mathrm{d}R_i^{\{k,m\}} \pm \mathrm{d}f_k \cdot R_i^{\{k,m\}}$ (from k exp., in m clusters), the fit returns the mean values $\bar{R}_m$ (and the renormalizations f_k of $R_i^{\{k,m\}} \pm \mathrm{d}R_i^{\{k,m\}}$).

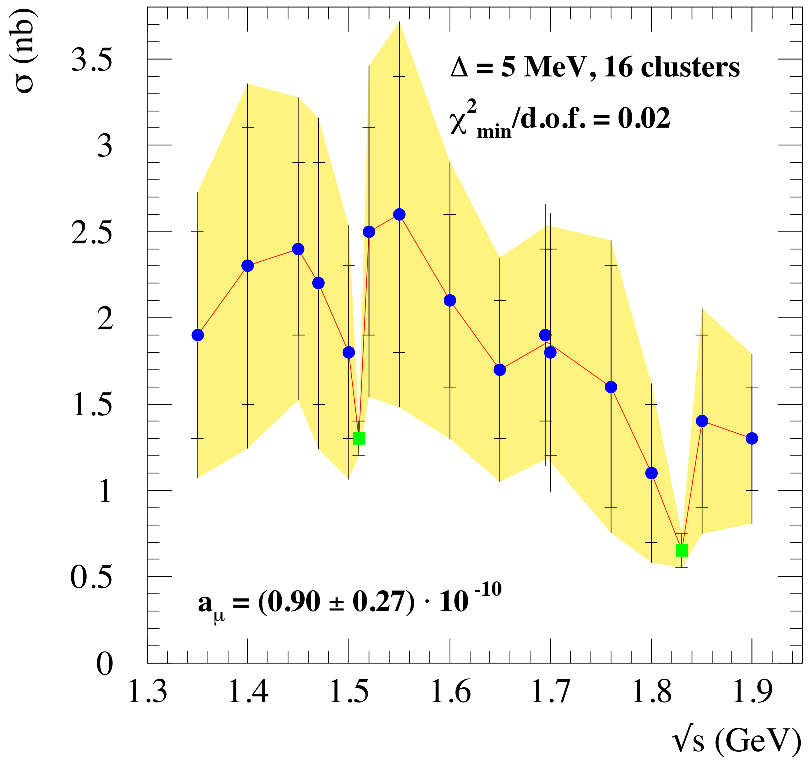
Advantages:

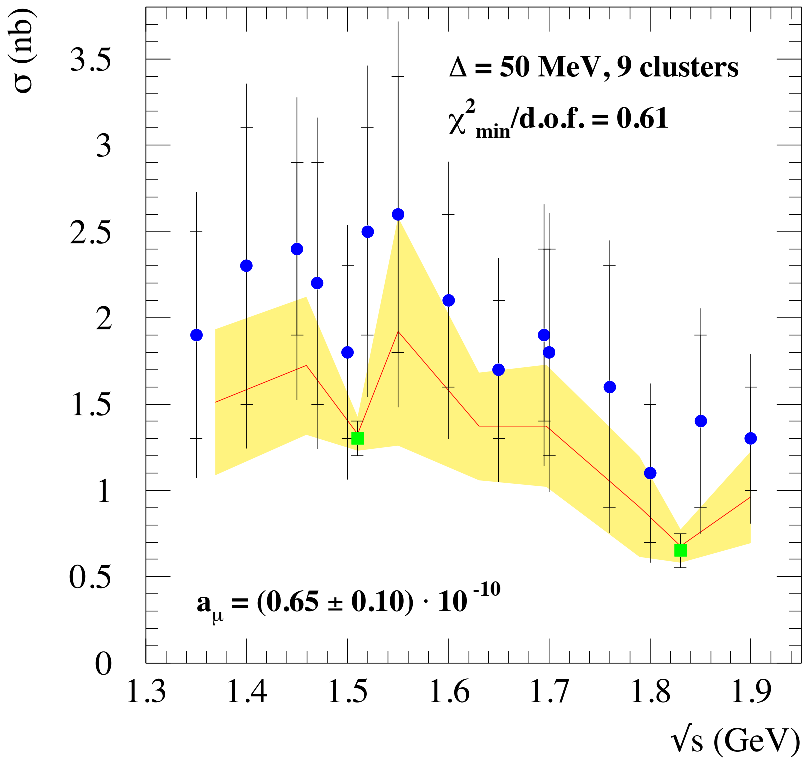
- No prejudice from TH-inspired modelling of R.
- Reliable error estimate using the complete covariance matrix (taking into account statistical and systematic (p.t.p. and overall) errors from all different experiments)
  $\hookrightarrow$ correlations over different energies important.
- Automatic check of data-consistency and fit-quality;
  minimal $\chi^2_{\mathrm{min}}/(d.o.f.)(\delta)$ determines choice of cluster size δ.
- Amazing stability of $a_\mu^{\mathrm{had,LO}}$ and its error.

HLMNT fit strategy:

How does it work? A few examples:

- Artificial 'demo' data for illustration:



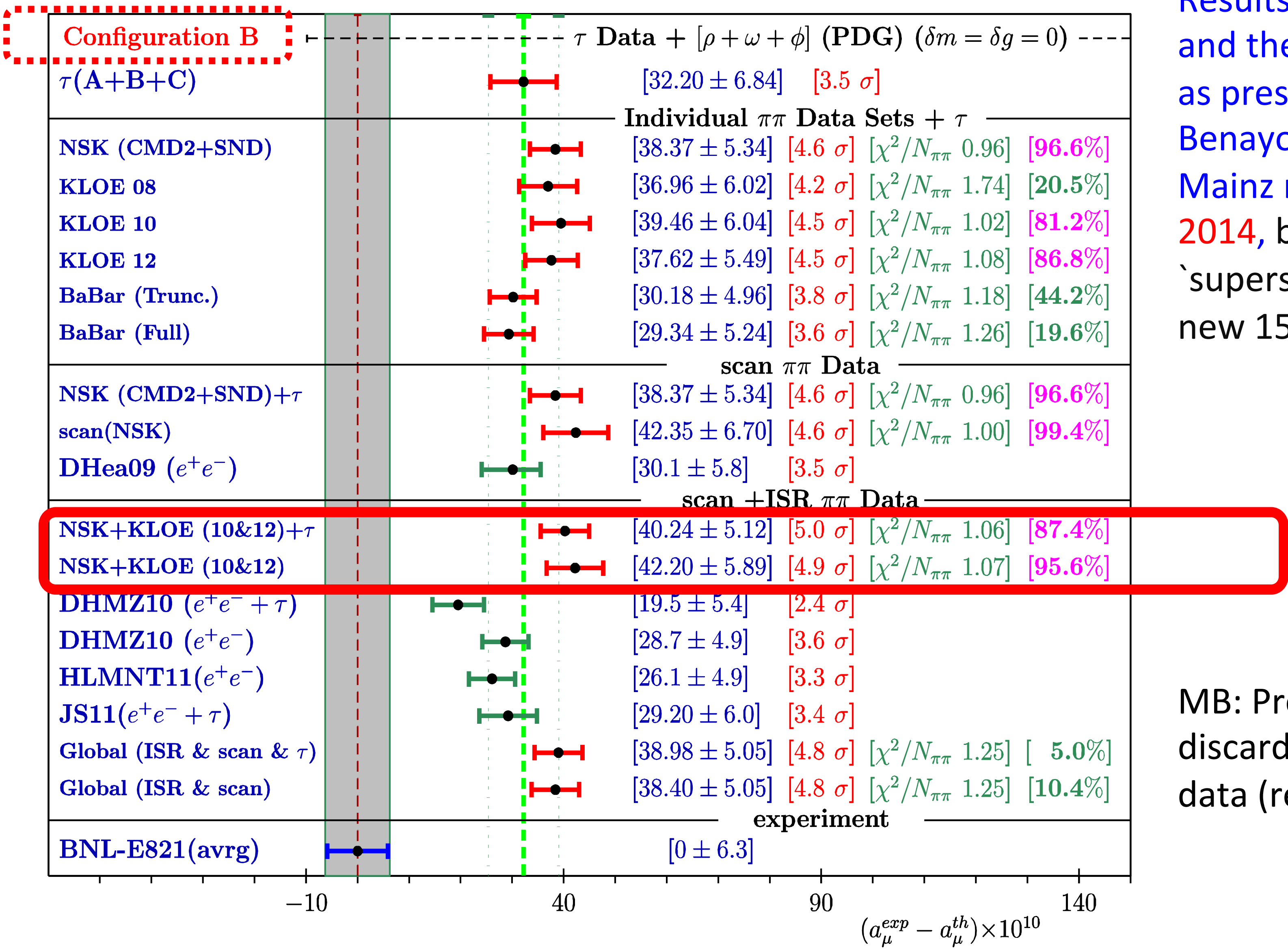


The two green 'high quality' points have 1% sys. error, the other set 30%

$\hookrightarrow$ 'maximal' adjustment of normalization of the latter by $1/1.35$;

$\hookrightarrow$ smaller a_μ value and error, fit still good, $\chi^2_{\rm min}/d.o.f. < 1$.

$\pi^+\pi^-$: HLS fit-based results from M Benayoun et al.



Results for g-2 and the discrepancy as presented by M. Benayoun at the Mainz meeting April 2014, but now `superseeded' by new 1507.02943.

MB: Preferred fits discard BaBar 2pi data (red framed)

$\pi^+\pi^-$: diff. betw. HLMNT & Benayoun et al (as of 2014)

- Taking only direct scan as baseline:
- Benayoun et al: -3.1 from HLS-based fit, -4.3 from KLOE10+12
- HLMNT: +5.5 from KLOE and BaBar (compared to scan only)

- So the big difference (~13×10^{-10}, 3.3 → 5σ) comes to a big part from the data input, i.e. if BaBar's 2π is used or not.
  (If used: error relatively poor despite stats due to inflation)

- Future SND, CMD-3, BELLE and BESIII 2π data may dilute the strong significance of BaBar
  [also more data from BaBar to be analysed!]

- Ideally find out why the different data sets are not consistent.
  If this could be achieved the 2π channel would be great!