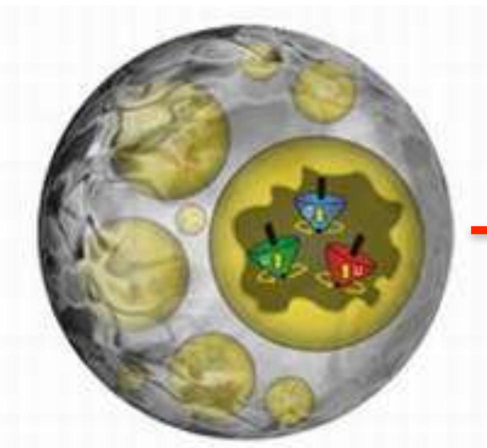
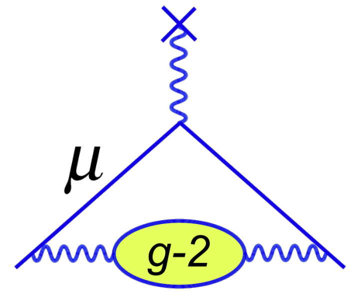
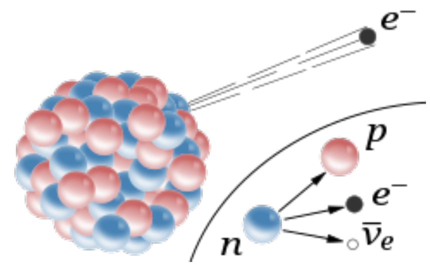
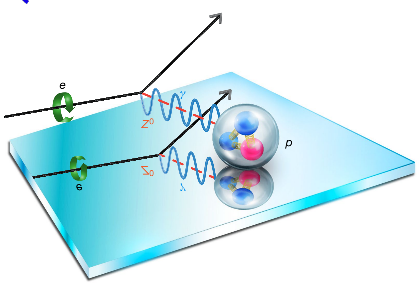
STRONG 2020

‘The strong interaction at the frontier of knowledge: fundamental research and applications’









WP21: JRA3 - PrecisionSM

QCD and precision hadron structurefor low-energy tests of the SM

Mikhail Gorshteyn - JGU Mainz

STRONG-2020 Kick-off meeting

October 23-25, 2019

JRA3 PrecisionSM - Composition

- JRA3 unifies 18 Institutions from 9 EU countries
- Fosters cooperation with 5 non-EU based partners (USA, Russia, China)
- Leading institutions: Mainz and Uppsala
- Spokespersons: Mikhail Gorshteyn (Mainz), Andrzej Kupsc (Uppsala)
- Goal: provide decisive support to the interpretation of low-energy precision tests of SM in the electroweak sector
- Dispersion relations as the main tool. Input extensively uses data, directly (HVP to muon g-2) or indirectly (HLbL to muon g-2, EW boxes for extraction of V_{ud} and weak mixing angle)

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824093.

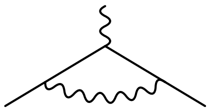
Muon g-2 and precision test of QED

Spokesperson: Andrzej Kupsc

Dirac theory: gyromagnetic ratio g=2

Small deviations observed in HF structure of atoms:
1948 explained by Schwinger - radiative correction

$$a_\mu = \frac{g-2}{2} = \frac{\alpha}{2\pi} = 0.001161$$



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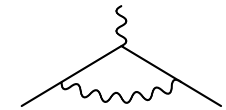
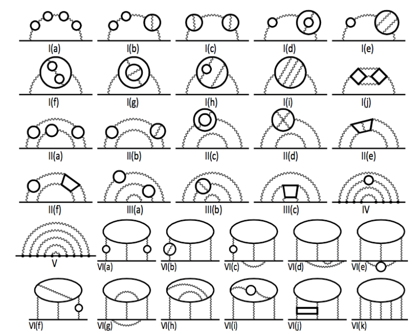


Since then QED calculations went a long way:
Aoyama, Hayakawa, Kinoshita, Nio 2012
Complete 5-loop QED calculation >12000 diagrams



a_μ^{QED} = 116 584 718.951 (0.009) (0.019) (0.007) (0.077) × 10^{-11}

errors from: lepton masses, 4-loop, 5-loop, α from ^{87}Rb

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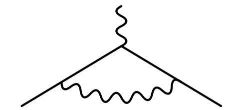

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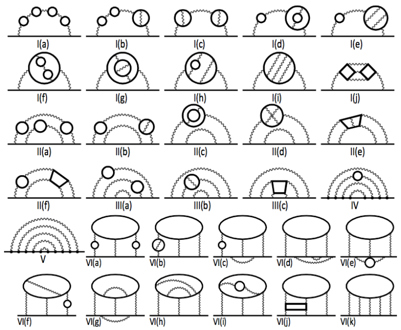

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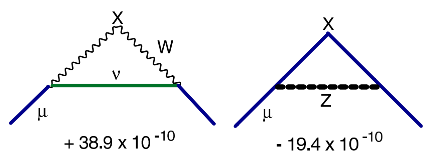
Electroweak corrections 1 and 2-loop
Czarnecki, Krause, Marciano, Vainshtein;
Knecht, Peris, Perrotet, de Rafael; Gnedinger, Stöckinger, Kim

$a_\mu^{EW(1+2\ loop)} = (153.6 \pm 1.0) \times 10^{-11}$



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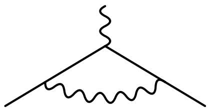

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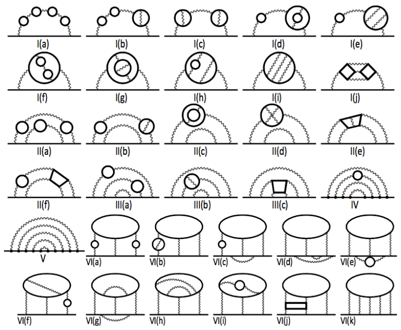

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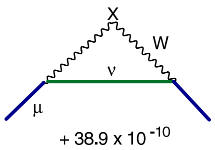
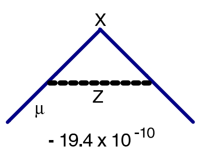
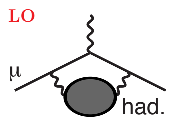
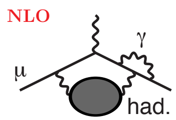


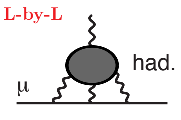


Hadronic corrections 2 and 3-loop: main limitation

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







Main focus of *Muon g-2 Theory Initiative*

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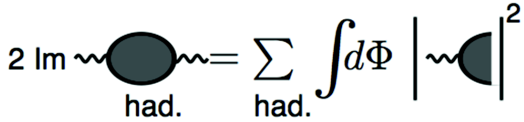
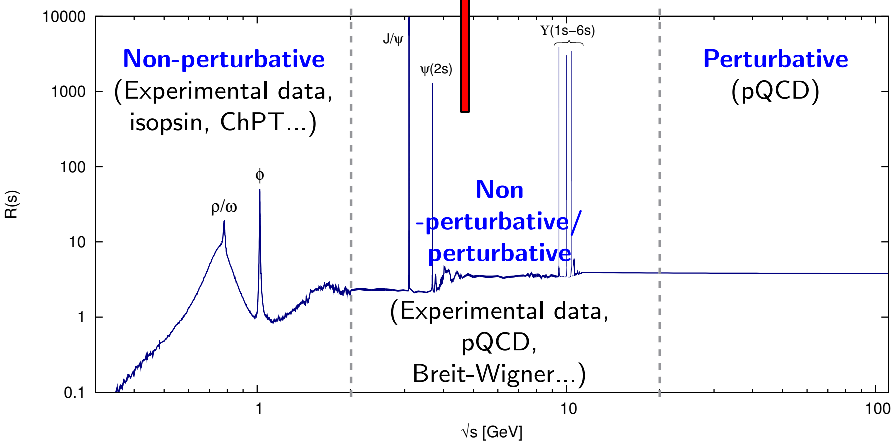
HVP Contribution to a_μ from Dispersion Relations

For HVP ⇒



⇒ $$\mathrm{Im}\Pi_{\mathrm{had}}(s) = \left(\frac{s}{4\pi\alpha}\right)\sigma_{\mathrm{had}}(s)$$

$$a_\mu^{\mathrm{had,\,LO\,VP}} = \frac{\alpha^2}{3\pi^2}\int_{s_{th}}^{\infty}\frac{\mathrm{d}s}{s}R(s)K(s),\ \text{where}\ R(s) = \frac{\sigma^0_{\mathrm{had},\gamma}(s)}{4\pi\alpha^2/3s}$$



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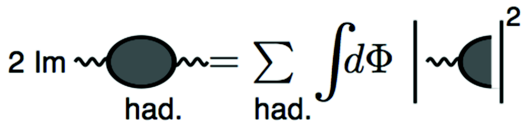
For HVP ⇒ 

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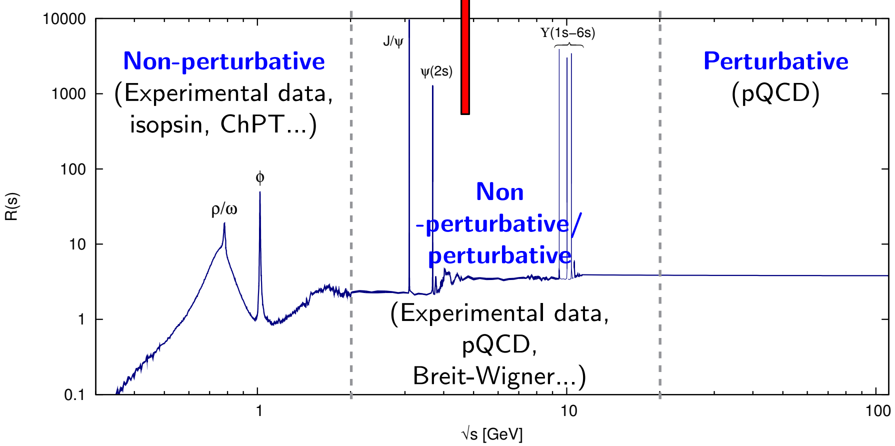
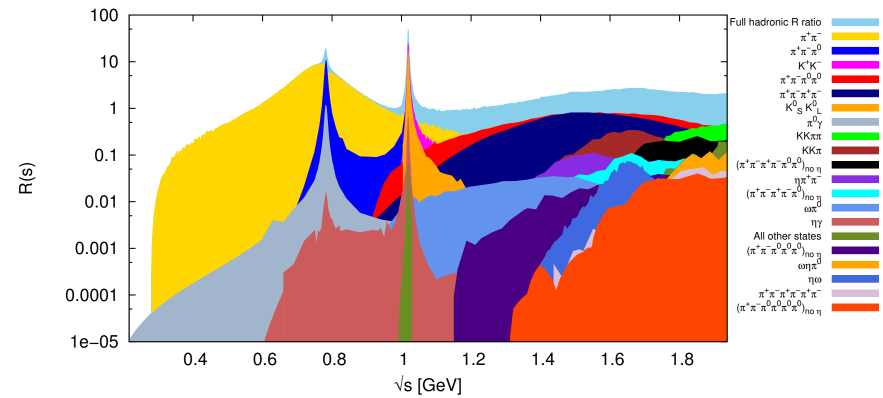


Low energies: sum ~35 exclusive channels (2π, 3π, 4π, 5π, 6π, KK, KKπ, KKππ, ηπ, …,)
Below 0.9 GeV dominated by 2π



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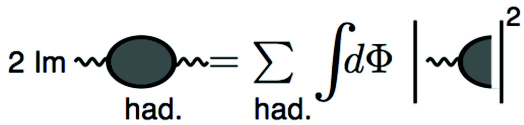
HVP Contribution to a_μ from Dispersion Relations

For HVP $\Rightarrow$  $\Rightarrow$ $\mathrm{Im}\Pi_{\mathrm{had}}(s) = \left(\frac{s}{4\pi\alpha}\right)\sigma_{\mathrm{had}}(s)$

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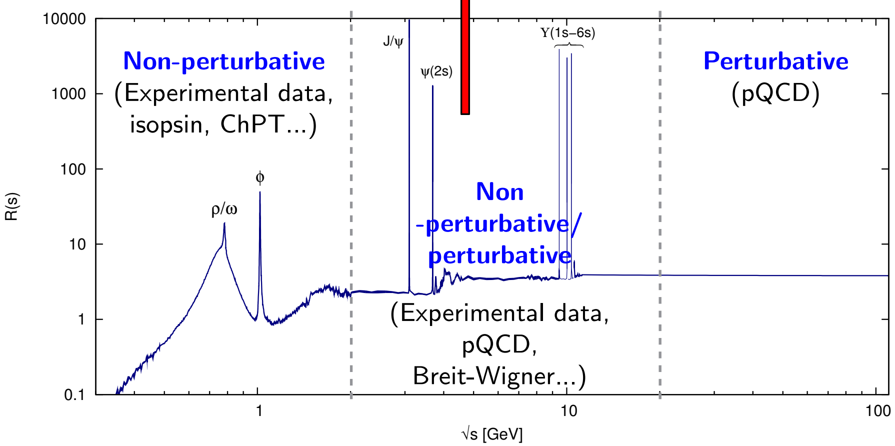

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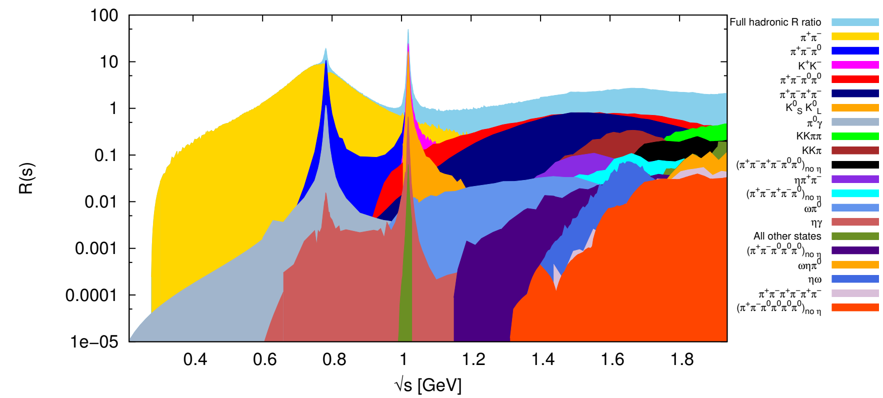

$$a_\mu^{\mathrm{had,\,LO\,VP}} = (693.3 \pm 2.5)\times 10^{-11} \quad a_\mu^{\mathrm{had,\,NLO\,VP}} = -(9.82 \pm 0.04)\times 10^{-11} \quad a_\mu^{\mathrm{had,\,NNLO\,VP}} = (1.24 \pm 0.01)\times 10^{-11}$$

Keshavarzi, Nomura, Teubner 2018

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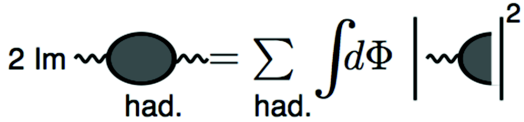
For HVP $\Rightarrow$ 

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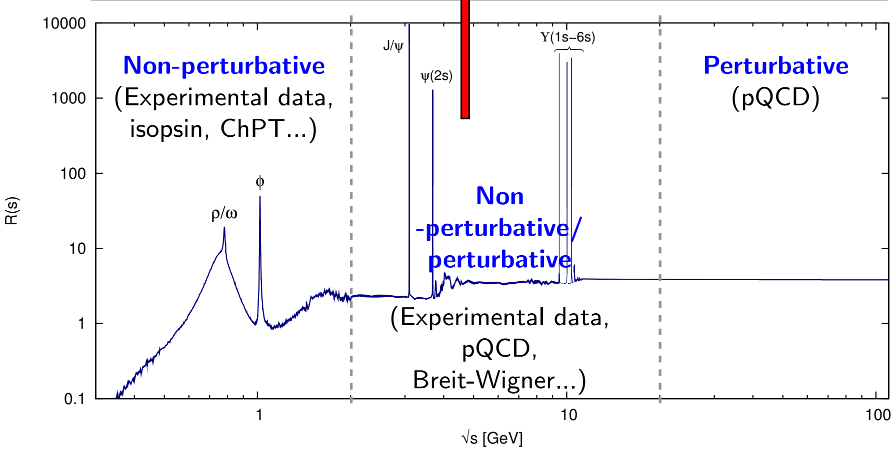

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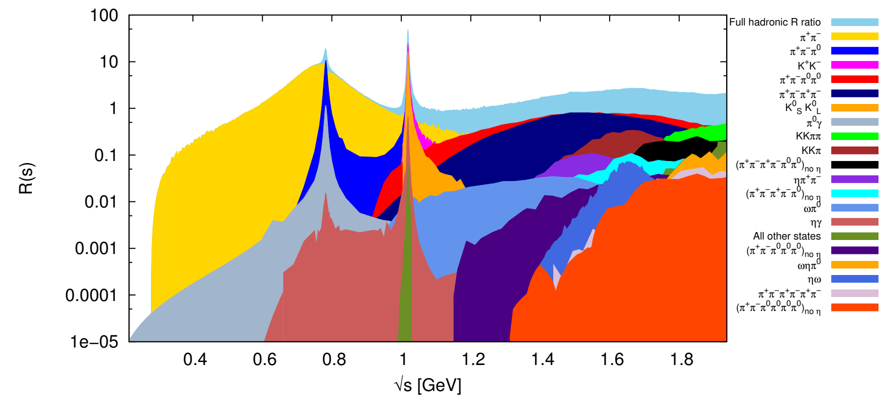

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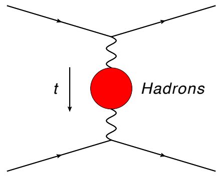
Keshavarzi, Nomura, Teubner 2018

Novel idea: MUonE @ CERN: 150 GeV muons scattering on atomic electrons
Probe the HVP in the space like regime - complementary to the R-scan
Carlone Calame, Passera, Trentadue, Venanzoni 2014



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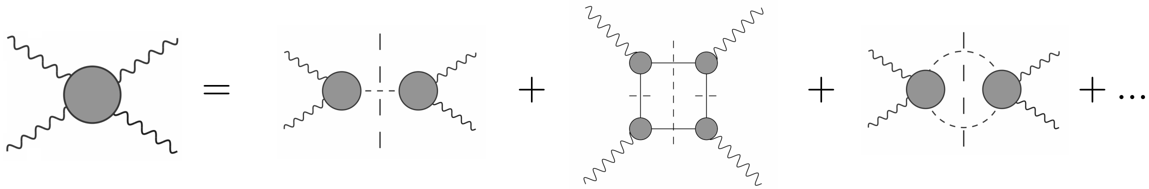
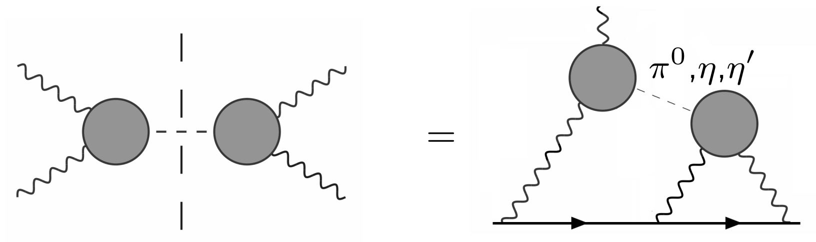
HVP Contribution to a_μ from Dispersion Relations

Hadronic LbL contribution is constrained by the data (but not fully determined)

For HLbL $\Rightarrow \Pi_{\mu\nu\lambda\sigma} = \Pi^{\text{pole}}_{\mu\nu\lambda\sigma} + \Pi^{\text{box}}_{\mu\nu\lambda\sigma} + \bar{\Pi}_{\mu\nu\lambda\sigma} + \dots$

$\Rightarrow$ 

$\Rightarrow$ Dominated by pole (pseudoscalar exchange) contributions

$\Pi^{\text{pole}}_{\mu\nu\lambda\sigma} =$ 

$\Rightarrow$ Sum all possible diagrams to get a_μ^{HLbL}

Pauk, Vanderhaeghen 2014;
Colangelo, Hoferichter, Procura, Stoffer 2017

Summary of HLbL contribution of (Colangelo, INT g-2 workshop September 2019):

$$a_\mu^{\text{HLbL}} \times 10^{11} = 93.8(4.0)^{\text{PS poles}} - 15.9(2)^{\text{pion box}} - 8(1)^{\text{S-wave}\ \pi\pi} - 2(3)^{\text{S,T} > 1\,\text{GeV}} + 8(3)^{\text{Axial}} + 10(10)^{\text{SD}} = 85 \pm (12 - 21)$$

Danilkin, Redmer, Vanderhaeghen 2019 $\quad a_\mu^{\text{HLbL}} \times 10^{11} = 87 \pm 13$

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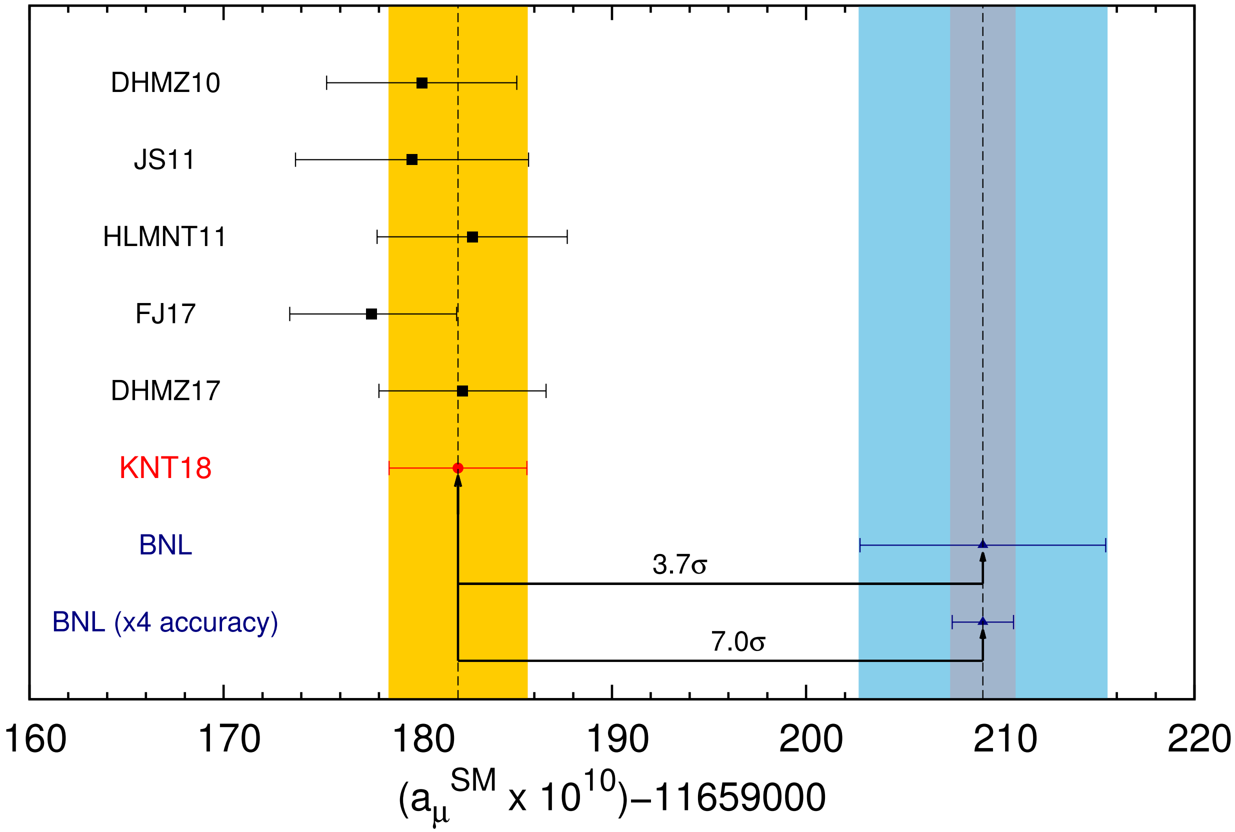
Muon g-2 Theory vs. Experiment

Teuber at INT g-2 workshop September 2019



New experiments: E989@FNAL (concluded - analysis), E34@J-PARC (start 2022 on): will reduce the exp. error by factor 4;

If central value stays — 7σ discrepancy; Theory uncertainty needs further reduction

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Hyperon and Antihyperon Physics

nature physics LETTERS
https://doi.org/10.1038/s41567-019-0494-8

Polarization and entanglement in baryon-antibaryon pair production in electron-positron annihilation

The BESIII Collaboration*

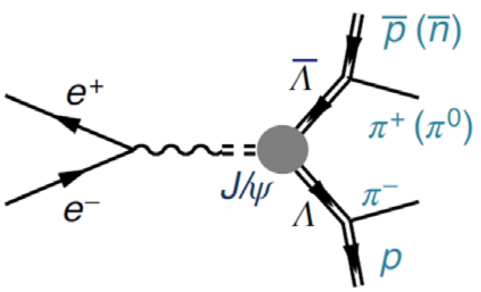
Online: May 6th

BESIII
arXiv:1808.08917

$e^+e^- \rightarrow J/\psi \rightarrow \Lambda\bar{\Lambda}$:

Observation of Λ transverse polarization

Determination of Λ decay asymmetry



G.Fäldt, AK PLB772 (2017) 16

E.Perotti,G.Fäldt,AK,S.Leupold,JJ.Song PRD99 (2019)056008

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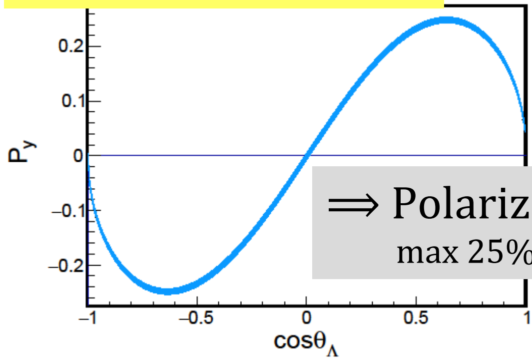
Hyperon and Antihyperon Physics

$\Delta\Phi = 42.3^o \pm 0.6^o \pm 0.5^o$



$\Longrightarrow$ Polarization:
max 25%

$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$

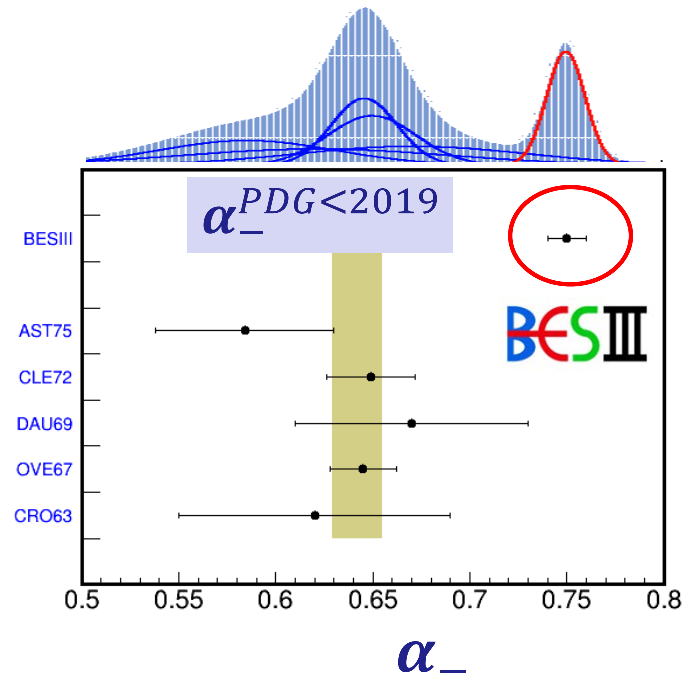
$\Delta I = \frac{1}{2}$ **rule violation**

CP test: $A_\Lambda = \dfrac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$

$A_\Lambda = -0.006 \pm 0.012 \pm 0.007$

$A_\Lambda = 0.013 \pm 0.021$
PS185 PRC54(96)1877

$\Lambda \rightarrow p\pi^-$: $\alpha_- = 0.750 \pm 0.009 \pm 0.004$



17(3)% larger

Included in the PDG 2019 update

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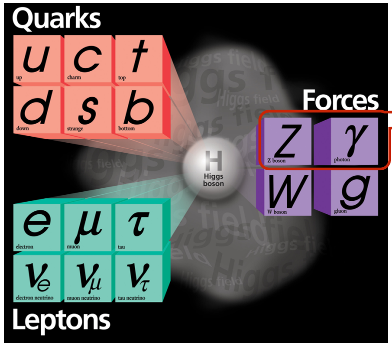
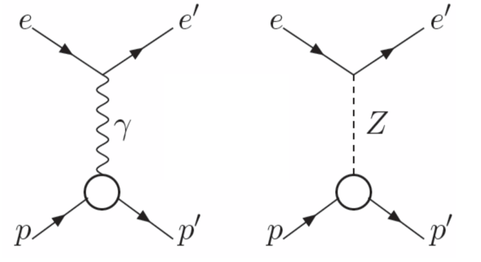
Precision determination of the weak mixing angle



Weak mixing angle - mixing of the NC gauge fields

$$\begin{pmatrix} \gamma \\ Z^0 \end{pmatrix} = \begin{pmatrix} \cos\theta_W & \sin\theta_W \\ -\sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} B^0 \\ W^0 \end{pmatrix}$$

WMA determines the relative strength of the weak NC vs. e.-m. interaction



$Q^p = +1$ $\quad$ $Q^p_W = 1-4\sin^2\theta_W$

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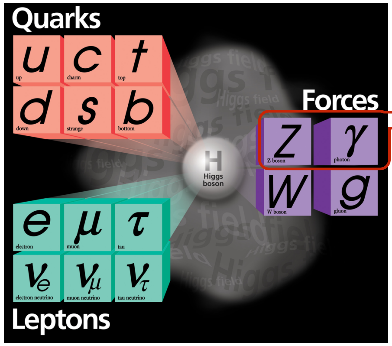

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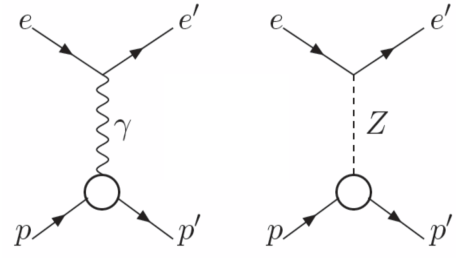

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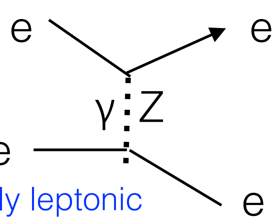
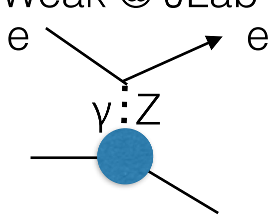
Møller scattering



Purely leptonic

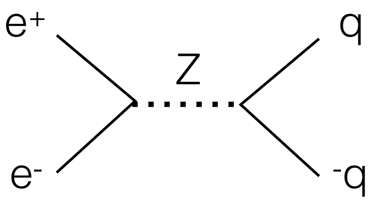
P2 MESA @ Mainz

Q-Weak @ JLab



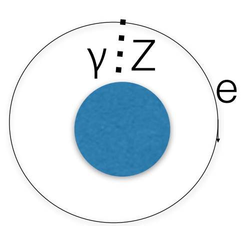
Coherent quarks in p or ^{12}C

Colliders



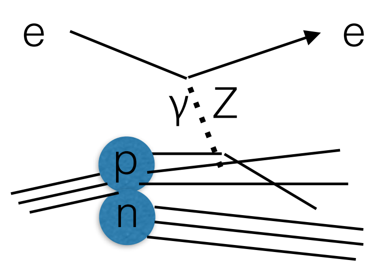
Z-pole measurement

Atomic PV



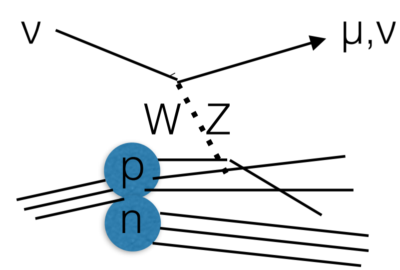
Coherent quarks in a nucleus

e-DIS @ JLab, EIC



Incoherent e-q scattering

ν-DIS @ NuTEV



Incoherent ν-q scattering

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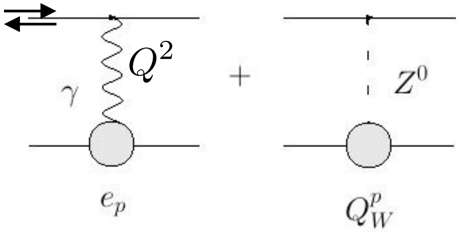
Weak charge of the proton from PVES

Elastic scattering of polarized electrons off unpolarized protons at low momentum transfer

$$A^{PV} = \frac{\sigma_{\rightarrow} - \sigma_{\leftarrow}}{\sigma_{\rightarrow} + \sigma_{\leftarrow}} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left[Q_W^p + Q^2 B(Q^2)\right]$$



Effects of hadronic structure - kinematically suppressed
Existing hadronic data and LQCD used to obtain B and δB

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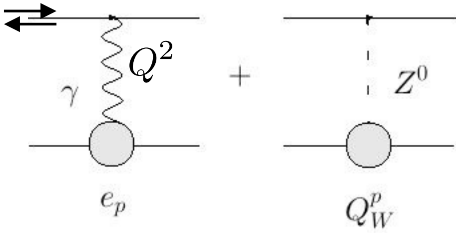

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Proton's weak charge suppressed in SM: $Q_W^p = 1 - 4\sin^2\theta_W \approx 0.07$
Reward: a factor ~ 16 gain in precision for $\sin^2\theta_W$

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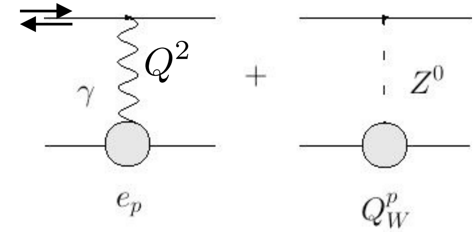

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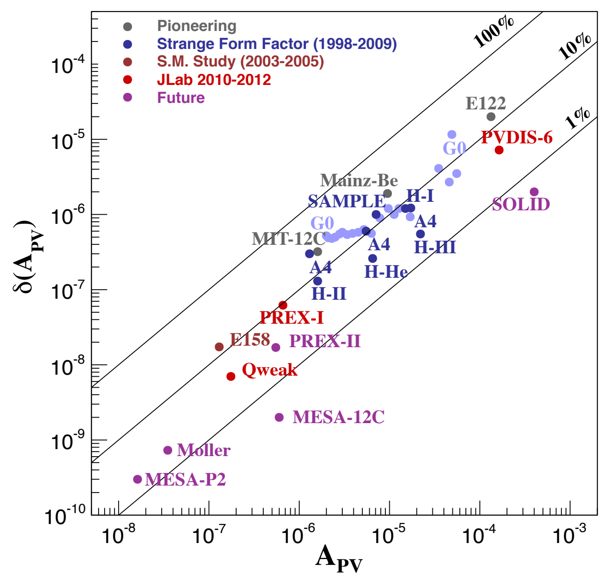
Qweak@JLab: Q^2~0.03 GeV^2
$A^{PV} = -(226.5 \pm 9.3)$ ppb
$Q_W^p = 0.0718 \pm 0.0044$ (rel. 6%)
D. Androic et al [Qweak Coll.], Nature 557 (2018), 207

P2 @ MESA/Mainz:
go down to Q^2~0.005 GeV^2
Unprecedented challenge: tiny asymmetry to 1.5%

PVeS Experiment Summary



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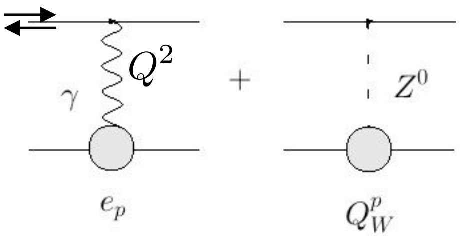

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Need to know radiative corrections sufficiently precise

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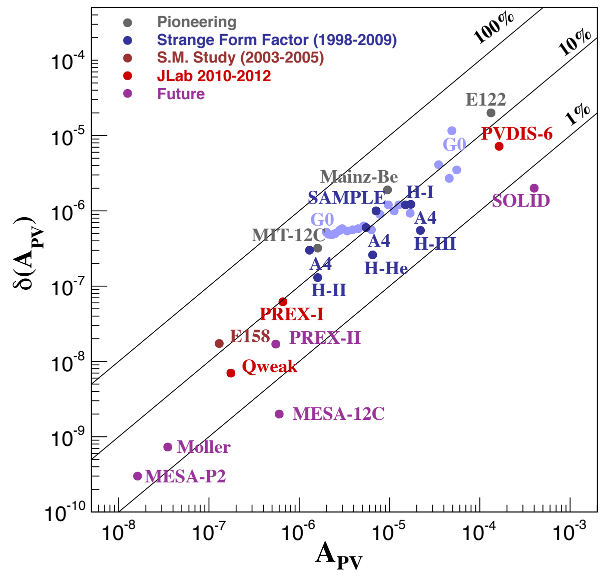

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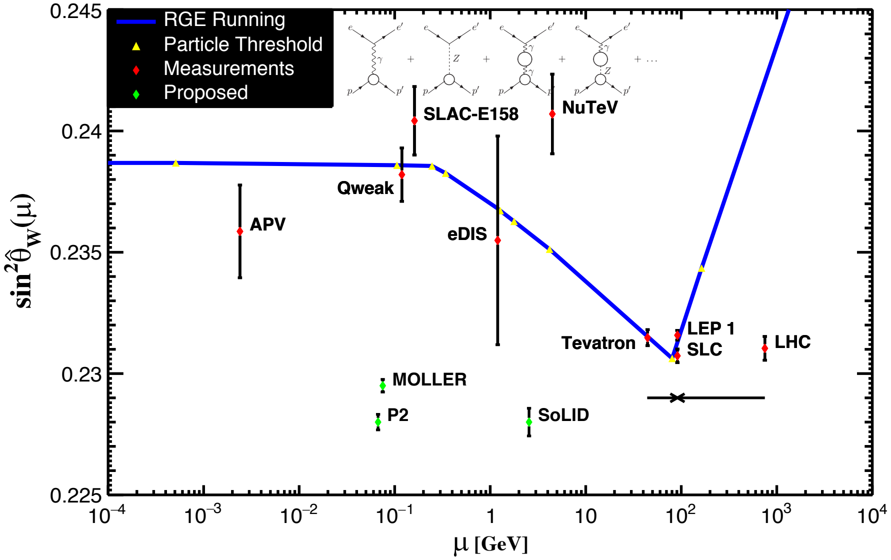
SM running of the weak mixing angle

Universal quantum corrections absorbed into running, scale-dependent $\sin^2\theta_W(\mu)$

SM uncertainty: few x 10^{-4}

Universal running - clean prediction of SM
Deviation anywhere - BSM signal



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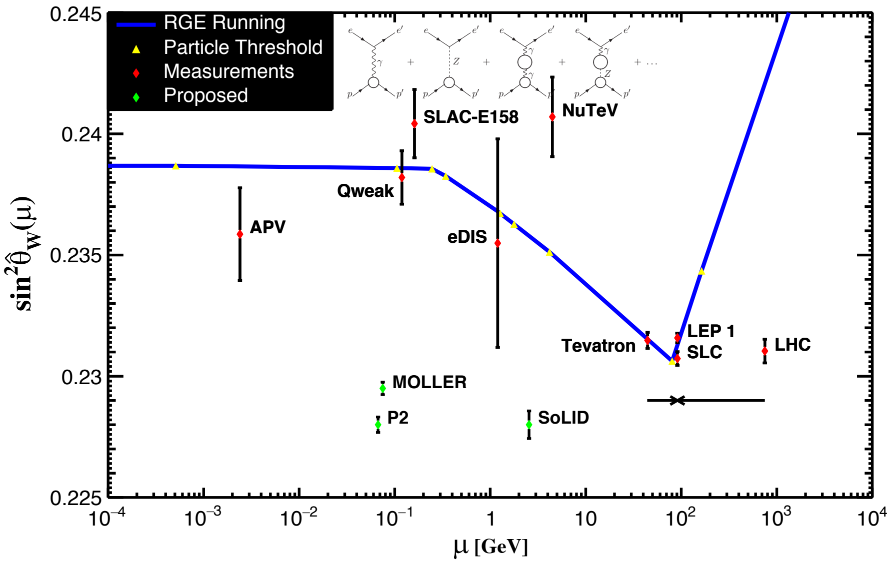

Process-specific SM radiative corrections:

$$Q_W^{\mathrm{p,\,1-loop}} = (1+\Delta_\rho+\Delta_e)(1-4\sin^2\hat{\theta}_W+\Delta_e') + \Box_{WW} + \Box_{ZZ} + \Box_{\gamma Z}$$

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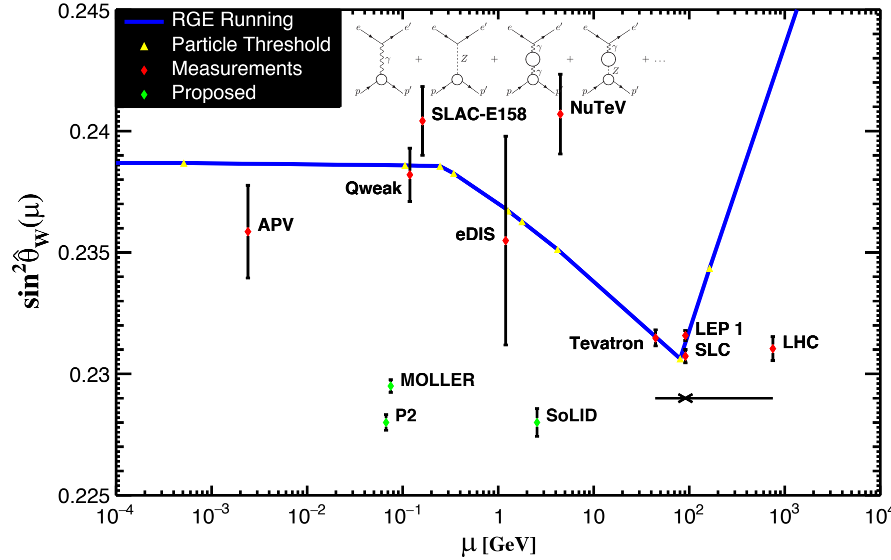

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Hadronic effects under control

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Marciano, Sirlin '83,84; Erler, Musolf '05

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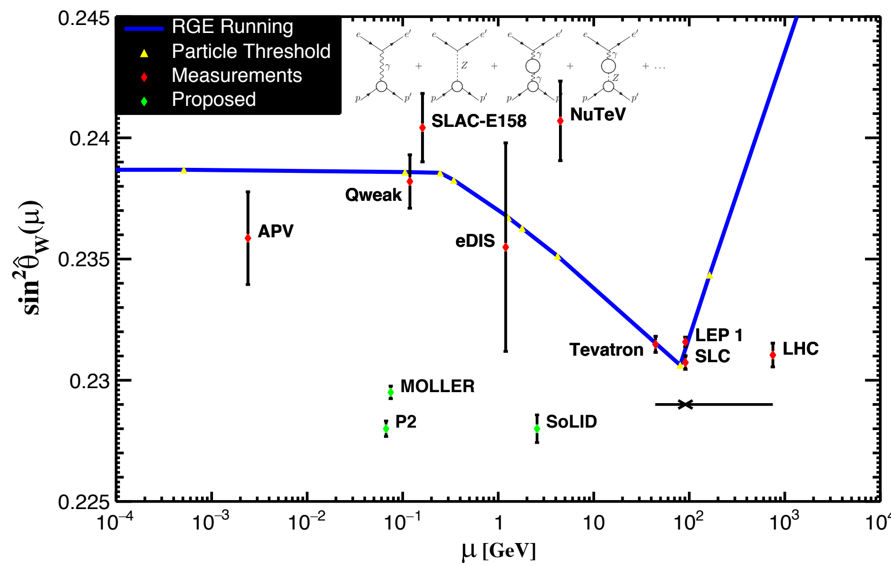

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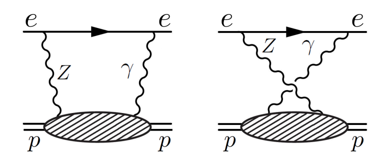

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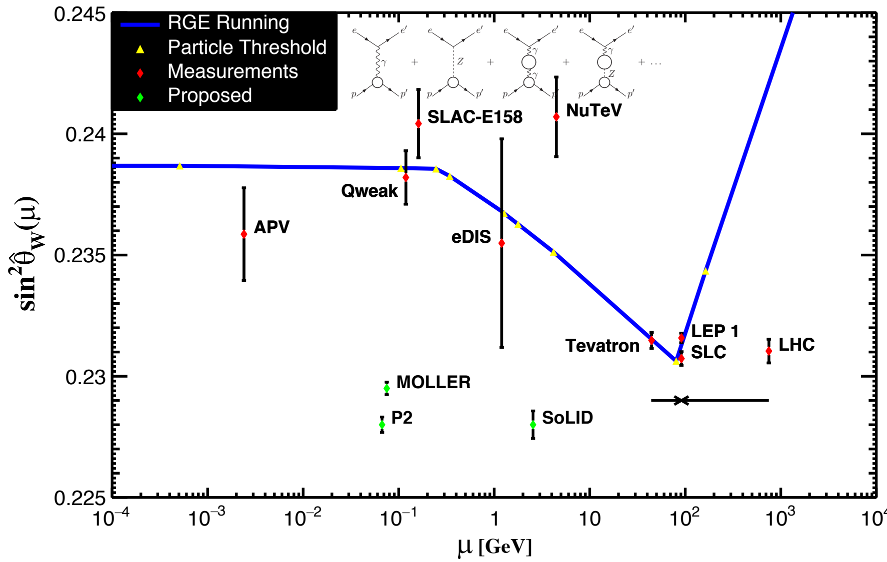

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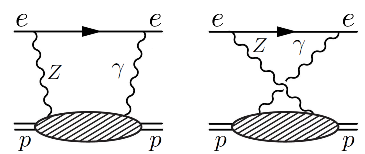

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MG, Horowitz '09; MG, Horowitz, Ramsey-Musolf '11: γZ-box from DR as function of energy

$$\Box_{\gamma Z}(E) = \frac{\alpha}{\pi}\int_0^\infty dQ^2 \int_{thr}^\infty dW^2 \left[A(E,W,Q^2)F_1^{\gamma Z} + B(E,W,Q^2)F_2^{\gamma Z} + C(E,W,Q^2)F_3^{\gamma Z}\right]$$

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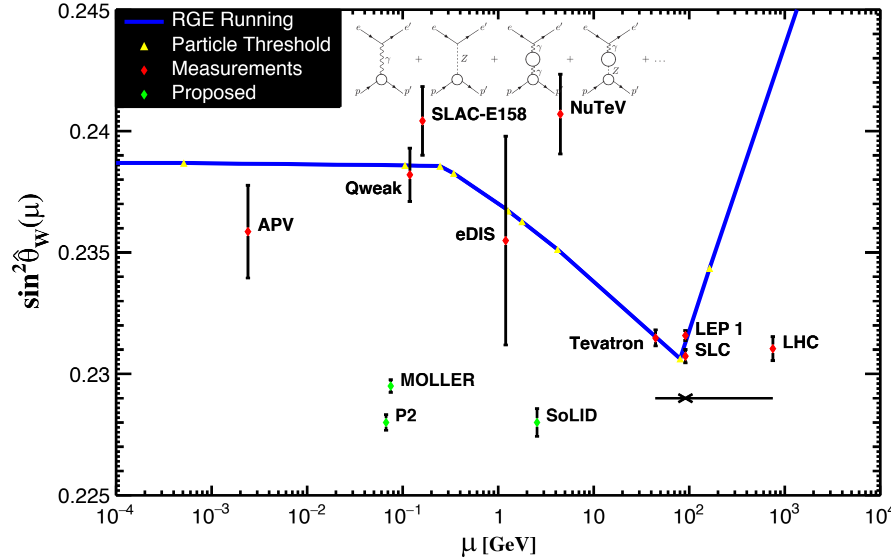

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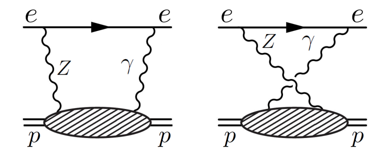

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Known kinematical functions

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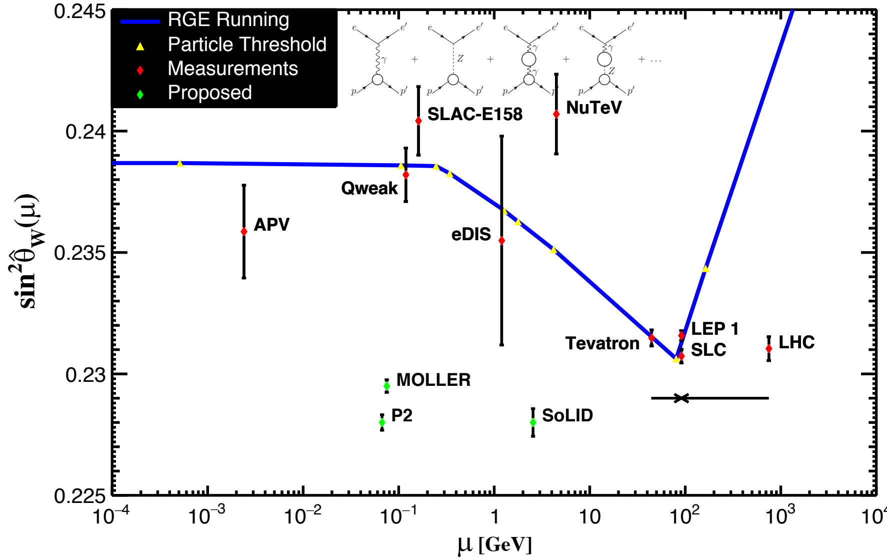

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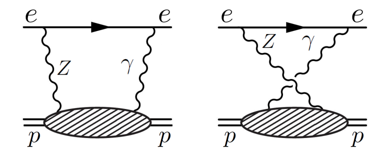

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Known kinematical functions

Inelastic structure functions (related to data)

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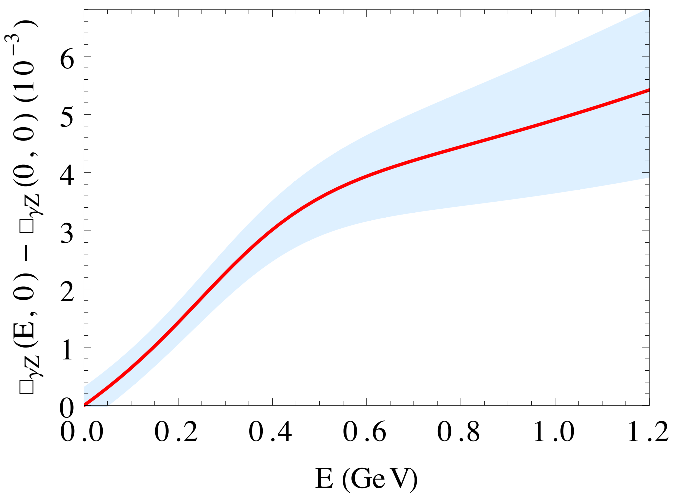
Electroweak boxes: non-universal corrections

Reference value: 1-loop SM $Q_W^p(SM) = 0.0713 \pm 0.0008$

7.6% correction in Q-Weak kinematics
- missed in the original analysis

$$\Box_{\gamma Z}(E = 1.165\,\mathrm{GeV}) = (5.4 \pm 2.0) \times 10^{-3}$$



MG, Horowitz, PRL 102 (2009) 091806;
Nagata, Yang, Kao, PRC 79 (2009) 062501;
Tjon, Blunden, Melnitchouk, PRC 79 (2009) 055201;
Zhou, Nagata, Yang, Kao, PRC 81 (2010) 035208;
Sibirtsev, Blunden, Melnitchouk, PRD 82 (2010) 013011;
Rislow, Carlson, PRD 83 (2011) 113007;
MG, Horowitz, Ramsey-Musolf, PRC 84 (2011) 015502;
Blunden, Melnitchouk, Thomas, PRL 107 (2011) 081801;
Rislow, Carlson PRD 85 (2012) 073002;
Blunden, Melnitchouk, Thomas, PRL 109 (2012) 262301;
Hall et al., PRD 88 (2013) 013011;
Rislow, Carlson, PRD 88 (2013) 013018;
Hall et al., PLB 731 (2014) 287;
MG, Zhang, PLB 747 (2015) 305;
Hall et al., PLB 753 (2016) 221;
MG, Spiesberger, Zhang, PLB 752 (2016) 135;
Erler, MG, Koshchii, Seng, Spiesberger, PRD100 (2019), 053007

Steep energy dependence observed - added strong motivation for P2 @ MESA

$$\Box_{\gamma Z}(E = 0.155\,\mathrm{GeV}) = (1.1 \pm 0.3) \times 10^{-3}$$

The model dependence: no or very little inelastic PVES data available

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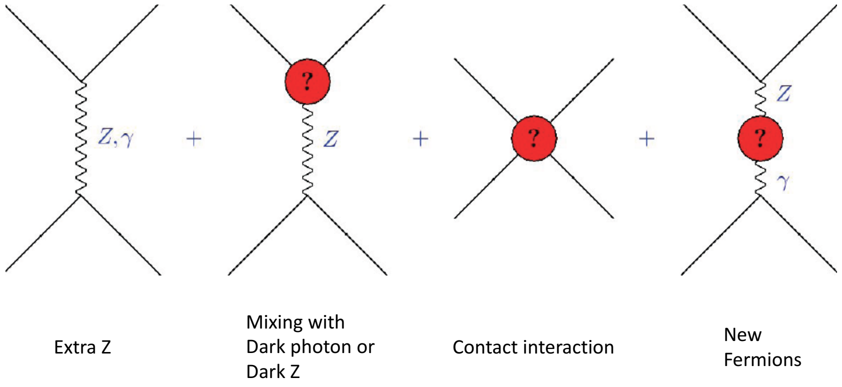
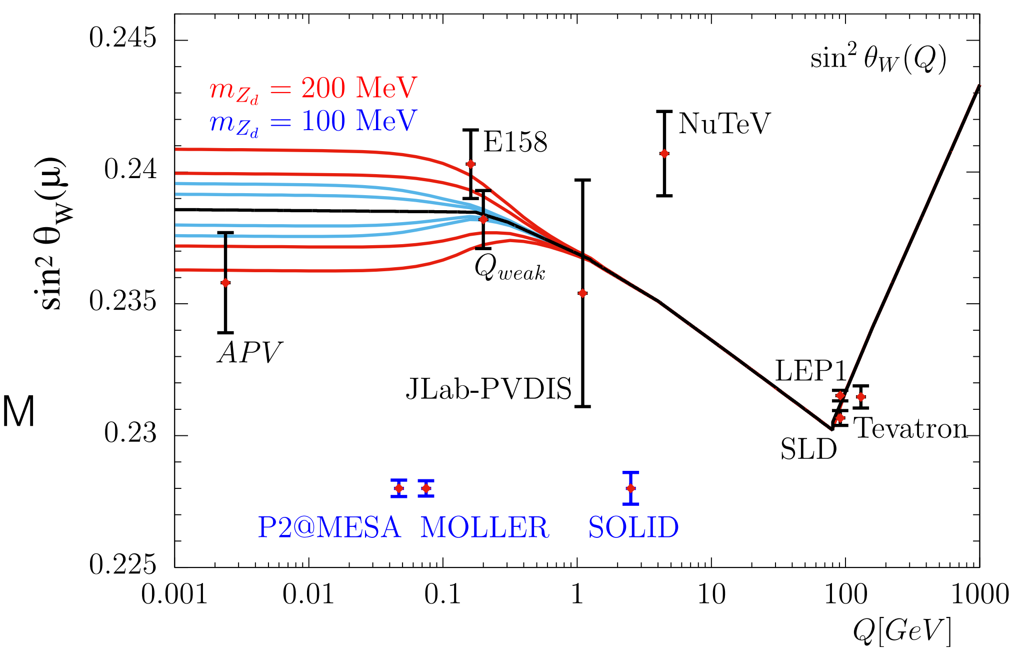
BSM contributions to WMA running



Heavy BSM reach: up to 50 TeV
Light dark gauge sector: down to 70 MeV
Complementary to colliders



P2@MESA will set stringent constraints on BSM

Precision comparable to Z-pole @ colliders

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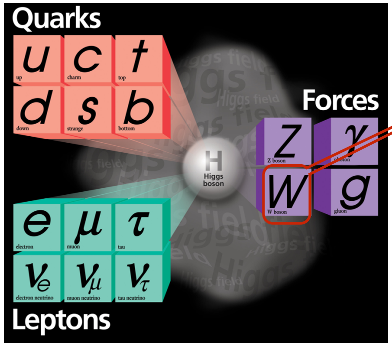
Precision determination of V_{ud}



Charged current interaction - β-decay (μ, $\pi^{\pm}$, n)

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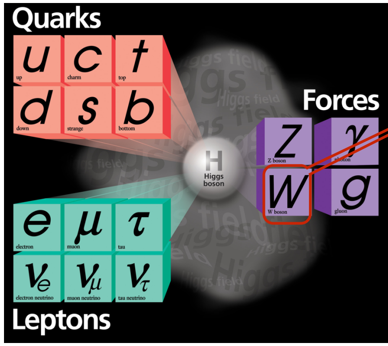

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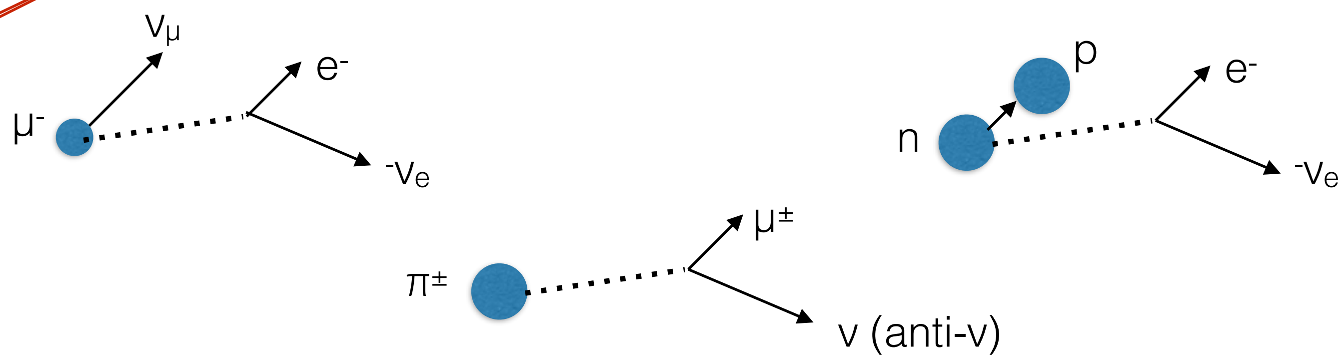

W coupling to leptons and hadrons very close but not exactly the same:
quark mixing - Cabbibo-Kabayashi-Maskawa matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM - Determines the relative strength of the weak CC interaction of quarks vs. that of leptons

CKM unitarity - measure of completeness of the SM: $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$

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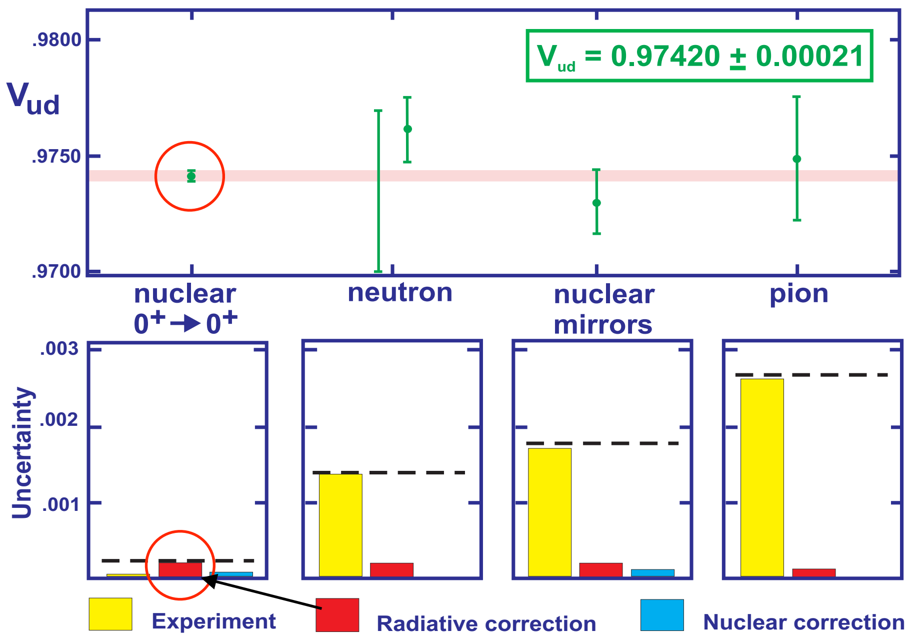
V_{ud} and CKM unitarity in early 2018

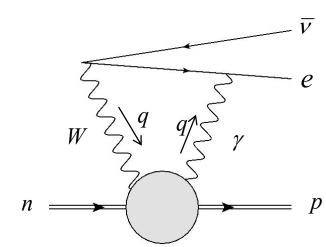


From neutron decay

$$|V_{ud}|^2 = \frac{5099.34s}{\tau_n(1+3g_A^2)(1+\Delta_R)}$$

From superallowed decays

$$|V_{ud}|^2 = \frac{2984.43s}{\mathcal{F}t(1+\Delta_R^V)}$$



Model dependence resides in γW-box $\Delta_R^V = 2\Box_{\gamma W}^{A\times V} + \ldots$

Previous calculation of γW-box: ***Marciano & Sirlin 2006***

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9994 \pm 0.0005$$

0+-0+ nuclear decays $|V_{ud}|^2 = 0.94906 \pm 0.00041$

Kl3 and Kl2 average $|V_{us}|^2 = 0.05031 \pm 0.00022$

B decays $|V_{ub}|^2 = 0.00002$

CKM unitarity: V_{ud} the main contributor to the sum and to the uncertainty

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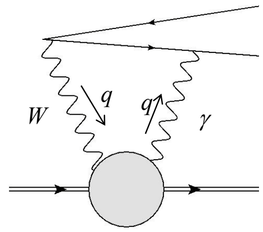
γW-box from Dispersion Relations

$$T_{\gamma W} = \sqrt{2} e^2 G_F V_{ud} \int \frac{d^4q}{(2\pi)^4} \frac{\bar{u}_e \gamma^\mu (\not{k} - \not{q} + m_e) \gamma^\nu (1-\gamma_5) v_\nu}{q^2[(k-q)^2 - m_e^2]} \frac{M_W^2}{q^2 - M_W^2} T^{\gamma W}_{\mu\nu}$$



Hadronic tensor: two-current correlator

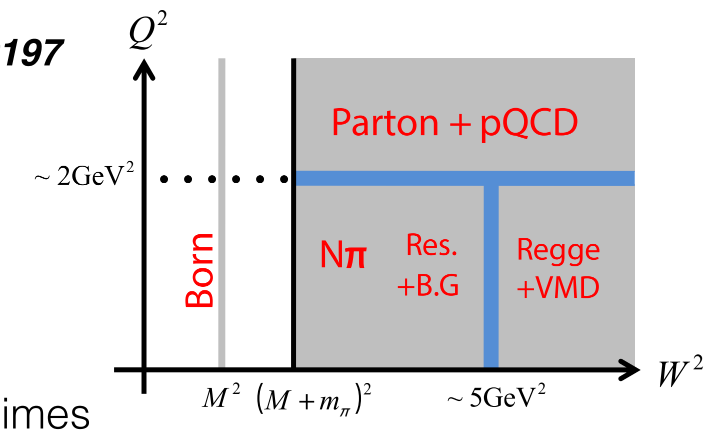
$$T^{\mu\nu}_{\gamma W} = \int dx e^{iqx} \langle f \,|\, T[J^\mu_{em}(x) J^{\nu,\pm}_W(0)] \,|\, i \rangle$$

General gauge-invariant decomposition of a spin-independent tensor

$$T^{\mu\nu}_{\gamma W} = \left(-g^{\mu\nu} + \frac{q^\mu q^\nu}{q^2}\right) T_1 + \frac{1}{(p\cdot q)} \left(p - \frac{(p\cdot q)}{q^2} q\right)^\mu \left(p - \frac{(p\cdot q)}{q^2} q\right)^\nu T_2 + \frac{i\epsilon^{\mu\nu\alpha\beta} p_\alpha q_\beta}{2(p\cdot q)} T_3$$

γW box from DR ***Seng, MG, Patel, Ramsey-Musolf, 1807.10197***

$$\mathrm{Re}\,\Box^{even}_{\gamma W} = \frac{\alpha}{\pi N} \int_0^\infty dQ^2 \int_{\nu_{thr}}^\infty d\nu \frac{F_3^{(0)}}{M\nu} \frac{\nu + 2q}{(\nu+q)^2}$$



Include dispersion in energy;
Connection to data established
Explicit matching between nuclear, hadronic and pQCD regimes

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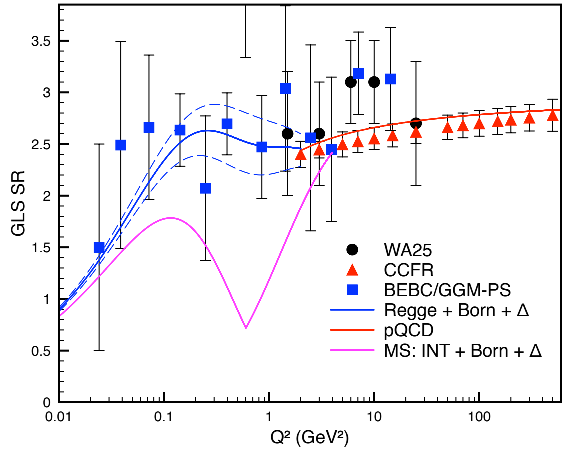
Input into the dispersion integral

Input into the integral was related to neutrino data on Gross-Llewellyn-Smith sum rule

Gross-Llewellyn-Smith sum rule $\int_0^1 dx(u_v^p(x) + d_v^p(x)) = 3$



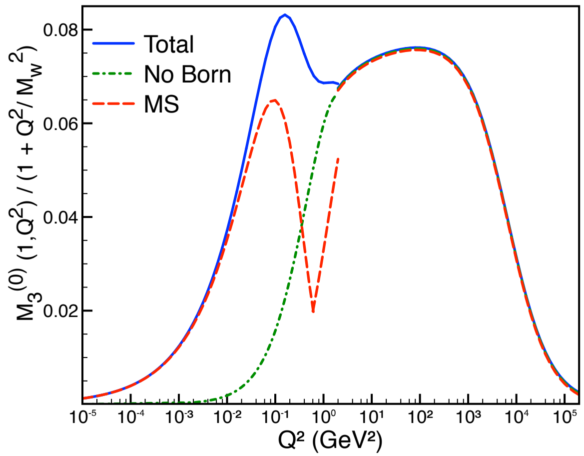
At sub-asymptotic Q^2 receives pQCD corrections

$$M_3^{WW}(1,Q^2) = 3(1 - \alpha_s/\pi - \ldots)$$

$M_3^{WW}(1,Q^2)$

Isospin symmetry

$M_3^{\gamma W}(1,Q^2)$



MS 2006: $\Delta_R^V = 0.02361(38) \quad |V_{ud}| = 0.97420(10)_{Ft}(18)_{RC}$

DR: $\Delta_R^V = 0.02467(22) \quad |V_{ud}| = 0.97370(10)_{Ft}(10)_{RC}$

Uncertainty halved; 3σ away from the old value

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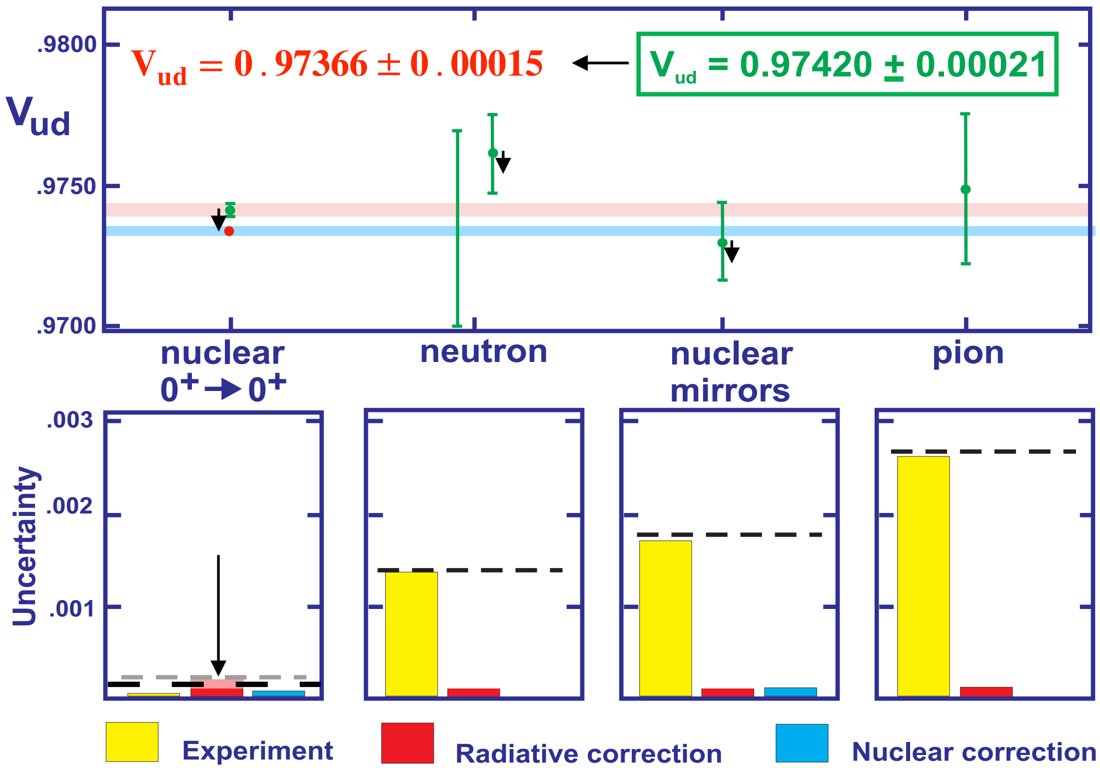
CKM unitarity in Fall 2018 - 5σ deficit

Seng, MG, Patel, Ramsey-Musolf, 1807.10197



$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9979 \pm 0.0004$$

0+-0+ nuclear decays $|V_{ud}|^2 = 0.94801 \pm 0.00029$

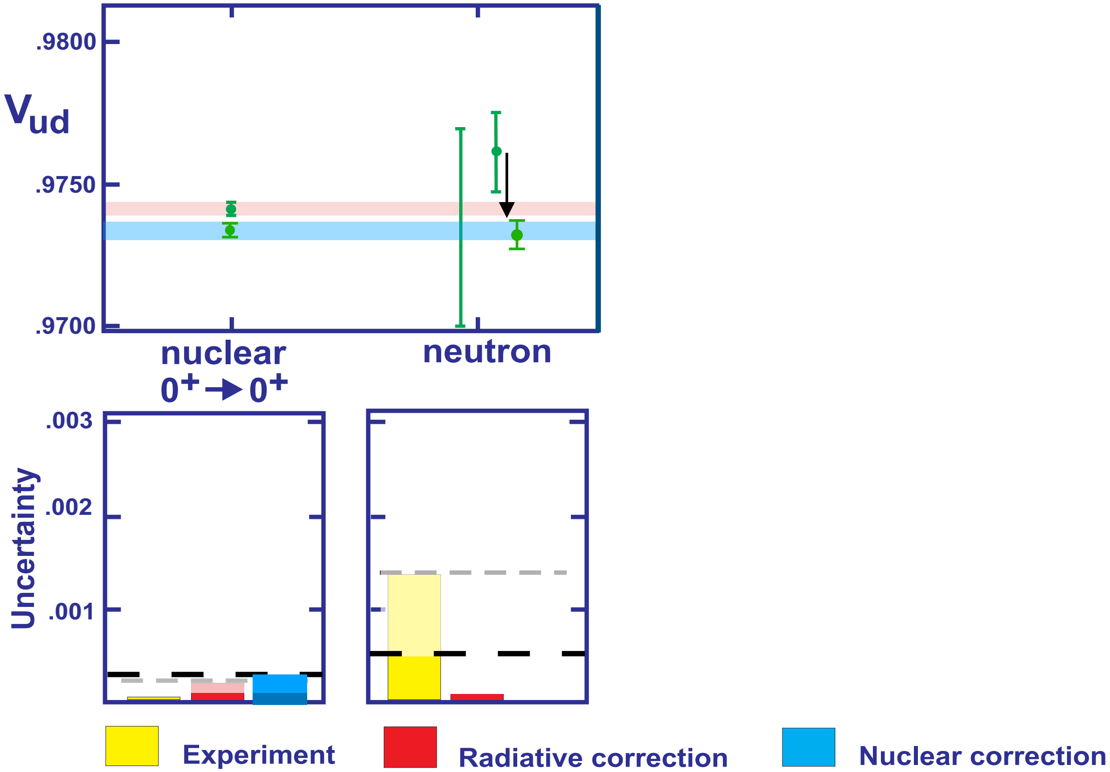
Kl3 decays $|V_{us}|^2 = 0.04987 \pm 0.00027$

CKM unitarity: V_{ud} und V_{us} contribute equally to the uncertainty

Bazavov et al. (FNAL/MILC), 1809.02827

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

CKM unitarity in December 2018 - 3σ deficit



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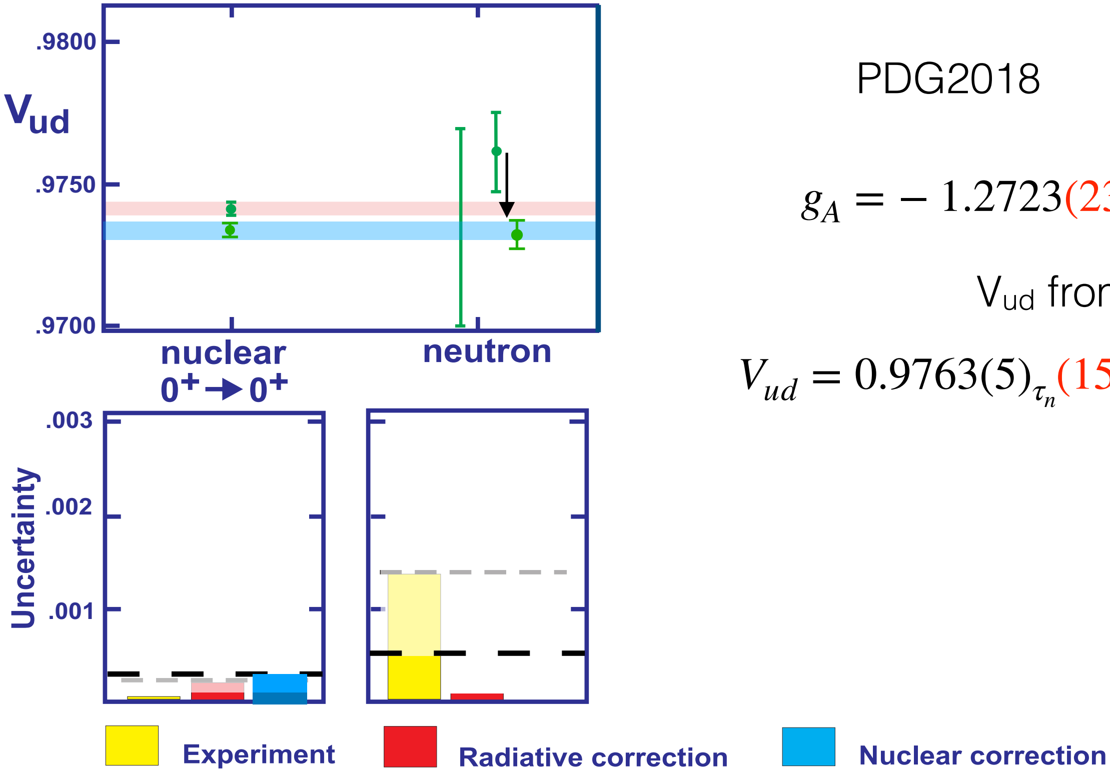
CKM unitarity in December 2018 - 3σ deficit



Major improvement in exp. determination of g_A

PDG2018

PERKEO-III

Märkisch et al., 1812.04666

$$g_A = -1.2723(23) \longrightarrow g_A = -1.2764(6)$$

V_{ud} from free neutron decay

$$V_{ud} = 0.9763(5)_{\tau_n}(15)_{g_A}(2)_{\mathrm{RC}} \longrightarrow V_{ud} = 0.9735(5)_{\tau_n}(3)_{g_A}(1)_{\mathrm{RC}}$$

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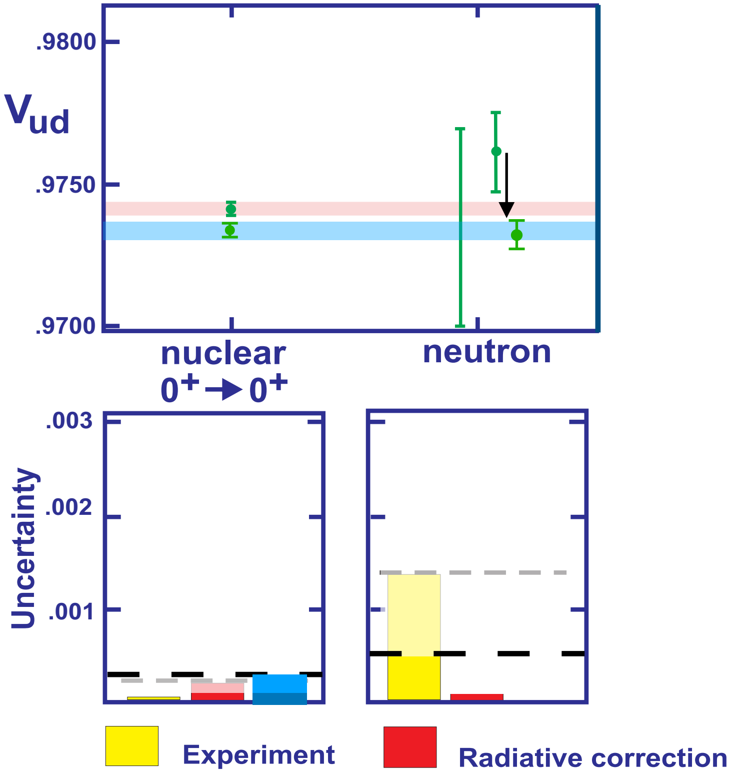
CKM unitarity in December 2018 - 3σ deficit



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Revision of nuclear corrections to 0^+- 0^+-beta decay

Seng, MG, Ramsey-Musolf, 1812.03352; MG 1812.04229

$$V_{ud} = 0.97366(10)_{\rm Ft}(10)_{\rm RC} \longrightarrow V_{ud} = 0.97366(32)_{\rm Ft}(10)_{\rm RC}$$

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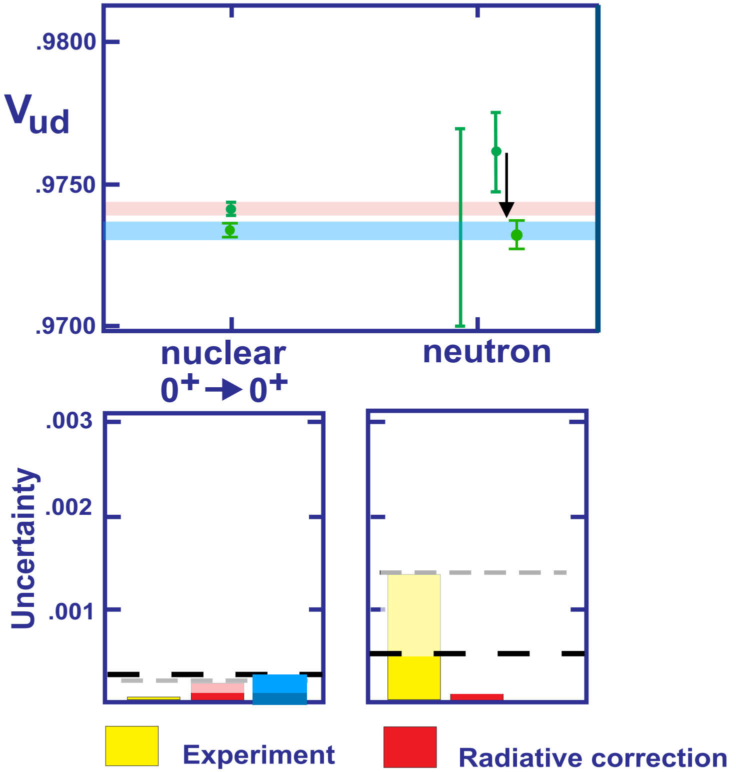
CKM unitarity in December 2018 - 3σ deficit



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$$V_{ud} = 0.97366(10)_{Ft}(10)_{RC} \longrightarrow V_{ud} = 0.97366(32)_{Ft}(10)_{RC}$$

Free neutron decay becomes competitive - τ_n!
Scrutiny of nuclear corrections with new methods
BSM: superallowed nuclear decays
 - main constraint on new S,T interactions!

Top-row unitarity: 2,5-3,5σ deficit

$$\Delta_u = -(0.0016 - 0.0021) \pm 0.0006$$

(depending on V_{us})

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EW MAID - model of exclusive EW reactions

Input necessary for EW box calculations

- structure functions with vector and axial weak current

$$\mathrm{Im}\langle N|T[J_Z^\mu J_\gamma^\nu]|N\rangle = \sum_X \rho_X \langle N|J_Z^\mu|X\rangle\langle X|J_\gamma^\nu|N\rangle$$

$$\mathrm{Im}\langle N|T[J_W^\mu J_\gamma^\nu]|N\rangle = \sum_X \rho_X \langle N|J_W^\mu|X\rangle\langle X|J_\gamma^\nu|N\rangle$$

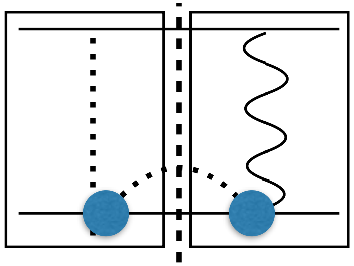
Saturate the dispersion integral with exclusive channels at low-energies, match onto pQCD, Regge

MAID — existing Mainz web-based partial wave analysis of PS meson e.m. production

Proposed weak MAID

Needed at

$Q^2 < 2\ \mathrm{GeV}^2$, $W<4$ GeV



$X = \pi N, \eta N, \eta' N, K\Lambda, K\Sigma$

Existing e.-m. MAID

$Q^2 < 2\ \mathrm{GeV}^2$, $W<2$ GeV

To saturate the dispersion integral for EW boxes extend MAID to include multi-pion, KK-bar, …

Has only been attempted in simple models - need to do better!
Currently: the absolute and relative strength of $\gamma(Z,W)N \to \rho N, \omega N, \phi N$ channels for W>2 GeV is used to constrain the HE continuum contribution to EW boxes within VDM - Regge model
- main uncertainty in the γZ- and γW-box (vector, axial NC, CC currents)

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WP 21: JRA 3 - PrecisionSM

- WP tasks:
- Task 1: Hadronic effects in precision tests of the weak sector of SM
  Task 1.1: Electroweak MAID
  Task 1.2: New neutrino pion-production MC simulator for DUNE, T2HK
  Task 1.3: Electroweak box correction calculations for PVES and β-decay

- Task 2: Hadronic effects in precision tests of the electromagnetic sector of the Standard Model
  Task 2.1: Database for hadronic VP + contribution to $(g-2)_\mu$
  Task 2.2: Database for hadronic LbL + contribution to $(g-2)_\mu$

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Progress and further a-do

To provide improved calculations:
new data if these directly determine the integrand of DR (HVP);
new methods to obtain input to DR from existing data (HLbL & EW boxes)

Plenary Meeting of PrecisionSM planned — **June 2-3, 2020 in Krakow, Poland**

- HVP and HLbL: new data (improved precision and coverage) + unified database
- Contact with HEP-DB group has been made; Alberto Lusiani is the Coordinator for submitting information to the database.
- First channel to submit data - $e^+e^- \to \pi^+\pi^-$

- MUonE: test measurements at CERN were conducted; dedicated MC & RC developed; postdoc position funded by STRONG-2020 to be filled

- Electroweak MAID: MG officially joined the Mainz-Tuzla-Zagreb Collaboration; the MAID web platform will straightforwardly accommodate the new EW MAID; work has started with focus on the upcoming DUNE@FNAL kinematics; early 2020 visit to FNAL planned; postdoc position funded by STRONG-2020 to be filled.

- EW boxes: dispersion representation obtained; established connection to exp. data; first calculations already show very high impact on the field; plans for Kl3 decay

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JRA3 - PrecisionSM : Deliverables

- Deliverables due for Reporting Period 1 (18 months, June 2019-November 2020): D21.1 is due M18 (November 2020)

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D21.1	Electroweak MAID	9 - JGU MAINZ	Websites, patents filling, etc.	Public	18

- D21.1 Electroweak MAID - Task well on track (joined MAID collaboration, several publications towards EW MAID); postdoc position to be filled soon

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JRA3 - PrecisionSM : Milestones

- MS37 corresponding to D21.1 has to be achieved M18
- First EW MAID option will include $\nu/\bar{\nu}$-induced single pion production off nucleon
- Extended MAID energy range W < 5 GeV (currently W < 2 GeV)
- Pilot EW MAID website expected to run in fall 2020

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS37	Weak MAID	9 - JGU MAINZ	18	Website up and running

- Summary: project work towards D21.1 and MS37 has started;
- At first stages of EW MAID local expertise in Mainz is sufficient
- Next steps will be done in a close collaboration with other nodes of JRA3 - Valencia, Krakow and Fermilab, involvement in JPAC@JLab is expected
- Dispersive formulation of RC to precision tests in context of this JRA have high impact on the field already

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