Particle Physics at the Precision Frontier

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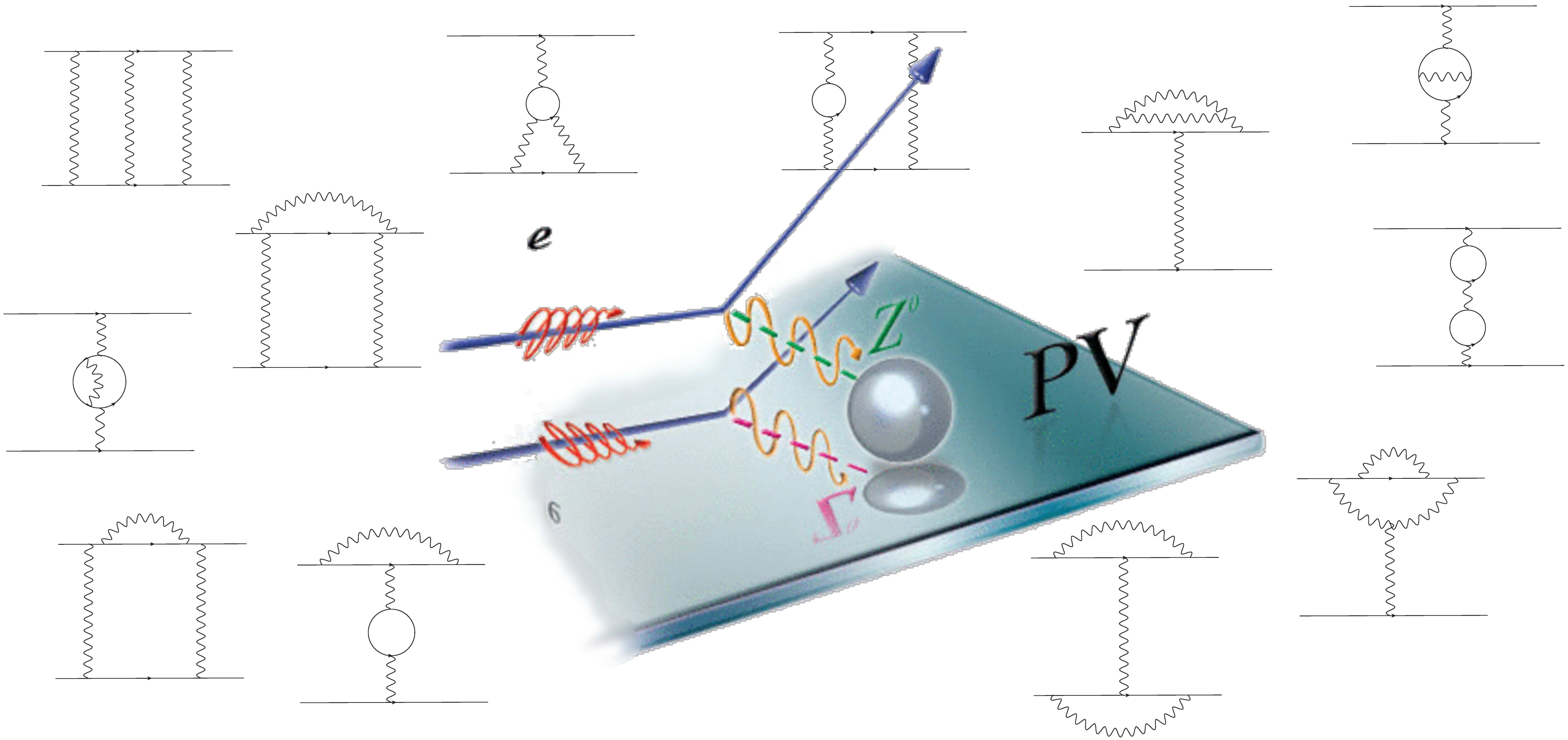
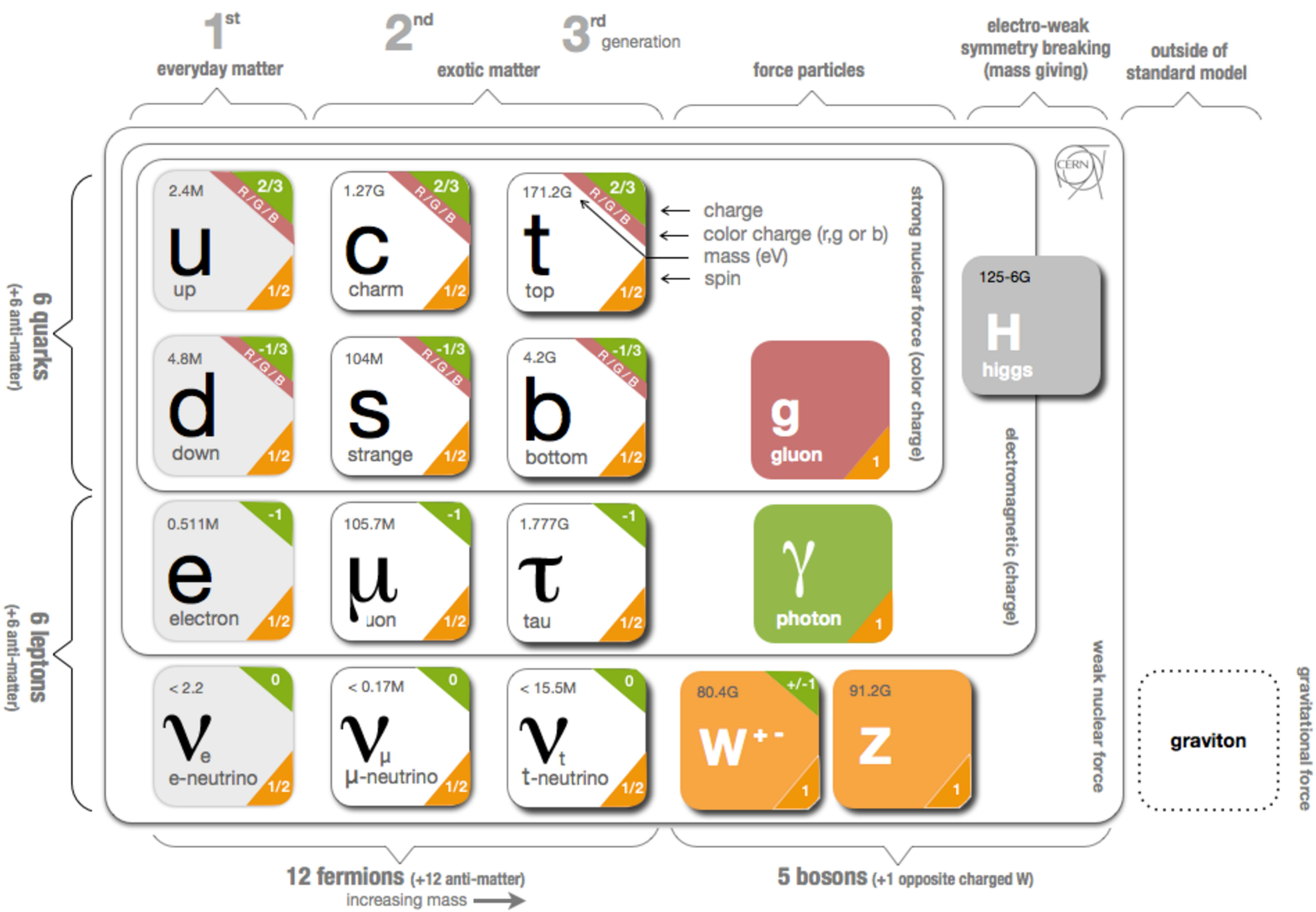


Standard Model



Questions need to be answered!

- Why 12 fermions only?
- Why masses of these particles are in the specific order?
- Why neutrinos have mass and how heavy are they?
- Why we have only four interactions?
- Why we have dominance of Matter over Anti-Matter?
- What is the Dark Matter?

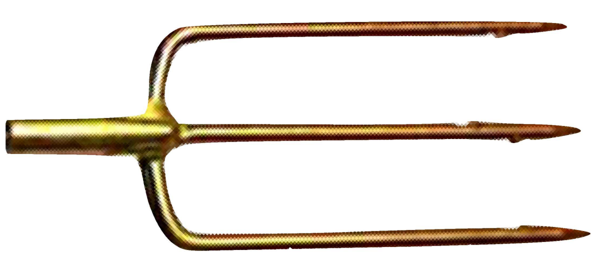
Frontiers of BSM Physics

To look for New Physics beyond the Standard Model, we use the **three-prong approach:**

The Energy Frontier (high-energy colliders)

The Intensity/Precision Frontier (intense particle beams)

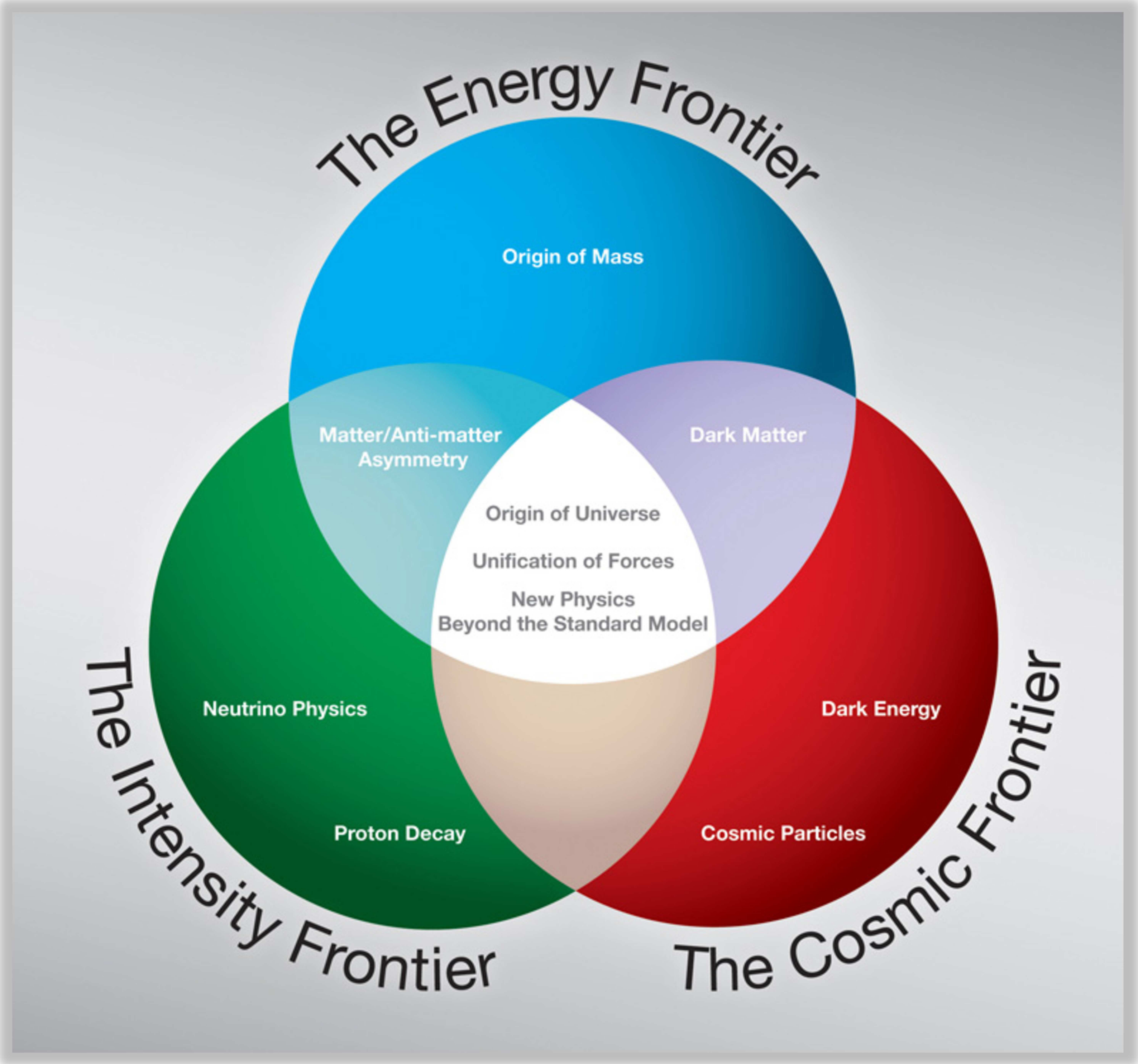
The Cosmic Frontier (underground experiments, ground and space-based telescopes)



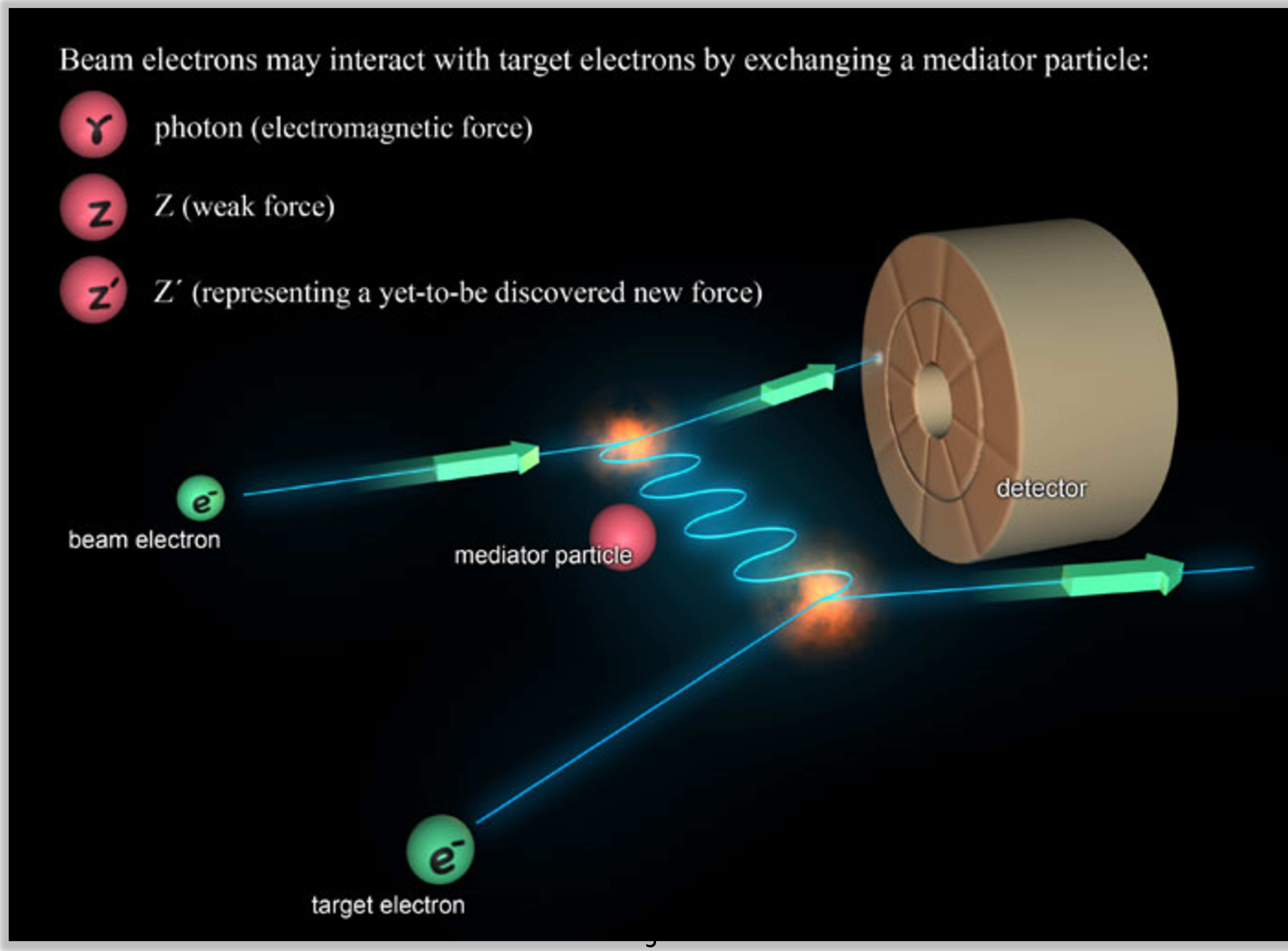
Energy

Intensity/Precision

Cosmic

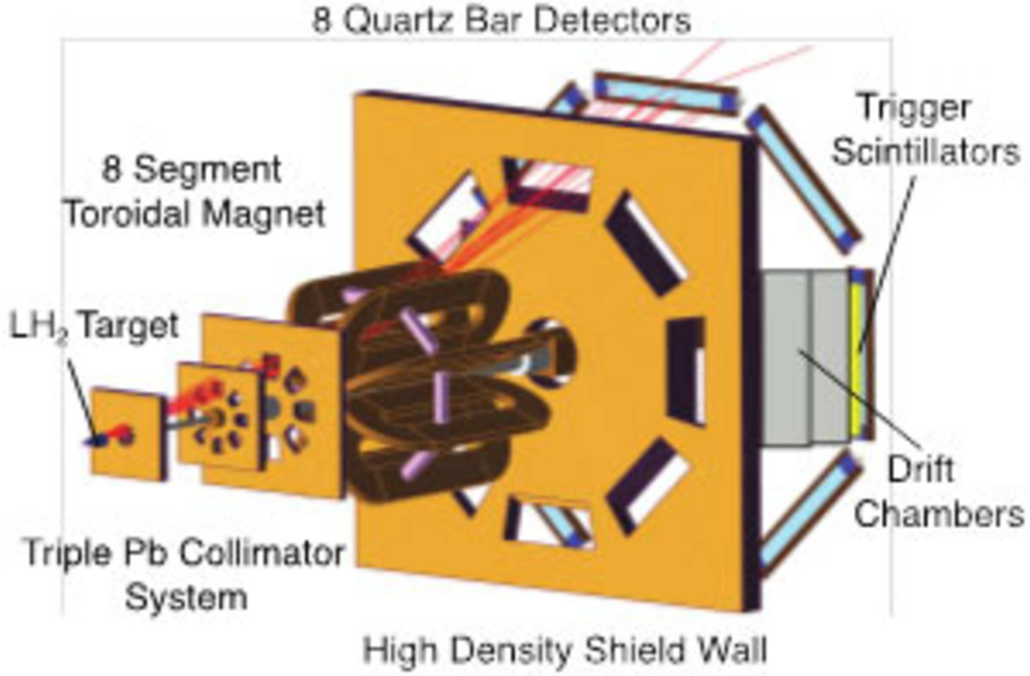


Precision Frontier

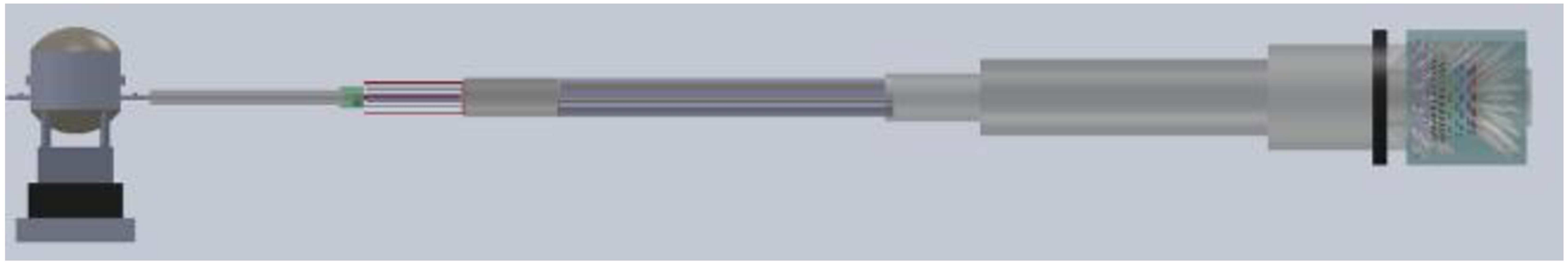


PV Experiments

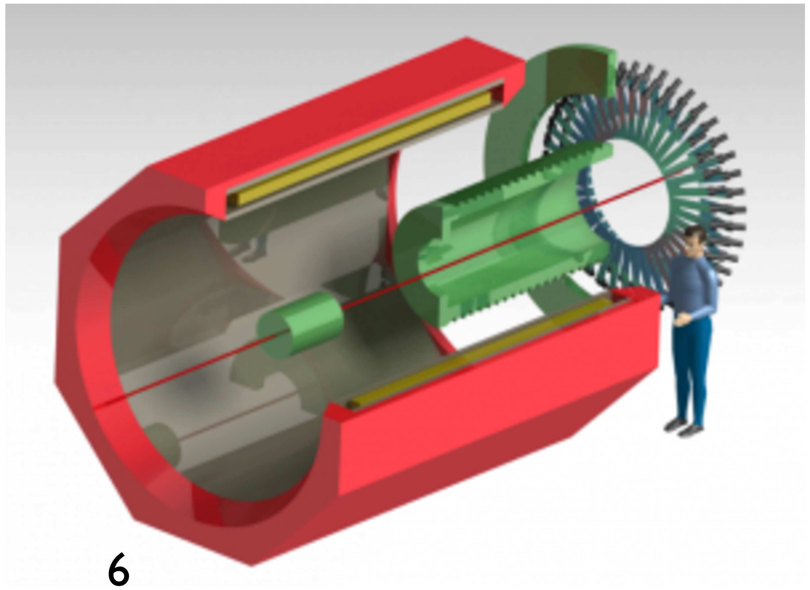
1. **Qweak: JLab (completed)**



2. **MOLLER: JLab (proposed)**

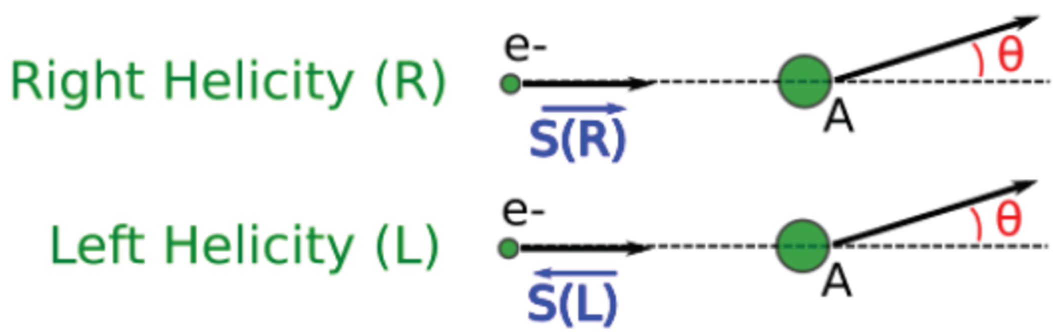


3. **P2: MESA (proposed)**



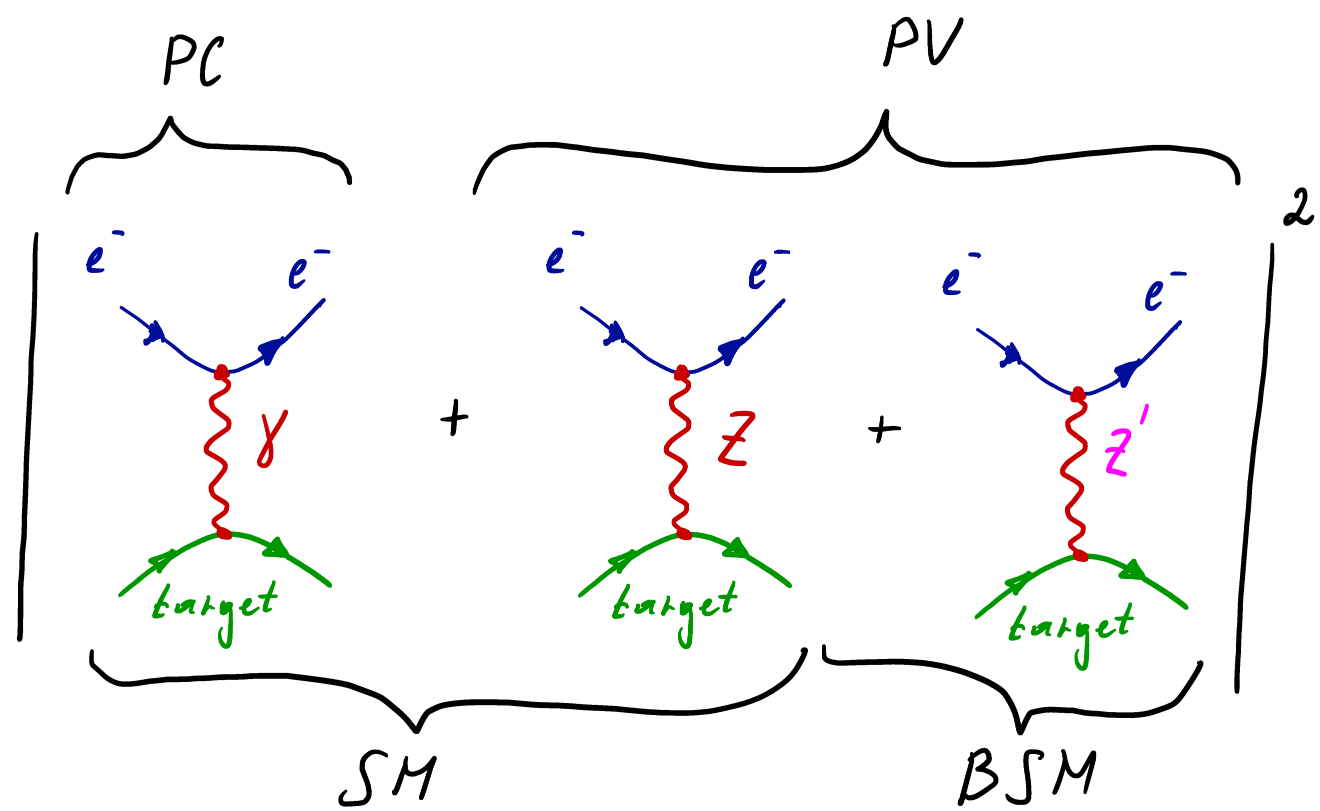
Precision PV Scattering

• To access the scale of the new physics at TeV level, we need to push one or more experimental parameters to the extreme precision.



$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

•New Physics/Weak-Electromagnetic Interference

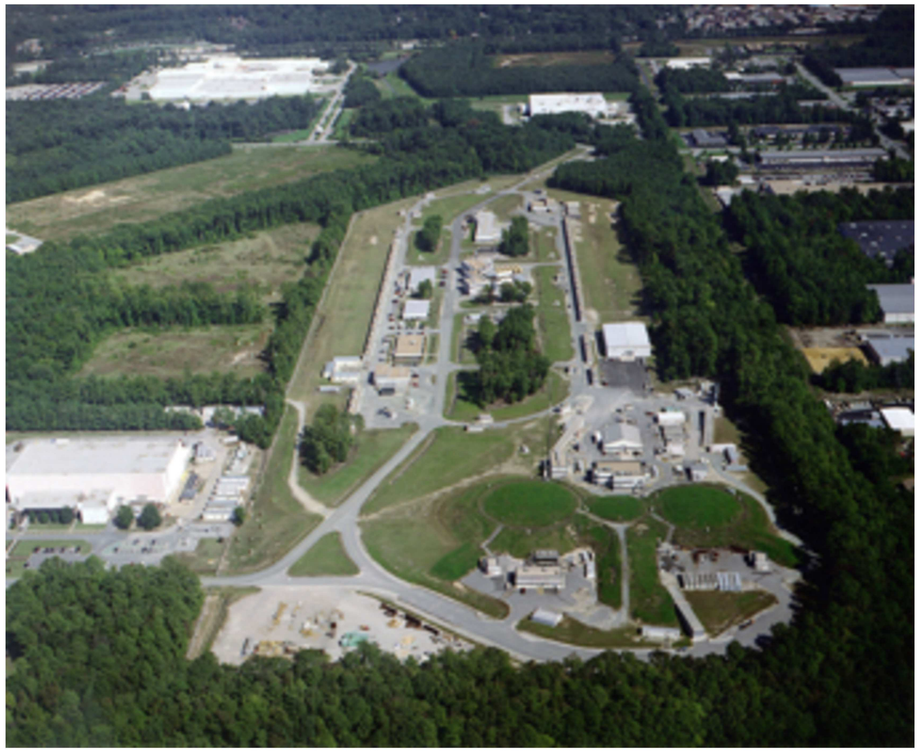


$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \simeq \frac{2Re(M_\gamma M_Z^+ + M_\gamma M_{NP}^+ + M_Z M_{NP}^+)_{LR}}{\sigma_L + \sigma_R}$$

Weak Charge of Proton: Qweak

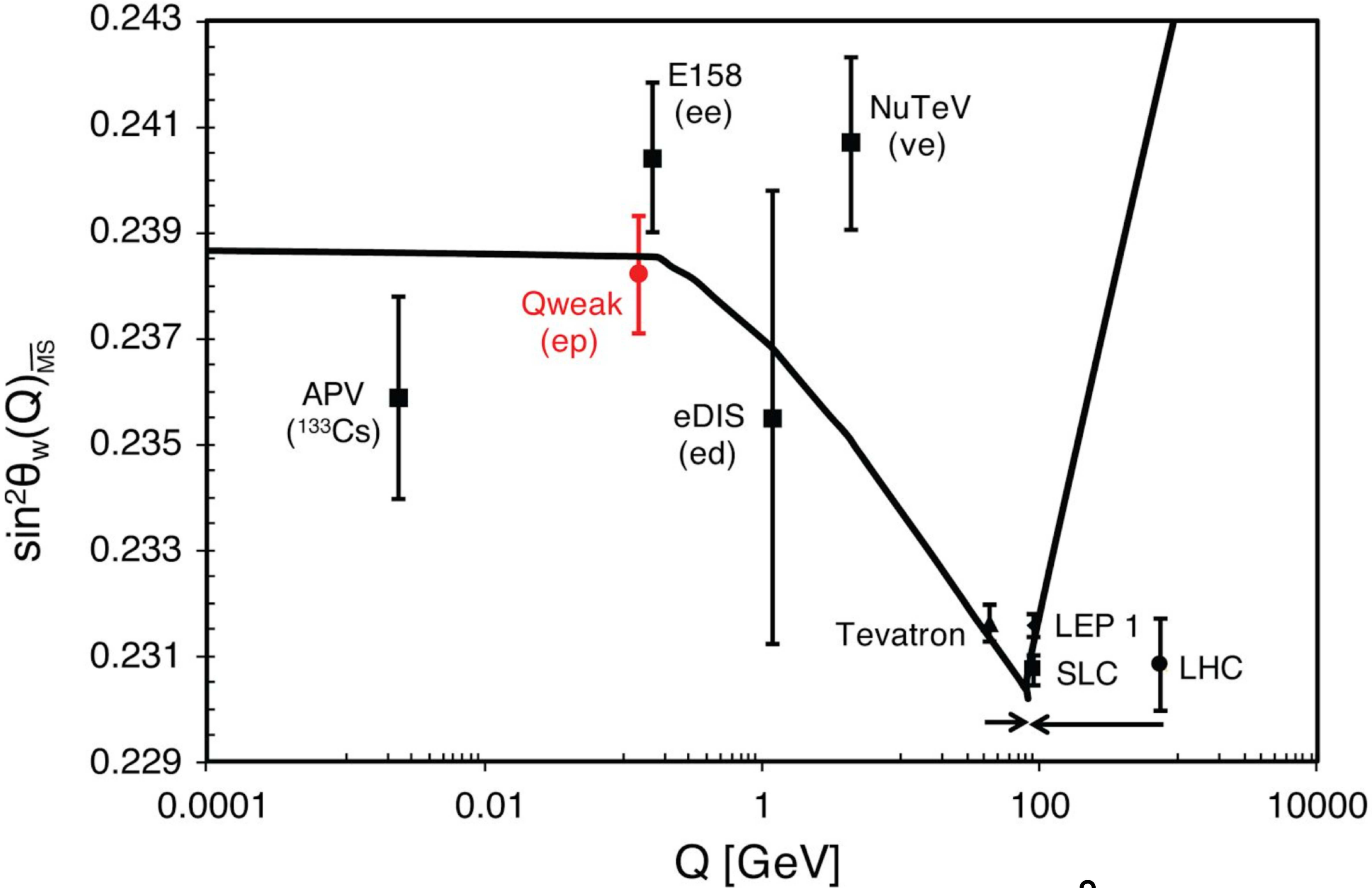
For proton (current Qweak at JLab, planned P2 at MESA in Mainz):

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left[Q_W(p) + F^p(Q^2,\theta)\right]$$



In SM weak charge at tree level:

$$Q_W(p) = 1 - 4\sin^2\theta_W$$



Since the value of the weak mixing angle is very close to 0.25, weak charge of proton (and electron) is suppressed in the SM, so $Q_W(p)$ and $Q_W(e) = -Q_W(p)$ offer a unique place to extract $\sin^2\theta_W$.

Solid curve by: J. Erler, M. Ramsey-Musolf and P. Langacker

Scale of BSM Physics in Weak Interactions

The low-energy effective electron-quark *A(e) × V (q)* Lagrangian:

$$\mathcal{L} = \mathcal{L}^{\mathrm{PV}}_{\mathrm{SM}} + \mathcal{L}^{\mathrm{PV}}_{\mathrm{NEW}}$$

$$\mathcal{L}^{\mathrm{PV}}_{\mathrm{SM}} = -\frac{G_F}{\sqrt{2}}\bar{e}\gamma_\mu\gamma_5 e \sum_q C_{1q}\ \bar{q}\gamma^\mu q$$

$$\mathcal{L}^{\mathrm{PV}}_{NEW} = \frac{g^2}{4\Lambda^2}\bar{e}\gamma_\mu\gamma_5 e \sum_f h^q_V\ \bar{q}\gamma^\mu q$$

where g is the coupling constant, Λ is the mass scale, and the h^q_V are the effective coefficients of the new physics.

$$\mathfrak{L} = -\frac{G_F}{\sqrt{2}}\bar{e}\gamma_\mu\gamma_5 e \sum_q \bar{q}\gamma_\mu q \left[C_{1q} - \underline{\frac{\sqrt{2}g^2}{G_F\Lambda^2}h^q_V} \right]$$

In SM at tree level: $Q^p_W(\mathrm{SM}) = -2(2C_{1u} + C_{1d})$ hence: $\frac{g^2}{\sqrt{2}G_F\Lambda^2} \approx \Delta Q^p_W$

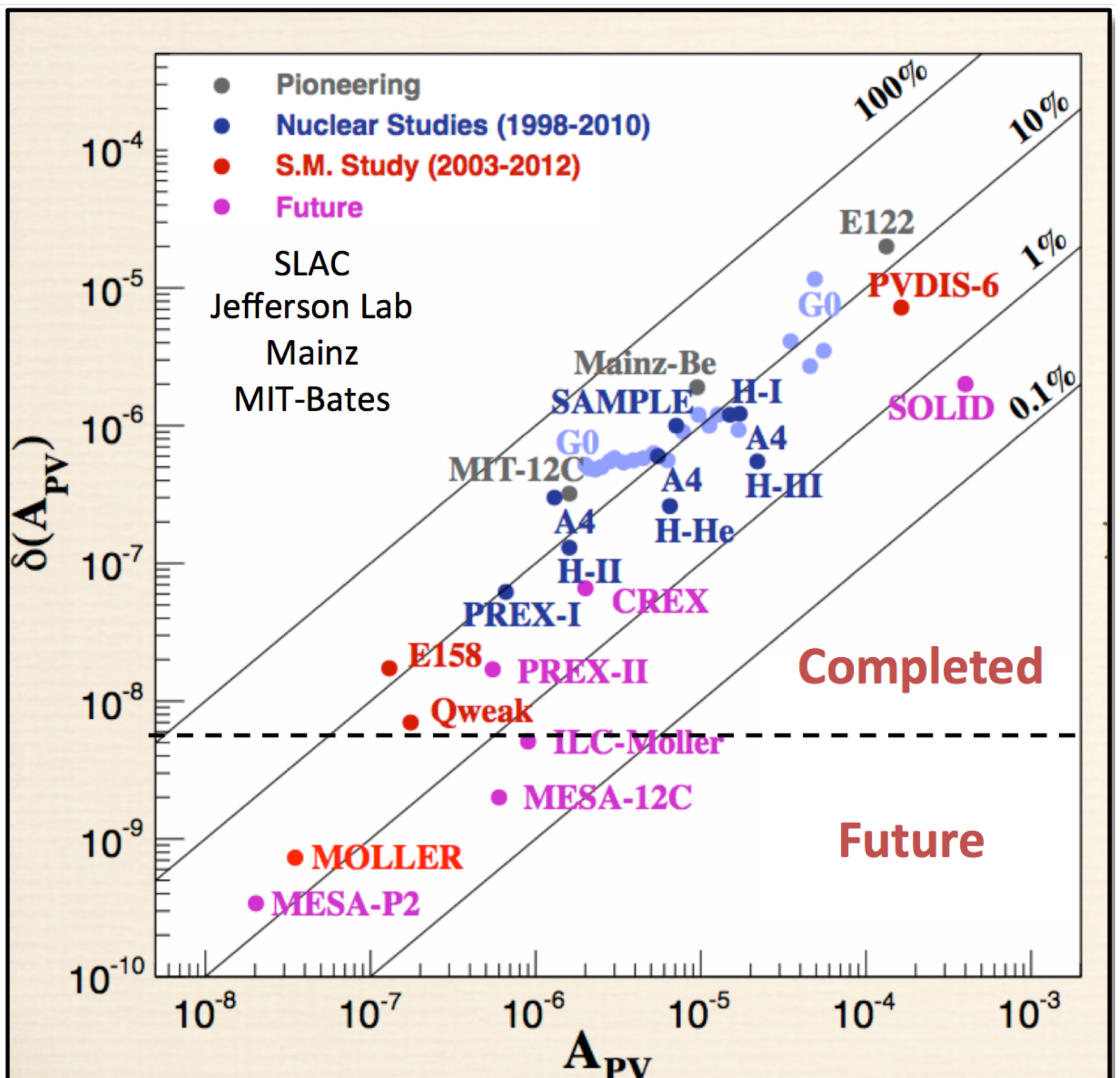
A precise measurement of $Q_W(p)$ (uncertainty of 0.0045 or 6%) would thus test new physics up to ~4 TeV scale:

$$\frac{\Lambda}{g} \approx \frac{1}{\sqrt{\sqrt{2}G_F|\Delta Q^p_W|}} = 3.7(TeV)$$

Precision Scattering: MOLLER

Asymmetry is an observable which is directly related to the interference term:

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \simeq \frac{2Re(M_\gamma M_Z^+ + M_\gamma M_{NP}^+ + M_Z M_{NP}^+)_{LR}}{\sigma_L + \sigma_R} \sim (10^{-5}\ to\ 10^{-4}) \cdot Q^2$$



To access multi-TeV electron scale it is required to measure:

$$\delta(\sin^2\theta_W) < 0.002$$

MOLLER experiment offers an unique opportunity to reach multi-TeV scale and will become complimentary to the LHC direct searches of the New Physics

Figure courtesy of Kent Paschke

Precision Scattering: MOLLER

The first observation of Parity Violation in Møller scattering was made by E-158 experiment at SLAC:

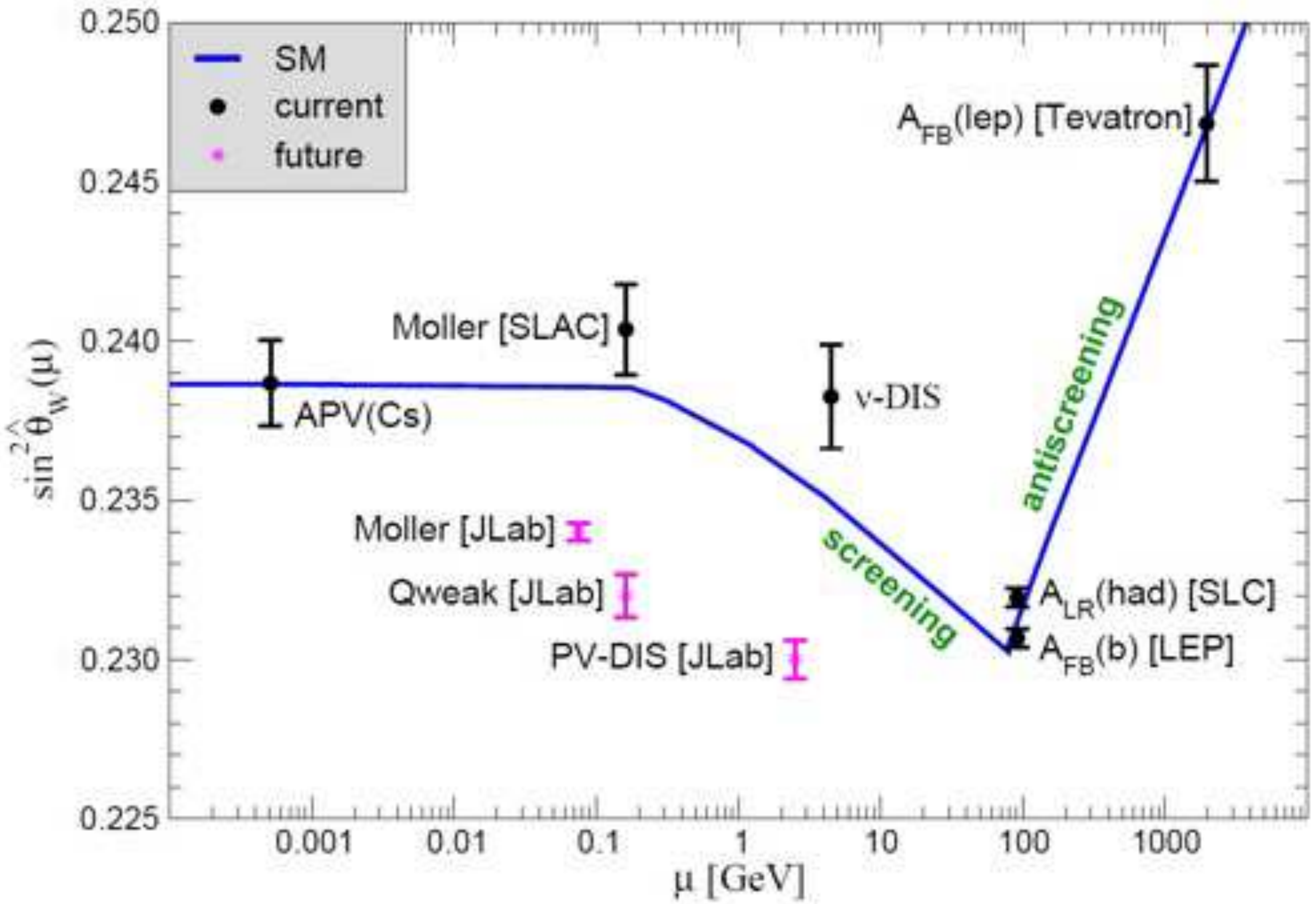
$$Q^2 = 0.026GeV^2, A_{LR} = (1.31 \pm 0.14(stat.) \pm 0.10(syst.)) \times 10^{-7}$$

$$\sin^2(\hat{\theta}_W) = 0.2403 \pm 0.0013 \text{ in } \overline{MS}$$

MOLLER, planned at JLab following the 11 GeV upgrade, will offer a new level of sensitivity and measure the parity-violating asymmetry in the scattering of longitudinally polarized electrons off unpolarized target to a precision of 0.73 ppb.

That would allow a determination of the weak mixing angle with an uncertainty of about 0.1%, a factor of five improvement in fractional precision over the measurement by E-158.

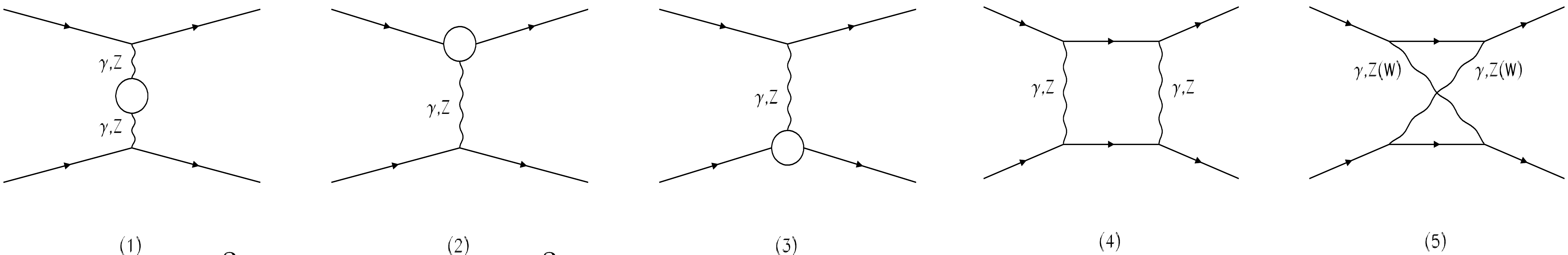
At this uncertainty MOLLER will reach a scale of 10 TeV!



J. Benesch et al., MOLLER Proposal to PAC34, 2008

Precision Scattering: MOLLER

Theory Input: NLO and NNLO corrections



$$\sigma = \frac{\pi^3}{2s}|M_0 + M_1|^2 = \frac{\pi^3}{2s}(M_0 M_0^+ + 2\mathrm{Re}M_1 M_0^+ + M_1 M_1^+) = \sigma_0 + \sigma_1 + \sigma_Q$$

$M_0 M_0^+ \propto \alpha^2$, $2\mathrm{Re}M_1 M_0^+ \propto \alpha^3$, $M_1 M_1^+ \propto \alpha^4$

$$\sigma_1 = \sigma_1^{BSE} + \sigma_1^{Ver} + \sigma_1^{Box}$$

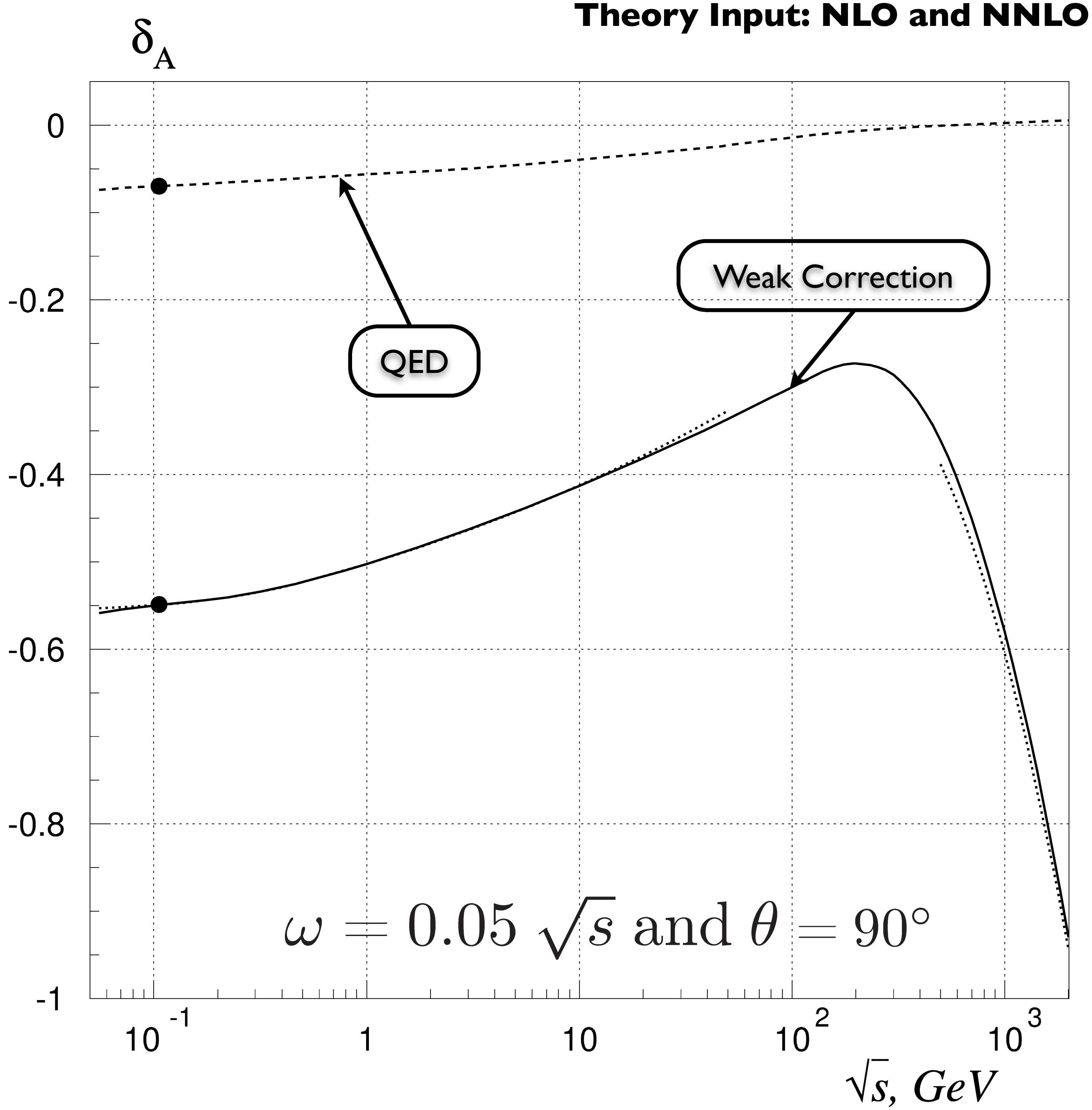
- Calculated in on-shell renormalization using:
  - Computer based using Feynarts, FormCalc, LoopTools and Form

  T. Hahn, Comput. Phys. Commun. 140 418 (2001);
  T. Hahn, M. Perez-Victoria, Comput. Phys. Commun. 118, 153 (1999);
  J. Vermaseren, (2000) [arXiv:math-ph/0010025]

  - "on paper" using approximations in small energy region $\frac{\{t,u\}}{m^2_{Z,W}} \ll 1$, for $\sqrt{s} \ll 30\ GeV$ andhigh energy approximation for $\sqrt{s} \gg 500\ GeV$

Precision Scattering: MOLLER

Theory Input: NLO and NNLO corrections



$$\delta_A = \frac{A^C_{LR} - A^0_{LR}}{A^0_{LR}}$$

The relative weak (solid line in DRC (semi-automated) and dotted line in HRC ("on paper") and QED (dashed line) corrections to the Born asymmetry A^0_{LR} versus $\sqrt{s}$ at $\theta = 90°$.

The filled circle corresponds to our predictions for the MOLLER experiment.

Precision Scattering: MOLLER

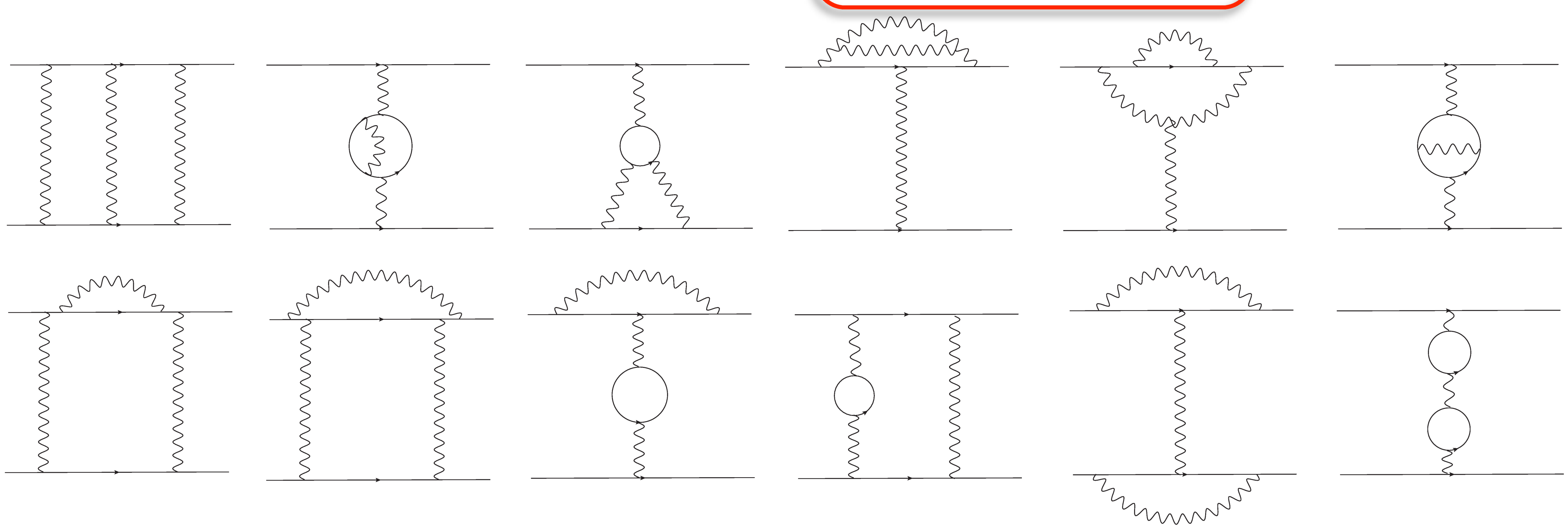
Theory Input: NLO and NNLO corrections

The Next-to-Next-to-Leading Order (NNLP) EWC to the Born (~ $M_0 M_0^+$) cross section can be divided into two classes:

- Q-part induced by quadratic one-loop amplitudes ~ $M_1 M_1^+$, and
- T-part – the interference of Born and two-loop diagrams ~ $2\mathrm{Re} M_0 M_{2\text{-loop}}^+$.

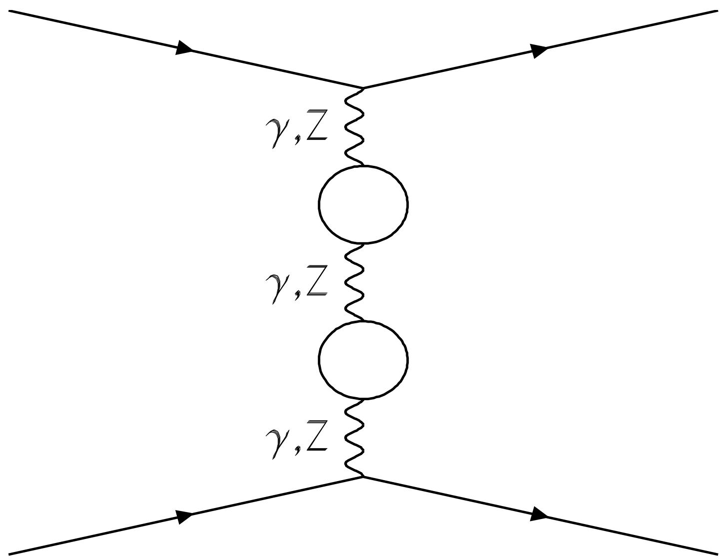
$$\sigma = \frac{\pi^3}{2s}|M_0 + M_1|^2 = \frac{\pi^3}{2s}(\underbrace{M_0 M_0^+}_{\propto \alpha^2} + \underbrace{2\mathrm{Re} M_1 M_0^+}_{\propto \alpha^3} + \underbrace{M_1 M_1^+}_{\propto \alpha^4}) = \sigma_0 + \sigma_1 + \sigma_Q$$

$$\sigma_T = \frac{\pi^3}{s}\ \mathrm{Re} M_2 M_0^+ \propto \alpha^4$$

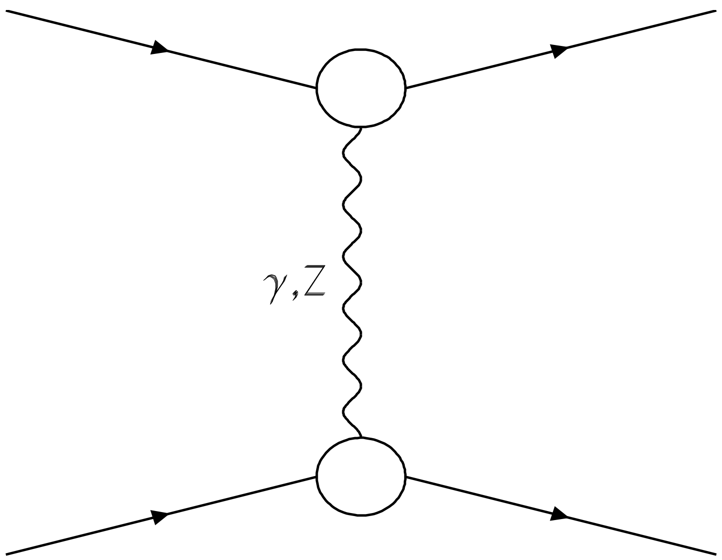


\+ ...

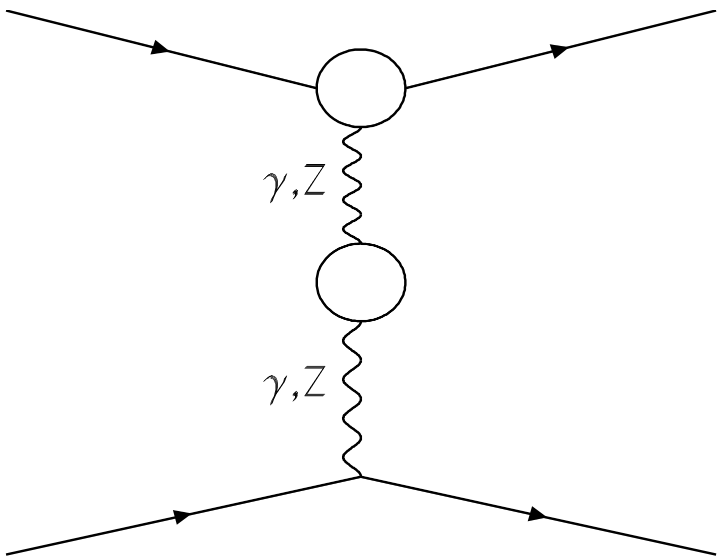
$(BSE+Ver)^2$ Two-Loops Contribution



(BBSE)



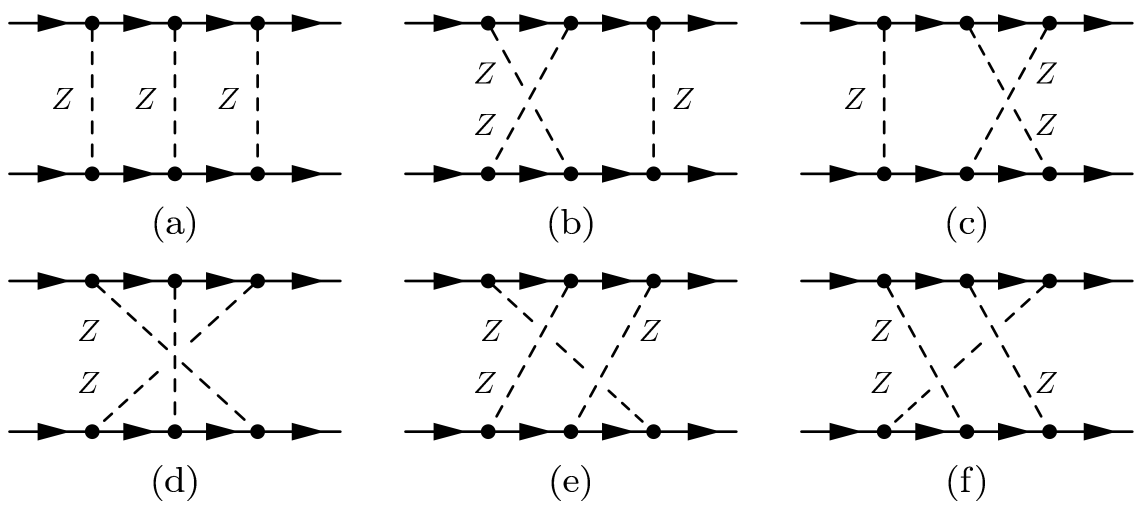
(VerVer)



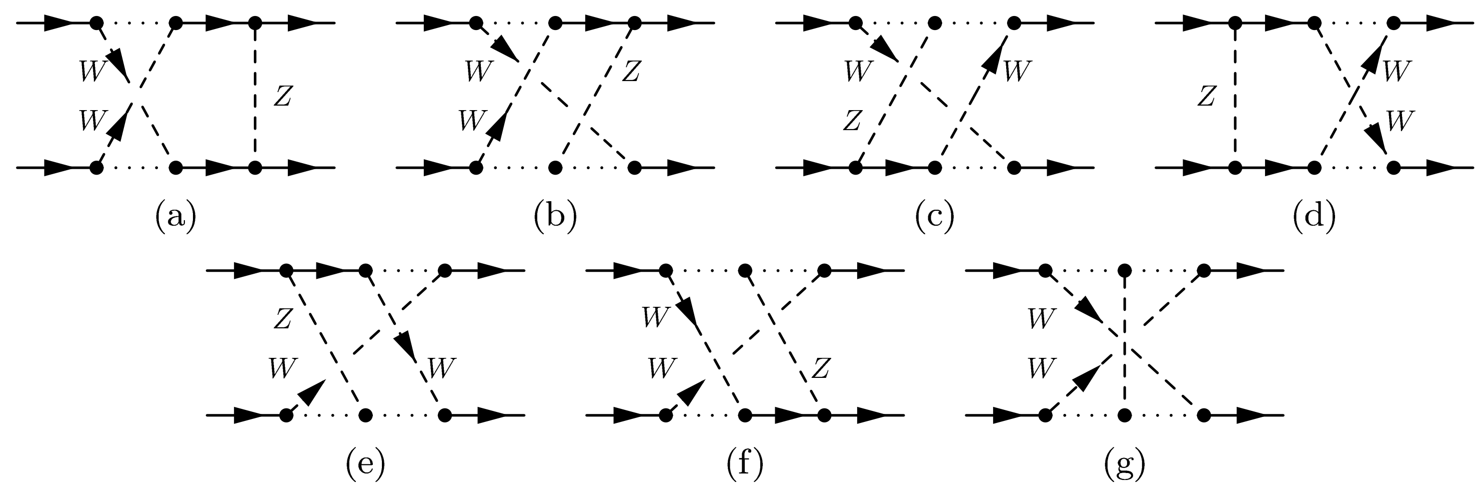
(VerBSE)

Two-loops t-channel diagrams from the gauge-invariant set of vertices and boson self-energies. Here, the circles represent the contributions of self-energies and vertex functions.

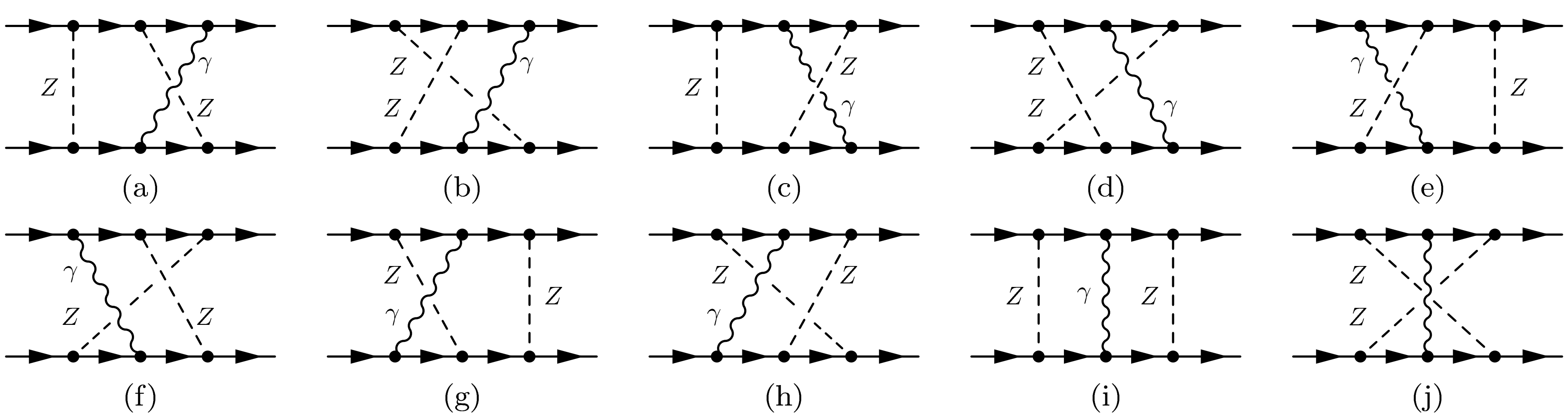
Ladder-Box Diagrams



Diagrams with ZZZ exchange.



Diagrams with WWZ exchange.



Diagrams with ZZγ exchange.

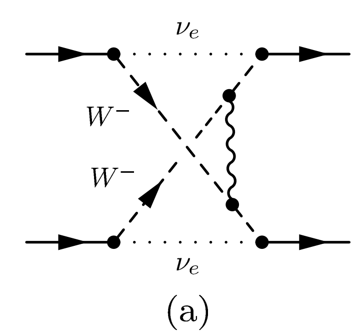
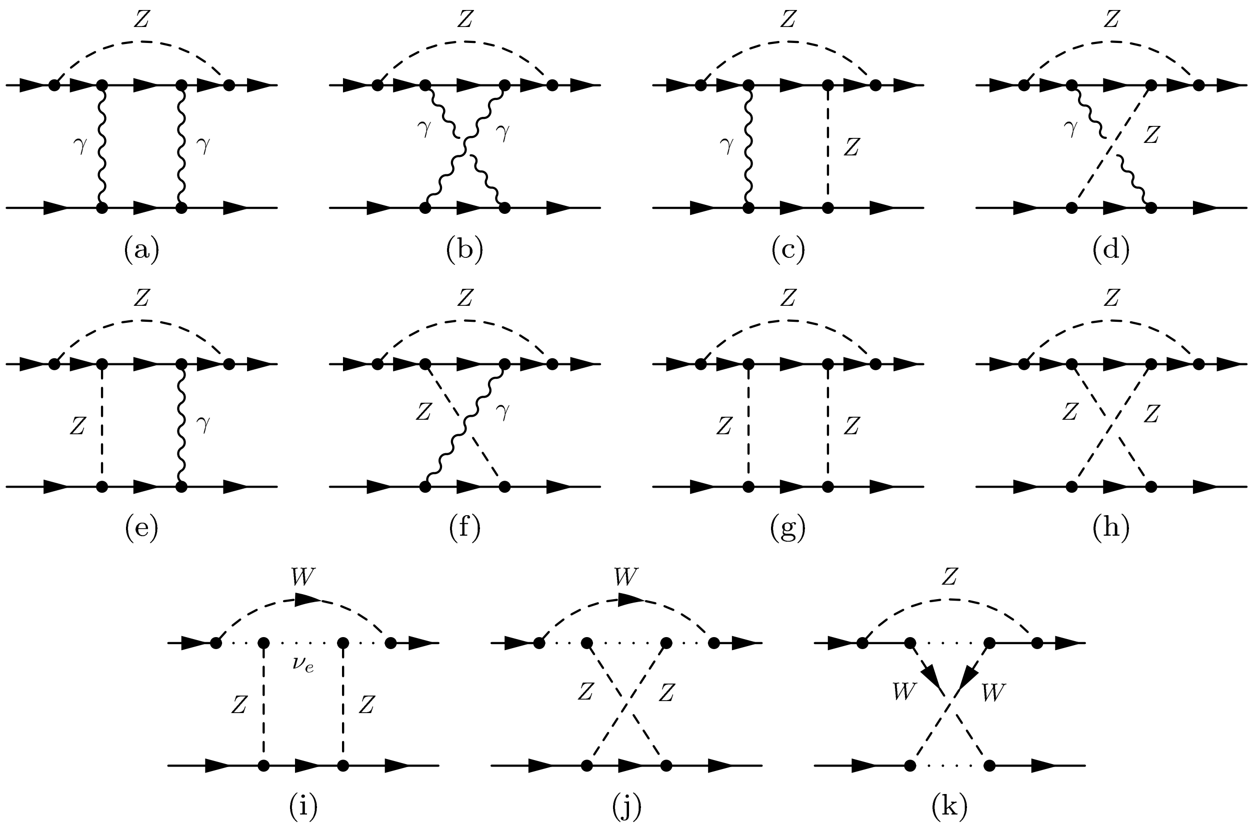


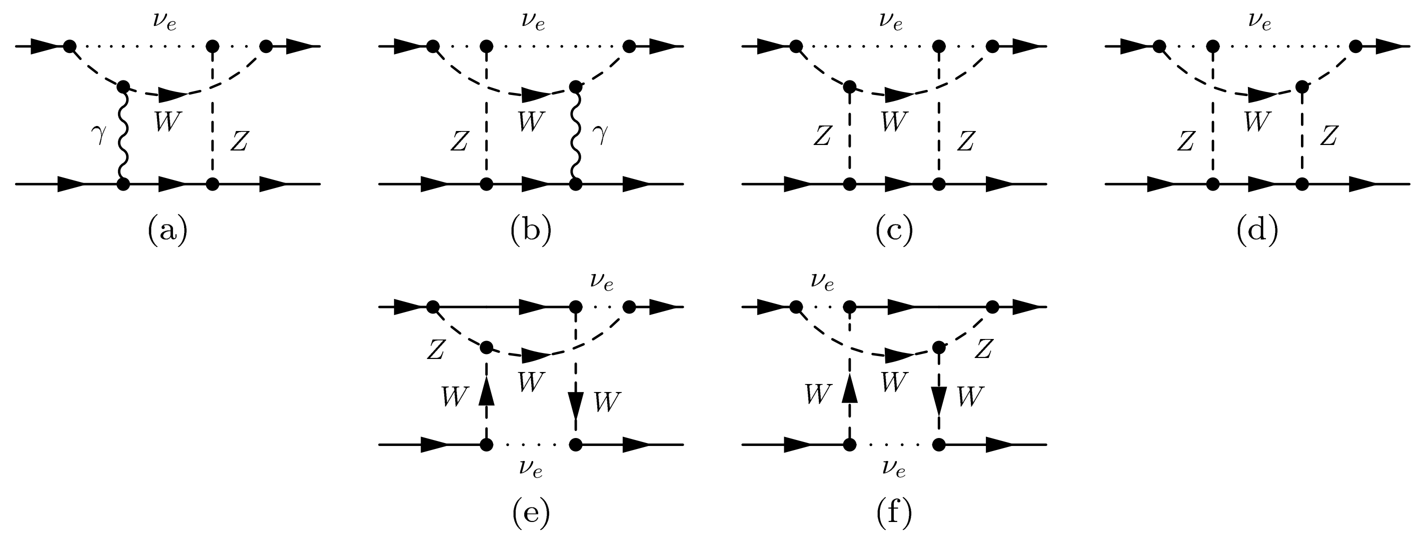
Diagram with W W γ exchange.

(Double Boxes)

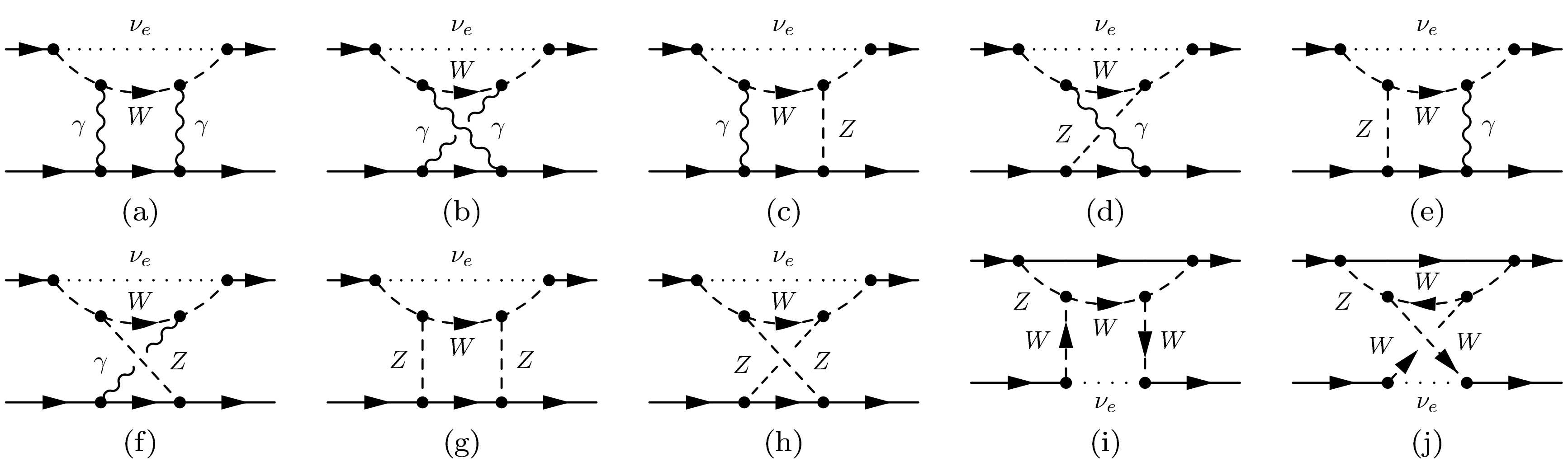
Decorated-Box Diagrams



Decorated boxes of type I.



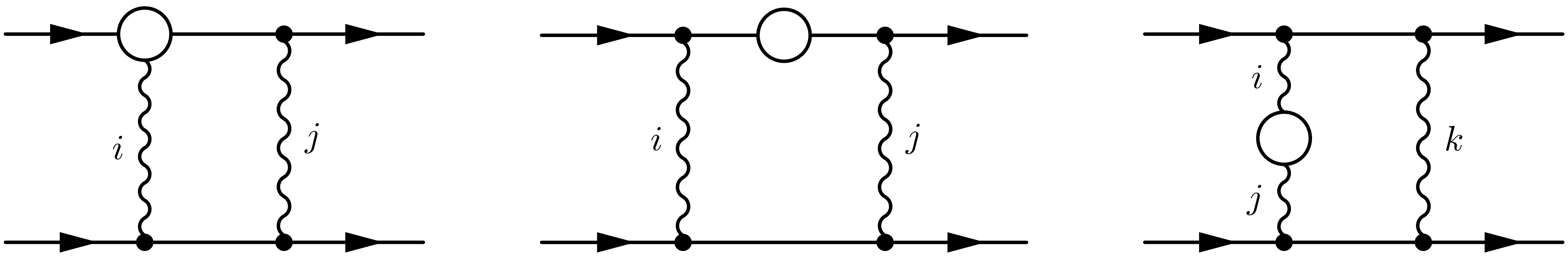
Decorated boxes of type III.



Decorated boxes of type II.

(Double Boxes)

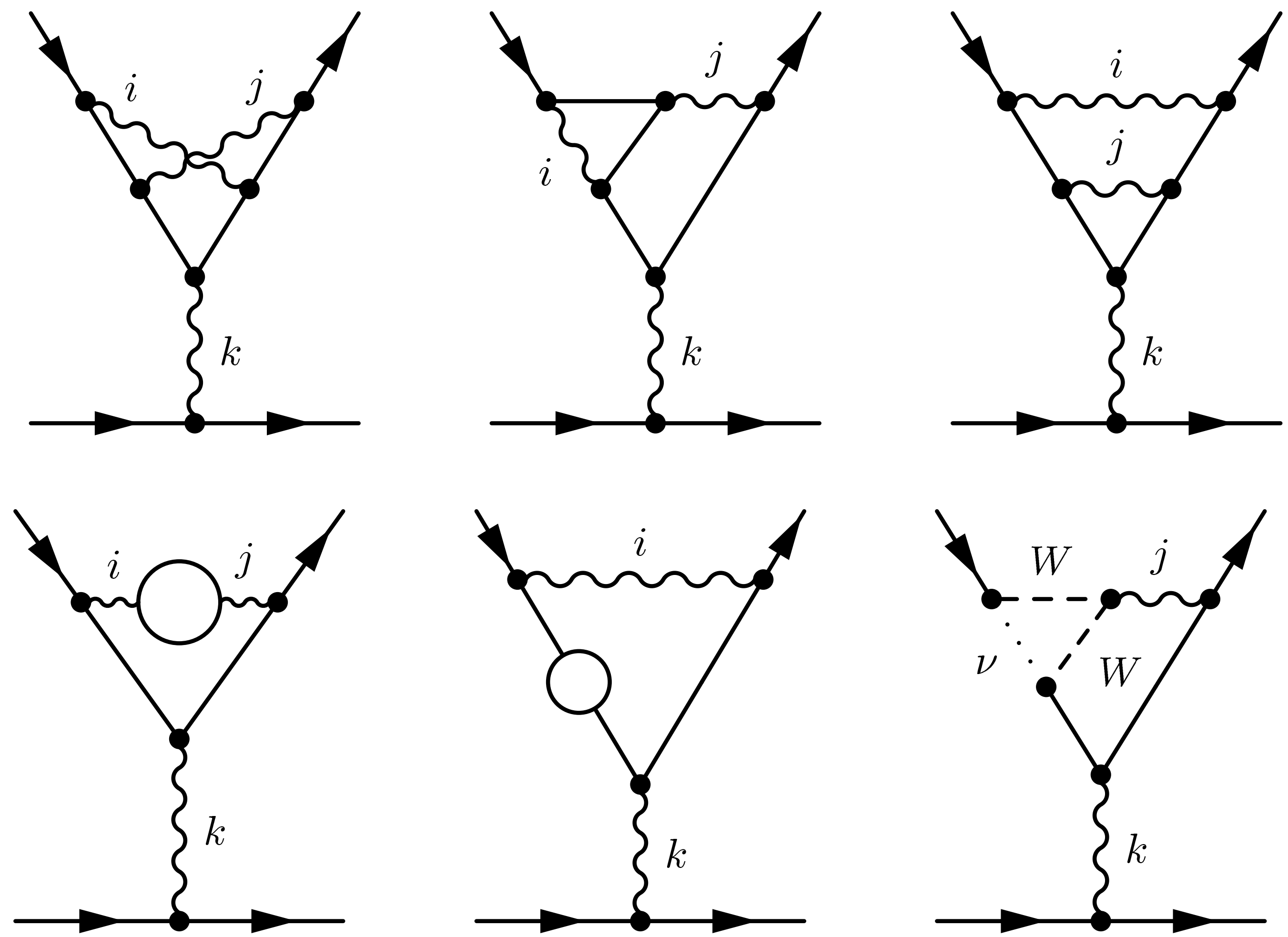
Boxes with Lepton Self-Energy and Vertex Insertions



Boxes with vertices (VB), fermion self-energy boxes FSEB and boson self-energy boxes BSEB.

(SE and Ver in boxes)

Double Vertices



Two loops electron vertices
(NNLO EW Vert)

Combination of Corrections

For the orthogonal kinematics: $\theta = 90^\circ$

Type of contribution	$\delta_A{}^C$
NLO	-0.6953
...+Q+ BBSE+VVer+	-0.6420
...+ double boxes	-0.6534
...+NNLO QED	-0.6500
...+SE and Ver in boxes	-0.6539
...+NNLO EW Ver	-0.6574

Correction to PV asymmetry:

$$\delta_A^C = \frac{A_{LR}^C - A_{LR}^0}{A_{LR}^0}$$

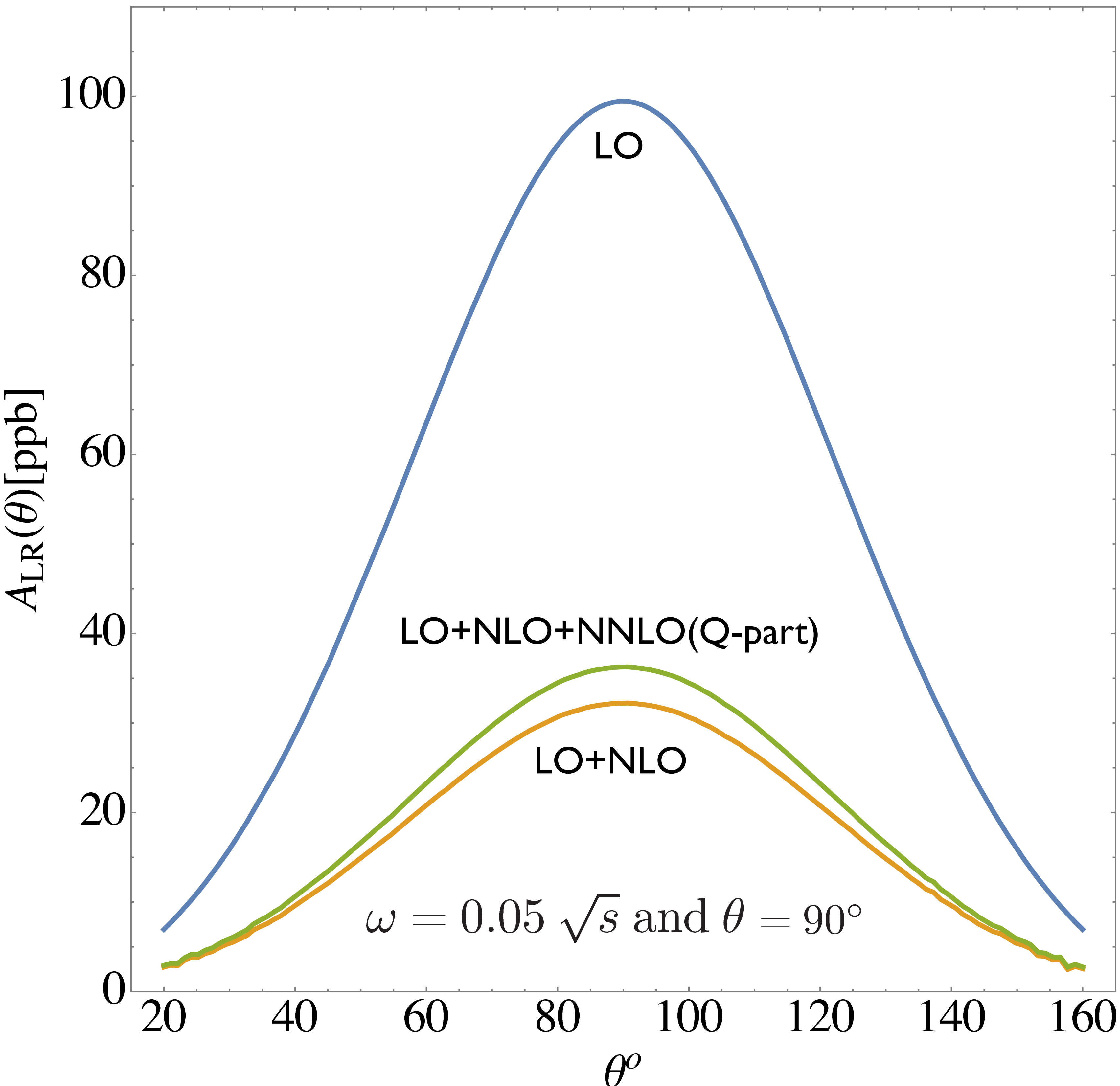
Soft-photon bremsstrahlung cut:

$$\omega = 0.05\sqrt{s}$$

"..." means all contributions from the lines above

A. Aleksejevs, S. Barkanova, Y. Kolomensky, E. Kuraev, V. Zykunov, Phys. Rev. D 85 (2012) 013007
A. Aleksejevs, S. Barkanova, Y. Kolomensky, E. Kuraev, V. Zykunov, Nuovo Cim. C035N04 (2012) 192-197
A. Aleksejevs, S. Barkanova, V. Zykunov, Phys. Atom. Nucl., 75(2012) 209-226
A. Aleksejevs, S. Barkanova, Y. Bystritskiy, A. Ilyichev, E. Kuraev, V. Zykunov, Phys. Rev. D 85 (2012) 013007
A. Aleksejevs, S. Barkanova, Y. Bystritskiy, E. Kuraev, V. Zykunov, Phys. Part. Nucl. Lett. 12(2015) 5 645-656
A. Aleksejevs, S. Barkanova, Y. Bystritskiy, E. Kuraev, V. Zykunov, Phys. of Part. and Nucl. Letters, (2016), 13-3, 310–317

PV Asymmetry



Predicted PV asymmetry (E_{lab} = 11GeV):

$A_{PV}^{(LO+NLO)}$ (90°) = 32.2 (ppb)

$A_{PV}^{(LO+NLO+Q\text{-}part)}$ (90°) = 36.2 (ppb)

$$m_W^2 = \frac{\pi\alpha}{\sqrt{2}G_\mu \sin^2\theta_W(1-\Delta r)}$$

Third Stage: Computer Algebra

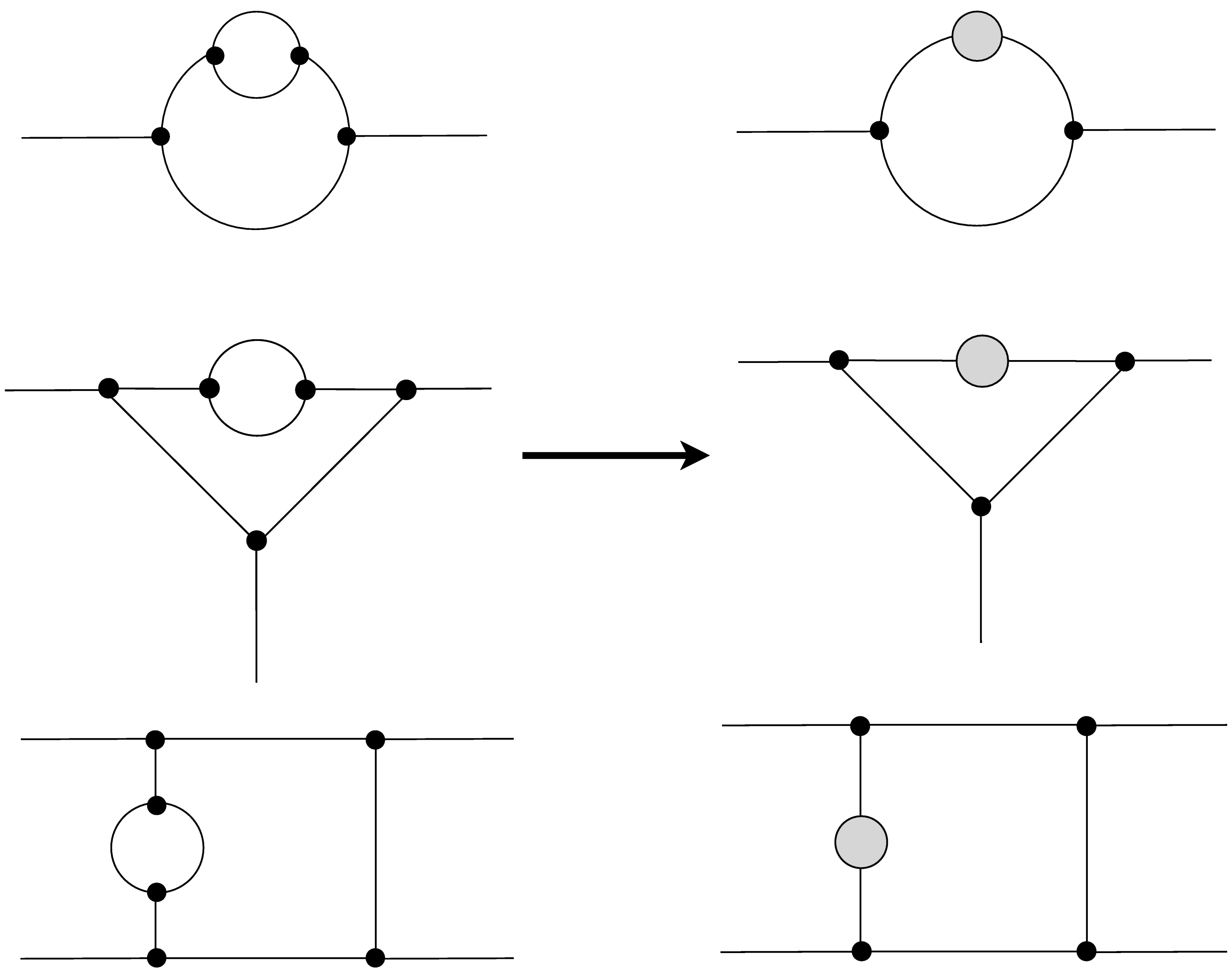
- The most of the leading two-loop EWC corrections to Moller process has been completed.

- It is essential to apply alternative approaches in two-loop EWC calculations for the cross-check purposes.

- We develop the third stage method which is based on the dispersive representation of many-point Passarino-Veltman functions.

- Advantages include not only cross checking previous results, but also our ability to retain kinematical dependence of two-loop EWC and inclusion of broader sets of two-loops graphs.

Sub-Loop Insertions: Self-Energy

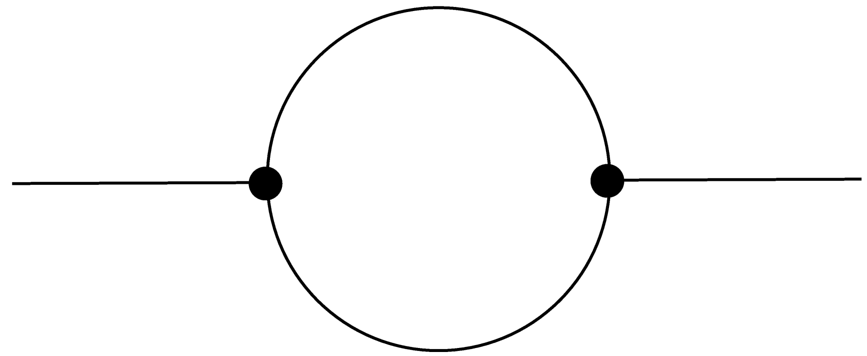


$$L(q^2) = \frac{1}{\pi}\int_{s_0}^{\infty} ds \frac{\Im L(s)}{s - q^2 - i\epsilon}$$

- Replace self-energy insertion by effective propagator

- Dispersive representation of self-energy sub-loop has propagator like structure with mass s

Self-Energy Sub-Loop



Vector boson: $\Sigma_{\mu\nu}^{V-V}(q) = \left(g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2}\right)\Sigma_T^{V-V}\left(q^2\right) + \frac{q_\mu q_\nu}{q^2}\Sigma_L^{V-V}\left(q^2\right)$

Fermion: $\Sigma^f(q) = \not{q}\,\omega_-\Sigma_L^f\left(q^2\right) + \not{q}\,\omega_+\Sigma_R^f\left(q^2\right) + m_f\Sigma_S^f\left(q^2\right)$

Each of the Σ terms are functions of:

$$B_{i,ij,ijk}\left(q^2, m_\alpha^2, m_\beta^2\right) = \frac{1}{\pi}\int\limits_{\left(m_\alpha+m_\beta\right)^2}^{\infty} ds\frac{\Im B_{i,ij,ijk}\left(s, m_\alpha^2, m_\beta^2\right)}{s - q^2 - i\epsilon}$$

Effective SE Propagators

Vector boson effective propagator:

$$\Pi^{V-V}_{\mu\nu}(q) = \Pi^{V-V}_{T,\mu\nu} + \Pi^{V-V}_{L,\mu\nu}$$

$$\Pi^{V-V}_{T,\mu\nu} = \frac{-ig_{\rho\mu}}{q^2 - m_V^2}\left[\frac{g^{\rho\sigma} - \frac{q^\rho q^\sigma}{q^2}}{s - q^2 - i\epsilon}\Im\Sigma^{V-V}_T\left(s, m_\alpha^2, m_\beta^2\right)\right]\frac{-ig_{\sigma\nu}}{q^2 - m_V^2}$$

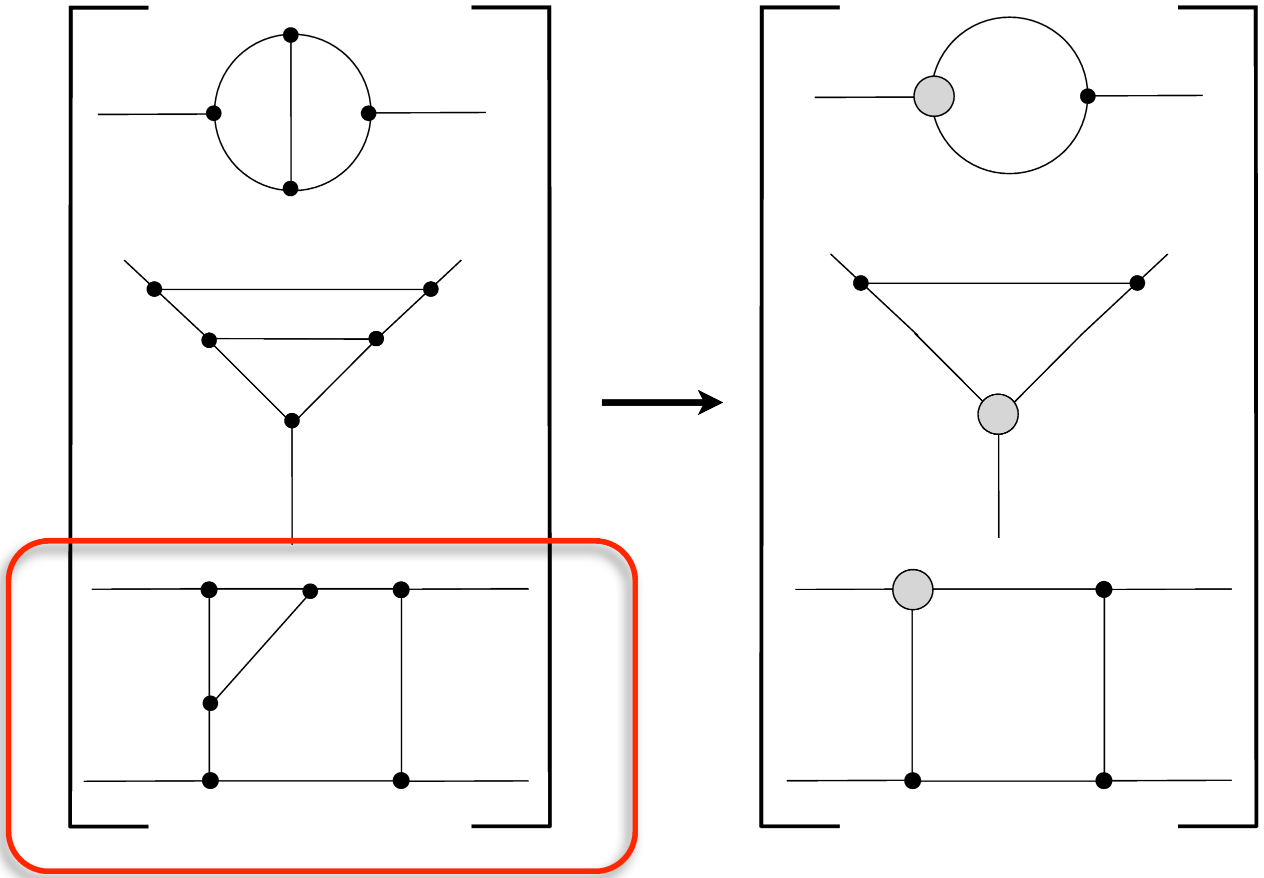
$$\Pi^{V-V}_{L,\mu\nu} = \frac{-ig_{\rho\mu}}{q^2 - m_V^2}\left[\frac{\frac{q^\rho q^\sigma}{q^2}}{s - q^2 - i\epsilon}\Im\Sigma^{V-V}_L\left(s, m_\alpha^2, m_\beta^2\right)\right]\frac{-ig_{\sigma\nu}}{q^2 - m_V^2}$$

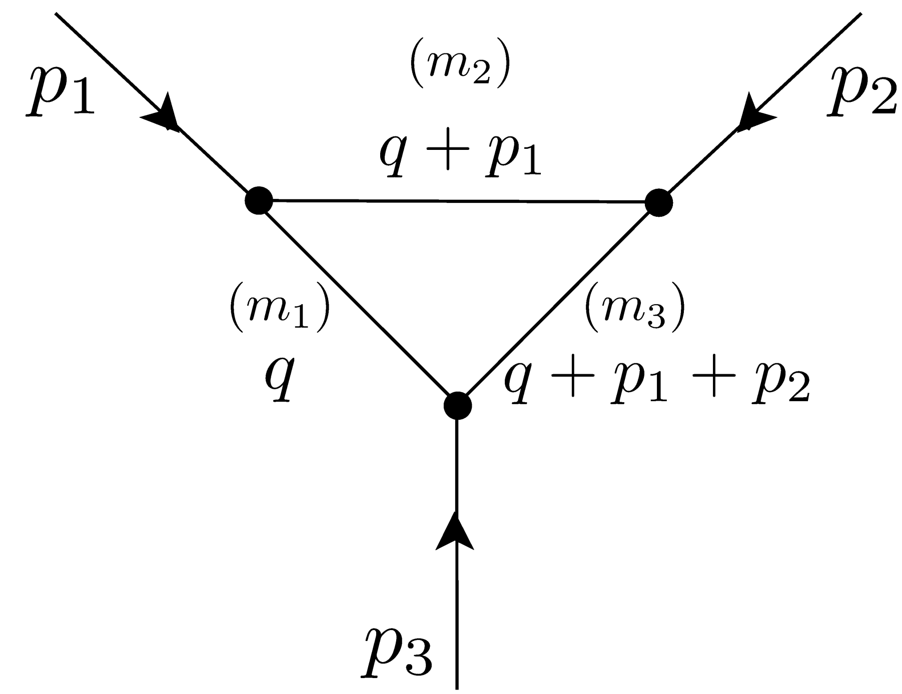
Fermion effective propagator:

$$\Pi^f(q) = \frac{1}{\not{q} - m_f}\left[\frac{G\left(q, s, m_\alpha, m_\beta\right)}{s - q^2 - i\epsilon}\right]\frac{1}{\not{q} - m_f}$$

Introduce effective propagators, and perform dispersive integration numerically later.

Triangle Insertion: Dispersive Approach



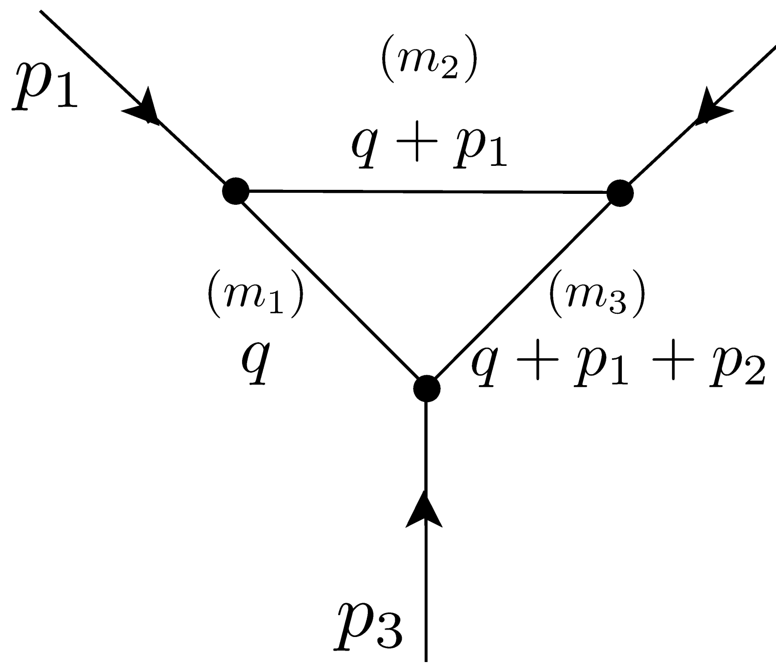


$$C_0 \equiv C_0\left(p_1^2, p_2^2, (p_1+p_2)^2, m_1^2, m_2^2, m_3^2\right) = \frac{\mu^{4-D}}{i\pi^{D/2}} \int d^Dq \frac{1}{\underbrace{[q^2 - m_1^2]\left[(q+p_1)^2 - m_2^2\right]}_{\text{join two propagators without } p_2} \left[(q+p_1+p_2)^2 - m_3^2\right]}$$

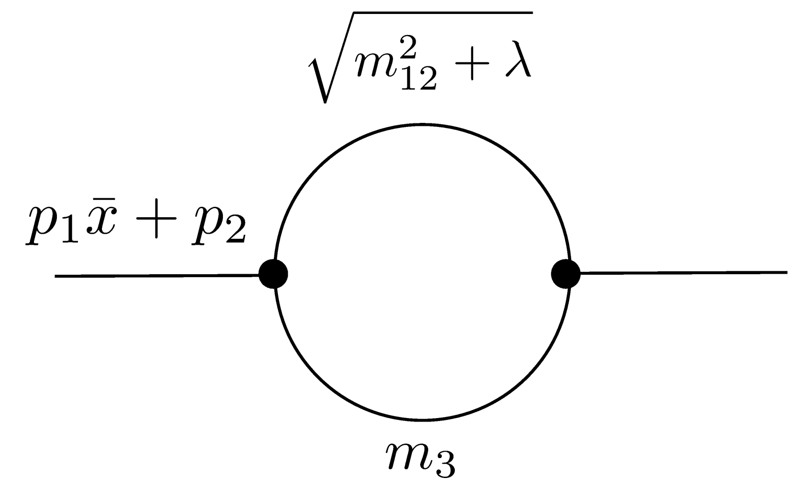
$$C_0 = \frac{\mu^{4-D}}{i\pi^{D/2}} \int_0^1 dx \int d^D\tau \frac{1}{\left[(\tau - (p_1\bar{x} + p_2))^2 - m_{12}^2\right]^2 [\tau^2 - m_3^2]}, \text{ here } \quad m_{12}^2 = m_1^2\bar{x} + m_2^2 x - p_1^2 x\bar{x}$$

$$\frac{1}{\left((\tau - (p_1\bar{x}+p_2))^2 - m_{12}^2\right)^2} = \lim_{\lambda\to 0} \frac{\partial}{\partial\lambda} \frac{1}{\left((\tau - (p_1\bar{x}+p_2))^2 - (m_{12}^2 + \lambda)\right)}$$

Second Loop Integration: Many-Point PV



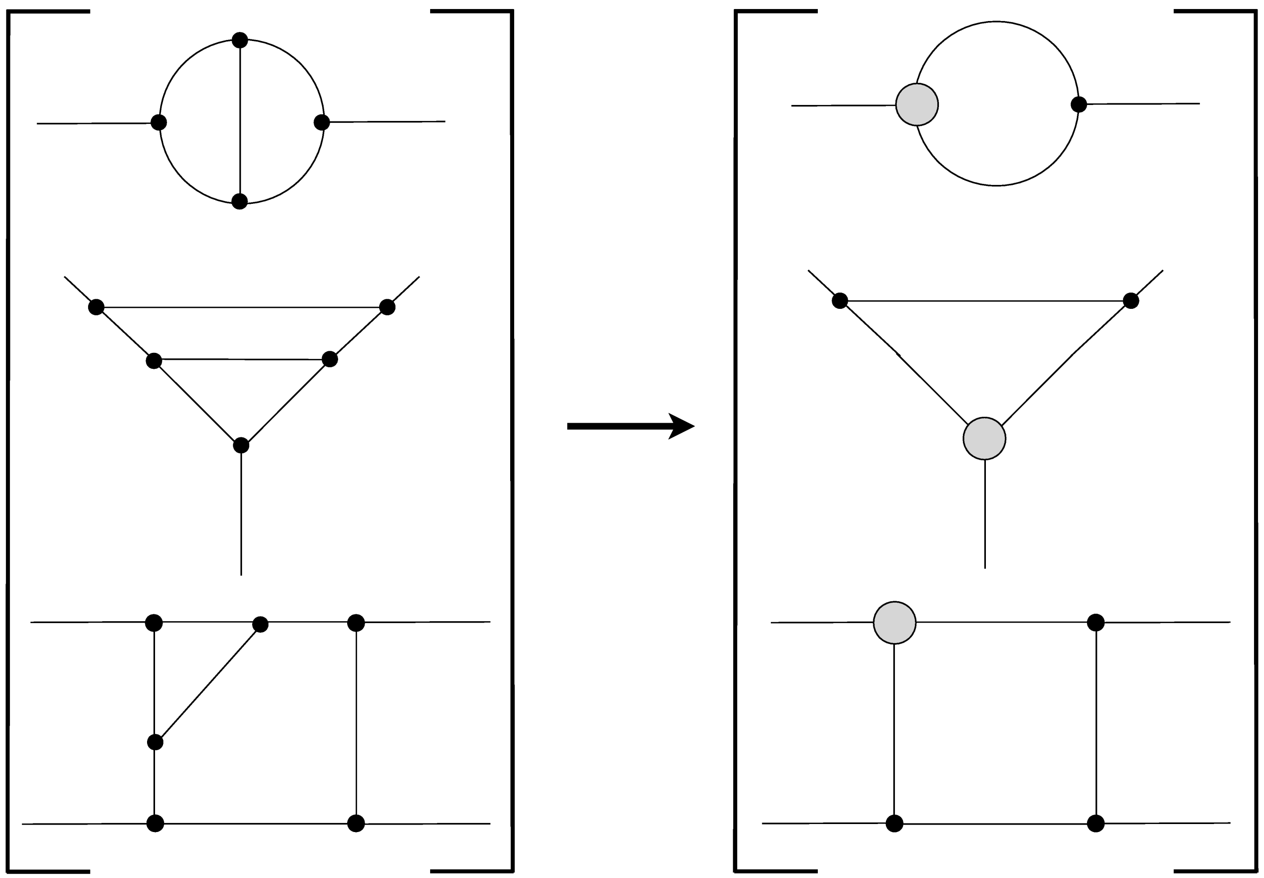
$$\lim_{\lambda\to 0}\frac{\partial}{\partial\lambda}\int_0^1 dx \left[\quad \right]$$



$$C_0 = \frac{\mu^{4-D}}{i\pi^{D/2}}\lim_{\lambda\to 0}\frac{\partial}{\partial\lambda}\int_0^1 dx\int d^D\tau\frac{1}{\left[(\tau-(p_1\bar{x}+p_2))^2-(m_{12}^2+\lambda)\right]\left[\tau^2-m_3^2\right]} = \lim_{\lambda\to 0}\frac{\partial}{\partial\lambda}\int_0^1 dx\; B_0\left((p_1\bar{x}+p_2)^2, m_3^2, m_{12}^2+\lambda\right)$$

$$C_0 = \lim_{\lambda\to 0}\frac{\partial}{\partial\lambda}\int_0^1 dx \int_{\left(m_3+\left(m_{12}^2+\lambda\right)^{1/2}\right)^2}^{\Lambda^2} ds\frac{\Im B_0\left(s, m_3^2, m_{12}^2+\lambda\right)}{s-(p_1\bar{x}+p_2)^2-i\epsilon}$$

Triangle Insertion: Dispersive Approach



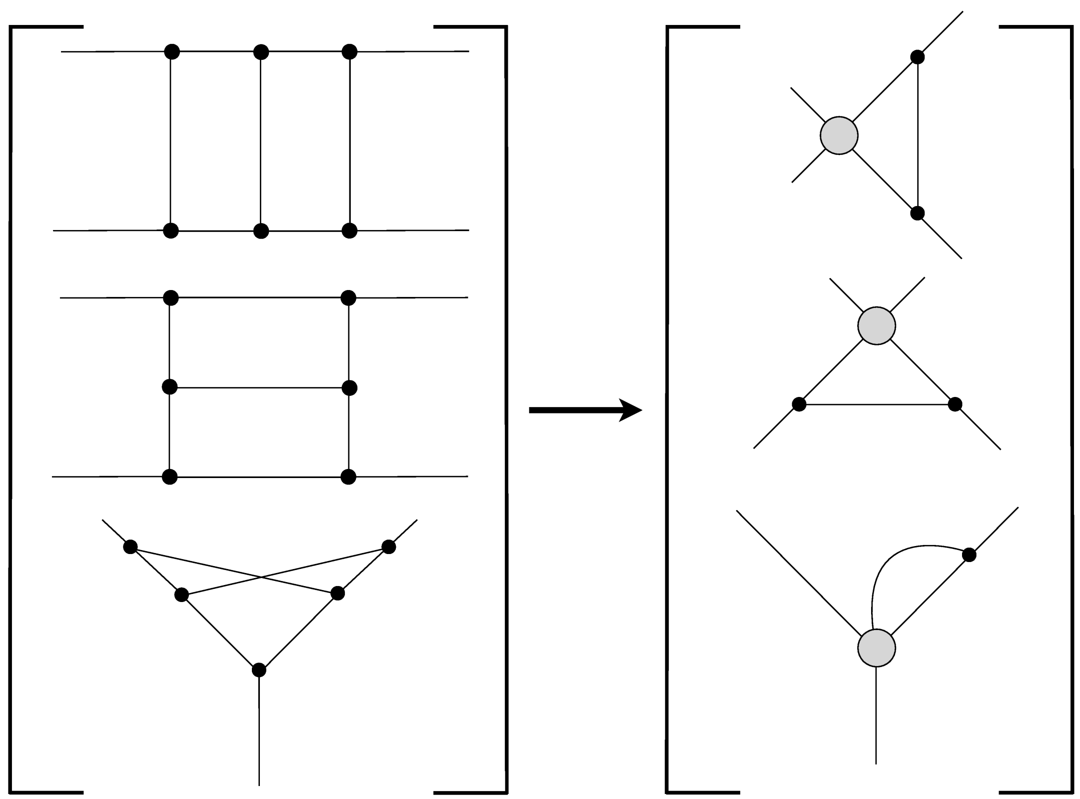
$$\Gamma = \hat{\mathbf{D}} \left[\frac{\Im F\left(s, m_3^2, m_{12}^2 + \lambda\right)}{s - \left(p_2 + p_1 \bar{x}\right)^2 - i\epsilon} \right]$$

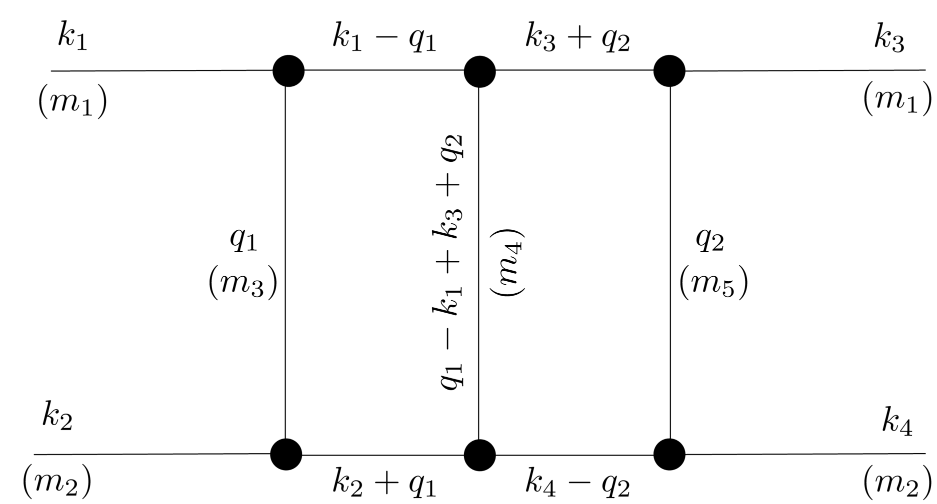
$$\hat{\mathbf{D}} = \lim_{\lambda \to 0} \frac{\partial}{\partial \lambda} \int_0^1 dx \int_{\left(m_3 + \left(m_{12}^2 + \lambda\right)^{1/2}\right)^2}^{\Lambda^2} ds \ldots$$

$$m_{12}^2 = m_1^2 \bar{x} + m_2^2 x - p_1^2 x \bar{x}$$

Subtracted vertex at zero momentum: $\hat{\Gamma} = \hat{\mathbf{D}} \left[\frac{\Im F\left(s, m_3^2, m_{12}^2 + \lambda\right) \left[\left(p_2 + p_1 \bar{x}\right)^2 - p_1^2 \bar{x}^2\right]}{\left[s - \left(p_2 + p_1 \bar{x}\right)^2 - i\epsilon\right] \left[s - p_1^2 \bar{x}^2\right]} \right]$

Box Insertion: Dispersive Approach





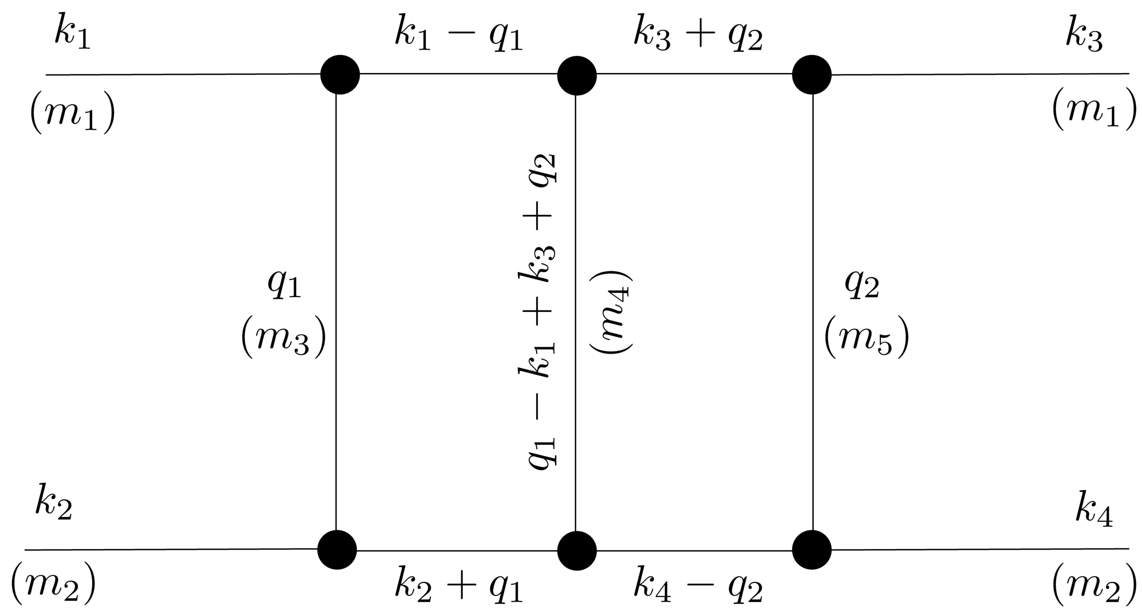
$$D_0 = \frac{1}{i\pi^2} \int \frac{d^4 q_1}{\underbrace{\left[q_1^2 - m_3^2\right]\left[(q_1+k_2)^2 - m_1^2\right]\left[(q_1-k_1)^2 - m_1^2\right]}_{\text{join three propagators without } q_2}\left[(q_1+q_2+k_3-k_1)^2 - m_4^2\right]}$$

$$D_0 = \frac{1}{\pi} \lim_{\lambda \to 0} \frac{\partial^2}{\partial \lambda^2} \int_0^1 dx dy \int_{r(x,y,\lambda)}^{\Lambda^2} ds \frac{\Im B_0\left[s, m_4^2, m_{123}^2 + \lambda\right]}{s - (q_2 + k_3 - x k_2 - k_1 \bar{y})^2 - i\epsilon}$$

$$r(x,y,\lambda) \quad = \quad \left(m_4 + (m_{123}^2 + \lambda)^{1/2}\right)^2 \theta\left(m_{123}^2\right) - \Lambda^2 \theta\left(-m_{123}^2\right)$$

$$m_{123}^2 \quad = \quad m_3^2\left(\bar{x} - y\right) + x^2 m_2^2 + y^2 m_1^2 - 2xy\left(k_1 k_2\right)$$

Box Insertion: Dispersive Approach



$$I_{d-box} = -\frac{1}{\pi}\hat{\mathbf{I}}_{\lambda xys} \int \frac{\Im B_0\left[s, m_4^2, m_{123}^2 + \lambda\right] d^4 q_2}{\underbrace{\left[q_2^2 - m_5^2\right]\left[(q_2+k_3)^2 - m_1^2\right]\left[(q_2-k_4)^2 - m_2^2\right]}_{\text{join three propagators with } q_2}\left[(q_2 + k_3 - x k_2 - k_1 \bar{y})^2 - s - i\epsilon\right]}$$

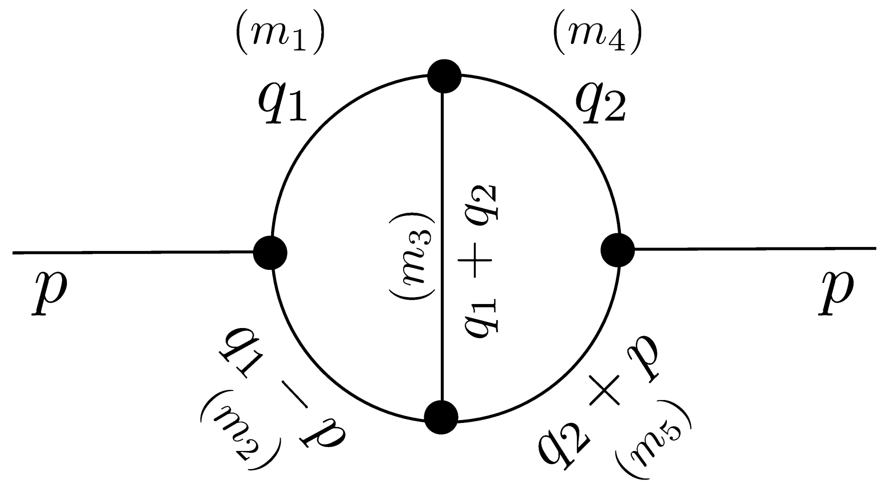
$$I_{d-box} = -\frac{1}{\pi}\hat{\mathbf{I}}_{\lambda xys}\hat{\mathbf{I}}_{\xi z\omega}\Im B_0\left[s, m_4^2, m_{123}^2 + \lambda\right] B_0\left[(\omega k_4 + \bar{z} k_3 - x k_2 - \bar{y} k_1)^2, m_{125}^2 + \xi, s\right]$$

$$\hat{\mathbf{I}}_{\lambda xys} \;=\; \lim_{\lambda\to 0}\frac{\partial^2}{\partial\lambda^2}\int_0^1 dx dy \int_{r(x,y,\lambda)}^{\Lambda^2} ds....$$

$$\hat{\mathbf{I}}_{\xi z\omega} \;=\; \lim_{\xi\to 0}\frac{\partial^2}{\partial\xi^2}\int_0^1 dz d\omega...$$

$$m_{125}^2 = m_5^2(\bar{z} - \omega) + m_1^2 z^2 + \omega^2 m_2^2 - 2z\omega(k_3 k_4)$$

Numerical Example



$$I_a = -\frac{1}{\pi^4}\int \frac{d^4q_1 d^4q_2}{\left[q_1^2-m_1^2\right]\left[(q_1-p)^2-m_2^2\right]\left[(q_1+q_2)^2-m_3^2\right]\left[q_2^2-m_4^2\right]\left[(q_2+p)^2-m_5^2\right]}$$

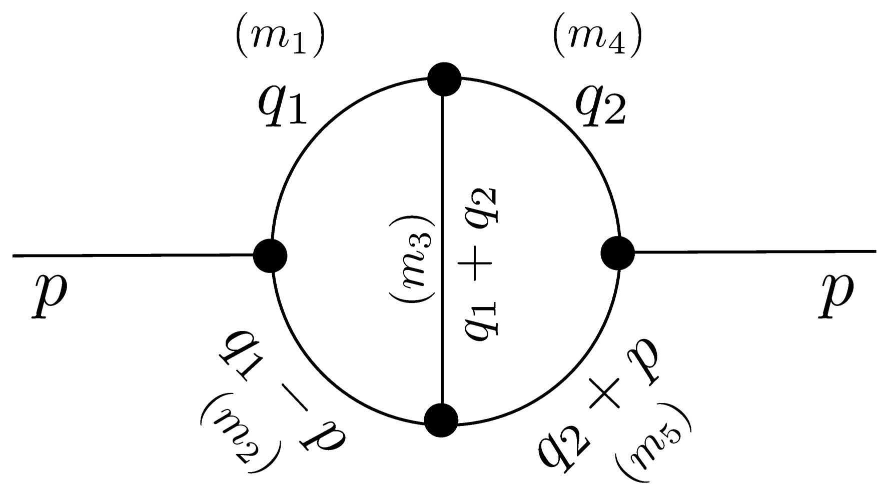
$$I_a = \frac{i}{\pi^3}\lim_{\lambda\to 0}\frac{\partial}{\partial\lambda}\int_0^1 dx \int_{\left(m_3+\left(m_{12}^2+\lambda\right)^{1/2}\right)^2}^{\Lambda^2} ds\, \Im B_0\left(s, m_3^2, m_{12}^2+\lambda\right)\int d^4q_2 \frac{1}{\left[q_2^2-m_4^2\right]\left[(q_2+xp)^2-s\right]\left[(q_2+p)^2-m_5^2\right]}$$

$$I_a = -\frac{1}{\pi}\lim_{\{\lambda,\xi\}\to 0}\frac{\partial^2}{\partial\lambda\partial\xi}\int_0^1 dxdy \int_{\left(m_3+\left(m_{12}^2+\lambda\right)^{1/2}\right)^2}^{\Lambda^2} ds\, \Im B_0\left(s, m_3^2, m_{12}^2+\lambda\right) B_0\left(p^2(x-y)^2, s, m_{45}^2+\xi\right)$$

$$m_{12}^2 = m_1^2\bar{x} + m_2^2 x - p^2\bar{x}x$$

$$m_{45}^2 = m_4^2\bar{y} + m_5^2 y - p^2\bar{y}y$$

Numerical Example



p^2 (GeV)^2	This work	[5]
-5.0	-0.22178	-
-1.0	-0.26919	-
-0.5	-0.27712	-
-0.1	-0.28360	-
0.1	-0.28714	-0.28701
0.5	-0.29443	-0.29479
1.0	-0.30449	-0.30493
5.0	-0.45230	-0.45241
10.0	-0.48618 - 0.35214 i	-0.48827-0.35266 i

[1] S. Bauberger, M. Bohm, Nucl. Phys. B 445, 25-46 (1995)

[This work] A. A, arXiv:1804.08914

$m_1^2 = 1$, $m_2^2 = 2$, $m_3^2 = 3$, $m_4^2 = 4$ and $m_5^2 = 5$ (GeV)^2

Conclusion

- We are now in the last stage of the NNLO EWC calculations for the MOLLER experiment.

- Automatization of the NNLO EWC calculations for MOLLER is currently under way.

- Our next goal is a full gauge-invariant set of two-loop EW graphs with SE and triangles insertions.

- Results to be obtained will be cross checked with our previous calculations and other literature.

- We are looking for additional collaborative projects in two-loops calculations for various processes.