Neutrino-Pair Exchange Long-Range Forces between Aggregated Matter

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Long-Range Weak Forces

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THE WEAK CHARGES OF MATTER

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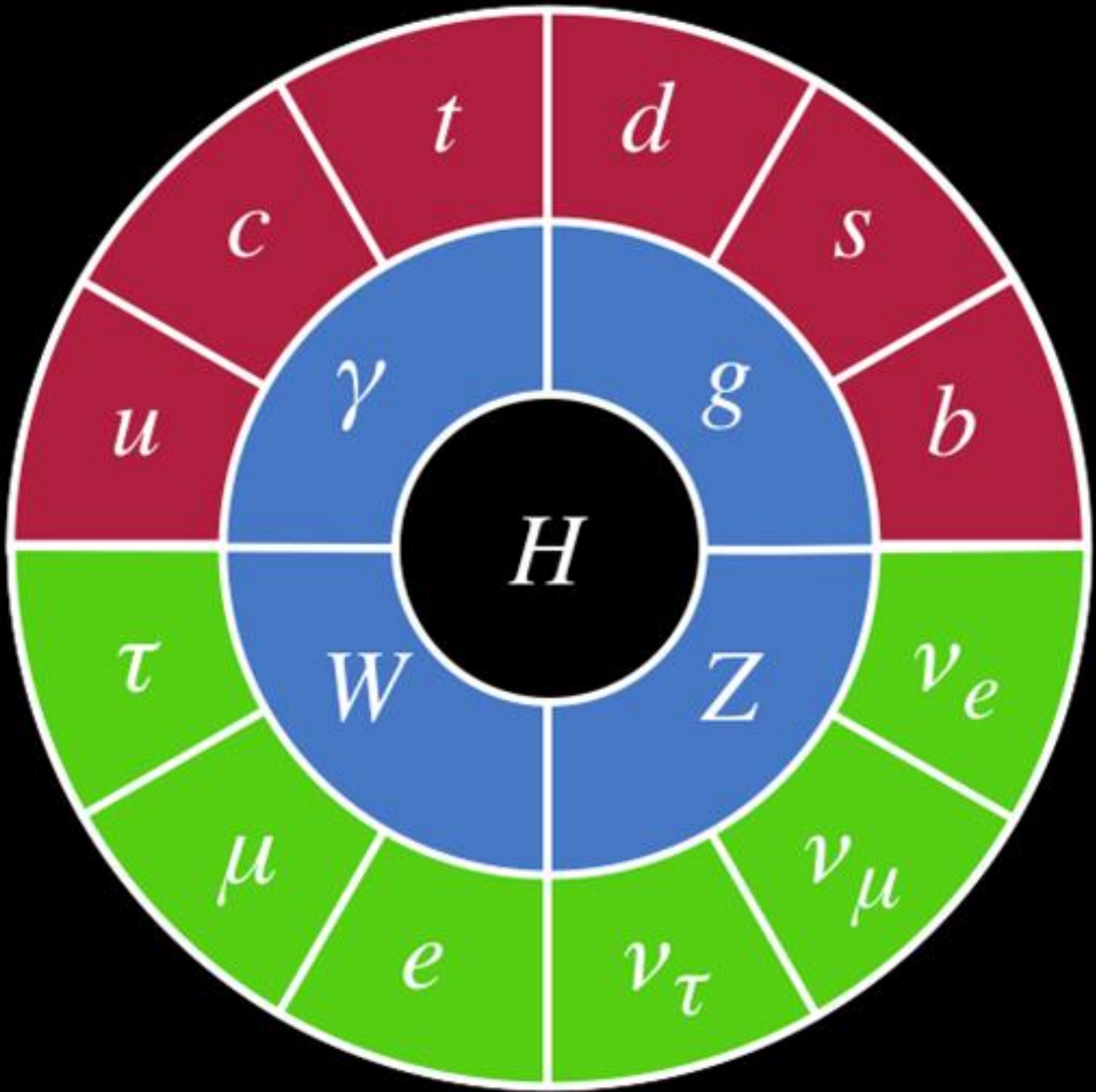
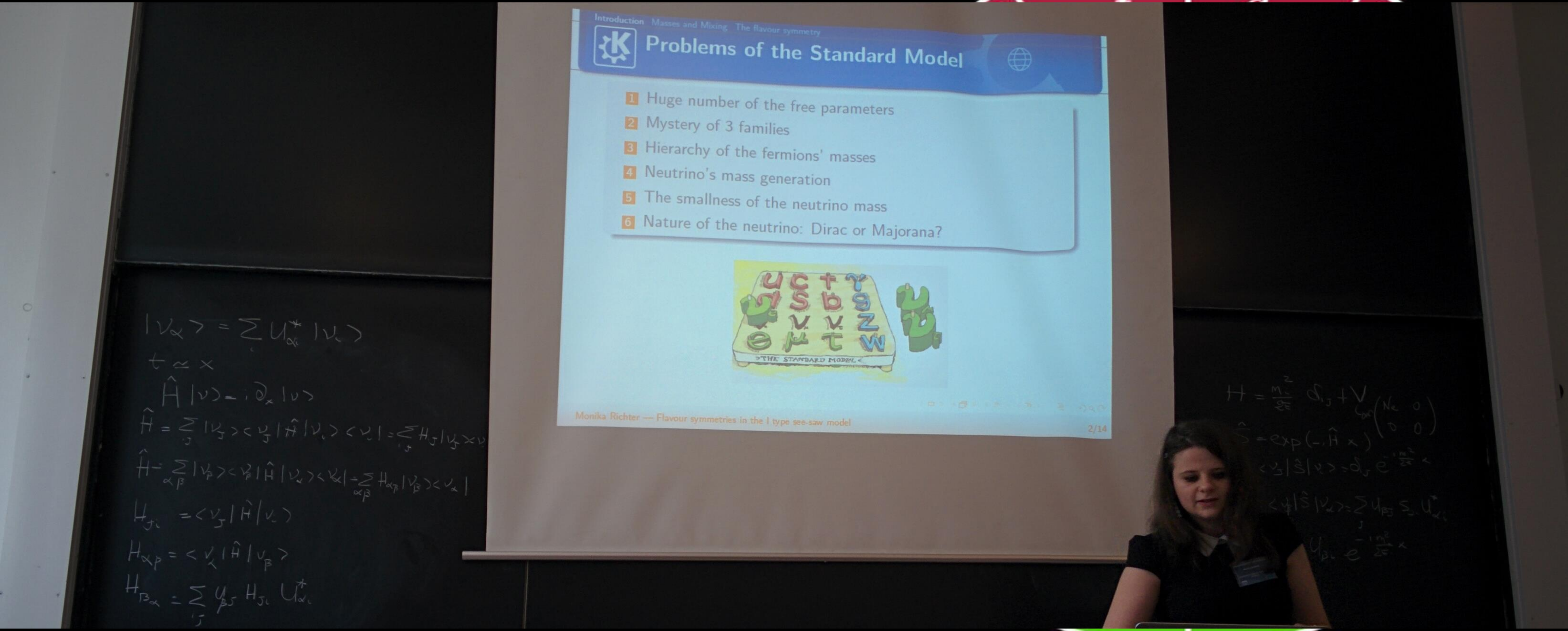
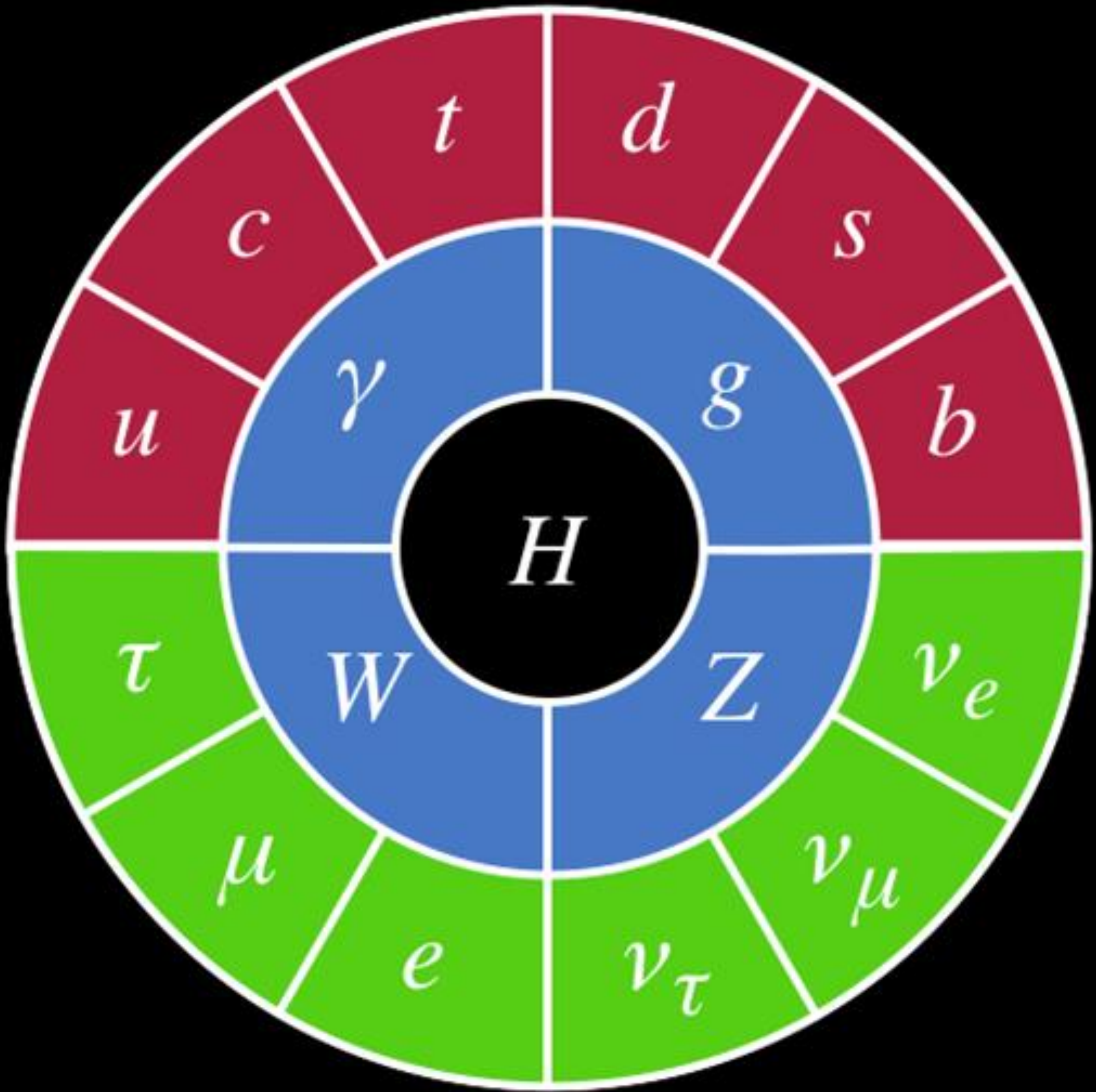
MOTIVATION



Motivation


Introduction Masses and Mixing The flavour symmetry
Problems of the Standard Model
1 Huge number of the free parameters
2 Mystery of 3 families
3 Hierarchy of the fermions' masses
4 Neutrino's mass generation
5 The smallness of the neutrino mass
6 Nature of the neutrino: Dirac or Majorana?
THE STANDARD MODEL
Monika Richter — Flavour symmetries in the I type see-saw model
2/14

MOTIVATION



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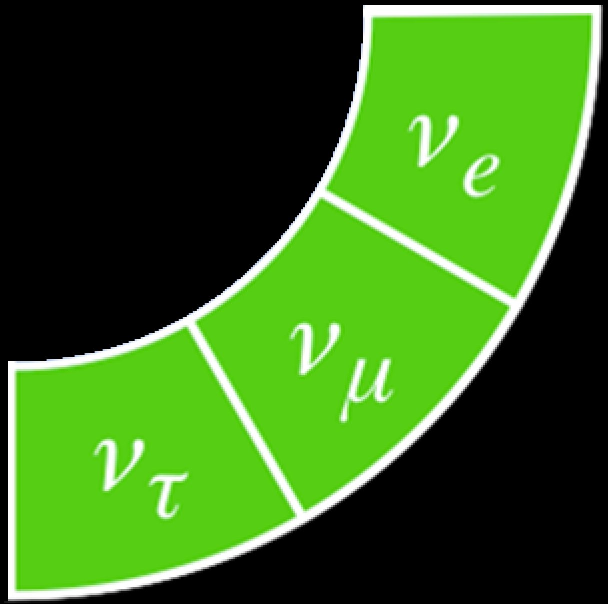

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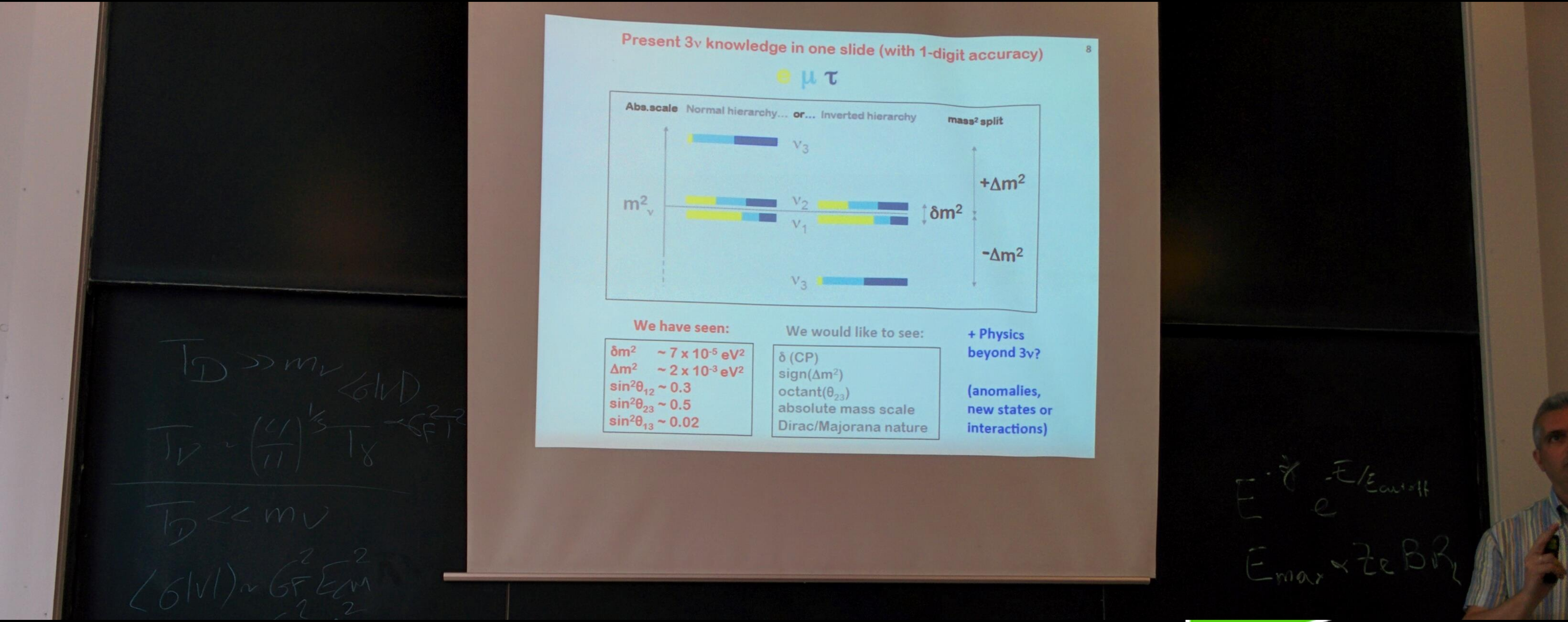
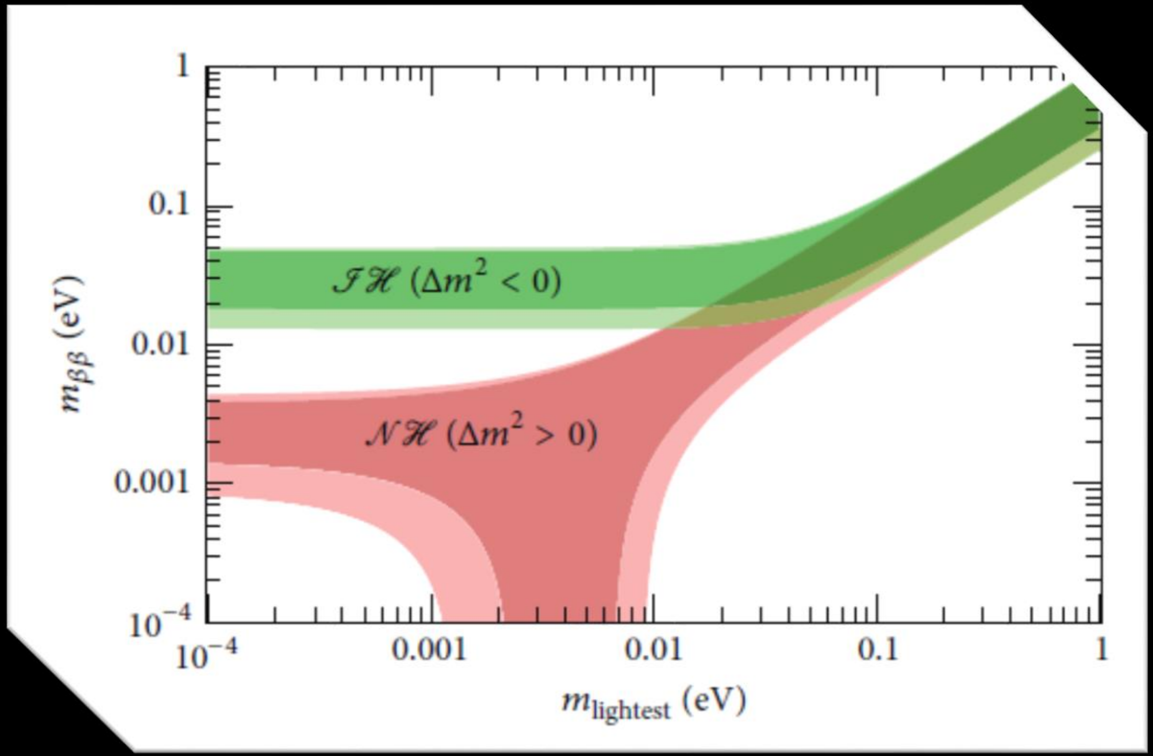
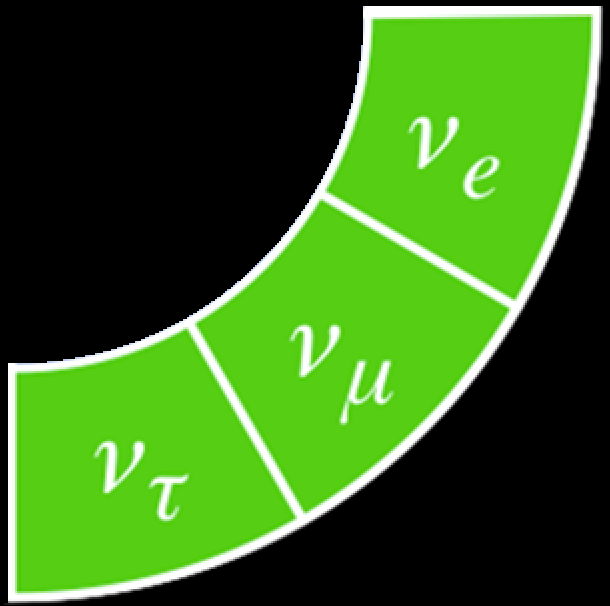


Present 3ν knowledge in one slide (with 1-digit accuracy)
8
e μ τ
Abs.scale
Normal hierarchy...
or...
Inverted hierarchy
mass² split
ν3
m²ν
ν2
ν1
+Δm²
δm²
-Δm²
ν3
We have seen:
δm² ~ 7 x 10⁻⁵ eV²
Δm² ~ 2 x 10⁻³ eV²
sin²θ12 ~ 0.3
sin²θ23 ~ 0.5
sin²θ13 ~ 0.02
We would like to see:
δ (CP)
sign(Δm²)
octant(θ23)
absolute mass scale
Dirac/Majorana nature
+ Physics beyond 3ν?
(anomalies, new states or interactions)

Motivation

- Mass Hierarchy
- Absolute mass scale
- Dirac/Majorana





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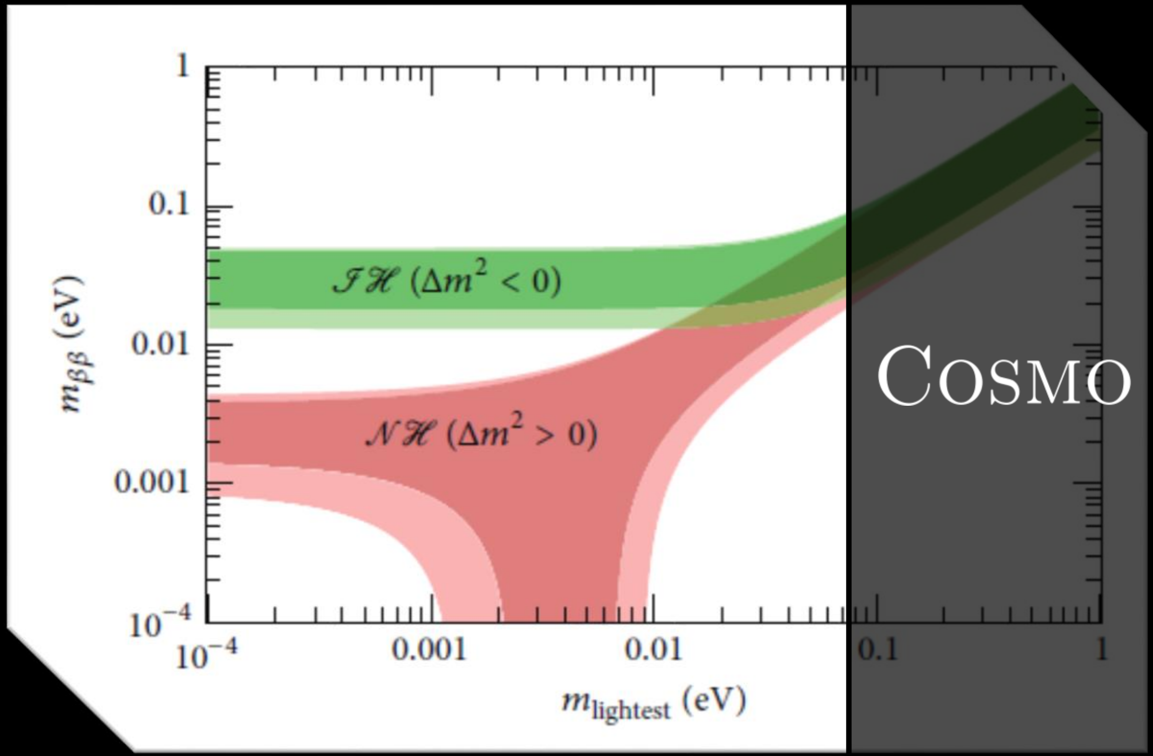

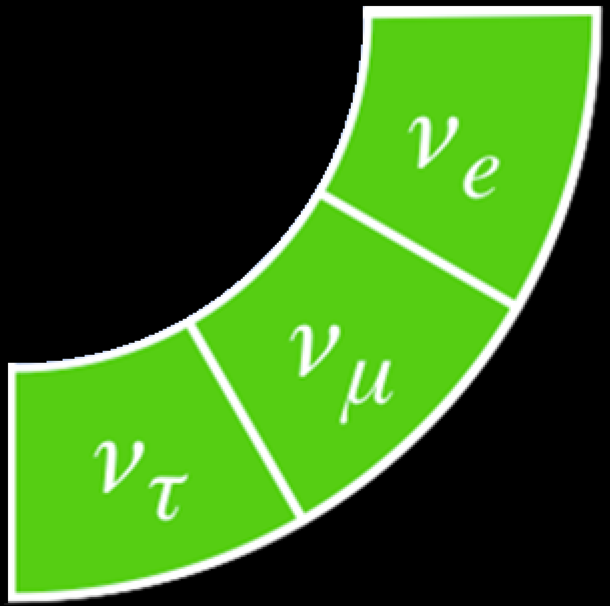

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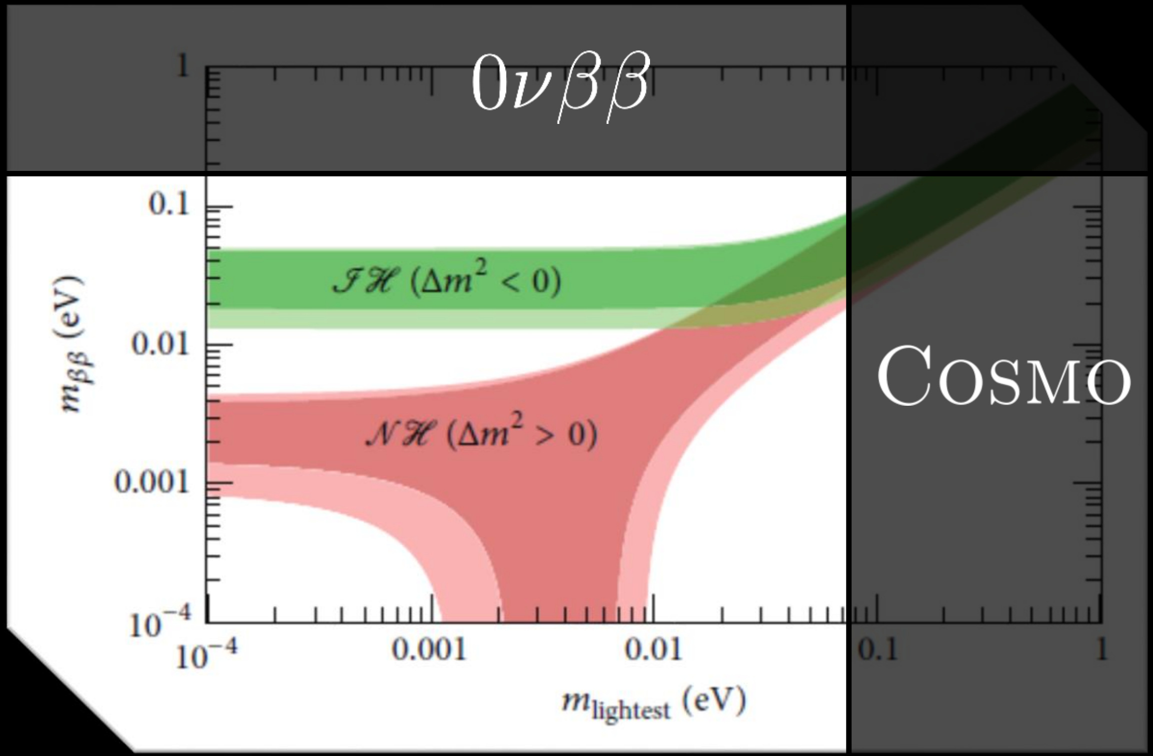

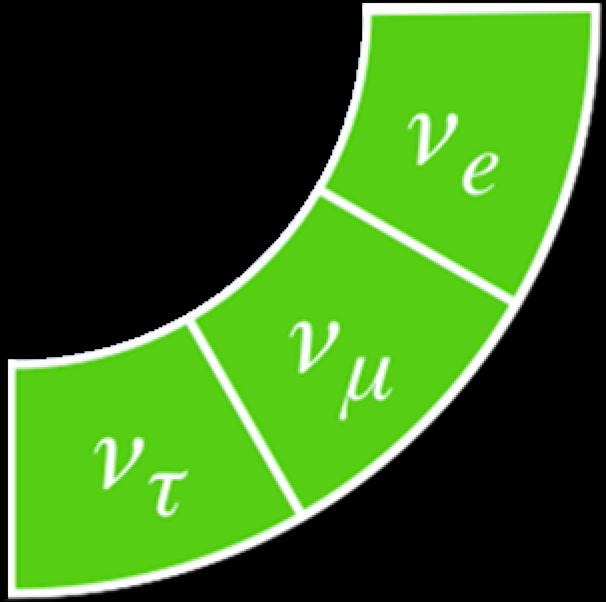

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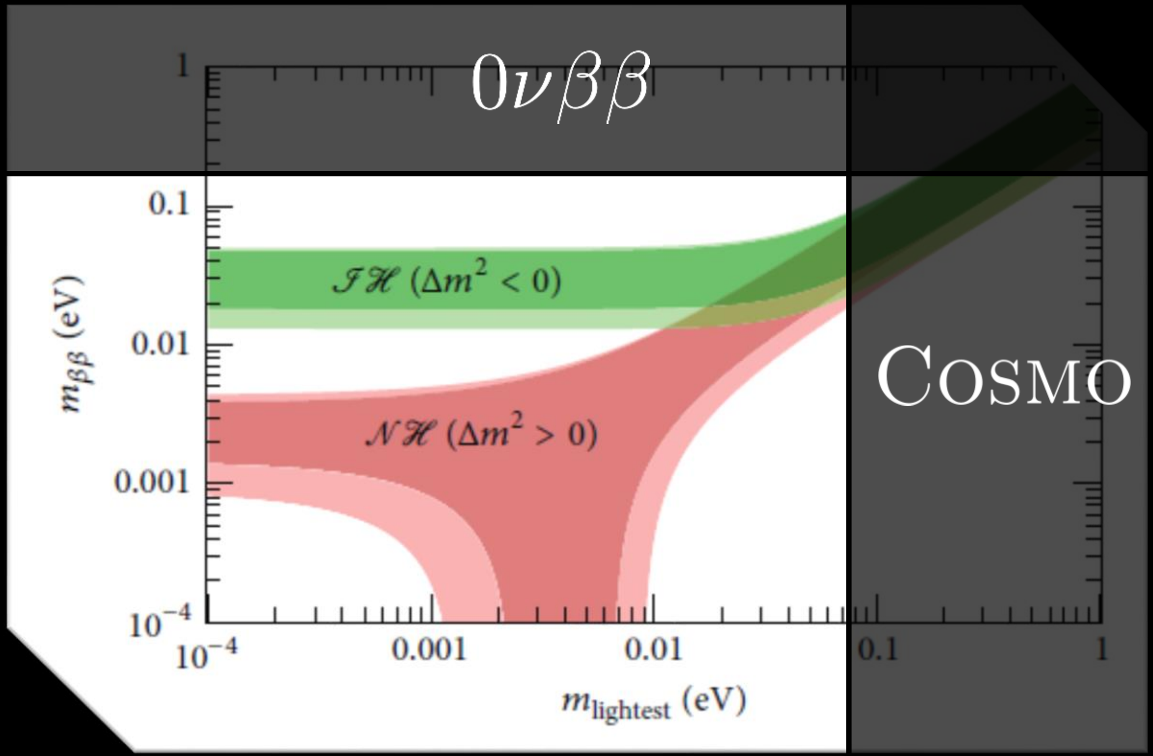
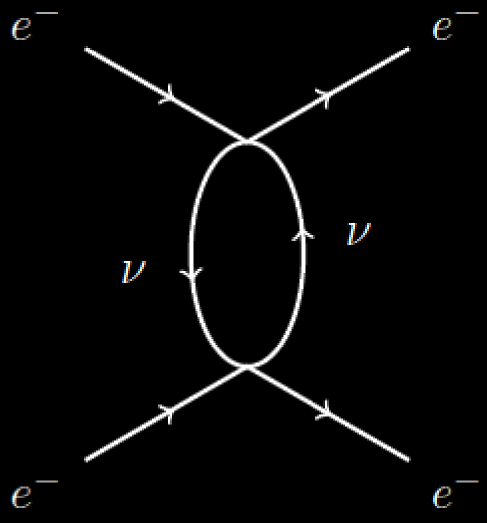
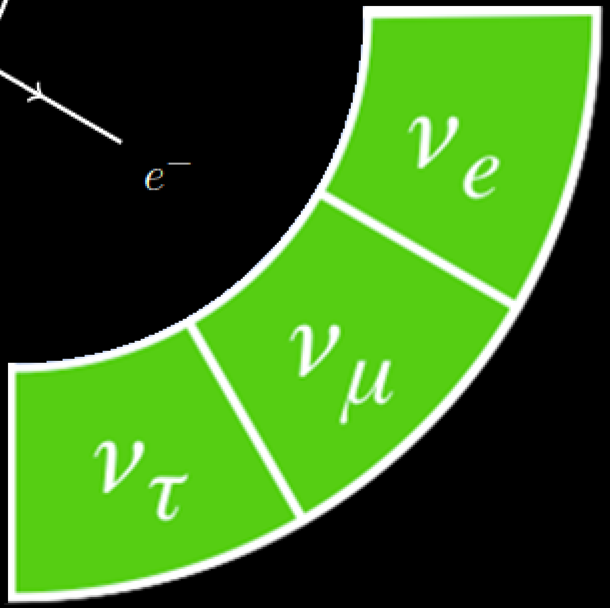
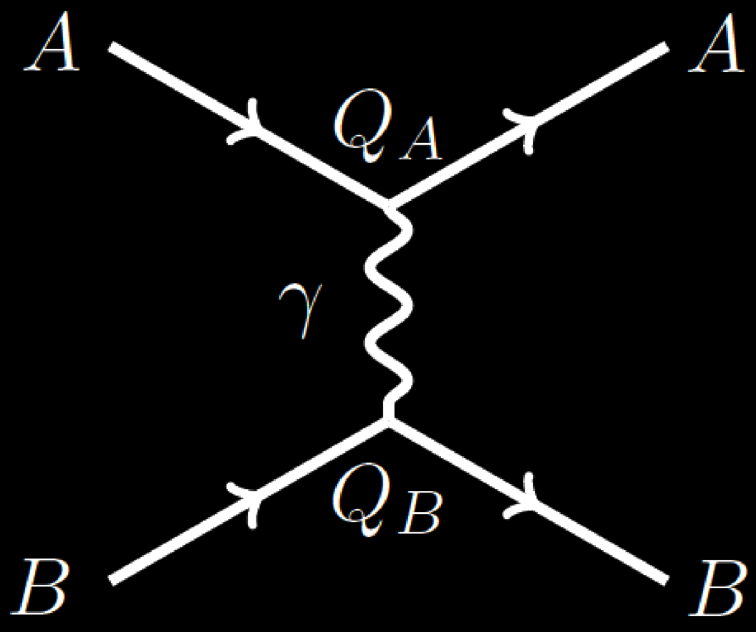






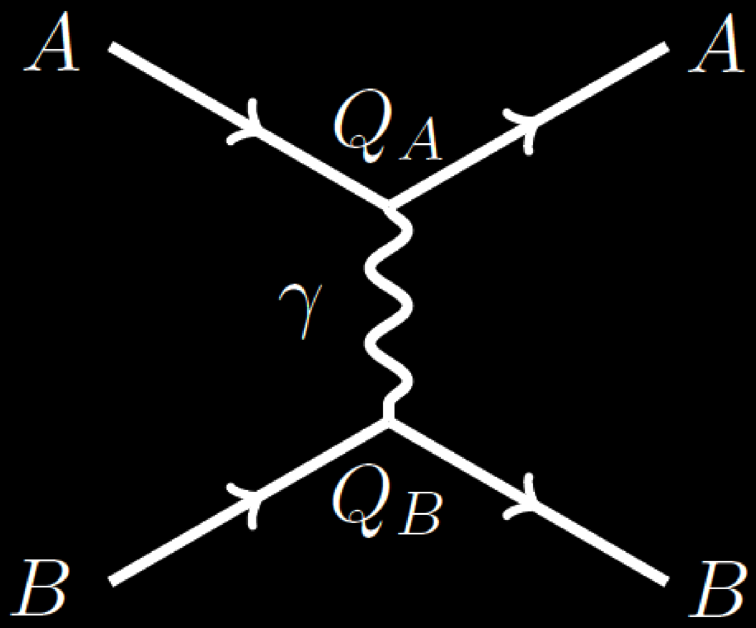
QED



$$M(q) = e^2 Q_A Q_B \, \frac{j_A \cdot j_B}{q^2}$$

QED

momentum



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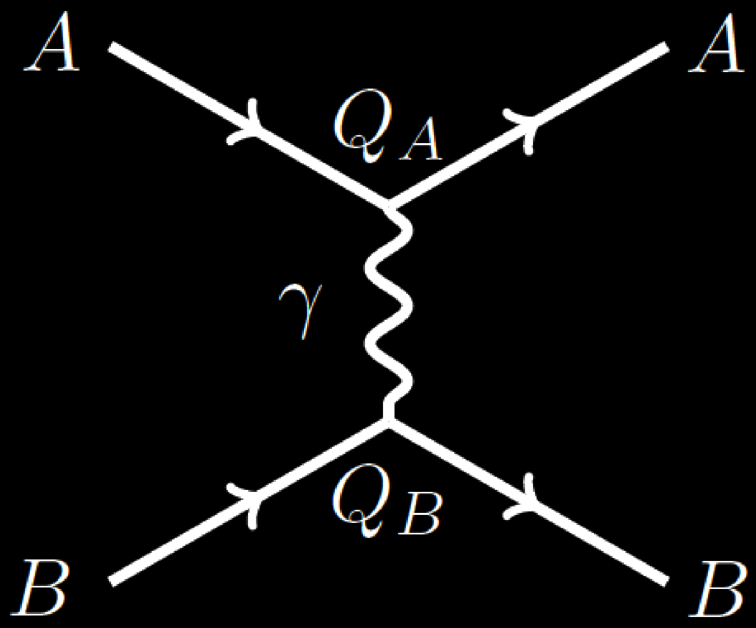
QED — Coulomb Potential

momentum $\xrightarrow{\mathcal{F}}$ position



$$M(q) = e^2 Q_A Q_B \frac{j_A \cdot j_B}{q^2}$$

$$V(r) = \frac{e^2}{4\pi} \frac{Q_A Q_B}{r}$$

QED

Coulomb Potential

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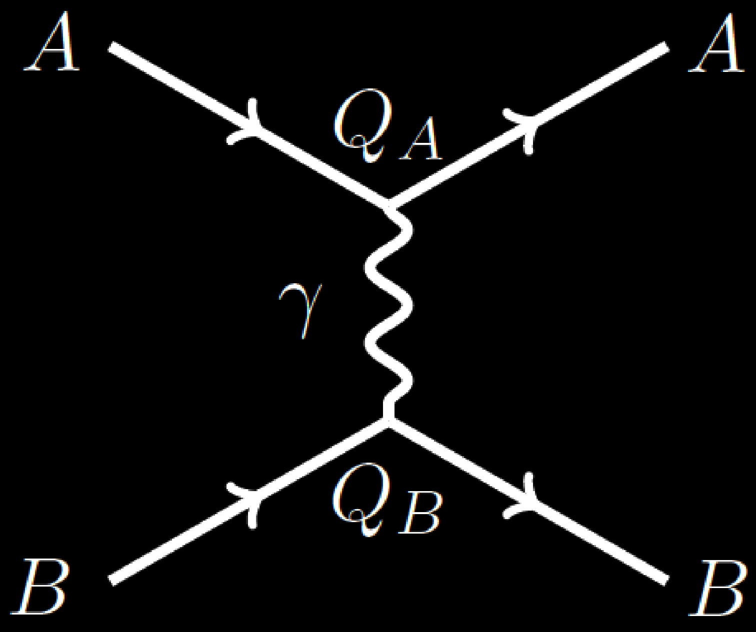

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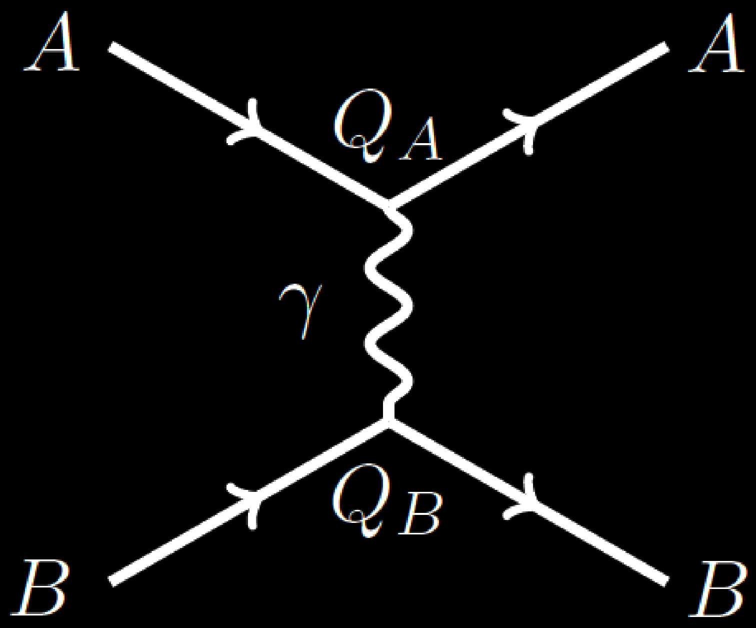
Photon is massless $\longrightarrow$ range is ∞

QED — Coulomb Potential

momentum $\xrightarrow{\mathcal{F}}$ position



$$V(r) = \frac{e^2}{4\pi}\frac{Q_A Q_B}{r}$$

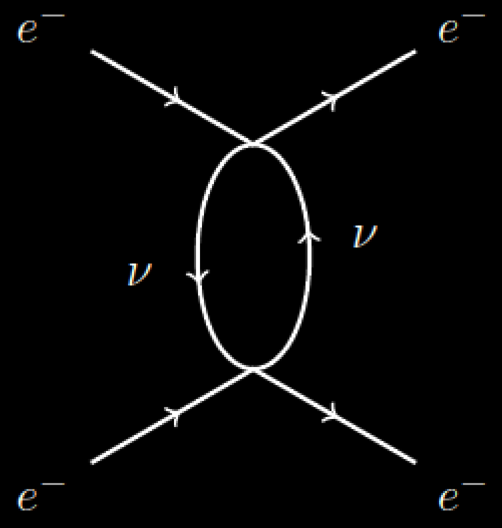
$$M(q) = e^2 Q_A Q_B \frac{j_A \cdot j_B}{q^2}$$

F … s $\longrightarrow$ range is ∞

Neutrinos nearly massless

ALREADY ON THE LITERATURE...

Hsu, Sikivie, arXiv:hep-ph/9211301



$$V(r) = \frac{G_F^2}{8\pi^3}\,\frac{1}{r^5}$$

– Only $ee \to ee$ scattering considered
– SM: massless neutrinos

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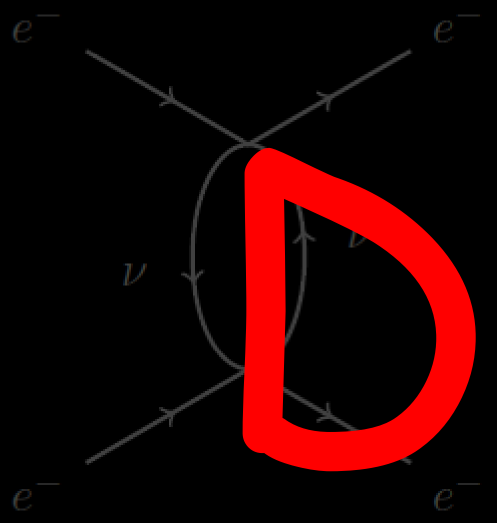

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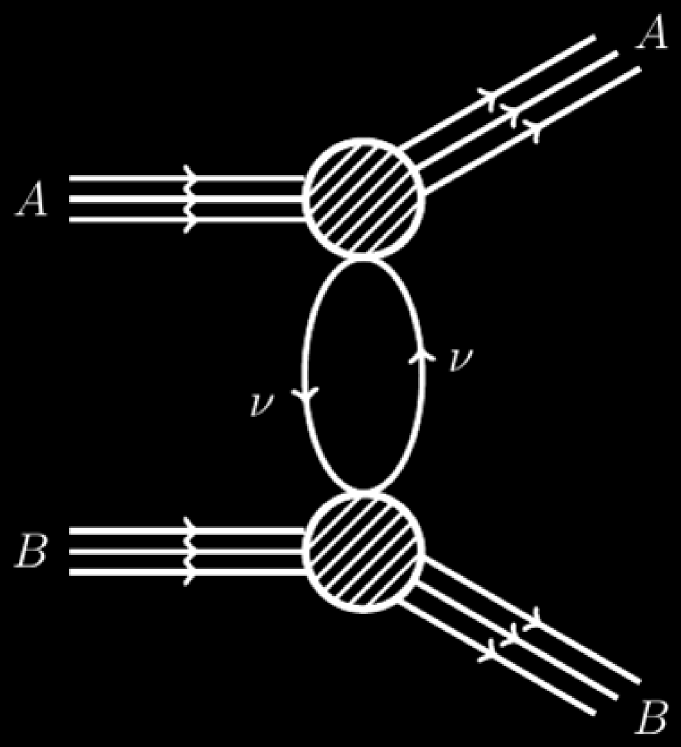
Dismised!

Long-range Weak Interaction

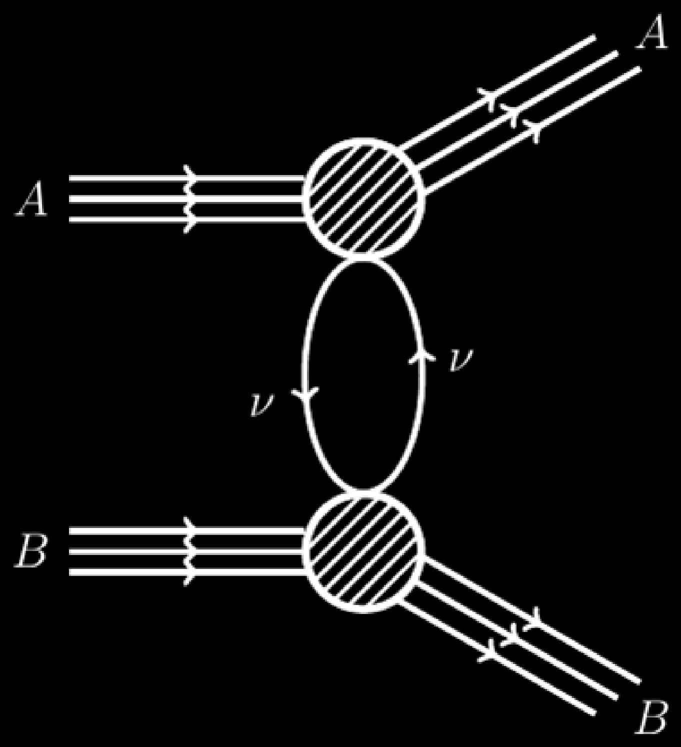
AS, arXiv:hep-ph/1606.05087



$$V(r) = \frac{G_F^2}{8\pi^3}\left[(2Z-N)^2 + 2N^2\right]\frac{1}{r^5}$$

LONG-RANGE WEAK INTERACTION

AS, arXiv:hep-ph/1606.05087



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A and B are *anything*

$Z = \#$ protons $= \#$ electrons
$N = \#$ neutrons

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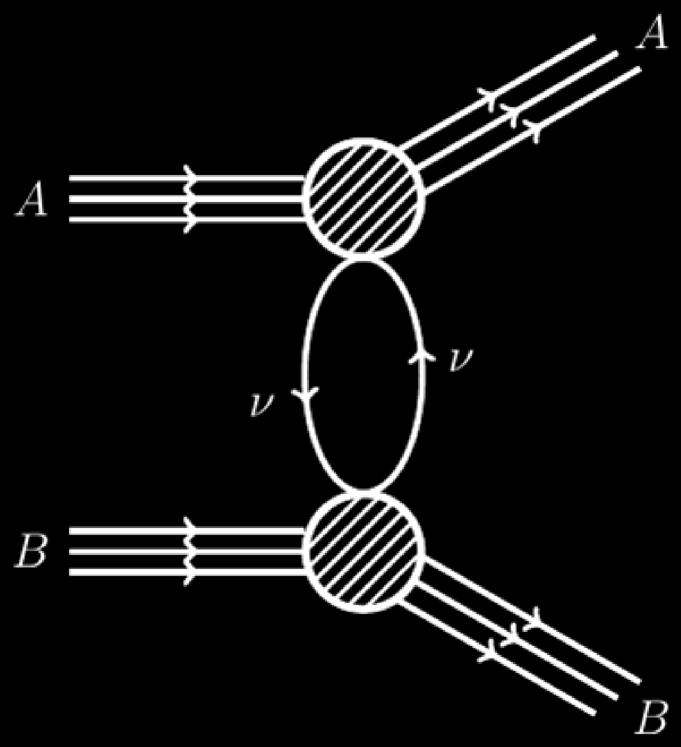

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Dispersion Relation

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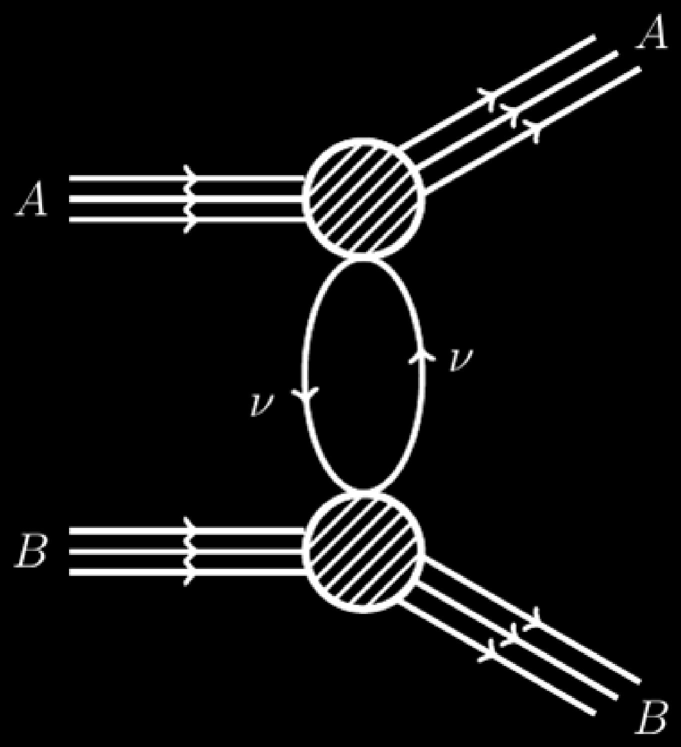

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Dispersion Relation

S–matrix Unitarity

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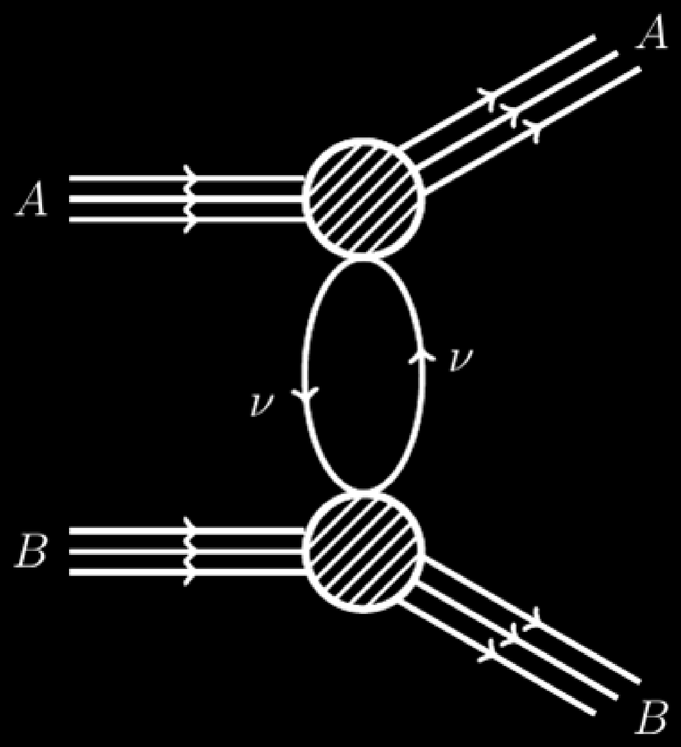

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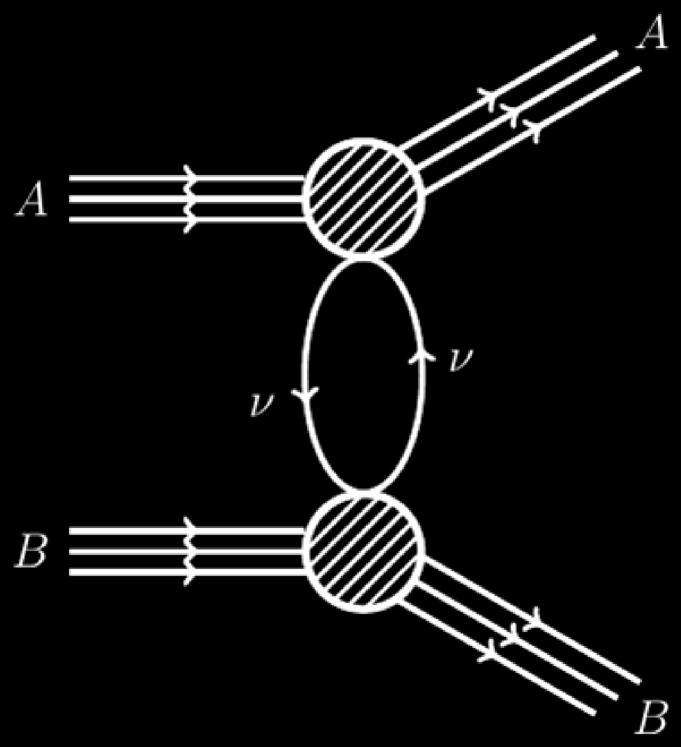
$S-$matrix Unitarity

Massless Neutrinos

Long-range Weak Interaction

AS, arXiv:hep-ph/1606.05087



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Low-energy limit

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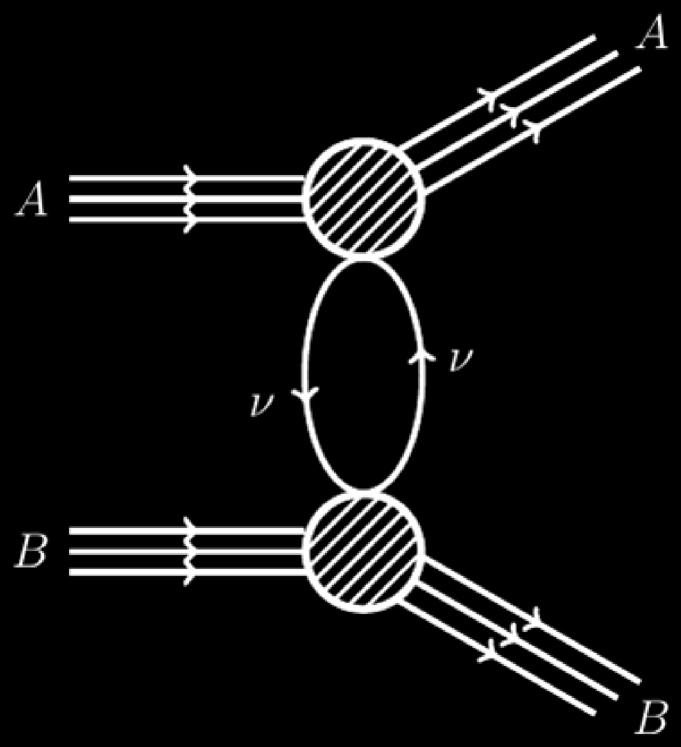

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Dispersion Relation
$S-$matrix Unitarity

Massless Neutrinos
Low-energy limit
Coherent limit

THE WEAK CHARGES OF MATTER

AS, arXiv:hep-ph/1606.05087

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THE WEAK CHARGES OF MATTER

AS, arXiv:hep-ph/1606.05087

$$Q_W^{\nu_e} = 2Z - N$$

$$Q_W^{\nu_\mu} = Q_W^{\nu_\tau} = -N$$

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THE WEAK CHARGES OF MATTER

AS, arXiv:hep-ph/1606.05087

$$Q_W^{\nu_e} = 2Z - N$$

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$$m \sim Z + N$$

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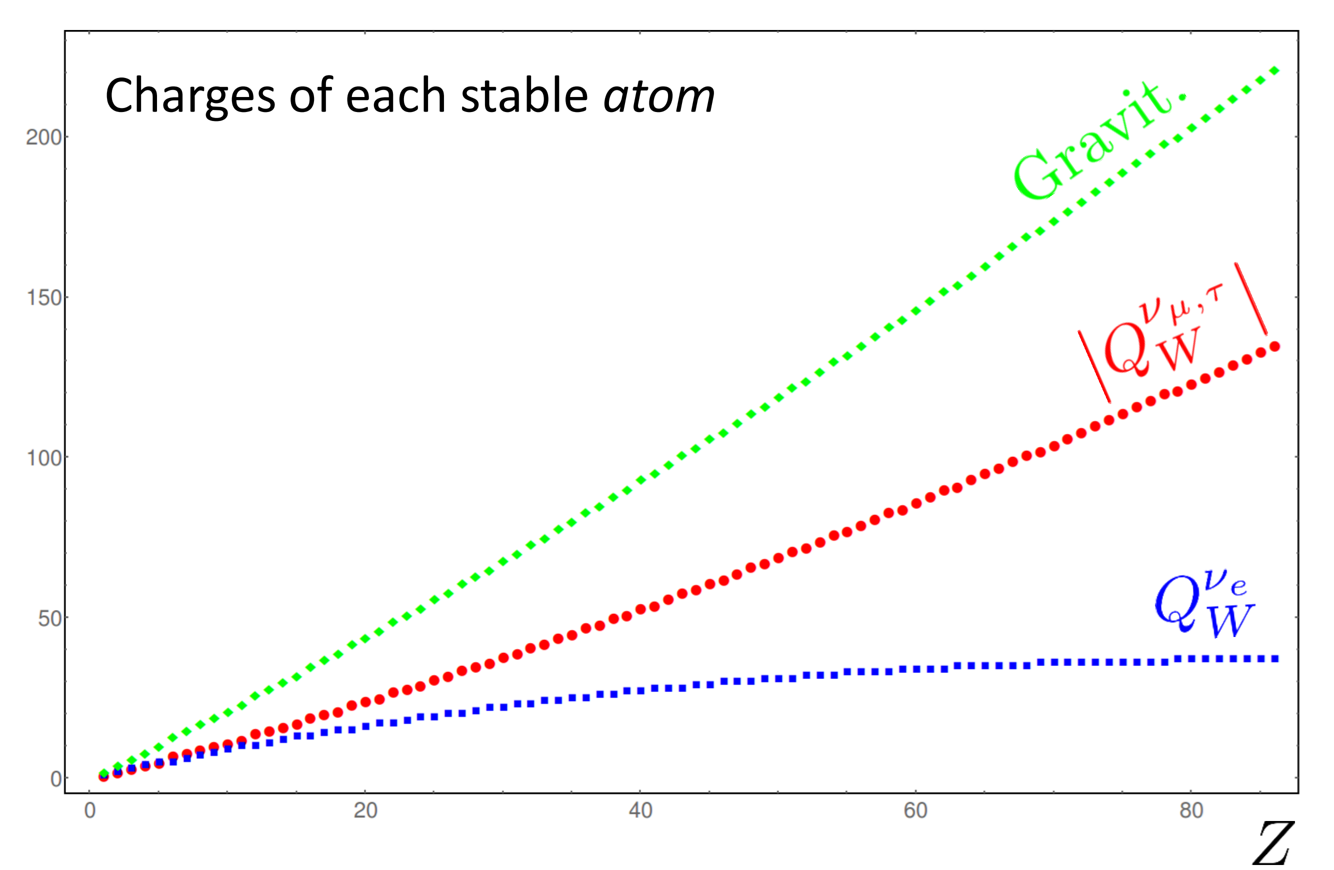

THE WEAK CHARGES OF MATTER (CONT'D)

AS, arXiv:hep-ph/1606.05087

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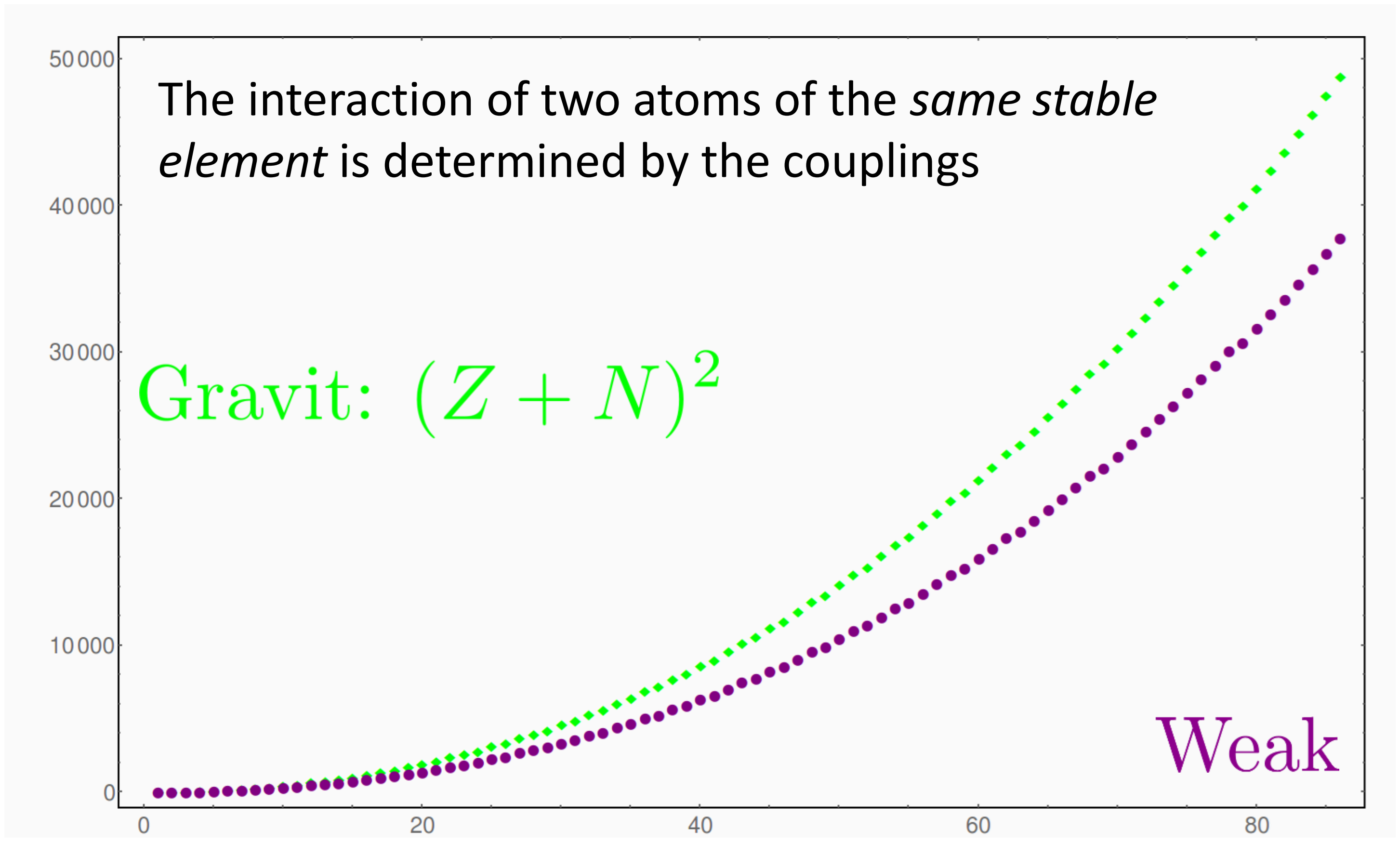

Final Remarks

- ✓ Interesting ranges

$$r_{\text{min}} \sim 1 \text{ nm}$$
$$r_{\text{max}} \sim m_\nu^{-1} \sim (0.1 \text{ eV})^{-1} \sim 1\,\mu\text{m}$$

a_0

e^{-2mr}

Need to recalculate with finite mass!

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Residual EM forces — can be shielded

Gravitation — repulsive!

deviations from Equivalence Principle

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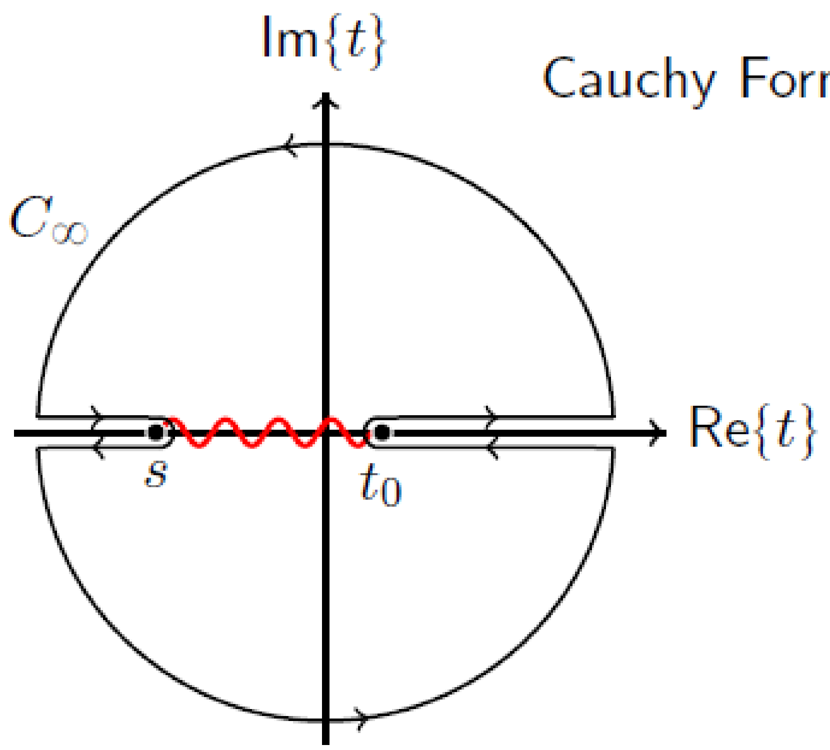
backup

Dispersion Relation



Cauchy Formula: $f(z) = \frac{1}{2\pi i} \int_C \mathrm{d}z' \frac{f(z')}{z' - z}$

Physical Region:

$-s \leqslant t \leqslant t_0$

$-M_A^2 \lesssim t \leqslant 4m_\nu^2$

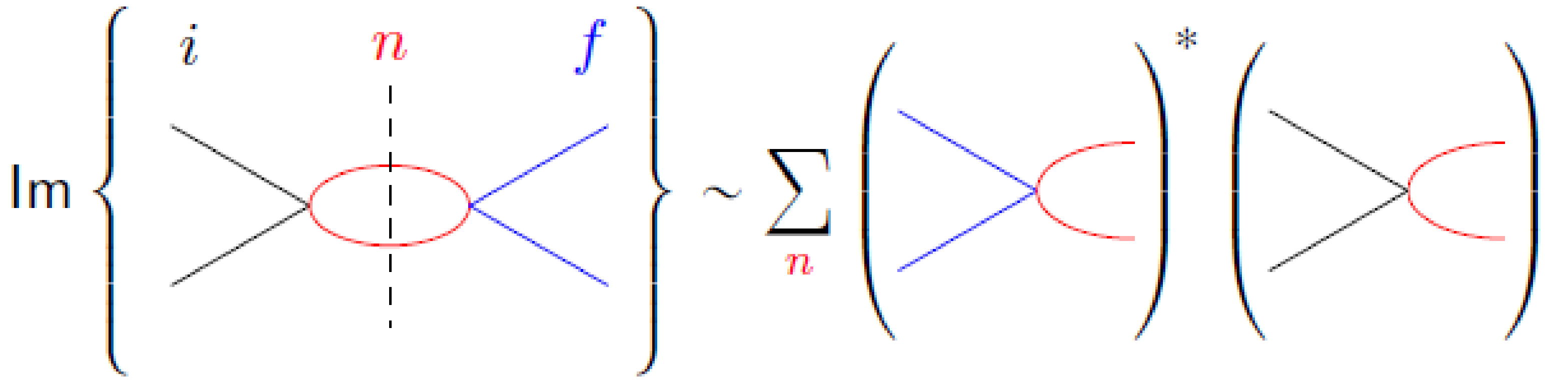
$$M(t;s) = \frac{1}{\pi} \int_{t_0}^{\infty} \mathrm{d}t' \frac{\mathrm{Im}\{M(t')\}}{t' - t} + \text{Short Range}$$

UNITARITY

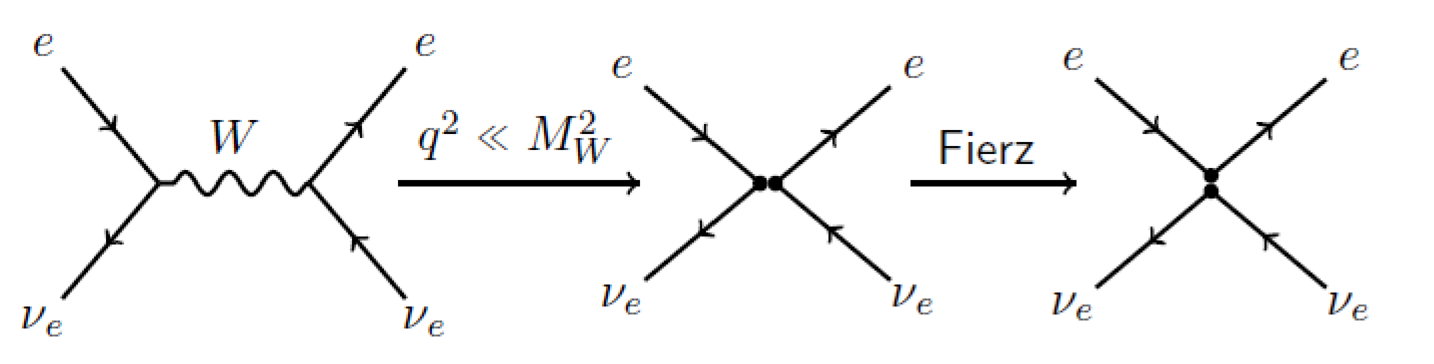
$$S^\dagger S = 1 \xrightarrow{S \equiv 1 + iT} -i(T - T^\dagger) = T^\dagger T$$

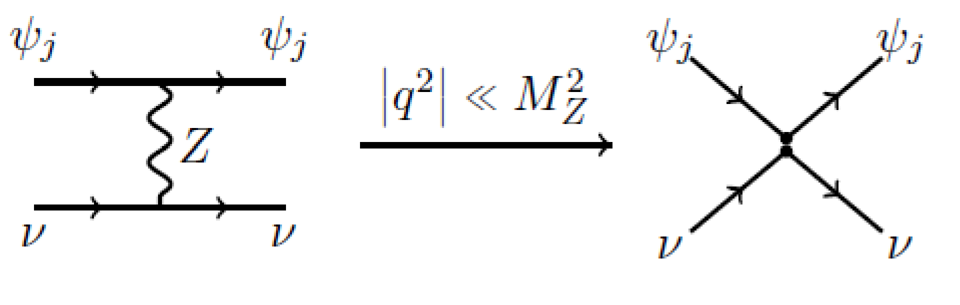
$$\mathcal{M}(i \to f) \sim \langle f|\, T\, |i\rangle$$

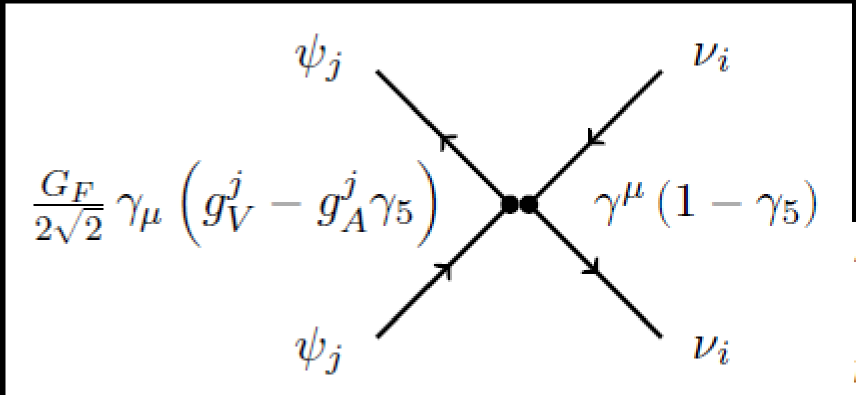
$$2\ \mathrm{Im}\,\{\langle f|\, T\, |i\rangle\} = \langle f|\, T^\dagger\, \mathbb{1}\, T\, |i\rangle$$
$$= \sum_n \langle f|\, T^\dagger |n\rangle \langle n| T\, |i\rangle$$



Low-Energy Limit







$\psi_j = e, p, n$

$\nu_i = \nu_e, \nu_\mu, \nu_\tau$

NC:	$p\,\nu_{e,\mu,\tau}$	$\longrightarrow$	$g_V^p = 1 - 4\sin^2\theta_W$
NC:	$n\,\nu_{e,\mu,\tau}$	$\longrightarrow$	$g_V^n = -1$
NC:	$e\,\nu_{\mu,\tau}$	$\longrightarrow$	$g_V^e = -1 + 4\sin^2\theta_W = -g_V^p$
NC+ CC:	$e\,\nu_e$	$\longrightarrow$	$\tilde{g}_V^e = 2 + g_V^e = 2 - g_V^p$

Coherent Contribution

Molecular matrix element

$$J_\mu(x) = \tilde{g}_V^e \langle A' | \bar{e}(x)\gamma_\mu e(x) | A \rangle - g_A^e \langle A' | \bar{e}(x)\gamma_\mu\gamma_5 e(x) | A \rangle$$

- Scalar, γ^0: number operator, $e^\dagger e$.
  COHERENT
- Pseudo-scalar, $\gamma^0\gamma_5$: matrix element $\sim \vec{\sigma}\vec{q}/M$.
  INCOHERENT, RELATIVISTIC
- Polar vector, $\vec{\gamma}$: matrix element $\sim \vec{q}/M$.
  RELATIVISTIC
- Axial vector, $\vec{\gamma}\gamma_5$: matrix element $\sim \vec{\sigma}$.
  INCOHERENT

$$J_0(x) = Z\,\tilde{g}_V^e\, e^{iqx}$$