Question

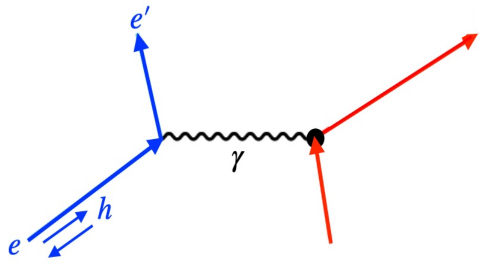
$$\frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

σ_R= Cross section for **right-handed** electrons
σ_L= Cross section for **left-handed** electrons
Unpolarized target

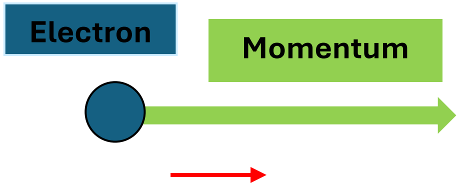
Question

$$\frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

σ_R= Cross section for **right-handed** electrons
σ_L= Cross section for **left-handed** electrons
Unpolarized target

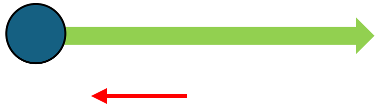


Right-handed



spin

Left-handed

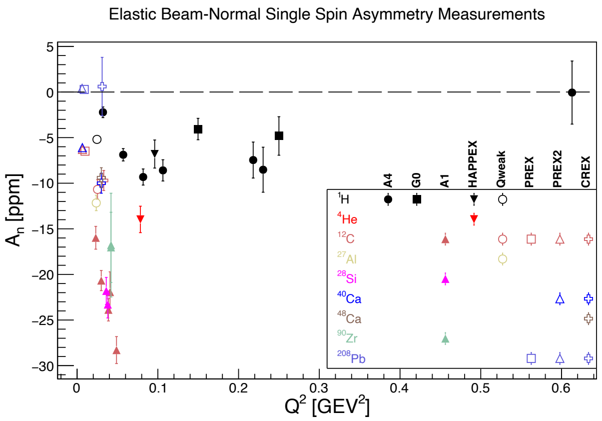


spin

Asymmetries

$$A_1(x, Q^2) \approx \frac{g_1(x, Q^2)}{F_1(x, Q^2)}$$

- Polarized lepton (e^-) & polarized target
  - Spin Structure of neutron (A_1^n) and proton (A_1^p) (DIS)
- Beam Normal SSA (transversely polarized electron)



Question

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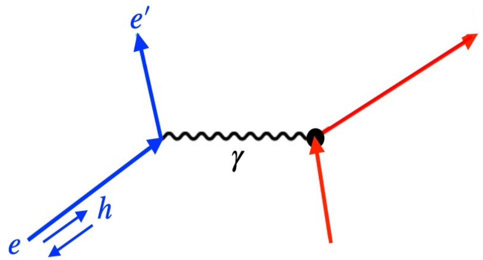
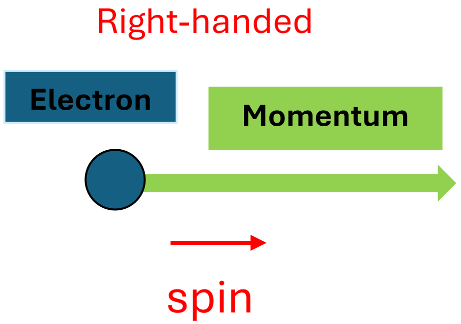
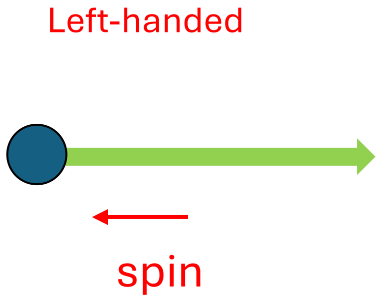
σ_L= Cross section for **left-handed** electrons
Unpolarized target



What do you expect the asymmetry to be?
=0?
≠0?
Why?





SoLID: Parity Violation (and Beyond)

Michael Nycz
University of Virginia

HUGS 2015


The 30th Annual Hampton University Graduate Studies Program
HUGS 2015

My Student Seminar (that I wasn't able to give)

F_2^n Structure Function and the EMC effect of the Deuteron

Mike Nycz

HUGS 2015

1

Outline

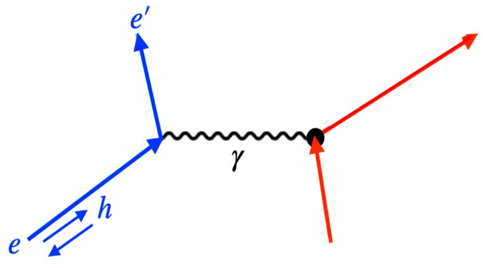
- Parity
- Historical Background
  - Parity and the Weak Force
- Parity Violation Measurements
  - SLAC E122, Jlab PVDIS (6 GeV)
- SoLID (**S**olenoidal **L**arge **I**ntensity **D**evice)
  - What, where, why, and how
- PVDIS program with SoLID
- Potential for Beyond the Standard Model Physics with SoLID & PVDIS

Question

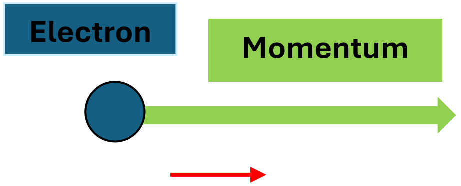
$$\frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

If parity symmetry is exact, the asymmetry should be 0 (within experimental uncertainties)

σ_R= Cross section for **right-handed** electrons
σ_L= Cross section for **left-handed** electrons
Unpolarized target



Right-handed



spin

Left-handed

spin

CPT Invariance

- Charge conjugation
  - reversing the electric charge (plus internal quantum numbers)
- Parity transformation
  - space inversion;
- Time reversal
  - $T: t \rightarrow$-t

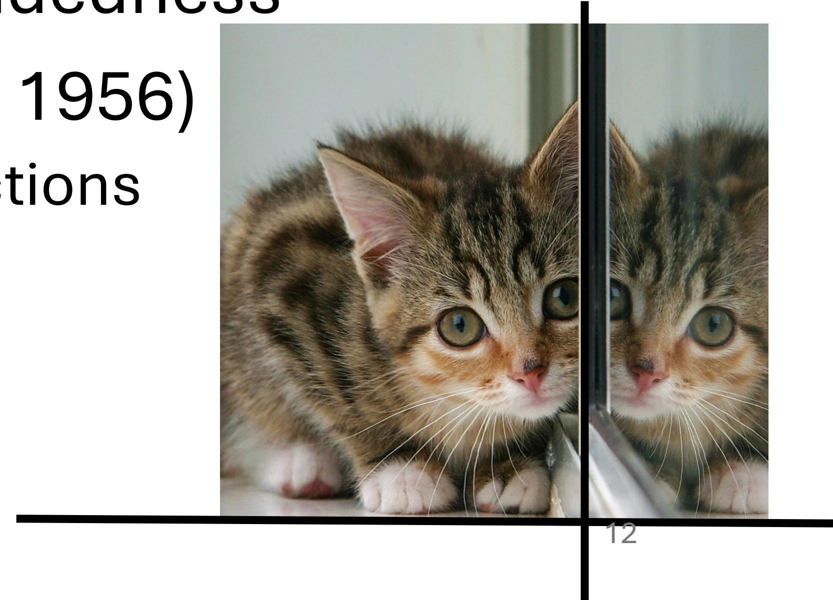
Parity (Circa 1956)

- Laws of physics were invariant under parity transformations

$$P\colon \begin{pmatrix} x \\ y \\ z \end{pmatrix} \longrightarrow \begin{pmatrix} -x \\ -y \\ -z \end{pmatrix}$$

- Should be no preference to either left- or right-handedness
- Existing experiments indicate (T.D. Lee & C.N Yang 1956)
  - Parity conservation in electromagnetic & strong interactions
- Parity conservation in weak interaction
  - *"extrapolated hypothesis without experimental evidence"*

$$P\colon \begin{pmatrix} x \\ y \\ z \end{pmatrix} \longrightarrow \begin{pmatrix} -x \\ y \\ z \end{pmatrix}$$



Parity

PHYSICAL REVIEW VOLUME 104, NUMBER 1 OCTOBER 1, 1956

Question of Parity Conservation in Weak Interactions*

T. D. LEE, *Columbia University, New York, New York*

AND

C. N. YANG,† *Brookhaven National Laboratory, Upton, New York*

(Received June 22, 1956)

The question of parity conservation in β decays and in hyperon and meson decays is examined. Possible experiments are suggested which might test parity conservation in these interactions.

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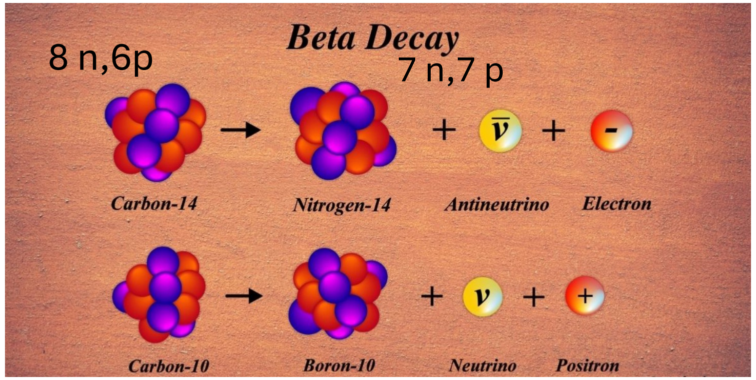
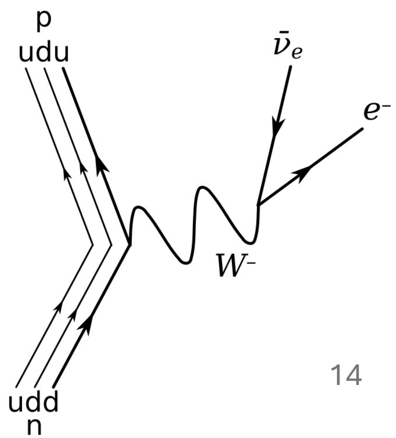


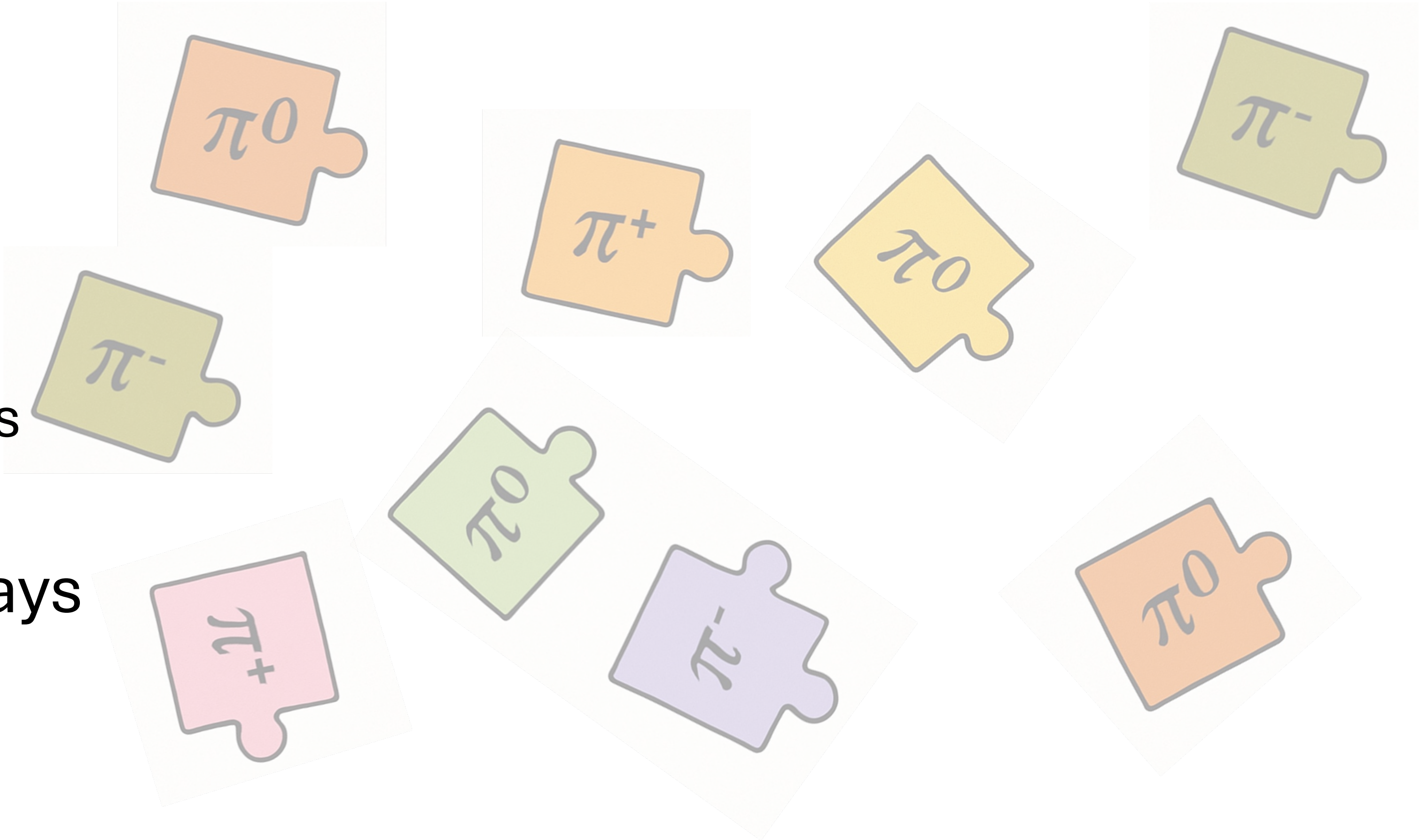


“extrapolated hypothesis without experimental evidence”

And perhaps experimental evidence to the contrary

θ-τ Puzzle

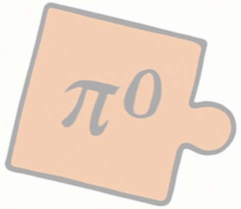
- θ^+ and τ^+particles
  - Same masses, lifetimes
  - Same particle?
- Observed particle decays
  - $\tau^+ \longrightarrow \pi^+\pi^+\pi^-$
  - $\theta^+ \longrightarrow \pi^+\pi^0$



<u>Puzzle</u>

- π has parity: (-1)
- The τ and θ have opposite parity
- Two particles with the same mass & lifetime
  - Opposite parity

θ-τ Puzzle



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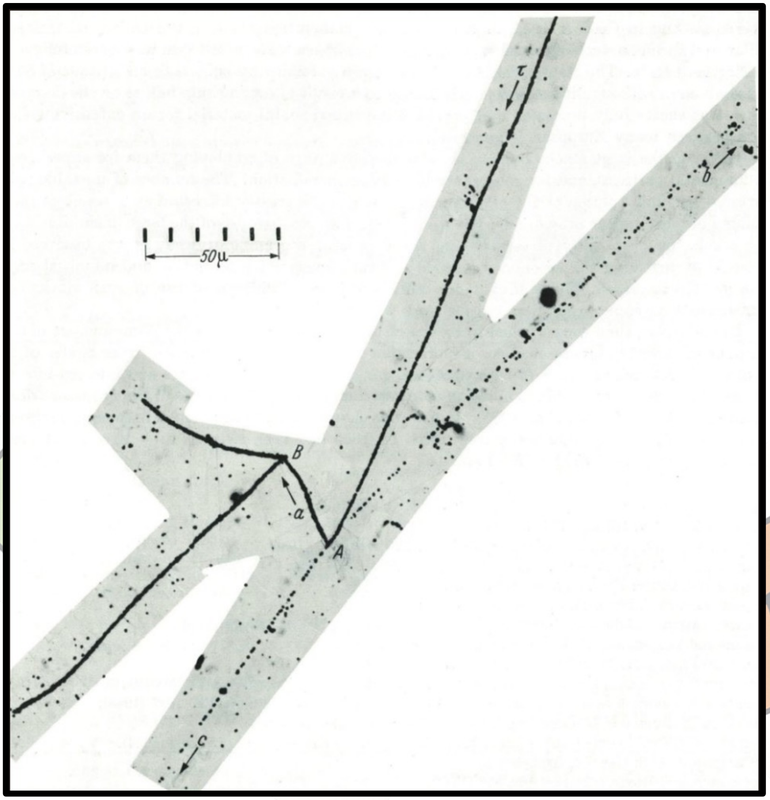
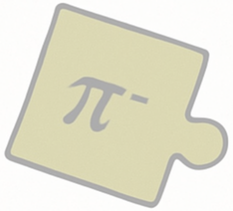
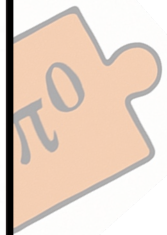
$\tau^+ \longrightarrow \pi^+\pi^+\pi^-$ (1949)







- Particle Decay in Emulsion
  - Fine silver halide grains
- Charged particle passes through emulsion
  - Leaves a trail of silver halide grains
- Length, density, scattering
  - Used to determine mass

θ-τ Puzzle

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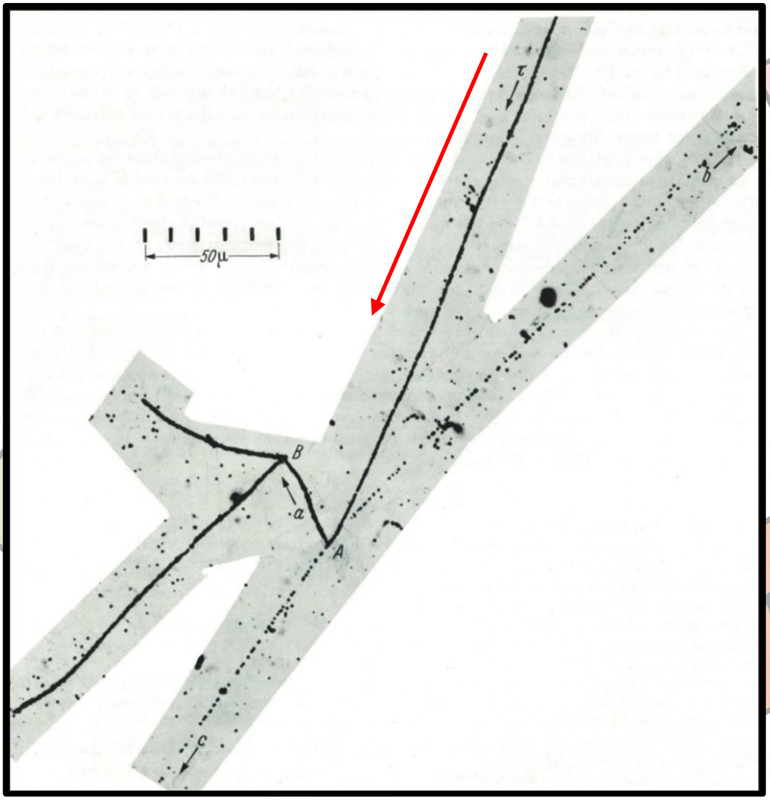

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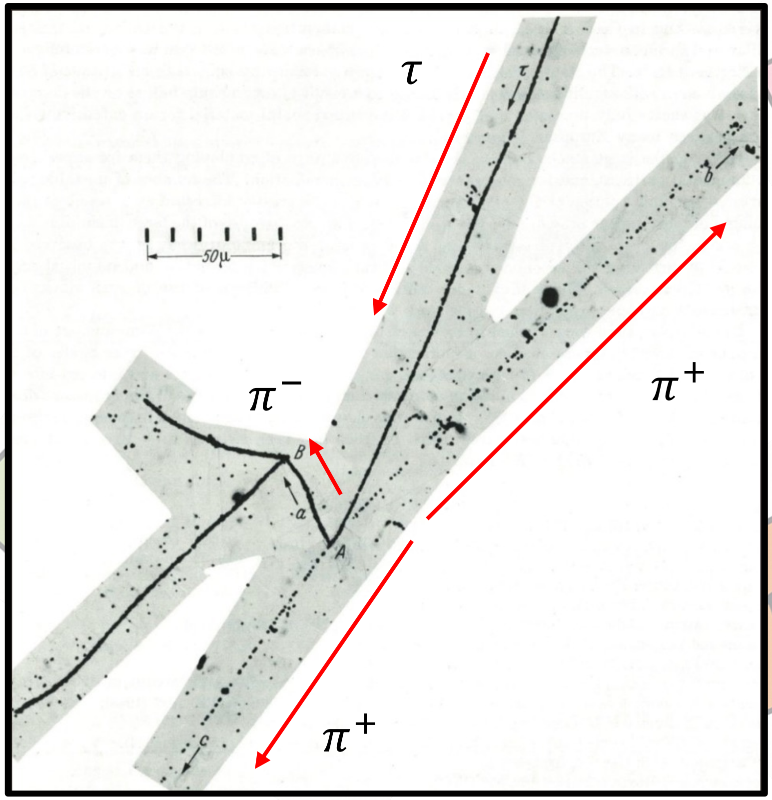
  - $\tau^+ \longrightarrow \pi^+\pi^+\pi^-$
  - $\theta^+ \longrightarrow \pi^+\pi^0$

Question
Are the τ^+ and θ^+ the same or different particle?
Why ?

$\tau^+ \longrightarrow \pi^+\pi^+\pi^-$ (1949)



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- Length, density, scattering
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Parity Violation: First Evidence

Experimental Test of Parity Conservation in Beta Decay*

C. S. Wu, *Columbia University, New York, New York*

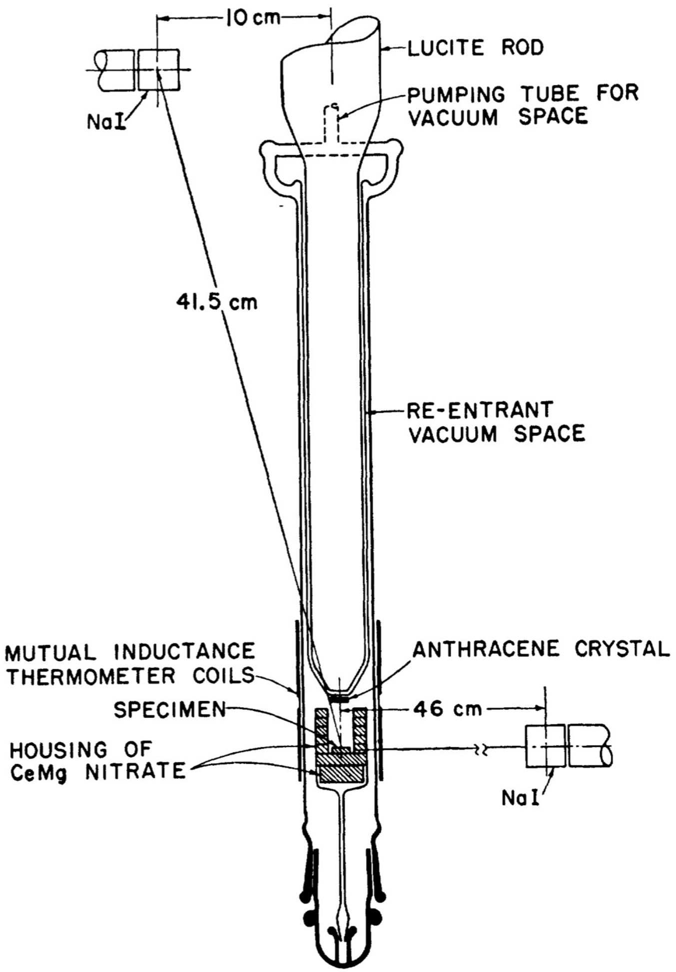
AND

E. Ambler, R. W. Hayward, D. D. Hoppes, and R. P. Hudson,
National Bureau of Standards, Washington, D. C.

(Received January 15, 1957)

Parity Violation: Evidence

- Chien-Shiung Wu: **1957**
  - β decay of cobalt-60 : $^{60}\mathrm{Co} \rightarrow {}^{60}\mathrm{Ni} + e^{-} + \overline{\nu}_{e}$
  - Placed in magnetic field + cooled to ~ 0.01K
- By cooling to low temperature
  - Spin of $^{60}\mathrm{Co}$ aligned with magnetic field
  - (Rose-Gorter polarization method)



Parity Violation: Experiment

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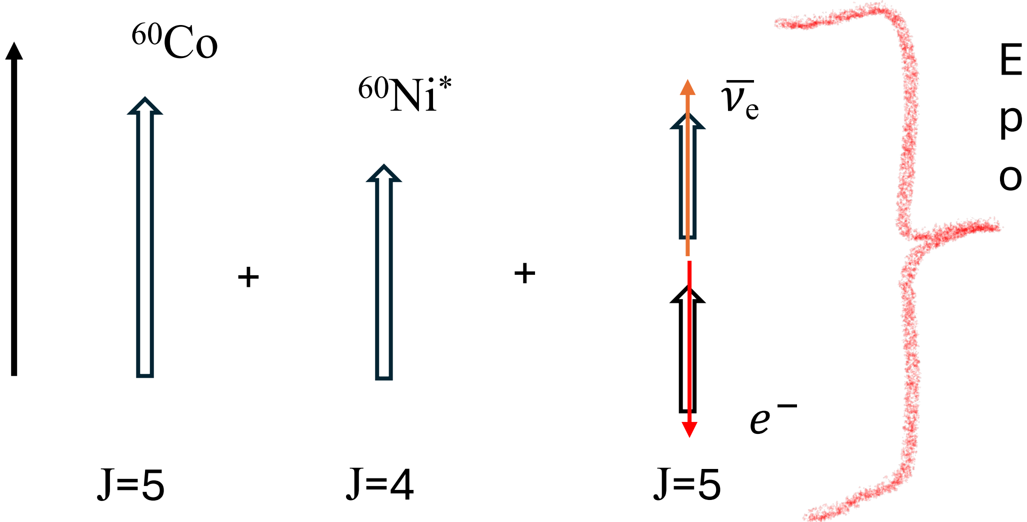

Electrons emitted preferentially in direction opposite nuclear spin

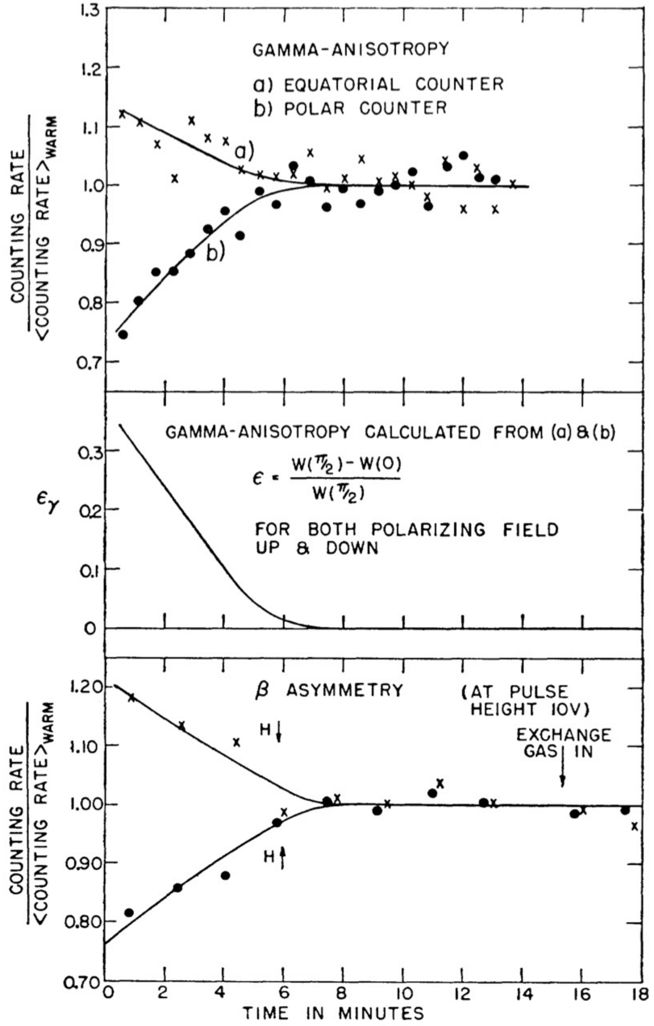

FIG. 2. Gamma anisotropy and beta asymmetry for polarizing field pointing up and pointing down.

Parity Violation: Experiment

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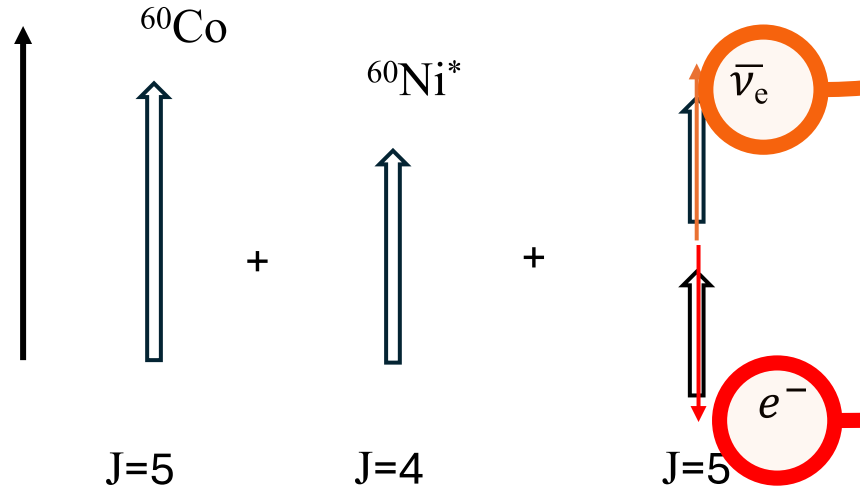

Right-handed anti-neutrino

Left-handed electron

<u>Weak Interaction</u>

- Only involve $\overline{\nu}_R$ & ν_L interact with weak force
- Absence of $\overline{\nu}_L$ & ν_R ➔ violation of parity invariance

Parity Violation: Conclusion

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"According to Lee and Yang the present experiment indicates not only that conservation of parity is violate ..."

Parity Violation

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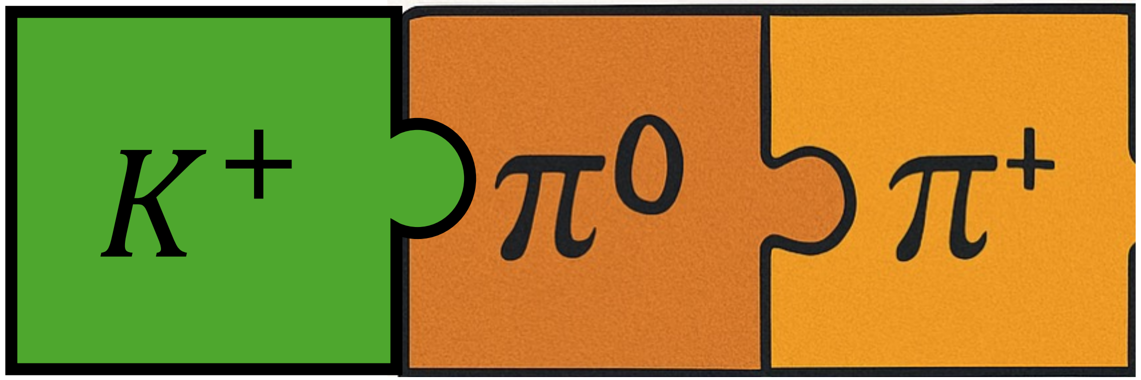
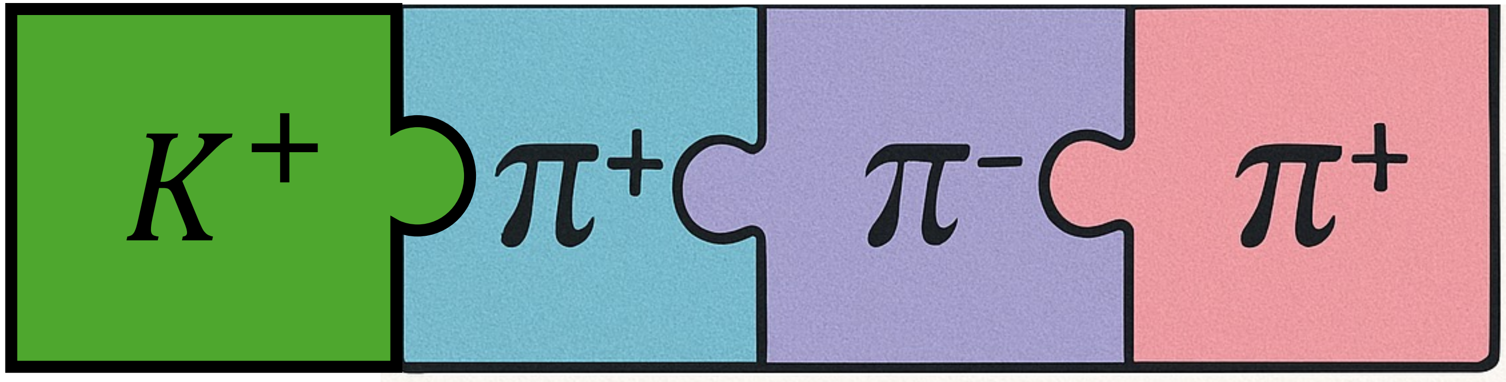
Nobel Prize (1957) was awarded jointly to Chen Ning Yang and Tsung-Dao (T.D.) Lee

" for their penetrating investigation of the so-called parity laws which has led to important discoveries regarding the elementary particles"

Solving the θ-τ Puzzle

- θ^+ and τ^+ particles
  - Same mass, lifetimes
  - Same particle?
- Observed particle decays
  - $\tau^+ \longrightarrow \pi^+\pi^+\pi^-$
  - $\theta^+ \longrightarrow \pi^+\pi^0$

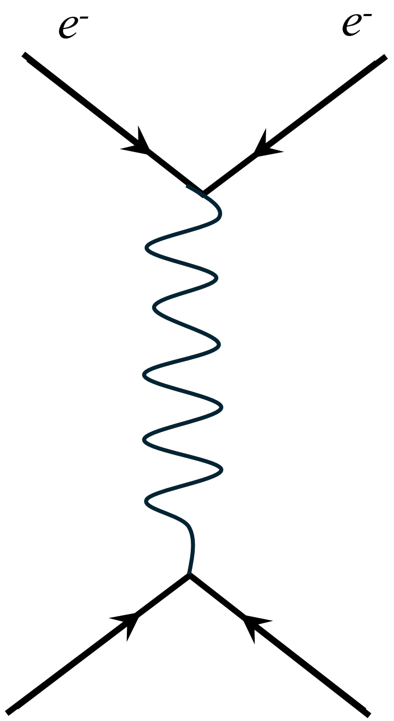


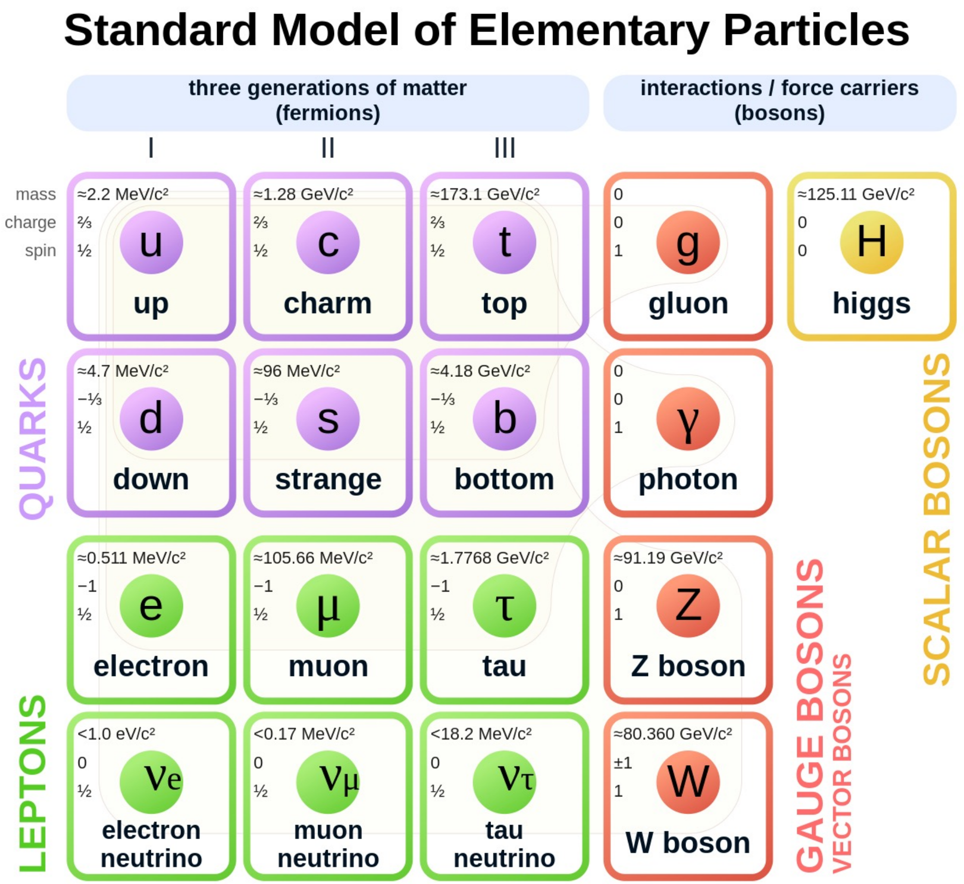


Same Particle: K^+

$K^+ \longrightarrow \pi^+\pi^+\pi^-$ **(Branching Ratio: 5.59 %)**
$K^+ \longrightarrow \pi^+\pi^0$ **(Branching Ratio: 20.66 %)**

Neutral Current





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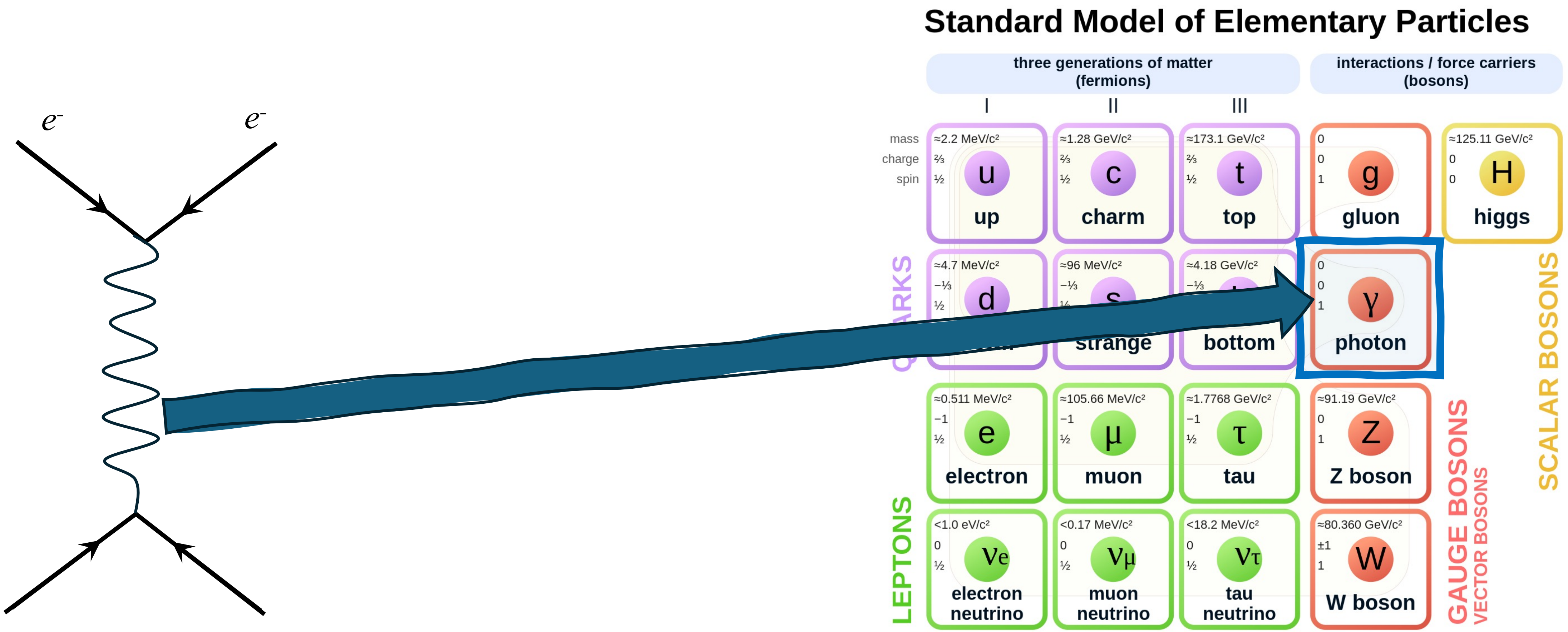

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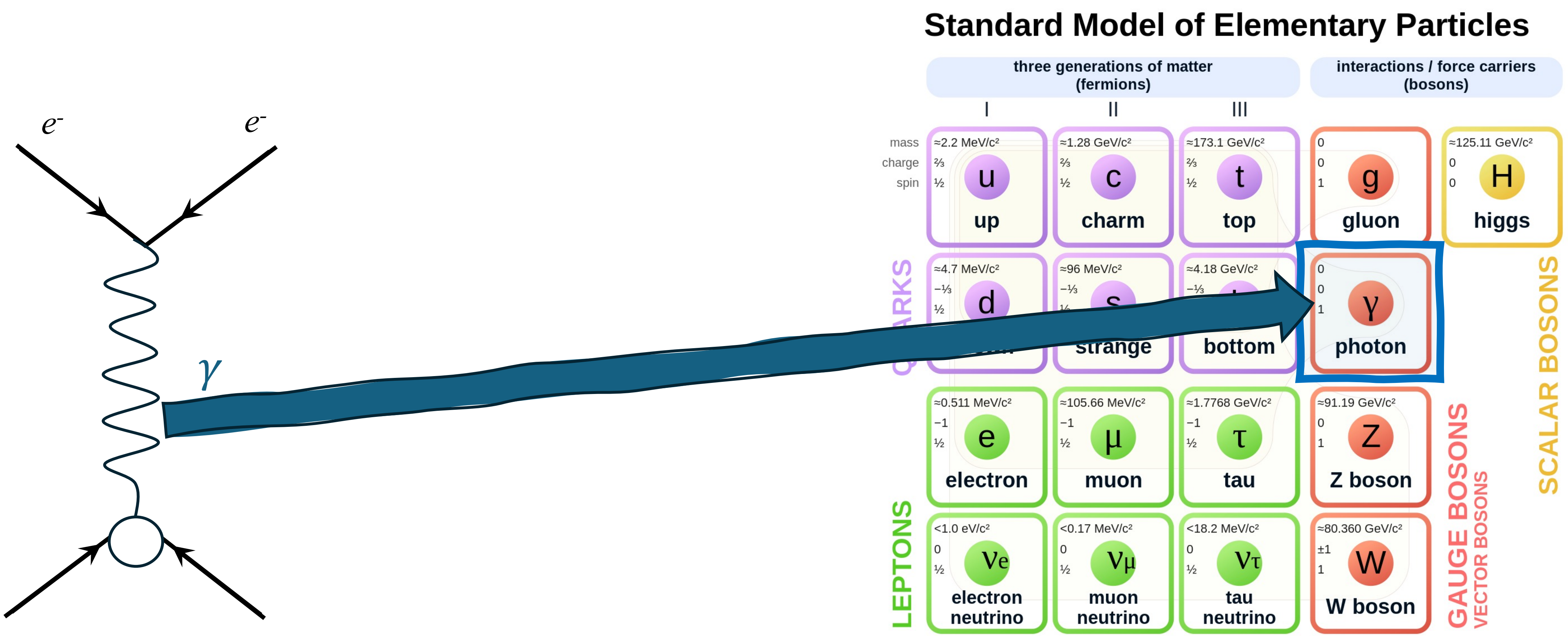

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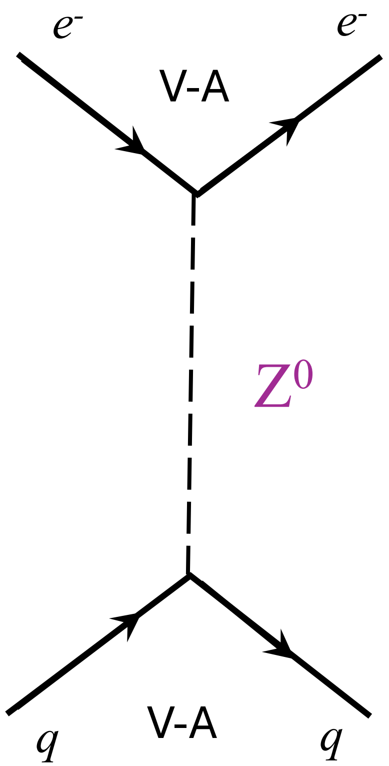
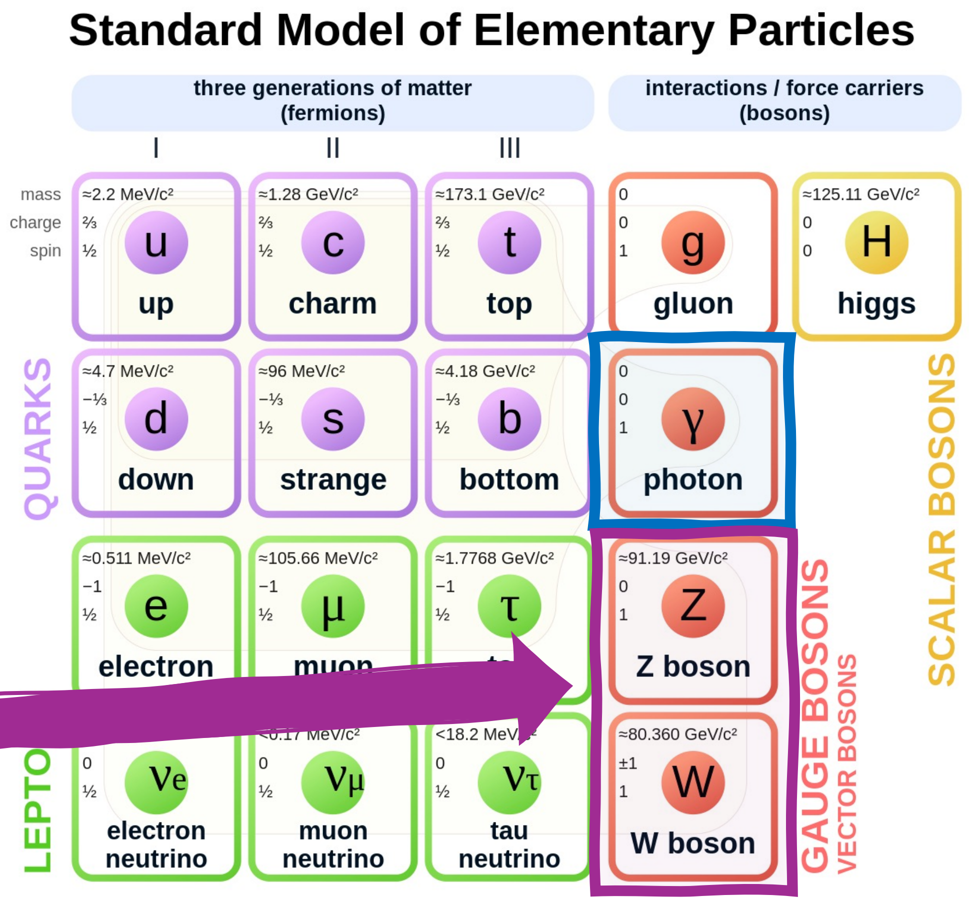
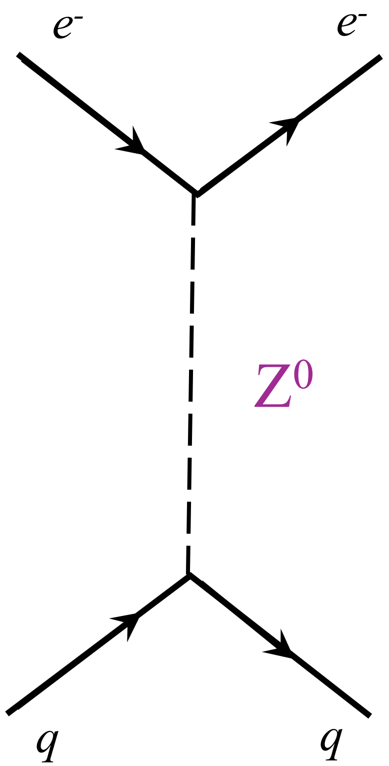


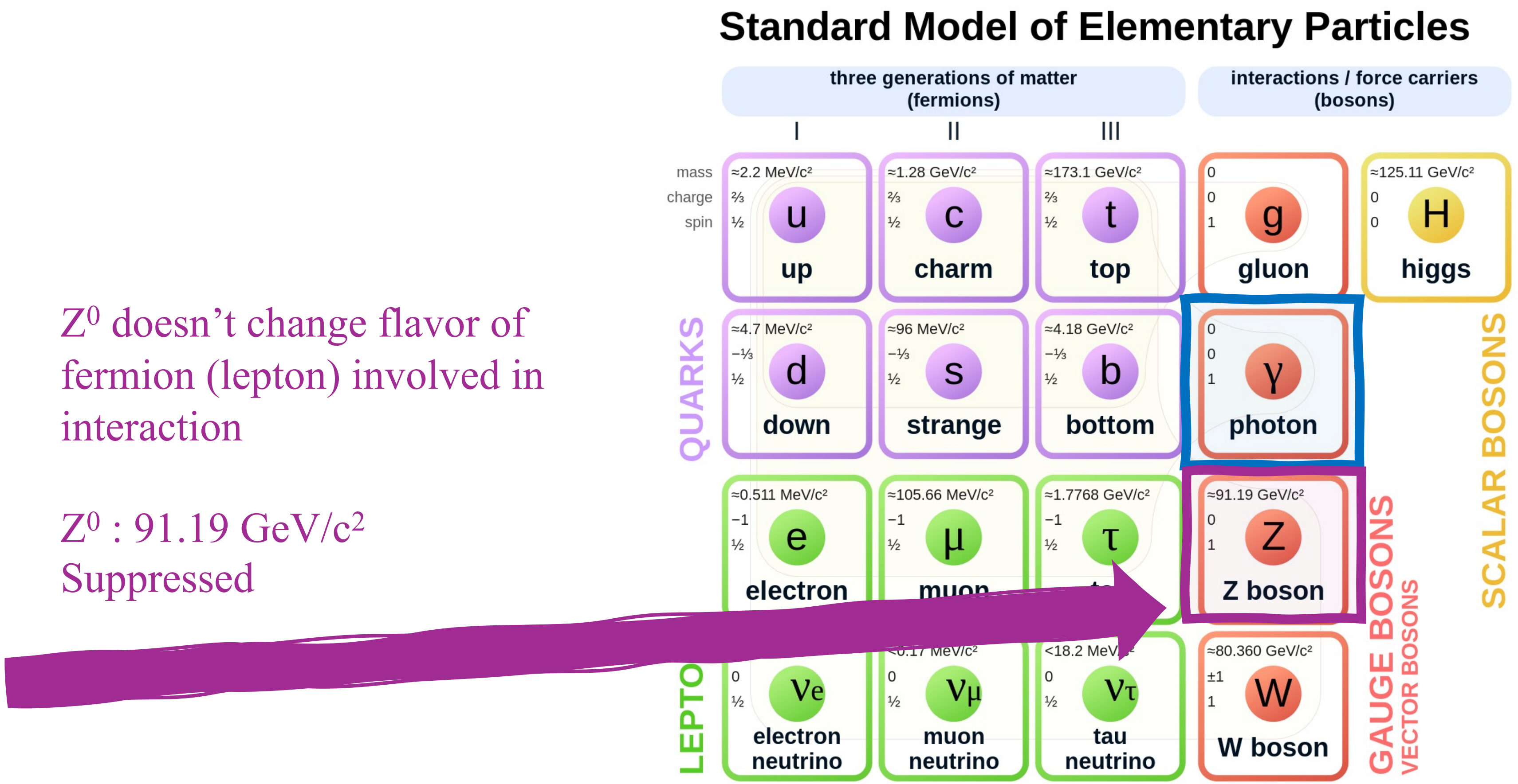
Z^0 doesn't change flavor of fermion (lepton) involved in interaction



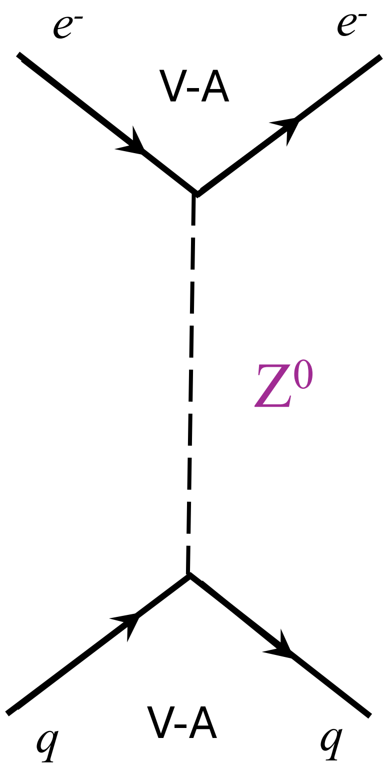


Z^0 doesn't change flavor of fermion (lepton) involved in interaction

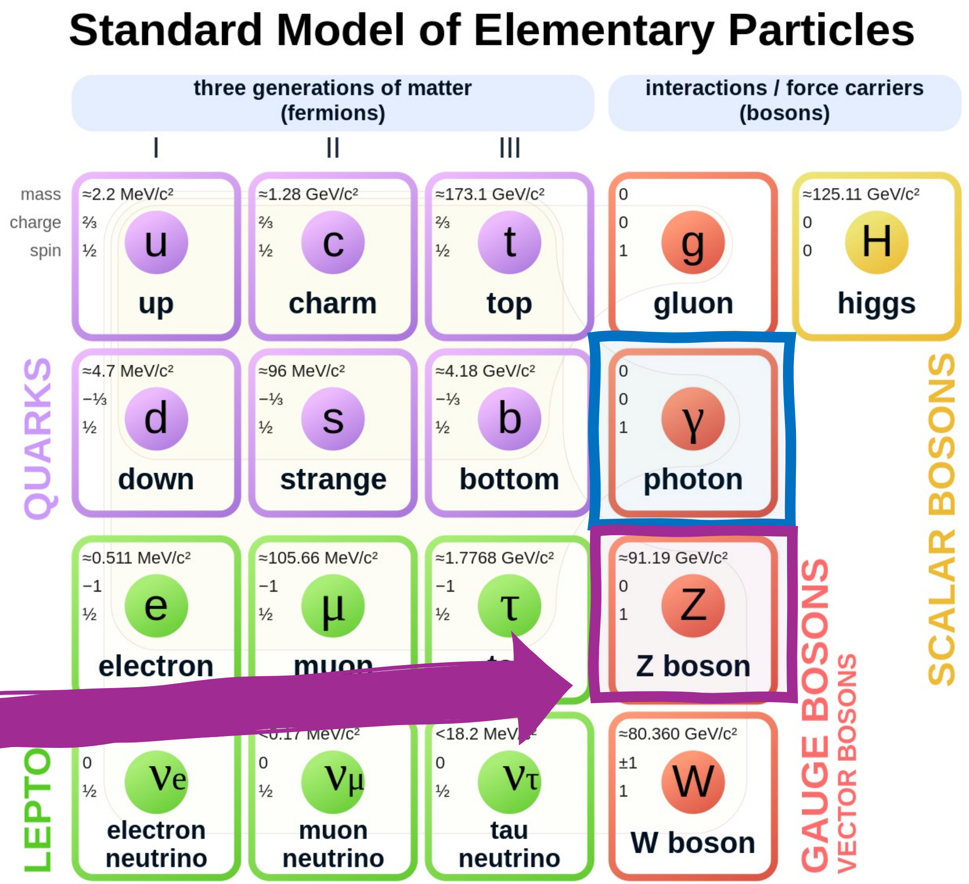
Z^0 : 91.19 GeV/c^2
Suppressed



Neutral Current



- Weak interaction requires 2 charges
  - g_L & g_R
- Vector & axial weak charges
  - $g_V = g_L + g_R$
  - $g_A = g_L - g_R$



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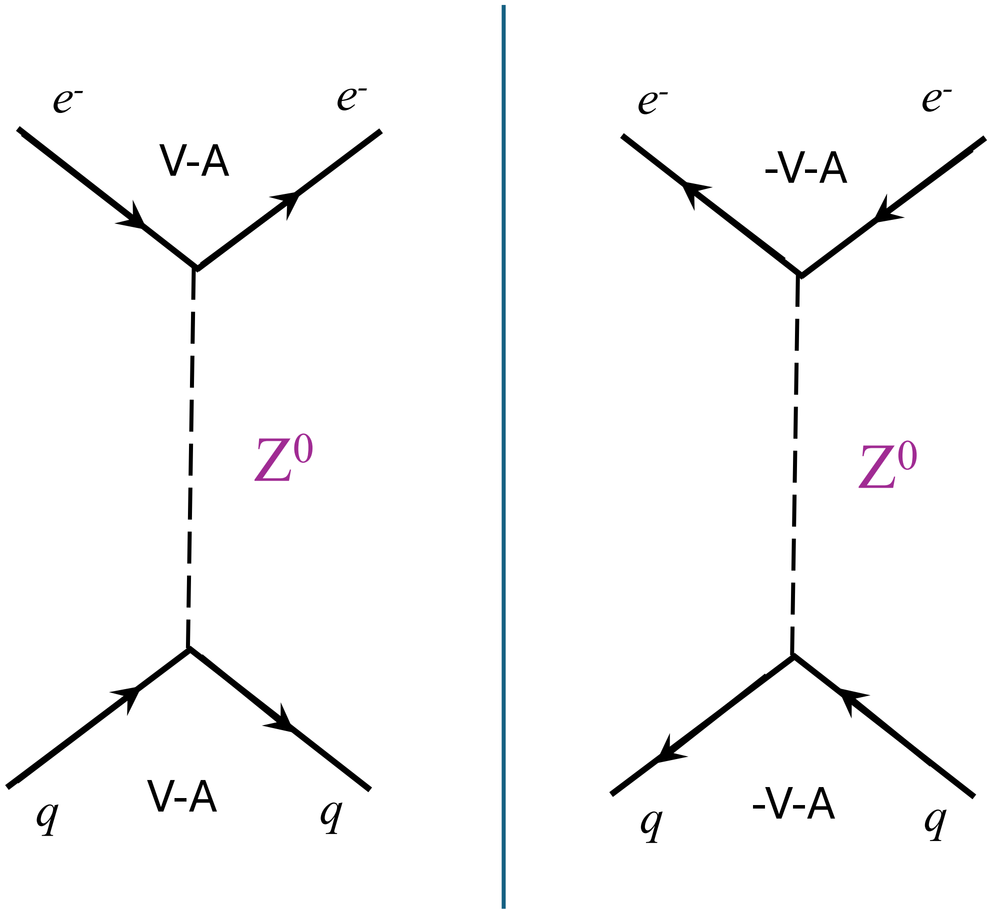

- $C_{1u} = g_A^e g_V^u \approx -\frac{1}{2} + \frac{4}{3}\sin^2\theta_W$
- $C_{1d} = g_A^e g_V^d \approx \frac{1}{2} - \frac{4}{3}\sin^2\theta_W$
- $C_{2u} = g_V^e g_A^u \approx -\frac{1}{2} + 2\sin^2\theta_W$
- $C_{2d} = g_V^e g_A^d \approx \frac{1}{2} - 2\sin^2\theta_W$

1. PVDIS Asymmetry is sensitive to both C_{1u} and C_{2u}
2. PVES (elastic) Asymmetry only sensitive to C_{1u}

PVES

Elastic (electron – proton)

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

$$A_{PV}/A_0 = Q_W^p + Q^2 B(Q^2, \theta)$$

$$Q_W^p = -2(2C_{1u} + C_{1d})$$

Deep Inelastic (electron-deuteron)

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

$$A_{PV} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}[a_1(x,Q^2)Y_1(x,y,Q^2) + a_3(x,Q^2)Y_3(x,y,Q^2)]$$

$$a_1 = \frac{6}{5}(2C_{1u} - C_{1d}),\ a_3 = \frac{6}{5}(2C_{2u} - C_{2d})$$

PVES

Elastic (electron – proton)

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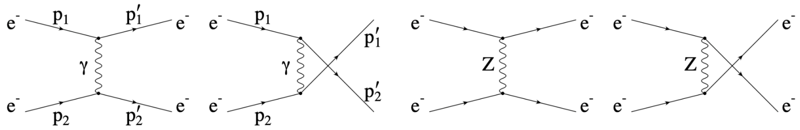
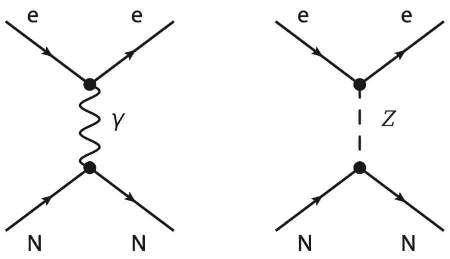
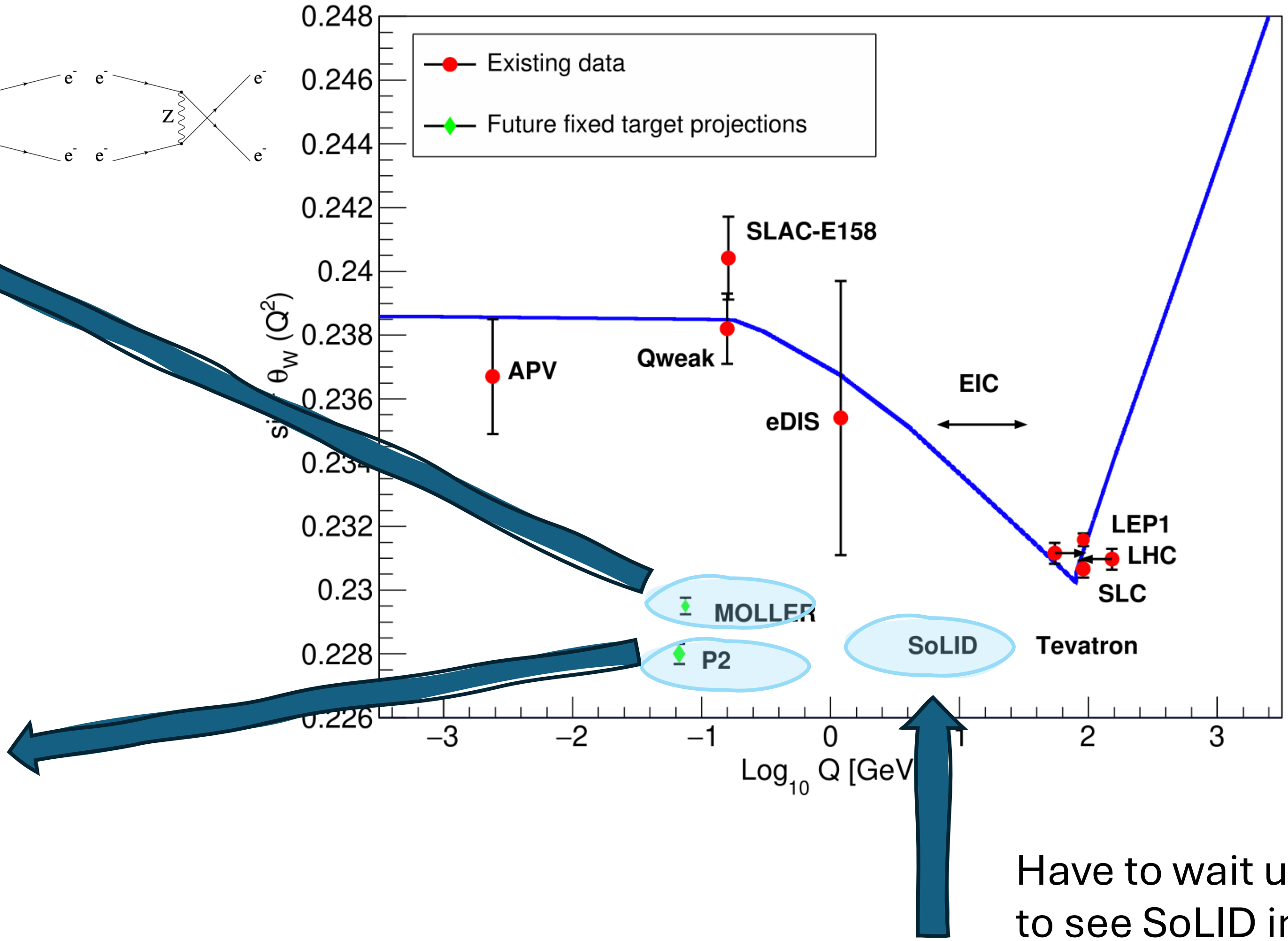
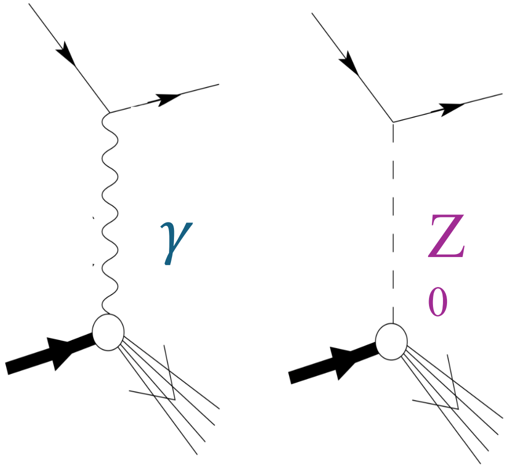
$$a_1 = \frac{6}{5}(2C_{1u} - C_{1d}),\ a_3 = \frac{6}{5}(2C_{2u} - C_{2d})$$

PVES Experimental Methods

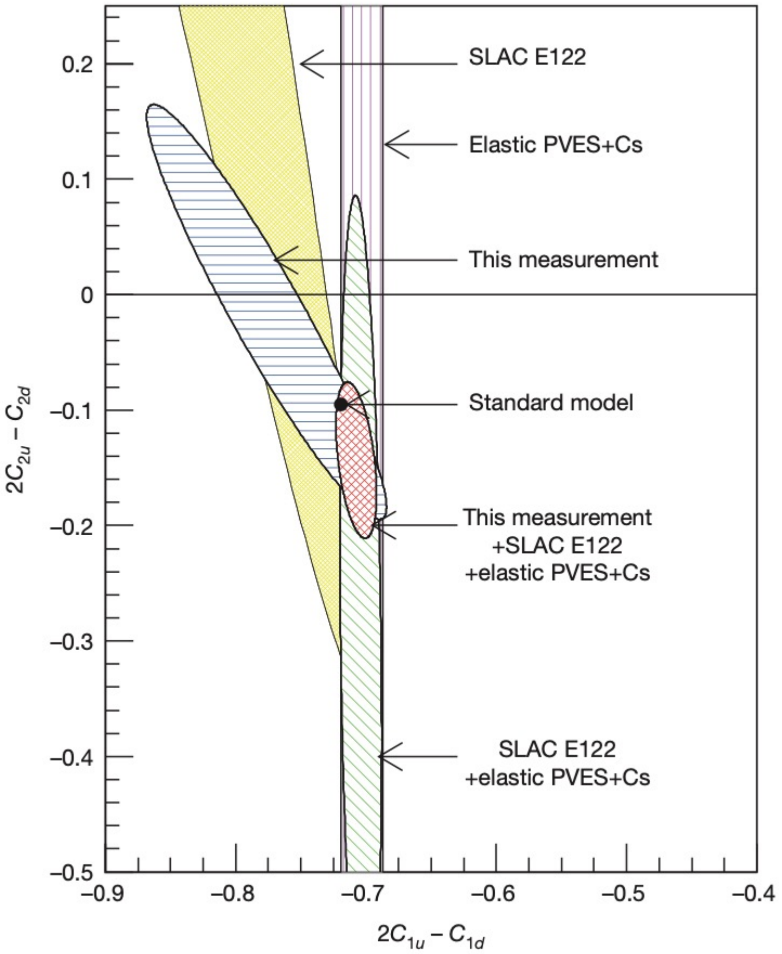








Have to wait until the end
to see SoLID impact!!



SLAC E122
Elastic PVES+Cs
This measurement
Standard model
This measurement
+SLAC E122
+elastic PVES+Cs
SLAC E122
+elastic PVES+Cs
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.9
−0.8
−0.7
−0.6
−0.5
−0.4
$2C_{2u} - C_{2d}$
$2C_{1u} - C_{1d}$

PVDIS

- Measurements
- E122 (SLAC)
- Jlab 6 GeV

SLAC E122: Parity Violation DIS

Volume 77B, number 3 PHYSICS LETTERS 14 August 1978

PARITY NON-CONSERVATION IN INELASTIC ELECTRON SCATTERING ☆

C.Y. PRESCOTT, W.B. ATWOOD, R.L.A. COTTRELL, H. DeSTAEBLER, Edward L. GARWIN, A. GONIDEC [1], R.H. MILLER, L.S. ROCHESTER, T. SATO [2], D.J. SHERDEN, C.K. SINCLAIR, S. STEIN and R.E. TAYLOR
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94305, USA

J.E. CLENDENIN, V.W. HUGHES, N. SASAO [3] and K.P. SCHÜLER
Yale University, New Haven, CT 06520, USA

SLAC E122

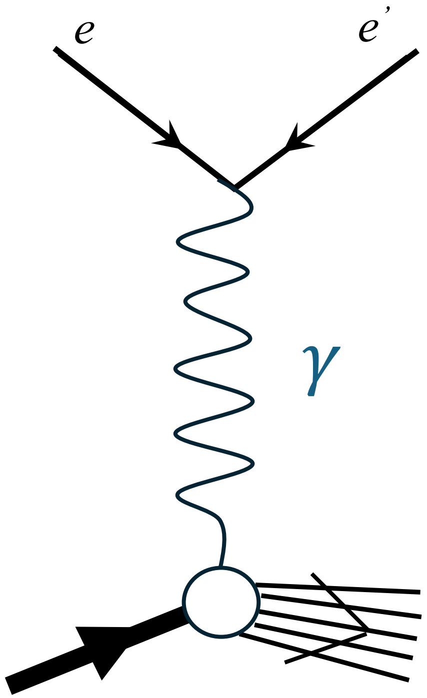
- Parity Violating **Deep Inelastic Scattering**

Deep Inelastic Scattering

$$M_\gamma = j_\mu \left(\frac{1}{q^2}\right) J^\mu$$

Electron (e^-) current

Hadronic current



Cross Section

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{Q^4}\left[\frac{2F_1(x)}{M}\sin^2\frac{\theta}{2} + \frac{F_2(x)}{\nu}\cos^1\frac{\theta}{2}\right]$$

Q^2 = Four Momentum Transfer Squared

E' = Energy Transfer

x = Bjorken x (fraction of longitudinal momentum carried by struck quark)

$$F_1(x) = \frac{1}{2}\sum_i e_i f_i(x)$$

$$F_2(x) = x\sum_i e_i f_i(x)$$

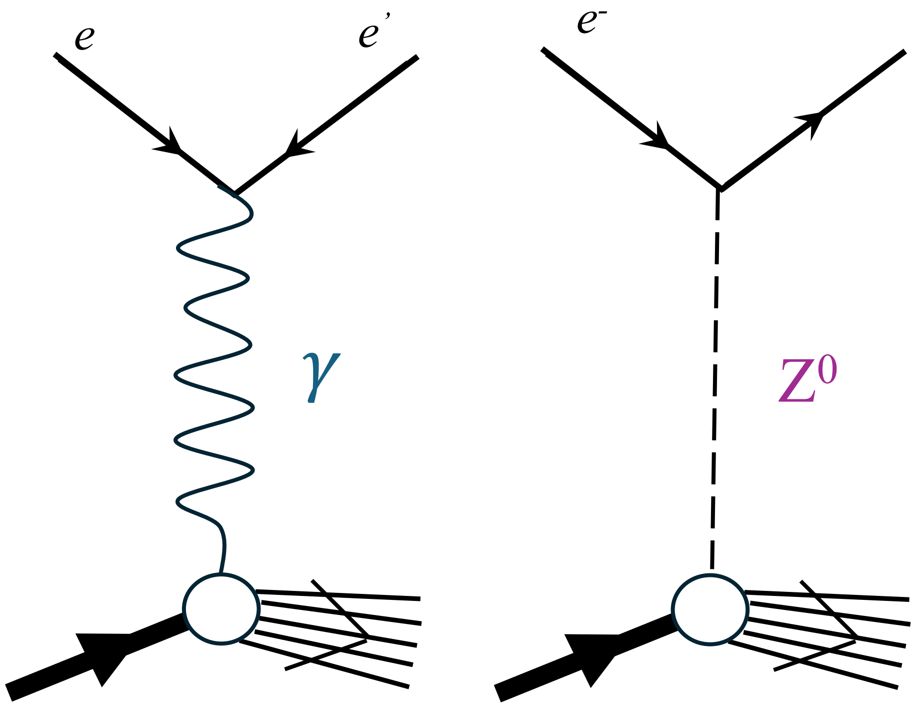
PVDIS

$$\frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

Asymmetry is due to the interference between electromagnetic and weak interactions

Parity violating

$$\mathcal{M}_\gamma = j_\mu \left(\frac{1}{q^2} \right) J^\mu, \quad \mathcal{M}_Z = j_\mu \left(\frac{1}{M_Z^2} \right) J^\mu.$$



SLAC E122

- Parity Violating **Deep Inelastic Scattering**
- Predications for the size of asymmetry for the experiment's kinematics :$\sim 10^{-4} Q^2$
- Previous experiments lacked sufficient precision to observe such effects
- Developed technique for high rates
  - Integrating phototubes vs counting electrons

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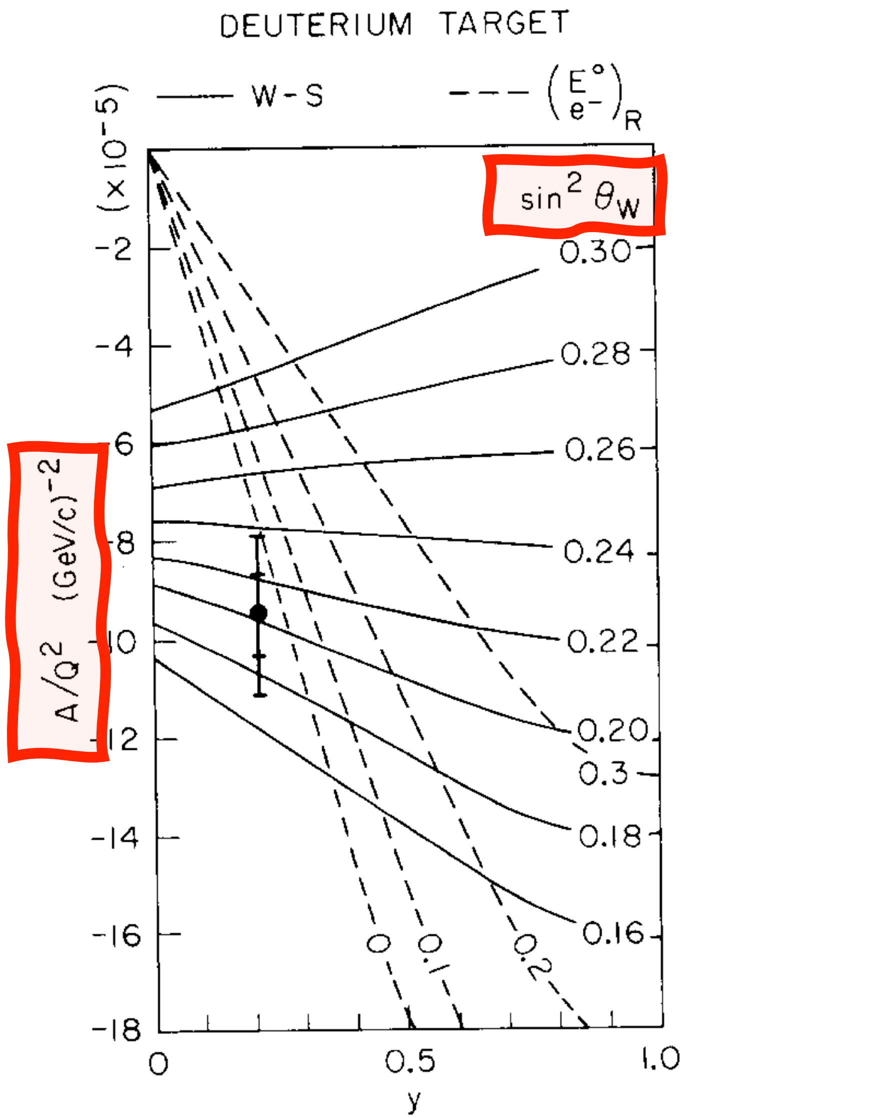

1979 Nobel Prize (Glashow, Salam, Weinberg) "Unification of the weak & electromagnetic forces"

Comparison of results with SU(2)×U(1) theories
1. Weinberg-Salam (solid line)
2. Hybrid (dashed line)

JLab PVDIS (6 GeV)

- PVDIS (electron-Deuteron)
- Jefferson Lab

  Hall A
- JLab DAQ limited 4 kHz
  - Expected rates - few hundred kHz
- Designed new scalar based DAQ
  - Worked up to ~600 kHz

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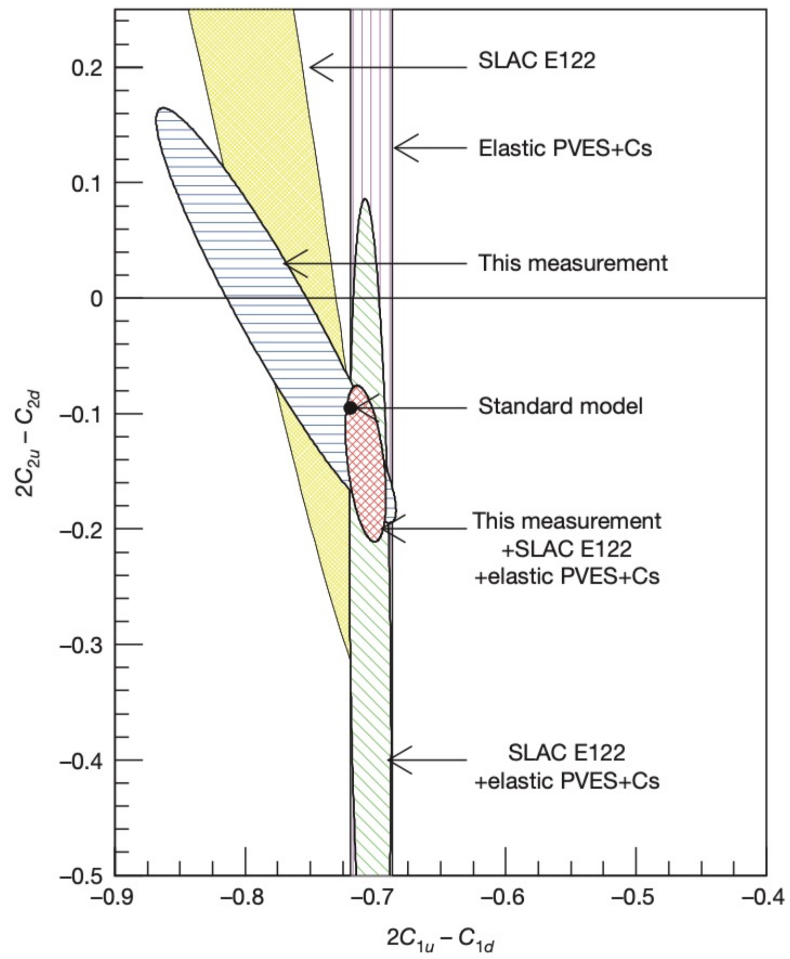
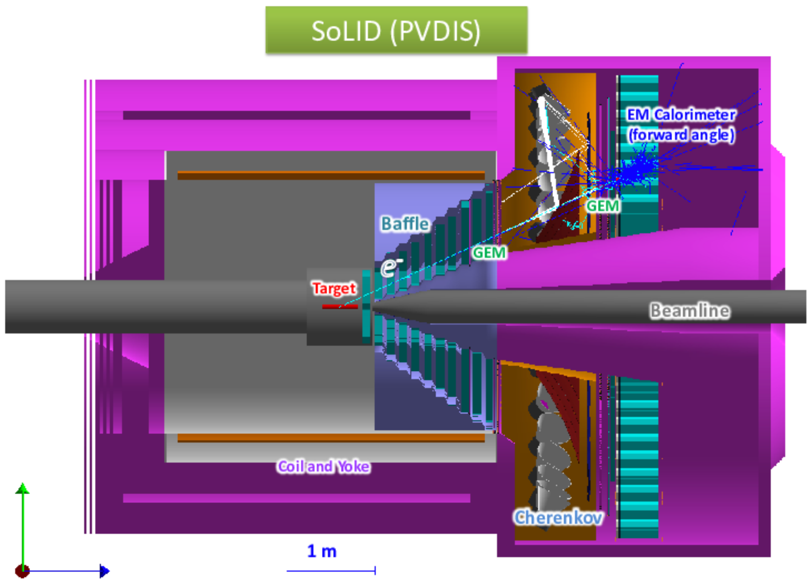
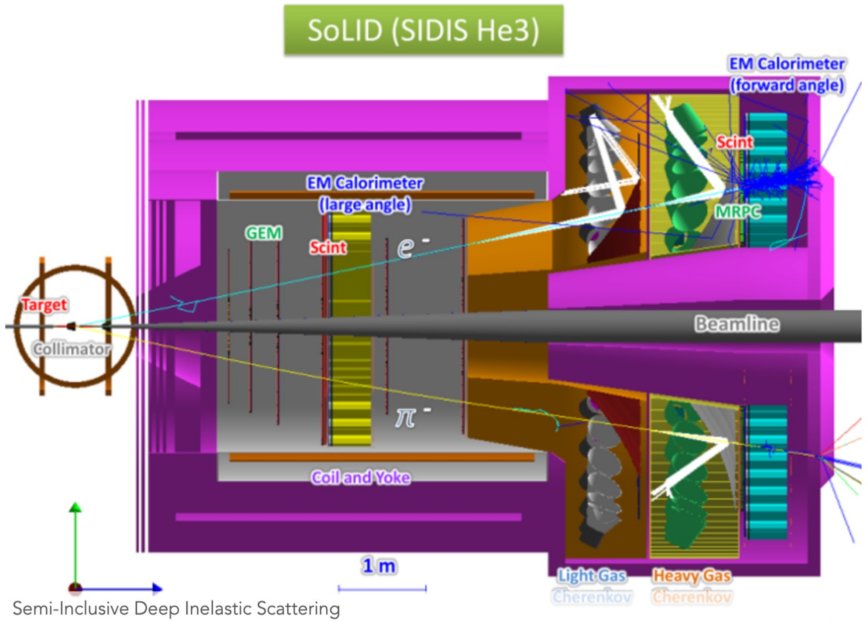
  Hall A
- JLab DAQ limited 4 kHz
  - Expected rates - few hundred kHz
- Designed new scalar based DAQ
  - Worked up to ~600 kHz
- Greatly improved the uncertainty r understanding of the effective electron–quark VA weak couplings



- Break

What is SoLID (Solenoidal Large Intensity Device)





Semi-Inclusive Deep Inelastic Scattering

- High luminosity
  - $L \sim 10^{37} - 10^{39}\ cm^{-2}s^{-1}$
- Large acceptance + full azimuthal coverage
  - Precision measurements over a wide phase space

SoLID (**So**lenoidal **L**arge **I**ntensity **D**evice)

High Luminosity

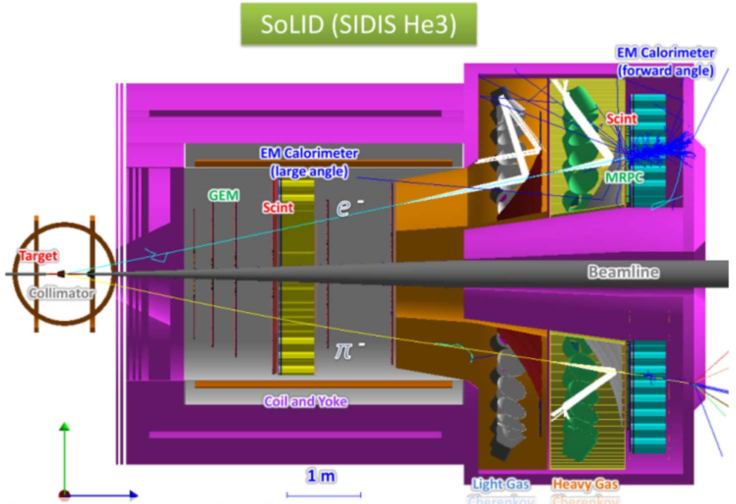
$L \sim 10^{37} - 10^{39}\ cm^{-2}s^{-1}$

[>100x CLAS12][>1000x EIC]

+

Large Acceptance

Full azimuthal ϕ coverage



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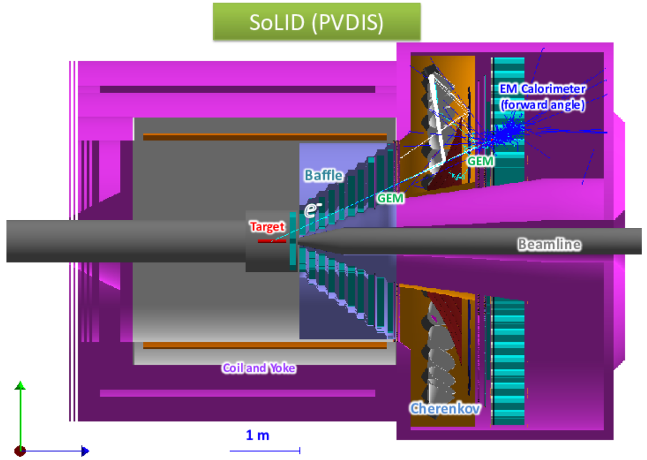
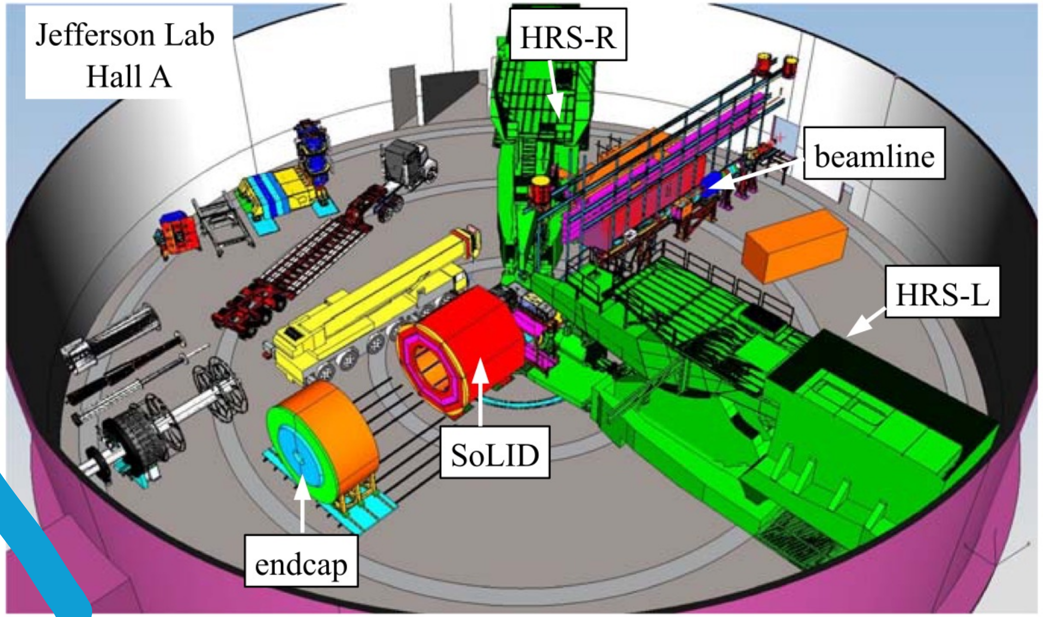


- CLEO Magnet
- Currently in the Test Lab
- Look for it on your tour of Test Lab on Friday!



- SoLID will be installed in Hall A
  - After completion of Moller experiment

SoLID High Luminosity Capability

- High luminosity capability due to
  - Advances in detector and computing
- Can take full advantage of the 12 GeV upgrade
- Radiation hard
- PVDIS configuration
  - 30 sectors (each with individual DAQs)
  - FADC readout 120 kHz
  - ~1% dead time

- GEMs (Gas Electron Multipliers)
- Cherenkov counters
  - Advanced photon detectors
- Electromagnetic calorimeters
  - Shashlik
- Baffles
  - Block photons
- LASPD (Scintillator Pad)

SoLID High Luminosity Capability

- High luminosity … on Multipliers)
  - Advances in de … ers
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  GeV upgrade … calorimeters
- Radiation hard
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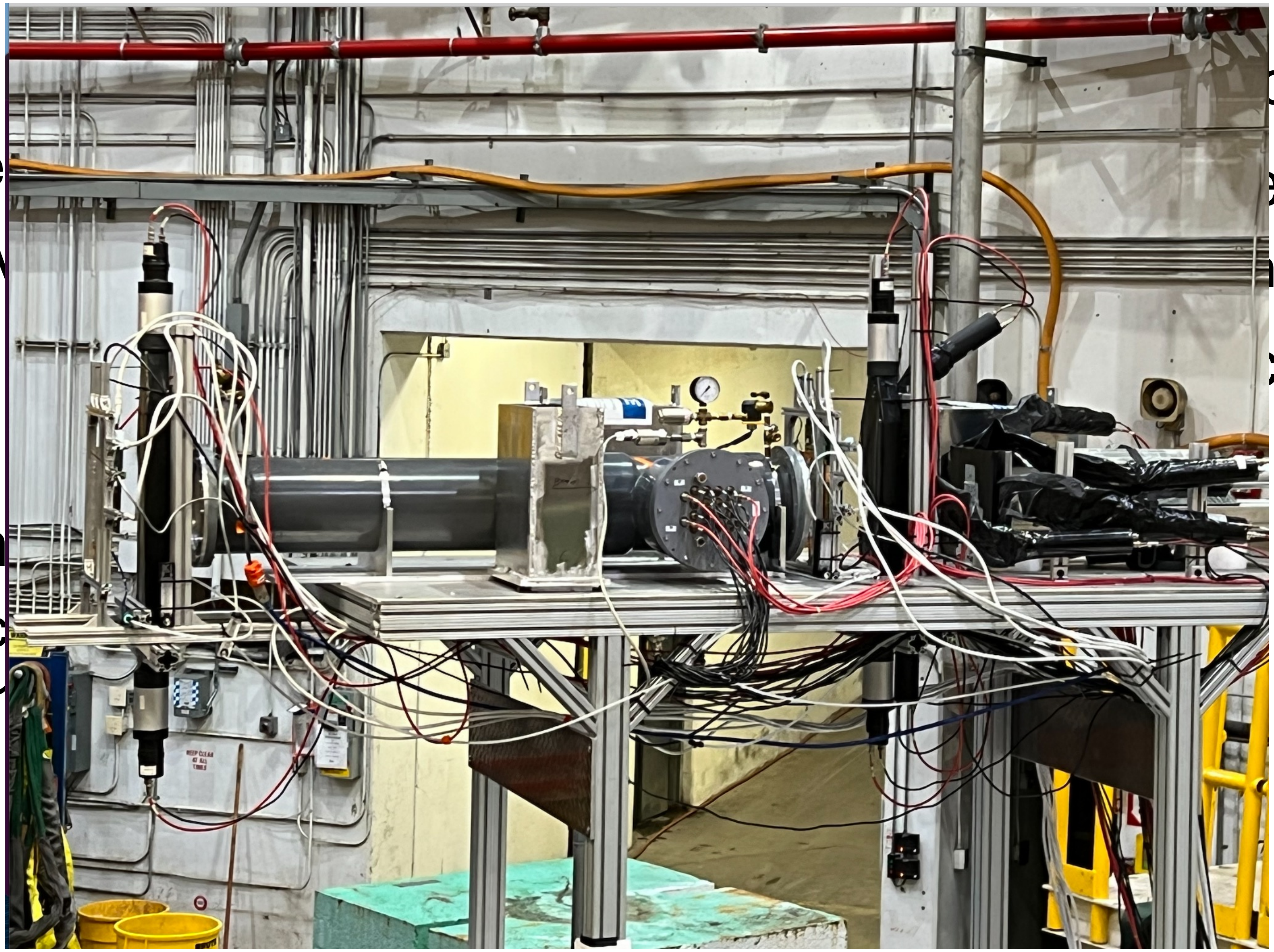


SoLID Experimental Program

SIDIS

PVDIS

J/Ψ

SoLID Experimental Program

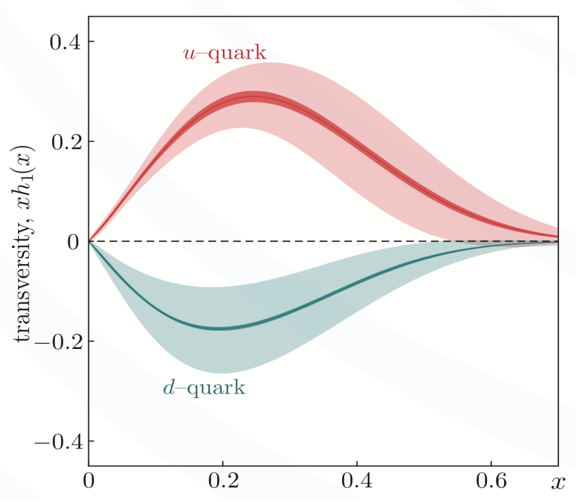
SIDIS

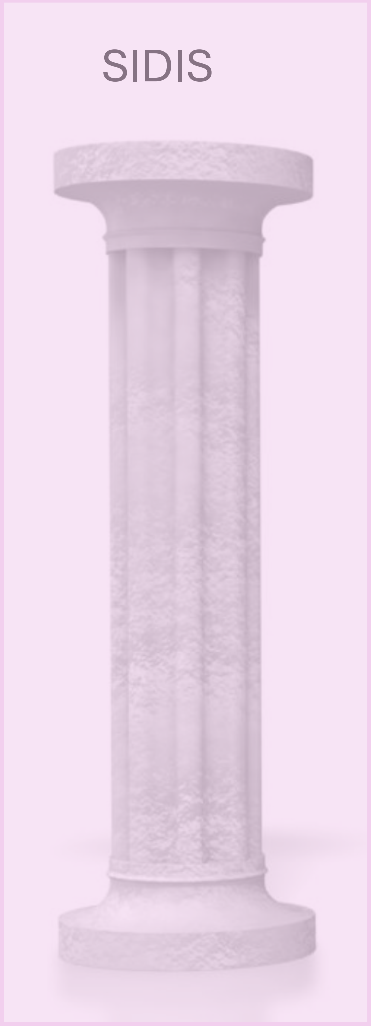
J/Ψ

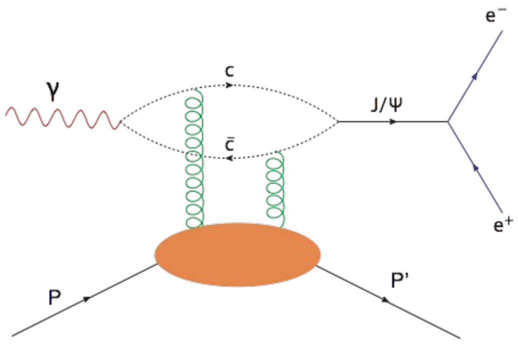
SoLID Experimental Program

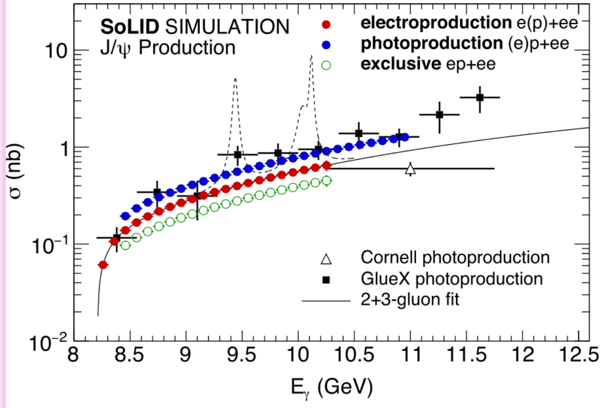
Leading Twist TMDs ○→ : Nucleon Spin ●→ : Quark Spin

Nucleon Polarization		Quark polarization: Un-Polarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
	U	f_1 =		$h_1^\perp$ = − Boer-Mulder
	L		g_1 = − Helicity	$h_{1L}^\perp$ = − Worm gear
	T	$f_{1T}^\perp$ = − Sivers	$g_{1T}^\perp$ = − Worm gear	Transversity h_{1T} = − ; Pretzelosity $h_{1T}^\perp$ = −



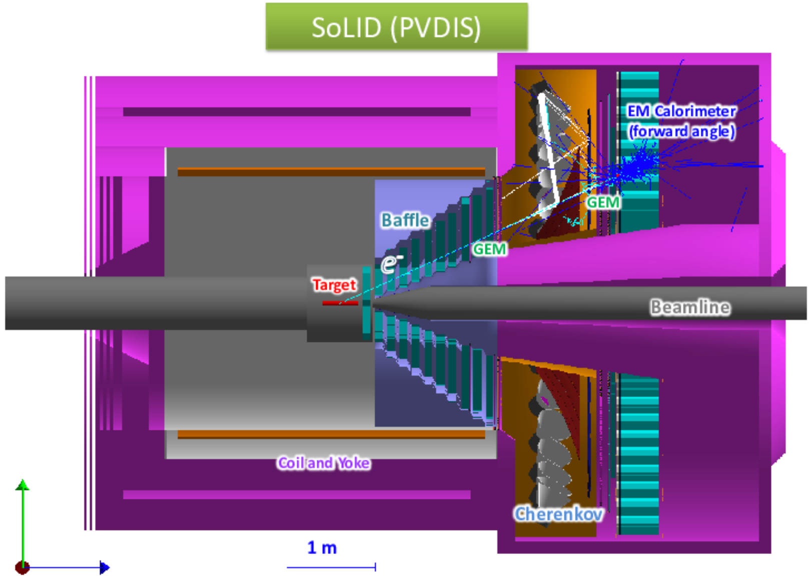






SoLID Experimental Program

SoLID PVDIS



- High luminosity
  - $L \sim 10^{37} - 10^{39}\ cm^{-2} s^{-1}$
- Large acceptance + full azimuthal coverage

<u>Experimental Details</u>

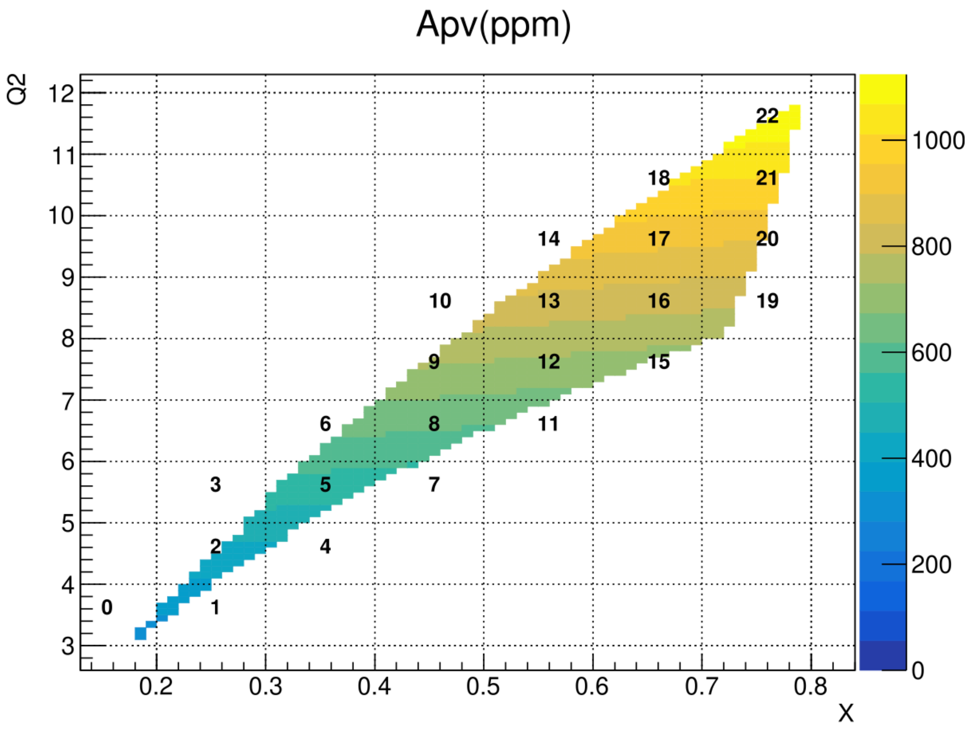
- 120 days
- 50 μA
- 40-cm liquid Deuterium
- 85% polarization

Can measure sub 1% (stat) asymmetry over a wide kinematic coverage

SoLID PVDIS Program

- **Parity Violating DIS on Isoscalar Deuteron**
  - Precision determination of electroweak parameters
  - Beyond-the-Standard Model (BSM) physics search
- **Parity Violating DIS on Proton Target**
  - d/u measurement
- **Parity Violating EMC Effect**
  - Isospin dependence of the EMC effect by the use of neutron-rich isotopes

Kinematic Coverage of PVDIS program



Can measure sub 1% (stat) asymmetry over wide kinematic coverage

SoLID PVIDS

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

In DIS regime, the asymmetry can be expressed as:

$$A_{PV} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}[a_1 + a_3 Y]$$

G_F=1.166 × 10^{-5} GeV^{-2}
(Fermi constant)

$$a_1(x) = 2g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}}, \quad a_3(x) = g_V^e \frac{F_3^{\gamma Z}}{F_1^{\gamma}} \quad , Y = \frac{1-(1-y)^2}{1-(1+y)^2}$$

Kinematic Factor

$$F_1^{\gamma}(x,Q^2) = \frac{1}{2}\sum Q_{q_i}^2 \left[q_i(x,Q^2) + \bar{q}_i(x,Q^2)\right] ,$$

$$F_1^{\gamma Z}(x,Q^2) = \sum Q_{q_i} g_V^i \left[q(x,Q^2) + \bar{q}_i(x,Q^2)\right] ,$$

$$F_3^{\gamma Z}(x,Q^2) = 2\sum Q_{q_i} g_A^i \left[q_i(x,Q^2) - \bar{q}_i(x,Q^2)\right]$$

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$g_{V,A}^{e,i}$ → vector and axial coupling of the electron or quark of flavor i

$$F_1^{\gamma}(x,Q^2) = \frac{1}{2}\sum Q_{q_i}^2 \left[q_i(x,Q^2) + \bar{q}_i(x,Q^2)\right] ,$$

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SoLID PVIDS: Deuteron

- Utilizing an Isoscalar target (Deuteron)
  - High x, there is a cancellation of structure functions
  - Asymmetry simplifies

$$A_{PV,(d)} = \frac{3G_F Q^2}{10\sqrt{2}\pi\alpha}\left[\left(2g_{AV}^{eu} - 2g_{AV}^{ed}\right) + R_V Y\left(2g_{VA}^{eu} - 2g_{VA}^{ed}\right)\right]$$

$$g_{AV}^{eu} = 2g_A^e g_V^u = -\frac{1}{2} + \frac{4}{3}\sin^2\theta_W \ ,$$

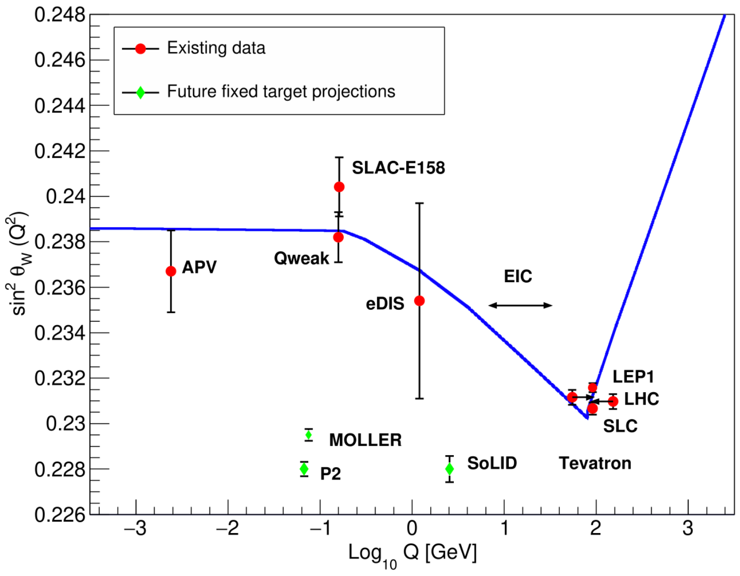
$$g_{VA}^{eu} = 2g_V^e g_A^u = -\frac{1}{2} + 2\sin^2\theta_W \ ,$$

$$g_{AV}^{ed} = 2g_A^e g_V^d = \frac{1}{2} - \frac{2}{3}\sin^2\theta_W \ ,$$

$$g_{VA}^{eu} = 2g_V^e g_A^d = \frac{1}{2} - 2\sin^2\theta_W \ .$$

SoLID PVIDS: Deuteron

- Dominant Uncertainties: experimental systematics
  - Beam polarimetry: 0.4%
  - Q^2 determination: 0.2%
  - Radiative corrections: 0.2%
- **Able to measure Apv to sub–percent level precision**



$$A_{PV}^{\mathrm{data}} = \boxed{A_{PV,(d)}^{\mathrm{SM}}}\left(1 + \frac{\beta_{\mathrm{HT}}}{(1-x)^3 Q^2} + \beta_{\mathrm{CSV}} x^2\right),$$

$$\longrightarrow \sin^2\theta_{\mathrm{w}}(Q^2)$$

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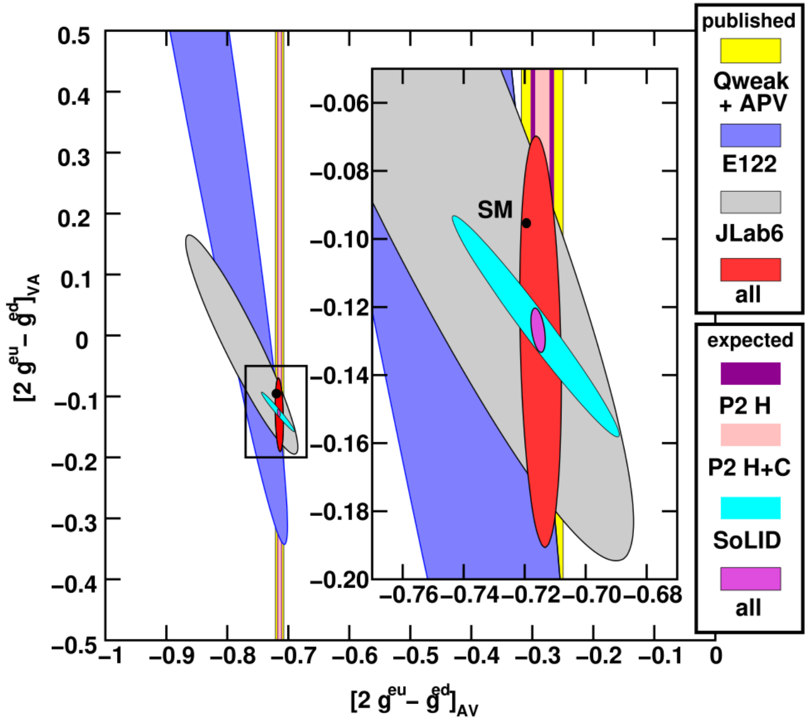
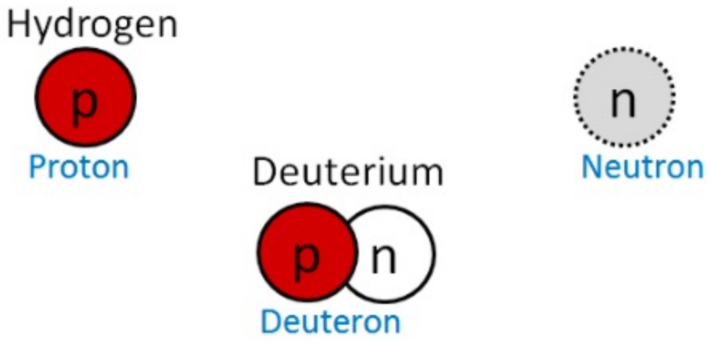


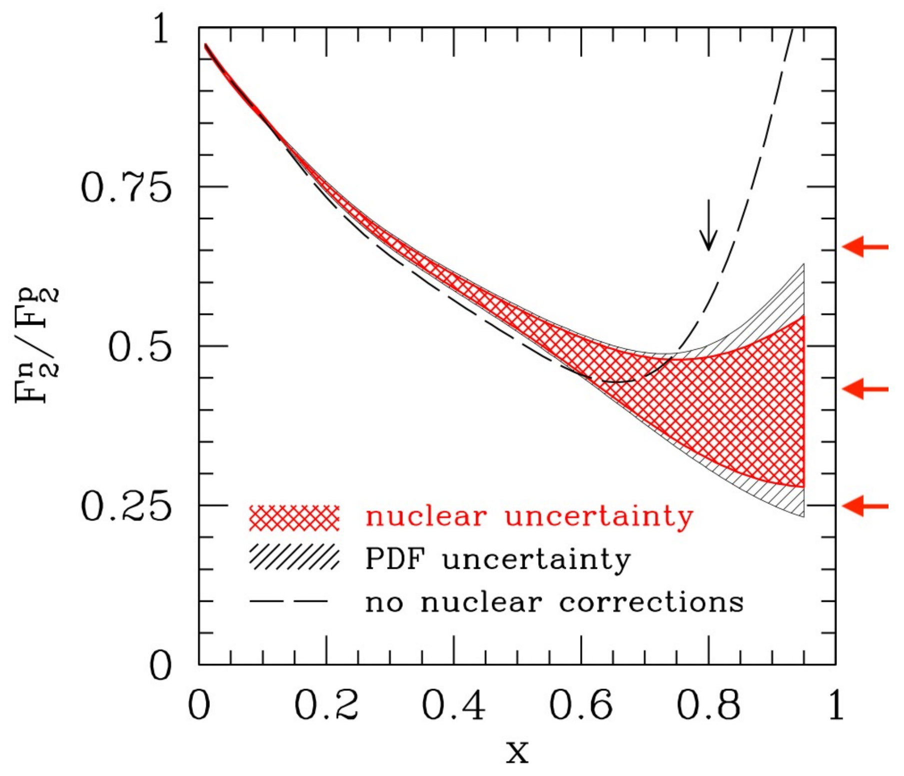
Simultaneous fit of $(2g_{AV}^{eu} - g_{AV}^{ed})$ and $(2g_{VA}^{eu} - g_{VA}^{ed})$

SoLID PVDIS Program: Proton

- Ratios F_2^n/F_2^p & d/u ($\lim x \longrightarrow 1$)
  - Provide clear way to examine theory
- Major hurdle
  - Extracting F_2^n
- $F_2^p \longrightarrow$ Hydrogen
- $F_2^n \longrightarrow$? (No free / stable neutron target)
- $F_2^D = F_2^n + F_2^p$

Measure





	F_2^n/F_2^p	d/u	A_1^n	A_1^p
SU(6)	2/3	1/2	0	5/9
Diquark Model/Feynman	1/4	0	1	1
Quark Model/Isgur	1/4	0	1	1
Perturbative QCD	3/7	1/5	1	1
Quark Counting Rules	3/7	1/5	1	1

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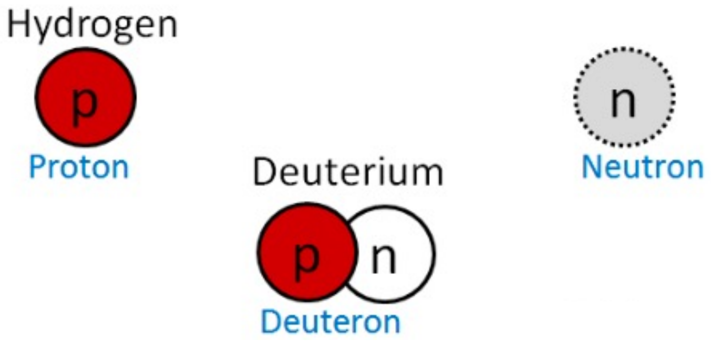

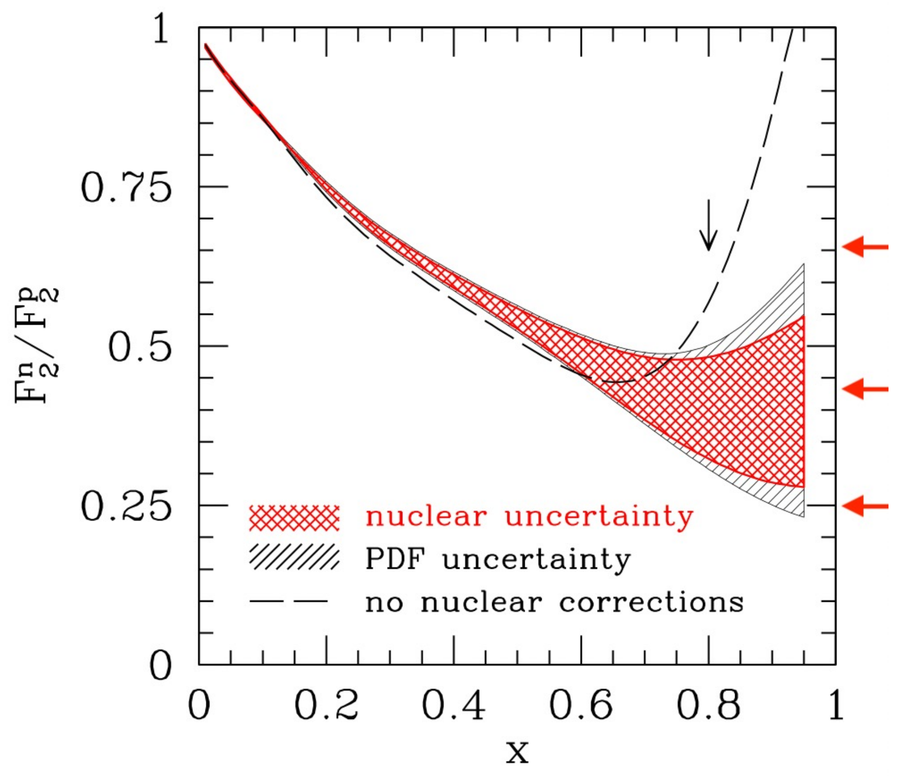

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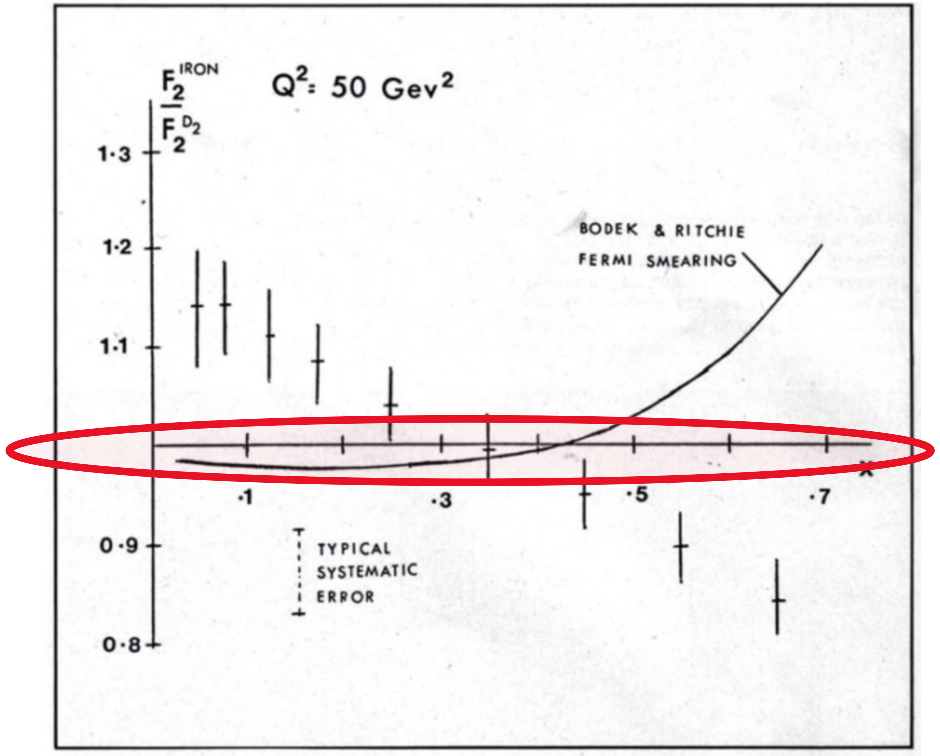
EMC Effect

$$F_2^D \neq F_2^n + F_2^p$$

- **E**uropean **M**uon **C**ollaboration: F_2^{Fe}/F_2^D
  - Expected the ratio to be ~ unity (x < 0.7)
  - Modification of quark distributions



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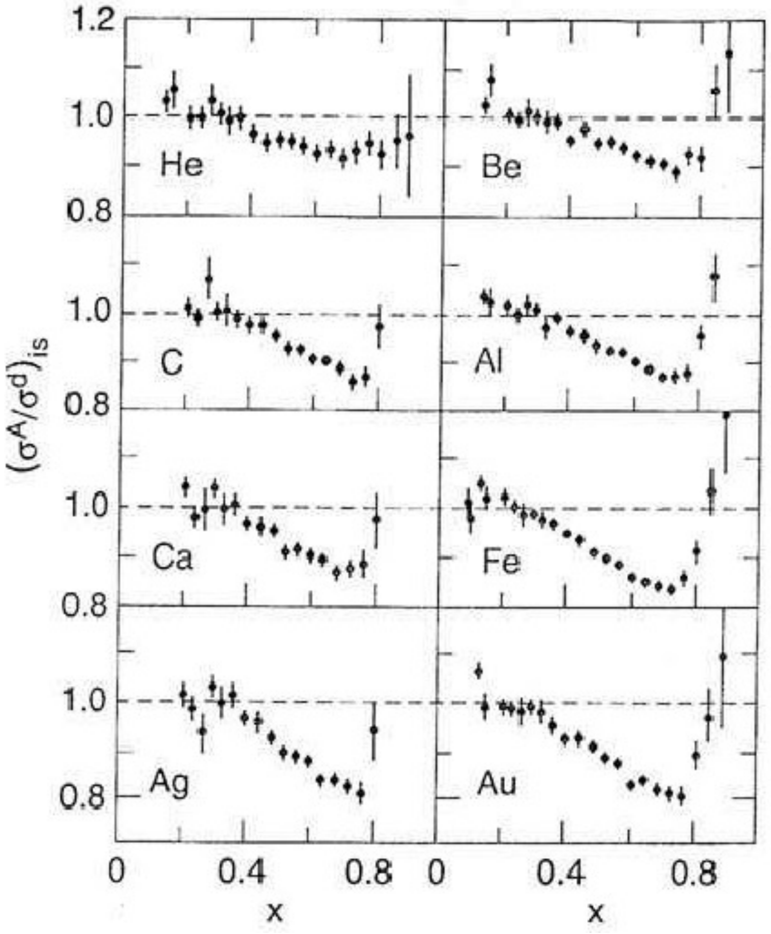
- **E**uropean **M**uon **C**ollaboration: F_2^{Fe}/F_2^D
  - Expected the ratio to be ~ unity (x < 0.7)
  - Modification of quark distributions
- Universal behavior



<u>Consequence</u>
⇒ Extracted F2n from ²H could have large uncertainties

Alternative Approaches
BoNus - Tag recoiling (low momentum) proton
MARATHON- Mirror nuclei
Parity Violating DIS (proton) - free of nuclear effects

SoLID PVDIS Program: Proton

Proton measurement

- Lack of free neutron target
  - Nuclear corrections in the deuteron (large uncertainties)
  - Measurement of d/u → challenging at high x
- BoNuS (**Barely** Off-Shell Neutron Structure)
  - Tag recoiling (low momentum) proton
- MARATHON (Ratio of A=3 mirror nuclei)
  - Nuclear effects cancel in ratio: $\frac{^{3}\mathrm{H}}{^{3}\mathrm{He}}$

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- SoLID PVDIS on the **Proton**
- d/u obtained free nuclear effects

$$A_{PV} = \frac{3G_F Q^2}{2\sqrt{2}\pi\alpha} \frac{\left(2g_{AV}^{eu} - \frac{d}{u} g_{AV}^{ed}\right) + Y\left[2g_{VA}^{eu} - \frac{d}{u} g_{VA}^{ed}\right]}{4 + \frac{d}{u}}$$

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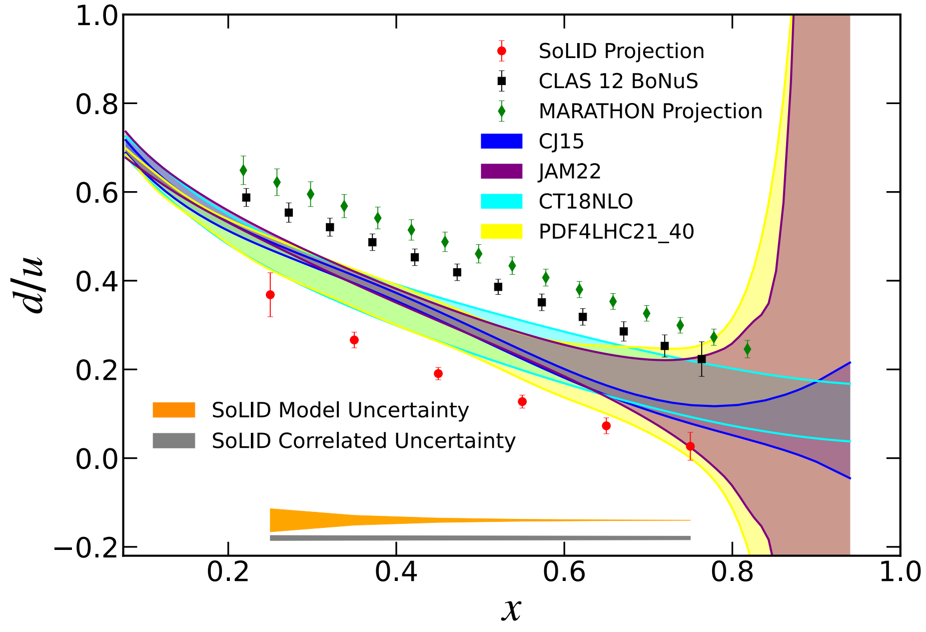
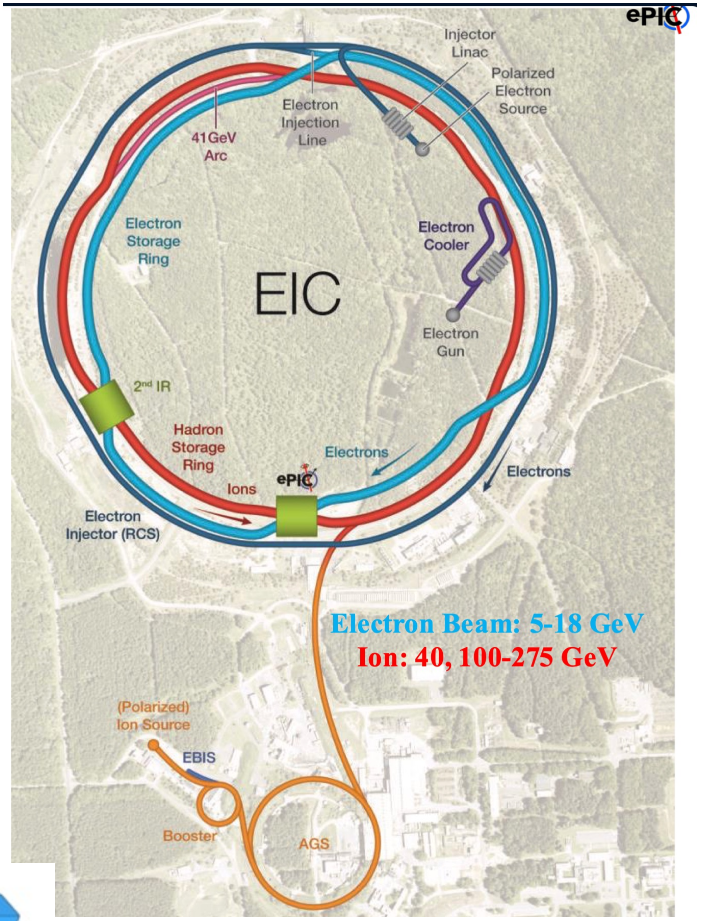
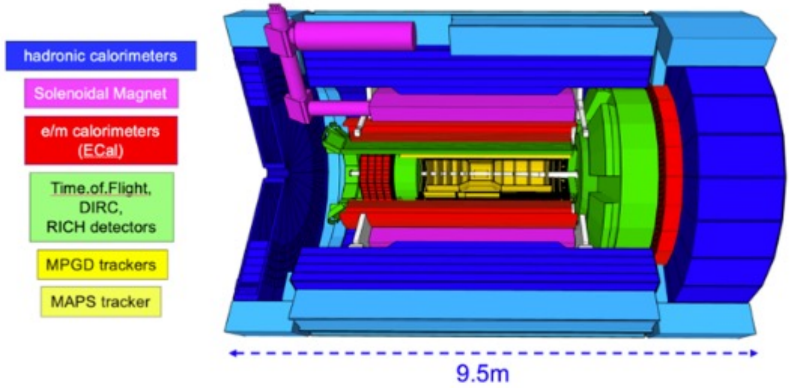


The Electron-Ion Collider

- High luminosity machine
  - (10^{33} - 10^{34} cm^{-2} s^{-1})
- Large center-of-mass energy range
  - √21-140 GeV
- Polarized e^-, protons and light ions beams
  - ≥70%
- Ions beam from deuteron to heavier nuclei
  - Gold, lead, or uranium

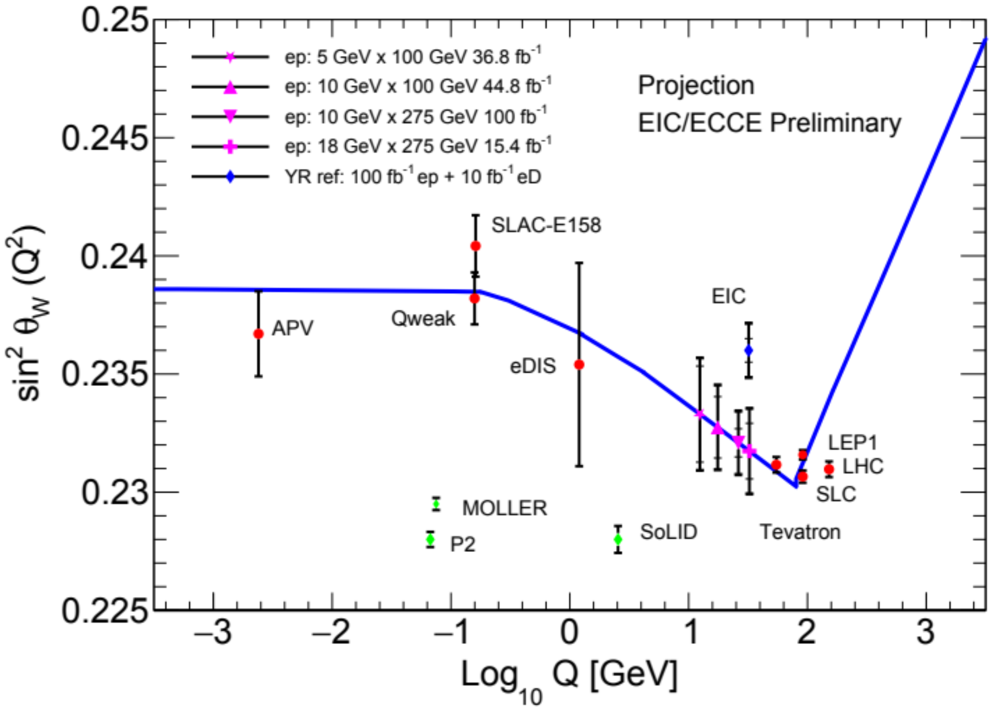


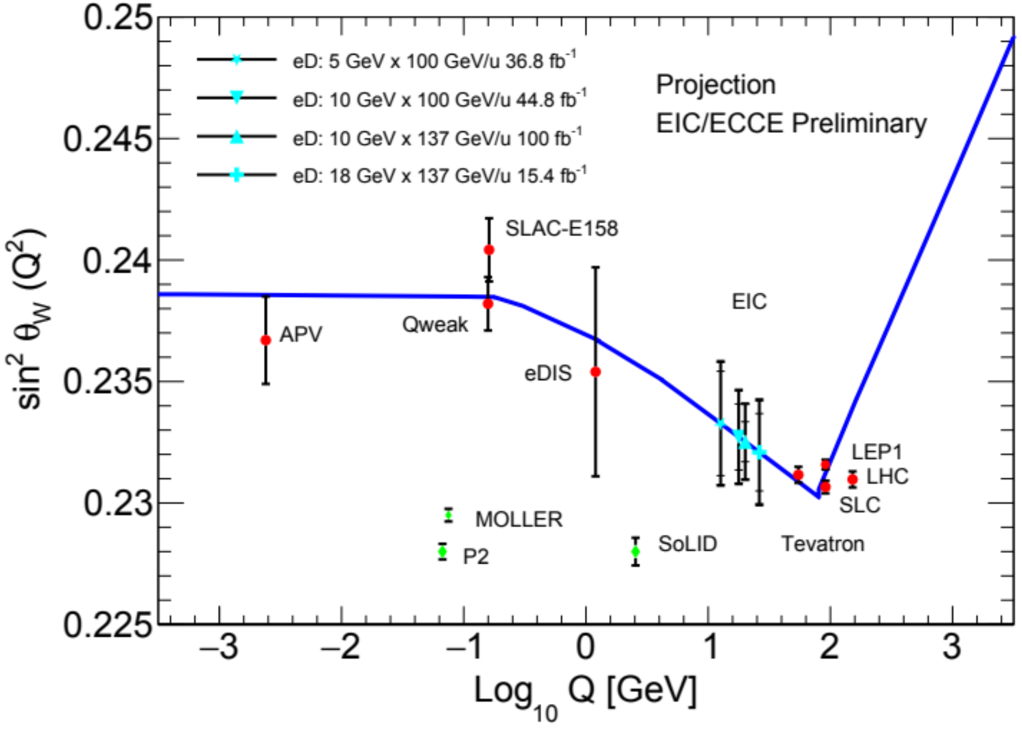


Settings

Electron Energy [GeV]	Proton Energy [GeV]	Annual Luminosity [fb^{-1}]		Electron Energy [GeV]	Deuteron Energy [GeV]	Annual Luminosity [fb^{-1}]
5	41	4.4		5	41	4.4
5	100	36.8		5	100	36.8
10	100	44.8		10	100	44.8
10	275	100		10	137	100
18	275	15.4		18	137	15.4
18	275	100				

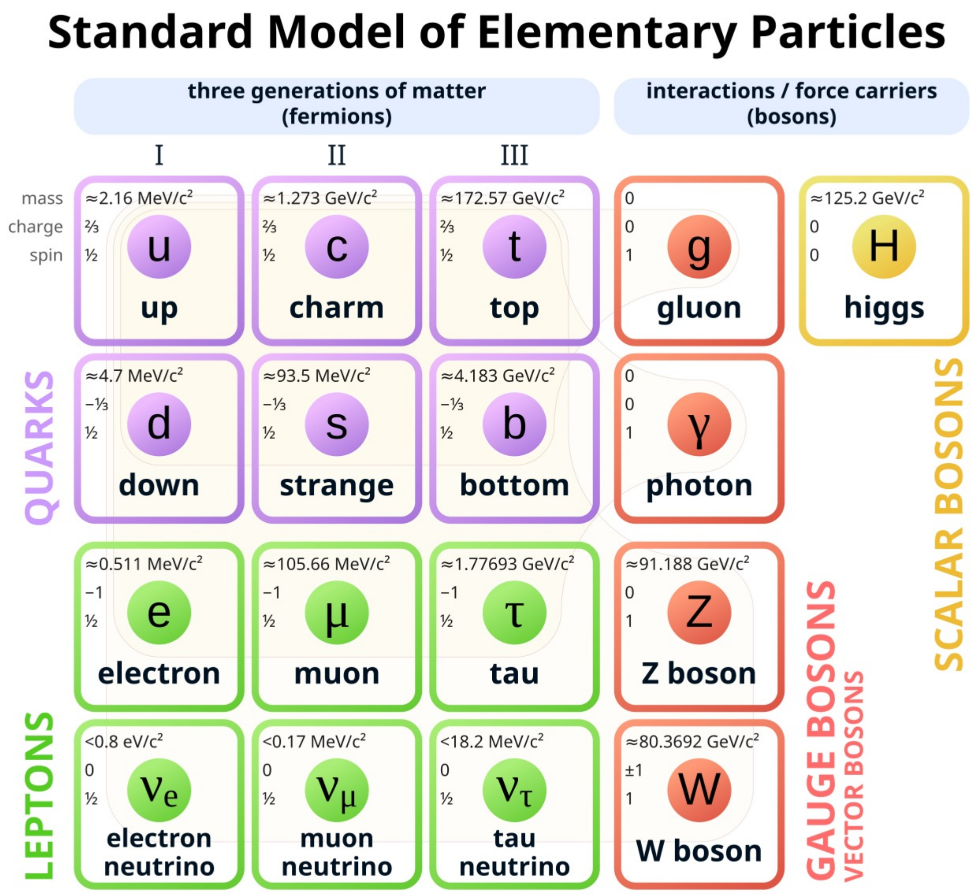
PVDIS at the EIC





The EIC can cover an unexplored region

The Standard Model and Searches for BSM



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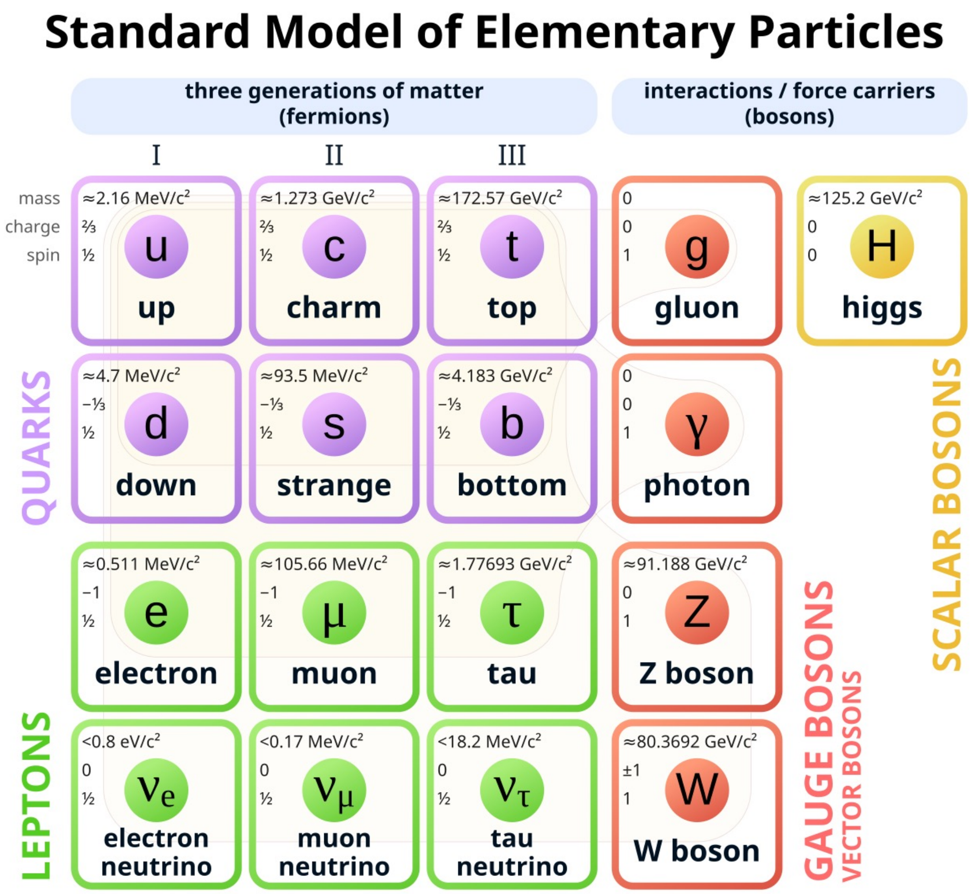
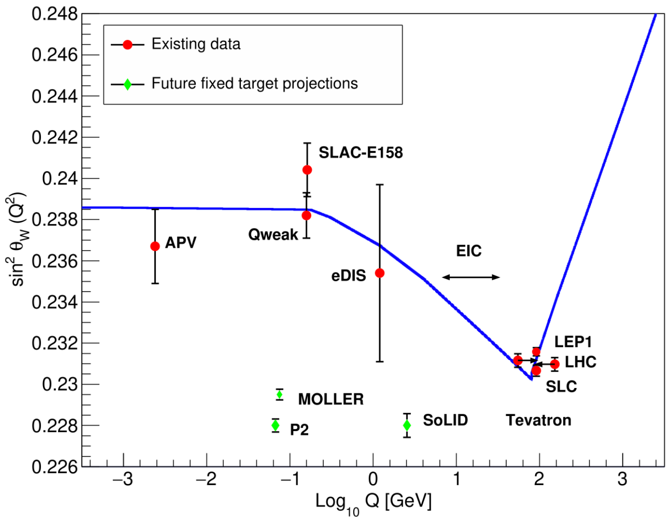


Puzzles

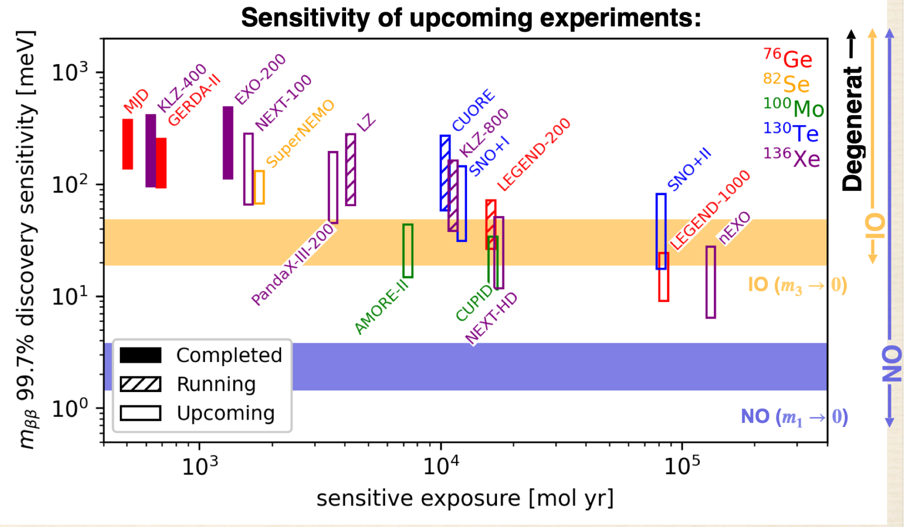
- Neutrino Flavor Oscillations
  - $m_{\nu} \neq 0$
- Baryon Asymmetry
- Dark Energy
- Dark Matter
- Higgs Mass Hierarchy Problem

Testing the Standard Model

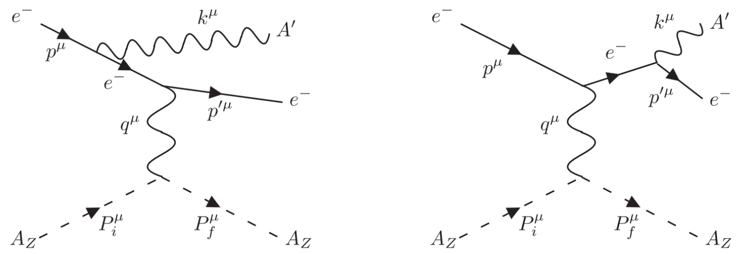
Precision measurements (***PVES*** / muon g-2)



Rare / forbidden processes

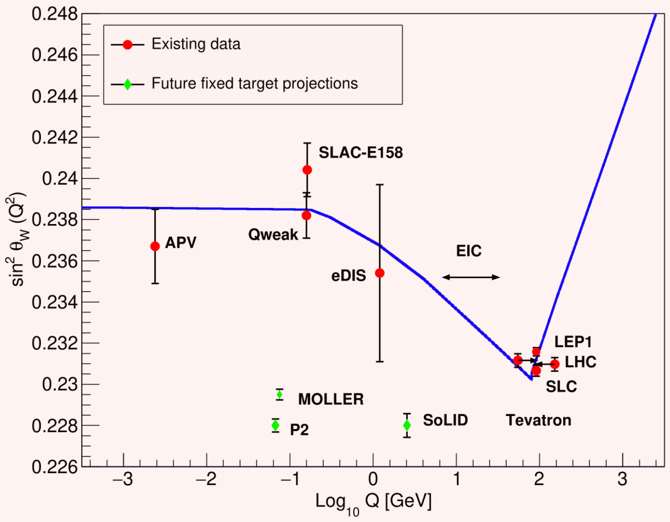


Searches of light & weakly coupled particles

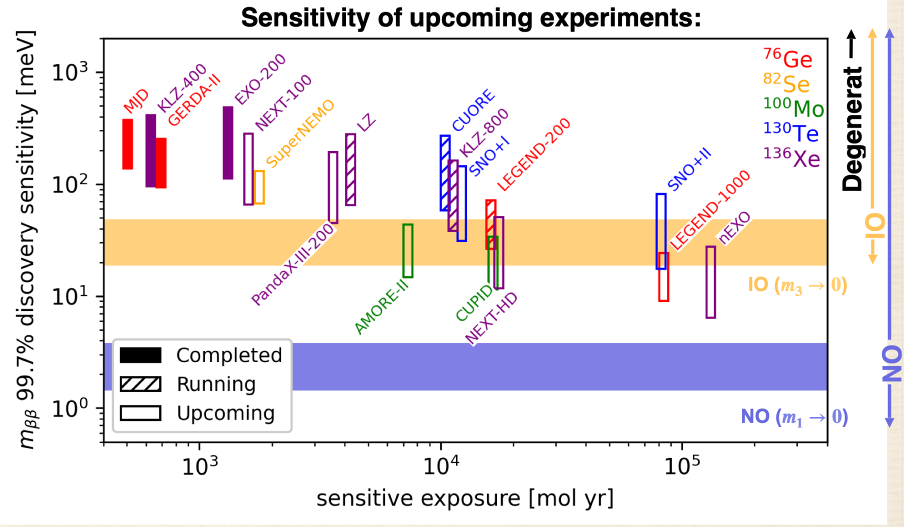


Testing the Standard Model

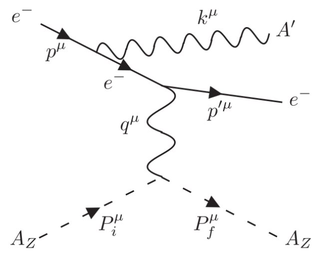
Precision measurements (***PVES*** / muon g-2)

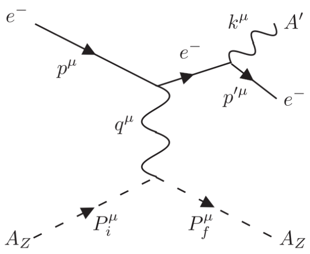


Rare / forbidden processes



Searches of light & weakly coupled particles





Summary

- There is a lot of interesting parity violating science upcoming at Jlab
  - MOLLER (PVES)
- SoLID (PVDIS program)
  - PVIDS with deuteron
  - PVDIS with proton
    PVEMC
- Great time to get involved!