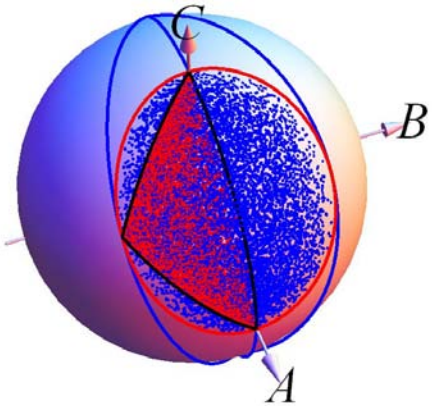
MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK
HEIDELBERG



Distinguish between Dirac&Majorana neutrinos in the presence of new interactions

Xun-Jie Xu
Max-Planck-Institut für Kernphysik, Heidelberg

Based on: **JHEP 05 (2017) 024**, arXiv:**1702.05721**.
With: **Werner Rodejohann**, **Carlos Yaguna**

Talk@WIN2017, UC Irvine

Why new interactions?

Only SM interactions: difference suppressed by mass

$$\text{Dirac}-\text{Majorana} \propto m_\nu$$

E.g.

$$0\nu\beta\beta,\ \nu+e^- \text{ scattering},\ Z^0 \text{ decay},\ \ldots$$

Reason:

$$\text{massless limit} = \text{SM}$$

New interactions: difference NOT suppressed

$$\text{Dirac}-\text{Majorana} \propto \text{new int.}$$

An early (1982) work by Rosen

VOLUME 48, NUMBER 13 PHYSICAL REVIEW LETTERS 29 MARCH 1982

Analog of the Michel Parameter for Neutrino-Electron Scattering: A Test for Majorana Neutrinos

S. P. Rosen
Physics Department, Purdue University, West Lafayette, Indiana 47907, and Physics Division, National Science Foundation, Washington, D. C. 20550[a]

(Received 23 December 1981)

Assume most general 4-fermion interactions

Rosen's ratio:

Define: the ratio of forward to backward scattering cross sections

$$R_\rho = 2 \text{ in SM}$$

$$0 \leq R_\rho \leq 4 \,(\text{Dirac}),$$
$$0 \leq R_\rho \leq 2 \,(\text{Majorana}).$$

most general 4-fermion interactions:

$$\mathcal{L} \supset \frac{G_F}{\sqrt{2}} \sum_{a=S,P,V,A,T} \overline{\nu}\Gamma^a \nu \left[\overline{\ell}\Gamma^a (C_a + D_a i\gamma^5)\ell\right]$$

$$\Gamma^a = \left\{I, i\gamma^5, \gamma^\mu, \gamma^\mu\gamma^5, \sigma^{\mu\nu} \equiv \tfrac{i}{2}[\gamma^\mu, \gamma^\nu]\right\}.$$

5 types of interactions

Scalar, **P**seudo-scalar, **V**ector, **A**xial-vector, **T**ensor

2×5=10 coupling constants

$$C_a,\ D_a \quad (a = S,\ P,\ V,\ A,\ T)$$

But

$$C_V = D_V = C_T = D_T = 0 \ \text{(Majorana)}$$

$$\mathcal{L} \supset \frac{G_F}{\sqrt{2}} \sum_{a=S,P,V,A,T} \overline{\nu}\Gamma^a \nu \left[\overline{\ell}\Gamma^a (C_a + D_a i\gamma^5)\ell\right]$$

$$\frac{d\sigma}{dT}(\nu+\ell) = \frac{G_F^2 M}{2\pi}\left[A + 2B\left(1-\frac{T}{E_\nu}\right) + C\left(1-\frac{T}{E_\nu}\right)^2\right]$$

T: Recoil energy, $(A,\ B,\ C)$ = functions of $(C_a,\ D_a)$.

Rosen's ratio:

$$R_\rho \equiv \frac{2(A+2B+C)}{A+C}$$

$$C_V = D_V = C_T = D_T = 0 \text{ (Majorana)}$$

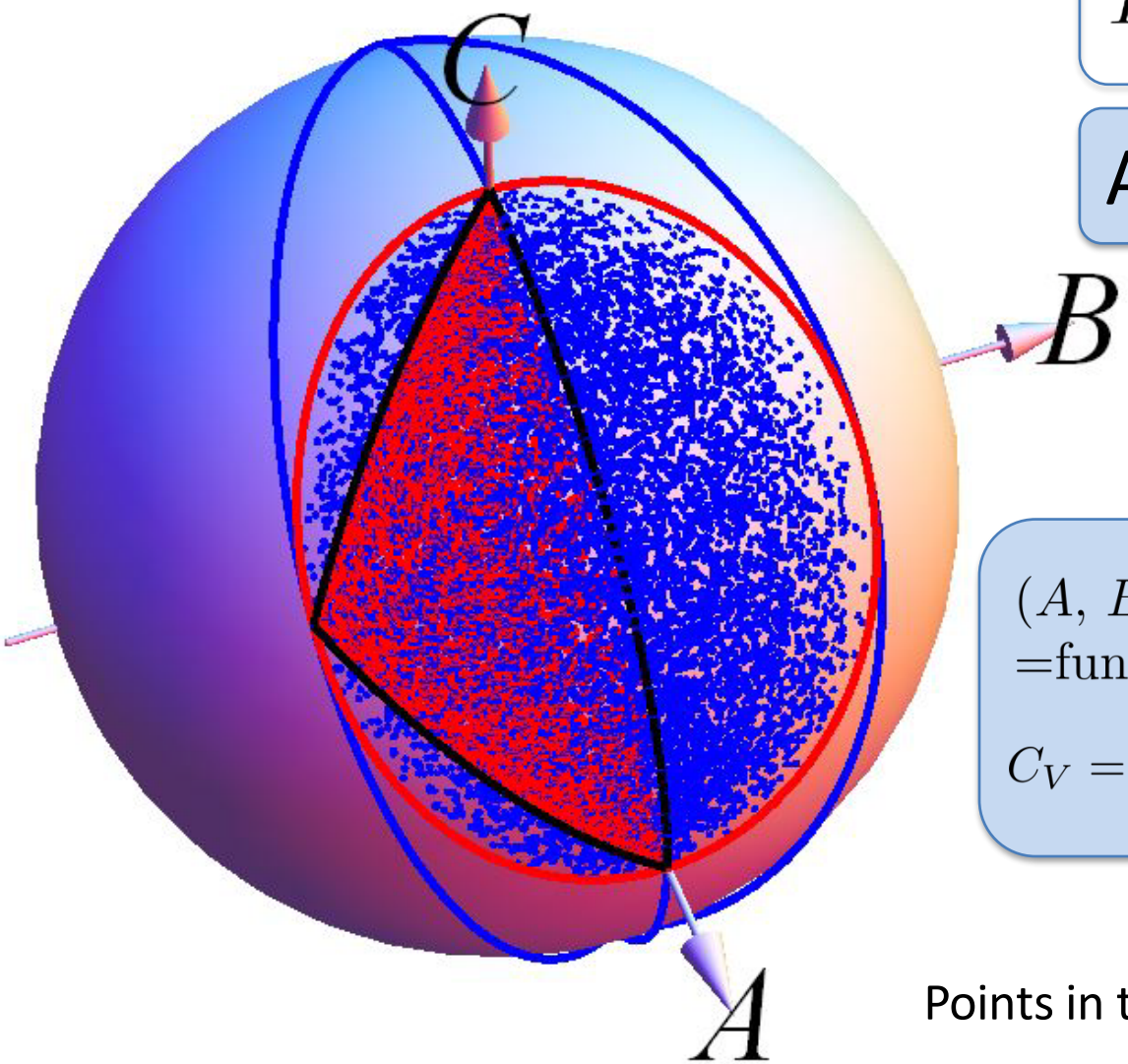
$0 \le R_\rho \le 4$ (Dirac),
$0 \le R_\rho \le 2$ (Majorana).

$$\frac{d\sigma}{dT}(\nu+\ell) = \frac{G_F^2 M}{2\pi}\left[A + 2B\left(1-\frac{T}{E_\nu}\right) + C\left(1-\frac{T}{E_\nu}\right)^2\right]$$

$$R_\rho \equiv \frac{2(A+2B+C)}{A+C}$$

Any other ratios?

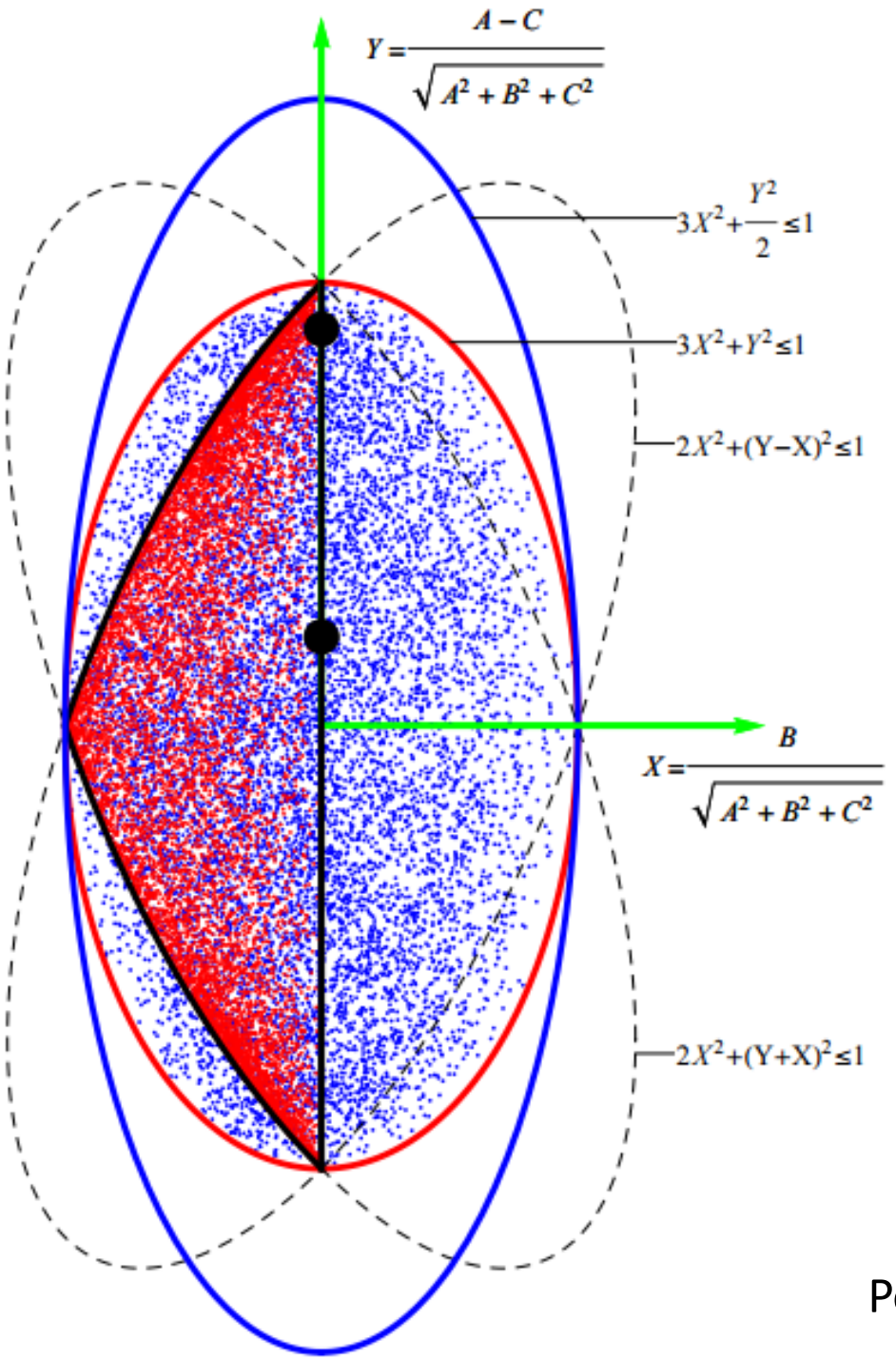
Yes



$(A,\, B,\, C)$
=functions of 10 parameters in $\mathcal{L}$.

$C_V = D_V = C_T = D_T = 0$ (Majorana)

Points in the plot: **Dirac** / **Majorana**



2D Projection

$$X \equiv \frac{B}{R}\,,\; Y \equiv \frac{A-C}{R}\,,$$

$$R \equiv \sqrt{A^2+B^2+C^2}$$

Dirac bound

$$3X^2 + Y^2 \leq 1$$

Proof: see 1702.05721

Majorana bound

$$2X^2 + (Y \pm X)^2 \leq 1$$

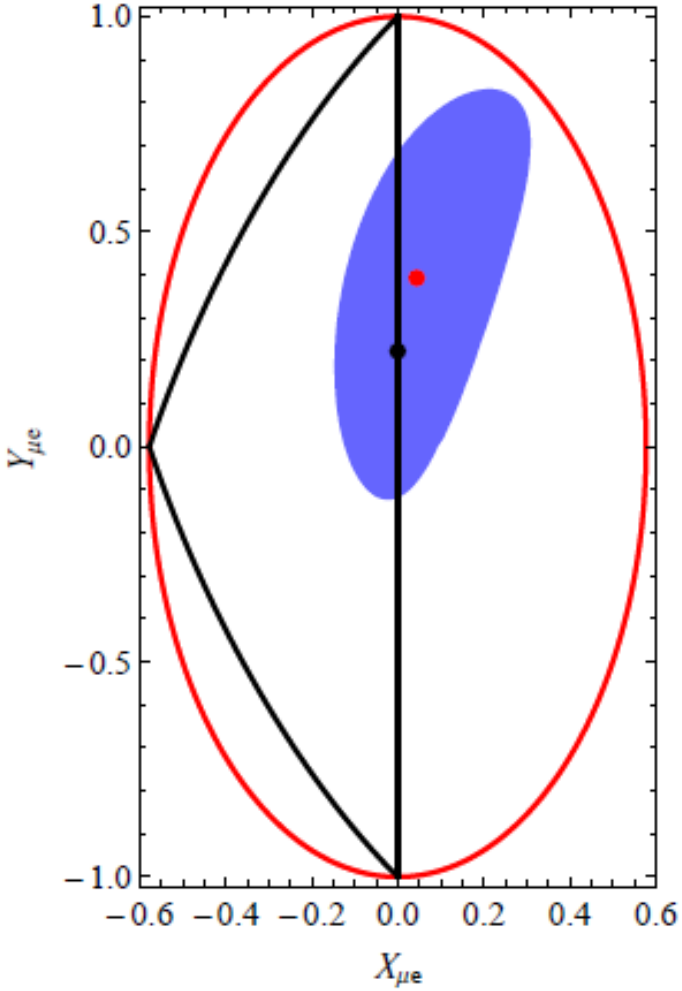
$$\text{and} \quad X \leq 0$$

Proof: see 1702.05721

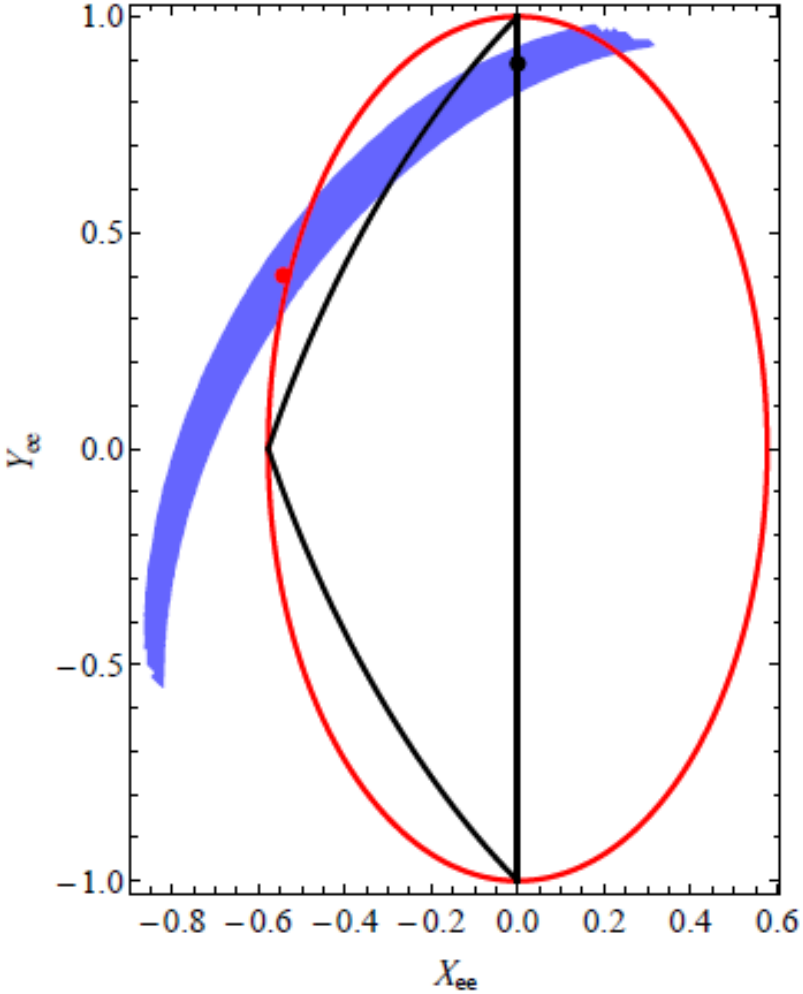
Points in the plot: **Dirac** / **Majorana**

Current experiments

CHARM-II

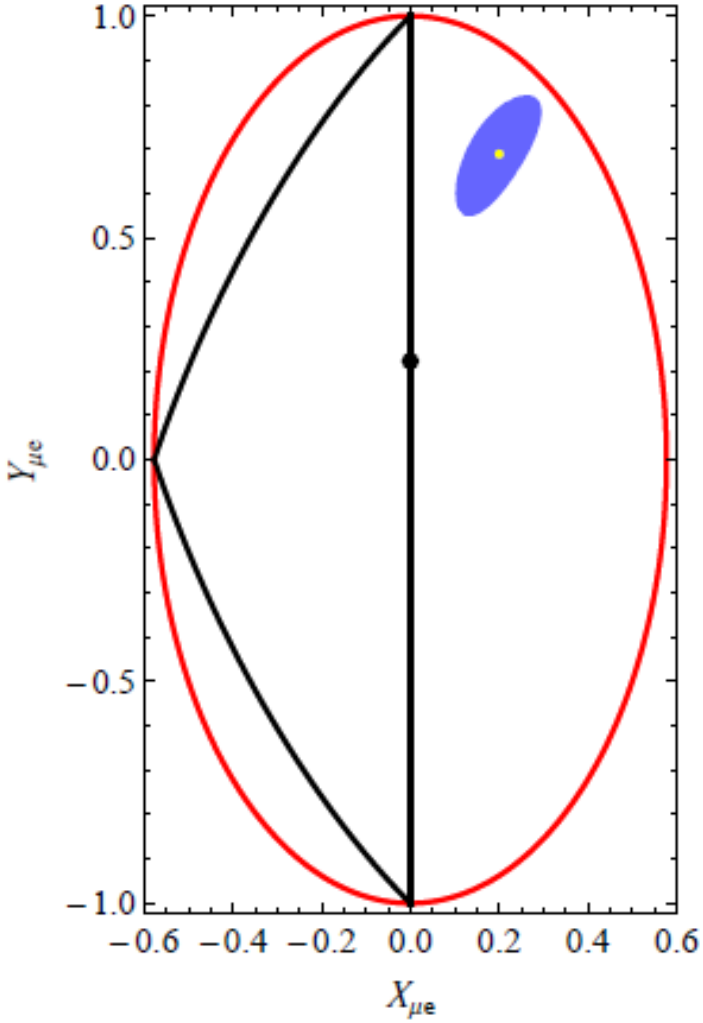


TEXONO

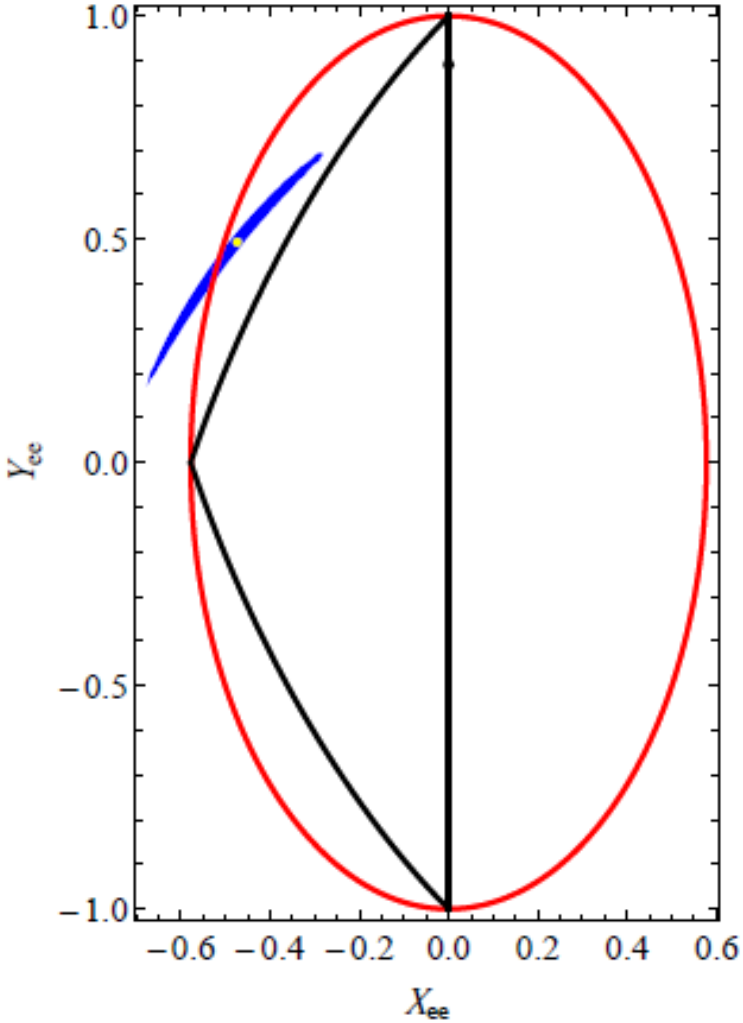


Future, ¼ uncertainties

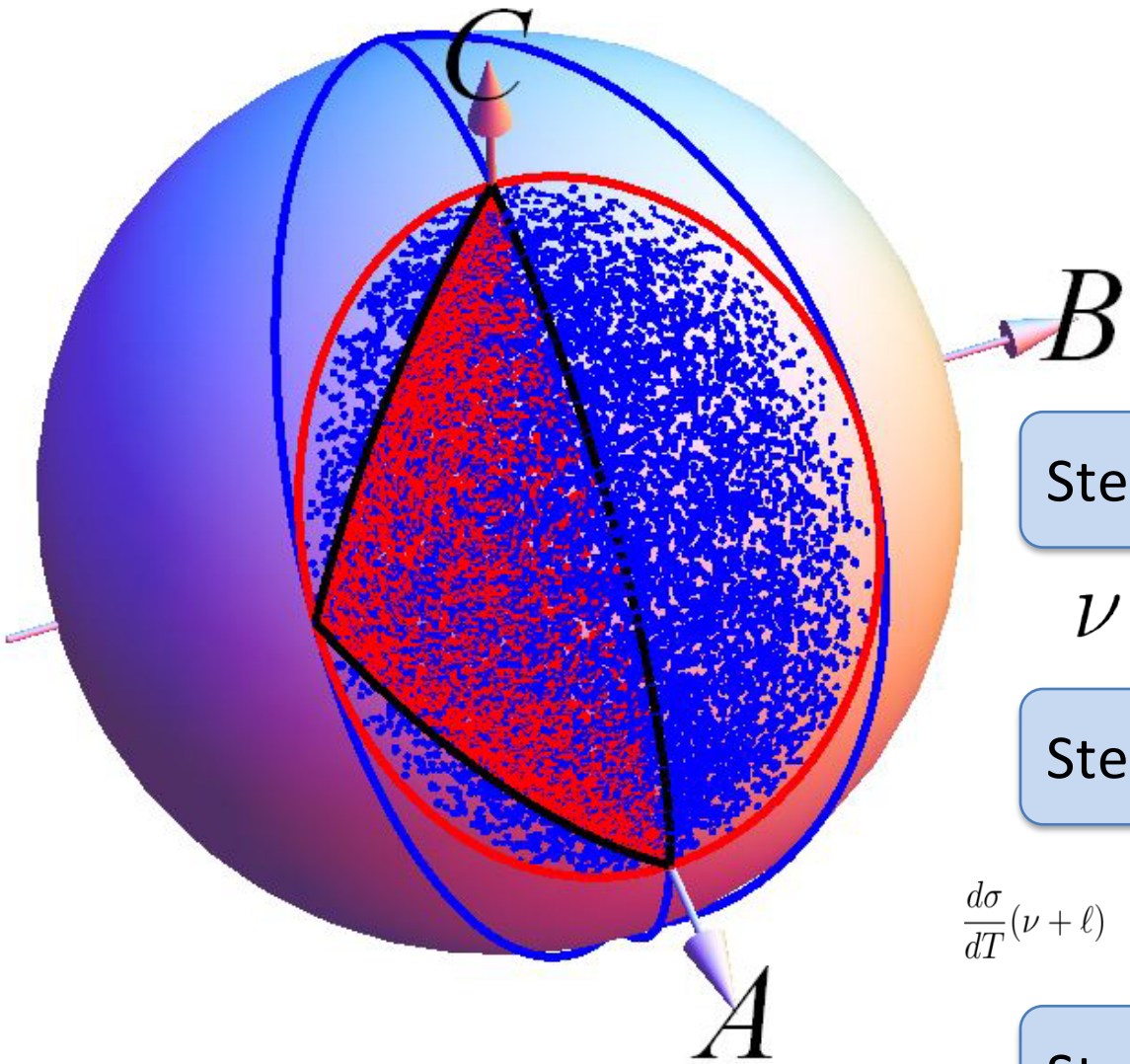
CHARM-II



TEXONO



Summary: D/M? How to Distinguish?



Step 1: neutrino scattering

$$\nu + e^- \rightarrow \nu + e^-$$

Step 2: measure A B C

$$\frac{d\sigma}{dT}(\nu + \ell) = \frac{G_F^2 M}{2\pi}\left[A + 2B\left(1 - \frac{T}{E_\nu}\right) + C\left(1 - \frac{T}{E_\nu}\right)^2\right]$$

Step 3: look at this ball

Thank you

Backup

$$\mathcal{L} \supset \frac{G_F}{\sqrt{2}} \sum_{a=S,P,V,A,T} \overline{\nu}\Gamma^a \nu \left[\overline{\ell}\Gamma^a (C_a + \overline{D}_a i\gamma^5)\ell\right]$$

$$\overline{\Gamma}^a \equiv \gamma^0 (\Gamma^a)^\dagger \gamma^0 = \Gamma^a \,.$$

$$D_a \equiv \begin{cases} \overline{D}_a & (a = S,\, P,\, T) \\ i\overline{D}_a & (a = V,\, A) \end{cases} ,$$

$$C_V = D_V = C_T = D_T = 0 \text{ (Majorana)}.$$

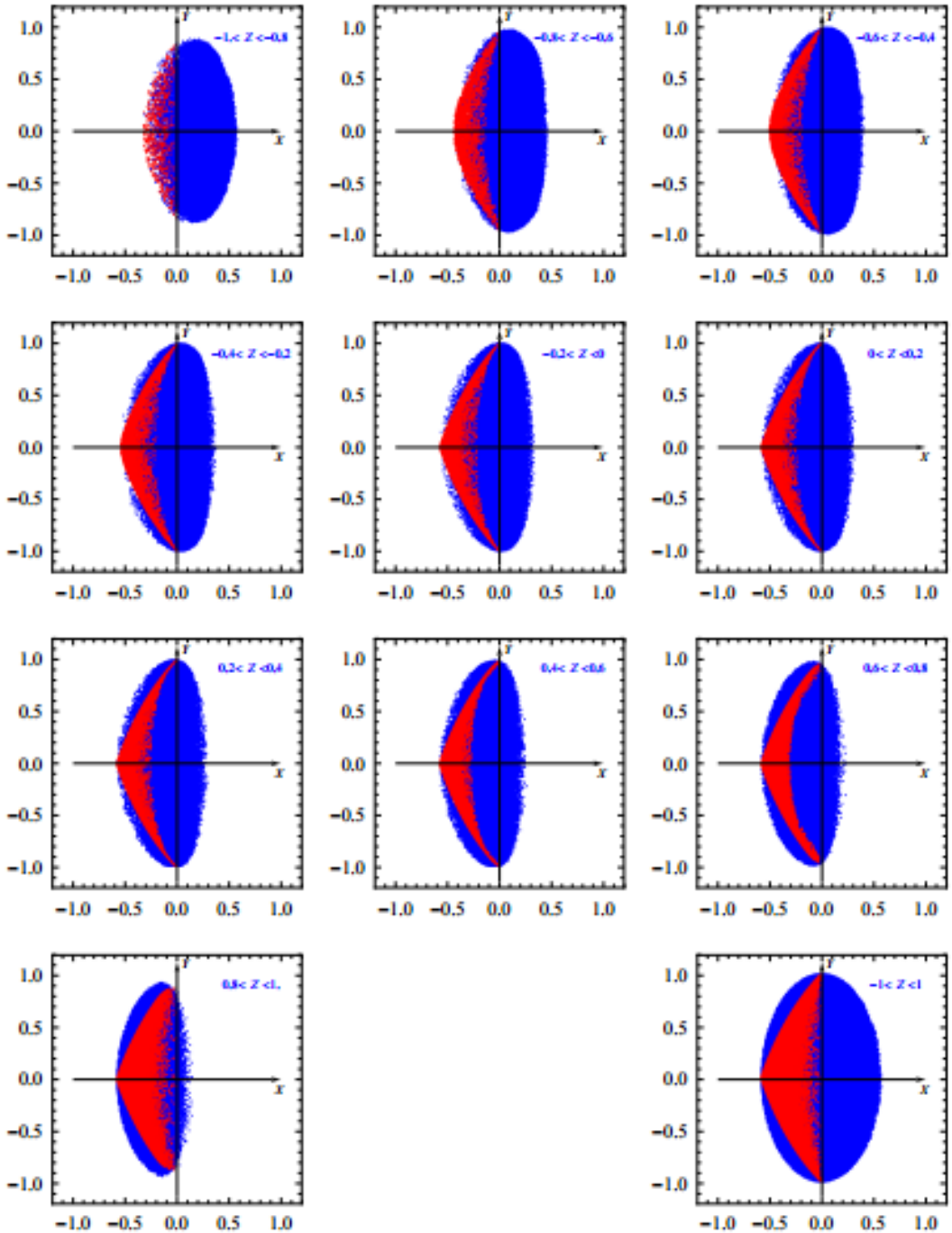
$$\frac{d\sigma}{dT}(\nu+\ell) = \frac{G_F^2 M}{2\pi}\left[A + 2B\left(1-\frac{T}{E_\nu}\right) + C\left(1-\frac{T}{E_\nu}\right)^2\right],$$

$$\frac{d\sigma}{dT}(\overline{\nu}+\ell) = \frac{G_F^2 M}{2\pi}\left[C + 2B\left(1-\frac{T}{E_\nu}\right) + A\left(1-\frac{T}{E_\nu}\right)^2\right],$$

$$A \equiv \frac{1}{4}\left(C_A - D_A + C_V - D_V\right)^2 + \frac{1}{2}C_P C_T + \frac{1}{8}(C_P^2 + C_S^2 + D_P^2 + D_S^2) - \frac{1}{2}C_S C_T + C_T^2 + \frac{1}{2}D_P D_T - \frac{1}{2}D_S D_T + D_T^2\,,$$

$$B \equiv -\frac{1}{8}\left(C_P^2 + C_S^2 + D_P^2 + D_S^2\right) + C_T^2 + D_T^2\,,$$

$$C \equiv \frac{1}{4}\left(C_A + D_A - C_V - D_V\right)^2 - \frac{1}{2}C_P C_T + \frac{1}{8}(C_P^2 + C_S^2 + D_P^2 + D_S^2) + \frac{1}{2}C_T C_S + C_T^2 - \frac{1}{2}D_P D_T + \frac{1}{2}D_S D_T + D_T^2\,,$$


-1.< Z <-0.8
-0.8< Z <-0.6
-0.6< Z <-0.4
-0.4< Z <-0.2
-0.2< Z <0
0< Z <0.2
0.2< Z <0.4
0.4< Z <0.6
0.6< Z <0.8
0.8< Z <1.
-1< Z <1
X
Y
1.0
0.5
0.0
−0.5
−1.0

$$\frac{d\sigma}{dT}(\nu+\ell) = \frac{{G_F}^2 M}{2\pi}\left[A + 2B\left(1-\frac{T}{E_\nu}\right) + C\left(1-\frac{T}{E_\nu}\right)^2 + D\frac{MT}{4E_\nu^2}\right],$$

$$\frac{d\sigma}{dT}(\overline{\nu}+\ell) = \frac{{G_F}^2 M}{2\pi}\left[C + 2B\left(1-\frac{T}{E_\nu}\right) + A\left(1-\frac{T}{E_\nu}\right)^2 + D\frac{MT}{4E_\nu^2}\right],$$

$$D \equiv (C_A - D_V)^2 - (C_V - D_A)^2 + C_S^2 - 4C_T^2 + D_P^2 - 4D_T^2.$$