Session: Quantum Field & String Theory

# Evidence for Pions and Kaons Being Spin-0 Vector Particles

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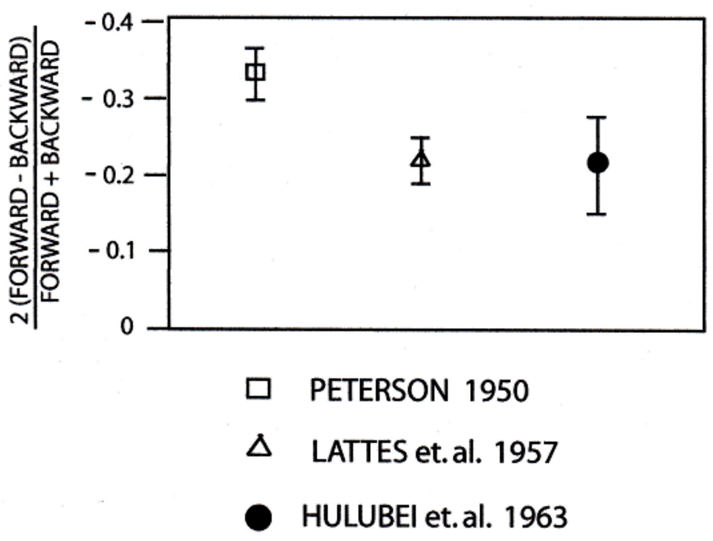
# Three Parts of Presentation

- 1) Solid Experimental Evidence that Pions Carry Directional Information

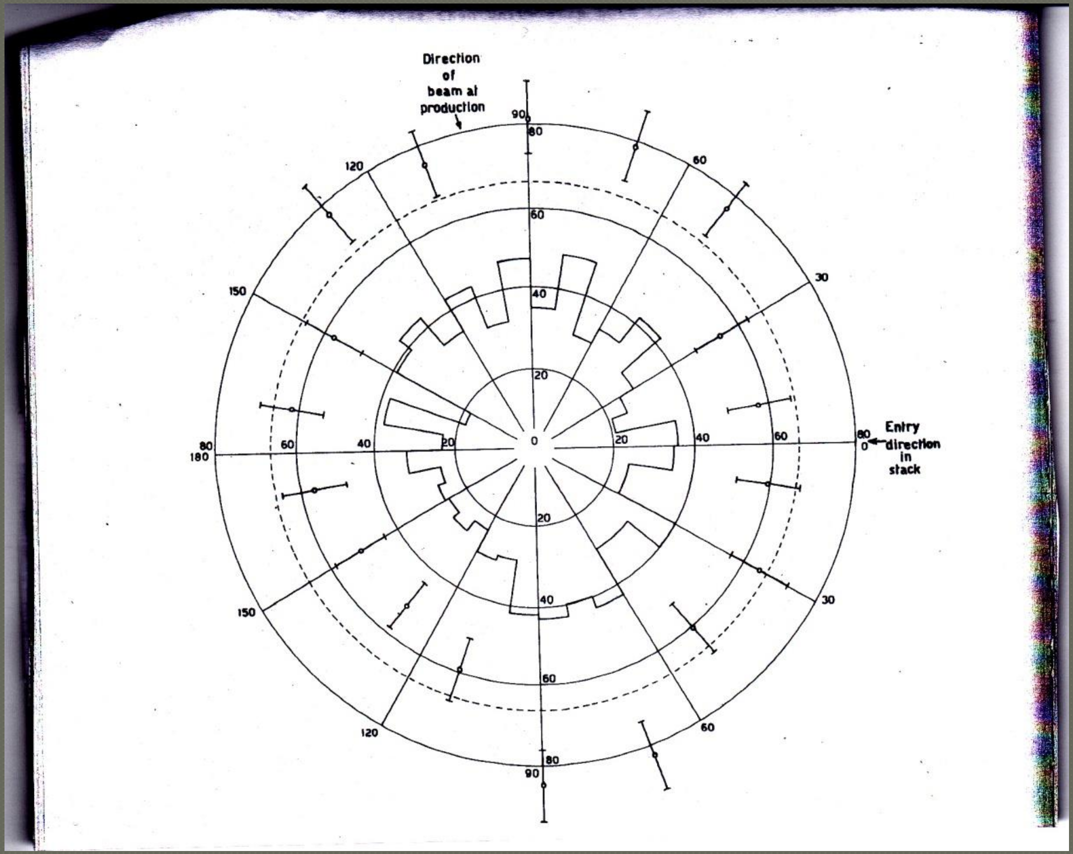
- 2) According to Theory, Spin-0 Particles Can be Four-vectors

- 3) Two Proposed Experiments that can Prove that Pions are Vector Particles

# Observed Asymmetry in π-μ Decay at Rest (emulsions)

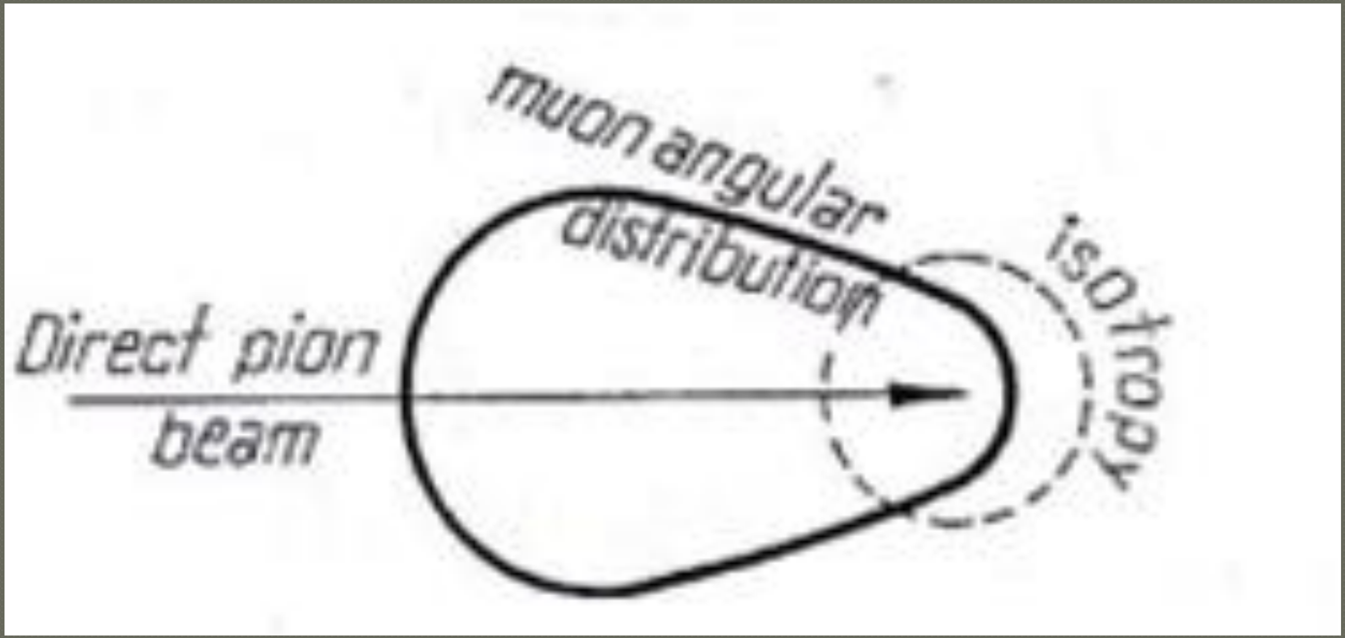


# Muon Distribution Relative to Pion and Proton Beam Directions




- Bhowmik, Evans, and Prowse, : Proceedings of the Padua-Venice Conference on Mesons and Recently Discovered Particles, p. IV-35 (1957)

# Angular Distribution of Muon Decays for Pion Beam Parallel to Proton Beam



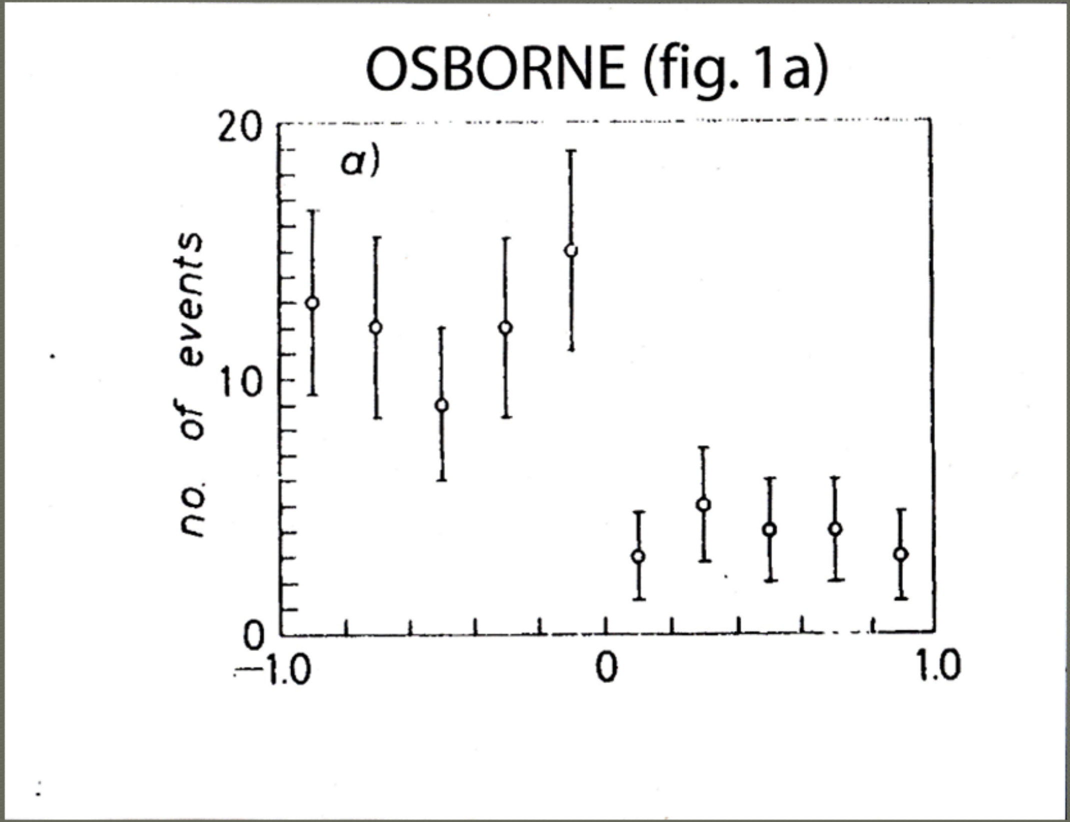
# Backward/Forward Asymmetry from $\tau$-$\pi$-$\mu$ Decay using Emulsion

TABLE I. $\pi-\mu$ decay of $\pi$'s from $\tau$ decay.

| $\pi$ energy | <12 Mev | <15 Mev | Total |
|---|---|---|---|
| B/F | 71/39=1.8 | 85/54=1.6 | 186/160=1.16 |

R. L. Garwin et. al. Phys. Rev. **108**, 1589 (1957)

# Asymmetry in K-π-μ-e chain



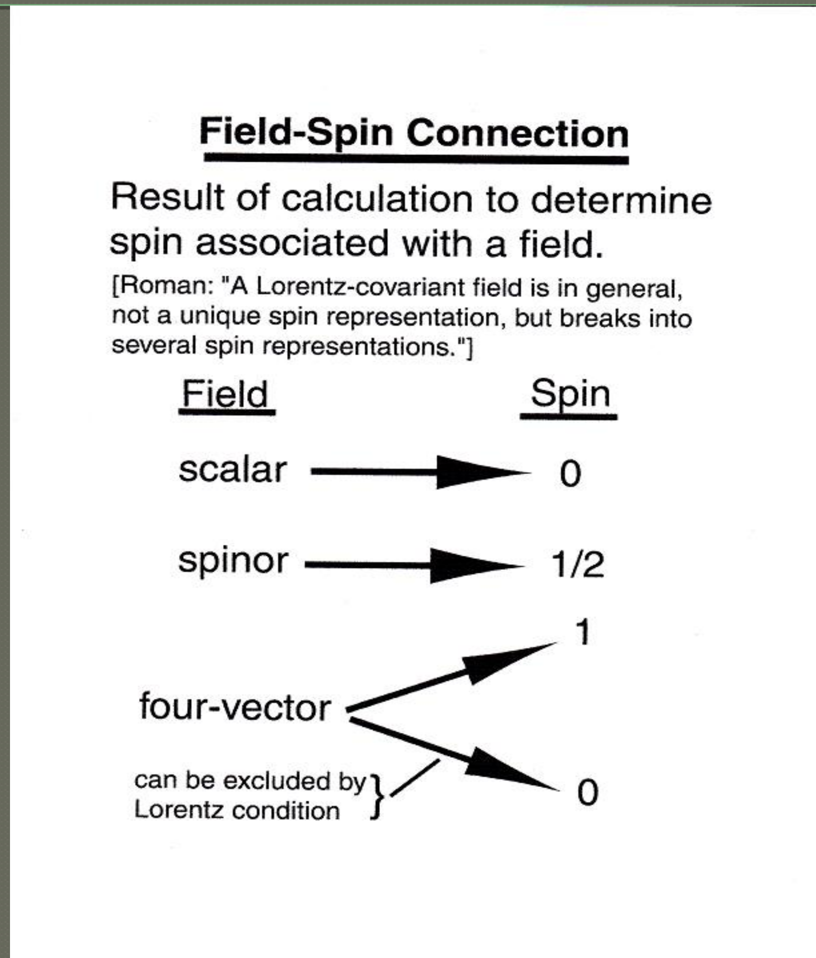

W. Z. Osborne, Nuovo Cimento **41A**, 389 (1966)

# Field-Spin Connection

- A Lorentz-covariant field is in general, not a unique spin representation, but breaks into several spin representations.
- The Lorentz covariant representation $D^{jj'}$ is associated with spatial rotations and with integer and half-integer spins.
- The spinor representations $D^{\frac{1}{2}\,0}$ and $D^{0\,\frac{1}{2}}$ correspond to spin ½ .
- A four-vector field that belongs to the $D^{\frac{1}{2}\,\frac{1}{2}}$ representation. $D^{\frac{1}{2}\,\frac{1}{2}}$ corresponds to spin 1 while $D^{\frac{1}{2}\,-\frac{1}{2}}$ corresponds to spin 0.

P. Roman, *Theory of Elementary Particles* (1960)

# Field-Spin Connection




P. Roman, *Theory of Elementary Particles* (1960) p. 99

# Vector Fields

"[From group theoretical methods] we see that there are just two possibilities for the spin of the particle described by the vector field…"

Spin Zero

$\varepsilon_{\mu}(p) = (i/\sqrt{2E})(E, p_1, p_2, p_3)$

Spin One

$\varepsilon^{\mu}(p, \sigma) = (i/\sqrt{2E})e^{\mu}(p, \sigma)$

S. Weinberg, **I** *The Quantum Theory of Fields* (1995) p. 208

# Composite Pion Field

$$V_\mu = \Psi^\dagger \gamma_0 \gamma_\mu \Psi.$$

$$V_\mu(R) = \sum_{\mathbf{P}} \frac{1}{\sqrt{2V\omega_P}} \sum_{\mathbf{n}} \left\{ [\chi_\mu(\mathbf{P},\mathbf{n})]\, e^{iPR} + \left[\chi_\mu^\dagger(\mathbf{P},\mathbf{n})\right] e^{-iPR} \right\}.$$

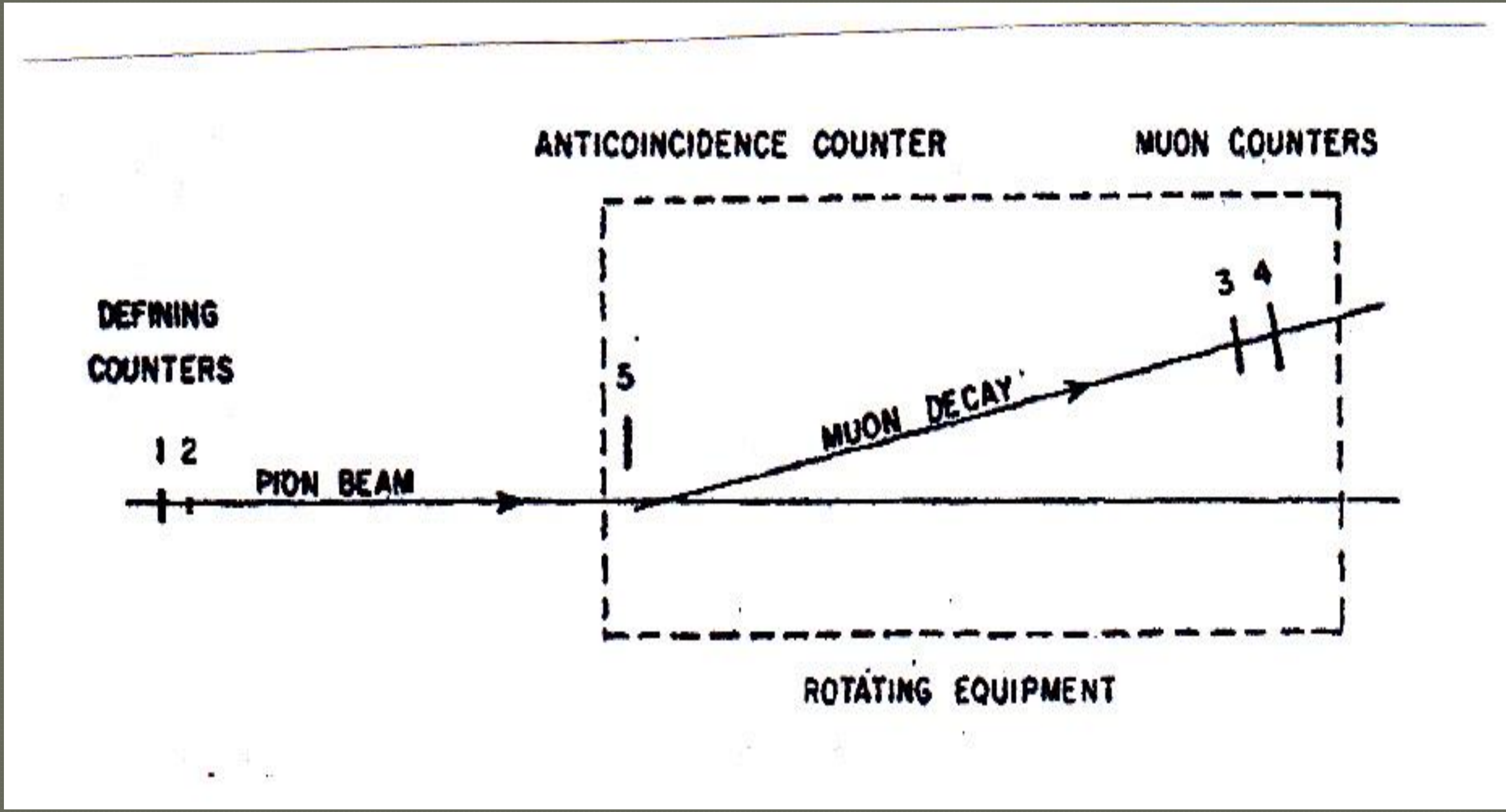
$$\epsilon_\mu^4(k,\mathbf{n}) = \frac{1}{m}\,(E, kn_1, kn_2, kn_3,)\,.$$

$$\partial V_\mu^2/\partial x_\mu^2 - M^2 V_\mu = 0,$$

$$(\partial V_\mu/\partial x_\mu) = \sum_{\mathbf{P}} \frac{i}{\sqrt{2V\omega_P}} \sum_{\mathbf{n}} \left\{ [P_\mu \chi_\mu(\mathbf{P},\mathbf{n})]\, e^{iPR} - \left[P_\mu \chi_\mu^\dagger(\mathbf{P},\mathbf{n})\right] e^{-iPR} \right\}.$$

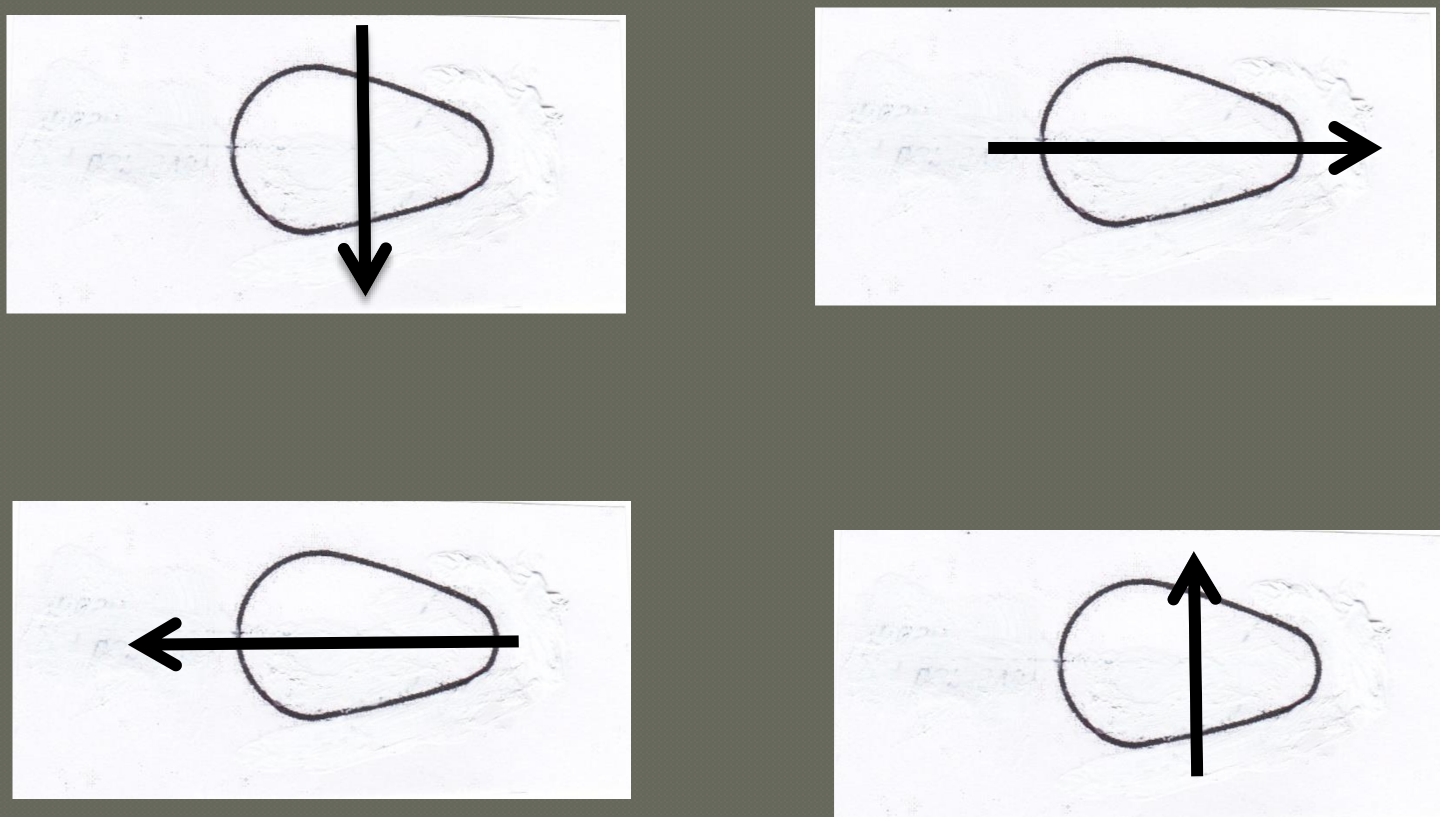
W. A. Perkins, EPL (Europhysics Letters) **114**, 41002 (2016)

# Counter Experiment to Detect Asymmetry in π-μ Decay

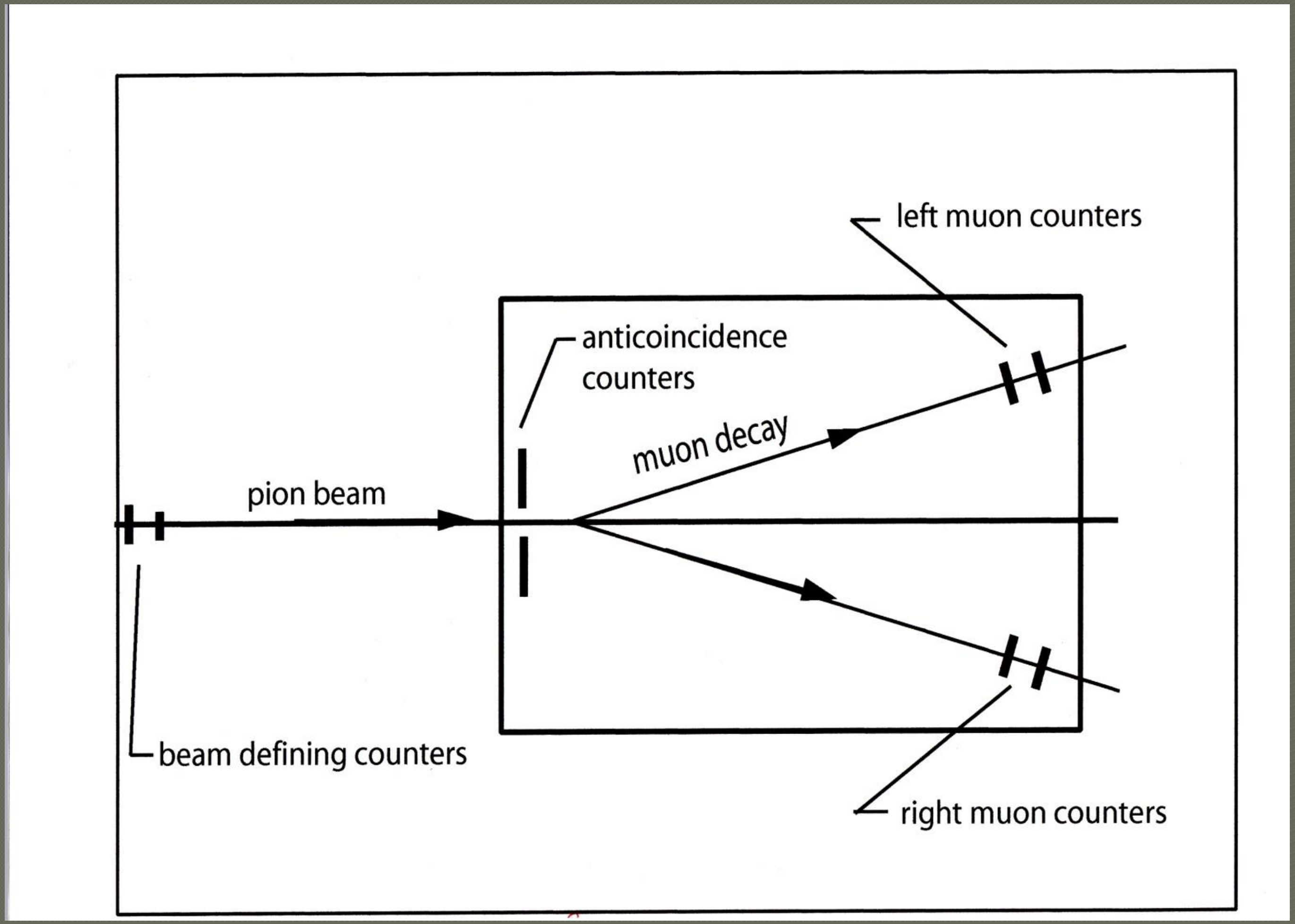



A. V. Crewe et. al. Phys. Rev. **108**, 1531 (1957)

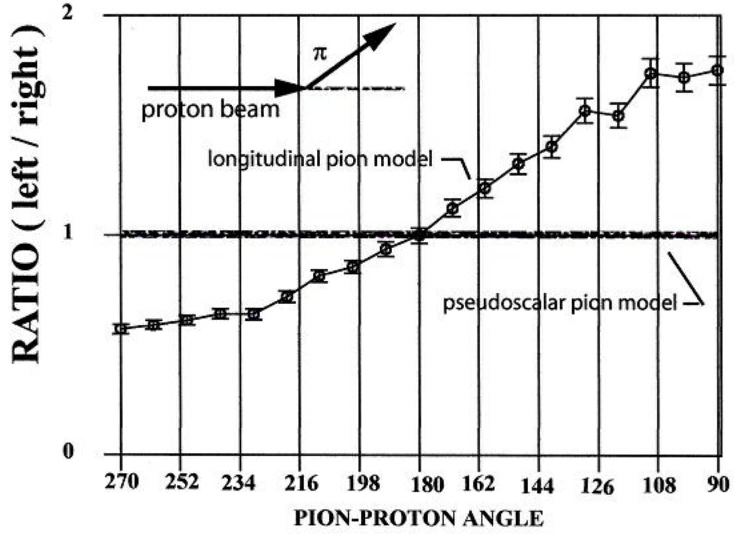
# Muon Distribution Relative to Pion Beam Direction



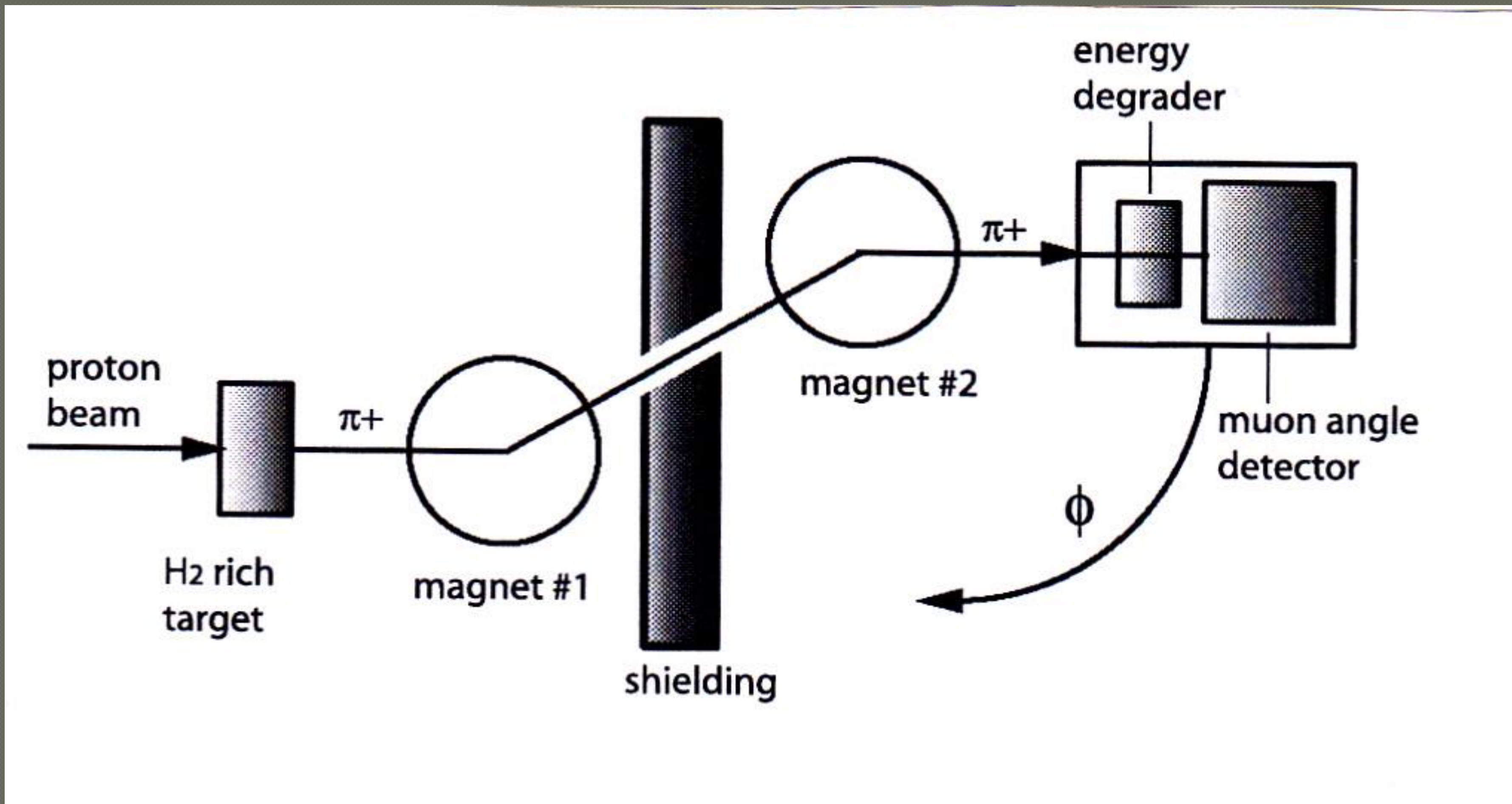
# Counter Experiment to Detect Asymmetry in π-μ Decay



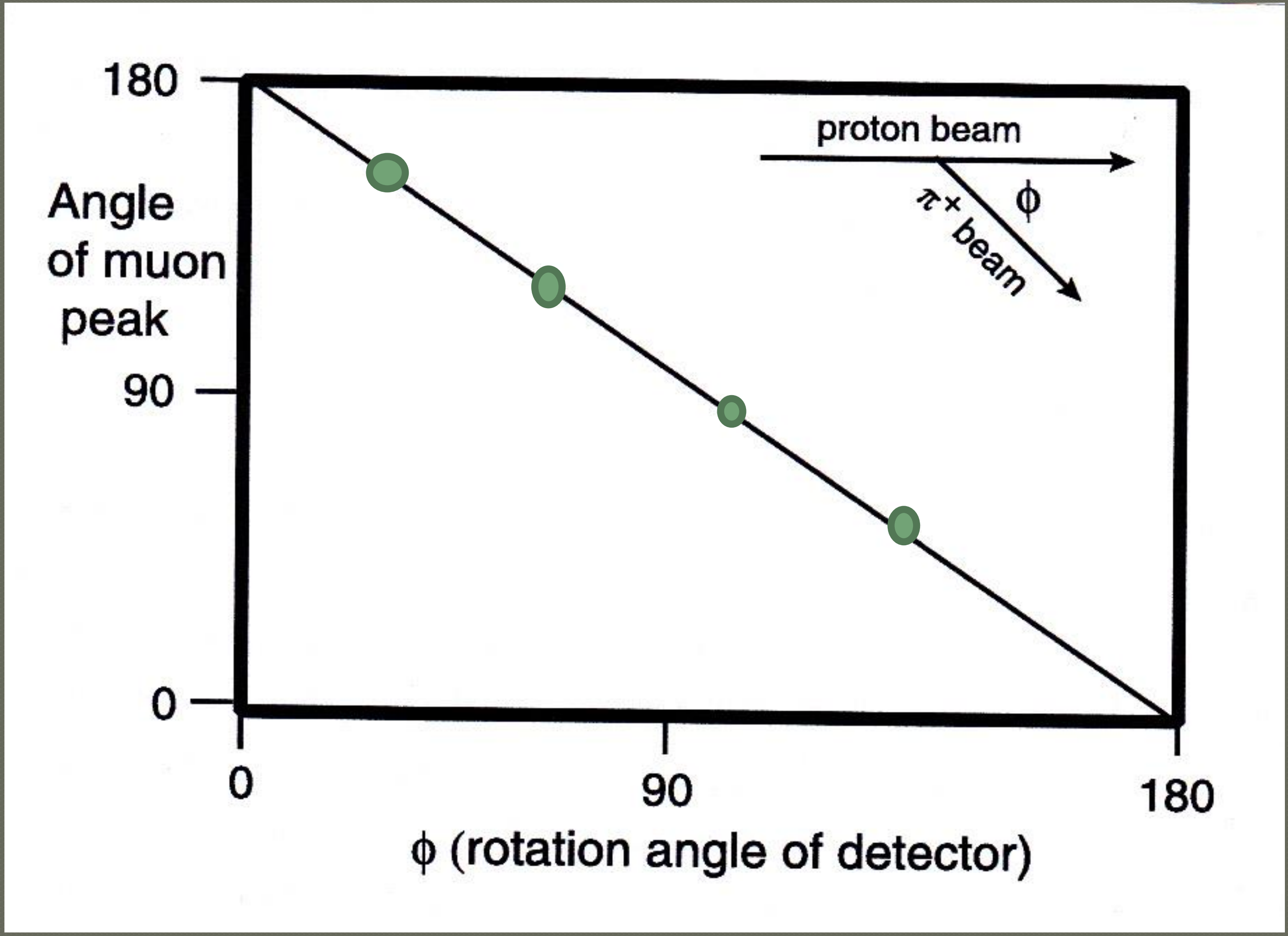
# Predicted Asymmetry for Vector Pion Model



# Emulsion Experiment to Detect Asymmetry in π-μ Decay



# Predicted Asymmetry for Vector Pion Model



# Conclusions

- Five experiments by five different research groups demonstrated that pions possess directional attributes with very small statistical uncertainty of in each experiment.
- A vector particle can have spin 0 (Roman, Weinberg)
- Two proposed experiments were discussed. Using new knowledge about spin-0 vector particles, one can vary the angle between the pion's polarization direction and the pion's momentum producing predictable results.
- Explanations for how pi-0 can be a vector particle exist, but leave that problem for later.

# References


[1] } V. Peterson, ``Mesons Produced in Proton-Proton Collisions," LBNL Report UCRL-713 (1950).

[2] C. M. G. Lattes, Notas de Fisica **4**, No. 8 (1958).

[3] H. Hulubei, J. S. Auslander, E. M. Friedlander, and S. Titeica, Phys. Rev. **129**, 2789 (1963).

[4] W. Z. Osborne, Nuovo Cimento **41A,** 389 (1966).

[5] R. L. Garwin et. al. Phys. Rev. **108**, 1589 (1957).

[6] P. Roman, *Theory of Elementary Particles* (North-Holland, Amsterdam) (1960) p. 99.

[6] S. Weinberg, *The Quantum Theory of Fields, Volume I, Foundations* (University Press, Cambridge) (1995) p. 208.

[7} W. A. Perkins, EPL (Europhysics Letters) **114**, 41002 (2016).

[8] A. V. Crewe et. al. Phys. Rev. **108**, 1531 (1957).

[9] B. Bhowmik, D. Evans, and D. J. Prowse, Proceedings of the Padua-Venice Conference on Mesons and Recently Discovered Particles, p. IV-35 (1957).

# Val Telegdi (1957) Conf. Talk

We now come to the main subject in the title of this resume - the spatial properties of $\pi$-meson - I have imagined that many people expected great changes in this field at this Conference. Unfortunately, we have heard many reports that show that very experienced people have been the victims of a bias, and that to our best knowledge there is no physical significance to be attached to the $\pi$-$\mu$-decay. The Rome group have examined if the bias can arise from distortion in emulsions but it must be stated in my opinion that although it has been shown by several emulsion workers to be a bias, the entire nature of the bias is not understood, and as it might be necessary in the future to rely at least in preliminary measurements on assymmetries made in emulsion, it is probably worth while going on with these studies, so that the question may be better understood in the future. It is remarkable that the bubble chambers have the same bias - I do not know anything about bubble chambers except that one takes pictures - so I will leave the subject to other people.

Electronically the Columbia people, by their classic methods of procession have shown, in this case by a chain of processions, that there is no correlation between the $\pi$ and the $\mu$-meson to within 2%. It was not reported at the Conference but the case of $\mu$-mesons in flight has also been studied at Chicago by Crew, Kruse, Ponder and Miller, again with a negative result - a possibility of an assymmetry of less than 3%. I think that the concensus of opinion would be that this effect does not exist, it was all very exciting but it is over now.

# π-μ-e asymmetry about x-axis, y-axis, and z-axis

TABLE II. Space components of cyclotron $\pi \rightarrow \mu$ emission asymmetry.

| | |
|---|---|
| $x$ | $0.004 \pm 0.018$ |
| $y$ | $0.025 \pm 0.018$ |
| $z$ | $-0.016 \pm 0.012$ |

R. L. Garwin et. al. Phys. Rev. **108**, 1589 (1957)

# Decay of Neutral Pion

- Can a vector particle decay into 2 photons?
- Vector states of 2 photons:

$$\varepsilon^1 \times \varepsilon^2 , \quad (\varepsilon^1 . \varepsilon^2)k$$

These vector states are asymmetric under interchange of the 2 photons. Thus, the 2 photons must be different.

# Composite Photon Theory Predicts Two Photons

$$\gamma = \nu_{2e}\overline{\nu}_{2e}$$

$$\overline{\gamma} = \nu_{1e}\overline{\nu}_{1e}.$$

Forming linear combinations which are eigenstates of CP

$$|\gamma_1\rangle = \frac{1}{\sqrt{2}}\left(|\gamma\rangle + |\overline{\gamma}\rangle\right)$$

$$|\gamma_2\rangle = \frac{1}{\sqrt{2}}\left(|\gamma\rangle - |\overline{\gamma}\rangle\right),$$

$$\pi^0 \rightarrow \Upsilon_1 + \Upsilon_2$$

# In 1938, Pryce Proved That the Photon Cannot be a Composite Particle?

- Pryce wrote a theorem  to prove that a composite photon is impossible. Using that theorem, one could prove that pions, kaons, etc. cannot be composite particles
- Pryce started with 4 solid postulates
- All the steps of his proof are correct
- However, the proof used a 5$^{th}$ postulate that is not valid
- The 5$^{th}$ postulate is that a composite photon must satisfy Bose commutation relations
- A composite photon satisfies the same commutation relations as Cooper Pairs