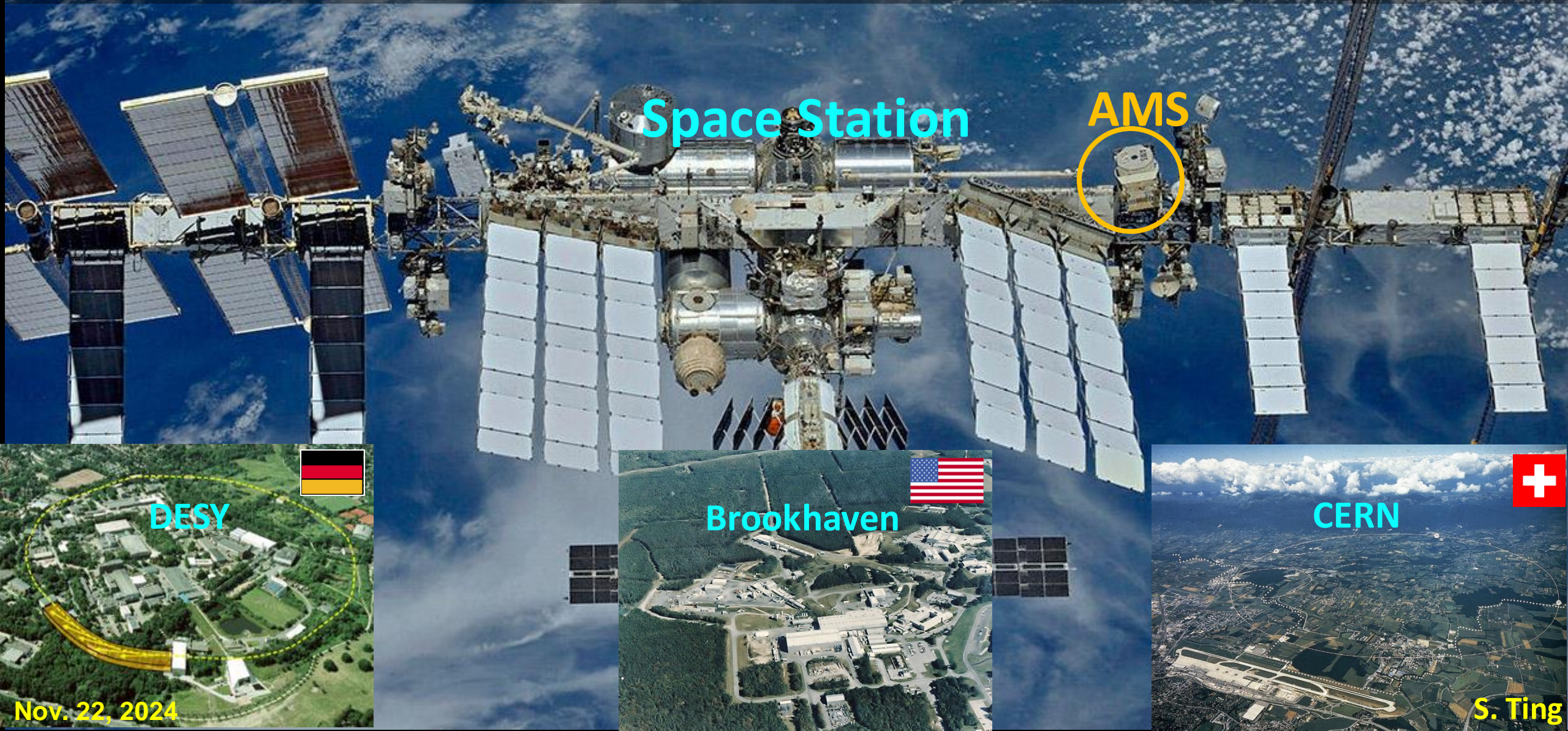
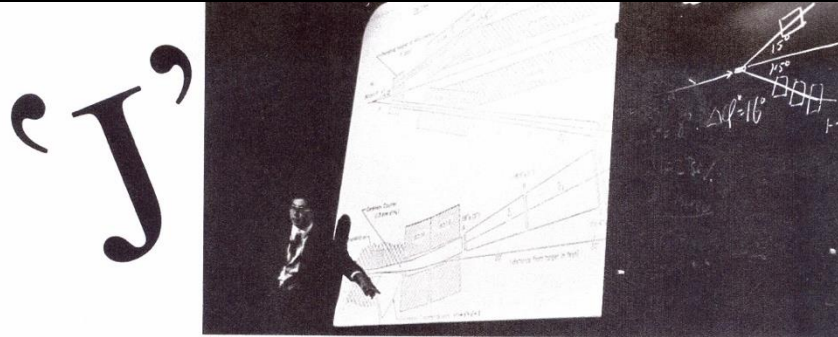


The November Revolution and Fifty Years of Electron and Positron Physics





Volume 28 - Number 47

BROOKHAVEN BULLETIN

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November 22, 1974

Physics Discovery Of The Decade Made At The AGS

The MIT/BNL Experiment

Horst Fiesche

The discovery of the J-particle promises to unlock a number of exciting mysteries which had arisen in the analysis of earlier experiments at the AGS, at Fermilab, and in the colliding beam facilities at the CEA and at Stanford (SLAC).

For some time now there have been indications of a high rate of direct production of single electrons and muons in high energy collisions of protons with matter. On the other side of the puzzle, recent experiments at the electron-positron colliding beam facilities at Cambridge (CEA) and at the SPEAR facility at the Stanford Linear Accelerator Center, had revealed anomalies in the rate of production of hadrons in the collisions of electrons with positrons. Two early experiments at the AGS four years ago had shown an excess in the direct production of muon pairs, i.e., muons made in association with their antiparticles of opposite charge. The experiments were too imprecise however to reveal whether or not the muon pairs came from the decay of a single parent particle.

Simultaneous Detection

More recent experiments have determined a ratio between the production rates of electrons or muons and of pions, but these experiments involved the identification of single electrons or muons together with an unanalyzed collection of other particles. The recent decisive MIT/BNL experiment was the first where electrons and positrons produced in interactions of a proton beam in a stationary target were detected simultaneously, in coincident pairs, in a precision double arm spectrometer. In the spectrometer the energy of each of these two particles was determined with sufficient precision so that one was able to show unambiguously that both were originating from a single parent particle, the J-particle, which in turn decayed into the electron-positron pair.

The simultaneous confirmation of the existence of the new particle at the SPEAR facility provides a striking example of the complementary nature of the various experimental techniques used in high energy physics research. While the MIT/BNL team established the direct production of the J-particle in high energy proton collisions on a stationary target (Beryllium in this case) and its decay into electron-positron pairs, the SPEAR team established the existence of a sharp peak in the production rate of hadrons in electron-positron collisions at exactly the same effective mass, and provided more precise evidence for the particle's unexpectedly long lifetime.

The AGS at Brookhaven National Laboratory operates in an energy domain where

many new aspects of nuclear forces are being uncovered and are expected to continue to be uncovered in the future. The rich field of subnuclear spectroscopy which is under intensive investigation at the AGS, has been expanded into new areas by this recent discovery. A wide variety of "probes" for the exploration of elementary particle interactions are maintained by the Laboratory on the experimental floor of the accelerator.

Primary-Secondary Beams

The primary proton beam accelerated in the AGS is not only used as a direct probe of nuclear structure, but it is intense enough so that it is used to create a diverse set of secondary beams. Beams of mesons, of pro-

tons, of muons, of antiprotons, of neutrino particles and even of short-lived hyperons, all beams of variable energy, can be generated by plunging the primary proton beam into primary targets where its available energy is converted into a large number of secondary reaction products.

These secondary particles emerging from the target are selected and collected into beam channels leading to the experimenter's own apparatus. There the interactions of the particles with matter are studied in very specific detail. The experimenters have a choice of beam spigots most suitable for their particular experiment. It is possible to distribute the intense primary proton beam onto four of five primary target stations

(Continued on page 2)

A J-Particle Is Born

Jean Burke

Excitement erupted when an announcement suddenly appeared over the T.V. monitors in the AGS building at one a.m. on November 11. It simply said, "Experiment 598 has discovered a new particle, J at 3.1 GeV." It was clear to all that they were witnessing the announcement of the most important physics discovery of the decade.

A new elementary particle had been found. The discovery was totally unexpected and a surprise to everyone. Responsible for the astonishing find, was a group from MIT headed by Samuel Ting of MIT and Y.Y. Lee of BNL.

The new particle was christened "J" because of its strong angular momentum. The letter J is frequently used in mathematical equations as a symbol for angular momentum. Coincidentally, the letter J is almost identical to the Chinese character for Ting.

The significance of the discovery lies in the particle's two unexpected properties, which lead the group to believe that it is not a member of any known particle family.

Particle-J is extremely heavy, having a mass equivalent to three protons. For such a heavy particle it has an amazingly long lifespan. Before decaying into an electron-positron pair, the particle lives for a billionth of a billionth of a second (10^{-18} sec). Most elementary particles do not live longer than 10^{-24} sec.

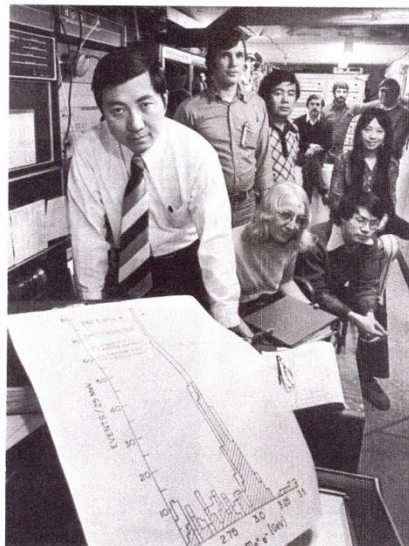
The particle was first seen by the MIT/BNL group last August and again in October. The discovery was kept secret until last week because the group wanted to verify their valuable find.

It was quite evident that the particle was genuine when the Stanford Linear Accelerator Center (SLAC), using a completely different technique, also found the particle. Since then the Frascati Laboratory in Italy has also reported seeing the particle.

In writing up their preliminary results, Frescati said, "Soon after the news that a particle of 3.1 GeV with a width consistent with zero had been observed at Brookhaven by the MIT Group, it was immediately decided to push ADONE (the Frascati accelerator) beyond its nominal limit of energy to look for this particle."

The experiment is one of the most complex to be set up on the AGS floor. Because of the radiation produced by protons bombarding the target, the equipment was imbedded in 10,000 tons of concrete and steel shielding. Close to 10,000 lbs. of soap (borax) were used to shield against neutrons. "When we went to the market and asked for 10,000 lbs. of soap, they thought we were crazy," recalls Ting. The experiment is essentially an outgrowth of a series of experiments which the group has been

(Continued on page 2)



Inside the trailer "where it all happened" are (standing left to right) Samuel Ting, Gary Krey, Y.Y. Lee, Peter Biggs, Paul Goldhagen, and Bruce Bailey. Seated in the foreground (left to right) are Ingrid Schultz, Joseph Leong and Sau Lan Wu. A graphic representation of the J-particle event is seen.

Photos by Humphrey

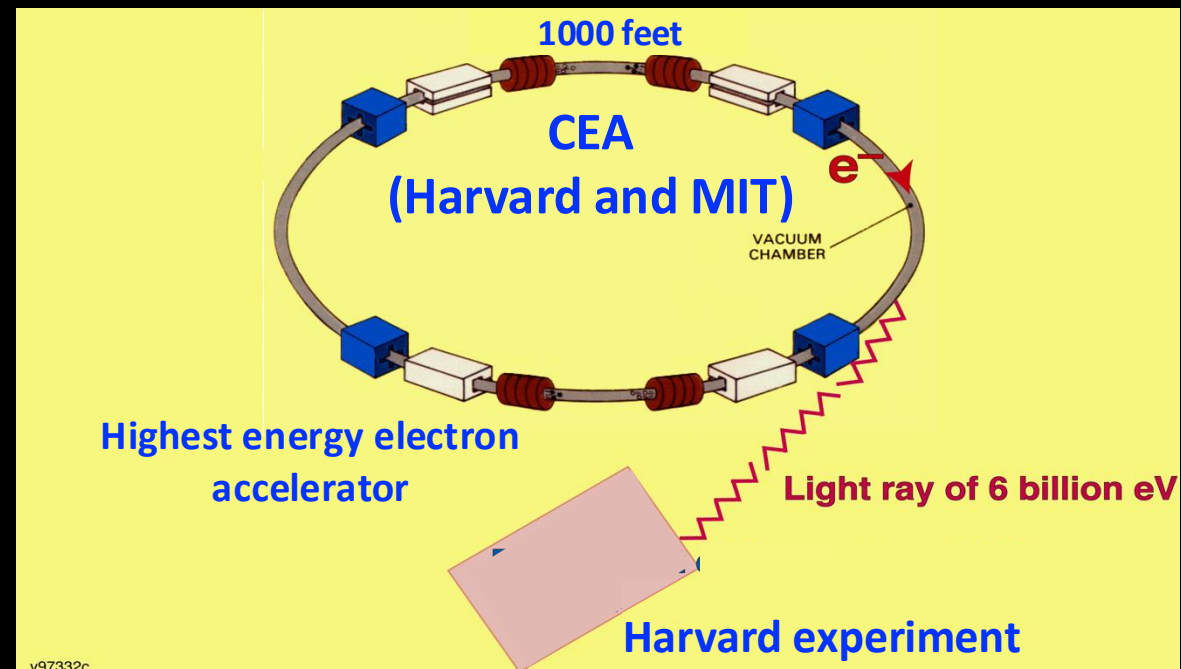
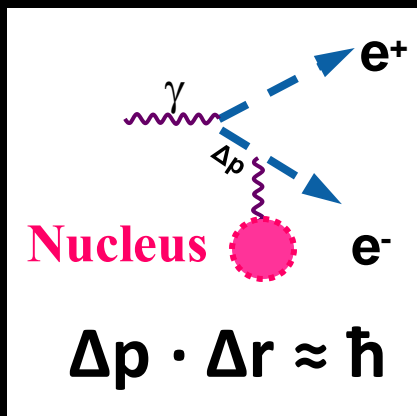
Experiments leading to the discovery of a new form of matter:

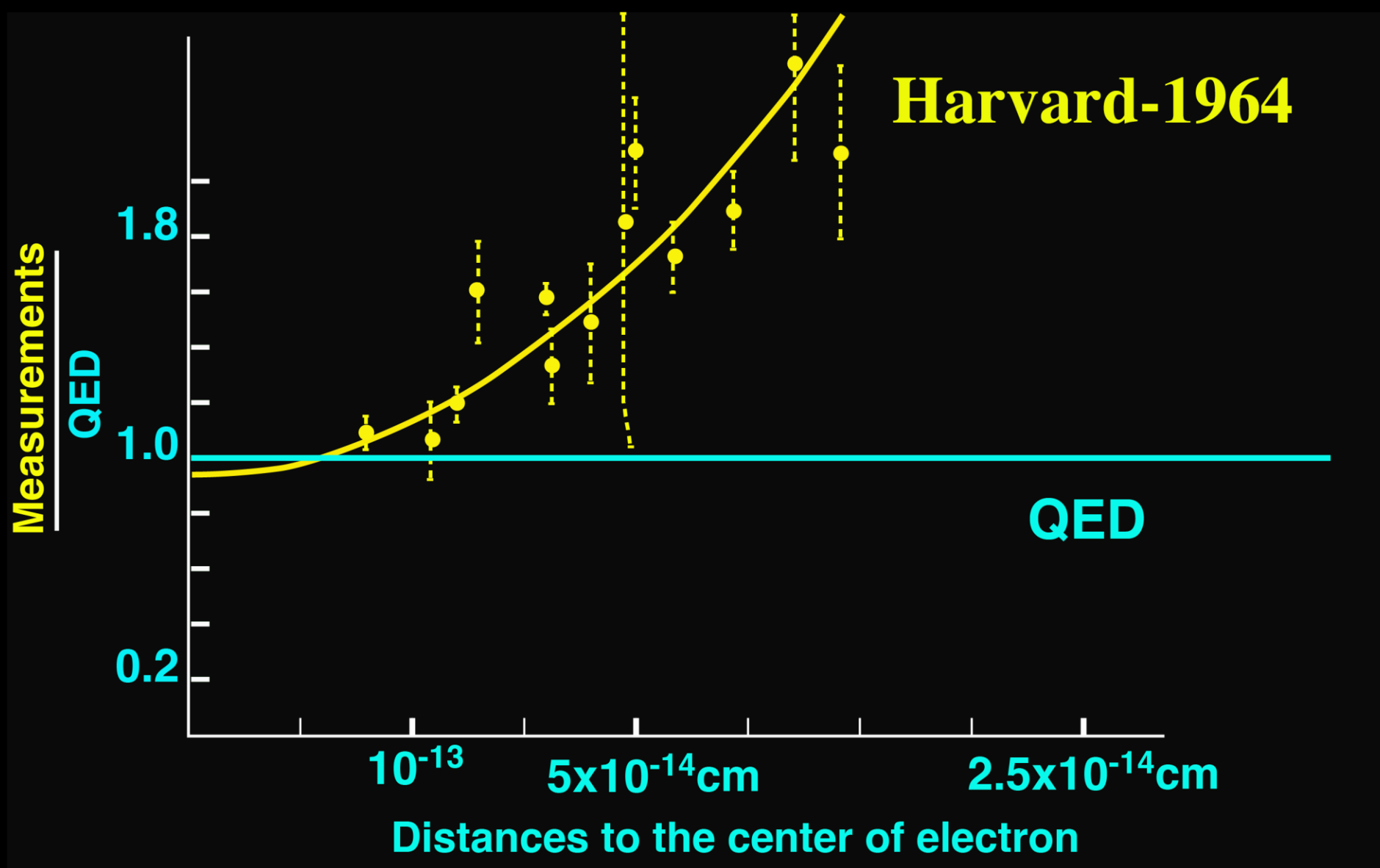
First Experiment - Measuring the size of electrons

Modern Electromagnetic Theory (QED) requires that electrons have no measurable radius (Feynman, Schwinger, Tomonaga - 1948)

The theory agreed well with all experiments until a 6 GeV electron accelerator (CEA) provided a most sensitive measurement of the size of the electron.

The Harvard experiment was done by the world's leading experts in the field who had spent many years to develop the technology.





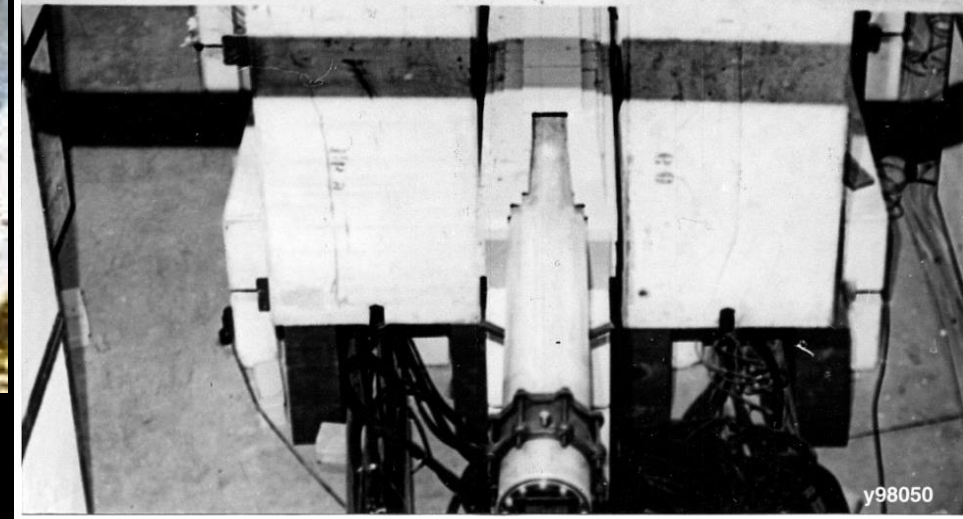
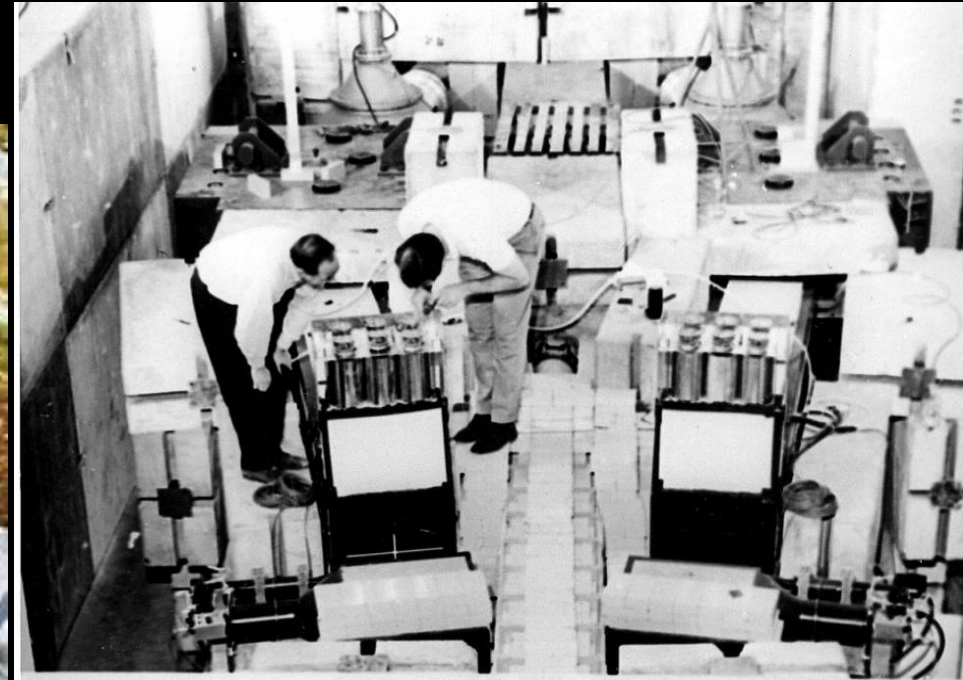
This data shows that the electron has a radius of $\sim 10^{-13}$ to 10^{-14} cm.
Most importantly, this experiment was independently confirmed by a group at the Cornell Electron Accelerator.

**Since those results touch upon the foundation of Modern Physics,
I decided to perform the experiment with an independent method**

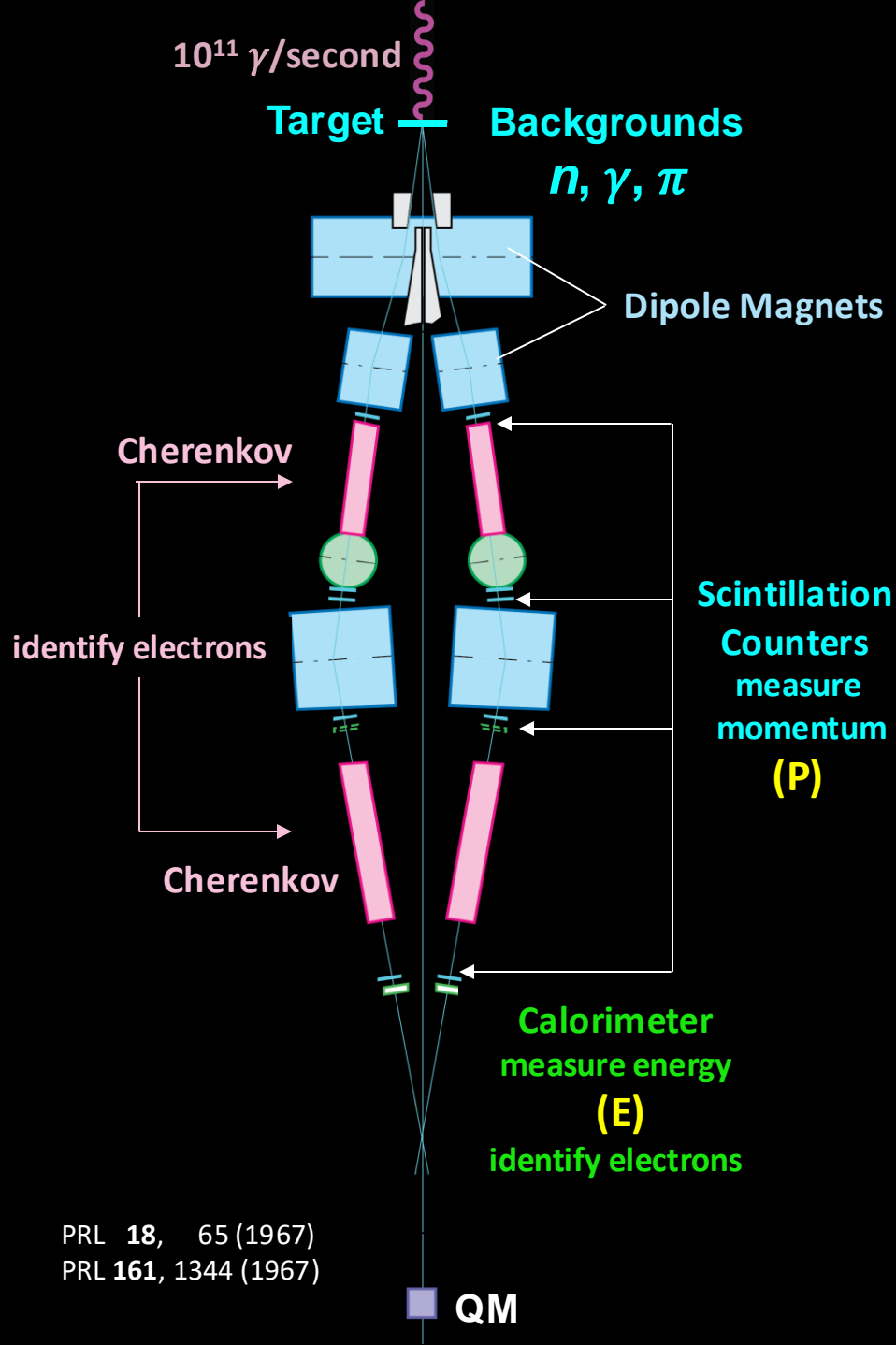
**At that time, I knew nothing about electron physics,
so I received no support in the U.S.**

**I decided to move to
the newly built 6 billion electron-Volt electron accelerator (DESY)
in Hamburg, Germany
to re-measure the size of the electron**

1965-1972: First set of experiments at DESY 6 GeV electron accelerator



Measuring electron-positron pairs (1966)

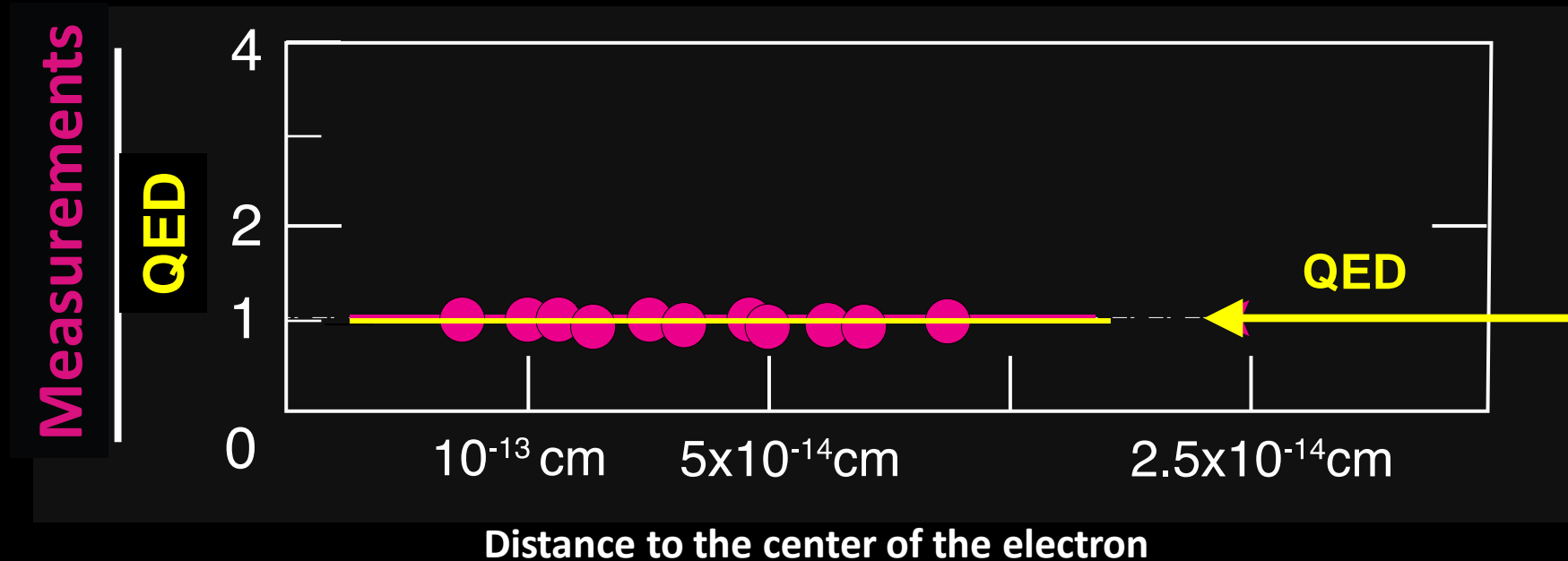


Unique features

1. None of the detectors see the target so they are not exposed to neutrons or gamma-rays backgrounds.
2. The acceptance is defined by counters, not by the aperture of the magnet.
3. Using two Cherenkov counters on each arm separated by magnets to identify e^\pm . The background e^\pm produced from interactions in the first counter are swept away by magnets and the e^\pm identification of the two counters are independent.
4. Using Dipoles magnets and counters to measure the momentum (P).
5. Using calorimeters to measure the energy (E).
6. To reject large pion background, require $E=P$.

After 8 months our group completed the experiment at DESY and discovered that:

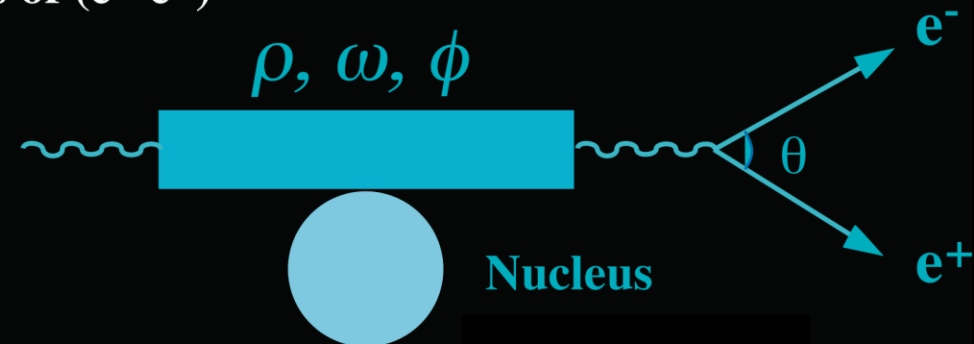
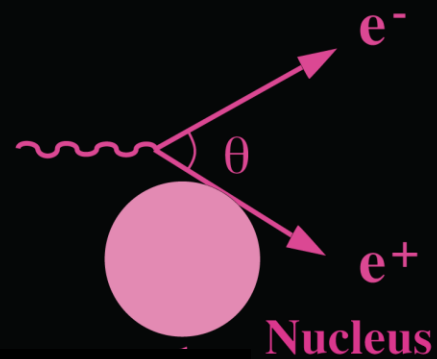
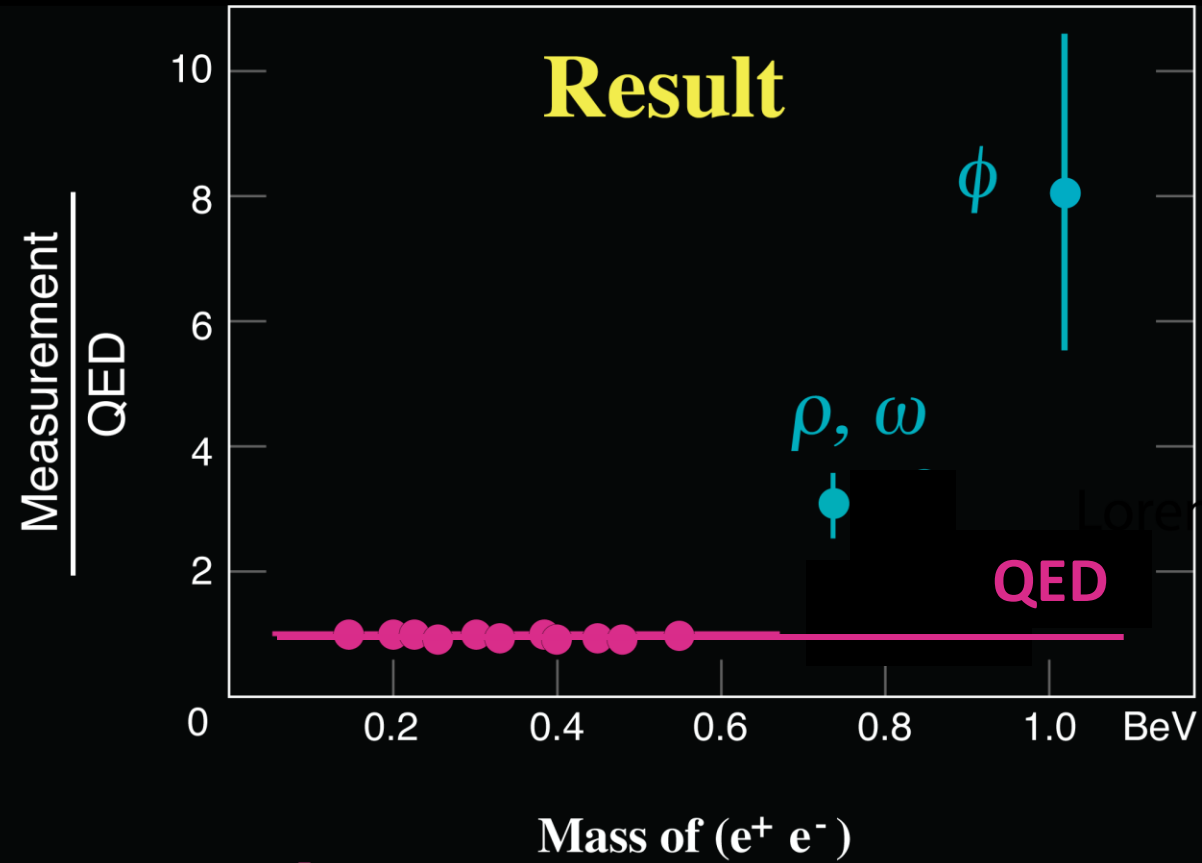
The electron indeed has no measurable size: Radius $< 10^{-14}$ cm



This result was first announced in 1966 at the “Rochester” conference at Berkeley (now known as the International Conference on High Energy Physics).

On this occasion I met W.K.H. Panofsky, Dick Feynman, and I.I. Rabi.
I maintained close contact with them for many years.

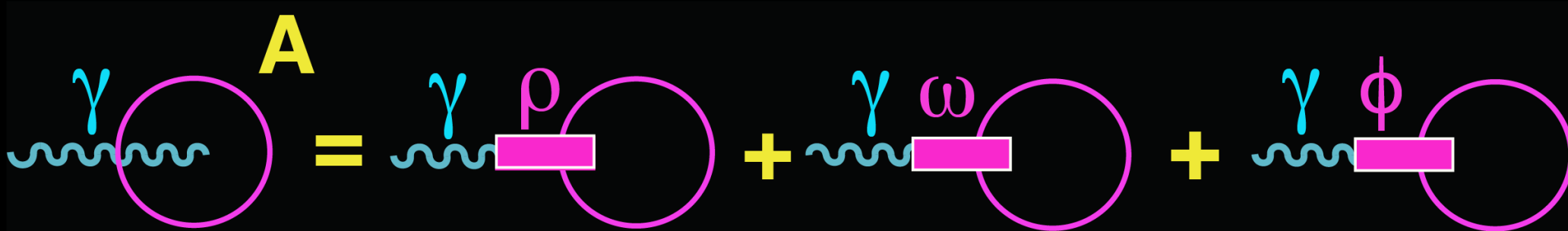
Experimental Results on Photons and Heavy Photons



Second Experiment: Photons and Heavy Photons

Photons and Heavy Photons have the same quantum numbers

$$J = 1 \quad C = -1 \quad P = -1$$



$$J_{\mu}(x) = - \left[\frac{m_{\rho}^2}{2\gamma_{\rho}} \rho_{\mu}(x) + \frac{m_{\omega}^2}{2\gamma_{\omega}} \omega_{\mu}(x) + \frac{m_{\phi}^2}{2\gamma_{\phi}} \phi_{\mu}(x) \right]$$

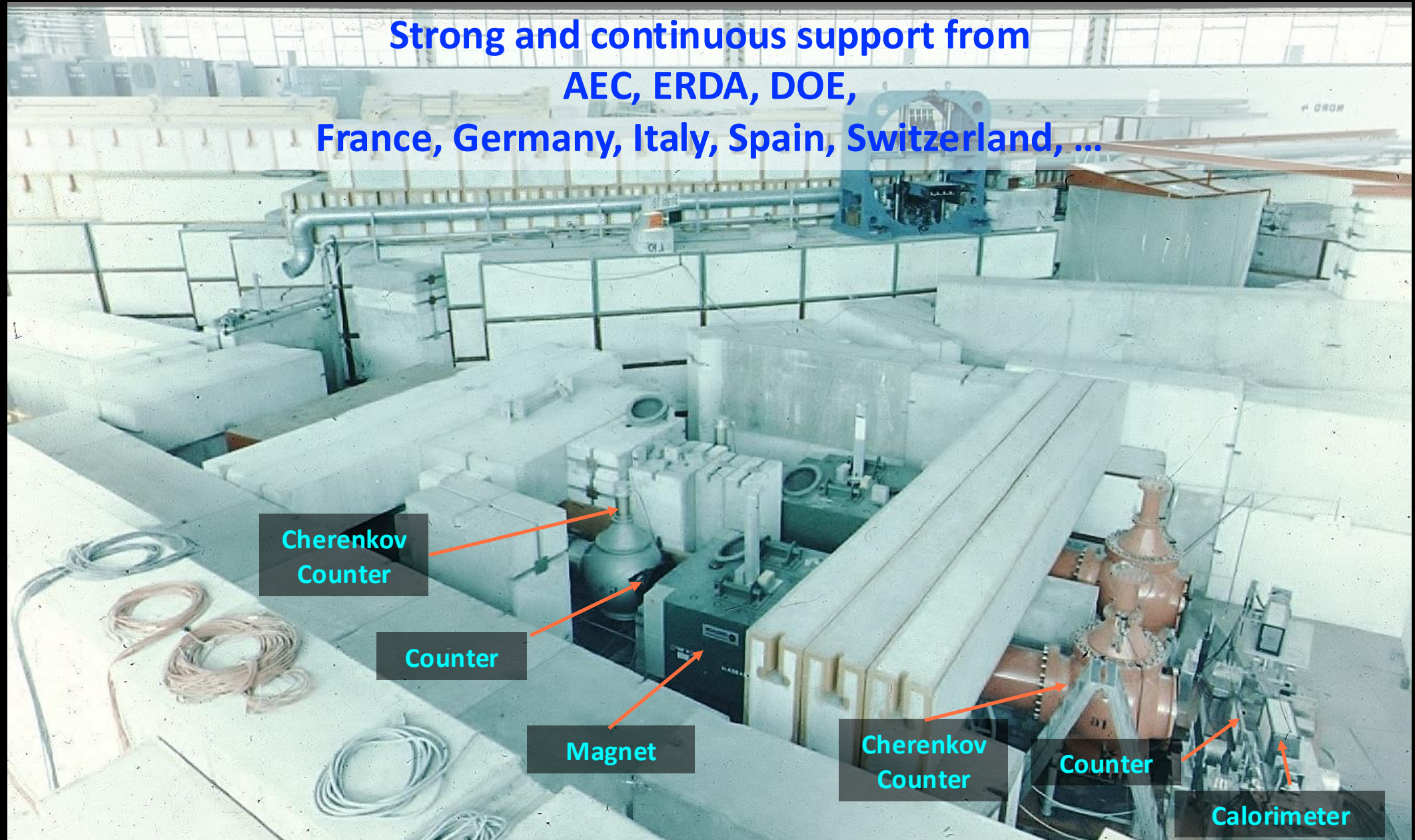
This is known as the **Vector Dominance Model**

Experimental question: what is the relationship between Photons & Heavy Photons?

I joined MIT in 1968 and started Heavy Photon Experiments at DESY

with major improvements in coordinate and momentum resolution and in particle identification

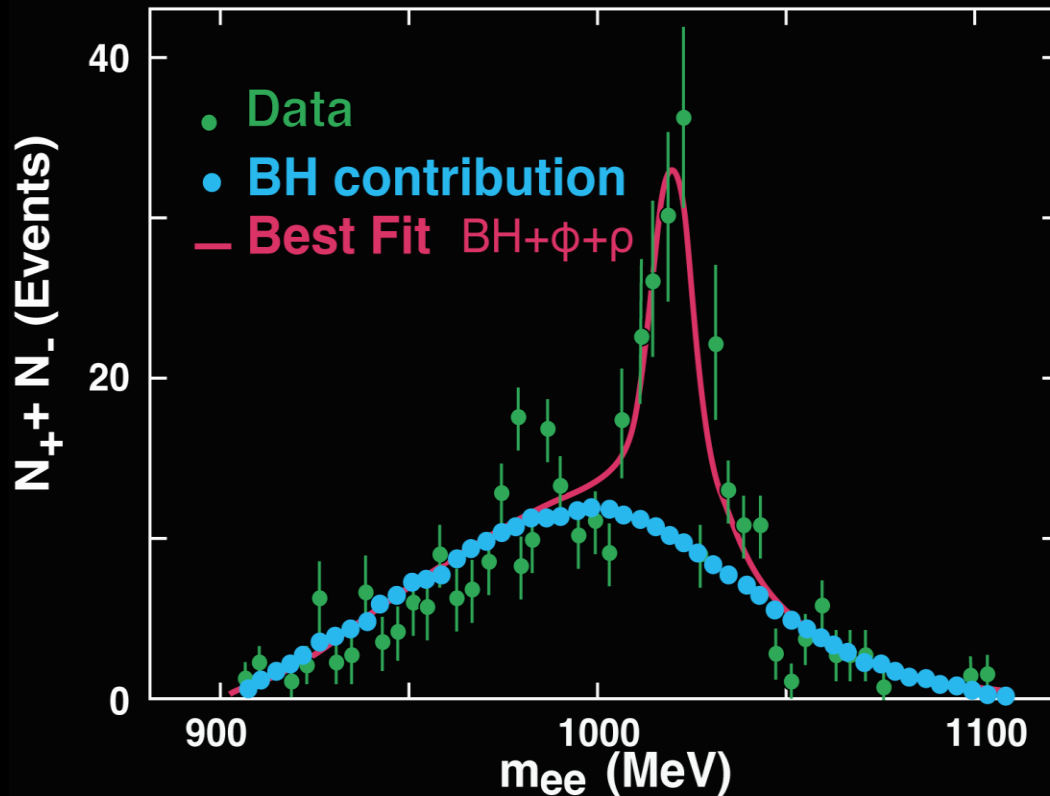
Strong and continuous support from
AEC, ERDA, DOE,
France, Germany, Italy, Spain, Switzerland, ...



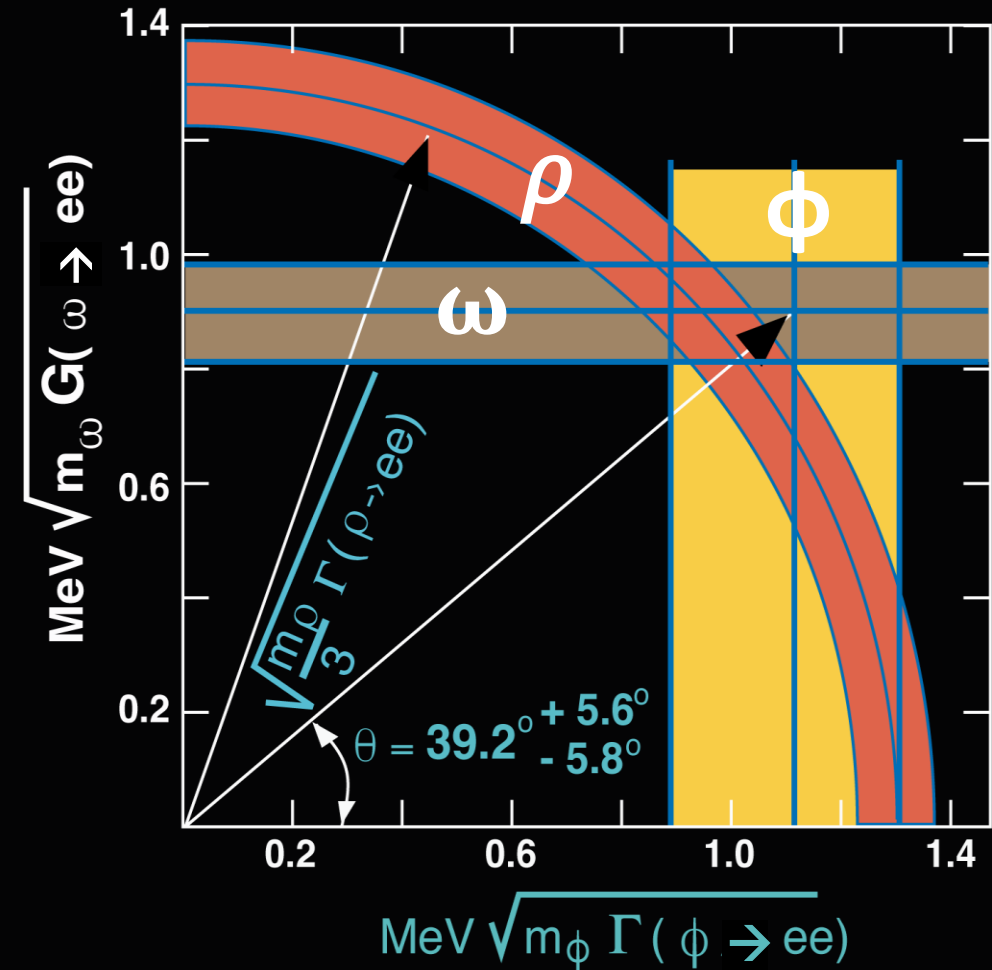
Result: Verification of Weinberg's first sum rule

$$\frac{1}{3} m_{\rho} \Gamma(\rho \rightarrow ee) = m_{\omega} \Gamma(\omega \rightarrow ee) + m_{\phi} \Gamma(\phi \rightarrow ee).$$

Leptonic decays of ϕ

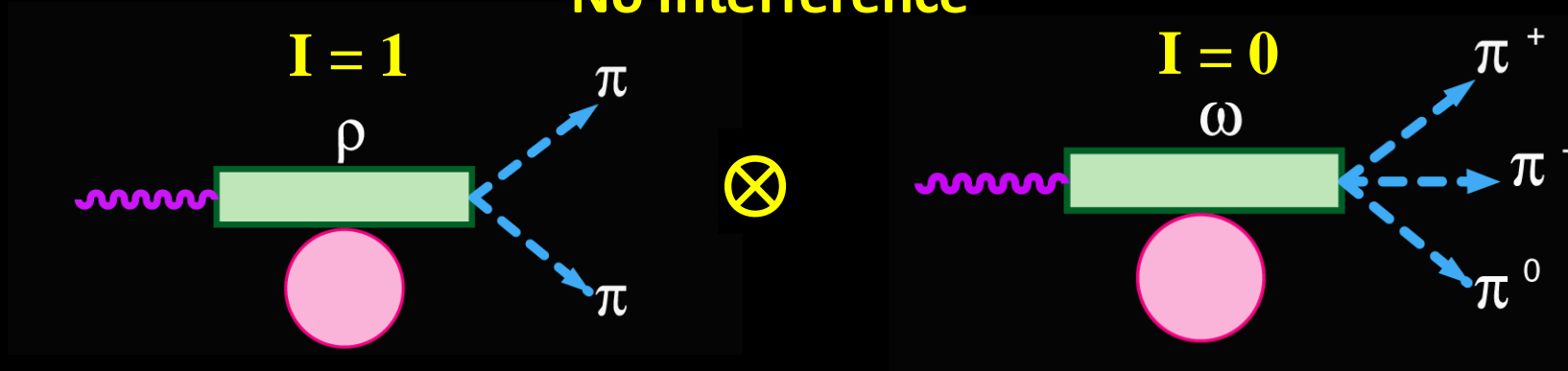


P. R. L., Vol 27, p.444, 1971

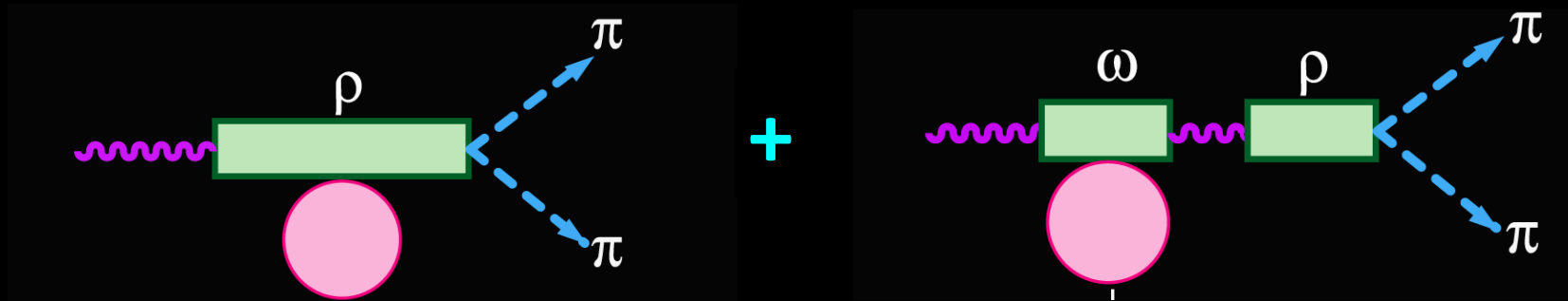


Experiments on Forbidden $\omega \rightarrow 2\pi$ Decays

No Interference



Interference



$\omega \rightarrow 2\pi$
had never
been observed

S. L. Glashow, P.R.L. 7, 469 (1961),

J. Bernstein and G. Feinberg, Nuovo Cimento 25, 1343 (1962)

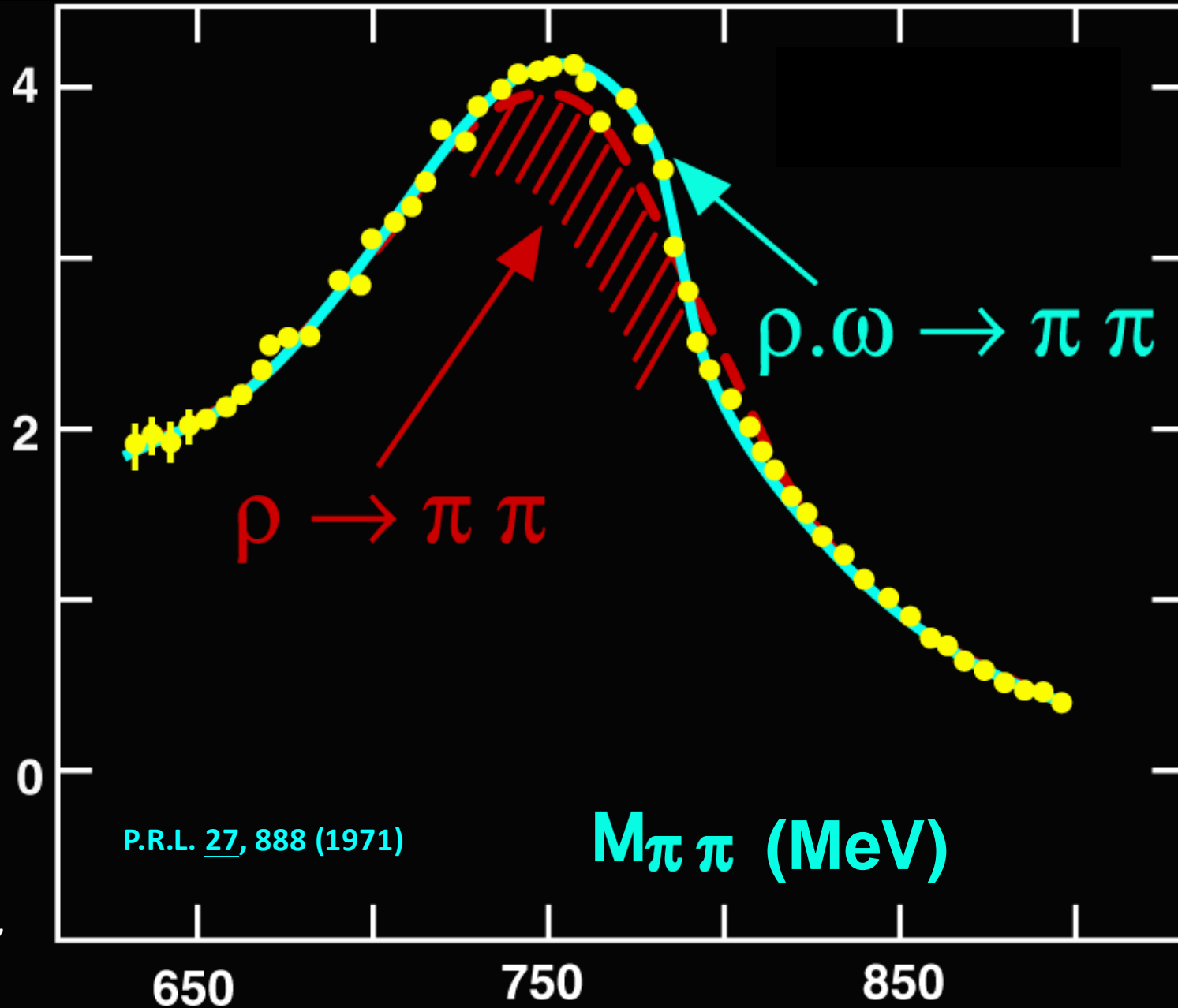
M. Gordin, P.L. 30B, 347 (1969)

R. G. Sachs, P.R. D 2, 133 (1970) + ...

J. Steinberger, P.R.L. 12, 517 (1964), **BR** < 0.1%

Result: Observation of Forbidden $\omega \rightarrow 2\pi$ Decays

$$\left. \frac{d\sigma}{dt dm} \right|_{p=6.4 \text{ GeV}} \left|_{t_1=0.001 \text{ CeV}} \left(\frac{\mu b}{\text{GeV}^2 \text{ MeV}} \right)$$



with U. Becker, W. Busza, M. Chen,
R. Marshall, G. H. Sanders *et al.*

Third Experiment: Discovery of the J particle

We learned that photons and heavy photons
do transform into each other.

Question: Why should there be only three heavy photons
all at mass ~ 1 GeV?

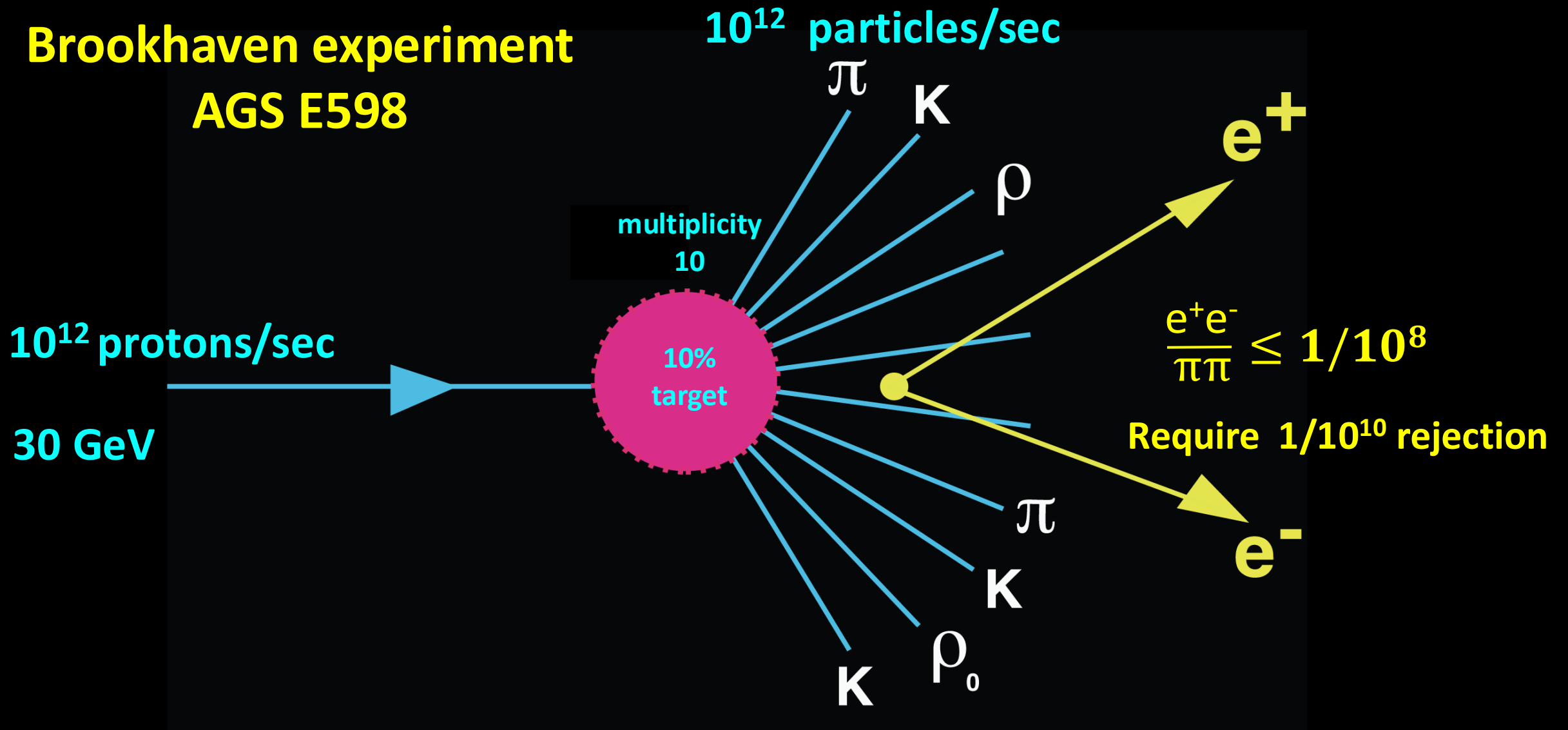
To go to higher mass we moved to a higher energy accelerator

The best way to search for vector mesons is through production experiments of the type $p + p \rightarrow V^0 + X$. The reasons are:
 \downarrow
 $e^+ e^-$

- (a) The V^0 are produced via strong interactions, thus a high production cross section.
- (b) One can use a high intensity, high duty cycle extracted beam.
- (c) An $e^+ e^-$ enhancement limits the quantum number to 1^- , thus enabling us to avoid measurements of angular distribution of decay products.

Contrary to popular belief, the $e^+ e^-$ storage ring is not the best place to look for vector mesons. In the $e^+ e^-$ storage ring, the energy is well-defined. A systematic search for heavier mesons requires a continuous variation and monitoring of the energy of the two colliding beams—a difficult task requiring almost infinite machine time. Storage ring is best suited to perform detailed studies of vector meson parameters once they have been found.

Brookhaven experiment AGS E598



During a rainstorm over New York city there are 10 billion rain drops/sec.
Try to find the one drop that is red.

**This experiment was not popular
with the physics community:**

- (1) Most physicists believed that the search for heavy photons was not the most interesting research subject**
- (2) Few believed that such a difficult experiment could be carried out successfully**

The proposal was rejected by most of the laboratories.

**It was finally accepted by
Brookhaven National Laboratory**

“During the construction of our spectrometers, and indeed during the entire experiment, I encountered much criticism. The problem was that in order to gain a good mass resolution it was necessary to build a spectrometer that was very expensive. One eminent physicist made the remark that **this type of spectrometer is only good for looking for narrow resonances —and there are no narrow resonances.**”

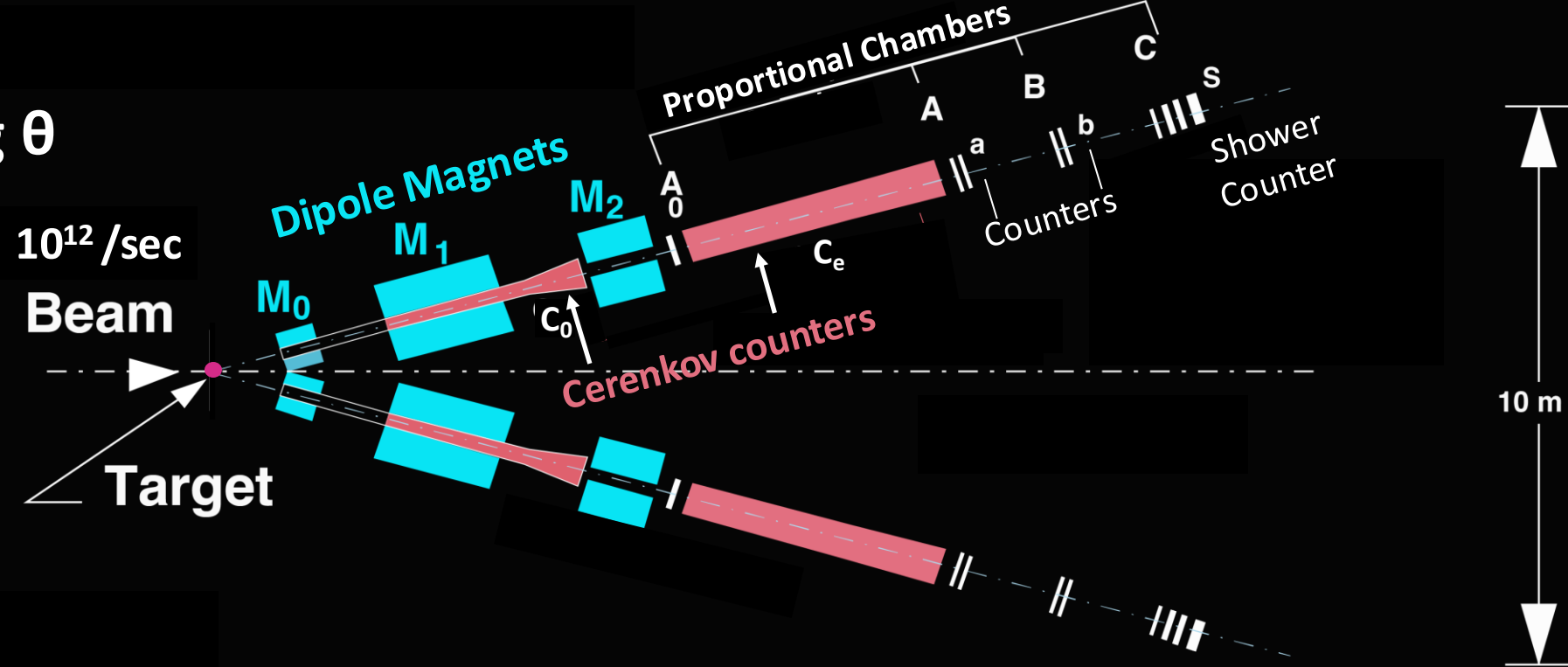
The discovery of the J particle: A personal recollection

(delivered on the occasion of the presentation of the 1976 Nobel Prizes in Physics).

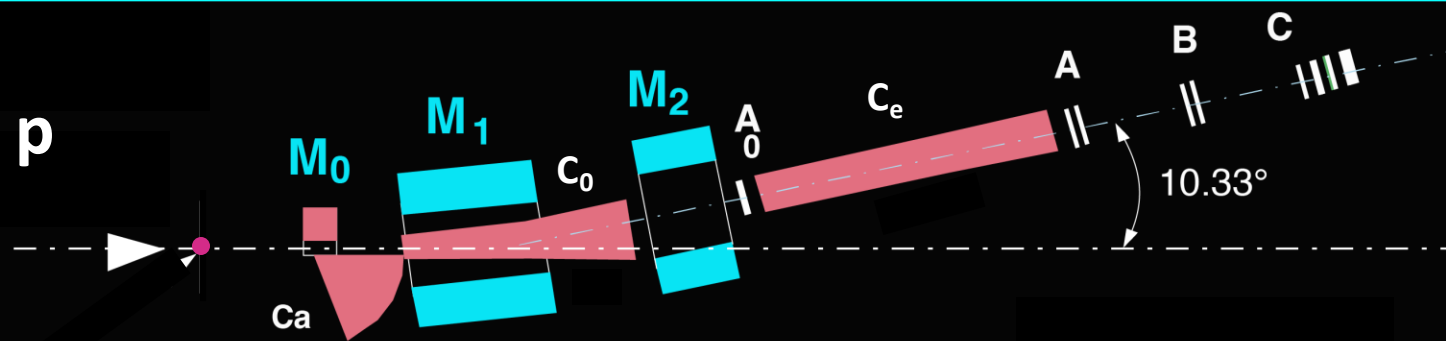
Rev. Mod. Phys. , Vol. 49, No. 2, April 1977

However, I received strong support from BNL, MIT and AEC (now DOE)

Top View measuring θ

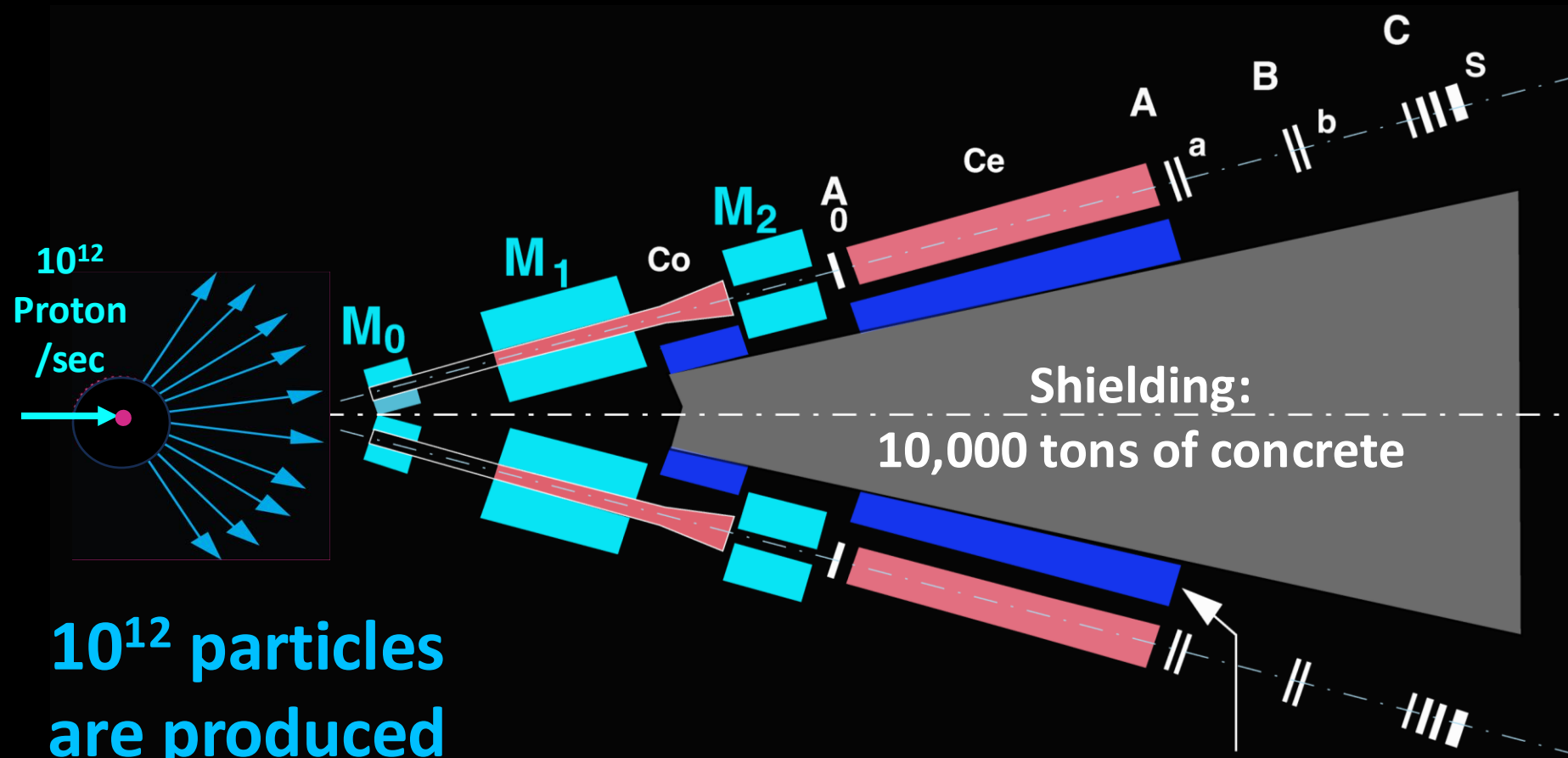


Side View measuring p



The detector follows the design of the first experiment at DESY

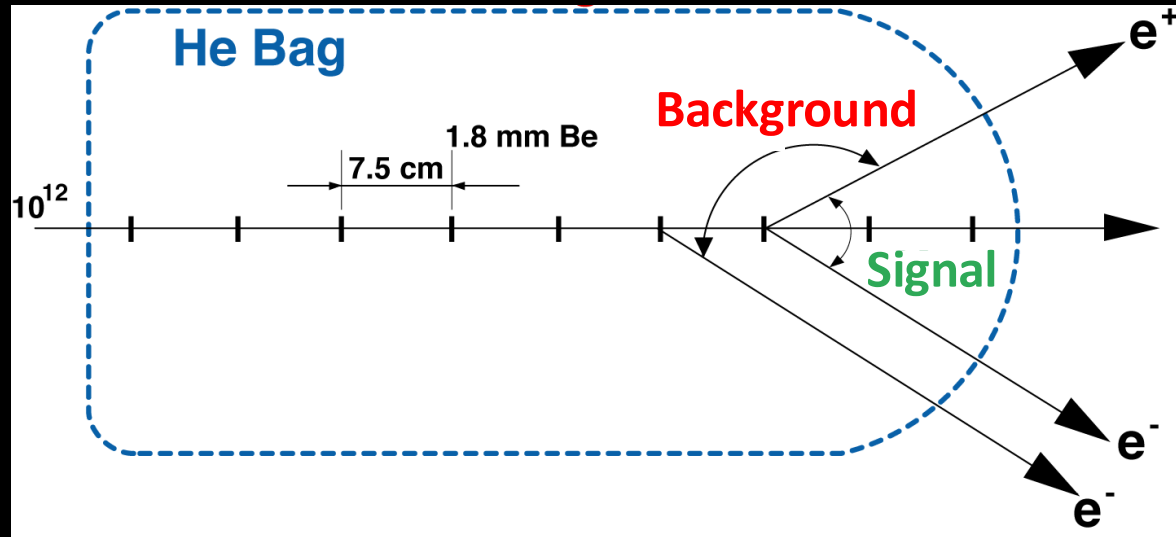
Radiation Protection



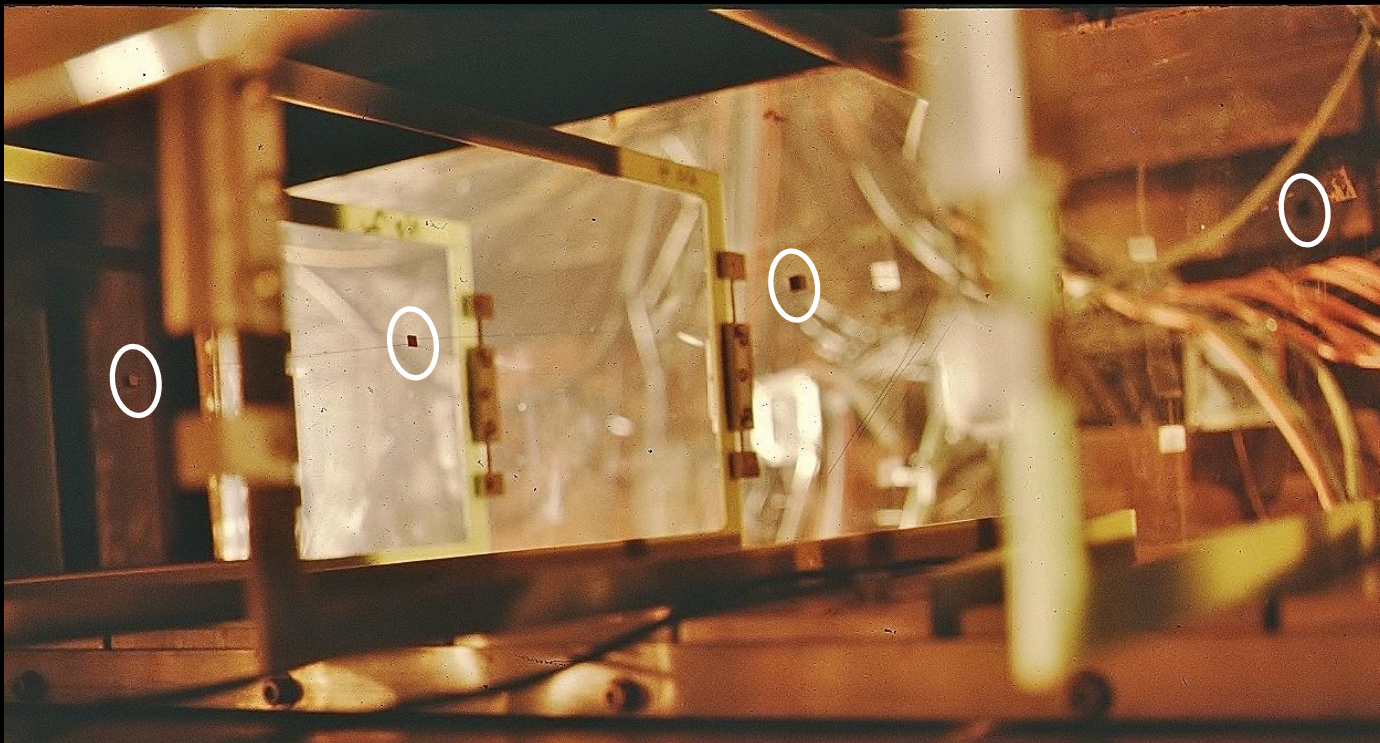
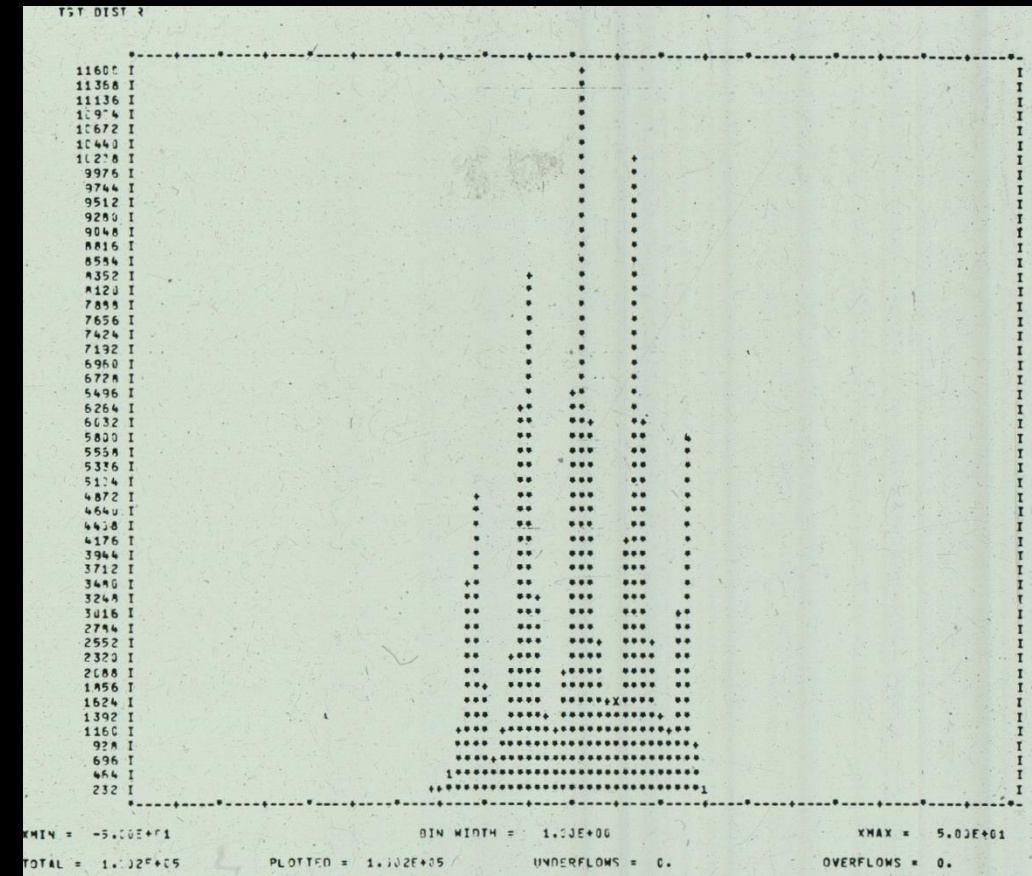
10^{12} particles
are produced
each second

+ 5 tons of ^{238}U
+ 100 tons of lead
+ 5 tons of soap

Separate thin targets to reduce the background

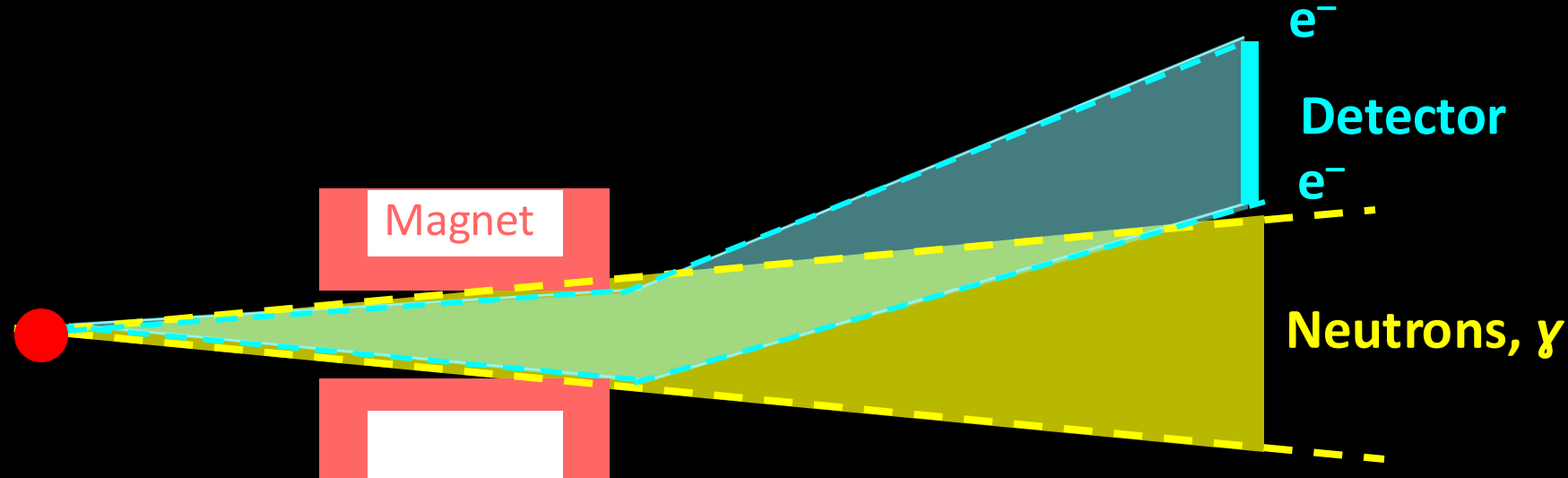


Target Event distribution

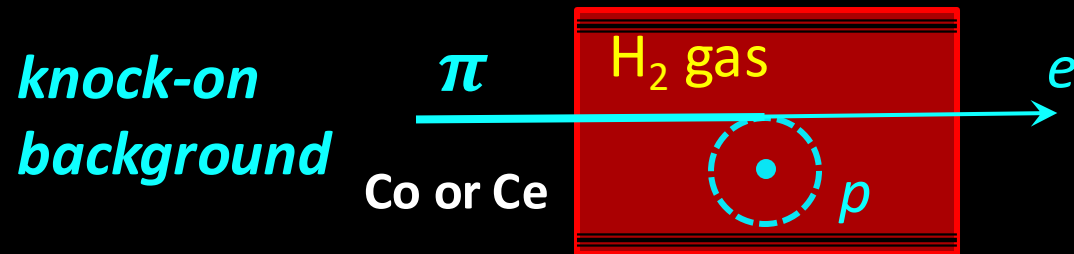
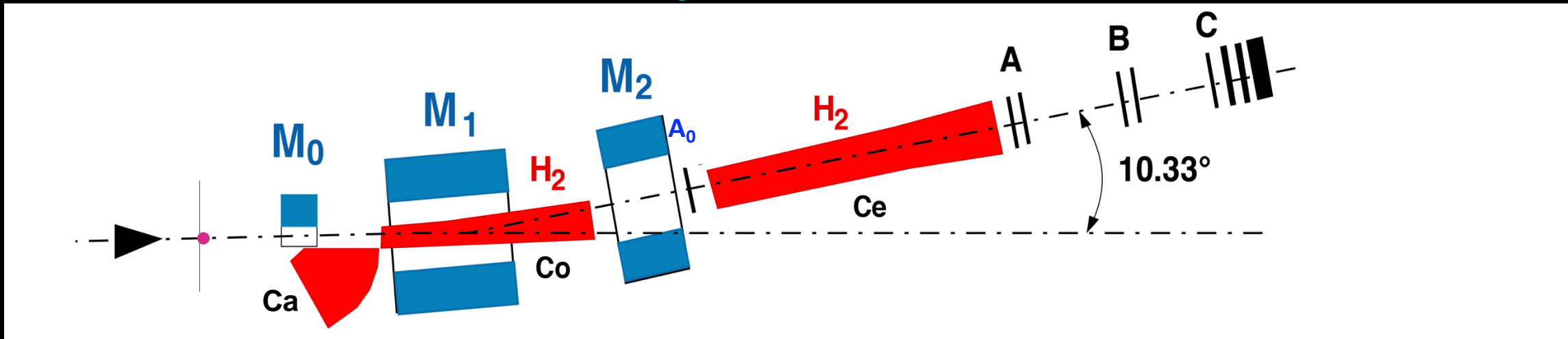


The Magnets

1. For each magnet, the field is measured with 3-D Hall probe, a total of 10^5 points.
2. The detector is smaller than the magnet aperture, the detector defines the acceptance.
3. The magnets bend charged particles to an angle such that the detectors are not exposed to photons or neutrons from the target.

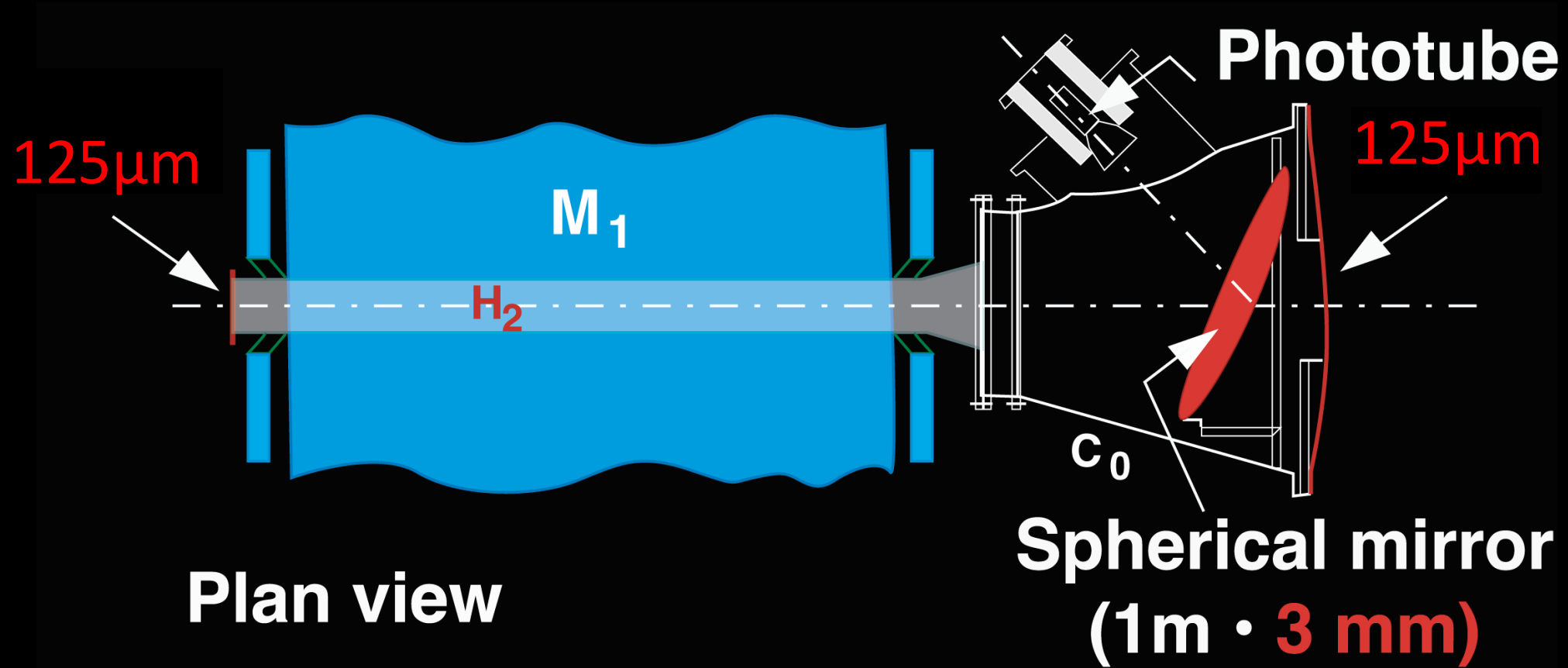


Hadron Rejection of 10^{10}



1. To reduce knock-on electrons, use H_2
2. The H_2 counter Co in the magnet is followed by another H_2 counter Ce behind the second magnet. The separation of the two counters Co, Ce by the strong magnet M_2 ensures that the minute number of knock-on electrons produced in the first counter Co are swept away and do not enter the second counter
3. All the inner surfaces of the Cherenkov counters are black to reduce scattered light

The π -e separation was achieved by four sensitive Cherenkov Counters Co, Ce



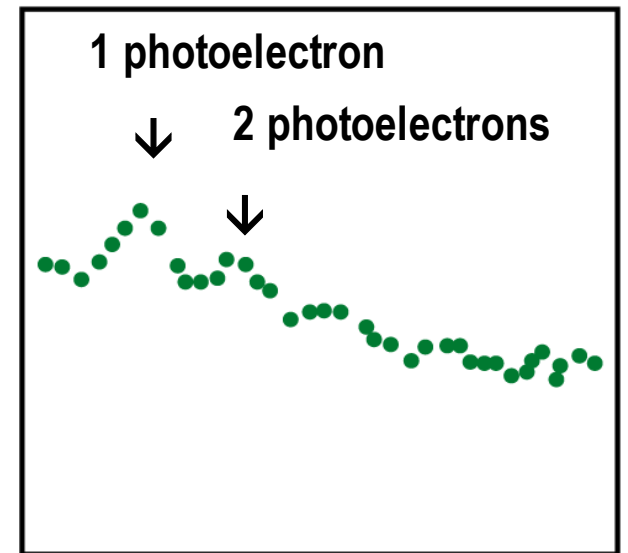
Designed with minimum material by J. J. Aubert, S. Ting, and M. Vivargent

The mirrors were made at the Precision Optical Workshop at CERN

Spherical Mirror



Number of events
(log scale)



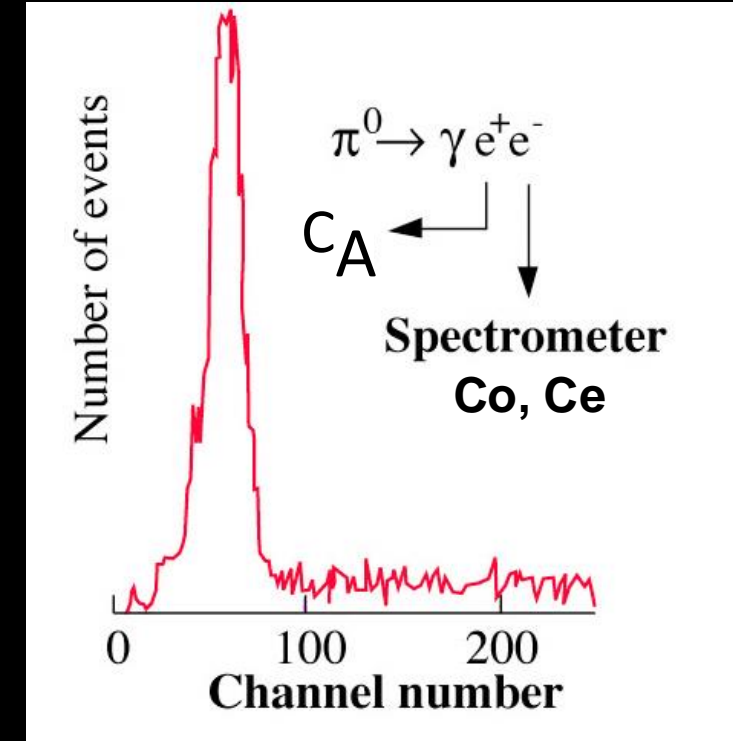
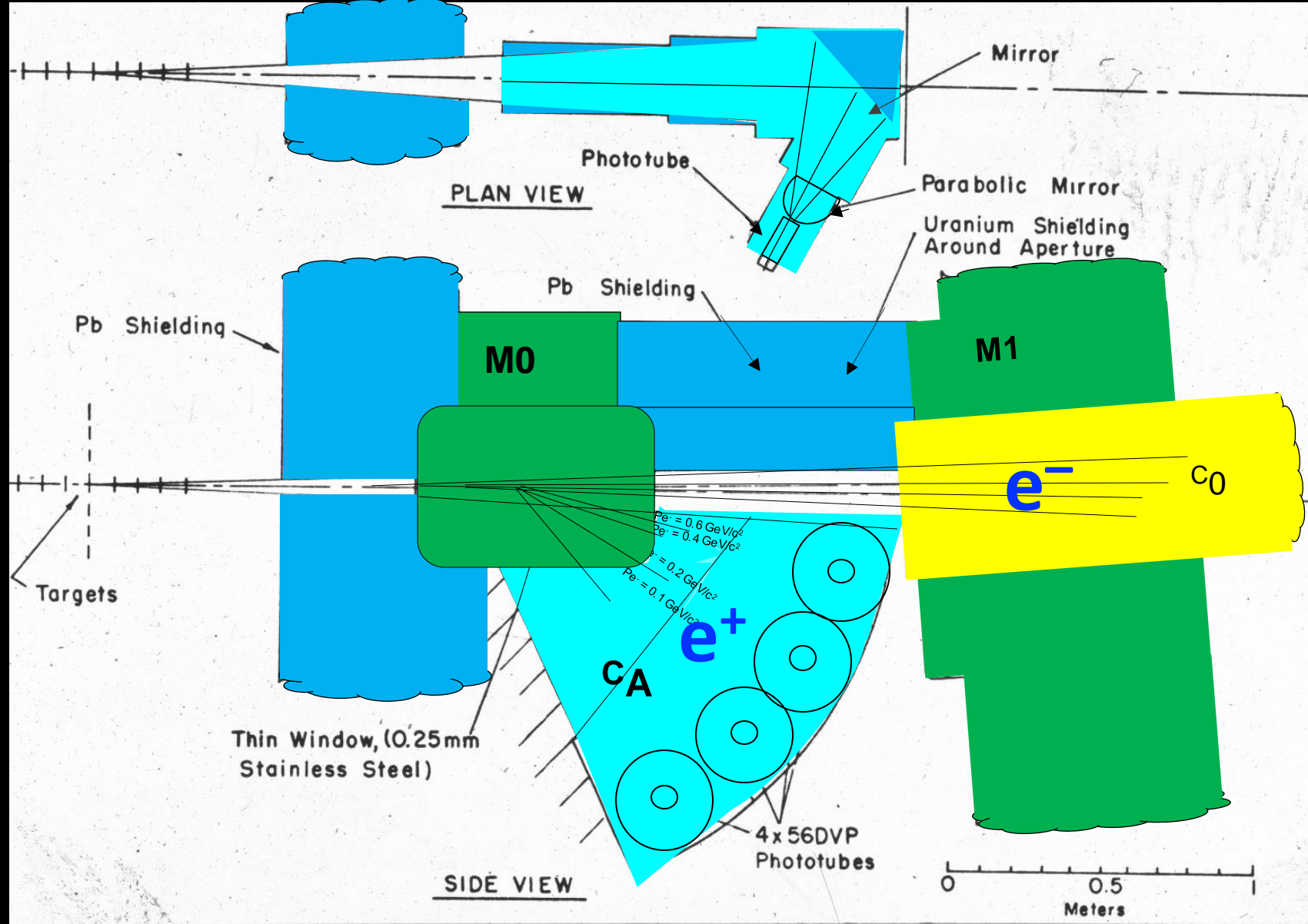
Pulse height

A photograph of the Cherenkov counter section of the UA1 experiment. Two technicians are visible working on the complex detector structure, which consists of numerous stacked modules and large cylindrical components. The text "Cherenkov Ce" is overlaid in blue.



A photograph of a man in a light blue shirt working at a desk in a room filled with large, multi-tiered electronic equipment racks. The racks are filled with numerous modules, each featuring a digital display showing numbers. The man is leaning over the desk, looking at a computer monitor. The room has a high ceiling with exposed pipes and a fluorescent light fixture.

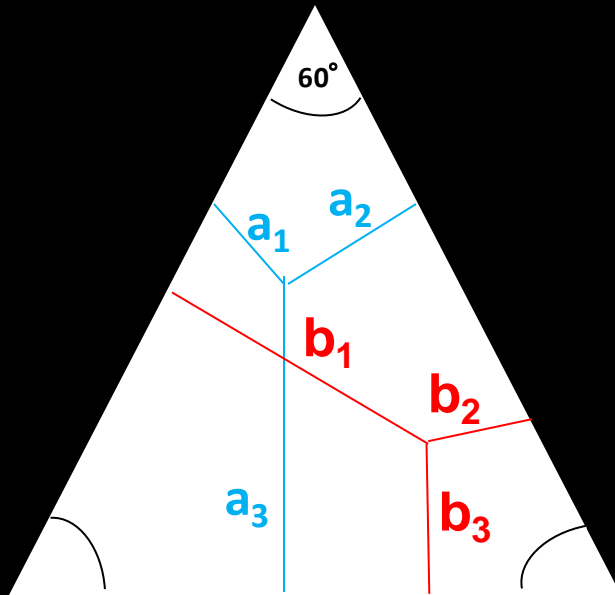
Detector calibration with a pure electron beam



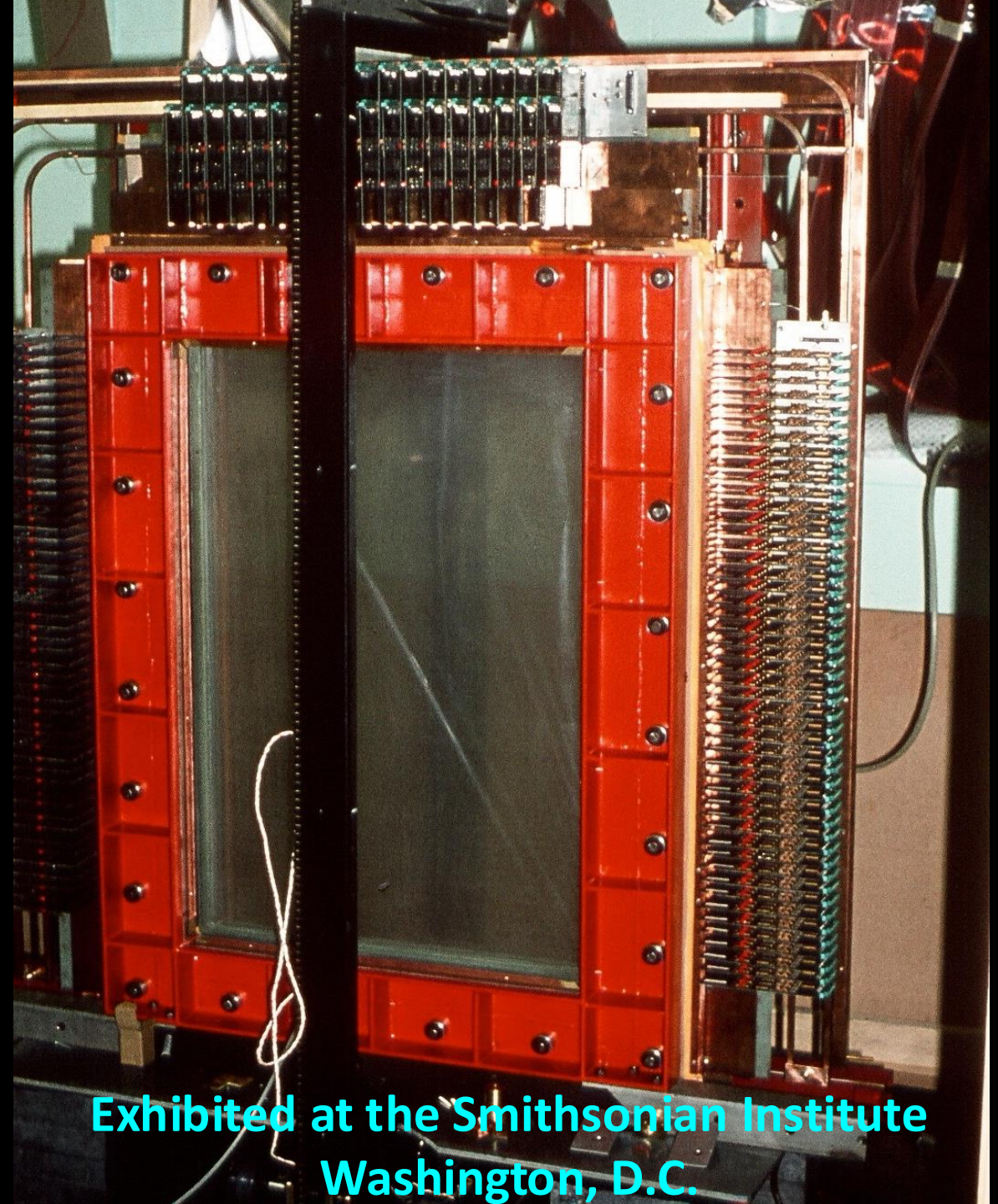
Position Detectors

designed by the
late Professor UJ Becker, MIT

To sort out multi-tracks,
the chambers
have 3 planes 60° apart



$$a_1 + a_2 + a_3 = b_1 + b_2 + b_3$$

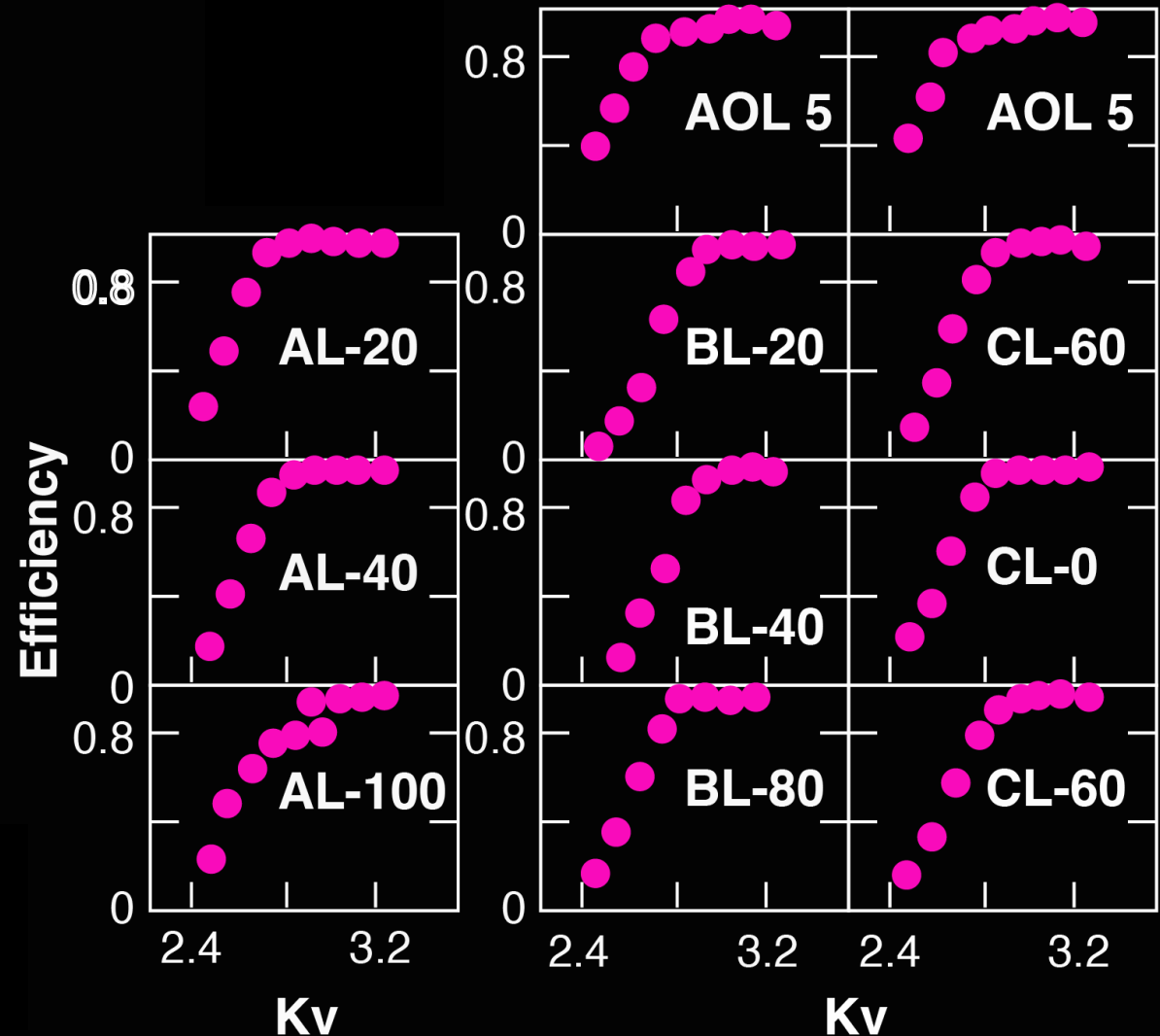
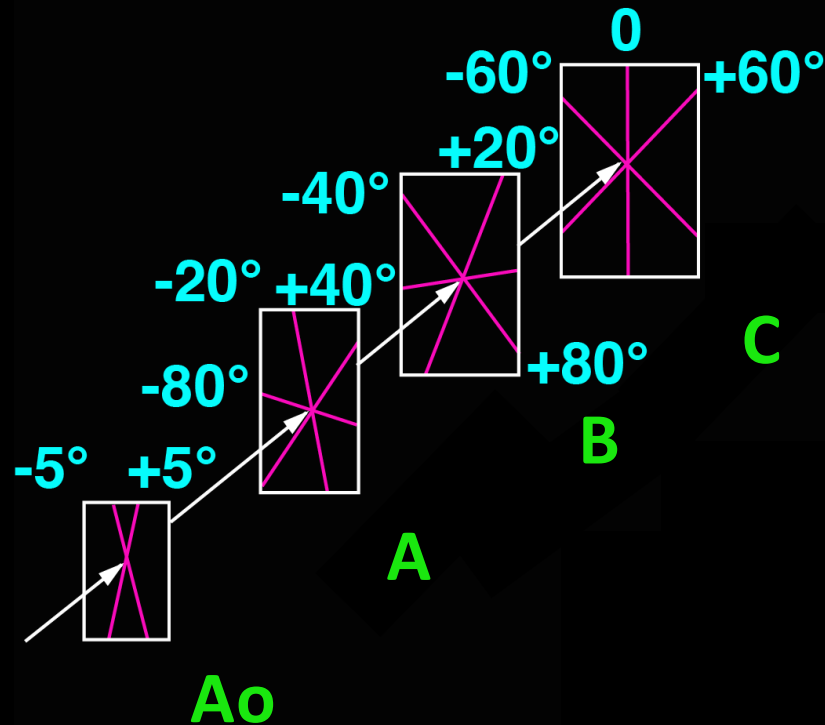


Exhibited at the Smithsonian Institute
Washington, D.C.

Position Detectors – accuracy 1 mm

10^4 wires, working at low voltage to prevent radiation damage

Rate 20 MHz





Professor UJ Becker
with precision tracker planes

In the early summer of 1974 we took some data in the high-mass region of 4-5 GeV. However, analysis of the data showed very few electron-positron pairs.

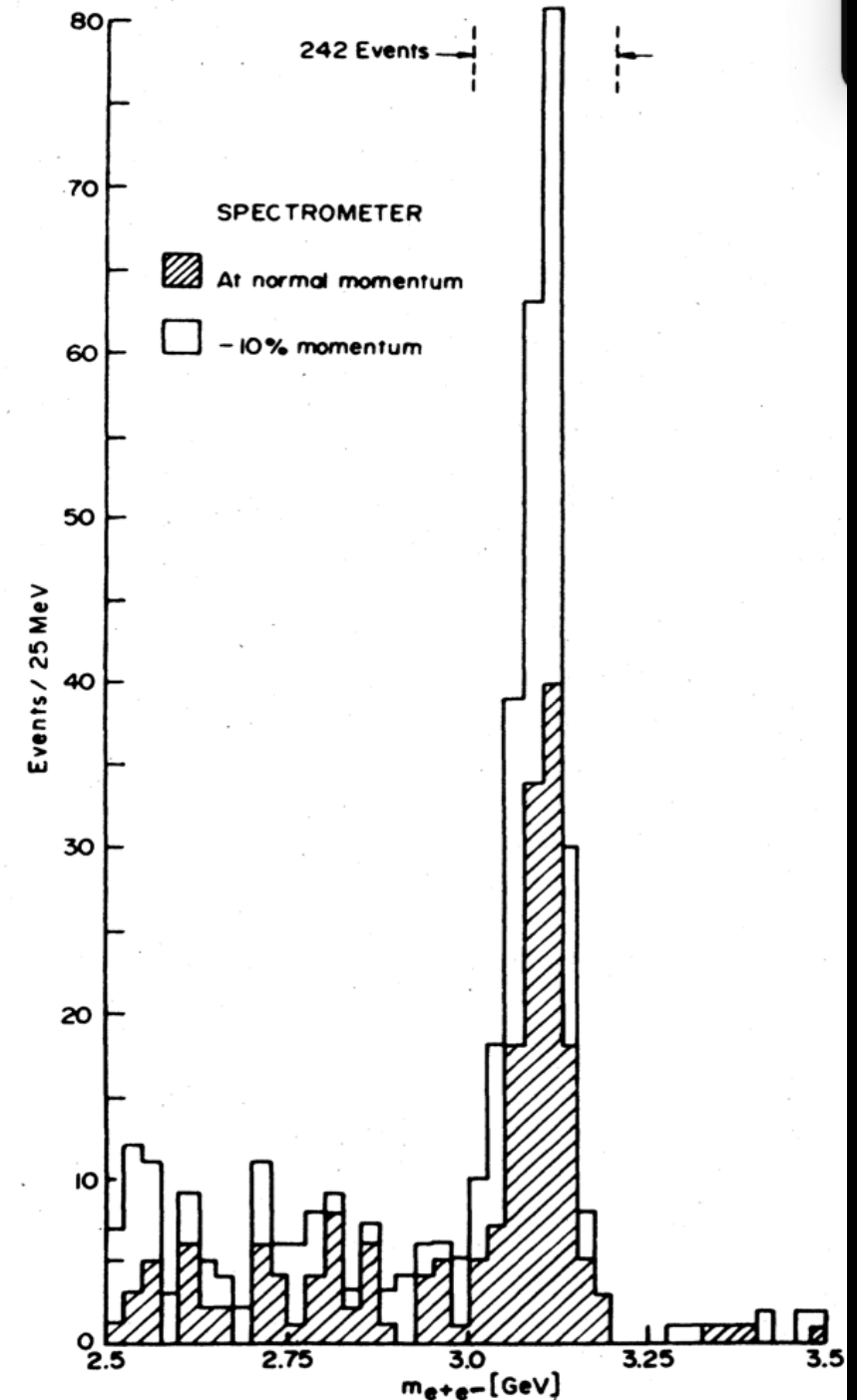
By the end of August we tuned the magnets to accept an effective mass of 2.5-4.0 GeV. Immediately we saw clean, real, electron pairs.

But most surprising of all is that most of the e^+e^- pairs peaked narrowly at 3.1 GeV [Fig. 12(a)]. A more detailed analysis shows that the width is less than 5 MeV!

Throughout the years, I have established certain practices in the group with regard to experimental checks on our data and on the data analysis. I list a few examples:

(i) To make sure the peak we observed was a real effect and not due to instrumentation bias or read-out error of the computer, we took another set of data, at a lower magnet current. This has the effect of moving the particles into different parts of the detector. The fact that the peak remained fixed at 3.1 GeV [Fig. 12(a)] showed right away that a real particle had been discovered.

FIG. 12 (a) Mass spectrum for events in the mass range $2.5 < m_{ee} < 3.5$ GeV/c. The shaded events correspond to those taken at the normal magnet setting, while the unshaded ones correspond to the spectrometer magnet setting at -10% lower than normal value.



(ii)

Two independent groups analyzed the data, starting from the reduction of raw data tapes, to form their own data summary tapes,

Two sets of Monte Carlo acceptance calculations,

Two sets of event reconstruction,

Two sets of data corrections,

Two sets of results which must agree with each other.

Two independent approaches have reached the same conclusions.

One analysis group was led by U. Becker, T. Rhodes, and W. Toki,
and the other by Min Chen

(iii) ...

These and many other checks convinced us that we had observed a real massive particle.

I was considering announcing our results during the retirement ceremony for V. F. Weisskopf, who had helped us a great deal during the course of many of our experiments. This ceremony was to be held on 17 and 18 October 1974. I postponed the announcement for two reasons.

First, there were speculations on high-mass e^+e^- pair production from proton-proton collisions as coming from a two-step process: $p + N \rightarrow \pi + \dots$ where the pion undergoes a second collision $\pi + N \rightarrow e^+ + e^- + \dots$. This could be checked by a measurement based on target thickness. The yield from a two-step process would increase quadratically with target thickness, whereas for a one-step process the yield increases linearly. This was quickly done

Second, we realized that there were earlier Brookhaven measurements (Leipuner et al. 1975) of direct production of muons and pions in nucleon-nucleon collisions which gave the μ/π ratio as 10^{-4} , a mysterious ratio that seemed not to change from 2000 GeV at the ISR down to 30 GeV.

This value was an order of magnitude larger than theoretically expected in terms of the three known vector mesons, ρ , ω , and φ , which, at that time, were the only possible "intermediaries" between the strong and electromagnetic interactions. We then added the J meson to the three and found that the linear combination of the four vector mesons could not explain the μ/π ratio either.

This I took as an indication that something exciting might be just around the corner, so I decided that we would make a direct measurement of this number.

Since we could not measure the μ/π ratio with our spectrometer, we decided to look into the possibility of investigating the e^-/π^- ratio.

On Thursday, 7 November, we made a major change in the spectrometer (see Fig. 13) to start the new experiment to search for more particles.

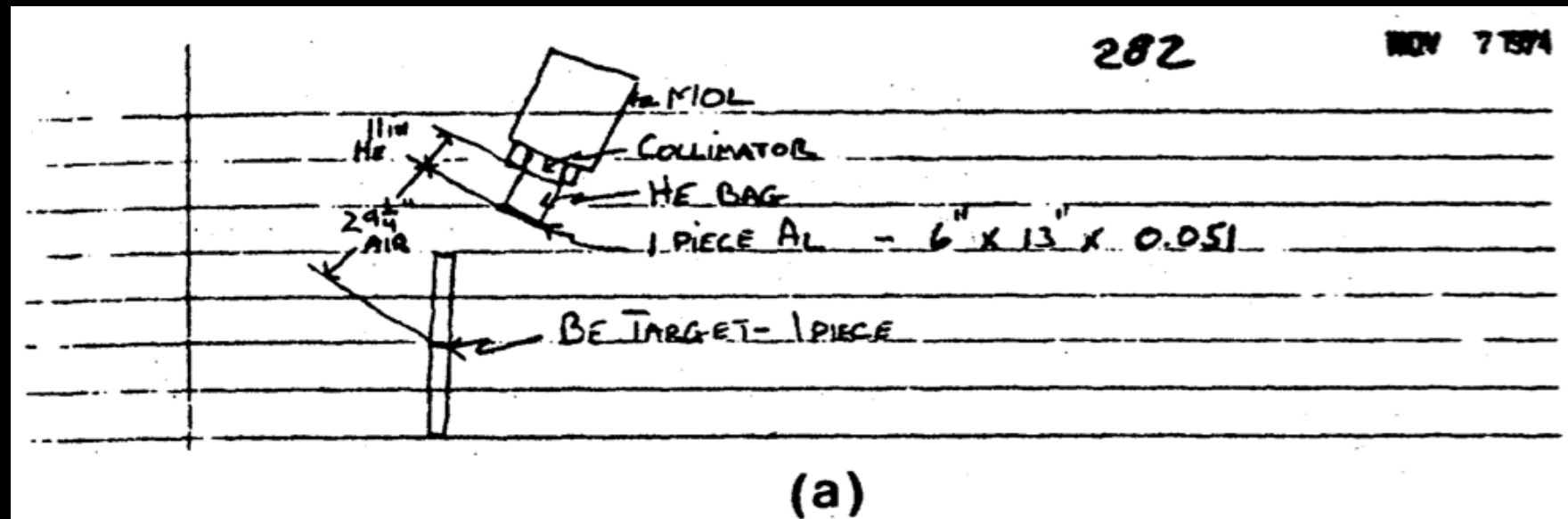
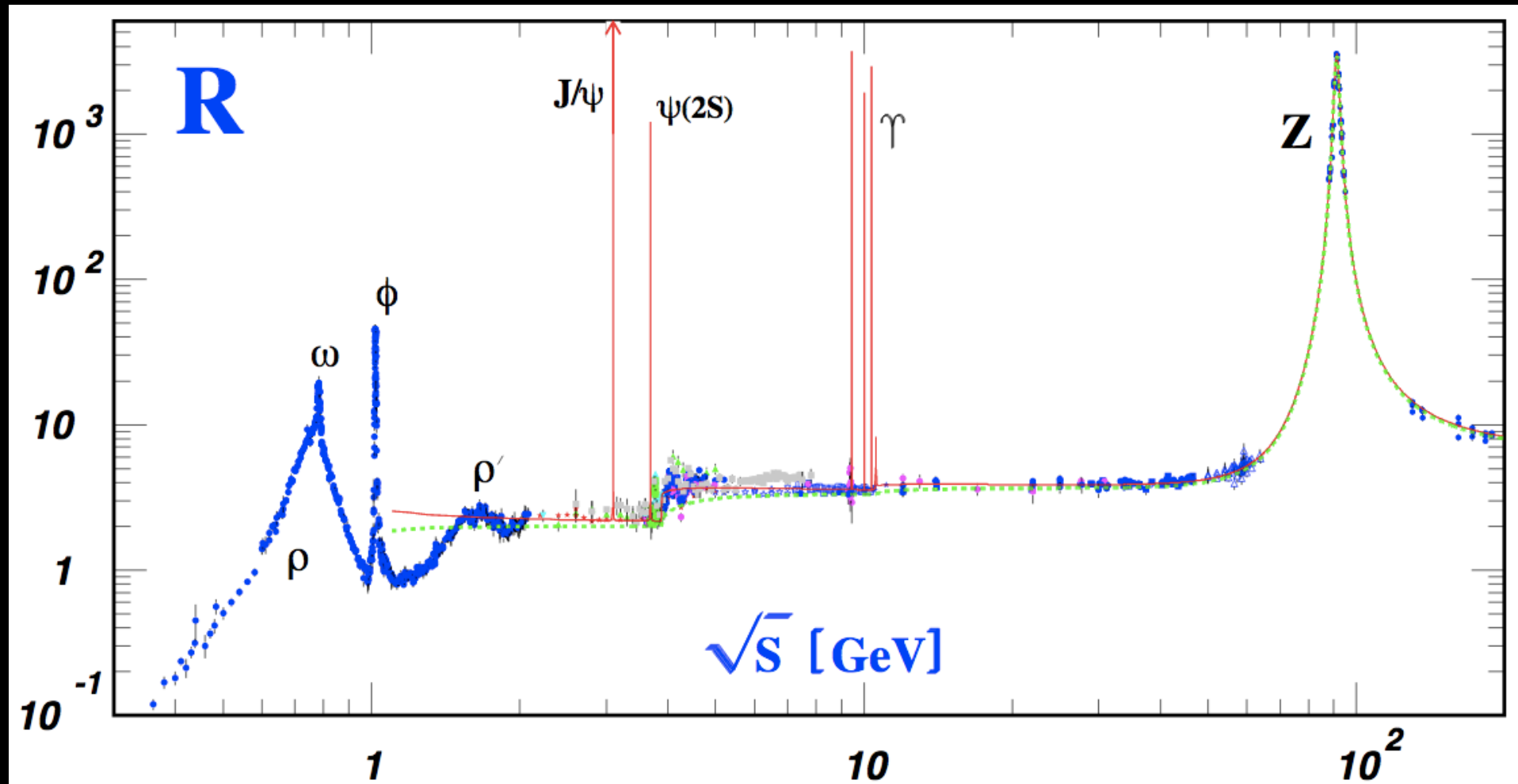


FIG. 13. (a) Aluminum foil arrangement in front of magnet M_0 in our new experiment to determine the e/π ratio. The converter was used to determine the electron background yield.



$$R \equiv \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$

Alvaro De Rujula, "When the Standard Model was Ignored"
at The Rise of Particle Physics, Sapienza University of Rome, Sep. 23, 2024

On 6 November I paid a visit to G. Trigg, Editor of Physical Review Letters, to find out if the rules for publication without refereeing had been changed. Following that visit, I wrote a simple draft in the style of our quantum electrodynamics paper of 1967 (Asbury et al. 1967). The paper emphasized only the discovery of J and the checks we made on the data without mention of our future plans.

On 11 November we telephoned G. Bellettini, the Director of Frascati Laboratory, informing him of our results.

Experimental Observation of a Heavy Particle J^\dagger

J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen, J. Leong, T. McCorriston, T. G. Rhoades, M. Rohde, Samuel C. C. Ting, and Sau Lan Wu
Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

and

Y. Y. Lee

Brookhaven National Laboratory, Upton, New York 11973

(Received 12 November 1974)

Nov. 12

We report the observation of a heavy particle J , with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + Be \rightarrow e^+ + e^- + x$ by measuring the e^+e^- mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.

Preliminary Result of Frascati (ADONE) on the Nature of a New 3.1-GeV Particle Produced in e^+e^- Annihilation*

C. Bacci, R. Balbini Celio, M. Berna-Rodini, G. Caton, R. Del Fabbro, M. Grilli, E. Iarocci, M. Locci, C. Mencuccini, G. P. Murtas, G. Penso, G. S. M. Spinetti, M. Spano, B. Stella, and V. Valente

The Gamma-Gamma Group, Laboratori Nazionali di Frascati, Frascati, Italy

and

B. Bartoli, D. Bisello, B. Esposito, F. Felicetti, P. Monacelli, M. Nigro, L. Paolufi, I. Peruzzi, G. Piano Mortemi, M. Piccolo, F. Ronga, F. Sebastiani, L. Trasatti, and F. Vanoli
The Magnet Experimental Group for ADONE, Laboratori Nazionali di Frascati, Frascati, Italy

and

G. Barbarino, G. Barbiellini, C. Bemporad, R. Biancastelli, F. Cevenini, M. Celveti, F. Costantini, P. Lariccia, P. Parascandolo, E. Sassi, C. Spencer, L. Tortora, U. Troia, and S. Vitale

The Baryon-Antibaryon Group, Laboratori Nazionali di Frascati, Frascati, Italy

(Received 18 November 1974)

Nov. 18

We report on the results at ADONE to study the properties of the newly found 3.1-BeV particle.

Discovery of a Narrow Resonance in e^+e^- Annihilation*

J.-E. Augustin,† A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman, G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie,† R. R. Larsen, V. Lüth, H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl, B. Richter, P. Rapidis, R. F. Schwitters, W. M. Tanenbaum, and F. Vannucci‡

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

G. S. Abrams, D. Briggs, W. Chinowsky, C. E. Friedberg, G. Goldhaber, R. J. Hollebeek, J. A. Kadyk, B. Lulu, F. Pierre,§ G. H. Trilling, J. S. Whitaker, J. Wiss, and J. E. Zipse

Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 9472

(Received 13 November 1974)

Nov. 13

We have observed a very sharp peak in the cross section for $e^+e^- \rightarrow \text{hadrons}$, e^+e^- , and possibly $\mu^+\mu^-$ at a center-of-mass energy of 3.105 ± 0.003 GeV. The upper limit to the full width at half-maximum is 1.3 MeV.

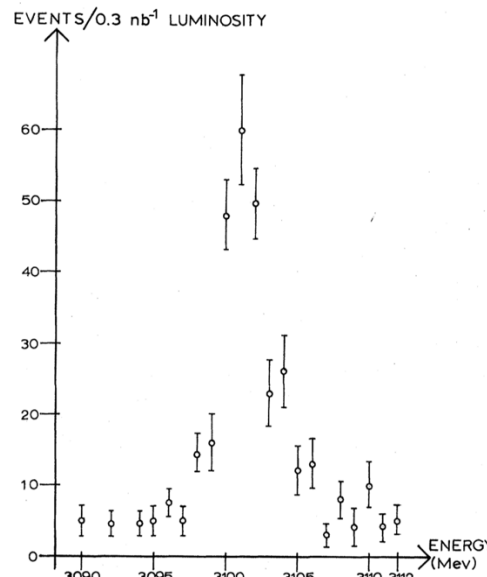


FIG. 1. Result from the Gamma-Gamma Group, total of 446 events. The number of events per 0.3 nb^{-1} luminosity is plotted versus the total c.m. energy of the machine.

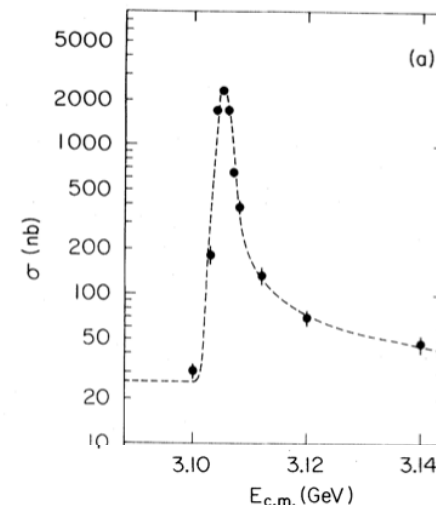


FIG. 1. Cross section versus energy for (a) multi-hadron final states, (b) e^+e^- final states, and (c) $\mu^+\mu^-$, $\pi^+\pi^-$, and K^+K^- final states. The curve in (a) is the expected shape of a δ -function resonance folded with the Gaussian energy spread of the beams and including radiative processes. The cross sections shown in (b) and (c) are integrated over the detector acceptance. The total hadron cross section, (a), has been corrected for detection efficiency.

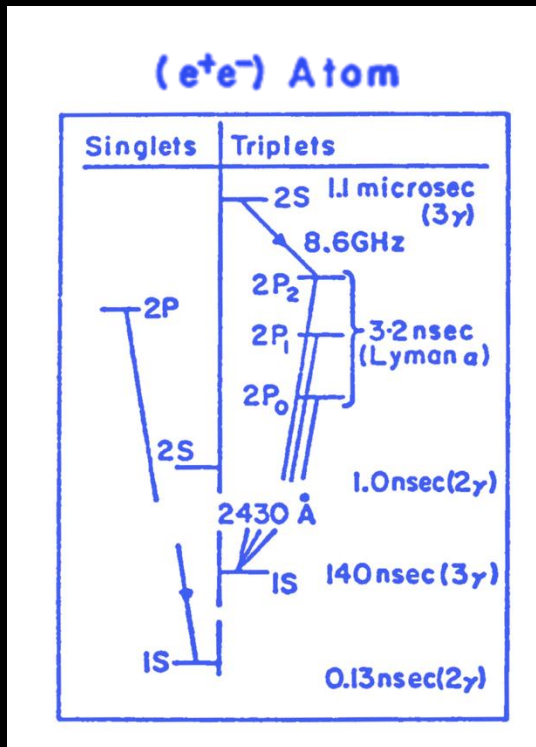


Members of the J-Particle Group

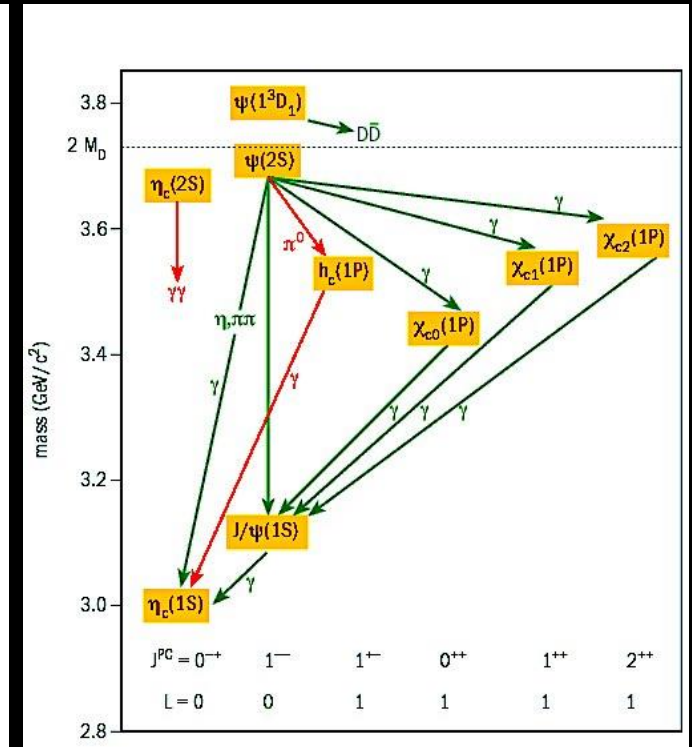
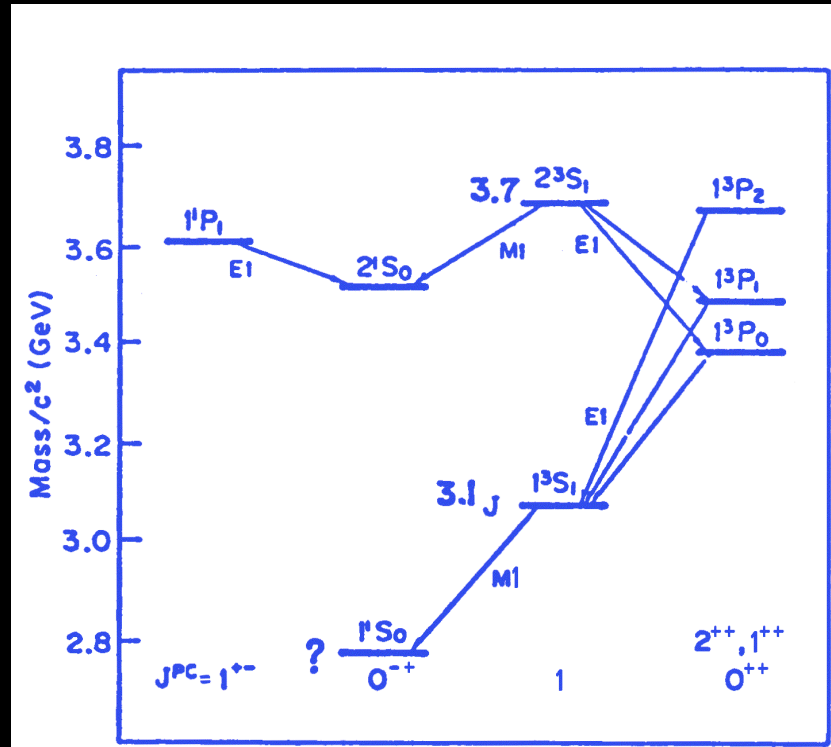
The unique properties of the J particle are:

1. Its lifetime is 10,000 times longer than other particles.
This implies the J particle is a new kind of matter
2. The spectrum is similar to positronium: This implies the J particle is made up of a new kind of Quark-Antiquark.

Positronium transitions



J/psi transitions



The discovery of the J particle confirmed the existence of the charmed quark predicted by S. Glashow, J. Iliopoulos, L. Maiani.

PHYSICAL REVIEW D

VOLUME 2, NUMBER 7

1 OCTOBER 1970

Weak Interactions with Lepton-Hadron Symmetry*

S. L. GLASHOW, J. ILIOPOULOS, AND L. MAIANI†

Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02139

(Received 5 March 1970)

We propose a model of weak interactions in which the currents are constructed out of four basic quark fields and interact with a charged massive vector boson. We show, to all orders in perturbation theory, that the leading divergences do not violate any strong-interaction symmetry and the next to the leading divergences respect all observed weak-interaction selection rules. The model features a remarkable symmetry between leptons and quarks. The extension of our model to a complete Yang-Mills theory is discussed.

The BNL proposal for the search for heavy photons (AGS E598) didn't mention the GIM mechanism as a motivation

Dec. 10, 1976 - Stockholm





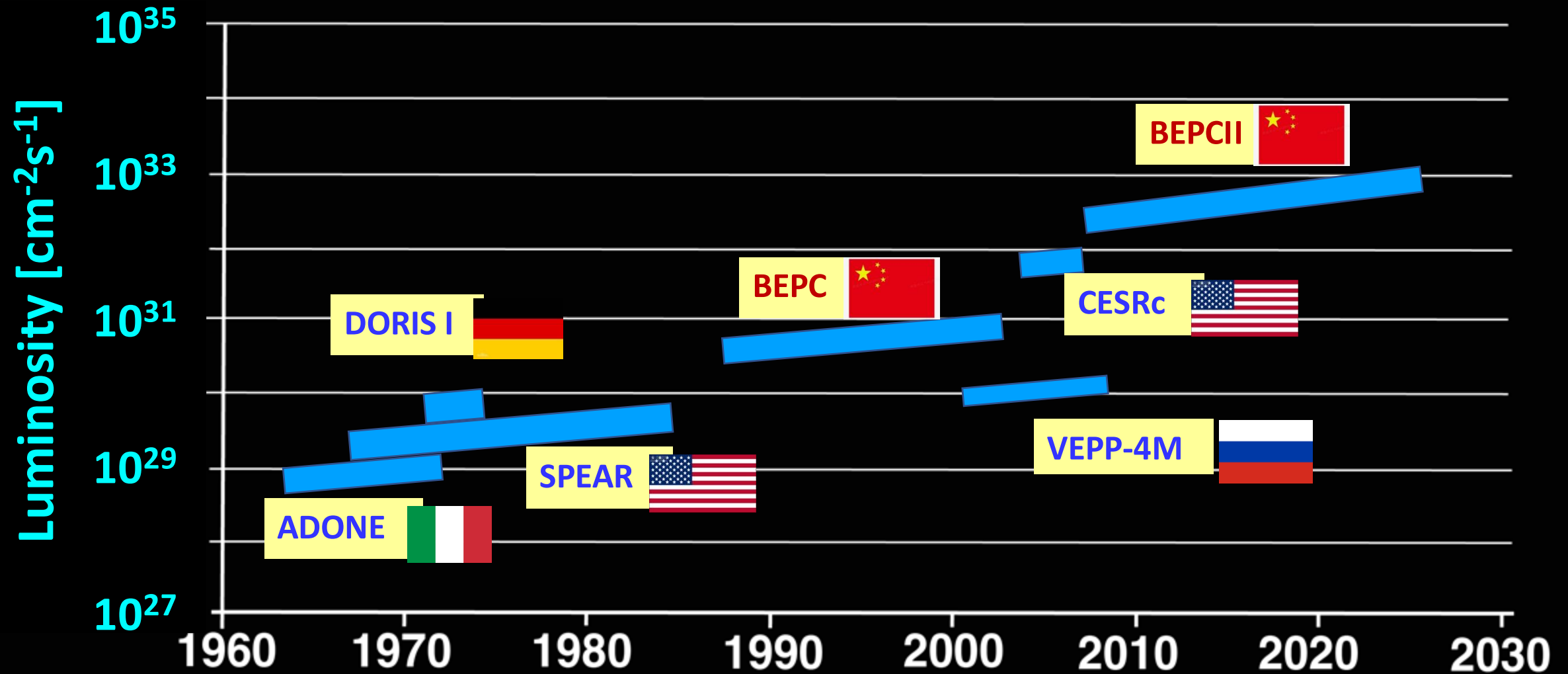
Attending the Nobel ceremony, Dec. 10, 1976

with key MIT physicists, M. Chen, U. Becker, J. Burger

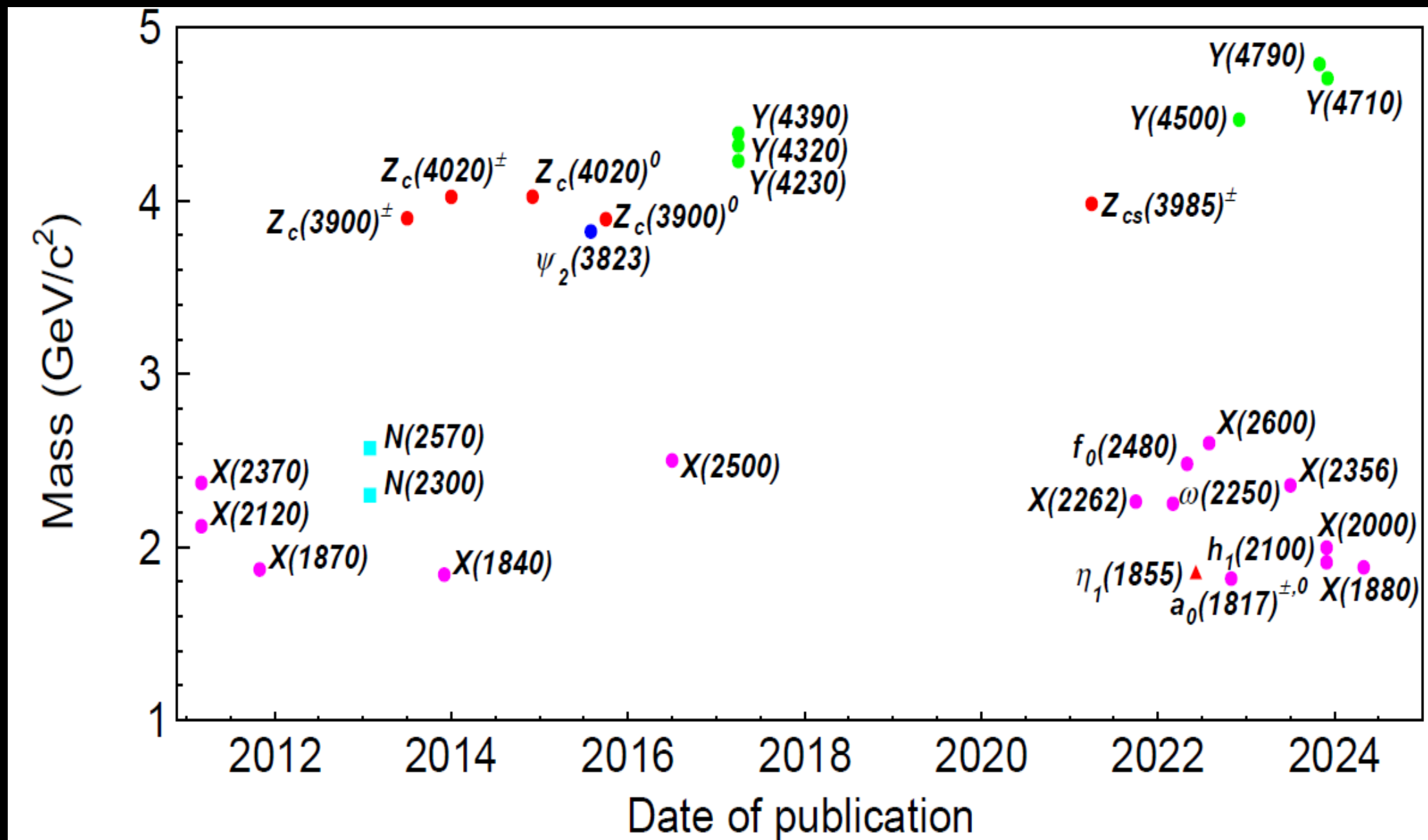


Understanding this new form of matter:

Tau-Charm Factories in the World

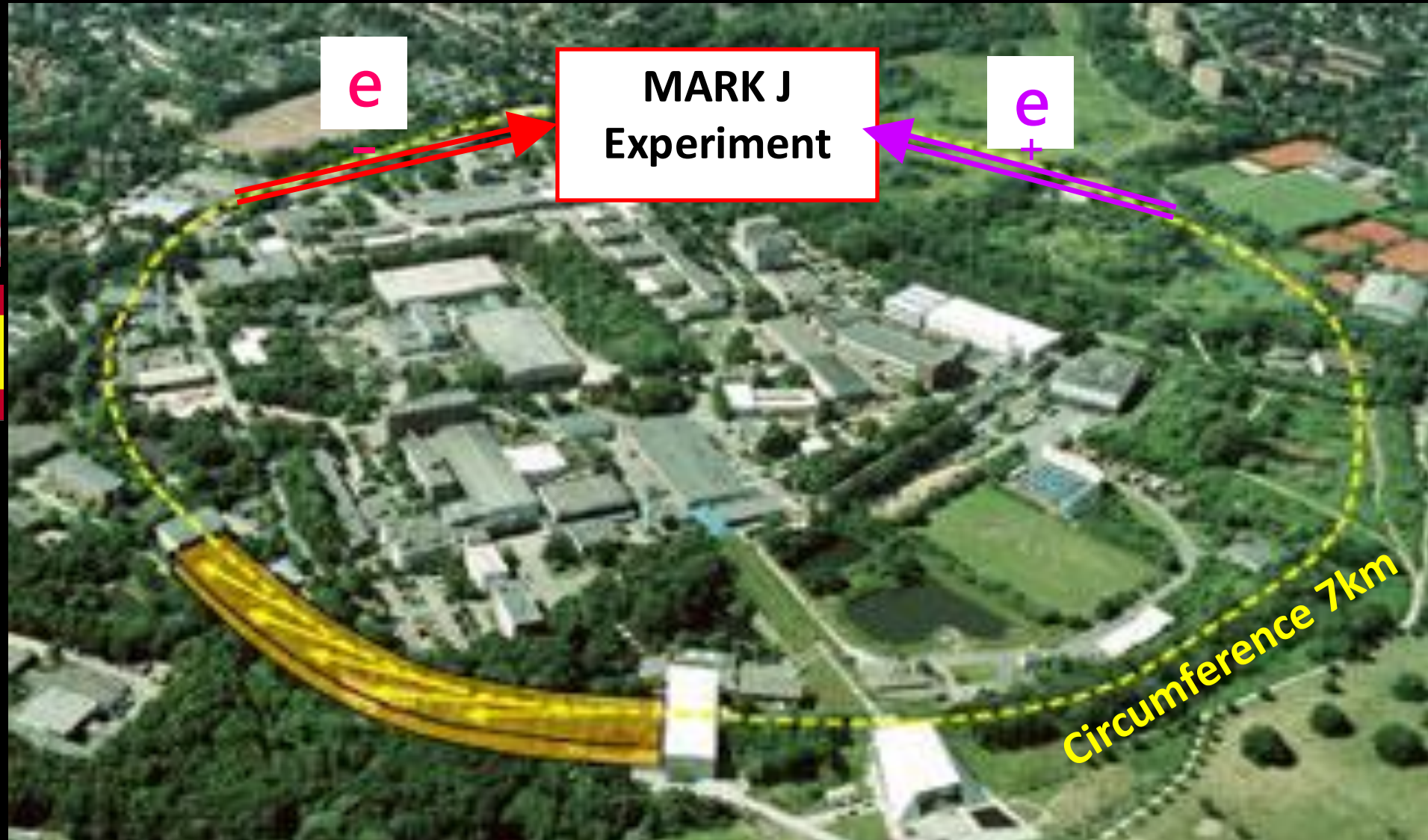


30 new hadrons discovered at BESIII from charmed meson production and decays



Electrons at Higher Energy

46 Billion Electron Volt Collider at DESY, Germany



Nuclear Physics **22** (1961) 579—588; © North-Holland Publishing Co., Amsterdam

PARTIAL-SYMMETRIES OF WEAK INTERACTIONS

SHELDON L. GLASHOW †

Institute for Theoretical Physics, University of Copenhagen, Copenhagen, Denmark

Received 9 September 1960

Abstract: Weak and electromagnetic interactions of the leptons are examined under the hypothesis that the weak interactions are mediated by vector bosons. With only an isotopic triplet of leptons coupled to a triplet of vector bosons (two charged decay-intermediaries and the photon) the theory possesses no partial-symmetries. Such symmetries may be established if additional vector bosons or additional leptons are introduced. Since the latter possibility yields a theory disagreeing with experiment, the simplest partially-symmetric model reproducing the observed electromagnetic and weak interactions of leptons requires the existence of at least four vector-boson fields (including the photon). Corresponding partially-conserved quantities suggest leptonic analogues to the conserved quantities associated with strong interactions: strangeness and isobaric spin.

5. Discussion

It seems remarkable that both the requirement of partial-symmetry and quite independent experimental considerations indicate the existence of neutral weakly interacting currents. It would be gratifying if the introduction of only a single neutral vector-meson field B could secure both partial-symmetry and the $\Delta I = \frac{1}{2}$ rule. Whether this is possible depends upon the extension of our

A MODEL OF LEPTONS*

Steven Weinberg†

Laboratory for Nuclear Science and Physics Department,
Massachusetts Institute of Technology, Cambridge, Massachusetts

(Received 17 October 1967)

Leptons interact only with photons, and with the intermediate bosons that presumably mediate weak interactions. What could be more natural than to unite¹ these spin-one bosons into a multiplet of gauge fields? Standing in

Proceedings of the 8th Nobel Symposium,
Ed. Svartholm, N., (Almqvist and Wiksell, Stockholm 1968)

Weak and electromagnetic interactions

By *Abdus Salam*

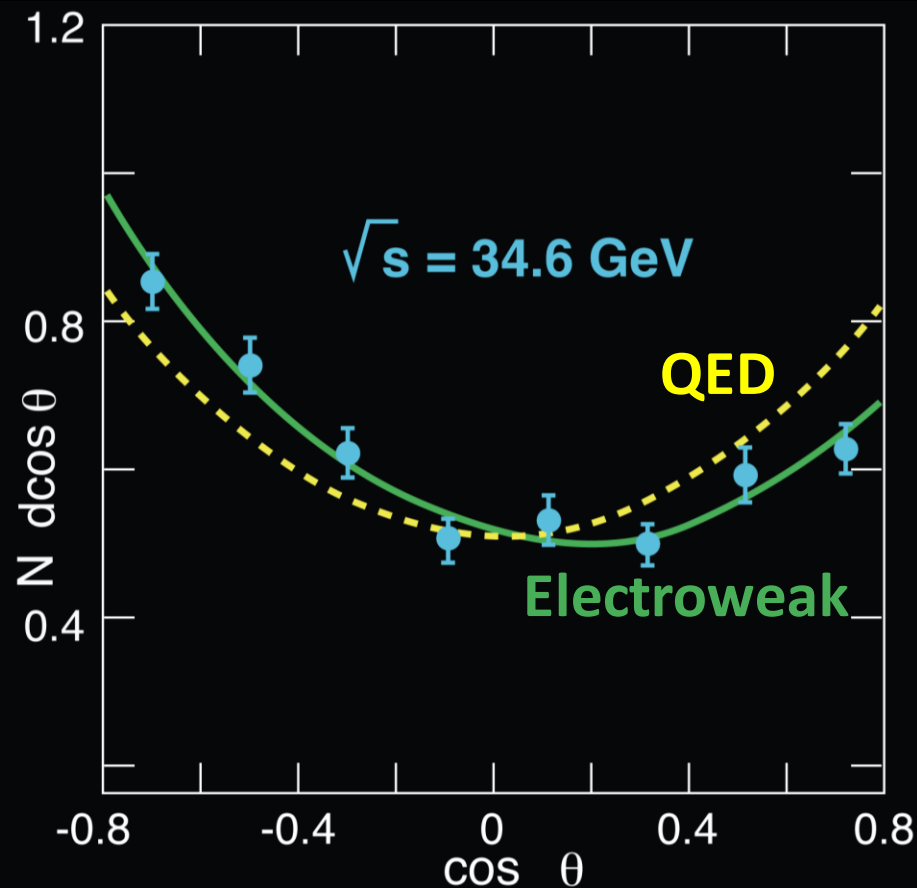
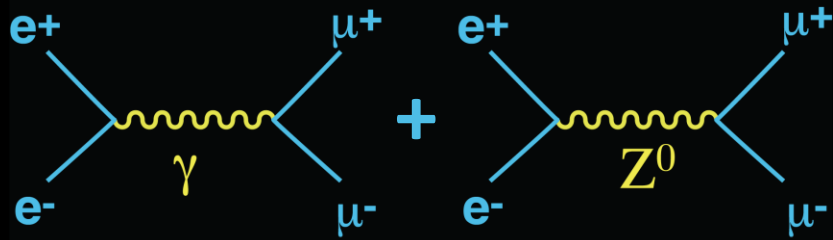
Imperial College of Science and Technology, London, and International Centre
for Theoretical Physics, Trieste, Italy

One of the recurrent dreams in elementary particle physics is that of a possible fundamental synthesis between electromagnetism and weak interaction. The idea has its origin in the following shared characteristics:

1. Both forces affect equally all forms of matter - leptons as well as hadrons.
2. Both are vector in character.
3. Both (individually) possess universal coupling strengths.

The earliest confirmation of electroweak theory

Measuring $e^+e^- \rightarrow \mu^+\mu^-$ forward-backward asymmetry



physics today

news

search & discovery

Electroweak interference confirmed

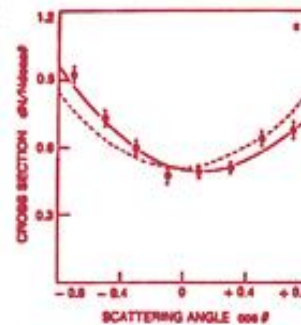
Before 1973, all observed weak interactions had involved charge exchange between the participating particles, implying that the carriers of the weak force were themselves always electrically charged. But if one is to unify the weak and electromagnetic interactions in a single gauge-invariant framework, one requires a weak analog of the uncharged photon—an electrically neutral, weak, spin-one boson. The discovery of the neutral-current weak interactions at CERN in 1973 (for example, the elastic scattering of neutrinos off nucleons) was thus a crucial piece of evidence for the Weinberg-Salam-Glashow electroweak gauge theory—the scheme that has since come to be regarded as the “standard theory” for the unification of the electromagnetic and weak interactions. Sheldon Glashow and Steven Weinberg (both then at Harvard) and Abdus Salam (Imperial College, London and International Centre for Theoretical Physics, Trieste) shared the 1979 Nobel Prize in Physics for this work.

If the neutral weak boson (called Z^0 , and expected to have a mass of about 90 GeV) does indeed exist, one should be able to see interference effects between electromagnetic and weak exchange mechanisms. Whenever a photon is exchanged, a Z^0 can be exchanged in the same reaction. The key experimental signature would be the observation of a forward-backward asymmetry due to the interference of the axial-vector part of the weak interaction with the purely vectorial electromagnetic interaction. (This should not be confused with parity violations observed in purely weak processes; these come from interference between the vector and axial-vector parts of the weak interaction alone.) At collision energies much below the Z^0 mass, however, the interference of the weak interaction with electromagnetic processes would be very small.

But PETRA, the e^+e^- colliding-beam storage ring at DESY (Hamburg), has for more than a year now been operating reliably with high luminosity at collision energies around 35 GeV. At this center-of-mass energy (more than a third of the supposed Z^0 mass), the Weinberg-Salam-Glashow theory predicts a forward-backward asymmetry A , given by $A = (N^+ - N^-)/(N^+ + N^-)$, where N^\pm is the number of μ^\pm emerging within 90° of the e^+ beam direction. In practice, the detectors cannot cover the entire 4π solid angle surrounding the collision region; spaces must be left open in the beam directions. One therefore measures the differential cross section $dN/d\cos\theta$ at various values of the scattering angle θ between the incident e^+ and emerging μ^+ . The overall asymmetry A is then determined by fitting a curve of the form predicted by W-S-G through the cross-section measurements and extrapolating to the full angular range.

The W-S-G theory predicts that the angular dependence of the differential cross section will have the general form $C_1(1 + \cos^2\theta) + C_2\cos\theta$. The second term, antisymmetric in θ , gives the forward-backward electroweak interference asymmetry. Its coefficient C_2 depends on the axial-vector coupling constant g_A of the Z^0 to the charged leptons, and on the Z^0 mass and the collision energy. The theory predicts that $g_A = 1/2$, with a much smaller vector coupling constant. With a Z^0 mass of about 90 GeV, inferred primarily from the neutrino experiments, one gets a predicted asymmetry A of about -9% for both the $\mu^+\mu^-$ and $\tau^+\tau^-$ final states at 35 GeV. Note that the sign of A is negative; each emerging lepton tends to follow the direction of the incident e^+ of the opposite sign. This will be the case so long as the center-of-mass energy is below the Z^0 mass.

This tendency of the emerging leptons to “remember” the directions of the incident charges is not *ipso facto* a violation of parity conservation. But the dominant electromagnetic reaction mechanism—a single-photon intermediate state—forbids such memory.



Nuclear Physics B111 (1976) 253–271

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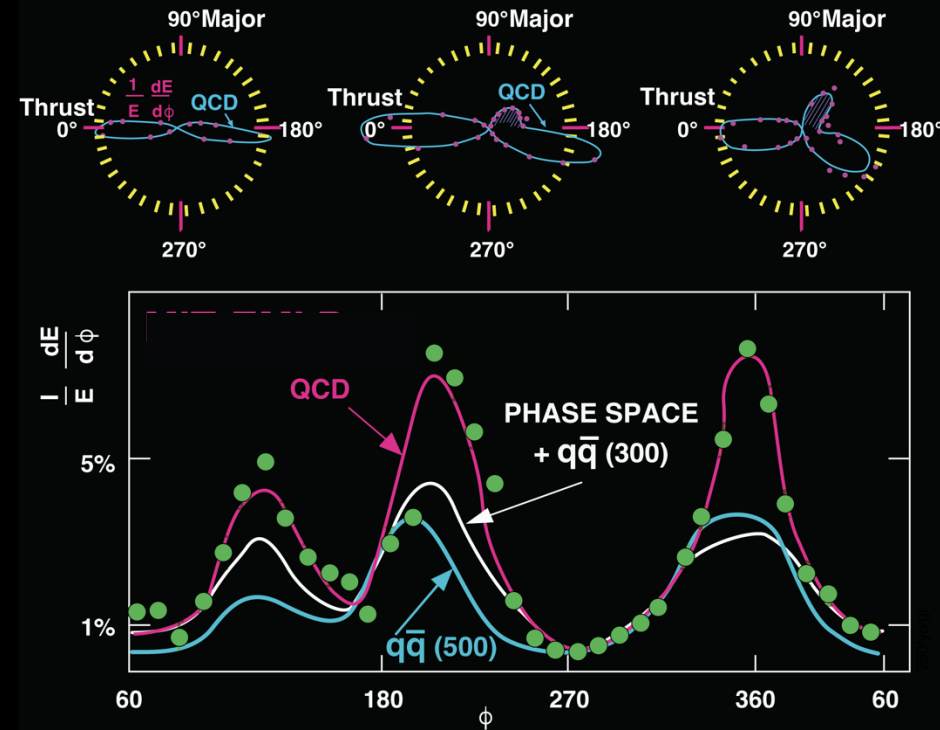
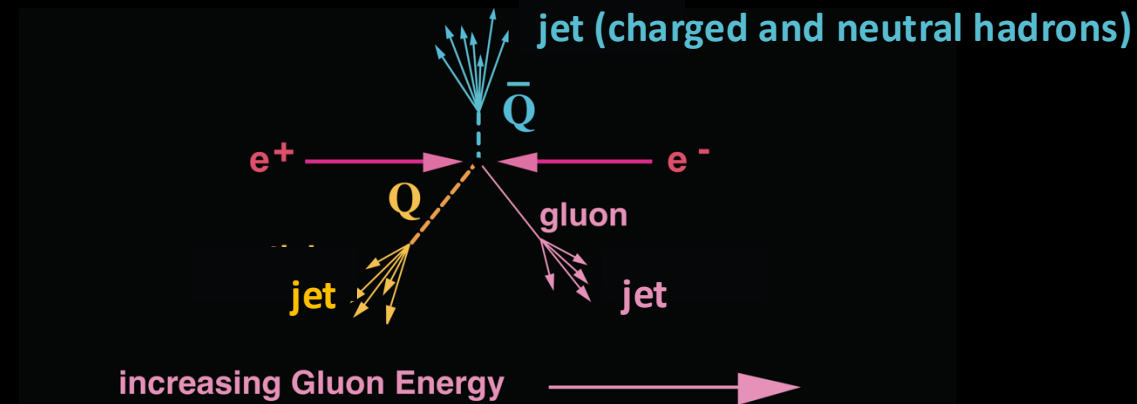
SEARCH FOR GLUONS IN e^+e^- ANNIHILATION

John ELLIS, Mary K. GAILLARD ^{*} and Graham G. ROSS

CERN, Geneva

We study the deviations to be expected at high energies from the recently observed two-jet structure of hadronic final states in e^+e^- annihilation. Motivated by the approximate validity of the naïve parton model and by asymptotic freedom, we suggest that hard gluon bremsstrahlung may be the dominant source of hadrons with large momenta transverse to the main jet axes. This process should give rise to three-jet final states. These may be observable at the highest SPEAR or DORIS energies, and should be important at the higher PETRA or PEP energies.

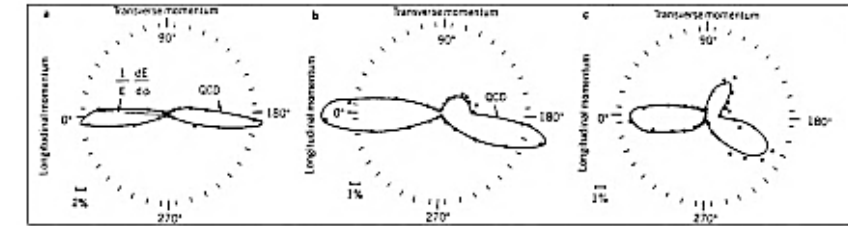
Discovery of Gluons at PETRA, Germany



Physics Today, February 1980 (p.17)

search & discovery

Evidence from PETRA adds support for QCD and gluons



Jets of hadrons produced in electron-positron collisions at PETRA. Each event has been rotated into a frame where both the longitudinal momentum and transverse momentum are maximized. Figures a, b and c are samples where the events become increasingly oblate. The distance from the center of the circle ($1/E dE/d\phi$) is a measure of the energy of the particles. In a the two large lobes are jets from decays of quark-antiquark pairs. The gluons have too little energy to create an additional jet. In b the third small lobe is mostly due to the jet from the decays of a low-energy gluon. In c the gluon has a distinct jet of its own (in the 90-180° region).

Over the past several years a theory of the strong interactions known as quantum chromodynamics has been developing. This theory assumes the existence of fractionally charged quarks of spin $\frac{1}{2}$ and that the force between the quarks is carried by a gluon, a massless spin-1 quantum. Like the quark, it is widely believed that the gluon is not directly observable.

Now experiments at PETRA, the new electron-positron storage ring at DESY

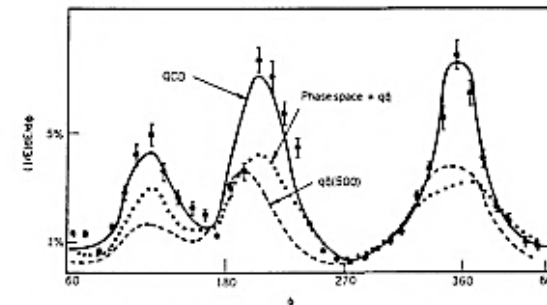
in Hamburg, Germany, which started operating last year with roughly 15 GeV in each beam, are showing evidence for the existence of gluons and are in agreement with the general picture of quantum chromodynamics. Very recent analyses of the PETRA data have determined a value of the strong-interaction coupling constant, α_s , which is consistent with earlier measurements involving the inelastic scattering of either neutrinos or muons on protons.

The experiments are being done by four groups at DESY—Jade, Mark J, Pluto and Tasso. Preliminary results were reported last summer and more recently at The American Physical Society meeting in Chicago in January.

At present we have evidence for five kinds of quark—up, down, strange, charmed, bottom—and the strong expectation of a sixth—top. Quantum chromodynamics requires that each kind of quark have a quantum number called color, which comes in three varieties. The three quark colors transform as a functional triplet of the group SU(3). To make this SU(3) symmetry a local gauge symmetry, one introduces eight vector gauge fields—colored gluons. Because the gluons carry color, they interact with each other and thereby lead to a decrease of the coupling as the energy is increased (asymptotic freedom).

Most of the evidence in favor of quantum chromodynamics preceded the theory. For example, the rate of a neutral pion decay into two photons was evidence that up and down quarks must come in three colors. In electron-positron interactions, the ratio of hadron production to lepton production could be explained by having colored quarks. Until QCD, no one could find a quantum field theory that could explain all the experimental results.

At about the same time as QCD was being developed, experiments on deep



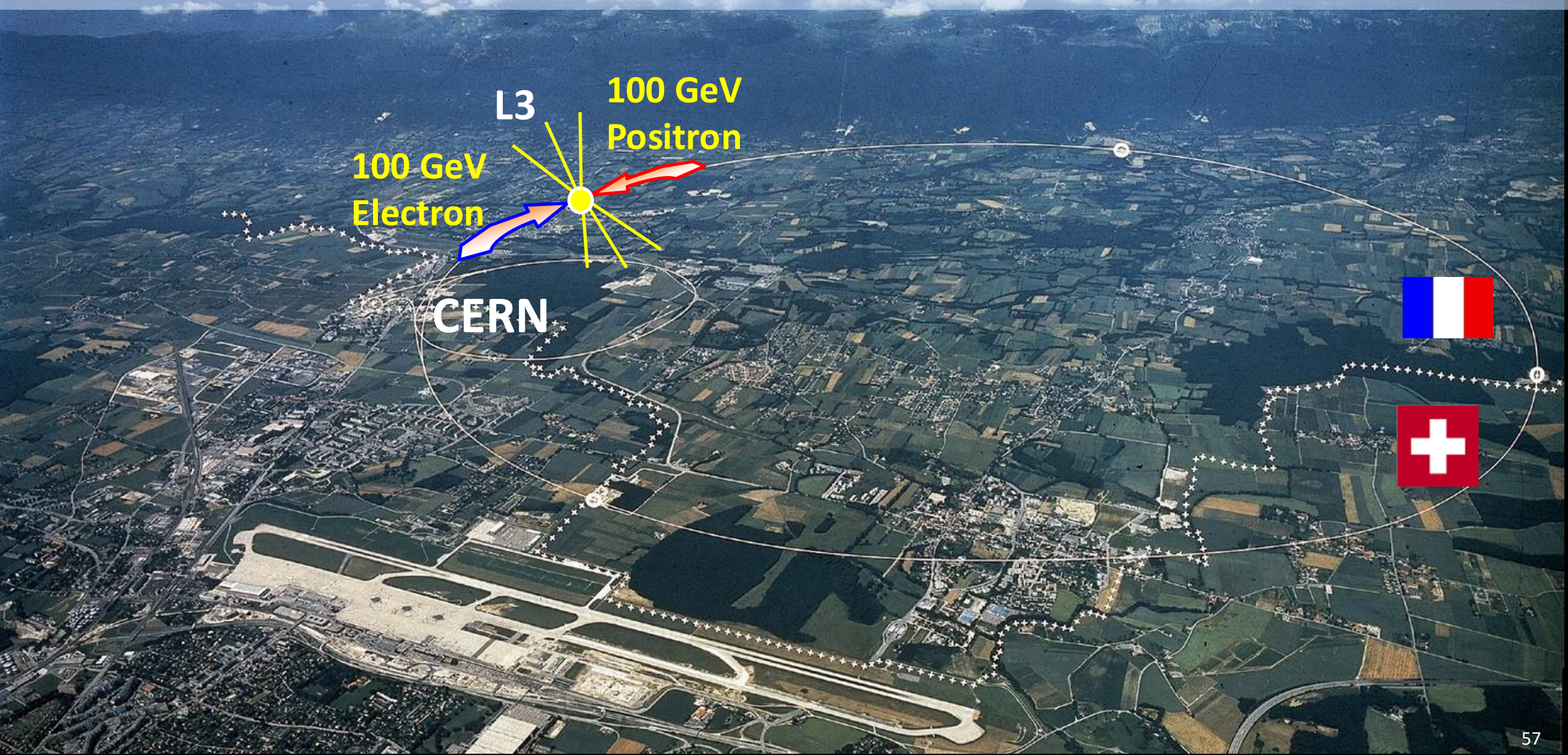
Unfolded energy flow diagram based on figure c, compared with QCD, quark-antiquark production (with average transverse momentum 500 MeV/c) and a model mixing $q\bar{q}$ and phase space.

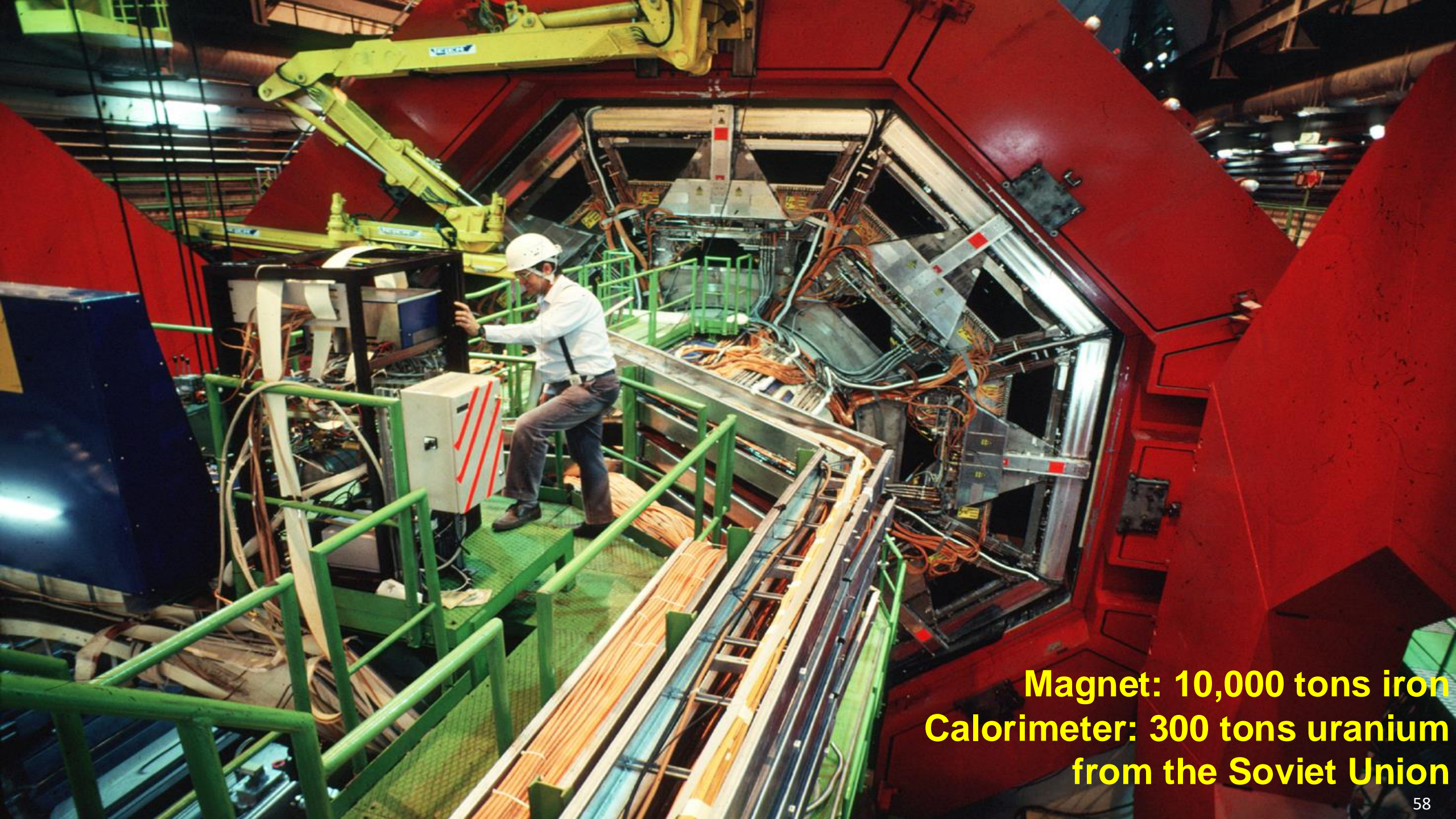
001 8028-18-0208 17 36 509 18 10 1980 American Institute of Physics

17

Each jet contains charged and neutral hadrons. There are many sources of three jet events. By measuring many three jet events, we discovered that their distribution agrees with QCD predictions.

Electron-Positron Physics at even higher energies: L3 Experiment at CERN (1982-2003)

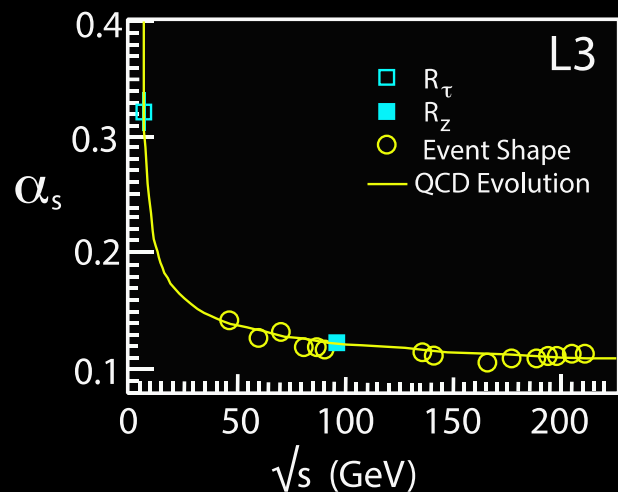
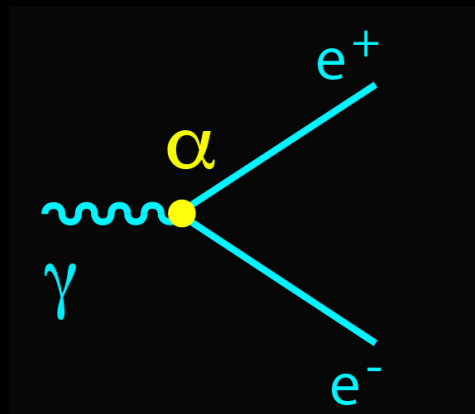
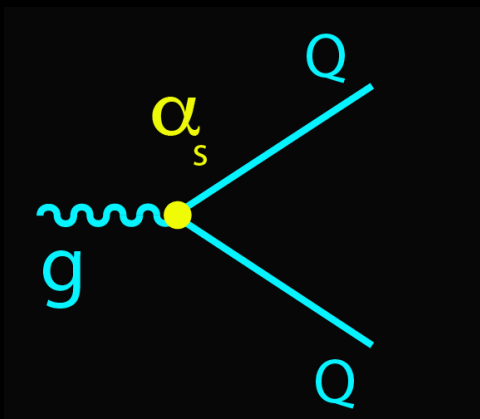




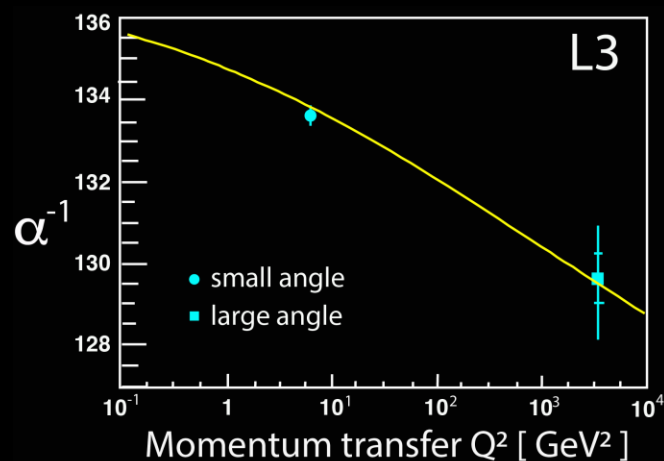
Magnet: 10,000 tons iron
Calorimeter: 300 tons uranium
from the Soviet Union

Important Results

1. Dependence of the coupling “constants” on energy



Phys. Lett. B [476](#) (2000) 40

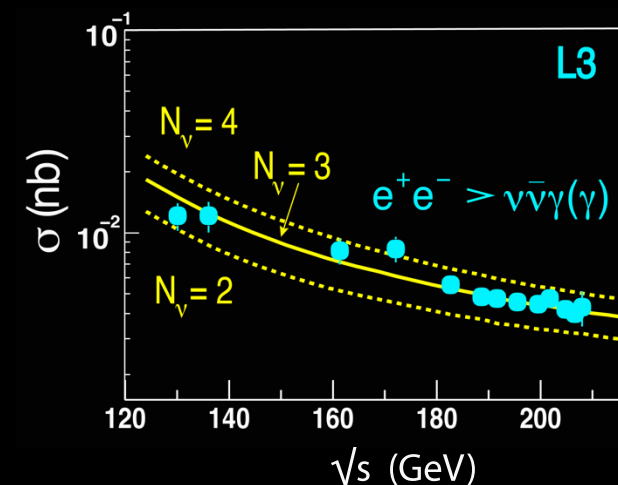


Phys. Lett. B [536](#) (2002) 217

2. Model independent number of neutrinos

$$e^+ e^- \rightarrow \nu \bar{\nu} \gamma$$

$$N_\nu = 2.98 \pm 0.064$$



Phys. Lett. B [587](#) (2004) 16

Ultraviolet Behavior of Non-Abelian Gauge Theories*

David J. Gross[†] and Frank Wilczek

Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540

(Received 27 April 1973)

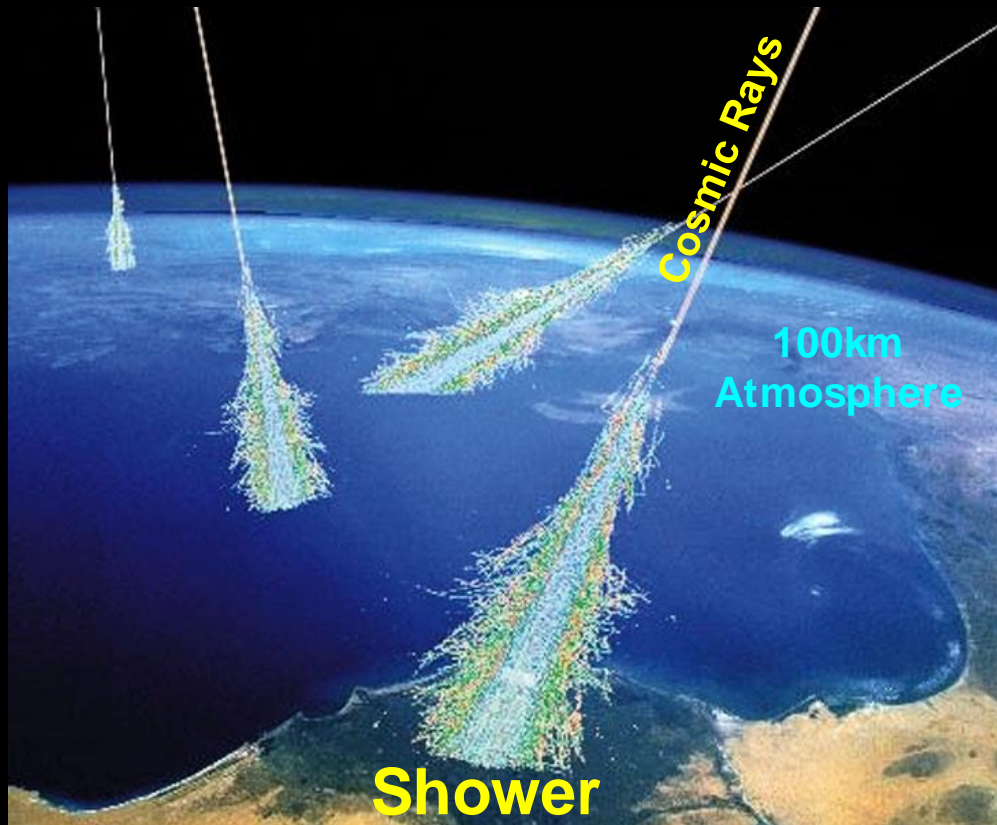
It is shown that a wide class of non-Abelian gauge theories have, up to calculable logarithmic corrections, free-field-theory asymptotic behavior. It is suggested that Bjorken scaling may be obtained from strong-interaction dynamics based on non-Abelian gauge symmetry.

Non-Abelian gauge theories have received much attention recently as a means of constructing unified and renormalizable theories of the weak and electromagnetic interactions.¹ In this note we report on an investigation of the ultraviolet (UV) asymptotic behavior of such theories. We have found that they possess the remarkable feature, perhaps unique among renormalizable theories, of asymptotically approaching free-field theory. Such asymptotically free theories will exhibit, for matrix elements of currents between on-mass-shell states, Bjorken scaling. We therefore suggest that one should look to a non-Abelian gauge theory of the strong interactions to provide the explanation for Bjorken scaling, which has so far eluded field-theoretic understanding.

Electrons and Positrons at highest energies: AMS on the Space Station

Charged cosmic rays have mass,
they are absorbed by the 100 km of Earth's atmosphere
(10m of water)

The properties ($\pm Z$, P) of charged cosmic rays cannot be
studied on the ground.



To measure cosmic ray
charge and momentum requires
a magnetic spectrometer in space



AMS is a space version of a precision detector used in accelerators

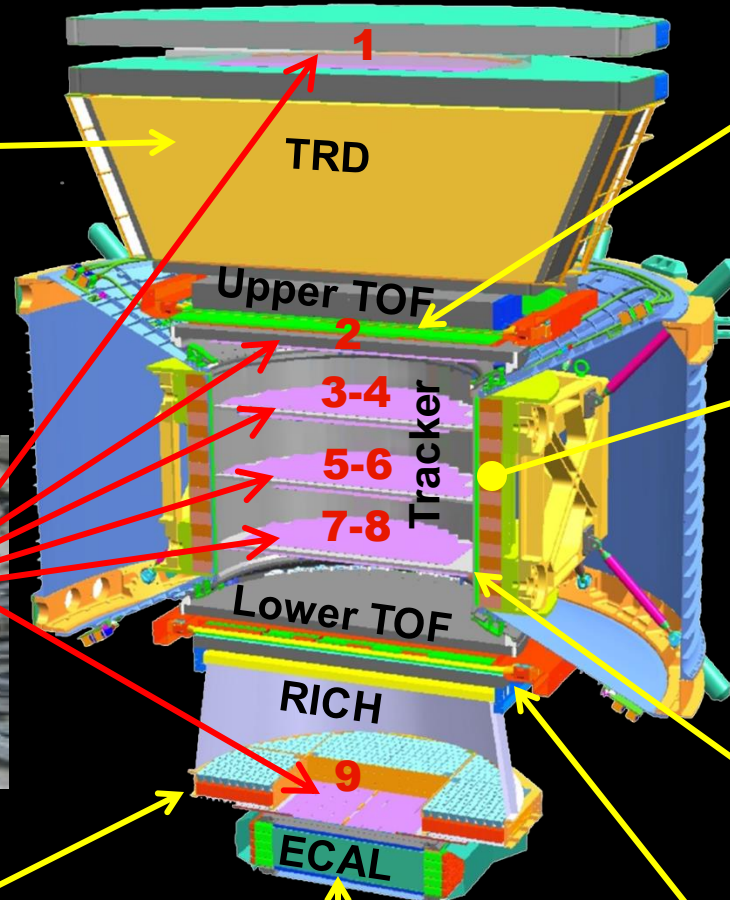
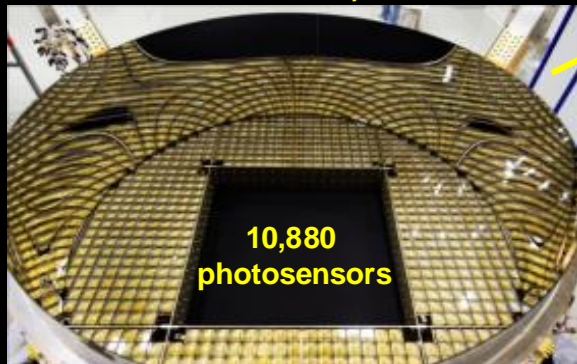
Transition Radiation Detector (TRD)
identify e^+ , e^-



Silicon Tracker
measure Z, P



Ring Imaging Cerenkov (RICH)
measure Z, E



Electromagnetic Calorimeter (ECAL)
measure E of e^+ , e^-



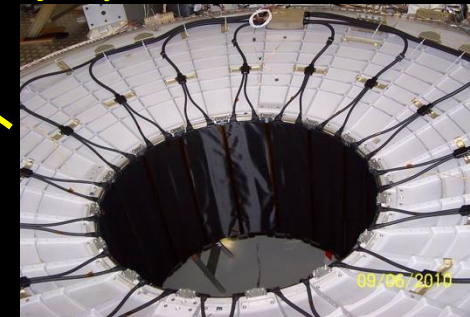
Upper TOF measure Z, E



Magnet identify $\pm Z$, P



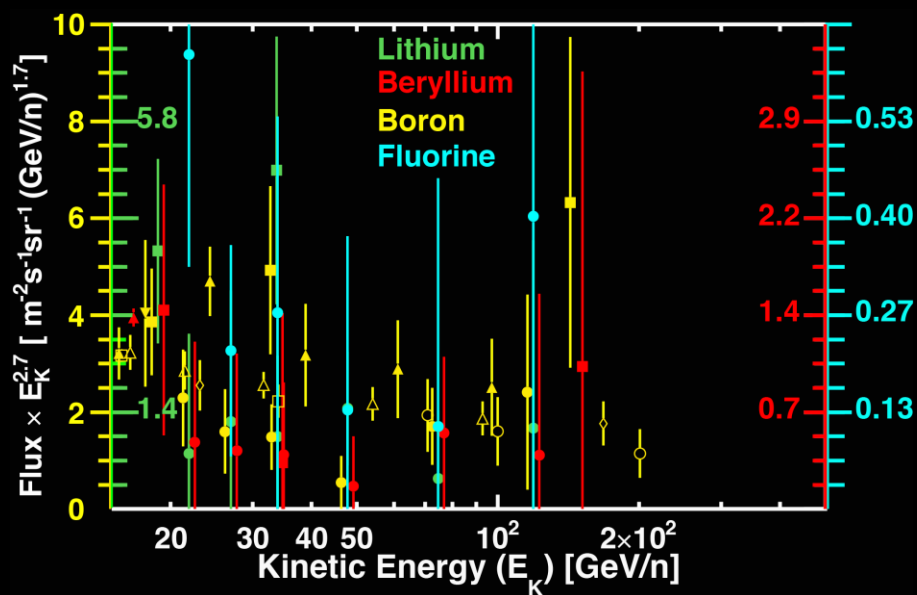
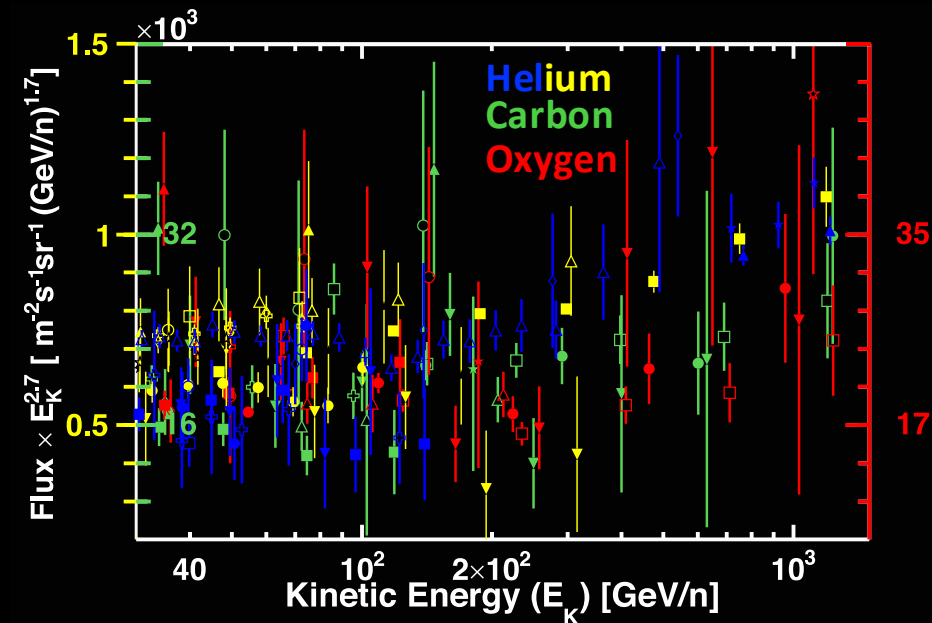
Anticoincidence Counters (ACC)
reject particles from the side



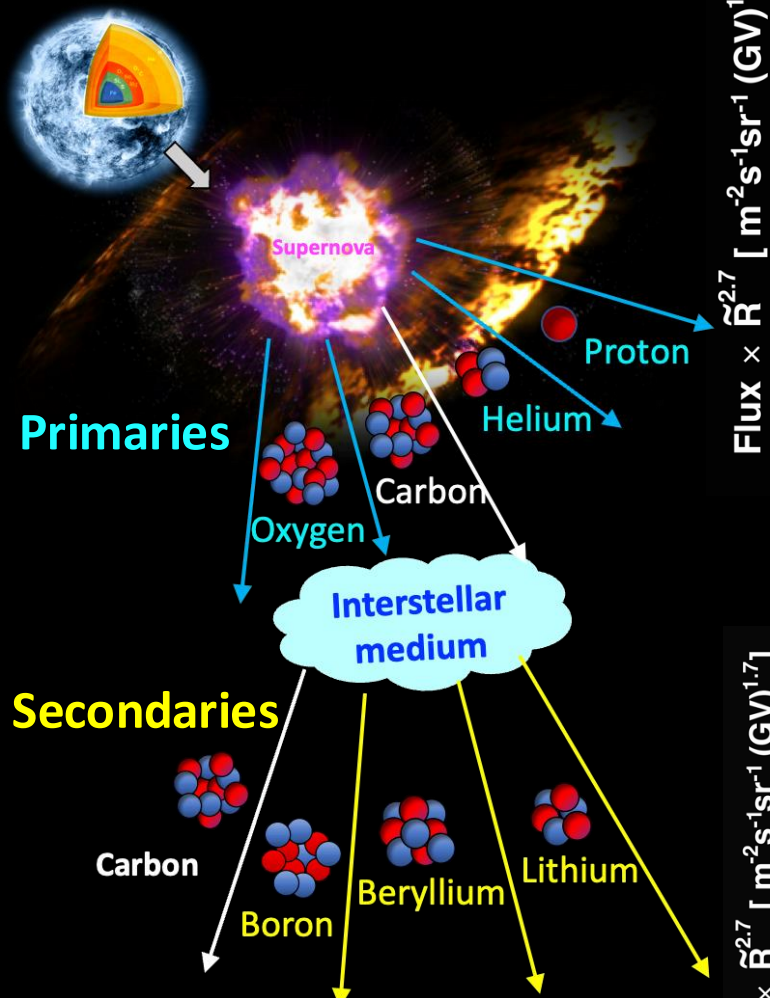
Lower TOF measure Z, E



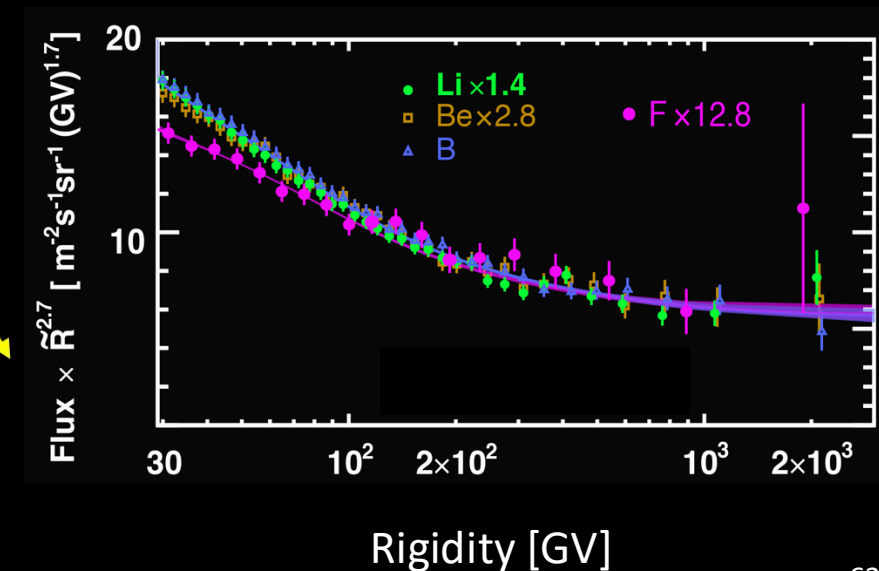
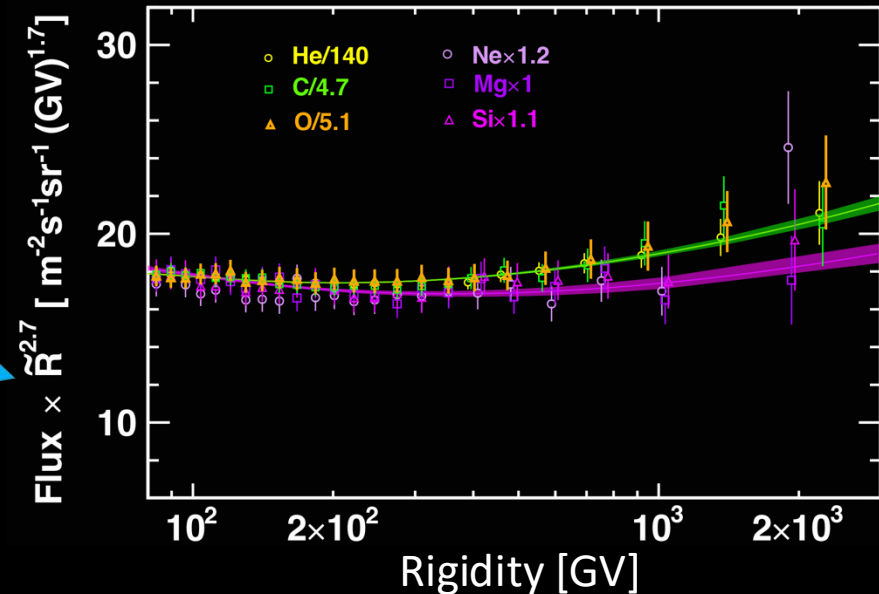
Before AMS



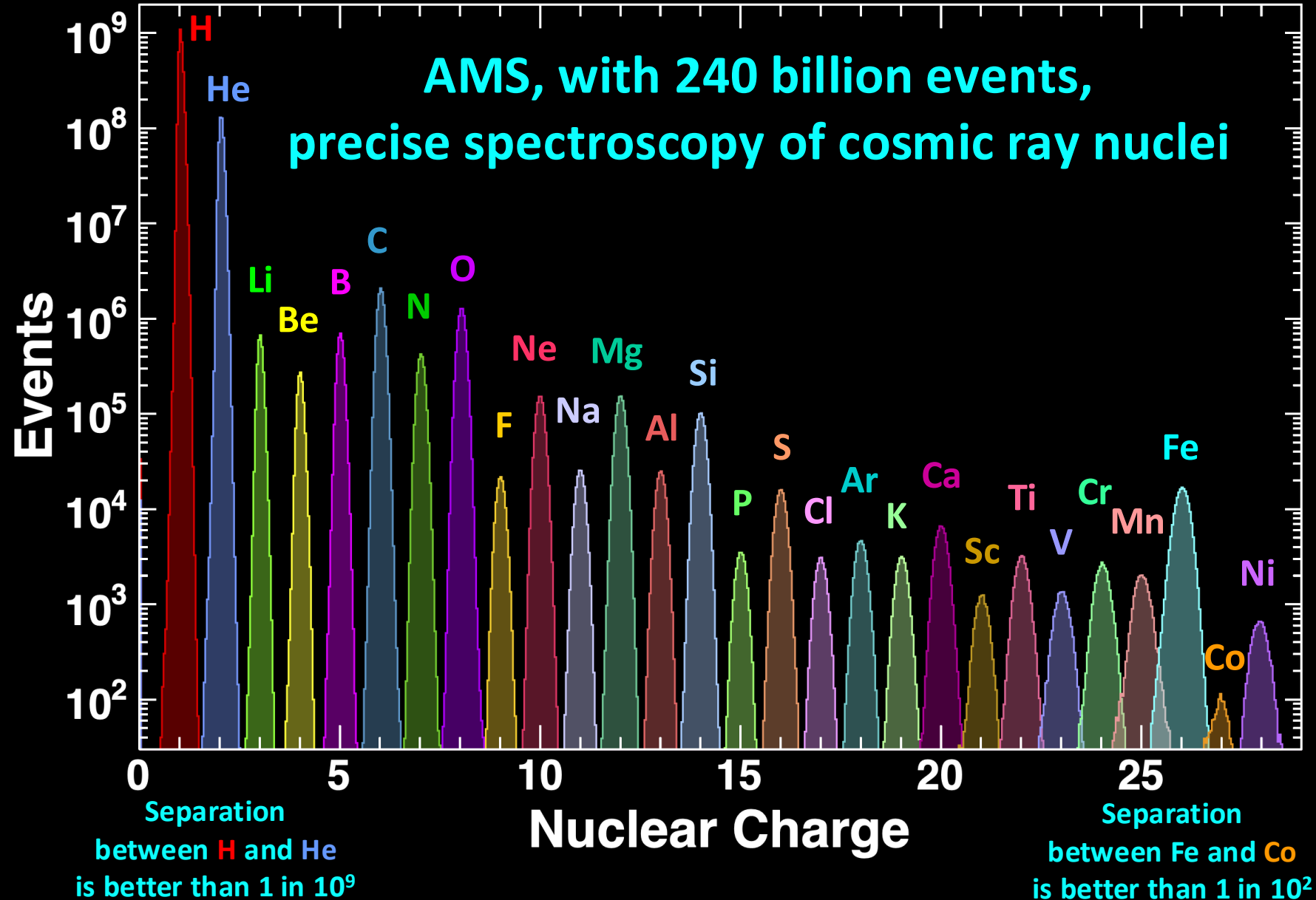
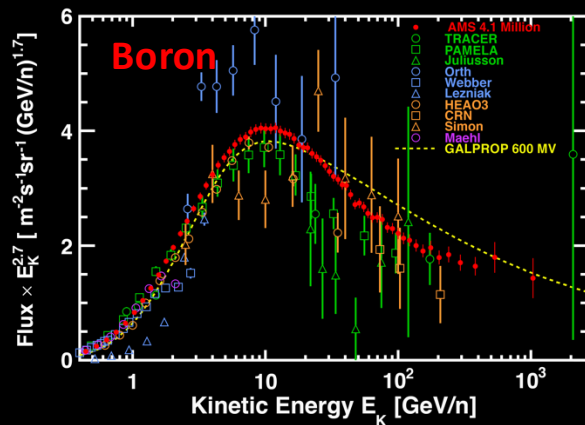
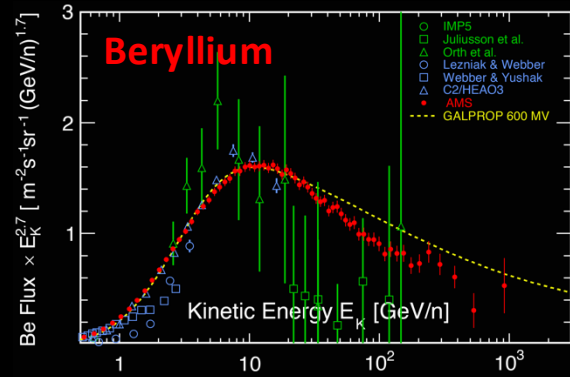
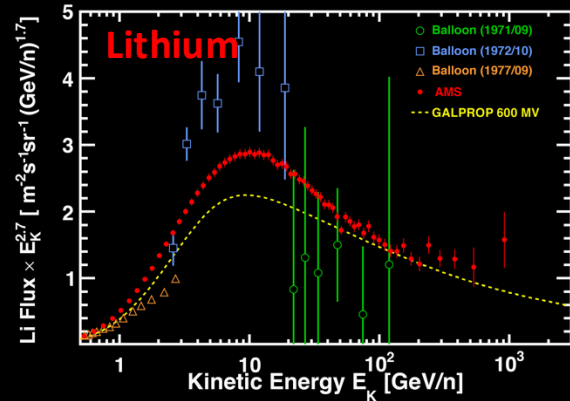
Properties of Cosmic Rays



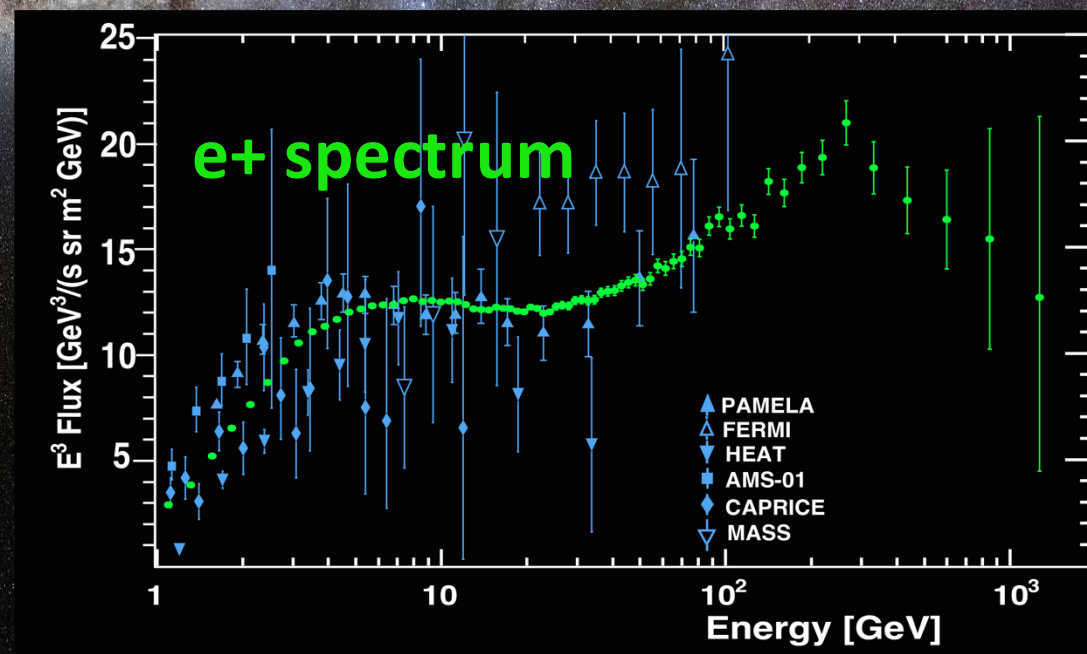
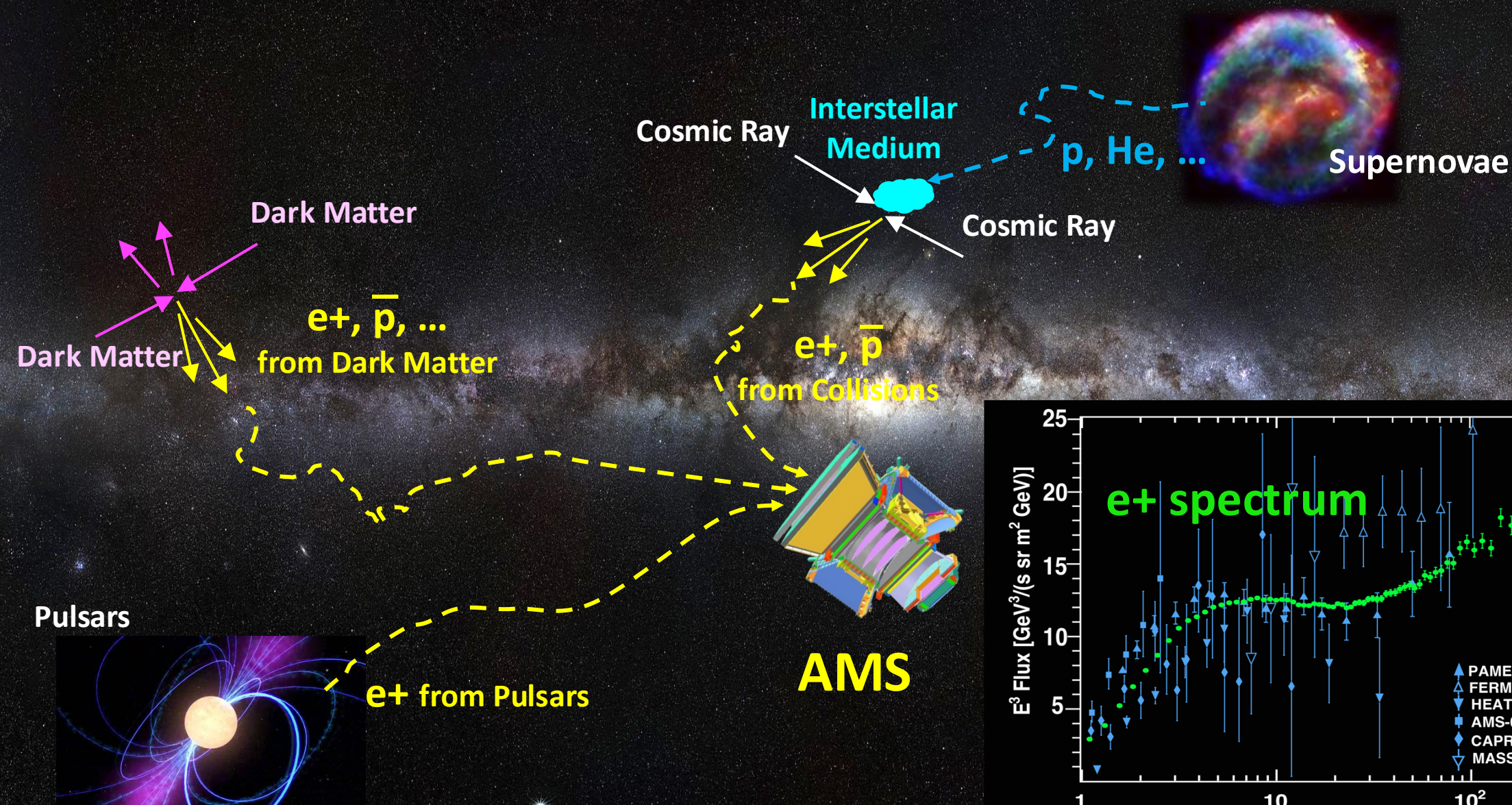
AMS



Spectroscopy of cosmic ray nuclei

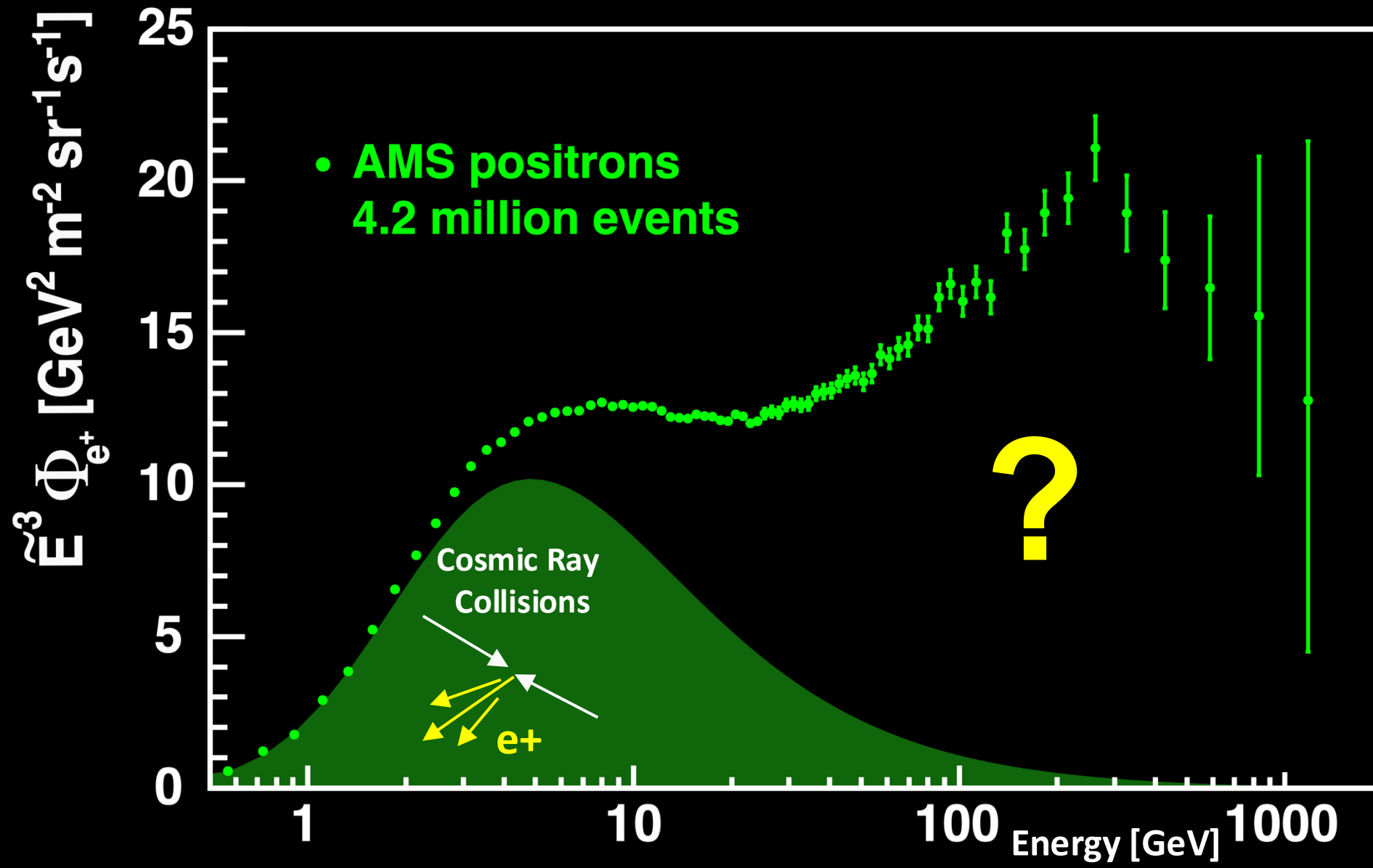


Latest Results on cosmic elementary particles: e^+ , e^- , and \bar{p}

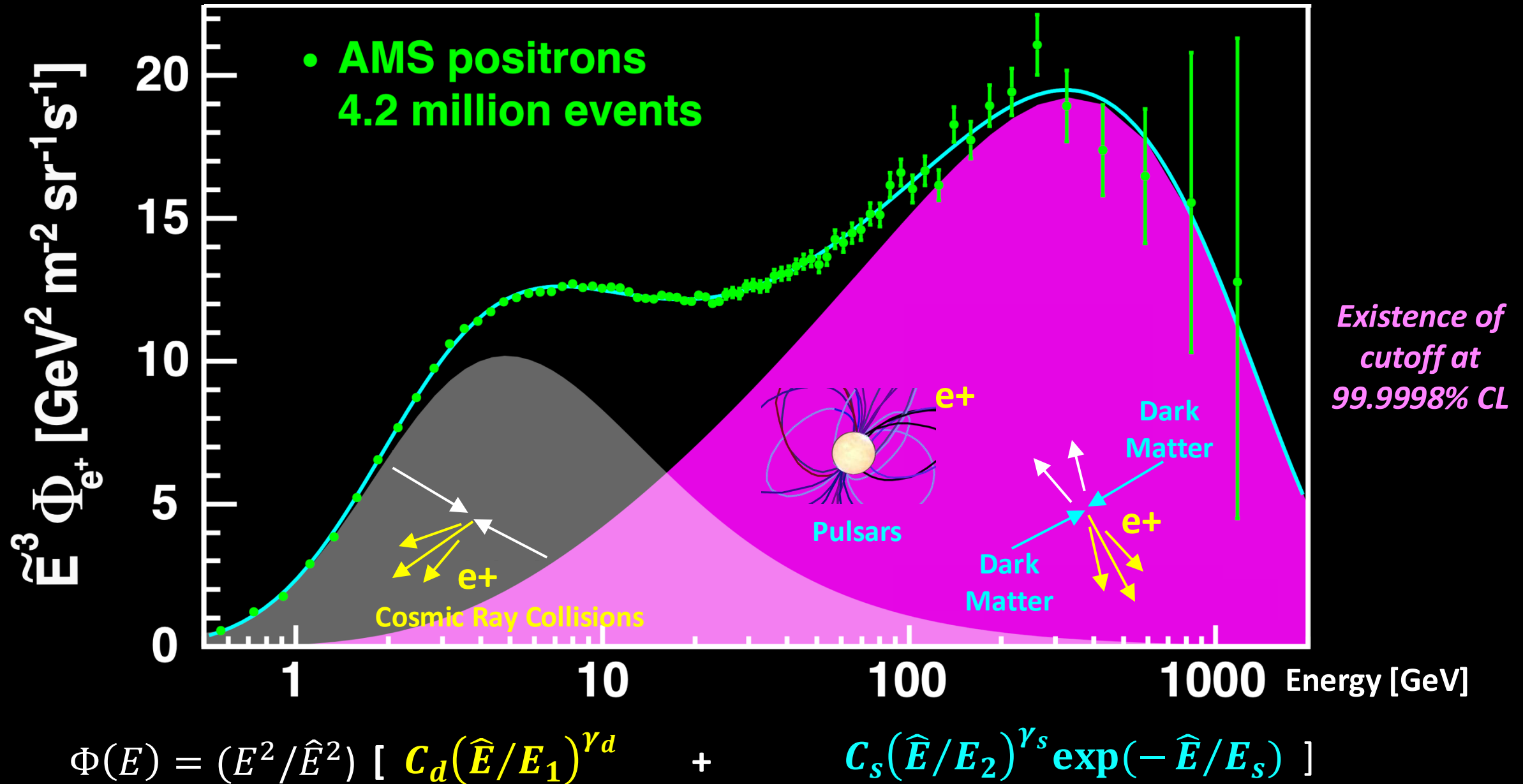


Low-energy positrons come from cosmic ray collisions

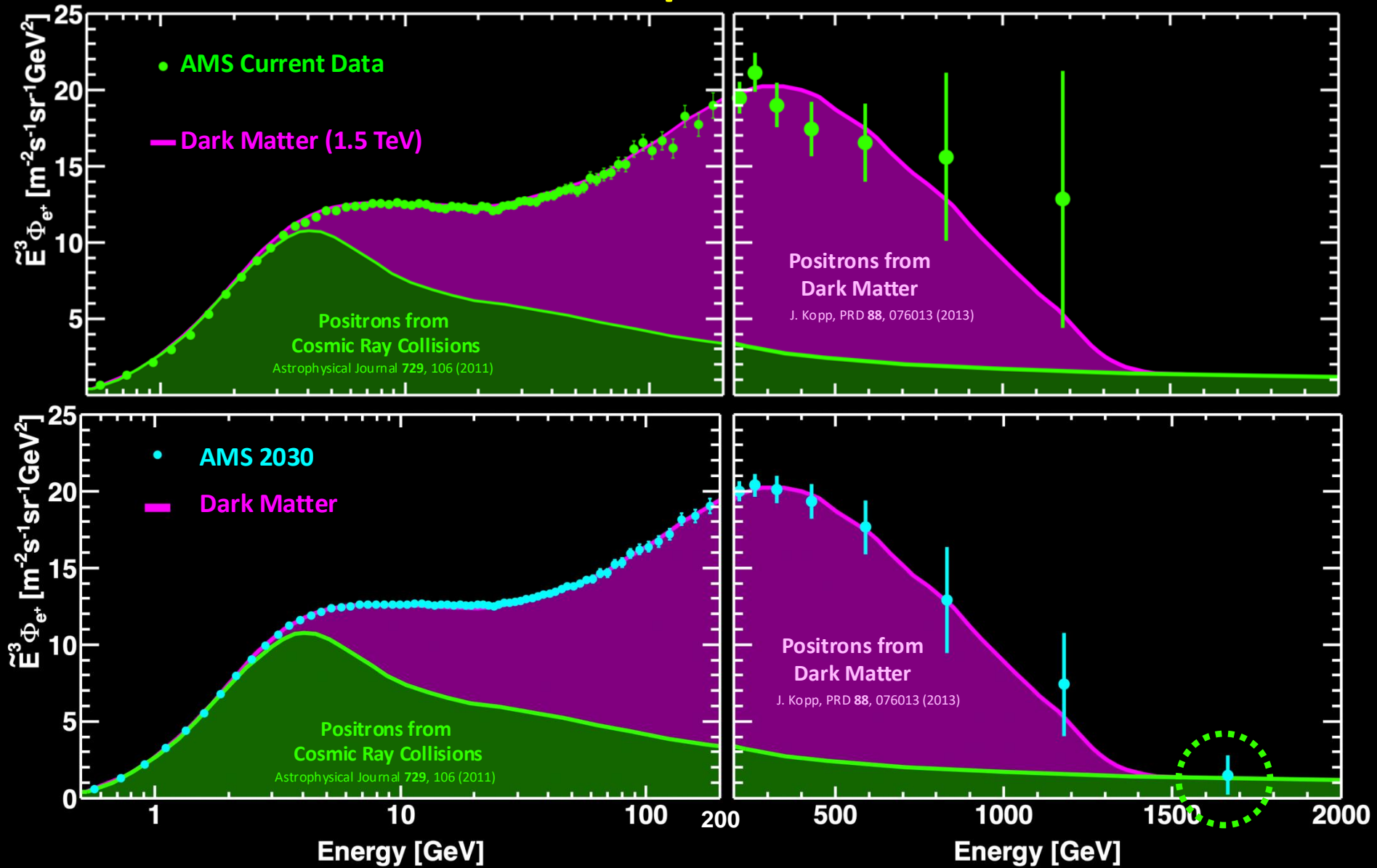
High-energy positrons must come from a new source



The positron flux is the sum of **low-energy part from cosmic ray collisions** plus a **high-energy part from pulsars or dark matter** with a cutoff energy



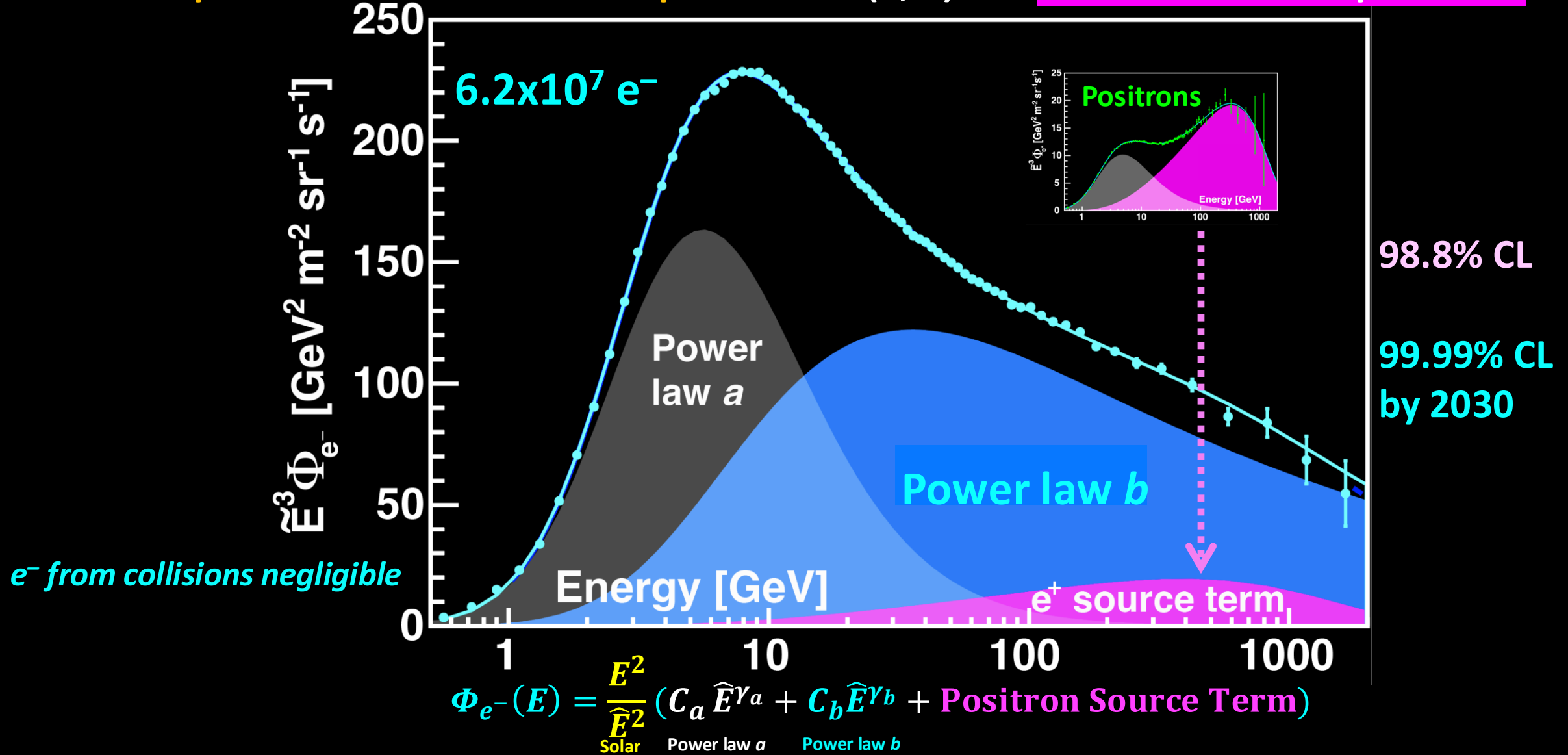
AMS Positron Spectrum to 2030



By 2030, AMS will ensure that the high energy positron spectrum drops off quickly in the 0.2-2 TeV region and the highest energy positrons **only come from cosmic ray collisions** as predicted for dark matter collisions

AMS Result on the electron spectrum

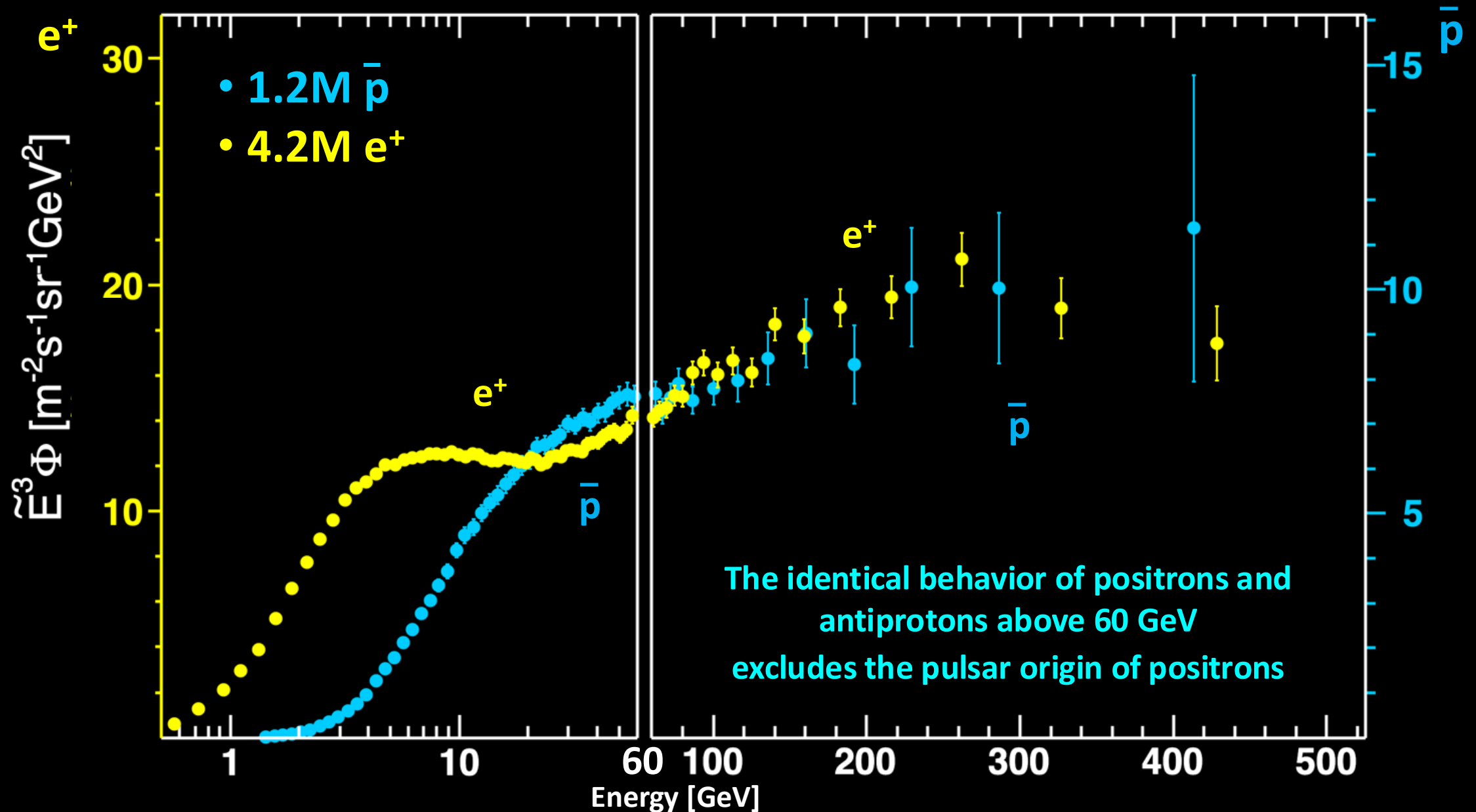
The spectrum fits well with two power laws (a , b) and a source term like positrons



New sources, like Dark Matter or Pulsars, produce equal amounts of e^+ and e^-

Cosmic Antiprotons and Positrons

Above 60 GeV, the \bar{p} and e^+ fluxes have identical rigidity dependence



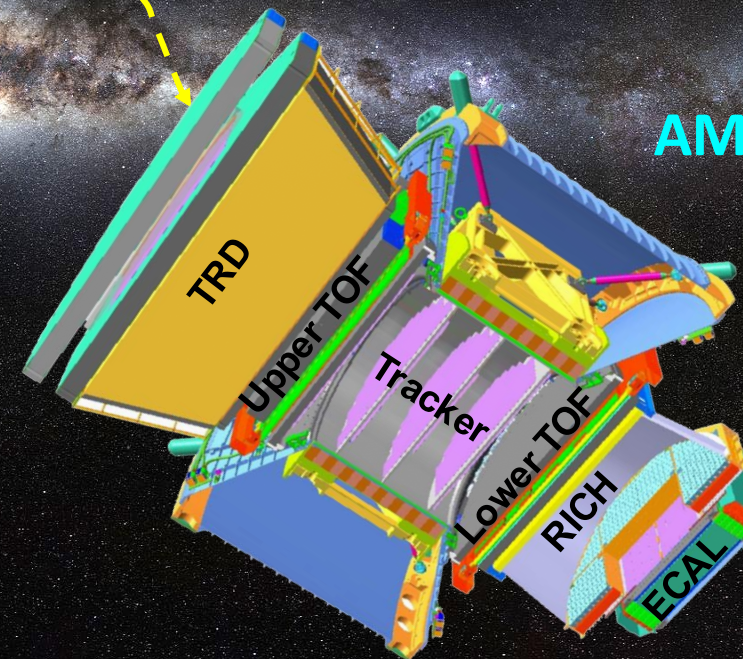
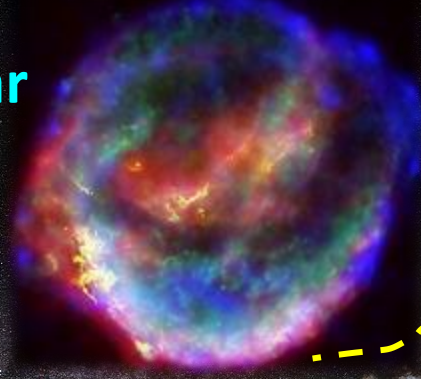
Latest AMS Results on Heavy Antimatter

Matter is defined by its mass M and charge Z .

Antimatter has the same mass M but opposite charge $-Z$.

\bar{D} , \bar{He} , \bar{C} , \bar{O} ...

Antimatter Star



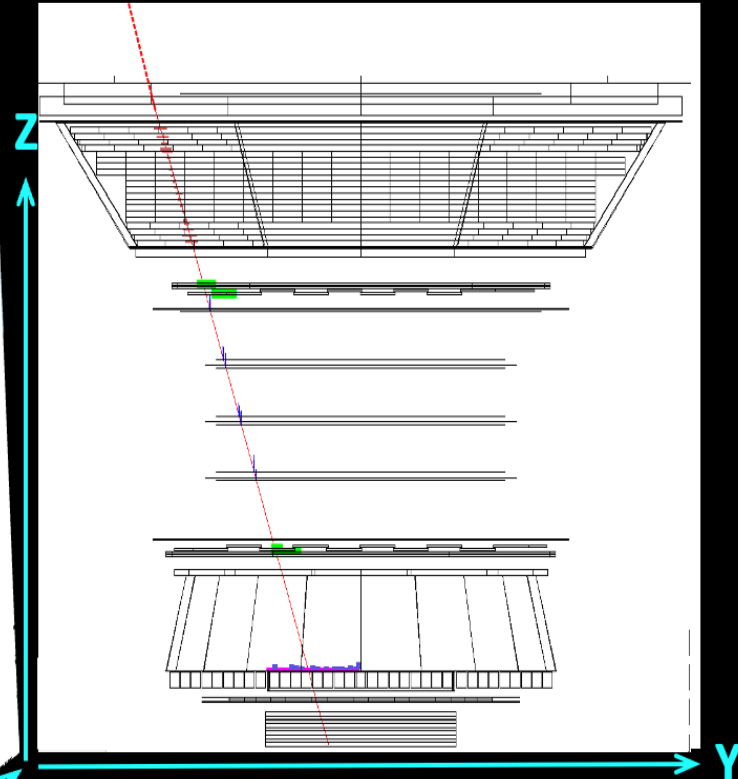
AMS on ISS

AMS is a unique antimatter spectrometer in space

Anti-⁴Helium Candidate

bending plane

non-bending plane



Cherenkov cone in RICH

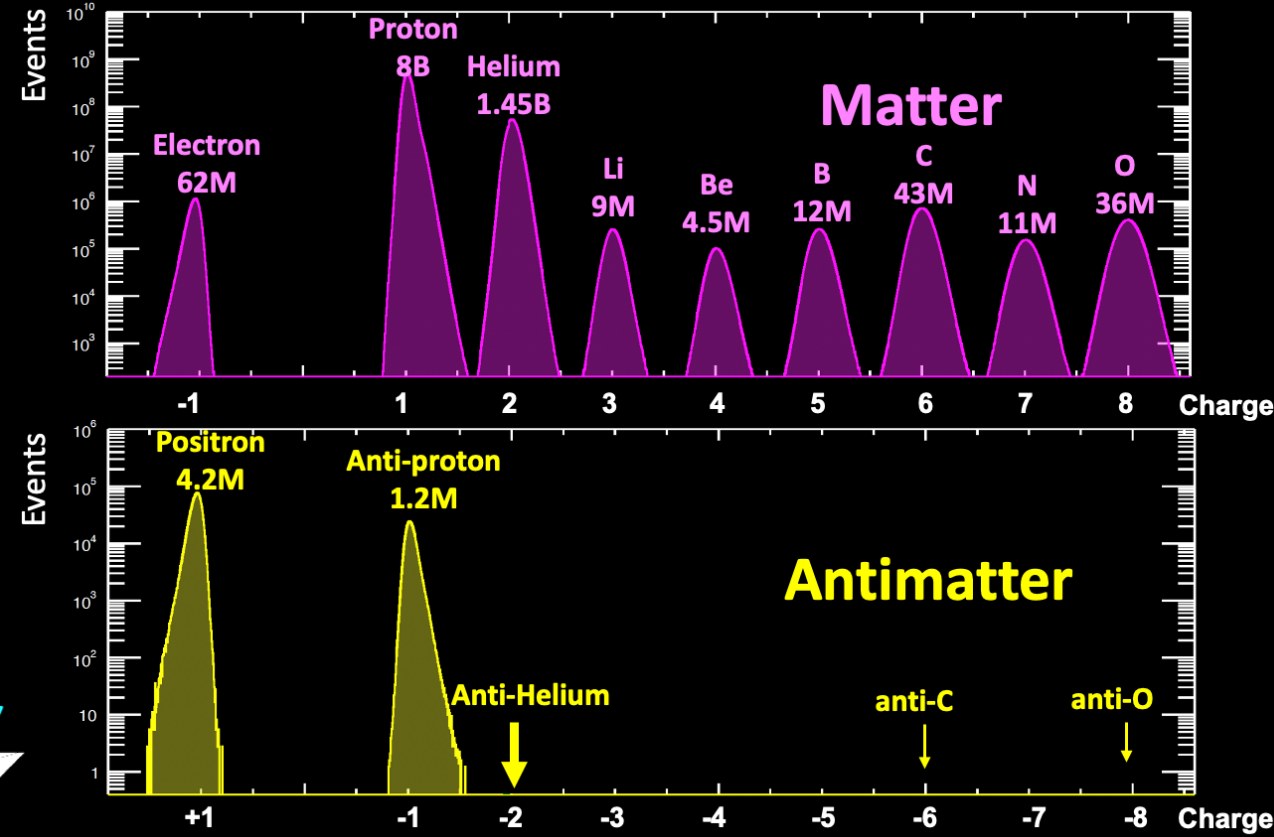
Charge = -2.05 ± 0.05

Mass = $3.81 \pm 0.29 \text{ GeV}/c^2$

⁴He: Charge = +2

Mass = $3.73 \text{ GeV}/c^2$

Current Matter and Antimatter



By 2030, AMS will have additional measurements in the study of antimatter: anti-deuterons, anti-helium, anti-carbon, and anti-oxygen.

AMS Upgrade

increase
acceptance
to 300%

New 4+4m²
Silicon Tracker Planes
transported to ISS via
SpaceX 34
April 2026

Canadarm

+74K
channels

final
installation
by
astronauts

AMS

International Space Station (ISS)

