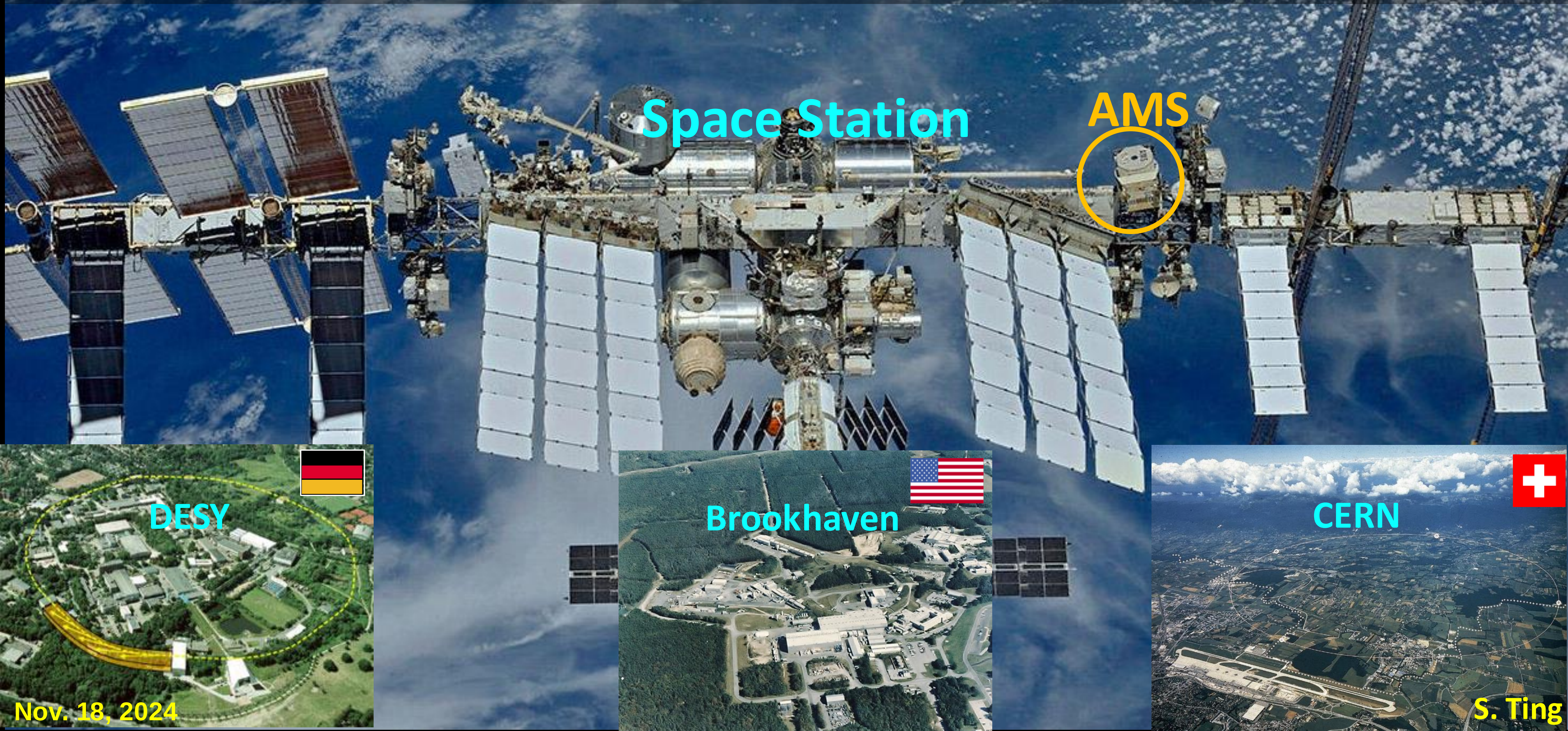
The November Revolution and Fifty Years of Electron and Positron Physics



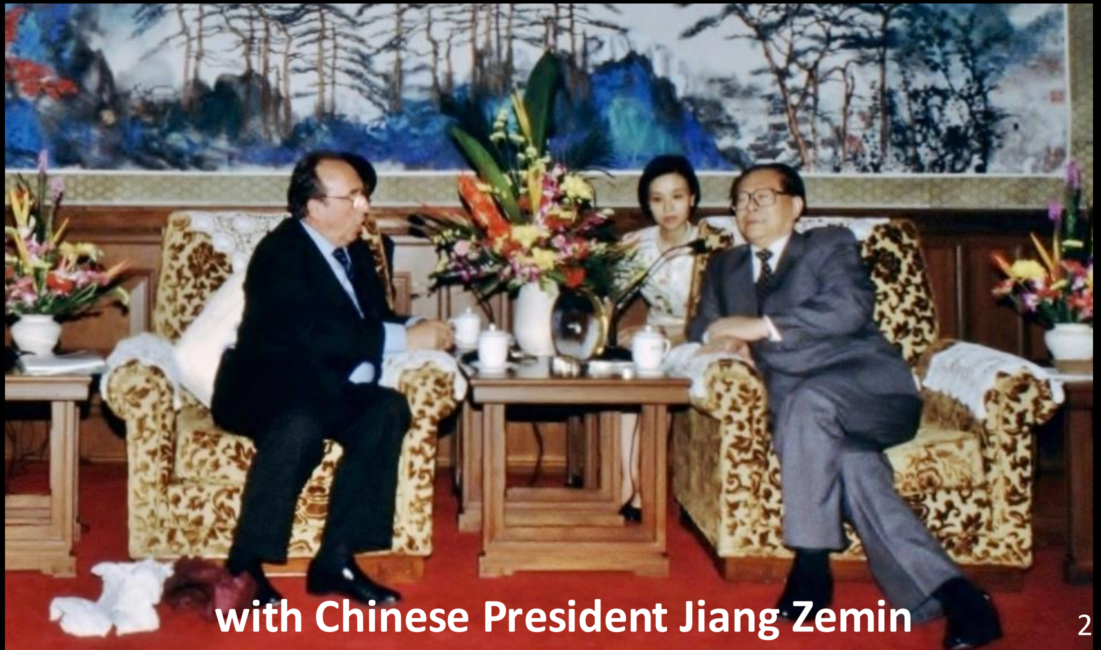
Nov. 18, 2024

S. Ting

My earliest collaborators

G. Cocconi, V. Cocconi, G. Bellattini

L. Maiani and I in New York and Columbia University



with Chinese President Jiang Zemin

It has been 50 years since: The discovery of a new form of matter, Nov 20, 1974

Il Messaggero
di Roma

Anno 96 — N. 296 S. Benigno vescovo Spediz. abbonamento postale Gruppo 1/70 IL GIORNALE DEL MATTINO Un numero L. 150 Mercoledì 20 novembre 1974

LA «PARTICELLA» PUO' DIVENTARE UN EPITAFFIO

I laboratori di Frascati rischiano lo smembramento

- Le preoccupazioni degli scienziati espresse a Pieraccini che ha porto le congratulazioni per l'eccezionale studio.
- Oggi arriva il prof. Ting che ha individuato l'« oggetto » a Brookhaven.
- Due nomi differenti trovati negli Usa per questo nuovo «personaggio» del mondo della fisica.

Un particolare di « Adone », l'anello di accumulazione, dove è avvenuta la individuazione della nuova particella elementare atomica

di LUCIANO RAGNO

Pieraccini ha portato le congratulazioni. E i fisici ne hanno approfittato per uno « sfogo ». « L'individuazione a Frascati della nuova particella elementare atomica due giorni dopo la sua scoperta negli Stati Uniti può essere l'epitaffio dei laboratori nazionali ». Il vice direttore dell'istituto nazionale di fisica nucleare prof. Giorgio Salvini è stato chiaro. Ed in molti si sono dichiarati d'accordo. I laboratori nazionali che hanno fatto convergere sull'Italia l'interesse del mondo scientifico corrono il rischio di essere smembrati. Il Cipe ha già deciso. I laboratori, che ora dipendono dal Cnen, dovrebbero essere privati della sezione «alte energie» destinata a passare all'istituto nazionale di fisica nucleare che non ha bilanci tali da assicurare la continuazione delle ricerche. «Le rimostranze non vengono fatte a titolo personale — ha detto Salvini — molti dei ricercatori di Frascati hanno un telegramma in tasca che assicura un posto negli USA, o in Germania o a Ginevra ». « Il prof. Bellettini, direttore dei laboratori: « Da quattro anni non viene assegnata una borsa di studio. Il nostro centro di calcolo è più piccolo di tante piccole università ».

Pieraccini ha recepito lo sfogo e non ha lasciato passare tempo per rispondere. « Il risultato di valore internazionale ottenuto in questi giorni — ha detto il Ministro — dà ai laboratori nazionali un potere contrattuale altissimo e questo è il primo motivo di ottimismo. Ma è anche indispensabile che fra voi tecnici ci sia una completa chiarezza sulla ristrutturazione degli organismi e sui programmi, compiti e necessità. Altrimenti sarebbe l'argomento più controproducente. Al Cipe si può sempre tornare a discutere sui programmi e sui finanziamenti. In ogni caso sarà una dura battaglia per la quale dovranno essere mobilitate forze politiche, della cultura e dell'informazione ».

Ha aggiunto: « C'è la resistenza di una classe politico-amministrativa di cultura non semplicemente umanistica, ma antiquata ».

Vedremo gli sviluppi.

Intanto si continua a studiare la particella. Rimane ancora un mistero. E' sempre valida la risposta che ha dato uno studioso alla richiesta sul ruolo del nuovo «personaggio» del mondo della fisica; «ad essere sincero devo dire che non lo so». Comunque, un progresso è stato fatto: il nome. A Brookhaven hanno deciso di chiamarla con la lettera «j». A Stanford «psi», cioè la ventitreesima lettera dell'alfabeto greco, minuscola. Da Frascati, all'annuncio americano si è risposto: « Non ci preoccupiamo della denominazione. Non ci compete. Abbiamo solo confermato non scoperto la esistenza della particella. Per noi potrebbe anche chiamarsi, per non fare torto a nessuno, «j-psi». Diplomazia a livello della fisica.

Un mistero la particella. Come se non bastasse è nato un « giallo ». Chi ha scoperto per primo questo nuovo «oggetto»? Brookhaven o Stanford? In un primo momento era stato detto che l'Università di Long Island aveva individuato l'esistenza della particella senza riuscire a stabilire la «stranezza». A questo, si affermò, era giunta l'équipe di fisici di Stanford. Ora si è appreso che la scoperta è stata contemporanea. Sarebbe andata così. Il prof. Samuel Ting, che insegna al MIT di Boston, telefona l'11 novembre sera, al collega prof. Wolfang Panofsky di Stanford per esporgli la sostanza delle osservazioni compiute con altri tre ricercatori, (Becher, Min Chen, Lee). «Non riesco a crederci — risponde Panofsky — poiché anche noi, senza aver concordato alcunché con altri studiosi abbiamo compiuto gli stessi esperimenti che hanno dato in pratica identici risultati ».

Sulla «Physical Review Letters » — la più prestigiosa rivista di fisica — compariranno il 2 dicembre le relazioni di Brookhaven e Stanford. Ma anche quella degli scienziati di Frascati. Un grande riconoscimento per l'équipe di ricercatori italiani che hanno svolto un lavoro di alto contenuto scientifico. E lo dimostra il fatto che il prof. Ting giungerà oggi a Frascati.

Domani senza giornali Emilia, Toscana e Marche

La Federazione nazionale della stampa italiana, e la Federazione unitaria poligrafici Cgil-Cisl-Uil comunicano: « Giovedì 21 novembre non usciranno i quotidiani del mattino e del pomeriggio in Emilia, Toscana e Marche, per lo sciopero dei giornalisti e dei poligrafici che inizierà domani mercoledì 20. Si conclude, così, con questa quarta fascia regionale, l'azione sindacale promossa dalla Fnsi e dalla Federazione unitaria poligrafici Cgil-Cisl-Uil per la difesa della libertà e della pluralità dell'informazione e per la riforma democratica della Rai-Tv. Le astensioni dal lavoro — che si sono articolate regionalmente nell'arco di quattro settimane e, che hanno riguardato tutti i mezzi di informazione — hanno inteso sviluppare l'azione che i sindacati del settore stanno portando avanti da oltre due anni per stimolare governo e forze politiche ad interventi legislativi capaci di liberare l'informazione da condizionamenti e pressioni, contribuendo così alla crescita democratica del nostro Paese ».

Vaticano

In dicembre il congresso dei gesuiti

Comincerà il primo dicembre prossimo a Roma, nella sede centrale di Borgo Santo Spirito, la trentaduesima congregazione generale della Compagnia di Gesù alla quale parteciperanno 240 congregati in rappresentanza di 30 mila membri sparsi in 80 nazioni. E' la settima volta, in oltre 400 anni di storia dell'Ordine, che la congregazione non viene convocata specificamente dopo la morte del generale per eleggerne il successore. L'ultima volta risale al 1964 quando appunto per la morte del generale Jaessens venne convocata la congregazione, che si articolò in due sessioni durante le quali venne eletto successore di Sant'Ignazio, il fondatore dell'Ordine, lo spagnolo Pedro Arrupe. La riunione di dicembre, come ha preannunciato padre Arrupe — ha lo scopo di « ricercare, precisare e concretizzare più efficacemente il genere di servizio che la compagnia deve rendere alla Chiesa in questo periodo di rapido cambiamento del mondo e di rispondere così alla sfida che ci lancia il mondo ». Dopo avere indicato la povertà come uno degli elementi capitali della vita della « Compagnia », padre Arrupe ha dichiarato anche che la povertà aveva subito deviazioni negli ultimi anni « a causa di abusi commessi nella applicazione di talune direttive date all'ultima congregazione generale » e ha sostenuto la necessità di ritrovare una « pratica più esigente della povertà »

Nuovi criteri per la valutazione dei film

Approvati dal Consiglio permanente della conferenza episcopale italiana ed entrati in vigore dopo sei mesi di sperimentazione, il primo ottobre scorso, i nuovi criteri per la valutazione e classificazione dei films e le nuove norme disciplinari per le sale dipendenti dall'autorità ecclesiastica sono state presentate ieri alla stampa.

Aspetto qualificante dei nuovi criteri, come hanno fatto osservare due responsabili della commissione nazionale, è la prevalenza data alla valutazione critica e morale del film piuttosto che allo spettatore, considerato in passato (in base all'età o maturità) idoneo o meno a vedere un dato film. I nuovi criteri prevedono una valutazione generale e una specifica. Per la prima vengono utilizzati i seguenti termini: accettabile (film positivo o comunque privo di elementi negativi); raccomandabile (film positivo di elevato valore formale e ricco di contenuti etico-culturali); discutibile (film che non può essere accettato in tutti i suoi aspetti); inaccettabile (film negativo per i contenuti etico-culturali che propone o per il « modo licenzioso e aberrante » con cui è trattata la materia).

Segue la specificazione data dai termini: semplice, difficile, ambiguo, scabroso, negativo, licenzioso. La classificazione può anche portare una annotazione sintetica nel caso di films accettabili o raccomandabili adatti anche per famiglie o adolescenti.

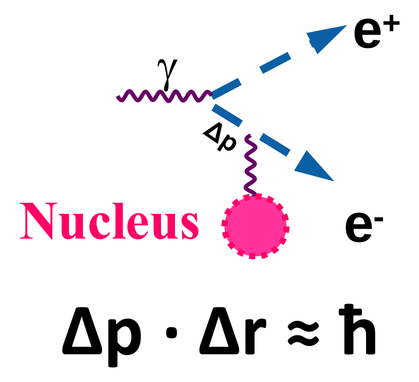
Experiments leading to the discovery of a new form of matter:

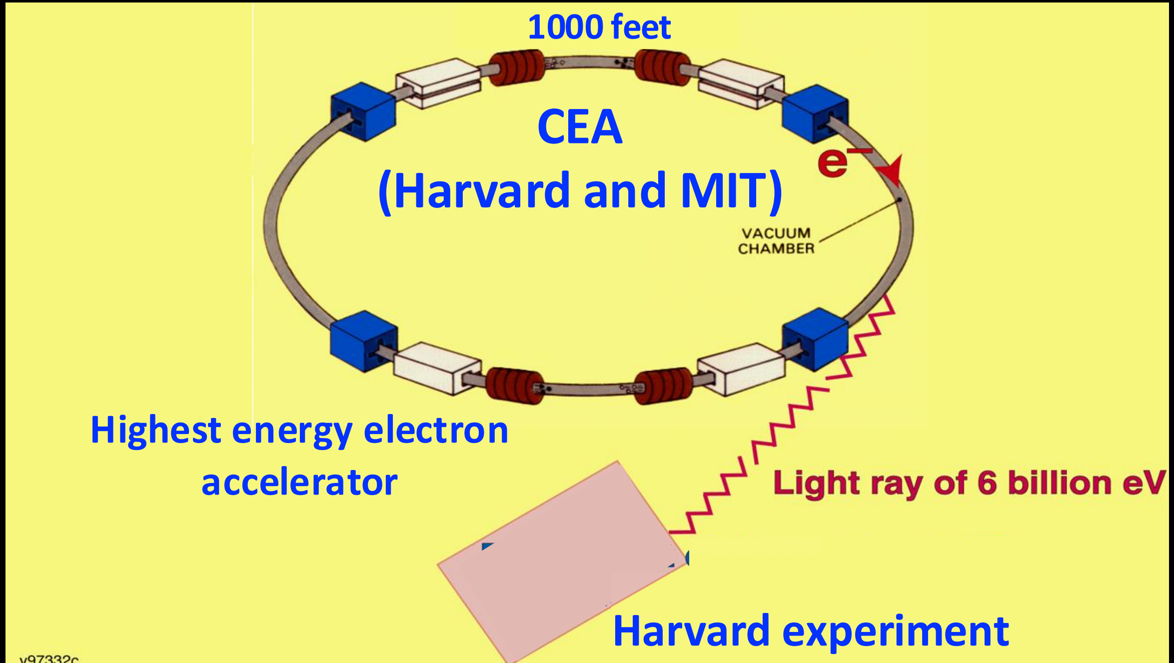
First Experiment - Measuring the size of electrons

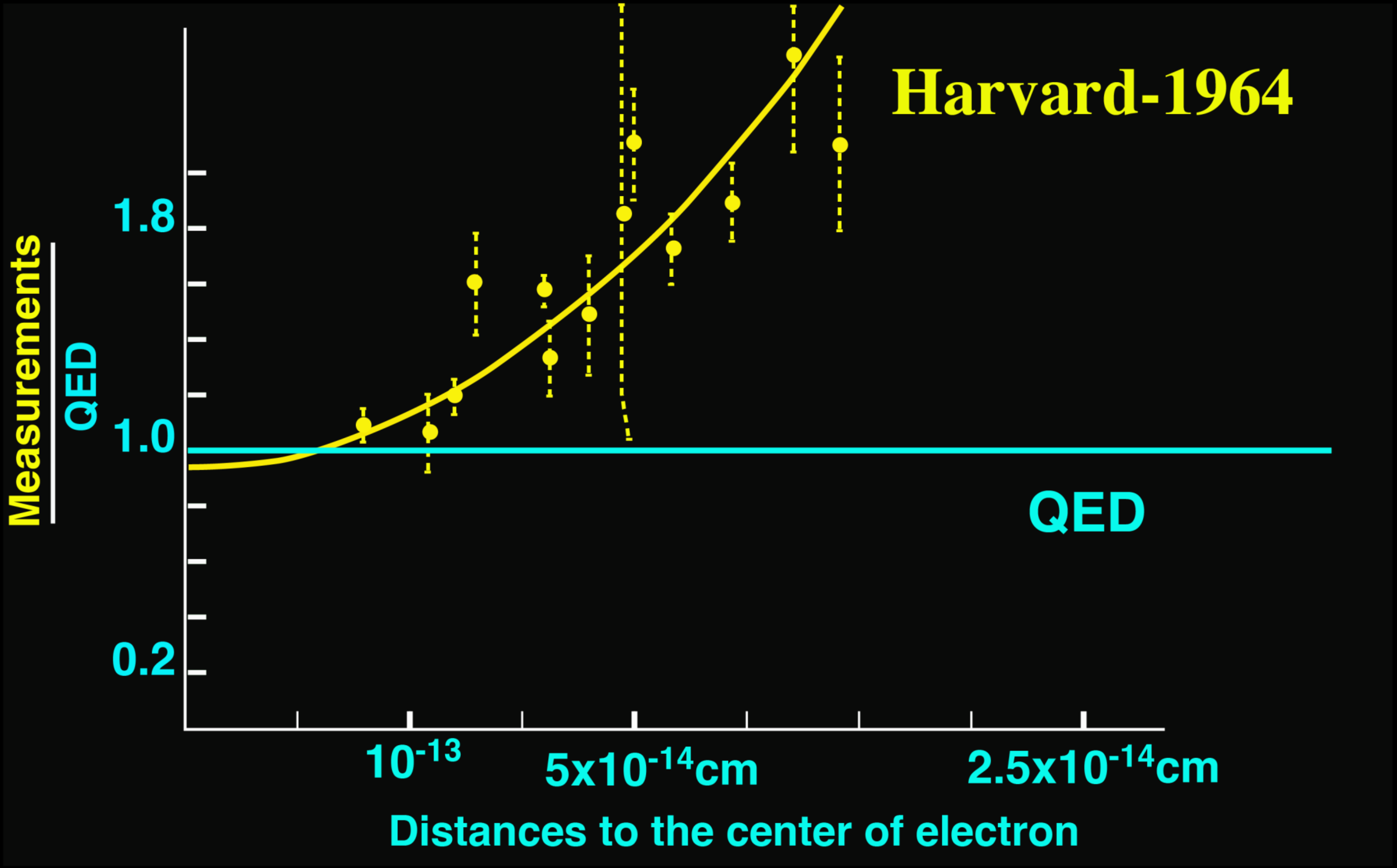
Modern Electromagnetic Theory (QED) requires that electrons have no measurable radius (Feynman, Schwinger, Tomonaga - 1948)

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 ~ 10^{-13} to 10^{-14} cm.

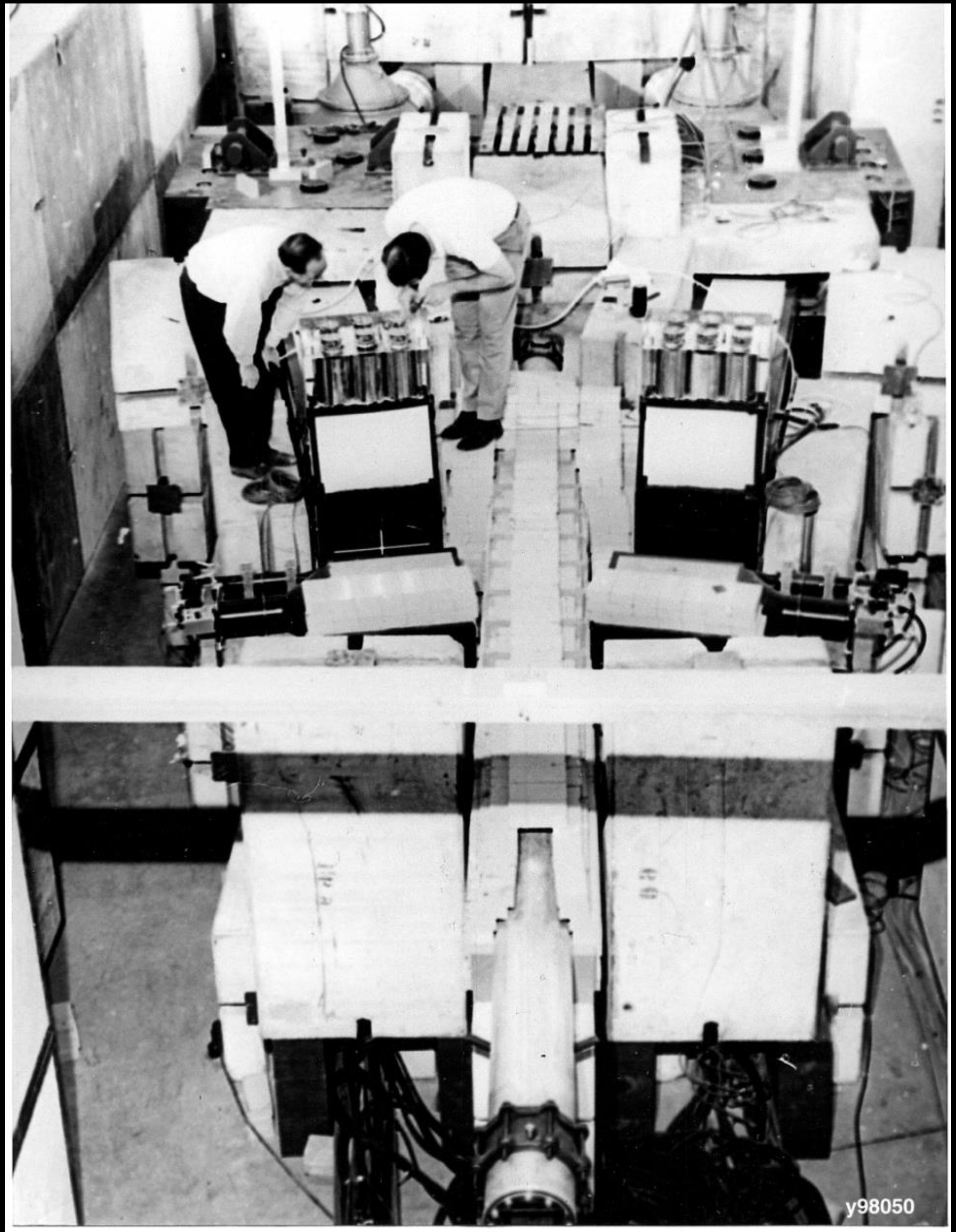
Most importantly, this experiment was independently
confirmed by a group at the Cornell Electron Accelerator.

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.

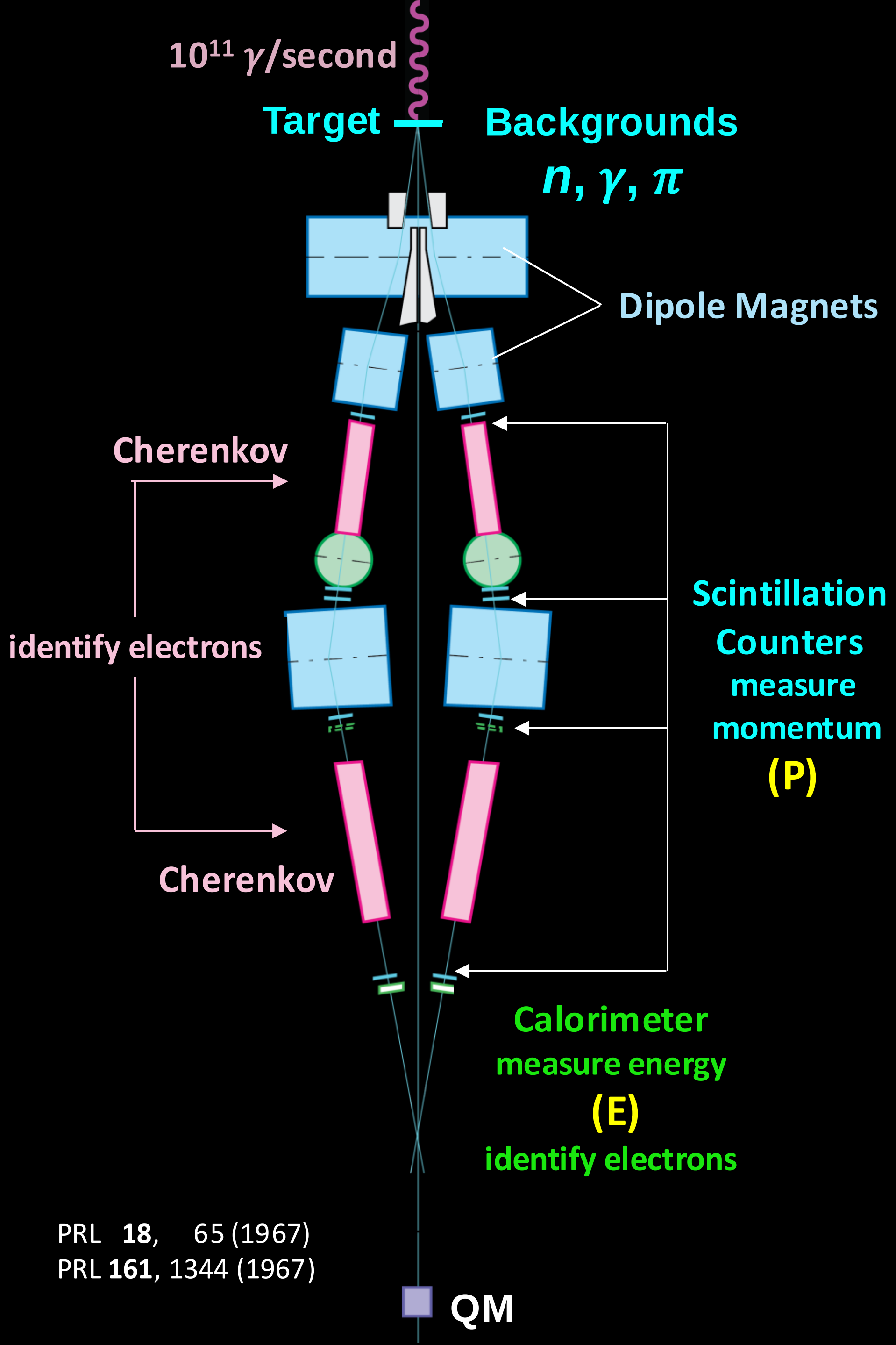
I decided to move to
the newly built 6 billion electron-Volt electron accelerator (DESY)
in Hamburg, Germany
to re-measure the size of the electron

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



Measuring electron-positron pairs (1966)

Unique features

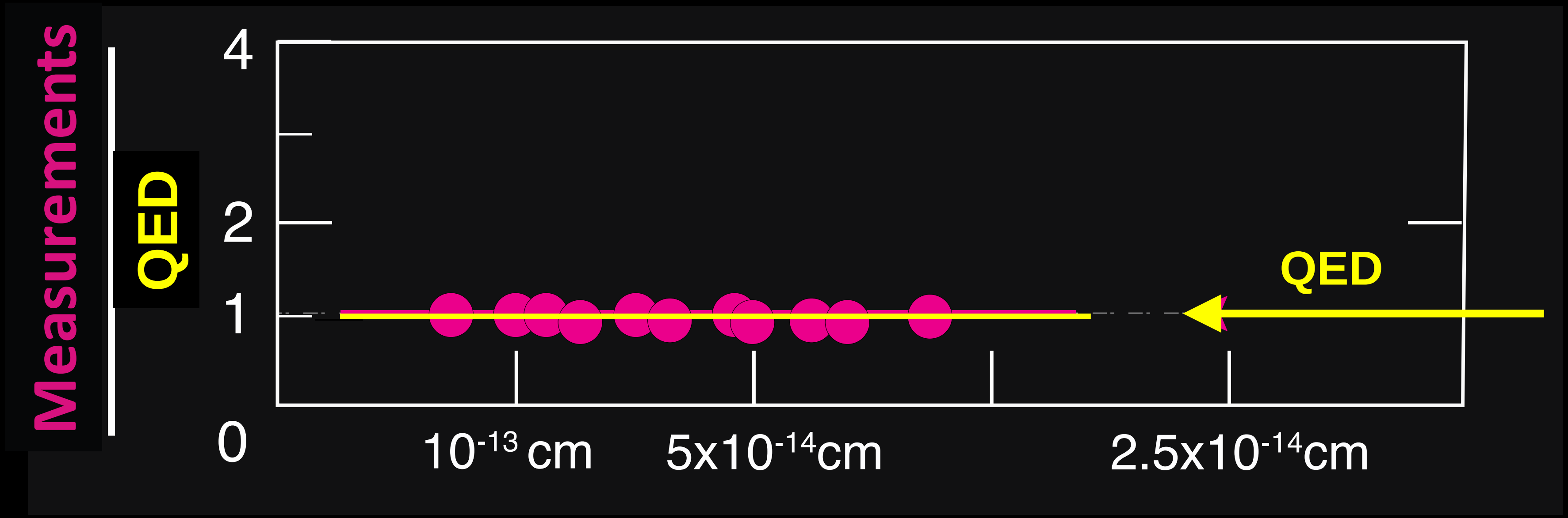


PRL **18**, 65 (1967)
PRL **161**, 1344 (1967)

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

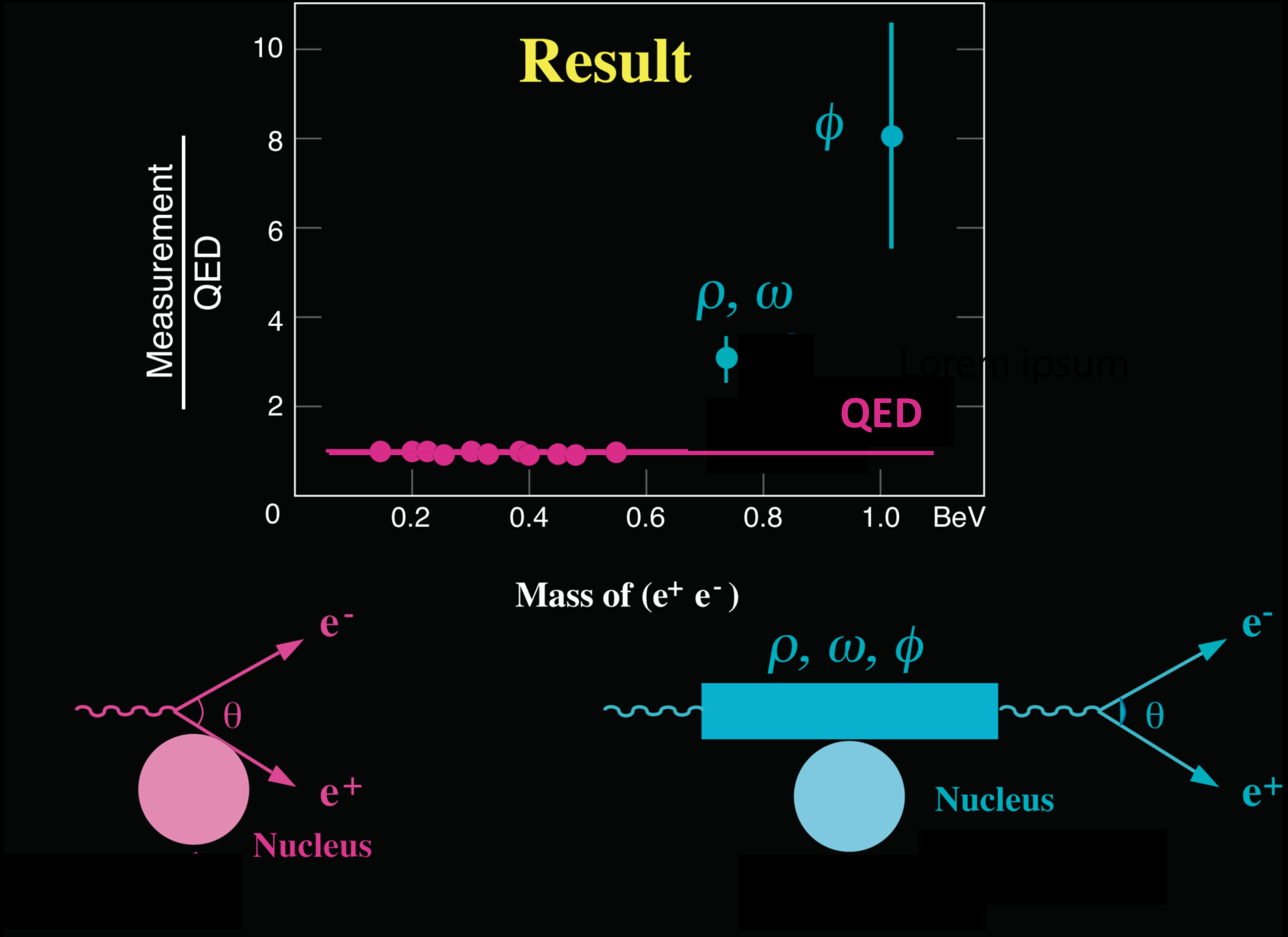


Distance to the center of the electron

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.

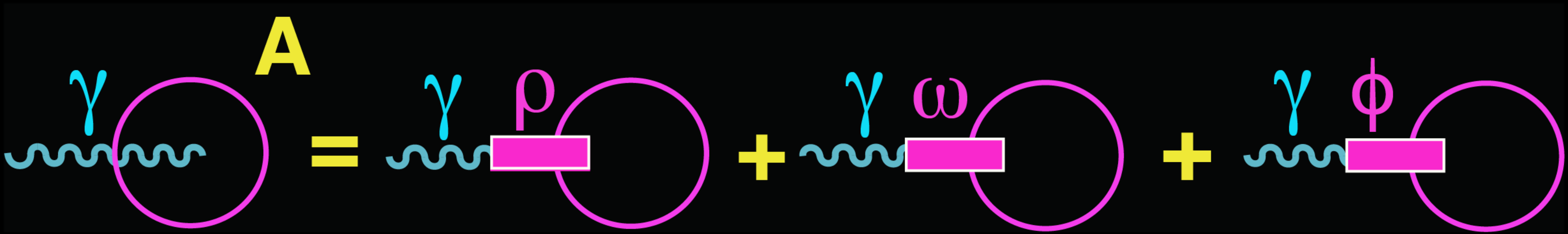
Experimental Results on Photons and Heavy Photons



Second Experiment: Photons and Heavy Photons

Photons and Heavy Photons have the same quantum numbers

J = 1 C = -1 P = -1



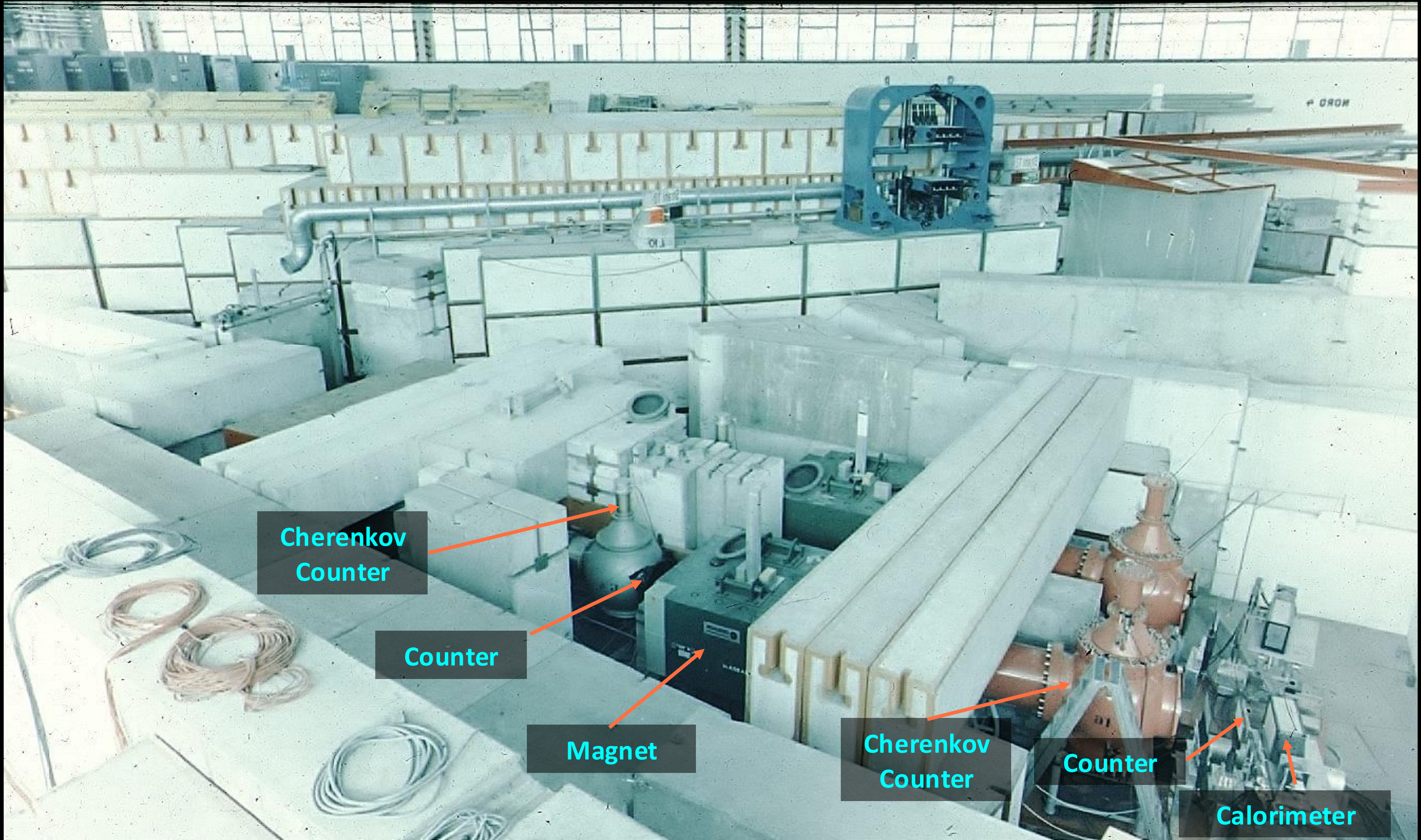
$$J_\mu(x) = -\left[\frac{m^2{}_\rho}{2\gamma_\rho}\rho_\mu(x) + \frac{m^2{}_\omega}{2\gamma_\omega}\ \omega_\mu\ (x) + \frac{m^2{}_\phi}{2\gamma_\phi}\phi_\mu\ (x)\right]$$

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

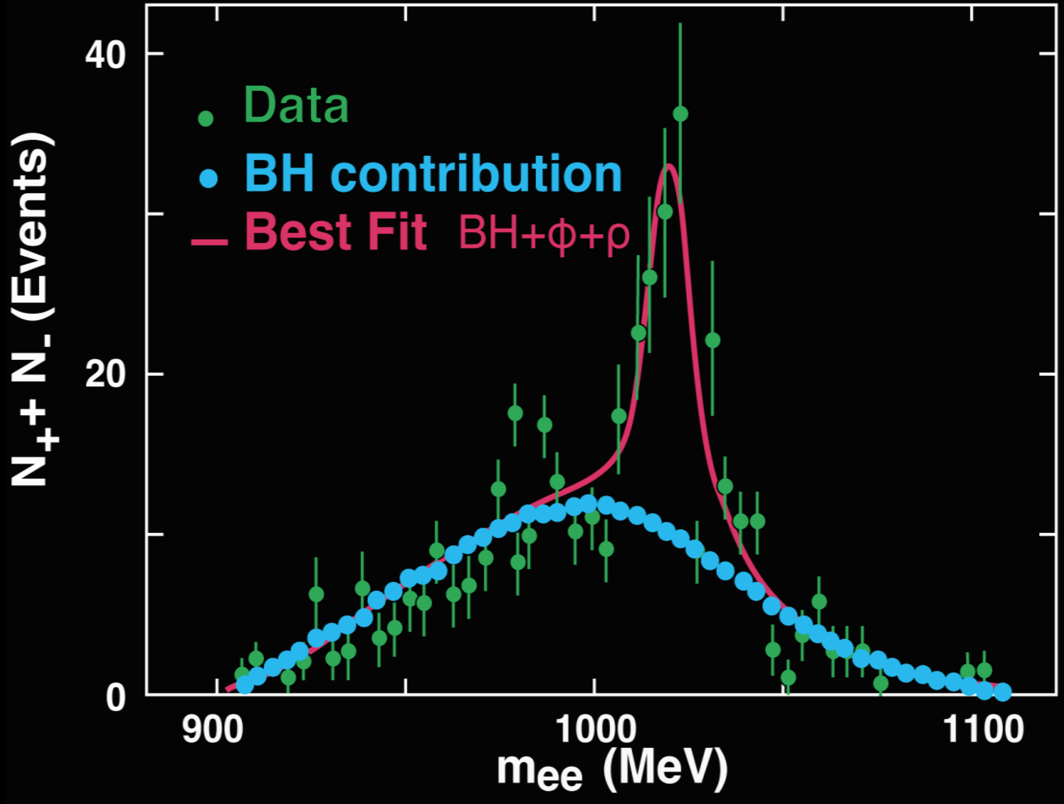
with major improvements in coordinate and momentum resolution and in particle identification



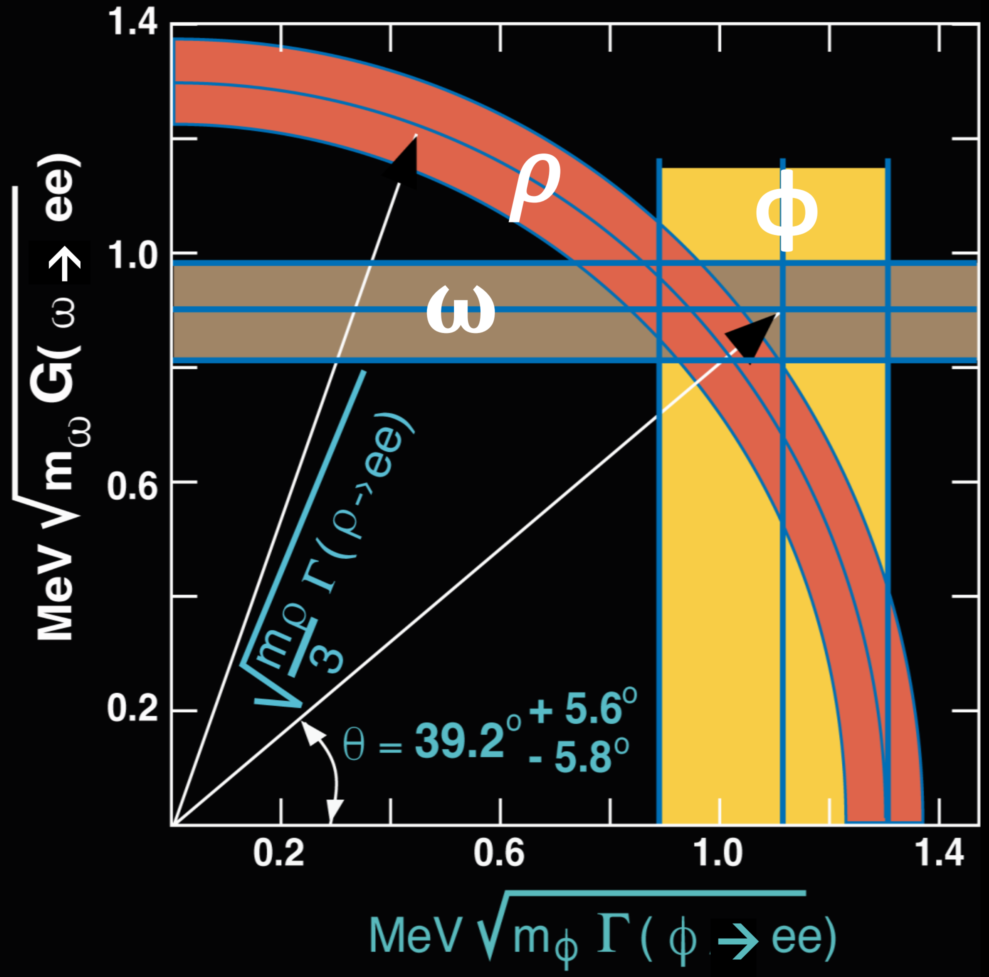
Result: Verification of Weinberg’s first sum rule

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

Leptonic decays of ϕ



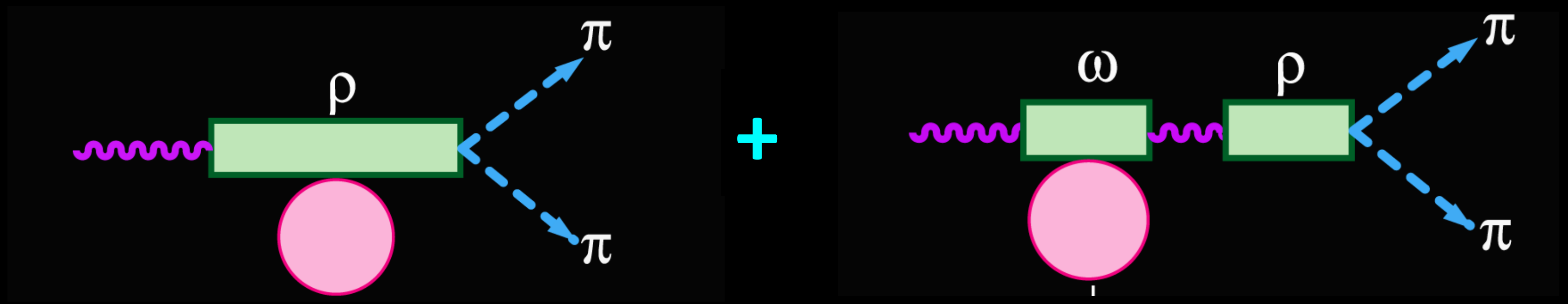
P. R. L., Vol 27, p.444, 1971



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

No Interference

Interference



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

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

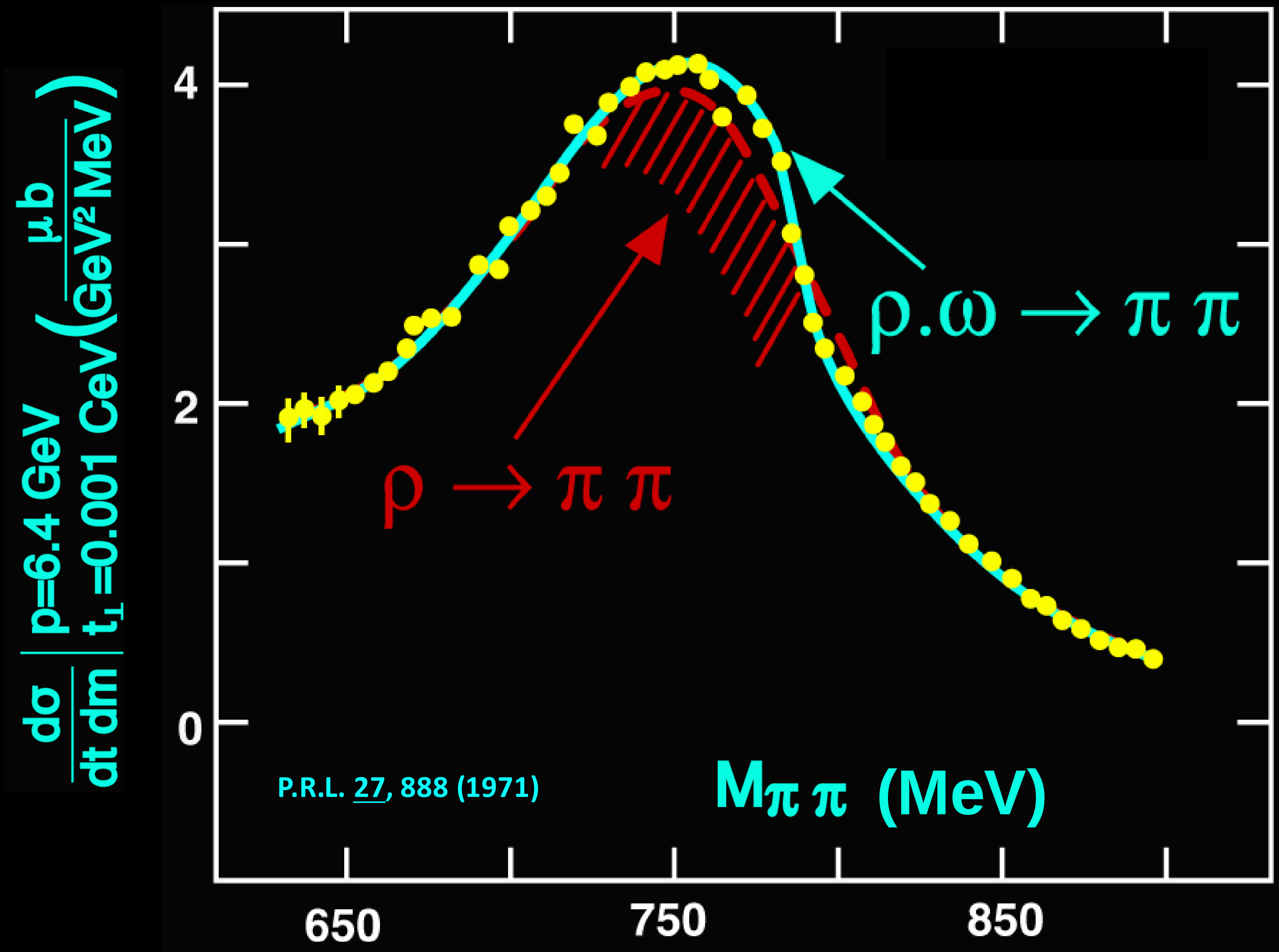
J. Bernstein and G. Feinberg, Nuovo Cimento 25, 1343 (1962)

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 ω → 2π Decays



P.R.L. 27, 888 (1971)

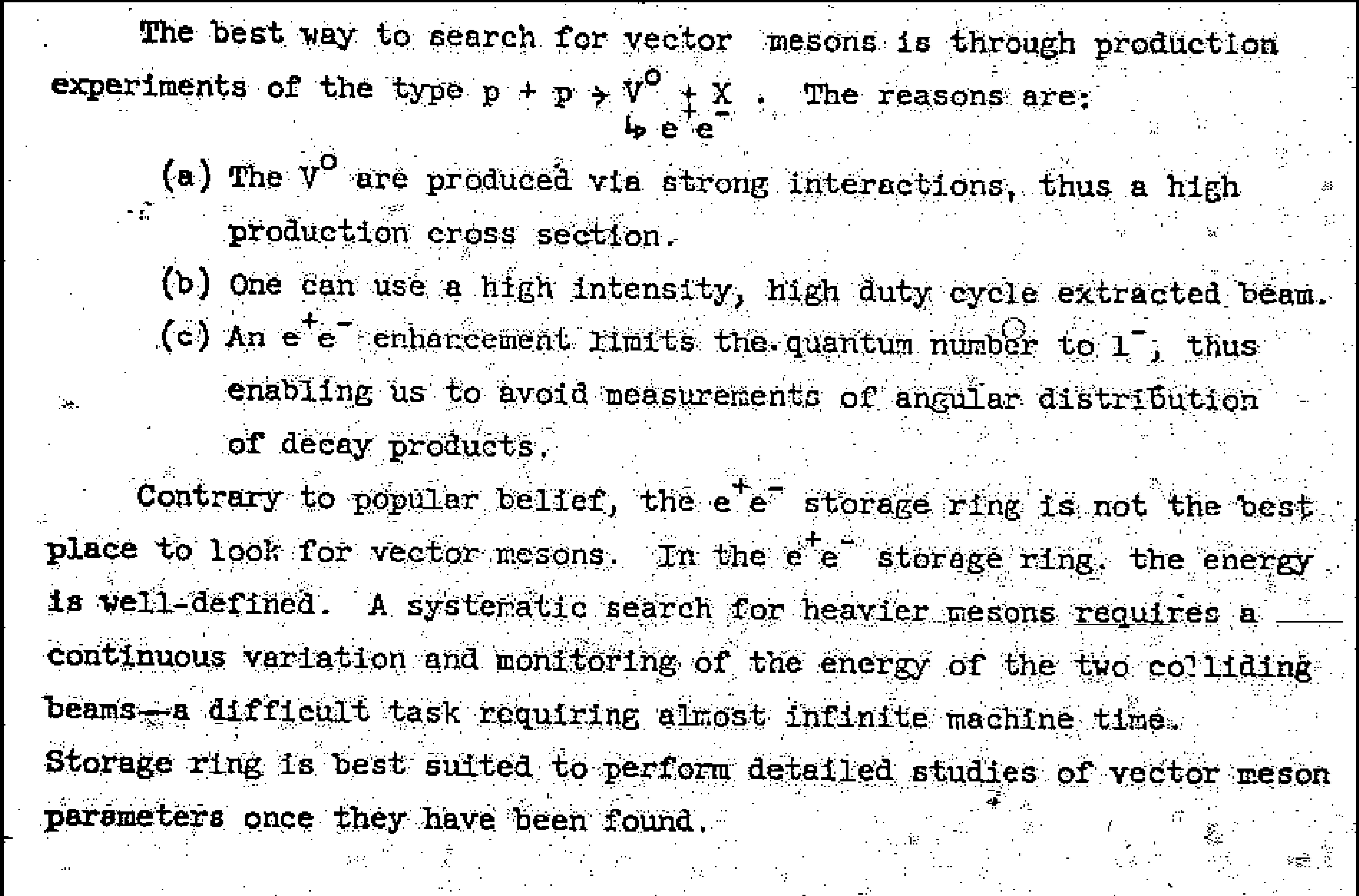
Third Experiment: Discovery of the J particle

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

Page 4 of Proposal AGS E598 (1972) to Brookhaven National Lab



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

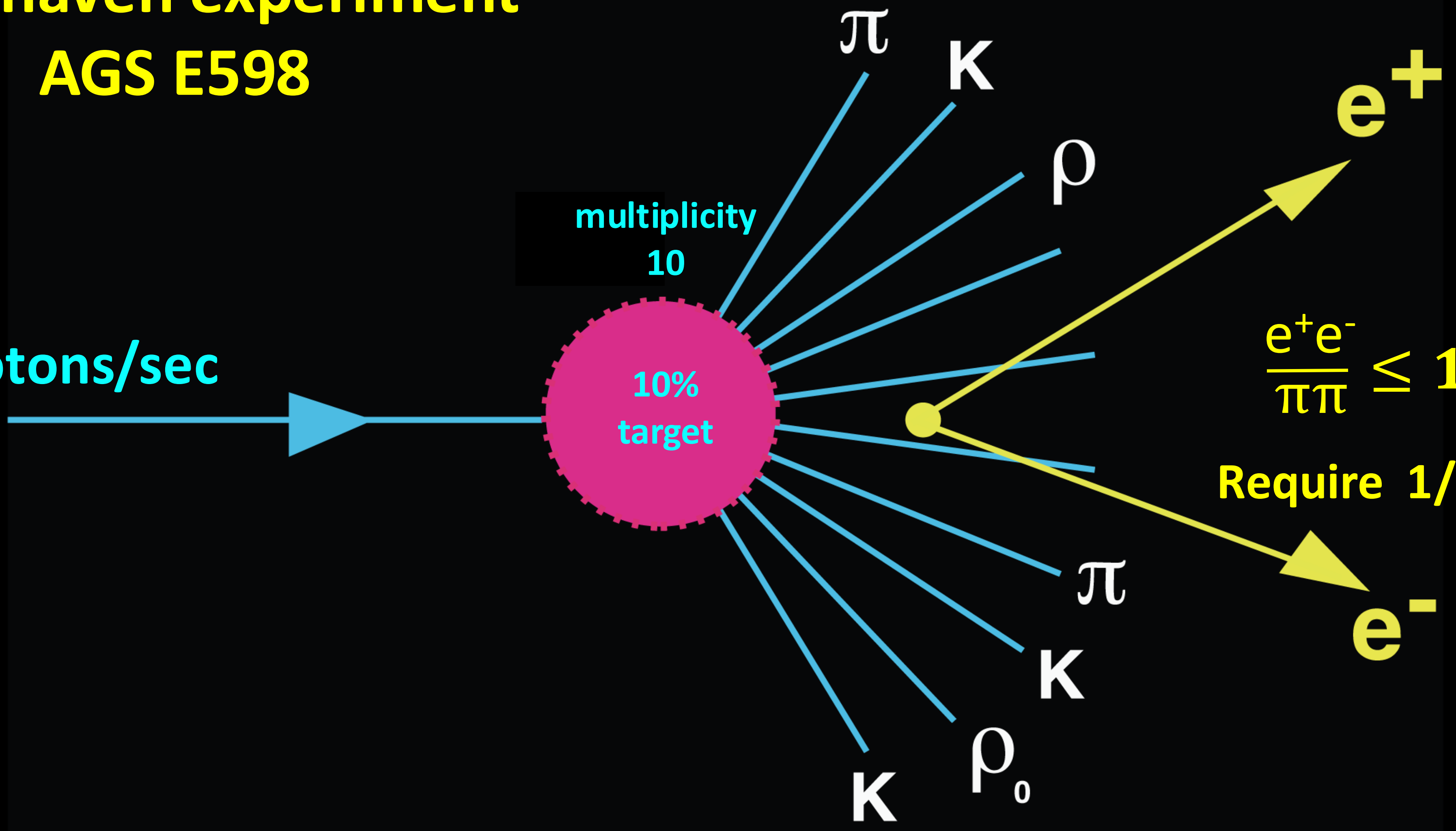
(a) The V^0 are produced via strong interactions, thus a high production cross section.

(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



10^{12} particles/sec

10^{12} protons/sec

30 GeV

multiplicity
10

10%
target

$$\frac{e^+e^-}{\pi\pi} \leq 1/10^8$$

Require $1/10^{10}$ rejection

During a rainstorm over **Rome** 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

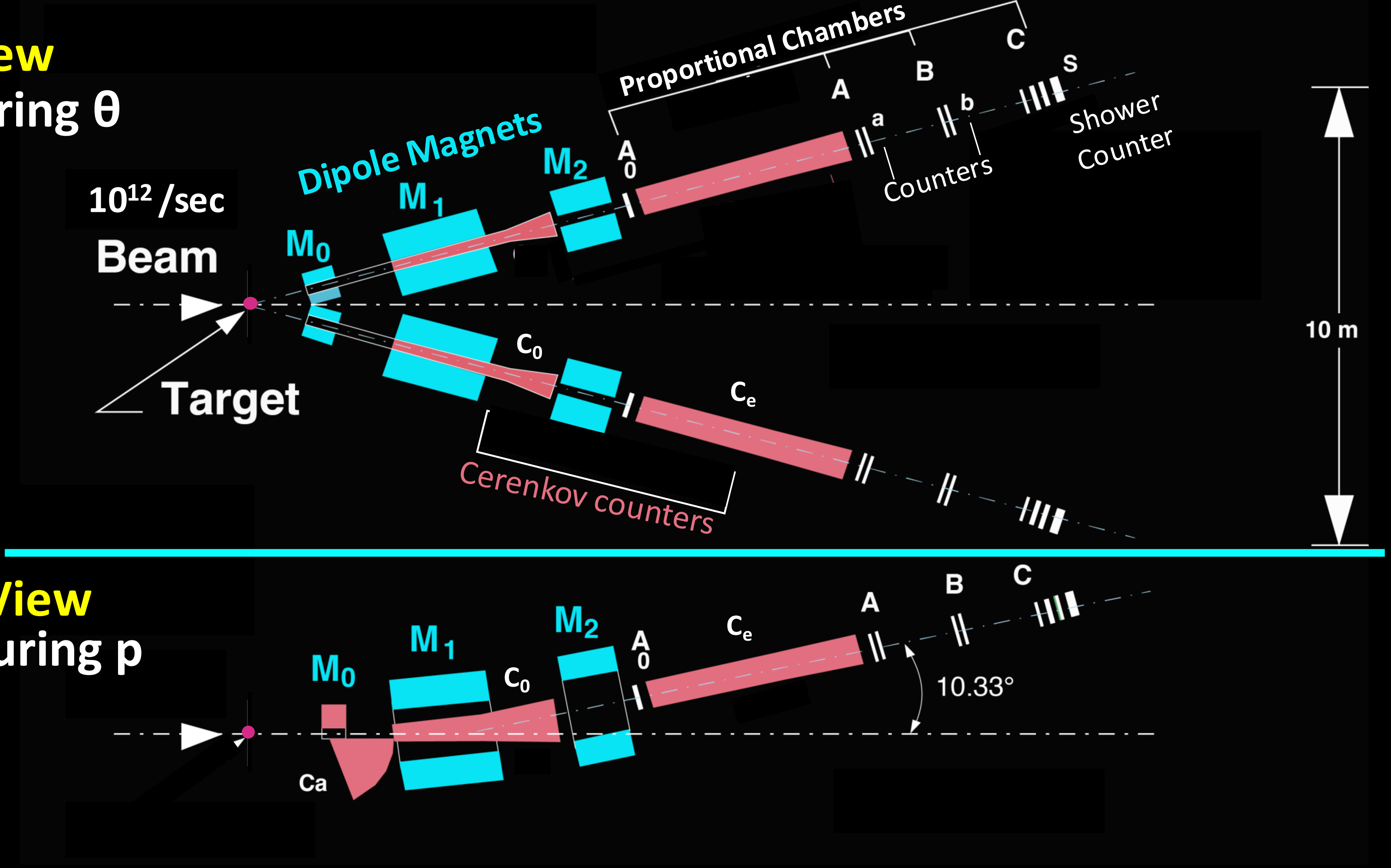
“During the construction of our spectrometers, and indeed during the entire experiment, I encountered much criticism. The problem was that in order to gain a good mass resolution it was necessary to build a spectrometer that was very expensive. One eminent physicist made the remark that this type of 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

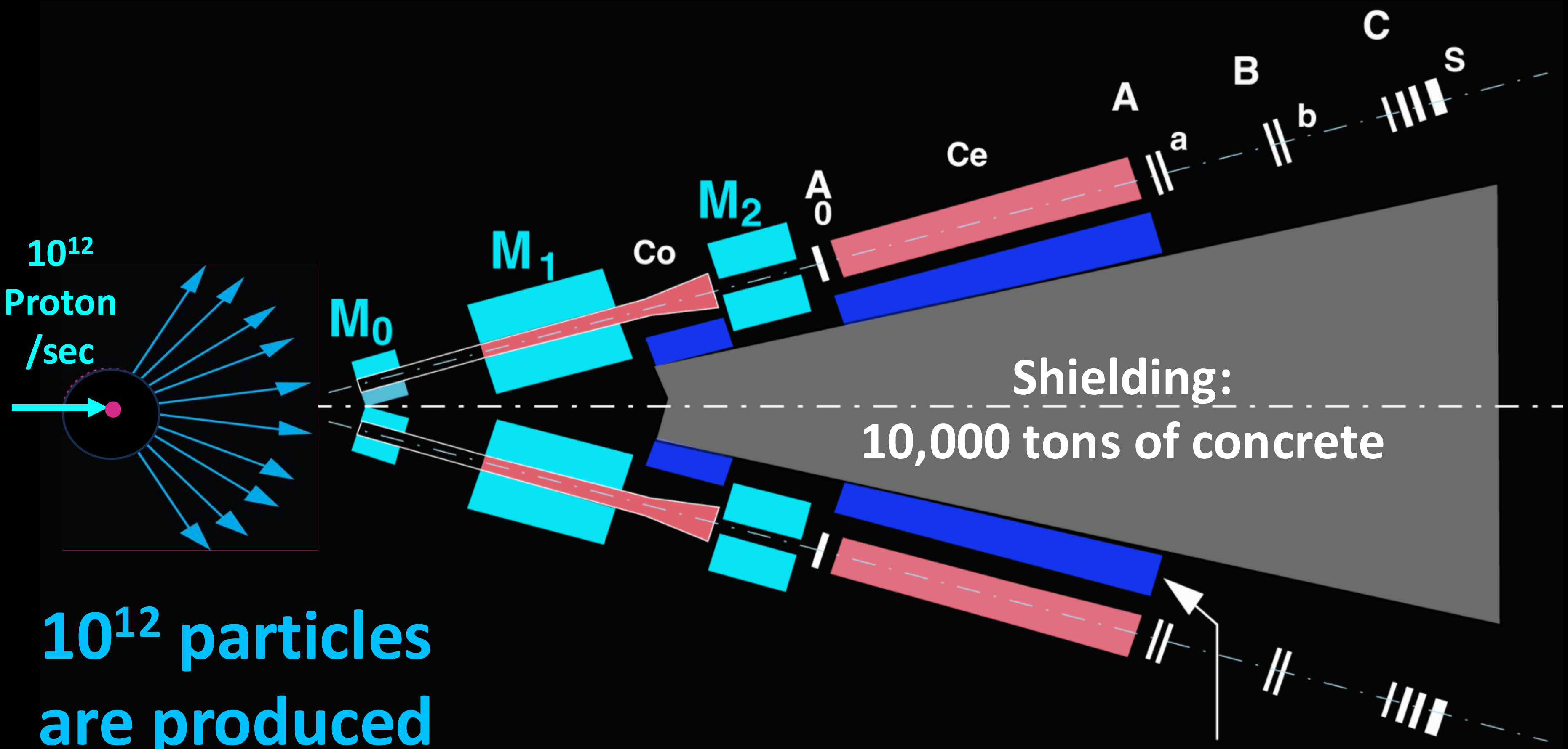
Top View
measuring θ



Side View
measuring p

The detector follows the design of the first experiment at DESY

Radiation Protection

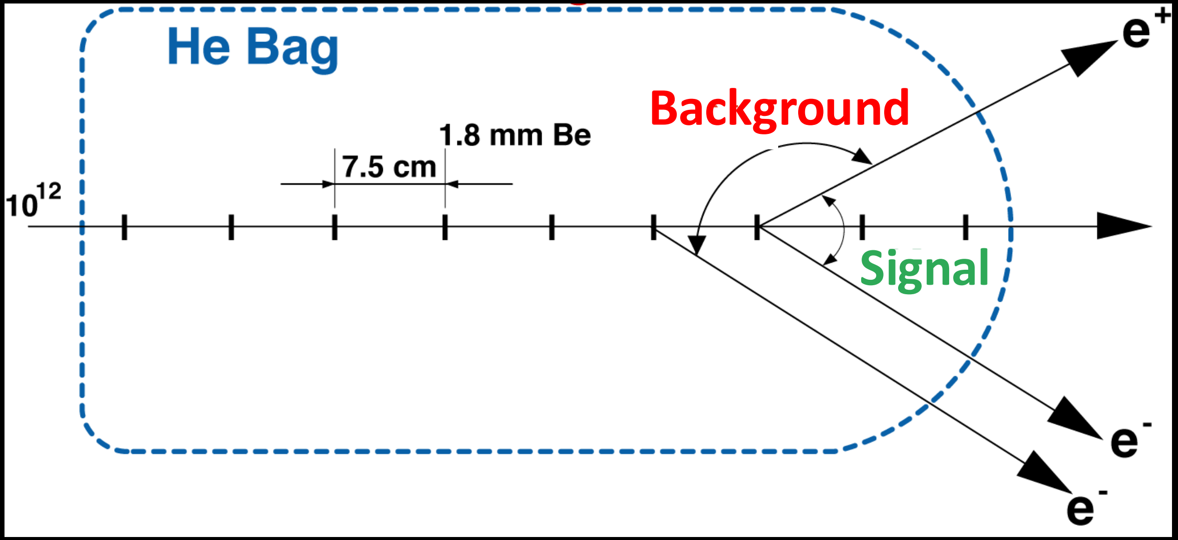


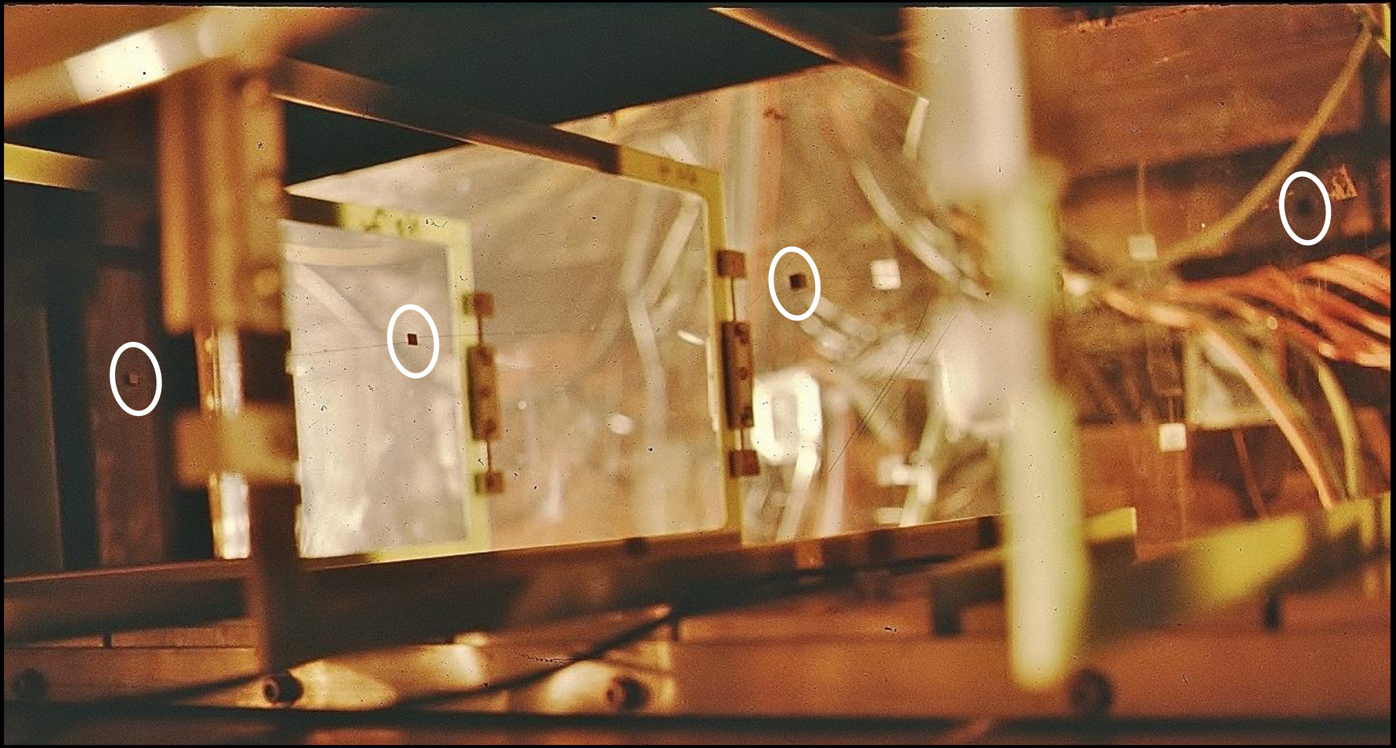
Shielding:
10,000 tons of concrete

10^{12} particles are produced each second

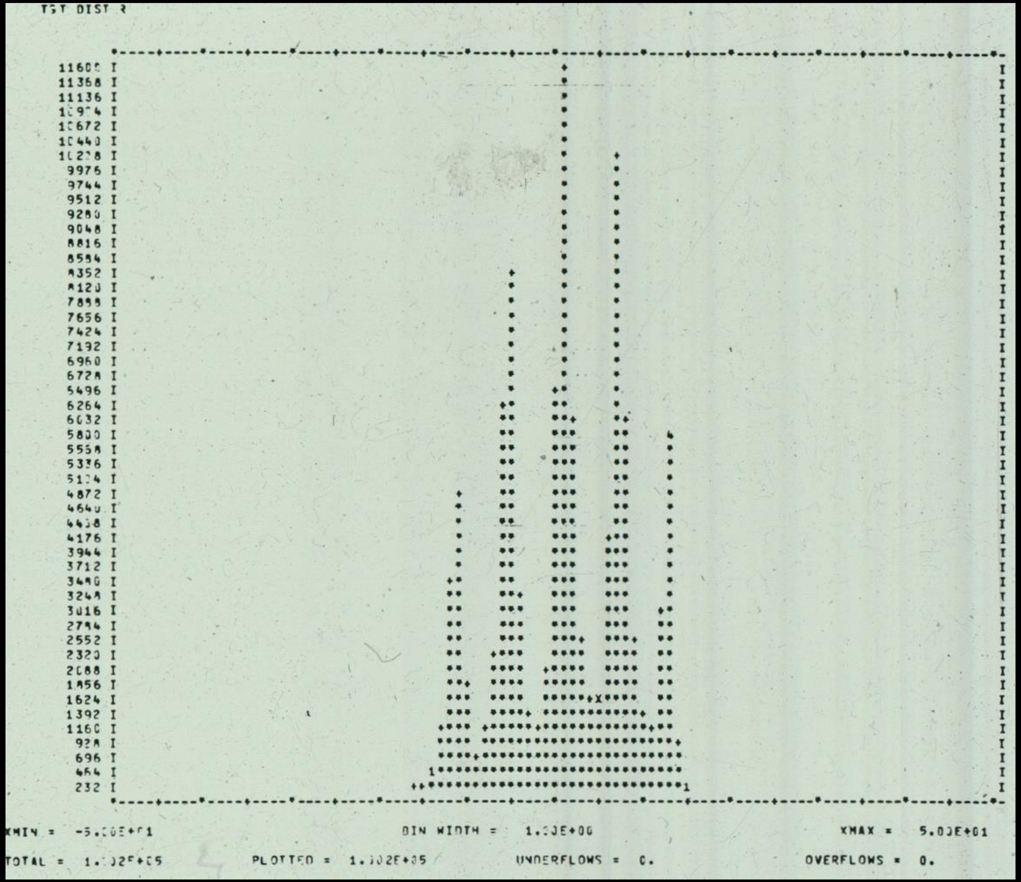
+ 5 tons of ^{238}U
+ 100 tons of lead
+ 5 tons of soap

Separate thin targets to reduce the background



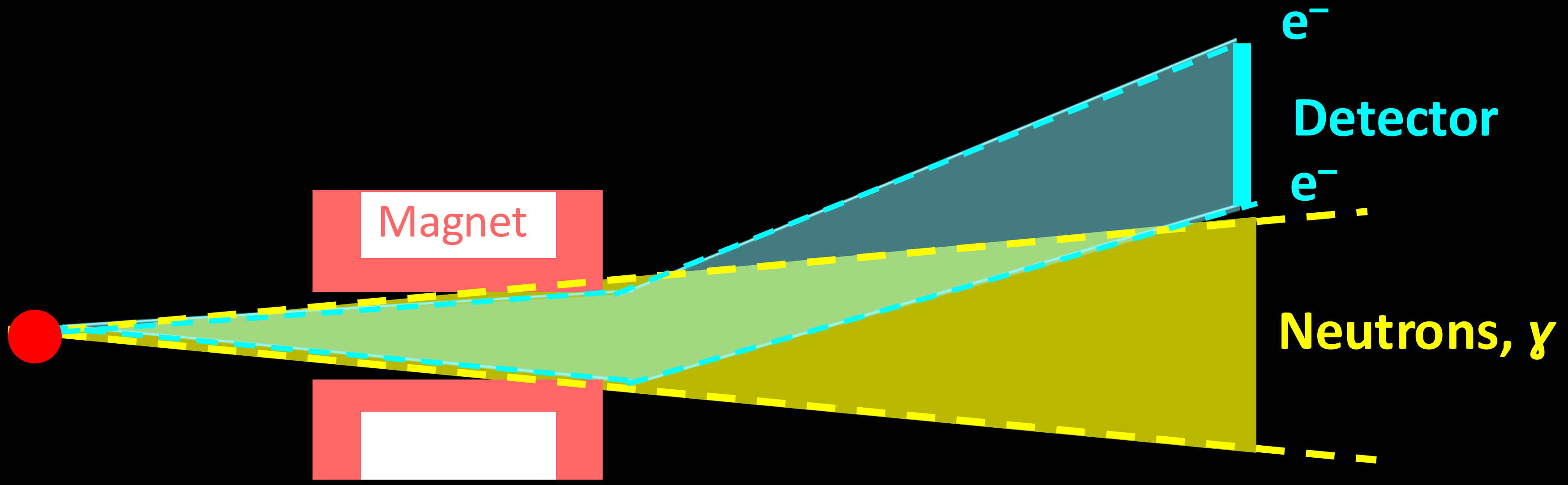


Target Event distribution

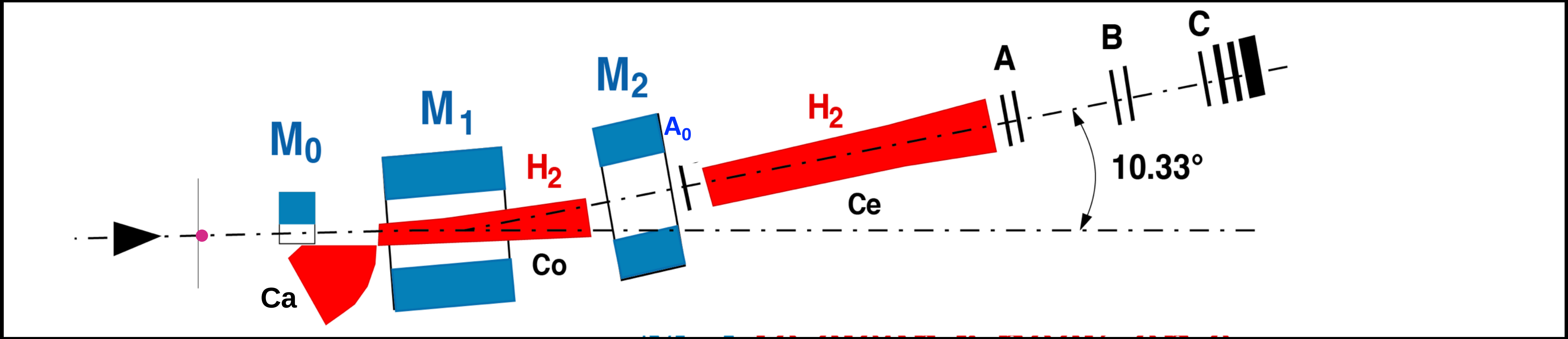


The Magnets

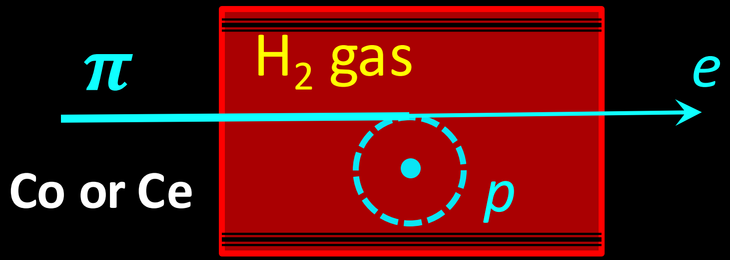
1. For each magnet, the field is measured with 3-D Hall probe, a total of 10^5 points.
2. The detector is smaller than the magnet aperture, the detector defines the acceptance.
3. The magnets bend charged particles to an angle such that the detectors are not exposed to photons or neutrons from the target.



Hadron Rejection of 10^{10}

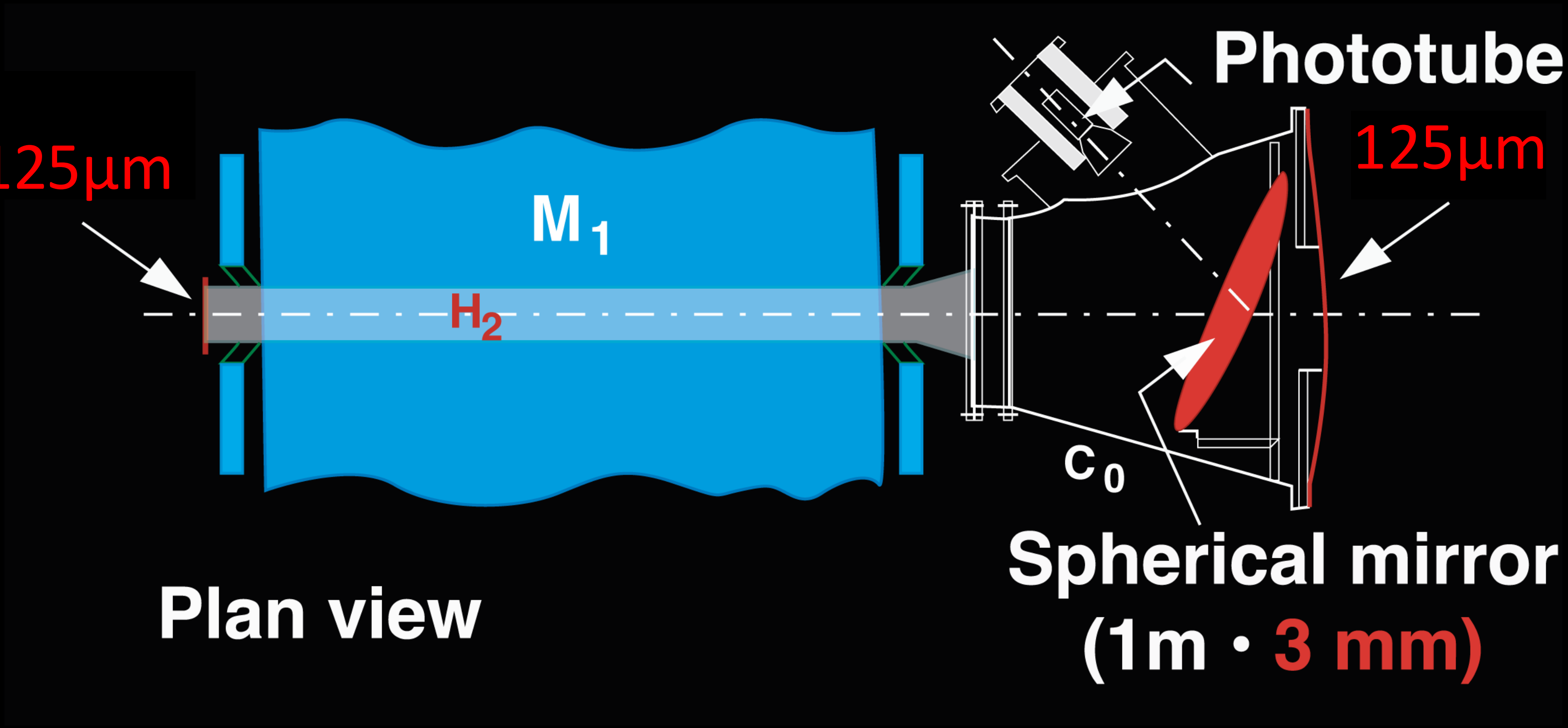


knock-on background



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

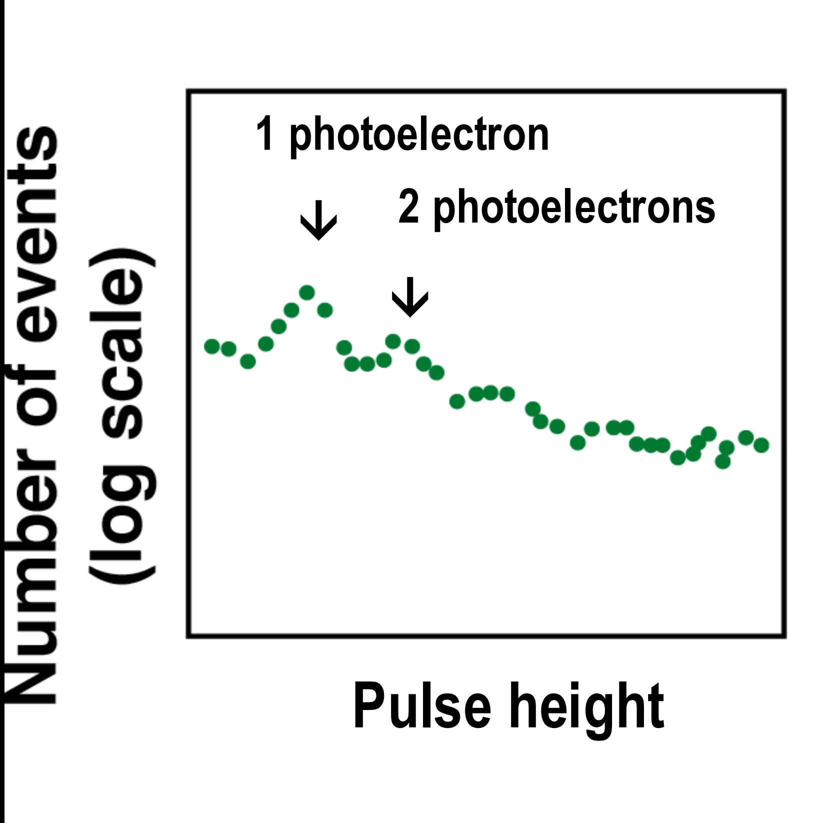
The π-e separation was achieved by four sensitive Cherenkov Counters Co, Ce



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

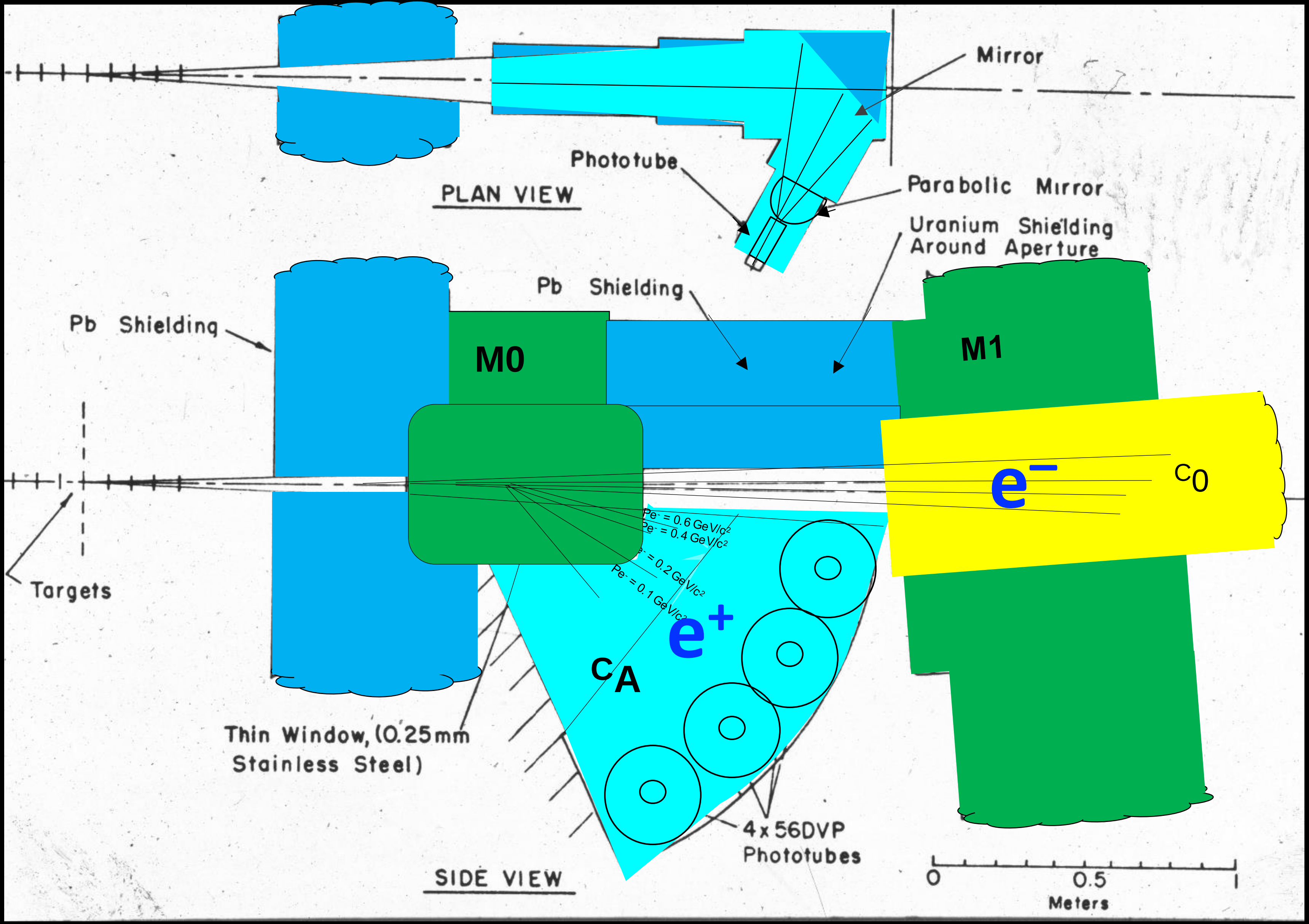
The mirrors were made at the Precision Optical Workshop at CERN

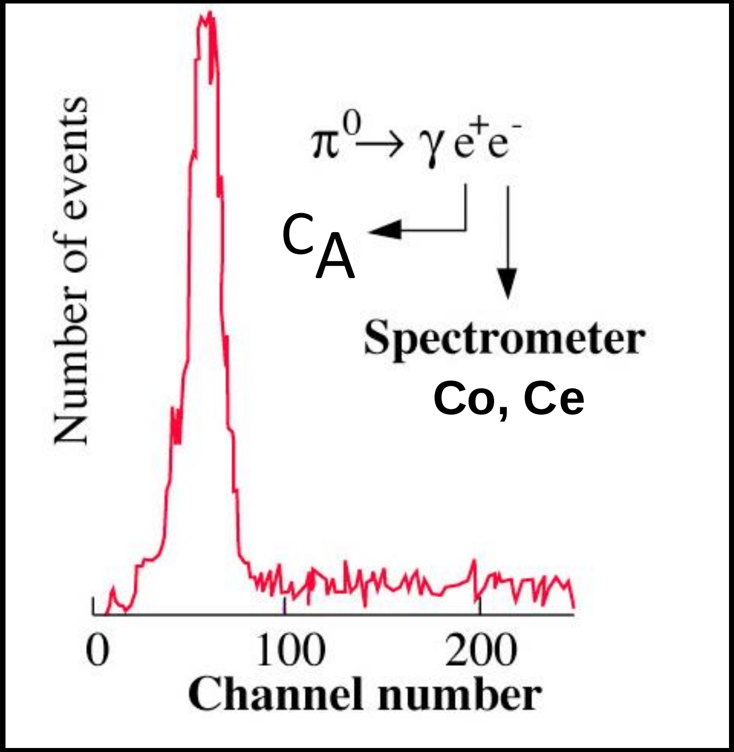
Spherical Mirror



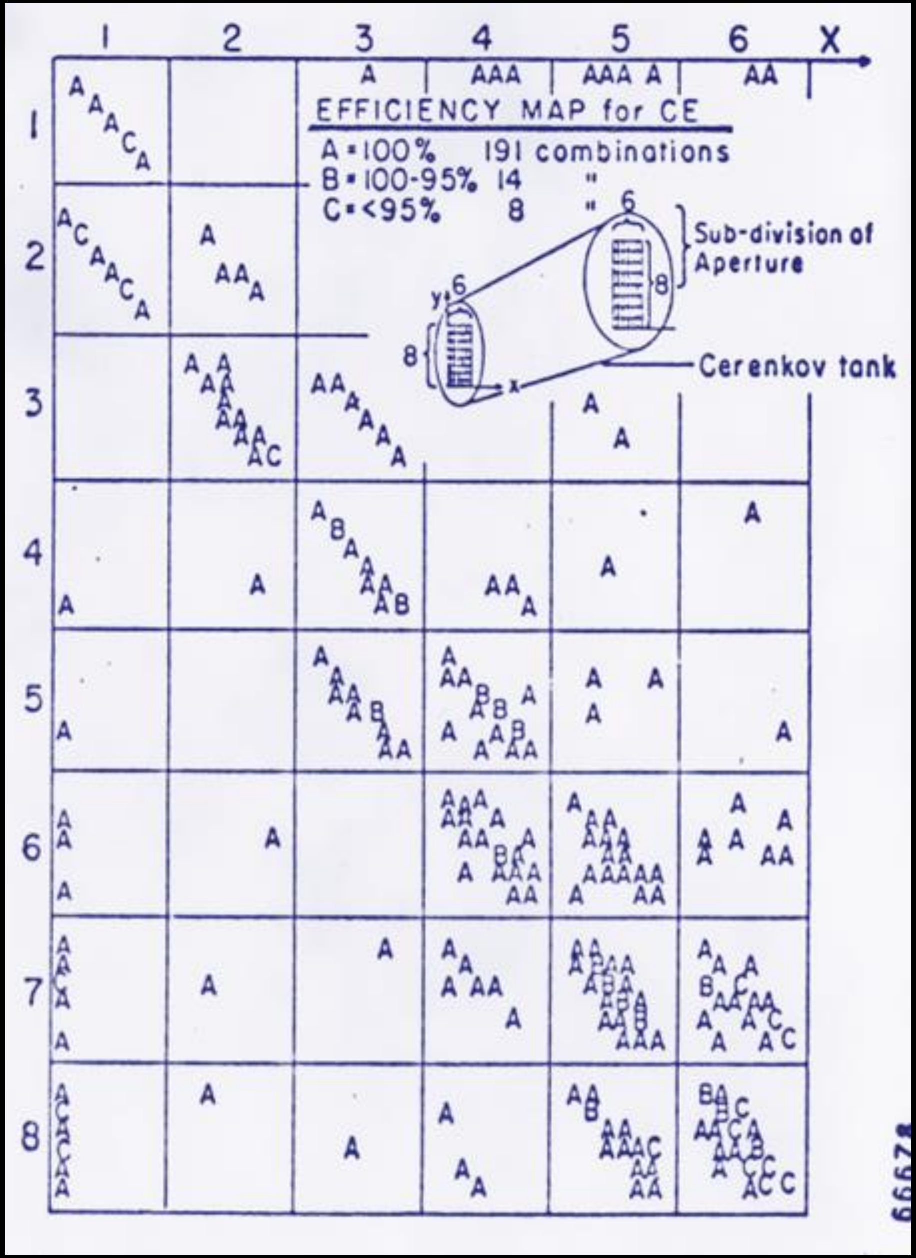
J. J. Aubert made major contributions to the experiment. Later became founder of the ANTARES project and Director-General, IN2P3, France

Detector calibration with a pure electron beam





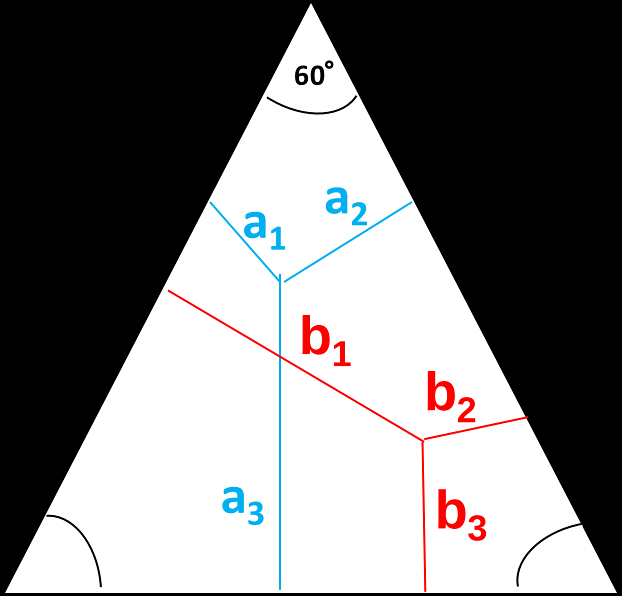
Ensure the efficiency of the Cherenkov counter is 100%



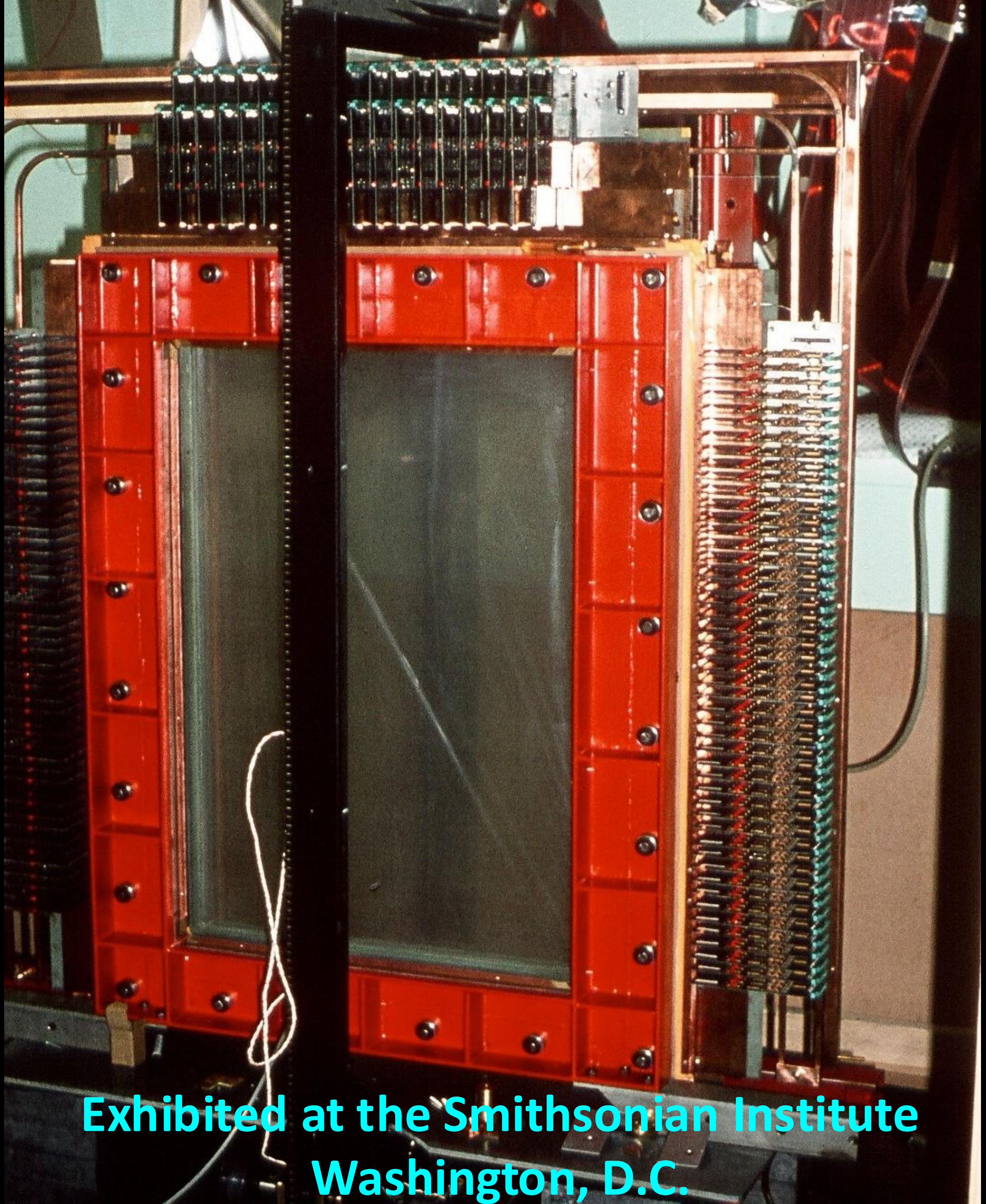
Position Detectors

designed by the
late Professor UJ Becker, MIT

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



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

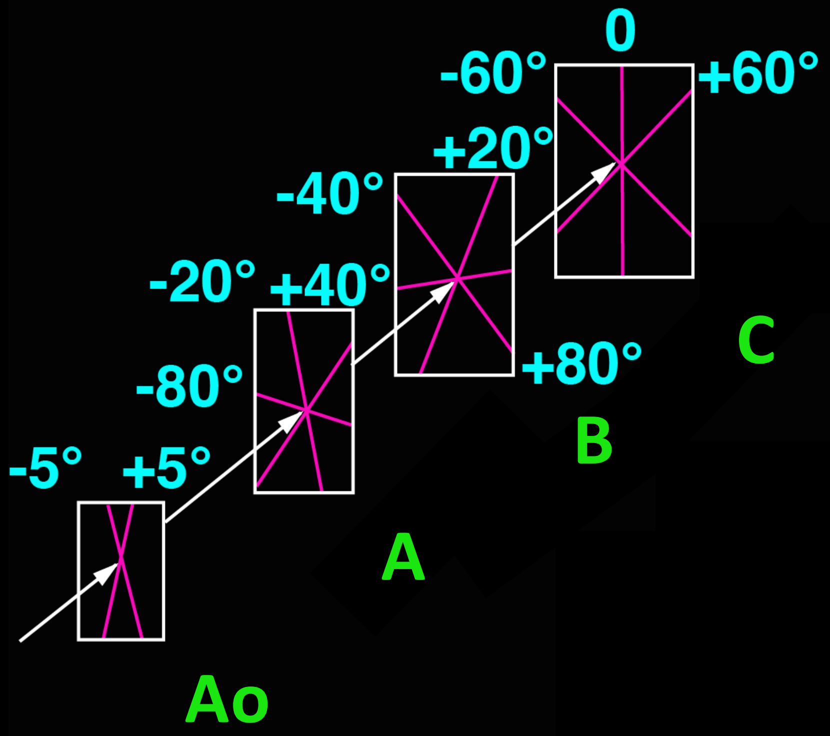


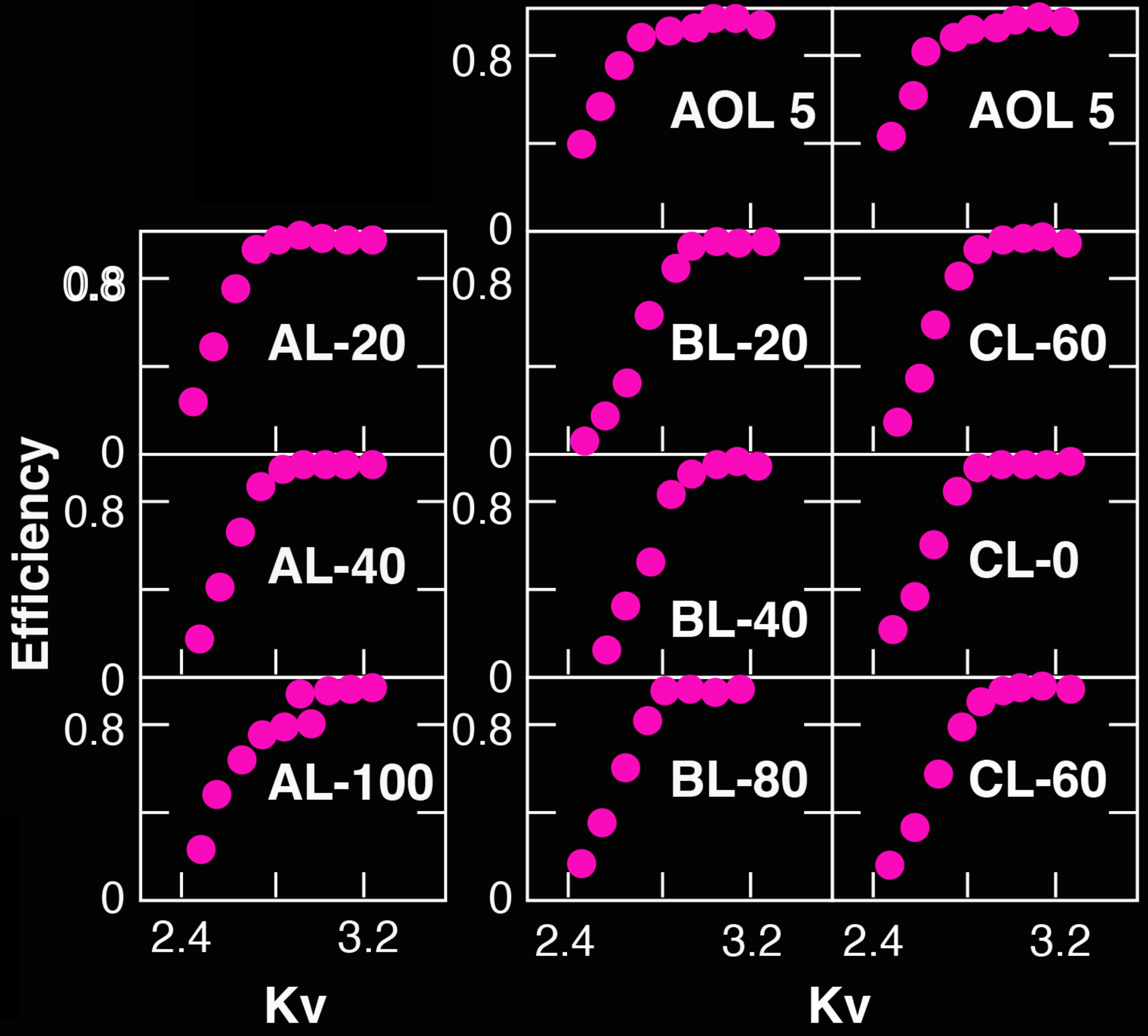
Exhibited at the Smithsonian Institute
Washington, D.C.

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

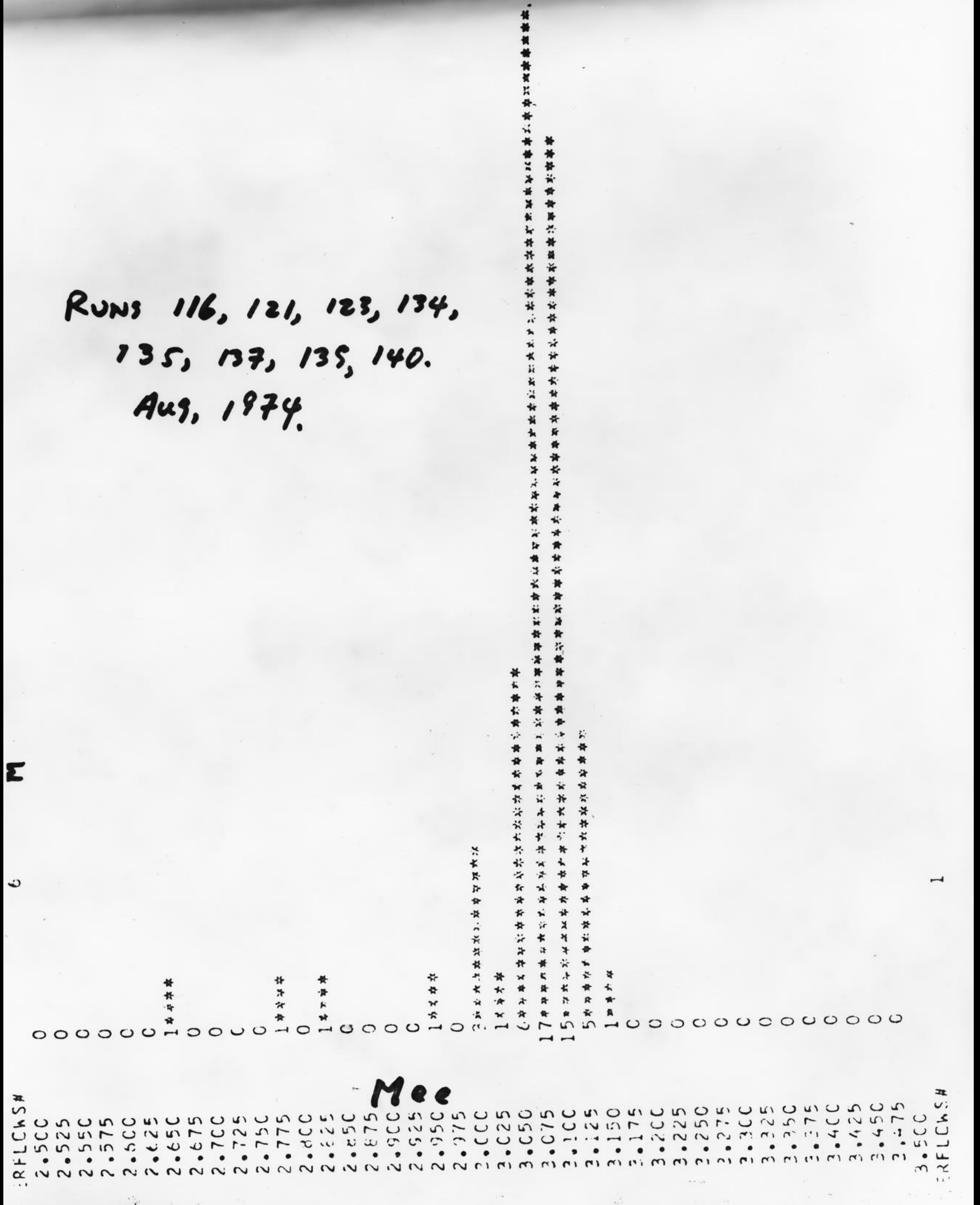
In the early summer of 1974 we took some data in the high-mass region of 4-5 GeV. However, analysis of the data showed very few electron-positron pairs.

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!

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

First data showing an unexpected peak at 3.1 GeV

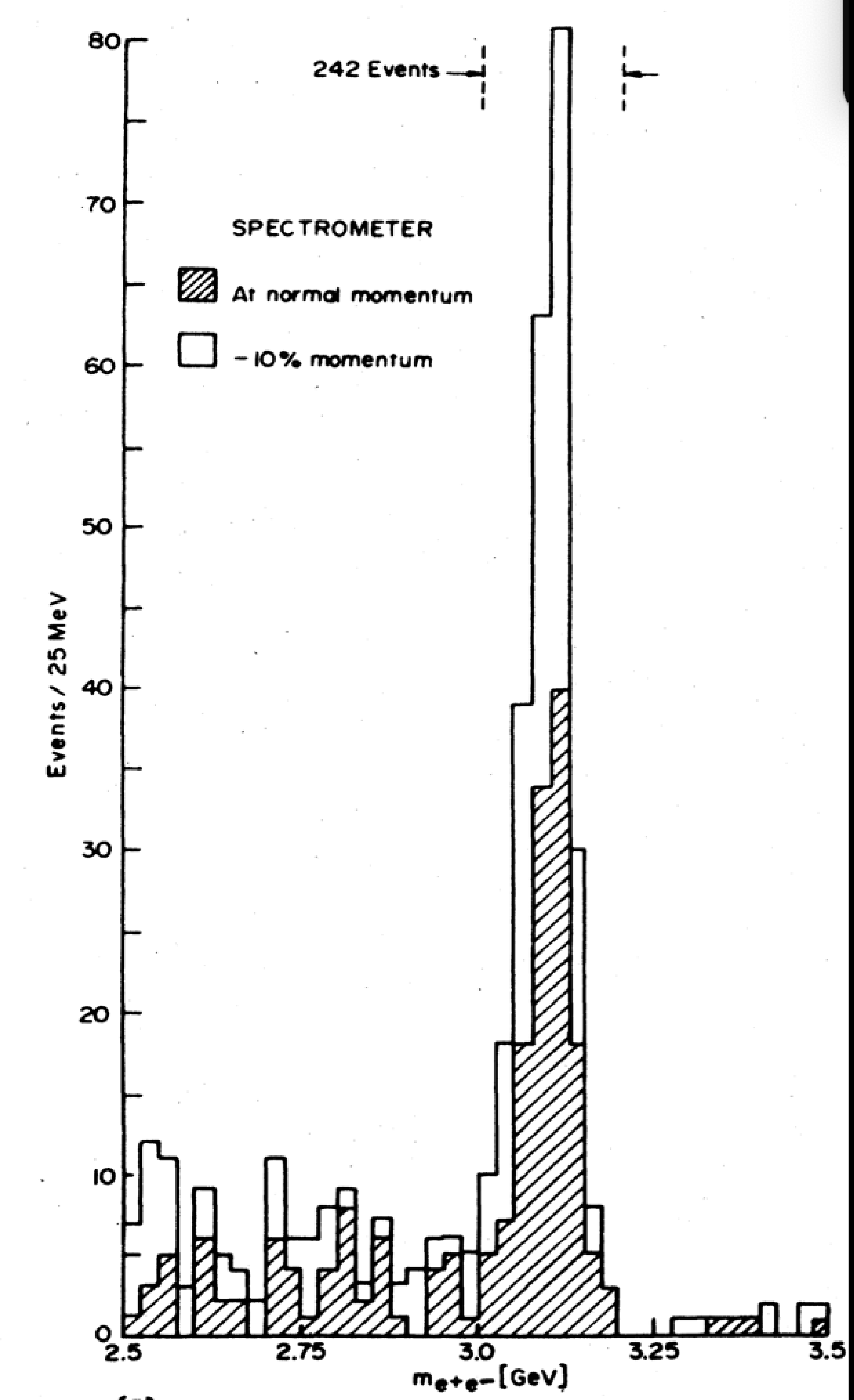


Throughout the years, I have established certain practices in the group with regard to experimental checks on our data and on the data analysis. I list a few examples:

(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.

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

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.



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

(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.

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

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: $p + N \rightarrow \pi + \cdots$ where the pion undergoes a second collision $\pi + N \rightarrow e^+ + e^- + \cdots$. 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

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

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.

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

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.

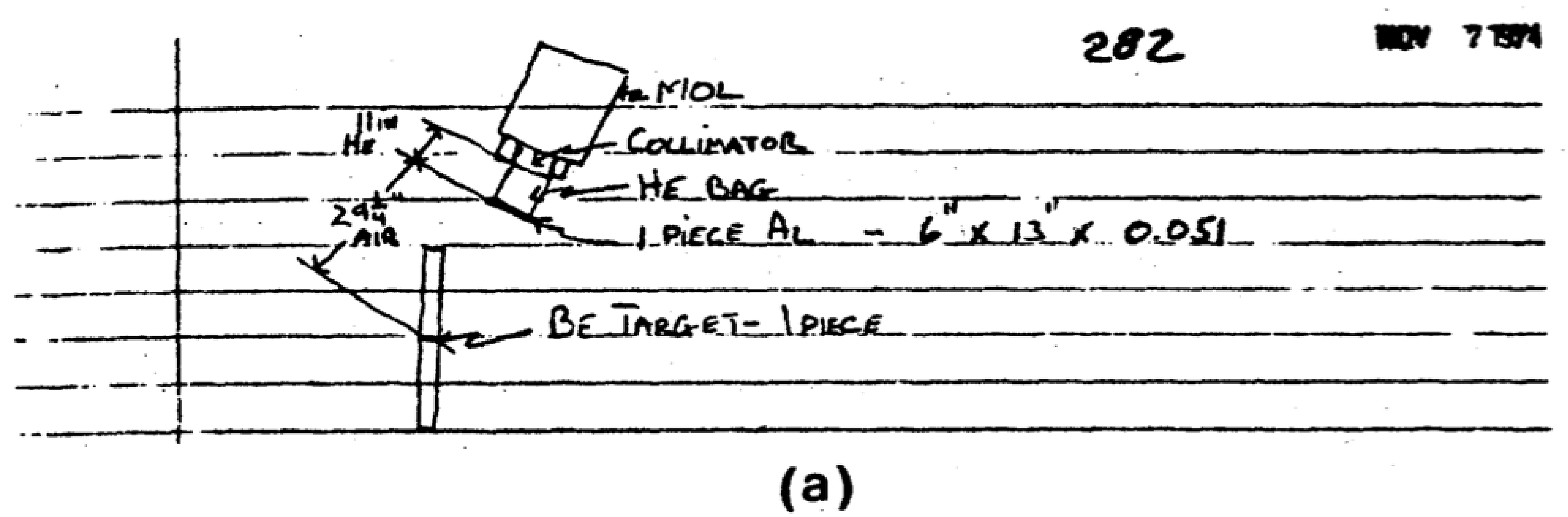
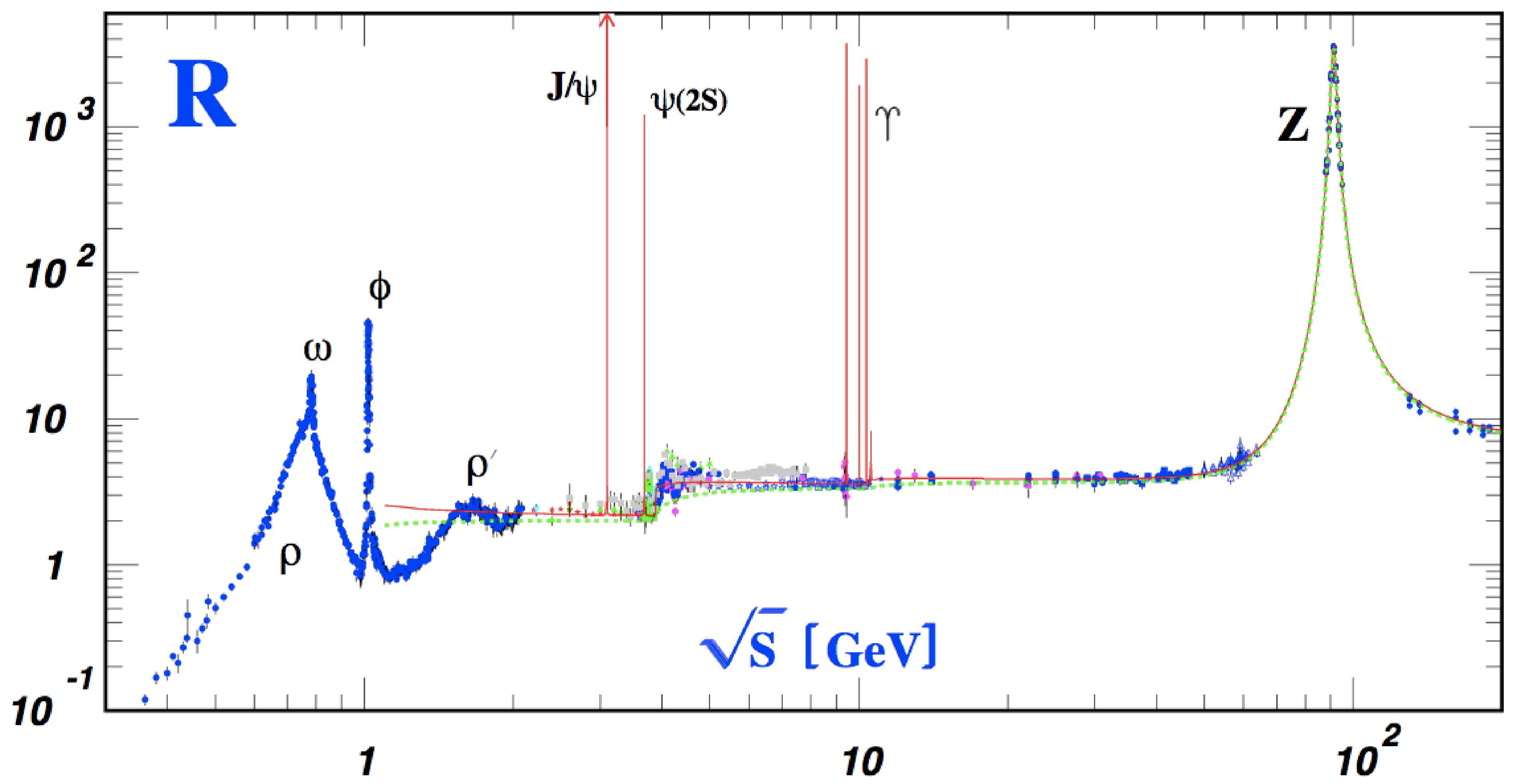


FIG. 13. (a) Aluminum foil arrangement in front of magnet M_0 in our new experiment to determine the e/π ratio. The converter was used to determine the electron background yield.

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



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

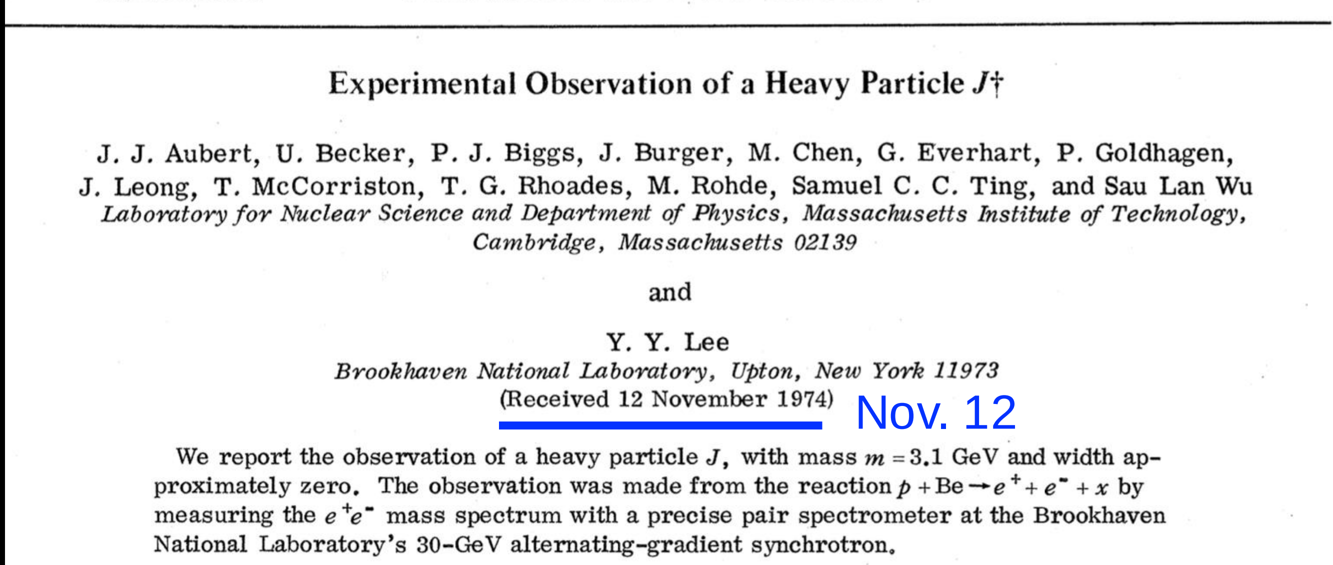
Alvaro De Rujula, “When the Standard Model was Ignored”
at The Rise of Particle Physics, Sapienza University of Rome, Sep. 23, 2024

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.

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

November Revolution 1974



Volume 33, Number 23 PHYSICAL REVIEW LETTERS 2 December 1974

Experimental Observation of a Heavy Particle J†

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

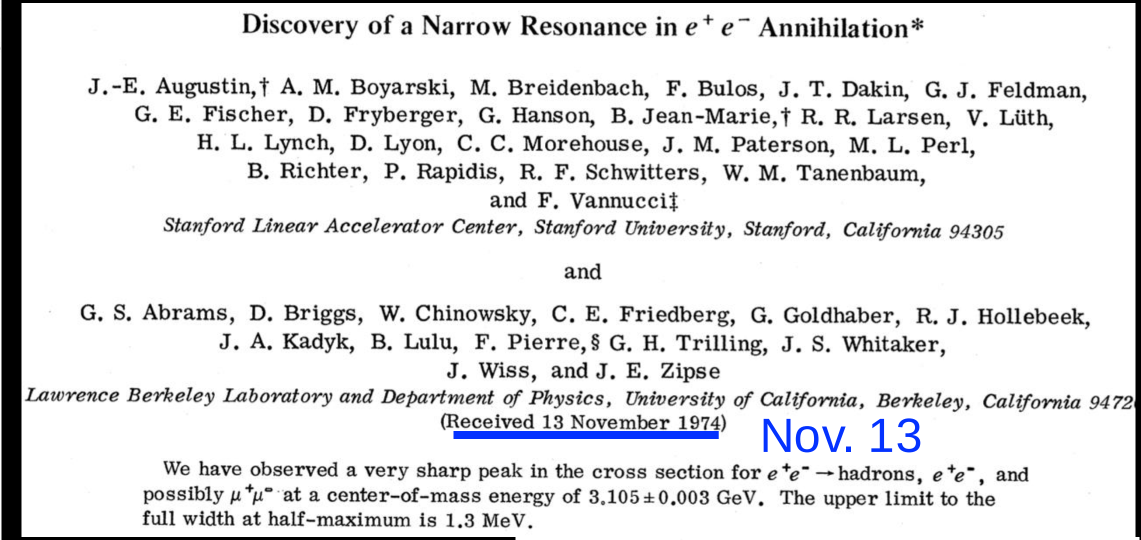
and

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 $p + \mathrm{Be} \rightarrow e^+ + e^- + x$ by measuring the e^+e^- mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.



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 $e^+e^- \rightarrow$ 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.

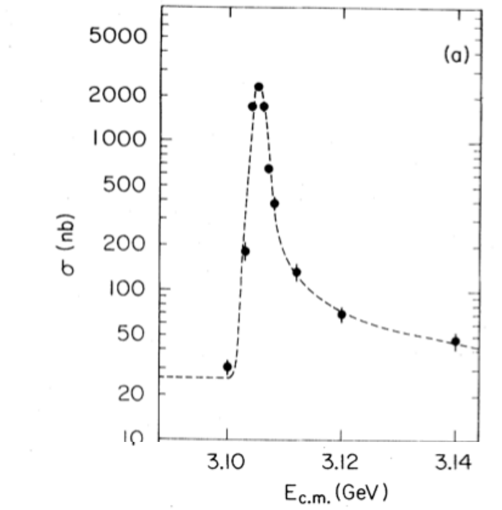
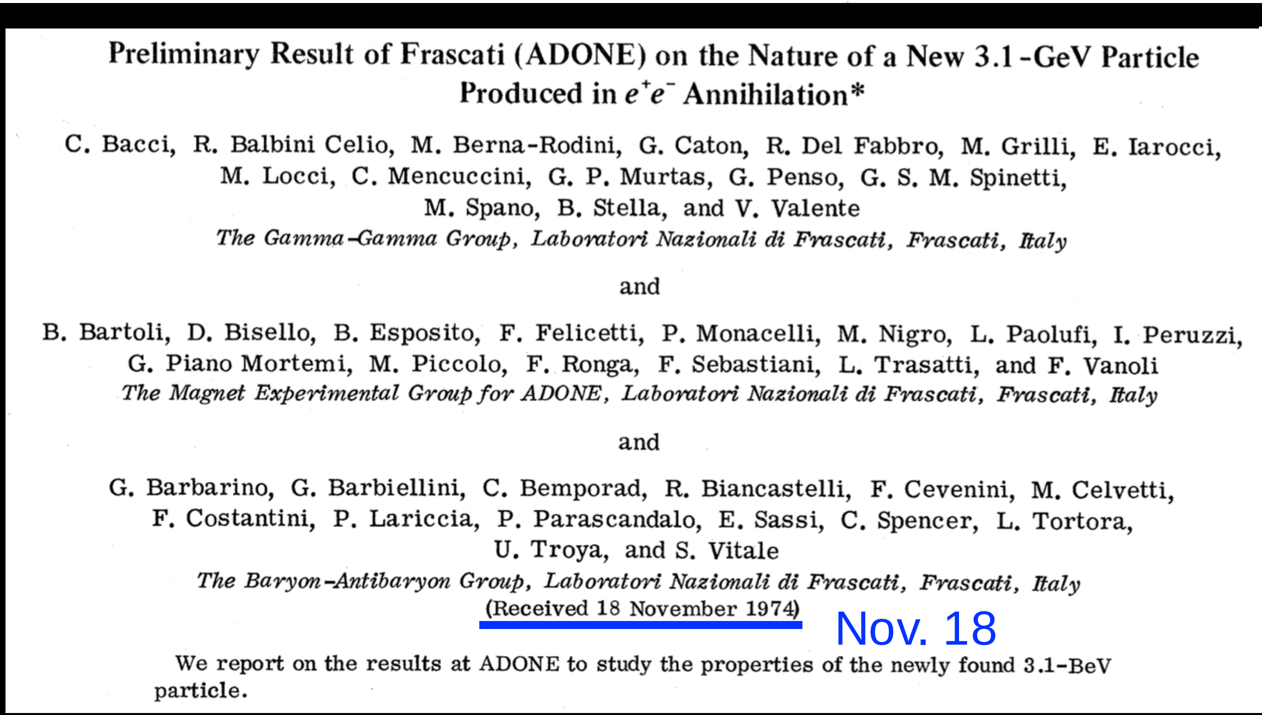


FIG. 1. Cross section versus energy for (a) multihadron final states, (b) e^+e^- final states, and (c) $\mu^+\mu^-$, $\pi^+\pi^-$, and K^+K^- final states. The curve in (a) is the expected shape of a δ-function resonance folded with the Gaussian energy spread of the beams and including radiative processes. 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.



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. Celvetti,
F. Costantini, P. Lariccia, P. Parascandalo, E. Sassi, C. Spencer, L. Tortora,
U. Troya, 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.

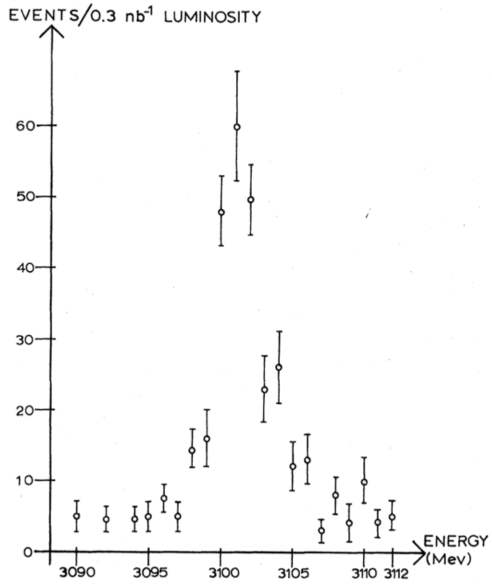
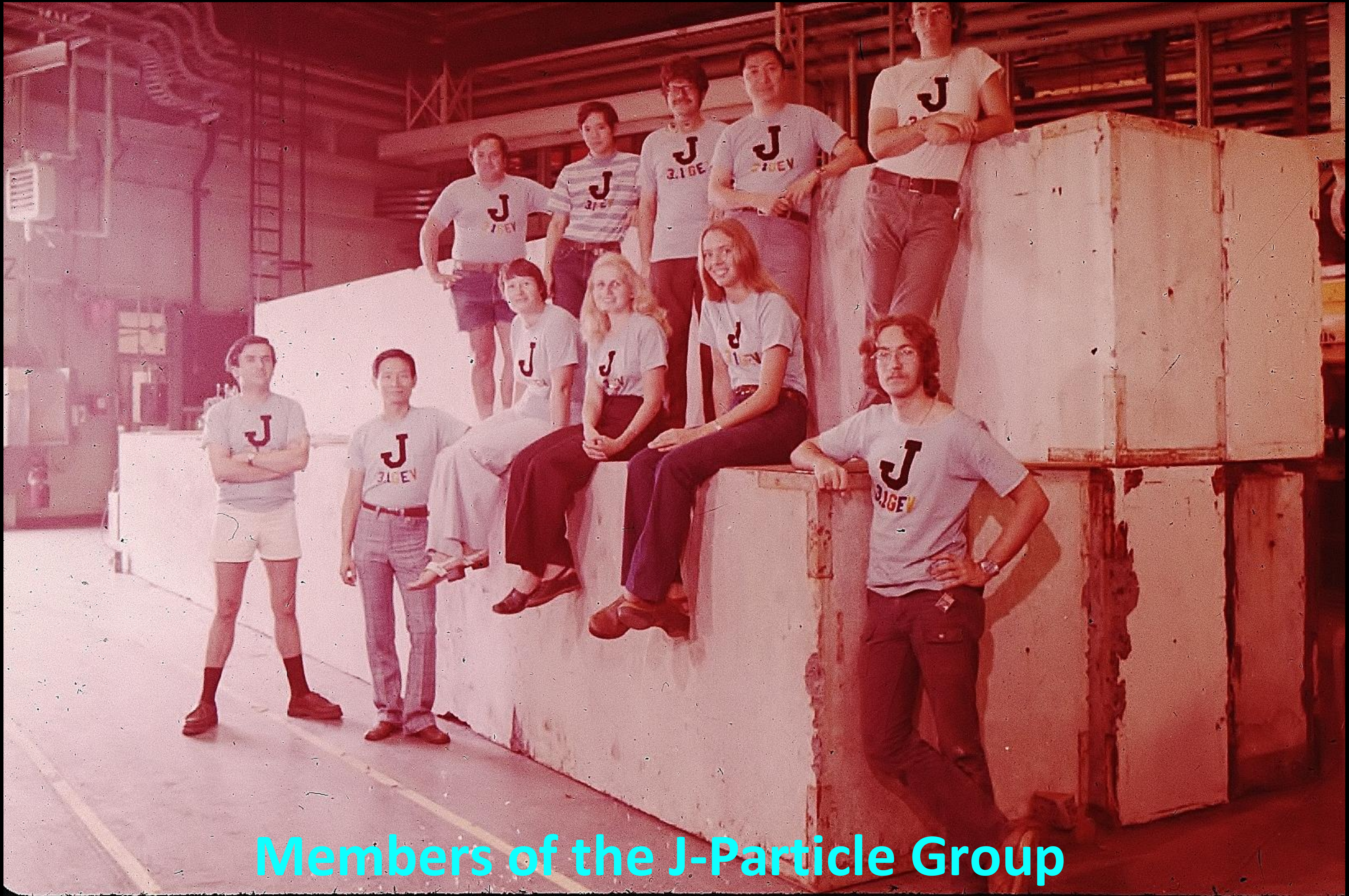


FIG. 1. Result from the Gamma-Gamma Group, total of 446 events. The number of events per 0.3 nb^{-1} luminosity is plotted versus the total c.m. energy of the machine.

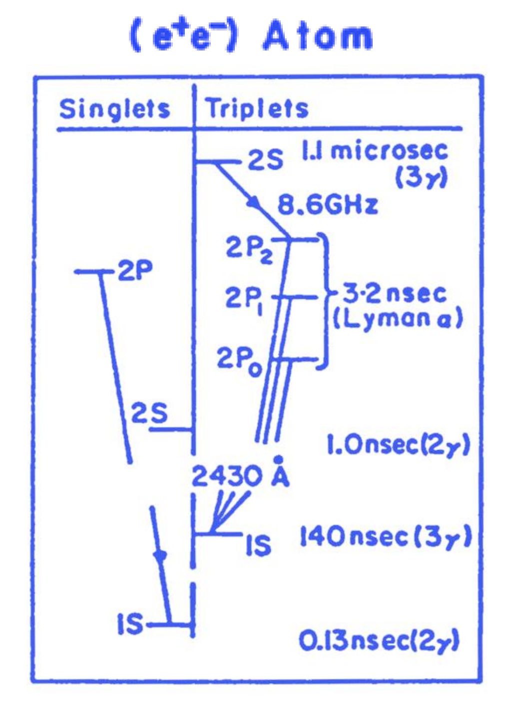


Members of the J-Particle Group

The unique properties of the J particle are:

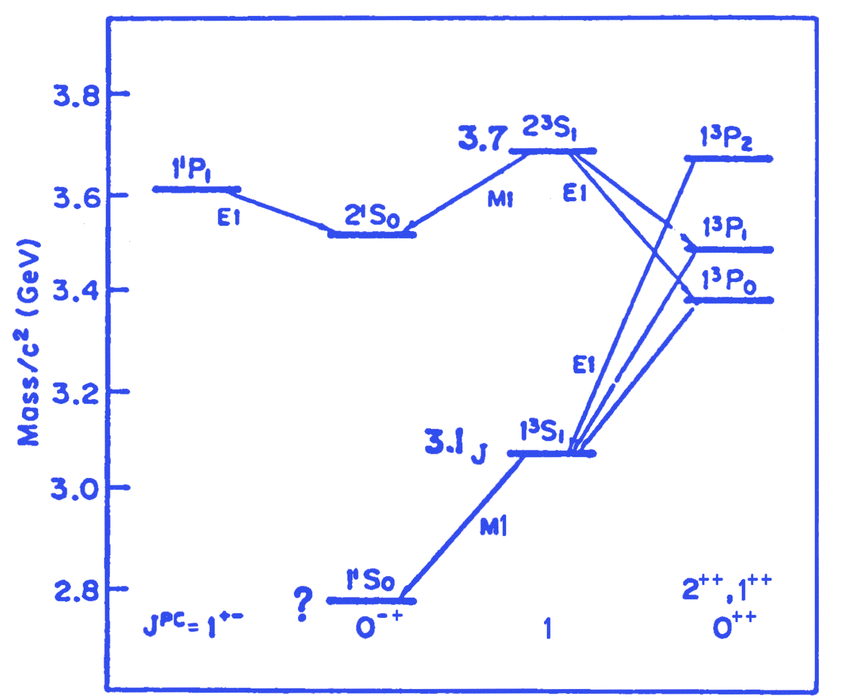
1. Its lifetime is 10,000 times longer than other particles.
   This implies the J particle is a new kind of matter
2. The spectrum is similar to positronium: This implies the J particle is made up of a new kind of Quark-Antiquark.

Positronium transitions

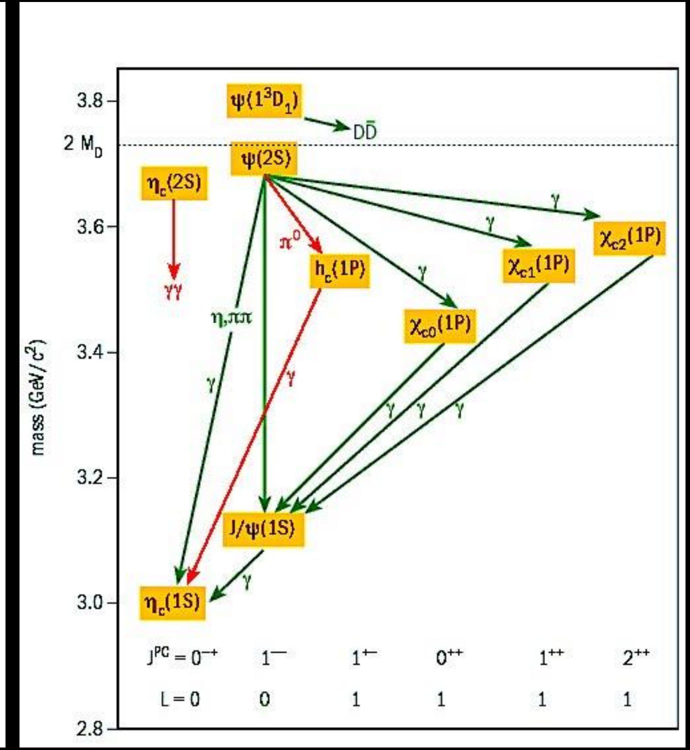


J/psi transitions

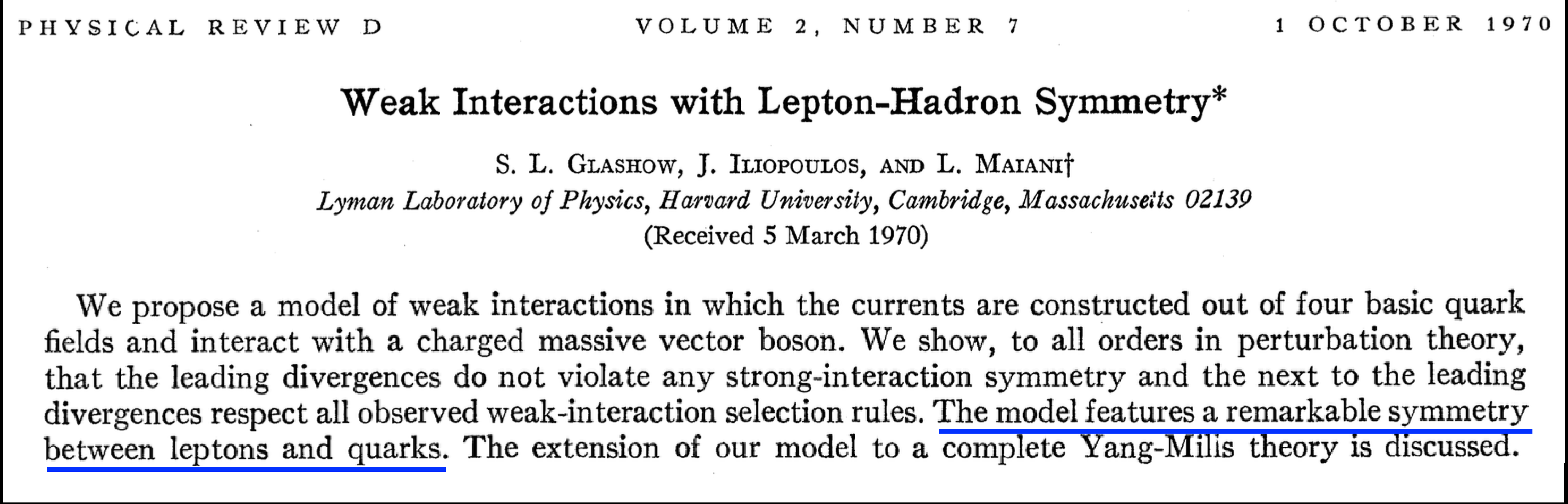
from SLAC



from DESY



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-Milis theory is discussed.

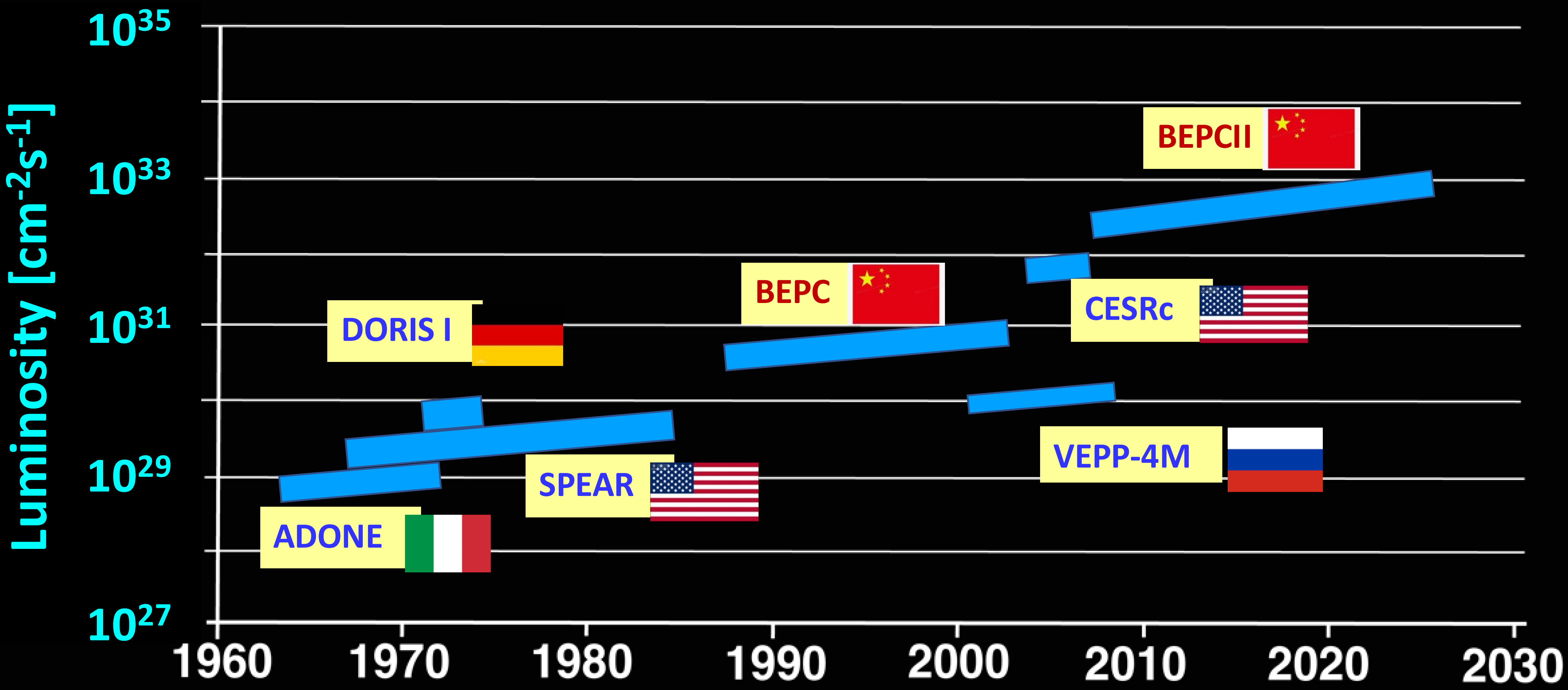
During the Summer of 1974, I had many interesting discussions with Shelly Glashow and Luciano Maiani

Dec. 10, 1976 - Stockholm

Attending the Nobel ceremony, Dec. 10, 1976

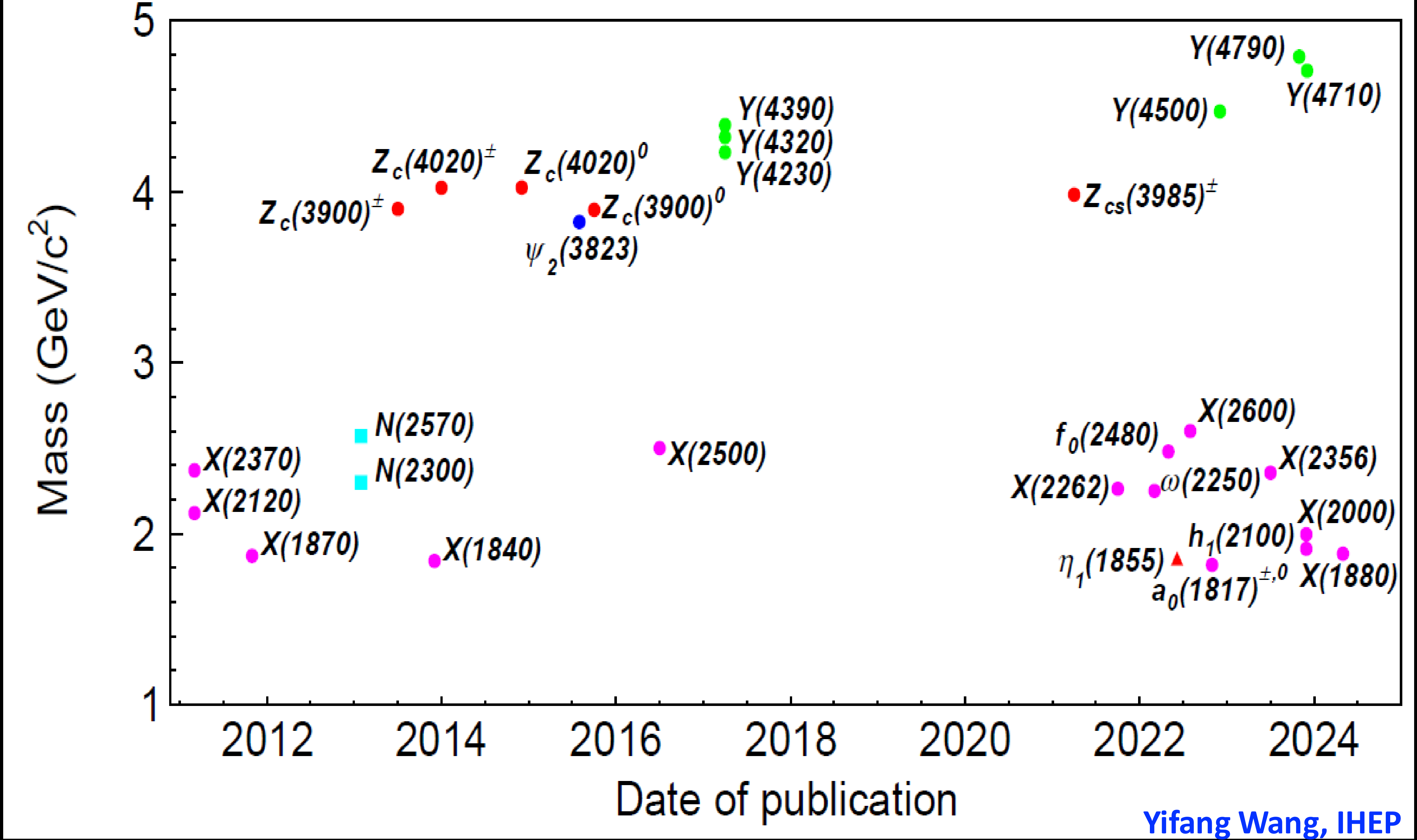
with M. Chen, U. Becker, J. Burger

Understanding this new form of matter: Tau-Charm Factories in the World



Yifang Wang, IHEP

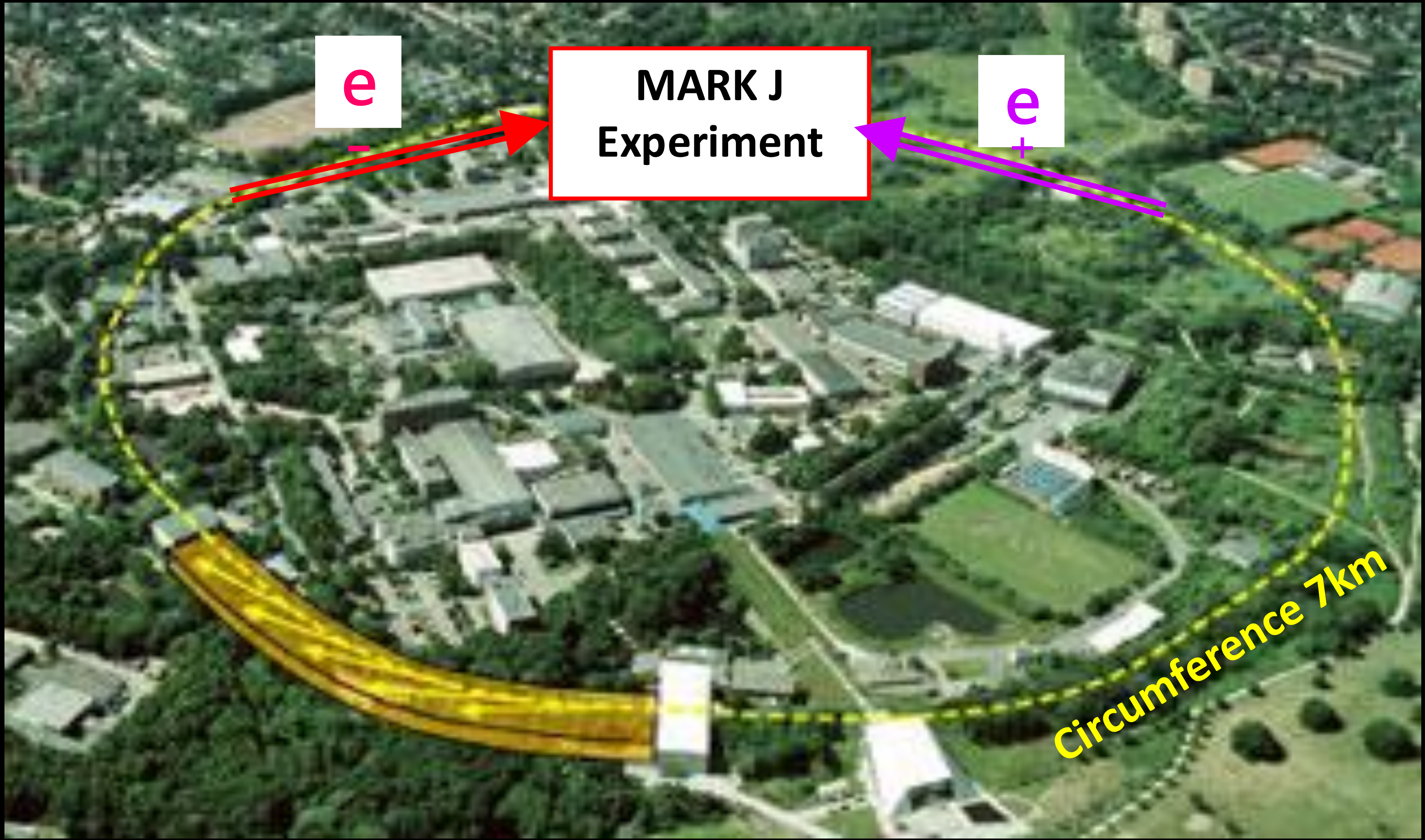
30 new hadrons discovered at BESIII from charmed meson production and decays

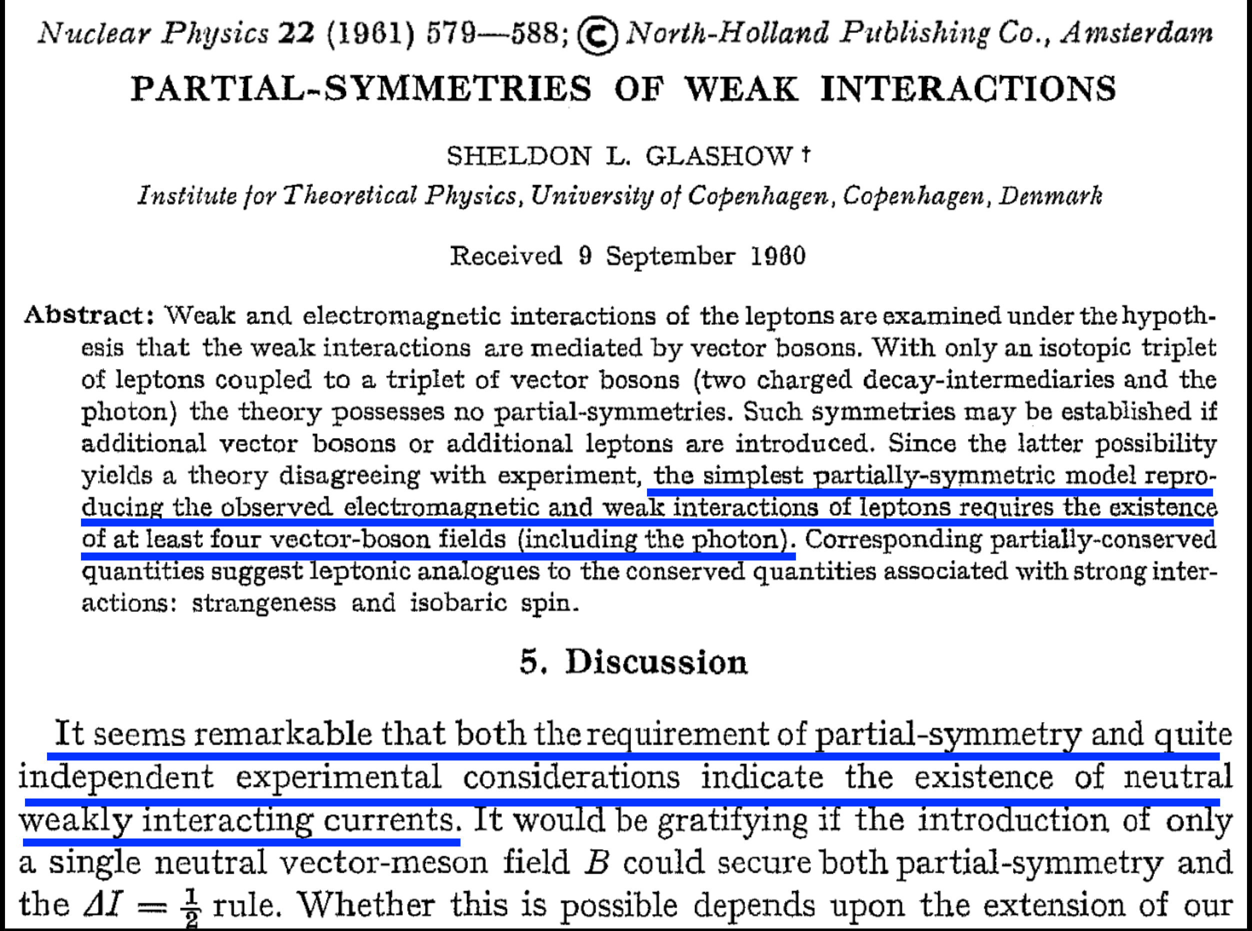


Yifang Wang, IHEP

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

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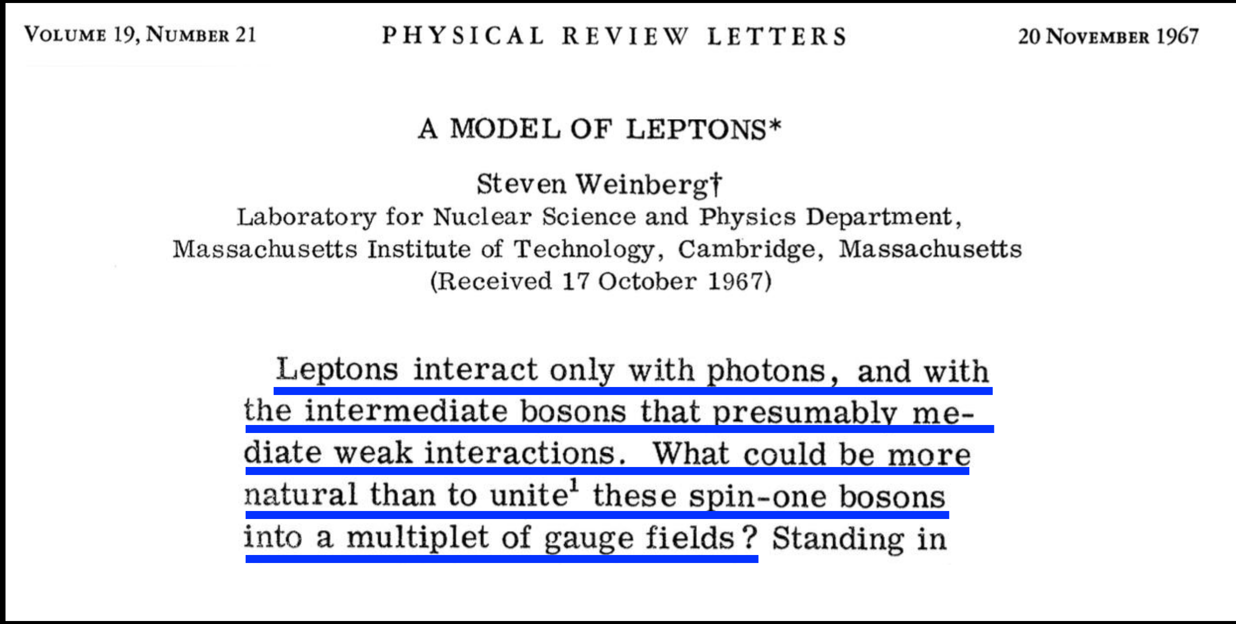

Volume 19, Number 21 PHYSICAL REVIEW LETTERS 20 November 1967

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 unite[1] these spin-one bosons into a multiplet of gauge fields? Standing in

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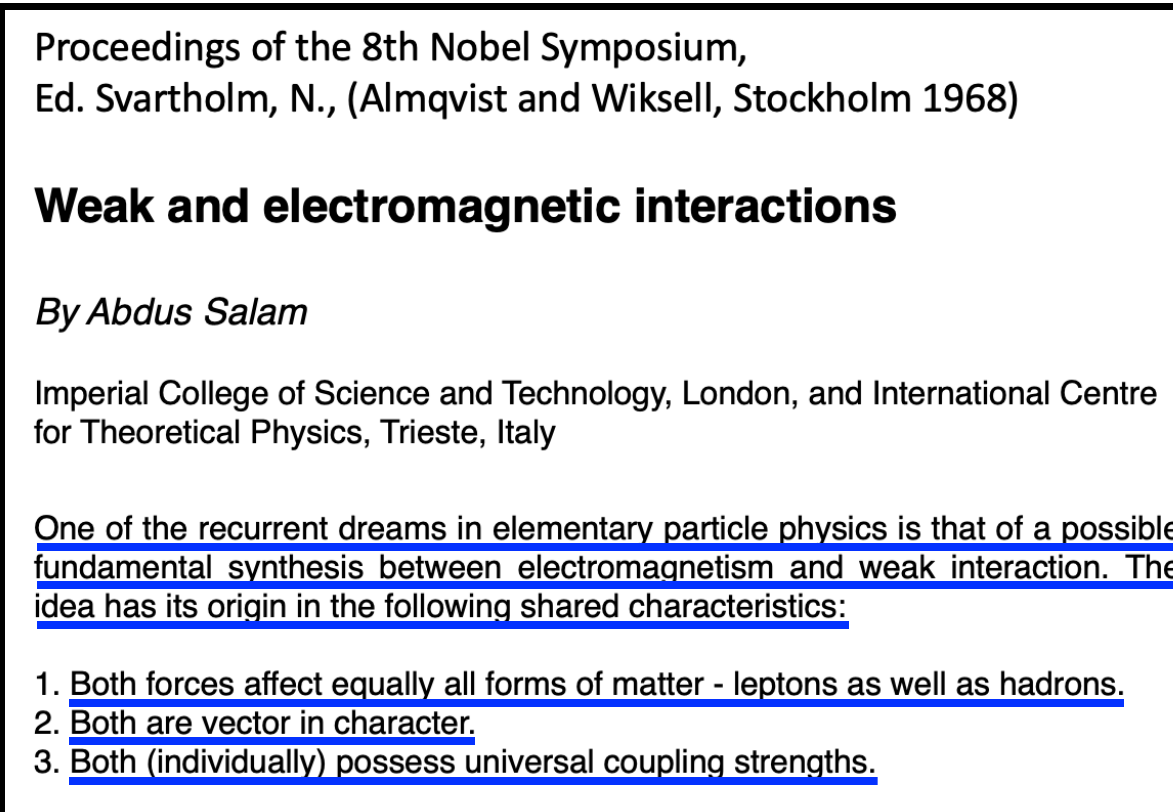


Proceedings of the 8th Nobel Symposium,
Ed. Svartholm, N., (Almqvist and Wiksell, Stockholm 1968)

Weak and electromagnetic interactions

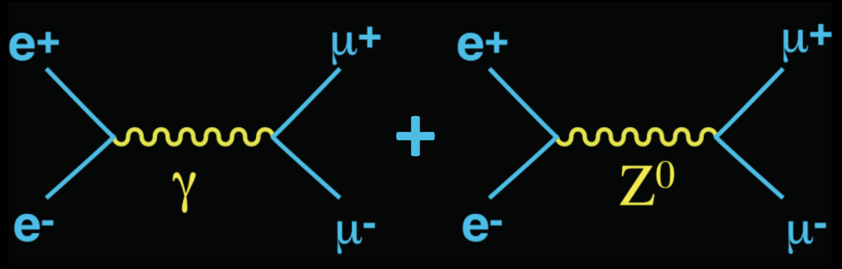
By Abdus Salam

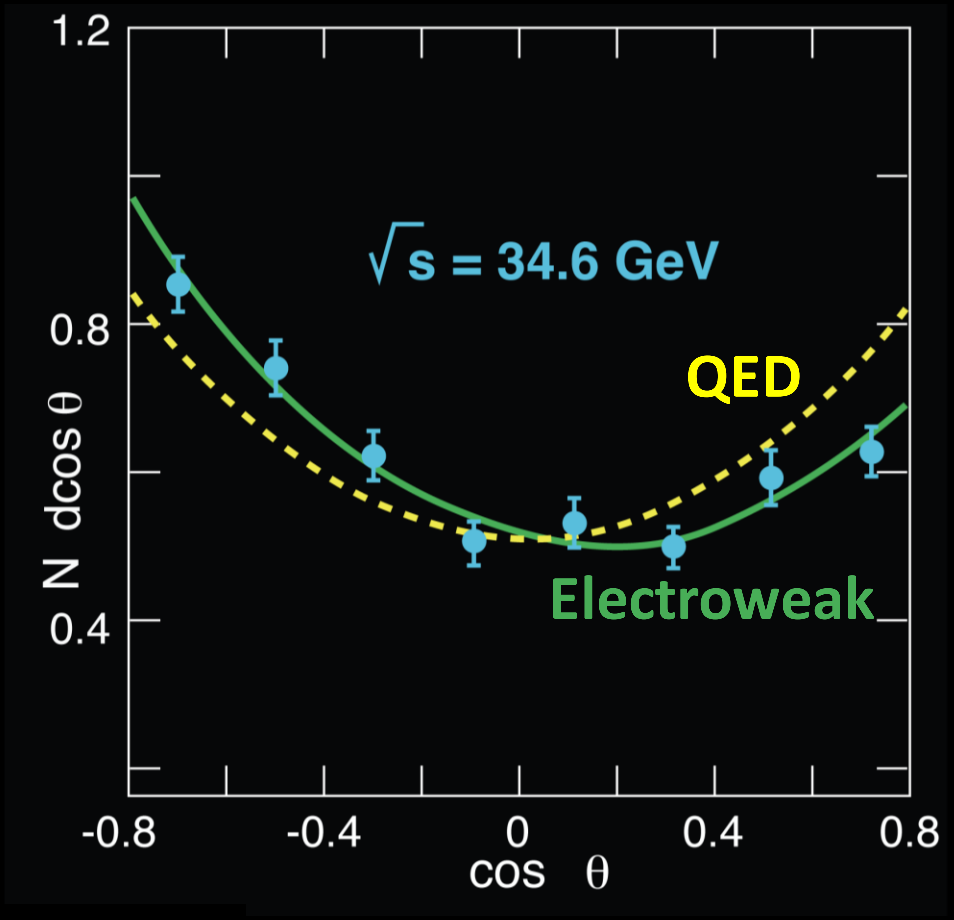
Imperial College of Science and Technology, London, and International Centre for Theoretical Physics, Trieste, Italy

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:

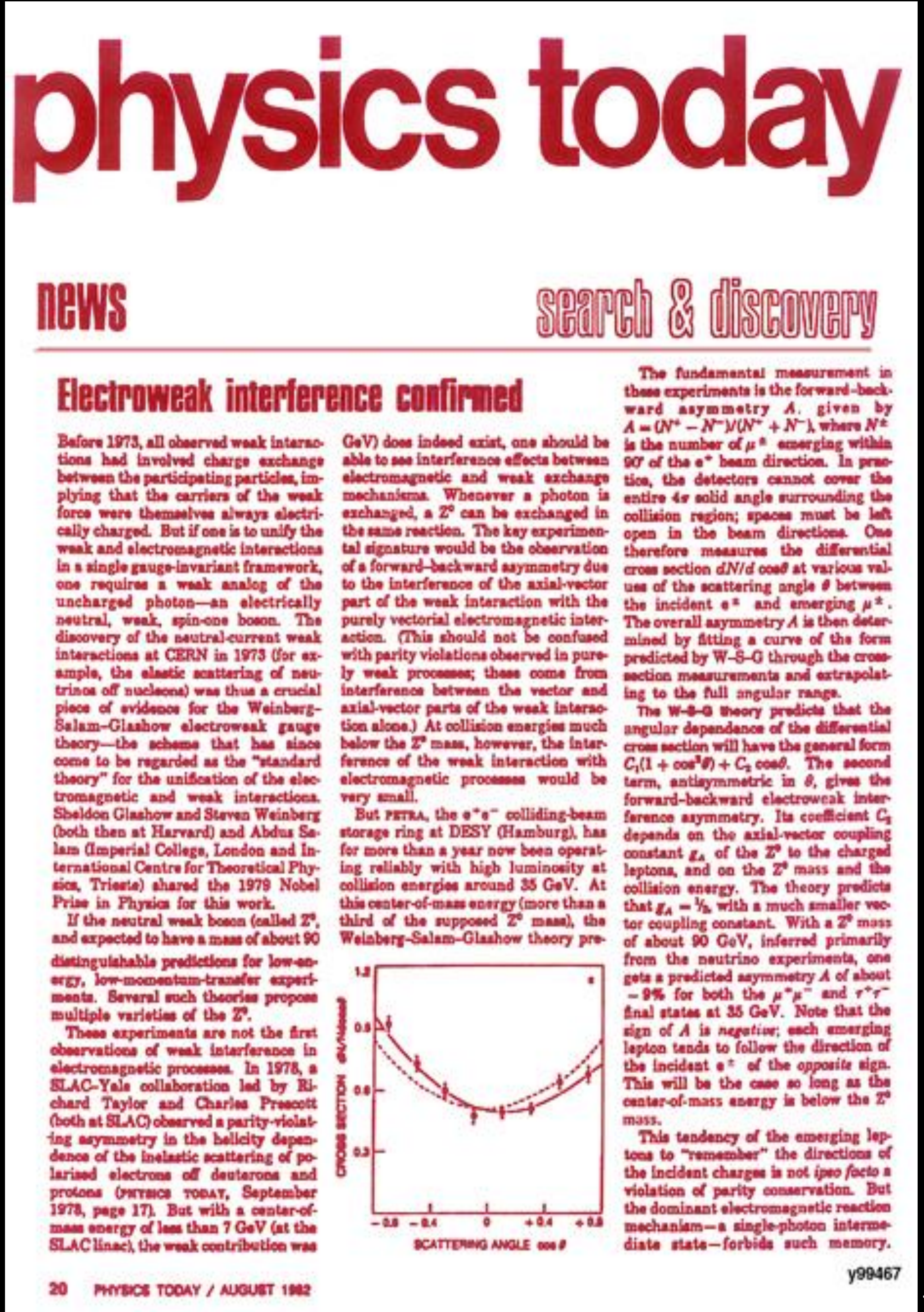
1. Both forces affect equally all forms of matter - leptons as well as hadrons.
2. Both are vector in character.
3. Both (individually) possess universal coupling strengths.

The earliest confirmation of electroweak theory
Measuring $e^+e^- \rightarrow \mu^+\mu^-$ forward-backward asymmetry





P.R.L. 48, 25 (21 June 1982)



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

distinguishable predictions for low-energy, low-momentum-transfer experiments. Several such theories propose multiple varieties of the Z^0.

These experiments are not the first observations of weak interference in electromagnetic processes. In 1978, a SLAC–Yale collaboration led by Richard Taylor and Charles Prescott (both at SLAC) observed a parity-violating asymmetry in the helicity dependence of the inelastic scattering of polarized electrons off deuterons and protons (PHYSICS TODAY, September 1978, page 17). But with a center-of-mass energy of less than 7 GeV (at the SLAC linac), the weak contribution was

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 pre-

The fundamental measurement in these experiments is the forward–backward asymmetry A, given by $A = (N^+ - N^-)/(N^+ + N^-)$, where $N^\pm$ is the number of $\mu^\pm$ 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 $e^\pm$ and emerging $\mu^\pm$. 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 $g_A = -\frac{1}{2}$, 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 $e^\pm$ 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.

20 PHYSICS TODAY / AUGUST 1982

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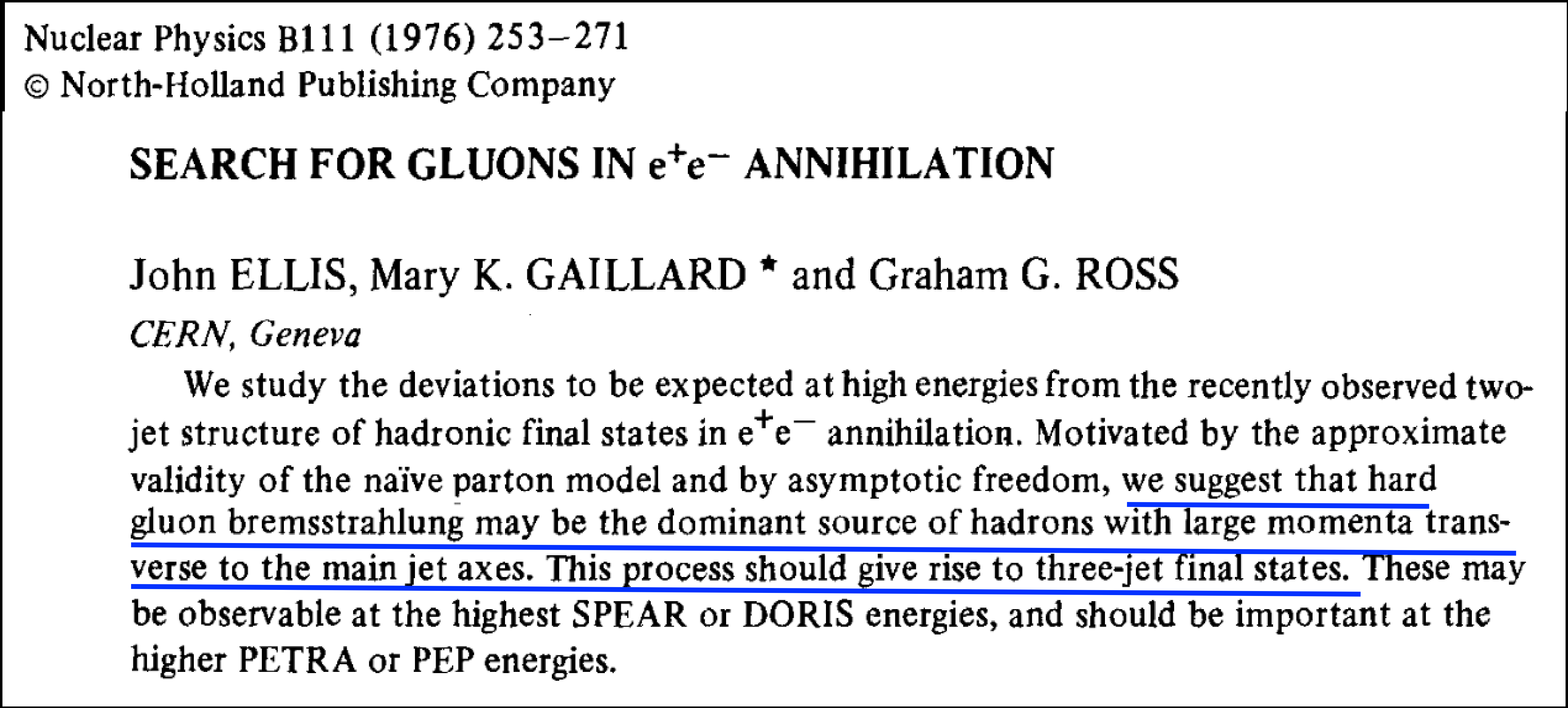


Nuclear Physics B111 (1976) 253–271

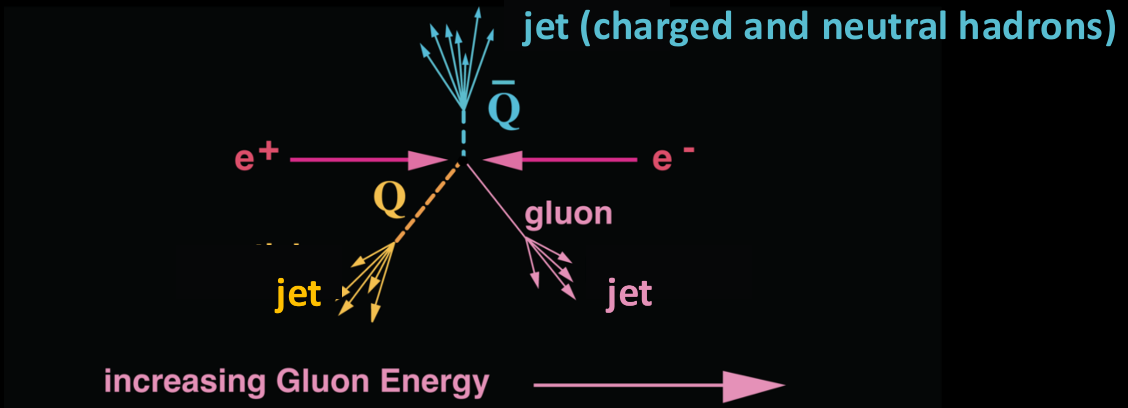
SEARCH FOR GLUONS IN e^+e^- ANNIHILATION

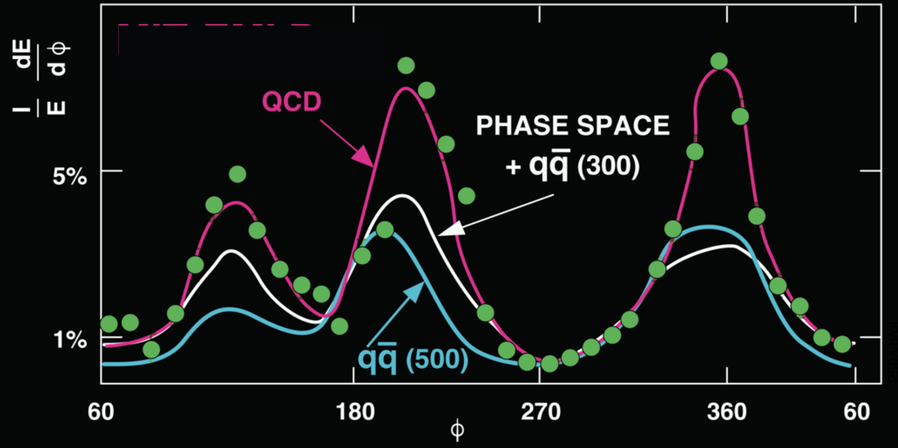
John ELLIS, Mary K. GAILLARD * and Graham G. ROSS

CERN, Geneva

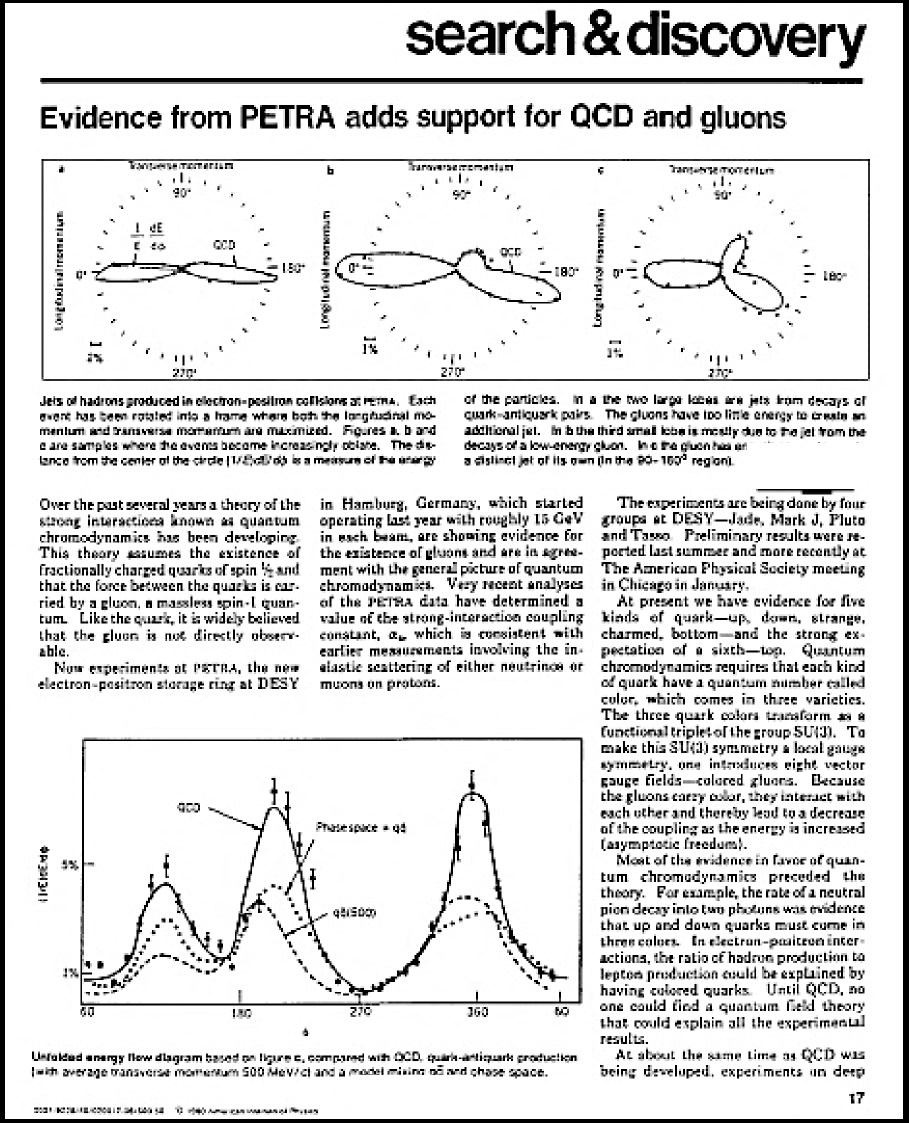
We study the deviations to be expected at high energies from the recently observed two-jet structure of hadronic final states in e^+e^- annihilation. Motivated by the approximate validity of the naïve parton model and by asymptotic freedom, we suggest that hard gluon bremsstrahlung may be the dominant 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 en

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 ½ 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.

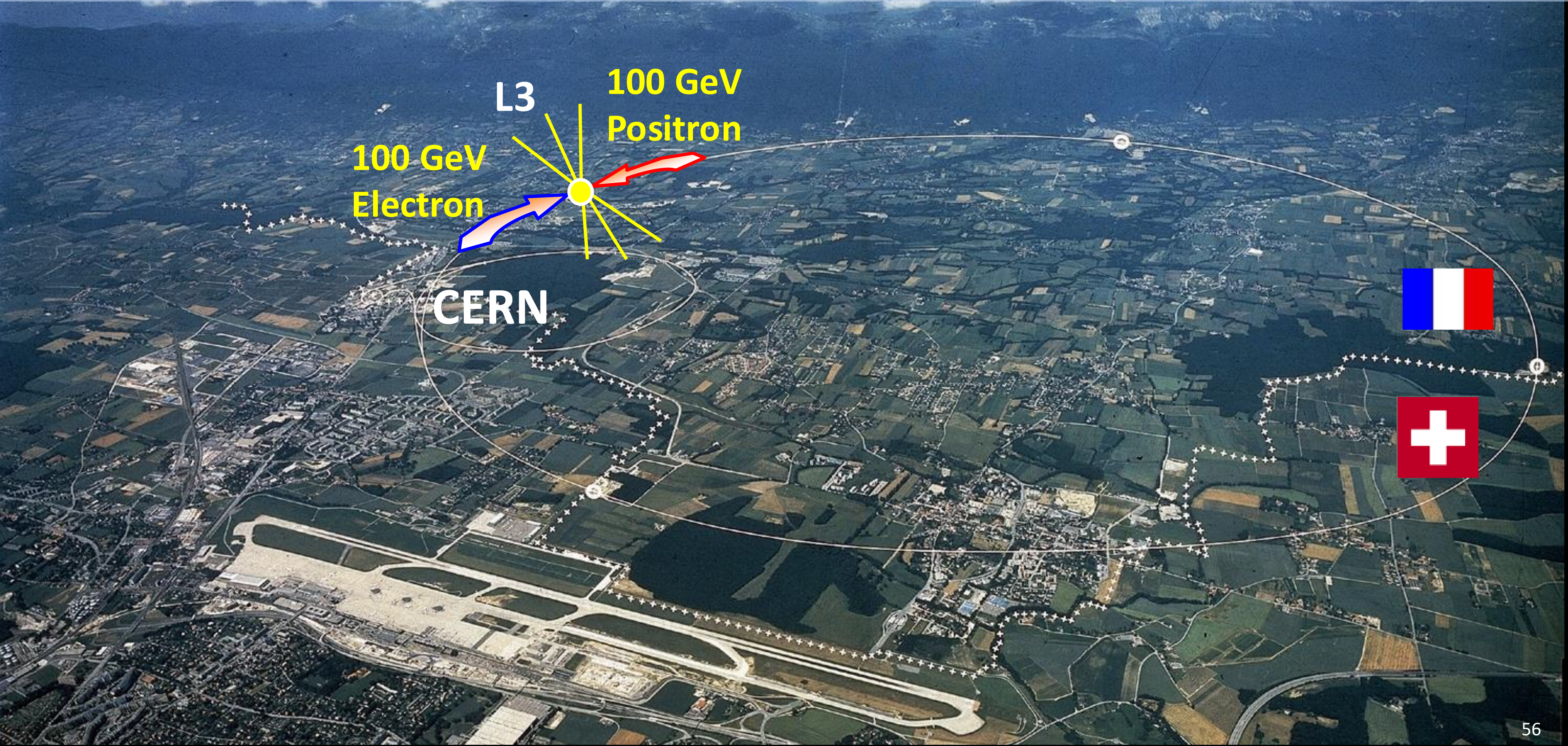
At about the same time as QCD was being developed, experiments on deep

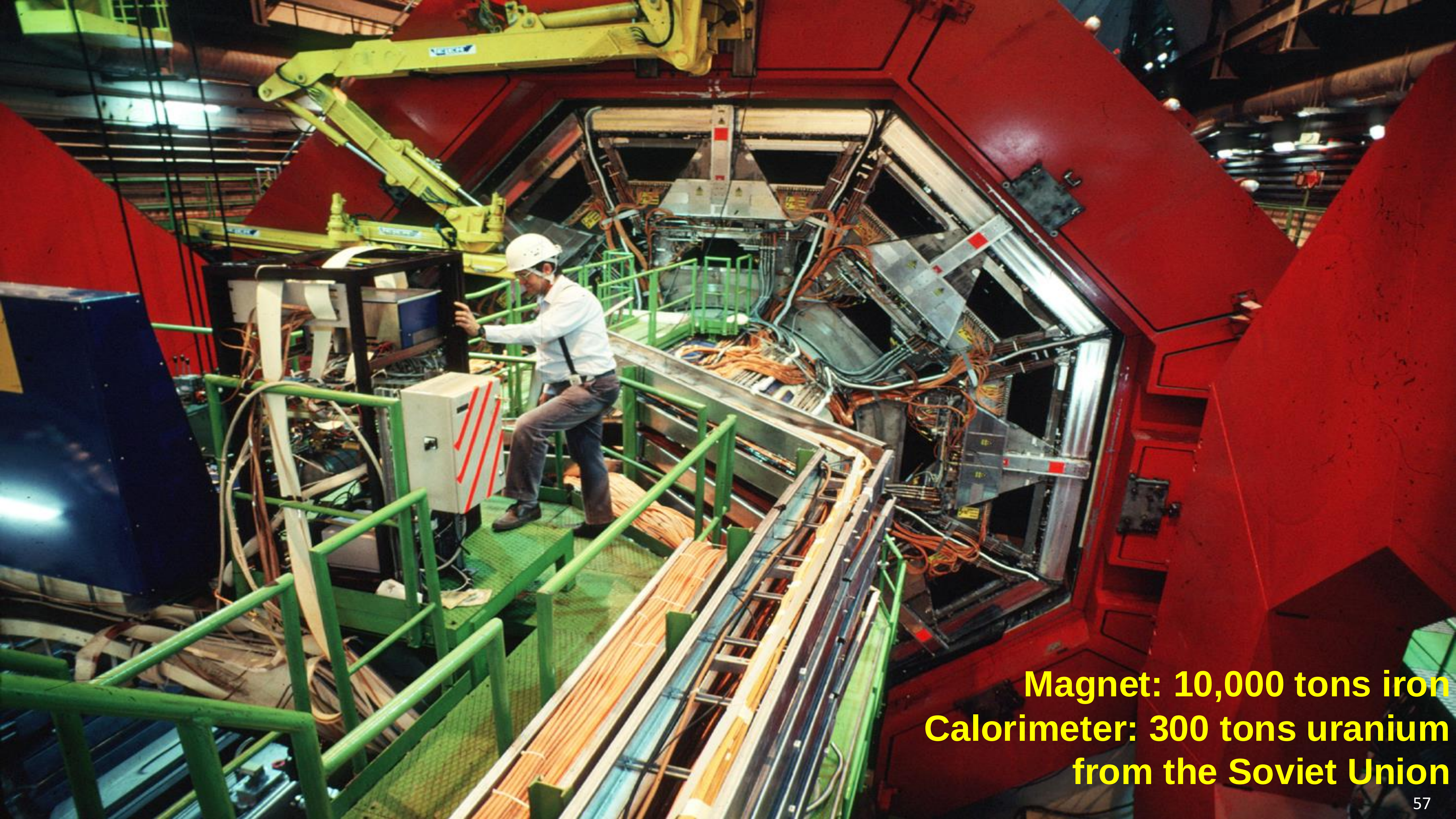
Unfolded energy flow diagram based on figure c, compared with QCD, quark-antiquark production (with average transverse momentum 500 MeV/c) and a model mixing $q\bar{q}$ and phase space.

0031-9228/80/020017-04/$00.50 © 1980 American Institute of Physics

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)

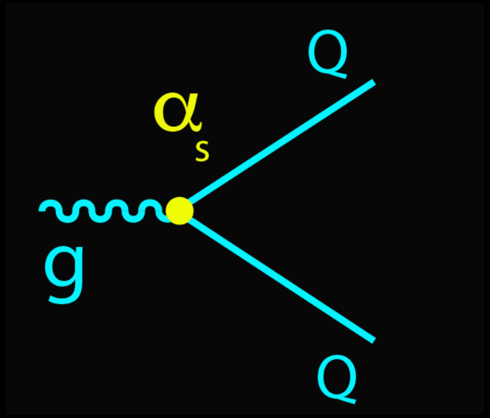


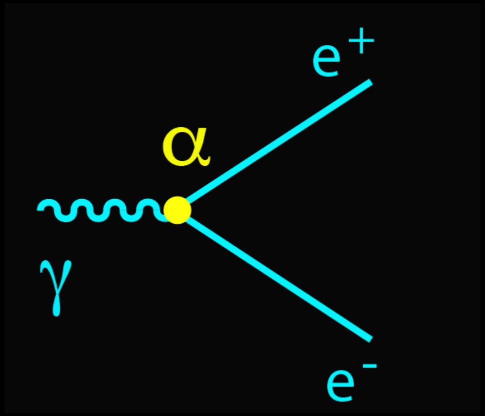


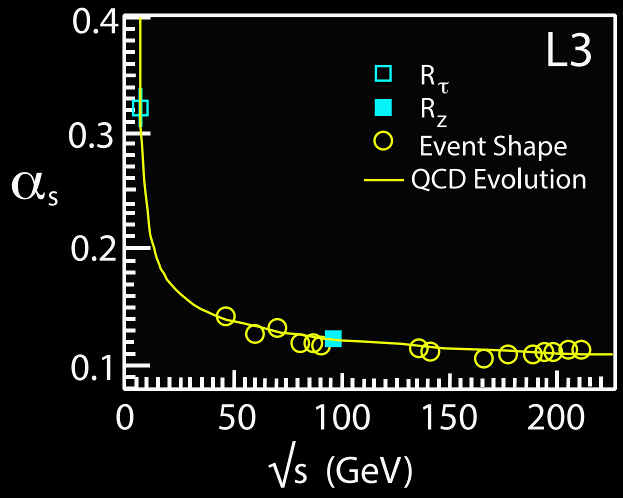
Magnet: 10,000 tons iron
Calorimeter: 300 tons uranium
from the Soviet Union

Important Results

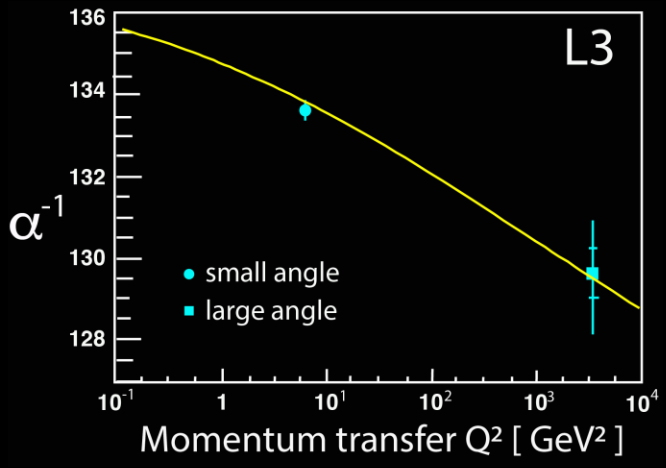
1. Dependence of the coupling “constants” on energy







Phys. Lett. B 476 (2000) 40

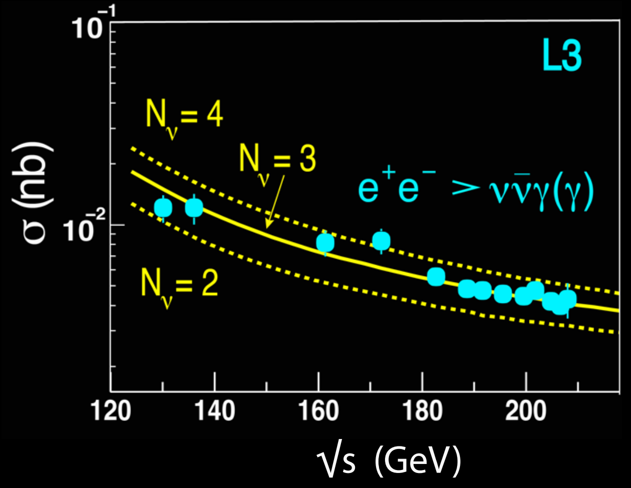


Phys. Lett. B 536 (2002) 217

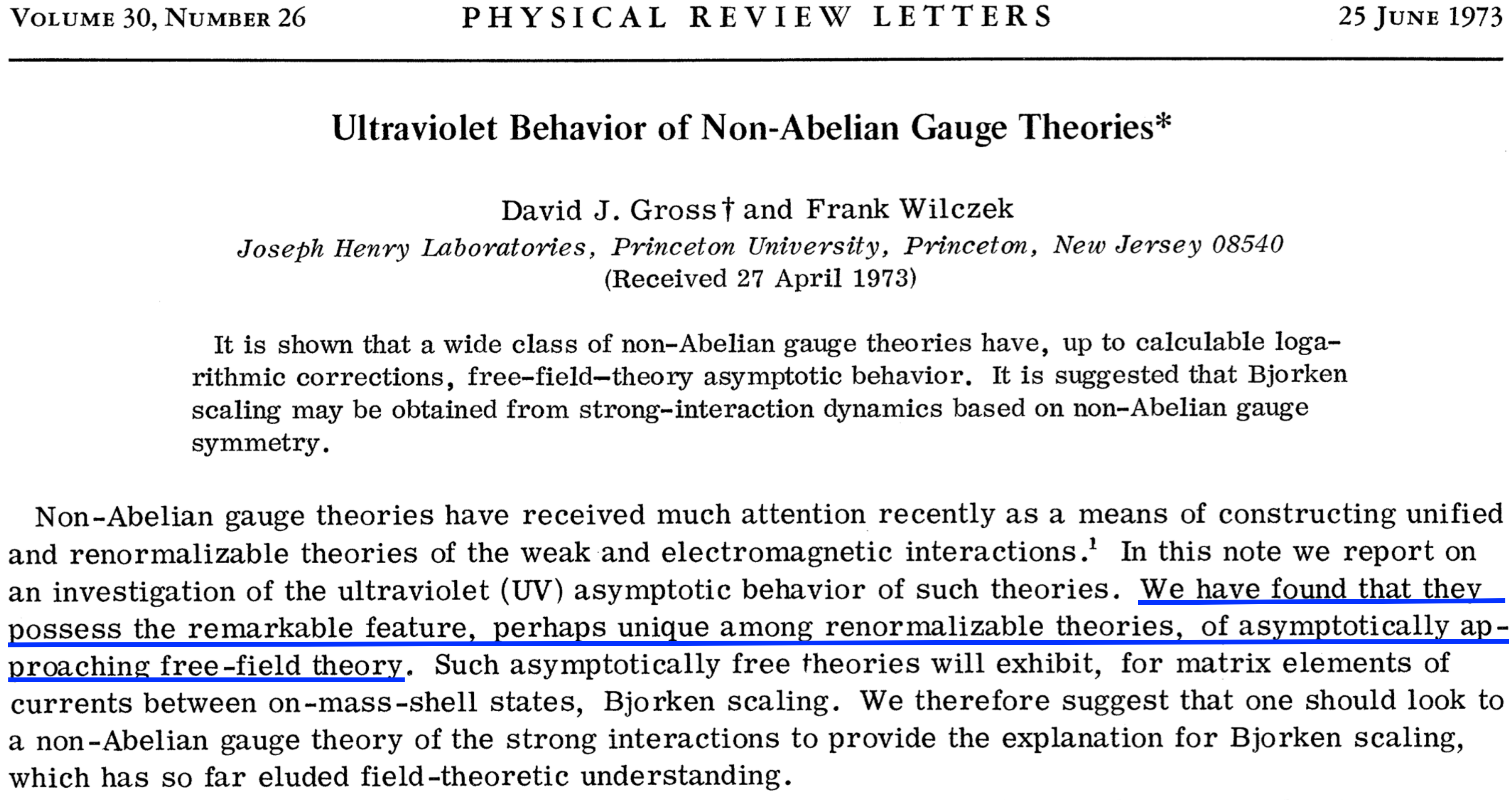
2. Model independent number of neutrinos

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

$N_\nu = 2.98 \pm 0.064$



Phys. Lett. B 587 (2004) 16



VOLUME 30, NUMBER 26 PHYSICAL REVIEW LETTERS 25 JUNE 1973

Ultraviolet Behavior of Non-Abelian Gauge Theories*

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

(Received 27 April 1973)

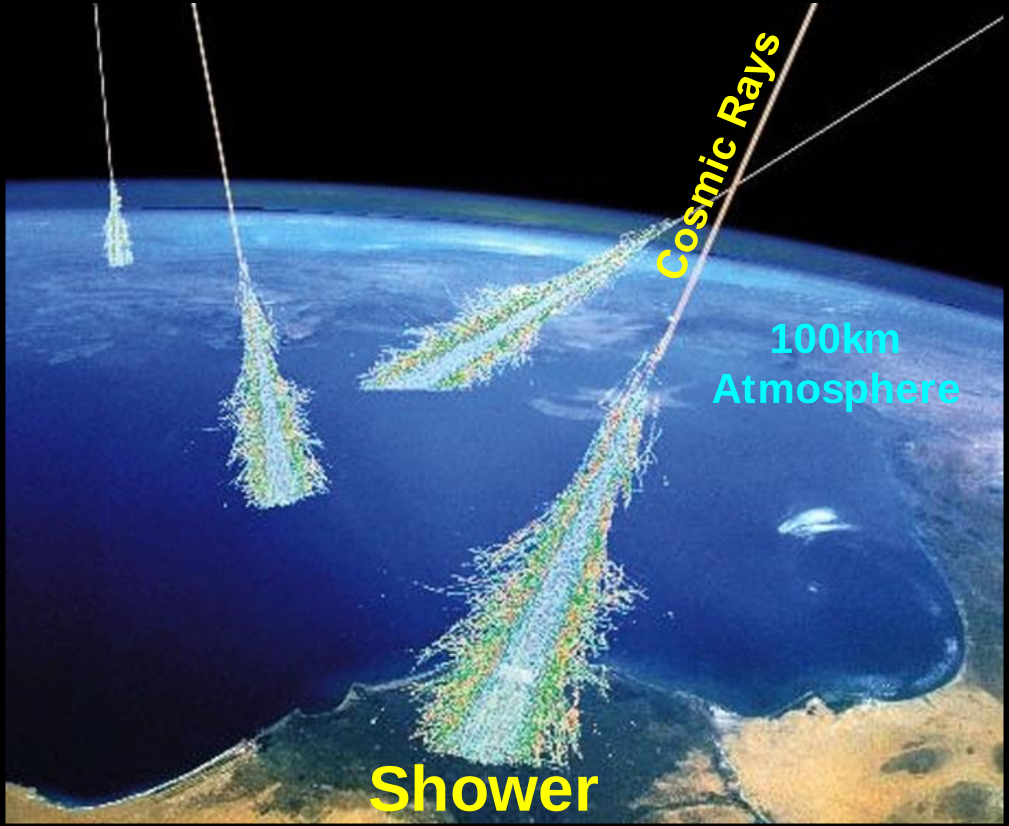
It is shown that a wide class of non-Abelian gauge theories have, up to calculable logarithmic corrections, free-field–theory asymptotic behavior. It is suggested that Bjorken scaling may be obtained from strong-interaction dynamics based on non-Abelian gauge symmetry.

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.



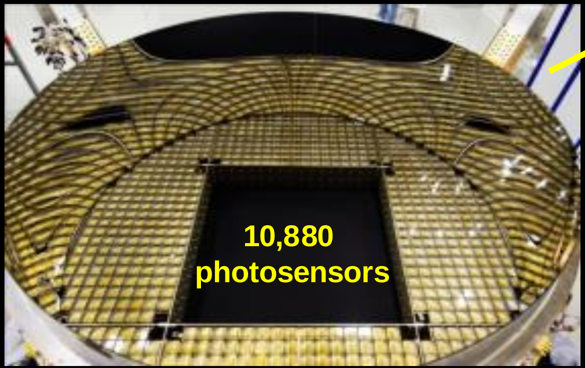
To measure cosmic ray
charge and momentum requires
a magnetic spectrometer in space

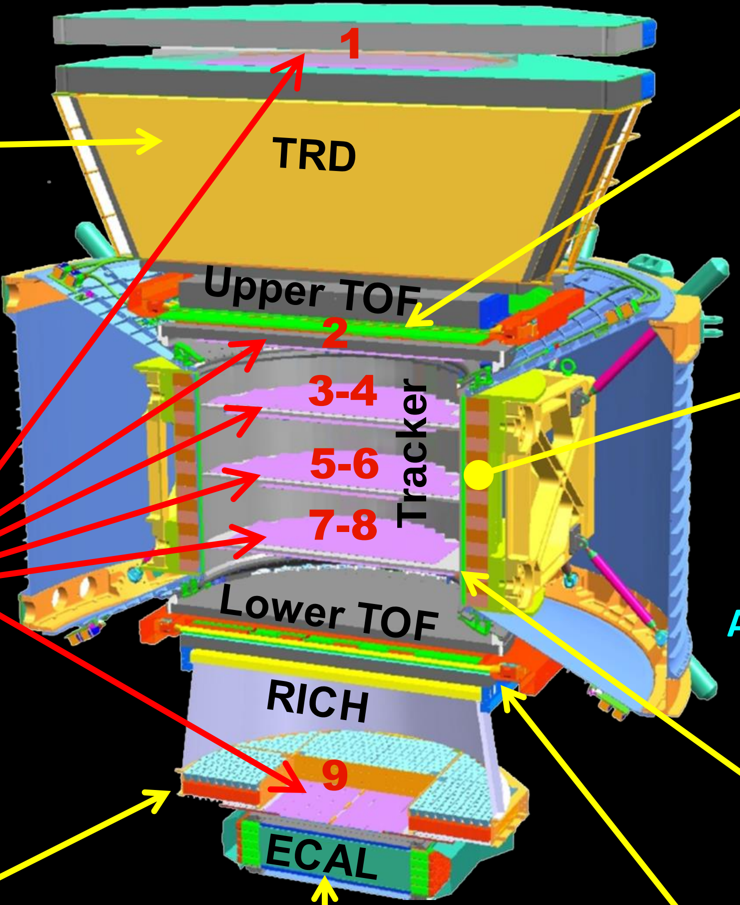
AMS is a space version of a precision detector used in accelerators

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

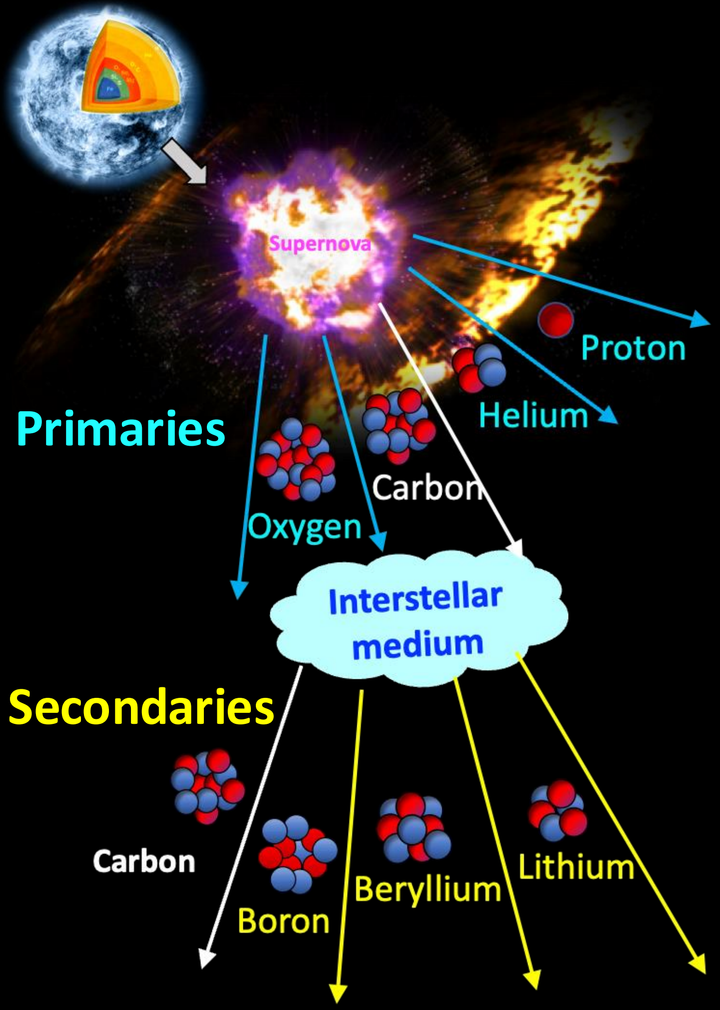
Magnet identify ±Z, P

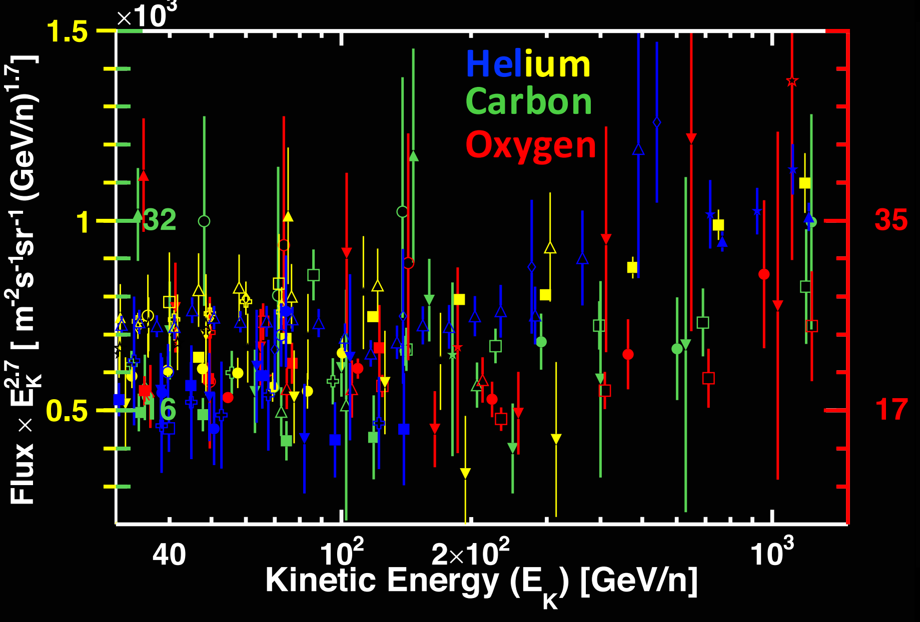
Anticoincidence Counters (ACC)
reject particles from the side

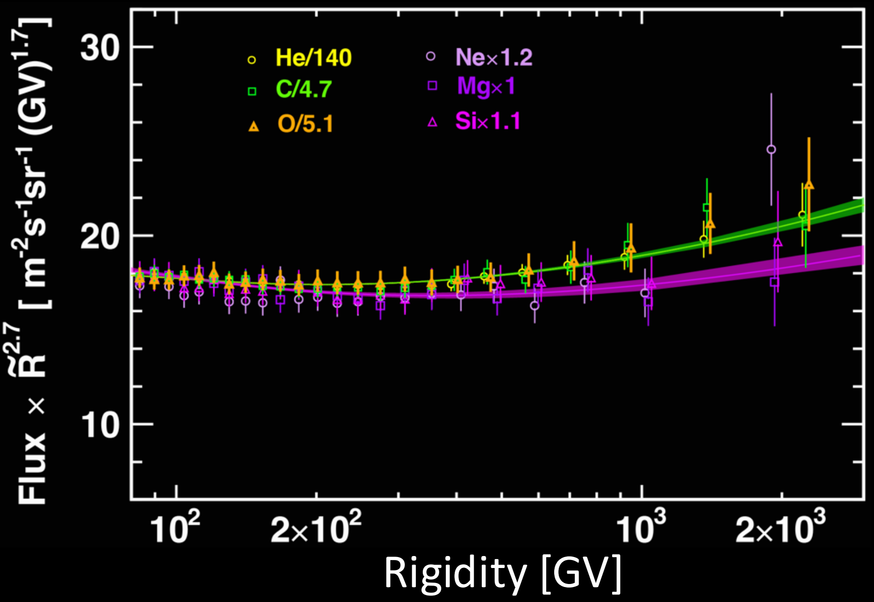
Lower TOF measure Z, E

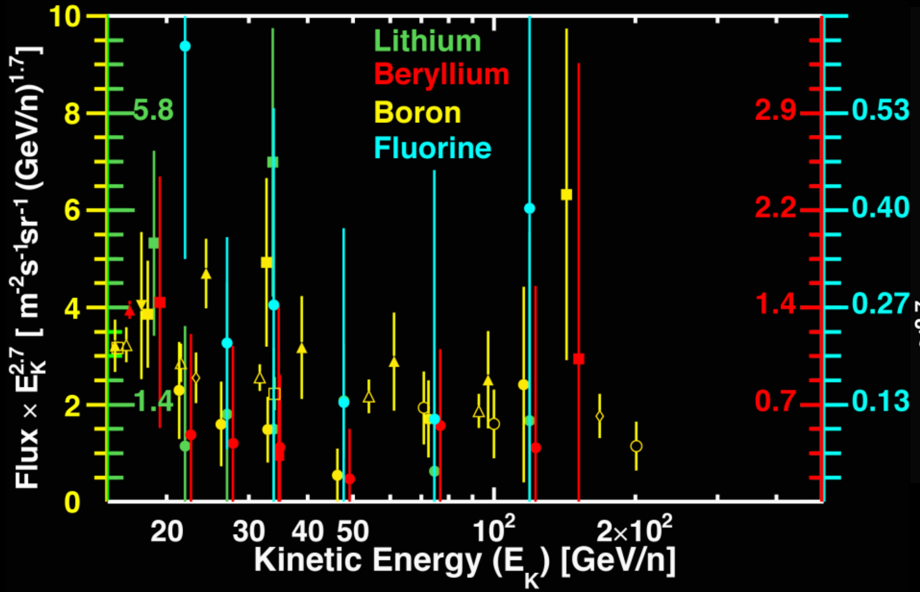
Summary of Cosmic Ray data before AMS

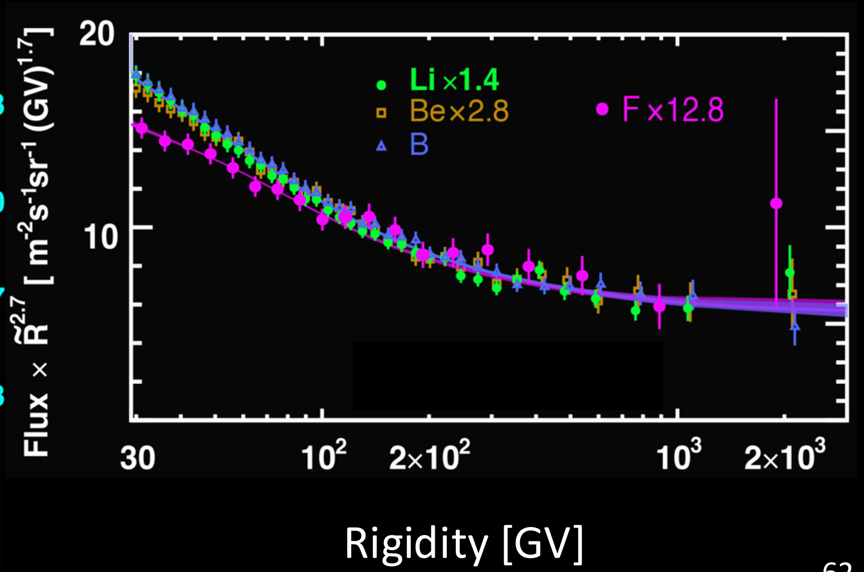
AMS data



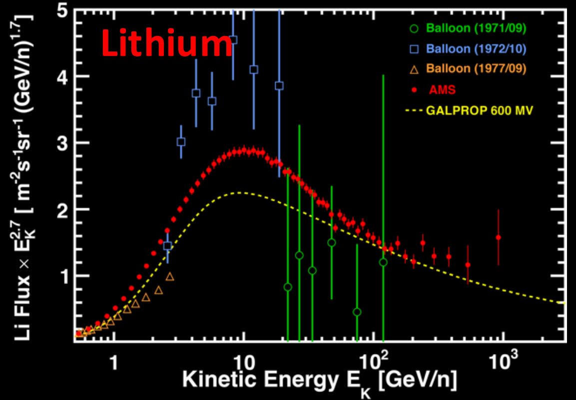


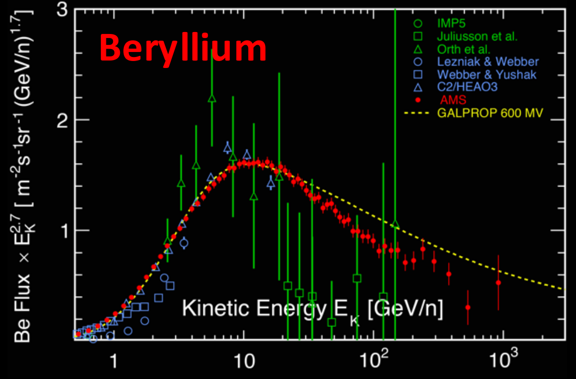


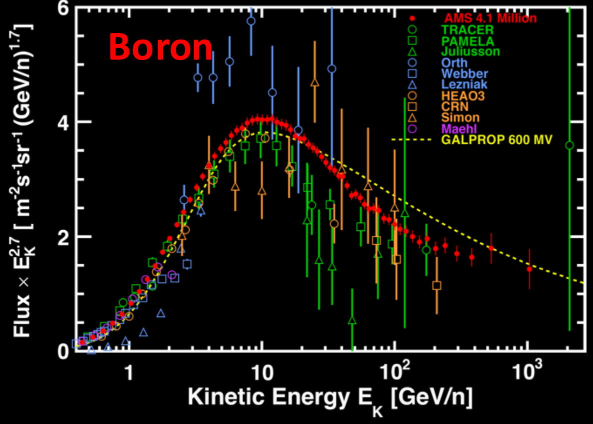


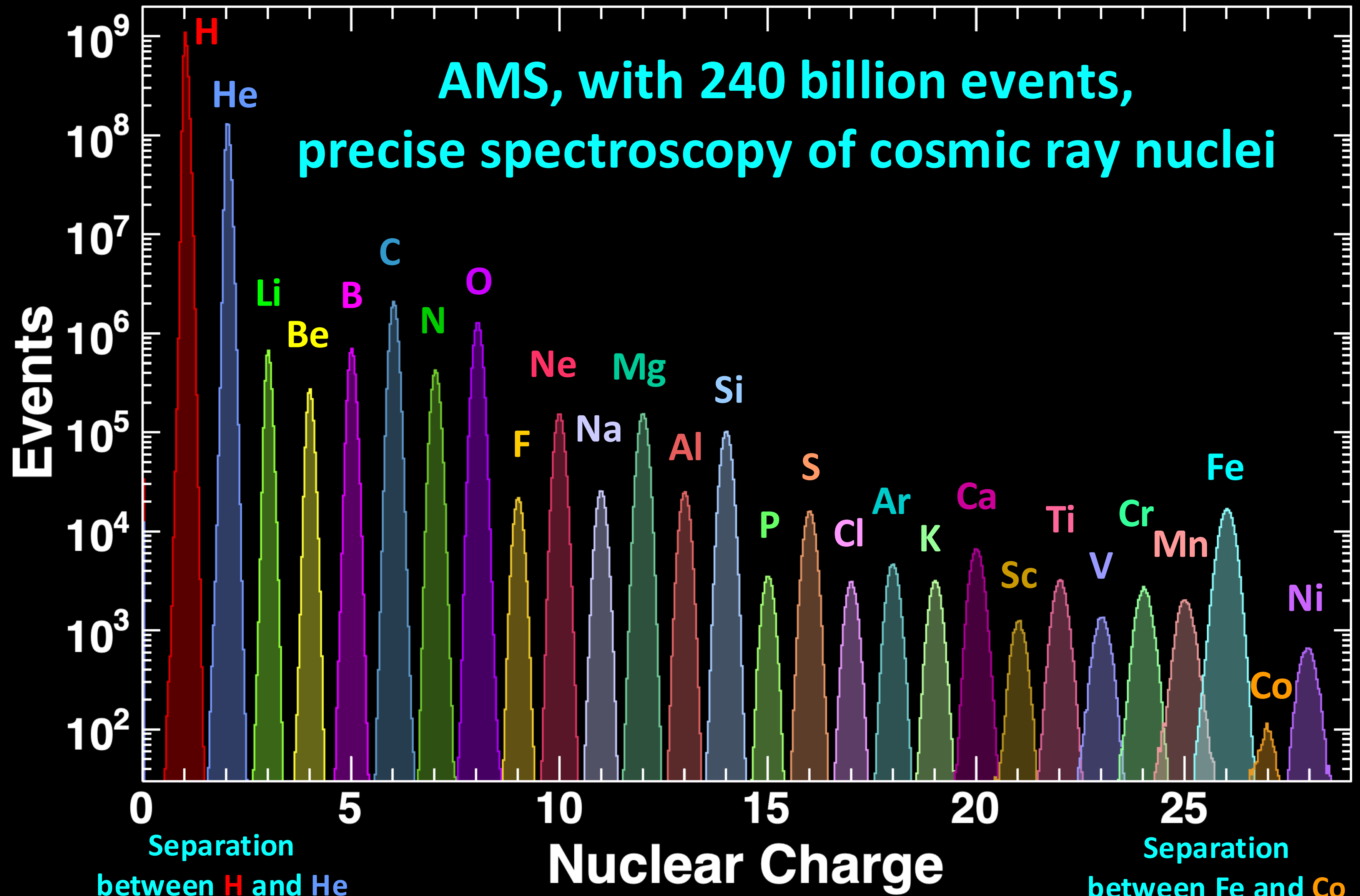


Spectroscopy of cosmic ray nuclei









AMS, with 240 billion events,
precise spectroscopy of cosmic ray nuclei

Separation between H and He is better than 1 in 10^9

Separation between Fe and Co is better than 1 in 10^2

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

Supernovae

p, He, …

Interstellar Medium

Cosmic Ray

Cosmic Ray

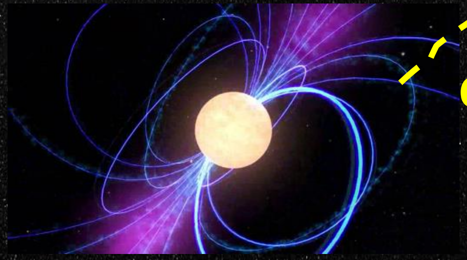
Dark Matter

Dark Matter

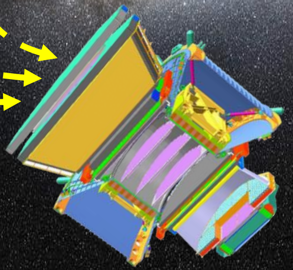
e+, $\bar{p}$, …
from Dark Matter

e+, $\bar{p}$
from Collisions

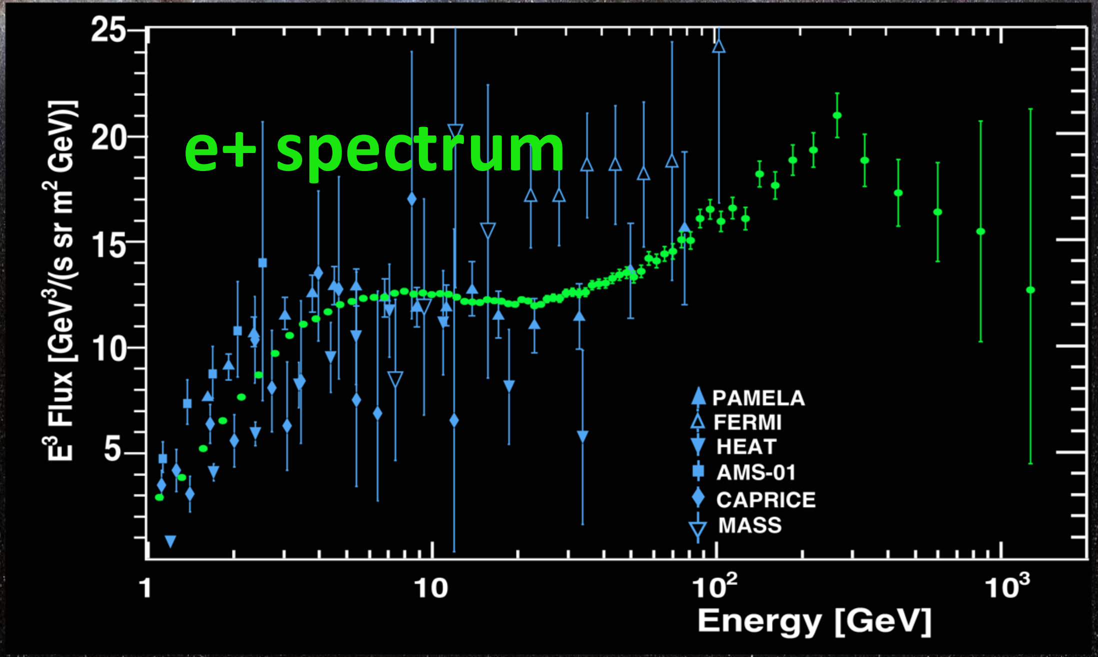
Pulsars



e+ from Pulsars

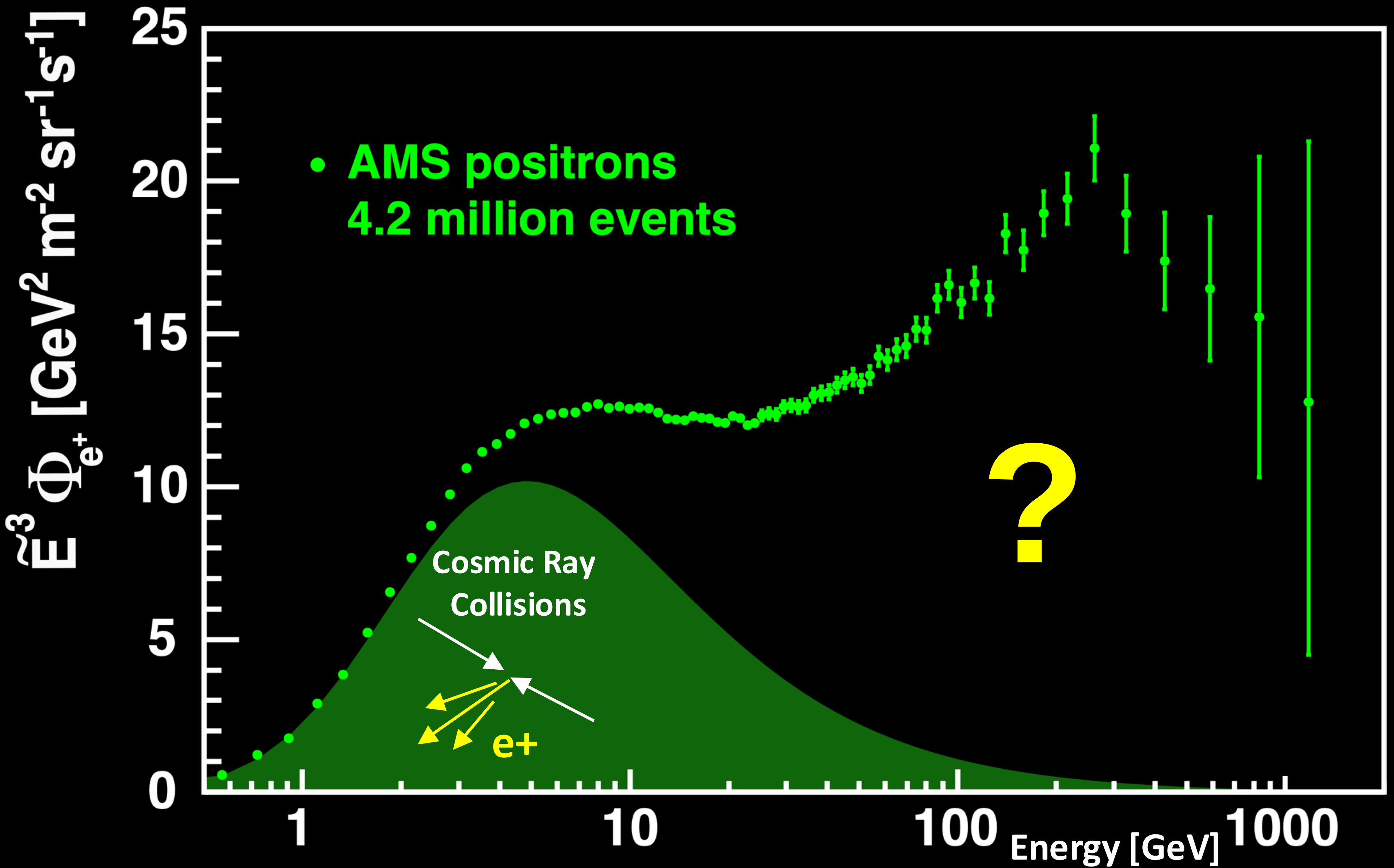


AMS



Low-energy positrons come from cosmic ray collisions

High-energy positrons must come from a new source

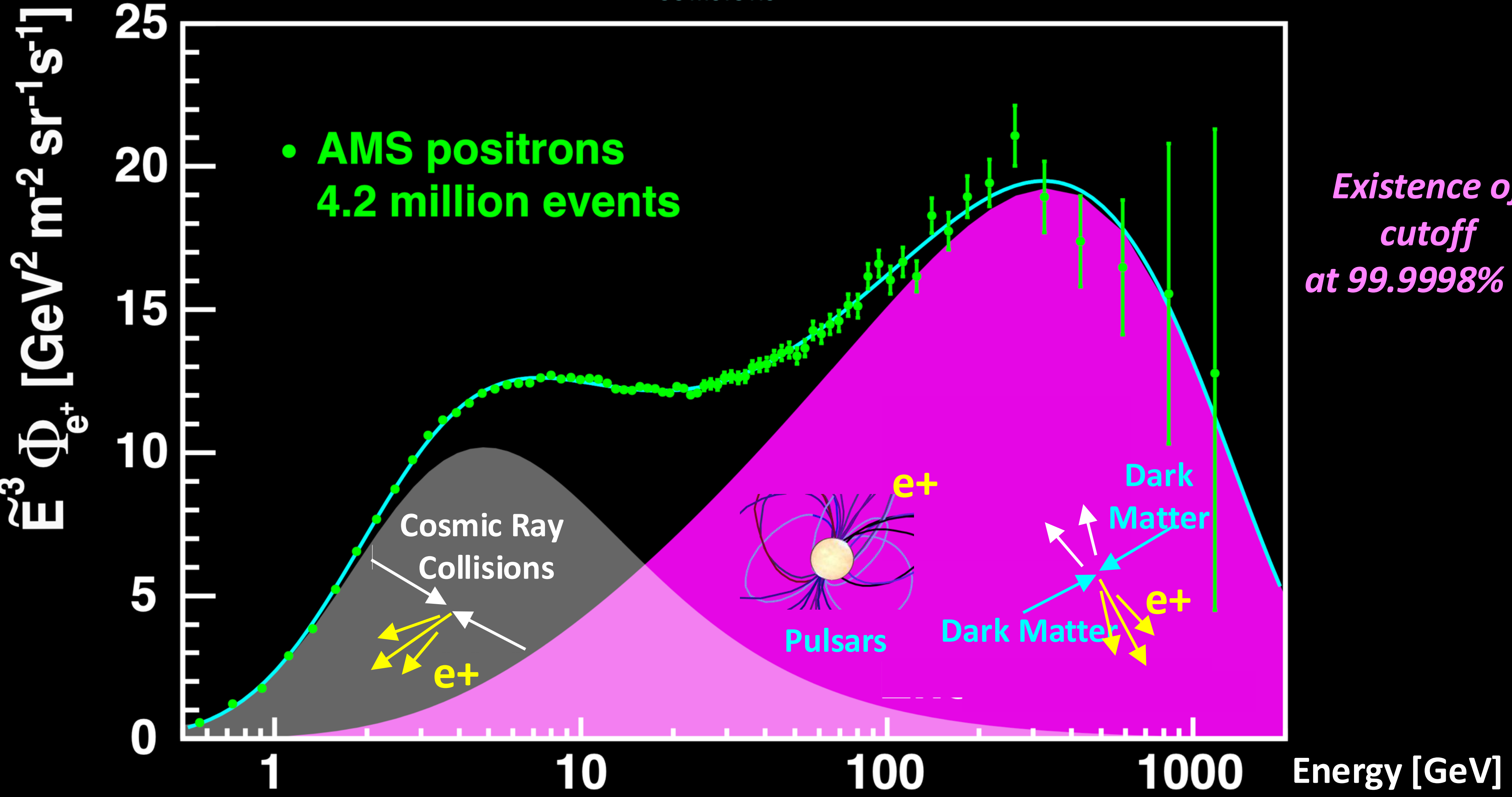


The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from pulsars or dark matter with a cutoff energy

Empirical model: $$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right]$$

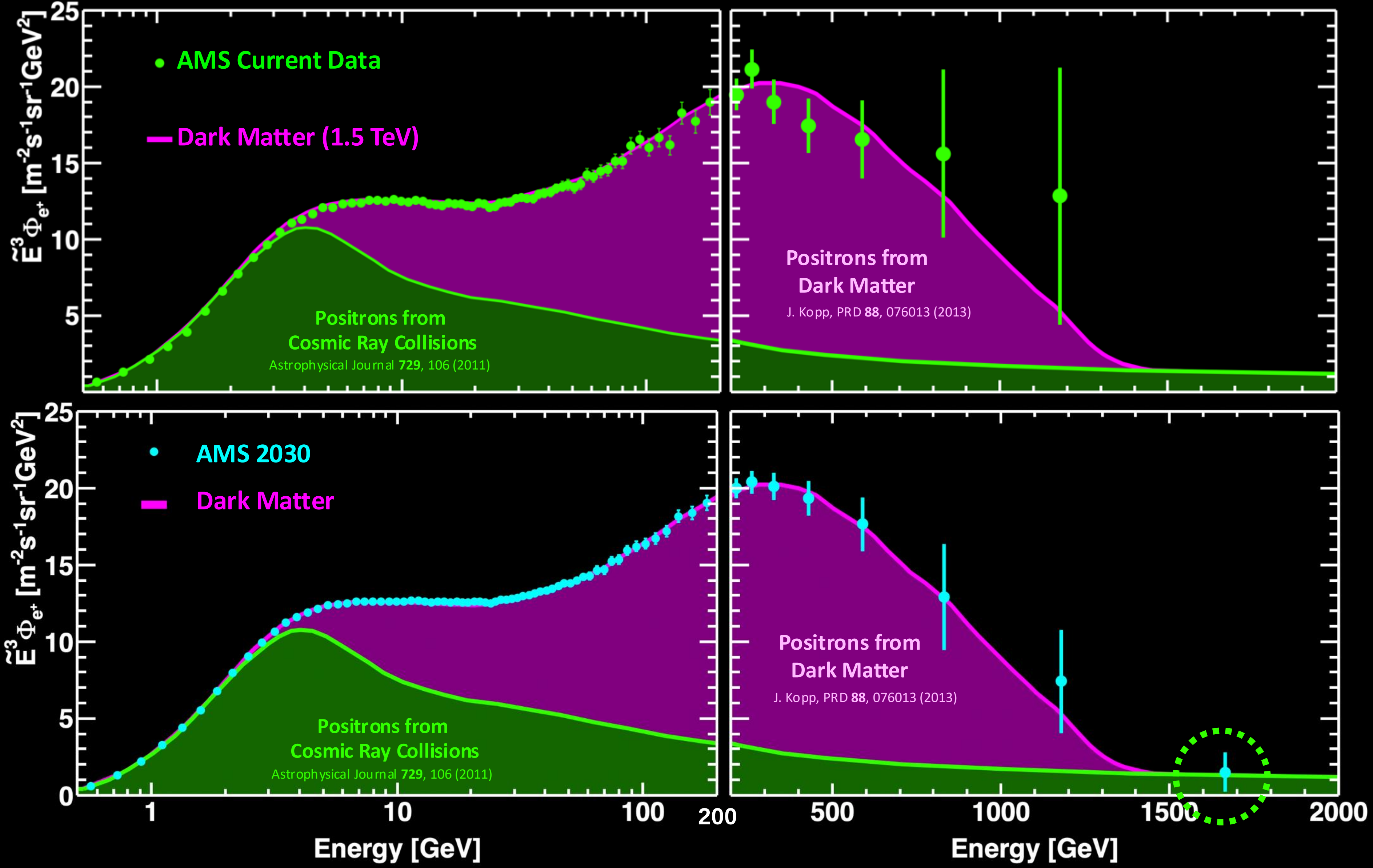
χ^2/dof = 63/66

Solar Collisions Pulsars or Dark Matter



Existence of cutoff at 99.9998% CL

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

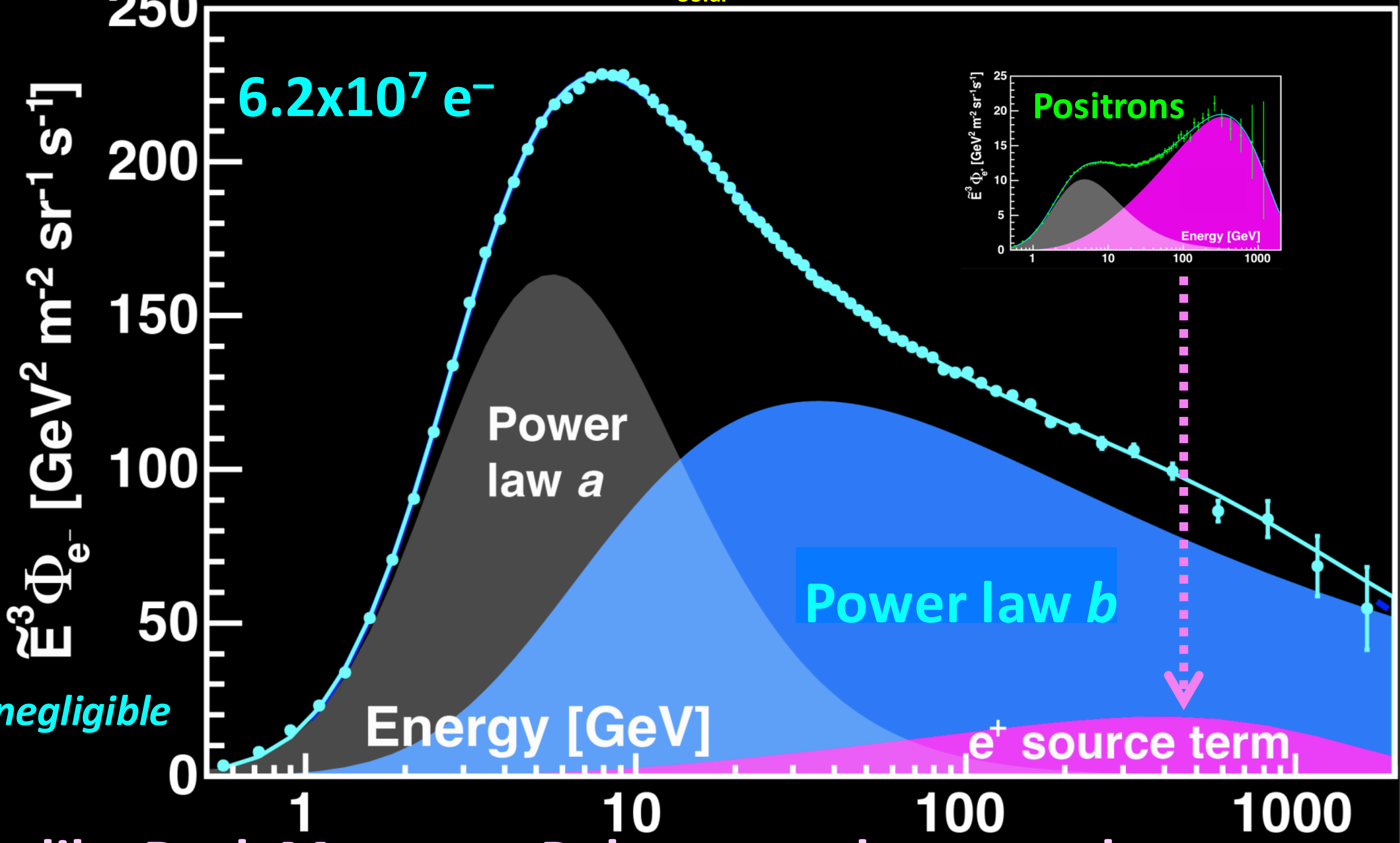
AMS Result on the electron spectrum

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

Empirical model: $\Phi_{e^-}(E) = \frac{E^2}{\widehat{E}^2}\left(C_a\,\widehat{E}^{\gamma_a} + C_b\widehat{E}^{\gamma_b} + \text{Positron Source Term}\right)$

Solar Power law *a* Power law *b*

χ^2/dof = 47/67



e⁻ from collisions negligible

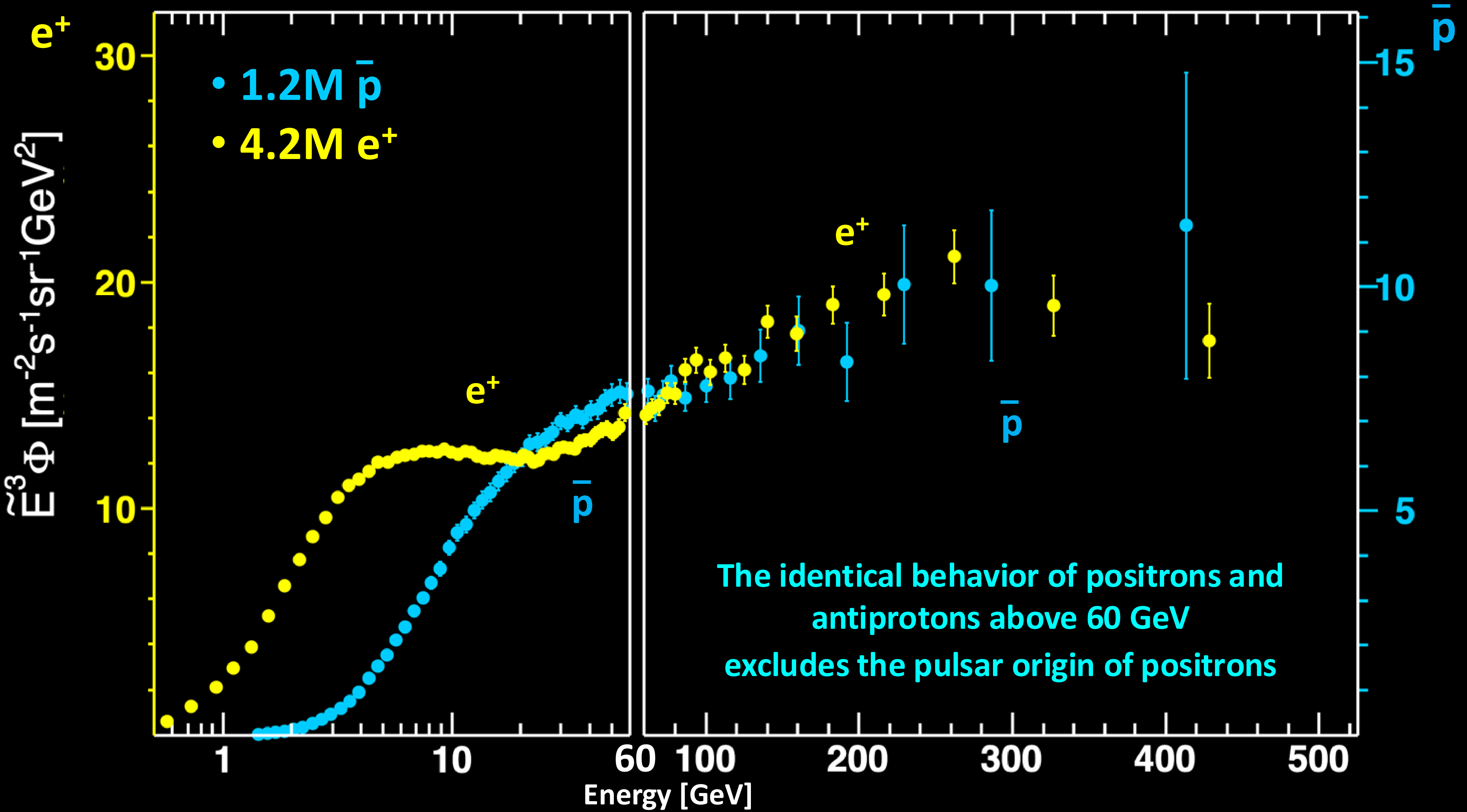
98.8% CL

99.99% CL
by 2030

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



The identical behavior of positrons and antiprotons above 60 GeV excludes the pulsar origin of positrons

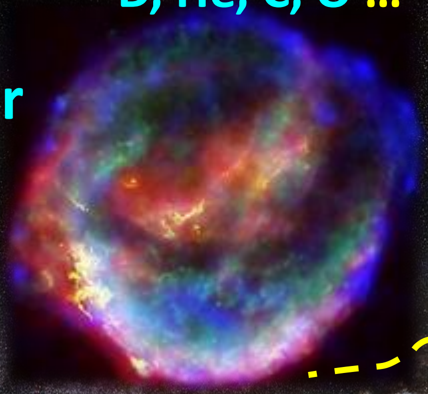
AMS Results on Heavy Antimatter

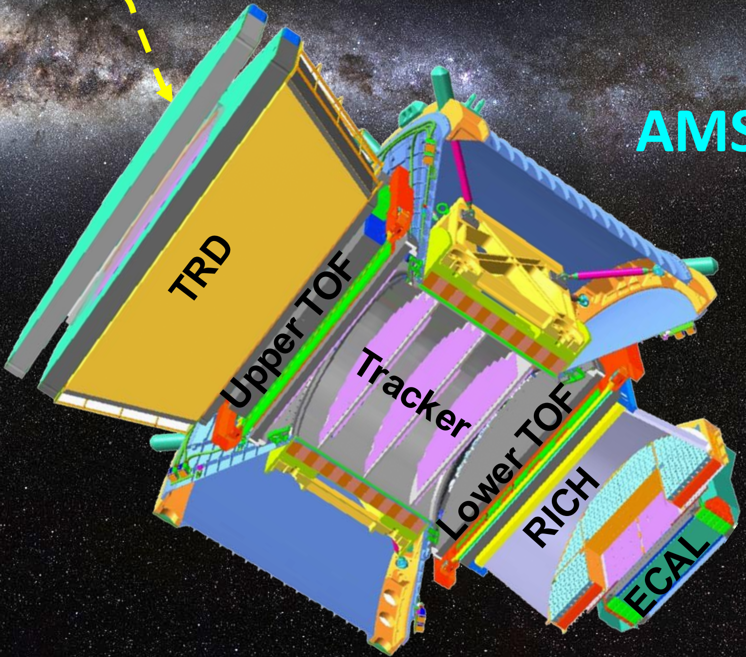
Matter is defined by its mass *M* and charge *Z*.

Antimatter has the same mass *M* but opposite charge –*Z*.

$\bar{D}$, $\overline{He}$, $\bar{C}$, $\bar{O}$ …

Antimatter Star

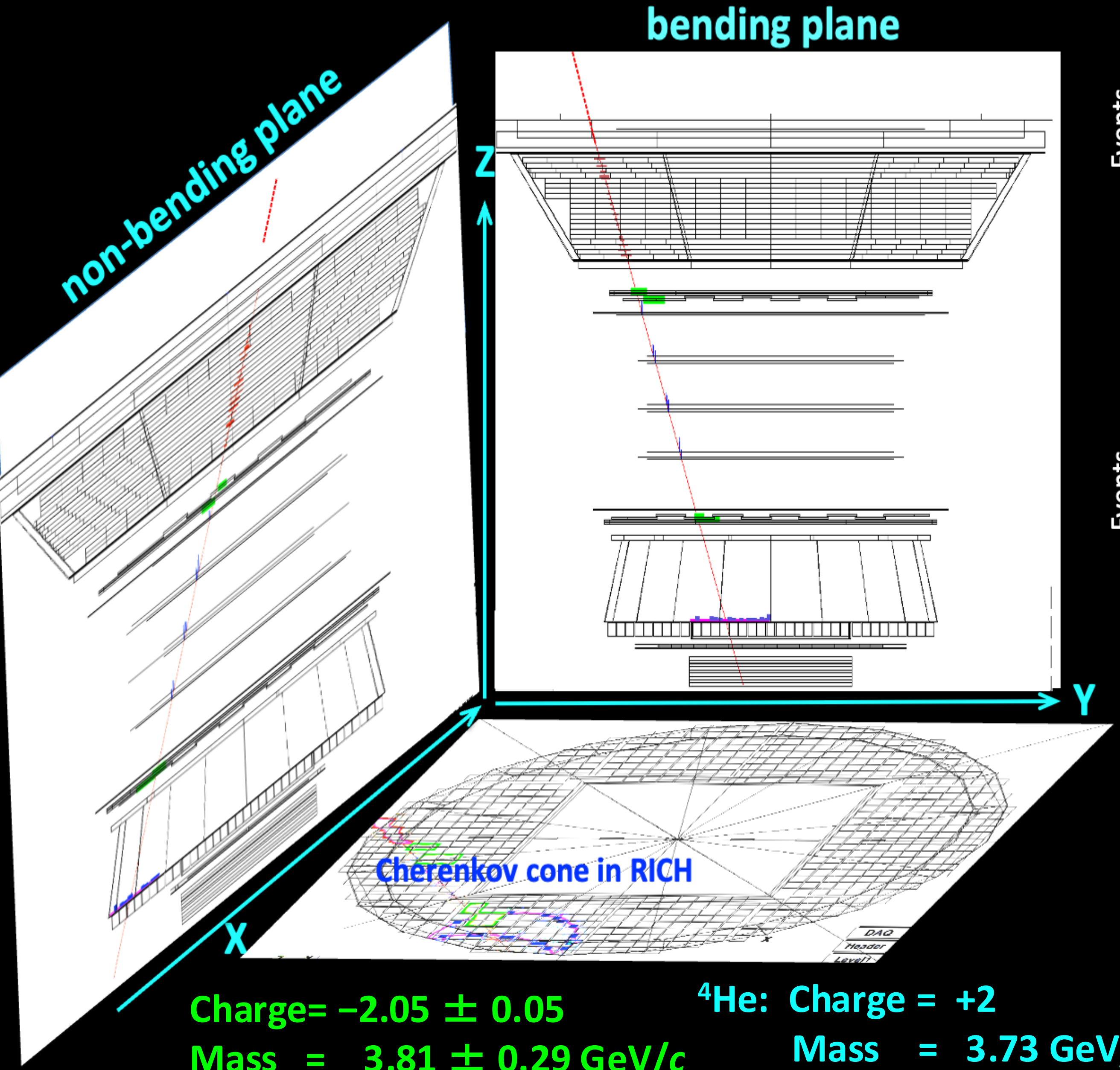




AMS on ISS

AMS is a unique antimatter spectrometer in space

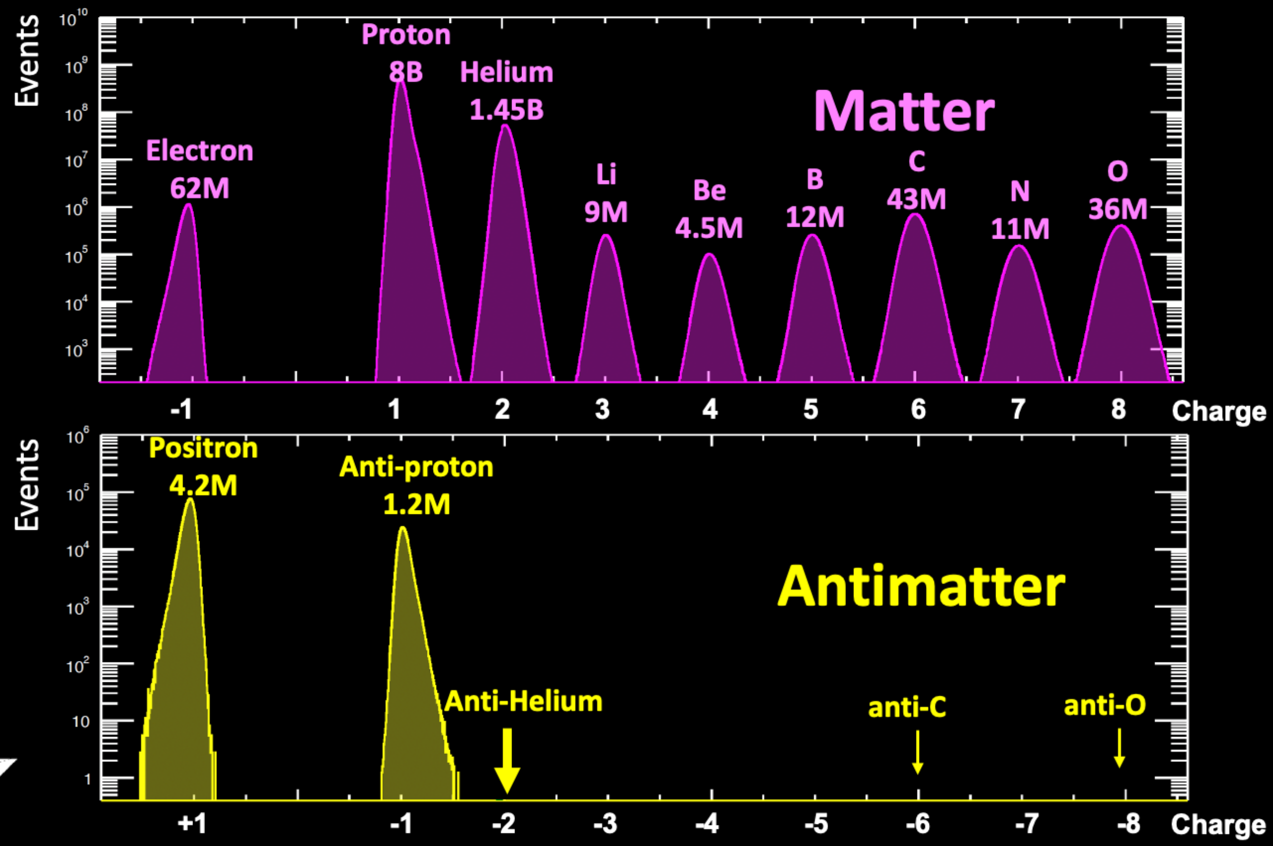
Anti-^{4}Helium Candidate



Charge= −2.05 ± 0.05
Mass = 3.81 ± 0.29 GeV/c

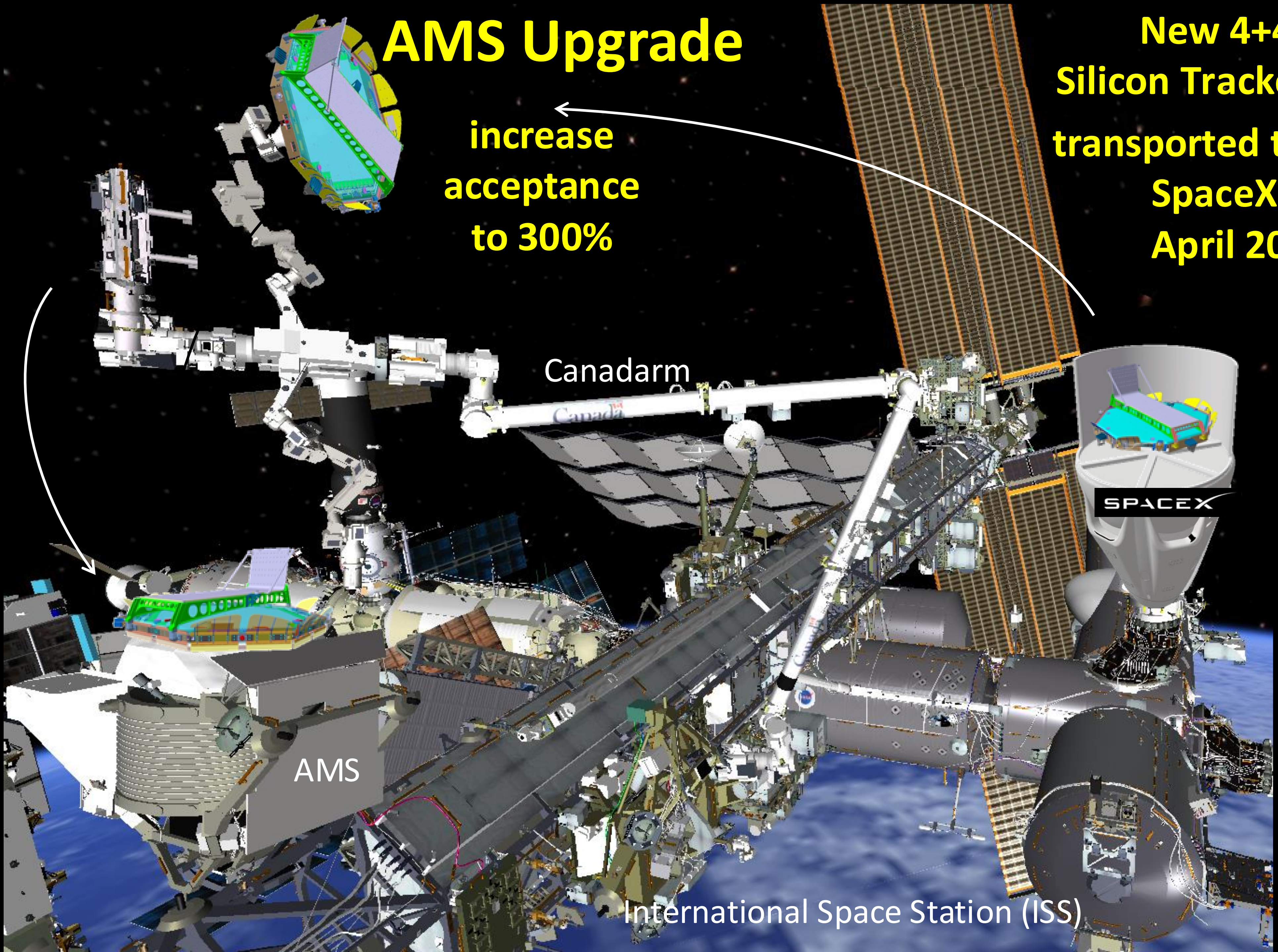
^{4}He: Charge = +2
Mass = 3.73 GeV/c^2

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



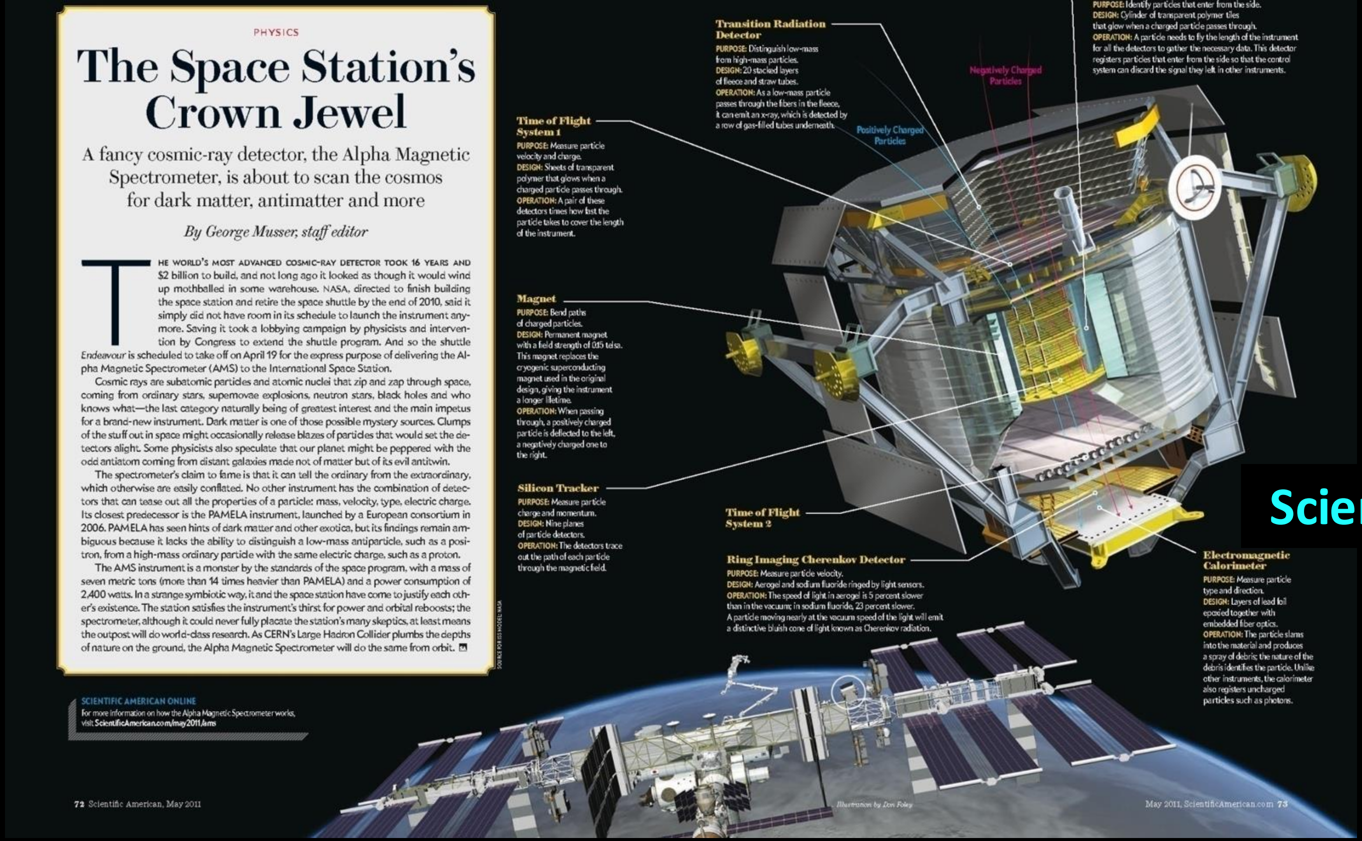
increase
acceptance
to 300%

New 4+4m^2
Silicon Tracker Planes

transported to ISS via
SpaceX 34
April 2026

+74K
channels

final
installation
by
astronauts



PHYSICS

The Space Station's Crown Jewel

A fancy cosmic-ray detector, the Alpha Magnetic Spectrometer, is about to scan the cosmos for dark matter, antimatter and more

By George Musser, staff editor

THE WORLD'S MOST ADVANCED COSMIC-RAY DETECTOR TOOK 16 YEARS AND $2 billion to build, and not long ago it looked as though it would wind up mothballed in some warehouse. NASA, directed to finish building the space station and retire the space shuttle by the end of 2010, said it simply did not have room in its schedule to launch the instrument anymore. Saving it took a lobbying campaign by physicists and intervention by Congress to extend the shuttle program. And so the shuttle *Endeavour* is scheduled to take off on April 19 for the express purpose of delivering the Alpha Magnetic Spectrometer (AMS) to the International Space Station.

Cosmic rays are subatomic particles and atomic nuclei that zip and zap through space, coming from ordinary stars, supernovae explosions, neutron stars, black holes and who knows what—the last category naturally being of greatest interest and the main impetus for a brand-new instrument. Dark matter is one of those possible mystery sources. Clumps of the stuff out in space might occasionally release blazes of particles that would set the detectors alight. Some physicists also speculate that our planet might be peppered with the odd antiatom coming from distant galaxies made not of matter but of its evil antitwin.

The spectrometer's claim to fame is that it can tell the ordinary from the extraordinary, which otherwise are easily conflated. No other instrument has the combination of detectors that can tease out all the properties of a particle: mass, velocity, type, electric charge. Its closest predecessor is the PAMELA instrument, launched by a European consortium in 2006. PAMELA has seen hints of dark matter and other exotica, but its findings remain ambiguous because it lacks the ability to distinguish a low-mass antiparticle, such as a positron, from a high-mass ordinary particle with the same electric charge, such as a proton.

The AMS instrument is a monster by the standards of the space program, with a mass of seven metric tons (more than 14 times heavier than PAMELA) and a power consumption of 2,400 watts. In a strange symbiotic way, it and the space station have come to justify each other's existence. The station satisfies the instrument's thirst for power and orbital reboosts; the spectrometer, although it could never fully placate the station's many skeptics, at least means the outpost will do world-class research. As CERN's Large Hadron Collider plumbs the depths of nature on the ground, the Alpha Magnetic Spectrometer will do the same from orbit. ■

SOURCE FOR ISS MODEL: NASA

SCIENTIFIC AMERICAN ONLINE
For more information on how the Alpha Magnetic Spectrometer works, visit ScientificAmerican.com/may2011/ams

PURPOSE: Identify particles that enter from the side.
DESIGN: Cylinder of transparent polymer tiles that glow when a charged particle passes through.
OPERATION: A particle needs to fly the length of the instrument for all the detectors to gather the necessary data. This detector registers particles that enter from the side so that the control system can discard the signal they left in other instruments.

Transition Radiation Detector
PURPOSE: Distinguish low-mass from high-mass particles.
DESIGN: 20 stacked layers of fleece and straw tubes.
OPERATION: As a low-mass particle passes through the fibers in the fleece, it can emit an x-ray, which is detected by a row of gas-filled tubes underneath.

Time of Flight System 1
PURPOSE: Measure particle velocity and charge.
DESIGN: Sheets of transparent polymer that glows when a charged particle passes through.
OPERATION: A pair of these detectors times how fast the particle takes to cover the length of the instrument.

Magnet
PURPOSE: Bend paths of charged particles.
DESIGN: Permanent magnet with a field strength of 0.15 telsa. This magnet replaces the cryogenic superconducting magnet used in the original design, giving the instrument a longer lifetime.
OPERATION: When passing through, a positively charged particle is deflected to the left, a negatively charged one to the right.

Silicon Tracker
PURPOSE: Measure particle charge and momentum.
DESIGN: Nine planes of particle detectors.
OPERATION: The detectors trace out the path of each particle through the magnetic field.

Time of Flight System 2

Ring Imaging Cherenkov Detector
PURPOSE: Measure particle velocity.
DESIGN: Aerogel and sodium fluoride ringed by light sensors.
OPERATION: The speed of light in aerogel is 5 percent slower than in the vacuum; in sodium fluoride, 23 percent slower. A particle moving nearly at the vacuum speed of the light will emit a distinctive bluish cone of light known as Cherenkov radiation.

Electromagnetic Calorimeter
PURPOSE: Measure particle type and direction.
DESIGN: Layers of lead foil epoxied together with embedded fiber optics.
OPERATION: The particle slams into the material and produces a spray of debris; the nature of the debris identifies the particle. Unlike other instruments, the calorimeter also registers uncharged particles such as photons.

Illustration by Don Foley

72 Scientific American, May 2011

May 2011, ScientificAmerican.com 73

Scientific American, May 2011

The discovery of the J particle 50 years ago opened up a new realm of physics.

Space is the ultimate laboratory. Space provides particles with much higher energies than accelerators. AMS results require the development of a new model of the cosmos.

Italian physicists and industry have made fundamental contributions to this experiment