

# 50th Anniversary of the Hadron Collider at CERN

## An Overview

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Life member of the Senate of the Italian Republic

October 14<sup>th</sup>, 2021

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Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949  
(WGBL S. 175)

BUNDESREPUBLIK DEUTSCHLAND



AUSGEGEBEN AM  
11. MAI 1953

DEUTSCHES PATENTAMT

PATENTSCHRIFT

Nr. 876 279

KLASSE 21g GRUPPE 36

W 687 VIII c / 21g

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Dr.-Ing. Rolf Widerøe, Oslo  
ist als Erfinder genannt worden

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Aktiengesellschaft Brown, Boveri & Cie, Baden (Schweiz)

Anordnung zur Herbeiführung von Kernreaktionen

Patentiert im Gebiet der Bundesrepublik Deutschland vom 8. September 1943 an

Patentanmeldung bekanntgemacht am 18. September 1952

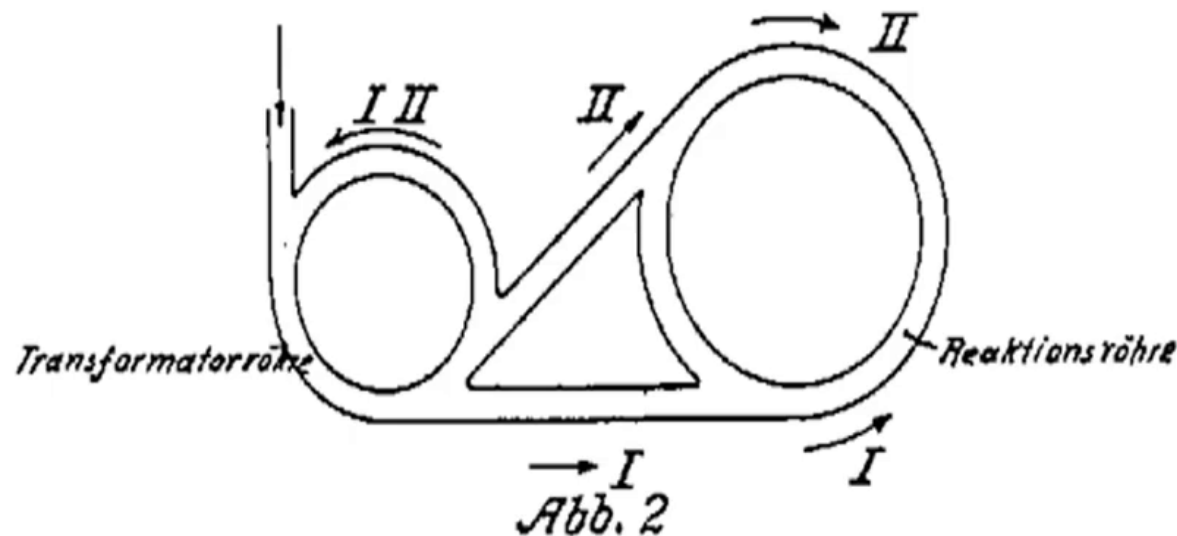
Patenterteilung bekanntgemacht am 26. März 1953

# The principle of the colliding beams

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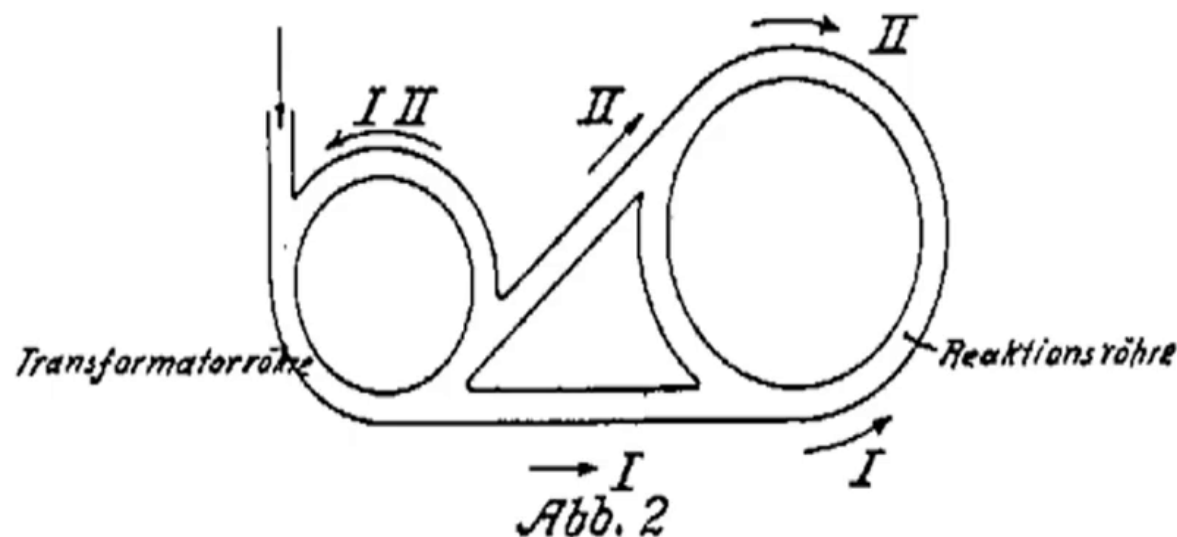
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- Moved to Switzerland in 1946 Widerøe was also a CERN consultant at the time of the alternating-gradient focusing principle for the 25 GeV CERN Proton Synchrotron.

# Bruno Touschek

- Among the key players was Widerøe's assistant, the Austrian Bruno Touschek (1921-1978 (aged 57), a victim of the Holocaust since his mother was Jewish. During the death march from the Hamburg prison, Touschek was shot by an SS officer, presumed being dead, and thus left behind fortunately still alive.

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- The SPEAR collider at the Stanford Linear Accelerator Center was completed in 1972 and soon contributed to discoveries of the  $\psi/J$  meson and the tau lepton, both recognized with Nobel Prizes to S.Ting and B.Richter (1976) and M.Pearl (1995).

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- The experiment was planned when the three researchers were associated with Columbia University in New York and carried out using the Alternating Gradient Synchrotron (AGS) at Brookhaven National Accelerator Laboratory at Long Island and with a fixed proton target.

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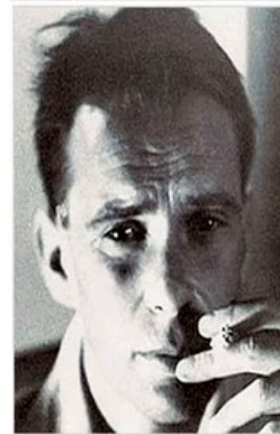
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- Experimental observations in neutrino interactions proved that beside the (then hypothetical] weak interaction mediated by the charged bosons  $W^{\pm}$  there was also a neutral electro-weak partner, the  $Z^0$ .
- This was, no doubt, another “Nobel Prize class” experimental discovery which was however never recognized — in my view, mainly because of the early death of Andre Lagarrigue.

# Early progress of colliders

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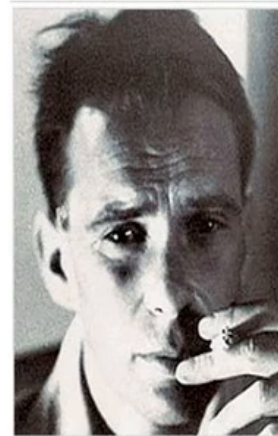
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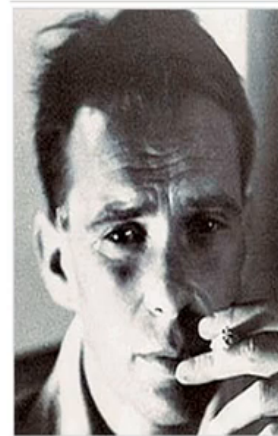
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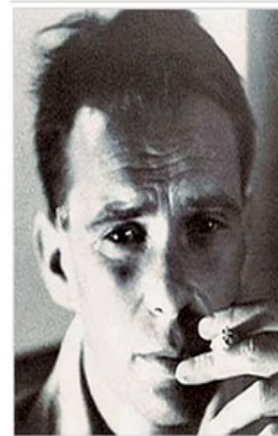
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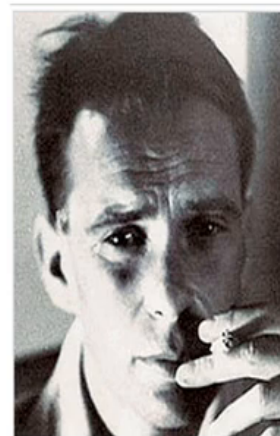
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- The p-p-bar accumulation for higher energies at the SPS and the beam-beam tune shift problem. *Fewer particles, higher tune shift!*
- The pessimism was conjugated with a widespread initial lack of confidence in hadron collisions in spite of the higher energies when compared for instance with  $e^+e^-$



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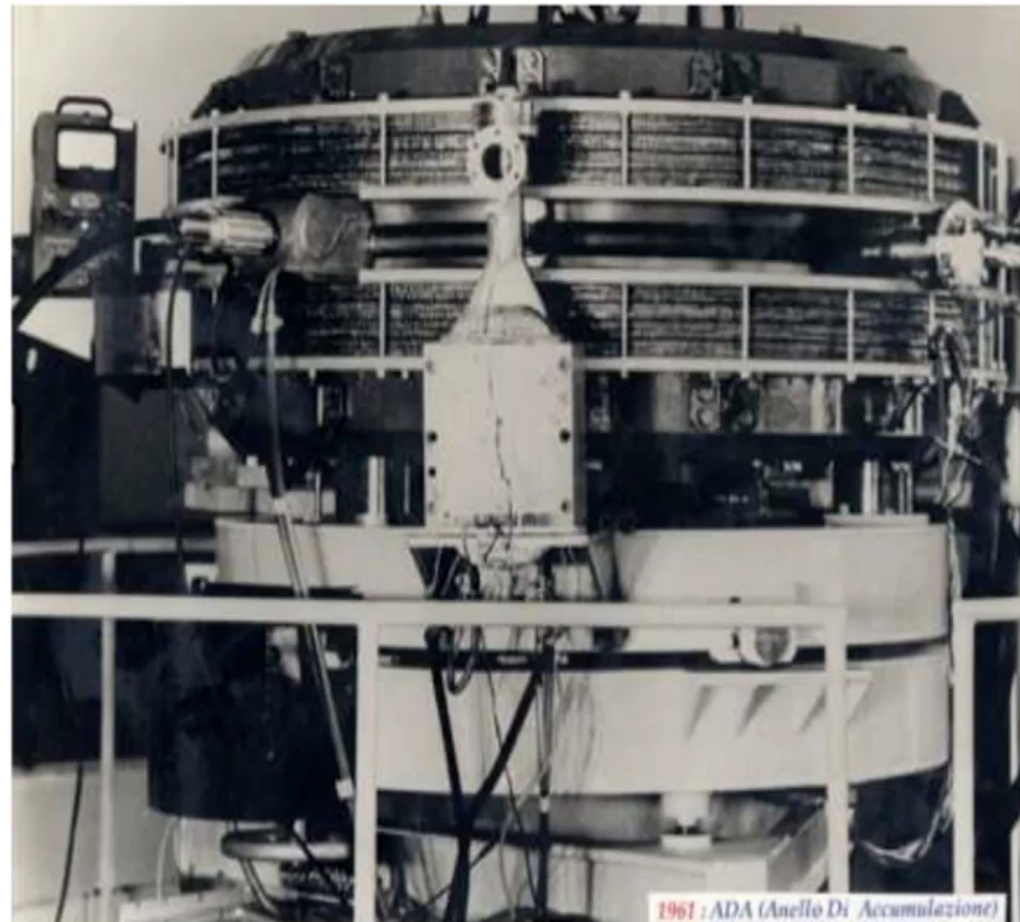
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ADA (*Anello Di Accumulazione*) at INFN, Frascati, Italy

– 250 MeV  $e^+$  x 250 MeV  $e^-$



– 1961 : Construction Finished

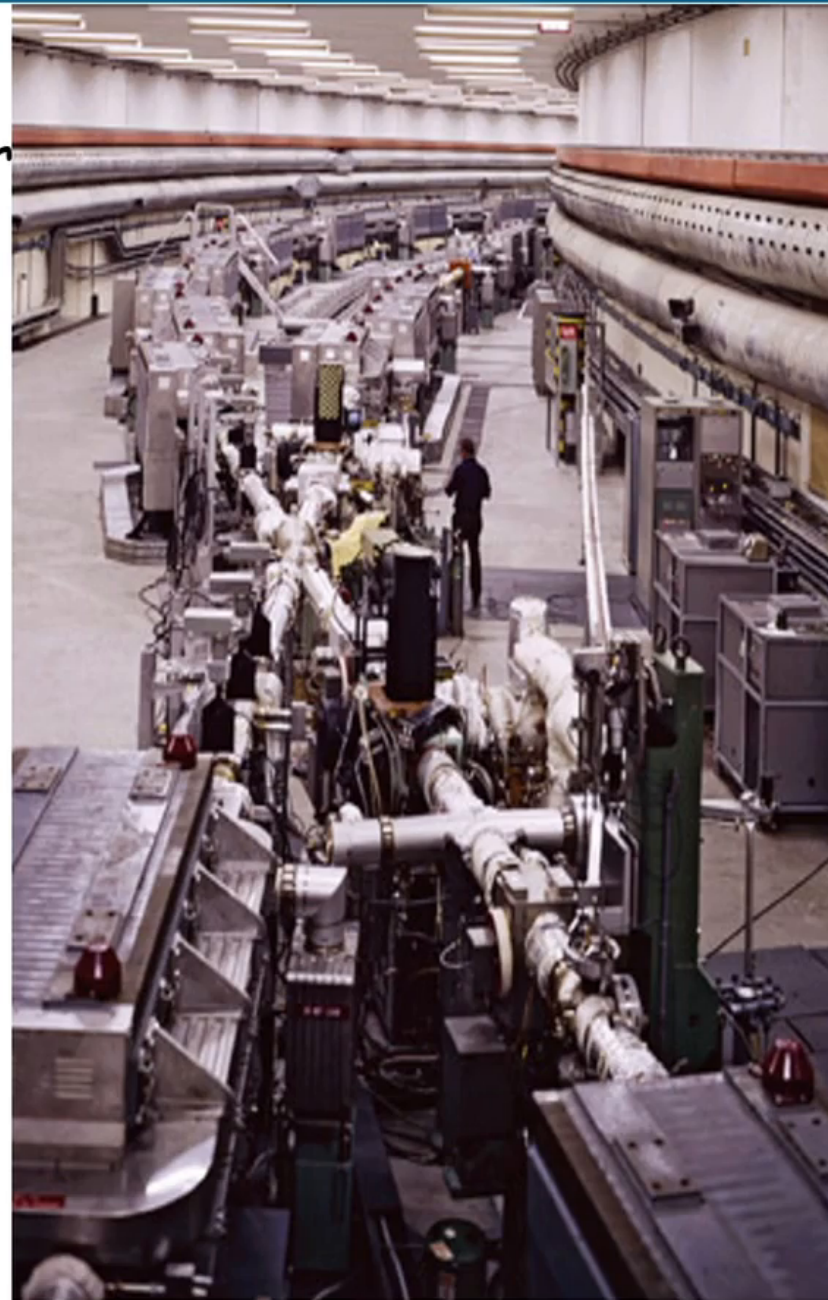
– ~ May-June 1964: Luminosity Detected

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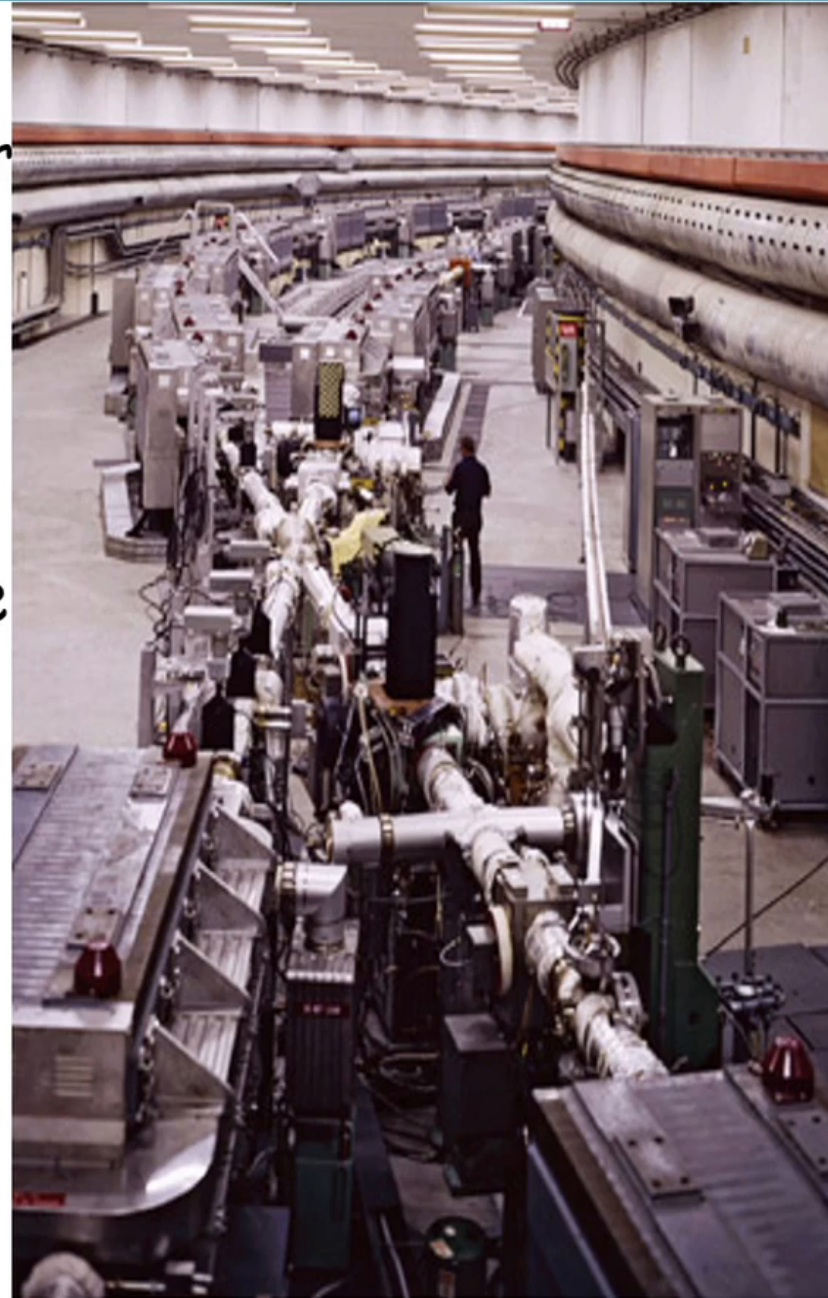
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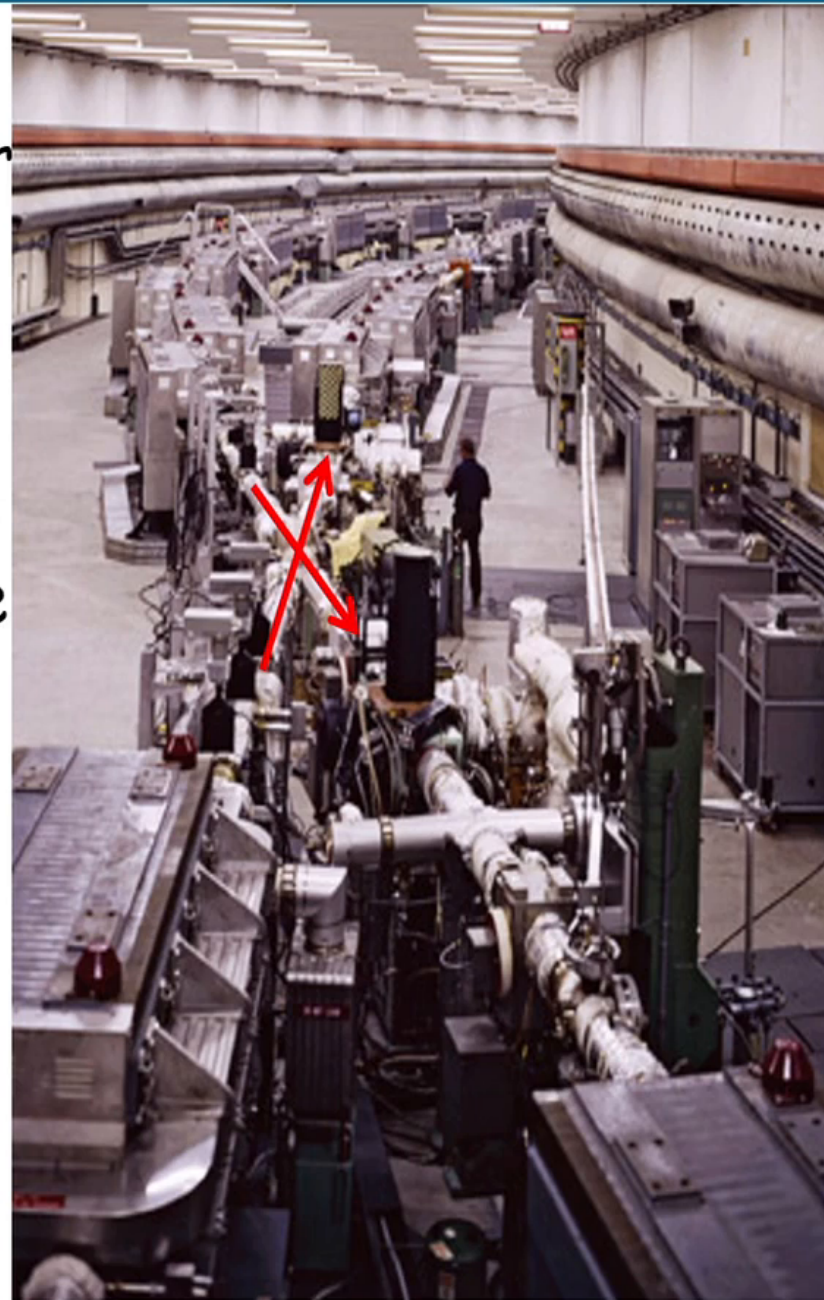
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- A stack of a DC current of up to 50 A has been stored from protons from the CERN-PS.



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- The advent of the ISR involved many advances in accelerator physics, including the first use of Stochastic Cooling and it held a record for luminosity at a hadron collider.

## Transforming an existing accelerator into a collider

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- Program approval June 1978 - First W's January 1983



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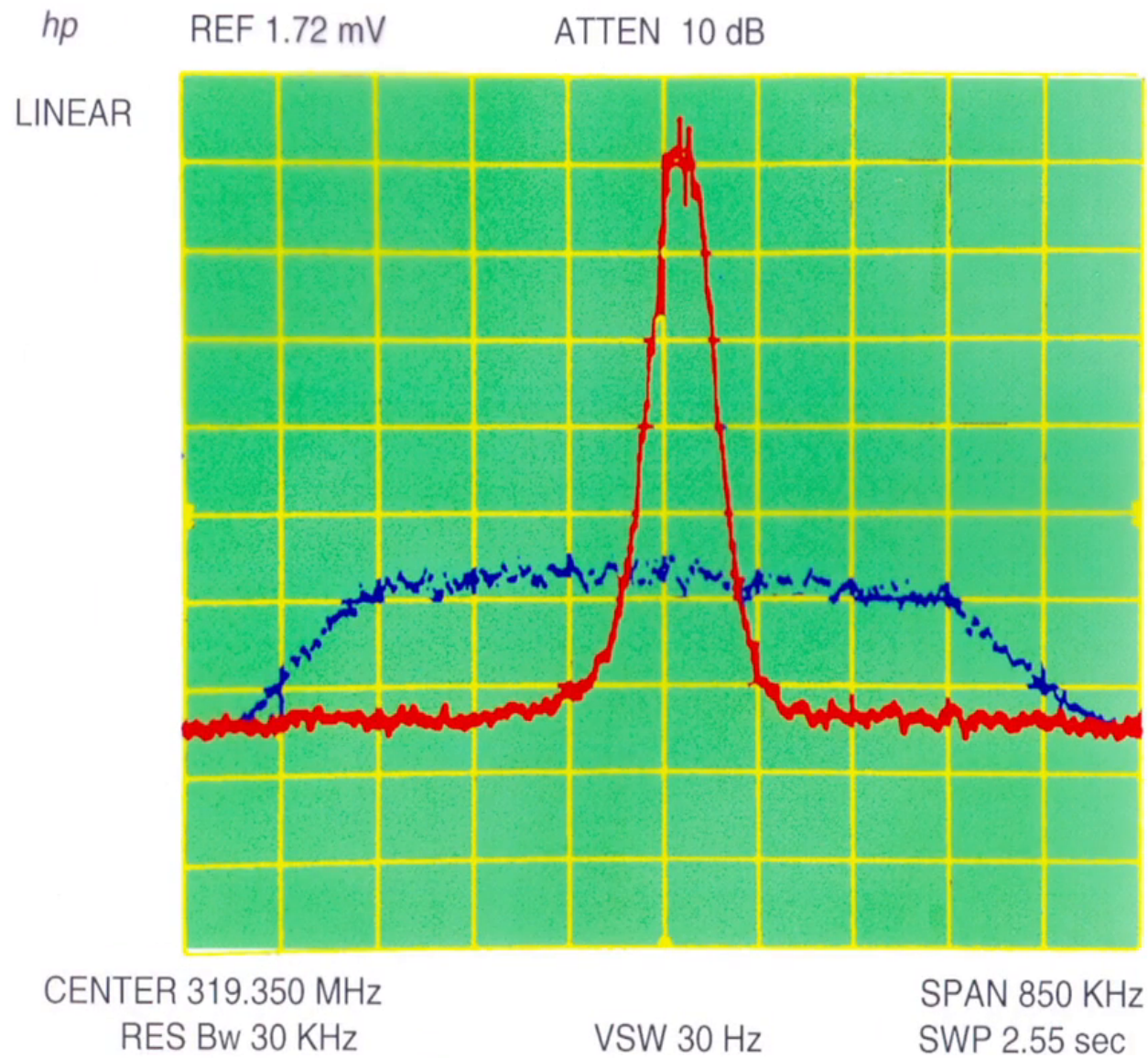
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- With some modifications, the cooler was later transplanted into LEAR (Low Energy Antiproton Ring) and then, with further modifications, into the AD (Antiproton Decelerator), where it cools antiprotons to this day.

# Antiproton Accumulator (AA) and Antiproton Collector (AC)



# Antiproton cooling in 2 sec !



Precooling  $6 \times 10^6$   $\bar{p}$ 's in 2 seconds. Longitudinal Schottky band at the 170th harmonic (314 MHz) before and after cooling.

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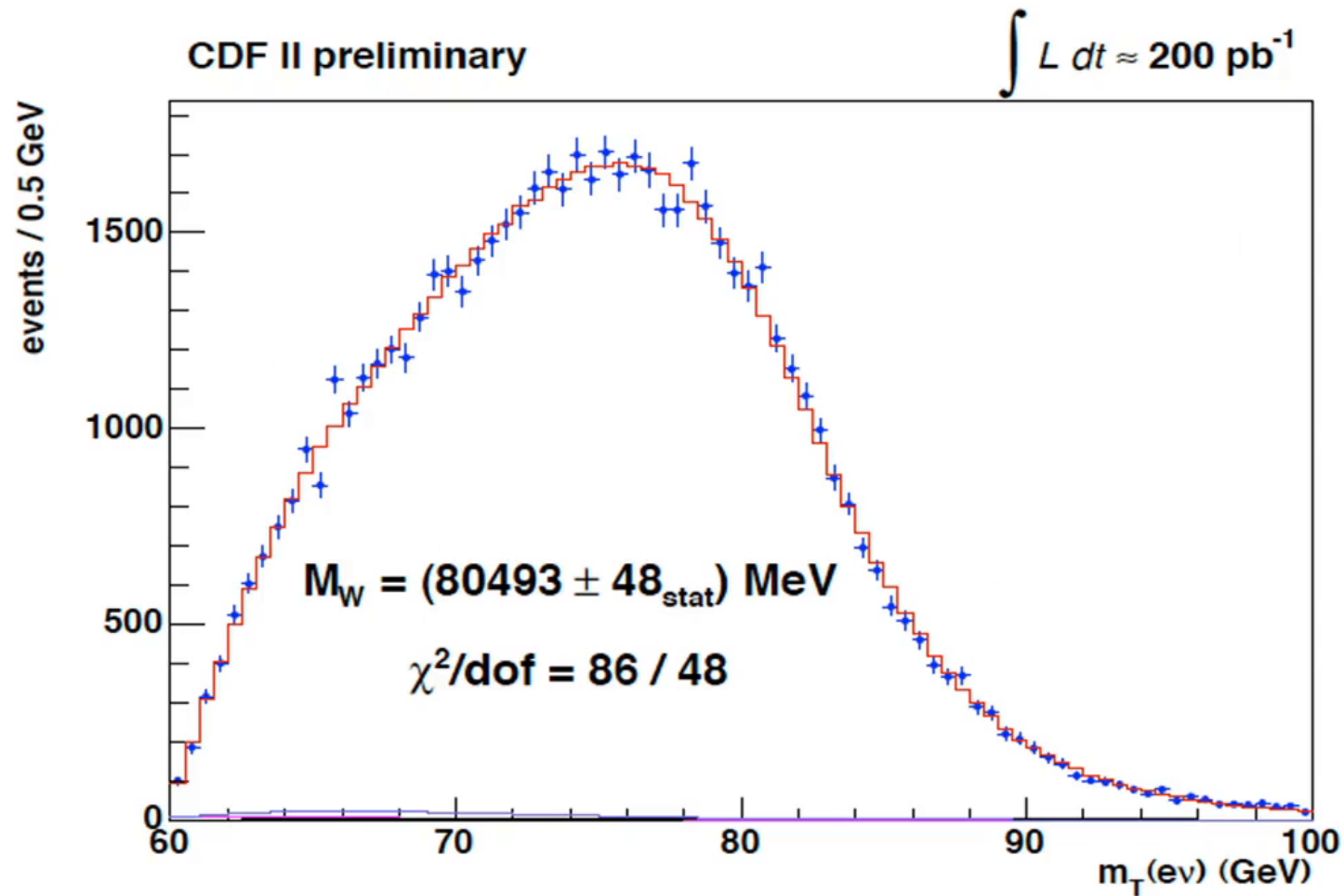
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- The conception, construction and operation of the SppS were considered as great technical achievements.

# CERN W-mass determination



*$W \rightarrow e \nu$  channel*

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- The theory (and the Nobel Prize) required also one new, massive neutral scalar particle, the Higgs— to be detected experimentally.

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C. Rubbia and S. van der Meer, in the first row, receiving the Prize with in the second row A. Salam (1, with the turban), S. Glashow (2) and S. Weinberg (3) celebrating at the 1984 Nobel Prize Ceremony

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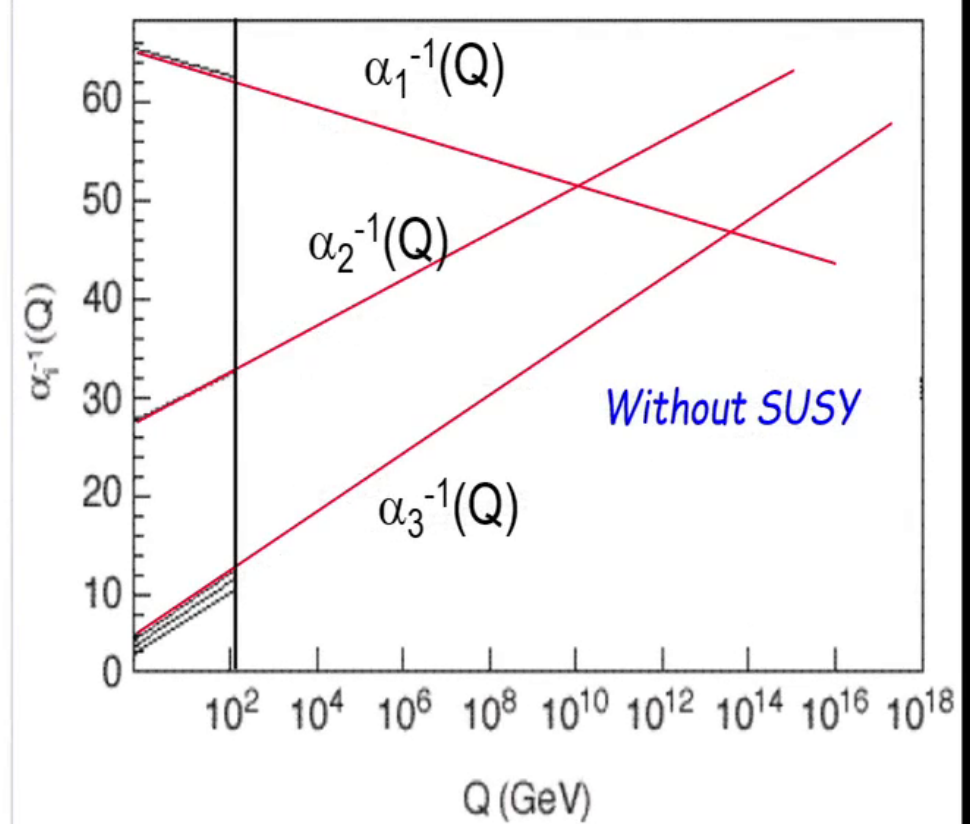
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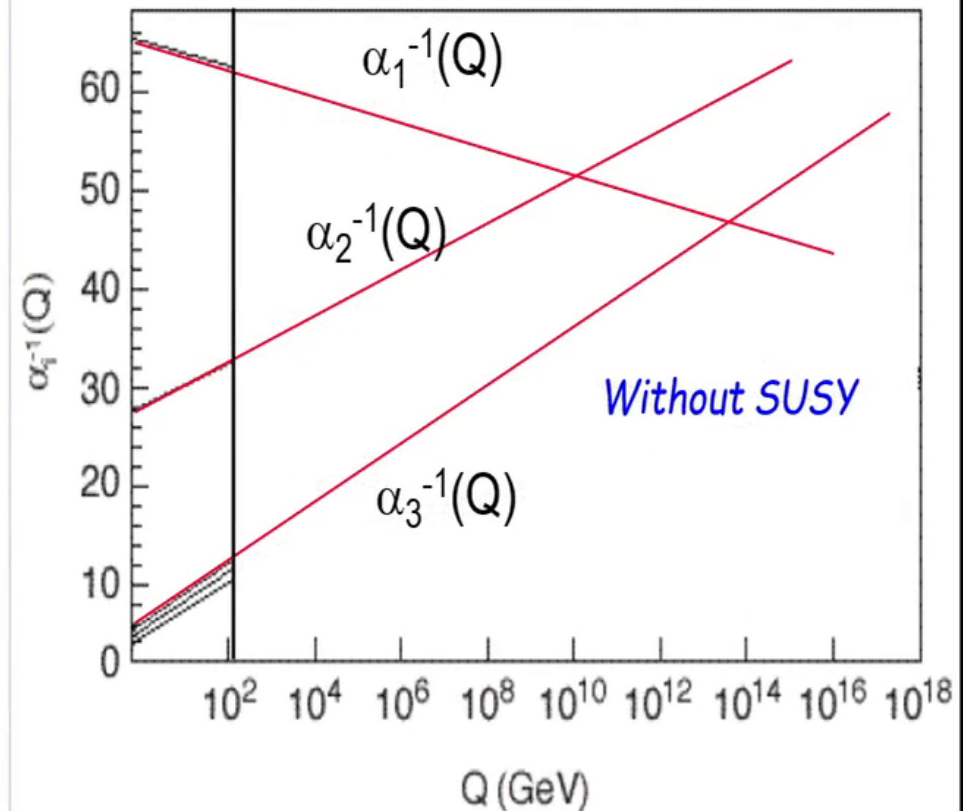
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# A Grand Unification ?



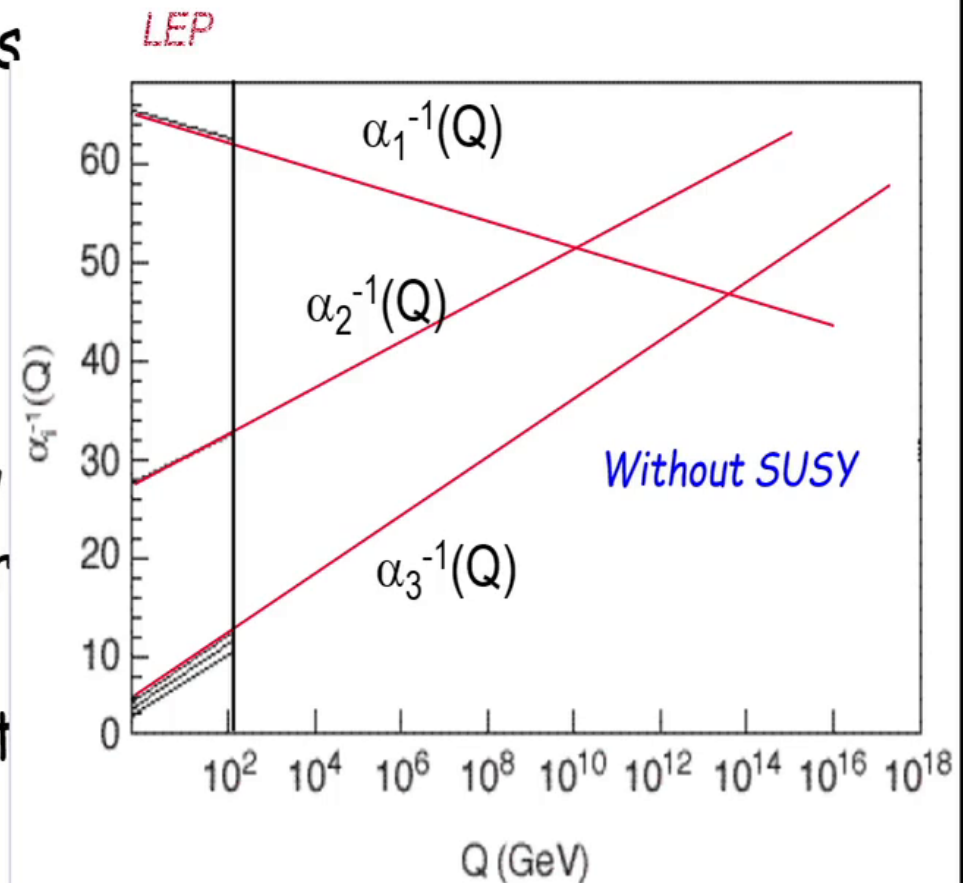
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- The running coupling constants of the three main different interactions may not simply converge to a common unified value.



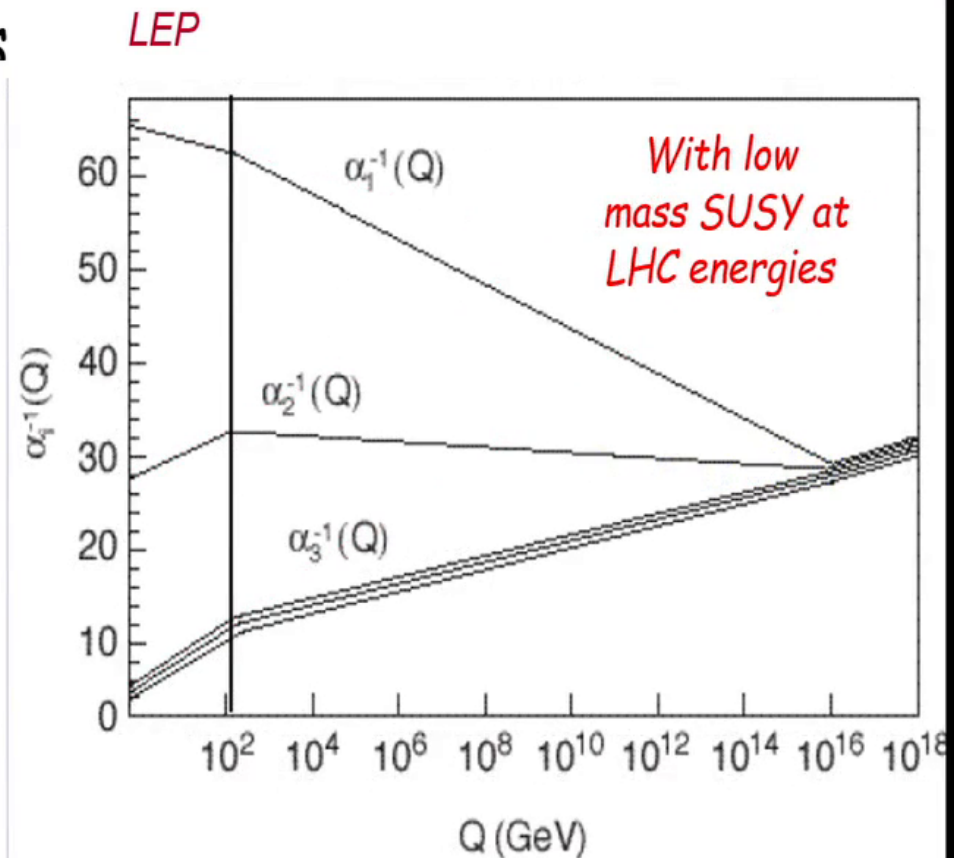
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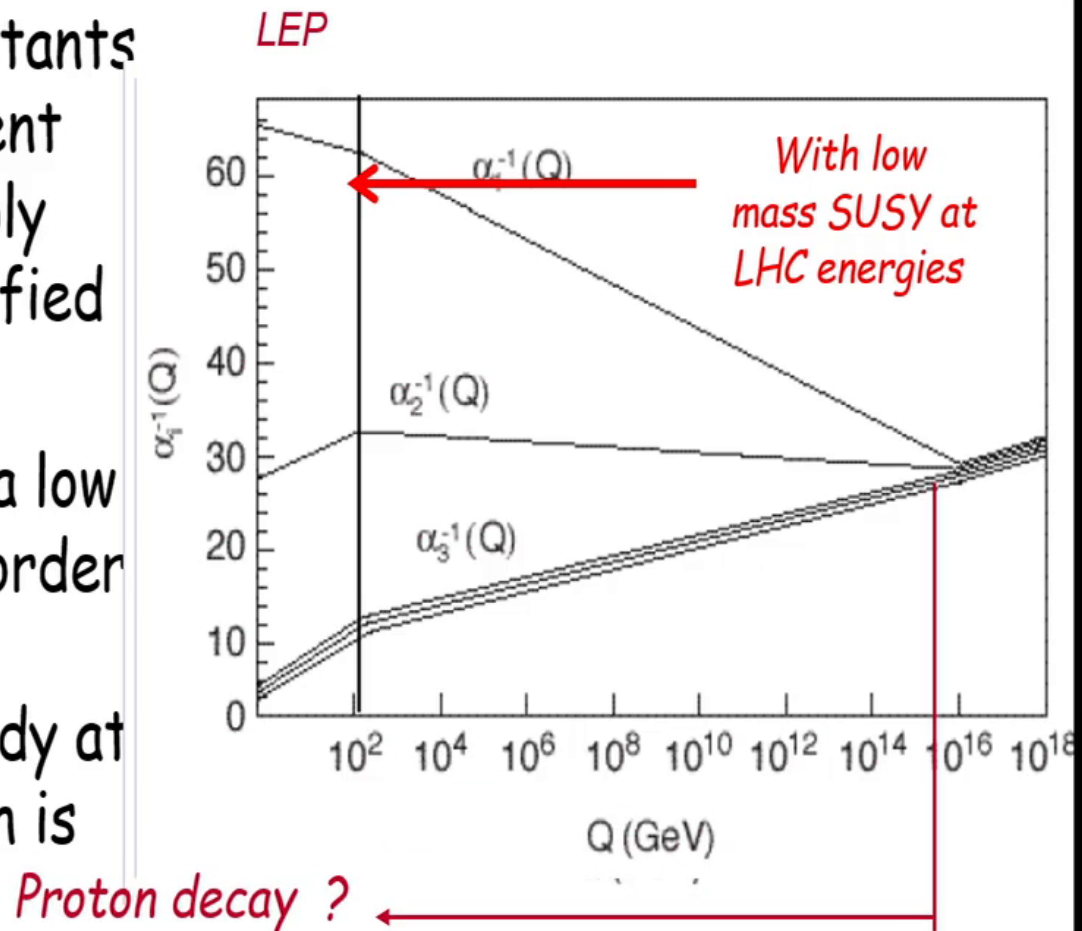
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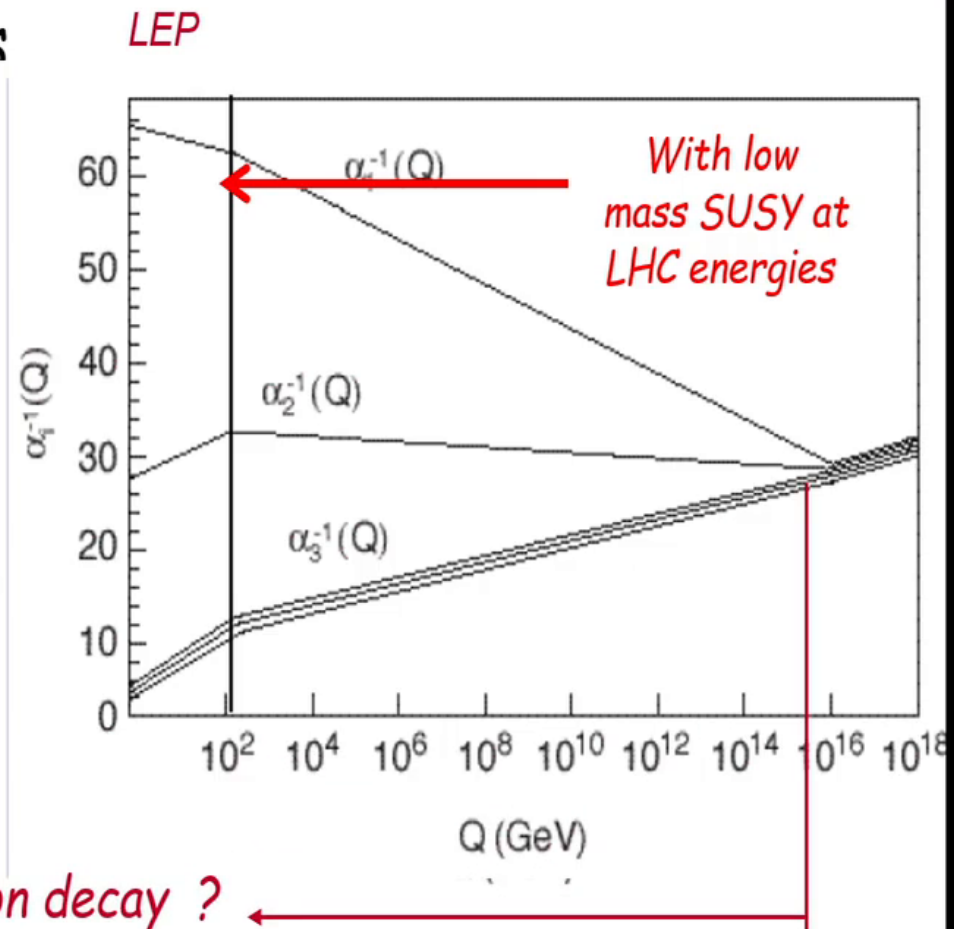
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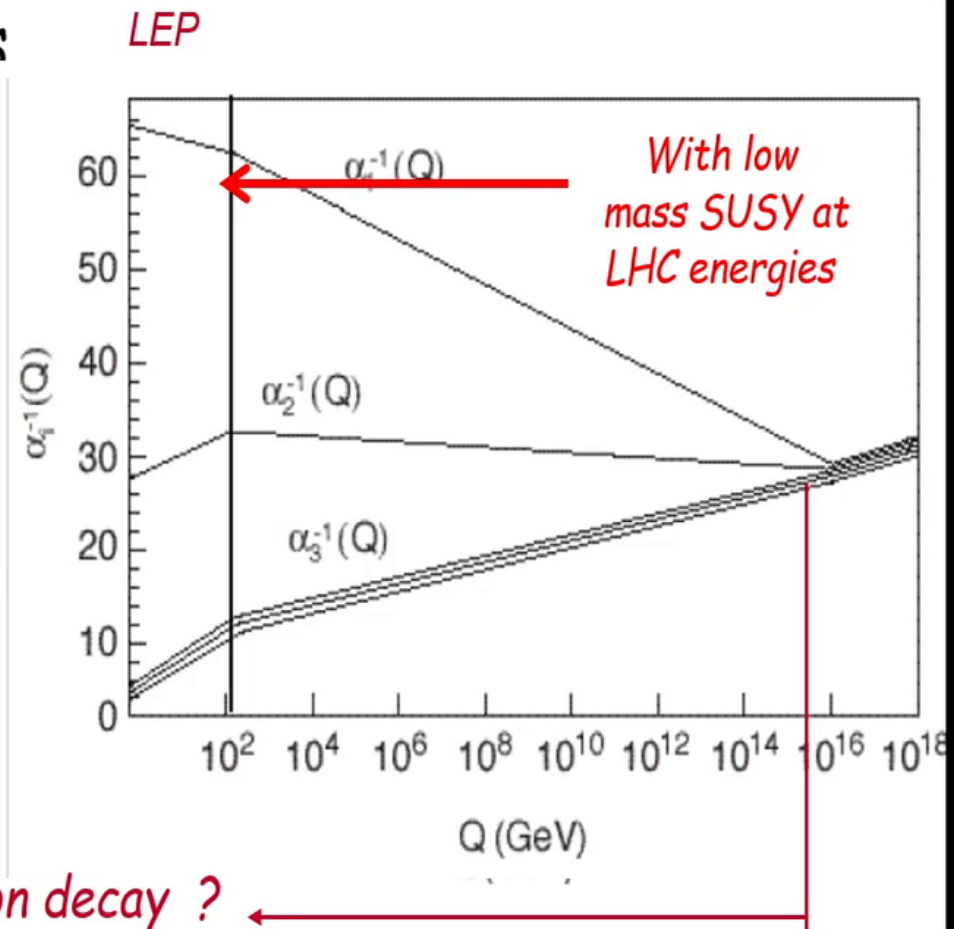
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- No doubt the convergence of all the three running coupling constants to a common value with lepton-quark unification is probably inevitable.
- However the mechanism of this change and mass values of its occurrence are vastly unknown (Pati-Salam, Georgi, Glashow, etc.)



# Collider options in the US

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- The LHC has then operated with 25 times higher energies per nucleon. As of 2018, RHIC and the LHC are the only operating hadron colliders in the world. But LHC uses mainly colliding protons and heavy ions only for about one month/year.

# The latest Nobel Prize for a CERN discovery !

- CMS and Atlas have observed in 2012 at the CERN LHC collider a narrow line of high significance at about 125 GeV mass, compatible with the Standard Model Higgs boson.
  - ATLAS:  $m_H = 125.5 \pm 0.2 \text{ (stat)} \pm 0.6 \text{ (sys)} \text{ GeV}$
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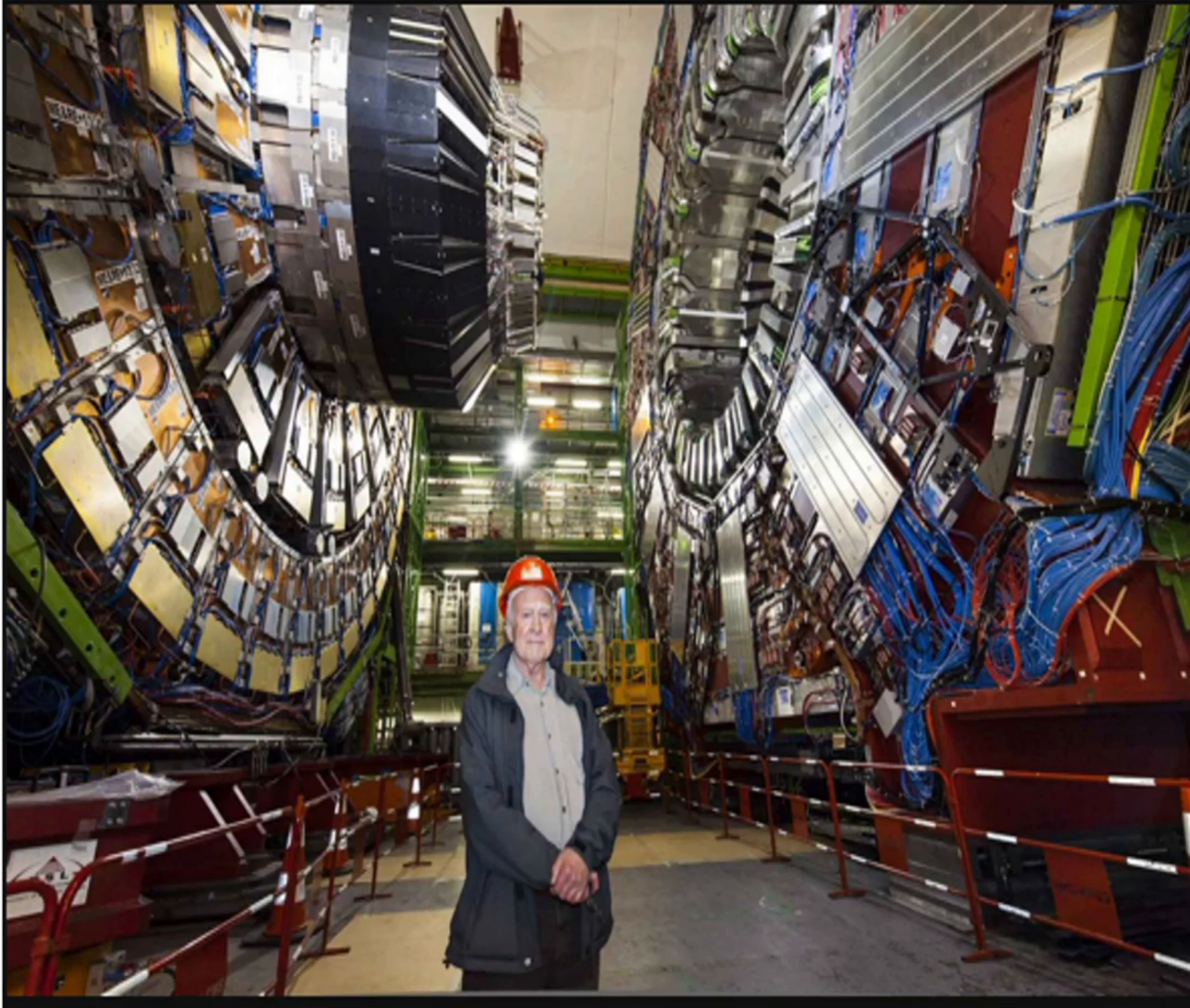
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- No experimentally confirmed evidence so far for additional "new physics" like SUSY.

# A quiet man making a big bang: Peter Higgs at CMS



October 14th, 2021

Slide# : 23

# The future of Higgs at the HL-LHC

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- $B(\gamma\gamma)$  with 0.2% is also substantive due to the high mass resolution and relatively low background.

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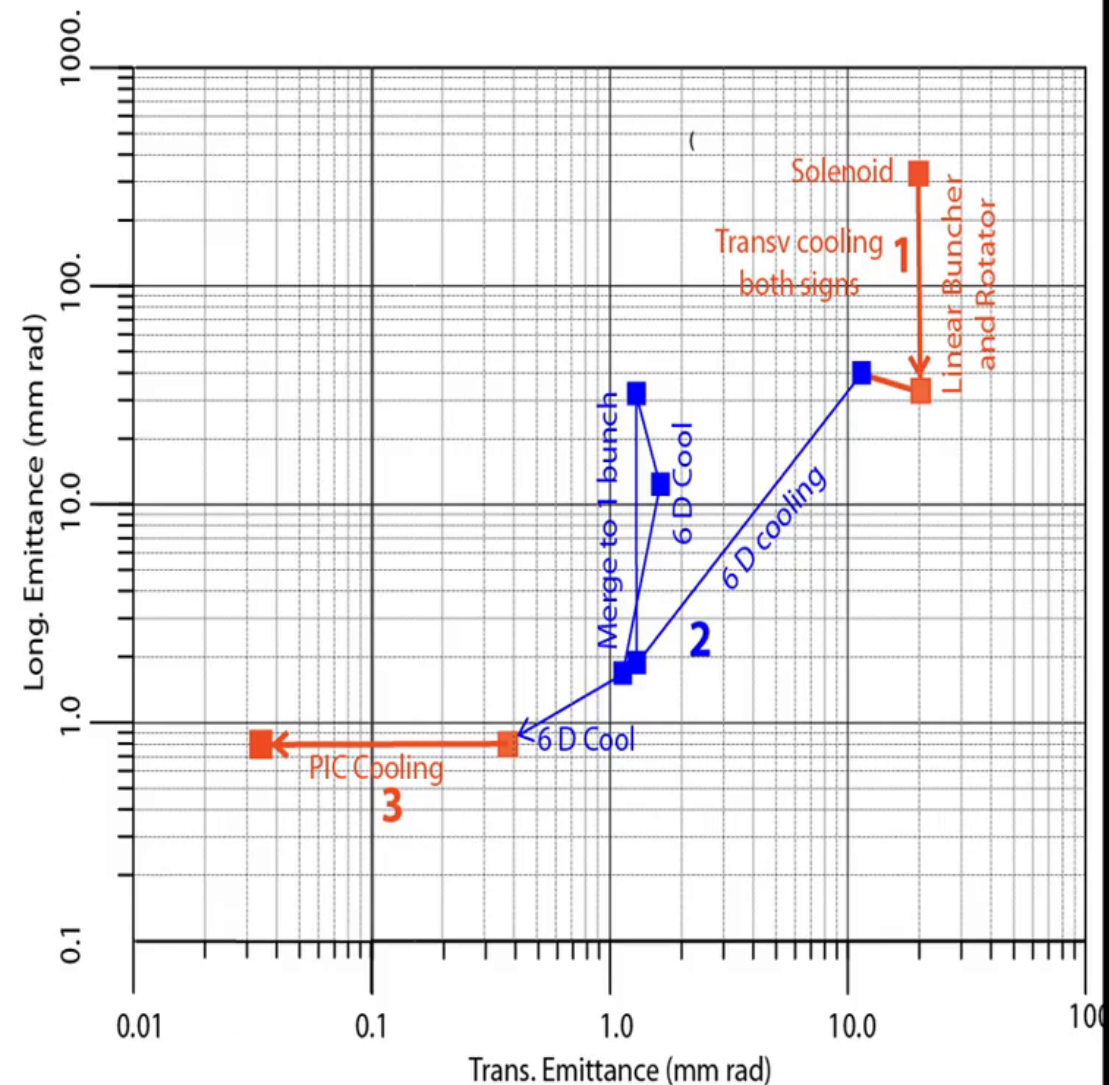
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- But this demand major R&D to produce adequate 6D compression.

# Muon cooling process at $\sqrt{s} = 126$ GeV

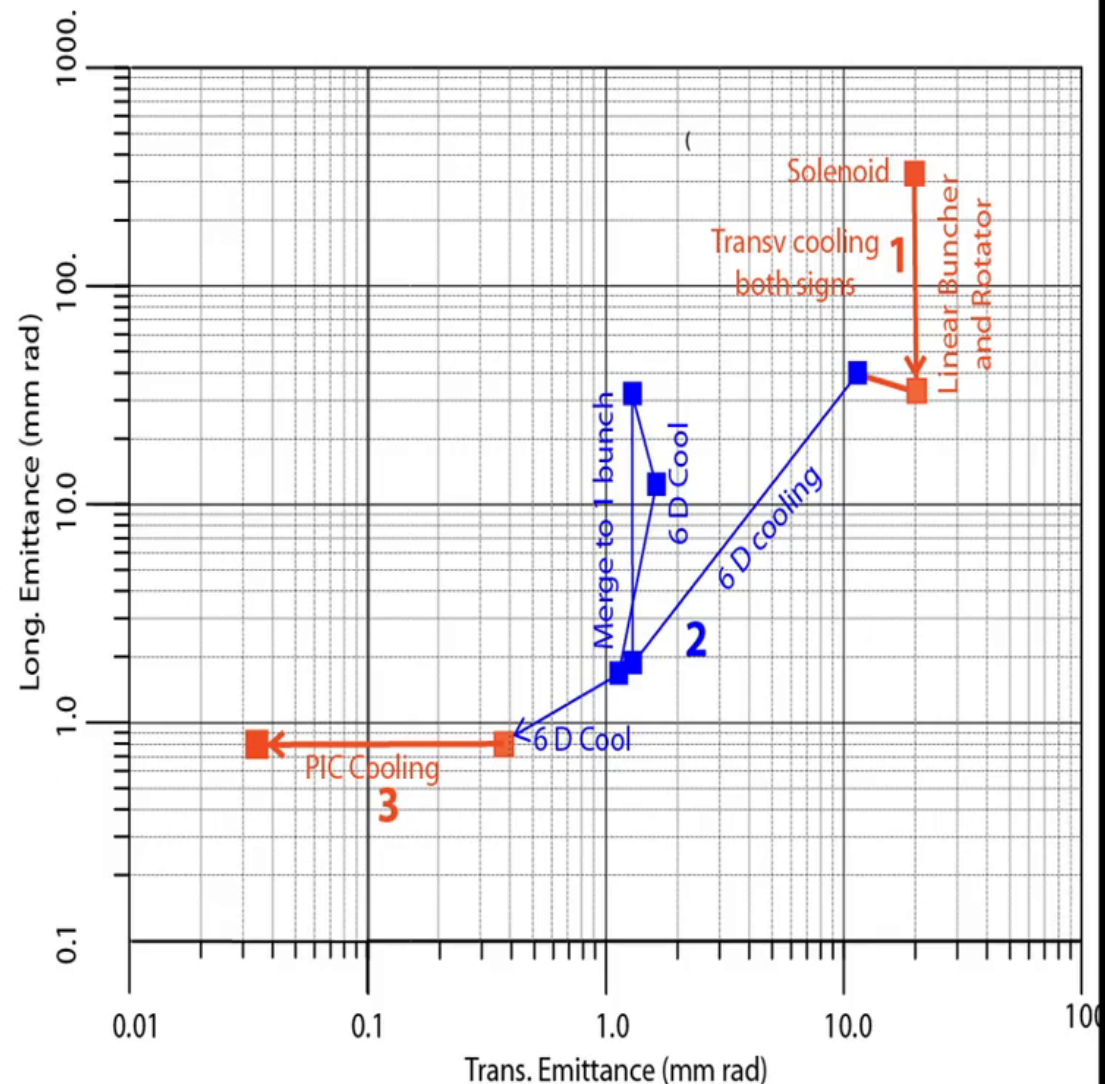
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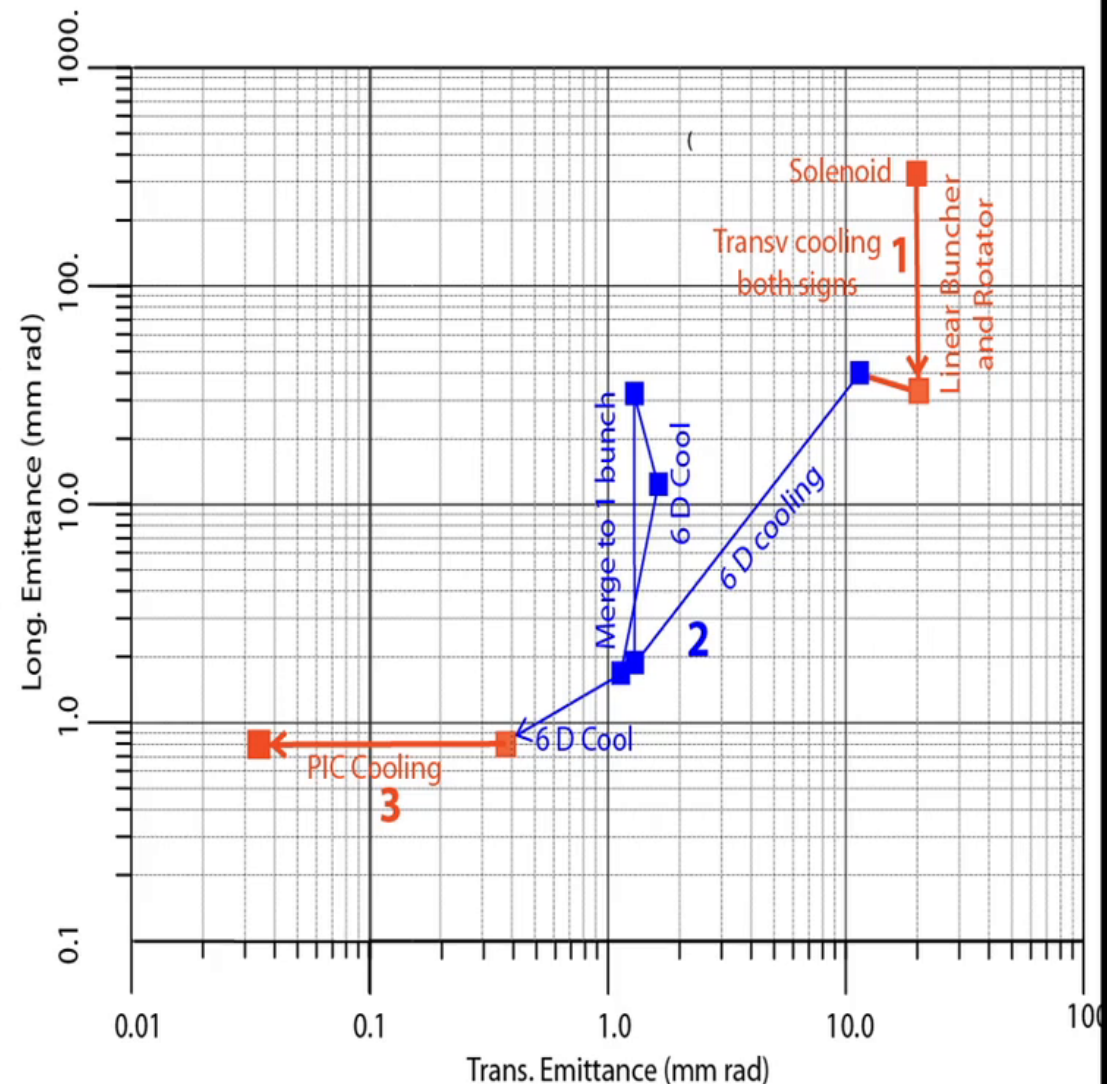
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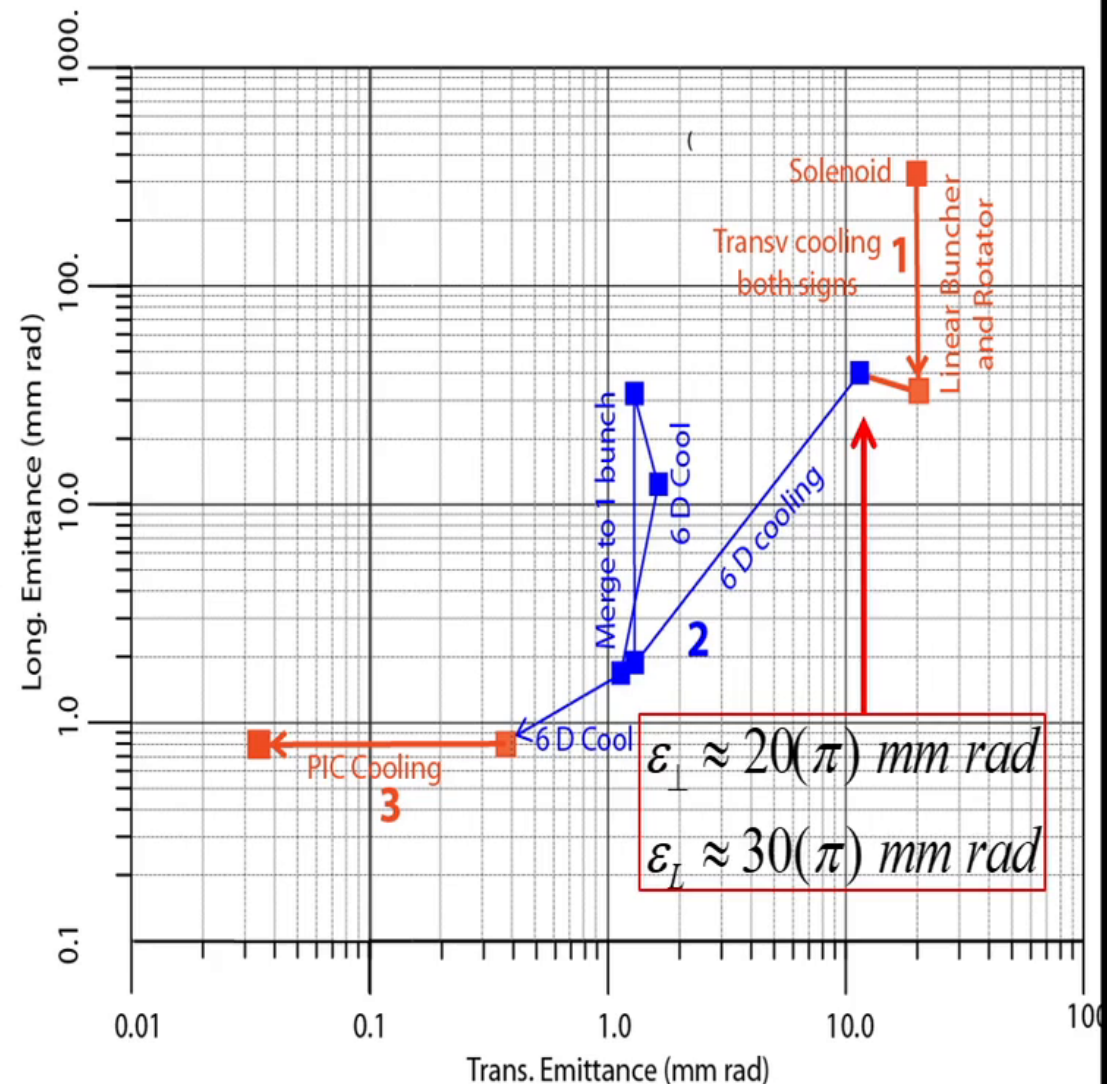
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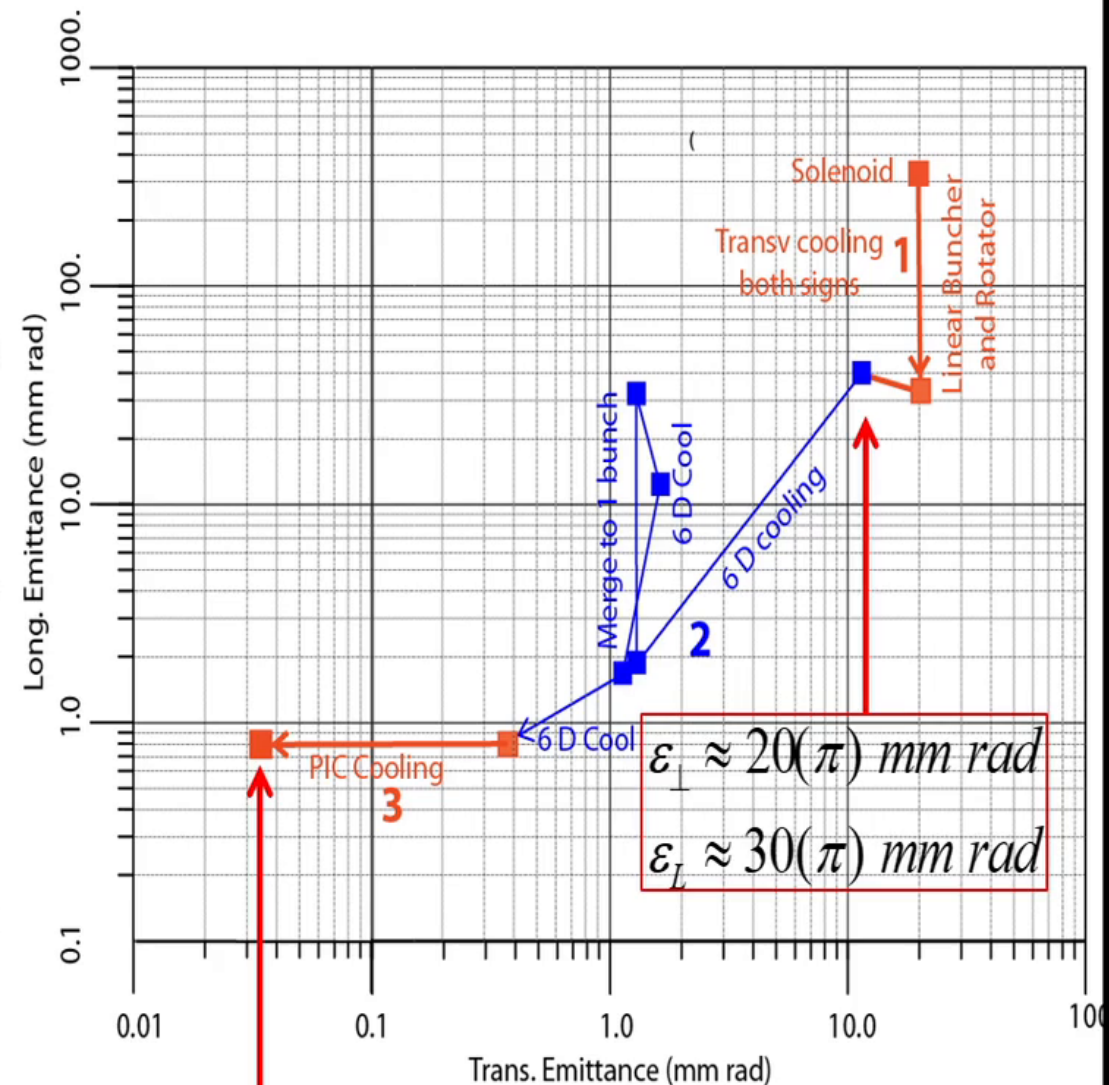
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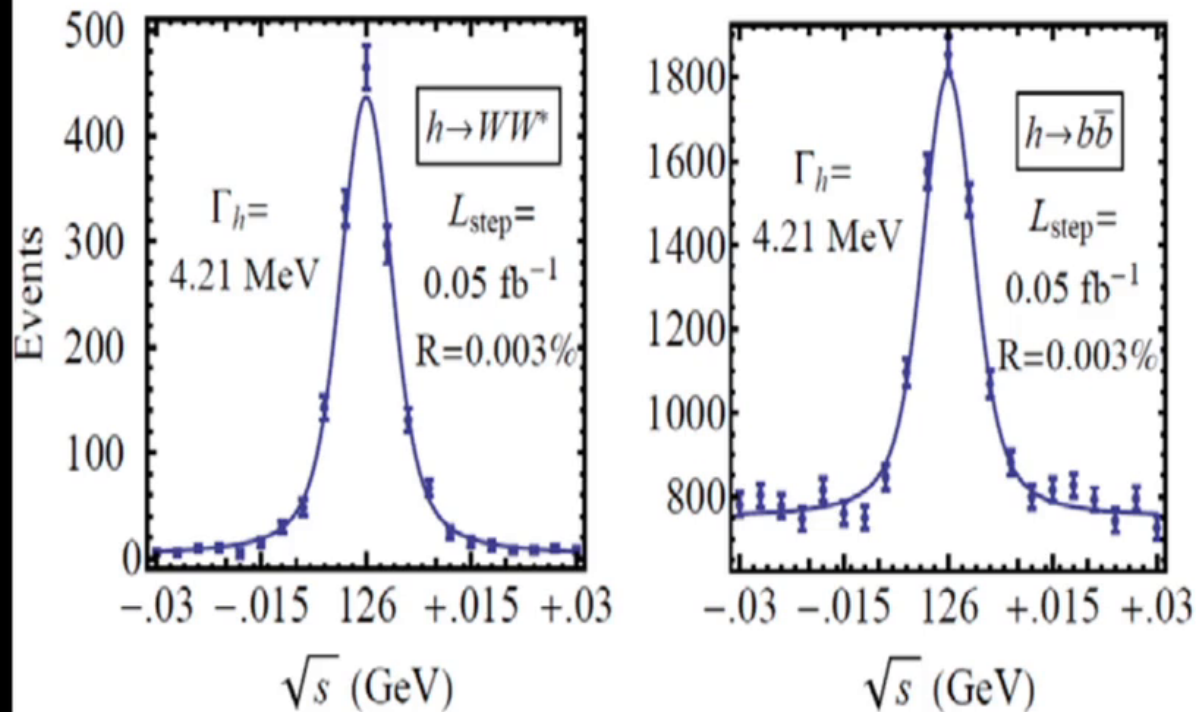


## Leading muon processes for the 125.5 GeV resonance

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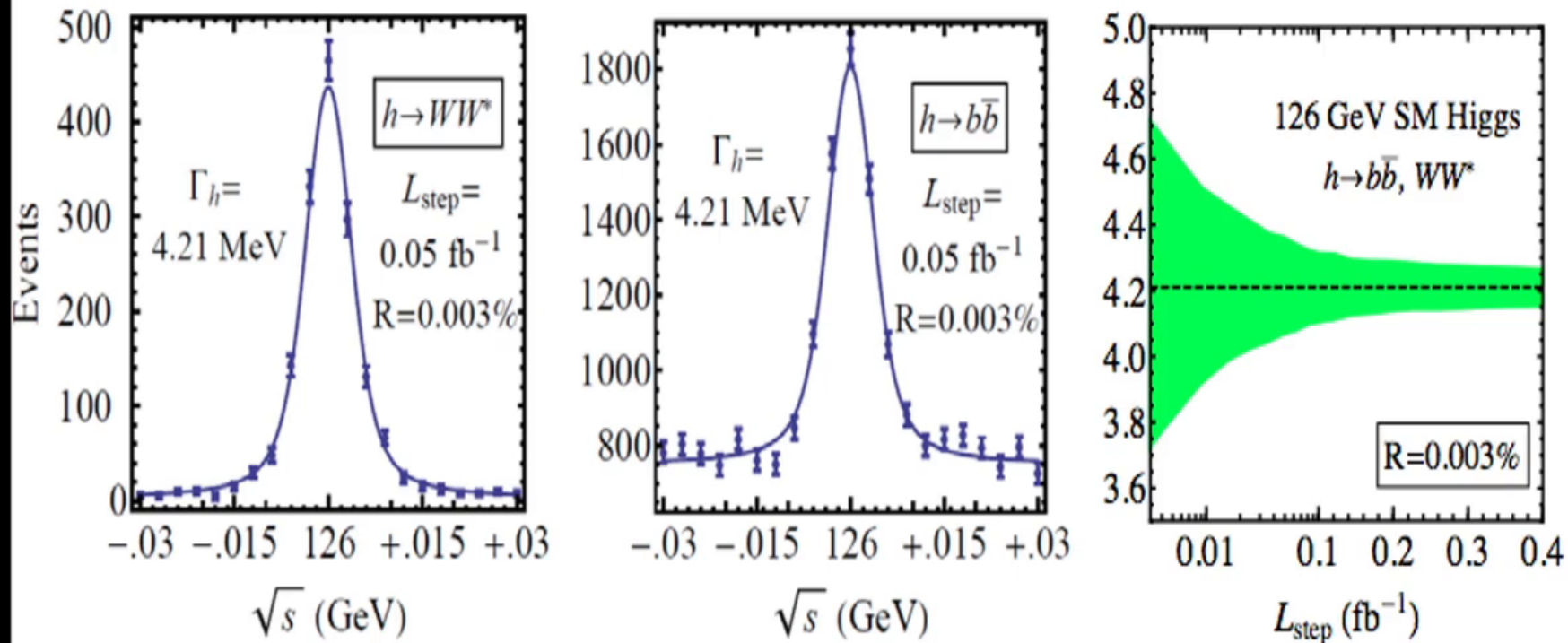
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- A luminosity of  $5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$  is achieved with  $1 \times 10^{12} \mu/\text{bunch}$ .
- The SM Higgs rate is  $\approx 44'000 \text{ ev/year}$  in each detector.
- An arrangement with at least two detector positions is needed

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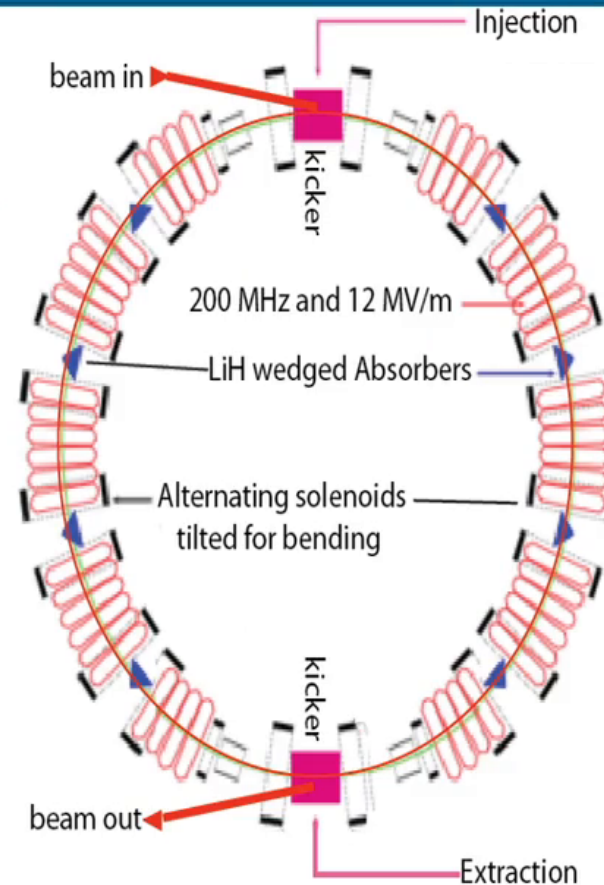
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- The goal is to prove experimentally the full 3D cooling.
- The other facilities, namely (1) the pion/muon production, (2) the final, high intensity cooling system (3) the subsequent muon acceleration and (4) the accumulation in a storage ring could be constructed later and only after the success of the initial cooling experiment has been confirmed at a lower cost.

# The RFOFO Ionization Cooling

- The design is based on solenoids tilted in order to ensure also bending. The LiH absorbers are wedge shaped to ensure longitudinal cooling.

Circumference	33	m
Total number of cells	12	
Cells with rf cavities	10	
Maximum axial field	2.77	Tesla
Coil tilt angle (degree)	3	degr
Average vertical field (T)	0.125	Tesla
Average momentum	220	MeV/c
Minimum transverse beta function	38	cm
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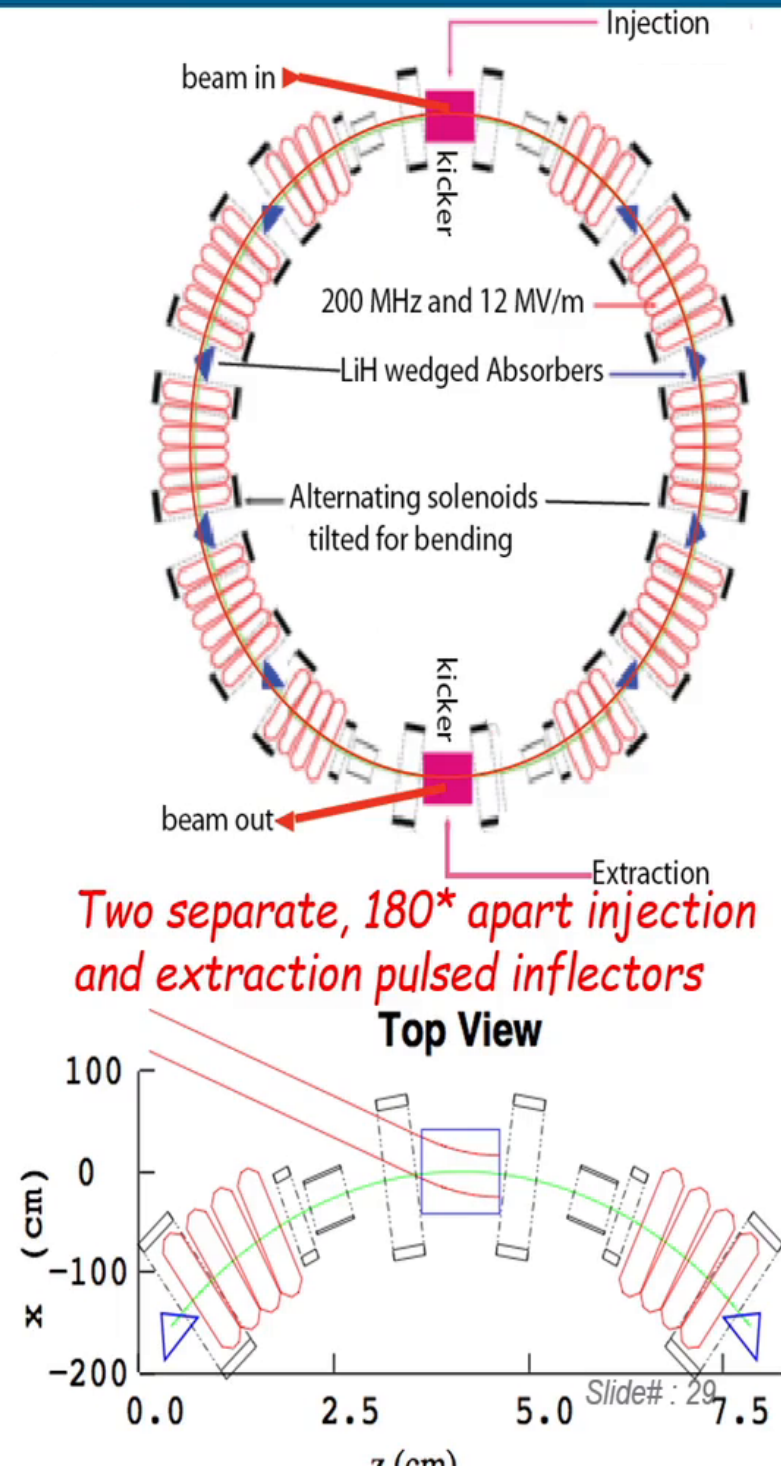


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- Medical and industrial markets exceed \$3.5 billion/y, and are growing at more than ten percent annually. Digital electronics now depend on particle beams for ion implantation, creating a \$1.5 billion annual market for ion-beam accelerators. All the products that are processed, treated or inspected by particle beams represent a collective annual value of more than \$500 billion.

## Conclusion: Impact of colliders on HEP

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- On the other end of the energy spectrum, very low energy pbar (LEAR) have permitted very fundamental discoveries.
- Equally revolutionary have been the associated development of instrumentation with the  $4\pi$  "hermetic" detectors (UA1,UA2), hadron calorimetry (Schopper) and drift chambers (Charpak, Nobel 1992) **which have ensured even with "Swiss watches" a detection capability comparable to the one of  $e^+e^-$**

# Conclusions

- Particle colliders have been in the forefront of scientific discoveries for more than half a century. The accelerator technology has progressed immensely, while the beam energy, luminosity, facility size and the cost have grown by several orders of magnitude. Essential contributions have expanded many different fields of applications.



Thank you !



# 50 years of Hadron Colliders at CERN

14<sup>th</sup> October 2021

- |       |  |
|-------|--|
| 14:00 | <b>Welcome:</b> Frédérick Bordry and Joachim Mnich                           |
| 14:02 | <b>Overview:</b> Carlo Rubbia  |
| 14:20 | <b>The ISR machine:</b> Steve Myers  |
| 14:40 | <b>ISR physics:</b> Ugo Amaldi   |
| 15:00 | <b>The SPS collider and LHC machines:</b> Lyn Evans                          |
| 15:20 | <b>SPS collider physics:</b> Felicitas Pauss                                 |
| 15:40 | <b>Break</b>   |
| 16:00 | <b>The LHC project:</b> Chris Llewellyn-Smith                                |
| 16:20 | <b>LHC physics:</b> Alice Ohlson, Patrick Rieck, Abideh Jafari, Basem Khanji |
| 17:00 | <b>The view from the USA:</b> Young-Kee Kim                                  |
| 17:20 | <b>HL-LHC and beyond:</b> Fabiola Gianotti                                   |