Personal memories on how particle physics experiments and apparatus evolved 1966-2016

Before starting the main subject , I should give a few memories of the first Moriond in 1966.

We were only 20 physicist + secretaries but with a few spouses and babies. About 10 theorist mostly from the theory lab LPTHE and 10 experimentalist mostly from LAL+1 Frascati + 1 Desy

We were lodged in a “chalet” and doing our “cleaning+cooking + dishes washing and drying” in turn … there were some meals better than others… I remember a delicious Vietnamese meal half by a theorist (Tran) and half from an experimentalist (Nguyen Ngoc Hoan) This was somewhat symbolic of the “Moriond Spirit” which was already present (am I allowed to say born!) at this first meeting. This was not “by chance”, the idea of the meeting was, and still is, that a casual atmosphere and a meeting in a single place would promote free-easy-in depth exchange between theorist and experimentalist.

Moriond 1966 (continued)

I appreciated very much the meeting . I remember a nice talk by Gourdin on the theory of 2γ exchange in ep scattering .

We also learned how to adapt to a meeting at high altitude: Moriond first casualty: snow-blindness for a few days to a LAL φ

So I remember I was shocked at the end, hearing a conclusion talk by Pierre Lehman (a senior physicist of LAL Orsay at the time, and future director of Dapnia Saclay and of IN2P3)

He insisted that Moriond should change and open – I thought how frustrating, it's a great idea why can't we just continue!

Of course he was right! Fairly rapidly Moriond grew (under the guidance of Tran and colleagues) but keeping the nice atmosphere and the fruitful exchanges.

A few memories memories at Meribel and Verbier but too dispersed.

Early particle physics apparatus

Early for me is when I started my thesis at the Harvard cyclotron in 1959.

Until 1960-61 the experiments in particle physics were mostly done by two types of instruments (very often (almost always!) physicist specialised in one of the two)

There were Visual device experiments using first cloud chambers and then bubble chambers after its invention 1952.

- **These were rather low rate experiments typically 1 picture per accelerator cycle (few seconds) and only a few tracks 10-20 per picture and therefore < 10-20 tracks/s**
- **Not very flexible: the liquid was the target and detector (there are exceptions! (H_2+Ne)…)**
- **But the information was extremely detailed. Wonderful success for SU3 resonances studies including the discovery of Ω baryon in 1964 , neutral current in neutrino interaction etc…**

And "Counter experiments" , using scintillators of various shapes and numbers, read by PMT.

- **They were flexible could count up to MHz of interaction, change geometry etc…**
- **could use PID with Cerenkov etc…**
- **but the number of counters was limited by the price of PMT and electronics (< 100's of channels?) => the granularity was very bad**

Then the spark chamber idea arrived!

Spark Chambers

Invented by 2 Japanese physicists in 1959=> spread like fire!

For those who have never seen or heard => simple description

- Assembly of 2 plates (later planes of wires) +HV pulse ≈10KV/cm => gas of Helium-Neon => sparks at place of track ionisation => then photograph
- gap of about 5mm to 1.5cm (compromise granularity – low capacity (rise time)
- permanent clearing field about 100V => clearing time about 1μs => can tolerate high rate of incident particle 10^5/s +> should decide trigger to send HV pulse in < 1μs (adjustable with clearing field)
- Very inexpensive and very flexible apparatus.
- Maximum trigger rate is few Hz (dead time of metastable ions & speed of camera)

Caught very rapidly most counter physicist integrated them in their apparatus

An early example : $\nu_\mu \neq \nu_e$ experiment 1961

Beautiful, very large apparatus 10 tons AL plates, detailed view of tracks

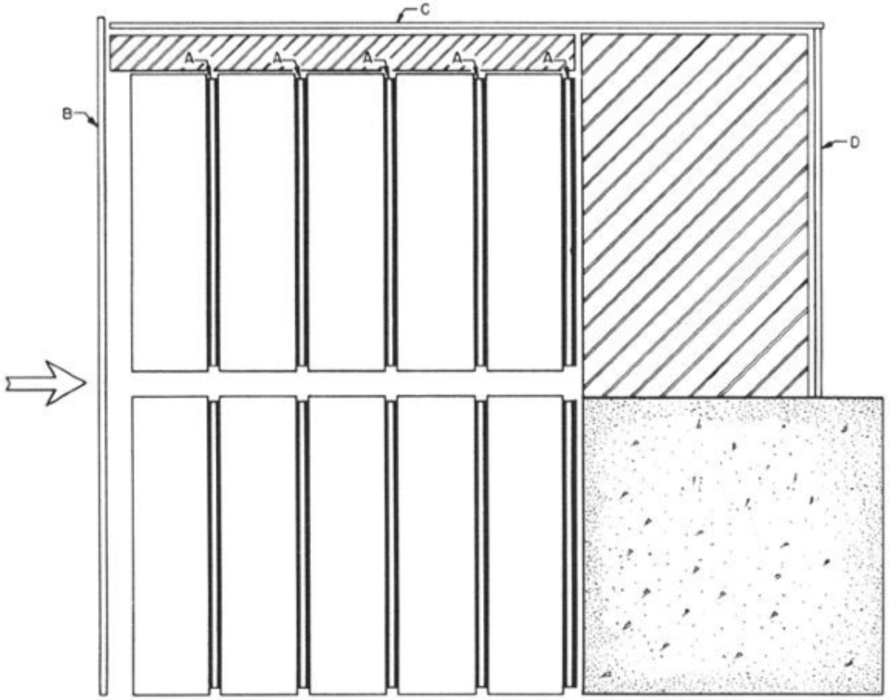
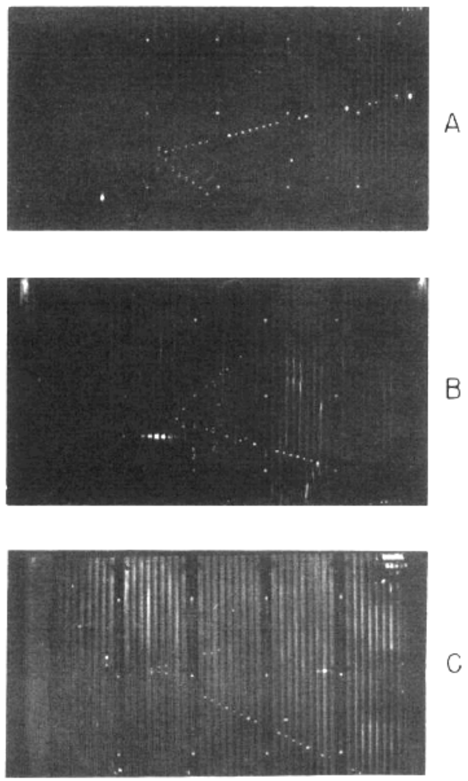
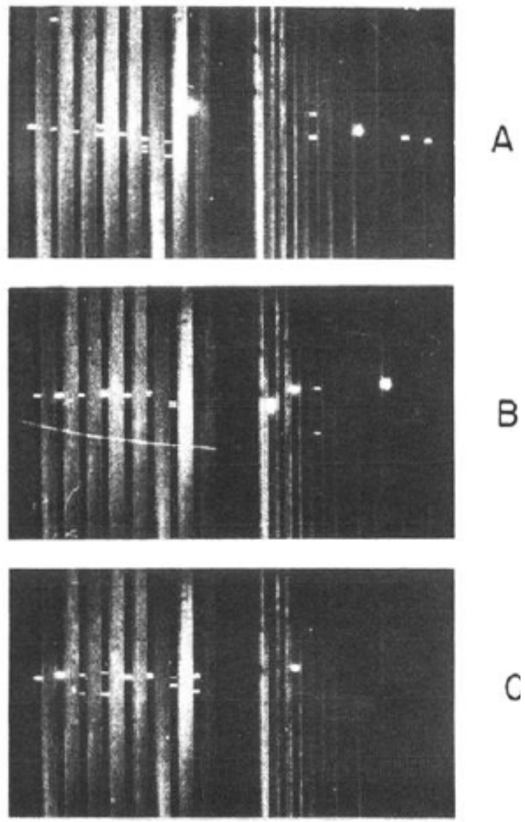


FIG. 3. Spark chamber and counter arrangement. *A* are the triggering slabs; *B*, *C*, and *D* are anticoincidence slabs. This is the front view seen by the four-camera stereo system.



}. 6. Vertex events. (A) Single muon of $p_\mu > 500$ and electron-type track; (B) possible example of two muons, both leave chamber; (C) four prong star v one long track of $p_\mu > 600$ MeV/c.



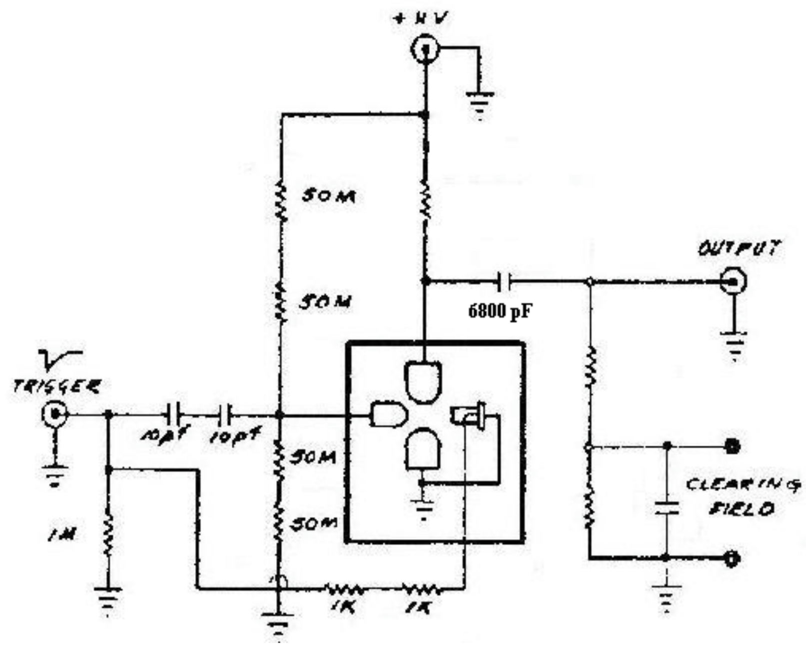
400-MeV electrons from the Cosm

Incredible success

Made possible experiments otherwise impossible (neutrino, storage ring)

The technique was, as you have seen by the neutrino example, rather simple, easy and fast to build and inexpensive compared to counters or Bubble Chambers.

A slightly tricky point was the tool to deliver a 6-10 KV pulse, but the technique of spark-Gap/Krytron existed from pulsed radar (and I discovered later that the Krytron was also used for the synchronous explosive of plutonium A bomb!)



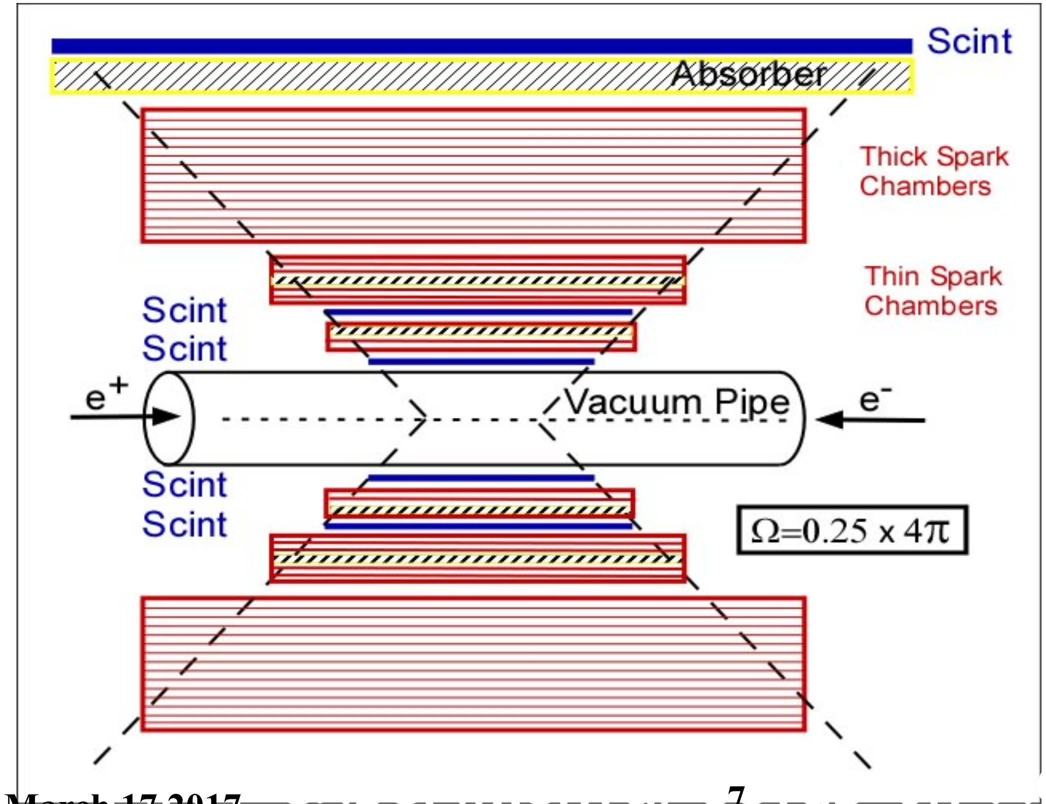
Example 2 :Initial Hardware on ACO storage ring in Orsay

1962-1967, plane optical spark chambers were used.

Events triggered by scintillators were recorded on a film by a camera

The thick brass plate spark chamber was used to separate μ from π by range (typically 21cm vs 17cm) and electrons by shower (not very good in brass plate!)

Modest trigger rate (<<1 trigger/s).



Example 3 : cylindrical spark chambers in ACO (data taking 1970)

Motivations:

Gain in angle coverage and compactness =>0.6X4π vs 0.25 before

Better π/μ/e identification and γ shower sampling by using lead absorbers

Difficulties:

Need for good optical quality

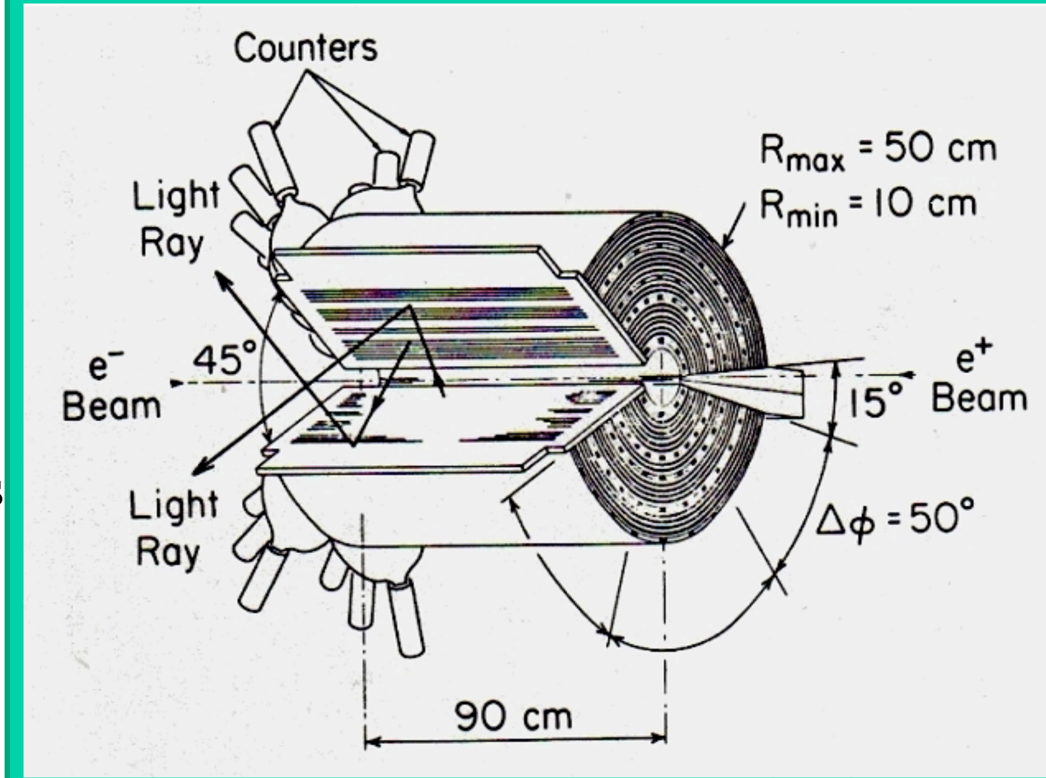
Good multitrack efficiency

Very tricky mechanical design

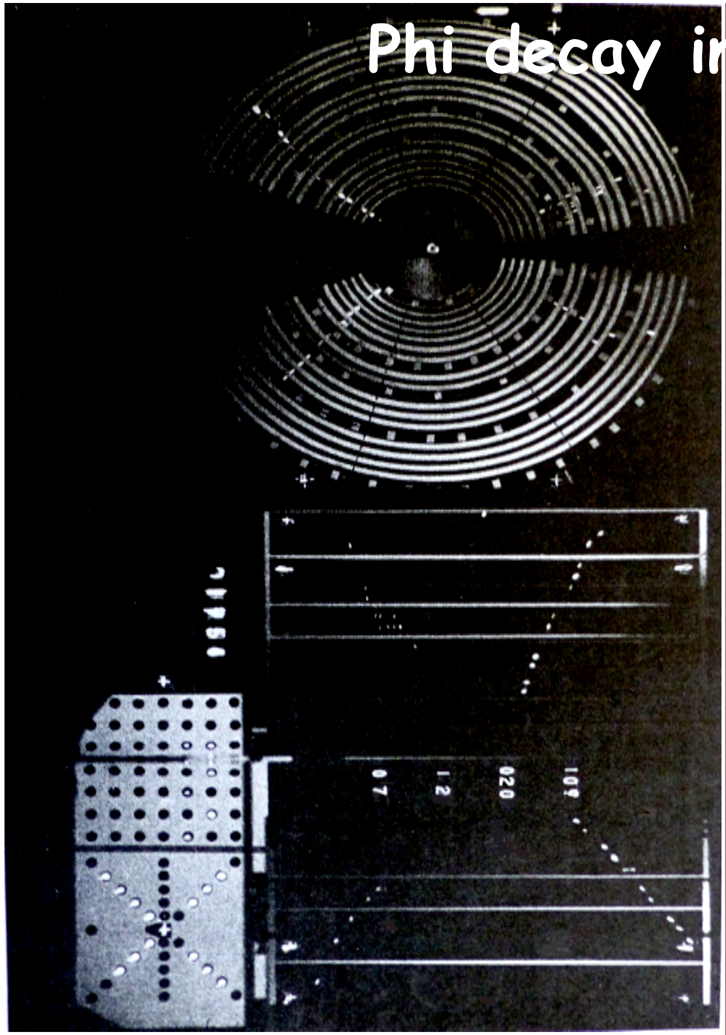
- Solution:

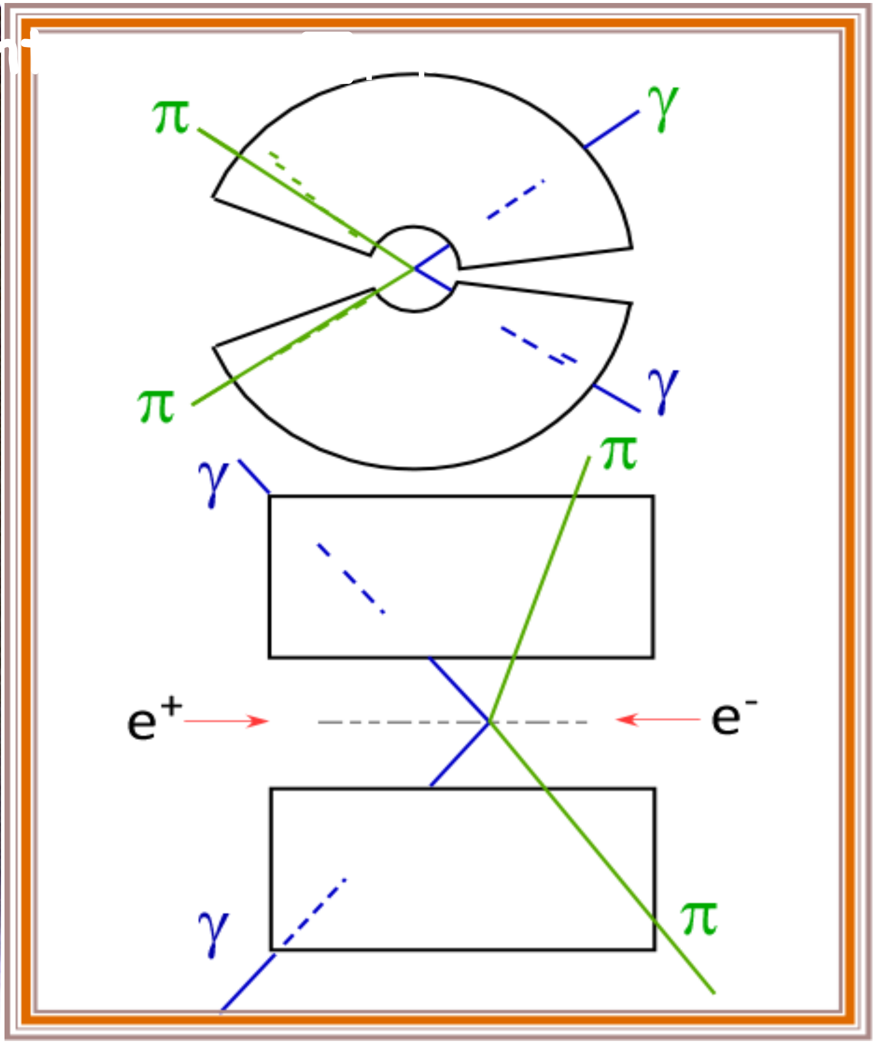
Sandwich made of:

- Self supporting chambers with thin walls made of low density foam material glued on each side to a Mylar and an aluminum foil
- 11 lead Sheet curved 0.5 X/X^0
- 4 scintillators layers=> trigger on π or γ



A $\pi^+\pi^-\pi^0$ event => $\pi^+ \pi^- \gamma \gamma$





The drawbacks and end of Spark Chambers

The rate of event was still quite limited (camera+ spark recovery)

The view could be very detailed but had to be examined by eye + measurement table (like bubble chambers) => army of scanners measurers (small army compared to bubble chambers)

In later year direct acquisition of data to computer (in 1970 DAQ computer at LAL had 12 Kbytes of core memory =>special funding to buy 4K more!!!)

Spark chambers with wires => sonic readout or magnetostrictive readout => directly to computer => allowed cylindrical detector like Mark1 at SLAC

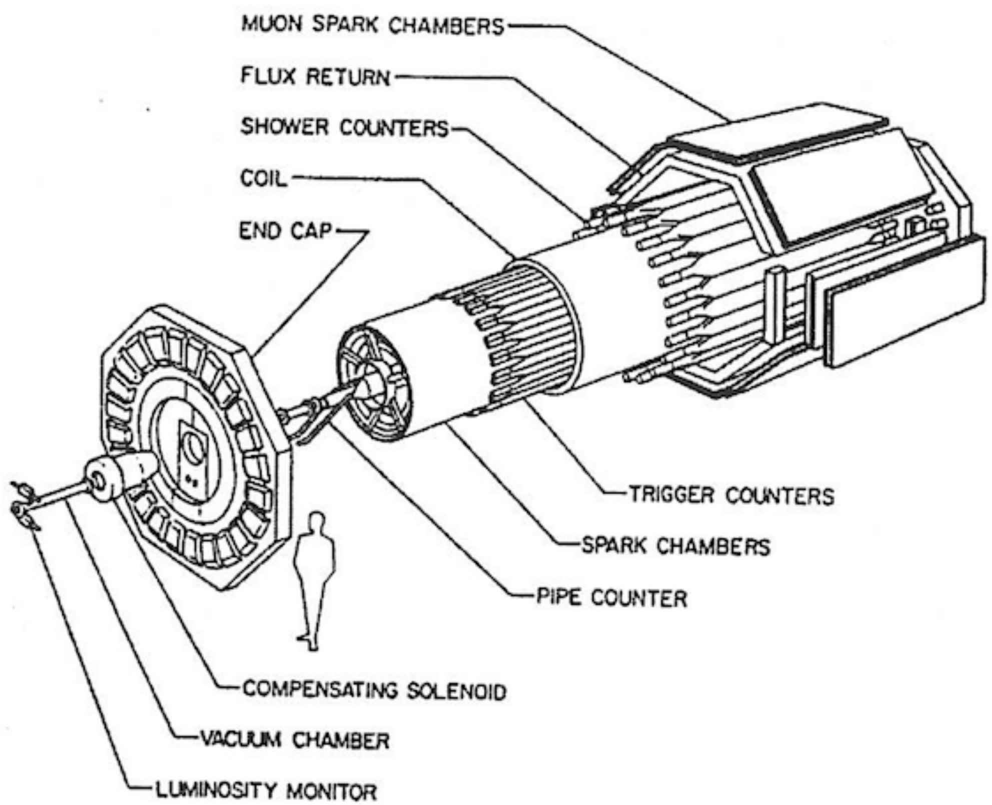
Streamer chambers => aborted sparks in gas (no plates, 3D pictures like bubble chambers => scanning and measuring) (Sad experience for me)

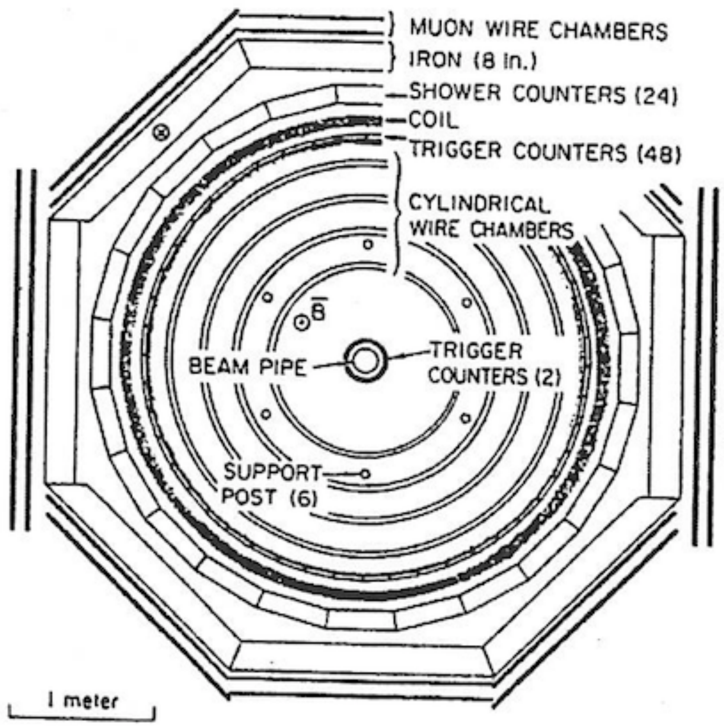
But in 1968 G.Charpak invented the MWPC possible because cost of amplifiers was dropping => rapid end of spark chambers within 3-6 years

MWPC still with us! But so intoxicated with visual device we needed event display for many years! For example UA1, UA2, LEP expts… even used to debug reconstruction programs! But much less used at Babar LHC for example!

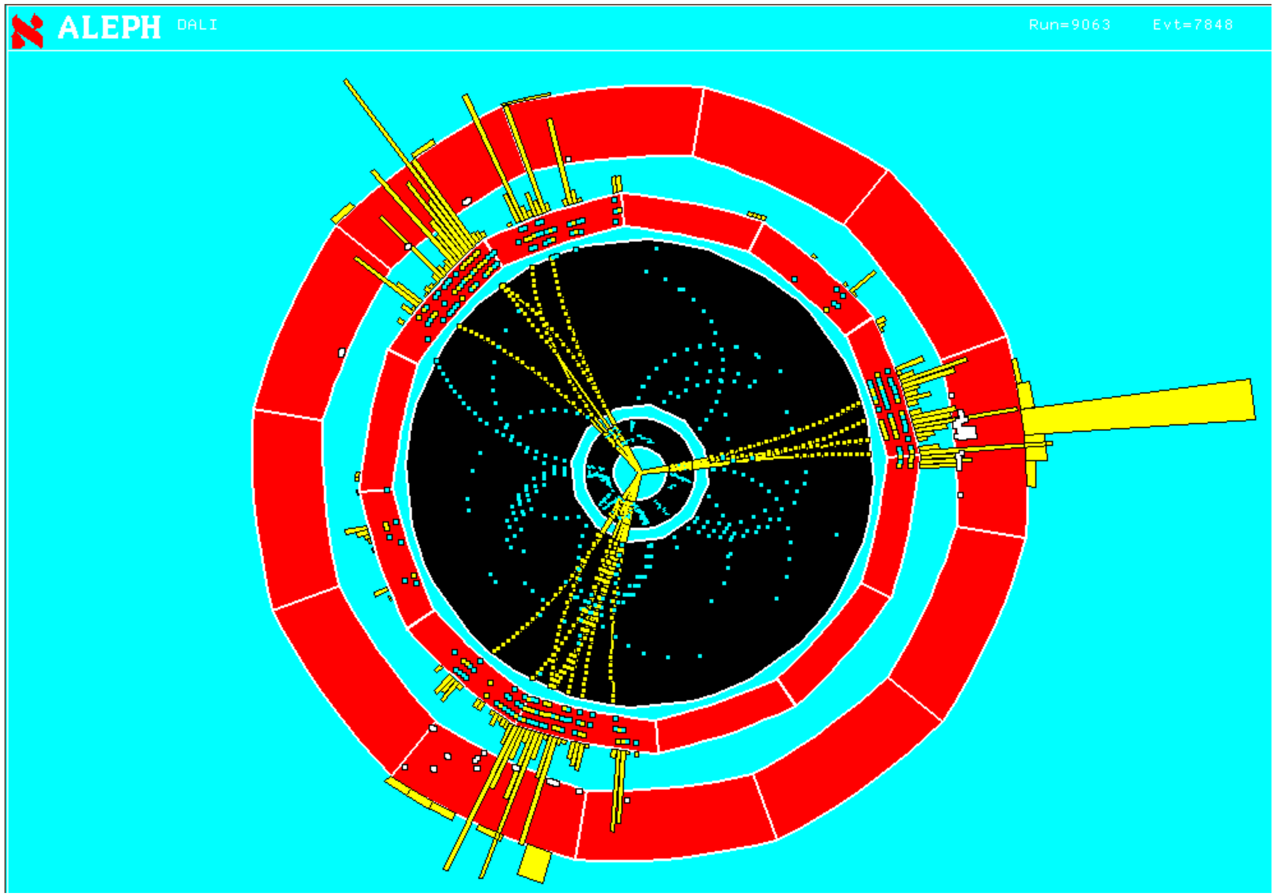
MARK1:Beautiful example of cylindrical spark chamber with magnetostrictive readout

It started operation in 1973 and is probably the most productive detector in particle physics history (Psi, Psi', charm, tau, spin of quarks). The first G P D but note e/γ rough counters…





ALEPH event display: 3 jet event



Impact of “educated guess” of physics program

In case of dedicated experiments (often the case at PS) the physics is “obvious” but for general purpose detectors the problem is different. An obvious example is the SFM at the ISR (proposed in 1969 operational in 1973).
Very ambitious technique: MWPC with almost 10^5 channels!!! Clever idea of a strong vertical field with opposite sign righ-left. Very efficient to analyse forward-backward high energy particle.
But almost blind at 90° … OK because (in 1969) hadron physics is at low-medium p_t!!!
But in 1973 the most important physics was at high p_t … at 90°…

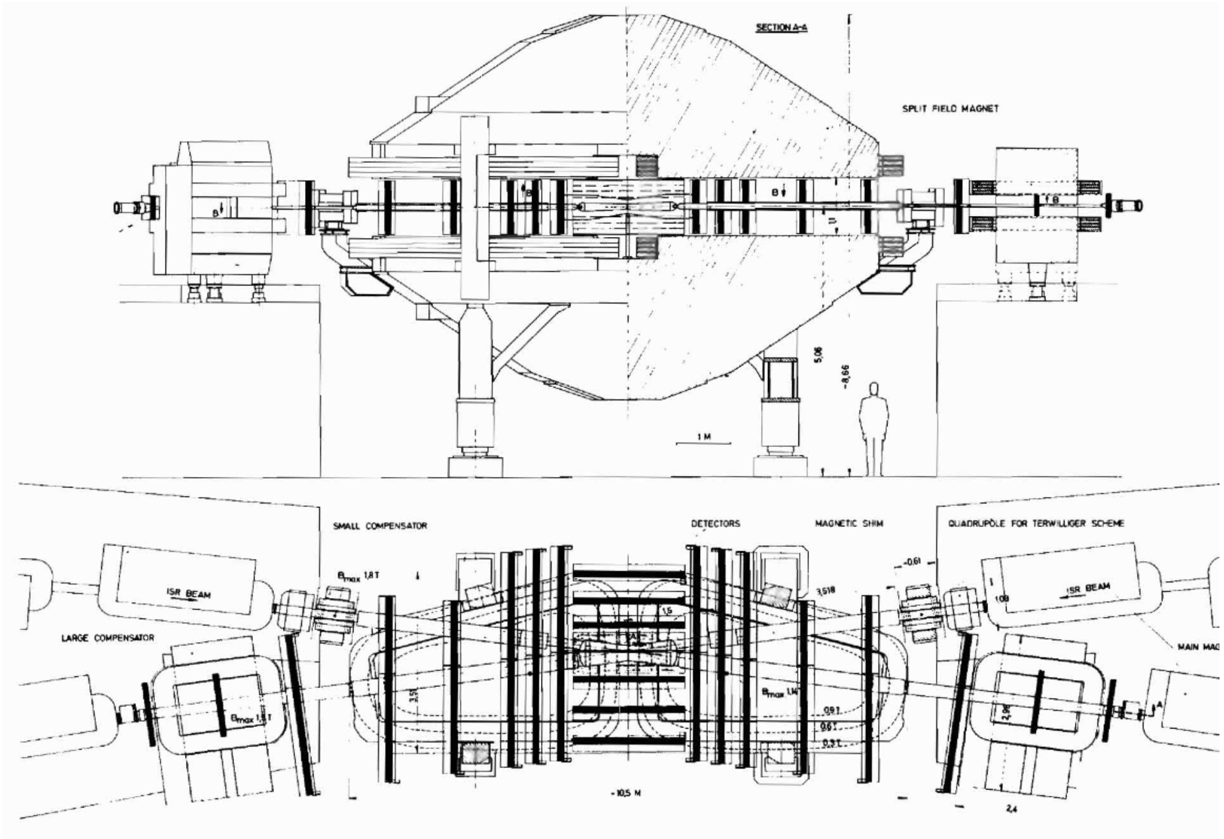


Fig. 1. Schematic layout of the Split Field Magnet facility on the Intersection region I-4. The multiwire proportional chambers, employed for the detection of the collision products, are also outlined.

Other ISR detectors

There had been other proposal more geared to 90° but they were turned down.

Luckily other detector looking at 90° were accepted, however less performing, using spark chambers instead of MWPC. For example the CCR apparatus (on the left) then CCRS (right) adding a magnet and cerenkov to improve the e identification. This did a lot of physics on the high Pt production and on e/π ratio but was not sensitive enough for J/Psi or Upsilon

=>lesson learned for future experiments at SPS UA1&UA2

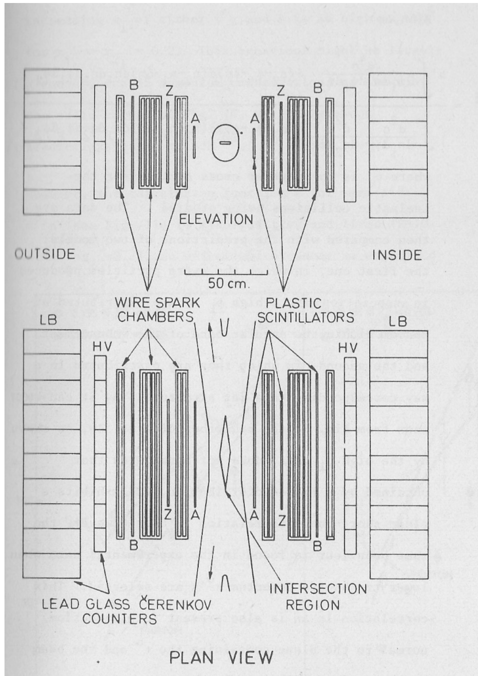
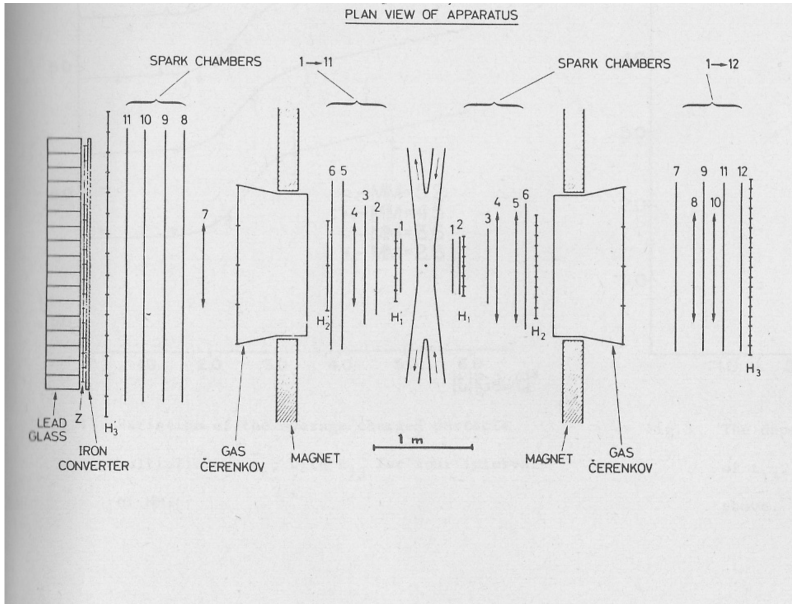


Fig.7 The CERN-Columbia-Rockefeller experimental set-up.



UA1 & UA2

Main physics goal: observe W&Z e/mu id , missing Pt, good momentum/energy measurement =>OK efficient design

But jet physics was not seen as a “key aim” It should be noted that jets had been seen in e+e- colliders but not in hadron collisions (claimed to be seen at ISR but far from obvious) and clearly at SPS the NA5 experiment saw nothing. =>

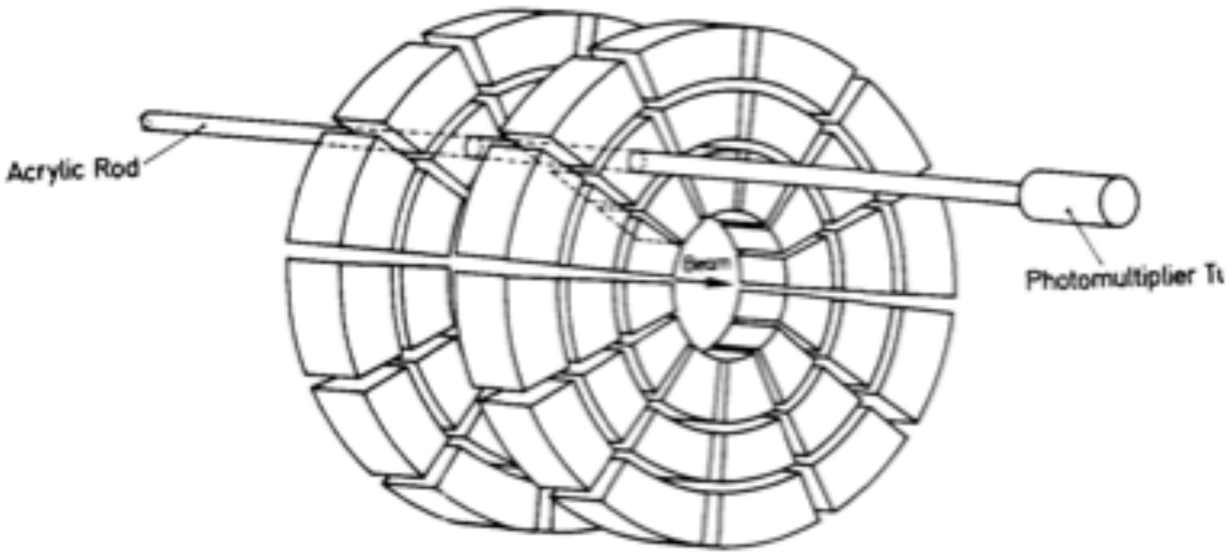
The granularity of the ECAL&HCAL of UA1 was not very good (gondola)

UA2 for economy reason had a B field only forward backward and only cells of calo towers for the rest (as in the first design of D0)

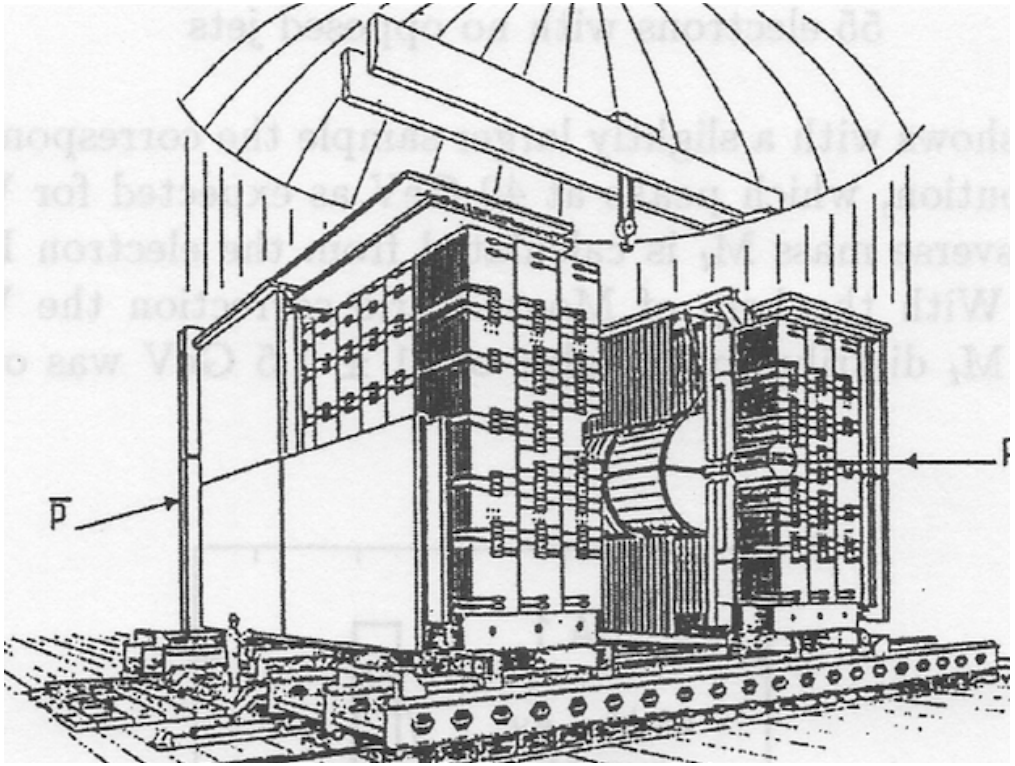
NA5

The NA5 experiment at the SPS had the idea to “see jets” by triggering on the sum of Et of calorimeter

Very nice idea but the SPS energy was too low => what was seen (1980) was high multiplicity of about <Pt> =500 Mev no jets



UA1&UA2



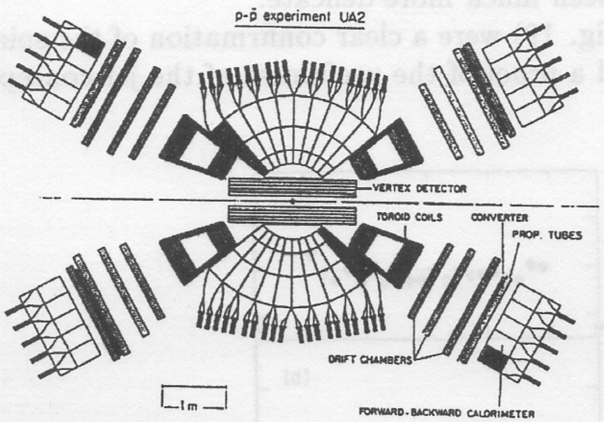


Figure 20 Polar view of the UA2 apparatus.

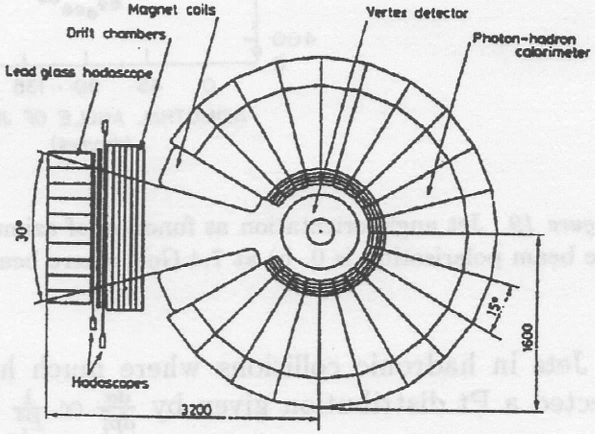


Figure 21 Azimuthal view of the UA2 apparatus.

First jet observation at a hadron collider ICHEP 1982

- **With the granularity of the calo system, it was easier for UA2 to see jet so jets in hadronic collisions were announced at the 1982 ICHEP, UA1 followed rapidly after.**
- **Lesson learned =>from previous e+e- detectors and UAs: for jet physics granularity of the calo is important.**

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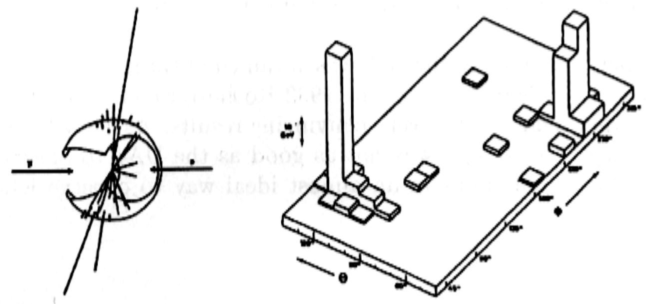

Figure 22 Angular distribution of energy in an event with $\sum E_t = 150$ GeV.

At $E_t > 80$ GeV close to 80% of the E_t was found in 2 clusters (Fig. 23).

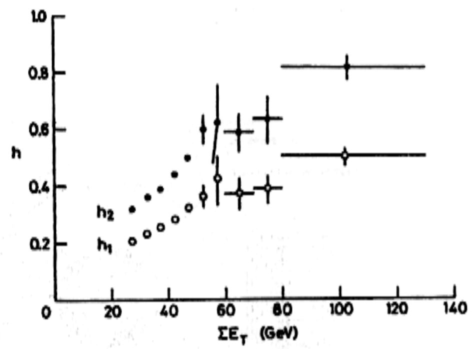

Figure 23 Fraction of the transverse energy of events measured in one (opened circles) or two jets (filled circles).

LEP detectors (I)

From the lesson on jets, all detectors were granular but DELPHI and ALEPH made it a key point: track detector were TPC giving points in space and hence with very good multitrack efficiency.

Their calo also had higher granularity than L3,OPAL. Liquid Argon detector had been used at ISR SPS PETRA etc… but not at LEP. At least for ALEPH the argument was the limited granularity compared to the 210,000 channels of the lead-MWPC ECAL Before the invention of the accordion technique used later for ATLAS, liquid Argon did not allowed the requested granularity. Granularity allowed to develop particle flow jet reconstruction.

Silicon detector close to the vertex for Beauty Charm and tau-lepton physics were clearly in the plans of all 4 experiments but even if they had been invented before, it was not an easy technique to implement at that time, and all 4 expts delayed their installation Delphi was the first one to have a working detector but in 1992 all 4 expts had them.

LHC

2 specialized detectors and 2 general purpose detectors

The aims of accuracy and granularity continued with new development.

With the high luminosity, tracking was of course more difficult than at LEP => as a consequence the amount of material before calo suffered (compromise in future detectors?)

To me the biggest breakthrough compared to previous experiments is the key role played by large computing farms, this allows to cope with the large event rate. They play a key role in the event selection. To have detector DAQ cards directly integrated in commercial PC's is extremely efficient.

Conclusion

The opinion of a physicist who started experimental physics in 1959 is probably not the best one for the future!!!

Ideas on new accelerator program start so much in advance now that one could imagine the key elements of a GPD detector frozen 15-20 years before data taking, this makes me feel uneasy we have seen such things in the space program and in my opinion it is far from ideal. How can we keep some flexibility?

(memories of choice of commercial computers vs dedicated processor in ALEPH, LHCb, LHCb-upgrade)

Will we succeed in using very fast detectors? If faster than about 50 ps it helps for reconstruction…

Can we obtain the speed, redundancy, accuracy of tracking with less material?

It will be your job not mine!

Thanks for the pleasure of being part of Moriond 50th anniversary.