From Experiments at Orsay to Experiments at CERN

A group of Bubble chamber physicist had moved, end of 1964, from Ecole Polytechnique Paris to join our lab.

But "counter physicist" were doing experiments only with LAL accelerators + storage ring .

P Lehman, a senior physicist with vision, pleaded that the lab had enough physicist and expertise and should also do counter experiments at CERN => very heated discussion in the lab: I was convinced that P. Lehman was right and joined him.

During 1969 the lab was reorganised with a division of "counter physics at CERN" We decided to collaborate with Ecole Polytechnique physicist for this adventure. P. Lehman headed a group starting a pion scattering experiment at CERN with spark chambers with electronic readout.

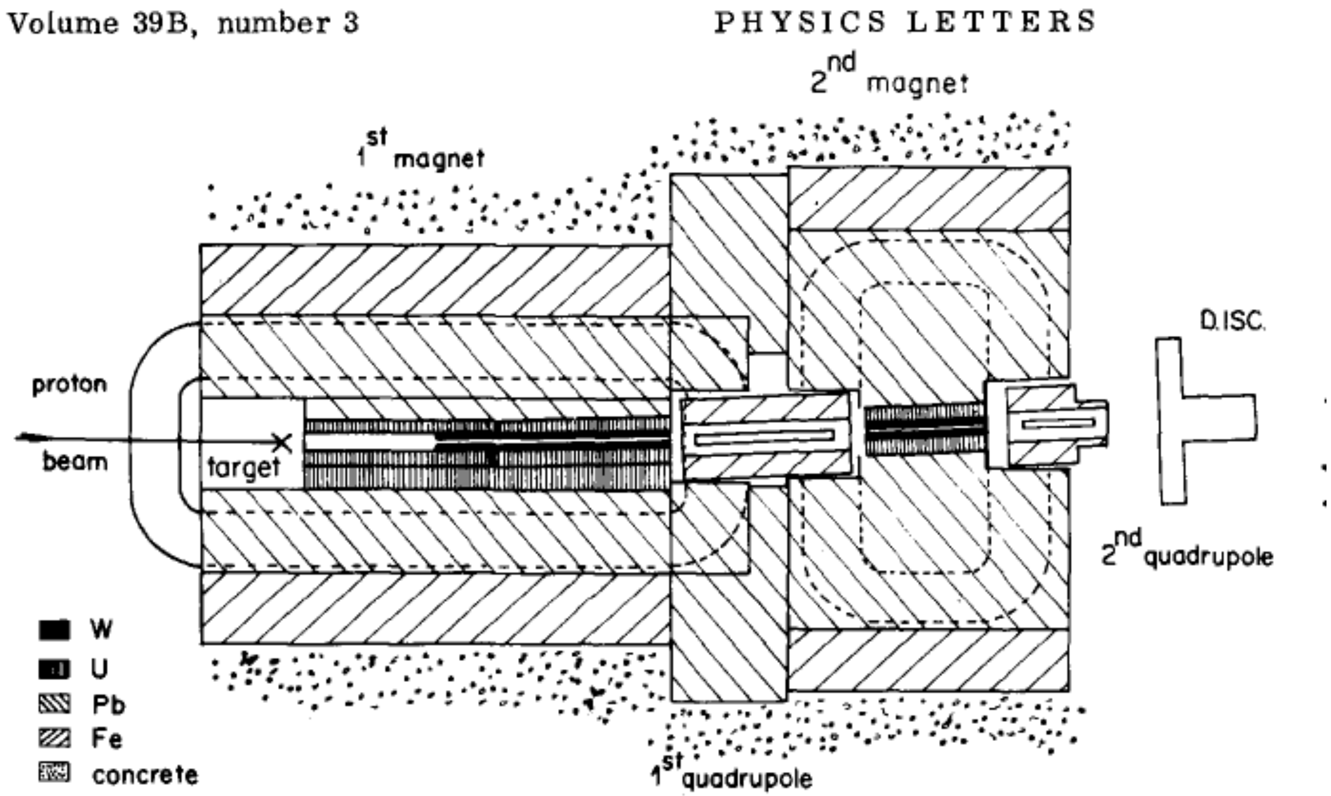
I was responsible for another group starting an experiment with a new hyperon beam produced by the CERN PS with 28 GeV protons.

Hyperon ≡ Strange Baryon

The main apparatus chosen was a streamer chamber with photograph readout.

The Hyperon beam(I)

The nice idea, which owe a lot to R.Meunier and his DISC, was to have a short beam since 20 GeV Σ decayed in about 40 cm



The Hyperon beam-The DISC

DISC = Differential Isochronous Cerenkov Counter : It was filled with SF6 at a pressure 10 to 16 Bar . (Meunier jewel ,R.Meunier was a Saclay physicist at CERN)

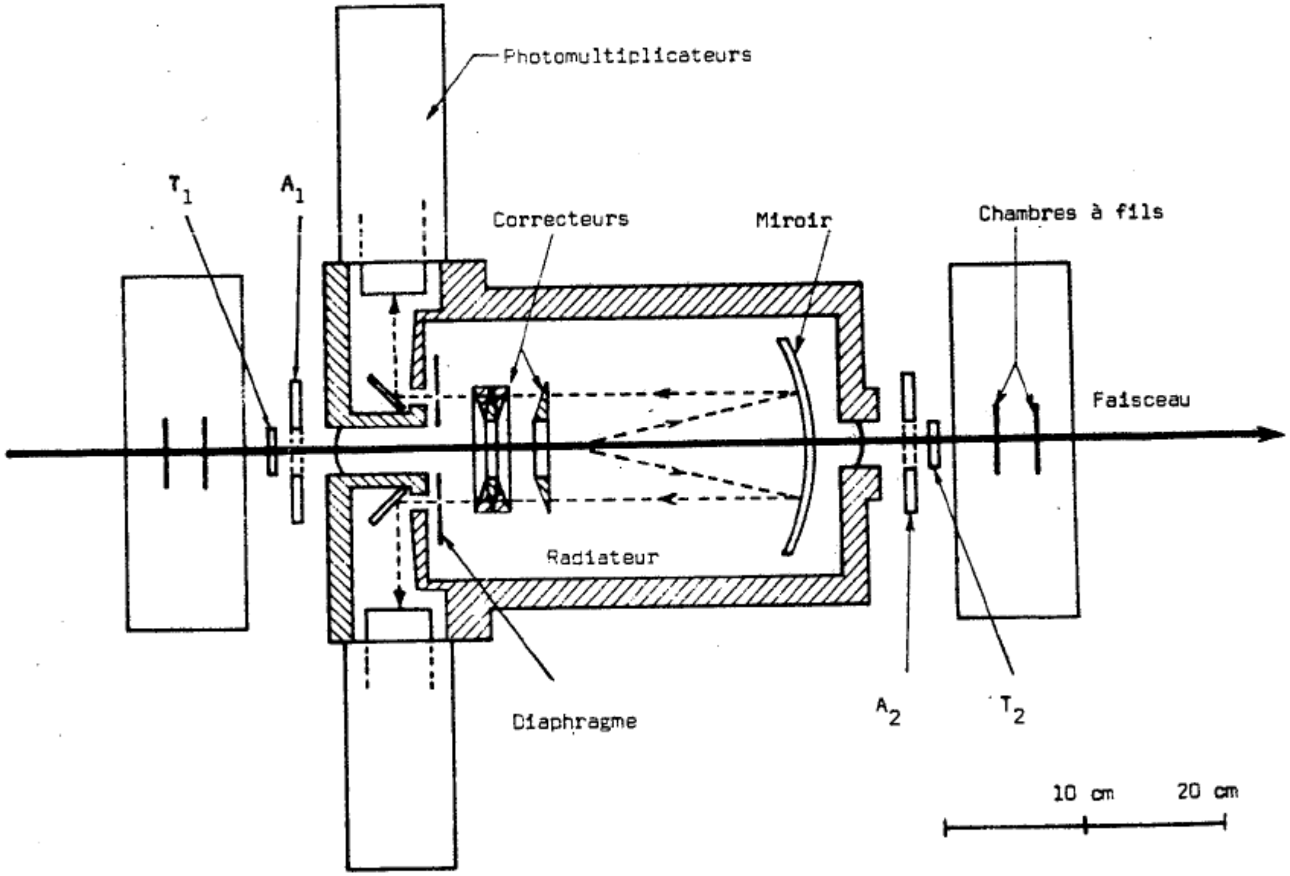
The trick was to have quartz and NaCl lens to correct the chromatic and spherical aberrations to select accurately the β, even with a high n (needed for short DISC)

Small "state of the art" MWPC chamber (built at Orsay) used to measure angles 10μ wires, spacing 1mm ,

use of SF6 in gas to limit the sensitive region 0.5mm.

Amplifiers were discrete transistors on PCB!

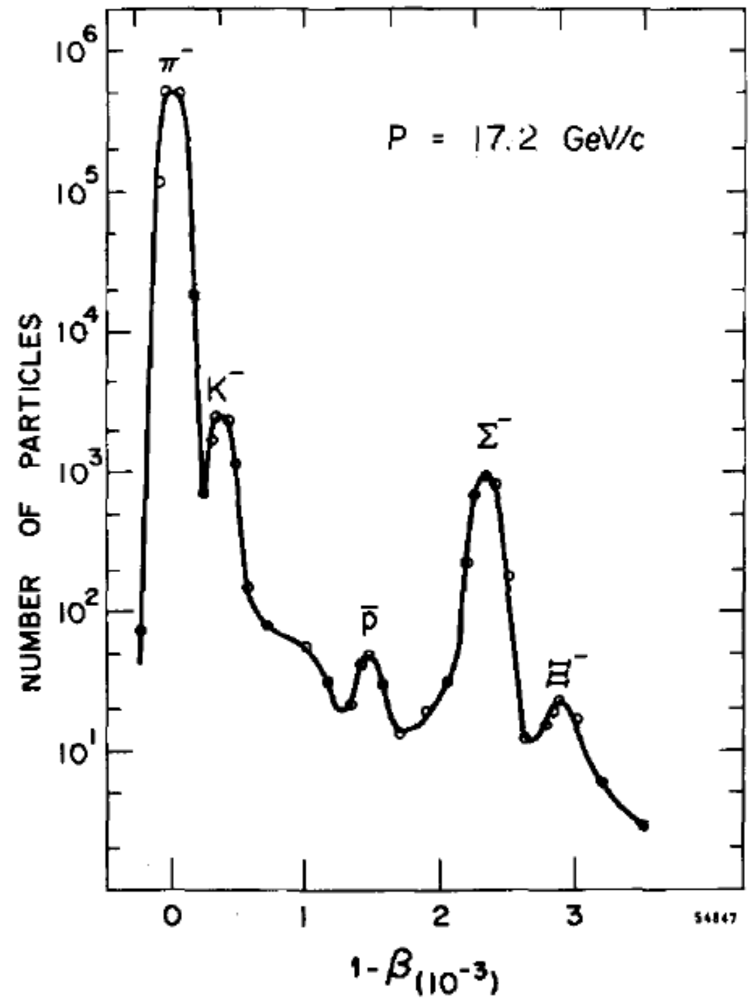
We had a computer with 12 then 16 Kbytes of memory!!!



Hyperon Production

Mass spectrum vs angle and momenta were measured and published in May 72

There are more Σ^- than pbar because of the difficulty to get high momentum antiquark produced by incident protons.
For 10^{11} protons per PS spill, we obtained and selected 50Σ^- and 1Ξ^- no Ω^- were identified (after looking at decay with the streamer chamber)



;.2. Velocity curve at 17.2 GeV/c showing the counting rate versus $1-\beta$.

Σ- total cross section

Rapidly after, we measured the total Σ p Σd cross section at 18.7 GeV and published in October 1972. The data taking took 2 periods of 15 days

The data was checked by measuring also proton-proton σ_{Tot}

Data were corrected for small angle elastic scattering using the small MWPC C1,C2,C3,C4

The result obtained is σ_{pp} - $\sigma_{\Sigma p}$ = 5.1±1.1mb while the quark model predicted 4.1±.9

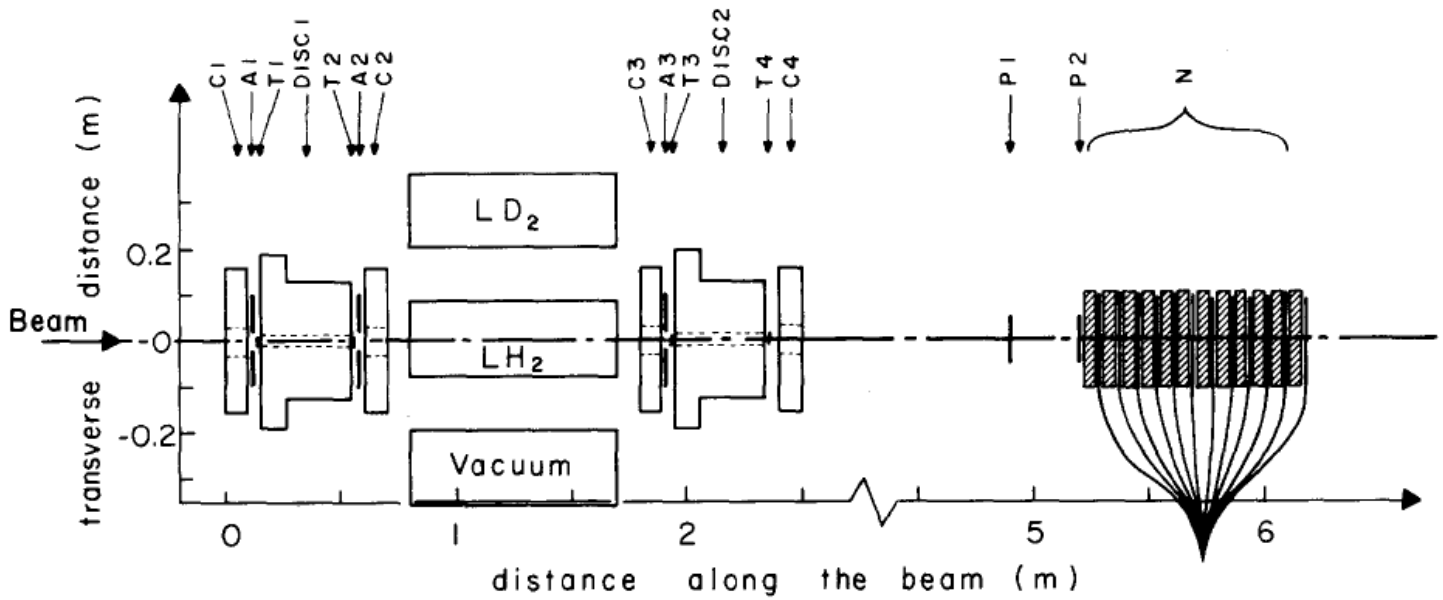


Fig. 1. Plan view of the experiment (note exaggerated transverse scale).

G_A/G_V for Σ semileptonic decay =>$n\mu^-\nu$

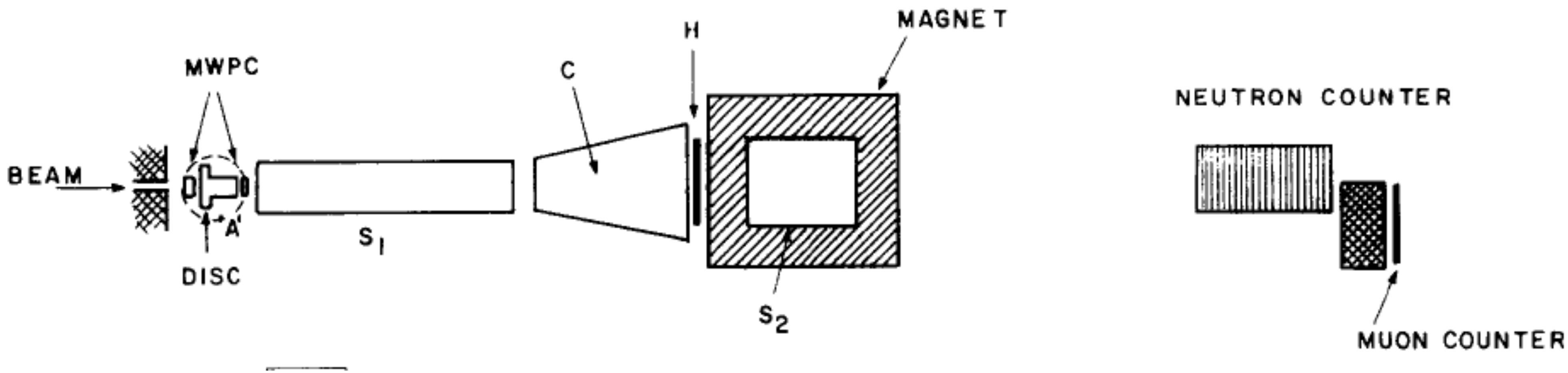
S1 and S2 were streamer chambers S1 3m long and S2 1.4m long and placed in a magnet were measuring the decay angles and momenta

S1 had 2X13cm gap and S2 2X26cm and a pulse of 20KV/cm during 10ns was used.

Streamer picture were measured with an automatic film-reading device previously used for bubble chamber pictures.

G_A/G_V was measured .17+-0.08 about 2 times more accurate than previous bubble chambers measurements (and published in 1977 note the long analysis time)

An experiment on diffractive interaction of Σ^- on p was tried but with no useful results.



Digression on Streamer chambers

They were derived from spark chambers but the idea was to have almost no material : in a large gap one produces "aborted sparks" a few mm long in HeNe gas.

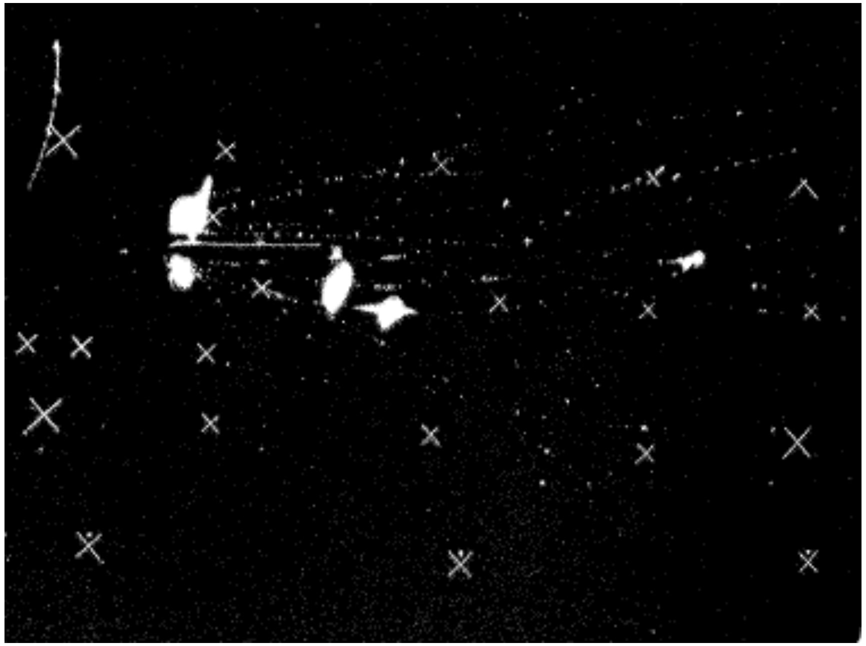
The mechanism was a very large HV pulse (in our case up to 500KV! during 10ns)

The memory time (about 1μs was adjusted by using a "poison gas" (SF6) attaching the electrons… but the sparks destroyed the SF6 so it was a difficult equilibrium!)

Many labs develop the device SLAC DESY CERN…

Technically it was quite difficult, and even more it meant a difficult analysis to take the information from the films.

Retrospectively, I think it was a big mistake to choose an optical device, MWPC were starting but we were scare to build large ones and the many layers needed.



Thinking of a SPS program

While we were organising at LAL our program to do experiments at CERN, we were aware that the Fermilab accelerator was being built: construction started around 1967 but first beam arrived in December 72 and stable beam only around 73-74.

Clearly our PS experiments were, at least partly seen by us as training for higher energy.

At CERN the ISR program had been decided.. It was the first hadron collider. 30X30 GeV decided in 1966 Its first collisions happened in 71 and design luminosity of 4 X 10^{30} in 1973.

Europe took quite some time to decide the SPS because many countries competed to have the site… until CERN showed it was much cheaper to build it at CERN

The SPS was finally decided and there was a meeting at the Italian city of Tyrrenia (on the sea close to Pisa) on September 1972 of many physicist to brain-storm on the experimental program. Some of the Orsay group continued on a hyperon beam program at SPS (without streamer chamber!!!) But with others and Aldo Michelini of CERN we started to work on a spectrometer project which became the NA3 experiment.

But first I will outline the status of particle physics in those years

Particle Physics Understanding in years 1967-1977 (I)

During this decade we gradually started to understand particle physics => the decade of the rise of the standard model… this is my brief and very personal account: first in hadronic physics.

SU3 had been invented in 1961 to classify particles (and it predicted the Ω^- seen in 64)

In 64 the idea of quarks as an explanation of SU3 was given but this did not mean quarks where point object. Hadron physics was often seen as the science of effective theory, parametrising forces among particles (π,ρ etc…) by exchanges of those same particles or by Regge poles… not false… but missing hard scattering!

The first experimental breakthrough came in 1968-69 with the deep inelastic results of SLAC which showed that partons (=quarks after some time) were point like i.e. fundamental

These were completed by the beautiful deep inelastic neutrino results of Gargamelle at CERN (1000 ν and 1000 νbar interactions presented at 1972 ICHEP) followed by Fermilab results. This was essential since ν and νbar allowed to separate the presence of quarks and antiquarks and establish the number of valence quark =3

One should not minimize the key role of theorist who actually through sum rule and use of current algebra had predicted this point like behaviour.

Point like partons at SLAC

Plotted σ/σ_{Mott}
σ_{Mott} is the calculated scattering on a point-like object.
W is the "excitation" (mass) of the proton after collision.
Elastic $W=m_{proton}$ =>form factor=> fast variation
Inelastic if W =1238 (N*), then also a form factor
But at large W no form factor!!! => scattering on point-like objects

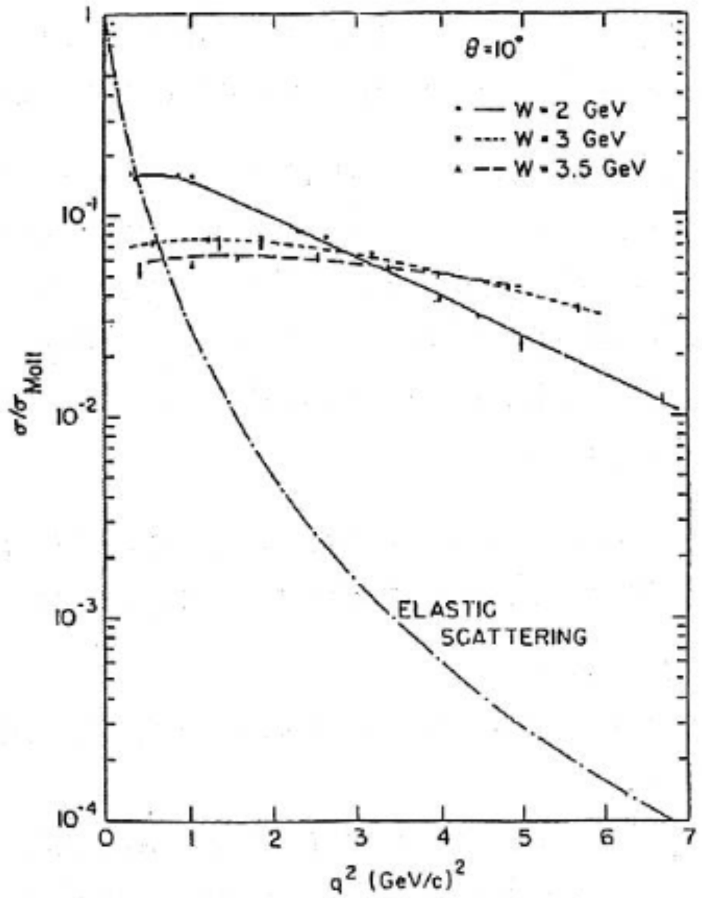


Figure 1 The elastic and inelastic cross-section as function of Q^2 showing the absence of form factor at large excitation energy.

Particle Physics Understanding in years <1977 (II)

Lepton physics was indicating new physics but impact on pure hadron physics was not immediate: To give an example the general purpose detector for the ISR built in 1970-1973 =>SFM (split field magnet). Very daring use of MWPC. Clever idea of two opposite field so has not to disturb the beams with vertical fields. But 0 field at 90° Apparatus blind at 90° “since it is well known that the hadronic physics is at limited pt” !!!

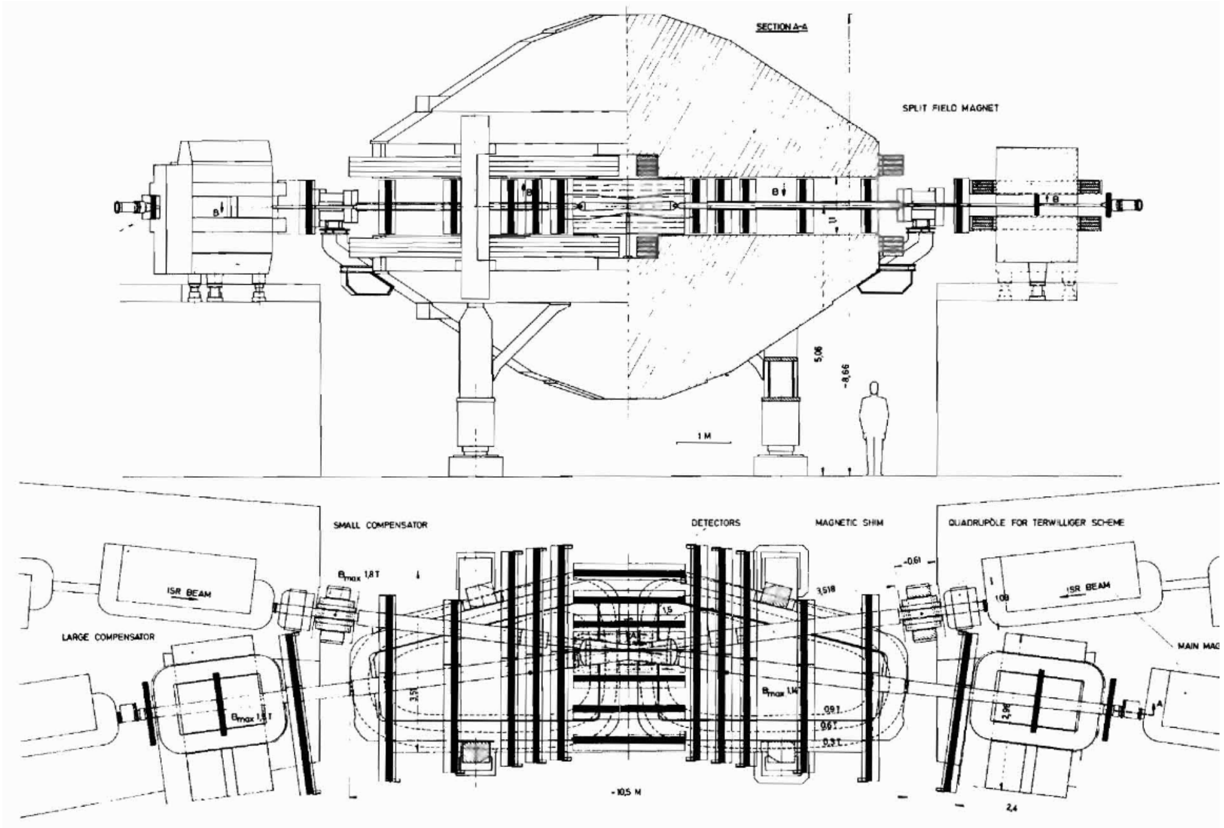


Fig. 1. Schematic layout of the Split Field Magnet facility on the Intersection region I-4. The multiwire proportional chambers, employed for the detection of the collision products, are also outlined.

Early ISR results

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

Luckily other detector looking at 90° were accepted, however initially less performing.
The initial apparatus was from CCR(on the left then joined by S (Saclay)(right) adding a magnet and cerenkov to improve the e identification.

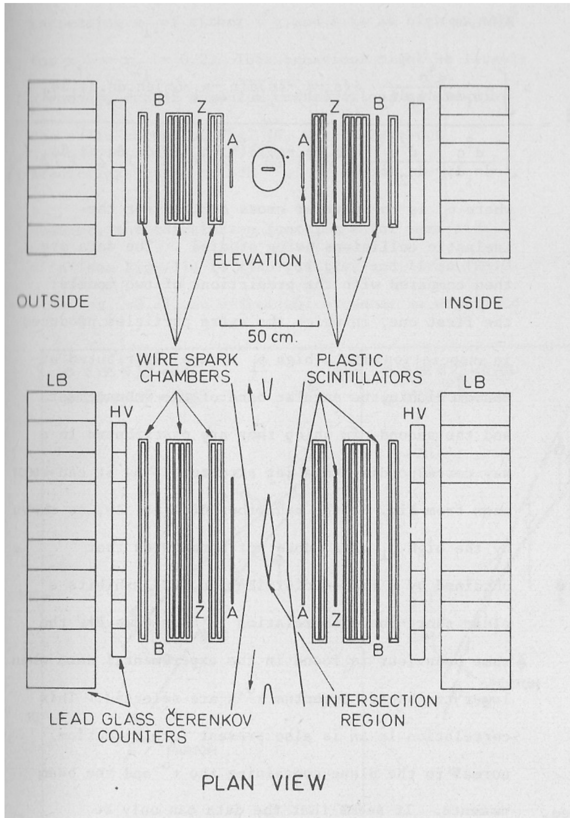
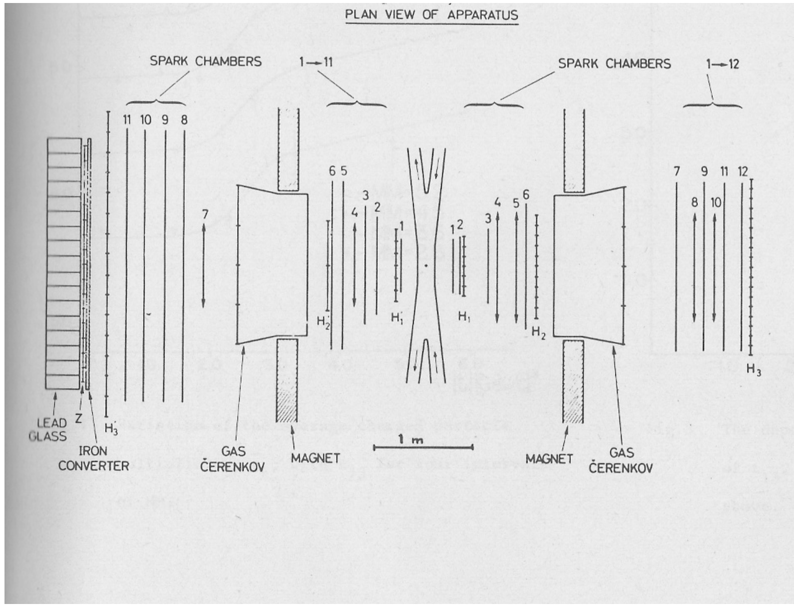


Fig.7 The CERN-Columbia-Rockefeller experimental set-up.



Other apparatus were built for example Pisa Stony Brook
Similar results were obtained from Fermilab

Hadron physics results at 1974 ICHEP

At the 1972 ICHEP almost all hadronic results were on low pt phenomena, but at the 1974 High Pt physics was a major subject. (As I will outline later our choice for the NA3 proposal submitted in 1974 was to focus on high P_t physics).

However the high P_t π^0 production decreased like $1/P_t^8$ This was not understood, as parton scattering should have been as $1/P_t^4$ We now know that the effective$1/P_t^8$ was an interplay of Distribution function, Parton scattering and Fragmentation function… the 8 was not fundamental (but high Pt not exponential was fundamental!).

Furthermore, it was found that high Pt lepton were also produced with a constant ratio $e/\pi = 10^{-4}$ The constant ratio was also an accident (a sum of many causes) one of the cause appeared sooner after in the 1974 November resolution (J/ψ)

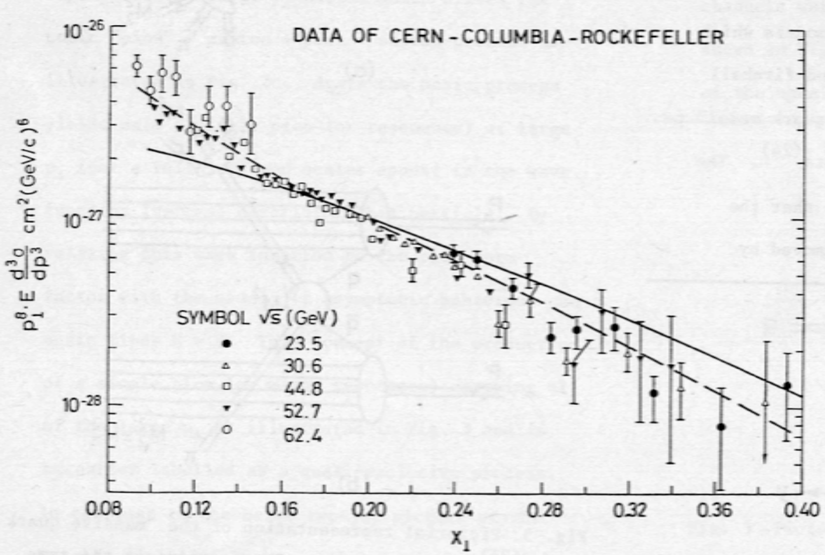


Fig. 6 Fit to the π^0 data with the "quasi-exclusive" parton model (22). The solid curve is for F(x) given by the experimental structure function νW_2 and the dashed curve is for $F(x) \sim (1-x)^3$.

Weak interaction and Flavor Physics in early 70's

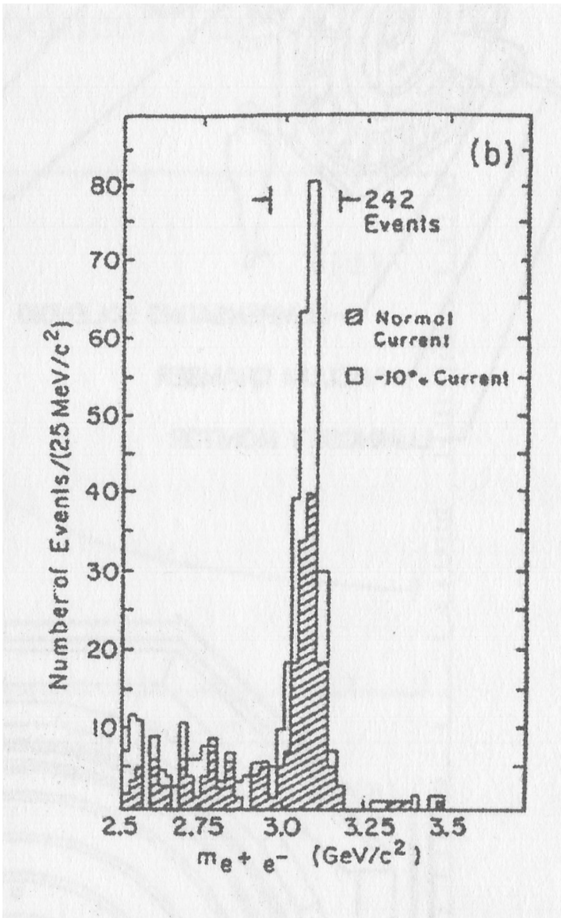
Meanwhile essential progress was happening in the area of weak interaction with the contribution of Glashow Salam Weinberg in the late 60's, and then Veltman and t'Hooft proving renormalizability in 1971.

Experimentally the turning point was the observation of neutrino neutral current interactions in the Heavy Liquid bubble chamber Gargamelle in 1973.

On the flavor side Glashow, Iliopoulos and Maiani had invented the GIM mechanism in 1970 explaining among other things the rareness of flavor changing neutral decays by the existence of a new quark charm… There was even a paper by Lee Rosner and Gaillard predicting a ccbar state in the summer of 1974

1974 The November revolution

Even, after the theorist predictions (mentioned above) the discovery of the J/Psi came as a shock!
It was so clean!
It was giving confort to GIM(new quark), to QCD(1973) (narrow resonance implied small α_s at large q2



Brookhaven results J/Psi=>ee

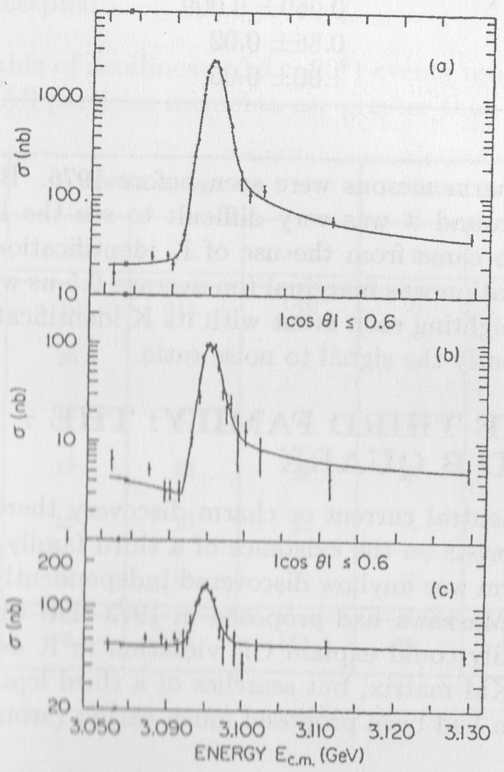


Figure 41 The ψ resonance cross-section as function of center of mass energy in a) the hadronic charmed, b) the muon channel and c) the Bhabha channel.

Slac results ee=>J/Psi=>hadrons(a), muons(b), e+e- (c)

Back to NA3

Just before the november revolution (october 1974) we had submitted a proposal to the SPS Cern expt committee =>after the influence of deep inelastic SLAC results and high pt physics at ISR and FNAL it was a spectrometer optimised for high pt physics

(signed by 8 France +2 Cern physicist (Michelini and Kienzle) I was responsible for the IN2P3 part. In 1980 we had increased to 25 France (from Orsay, Ecole polytechnique, College de France, Saclay) +8 CERN physicist)

The fundamental idea was to trigger on particles (π,μ,e,γ) with large Ptv (Pt vertical)

- Use a magnet with a vertical field the vertical angle θv is unchanged .
- Measure p with bending in horizontal plane(pad chambers see next) or E with calorimeters
- =>Ptv well defined
- The important point is to have a magnet with a large vertical aperture (special superconducting magnet) with a cylindrical opening 1.6m diameter allowing θv of 0.175 rad. With incident pions of 300 GeV/c 0.175 rad in the lab system corresponds to about 130° in the center of mass system.
- The tracking was done by series of wire chambers (31 planes, up to 4mX4m size, 26000 wires total! Ambitious !)
- Cerenkov for pid foreseen in the middle (but not used) , and calorimeters were used at the end for e,γ,h
- We had a computer system with 400Kbytes of fast external memory (400 evts/spill 1Kbyte each)

About 3 years of construction then data taking in 1978

NA3 apparatus seen from side (a) and above (b)

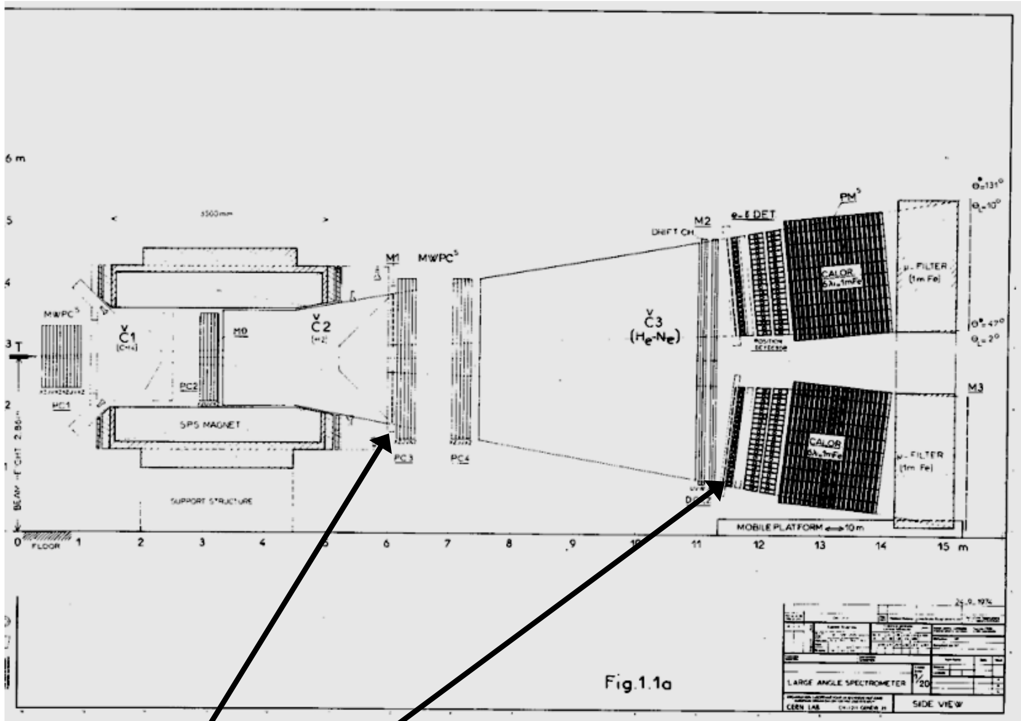


Fig.1.1a

M1,M2 =trigger chambers => see next slide

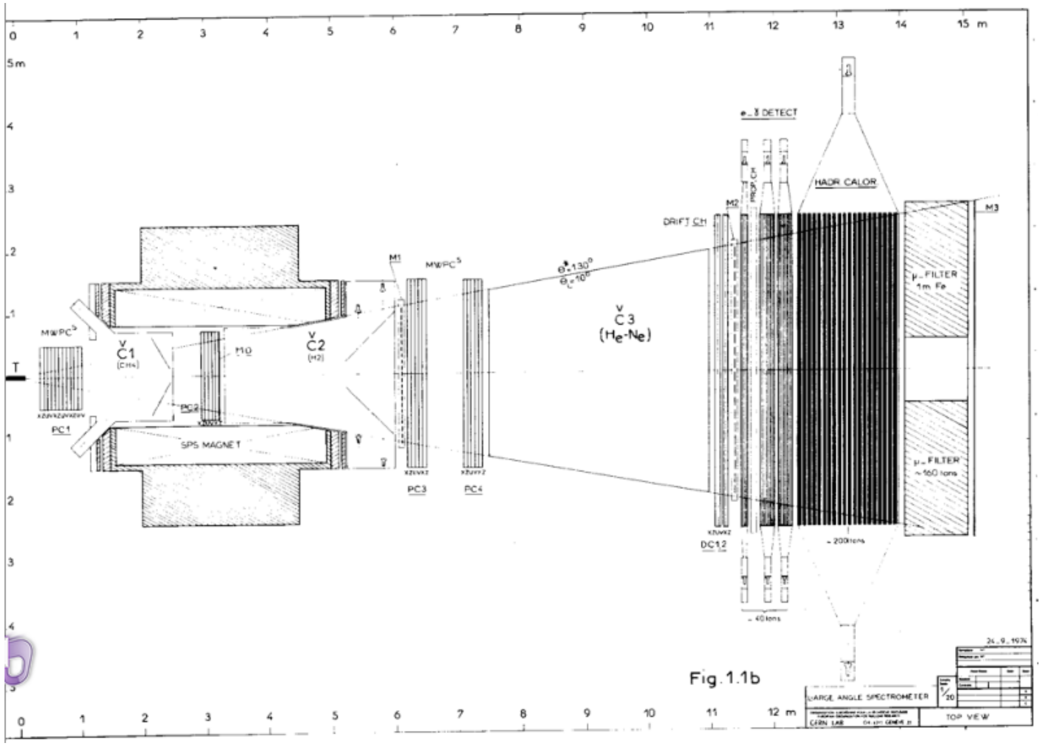
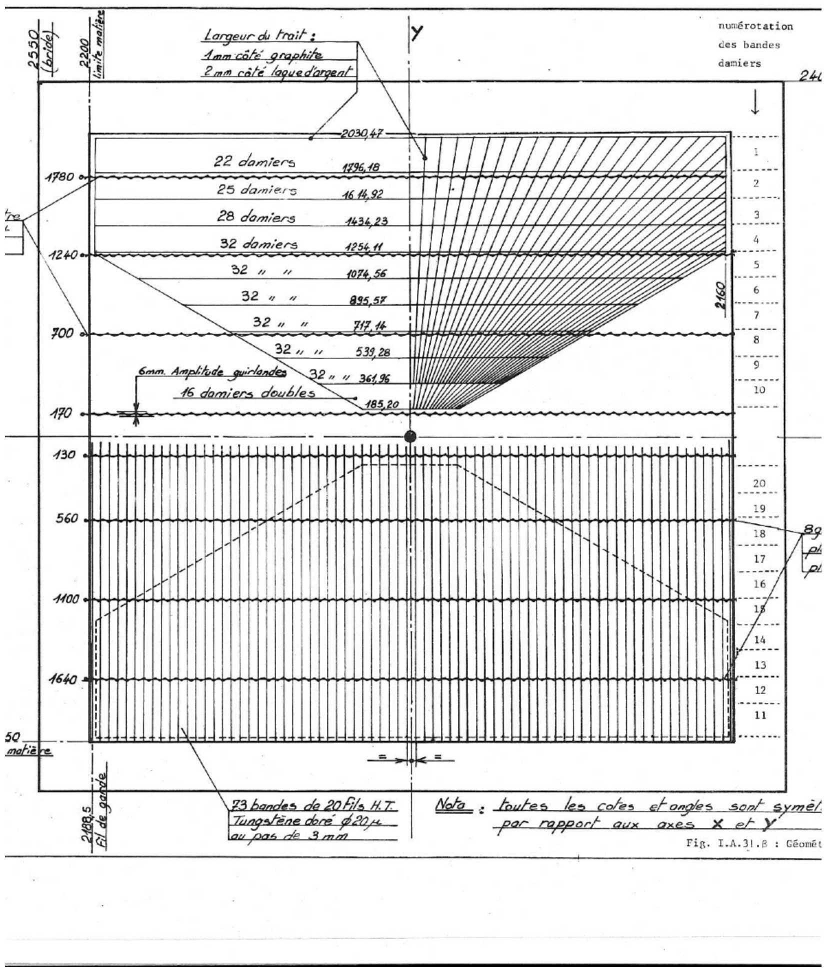


Fig.1.1b

Pad chamber for trigger

Innovative device for trigger (built in LAL-Orsay): use cathode readout of MWPC (use graphited mylar for cathode plane, transparent to pulse, give a shape to the pads on other side of mylar using silver paint, bring signals to the side with wires)

2 chambers, like image on the right (20 lines X ≤64 pads):
shapes and size of pad are such that a particle going in straight line from the target (infinite momentum) goes in the same line number and pad number in M1 and M2, the bending of the magnet (for a given momentum) changes the pad number. The geometry are such that the pad number difference (Δn) in the 2 chambers M1 and M2 gives Ptv, for example if Δn ≤ 5 then the particle has Ptv>1GeV/c.
Fast electronics (for 1977!) encode pad number and does subtraction in 100ns, independently in each line. Then combine lines. Like one particle with Ptv>1GeV/c or 2 particles with Ptv>0.7 GeV/c
System worked beautifully.



Other innovations in NA3

The MWPC could be operated at high rate typical current of about >10µA during beam corresponding to > few*10^8 particles per SPS pulse (of about 1s).

The use of graphited mylar as cathode was very important: it limited the energy in case of spark => no broken wire during the experiment

In the beam region there was a small diameter with lower voltage on cathode to limit the current.

Since the wires where quite long (up to 4m) there were supported every 40cm to keep the wires well centered (garland), a wire with HV in the support prevented efficiency degradation.

Sometime some "corona current" would start in the MWPC, but since the SPS spill was about, 1 second on, 6 second off, one could decrease the HV periodically during the off period to stop the corona current.

Another big asset was the excellent beam line built by CERN with 3-5x10^7 pions/pulse the beam was equipped with CEDAR Cerenkov (corrected for chromatic effect) identifying K^- and antiproton in π^- beam, we implemented TDC to measure the timing =>good PID even in a beam of 3-5x10^7 .=> >10^6 K per pulse >2x10^5 pbar

Drell Yan

While building the detector 1974-1978 we

1) Heard the news of the November revolution

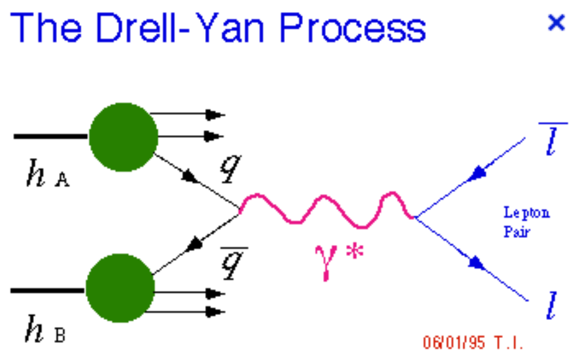
2) Receive advice from theorist (Peskin?) : hadrons are so complicated that to understand something there must be leptons in initial or final state!

So decide to start our high Pt physics with Drell Yan studies

The Drell Yan process was invented in 1970 at SLAC

It corresponds to qqbar annihilation to a lepton pair

In the hadron-hadron center of mass the q and qbar carry a fraction x_1, x_2 of the hadrons momentum



Neglecting the transverse momentum of partons

And noting S the total energy squared in the hh center of mass then:

$$M^2_{\mu\mu} = x_1 x_2 S \quad ; \quad X_{\mu\mu} = 2\, P^*_{L\mu\mu}/\sqrt{S} = x_1 - x_2$$

Measuring the dimuon, one can solve for X_1 and X_2.

Importance Drell Yan measurement(initially)

1)From the x distribution one can check a very important fact: to annihilate, the colour of quarks and antiquarks have to match. This fact decreases the predicted cross section by a factor 3.

2) Doing Drell Yan with incident pions, kaons one can have access to the structure functions of those particles, inaccessible by e or ν scattering. The formula for the cross section is below as function of X1 and X2 defined before:

$$\frac{d^2\sigma}{dX_1 dX_2} = \frac{4\pi\alpha^2}{3sX_1X_2} \times \frac{1}{3} \times \sum_i \frac{Q_i^2}{X_1X_2} \left[f_i^{h1}(X_1) f_{\bar{i}}^{h2}(X_2) + f_{\bar{i}}^{h1}(X_1) f_i^{h2}(X_2) \right]$$

The term $\frac{4\pi\alpha^2}{3sX_1X_2}$ is the cross-section for qqbar annihilation to mu pair

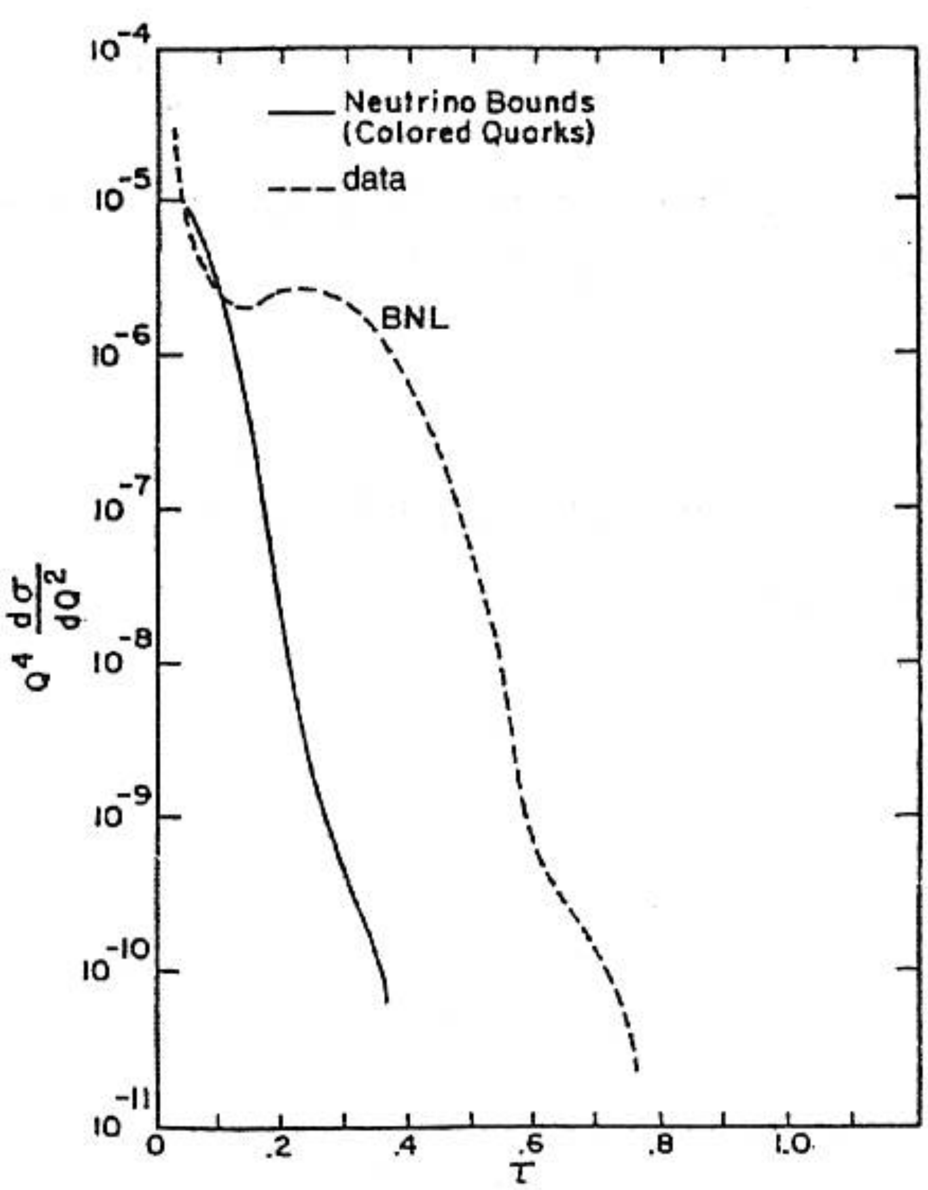
The 1/3 term is for colour matching

The Q_i^2 is the square of the quark charges $(1/3)^2$ or $(2/3)^2$ and the f are the probabilities to find a quark and a antiquark with at fraction x of the hadron momentum.

Remark that for example a π^- will have a ubar valence antiquark of charge -2/3 , while a π^+ will have a valence antiquark of charge +1/3 . In a proton to find antiquark one has to look for sea-quark that have a smaller value of f(x) for sizeable x

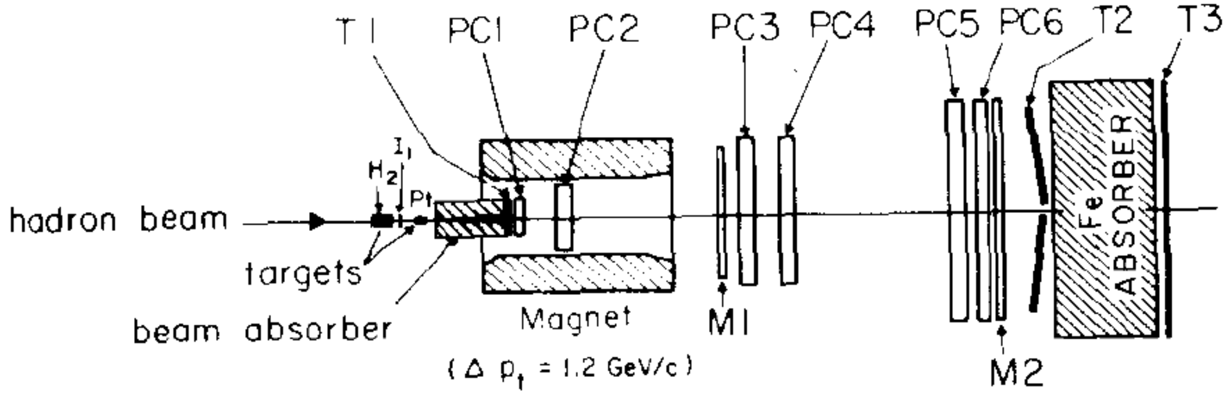
First Drell Yan experiment at Brookhaven

First result of D-Y obtained in 1970, by L.Lederman et all
Cross section as function of the reduced mass τ=M/(sqrt(s))
Apparatus constructed with poor resolution, so the J/psi contribution was not understood (and not discovered then!)
As a result the Drell Yan contribution could not be evaluated (some theorist talk of ro-like resonance giving the bump!).
Of course as you know, L. Lederman later built a much better apparatus at FNAL and measured Drell Yan in pp collisions and discovered the upsilon Y in 1976-1977



NA3 apparatus for Drell Yan studies

Simplified apparatus (no č) Use an absorber to see only the muon tracks. The accuracy limited by multiple scattering was good enough to separate tracks from targets: H_2(2g),Pt(120g) (Pt=platinum) and dump



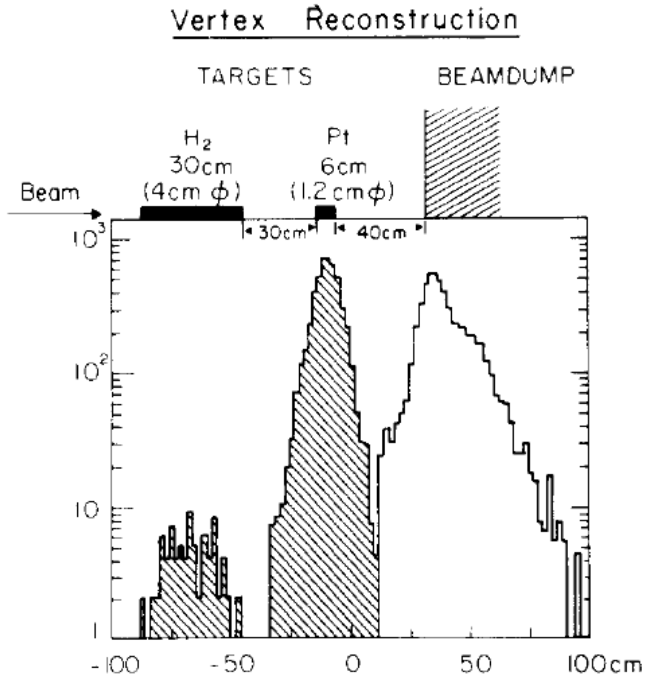


Fig. 6. Off-line reconstruction of events: vertex of dimuons with $M_{\mu\mu} > 5$ GeV/c^2.

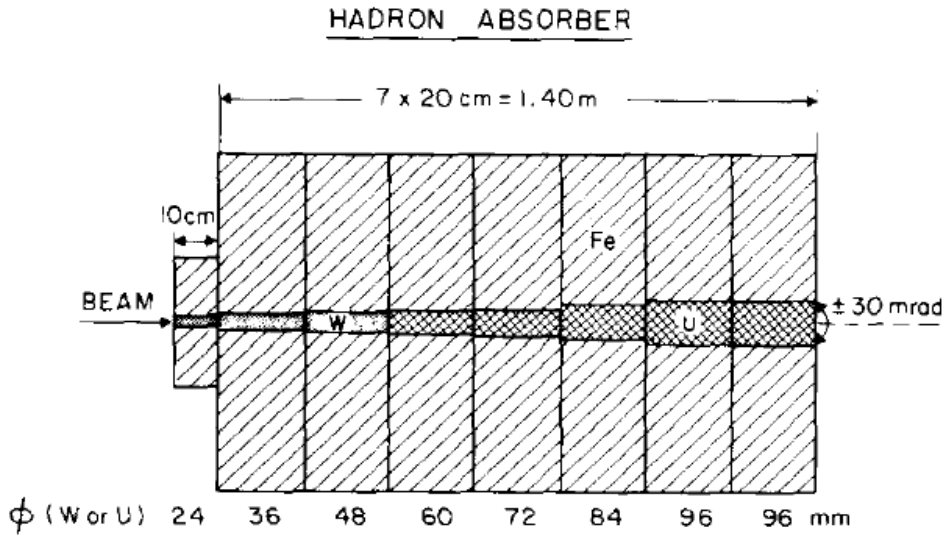


Fig. 3. The hadron absorber with its central heavy plug.

First spectrum in mid 78

The apparatus worked very rapidly beautifully, due to the good acceptance, the good resolution the good trigger, the high quality and intense beams. We had 3 3-stars Phds- a real pleasure!
One could see rapidly the DY the J/Psi and the Y.
Well for the Y we published in September 1979 we were too late by about 1.5 year compared to L.Lederman at FNAL!
We accumulated DY data during 1978-1979
We had also a competitor at FNAL with pion beams (no K or pbar id) : CIP Chicago-Indiana-Princeton.
They obtained some result about 1 year before us but we had about 20 times the stat.
We had a huge stat of J/Psi (a few millions! 4 years after J/Psi dicovery!) => detailed studies+ nice constraint on gluon distribution in the proton but I will present only briefly the J/PSI results (lack of time)

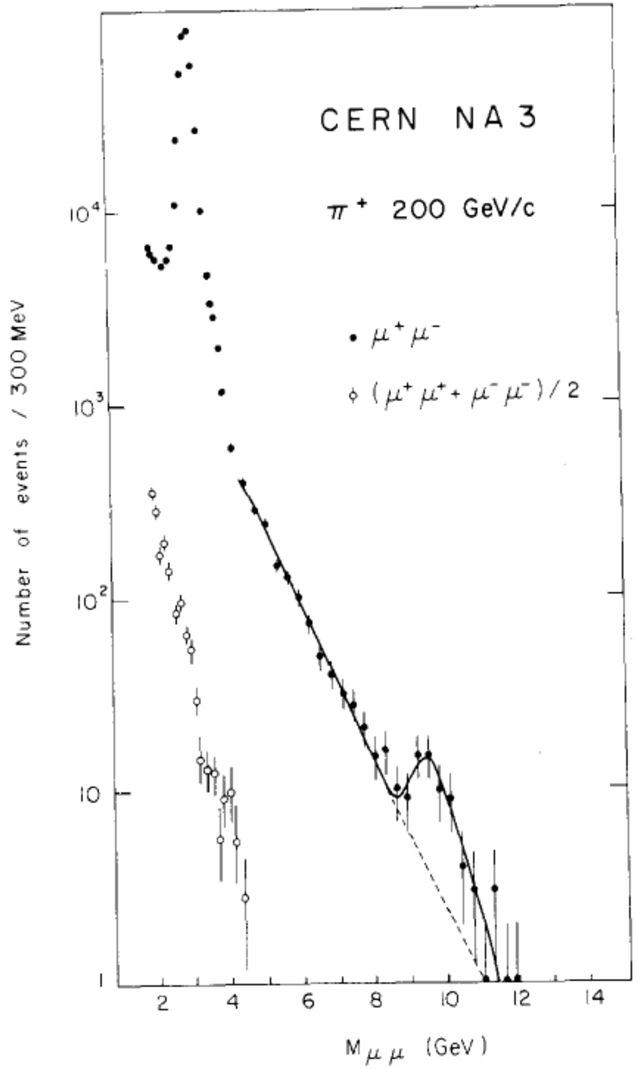
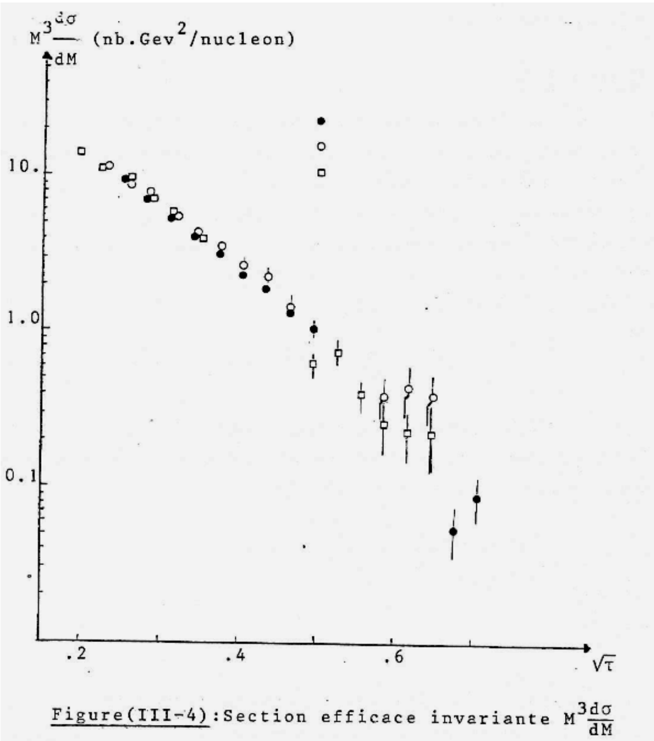
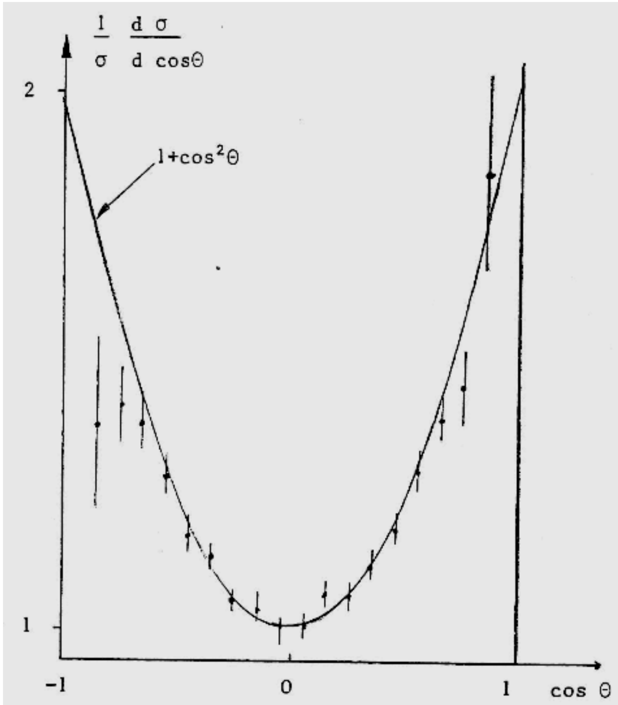


Fig. 9. Dimuon mass spectrum produced by incident π^+ of 200 GeV/c. The ψ and Υ signals are seen at 3.1 and 9.5 GeV

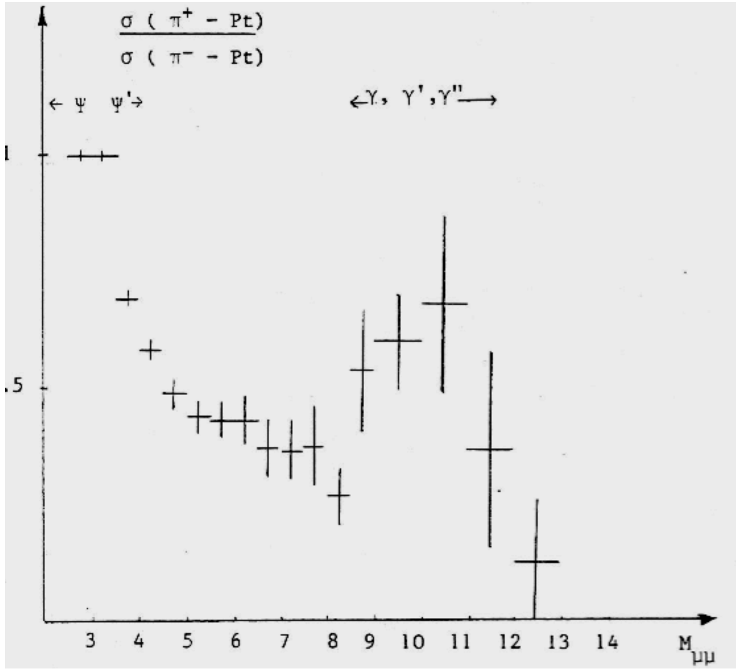
Some checks of Drell Yan behaviour (π on platinum)



Scaling: 280,200,150 GeV
As function of τ=M/sqrt(s)
$M^3 * d\sigma/dM$ is constant
Well verified



M angular distribution in μμ center of mass is as predicted $1+\cos^2\theta$ This was important since some theorist predicted some $\sin^2\theta$ contribution.



Ratio of cross section π+/π- on ≈ isoscalar target vs mass
Ratio=1 for resonances (isospin conservation)
ratio predicted 1/4 if pure π valence antiquark annihilation

Proton structure functions from neutrino deep inelastic scattering

In 1978-79 good quality high statistics data from neutrino experiment existed:

There were 65K events ν and 23K from νbar from CDHS at CERN and a similar number from CFRR at FNAL but with some questions on the normalisation so we used CDHS structure function.

For a $\langle Q^2 \rangle$ of 20 GeV^2 and for a target with Isospin ≈ 0 the valence quark structure function (u=d) can be modelled as $x^\alpha * (1-x)^\beta$ the fitted values are

$\alpha = 0.5 \pm 0.02$ $\beta = 2.8 \pm 0.1$

The sea quarks distribution for nucleon is $S_n = As * (1-X)^{\beta s}$

With $\beta s = 9.4 \pm 1$ As=0.37

Initial data

It was possible to see rapidly from initial data that the distribution of quark momentum in pions was quite different from the one in nucleons

(Already noticed by the CIP experiment at FNAL)

One could do $\pi^- - \pi^+$ to cancel the sea quark contributions

For the valence one found $F= x^{0.4\pm.04} * (1-x)^{0.9\pm.05}$ instead of $x^{0.5} * (1-x)^{2.8}$ for nucleon… not unreasonable if you have 2 valence quark instead of 3 it is normal to have a higher probability to have a quark with a high value of x

But the the cross section when asking that F is normalized to 1 antiquark in the π was bigger than predicted by a factor of about 2 =>big surprise !!!

It was a shock: did it mean that the 1/3 coefficient, in the DY formula, due to colour matching was wrong???

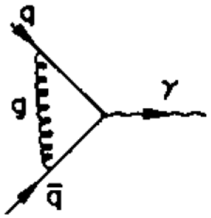
We decided to organise in autumn 78 (or Spring 79?) a collaboration meeting to review internally our results but we also invited theorist

It took place about half way between CERN and Paris which happened to be in the middle of Burgundy vineyards (miam!)

The K Factor (I)

Well we had good meals! (and good wines !) But we also discovered that theorist were, very recently, calculating QCD corrections to the Drell Yan process and finding a big factor (factor K)

There are QCD corrections from soft gluons emission or from vertex diagram to deep inelastic or to DY



They give corrections like:
$(1-(2\alpha_s/3\pi)*(1+(4/3)*\log^2(Q_1^2/Q_2^2)))$
These cause small scaling violation correction for deep inelastic scattering as function of Q^2.

But when comparing neutrino scattering at Q^2 of 25 to DY at Q^2 of 25 GeV^2 the sign of Q^2 changes => $\log^2(-1)$ =>$-\pi^2$ about =10! The K factor was expect to be constant vs x

Plot Fπ

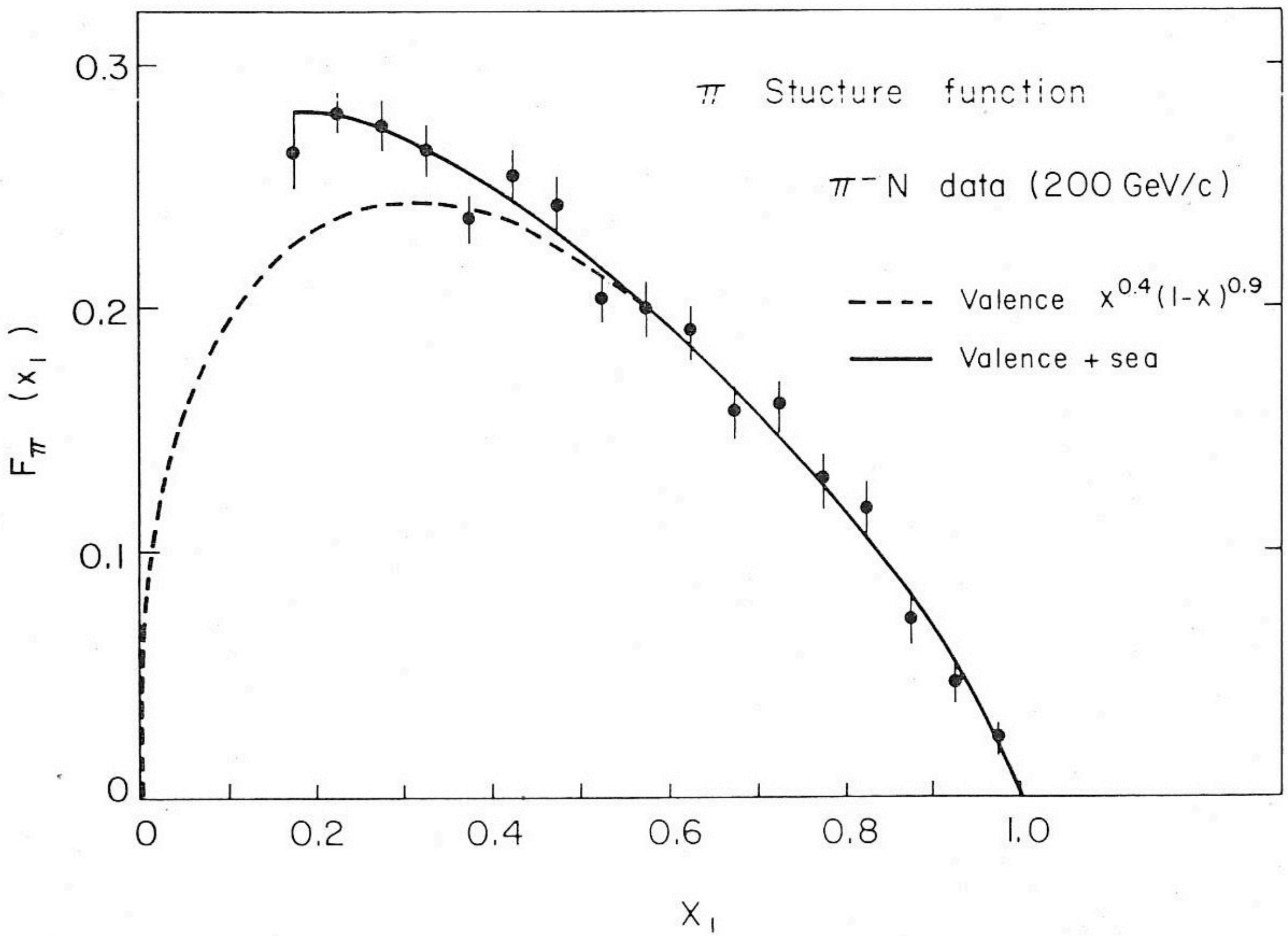


Fig. 18. The π structure function.

The K factor(II)

By the time of the Geneva EPS conference end of June 79 or the lepton photon conference in FNAL(08/79) the K factor was an important subject allowing to check large QCD effect: the first order correction was 1+0.6 The higher order were thought to be obtained by exponentiation $\Rightarrow e^{0.6} = 1.82$

The NA3 experiment had been the first one to announce the effect and in summer 79 was one of the two expts. The other experiment was Lederman et al, at FNAL, doing p +tungsten, therefore it depended on collisions of valence quark on sea-antiquarks (or the reverse) and sea antiquark distributions were less precisely known. Other experiments presented results in the following months.

Finally the NA3 expt had also results from antiproton-Pt and p-Pt interaction and by doing pbar minus p one could have results from a pure valence valence collision and obtain a similar K factor (but only 50 events summer 79, more later).

A paper was published in December 79 (Phys lett 89B 145) giving our results on the K factor

$K = (d^2\sigma/dx_1 dx_2)_{exp}/(d^2\sigma/dx_1 dx_2)_{DY\ model}$.

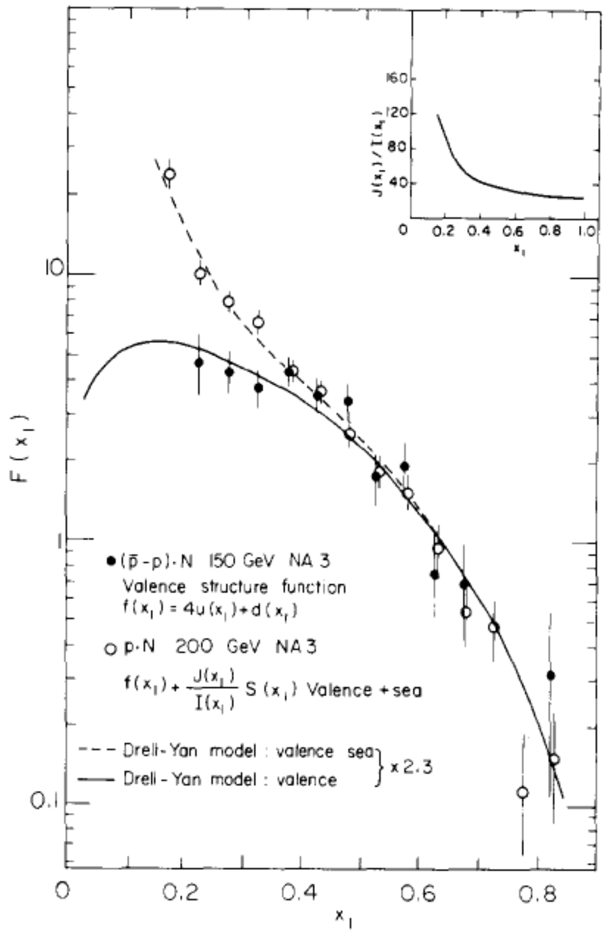
Reaction	pN	$\bar{p}N$	π^-N	π^+N	π^-H_2	$(\pi^- - \pi^+)N$
K	2.2 ± 0.4	2.4 ± 0.5	2.2 ± 0.3	2.4 ± 0.4	2.4 ± 0.4	2.2 ± 0.4
Events	960	44	5607	2073	138	–

The K factor (III)

From the table (preceding slide) one could conclude:

- It is not a nuclear effect since it is seen also on the H^2 target
- It is not a sea quark effect since it is seen also in antiproton-proton data
- It is not a "hadronic source" effect since it is seen in $\pi^- - \pi^+$ data

So we concluded that the large QCD correction was the most probable explanation.
Later (published Nov1980) we obtained 240 DY events from pbar Pt interaction at 150 GeV The valence and valence +sea structure functions are shown on the figure ➔
The data agreed very well with the shape of CDHS structure functions thus confirming that the K factor is ≈ constant vs x



The K/π structure function

From the same 150 GeV data taking, 700 DY events produced by K^- were obtained the ratio of structure function is shown here.

At large x the ubar valence antiquark role dominates but a K^- is a ubar-s while a π^- is a ubar-d.

Because of the bigger mass of the S-quark the ubar in the K^- has a smaller probability to have a large x value, as is seen: theorist made predictions of the effect (dotted and solid curve).

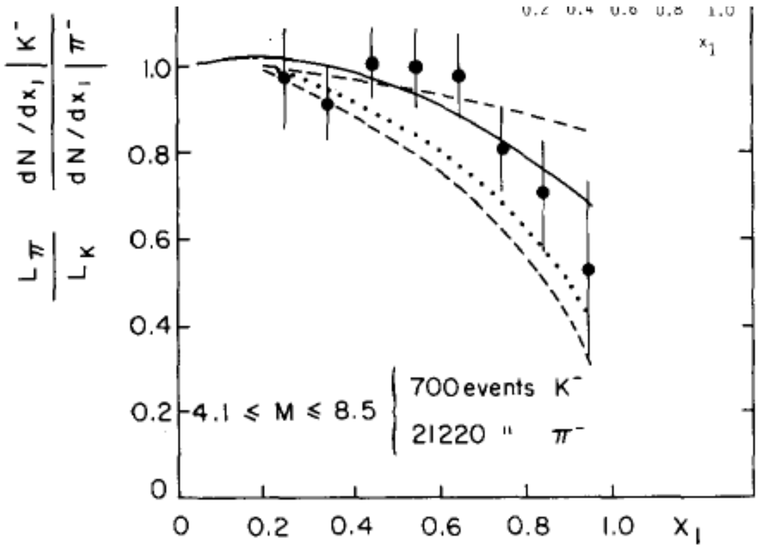


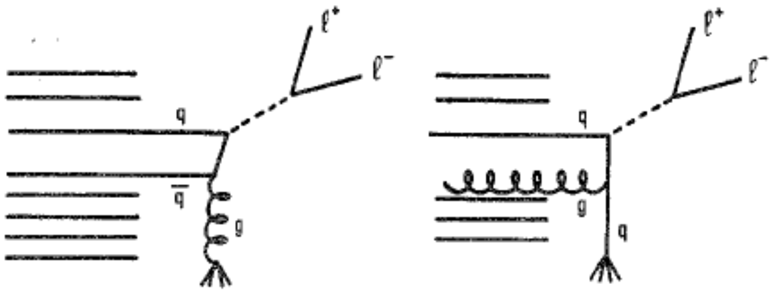
Fig. 2. The data points represent $(L_\pi/L_K)(dN/dx_1)_K/(dN/dx_1)_\pi$ as defined by eq. (4). The dashed curves represent the limits of the ratio $[\bar{u}_K(x_1)/\bar{u}_\pi(x_1)]C(x_1)^{-1}$ where $C(x_1)$ is defined in eq. (3), $\bar{u}_K/\bar{u}_\pi$ and $s_K/\bar{u}_K$ are taken from ref. [5], and the ratio $J(x_1)/I(x_1)$ is shown in the insert. The upper (lower) curve corresponds to $A = 1/8$ ($A = 1/2$). The dotted and solid curves represent the ratio $\bar{u}_K/\bar{u}_\pi$ from refs. [6] and [7], respectively.

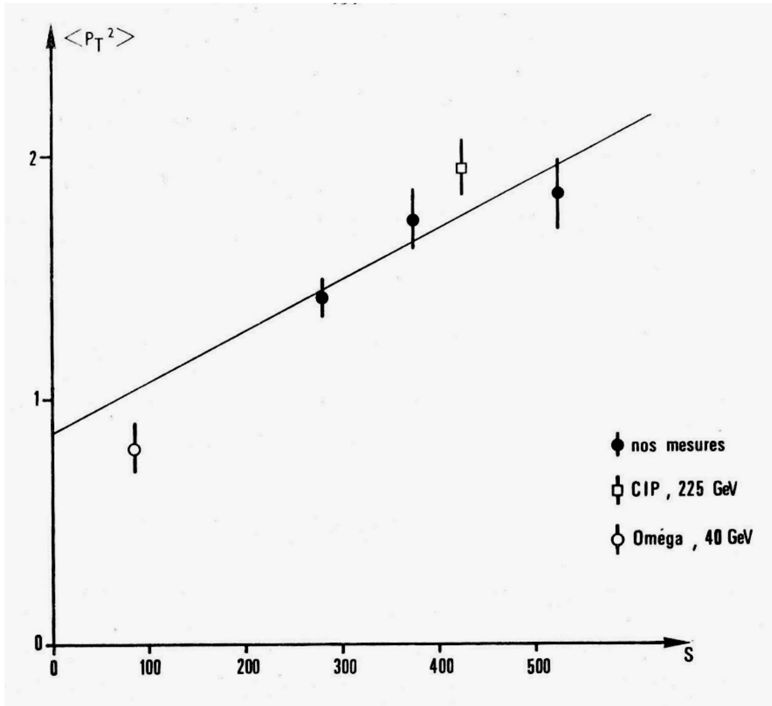
Pt distribution

The dimuon can have a transverse momentum Pt with respect to the incident particle direction, this Pt results from incident gluon effect or from gluon emission (below).

The problem is that part of the Pt is caused simply by intrinsic Pt of the quarks inside hadrons (Kt). As function of s the effect of Kt should be constant but the effect of the gluon should scale and therefore $<Pt^2>$ should grow linearly as s

This is what is shown on the plot of our results (+2 other experiments) The events selected have 0.25<Mμμ/Sqrt(s)<0.37





J/Psi results (I)

The interest of the high statistics J/Psi result is that a sizeable fraction of the cross-section was supposed to result (at least partly) from a gluon-gluon collision (even if a 1^{--} particle cannot couple to 2 gluons => soft gluon emission = colour octet model). Results could therefore be used to measure the pi and proton gluon structure functions.

However a key point was to check that the reaction resulted from parton-parton collision. In this case the cross section should grow linearly with A (as Drell-Yan) comparing H_2 and Platinum: It was found that at large x a sizeable fraction had a “diffractive” mechanism assume to grow as $A^{0.7}$

Also by comparing π- and π+ and p and pbar one can separate production by antiquark-quark annihilation or by gluon gluon collision.

J/Psi results(II)

The extraction of the J/Psi "diffractive" component σ_d: top is the x distribution of this component σ_d, bottom is the fraction of the "diffractive component" vs x

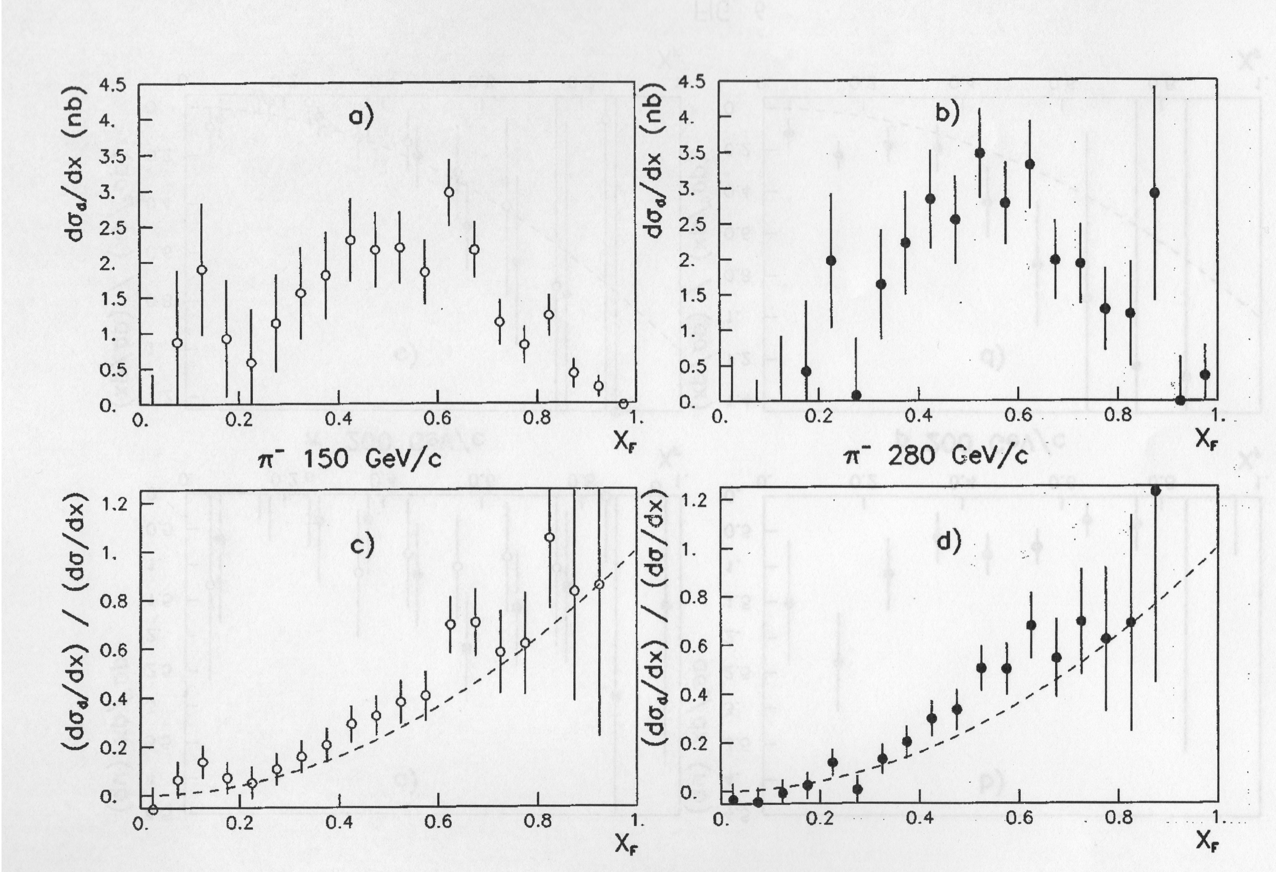


FIG. 5

J/Psi results (III)

The x distribution of the "non-diffractive" J/psi

The results of the fit are also shown
Dashed-line (upper) is gluon-gluon
Dot dashed line (lower) is qqbar fusion
The full line is the sum.
Expressing the gluon structure function as $(1-X)^{Ng}$ one obtains with high accuracy Ng = 5.1±0.2 for the proton and Ng=2.4±0.6 for the pion.
However there is also some uncertainty from the model used to extract the "diffractive part" and from the model to go from 2 gluons=>J/Psi

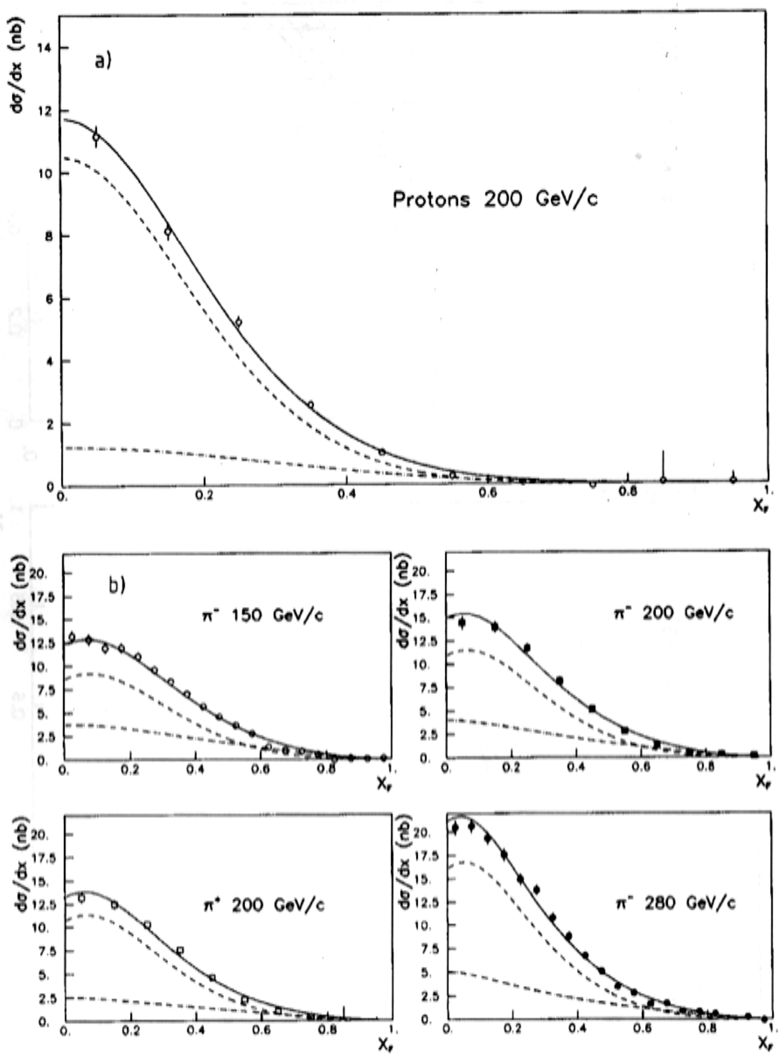


FIG. 7

Direct photon measurements in NA3(I)

To study gluon effects a possibility is to measure the production of photons at large Pt. It is like the muon pair production at large Pt (preceding slides) except that instead of having a virtual photon going to a μμ pair one has a real photon. The cross section is therefore larger.

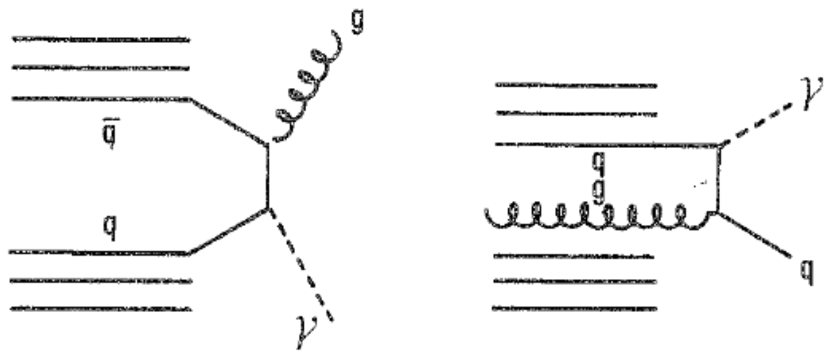
However it is a very difficult measurement because of a large background from π^0,η^0 etc… decaying to photon, this background is 10 to 20 times larger than the signal.

This background is decreased, by about 10, by veto of π^0,η^0 candidates and the remaining background subtracted.

I participated very little to this program since

1) For personal (family) reason I had to be based in Paris in those years.
2) I had been contacted to form what became the ALEPH experiment and I started to spend a lot of time on the ALEPH apparatus conception.

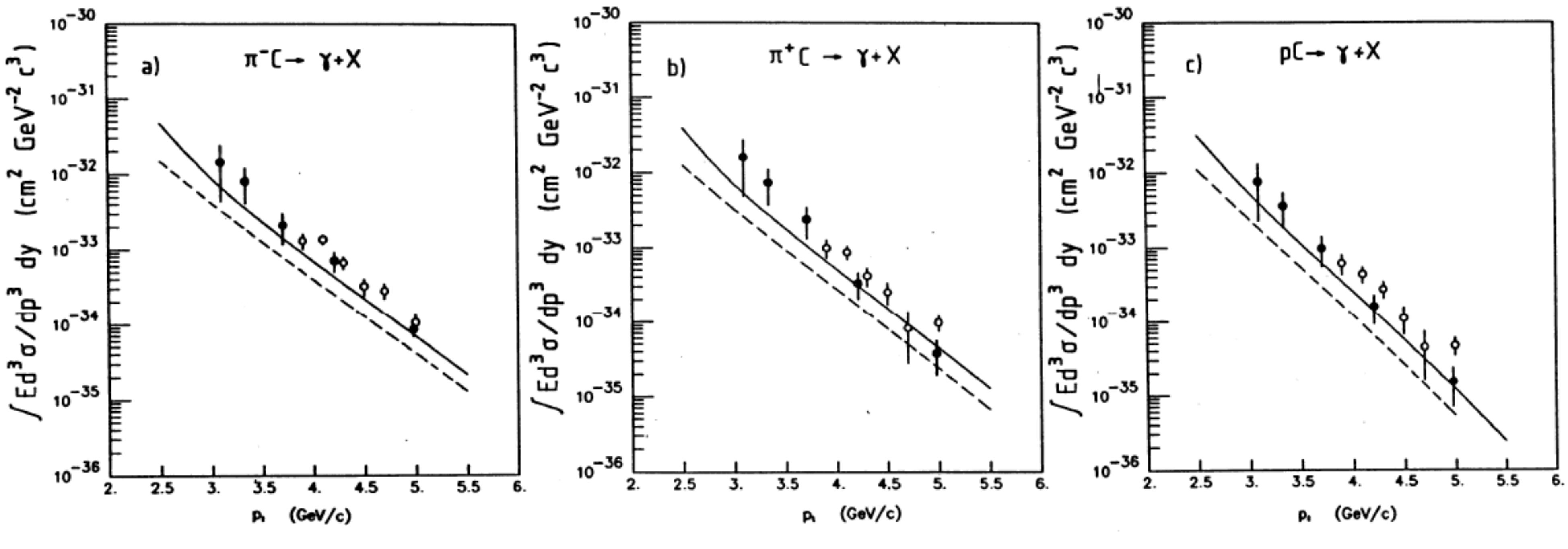
So I will only briefly mention the main result.



Direct photon measurements in NA3(II)

Data were taken in 2 modes the photons were directly detected in the calorimeter (open points) or converted before the magnet as e+e- pair and triggered by the pad chambers (full points) =>the results agree

The results were used to measure the proton gluon structure function parametrized as A * $(1\text{-}x)^{N_g}$ The fits find N_g=7±2 for the proton interesting and "clean" but not a very strong constraint.



ICHEP 1980 Madison(I)

I was asked summer 1980 to present a plenary talk at ICHEP Madison on hadron interactions

There were results from 7 experiments on Drell Yan (Table 1 below); and 3 experiments from FNAL and ISR on direct photons. There were also results on high pt hadrons in hadron collisions but without a real understandable behaviour.

Of special importance was the NA5 result at the SPS with a multicell 2π cylindrical calorimeter. NA5 was triggering on the sum of Pt of all cells in the hope of observing jets in an unbiased way! The results was sadly that (for 4<Pt<12) no jet were seen only a symmetric high multiplicity "explosion" of many low pt particles I concluded that one probably must wait for higher energy of the CERN ppbar collider to see jets in hadron collisions.

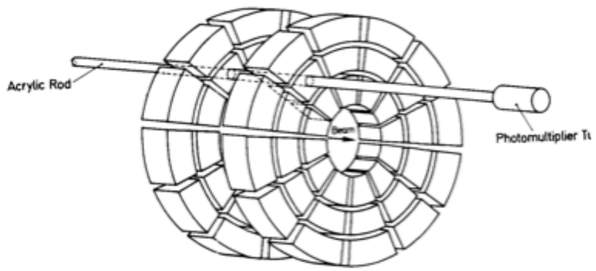


TABLE I

Incident particle	Energy GeV	Accelerator	Apparatus	Abbreviation used in the text
p	200-400	Fermilab	Two arms spectrometer	CFS[2]
p	400	"	Iron Toroids	MWNT[3]
p	$\sqrt{S}$ = 62	ISR	Iron Toroids	CHAMNP[4]
p	$\sqrt{S}$ = 30,53,62	ISR	Liquid Argon Cal.	A^2BCSY[5]
$\pi^{\pm}(K^{\pm}p\bar{p})$	40 GeV	SPS	Ω Spectrometer	BCX[6]
$\pi^{\pm}K^{\pm}$	150 GeV	SPS	Dump+Spectrometer	NA3[7]
$\pi^{\pm}K^{\pm}p\bar{p}$	200 GeV			
π^-	280 GeV			
$\pi^{\pm}$	225 GeV	Fermilab	Dump+Spectrometer	CIP[8]

Jet observation (I)

There was already evidence for the production of jets as the result of hadronisation of quarks in the reaction e+e- => qqbar at SPEAR at SLAC in 1975

In the summer of 1979, even gluon jets were observed, in 3jet events, at the Petra e+e- storage ring at DESY.

But as you heard in hadron-hadron collision no clear evidence of jets were seen (remember the NA5 results)

But at the 1982 ICHEP the UA2 experiment at the CERN ppbar collider (sqrt(s)=600 GeV) presented results triggering (as NA5 had done!) on the sum of Pt of a multi-cell calorimeter around the collision point.

Because of the multi-cell construction of the UA2 calorimeter with good granularity it was easier for UA2 to rapidly observe jets but UA1 quickly performed after a similar analysis.

Jet Observation (II)

The UA2 result at ICHEP 1982:
One can see that, when the total Et is about 60 GeV about 60% of the Et is in 2 jets of typically 5 cells. An event at Et=150 GeV is spectacular!

The ALEPH collaboration had started to design its apparatus and this observation was a nice confirmation that our choice of good granularity for the calorimeter was a correct one.
Then in 1983 the W and 1984 the Z were observed in UA1 and UA2.
Next lecture I will describe ALEPH its construction and physics program essentially devoted to study of these Z and W observed first by UA1,UA2.

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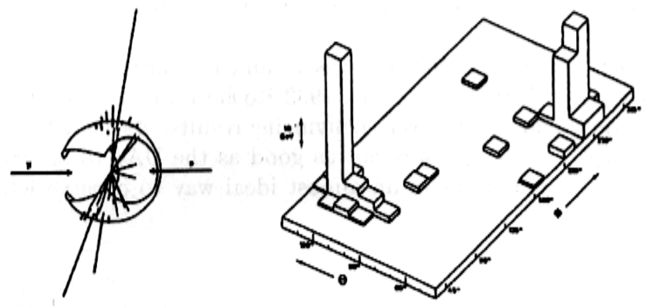

Figure 22 Angular distribution of energy in an event with $\sum E_t = 150$ GeV.

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

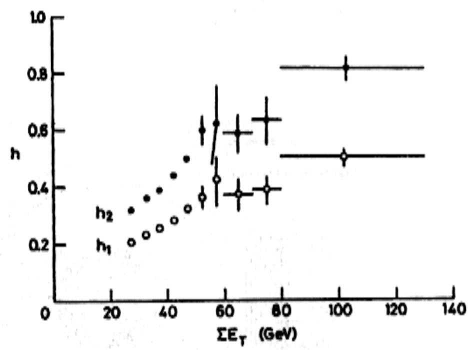

Figure 23 Fraction of the transverse energy of events measured in one (opened circles) or two jets (filled circles).

EXTRA MATERIAL

Digression on electronics progress (integrated circuits)

The integrated circuit patent dates from 1959

But until about 1969 they were either not fast enough or not cheap enough, so electronics was mainly made of individual transistor and resistor + capacity

To my memory the first big order for integrated circuit amplifier for MWPC was for the Split Field Magnet chambers ordered around 1970-71 (?) and Texas instrument actually could not achieve the production on time.

But by 1974 it had become "trivial use" and allowed to make spectacular progress in apparatus.

Why is it Drell Yan that has the K factor and not deep inelastic structure functions

I explained (I hope convincingly!) why the structure functions F extracted from deep inelastic scattering or from Drell Yan measurements differed by a K factor of about 1.8

But why the integral of F_3 from deep inelastic gives approximately the correct number of valence quarks (within about 15%) with the result of Drell Yan of by a factor 1.8, instead of Drell Yan giving the correct result and deep inelastic being too small by a factor 1.8???

Integral of F_3 => Gross,Llewellyn-Smith sum rule => before lectures I asked again theorist => answer: "very tricky question"!!! Using current algebra one had proven (ADLER sum rule) that the integral of xF_3 is independent of Q^2 in deep inelastic scattering so it is plausible that the integral of F_3 has only small Q^2 dependant corrections….