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Giorgio Bellettini: The ISR years (and before)

M. Albrow
Fermi National Accelerator Laboratory - Chicago, IL 60510, USA

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Summary. — In honor of Giorgio Bellettini's 80th birthday, I present stories of his early career, through the Intersecting Storage Ring (ISR) years.

PACS 01.60.+q – Biographies, tributes, personal notes, and obituaries.
PACS 13.85.Lg – Total cross sections.
PACS 13.85.Hd – Inelastic scattering: many-particle final states.

1. – Before the ISR

Giorgio was born on May 5th 1934, so it is time to celebrate his 80th birthday. Happily he still appears to be very fit, sitting in the front row and asking many very perceptive questions. I had the pleasure of knowing him personally from the days of the first collisions at the CERN Intersecting Storage Rings (ISR), the first hadron-hadron ($p + p$) collider, until its closure 12 years later, and also as a collaborator on CDF at Fermilab for the past 22 years (Giorgio was there much earlier, and is still active in CDF).

Giorgio was a student at Scuola Superiore in Pisa (1953-55) and graduated with Laurea *Cum Laude* at the University of Pisa in 1957. This first experimental work involved scanning nuclear emulsions, exposed to an antiproton ($\sim 150\,\mathrm{MeV}$) beam at Lawrence Berkeley Laboratory and sent to Pisa. There were just 15 annihilation "stars". From the range of only four antiprotons they quoted a mass value for the antiproton: $M(\bar{p}) = (0.998 \pm 0.015) \times M(p)$! From 1960 to 1963 Giorgio was the group leader at Frascati for an experiment to measure the π^0 lifetime using the Primakoff effect, observing it for the first time. A photon beam hits a hydrogen target, and the reaction $\gamma + \gamma \to \pi^0$ can occur, where the second ("target") photon is virtual, in the electric field of the proton. This was done with Lorenzo Foà, Bemporad and Braccini (small groups in those days!). The inferred value of the π^0 lifetime they obtained, $(0.730 \pm 0.105) \times 10^{-16}\,\mathrm{s}$, was much better, and lower, than previous measurements by different techniques (which showed a significant downward trend over the preceding five years). It is perfectly consistent with the present day PDG value of $(0.852 \pm 0.018) \times 10^{-16}\,\mathrm{s}$.

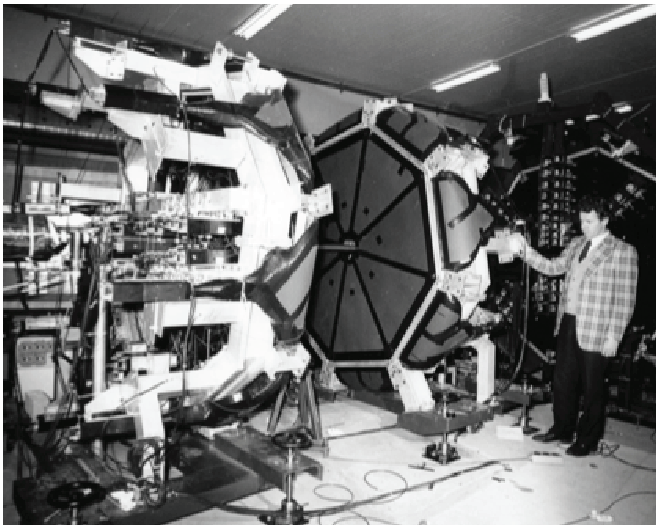

Fig. 1. – Giorgio with the $4\pi-\varepsilon$ scintillation counter arrays of the Pisa-Stony Brook experiment.

Giorgio then went to CERN as a Fellow (1964-66) to work in Giuseppe Cocconi's group on elastic scattering (and σ_{TOT}) of $\pi^\pm$, $K^\pm$, p and $\bar{p}$ on protons, neutrons and nuclei at 6–18 GeV/c at the Proton Synchrotron (PS). He returned as a Visitor in 1967-1970 to work with Luis Dick's group, with Michel Borghini and Luigi Di Lella, studying elastic scattering again but with a polarized target. I found this interesting personally as I measured the same processes at lower momenta (in the resonance region, 1–3 GeV/c), with Borghini's polarized target, when I went to CERN as a post-doctoral Fellow (with J.C.Sens) in 1968-1971, and of course we referred to Belletini's papers, although I did not yet know him.

2. – Giorgio and the Intersecting Storage Rings

In January 1971 the first pp collisions were observed in the ISR. Those of you under 50 years old may think "ISR" means initial state radiation; older people remember it as the first hadron-hadron collider that took us into the realm of the cosmic rays, from lab momenta of 28 GeV/c up to about 2000 GeV/c (equivalent)([1]). We did not know what would happen. Would free quarks be emitted? What about weak bosons, if their mass was only a few GeV? How to cope with high multiplicity events? (Answer: Invent single particle inclusive spectra.) Would we reach "asymptopia" with $\sigma_T(pp)$ staying flat for ever? The last question was dramatically answered by the Pisa-Stony Brook Group, of which Giorgio was spokesman, and simultaneously by the CERN-Rome Group (*those Italians!*). The P-SB group surrounded Intersection Region I8 (so the experiment was R(ings)801) with scintillation counter hodoscopes, fig. 1, making the first $\Delta\Omega = 4\pi - \varepsilon$ detector at a hadron collider. (The ε is for the incoming and outgoing beam pipes.) They measured the total rate of interactions, together with the luminosity, given by the beam currents and their profiles. Prior to Van der Meer's method of measuring the

([1]) The LHC at $\sqrt{s} = 8$ TeV is equivalent to a 3.2×10^7 GeV proton on a fixed target!

luminosity by scanning the beams through each other (vertically, as the ISR beams were flat ribbons, and not bunched) the group measured the beam profiles directly to get the luminosity [1]. As soon as Van der Meer scans were performed that method was adopted, and became routine for all the experiments.

Measuring at four $\sqrt{s(pp)}$ values they found a very significant rise of σ_T with energy, which at lower energies had decreased, then flattened out. (At the intermediate energies at Serpukhov, data suggested a rise, but the significance was not high enough to be convincing.) The CERN-Rome group measured elastic pp scattering, with miniature scintillator hodoscopes very close to the beam in Roman (hence the name) pots, a clever moveable vacuum vessel. Using the optical theorem they calculated σ_T. The two groups published their discovery of the rising total cross section in the same issue of *Physics Letters* (2 April 1973) [2, 3]. Note that this was 41 years ago this week. We now know that the cross section rises from about 40 mb (ISR) to about 100 mb (LHC), protons get larger and blacker with energy, and there is no asymptopia. New physics thresholds come in over this range (heavy quarks, high-p_T phenomena, and especially the rise of low-x_{Bj} gluons). In Regge theory the rise of σ_T meant there had to be a Regge trajectory with intercept above 1.0, the pomeron (if you are younger than 50, think of this as a pair of gluons in a color singlet, exchanged in the t-channel. Of course it is more complicated, more like a ladder with quark- and maybe pion-loops). Heisenberg had actually suggested in 1953 (*sic*) [4] that the total cross section might rise due to pion exchange being allowed at larger impact parameters at higher energy; but that is clearly not the main reason.

There was an idea by Yang *inter alia* [5] that when a target proton is hit by a very high energy proton its fragmentation products (in the target frame) tend to a limiting distribution independent of p_{beam}. This is the "Hypothesis of Limiting Fragmentation, HLF". As the ISR had two independent rings, they could be run with different energies and the P-SB group tested this by measuring the pseudorapidity, η, distribution of produced particles in the direction of a 15.4 GeV/c (or 26.6 GeV/c) proton when the other proton had 15.4 GeV/c or 26.6 GeV/c. They made a nice demonstration [6] of the HLF, that the proton fragments independently of the incoming proton's momentum, which is Feynman scaling in another form. Of course the energy range of this test was rather small, and we now know that the HLF (and Feynman scaling) is only approximate; QCD violates scaling. The fact that the ISR had two independent rings later enabled it to provide $p\bar{p}$, pd, dd, $p\alpha$, and $\alpha\alpha$ (at $\sqrt{s} = 126$ GeV) collisions. Had there been a Pb-ion injector one could have done Pb-Pb collisions, as we do now at the LHC, but the ISR was terminated before such physics generated much interest.

By measuring the η, ϕ of the $N^{\pm}$ produced charged particles P-SB studied single particle distributions over $-5 \leq \eta \leq +5$ as well as correlations. They demonstrated [7] 2-body correlations by selecting events with a particle at η_1, which they varied, and observing the η_2 distribution of associated particles, which showed a peak around η_1. They could go much further in studying event structure. One much-quoted (but not published) observation [8] selected events with $N^{\pm} = 5, 6, \ldots 13$, and plotted $\Delta\eta = (\eta_1 - \eta_2)$ *vs.* $\langle\eta\rangle = (\eta_1 + \eta_2)/2$, see fig. 2. For low multiplicity this showed that the particles were mostly in a leading cluster in one beam direction or the other, with few (or no) central particles, but by $N^{\pm} = 13$ the particles tended to be central. This was an early study of diffractive and rapidity gap processes. Meanwhile in Intersection 2 the Small Angle Spectrometer, R201, discovered [9] a peak in the Feynman-x distribution of protons at $x_F > 0.95$. This showed that proton diffraction dissociation, previously limited to masses less than about 2.5 GeV/c^2, scaled with $\sqrt{s}$ and reached 15 GeV/c^2 at the ISR (that scaling implies diffractive masses of nearly 1800 GeV/c^2 at the LHC(8 TeV)!).

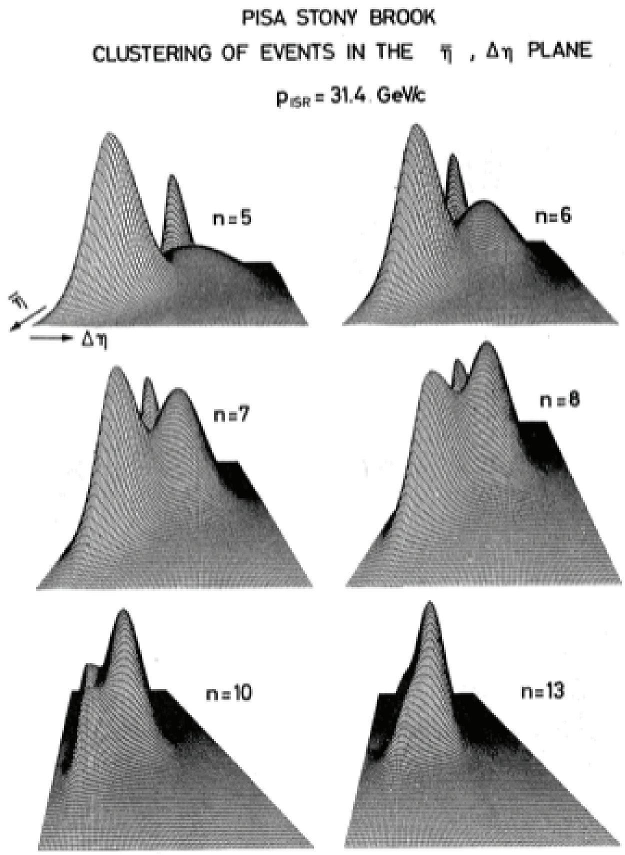

Fig. 2. – Clustering of charged particles in the $\langle\eta\rangle$ *vs.* $\Delta\eta$ plane for different multiplicities, n, at $\sqrt{s} = 63\,\text{GeV}$.

In 1973 other ISR experiments discovered that the production of particles at high p_T (a few GeV/c) was *much* higher than naïvely expected, although recently proposed by Berman, Bjorken and Kogut [10] in the parton model. Those authors also suggested that high p_T particles would occur in jets (which they called "cores"). Very quickly after the high-p_T discovery, P-SB added a lead-glass array at $\eta \sim 0$ to trigger on high-p_T π^0 (out to about $4.5\,\text{GeV}/c$) and study correlations with the high p_T particle. They observed [11] a growth of the away side density $\mathrm{d}N^{\pm}/\mathrm{d}\eta$ with $p_T(\pi^0)$. I note that Bellettini's collaborators on this paper included several future spokespersons of large collider experiments ... Paul Grannis (D0), Luciano Ristori (CDF), Dan Green (BTeV), Lorenzo Foà (ALEPH, CMS CB Chair) and other high-flyers; not bad for a group of 20 people. The clear observation of high-E_T jets in hadron-hadron collisions was a long saga, culminating in 1982 with the full-azimuth uranium-scintillator calorimeter of the Axial Field Spectrometer (R807, having inherited the P-SB intersection region) and UA2 at the Sp$\bar{\text{p}}$S Collider (published in the same issue of *Physics Letters*).

Bellettini's next experiment at the ISR was done jointly with Sam Ting's MIT group on high mass $\mu^+\mu^-$ production [12] with a large, full azimuth muon detector in I2. The

Fig. 3. – Giorgio, as the last chairman of the ISRC, handing the symbolic key to Viki Weisskopf, Director General during ISR construction. Herwig Schopper (CERN DG) and Kjell Johnsen are on the left.

mass spectrum $\mathrm{d}\sigma/\mathrm{d}M$ extended from 2.5–20 GeV/c^2, with a "huge" J ($= J/\psi$) signal and a clear Υ bump. A pity the ISR did not discover these particles; for a discussion see [13]. Paul Grannis remembered Giorgio's leadership also on the football (soccer) field between the P-SB team and Ting's MIT team (P-SB won).

Elsewhere around the Rings were many other experiments. I was in I2 where there were four together; two single-arm spectrometers discovered high mass diffraction and high-p_T production, and a large spark chamber looked for direct high-p_T muons from $W^\pm$ decay (maybe $M(W) \sim 3\,\mathrm{GeV}/c^2$!?). Another experiment searched for free fractionally-charged quarks, finding none in 10^{10} charged hadrons.

Giorgio became Director of Frascati, and then Chairman of the ISR Committee (1980-1984). This was a very active period, when pp colliding beam experiments finally reached a new level of sophistication and maturity. R806/R807, the inheritors of "Giorgio's" Intersection 8, had in various stages liquid argon calorimeters (discovering direct photons), transition radiation detectors, large Cherenkov counters and MWPCs, a full-azimuth drift chamber and a uranium scintillator calorimeter. It was an exciting time, and I was glad to be a part of it. Under Giorgio's chairmanship the ISR running was granted a modest extension, but its closure in 1984 (to make way for LEP) seemed premature to many of us. At its closing ceremony (26 June 1984) Giorgio presented [14] the "ISR Key" to Viki Weisskopf, who was CERN Director General during the ISR construction, see fig. 3. That key had been first presented by Heisenberg to Eduoardo Amaldi when the machine was inaugurated in 1971. So Giorgio was prominent in the ISR from the beginning to the end. He moved on to the Fermilab Tevatron and CDF, but that is another story [15].

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I thank the organizers of the La Thuile 2014 Workshop for inviting me to give this talk, and Giorgio Bellettini for his great contributions to the ISR physics and to CDF.

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