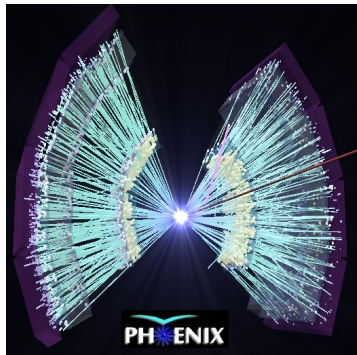


High p_T physics from the AGS to the ISR to RHIC

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Upton, NY 11973 USA

Progress in High- p_T Physics at RHIC
RBRC Workshop, BNL
March 17, 2010



Timeline of hard-constituent Scattering

- 1968--Deeply Inelastic scattering of electrons on protons observed at SLAC. First direct indication of sub-constituents of proton, “partons” as explained by Bjorken scaling [J.D. Bjorken, Phys. Rev. **179**, 1547 (1969)]
- 1971--High p_T scattering of “partons” via QED predicted for p-p collisions by Bjorken, Berman, Kogut [BBK, Phys. Rev. **D4**, 3388 (1971)]
- 1972 First evidence of hard-scattering of constituents discovered at CERN ISR--attention turns from spectroscopy to “high p_T physics”
- 1974-- J/ψ discovered at BNL and SLAC-people start believing that partons are real and are the same as quarks.
- 1972-1982 properties of hard-scattering and “Jets” mapped out at CERN-ISR for a decade 1975,1977-78 first theory papers on QCD applied to hard-scattering
- 1982-Constituent-scattering Angular distribution measured at ISR in agreement with QCD. (Rutherford scattering of quarks). SppS (UA2)-first observation of unbiased Jets in hadron collisions.

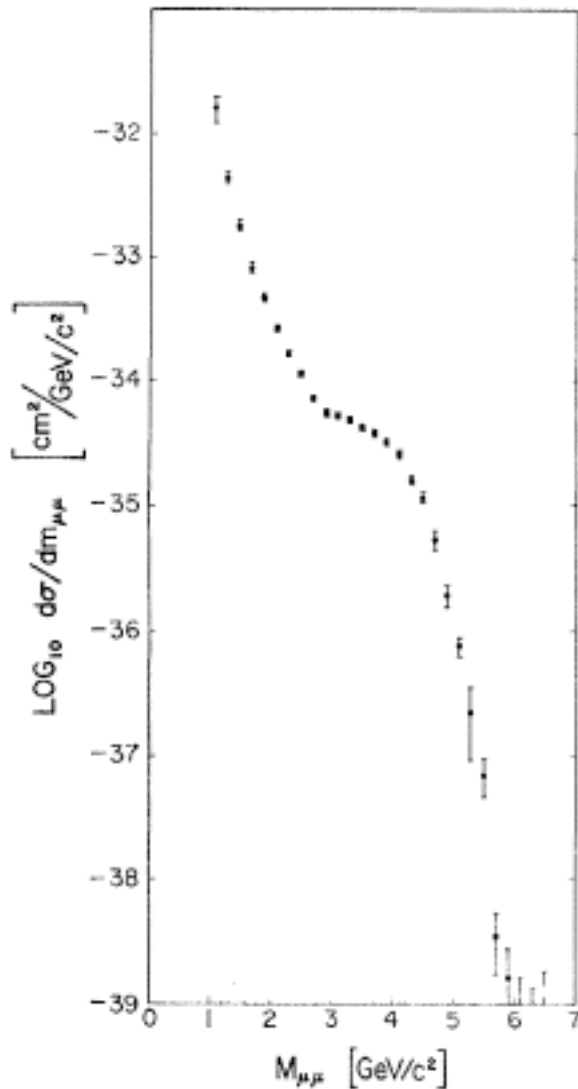
Searches for W boson in p-p collisions

- 1965-1969 Beam dump experiments at ANL-ZGS and BNL-AGS looking for “large angle” muons didn’t find any. [ZGS-Lamb, et al PRL **15**, 800 (1965), AGS-Burns, et al, ibid 830, AGS-Wanderer et al, PRL **23**, 729 (1969)]
- How do you know how many W should have been produced?
- Chilton, Saperstein, Shrauner [PR**148**, 1380 (1966)] emphasize the importance of the timelike form factor, which is solved by
- Y. Yamaguchi [Nuovo Cimento **43**, 193 (1966)] Timelike form factor can be found by measuring the number of lepton pairs e^+e^- or $\mu^+\mu^-$ “massive virtual photons” of the same invariant mass; BUT the individual leptons from these electromagnetically produced pairs might mask the leptons from the $W^\pm$.
- This set off a spate of single and di-lepton experiments, notably the discovery by Lederman et al of “Drell-Yan” production at the BNL-AGS, E70 at FNAL and CCR at the CERN-ISR.

AGS-1969-71 Discovery of 'Drell-Yan' and ??

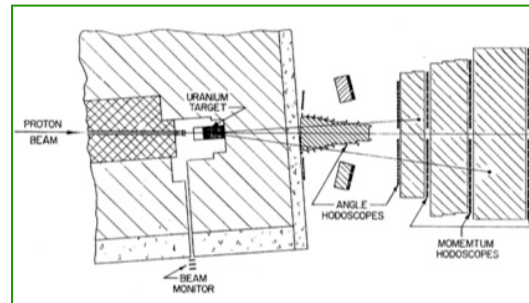
VIEW LETTERS

4 JANUARY 1971



$$p+U \rightarrow \mu^+ \mu^- + X$$

$$\sqrt{s_{NN}} = 7.4 \text{ GeV}$$



This is why I
NEVER plot
theory curves
on any of my
data

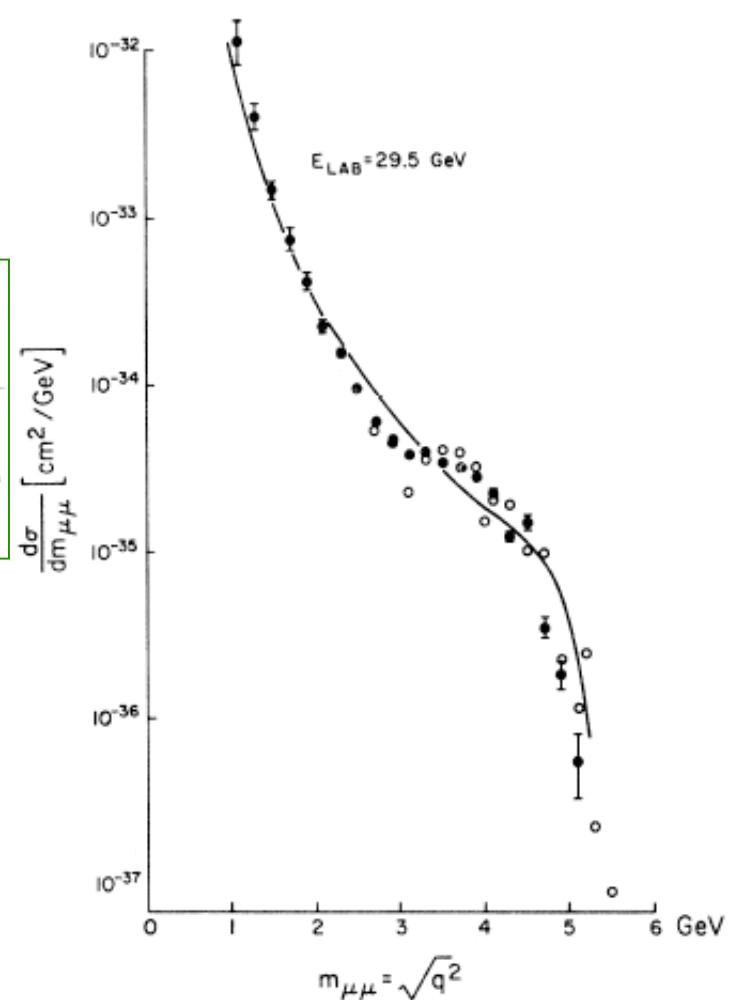


FIG. 2. Experimental cross section of Christenson

et al., Ref. 8.

Christenson, Lederman...PRL **25**, 1523 (1970)

long forgotten 'Theory' Altarelli, Brant Preparata PRL **26** 42 (1971)

LML very excited in 1970: AGS-diμ continuum + Bj scaling → W cross section at any $\sqrt{s}$

Proposal to The National Accelerator Laboratory

E70-(F)NAL

"Study of Lepton Pairs from Proton-Nuclear Interactions;

Search for Intermediate Bosons and Lee-Wick Structure"

W. LEE, L.M. LEDERMAN, J. APPEL, Columbia University,

M. TANNENBAUM, Harvard University, L. READ, J. SCULLI,

T. WHITE, and T. YAMANOUCHI, National Accelerator

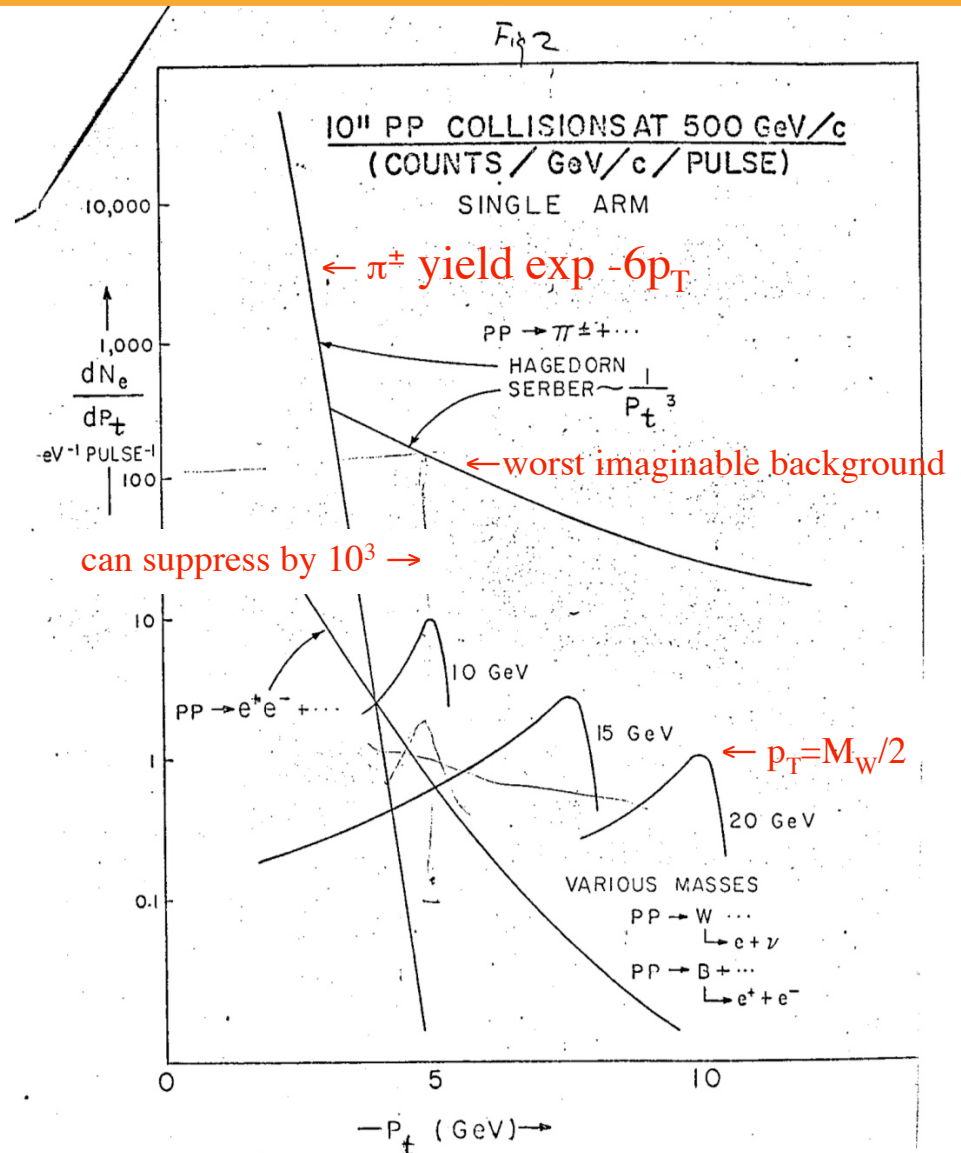
Laboratory.

ABSTRACT

We propose to observe lepton pairs emerging from high energy proton-nuclear collisions. Large effective mass pairs probe the hadronic electromagnetic structure. The continuum mass spectrum will be measured and any resonant structures in the mass range up to ~ 28 GeV will be detected with great sensitivity. The data provides a prediction, via Conserved Vector Current theory, for the production cross section for weak vector bosons and these are also sought in the mass range ~ 8 -25 GeV. We also propose an initial photon-electron beam survey at high transverse momentum which is also a W-search with good sensitivity.

June 17, 1970 + addendum Dec 1970 →

Correspondent: L. M. Lederman, Columbia University



The CERN ISR was the first Hadron Collider and made many discoveries and developed many techniques which are in use in Au+Au and p-p collisions at RHIC today.

G. Giacomelli and M. Jacob, Phys. Rept. **55** (1979) 1-132
M. Jacob and K. Johnsen, CERN Yellow Report 84-13

- The rapidity plateau (although several of my RHI colleagues don't believe in a plateau). Will not be discussed in this talk.
- Hard scattering in p-p collisions via particle production at large p_T which proved that the partons of DIS strongly interacted with each other. x_T scaling measurements to find the underlying physics.
- Proof using same-side and away side two particle correlations that high p_T particles in p-p collisions are produced from states with two roughly back-to-back jets which are the result of scattering of constituents of the nucleons as described by QCD, which was developed during the course of these measurements.

CERN-ISR Discoveries, cont'd

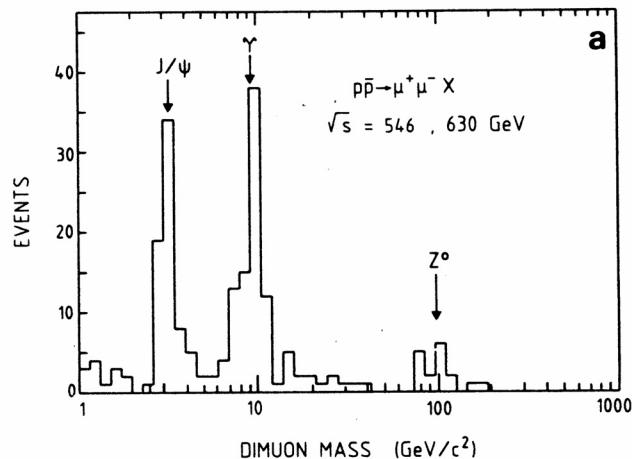
- direct lepton ($e^\pm$) production from the decay of (unknown at that time-1974) particles composed of b and c quarks.
- first and only J/Psi cross section measurement for all pair $p_T \geq 0$ at a hadron collider, until PHENIX at RHIC [[PRL 92 \(2004\) 051802](#)] and CDF [[PRD 71\(2005\) 032001](#) (15 years after their first publication)]
- direct photon production

J/Psi suppression has been the gold plated signature for the quark gluon plasma in AA

The Road To Success in HEP

ETTERS B

5 March 1987



$p_T(\mu) \geq 3 \text{ GeV}/c$, UA1 Phys. Lett. B186, 237 (1987)

The Road To Success in HIP



Status of QCD Theory in 1978

- The first modern **QCD** calculation and prediction for high p_T single particle inclusive cross sections including non-scaling and initial state radiation was done in 1978 by J. F. Owens, E. Reya, M. Gluck, PRD **18**, 1501 (1978), “*Detailed quantum-chromodynamic predictions for high- p_T processes*,” and J.F. Owens, J. D. Kimel, PRD **18**, 3313 (1978), “*Parton-transverse-momentum effects and the quantum-chromodynamic description of high- p_T processes*”.
- This work was closely followed and corroborated by Feynman, Field, Fox PRD **18**, 3320 (1978), “*Quantum-chromodynamic approach for the large-transverse-momentum production of particles and jets*.”
- Unfortunately jets in 4π Calorimeters at ISR energies or lower are invisible below $\sqrt{s} \approx E_T \leq 25$ GeV, which led to considerable confusion in the period 1980-1982.

QCD and Jets

are now a cornerstone of the standard model

- Incredibly at the famous Snowmass conference in July 1982, many if not most people were skeptical

e.g. MJT Seminar 3/22/82

WHY I BELIEVE
IN JETS

IN SPITE OF
CALORIMETER EXPERIMENTS

M. J. TANNENBAUM 3/22/82

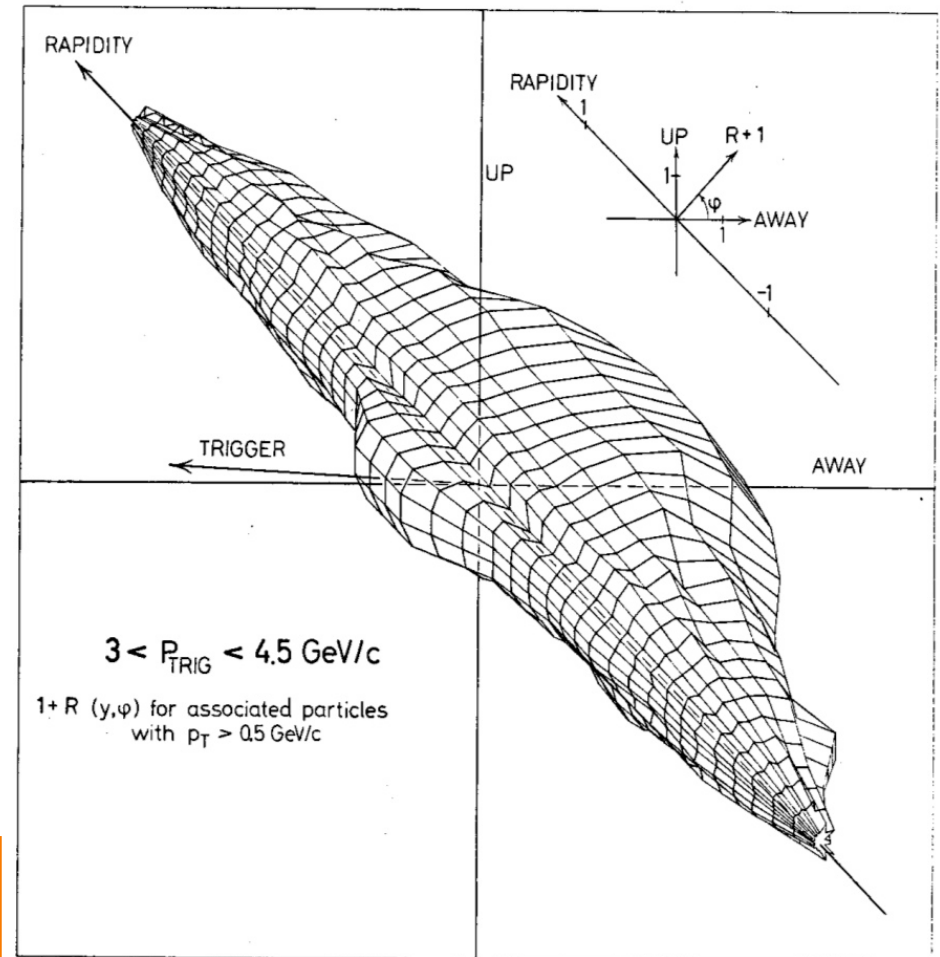
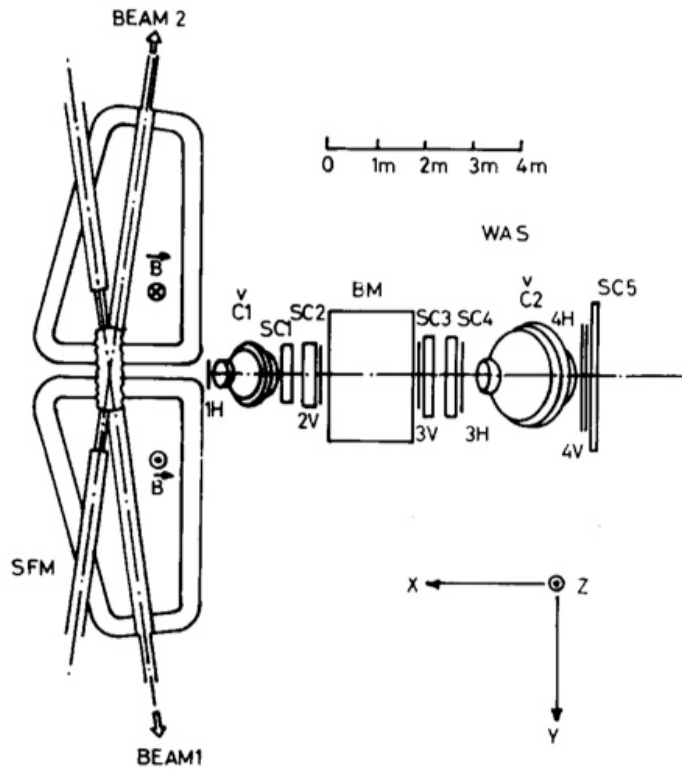
FOR QCD TESTS MUST
MINIMIZE THE EFFECT OF JETS

- The International HEP conference in Paris, three weeks later, July 26--31, 1982 changed everything.

At the CERN ISR from 1975-1982 two-particle correlations showed unambiguously that high p_T particles come from jets.

For the past decade these single and two-particle techniques were used exclusively at RHIC for hard-scattering, with outstanding results...

British French Scandinavian “Ridge”



Split Field magnet, horrible magnetic field uniformity. Track recon took ~5 yrs to develop + 1 hour of CDC7600 per hour of data! Great acceptance when it finally worked.

BFS
NPB145(1978) 308