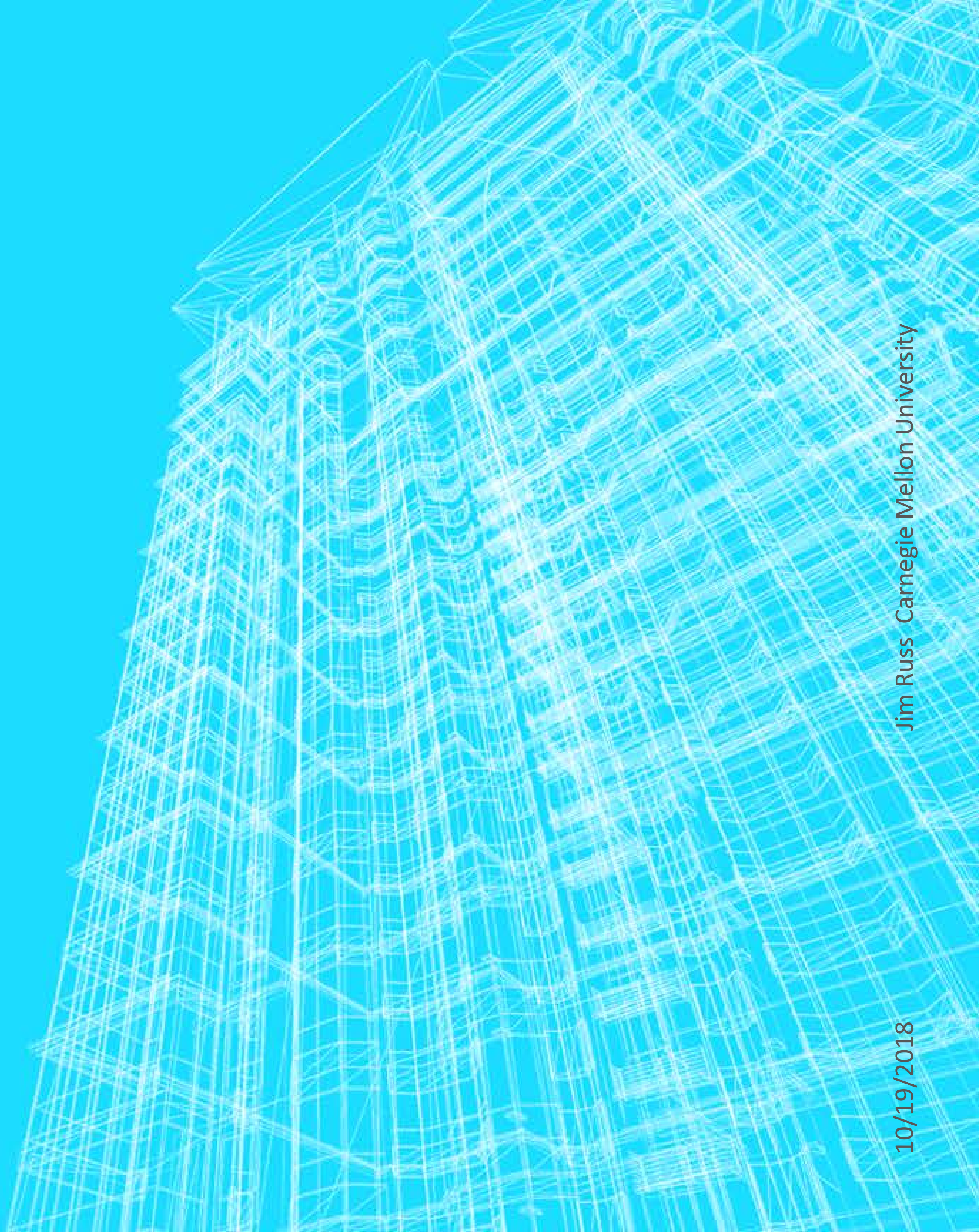
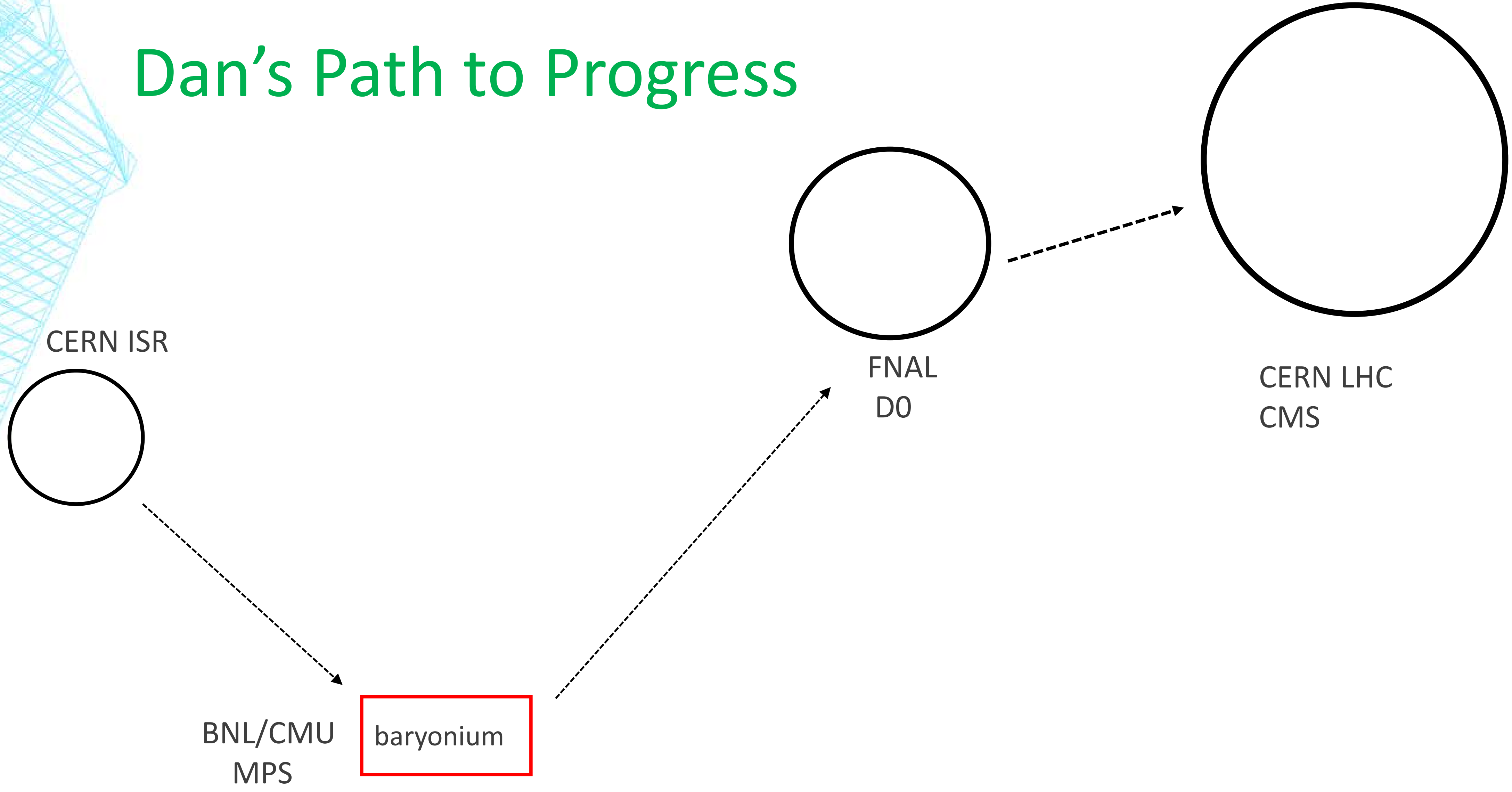
THE DANFEST

Search for Baryonium States Using the Brookhaven Multiparticle Spectrometer



Jim Russ Carnegie Mellon University

Dan’s Path to Progress



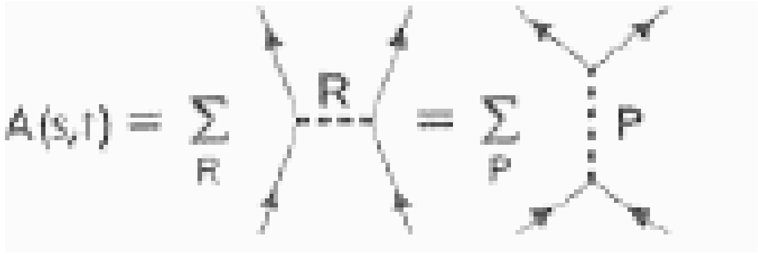
A fixed target (4π in CM)
spectrometer experiment

WHAT IS BARYONIUM?

- We learned about positronium in college: e^+e^- bound state
- 1974: charmonium: $c\bar{c}$ strongly bound state
- 1978 bottomonium: $b\bar{b}$
- 1949: Fermi and Yang suggested that π mesons might be stable nucleon-antinucleon bound states
- s-channel production of Δ resonances and availability of separated pbar beams at AGS, CERN stimulated searches for narrow s-channel p pbar resonances: *baryonium*

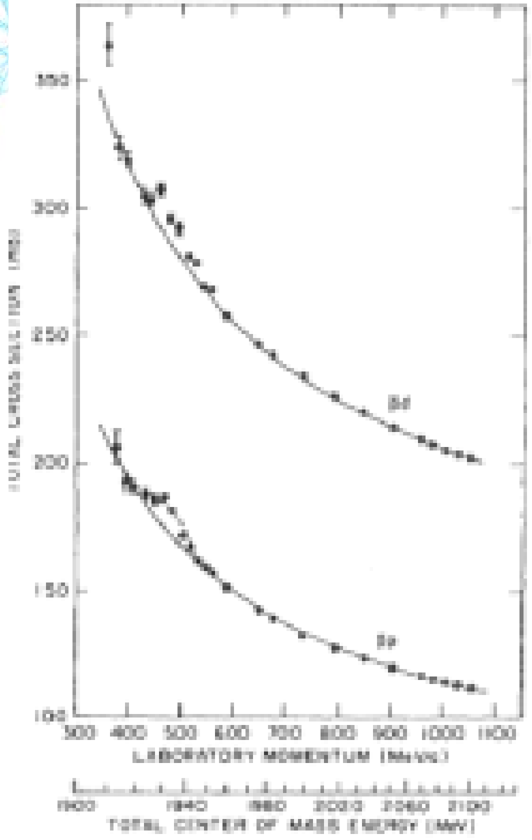
Analyticity and Duality in s- and t- channels

- s-channel resonances associated with complex poles in S-matrix

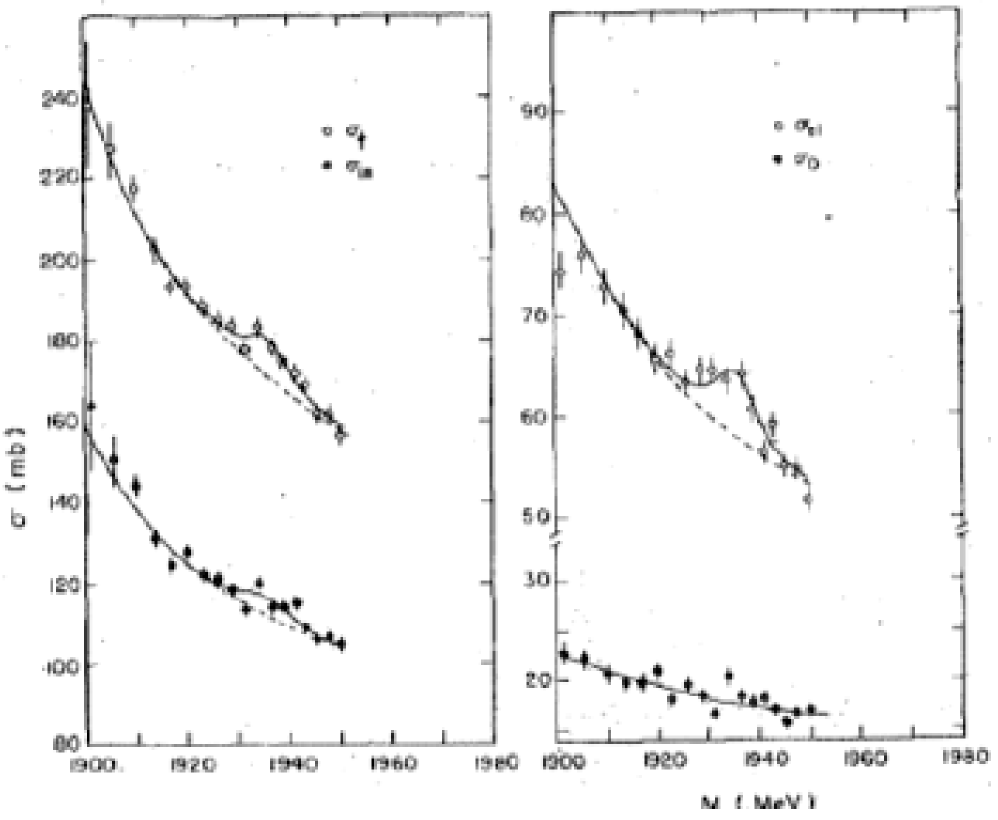


- Duality: t-channel scattering matrix has matching pole structure that influences analytic scattering amplitudes and phase shifts (R. Cutkosky (CMU) 1972)
- Exotic $p\bar{p}$ heavy mesons should have suppressed decay rates and be narrow (R.L. Jaffee and F. Low (1979))

Evidence for s-channel $p\bar{p}$ resonance



Carroll, et al.
BNL counter



Chaloupka, et al. CERN BC

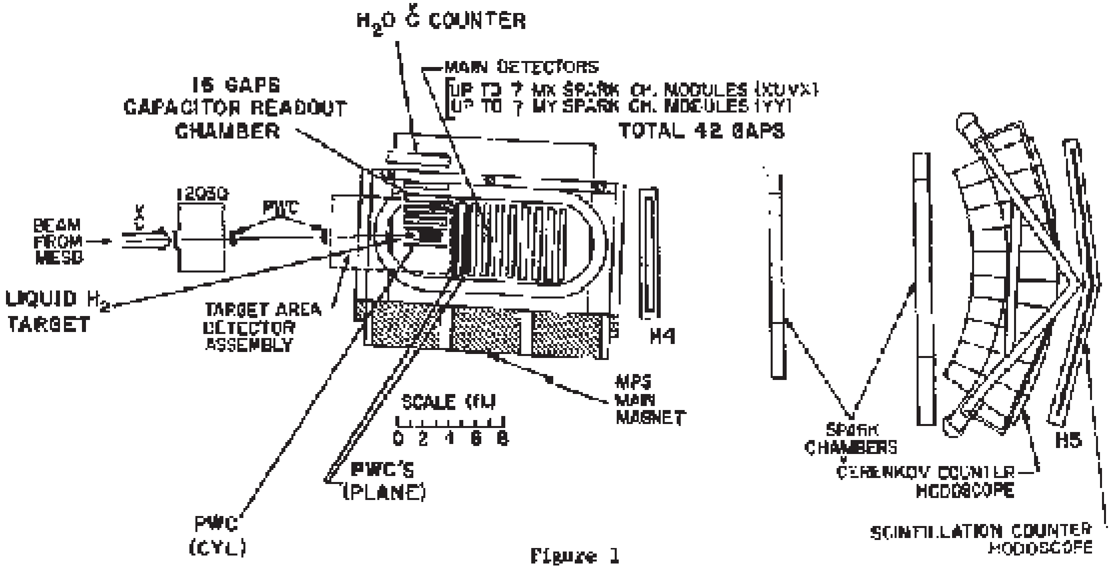
Two very different experiments report the 1935 MeV resonance with width ~ 5 MeV, confirmed by two more counter experiments

A t-channel search for the S(1935)?

- Reaction 1: $\pi^+ + p \rightarrow (p\,\bar{p})_f + \Delta^{++}$ involves heavy meson exchange akin to ρ production
- Heavy meson exchange falls slower in t than π exchange → cover wide t region.
- Advantage: fast antiproton has low annihilation, elastic scattering cross sections compared to s-channel studies
- Detector requirements: full reaction coverage in CM frame with excellent momentum resolution and pion rejection for forward particles

THE BNL MULTIPARTICLE SPECTROMETER

- LH_2 target inside cylindrical spark chambers gives 4π coverage in CM frame. See all charged tracks in an interaction.



- Forward hodoscope identifies and sign-selects high-momentum tracks. Cerenkov counter tags pions

Extracting the Physics – Enter Dan Green

- 1978: ~~GEANT.~~
- ~~ROOT,~~ ~~PAW.~~
- code in FORTRAN

Dan's CERN background let him lead the software development

- He was our CERNLIB guru
- His style fit the needs perfectly: insightful, orderly, and didactic.

- Dan helped the students build a complete simulation and analysis library.

```
      SUBROUTINE D3BOD(XM,P1,P2,P3,XE1,XE2)
      external rand
C     DOES 3 BODY PHASE SPACE FOR CM ENERGY XM,PRODUCTS +1,P2,P3
C     P IS 8-D X,Y,Z,AX,AY,AZ,P,M
      DIMENSION P1(8),P2(8),P3(8)
C     FIND MAX CM ENERGIES
      XE1M=(XM*XM+P1(8)*P1(8)-(P2(8)+P3(8))**2)/(2.*XM)
      XE2M=(XM*XM+P2(8)*P2(8)-(P1(8)+P3(8))**2)/(2.*XM)
C     PICK ENERGIES UNIFORMLY WITHIN KINEMATIC LIMITS
    2 CONTINUE
      XE1=P1(8)+Rand(1)*(XE1M-P1(8))
      XE2=P2(8)+Rand(1)*(XE2M-P2(8))
      XE3=XM-XE1-XE2
C     CHECK ENERGY CONSERVATION
      IF(XE3.LT.P3(8)) GO TO 2
C     CHECK IF MOMENTUM CONSERVATION IS POSSIBLE
      P1(7)=SQRT(XE1*XE1-P1(8)*P1(8))
      P2(7)=SQRT(XE2*XE2-P2(8)*P2(8))
      P3(7)=SQRT(XE3*XE3-P3(8)*P3(8))
C     LOOK AT 1-2 OPENING ANGLE
C   PROTECT AGAINST DIVIDE BY ZERO
        IF(P1(7).LT..000001)P1(7)=.000001
        IF(P2(7).LT..000001)P2(7)=.000001
      CT12=(P3(7)*P3(7)-P2(7)*P2(7)-P1(7)*P1(7))/(2.*P1(7)*P2(7))
      IF(ABS(CT12).GE.1.) GO TO 2
C     IF INSIDE KINEMATIC BOUNDARY NOW ORIENT
             CT1=-1.+2.*Rand(1)
      ST1=SQRT(1.-CT1*CT1)
      PH1=6.2832*Rand(1)
      CP1=COS(PH1)
      SP1=SIN(PH1)
      P1(4)=ST1*CP1
      P1(5)=ST1*SP1
      P1(6)=CT1
C     1-2 OPENING ANGLE FIXED BY MOM CONS,PICK PHI2 UNIFORMLY WHEN P1
C     IS THE Z AXIS,THEN EULER TO CM FRAME,P3 VIA MOM CONS
      PH2=6.2832*Rand(1)
      ST12=SQRT(1.-CT12*CT12)
      P2(4)=ST12*COS(PH2)
      P2(5)=ST12*SIN(PH2)
      P2(6)=CT12
      TP4=P2(4)
      P2(4)=CT1*CP1*P2(4)-SP1*P2(5)+ST1*CP1*P2(6)
      P2(5)=CT1*SP1*TP4+CP1*P2(5)+ST1*SP1*P2(6)
      P2(6)=-ST1*TP4+CT1*P2(6)
      P3(4)=(-P2(7)*P2(4)-P1(7)*P1(4))/P3(7)
      P3(5)=(-P2(7)*P2(5)-P1(7)*P1(5))/P3(7)
      P3(6)=(-P2(7)*P2(6)-P1(7)*P1(6))/P3(7)
      RETURN
      END
```

Jim Russ Carnegie Mellon University

10/19/2018

Testing, testing – establishing sensitivity

Dan took a lead role in analyzing the calibration experiments needed to validate the efficiency code and determine the sensitivity:

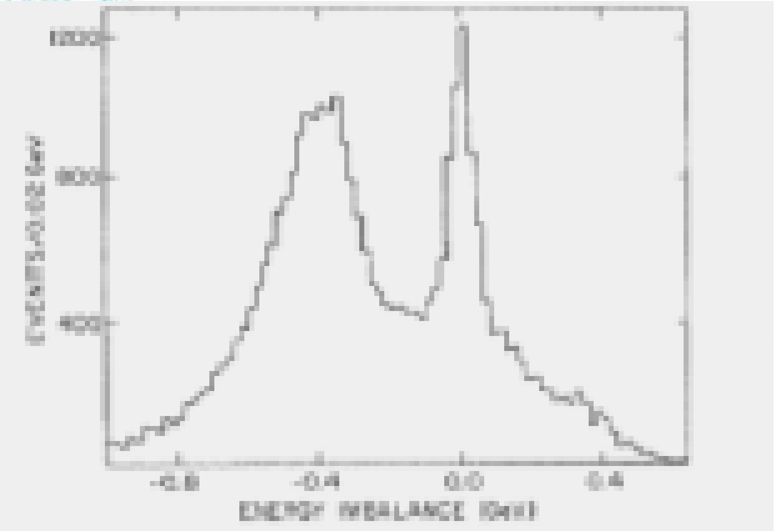
- Cylindrical chamber reconstruction: large-t pion elastic scattering
- Forward chamber reconstruction: inclusive Λ^0 reconstruction
- Full angular coverage: Jackson angle measurements for final state resonances from $\pi^+ + p \rightarrow \rho^0 + \Delta^{++}$ [2]
- Sensitivity also established from comparing our normalization of Reaction 2 to BC measurements at similar energies.

The Measurement

- What do we expect to see?
  - If there is no meson exchange coupling to a $p\bar{p}$ system, there would be no events over background
  - If the S(1935) is a particle, the $p\bar{p}$ mass spectrum should be enhanced at 1935
  - If there is meson exchange coupling to a $p\bar{p}$ system with no t-channel pole, the mass spectrum will be featureless

- All 4-prong events with forward π veto are tested against
- Reaction 1: $\pi^+ + p \rightarrow (p\bar{p})_f + \Delta^{++}$

Results

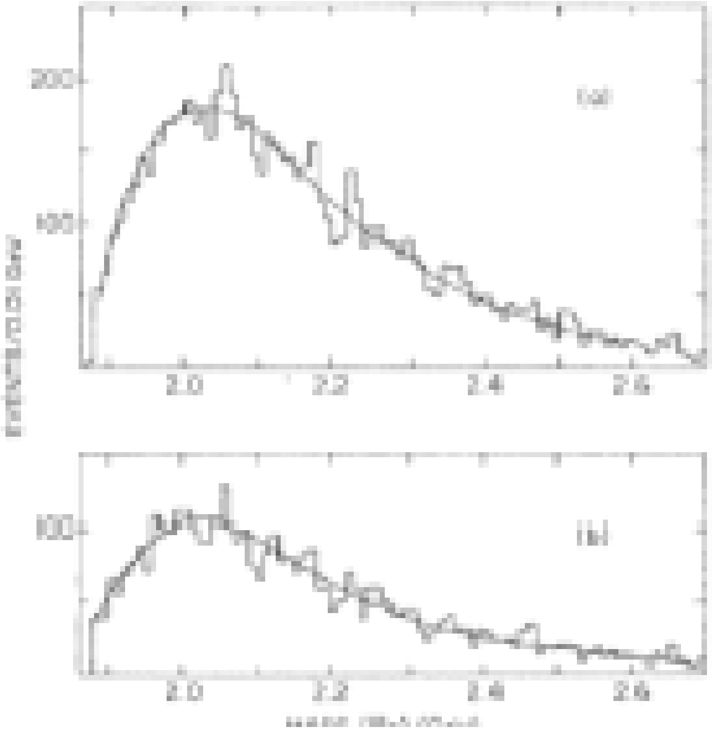


- Energy imbalance, $\sqrt{s} - E_1 - E_2 - E_3 - E_4$, zero for reaction 1 with perfect measurement
- Forward K^+K^- system: negative, since tracks are given m_p

- Select events with |energy imbalance| < 100 MeV

- Plot $p\bar{p}$ mass spectrum

No Baryonium to be seen



(a) All 4-prong events analyzed as Reaction 1

Polynomial fit to spectrum

(b) 4-prong events analyzed as Reaction 1 and $M_{\pi p}$ < 1.4 GeV

Sensitivity at 1935 MeV: 0.7 evnt/nb;

95% CL upper limit for S production: < 40 nb

Epilogue – Epitaph for Baryonium

The study of exotic mesons in formation and production experiments continued for another five years after this negative result. (Review: T. Kamae, Nucl. Phys. A374, 25 (1982))

- New formation experiments with PWCs and/or thin scintillators did not confirm the previous results.
- Exotic states with strange mesons came and went
- LEAR made definitive partial wave studies that established the absence of exotic states in $p\bar{p}$ formation interactions.