*

MESON SCATTERING FROM A PHOTON TARGET:

POLARIZABILITIES

HYBRID MESONS

CHIRAL ANOMALY

RADIATIVE TRANSITIONS

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TEL AVIV UNIVERSITY

20 FEB. 2002
TRIESTE, ITALY

HADRON
STRUCTURE
&
SPECTROSCOPY

PRIMAKOFF PHYSICS
STATUS AND PROSPECTS
AT [COMPASS]

COMPASS COMPETITION METHOD

HOW TO STUDY $\gamma\pi$ INTERACTIONS?

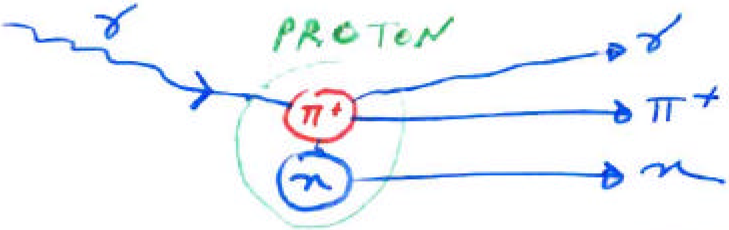
(1) γ BEAM, "π" TARGET

CHEW-LOW PION POLE EXTRAPOLATION
INSIDE PROTON

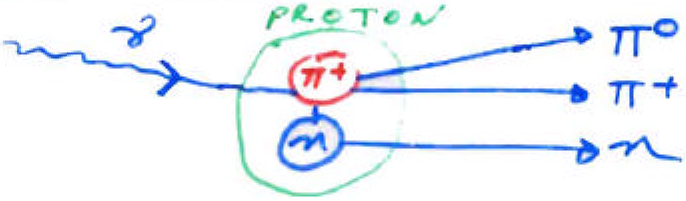
* SOME γ BEAM EXPERIMENTS:

(A) MAINZ, PION POLARIZABILITY

VIA $\gamma\pi^+ \to \gamma\pi^+$ COMPTON SCATTERING



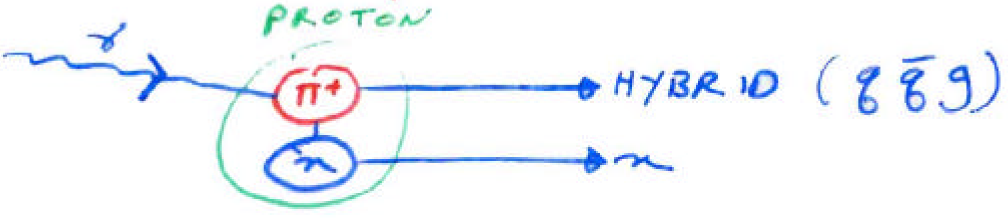
(B) JLAB, CHIRAL ANOMALY



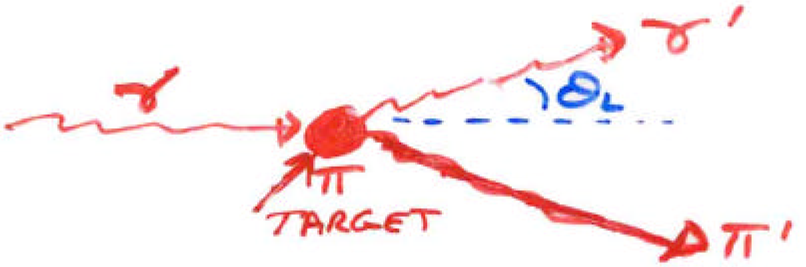
VIA $\gamma\pi^+ \to \pi^0\pi^+$

(C) JLAB HALL-D UPGRADE, HYBRID MESONS $(q\bar{q}g)$

VIA $\gamma\pi^+ \to$ HYBRID

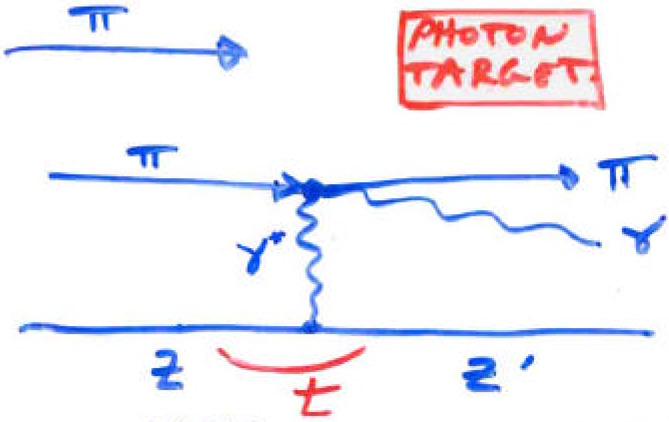


HOW TO MAKE A CLEANER PION TARGET, IF IT DECAY?

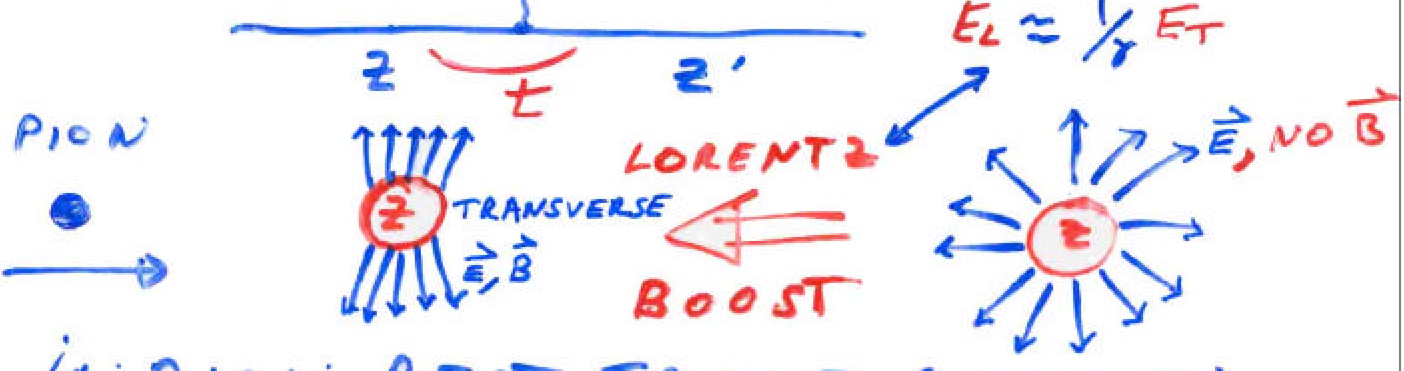


WE CANNOT USE "NORMAL" γ- BEAM. USE "PRIMAKOFF" SCATTERING.

* (2) WE USE HIGH ENERGY PION BEAM (HIGHER π LIFETIME) AND A PHOTON TARGET.



INTERACTION MEDIATED BY PHOTON EXCHANGE



IN PION REST FRAME (TARGET), COULOMB FIELD CONTRACTED (LORENTZ) INTO A PHOTON OF RADIATION (γ*).

COMPASS PRIMAKOFF ACTIVITIES ($\gamma \overset{\Updownarrow}{\gamma^*} \to \pi^0$)

SIMULATIONS:

TUM: R. KUHN, S. PAUL

LMU: M. SANS MERCE, M. FAESSLER

TORINO: M. COLANTONI, R. BERTINI

TELAVIV: M. MOINESTER

DUBNA: A. OLSHEVSKI

TRIGGER TESTS:

DUBNA: A. SADOVSKI, A. OLSHEVSKI

ECAL2: CALORIMETER ADC PRODUCTION

TUM, DUBNA.

COMGEANT: V. ALEXAKHINE,

\+ GLOBAL COMPASS EFFORT
OF ALL COMPASS GROUPS.

PION POLARIZABILITY

ELECTRIC $\bar{\alpha}_\pi \simeq -\bar{\beta}_\pi$ MAGNETIC

VERY **SOLID** CHIRAL SYMMETRY PREDICTION USING EFFECTIVE CHIRAL LAGRANGIAN: $\mathcal{L}_{EFF}$

UNITARY VIA PION LOOPS

COVERGENCE VIA "EXPERIMENTAL"

L_i^r COUPLING CONSTANTS

RADIATIVE π DECAY $\Rightarrow (L_9^r + L_{10}^r)$

$$\bar{\alpha}_\pi = -\bar{\beta}_\pi = \frac{4\alpha_f}{m_\pi f_\pi^2}(L_9^r + L_{10}^r)$$

$$= 2.7 \pm 0.4 \times 10^{-43}\ cm^3$$

+ SMALL HIGHER ORDER CORRECTIONS

ALSO DYNAMIC DESCRIPTION:
(MODEL DEPENDENT)

$\bar{\alpha}_\pi = 2.6$

STUDY VIA $\gamma\pi \rightarrow \gamma\pi$
AND $\gamma\pi \rightarrow a_1$

PION POLARIZABILITY STATUS

SERPUKHOV EXPERIMENT (40 GeV π^-) $\boxed{\bar{\alpha}_\pi = 6.8 \pm 1.4 \pm 1.2 \times 10^{-43} cm^3}$

χ_{PT} $\bar{\alpha}_\pi = 2.7 \pm 0.4 \times 10^{-43} cm^3$

QUALITY EXPERIMENT WITH $\pm\Delta\bar{\alpha}_\pi \simeq 0.4$ SHOULD GIVE EXCELLENT AGREEMENT WITH χ_{PT}.

NEED IMPROVED π DATA.

KAON DATA FOR $\bar{\alpha}_K$ ALSO OF HIGH INTEREST.

NO PREVIOUS DATA FOR $\bar{\alpha}_K$

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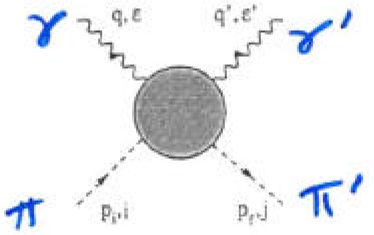
PION POLARIZABILITY

RCS **Real Compton Scattering** $q^2 = q'^2 = 0$



In LAB frame and Lorentz gauge

$$\mathcal{M} = \underbrace{-2ie^2\vec{\epsilon}^{\,\prime\star}\cdot\vec{\epsilon}}_{\text{point particle without structure}}$$

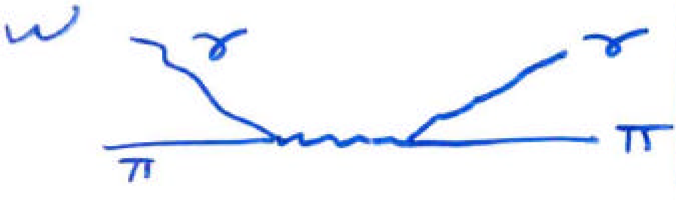
$$\underbrace{+2iM_\pi\omega\omega'\left(4\pi\bar{\alpha}_E\vec{\epsilon}^{\,\prime\star}\cdot\vec{\epsilon}+4\pi\bar{\beta}_M\hat{q}'\times\vec{\epsilon}^{\,\prime\star}\cdot\hat{q}\times\vec{\epsilon}\right)}_{\sim\text{ electromagnetic polarizabilities}}$$

unpolarized differential cross section

$$\begin{aligned}\frac{d\sigma}{d\Omega_{lab}} &= \frac{e^4}{(4\pi)^2M_\pi^2}\left(\frac{\omega'}{\omega}\right)^2\frac{1+\cos^2(\theta)}{2}\\ &-\left(\frac{\omega'}{\omega}\right)^2\frac{e^2}{4\pi M_\pi}\omega\omega'\left[\bar{\alpha}_E(1+\cos(\theta)^2)\right.\\ &\left.+2\bar{\beta}_M\cos(\theta)\right]+\mathcal{O}\left(\omega^2\omega'^2\right)\end{aligned}$$

- $\cos(\theta) = \hat{q}\cdot\hat{q}'$
- $\omega' = \omega\left[1+\frac{\omega}{M_\pi}(1-\cos(\theta))\right]^{-1}$

COMPTON SCATTERING



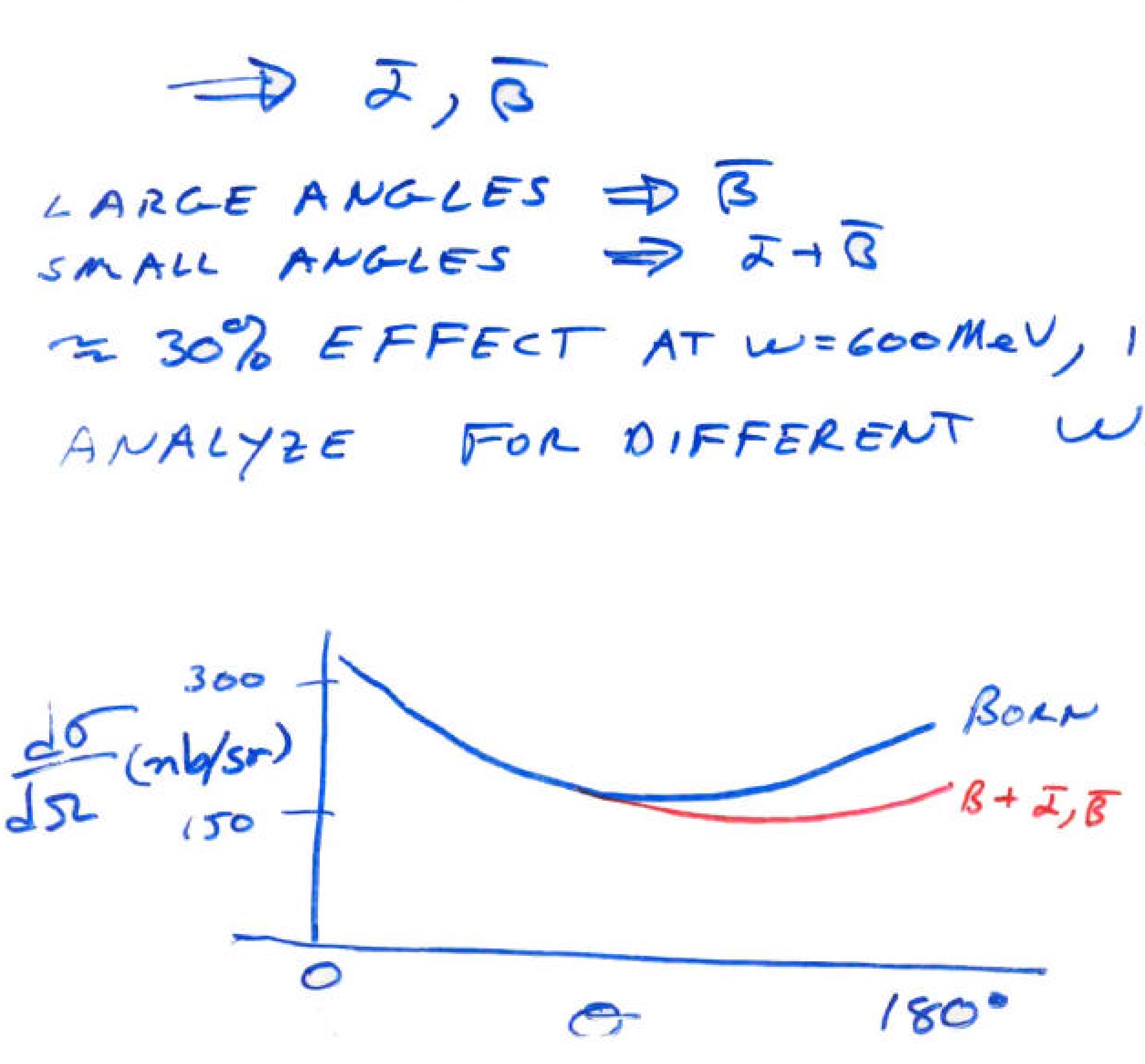
SENSITIVE
TO
POLARIZABILITIES

$$f_C = f_T + f_R(\bar{\alpha}, \bar{\beta})$$

$$\sum f_C^2 \longrightarrow \frac{d\sigma(\omega)}{d(\cos\theta)} = f(\bar{\alpha}, \bar{\beta}, \omega, \theta)$$

$$\Rightarrow \bar{\alpha}, \bar{\beta}$$

LARGE ANGLES ⇒ $\bar{\beta}$
SMALL ANGLES ⇒ $\bar{\alpha} + \bar{\beta}$
≈ 30% EFFECT AT ω=600MeV, 180°
ANALYZE FOR DIFFERENT ω.

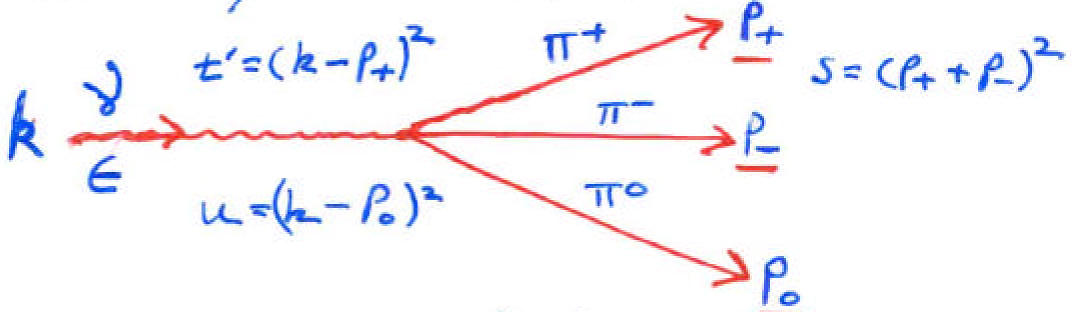


CHIRAL ANOMALY

WZW TERM OF EFFECTIVE CHIRAL LAGRANGIAN DESCRIBES UNNATURAL PARITY $\underline{\pi^0 \to 2\gamma}$ AND $\gamma \to 3\pi$ TRANSITIONS

ARISES FROM BREAKING OF SYMMETRY IN CLASSICAL LAGRANGIAN BY QUANTIZATION

ANOMALY IN $F_{3\pi}(\gamma \to 3\pi)$



$$A_{\gamma 3\pi} = i F_{3\pi}(s,t',u)\, \epsilon^{\mu\nu\alpha\beta} \epsilon_\mu P_{0\nu} P_{+\alpha} P_{-\beta}$$

AT $O(p^4)$, AT ZERO MOMENTUM,

$$F_{3\pi}(0,0,0) = \sqrt{4\pi\alpha}\; N_c / 12\pi^2 f_\pi^3 \; \text{GeV}^{-3}$$

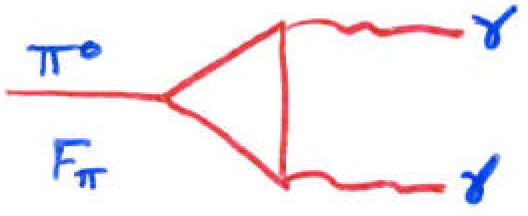
FOR $\pi^0 \to 2\gamma$, $F_\pi(0) = \frac{\alpha N_c}{3\pi f_\pi}$ GeV^{-1} ✓ EXP. VS. THEORY

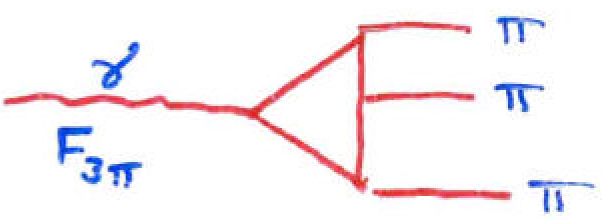
CHIRAL ANOMALY TEST

WZW - ANOMALY   EVEN $\updownarrow$ ODD

$\pi^0 \to 2\gamma$ $\gamma \to 3\pi$

DESCRIBED BY LOOP DIAGRAMS





$F_\pi^{EXP}(0) \approx F_\pi^{THEORY}(0)$ $(N_c = 3)$

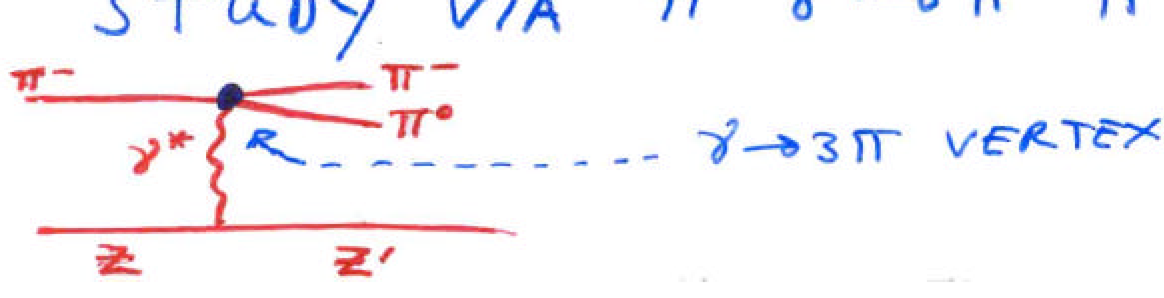
$$\left\{\begin{array}{ll} F_{3\pi}^{TH}(0) = 9.7 & O(p^4) \\ \Updownarrow & \\ F_{3\pi}^{EXP}(0) = 12.9 \pm 0.9 \pm 0.5 \ GeV^{-3} & \end{array}\right.$$

ANTIPOV ET AL (SERPUKHOV)

$F_{3\pi} \Rightarrow N_c = 4$: NEED HIGHER QUALITY DATA!

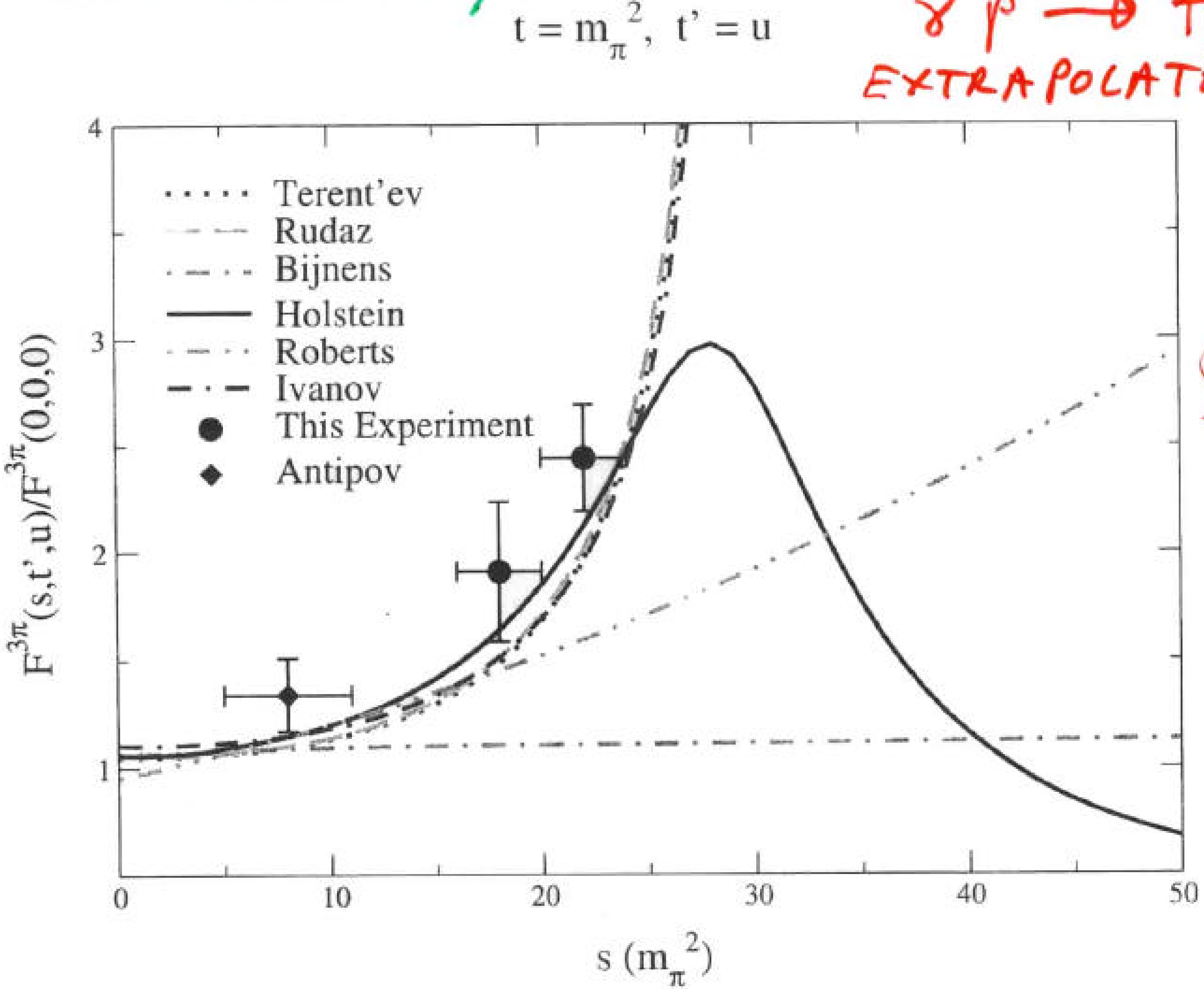
NEED χPT $O(p^6)$ + ...

* STUDY VIA $\pi^- \gamma^* \to \pi^- \pi^0$



B. ASAVAPIBHOP, U. MASS. Ph.D. Thesis, May 2000
WITH R. MISKIMEN ET. AL. (CLAS).
(PRELIMINARY)

$\gamma p \rightarrow \pi^+ \pi^0 n$
EXTRAPOLATE TO
PION POLE



$N_c \simeq 4$
(ANTIPOV ET AL)

JLAB HIGHER
$S(\pi^- \pi^0)$ DATA.

DIFFICULT
TO EXTRAPOLATE
TO $F_{3\pi}(0)$

COMPASS
GETS LOW-S
DATA

Figure 7.26 A comparison between the $F^{3\pi}(s, t', u)$ extracted from this experiment and theoretical calculation.

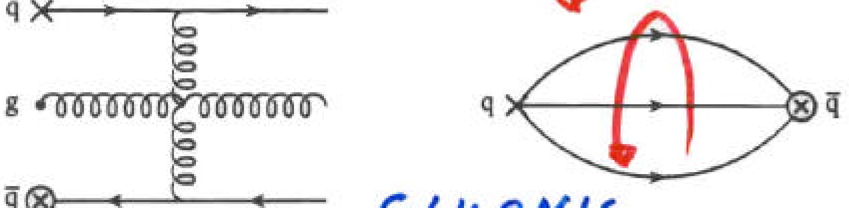
QCD : (1) ASYMPTOTIC FREEDOM → PERTURBATIVE QCD
*(2) CONFINEMENT → FORMATION OF HADRONS

QCD Mesons

GLUONIC GD. ST.

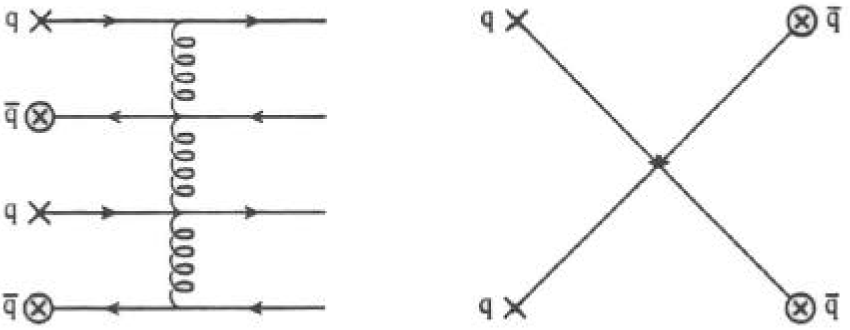
NORMAL
MESON

GLUONIC FLUX LINES
OF COLOR FIELD
→ FLUXTUBE



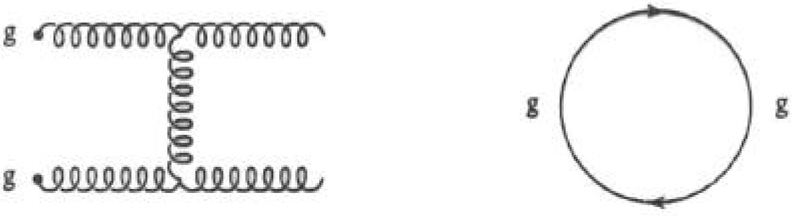
GLUONIC
EXCITED ST.

*
QUARK-GLUON
HYBRID
MESON
EXOTIC



FOUR-QUARK
MOLECULE
OR
TIGHTLY BOUND

*



GLUEBALL

HYBRID MESON ≡ QUARK-GLUON COMBINATION

GLUONIC FLUX TUBE IS SLACK,
SPINS ABOUT AXIS, ROTATIONAL ENERGY,
CORRESPONDS TO EXTRA GLUON,
CONSTITUENT GLUON.

WHY IS IT IMPORTANT TO OBSERVE GLUONIC EXCITATIONS

LOOK FOR ($q\bar{q}g$) GLUONIC HYBRIDS

UNDERSTANDING EXPLICIT GLUE IS CRITICAL, CONSIDERING THAT MOST OF MASS OF HADRON IS MADE OUT OF GLUONS.

HYBRID MESONS CONTAIN EXPLICIT GLUE, AS OPPOSED TO HIDDEN GLUE IN CONVENTIONAL MESONS.

$$|\text{NORMAL MESON}\rangle = \alpha\, q\bar{q} + \beta\, q\bar{q}g + \gamma\, q\bar{q}q\bar{q} + \cdots$$

$$|\text{HYBRID MESON}\rangle = \times \quad \beta\, q\bar{q}g + \gamma\, q\bar{q}q\bar{q} + \cdots$$

* MOST UNAMBIGUOUS HYBRID SEARCH EXPERIMENTS FOCUS ON J^{PC} EXOTICS (ODDBALLS) WITH $J^{PC} = 1^{-+}, 0^{+-}, 2^{+-}$ FOR ISOSPIN 1. THESE J^{PC} <u>CANNOT</u> BE $q\bar{q}$.

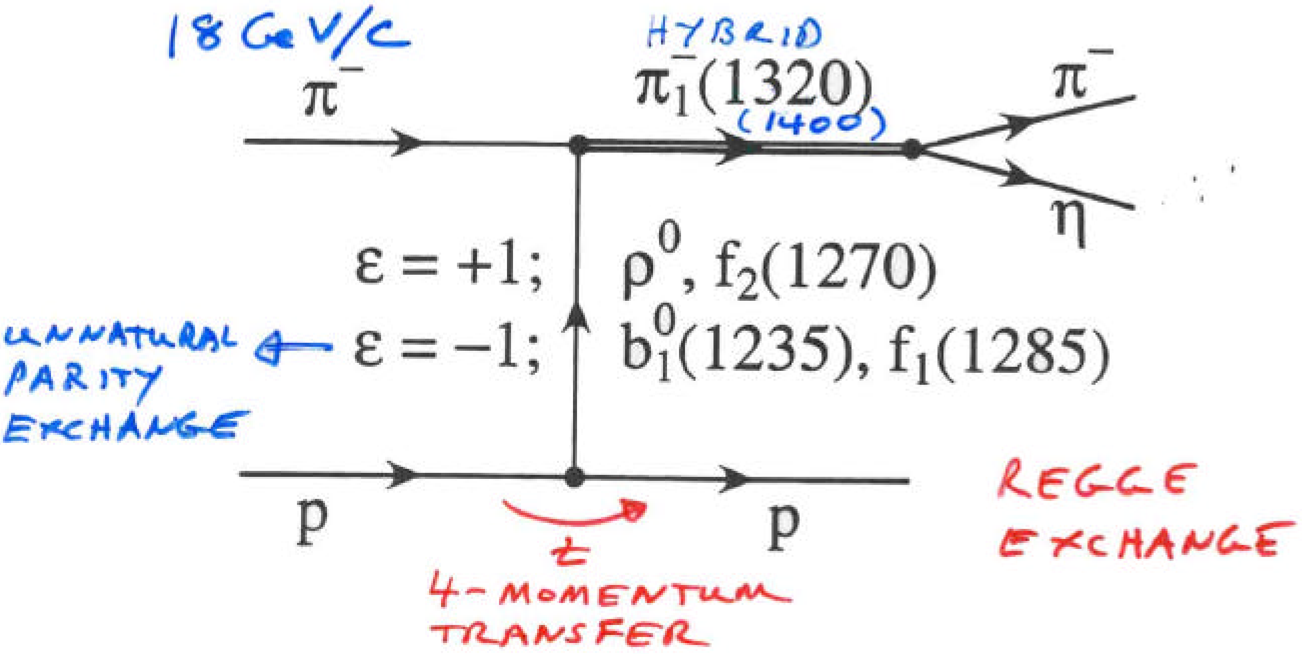
*

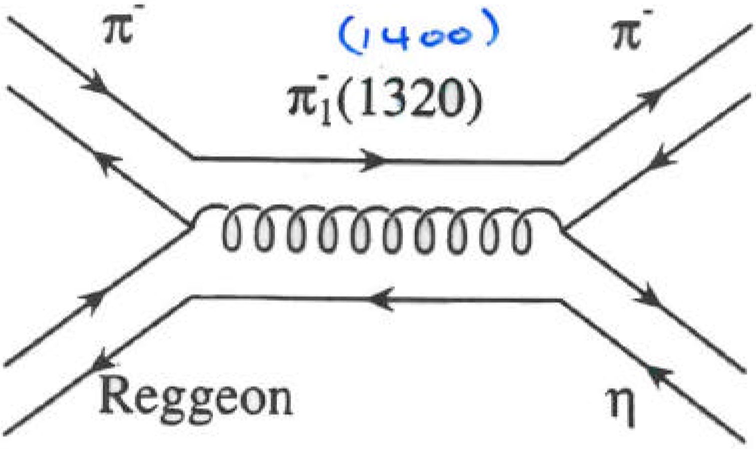
Production of a Hybrid Meson (BNL)

OR 4q OR "BACKGROUND"

E852 + VES + ...

$I^G(J^{PC}) = 1^-(1^{-+})\ \pi_1(1320)$ 1400





FINAL STATE INTERACTIONS WITH p.
AVOIDED IN PRIMAKOFF PRODUCTION.

HAVE HYBRIDS BEEN DISCOVERED?

1.4 AMBIGUOS
1.6, 1.9 POSSIBLE

DONNACHIE / PAGE:

1.4 GeV STATE RESULTS FROM INTERFERENCE OF NON-RESONANT DECK BACKGROUND PEAKING NEAR 1.4 GeV WITH HYBRID RESONANCE AT 1.6 GeV.

DECK INVOLVES $\pi\rho$ INELASTIC SCATTERING INTO $\eta\pi p$ VIA ρ-EXCHANGE. IT IS ONLY OPERATIVE FOR $\pi\rho$. MAY BE RULED OUT BY CB $\bar{p}d \to \pi^-\pi^0\eta p$ SIGNAL.

TO SOLVE AMBIGUITIES, NEED COMPLEMENTARY DATA FROM MANY DIFFERENT EXPERIMENTAL METHODS, INCLUDING PRIMAKOFF.

SAFEST: NO DISCOVERY CLAIM AT THIS POINT

HAVE HYBRIDS BEEN DISCOVERED?

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SAFEST: NO DISCOVERY CLAIM
AT THIS POINT

$J^{PC} = 1^{-+}$ SUMMARY

≈ 3 EXOTIC ≠ $q\bar{q}$ "SIGNALS"

≈ M (GeV)	≈ Γ (MeV)	DECAY
1.4	300	$\eta\pi$
1.6	300	$(f_1\pi)$, $\eta'\pi$, $\boxed{\underline{\rho\pi}}$, $b_1\pi$ (83) $\boxed{(134)}$ (83)
1.9	300	$f_1\pi$, ...

VIA $\pi^- p \to$ HY p, $\pi^- p \to$ HY n

$\bar{p} n \to \pi^-\pi^0\eta$, $p\bar{p} \to 2\pi^0\eta$

---

* HAVE HYBRIDS BEEN DISCOVERED?

WHY SO MANY 1^{-+} RESONANCES?

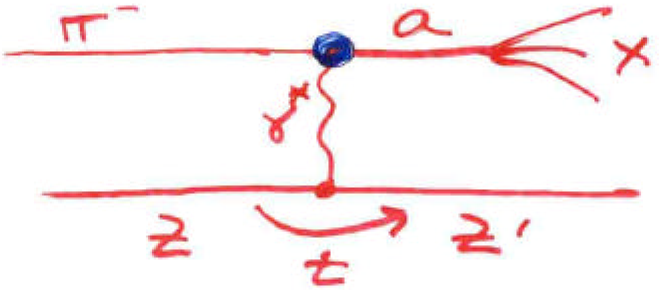
$\pi_1(1.4)$ AND $\pi_2(1.6)$ HAVE MASS LOWER THAN PREDICTED, WITH S-S P-WAVE DECAY $[\pi\eta, L=1]$, AND NOT S-P S-WAVE DECAY $[b_1\pi, L=0]$ AS PREDICTED.

ARE SOME 4q ($qq\bar{q}\bar{q}$) RESONANCES?
OR BACKGROUNDS

SAFEST: NO DISCOVERY CLAIM

NEED DATA VIA MANY DIFFERENT METHODS, INCLUDING PRIMAKOFF

PRIMAKOFF PRODUCTION OF MESON (a) PROPORTIONAL TO RADIATIVE WIDTH $\Gamma(a \to \pi\gamma)$



$a = \rho^-$, $X = \pi^-\pi^0$

$a = \pi_1$ HYBRID, $X = \pi^-\eta$, ETC.

$$\frac{d\sigma}{dt\, dm_a^2} \simeq Z^2 \frac{(t-t_0)}{t^2} \frac{\Gamma(a \to \pi^-\gamma)}{(m_a^2 - m_\pi^2)}$$

CROSS SECTION FOR CHANNEL X DEPENDS ON BRANCHING RATIO $B(a \to X)$

*

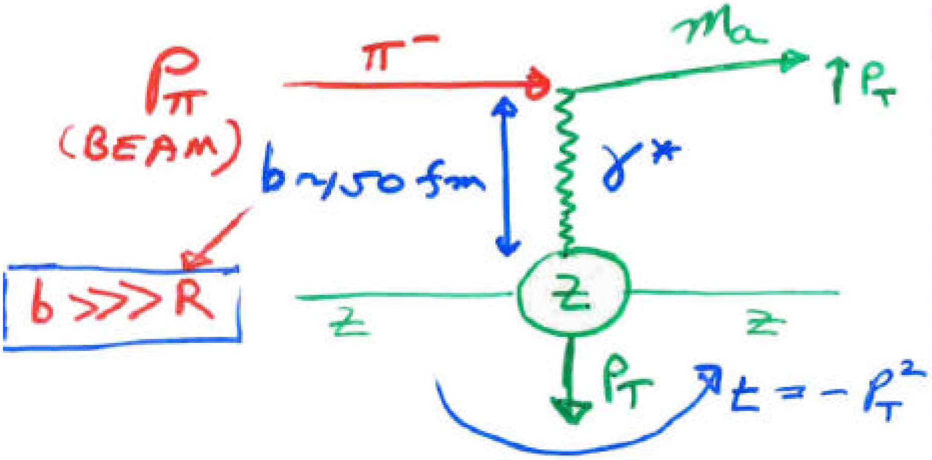
SOME RADIATIVE WIDTHS

 $\Gamma(\rho^- \to \pi^-\gamma)$ $\simeq$ 70 KeV	 $\Gamma(a_2^- \to \pi^-\gamma)$ $\simeq$ 300 KeV	 $\Gamma(\pi_1^- \to \pi^-\gamma)$ $\simeq$ 75 – 750 KeV

IF $\Gamma(\pi_1^- \to \pi^-\rho)$ $\simeq$ 10 – 100 MeV

VECTOR DOMINANCE MODEL RELATES $\Gamma(\pi_1^- \to \pi^-\gamma)$ TO $\Gamma(\pi_1^- \to \pi^-\rho)$

PRIMAKOFF SCATTERING OF π^- FROM VIRTUAL PHOTON TARGET is A $\boxed{\text{HYPO-PERIPHERAL}}$ REACTION. $\boxed{\text{NO FSI.}}$



$$d\sigma \simeq \frac{dt}{t} \simeq \frac{dp_T^2}{p_T^2 + |t_0|}$$

$$p_T^2 \simeq |t_0|$$

UNCERTAINTY PRINCIPLE

$$b\, p_T \simeq \frac{\pi}{2}$$

$$b \simeq \frac{\pi}{2\sqrt{t_0}}$$

THE MINIMUM FOUR-MOMENTUM TRANSFER t_0 TO TARGET NUCLEUS is

$$t_0 = -p_{T,MIN}^2 = -\frac{(m_a^2 - m_\pi^2)^2}{4\, p_\pi^2}$$

---

* FOR $m_a = 1$ GeV, $p_\pi = 200$ GeV,

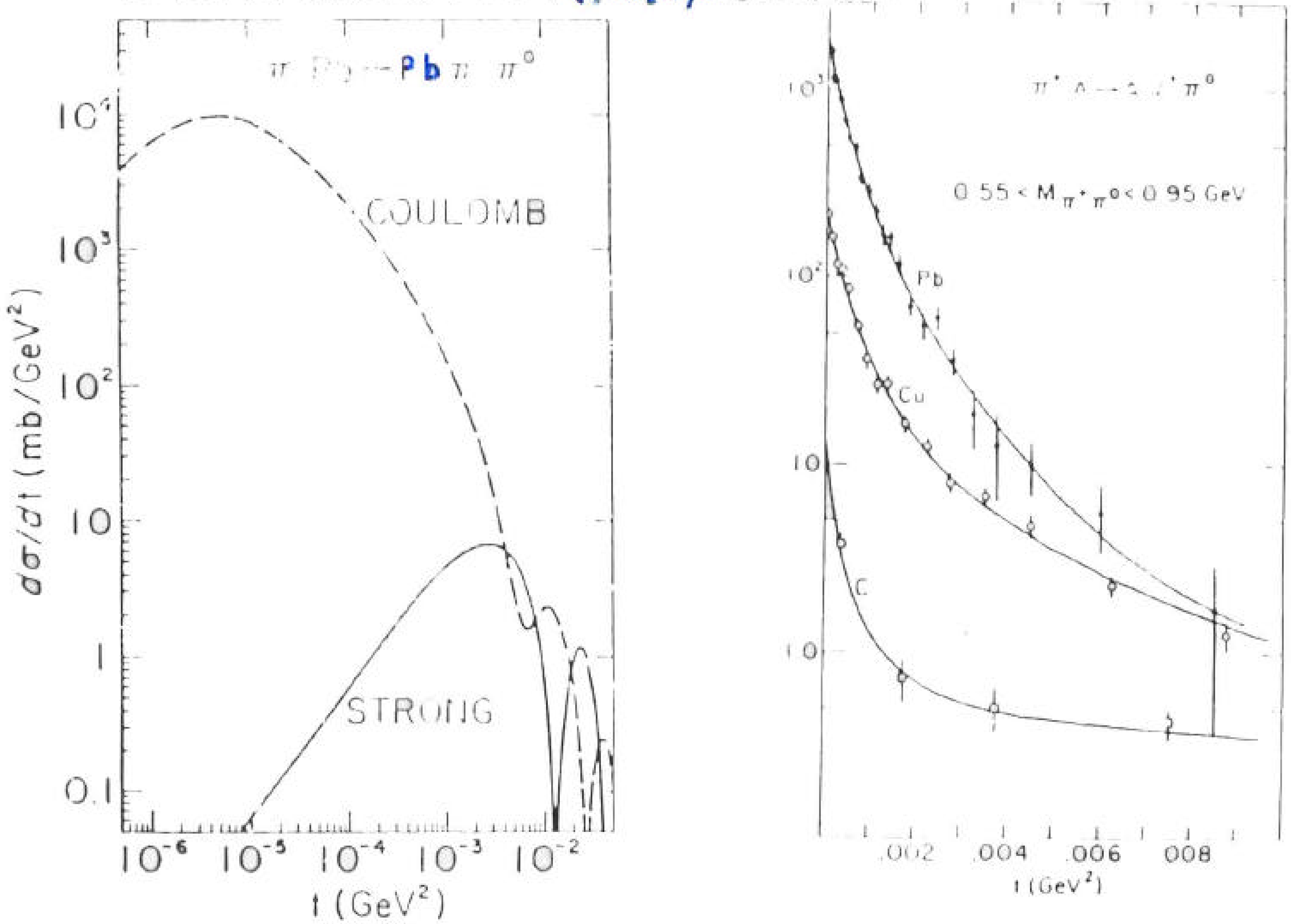
$t_0 = 5 \times 10^{-6}$ GeV^2, $p_{T,MIN} = 2$ MeV/c

HYPO-PERIPHERAL IMPACT PARAMETER $b \simeq 150$ fm.

NUCLEUS REMAINS INTACT WITH LOW RECOIL ENERGY, NO FSI.
AND SEPARATED FROM LARGE p_T MESON EXCHANGE

E272 $\pi^+ A \to \pi^+ \pi^0 A$ AT 200 GEV

COULOMB + STRONG FIT: $\Gamma(\rho^+ \to \gamma\pi) = 60 \pm 4$ keV



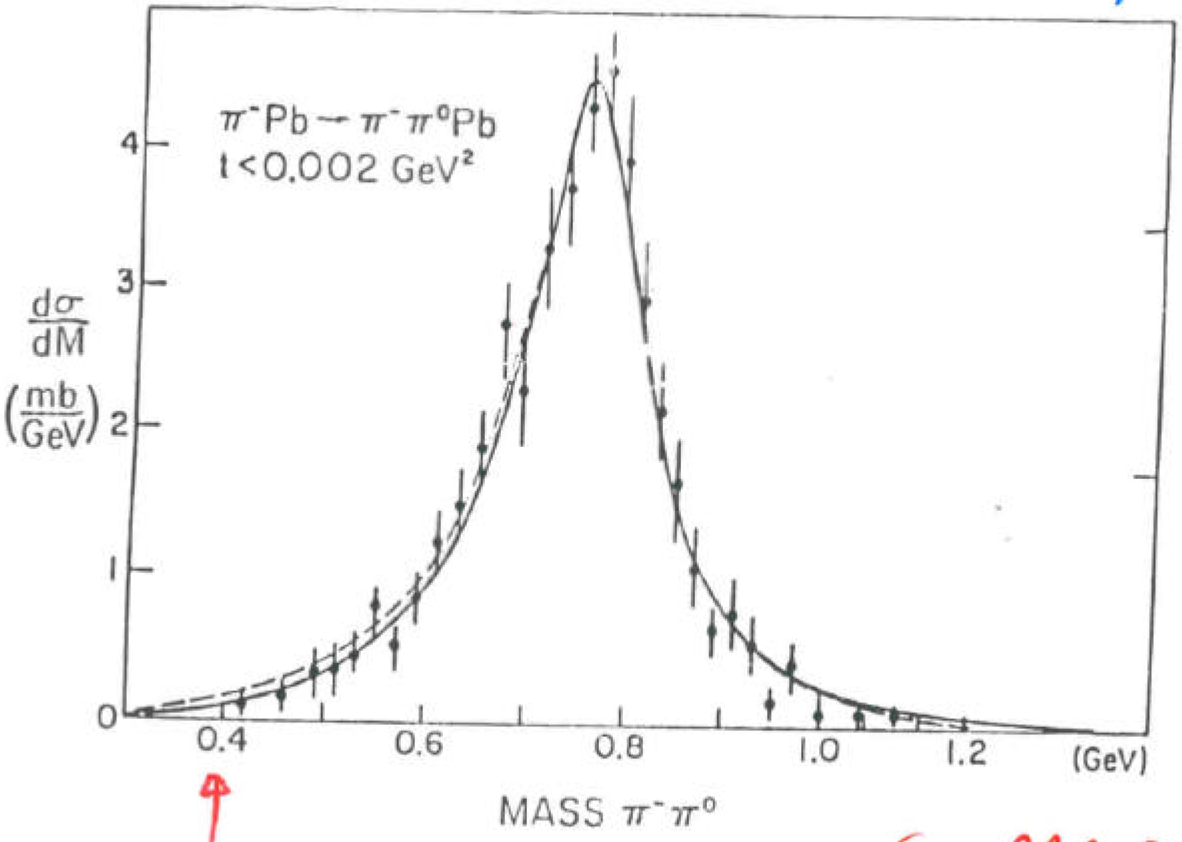
DIFF. C.S.
LOW BY
G-PARITY

$\pi^- \gamma \rightarrow \rho^- \rightarrow \pi^- \pi^0$

FERMILAB

FNAL E272

STUDY $\gamma \rightarrow 3\pi$ CHIRAL ANOMALY AMPLITUDE +
RHO
RADIAT.
TRANSITION



$\Gamma(\rho^- \rightarrow \pi^- \gamma)$
$\approx$ 70 KeV

CHIRAL ANOMALY
REGION
$\pi^- \gamma \rightarrow \pi^- \pi^0$

G-PARITY
NO $\pi^- \mathbb{P} \rightarrow \pi^- \pi^0$
BACKGROUND

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E272 DATA $\pi^+ A \to \pi^+ f_1 A$ AT 200 GEV

DOMINATED BY DIFFRACTIVE πf_1 $J^{PC} = 1^+$

WHAT IS J^{PC} OF COULOMB ENHANCEMENT?

~ 25 EXCESS

20 EVENTS

$\Gamma(\hat{\rho} \to \pi\gamma) \times BR(\hat{\rho} \to \pi f_1)$

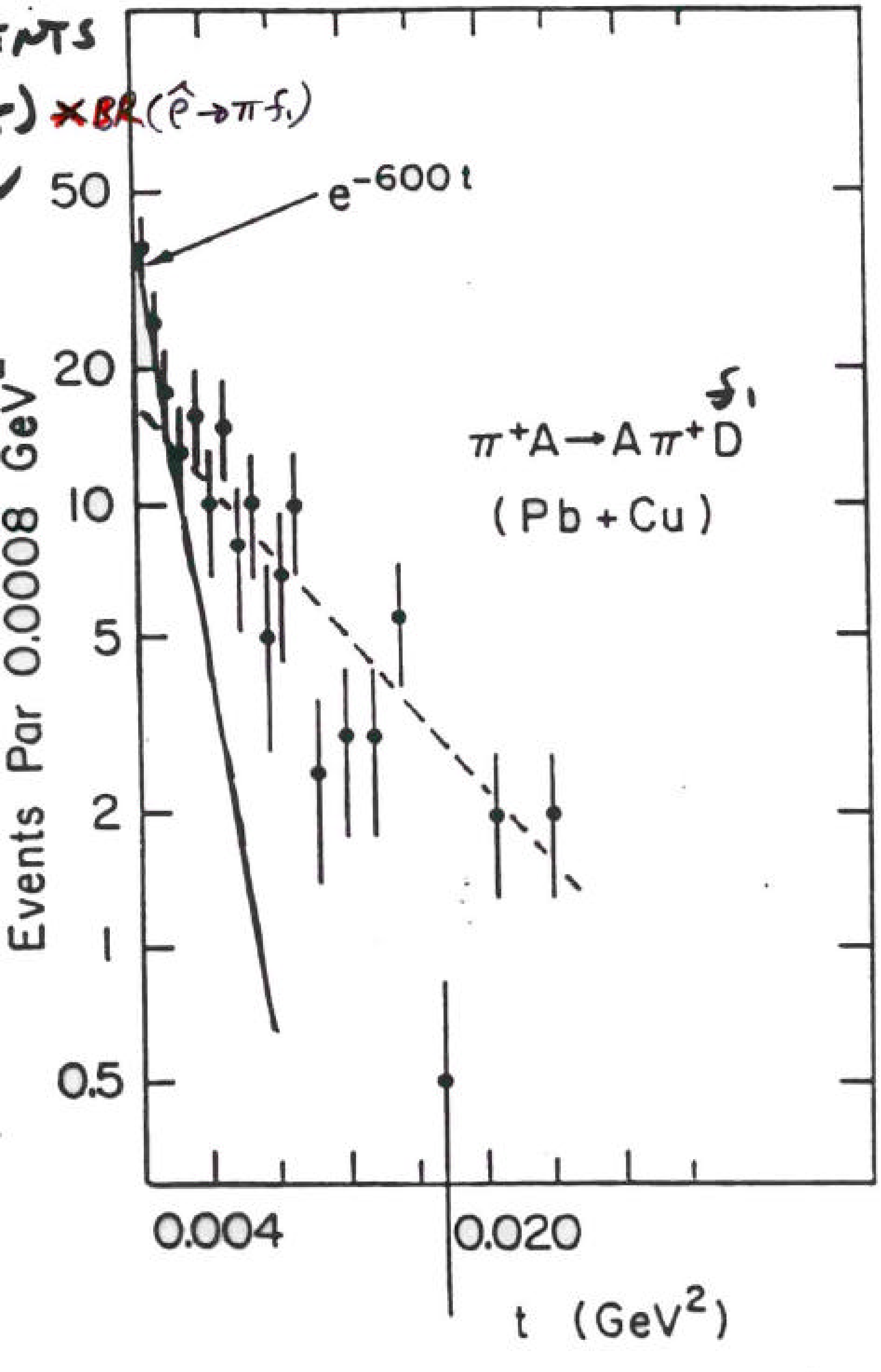
= 1000 KeV

WE ASSUMED

$\Gamma(\hat{\rho} \to \pi\gamma)$

= 25-750 KeV

FROM VDM



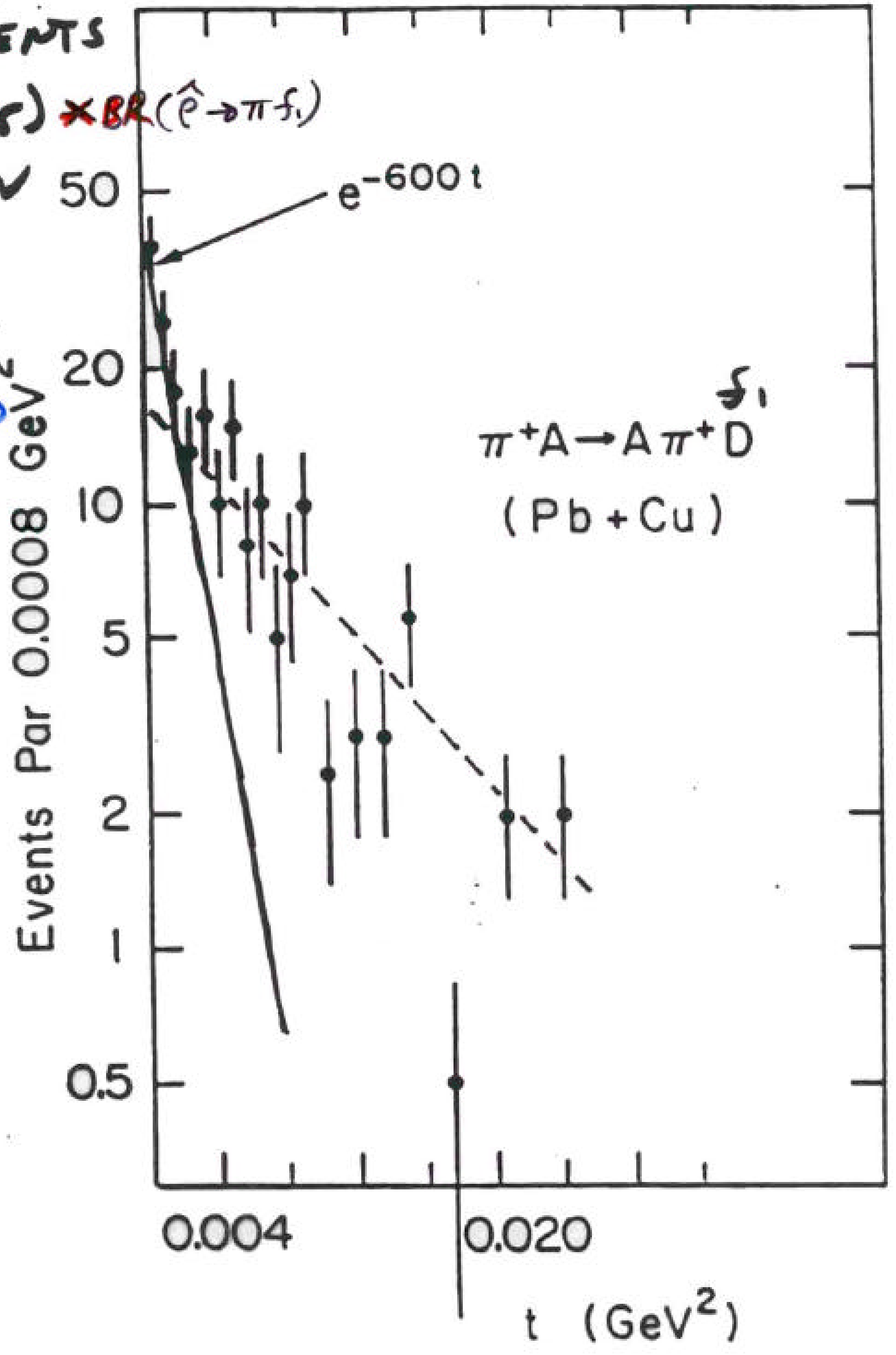
E272 DATA $\pi^+ A \to \pi^+ f_1 A$ AT 200 GEV

DOMINATED BY DIFFRACTIVE πf_1 $J^{PC} = 1^+$

WHAT IS J^{PC} OF COULOMB ENHANCEMENT?

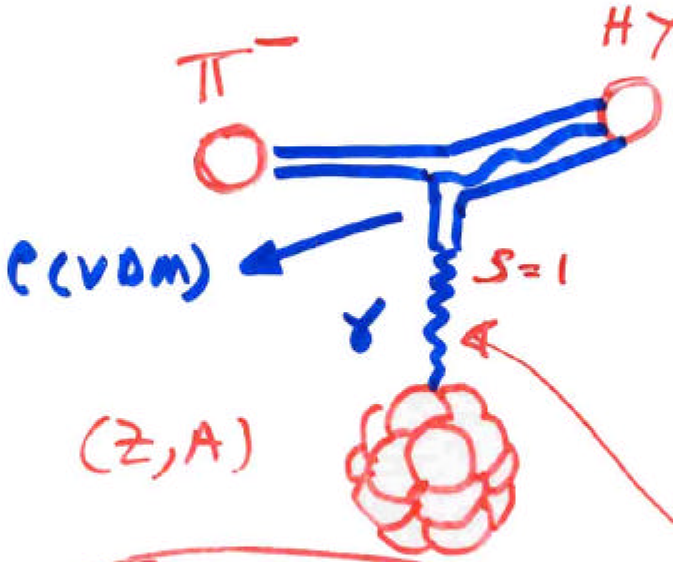
~25 EXCESS
20 EVENTS
$\Gamma(\hat{\rho} \to \pi\gamma) \times BR(\hat{\rho} \to \pi f_1)$
= 1000 KeV

WE
ASSUMED
$\Gamma(\hat{\rho} \to \pi\gamma)$
= 75-750
KeV
FROM
VDM



PRIMAKOFF AND PHOTOPRODUCTION (HYBRIDS)

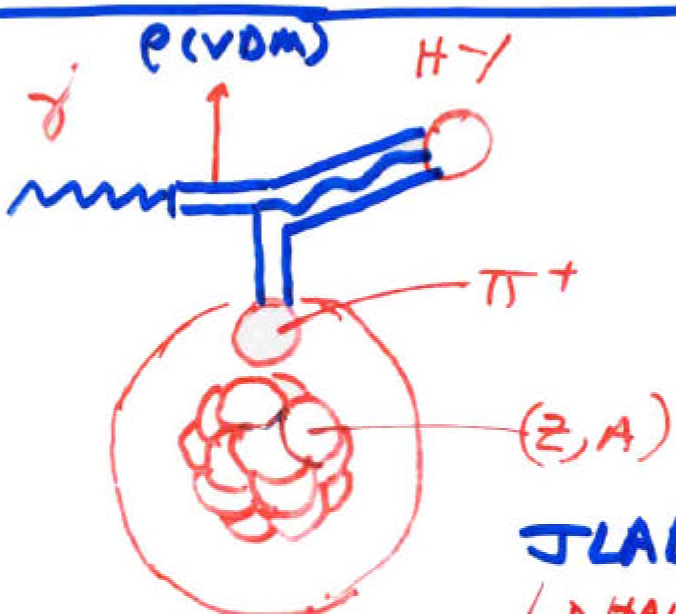
HY $\leftrightarrow$ $\rho\pi$ COUPLING REQUIRED



COMPASS

VDM: USE VIRTUAL ρ FOR HYBRID MESON PRODUCTION

VIRTUAL PHOTON IN COULOMB FIELD (PHOTON TARGET)



TAGGED γ PRODUCTION WITH PION CLOUD

JLAB, MAMI-C, ELSA

↳ HALL D UPGRADE, $150M

HYBRIDS

WHY PRIMAKOFF?

HYBRID (π_1, ETC.) COUPLES TO $\pi\rho$.

BY VDM, EXPECT

$$\Gamma(\pi_1 \to \pi\gamma) = \frac{\alpha}{(\gamma_\rho^2/\pi)} \left(\frac{k_\gamma}{k_\rho}\right)^3 \Gamma(\pi_1 \to \pi\rho)$$

γ_ρ^2/π = ρ-γ COUPLING

$k_\gamma, k_\rho \Rightarrow$ C.M. MOMENTA IN π_1 FRAME.

ASSUME $\Gamma(\pi_1 \to \pi\rho) = 10-100$ MeV
(BASED ON EXPERIMENT)

$$\downarrow$$

$\Gamma(\pi_1 \to \pi\gamma) = 75-750$ KeV

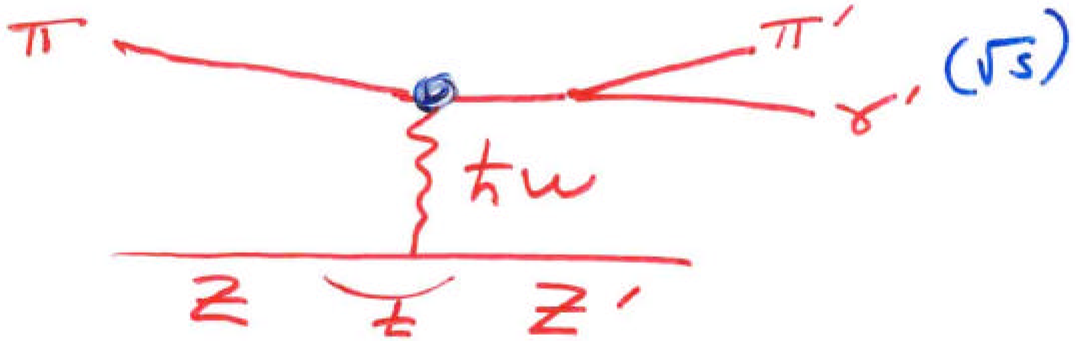
* 190 GeV π BEAM $\Rightarrow$ $\boxed{125-1250\ \mu b}$
HYBRID PRODUCTION C.S.

COMPASS: 190 GeV π's
(PRIMAKOFF / STRONG) BEST AT $\boxed{190\text{ GeV}}$.

CLEAN, WELL UNDERSTOOD SIGNALS
WITH CLEAR t-DISTRIBUTION.
MINIMIZE FINAL STATE INTERACTIONS
GOOD COUNT RATE: 1.4 – 3.0 GeV
HYBRIDS

KINEMATICS

$$\pi + Z \longrightarrow \pi' + Z' + \gamma'$$



4 MOMENTA: p_π, p_Z, $p_{\pi'}$, $p_{Z'}$, k'

$$k = p_\gamma = p_Z - p_{Z'}$$

k IS 4-MOMENTUM TRANSFER TO Z.

$t = k^2 \equiv -m^2(v)$ (SMALL)

t_0 = MINIMUM t TO PRODUCE MASS $\sqrt{s}$.

$\sqrt{s}$ = MASS OF $\gamma'\pi'$ FINAL SYSTEM

* IN π RESTFRAME: $\omega = \frac{(s - m_\pi^2)}{2 m_\pi} = E_\gamma$

SELECT ω BY ANALYSIS CUTS

$$\frac{d\sigma}{dt\,ds\,d\Omega} = \frac{Z^2 \alpha_s}{\pi} \frac{t - t_0}{t^2} \frac{1}{s - m_\pi^2} \frac{d\sigma_{\gamma\pi}}{d\Omega}$$

EM CROSS SECTION, Z^2, $1/t$

*

$\pi^- + Z \rightarrow \pi^- + \gamma + Z$

ANTIPOV ET AL, 40 GeV

~ 7000 EVENTS

$\sigma \simeq Z^2$

PRIMAKOFF COULOMB PEAK

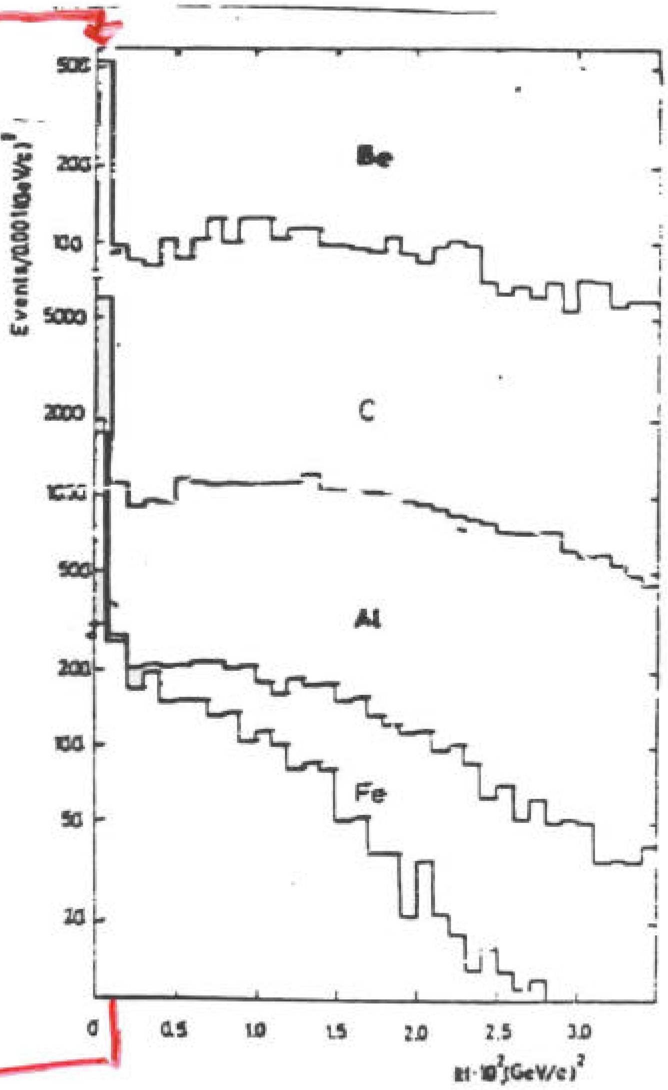


Fig. 2. Distribution of events over four-momentum transfer for Be, C, Al, and Fe targets.

HIGHER ENERGY AT COMPASS

⇓

LOWER t

SMALLER STRONG BKGD

MORE COMPLETE ANGULAR ACCEPTANCE

C12 STRONG BKGD 2.5% AT 40 GeV

$t \simeq 10^{-3}\ \mathrm{GeV}^2$

FOUR-MOMENTUM TRANSFER TO TARGET NUCLEUS

* $\pi^- + Z \rightarrow \pi^- + \gamma + Z$

ANTIPOV ET AL, 40 GeV

~7000 EVENTS

$\sigma \simeq Z^2$

PRIMAKOFF COULOMB PEAK

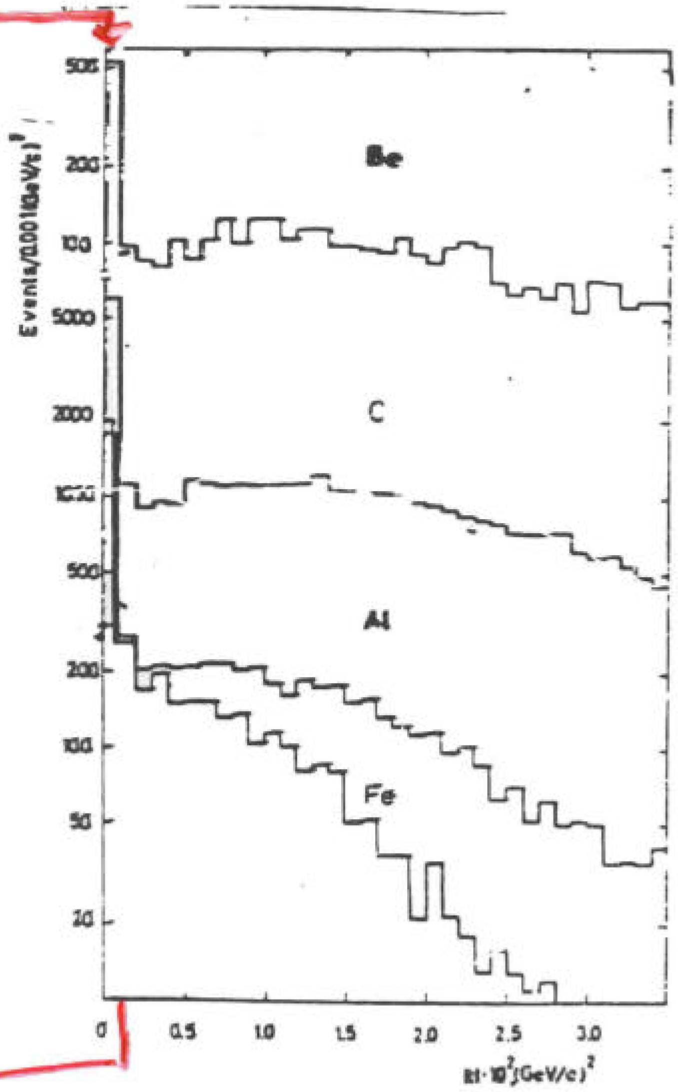


Fig. 2. Distribution of events over four-momentum transfer for Be, C, Al, and Fe targets.

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C12 STRONG BKGD 2.5% AT 40GeV

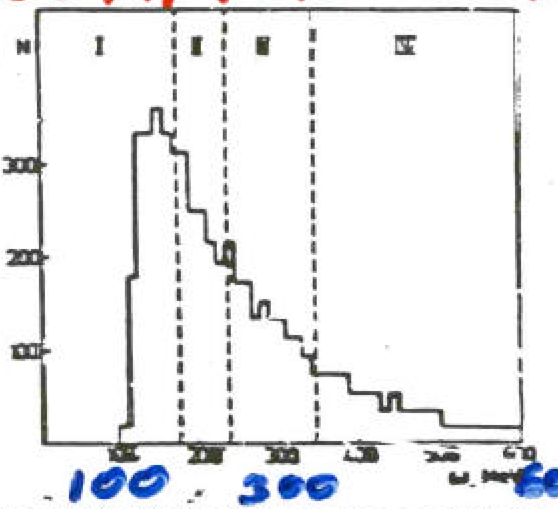
$t \simeq 10^{-3}\,\mathrm{GeV}^2$

FOUR-MOMENTUM TRANSFER TO TARGET NUCLEUS

40 GeV SERPUKHOV
π COMPTON SCAT.:

EVENTS VS. E_γ

$$w = \frac{(s_1 - m_\pi^2)}{2 m_\pi}$$



π REST FRAME

Fig. 2. Distribution of the pion Compton-effect events in the pion rest frame over the incident photon energy ω_1

$$\gamma \pi \rightarrow \gamma \pi$$

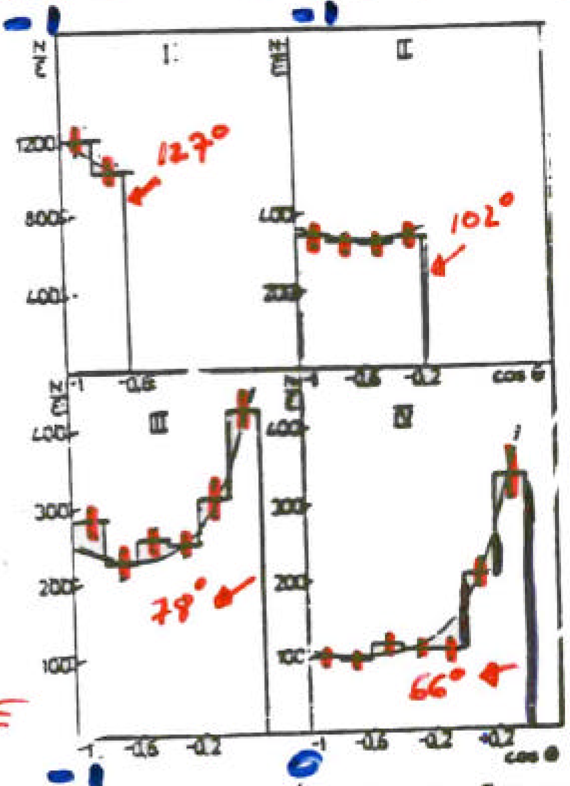
ANGULAR DISTRIBUTION

≈ 90-180°

RESTRICTED
ANGULAR
ACCEPTANCE

⇓

COMPASS
CLOSE
TO
FULL
ACCEPTANCE



7000 EVENTS

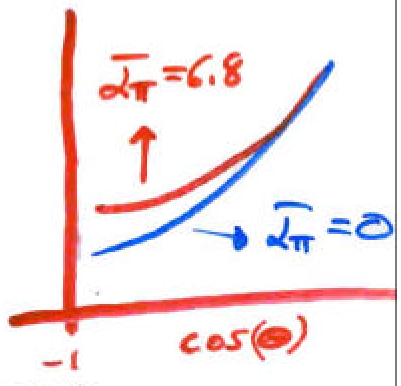
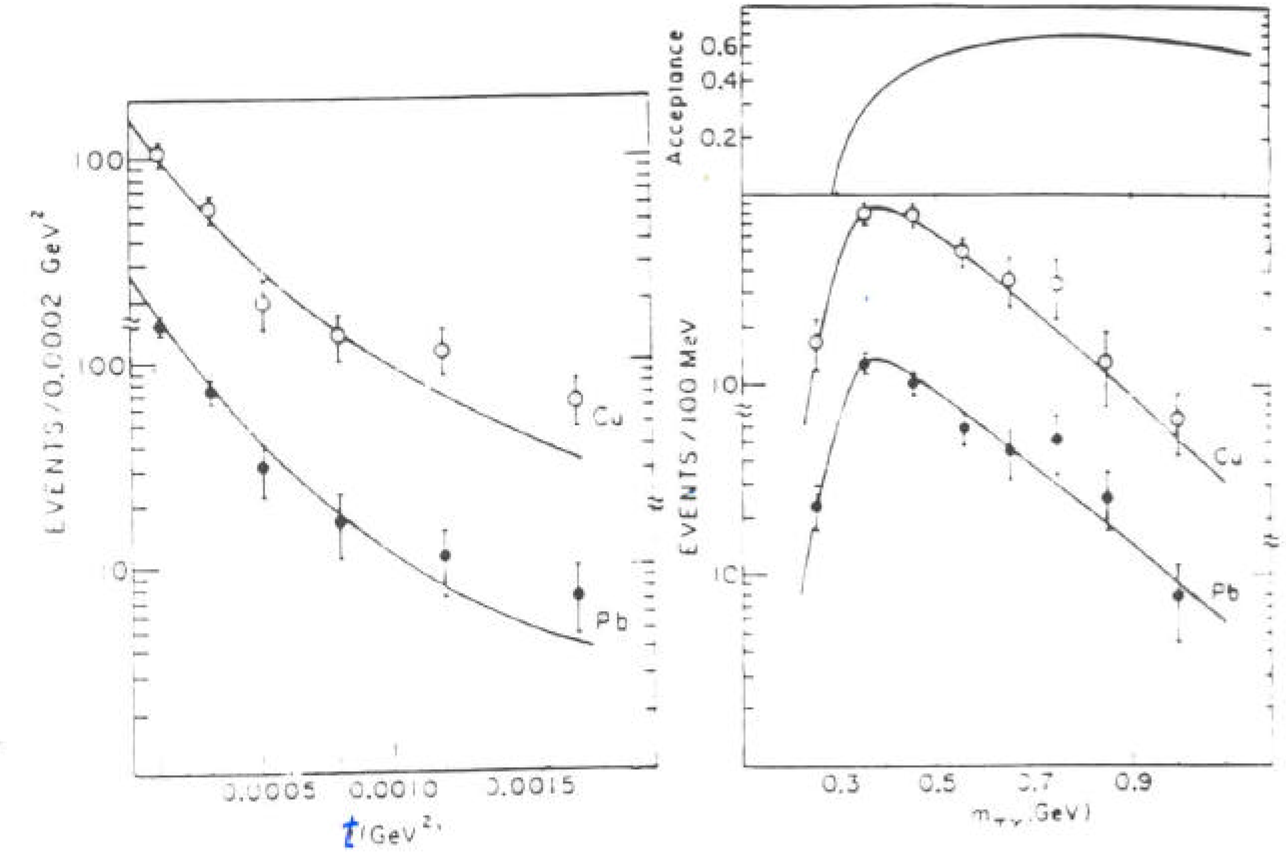


Fig. 3. Spectra of the pion Compton-effect events over cos θ, corrected for detection efficiency, for different ω_1-regions. Solid line is the result of fit with polarizabilities

E 272 $\pi^+ A \to \pi^+ \gamma A$ 200 GEV

PRIMAKOFF COMPTON SCATTERING

CURVES: ABSOLUTE QED PREDICTION!
(+ DETECTOR RESOLUTION)

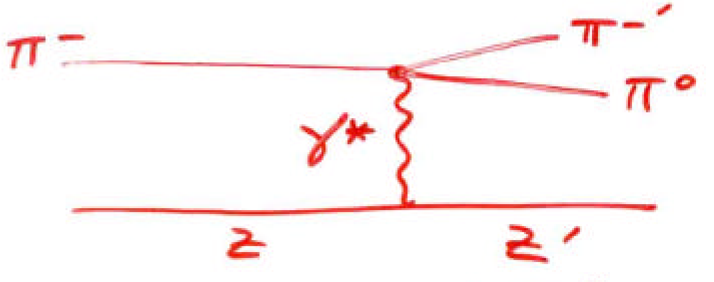


SMALL DEVIATION EXPECTED
→ MEASURE π POLARIZABILITIES

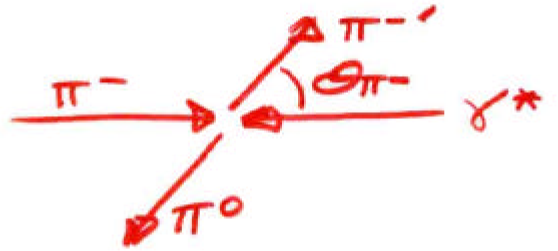
t-DISTRIBUTION FOLLOWS PRIMAKOFF — STRONG BACKGROUNDS NEGLIGIBLE. 200 GeV PREFERRED TO 40 GeV SERPUKHOV.

CHIRAL ANOMALY

$$\pi^- \, Z \longrightarrow \pi^{-'} \, Z' \, \pi^0$$



$) \sqrt{s} = M(\pi^- \pi^0)$



$$P_\gamma = P_Z - P_{Z'} \qquad t = P_\gamma^2$$

$$\frac{d\sigma}{dt\,ds\,d\Omega} = \frac{Z^2 \alpha}{\pi} \, \frac{1}{s - m_\pi^2} \, \frac{t - t_0}{t^2} \, \frac{d\sigma_{\gamma\pi}}{d\Omega}$$

$$\frac{d\sigma_{\gamma\pi}}{d\Omega} = \frac{(F_{3\pi})^2}{128\pi} \, \frac{s}{16\pi} \left(1 - \frac{4 m_\pi^2}{s}\right)^{3/2} (s - m_\pi^2) \sin^2 \theta_{\pi^-}$$

LOOK FOR $\sin^2 \theta_\pi$ COMPONENT

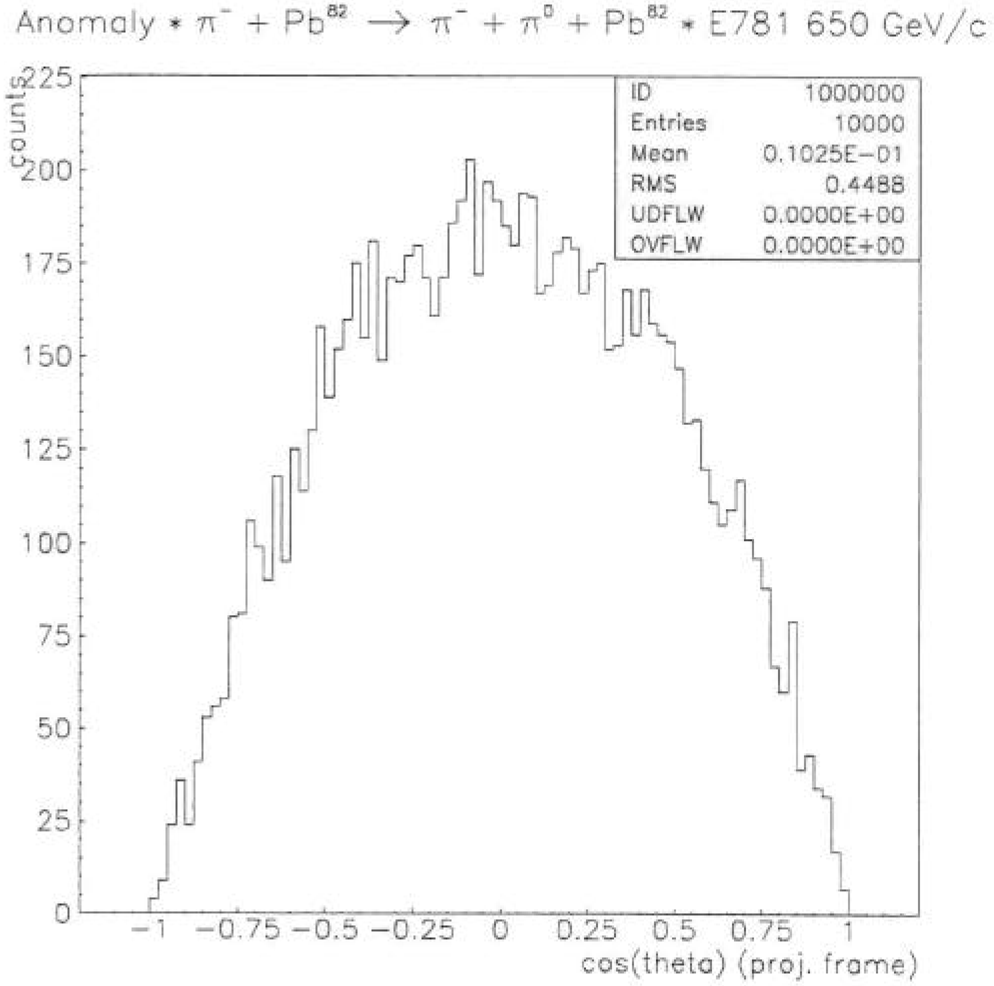
AT LOW $\sqrt{s} = M(\pi^- \pi^0)$

ABSOLUTE CROSS SECTION

FIXES $F_{3\pi}(0)$

*

CHIRAL ANOMALY SIMULATIONS
WITH "ANOMALY" GENERATOR.



EXP. PROGRAM STATUS

Ⓐ POLARIZABILITIES

LAB	REACTION	STATUS
SERPUKHOV	$\pi^-\gamma^* \to \pi^-\gamma$ $(\pi^- Z \to \pi^- Z \gamma)$	PUBLISHED ± ?
CERN COMPASS	$\pi^-\gamma^* \to \pi^-\gamma$ $K^-\gamma^* \to K^-\gamma$	≥ 2003
MAINZ	$\gamma\pi^+ \to \gamma\pi^+$ $(\gamma p \to \gamma\pi^+ n)$	2000 – 2003
JLAB+GRAL	$\gamma\pi^+ \to \gamma\pi^+$	> 2004

Ⓑ $\gamma \to 3\pi$ CHIRAL ANOMALY

LAB	REACTION	STATUS
SERPUKHOV	$\pi^-\gamma^* \to \pi^-\pi^0$ $(\pi^- Z \to \pi^- Z \gamma)$	PUBLISHED ± ?
JLAB	$\gamma\pi^+ \to \pi^0\pi^+$ $(\gamma p \to \pi^0\pi^+ n)$ $\vec{\gamma}\pi^+ \to \pi^0\pi^+$	2002 > 2004
CERN COMPASS	$\pi^-\gamma^* \to \pi^-\pi^0$ $\pi^-\gamma^* \to \pi^-\eta$	≥ 2003 ≥ 2003 (+VES)
CERN COMPASS	$\pi^- e \to \pi^-\pi^0 e$	! POSSIBLE

* + MANY THEORY PAPERS

($q\bar{q}g$) HYBRID MESONS

*

© HYBRIDS

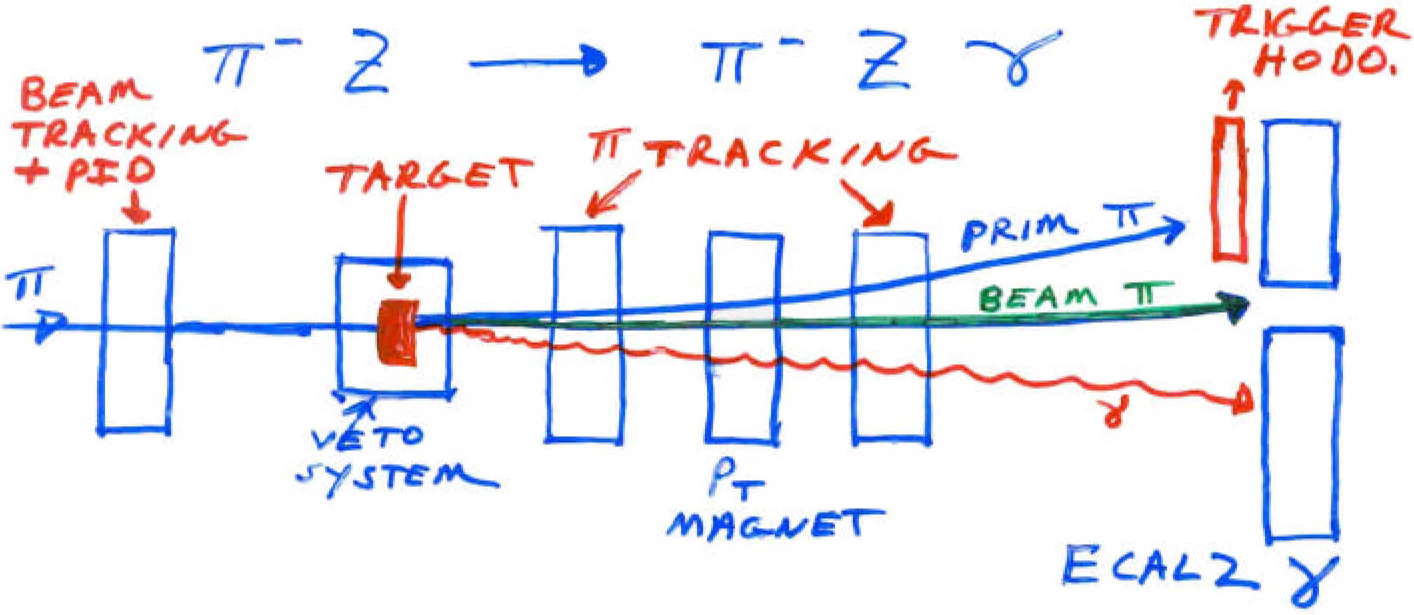
LAB	REACTION	STATUS
BNL, VES, CB, KEK	$\pi^- p \to$ HYBRID $p\bar{p} \to$ HYBRID	??? PUBLISHED
JLAB HALL-D	$\gamma\pi^+ \to$ HYBRID ($\gamma p \to$ HYBRID$+n$)	> 2005 ≈ $150 M
GSI HESR	$p\bar{p} \to$ HYBRID	> 2005
CERN COMPASS	$\pi^- \mathbb{P} \to$ HYBRID (DIFFRACTIVE PROD.)	> 2003
CERN COMPASS	$pp \to$ GLUEBALL $pp \to$ HYBRID (CENTRAL PROD.)	> 2003
CERN COMPASS	$\pi^-\gamma^* \to$ HYBRID [$K^-\gamma^* \to$ HYBRID] (PRIMAKOFF PROD.)	> 2003

+ NEW HADRON FACILITY (KEK, JAPAN)
+ τ-CHARM BEIJING + NOVOSIBIRSK,
CLEO-III, BABAR & BELLE, DAΦNE,
RHIC@BNL, LHC, ..., + $K^- p \to (s\bar{s}g)\,\Lambda$, ...

+ NARROW HYBRID CHARMONIUM $c\bar{c}g$,
< 4.3 GeV, EASIER TO ANALYZE

SCHEMATIC: POLARIZABILITY SETUP

$$\pi^- Z \longrightarrow \pi^- Z \gamma$$



① BEAM TRACKING – MEASURE P_π
PID: K VS. π VIA CEDARS CERENKOV

② TARGET: 3 mm Pb
VETO: SCINTILLATORS

③ DOWNSTREAM π TRACKING: MEASURE P'_π

④ SM1/SM2 P_T MAGNETS: MOMENTUM ANALYSIS

⑤ TRIGGER HODOSCOPES: TAG PRIMAKOFF
PIONS WHICH LOST >25% EBEAM.
NO TRIGGER FOR NON-INTERACTING BEAM π.

MORE SOPHISTICATED ENERGY LOSS TRIGGER
POSSIBLE WITH HODOSCOPE PAIR AFTER MAGNET.

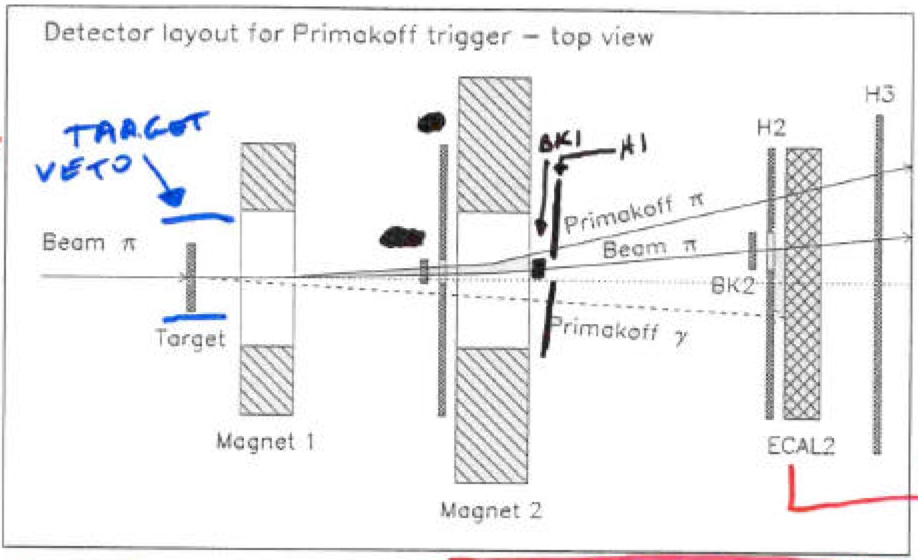
BEAM π'S PASS THROUGH HOLE IN ECAL2.

⑥* γ DETECTION: ECAL2 EM CALORIMETER,
MEASURE POSITION & ENERGY OF γ
FOR E_γ > 25% EBEAM. 8000 CHANNELS BEST.

⑦ πγ COINCIDENCE FOR POLARIZABILITY.

HADRON-PHOTON INTERACTIONS AT COMPASS (CERN)

NEW FIELD



NOT POSSIBLE AT SELEX

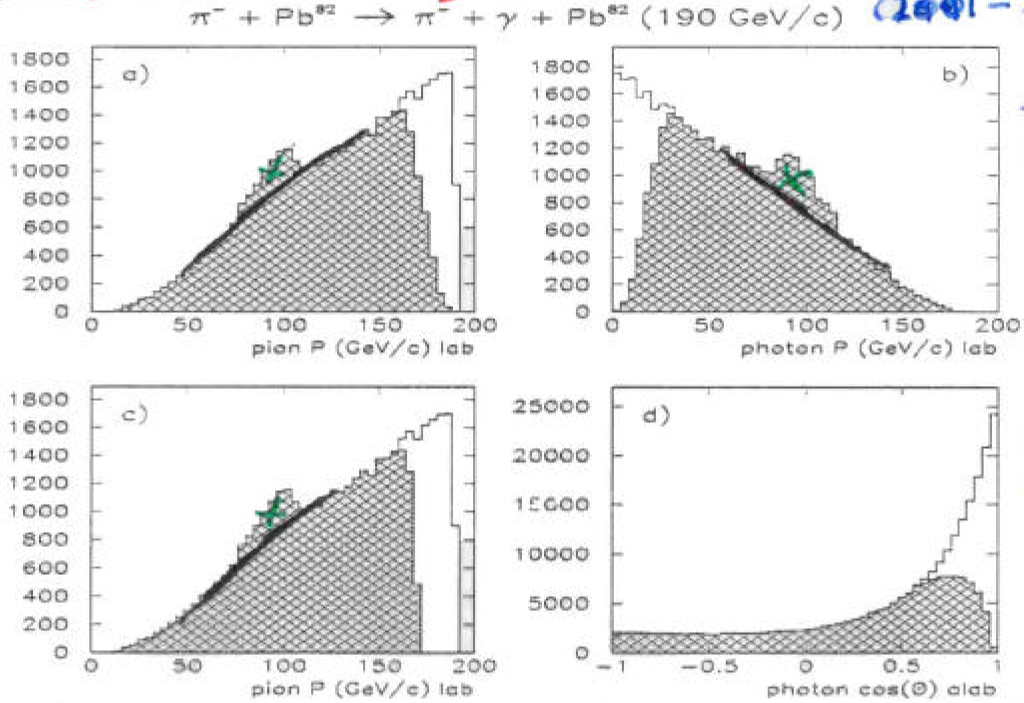
SIZE IMPORTANT

PRIMAKOFF TRIGGER: π POLARIZABILITY $\pi\gamma \to \pi\gamma$, CHIRAL ANOMALY $\pi\gamma \to \pi\pi^0$, $\pi\gamma \to$ HYBRIDS

ALSO KAON BEAM PHYSICS

Figure 2: Detector layout for the COMPASS Primakoff trigger. BK1,BK2=beam killer system, H1,H2,H3=hodoscope system for charged particle vetoing and Primakoff pion detection, ECAL2=second-photon calorimeter.

*COMPASS $\pi\gamma$ PRIMAKOFF INTERACTION PROGRAM. 190 GeV/c, DEDICATED TRIGGER, DEDICATED EXPERIMENT, LOWER BACKGROUNDS, IMPROVED STATISTICS, 6 YEAR EXPERIMENT (2001 – 2007)



FOR μ & π PHYSICS

GOOD ACC.

ACCEPTANCE STUDIES OF TRIGGER

Figure 3: MC simulation of the pion polarizability measurement in the COMPASS 190 GeV/c beam: (a), (b) - Effect of beam killer system on the acceptance of the Primakoff pion and photon momentum distributions; (c) - Effect on Primakoff pion momenta distribution of beam killer system together with ECAL2 set at 20 GeV lower threshold; (d) - Acceptance for $\gamma\pi \to \gamma\pi$ angular distribution versus $\cos(\theta)$, with θ the γ scattering angle in the alab frame. The hatched areas of the histograms correspond to kinematic regions accepted by the trigger.

POLARIZABILITY STATISTICS

AT 2×10^7 π/S DURING BEAM BURST, WITH 31% D.C., FOR 2 MONTH RUN, GET 3.2×10^{13} BEAM PIONS.

PRIMAKOFF INT. PROB., $R = \sigma N_T$

$\sigma_{pol.} = 0.5$ mb, $N_T = 10^{22}$ cm^{-2}, $R = 5 \times 10^{-6}$

GLOBAL RUN EFFICIENCY $\epsilon_R = 24\%$

DUE TO TRACKING (92%), γ DETECT. (58%), ACC. & COMPASS OPERATION (60%), ANALYSIS CUTS TO REDUCE BACKGROUNDS (75%).

$$\left.\begin{array}{l}\text{POLARIZABILITY}\\ \text{EVENTS}\end{array}\right\} \boxed{\begin{array}{l} 4 \times 10^7 \\ 6 \times 10^5 \end{array}} \begin{array}{l}\text{FOR } \pi^- \\ \text{FOR } K^- \text{ [FIRST!]}\end{array}$$

* RETRIEVING π POLARIZABILITIES:

COMPASS THESIS SIMULATION STUDIES BY R. KUHN, M. SANS MERCE, M. COLANTONI.

GENERATE, RECONSTRUCT, ANALYZE π POL. EVENTS.

$\Delta \bar{\alpha}_\pi, \Delta \bar{\beta}_\pi < 0.1$ (STATISTICAL)

COMPASS STATISTICS $\approx$ 6000 * SERPUKHOV

ALLOWS CAREFUL SYSTEMATIC ERROR STUDIES

GOAL (SYST. + STAT.): $\Delta \bar{\alpha}_\pi \approx \Delta \bar{\beta}_\pi \approx 0.4$

+ FIRST KAON POL.

CHIRAL ANOMALY STATISTICS

SAME 2 MONTH RUN

3.2×10^{13} BEAM PIONS

PRIMAKOFF INT. PROB. $R = \sigma N_T$

$\sigma_{C.A.} = 120 \times 10^{-33}\ \mathrm{cm}^2$, $N_T = 10^{22}\ \mathrm{cm}^{-2}$

$(S_1(\pi^-\pi^0) = 4\text{–}10\ m_\pi^2)$ $R = 1.2 \times 10^{-9}$

GLOBAL RUN EFFICIENCY $\epsilon_R = \frac{24}{2}\%$

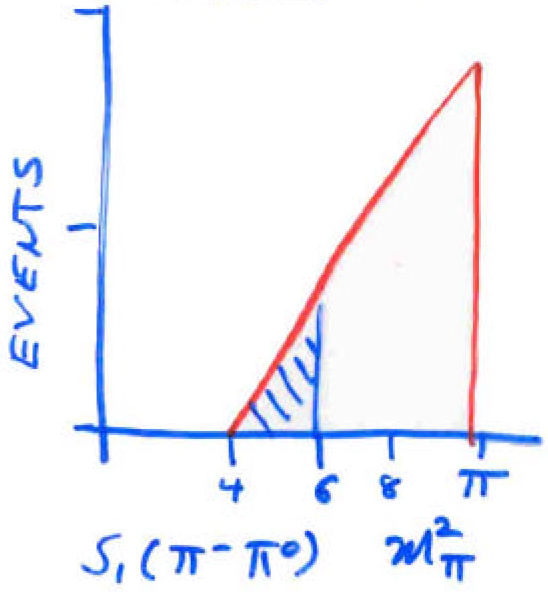
π^0 DETECTION EFF. ≈ 29%

NEED SIMULATIONS

C.A. EVENTS ≈ 4500 (25 × SERPUKHOV)

*TO REDUCE ERRORS EXTRAPOLATING TO THRESHOLD, WE AIM FOR GOOD STATISTICS IN $S_1(\pi^-\pi^0) = 4\text{–}6\ m_\pi^2$.

EXPECT 450



$\pi^-\gamma \longrightarrow \pi^-\pi^0$

AIM FOR EXCELLENT STATISTICS IN CLEAN HYPO-PERIPHERAL C.A. PRIMAKOFF REACTION VERSUS RECENT JLAB π POLE METHOD AND VERSUS PREVIOUS SERPUKHOV EXPERIMENT.

HYBRID STATISTICS

SAME 2 MONTH RUN

3.2 × 10^{13} BEAM PIONS

PRIMAKOFF INT. PROB. $R = \sigma N_T$

$\sigma_{HY}^{1.5GeV} = (125-1250) \times 10^{-30}\,cm^2$, $N_T = 10^{22}\,cm^{-2}$

$R = (1.2-12) \times 10^{-6}$ (FOR 1.5GeV HYBRID)

GLOBAL RUN EFF. $\epsilon_R = \frac{24}{2}\%$

NEED SIMULATIONS

CROSS SECTION IS FOR HYBRID EVENTS IN <u>ALL</u> DECAY CHANNELS

πf_1, $\pi \rho$, $b_1 \pi$, $\pi \eta$, $\pi \eta'$, ETC.

ASSUME FIXED $\Gamma(\text{HYBRID} \to \pi\gamma) = 75-750$ KeV

---

*

→ NEED STATISTICS IN EACH CHANNEL

m^{π}_{HYBRID} (GeV)	ALL CHANNELS
1.5	$(46-460) \times 10^5$
2.0	$(7.5-75) \times 10^5$
2.5	$(1.8-18) \times 10^5$
3.0	$(0.46-4.6) \times 10^5$

≈ 1.5% FOR KAONIC HYBRIDS

→ IF HYBRID → $\pi\rho$

POTENTIALLY GOOD STATISTICS EVEN UP TO $m^{\pi}_{\text{HYBRID}} = 3$GeV.

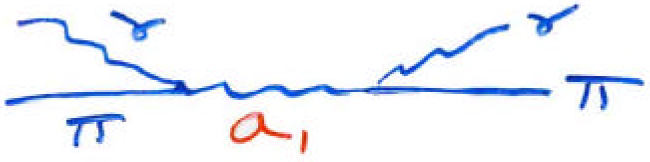
[FIRST POSSIBLE KAONIC HYBRIDS ($\bar{u}sg$)
FIRST <u>EVER</u> PRIMAKOFF STUDY]

POLARIZABILITY SUMMARY

(1) COMPASS PION (KAON) POLARIZABILITY STUDIES PLANNED, DEDICATED RUNS,
HIGH STATISTICS, FULL $d\sigma/d\Omega$.

(2) CALIBRATE VIA μ BEAM,
$\gamma\mu \to \gamma\mu$

(3) MEASURE ASSOCIATED RADIATIVE (a_1) TRANSITION



* (4) AIM FOR HIGH QUALITY COMPARISON OF THEORY (χ_{PT}, ETC.) AND EXPERIMENT.

(5) 4×10^{7} EVENTS, π^-
6×10^{5} EVENTS, K^-

(6) $\Delta\bar{\alpha}_\pi \simeq 0.4 \times 10^{-43}\ cm^3$ GOAL
FIRST KAON POLARIZABILITY

CHIRAL ANOMALY SUMMARY

(1) COMPASS $\pi^- \gamma^* \to \pi^- \pi^0$

CHIRAL ANOMALY STUDY CAN GIVE EXCELLENT STATISTICS IN 2 MONTHS.

(2) MAY GET DATA ALSO FOR $\pi^- \gamma^* \to \pi^- \eta$ AND $K^- \gamma^* \to K^- \pi^0$

(3) $\pi^- \gamma^* \to \pi^- \pi^0$ CHANNEL ALSO GIVES IMPROVED $\Gamma(\rho^- \to \pi^- \pi^0)$ RADIATIVE WIDTH.

(4) VERY COMPETITIVE WITH JLAB AND SERPUKHOV.

(5) CAN MAKE DEFINITIVE CHIRAL ANOMALY TEST AND SOLVE PAST AMBIGUITIES.

(6) JLAB DATA IS FAR FROM THRESHOLD, EXTRAPOLATION DIFFICULT.

*

HYBRID SUMMARY

(1) STUDY $\pi^- \gamma \rightarrow Hy \rightarrow \rho\pi, \eta\pi, \eta'\pi, b_1\pi, f_1\pi$
TO M(HYBRID) ≈ 3 GeV.

(2) COMPLEMENT JLAB, GSI (PAST)
AND BNL, VES, KEK, CB, ... (PAST)

(3) CHANGE (IMPROVE) PWA UNCERTAINTIES, IMPROVE RELATIVE STRENGTH OF HYBRID TO BACKGROUNDS. HELP DECIDE HYBRID VERSUS 4q VERSUS BACKGROUND.

(4) FINAL STATE INTERACTIONS REDUCED. b>>>R.

(5) PRIMAKOFF SEES HYBRIDS THAT COUPLE TO $\pi\rho$.
REDUCES OVERLAPPING STATES

(6) SUPPRESS MESON EXCHANGE BACKGROUNDS BY t-CUT.

(7) SEPARATE PRIMAKOFF & DIFFRACIVE BY SHARP LOW-t PRIMAKOFF PEAK.

[(8) TRY FOR KAONIC HYBRIDS.]
*

CONCLUSIONS

① GOOD PROSPECTS FOR PION (KAON) POLARIZABILITIES AND RADIATIVE TRANSITIONS VIA PRIMAKOFF SCATTERING

② GOOD PROSPECTS FOR CHIRAL ANOMALY TEST VIA MEASURE $\gamma \to 3\pi$ $F_{3\pi}$ AMPLITUDE

③ SEARCH FOR HYBRID (EXOTIC) MESONS VIA PRIMAKOFF. CLEAN, GOOD STATISTICS, UP TO 3GeV MASS, [ALSO KAONIC HYBRIDS.]

UNIQUE OPPORTUNITY FOR CERN COMPASS.

FOR VARIED, QUICK, HIGH-YIELD, HIGH INTEREST, PHYSICS OUTPUT