Decays into $\pi^+\pi^-$ of the $f_0(1370)$ scalar glueball candidate in pp central exclusive production experiments

Ugo Gastaldi and Mirko Berretti

4° Elba Workshop on Forward Physics @LHC Energy May 2018

STAR low l-tl data + general features of CEP exps.:

clear evidence of f0(1370) existence from decays into π+π- in pp CEP

continuum may stop before 1100 MeV (''red dragon'' split) at lowl-tl

high $\sqrt{s}$ low $l-t$ l enhances 0++ depresses 2++ production

status of scalar glueball search

pp CEP evolution

Φ, $\sqrt{s}$, $l-tl$ dependences

STAR data

open problems after assessment of independent existence of f0(1370)

outlook

references to experimental and theoretical work in

arXiv:1804.09121 hep-ph

Conclusions of 2013 Ochs review on glueballs

IOP Publishing — Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **40** (2013) 043001 (68pp) doi:10.1088/0954-3899/40/4/043001

TOPICAL REVIEW

The status of glueballs

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Abstract

Calculations within QCD (lattice and sum rules) find the lightest glueball to be a scalar with mass in the range of about 1000–1700 MeV. Several phenomenological investigations are discussed which aim at the identification of the scalar meson nonets of lowest mass and the super-numerous states if any. Results on the flavour structure of the light scalars $f_0(500)$, $f_0(980)$ and $f_0(1500)$ are presented; the evidence for $f_0(1370)$ is scrutinized. A significant surplus of leading clusters of neutral charge in gluon jets is found at LEP in comparison with MCs, possibly a direct signal for glueball production; further studies with more energetic jets at LHC are suggested. As a powerful tool in the identification of the scalar nonets or other multiplets, along with signals from glueballs we propose the exploration of symmetry relations for decay rates of $C = +1$ heavy quark states like χ_c or χ_b. Results from χ_c decays are discussed; they are not in support of a tetra-quark substructure of $f_0(980)$. A minimal scenario for scalar quarkonium-glueball spectroscopy is presented.

(Some figures may appear in colour only in the online journal)

11. Summary and conclusions

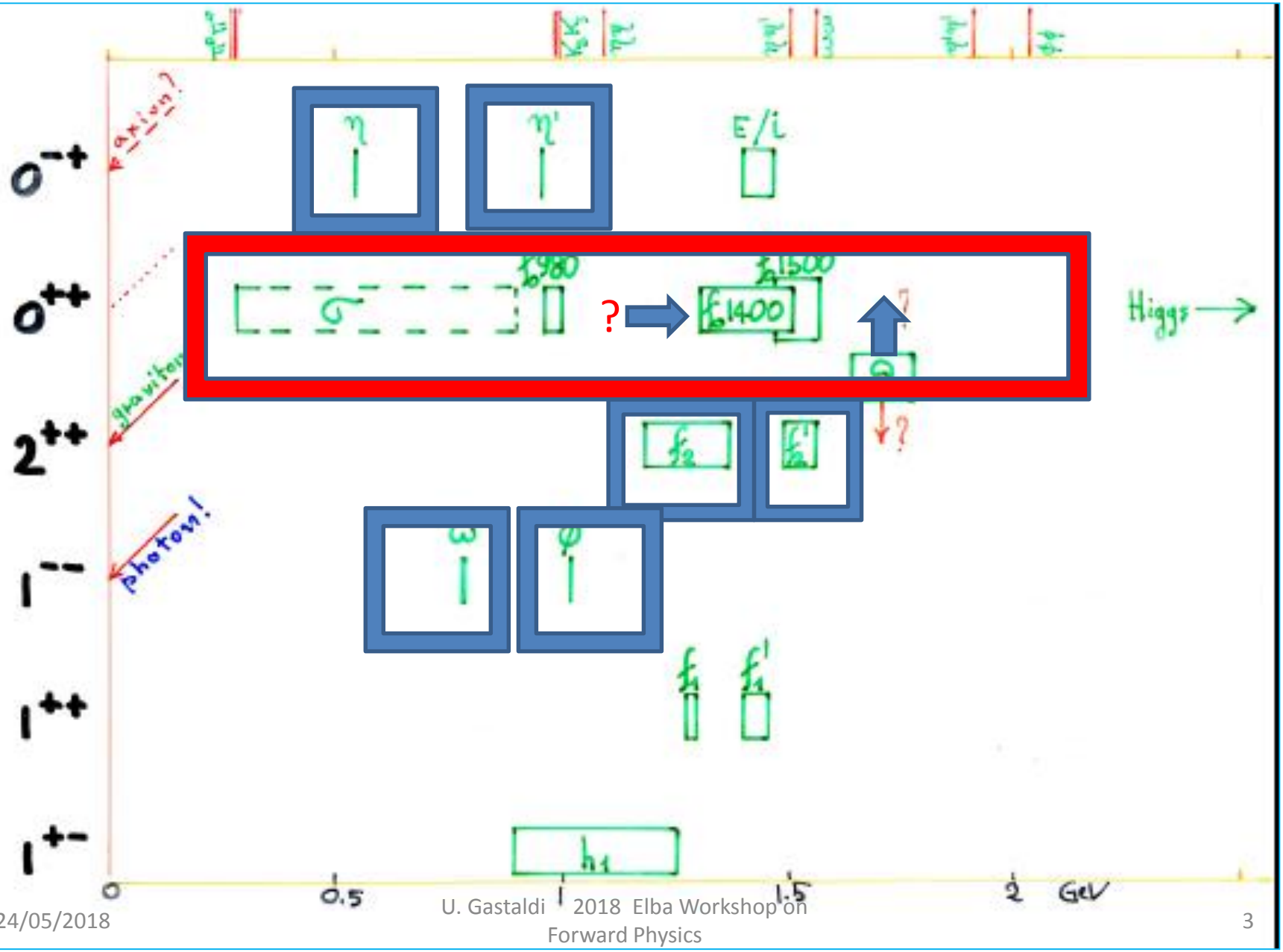
In a summary of our results we try to answer some questions and we provide a minimal mixing scenario for the scalar mesons with glueball which takes into account some relevant findings.

11.1. Is there any experimental evidence for the existence of glueballs?

We have studied different scenarios for a scalar meson spectroscopy which includes the lightest glueball of QCD. None of the schemes considered is without problem. It remains unsatisfactory, if the existence of the glueball as a fundamental prediction of QCD, at the end depends on whether such a controversial state like $f_0(1370)$ does exist. We have therefore looked after other criteria as well.

There appears to be one observation which can be considered as a direct hint for the existence of glueballs. That is the observation of several LEP experiments that the leading system in a gluon jet has an excess of neutral charge, in one measurement by 40%, if compared

58


0^{-+}
0^{++}
2^{++}
1^{--}
1^{++}
1^{+-}
axion?
graviton
photon!
η
η'
E/i
$f_0(980)$
σ
?
$f_0(1500)$
$f_0(1400)$
Higgs
?
f_2
f_2'
ω
ϕ
f_1
f_1'
h_1
0
0.5
1
1.5
2
GeV

Scalar mesons and glueballs

σ, f0(980), f0(1370), f0(1500), f0(1710)

too many candidates for 2 places in scalar mesons nonet

several scenarios envisaged

σ + f0(1370) = ''red dragon'' gluonium ?? continuum ??

σ and f0(980) the two isoscalar scalars of 0++ nonet
and 2 of the other 3 radial exitations??

σ with large gg content ??

f0(980) qbarqbarqq tetraquark state ?? KKbar molecule ??

3 of the high mass 0++ from mixing of 0++ gg and 2 qqbar ??

Essential to assess independent existence of f0(1370) meson and confirm mass, width and decay BR measured in pbar at rest exps.

$f_0(1710)$ [t]

$I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 1723^{+6}_{-5}$ MeV (S = 1.6)
Full width $\Gamma = 139 \pm 8$ MeV (S = 1.1)

$f_0(1710)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}$	seen	706
$\eta\eta$	seen	665
$\pi\pi$	seen	851
$\omega\omega$	seen	360

$f_0(1500)$ [n]

$I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 1504 \pm 6$ MeV (S = 1.3)
Full width $\Gamma = 109 \pm 7$ MeV

$f_0(1500)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
$\pi\pi$	(34.9±2.3) %	1.2	740
$\pi^+\pi^-$	seen		739
$2\pi^0$	seen		740
4π	(49.5±3.3) %	1.2	691
$4\pi^0$	seen		691
$2\pi^+2\pi^-$	seen		686
$2(\pi\pi)_{S\text{-wave}}$	seen		–
$\rho\rho$	seen		†
$\pi(1300)\pi$	seen		143
$a_1(1260)\pi$	seen		217
$\eta\eta$	(5.1±0.9) %	1.4	515
$\eta\eta'(958)$	(1.9±0.8) %	1.7	†
$K\overline{K}$	(8.6±1.0) %	1.1	568
$\gamma\gamma$	not seen		752

Citation: C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016)

$f_0(1370)$ [j]

$I^G(J^{PC}) = 0^+(0^{++})$

Mass m = 1200 to 1500 MeV
Full width Γ = 200 to 500 MeV

$f_0(1370)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	seen	672
4π	seen	617
$4\pi^0$	seen	617
$2\pi^+2\pi^-$	seen	612
$\pi^+\pi^-2\pi^0$	seen	615
$\rho\rho$	dominant	†
$2(\pi\pi)_{S\text{-wave}}$	seen	–
$\pi(1300)\pi$	seen	†
$a_1(1260)\pi$	seen	35
$\eta\eta$	seen	411
$K\overline{K}$	seen	475

f0(1370) cinderella 0++ scalar isoscalar meson of PDG

Citation: C. Patrignani et al. (Particle Data Group), Chin. Phys. C, 40, 100001 (2016)

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$K\overline{K}$	seen	475

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Mass m = 1504 ± 6 MeV (S = 1.3)
Full width Γ = 109 ± 7 MeV

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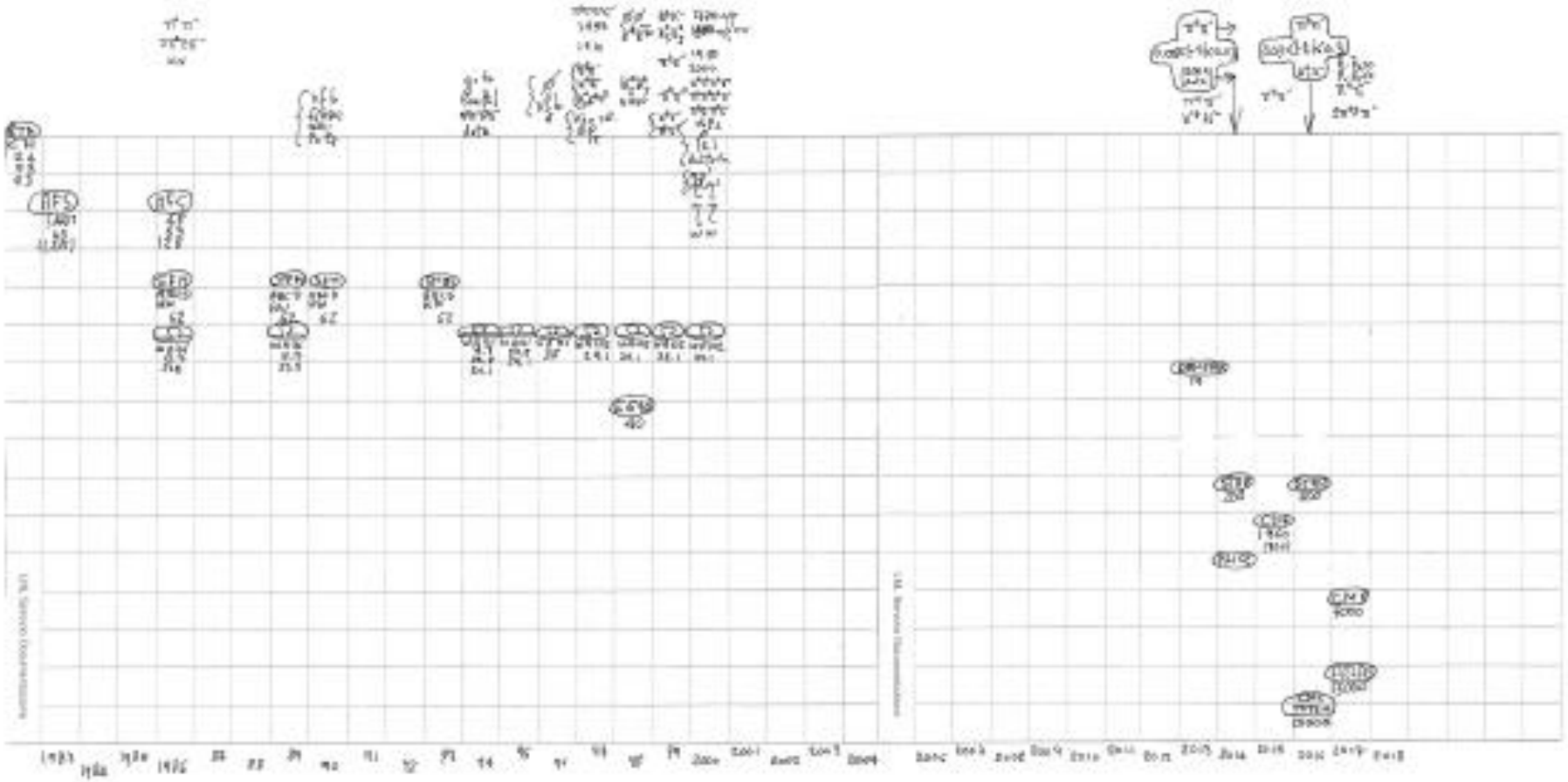
$f_0(1710)$ [r] $I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 1723^{+6}_{-5}$ MeV (S = 1.6)
Full width Γ = 139 ± 8 MeV (S = 1.1)

$f_0(1710)$ DECAY MODES	Fraction (Γ_j/Γ)	p (MeV/c)
$K\overline{K}$	seen	706
$\eta\eta$	seen	655
$\pi\pi$	seen	851
$\omega\omega$	seen	360

35 years of CEP



dependence on the angle ϕ between the scattering planes of the two protons
ABCDHW Collab. at SFM

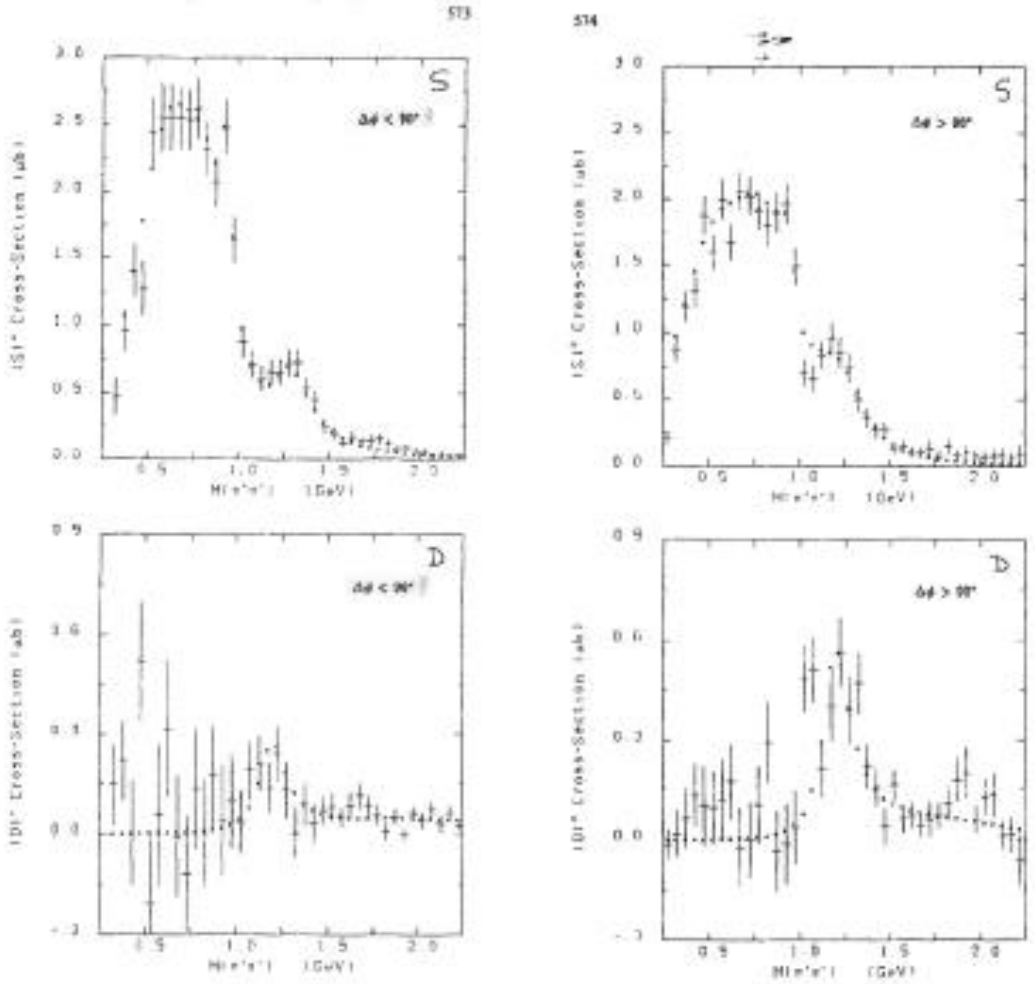
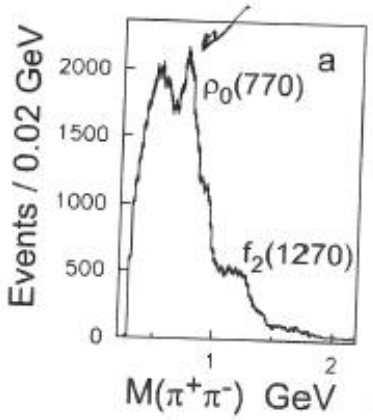


Fig. 8: Dependence on the angle ϕ between the scattering planes of the two protons in pp CEP measured at SFM (from [38])

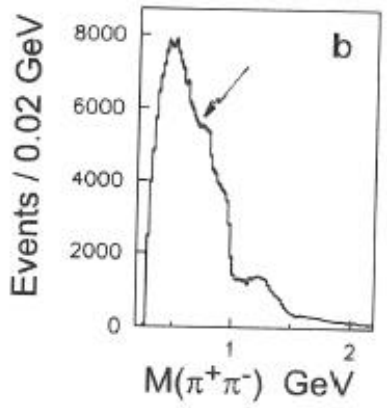
√s effect

$\sqrt{s} = 12.7$ GeV



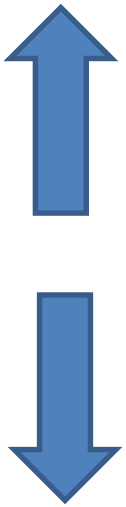
WA76

$\sqrt{s} = 29$ GeV



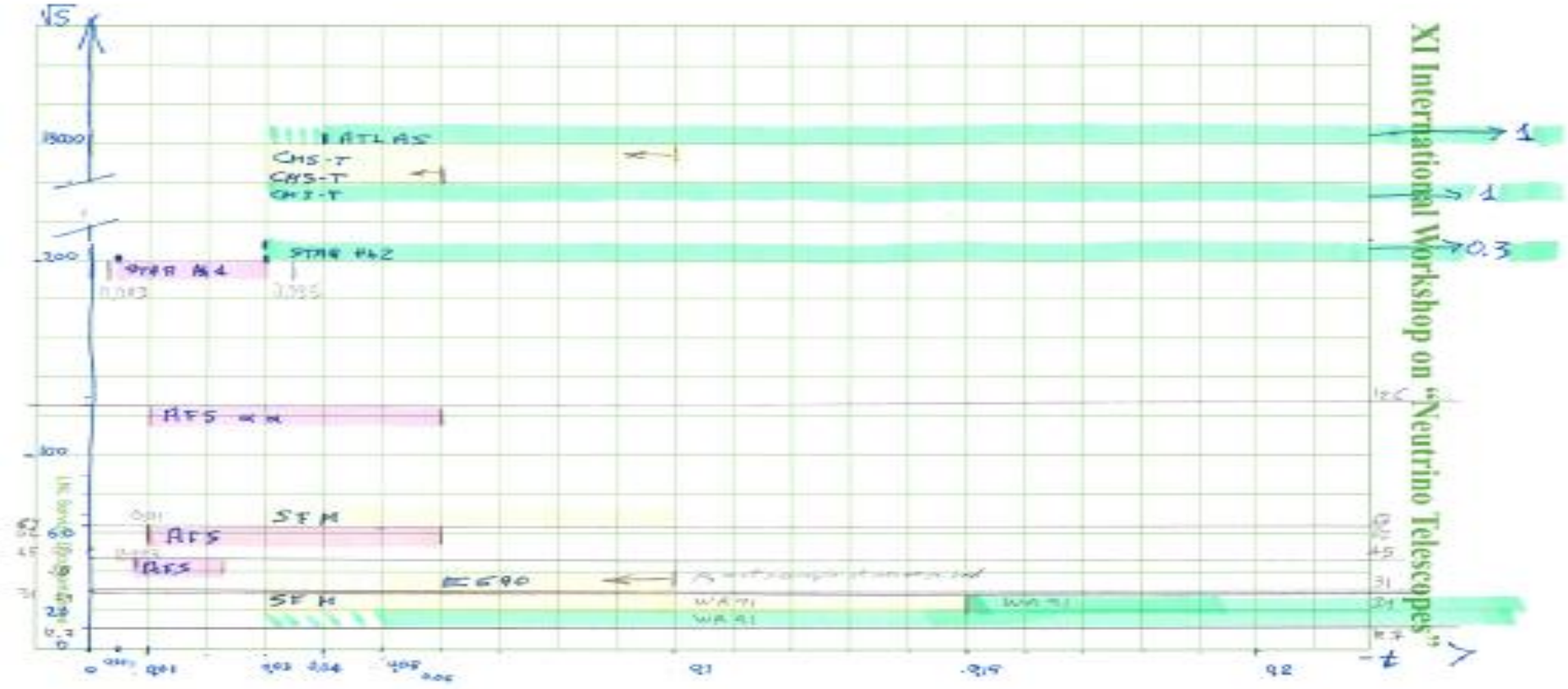
√s

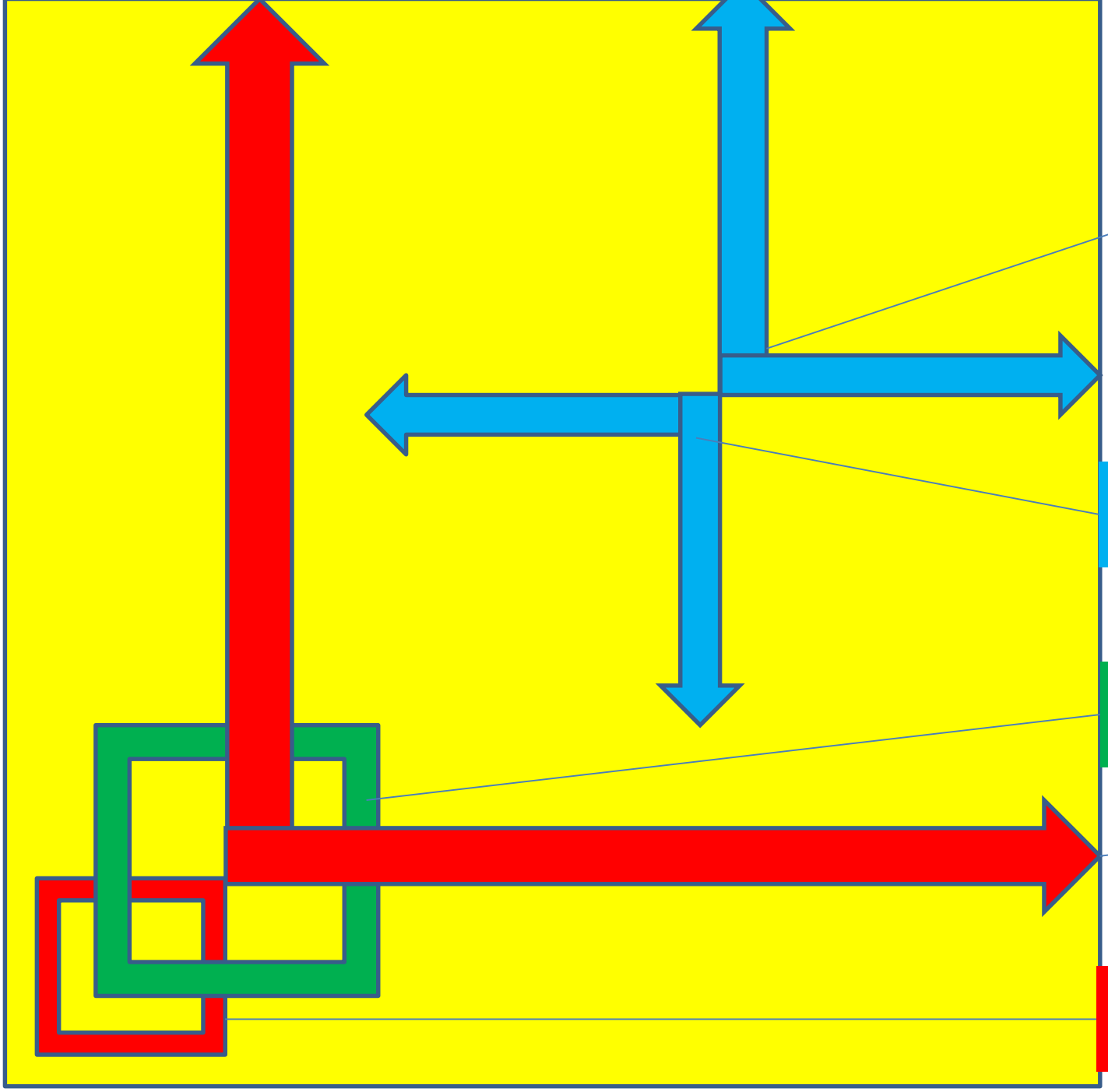
1--



Increasing cms $\sqrt{s}$ energy $J^{PC} = 1^{--}$ and other non 0^{++}, 2^{++} meson production in CEP is depressed

$\sqrt{s}$ *and* l-tl coverage of several pp CEP exps.

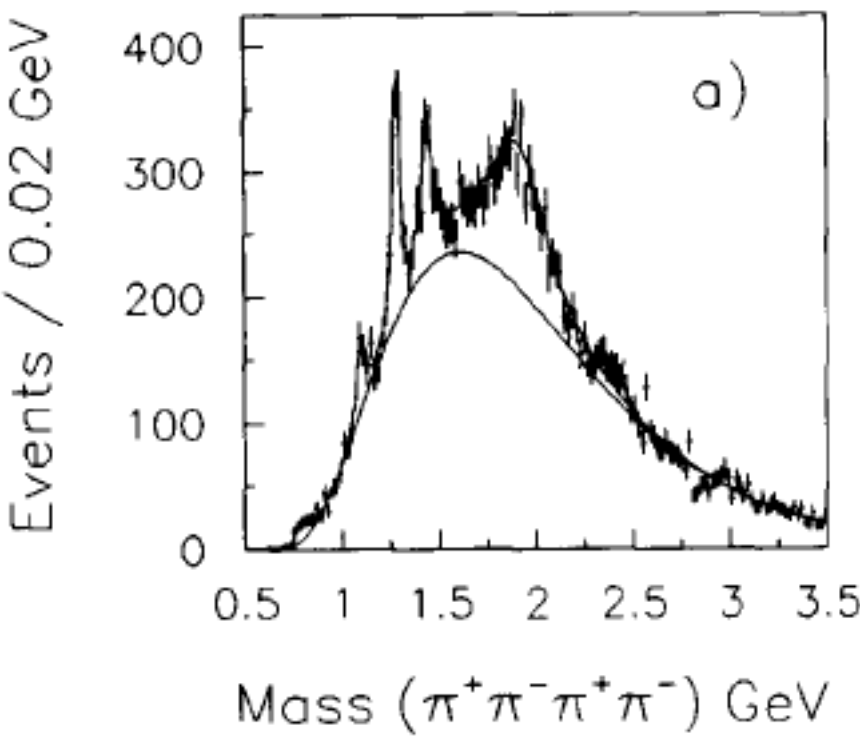



WA91 29 GeV
0.15 < l-t l
WA91 29 GeV
l-t l < 0.15 GeV2
AFS at ISR 63 GeV
0.01< l-t l<0.06 GeV2
STAR 200 GeV
0.03 < l-t l
STAR 200 GeV
0.003< l-t l<0.03 GeV2

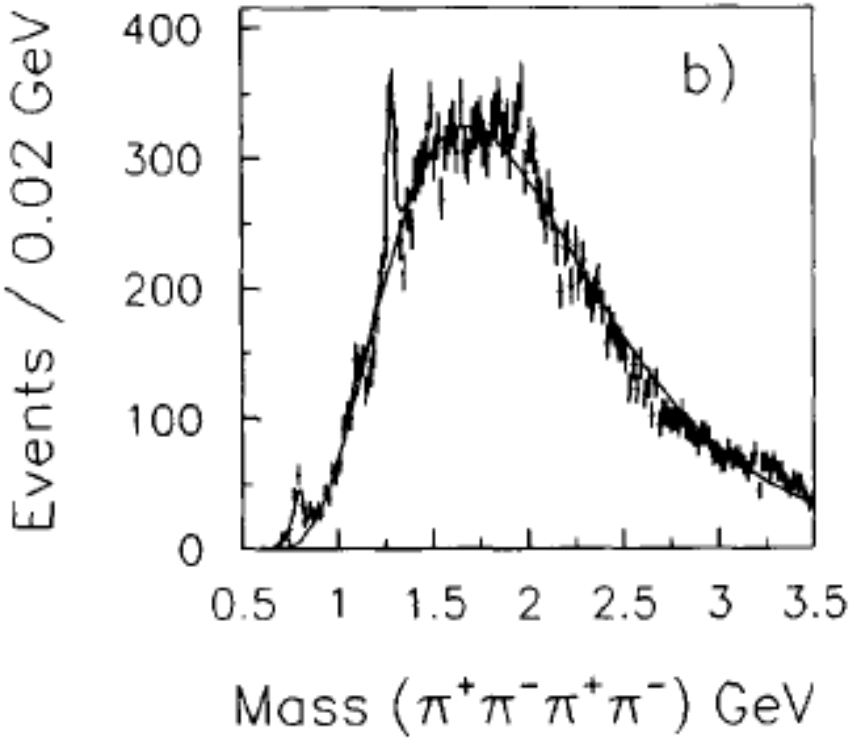
effect of l-tl cut at same √s = 29 GeV

WA91

l-tl < 0.15 GeV2

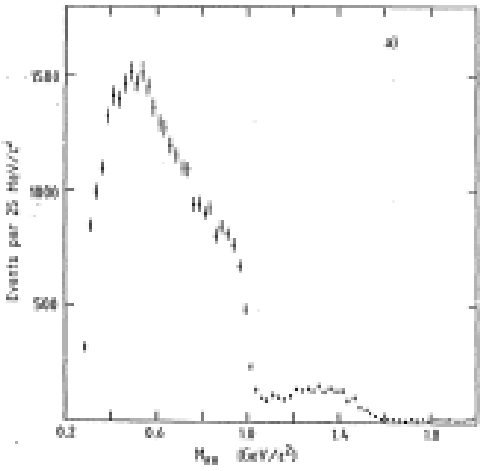


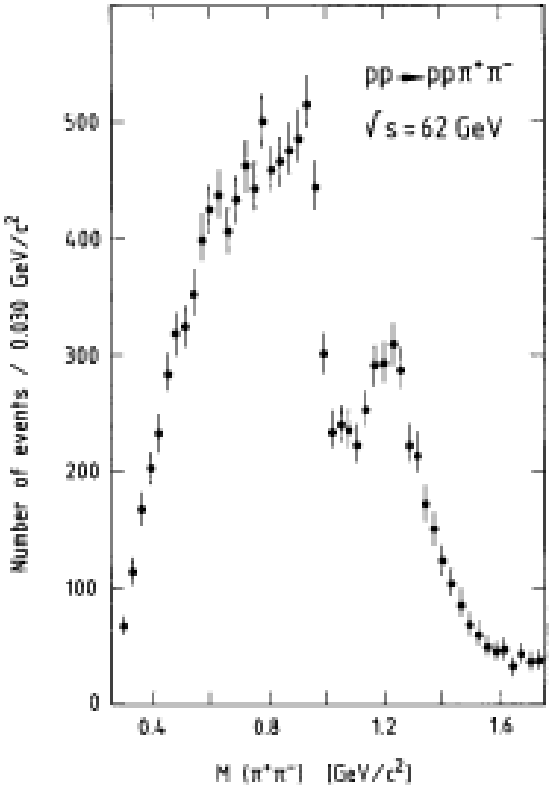
l-tl > 0.15 GeV2



effect of l-tl cut at same √s = 63 GeV

AFS
0.015 <l-tl<0.045





ABCDHW at SFM
l-tl > 0.08 GeV2

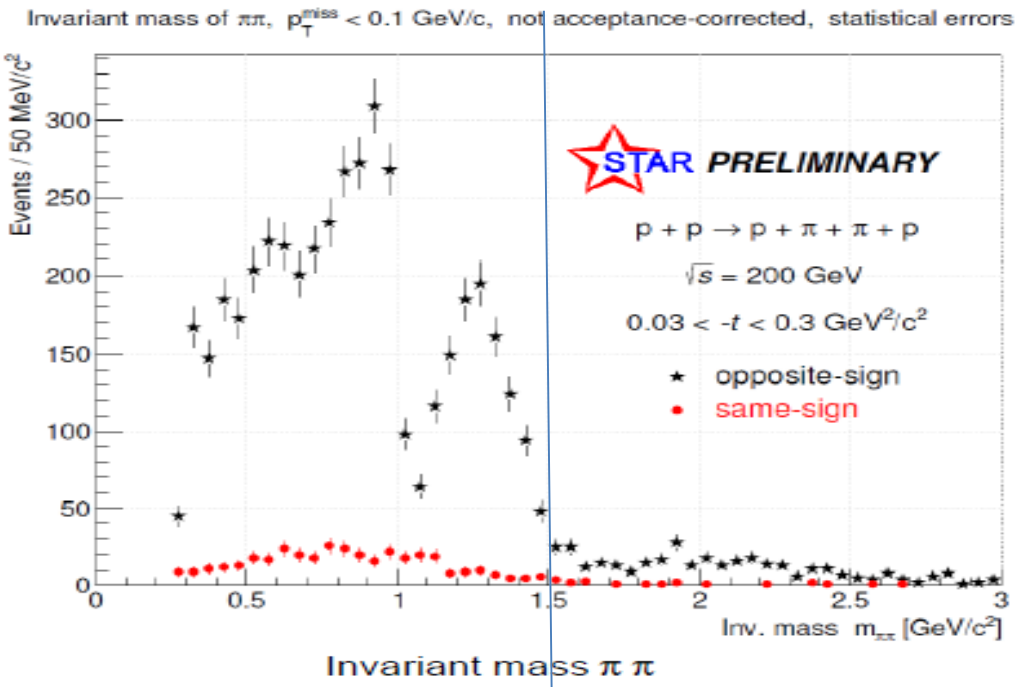
Fig. 6: $\pi^+\pi^-$ mass plot in pp CEP data at AFS (left plate, from [35]) and at SFM (right plate, from [37]).

STAR data

2015 run

l-tl > 0.03 GeV2

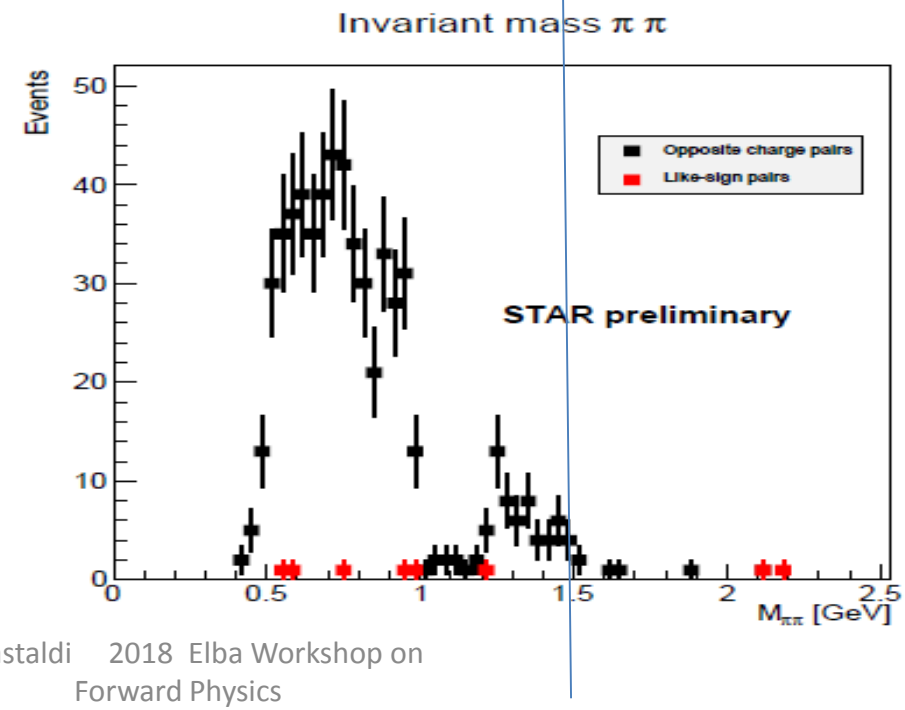
200 GeV



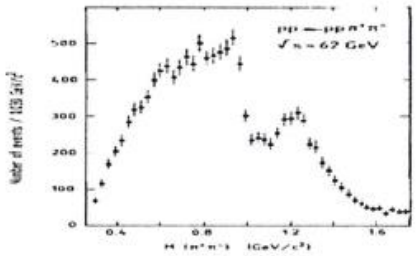
2012 run

l-tl < 0.03 GeV2

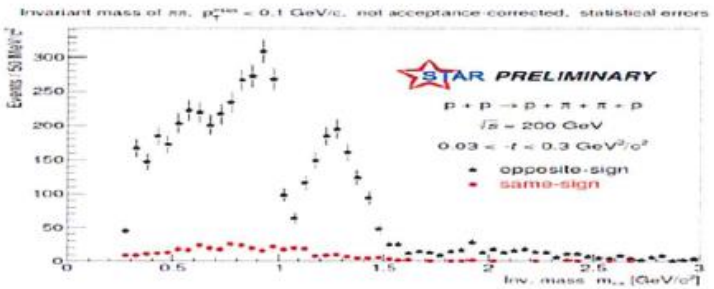
200 GeV

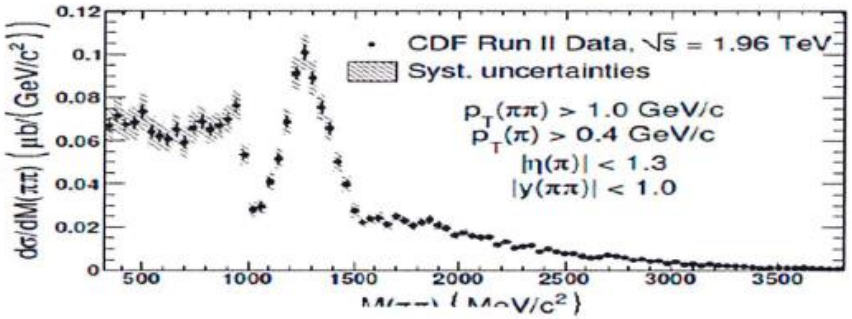


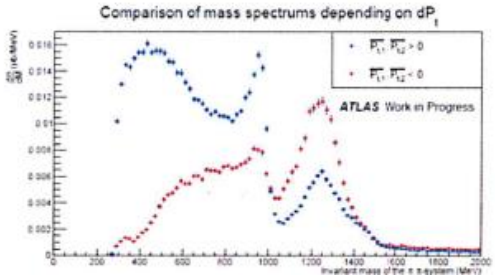
high l-tl window data



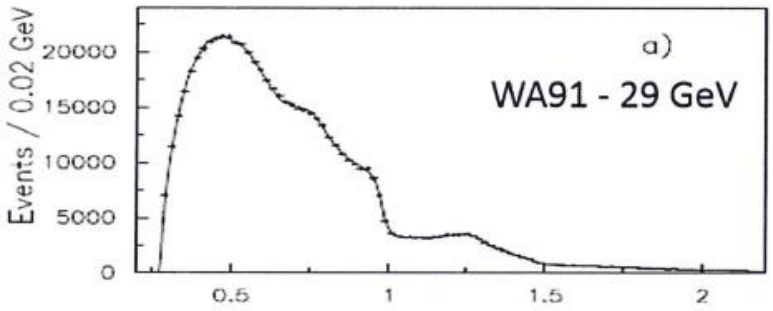
ISR - SFM

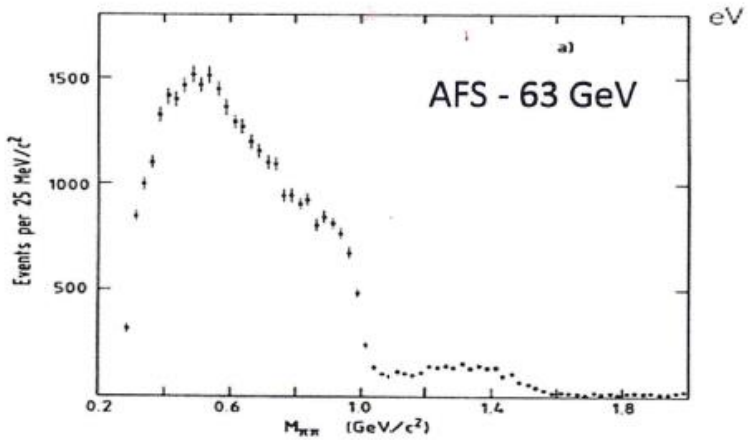


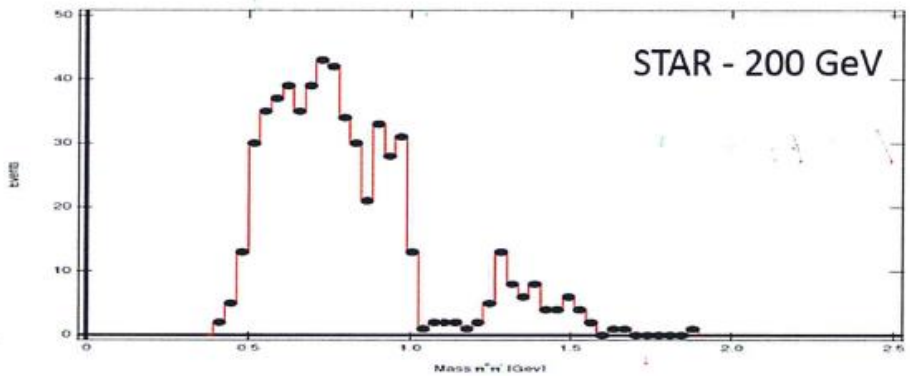




low l-tl window data







STAR low |-t| data

0.003 < |-t1|, |-t2| < 0.03 GeV2

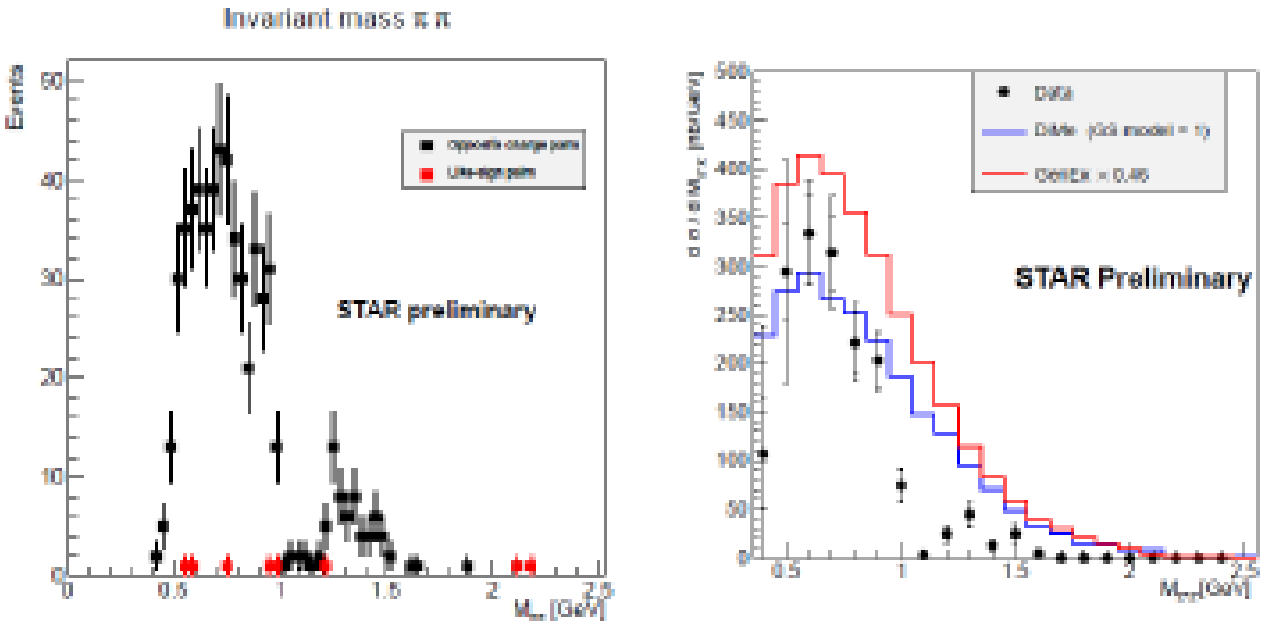


Fig. 9: $\pi^+\pi^-$ mass plot of STAR pp CEP data for the 2009 run with 0.003 $|-t_1|, |-t_2|$ 0.03 GeV^2 kinematic coverage of both scattered protons: row data left plate (from [67]), acceptance corrected data (right plate from [68]).

1972 and 1975 predictions of existence of glueballs

Current Algebra: Quarks and What Else?

Harald Fritzsch*†

and

Murray Gell-Mann**†

CERN, Geneva, Switzerland

Proceedings of the XVI International Conference on High Energy Physics, Chicago, 1972. Volume 2, p. 135 (J. D. Jackson, A. Roberts, eds.)

Abstract

After receiving many requests for reprints of this article, describing the original ideas on the quark gluon gauge theory, which we later named QCD, we decided to place the article in the e-Print archive.

*On leave from the Max-Planck-Institut für Physik und Astrophysik. München, Germany.

†Present address: Lauritsen Laboratory of High Energy Physics, California, Institut of Technology, Pasadena, California.

**John Simon Guggenheim Memorial Foundation Fellow.

IL NUOVO CIMENTO Vol. 30 A, N. 3 1 Dicembre 1975

Ψ-Resonances, Gluons and the Zweig Rule (*) (**).

H. FRITZSCH and P. MINKOWSKI

California Institute of Technology - Pasadena, Cal.

(ricevuto il 30 Giugno 1975)

Summary. — On the basis of the quark-gluon field theory we discuss the dynamical manifestations of gluons in hadron physics. Especially we concentrate on the Zweig rule for meson decays and the decays of the Ψ-resonances. Depending on the various possibilities for the spectrum of the glue mesons, we describe both the glue annihilation and the mixing mechanism for the Zweig-rule-violating meson decays. Furthermore we discuss the break-down of PCAC for the pseudoscalar analogue of the Ψ-meson and the importance of the glue mixing term for the mass spectrum of the pseudoscalar mesons.

1. – Introduction.

The recent observation of narrow resonances in the e^+e^- channel (1) has renewed the speculations about the existence of further quantum numbers

(*) To speed up publication, the authors of this paper have agreed to not receive the proofs for correction.

(**) Work supported in part by the Energy Research and Development Administration. Prepared under Contract AT(11-1)-68 for the San Francisco Operations Office.

(1) J. J. AUBERT, U. BECKER, J. P. BIGGS, J. BURGER, M. CHEN, G. EVERHART, P. GOLDHAGEN, J. LEONG, T. MCCORRISTON, T. G. RHOADES, M. ROHDE, S. C. C. TING, S. L. WU and Y. Y. LEE: *Phys. Rev. Lett.*, **33**, 1404 (1974); J.-E. AUGUSTIN, A. M. BOYARSKI, M. BREIDENBACH, F. BULOS, J. T. DAKIN, G. J. FELDMAN, G. E. FISCHER, D. FRYBERGER, G. HANSON, B. JEAN-MARIE, R. R. LARSEN, V. LÜTH, H. L. LYNCH, D. LYON, C. C. MOREHOUSE, J. M. PATERSON, M. L. PERL, B. RICHTER, P. RAPIDIS, R. F. SCHWITTERS, W. M. TANENBAUM, F. VANNUCCI, G. S. ABRAMS, D. BRIGGS, W. CHINOWSKY, C. E. FRIEDBERG, G. GOLDHABER, R. J. HOLLEBEEK, J. A. KADYK, B. LULU, F. PIERRE, G. H. TRILLING, J. S. WHITAKER, J. WISS and J. E. ZIPSE: *Phys. Rev. Lett.*, **33**, 1406 (1974); C. BACCI, R. BALDINI CELIO, M. BERNARDINI,

Conclusions of 2013 Ochs review on glueballs

IOP Publishing — Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. **40** (2013) 043001 (68pp) doi:10.1088/0954-3899/40/4/043001

TOPICAL REVIEW

The status of glueballs

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(Some figures may appear in colour only in the online journal)

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In a summary of our results we try to answer some questions and we provide a minimal mixing scenario for the scalar mesons with glueball which takes into account some relevant findings.

11.1. Is there any experimental evidence for the existence of glueballs?

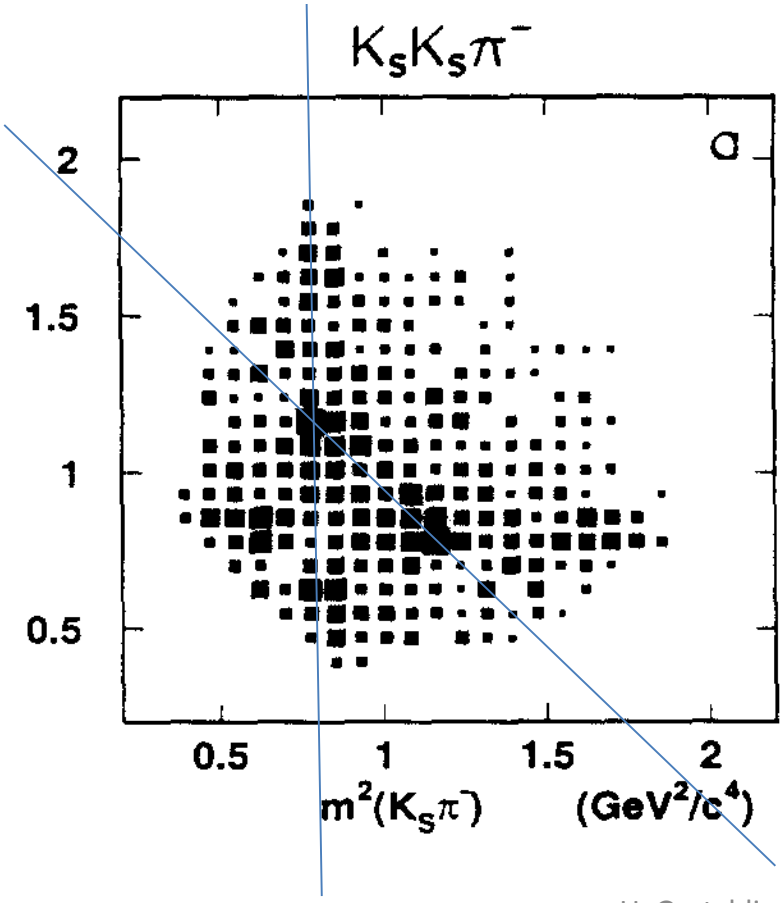
We have studied different scenarios for a scalar meson spectroscopy which includes the lightest glueball of QCD. None of the schemes considered is without problem. It remains unsatisfactory, if the existence of the glueball as a fundamental prediction of QCD, at the end depends on whether such a controversial state like $f_0(1370)$ does exist. We have therefore looked after other criteria as well.

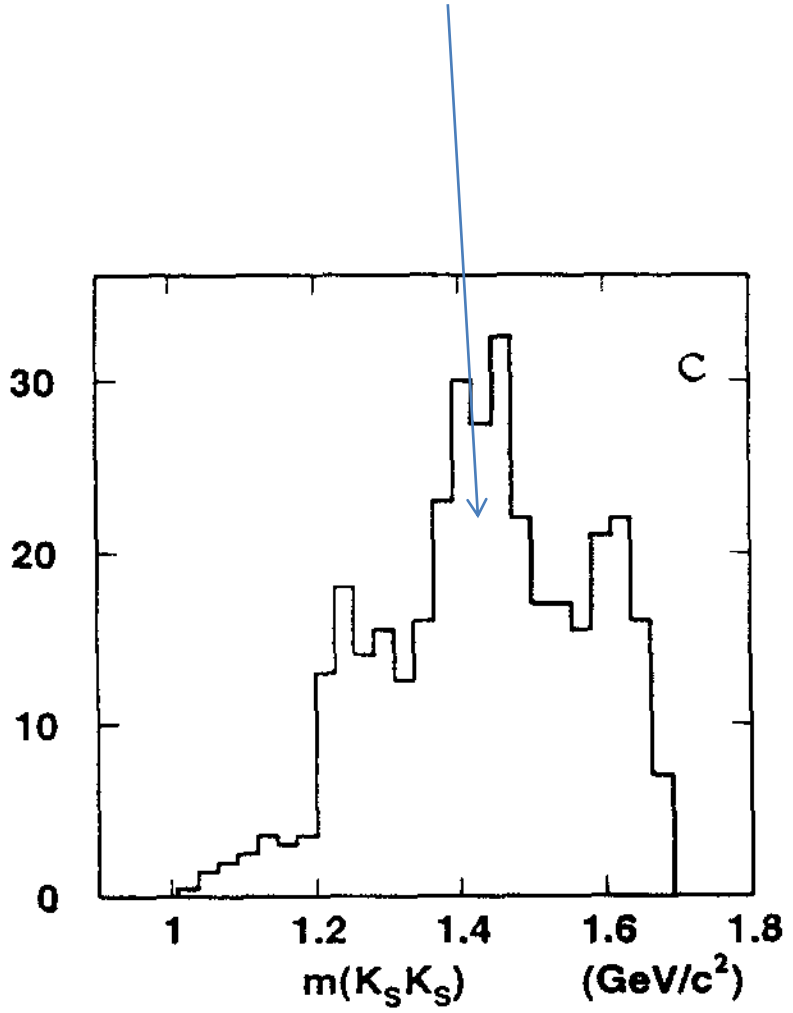
There appears to be one observation which can be considered as a direct hint for the existence of glueballs. That is the observation of several LEP experiments that the leading system in a gluon jet has an excess of neutral charge, in one measurement by 40%, if compared

58

Evidences of existence of f0(1370)

pbar at rest in CERN and BNL
D2 bubble chambers

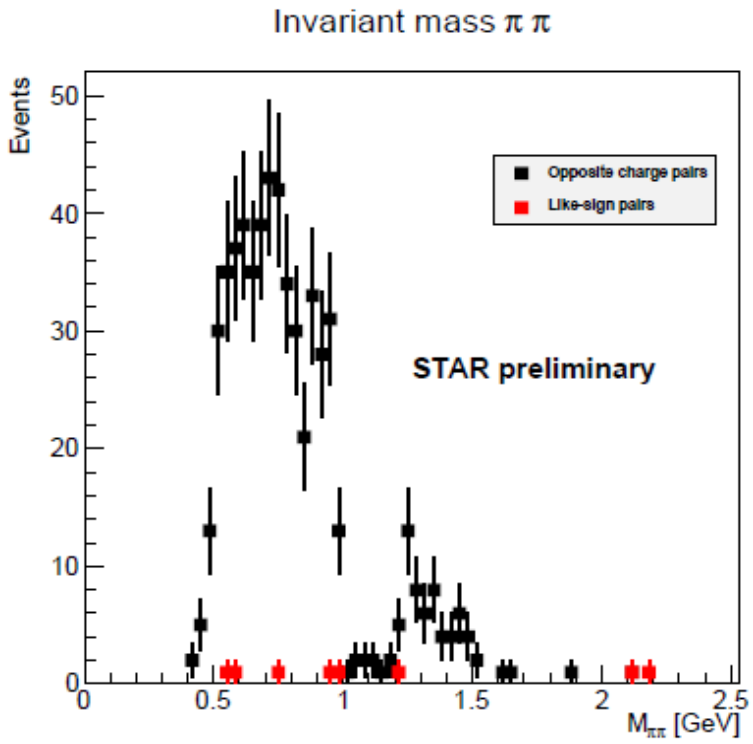


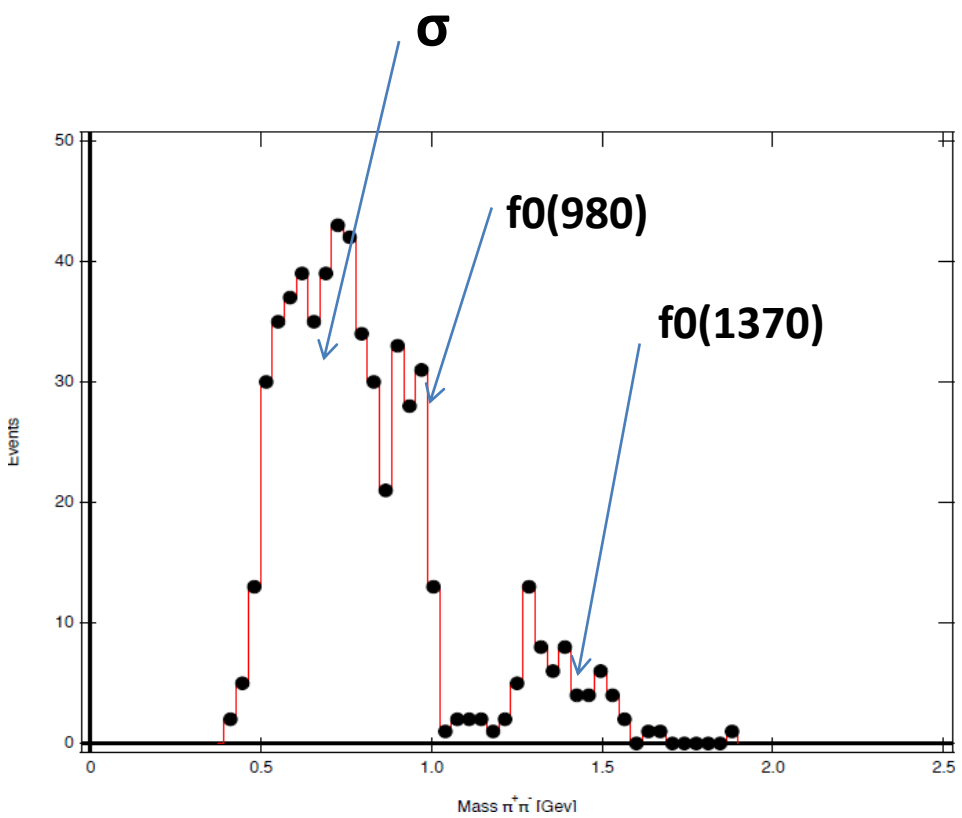


Evidences of existence of f0(1370)

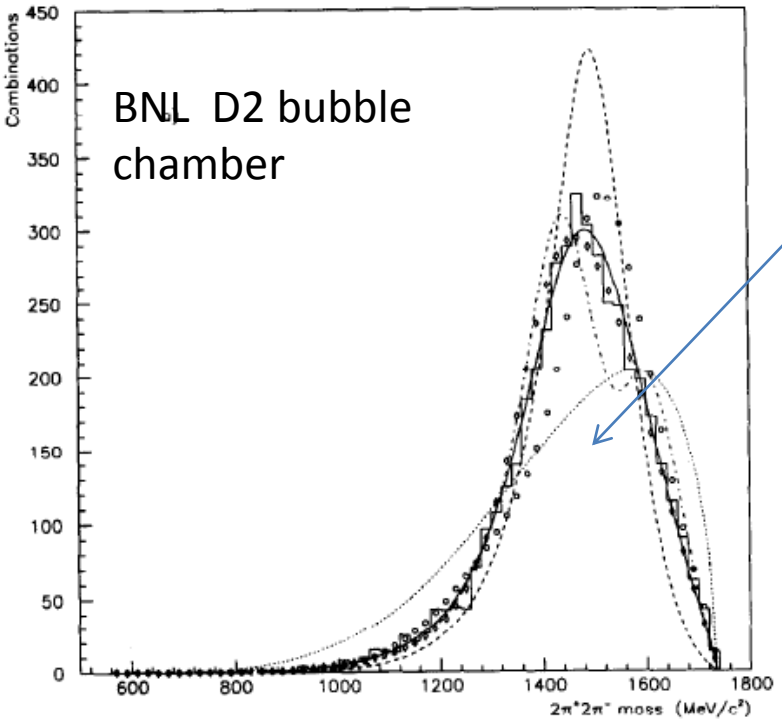
STAR π+π- mass spectrum 2009 data

$\sqrt{s} = 200\ GeV$ 0.003 < l-t1l, l-t2l < 0.03 GeV2

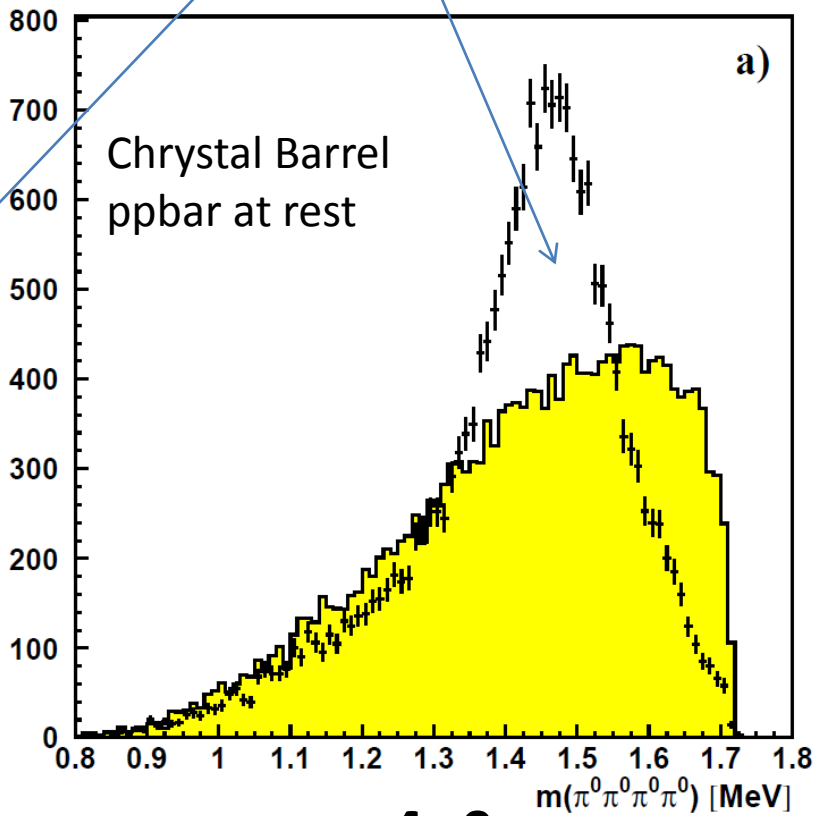




Evidences of existence of f0(1370)

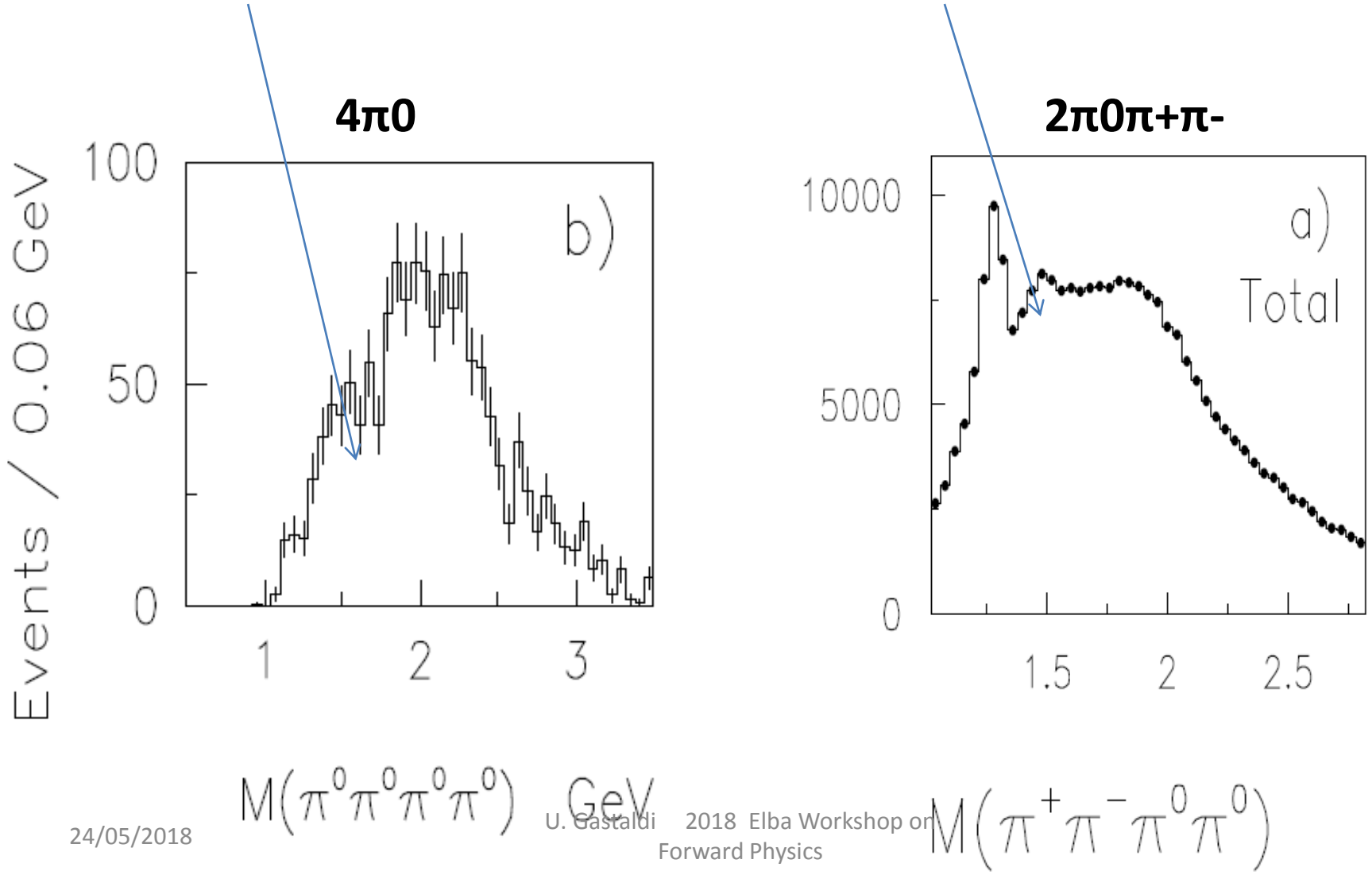


π+π-π+π-

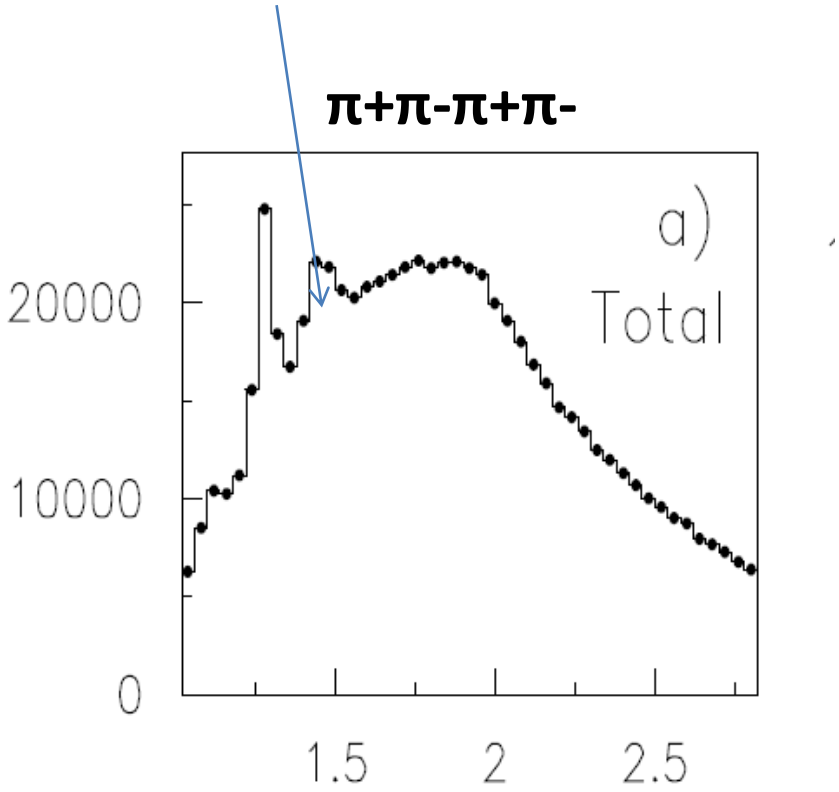


4π0

WA102 pp CEP of 4π0 and 2π0π+π-



WA102 pp CEP of π+π-π+π-



total and partial decay widths of $f_0(1370)$ and $f_0(1500)$

The CRYSTAL BARREL Collaboration: 4π-decays of scalar and vector mesons

Table 4. Partial widths Γ_i (in MeV) of $f_0(1370)$ and $f_0(1500)$ for decays into two pseudoscalar particles and into four pions assuming that all decay modes are observed. The error of the total width is included in the errors for the partial widths. The pseudoscalar branching ratios to calculate the partial widths are taken from [30–32]

	Γ_{tot}	$\sigma\sigma$	$\rho\rho$	$\pi(1300)\pi$	$a_1\pi$
		$\pi\pi$	$\eta\eta$	$\eta\eta'$	$K\bar{K}$
$f_0(1370)$	275 ± 55	120.5 ± 45.2	62.2 ± 28.8	41.6 ± 22.0	14.1 ± 7.2
		21.7 ± 9.9	0.41 ± 0.27		(7.9 ± 2.7) to (21.2 ± 7.2)
$f_0(1500)$	130 ± 30	18.6 ± 12.5	8.9 ± 8.2	35.5 ± 29.2	8.6 ± 6.6
		44.1 ± 15.3	3.4 ± 1.2	2.9 ± 1.0	8.1 ± 2.8

Too low by factor >2.5

Crystal Barrel and WA102 data on f0(1370) and f0(1500)

Table 3. Partial widths Γ_i (in MeV) of $f_0(1370)$ and $f_0(1500)$ (from [35]), $\Gamma_{tot}(f_0(1370)) = 275 \pm 55$ MeV, $\Gamma_{tot}(f_0(1500)) = 130 \pm 30$ MeV. σ is used as an shortcut for the $\pi\pi$-S wave.

	$\sigma\sigma$ $\pi\pi$	$\rho\rho$ $\eta\eta$	$\pi(1300)\pi$ $\eta\eta'$	$a_1\pi$ KK
$f_0(1370)$	120.5 ± 45.2	62.2 ± 28.8	41.6 ± 22.0	14.1 ± 7.2
	21.7 ± 9.9	0.41 ± 0.27		(7.9 ± 2.7) to (21.2 ± 7.2)
$f_0(1500)$	18.6 ± 12.5	8.9 ± 8.2	35.5 ± 29.2	8.6 ± 6.6
	44.1 ± 15.3	3.4 ± 1.2	2.9 ± 1.0	8.1 ± 2.8

Central production (data from WA102)

Not only the Crystal Barrel, but also the WA102 experiment has investigated the decay of scalar resonances into two pseudoscalar particles and into 4π [36]. The relative decay rates found by WA102 for the $f_0(1370)$, the $f_0(1500)$, and the $f_0(1710)$ are as follows [29]:

	$\pi\pi$:	KK :	$\eta\eta$:	$\eta\eta'$:	4π
$f_0(1370)$	1 :	0.46 ± 0.19 :	0.16 ± 0.07 :	– :	34.0^{+22}_{-9}
$f_0(1500)$	1 :	0.33 ± 0.07 :	0.18 ± 0.03 :	0.096 ± 0.026 :	1.36 ± 0.15
$f_0(1710)$	1 :	5.0 ± 0.7 :	2.4 ± 0.6 :	< 0.18 :	< 5.4

conflicting results

Crystal Barrel and BC : σσ dominant decay of f0(1370) ρρ decay 2 times less intense

WA 102 : ρρ dominant decay of f0(1370) σσ decay < 25% of ρρ decay

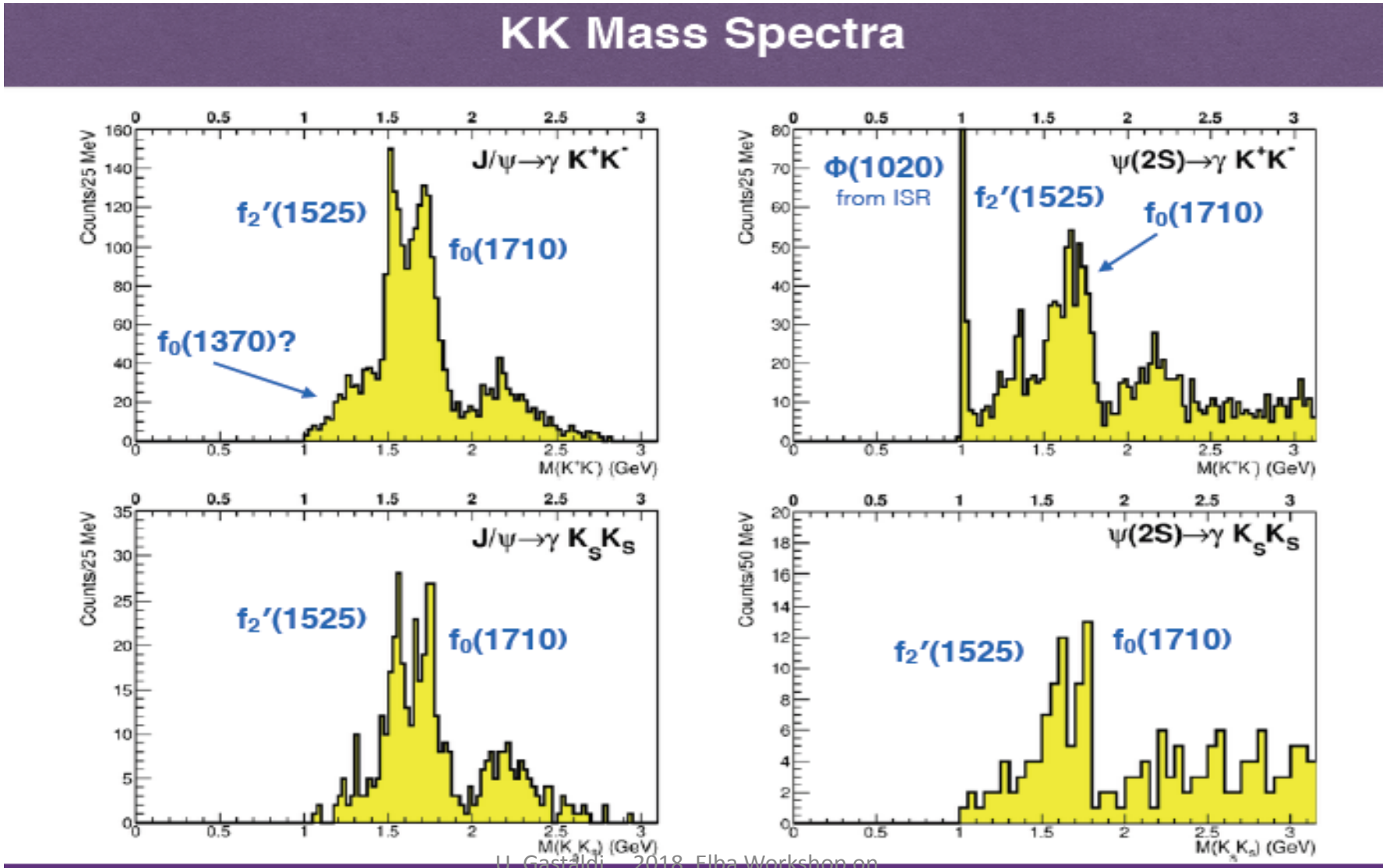
conclusions and prospects

f0(1370) existence established

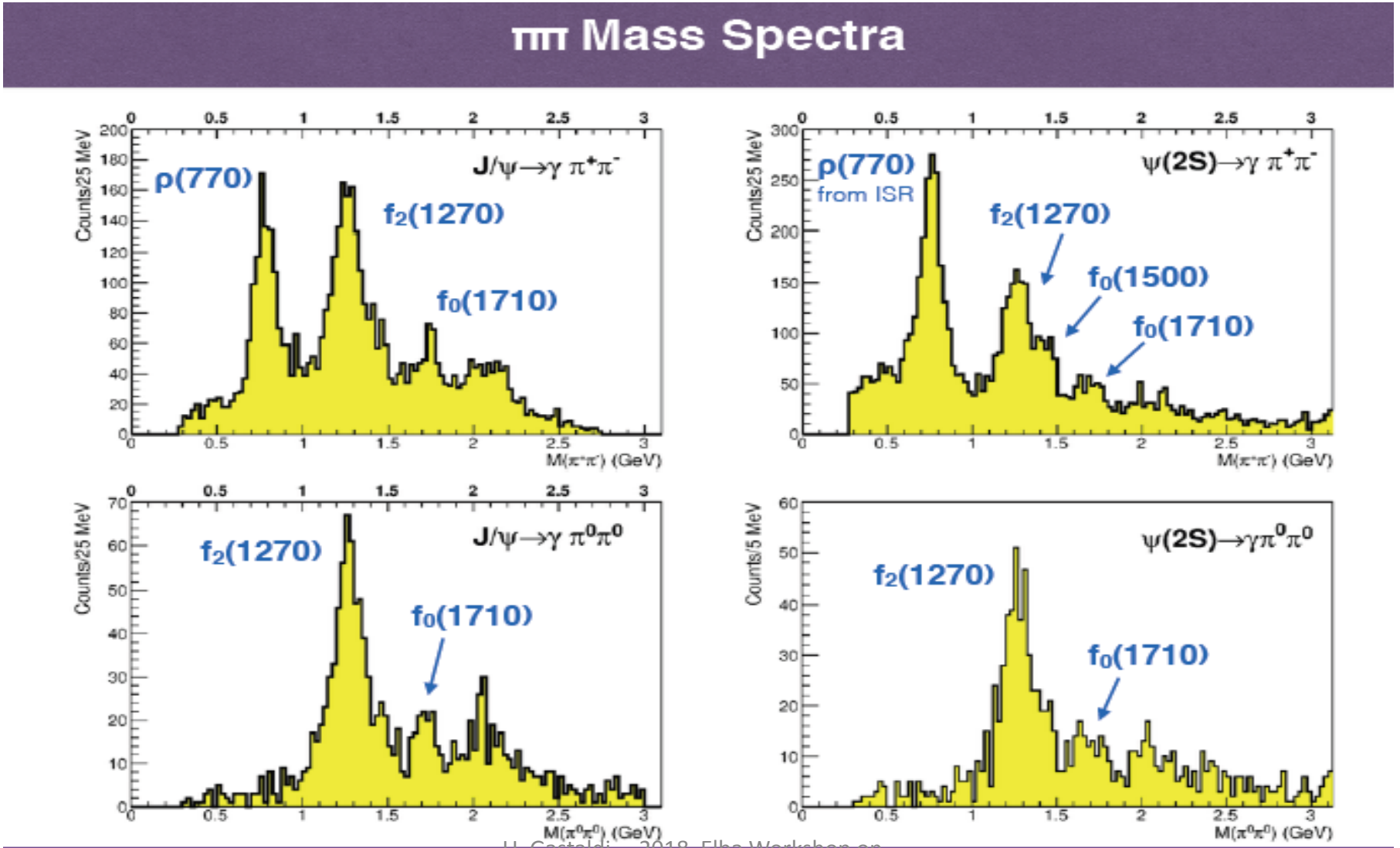
measure precisely BR(KKbar)/ BR(ππ), BR(σσ)/ BR(ππ) , BR(ρρ)/ BR(ππ) of decays of f0(1370) and f0(1500) to identify scalar gluonium ground state

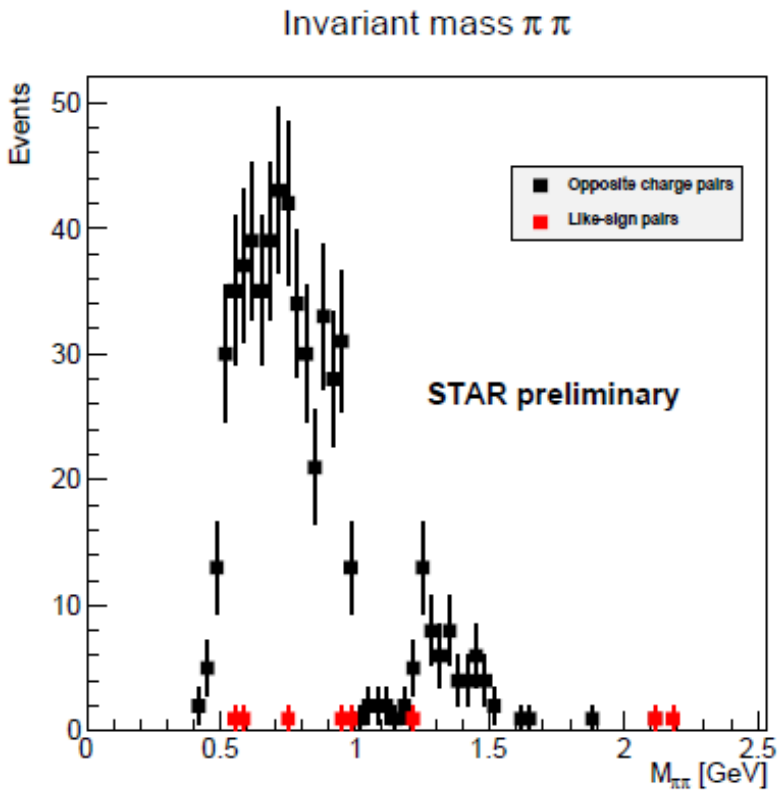
go to very low l-tl at LHC to get pure spectra of 0++ scalar mesons and glueball in pp CEP (roman pot detectors essential)

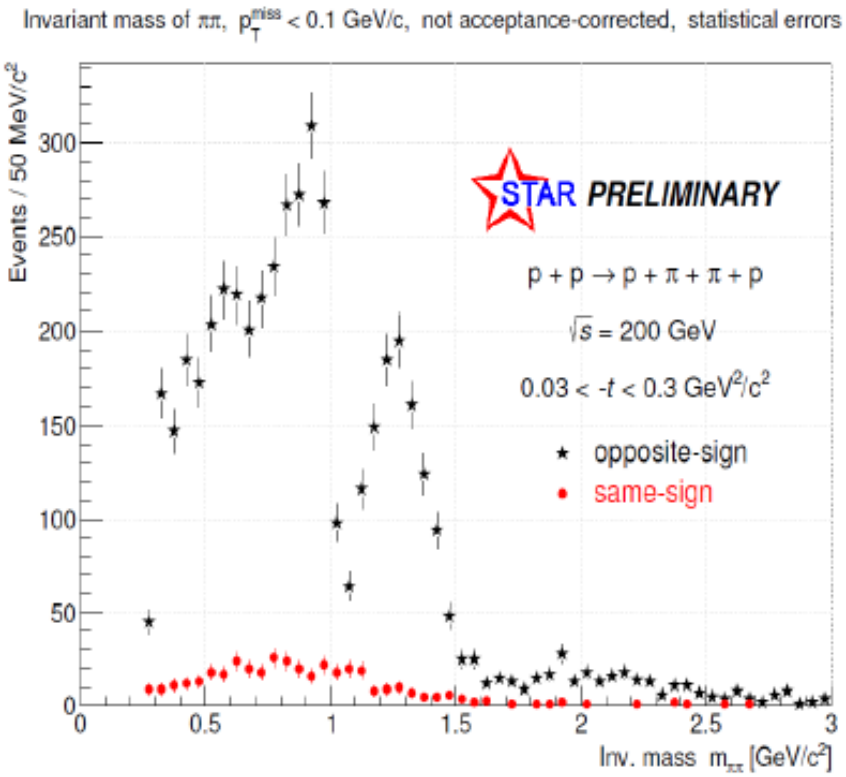
CLEO data


KK Mass Spectra
J/ψ→γ K⁺K⁻
f₂′(1525)
f₀(1710)
f₀(1370)?
Counts/25 MeV
M(K⁺K⁻) (GeV)
ψ(2S)→γ K⁺K⁻
Φ(1020)
from ISR
f₂′(1525)
f₀(1710)
Counts/25 MeV
M(K⁺K⁻) (GeV)
J/ψ→γ K_SK_S
f₂′(1525)
f₀(1710)
Counts/25 MeV
M(K_SK_S) (GeV)
ψ(2S)→γ K_SK_S
f₂′(1525)
f₀(1710)
Counts/50 MeV
M(K_SK_S) (GeV)

CLEO data


ππ Mass Spectra
ρ(770)
f2(1270)
f0(1710)
J/ψ→γ π+π-
Counts/25 MeV
M(π+π-) (GeV)
ρ(770)
from ISR
f2(1270)
f0(1500)
f0(1710)
ψ(2S)→γ π+π-
Counts/25 MeV
M(π+π-) (GeV)
f2(1270)
f0(1710)
J/ψ→γ π0π0
Counts/25 MeV
M(π0π0) (GeV)
f2(1270)
f0(1710)
ψ(2S)→γπ0π0
Counts/5 MeV
M(π0π0) (GeV)


Invariant mass π π
Events
Opposite charge pairs
Like-sign pairs
STAR preliminary
$M_{\pi\pi}$ [GeV]


Invariant mass of ππ, p_T^{miss} < 0.1 GeV/c, not acceptance-corrected, statistical errors
Events / 50 MeV/c^2
STAR PRELIMINARY
p + p → p + π + π + p
$\sqrt{s}$ = 200 GeV
0.03 < -t < 0.3 GeV^2/c^2
opposite-sign
same-sign
Inv. mass $m_{\pi\pi}$ [GeV/c^2]