FAIR perspectives for hadron physics

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Trento, February 22, 2013

Like social elephants, quarks only exist in groups with other quarks and are never found alone. Composite particles made of quarks are called

HADRONS

Although individual quarks have fractional electrical charges, they combine such that hadrons have a net integer electric charge. Another property of hadrons is that they have no net color charge even though the quarks themselves carry color charge (we will talk more about this later).

There are two classes of hadrons (try putting your mouse on the elephants):

BARYONS

...are any hadron which is made of three quarks (qqq).

Because they are made of two up quarks and one down quark (uud), **protons** are baryons. So are **neutrons** (udd).

MESONS

...contain one quark (q) and one antiquark ($\bar{q}$).

One example of a meson is a pion (π^+), which is made of an up quark and a down anitiquark. The antiparticle of a meson just has its quark and antiquark switched, so an antipion (π^-) is made up a down quark and an up antiquark.

Because a meson consists of a particle and an antiparticle, it is very unstable. The kaon (K^-) meson lives much longer than most mesons, which is why it was called "strange" and gave this name to the strange quark, one of its components.

A weird thing about hadrons is that only a very very very **small part of the mass of a hadron** is due to the quarks in it.

Glueballs $\rightarrow$ Creation of Mass

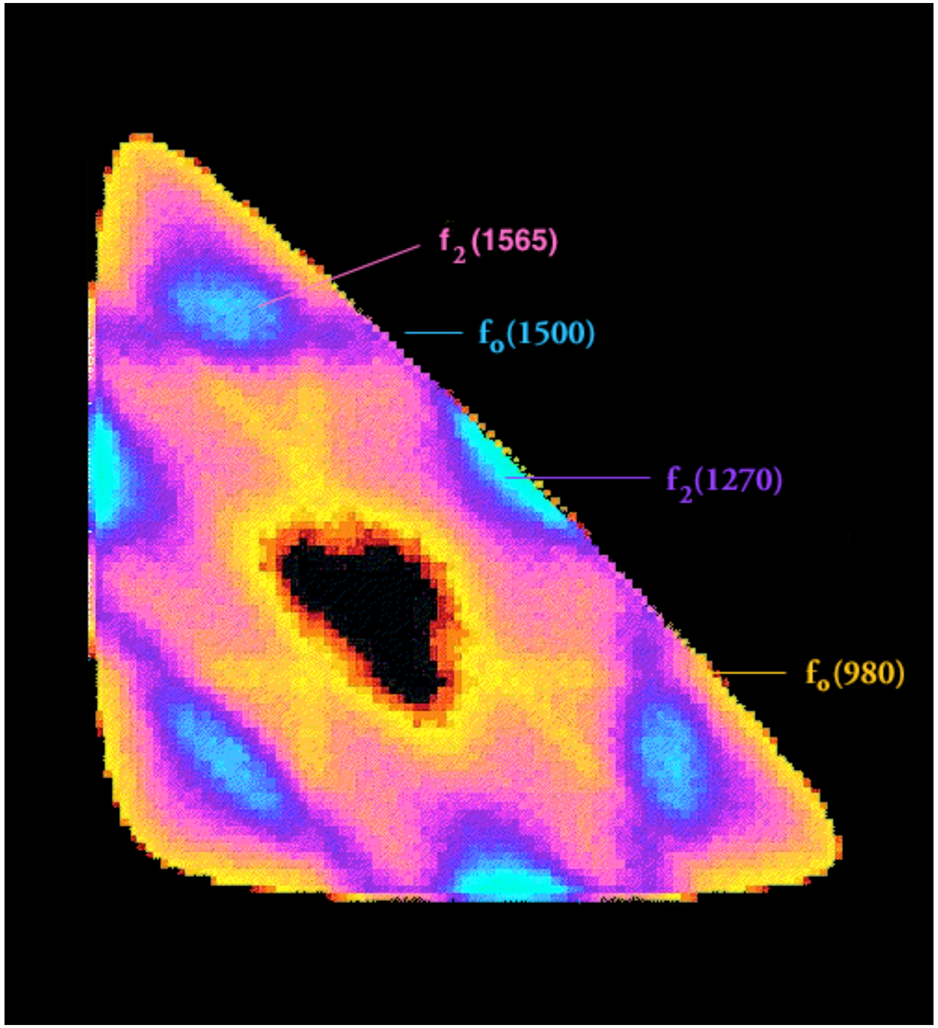
A few % of the proton mass is generated due to the **Higgs mechanism**.

Most of the proton mass is created by the **strong interaction**.

Glueballs gain their mass solely by the strong interaction and are therefore an unique approach to the mass creation by the strong interaction.

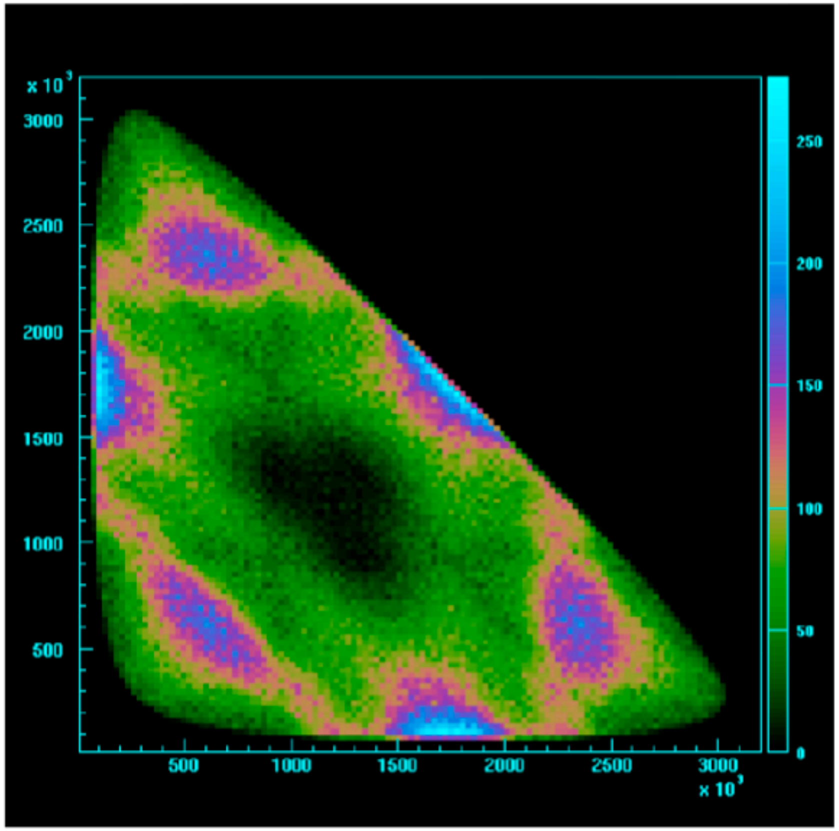
Crystal Barrel

$\bar{p}p \rightarrow \pi^0\pi^0\pi^0$ Dalitz plot

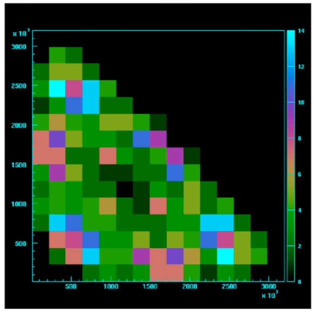


700000 events = 6×700000 entries

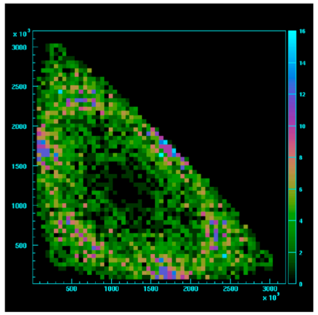
100,000 events



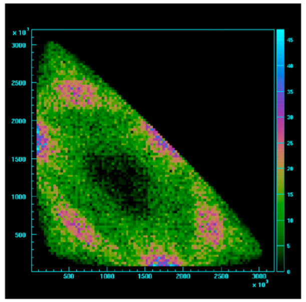
100 events



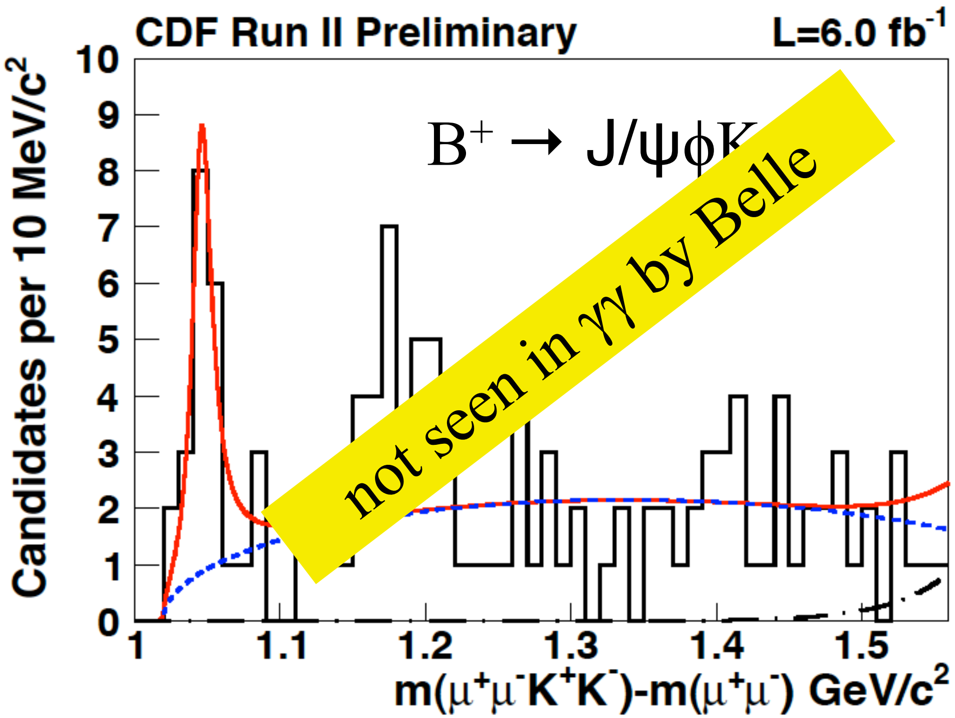
1000 events



10,000 events



The X(4140)



$$M = 4143.4^{+2.9}_{-3.0}(\text{stat.}) \pm 1.2 \text{ MeV/c}^2$$

$$\Gamma = 11.7^{+8.3}_{-5.0}(\text{stat.}) \pm 3.7 \text{ MeV/c}^2$$

CDF collaboration, T. Aaltonen et al.;. Phys. Rev. Lett., 102:242002 (2009).
CDF/DOC/BOTTOM/PUBLIC/10244;
http://www-cdf.fnal.gov/physics/new/bottom/100701.blessed-jpsiphi6.0/cdf10244_y4140_public.pdf

Belle collaboration, Cp. Shen eta al., Phys.Rev.Lett.104:112004,2010.

Test for glueball properties

	$f_0(1500)$	$\eta_L(1410)$
Seen in antiproton annihilations	✔	✔
Seen in radiative J/ψ decays	✔	✔
Seen in central production	✔	✖*
Not seen in $\gamma\gamma$ collisions	✔	✔
Supernumerous to the nonet	✔	✔

* maybe due to kinematical suppression

The $\eta_L(1410)$ has strong affinity for glue and all signatures of a glueball.

F.E. Close, G.R. Farrar, Z. Li, Phys. Rev. D55, 5749 (1997).

Problem:

Lattice calculations put the pseudoscalar glueball at ~2.3 GeV.

Exotic interpretation:

gluino-gluino bound state

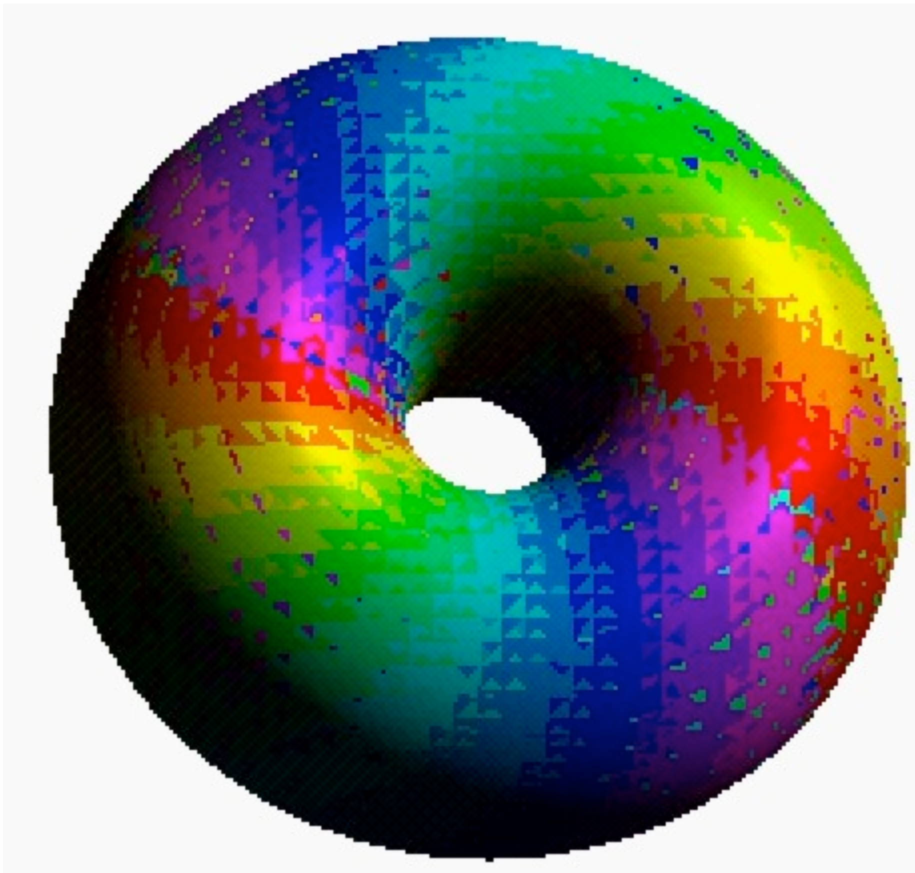
G.R. Farrar, Phys. Rev. Lett. 76, 4111 (1996).

Claim:

The $\eta_L(1410)$ appears naturally as the pseudoscalar glueball if glueballs are closed gluonic fluxtubes.

GLUEBALLS, FLUXTUBES AND $\eta(1440)$.
L. Fadeev, A. Niemi and U. Wiedner
Phys.Rev.D70:114033, 2004

Are glueballs configurations of twisted or knotted colored flux?



Twist can be left-handed or right-handed:

$$\left|\pm\right\rangle = \frac{1}{\sqrt{2}}\left(\left|L\right\rangle \pm \left|R\right\rangle\right)$$

Glueballs could appear as mass degenerate parity doublets and should be produced with similar production rates.

This is the case for the $f_0(1500)$ and the $\eta_L(1410)$.

Production rates

Antiproton reactions:

$$\mathtt{BF}(p\bar{p} \rightarrow f_0(1500)) \;=\; (7.7 \pm 3.8) \times 10^{-3}$$

$$\mathtt{BF}(p\bar{p} \rightarrow \eta_L(1410)\pi\pi) \;=\; (5.3 \pm 1.7) \times 10^{-3}$$

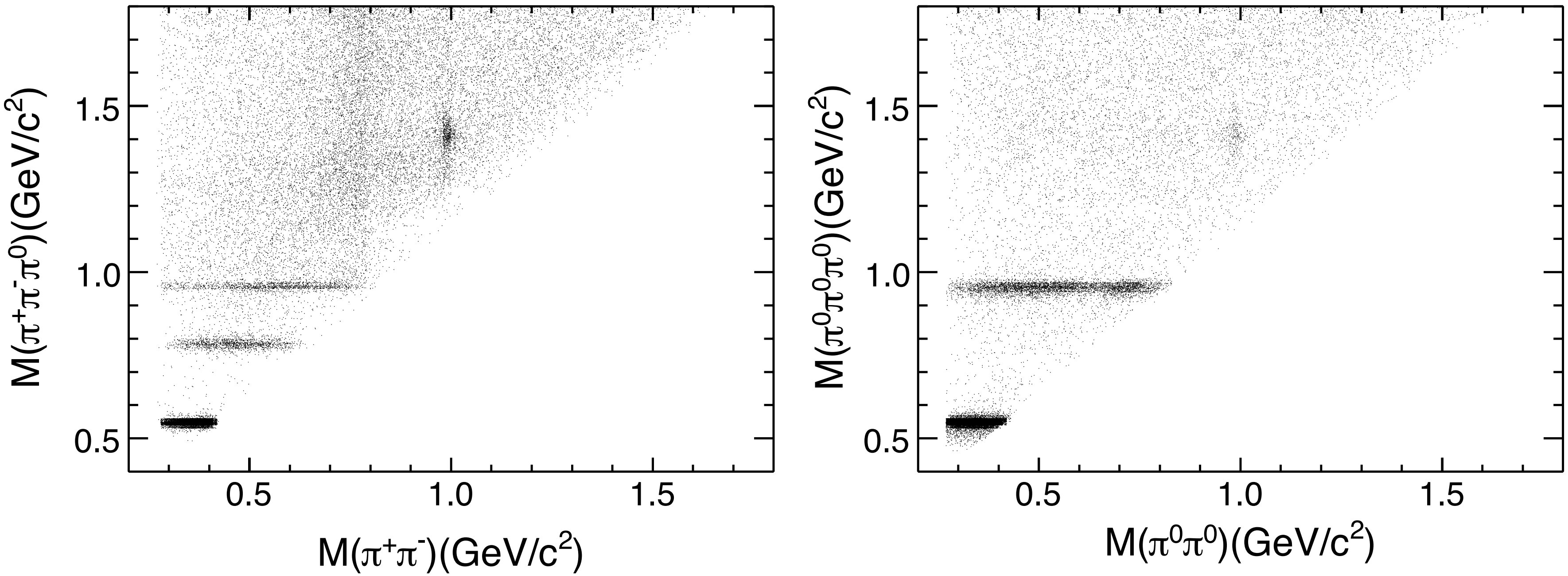
Radiative J/ψ decays:

$$\mathtt{BF}(J/\psi \rightarrow \gamma f_0(1500)) \;=\; (1.3 \pm 0.3) \times 10^{-3}$$

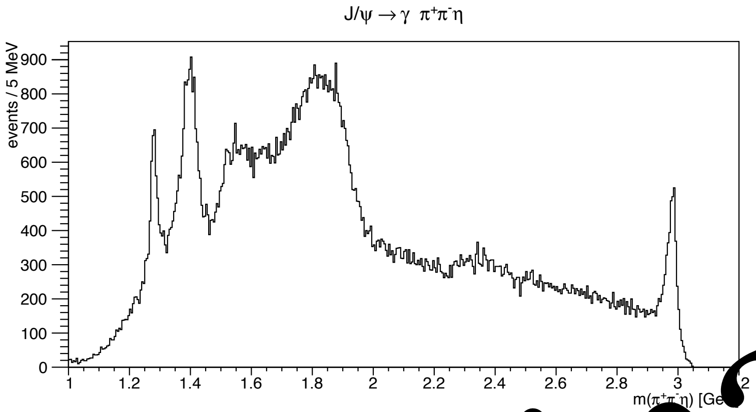
$$\mathtt{BF}(J/\psi \rightarrow \gamma \eta_L(1410)) \;=\; (1.0 \pm 0.46) \times 10^{-3}$$

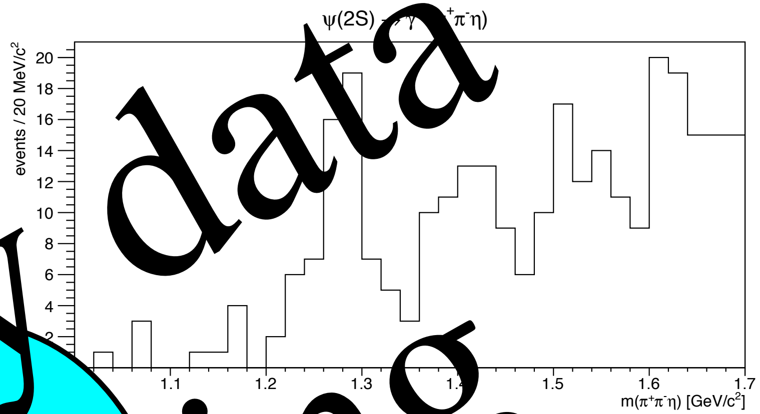
Isospin violating decays of η(1440)

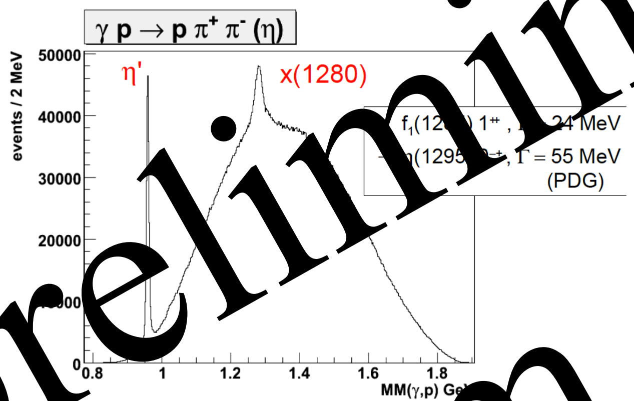
$$\eta(1440) \rightarrow f_0(980)\, \pi^0$$

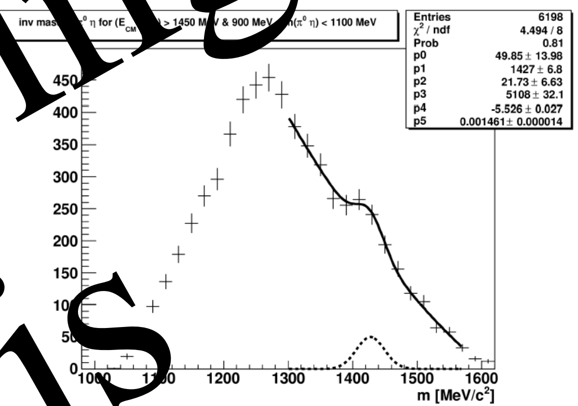


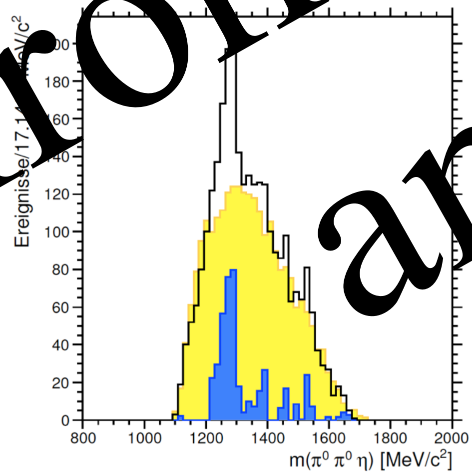
BES 3 collaboration: Phys. Rev. Lett. 108: 182001 (2012)arXiv:1201.2737v1.

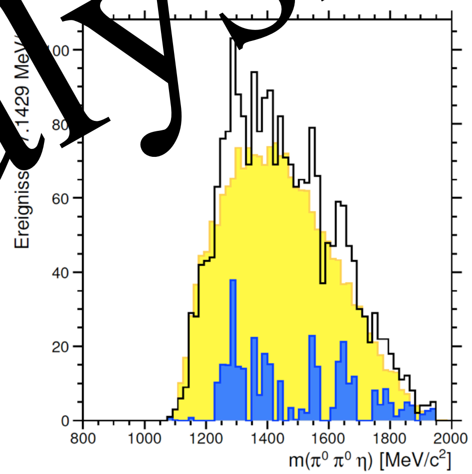








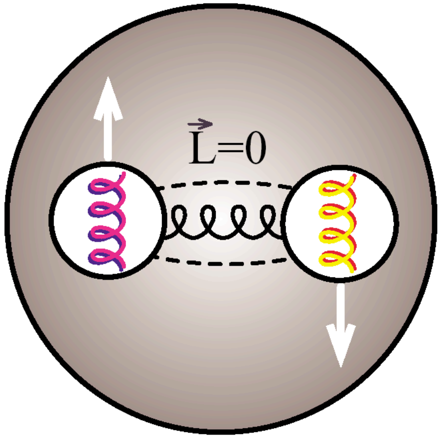




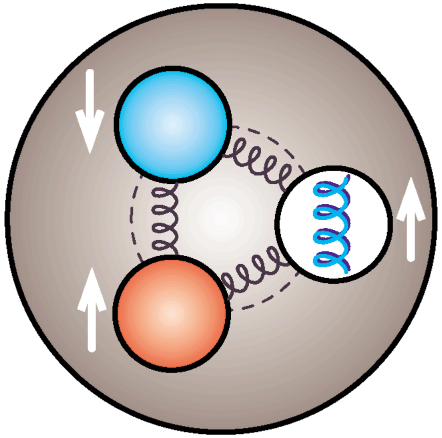
preliminary data from ongoing analysis

η(1440) produced in different processes

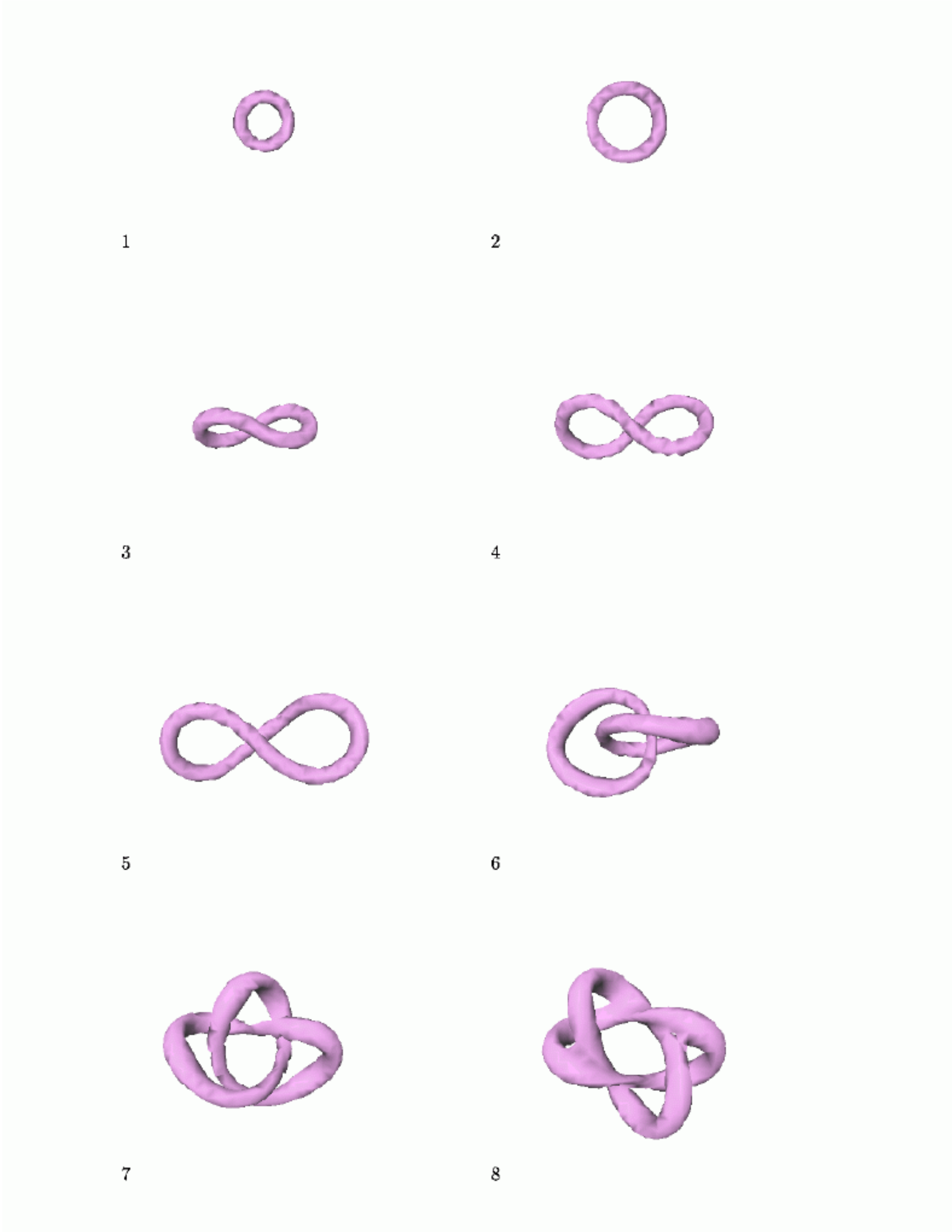
Do gluonic excitations look like …



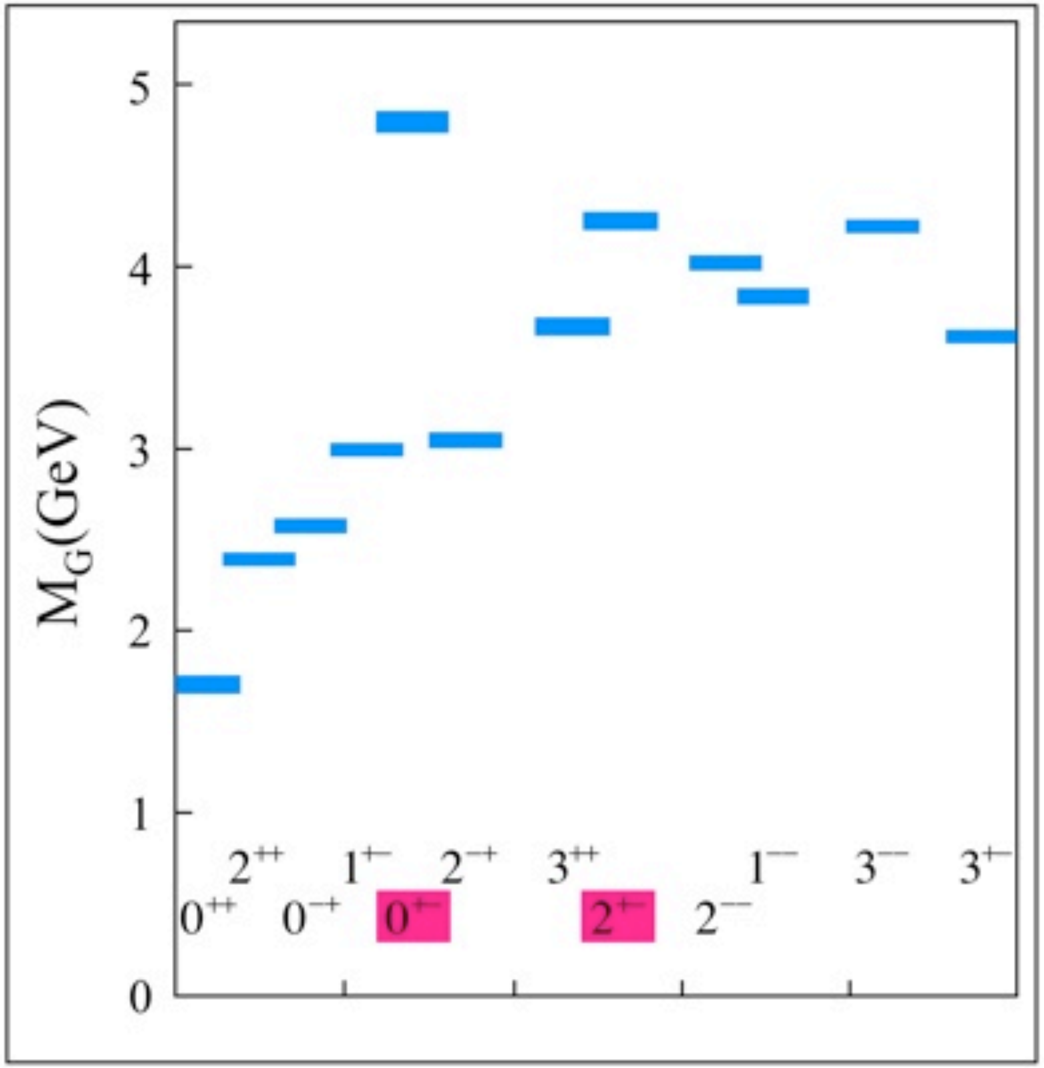
Glueball (gg)



Hybrid ($q\bar{q}g$)


1
2
3
4
5
6
7
8

The glueball spectrum

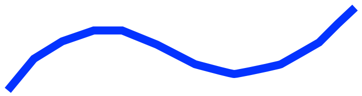


K.A. Meissner:

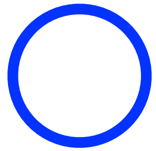
- strongly coupled bound states (glueballs with 0^{++} etc.) could be described by gravitational solutions but...

K.A. Meissner, QCD and weak scales connection – p. 17/20

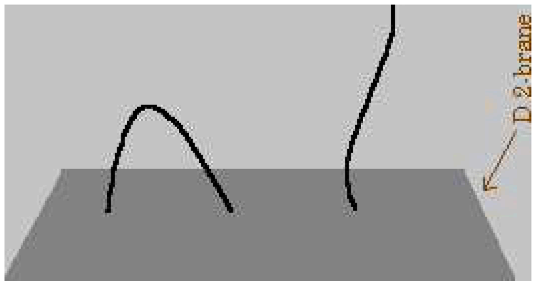
Open Strings



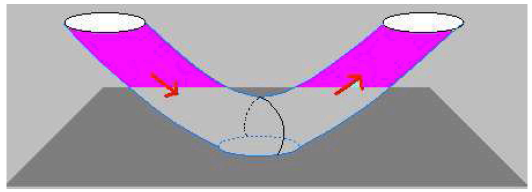
Closed Strings



String World

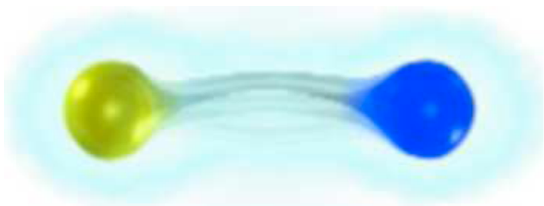


representing gauge theories

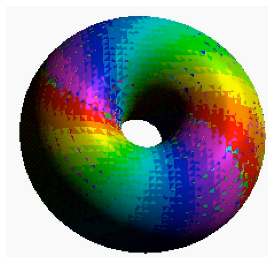


representing gravitation

Hadron World



meson



glueball

Summary

PANDA physics

$$\updownarrow$$

LHC physics

$$\updownarrow$$

sub-Planck physics

In fact, his work led to two sets of very useful results. The first, purely pedagogical, is embodied in the *Feynman Lectures on Gravitation* (publication [123]). In those lectures, Feynman develops the quantum field theory of a neutral massless spin 2 particle (the *graviton*), emphasizing the special features that arise, in comparison to theories of spin 0 and spin 1 particles, as well as the complications that result for a zero-mass particle in trying to create a self-consistent theory. As in the case of spin 1, masslessness results in redundant degrees of freedom, since Lorentz invariance requires that a *massless* particle can spin only along or opposite to its direction of momentum (positive or negative *chirality*), while a massive spin 2 particle may take up five different orientations relative to any arbitrary quantization direction. Eliminating the unwanted degrees of freedom is achieved by imposing certain "gauge conditions," which in the gravitational case brings about nonlinearity in the form of graviton–graviton interaction. Feynman shows that the classical limit of a properly gauged massless spin 2 theory is described by the Einstein gravitational field equations.[3]

Hadron physics is the place on earth to study non-Abelian massless gauge boson - gauge boson interaction

How to Calculate Meson Spectra from String Theory

Johanna Erdmenger

Max-Planck-Institut für Physik, München

work in collaboration with J. Babington, Z. Guralnik, I. Kirsch (HU Berlin),
R. Apreda, J. Große (HU Berlin/MPI München), N. Evans (Southampton)

For a review see: Eur.Phys.J.A35:81-133,2008

AdS/CFT Correspondence

(Maldacena 1997, AdS: Anti de Sitter space, CFT: conformal field theory)

- Duality Quantum Field Theory $\Leftrightarrow$ Gravity Theory
- Arises from String Theory in a particular low-energy limit
- Duality: Quantum field theory at strong coupling

  $\Leftrightarrow$ Gravity theory at weak coupling
- Works for large N gauge theories at large 't Hooft coupling λ

Conformal field theory in four dimensions

$\Leftrightarrow$ Supergravity Theory on $AdS_5 \times S^5$

Comparison with experimental results

$\mathrm{D4/D8/\bar{D}8}$ brane model – spontaneous breaking of $SU(N_f) \times SU(N_f)$

Sakai+Sugimoto 12/2004

vector and axial vector mesons
(obtained from gauge field fluctuations as described by the DBI action)

meson mass ratio:

Experiment:

$$\frac{m_{a_1}^2}{m_\rho^2} = \frac{(1230\mathrm{MeV})^2}{(776\mathrm{MeV})^2} = 2.51$$

Stringy model:

$$\frac{m_{a_1}^2}{m_\rho^2} = 2.4$$

$(\rho : C = -1, a_1 : C = +1)$

In the model of Sakai+Sugimoto, it is also possible to have $N_f > 1$.

LBNL-42987
UCB-PTH-99/08
hep-th/9903142

Glueball Mass Spectrum from Supergravity*

see also: JHEP 9901:017,1999

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Theoretical Physics Group
Ernest Orlando Lawrence Berkeley National Laboratory
University of California, Berkeley, CA 94720
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University of California, Berkeley, CA 94720

...

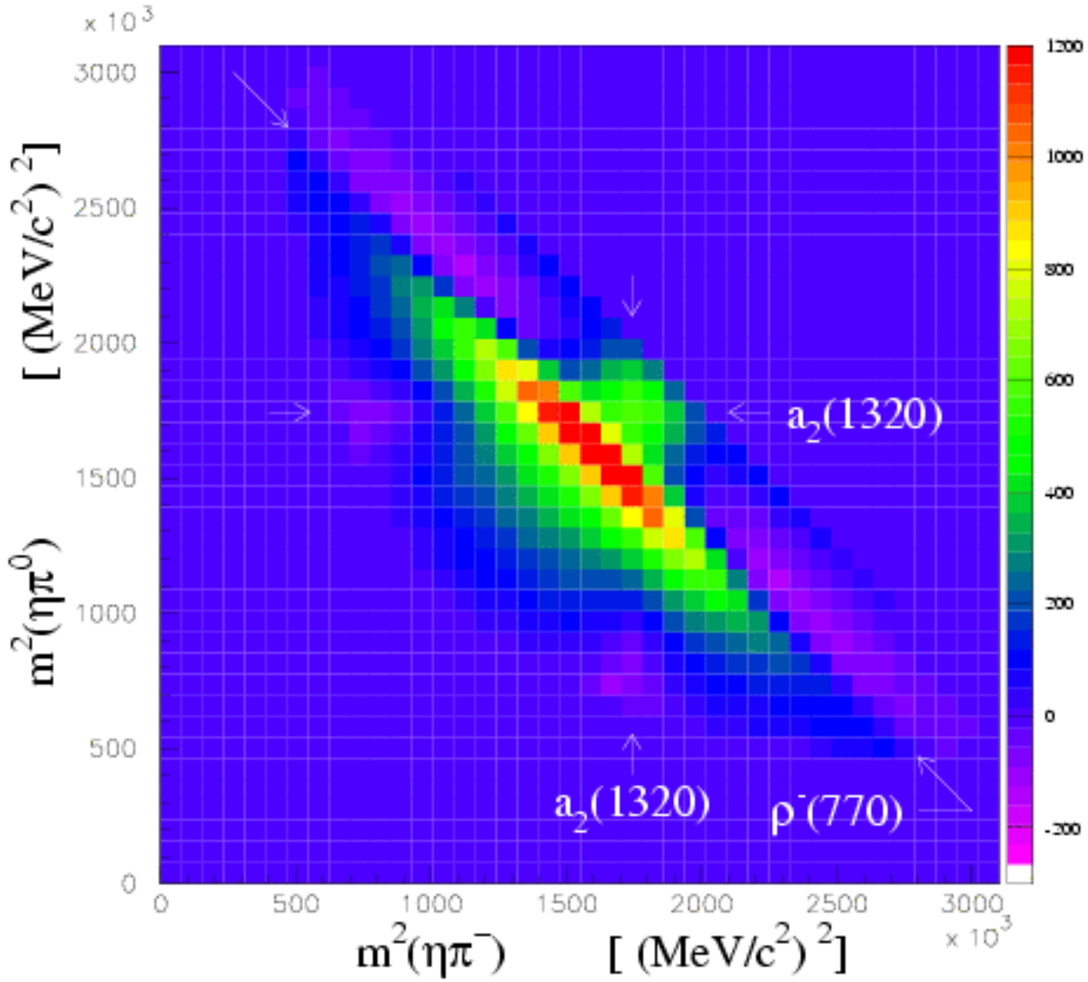
TABLE III. Masses of the first few 0^{++} glueballs in QCD_4, in GeV, from supergravity compared to the available lattice results. The first column gives the lattice result [7,16,17], the second the supergravity result for $a = 0$ while the third the supergravity result in the $a \to \infty$ limit. The change from $a = 0$ to $a = \infty$ in the supergravity predictions is tiny. Note, that for the excited state the supergravity calculation came before the lattice results.

state	lattice, $N = 3$	supergravity $a = 0$	supergravity $a \to \infty$
0^{++}	1.61 ± 0.15	1.61 (input)	1.61 (input)
0^{++*}	2.48 ± 0.18	2.55	2.56
0^{++**}	-	3.46	3.48
0^{++***}	-	4.36	4.40

...

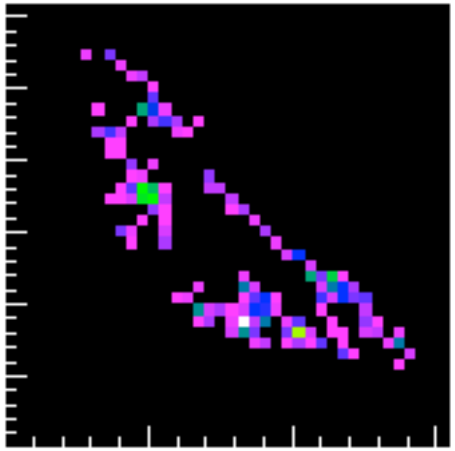
$$\bar{p}d \rightarrow \pi^-\pi^\circ\eta + p$$

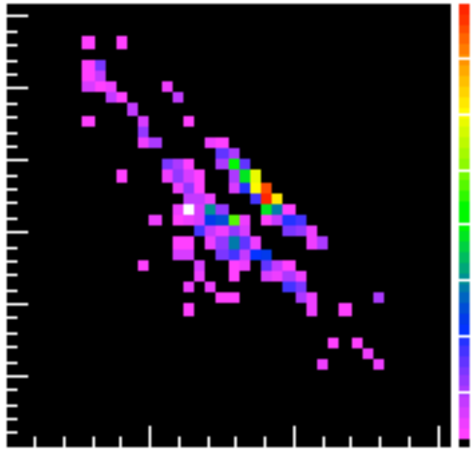
spectator
(<100 MeV/c)



Dalitz plot fits

Difference data-fit
with
“standard” resonances
χ^2 / d.o.f = 3.07

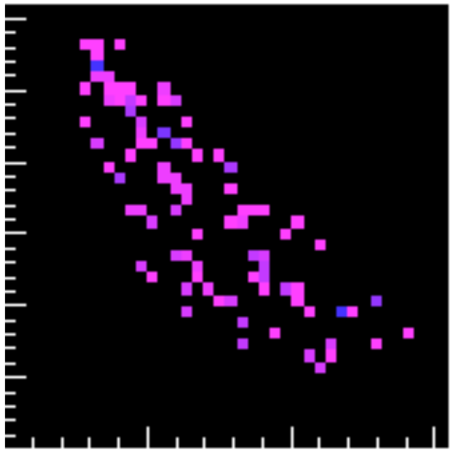


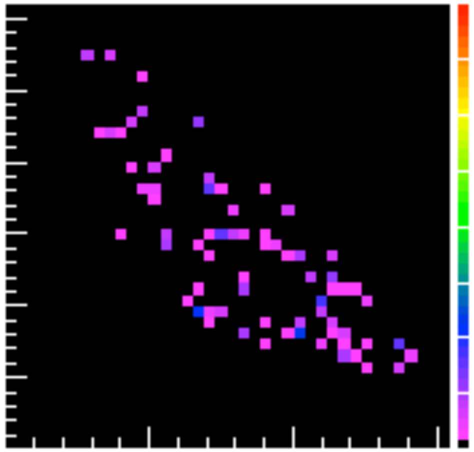


Fit exceeds data

Data exceed fit

Include exotic
$J^{PC} = 1^{-+}\ \pi_1(1400)$
in fit
χ^2 / d.o.f = 1.29





Properties of the $\pi_1(1400)$

Decay: $(\eta\pi)_{L=1}$
Mass: 1400 ± 30 MeV
Width: 310 ± 70 MeV
Quantum numbers: $J^{PC} = \boxed{1^{-+}}$

not possible from $\bar{q}q$

$$\vec{J} = \vec{L} + \vec{S}$$

$$P = (-1)^{L+1}$$

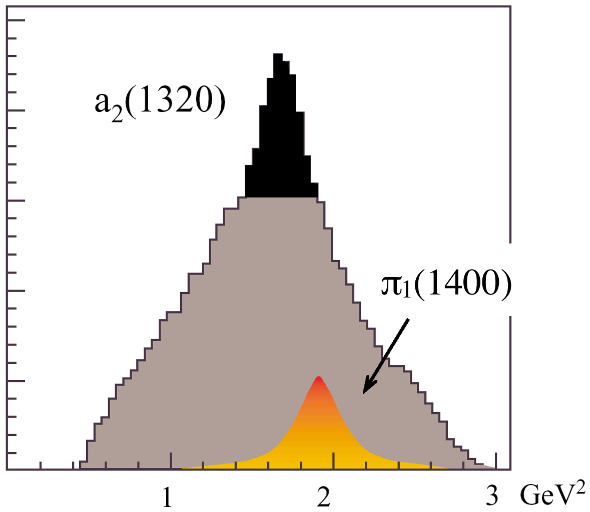
$$C = (-1)^{L+S}$$

Previous indications of this resonance:

$\pi^- p \to (\pi^0\eta)n$ (GAMS/CERN, 100 GeV/c, 1988)
$\pi^- p \to (\pi^0\eta)n$ (VES/Serpukhov, 100 GeV/c, 1993)
$\pi^- p \to (\pi^0\eta)n$ (E852/Brookhaven, 18 GeV/c, 1997))

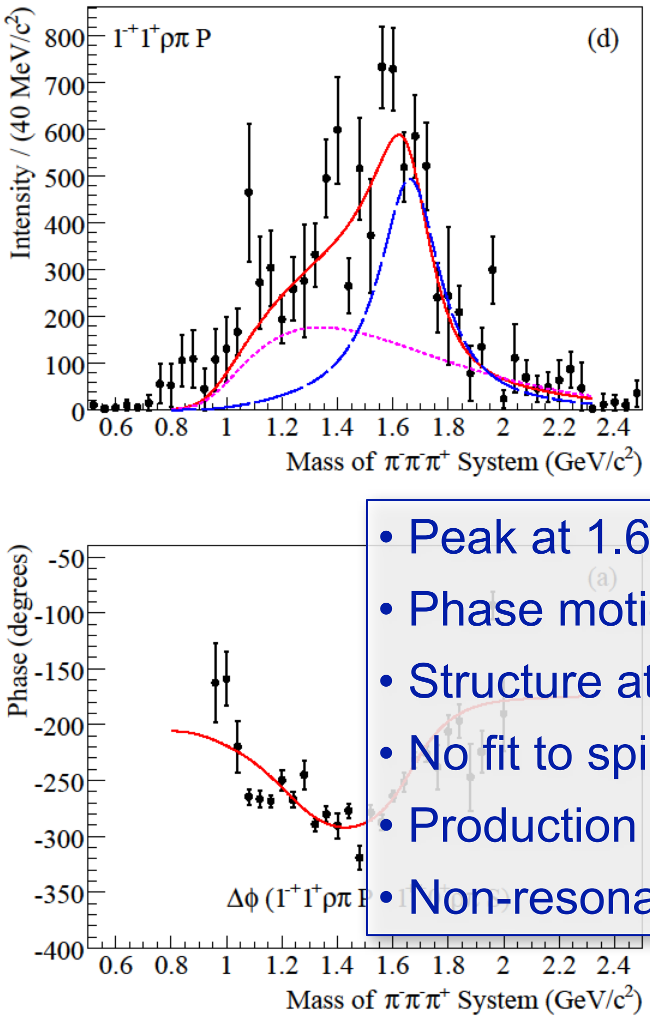
M: 1300 - 1400 MeV/c^2, Γ: 150 - 400 MeV

Exotic production in $\bar{p}p$:



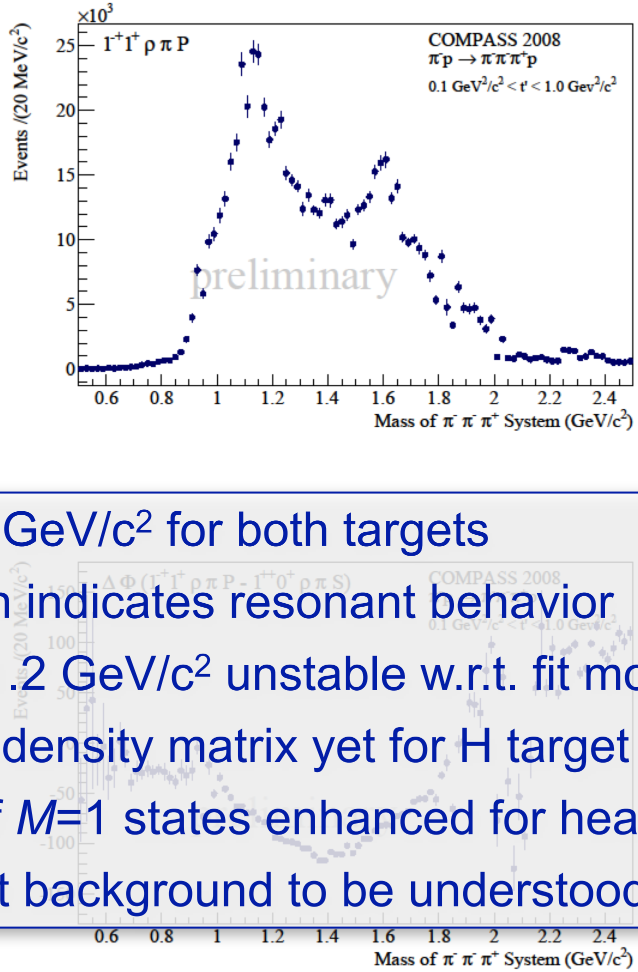
$J^{PC}=1^{-+}$ – Pb vs H Target

$\pi^- \, Pb \rightarrow \pi^- \, \pi^- \, \pi^+ \, Pb$



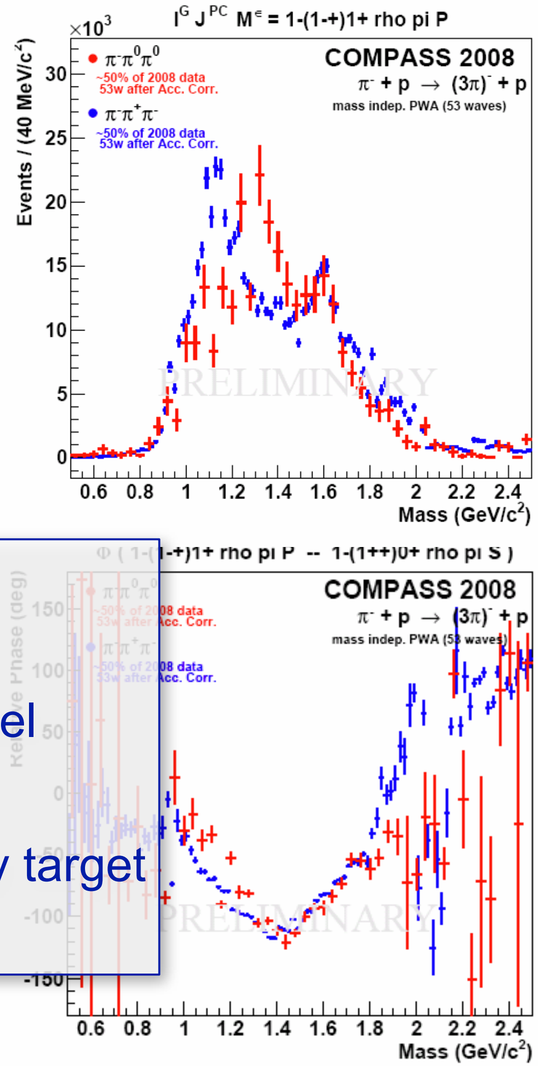
[Alekseev et al., Phys. Rev. Lett. 104, 241803 (2010)]

$\pi^- \, p \rightarrow \pi^- \, \pi^- \, \pi^+ \, p$



[F. Haas, arXiv:1109.1789 (2011)]

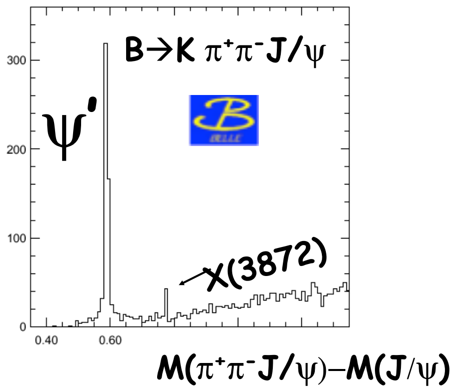
$\pi^- \, p \rightarrow \pi^- \, \pi^0 \, \pi^0 \, p$



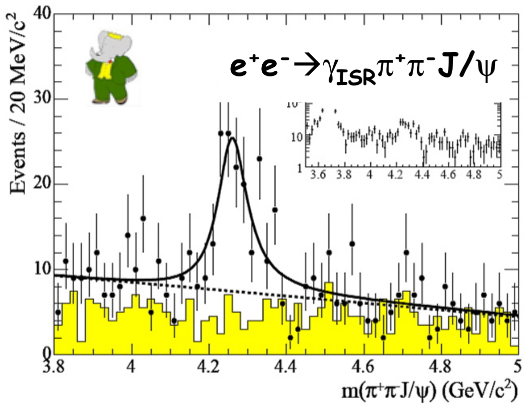
- Peak at 1.67 GeV/c² for both targets
- Phase motion indicates resonant behavior
- Structure at 1.2 GeV/c² unstable w.r.t. fit model
- No fit to spin-density matrix yet for H target
- Production of *M*=1 states enhanced for heavy target
- Non-resonant background to be understood

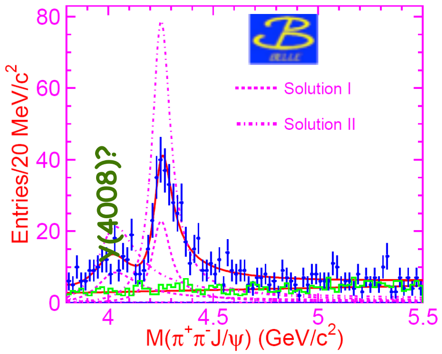
X and Y mesons

X(3872)

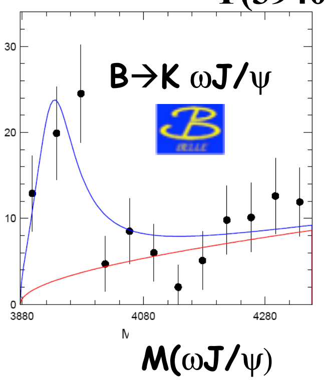


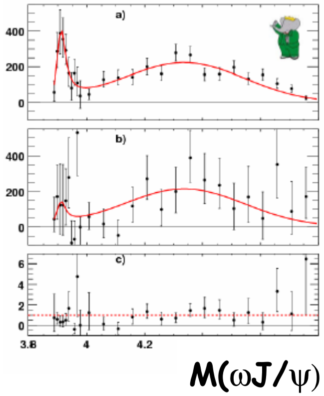
Y(4260)



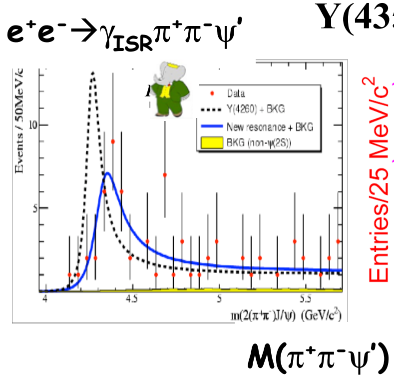


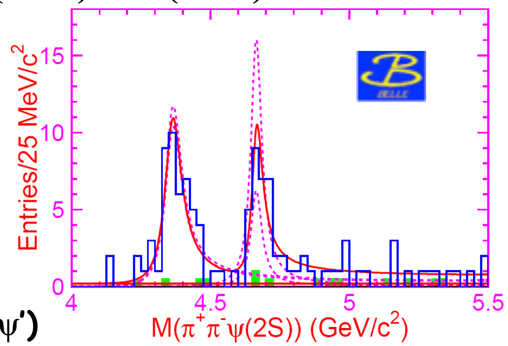
Y(3940)



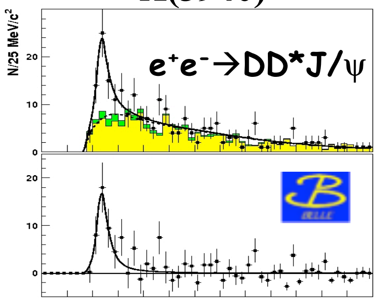


Y(4350) & Y(4660)



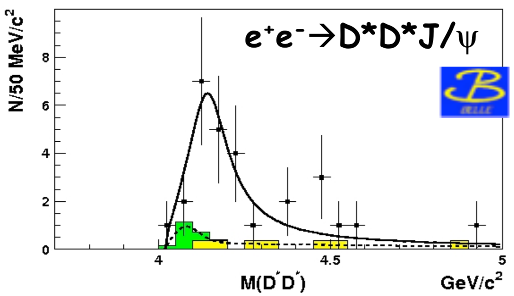


X(3940)



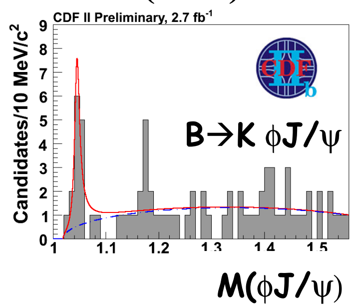
M(DD*)

X(4160)

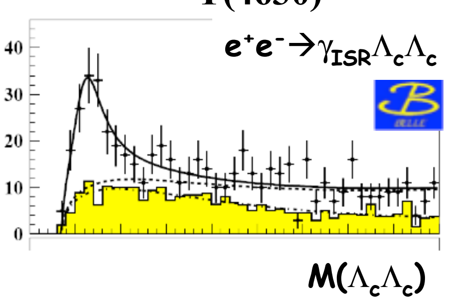


M(D*D*)

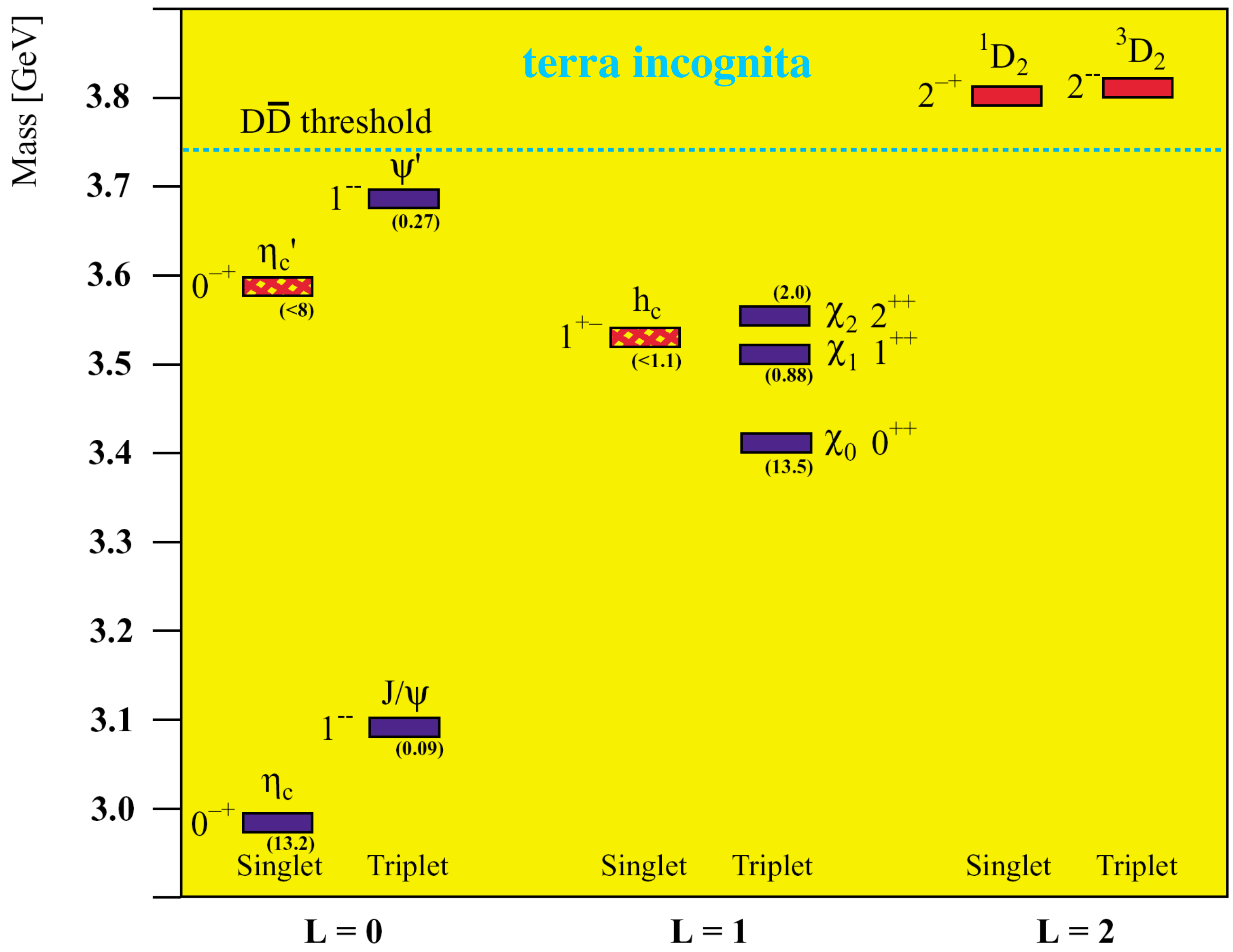
Y(4140)

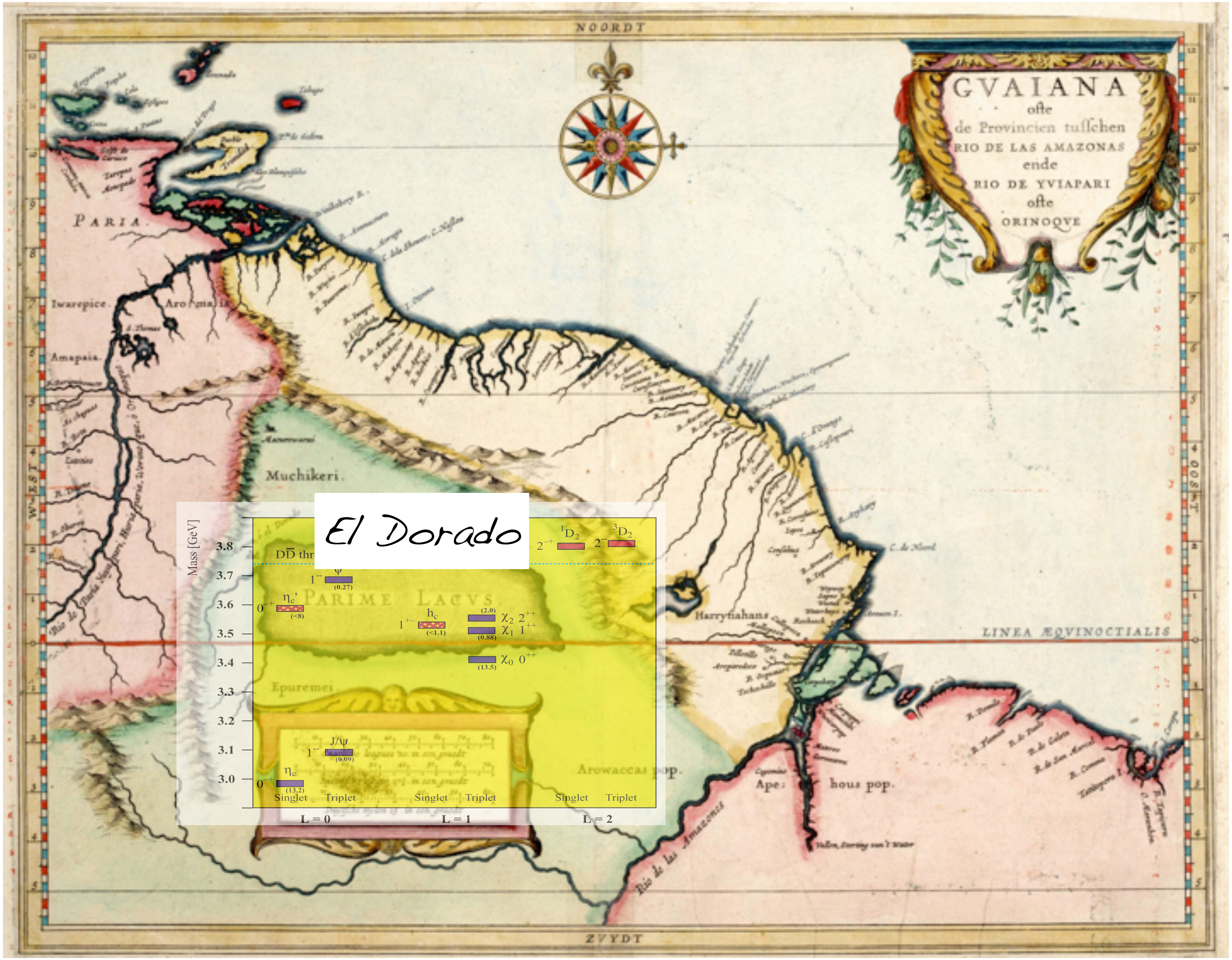


Y(4630)



The charmonium spectrum




El Dorado
Mass [GeV]
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
DD̄ thr
1⁻⁻ ψ (0.27)
0⁻⁺ η_c' (<8)
1⁺⁻ h_c (<1.1)
χ_2 2⁺⁺ (2.0)
χ_1 1⁺⁺ (0.88)
χ_0 0⁺⁺ (13.5)
1⁻⁻ J/ψ (0.09)
0⁻⁺ η_c (13.2)
2⁻⁺ ¹D_2
2⁻⁻ ³D_2
Singlet
Triplet
Singlet
Triplet
Singlet
Triplet
L = 0
L = 1
L = 2
NOORDT
ZVYDT
W'EST
OOST
GVAIANA
ofte
de Provincien tusschen
RIO DE LAS AMAZONAS
ende
RIO DE YVIAPARI
ofte
ORINOQVE
LINEA ÆQVINOCTIALIS
PARIA
PARIME LACVS
Muchikeri
Epuremei
Iwarepice
Amapaia
Arowaccas pop.
hous pop.
Harryfiahans
Rio de las Amazonas

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About 224,000 results (0.31 seconds)

[**X** (**3872**) as a **molecular** DD* state in a potential model]
arxiv.org › hep-ph
by IW Lee - 2009 - Cited by 36 - Related articles
Oct 6, 2009 – Abstract: We discuss the possibility that the **X**(**3872**) can be a hadronic DD* bound state in the framework of a potential model. The potential is **...**

[**X** (**3872**) is not a true **molecule**]
arxiv.org › hep-ph
by S Coito - 2012
Dec 4, 2012 – Some conclude from this mass coincidence that **X**(**3872**) is a meson-meson **molecule**, whatever the dynamics giving rise to the state.

[Is the **X** (**3872**) a **molecule**?]
arxiv.org › hep-ph
by S Coito - 2012 - Related articles
Sep 6, 2012 – Abstract: Because of the controversial **X**(**3872**) meson's very close proximity to the $D^0\bar{D}^{*0}$ threshold, this charmonium-like **...**

[Is the Exotic Hadron **X** (**3872**) a D0 D* 0 **Molecule**: Precision **...**]
arxiv.org › hep-ex
by A Tomaradze - 2012
Dec 17, 2012 – Abstract: It has been proposed that the recently discovered archetypical "exotic" meson, **X**(**3872**), with M(**X**(**3872**))=3871.68+-0.17 MeV/c^2, **...**

[PDF] [**X**(**3872**) - of the Quarkonium Working Group - Infn]
www.qwg.to.infn.it/WS-jun06/WS4talks/Tuesday_PM/Richard.pdf
File Format: PDF/Adobe Acrobat - Quick View
Meson **molecules**. Diquark–antidiquark. QCD Sum Rules. 4. Chromomagnetic interaction. General considerations. First applications. Application to the **X**(**3872**) **...**

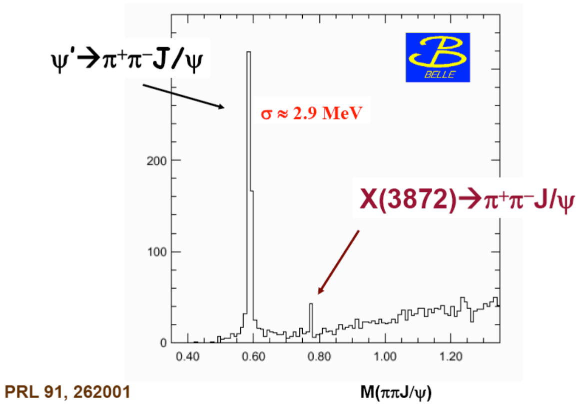
[PDF] [Is the **X**(**3872**) a **molecule**? - Indico]
indico.cern.ch/materialDisplay.py?contribId=15&materialId...
File Format: PDF/Adobe Acrobat - Quick View
Excited QCD 2012, Peniche, 7th February. Is the **X**(**3872**) a **molecule**? Susana Coito. CFIF, Instituto Superior Técnico, Lisboa. Supervisors: George Rupp, Eef **...**

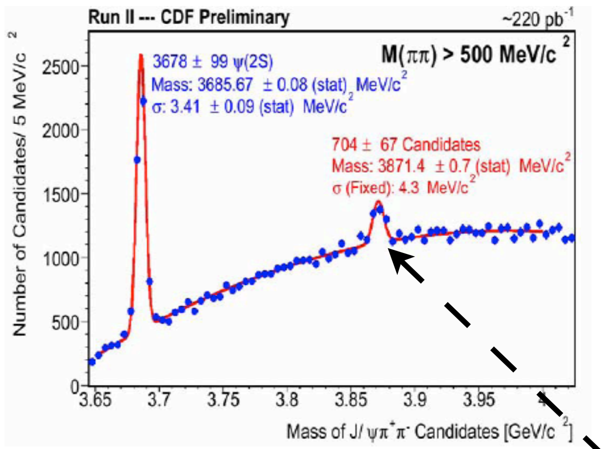
Ulrich Wiedner

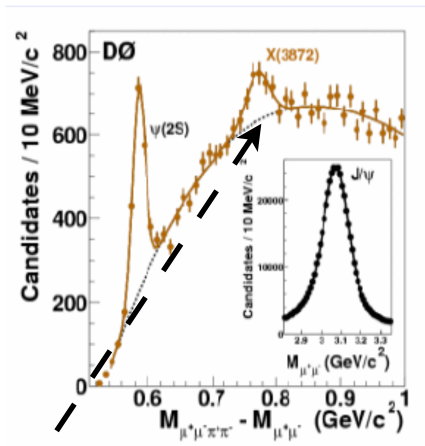
X(3872)

$B \to KX;\ p\bar{p}$
$X \to \pi^+\pi^- J/\psi$
$X \to \pi^+\pi^-\pi^0 J/\psi$
$X \to \gamma J/\psi;\ X \to \gamma\psi(2S)$
$X(3875) \to D^0\bar{D}^0\pi^0$

$J^{PC} = 1^{++}$ (or 2^{-+})
$M = 3871.68 \pm 0.17$ MeV
$\Gamma < 1.2$ MeV
$> 10\ \sigma$





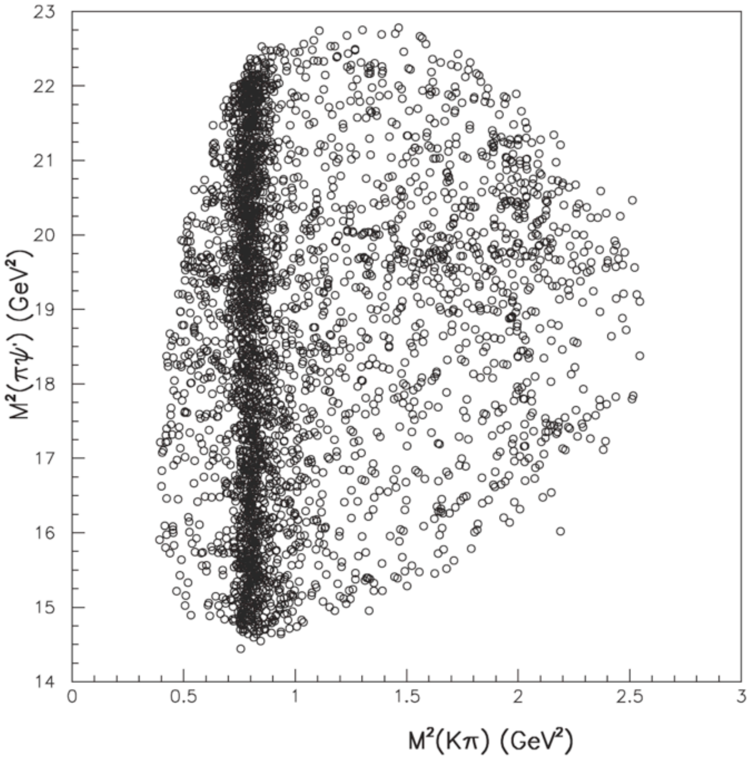


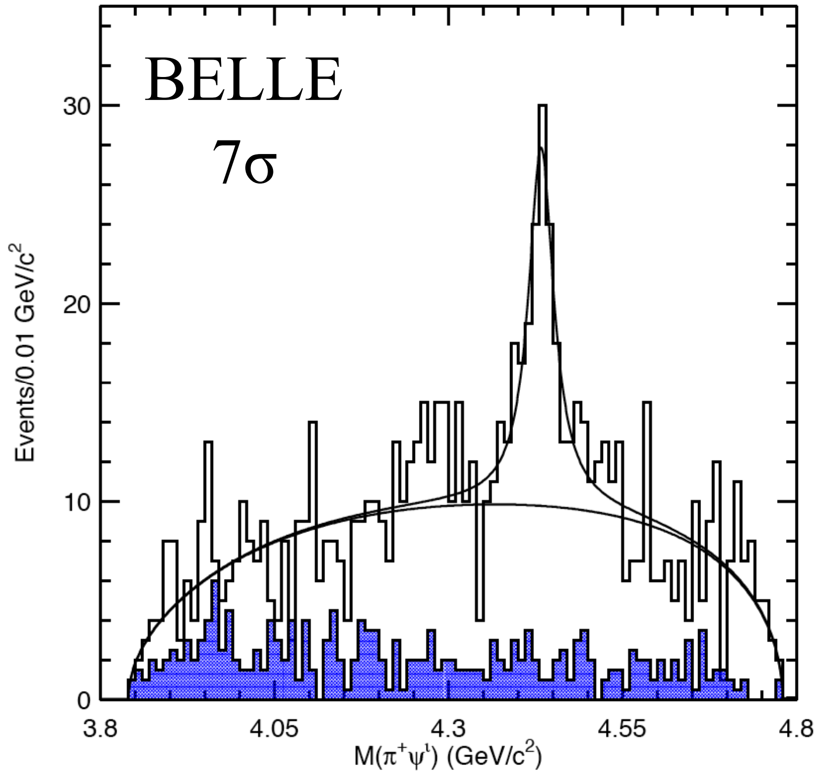
X(3872)

?

DD* molecule
threshold effect
<u>tetraquark</u>

Z^+ (4430) - a new state of matter (tetraquark) decaying into $\pi^+\psi'$





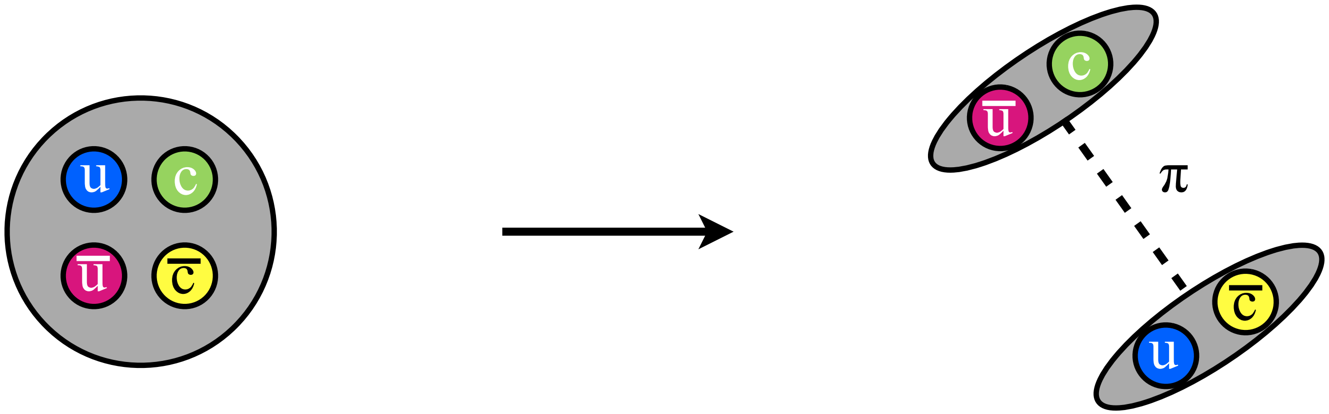
$$M = (4.433 \pm 0.004\ (\text{stat}) \pm 0.001\ (\text{syst}))\ \text{GeV}$$

$$\Gamma = (0.044^{+0.017}_{-0.011}\ (\text{stat})^{+0.030}_{-0.011}\ (\text{syst}))\ \text{GeV}$$

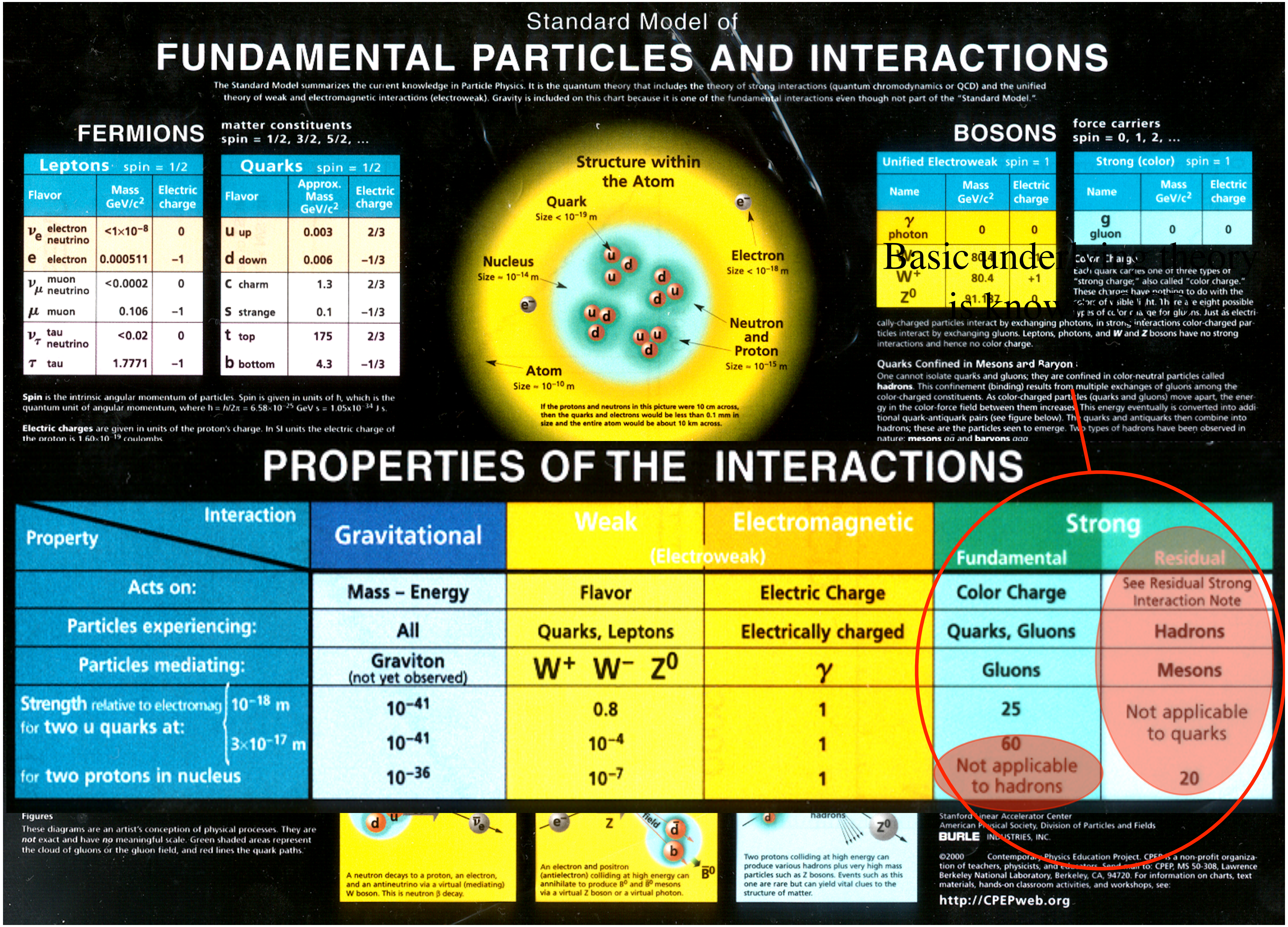
$$\mathcal{B}(B \to KZ(4430) \times \mathcal{B}(Z \to \pi^+\psi') = (4.1 \pm 1.0\ (stat) \pm 1.3\ (syst)) \times 10^{-5}$$

PRL 100, 142001 (2008)
arXiv:0708.1790 [hep-ex]

4-quark state　　　　　　　　$D\text{-}\bar{D}$-“molecule”



Transition from color forces to colourless nuclear forces ?

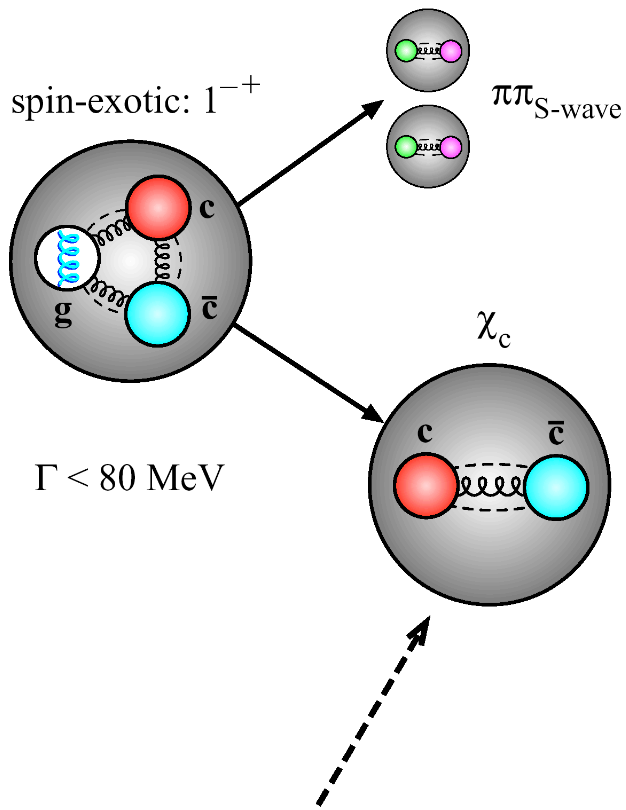


Basic underlying theory is known

Ulrich Wiedner

Decay of charmonium hybrids

Lattice results*



Decay of charmonium provides a clean "tag".

*UKQCD, C. McNeile et al.; Phys.Rev.D 65:094505, 2002; C. Michael, hep-lat/0207017.

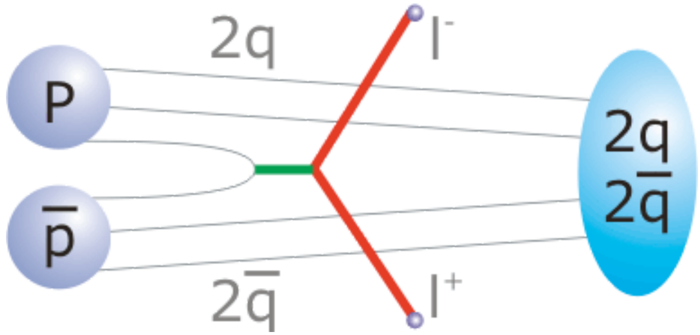
Proton-Antiproton contains already a 4-Quark-System

Idea: Dilepton-Tag from Drell-Yan-Production

Advantages

- Trigger
- less J^{PC}-Ambiguities
- 1200 E./day @ 12 GeV
- 300 E./day @ 5-8 GeV

antiproton-Beam
(for $L=10^{32}cm^{-2}s^{-1}$)



Bannikov, Gornuschkin, Kopeliovich, Krumshtein and Sapozhnikov, JINR E1-92-344 (1992)

Exotics

What we know:

$\pi_1(1400)$

Mass: 1400 ± 30 MeV
Width: 310 ± 70 MeV
Decay: $(\eta\pi)_{L=1}$
$J^{PC} = 1^{-+}$

A. Abele et al., Phys. Lett. B 423 (1998) 175.

$\pi_1(1660)$

Mass: $1660 \pm 10^{+0}_{-64}$ MeV/c^2
Width: $269 \pm 21^{+42}_{-64}$ MeV/c^2
Decay: $(\rho\pi)$
$J^{PC} = 1^{-+}$

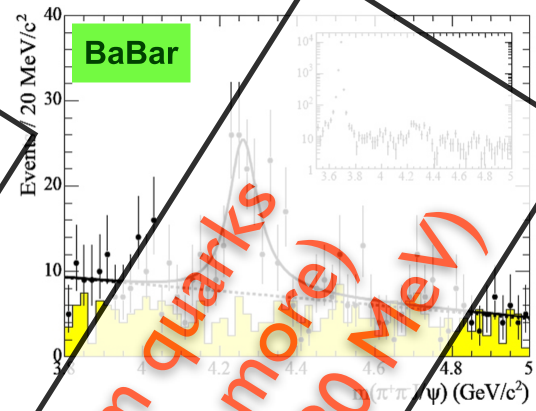
M.G. Alekseev et al., PRL 104 (2010) 241803

light quarks: BROAD (~300 MeV) (likely unmixed)

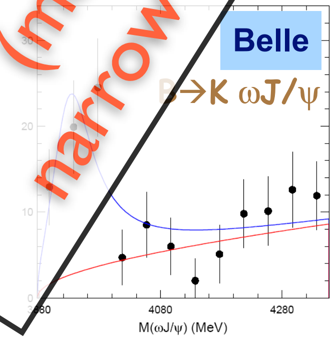
$s\bar{s}$ hybrids

?????!

Y(4260)



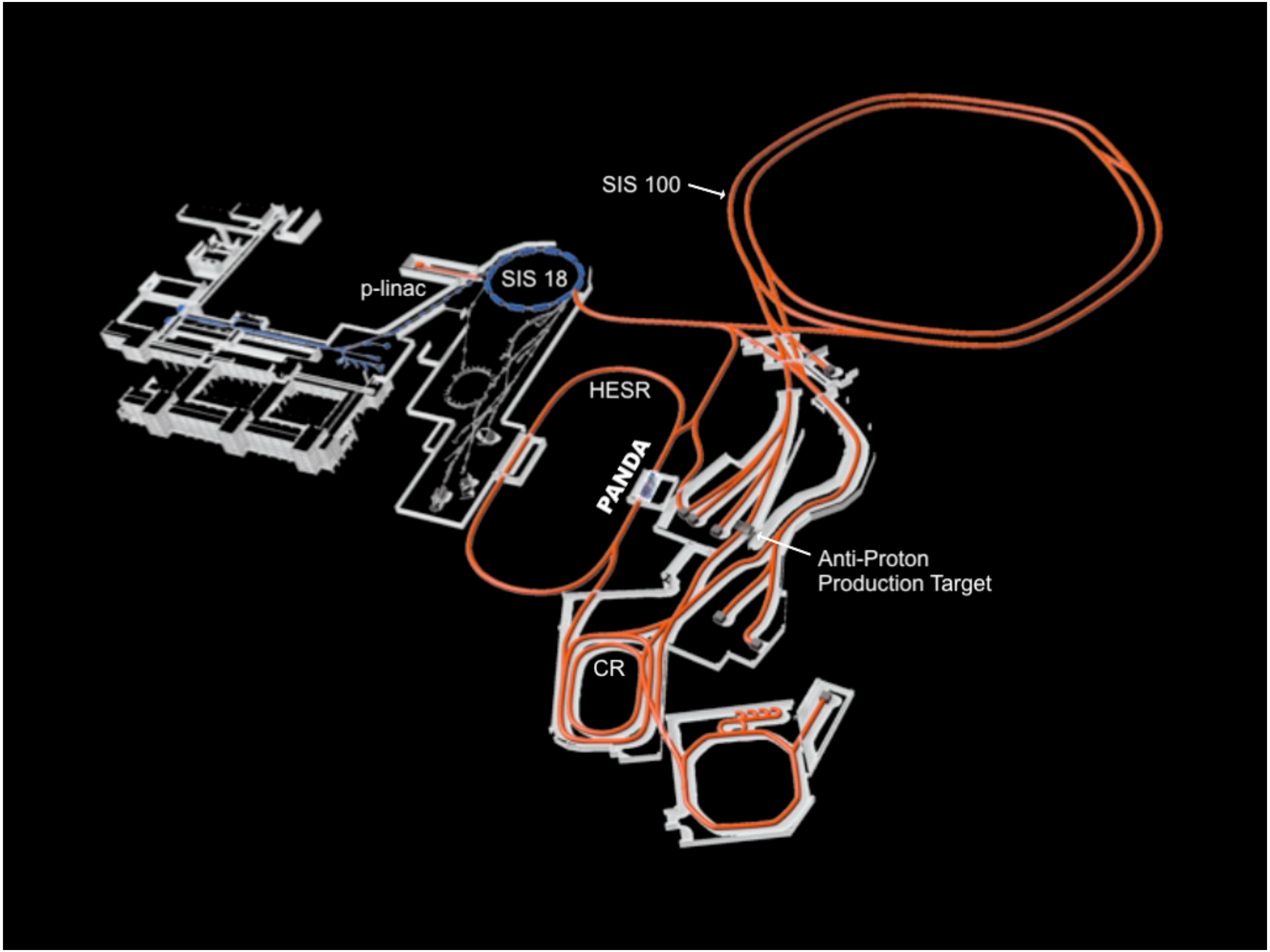
Y(3940)



charm quarks (much more) narrow (~80 MeV)

JLAB@12 GeV

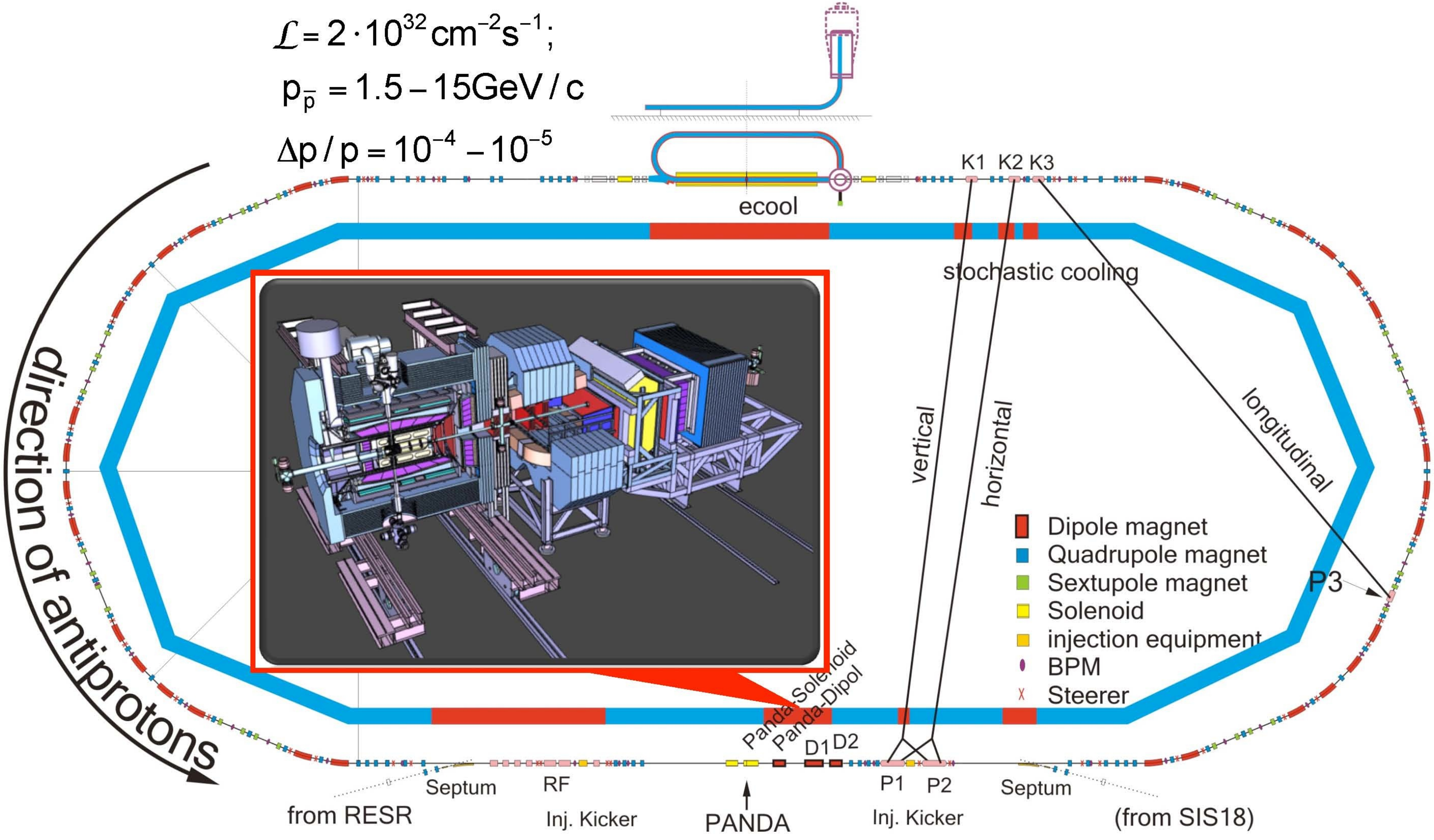
PANDA


SIS 100
SIS 18
p-linac
HESR
PANDA
Anti-Proton
Production Target
CR

$$\mathcal{L} = 2 \cdot 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1};$$

$$p_{\bar{p}} = 1.5 - 15\,\mathrm{GeV}/c$$

$$\Delta p / p = 10^{-4} - 10^{-5}$$



PANDA Collaboration

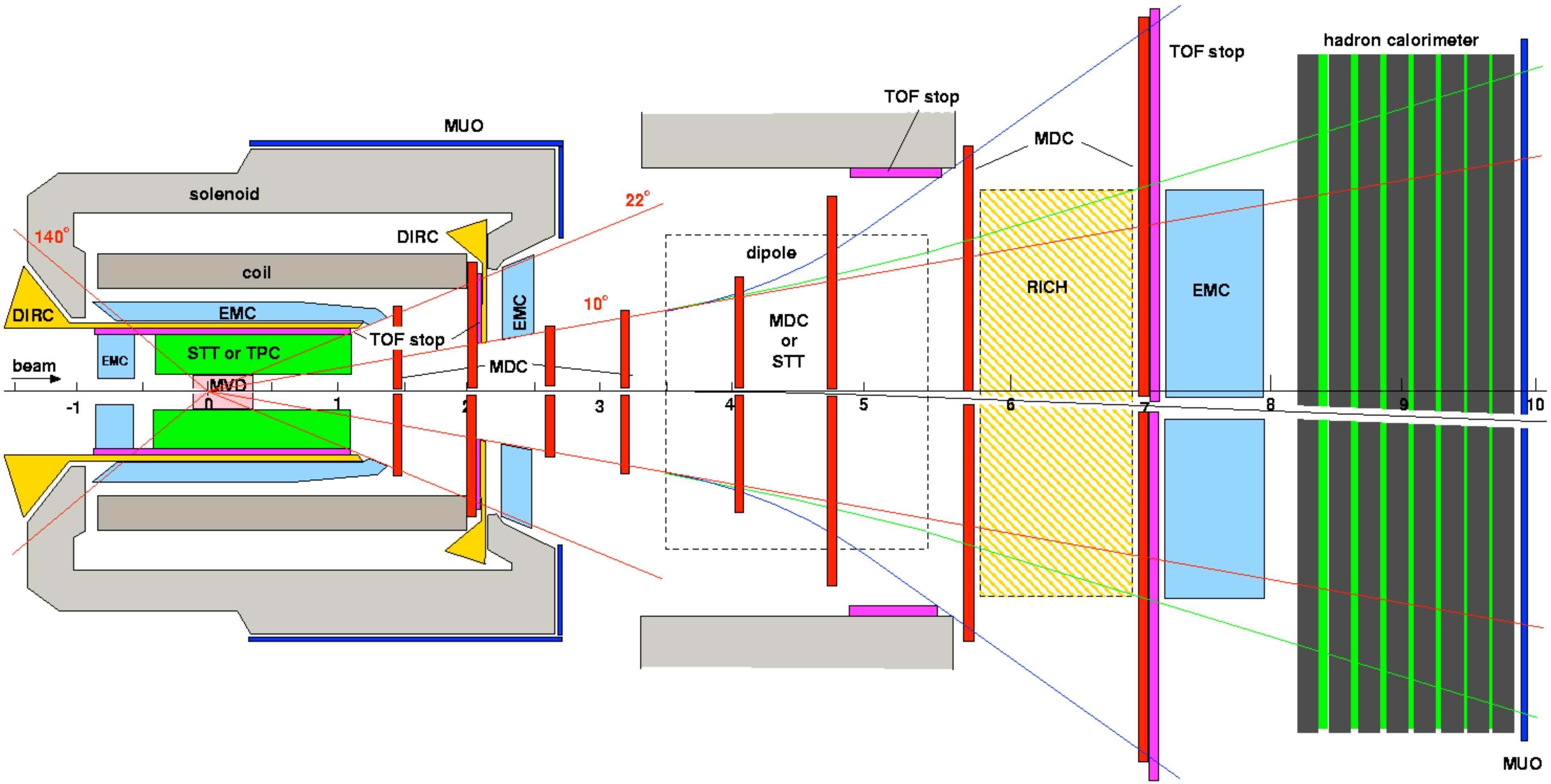
- At present a group of **500 physicists** from 62 institutions and 16 countries

Australia – Austria – Belaruz – China – France – Germany – India – Italy – The Netherlands – Poland – Romania – Russia – Sweden – Switzerland – U.K. – U.S.A.

AMU Aligarh, Basel, Beijing, BITS Pillani, Bochum, IIT Bombay, Bonn, Brescia, IFIN Bucharest, IIT Chicago, AGH-UST Cracow, JGU Cracow, IFJ PAN Cracow, Cracow UT, Edinburgh, Erlangen, Ferrara, Frankfurt, Gauhati, Genova, Giessen, Glasgow, GSI, FZ Jülich, JINR Dubna, Katowice, KVI Groningen, Lanzhou, Legnaro, LNF, Lund, Mainz, Minsk, ITEP Moscow, MPEI Moscow, TU München, Münster, BARC Mumbai, Northwestern, BINP Novosibirsk, IPN Orsay, Pavia, IHEP Protvino, PNPI St.Petersburg, South Gujarat University, SVNIT Surat, Sadar Patel University, KTH Stockholm, Stockholm, FH Südwestfalen, Suranaree University of Technology, Sydney, Dep. A. Avogadro Torino, Dep. Fis. Sperimentale Torino, Torino Politecnico, Trieste, TSL Uppsala, Tübingen, Uppsala, NCBJ Warsaw, TU Warsaw, AAS Wien

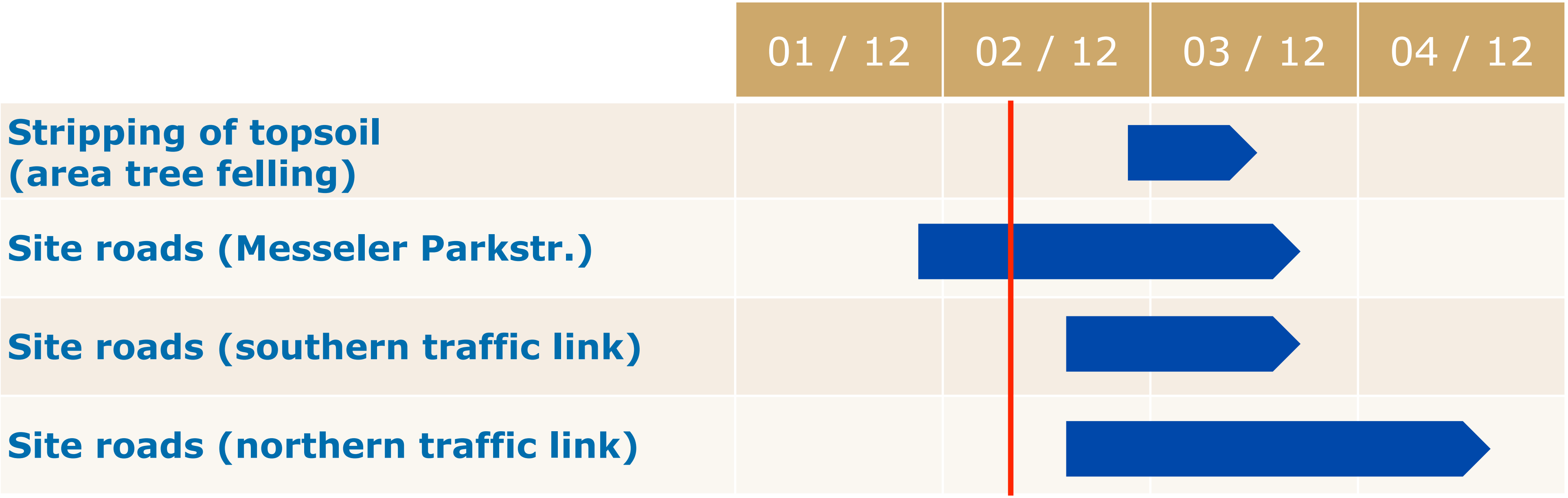
http://www.gsi.de/panda

Layout of the detector (top view)



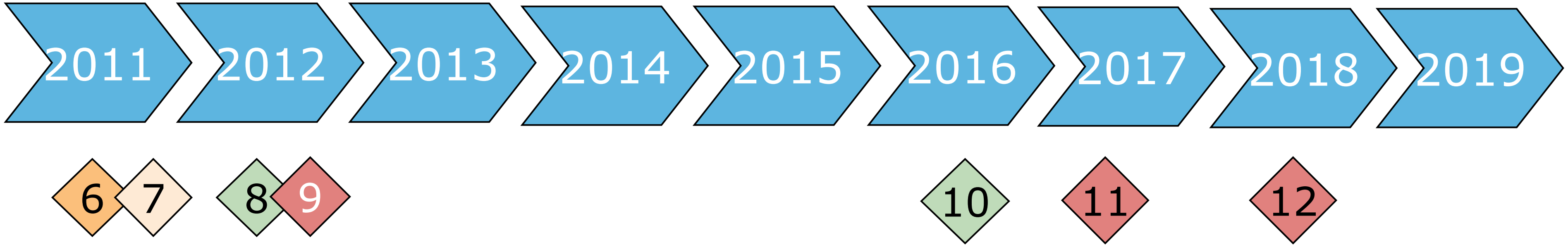
Ulrich Wiedner

Further Preparatory Work



Experimental Site 2012

Timeline



- 6 Building permits
- 7 Site preparation
- 8 Civil construction contracts
- 9 Building of accelerator & detector components
- 10 Completion of civil construction work
- 11 Installation & commissioning of accelerators and detectors
- 12 Start Data taking

Google earth

Thank you!