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SUMMER SCHOOL ON PARTICLE PHYSICS

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A NEW CHARMING AND STRANGE MESON IN BaBar

Special Lecture

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A new charming and strange meson in BaBar

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Outline

- BaBar and PEPII
- CP physics at BaBar
- Charm bound states
- Ds(2317) et al.
- Theoretical excitation
- Conclusions

BaBar Mission

- Study CP violation in B sector
- Study B rare decays (b->sγ, b->sll, b->dγ...)
- Make use of the high luminosity for studying charm and τ physics
- Be ready for New Physics

CP violation and Standard Model

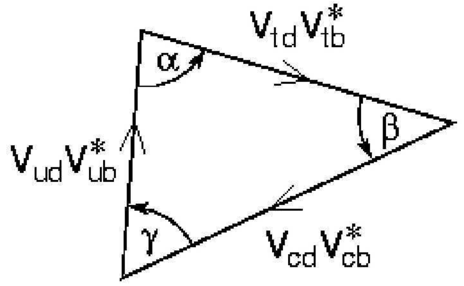
- CP violation generated by complex coupling constant
- Quark mixing matrix

Cabibbo **K**obayashi **M**askawa **matrix** $\lambda = \sin(\theta_{Cabibbo})$

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \qquad V \cong \begin{bmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix}$$

- 3 quark generations → one non-removable phase

The 'Triangles'



(a)

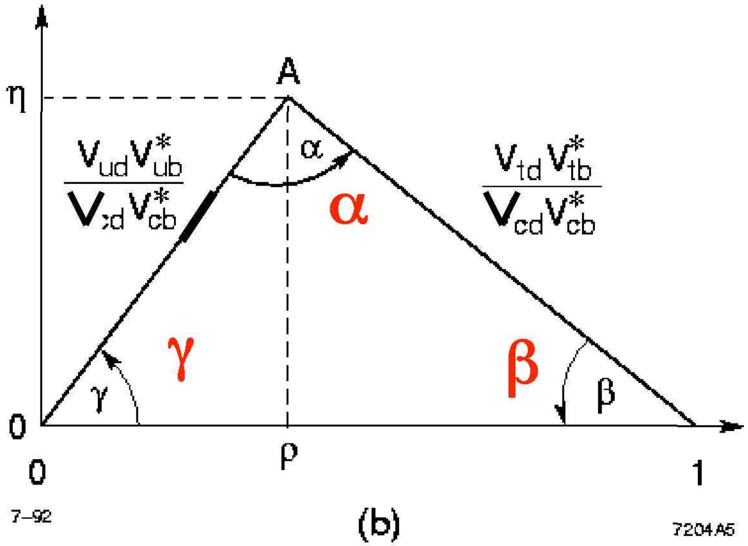
- CKM matrix is unitary

B$_d$ system

$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0 \Rightarrow$$

phases → angles α, β, and γ

(OK, I know, ϕ_2, ϕ_1 and ϕ_3)



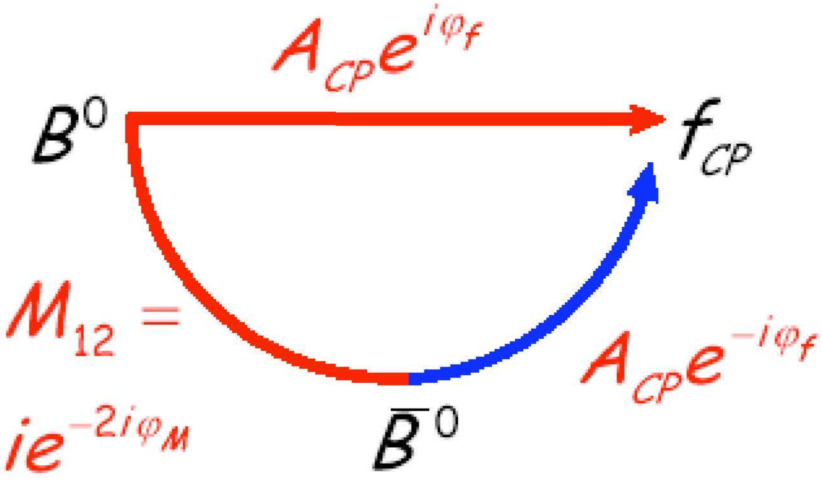
(b)

CP violation proportional to triangle area:

measure sides and angles independently

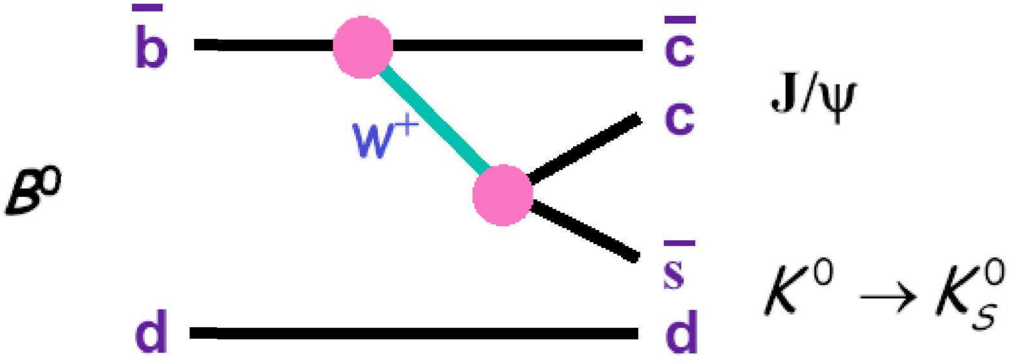
CP violation in B system

- CPV through interference of decay amplitudes
- CPV through interference of mixing diagram
- CPV through interference between mixing and decay amplitudes



Directly related to CKM angles for single decay amplitude

The Golden Channel



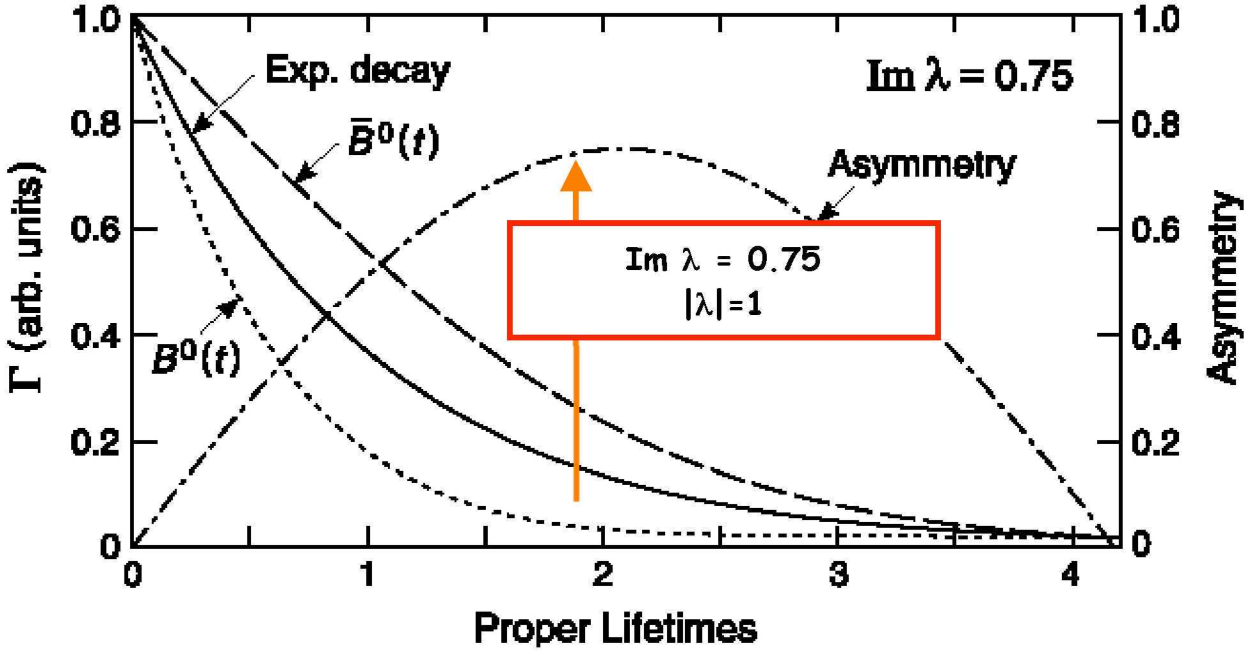
CP Eigenstate:
η_{CP} = -1

CP parameter

$$\mathrm{Im}\,\lambda_{b\to c\bar{c}s} = \eta_{f_{CP}}\,\mathrm{Im}\left\{\underbrace{\boxed{\frac{V_{cb}V_{cs}^*}{V_{cb}^*V_{cs}}}}_{\text{Quark subprocess}} \times \underbrace{\boxed{\frac{V_{tb}V_{td}^*}{V_{tb}^*V_{td}}}}_{B^0\text{ mixing}} \times \underbrace{\boxed{\frac{V_{cd}^*V_{cs}}{V_{cd}V_{cs}^*}}}_{K^0\text{ mixing}}\right\} = \eta_{f_{CP}}\,\mathrm{Im}\frac{V_{td}^*}{V_{td}} = \eta_{f_{CP}}\sin 2\beta$$

$$A_{f_{CP}}(t) = \frac{\Gamma(\bar{B}^0_{phys}(t)\to f_{CP}) - \Gamma(B^0_{phys}(t)\to f_{CP})}{\Gamma(\bar{B}^0_{phys}(t)\to f_{CP}) + \Gamma(B^0_{phys}(t)\to f_{CP})} = -\mathrm{Im}\,\lambda_{f_{CP}}\sin\Delta m_d t$$

Time dependent CP asymmetries



Im λ = 0.75
|λ|=1

$$a_{f_{CP}}(\Delta t)=\frac{N[\overline{B}^{0}_{phys}\rightarrow f_{CP}(\Delta t)]-N[B^{0}_{phys}\rightarrow f_{CP}(\Delta t)]}{N[\overline{B}^{0}_{phys}\rightarrow f_{CP}(\Delta t)]+N[B^{0}_{phys}\rightarrow f_{CP}(\Delta t)]}$$

Neutral B Time Evolution

L=1 $B^0\bar{B}^0$ system requires antisymmetric initial-state wave function in $\Upsilon(4S)$ frame:

$$S(t_f,t_b)=1/\sqrt{2}\Big[B^0_{phys}(t_f,\theta,\varphi)\bar{B}^0_{phys}(t_b,\pi-\theta,\varphi+\pi) - \bar{B}^0_{phys}(t_f,\theta,\varphi)B^0_{phys}(t_b,\pi-\theta,\varphi+\pi)\Big]\sin\theta$$

(θ,φ) are wrt e^- beam direction;

(f,b) are the forward (backward) going B meson,

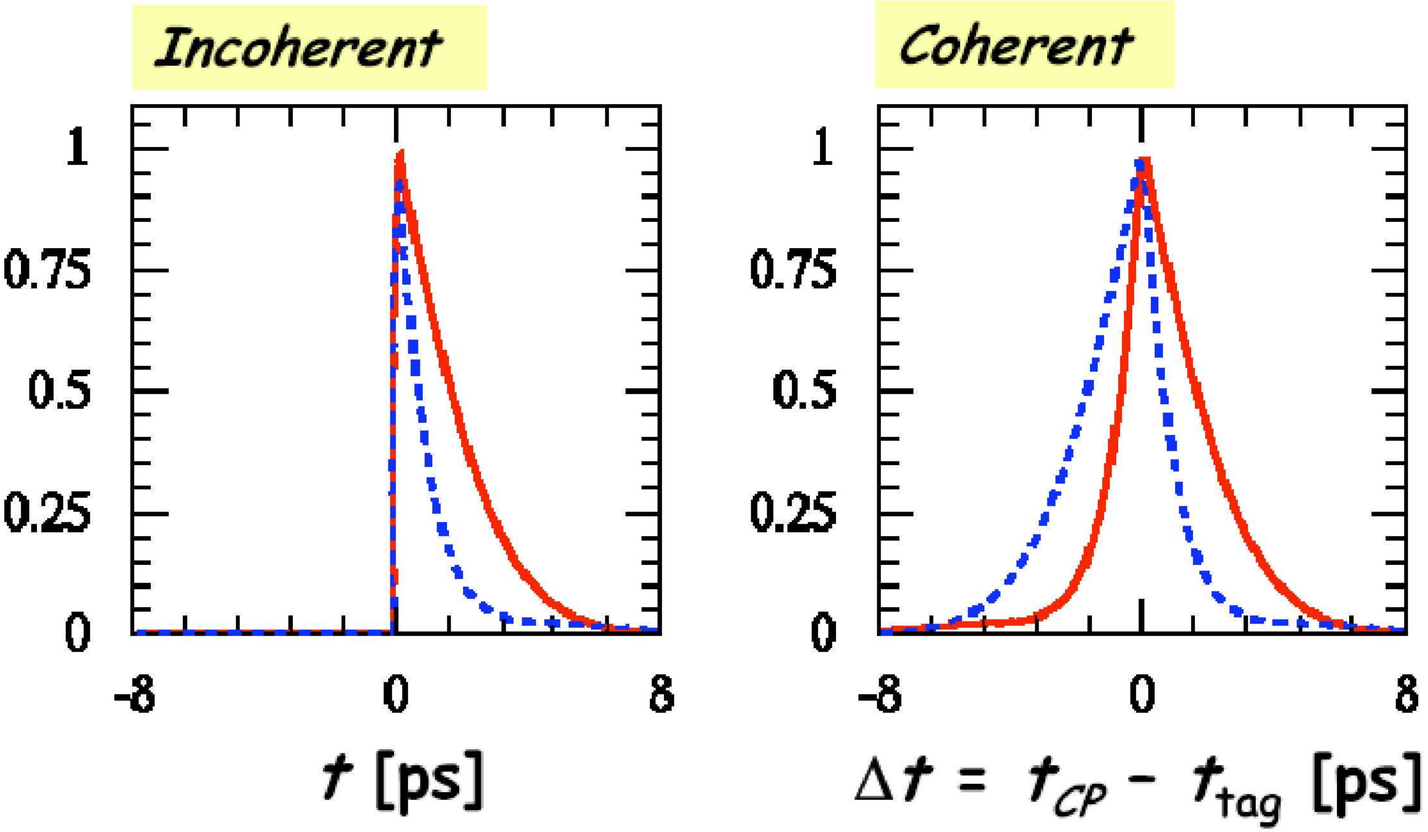
with $(\theta_f < \pi/2)$ and $t_f = t_b$ until one B meson decays

Consequently $B^0\bar{B}^0$ evolves coherently until one B mesons decays

- At any given time, until one of the *B* mesons decays, there is exactly one B^0 and one $\bar{B}^0$ including at time $\Delta t = t_{CP} - t_{tag} = 0$
- *CP*/Mixing oscillation clock only starts ticking at the time of the first decay, relevant time parameter is Δt
- Half of the time the *CP* eigenstate *B* decays first ($\Delta t < 0$)

Neutral B Time Evolution

Evolution for $B^0(\bar{B}^0)$ state at $t_{CP} = 0$



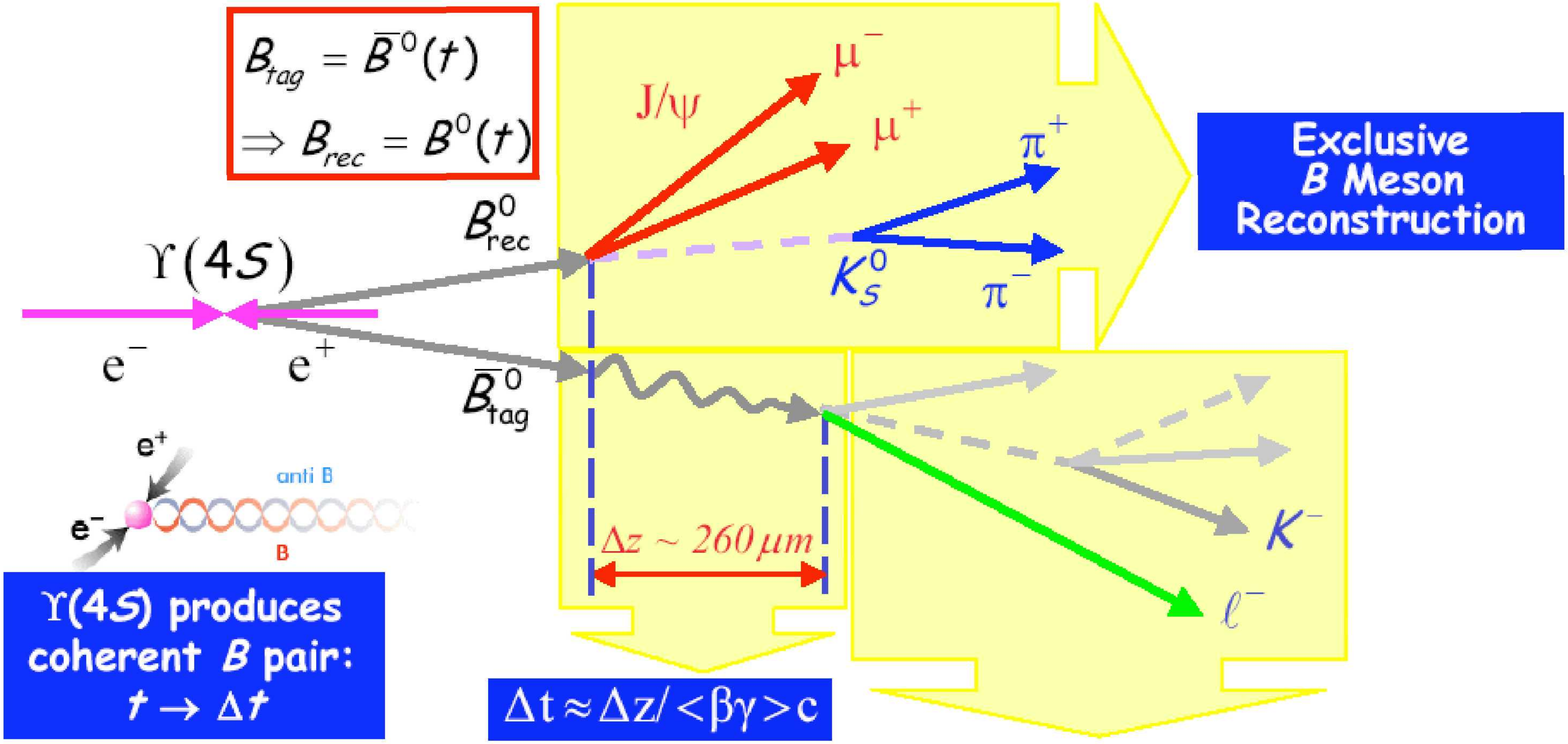
For coherent source, integrated asymmetry is zero: must do a time-dependent analysis

$$\int_{-\infty}^{+\infty} F(\Delta t)\, d\Delta t = \int_{-\infty}^{+\infty} \bar{F}(\Delta t)\, d\Delta t$$

Experimental Technique for B-factories

$B_{tag} = \bar{B}^0(t)$

$\Rightarrow B_{rec} = B^0(t)$



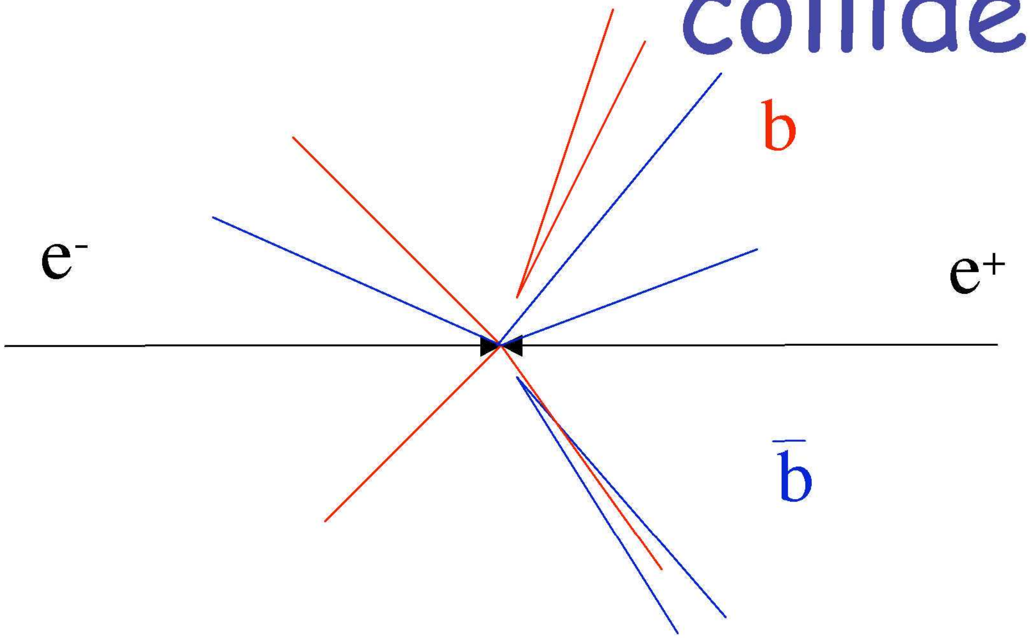
Exclusive *B* Meson Reconstruction

$\Upsilon(4S)$ produces coherent *B* pair: $t \rightarrow \Delta t$

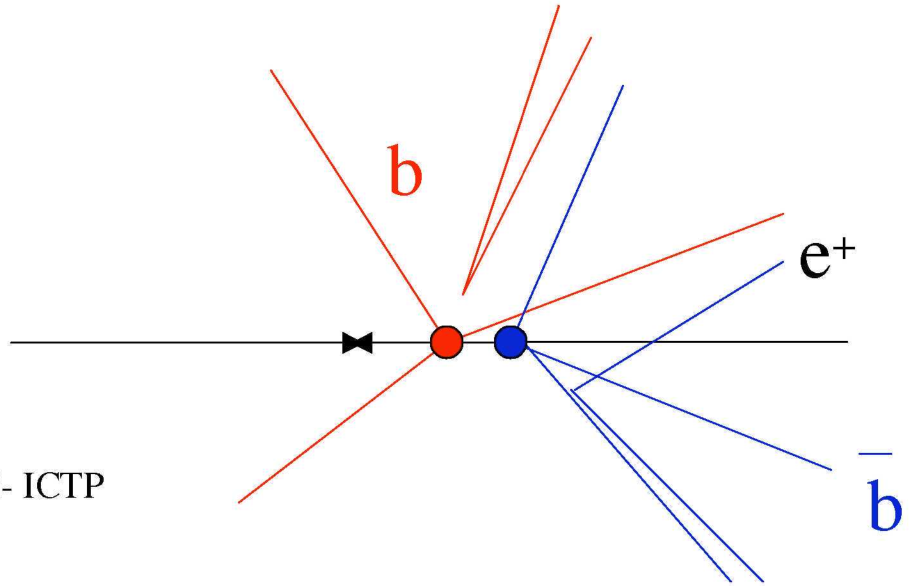
$\Delta t \approx \Delta z / <\beta\gamma> c$

***B*-Flavor Tagging**

Requires a new type of collider



Symmetric (CESR)



Asymmetric (boosted):
PEPII, KEKB

The crucial parameter

At Υ(4S) center of mass energy in a symmetric collider : $\Upsilon(4S) \to B^0\overline{B}^0$ and $p(B^0) \sim 300$MeV.

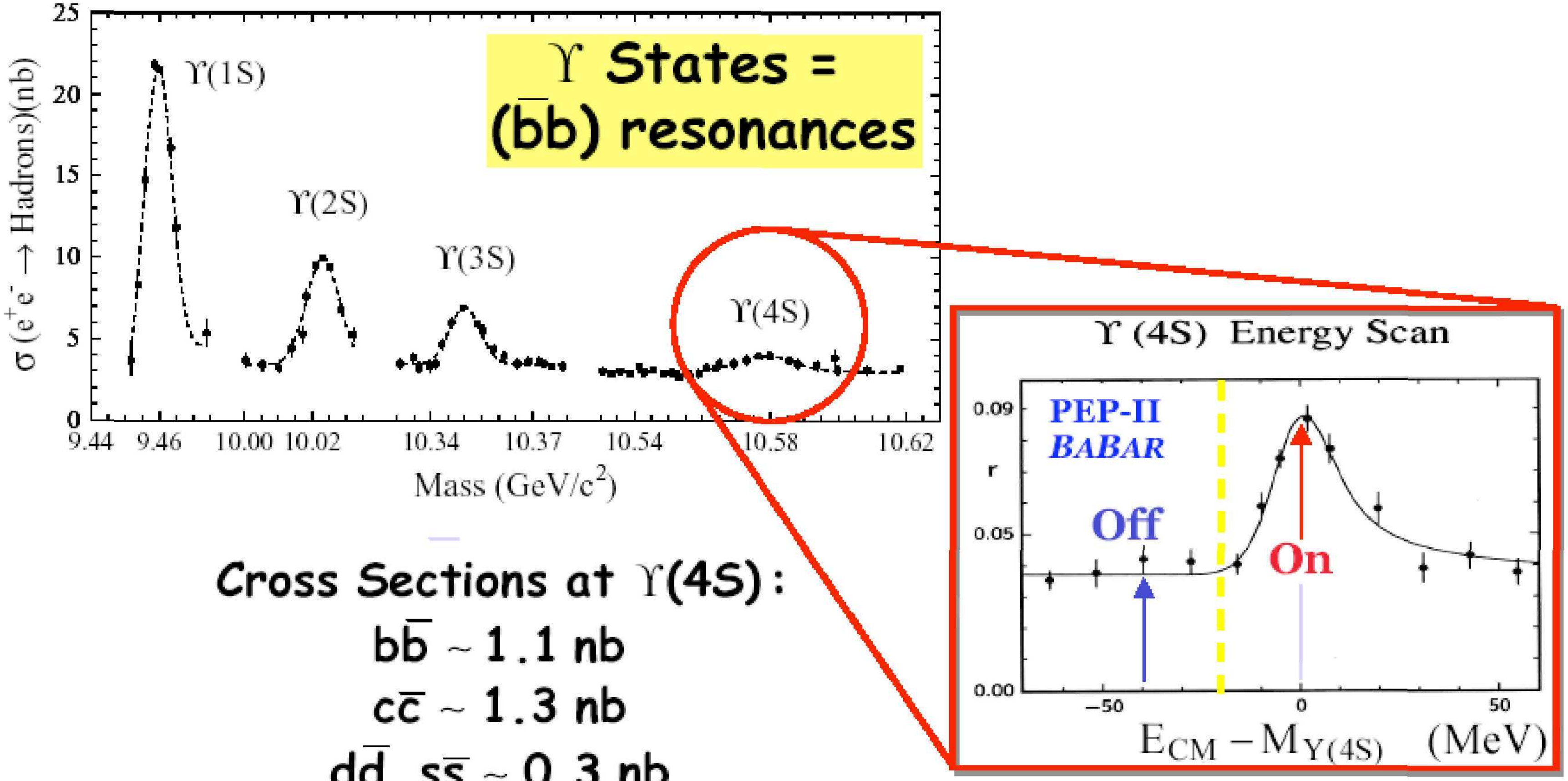
Given the 1.6ps lifetime, $\beta\gamma c\tau \sim 3*160*0.3/5 \sim 30\mu$

Much beyond the possibility of vertexing capability of a Silicon Vertex Tracker. Not to mention the confusion of which (B) is which.

If you collide 9 GeV e^- on 3 GeV e^+ you have the same CM energy with some boost $\beta\gamma=(E_e-E_{e+})/E_{CM} \sim 0.5-0.6$ and the separation becomes $\beta\gamma c\tau \sim 250\mu$.

Moreover you can assign tracks to each B

The B-factory output



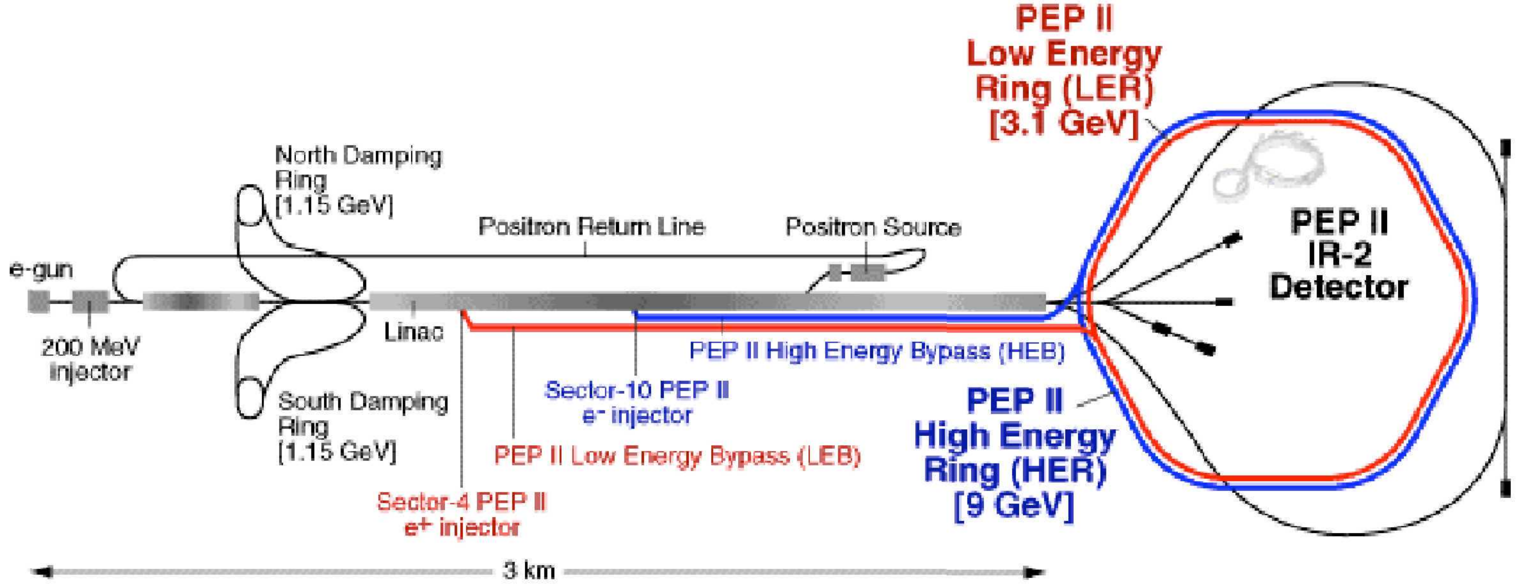
Υ States =
$(b\bar{b})$ resonances

Cross Sections at Υ(4S):

$b\bar{b}$ ~ 1.1 nb
$c\bar{c}$ ~ 1.3 nb
$d\bar{d}$, $s\bar{s}$ ~ 0.3 nb
$u\bar{u}$ ~ 1.4 nb

$$e^+e^- \to \Upsilon(4S) \to B\bar{B}$$
$L = 1$ state

BaBar and PEP-II @ SLAC

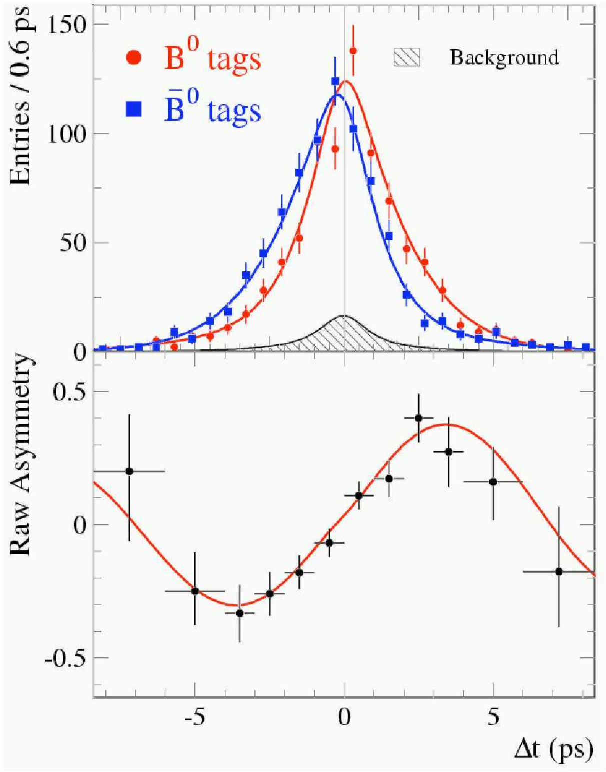


High luminosity asymmetric B factory @ $\Upsilon(4S)$

9 GeV e^- on 3.1 GeV e^+

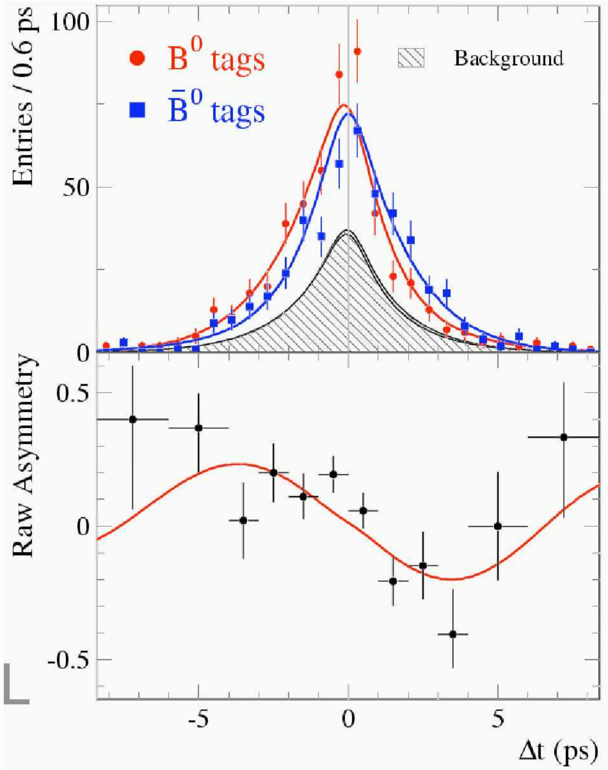
$\Upsilon(4S)$ **boost:** $\langle\beta\gamma\rangle \approx 0.55$

BaBar result on sin2β



K_S

K_L



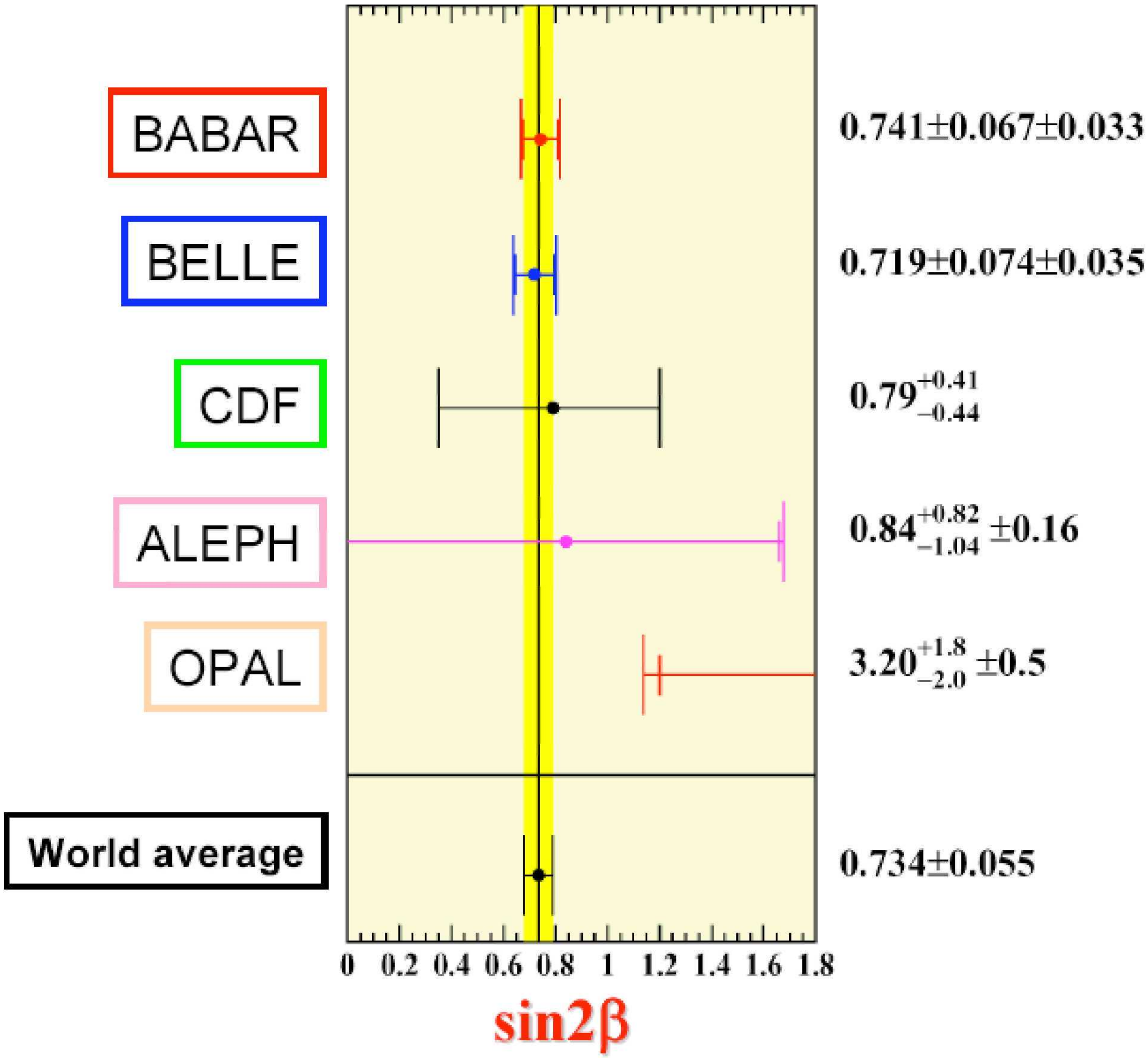
hep-ex/ 0207042 (PRL)

2641 tagged events (78% purity; 66% tagged)

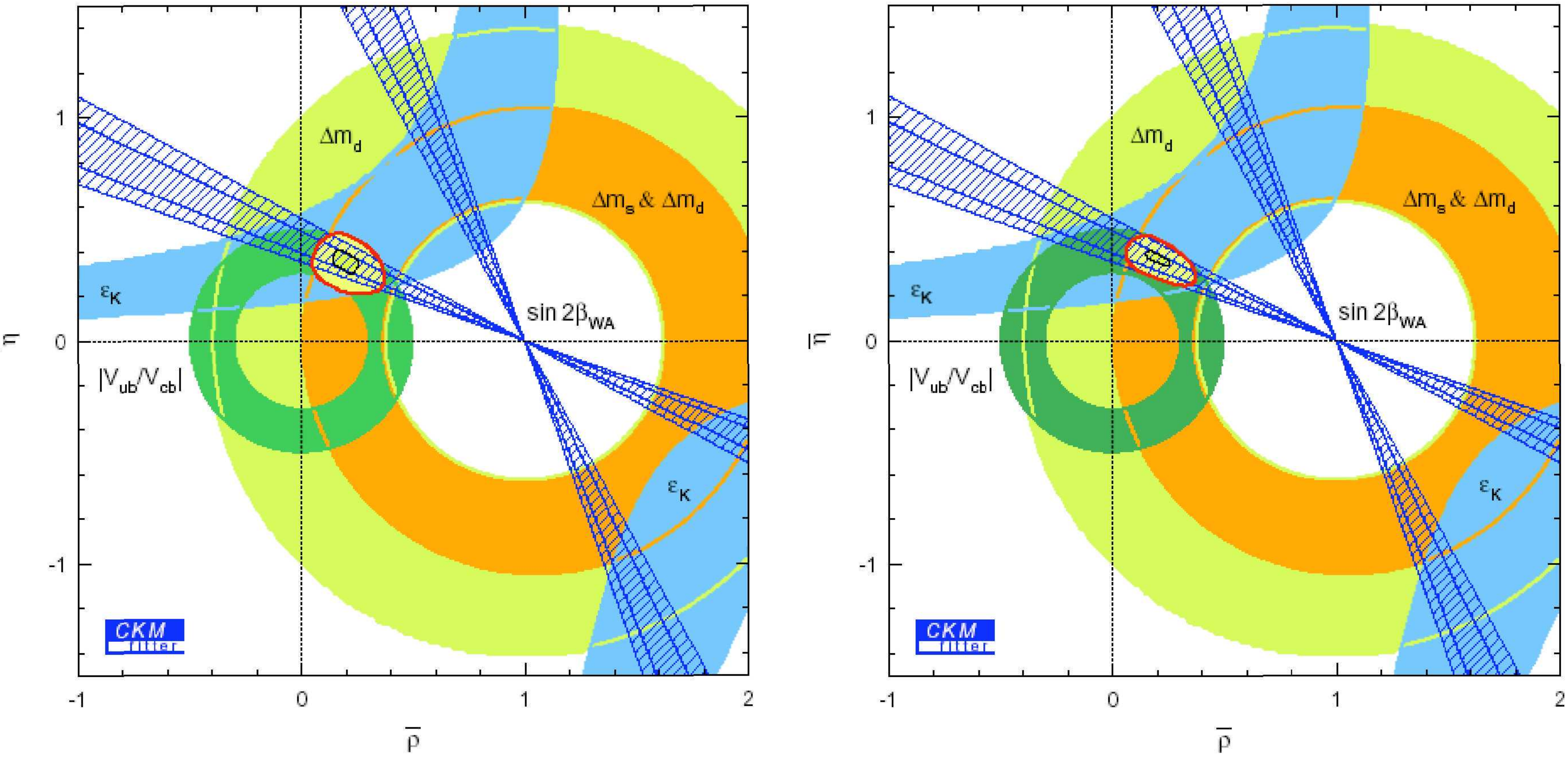
$\sin 2\beta = 0.741 \pm 0.067 \pm 0.034$

$|\lambda| = 0.948 \pm 0.051 \pm 0.030$

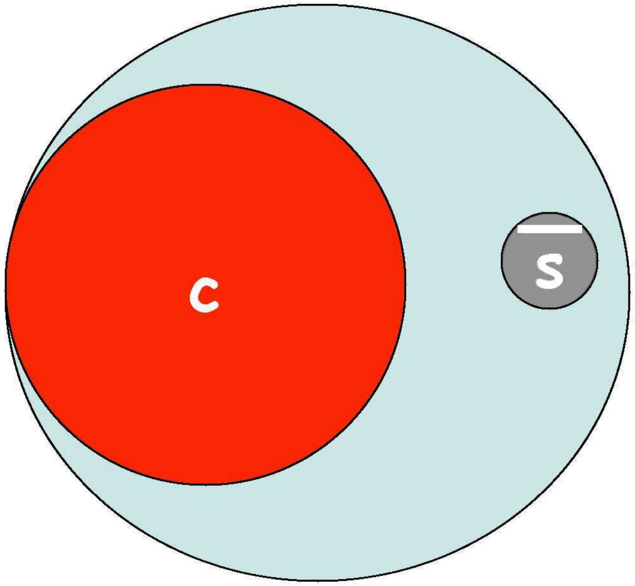
Averaging over the world



compare-constrain



Description of charmed bound states ($c\bar{q}$)



A fair description is an Hydrogen like bound state with some striking difference, like the the need of incorporating in the potential both the asymptotic freedom and the confinment

State classification (I)

In analogy with H atom the most convenient classification of states is given in terms of:

$j= l+s_1$ (l= orbital angular momentum; s_1= light quark spin)
(j is conserved in the limit that m_c goes to ∞)

Example: for P-wave states , $j=3/2$ and $1/2$ are possible (spin-orbit separation)

However one shall take into account the hyperfine structure (spin-orbit coupling of heavy quark, spin-spin........)

State classification (II)

This way the degeneracy is further reduced.
The quantity conserved is **J**= **j**+**s**$_2$
(remember **j**= **l**+**s**$_1$ and **s**$_2$= heavy quark spin)

Example: for P-wave states where j=3/2 and 1/2 are possible you can have **J** =2 ,0 (and since **l** =1 ; **S**= **s**$_1$+**s**$_2$ =1) spin triplet states or **J** =1 (with **l** =1 ; **S**= **s**$_1$+**s**$_2$ =1, 0) spin singlet or triplet states.

One last thing : Parity (P) is defined as P= $(-1)^{L+1}$

Zoology

The particles will be classified therefore according to:

$^{2S+1}L_J$ and J^P plus a nickname that identifies the entire family.

Back to our practical case, the mesons formed by a $c\bar{s}$ quark pair will be all called D_s.

The ground state will be (l=0, s=0) therefore $^1S_0$ 0^- (D_s) and the other (l=0, s=1) will be classified as $^3S_1$ 1^- (D^*_s)

The P-wave states

$^{2S+1}L_J$ and J^P

l=1, S=0 : $^1P_1$ 1^+

l=1, S=1 : $^3P_2$ 2^+

l=1, S=1 : $^3P_0$ 0^+

l=1, S=1 : $^3P_1$ 1^+

An important role will be still played by $j= l+s_1$ which is almost conserved. The ground states have j=1/2 making difficult the decay of the P-wave states having j=3/2 (will observe narrow resonances)

Potential model (orthodoxy)

$$\mathcal{H} = \mathcal{H}^{(0)} + \frac{1}{m_h}\mathcal{H}^{(1)} + \frac{1}{m_h^2}\mathcal{H}^{(2)} + \ldots$$

Total wavefunction

- n, the number associated with the radial excitations;
- ℓ, the orbital angular momentum;
- j, the total angular momentum of the light quark;
- m, the component of j along the $\widehat{z}$ axis;
- J, the total angular momentum of the system;
- M, the component of J along the $\widehat{z}$ axis;
- S, the spin of the heavy quark along the $\widehat{z}$ axis;

Clebsch-Gordan

HQ spinor

$$\Psi_{n,\ell,j,J,M}(r,\theta,\varphi) = \sum_{S\in\left\{-\frac{1}{2},+\frac{1}{2}\right\}} C^{J,M}_{j,m;\frac{1}{2},S}\,\psi_{n,\ell,j,m}(r,\theta,\varphi) \otimes \xi_S$$

M. Di Pierro and E. Eichten
hep-ph/0104208

The potential

$$\mathcal{H}^{(0)} = \gamma^0(-i\partial\!\!\!/ + m_q) + V(r)$$

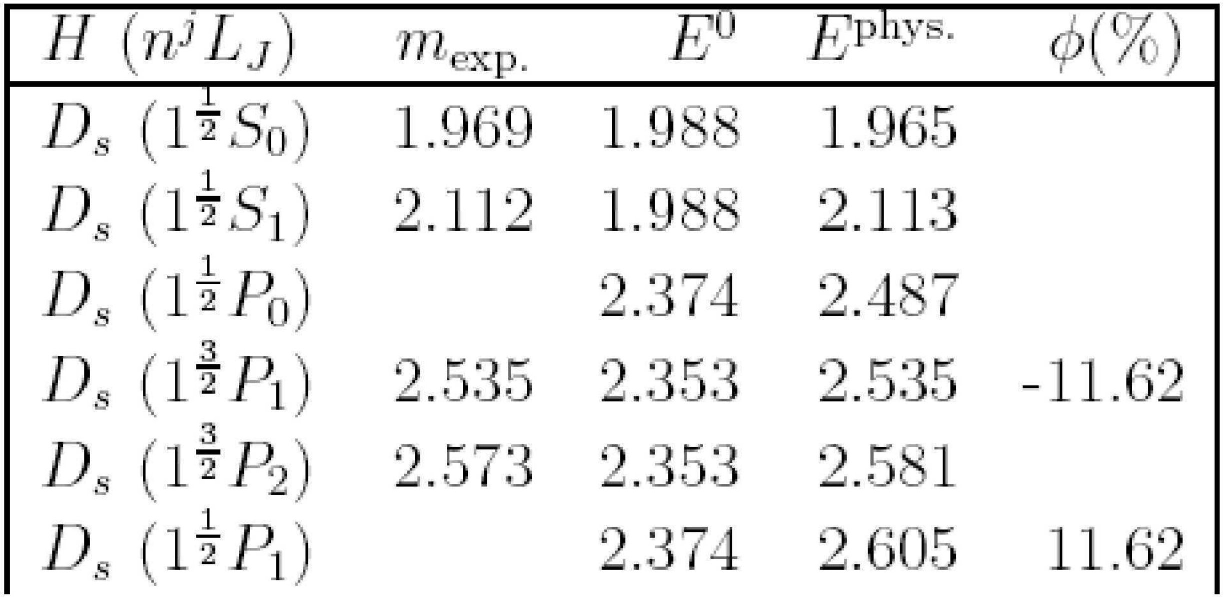
$$V(r) = M_h + \gamma^0 V_s(r) + V_v(r)$$

$V \sim V_v \sim 1/r$ Asymptotic freedom

$$V_v(r) = -\frac{4}{3}\int |\Phi(x)|^2 \frac{\alpha_s}{|\mathbf{r}-\mathbf{x}|} \mathrm{d}^3x = -\frac{4}{3}\frac{\alpha_s}{r}\mathrm{erf}(\lambda r)$$

$V \sim V_s \sim r$; $V_s(r) = br + c$ confinement

to make the story short



$H\ (n^jL_J)$	$m_{\text{exp.}}$	E^0	$E^{\text{phys.}}$	$\phi(\%)$
$D_s\ (1\frac{1}{2}S_0)$	1.969	1.988	1.965	
$D_s\ (1\frac{1}{2}S_1)$	2.112	1.988	2.113	
$D_s\ (1\frac{1}{2}P_0)$		2.374	2.487	
$D_s\ (1\frac{3}{2}P_1)$	2.535	2.353	2.535	-11.62
$D_s\ (1\frac{3}{2}P_2)$	2.573	2.353	2.581	
$D_s\ (1\frac{1}{2}P_1)$		2.374	2.605	11.62

$^1S_0$ 0^-

$^3S_1$ 1^-

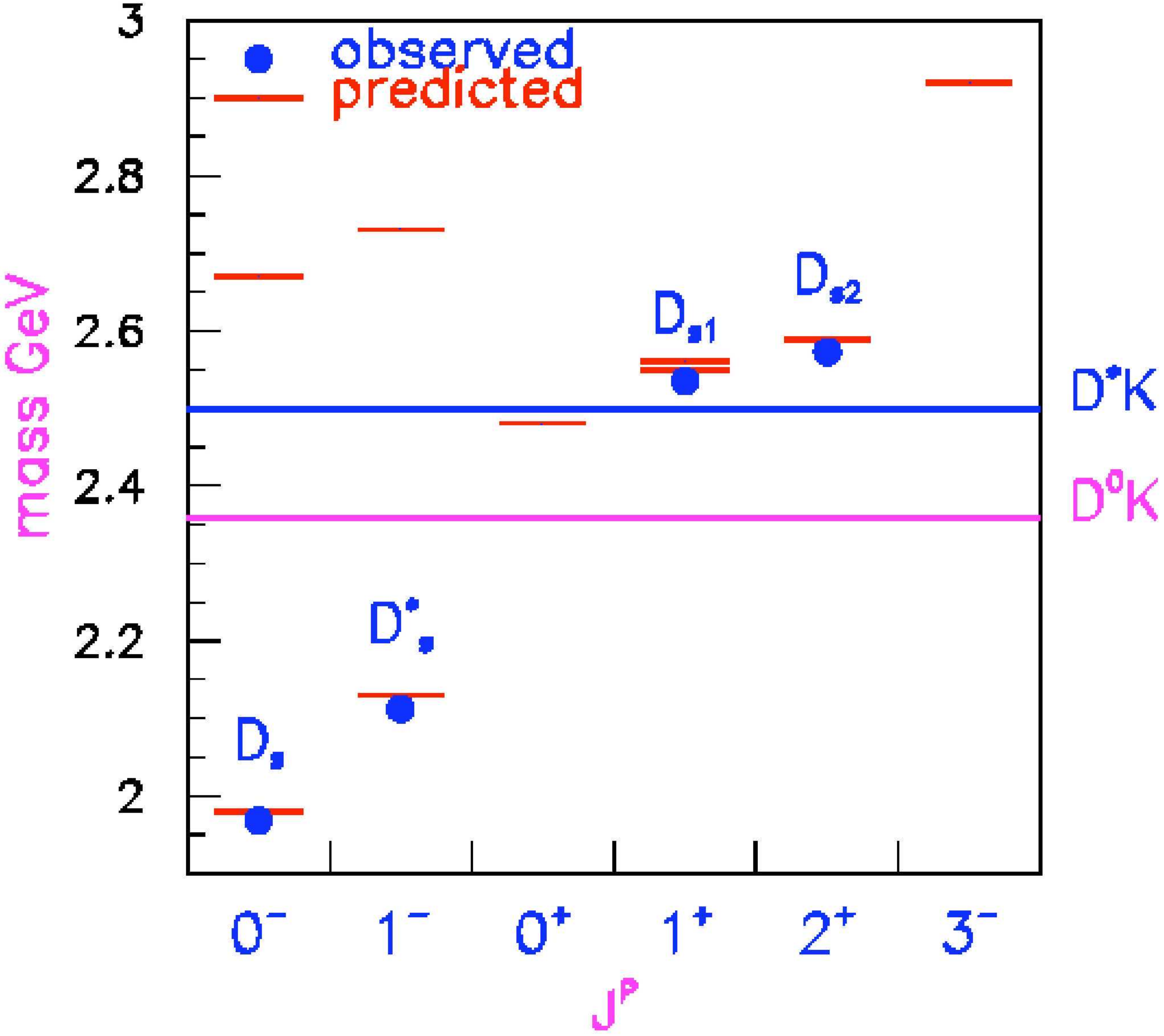
$^3P_0$ 0^+

$^1P_1$ 1^+

$^3P_2$ 2^+

$^3P_1$ 1^+

graphically (till a month ago)

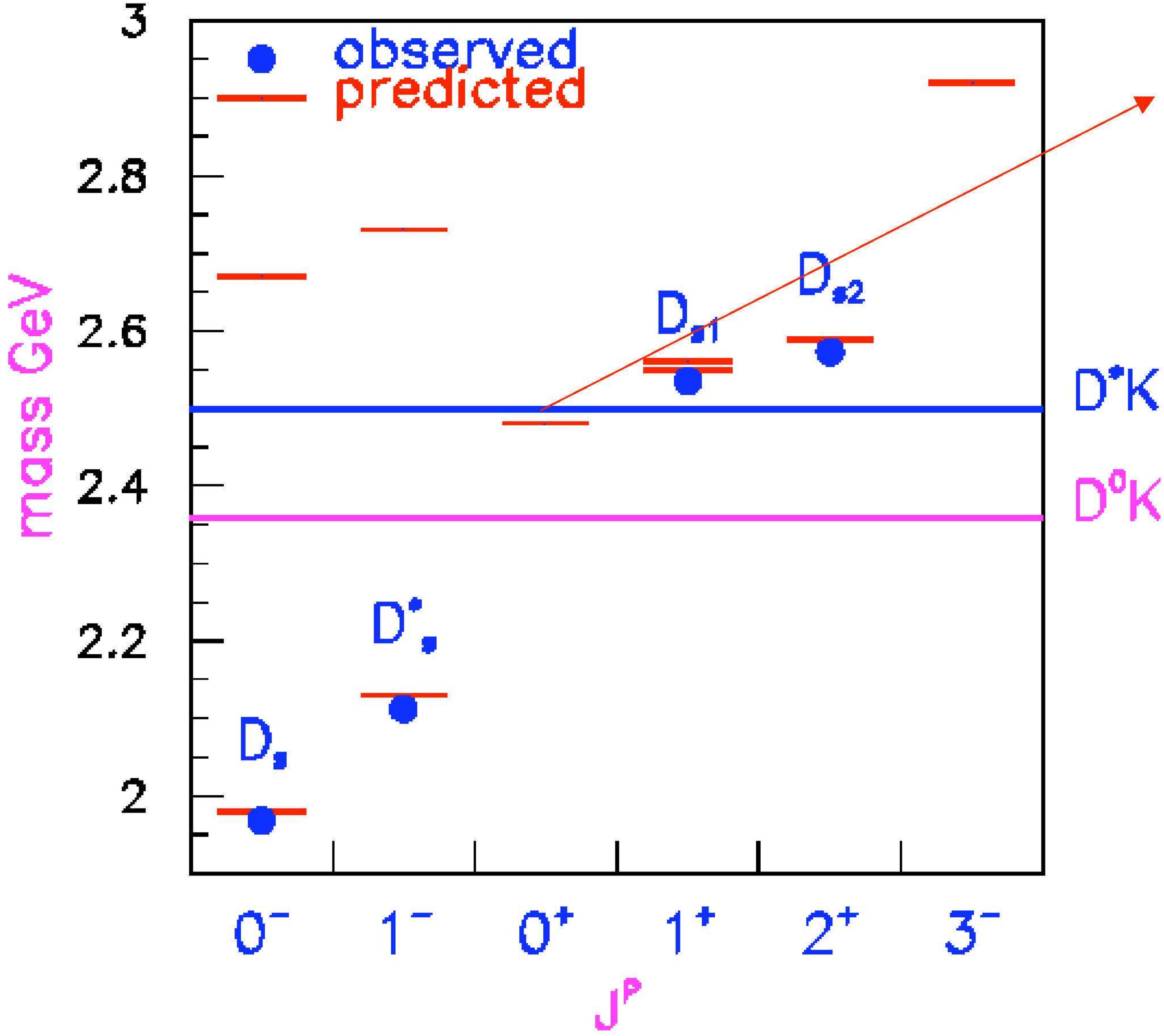


1) Observation very close to prediction for what the mass is concerned

2) Indeed the j=3/2 states are narrow as expected

if the experimentalists were to blindly believe theoreticians, the game would be over and no new particles could have been observed

indeed the first missing state…….

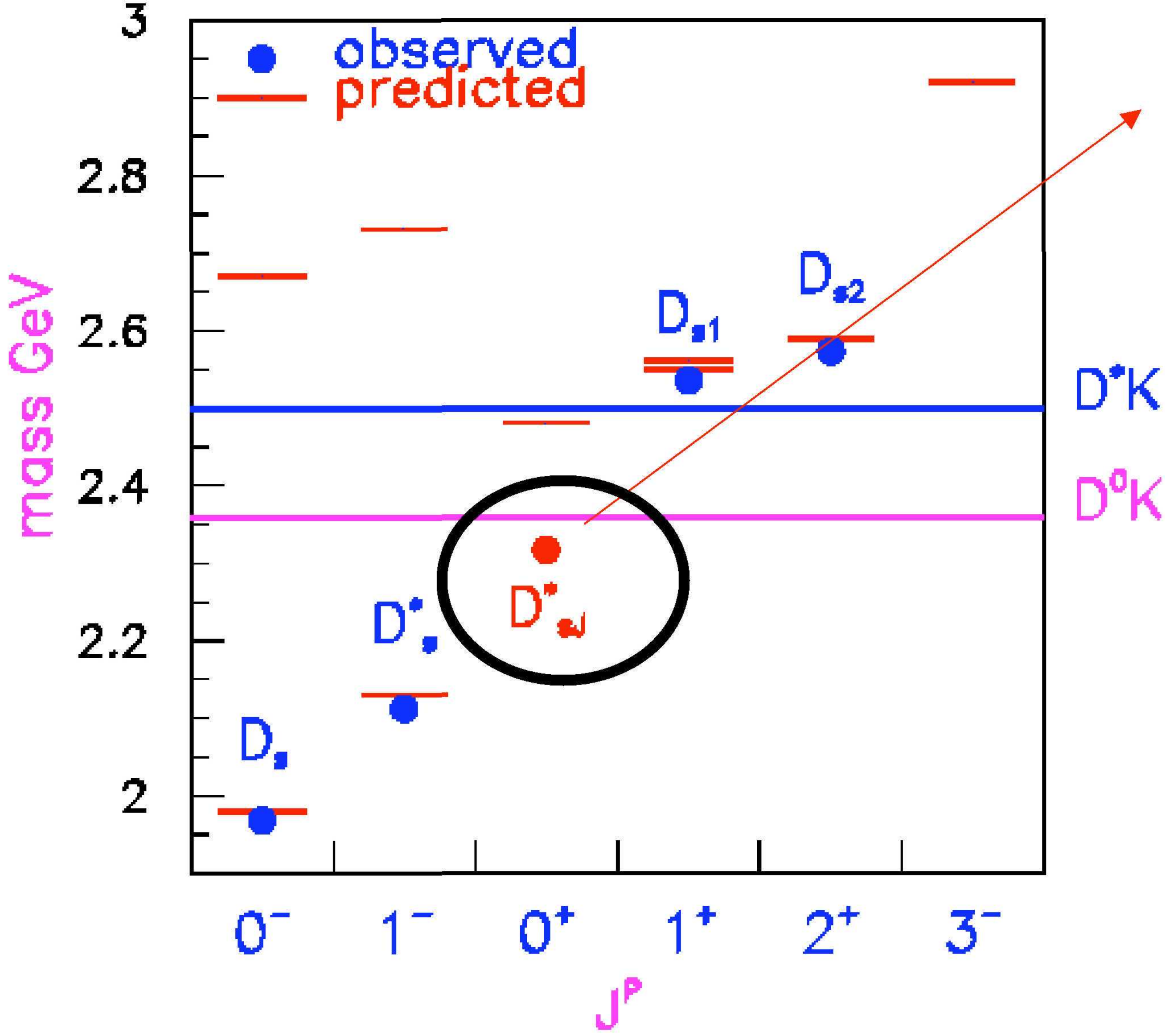


1) This is $^3P_0$ 0^+ (j=1/2).

2) Is well above the D^0K threshold

3) There is no suppression whatsoever so is expected to be a couple of 100 MeV wide

Surprise...........!!!!!!!!!!!!



1) This might be $^3P_0$ 0^+(j=1/2).

2) Is well below the D^0K threshold

3) It is very narrow

Back to reality:
a new particle is borne

Step 1: Find a D_s

Step 2) Find a π^0

Step 3) Make the invariant mass $D_s\pi^0$

Step 4) according to theory: observe nothing and go home

thanks to Nature: see a bump and be happy

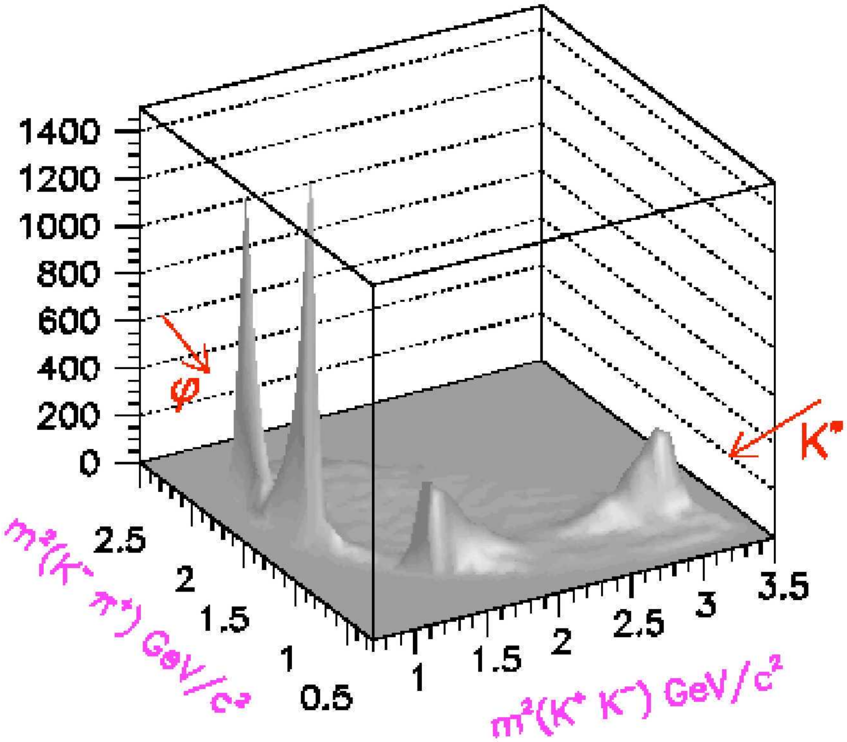
Law of nature: theoreticians always win. They start to write papers !

D_s-> $K^+K^-\pi^+$

Already in this simple system there are two possibilities:

D_s->$\Phi\pi$ (Φ->KK) or D_s-> K*K (K*->Kπ)

Note please: P -> V P

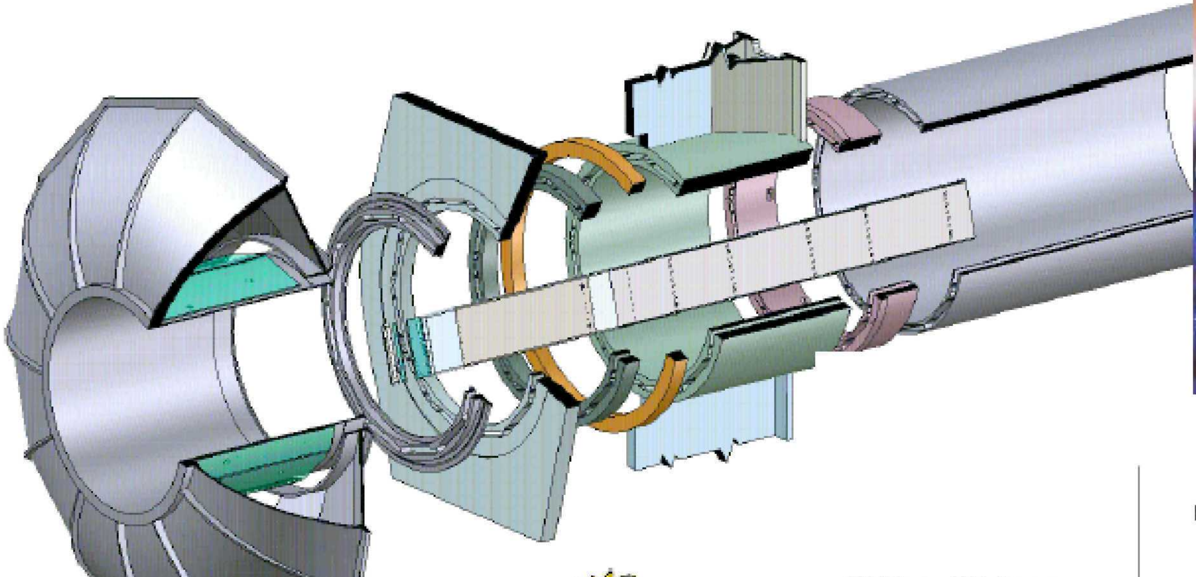


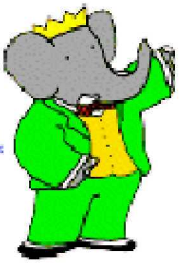
charge conjugation implied everywhere

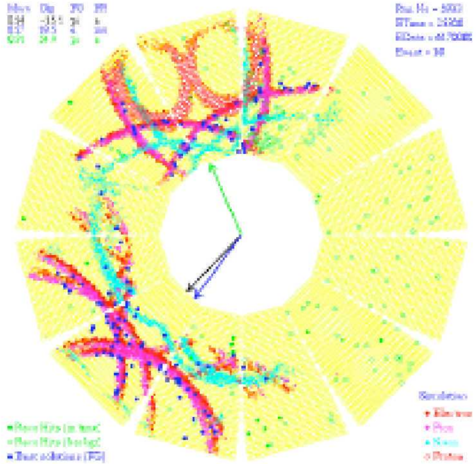
Experimental issues

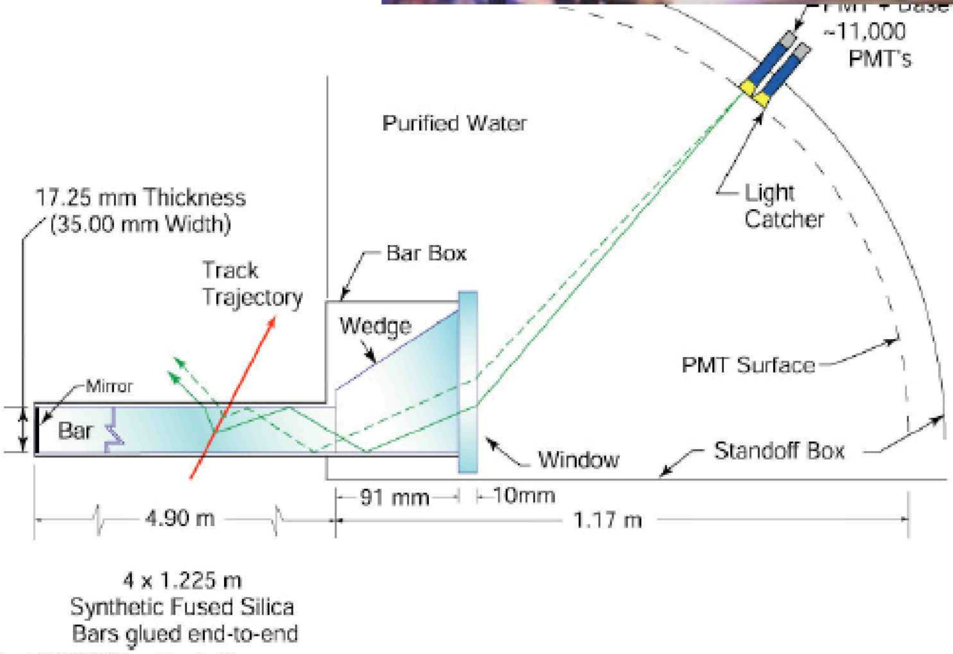
- Separation of π from K
- Invariant mass and vertexing
- Improve signal over background making use of helicity in P->VP decay

My only experimental pride: the DIRC

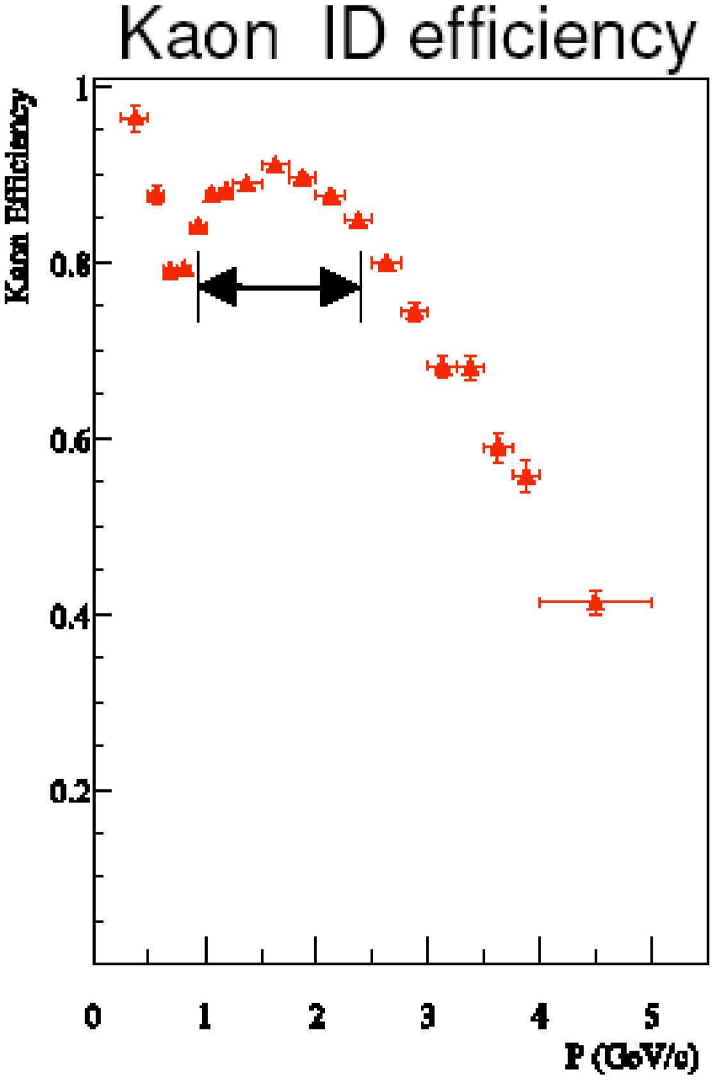


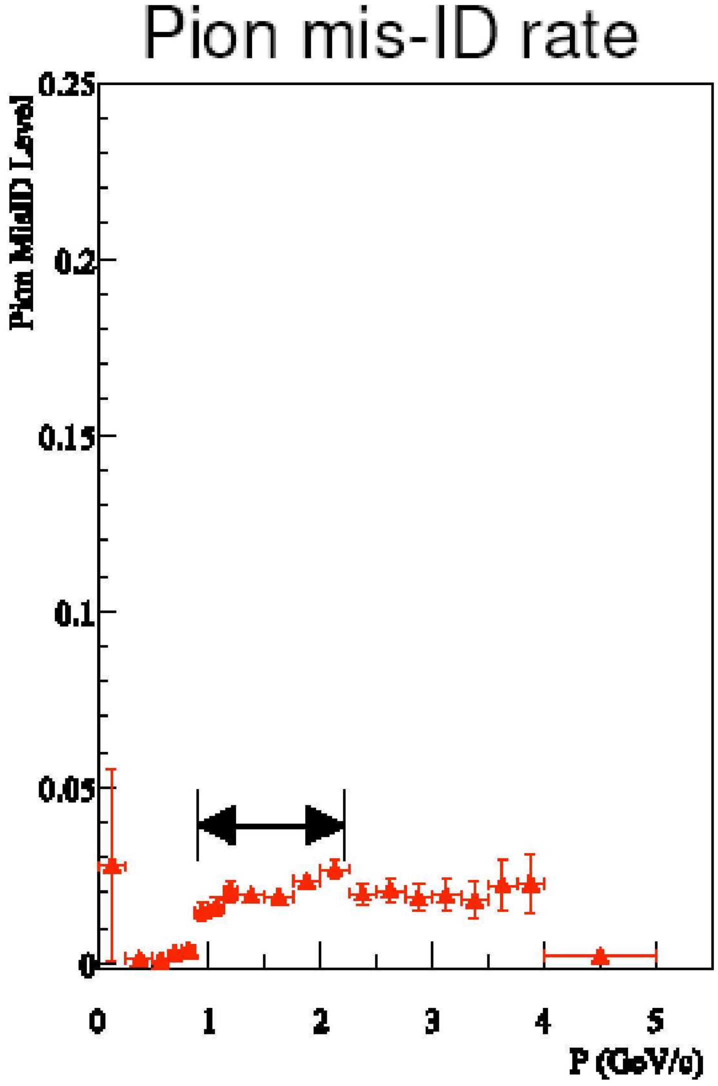






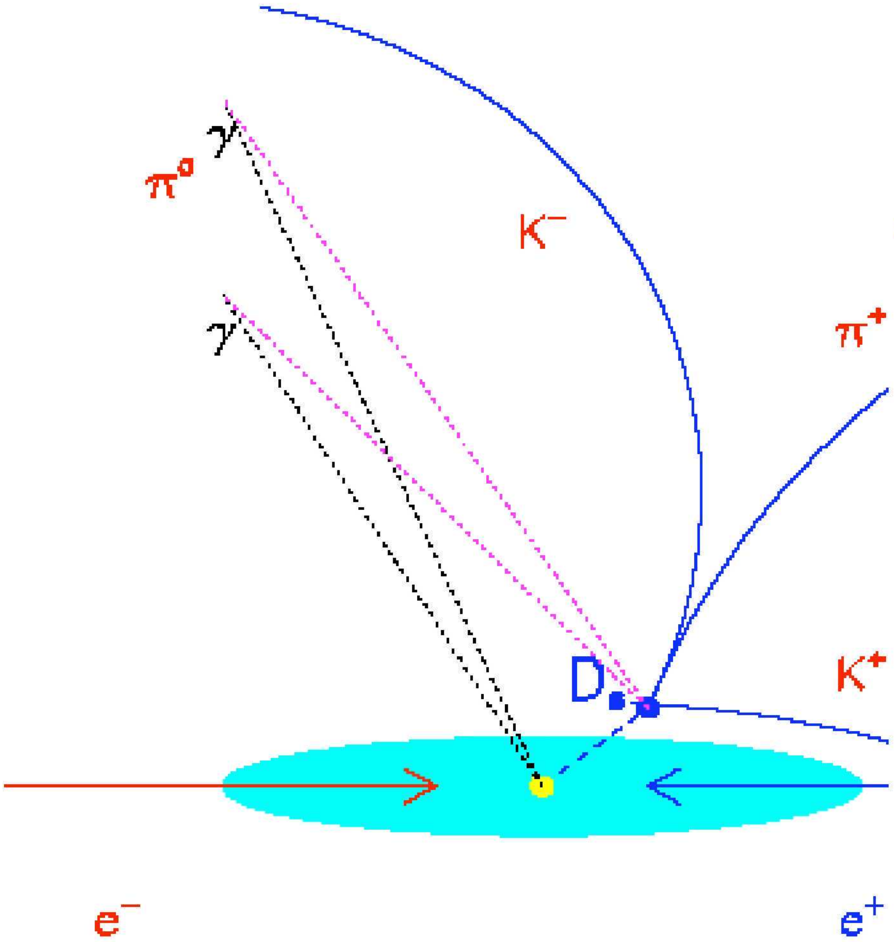
Telling a Kaon from a pion

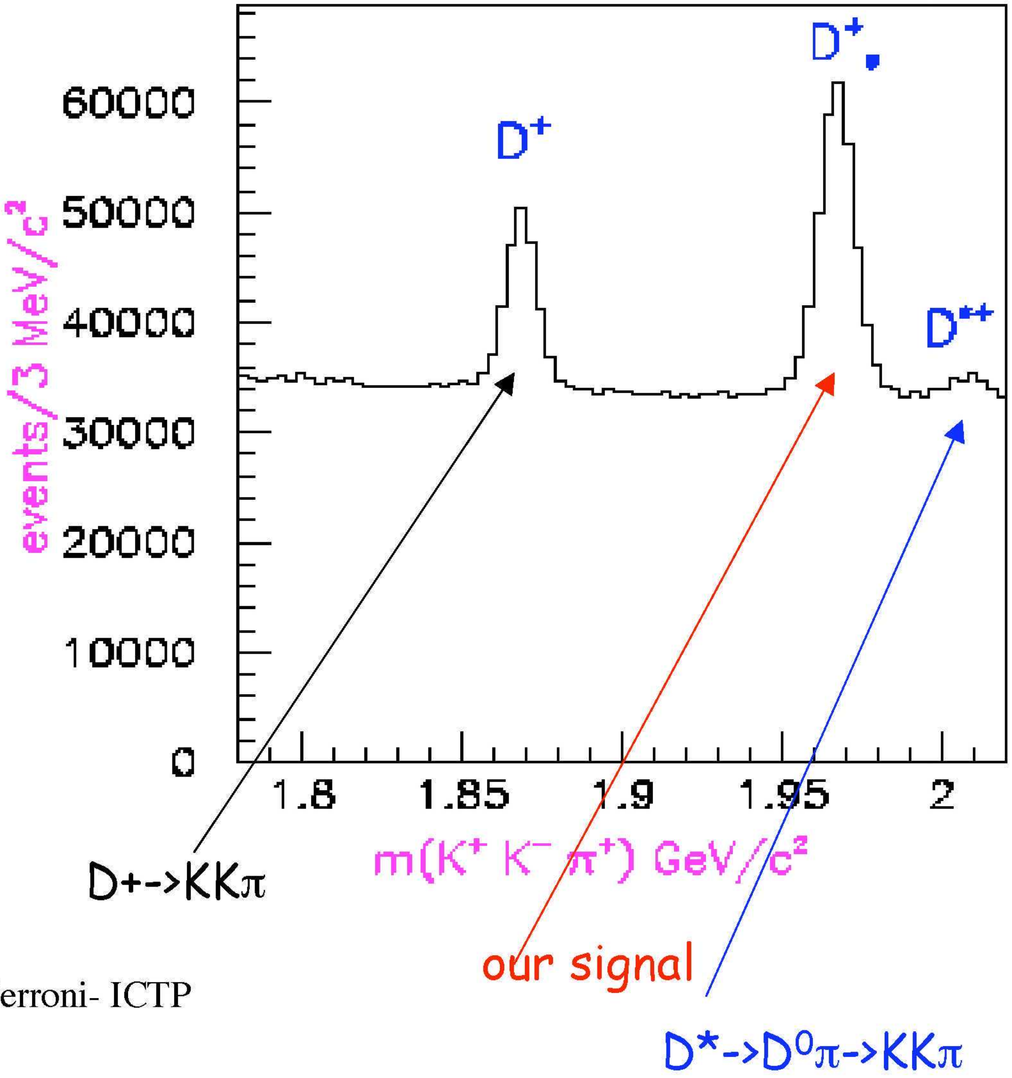

Kaon ID efficiency


Pion mis-ID rate

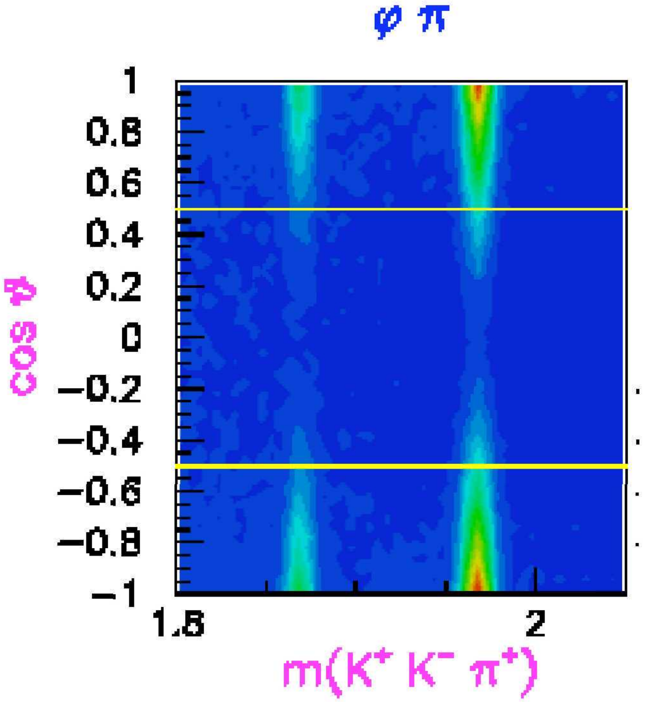
↔ Momentum range of interest

Making a particle out of three tracks

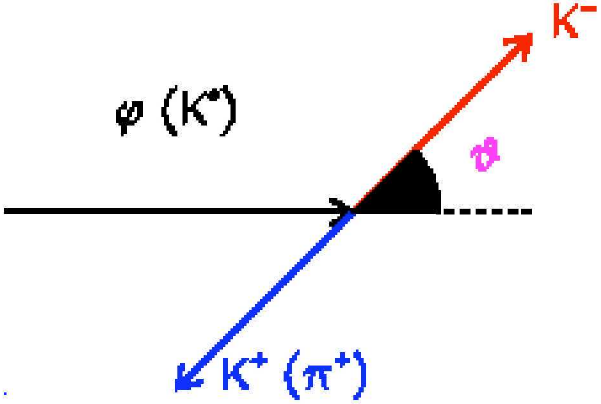




Cleaning up using helicity angle

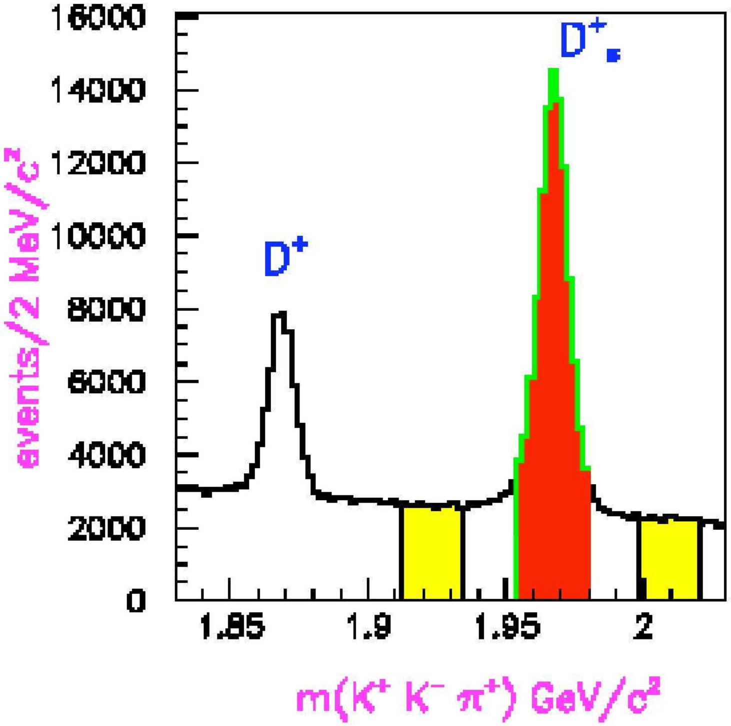


P-> VP followed by V->PP



expect $\cos^2\theta$

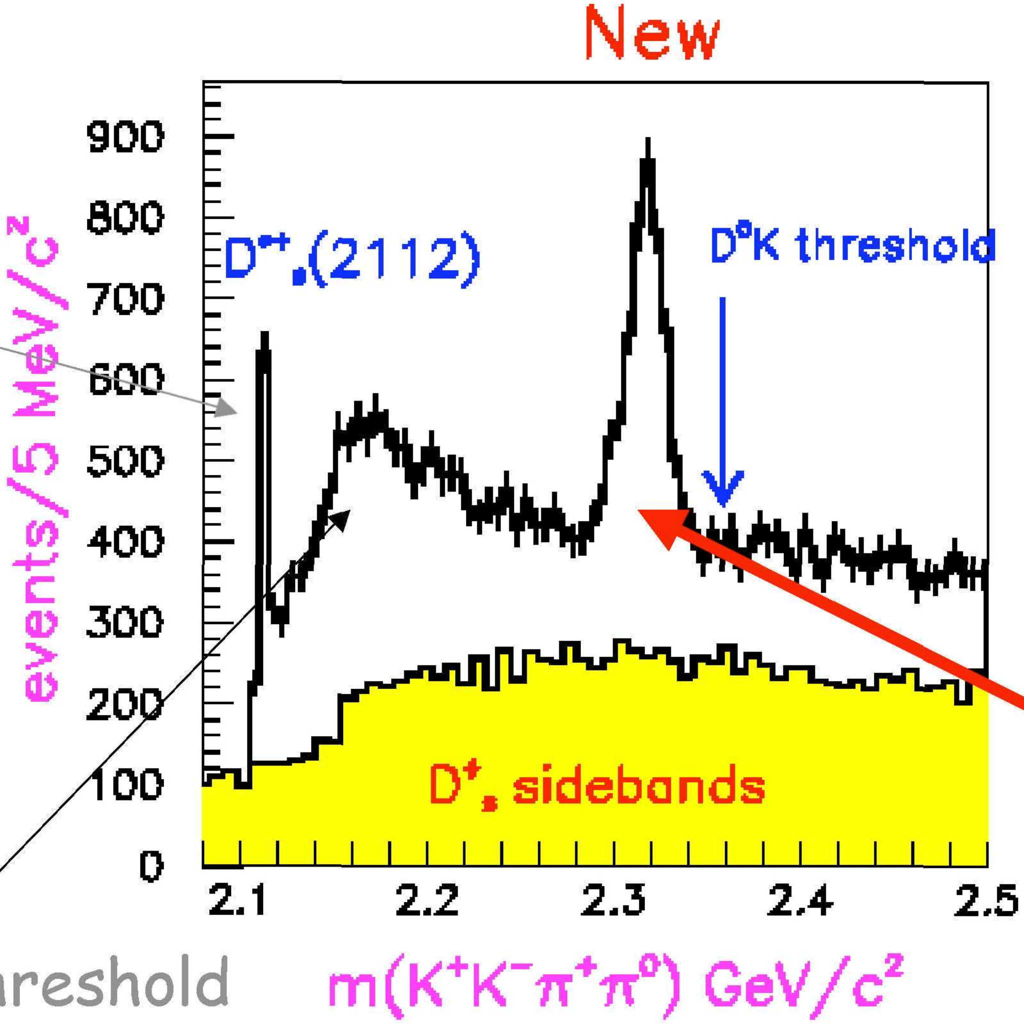
Finally the D_s we like



🟥 signal

🟨 sidebands (for background studies)

Combine D_s with a π^0

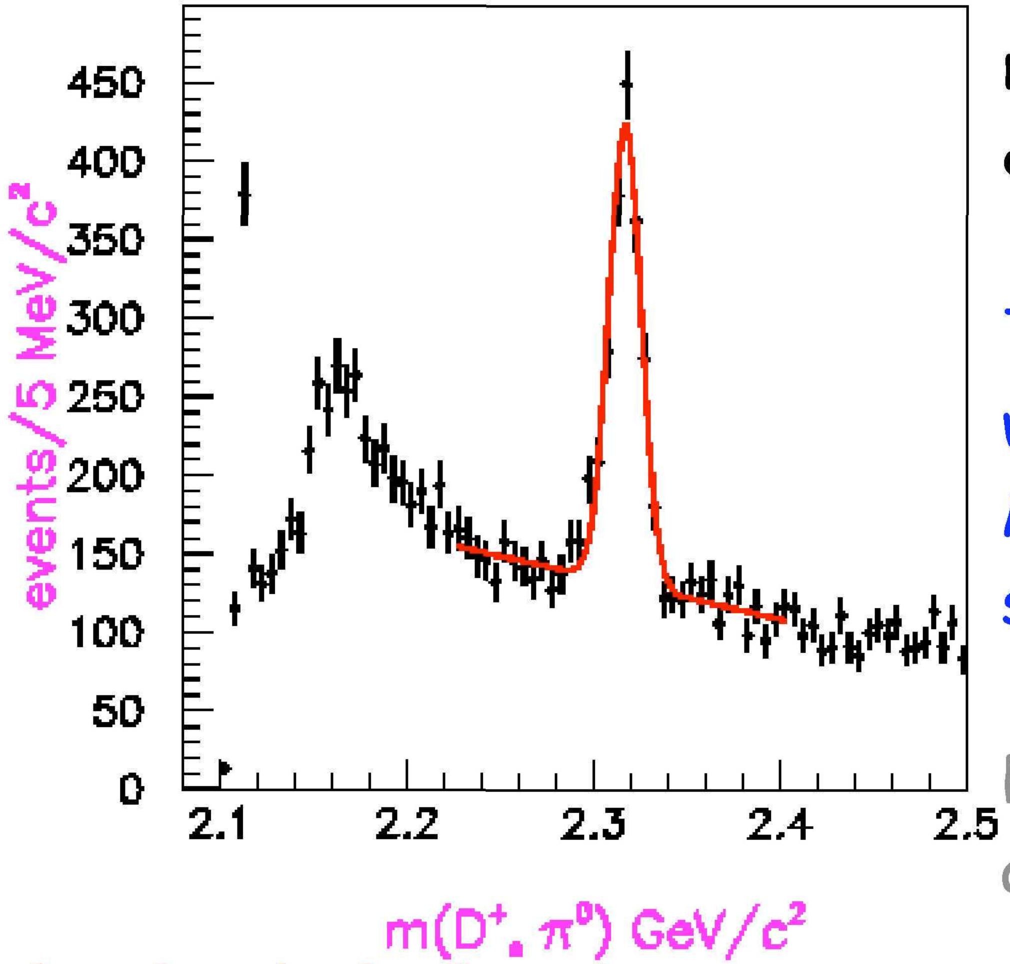


Remnant of a huge D* peak chopped by phase space

The new guy

The threshold behaviour

Ds(2317)-> $D_s\pi^0$



m= 2316.8+/-0.4 MeV

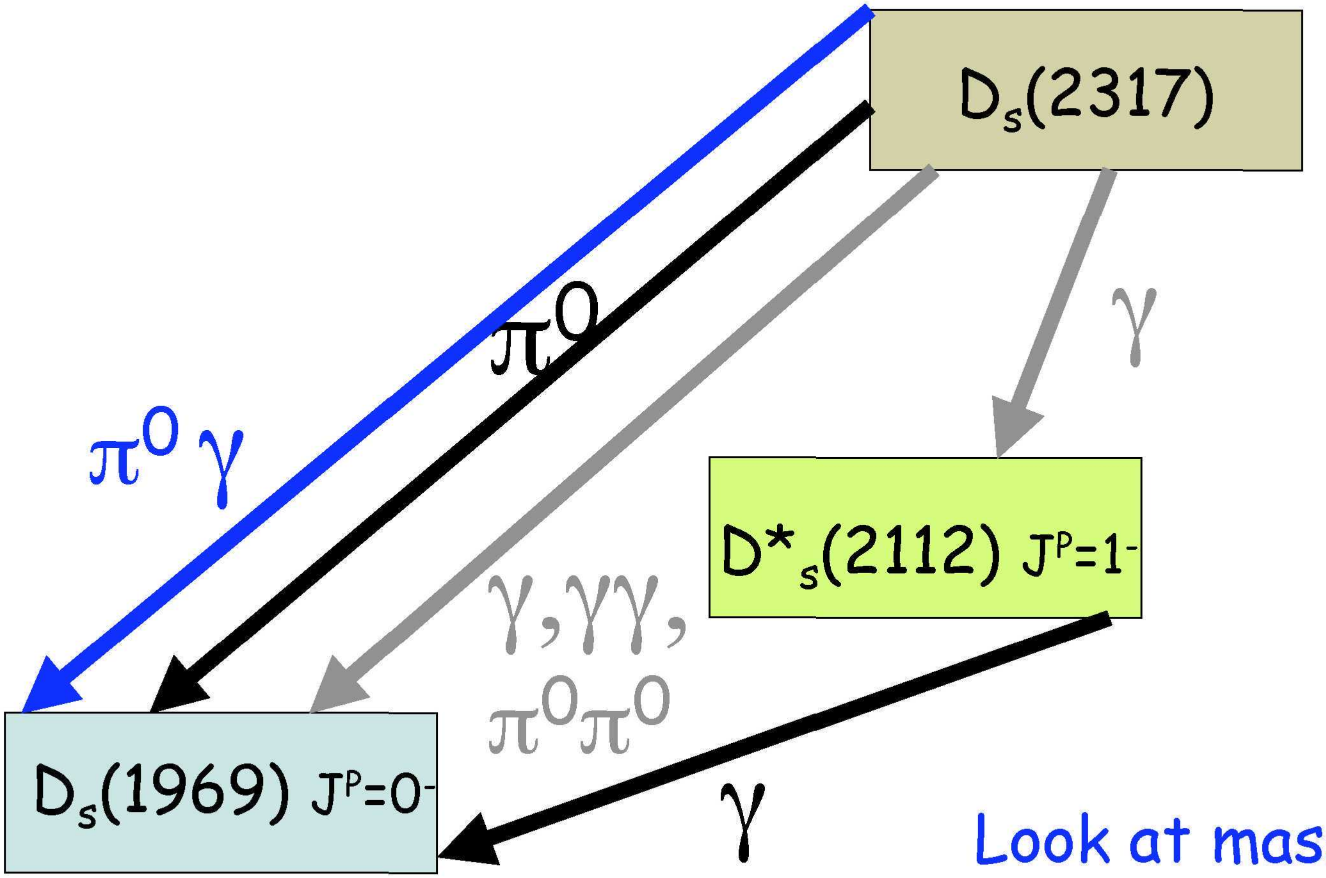
σ= 8.4+/-0.4 MeV

This is perfectly consistent with the prediction of our MonteCarlo simulation for a state essentially Zero width.

Remember that we would always observe :

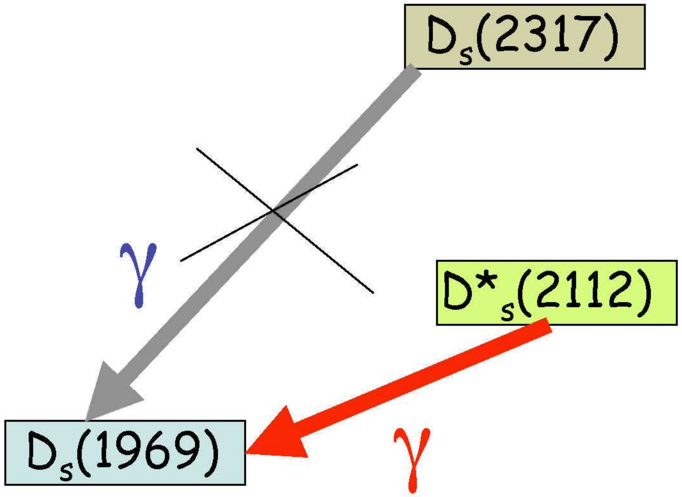
$$\sigma = \sqrt{\sigma^2_{intrinsic} + \sigma^2_{exp}}$$

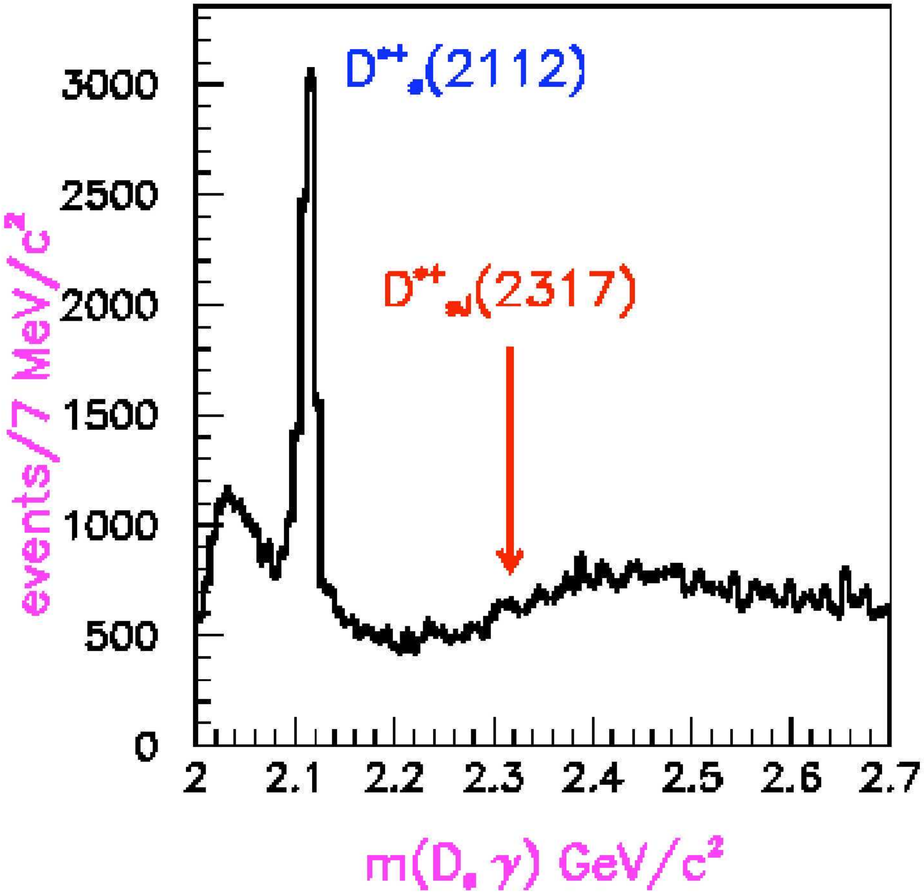
Any other decay mode ?



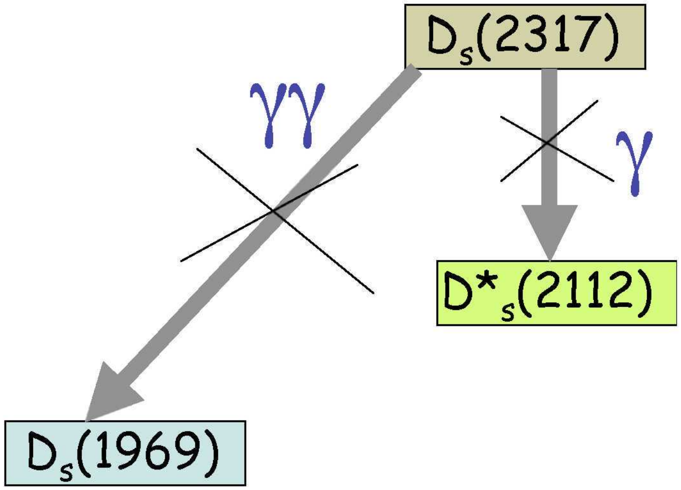
Look at mass spectra

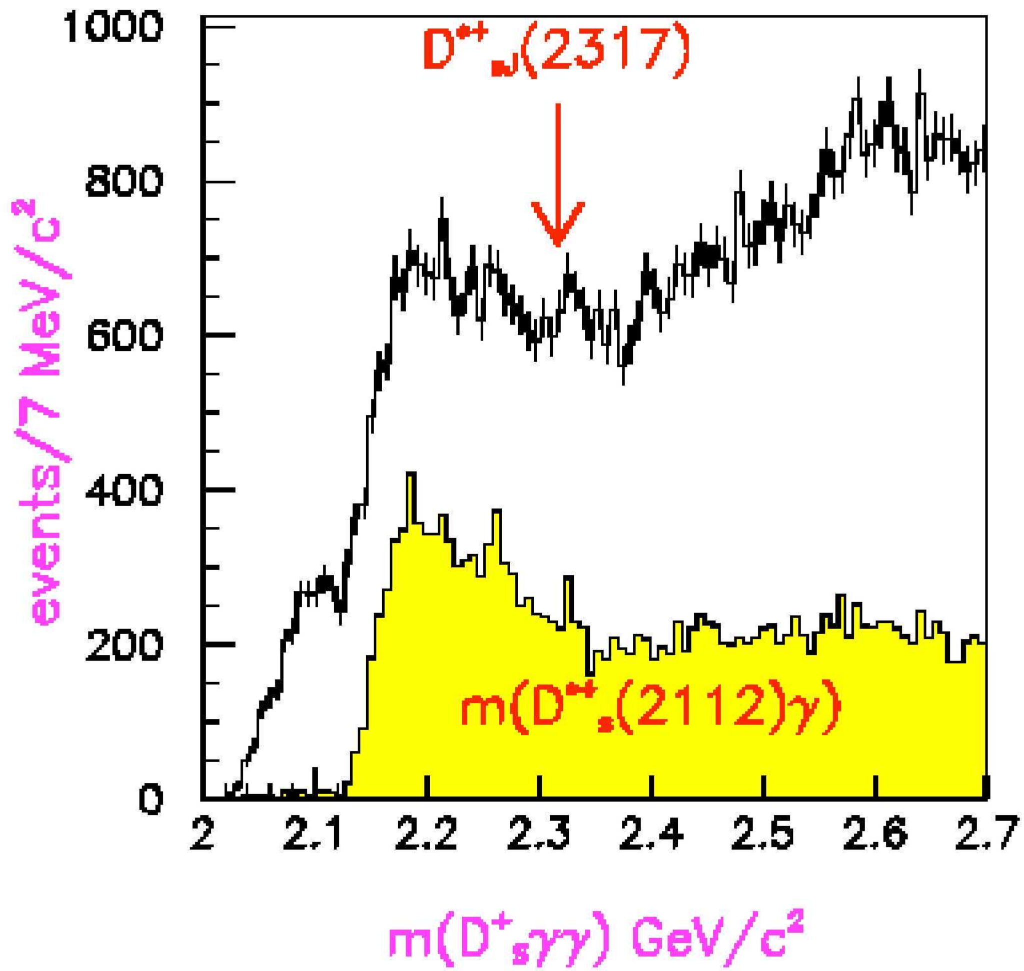
Not this one ($D_s(2317) \to D_s\gamma$)



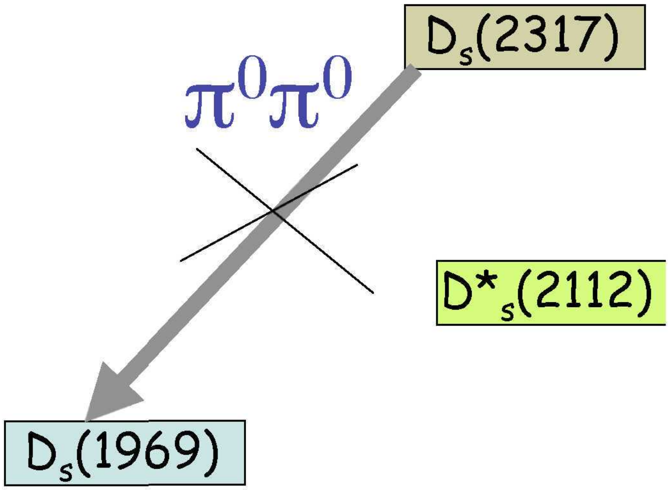


Nor these two $(D_s(2317)\text{->}D_s\gamma\gamma)$ $(D_s(2317)\text{->}D^*_s\gamma)$





And not even ($D_s(2317) \to D_s\pi^0\pi^0$)

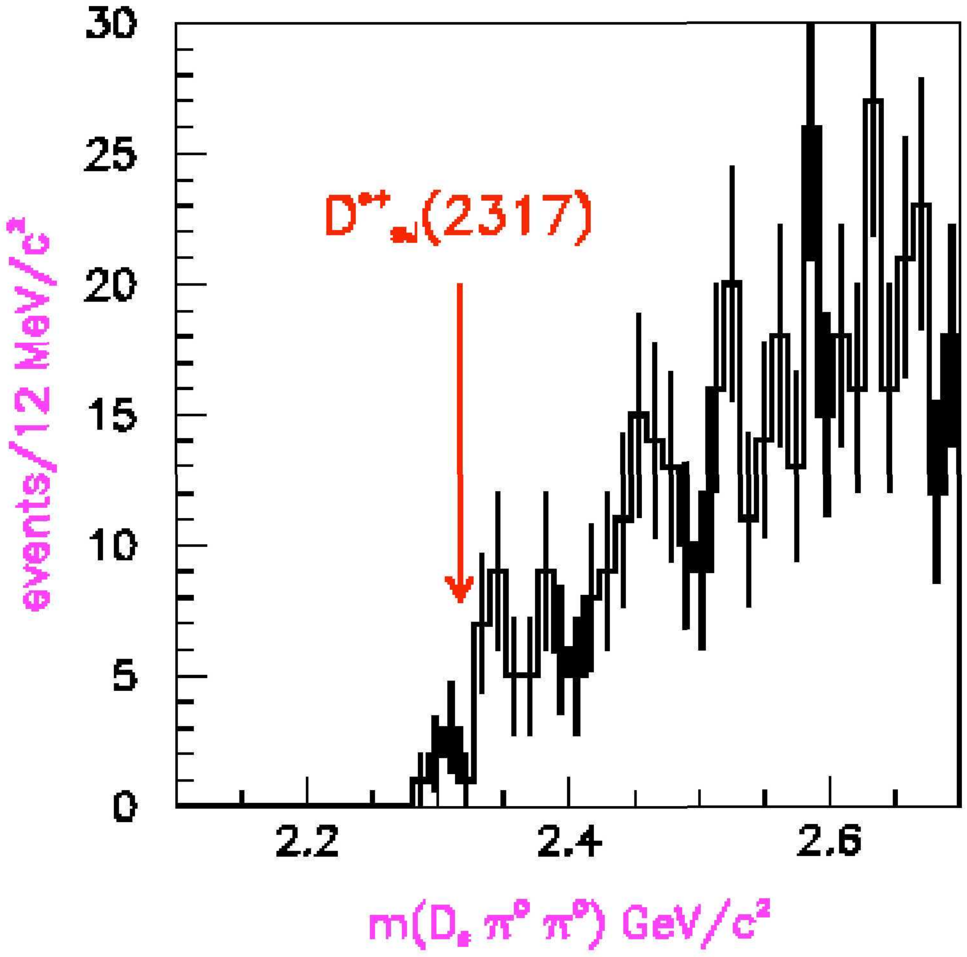


$D_s(2317)$

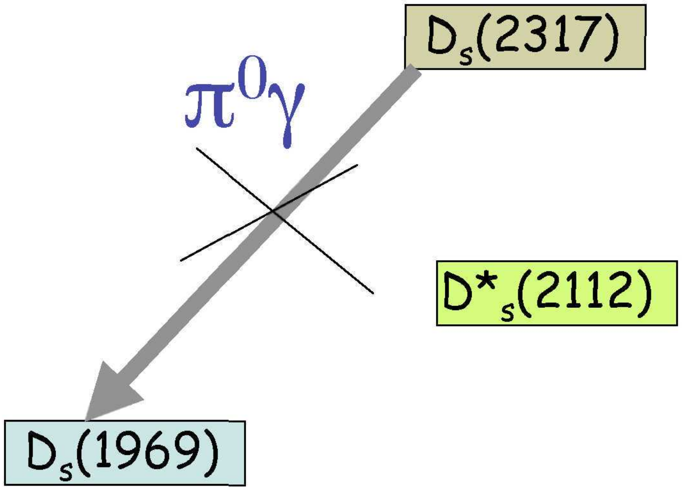
$\pi^0\pi^0$

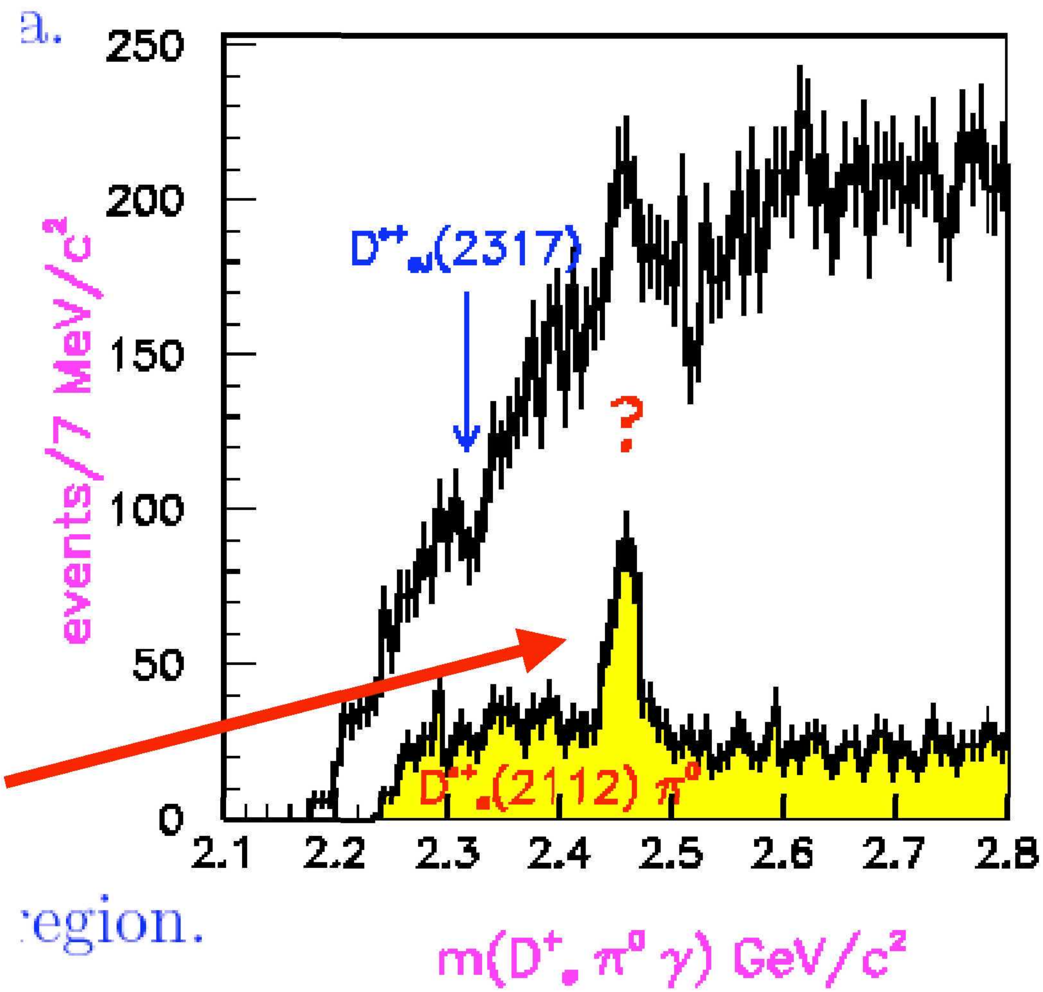
$D^*_s(2112)$

$D_s(1969)$



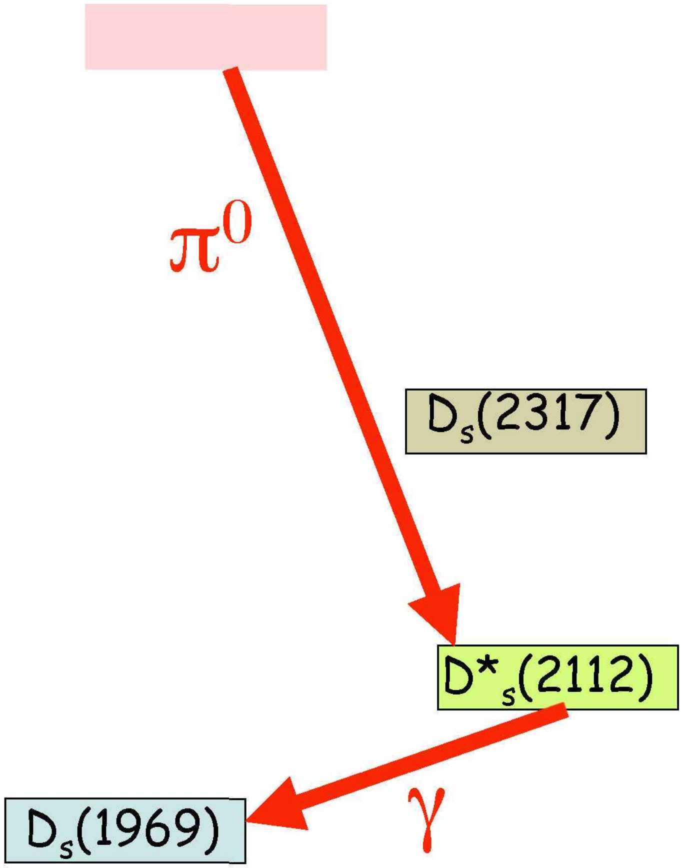
$D_s(2317)$->$D_s\pi^0\gamma$ is not positive either

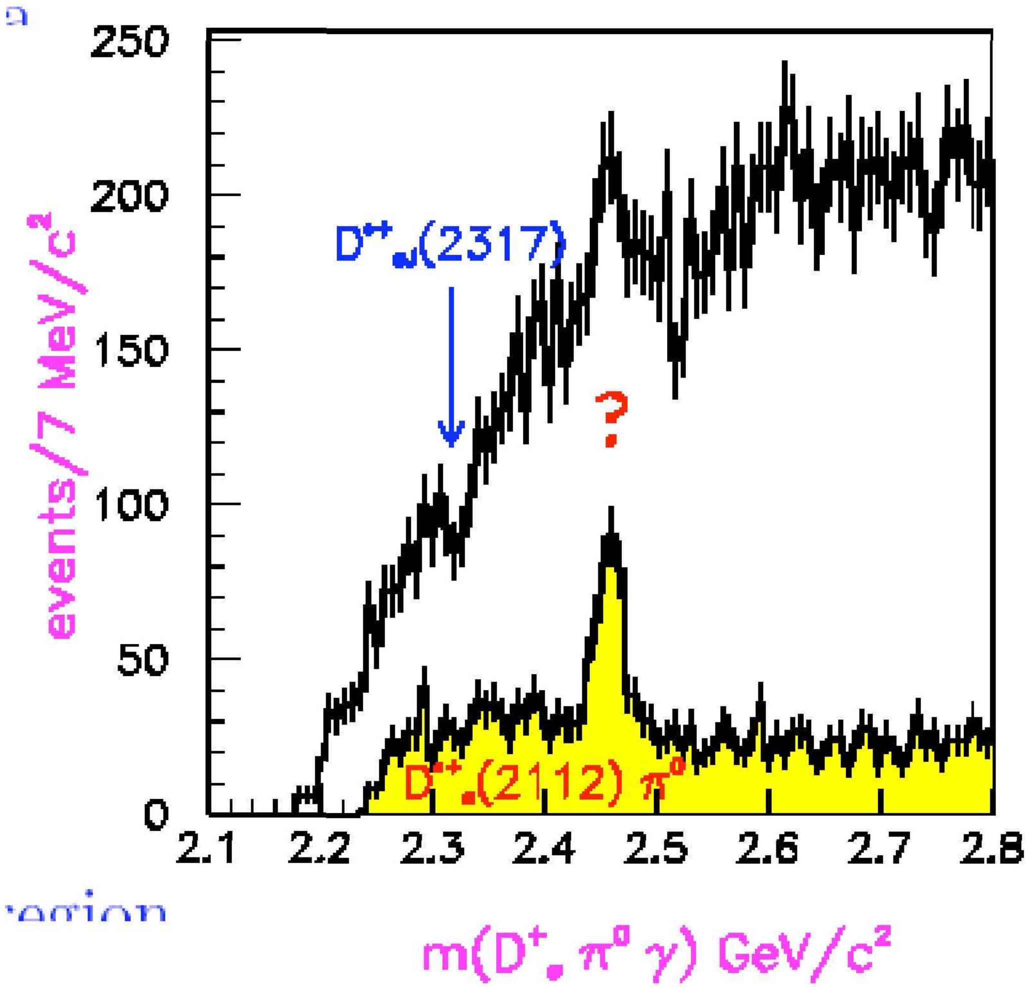




However

Another state exists

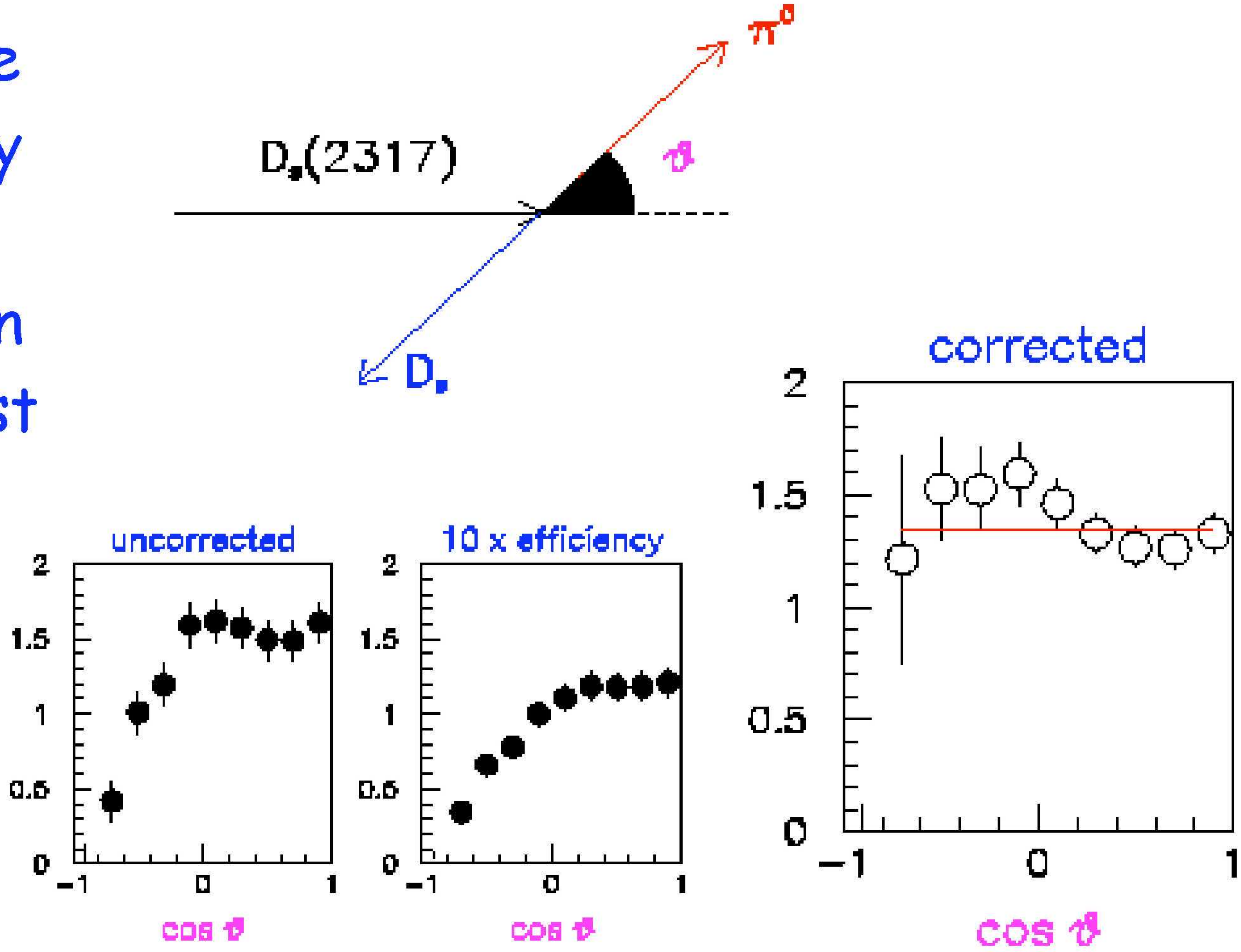




$$m(D^+_{sJ}(2457)) = 2.457 \pm 0.001 GeV/c^2$$

One more element (and then a break)

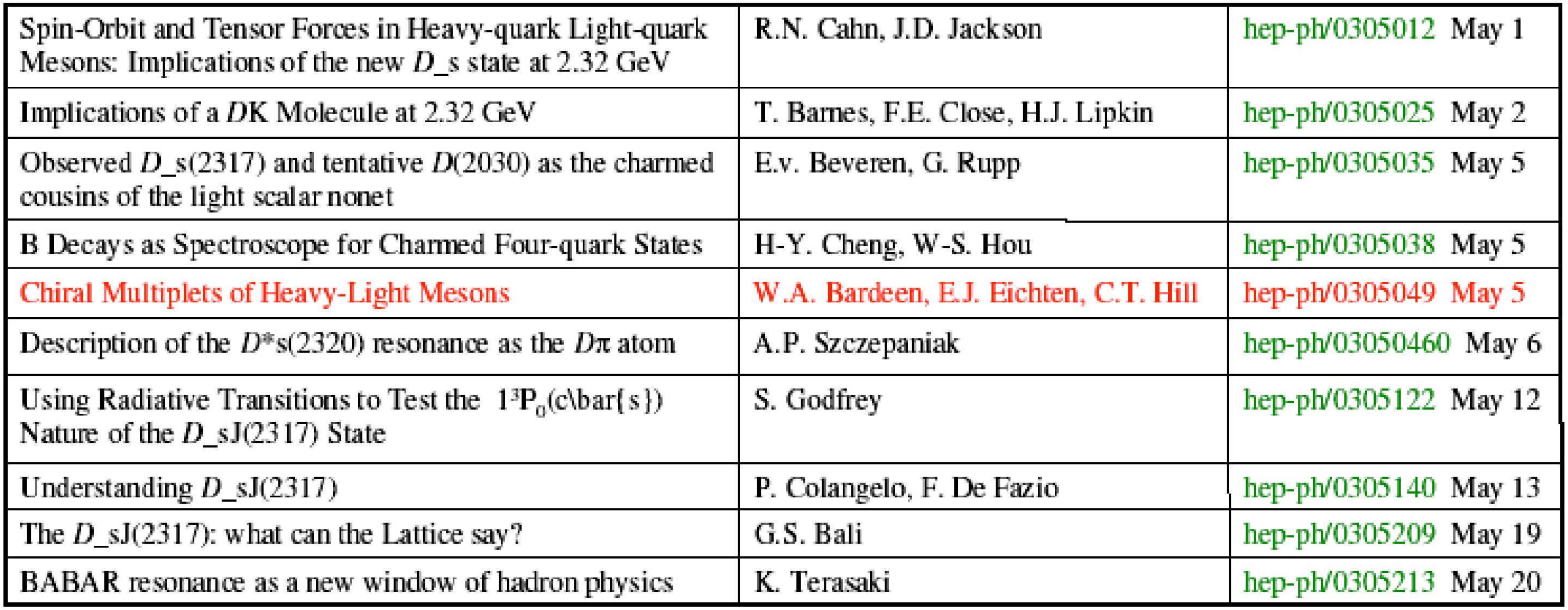
Although not the unique possibility the distribution of the π^0 angle in the $D_s(2317)$ rest frame w.r.t. the flight direction suggests a Spin 0 state



Summary so far

- A new $c\bar{s}$ state has been discovered
- It has a mass of 2317 MeV which is in strong disagreement with the prediction of the potential models
- It is most likely a 0^+ state of very narrow width
- There is a hint for an additional state at 2460 MeV (also narrow)

Trigger to many papers



Spin-Orbit and Tensor Forces in Heavy-quark Light-quark Mesons: Implications of the new D_s state at 2.32 GeV	R.N. Cahn, J.D. Jackson	hep-ph/0305012 May 1
Implications of a DK Molecule at 2.32 GeV	T. Barnes, F.E. Close, H.J. Lipkin	hep-ph/0305025 May 2
Observed D_s(2317) and tentative D(2030) as the charmed cousins of the light scalar nonet	E.v. Beveren, G. Rupp	hep-ph/0305035 May 5
B Decays as Spectroscope for Charmed Four-quark States	H-Y. Cheng, W-S. Hou	hep-ph/0305038 May 5
Chiral Multiplets of Heavy-Light Mesons	W.A. Bardeen, E.J. Eichten, C.T. Hill	hep-ph/0305049 May 5
Description of the D*s(2320) resonance as the Dπ atom	A.P. Szczepaniak	hep-ph/03050460 May 6
Using Radiative Transitions to Test the $1^{3}P_{0}$(c\bar{s}) Nature of the D_sJ(2317) State	S. Godfrey	hep-ph/0305122 May 12
Understanding D_sJ(2317)	P. Colangelo, F. De Fazio	hep-ph/0305140 May 13
The D_sJ(2317): what can the Lattice say?	G.S. Bali	hep-ph/0305209 May 19
BABAR resonance as a new window of hadron physics	K. Terasaki	hep-ph/0305213 May 20

Different paths

- Revised potential model for ($0^+,1^+$) $c\bar{s}$ doublet hep-ph/0305012
- Dπ atom hep-ph/0305025
- Lattice predi hep-ph/03050460
- Exotic DK molecule hep-ph/0305209
- Chiral simmetry hep-ph/0305049

Revised potential

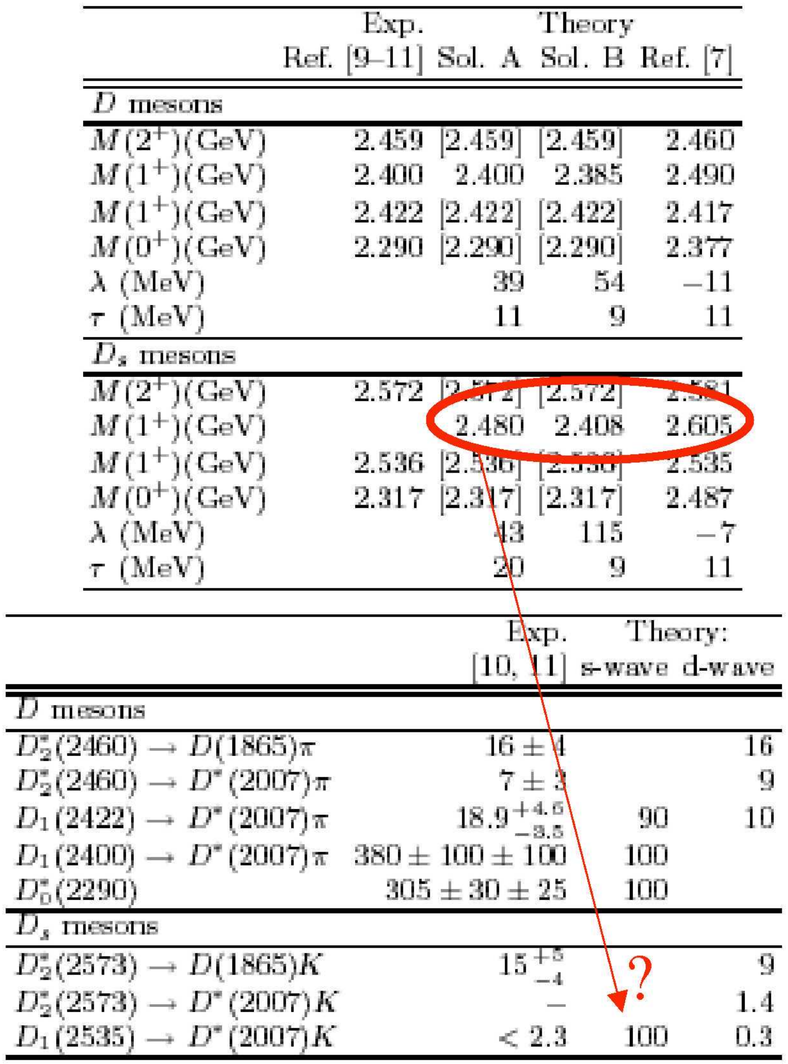
Spin-Orbit and Tensor Forces in Heavy-quark Light-quark Mesons: Implications of the New D_s State at 2.32 GeV

Robert N. Cahn and J. David Jackson
Lawrence Berkeley National Laboratory
1 Cyclotron Rd.,
Berkeley, CA 94720

$$V_{quasi-static} = V + S + \left(\frac{V' - S'}{r}\right) \boldsymbol{\ell} \cdot \left(\frac{\boldsymbol{\sigma}_1}{4m_1^2} + \frac{\boldsymbol{\sigma}_2}{4m_2^2}\right) + \left(\frac{V'}{r}\right) \boldsymbol{\ell} \cdot \left(\frac{\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2}{2m_1 m_2}\right)$$

$$+ \frac{1}{12 m_1 m_2}\left(\frac{V'}{r} - V''\right) S_{12} + \frac{1}{6 m_1 m_2} \nabla^2 V \, \boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2$$

The discovery of the $D^*_{sJ}(2317)$ has provided an important clue to heavy-quark light-quark spectroscopy by nailing down a p-wave state with $j = 1/2$. Puzzles remain. The anticipated discovery of the accompanying $j = 1/2$ state with $J = 1$ should add important new information, but it is not likely to resolve all the questions we have described.

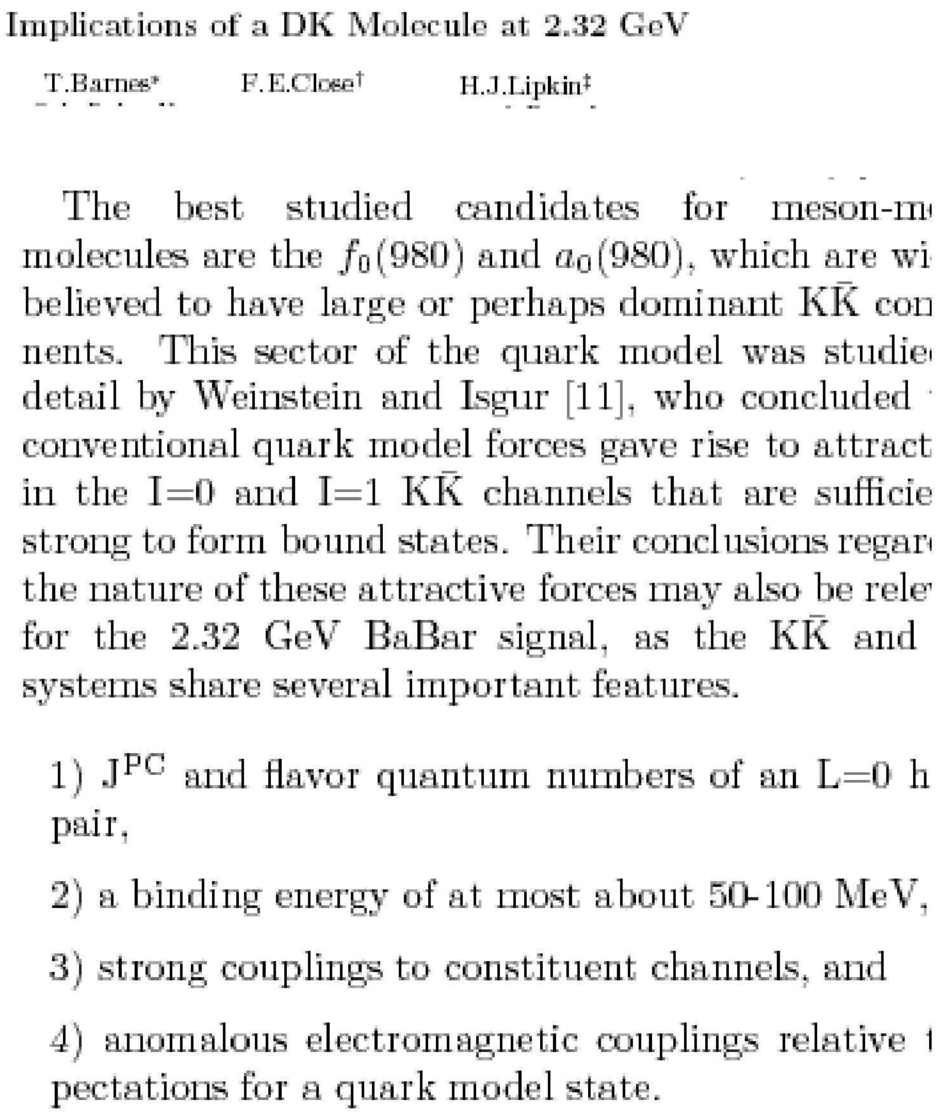


	Exp.	Theory		
	Ref. [9–11]	Sol. A	Sol. B	Ref. [7]
D mesons				
$M(2^+)$(GeV)	2.459	[2.459]	[2.459]	2.460
$M(1^+)$(GeV)	2.400	2.400	2.385	2.490
$M(1^+)$(GeV)	2.422	[2.422]	[2.422]	2.417
$M(0^+)$(GeV)	2.290	[2.290]	[2.290]	2.377
λ (MeV)		39	54	−11
τ (MeV)		11	9	11
D_s mesons				
$M(2^+)$(GeV)	2.572	[2.572]	[2.572]	2.581
$M(1^+)$(GeV)		2.480	2.408	2.605
$M(1^+)$(GeV)	2.536	[2.536]	[2.536]	2.535
$M(0^+)$(GeV)	2.317	[2.317]	[2.317]	2.487
λ (MeV)		43	115	−7
τ (MeV)		20	9	11

	Exp.	Theory:	
	[10, 11]	s-wave	d-wave
D mesons			
$D^*_2(2460) \rightarrow D(1865)\pi$	16 ± 4		16
$D^*_2(2460) \rightarrow D^*(2007)\pi$	7 ± 3		9
$D_1(2422) \rightarrow D^*(2007)\pi$	$18.9^{+4.6}_{-3.5}$	90	10
$D_1(2400) \rightarrow D^*(2007)\pi$	$380 \pm 100 \pm 100$	100	
$D^*_0(2290)$	$305 \pm 30 \pm 25$	100	
D_s mesons			
$D^*_2(2573) \rightarrow D(1865)K$	15^{+5}_{-4}		9
$D^*_2(2573) \rightarrow D^*(2007)K$	–		1.4
$D_1(2535) \rightarrow D^*(2007)K$	< 2.3	100	0.3

?

DK molecule



Implications of a DK Molecule at 2.32 GeV

T.Barnes* F.E.Close† H.J.Lipkin‡

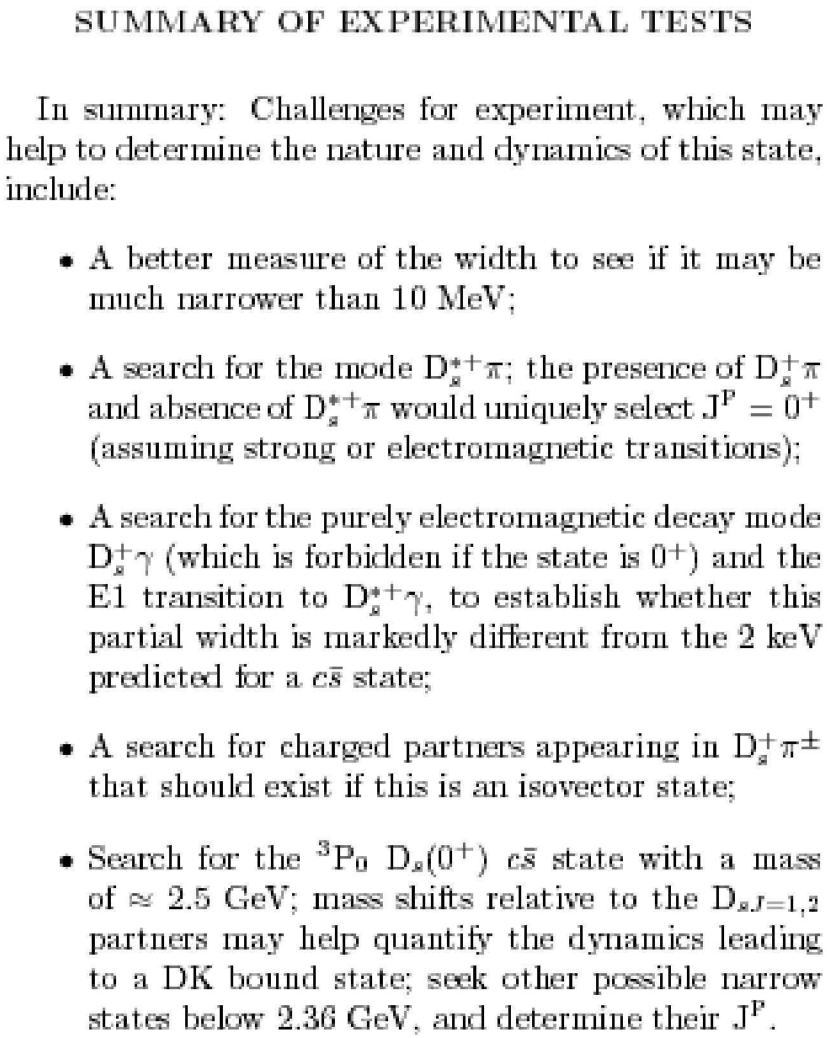
The best studied candidates for meson-m
molecules are the $f_0(980)$ and $a_0(980)$, which are wi
believed to have large or perhaps dominant $K\bar{K}$ con
nents. This sector of the quark model was studie
detail by Weinstein and Isgur [11], who concluded
conventional quark model forces gave rise to attract
in the I=0 and I=1 $K\bar{K}$ channels that are sufficie
strong to form bound states. Their conclusions regar
the nature of these attractive forces may also be rele
for the 2.32 GeV BaBar signal, as the $K\bar{K}$ and
systems share several important features.

1) J^{PC} and flavor quantum numbers of an L=0 h
pair,

2) a binding energy of at most about 50-100 MeV,

3) strong couplings to constituent channels, and

4) anomalous electromagnetic couplings relative
pectations for a quark model state.



SUMMARY OF EXPERIMENTAL TESTS

In summary: Challenges for experiment, which may help to determine the nature and dynamics of this state, include:

- A better measure of the width to see if it may be much narrower than 10 MeV;
- A search for the mode $D_s^{*+}\pi$; the presence of $D_s^+\pi$ and absence of $D_s^{*+}\pi$ would uniquely select $J^P = 0^+$ (assuming strong or electromagnetic transitions);
- A search for the purely electromagnetic decay mode $D_s^+\gamma$ (which is forbidden if the state is 0^+) and the E1 transition to $D_s^{*+}\gamma$, to establish whether this partial width is markedly different from the 2 keV predicted for a $c\bar{s}$ state;
- A search for charged partners appearing in $D_s^+\pi^\pm$ that should exist if this is an isovector state;
- Search for the $^3P_0$ $D_s(0^+)$ $c\bar{s}$ state with a mass of $\approx$ 2.5 GeV; mass shifts relative to the $D_{sJ=1,2}$ partners may help quantify the dynamics leading to a DK bound state; seek other possible narrow states below 2.36 GeV, and determine their J^P.

Dπ atom

Description of the $D_s^*(2320)$ resonance as the $D\pi$ atom

Adam P. Szczepaniak
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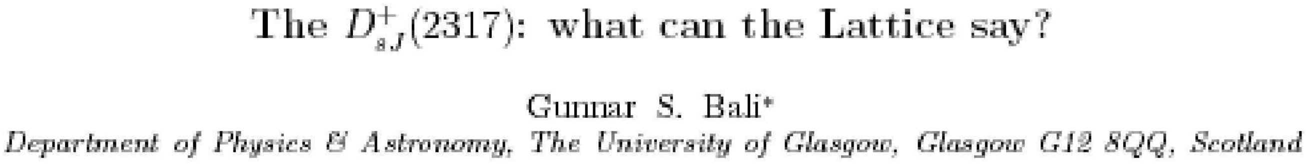
strong flavor-singlet attraction between the pion and the $c\bar{s}$ mesons. Since $m_\pi/m_{c\bar{q}} < 10\%$ one could consider the BaBar state as a result of a pion being captured by a non-relativistic (even static) charmed meson. Since the width of the resonance measured by BaBar, ($\Gamma \lesssim 10$ MeV) is small compared to the energy difference between nearby coupled channels, *e.g.* $|m_{D_s^*(2320)} - m_{DK}^{tr}| = 40$ MeV, channels other than the measured $D_s\pi$ should be unimportant.

In summary we have found that using reasonable assumptions regarding flavor-independent interactions between the pion and the charmed-strange mesons, with natural parameters it is possible to reproduce a narrow resonance in the $D\pi$ spectrum. Such states should also be present in other charge modes, *e.g.* $D_s\pi^\pm$. We have also checked that our findings are insensitive to the details of a formulation, *e.g.* we studied the nonrelativistic approximation and used the N/D method [6].

Lattice calculation



The $D_{sJ}^{+}(2317)$: what can the Lattice say?

Gunnar S. Bali*

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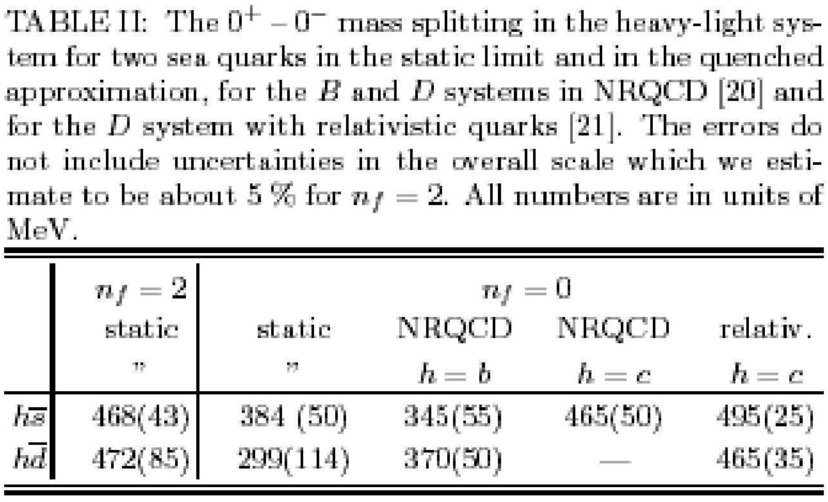


TABLE II: The $0^{+} - 0^{-}$ mass splitting in the heavy-light system for two sea quarks in the static limit and in the quenched approximation, for the B and D systems in NRQCD [20] and for the D system with relativistic quarks [21]. The errors do not include uncertainties in the overall scale which we estimate to be about 5 % for $n_f = 2$. All numbers are in units of MeV.

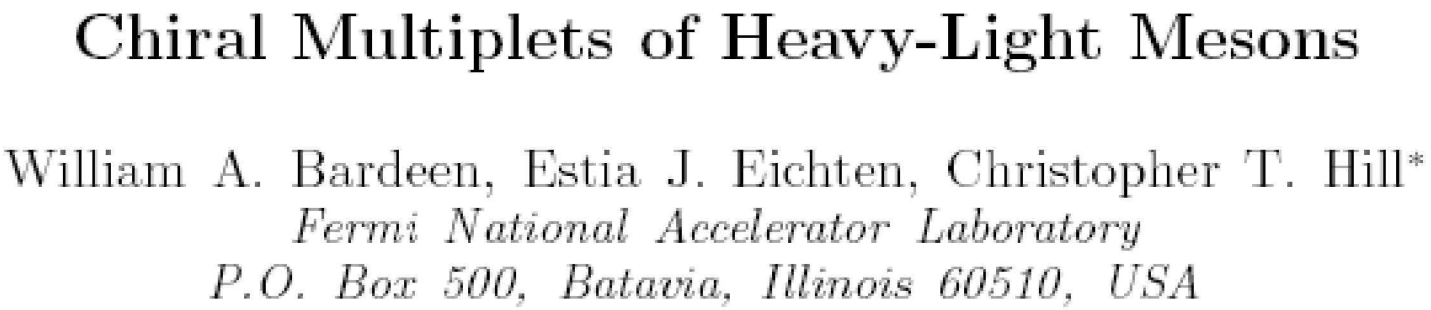
	$n_f = 2$	$n_f = 0$			
	static	static	NRQCD	NRQCD	relativ.
	"	"	$h = b$	$h = c$	$h = c$
$h\bar{s}$	468(43)	384 (50)	345(55)	465(50)	495(25)
$h\bar{d}$	472(85)	299(114)	370(50)	—	465(35)

Relativistic split (495) much larger than quenched static (384) suggesting an equivalent correction to unquenched static. It would give a 0^{+}-0^{-} split of 600 MeV -> Ds(2.57(0.11)).

The quenched NRQCD or relativistic Model would give ~2.47 GeV

None will give 2.317 !!!!!!

The chiral simmetry



Chiral Multiplets of Heavy-Light Mesons

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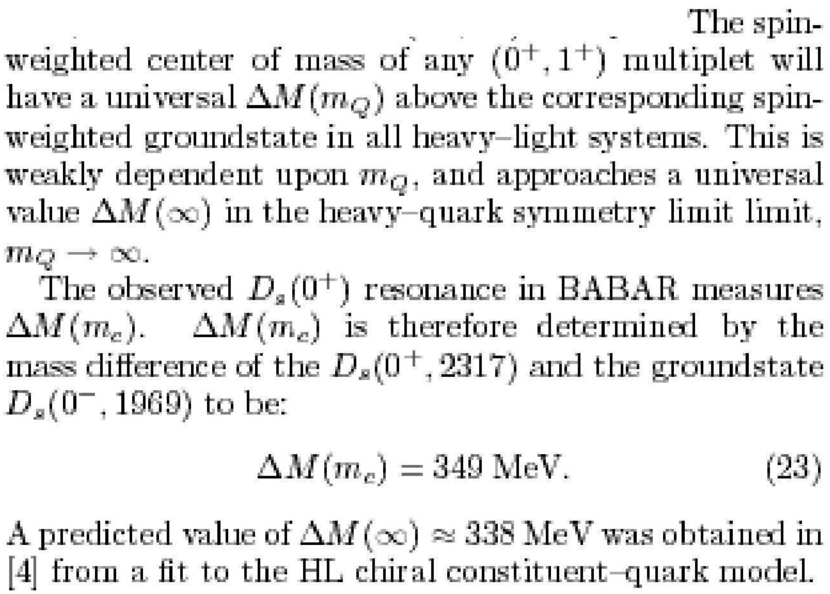
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510, USA



The spin-weighted center of mass of any $(0^+, 1^+)$ multiplet will have a universal $\Delta M(m_Q)$ above the corresponding spin-weighted groundstate in all heavy–light systems. This is weakly dependent upon m_Q, and approaches a universal value $\Delta M(\infty)$ in the heavy–quark symmetry limit limit, $m_Q \to \infty$.

The observed $D_s(0^+)$ resonance in BABAR measures $\Delta M(m_c)$. $\Delta M(m_c)$ is therefore determined by the mass difference of the $D_s(0^+, 2317)$ and the groundstate $D_s(0^-, 1969)$ to be:

$$\Delta M(m_c) = 349 \text{ MeV}. \tag{23}$$

A predicted value of $\Delta M(\infty) \approx 338$ MeV was obtained in [4] from a fit to the HL chiral constituent–quark model.

$(0^+,1^+)$-$(0^-,1^-)$ split

Universal in the limit of infinite heavy quark mass

looks predictive

Using $\Delta M(m_c)$ we predict the $D_s(1^+)$ mass:

$$M(D_s(1^+)) = 2460 \text{ MeV}$$

system	transition	Q(keV)	overlap	dependence	Γ (keV)	exptl BR
$(c\bar{u})$	$1^- \to 0^- + \gamma$	137	0.991	$r_{\bar{c}u}$	33.5	$(38.1 \pm 2.9)\%$
	$1^- \to 0^- + \pi^0$	137		g_A	43.6	$(61.9 \pm 2.9)\%$
	total				77.1	
$(c\bar{d})$	$1^- \to 0^- + \gamma$	136	0.991	$r_{\bar{c}d}$	1.63	$(1.6 \pm 0.4)\%$
	$1^- \to 0^- + \pi^0$	38		g_A	30.1	$(30.7 \pm 0.5)\%$
	$1^- \to 0^- + \pi^+$	39		g_A	65.1	$(67.7 \pm 0.5)\%$
	total				96.8	96 ± 22
$(c\bar{s})$	$1^- \to 0^- + \gamma$	138	0.992	$r_{\bar{c}s}$	0.43	$(94.2 \pm 2.5)\%$
	$1^- \to 0^- + \pi^0$	48		$g_A\delta_{\eta\pi^0}$	0.0079	$(5.8 \pm 2.5)\%$
	total				0.44	
$(c\bar{s})$	$0^+ \to 1^- + \gamma$	212	2.794	$r_{\bar{c}s}$	1.74	
	$0^+ \to 0^- + \pi^0$	297		$G_A\delta_{\eta\pi^0}$	21.5	
	total				23.2	
$(c\bar{s})$	$1^+ \to 0^+ + \gamma$	138	0.992	$r'_{\bar{c}s}$	2.74	
	$1^+ \to 0^+ + \pi^0$	48		$g_A\delta_{\eta\pi^0}$	0.0079	
	$1^+ \to 1^- + \gamma$	323	2.638	$r_{\bar{c}s}$	4.66	
	$1^+ \to 0^- + \gamma$	442	2.437	$r_{\bar{c}s}$	5.08	
	$1^+ \to 1^- + \pi^0$	298		$G_A\delta_{\eta\pi^0}$	21.5	
	$1^+ \to 0^- + 2\pi$	221		$g_A\delta_{\sigma_1\sigma_3}$	4.2	
	total				38.2	

$D_s(2317) \to D^*\gamma$
much less than
$D_s(2317) \to D\pi^0$

$D_s(2460) \to D\gamma$
less than
$D_s(2460) \to D^*\pi^0$

Also explain the narrow width

Understanding $D_{sJ}(2317)$

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isospin violating transition $D_{s0} \to D_s\pi^0$

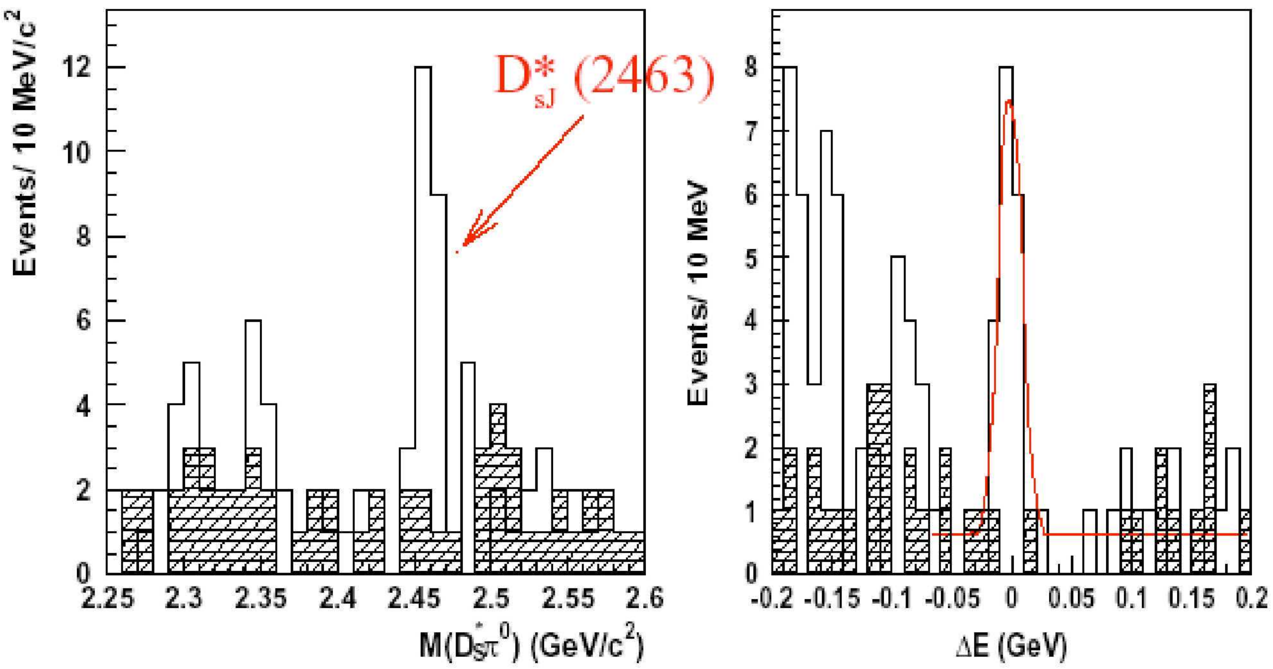
$$\mathcal{L}_{mixing} = \frac{\tilde{\mu}}{2}\frac{m_d - m_u}{\sqrt{3}}\pi^0\eta$$

$$\mathcal{M} = \begin{pmatrix} \sqrt{\frac{1}{2}}\pi^0 + \sqrt{\frac{1}{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\sqrt{\frac{1}{2}}\pi^0 + \sqrt{\frac{1}{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\sqrt{\frac{2}{3}}\eta \end{pmatrix}$$

$$\Gamma(D_{s0} \to D_s\pi^0) = \frac{1}{16\pi}\frac{h^2}{f^2}\frac{M_{D_s}}{M_{D_{s0}}}\left(\frac{\boxed{m_d - m_u}}{m_s - \frac{m_d + m_u}{2}}\right)^2\left(1 + \frac{m_{\pi^0}^2}{|\vec{p}_{\pi^0}|^2}\right)|\vec{p}_{\pi^0}|^3$$

take the challenge and change experiment

$DD^*_s\pi^0$ decay mode (Belle, preliminary)

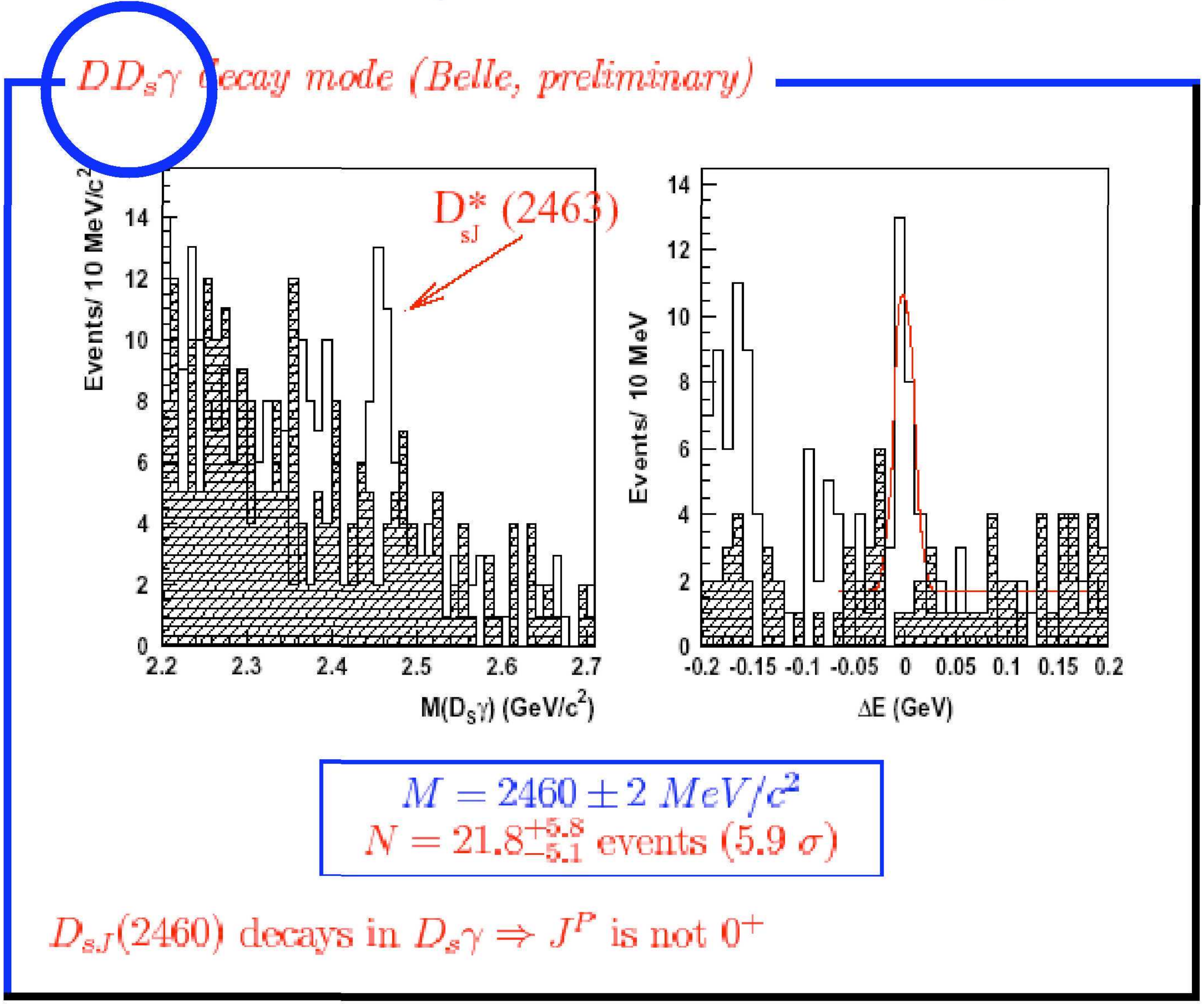


$$M = 2460 \pm 3 MeV/c^2$$
$$N = 16.7^{+4.8}_{-4.1} \text{ events } (6.0\ \sigma)$$

This is a different technique.
Take a BB event.
Look for B decaying as B-> $D^{(*)}_s D$ and study the $D^{(*)}_s$

Here they demonstrate that $D_s(2460)\text{->}D^*_s\pi^0$ occurs

Fully uncover D_s(2460)



$DD_s\gamma$ decay mode (Belle, preliminary)

$M = 2460 \pm 2\ MeV/c^2$

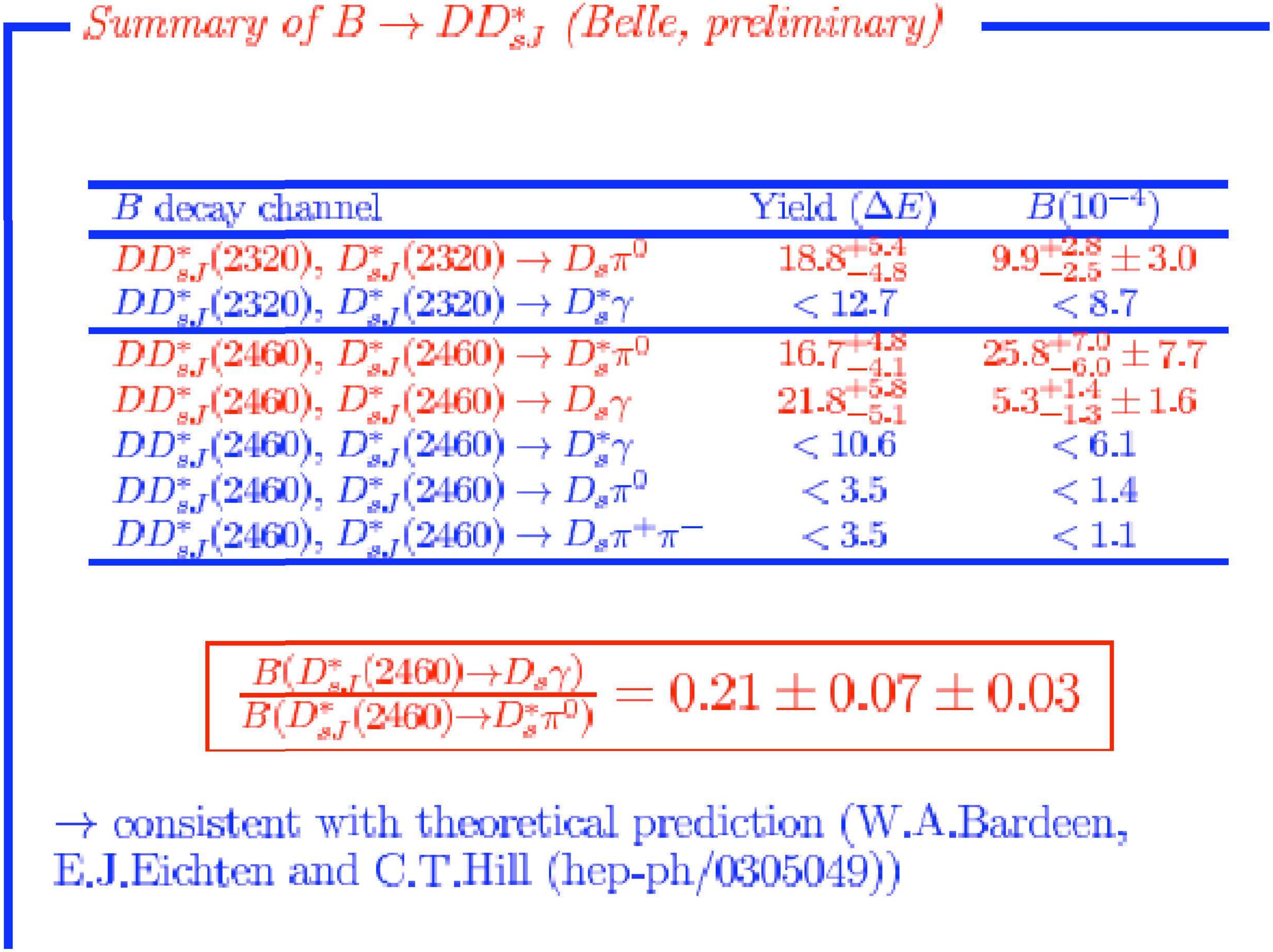
$N = 21.8^{+5.8}_{-5.1}$ events $(5.9\ \sigma)$

$D_{sJ}(2460)$ decays in $D_s\gamma \Rightarrow J^P$ is not 0^+

Here they demonstrate that D_s (2460)->$D_s\gamma$ occurs

Since D_s is a spin 0 state, this decay positively shows that D_s (2460) is not a spin 0 particle

in fair agreement with predictions



Summary of $B \to DD^*_{sJ}$ *(Belle, preliminary)*

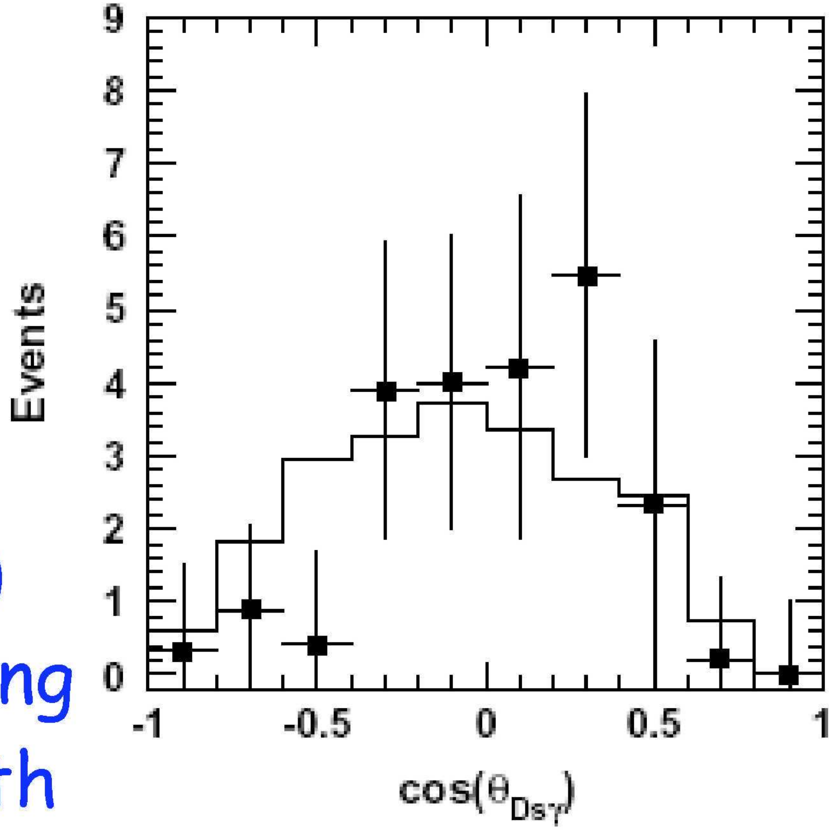
B decay channel	Yield (ΔE)	$\mathcal{B}(10^{-4})$
$DD^*_{sJ}(2320)$, $D^*_{sJ}(2320) \to D_s\pi^0$	$18.8^{+5.4}_{-4.8}$	$9.9^{+2.8}_{-2.5} \pm 3.0$
$DD^*_{sJ}(2320)$, $D^*_{sJ}(2320) \to D^*_s\gamma$	< 12.7	< 8.7
$DD^*_{sJ}(2460)$, $D^*_{sJ}(2460) \to D^*_s\pi^0$	$16.7^{+4.8}_{-4.1}$	$25.8^{+7.0}_{-6.0} \pm 7.7$
$DD^*_{sJ}(2460)$, $D^*_{sJ}(2460) \to D_s\gamma$	$21.8^{+5.8}_{-5.1}$	$5.3^{+1.4}_{-1.3} \pm 1.6$
$DD^*_{sJ}(2460)$, $D^*_{sJ}(2460) \to D^*_s\gamma$	< 10.6	< 6.1
$DD^*_{sJ}(2460)$, $D^*_{sJ}(2460) \to D_s\pi^0$	< 3.5	< 1.4
$DD^*_{sJ}(2460)$, $D^*_{sJ}(2460) \to D_s\pi^+\pi^-$	< 3.5	< 1.1

$$\boxed{\frac{\mathcal{B}(D^*_{sJ}(2460) \to D_s\gamma)}{\mathcal{B}(D^*_{sJ}(2460) \to D^*_s\pi^0)} = 0.21 \pm 0.07 \pm 0.03}$$

→ consistent with theoretical prediction (W.A.Bardeen, E.J.Eichten and C.T.Hill (hep-ph/0305049))

J^P assignement of $D_s(2460)$

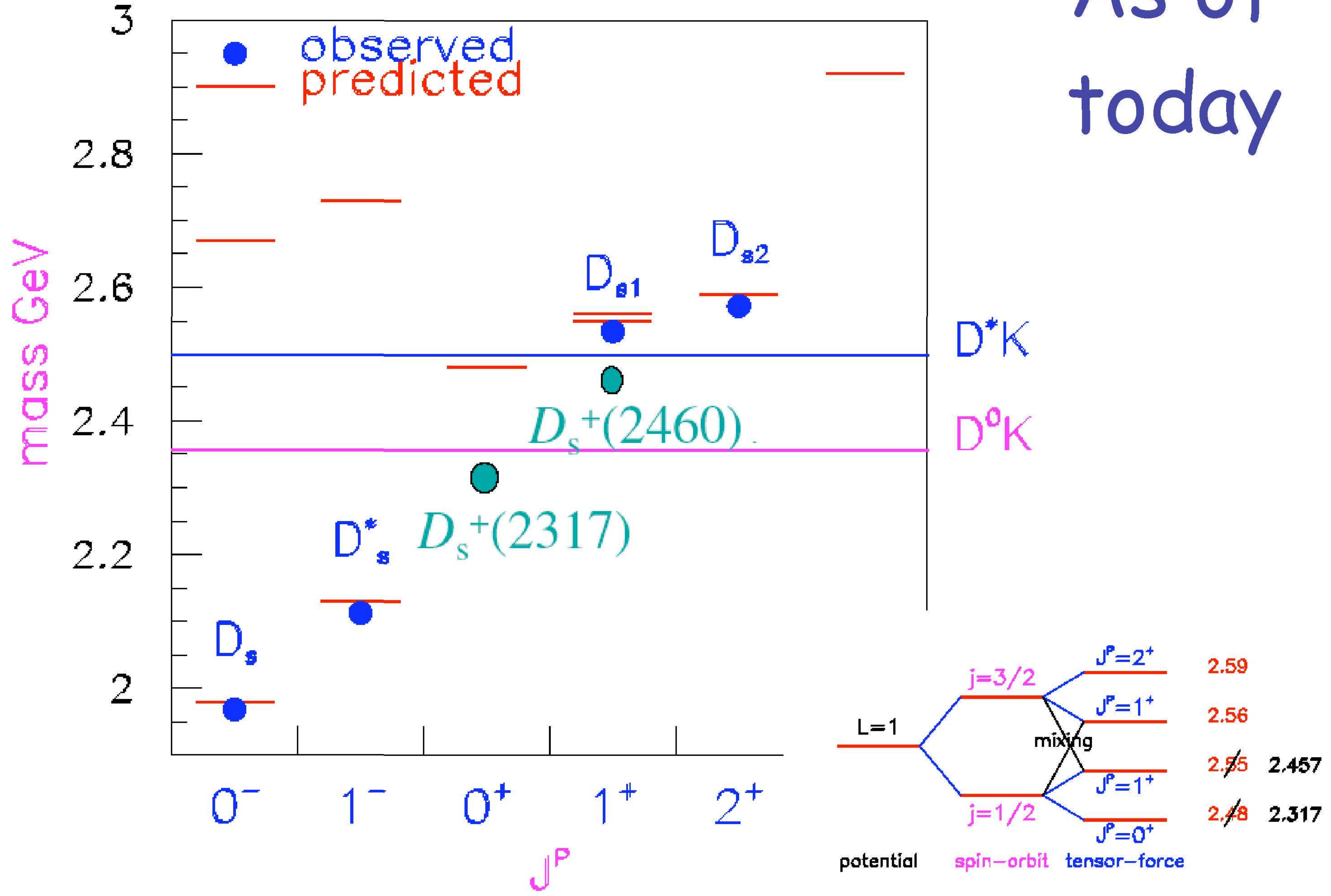
In the B-> $D_s(2460)D$ decay (followed by $D_s(2460)$-> $D_s\gamma$) measure the angle between $D_s(2460)$ momentum in the B rest frame and D_s momentum in the $D_s(2460)$ rest frame.



Expect $\sin^2\theta$ if $J^P = 1^+$

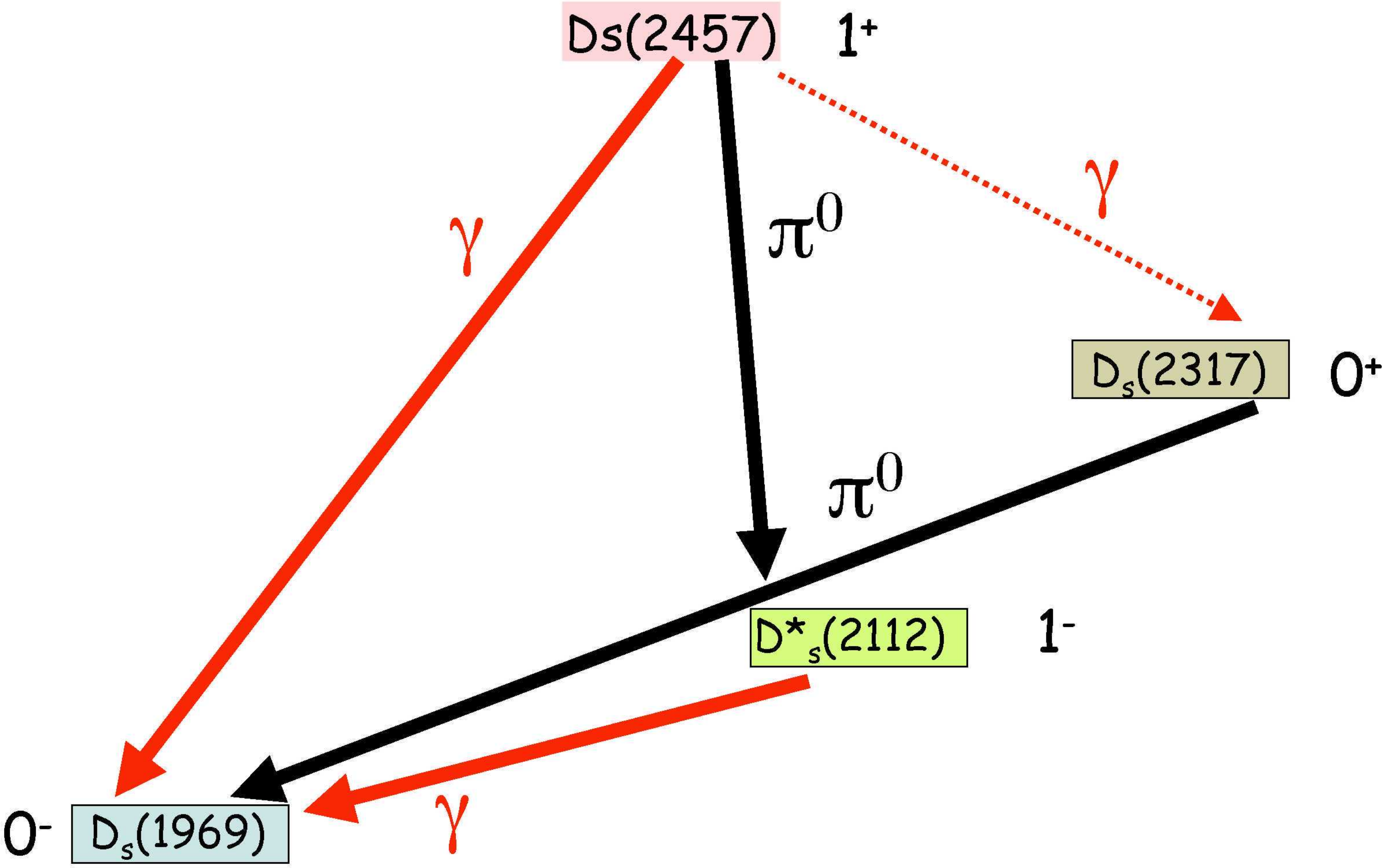
It looks really like $D_s(2317)$ and $D_s(2460)$ are the missing 0^+, 1^+ state of $c\bar{s}$ system with L=1

As of today



observed
predicted
mass GeV
3
2.8
2.6
2.4
2.2
2
D_s
D^*_s
D_{s1}
D_{s2}
$D_s^+(2317)$
$D_s^+(2460)$
D*K
D^0K
0^-
1^-
0^+
1^+
2^+
J^P
L=1
j=3/2
j=1/2
mixing
$J^P=2^+$
$J^P=1^+$
$J^P=1^+$
$J^P=0^+$
2.59
2.56
~~2.55~~ 2.457
~~2.48~~ 2.317
potential
spin−orbit
tensor−force

So far this has been the harvest



Ds(2457) 1^+

γ

π^0

γ

$D_s(2317)$ 0^+

π^0

$D^*_s(2112)$ 1^-

0^- $D_s(1969)$

γ

Conclusions

- Charm physics is nice and full of surprises
- Never believe too much to theorists
- BaBar and Belle will get you alive for a couple of more years

Physics is a joy of life. Do it as best as you can.