A study of the scan of the $D_{s0}^{*}(2317)^{+}$ mass with pandaroot

March 16th, 2015 | Elisabetta Prencipe, Forschungszentrum Jülich | PANDA Coll. Meeting, Giessen

Outline

- Theoretical aspects
- Recent observations
- Simulation: $\bar{p}p \rightarrow D_s^- D_{s0}^*(2317)^+$
- Proposed analysis strategy
- Comparison signal/background
- Summary

Unexpected observations in the D_s spectrum

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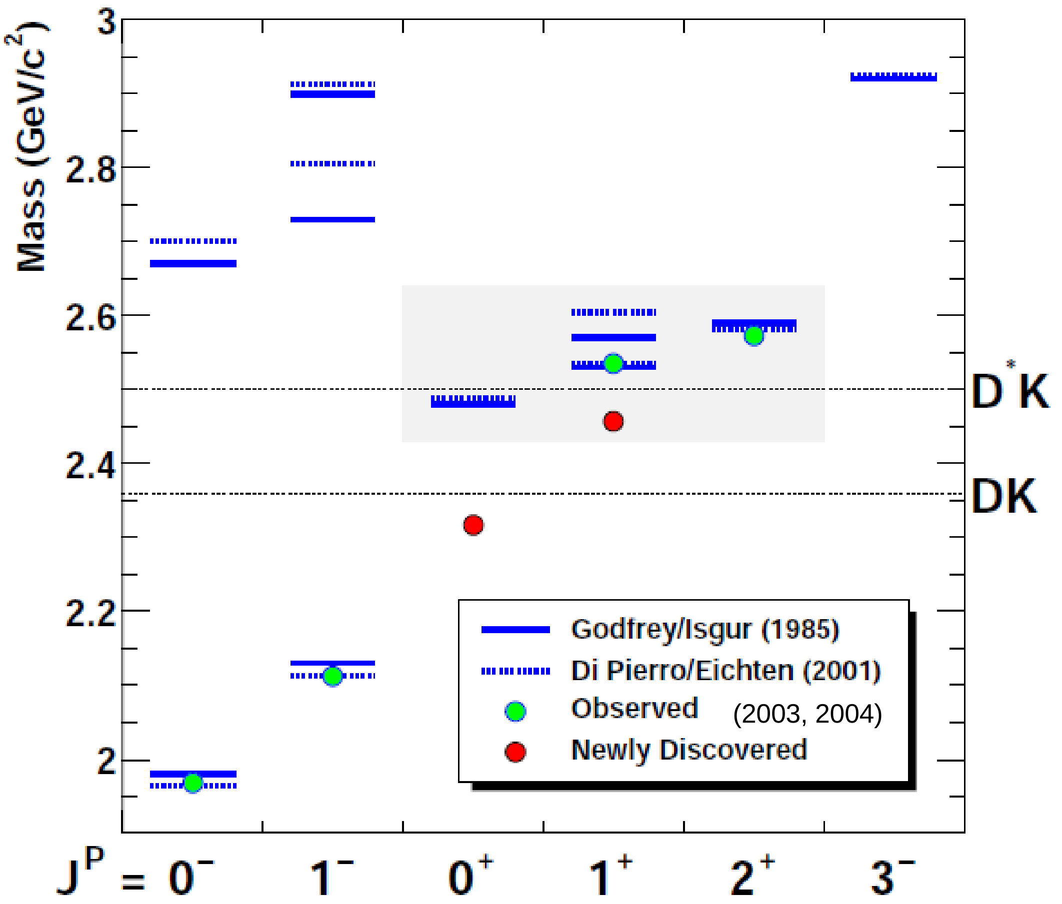
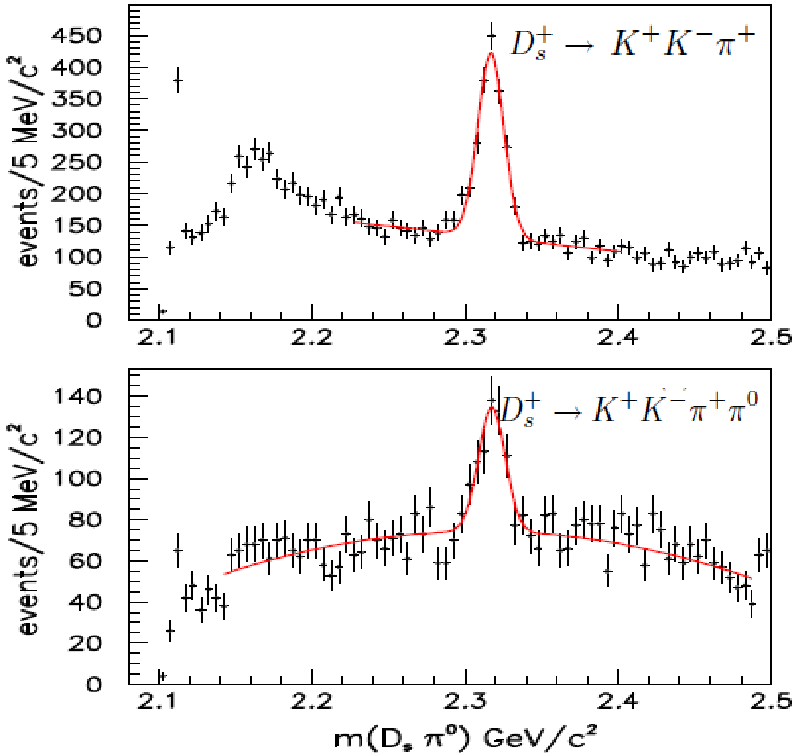
D mesons: $|c\bar{u}\rangle$, $|c\bar{d}\rangle$ Charged, neutral mesons

D_s mesons: $|c\bar{s}\rangle$ Charged mesons, only

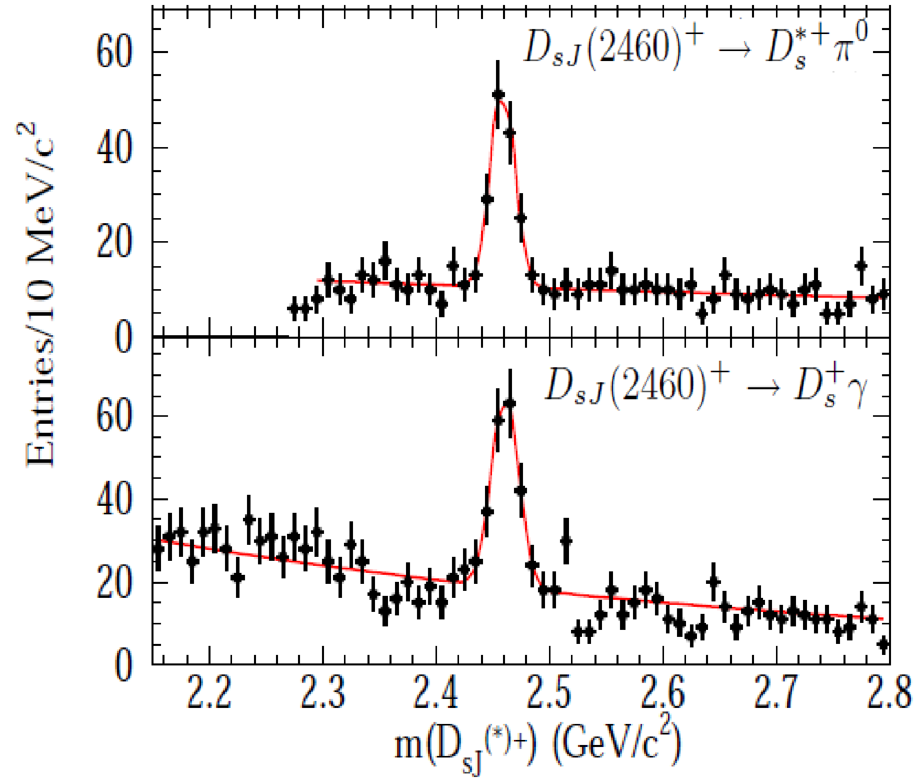


Observation of $D_{s0}^*(2317)$ and $D_{s1}(2460)$

BABAR, PRL 90 (2003) 242001



BABAR, PRL 93 (2004) 181801



$m(D_{s0}^*(2317)^+) = (2317.7 \pm 0.6)$ MeV/c^2

$\Gamma < 3.8$ MeV CL=95.0%

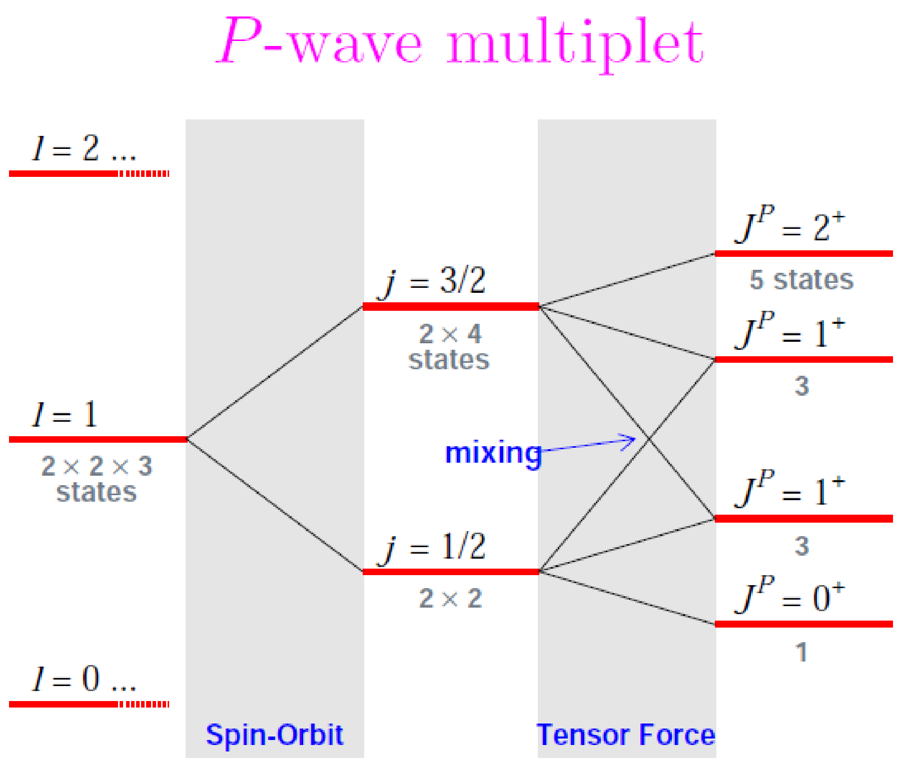
$m(D_{s1}(2460)^+) = (2459.5 \pm 0.6)$ MeV/c^2

$\Gamma < 3.5$ MeV CL=95.0%

- Narrow decay width suggests isospin violating decays, $I \neq 1 \Rightarrow$ hence $I=0$
- Spin parity to be confirmed

CLEO, PRD 68 (2003) 032002
BELLE, PRL 92 (2004) 012002
BABAR, PRD 74 (2006) 032007

D_s level scheme



- Conventionally interpreted as the hydrogen atom splitting levels (quark model)
- m(D_{s0}*$(2317)^+$) and m($D_{s1}$$(2460)^+$) found 180 MeV/c^2 and 70 MeV/c^2 below what predicted by potential models, respectively → Not understood!

Experimental overview of D_{s0}*(2317) and D_{s1}(2460)

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Decay Channel	$D^*_{sJ}(2317)^+$	$D_{sJ}(2460)^+$
$D_s^+\pi^0$	Seen	Forbidden
$D_s^+\gamma$	Forbidden	Seen
$D_s^+\pi^0\gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+\pi^0$	Forbidden	Seen
$D^*_{sJ}(2317)^+\gamma$	Seen	Allowed
$D_s^+\pi^0\pi^0$	Forbidden	Allowed
$D_s^+\gamma\gamma$ (a)	Allowed	Allowed
$D_s^*(2112)^+\gamma$	Allowed	Allowed
$D_s^+\pi^+\pi^-$	Forbidden	Seen

(a) Non-resonant only

- $D_{s0}^*(2317)^+$ is found below the DK threshold:
- $D_{s0}^*(2317)^+$ can in principle decay
  - electromagnetically (no exp. evidence); or
  - through isospin-violation $D_s^+\pi^0$ strong decay

Is D_{s0}^* the missing 0^+ state of the $c\bar{s}$-*spectrum*?

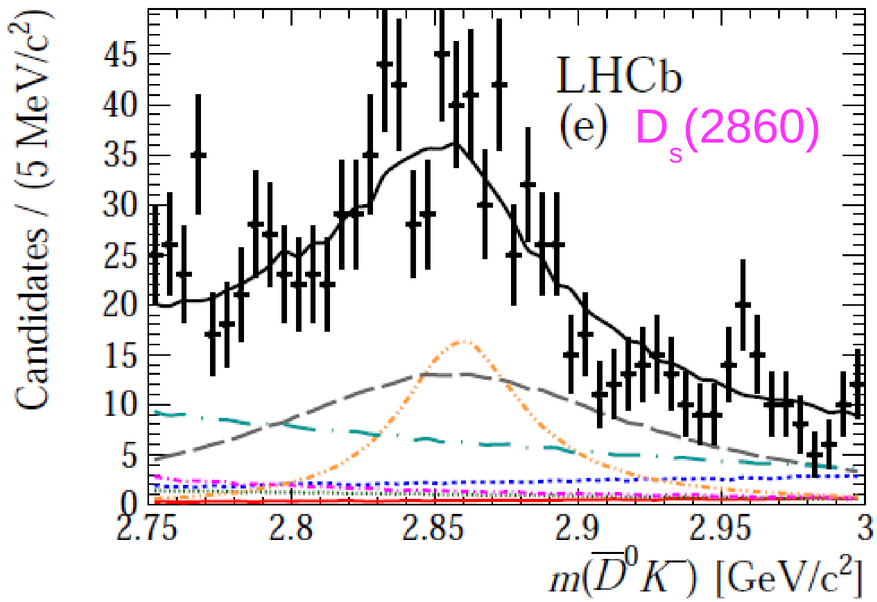
- $D_{s1}(2460)^+$ observed in the inv. mass $D_s^+\gamma$
- Spin <u>at least</u> 1
- We can exclude the hypothesis 0^+, because $D_{s1}(2460)^+ \to D_s^+\gamma$

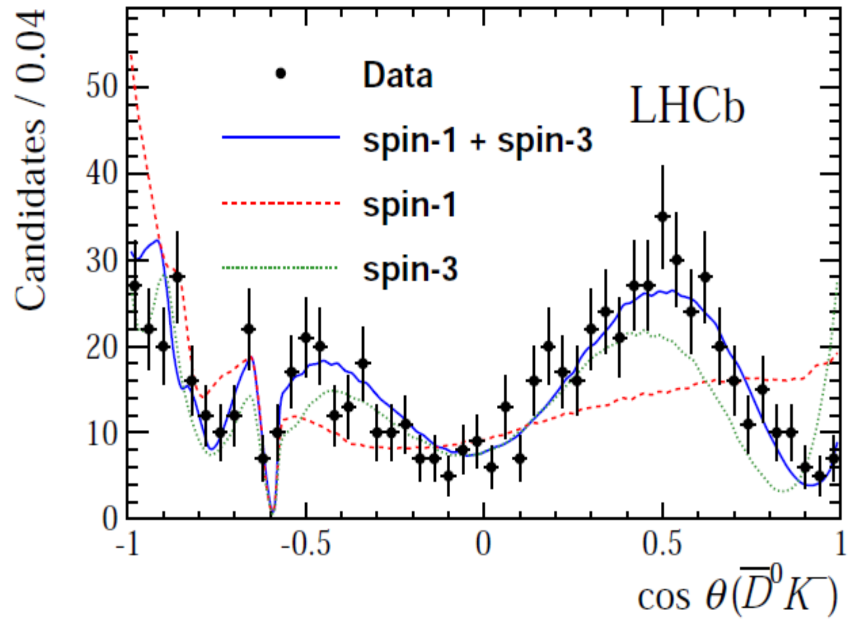
Is D_{s1} the missing 1^+ of the $c\bar{s}$-*spectrum*?

Do these 2 particles belong to the same family of exotics?

...more and more D_{sJ} states

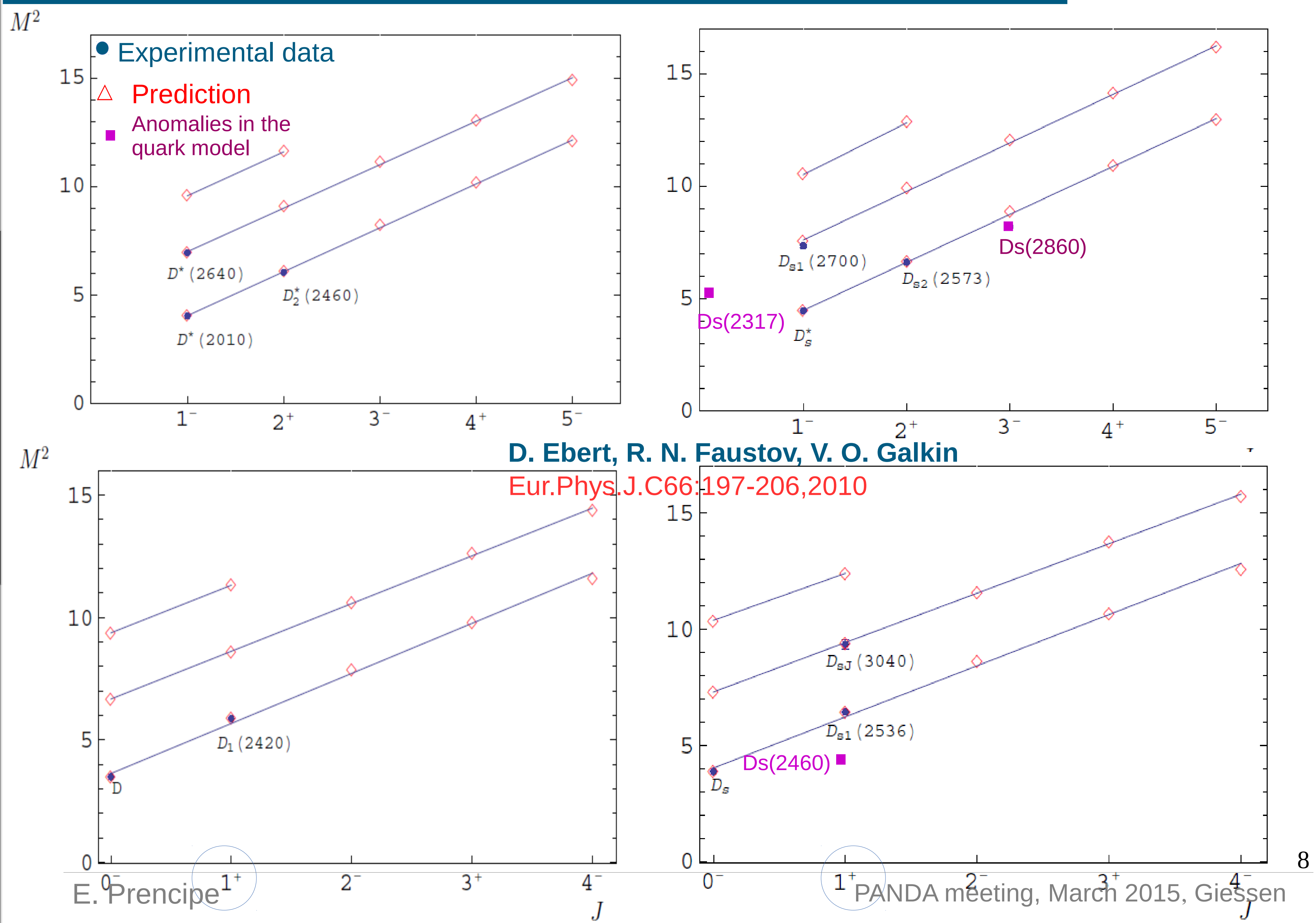
LHCb, PRL 113 (2014) 162001





- Angular analysis of $B^0_s \to D^0K^+\pi^-$ at LHCb: first observation of heavy-flavored spin-3 resonance (first observation of J=3 in B decays)
- Possible explanation of $D_s(2860)$ as overlap of 2 resonances, with J=1 and J=3
- $D_{s0}^*(2317)$, $D_{s1}(2460)$ and $D_s(2860)$ are anomalies in the quark model: they do not fit linear Regge trajectories

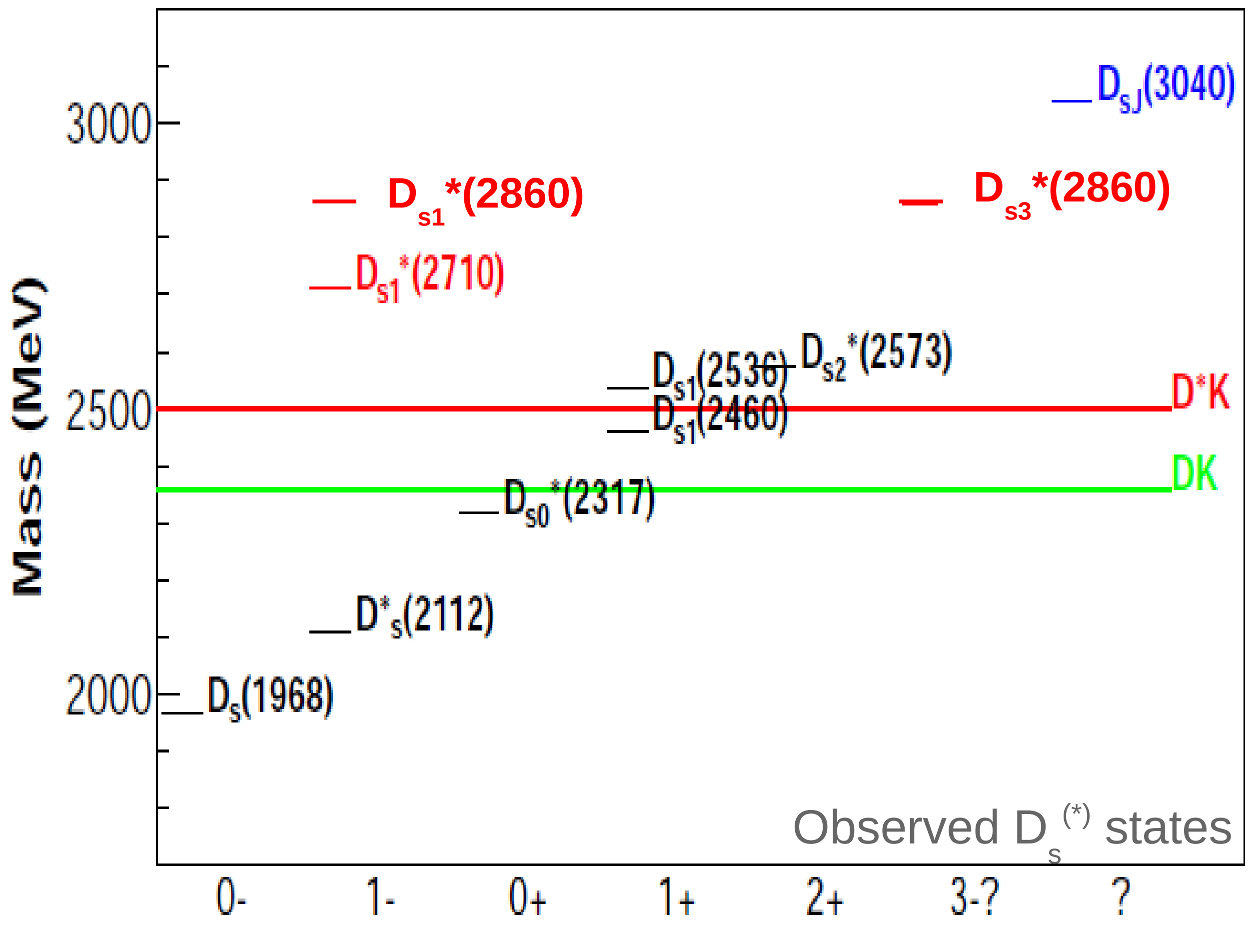
Regge trajectories with quark model



D. Ebert, R. N. Faustov, V. O. Galkin

Eur.Phys.J.C66:197-206,2010

D_s spectroscopy, today



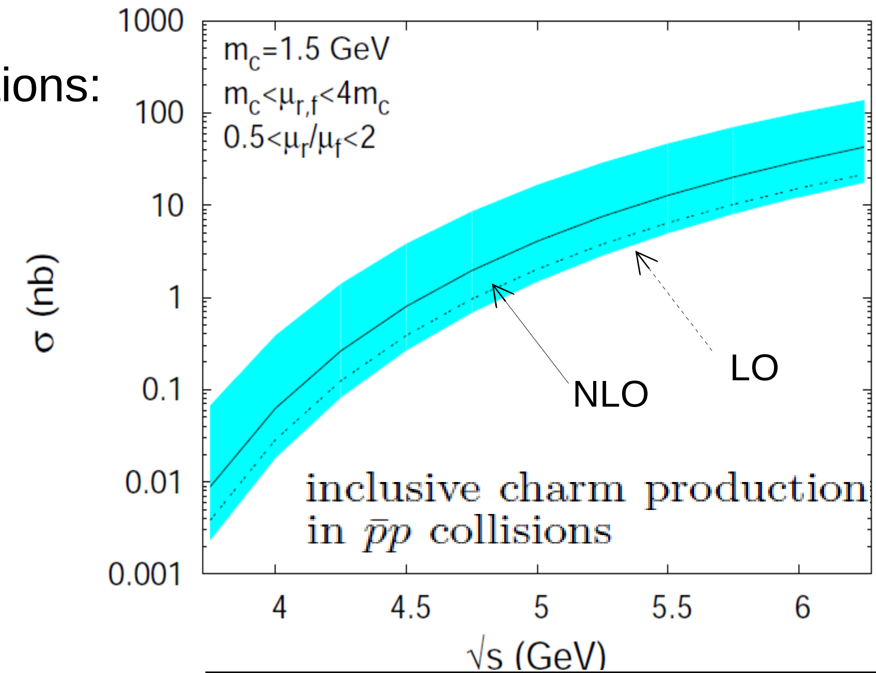
What can we do more?

How can we do that?

A quick look to theoretical predictions

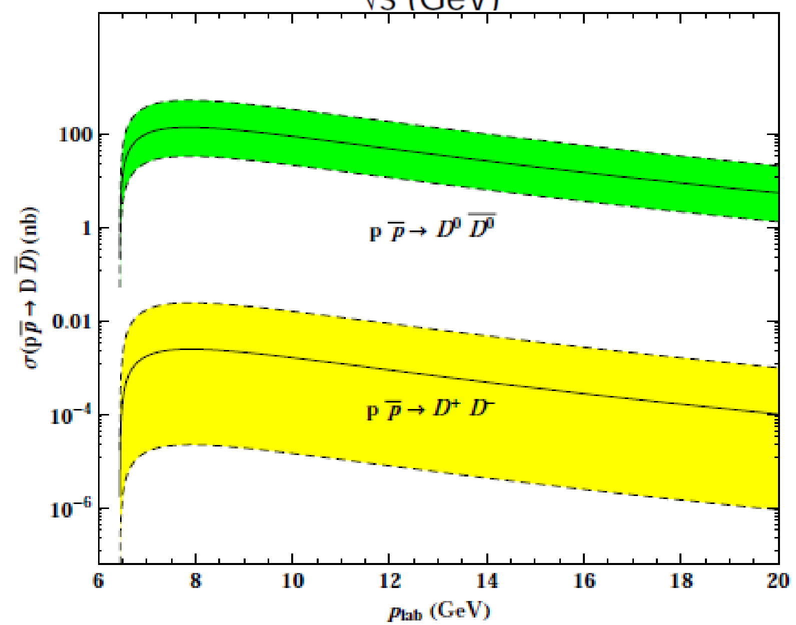
- Different models, different cross section predictions:

PRD 79 (2009) 114005
E. Braaten, P. Artoisenet
Perturbative calculations in open charm



Alternatively:

Eur. Phys. J. A 48 (2012) 31
A. Khodjamirian, C. Klein, T. Mannel, Y.M. Wang
Regge theory calculation
Coupling from QCD Sum rules

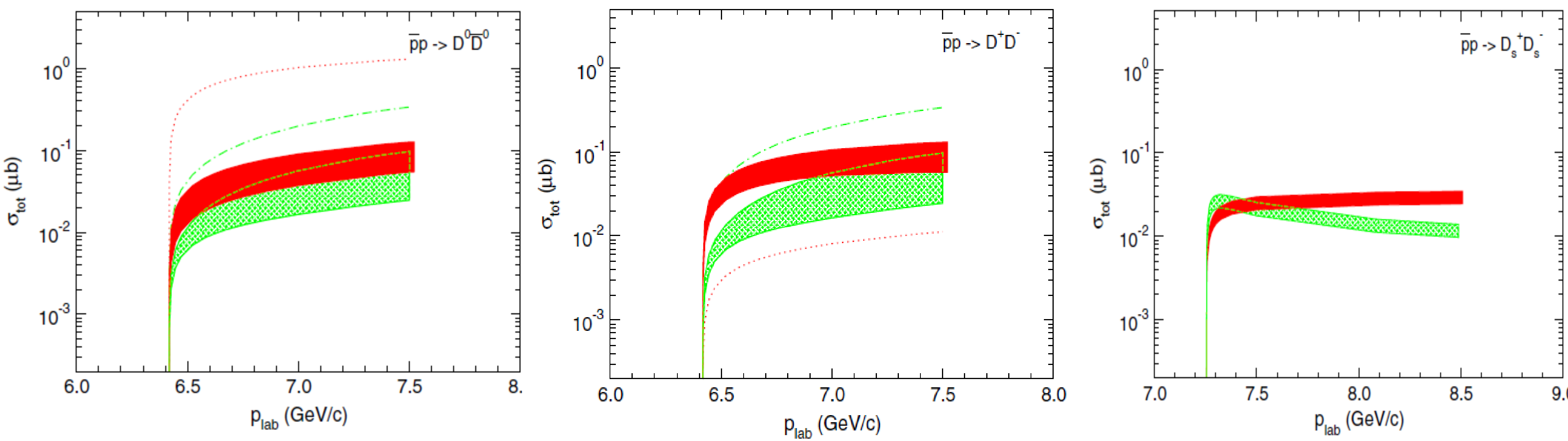


A quick look to theoretical predictions

PRD 89 (2014) 114003

J. Haidenbauer, G. Krein

Baryon exchange and quark model in SU(4)

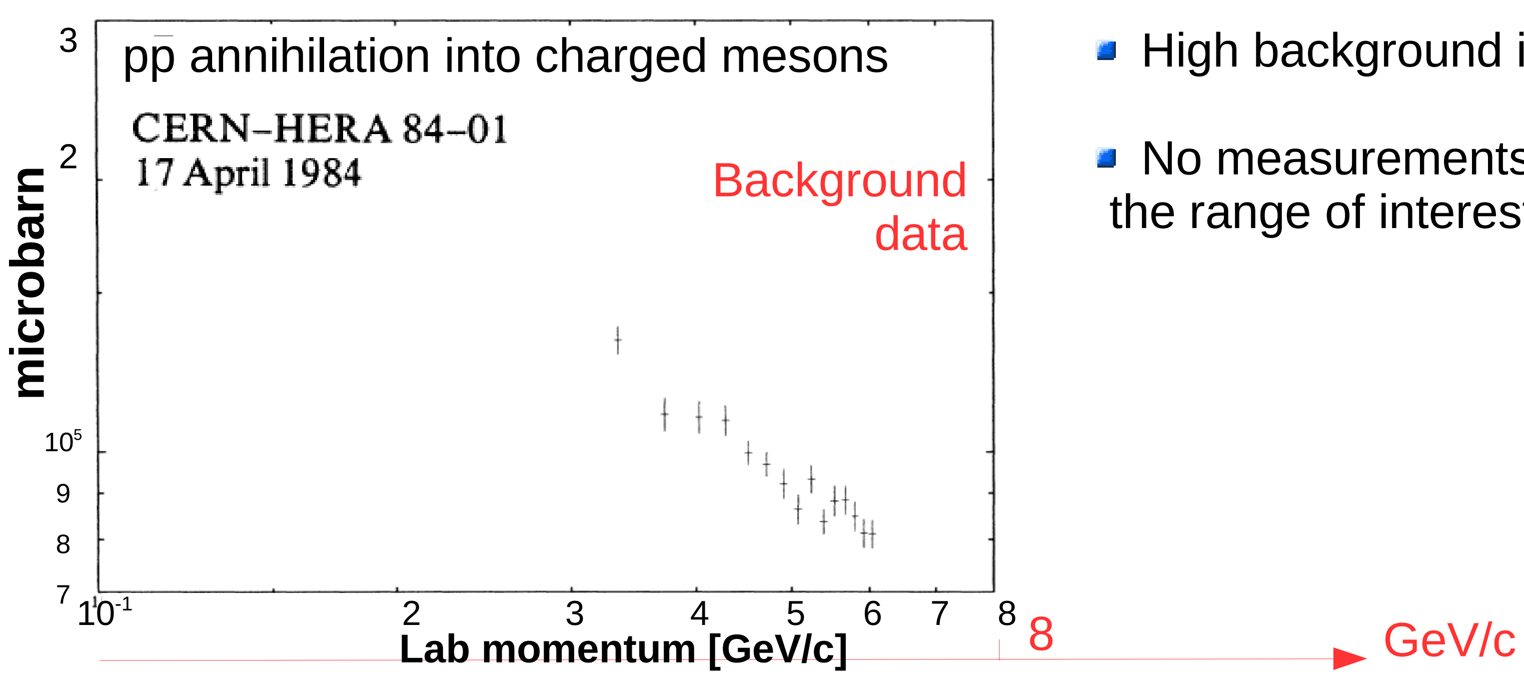


- Prediction valid only for ground states
- Perturbative estimations turn out to underestimate the cross section (from known meas.)
- For excited states (e.g. $D_{s0}^*(2317)$), challenging to make rigorous calculation for the cross section in $\bar{p}p$ interactions ⇨ **NEED DATA!**

Background cross section

- $\sigma(\bar{p}p \rightarrow D\bar{D})$ expected <100nb
- Inclusive search: better for cross section measurement, but higher background. Challenge!
- Exclusive cross section measurement: theoretical predictions are difficult

V. Flaminio, W.G. Moorhead, D.R.O. Morrison, N. Rivoire

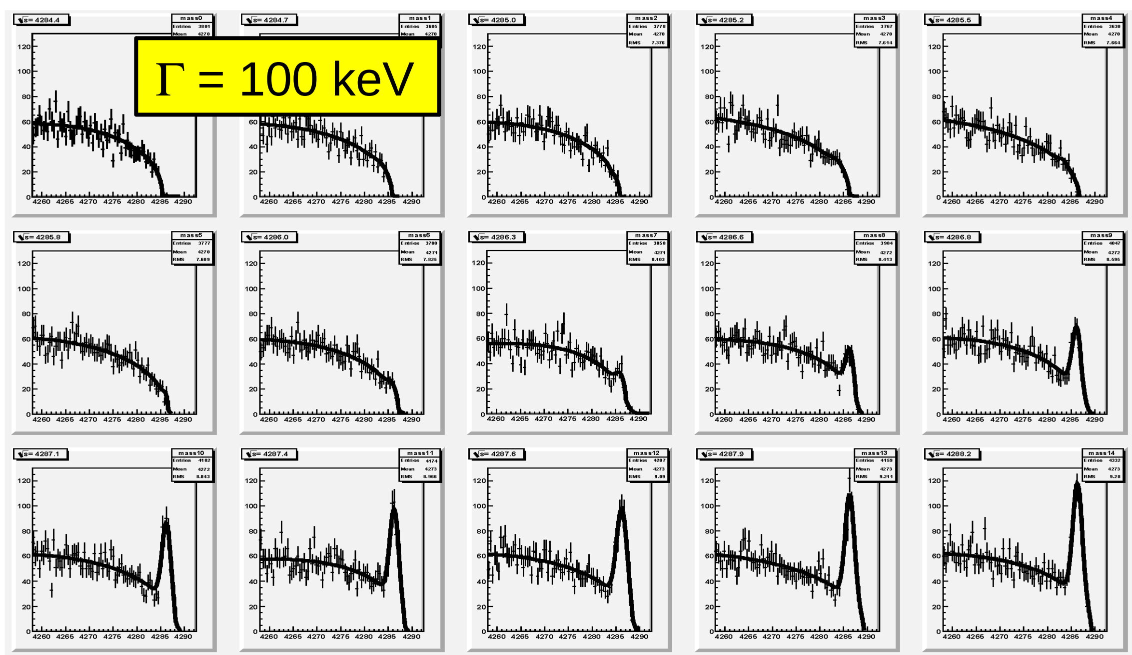


- High background is expected
- No measurements in $\bar{p}p$ for the range of interest!

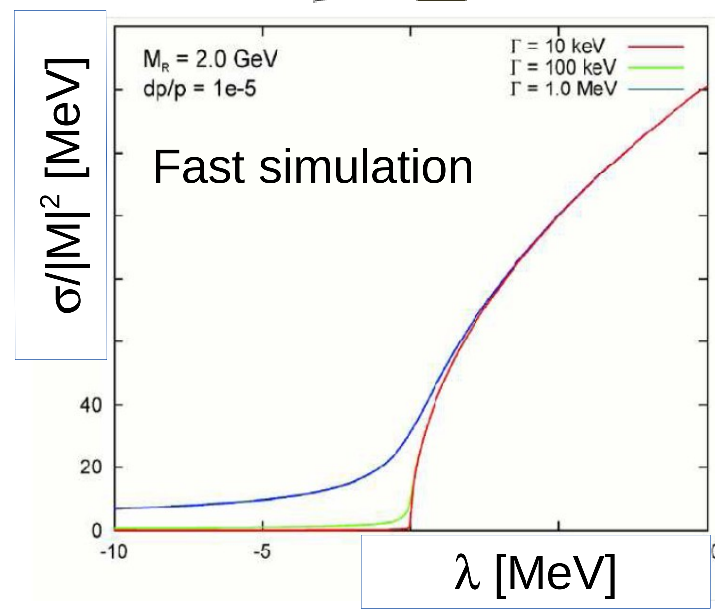
- Simulations in $\bar{P}$ANDA for the D_{s0}* and D_{s1} cross section: p > 8.8 GeV/c

Status of the work in $\bar{P}$ANDA: strategy

- Simulation of signal and background events, to fix a selection
- Identify the main variables to reject the huge background: Fisher (F), ΔE, inv. mass system
- Write a likelihood fit with figure(s) of merit, and extract yield
- Draw the excitation function of the cross section of the system $[D_s D_{s0}^*(2317)^+]$ to measure the width of $D_{s0}^*(2317)^+$



PhD thesis, M. Mertens



$$\sigma(\lambda) = \sqrt{m_R \Gamma} |M^2| \frac{1}{\pi} \int_{-\infty}^{\lambda} \mathrm{d}x, \frac{\sqrt{\lambda - x}}{x^2 + 1}$$

Excitation function of the cross section

Status of the work in PANDA: strategy

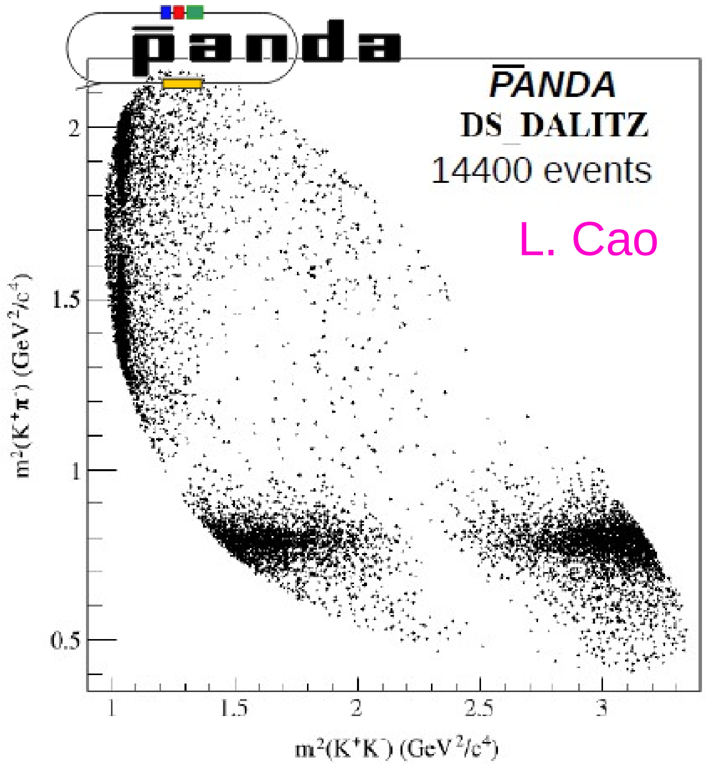
- Pre-selection for $\bar{p}p \rightarrow Ds^- D_{s0}^*(2317)^+$:
  - single tag technique: D_s^- tagged to $K^+K^-\pi^-$
  - 4mom. D_s^- fully reconstructed
  - $D_{s0}^*(2317)^+$: missing mass of the event
  - Vtx fitter : Prob χ^2>1%, χ^2 <19
  - POCA (x,y) vtx very loose cut: 20 mm

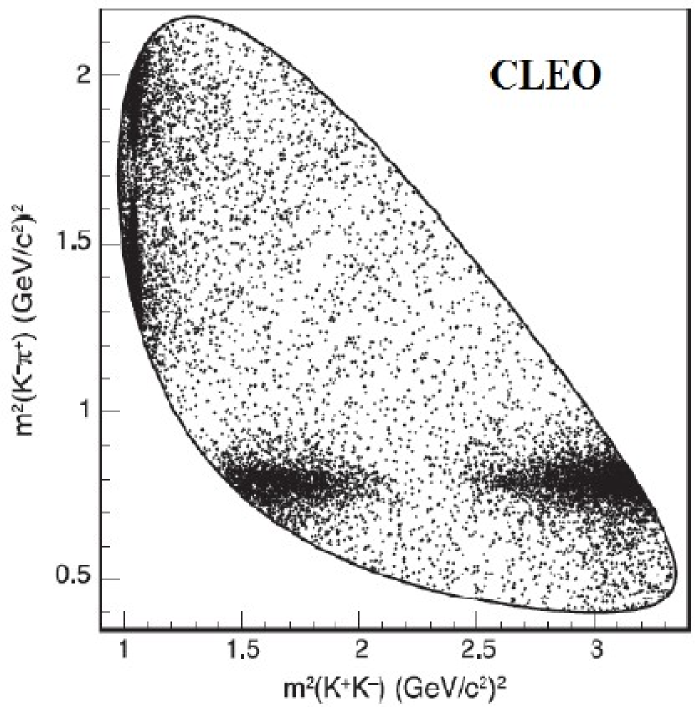
- Selection:
  - Study kinematic of the event (background rejection): $p^{(*)}$, $\theta^{(*)}$, resolution
  - Fit total system $D_s^- + D_{s0}^*(2317)^+$
  - Fit parameters: mass and width of the system $D_s^- + D_{s0}^*(2317)^+$
  - Figures of merit: M_{sys}, ΔE_{sys}, Fisher(NN) discriminant

- MC generators:
  - Signal events: EvtGen
  - Background events: DPM
  - Continuum background

The model

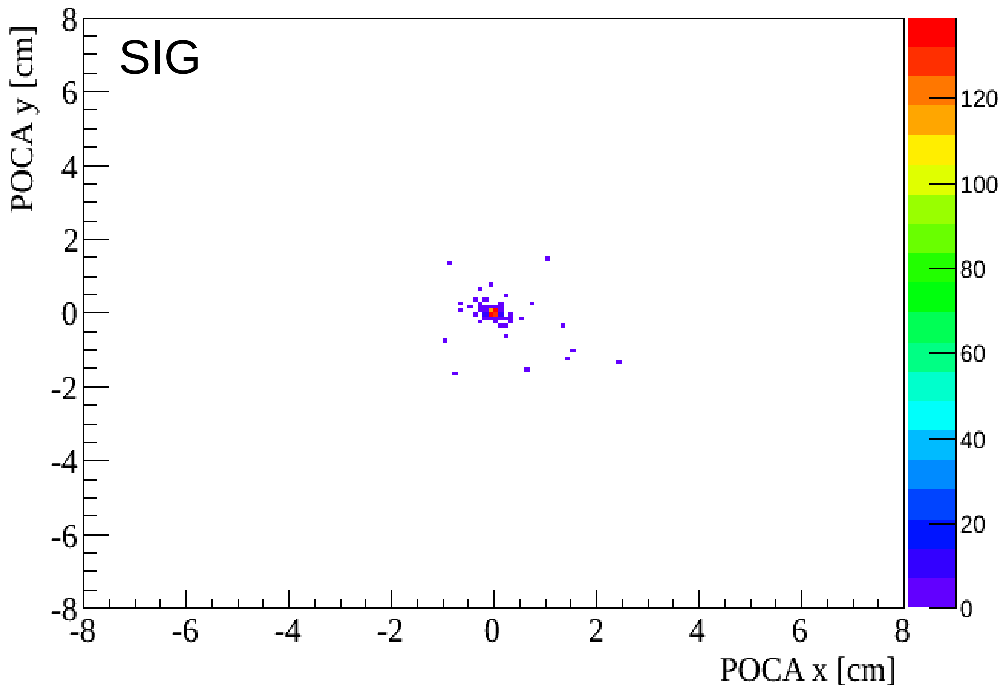
- **Full simulations** (simulation, digitization, reconstruction, PID)
- Full magnetic field map
- Real track finder, real PID methods
- Realistic model for simulation: DS_DALITZ (from BaBar/CLEO data)

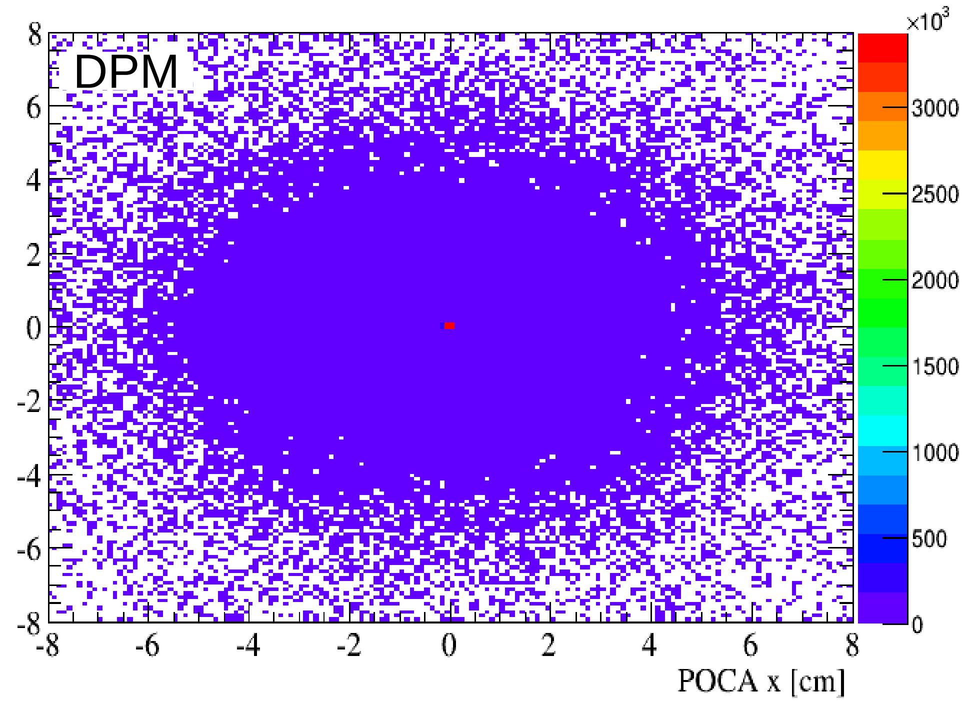


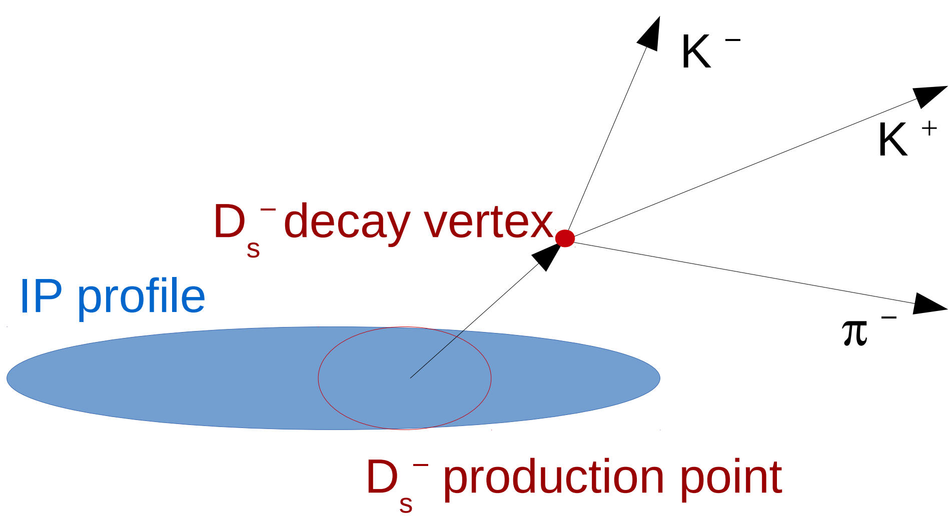


D_s vertex reconstruction

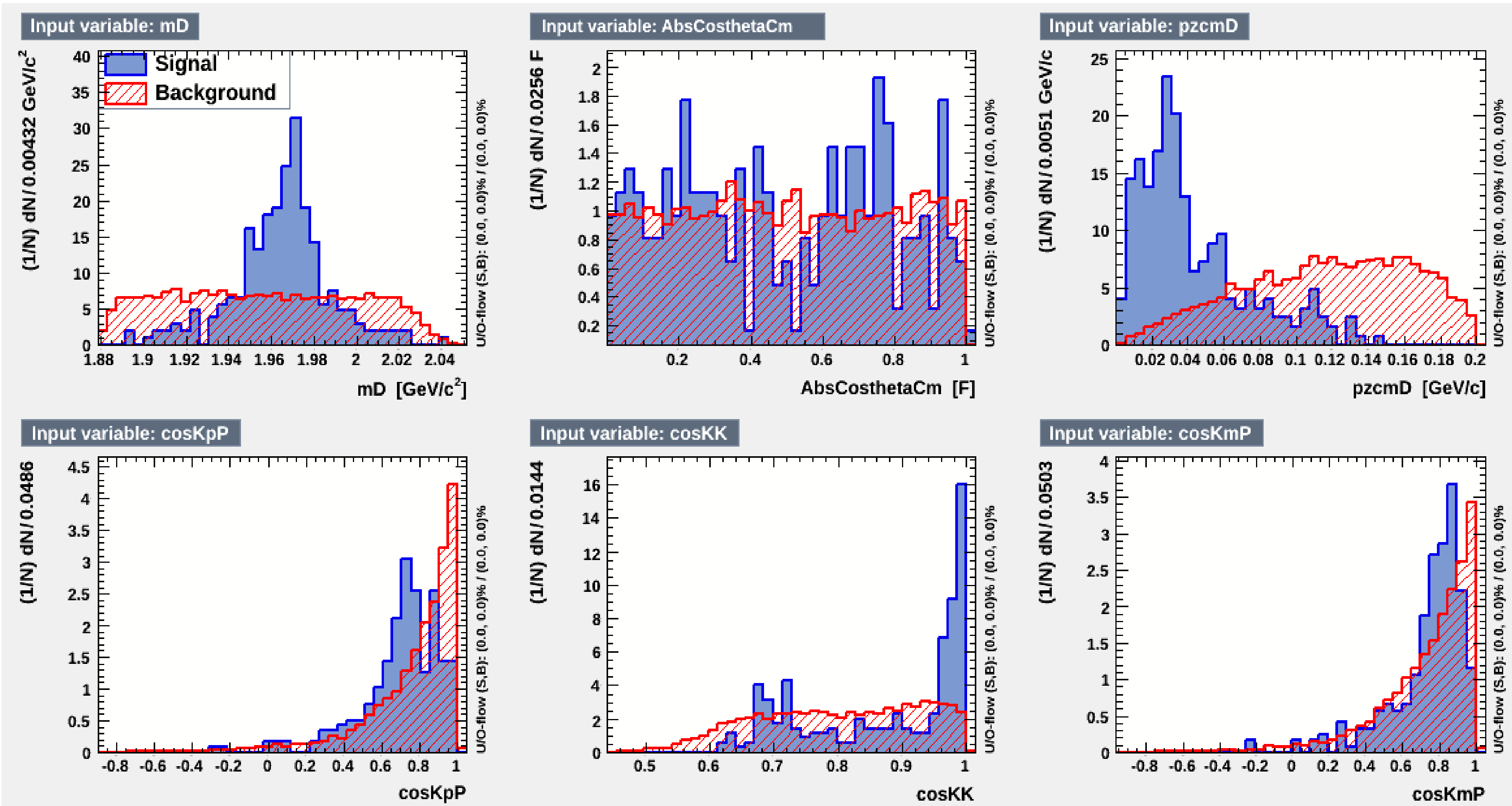
After pre-selection:







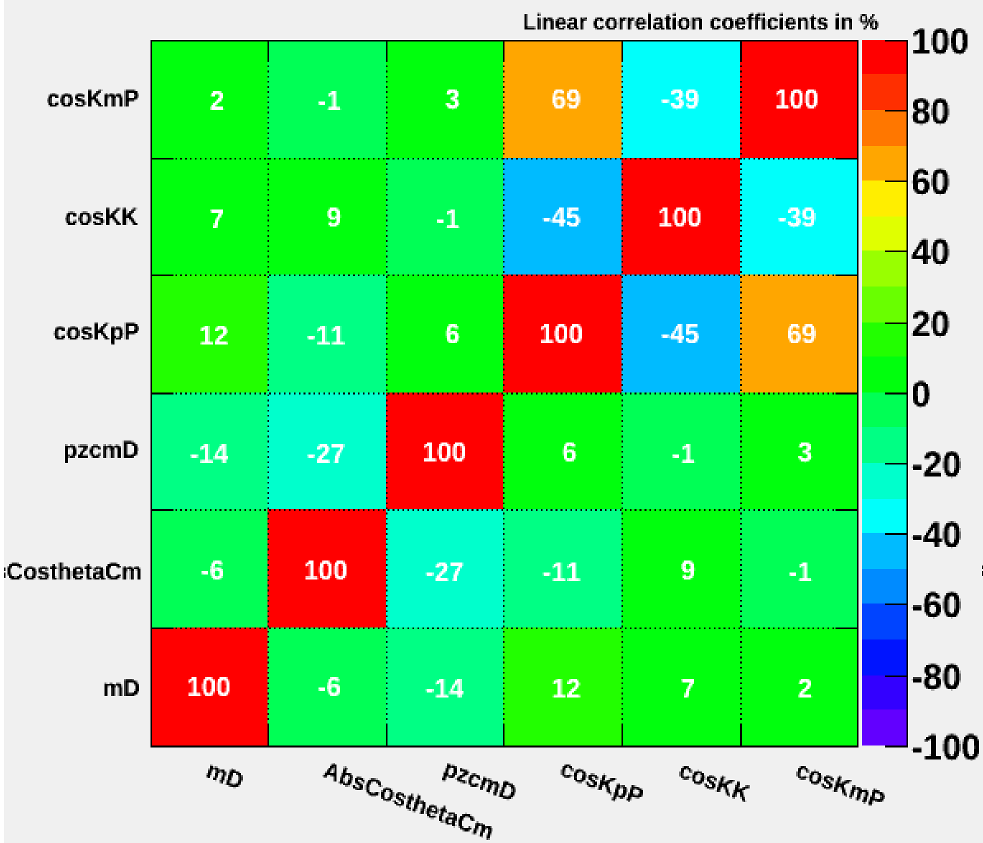
Fisher discriminant: input variables



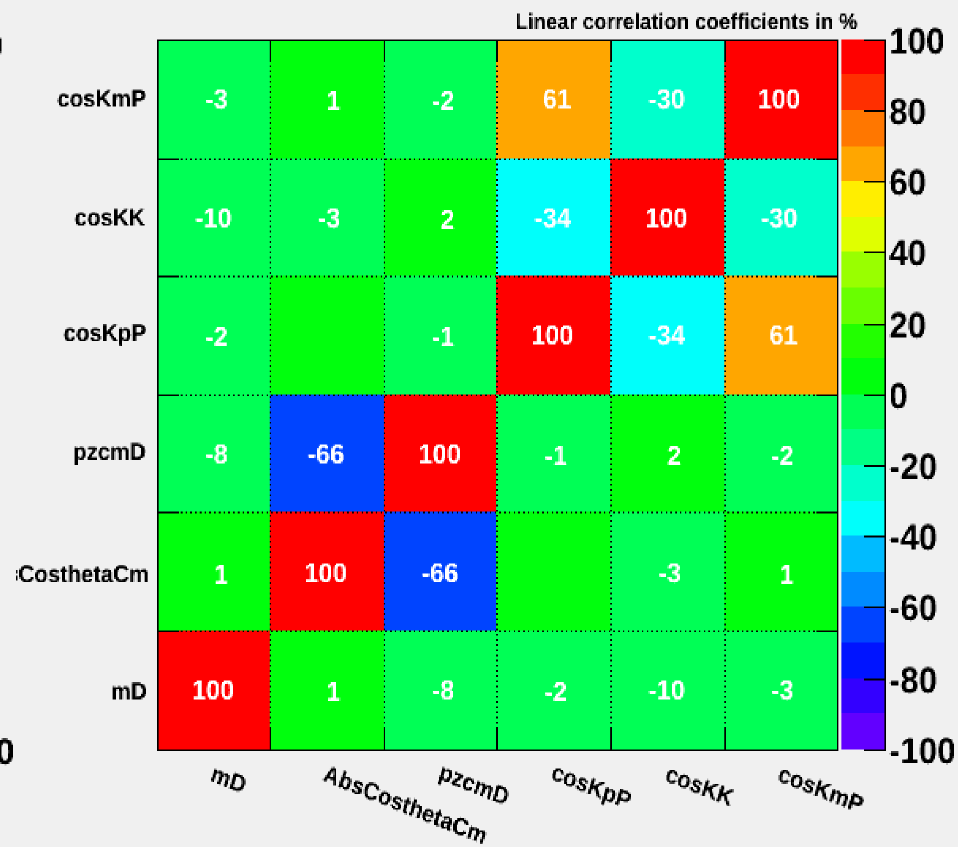
- Histograms are normalized
- Non correlated variables

Fisher discriminant: correlation

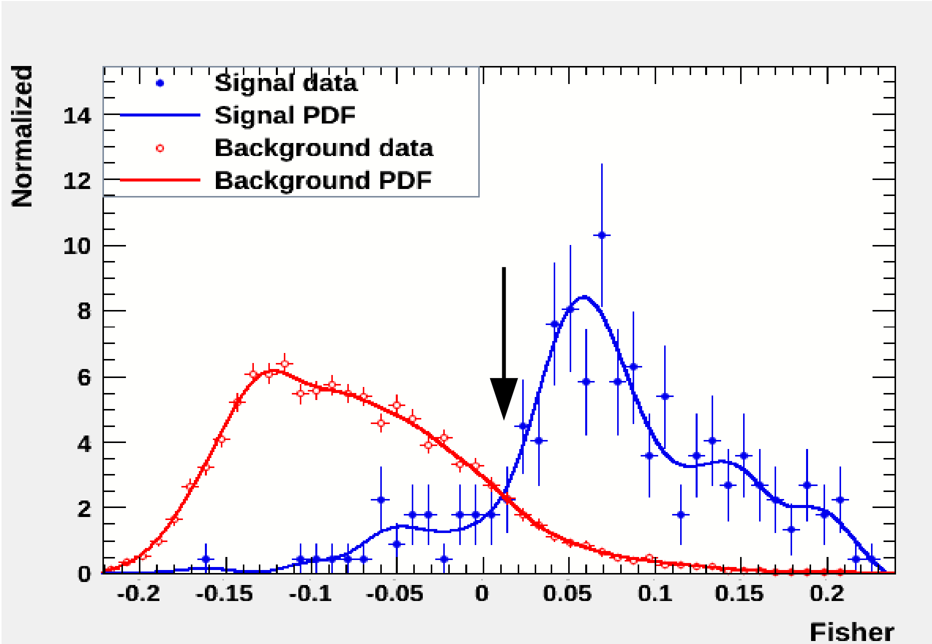
Correlation Matrix (signal)



Correlation Matrix (background)

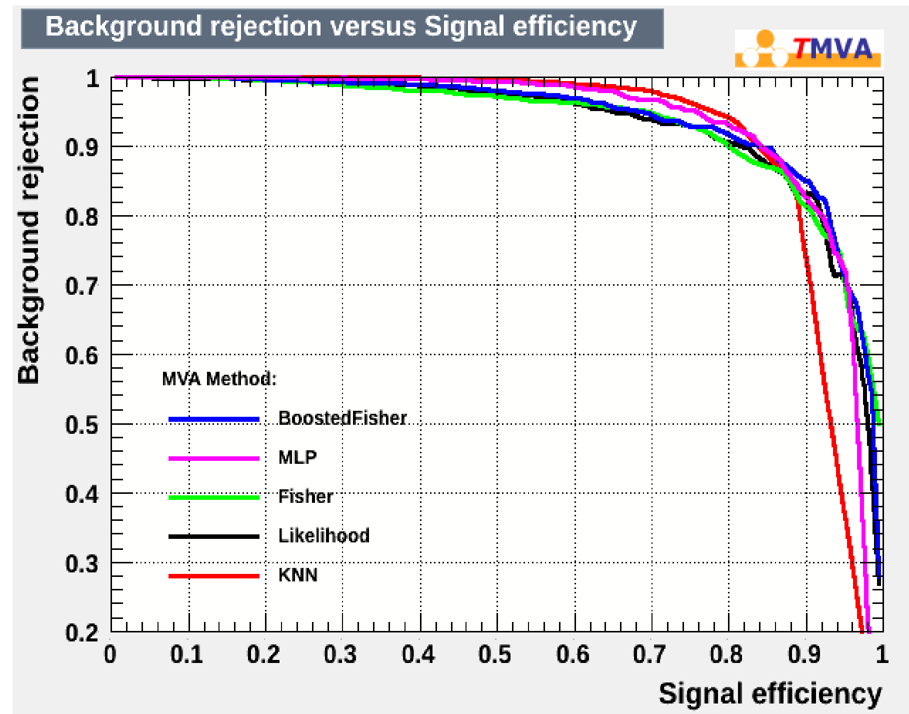


Fisher discriminant: output distribution



Starting point:

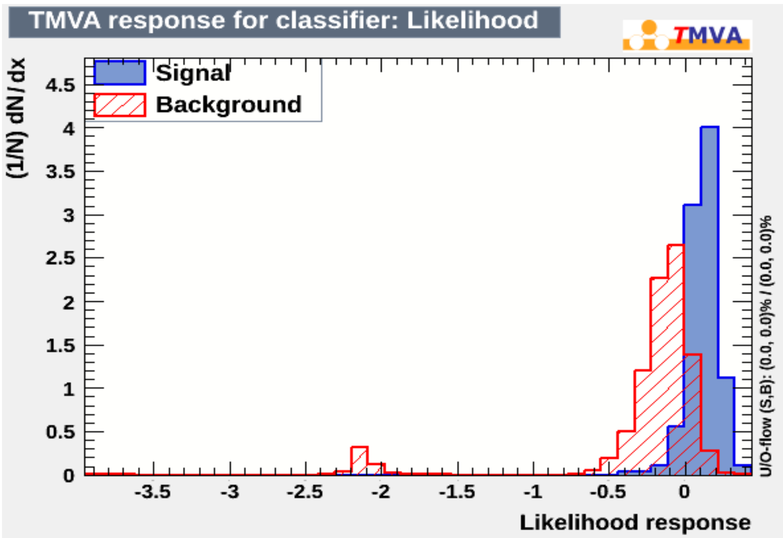
- Fisher discriminant = linear combination of variables
- Easy to implement in the analysis procedure!

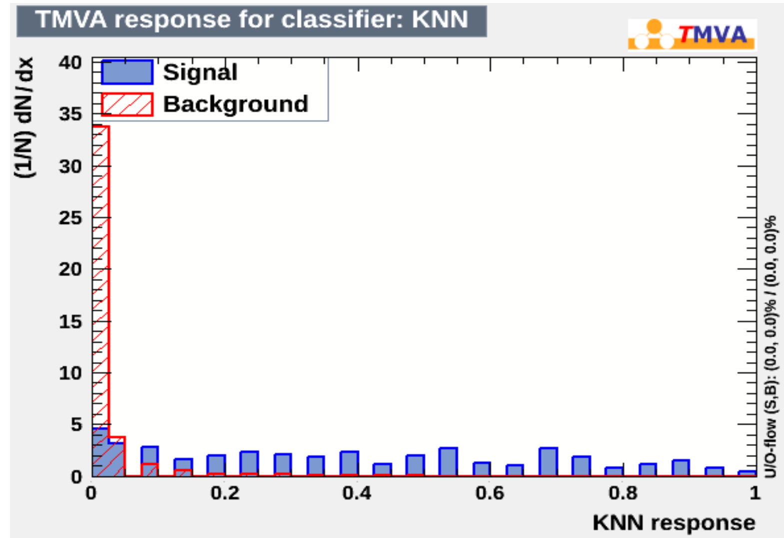


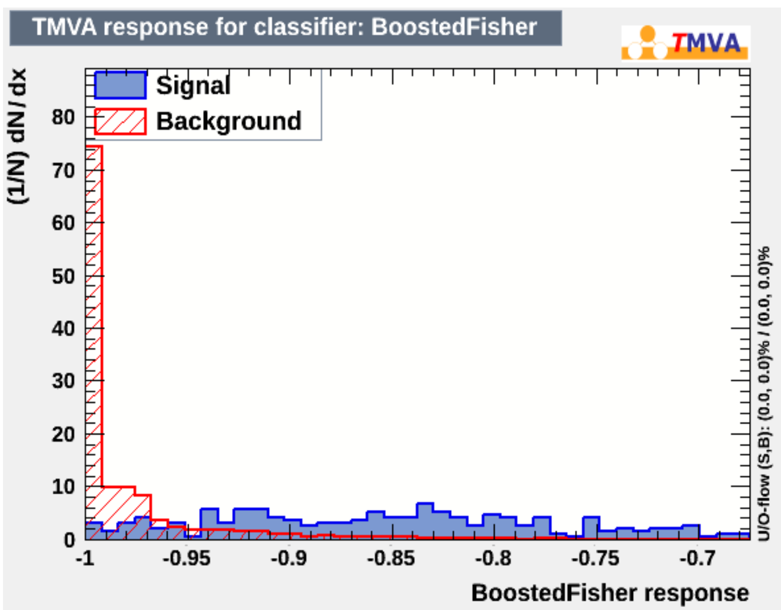
- Several methods under investigation
- Neural network (MLP): higher (but similar) rejection power compared to the Fisher discriminant

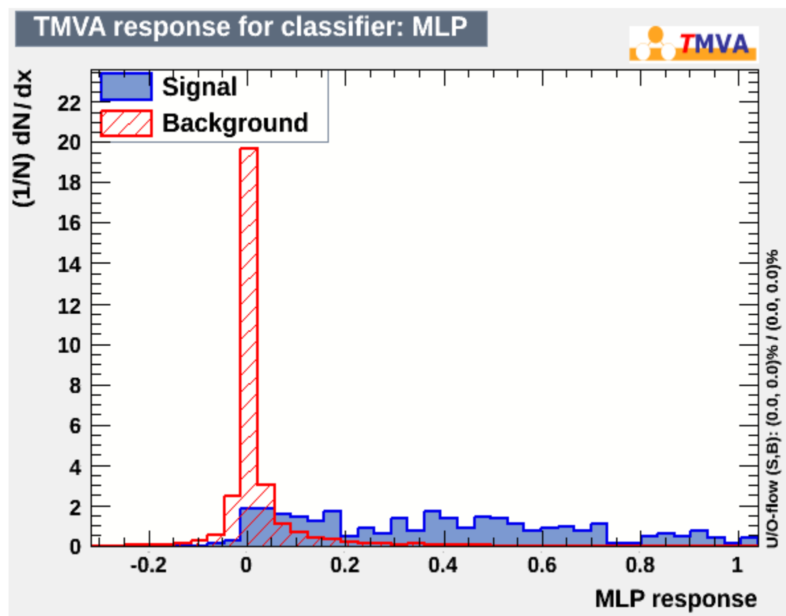
Work in progress...

Several attempts of bkg discriminants

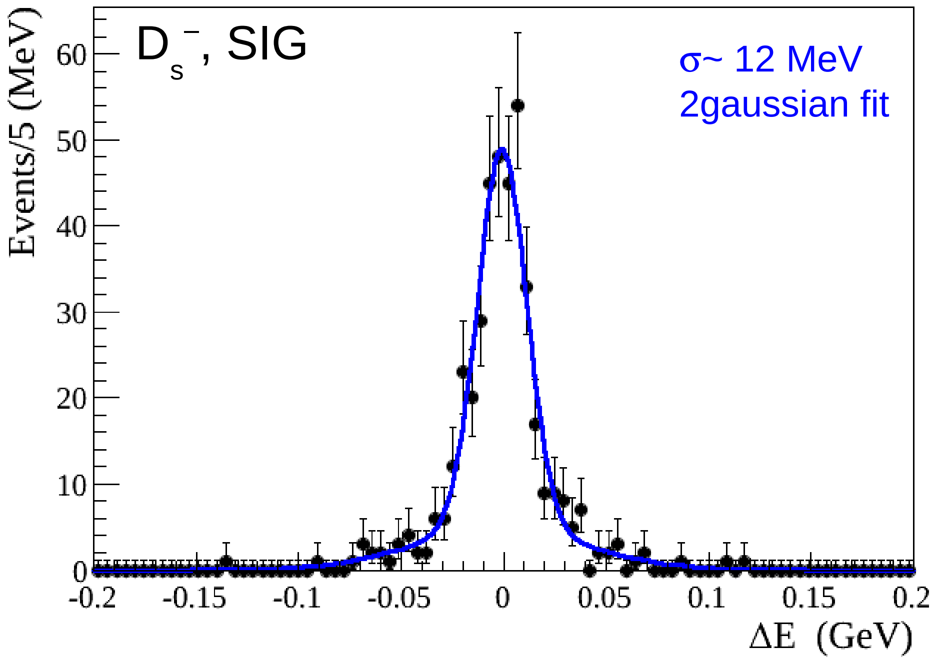


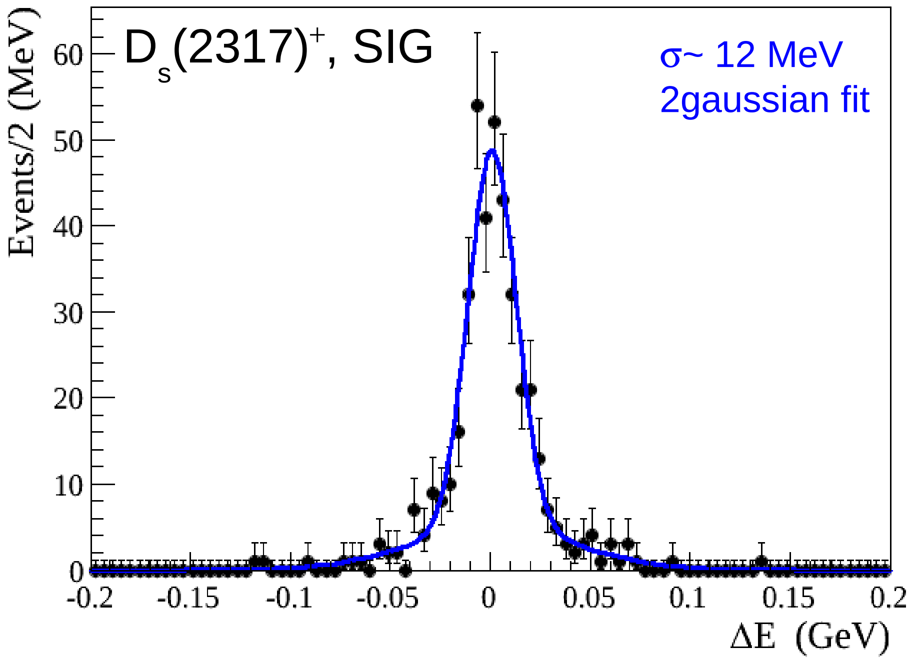


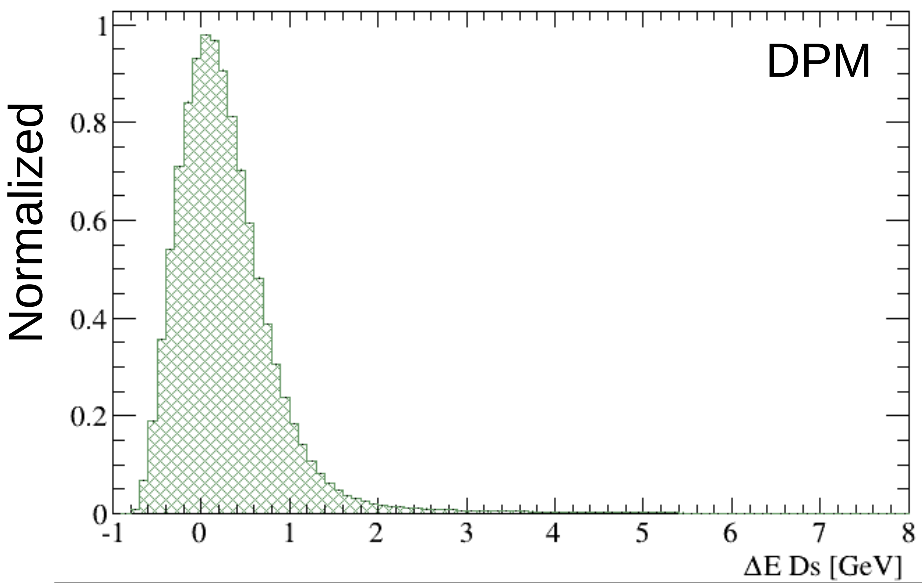




ΔE distributions

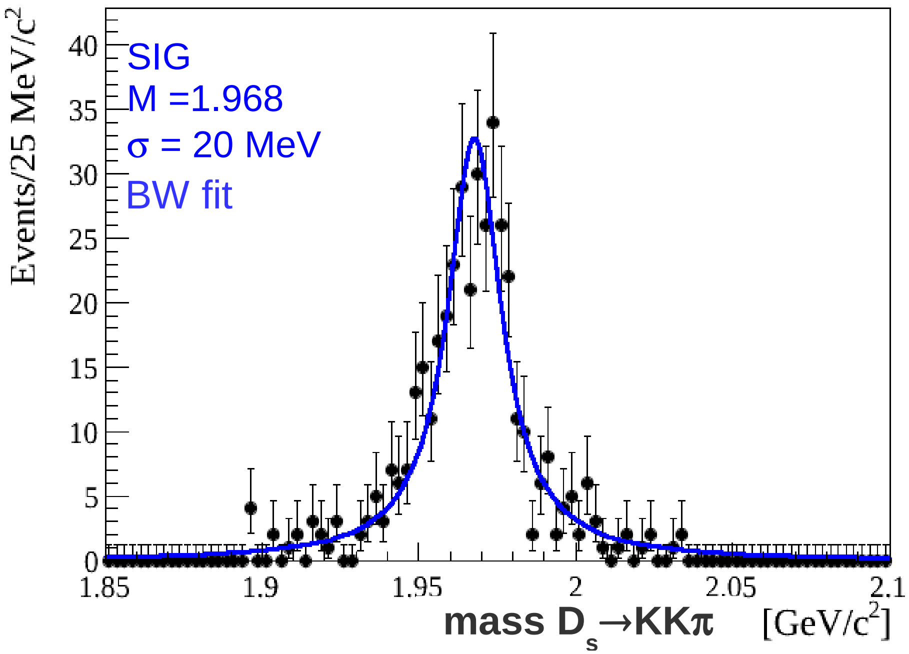


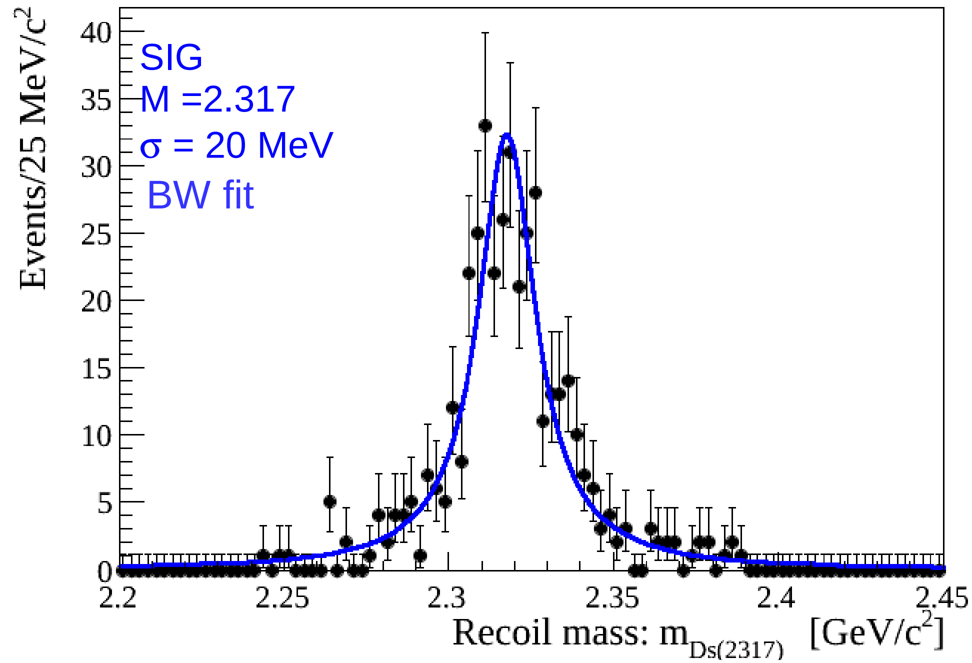


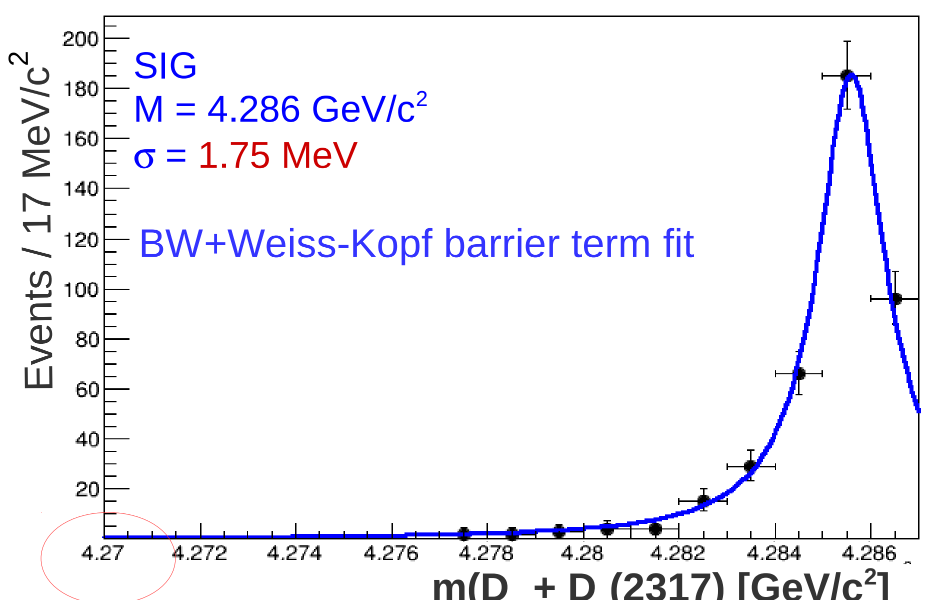


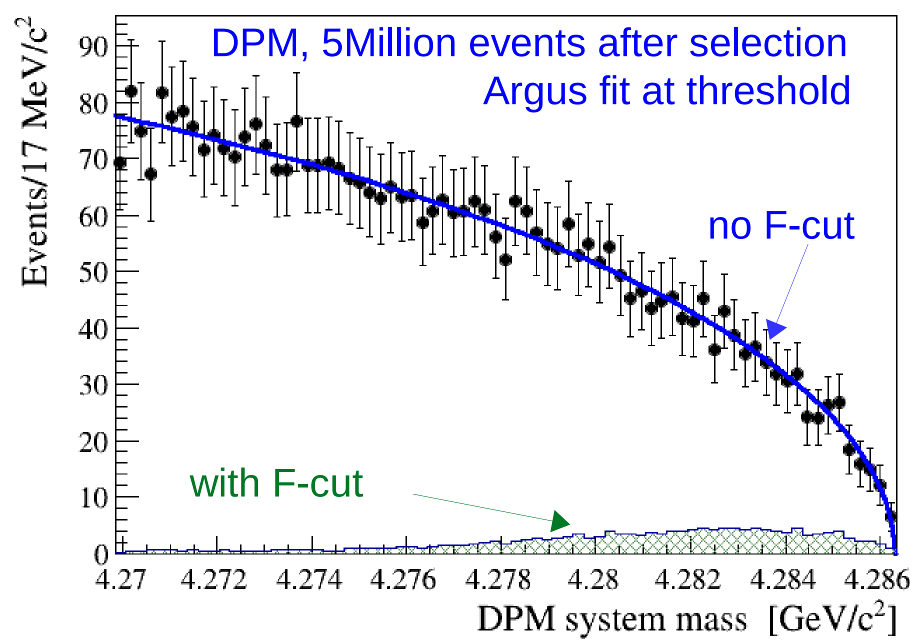
$$\Delta E = E^* - E_{beam}$$

Invariant mass fit



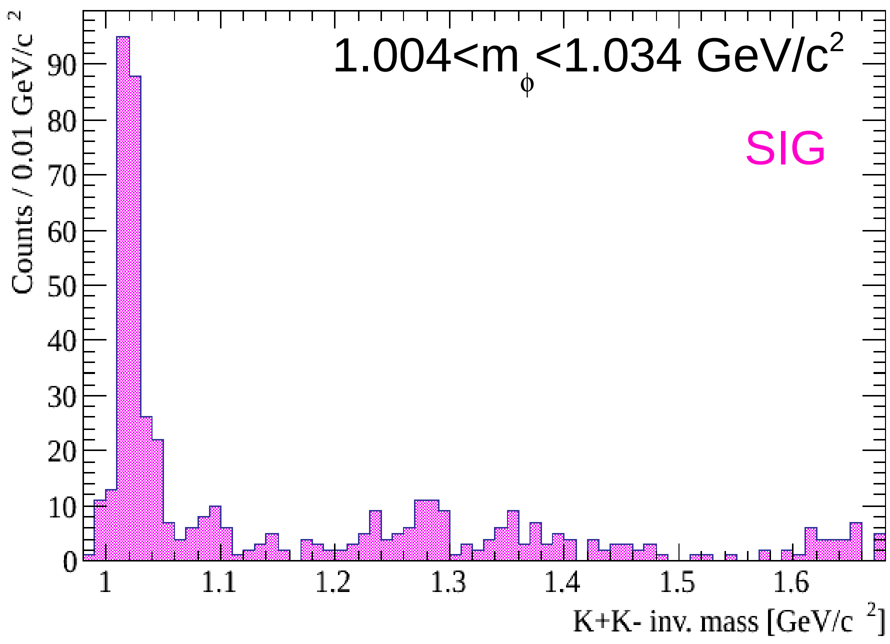


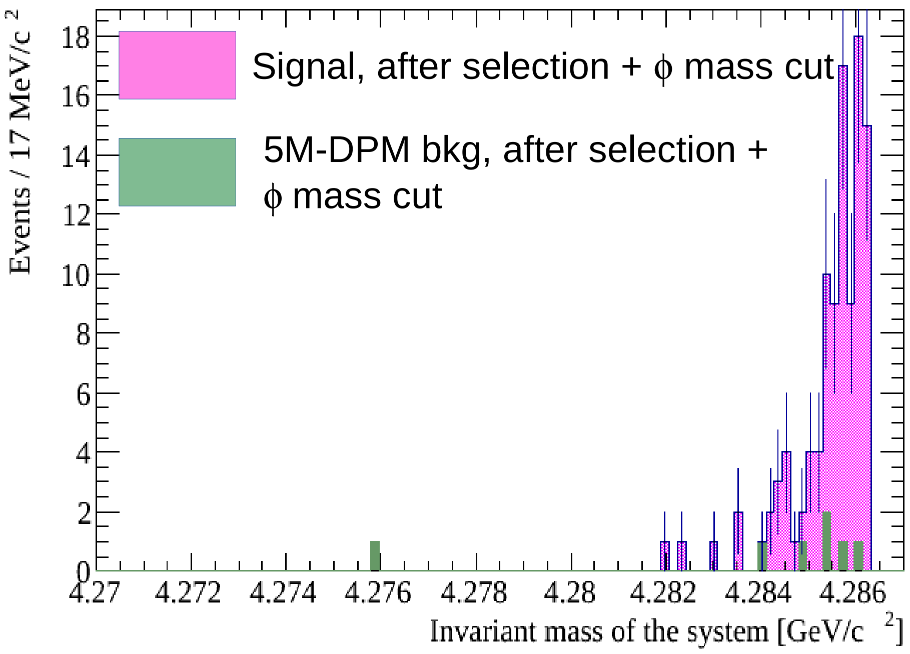




Preliminary results after selection

- Channel: $\bar{p}p \rightarrow D_s^- D_{s0}^*(2317)^+$, beam momentum = 8.80235 GeV/c
  $D_s \rightarrow K^+K^-\pi^-$
  $D_{s0}^*(2317)^+$: inclusively reconstructed as missing mass of the event





- Signal sample: 3000 events. After selection (all K^+K^- range in D_s decay): ε ~14%
  After selection (ϕ signal area): ε ~4%

Bkg comparison at different beam momentum

- $\bar{p}p \rightarrow D_s^- D_{s0}^*(2317)^+$
- Extrapolation at threshold: p =8.80235 GeV/c, M = 4.28629 GeV/c^2;
  5 million events reduced to 5 events in the signal area after a preliminary selection; inclusive approach.

- Assuming at threshold:
  σ(signal) = 2 nb; σ(bkg): 2 mb ⇨ S/B = 1/28 in the signal area.
  σ(signal) = 20 nb; σ(bkg): 2 mb ⇨ S/B ~ 1/3 in the signal area

$\bar{P}$ beam (GeV/c)	DPM, selected events (ϕ area)
8.77913 (below)	4
8.80235 (threshold)	5
8.80855 (above)	4

Sample: 5 Million events

No differences observed at different p_{beam}

Need more statistics: work in progress...

Expectations with $\overline{\text{P}}$ANDA

- General remarks:
  ① single-tag mode (D_s^- is tagged to $K^+K^-\pi^-$);
  ②(semi-)inclusive approach;
  ③ unknown cross section, but σ expected in **[10-100] nb**;
- ④ $\mathcal{L}$= **0.864** pb^{-1}/day, $N = \mathcal{L} \cdot \sigma \cdot \varepsilon \in$ [65-646] D_s events/day!
  scaled by $BR(D_s \to KK\pi)$ = 5.34% and with efficiency ε = **14%**

- Bkg suppression good in inclusive analysis if $m(KK) \in [1.004;1.034]$ GeV/c^2

- For comparison, at B factories:
  BABAR: in $e^+e^- \to c\bar{c}X$, $\mathcal{L}$=91 fb^{-1}, **1267** $D_s(2317)$ selected;
  BELLE II (future): expected on $\mathcal{L}$=10 ab^{-1} **87 000** $D_s(2317)$ in 2020.

Belle II will <u>never</u> scan the inv. mass system in 100-keV-steps
$\overline{\text{P}}$ANDA: <u>unique experiment</u> that can reveal the molecular nature of $D_{s0}^*(2317)^+$

- Possible problems, still to be solved:

 - Coulomb scattering
 - Interference effects
 - Formula for the excitation cross section

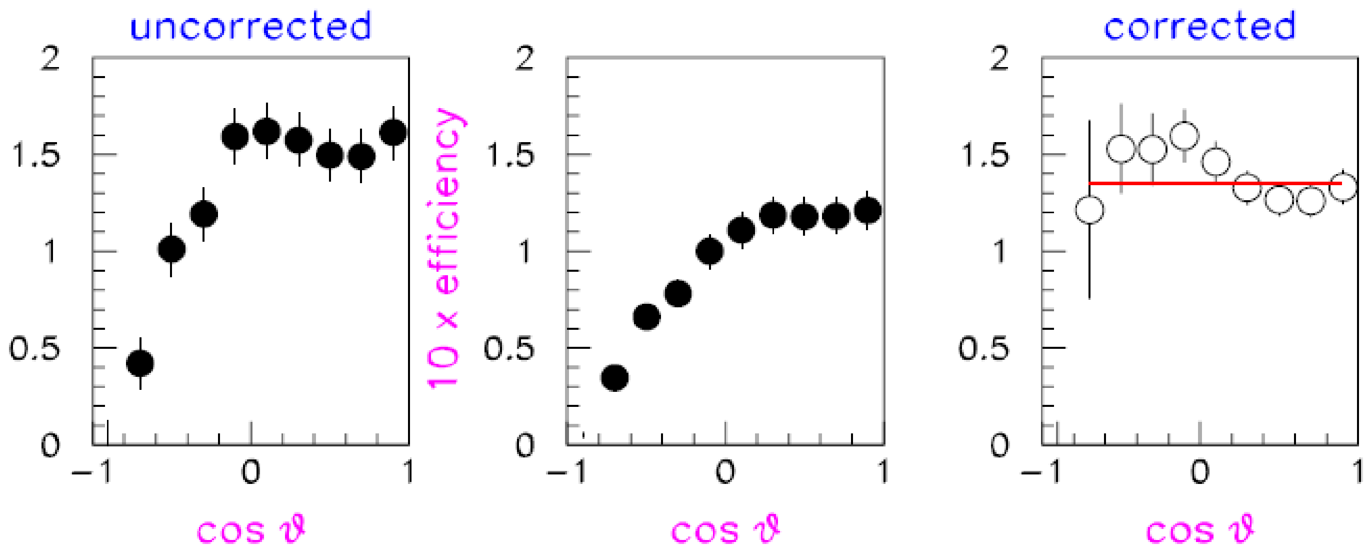
Summary

- Full simulation with signal/background: started
- Fisher (NN) discriminant under study
- High background level, especially for inclusive analysis
- Need to run higher statistics to parametrize the background distribution
- Plan for the future: publication!

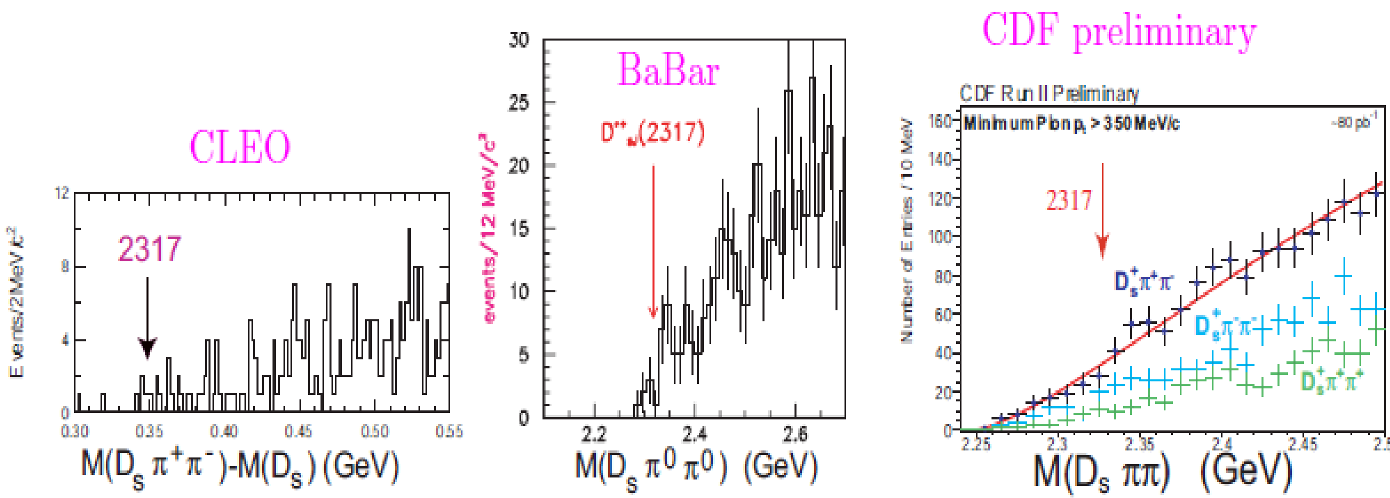
Backup slides

$D_{s0}^{*}(2317)^{+}$ Spin parity

- $D_{sJ}^{*}(2317) \to D_s \pi^0$. If parity conserved, then natural J^P (hence *)



- $D_{sJ}^{*}(2317) \to D_s \pi^0$ helicity angle distribution consistent with uniform, or isotropic polarization
  ⇩
  $J = 0^+$



- $D_{sJ}(2317)$ not seen in $D_s\pi^+\pi^-$, nor in $D_s\pi^0\pi^0 \Rightarrow$ these decay modes are forbidden for 0^+

CLEO, PRD 68 (2003) 032002
BELLE, PRL 92 (2004) 012002
BABAR, PRD 74 (2006) 032007

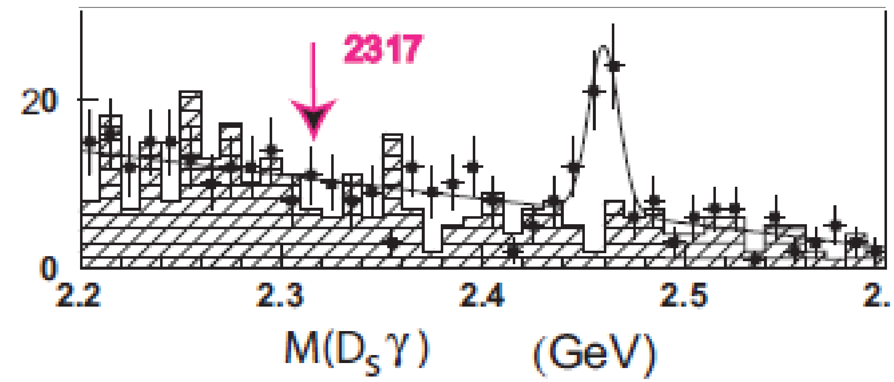
$D_{s0}^*(2317)^+$ Spin parity

- If $D_{sJ}(2317)$ has spin 0, the decay to $D_s\gamma$ is forbidden

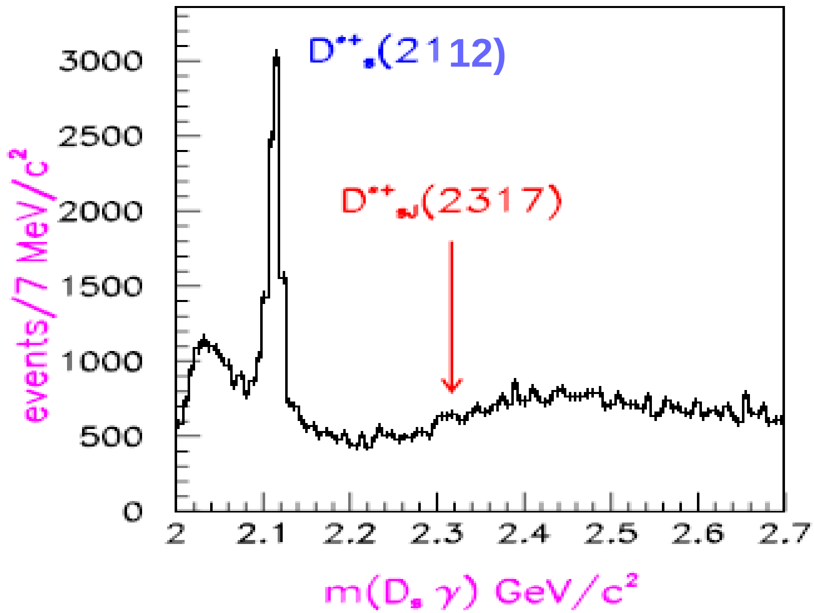
Not Found!

BELLE, PRL 92 (2004) 012002

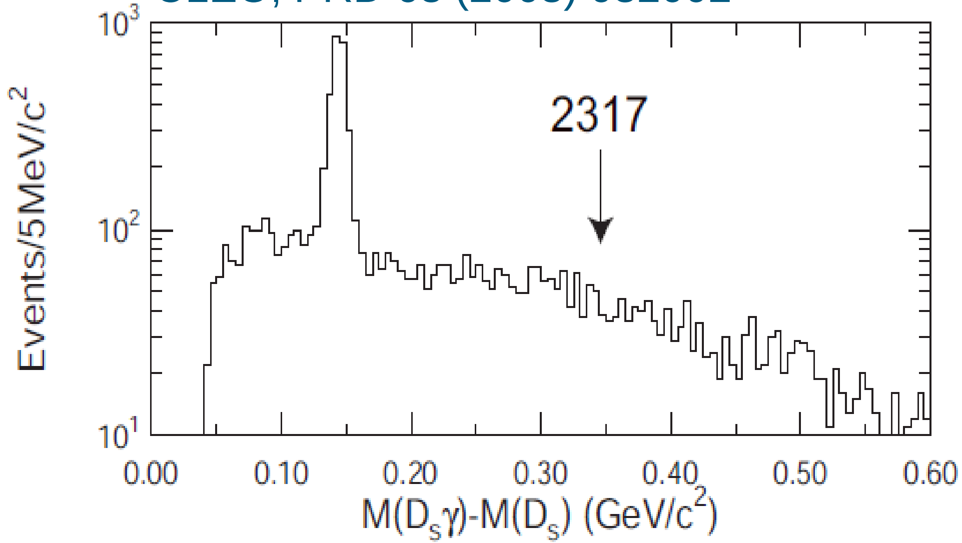
$B \to DD_s\gamma$



BABAR, PRD 74 (2006) 032007



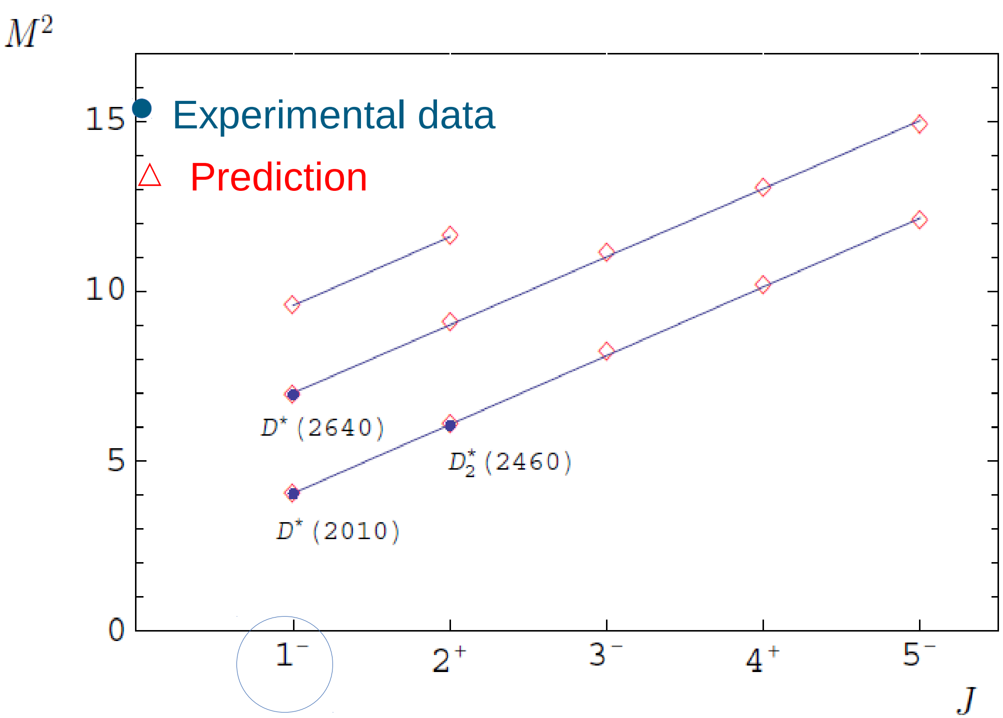
CLEO, PRD 68 (2003) 032002

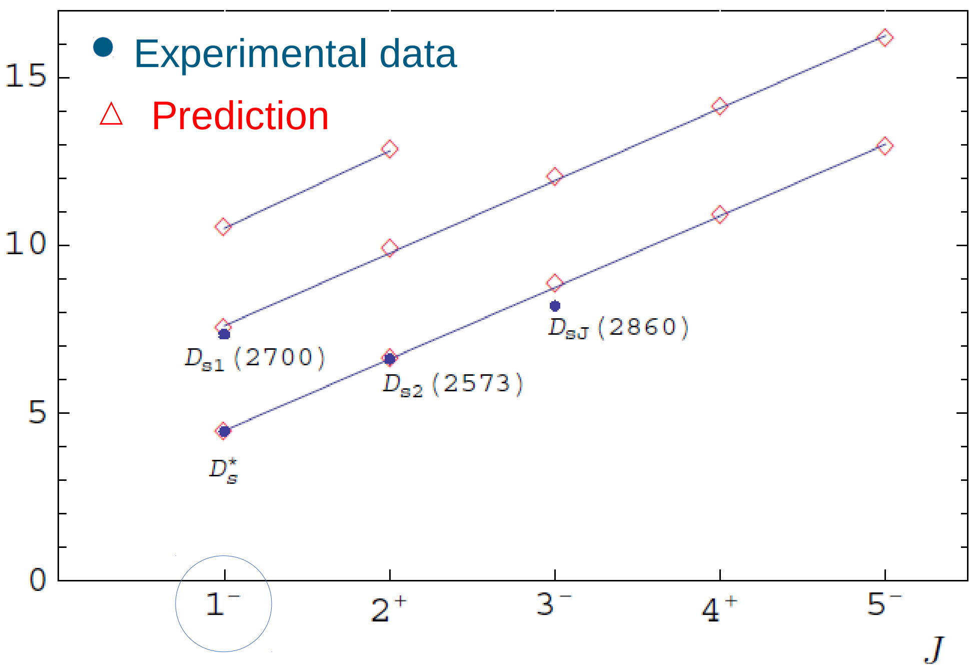


Cross section

- In the theoretical calculation for the cross section of $\bar{p}p \to \bar{D}D$ states, vector states could be involved in the loop, but technical problems occur.
- There are divergences difficult to cure.
- *Regge trajectories* are introduced for this purpose (α).

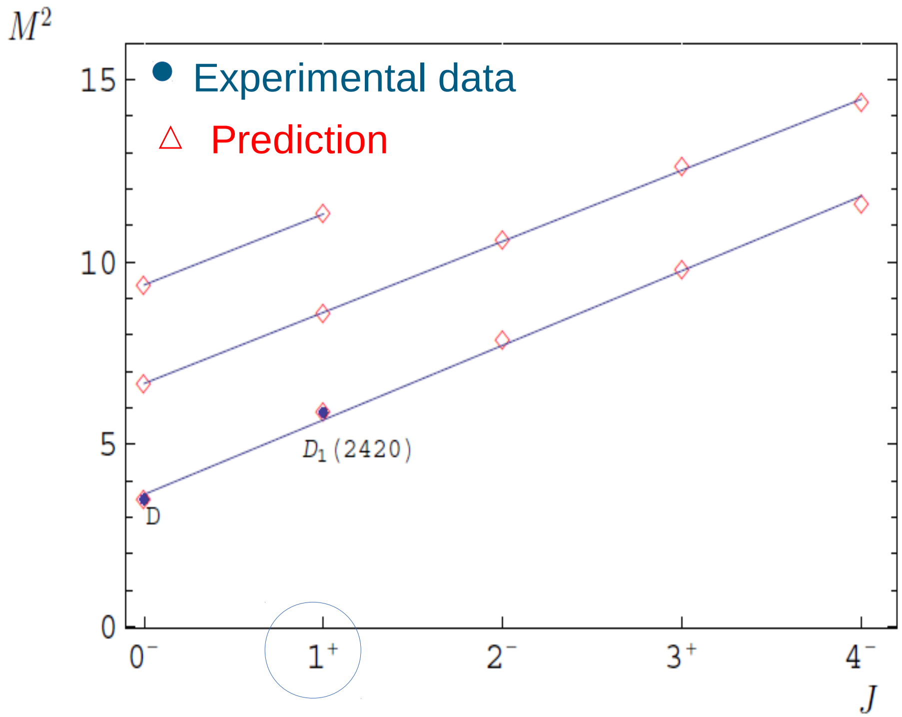
D. Ebert, R. N. Faustov, V. O. Galkin
Eur.Phys.J.C66:197-206,2010

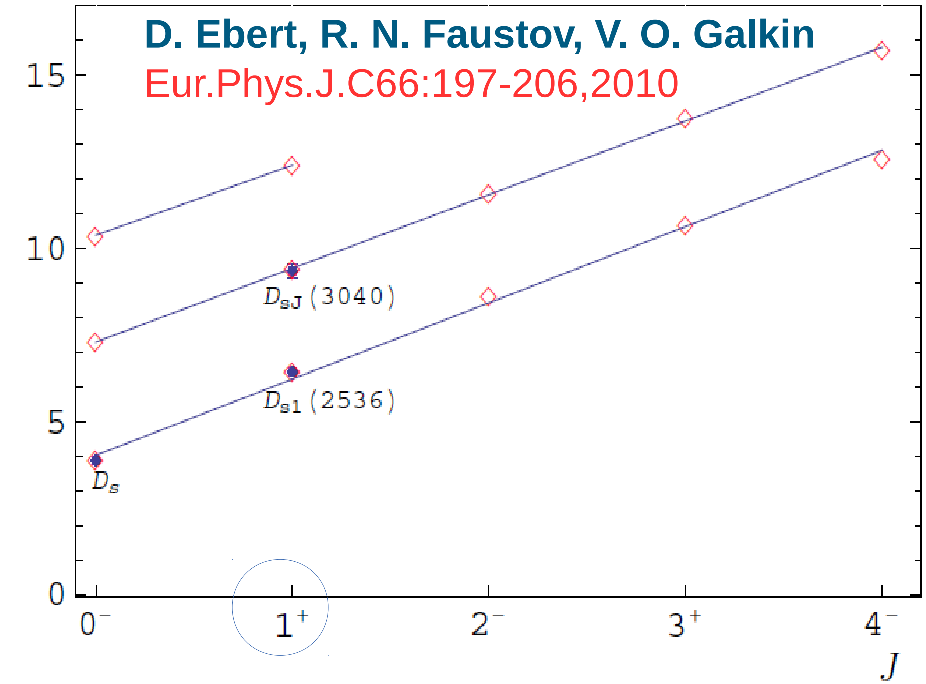




- Regge trajectories for D(s) mesons with natural parity
- Both light (q=u,d,s) and heavy (Q=c,b) quarks are treated fully relativistically without application of the heavy quark $1/m_Q$ expansion.

Cross section





- Regge trajectories for D(s) mesons with unnatural parity

We calculated the masses of ground, orbitally and radially excited heavy-light mesons up to rather high excitations. This allowed us to construct the Regge trajectories both in (J, M^2) and (n_r, M^2) planes. It was found that they are almost linear, parallel and equidistant. Most of the available experimental data nicely fit to them. Exceptions are the anomalously light $D^*_{s0}(2317)$, $D_{s1}(2460)$ and $D^*_{sJ}(2860)$ mesons, which masses are 100-200 MeV lower than various model predictions. The masses of the charmed-strange $D^*_{s0}(2317)$, $D_{s1}(2460)$ mesons almost coincide or are even lower than the masses of the partner charmed $D^*_0(2400)$ and $D_1(2427)$ mesons. These states thus could have an exotic origin. It will be very important to find the bottom counterparts of these states in order to reveal their nature.