First Year Physics at Belle II

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First question: where to run

Experiment	Scans/Off. Res.	$\Upsilon(5S)$		$\Upsilon(4S)$		$\Upsilon(3S)$		$\Upsilon(2S)$		$\Upsilon(1S)$	
		10876 MeV		10580 MeV		10355 MeV		10023 MeV		9460 MeV	
	fb^{-1}	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6
CLEO	17.1	0.4	0.1	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan		433	471	30	122	14	99	–	
Belle	100	121	36	711	772	3	12	25	158	6	102

- Goal is to produce impactful publications as soon as possible
- Existing data sets at Υ(4S,5S) are too large
- Below Υ(4S)
  - Υ(3S) offers greatest access to lower bottomonium states
  - Scan for direct production of $\Upsilon(n^3D_1)$ states
- Above Υ(5S)
  - Scans have been done by both BaBar and Belle
  - ~6fb^{-1} accumulated by Belle at the Υ(6S)

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Energy	Outcome	Lumi (fb^{-1})	Comments
$\Upsilon(1S)$ On	N/A	60+	-No interest identified for Phase 2 -Low energy
$\Upsilon(2S)$ On	N/A	200	-No interest identified for Phase 2
$\Upsilon(1D)$ Scan	Particle discovery	10-20	-Accessible in B Factories?
$\Upsilon(3S)$ On	Many topics	200+	-Known resonance -High luminosity requirement: Phase 3
$\Upsilon(3S)$ Scan	Precision QED	~10	-Understanding of beam conditions needed
$\Upsilon(2D)$ Scan	Particle discovery	10-20	-Unknown mass
$\Upsilon(4S)$+ Scan	Particle discovery?	10+?	-Energy to be determined
Y(6S) On	Particle discovery?	30+?	-Upper limit of machine energy
Single γ	New physics?	30+	-Special triggers required

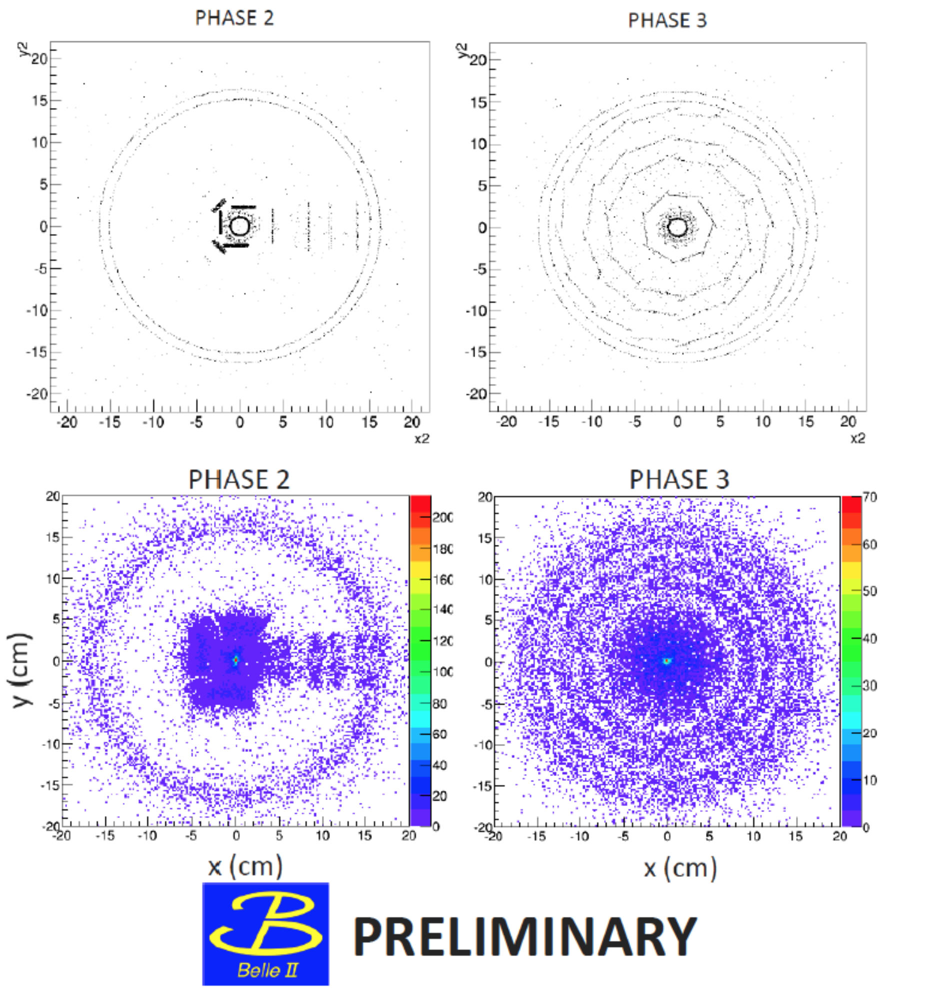
Oggi parlero' di opzioni sopra la Y(4S)

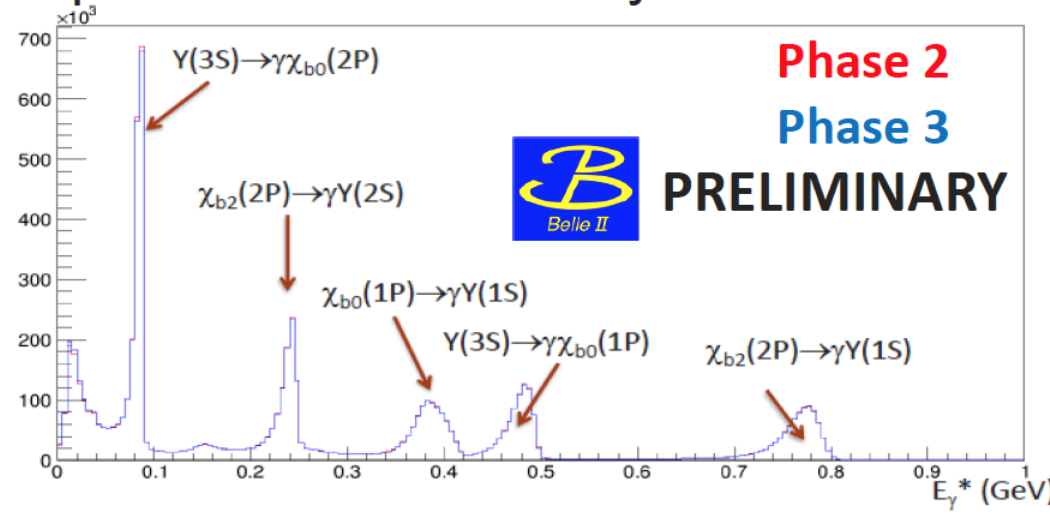
Boundary conditions

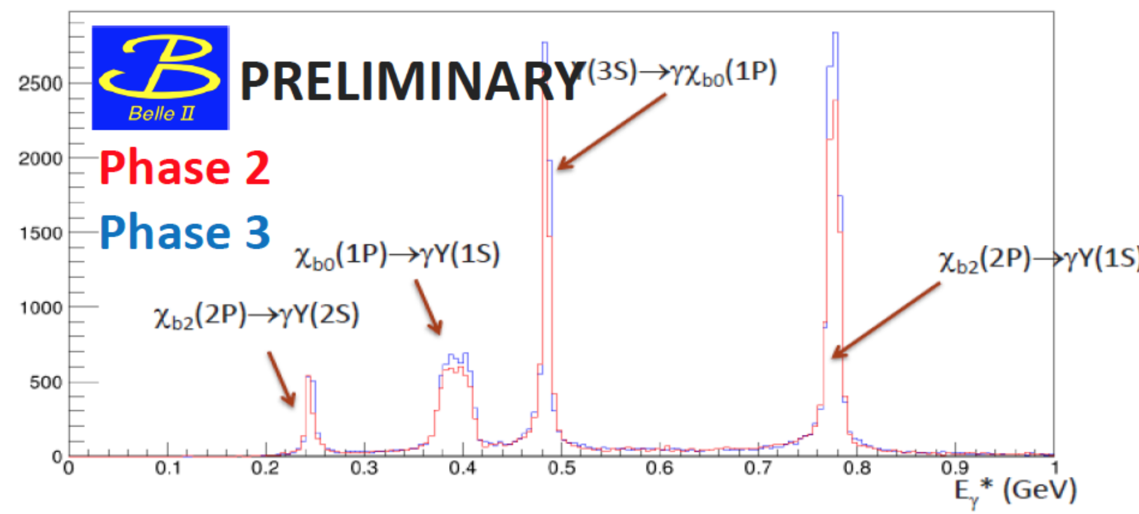
- Goals of Phase 2
  - Machine study for settings to reach high luminosity
  - Understand beam background for safe VXD installation
  - Establish conditions for stable machine operation
  - Reach target luminosity of ~1×10^{34} cm^{-2} s^{-1}
- Phase 2 Operating Conditions
  - ~4-5mos. of machine studies, ~1-2mos. physics
  - Energy spread assumed to be ~5MeV (similar to Belle)
  - Maximum possible energy 11.06 - 11.25 GeV
  - Stable operation close to $\Upsilon(4S)$ strongly preferred
  - Large uncertainty on Phase 2 luminosity (20±20 fb^{-1})
- Phase 3
  - Operate at nominal conditions ($1+\times10^{34}$ cm^{-2} s^{-1})
  - Some combination of $\Upsilon(4S)$ and other energies?

Performance: conversions

- Conversion photons: sacrifice efficiency for improved resolution
- Consider increased material to compensate for luminosity

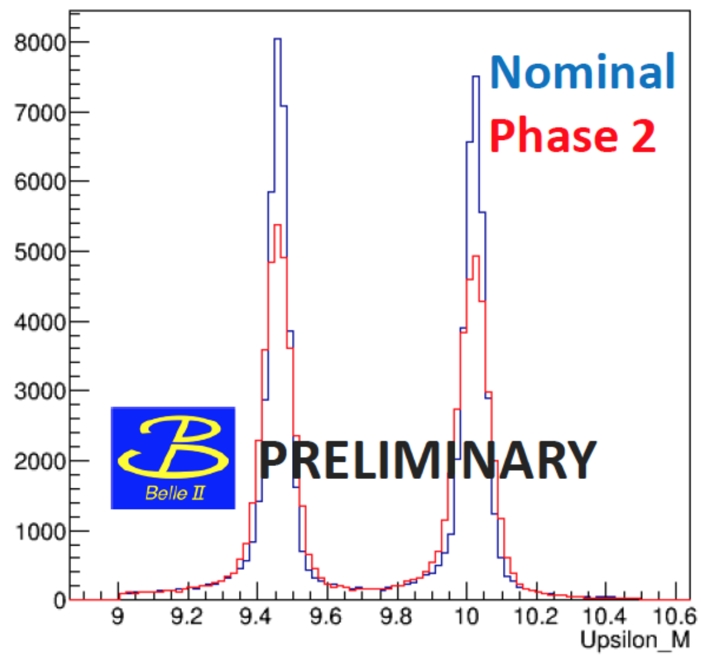




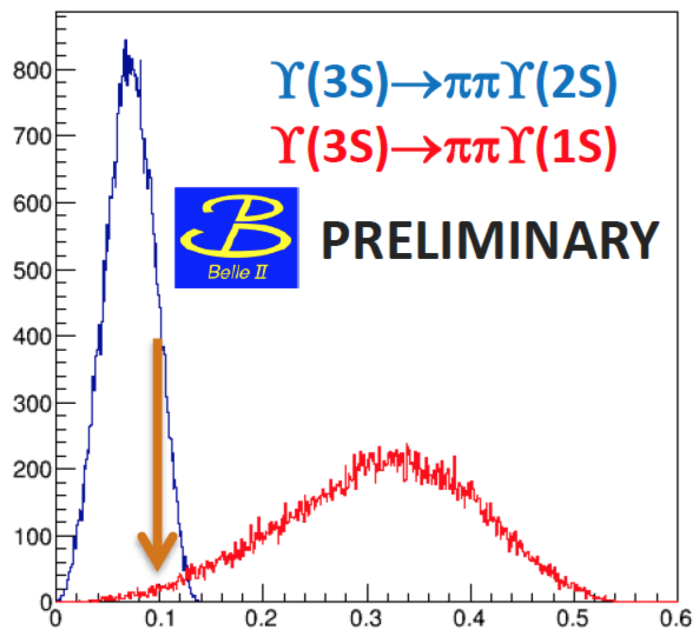


Performance: tracking

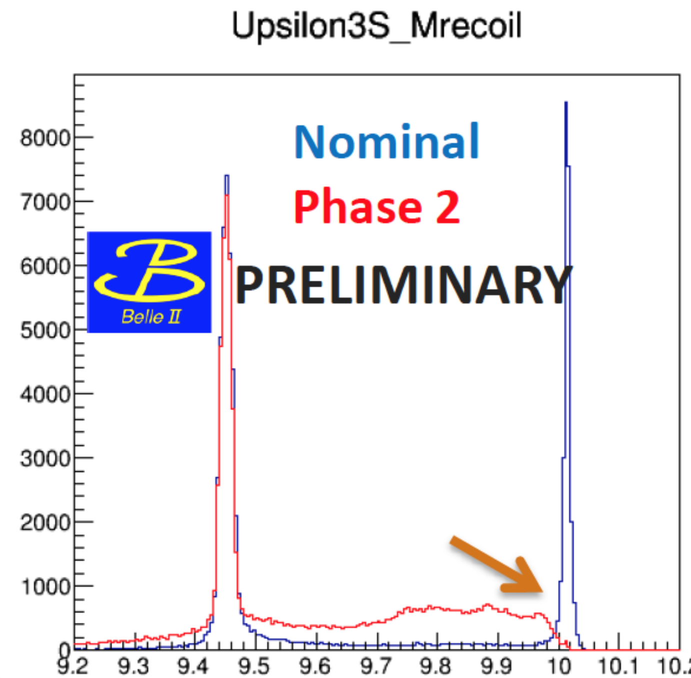
- $\Upsilon(3S)\to\pi^+\pi^-\Upsilon(1S/2S)\to\mu^+\mu^-$ MC (50/50 split)
- Impact of lack of VXD: $\Upsilon(3S)\to\pi^+\pi^-\Upsilon(2S)$ not feasible
- $\Upsilon(nS)\to\mu\mu$ mass resolution affected as well



m(Υ(1S,2S) → μμ)



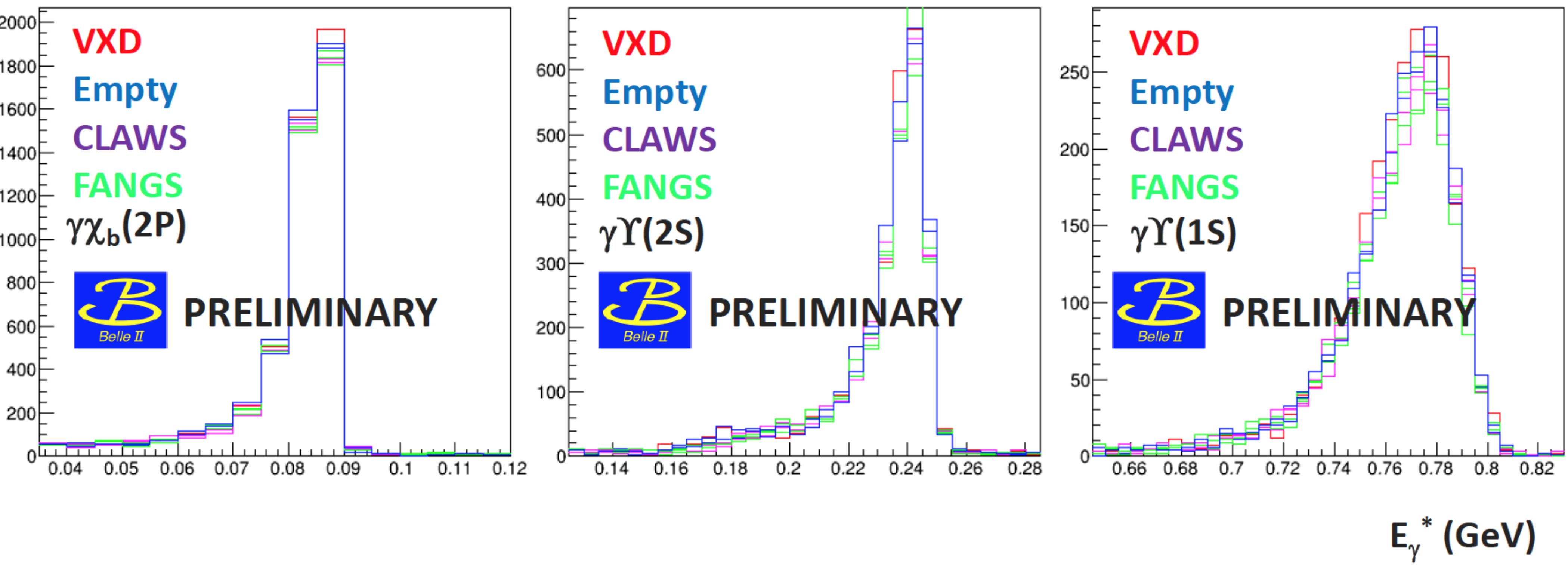
Υ(3S) → ππ Υ(pS)(μμ)
Minimum pion momentum



M(ππ) recoil mass

Performance: photons

- Phase 2 material effects do not appear to be significant for ECL
- Photon energy for $\Upsilon(3S) \to \gamma\chi_{b2}(2P) \to \gamma\Upsilon(1S/2S)(\mu^+\mu^-)$ MC



High energy scans

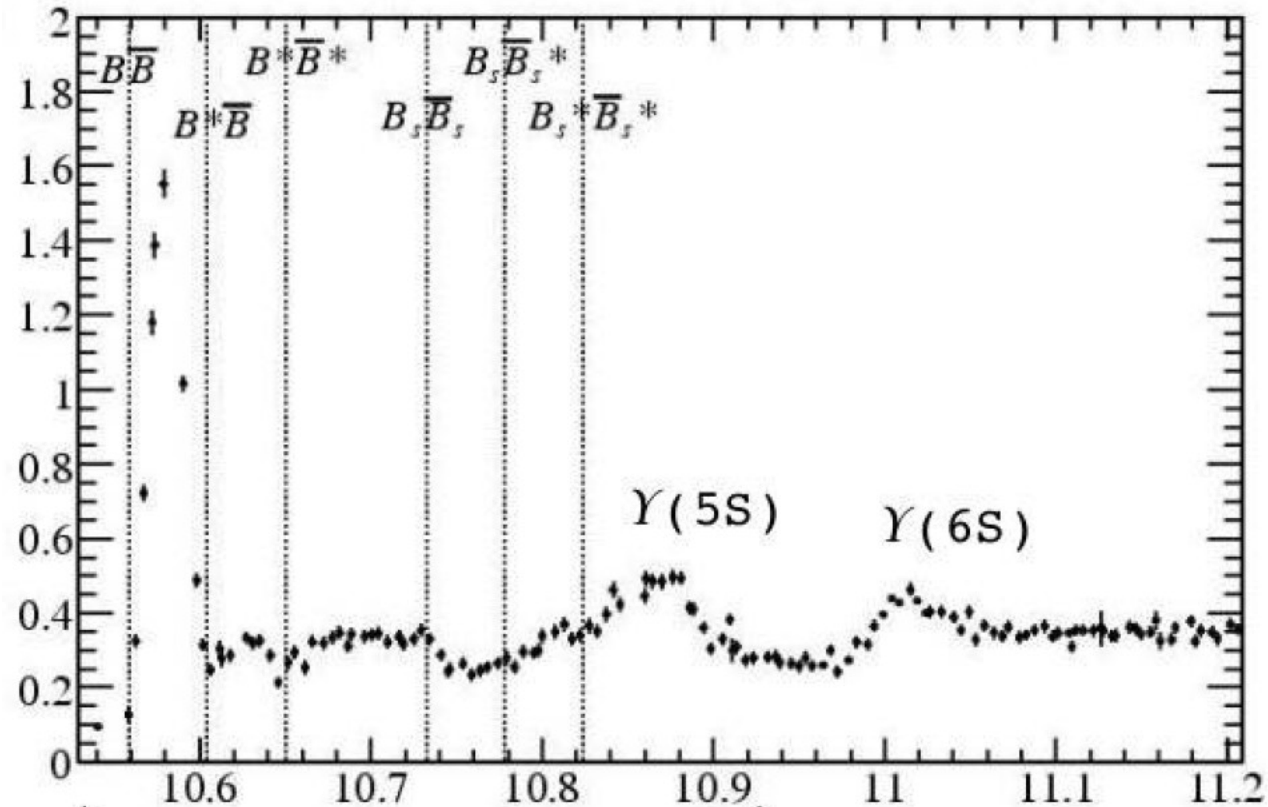
BABAR :
PRL102:012001 (2009)

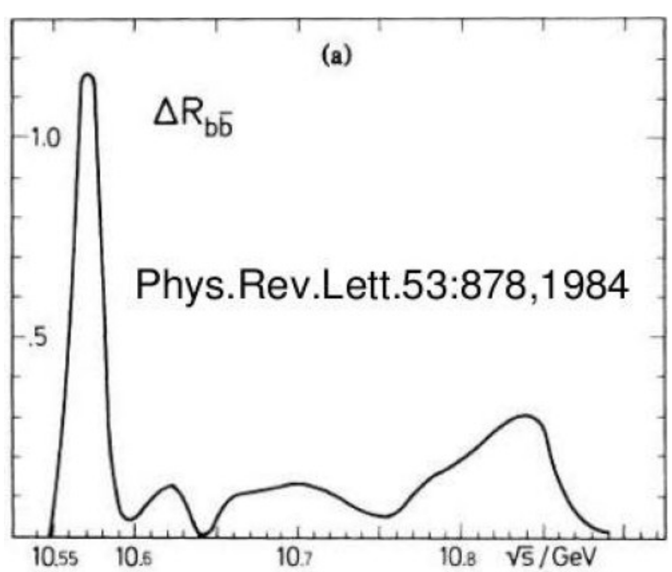
Ldt = 25 pb^{-1} per point,
E=10.54-11.2 ; dE=5 MeV
Total 3.3fb^{-1}

Rb=σ(bb)/σ(μμ)

Impressive match with prediction by Tornqvist
PRL 53:878 (1984)

Tornqvist used Eichten's *coupled channel model*.





CCC Model

E. Eichten
QWG 2008, Nara

- Updated model
  - Physical masses for heavy flavor mesons
  - Measured masses for quarkonium states
- Added features
  - Include relativistic corrections - Tensor interaction
  - Include EM current couplings to $^3D_1$ states
- Some tuning
  - Fit the leptonic width of 1S (cc, bb) and 1D (cc) states
  - Allow some adjustment of resonance masses above threshold.

Eichten 2008: rethinking at CCCM

The bottom threshold region is simple compared to the charm region:

Can ignore D states

- Direct coupling of EM current to n^3D_1 states is small.
- Negligible mixing between $^3S_1$ and $^3D_1$ states.

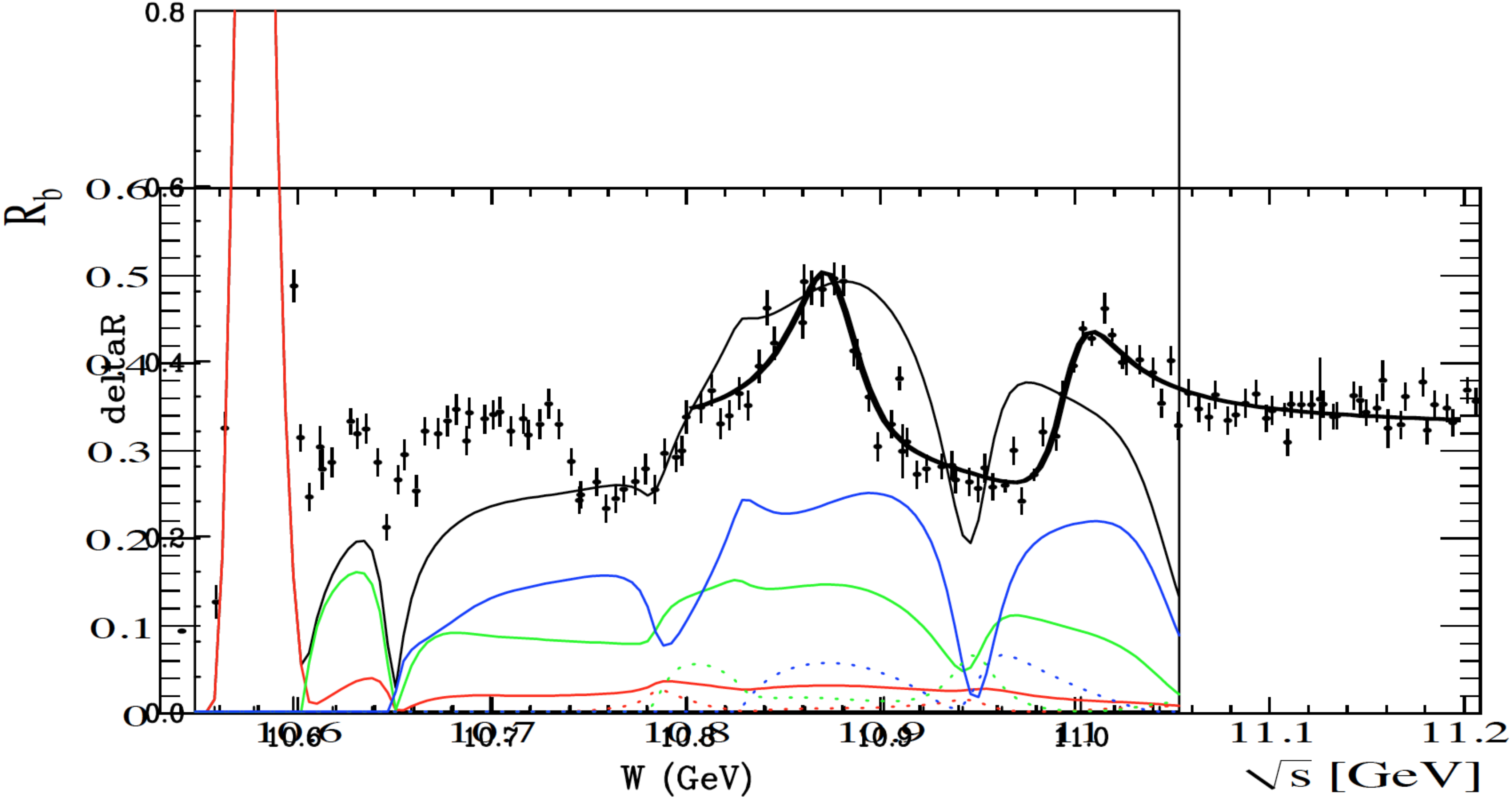
Only the ground state B mesons are needed (B, B^*, B_s, B_s^*)

Analysis includes the lowest seven $^3S_1$ (bb) states and nine final heavy-light pair states.

Mass differences between B_u and B_d states can be ignored.

$$m(B^0) - m(B^+) = 0.37 \pm 0.24 \text{ MeV}$$

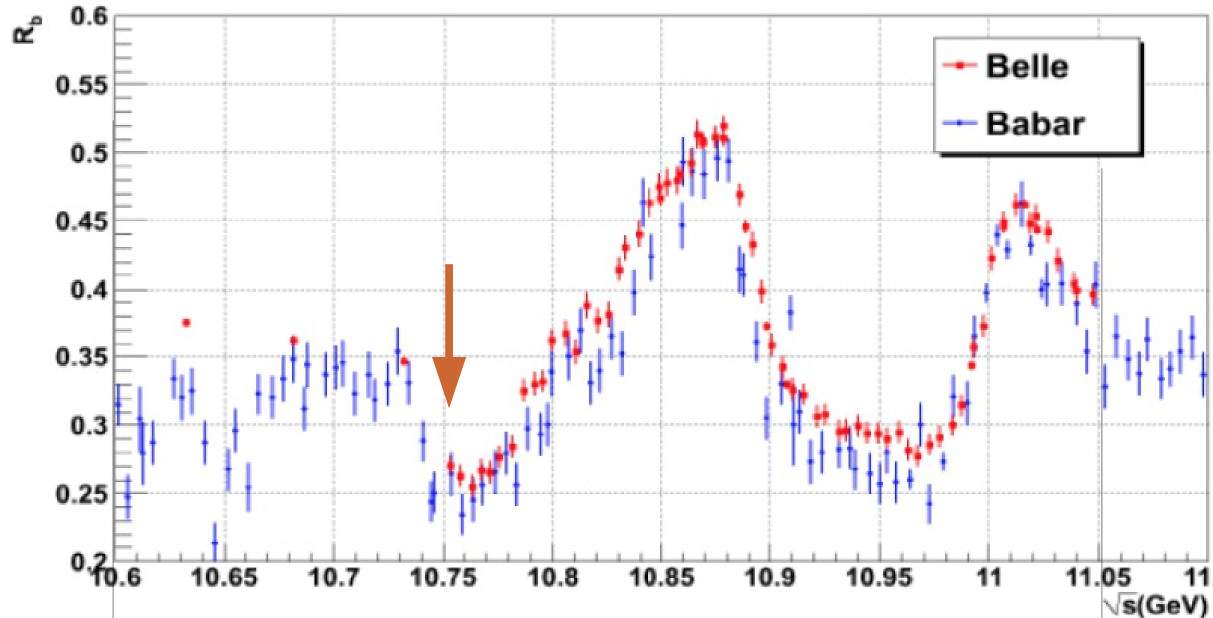
Eichten 2008: rethinking at CCCM

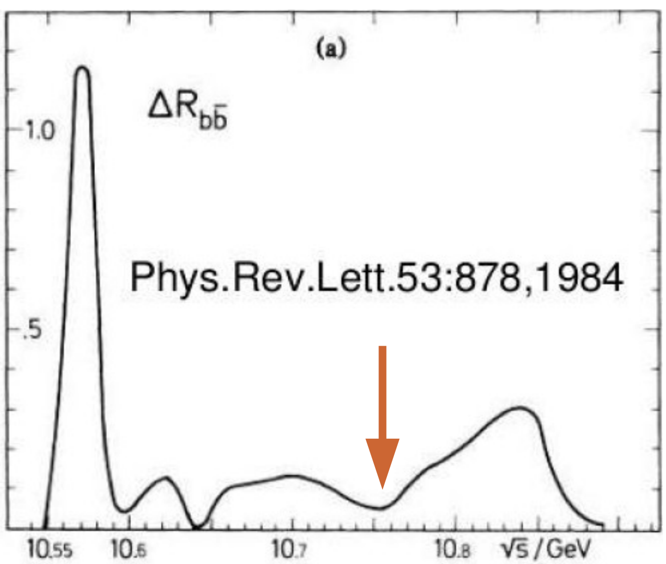


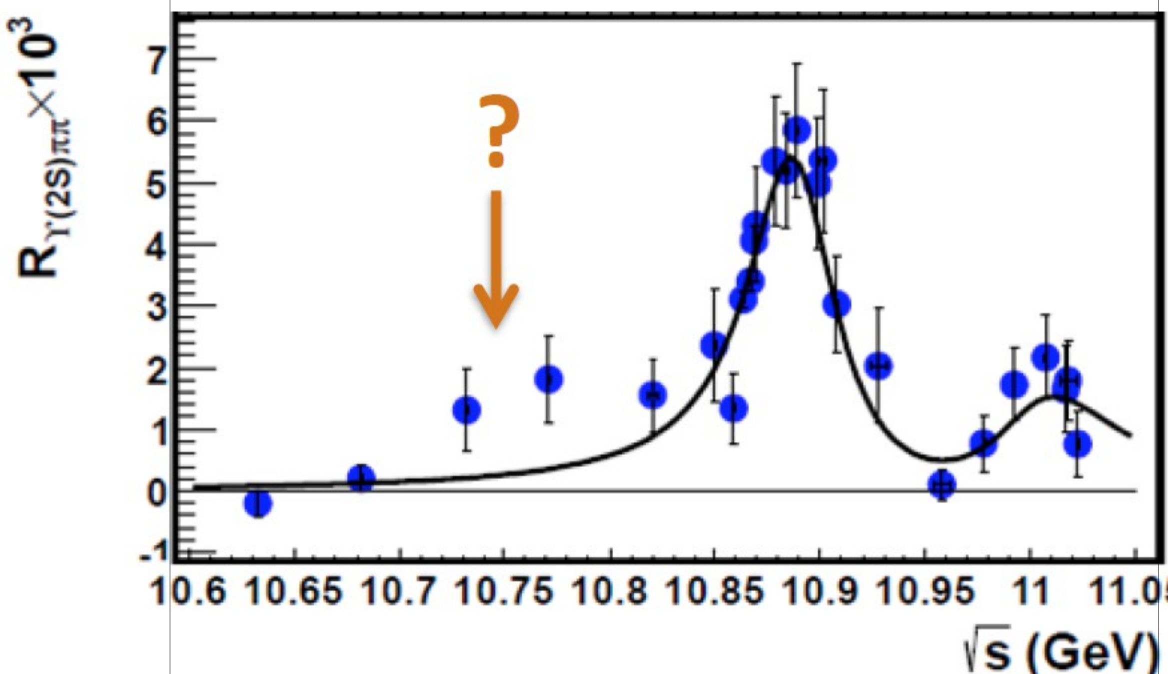
BELLE-I scans

- 61 points, 50/pb, 10.75-11.05 GeV
- 16 points, 1/fb, 10.63-11.02 GeV

Not just Rb analysis: also $\Upsilon\pi\pi$
Exclude Ali's peak at 10.91

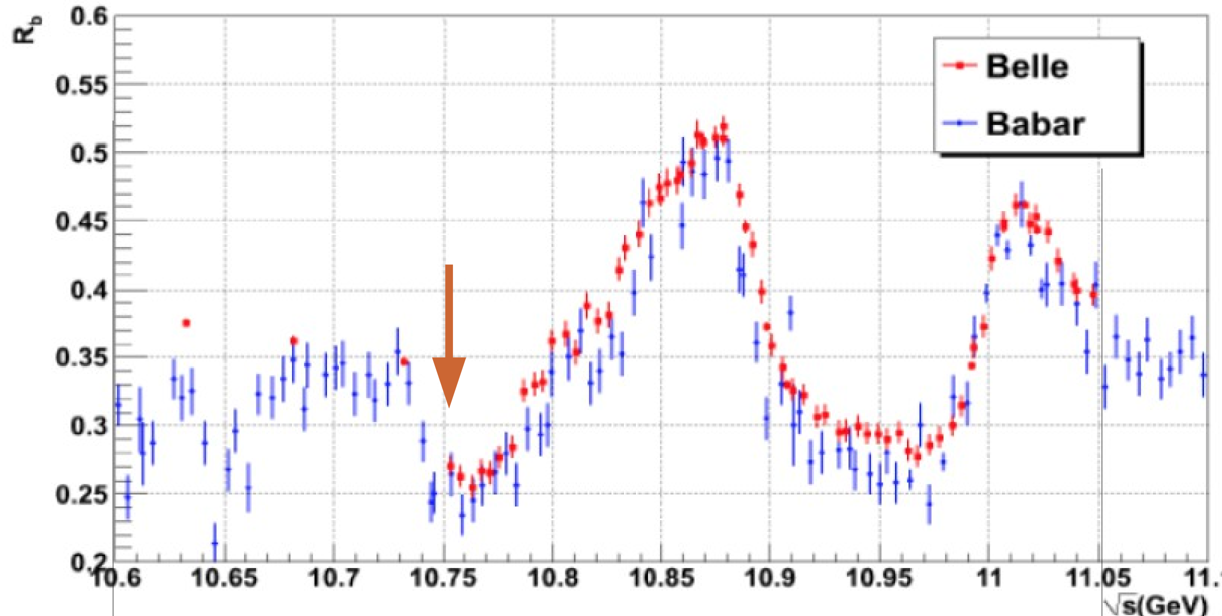


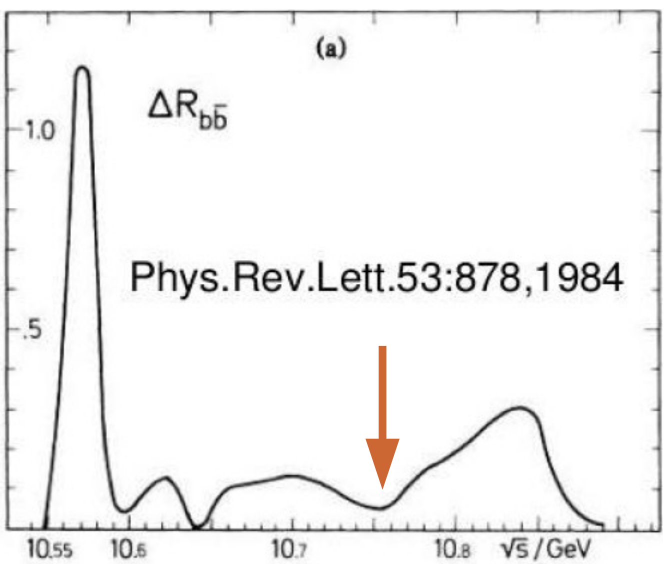


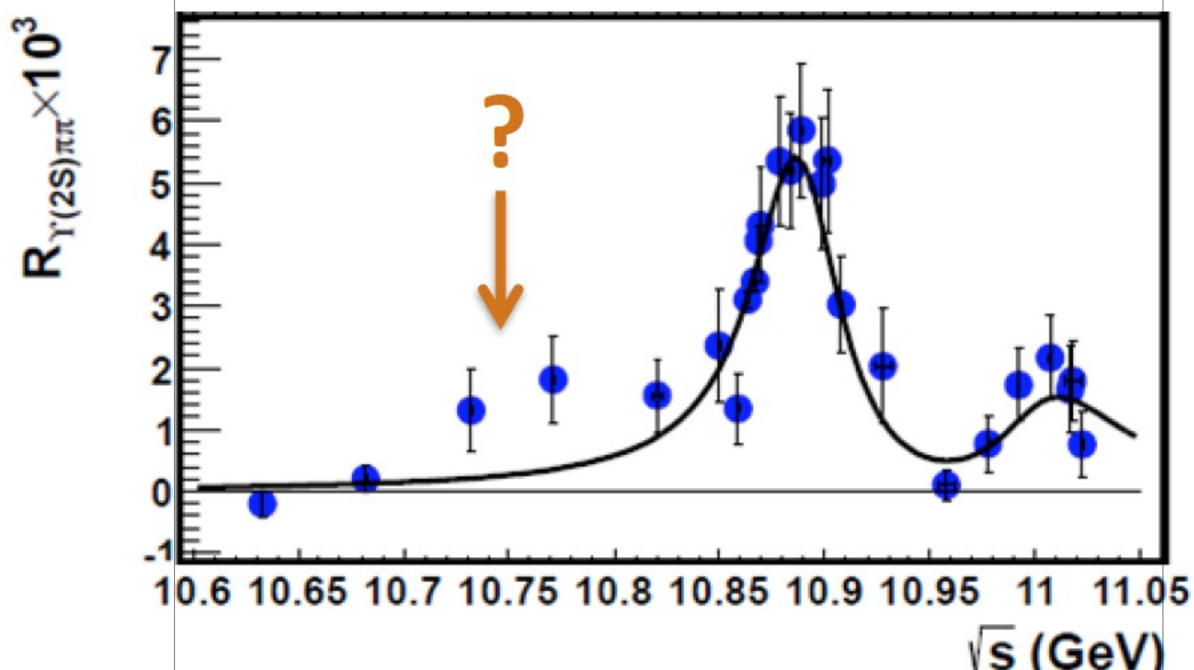


BELLE-II wishes

We may think to take 10 fb^{-1} at 10.75 (where Rb collapses and R_Υ starts rising); *not a scan*, just stay there

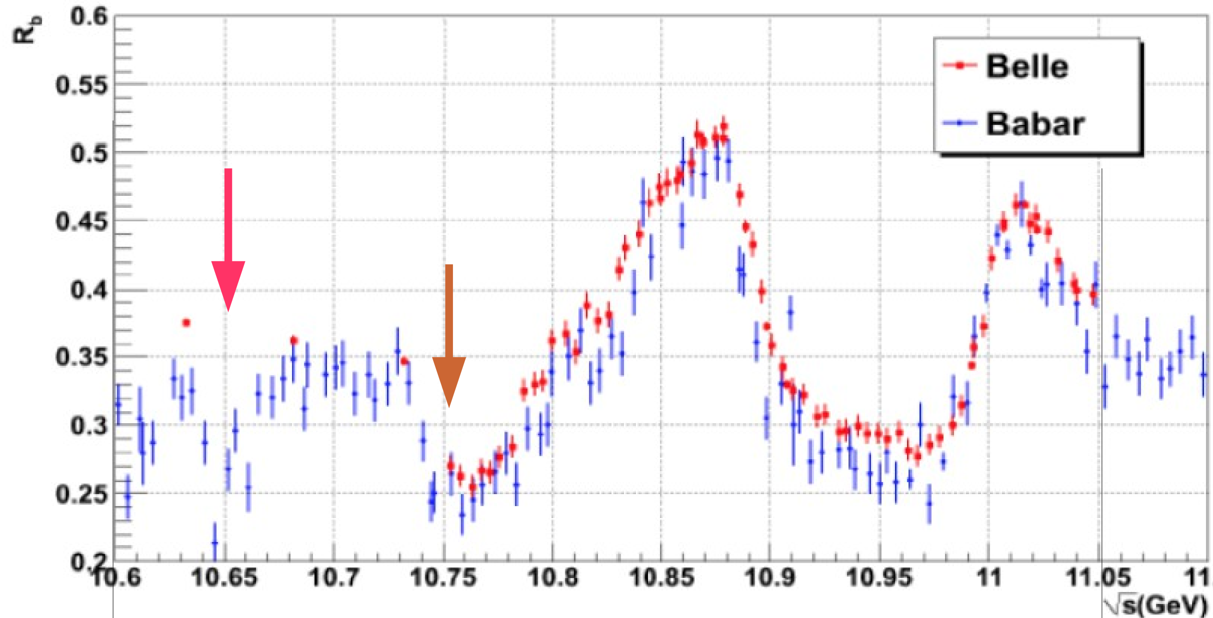


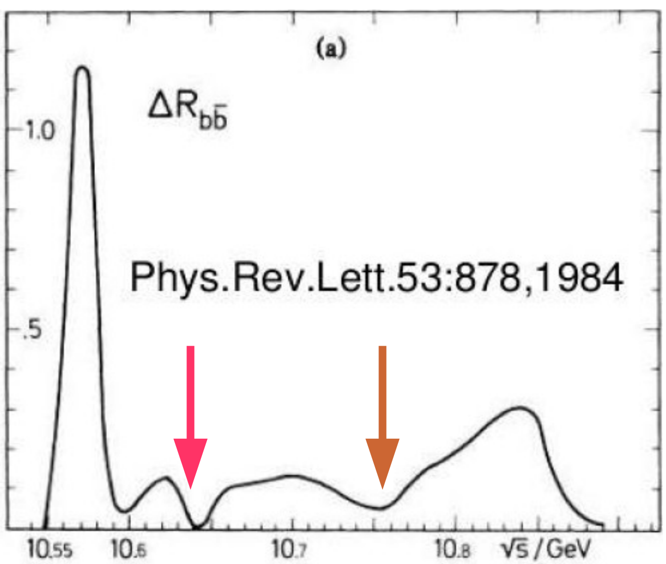


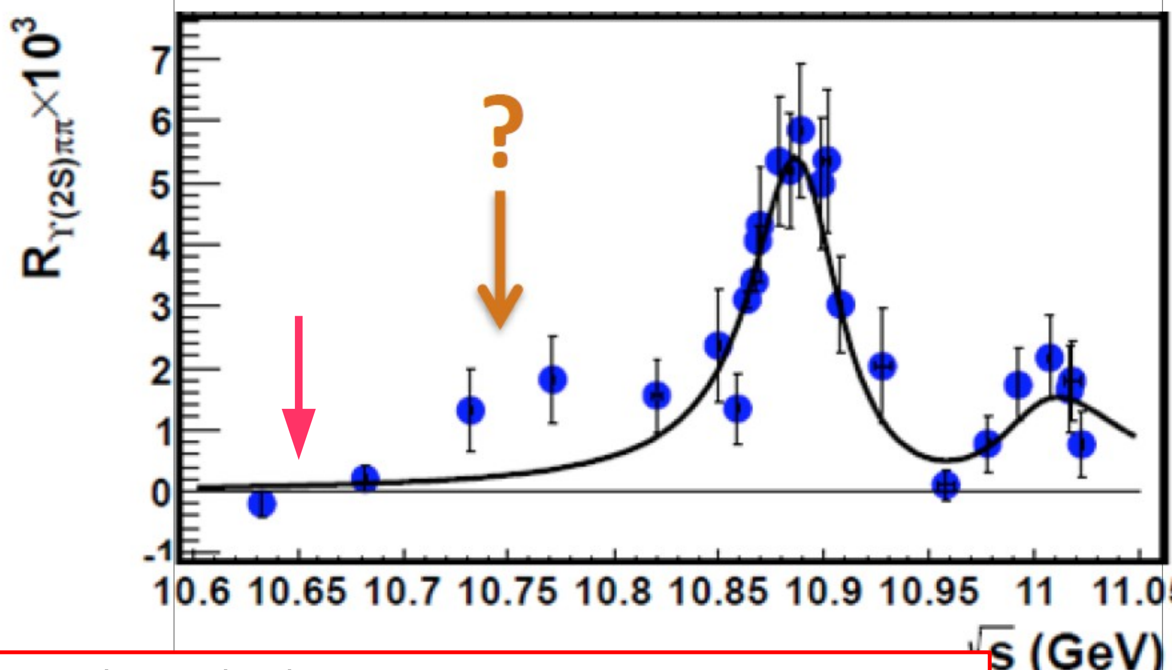


wishes for BELLE-II

We may think to take 10 fb^{-1} at 10.75 (where Rb collapses and R_Y starts rising) ... and 10 fb^{-1} at 10.65 (where Rb shows a dip, just above the B*B* threshold)

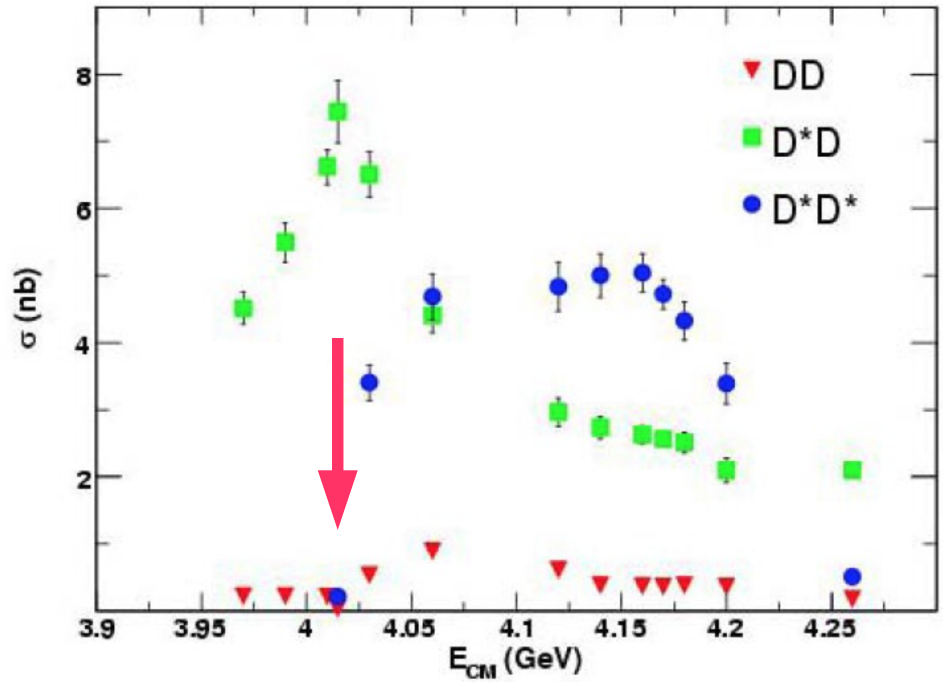




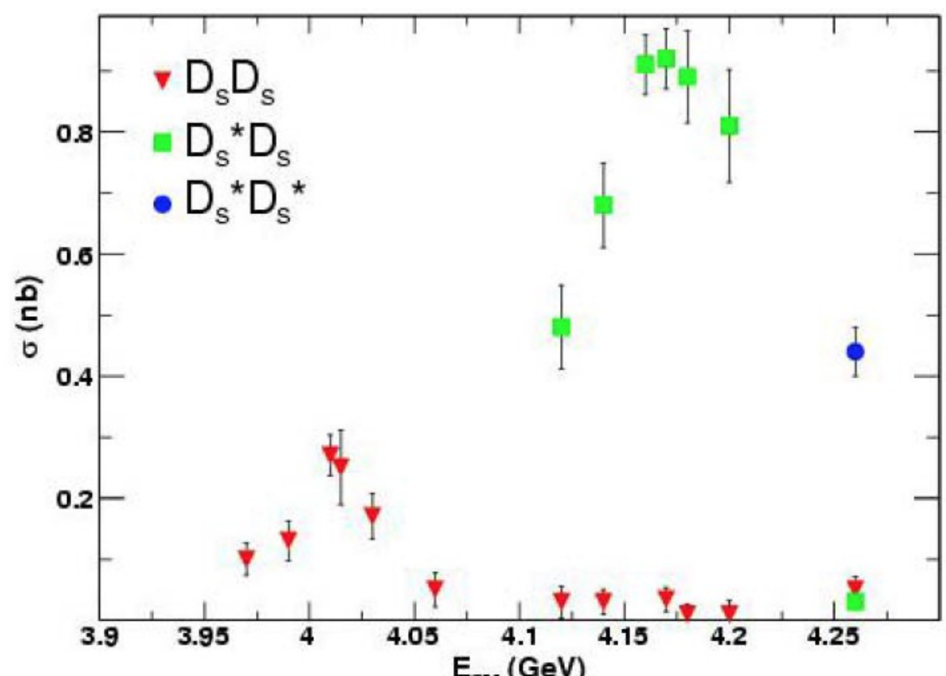


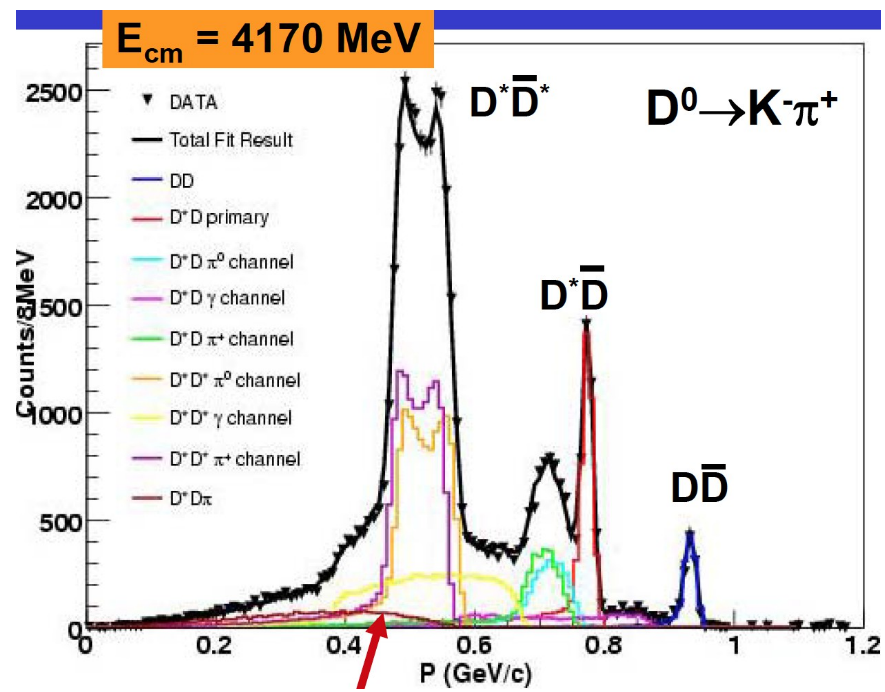
Study these channels: BB,B*B,B*B*,Yππ,Yη at 10.65,10.75

CLEO-c scans in Charmonium region

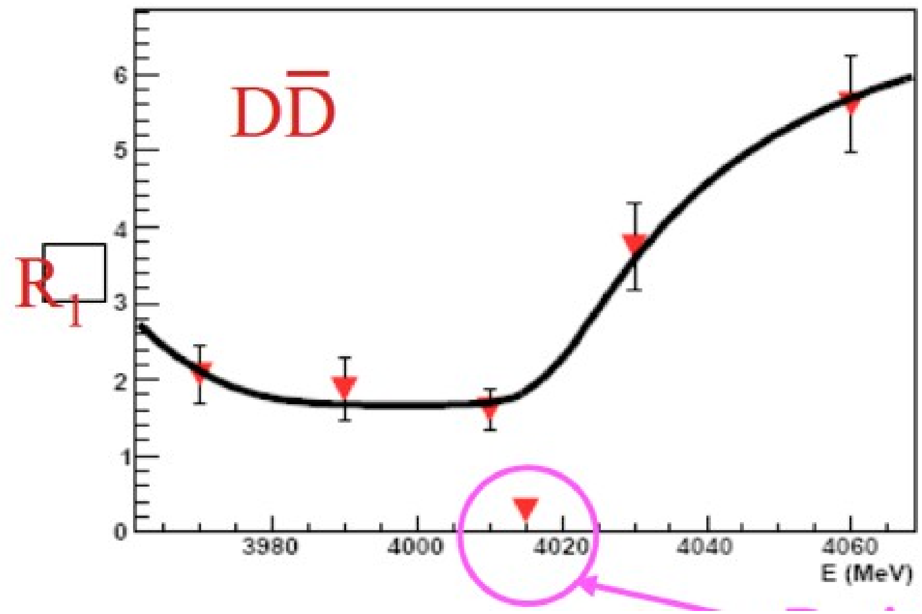


BELLE, BABAR (ISR) and CLEO-C have scanned the charmonium region deconvoluting all 2,3,4 body contributions. The D*D* threshold region at Ecm=4015 MeV is particularly interesting.

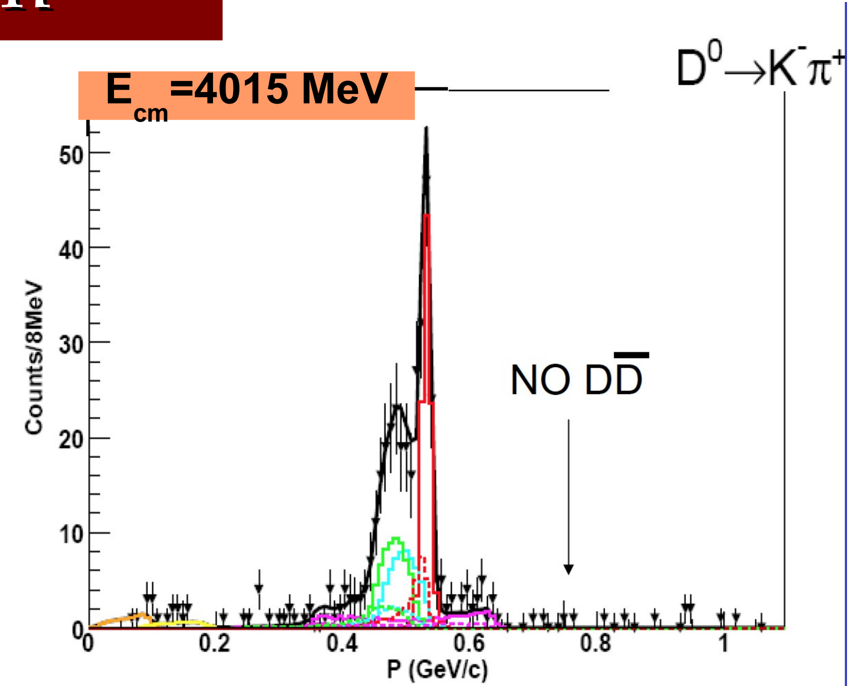


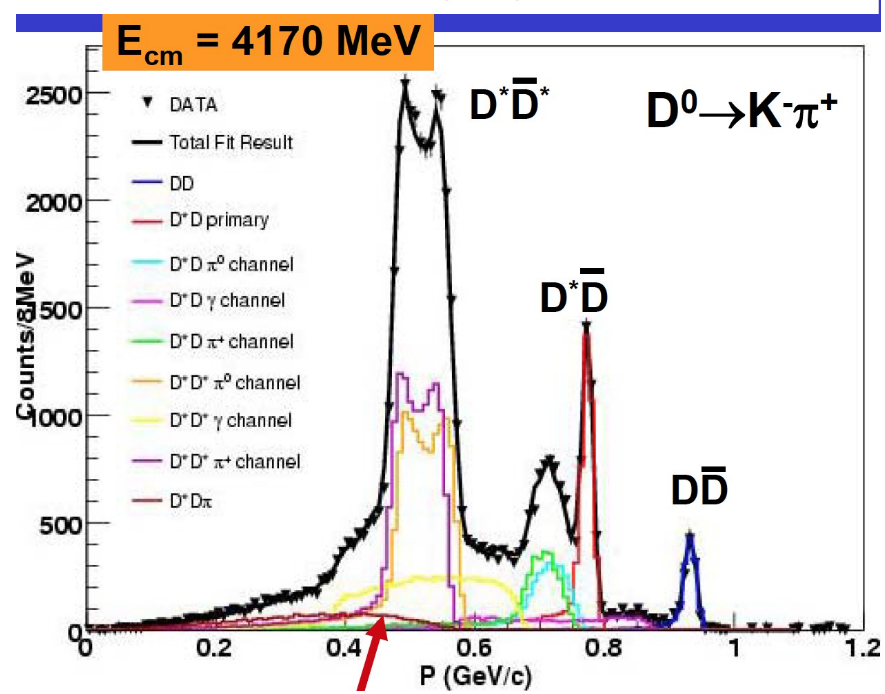


CCCM in Charmonium region

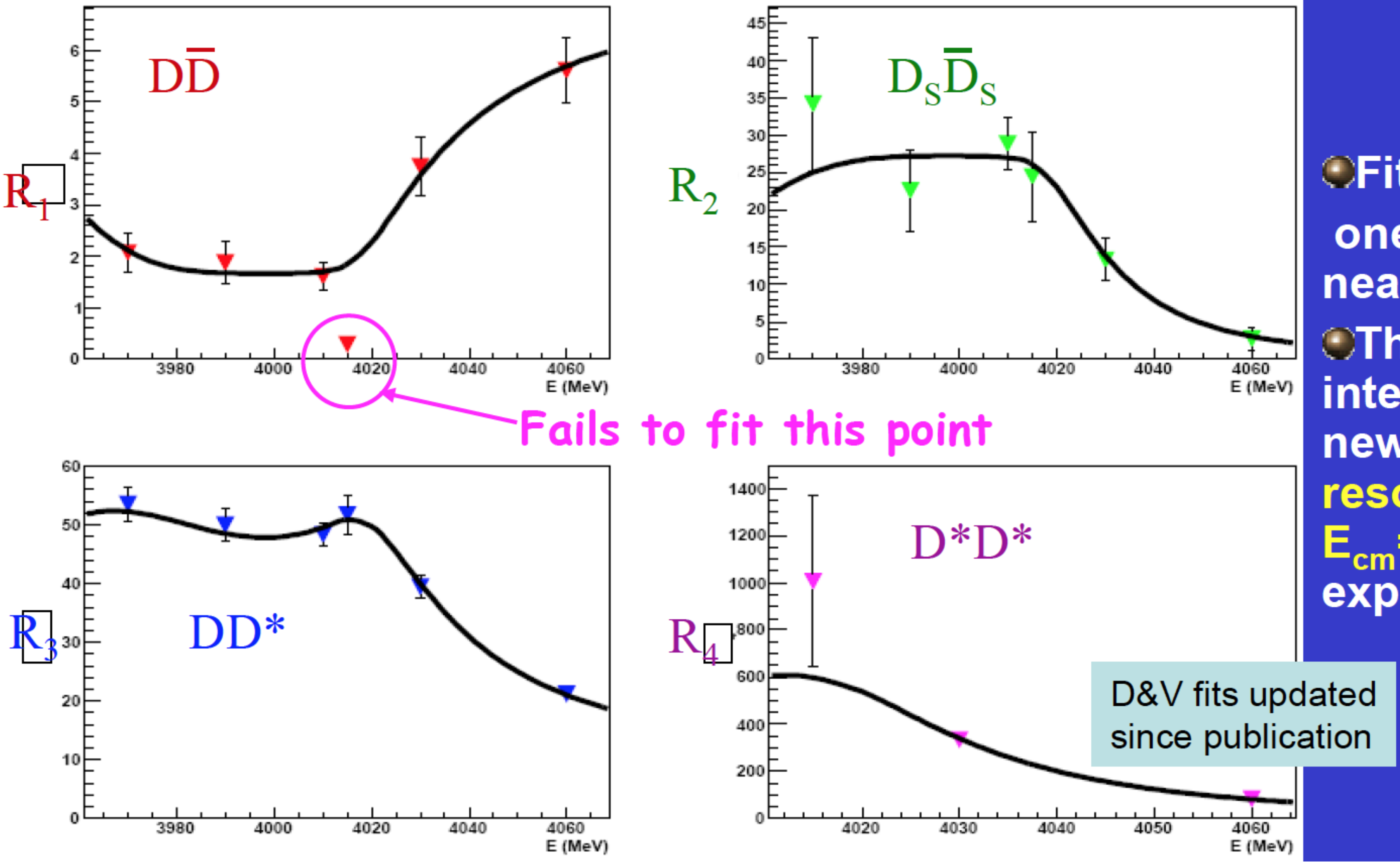


Sudden drop of the $D^0\overline{D}^0$ cross-section at Ecm = 4015 GeV





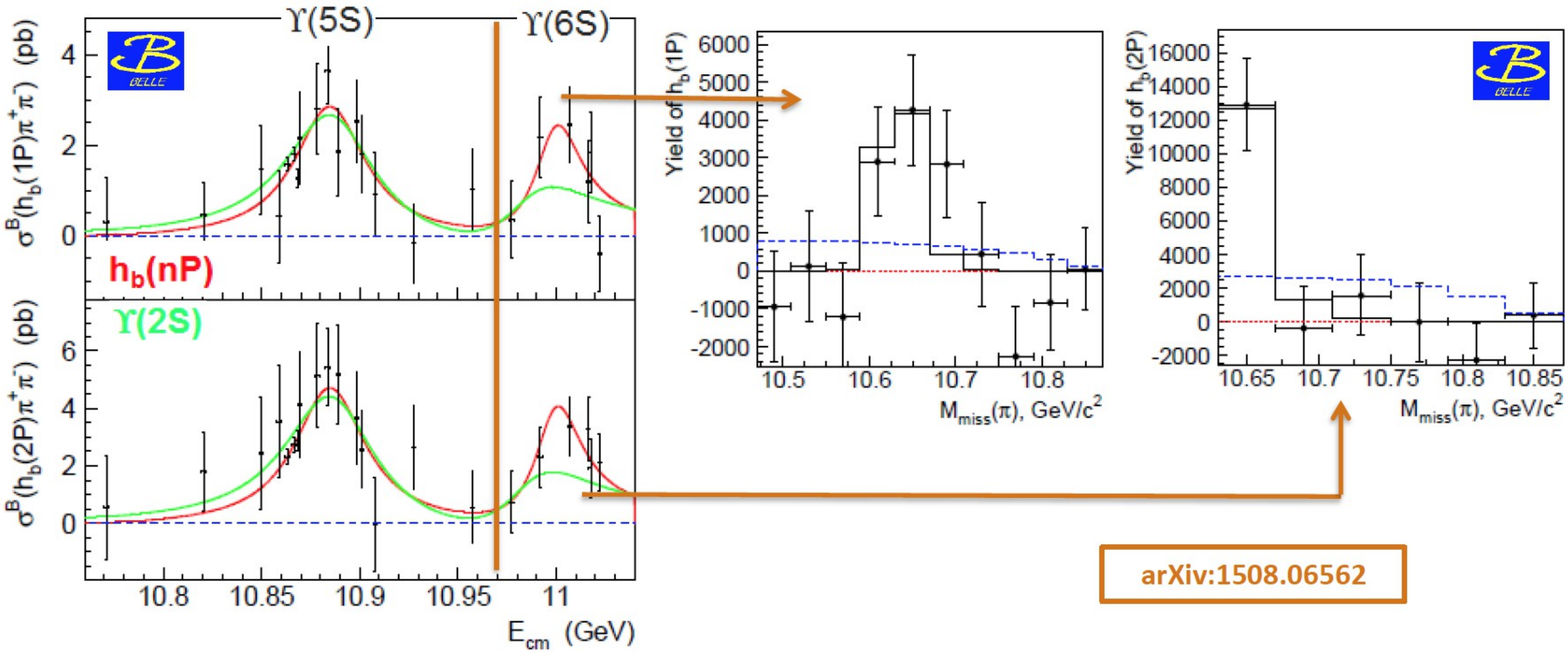
- Model of **Dubynskiy & Voloshin** [Mod. Phys. Lett. A21, 2779 (2006)]
- Express exclusive channels in terms of dimensionless R_k
- Parametrize R_k in terms of expected threshold behavior & relative production rates in the presence of a ψ(4040)



- Fit to CLEO data: one large deviation near D*D* threshold
- This model needs interference with a new narrow resonance at E_{cm}=4015 MeV to explain dip in DD

Y(6S) results in Belle-I

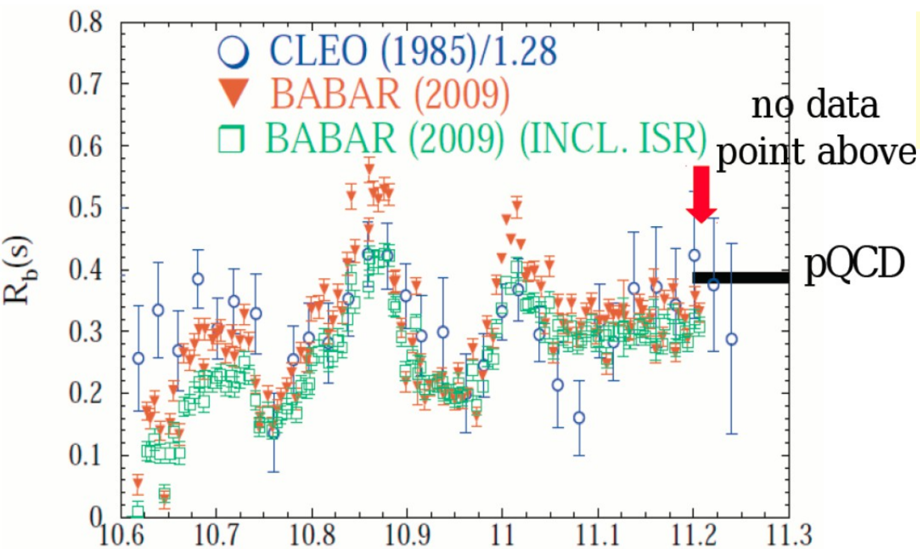
- Preliminary evidence for $\Upsilon(6S)\to\pi\pi h_b(nP)$, via $\pi Z_b^{\pm}(106XX)$ decay



arXiv:1508.06562

- Resonance structure of $\Upsilon(6S) \to \pi\pi\Upsilon(pS)$ decays not fully studied

SuperKEK Limits

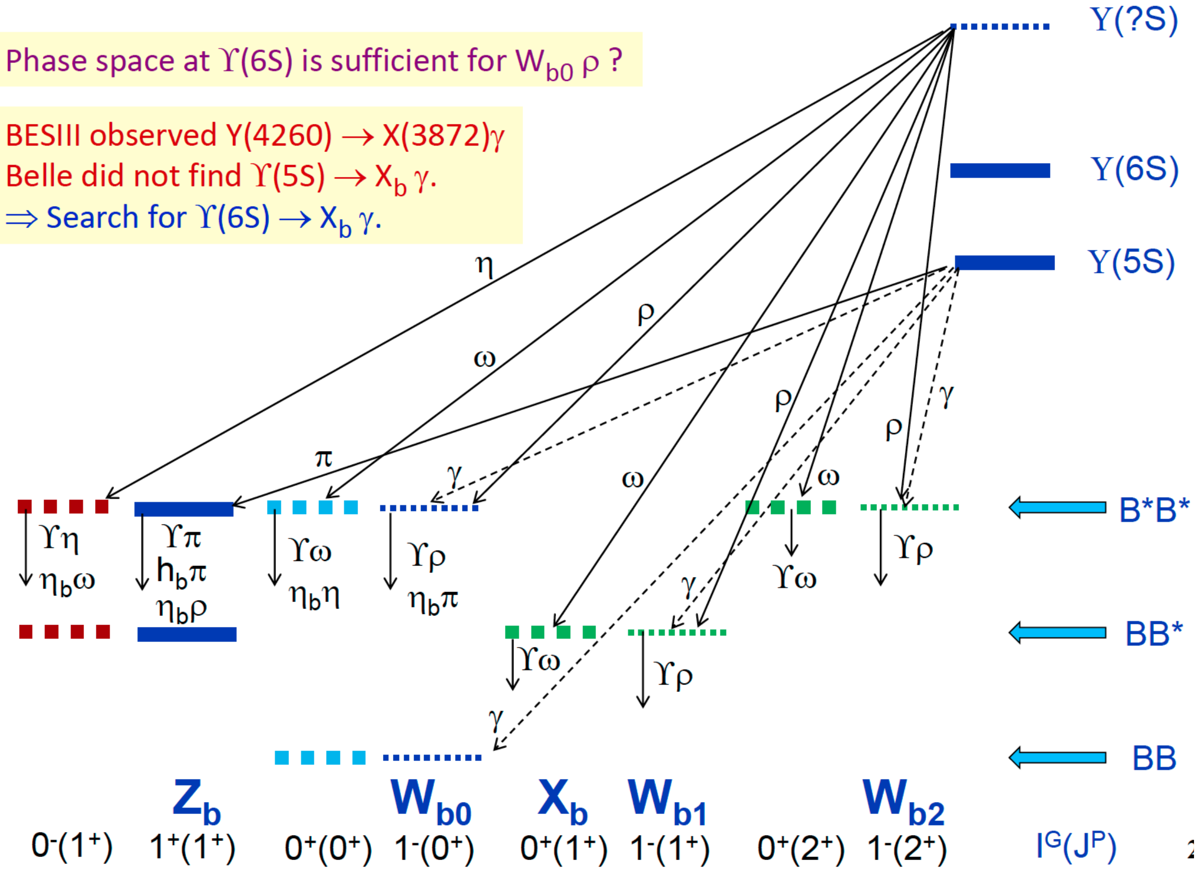


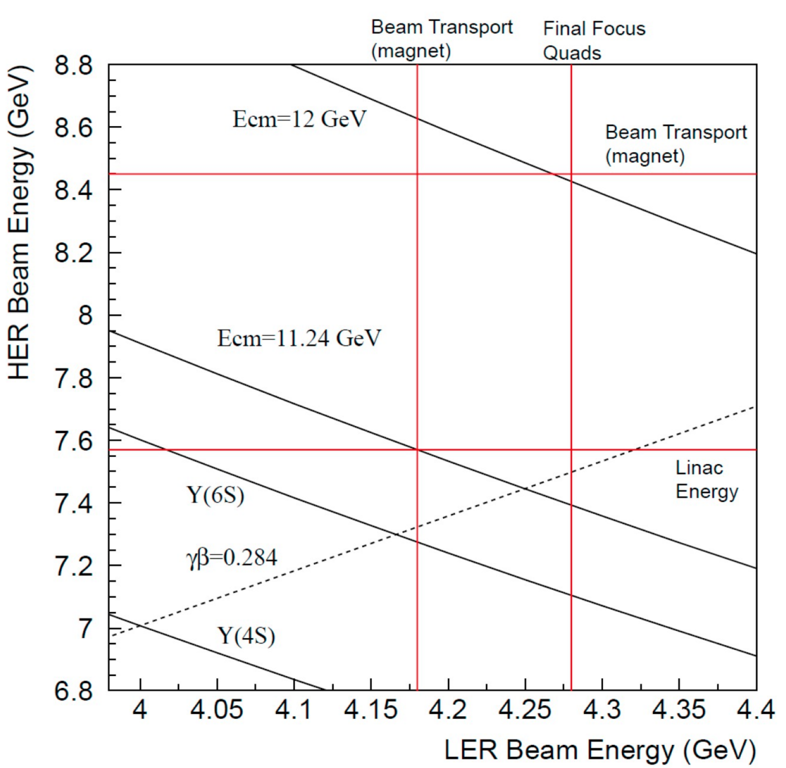
Voloshin PRD84, 031502 (2011)

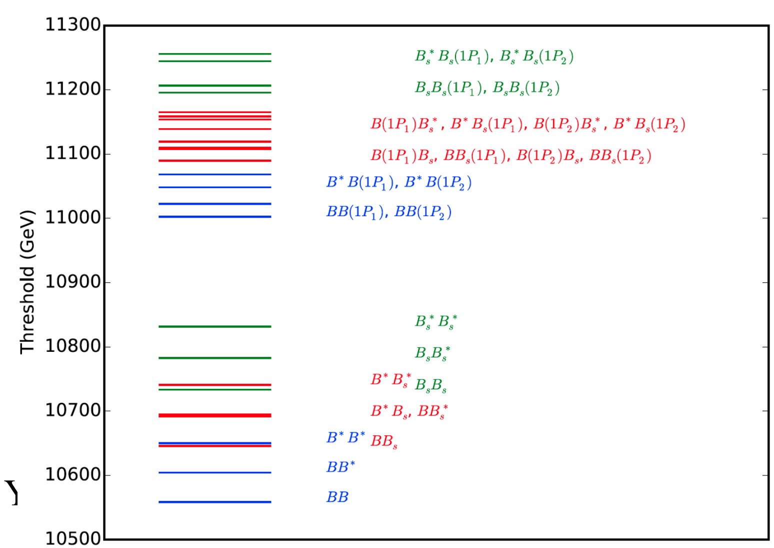
12GeV

Phase space at $\Upsilon(6S)$ is sufficient for $W_{b0}\,\rho$?

BESIII observed Y(4260) → X(3872)γ
Belle did not find $\Upsilon(5S) \to X_b\,\gamma$.
⇒ Search for $\Upsilon(6S) \to X_b\,\gamma$.







Conclusioni

Partiamo dal presupposto che Ldt<40fb^{-1}

Risoluzione energia dei fotoni non eccessiva

Molto inefficienti su low momentum tracks.

Y(3S) e' la best option per ~ 150 fb^{-1} ed e' preferibile farla in fase 3

Un test run sul picco della Y(6S), anche di soli 40fb^{-1} , ci darebbe 10x gli eventi presi in Belle-I. SE i macchinisti sono disposti ad andare cosi in alto, questo e' il punto piu' interessante.

Le zone dei due dip in Rb, 10.65 +10.75 GeV, si prestano a studi sui coupled channels effects.

Outline

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Physics with 600 M Y(3S):
- The η,π transitions
- Hindered E1 transitions
- M1 transitions to η_b(1,2S)
- D waves
- Y(3S) → ππ Y(1,2S)
- Antinuclei from Y(3S)

Target Ldt: 150 fb^{-1}

All during BEAST-2 Phase?
Or
50 during BEAST-2, and 100 while taking first Y(4S) data (3 ab^{-1})

Alternative scenarios:

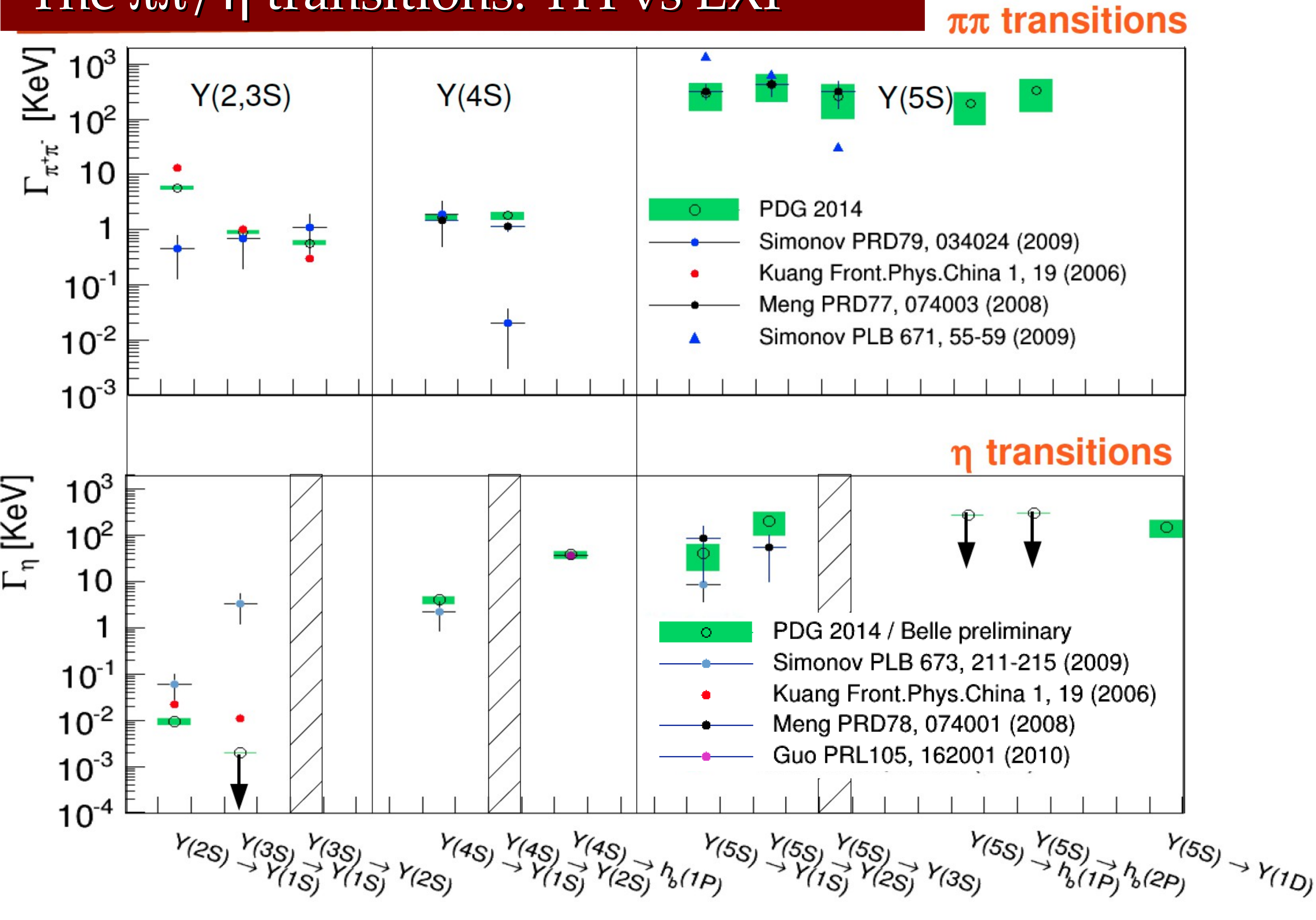
Running at ϒ(4S) and continuum point
Running at ϒ(6S), 30 fb^{-1} = 6x Belle-I

Scan of $\Upsilon(1^3D_1)$, 7x2fb^{-1} points , 14 total
Scan of $\Upsilon(2^3D_1)$, 10x1.5fb^{-1} points , 15 total

Can we do them during BEAST-2 Phase?

Luminosity ramp-up scenarios:
- at L1 = 1×10^{34}, 0.75 fb^{-1} / day
  How many days to reach L1?
  How long will Phase-II last?

The ππ / η transitions: TH vs EXP



Hadron transition puzzle: solved?

From Eichten's talk at Krakow

- Above heavy flavor production threshold the usual QCDME fails.
  - The transitions rate are much larger than expected.
  - The factorization assumption fails. Heavy quark and light hadronic dynamics interact strongly due to heavy flavor meson pair (four quark) contributions to the quarkonium wavefunctions. Magnetic transitions not suppressed.
  - A new mechanism for hadronic transitions is required.
- A new mechanism, in which the dynamics is factored differently, is purposed.
  - It requires an intermediate state containing two narrow heavy-light mesons nearby and near threshold (v -> zero). This is the factor. Other light hadrons may be present or not.
    - The production of this state from the initial state is calculated using familiar strong dynamics of coupled channels.
    - The evolution of this threshold system into the final quarkonium state and light hadrons requires a new threshold dynamics.
- HQS as well as the usual SU(3) and chiral symmetry expectations are recovered.
- Resolves the puzzles in η transitions.

Hadron transitions: a new paradigm?

From Eichten's talk at Krakow

For lower states, QCDME works:

$$R_{Q\bar{Q}}(n \to m) \equiv \frac{\Gamma(n^3S_1 \to m^3S_1 + \eta)}{\Gamma(n^3S_1 \to m^3S_1 + \pi^+\pi^-)} :$$

Ratio	theory	experiment
$R^{c\bar{c}}(2 \to 1)$	3.29×10^{-3}	9.78×10^{-2}
$R^{b\bar{b}}(2 \to 1)$	1.16×10^{-3}	1.16×10^{-3}
$R^{b\bar{b}}(3 \to 1)$	4.57×10^{-3}	$< 4.13 \times 10^{-3}$
$R^{b\bar{b}}(4 \to 1)$	2.23×10^{-3}	2.45
$R^{b\bar{b}}(4 \to 2)$	5.28×10^{-4}	

~ 30 > theory
sets $C_3/C_1 = 0.143 \pm 0.024$
related to ππ suppression

~ 1000 > theory

$2M(D^0)\text{-}M(\psi') = 53.11\ \mathrm{MeV}/c^2$ $\quad$ $2M(B^0)\text{-}M(\Upsilon 3S) = 204\ \mathrm{MeV}/c^2$

$2M(D^+)\text{-}M(\psi') = 43.57\ \mathrm{MeV}/c^2$ $\quad$ $2M(B^+)\text{-}M(\Upsilon 3S) = 204\ \mathrm{MeV}/c^2$

$2M(D_s)\text{-}M(\psi') = 250.5\ \mathrm{MeV}/c^2$ $\quad$ $2M(B_s)\text{-}M(\Upsilon 3S) = 378\ \mathrm{MeV}/c^2$

Large enhancement of $\psi' \to \eta\psi$ explained by the proximity of the $D\bar{D}, D_s\bar{D}_s$ thresholds.

Large isospin violation in $\psi' \to \pi h_c$ due to the large D^0-D^+ mass difference

In bottomonium , degenerate $B^0\bar{B}^0$ / B^+B^- threshold → no isospin violation

The eta transition 3S to 1S is still in the ballpark: wavefunction overlaps can suppress is , like it happens in hindered E1 transitions. **We ought to measure it, and (precisely) the E1 hindered transitions from 3S to 1P states.**

The η transitions

Testing QCD multipole expansion
In low mass region:
$\Upsilon' \to \eta\Upsilon$: M2*E1+M1*M1
$\Upsilon' \to \pi\pi\Upsilon$: E1*E1
$(\Upsilon' \to \eta\Upsilon)/(\Upsilon' \to \pi\pi\Upsilon) \sim (\Lambda_{QCD}/m_b)^2$

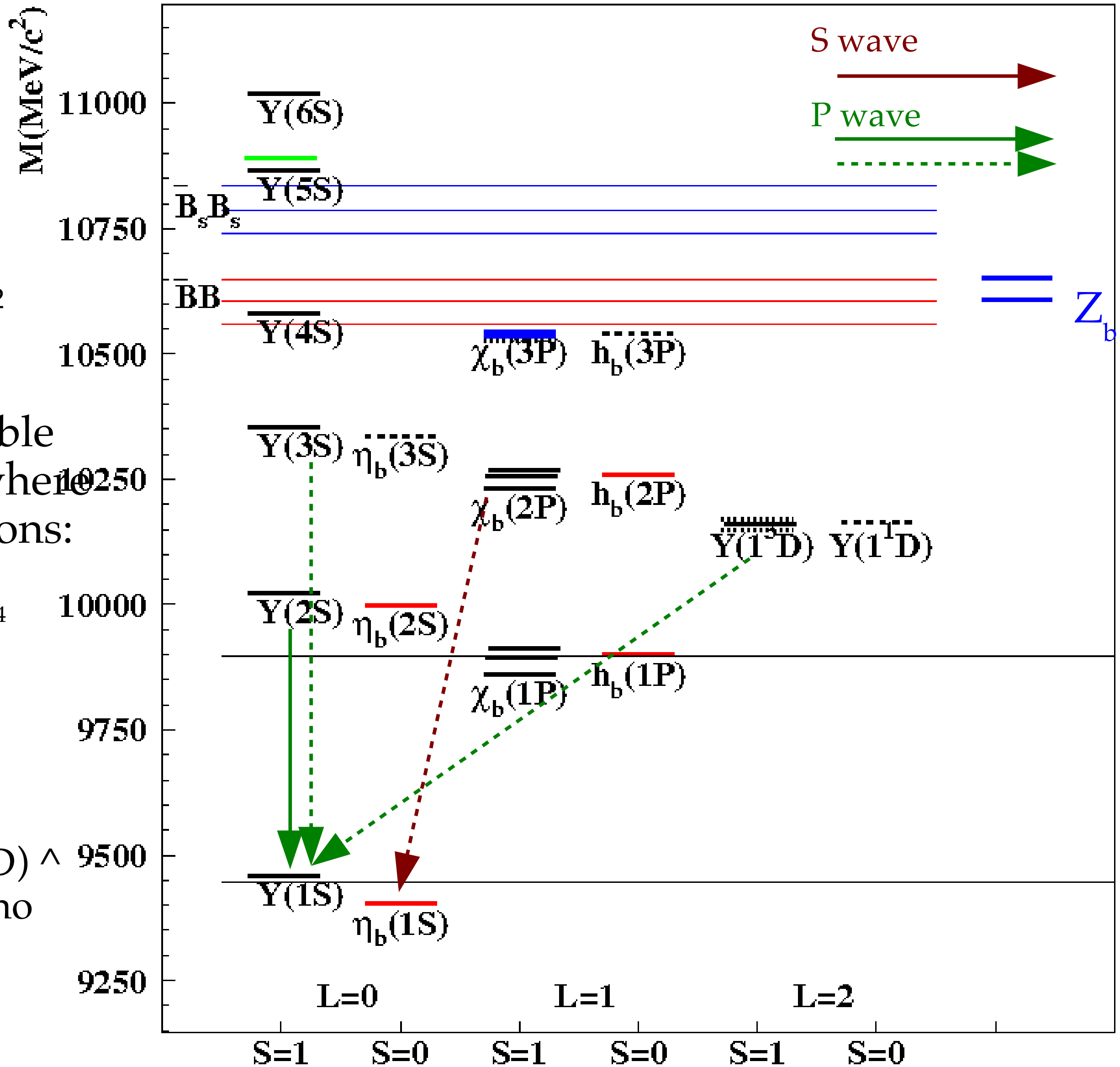
Three more transitions should be visible from Υ(3S) but experimental limits, where available, are below theory expectations:

- B(Υ(3S) ⟶ ηΥ(1S)) theory: $5\text{-}10\times 10^{-4}$
BaBar PRD84,42003(2011) $<1\times10^{-4}$

- Υ(1D) ⟶ ηΥ(1S)
Voloshin: PLB 562, 68(2003)
QCD Axial Anomaly should enhance Υ(1D) ^ ηΥ(1S) with respect to Υ(1D) ^ ππΥ(1S): no quantitative estimates available.

- B(χ_{b0}(2P) ⟶ η η_b)~ few 10^{-3} (S-wave)
Voloshin: Mod.Phys.Lett. A19, 2895(2004)

$$\frac{\Gamma(\chi_{b0}(2P)\to\eta\eta_b)}{\Gamma(\chi_{b0}(2P)\to\gamma\Upsilon)} \approx \frac{\pi^3}{3\alpha}\frac{p_\eta f_\eta^2 m_\eta^4}{\omega_\gamma^3 m_b^2\Delta^2} \approx 0.2\left(\frac{f_\eta}{0.16\ \text{GeV}}\right)^2\left(\frac{1\ \text{GeV}}{\Delta}\right)^2$$



Tetraquark-mania

From Ali's talk
at Krakow

Label	J^{PC}	charmonium-like State	charmonium-like Mass [MeV]	bottomonium-like State	bottomonium-like Mass [MeV]
X_0	0^{++}	—	3756	—	10562.2
X'_0	0^{++}	—	4024	—	10652.2
X_1	1^{++}	$X(3872)$	3890	—	10607.2
Z	1^{+-}	$Z_c^+(3900)$	3890	$Z_b^{+,0}(10610)$	10607.2
Z'	1^{+-}	$Z_c^+(4020)$	4024	$Z_b^+(10650)$	10652.2
X_2	2^{++}	—	4024	—	10652.2
Y_1	1^{--}	$Y(4008)$	4024	$Y_b(10891)$	10891.1
Y_2	1^{--}	$Y(4260)$	4263	$Y_b(10987)$	**10987.5**
Y_3	1^{--}	$Y(4290)$ (or $Y(4220)$)	4292	—	**10981.1**
Y_4	1^{--}	$Y(4630)$	4607	—	11135.3
Y_5	1^{--}	—	6472	—	13036.8

BEAST-II inventory

Feb. 4, 2015

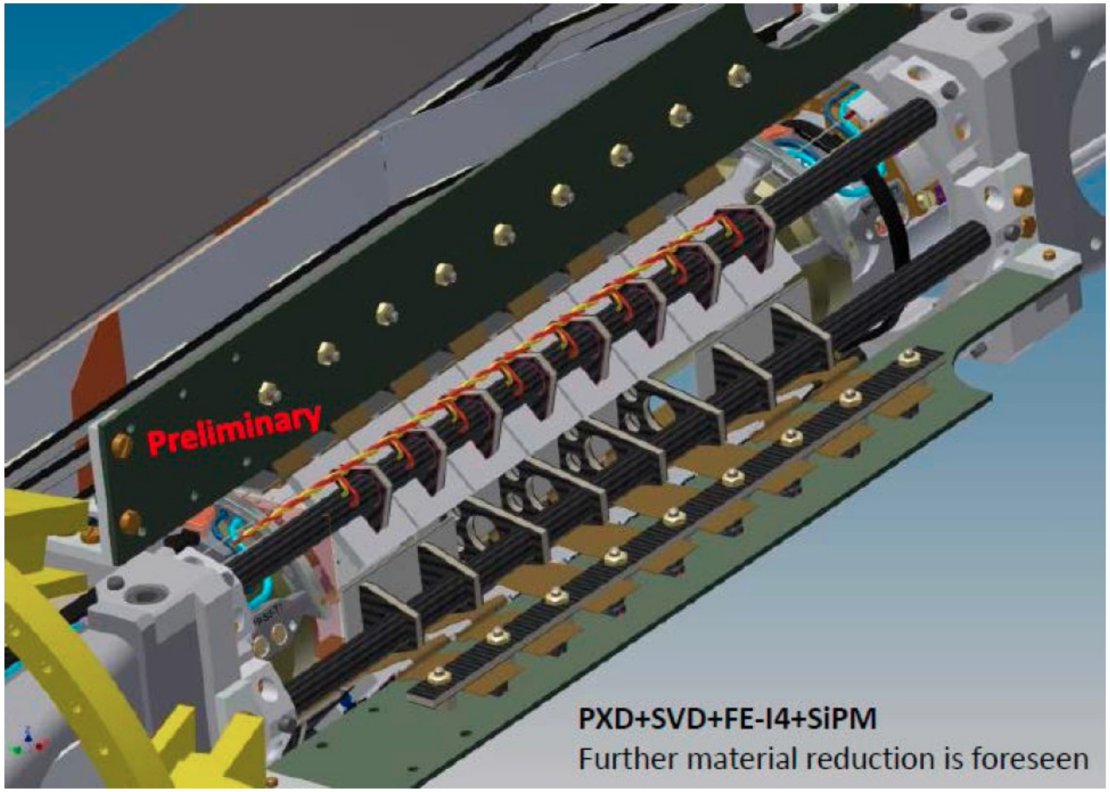
Phase-2 sensors in VXD volume

sensor	contact person	number	location	DAQ	note
PXD + SVD	C. Marinas K. Nakamura	2 PXD ladders 4 SVD ladders	decided +X	Belle II DAQ	
diamond w/ PIN diode (beam BG, abort)	L. Vitale	4 diamonds 64 PIN diodes	diamond: decided	Belle II monitor DB (EPICS)	PIN diode location: around diamond and beam pipe
FE-I4 pixels (Synchrotron rad. and track multiplicity)	C. Marinas	3 arms	decided (90, 180, 270)	?	arm design has to be fixed
CLAWS (beam BG)	C. Marinas	2 ladders	decided (135 and 225)	?	
Scintillator PIN diode (beam BG)	H. Nakayama K. Nakamura	~60 (scintillator) ? (PIN diode)	not decided	?	Basically put them around QCS
BGO (Bhabha events)	J. Liau	8 (if space allows)	under discussion	BEAST DAQ	Acceptance is overlapped with PXD cooling block.
temperature (NTC), humidity (DMT242B) (crosscheck for FOS)	L. Vitale	not decided	not decided	Belle II monitor DB	
FOS + L-shape (temp. and humidity)	I. Vila D. Moya	?	?	?	sensor on outer cover?
PLUME (beam BG)	I. Ripp-Baudot	1 ladder	not decided	EPICS DB BEAST DAQ?	baseline: PLUME-2 (hopefully PLUME-3)

See backup slides for more on these systems.

Phase 2 Detectors

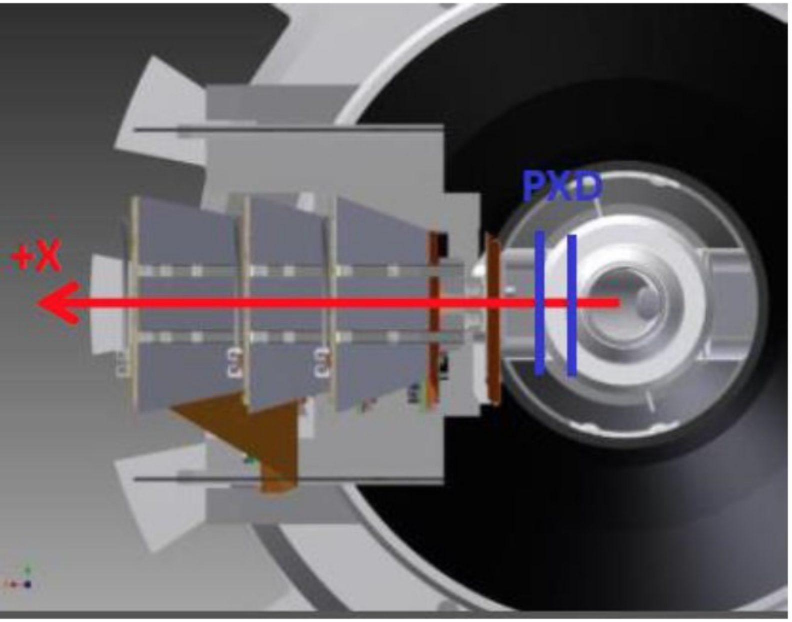
- VXD BEAST assembly
  - SVD, PXD ladders
  - Dedicated background and environment sensors (see next page)
- Scintillators and PIN diodes around QCS
- Neutron detector in dock space

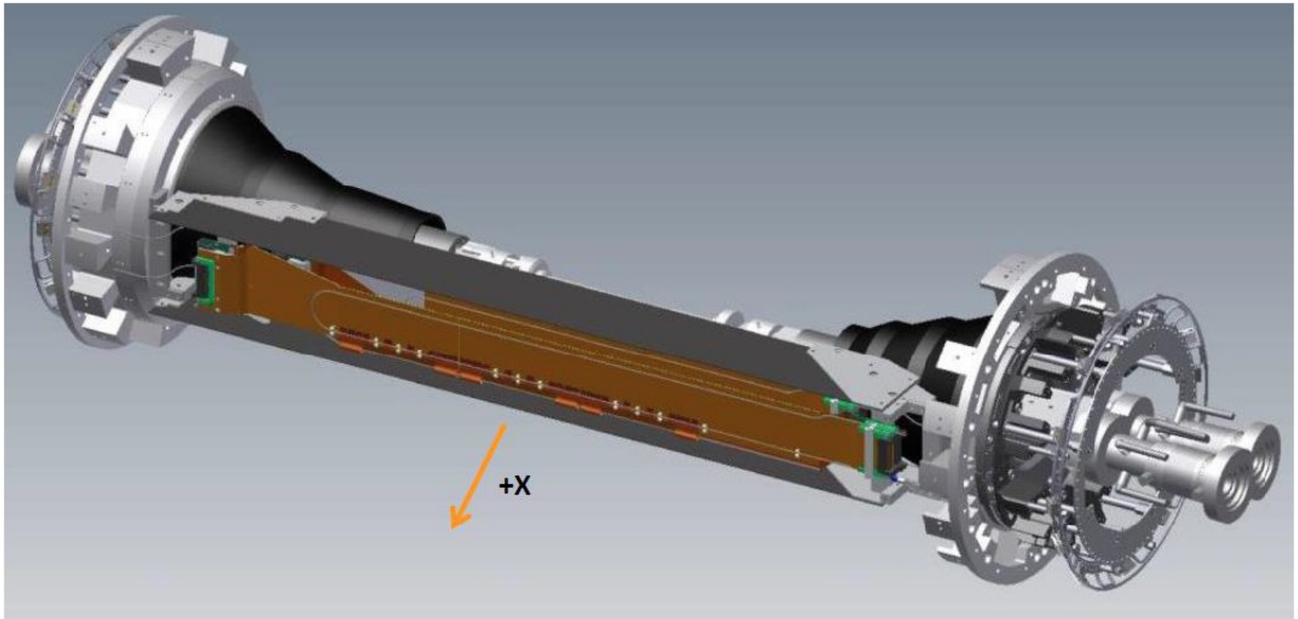


- **B**eam **E**xorcism for **A ST**able Belle II
- Collection of radiation monitoring detectors used during beam commissioning stages (Phase 1 and Phase 2)
- Inner detector
  - One octant of PXD + SVD (integrated into Belle 2 DAQ)
  - FANGS, CLAWS, PLUME: 5 out of 8 remaining octants
  - Designed to minimize amount of additional material
- Outer detector
  - Nominal Belle II configuration
  - Drift chamber (CDC), PID (TOP/ARICH), calorimeter (ECL), muons (KLM)
- Other
  - "Dock space" has He-3 and TPCs for neutron detection
  - Beampipe has ~6μm gold plating (compared to 10μm for nominal)

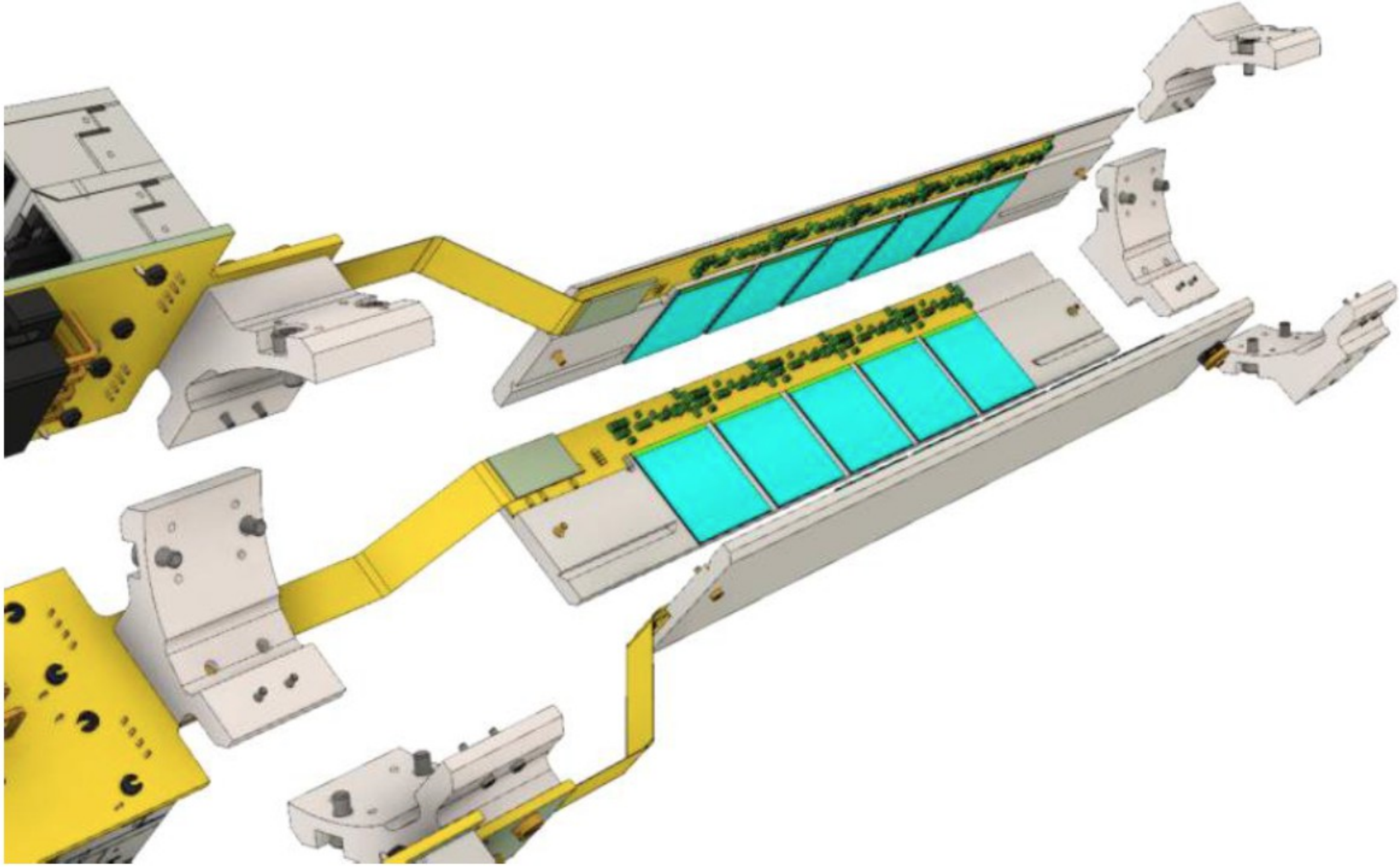
VerteX Detector configuration

- 2 PiXel Detector / 4 Silicon Vertex Detector ladders
- Similar to final Belle II vertex detector components
- Located at $\phi=0^{o}$
- Integrated into Belle II DAQ system

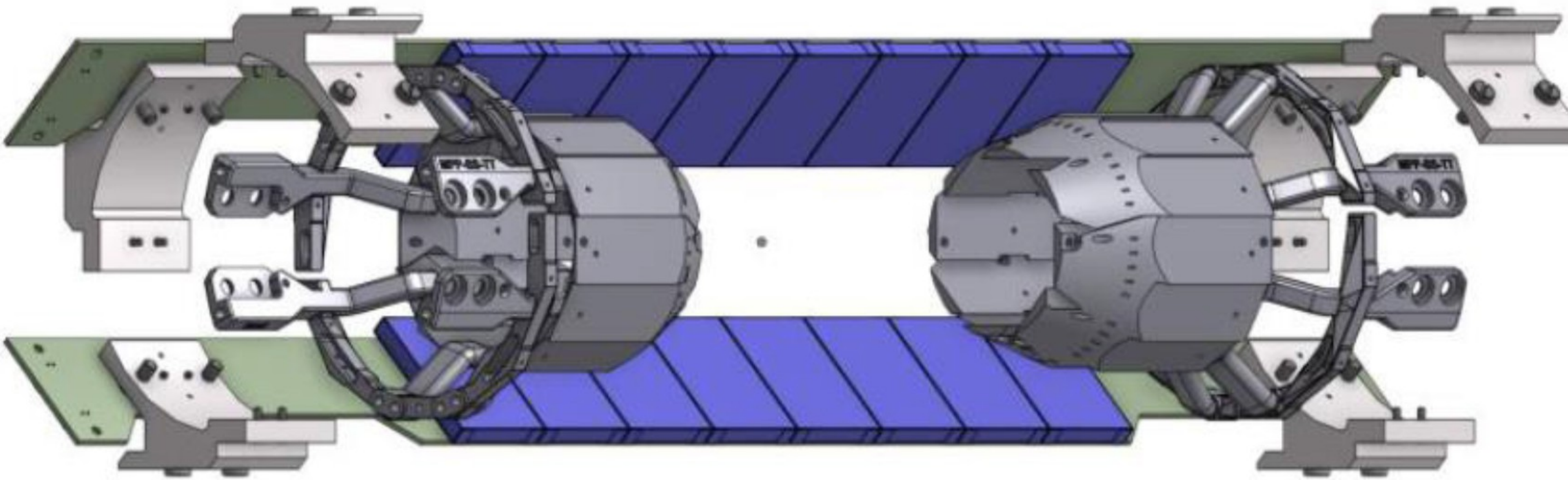




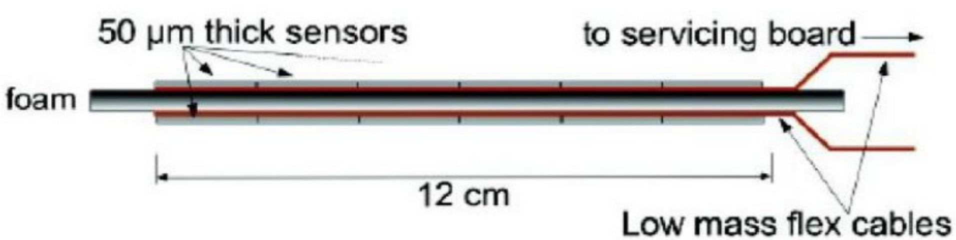
- **FE-I4 ATLAS Near Gamma Sensors**
  - Radiation-hard Si pixel detectors
  - Located at $\phi=90^o$, 180^o, 270^o

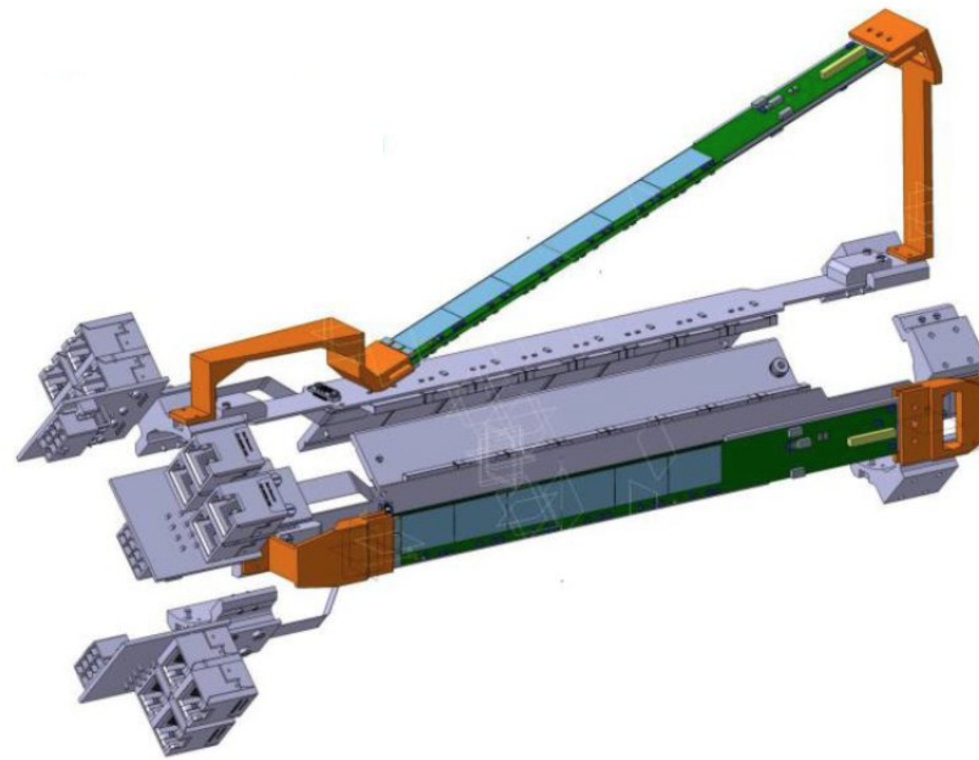


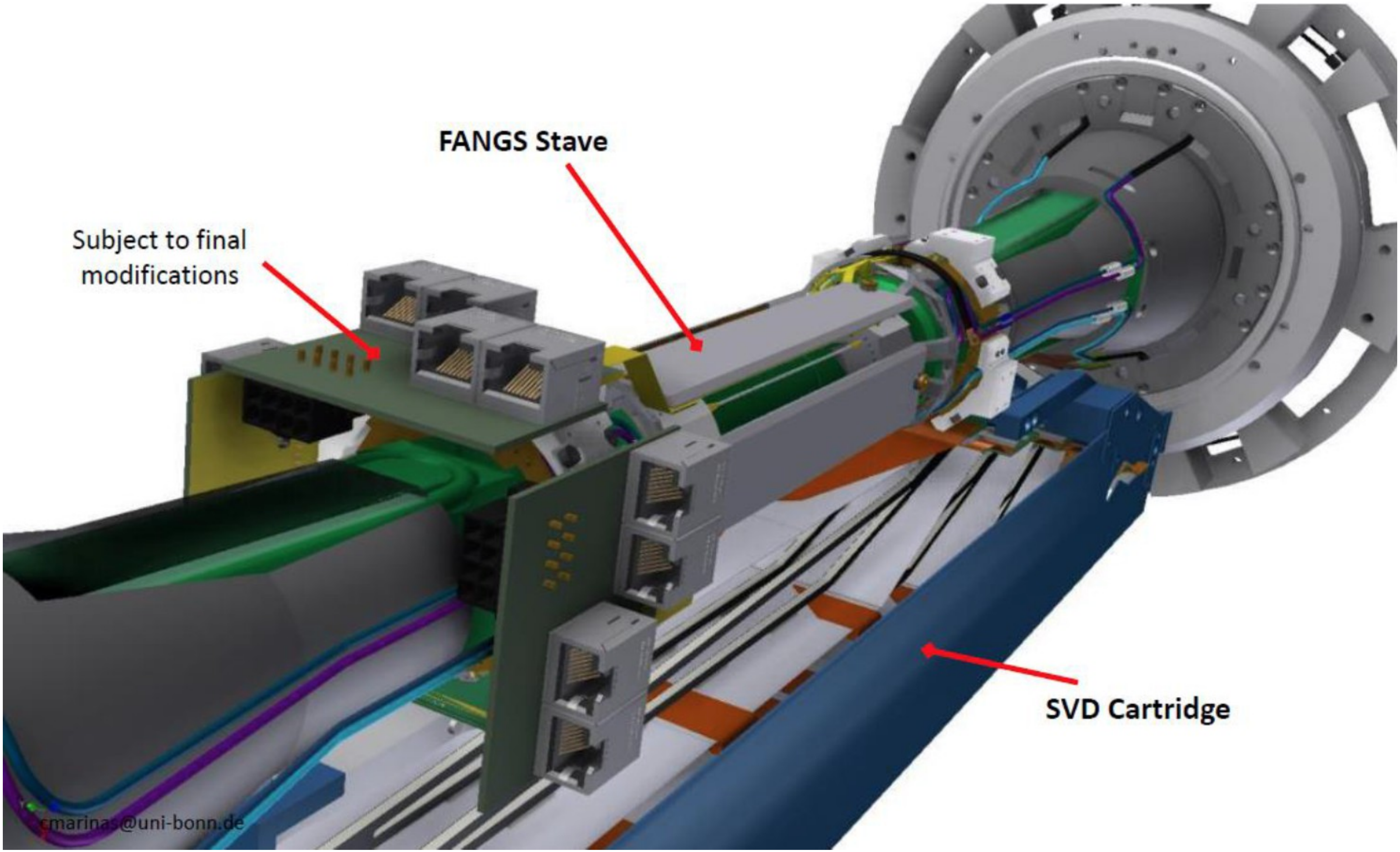
- sCintillation Light And Waveform Sensors
  - Plastic scintillator with Si photomultipler readout
  - Located at ϕ=135° and 225°

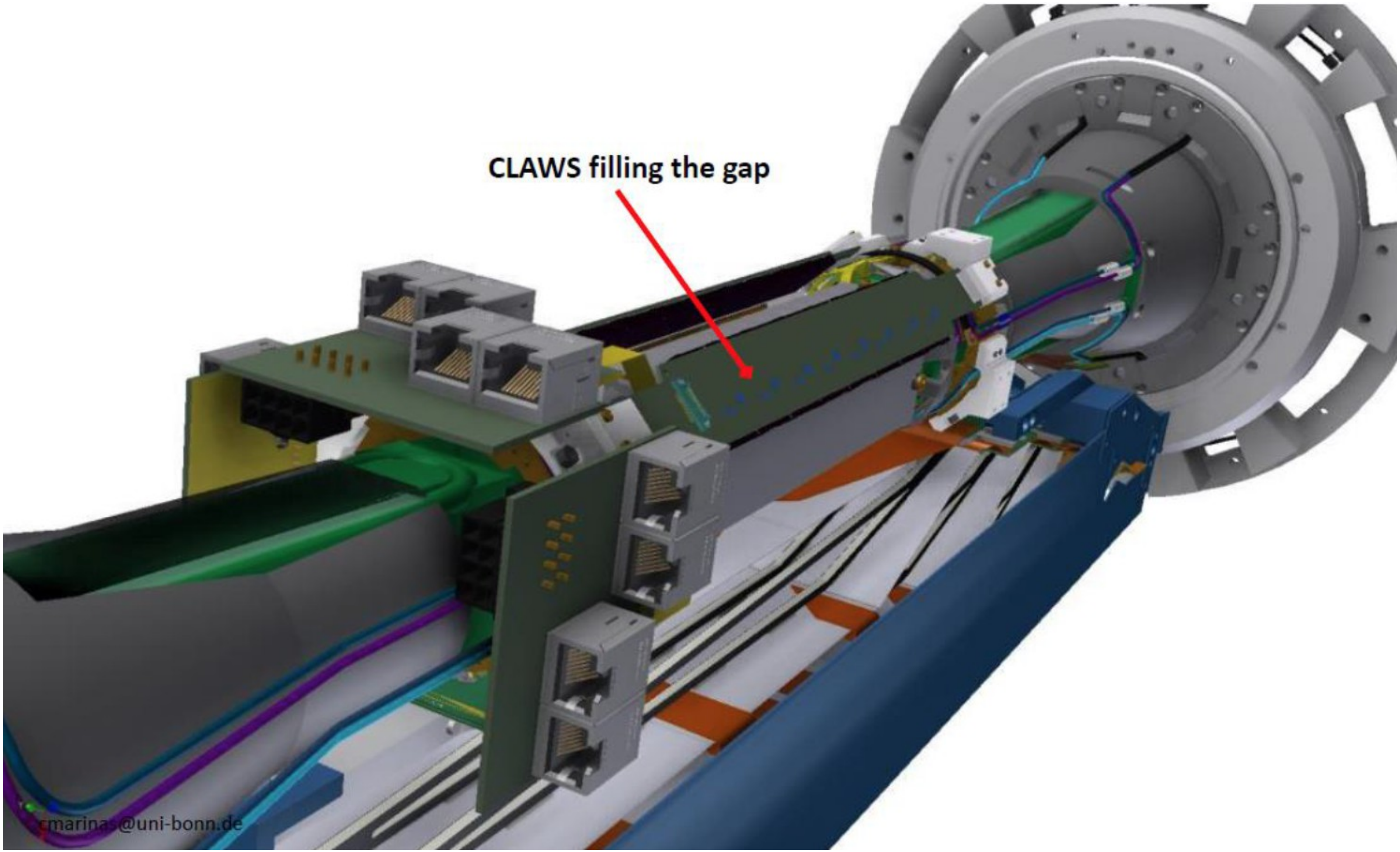


- **P**ixelated **L**adder with **U**ltra-low **M**aterial **E**mbedding
  - CMOS pixels on light support structure
  - Complementary to CLAWS, same location
  - Final orientation under study






FANGS Stave
Subject to final modifications
SVD Cartridge
cmarinas@uni-bonn.de


CLAWS filling the gap
cmarinas@uni-bonn.de

Neutron Detectors

- He-3 tubes and micro-TPCs in dock space
  - TPCs image direction of incoming fast neutrons, but detected rate is low
  - He-3 measure rate of thermal neutrons, which is high