Early Physics at Belle II
Studies on Quarkonia

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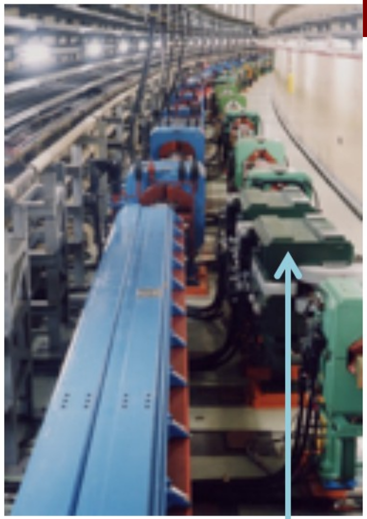
INFN Torino

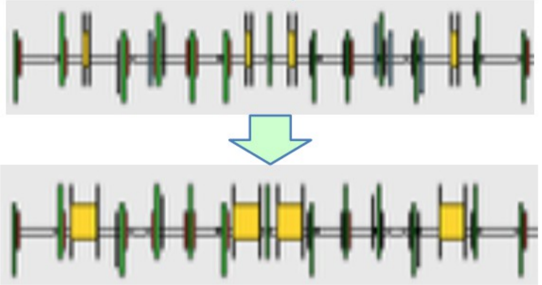
QWG
@ PNNL

Richland, WA (USA)   June 6-10, 2016

From KEKB to Super-KEKB

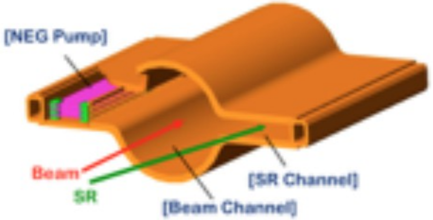


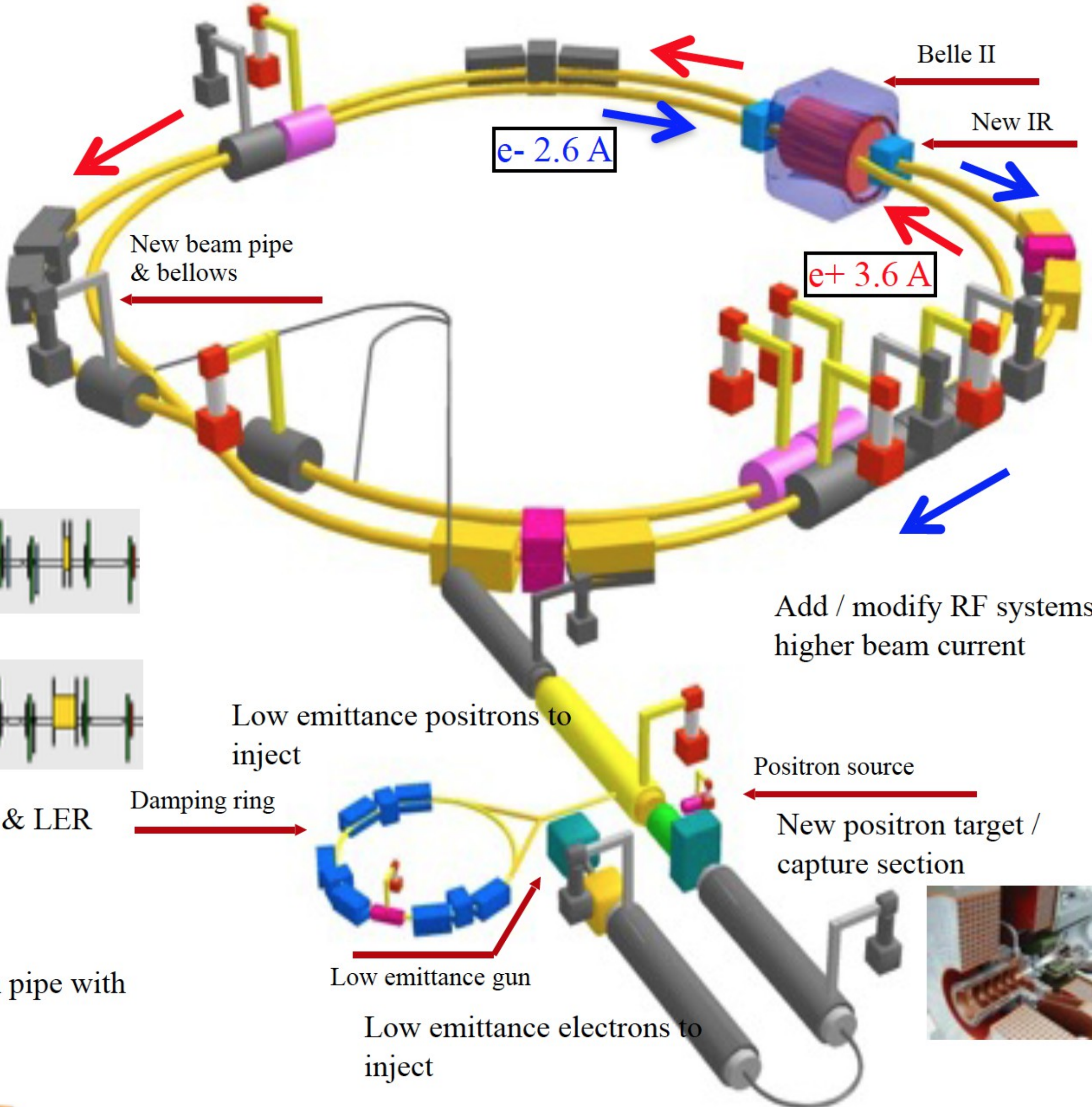
Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance

TiN-coated beam pipe with antechambers





e- 2.6 A

e+ 3.6 A

Belle II

New IR

New beam pipe & bellows

Low emittance positrons to inject

Damping ring

Low emittance gun

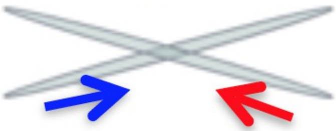
Low emittance electrons to inject

Positron source

New positron target / capture section

Add / modify RF systems for higher beam current

Colliding bunches



New superconducting / permanent final focusing quads near the IP

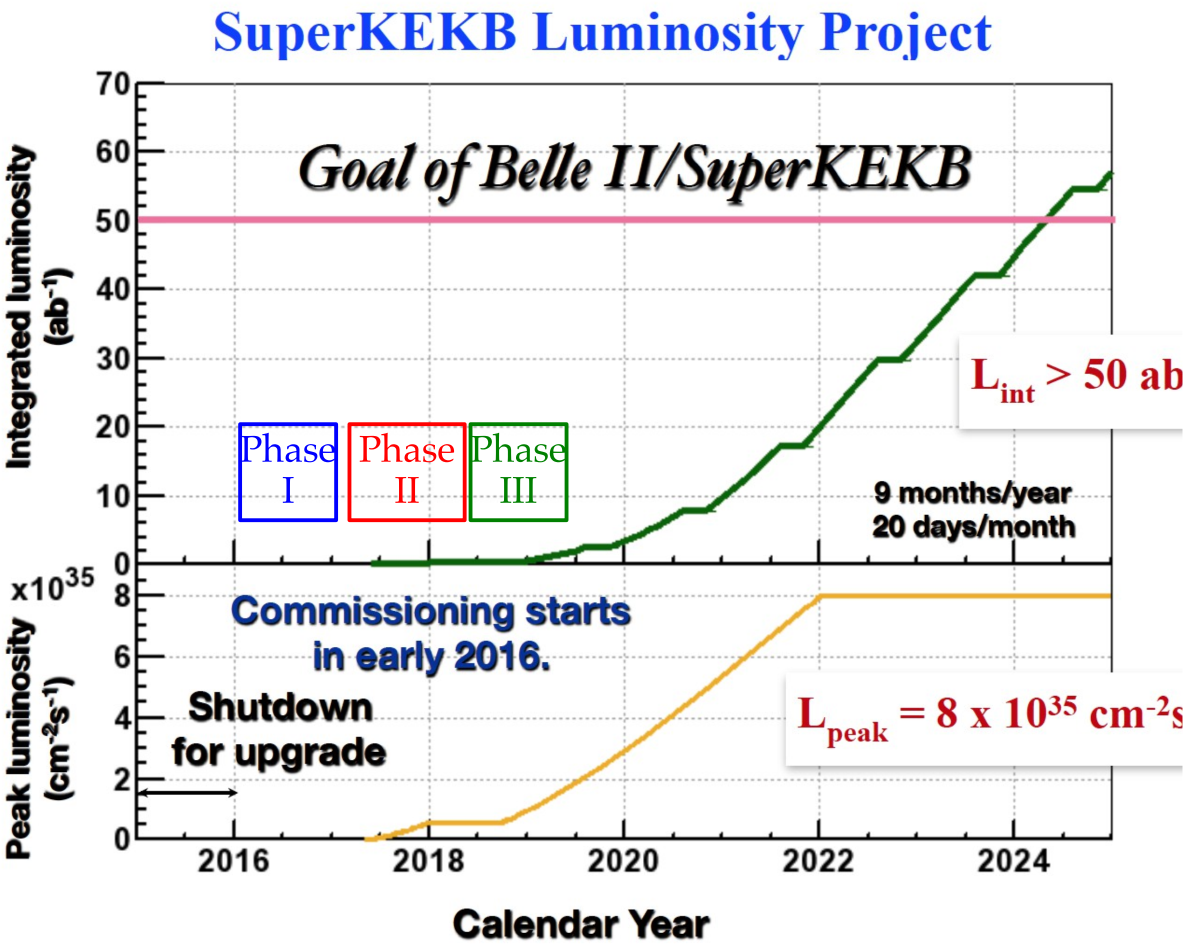
To obtain x40 higher luminosity

Belle-II Schedule

Short Term:
- Phase I (2016-7): detector integration, first beams
- Phase II (2017-8): detector in, no VXD, limited PID, lumi ~ Belle-I

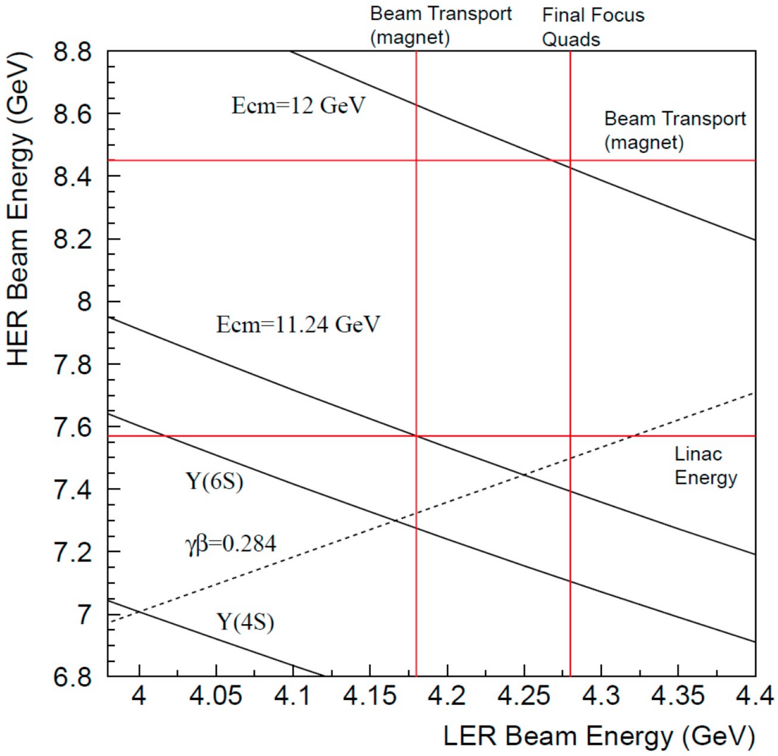
Mid Term:
- Phase III (2018) : full detector , luminosity ramping up

Long Term:

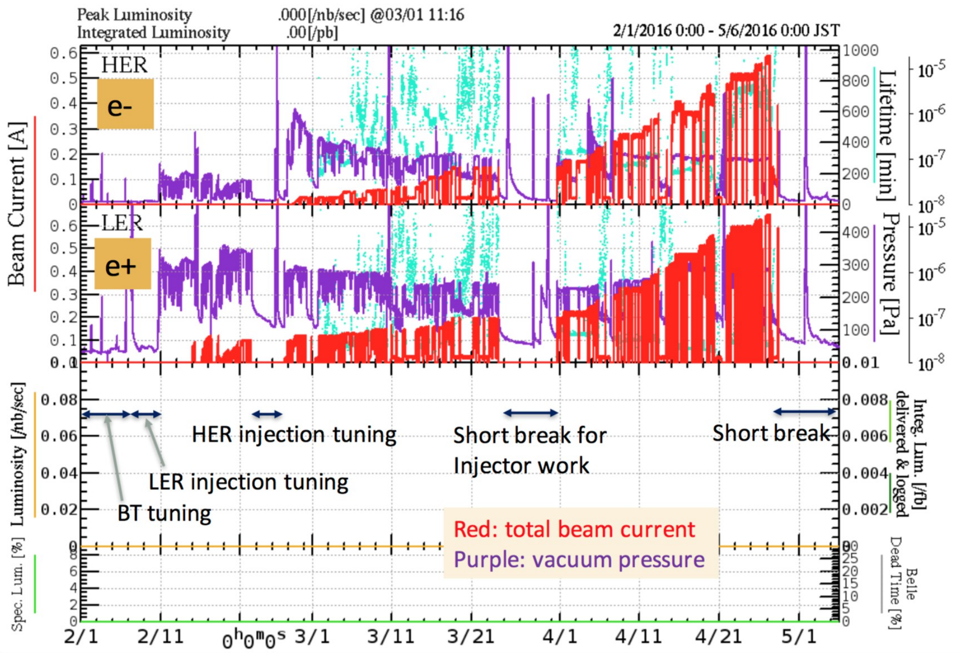


SuperKEK-B goals for Phase-II:
- understand beam backgrounds
- establish conditions for stable operation
- target lumi: 1x10^{34} (0.5xKEKB)

Phase-II operating conditions :
- 4-5 months: machine studies
- *Some* time for physics ($\int$Ldt = 20±20 fb^{-1}) , preferably at energies close to Υ(4S)



KEKB Phase-I



From Funakoshi-san report 2 weeks ago :

- Much faster startup than KEKB
  - KEKB beam currents achieved after first 3 months
    LER: ~300mA, HER: ~200mA
  - SuperKEKB beam currents achieved after first 3 months
    LER: ~650mA, HER: ~590mA
- Compared with KEKB…
  - Each hardware component has been upgraded with experiences at KEK and has worked fine (RF, Magnet, Vacuum…)
  - The bunch-by-bunch feedback system has more effectively suppressed instabilities.
  - Operational tools (such as closed orbit correction system) has worked fine based on experiences at KEKB.
  - Less machine troubles than KEKB so far

Great progress in squeezing the emittance (in ONE week!)

$\varepsilon_y = 96$ pm ($\beta_y = 67$ m@source)
$\varepsilon_y / \varepsilon_x = 5.3$ % ($\varepsilon_x = 1.8$ nm)

March 23, 2016

$\varepsilon_y = 280$ pm ($\beta_y = 9.7$ m@source)
$\varepsilon_y / \varepsilon_x = 5.3$ % ($\varepsilon_x = 5.3$ nm)

April 5, 2016

$\varepsilon_y = 20$ pm ($\beta_y = 67$ m@source)
$\varepsilon_y / \varepsilon_x = 1.1$ % ($\varepsilon_x = 1.8$ nm)

Target vertical emittance in Phase 1 is 10pm.

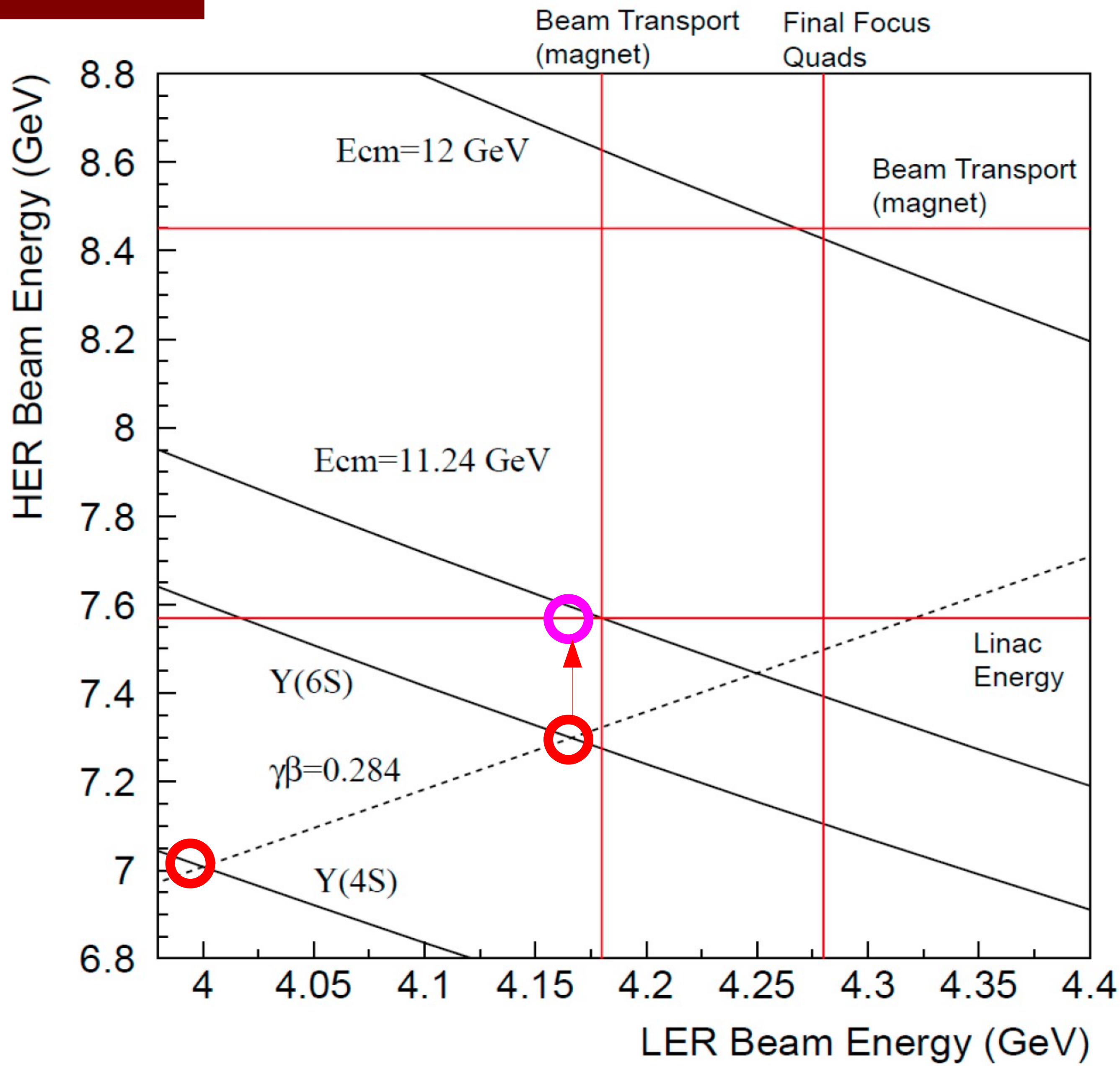
Super KEKB limitations

Y(6S) peak energy can be reached keeping the same beam asymmetry (i.e. the same boost) used for standard running at Y(4S)

The LER beam is limited by magnets in the beam transport line.

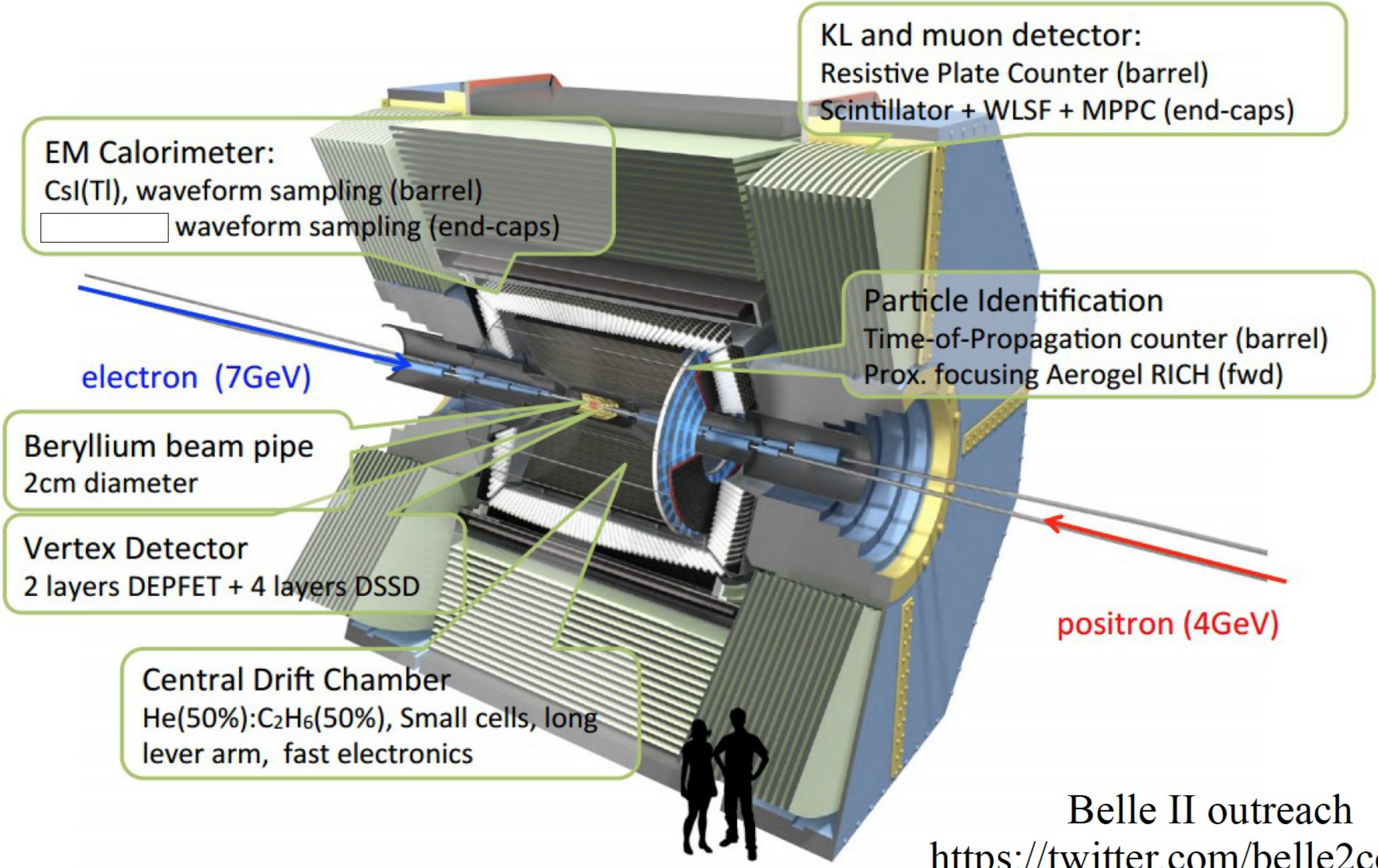
To reach Ecm=11.24 GeV ($\bar{\Lambda}_c\Lambda_c$ threshold) we can increase HER energy only, up to 7.55 GeV. (max Linac Energy)

$\bar{B}_c B_c$ threshold: 12.55 GeV



Belle-II Detector

[Belle II TDR, KEK Report 2010-1]



KL and muon detector:
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (end-caps)

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
waveform sampling (end-caps)

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

electron (7GeV)

Beryllium beam pipe
2cm diameter

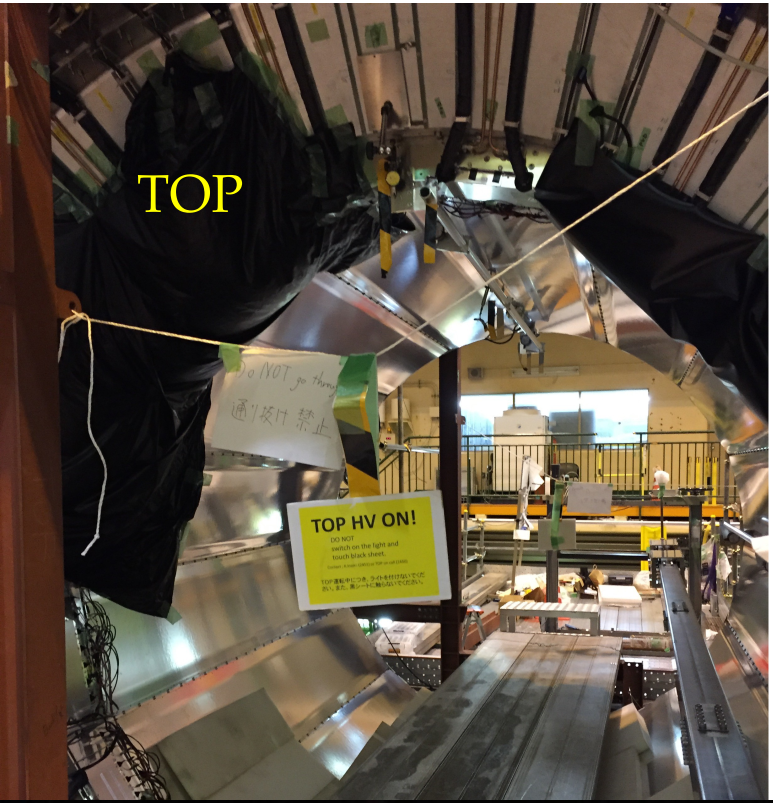
Vertex Detector
2 layers DEPFET + 4 layers DSSD

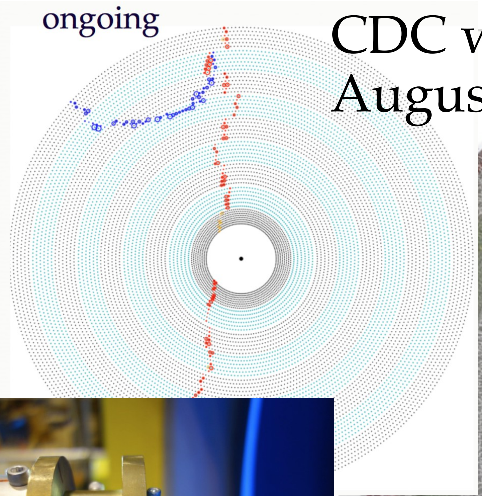
positron (4GeV)

Central Drift Chamber
He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

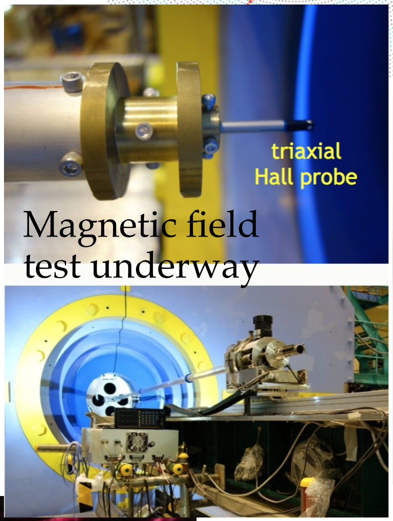
Belle II outreach
https://twitter.com/belle2collab/
https://www.facebook.com/belle2collab/

Belle-II commissioning

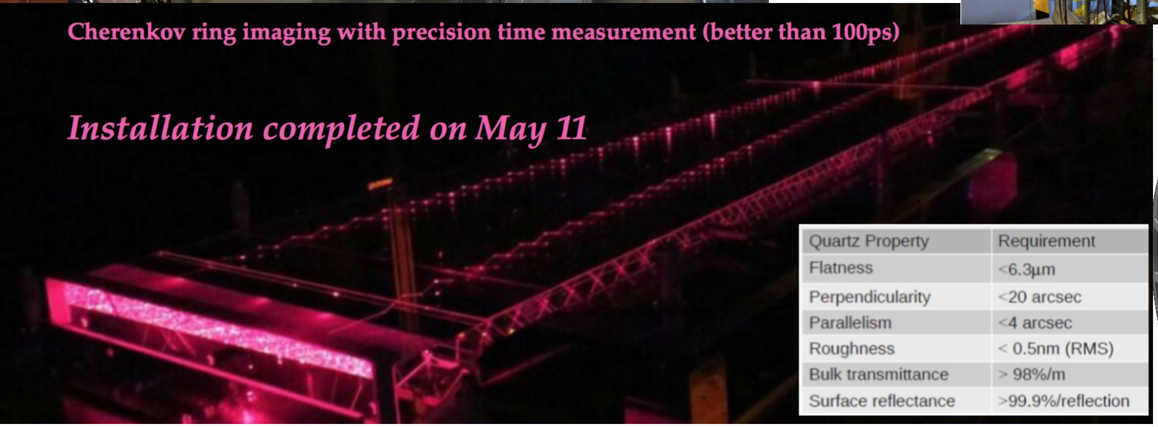




CDC will be installed in August



Magnetic field test underway

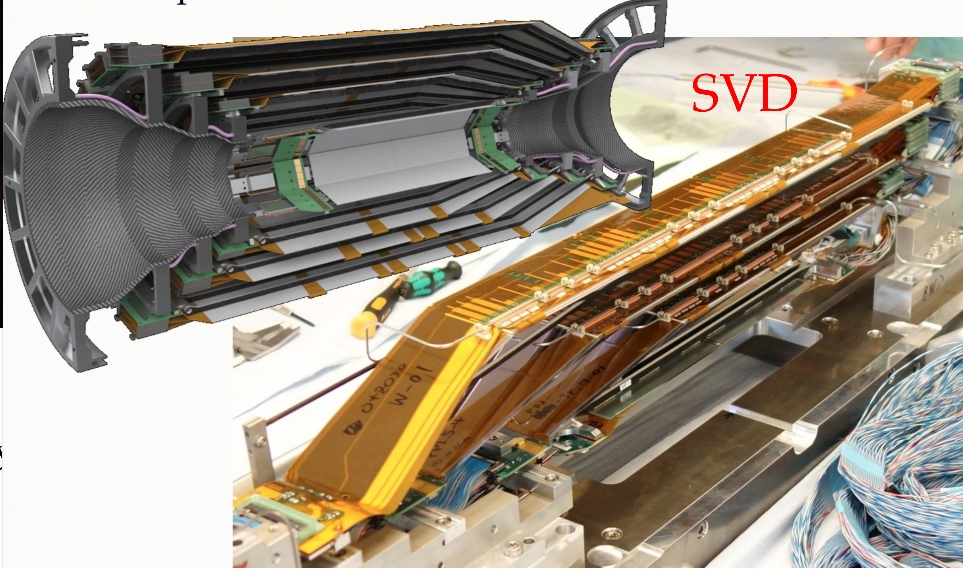


Cherenkov ring imaging with precision time measurement (better than 100ps)

Installation completed on May 11

Quartz Property	Requirement
Flatness	<6.3μm
Perpendicularity	<20 arcsec
Parallelism	<4 arcsec
Roughness	< 0.5nm (RMS)
Bulk transmittance	> 98%/m
Surface reflectance	>99.9%/reflection

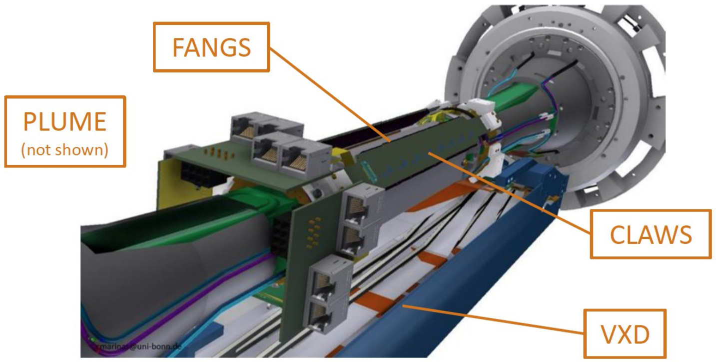
- A complete ladder set of SVD was tested in DESY

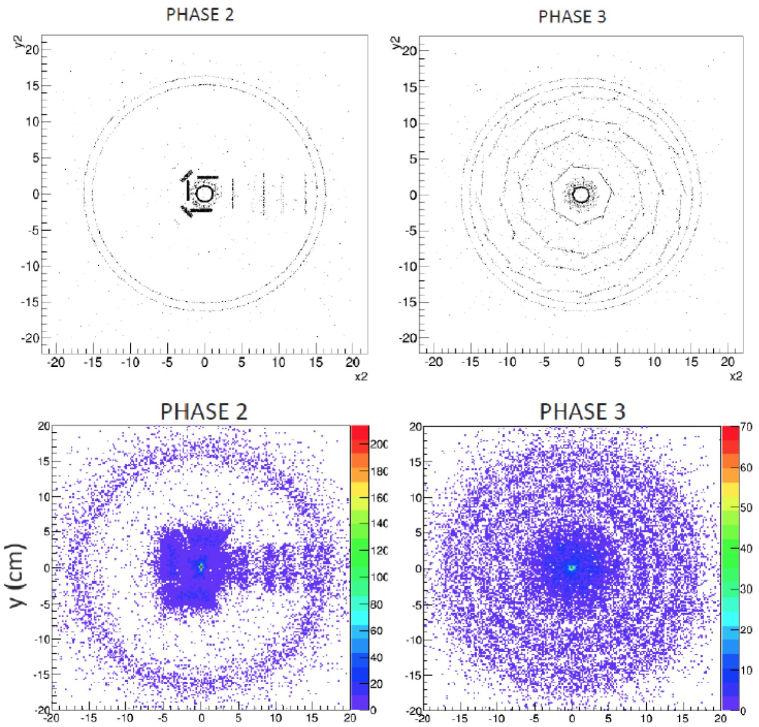


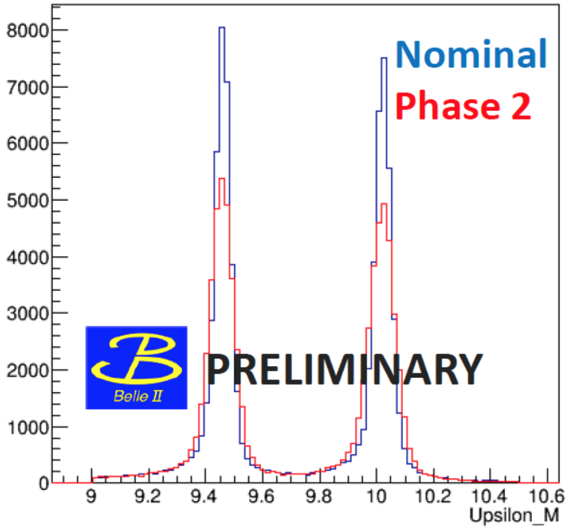
Phase II Tracking

During Phase-II we can do physics with limited performance: the inner region will be equipped with BEAST-2 sensors, to monitor beam backgrounds and test the final SVD detectors.

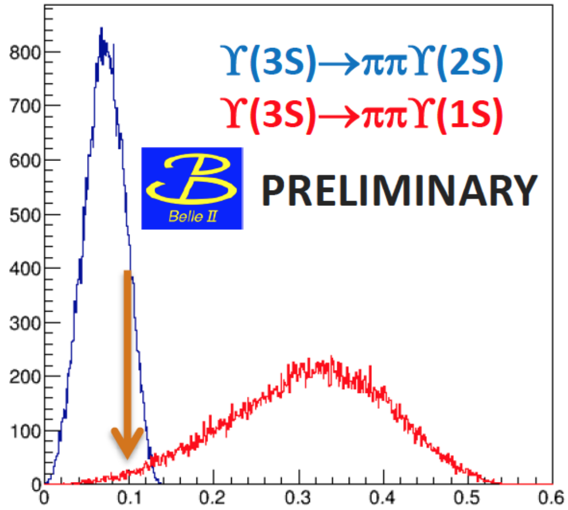
No low momentum tracking (slow pions do not cross all CDC layers)



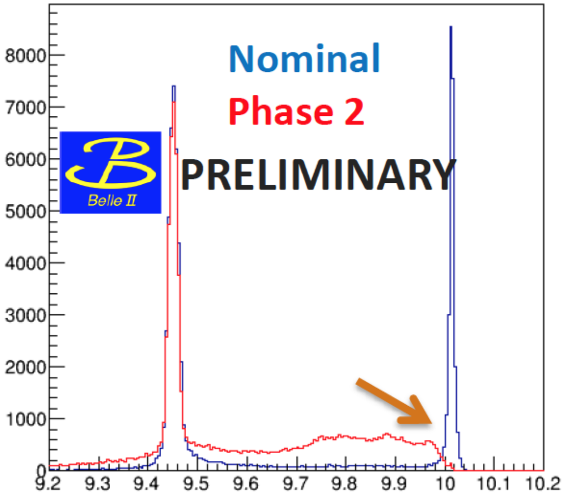




m(Υ(1S,2S) → μμ)



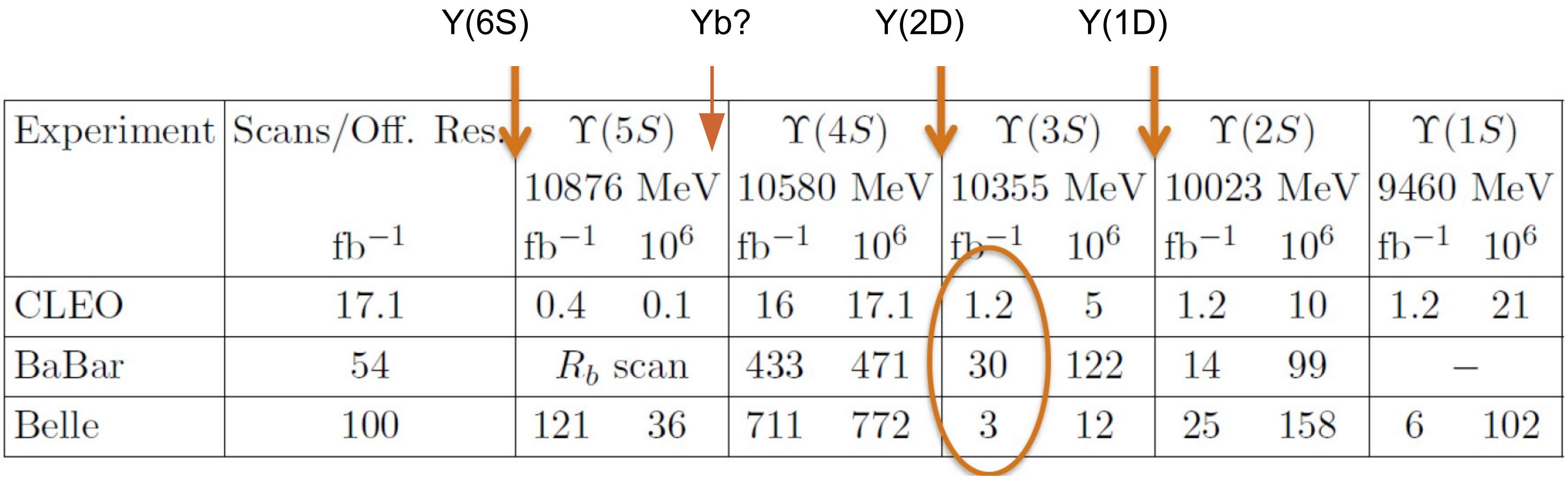
Υ(3S) → ππ Υ(pS)(μμ)
Minimum pion momentum



M(ππ) recoil mass

First question: where to run

Energy	Outcome	Lumi (fb^{-1})	Comments
ϒ(1S) On	N/A	60+	-No interest identified -Low energy
ϒ(2S) On	New physics searches	20+	-Requires special trigger
ϒ(1D) Scan	Particle discovery	10-20	-Already accessible in B Factories?
ϒ(3S) On	Many -onia topics	200+	-Known resonance -Luminosity requirement: Phase 3
ϒ(3S) Scan	Precision QED	~10	-Understanding of beam conditions needed
ϒ(2D) Scan	Particle discovery	10-20	-Unknown mass
>ϒ(4S) On	Particle discovery?	10+?	-Energy to be determined
ϒ(6S) On	Particle discovery?	30+?	-Upper limit of machine energy
Single γ	New physics?	30+	-Special triggers required



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

Scenarios for Phase-II

Where to run for Ldt ~ 10 fb^{-1}?

- E = 10.65 GeV

Dip in Rb , just on B*B* threshold

- E = 10.75 GeV

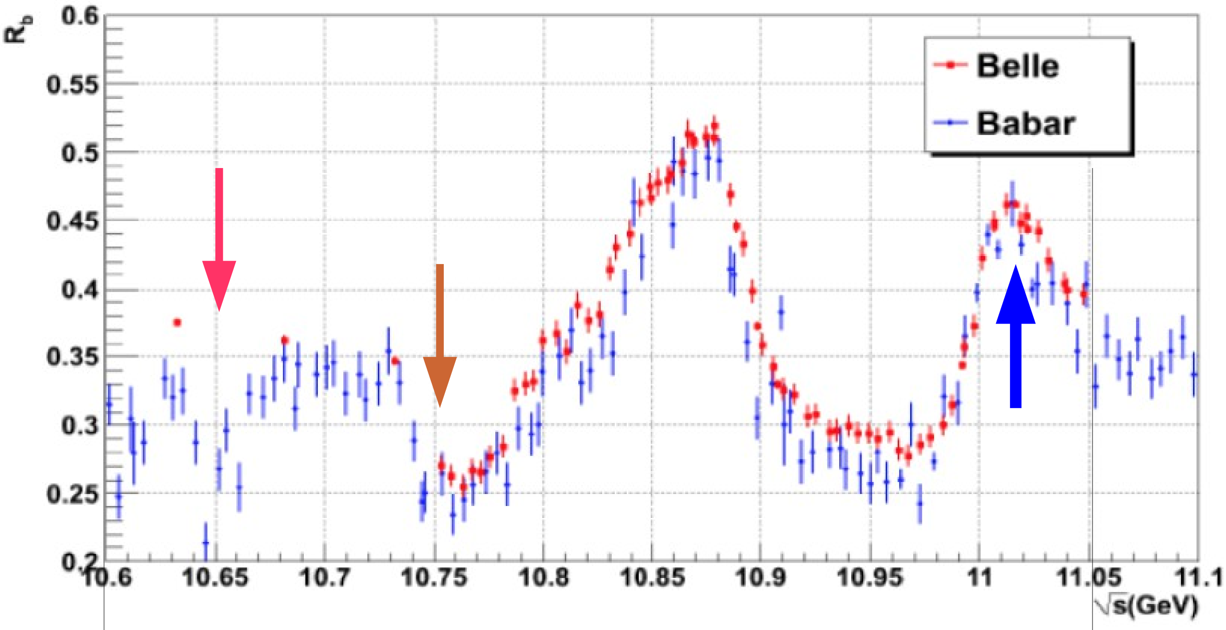
Above Rb drop at 10.74

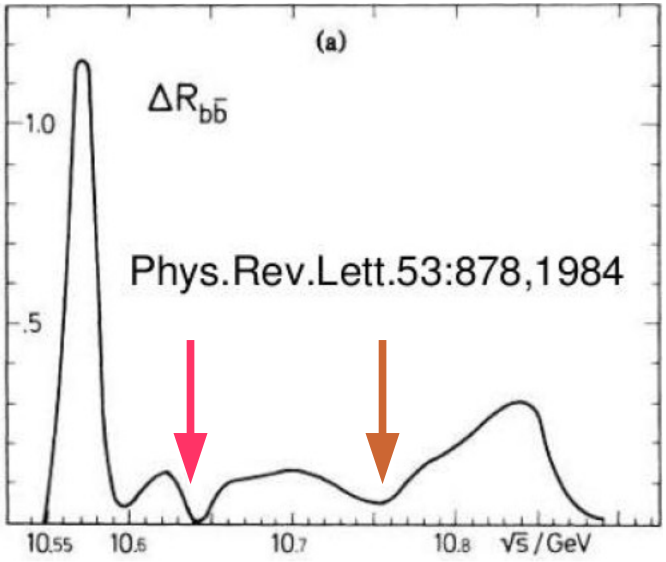
Bump observed in R_Υ

- E = 11.02 GeV

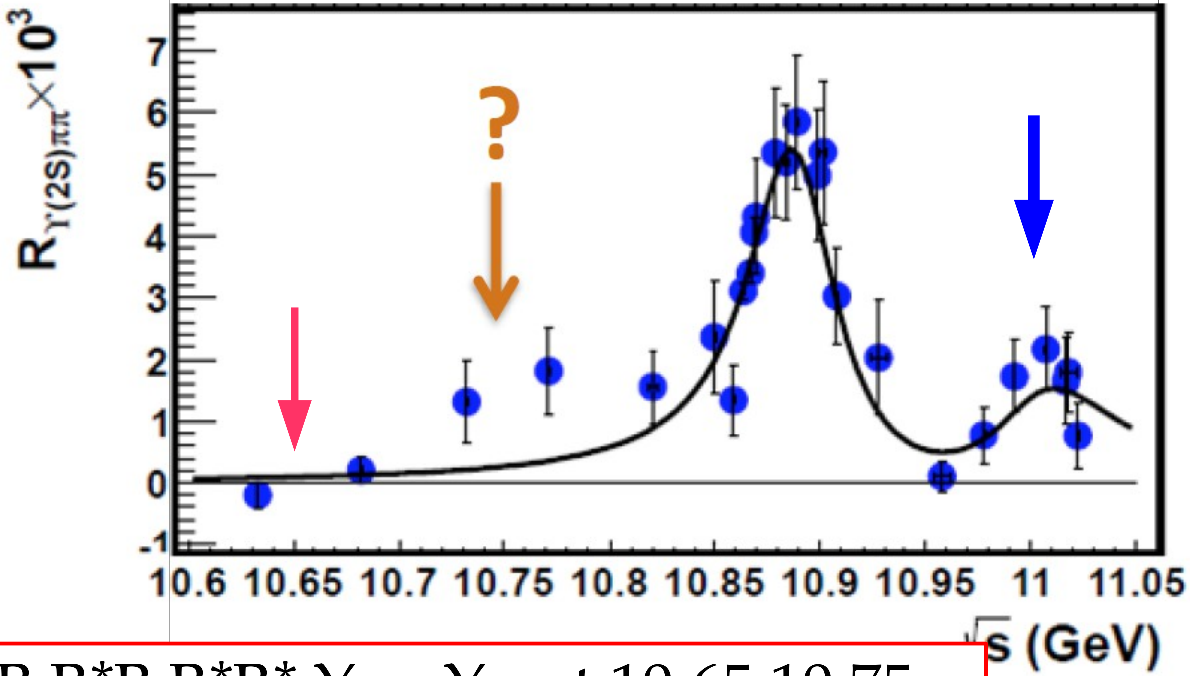
Υ(6S) peak,

6pt scan (1 fb^{-1} each) in Belle-I





Phys.Rev.Lett.53:878,1984

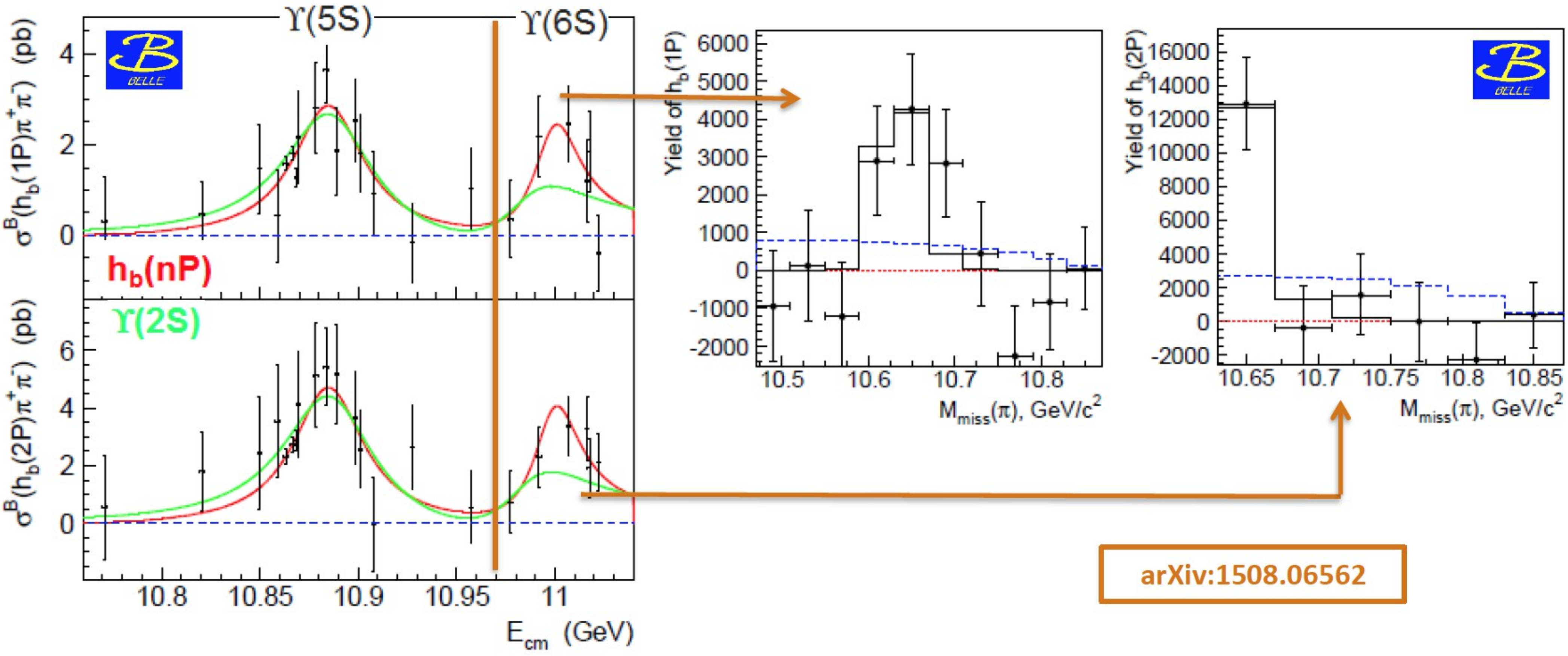


Study these channels: BB,B*B,B*B*,Υππ,Υη at 10.65,10.75

Υ(6S) results in Belle-I

See Mizuk's talk on wednesday

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

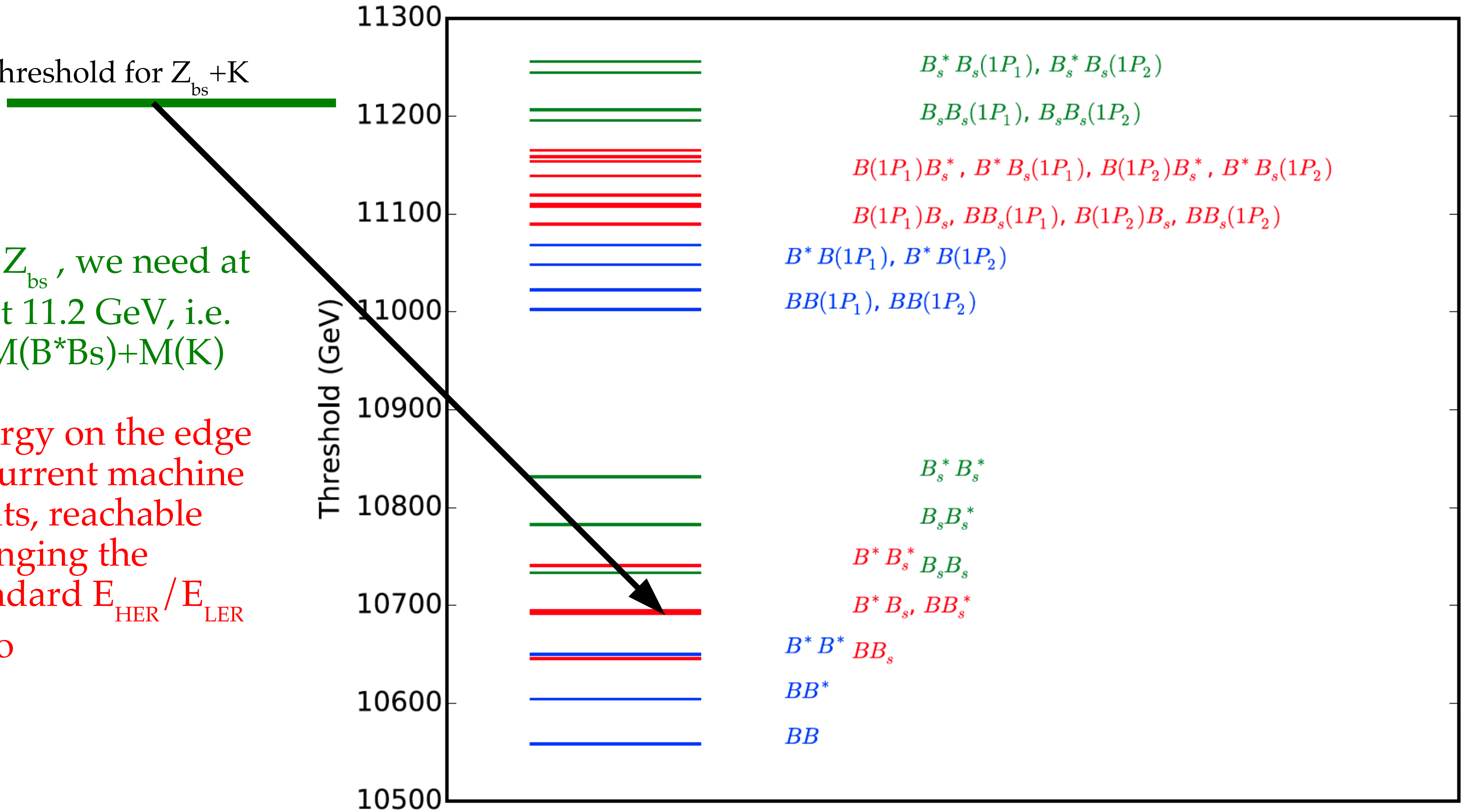


arXiv:1508.06562

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

Z_{bs} *searches in Belle-II*

Threshold for Z_{bs}+K



For Z_{bs} , we need at least 11.2 GeV, i.e. E>M(B*Bs)+M(K)

Energy on the edge of current machine limits, reachable changing the standard E_{HER}/E_{LER} ratio

Access to lower bottomonia limited to h_b(1P) and Y(1,2S)

Spectrum below threshold

Below threshold:

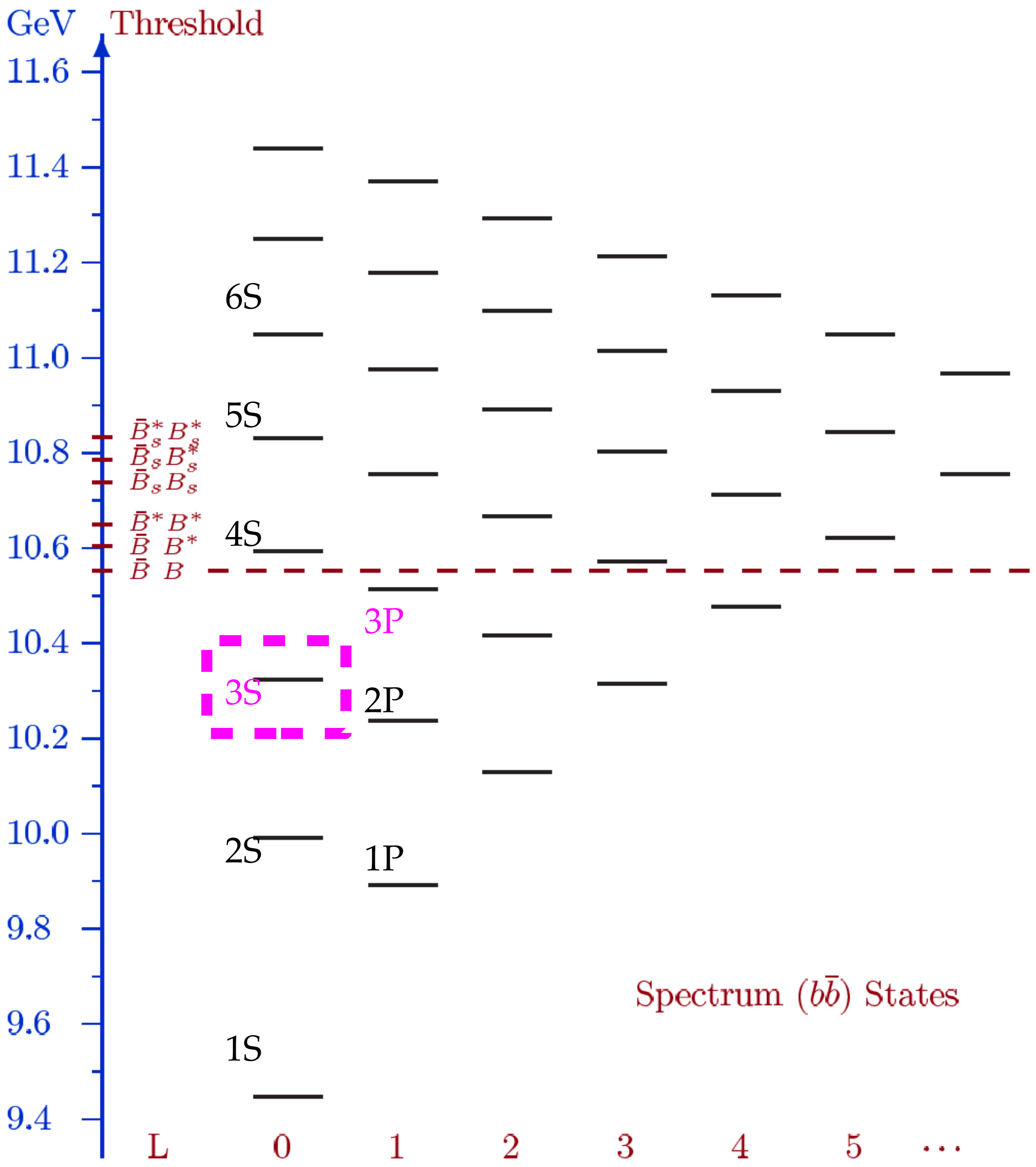
* 3S: $\eta_b(3S)$ not yet observed by anyone, maybe reachable from $h_b(3P)$?

* 3P: $\chi_b(3P)$ discovered at LHC, not yet resolved, can we see them from 4S?

$h_b(3P)$: too high to be reached from 5S via Z_b, maybe from 6S? How?

* 1D states : triplet states BEST STUDIED from 3S, singlet (2^{-+}) *maybe* reachable from $h_b(2P)$

* 2D, 1F, 1G: totally unknown
We propose to search for the lowest member of the 2D triplet with a scan.
The others *may* be reached from 6S.
The 1F triplet $2,3,4^{++}$ is very close in mass to Y3S, but may be reached from the 2D triplet via E1 radiative transitions.



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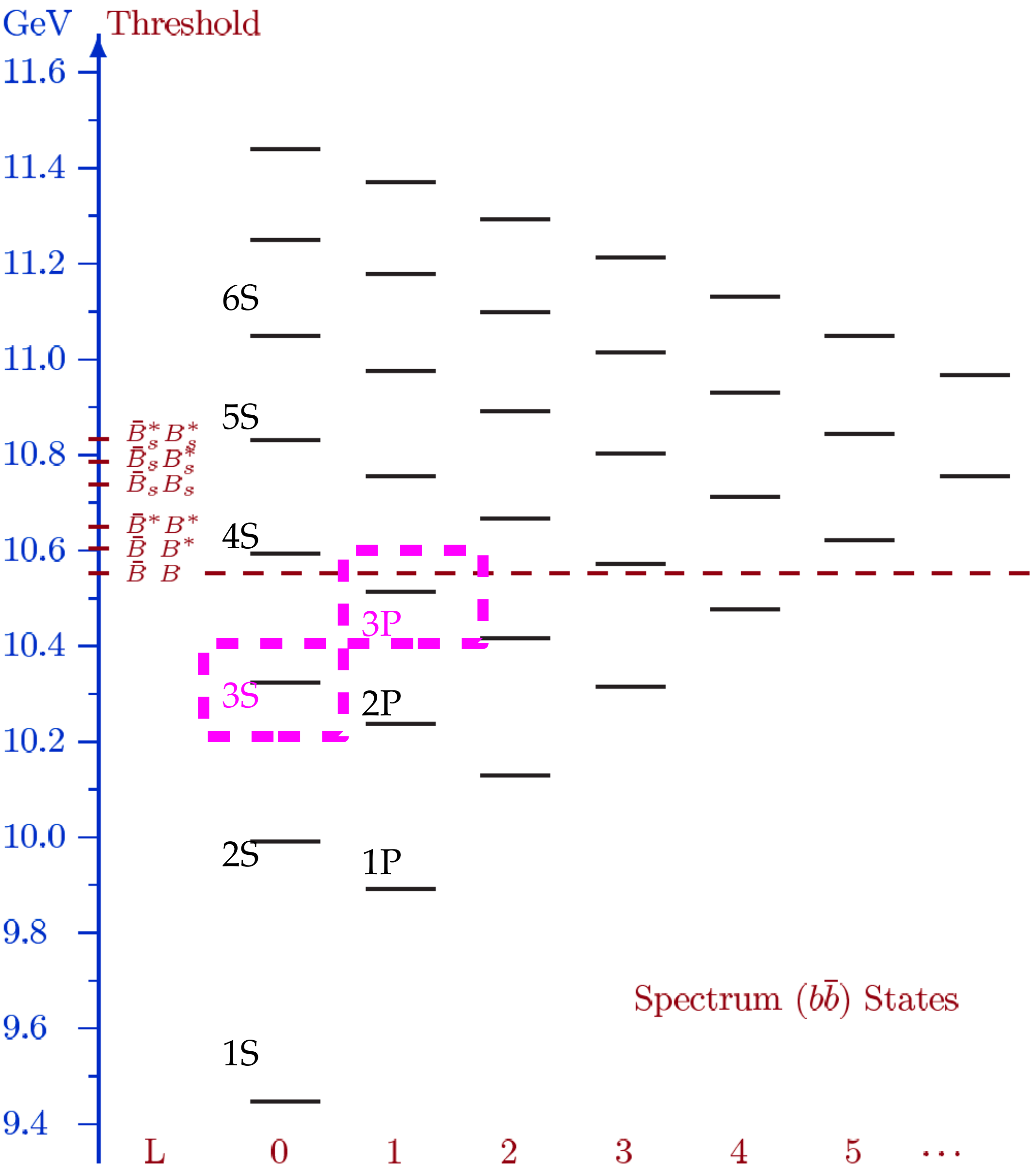

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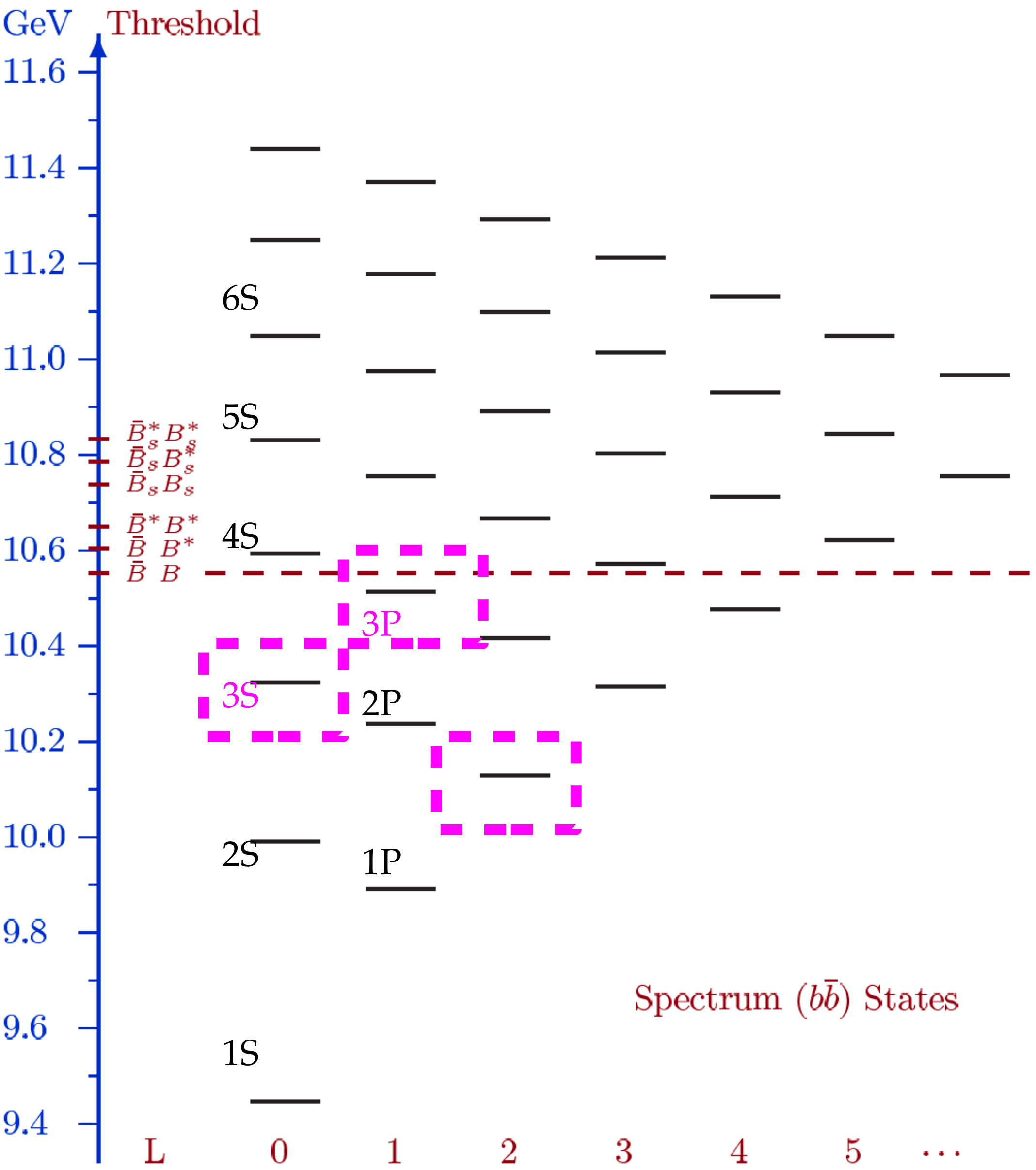

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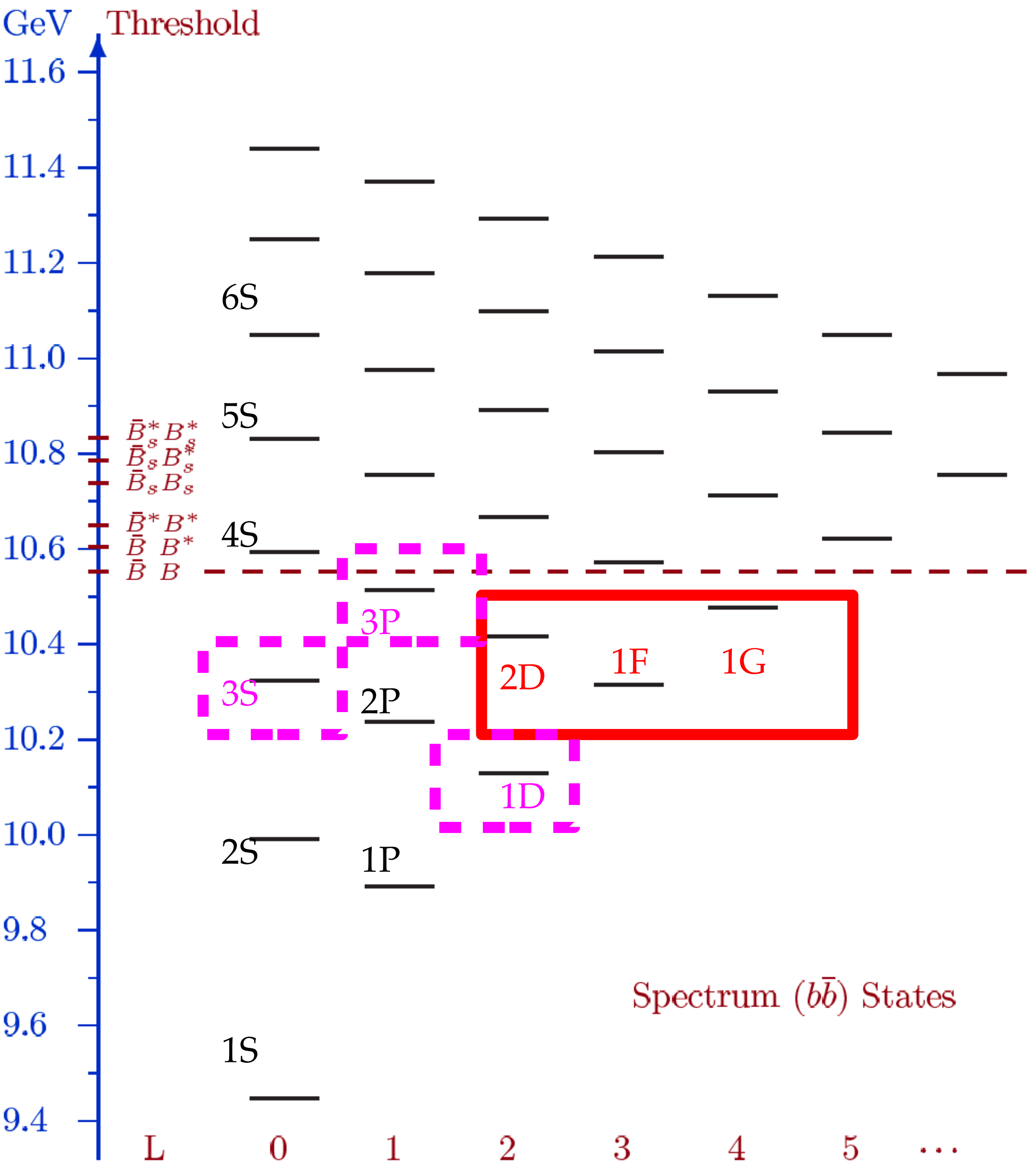
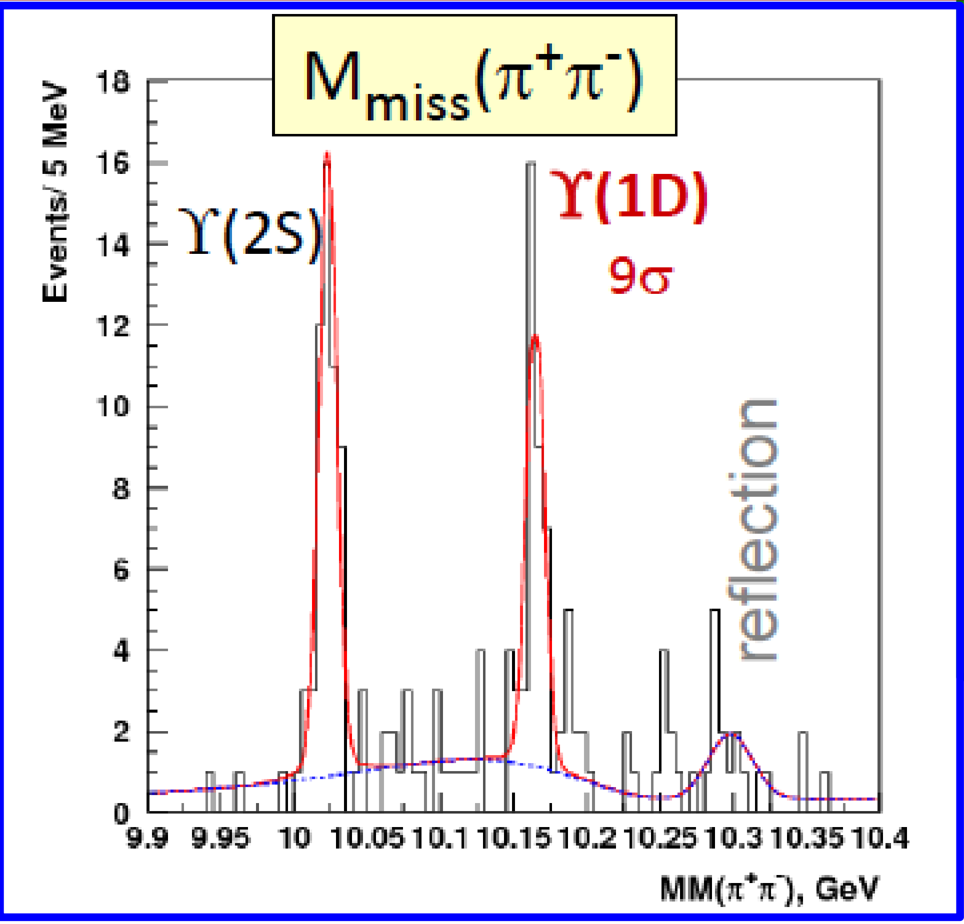
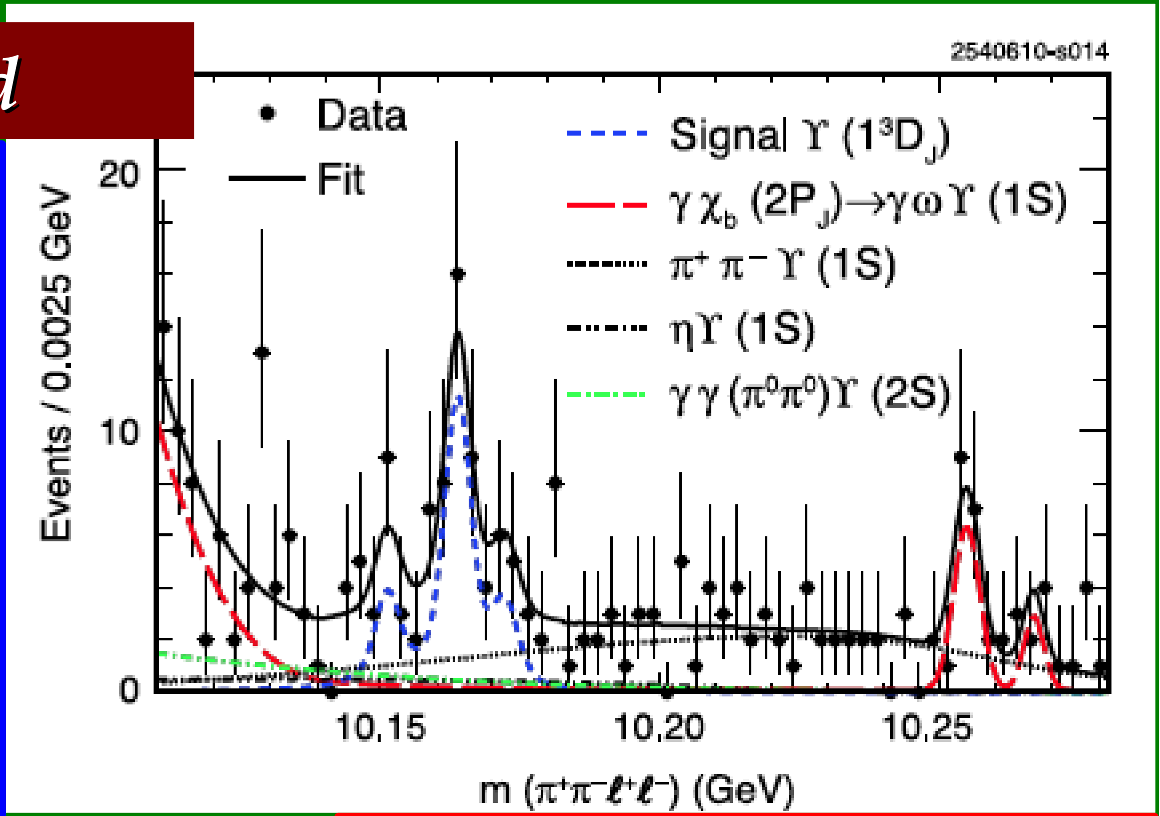
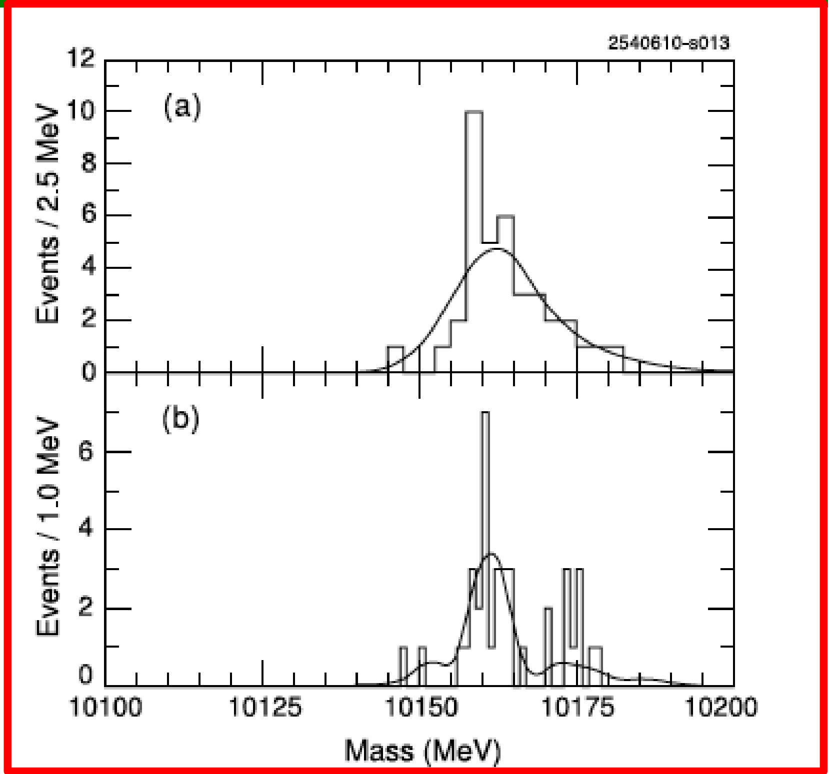


Υ(1D) triplet still unresolved





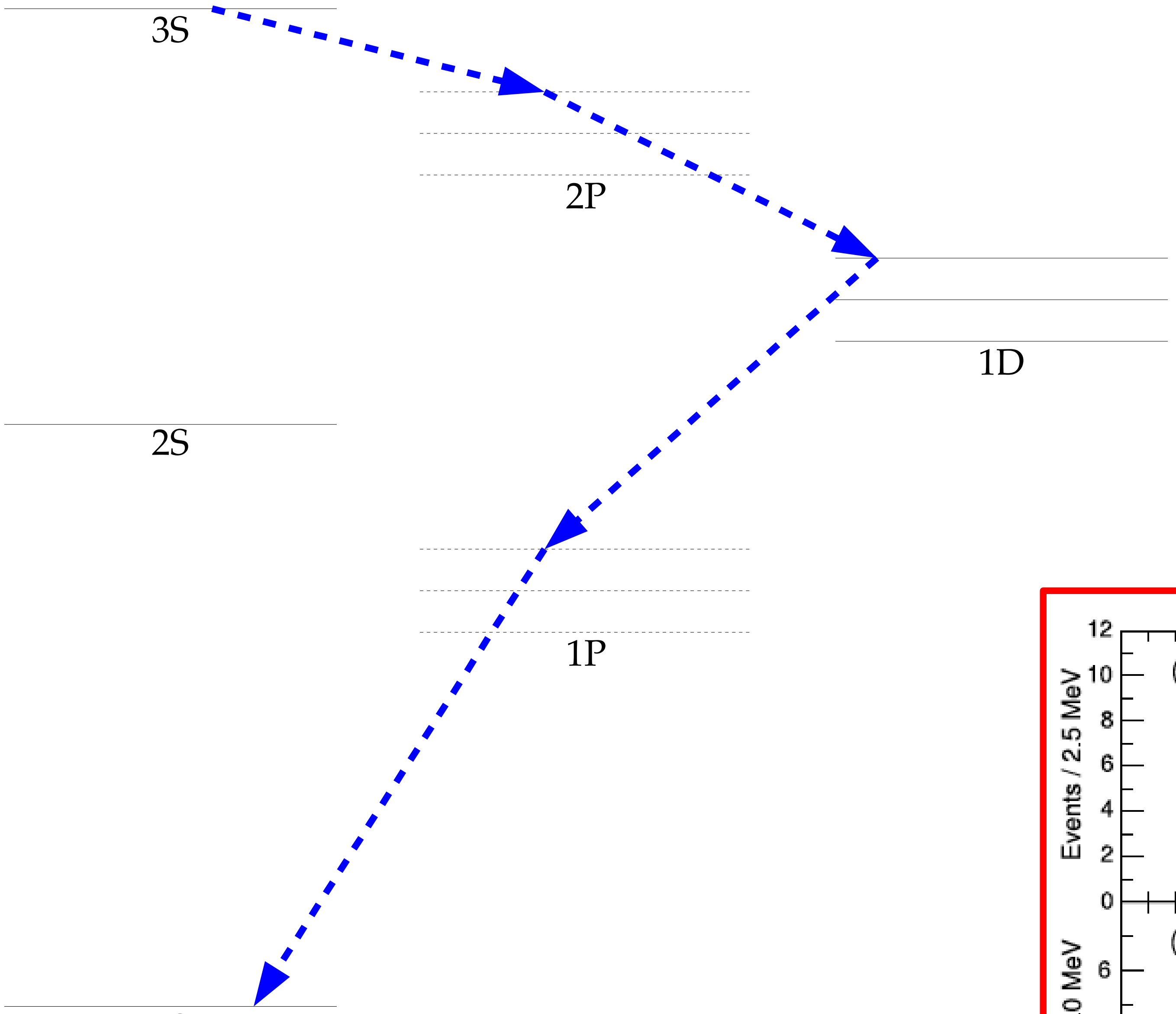


Belle (from 5S) $10164.7 \pm 1.4 \pm 1.0$ MeV

BaBar (from 3S) $10164.5 \pm 0.8 \pm 0.5$ MeV

CLEO (from 3S) $10161.1 \pm 0.6 \pm 1.6$ MeV

Four photon cascades



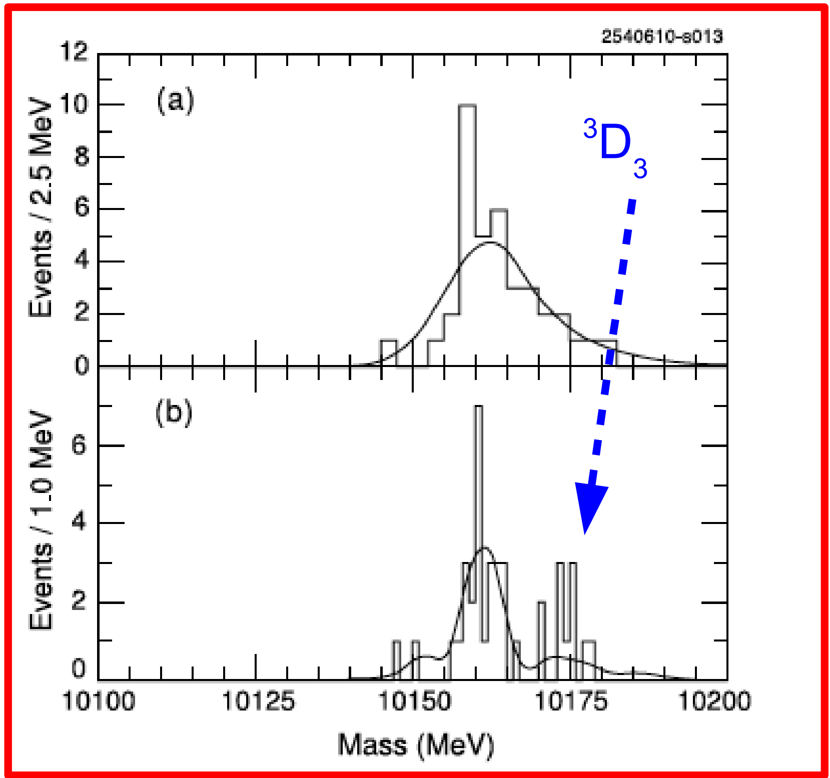
Event yields with 1G
Y(3S) decays
Godfrey,Moats
PR D92, 054034 (2015)

6.8k $^3D_3$ via 2,2 only

19 k $^3D_2$

- 15 k $^3D_2$ via 1,1
- 2.5k $^3D_2$ via 1,2
- 1.6k $^3D_2$ via 2,1

2.4k $^3D_1$ via 2,1



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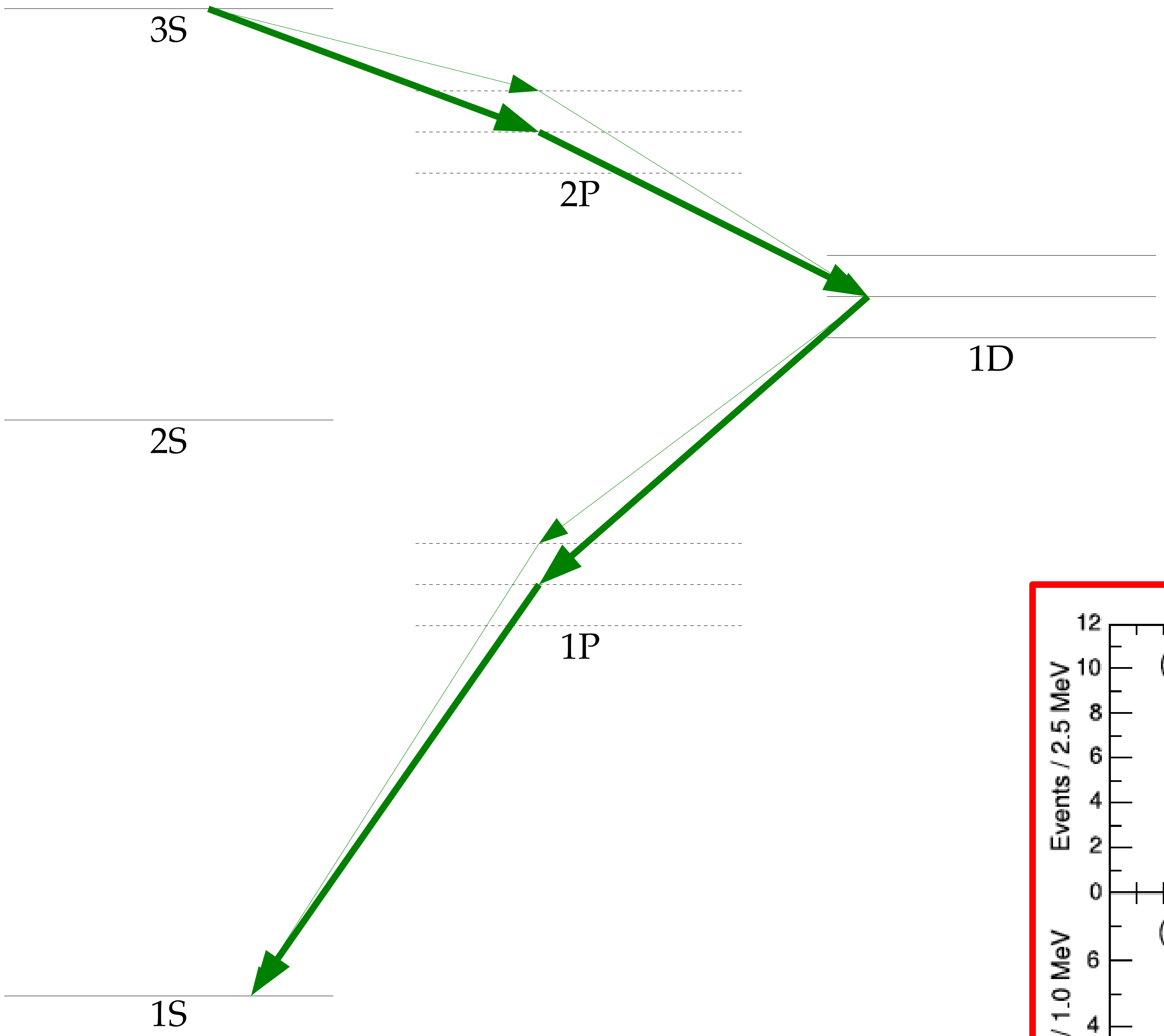

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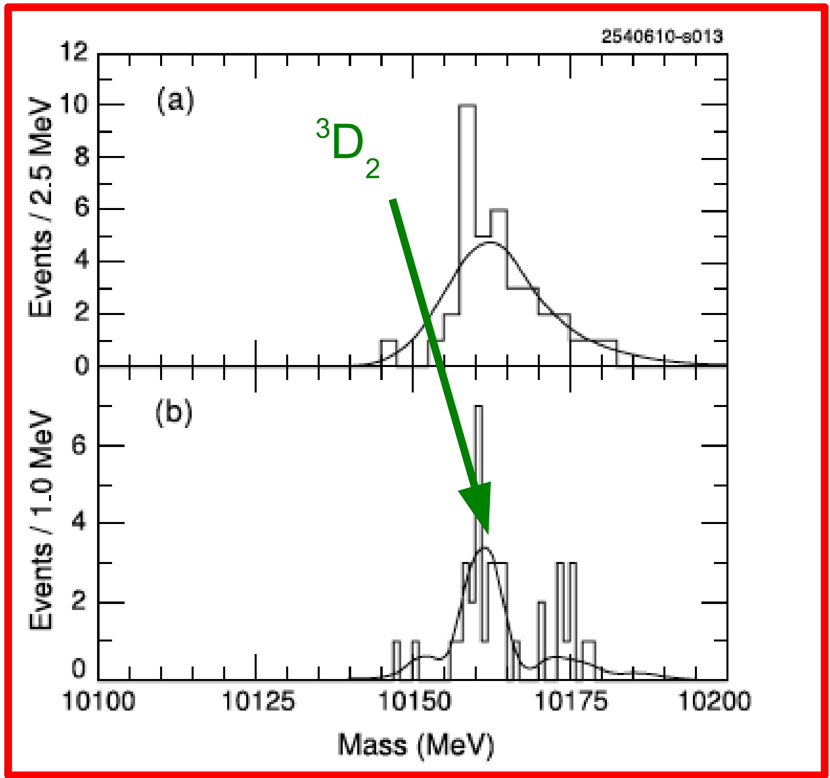
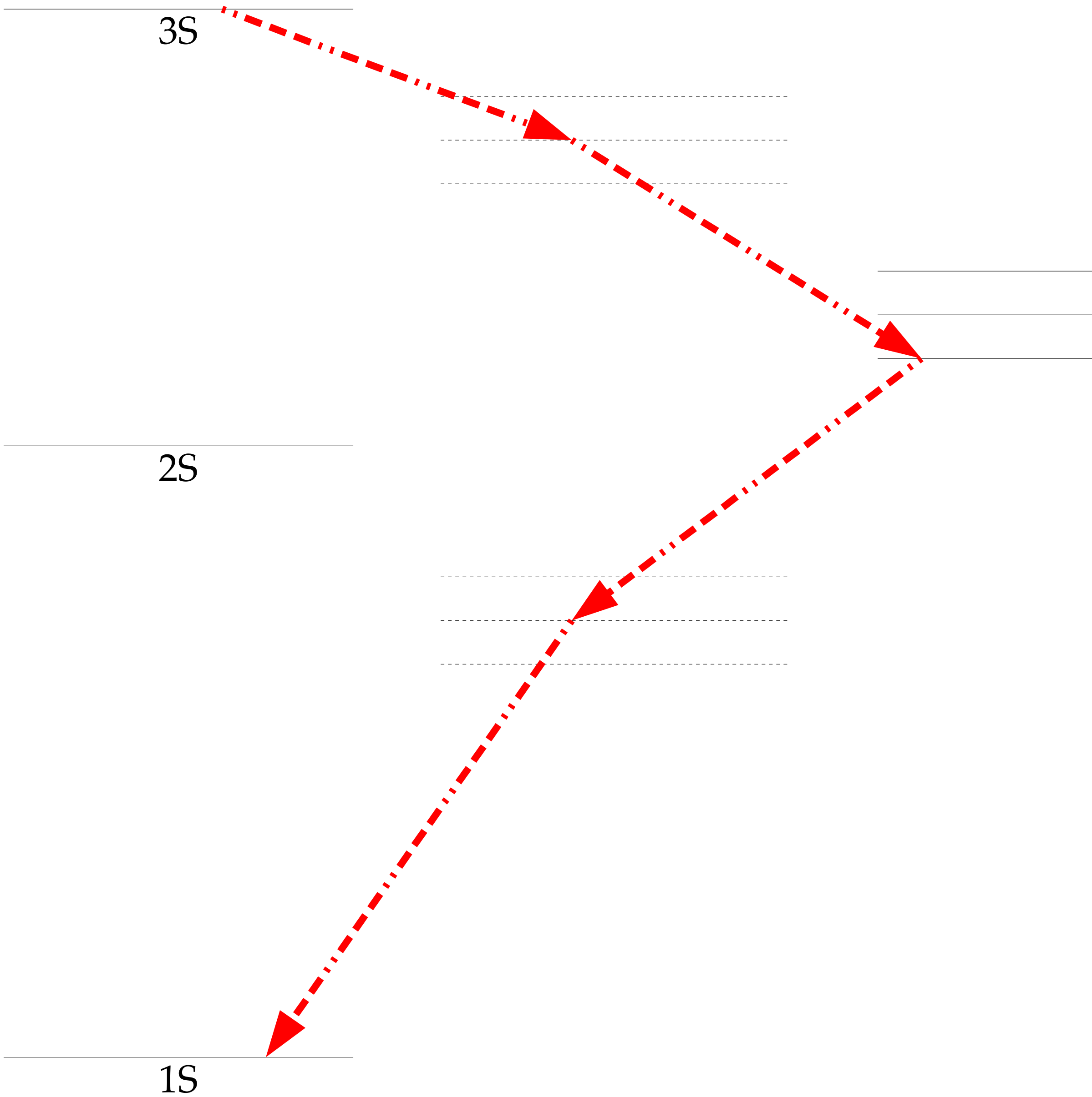


Four photon cascades

Event yields with 1G Υ(3S) decays
(assuming Υ(1S) decay to μμ)

Godfrey,Moats
PR D92, 054034 (2015)



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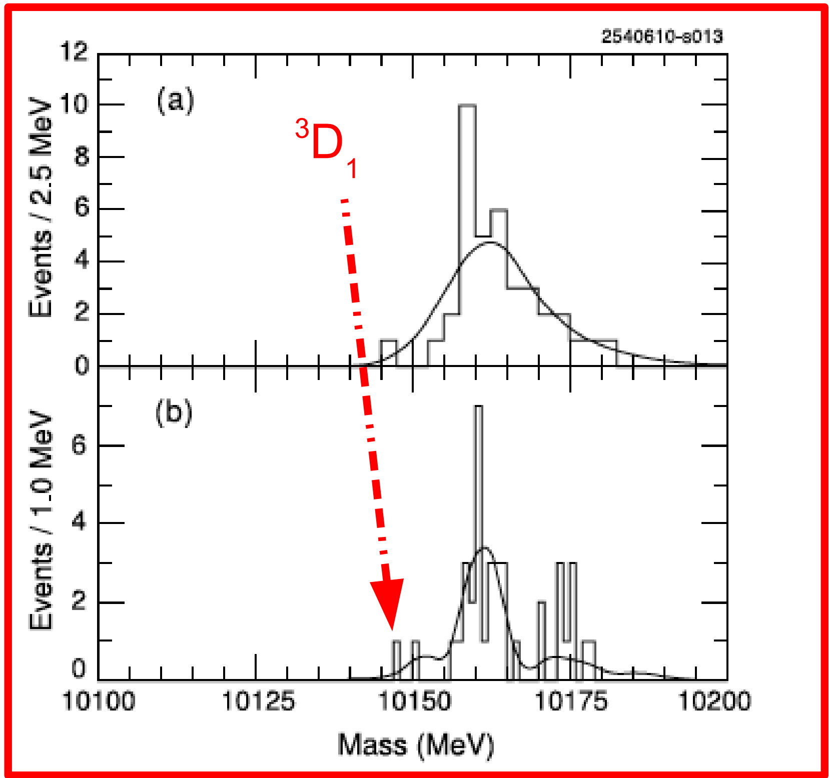

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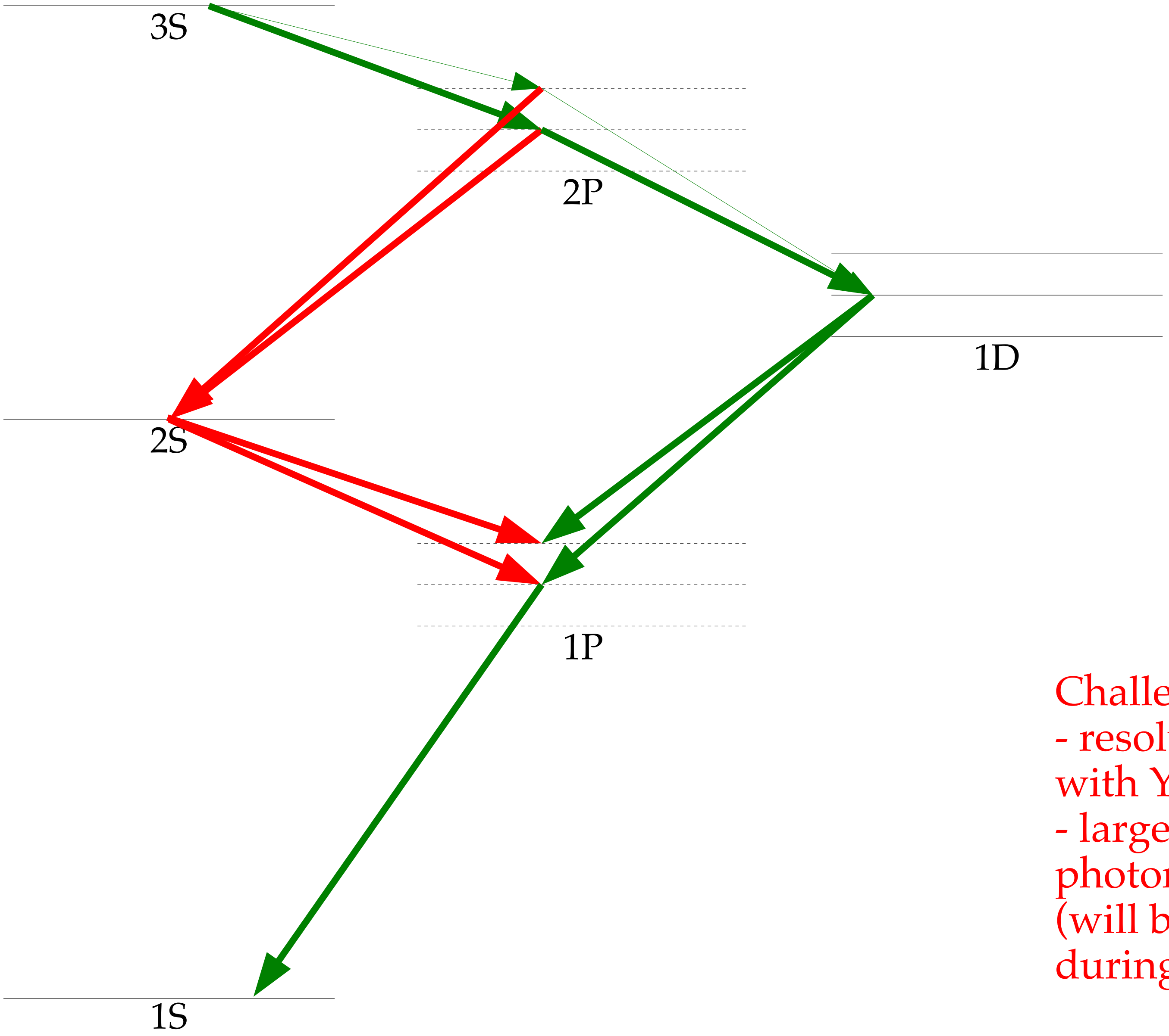

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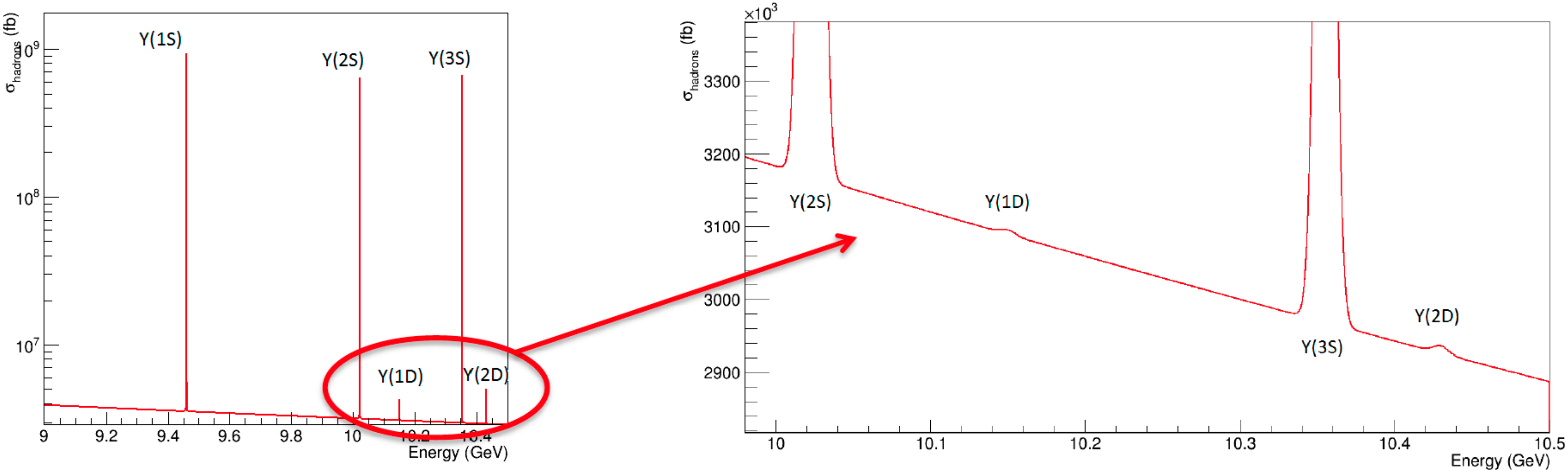
1.6k $^3D_2$ via 2,1
2.4k $^3D_1$ via 2,1

Challenges:
- resolve ambiguities with Y(2S)
- large uncorrelated photon backgrounds (will be measured during Phase-II)

Scanning $Y(1,2^3D_1)$?

Observable : e+e- to hadrons

Continuum cross section: $\sigma = N_c Q_f^2 \frac{86.8\ \mathrm{nb}}{s\,(\mathrm{GeV}^2)}$



Search for 1D: 7 point scan (5 MeV steps) around 10.15 GeV

Search for 2D: 7 point scan (5 MeV steps?) around 10.43 GeV

IF the 2S scan is successful, we may envisage a longer run on 2D peak and search for 1F states (single photon spectrum, probably large background from ISR Y(3S))

Dipion transitions: BELLE-II vs Babar

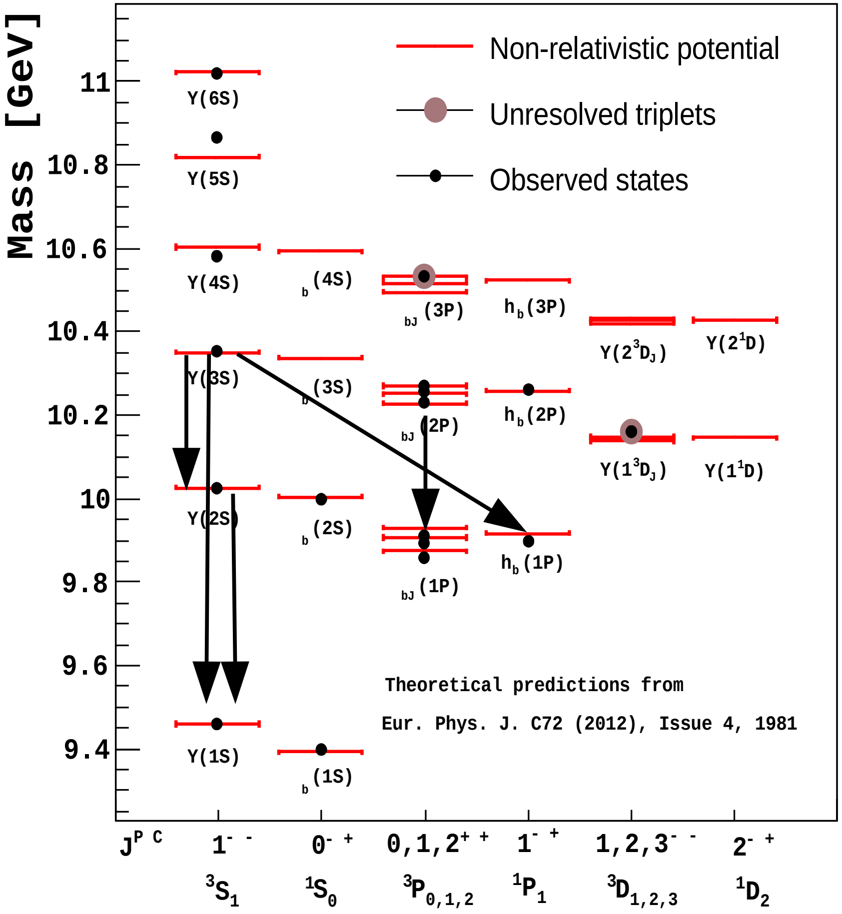
Babar: two analyses:

- **Aubert et al., PRD78, 112002 (2008)**

Using data from Y(4S): ISR exclusive decays

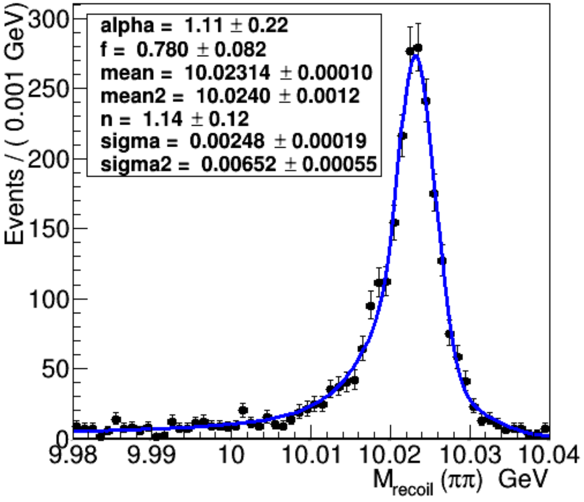
- **Lees et al, PRD84, 011104 (2011)**

Inclusive dipion transitions from 108 M Y(3S)

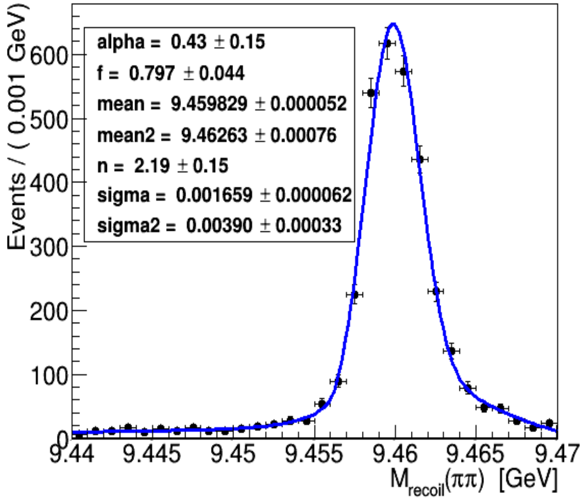


Tamponi @ B2TIP2016

Y(3S) → Y(2S) MC



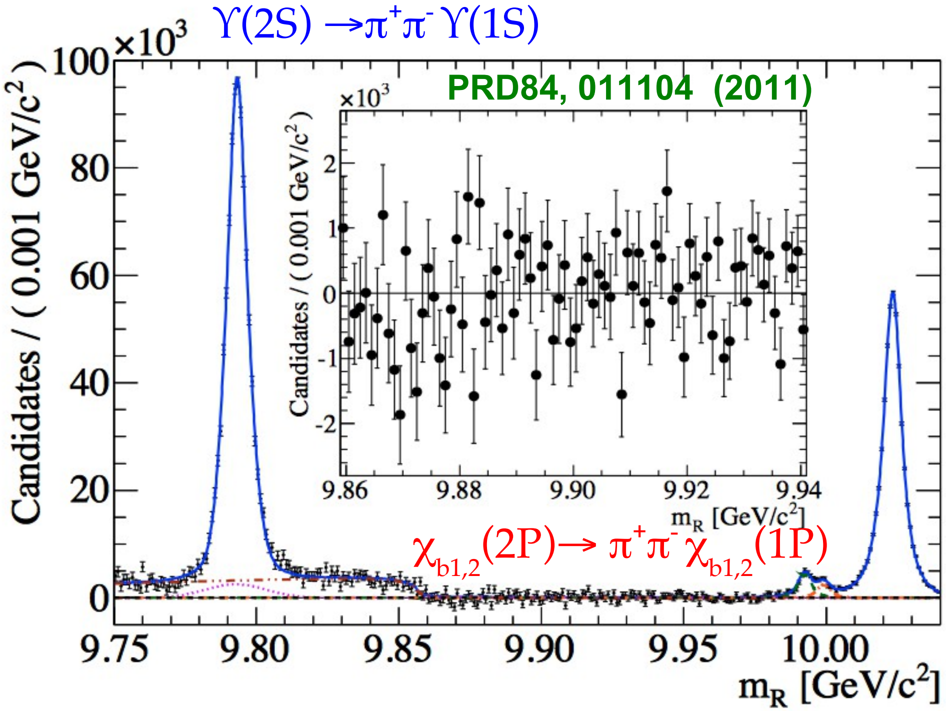
Y(3S) → Y(1S) MC

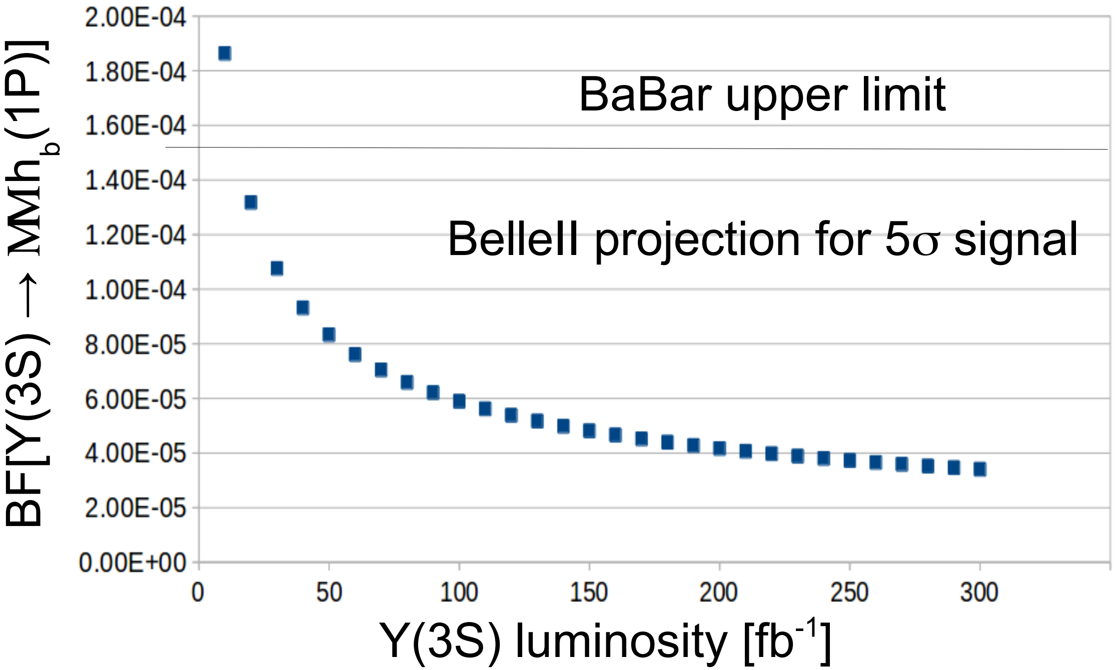


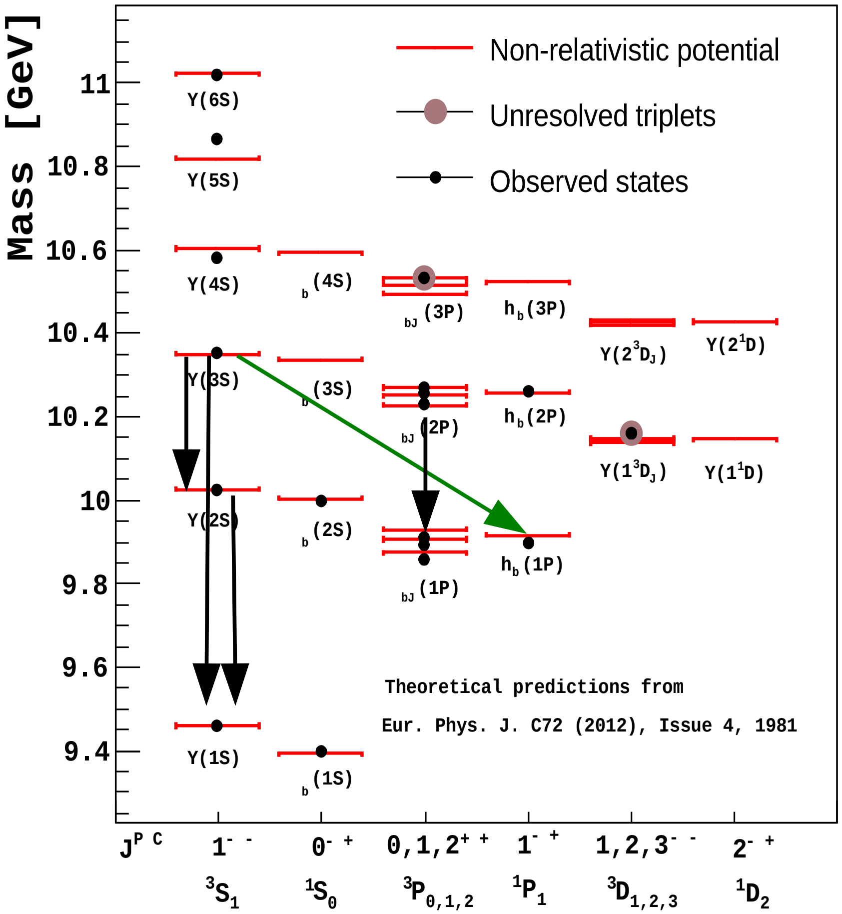
Better resolution and better efficiency

	BaBar σ	BaBar ε	BelleII σ	BelleII ε
Y(3S) → Y(2S)	~4 MeV	16.7 %	2.5 MeV	45%
Y(3S) → Y(1S)	< 4 MeV	41.8%	1.8 MeV	63%

$\Upsilon(3S) \rightarrow \pi^+\pi^2 h_b(1P)$



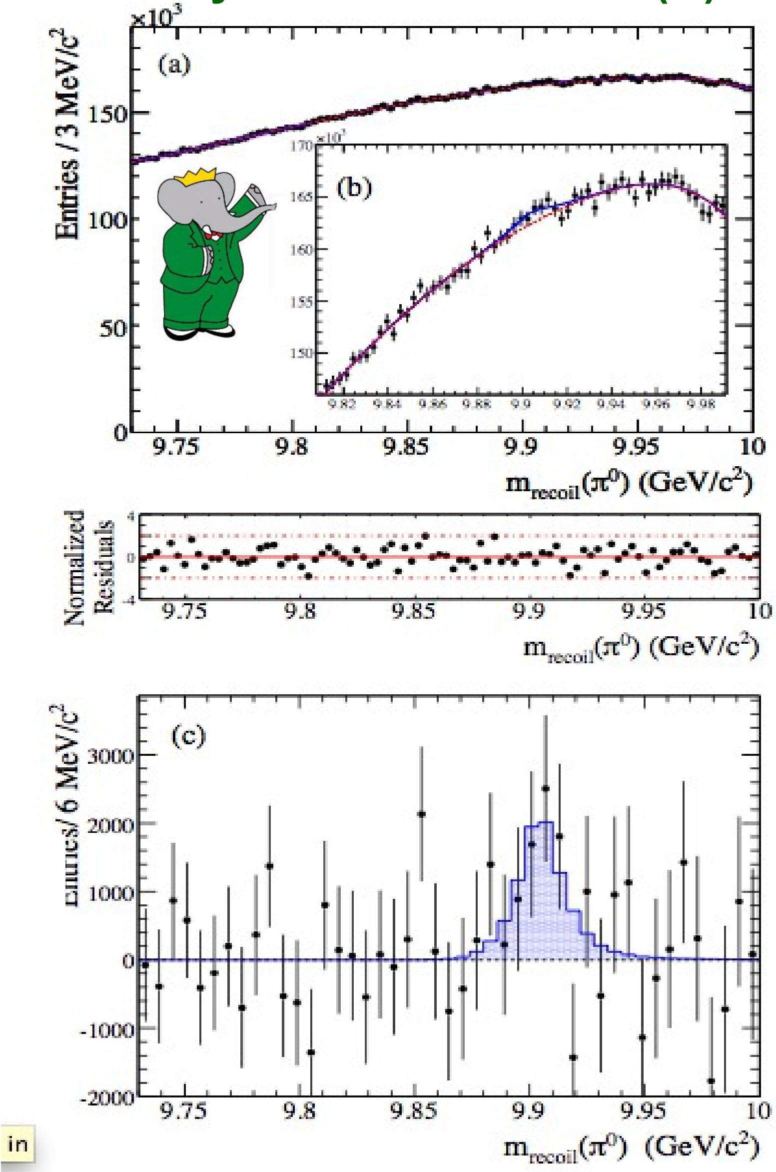




Great improvement thanks to better resolution

$Y(3S) \rightarrow \pi^0 h_b(1P)$

Phys.Rev.D 84 091101(R)

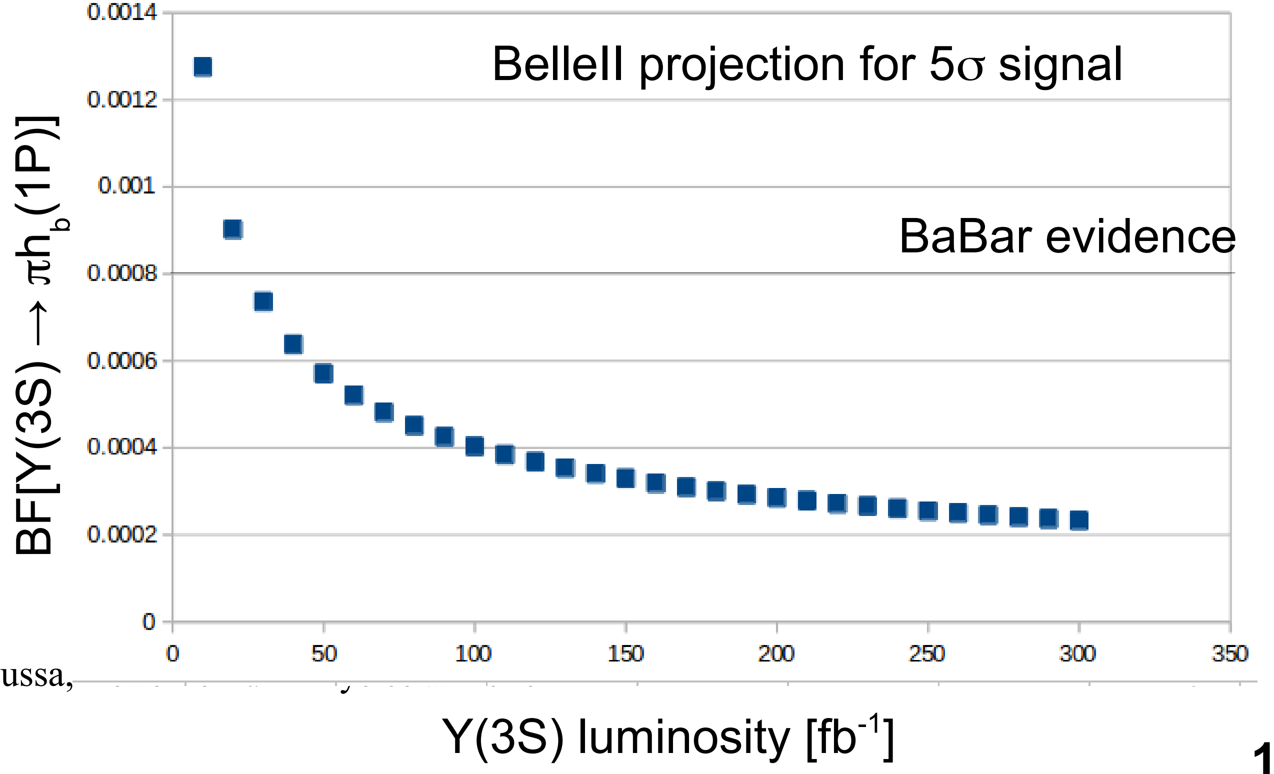


Controversial evidence of
$Y(3S) \rightarrow \pi^0\ h_b(1P) \rightarrow \gamma\ \pi^0\ \Gamma_b(1S)$

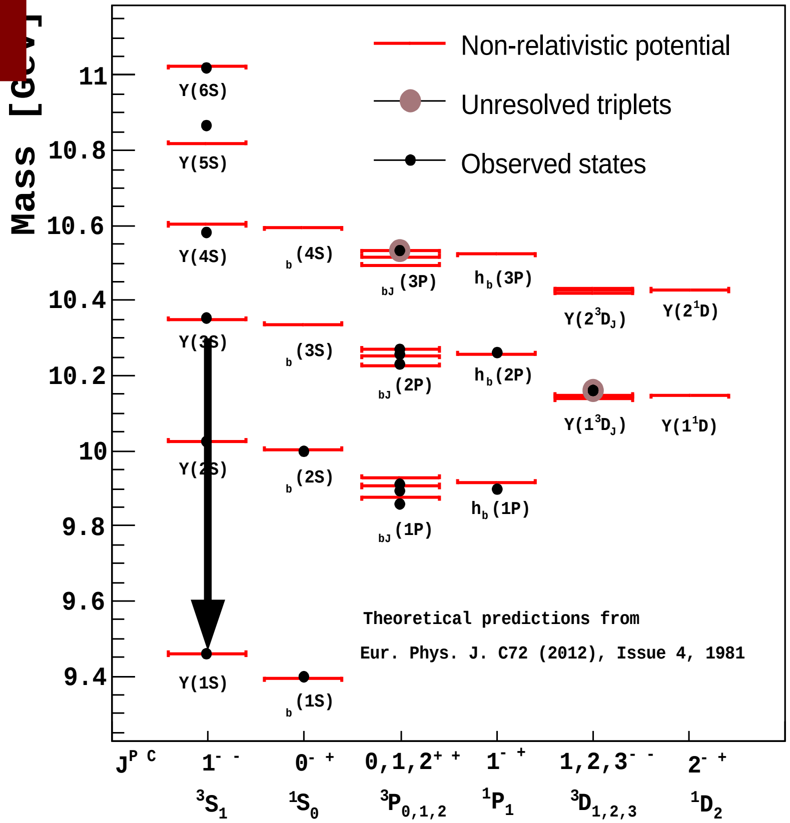
Isospin violating

$$\frac{B[Y(3S) \rightarrow \pi^0 h_b(1P)]}{B[Y(3S) \rightarrow \eta Y(1S)]} > 10$$

Isospin preserving



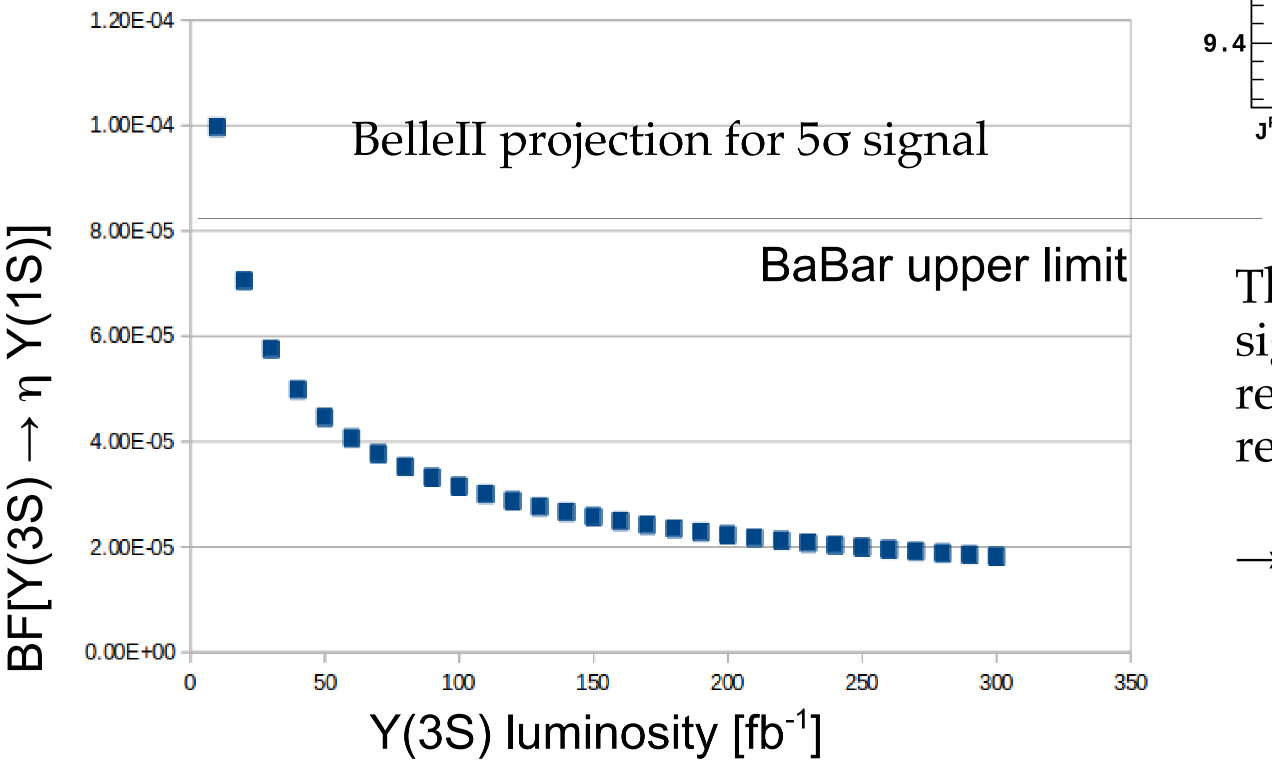
η *transitions from Υ(3S)*



Testing QCD multipole expansion

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

- **B(Υ(3S) ⟶ ηΥ(1S))**   theory: 5-10× 10^{-4}
  BaBar: <1x10^{-4}



The projection assumes a significant improvement of the reconstruction performances w/ respect to BaBar

→ compare Belle and BaBar on Υ(2S) →ηΥ(1S)

η transitions from Y(3S)

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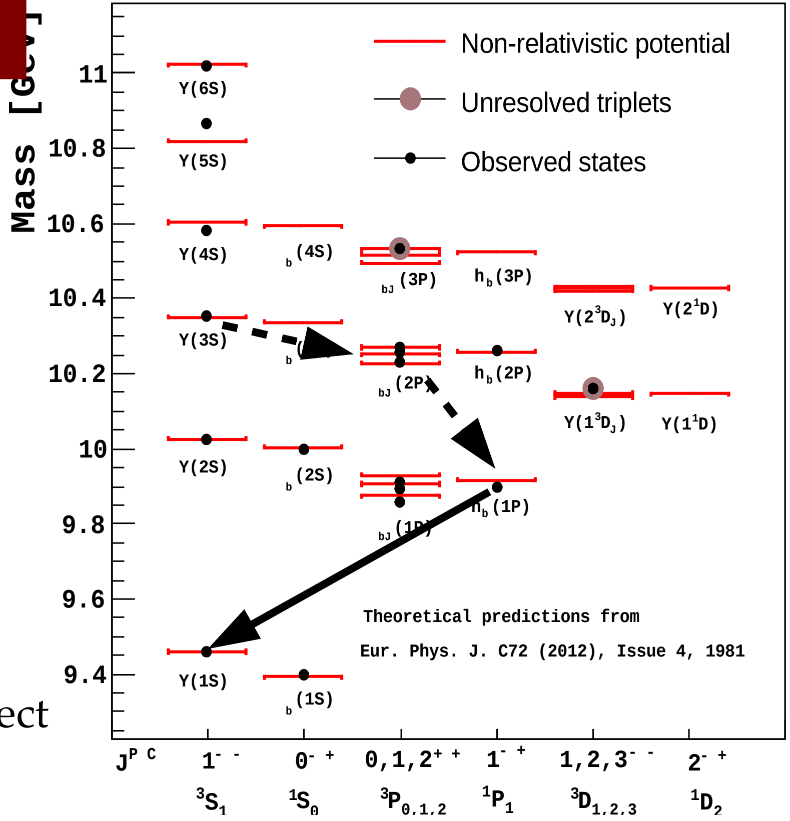
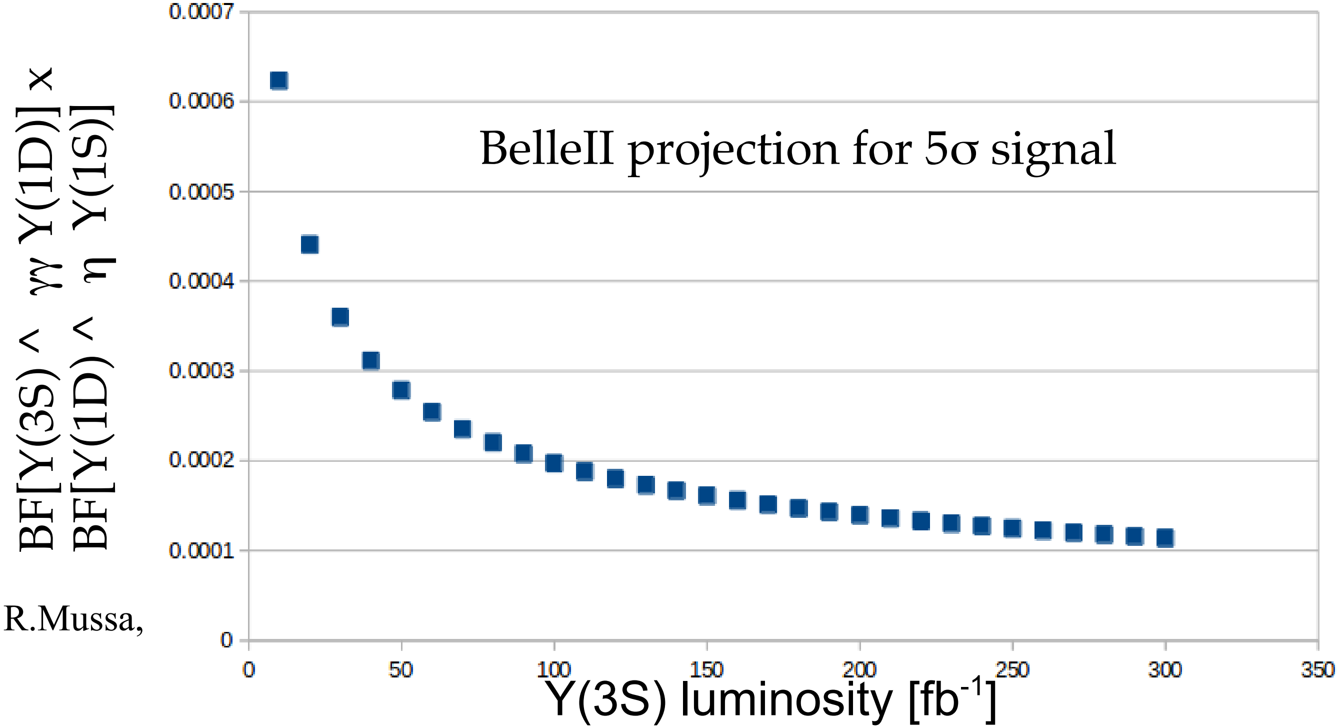
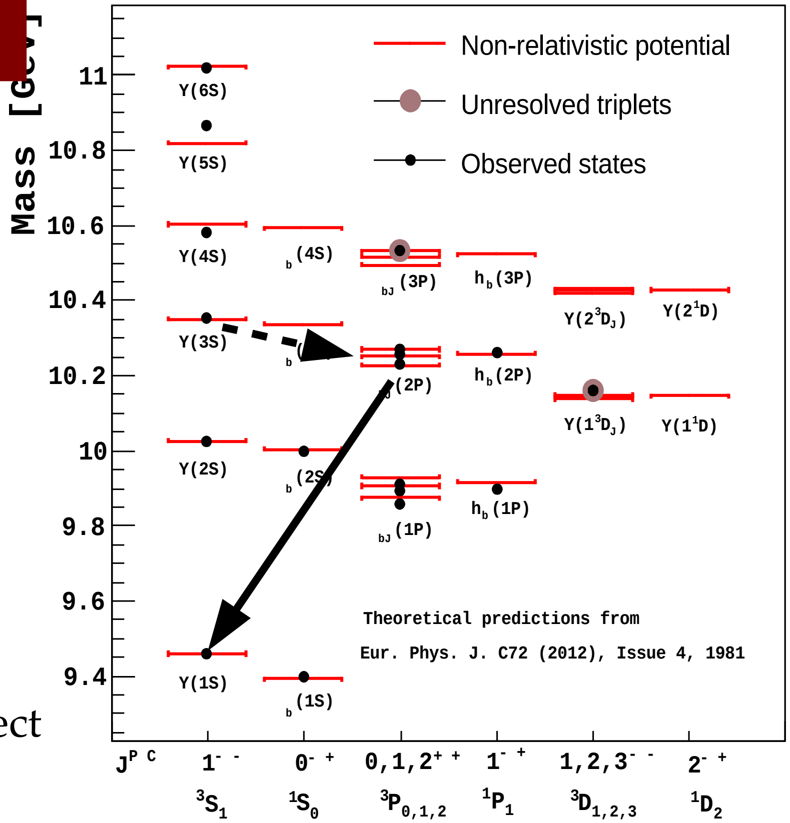
- Y(1D) ⟶ ηY(1S) Voloshin: PLB 562, 68(2003)
QCD Axial Anomaly should enhance Y(1D) → ηY(1S) with respect to Y(1D) → ππY(1S)

→ no quantitative analysis
→ Y(1D) reconstruction through radiative cascade:
High sensitivity to low energy backgrounds





η transitions from Υ(3S)



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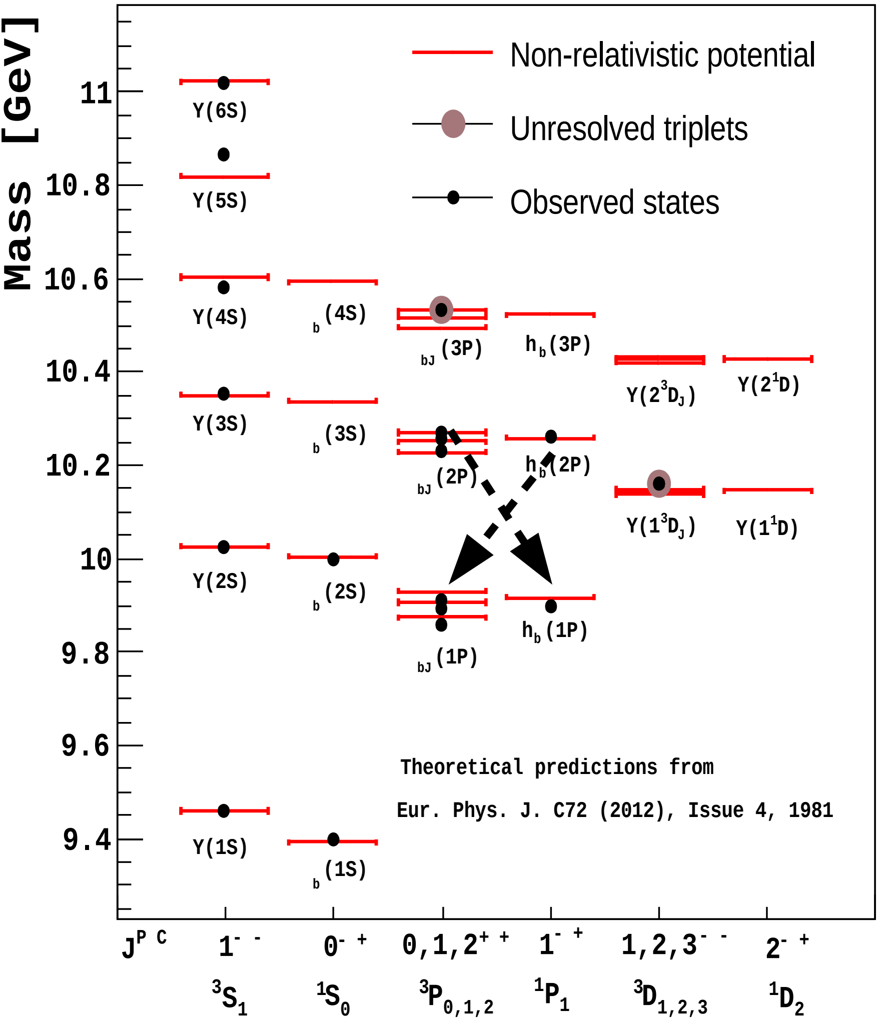
→ no quantitative analysis
→ Υ(1D) reconstruction through radiative cascade:
High sensitivity to low energy backgrounds

Voloshin: Mod.Phys.Lett. A19, 2895(2004)

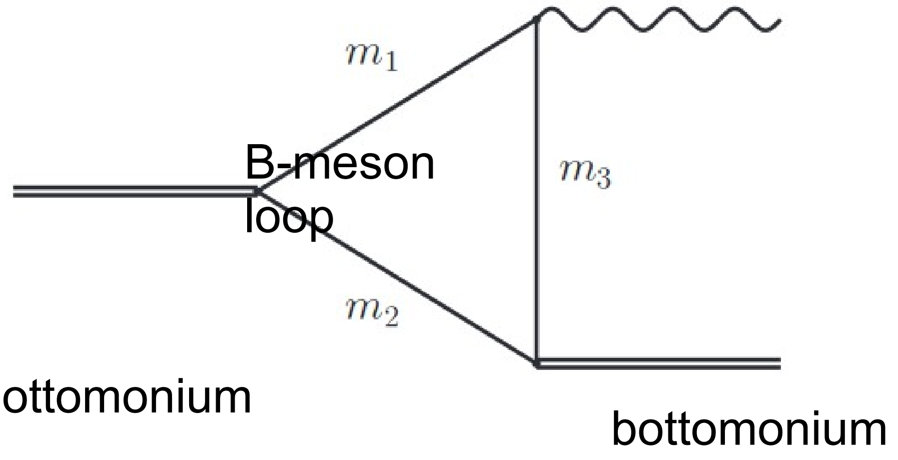
- χ_{b0}(2P) ⟶ η η_b
→ BF of the order of few 10^{-3} (S-wave)
→ BelleII estimate ~40 M χ_{b0}(2P) → **~10000 reconstructed events**
→ full inclusive analysis, low energy photons: hard to estimate the backgrounds now...

Hindered M1 transitions from Υ(3S)



Spin triplet - spin singlet transitions
sensitive to heavy quark spin symmetry breaking

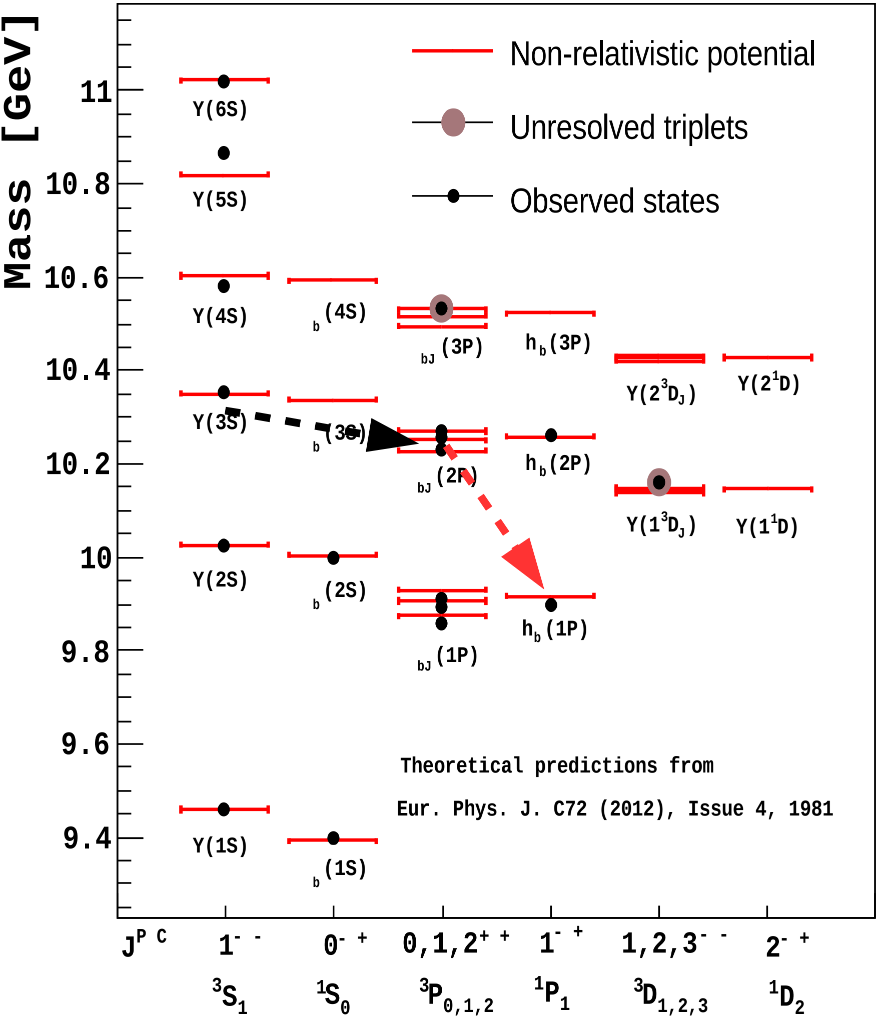
Very recent paper: arXiv:1604.00770

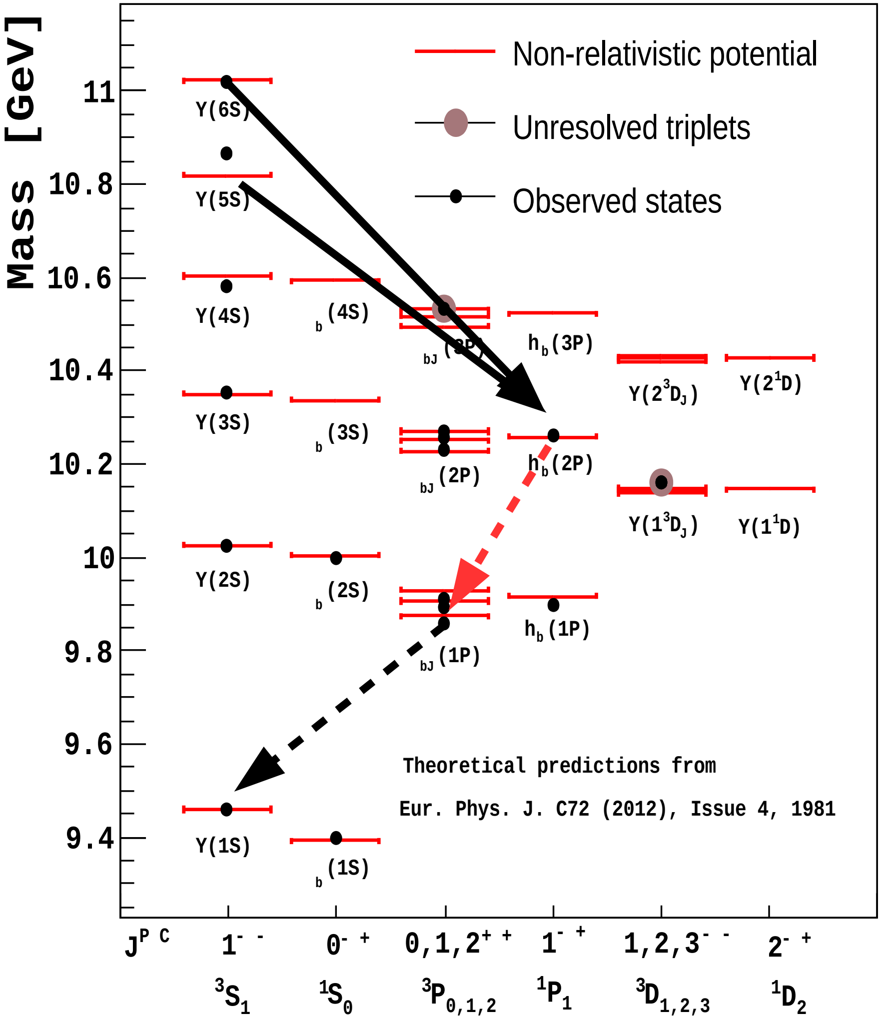


$\chi_{b0} \to h_b\gamma$	$[B^*, \bar{B}^*, B], [B^*, \bar{B}^*, B^*], [B, \bar{B}, B^*]$
$\chi_{b1} \to h_b\gamma$	$[B^*, \bar{B}, B^*], [B, \bar{B}^*, B^*]$
$\chi_{b2} \to h_b\gamma$	$[B^*, \bar{B}^*, B], [B^*, \bar{B}^*, B^*]$
$h_b \to \chi_{b0}\gamma$	$[B^*, \bar{B}, B], [B, \bar{B}^*, B^*], [B^*, \bar{B}^*, B^*]$
$h_b \to \chi_{b1}\gamma$	$[B^*, \bar{B}, B^*], [B^*, \bar{B}^*, B]$
$h_b \to \chi_{b2}\gamma$	$[B, \bar{B}^*, B^*], [B^*, \bar{B}^*, B^*]$

Components of the loop for different transitions

Hindered M1 transitions between P waves





$\chi_{bJ}(2P) \to \gamma h_b(2P)$

→ requires Υ(3S) data
→ High background (inclusive reconstruction)

$h_b(2P) \to \gamma\chi_{bJ}(1P)$

→ requires Υ(5,6S) data
→ Low background (exclusive reconstruction)

Antinuclei in Y(3S) decays

CLEO results :

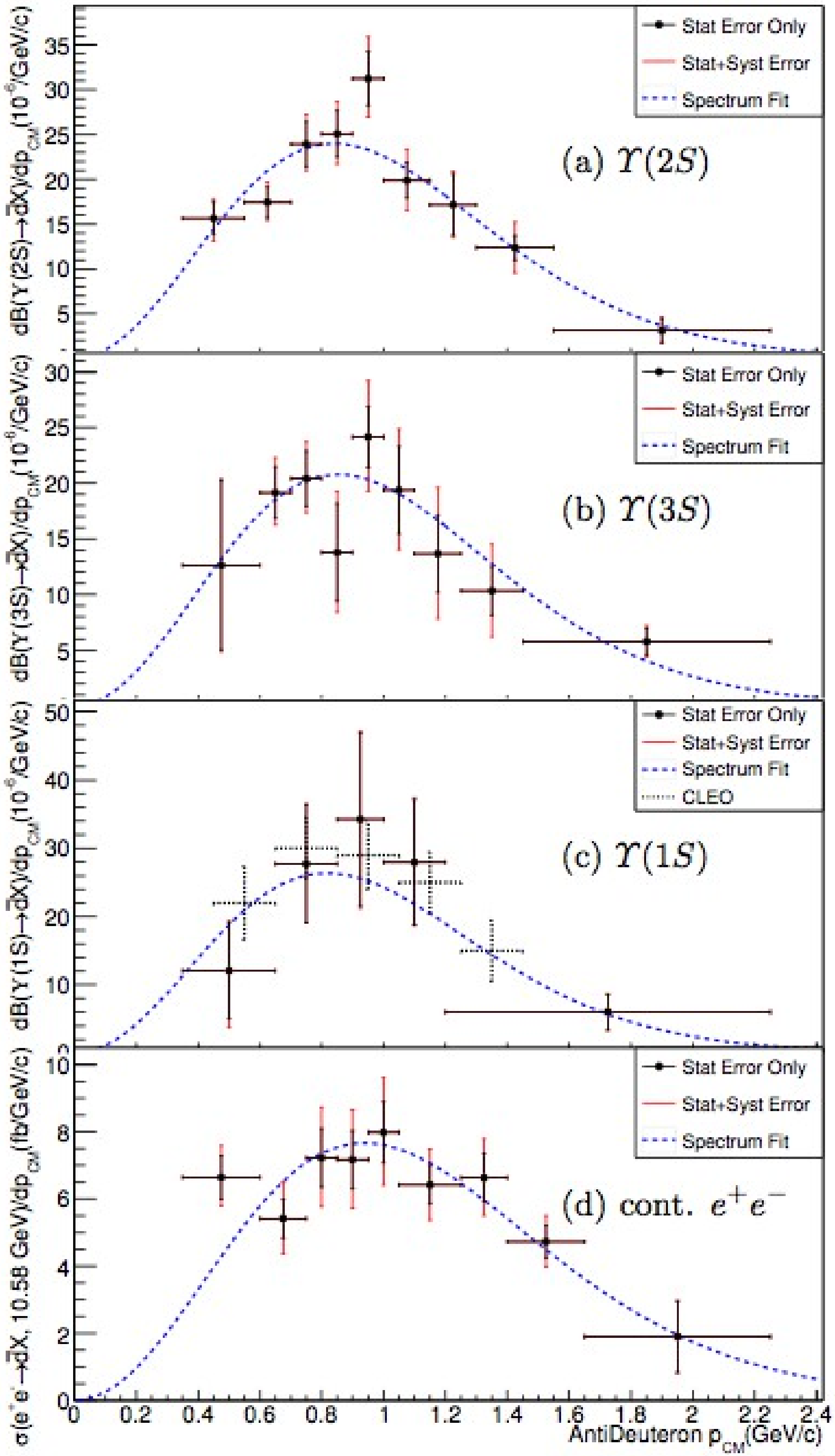
$$\mathcal{B}^{\,\mathrm{dir}}(\Upsilon(1S) \to \bar{d}X) = (3.36 \pm 0.23 \pm 0.25) \times 10^{-5}.$$

$$\mathcal{B}(\Upsilon(2S) \to \bar{d} + X) = (3.37 \pm 0.50 \pm 0.25) \times 10^{-5}.$$

BABAR results :

Resonance	Onpeak	# of Υ Decays	Offpeak
$\Upsilon(4S)$	$429\,\mathrm{fb}^{-1}$	463×10^6	$44.8\,\mathrm{fb}^{-1}$
$\Upsilon(3S)$	$28.5\,\mathrm{fb}^{-1}$	116×10^6	$2.63\,\mathrm{fb}^{-1}$
$\Upsilon(2S)$	$14.4\,\mathrm{fb}^{-1}$	98.3×10^6	$1.50\,\mathrm{fb}^{-1}$

Process	Rate
$\mathcal{B}(\Upsilon(3S) \to \bar{d}X)$	$(2.33 \pm 0.15^{+0.31}_{-0.28}) \times 10^{-}$
$\mathcal{B}(\Upsilon(2S) \to \bar{d}X)$	$(2.64 \pm 0.11^{+0.26}_{-0.21}) \times 10^{-}$
$\mathcal{B}(\Upsilon(1S) \to \bar{d}X)$	$(2.81 \pm 0.49^{+0.20}_{-0.24}) \times 10^{-}$
$\sigma(e^+e^- \to \bar{d}X)$ $[\sqrt{s} \approx 10.58\,\mathrm{GeV}]$	$(9.63 \pm 0.41^{+1.17}_{-1.01})$ fb
$\dfrac{\sigma(e^+e^- \to \bar{d}X)}{\sigma(e^+e^- \to \mathrm{Hadrons})}$	$(3.01 \pm 0.13^{+0.37}_{-0.31}) \times 10^{-}$



With 0.8-1 Billion Y(3S) decays, we can *search for anti-tritium and He-3 production in bottomonium*

Only from Υ(5,6S): $\eta_b(1S) \rightarrow \gamma\gamma$

Search for $\eta_b(1S) \rightarrow \gamma\gamma$

via exclusive channel: $\pi^+\pi^-\gamma(\gamma\gamma)$!!

NRQCD NNLL prediction:

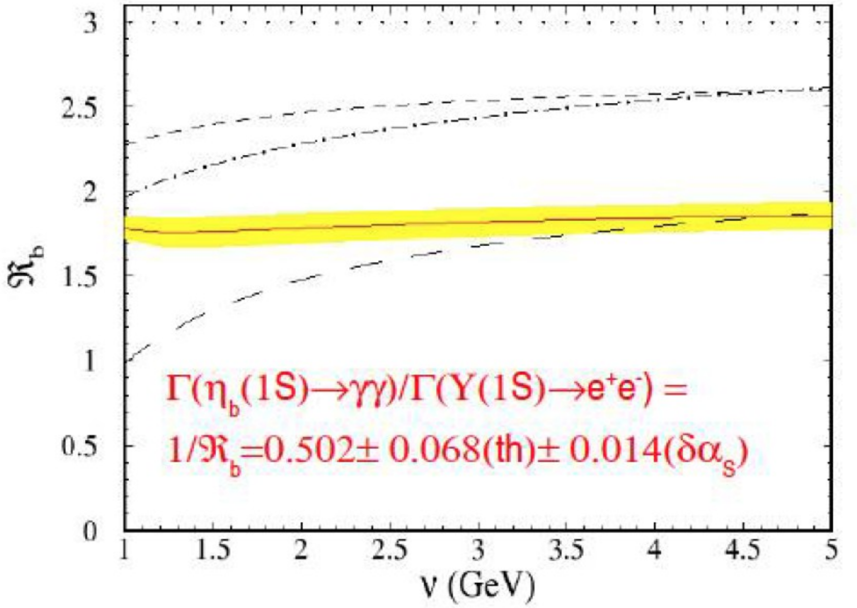
Penin et al., NP B699(2004),183

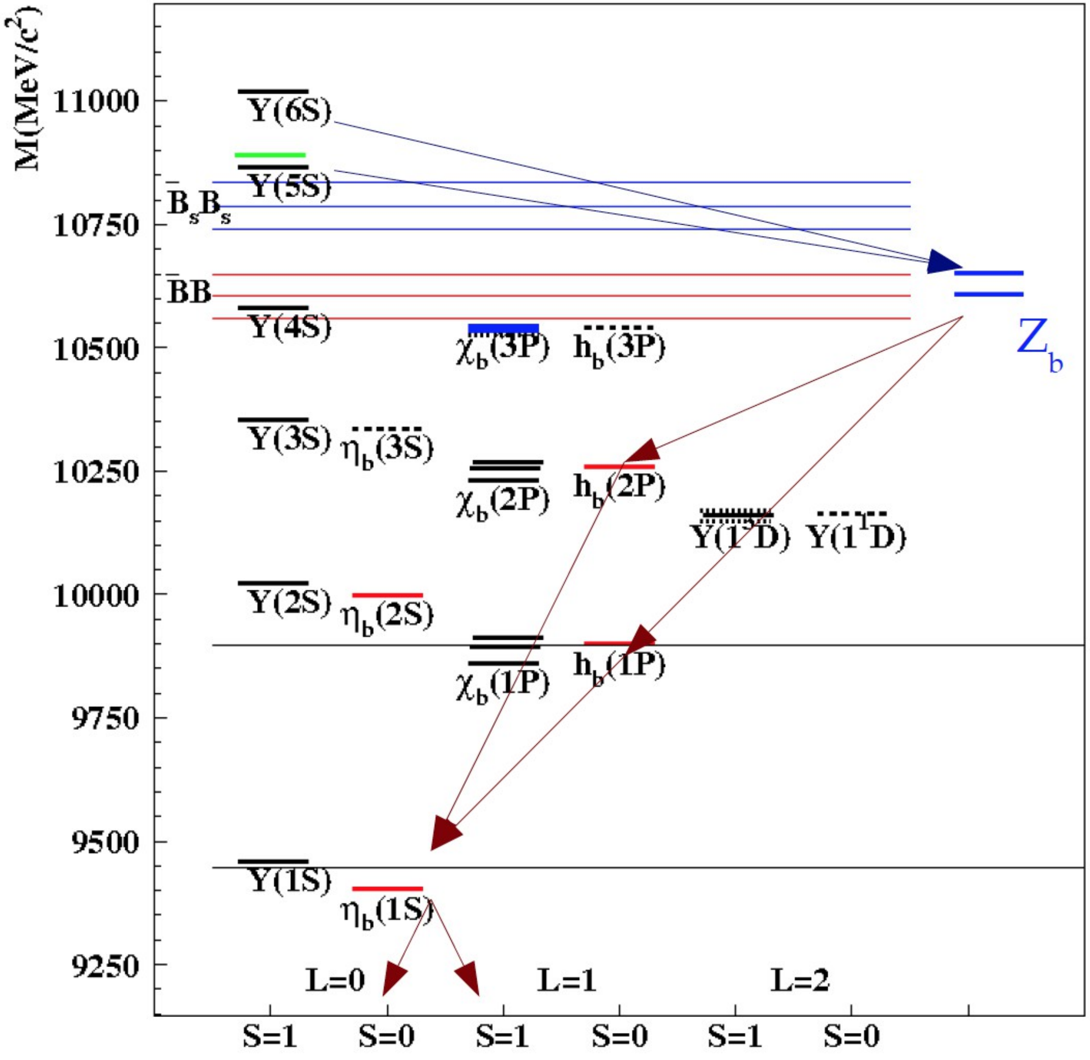
$\Gamma(\eta_b(1S) \rightarrow \gamma\gamma) = 0.66 \pm 0.09$ keV

With $\Gamma(\eta_b) = 10$ MeV,

$BR(\eta_b(1S) \rightarrow \gamma\gamma) = 0.66 \cdot 10^{-4}$

~25 events with 1 ab^{-1} at Υ(5S) or Υ(6S)

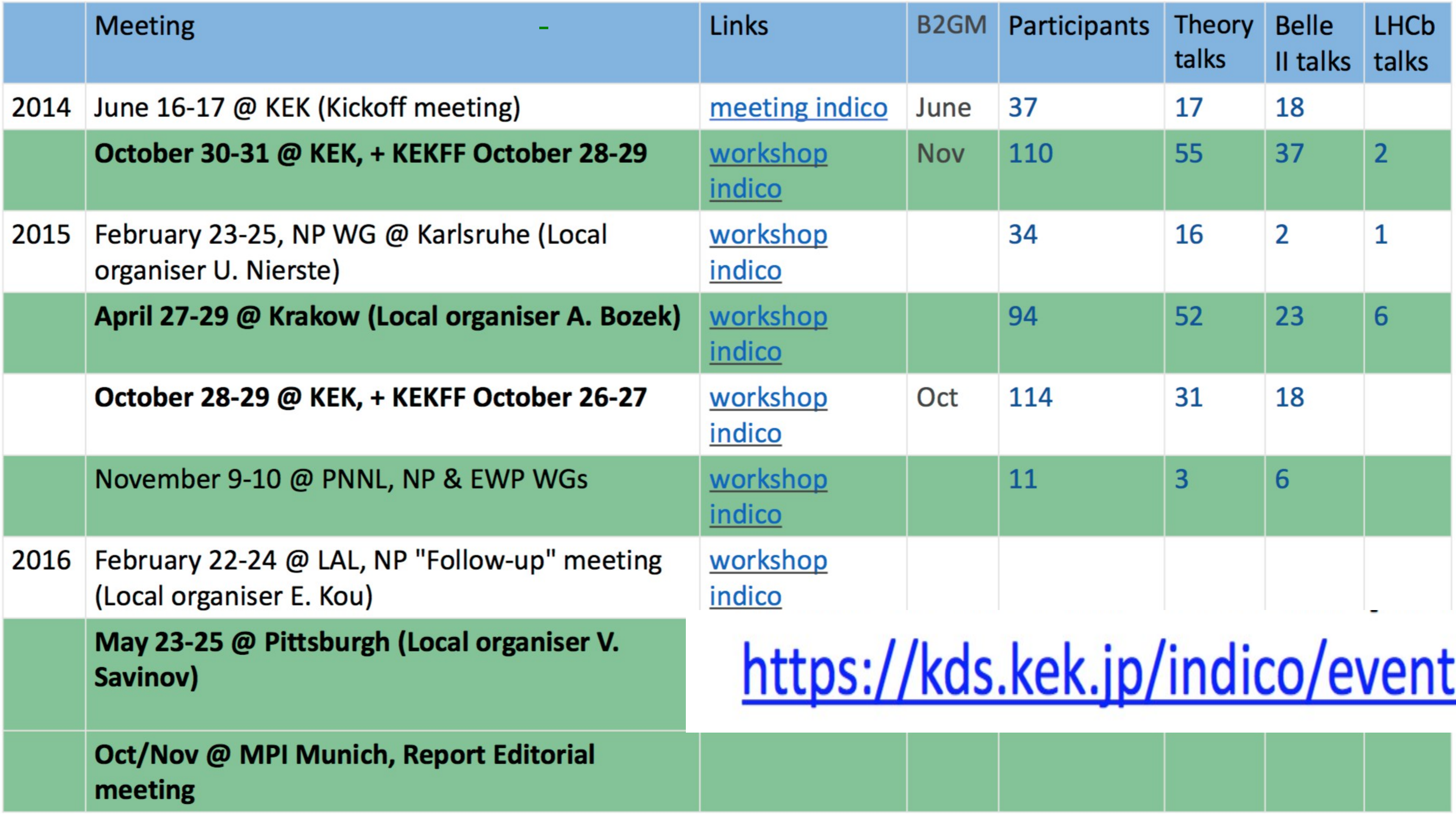




Belle-II Theory Interface Platform (B2TIP)

Impact of new hardware
New analysis methods
New Trigger
Expected Precision

Impact ofTheory Landscape after Belle/Babar/LHCb
Progress in QCD?
New Physics after LHC run 2
GREEN PAPER on Belle-II Physics in preparation



	Meeting	Links	B2GM	Participants	Theory talks	Belle II talks	LHCb talks
2014	June 16-17 @ KEK (Kickoff meeting)	meeting indico	June	37	17	18	
	October 30-31 @ KEK, + KEKFF October 28-29	workshop indico	Nov	110	55	37	2
2015	February 23-25, NP WG @ Karlsruhe (Local organiser U. Nierste)	workshop indico		34	16	2	1
	April 27-29 @ Krakow (Local organiser A. Bozek)	workshop indico		94	52	23	6
	October 28-29 @ KEK, + KEKFF October 26-27	workshop indico	Oct	114	31	18	
	November 9-10 @ PNNL, NP & EWP WGs	workshop indico		11	3	6	
2016	February 22-24 @ LAL, NP "Follow-up" meeting (Local organiser E. Kou)	workshop indico					
	May 23-25 @ Pittsburgh (Local organiser V. Savinov)						
	Oct/Nov @ MPI Munich, Report Editorial meeting						

https://kds.kek.jp/indico/event/19723/

Summaries & minutes of the workshops
https://d2comp.kek.jp/collection/Public%20Memo

https://belle2.cc.kek.jp/~twiki/bin/view/B2TiP

Wrapping it up ....

Belle-II hopes to do some valuable physics during phase-II run , without low momentum tracking , and no vertexing.

A pilot run on Y(6S) peak, even with only 20fb^{-1} , will give us about the 10x data taken in Belle-I. This will be a pilot run, to plan future studies in this interesting region.

Searches for exotics are feasible at 10.65+10.75 GeV, also

200-300 fb^{-1} at (and about) the Y(3S) peak will allow to publish >10 physics papers after the first year of data taking :

- *Rare η transitions* - *Spectroscopy of D(F) waves*
- *Hindered radiative transitions* - *Antitritium, He-3 in Y decays*

Scans of the Y(1D) and Y(2D) regions are planned for Phase-III

Looking forward showing first results from Belle-II in 2018