Future Direction in High Energy QCD
At RIKEN, October 2011

QCD at KEKB and SuperKEKB

Toru Iijima

Kobayashi-Maskawa Institute

Nagoya University

October 22, 2011

Talk Outline

- Polarized Fragmentation Functions
- Hadron Spectroscopy
- SuperKEKB/Belle II

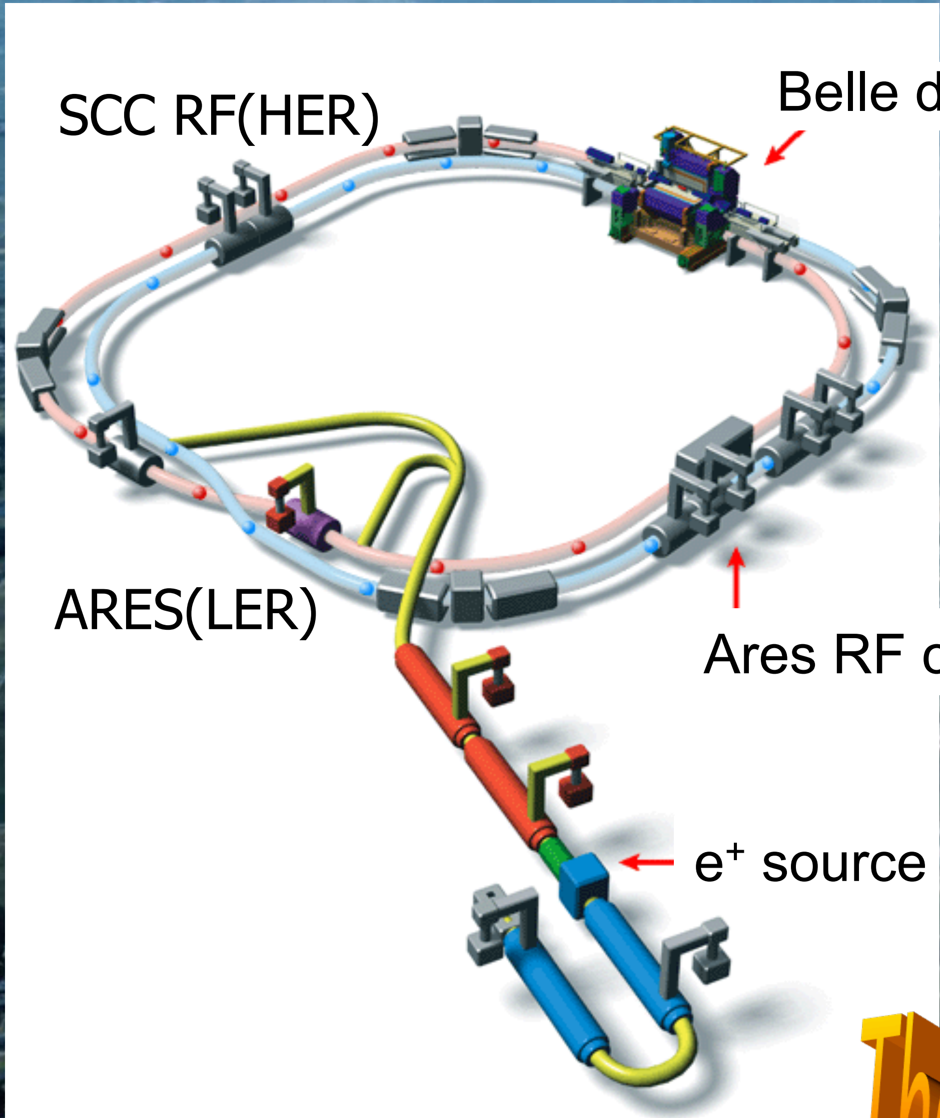
(Deep) Apology

I can't cover all subjects.

I am not an expert of FF.

(RIKEN people know better)

The KEKB Collider



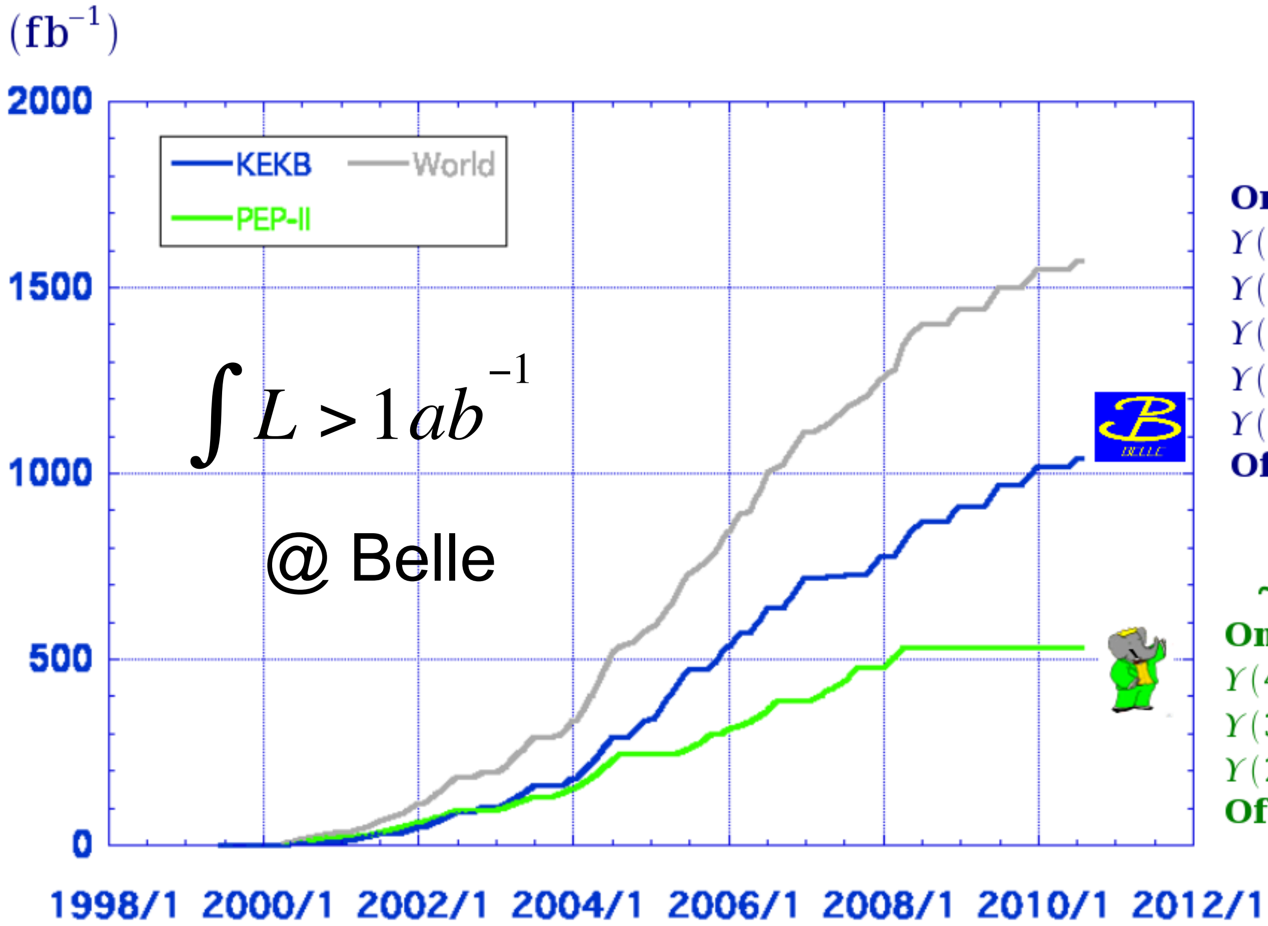
- e^- (8.0GeV) × e^+ (3.5GeV)
  - ⇒ $\Upsilon(4S) \to B\bar{B}$
  - ⇒ Lorentz boost: $\beta\gamma = 0.425$
- Finite crossing angle
  - 11mrad ×2
- Operation since 1999.

Peak luminosity

$2.1 \times 10^{34}\ cm^{-2}s^{-1}$!

The World Highest Luminosity

Luminosity at B Factories



> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 24 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

KEKB/Belle operation terminated
at 9:00am, June 30, 2010

Characteristic of the B-factory

- Acceptance: 0.9 ×4π
- Vertex resolution

  σ(J/ψ →ll) ~75nm
- Momentum resolution

  σ(Pt) = 0.19·Pt ⊕ 0.34/β %
- Energy resolution

  σ(Eγ)/Eγ =1.8% @ 1GeV
- Particle ID

  e, μ, π, K, p
- Minimum bias trigger

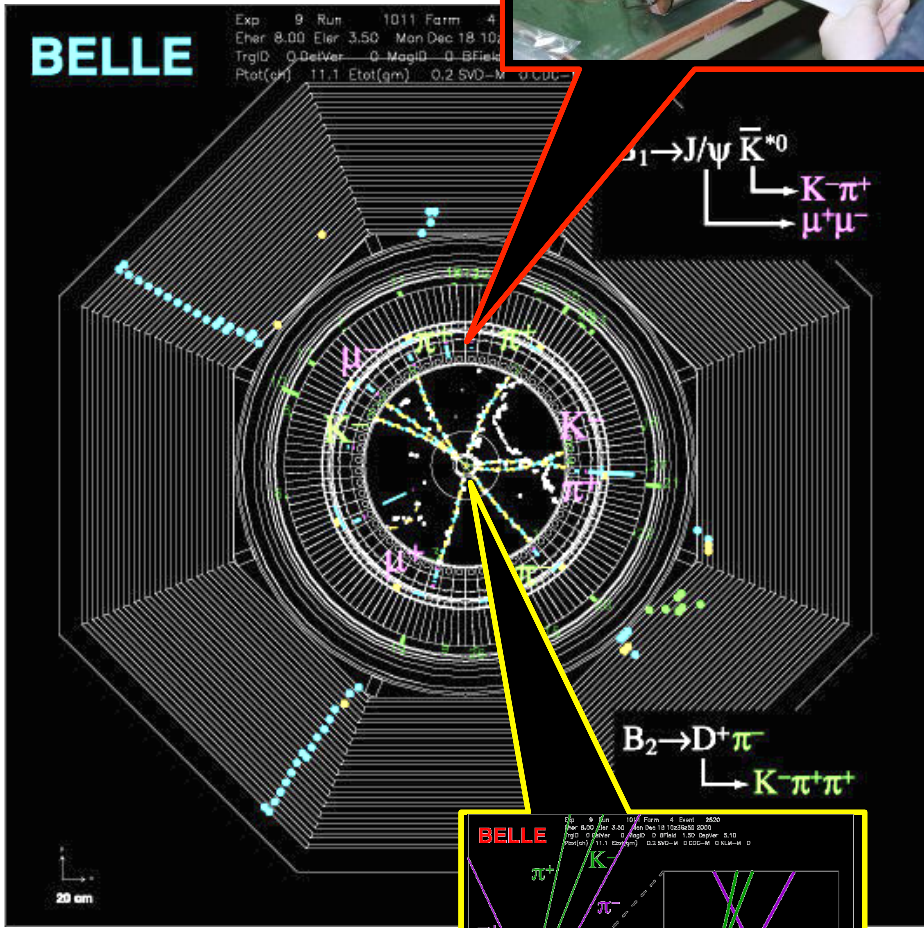
  Evis >= 1GeV & Ntrk >= 2

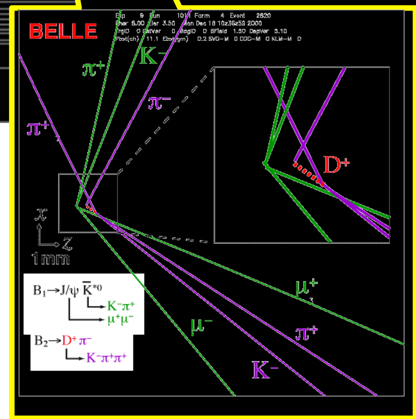
  & Ncluster >= 4

➡ essentially no loss for $B\bar{B}$.

Clean environment.

Well defined kinematics

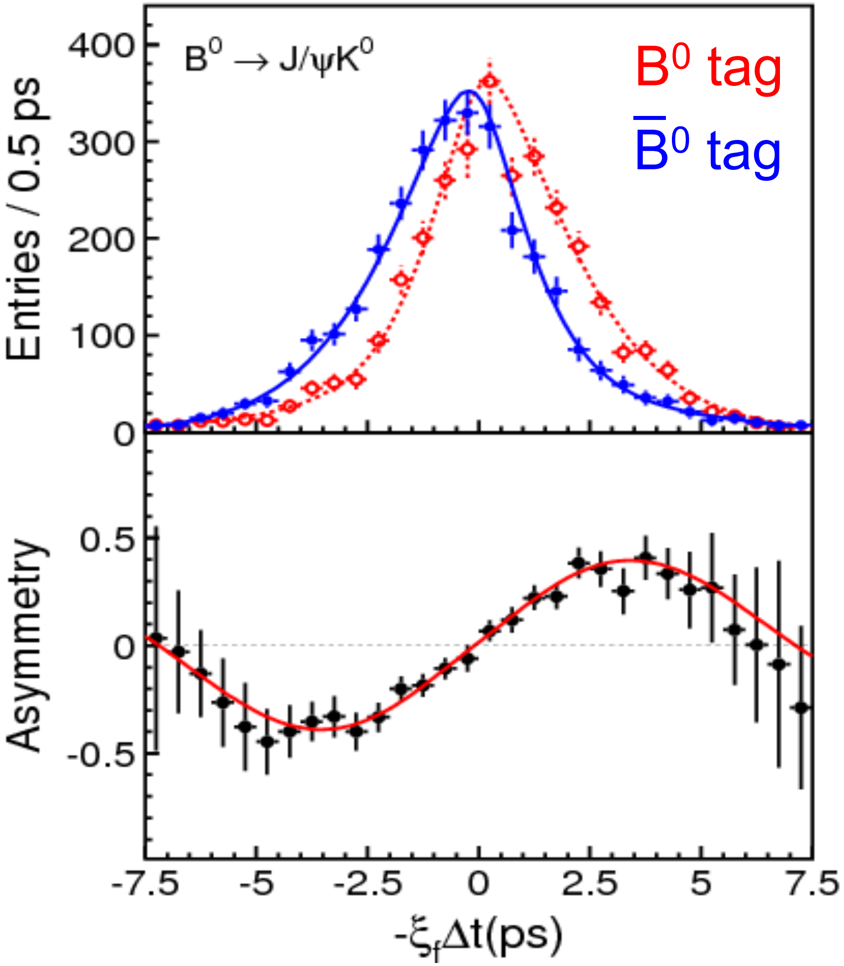


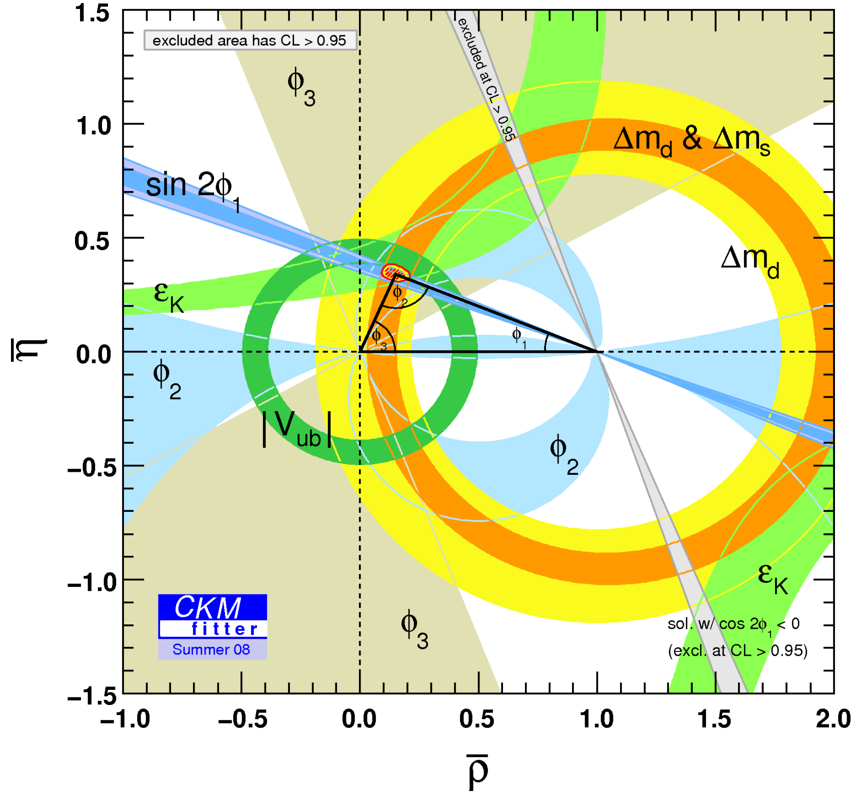


Achievement of the B-factories

Belle 2006 (532M $B\overline{B}$)

$\sin 2\phi_1 = 0.642 \pm 0.031\ (\text{stat}) \pm 0.017\ (\text{syst})$





Belle Studies for Nucleon Spin Structure

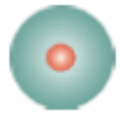
- Transverse spin structure of the nucleon is only poorly understood.
- Its extraction requires spin-dependent fragmentation functions (FF).
  - Collins FF
  - Interference FF (IFF)

"quark polarimeter"

Unpolarized PDF

q(x)

$f_1^q(x)$



Helicity PDF

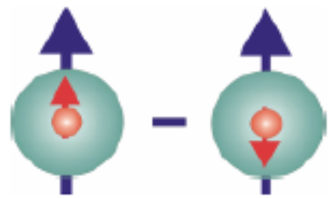
Δq(x)

$g_1^q(x)$

Transversity PDF

$\Delta_T q(x)$

$h_1^q(x)$



Measurements at RHIC, SIDIS etc.:

Transversity $\Delta_T q(x)$ x { Collins FF / IFF }

Measurements at Belle (e+e-)

Collins FF x Collins FF

IFF x IFF

→ Transversity

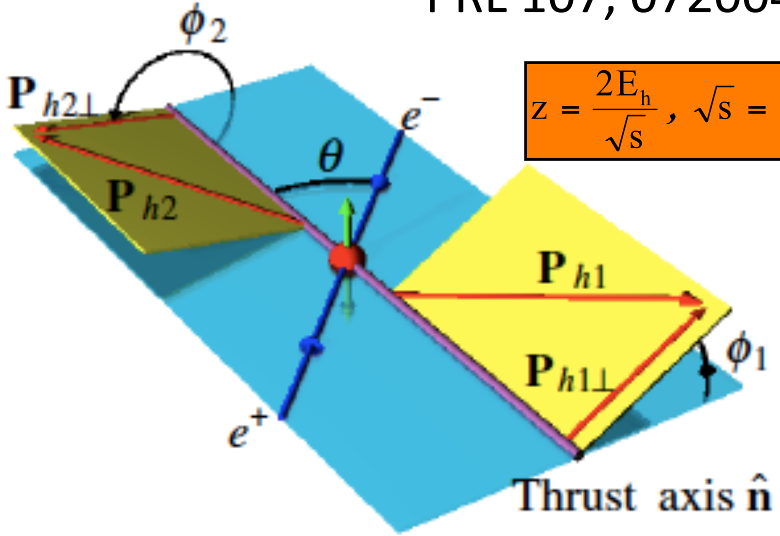
Collins Fragmentation Function

PRL 107, 072004 (2011)

- Collins effect:

Relation between transverse quark spin and the final state azimuthal distribution of hadrons.

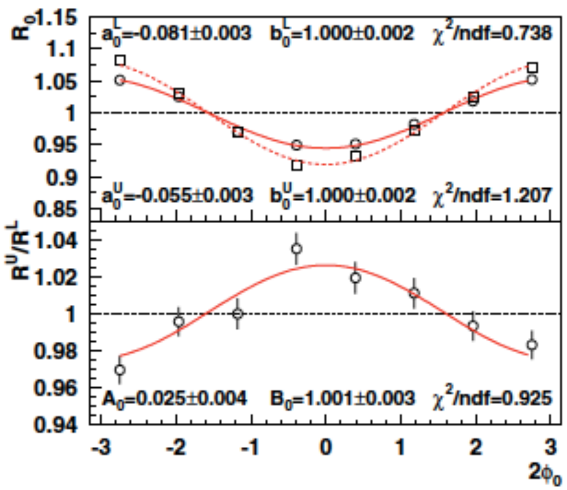
$$D_{hq^\uparrow}(z, \mathbf{P}_{h\perp}) = D_1^q(z, P_{h\perp}^2) + H_1^{\perp q}(z, P_{h\perp}^2) \times \frac{(\hat{\mathbf{k}} \times \mathbf{P}_{h\perp}) \cdot \mathbf{S}_q}{z M_h},$$

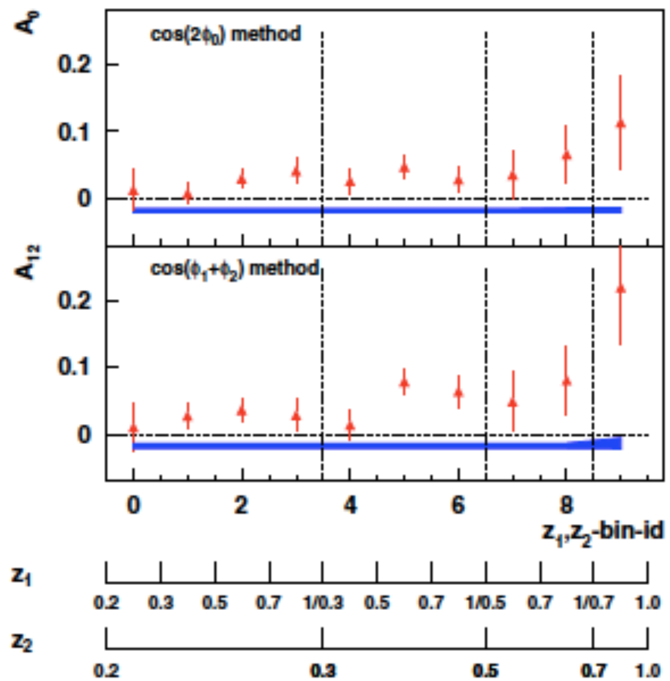


$$z = \frac{2E_h}{\sqrt{s}}, \quad \sqrt{s} = 10.52\ GeV$$

$$\frac{d\sigma(e^+e^- \to h_1 h_2 X)}{d\Omega dz_1 dz_2 d^2 q_T} = \cdots B(y) \cos(\varphi_1 + \varphi_2) H_1^{\perp[1]}(z_1) \overline{H}_1^{\perp[1]}(z_2)$$

$$B(y) = y(1-y) \overset{cm}{=} \frac{1}{4} \sin^2 \Theta$$



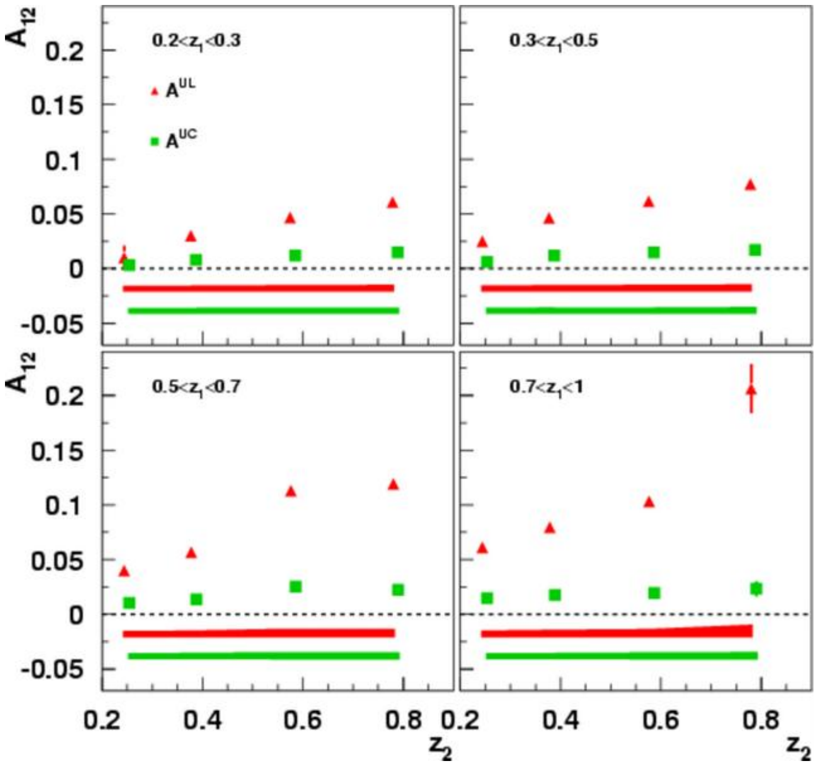


29 fb^{-1}

First direct evidence of the Collins effect

Belle Collins FF → Transversity PDF

547 fb^{-1} PRD 78, 032011 (2008)



Red points : $\cos(\phi_1 + \phi_2)$ moment of unlike sign pion pairs over like sign pion pair ratio : A^{UL}

Green points : $\cos(\phi_1 + \phi_2)$ moment of Unlike sign pion pairs over any charged pion pair ratio : A^{UC}

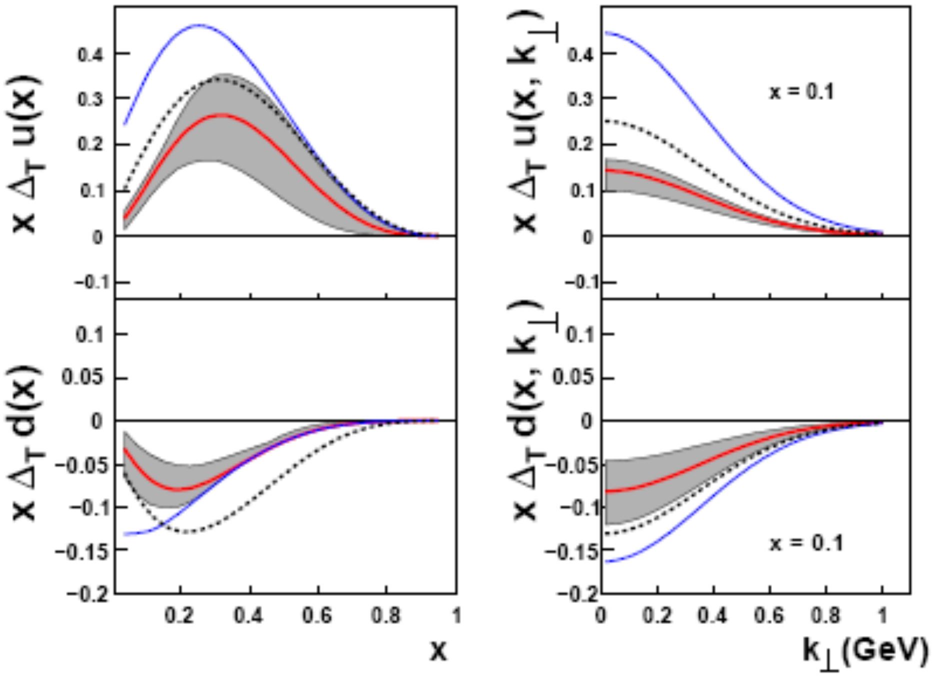
First Global Analysis Results

Phys. Rev. D75, 054032 (2007)

Update in Nucl. Phys. Proc. Suppl. 191, 98 (2009)

Together with HERMES, COMPASS

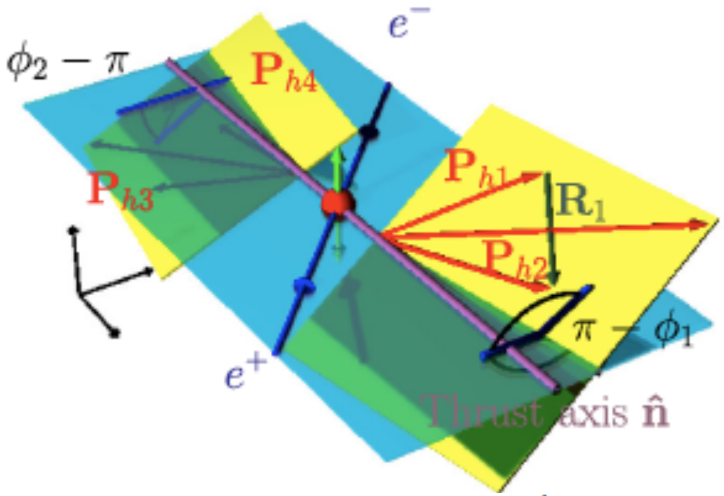
First, still model-dependent extraction.



Interference FF (IFF)

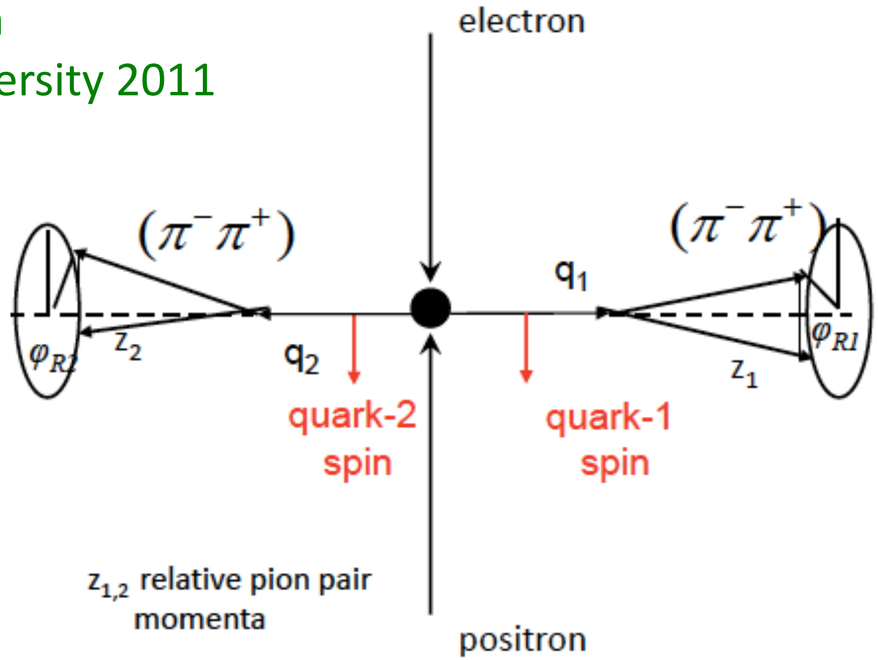
PRL 107, 072004 (2011)

- IFF is sensitive to the transverse polarization of the fragmenting quark.
- Complementary to Collins FF.
- By detecting the 2nd hadron, the sensitivity to the quark spin survives integration over transverse momenta.



Interference effect in e^+e^- quark fragmentation will lead to azimuthal asymmetries in di-hadron correlation measurements!

A. Vossen
@ Transversity 2011

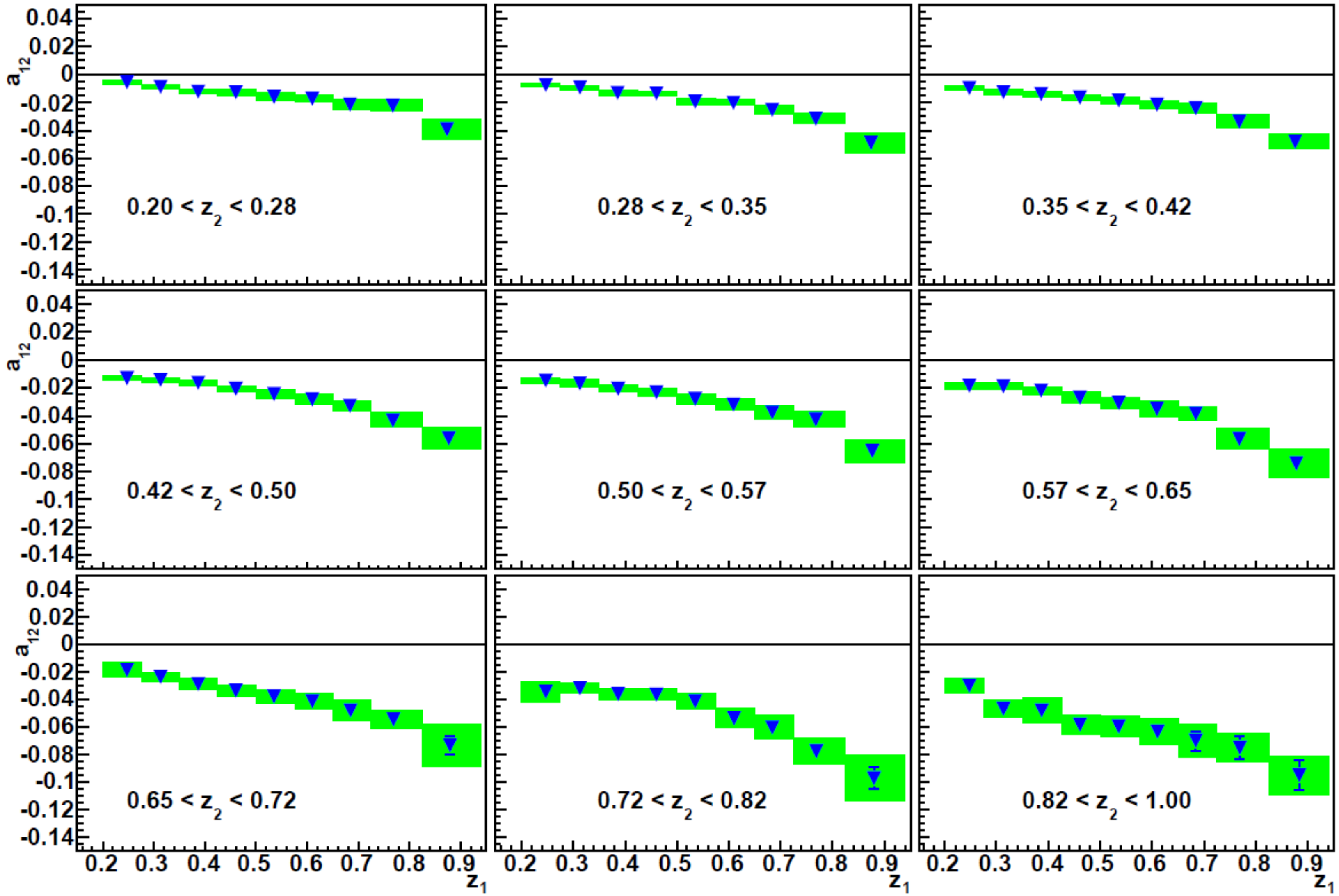


Experimental requirements:

- Small asymmetries ➔ very large data sample!
- Good particle ID to high momenta.
- Hermetic detector
- Observable: $\cos(\varphi_{R1}+\varphi_{R2})$

modulation measures $H_1^{\angle}\overline{H}_1^{\angle}$

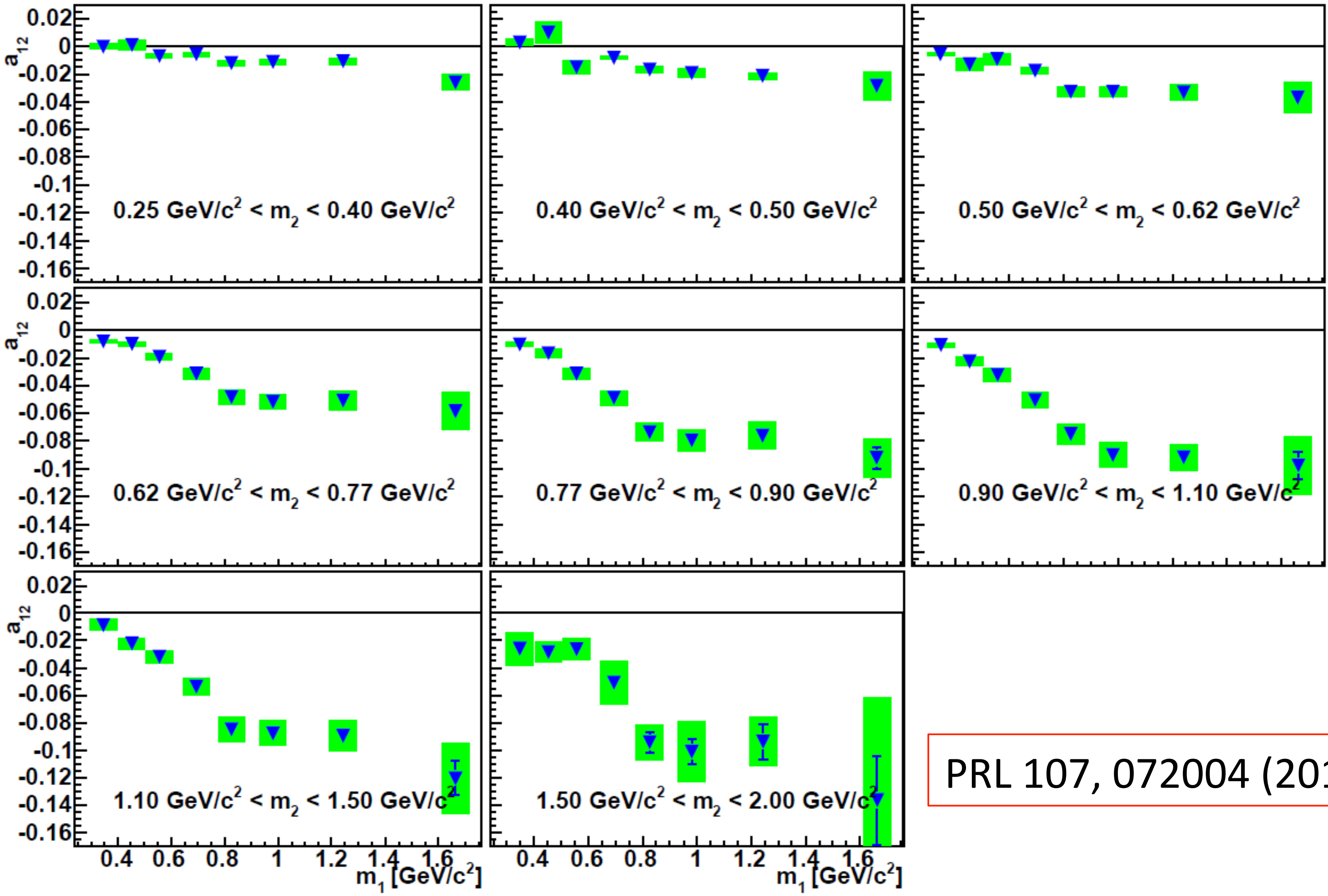
IFF Results: (z_1 x z_2) binning



- Magnitude increasing with z

PRL 107, 072004 (2011)

IFF Results: (m_1 x m_2) binning



PRL 107, 072004 (2011)

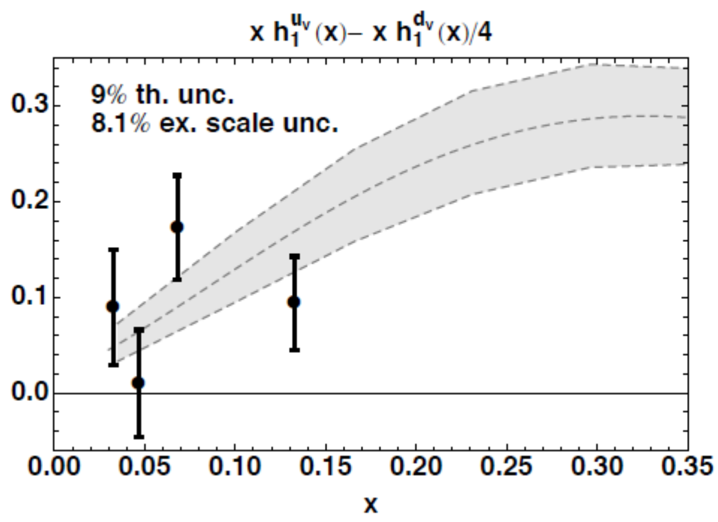
Magnitude increasing with mass, then leveling off

First Transversity Extraction

- From HERMES + Belle IFF data.

Alessandro Bacchetta at RHIC DY workshop May 2011:

First glimpses at transversity



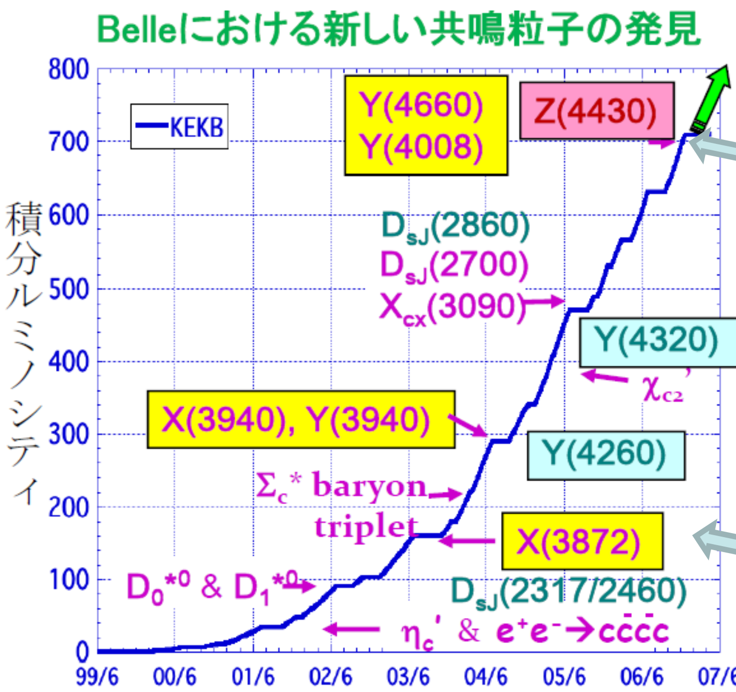
Not in disagreement with Anselmino et al.

Bacchetta, Radici, Courtoy, arXiv:1104.3855

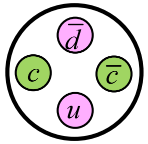
Monday, 6 June 2011

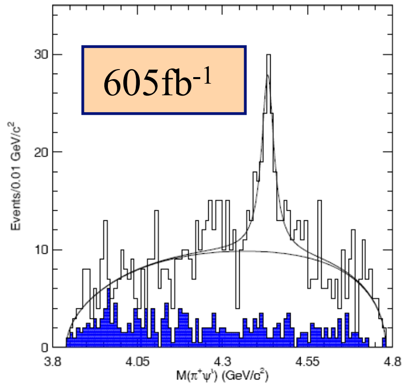
- Early studies indicate little effect of evolution in Collins function, both results comparable
- Preliminary data by Compass and PHENIX not used

New Hadrons at Belle

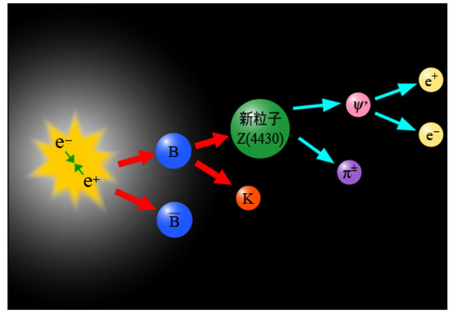


Z(4430)
荷電粒子

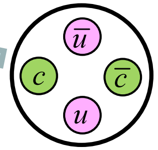


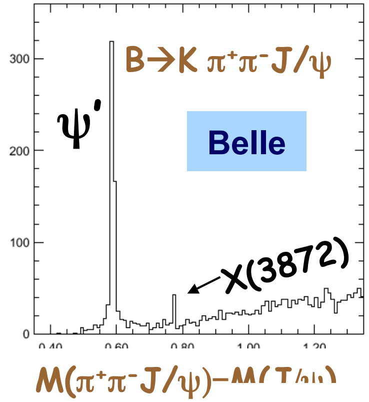


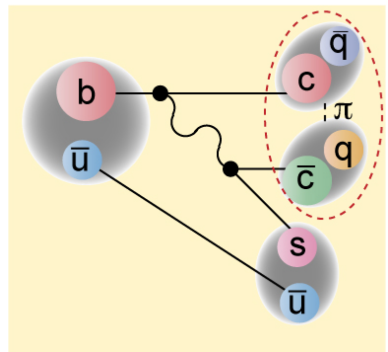
生成プロセス



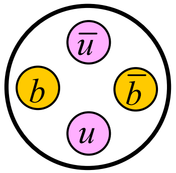
X(3872)
中性粒子







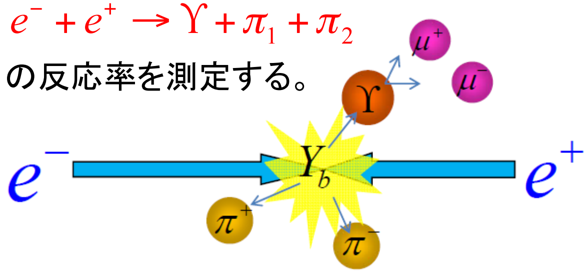
Y_b(10890)
2008年8月
ボトムクォークを含んだエキゾチックハドロンの候補

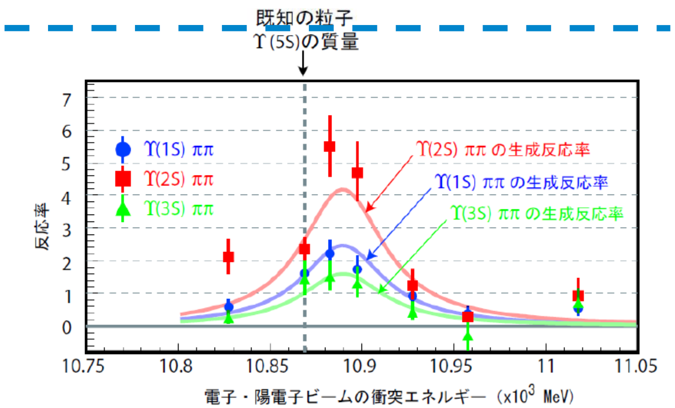


電子・陽電子の衝突エネルギーを変えながら、

$$e^- + e^+ \rightarrow \Upsilon + \pi_1 + \pi_2$$

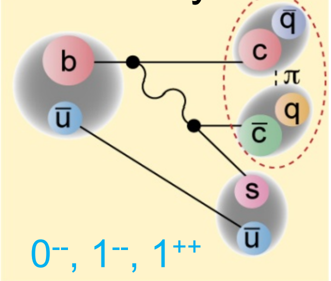
の反応率を測定する。



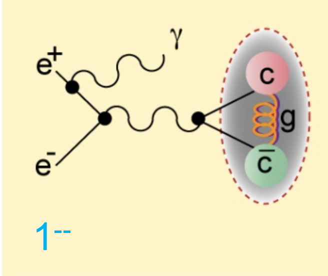


XYZ at B Factories

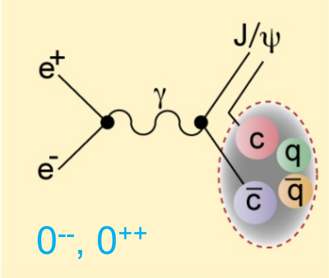
B decay



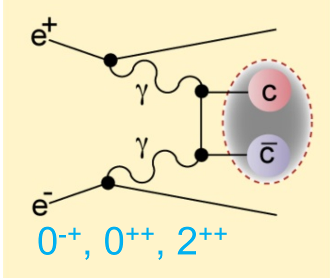
ISR



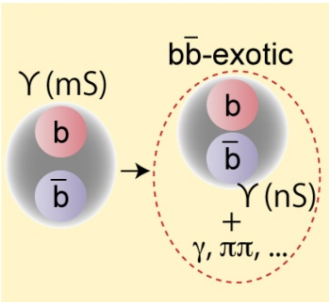
Double-charm



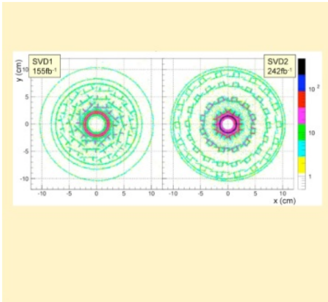
Two-photon



Energy scan



SVD as a target



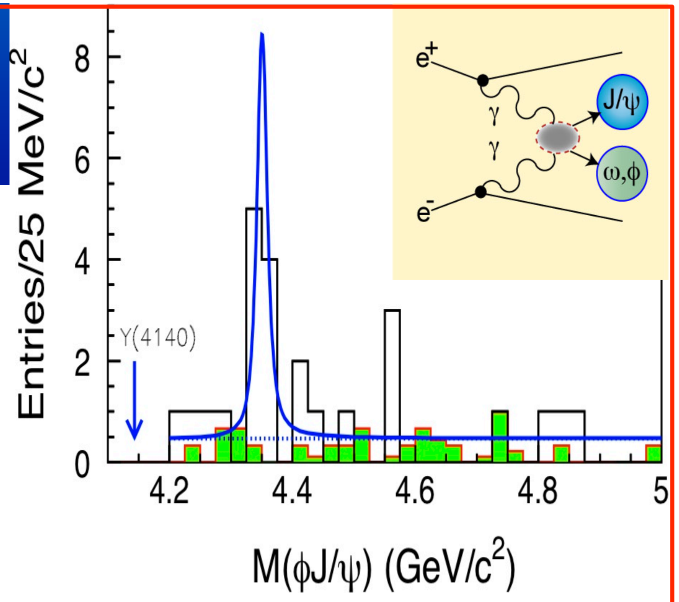
State	Mass (MeV)	Width (MeV)	Decay	Production
Ys(2175)	2175±8	58±26	ϕf_0	ISR
X(3872)	3871.84±0.33	<0.95	$J/\psi\pi\pi$, $J/\psi\gamma$	B decay
X(3872)	3872.8 +0.7/-0.6	3.9 +2.8/-1.8	$D^{*0}D^0$	B decay
Z(3940)	3929±5	29±10	DD	$\gamma\gamma$
X(3940)	3942±9	37±17	DD*	Double-charm
Y(3940)	3942±17	87±34	$J/\psi\omega$	B decay
Y(4008)	4008 +82/-49	226 +97/-80	$J/\psi\pi\pi$	ISR
$Z(4051)^+$	4051 +24/-43	82 +51/-28	$\pi\chi_{c1}$	B decay
X(4160)	4156±29	139 +113/-65	D*D*	Double-charm
$Z(4248)^+$	4248 +185/-45	177 +320/-72	$\pi\chi_{c1}$	B decay
Y(4260)	4264±12	83±22	$J/\psi\pi\pi$	ISR
Y(4350)	4361±13	74±18	$\psi'\pi\pi$	ISR
$Z(4430)^+$	4433±5	45 +35/-18	$\psi'\pi$	B decay
Y(4660)	4664±12	48±15	$\psi'\pi\pi$	ISR
$Y_b(10890)$	10889.6±2.3	54.7 +8.9/-7.6	$\pi\pi\Upsilon(nS)$	e^+e^- annihilation
Y(3915)	3915±4	17±10	$J/\psi\omega$	$\gamma\gamma$
X(4350)	4350 +4.7/-5.1	13 +18/-14	$J/\psi\phi$	$\gamma\gamma$
$Z_b(10610)$	10608.4±2.0	15.6±2.5	($\Upsilon(nS)$ or h_b) π	$\Upsilon(5S)$ /Y_b decay
$Z_b(10650)$	10653.2±1.5	14.4±3.2	($\Upsilon(nS)$ or h_b) π	$\Upsilon(5S)$ /Y_b decay

Recent Results

Newly observed hadronic states

- Y(3915) [$\gamma\gamma \rightarrow J/\psi\ \omega$] : PRL 104, 092001 (2010)
- X(4350) [$\gamma\gamma \rightarrow$ J/y ϕ] : PRL 104, 112004 (2010)
- h_b(1P,2P) [Υ(5S)$\rightarrow\pi\pi$ X_{miss}]

  arXiv: 1103.3419, submitted to PRL



- Z^+_b(10610, 10650) [π+Υ(1S,2S,3S) (n=1,2,3) or h_b(1P,2P)]

  arXiv: 1110.2251, submitted to PRL

Detailed properties of X(3872)

- Obs. of X(3872) $\rightarrow J/\psi\ \gamma$ & search for X(3872)$\rightarrow\psi'\gamma$

  PRL 107, 091803 (2011)
- Study of B $\rightarrow$ K X(3872) $\rightarrow$ K D^{*0} D^0 decay : PRD 81, 031103 (2010)
- Comparison of X(3872) from B^+/B^0 decays : arXiv: 0809.1224
- X(3872) $\rightarrow \pi^+\pi^-$ J/ψ angular distribution etc. : PRD 84, 052004(R) (2011)

Introduction to $h_b(nP)$

$(b\bar{b})$: S=0 L=1 $J^{PC}=1^{+-}$

Expected mass

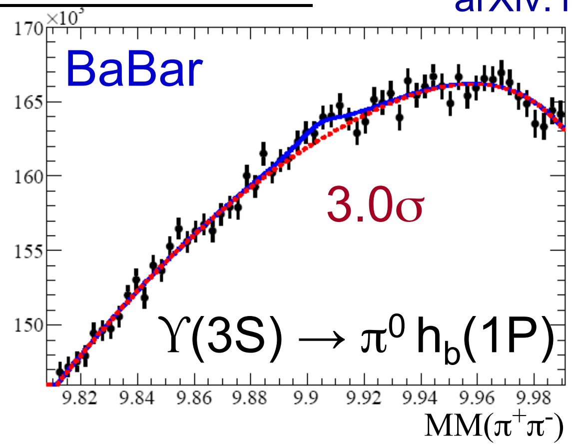
$\approx (M\chi_{b0} + 3\,M\chi_{b1} + 5\,M\chi_{b2}) / 9$

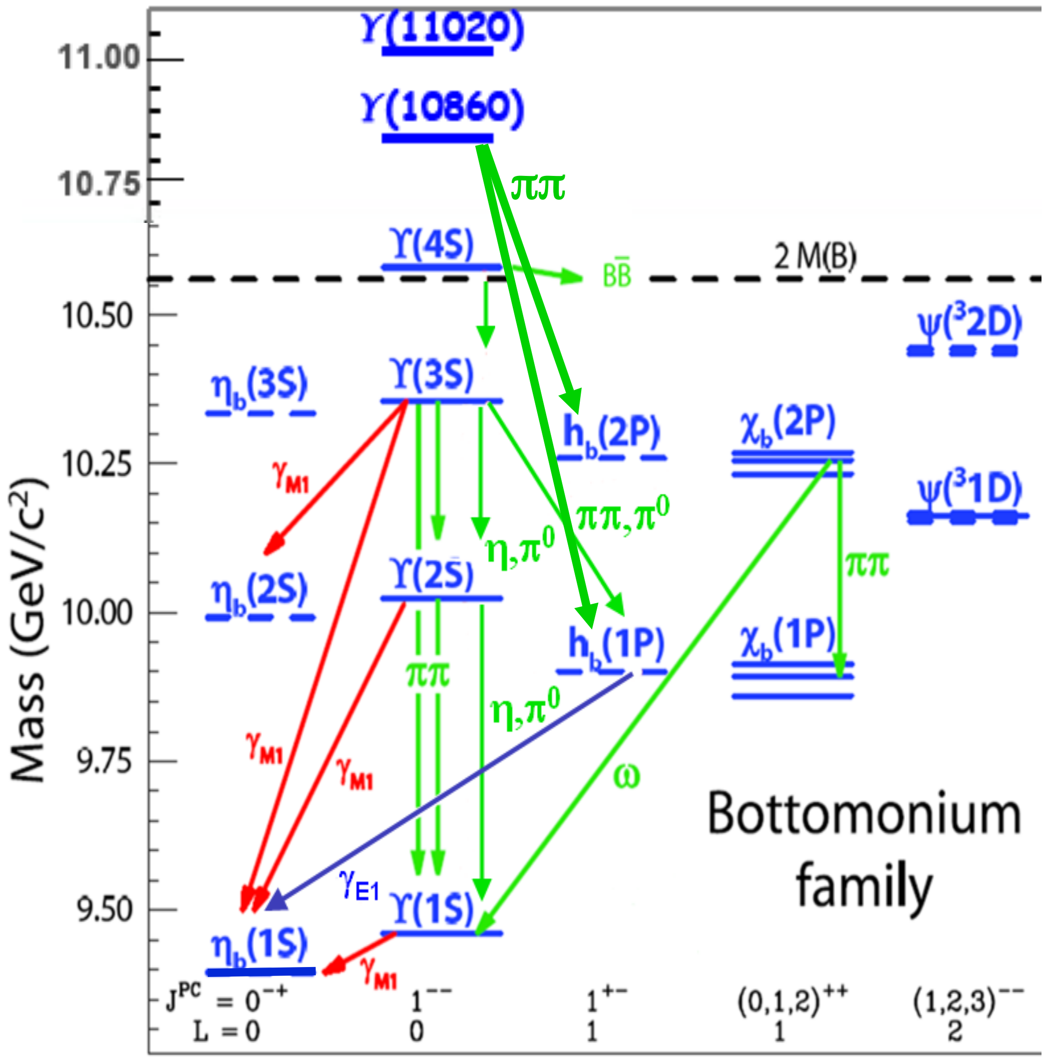
$\Delta M_{HF} \Rightarrow$ test of hyperfine interaction

For h_c $\Delta M_{HF} = -0.12 \pm 0.30$ MeV,
expect smaller deviation for $h_b(nP)$

Previous search

arXiv:1102.4565





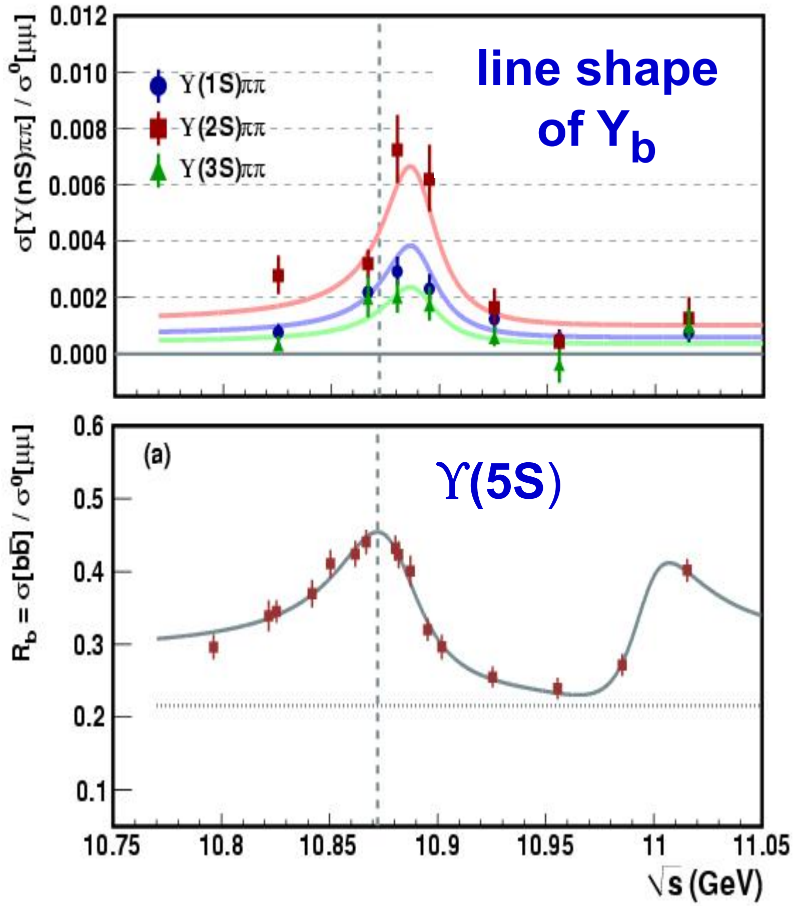
Nature of $\Upsilon(5S)$

Anomalous production of $\Upsilon(nS)\,\pi^+\pi^-$

PRL100,112001(2008)	Γ(MeV)
$\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(5S) \to \Upsilon(3S)\pi^+\pi^-$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.0060
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.0009
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	0.0019

10^2

PRD82,091106R(2010)



Simonov JETP Lett 87,147(2008)

1. Rescattering $\Upsilon(5S) \to BB\pi\pi \to \Upsilon(nS)\pi\pi$?

2. Similar effect in charmonium?

Y(4260) with anomalous $\Gamma(J/\psi\,\pi^+\pi^-)$

$\Rightarrow$ assume $\exists\, Y_b$ close to $\Upsilon(5S)$

to distinguish $\Rightarrow$ energy scan

$\Rightarrow$ shapes of R_b and $\sigma(\Upsilon\pi\pi)$ different (2σ)

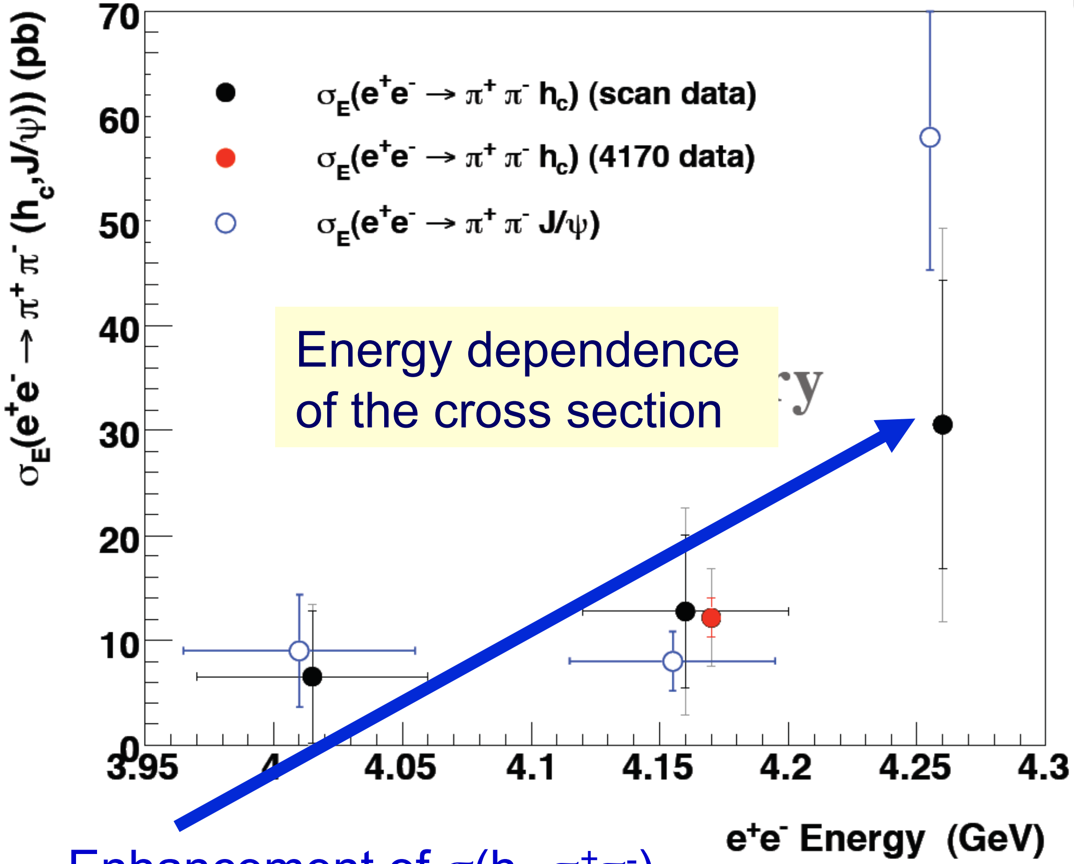
Nature of $\Upsilon(5S)$ is puzzling and not yet understood

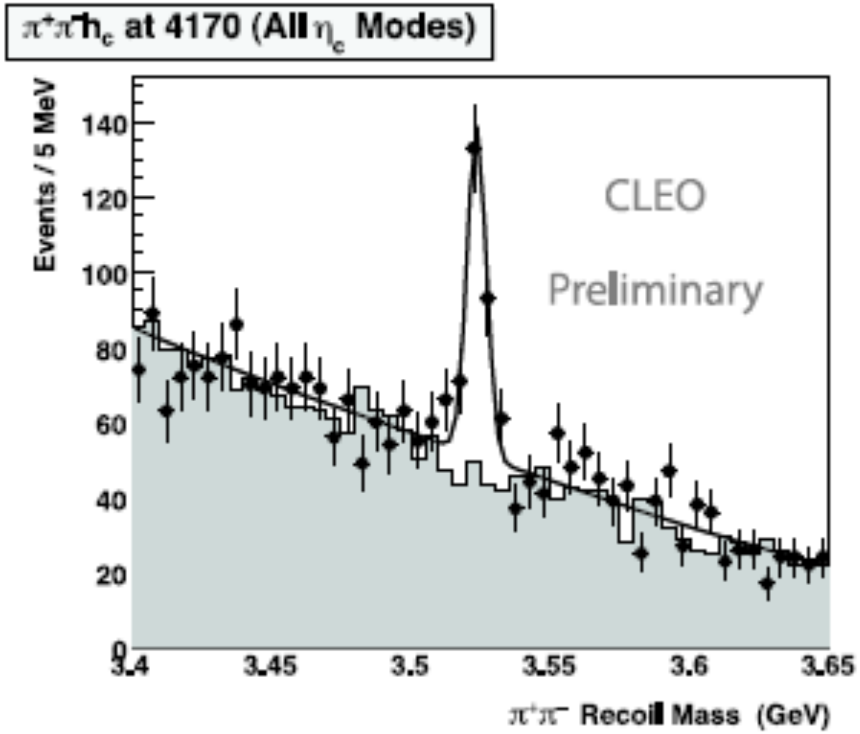
$Y(4260) \to h_c \pi^+\pi^-$?

Observation of $e^+e^- \to \pi^+\pi^- h_c$ by CLEO

arXiv:1104.2025

Ryan Mitchell @ CHARM2010





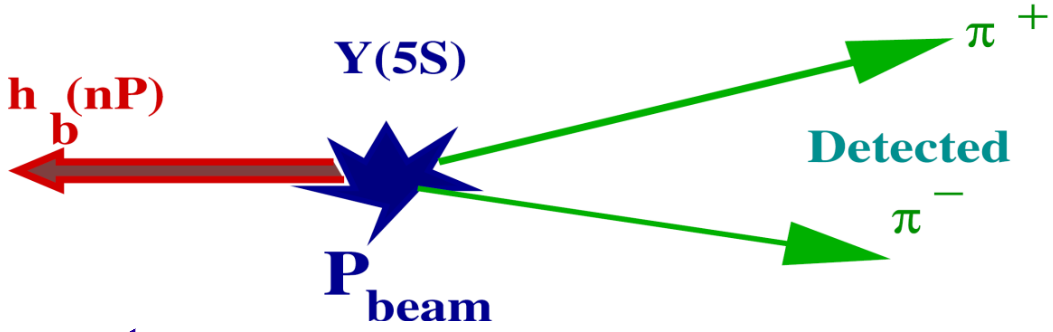
Enhancement of $\sigma(h_c \pi^+\pi^-)$ @ Y(4260)

$\Rightarrow$ $\sigma(h_b \pi^+\pi^-)$ is enhanced @ Y_b?

$\Rightarrow$ Belle search for h_b in $\Upsilon(5S)$ data

h_b Search : Method

"$\Upsilon(5S)$" $\rightarrow h_b \pi^+\pi^-$



Missing mass to $\pi^+\pi^-$ system

$$M_{hb(nP)} = \sqrt{(P_{\Upsilon(5S)} - P_{\pi+\pi-})^2} \equiv MM(\pi^+\pi^-)$$

[$\Upsilon(5S) \rightarrow \Upsilon(nS)\pi^+\pi^-$: control sample]

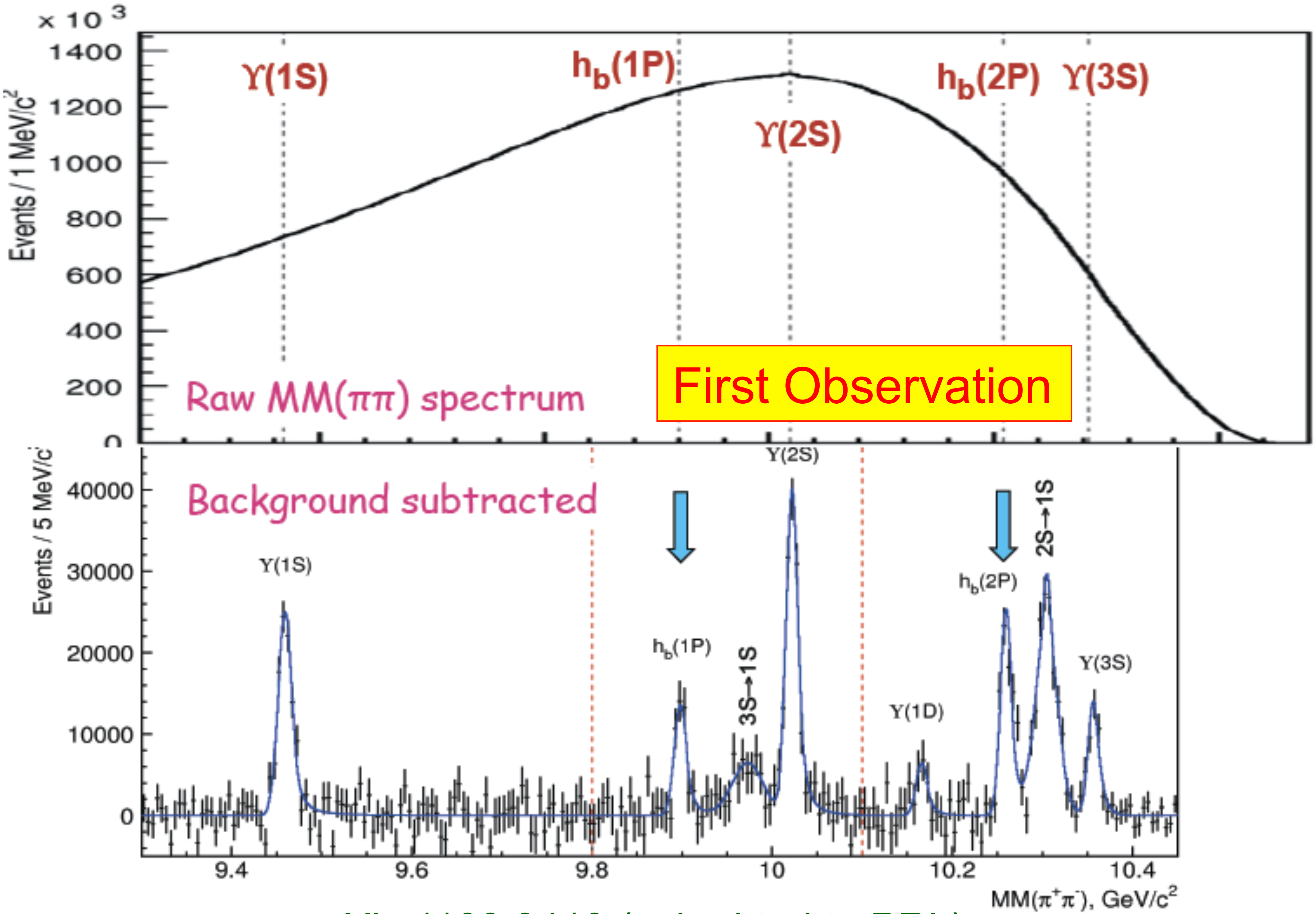
Simple selection :

- good quality, positively identified

Suppression of continuum events

FW R_2<0.3 (isotropic decay topology)

h_b : Missing Mass Dist.



arXiv:1103.3419 (submitted to PRL)

Charged Bottomonium-like Z_b^+

Unusually large production rate!

→ Exotic states ?

"Yb" $\rightarrow \Upsilon(nS)\pi^+\pi^-$

Charged Bottomonium-like States ?

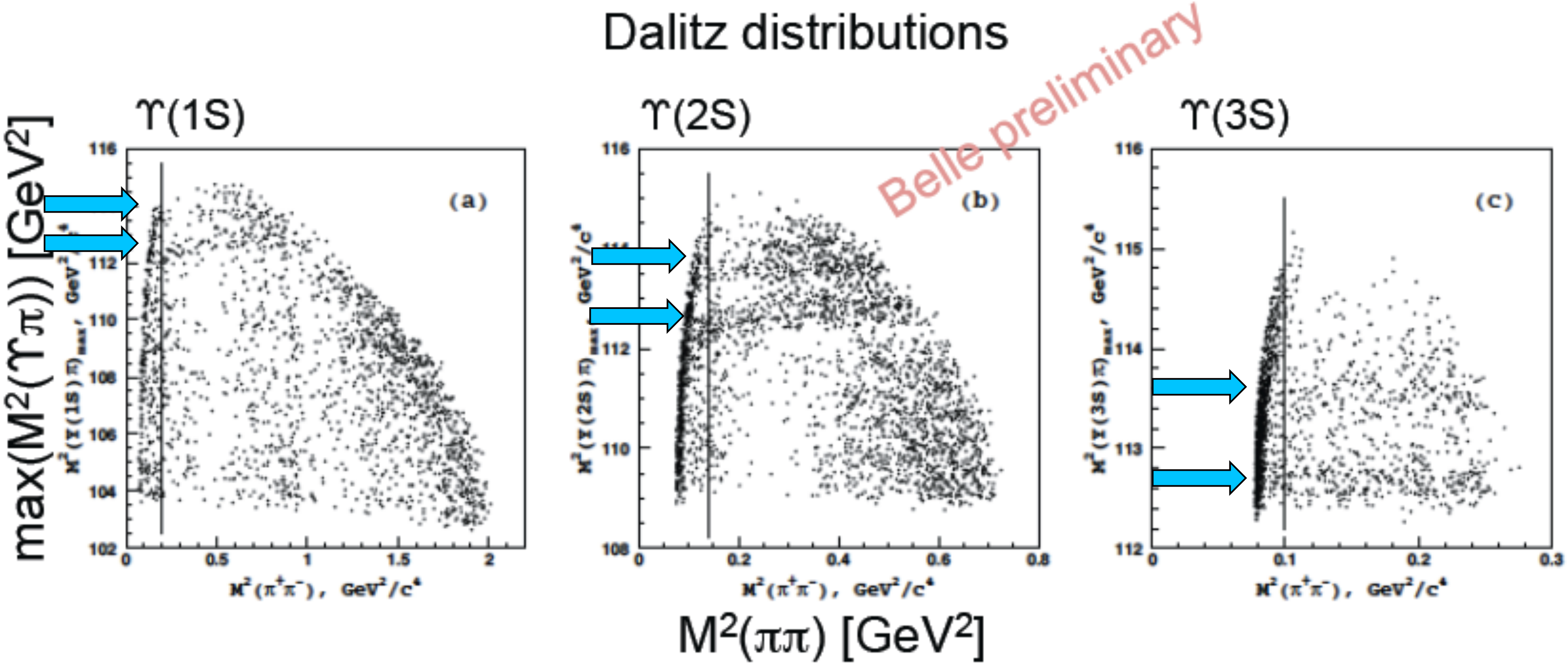
"Yb" $\rightarrow h_b(mP)\pi^+\pi^-$

cf) Charm: $B \rightarrow \psi' \pi^+ K^-$ $Z^+(4430)$

$B \rightarrow \chi_{c1} \pi^+ K^-$ $Z^+(4050)$, $Z^+(4250)$

$\Upsilon(nS)\pi^+\pi^-$

arXiv:1105.4583



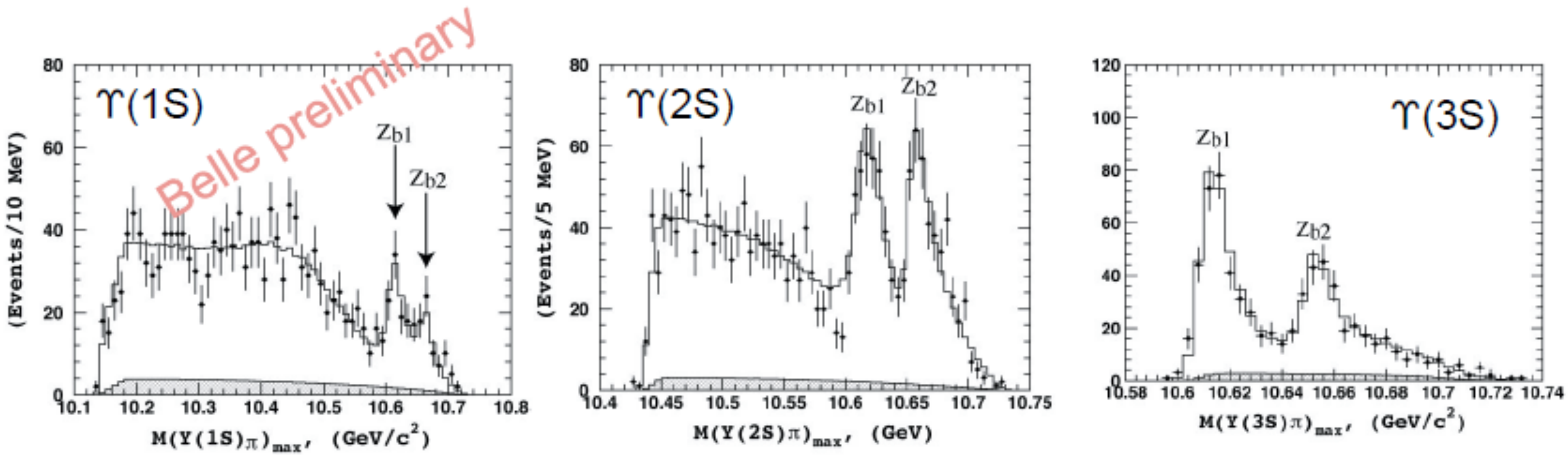
Dalitz Plot Amplitude analysis

2 Resonances (Z_b) + $f_0(980)$ + $f_2(1275)$ + NR

$\Upsilon(nS)\pi^+\pi^-$

arXiv:1105.4583

Projections to max(M(ϒπ)) axis



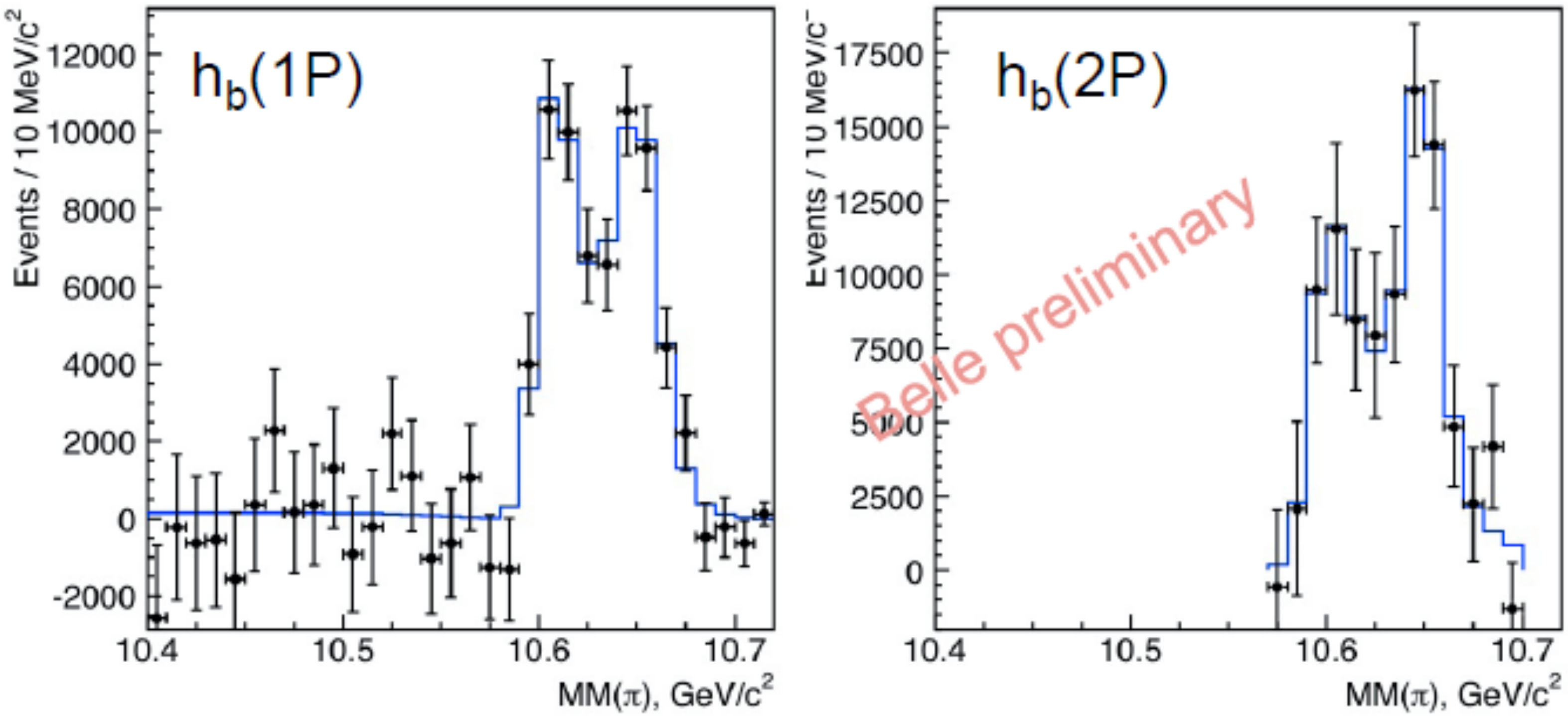
max(M(ϒπ)) [GeV]

Two resonances: $Z_b^+(10510)$, $Z_b^+(10560)$

Two peaks at the same positions in the 3 modes.

$h_b(nP)\pi^+\pi^-$

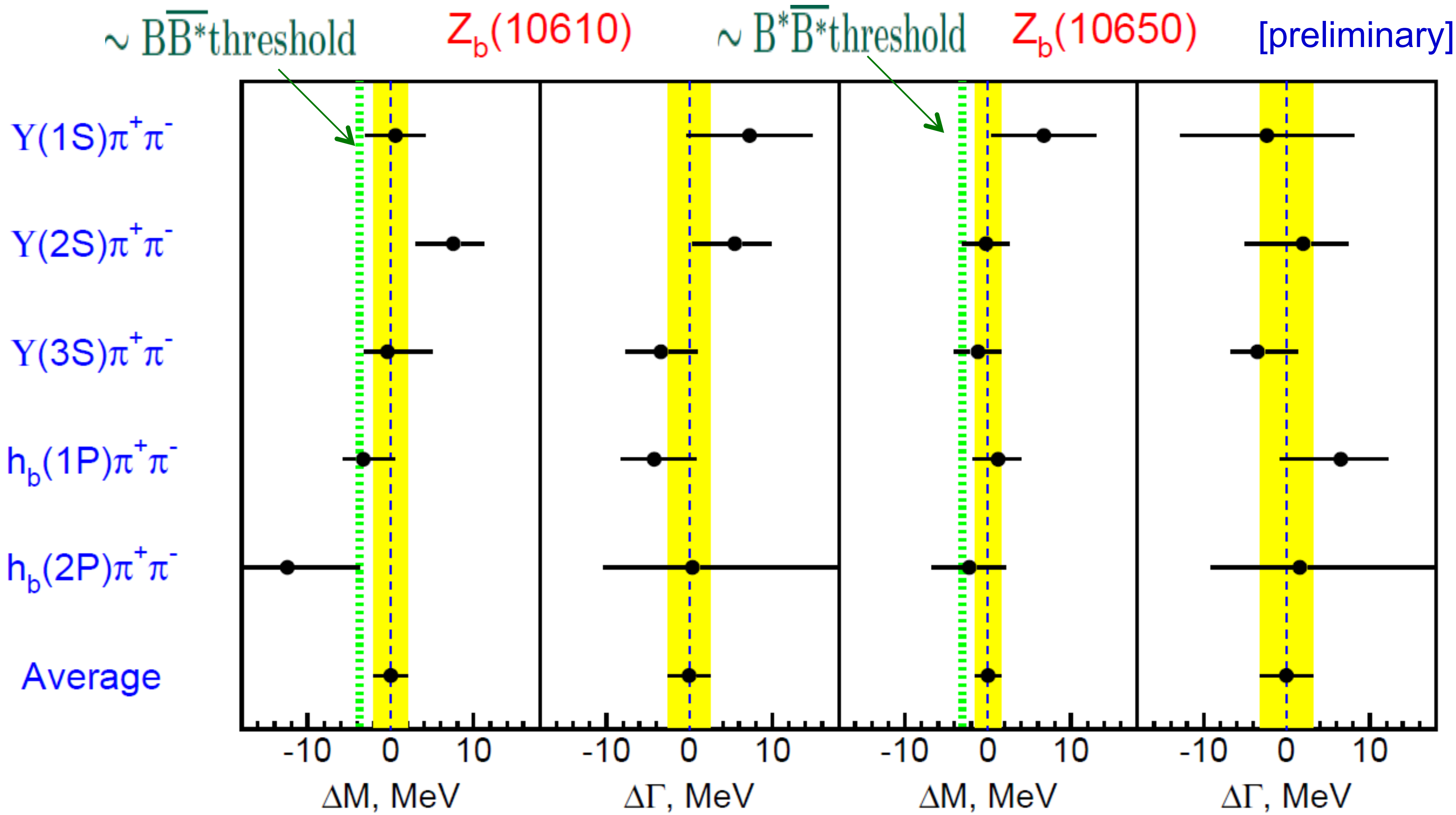
arXiv:1105.4583



$M(h_b\pi^+)$ = Missing Mass against π^-

Two peaks at the positions same as $\Upsilon(nS)\pi^+\pi^-$

$Z_b(10610)$ & $Z_b(10650)$



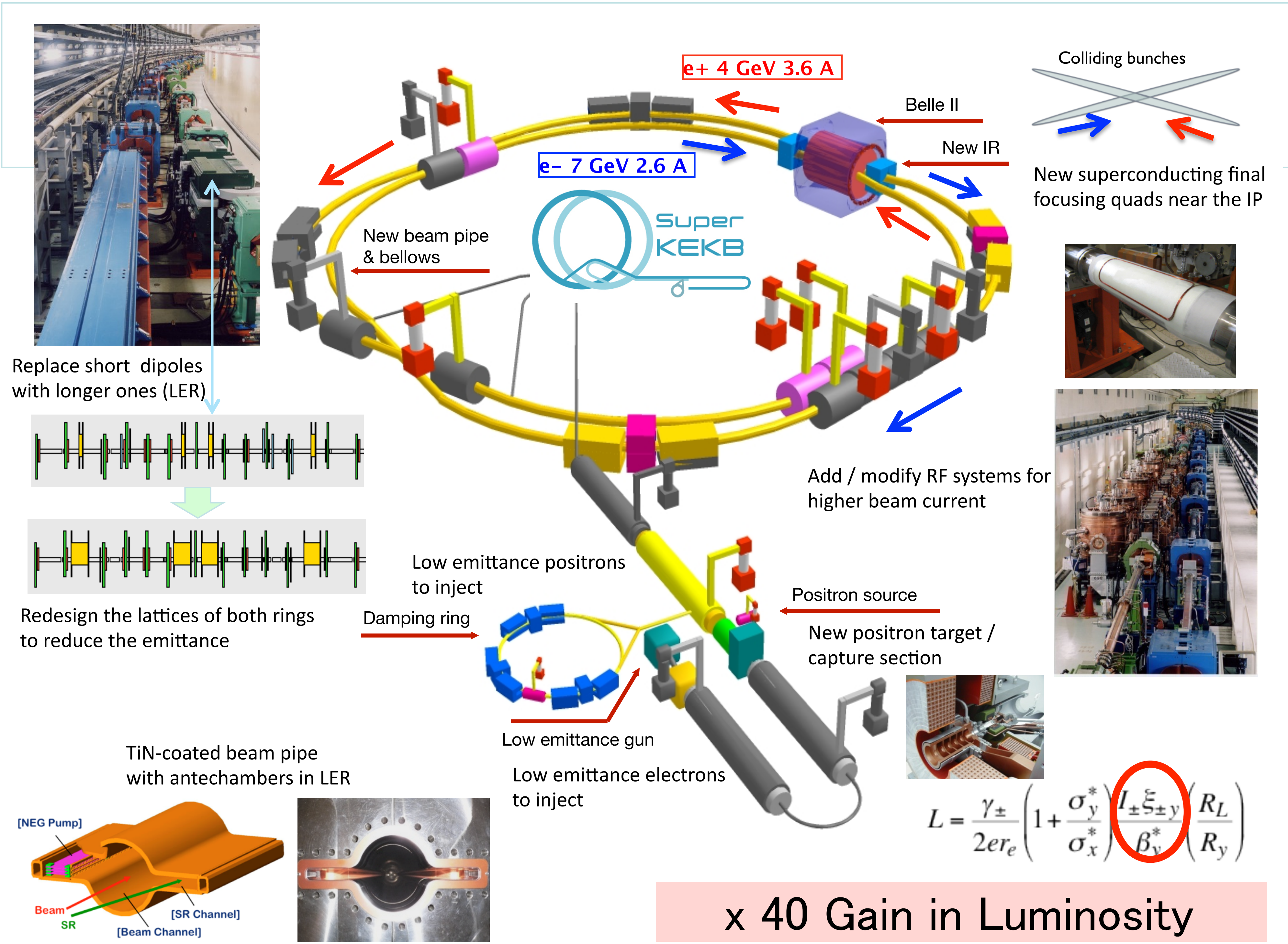
M=10608.4±2.0 MeV

Γ=15.6±2.5 MeV

M=10653.2±1.5 MeV

Γ=14.4±3.2 MeV

arXiv:1105.4583


e+ 4 GeV 3.6 A
e− 7 GeV 2.6 A
Belle II
New IR
Colliding bunches
New superconducting final focusing quads near the IP
SuperKEKB
New beam pipe & bellows
Replace short dipoles with longer ones (LER)
Redesign the lattices of both rings to reduce the emittance
Add / modify RF systems for higher beam current
Low emittance positrons to inject
Positron source
Damping ring
New positron target / capture section
Low emittance gun
Low emittance electrons to inject
TiN-coated beam pipe with antechambers in LER
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$
x 40 Gain in Luminosity

How to achieve "Super Luminosity"

Luminosity formula

Stored current

Beam-beam parameter

Lorentz factor

$$L = \frac{\gamma_{\pm}}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

Geometrical reduction factors due to crossing angle and hour-glass effect

0.8~1 (short bunch)

Classical electron radius

Beam size ratio
1~2% @IP

Vertical β at the IP

For higher Luminosity;	In case of KEKB → SuperKEKB	
1) Vertical β function at IP (β_y^*):	5.9 → 0.27/0.30mm	(x20)
2) Increase beam currents:	1.7/1.4 → 3.6/2.7 A	(x 2)
3) Increase ξ_y	0.09 → 0.09	(x 1)

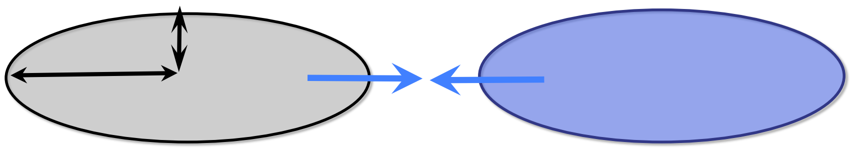
Basic concept: "Nano-beam scheme"

Invented by P. Raimondi for SuperB

Collision Scheme

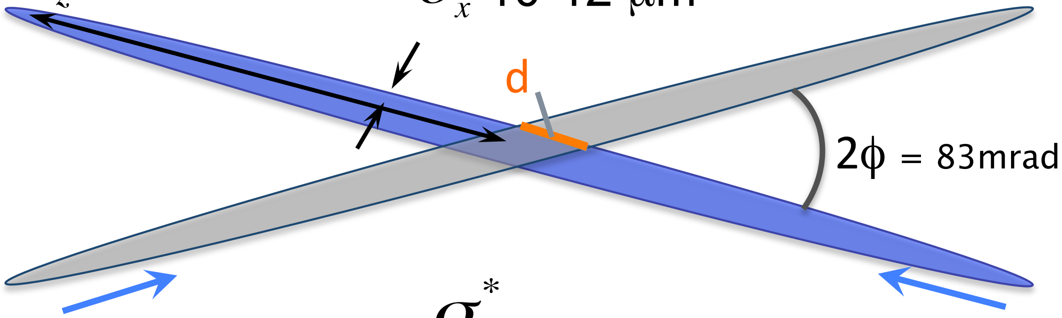
Y. Ohnishi et al.

KEKB head-on (crab crossing)



overlap region = bunch length

Nano-Beam SuperKEKB



$$d = \frac{\sigma_x^*}{\phi}$$

Half crossing angle: ϕ

overlap region << bunch length

Hourglass requirement

$$\beta_y^* \geq \sigma_z \quad \sim 6 \text{ mm}$$

$$\beta_y^* \geq \frac{\sigma_x^*}{\phi} \quad \sim 300\ \mu\text{m}$$

Vertical beta function at IP can be squeezed to ~300μm.
Need small horizontal beam size at IP.
→ low emittance, small horizontal beta function at IP.

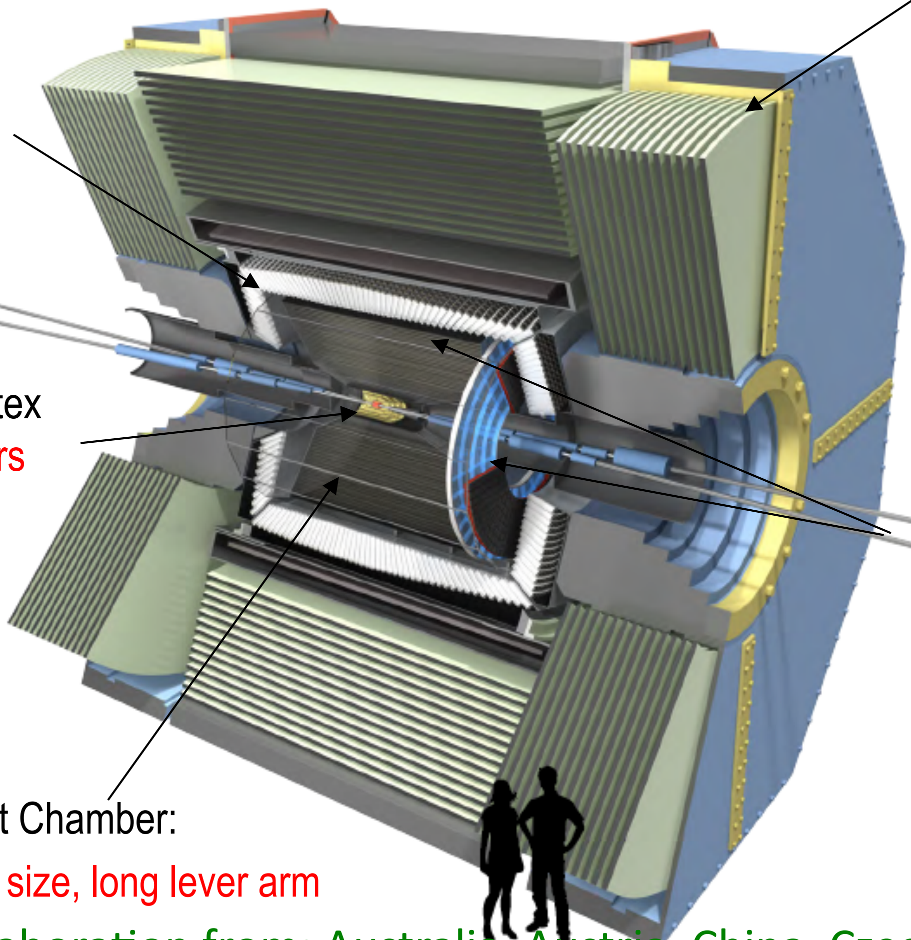
Belle II Detector

Belle II T-shirts
1300 Yen

- Deal with higher background (10-20×), radiation damage, higher occupancy, higher event rates (L1 trigg. 0.5→30 kHz)
- Improved performance and hermeticity

CsI(Tl) EM calorimeter:
waveform sampling electronics, pure CsI for endcaps

RPC μ & K_L counter:
scintillator + Si-PM for end-caps



4 layers DS Si vertex detector → 2 layers PXD (DEPFET), 4 layers DSSD

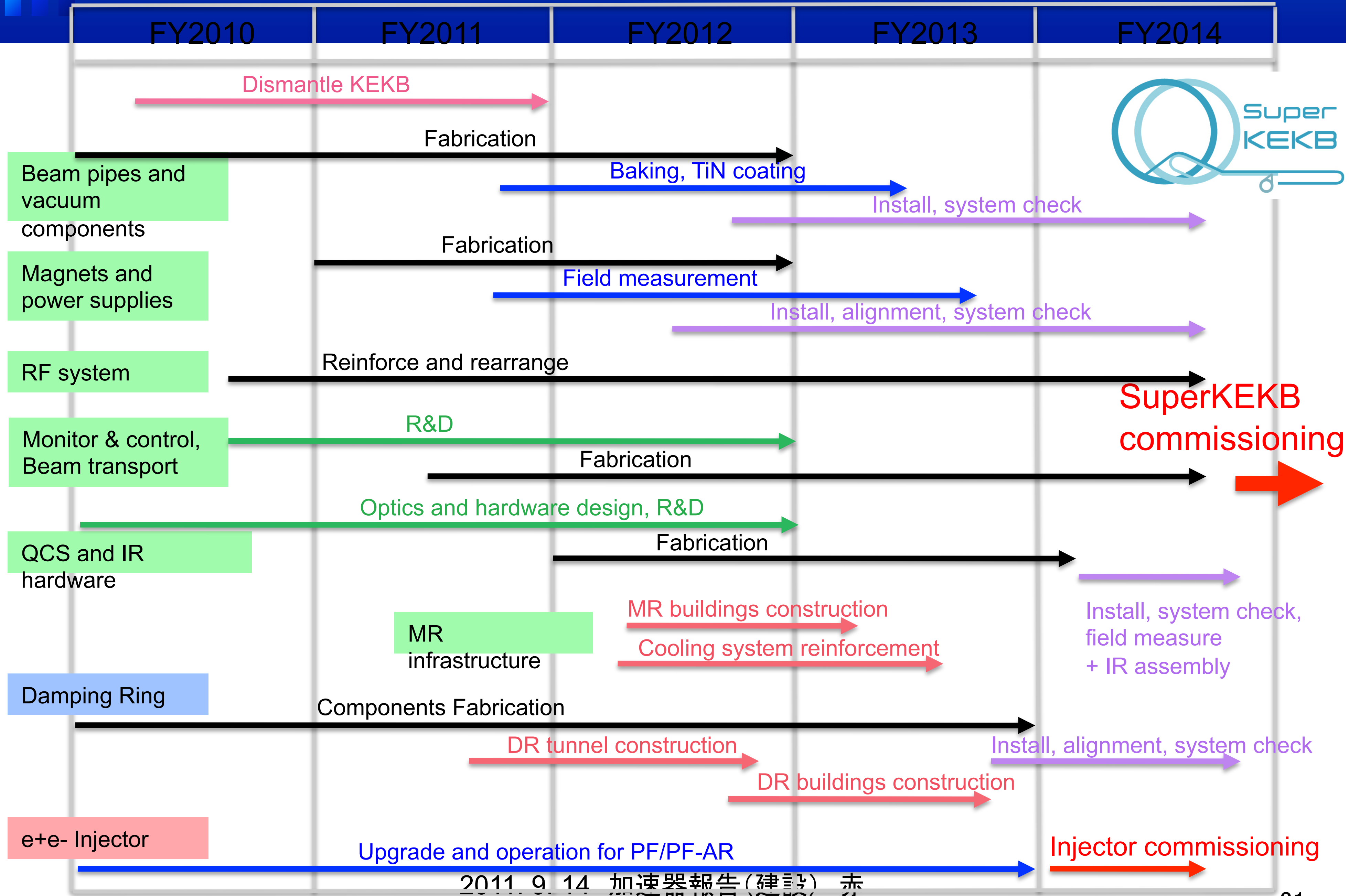
Time-of-Flight, Aerogel Cherenkov Counter →
Time-of-Propagation (barrel), prox. focusing Aerogel RICH (forward)

Central Drift Chamber:
smaller cell size, long lever arm

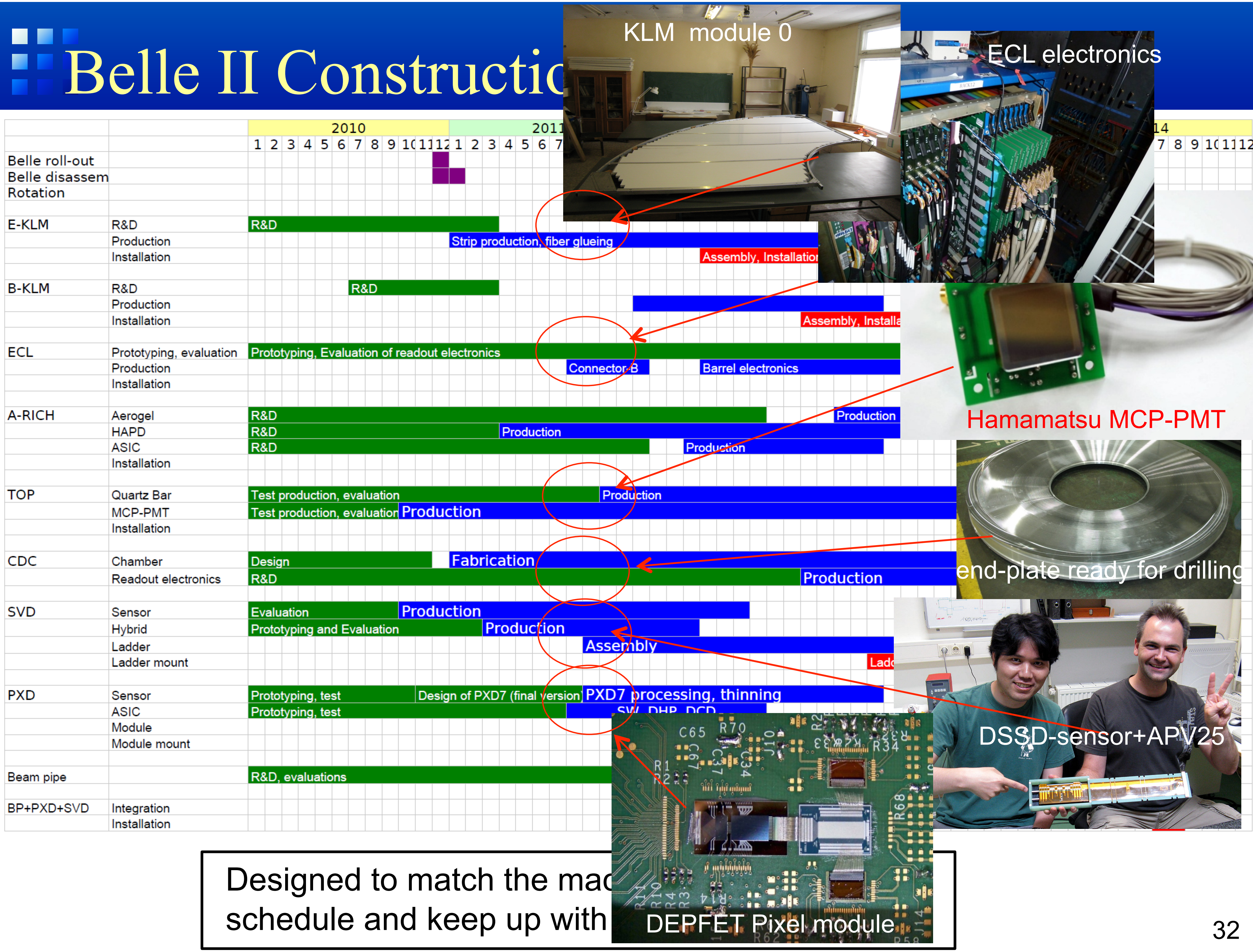
International collaboration from: Australia, Austria, China, Czech, Germany, Inida, Korea, Poland, Russia, Saudi Arabia, Slovenia, Spain, Taiwan, USA, Japan

SuperKEKB construction schedule

Revised on Sep. 10, 2011



Belle II Constructio

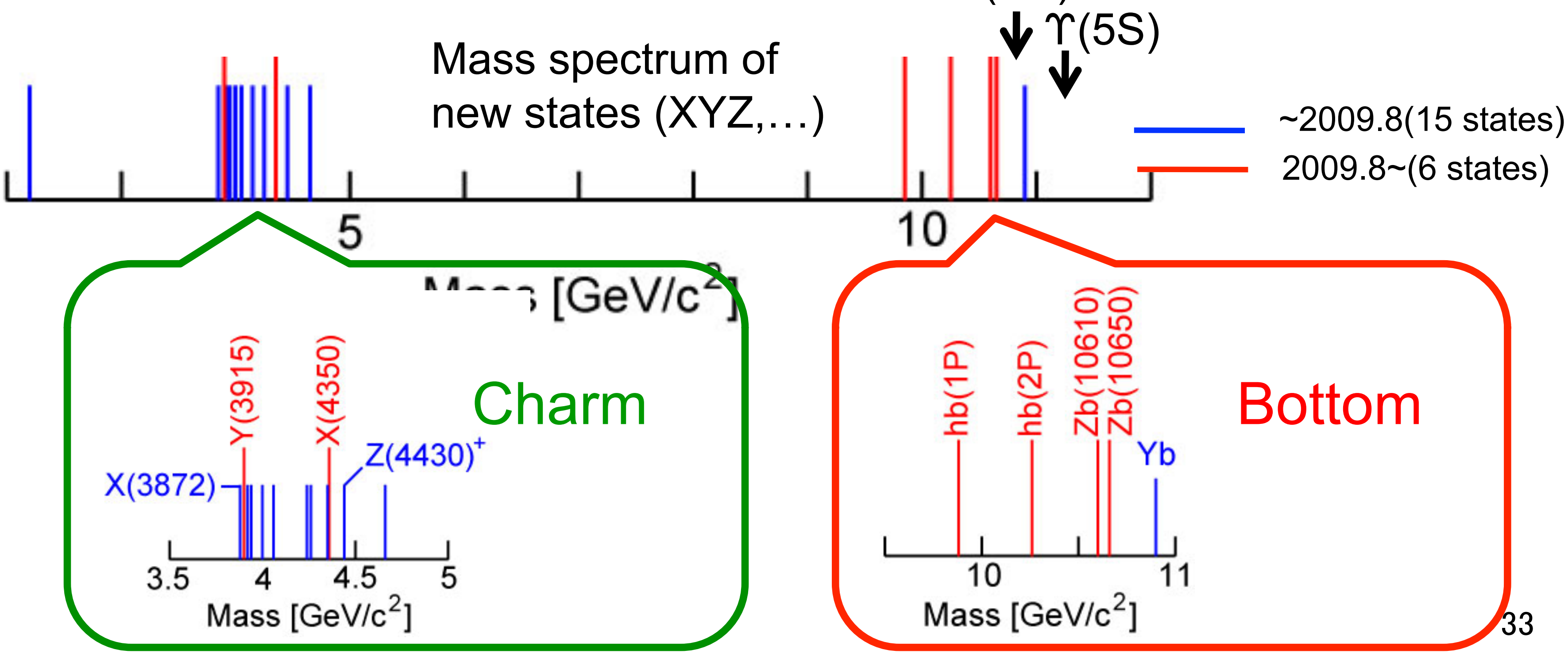


Designed to match the mac
schedule and keep up with

Summary

- B factories have played unique role also in QCD physics. More results will come from existing large data.
  - Structure functions
    - First measurements of Collins FF, IFF,
  - Spectroscopy

- Unpolarized FF (π, η, K, p,..)
- Continue measuring Spin-dep. FF
  - kT dep. of Collins function,
  - π^0, η, K Collins
  - πK, KK IF
- Others…



Outlook

Upgrade to SuperKEKB/Belle II in progress. Collins will start from 2015.

More opportunities

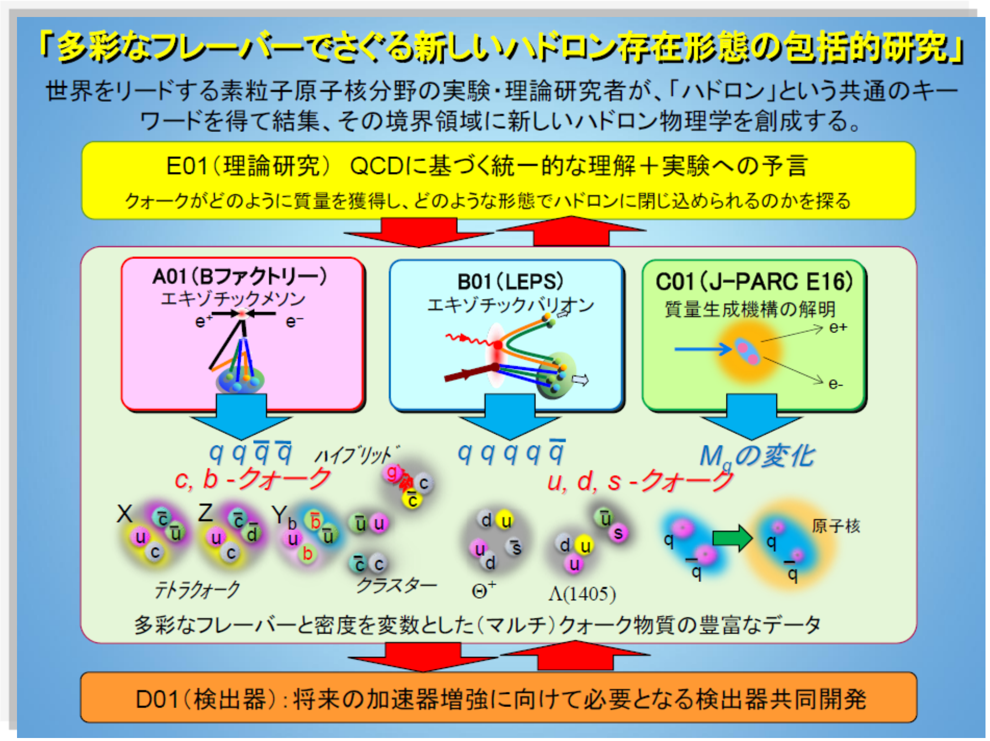
- Fragmentation Physics
  - High precision fragmentation function
  - With variety of final states
- Spectroscopy
  - More new states w/ variety of flavors
  - Properties of observed states (J^{PC}, decay modes,...)

I am sure SuperKEKB/Belle II will be a great tool also for QCD qualitatively, and want more (quantitative) studies.

Your inputs are very welcome !

Advertisement

Grant-in-aid for innovative scientific research area
”Elucidation of new hadrons with a variety of flavors”.
We welcome your contribution !

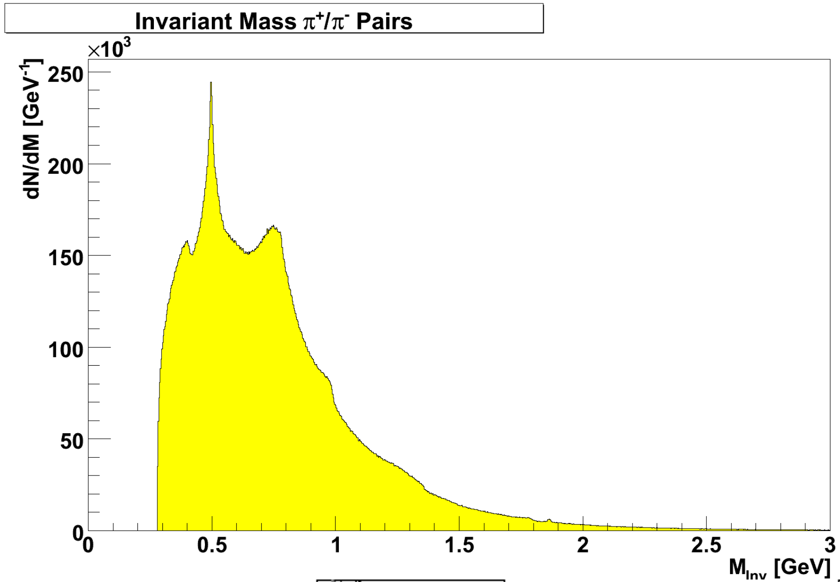


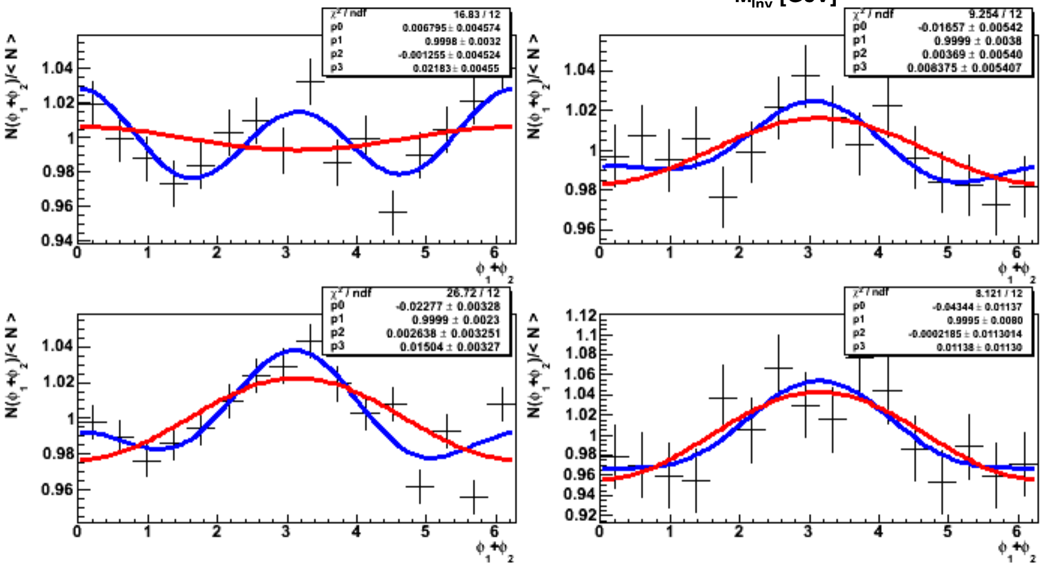
Visit our home page !
http://www.hepl.phys.nagoya-u.ac.jp/public/new_hadron/index.html

公募研究募集中！

Backup

Asymmetry extraction





- Build normalized yields:

$$\frac{N(\phi_1+\phi_2)}{\langle N \rangle},$$

- Fit with:

$$a_{12}\cos(\phi_1+\phi_2)+b_{12}$$

or

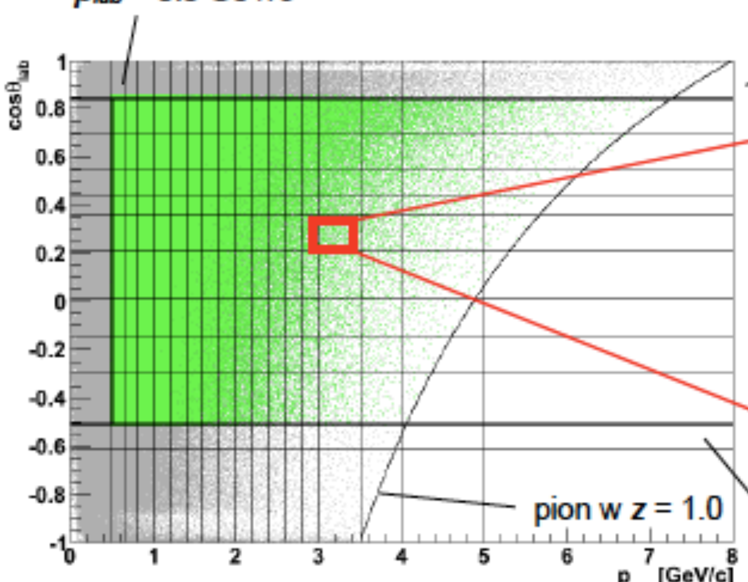
$$a_{12}\cos(\phi_1+\phi_2)+b_{12}+$$
$$c_{12}\cos 2(\phi_1+\phi_2)+d_{12}\sin(\phi_1+\phi_2)$$

Amplitude a_{12} directly measures
(IFF) x (-IFF)
(no double ratios)

Unpolarized Fragmentation Functions

- Precision Measurement of unpolarized FFs important for almost all extractions of PDFs
- But this is a hard measurement, at Belle
  - Extensive systematic studies for PID effects: calibration & deconvolution/ correction
  - further corrections for momentum smearing, acceptance effects, ….

PID correction: $\vec{\tilde{N}}_j = \hat{P}\,\vec{N}_i$ → $\vec{N}_i = \hat{P}^{-1}\,\vec{\tilde{N}}_j$: PID correction by inversion of PID probability matrix.



scatter plot: e, μ, π, K and p tracks from 4e+05 events

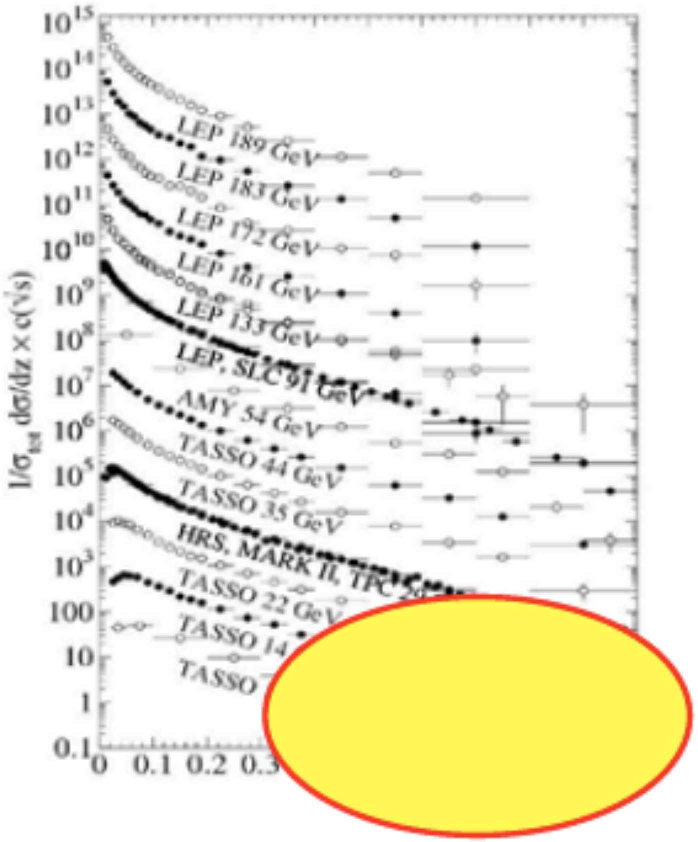
filling matrix of PID probabilities for each single bin from real data calibration

$$[P]_{ij}\,(p_{lab}, \cos\theta_{lab}) = \begin{pmatrix} p(e\to\tilde{e}) & p(\mu\to\tilde{e}) & p(\pi\to\tilde{e}) & p(K\to\tilde{e}) & p(p\to\tilde{e}) \\ p(e\to\tilde{\mu}) & p(\mu\to\tilde{\mu}) & p(\pi\to\tilde{\mu}) & p(K\to\tilde{\mu}) & p(p\to\tilde{\mu}) \\ p(e\to\tilde{\pi}) & p(\mu\to\tilde{\pi}) & p(\pi\to\tilde{\pi}) & p(K\to\tilde{\pi}) & p(p\to\tilde{\pi}) \\ p(e\to\tilde{K}) & p(\mu\to\tilde{K}) & p(\pi\to\tilde{K}) & p(K\to\tilde{K}) & p(p\to\tilde{K}) \\ p(e\to\tilde{p}) & p(\mu\to\tilde{p}) & p(\pi\to\tilde{p}) & p(K\to\tilde{p}) & p(p\to\tilde{p}) \end{pmatrix}$$

A. Vossen
@ Transversity 2011

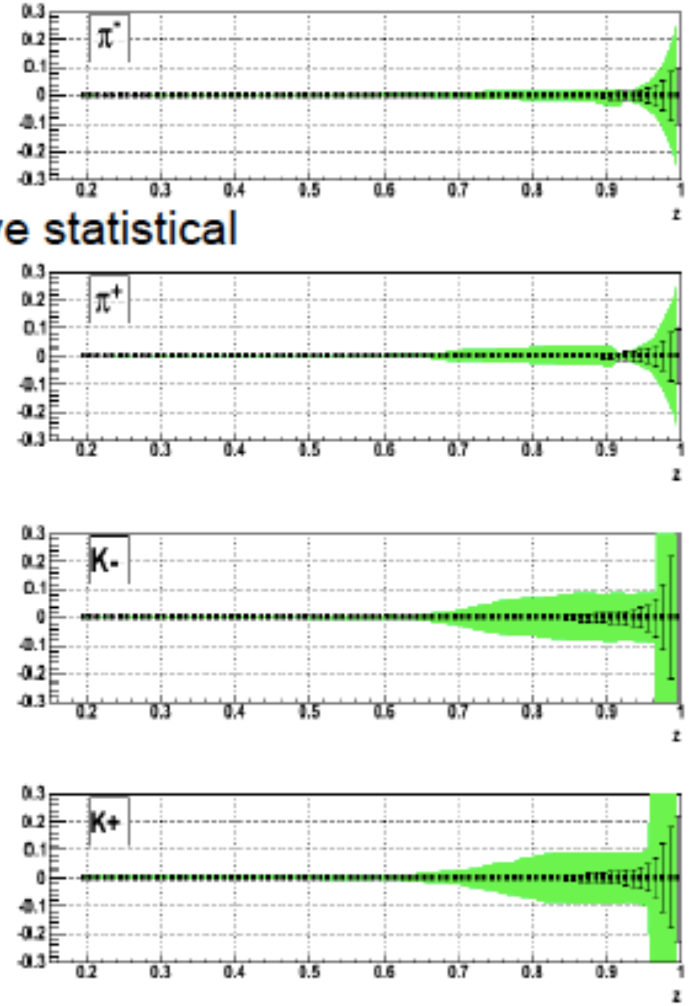
Unpolarized Fragmentation Functions

- Measurement will give precision data set for low Q^2 and high z:



e+e- -> h+- X data

Projected relative statistical and systematic uncertainties



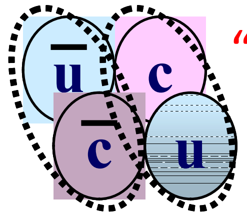
In the future: include k_t dependence and measure di-hadron FFs needed for transversity extraction from di-hadron correlations

A. Vossen
@ Transversity 2011

Possible Interpretation

- **Tetraquarks:** diquark-antidiquark $[cq][\bar{c}\bar{q}]$
  - Tightly bound diquarks (gluon exchange)
  - Decay proceeds with „coloured” quarks rearrange into „white” mesons

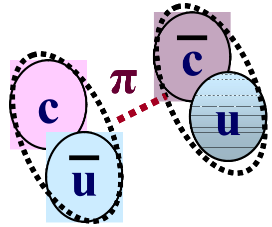
Tetraquark



“Di-quark”

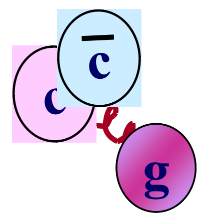
- **Molecules:** $M(c\bar{q})M(\bar{c}q)$
  - Meson and antimeson loosely bound (pion exchange)
  - Decay: dissociation into constituent mesons

$D^{(*)}D^{(*)}$ Molecule



- **Hybrids:** $c\bar{c}$ + excited gluon (excited flux-tube)
  - Lattice QCD predicts lightest hybrids @ 4.2GeV
  - Exotic quantum numbers $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$...
  - $\Gamma(H \to D\bar{D}^{**}) > \Gamma(H \to D\bar{D}^{(*)})$
  - Large $\Gamma(H \to \psi\pi\pi, \psi\omega, \ldots)$

Hybrid



X(3872) Radiative Decays

$X(3872) \to J/\psi\,\gamma$

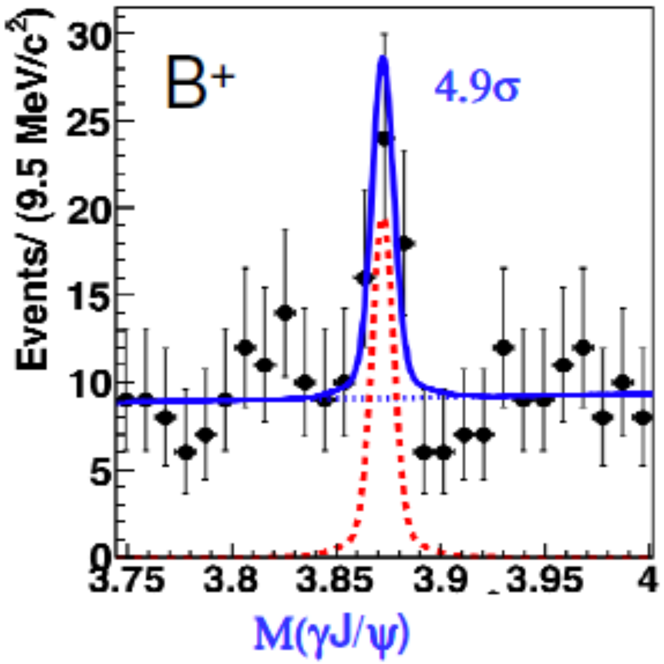
C = +

$X(3872) \to \psi'\_\gamma$

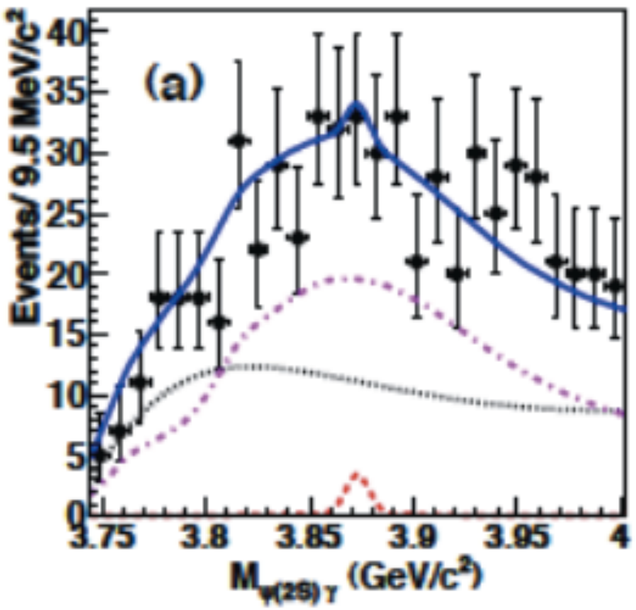
信号見えず: D^0-D^{*0} molecule

$$\frac{Br(X(3872) \to \psi'\,\gamma)}{Br(X(3872) \to J/\psi\,\gamma)} < 2.1$$

$B^\pm \to J/\psi\,\gamma\,K^\pm$



$B^\pm \to \psi'\,\gamma\,K^\pm$



arXiv:1105.0177 (accepted by PRL)

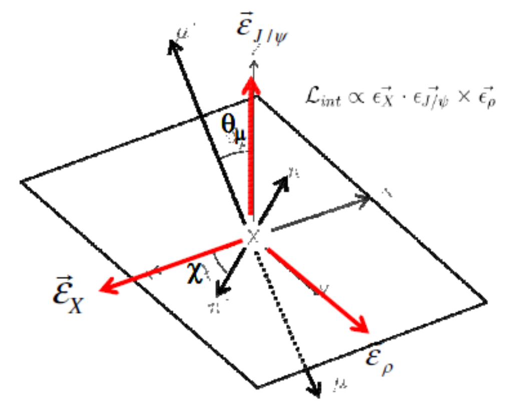
J^{PC} of X(3872)

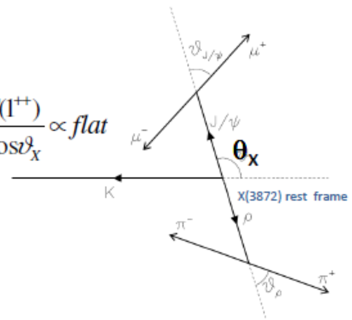
- Evidence of X(3872)→J/ψ γ, J/ψ ρ imply C-even assignment.
- X(3872)→J/ψ ρ is right at the threshold.

favor low values of spin quantum numbers.

B→KX(3872)→KρJ/ψ

Angular distribution





$$\frac{d\Gamma(1^{++})}{d\cos\vartheta_X} \propto flat$$

$$\frac{d\Gamma(1^{++})}{d\cos\chi d\cos\vartheta_\mu} \propto \sin^2\chi \sin^2\vartheta_\mu$$

2^{-+}

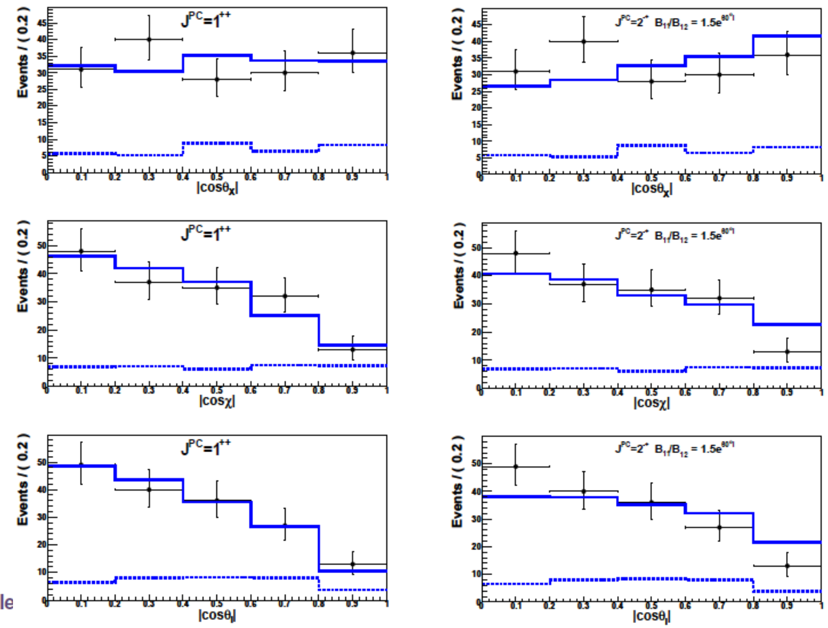
$$\alpha = 1: \frac{d\Gamma}{d\cos\vartheta_X} \propto 1 + 3\cos^2\vartheta_X$$

$$\alpha = 0: \frac{d\Gamma}{d\cos\vartheta_X} \propto \sin^2\vartheta_X$$

J. Rosner PRD 70, 092023 (2004)

comple

Include relative phase



arXiv:1107.0163 (submitted to PRD)

All J^{PC} values other than 1^{++} or 2^{-+} are ruled out.

consistent with the CDF result.

PRL 98, 132002 (2007)

Machine Parameters

		SuperKEKB		SuperB (base line)	
Parameters	unit	LER	HER	LER	HER
Circumference	m	3016.3		1258.4	
Energy	GeV	4	7	4.18	6.7
Half x-ing angle	mrad	41.5		33	
β_x^* / β_y^* at IP	mm	32 / 0.27	25 / 0.31	32 / 0.205	26 / 0.253
Hor. emittance (ε_x)	nm	3.2	5.0	2.46	2.00
σ_x / σ_y at IP	μm	10.2/0.059	7.75/0.059	8.872 / 0.036	7.211 / 0.036
Beam-beam (ξ_y)		0.0886	0.0830	0.0971	0.0970
$N_{bunches}$		2500		978	
Beam currents	A	3.6	2.6	2.447	1.892
Luminosity	$cm^{-2}s^{-1}$	0.8×10^{36}		1.0×10^{36}	

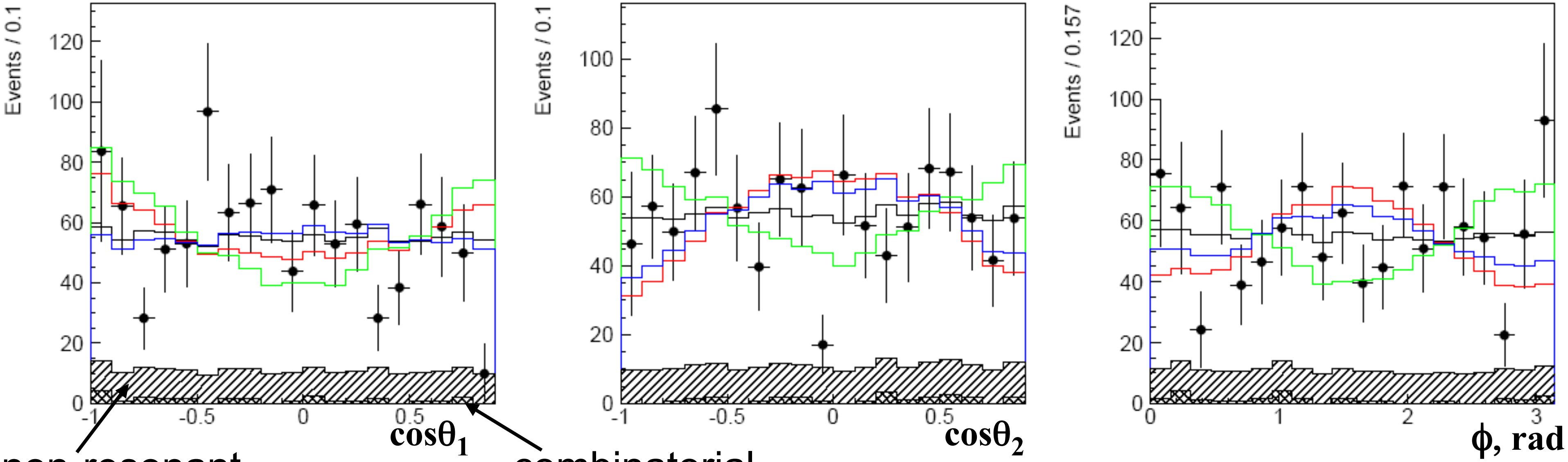
Compared to KEKB/PEP II

- Smaller beam size and higher currents.
- Larger (half) crossing angle than (11mrad @ KEKB)
- Less energy asymmetry (higher E_{LER}) for longer Touschek lifetime (LER).

Angular analyses

Definition of angles $\theta_i = \angle(\pi_i, e^+)$, $\phi = \angle[\text{plane}(\pi_1, e^+), \text{plane}(\pi_1, \pi_2)]$

Example : $\Upsilon(5S) \to Z_b^+(10610)\,\pi^- \to [\Upsilon(2S)\pi^+]\,\pi^-$



non-resonant combinatorial

Color coding: J^P= **1⁺** **1⁻** **2⁺** **2⁻** (0± is forbidden by parity conservation)

Best discrimination: **cosθ_2** for **1⁻** (3.6σ) and **2⁻** (2.7σ);

cosθ_1 for **2⁺** (4.3σ)

Summary of angular analyses

All angular distributions are consistent with $J^P=1^+$ for $Z_b(10610)$ & $Z_b(10650)$.

All other J^P with $J\leq 2$ are disfavored at typically 3σ level.

Probabilities at which different J^P hypotheses are disfavored compared to 1^+

<table>
<tr><th rowspan="2">J^P</th><th colspan="3">$Z_b(10610)$</th><th colspan="3">$Z_b(10650)$</th></tr>
<tr><th>$\Upsilon(2S)\pi^+\pi^-$</th><th>$\Upsilon(3S)\pi^+\pi^-$</th><th>$h_b(1P)\pi^+\pi^-$</th><th>$\Upsilon(2S)\pi^+\pi^-$</th><th>$\Upsilon(3S)\pi^+\pi^-$</th><th>$h_b(1P)\pi^+\pi^-$</th></tr>
<tr><td>1^-</td><td>3.6σ</td><td>0.3σ</td><td>0.3σ</td><td>3.7σ</td><td>2.6σ</td><td>2.7σ</td></tr>
<tr><td>2^+</td><td>4.3σ</td><td>3.5σ</td><td rowspan="2">4.3σ</td><td>4.4σ</td><td>2.7σ</td><td rowspan="2">2.1σ</td></tr>
<tr><td>2^-</td><td>2.7σ</td><td>2.8σ</td><td>2.9σ</td><td>2.6σ</td></tr>
</table>

Preliminary:

procedure to deal with non-resonant contribution is approximate,
no mutual cross-feed of Z_b's

Summary

arXiv:1103.3419
submitted to PRL

First observation of **h_b(1P)** and **h_b(2P)**

Hyperfine splitting consistent with zero, as expected
Anomalous production rates

Observation of two charged bottomonium-like resonances in 5 final states

update of
arXiv:1105.4583,
to be submitted to PRL

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

Z_b(10610)	M = 10607.2 ± 2.0 MeV Γ = 18.4± 2.4 MeV
Z_b(10650)	M = 10652.2 ± 1.5 MeV Γ = 11.5 ± 2.2 MeV

Masses are close to BB* and B*B* thresholds – molecule?

Angular analyses favour $J^P = 1^+$, decay pattern $\Rightarrow$ $I^G = 1^+$

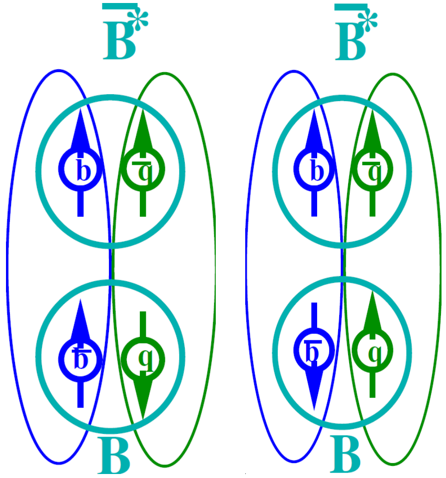
Heavy quark structure in Z_b

arXiv:1105.4473

Wave func. at large distance – free B(*)B*

$$|Z_b\rangle = \frac{1}{\sqrt{2}} 0^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}} - \frac{1}{\sqrt{2}} 1^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}}$$

$$|Z_b'\rangle = \frac{1}{\sqrt{2}} 0^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}} + \frac{1}{\sqrt{2}} 1^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}}$$



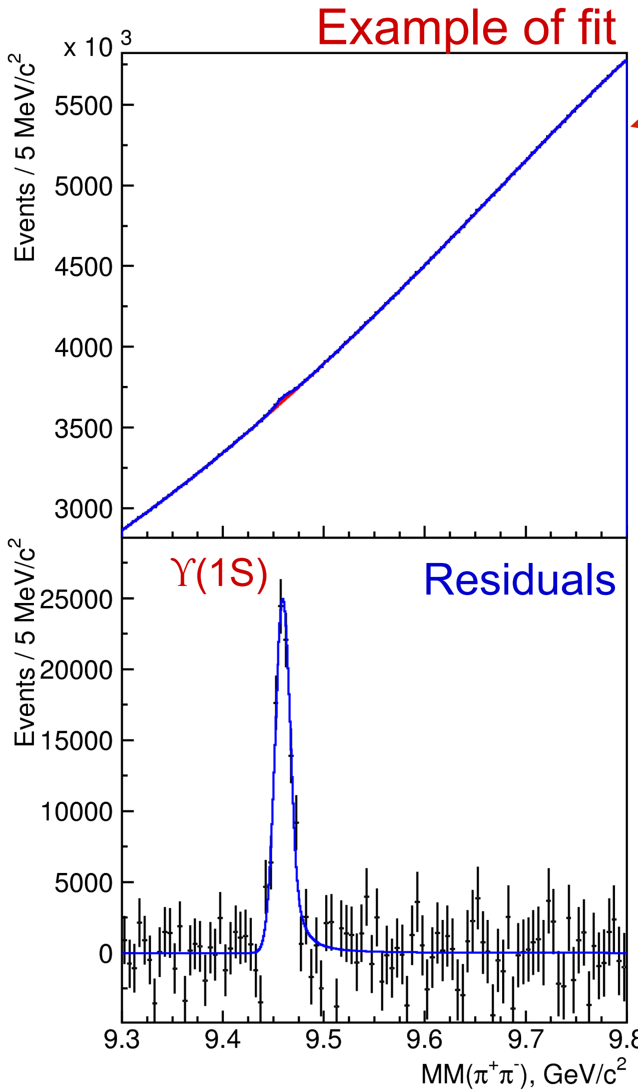
Explains

- Why $h_b\pi\pi$ is unsuppressed relative to $\Upsilon\pi\pi$
- Relative phase ~0 for Υ and ~180^0 for h_b
- Production rates of $Z_b(10610)$ and $Z_b(10650)$ are similar
- Widths –"–

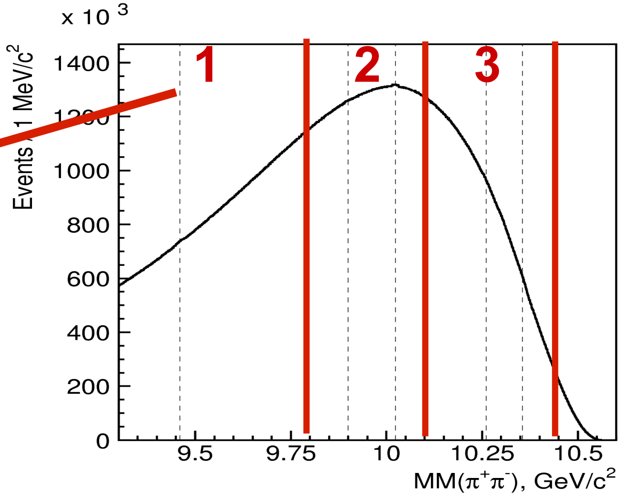
Predicts

- Existence of other similar states

Description of fit to MM($\pi^+\pi^-$)



Three fit regions

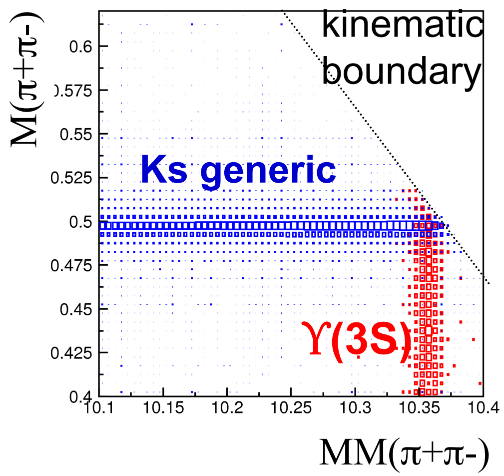


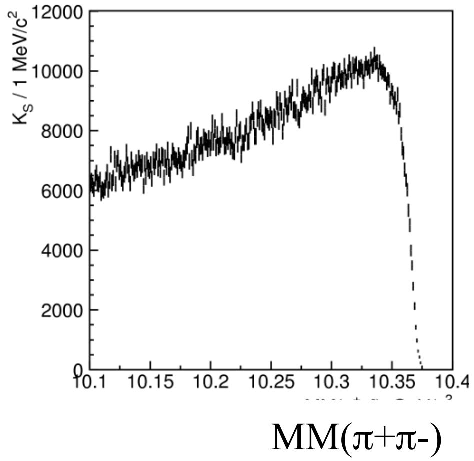
BG: Chebyshev polynomial, 6^{th} or 7^{th} order

Signal: shape is fixed from $\mu^+\mu^-\pi^+\pi^-$ data

"Residuals" – subtract polynomial from data points

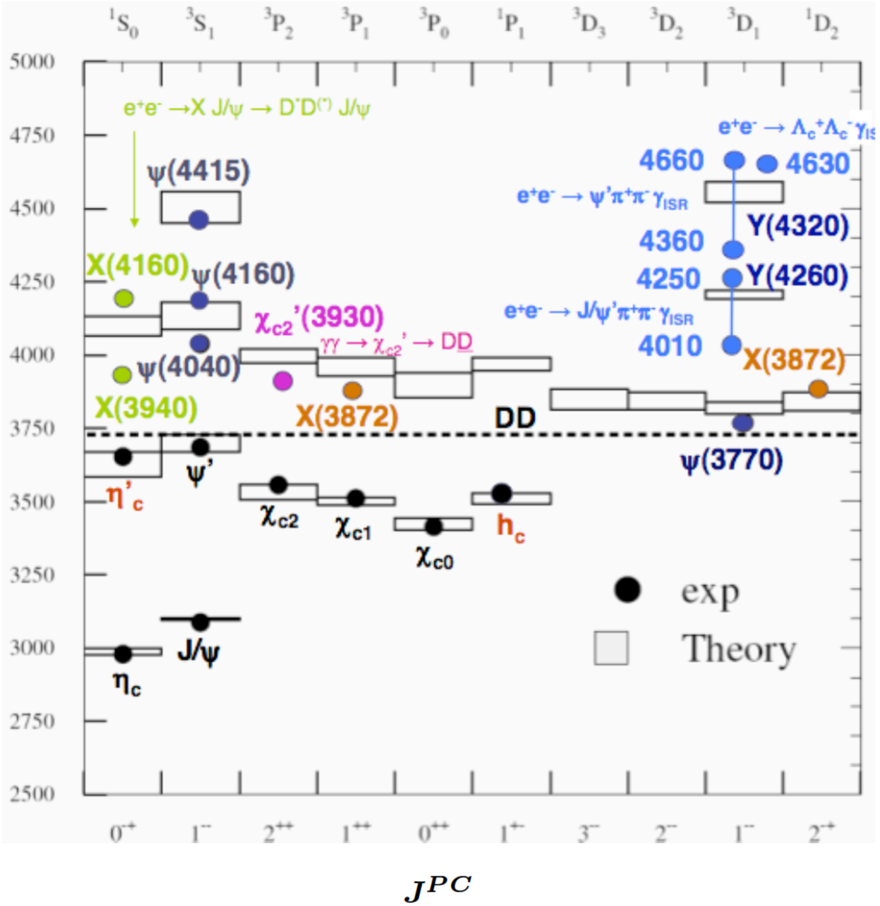
K_S contribution: subtract bin-by-bin





Charmonia

M. Nielsen @ Charm2010



$n^{(2S+1)}L_J$

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

- Below DD threshold;
  - All charmonium states have been observed.
  - Spectra are in good agreement with naïve quark model

$$V_{QCD} = -\frac{4}{3}\frac{\alpha_S}{r} + kr$$

- Above DD threshold;

  Observed States DO NOT
  - fit to the predicted spectrum.
  - Decay into $D^{(*)}D^{(*)}$

Much more complicated.