Prospects for $B \rightarrow D^{**}$ @ Belle II

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$B \rightarrow D^{**}$ Workshop

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On Behalf of the Belle II collaboration

Belle II

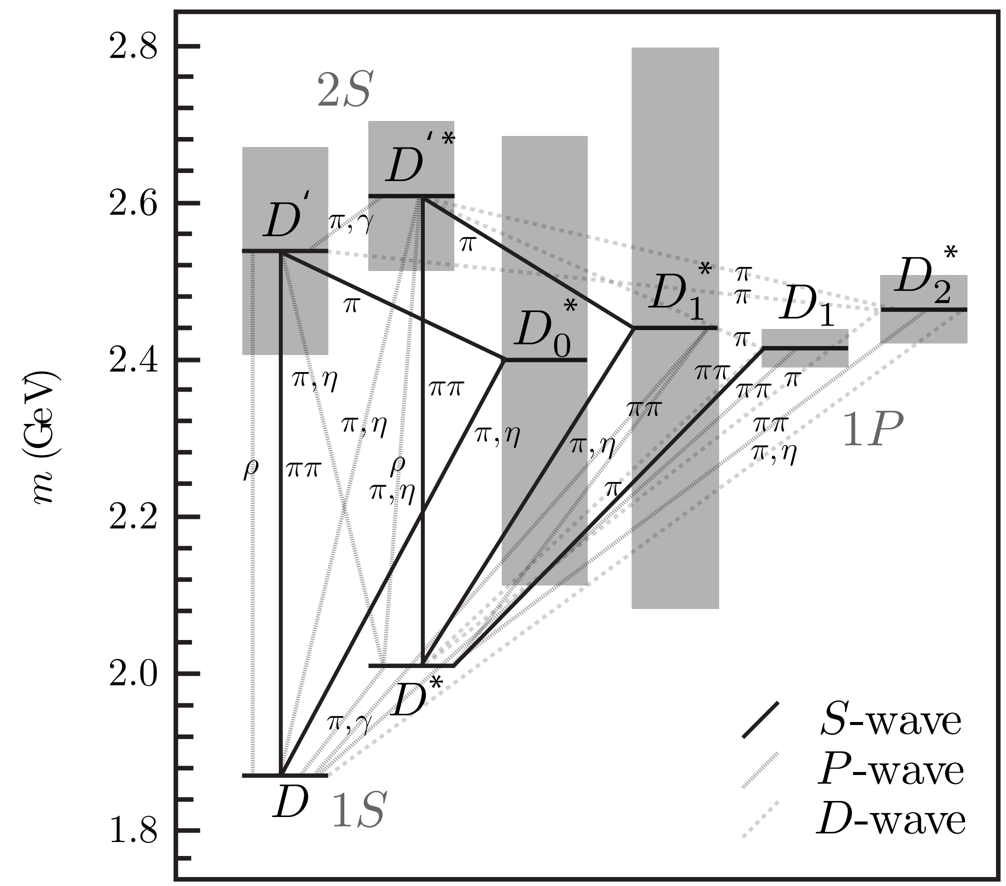
universitätbonn

Introduction

- Many puzzles surround B→D**, from understanding HQET to controlling background in V_{qb} and NP searches.
- SuperKEKB: 40X Luminosity of KEKB and Belle II detector upgrade will shed more light on these mechanisms
  - **Semileptonic, Hadronic, Υ(5S)→B_s**
- Focus on where High Luminosity e^+e^- outperforms LHC high rate.
  - Excellent **neutral mode sensitivity**.
  - Low backgrounds, **low trigger bias**, **B-tagging(coherent)**, many control samples.
  - Good kinematic resolution,
    - **Dalitz** plots analyses straightforward.
    - **Absolute branching fractions** can be measured.
    - **Missing momentum** analyses are straightforward.

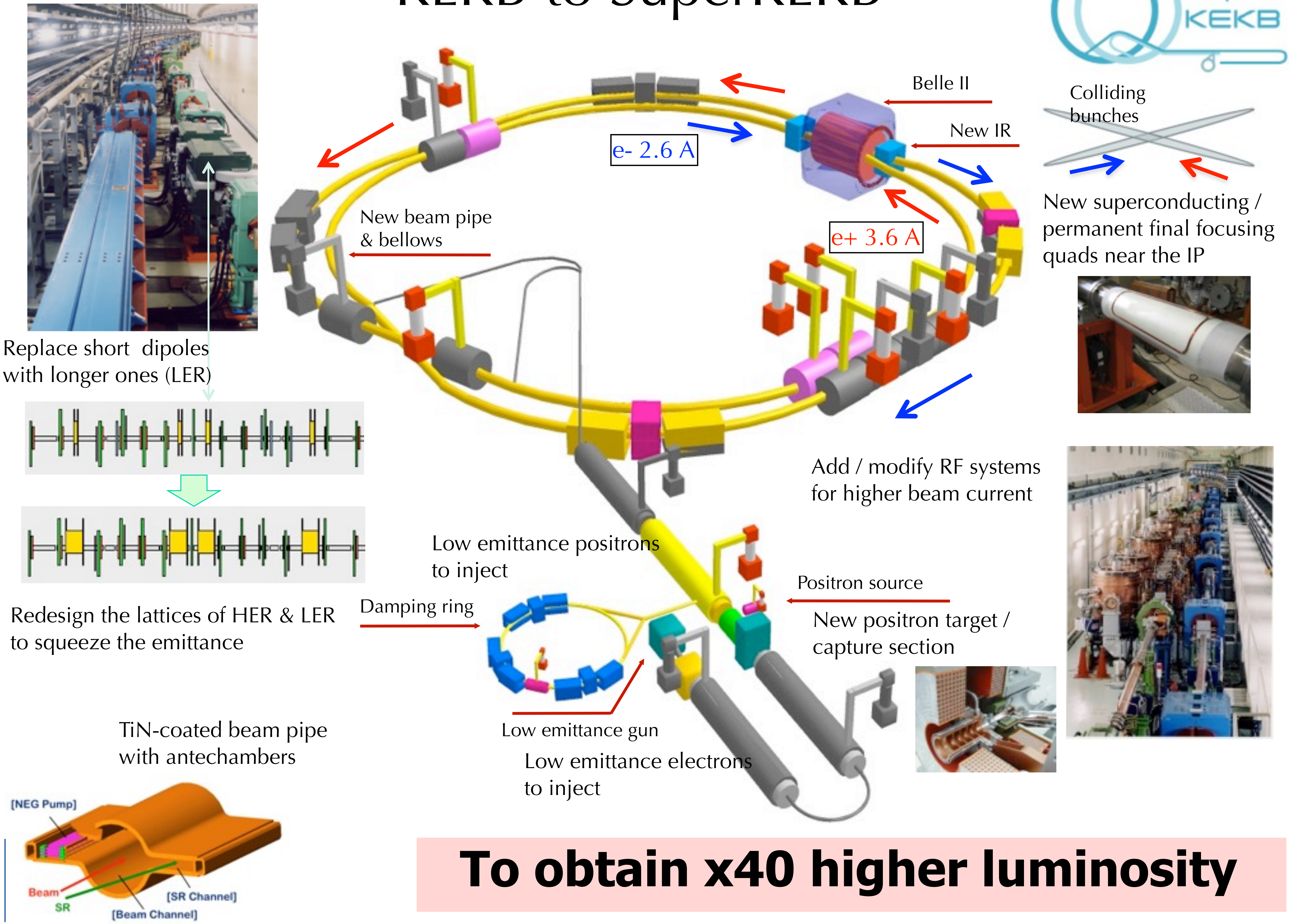
$B_{(s)} \to D_{(s)}^{**}$ @ Belle II

- Checklist:
  - **Neutral** modes.
  - Higher **multiplicity** modes.
  - **Differentials** in q^2, helicity.
  - $D^{(*,**)}\,\tau\,\nu$ modes.
  - Search for radial excitation modes.
  - Large Υ(5S) sample (possible).
- Better understanding of $D^{**} \to f$ decay modes.

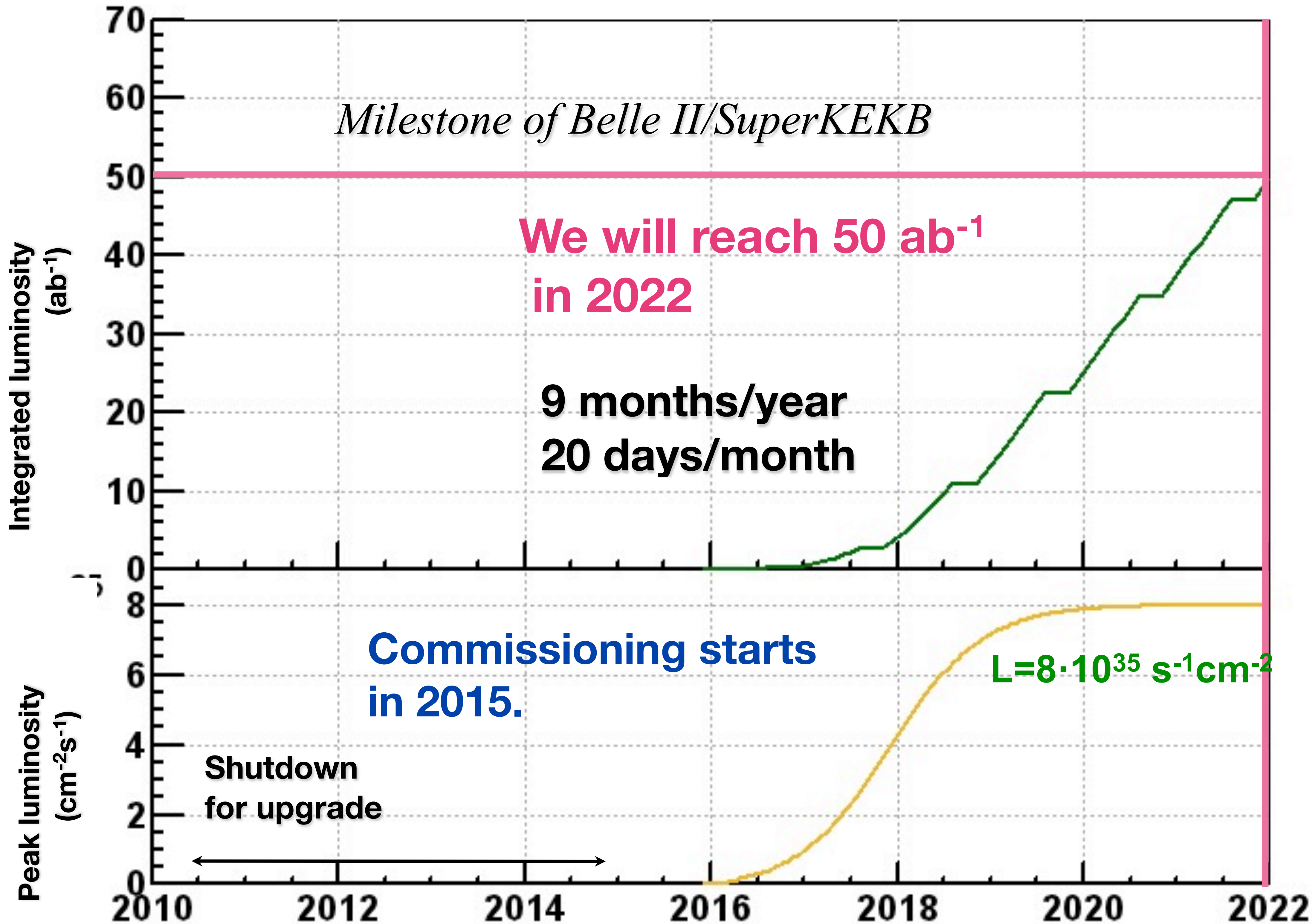


D	Observed	Possible(Not seen)
D_0^*	$D\pi$	$D\eta$
D_1^*	$D^*\pi, D\pi\pi$	$D\eta$
D_1	$D^*\pi, D\pi\pi$	
D_2^*	$D^{(*)}\pi$	$D\eta$, $D^{(*)}\pi\pi$
D′		$D(\rho)(\pi\pi), D^*(\eta)(\pi)$
D′*		$D^*(\rho)(\pi\pi), D(\eta)(\pi)$

KEKB to SuperKEKB



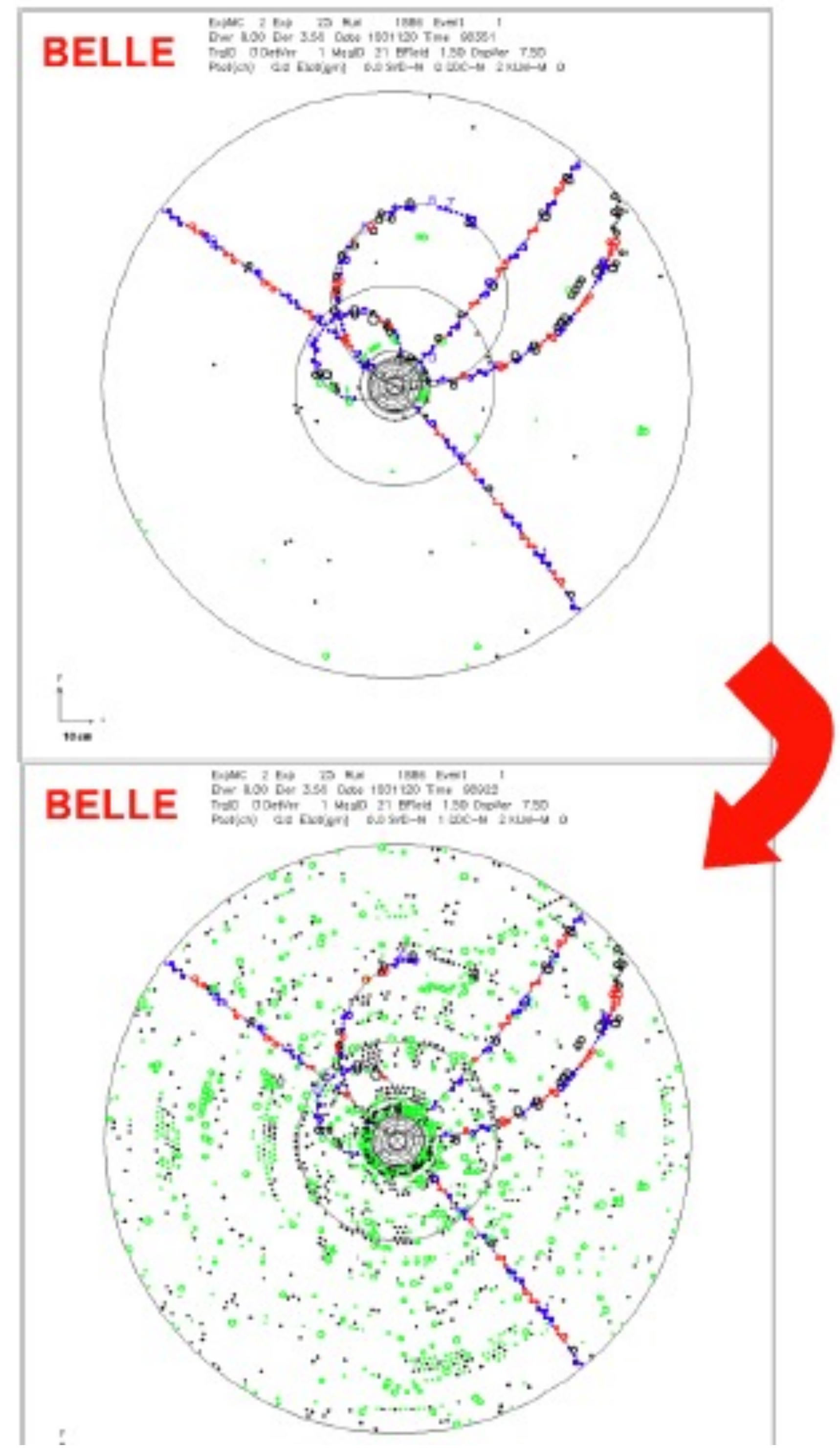
Luminosity Prospects SuperKEKB



The schedule is likely to shift by a few months because of a new construction/commissioning strategy for the final quads.

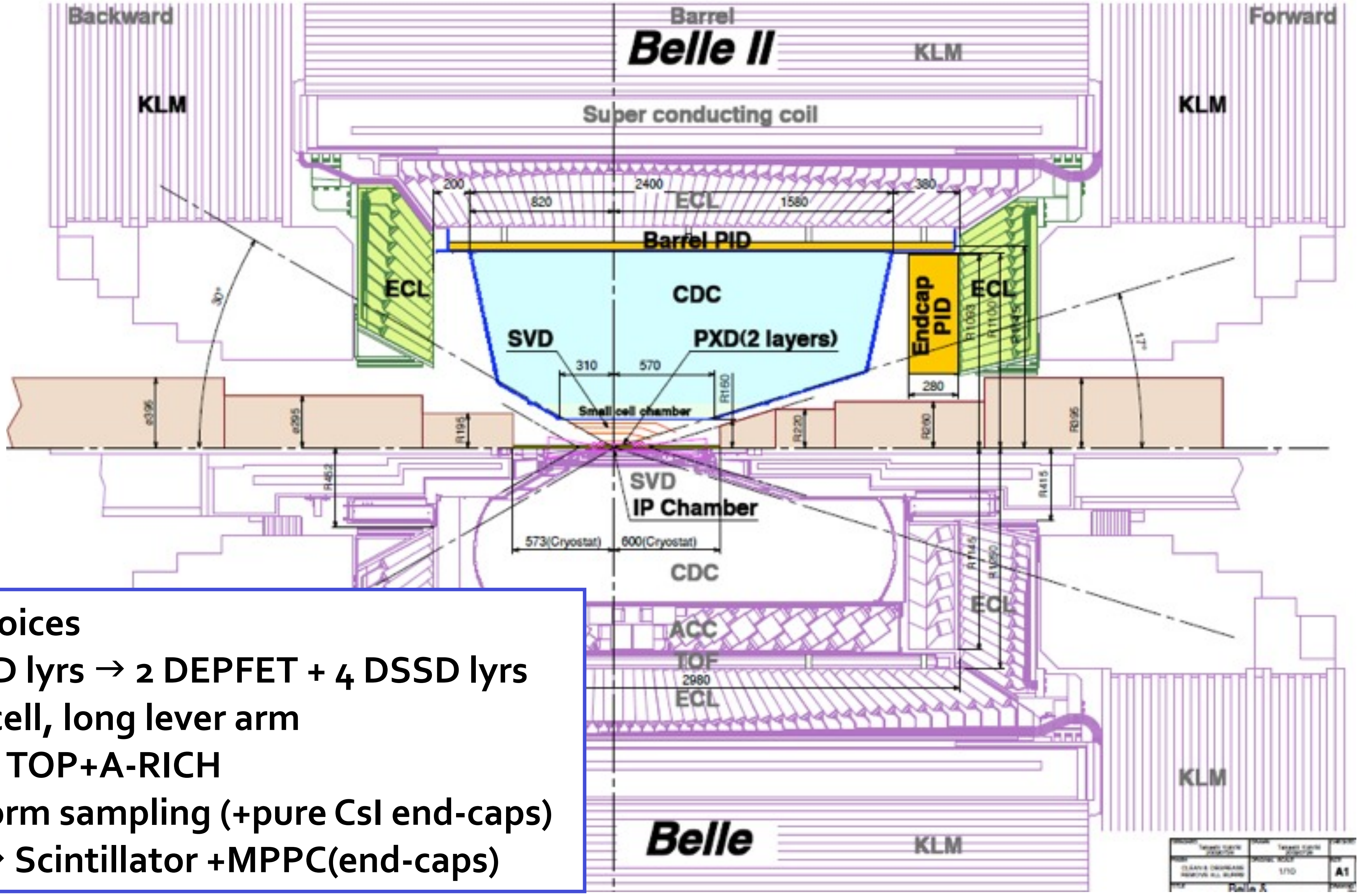
Belle II Detector Upgrade

- Challenges:
  - Higher background (×10-20) from Touschek, higher event rate (×10)
    - radiation damage and occupancy
    - fake hits and pile-up noise in the EM
- Targeted improvements:
  - Increased **hermeticity (ν recon.)**
  - Increased **K_S** efficiency
  - Improved **IP** and secondary vertex resolution
  - Improved **π/K** separation
  - improved **π^0** efficiency
  - add **PID** in **endcaps**
  - preserve **μID at high rates**



- **Belle event with increased background overlaid.**

The Detector: (Belle→Belle II)

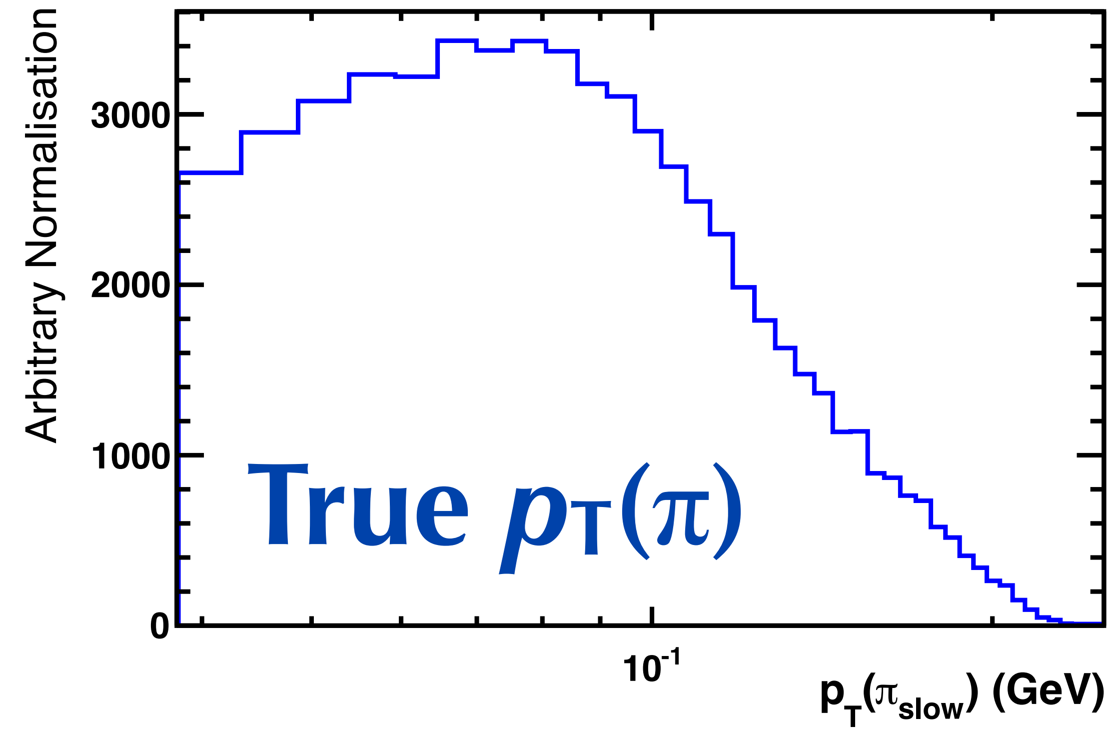


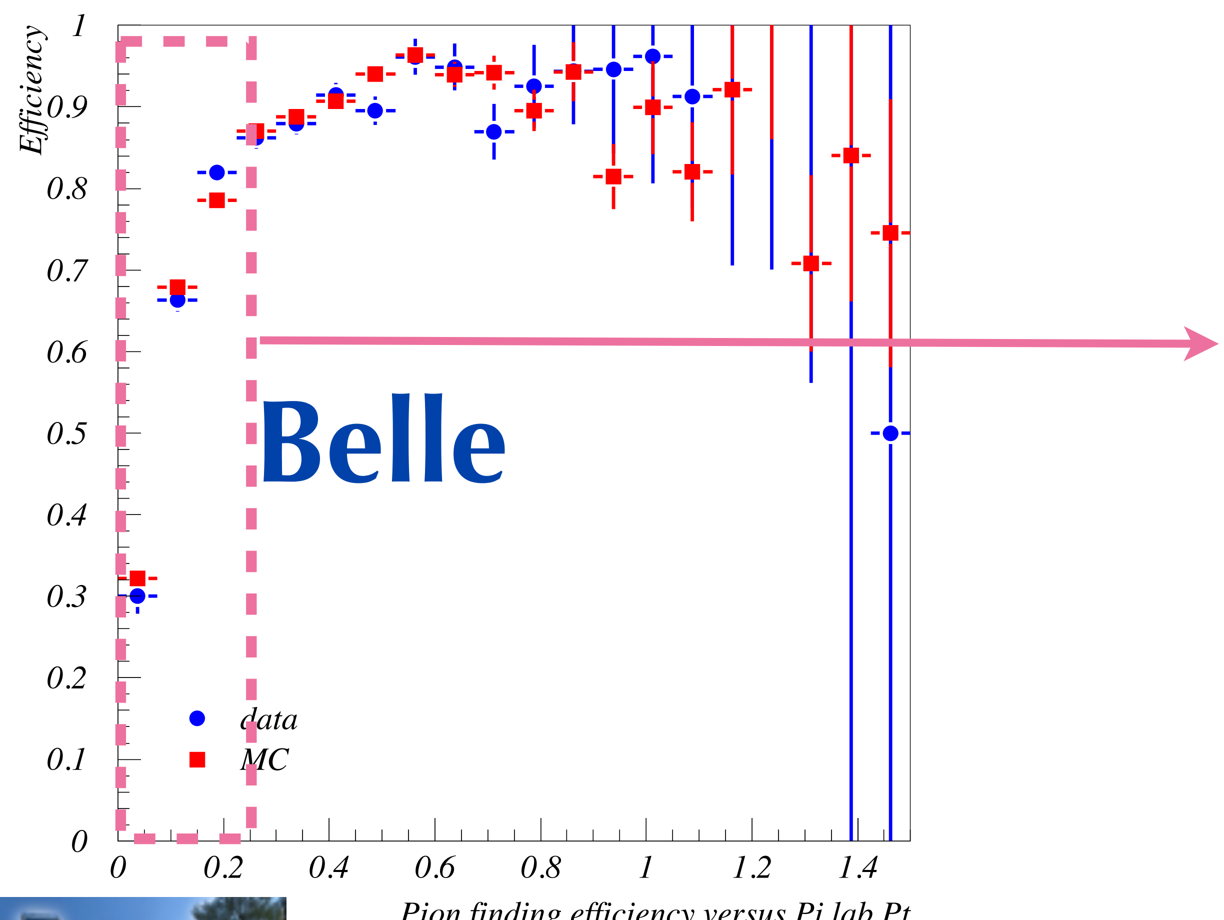
Detector Choices
SVD: 4 DSSD lyrs → 2 DEPFET + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI end-caps)
KLM: RPC → Scintillator +MPPC(end-caps)

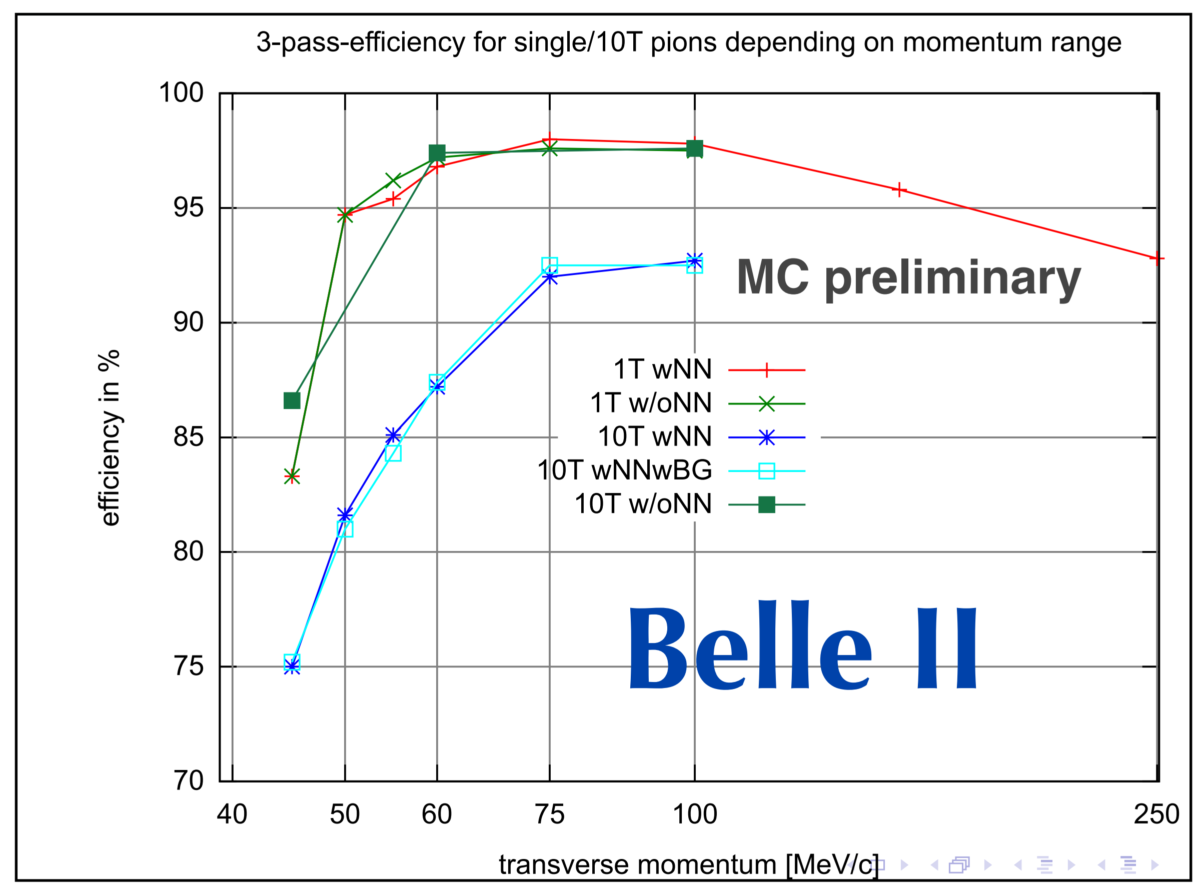
- **hermeticity**: detectors closer to beam-pipe
- There should be **improvements** in **all experimental systematic errors**.

Slow pion tracking

- Belle used combined SVD(Si)+CDC(Wire) for track finding, low efficiency at low p_T.
- Belle II will have standalone **silicon track finding (4+2 layers)**. Slow π tracking enhanced considerably.
  - Fast “cellular automaton” method.



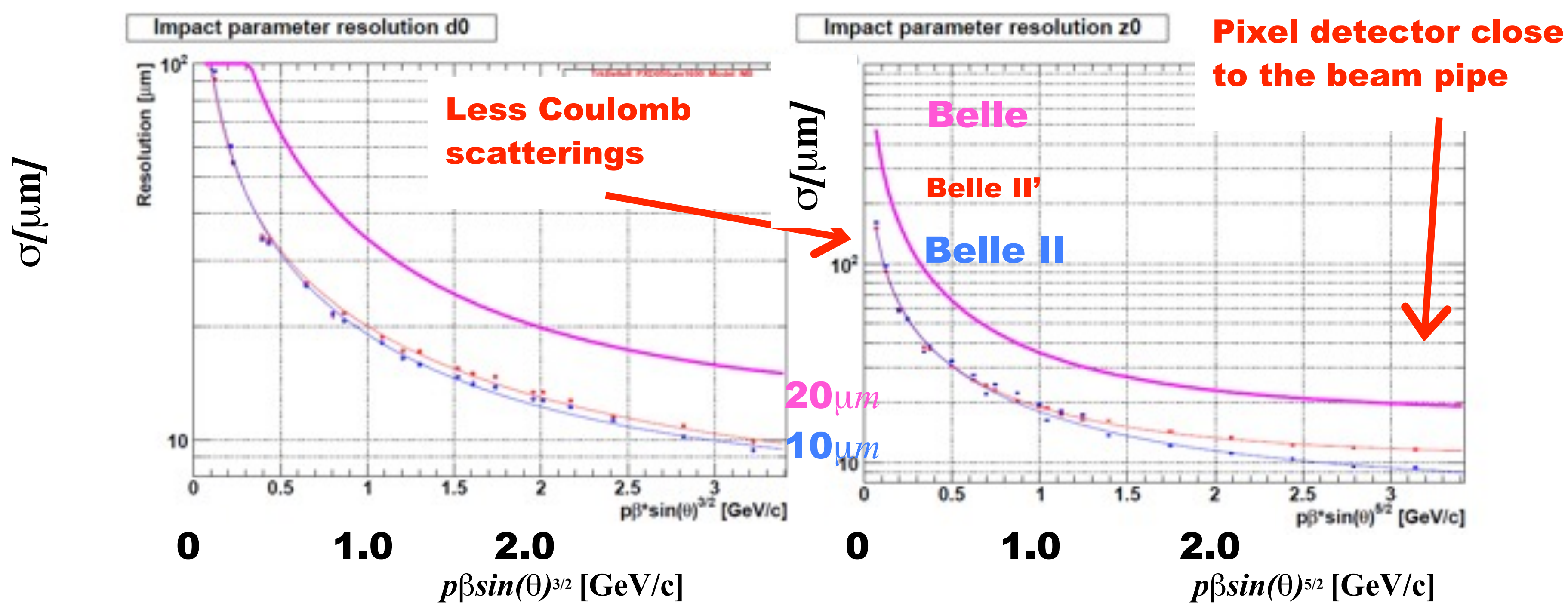


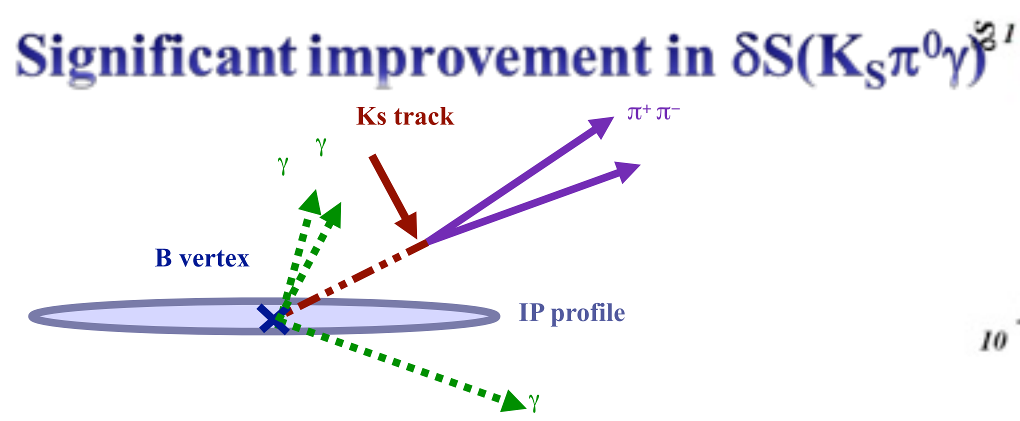


IP and Vertexing improvements

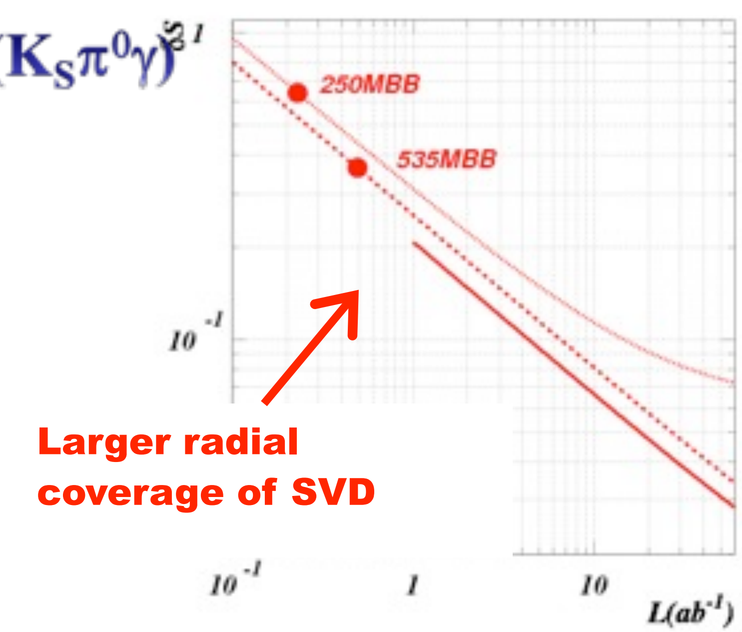
- New Vertexing layout: **PIXEL**+STRIPS resolution: 20μm to 10μm (large p).
- Also significant improvements to tracking/vertexing software. (May be used in some updated Belle I measurements in the near future!)

- Better B-tagging and charm vertex isolation.



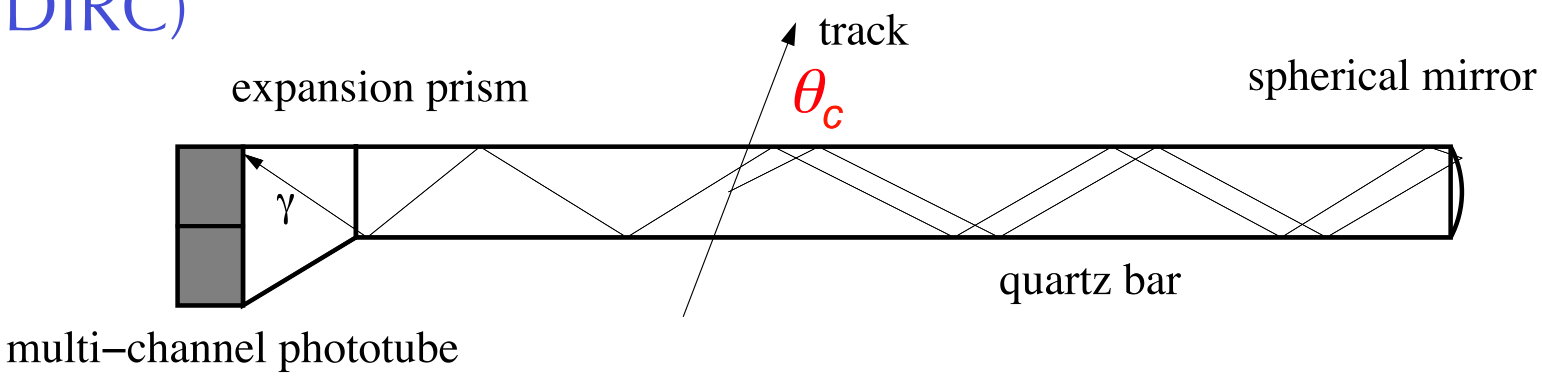


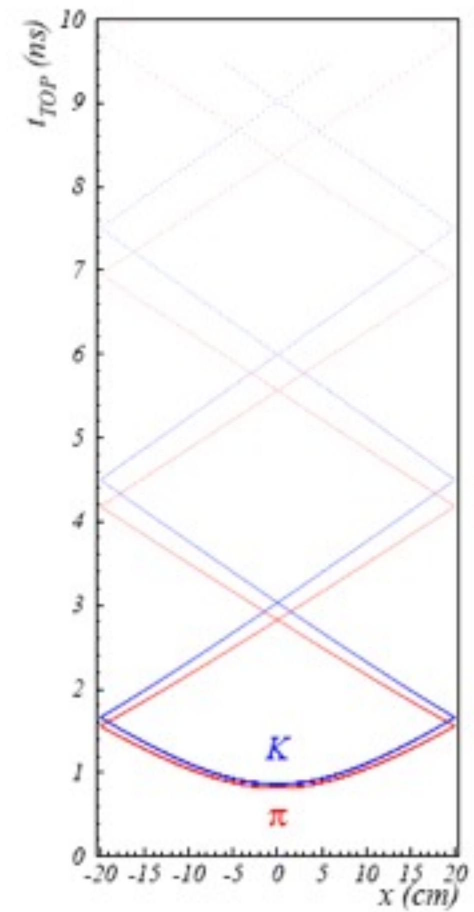
B decay point reconstruction with K_S trajectory



Particle Identification

- Barrel: Time of propagation:
  - Cherenkov ring imaging with precise time measurement.
  - Internal reflection of Cerenkov ring images from quartz (like BaBar DIRC)

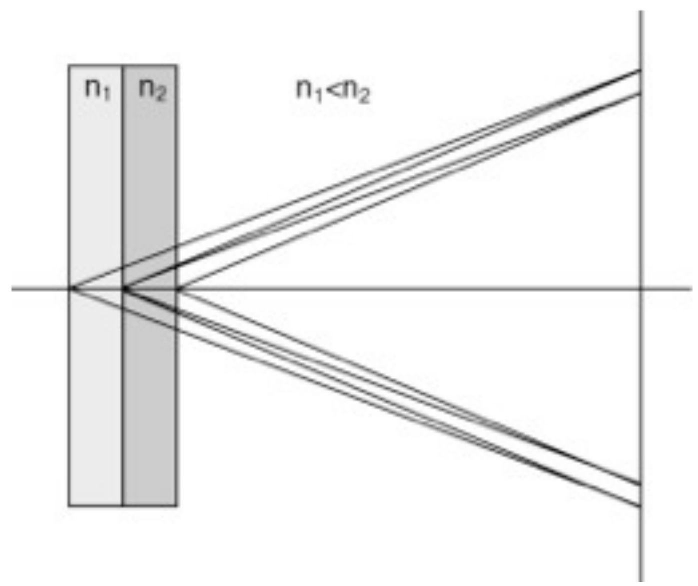


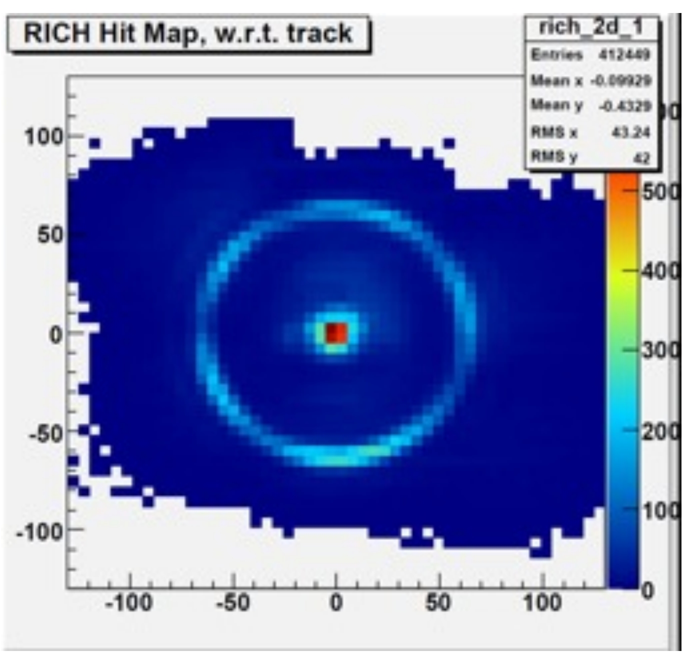


	ππ eff.	fake
TOP	98.1%	2.9
Belle	88.5	11.6

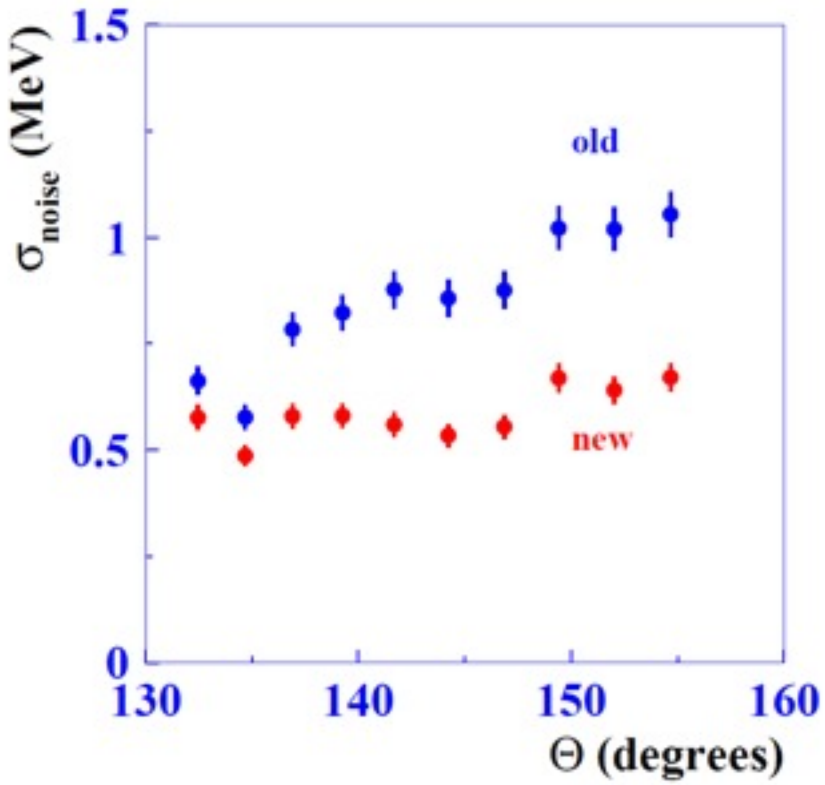
⇒ substantial improvement over Belle. This will help for, e.g., separating $D_s^+ \to K^- K^+ \pi^+$ from $D^+ \to K^- \pi^+ \pi^+$, removing $D^0 \to K^- \pi^+ \pi^0$ from $D^0 \to K^- K^+$, etc.

- Endcap: Aerogel ring imaging Cherenkov.
  - novel "focusing" two layer radiator





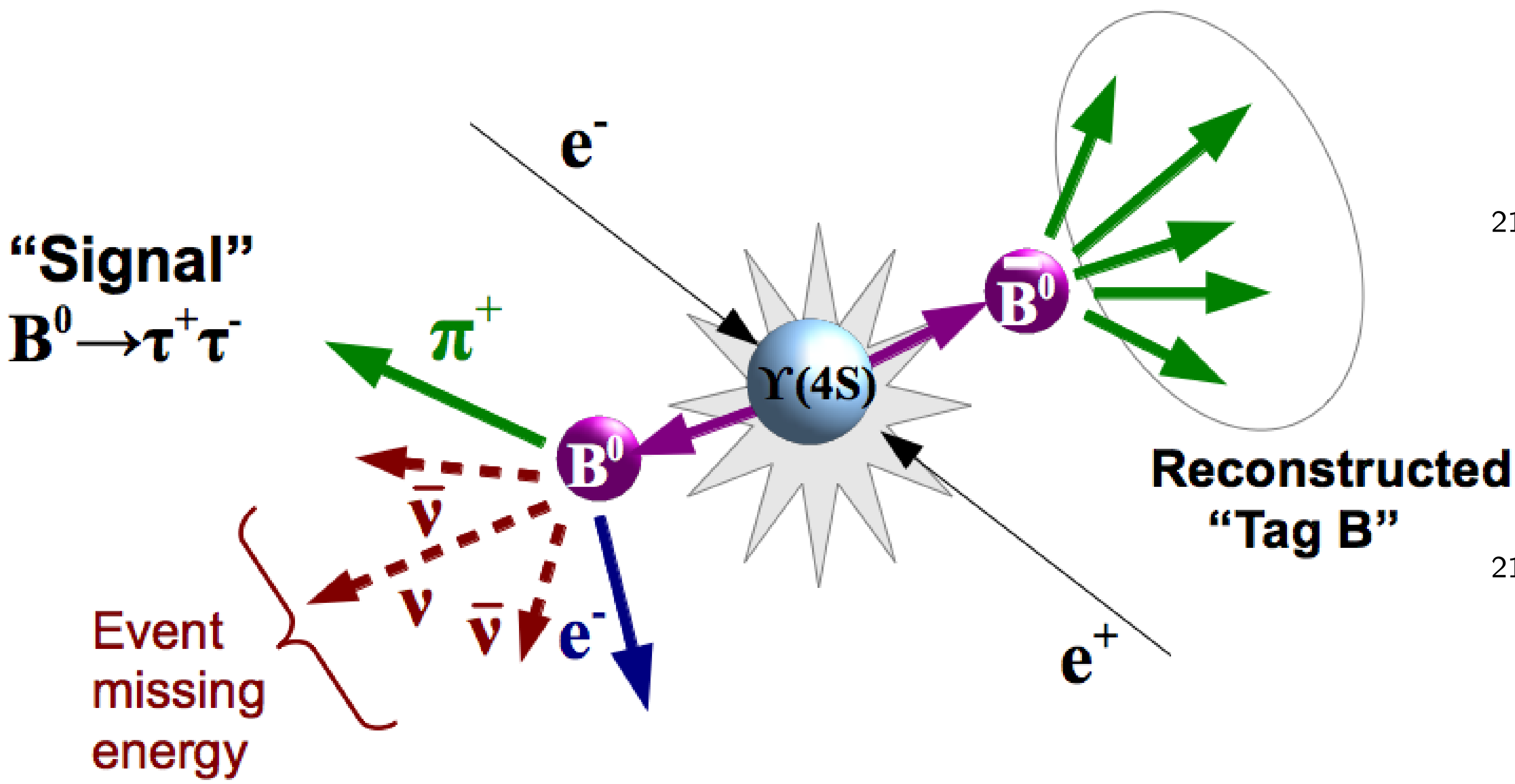
Calorimeter



- ECL Improved to handle higher rates.
  - Barrel electronics with waveform sampling.
  - CsI coverage extended to endcap (Pure CsI): hermeticity.
- Resolution similar to Belle I (which is very good)

The Analysis Tool of Belle II's future: B tagging

- Use a "Tagged B" to define 4-momenta of "Signal B":
  - Tagged B Hadronic decays : Signal B momenta well-defined.



- The number of reconstructed B_{tag} decay modes can be >1000 (Babar ultimately used ~1900).
- Look for excess neutral energy ("$E_{extra/ECL}$") and excess tracks not assigned to tagged or signal B.

Uncertainties with 1st Gen. B factories

1. Measurements of specific D^{**} modes in hadronic B decays already **done reasonably well.**

2. So far no attempts at neutral modes in hadronic B decays, or any absolute D^{**} measurements.

3. Most current semileptonic decay uncertainties will scale down with Luminosity.

Very rough summary of selected measurements

	$B^0 \to D^0\pi^+\pi^-$ (Belle) 2006 357 fb^{-1}	$B^0 \to D^+\pi^+\pi^-$ (Babar) 2009 383 fb^{-1}	$B \to D^{**}\, l\, \nu$ (Belle) 2008 657fb^{-1}
PID	0.05	0.015	0.01
Backgrounds	0.05	0.015	0.1-0.25
Signal PDFs		0.01	
Tracking/Photon	0.05	0.025	0.02
BF(Charm)	0.024	0.023	0.01
Modelling			0.07
Normalisation		0.016	0.10
Total Systematic	0.09	0.04	0.16-0.28
Stat	~0.05-0.2	~0.05	0.2

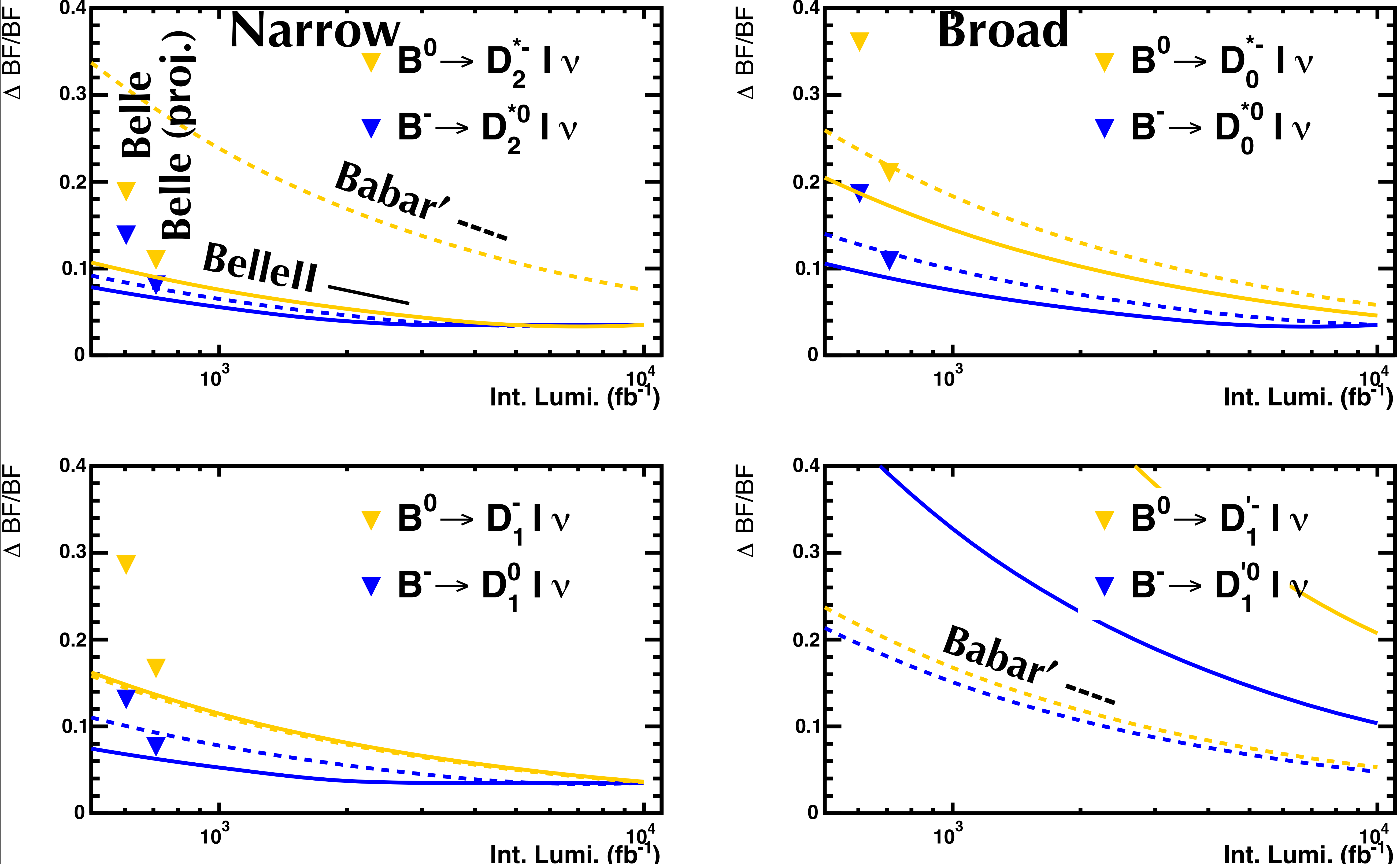
In all cases, non-saturation of D^{**} decay modes.

$B \to D^{**} l\ \nu$: outlook

- Reconstruction, analysis software for Belle II still in preparation.
- Outlook based on
  - **Existing** Belle (or Babar) **measurements**: extrapolated based on (**privately**) *estimated* performance improvements and integrated luminosity (Only measured $D^{**} \to D^{(*)}\pi$ modes extrapolated.)
  - **Unmeasured**: order of magnitude estimates (efficiencies difficult to estimate).

- **Belle I**: PRD.77.091503
- ***Near future:*** **Belle I: update**: B_{tag} efficiency improved, ***results pending***.
- **Extrapolation** of existing measurements:
  - **Belle II:** guesstimated 1.5x stat. power from efficiency and background rejection improved over **Belle I** (ultimately mode dependent).
  - **BaBar**: Simple luminosity scaling, for reference (PRL.101.261802)

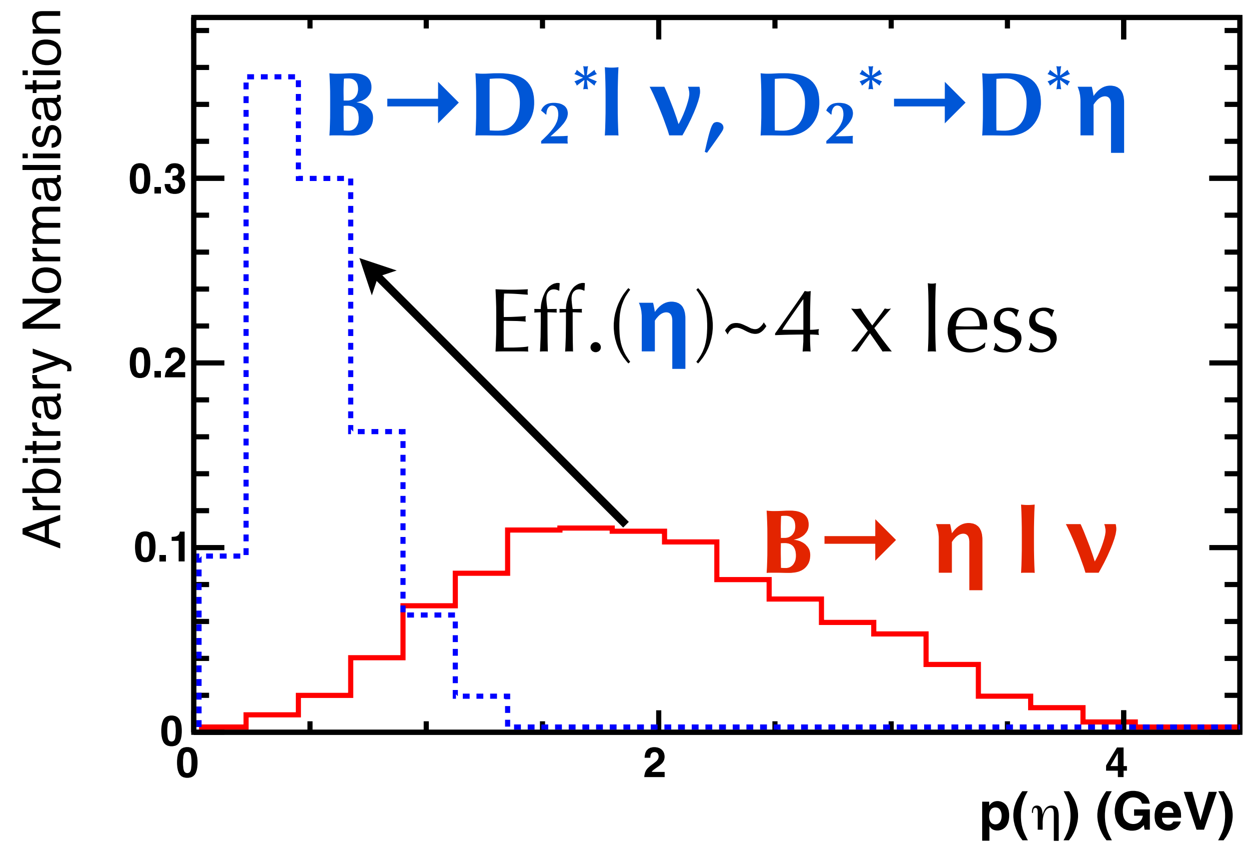
$B \to D^{**} l \nu$: outlook



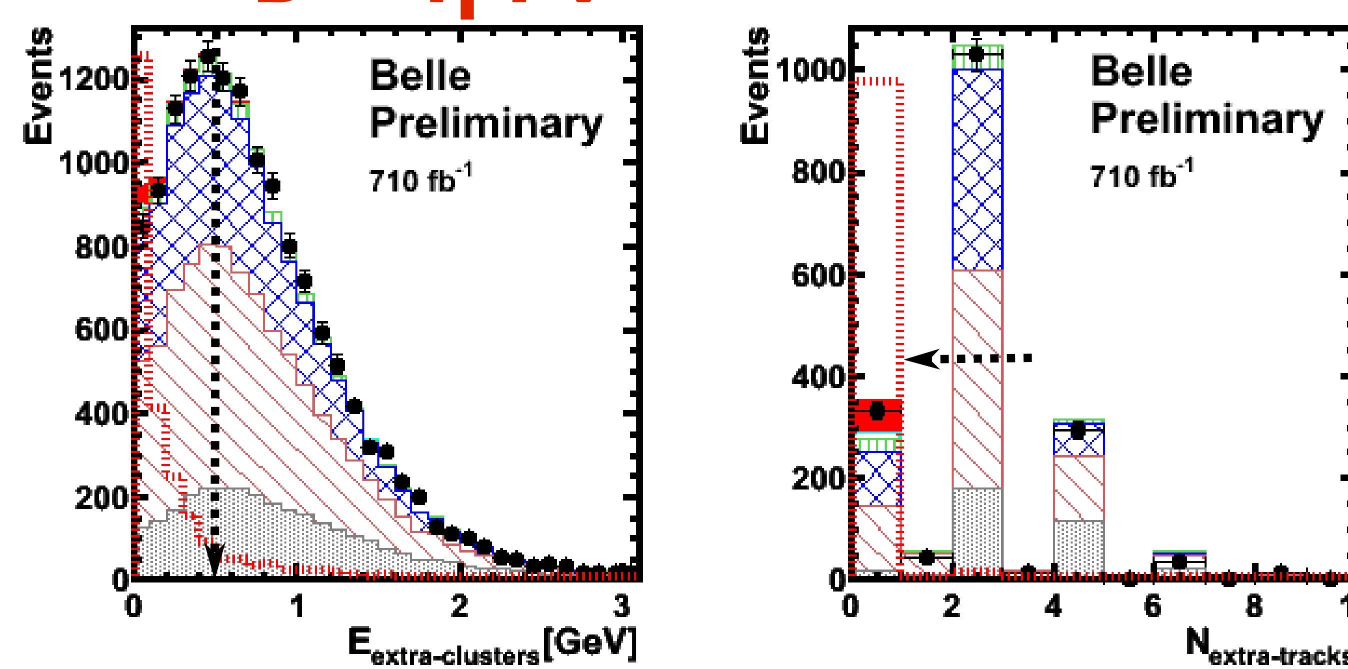
B→D** l ν: Neutral modes outlook

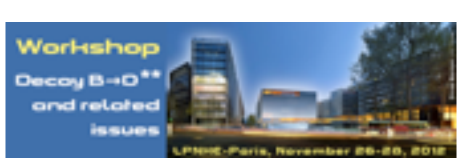
- e.g. D**→Dη
  - **Relatively slow η** (low efficiency, **large photon background**), not on threshold .
- Other: D**→Dρ(ππ,ππ^0), D**→D(ππ,ππ^0)

Crude estimate....	D^{0}η	D$^+$η	ηlν
BF(B→D**$_{narrow}$) approximation	1.00%	1.00%	0.004%
BF(D^0→Kπ,K3π) ,BF(D$^+$→Kππ)	12%	9%	-
BF(D**→ηD) (assume)	20%	20%	-
BF(η→γγ,πππ^0)	62%	62%	62%
Efficiency(estimate)	3%	2%	20%
B$_{tag}$ eff.	0.5%	0.3%	0.5%
700 fb^{-1}	15	5	32
50 ab^{-1}	1046	353	2294



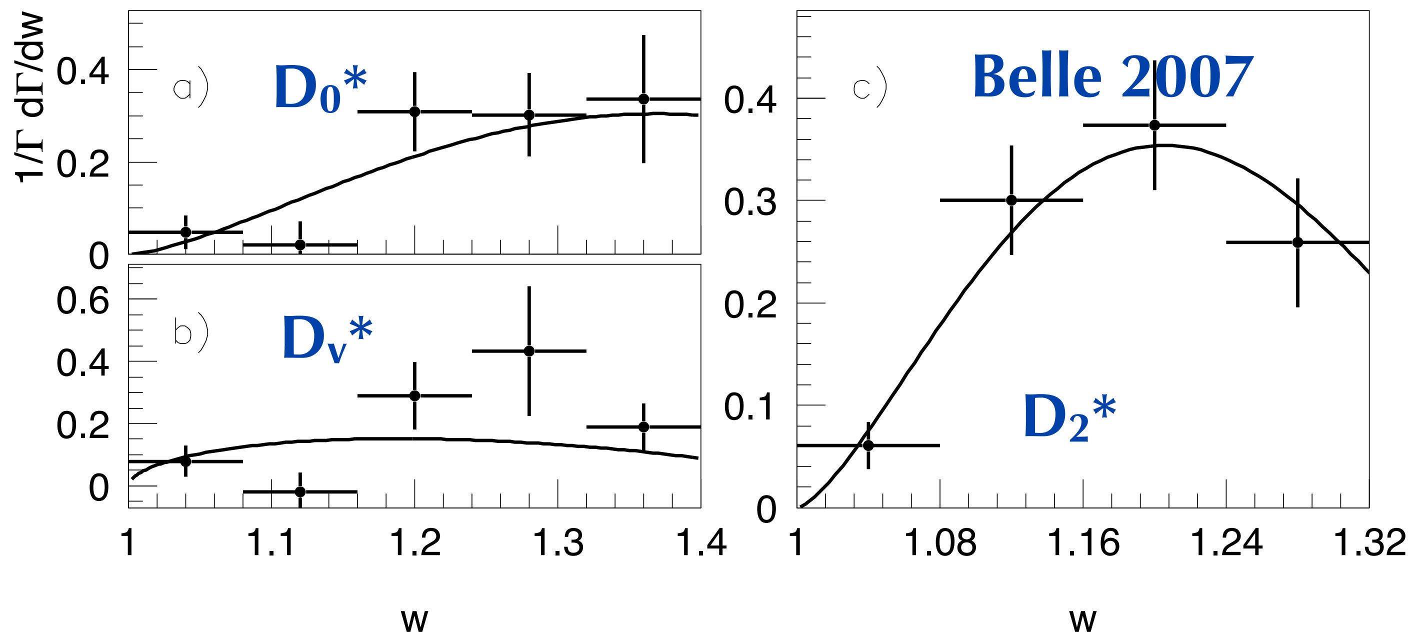
B→ η l ν

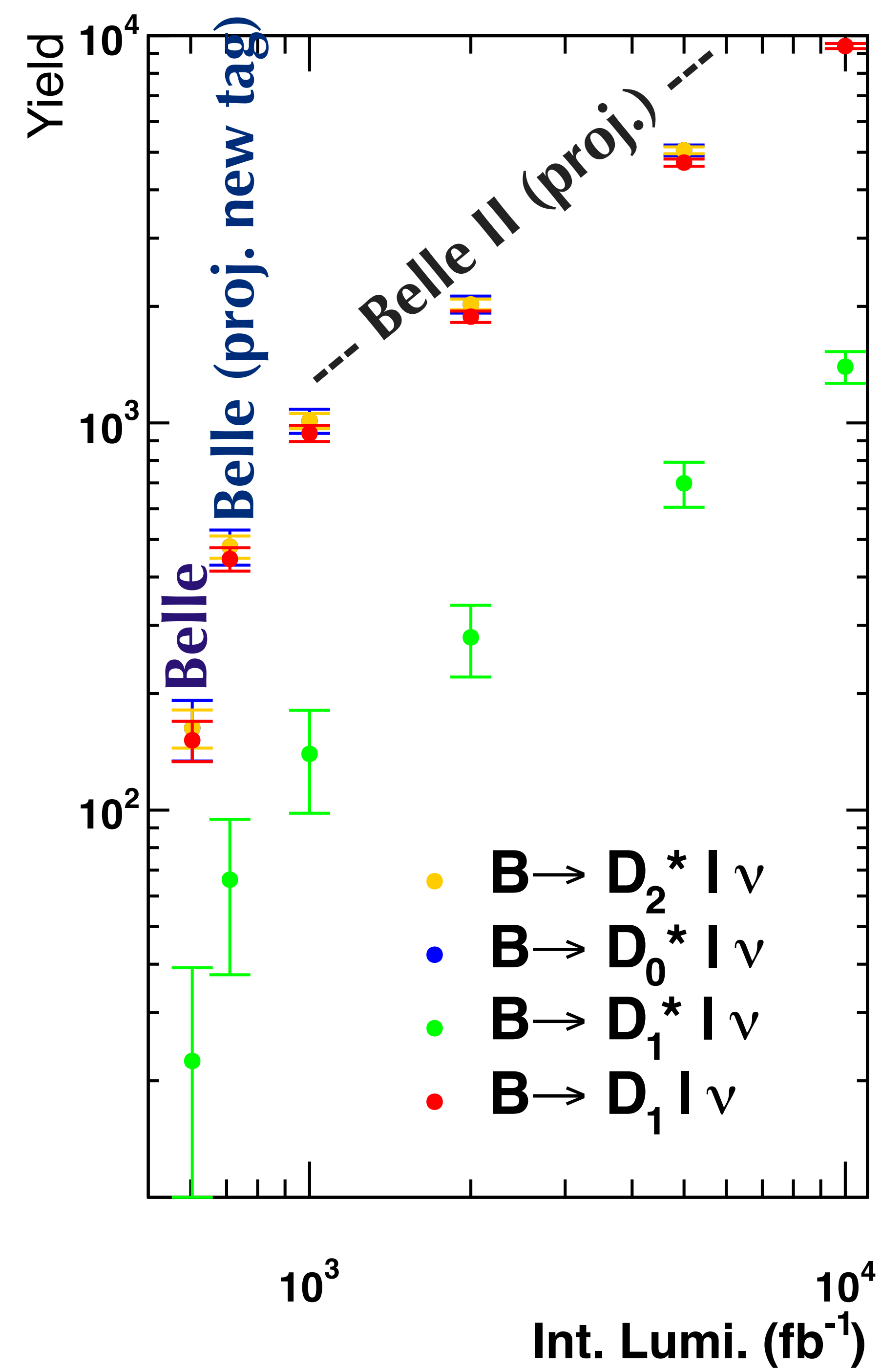




$B \to D^{**} \, l \, \nu$ Decay Differentials

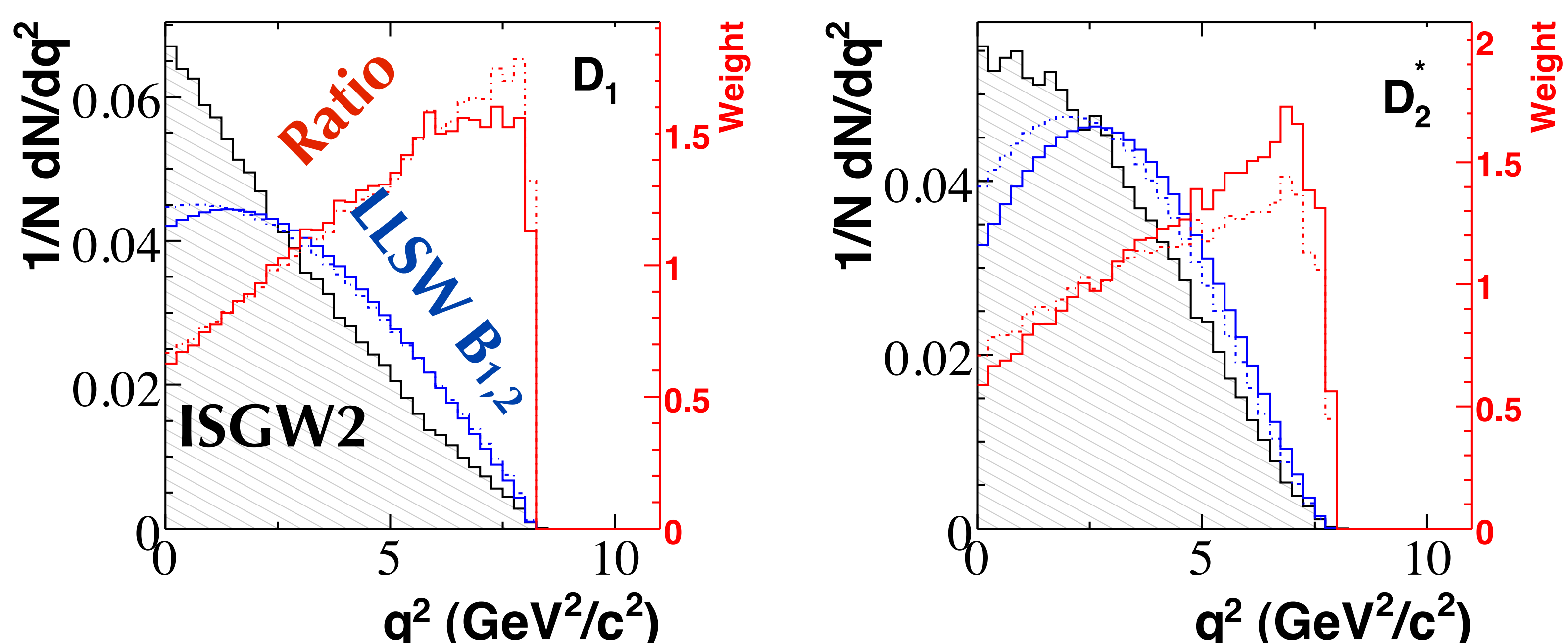
- *Still* have limited experimental information on the decay differentials.





Several models in PRD 57 308 (1998) "LLSW".

Are these reliable? Belle II will *precisely* test them.

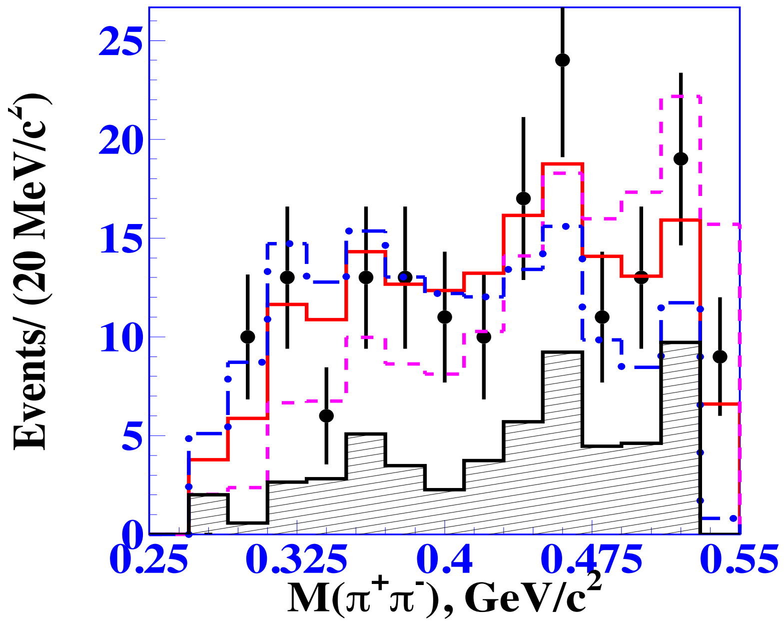


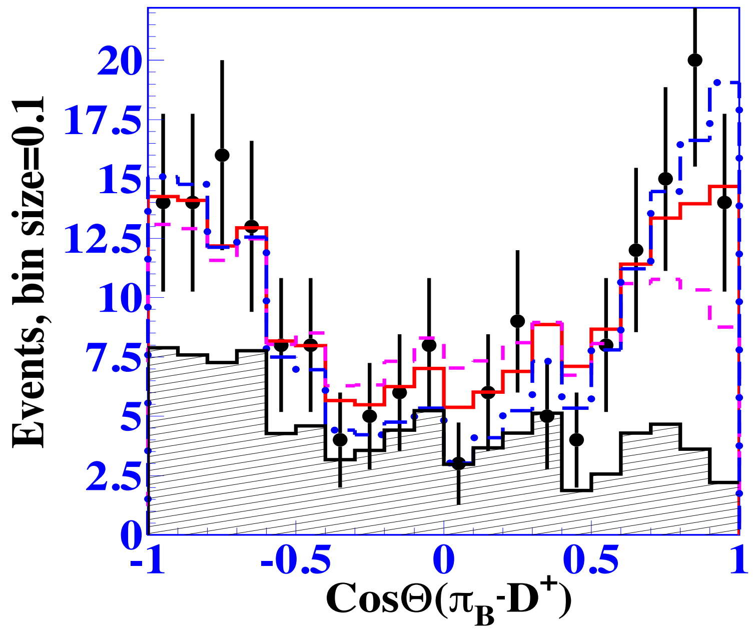
$B \to D' l \nu$: Radially excited modes outlook

- $D_1'^{(*)} \to D^{(*)}\pi\pi$ or
  $\to D_{broad}^{**}\pi$
  - 2π+ emission not examined/seen in SL decays (Belle I still to prepare a final result).
- Expect LHCb could (clearly) confirm&characterise $2\pi^{\pm}$ modes in SL decays, but the full width must be studied at Belle II.

- c.f. Belle $D_1 \to D\pi\pi$ (150 fb^{-1}) (confirmed by LHCb: PRD 84.092001)

Belle: Phys.Rev.Lett.94:221805,2005

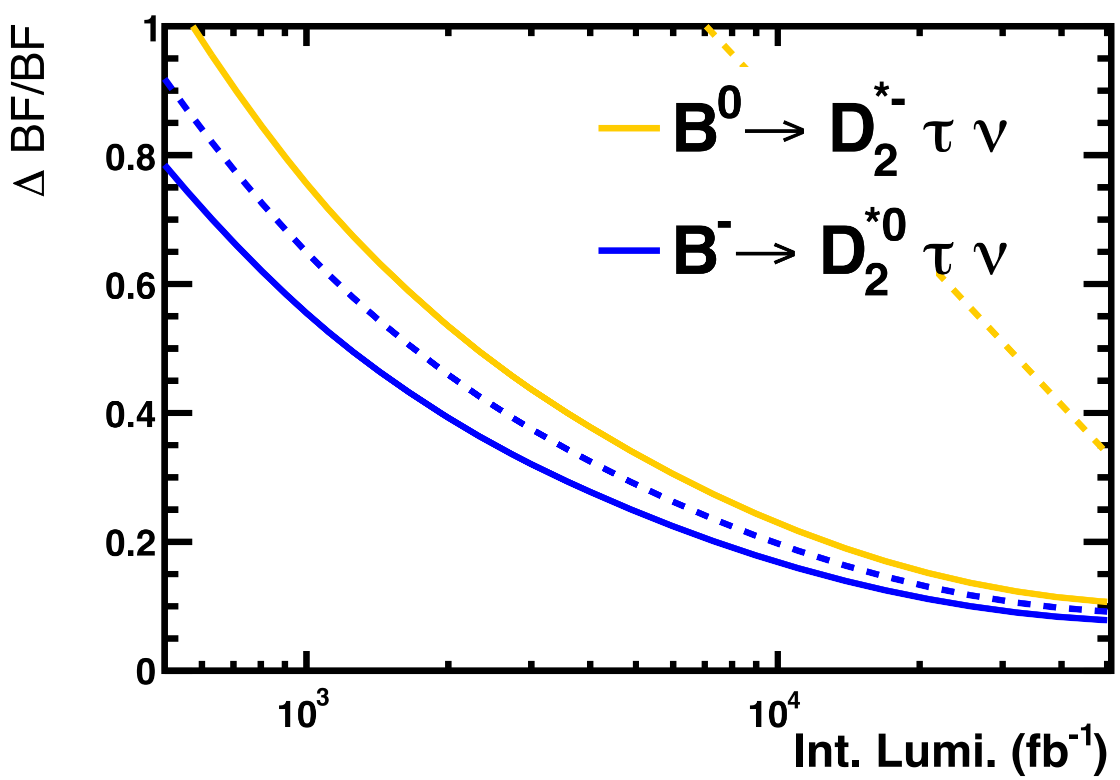


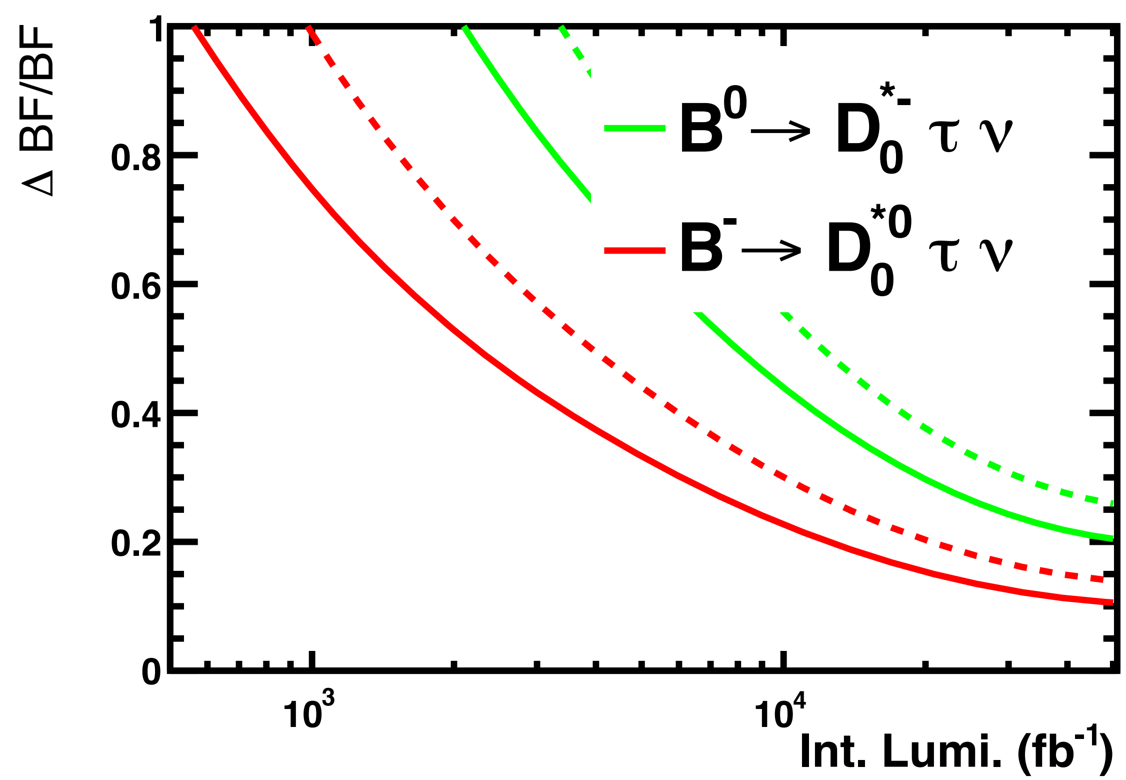


$B \to D^{**} \tau \nu$?

- To reach high precision (at Belle II) in $B \to D^{(*)} \tau \nu$, D^{**} modes may need to be considered.
- Theory expectation?
- (Clearly) No measurements exist:
  - $BF(D^{**}\tau\nu)/BF(D^{**}l\nu)$~0.3 x phase space, $BF(\tau \to l\nu\nu)$~0.35
  - Eff~0.3 (low momentum)
    - Below assume ~1% statistical power of $B \to D^{**} l \nu$ (background conditions difficult to estimate)

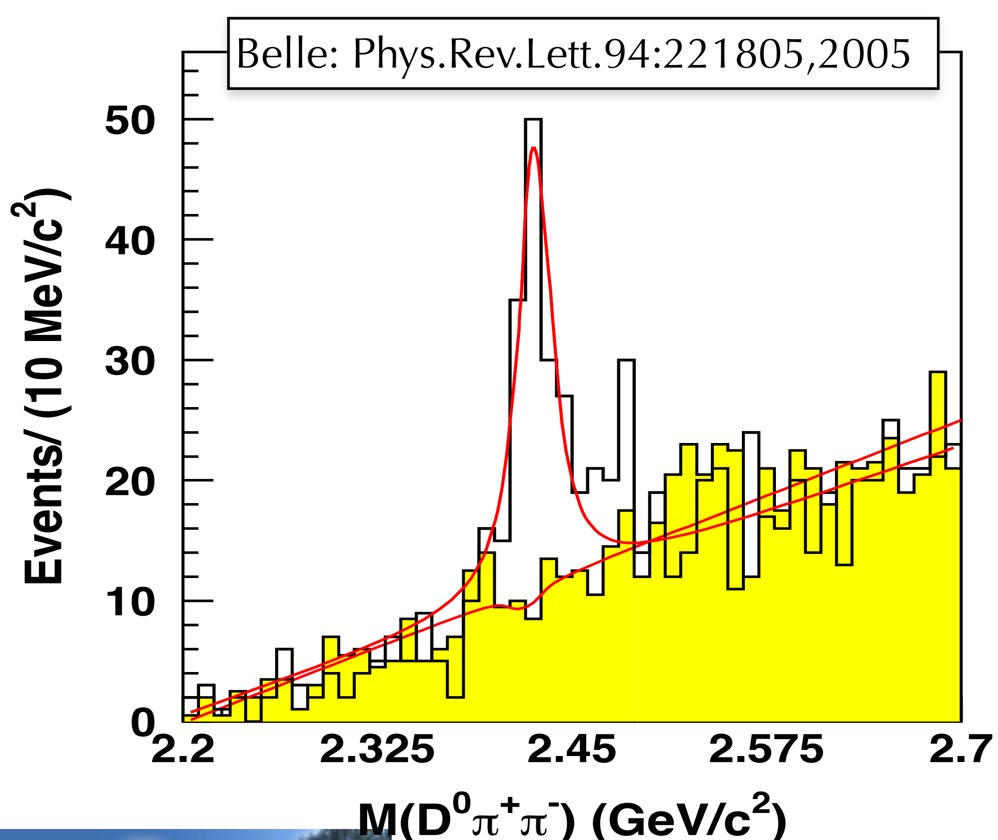
- Only constraints from inclusive & $D^{(*)} \tau \nu$
- $b \to X_c \tau \nu$: measured at LEP
  - BF=2.43±0.23
  - Background: $\mathbf{B \to X_c\, l\, \nu}$, $B \to X_c\, D(\to \mathbf{l}\, \nu\, X)$





Hadronic B decay modes: Outlook

- Belle II strengths are **neutral mode** measurements.
  - Bkg suppression improved due to dedicated **low p_t** track finding&**hermeticity**.
  - γ resolution similar to Belle I.
  - **Neutral modes will have high background** (but new high purity methods could be employed)

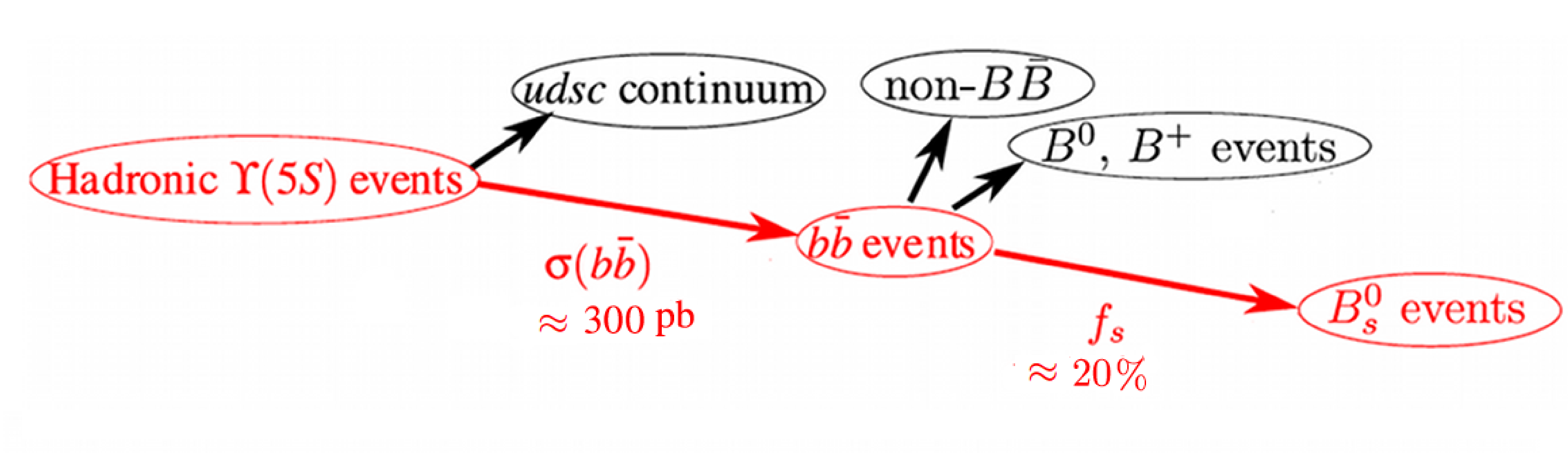


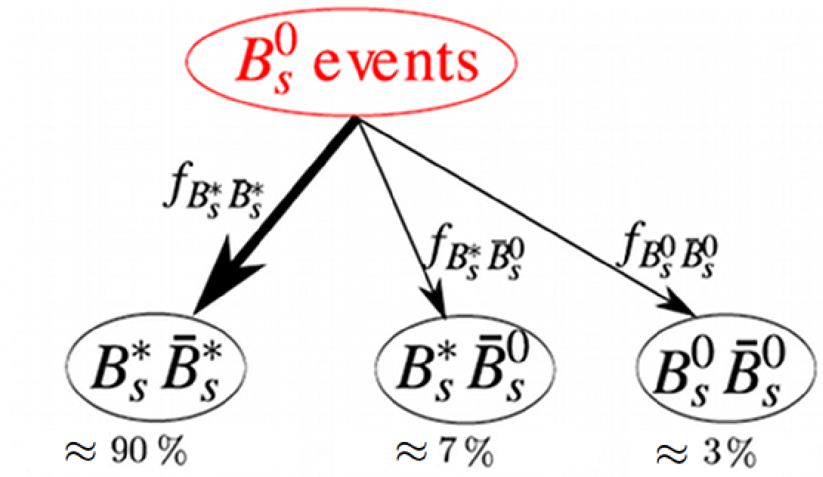
D** mode	$D^0\eta$	$D^+\eta$	$D^0\pi$	$D^+\pi$
BF($B\to D^{**}$) approx.	0.02%	0.02%	0.02%	0.02%
BF($D^0\to K\pi$) +BF($D^+\to K\pi\pi$)	12%	9%	12%	9%
BF($\eta\to\gamma\gamma,\pi\pi\pi^0$)	62%	62%	-	-
Efficiency(estimate)	6%	4%	30%	21%
700 fb^{-1} Untagged	1250	656	10080	5292
50 ab^{-1} Untagged	89280	46872	720000	378000
B_{tag} eff.	0.5%	0.5%	0.5%	0.5%
700 fb^{-1} B-tag	6	3	50	26
50 ab^{-1} B-tag	446	234	3600	1890

No data available to estimate uncertainty (for $D^0\eta$, $D^+\eta$)

Just for reference (for $D^0\pi$, $D^+\pi$)

$\Upsilon(5S) \to B_s \to D_s^{**}$





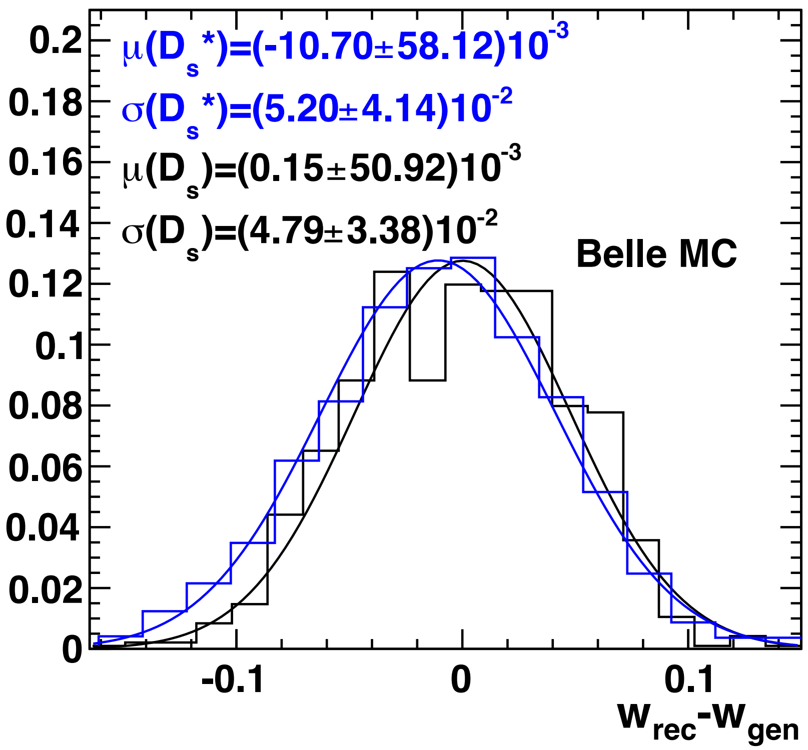
Modes	Width	*Dominant* X_c mode
D_s	-	$KK\pi$
D_s^*	-	$D_s\,\gamma$
$D_{s0}^*(2317)$	-	$D_s\,\pi^0$
$D_{s1}(2460)$	-	$D_s^*\,\pi^0$
$D_{s1}'(2536)$	1 MeV	$D^*\,K$
$D_{s2}^*(2573)$	17 MeV	$D^0\,K$

- **Most have $\geq$ 2 neutrals (π^0&ν), best at e^+e^-!**
- $\sigma_{bb}^{(\sqrt{s}=10.87\,GeV)}/\sigma_{bb}^{(\sqrt{s}=10.58\,GeV)}$~0.3
- **f_s~0.199±0.030 ~14M B_s^0 in 121 fb^{-1}**
- Excited production: kinematic smearing
  - **BF($\Upsilon(5S) \to B_s^* B_s^*$)~90%**
  - **$B_s^* \to B_s\gamma$, m(B_s^*)-m(B_s)≃49 MeV**

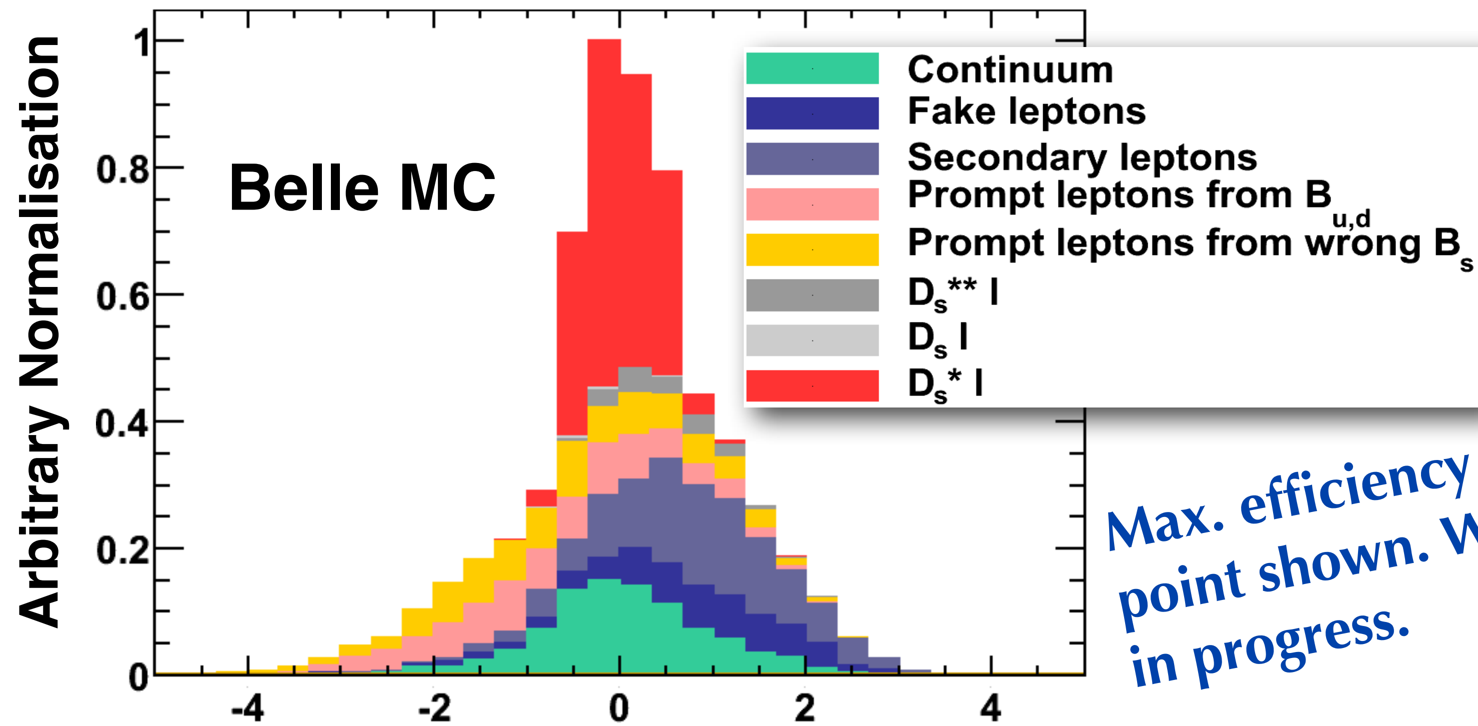
$B_s^0 \rightarrow D_s^{*\pm}\, l\, \nu$ @ 121 fb^{-1}, MC

- Untagged approach *shown*: $\boldsymbol{X_{miss}}$
- $\boldsymbol{B_{ud}}$ cross feed from~**6 • 10^{-4}**BF(***B→Ds(*)±Klν***)**×4*(fud/fs)*** (precision measurement at Belle II)
- Resolution: **Kinematic smearing** due to Υ(5S) decay, and **γ in $D_s^* \rightarrow D_s\gamma$**

- **$B_s^0 \rightarrow D_s^{*\pm}\, l\, \nu$, $D_s^* \rightarrow D_s\, \gamma$, $D_s \rightarrow \Phi(KK)\pi$ (p_{lep}>0.5 GeV)**

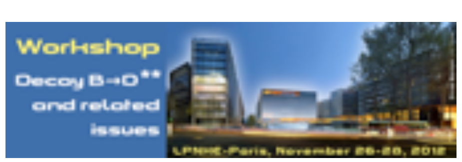


$$w \equiv v_B \cdot v_{D^*} = E_{D^*}/m_{D^*} = \frac{m_B^2 + m_X^2 - q^2}{2 m_B m_{D^*}}$$



Max. efficiency point shown. Work in progress.

$$X_{\rm mis} = \frac{\left[E_{\rm beam} - E_{\Upsilon(5S)}(D_s^*\ell)\right] - |\vec{p}_{\Upsilon(5S)}(D_s^*\ell)|}{\sqrt{E_{\rm beam}^2 - m_{B_s}^2}}$$



Yield projections

- (My) Rough estimates for Signal: ***$B_s \to D_s(\Phi\pi) l\nu X$***
  - **D_s** tagging could be extended , e.g. ***($\Phi\pi, K_SK, K^*K$) (~x3 eff. w/r/t Belle result)***
  - **Lepton tag is a clean high statistics approach**
  - **B_s Full Recon**: take Eff(B^0) as a guide
  - Too early to quote precise, expected precision on exclusive modes.

			Yields (tagging x efficiency x BF)										
Tag Method	**Tag Eff.**	N_{Bs}/N_B	**121 fb^{-1}(5 ab^{-1})**										
			$Xl\nu$	$\Delta stat$	Δsys	$D_s l\nu$		$D_s^* l\nu$		$D_{s0}^* l\nu$		$D_{s2}^* l\nu$	
Untagged	2	**$f_s/f_{d,u} \simeq 0.25$**	2.7M	-	-	7200		10900		800		1300	
Lepton tag	0.1	**$f_s/f_{d,u} \simeq 0.25$**	**135k**	**-**	**-**	370	(15,000)	534	(22,000)	40	(1,600)	(70)	(2,800)
D_s:$\Phi\pi, K_SK, K^*K$	0.04	**$10 \cdot f_s/f_{d,u}$**	**27k**	**3%**	**7%**	140	(6,000)	200	(8,500)	16	(650)	(26)	(1,000)
B_s Full Recon.	0.004	**≫10**	5400	2%	~4%	15	**(620)**	20	**(880)**	2	**(70)**	**(3)**	(110)

(My) Expected error @ 5 ab^{-1} ~ 10%

Conclusions

- B-factories have proven to provide useful input to $B \to D^{**}$ physics, but there are persistent puzzles needing (much) more e^+e^- *data*.

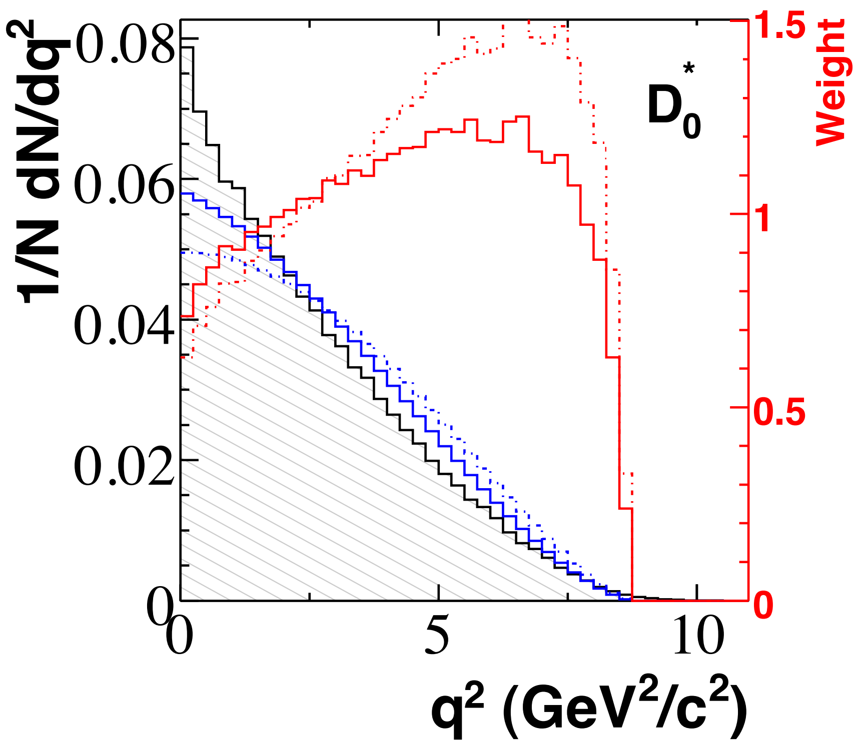
- Major upgrade at KEK during 2010-15 to increase L x 40.
  - Belle II is essentially a new project: many components and most electronics will be replaced.
  - Slow pion tracking, and PID will be enhanced greatly.
  - Neutral decay modes and broad resonances (crucial to understand full decay width) will be studied precisely, best done at e^+e^-.

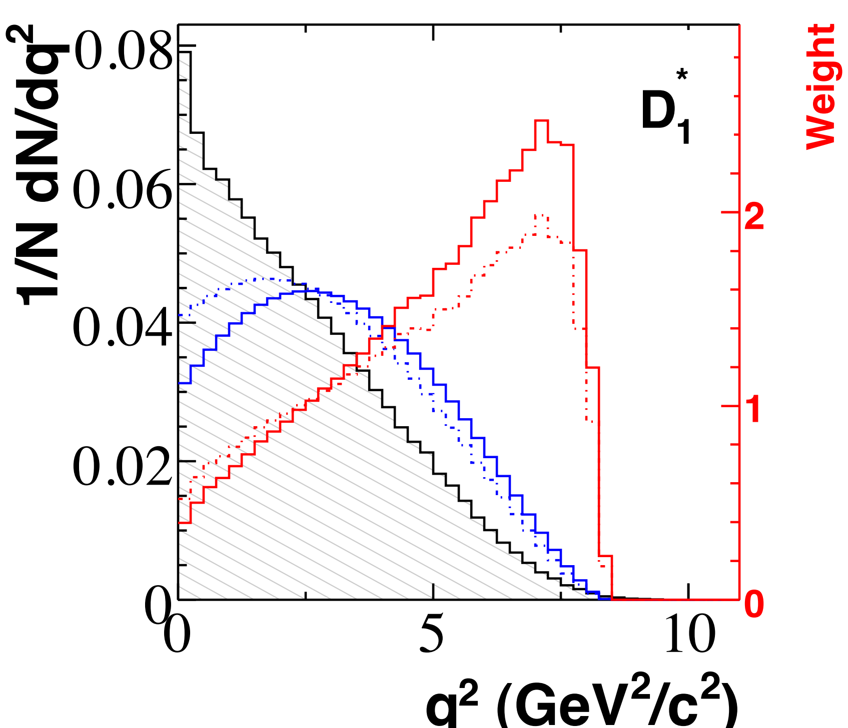
- *Have not yet finished analysing Belle I data! Expect new results in semileptonic and hadronic modes.*

Backup

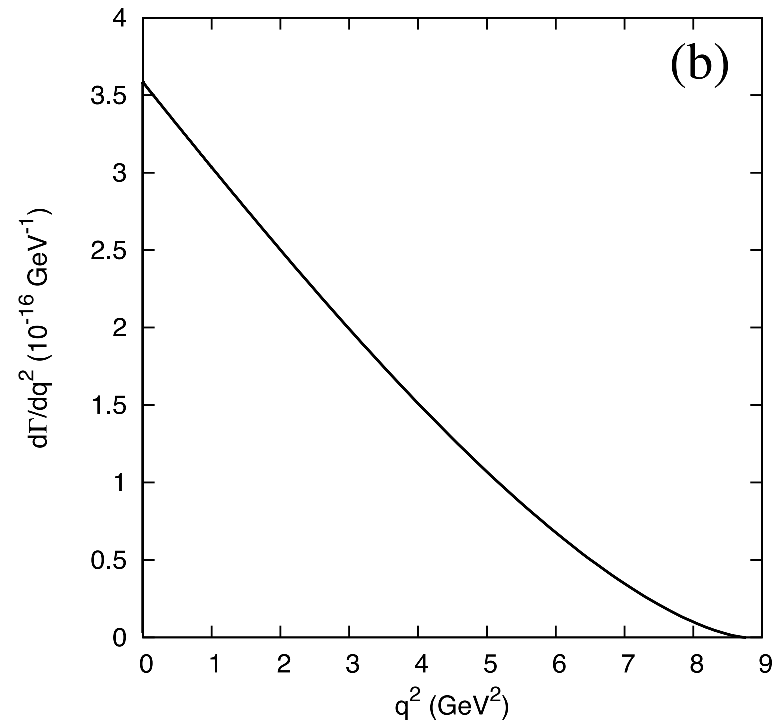
$B_s \rightarrow D_s^{**} l\nu$ Shapes

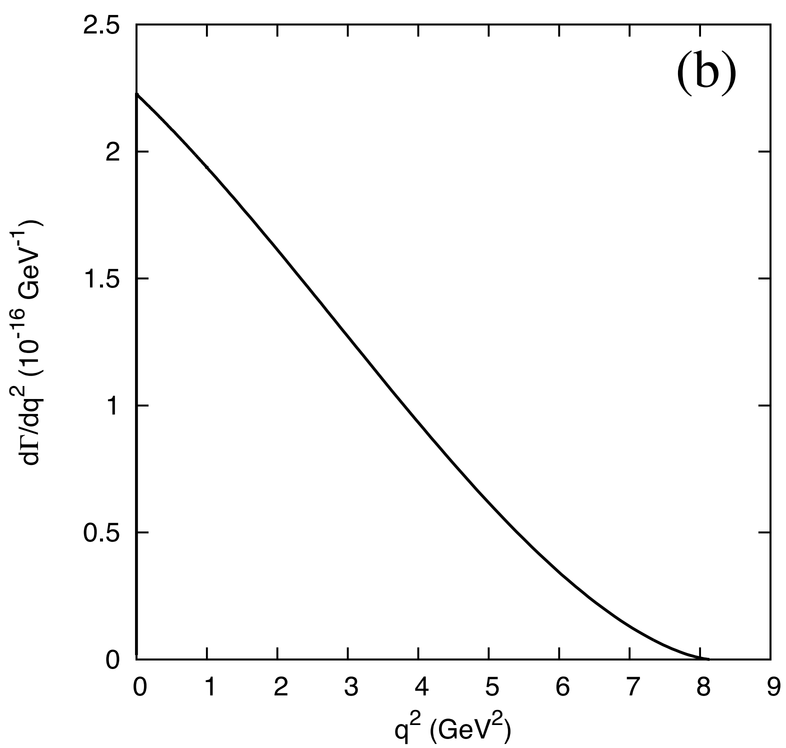
$B \rightarrow D^{**} l\nu$





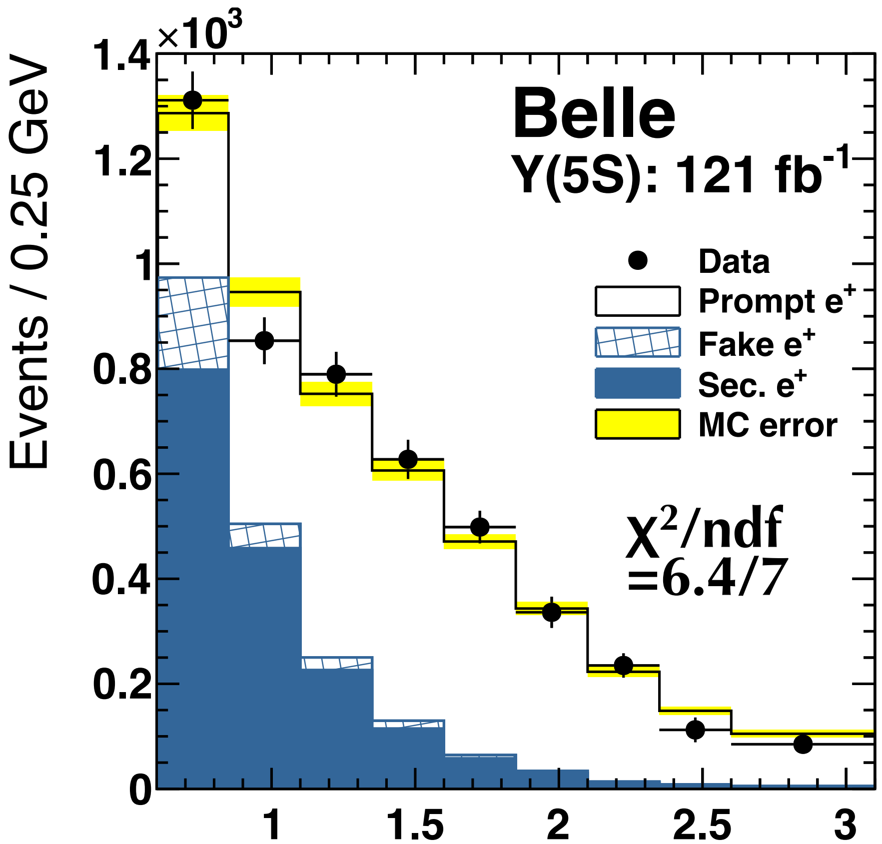
$B_s \rightarrow D_s^{**} l\nu$



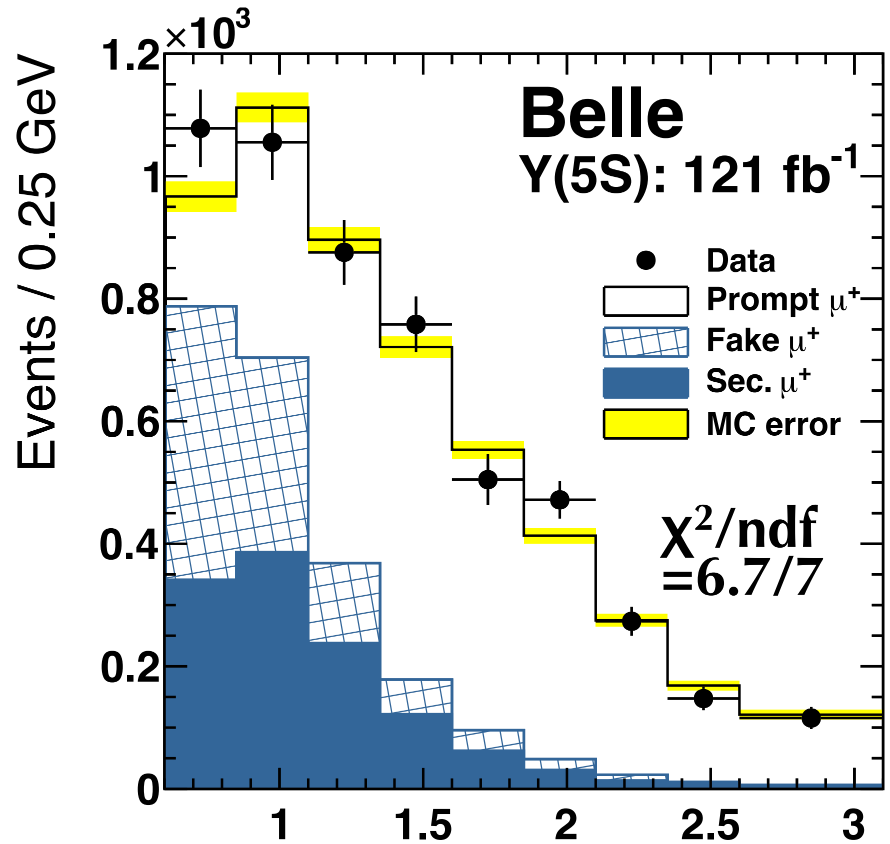


- Recent calculations in:
  - Semileptonic ***B*** and $\boldsymbol{B_s}$ decays into orbitally excited charmed mesons, J. Segovia,et al.,Physical Review D 84, 094029 (2011), arXiv: 1107.4248
  - A lot like ISGW2 (black)

Belle Inclusive



$N(D_s^- e^-)=4260\pm190$



$N(D_s^- e^-)=4760\pm230$

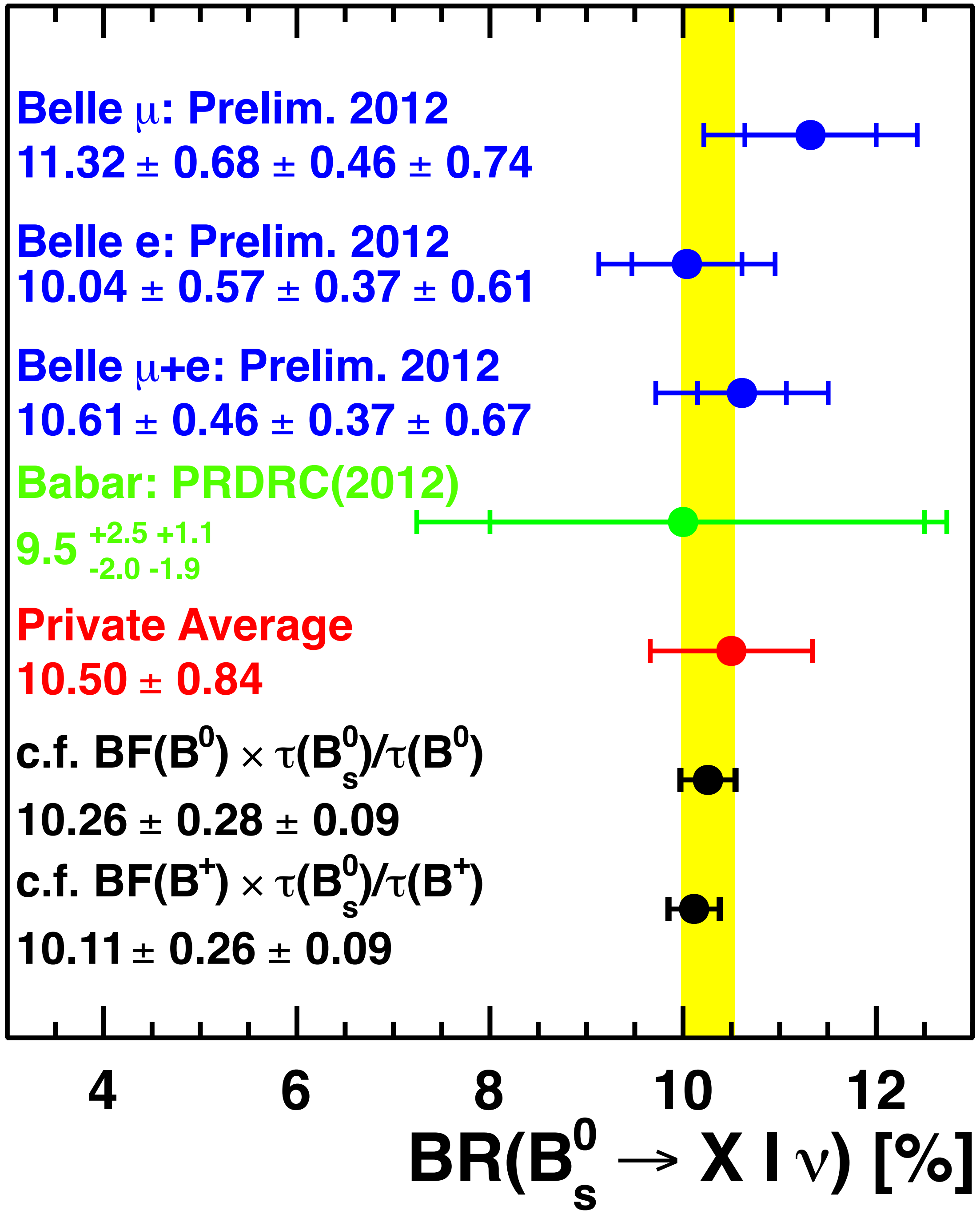
Two component fraction fit: **prompt leptons** and **secondary and fake** leptons

$$\frac{N(D_s^- e^-)}{N(D_s^-)} = 0.0426 \pm 0.0020 \pm 0.0013$$

$$\frac{N(D_s^- \mu^-)}{N(D_s^-)} = 0.0471 \pm 0.0024 \pm 0.0016$$

Rel. Systematic Uncertainty	e^-	μ^-
Lepton ID, fake rate	0.7	1.4
D_s efficiency	0.8	0.8
KKπ fit	2.0	2.2
Secondary leptons	1.0	1.5
Continuum	1.1	
Semileptonic Width Composition	1.2	

Inclusive Summary



- Belle: Model independent
- ~10% limit on SU3 symmetry breaking
- Systematics limited!
  - Due to tagging techniques.
  - **B_s full reconstruction** (particularly >1 ab^{-1}) will help, but there is still some kinematic smearing
- Can still improve ***f_s* & *D_sX*** with current 5S data. (not yet measured for 121 fb^{-1})

$$\frac{\Gamma(B_s^0 \to X\ell\nu)}{\Gamma(B_d^0 \to X\ell\nu)} \cdot \frac{\tau(B_s^0)}{\tau(B_d^0)} = \frac{\mathcal{B}(B_s^0 \to X\ell\nu)}{\mathcal{B}(B_d^0 \to X\ell\nu)}$$

Broad physics program

B Physics @ Y(4S)

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ ($J/\psi K^0$)	0.018	0.005 (†)
$\cos(2\beta)$ ($J/\psi K^{*0}$)	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi \pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (∗)
$S(\eta' K^0)$	0.05	0.01 (∗)
$S(K^0_S K^0_S K^0_S)$	0.15	0.02 (∗)
$S(K^0_S \pi^0)$	0.15	0.02 (∗)
$S(\omega K^0_S)$	0.17	0.03 (∗)
$S(f_0 K^0_S)$	0.12	0.02 (∗)
γ ($B \to DK$, $D \to CP$ eigenstates)	$\sim 15^\circ$	2.5°
γ ($B \to DK$, $D \to$ suppressed states)	$\sim 12^\circ$	2.0°
γ ($B \to DK$, $D \to$ multibody states)	$\sim 9^\circ$	1.5°
γ ($B \to DK$, combined)	$\sim 6^\circ$	1–2°
α ($B \to \pi\pi$)	$\sim 16^\circ$	3°
α ($B \to \rho\rho$)	$\sim 7^\circ$	1–2° (∗)
α ($B \to \rho\pi$)	$\sim 12^\circ$	2°
α (combined)	$\sim 6^\circ$	1–2° (∗)
$2\beta + \gamma$ ($D^{(*)\pm}\pi^\mp$, $D^\pm K^0_S \pi^\mp$)	20°	5°

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\|V_{cb}\|$ (exclusive)	4% (∗)	1.0% (∗)
$\|V_{cb}\|$ (inclusive)	1% (∗)	0.5% (∗)
$\|V_{ub}\|$ (exclusive)	8% (∗)	3.0% (∗)
$\|V_{ub}\|$ (inclusive)	8% (∗)	2.0% (∗)
$\mathcal{B}(B \to \tau\nu)$	20%	4% (†)
$\mathcal{B}(B \to \mu\nu)$	visible	5%
$\mathcal{B}(B \to D\tau\nu)$	10%	2%
$\mathcal{B}(B \to \rho\gamma)$	15%	3% (†)
$\mathcal{B}(B \to \omega\gamma)$	30%	5%
$A_{CP}(B \to K^*\gamma)$	0.007 (†)	0.004 († ∗)
$A_{CP}(B \to \rho\gamma)$	~ 0.20	0.05
$A_{CP}(b \to s\gamma)$	0.012 (†)	0.004 (†)
$A_{CP}(b \to (s+d)\gamma)$	0.03	0.006 (†)
$S(K^0_S \pi^0 \gamma)$	0.15	0.02 (∗)
$S(\rho^0\gamma)$	possible	0.10
$A_{CP}(B \to K^*\ell\ell)$	7%	1%
$A^{FB}(B \to K^*\ell\ell)s_0$	25%	9%
$A^{FB}(B \to X_s\ell\ell)s_0$	35%	5%
$\mathcal{B}(B \to K\nu\bar{\nu})$	visible	20%
$\mathcal{B}(B \to \pi\nu\bar{\nu})$	–	possible

Charm mixing and CPV

Mode	Observable	$\Upsilon(4S)$ (75 ab^{-1})	$\psi(3770)$ (300 fb^{-1})
$D^0 \to K^+\pi^-$	x'^2	3×10^{-5}	
	y'	7×10^{-4}	
$D^0 \to K^+K^-$	y_{CP}	5×10^{-4}	
$D^0 \to K^0_S\pi^+\pi^-$	x	4.9×10^{-4}	
	y	3.5×10^{-4}	
	$\|q/p\|$	3×10^{-2}	
	ϕ	2°	
$\psi(3770) \to D^0\overline{D}^0$	x^2		$(1-2) \times 10^{-5}$
	y		$(1-2) \times 10^{-3}$
	$\cos\delta$		$(0.01-0.02)$

B_s Physics @ Y(5S)

Observable	Error with 1 ab^{-1}	Error with 30 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}	0.03 ps^{-1}
Γ	0.07 ps^{-1}	0.01 ps^{-1}
β_s from angular analysis	20°	8°
$A^s_{\rm SL}$	0.006	0.004
$A_{\rm CH}$	0.004	0.004
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	$< 8 \times 10^{-9}$
$\|V_{td}/V_{ts}\|$	0.08	0.017
$\mathcal{B}(B_s \to \gamma\gamma)$	38%	7%
β_s from $J/\psi\phi$	10°	3°
β_s from $B_s \to K^0\bar{K}^0$	24°	11°