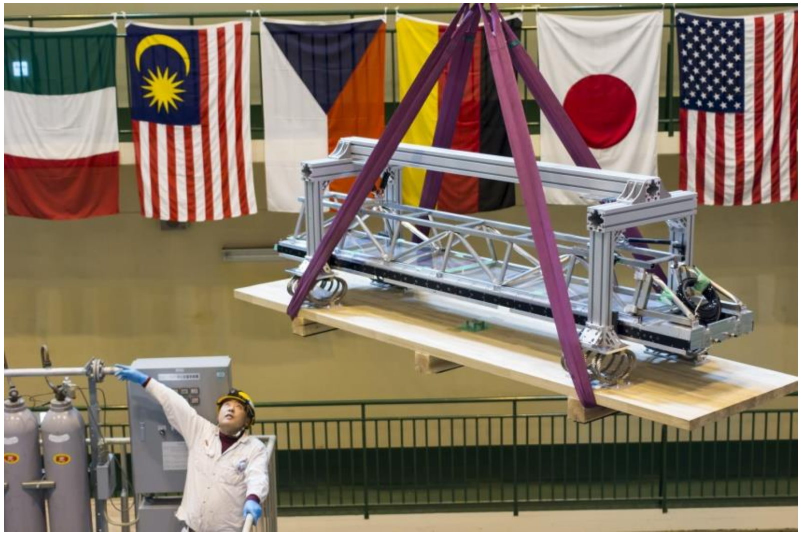
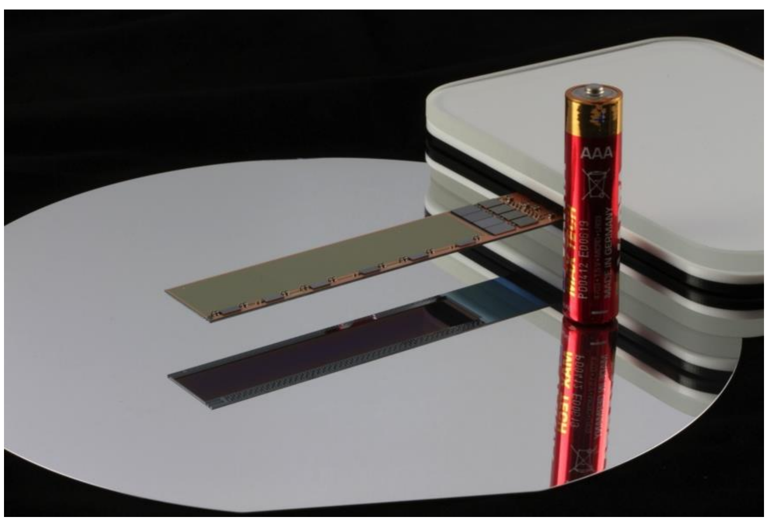
# Belle II Physics and Construction Status

Tom Browder (University of Hawai'i at Manoa)



1st TOP module arriving at Tsukuba Hall



1st DEPFET pixel detector plane

- -Recent News from Japan
- -Tau Lepton Flavor Violation
- -The Dark Sector

Excitement and High Stakes in Flavor Physics:

- -Connections to the *charged Higgs*
- -Rare B Decays + NP

*Flavor Physics, The Next Generatio*

Belle II/SuperKEKB

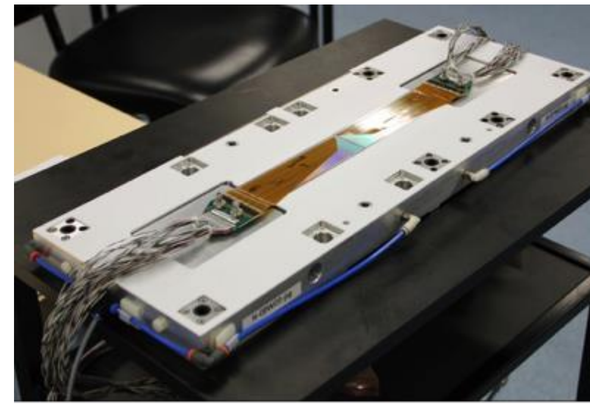
Apologies: LHCb was covered in C. Bozzi's plenary.
I have borrowed slides from many excellent physicists and will aim for "a big picture overview" In flavor physics but skip most details.

# Belle II in Australia

Melbourne:

(Dr. Phil Urquijo, Assoc. Prof. Martin Sevior, Prof. Geoff Taylor, Prof. Elisabetta Barberio)

Construction of L3 and software of Belle II silicon detector, Physics Coordination (Urquijo), HLT & L1 menu software (leadership), GRID Computing (leadership of skimming), Governance; Belle measurements of EWP, semileptonic and hadronic B decays; Belle II studies of dark sectors and tau LFV.



Sydney:

Prof. Kevin Varvell, Dr. Bruce Yabsley

RPC μ trigger/readout, software;
Belle measurements of leptonic & semileptonic B decays; B factory legacy book.


928 pages

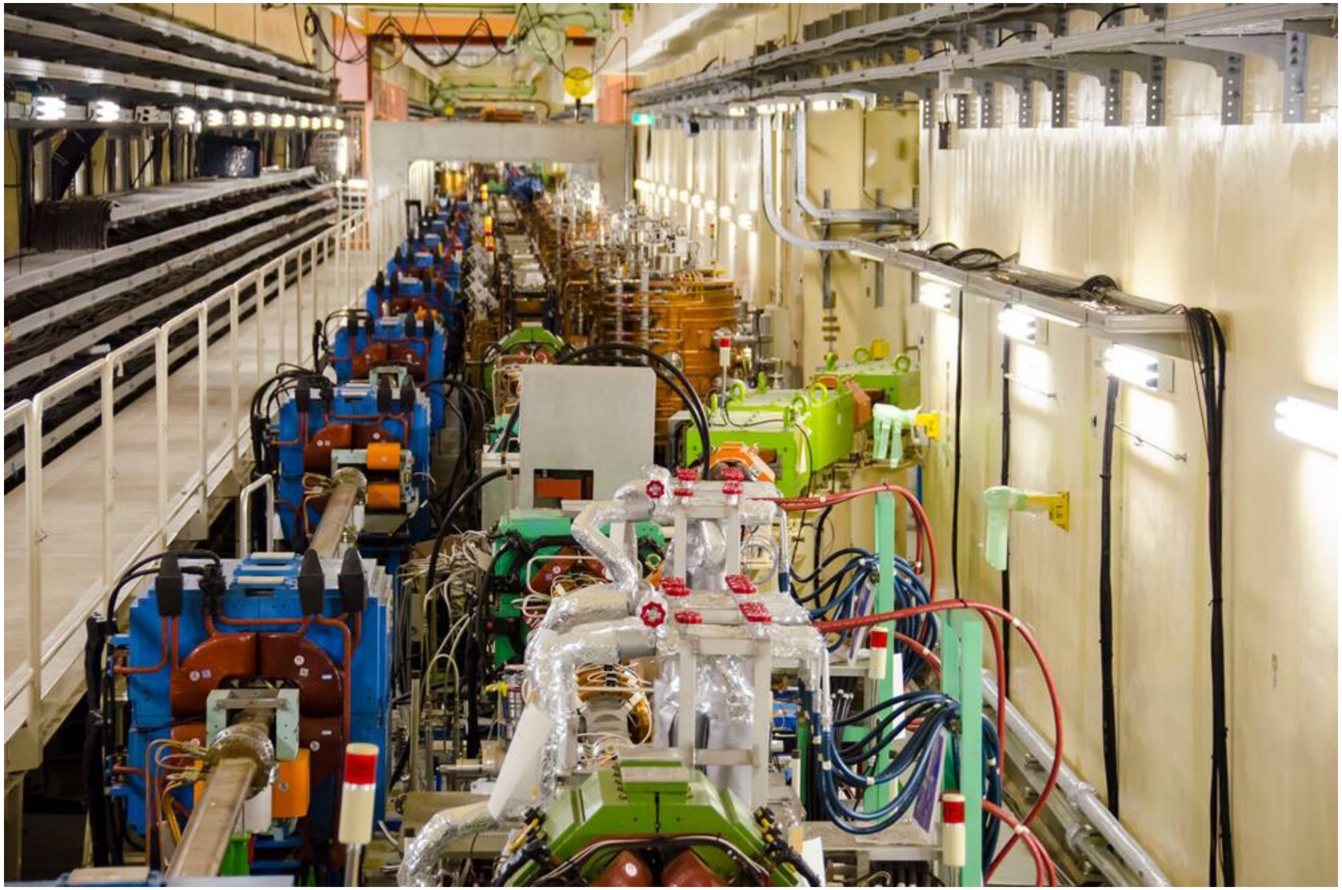
Adelaide:

Assoc. Prof. Paul Jackson

Recently joined on physics analysis and GRID computing.

Feb 2016: First Turns at SuperKEKB (4 GeV e+'s and 7 GeV e-'s)

NEWS

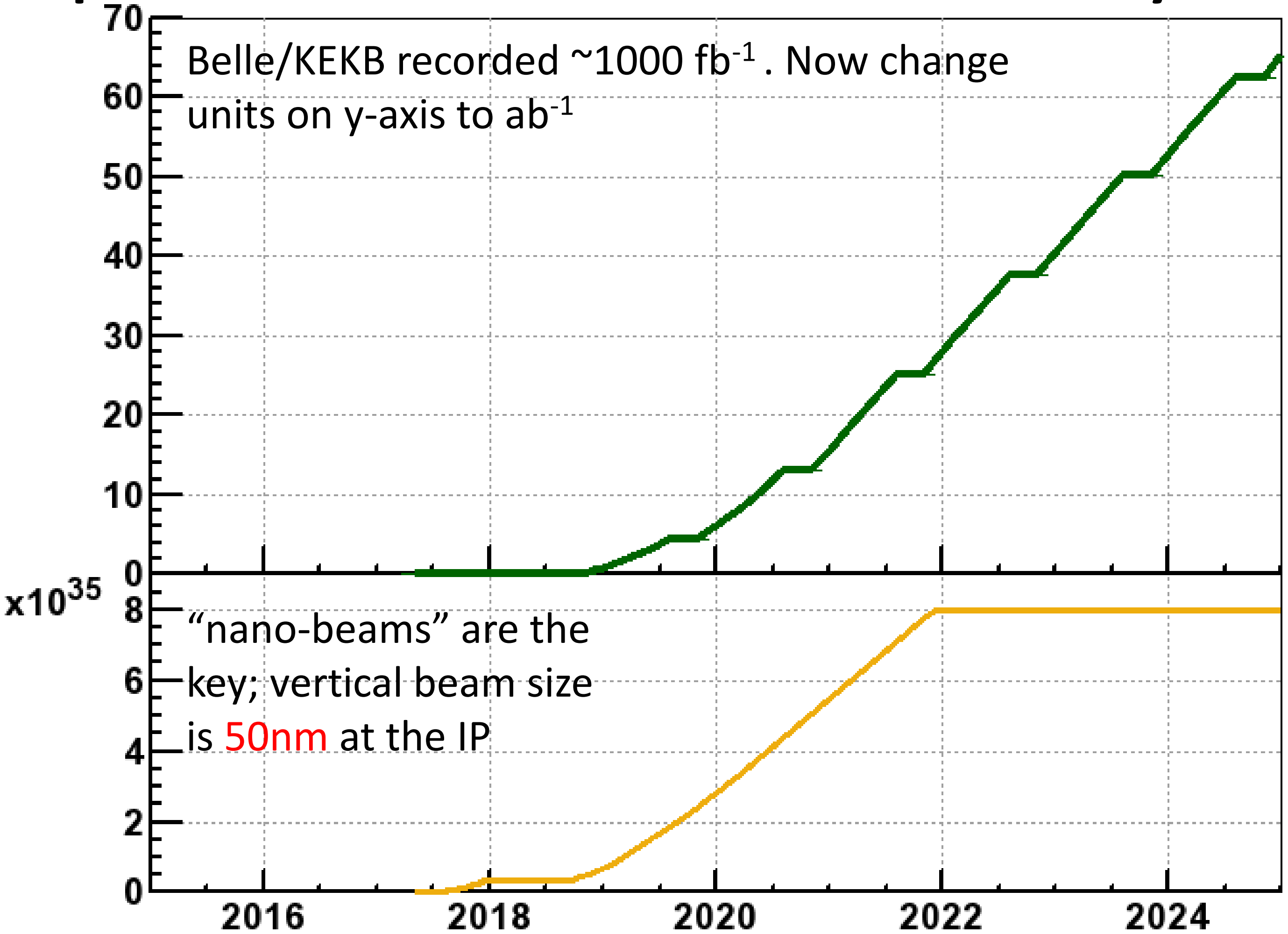


June 28, 2016 (LER beam current at 1000 mA, HER at 870 mA)

2017: Collisions at the Y(4S) will produce pairs of QM entangled (B-anti B) mesons

First new particle collider since the LHC (*intensity frontier* rather than energy frontier; $e^+ e^-$ rather than p p)

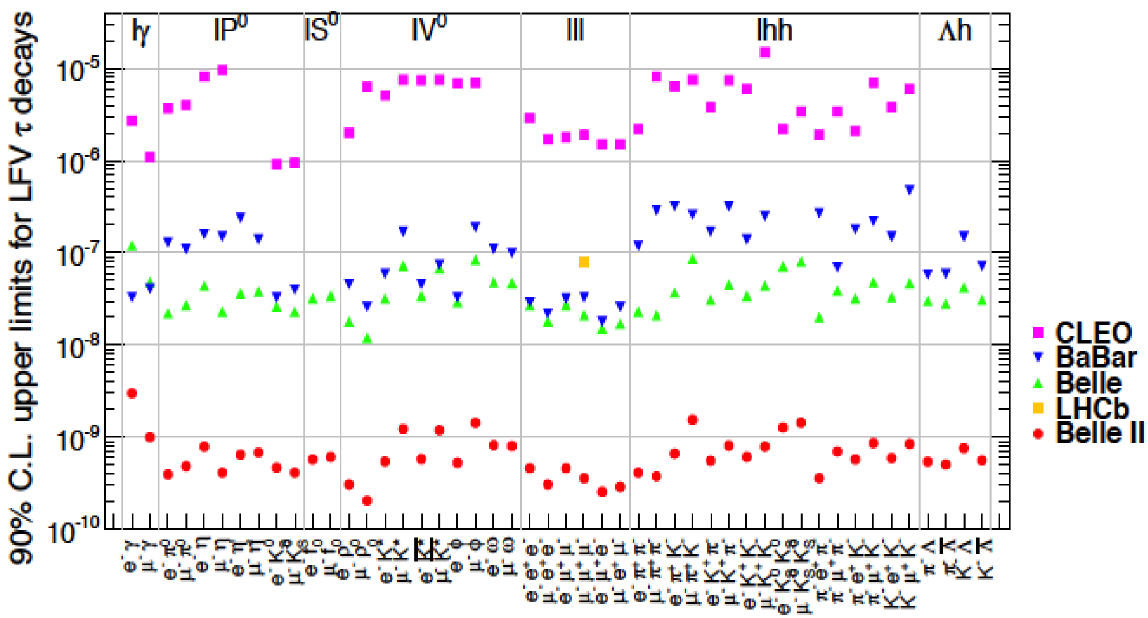
# SuperKEKB/Belle II Luminosity Profile




N.B. To realize this steep turn-on, requires close cooperation between Belle II and SuperKEKB [and *international collaboration* on the accelerator].

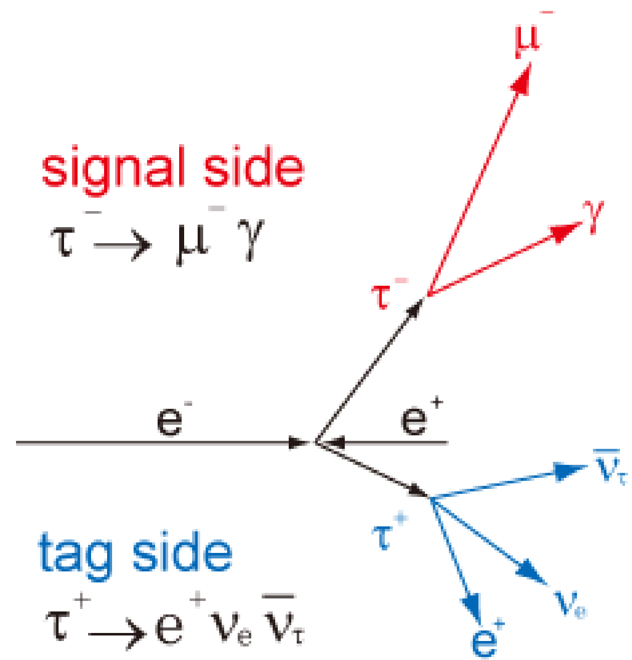
This plot assumes a *full* and *stable* operation funding profile.

# Tau Lepton Flavor Violation




Note vertical log-scale (50 $ab^{-1}$ assumed for Belle II; 3 $fb^{-1}$ result for LHCb

Example of the decay topology




***<u>Belle II will push many limits below $10^{-9}$</u>***;

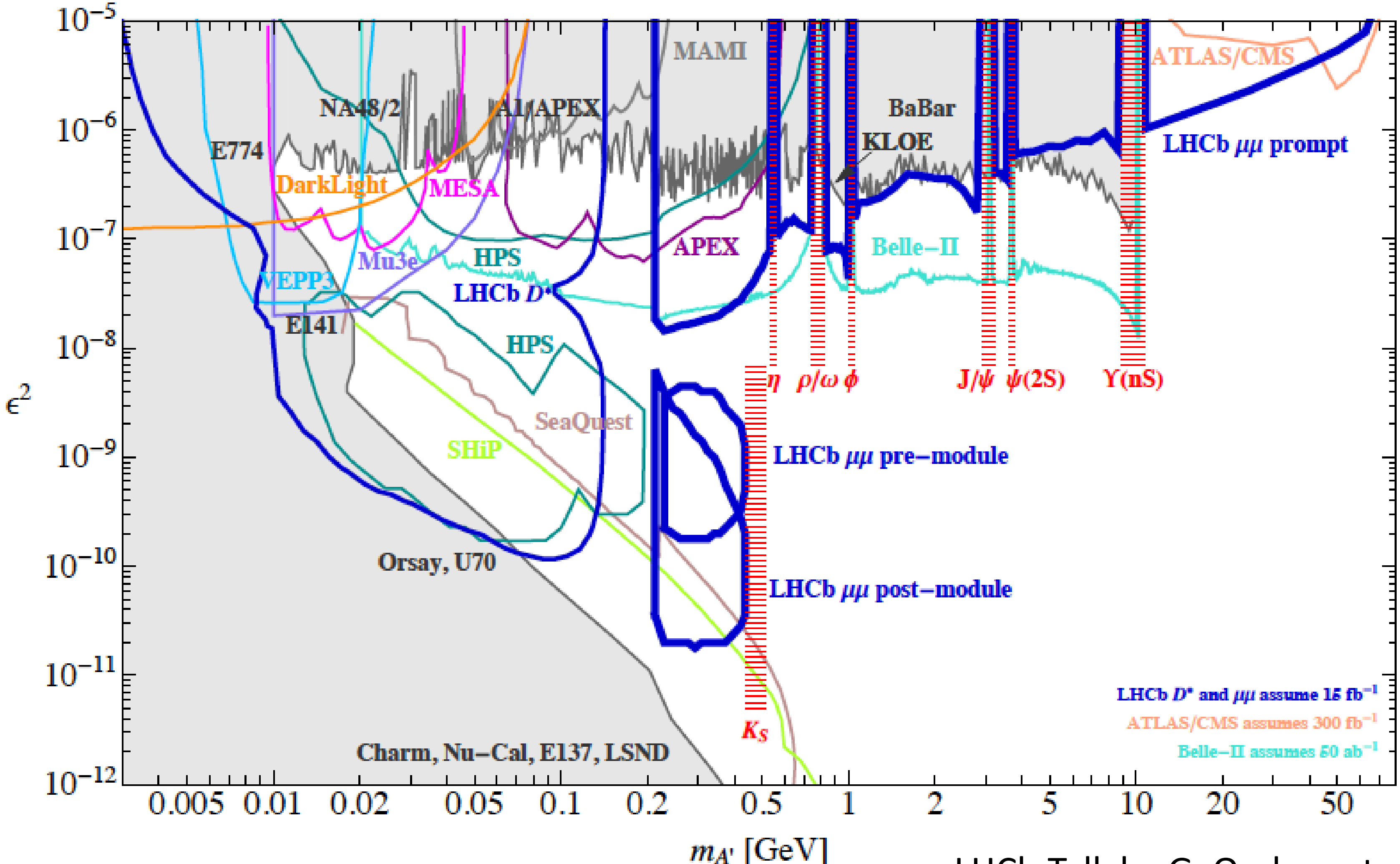
LHCb, CMS and ATLAS have very limited capabilities.

The modes τ→μγ and τ →μ h+ h-
Provide important constraints on H→μτ

LHCb talk by G. Onderwater

# "Dark Photon"→$e^+e^-$ sensitivity

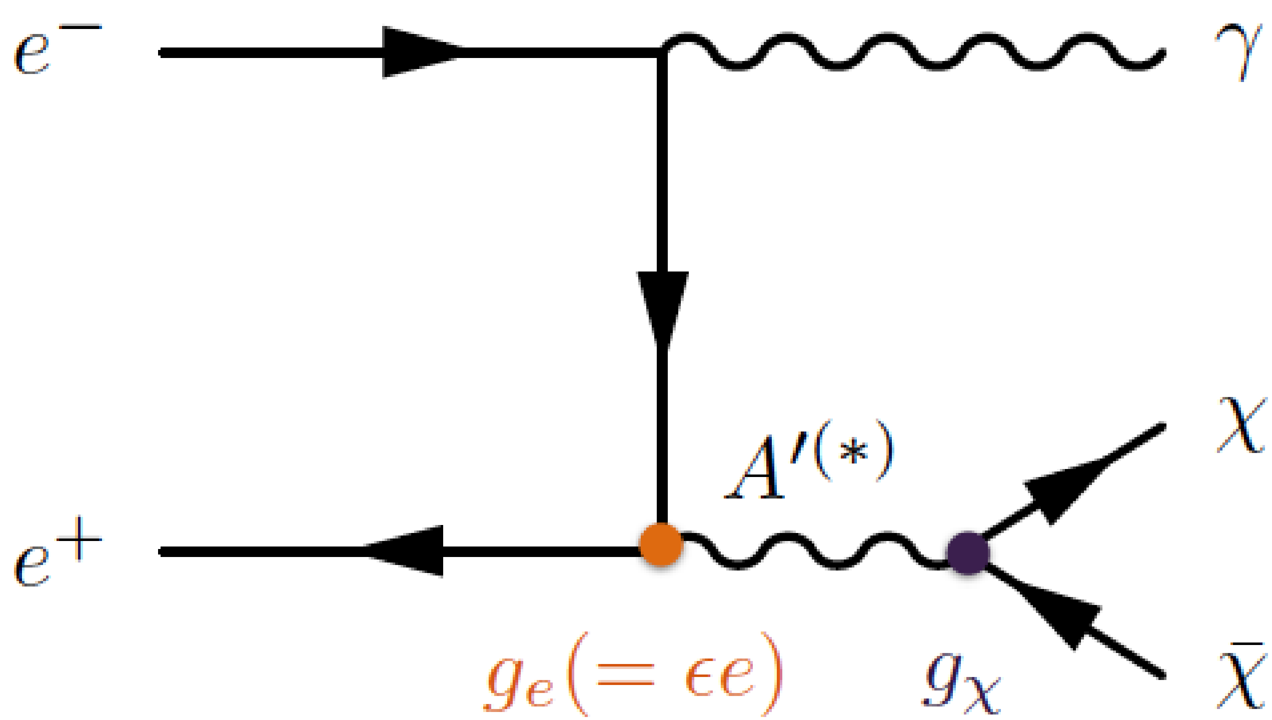
One process used in Belle II is $e^+e^- \to \gamma A' \to e^+e^-$




LHCb Talk by G. Onderwater

# “Light DM” sensitivity in $e^+e^- \rightarrow \gamma$+nothing

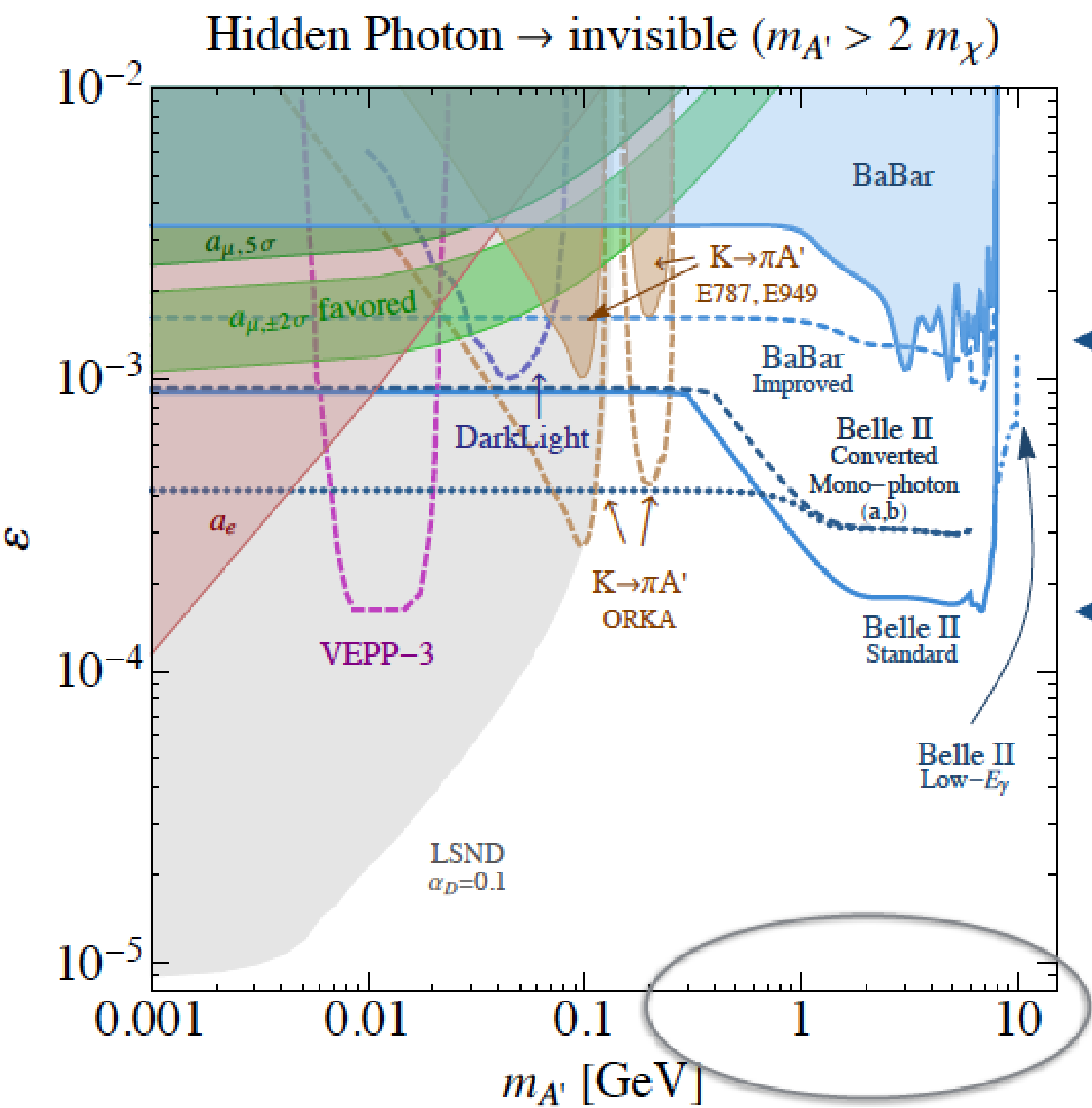
Signal: mono-photon event




YiMing Zhong et al. (B2TIP)

Requires a special new trigger that is being developed for Belle II

# "Light DM" sensitivity in γ+nothing



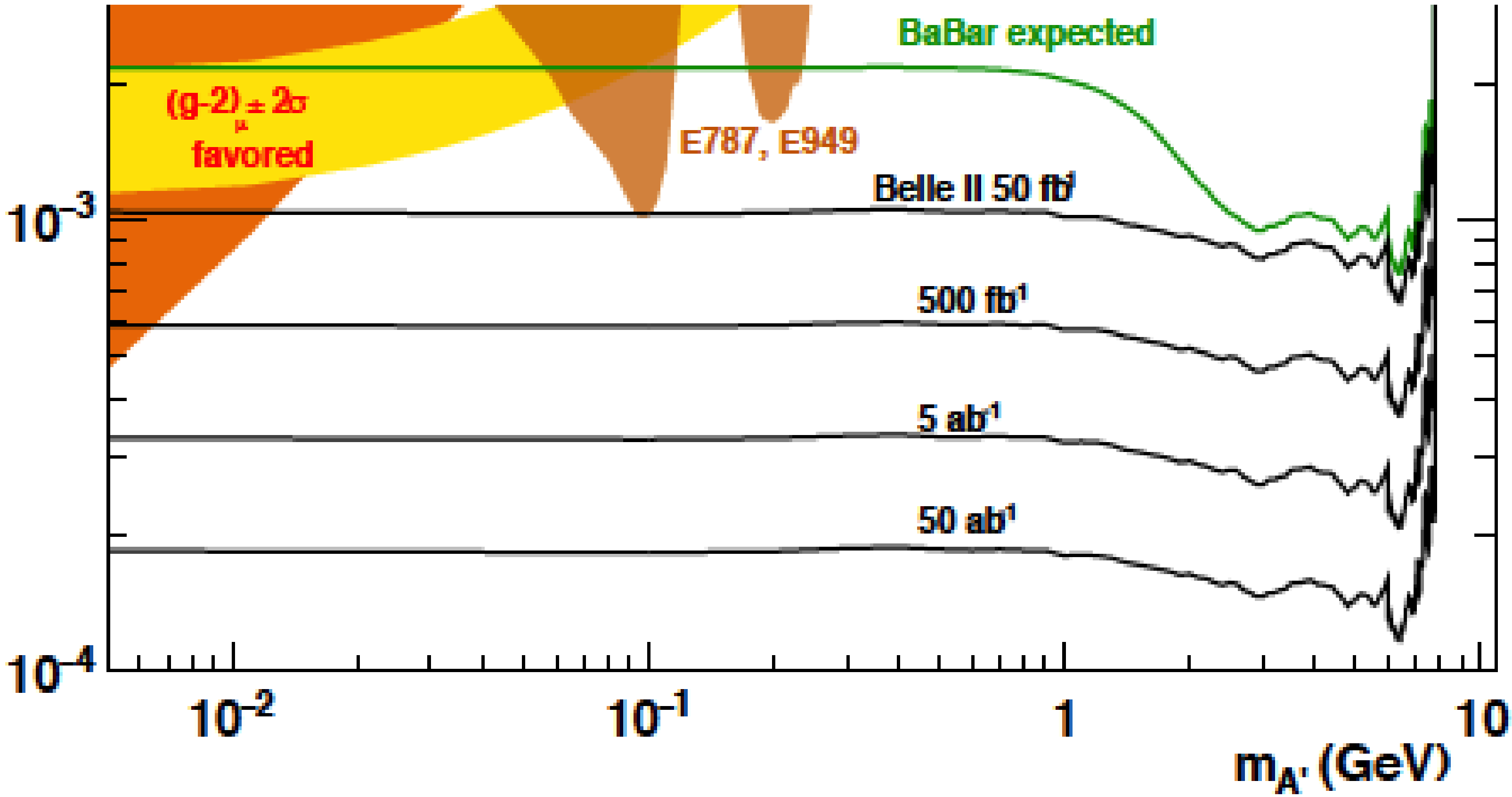

see also Izaguirre et al, 2013

BaBar

Belle II projections

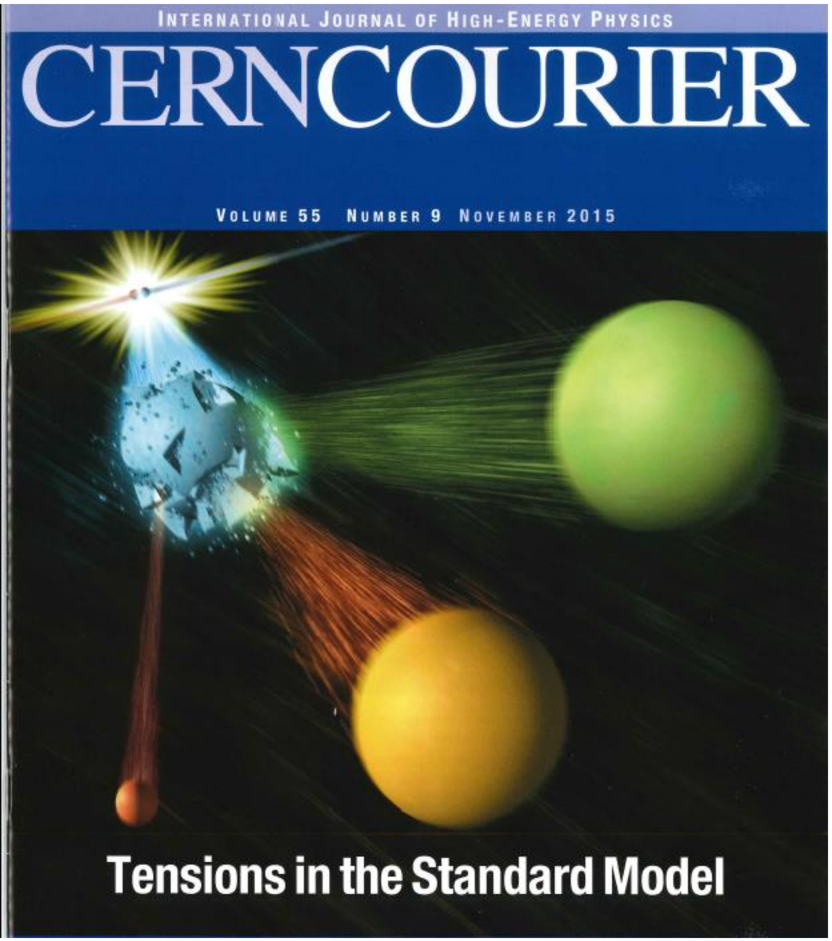
the best probe for 100 MeV-10 GeV A′

# “Light DM” sensitivity in γ+nothing




Sensitivity increases rapidly with integrated luminosity

# “Missing Energy Decays” of the B meson

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## 2 Accelerators Find Particles That May Break Known Laws of Physics

The LHC and the Belle experiment have found particle decay patterns that violate the Standard Model of particle physics, confirming earlier observations at the BaBar facility

By Clara Moskowitz | September 9, 2015 | Véalo en español

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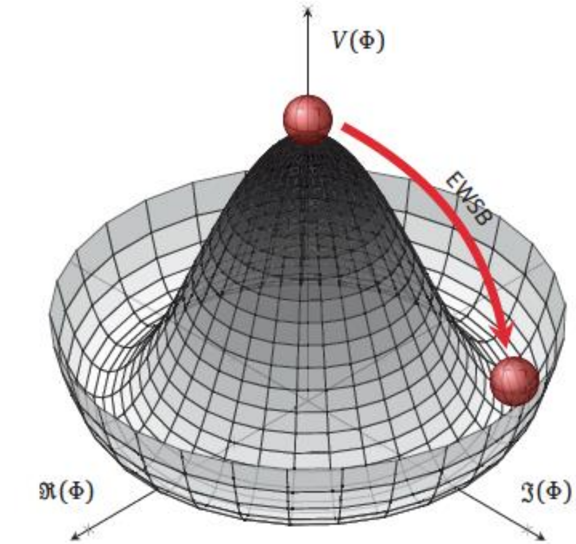
## Democracy suffers a blow—in particle physics

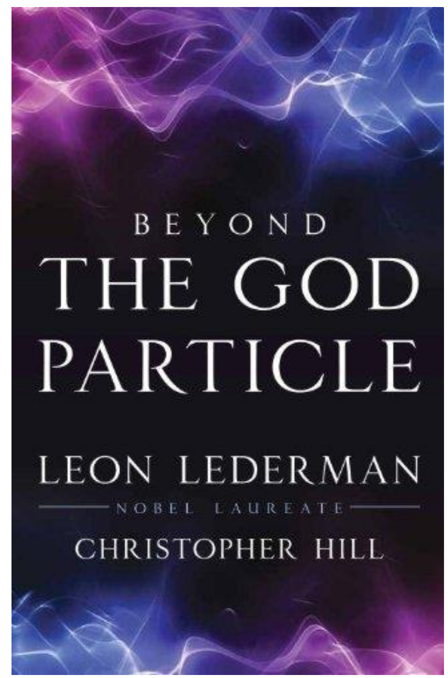
Three independent B-meson experiments suggest that the charged leptons may not be so equal after all.

Steven K. Blau 17 September 2015

The BEH boson is now firmly established by experimental results from ATLAS and CMS. *Now planning for future Higgs flavor factory facilities (e.g ILC, HL-LHC, CEPC, FCC).*




Does the GP (Brout-Englert-Higgs particle) have a “brother” i.e. the charged Higgs ?



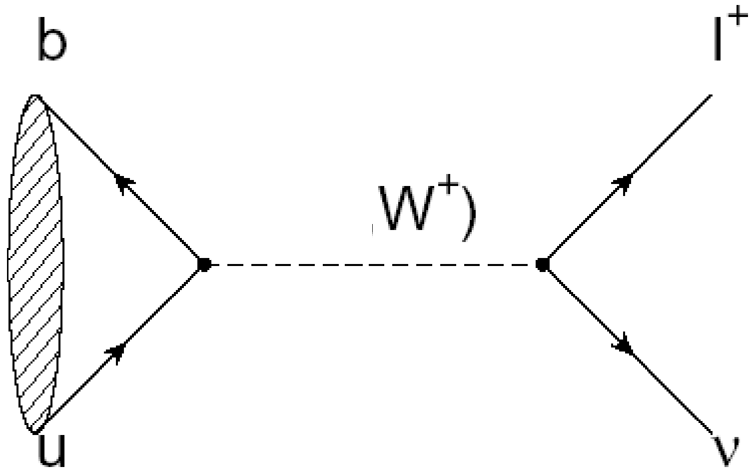

Y. Nambu, 1921-2015

Measurements at Belle II and direct searches at hadron colliders take *complementary* approaches to this important question.

# B→τ ν

## (Decay with *Large* Missing Energy)

Sensitivity to new physics from a *charged Higgs*




$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$\mathcal{B}_{(B\to\tau\nu)} = \mathcal{B}_{SM} \times \left(1 - \tan^2\beta \frac{m_{B\pm}^2}{m_{H\pm}^2}\right)$$

*W.S.Hou*,. PRD 48, 2342 (*1993*)

*The B meson decay constant, determined by the B wavefunction at the origin*

($|V_{ub}|$ taken from indep. measurements.)

# Consumer's Guide to the Charged Higgs

- *Higgs doublet of type I* ($\phi_1$ couples to upper (u-type) and lower (d-type) generations. No fermions couple to $\phi_2$)

- *Higgs doublet of type II* ($\phi_u$ couples to u type quarks, $\phi_d$ couples to d-type quarks, u and d couplings are different; $\tan(\beta) = v_u/v_d$) [favored NP scenario e.g. MSSM, generic SUSY]

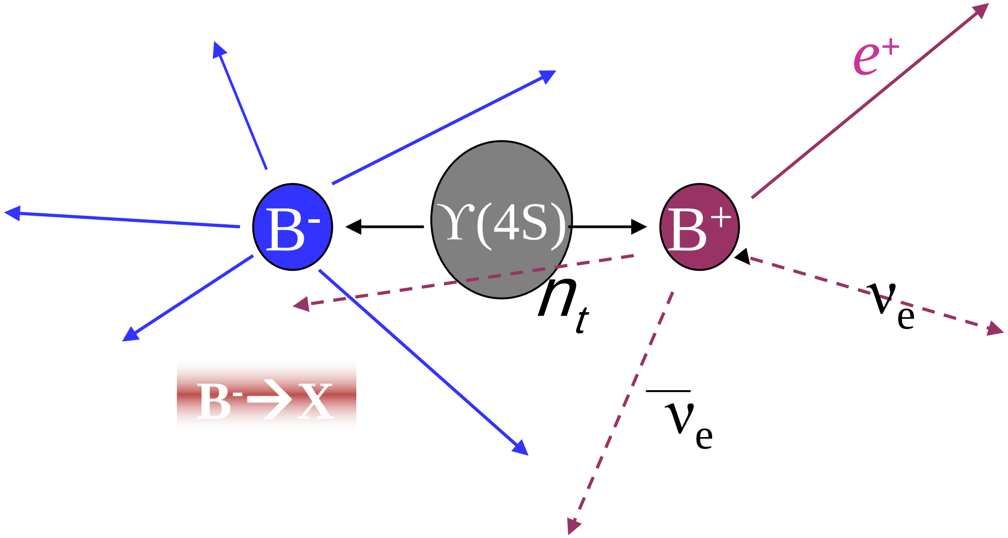
- *Higgs doublet of type III* (not type I or type II; anything goes.

"FCNC hell"→many FCNC signatures)

Talks by Howie Haber, Marcela Carena, Xiao-Gang He at SUSY2016

Thanks to theorist Xerxes Tata

# *Why measuring $B^+ \rightarrow \tau^+ \nu$ is non-trivial*



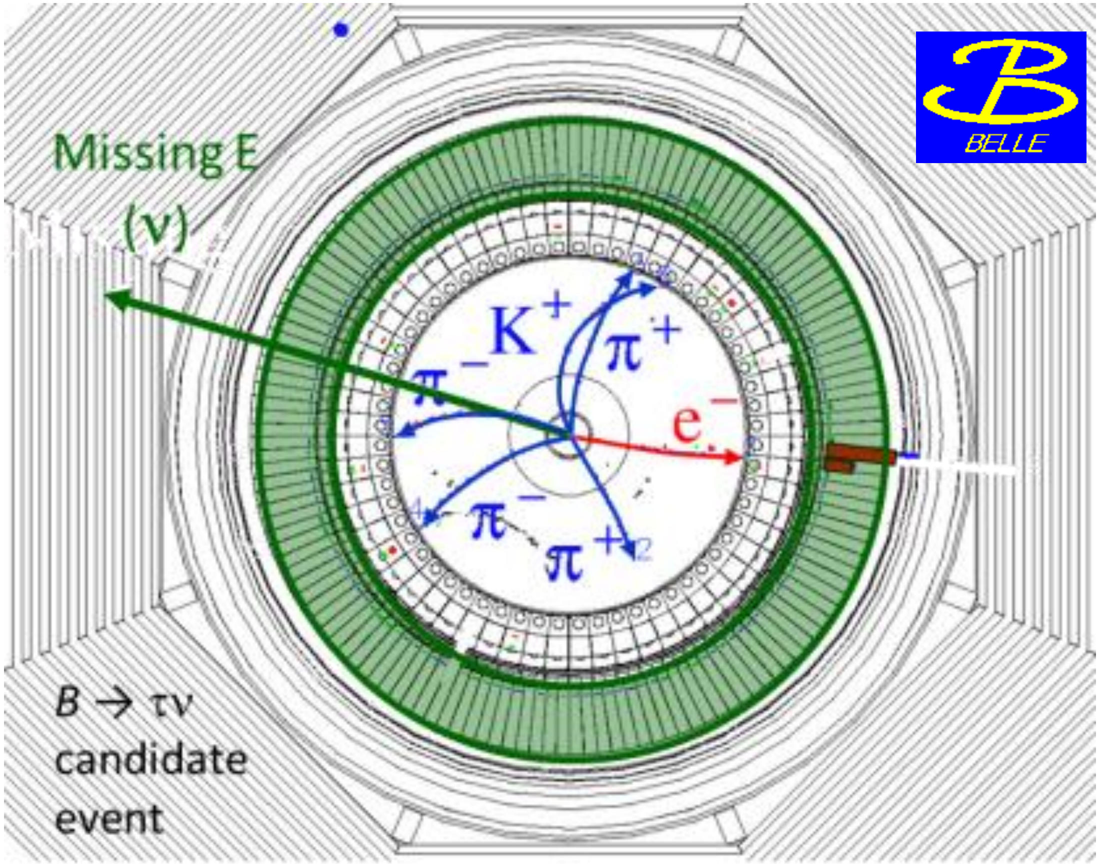

Most of the sensitivity is from tau modes with 1-prongs.

*The experimental signature is rather difficult:*
*B decays to a single charged track + nothing*

(This may be hard at a hadron collider)

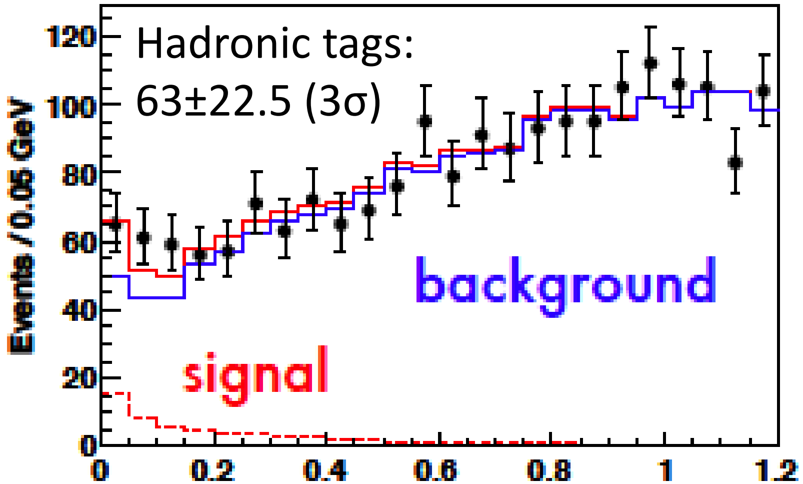
# *Example of a Missing Energy Decay* (B→τν) *in* <u>*Data*</u>

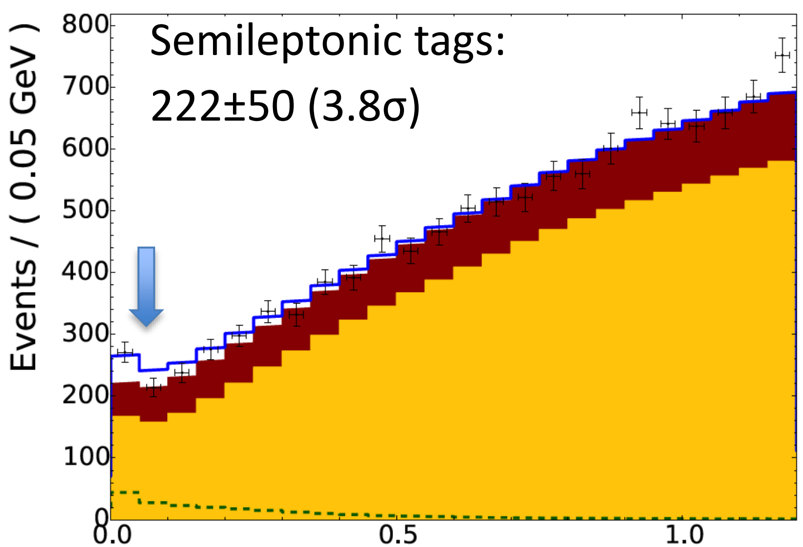
$$B^+ \to D^0\pi^+$$
$$(\to K\pi^-\pi^+\pi^-)$$
$$B^- \to \tau(\to e\nu\bar{\nu})\nu$$

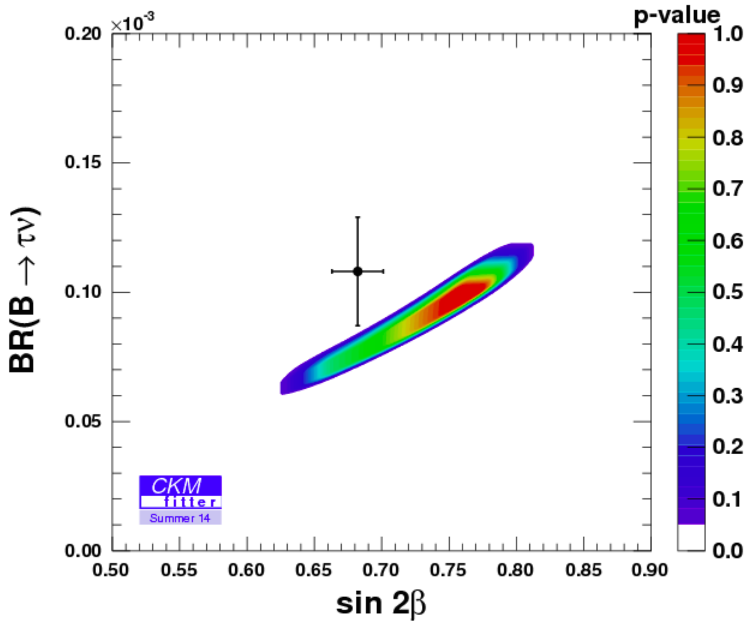



The clean e+e- environment makes this possible

Example: Belle B→τν results with full *reprocessed* data sample and either hadronic or semileptonic tags (PRD 92, 051102 (2015))



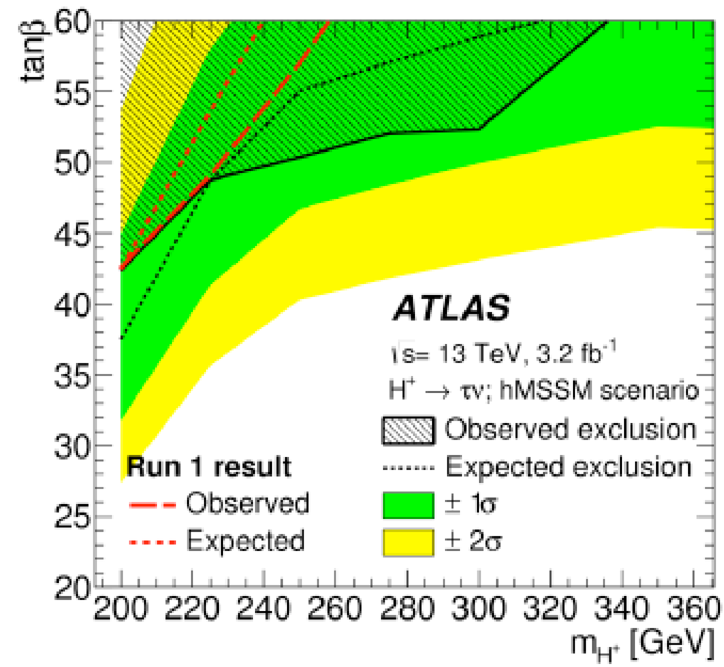

With the full B factory statistics only "evidence". No single observation from either Belle or BaBar.

➔The horizontal axis is the "Extra Calorimeter Energy"

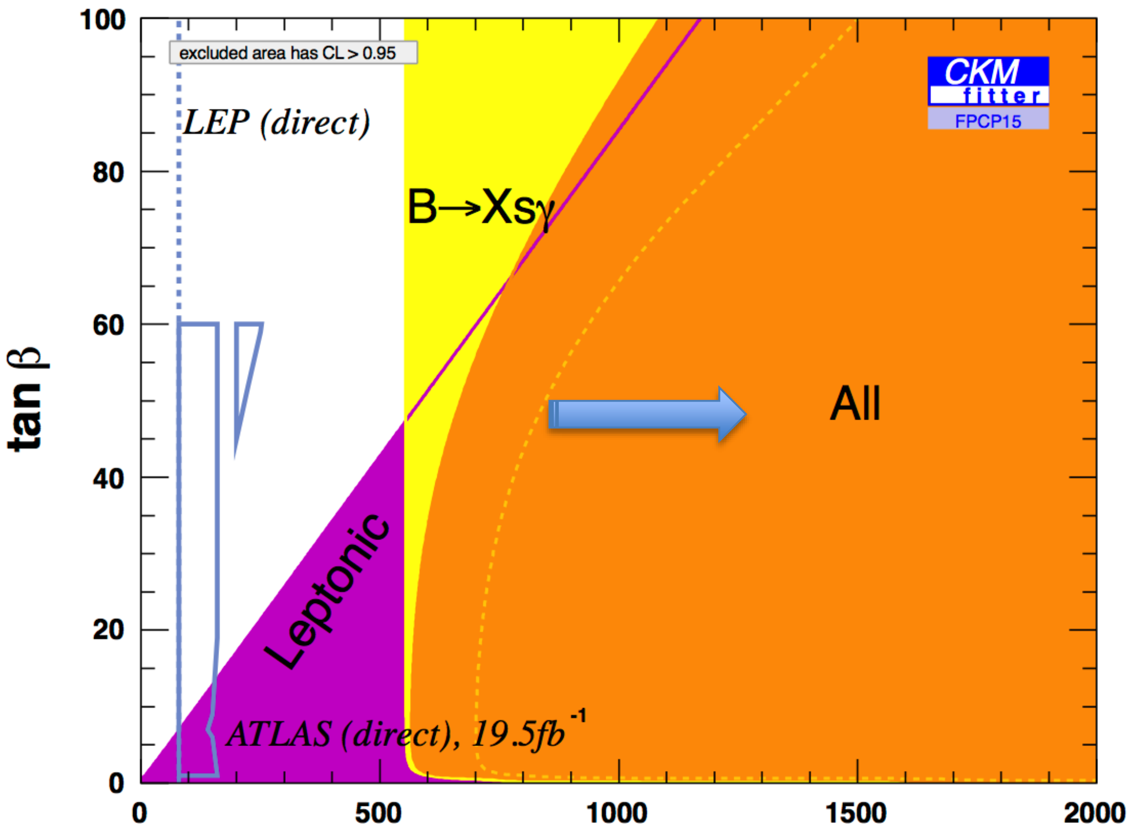
# Complementarity of e+ e- factories and LHC

Thanks to Luis Pesantez and Phil Urquijo

The current combined B→τυ limit places a stronger constraint than direct searches from LHC exps. for the next few years.



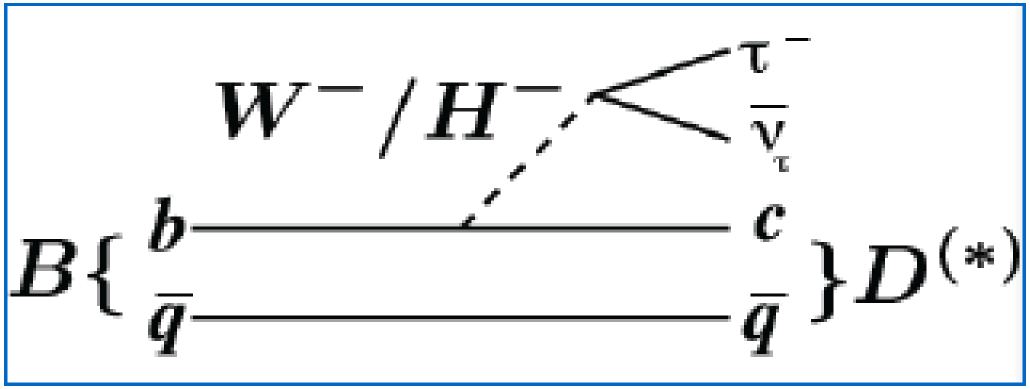

$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)$$

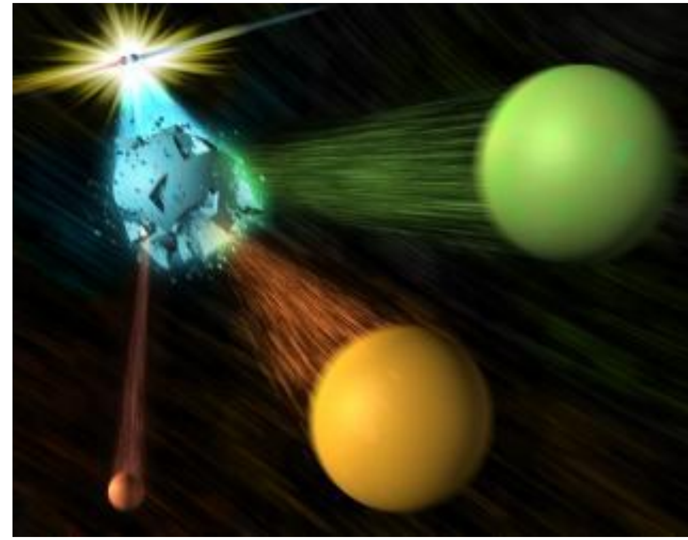



Currently inclusive b→sγ rules out $m_{H+}$ below ~480 GeV/c$^2$ range at 95% CL (independent of tanβ), M. Misiak et al. (assuming no other NP)

http://arxiv.org/abs/1503.01789

# *A three-body tale*



$$\mathcal{R}(D^{(*)})_{2\mathrm{HDM}} = \mathcal{R}(D^{(*)})_{\mathrm{SM}} + A_{D^{(*)}} \frac{\tan^2\beta}{m_{H^+}^2} + B_{D^{(*)}} \frac{\tan^4\beta}{m_{H^+}^4}$$

| | $D\tau\nu$ | $D^*\tau\nu$ |
|---|---|---|
| $A_{D^{(*)}}$ (GeV$^2$) | $-3.25 \pm 0.32$ | $-0.230 \pm 0.029$ |
| $B_{D^{(*)}}$ (GeV$^4$) | $16.9 \pm 2.0$ | $0.643 \pm 0.085$ |

$$R(D^{(*)}) = \frac{\mathcal{B}(\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell)}$$

$\longrightarrow$ Signal

$\longrightarrow$ Normalization ($l = e$ or $\mu$)

Slide adapted from A. Soffer

Example from a BaBar paper

<u>Signals in $B \to D^{(*)} \tau\nu$ (489±63, 888±63)</u>

Missing mass variable:

$$m_{miss}^2 = p_{miss}^2 = (p[e^+e^-] - p_{tag} - p_{D(*)} - p_l)^2$$

$P_l^*$ = momentum of lepton in B rest frame

**But wait !!! Now $B \to D^* \tau\nu$ *possible* at LHCb.**

*Production of B meson pairs at threshold is critical to the separation of backgrounds from the missing energy/ momentum signal.*

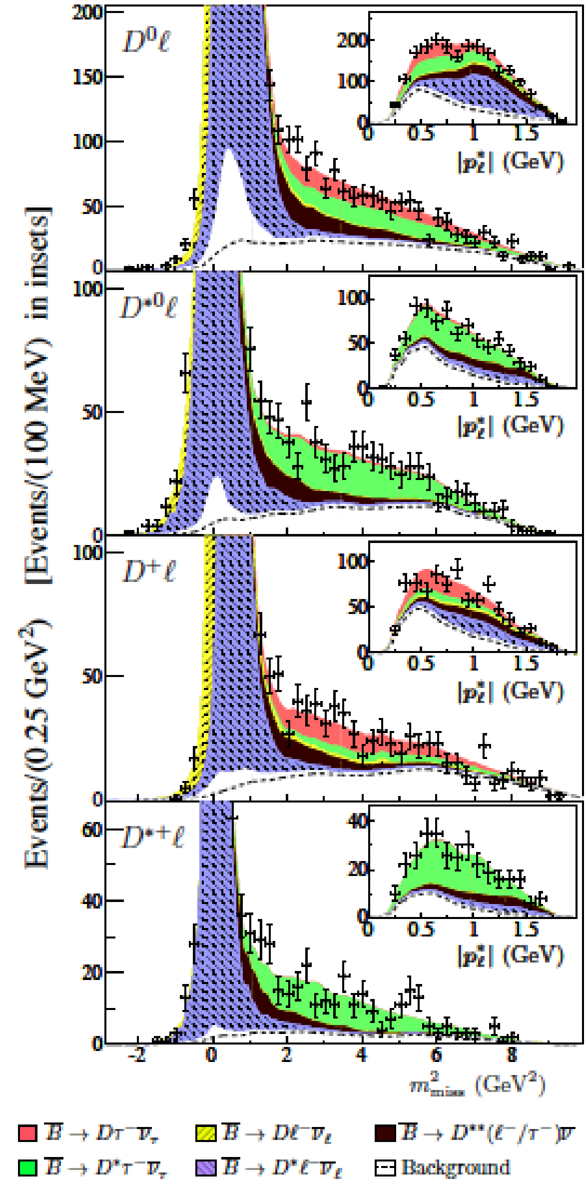
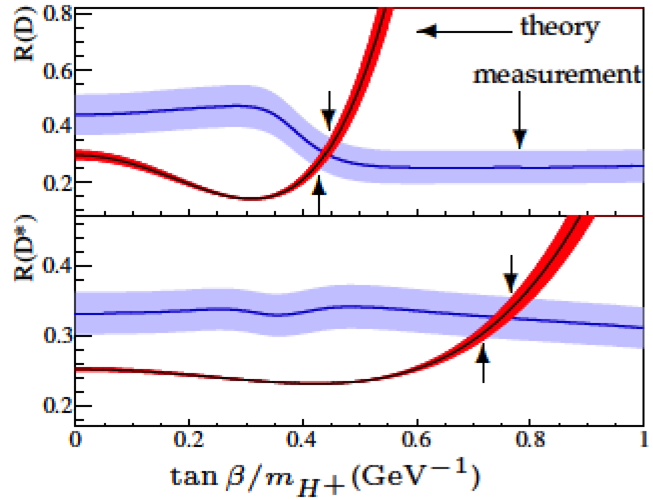



FIG. 1. (Color online) Comparison of the data and the fit projections for the four $D^{(*)}\ell$ samples. The insets show the $|p^*_\ell|$ projections for $m^2_{miss} > 1\,\text{GeV}^2$, which excludes most of the normalization modes. In the background component, the region above the dashed line corresponds to charge cross-feed, and the region below corresponds to continuum and $B\bar{B}$.

BaBar collaboration, Phys. Rev. Lett. 109, 101802 (2012)

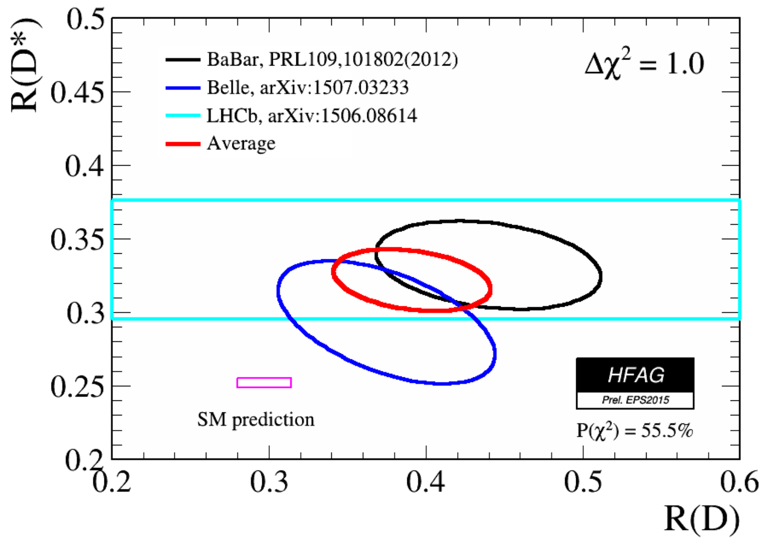
"However, the combination of R(D) and R(D*) excludes the type II 2HDM charged Higgs boson with a 99.8% confidence level for any value of $\tan(\beta)/m_{H+}$"




In other words, found NP but *killed* the 2HDM NP model.

*This was not the end of the "three-body tale" and stimulated much additional experimental and theoretical work.*

# Apres Nagoya 2015: *World Averages* for R(D) and R(D$^*$)




July 23, 2015

<u>Now 3.9σ from SM</u>

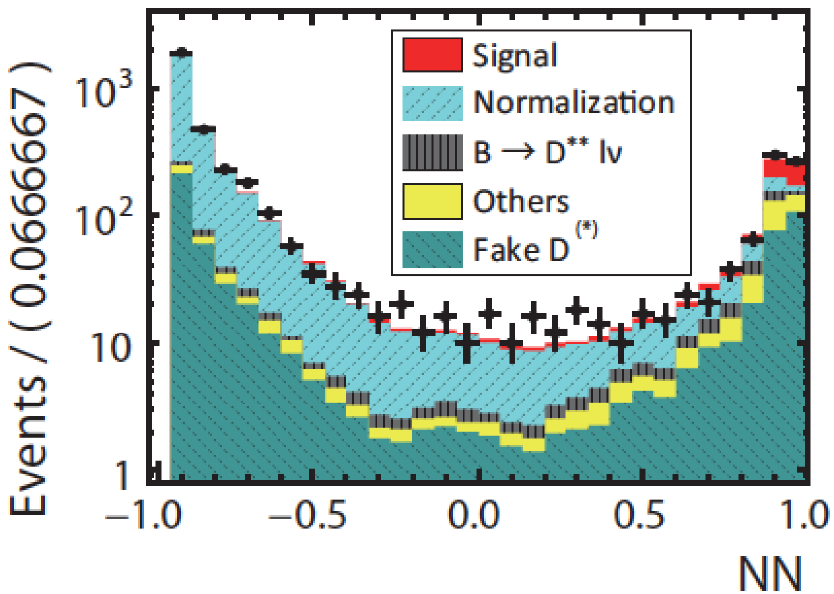
| | $R(D)$ | $R(D^*)$ |
|---|---|---|
| BaBar | $0.440 \pm 0.058 \pm 0.042$ | $0.332 \pm 0.024 \pm 0.018$ |
| Belle | $0.375^{+0.064}_{-0.063} \pm 0.026$ | $0.293^{+0.039}_{-0.037} \pm 0.015$ |
| LHCb | | $0.336 \pm 0.027 \pm 0.030$ |
| Average | $0.388 \pm 0.047$ | $0.321 \pm 0.021$ |
| SM expectation | $0.300 \pm 0.010$ | $0.252 \pm 0.005$ |
| Belle II, 50/ab | $\pm 0.010$ | $\pm 0.005$ |

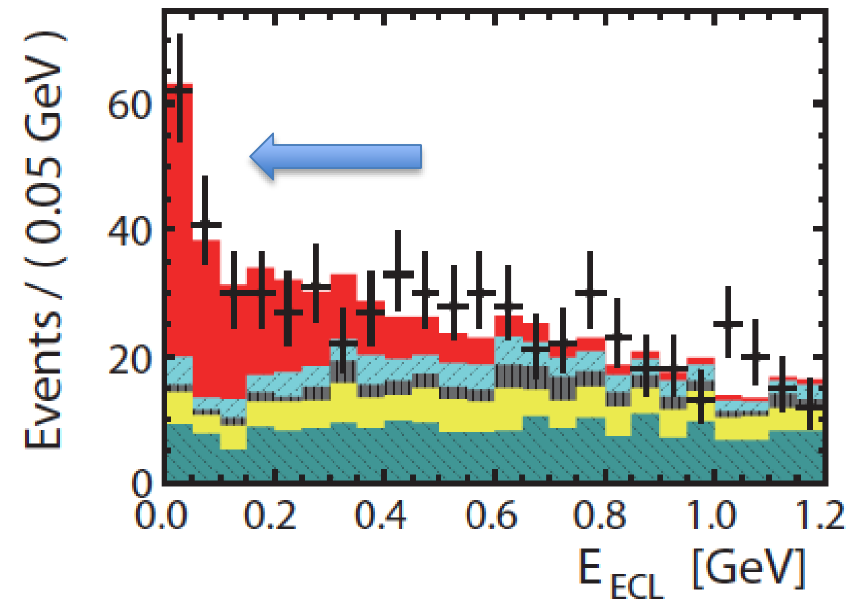
It is *obvious* that we <u>need two orders of magnitude of data</u> to solve these issues related to the <u>*charged Higgs*</u>.

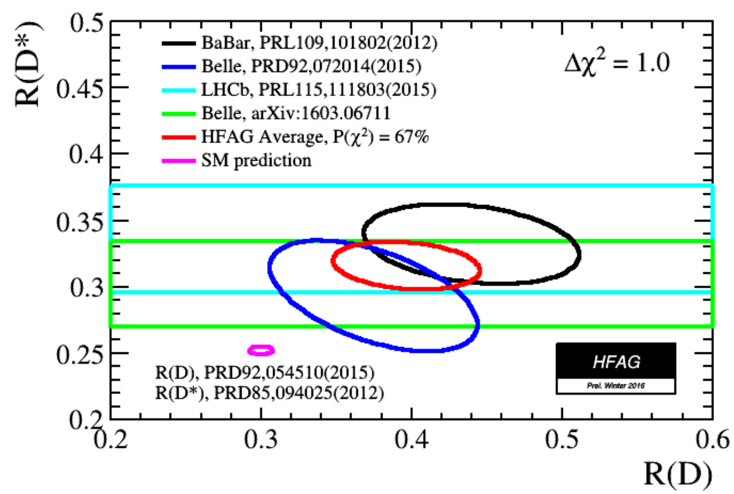
# One more Belle update, March 2016 (Moriond)

Uses semileptonic tagging

$$\mathcal{R}(D^*) = 0.302 \pm 0.030(\text{stat}) \pm 0.011(\text{syst}$$



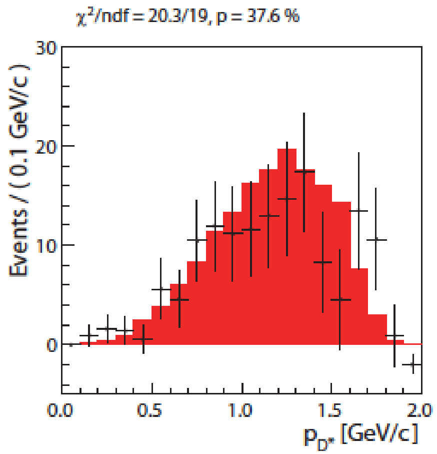

April 2016:
The WA is now
4.0σ from the SM

arXIv: 1603.06711

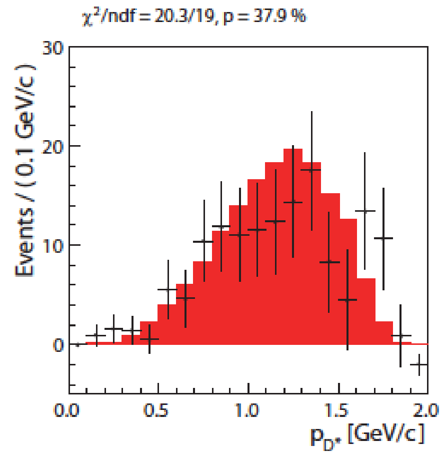
# Belle update, March 2016

http://arxiv.org/abs/1603.06711

Try to distinguish SM and charged Higgs in kinematic distributions.

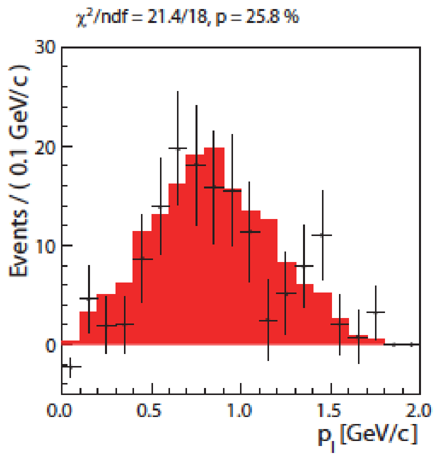



(a)SM.

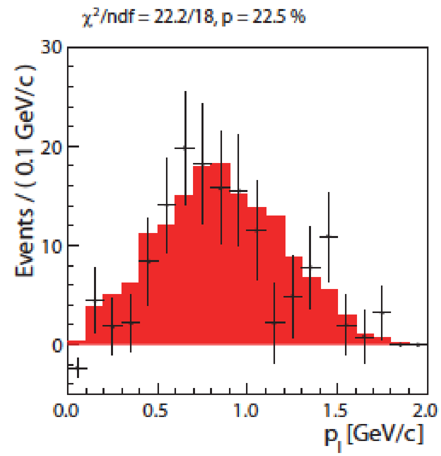



(b)Type II 2HDM with $\tan\beta/m_{H^+} = 0.7$ GeV$^{-1}$.

Both fit well.




(d)SM.




(e)Type II 2HDM with $\tan\beta/m_{H^+} = 0.7$ GeV$^{-1}$.

Parallel talk by M. Rozanska, SUSY2016

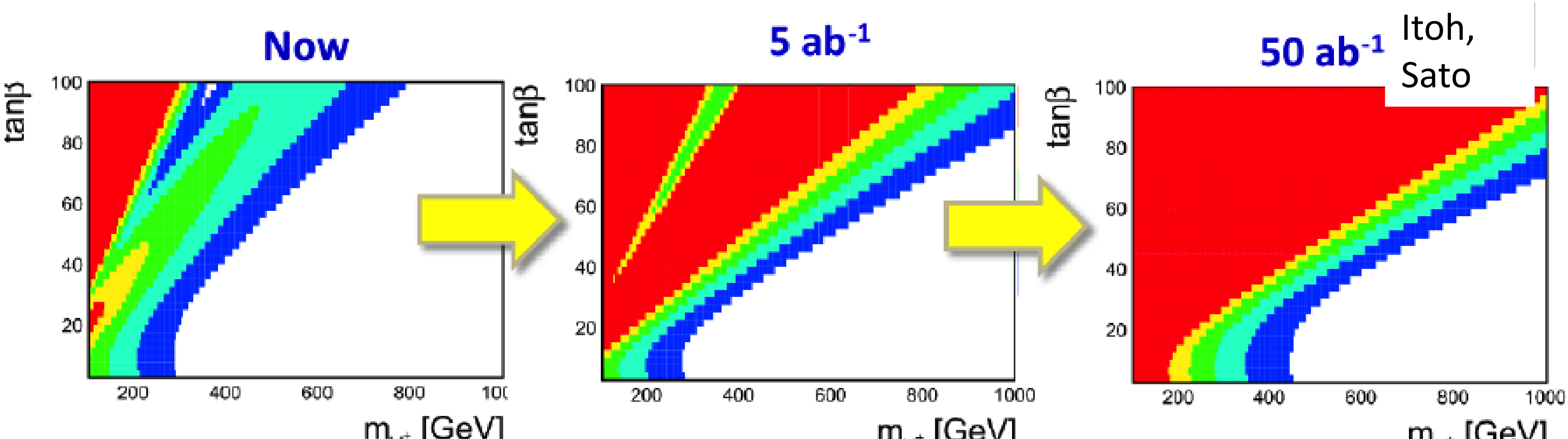
Can also constrain other types of NP couplings (e.g. leptoquarks) , *but need much more data*

Credit: Djouadi

Simple message from the world's flavor physicists:


With apologies to Herodotus, Thucydides, Sparta, Persia…

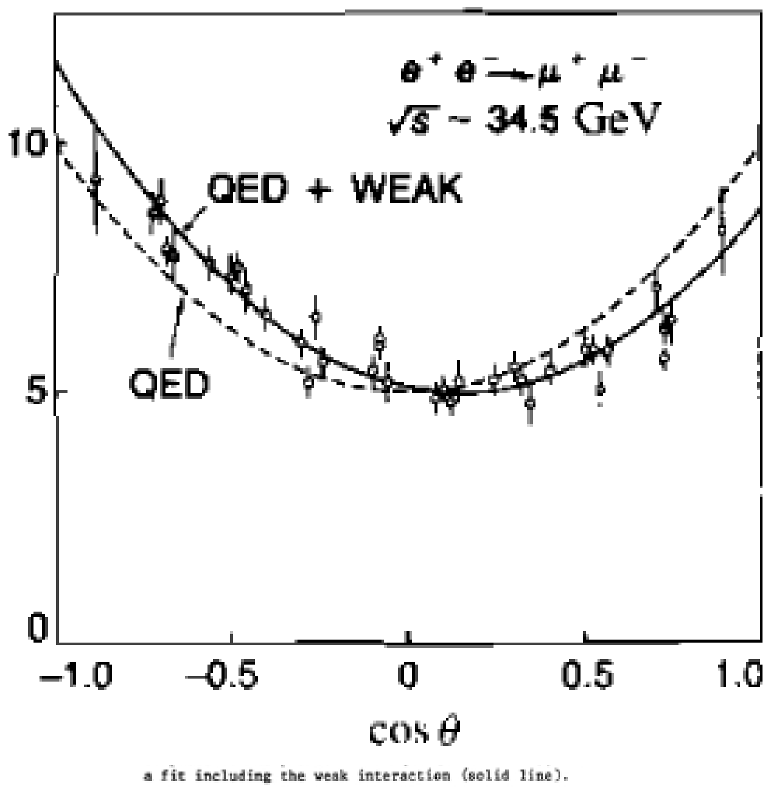
# Initial Belle II projections for charged Higgs sensitivity

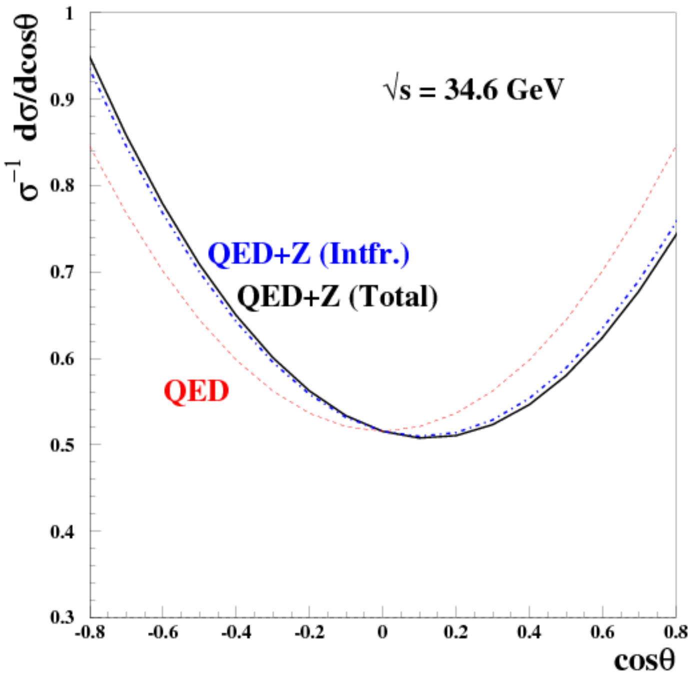


# Red Hot Flavor Physics

The stakes are getting higher

# *High Energy Physics History: finding NP in $A_{FB}$ (using interference)*

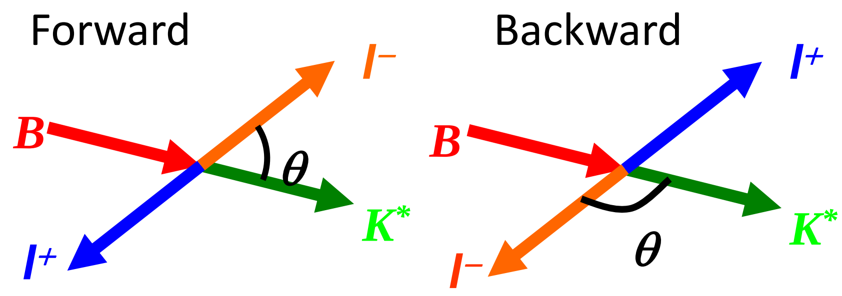



*Conclusion: There is a Z boson at higher energy even though colliders of the time did not have enough $\sqrt{s}$ to produce it*

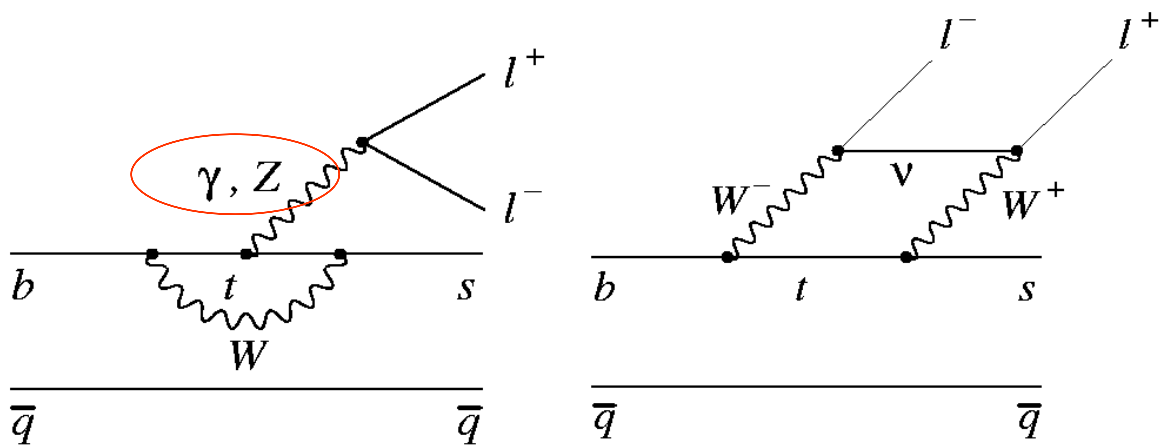
# $A_{FB}(B \rightarrow K^* l^+ l^-)(q^2)$

*The SM forward-backward asymmetry in $b \rightarrow s\, l^+\, l^-$ arises from the* ***interference*** *between $\gamma$ and $Z^0$ contributions.*



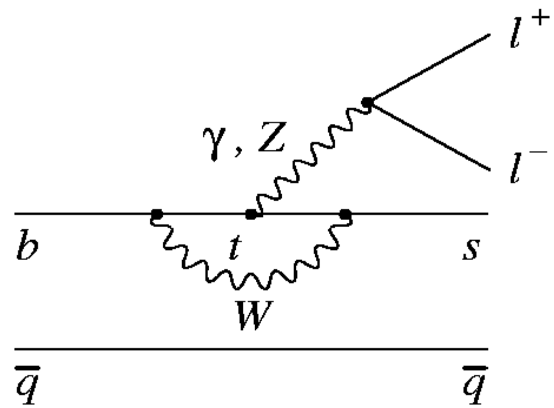

$$A_{FB}(B \to K^* \ell^+ \ell^-) = -C_{10}\xi(q^2)\left[Re(C_9)F_1 + \frac{1}{q^2}C_7 F_2\right]$$

Ali, Mannel, Morozumi, PLB273, 505 (1991)




Note that all the heavy particles of the SM (W, Z, top) enter in this decay.

# More on $A_{FB}(B \rightarrow K^* l^+ l^-)(q^2)$




Can in effect vary √s for NP

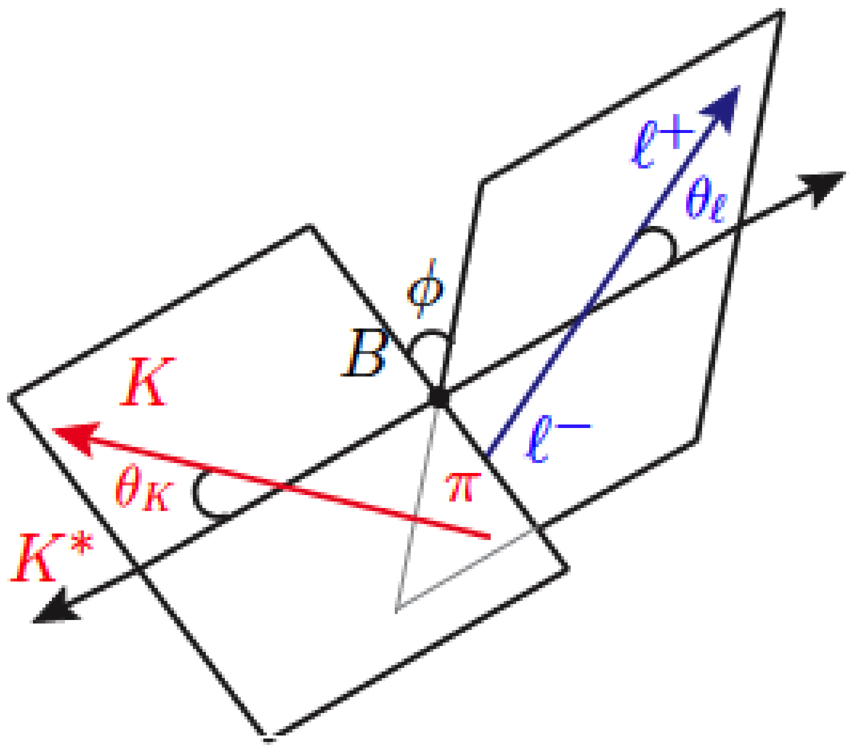
*$A_{FB}$ depends on $q^2 = M^2(l^+l^-)$*

$$A_{FB}(B \to K^* \ell^+ \ell^-) = -C_{10}\xi(q^2)\left[Re(C_9)F_1 + \frac{1}{q^2}C_7F_2\right]$$

Ali, Mannel, Morozumi, PLB273, 505 (1991)

The "zero-crossing" of $A_{FB}$ depends only on a ratio of form factors and is a *clean* observable.

# $B \to K^* l\, l$ angular variables (skip today)




$K^*$ and $l^+ l^-$ helicity angles

Angle ϕ between *the normals* to the two decay planes.

N.B. Recent LHCb measurements include ϕ angle data

From http://xxx.lanl.gov/pdf/1606.0091

# B→K*l⁺l⁻(q²) bootcamp (*for reference*)

## Angular dependence


$$\frac{1}{d(\Gamma+\bar{\Gamma})/dq^2}\frac{d^3(\Gamma+\bar{\Gamma})}{d\vec{\Omega}} =$$

$F_L$ is the longitudinal polarization fraction.

$$\frac{9}{32\pi}\left[\begin{array}{l}\frac{3}{4}(1-F_L)\sin^2\vartheta_K + F_L\cos^2\vartheta_K \\ +\frac{1}{4}(1-F_L)\sin^2\vartheta_K\cos 2\vartheta_L \\ -F_L\cos^2\vartheta_K\cos 2\vartheta_L + S_3\sin^2\vartheta_K\sin^2\vartheta_L\cos 2\phi \\ +S_4\sin 2\vartheta_K\sin 2\vartheta_L\cos\phi + \\ + \qquad + S_7\sin 2\vartheta_K\sin\vartheta_L\sin\phi \\ + \end{array}\right]$$

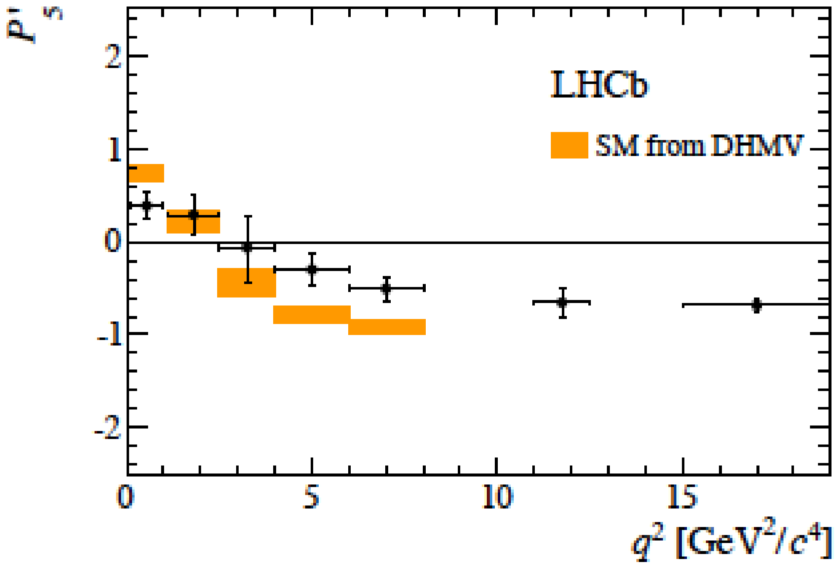
(-) means the term is only in G- $\bar{G}$

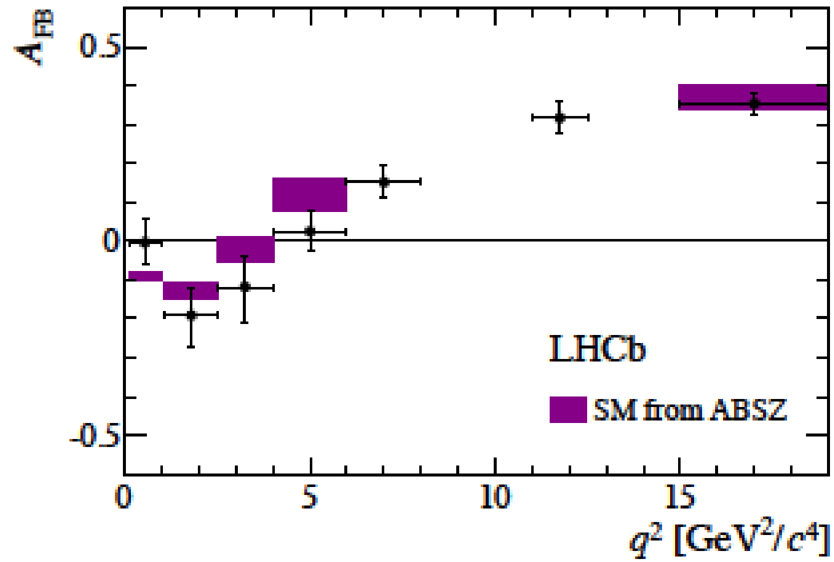
*Introduce $P'_{4,5} = S_{4,5}/\mathrm{sqrt}[F_L(1-F_L)]$ to reduce/eliminate dependence on form factors*

Thanks to Rahul Sinha

# *LHCb 3fb$^{-1}$ results on $B \rightarrow K^{*} \mu^{+}\mu^{-} (q^2)$*

Angular Asymmetries based on 2398±57 signal events




"The $P_5'$ measurements are only compatible with the SM prediction at a level of 3.7σ…..A mild tension can also be seen in the $A_{FB}$ distribution, where the measurements are systematically <=1σ below the SM prediction in the region $1.1<q^2< 6.0$ GeV$^2$"

Blank regions are the J/ψ and ψ′ vetos

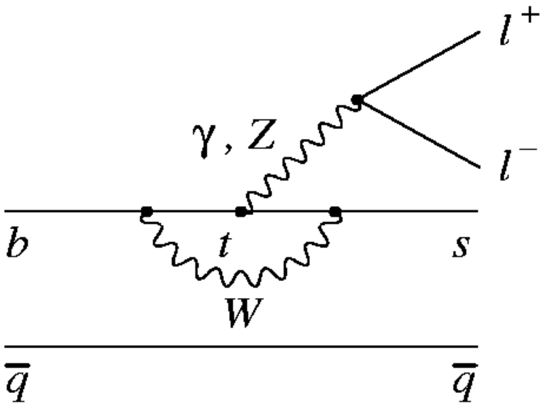
Theory from http://arxiv.org/abs/1510.04329

R. Aaij et al., JHEP 1602, 104 (2016)

# *Recent LHCb results on $B \rightarrow K^* \mu^+ \mu^-$ (q$^2$)*

*<u>Is HEP History repeating itself</u>* ? *[But be sure this is not a tricky SM form factor effect.]*

Why does NP appear first in this mode (and not others) ?




Possible answer: All the heavy particles of the SM (t, W, Z) and maybe NP (except the Higgs) appear here. Sensitive to NP via interference (<u>linear effects and many types of couplings</u>).

# NP could mean "new particles" (bump in some mass spectrum a the LHC) or "new couplings" (flavor physics)

*We would be happy to break the Standard Model.*

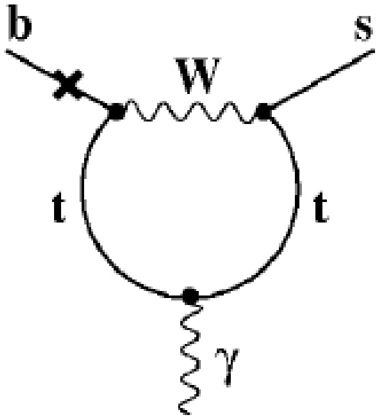
Places where we might find New couplings

$$b \to s\gamma(^*) : \mathcal{H}_{\Delta F=1}^{SM} \propto \sum_{i=1}^{10} V_{ts}^* V_{tb} C_i Q_i + \ldots$$

$$Q_7 = \frac{e}{g^2} m_b \, \bar{s}\sigma^{\mu\nu}(1+\gamma_5)F_{\mu\nu}\, b \quad \text{[real or soft photon]}$$

$$Q_9 = \frac{e^2}{g^2} \bar{s}\gamma_\mu(1-\gamma_5)b \, \bar{\ell}\gamma_\mu \ell \quad [b \to s\mu\mu \text{ via } Z\text{/hard } \gamma]$$

$$Q_{10} = \frac{e^2}{g^2} \bar{s}\gamma_\mu(1-\gamma_5)b \, \bar{\ell}\gamma_\mu\gamma_5 \ell \quad [b \to s\mu\mu \text{ via } Z]$$



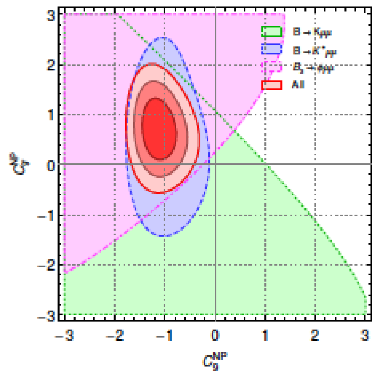

Right-handed currents: $1-\gamma_5 \rightarrow 1+\gamma_5$

# A recent example of NP Fits to B→s l l data

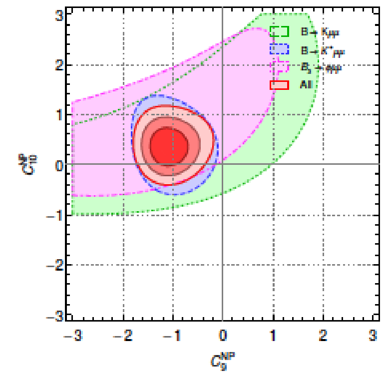
| | | $C_7^{NP}$ | $C_9^{NP}$ | $C_{10}^{NP}$ | $C_{7'}^{NP}$ | $C_{9'}^{NP}$ | $C_{10'}^{NP}$ |
|---|---|---|---|---|---|---|---|
| $C_9^{NP}$ | 4.47 | 0.07 | * | 1.54 | 0.92 | 2.00 | 1.89 |

L. Hofer et al., Moriond March 2016

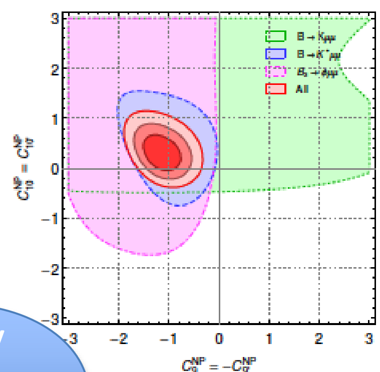
| $(C_9^{NP}, C_{9'}^{NP})$ |
|---|
| $(-1.12, 0.77)$ |
| 4.5 |



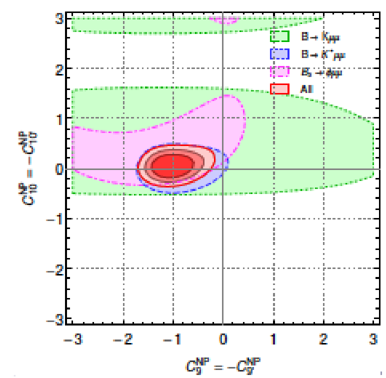
| $(C_9^{NP}, C_{10}^{NP})$ |
|---|
| $(-1.08, 0.33)$ |
| 4.3 |



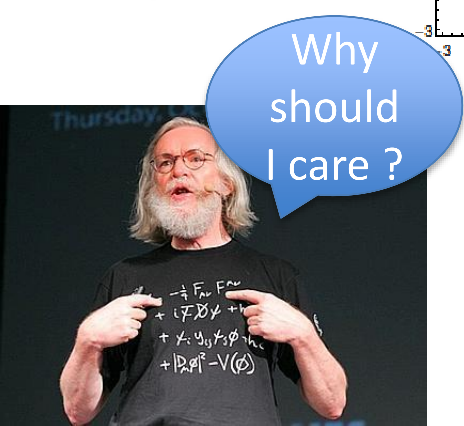
| $(C_9^{NP} = -C_{9'}^{NP}, C_{10}^{NP} = C_{10'}^{NP})$ |
|---|
| $(-1.15, 0.34)$ |
| 4.7 |



| $(C_9^{NP} = -C_{9'}^{NP}, C_{10}^{NP} = -C_{10'}^{NP})$ |
|---|
| $(-1.06, 0.06)$ |
| 4.4 |



Fits use LCSR at low $q^2$ and lattice form factors at high $q^2$ and all data on b→s l l




These plots *mean* there are NP coupling(s) in the weak interaction

# *Theory issues on B→K$^*$ $\mu^+\mu^-$ ($q^2$)*

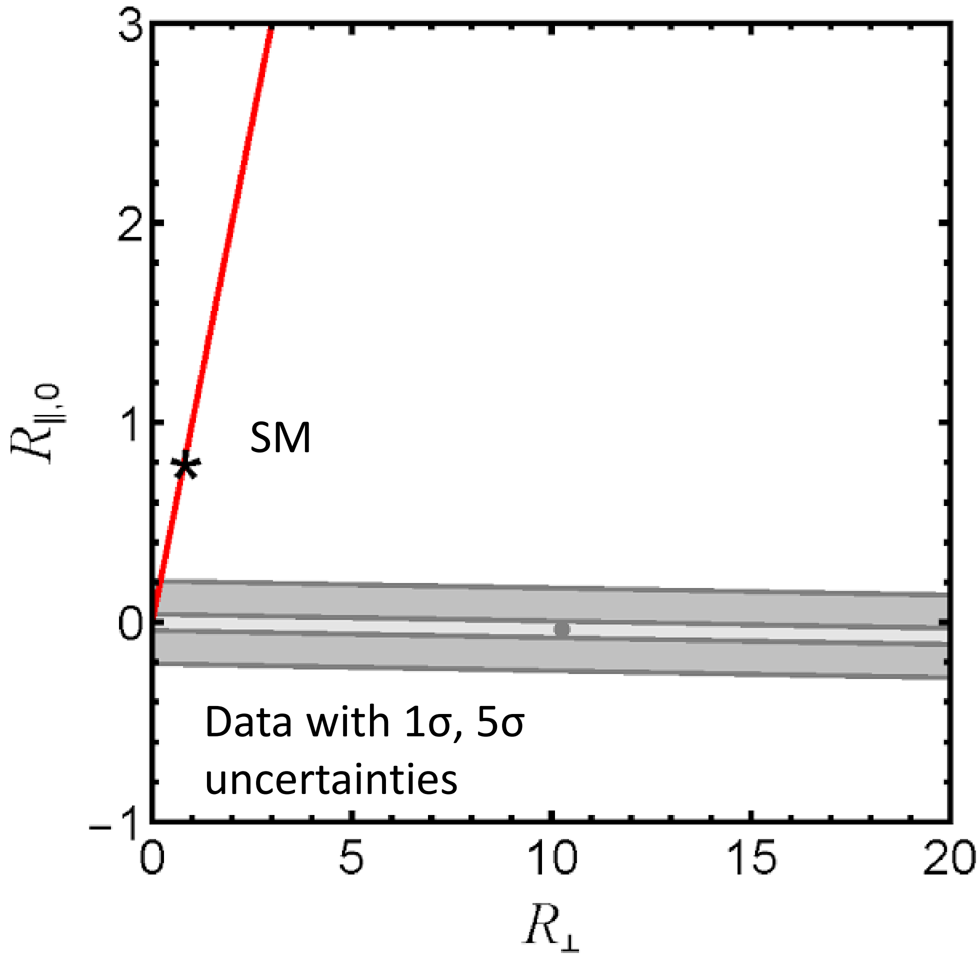
➔Check dependence on light-cone form factors (some checks already done by Lattice QCD groups)

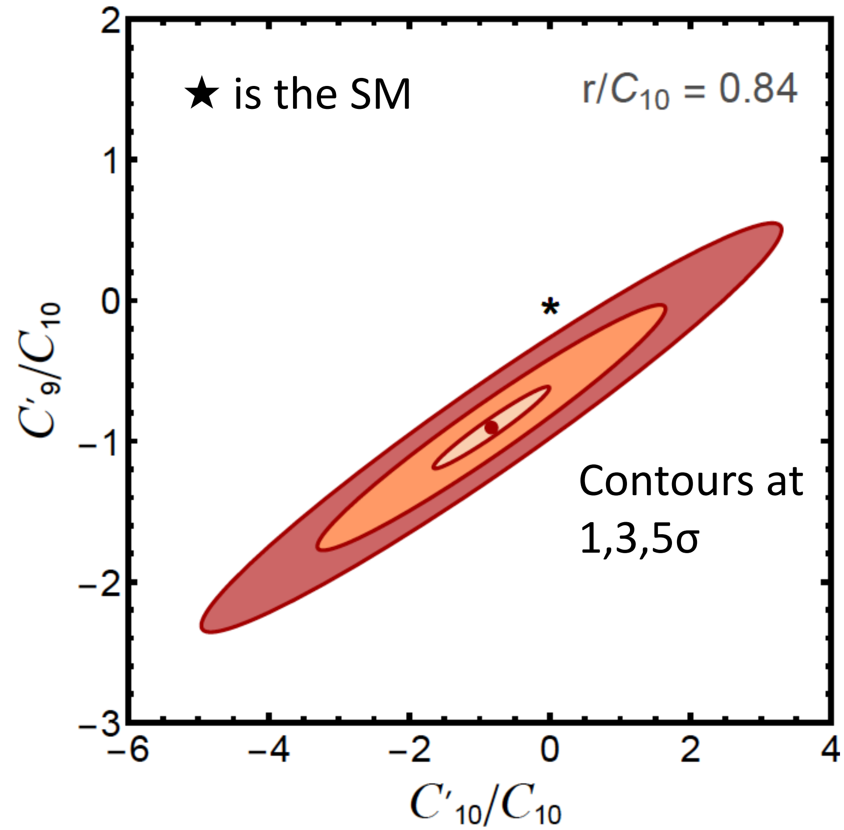
Major concern


➔Can tails of large B→K* [c-cbar] or *non-factorizable effects* produce the anomalies found in the angular distributions ? (If all non-perturbative effects float with arbitrary normalization in the fit then the data can explained, http://lanl.arxiv.org/abs/1512.07157)

→ Use data near $q^2 = q^2_{max}$ (K* at rest), where symmetry works (Heavy Quark Effective Theory) and constrains ratio of polarizations (no hadronic corrections)➔<u>Still find NP</u>

# Fit LHCb finely binned angular data at $q^2_{max}$ (HQET limit)




*5σ signal for NP, requires right-handed currents*

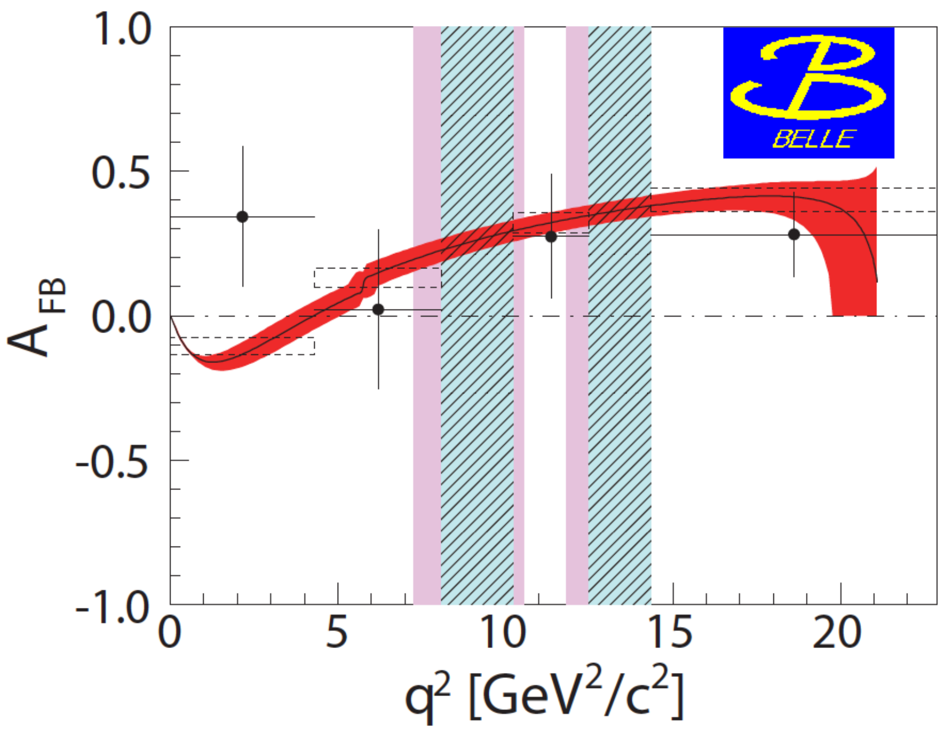
A. Karan et al. (arXiv: 1603.04355) [R.Sinha group]

Still confirmation and more data is needed to close the case for NP

# Paths to the future: $A_{FB}(q^2)$ for Inclusive $b \to s\, l^+ l^-$

(Skip if time is short)

~301 $b \to s\, l^+l^-$ signal events in Belle data sample




*No form factors*

Precise result useful for NP diagnosis but ***Belle II only*** (see http://arxiv.org/abs/1503.04849)

http://arxiv.org/abs/1402.7134

To appear in PRD.

TABLE II. Fit results for the four $q^2$ bins. For $\mathcal{A}_{\rm FB}$, the first uncertainty is statistical and the second uncertainty is systematic. $\mathcal{A}_{\rm FB}$ values predicted by the SM [4, 7] are also shown with systematic uncertainties. For the signal yields, only statistical uncertainties are shown. The uncertainties of $\alpha$ and $\beta$ are due to the statistical uncertainties of the MC.

| | 1st bin | 2nd bin | 3rd bin | 4th bin |
|---|---|---|---|---|
| $q^2$ range [GeV$^2/c^2$] $(B \to X_s e^+ e^-)$ $(B \to X_s \mu^+ \mu^-)$ | [0.2,4.3] | [4.3,7.3] [4.3,8.1] | [10.5,11.8] [10.2,12.5] | [14.3, 25.0] |
| $\mathcal{A}_{\rm FB}$ | $0.34 \pm 0.24 \pm 0.02$ | $0.04 \pm 0.31 \pm 0.05$ | $0.28 \pm 0.21 \pm 0.01$ | $0.28 \pm 0.15 \pm 0.01$ |
| $\mathcal{A}_{\rm FB}$ (theory) | $-0.11 \pm 0.03$ | $0.13 \pm 0.03$ | $0.32 \pm 0.04$ | $0.40 \pm 0.04$ |
| $N^{ee}_{\rm sig}$ | $45.6 \pm 10.9$ | $30.0 \pm 9.2$ | $25.0 \pm 7.0$ | $39.2 \pm 9.6$ |
| $N^{\mu\mu}_{\rm sig}$ | $43.4 \pm 9.2$ | $23.9 \pm 10.4$ | $30.7 \pm 9.9$ | $62.8 \pm 10.4$ |
| $\alpha^{ee}$ | $1.289 \pm 0.004$ | $1.139 \pm 0.003$ | $1.063 \pm 0.003$ | $1.121 \pm 0.003$ |
| $\alpha^{\mu\mu}$ | $2.082 \pm 0.010$ | $1.375 \pm 0.003$ | $1.033 \pm 0.003$ | $1.082 \pm 0.003$ |
| $\beta$ | 1.000 | $1.019 \pm 0.003$ | $1.003 \pm 0.000$ | 1.000 |

TABLE I: Projections for the statistical uncertainties on the $B \to K^{(*)} \nu \bar{\nu}$ branching fractions.

| Mode | $\mathcal{B}$ $[10^{-6}]$ | Efficiency Belle $[10^{-4}]$ | $N_{\text{Backg.}}$ 711 $\text{fb}^{-1}$ Belle | $N_{\text{Sig-exp.}}$ 711 $\text{fb}^{-1}$ Belle | $N_{\text{Backg.}}$ 50 $\text{ab}^{-1}$ Belle II | $N_{\text{Sig-exp.}}$ 50 $\text{ab}^{-1}$ Belle II | Statistical error 50 $\text{ab}^{-1}$ | Total Error |
|---|---|---|---|---|---|---|---|---|
| $B^+ \to K^+ \nu \bar{\nu}$ | 3.98 | 5.68 | 21 | 3.5 | 2960 | 245 | 23% | 24% |
| $B^0 \to K^0_S \nu \bar{\nu}$ | 1.85 | 0.84 | 4 | 0.24 | 560 | 22 | 110% | 110% |
| $B^+ \to K^{*+} \nu \bar{\nu}$ | 9.91 | 1.47 | 7 | 2.2 | 985 | 158 | 21% | 22% |
| $B^0 \to K^{*0} \nu \bar{\nu}$ | 9.19 | 1.44 | 5 | 2.0 | 704 | 143 | 20% | 22% |
| $B \to K^* \nu \bar{\nu}$ combined | | | | | | | 15% | 17% |

Ans: Verify hint of lepton universality breakdown at Belle II (good electron eff and mass resolution)

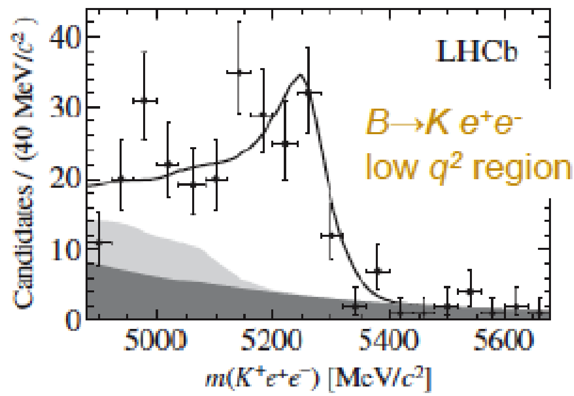
Control region gives $R_K$ consistent with unity. Interesting, low $q^2$ region gives:

$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

which is 2.6σ from unity, 3σ if BaBar included.

R. Aaij et al. (LHCb collab); PRL 113, 151601 (2014)

According to http://xxx.lanl.gov/abs/1605.07633, no significant SM radiative corrections

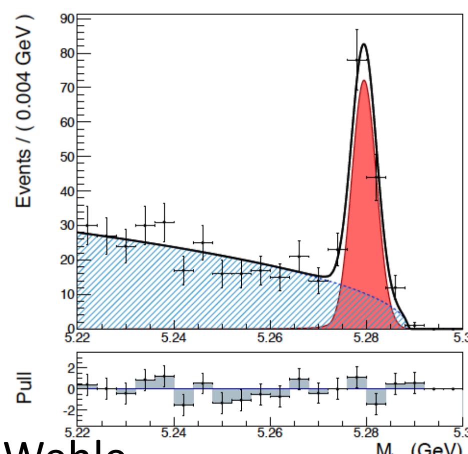


# “We need more data !!”

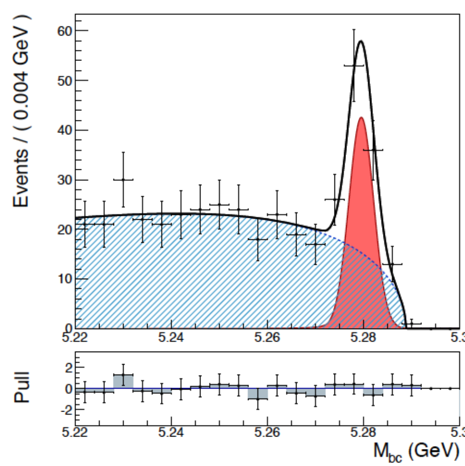
Apologies to Director Akira Kurosawa

*To find out whether there are NP couplings in the weak interaction*

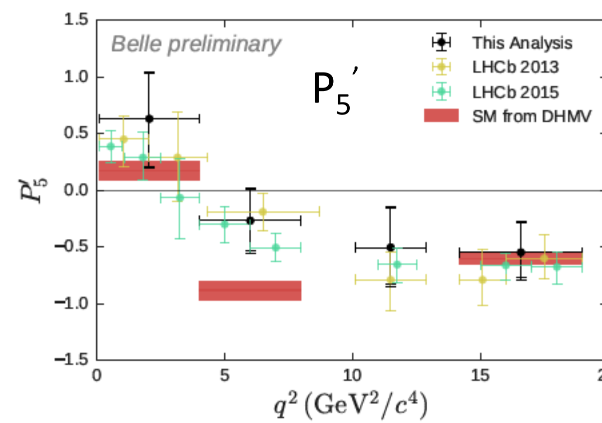
Signal of
~187 events



(a) $B^0 \to K^*(892)^0\mu^+\mu^-$

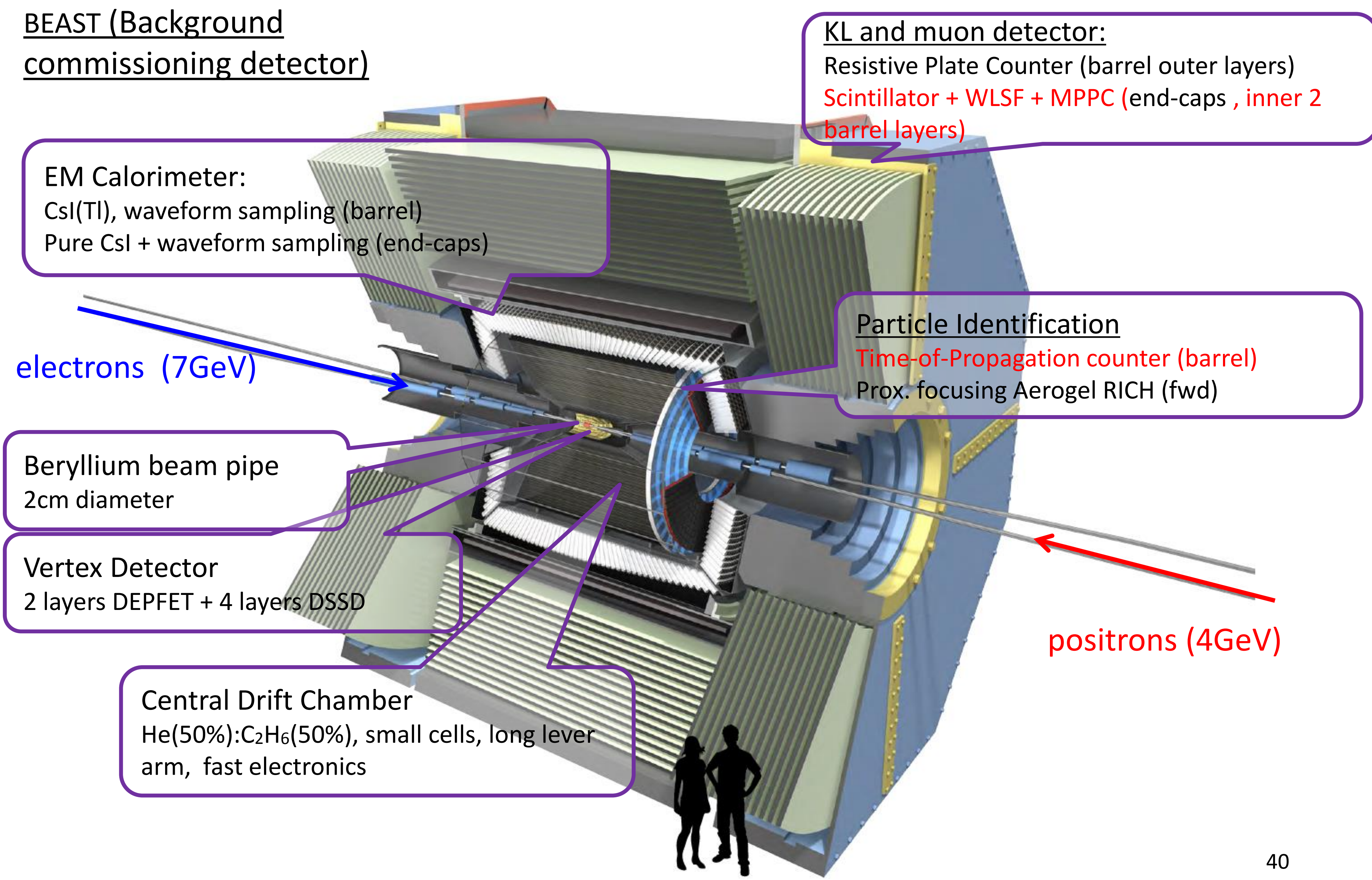


(b) $B^0 \to K^*(892)^0e^+e^-$



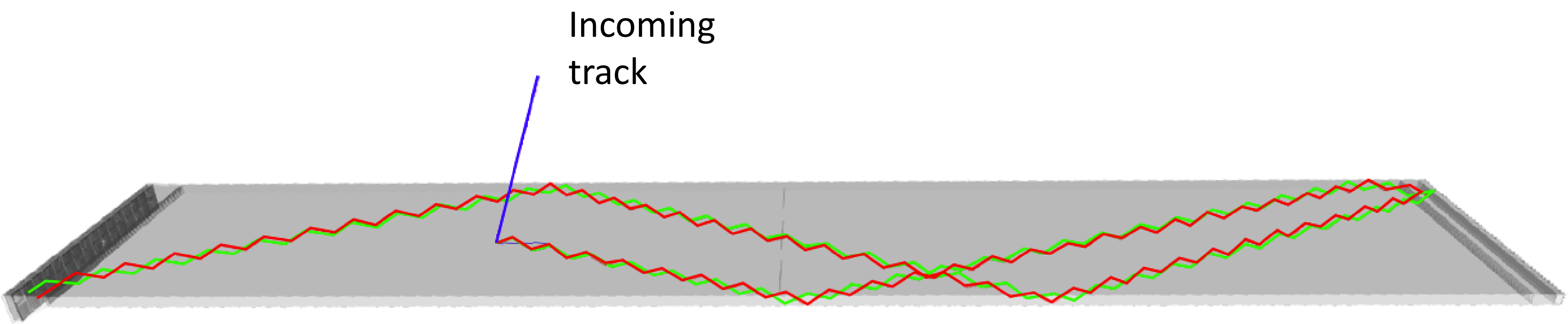

Belle I data S. Wehle,
DESY, arXiv: 1604.04042

# Belle II Detector

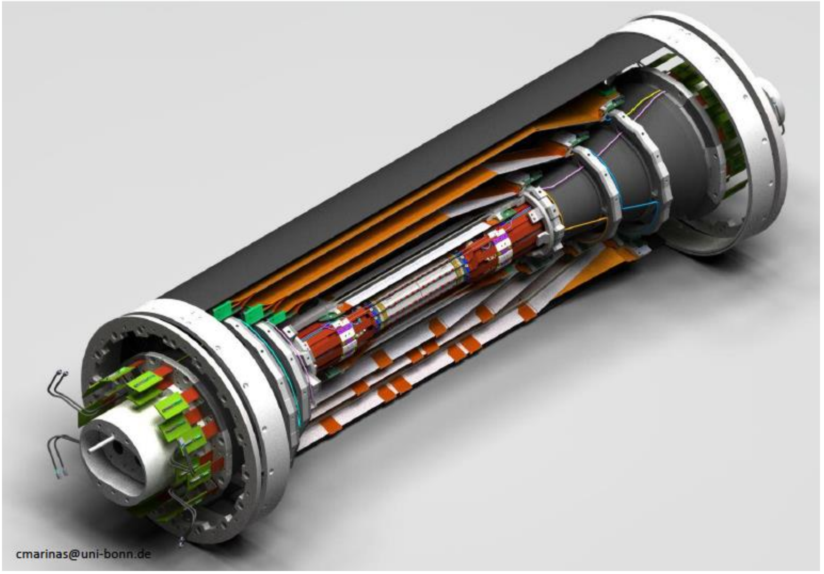


# Barrel Particle Identification

A GEANT4 event display of a 2 GeV pion and kaon interacting in a TOP [time of propagation] quartz bar. (Japan, US, Slovenia, Italy)




# Vertexing/Inner Tracking




Beampipe r= 10 mm

DEPFET pixels (Germany, Czech Republic, Spain…)

- Layer 1 r=14 mm
- Layer 2 r= 22 mm

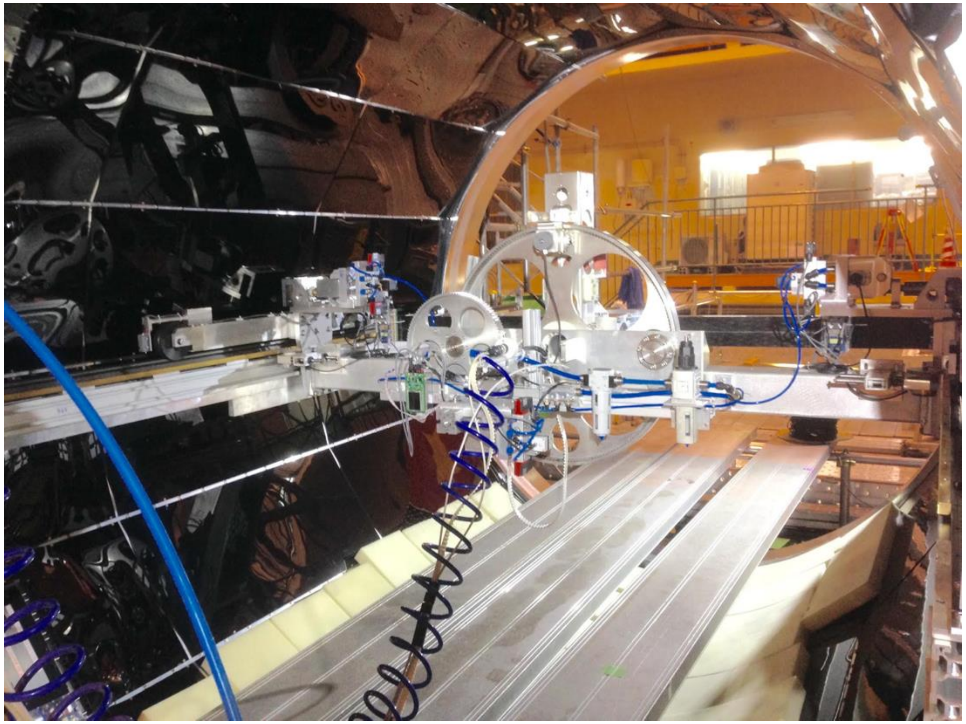
DSSD (double sided silicon detectors)

- Layer 3 r=38 mm (Australia)
- Layer 4 r=80 mm (India)
- Layer 5 r=115 mm (Austria)
- Layer 6 r=140 mm (Japan)

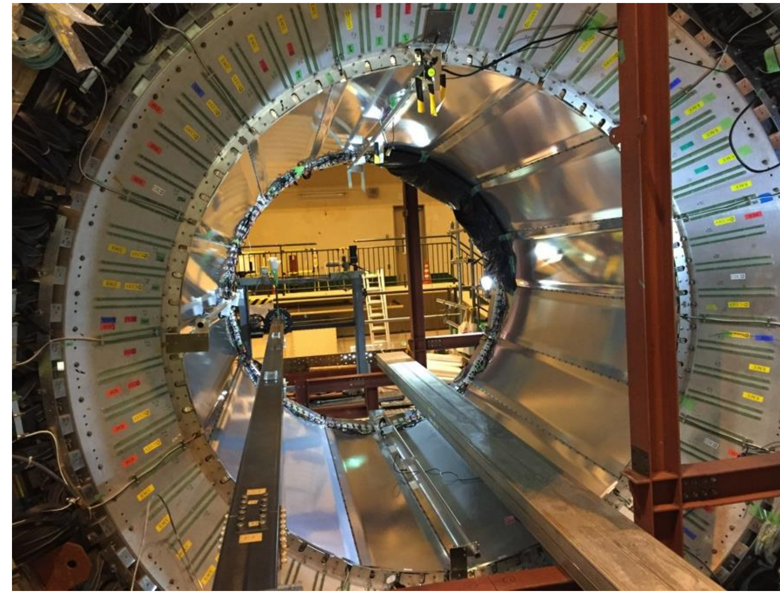
FWD/BWD Italy

+Poland (software), Korea

# Outer detector at Tsukuba Hall



June 2016: Precision field mapper inside Belle II

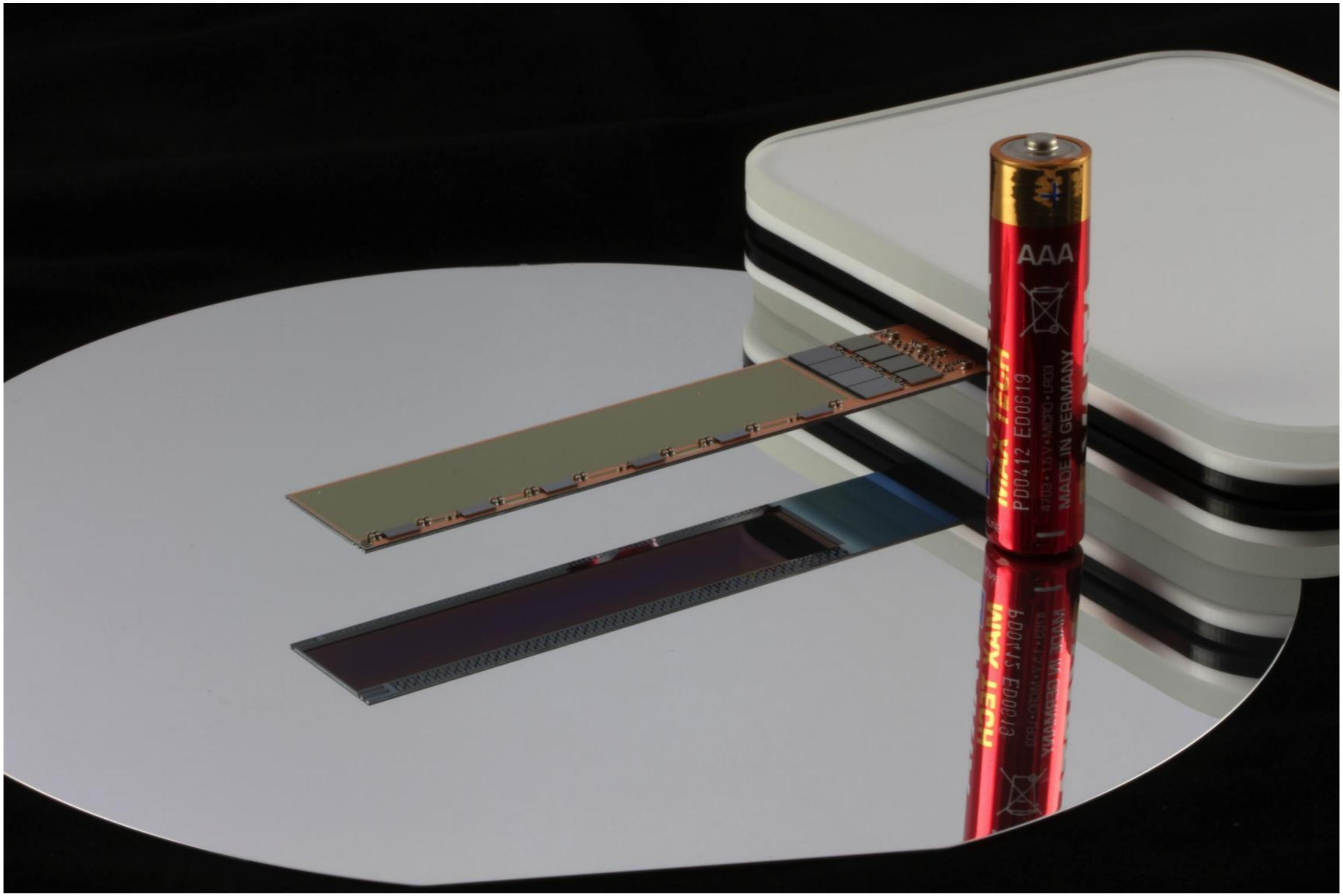


May 2016:TOP in Belle II structure

CDC (Central Drift Chamber)

Status: May 20, 2016 all 16 TOP modules were installed into the Belle II structure. Magnetic field mapping on-going then CDC installation in 2nd half of August.

# “Full sized” pixel detector module 0

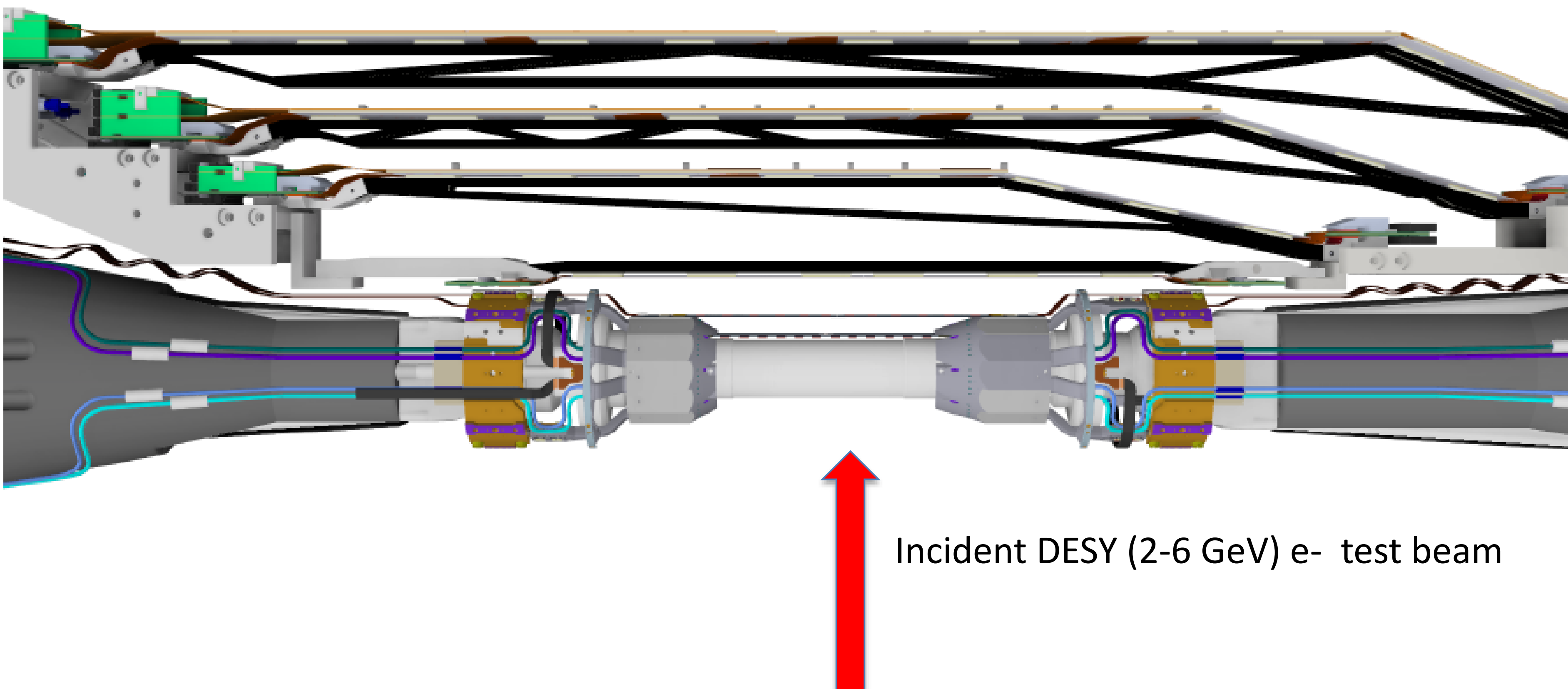



<u>75 µm thick,</u> minimize Multiple Scattering

Pixel detector group from many institutes and universities in Germany, also Czech Republic and Spain.

# April 2016: Belle II VXD beam test at DESY

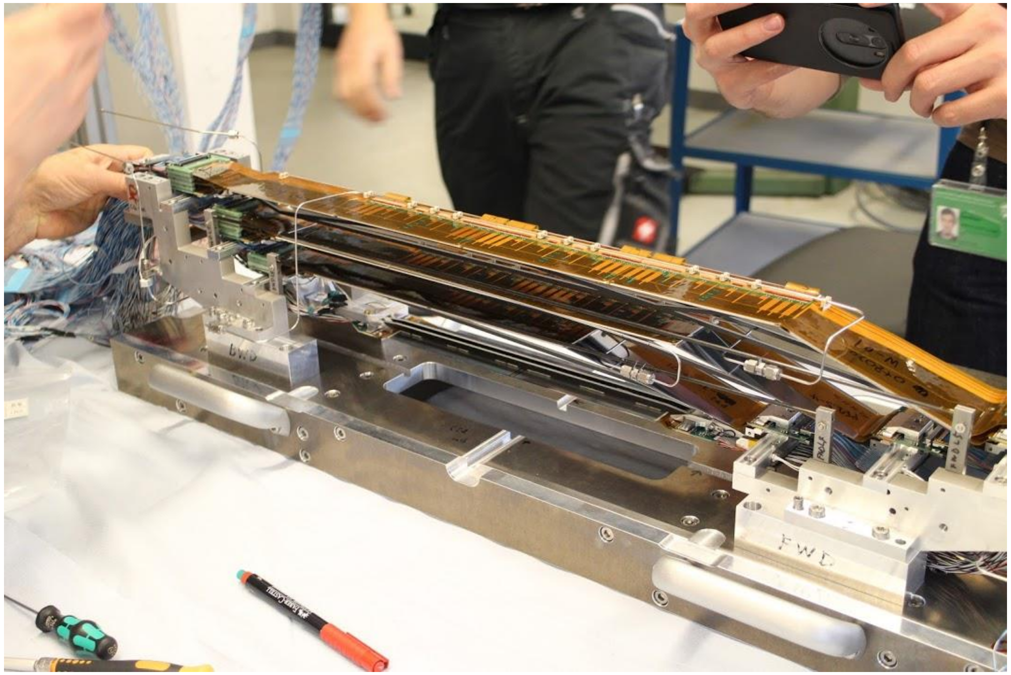
(DESY provides the infrastructure and facilities for this critical beam test)



# April 2016: Two *full-sized* Belle II DEPFET pixel detector Modules with 4 SVD ladders at DESY.
# (readout full VXD system with beam)

Test full-sized PXD modules in a beam.
[Checked efficiency and S/N].

Working examples of L3, L4, L5, L6 SVD ladders



Test the integrated PXD-SVD system. This includes ROI (region of interest) extrapolation from the SVD tracker to the PXD, which is needed to reduce the *large data volume*.

# Some Belle II jargon

*<u>BEAST PHASE I</u>*: Simple background commissioning detector (diodes, diamonds TPCs, crystals…). No final focus. Only *single* beam background studies possible [started in Feb 2016 and completed in June 2016].


*<u>BEAST PHASE II</u>*: More elaborate inner background commissioning detector. <u>Full Belle II outer detector</u>. Full superconducting final focus. *No vertex detectors. Collisions !*

# *HEP world: So when do we start Belle II ?*

BEAST PHASE I: Feb-June 2016 (Belle II roll-in at the end of the year).

BEAST PHASE II: Starts in Dec 2017 [damping ring commissioning; First collisions; limited physics without vertex detectors]

QCSL at KEK, Dec 2015

Belle II Physics Running: late Fall 2018 [vertex detectors in]

QCSR will be at KEK, Nov 2016

# Conclusions

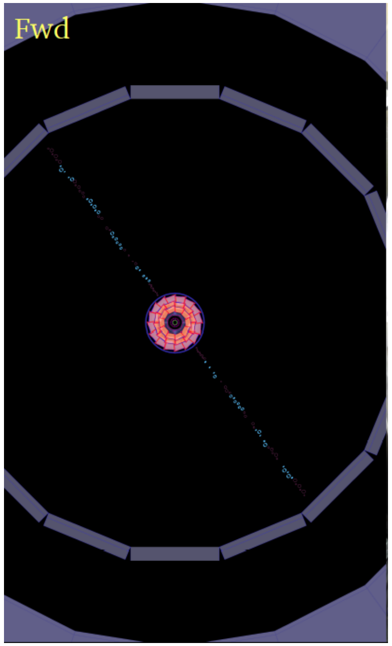
- Flavor physics is exciting and fundamental. *Did we just find NP via new weak interaction couplings ?*
- *Flavor could be the path for the future of HEP but we need much more data.*
- *Time for a Paradigm Shift ?*

*SuperKEKB Phase I commissioning Feb-June, 2016. Belle II rolls in at the end of the year. First collisions in fall 2017. Belle II physics runs in 2018 [and the LHCb upgrade in ~2021]. These facilities will inaugurate a new era of flavor physics and the study of CP violation.*

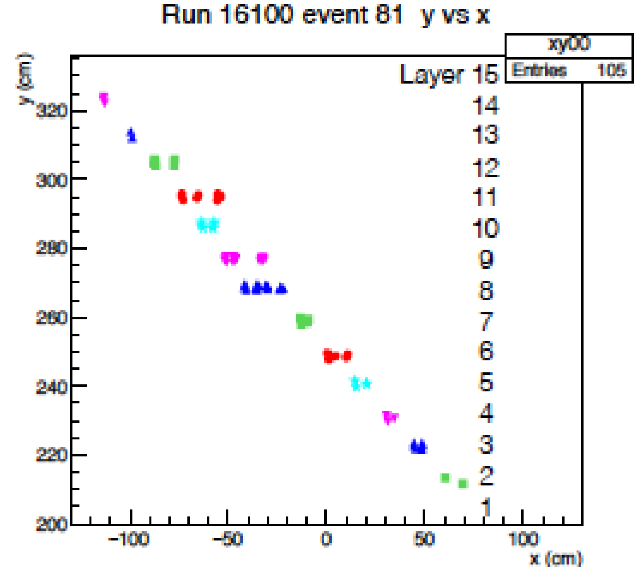
# Backup slides

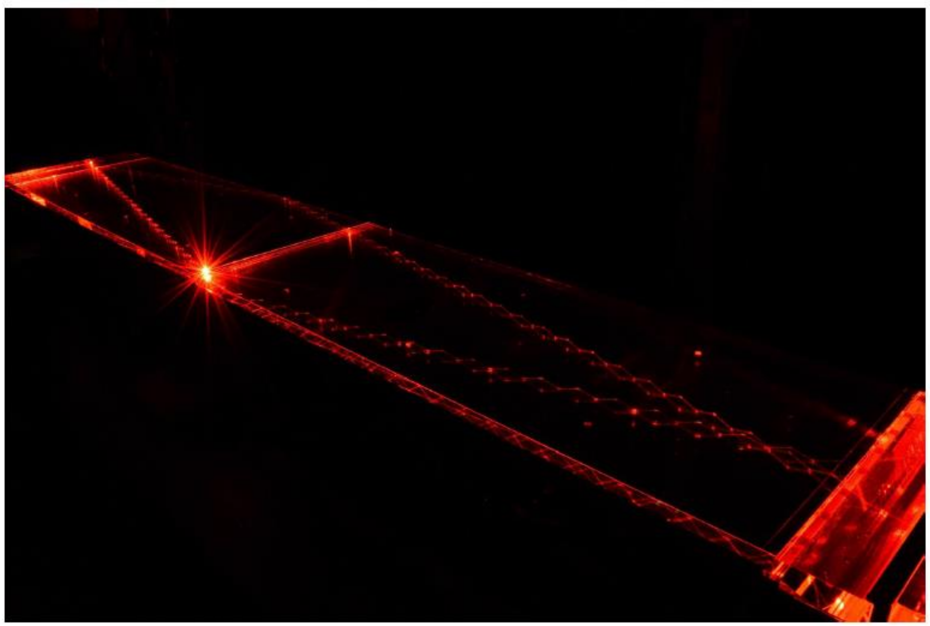
Australian Belle II Silicon Vertex Detector Construction Team

Cosmic ray in the partially instrumented CDC tracker

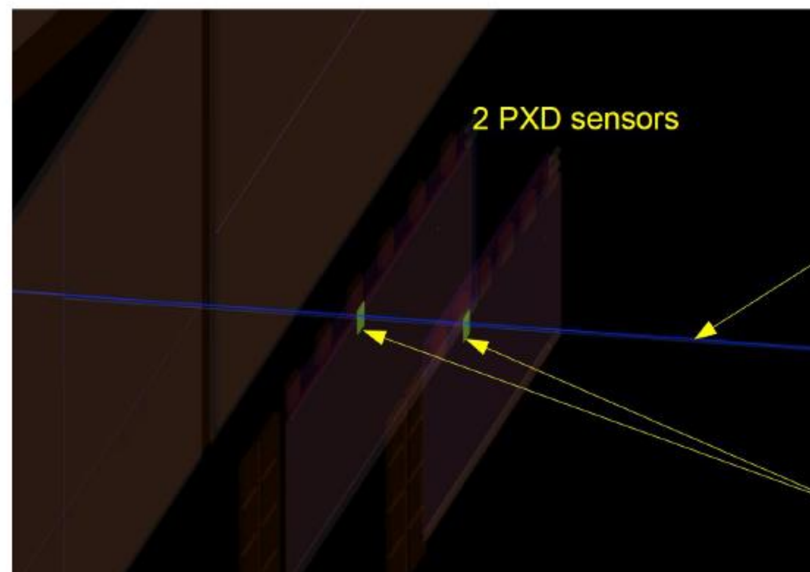



Cosmic ray muon in the partially instrumented barrel KLM RPC system



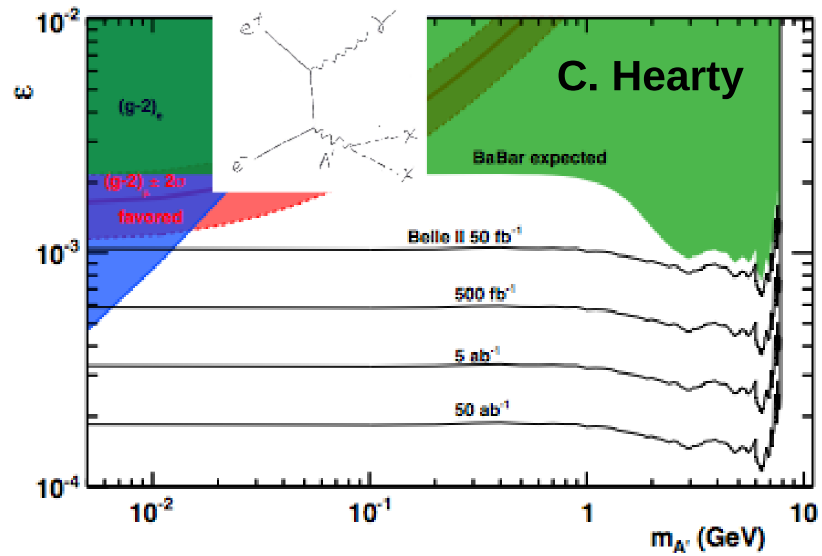
Total internal reflection of laser light in a TOP module

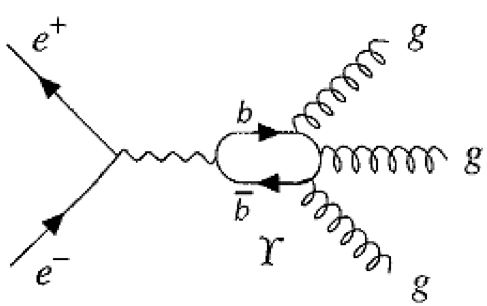



Matched PXD hits from a projected SVD track in the DESY $e^-$ test beam

# Beast Phase II & New Triggers

- Update to First-physics report: [BELLE2-NOTE-PH-2015-003]() Υ(2S), Υ(3S), Υ(6S), Scan proposals
- Beast Phase II Physics Task Force formed to study physics with this configuration (B. Fulsom).
- Belle Υ(1S) decay data used for Pythia 8 MC tuning in Belle II (U. Tamponi).



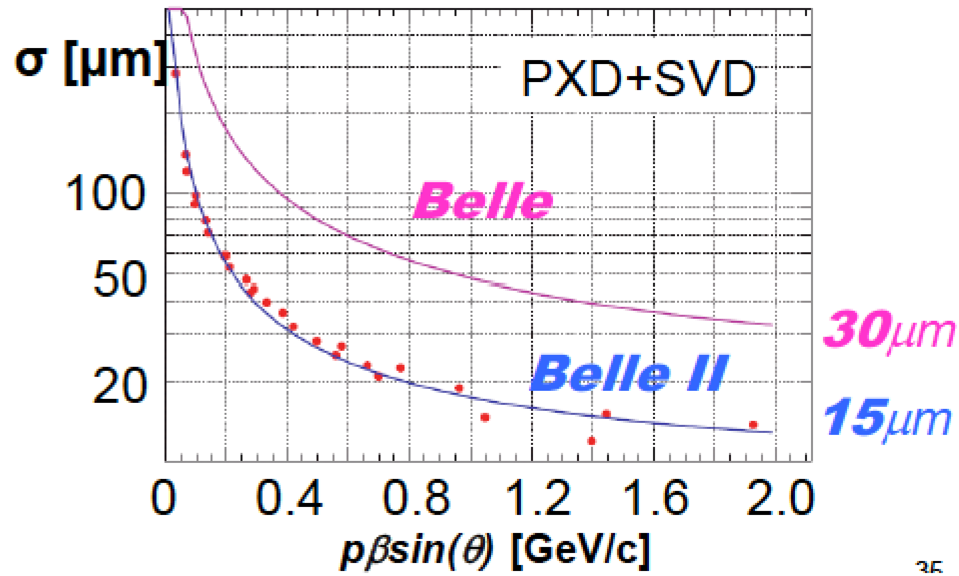




| Triggers | | Some Ideas C-H. Li |
|---|---|---|
| Single Photon (γ) | | • Cascade: different thresholds with separate pre-scale factors<br>• Use different pre-scale factors for Barrel and Endcap |
| $e^+e^-$ | | • two Bhabha triggers, "accept" and "veto"<br>• "accept" : flattening scheme<br>• "veto": 2D→3D ECL Bhabha is being investigated<br>• salvage: retain a pre-scaled sample of physics triggers without veto |
| $\mu^+\mu^-$ | | • independent CDC and KLM triggers for luminosity systematics |
| $\gamma\gamma$ | | • reduce pre-scale to 10 instead of 100 |
| γ+ 2 trks | $\gamma e^+e^-$ [hlt] | • dedicated triggers for calibration (CDC,ECL) |
| | $\gamma\mu^+\mu^-$ | • dedicated triggers for detectors study (CDC, ECL, KLM) |
| | $\gamma h^+h^-$ | • high efficiency for all γ energies and $h^+h^-$ invariant masses<br>• one high energy cluster in ECL, one track in opposite hemisphere |
| Additional trigger information | | • CDC-TOP-ECL-KLM Matching<br>• More detectors information…… |

- HLT & L1 Trigger Menu under design. Evolving [Trigger Menu (Link)]().

In $e^+ e^-$ scattering at 10-11 GeV, a *critical issue* for vertexing is multiple scattering.

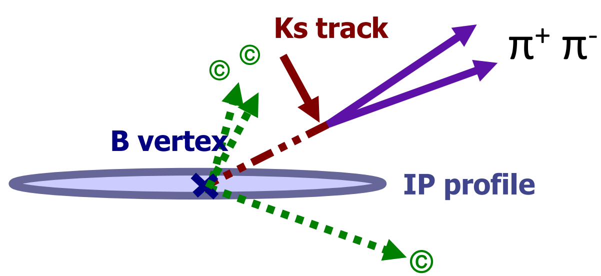
Reduce the multiple scattering lever arm; reduce $X_0$ (to preserve intrinsic resolution)

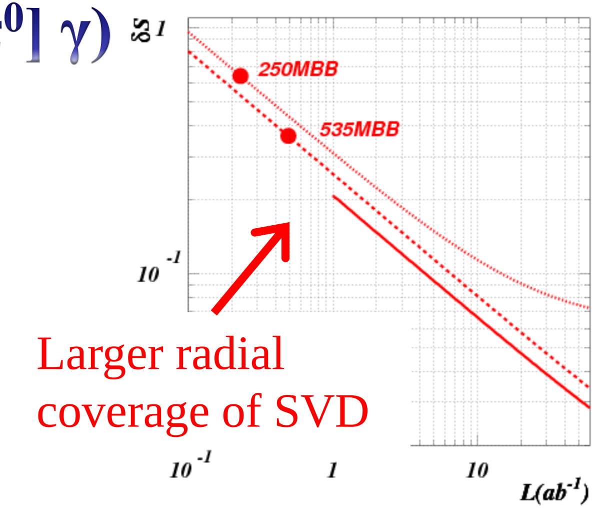



Belle: r(beampipe) 2 cm→1.5 cm
Belle II: r(beampipe) 1cm

Improved resolution and nano-beams will open new possibilities for vertex analysis

## Large improvement in $\Delta S(B \rightarrow [K_S \pi^0] \gamma)$




B decay point reconstruction from the $K_S$ vertex, used in searches for *NP right handed currents*.

# Consumer's guide to charged Higgs

- *Higgs doublet of type I* ($\phi_1$ couples to upper (u-type) and lower (d-type) generations. No fermions couple to $\phi_2$)

- *Higgs doublet of type II* ($\phi_u$ couples to u type quarks, $\phi_d$ couples to d-type quarks, u and d couplings are different; $\tan(\beta) = v_u/v_d$) [favored NP scenario e.g. MSSM, generic SUSY]

- *Higgs doublet of type III* (not type I or type II; anything goes. "FCNC hell"→many FCNC signatures)

Talks by Howie Haber, Marcela Carena, Xiao-Gang He at SUSY2016

Thanks to theorist Xerxes Tata

# Executive Summary of Detector Construction Status

- Outer detector: EKLM, BKLM, TOP are installed; CDC in August; readout and DAQ integration is a lingering concern. *Endcap* ARICH schedule (HV hardware and sparking of HAPDs) may delay Phase II startup by 1 month. *Roll-in* of outer detector by ~Christmas.
- Inner detector: *SVD production has started*; some technical surprises; concerns about L6 schedule and manpower; *PXD production is gearing up*. Problems with SVD-PXD readout/DAQ integration revealed by April 2016 DESY beam test. Tests of $CO_2$ cooling and RVC (Remote Vacuum Connection) on track in Germany but need to be integrated at Tsukuba Hall in 2017.
- *Overall, Belle II construction and integration are on-track but the schedule is tight*. The Belle II collaboration is fully mobilized and performed well for the outer detector.

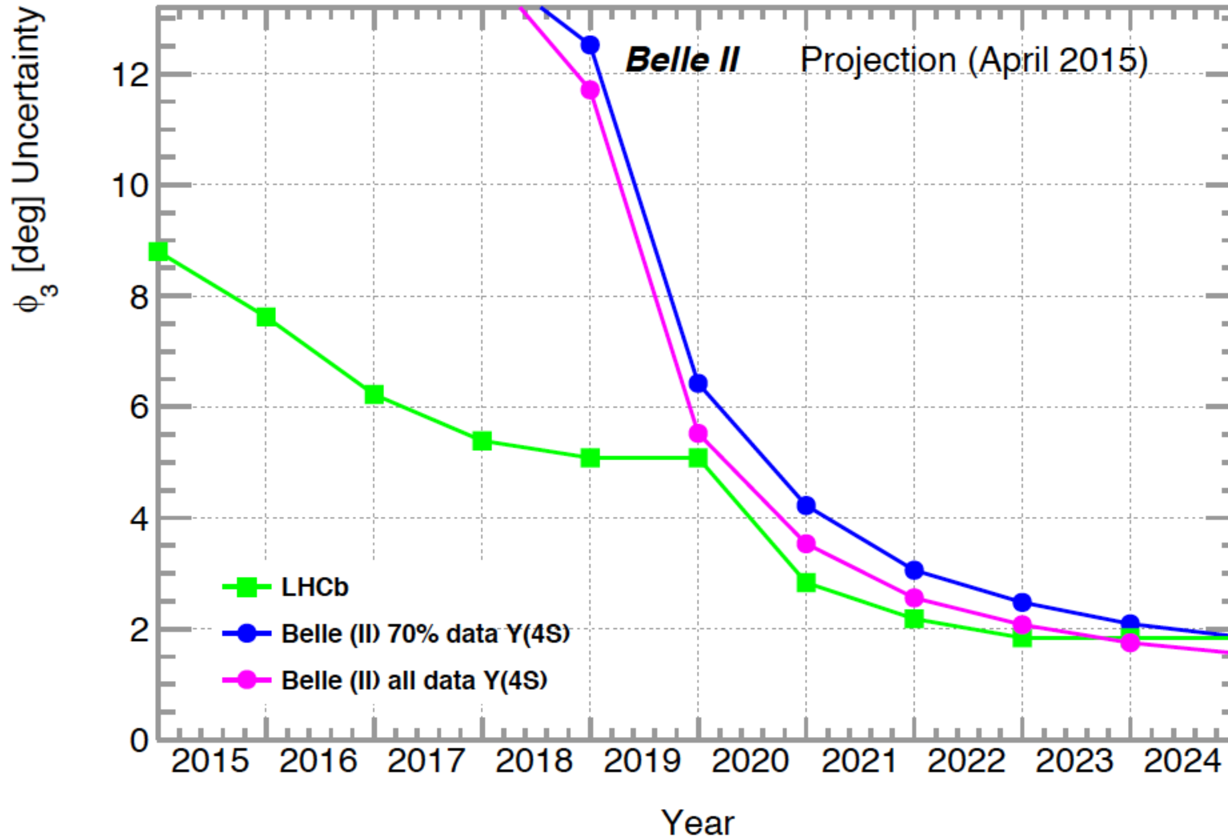
# *Physics Reach of Belle II and the LHCb upgrade*

*Competition* and complementarity

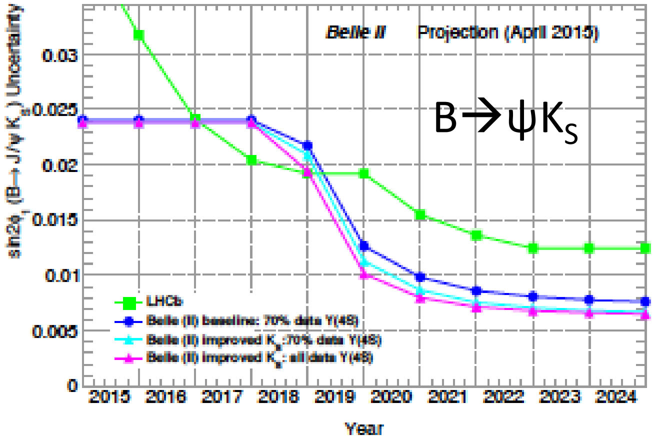

Gelato flavors in Asakusa

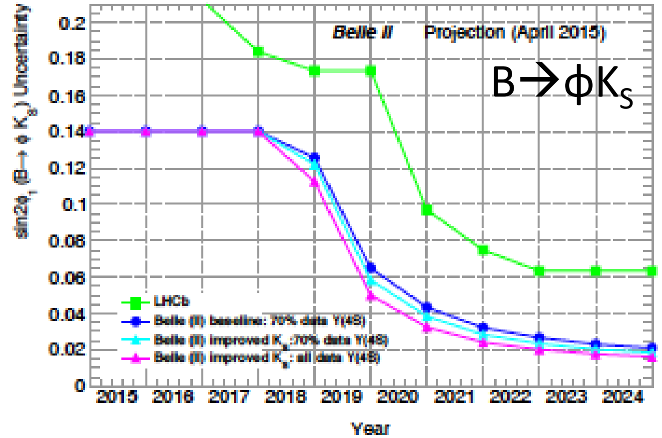

Tofu Gelato ?

| Observable | Expected th. accuracy | Expected exp. uncertainty | Facility |
|---|---|---|---|
| CKM matrix | | | |
| $\lvert V_{us}\rvert$ $[K \to \pi \ell \nu]$ | ** | 0.1% | $K$-factory |
| $\lvert V_{cb}\rvert$ $[B \to X_c \ell \nu]$ | ** | 1% | Belle II |
| $\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$ | *** | 0.1% | $K$-factory |
| charm and $\tau$ | | | |
| $\mathcal{B}(\tau \to \mu\gamma)$ | *** | $3 \cdot 10^{-9}$ | Belle II |
| $\lvert q/p\rvert_D$ | *** | 0.03 | Belle II |
| $arg(q/p)_D$ | *** | 1.5° | Belle II |



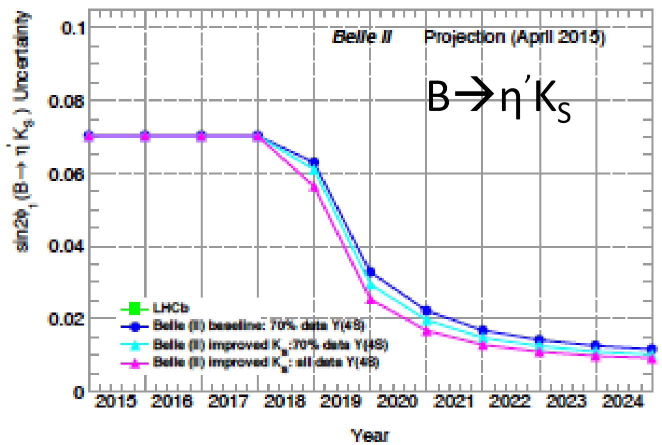
Tight race



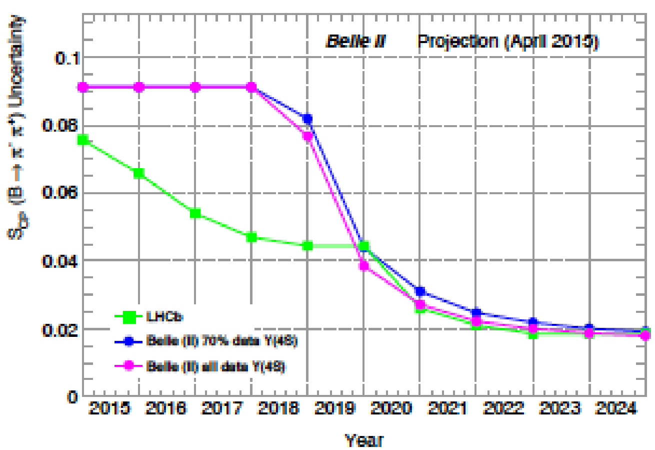

Belle II ahead

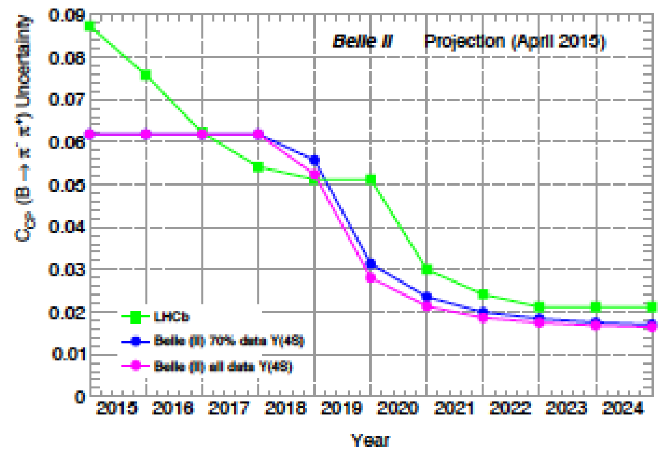
Belle II dominates here




Tight race

B→$\pi^+ \pi^-$ CPV



# So when do we start Belle II ?

BEAST PHASE I: Started in Feb 2016 (Belle II roll-in at the end of the year) and ends this week.

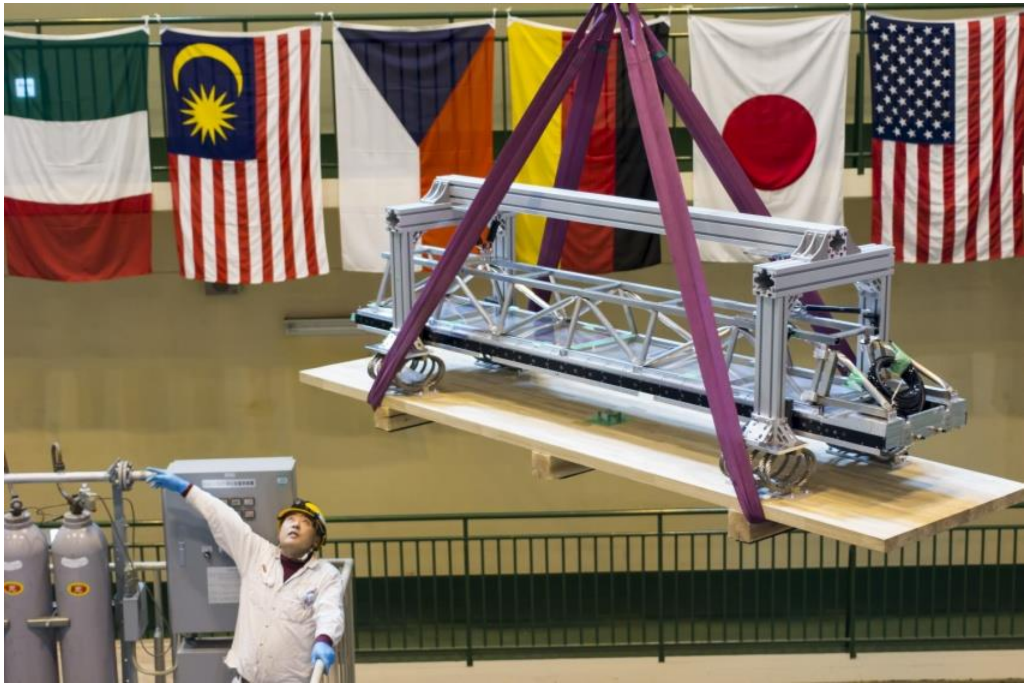
BEAST PHASE II: Starts in Dec 2017 [damping ring commissioning; First collisions; limited physics without vertex detectors]

Belle II Physics Running: late Fall 2018 [vertex detectors in]

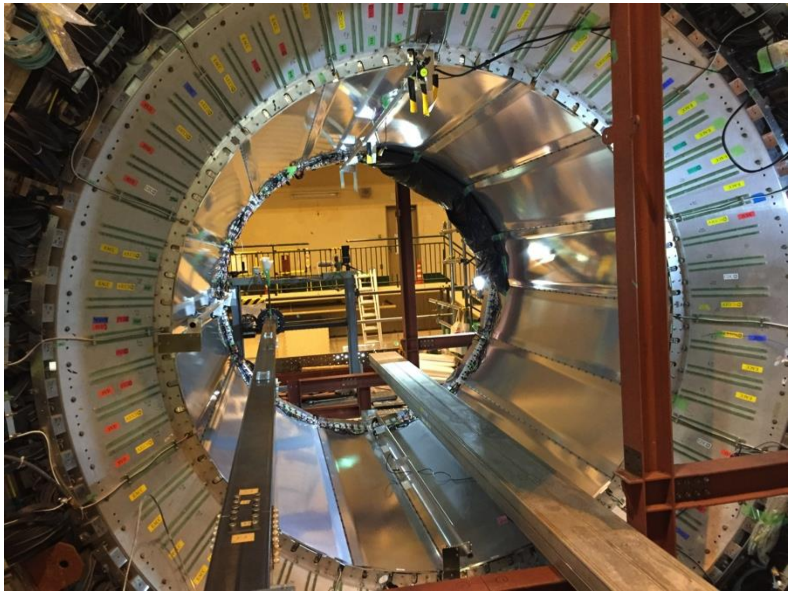
QCSL at KEK, Dec 2015

QCSR will be at KEK, Nov 2016

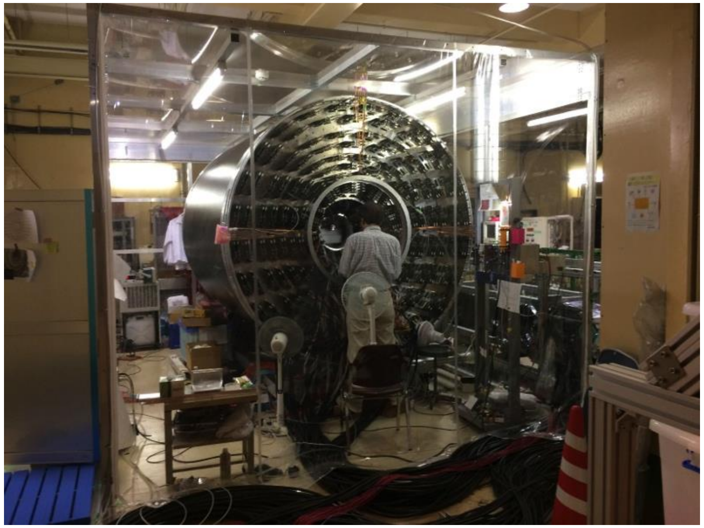
# Belle II at Tsukuba Hall



First TOP module arriving at Tsukuba Hall



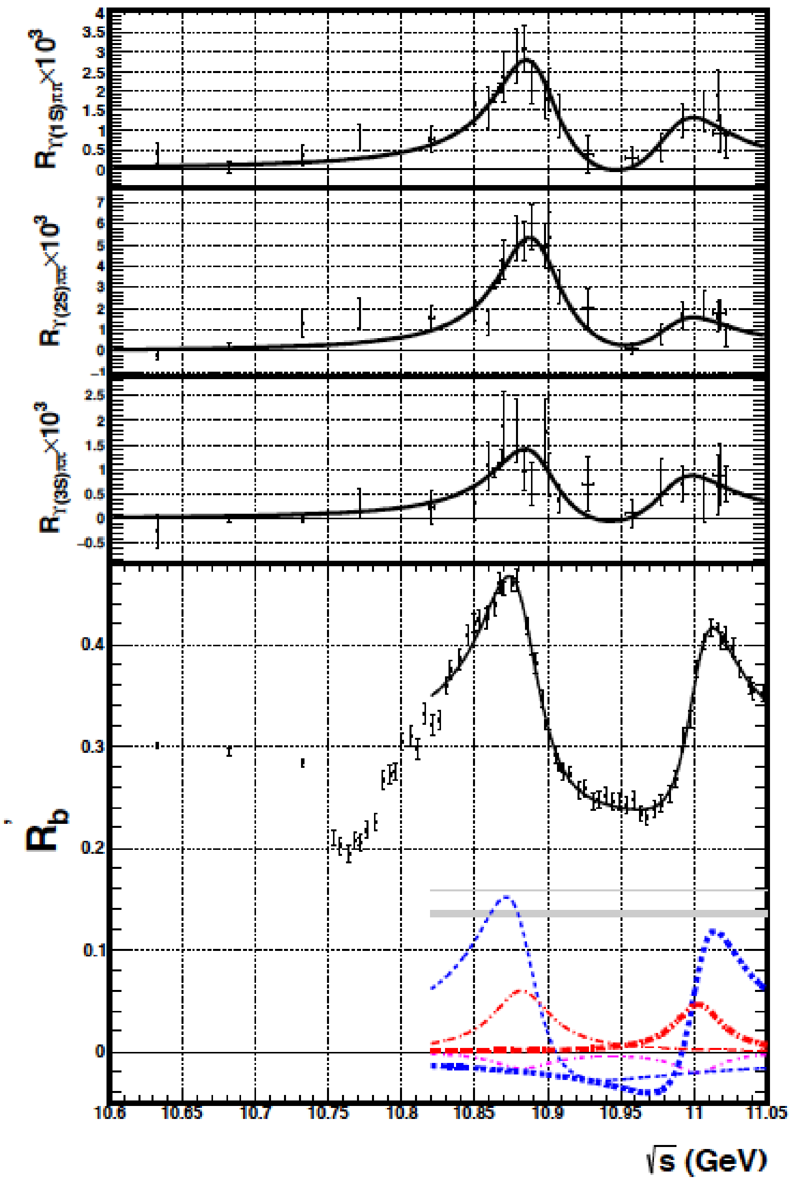
May 2016:TOP in Belle II structure



CDC (Central Drift Chamber)

Update: May 20, 2016 all 16 TOP modules were installed into the Belle II structure. Magnetic field mapping on-going in June-July, then CDC installation in 2nd half of August.

# Upsilon(5S)/(6S) energy region



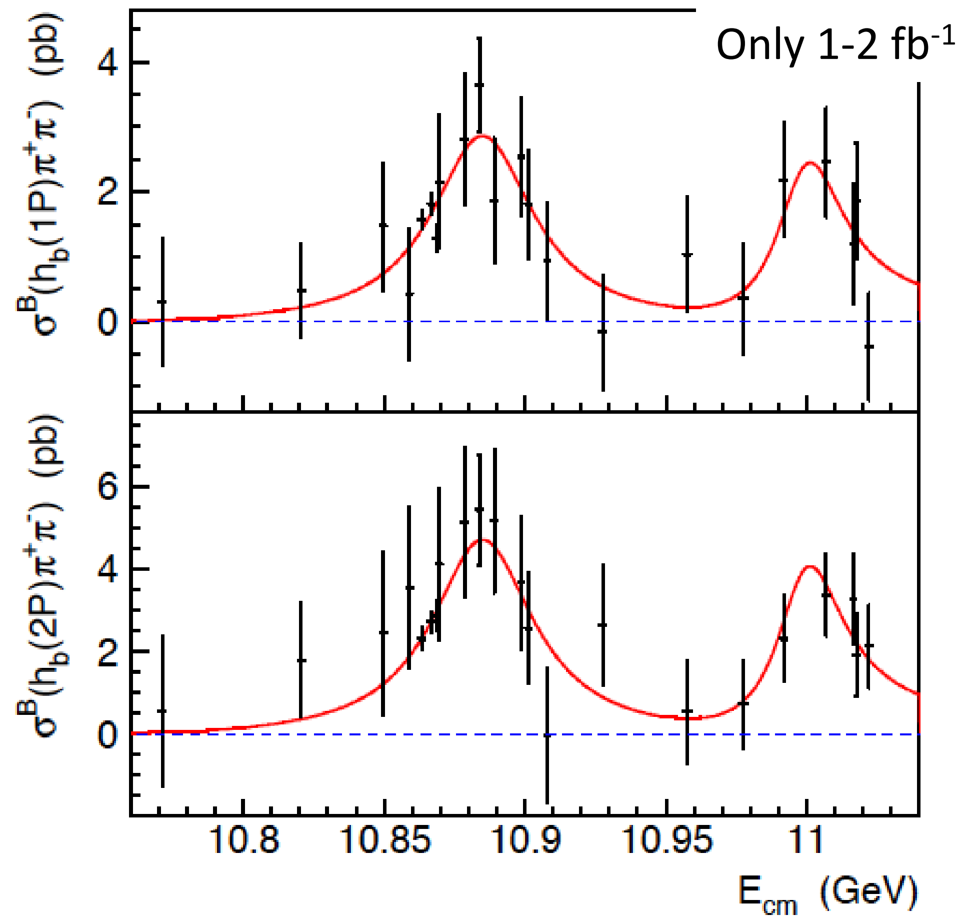
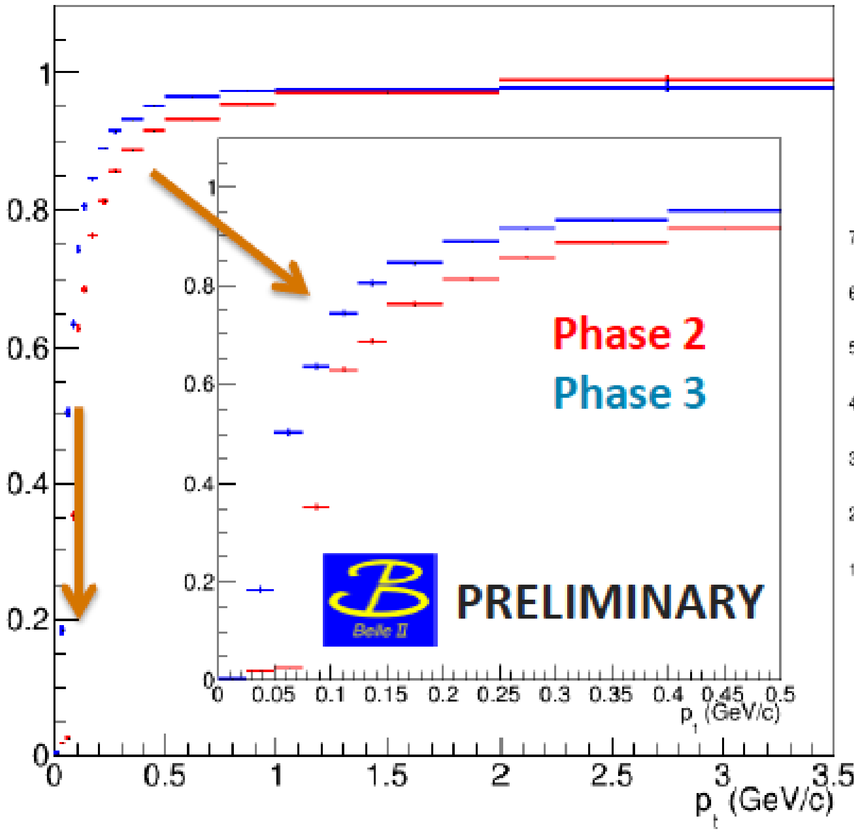



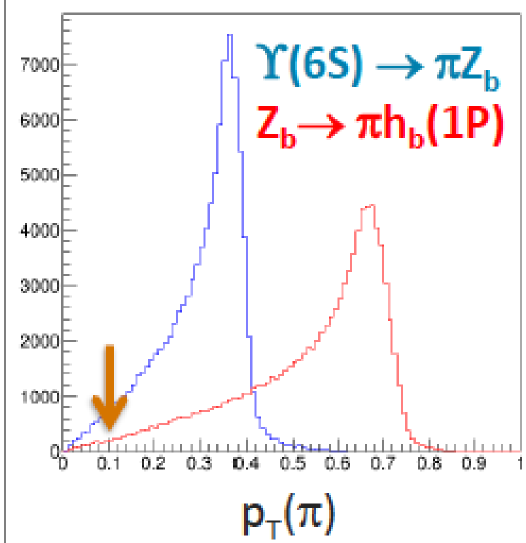

FIG. 1: (colored online) Cross sections for the $e^+e^- \to h_b(1P)\pi^+\pi^-$ (top) and $e^+e^- \to h_b(2P)\pi^+\pi^-$ processes as a function of c.m. energy. Points with error bars are the data, red solid curves are the fit results.

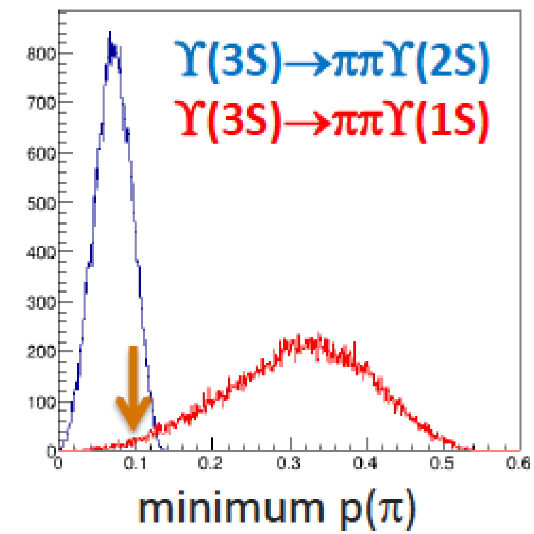
# Issues for special Upsilon(nS) runs

- Lack of vertex detector diminishes low $p_T$ track reconstruction
- $\Upsilon(3S)\to\pi^+\pi^-\Upsilon(2S)$ infeasible, but $\Upsilon(6S)\to\pi Z_b\to\pi h_b(nP)$ unaffected




PRELIMINARY



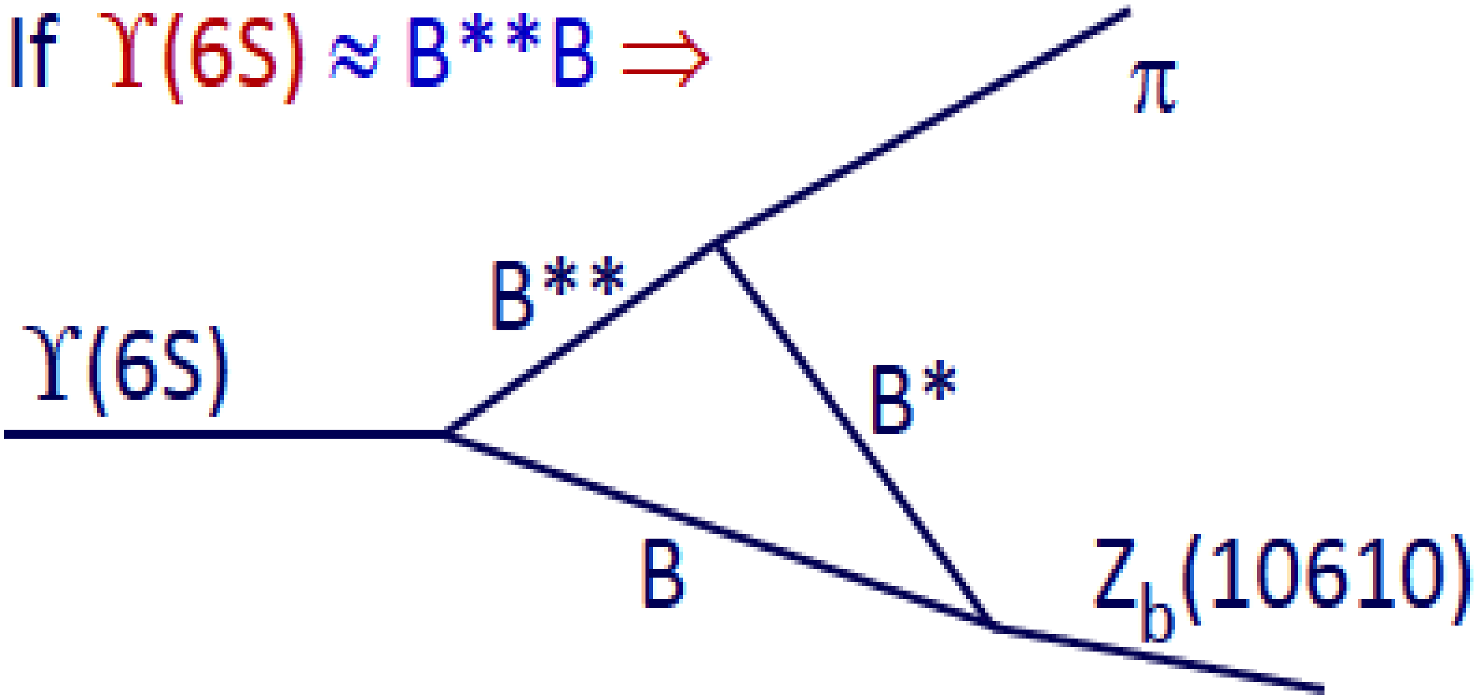
A. E. Bondar, M. B. Voloshin
Phys. Rev. D 93, 094008 (2016)

# Upsilon(6S) issues

What happens at $\Upsilon(6S)$?

R. Mizuk@B2TIP, Krakow

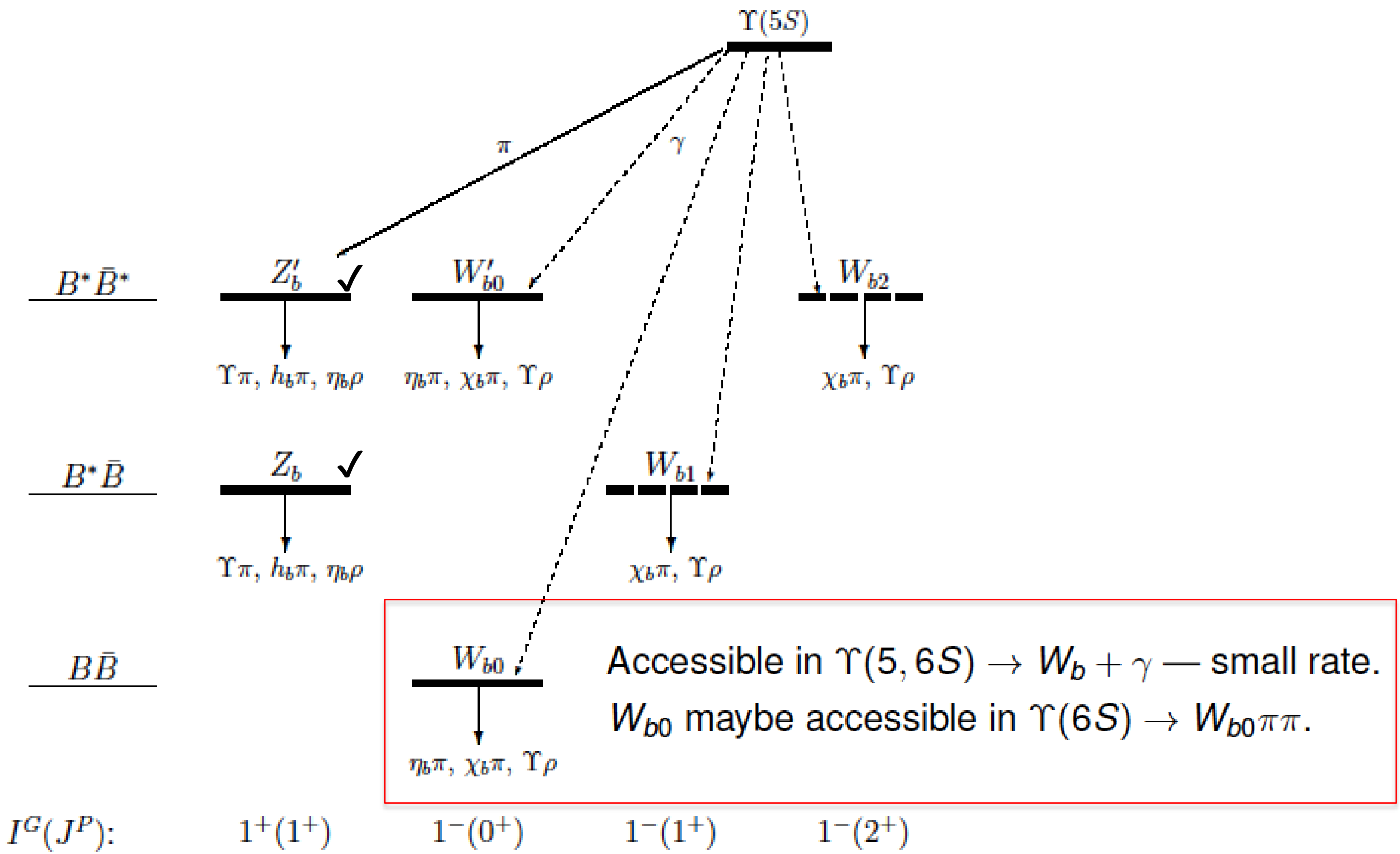
If $\Upsilon(6S) \approx B^{**}B \Rightarrow$




no way to produce $B^*B^*$ molecule = $Z_b(10650)$

Voloshin,
B2TIP Pittsburgh

# Upsilon(6S) issues



# Hunting for (b bbar g) "QCD hybrids"

Tetraquark (4-quark) states such as the Z(4430) first seen by Belle in 2003
Pentaquark (5-quark) states first observed by LHCb in 2015

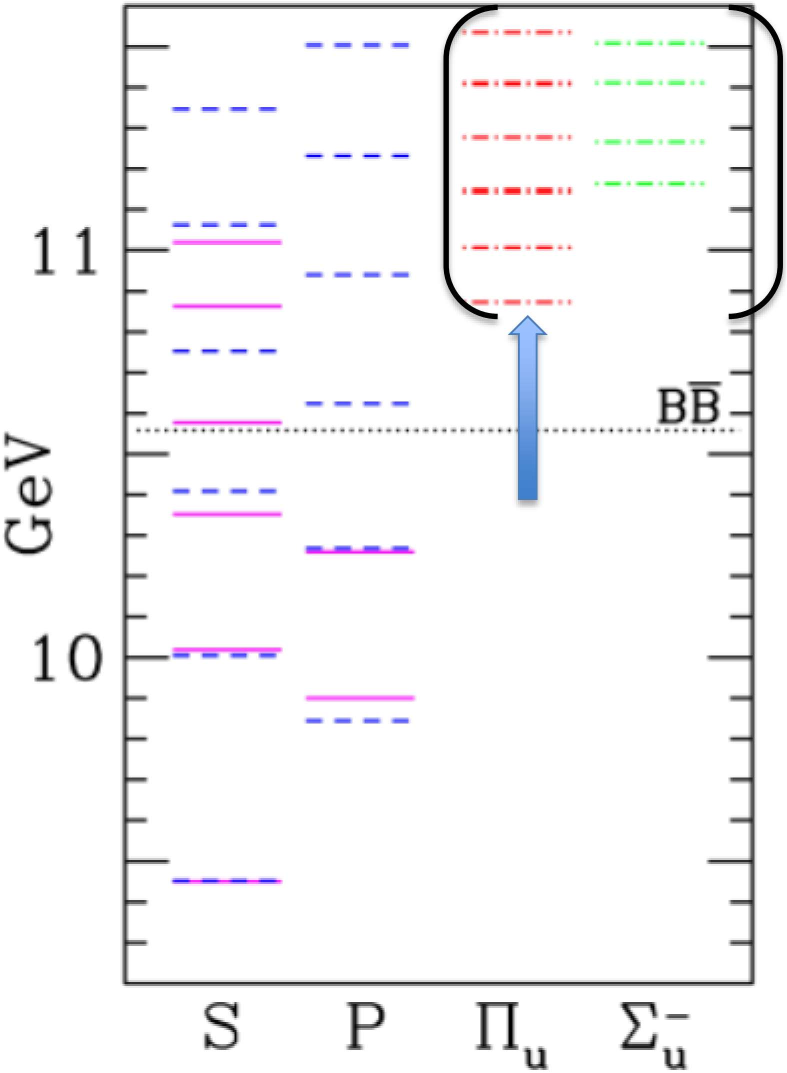



TABLE VI. 10.7 GeV $b\bar{b}$ hybrid decay modes (MeV).

| | | | alt | 10.9 GeV hybrid | standard | IKP | reduced |
|---|---|---|---|---|---|---|---|
| $2^{-+}$ | $B^*B$ | P | .1 | 0 | .5 | 3 | 44 |
| $1^{-+}$ | $B^*B$ | P | .1 | 0 | .5 | 3 | 44 |
| $0^{-+}$ | $B^*B$ | P | .5 | 0 | 2 | 13 | 177 |
| $1^{--}$ | $B^*B$ | P | .2 | 0 | 1.2 | 7 | 88 |
| $2^{+-}$ | $B^*B$ | D | .08 | .05 | .25 | 1 | 22 |
| $1^{+-}$ | $B^*B$ | S | .02 | .1 | .2 | 5 | 13 |
| | $B^*B$ | D | .02 | .02 | .15 | .6 | 12 |
| $1^{++}$ | $B^*B$ | S | .01 | .05 | .25 | 2 | 7 |
| | $B^*B$ | D | .1 | .05 | .5 | 1 | 24 |

Page, Swanson and Szczepaniak
Phys. Rev D. 59, 034016 (1999)

# Review of Phase II recommendations

installed in the detector, which will complete the detector packages. A successful Phase 2 beam run is crucial for early advancement of the ultimate particle physics program. Phase 3 of the accelerator commissioning will begin when the Belle detector is complete.

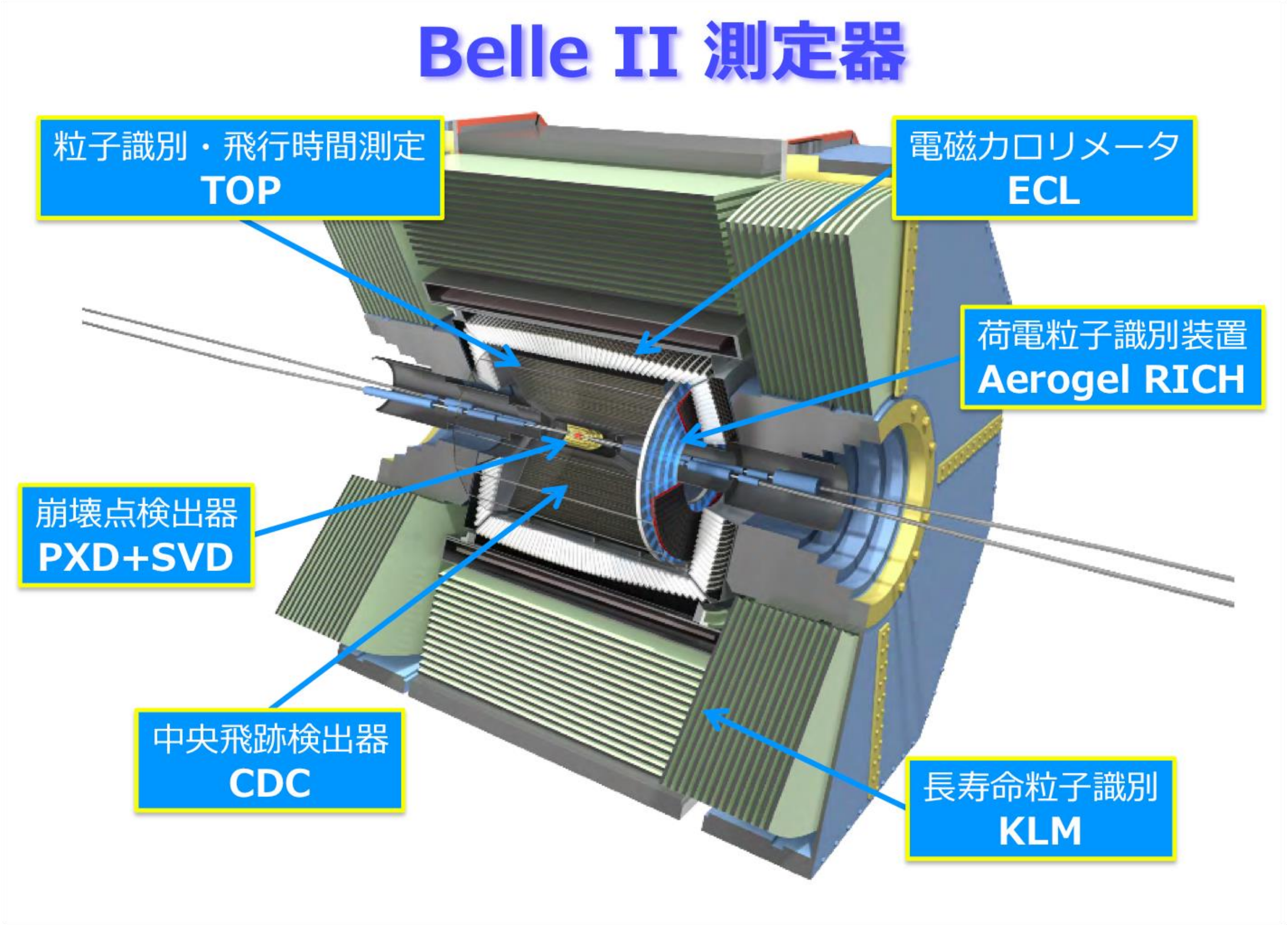
7) Belle II and SuperKEKB management teams should jointly develop the run objectives and parameters for the early physics running in SuperKEKB Phase 2 commissioning by fall 2015. In light of the delays caused by the budget shortfall, every effort should be made to take physics data as soon as possible, preferably during Phase 2 commissioning.

Latest Proposal:

Once collisions are established, record ~2 $fb^{-1}$ at the Upsilon(4S); verify functionality of Belle II; check B meson reconstruction.

<u>Take remaining ~20 $fb^{-1}$ at the peak of the Upsilon(6S)</u> (build a unique dataset for strong interaction physics to provide initial early Belle II physics publications.)

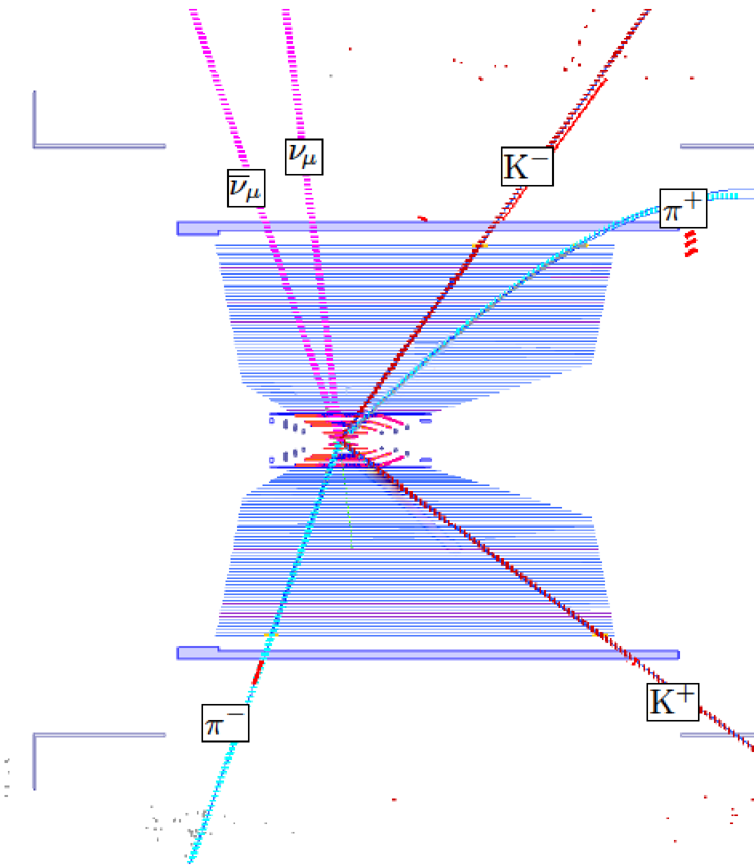
# More backup material



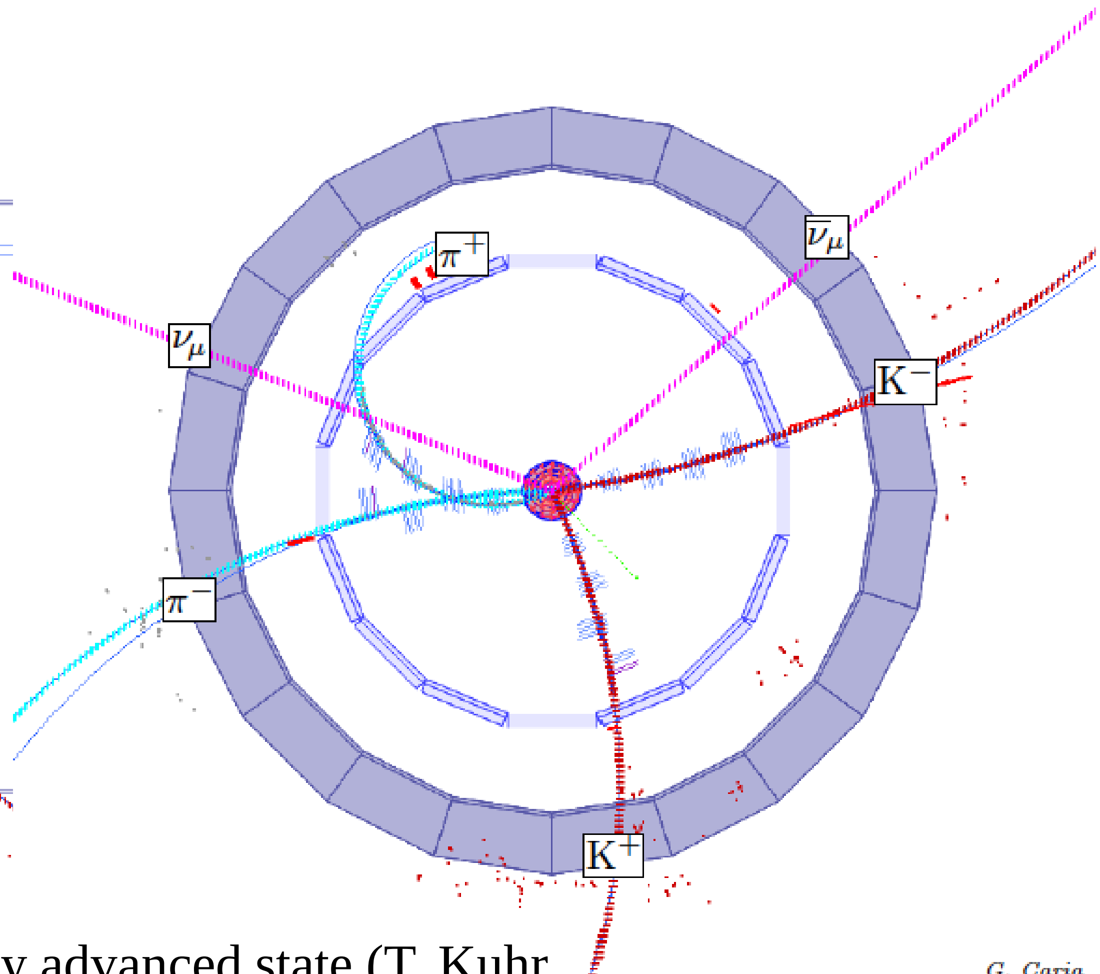
# "Missing Energy Decay" in a Belle II GEANT4 MC simulation

## Signal $B \rightarrow K \nu \nu$ tag mode: $B \rightarrow D\pi$; $D \rightarrow K\pi$

View in r-z




Zoomed view of the vertex region in r--phi

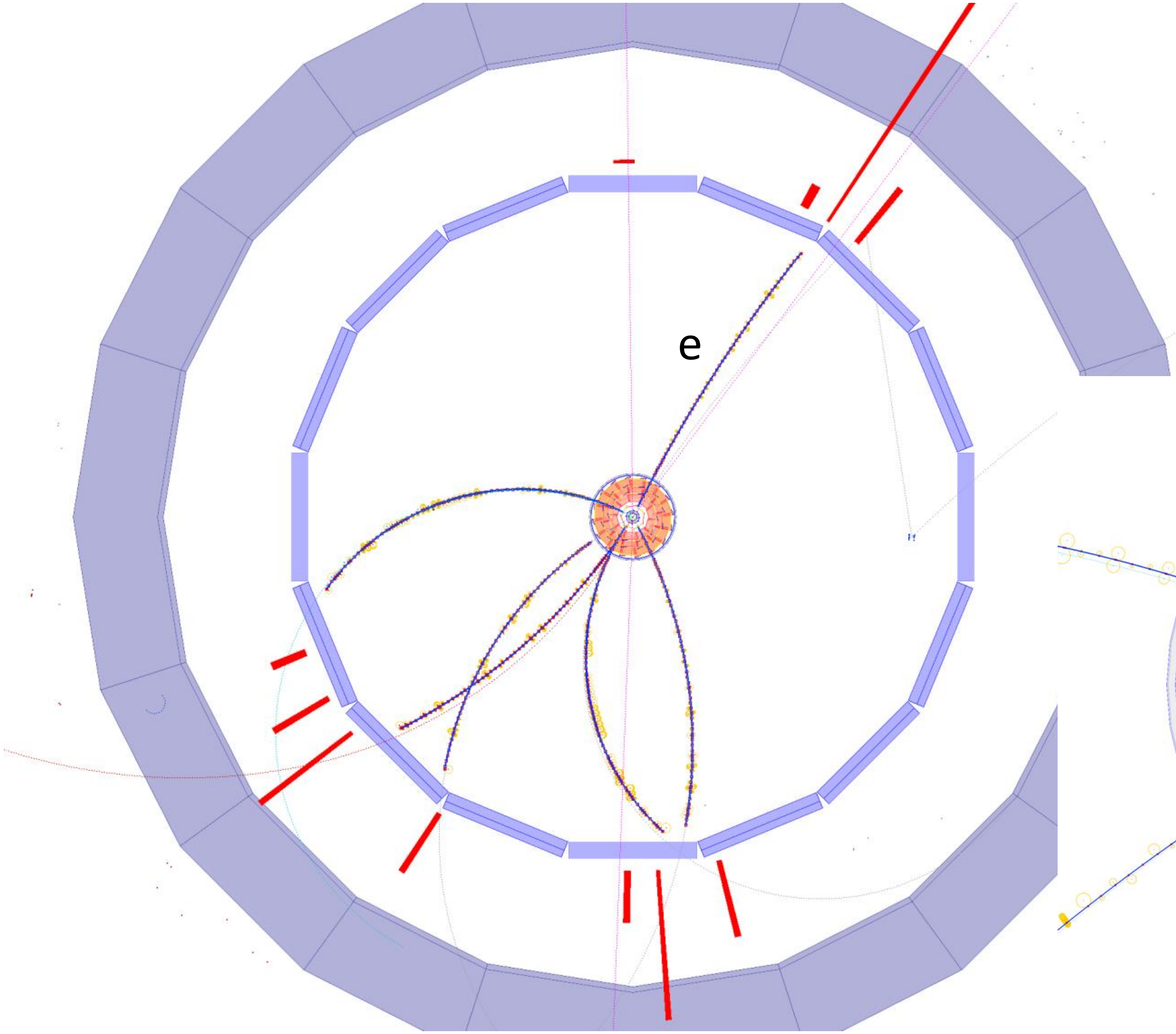



G. Caria

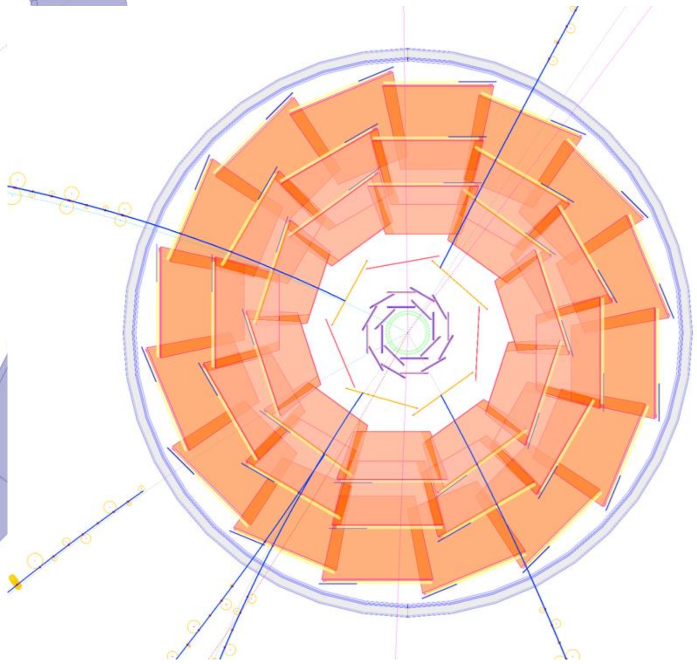
➔Belle II Software is in a fairly advanced state (T. Kuhr (LMU) is the Belle II software coordinator)

# “Missing Energy Decay” in a Belle II GEANT4 MC simulation

$B \rightarrow \tau\nu,\ \tau \rightarrow e\nu\nu$ $\quad$ $B \rightarrow D\pi,\ D \rightarrow K\pi\pi\pi$



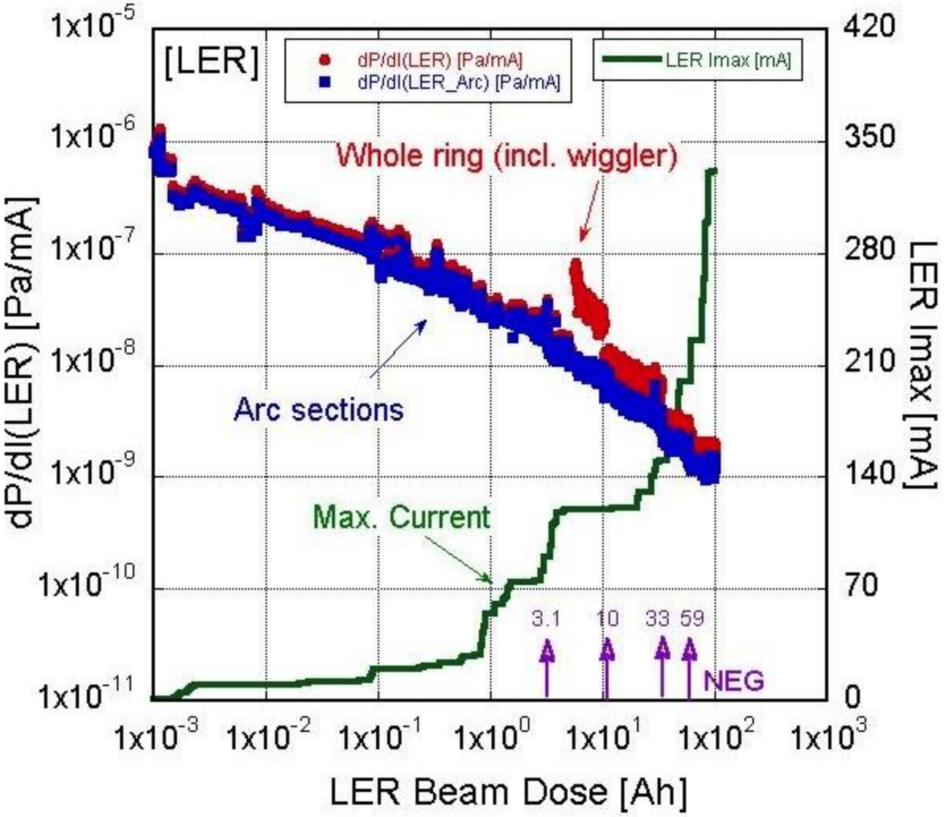

Zoomed view of the vertex region



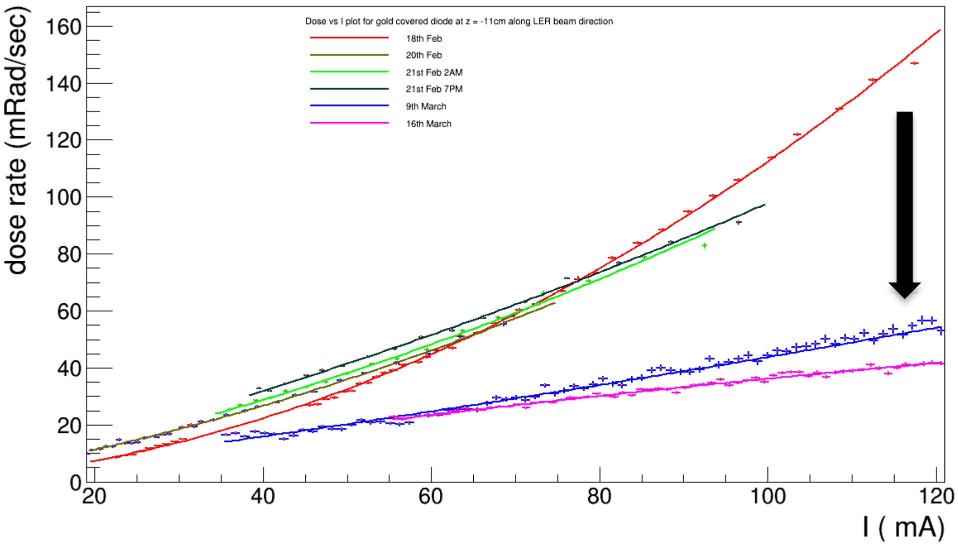
# BEAST Phase I Highlight

## SuperKEKB vacuum scrubbing to reduce *LER* beam gas backgrounds in Belle II

LER integrated beam dose > 100 A-h

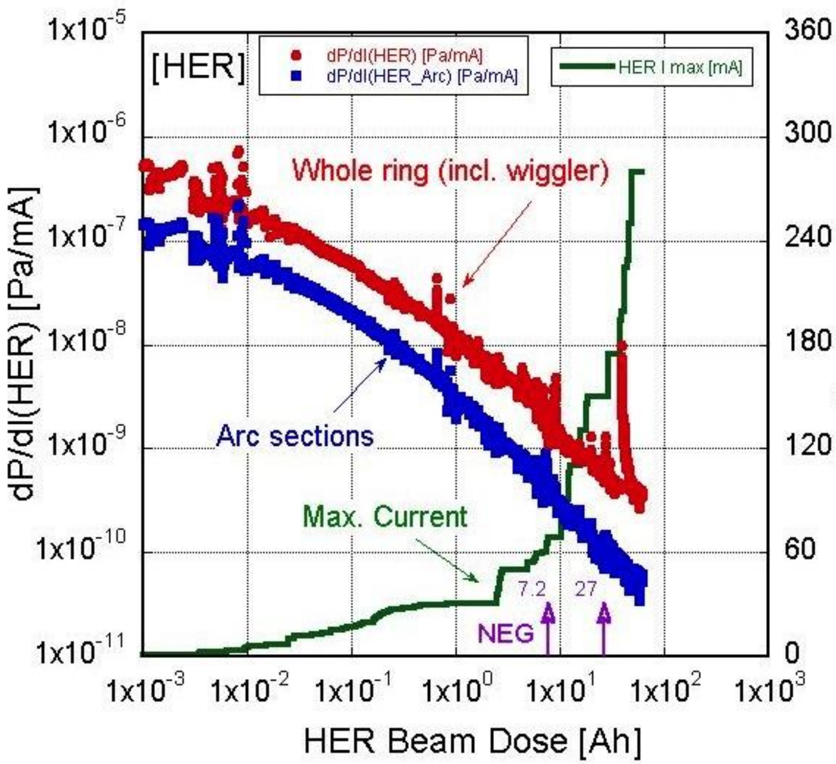



BEAST background in the LER vs time

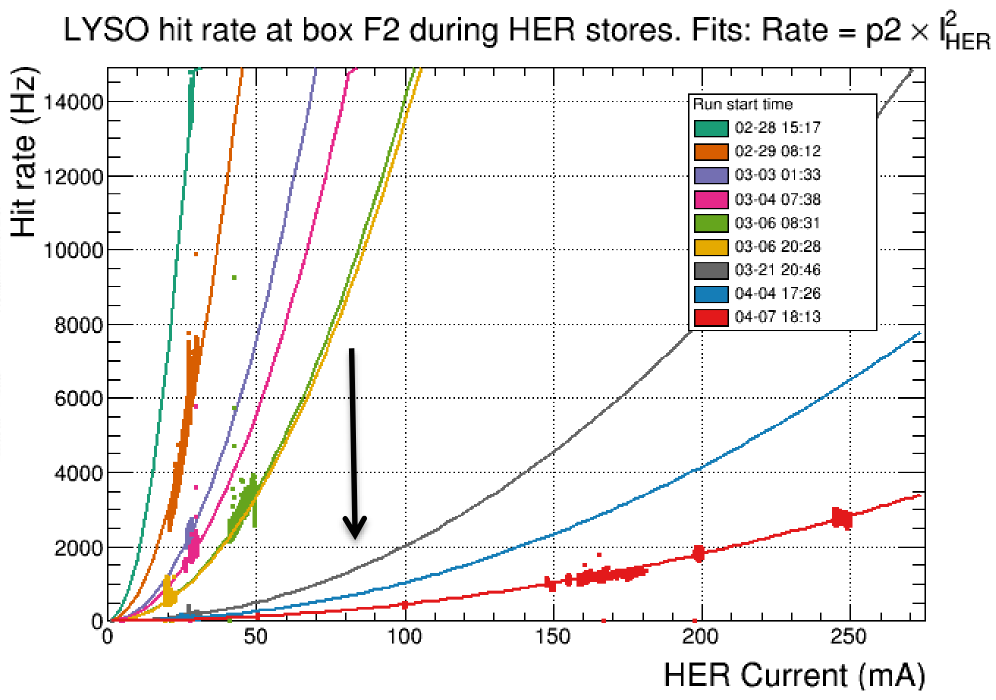



BEAST data shows the LER backgrounds decreasing as vacuum scrubbing proceeds.

# SuperKEKB vacuum scrubbing to reduce *HER* beam gas backgrounds in Belle II




BEAST background in the HER vs time

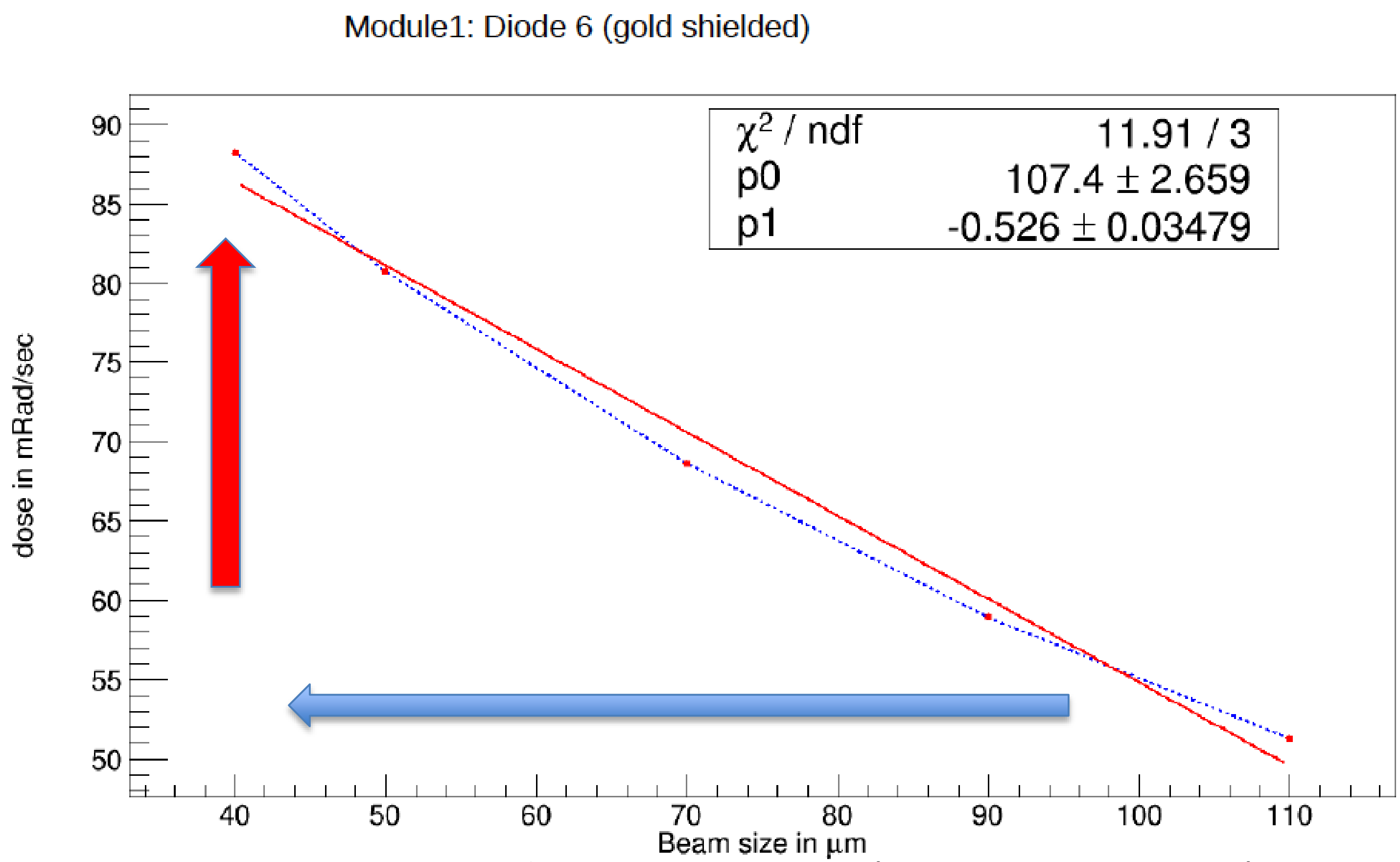



BEAST data shows the HER backgrounds decreasing as vacuum scrubbing proceeds.

# BEAST Phase I Highlight

## April 2016: Large Touschek background observed in the LER

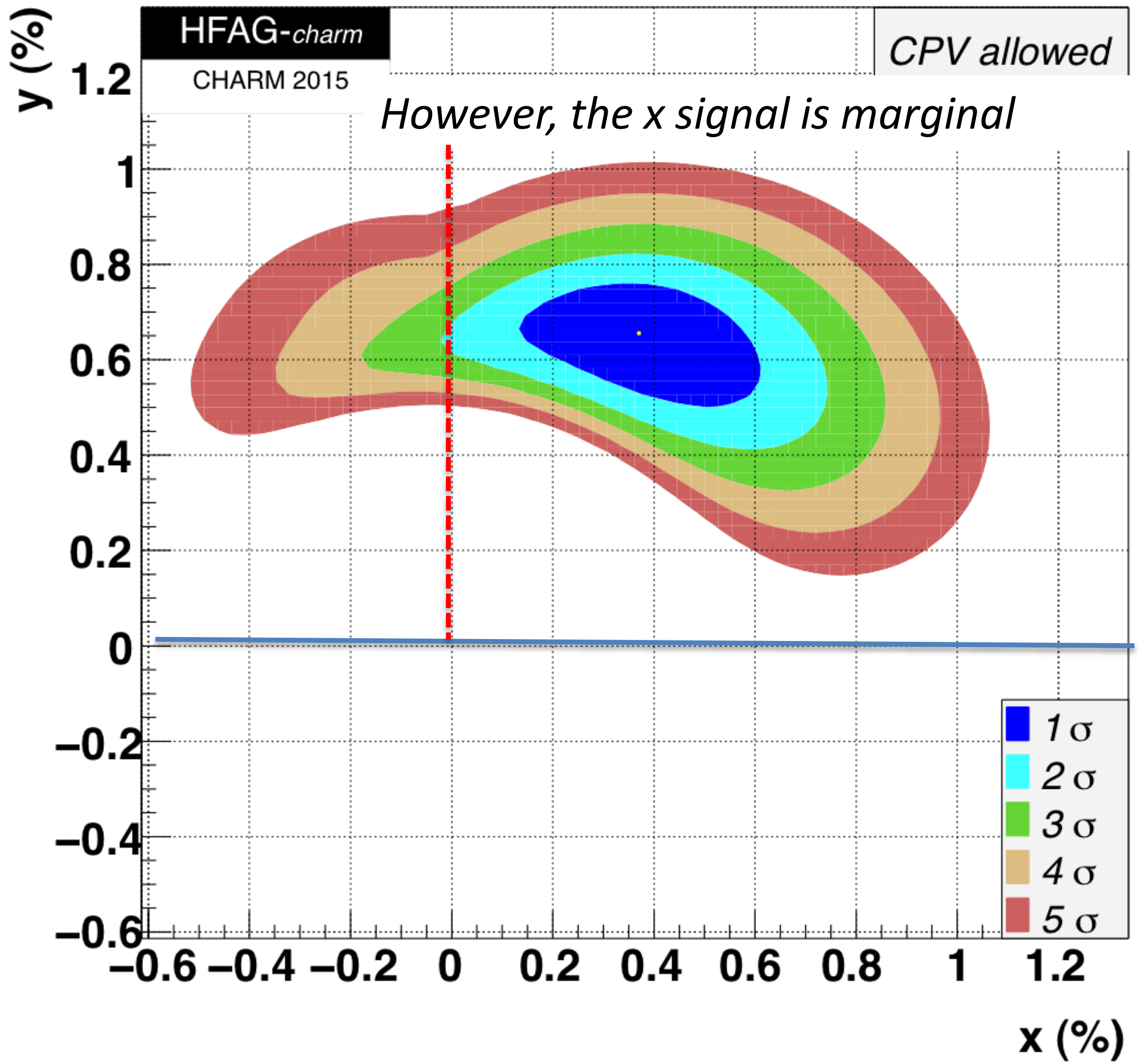
Bkg in BEAST




Vertical beam size from size monitor (*not* measured at IP)

→Will need excellent collimators to handle nano-beam backgounds.

# Mixing and CP violation in the D system




There is a very strong y signal

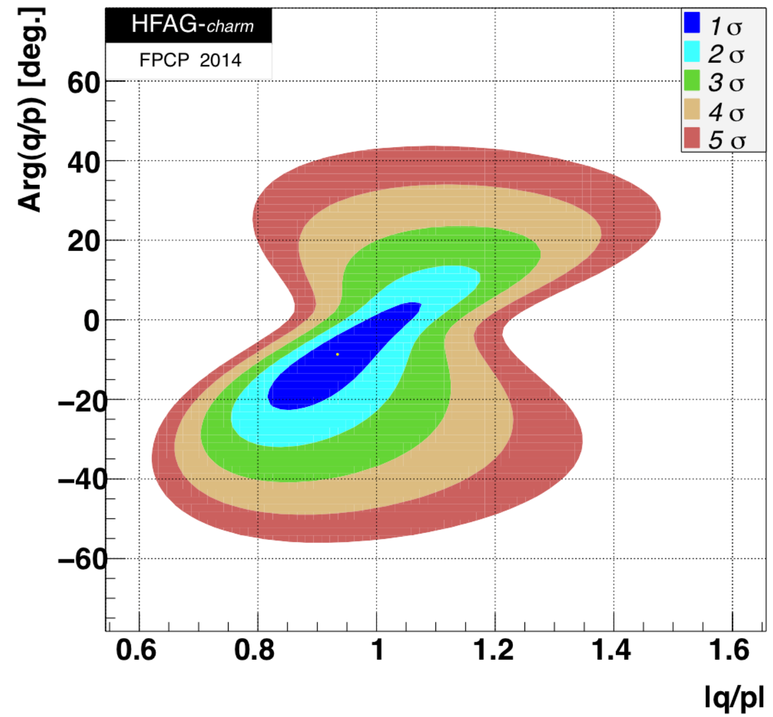
# D mixing: Another new physics phase !

$$\varphi \sim \frac{2\eta A^2 \lambda^5}{\lambda} \sim O(10^{-3})$$

CPV in D system negligible in SM

CPV in interf. mix./decay:

$$\mathrm{Im}\frac{q}{p}\frac{\bar{A}_f}{A_f} \equiv (1+\frac{A_M}{2})e^{i\varphi} \neq 0; \varphi \neq 0$$




*The existence of D mixing (if x is non-zero) allows us to look for another poorly constrained new physics phase but this time from up-type quarks.*

(c.f. CPV in $B_s$ mixing)

Current WA sensitivity ~±$20^0$, 50 $ab^{-1}$ go below $2^0$

# CPV in the charged lepton sector

- There is mixing in the neutrino (neutral lepton) sector. CP violation is possible too.

BaBar rate anomaly ??

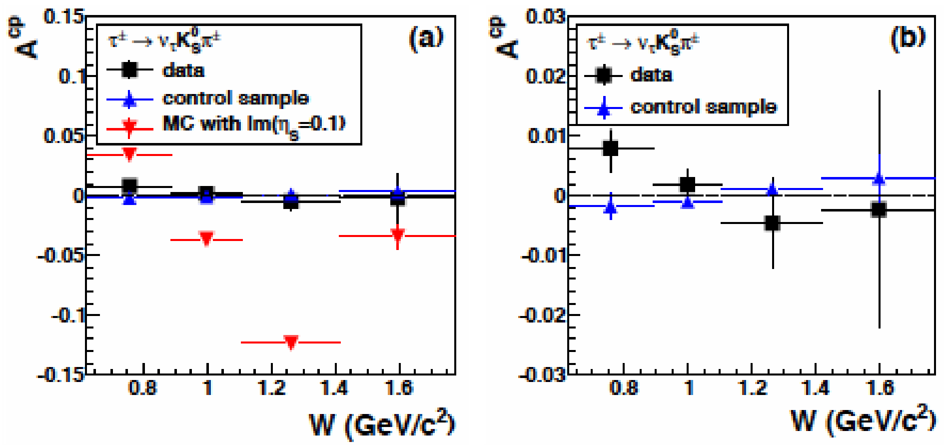



FIG. 2. (a) Measured CP violation asymmetry after background subtraction (squares). The vertical error bars are the statistical error and systematic errors added in quadrature. The CP asymmetry measured in the control sample is indicated by the blue triangles (statistical errors only) and the inverted red triangles show the expected asymmetry for $\Im(\eta_S) = 0.1$ [$\Re(\eta_S) = 0$]. (b) Expanded view (the vertical scale is reduced by a factor of five).

## Can we explore at Belle II ?

Theoretical predictions for $\Im(\eta_S)$ can be given in context of a MHDM with three or more Higgs doublets [4, 5]. In such models $\eta_S$ is given by [12]

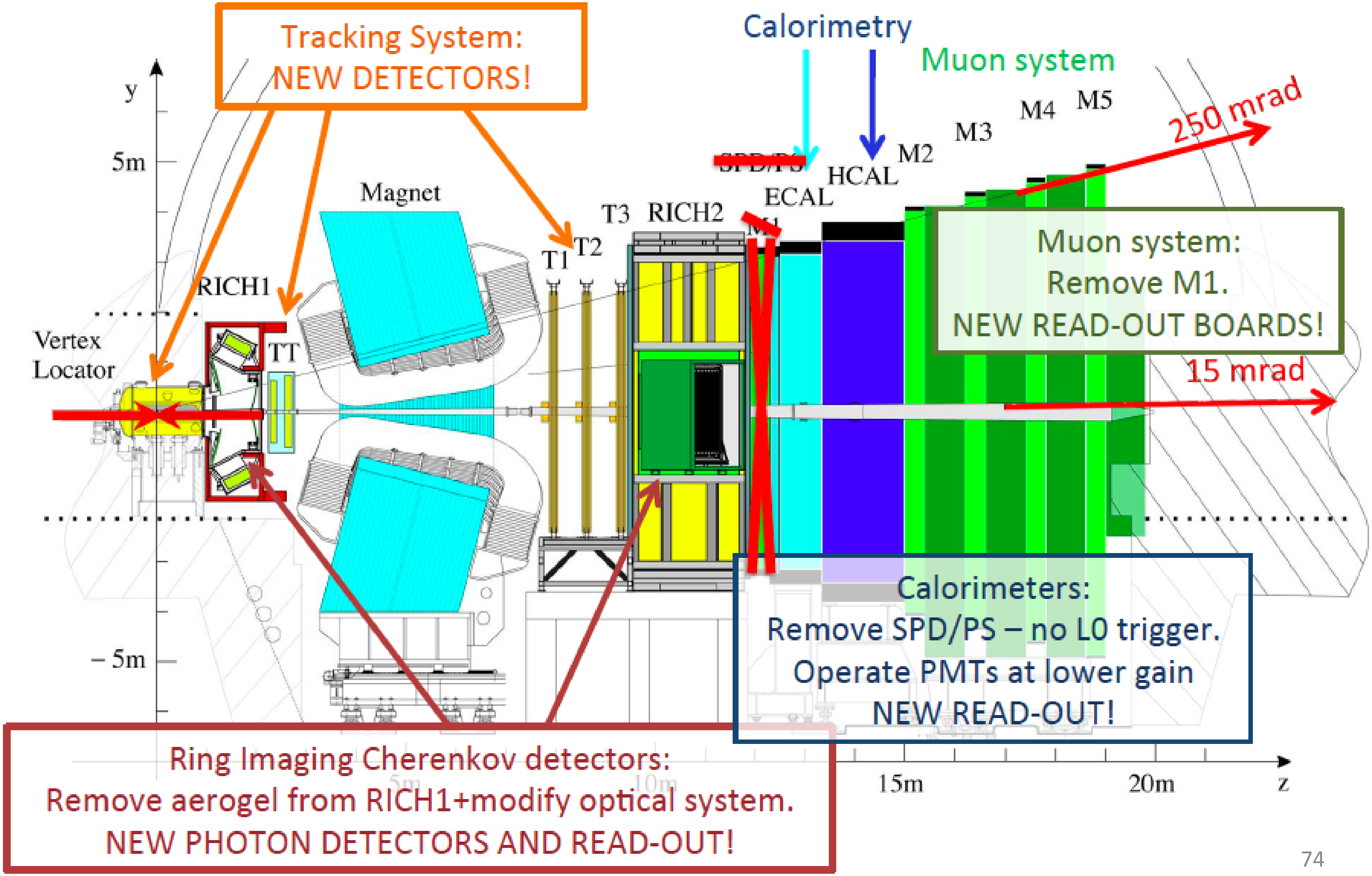
$$\eta_S \simeq \frac{m_\tau m_s}{M_{H^\pm}^2} X^* Z \qquad (10)$$

if numerically small terms proportional to $m_u$ are ignored. Here, $M_{H^\pm}$ is the mass of the lightest charged Higgs boson and the complex constants $Z$ and $X$ describe the coupling of the Higgs boson to the $\tau$ and $\nu_\tau$ and the $u$ and $s$ quarks, respectively (see [5, 12]). The limit $|\Im(\eta_S)| < 0.026$ is therefore equivalent to

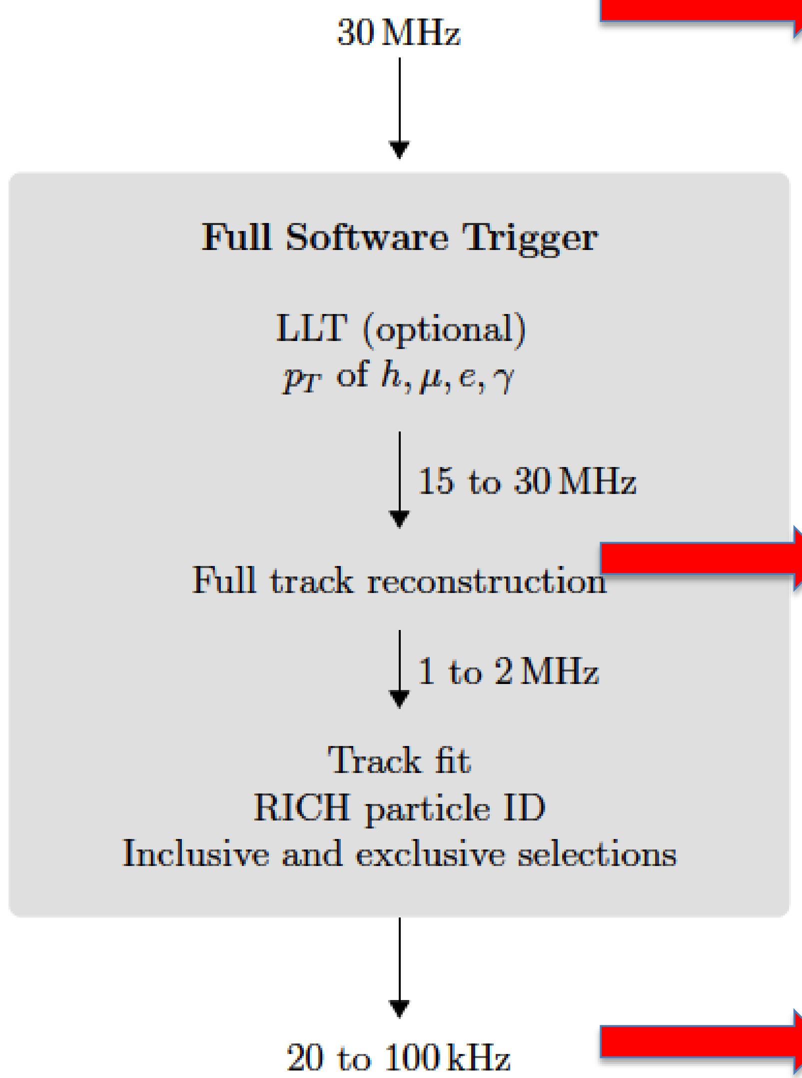
$$|\Im(XZ^*)| < 0.15 \frac{M_{H^\pm}^2}{1\,\mathrm{GeV}^2/c^4}. \qquad (11)$$

M. Bischofberger et al, Phys. Rev. Lett. 107, 131801 (2011)

# Upgraded LHCb detector



# LHCb Upgrade: *Key Feature* is Trigger-less readout




- Trigger-less read-out.
- Zero suppression in front-ends.
- Full detector data to Full Software Trigger.
- Inelastic collision rate is 30 MHz.

- Low level trigger as throttle.
- Partial information from muon system and calorimeters.

- Full event reconstruction.
- Run-by-run detector calibration.

- Perform simplified Kalman track fit.
- Add RICH information.
- Inclusive and exclusive selections.

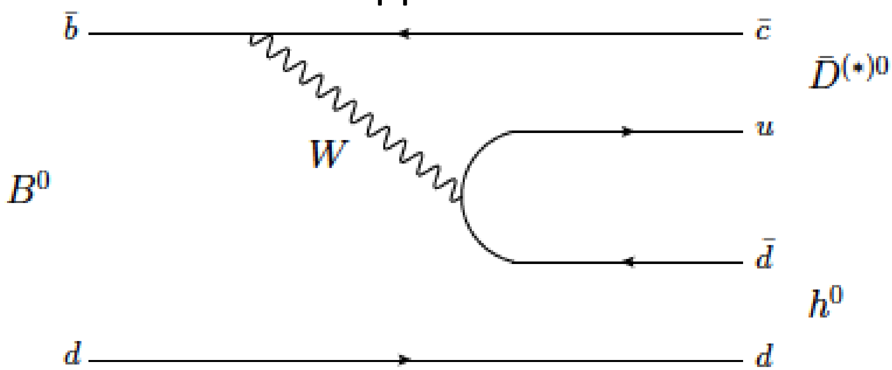
- 2 – 10 GBytes/s to storage.

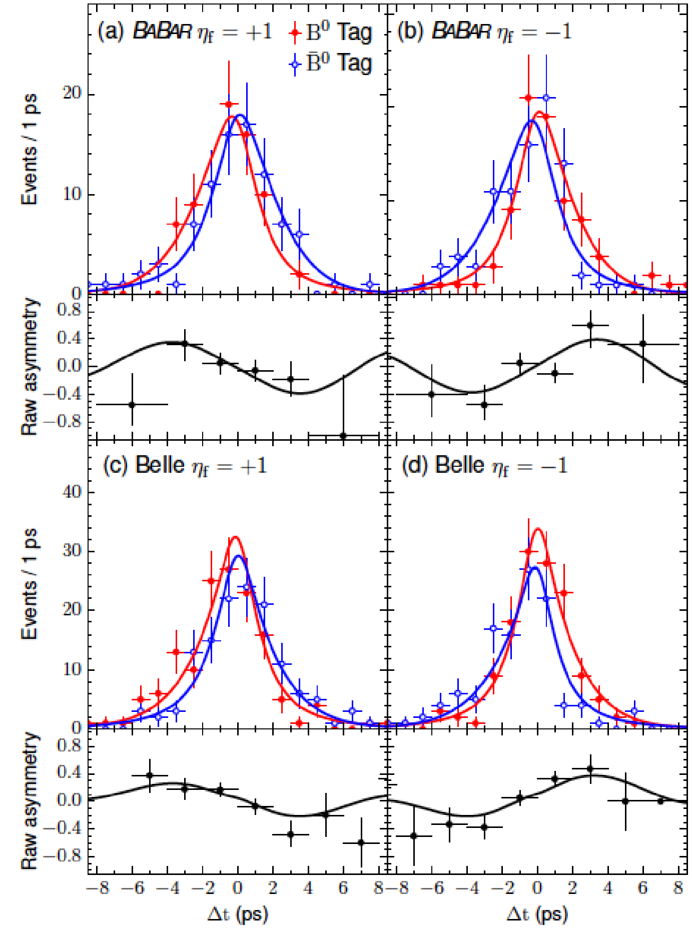
B factories: *Check CP violation in b→c [ubar d] processes*

## 2015: First joint BaBar-Belle data analysis

M. Rohrken et al

"Color-suppressed" B→D h




where $D^0$ is a CP eigenstate and $h^0=\pi^0$, η, ω

Combining Belle and BaBar datasets, ~1260 signal events, obtain a 5.4σ CP violation signal➔First observation

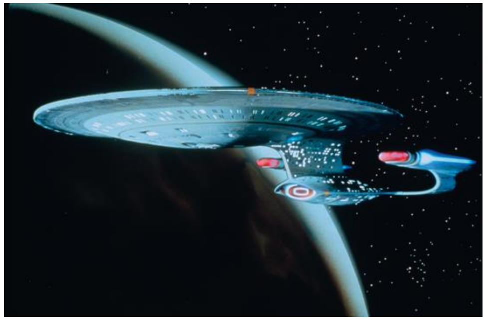
$\sin(2\beta_{eff})=0.66\pm0.10(stat)\pm0.06(sys)$

Phase of $V_{td}$ again

Conclusion: CP violation in b→c ubar d modes is the same as in b→c cbar s modes (e.g. B→J/ψ $K_S$)

# More backup

# *Innovative Technologies in Belle II*



Pixelated photo-sensors play a central role

MCP-PMTs in the iTOP

HAPDs in the ARICH

SiPMs in the KLM, DEPFET pixels

Waveform sampling with precise timing is "saving our butts".

Front-end custom ASICs (Application Specific Integrated Circuits) for all subsystems ➔ a 21$^{st}$ century HEP experiment.

Pixel detector [3 custom German ASICs: DCD, DHP, Switcher]

KL/muon detector (TARGETX ASIC)

Electromagnetic calorimeter

(New waveform sampling backend with good timing)

iTOP particle identification (IRSX ASIC)

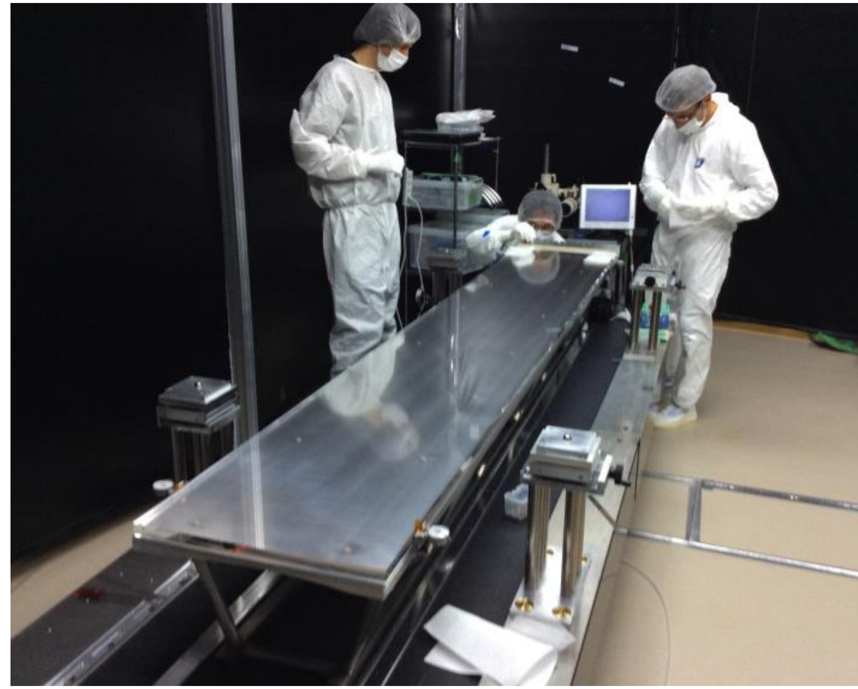
Aerogel RICH (KEK custom ASIC)

Central Drift Chamber (KEK custom ASIC)

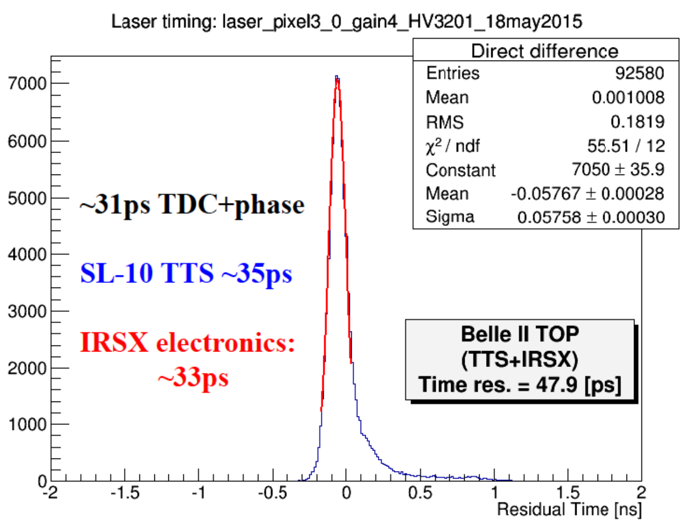
SVD (APV2.5 readout chip adapted from CMS)

# Belle II iTOP at Fuji Hall/Hawaii


Module 01 assembly at Fuji Hall



Module 04 assembly at Fuji Hall

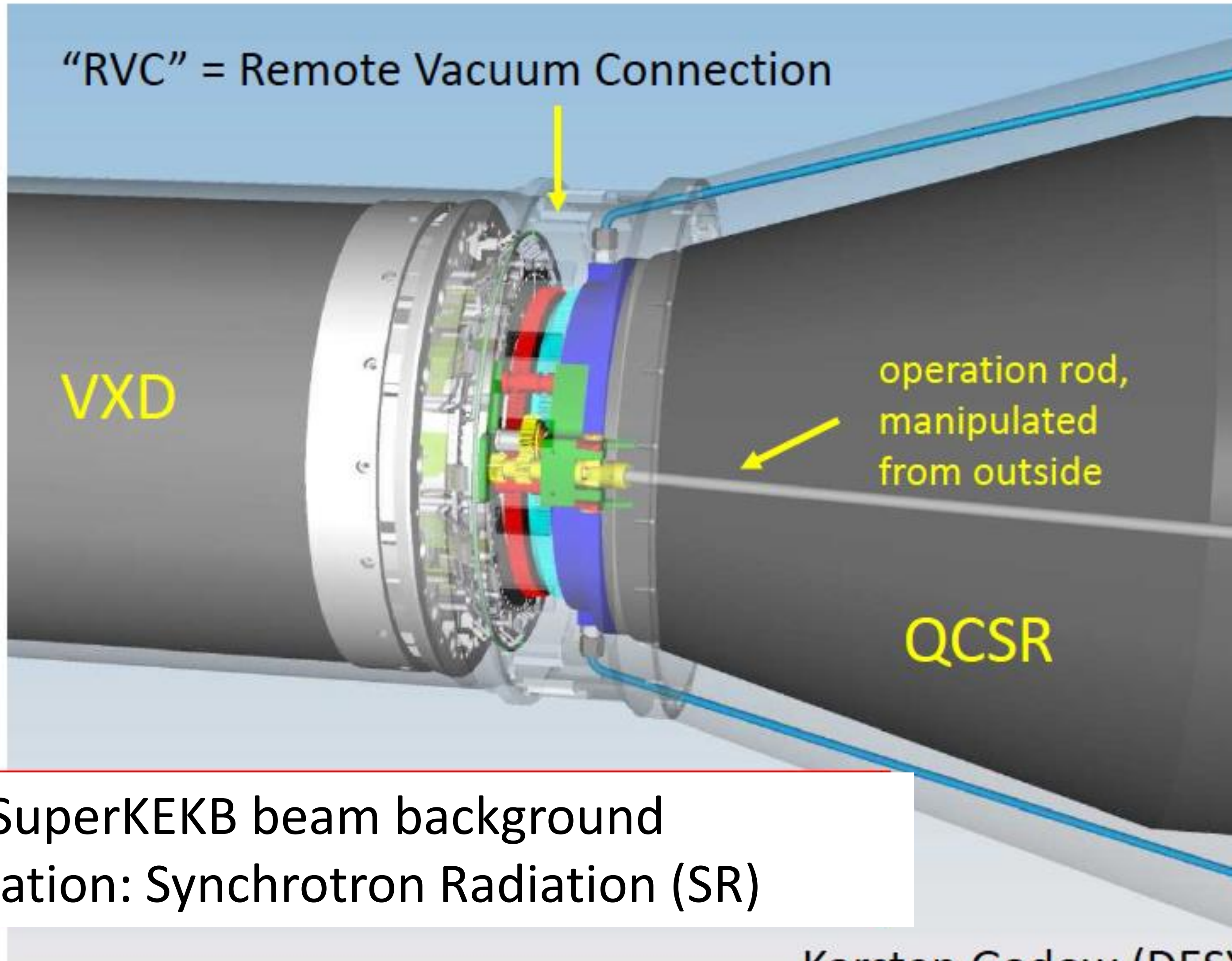



Production testing of readout with single photo-electron laser pulses in Hawaii; electronics resolution ~35ps

All quartz and electronics in hand; now testing and assembling.

# DESY contributions to SuperKEKB

RVC *An important piece of SuperKEKB*



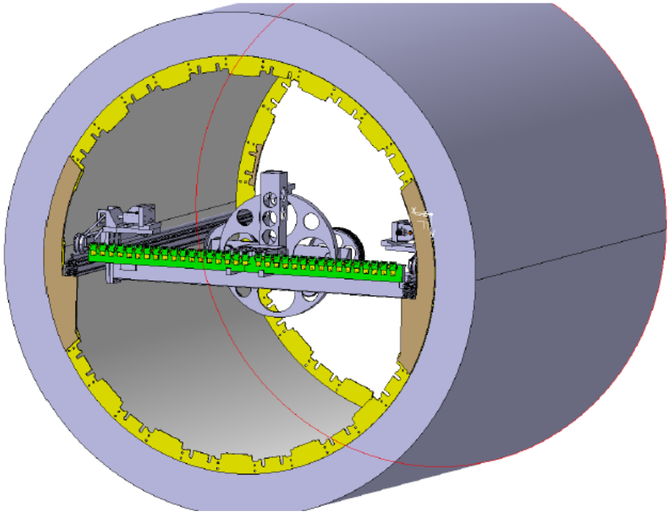

Also SuperKEKB beam background simulation: Synchrotron Radiation (SR)

Karsten Gadow (DESY)

# Major DESY *contributions* to Belle II

Thermal mockup of the vertex detectors/$CO_2$ cooling

(many initial results, on-going)



Precise mapping of the 1.5 T B field of the Belle II superconducting solenoid

(starts June 2016)

Software Alignment of Belle II detectors

(standard Belle II package)

GRID computing and Collaborative Computing Services for Belle II (starts summer 2016)

Not a complete list !