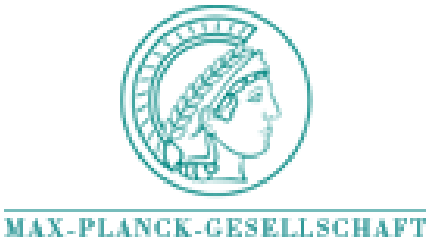


Belle II studies of missing energy decays and searches for dark photon production

Luigi Li Gioi

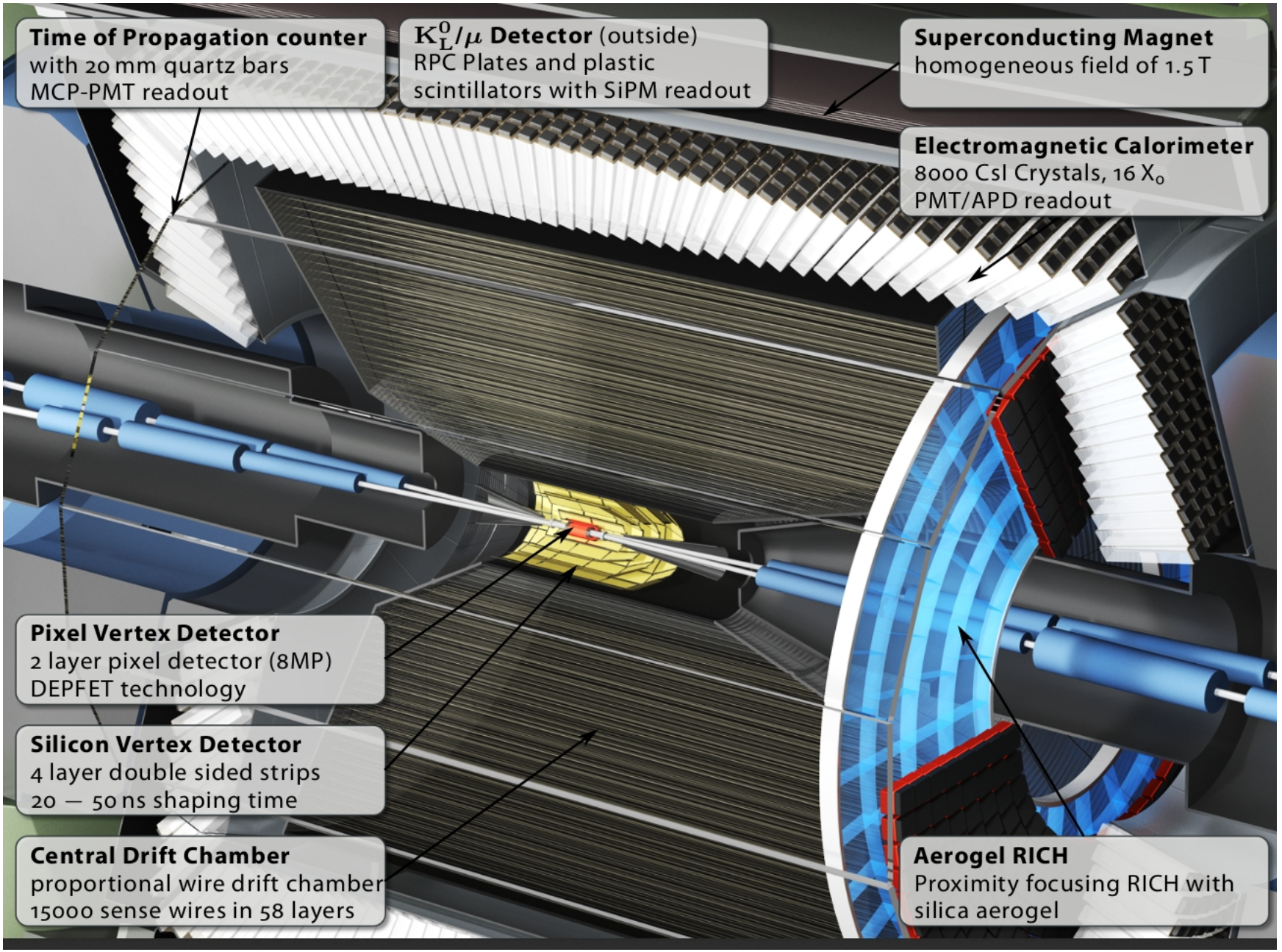
Max-Planck-Institut für Physik, München

- $B \to l \nu \ (\gamma)$
- $B \to D^{(*)} \tau \nu$
- |Vub| and |Vcb|
- Dark sector

LHC ski 2016

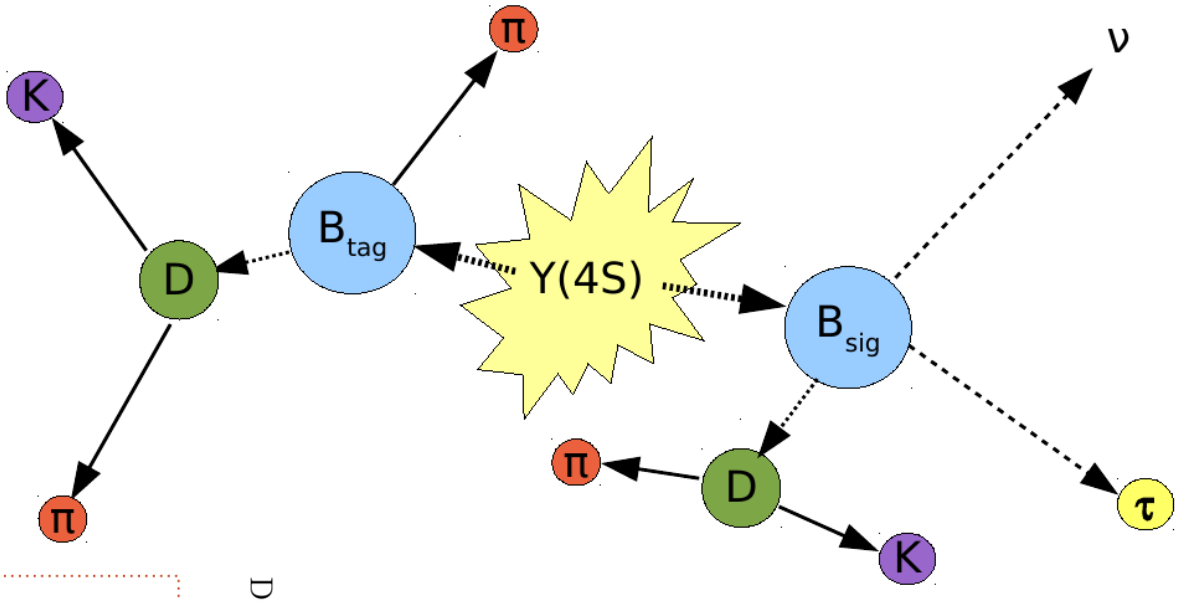
Obergurgl University center, April 14th 2016

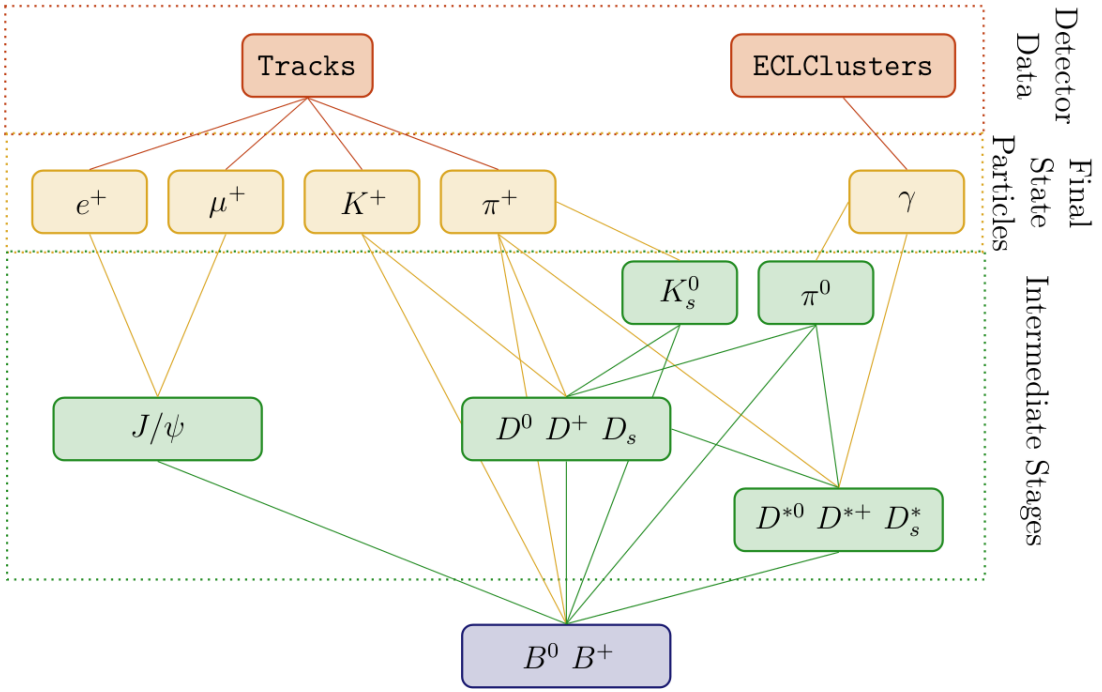
Belle II


Time of Propagation counter
with 20 mm quartz bars
MCP-PMT readout
K_L^0/μ **Detector** (outside)
RPC Plates and plastic
scintillators with SiPM readout
Superconducting Magnet
homogeneous field of 1.5 T
Electromagnetic Calorimeter
8000 CsI Crystals, 16 X_0
PMT/APD readout
Pixel Vertex Detector
2 layer pixel detector (8MP)
DEPFET technology
Silicon Vertex Detector
4 layer double sided strips
20 — 50 ns shaping time
Central Drift Chamber
proportional wire drift chamber
15000 sense wires in 58 layers
Aerogel RICH
Proximity focusing RICH with
silica aerogel

Full event interpretation

- One B meson fully reconstructed.
- Momentum of other B meson known.
- All other final state particles belong to the other B meson.
- Reconstruction of B decays with neutrinos.

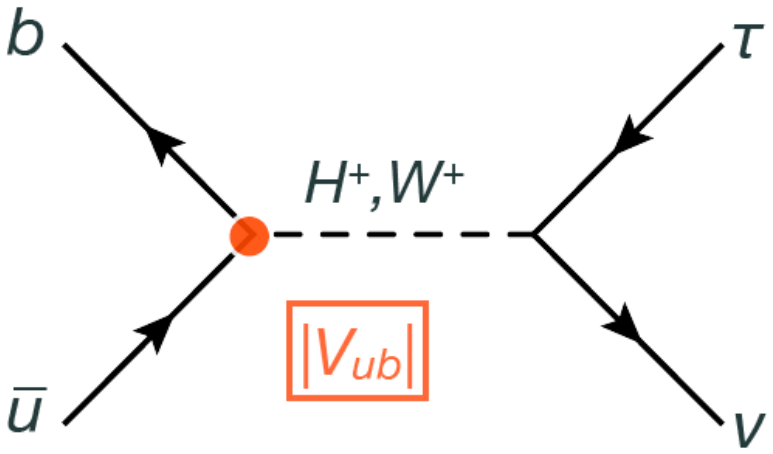




Hierarchical Approach:

- Final-state particle candidates are selected
  - Classification methods are trained using the detector information
- intermediate particle candidates are reconstructed
  - multivariate classifier is trained for each employed decay channel
- All information about a candidate into a single value: the signal-probability

Charged Higgs



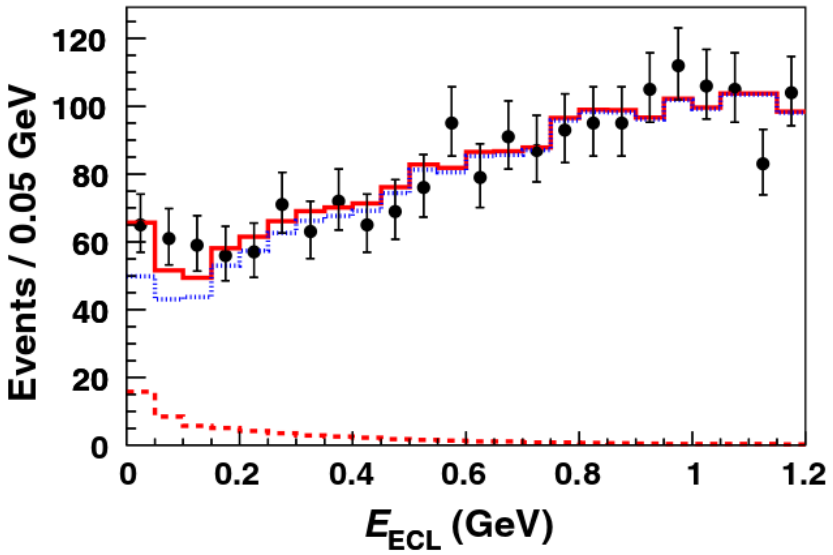
Belle, B→ τν (Had) PRL 110 131801 (2013)
Belle, B→ τν (SL) PRD 92 051102 (2015)

Helicity suppressed
Very small in SM.
NP could Interfere e.g. charged Higgs.

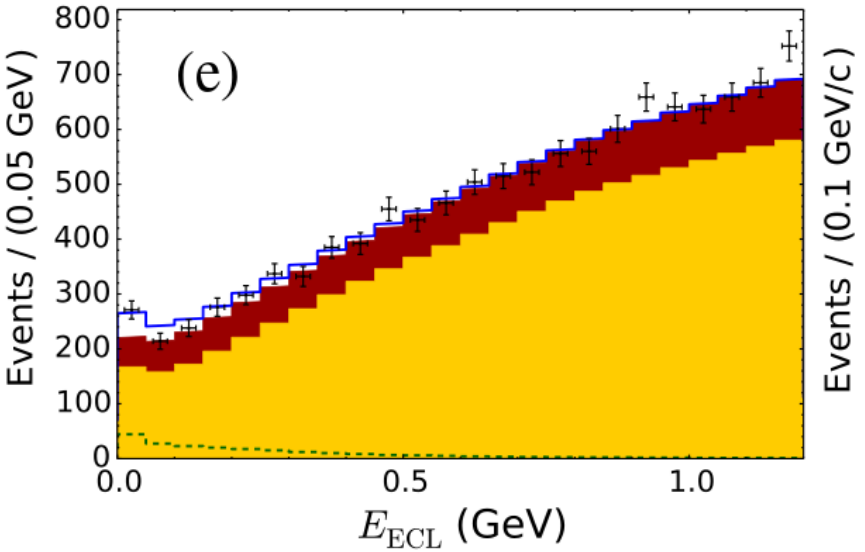
$$\mathrm{BR}(B_u \to \tau\nu_\tau) = \frac{G_F^2 f_B^2 |V_{ub}|^2}{8\pi} \tau_B m_B m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 \left[1 - \left(\frac{m_B^2}{m_{H^+}^2}\right) \lambda_{bb}\lambda_{\tau\tau}\right]^2$$

Type	λ_{DD}	λ_{LL}
I	$\cot\beta$	$\cot\beta$
II	$-\tan\beta$	$-\tan\beta$
III	$-\tan\beta$	$\cot\beta$
IV	$\cot\beta$	$-\tan\beta$

Belle, B→ τν (Had)

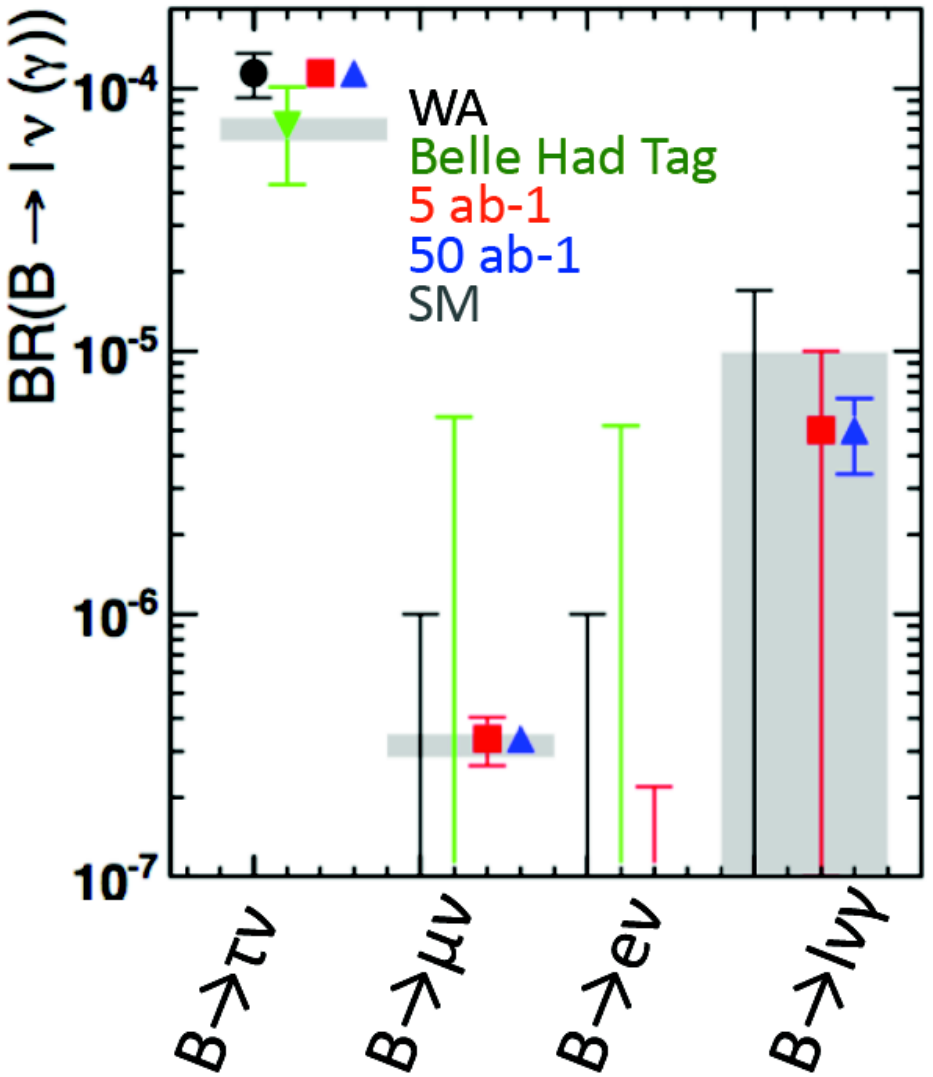


Belle, B→ τν (SL)



Belle II B → l ν (γ) Projections

A photon in the final state would remove the helicity suppression enhancing the weak decay amplitude



Belle, B→ μν, eν (Had) PRD 91 112009 (2015)
Belle, B→ l ν γ (SL) PRD 92 051102 (2015)

$$\mathcal{B}(B^+ \to e^+\nu_e\gamma) < 6.1 \times 10^{-6}$$
$$\mathcal{B}(B^+ \to \mu^+\nu_\mu\gamma) < 3.4 \times 10^{-6}$$
$$\mathcal{B}(B^+ \to \ell^+\nu_\ell\gamma) < 3.5 \times 10^{-6}$$

Belle Had:

$$\mathcal{B}(B^- \to \tau^-\bar{\nu}_\tau) = [0.72^{+0.27}_{-0.25}(\text{stat}) \pm 0.11(\text{syst})] \times 10^{-4}$$

Belle SL:

$$\mathcal{B}(B^+ \to \tau^+\nu_\tau) = [1.25 \pm 0.28(\text{stat.}) \pm 0.27(\text{syst.})] \times 10^{-4}$$

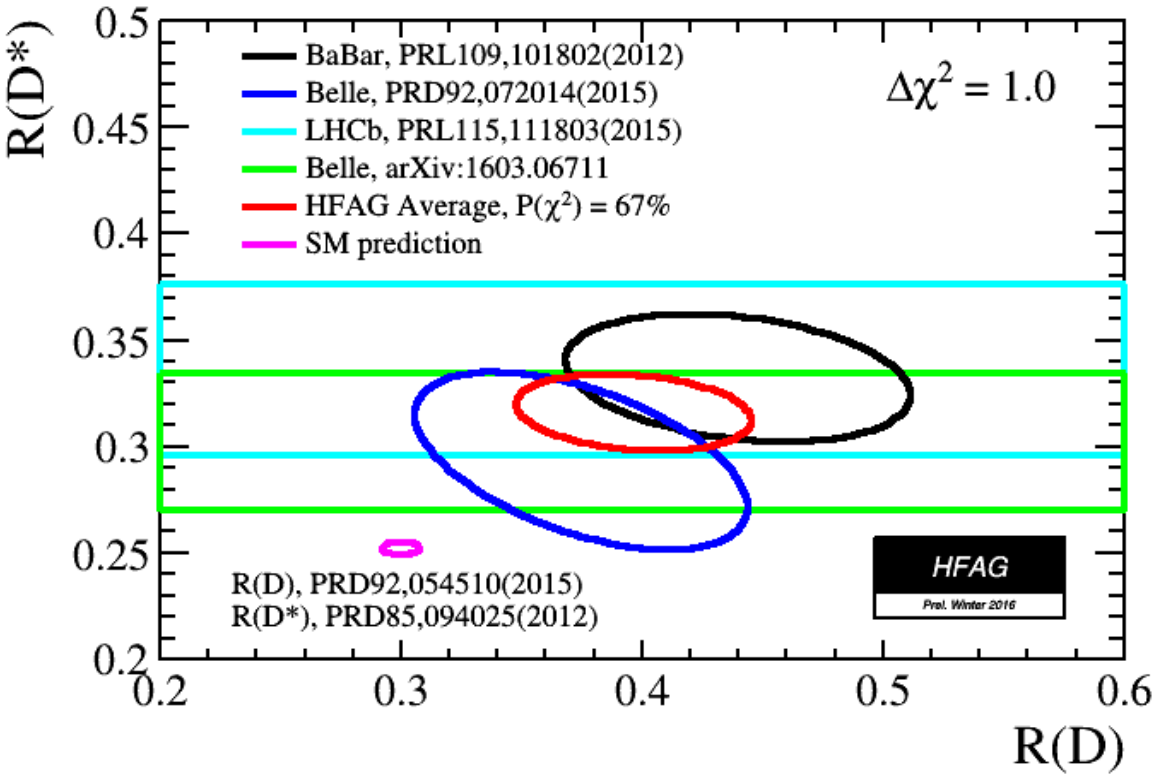
Belle II expected precision:

- B → τν : 5 %
- B → μν, eν, l ν γ : 10 %

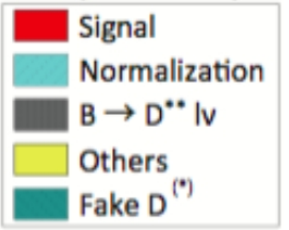
$B \to D^{(*)} \tau \nu$

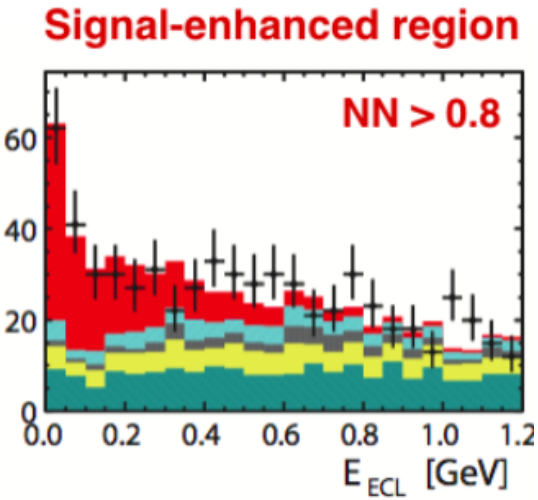
Difference with the SM predictions is at 4.0 σ level

Belle PRD 92 072014 (2015)
BaBar PRL 109 101802 (2012)
PRD 88 072012 (2013)
LHCb PRL 115 111803 (2015)



$$R(D^{(*)}) = \frac{\Gamma(B^0 \to D^{(*)} \tau \nu)}{\Gamma(B^0 \to D^{(*)} l \nu)_{l=\mu,e}}$$

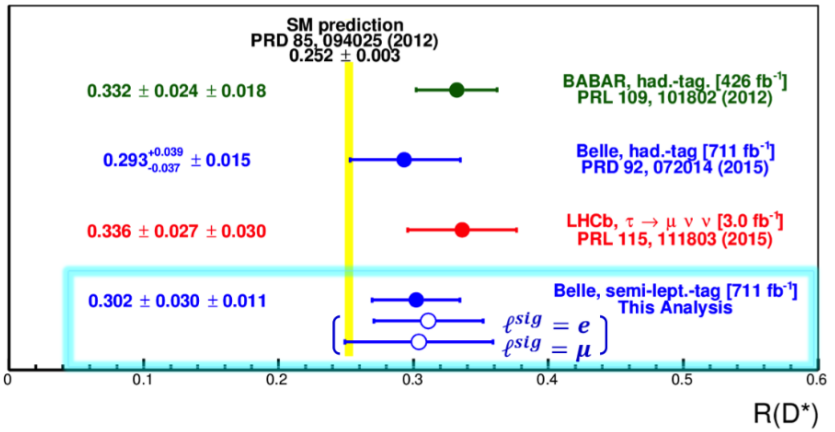




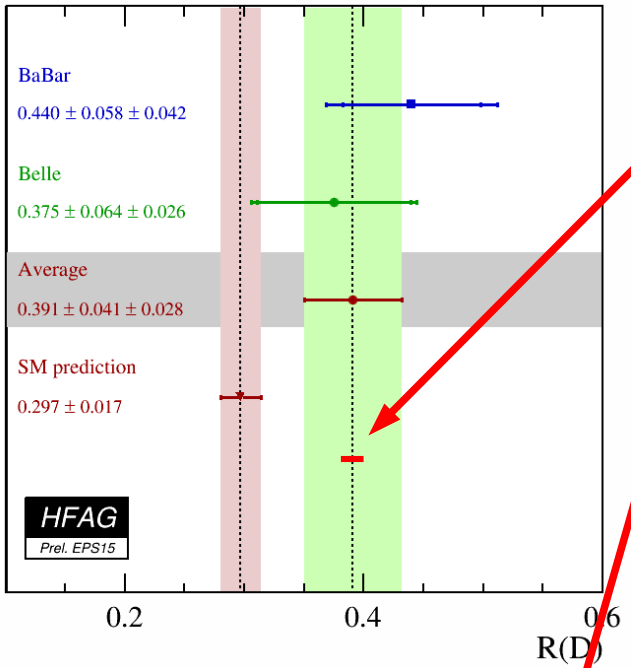
ArXiv:1603.06711

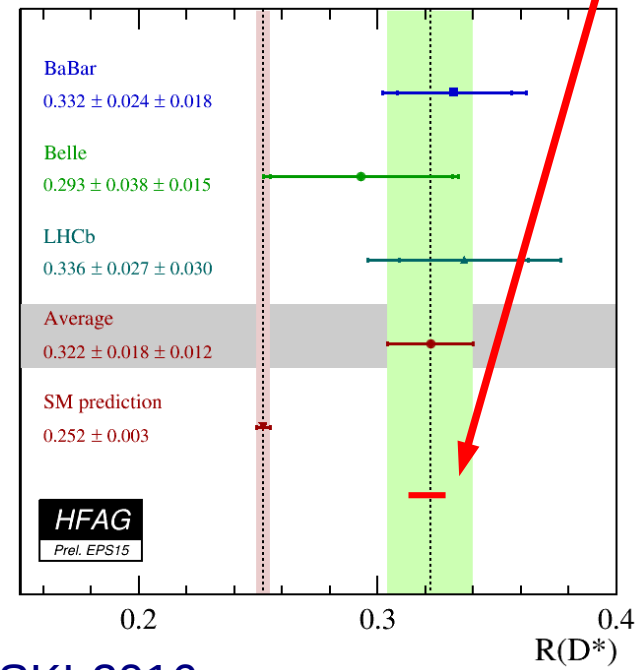
New belle measurement with semileptonic tag:

$$\mathcal{R}(D^*) = 0.302 \pm 0.030(\text{stat}) \pm 0.011(\text{syst}) \quad (13.8\sigma)$$

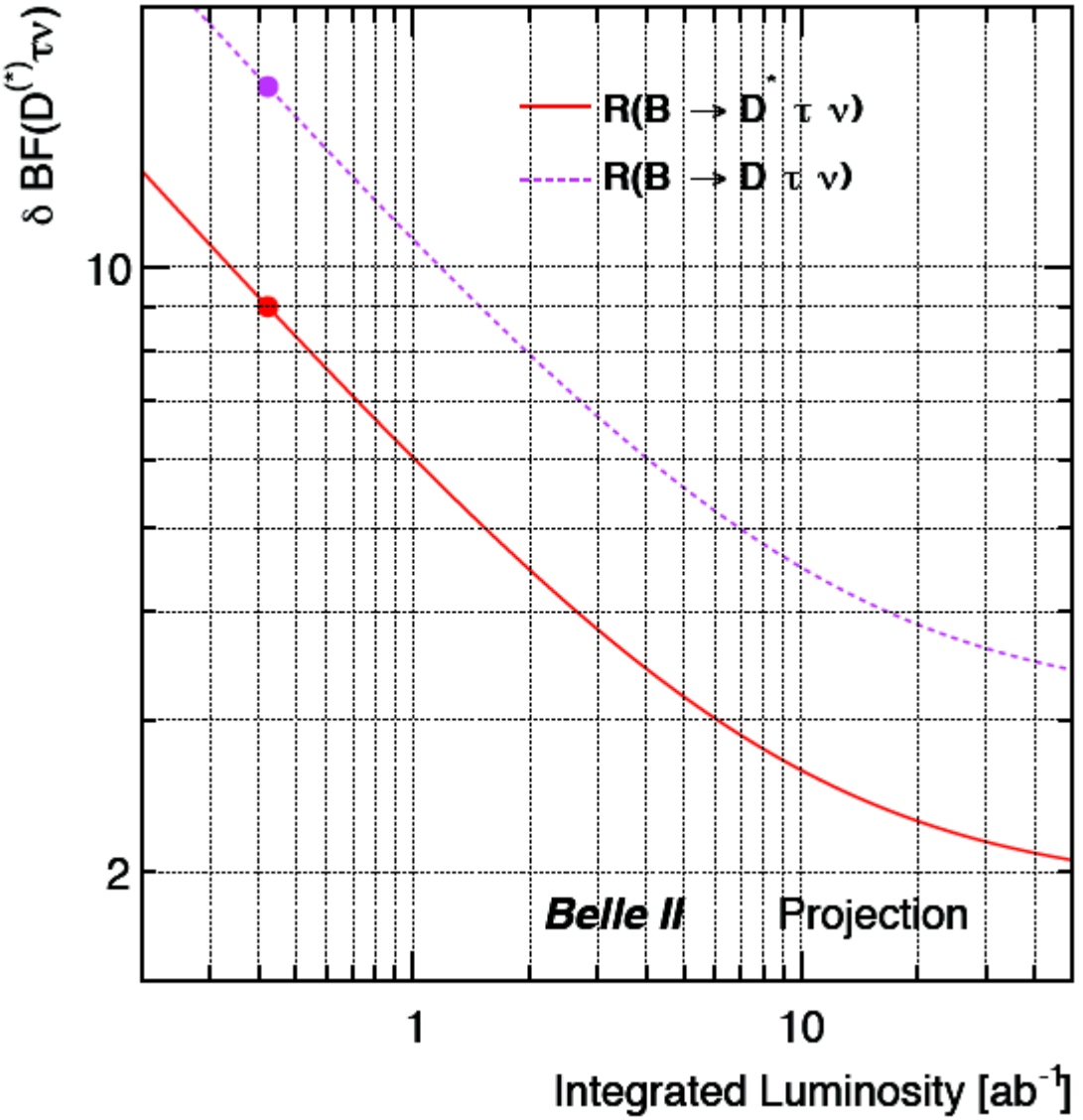


Belle II: B → $D^{(*)}$ τ ν





Belle II: better low p_T tracking and low p PID.

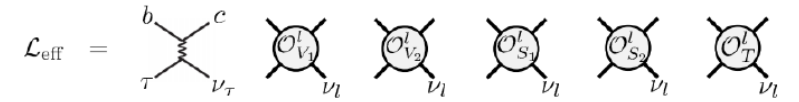


$B \to D^{(*)}\ \tau\ \nu$: R_2-type leptoquarks

ArXiv:1603.06711

Bosons which couple to a lepton-quark pair.
Carry color & electric charge, baryon &lepton #.
Unified description of leptons and quarks.

$$-\mathcal{L}_{\text{eff}} = 2\sqrt{2}G_F V_{cb} \sum_{l=e,\mu,\tau} [(\delta_{l\tau} + C^l_{V_1})\mathcal{O}^l_{V_1} + C^l_{V_2}\mathcal{O}^l_{V_2} + C^l_{S_1}\mathcal{O}^l_{S_1} + C^l_{S_2}\mathcal{O}^l_{S_2} + C^l_T\mathcal{O}^l_T]$$



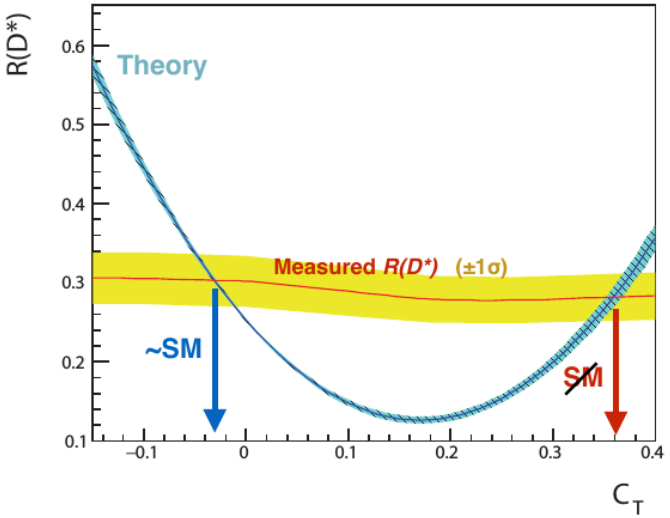
6 LQ models in b → c τ ν decays

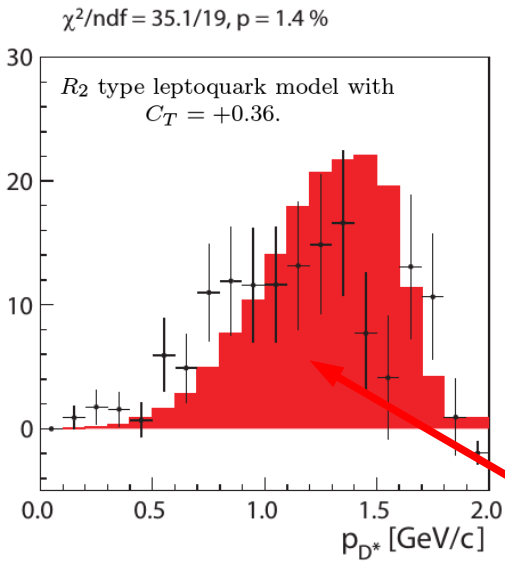
- $B \to D^{(*)}\ \tau\ \nu$ is sensitive to the tensor operator.
- R_2 -type LQ model good candidate for compatibility test.
- Relative Wilson coeffs. $C_{S2} = +7.8\ C_T$ at the b mass scale, assuming M_{LQ} = O(1) TeV.

Six LQ Models		$O^l_{V_1}$	$O^l_{V_2}$	$O^l_{S_1}$	$O^l_{S_2}$	O^l_T
Scalar	S_1	●			●	−●/4
	S_3	●				
	R_2				●	●/4
Vector	V_2^μ			●		
	U_1^μ	●		●		
	U_3^μ	●				

Assignment of Quantum Numbers

	S_1	S_3	V_2	R_2	U_1	U_3
spin	0	0	1	0	1	1
$F = 3B + L$	−2	−2	−2	0	0	0
$SU(3)_c$	3^*	3^*	3^*	3	3	3
$SU(2)_L$	1	3	2	2	1	3
$U(1)_{Y=Q-T_3}$	1/3	1/3	5/6	7/6	2/3	2/3



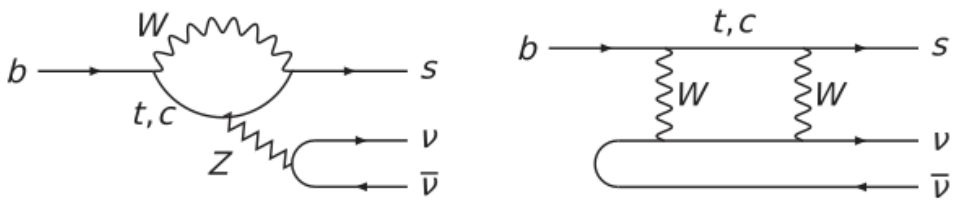


Compatibility test: (Preliminary)

- Two favored regions found:
  - SM-like @ $C_T = -0.03$
  - Non-SM-like @ $C_T = +0.36$

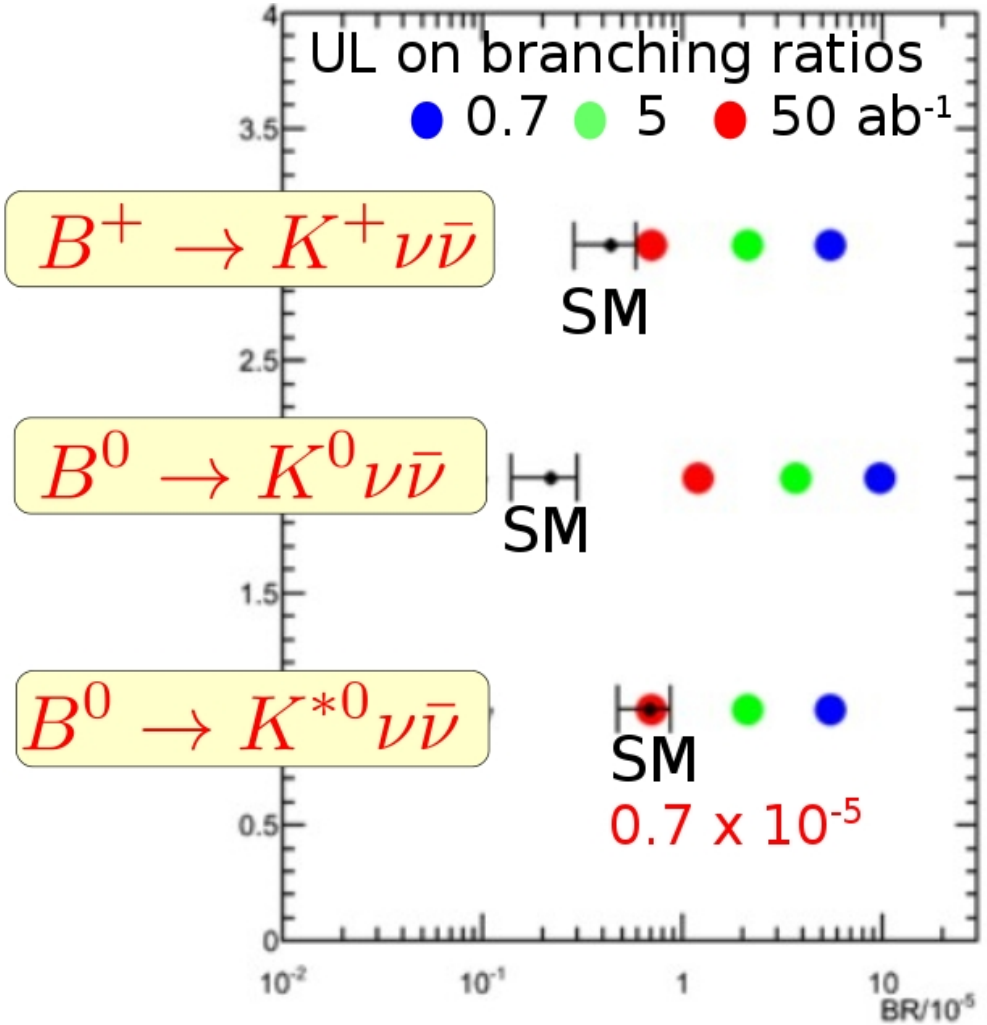
Large disagreement in D* momentum distribution

B → K(*) ν ν



$$\mathrm{BR}(B^+ \to K^+ \nu\bar{\nu})_{\mathrm{SM}} = (4.68 \pm 0.64) \times 10^{-6}$$
$$\mathrm{BR}(B^0 \to K^{*0} \nu\bar{\nu})_{\mathrm{SM}} = (9.48 \pm 1.10) \times 10^{-6}$$

Babar, B → K(*) ν ν , PRD 87, 112005 (2013)
Belle, B → K(*)/π/ρ ν ν, PRD 87, 111103(R) (2013)



Various new-physics scenarios exist that could significantly enhance the B → K(*) ν ν branching fractions

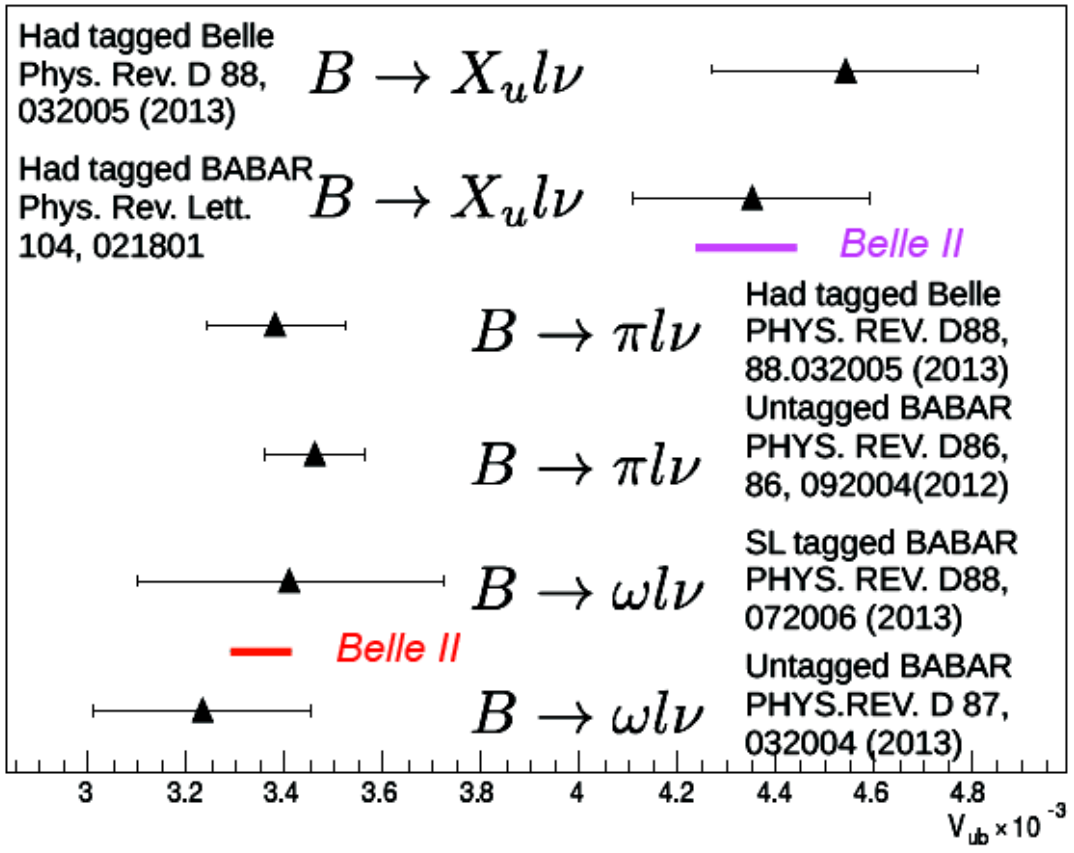
Ultimate test of Belle II

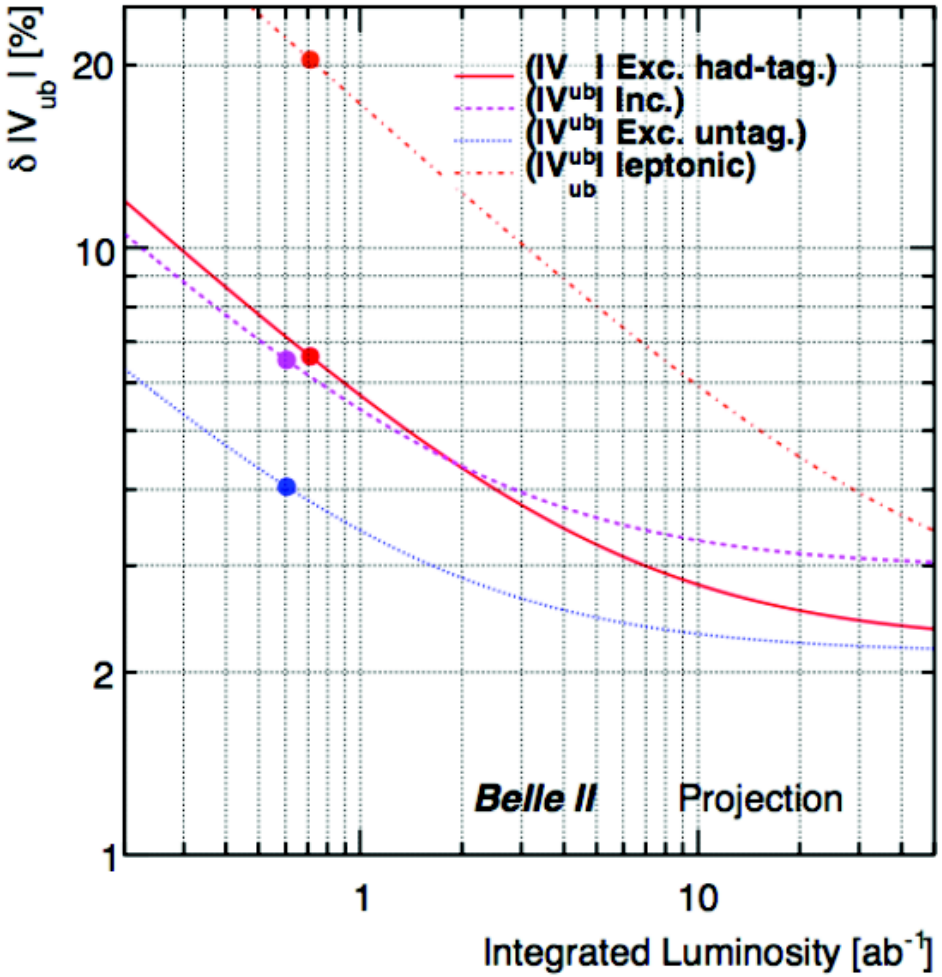
- Better B-Tag efficiency, better KLID, Ks efficiency 30% better.
- B → K(*) ν ν can be probed at 5σ

|Vub| and |Vcb|: Future

There is currently a 3σ discrepancy between exclusive and inclusive measurements for both |Vcb| and |Vub|. Belle II should resolve this.

Alexander Ermakov (FPCP14):





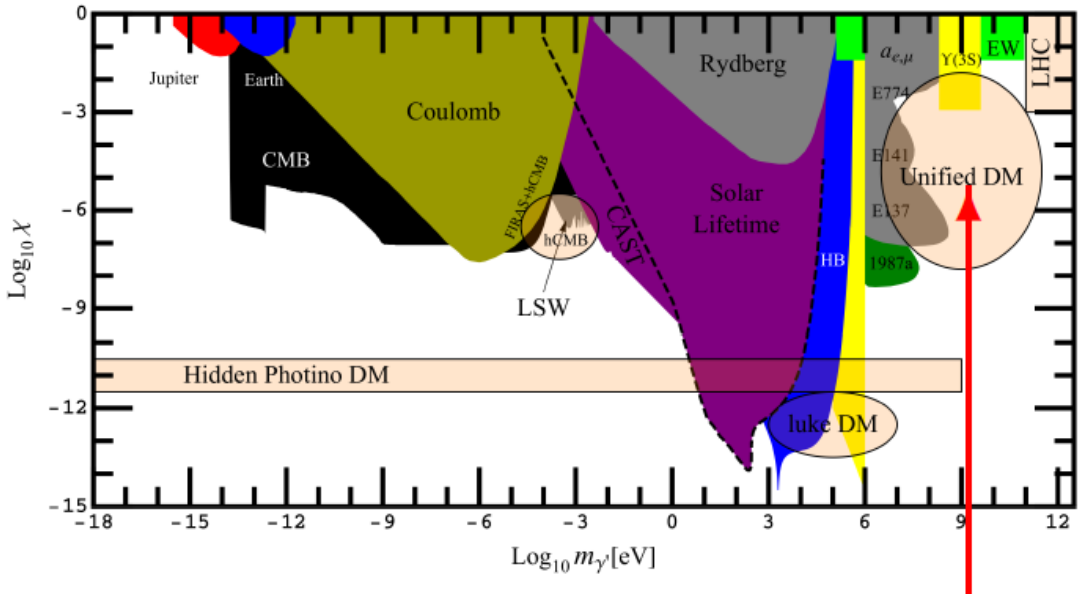
Dark gauge bosons

Dark gauge bosons, or dark photons, A' = γ' = A = U, have been searched since the late 80s and are postulated to have:

- Very small couplings to Standard Model particles
- Low mass: of order MeV to GeV

Recent interest in dark sector models (Unied DM) that:

- Explain observed anomalies
- Often introduce, in addition, a dark Higgs boson, h', by a Higgs mechanism



arXiv:1002.0329v1

astrophysical and cosmological constraints and experimental limits

kinetic mixing ($\chi = \varepsilon$) vs. A' boson mass

BaBar, Belle, and Belle II can cover region between a few MeV/c^2 and 10 GeV/c^2

Belle limits

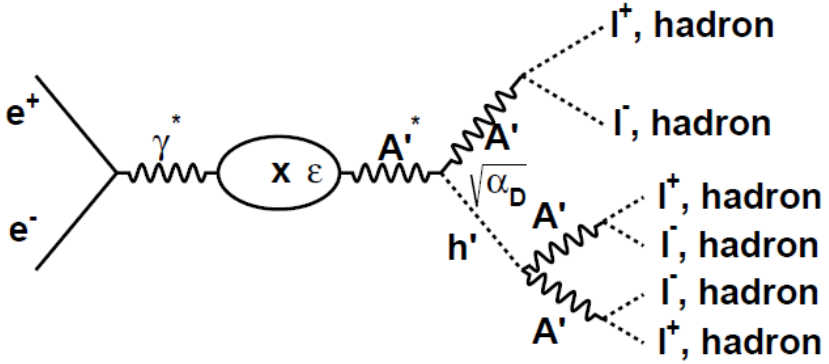
PRL 114, 211801 (2015)

Production in the Higgs-strahlung channels, $e^+e^- \rightarrow A'h'$, with $h' \rightarrow A'A'$.

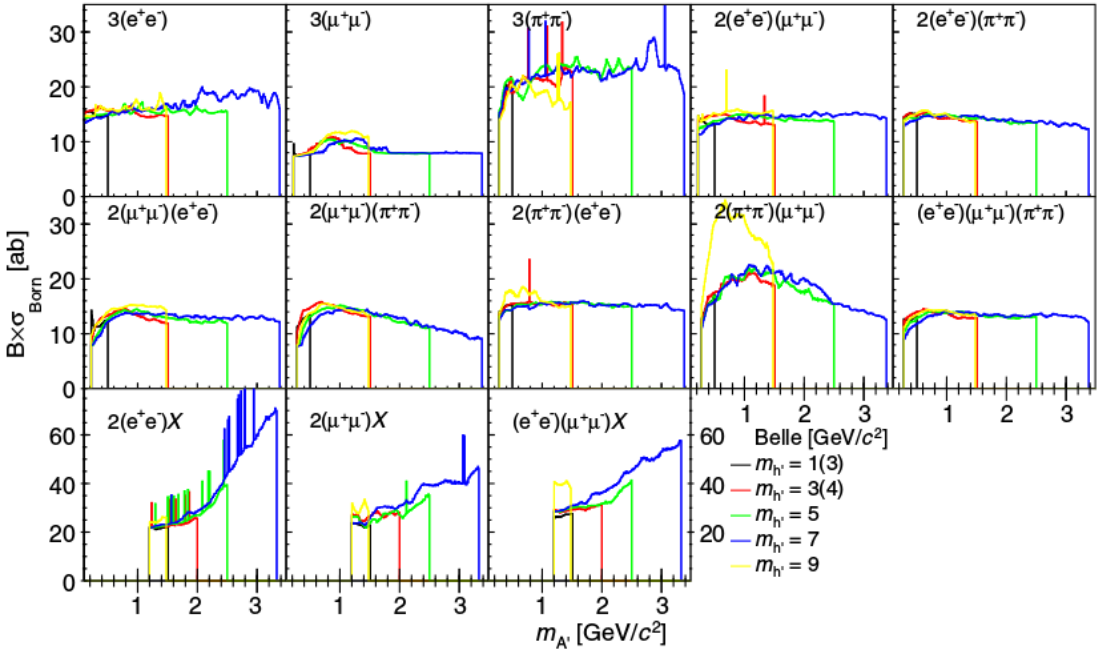
- A' and h' assuming prompt decays
- $m_{h'} > 2m_{A'}$
- $0.1 < m_{A'} < 3.5$ GeV/c^2 and $0.2 < m_{h'} < 10.5$ GeV/c^2

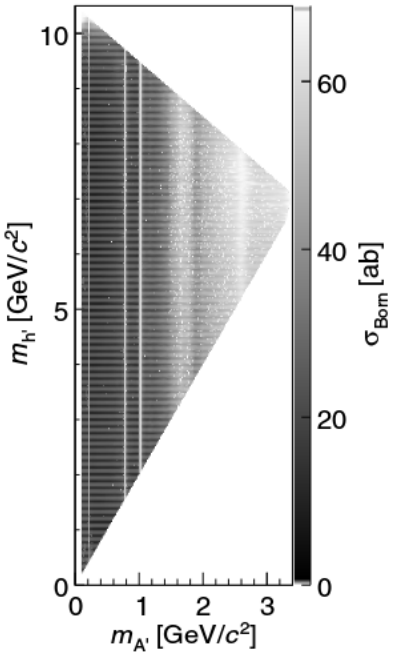
α_D : (A' – h') coupling constant

ε : kinematic mixing



Belle limits on B × σ_{Born} and σ_{Born}





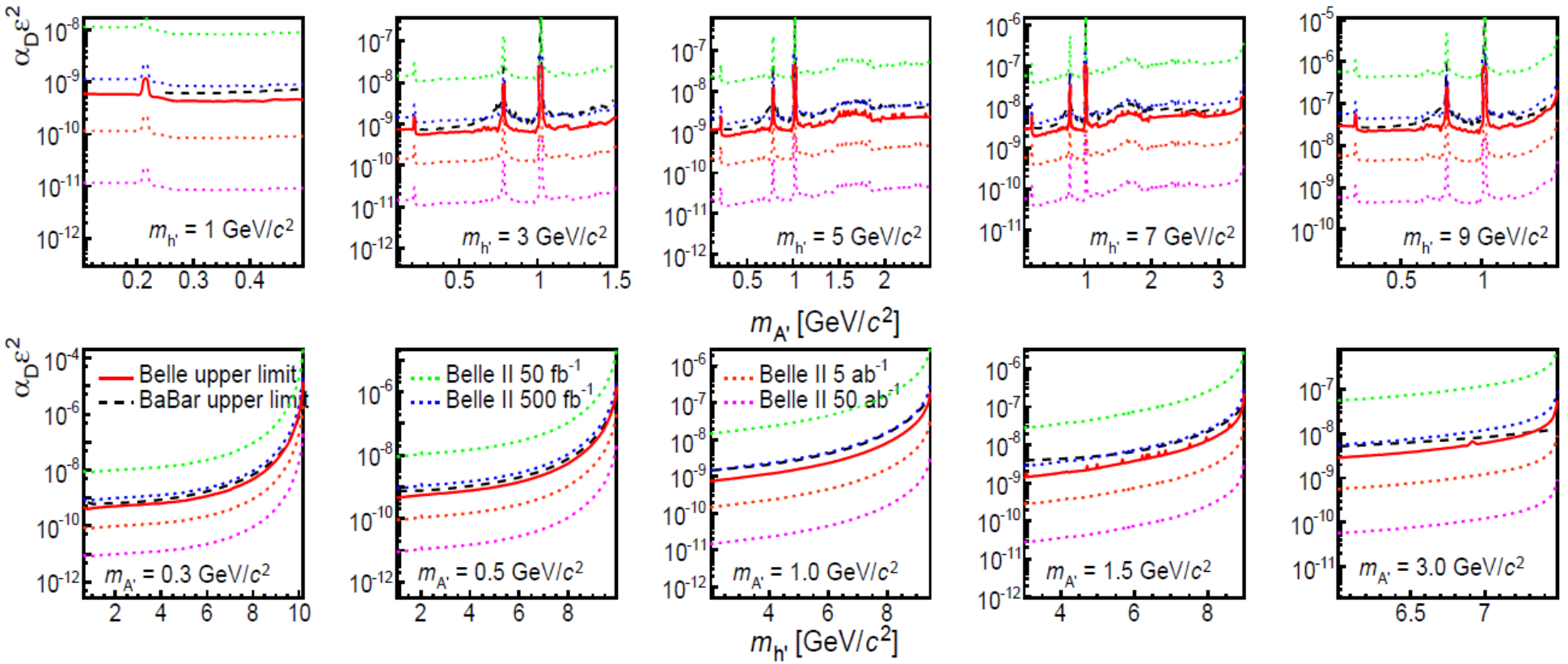
90% CL upper limit on the combined Born cross section

90% CL upper limit for each of the 13 final states

Belle(II) limits on $\alpha_D \varepsilon^2$

Belle combined limits compared to BaBar combined limits and Belle (II) expectations

Assuming branching fractions and couplings versus cross section from
B. Batell et al. PRD 79 (2009) 115008



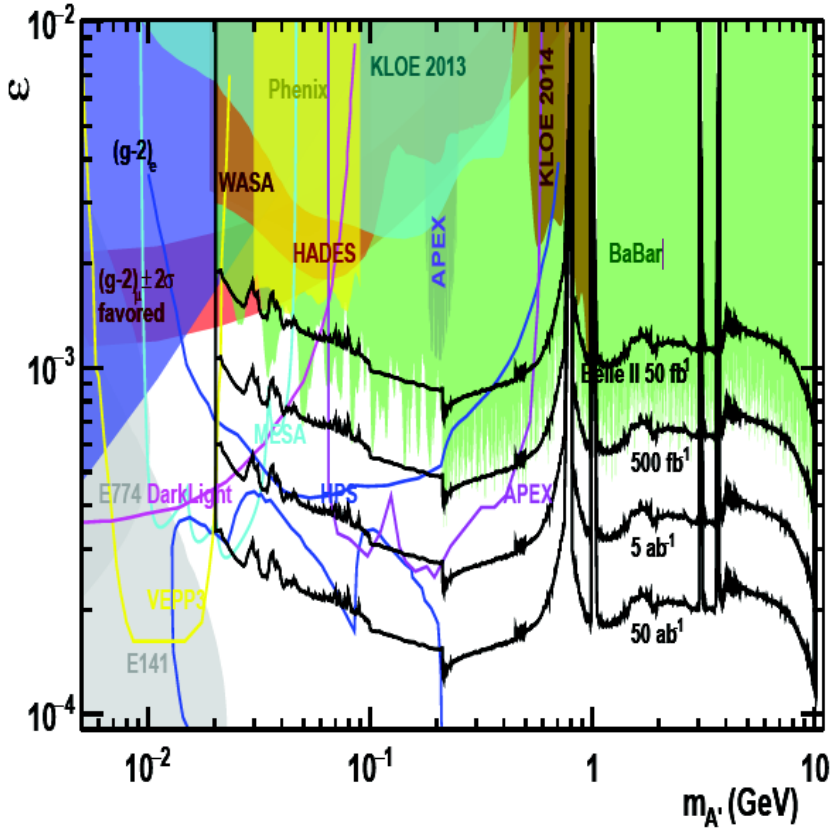
90% CL upper limit on the product $\alpha_D \varepsilon^2$ versus dark photon mass (top row) and dark Higgs boson mass (bottom row)

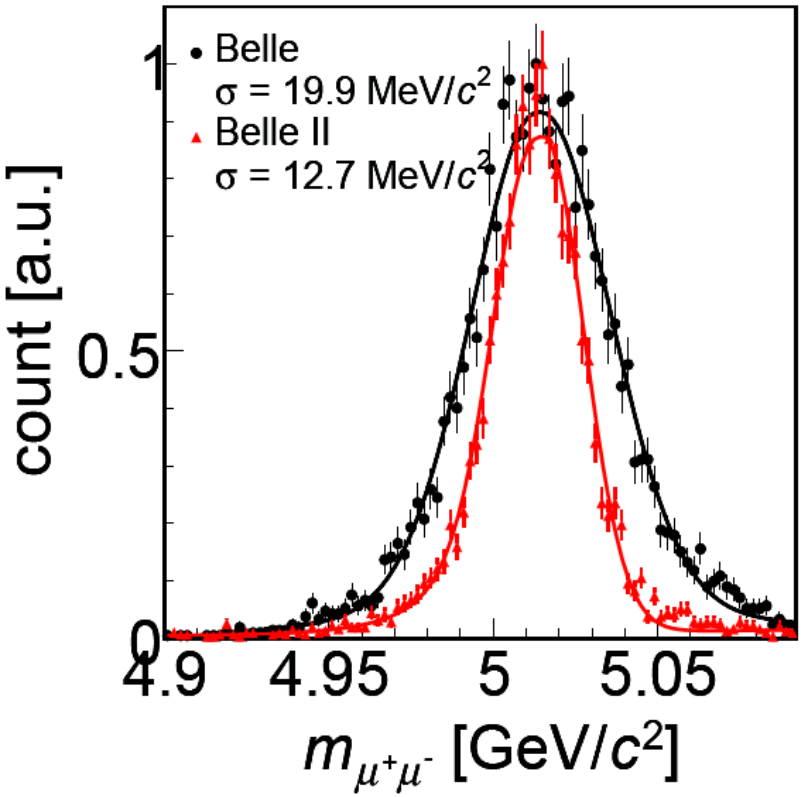
Belle II prospects for radiative decays

C. Hearty, B2TIP2014

Predicted Belle II upper limits extrapolated from BaBar PRL 113, 201801 (2014)

- $e^+e^- \rightarrow \gamma A'$, with $A' \rightarrow l^+l^-$, with l = e, μ
- Extrapolation assuming BaBar trigger efficiency





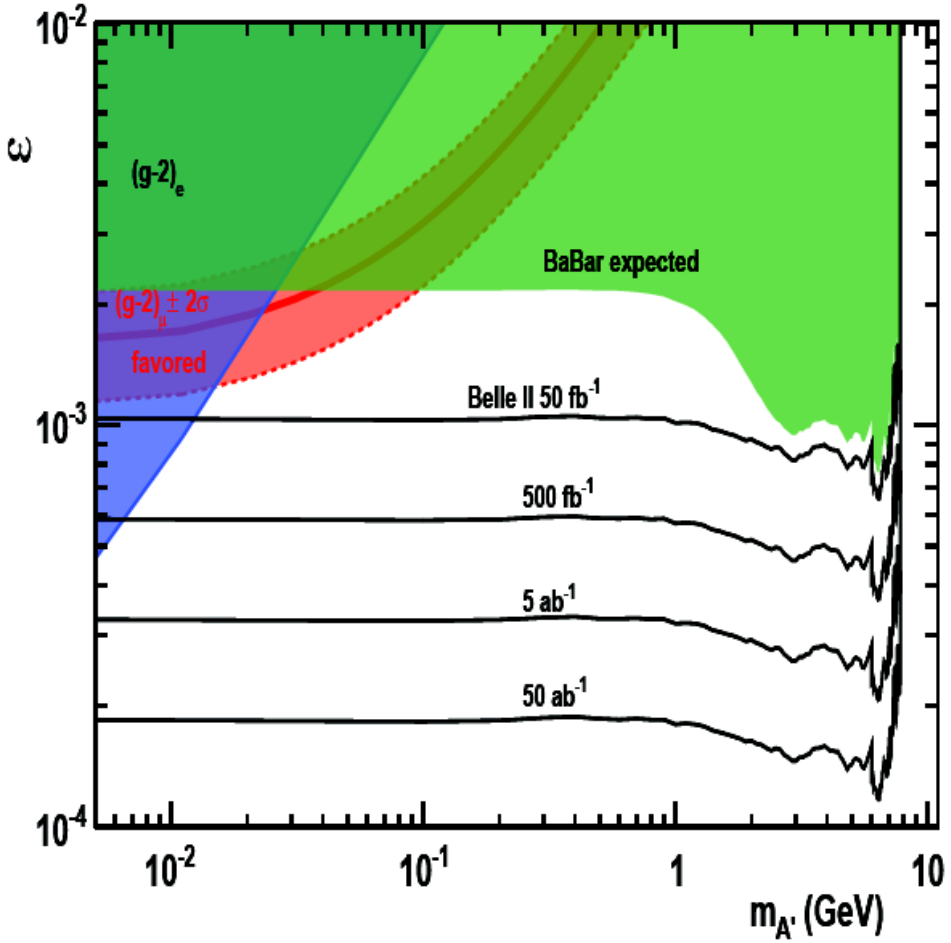
Belle II di–muon invariant mass resolution improved by 35% compared to Belle

Belle II prospects for radiative decays

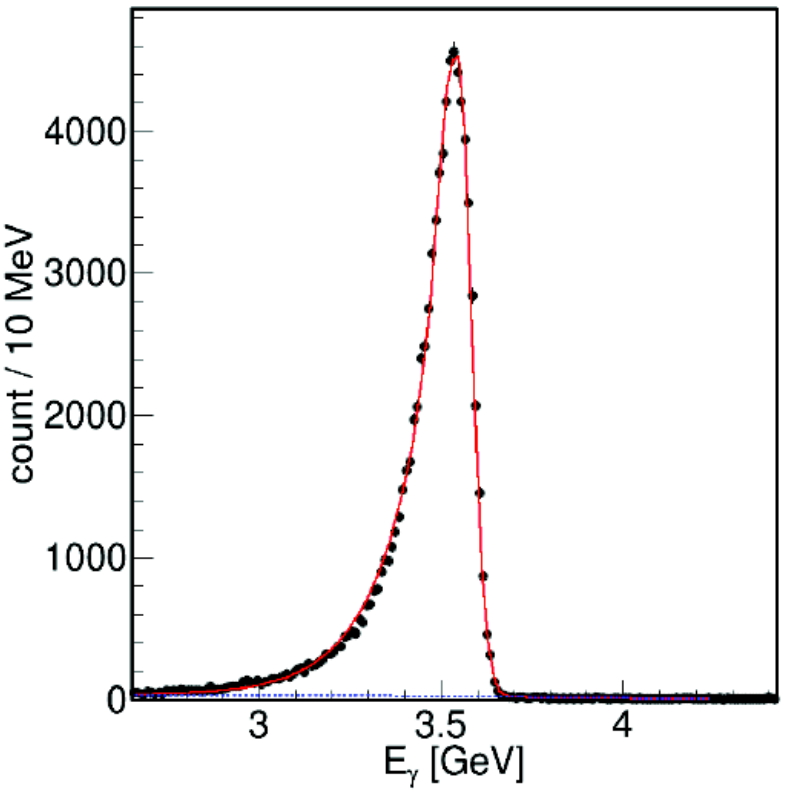
C. Hearty, B2TIP2014

Predicted Belle II upper limits extrapolated from BaBar arxiv:0808.0017

- $e^+e^- \rightarrow \gamma A'$, with $A' \rightarrow \chi\chi$, χ light dark matter R. Essig et al. arXiv:1309.5084
- Extrapolation assuming BaBar trigger efficiency



Simulated mono-energetic photon signature for $m_{A'} = 6$ GeV/c^2



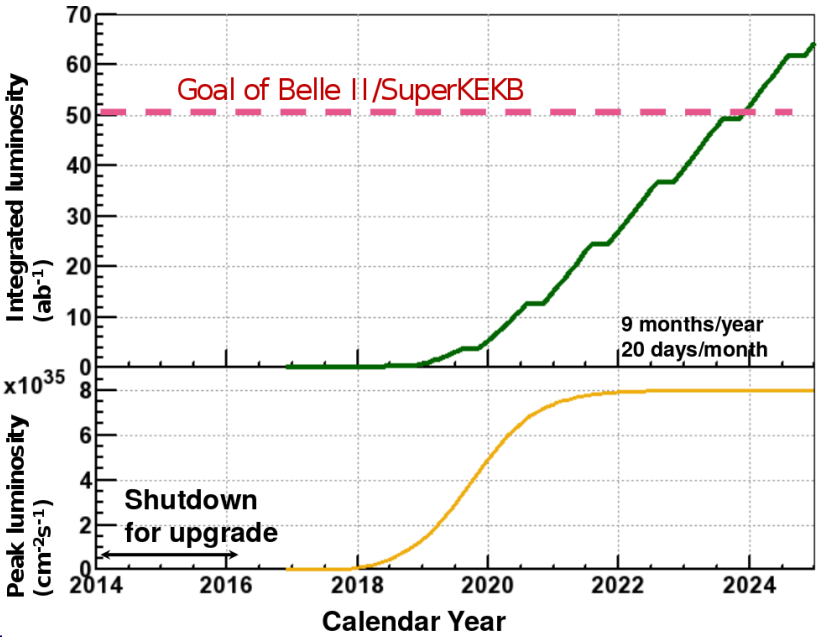
Summary

- Rich physics program at SuperKEKB/BelleII in preparation
- Today: missing energy and dark photon

- Decays of B meson with large missing energy can only be studied at e+e- colliders
  - The anomaly in $B \rightarrow D^{(*)} \tau \nu$ will be resolved in the first years of data taking
  - $B \rightarrow K^{(*)} \nu \nu$ will be the ultimate test for Belle II

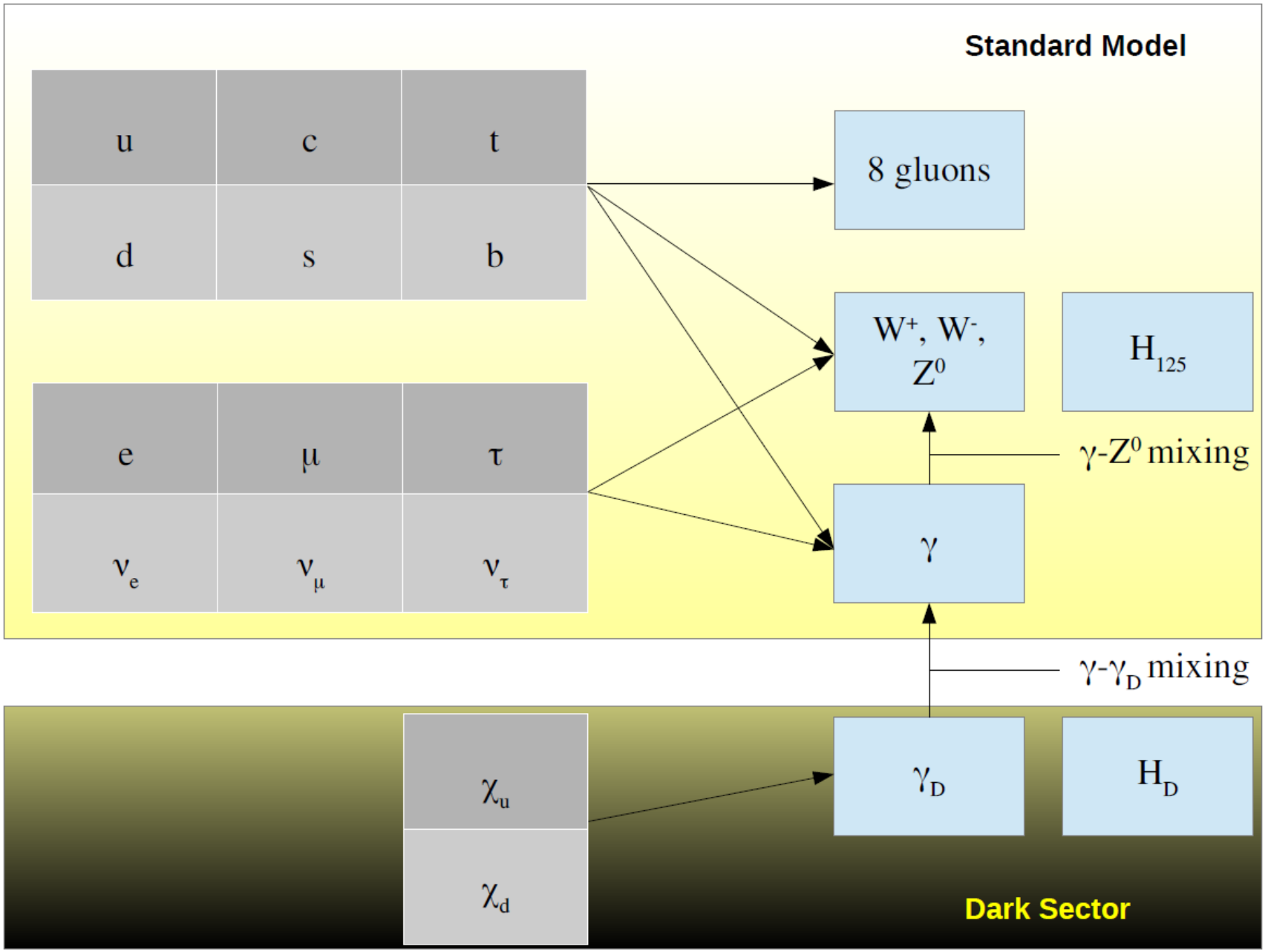
- Lack of experimental evidence for WIMPs support the idea to test alternative explanations for dark matter, for example dark sector models involving a dark photon
  - Belle II will cover additional regions of the parameter space of the dark photon mass vs. mixing parameter
  - During the first years of data taking higher low multiplicity and single photon trigger rate is expected

- SuperKEKB commissioning already started
- BelleII sub--detectorspartially built, and DAQ integrated
- Belle II first physics in 2018

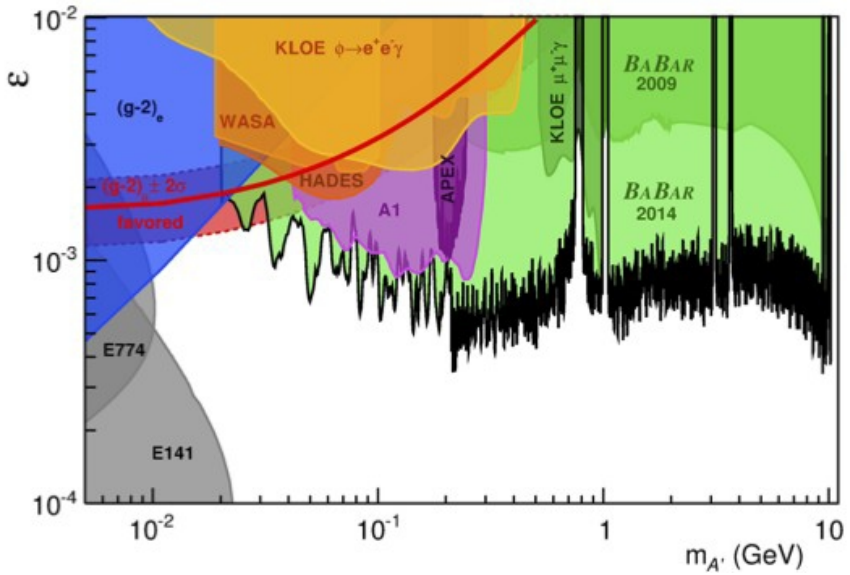


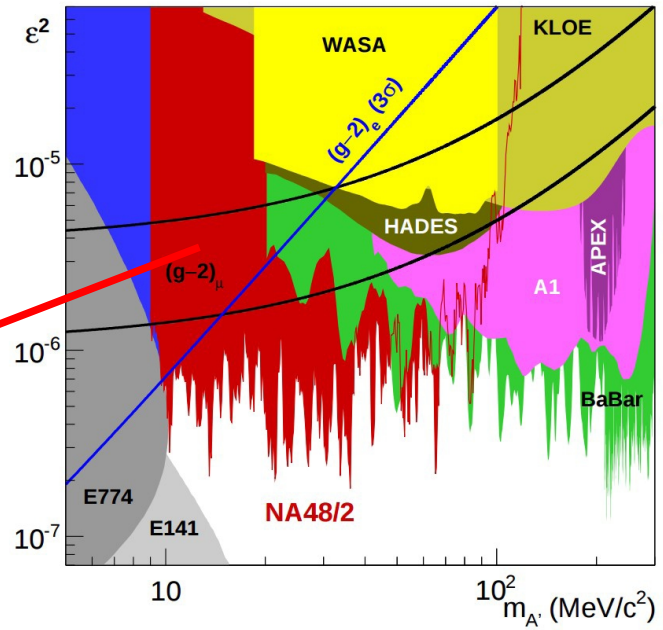
Backup slides

Dark sector


Standard Model
u
c
t
d
s
b
e
μ
τ
ν_e
ν_μ
ν_τ
8 gluons
W^+, W^-, Z^0
H_{125}
γ-Z^0 mixing
γ
γ-γ_D mixing
χ_u
χ_d
γ_D
H_D
Dark Sector

Dark photon: current limits



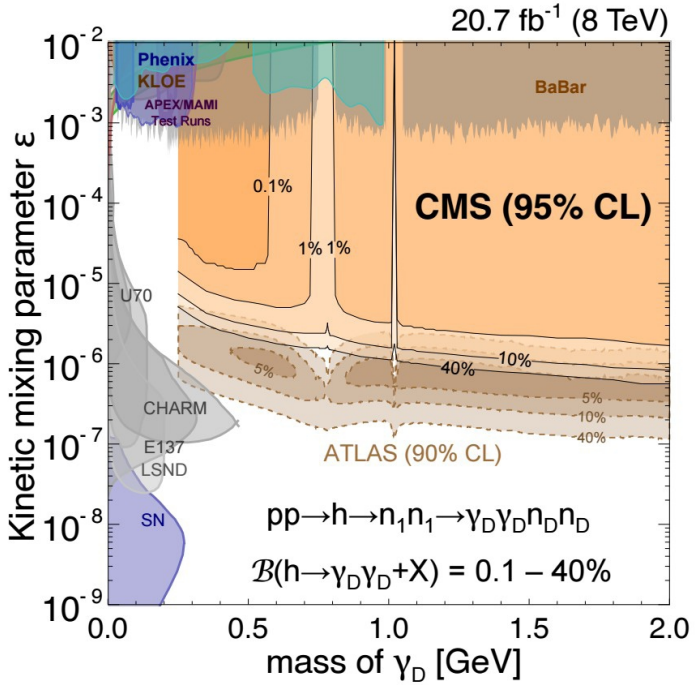


dark photon explanation of $(g-2)_\mu$ ruled out for $A' \to e^+e^-$

NA48 arXiv:1504.00607
π^0 decays

Many constraints for different regions of the parameter space from different experiments:

- top left: BaBar ,
- bottom left NA48,
- bottom right CMS (containing ATLAS) [highly model dependent]



arXiv:1506.00424 [hep-ex]
Long lived, decays to leptons