LHCb and Belle II Overview

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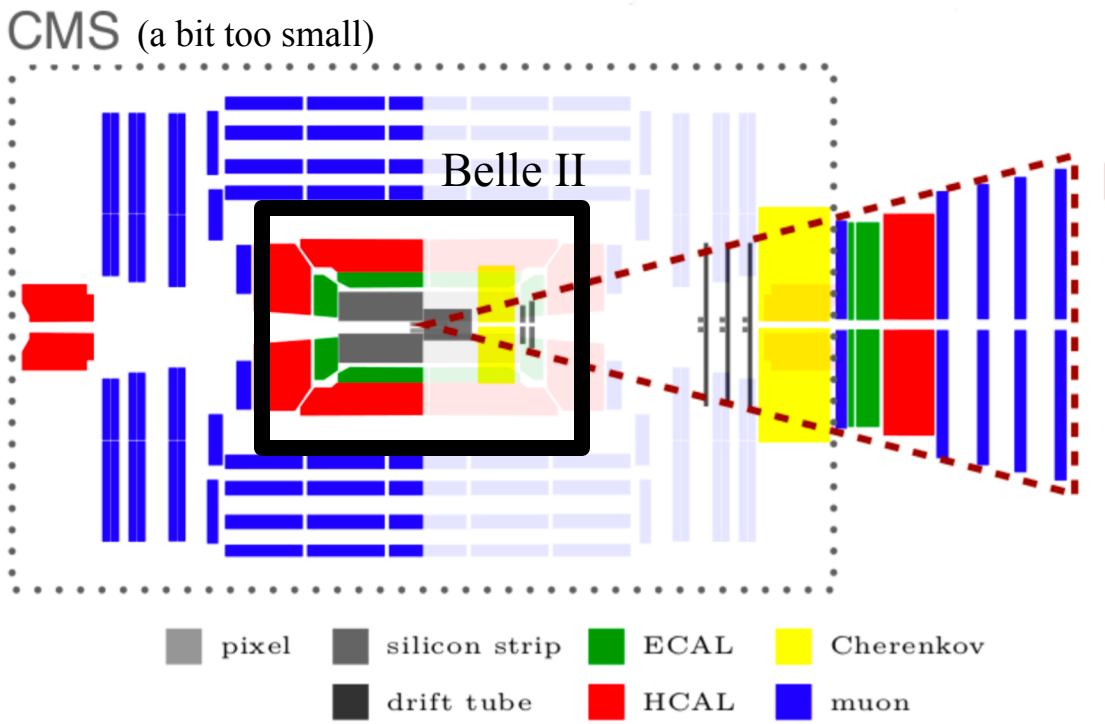
On behalf of the Belle II and LHCb collaborations

Fifth workshop of the LHC LLP Community, CERN, May 2019

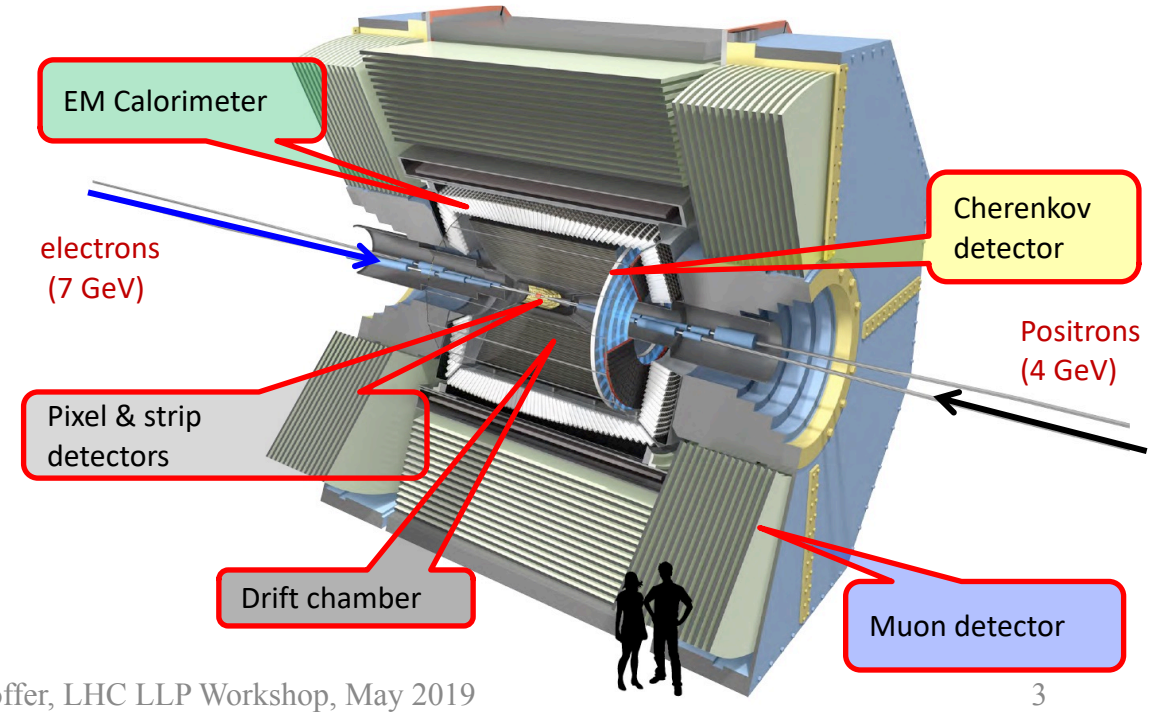
Outline

- Comparison of the two experiments
- LLP results from LHCb
- LLP results from BABAR & Belle
- Belle II operation status
- Some additional Belle II LLP prospects
- Points for discussion / thoughts

Detectors



Tracking @ $r < 120$ cm
Muons @ $r < 300$ cm



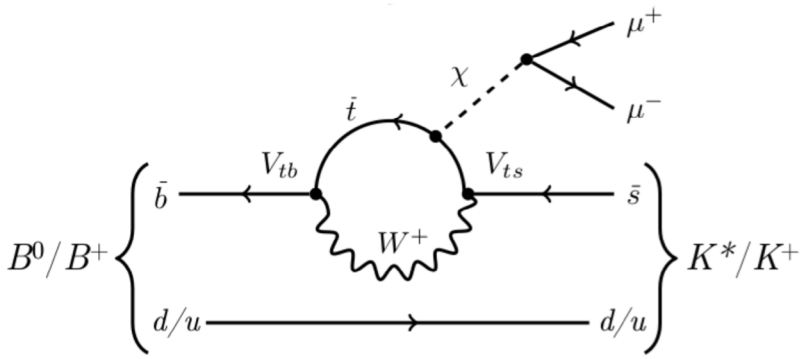
Competition and Complementarity

(Caveat: generic statements, impact is analysis dependent)

Property	LHCb	Belle II
$\sigma_{b\bar{b}}$ (nb)	~150,000	~1
$\int L\,dt$ (fb^{-1}) by ~2027	~25	~50,000
Background level	High	Low
Typical efficiency	Low	High
Initial state	Not well known	Well known
Decay-time resolution	Excellent	Very good
Collision spot size	Large ($10\times10\times10^5\,\mu\mathrm{m}^3$)	Tiny ($6\times0.06\times10^2\,\mu\mathrm{m}^3$)
LLP-sensitive Size	Large	Small
Typical boost of LLP	Large	Small
Mass reach	High	Low
τ physics capability	Limited	Excellent

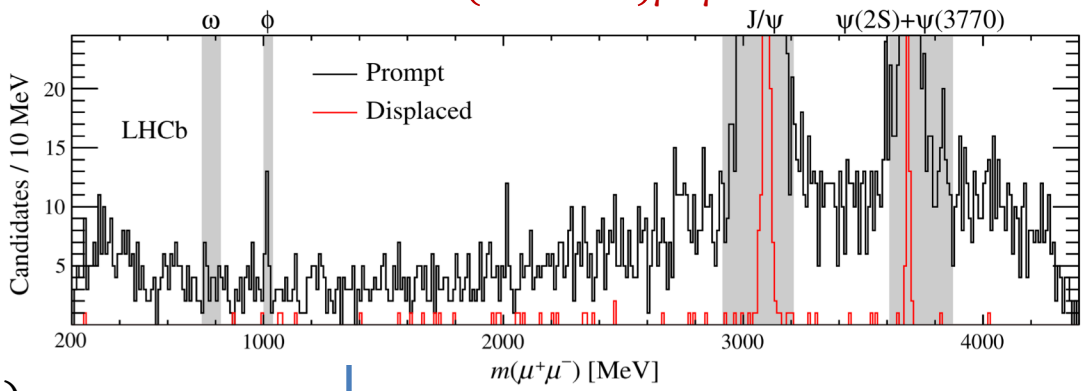
LLP searches at LHCb

LHCb searches in $B \to K^{(*)}\chi(\to \mu^+\mu^-)$

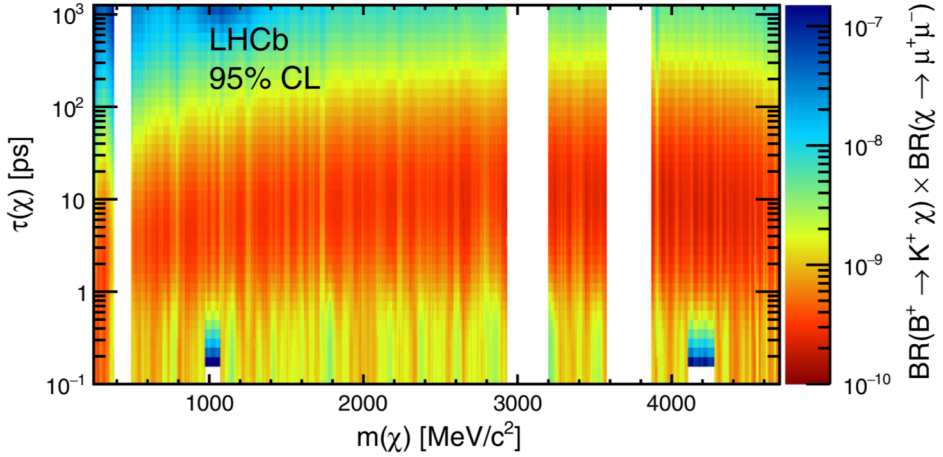


PRL 115 (2015) 161802, PRD 95 (2017) 071101 (R)

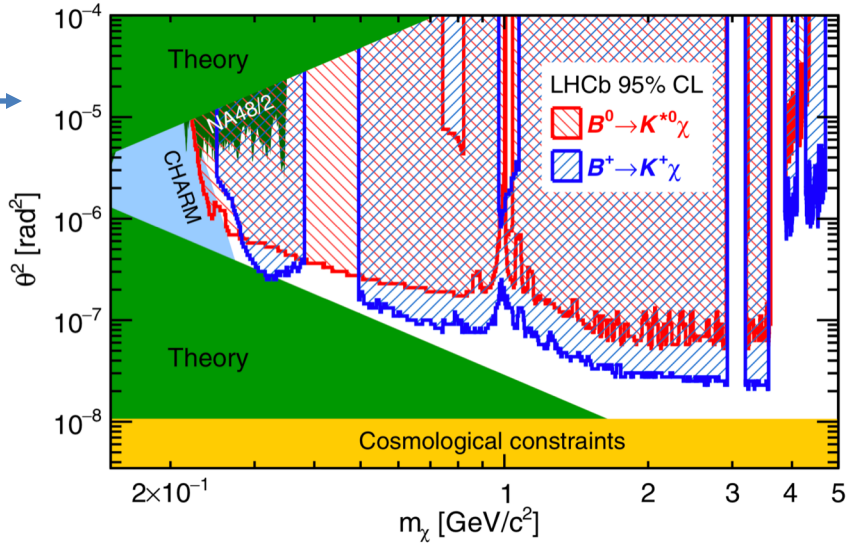
$B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$



- Search for peak in $m(\mu^+\mu^-)$
- Limits on $Br(B^+ \to K^+\chi(\to \mu^+\mu^-))$



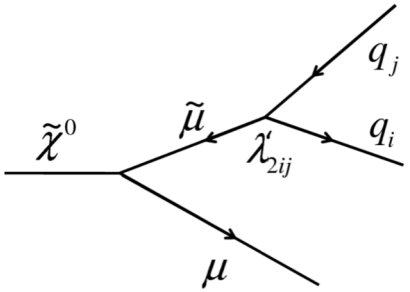
Limits on inflaton χ, JHEP 05 (2010) 10



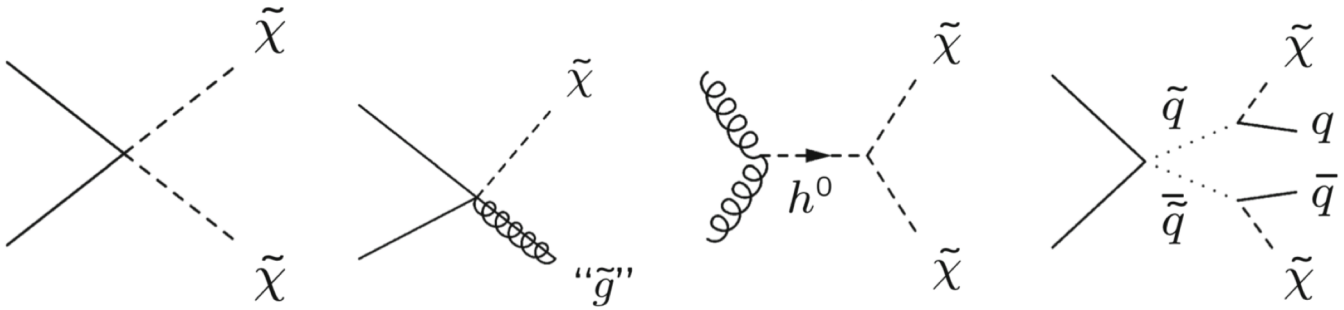
LHCb search in μ + jets

EPJC (2017) 77:224
7 & 8 TeV, 3 fb^{-1}

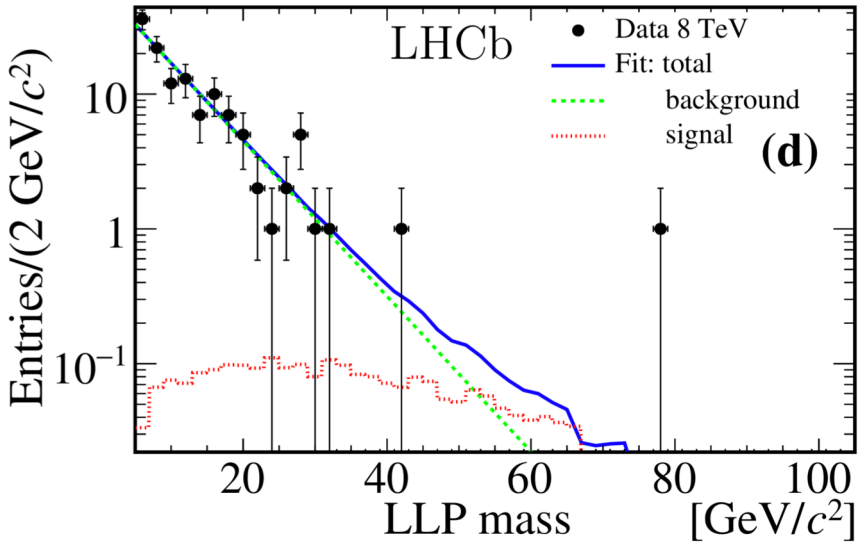
RPV:



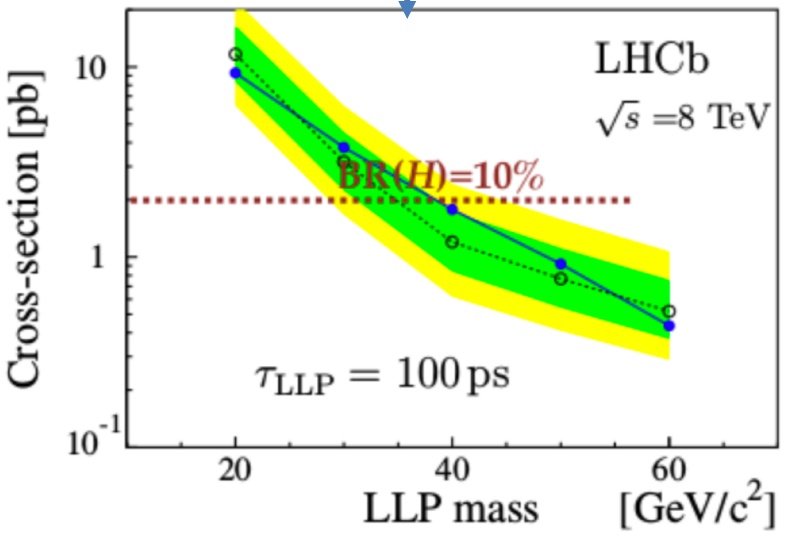
various neutralino production modes:



Example data:

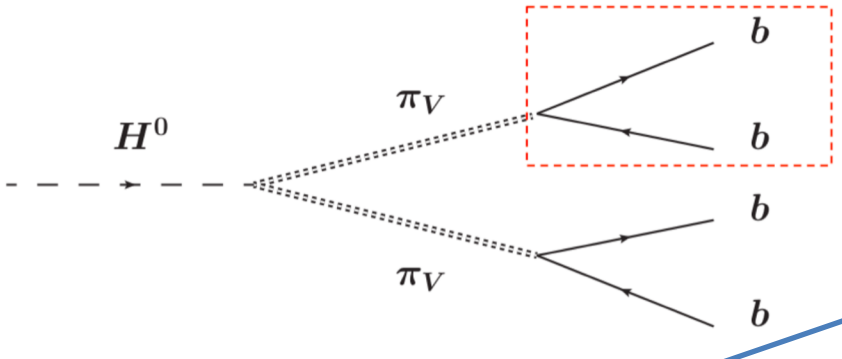


Example limits



Has this be compared with, e.g., ATLAS (PRD 92 (2015) 072004)?

LHCb search for displaced dijet

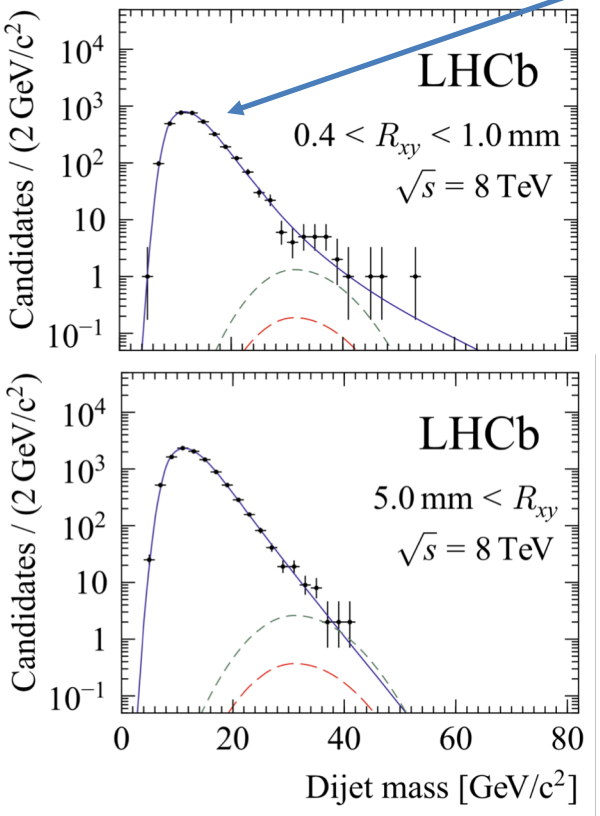


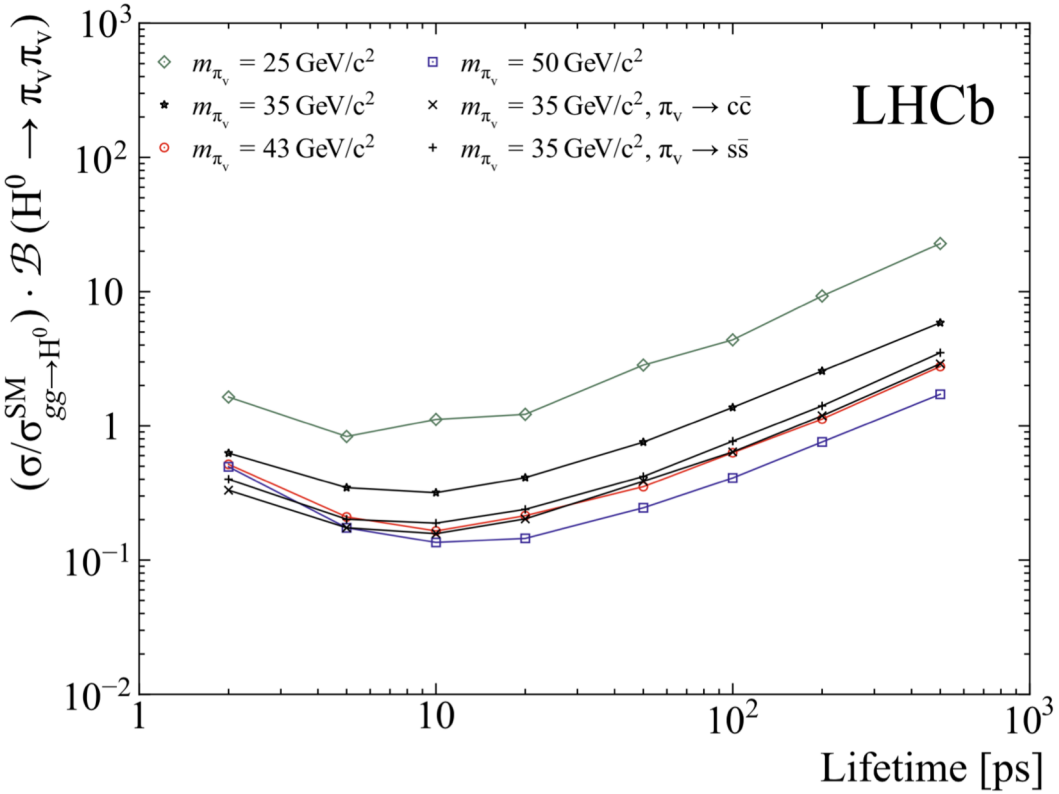
EPJC (2017) 77:812, 7 & 8 TeV, 2 fb^{-1}

Typically, 1 hidden-valley π_V in LHCb acceptance.

Bgd. mostly heavy flavor, material interactions.

Example data:

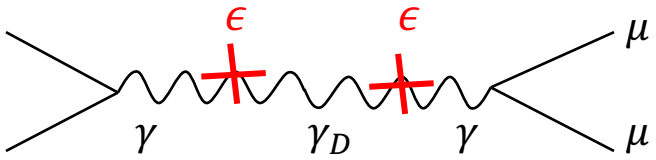




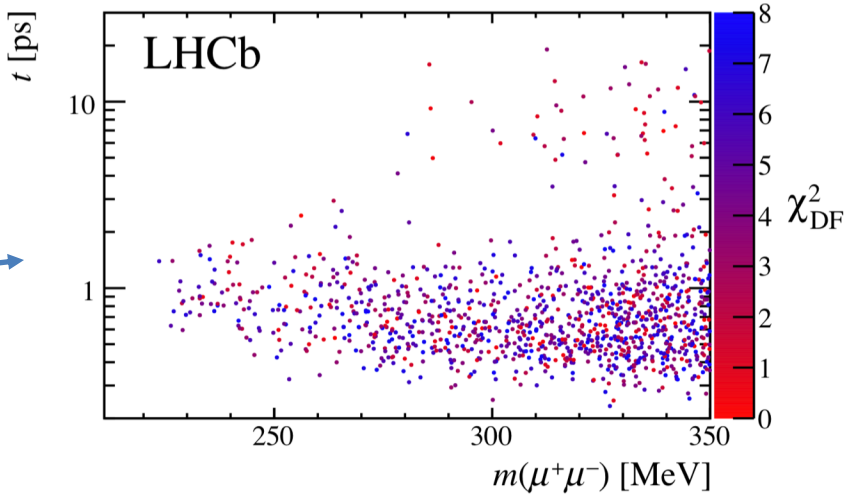
LHCb search for displaced dark photon

LLP γ_D with vector portal only is difficult for colliders:

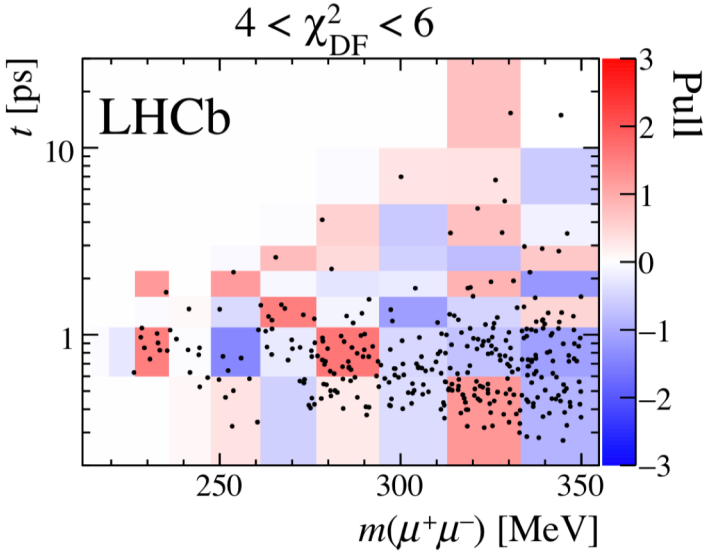
PRL 120, 061801 (2018)



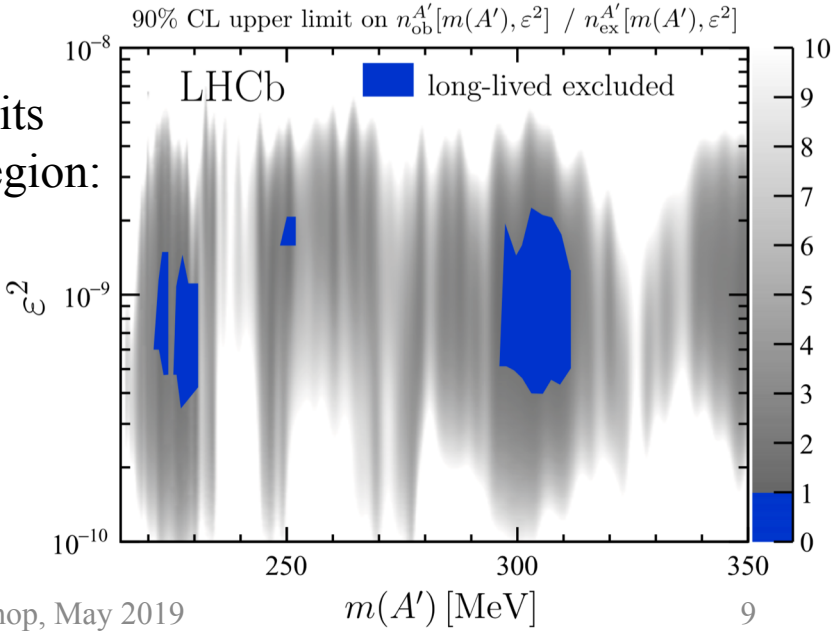
Fit the data in
$m(\mu^+\mu^-)$, decay time, fit χ^2 (3 DoF).



Example fit in one χ^2 bin:



First limits
in this region:

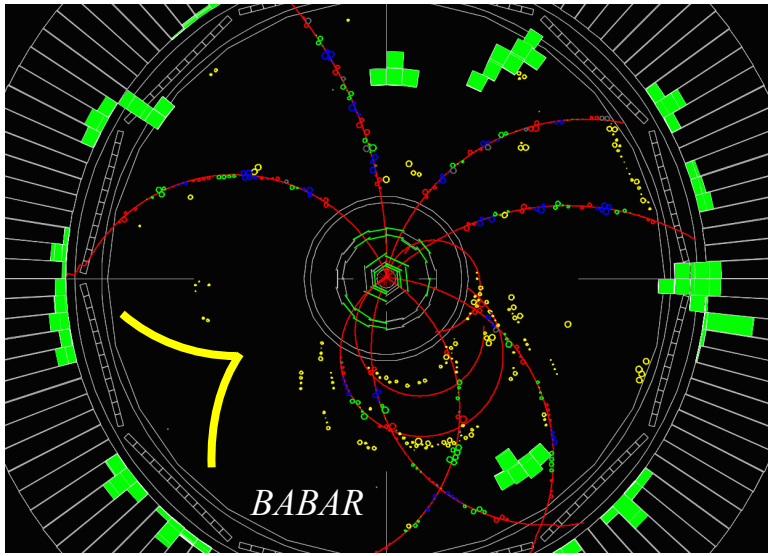


e^+e^- B-factory results before Belle II: BABAR & Belle

BABAR LLP search

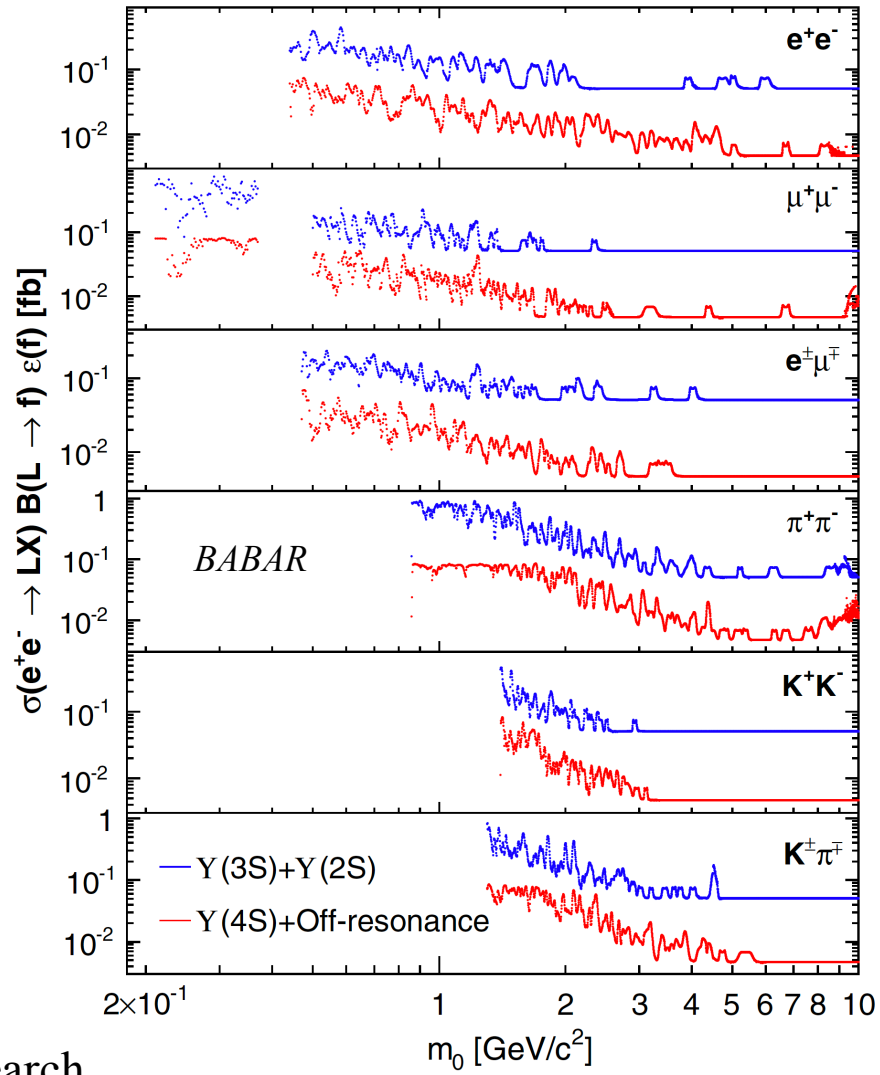
PRL 114, 171801 (2015)
490 fb^{-1}

- Production-model independent analysis
- Just assume LLP → 2 tracks



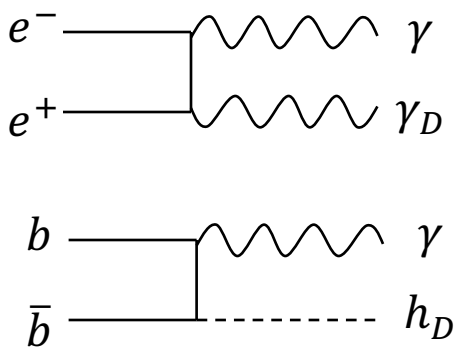
- Minimal material veto
- Search for mass peak

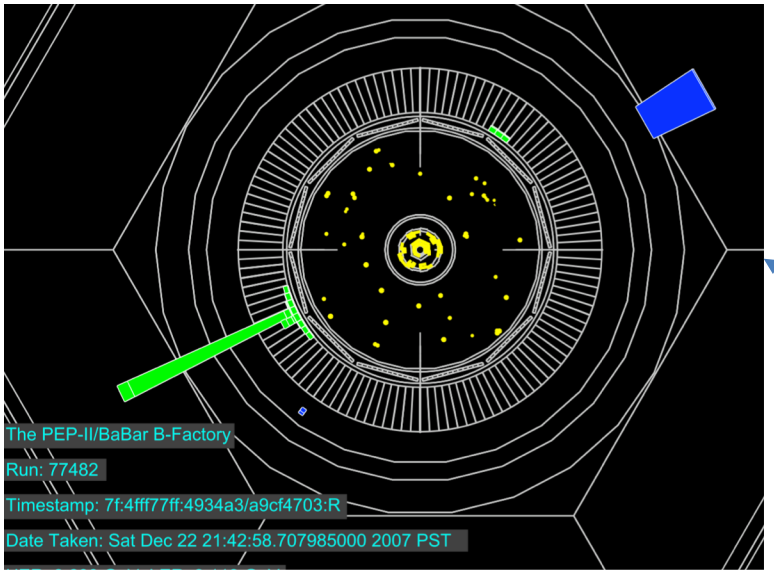
- Model-independent limits
  to be used with efficiency tables vs. $p_T, c\tau, m$.
- For given model, less sensitive than dedicated search



BABAR dark-photon/Higgs search

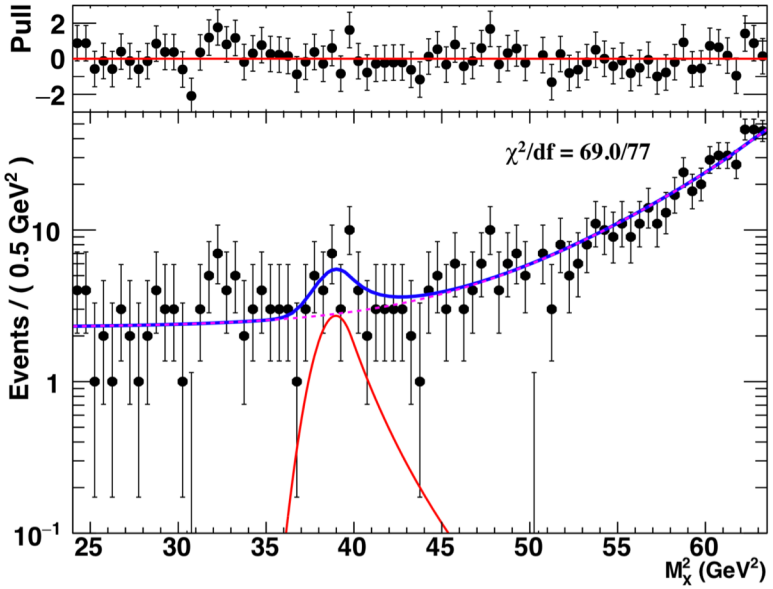
PRL 119 (2017) 131804



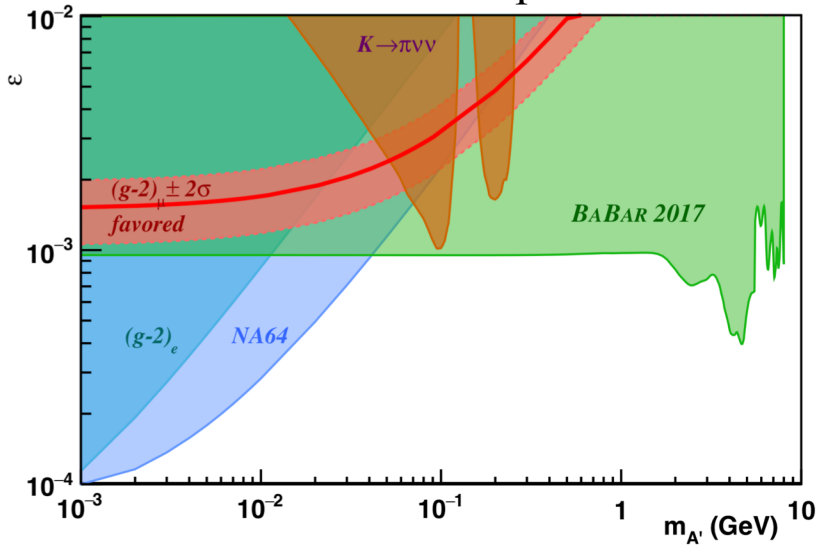


- Require only 1 γ
- Calculate recoil mass
- 1-γ trigger available only for 53 fb^{-1}
- Background from $e^+e^- \rightarrow \gamma\gamma$ with a γ → ECAL crack, if not seen in muon system

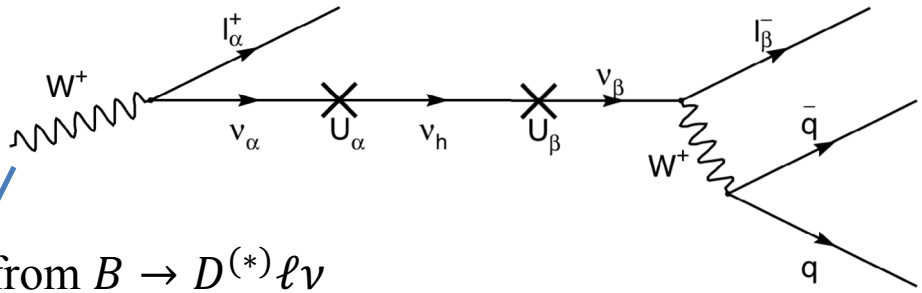
Example fit to recoil mass



Dark-photon limits



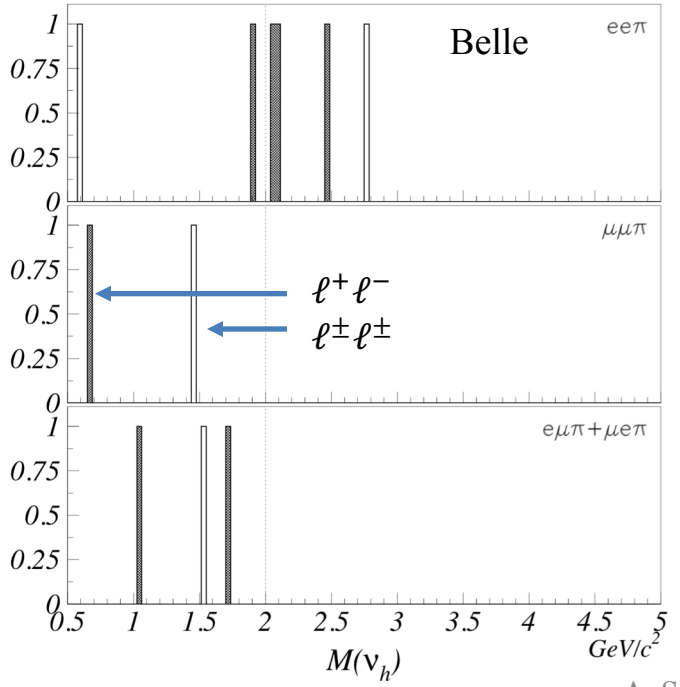
Belle search for heavy neutral lepton (HNL)

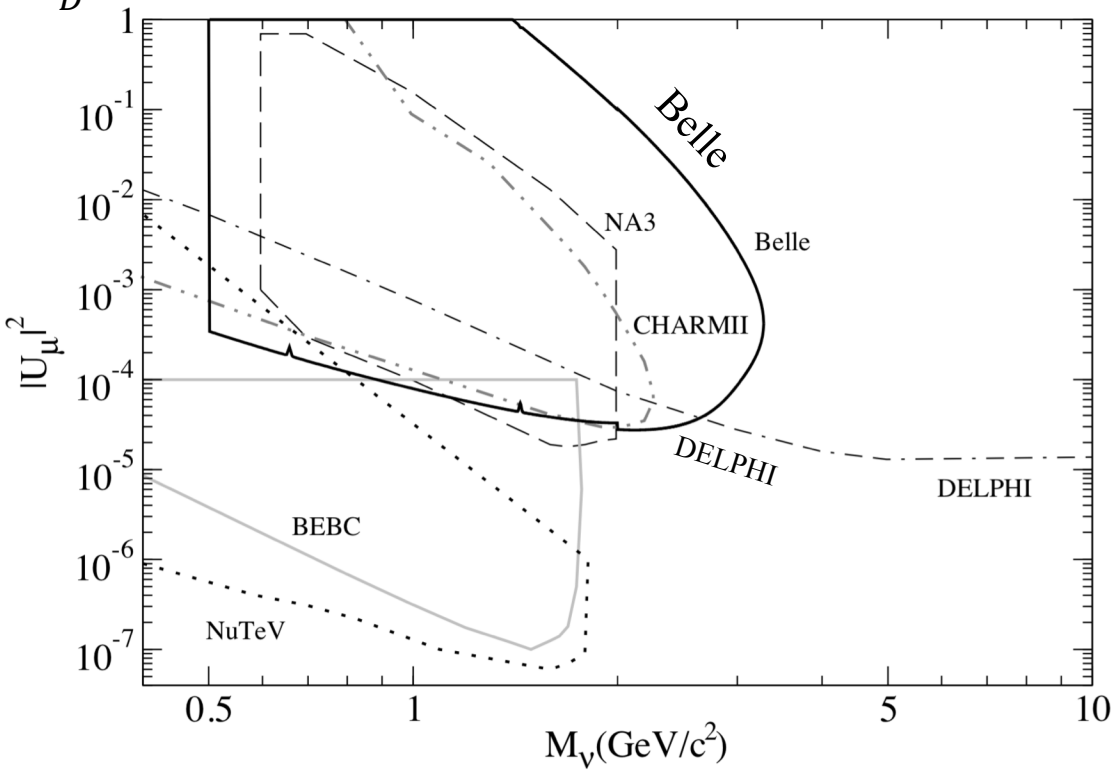


W^* from $B \to D^{(*)}\ell\nu$

PRD 87, 071102 (2013)
772×10^6 $B\bar{B}$ events

Require prompt lepton and $\ell\pi$ disp. vtx.
For $m_{\nu_h} < 2$ GeV, require recoil mass ~ m_D





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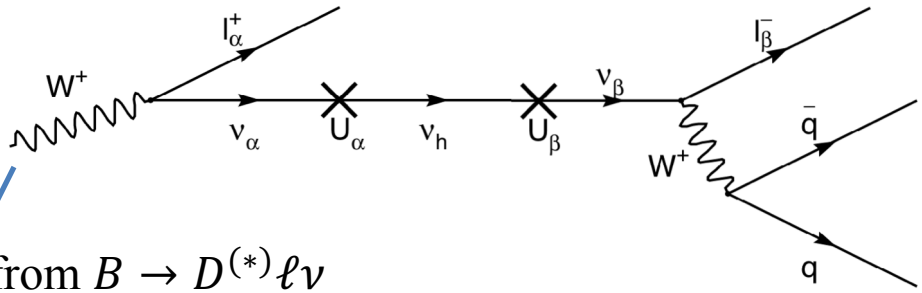

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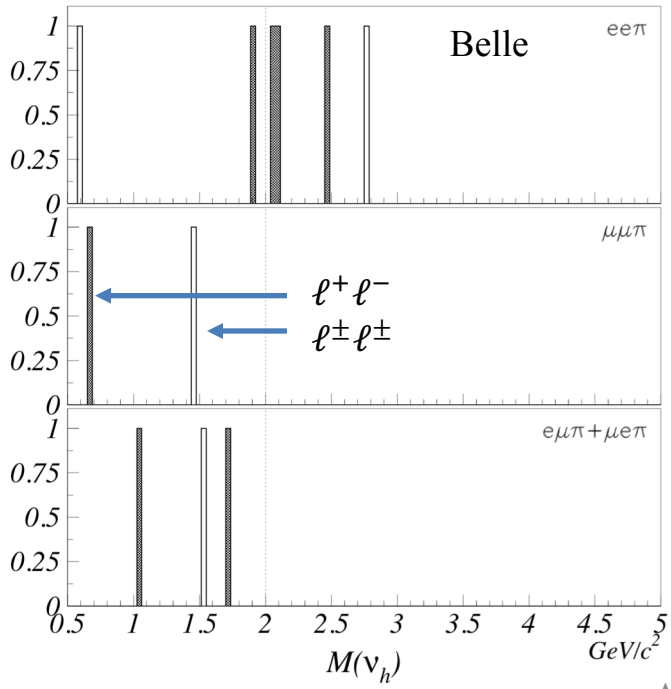
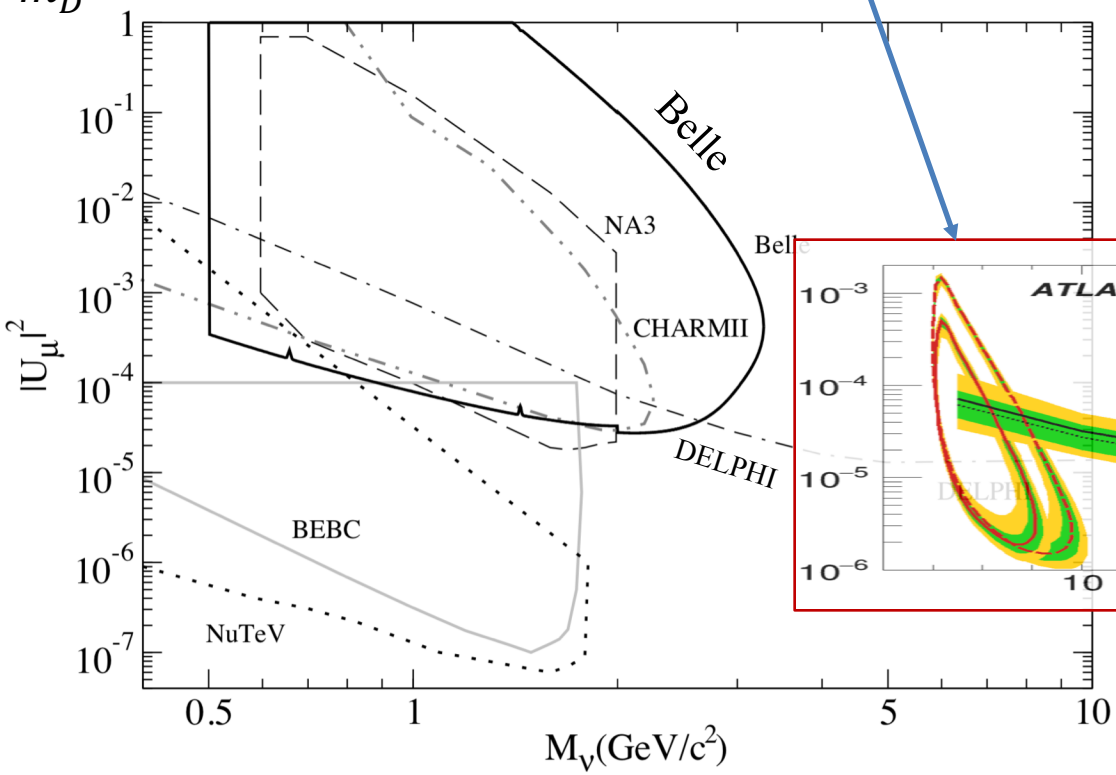
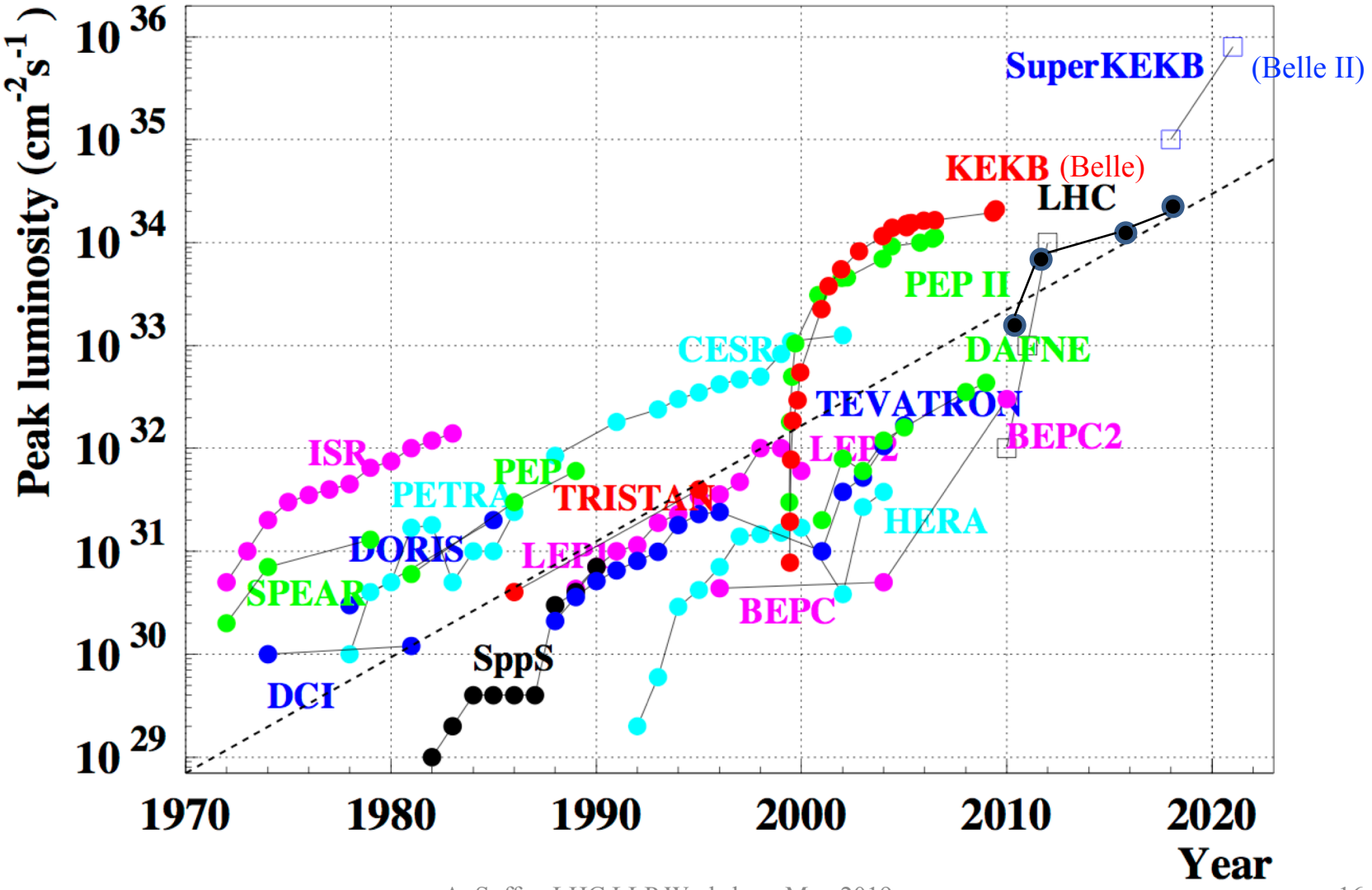


ATLAS 1905.09787 from last Friday,
ν_μ-mixing HNL from on-shell W decays



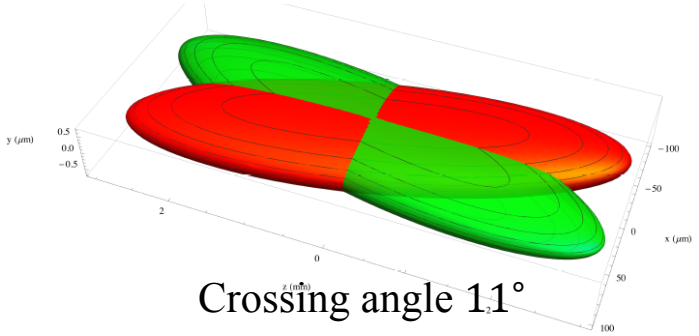
Belle II status

Moore's law of collider luminosity



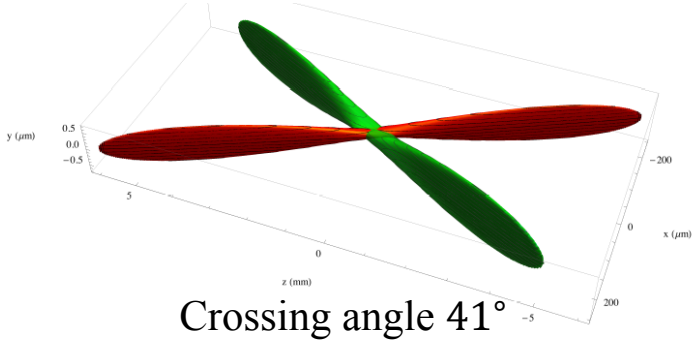
40-fold increase in luminosity wrt. Belle

Beams at KEKB (Belle)

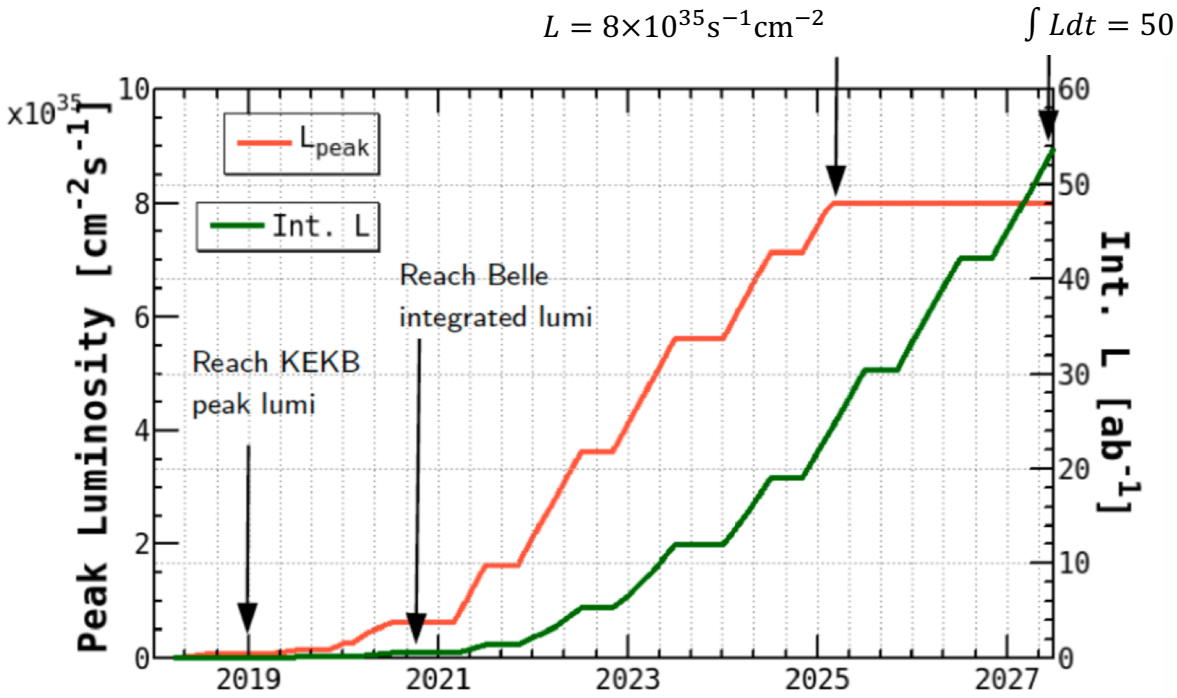


Crossing angle 11°

Nanobeams at SuperKEKB (Belle II)

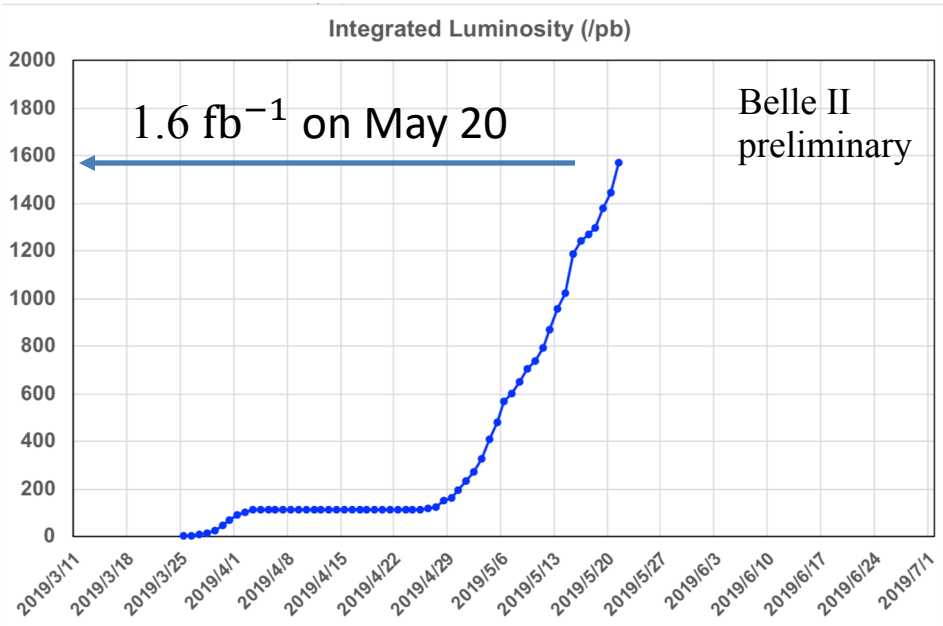


Crossing angle 41°

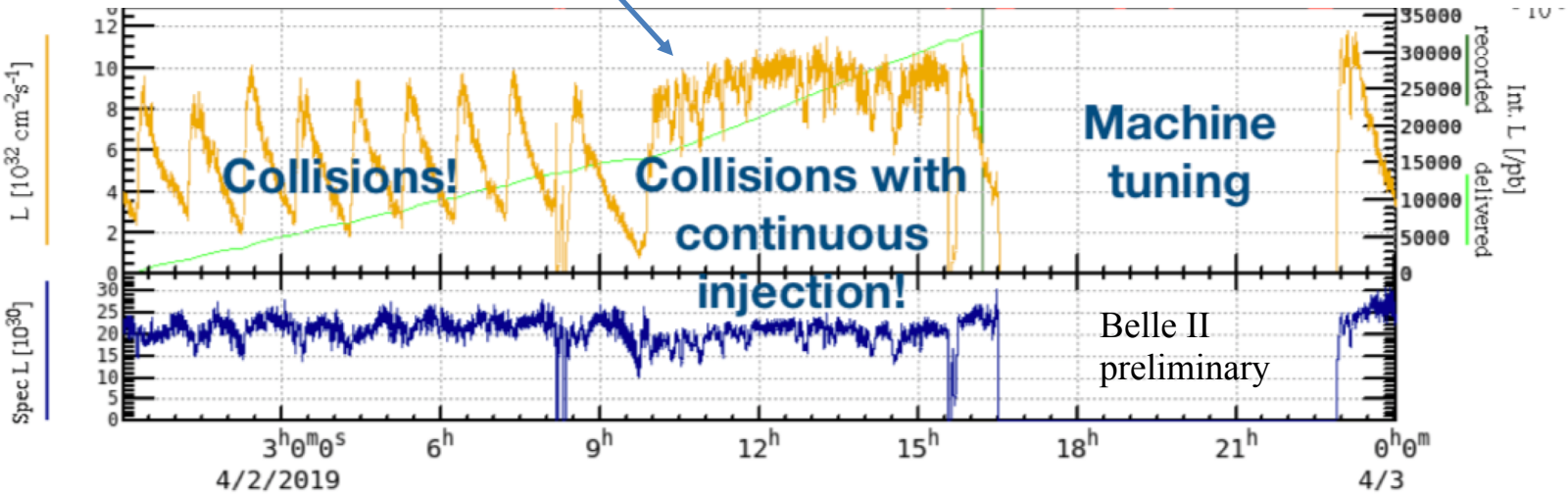


2019 machine performance

- Integrated luminosity sufficient for commissioning studies
- Peak luminosity ~1/6 that of Belle



- At design luminosity, beam lifetime is O(minutes)
- Necessitates "continuous injection", started last month:
(also used @ BABAR & Belle)

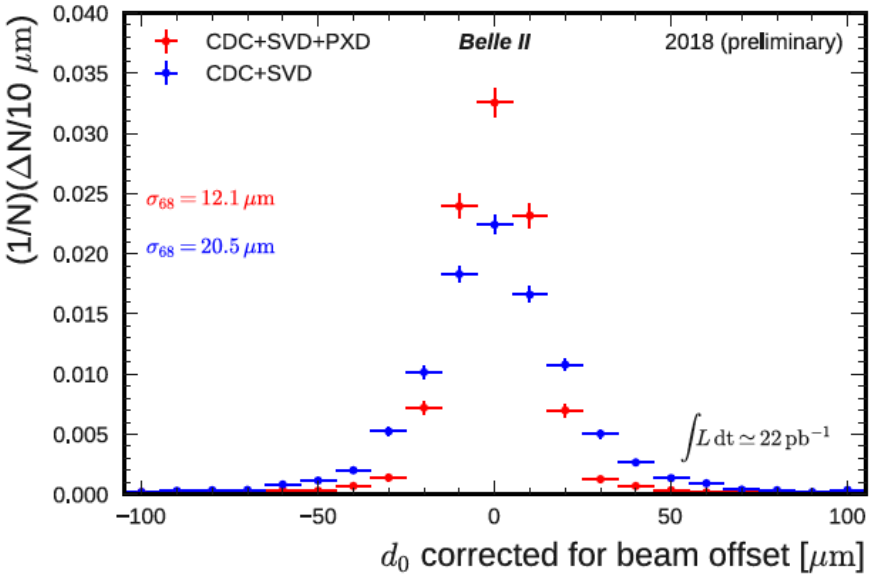


2018 detector performance

0.5 fb^{-1} collision data
with 1 vertex-detector sector

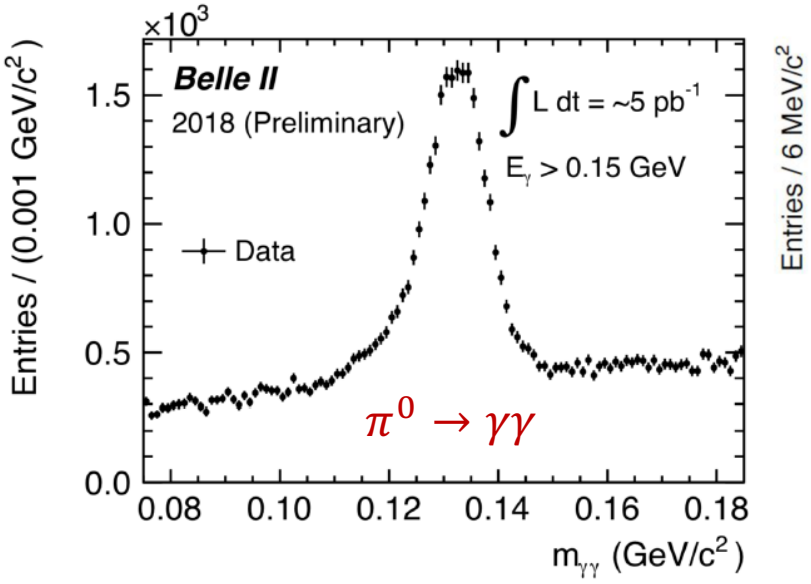
$$\sigma(d_0) = a + \left(\frac{b}{\tilde{p}}\right)^2$$

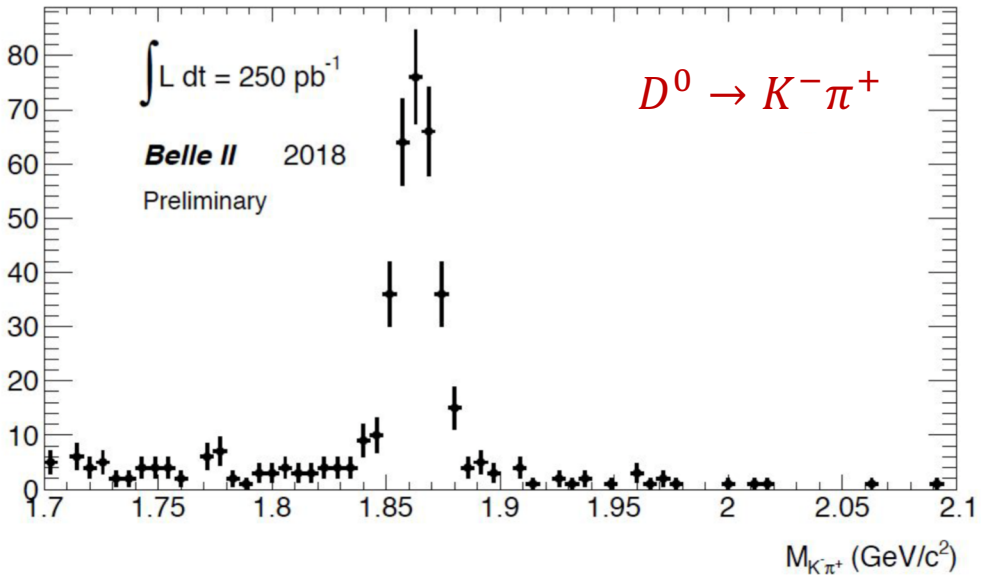
$\tilde{p} = p\beta \sin^{3/2}\theta$ (> 2.0 GeV)
$a = 7.3 \pm 0.3$ μm
$b = 28.4 \pm 0.9$ μm GeV

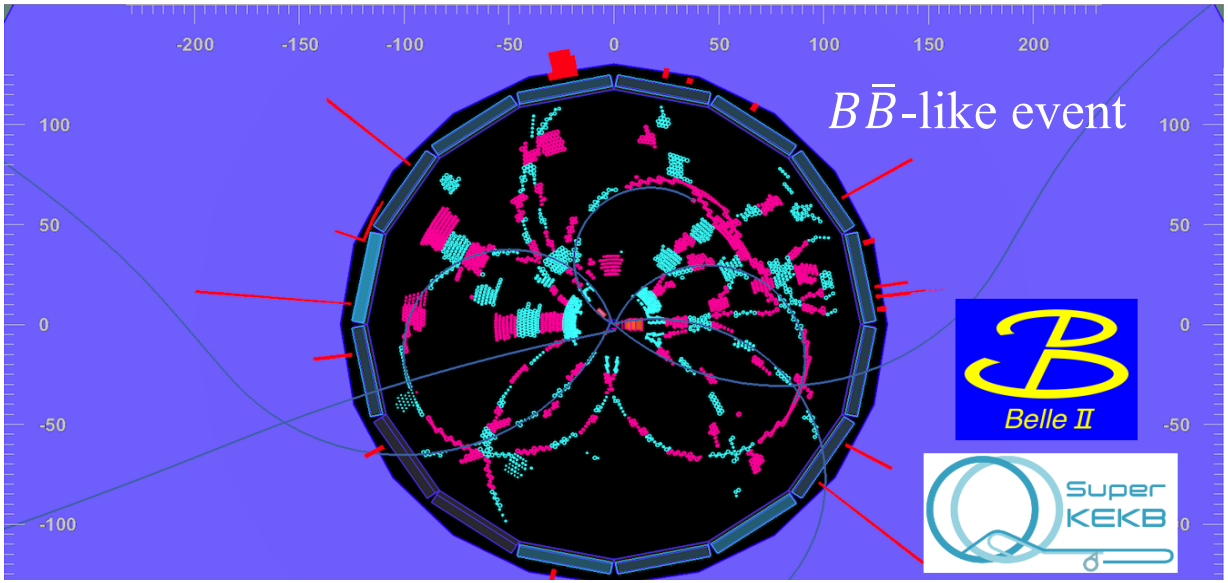


BELLE2-NOTE-PH-2018-040

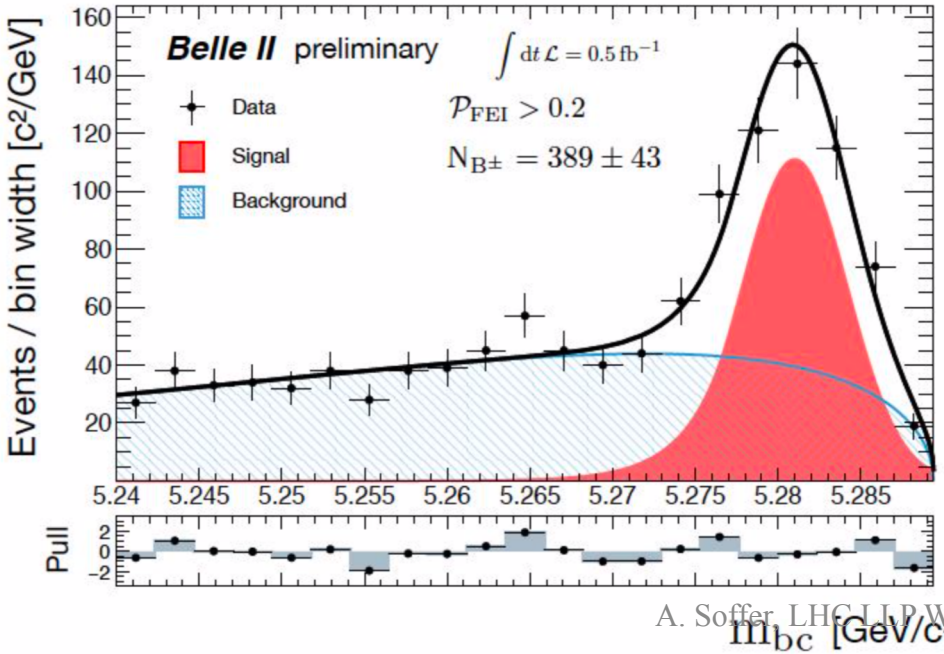
σ(d₀) = **12 μm** (10 μm expected)
~ factor 2 better than at Belle



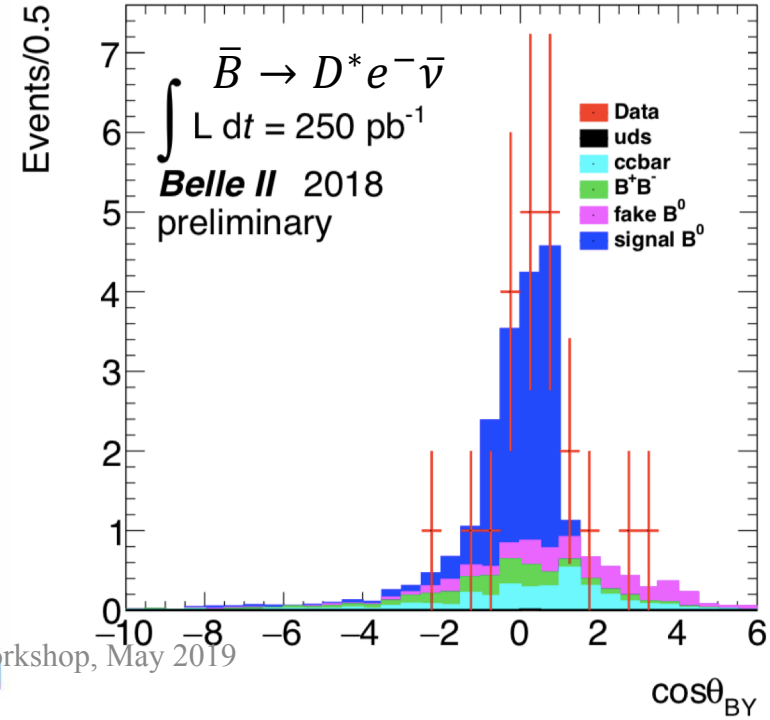




Reconstructed hadronic B decays



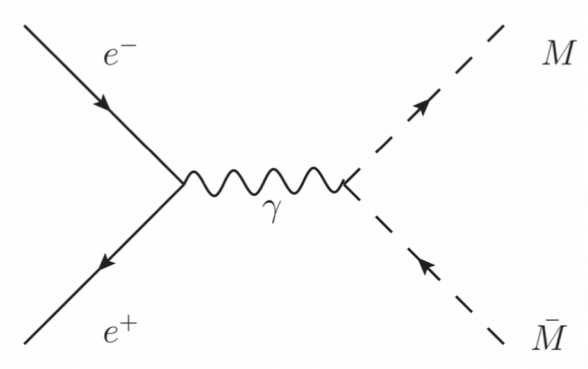
Reconstructed semileptonic B decays



Some studies of LLPs at Belle II

See also Belle II Physics Book, 1808.10567

Magnetic monopoles

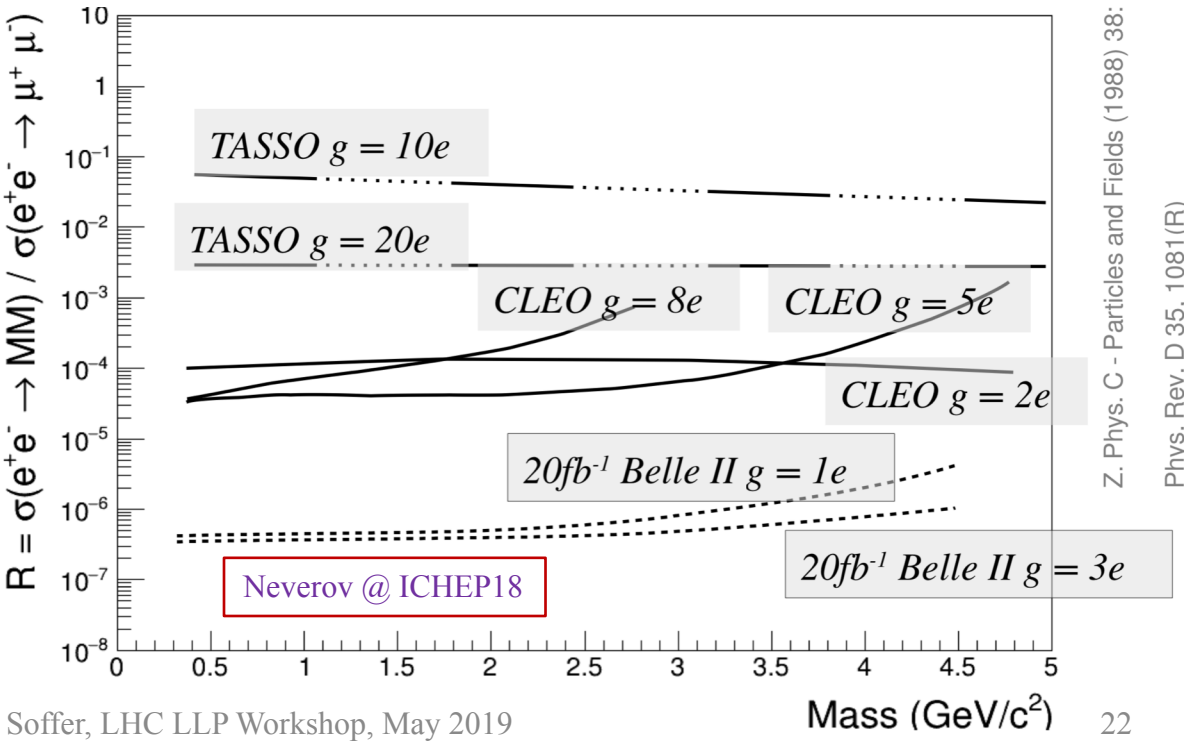


Most searches focus on high-charge monopoles.
$g = O(e)$ range not well constrained.
Low dE/dx → fewer hits → low tracking efficiency (no $1/\beta^2$ factor)

Trigger: $\Delta\phi \sim \pi$ ECAL clusters
Dedicated tracking:

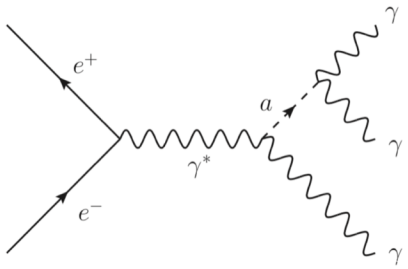
$$z(s) = z_0 + \frac{p_z}{p_T}s + \frac{gBm}{2p_T^2}s^2$$

Projected sensitivity with early phase-3 data (20 fb^{-1})

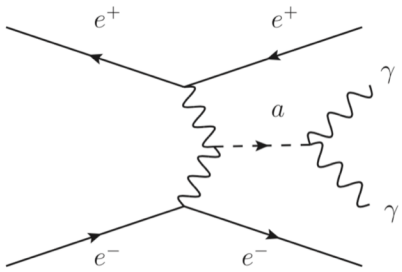


Axion-like particle (ALP)

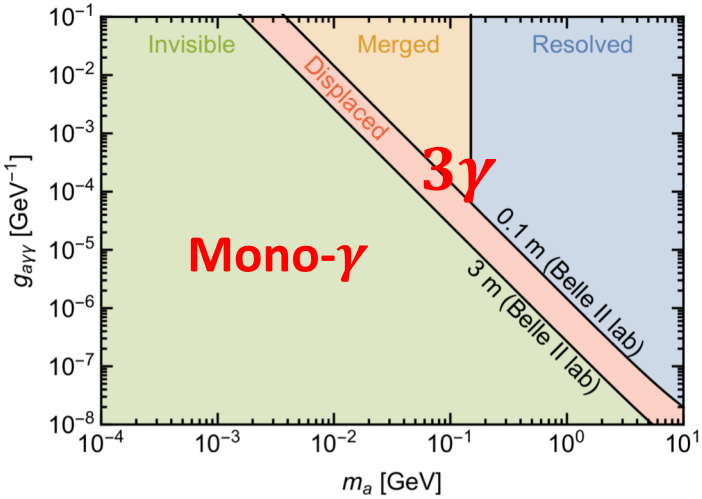
JHEP 1712 (2017) 094



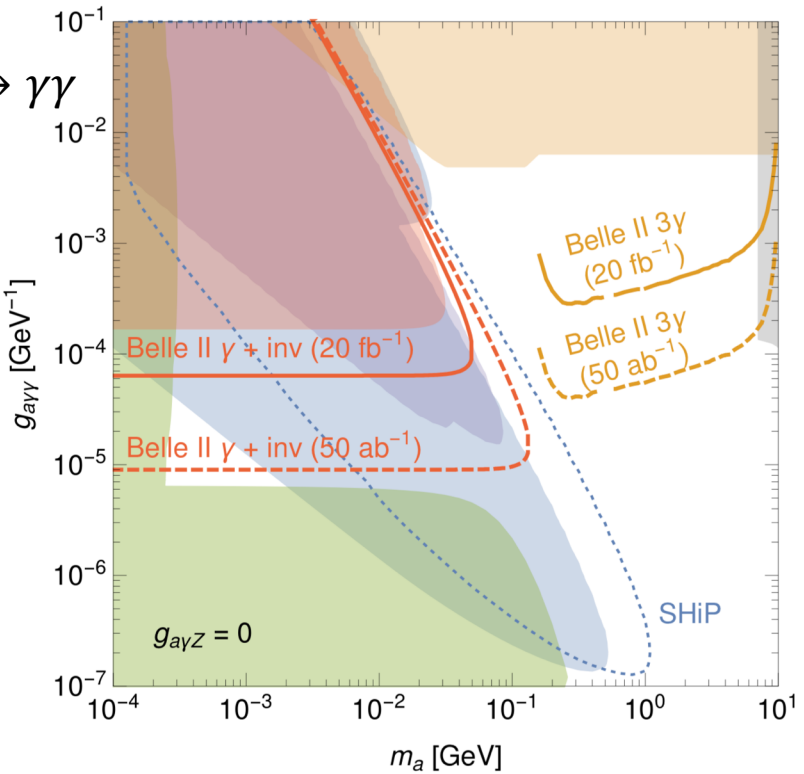
ALP-strahlung



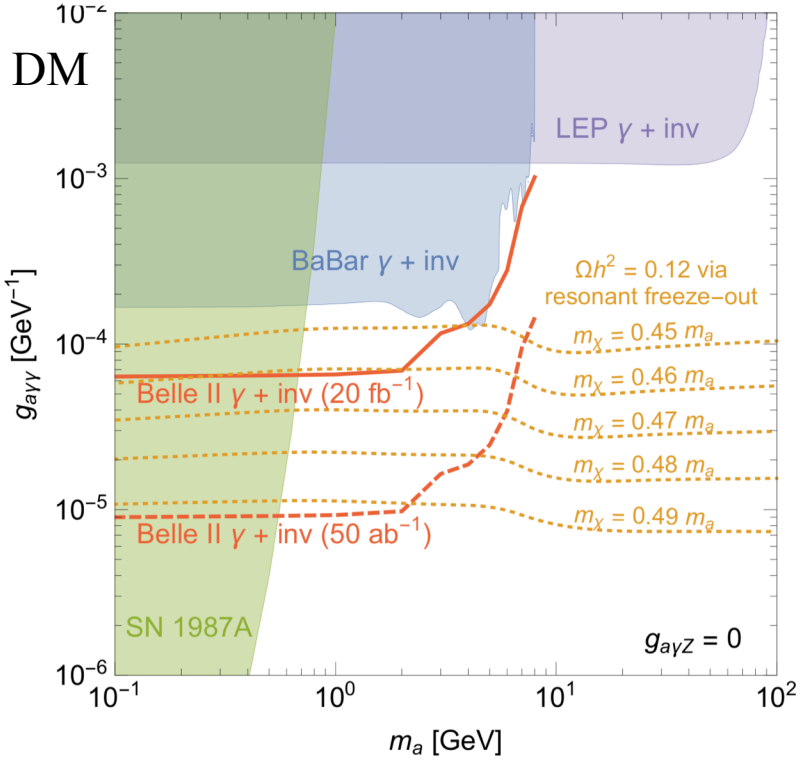
$\gamma\gamma$-fusion



$a \to \gamma\gamma$

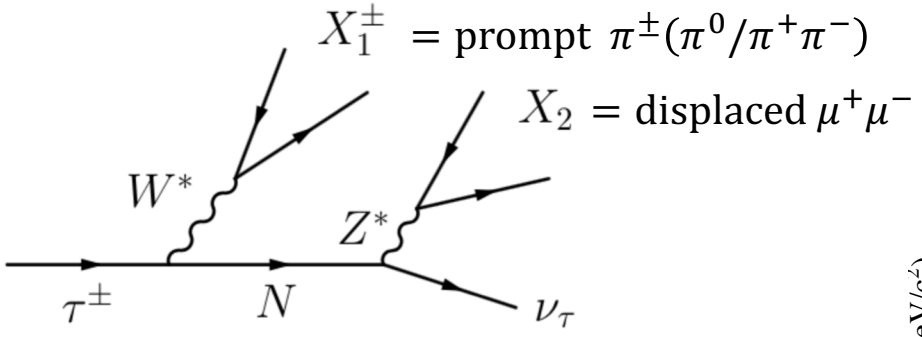


$a \to$ DM

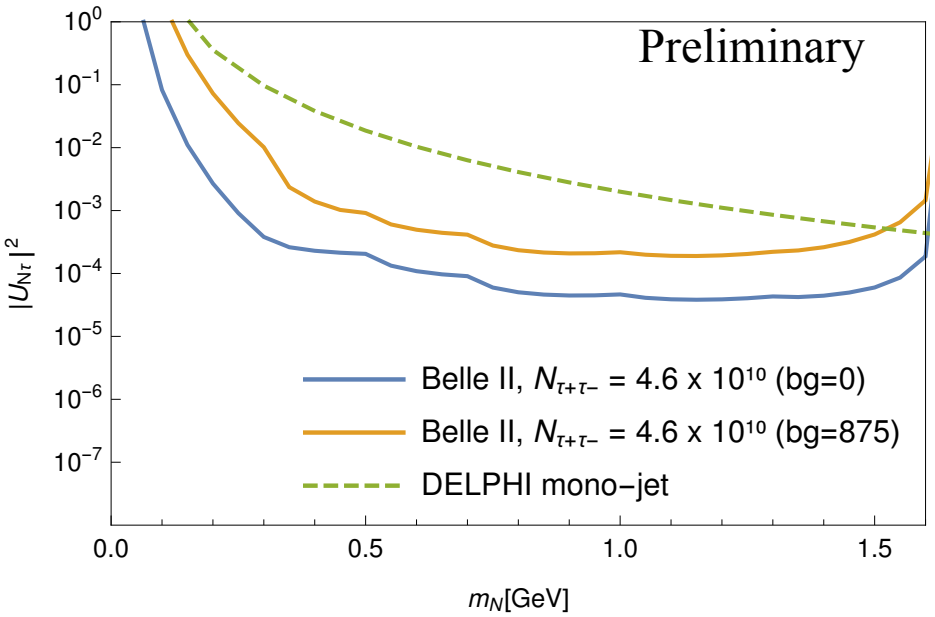


HNL that mixes predominantly with ν_τ

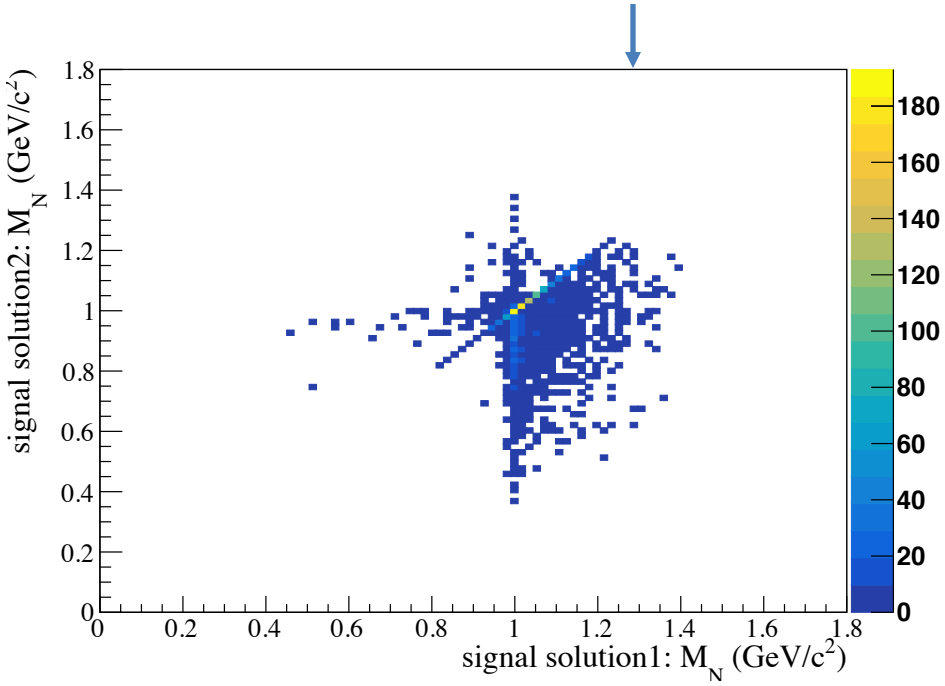
Dib, Helo, Nayak, Neill, AS, Zamora-Saa, in preparation



Very low acceptance: $\gamma\beta c\tau \gg$ detector



Enough constraints to obtain HNL mass with 2-fold ambiguity (smeared b/c of detector resolution)



17 bgd. evts/ab^{-1}, mostly $\tau\tau$, before cutting on m_1 vs. m_2

Points for discussion / personal thoughts

- LHCb and Belle II (will) have unique LLP sensitivities
- LHCb has probed:
  - a LL dark γ in the difficult, vector-portal-only scenario
  - muonic decays of LLPs from B-meson decays
    - ATLAS & CMS can probably compete (given success with $B_s \to \mu\mu$)
  - Higgs → LLP decays, exploiting soft-trigger capability
    - ATLAS & CMS compete with VH/VBF, and ggF + dedicated triggers
  - EW-scale SUSY scenarios
    - comparison to ATLAS/CMS not clear to me (but probably known at LHCb)
- Belle II has best sensitivity in:
  - mono-photon scenarios
  - LLPs related to the τ lepton
  - (probably) non-muonic decays of LLPs from B/D-meson decays
- Additional ideas sure to arise
    - E.g., see talks at previous LLP workshops