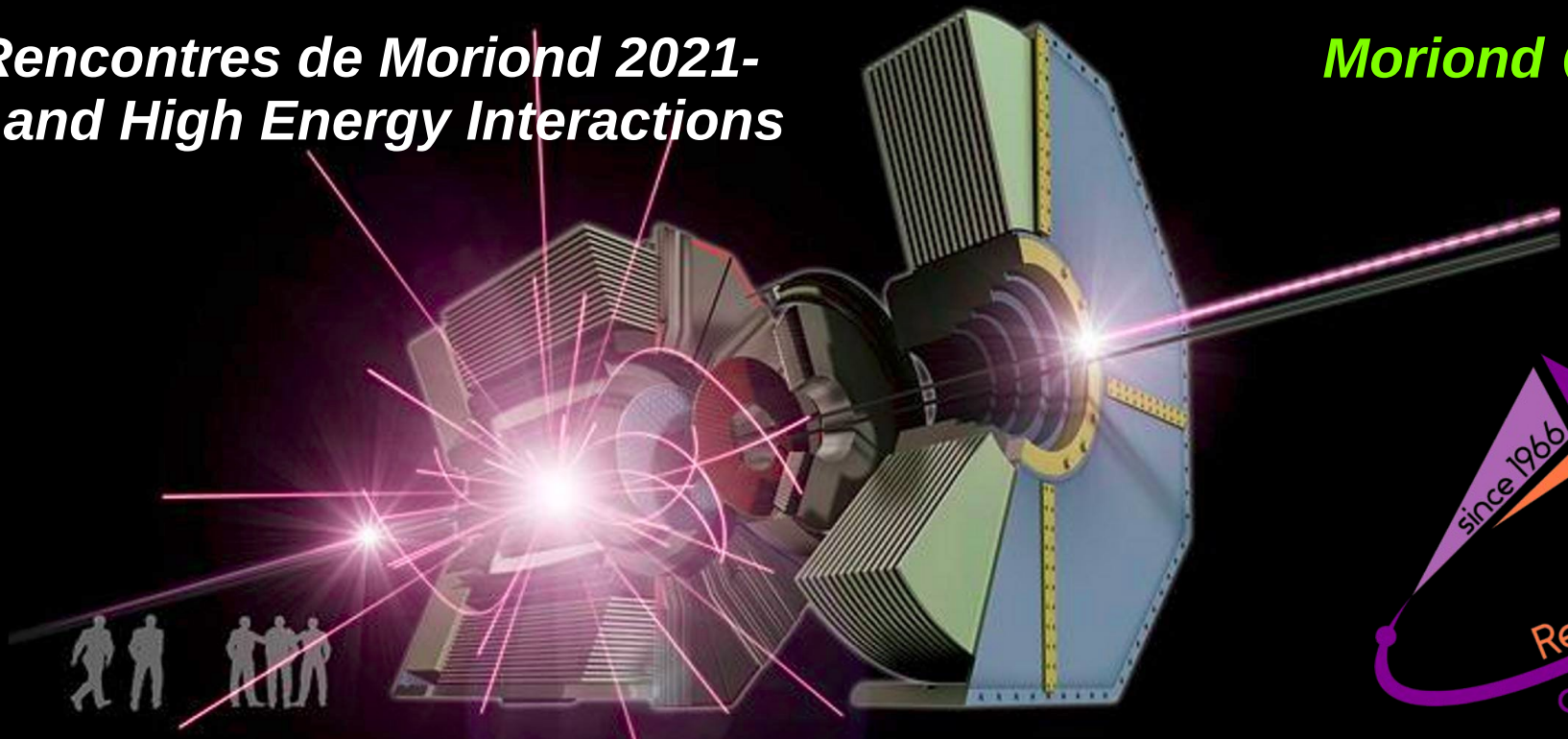
55th Rencontres de Moriond 2021-
QCD and High Energy Interactions

Moriond @ home



New Phenomena Session

Latest results on τ and dark sector physics at Belle II

European Research Council
Established by the European Commission

31/03/2021

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HEPHY
INSTITUT FÜR HOCHENERGIEPHYSIK

FWF
Der Wissenschaftsfonds.

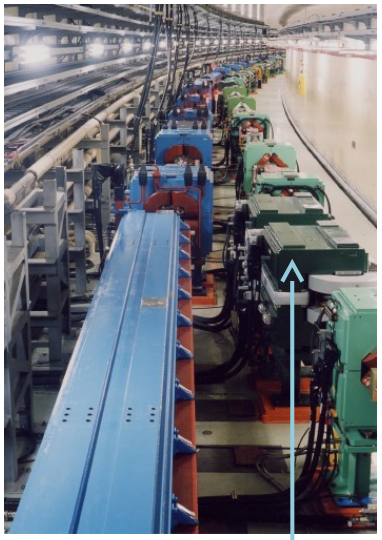
ÖAW
ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

Belle II

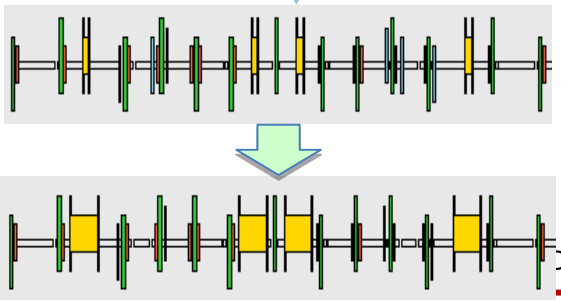
InterLeptons

See also Saurabh Sandilya's presentation

KEKB to SuperKEKB

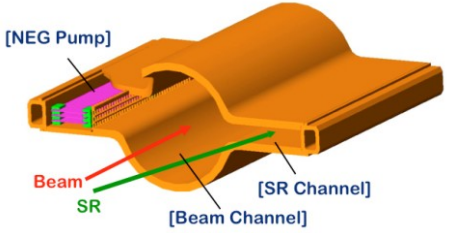


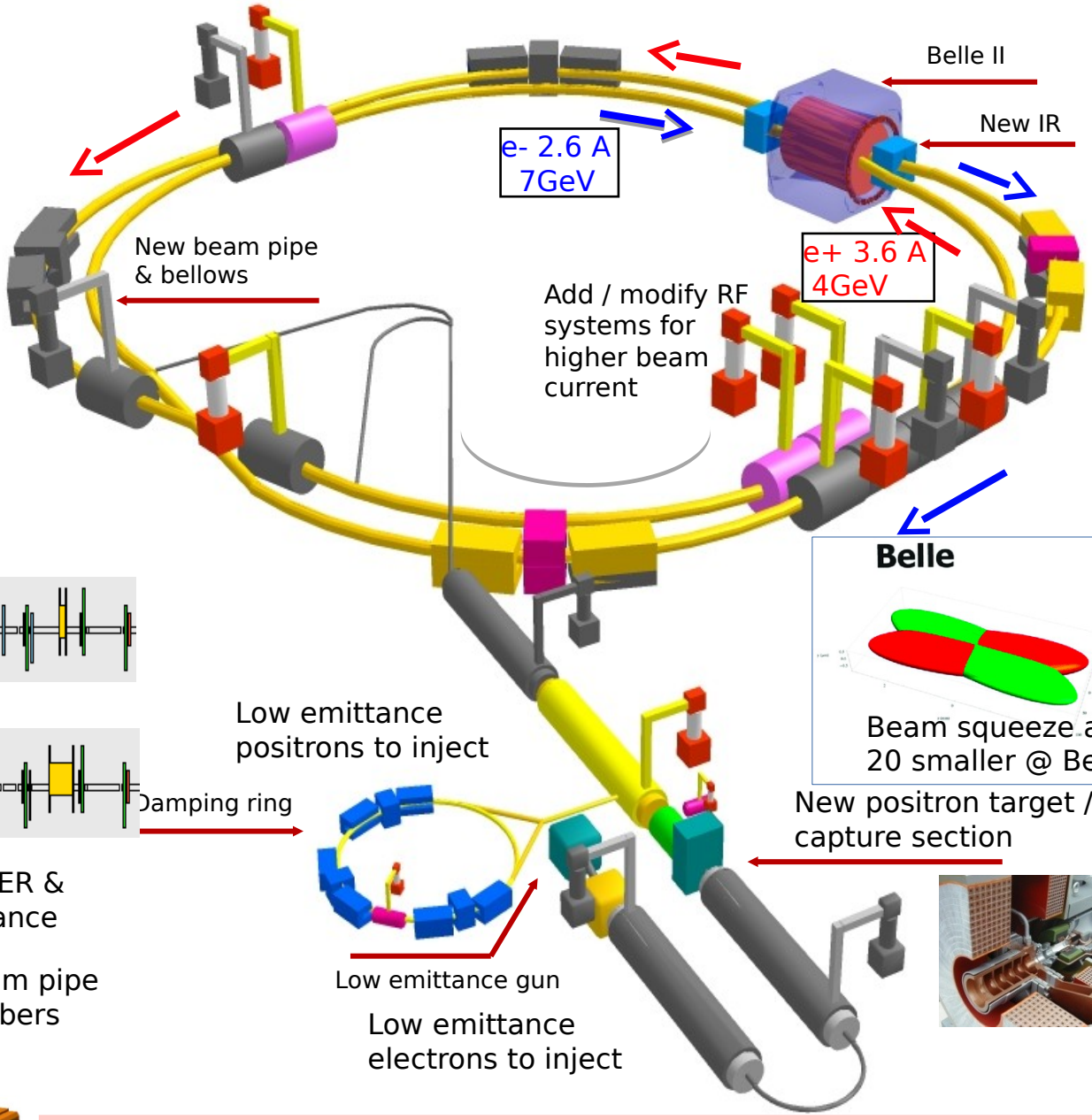
Replace short dipoles with longer ones (LER)



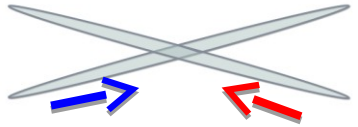
Redesign the lattices of HER & LER to squeeze the emittance

TiN-coated beam pipe with antechambers

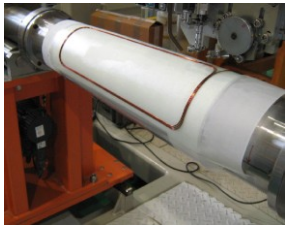


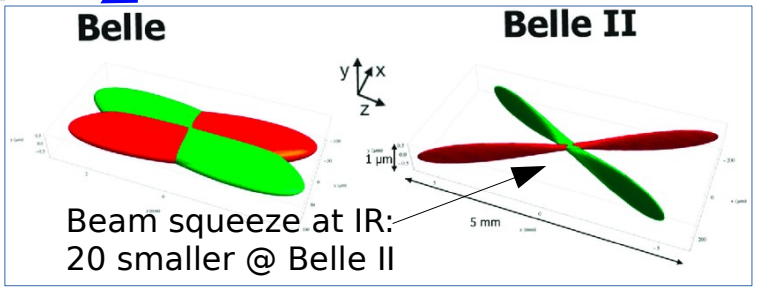


Colliding bunches



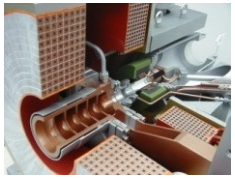
New superconducting /permanent final focusing quads near the IP





Beam squeeze at IR:
20 smaller @ Belle II

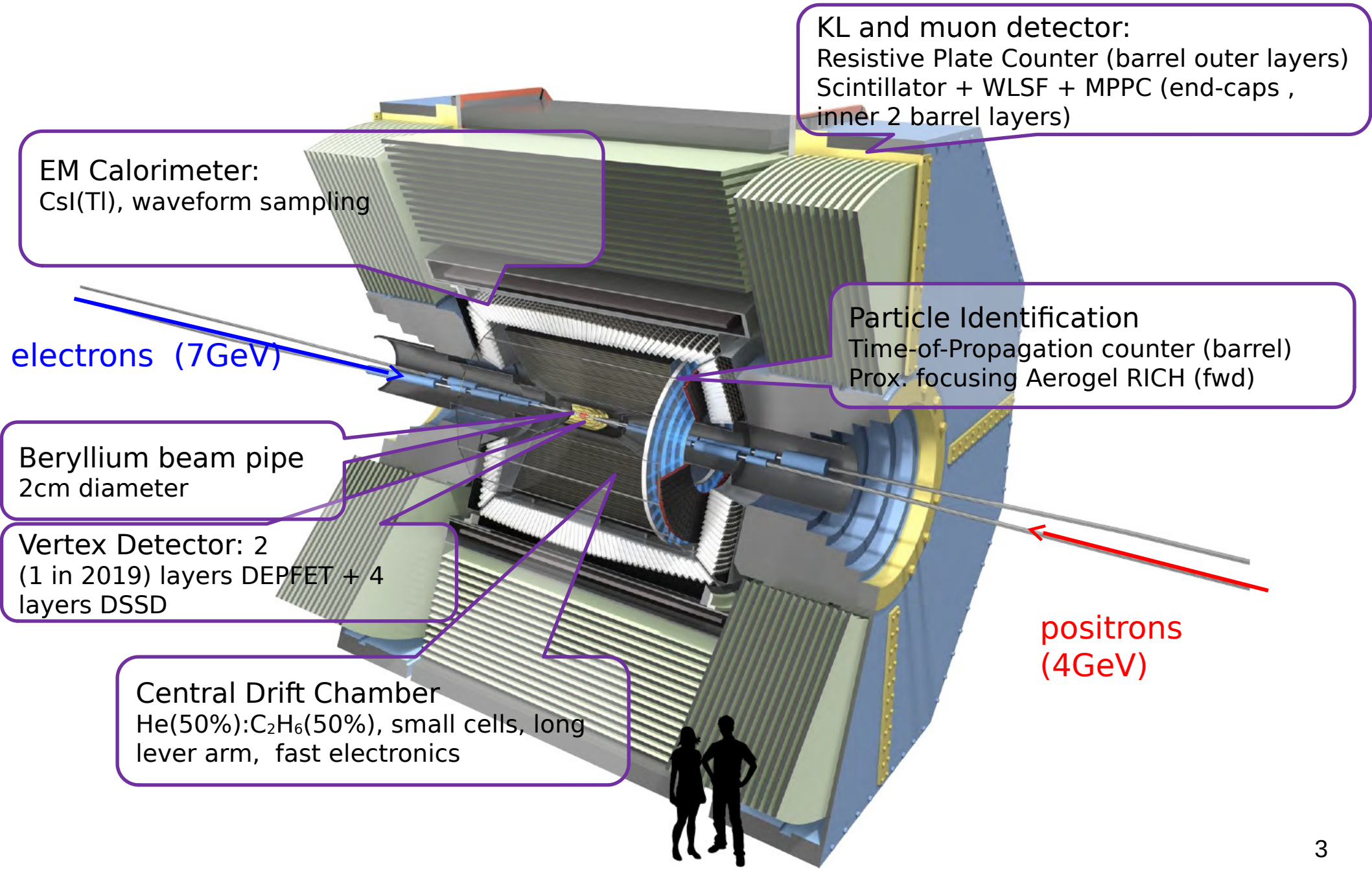
New positron target / capture section



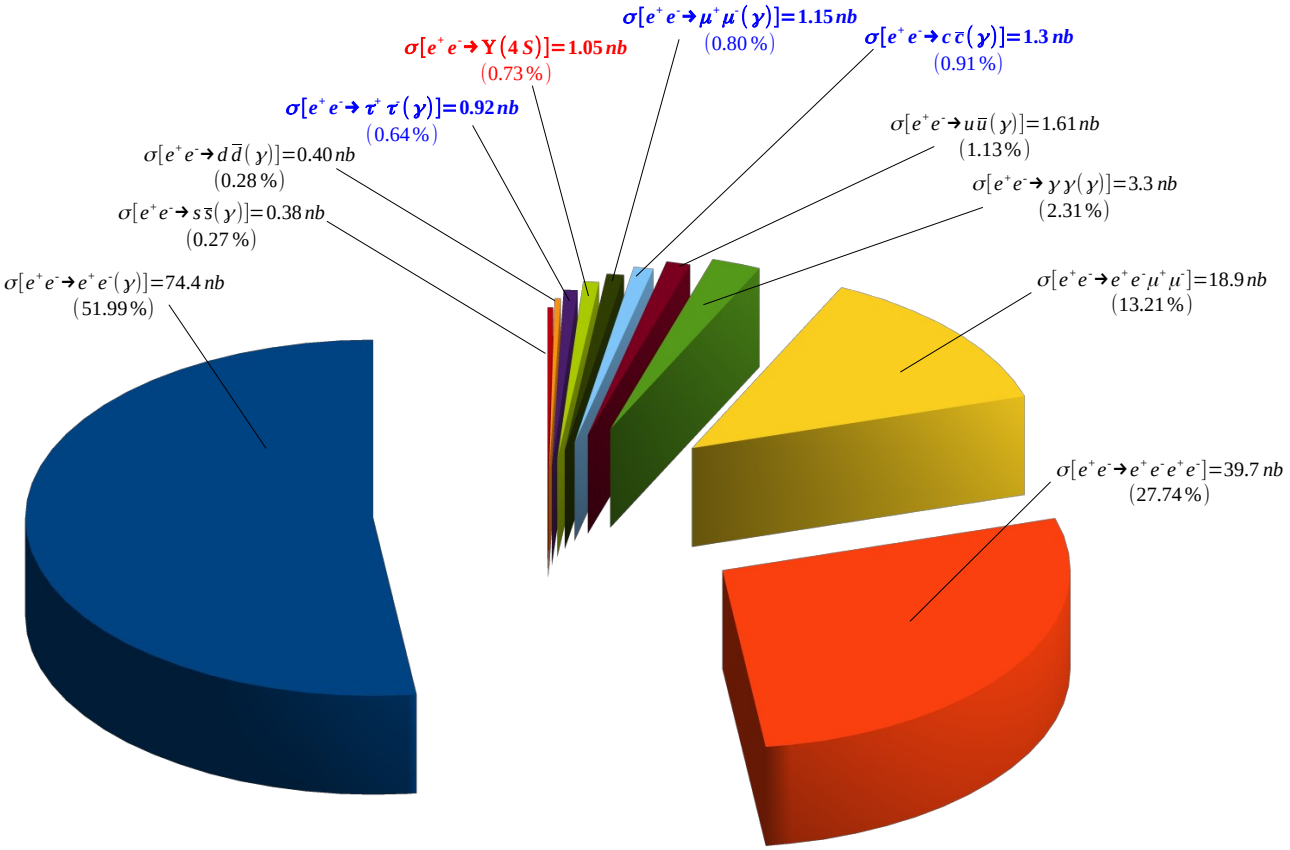
Expect x30 higher luminosity from $2.2 \times 10^{34} \rightarrow 6.5 \times 10^{35}$ $cm^{-2}s^{-1}$

See also Saurabh Sandilya's presentation

Belle II Detector Elements



What happens in e^+e^- collisions at SuperKEKB?



See *The Belle II Physics Book*

Physics process	Cross section [nb]	Cuts
$\Upsilon(4S)$	1.05 ± 0.10	-
$u\bar{u}(\gamma)$	1.61	-
$d\bar{d}(\gamma)$	0.40	-
$s\bar{s}(\gamma)$	0.38	-
$c\bar{c}(\gamma)$	1.30	-
$e^+e^-(\gamma)$	300 ± 3 (MC stat.)	$10^\circ < \theta^*_{e's} < 170^\circ$, $E^*_{e's} > 0.15$ GeV
$e^+e^-(\gamma)$	74.4	e's (p >0.5GeV) in ECL
$\gamma\gamma(\gamma)$	4.99 ± 0.05 (MC stat.)	$10^\circ < \theta^*_{\gamma's} < 170^\circ$, $E^*_{\gamma's} > 0.15$ GeV
$\gamma\gamma(\gamma)$	3.30	γ's (p >0.5GeV) in ECL
$\mu^+\mu^-(\gamma)$	1.148	-
$\mu^+\mu^-(\gamma)$	0.831	μ's (p >0.5GeV) in CDC
$\mu^+\mu^-\gamma(\gamma)$	0.242	μ's (p >0.5GeV) in CDC, $\geq 1\ \gamma$ (E_γ >0.5GeV) in ECL
$\tau^+\tau^-(\gamma)$	0.919	-
$\nu\bar{\nu}(\gamma)$	0.25×10^{-3}	-
$e^+e^-e^+e^-$	39.7 ± 0.1 (MC stat.)	$W_{\ell\ell} > 0.5$GeV
$e^+e^-\mu^+\mu^-$	18.9 ± 0.1 (MC stat.)	$W_{\ell\ell} > 0.5$GeV

σ: cross-section of the process to be studied in the specific experiment

$$N = L \times \sigma \times \varepsilon$$

Number of events of a process

L: luminosity of an experiment

ε: total efficiency, including trigger.

@ Belle II many new triggers developed specifically for low multiplicity events

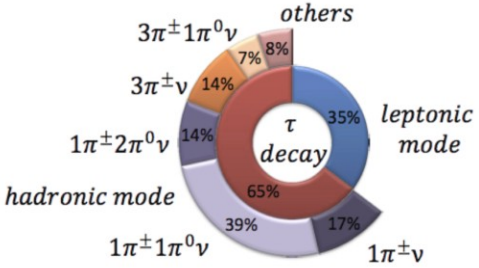
A **SuperB** factory is also a **Super-charm** factory, a **Super-τ** factory, etc..
This is a great feature of this collision scheme that we can take advantage of.

As of today @ Belle II $\int L\,dt = O(100\ fb^{-1})$

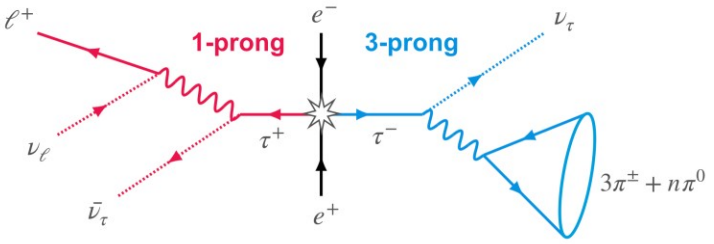
Physics with τ at Belle II

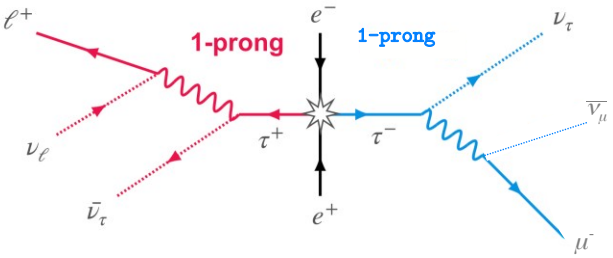
$\sigma[e^+e^- \to \tau^+\tau^-] = 0.92\,nb\,@\,Belle\,II$ → Large production cross-section

Many final states



Different reconstruction techniques





τ as a probe of new physics and of detector performance

Some ongoing physics analyses

- τ mass/lifetime measurements
- LFV $\tau \to l\gamma$
- LFV $\tau \to lll$
- LFV $\tau \to l\pi^0$
- LFV & LNV $\tau \to lhh$
- LFUV $\tau^+ \to l^+\nu_l\bar{\nu}_\tau$, $\tau \to h\nu$
- $|V_{us}|$ from $\tau \to h\nu$
- Absolute BF measurements for $\tau^+ \to l^+\nu_l\bar{\nu}_\tau$
- Dalitz analysis of $\tau \to 3\pi\nu$
- Search for $\tau \to l\alpha$

Some technical studies

- Tracking efficiency [BELLE2-NOTE-PL-2020-014]
- Trigger efficiency [BELLE2-NOTE-PL-2020-015]
- Particle (mis-)identification [BELLE2-CONF-PH-2021-002]
- Etc.

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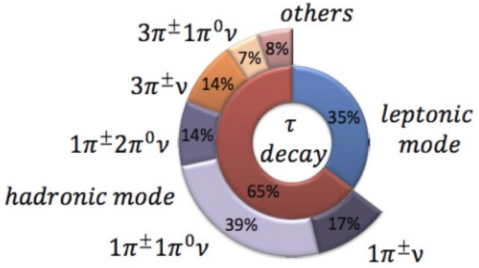

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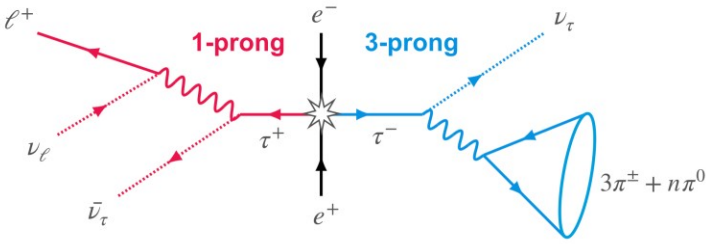

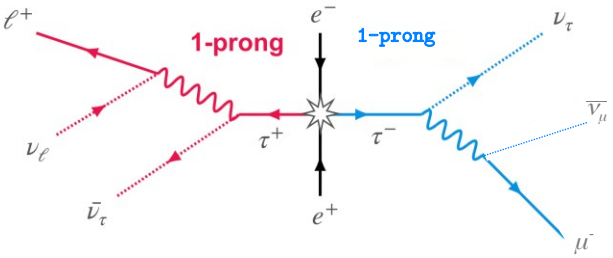

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- **Search for $\tau \to l\alpha$**

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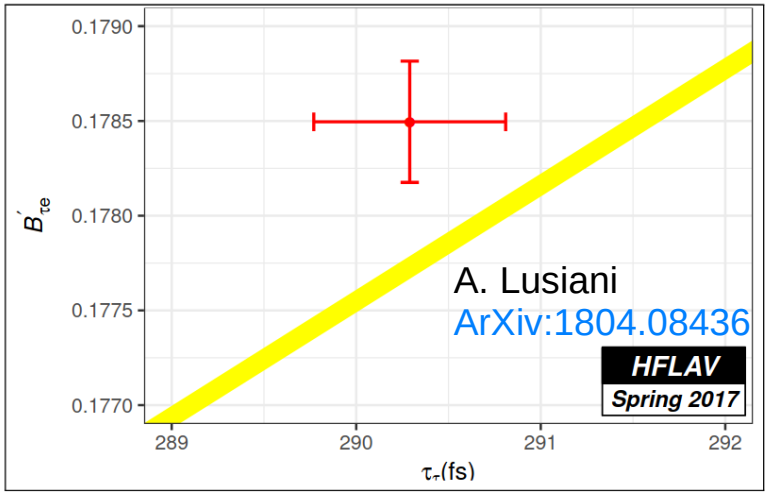
- Etc.

τ mass measurement at Belle II

- τ mass poorly known compared to *e* or μ (a few orders of magnitude less precise)
- Important parameter in lepton universality tests

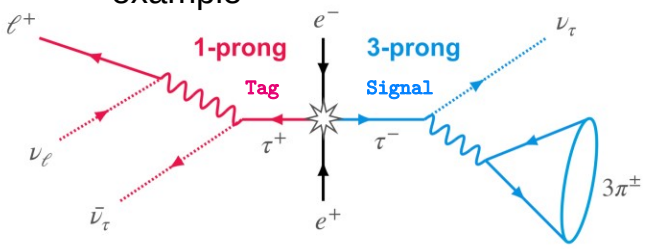
$$B^{SM}_{\tau\to l} \propto B_{\mu\to e}\,\frac{\tau_\tau}{\tau_\mu}\,\frac{m_\tau^5}{m_\mu^5}$$



3x1 topology to extract the mass

"Pseudomass" calculated from the 4-momentum of the 3-pion system

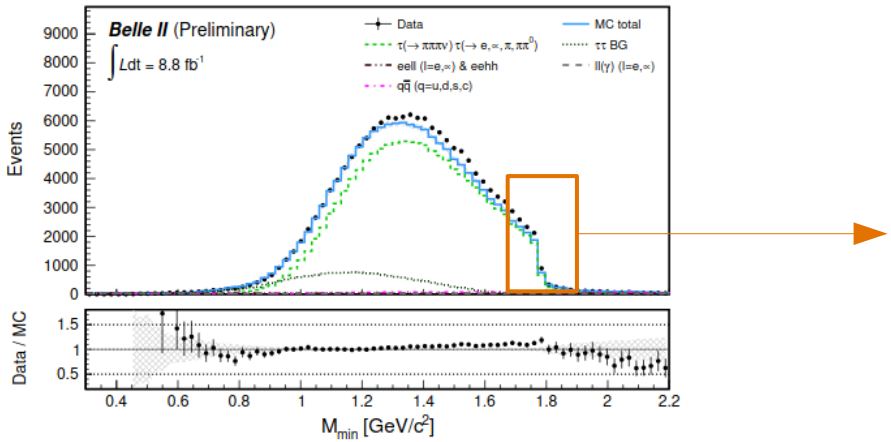
example

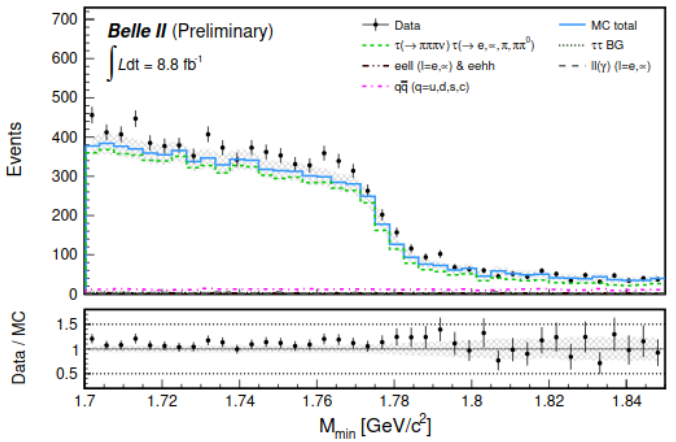


$$\textit{Signal}: \quad \tau^- \to \pi^+\pi^-\pi^-\nu_\tau \quad (BF \sim 9.3\,\%)$$

$$\textit{Tag}: \quad \tau^- \to l^-\bar{\nu}_l\,\nu_\tau,\ \pi^-\nu_\tau,\ \pi^-\pi^0\nu_\tau \quad \left(\sum BF \sim 71.52\%\right)$$

$$M_{\min} = \sqrt{M_{3\pi}^2 + 2(E_{\text{beam}} - E_{3\pi})(E_{3\pi} - P_{3\pi})} \le m_\tau$$





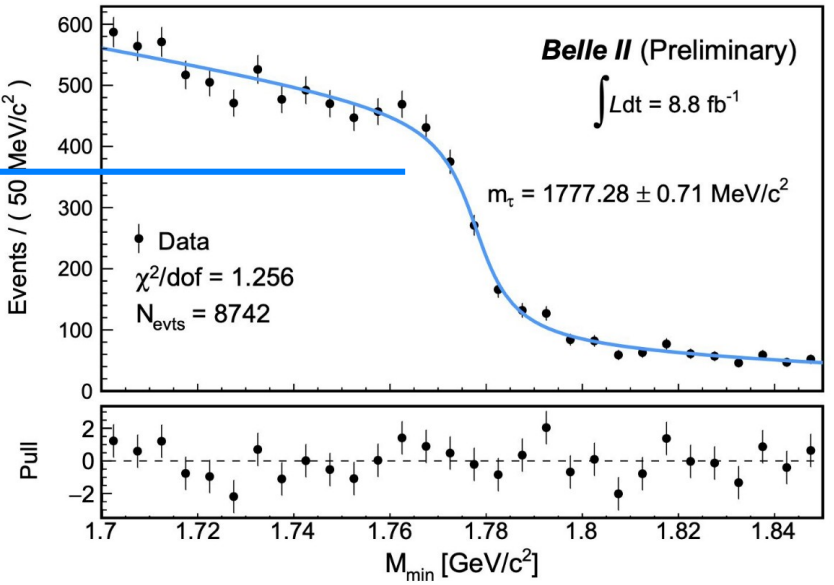
τ mass measurement at Belle II

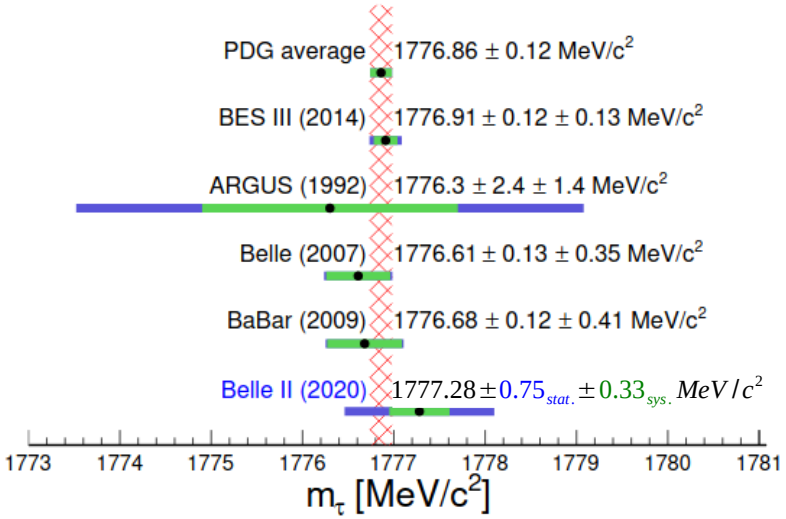
Perform an unbinned maximum likelihood fit to the data using an empirical fit function

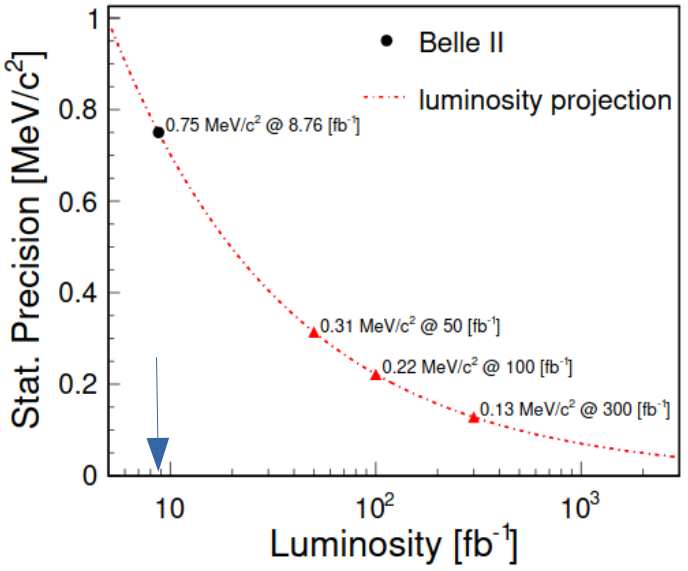
$$F(M_{min}|\overline{P}) = (P_3 + P_4 M_{min}) \tan^{-1}\left(\frac{M_{min} - P_1}{P_2}\right) + P_5 M_{min} + 1$$

$$m_\tau = 1777.28 \pm 0.75_{stat.} \pm 0.33_{sys.}\ MeV/c^2$$

Main source of systematic uncertainties due to tracking corrections → expected to improve as we understand our detector better





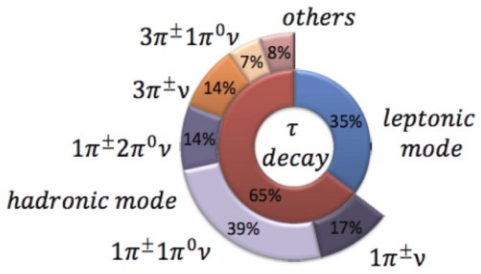


As of today @ Belle II $\int L\,dt = O(100\ fb^{-1})$

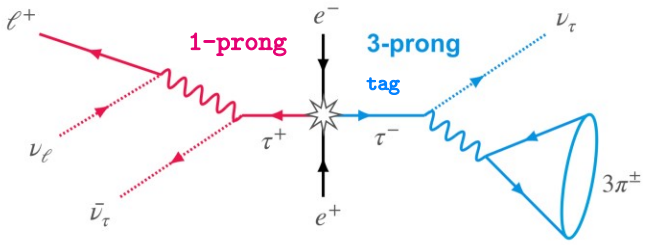
Search for τ → lα at Belle II

- Possible new light boson α in tau decays
- Previous search from ARGUS (1995, 476/pb) and MARK III (1985, 9.4/pb)

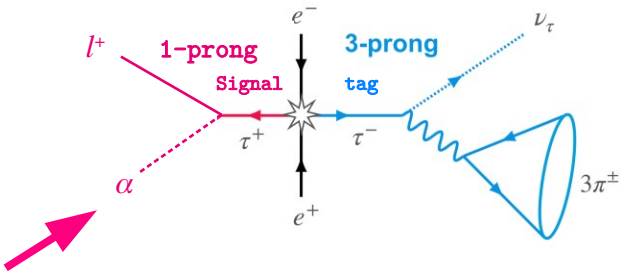
3x1 topology to search for α

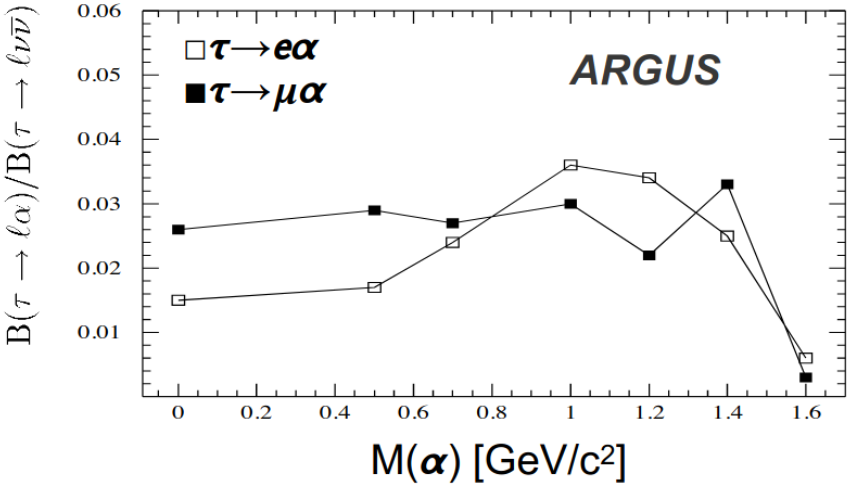


SM background



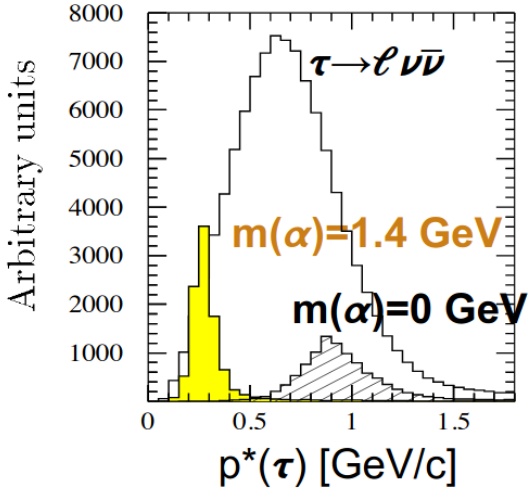
signal





Signal and background share same final state but different kinematics.

- In the τ rest frame the lepton momentum has a peaking structure



Z.Phys. C68 (1995) 25-28

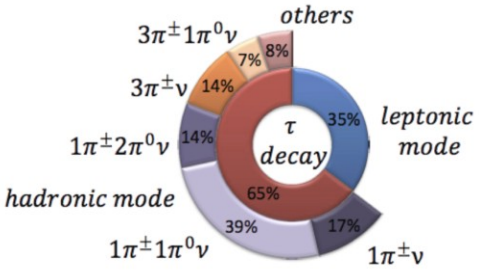
We also test an alternative method in tau pseudo rest-frame using the thrust vector:

$$\vec{T} = max\left(\frac{\sum_i \vec{p}_i \hat{T}}{|p_i|}\right)$$

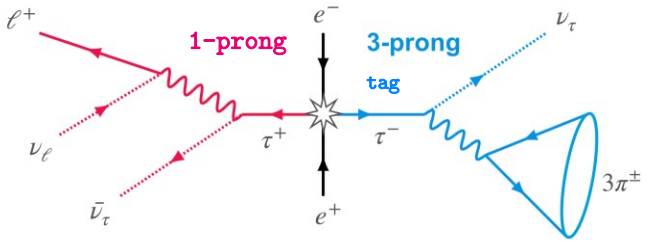
Search for $\tau \to l\alpha$ at Belle II

- Possible new light boson α in tau decays
- Previous search from ARGUS (1995, 476/pb) and MARK III (1985, 9.4/pb)

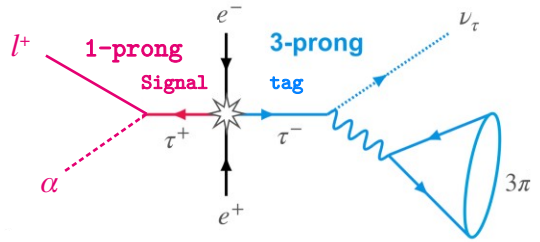
3x1 topology to search for α



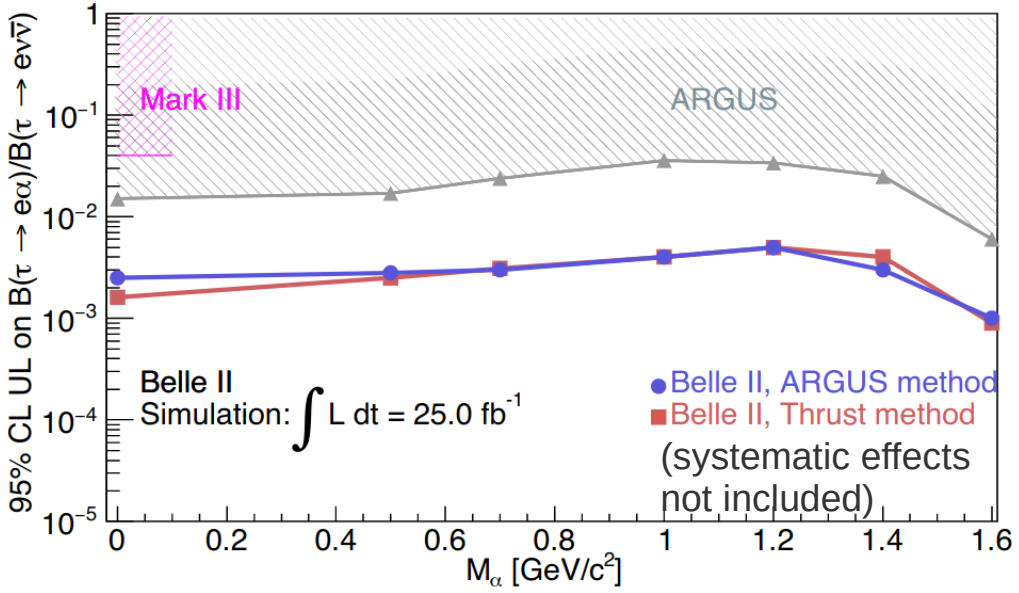
SM background

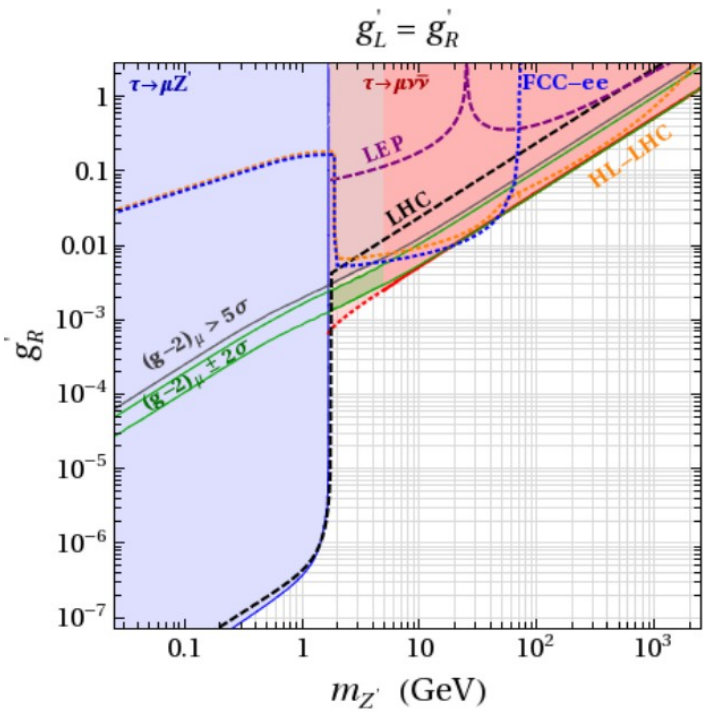


signal



- UL is provided for the ratio $Br(\tau \to e\alpha)/Br(\tau \to e\nu\nu)$

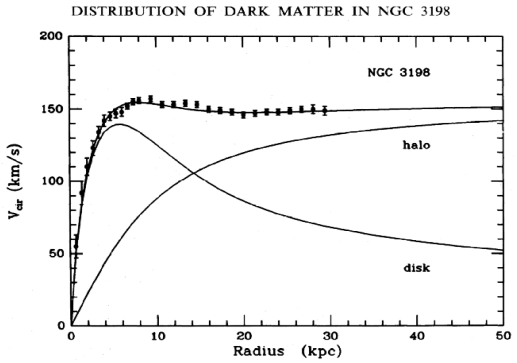


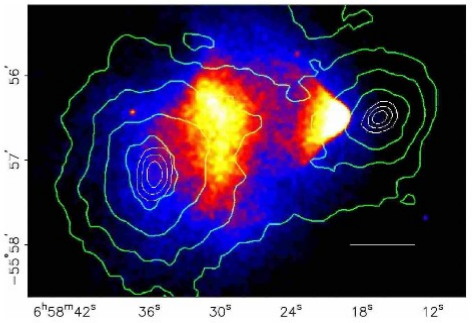


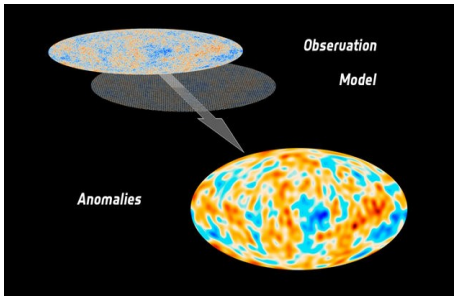
See BELLE2-NOTE-PL-2020-018

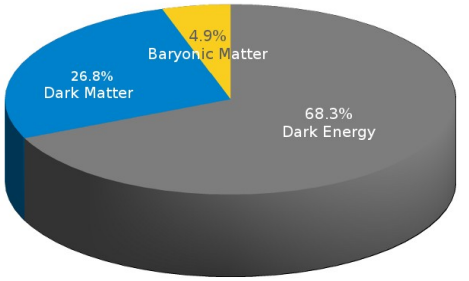
https://arxiv.org/pdf/1607.06832.pdf

Dark matter?

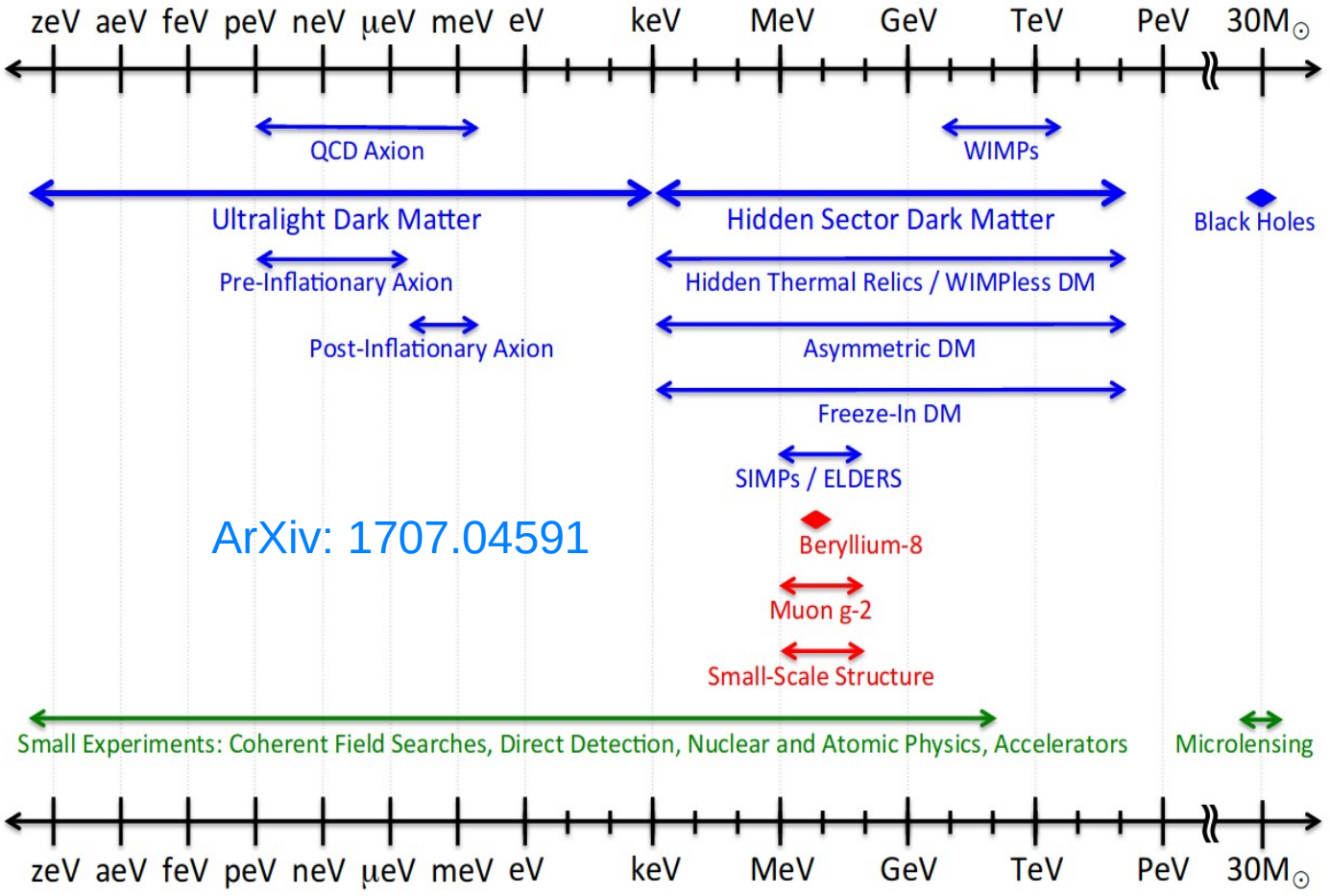








Dark Sector Candidates, Anomalies, and Search Techniques



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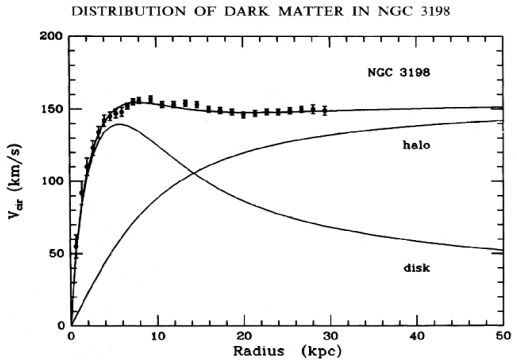
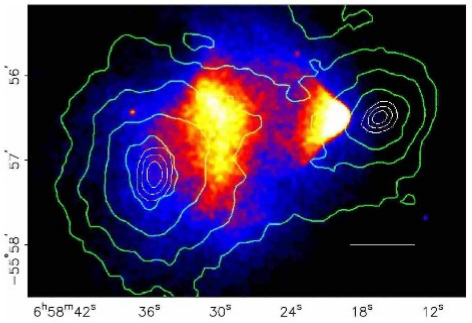
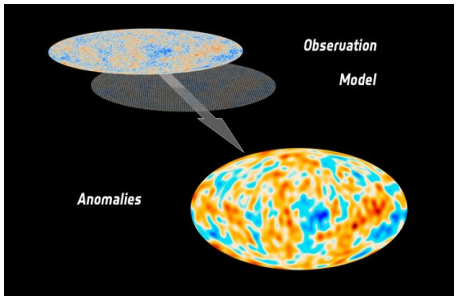
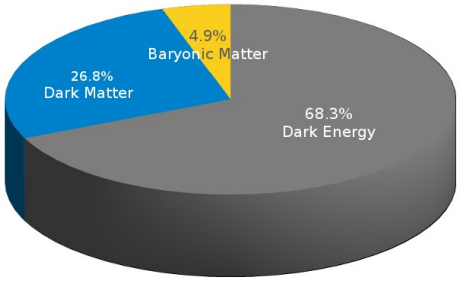
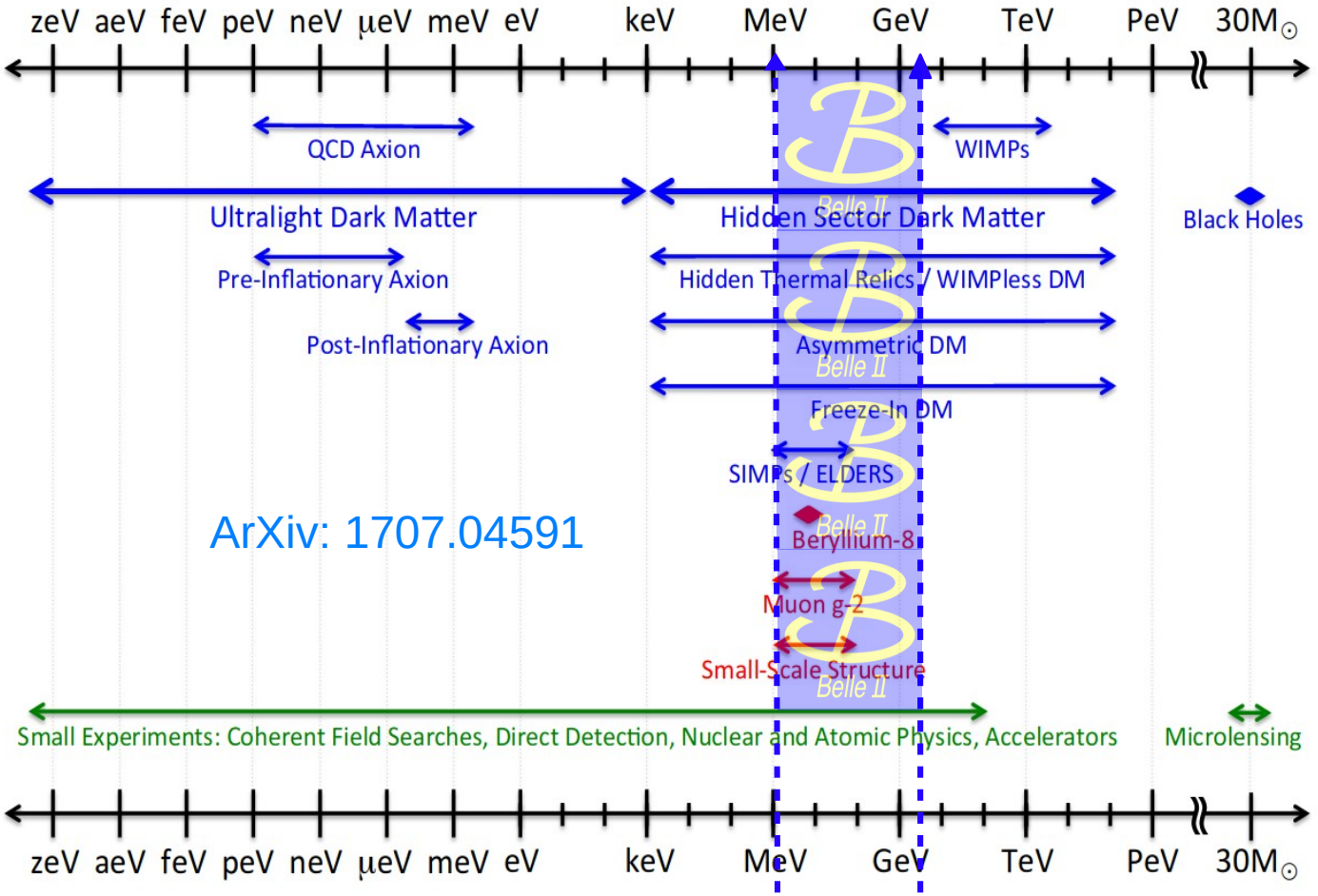




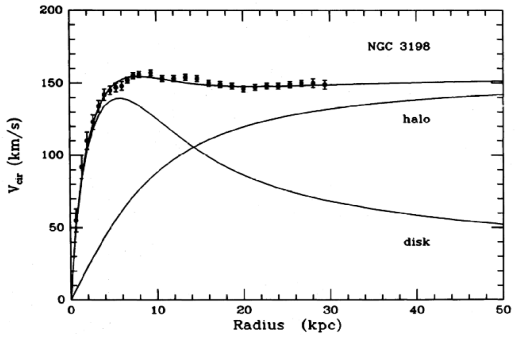


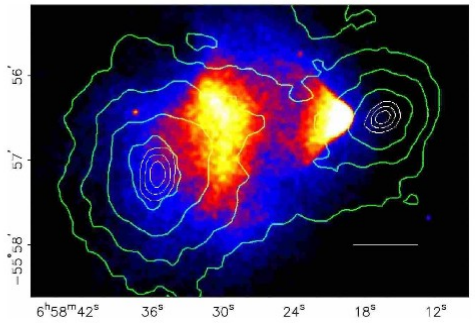


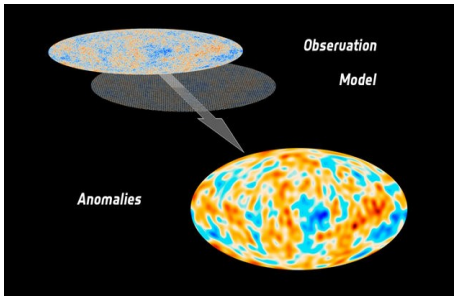
Dark Sector Candidates, Anomalies, and Search Techniques

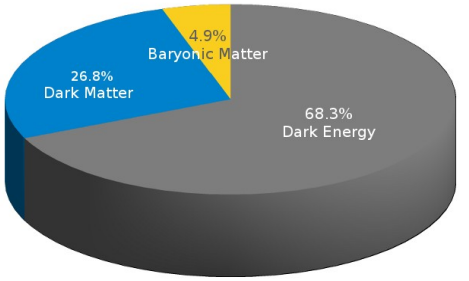


Searching for Dark Matter and Forces @ Belle/Belle II









Belle II

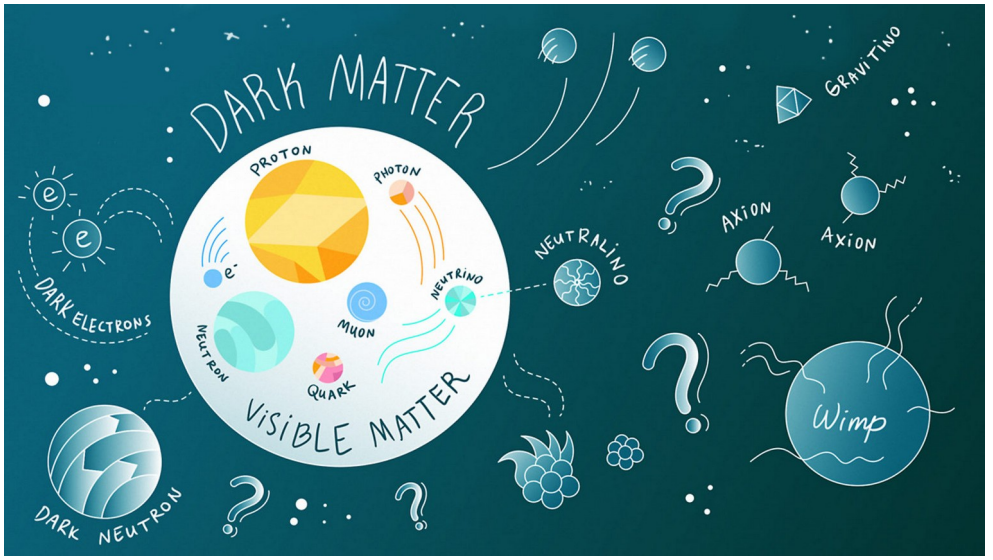
Search for events with missing energy, particle disappearance, dark forces, single/multi-photon final state events, etc.

Belle II

Some ongoing searches

- Dark photon, visible and invisible decays
- Light Z' boson, visible and invisible decays
- Dark higgs boson
- Magnetic monopoles
- Axion like particles
- Long lived particles

From Symmetry Magazine ←



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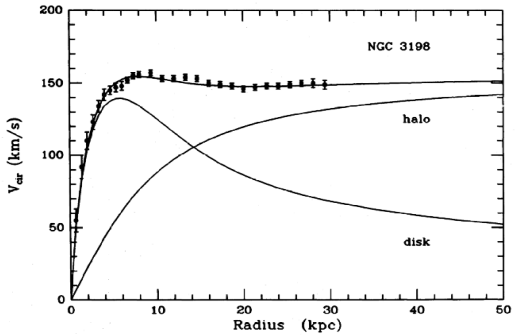

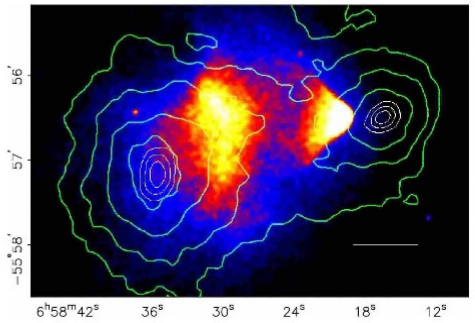

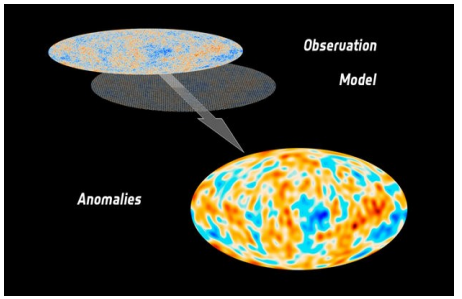

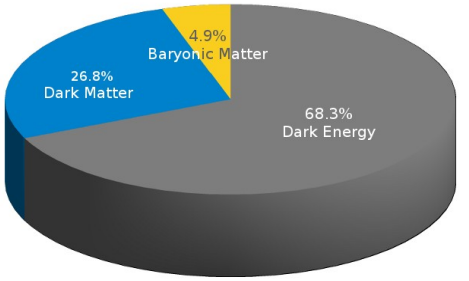

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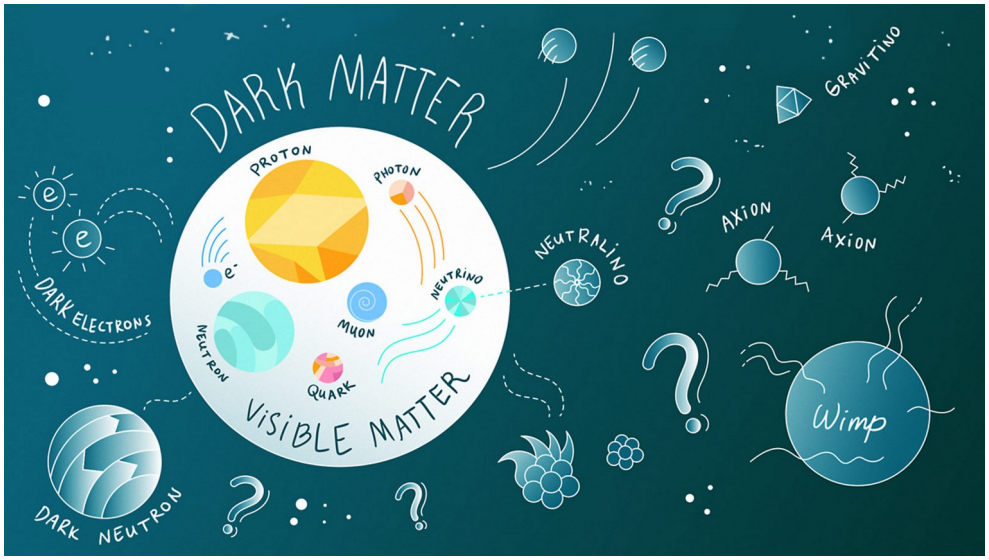

Lepton non-universal coupling: the L_μ-L_τ model and a dark Z'

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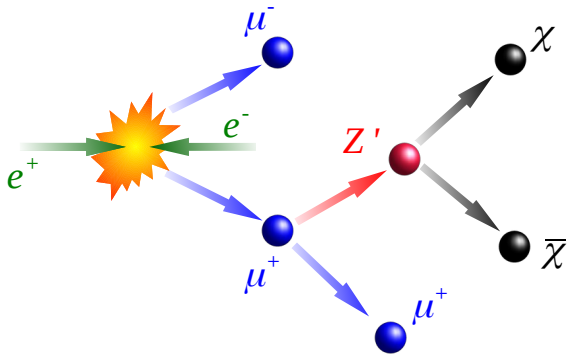
The equations for the partial widths are,



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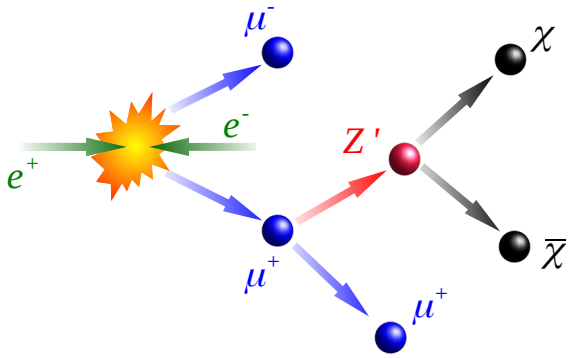

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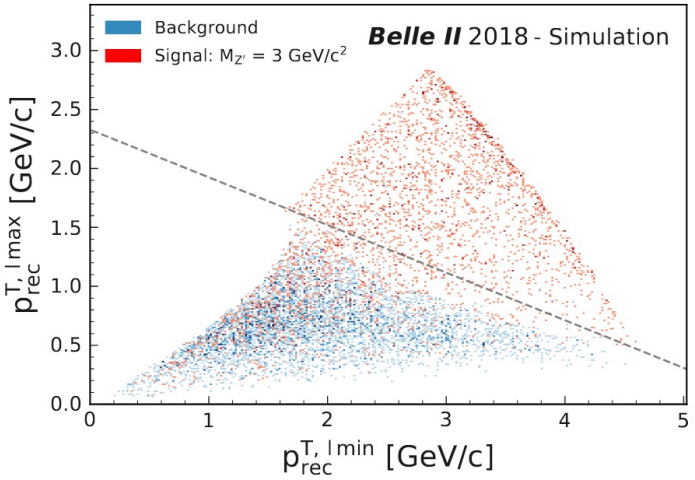
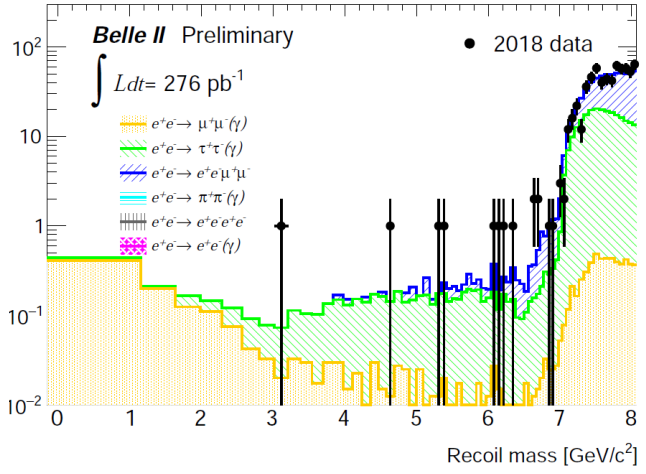
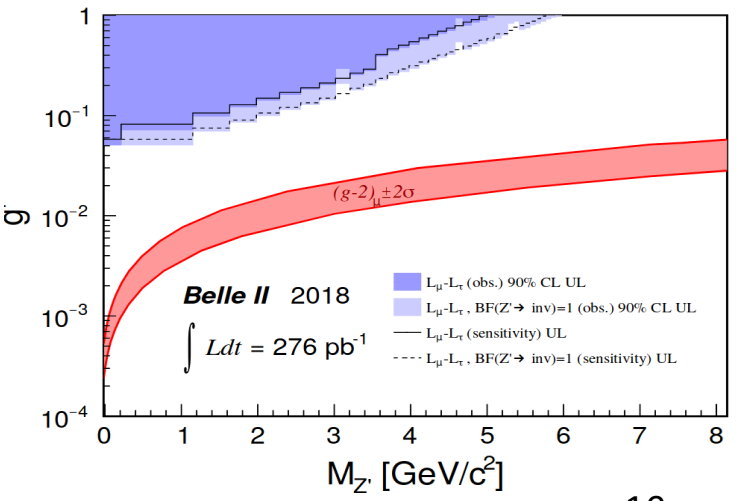
First physics paper @Belle II, PRL **124**, 141801 (2020), arXiv:1912.11276







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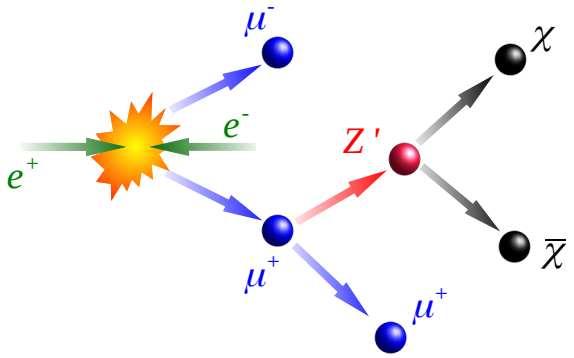

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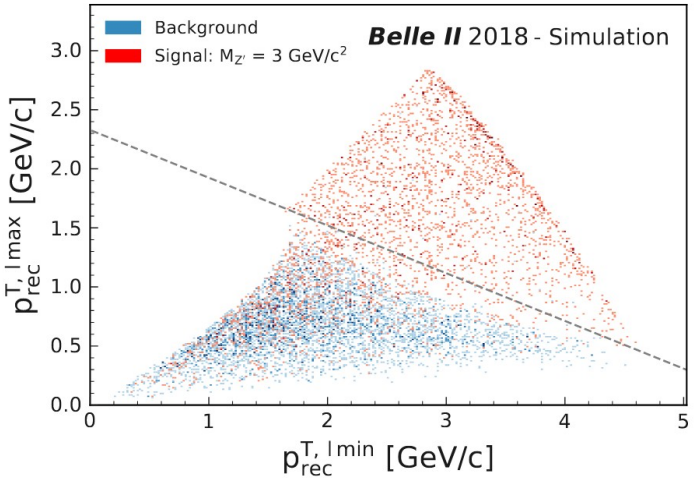
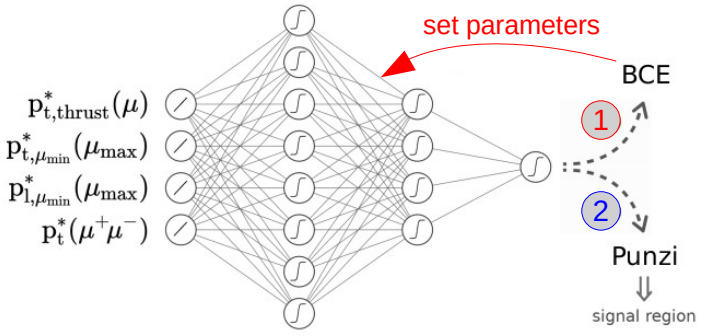
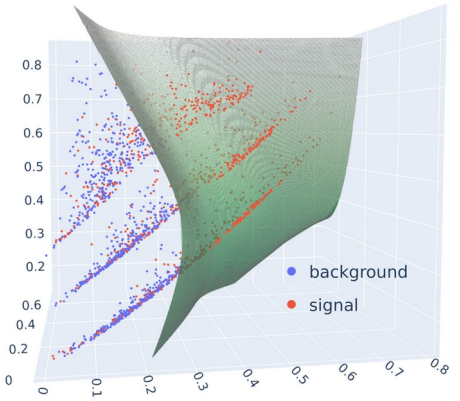
New and improved PID system (KLM) and new machine learning analysis techniques based on artificial neural networksANNs, provide better selection and better sensitivities







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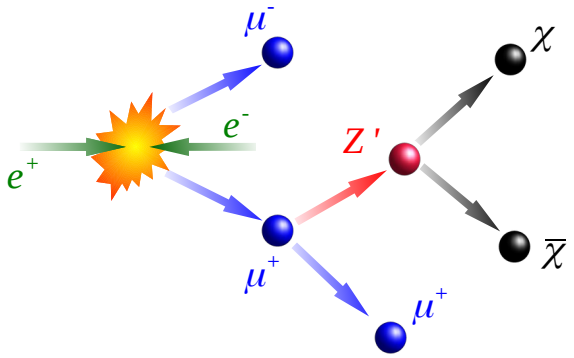

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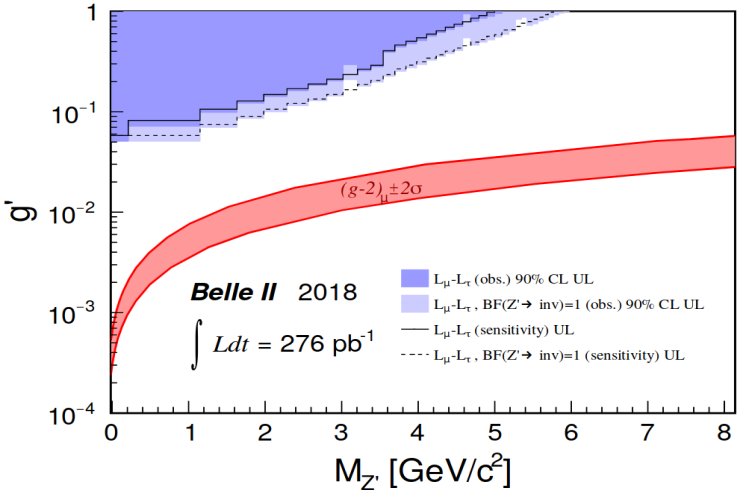
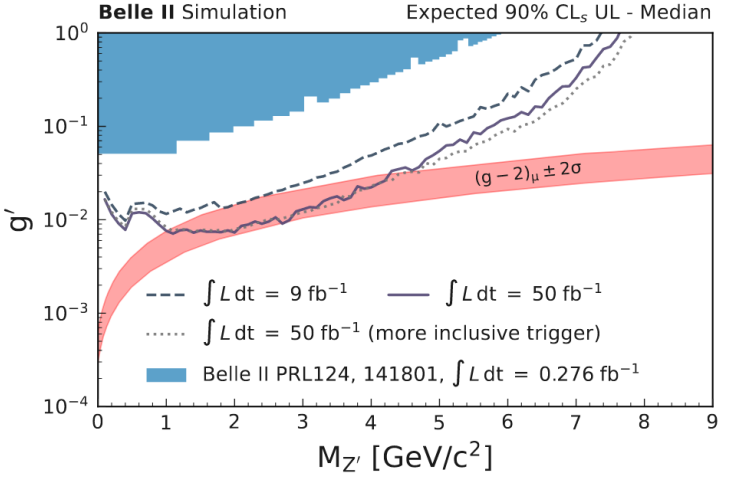
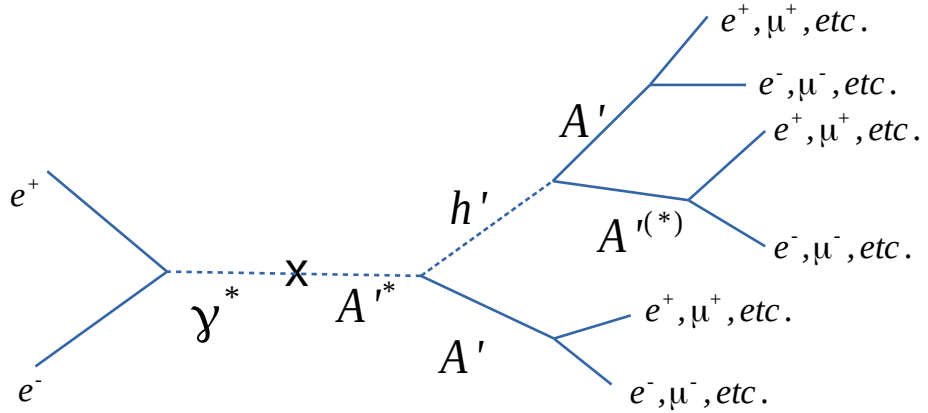


In the near term



Dark Higgs-strahlung @ Belle II

See B. Batell, M. Pospelov, and A. Ritz Phys. Rev. D 79, 356 115008 (2009), arXiv:0903.0363



Thanks to (small) kinetic mixing with the standard model photon, the dark photon A' can decay to standard model final states

Higgs-strahlung process

h'= dark Higgs,
A'= dark photon
Higgs-strahlung: h' decays depending on $M_{h'}$ and $M_{A'}$. Measures the coupling constant of the dark photon to the dark Higgs, α_D.

$M_{h'}>2M_{A'}$: $h' \rightarrow A'A'$, Very low background.

Exclusive: 3 charged tracks pairs with same invariant mass and total energy of the event.

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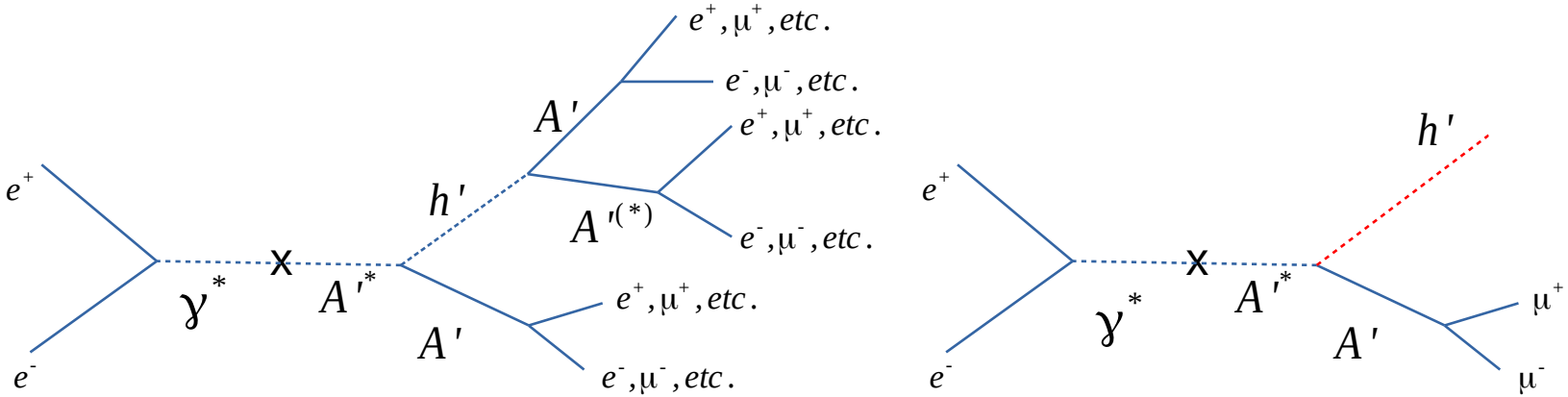

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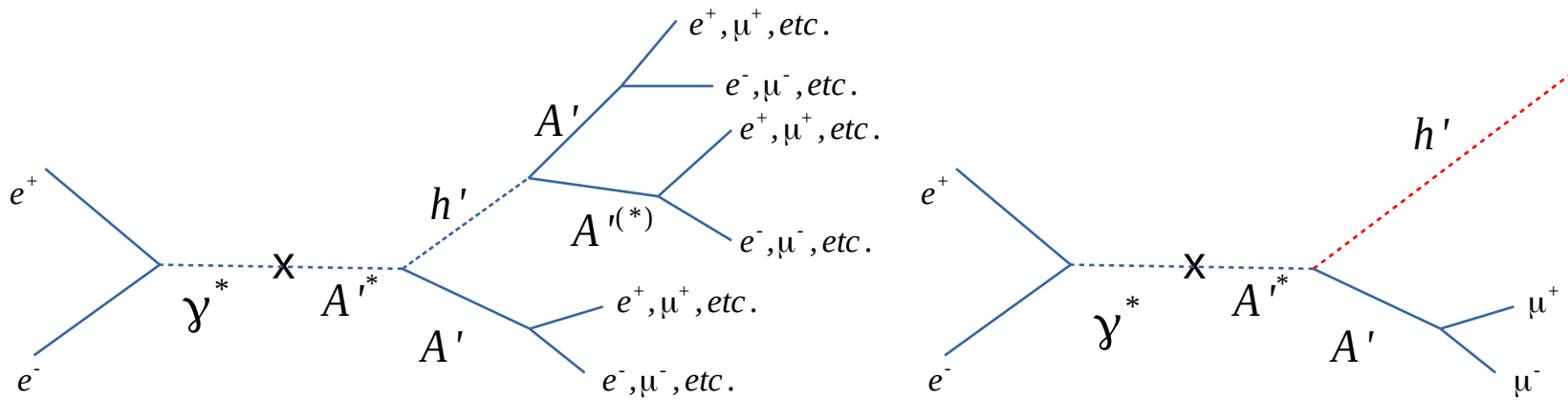

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Dark Higgs-strahlung @ Belle II with 10/fb

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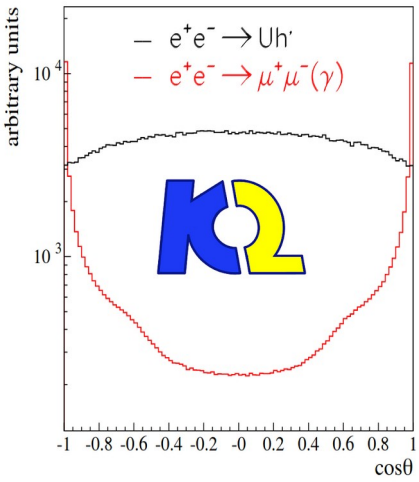
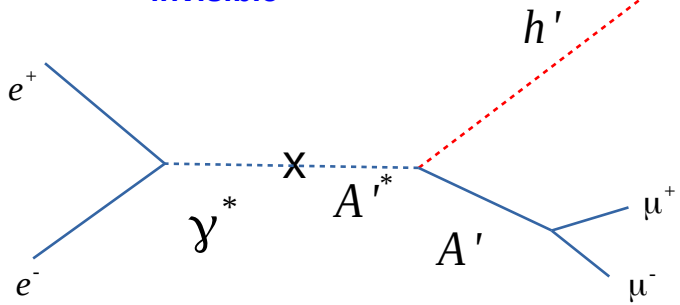


KLOE-2
ArXiv: 1501.06795

- Identical final state as for the invisible Z' search
- Low SM background
- Allows simultaneous search of a dark Higgs boson and of dark photon
- Existing limits only from KLOE

Current focus on $\mu^+\mu^-$+invisible final state, plans to extend to e^+e^-+invisible



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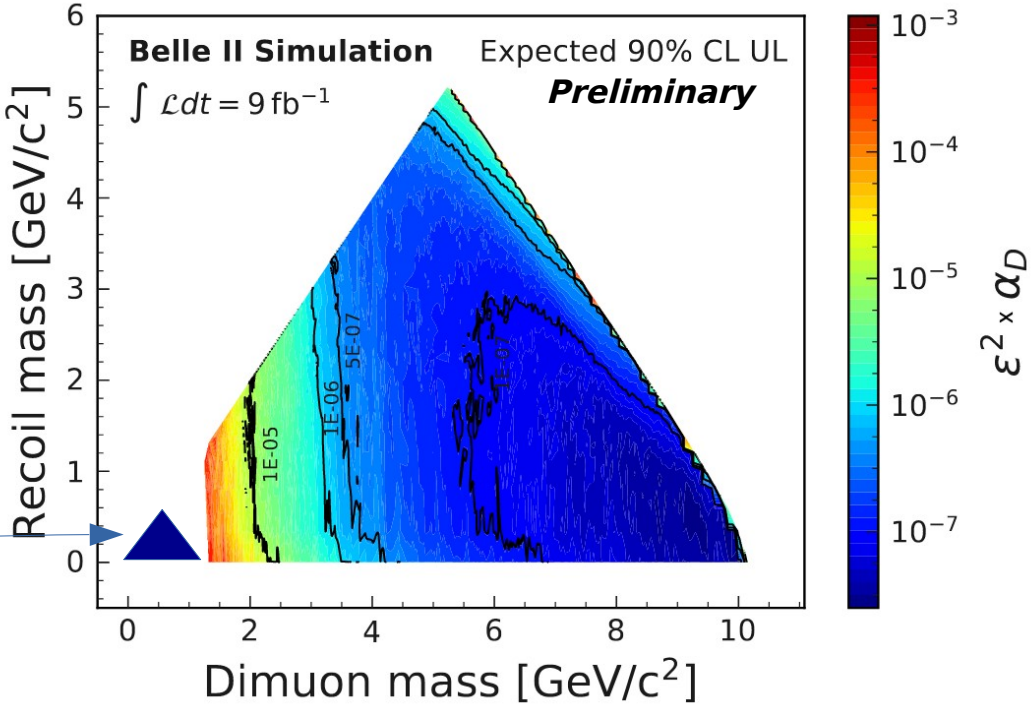
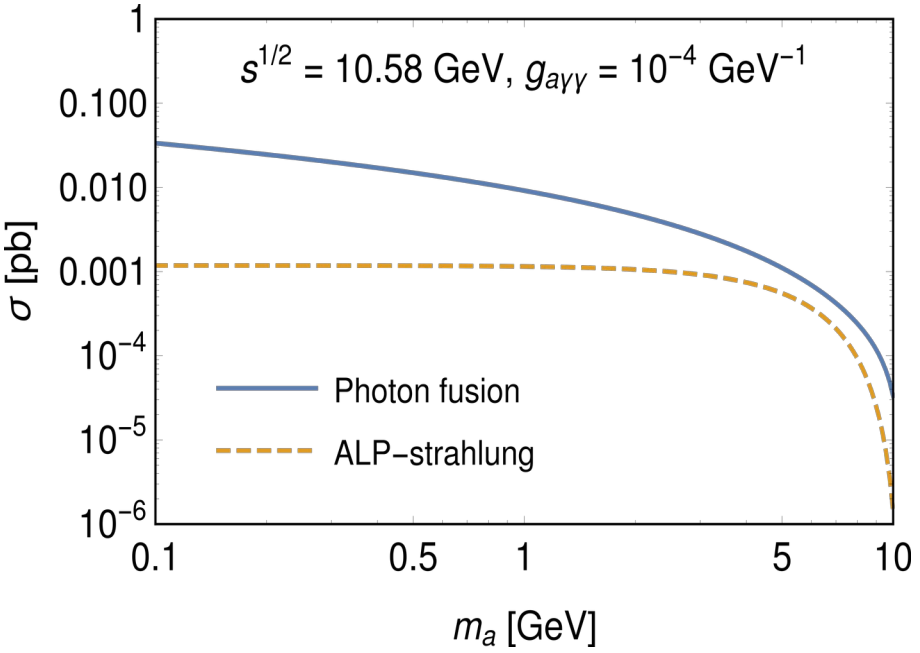


Approaching data unblinding!

KLOE-2
ArXiv: 1501.06795

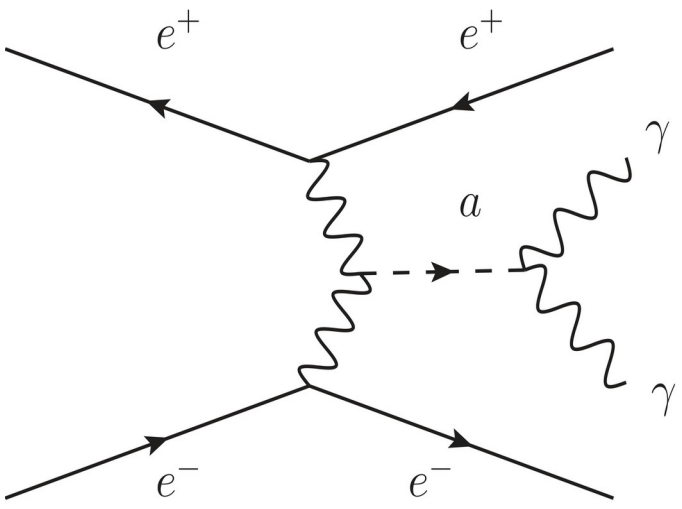
Axion Like Particles (ALPs) at Belle II

$$\mathcal{L} \supset -\frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu}\tilde{F}^{\mu\nu} - \frac{g_{a\gamma Z}}{4} a F_{\mu\nu}\tilde{Z}^{\mu\nu} - \frac{g_{aZZ}}{4} a Z_{\mu\nu}\tilde{Z}^{\mu\nu} - \frac{g_{aWW}}{4} a W_{\mu\nu}\tilde{W}^{\mu\nu}$$

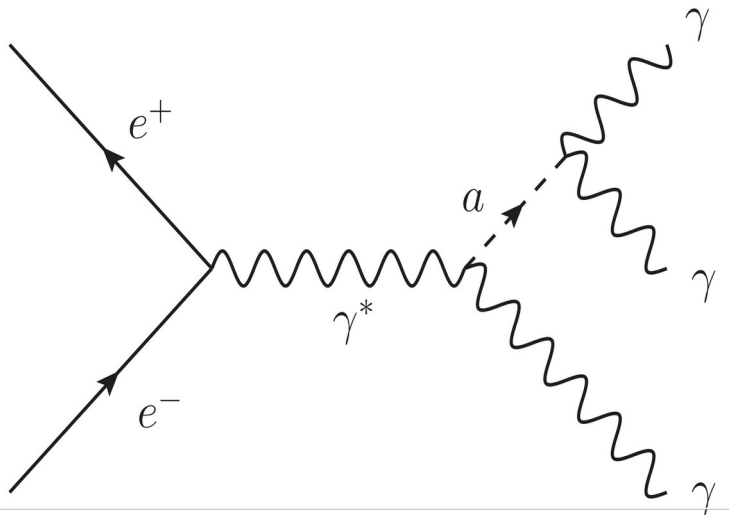


JHEP 1712 (2017) 094

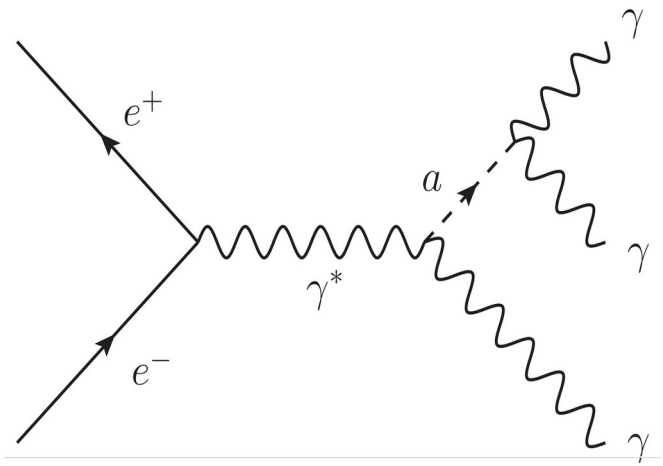
Photon fusion

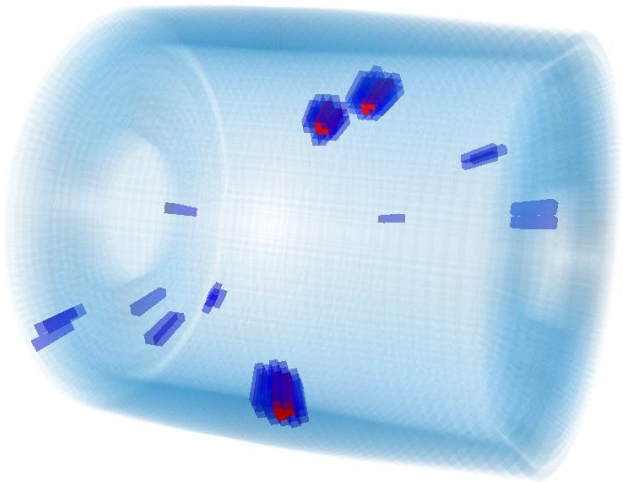


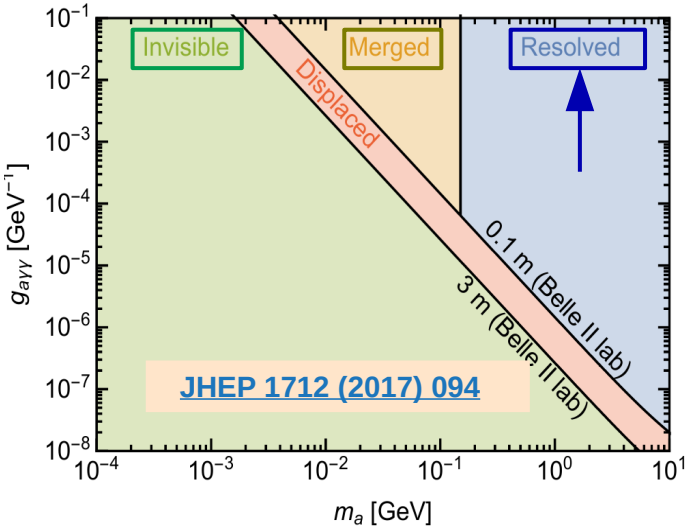
ALP-strahlung



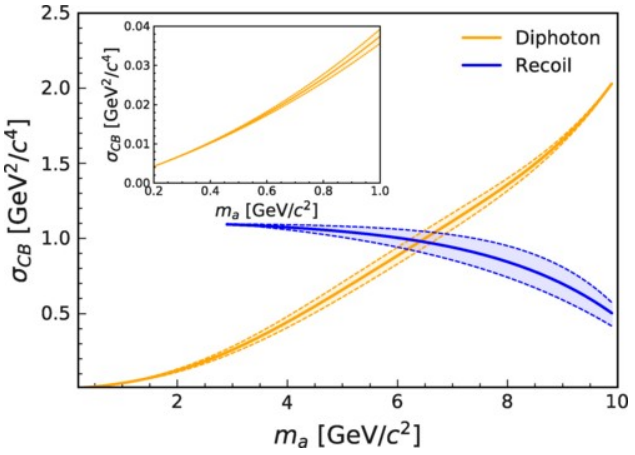
ALPstrahalung at Belle II

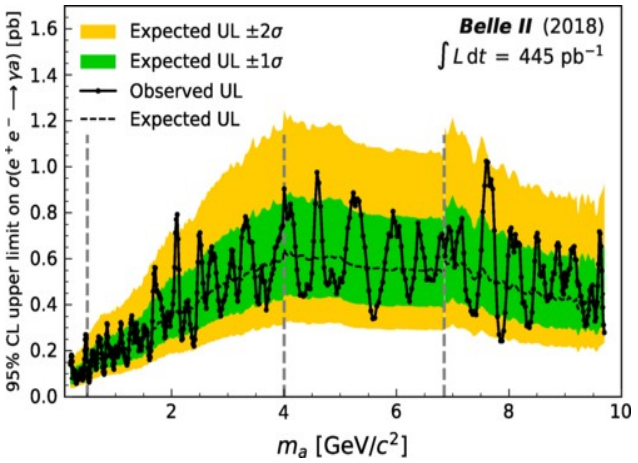


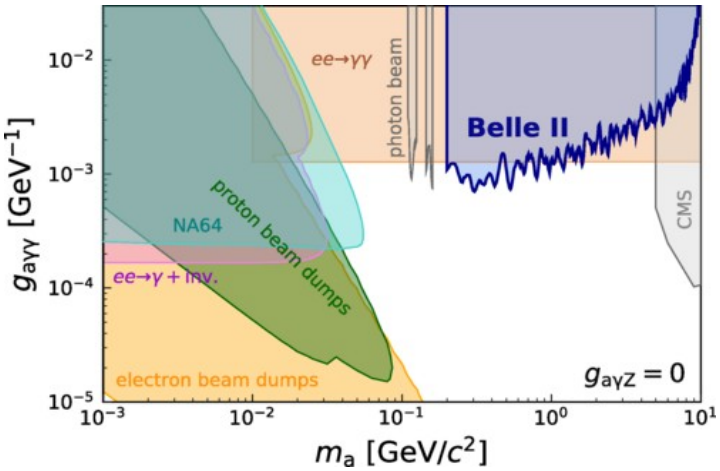




- Three photons that add up to the beam energy + bump on diphoton mass.
- SM background: $e^+e^- \rightarrow \gamma\gamma(\gamma)$, $e^+e^- \rightarrow e^+e^-(\gamma)$, and $e^+e^- \rightarrow$ scalar+$\gamma(\gamma)$







→ **ArXiv: 2007.13071**

→ **Phys. Rev. Lett. 125, 161806**

New Phenomena Session

Latest results on τ and dark sector physics at Belle II

Summary

- Presented a selection of recent results and ongoing analyses
- We are accumulating data at unprecedented luminosity
- Many new results to be expected in the near future

31/03/2021
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Moriond QCD 2021: very unusual conference settings… Still an amazing event!

Thank you for your attention!

31/03/2021
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Belle II

InterLeptons