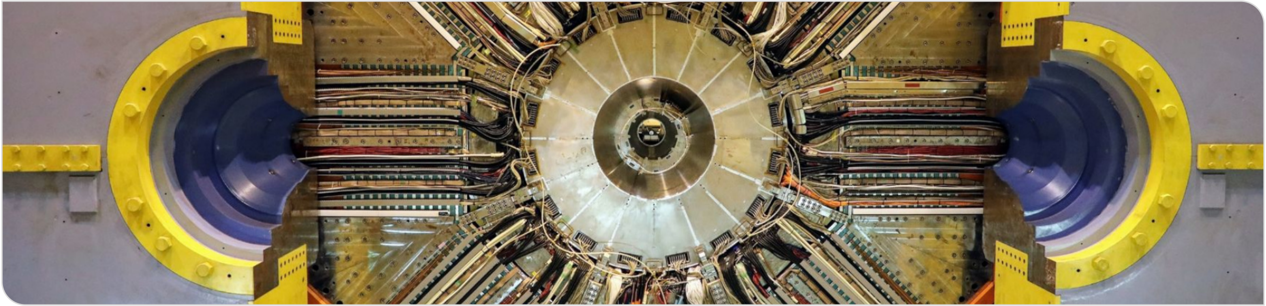
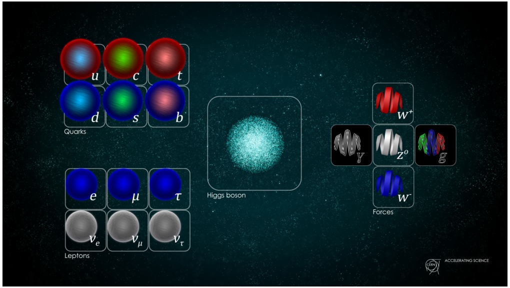
Belle II on NEMO: Flavour and Dark Matter Physics

Patrick Ecker, **Matthias J. Schnepf** | 25. September 2024



Particle Physics

- the Standard Model (SM) of particle physics
  - world is built of elementary particles
    - mesons: made of quarks-antiquark pair
    - baryons: made of three quarks, e.g., proton, neutron
  - describes the forces and interactions of particles
  - complete since the discovery of the Higgs Boson ("God Particle")
- some parameters need to be measured, e.g. masses



https://home.cern/science/physics/standard-model

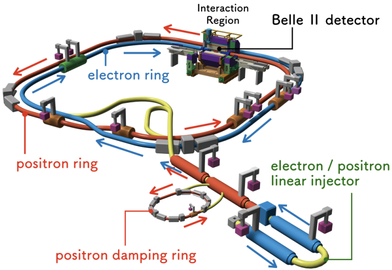
Open Questions

- Where is the antimatter?
- What is the invisible mass in the universe (dark matter)?
- Is there a universal force?

NASA picture of the day 26.7.24

Belle II

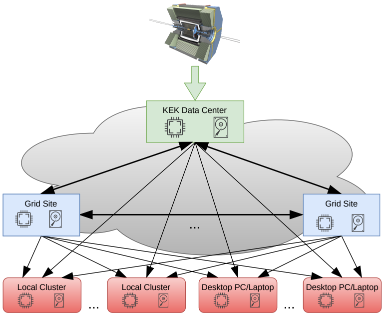
- Belle II particle physics experiment at SuperKEKB accelerator in Japan near Tokyo
- collision of electrons and positrons to create other particles
- clean collision events
- B-factory: creates mostly B mesons
- worldwide collaboration
  - more than 1000 people in 28 countries
  - KIT is in the top 10 of the biggest groups
- will collect 50 times more data than Belle



www.kek.jp

Physics Analysis Workflow

- collaboration
  - record collision events
  - simulate events
  - reconstruct recorded and simulated events
  - study detector and machine effects
  - mostly done on worldwide distributed computing infrastructure, so-called Grid (common resources)
- analyst
  - select events necessary for the analysis
  - analyze data, mainly compare distributions via statistical methods
  - mostly done on local/institute resources, e.g., NEMO (premium resources)



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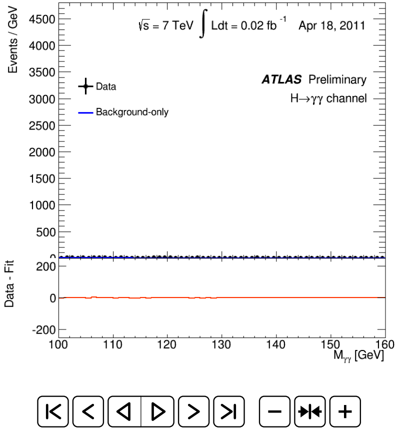

cds.cern.ch ATLAS-PHOTO-2012-001

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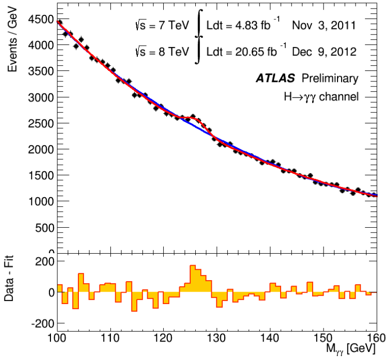

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Flavor Physics at Belle II

- flavor physics: study quarks and leptons and their bounding states
- B mesons are ideal to study flavor physics
- B meson
  - easy to detect
  - several hundred decays
- precise measurement of the decays is key to understand matter-antimatter asymmetry

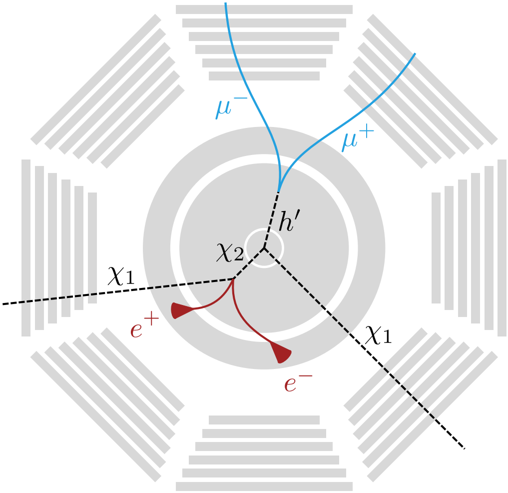
Citation: S. Navas *et al.* (Particle Data Group), Phys. Rev. D **110**, 030001 (2024)

B^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\ell^+ \nu_\ell X$	[a]	(10.33 ± 0.28) %		–
$e^+ \nu_e X_c$		(10.1 ± 0.4) %		–
$\ell^+ \nu_\ell X_u$	[a]	(1.51 ± 0.19) $\times 10^{-3}$		–
$D \ell^+ \nu_\ell X$	[a]	(9.1 ± 0.8) %		–
$D^- \ell^+ \nu_\ell$	[a]	(2.12 ± 0.06) %		2309
$D^- \tau^+ \nu_\tau$		(9.9 ± 2.1) $\times 10^{-3}$		1909
$D^*(2010)^- \ell^+ \nu_\ell$	[a]	(4.90 ± 0.12) %		2257
$D^*(2010)^- \tau^+ \nu_\tau$		(1.45 ± 0.10) %	S=1.3	1838
$\overline{D}^{(*)} n\pi \ell^+ \nu_\ell (n \geq 1)$	[a]	(2.3 ± 0.5) %		–
$\overline{D}^0 \pi^- \ell^+ \nu_\ell$	[a]	(3.64 ± 0.20) $\times 10^{-3}$		2308
$D_0^*(2300)^- \ell^+ \nu_\ell$, $D_0^{*-} \to \overline{D}^0 \pi^-$	[a]	< 4.4 $\times 10^{-4}$	CL=90%	–
$D_2^*(2460)^- \ell^+ \nu_\ell$, $D_2^{*-} \to \overline{D}^0 \pi^-$	[a]	(1.41 ± 0.20) $\times 10^{-3}$	S=1.7	2065
$\overline{D}^{*0} \pi^- \ell^+ \nu_\ell$	[a]	(5.44 ± 0.28) $\times 10^{-3}$		2256
$D_1(2420)^- \ell^+ \nu_\ell$, $D_1^- \to \overline{D}^{*0} \pi^-$	[a]	(2.85 ± 0.25) $\times 10^{-3}$		–
$D_1(2420)^- \ell^+ \nu_\ell$, $D_1^- \to D^- \pi^+ \pi^-$	[a]	(1.02 ± 0.16) $\times 10^{-3}$		–
$D_1'(2430)^- \ell^+ \nu_\ell$, $D_1'^- \to \overline{D}^{*0} \pi^-$	[a]	(2.5 ± 0.6) $\times 10^{-3}$		–
$D_2^*(2460)^- \ell^+ \nu_\ell$, $D_2^{*-} \to \overline{D}^{*0} \pi^-$	[a]	(6.6 ± 1.1) $\times 10^{-4}$		2065
$D^- \pi^+ \pi^- \ell^+ \nu_\ell$	[a]	(1.45 ± 0.22) $\times 10^{-3}$		2299
$D^{*-} \pi^+ \pi^- \ell^+ \nu_\ell$	[a]	(5.1 ± 2.3) $\times 10^{-4}$		2247
$\rho^- \ell^+ \nu_\ell$	[a]	(2.94 ± 0.21) $\times 10^{-4}$		2583
$\pi^- \ell^+ \nu_\ell$	[a]	(1.50 ± 0.06) $\times 10^{-4}$		2638
$\pi^- \tau^+ \nu_\tau$		< 2.5 $\times 10^{-4}$	CL=90%	2339
Inclusive modes				
$K^\pm X$		(78 ± 8) %		–
$D^0 X$		(8.1 ± 1.5) %		–
$\overline{D}^0 X$		(47.4 ± 2.8) %		–
$D^+ X$		< 3.9 %	CL=90%	–
$D^- X$		(36.9 ± 3.3) %		–
$D_s^+ X$		(10.3 $^{+2.1}_{-1.8}$) %		–
$D_s^- X$		< 2.6 %	CL=90%	–
$\Lambda_c^+ X$		< 3.1 %	CL=90%	–

https://pdg.lbl.gov   Page 32   Created: 5/31/2024 10:13

Dark Matter at Belle II

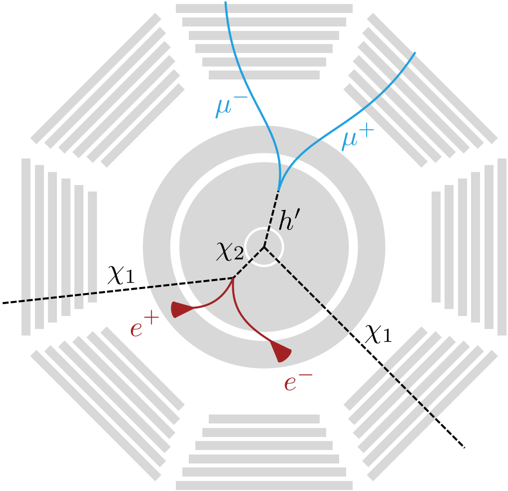
- some theory models predict a "dark Higgs" (Higgs boson that does not interact much with "visible" particles)
- electron-positron collision results in dark matter particles and a dark Higgs boson, which decay in SM particles
- SM particles can be reconstructed to determine their daughter particles' position, momentum, and energy



PhD Thesis Patrick Ecker

Search for Dark Matter at Belle II

- PhD Thesis of Patrick Ecker (KIT)
- compare distributions of recorded events with simulated SM and dark Higgs events via statistical methods



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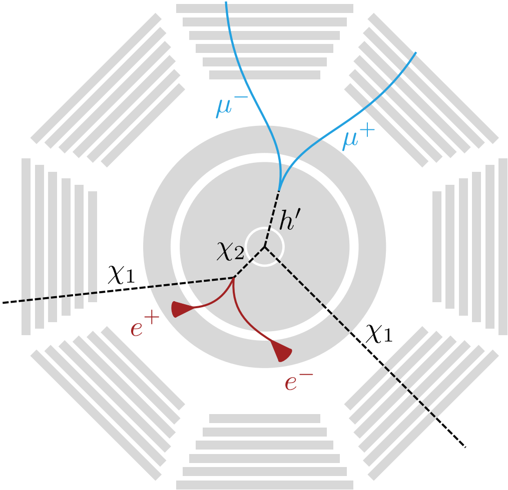
- Dark Higgs events can be simulated
  - seven parameters of the dark Higgs process are not defined by models
  - more than 35000 different parameter combinations were simulated



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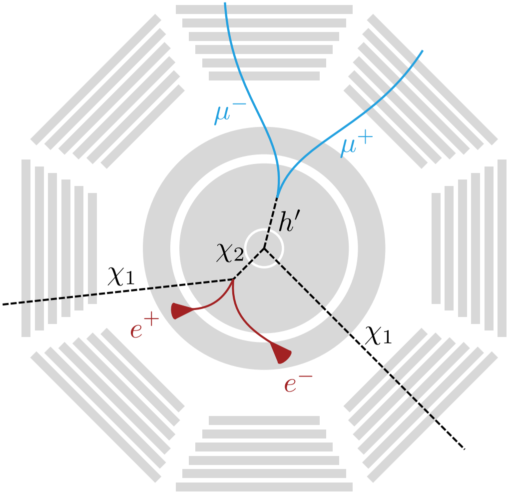

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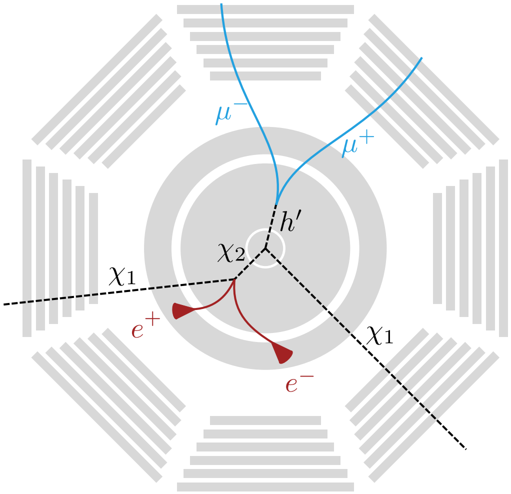

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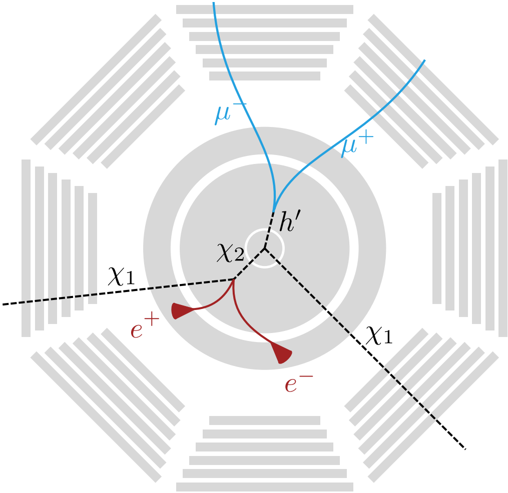

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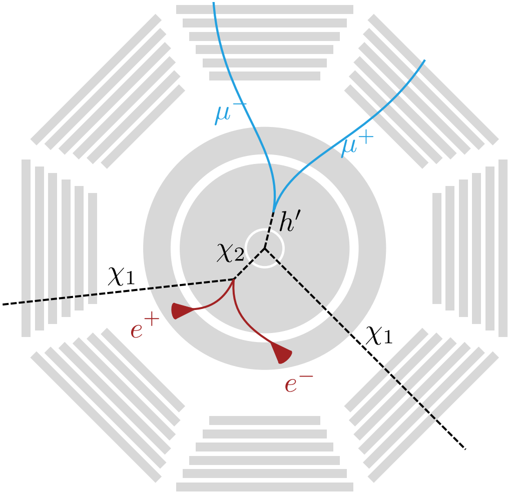
- about 100 TB storage space and 1.2mil CPUh needed



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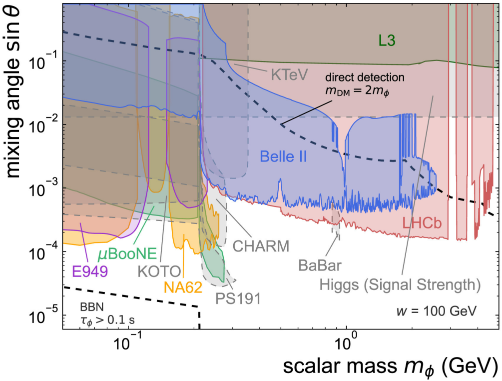
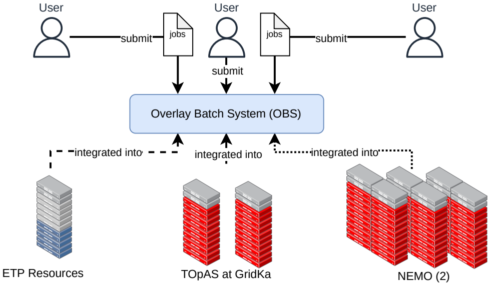
- about 100 TB storage space and 1.2mil CPUh needed
- result
  - will be published
  - discovery of dark Higgs or (more likely) new exclusion limits on dark Higgs



Dark Higgs bosons at colliders, https://doi.org/10.1016/j.ppnp.2024.104105

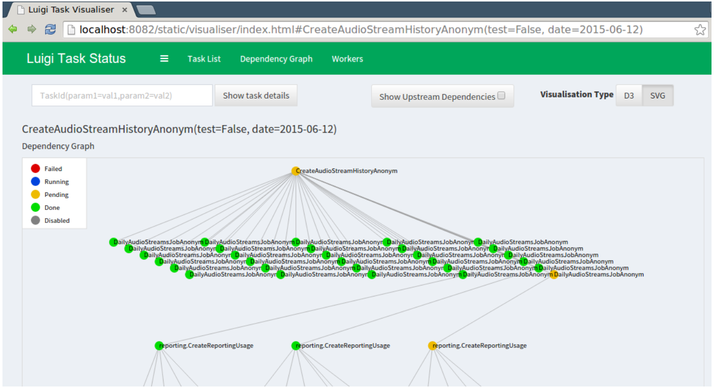
Computing Infrastructure

- users submit jobs to Overlay Batch System (OBS)
- different resources are (dynamically) integrated into the OBS (several thousand cores)
- resources provide a homogeneous software environment via container
- Grid storage
  - accessible on all resources via Grid protocols
  - 250 TB for KIT Belle II group



b2luigi

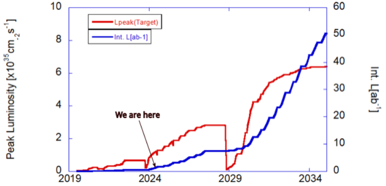
- Analyses contain complex workflows and should be reproducible
- Workflow Management Tool Luigi from Spotify
- b2luigi add Grid and Batch System support to Luigi



Luigi, Spotify

Conclusion and Outlook

- Belle II studies the fundamental principles of the universe
- Belle II at KIT does several analyses on different topics, e.g., flavor physics, and dark matter search
- NEMO helped a lot to analyze data and produce simulations
- Happy to use NEMO 2 for further analysis with more data



https://www.belle2.org/research/luminosity/

Backup