2. Intensity Frontier

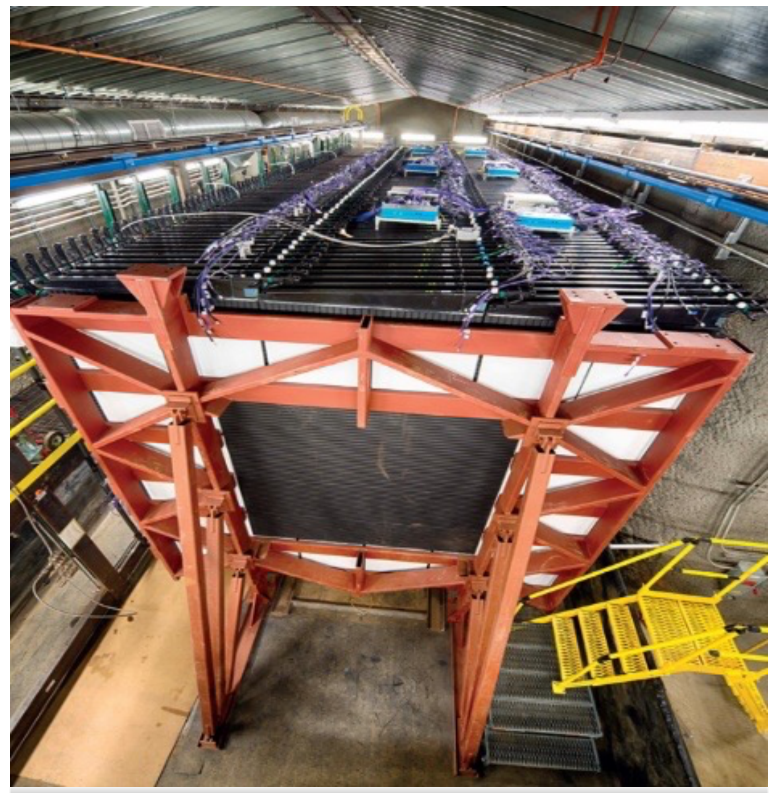
US Intensity Frontier Experiments

by H. Murayama @ 13th ICFA seminar

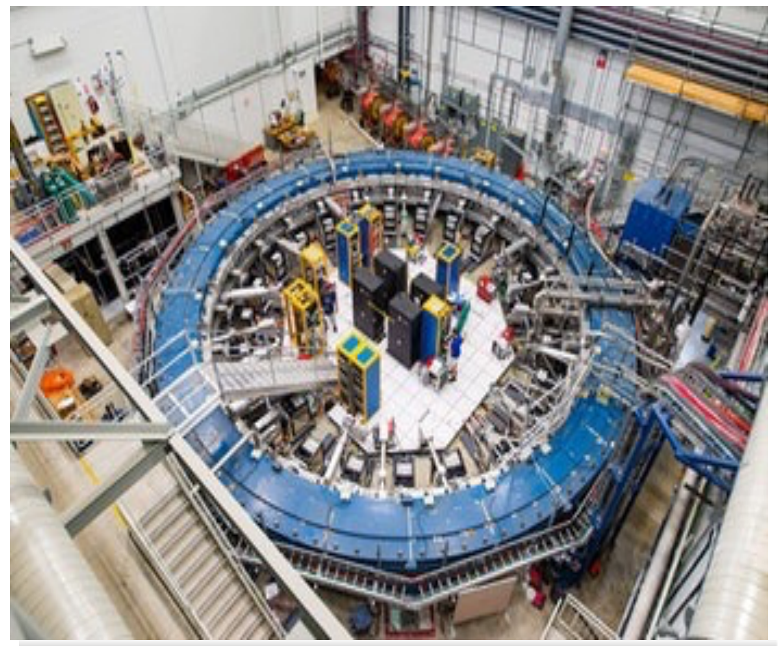
	Energy Frontier	Intensity Frontier	Cosmic Frontier
Higgs Boson	●		
Neutrino Mass		●	●
Dark Matter	●	●	●
Cosmic Acceleration			●
Explore the Unknown	●	●	●

ICARUS at Fermilab

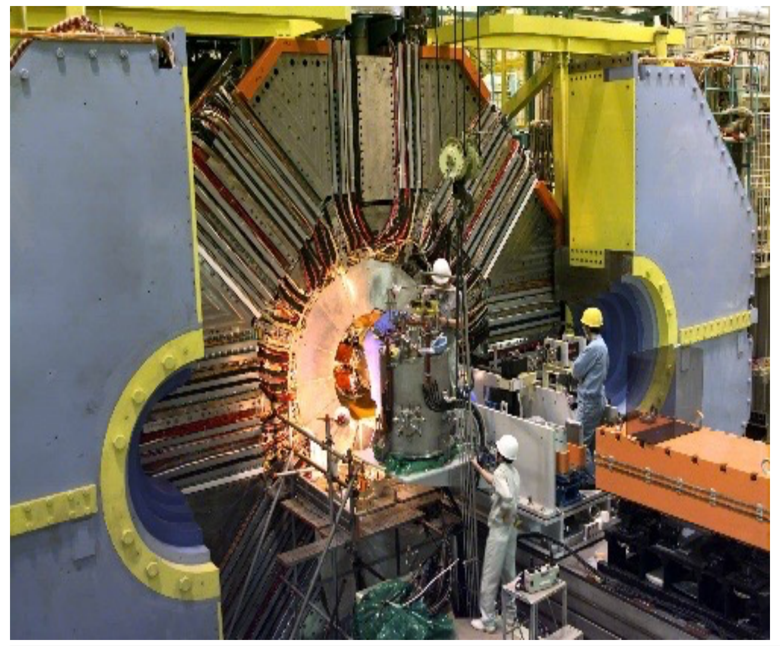
Mu2E at Fermilab



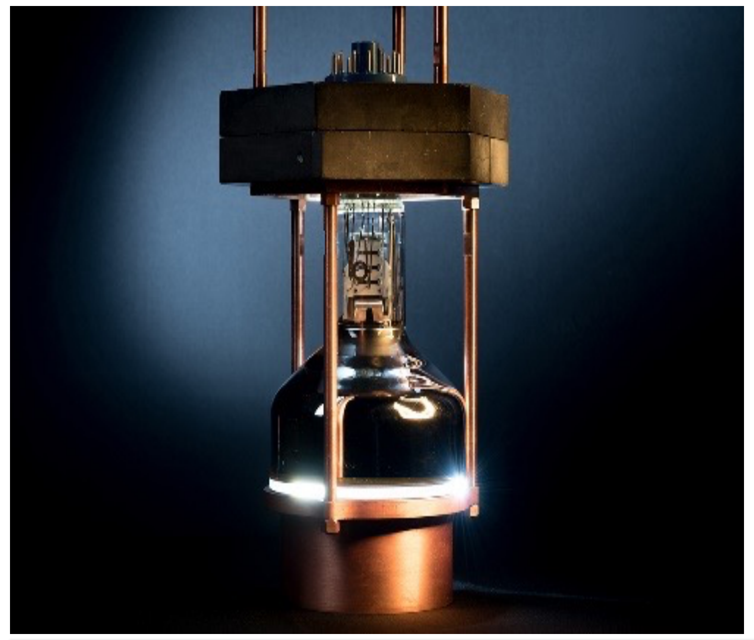
NOvA at Fermilab and Ash River



Muon g-2 at Fermilab

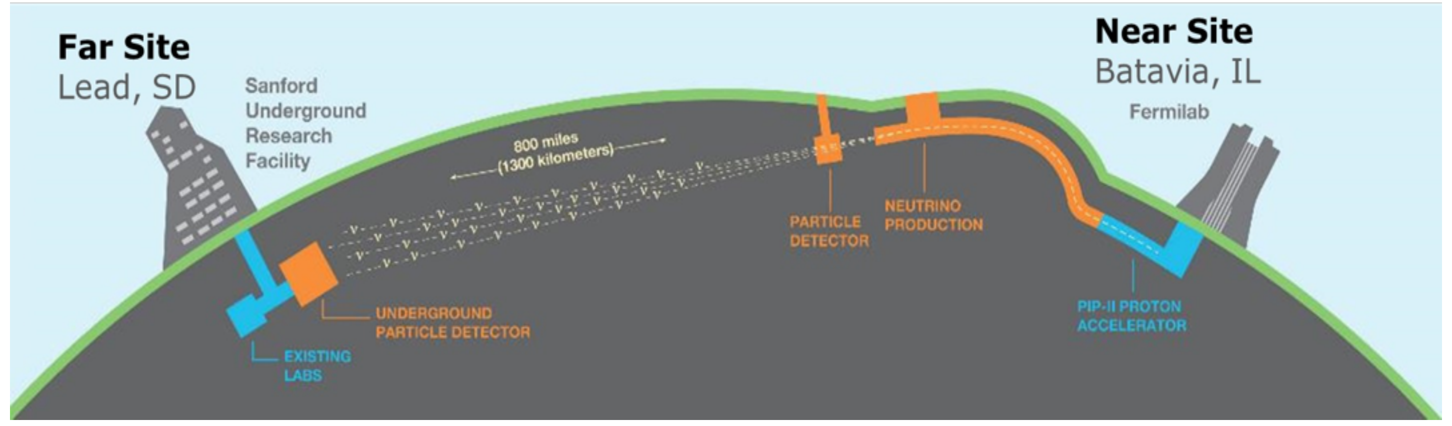


Belle II at KEK, Japan



COHERENT at ORNL

Fermilab Accelerator Complex



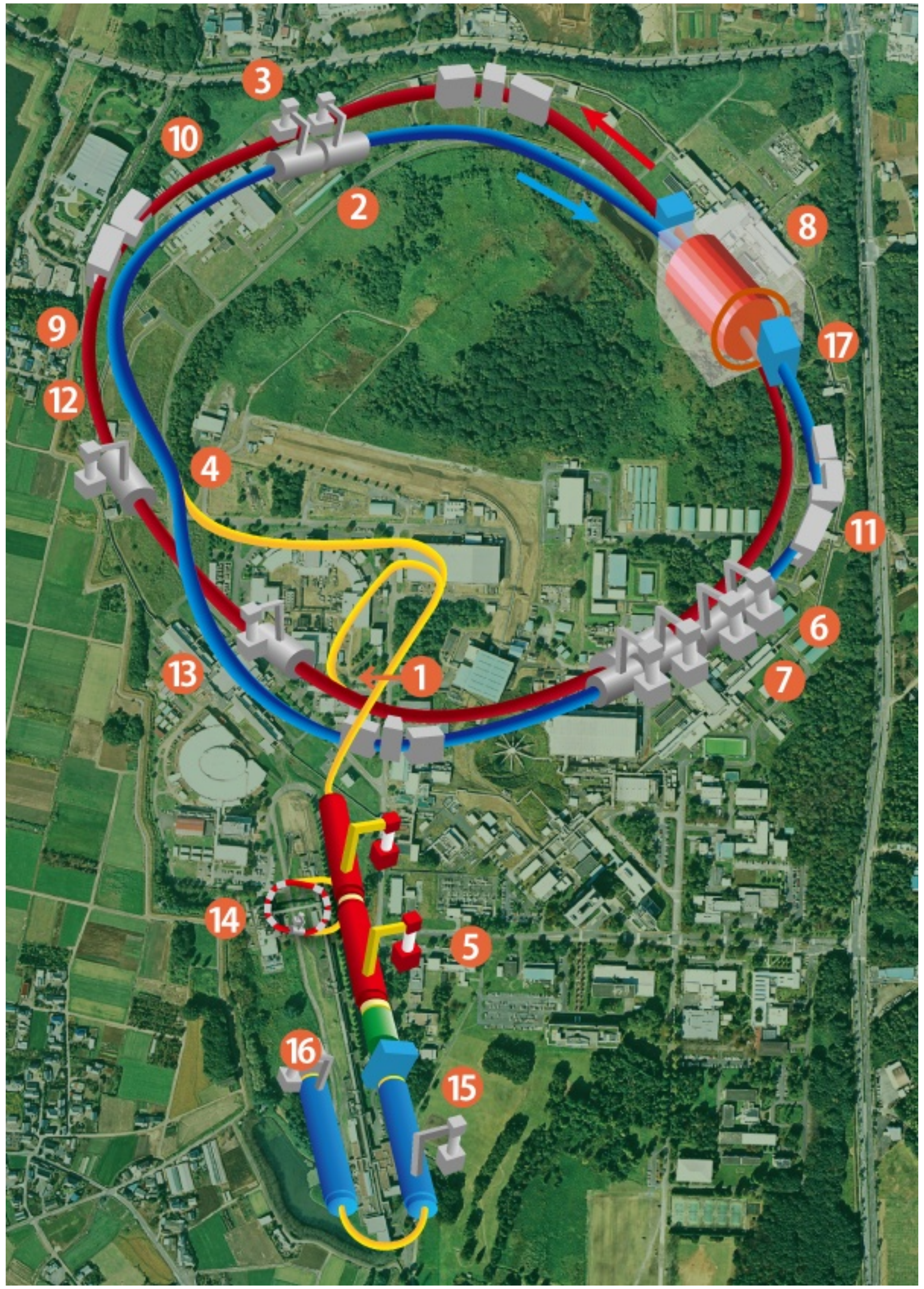
DUNE at Fermilab and Lead, SD

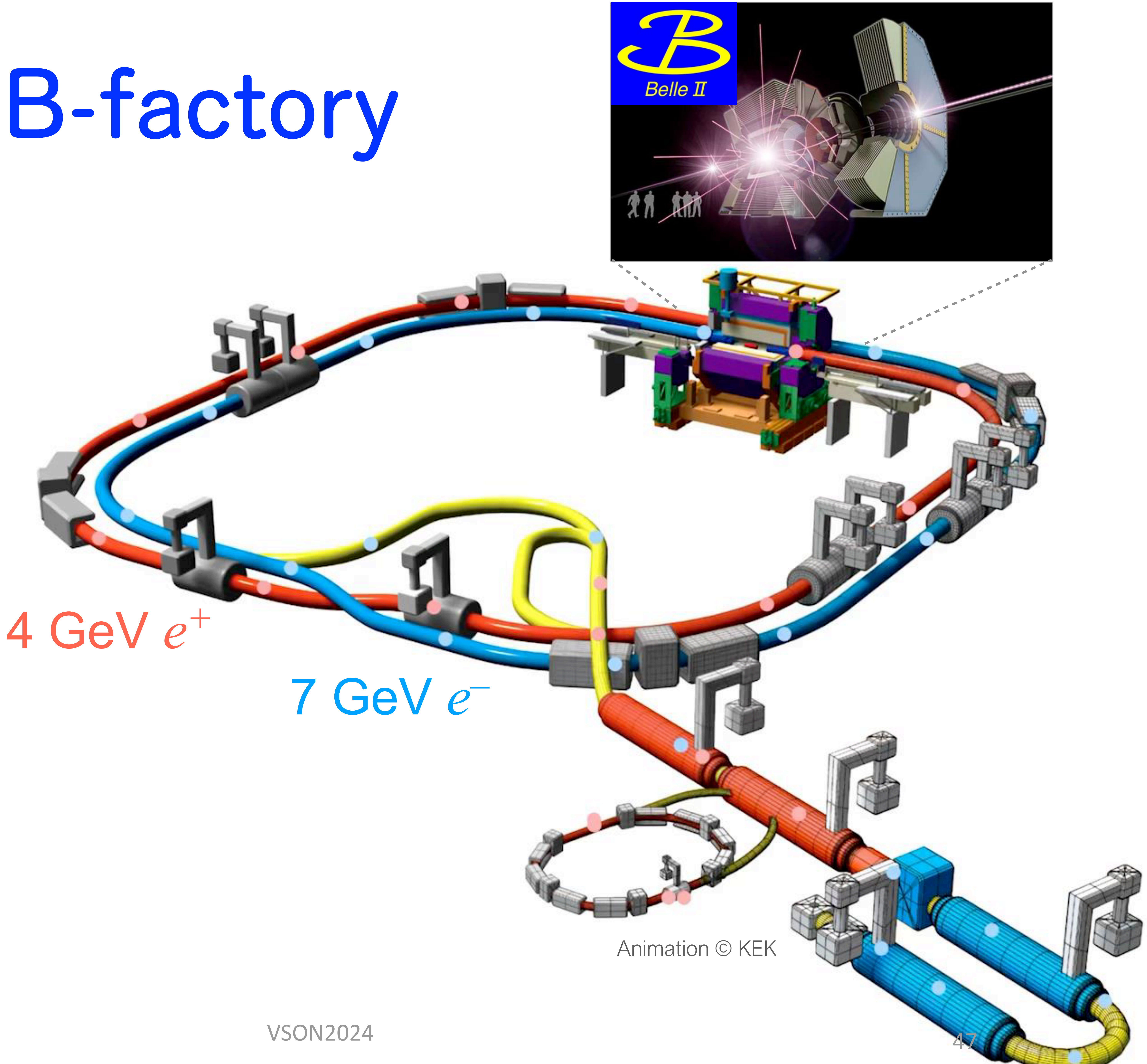
What experiments are there?

- CERN (Europe)
  - LHC/ATLAS, CMS, LHCb, FASAR, SND, milliQan, NA62, DsTau, (CEPE)
- PSI (Switzerland)
  - MEG II
- Fermilab (US)
  - Muon g-2, Mu2e, Neutrino experiments: DUNE, NOvA, SBN, ICARUS, etc.
- KEK/J-PARC (Japan)
  - Super-KEKB/Belle II, J-PARC/T2K, KoTO, COMET, muon g-2, JSNS^2, Super-K, Hyper-K, KAGLA, KamLAND, (ILC)
- IHEP (China)
  - BESSIII, JUNO, (CEPC)
- *Cosmology and Astro-particle experiments*

B (and charm)

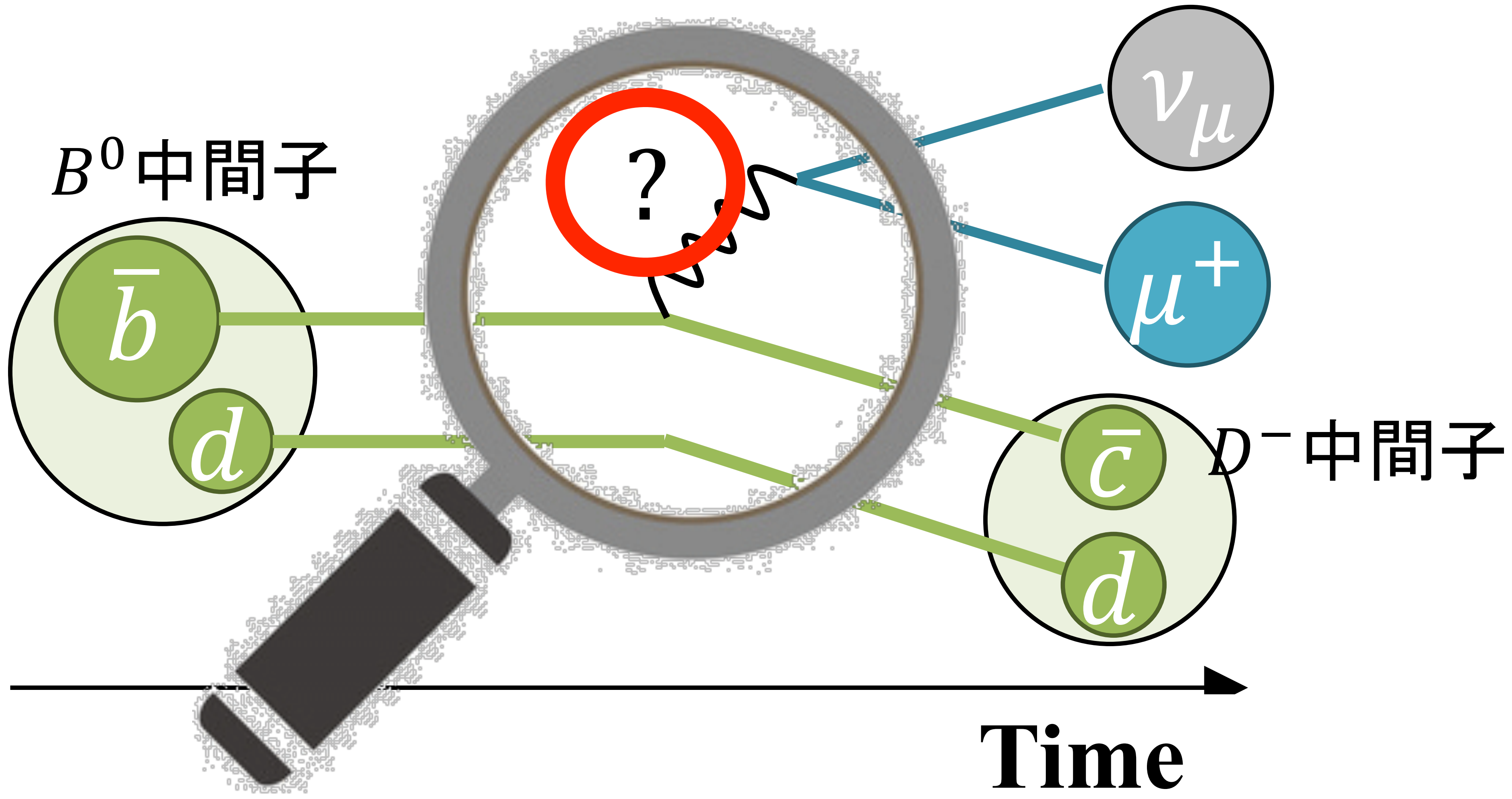
B-factory


3
10
2
8
9
17
12
4
11
6
13
1
7
14
5
16
15

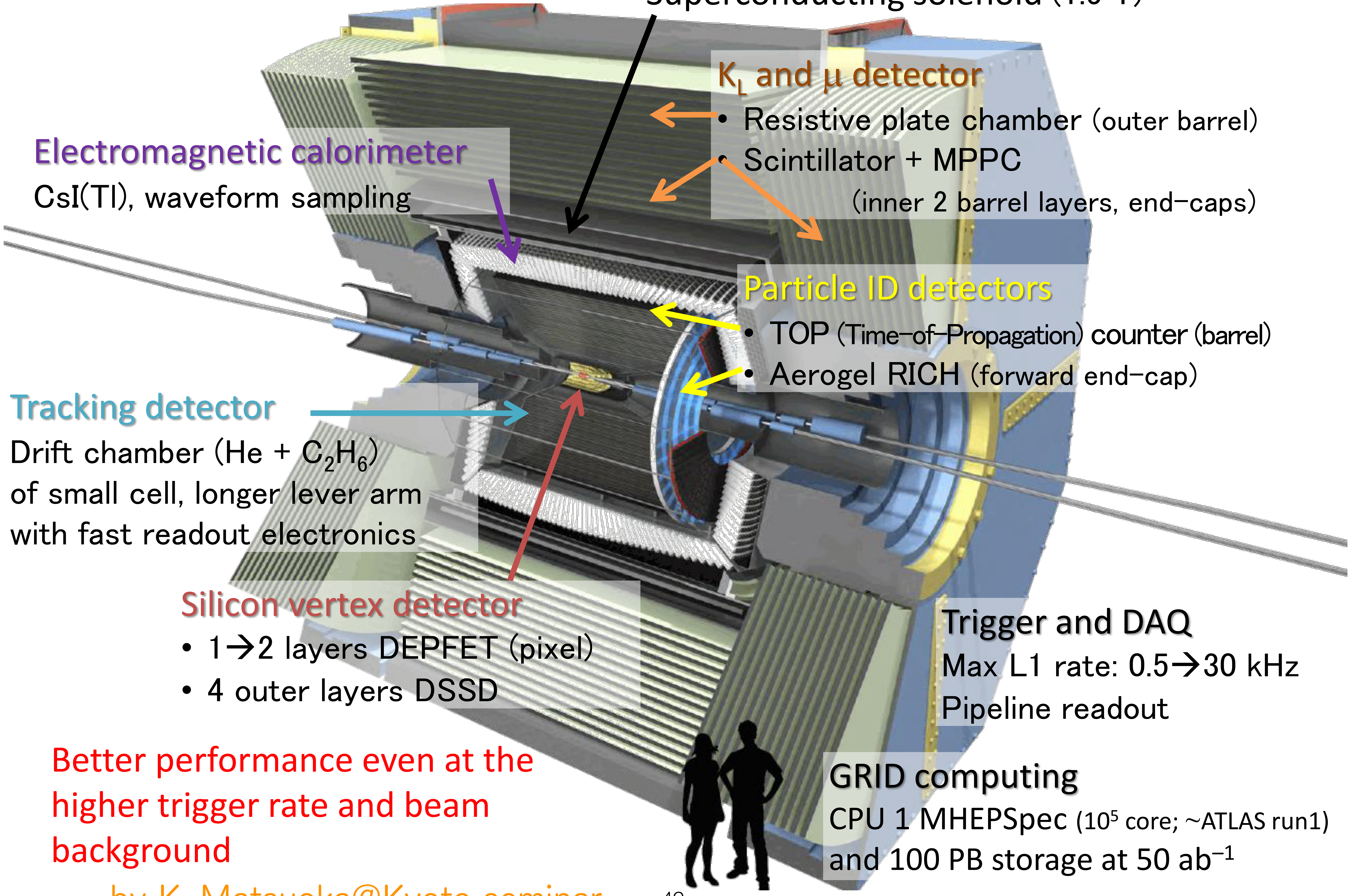

Belle II
4 GeV e^+
7 GeV e^-
Animation © KEK

Basic ideas

- Quantum effects generate high-energy phenomena with a certain probability as intermediate states
- The intermediate state is indirectly probed by precise measurements because the probability including high-energy phenomena is rare.

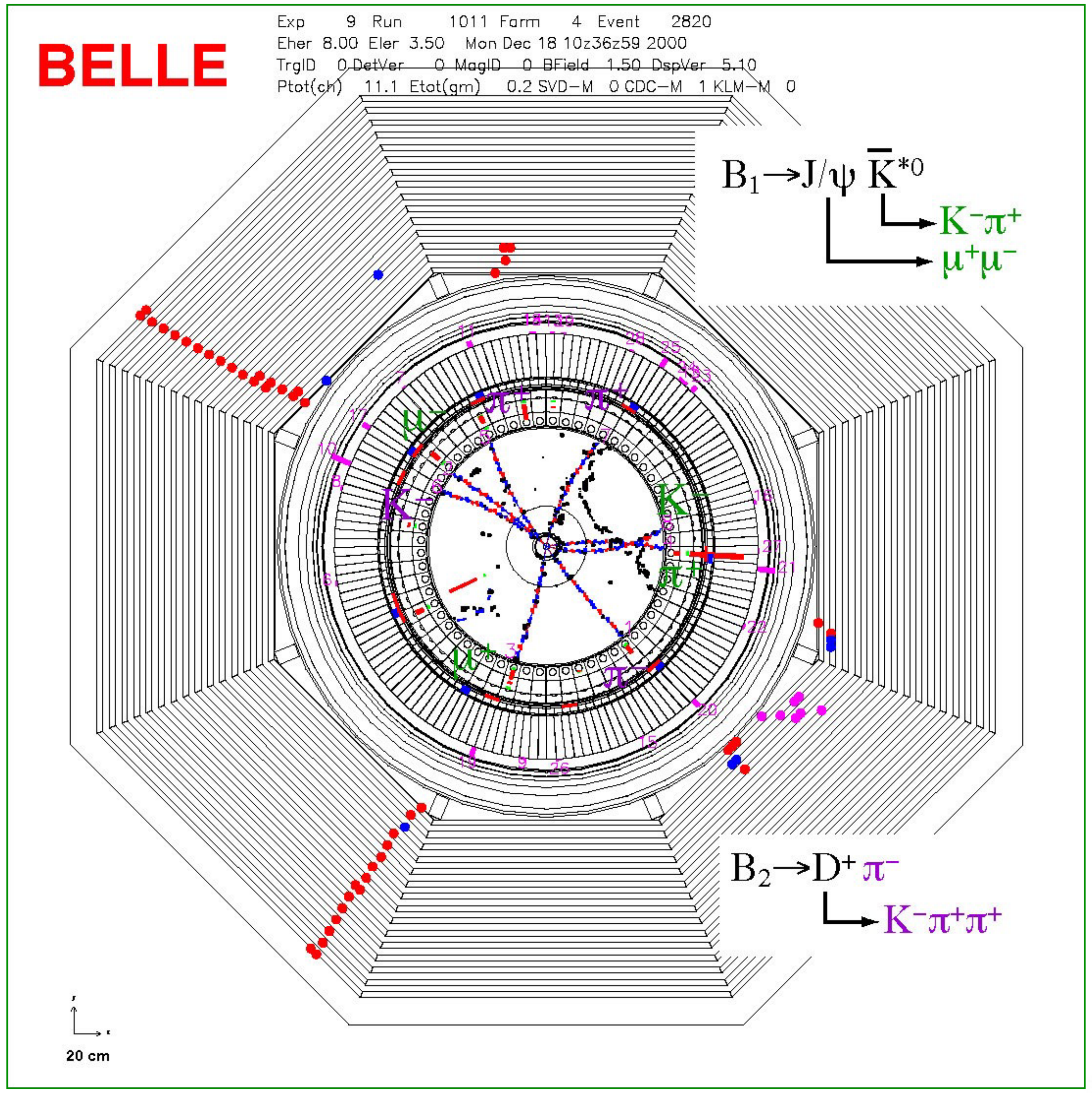


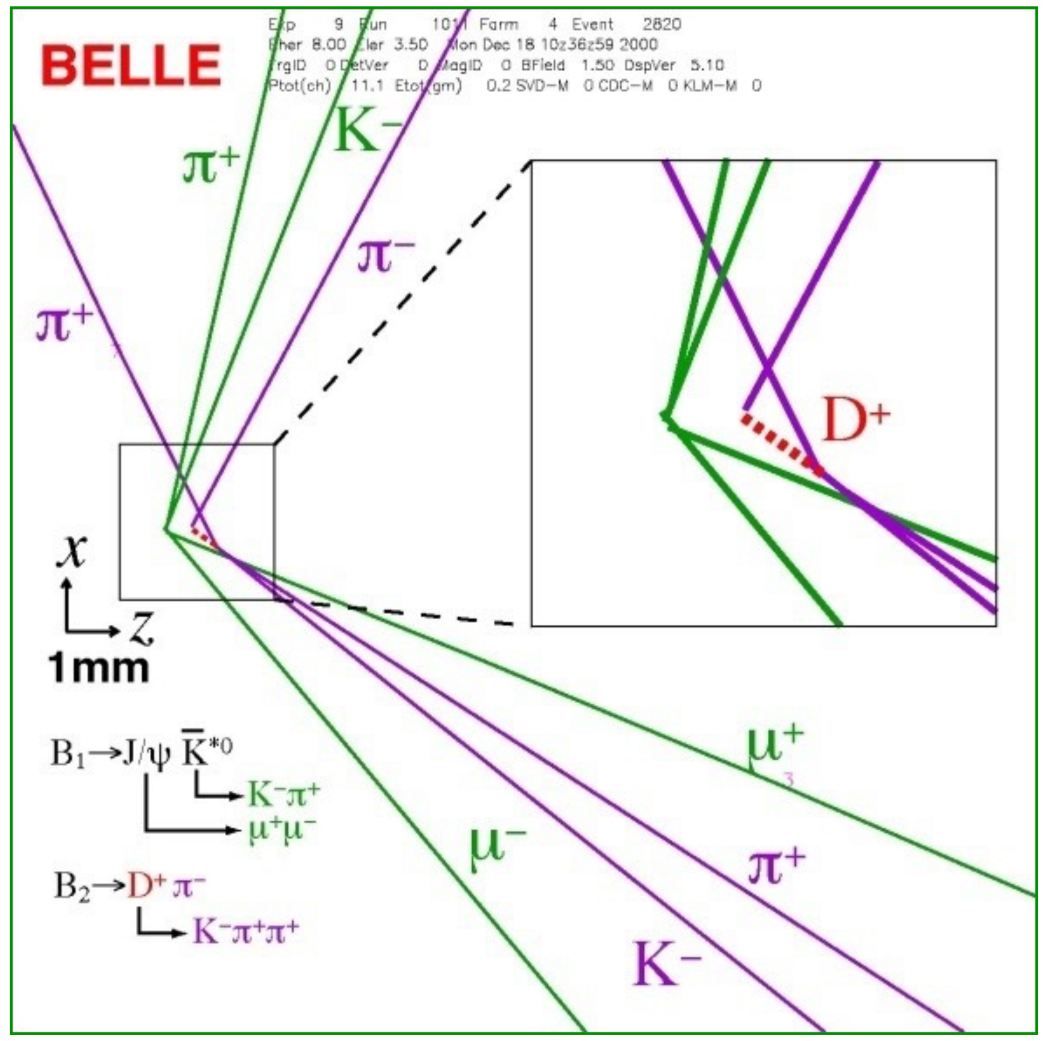
Belle II Detector



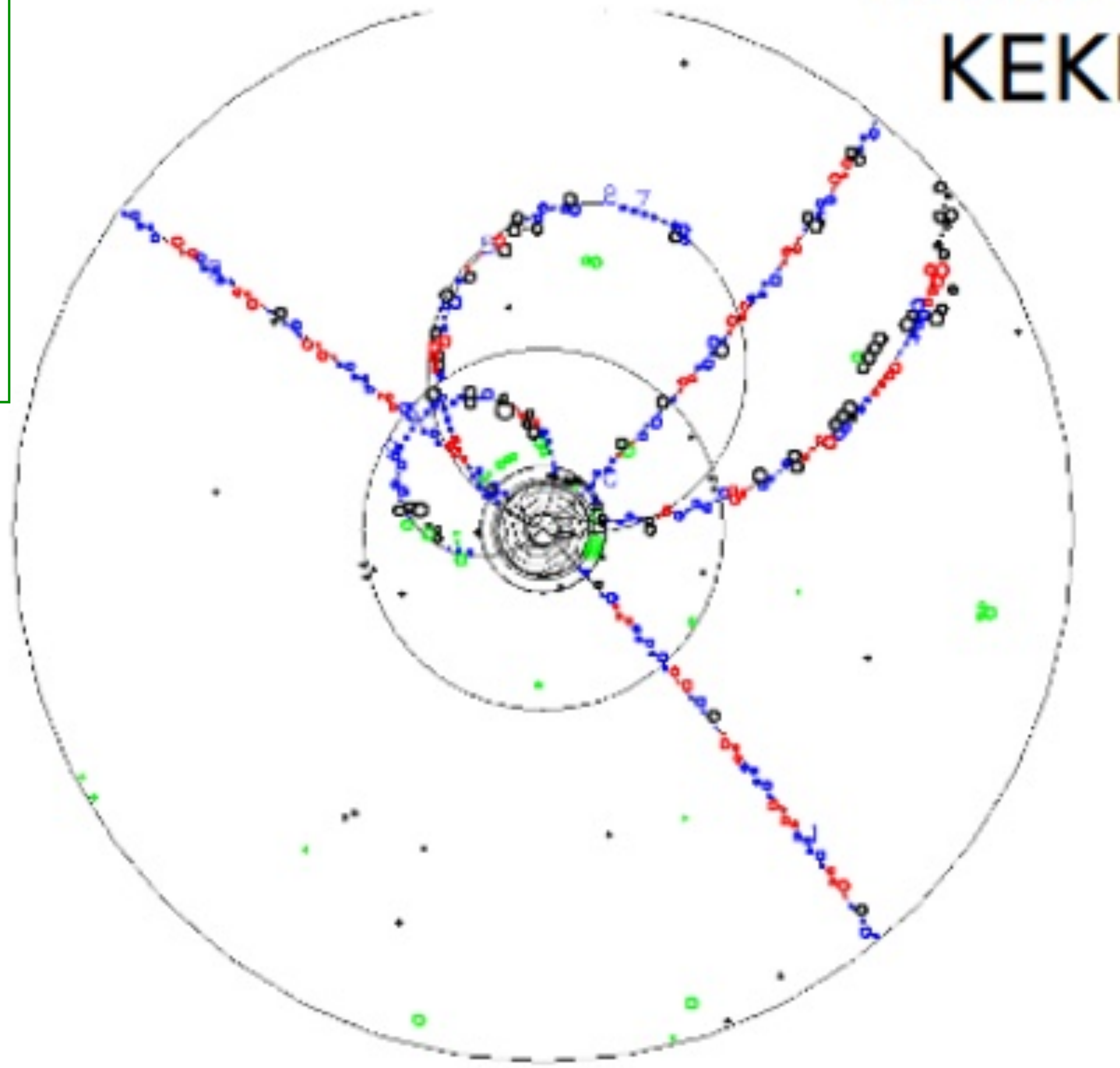
Better performance even at the higher trigger rate and beam background

by K. Matsuoka@Kyoto seminar

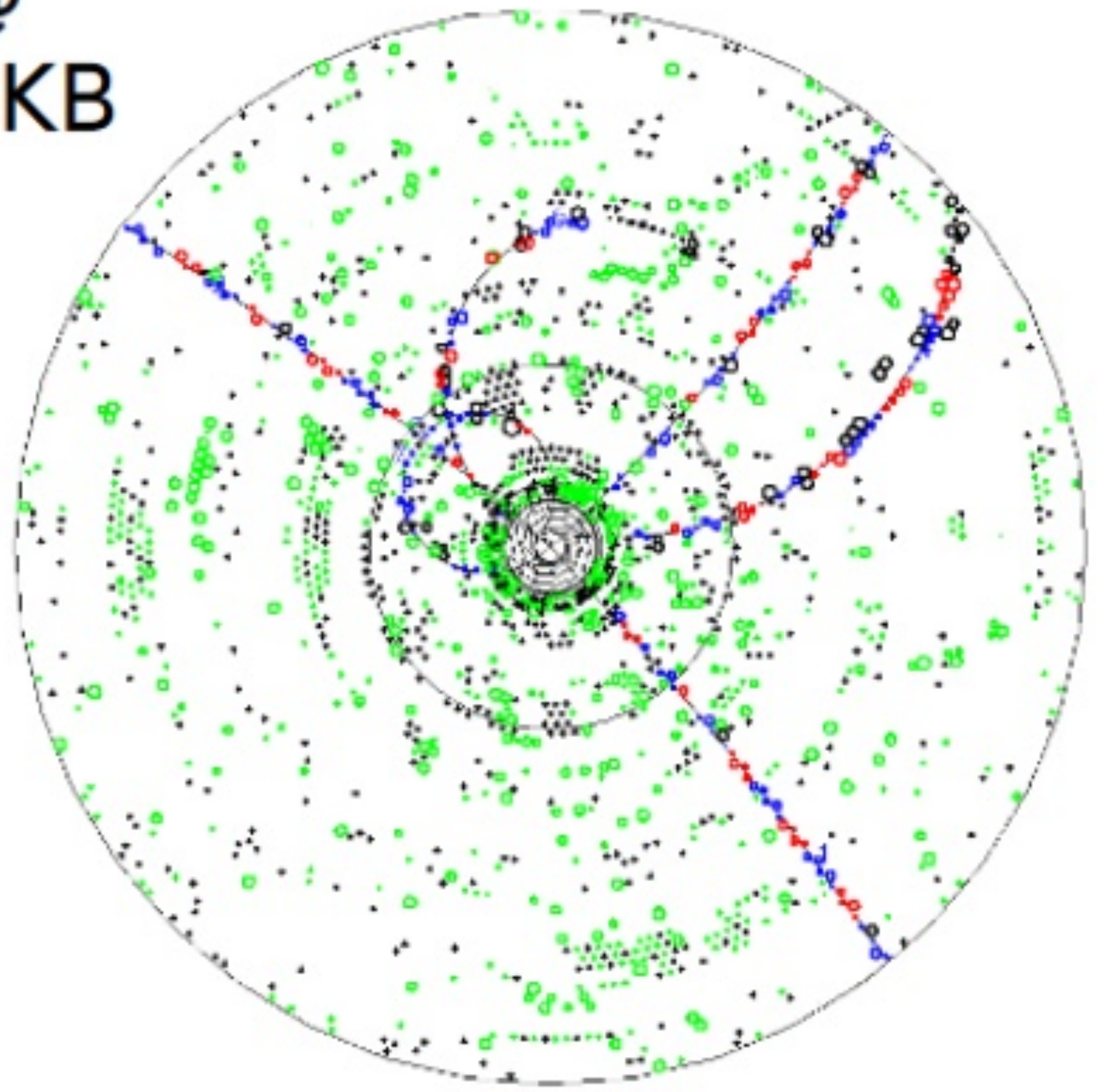




Belle @ KEKB



Belle @ SuperKEKB



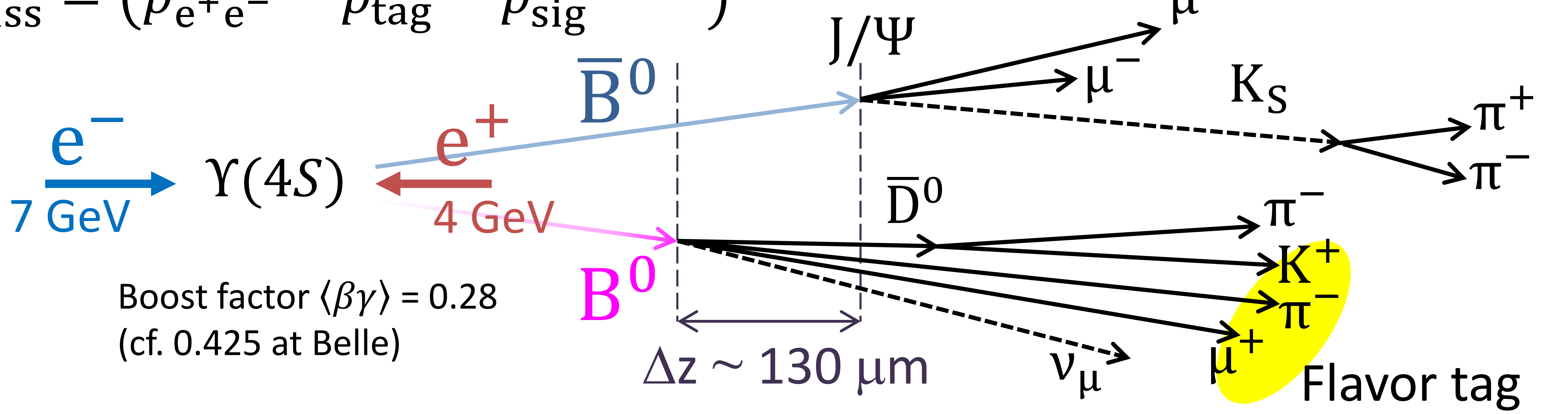
The same event with simulated background at 8 x 10^{35} $cm^{-2}s^{-1}$

Super-KEKB/Belle II Basic

✓ e^+e^- collistions at (or around) $\Upsilon(4S)$
- Well-known initial state kinematics
- $B\bar{B}$ production from $\Upsilon(4S)$ without extra energy
- No event pile-up

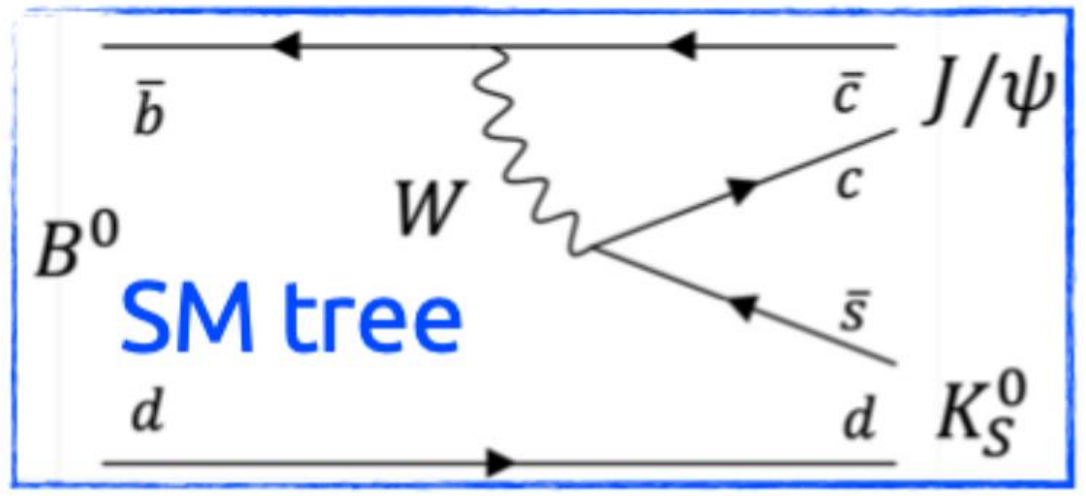
✓ Hermetic Belle II detector capable of detecting charged particles and reconstructing neutrals (γ, π^0, K_L^0, etc) with high efficiencies.

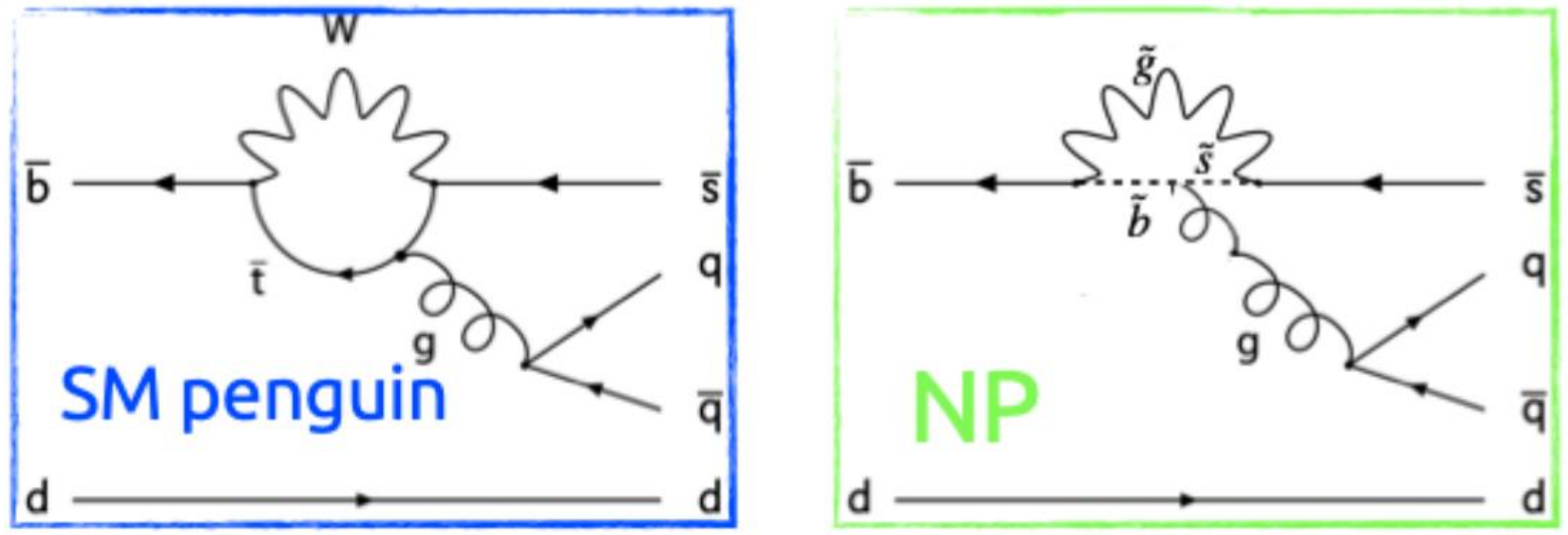
➢ Tagging one of the B's to infer the other B flavor and momentum.
- Powerful S/N separation
- $m_{\text{miss}}^2 = \left(p_{\text{e}^+\text{e}^-} - p_{\text{tag}} - p_{\text{sig}}^{\text{detected}}\right)^2$

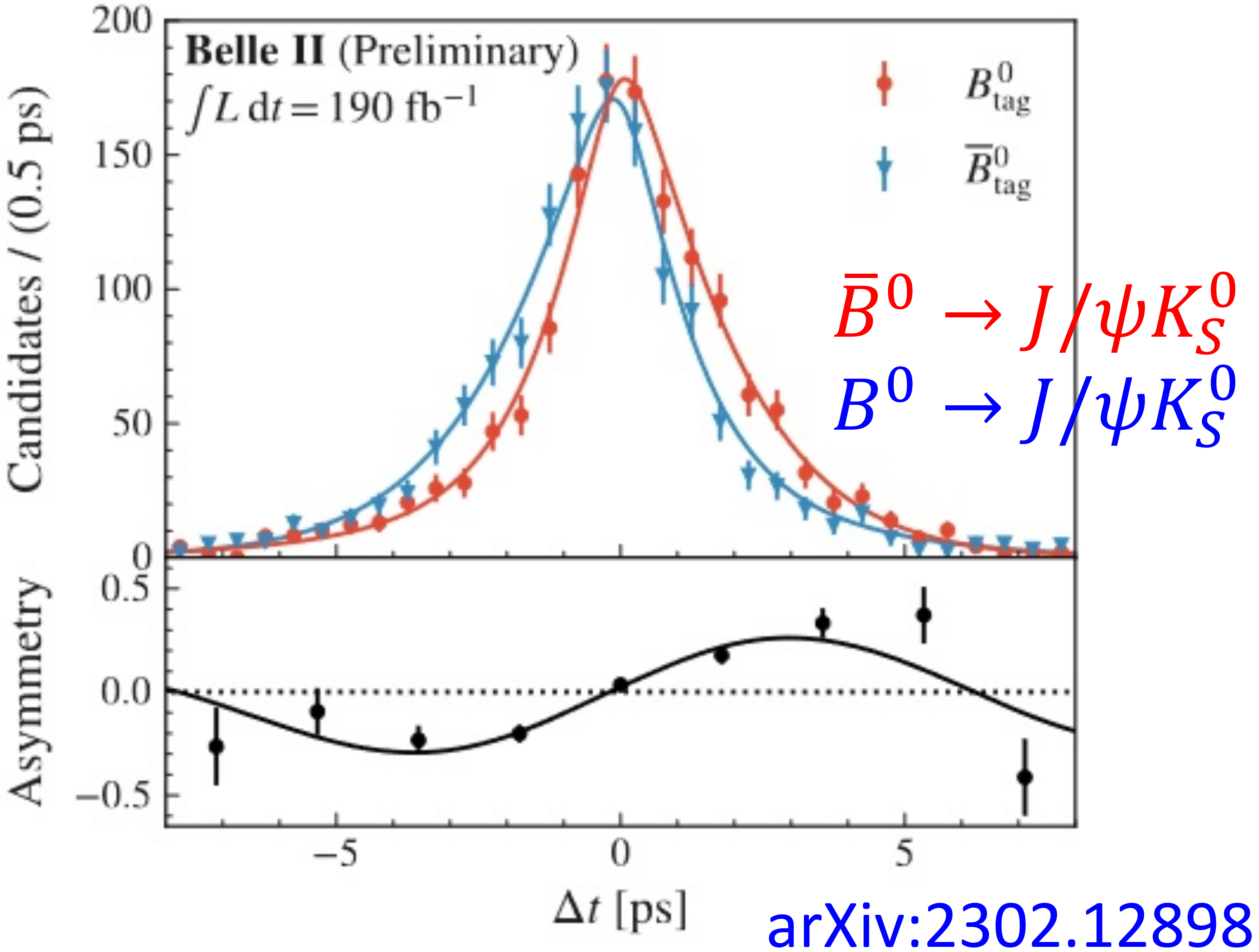


by K. Matsuoka@Kyoto seminar

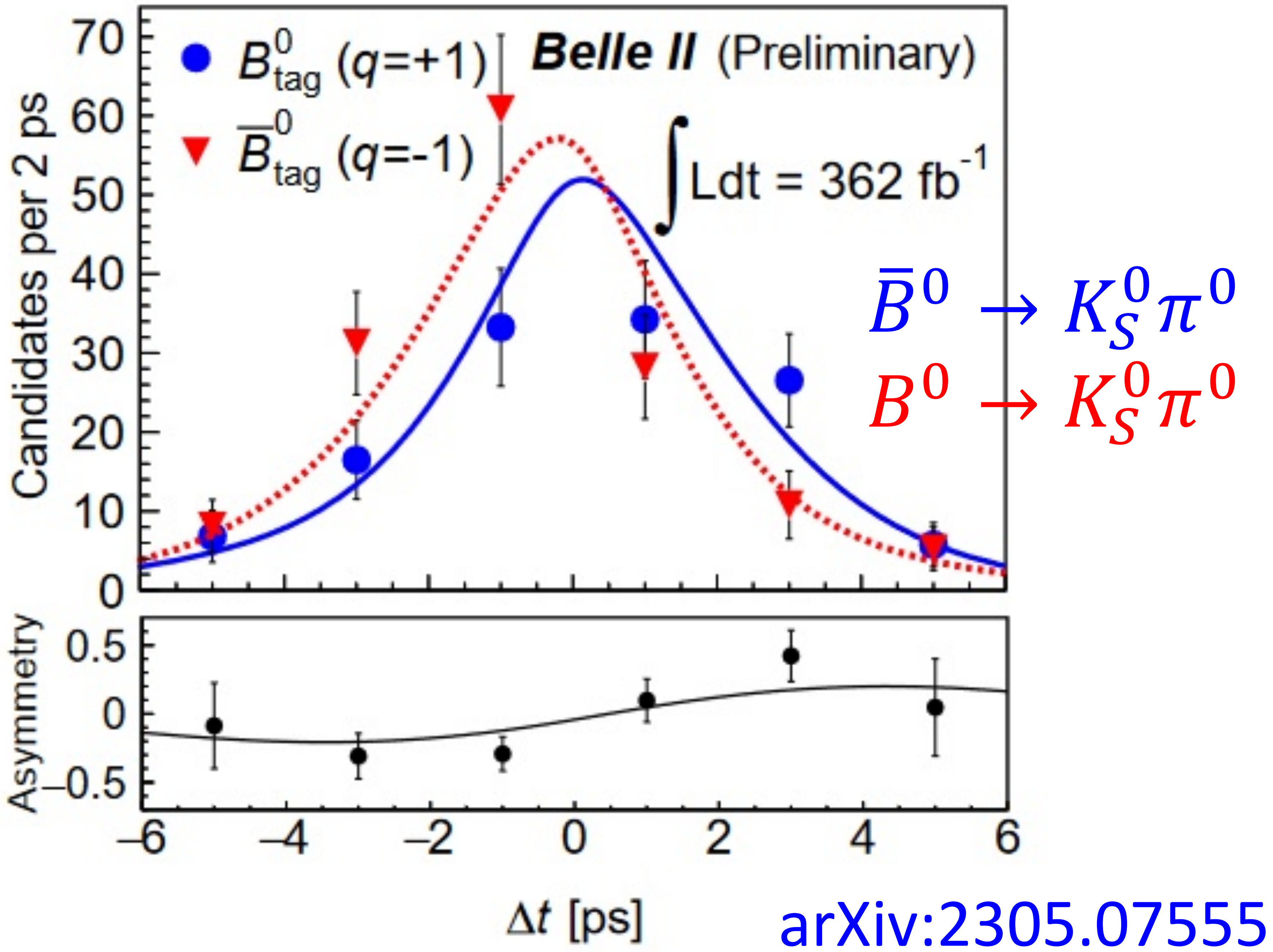
CP Violation in B decays







arXiv:2302.12898



arXiv:2305.07555

Belle II: $S = 0.720 \pm 0.062 \pm 0.016$
Belle: $S = 0.667 \pm 0.023 \pm 0.012$
($S \approx \sin 2\phi_1$ in this mode)

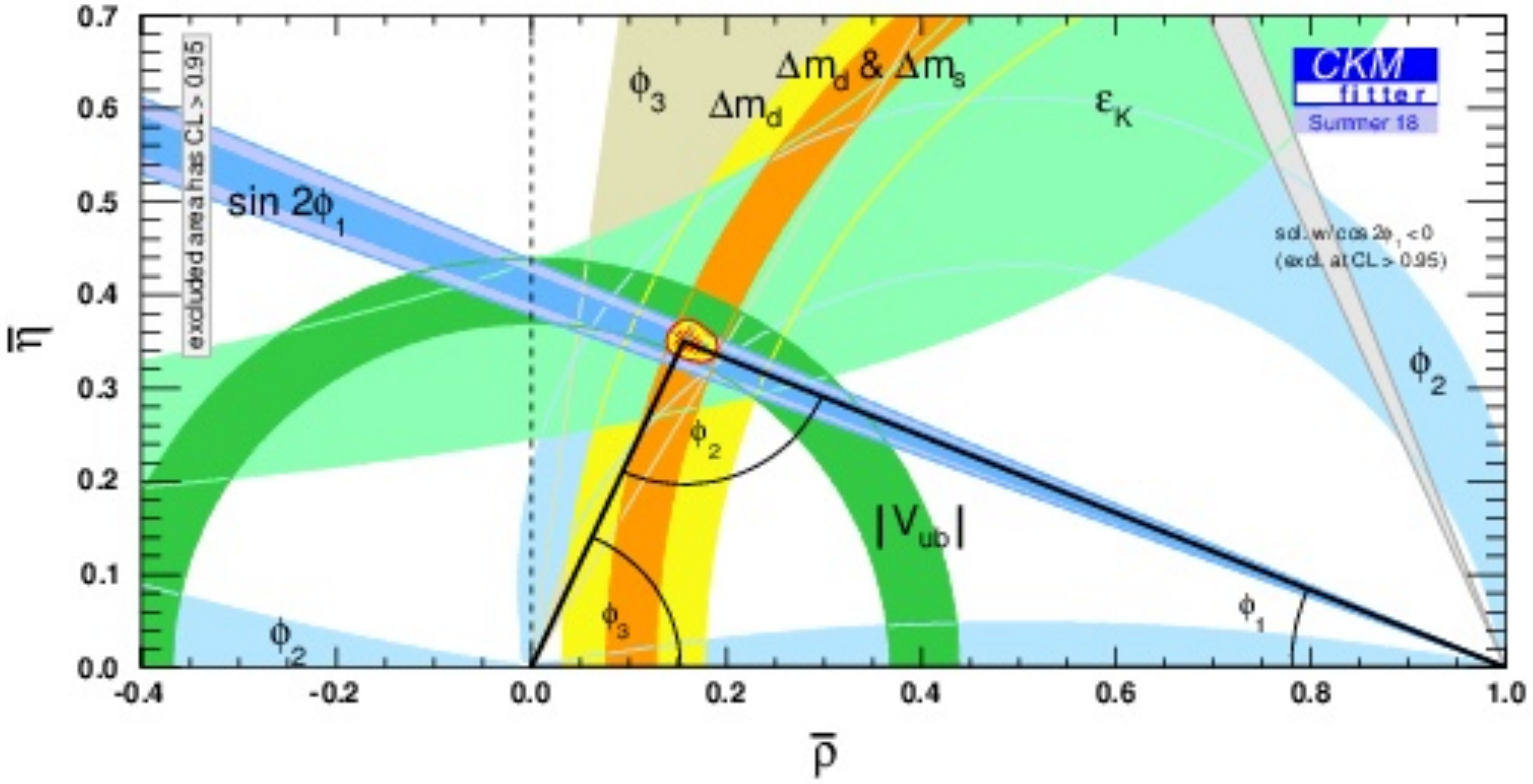
Belleの約60%のデータで凌駕する精度
Belle II: $S = 0.75\ ^{+0.20}_{-0.23} \pm 0.04$
Belle: $S = 0.67 \pm 0.31 \pm 0.08$

by K. Matsuoka@Kyoto seminar

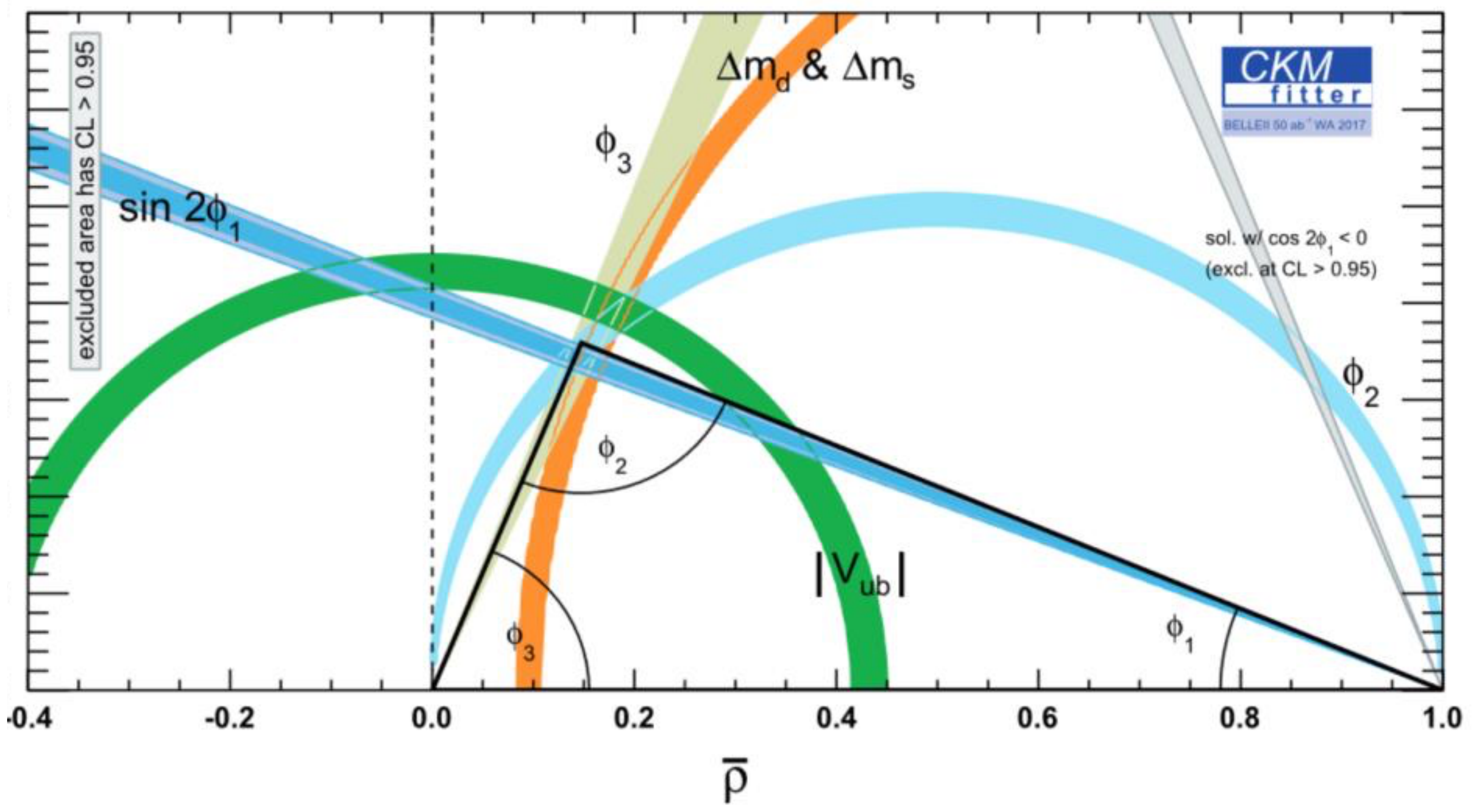
Precision measurements

Fig. 226 of [Prog. Theor. Exp. Phys. 2019, 123C01]

Before Belle II (2018)



Belle II 50 ab^{-1} + LHCb 23 fb^{-1} + LQCD



The Standard Model has been tested with ~10% precision.

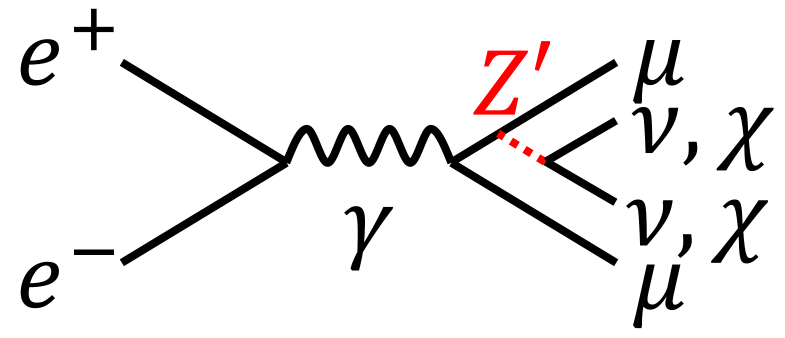
→ Search for non-standard effects that can only appear as small corrections to the Standard Model.

Access higher energy scales via quantum effects than are directly reachable at current or future colliders.

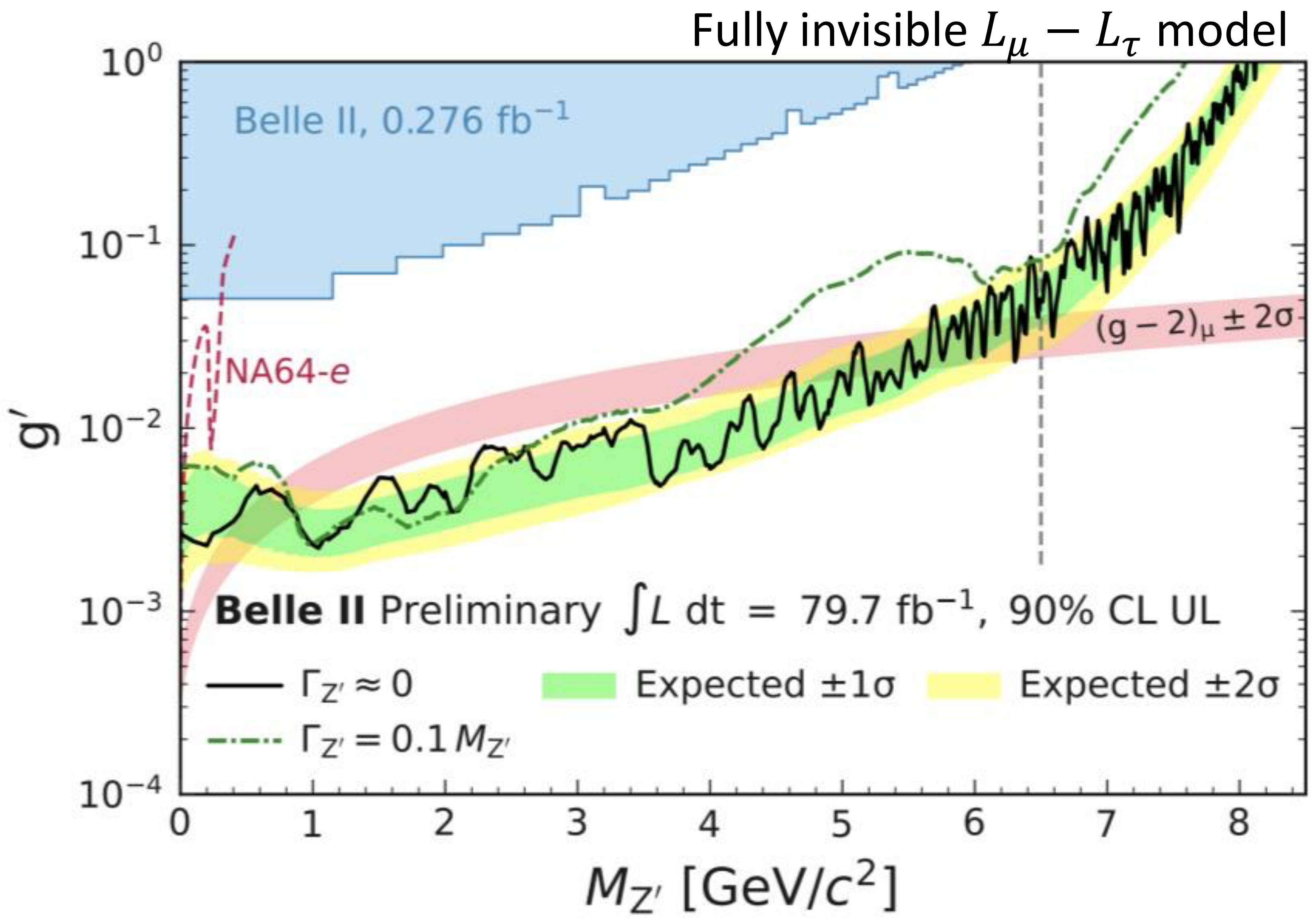
e.g. $\Lambda < \sim 1000$ TeV in B^0 mixing ($\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \frac{1}{\Lambda^2}\mathcal{O}_{\Delta F=2}$) [arXiv:1302.0661]

Search for Dark particles

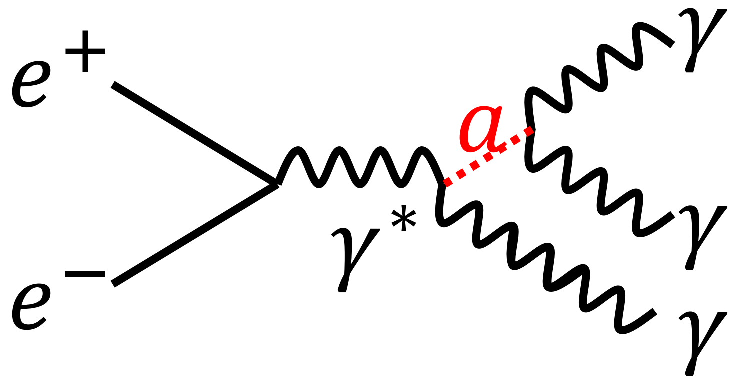
- Z' or LFV Z' to invisible



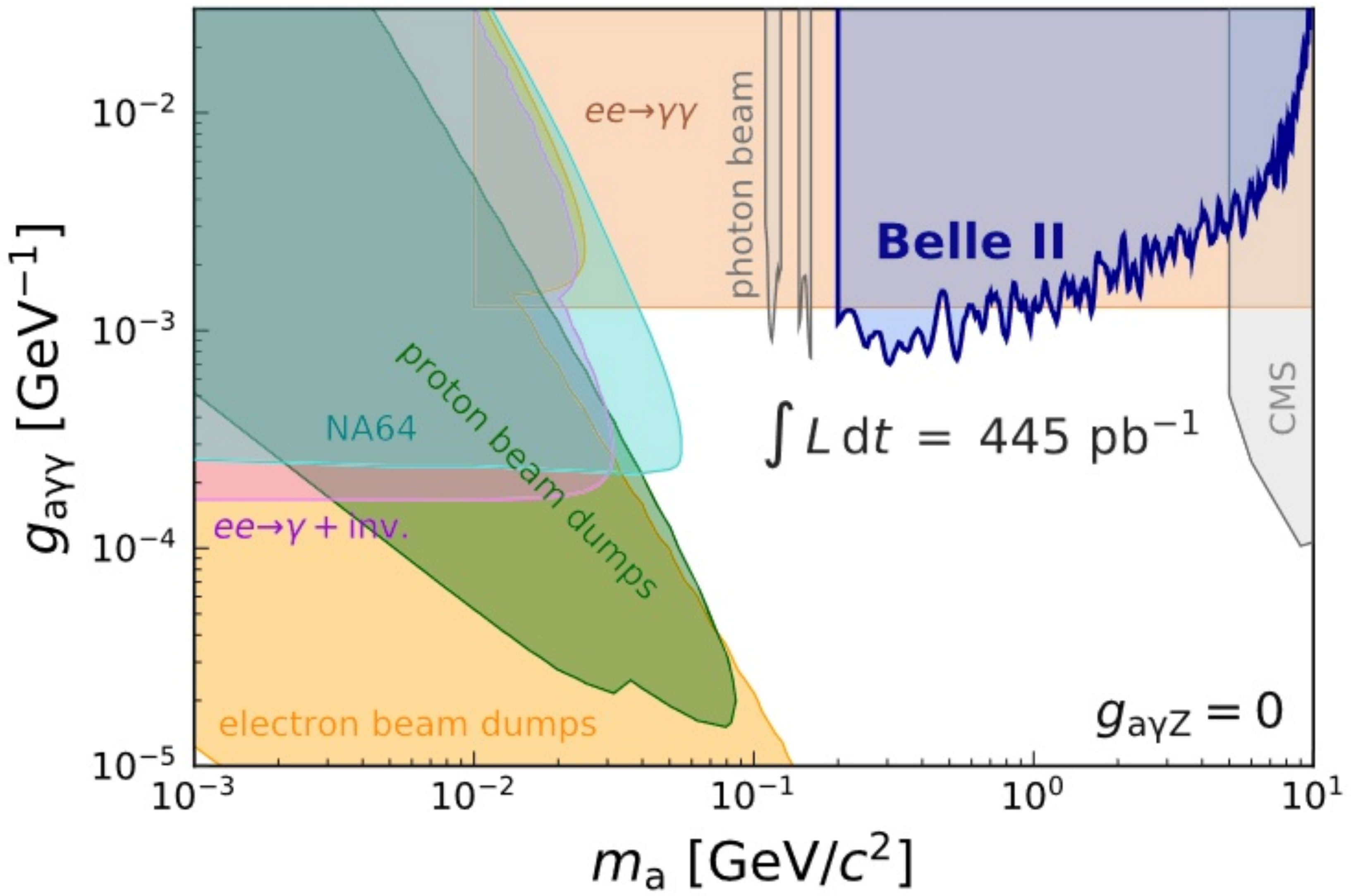
PRL 124, 141801 (2020) … 1st Belle II physics paper
arXiv:2212.03066 … update, 2022



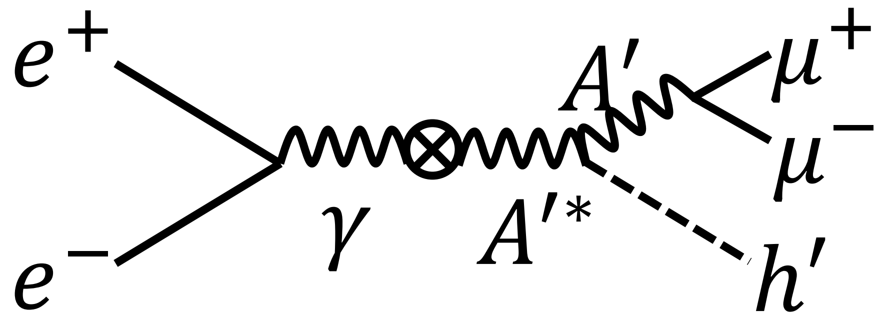
- Axion Like Particle



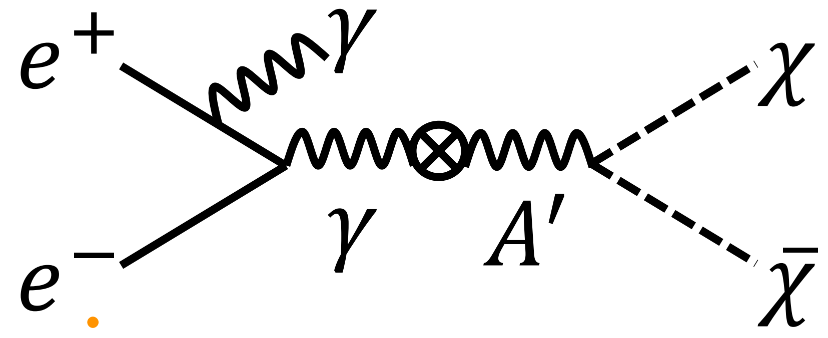
PRL 125, 161806 (2020) … 2nd Belle II physics paper



- Dark higgstrahlung
  PRL 130, 071804 (2023)

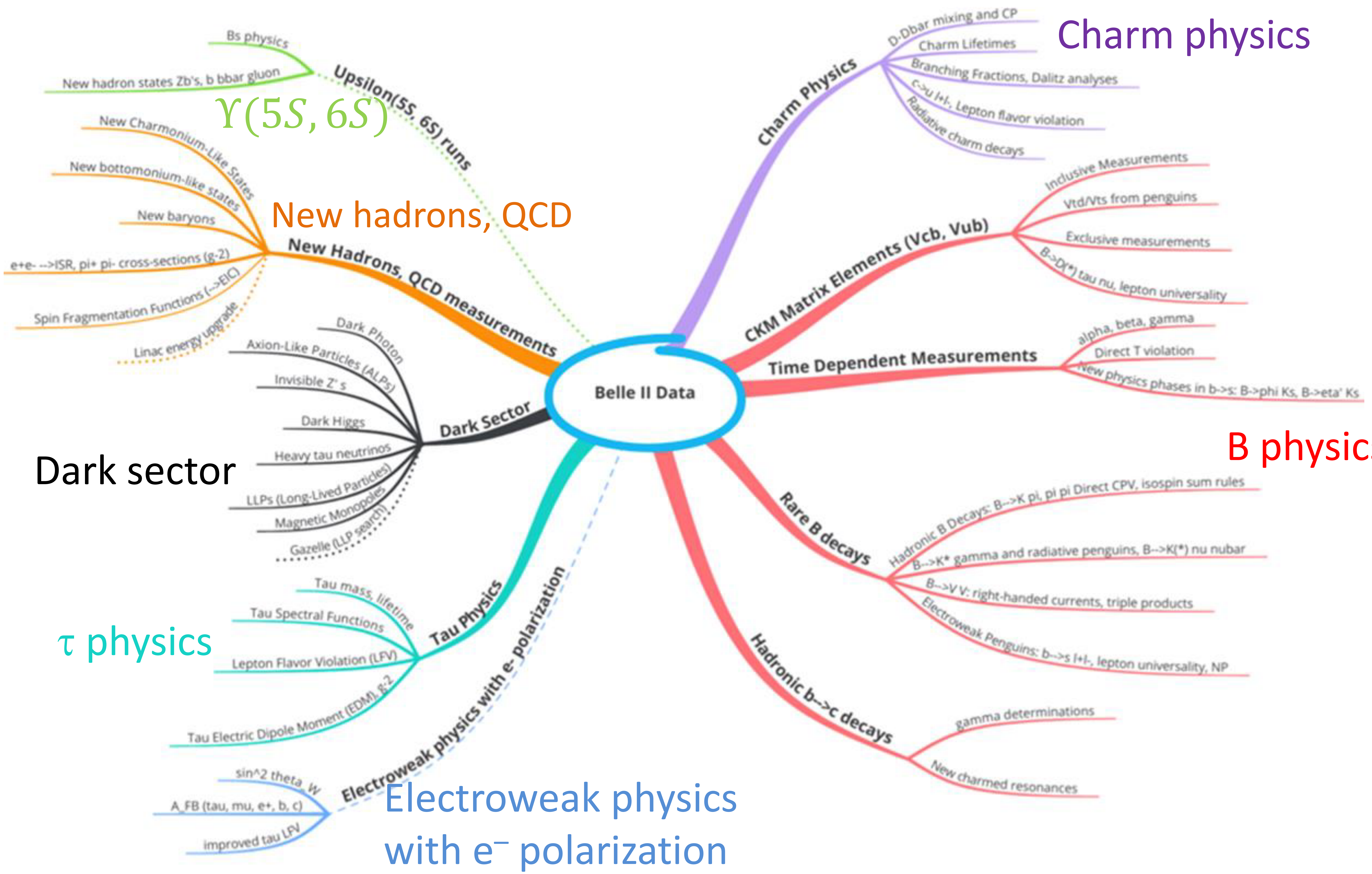


- Invisible dark photon



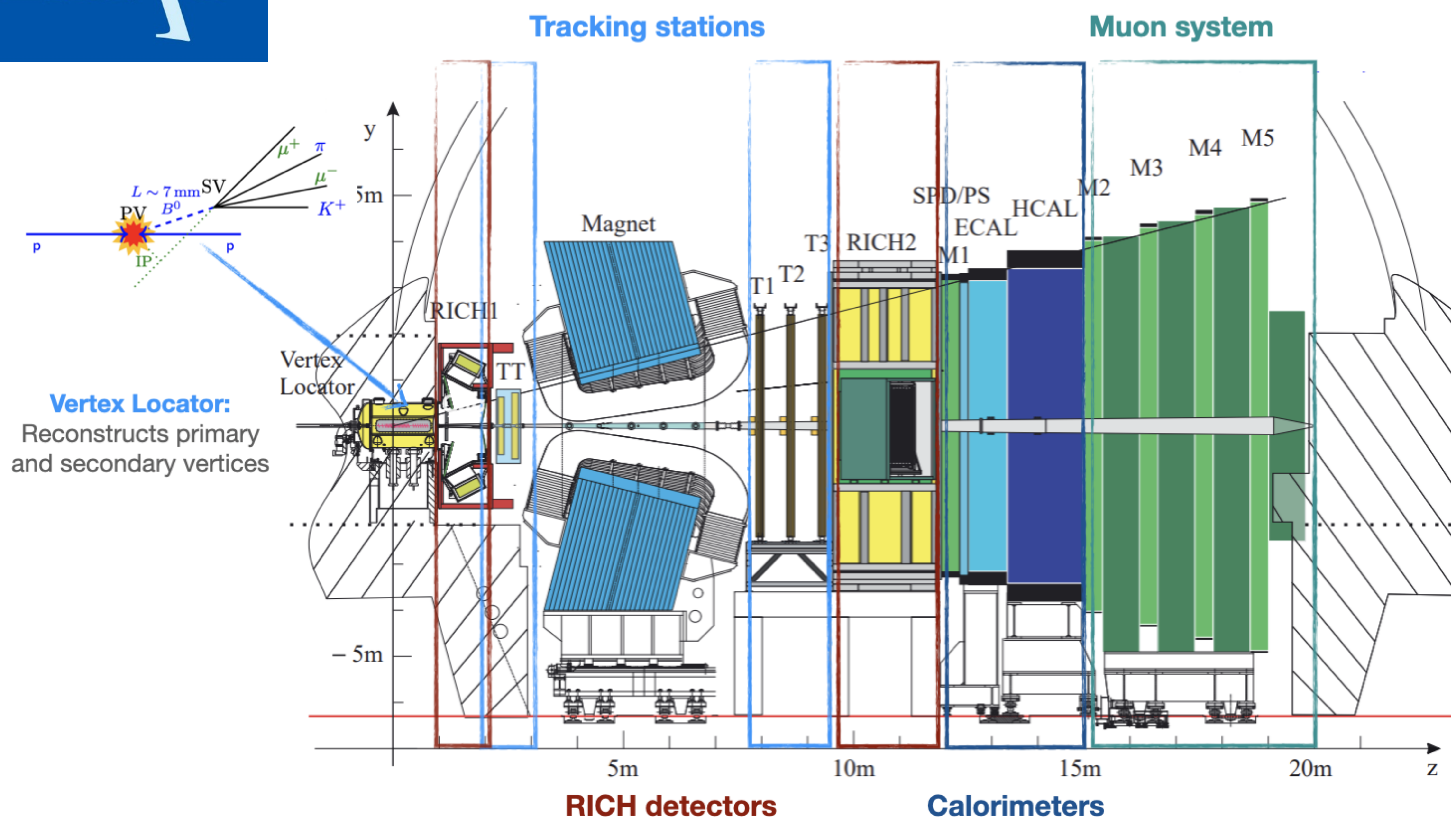
- Visible dark photon
- $Z' \to \mu\mu$
- Inelastic dark matter
- Dark scalar

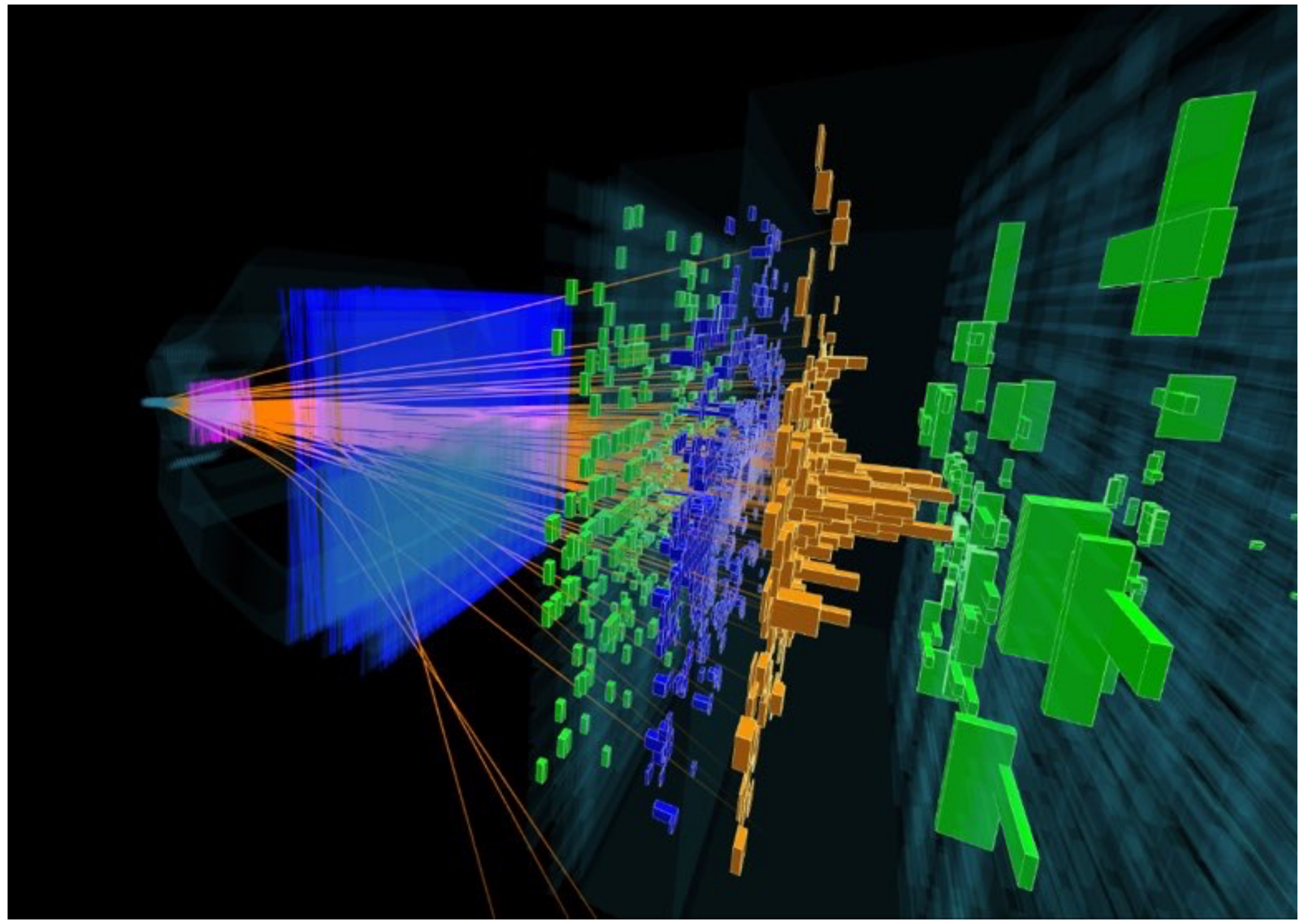
by K. Matsuoka@Kyoto seminar



by K. Matsuoka@Kyoto seminar

LHCb



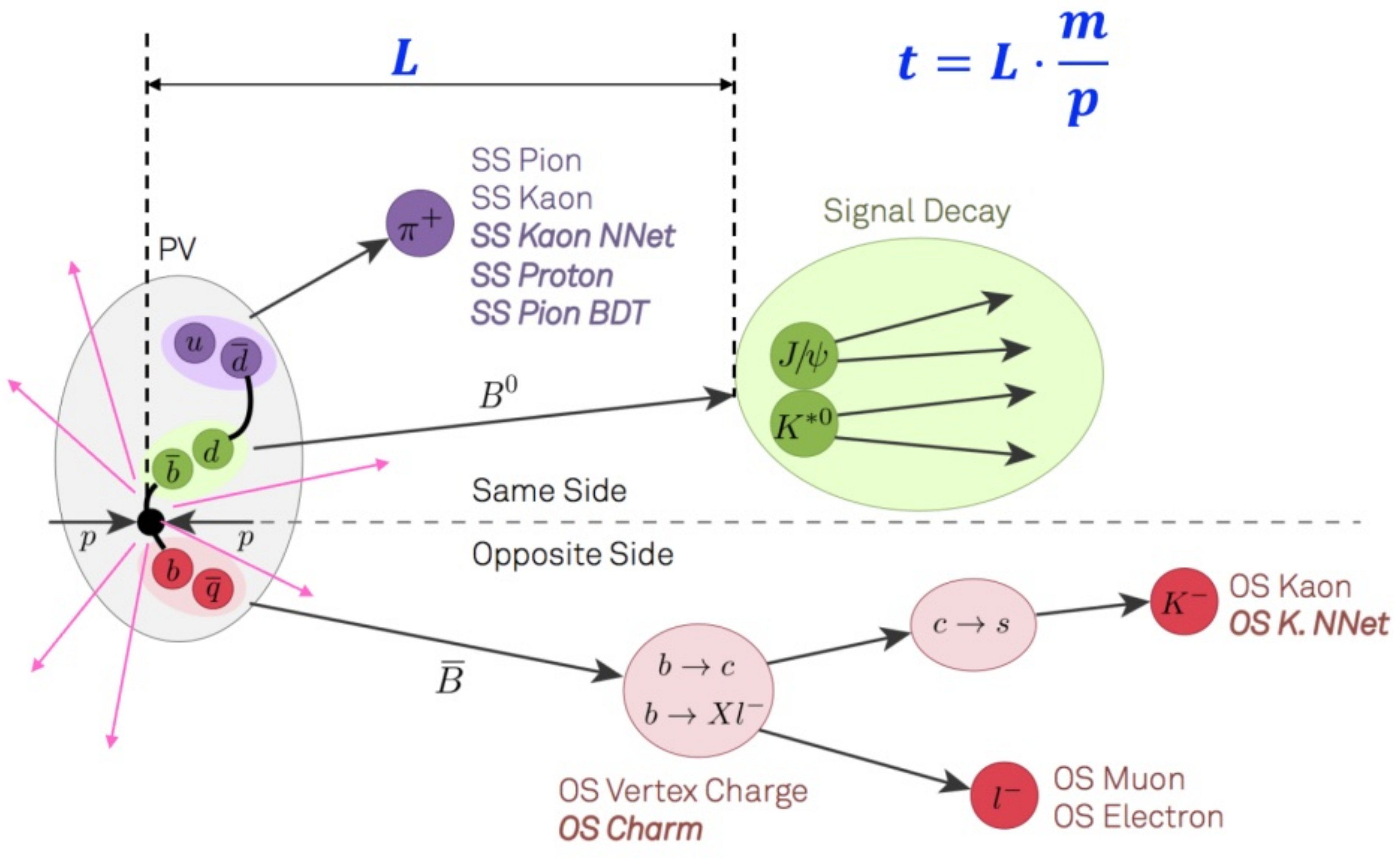


Access to tiny BRs
All *b*-hadrons types
LHC complex environment

- Forward detector specialised in measuring properties of *b* and *c* hadrons
- Run 1 [2011-2012]: 7-8 TeV and 3 fb^{-1}
- Run 2 [2015-2018]: 13 TeV and 6 fb^{-1}

JINST 3 (2008) S08005

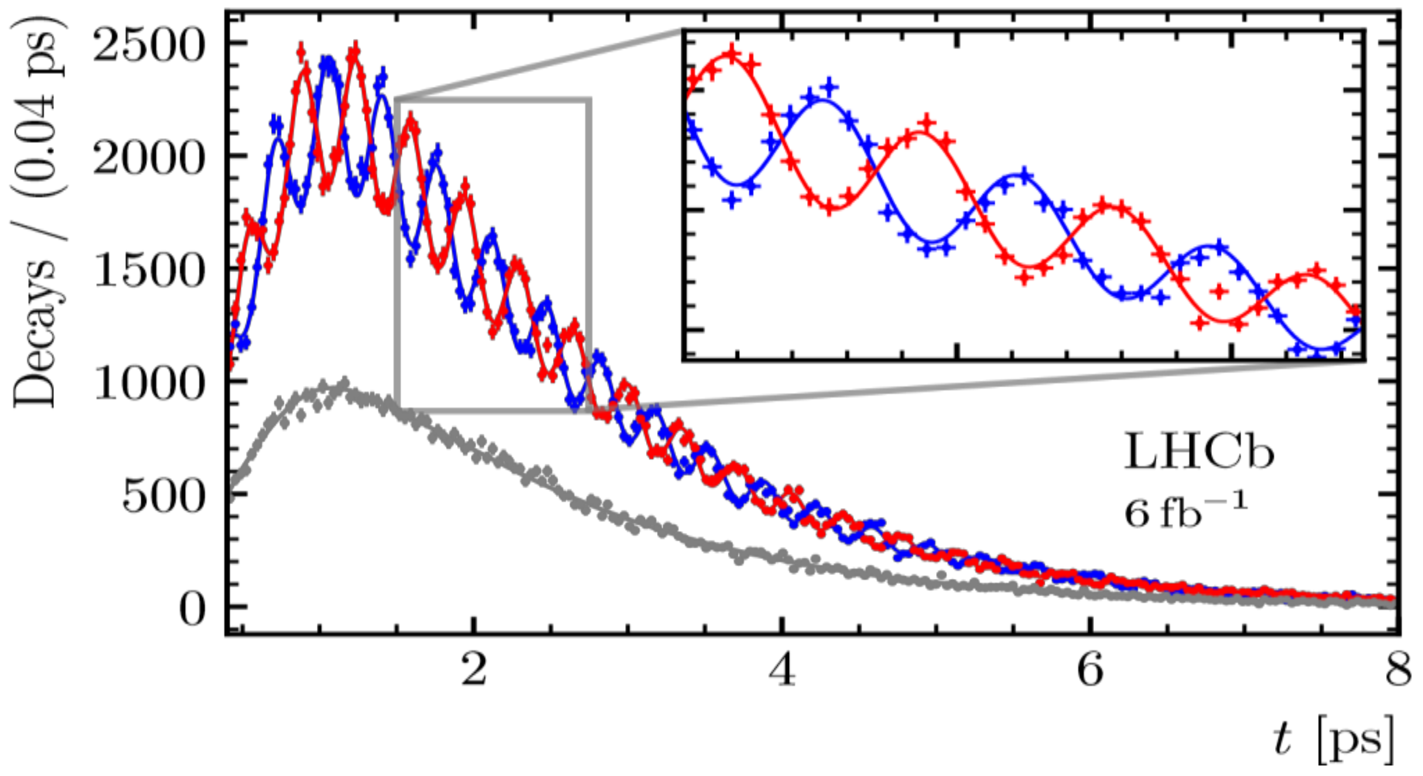
LHCb method for TD study



- Flavour tagging: info from other B & fragmentation particles
  $\epsilon_{\text{tag}}(1 - 2\omega)^2 \sim 5\%$
- Large boost from pp collision
  $\beta\gamma \sim 10,\ L \sim 1$ cm
- Silicon vertex system
  $\sigma_t \sim 45$ fs

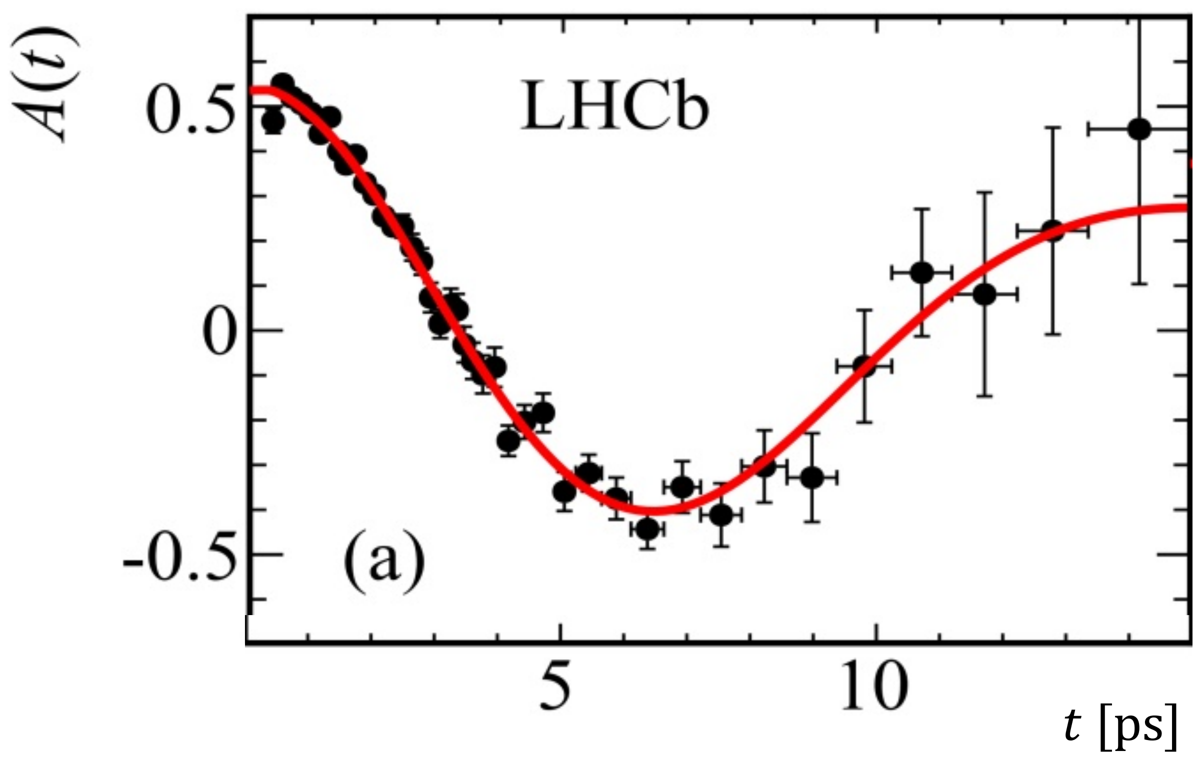
Int. J. Mod. Phys. A30 (2015) 1530022

$B_s^0 \to D_s^- \pi^+$ Nature Physics 18 (2022) 1-5



$\Delta m_s = 17.7656 \pm 0.0057(\text{comb})\ \text{ps}^{-1}$

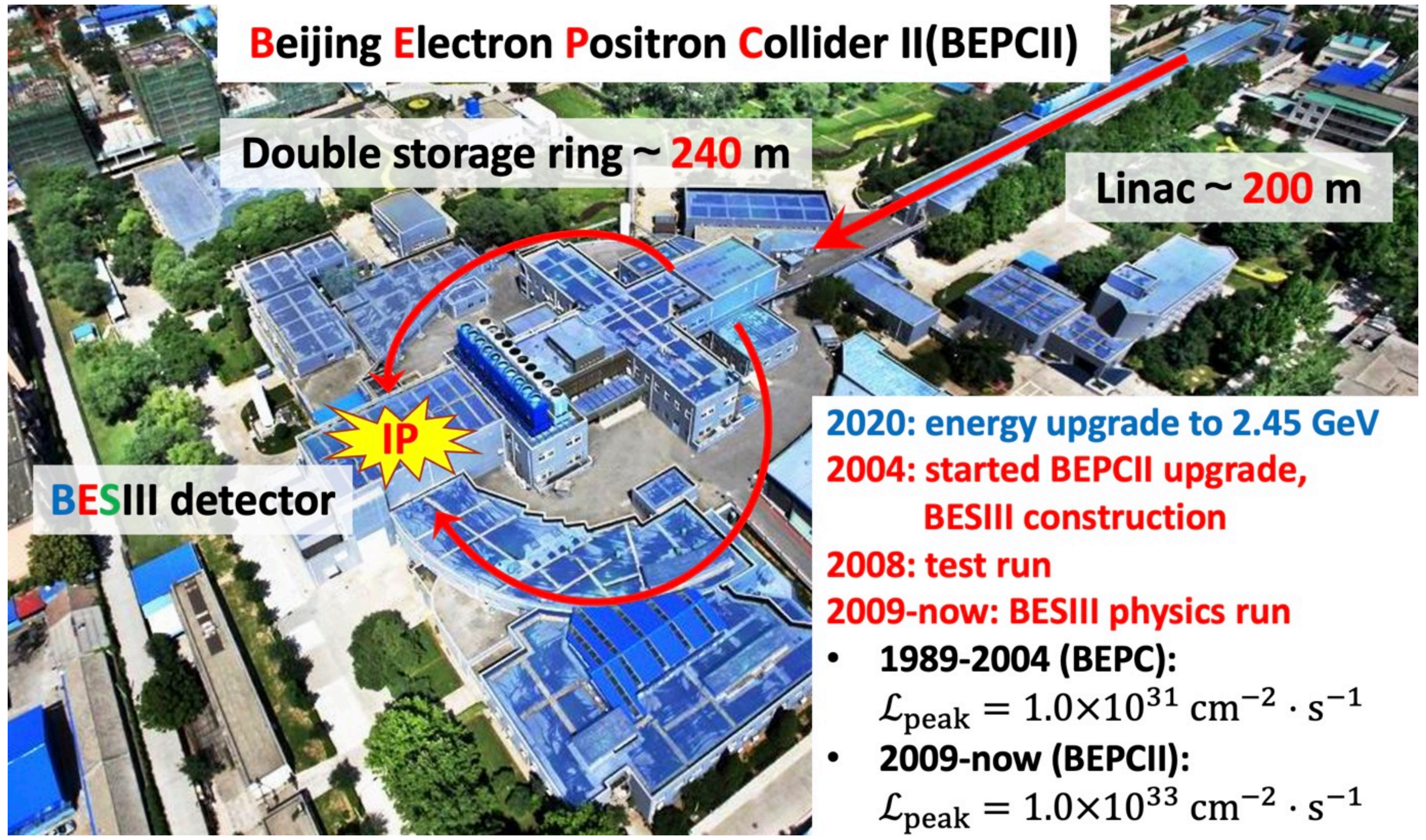
$B_d^0 \to D^{(*)-}\mu^+\nu$ EPJC 76 (2016) 412



$\Delta m_d = 0.5050 \pm 0.0021(\text{stat}) \pm 0.0010(\text{syst})\ \text{ps}^{-1}$

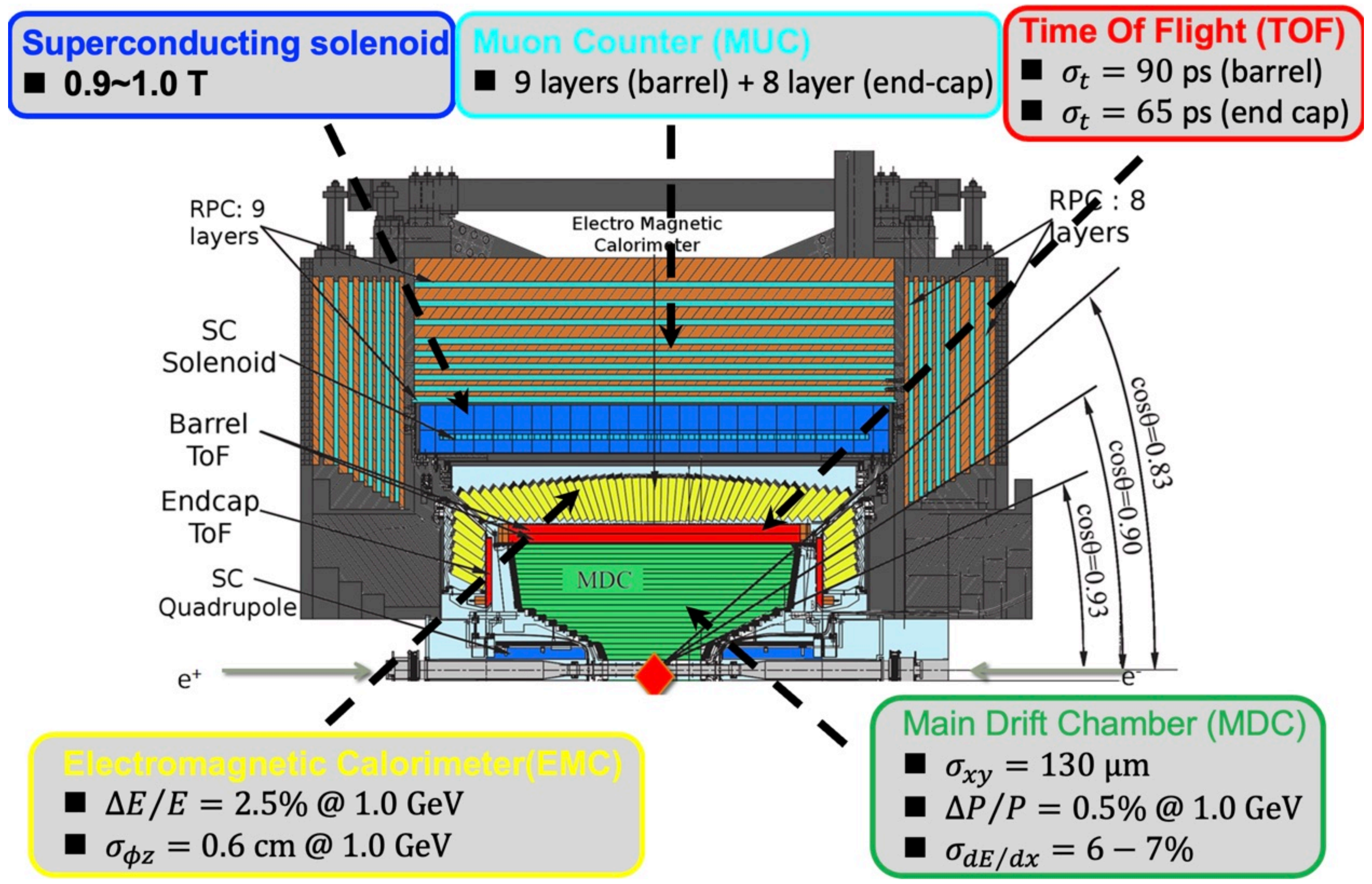
by Y. Xie @31st Lepton Photon Conf.

BEPCII & BESIII

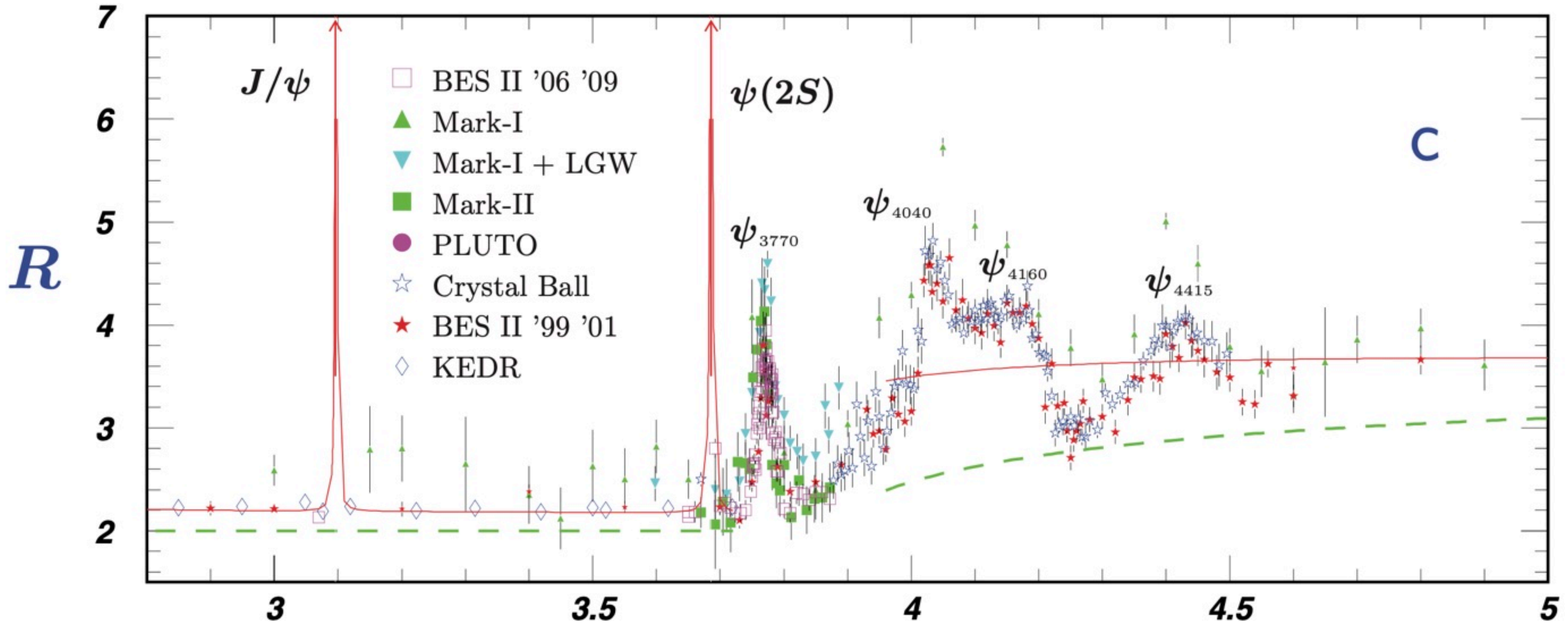


- 2020: energy upgrade to 2.45 GeV
- 2004: started BEPCII upgrade, BESIII construction
- 2008: test run
- 2009-now: BESIII physics run

- **1989-2004 (BEPC):** $\mathcal{L}_{\rm peak} = 1.0\times10^{31}\ {\rm cm^{-2}\cdot s^{-1}}$
- **2009-now (BEPCII):** $\mathcal{L}_{\rm peak} = 1.0\times10^{33}\ {\rm cm^{-2}\cdot s^{-1}}$



$$\sqrt{s} = 2.0 - 4.95\ \text{GeV}$$



Measurements of the R value at BESIII

Hao Zhang (on behalf of the BESIII collaboration)
zh4710jj@mail.ustc.edu.cn, University of Science and Technology of China

31st Lepton Photon Conference 2023
MELBOURNE CONVENTION & EXHIBITION CENTRE
17 - 21 JULY

Definition of R value

The $\boldsymbol{R}$ value is defined as the leading-order production cross section ratio of hadronic events and muon pairs in the e^+e^- annihilation:

$$\boldsymbol{R} \equiv \frac{\sigma^0(e^+e^- \to \text{hadrons})}{\sigma^0(e^+e^- \to \mu^+\mu^-)} \equiv \frac{\sigma^0_{\text{had}}}{\sigma^0_{\mu\mu}}$$

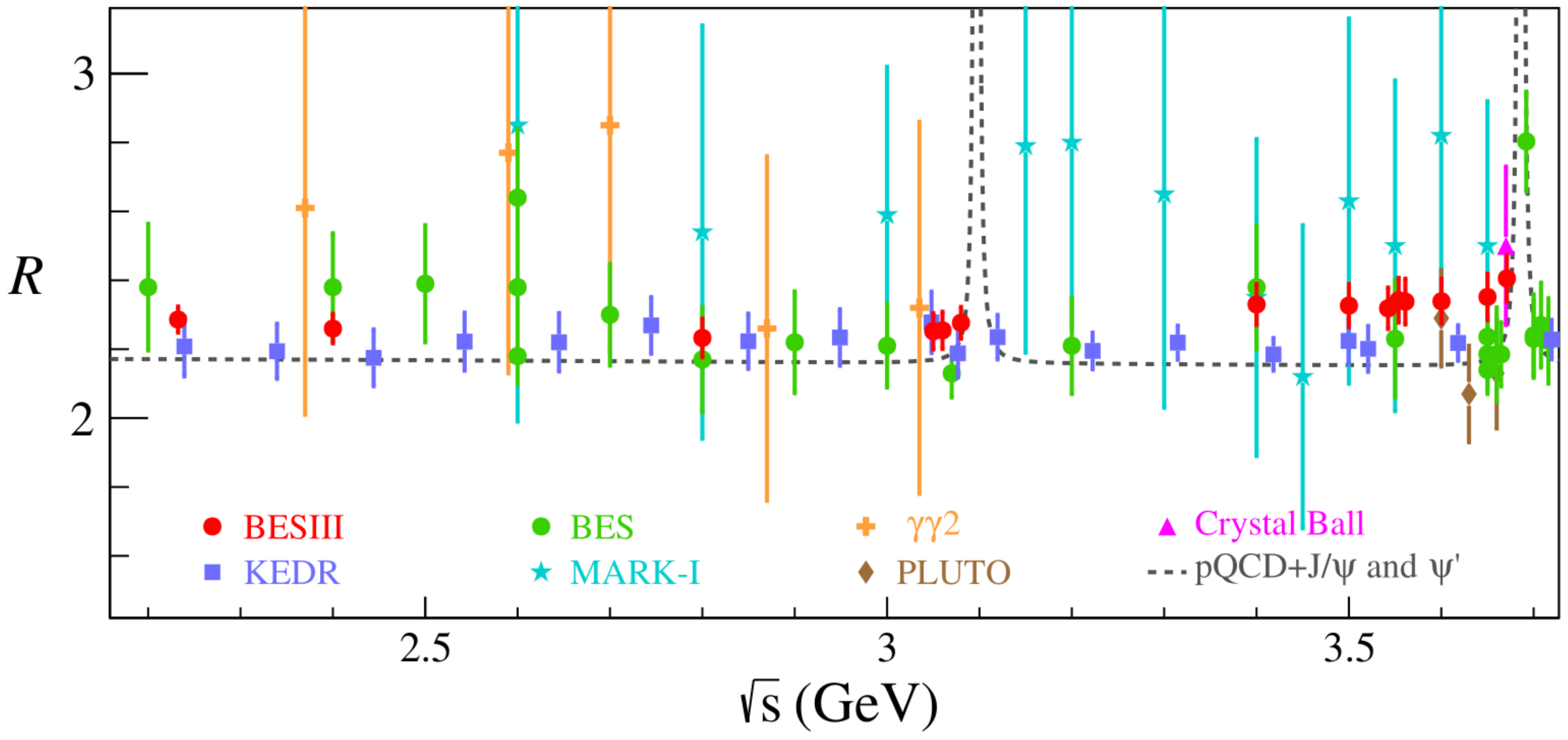
$$\sigma^0_{\mu\mu}(s) = \frac{4\pi\alpha^2}{3s}\frac{\beta_\mu(3-\beta_\mu^2)}{2}, \text{ with } \beta_\mu = \sqrt{1-4m_\mu^2/s}$$

Measurement of $\boldsymbol{R}$ value $\Longleftrightarrow$ Measurement of **total cross section of hadron production**

Summary

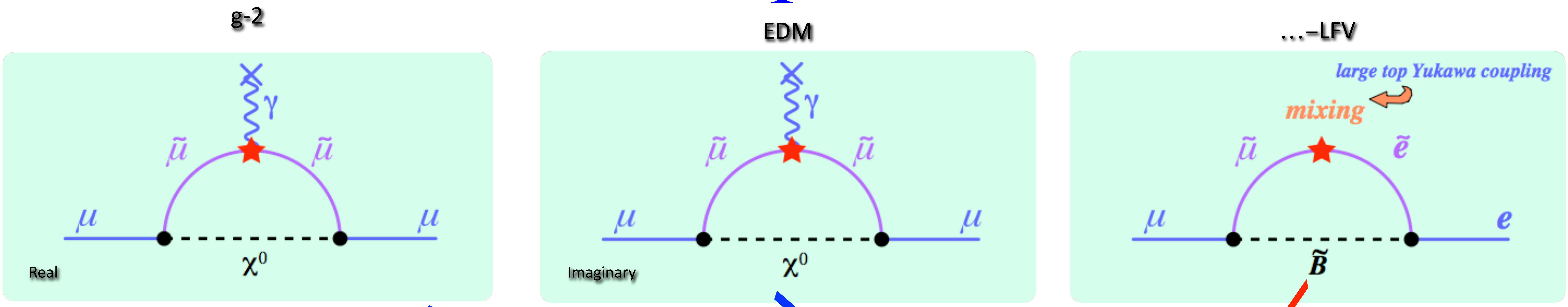
R value measurement at BESIII

- Precision better than 2.6% below 3.1 GeV and 3.0% above **[Phys. Rev. Lett. 128, 062004 (2022)]**



Muon

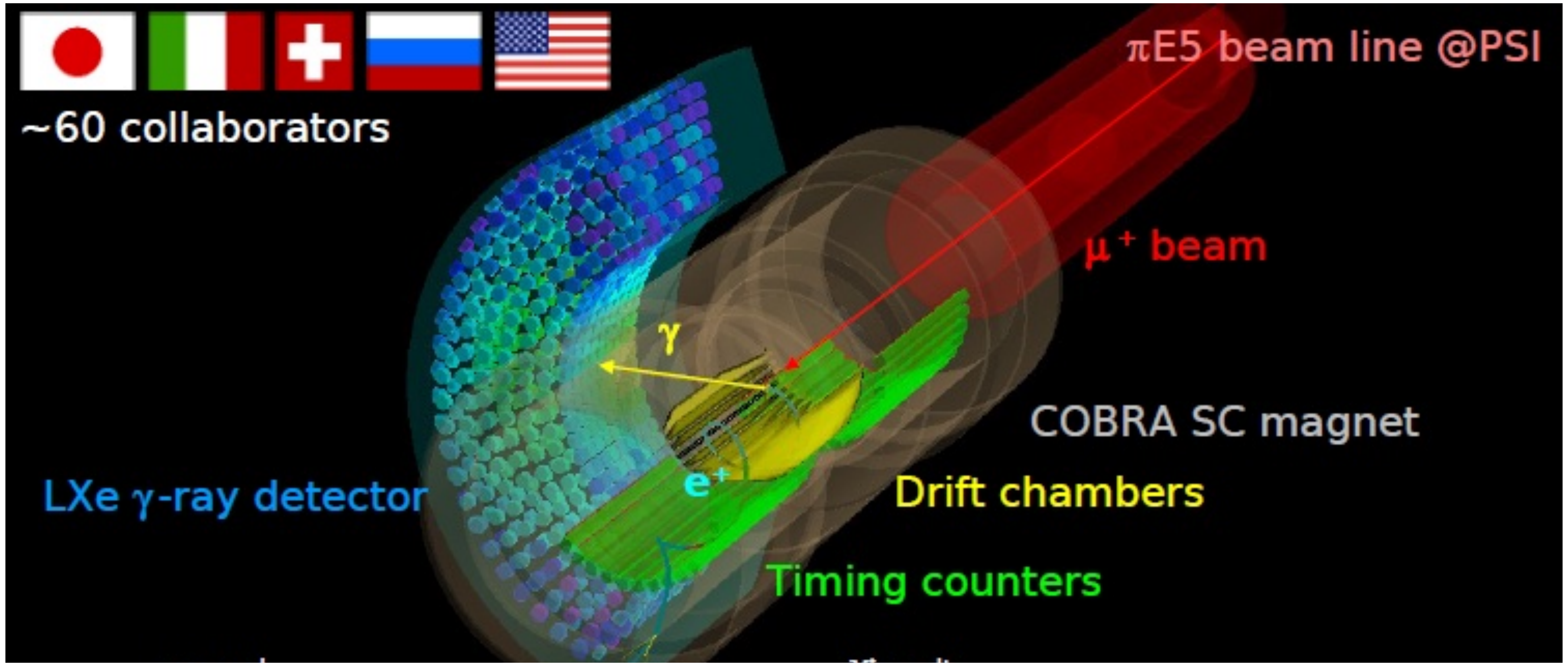
Muon experiments



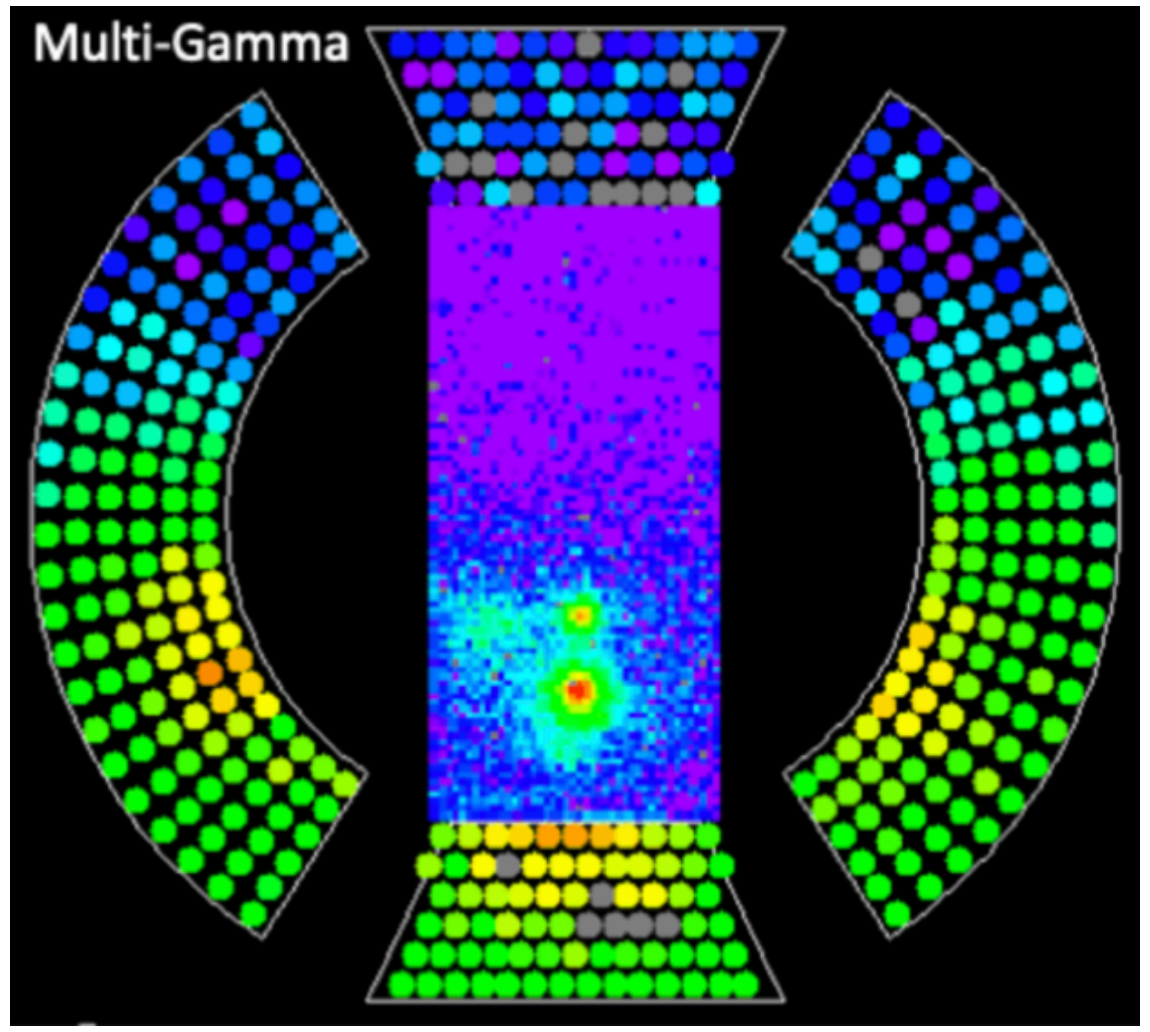
- μ→eγ search
- μ-e conversion search
- g-2
- μ-EDM

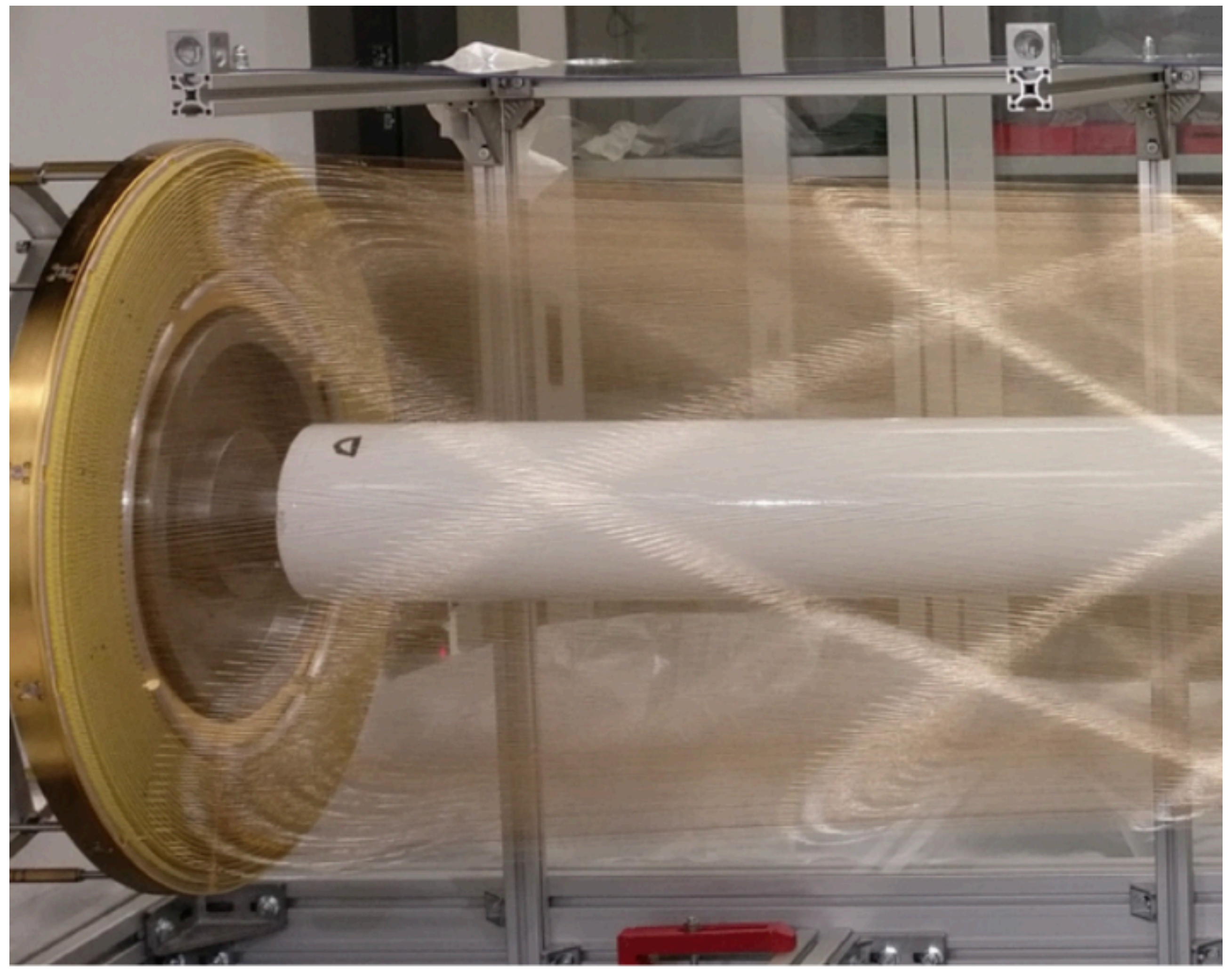
$$\begin{pmatrix} m^2_{\tilde{e}\tilde{e}} & \Delta m^2_{\tilde{e}\tilde{\mu}} & \Delta m^2_{\tilde{e}\tilde{\tau}} \\ \Delta m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & \Delta m^2_{\tilde{\mu}\tilde{\tau}} \\ \Delta m^2_{\tilde{\tau}\tilde{e}} & \Delta m^2_{\tilde{\tau}\tilde{\mu}} & m^2_{\tilde{\tau}\tilde{\tau}} \end{pmatrix}$$

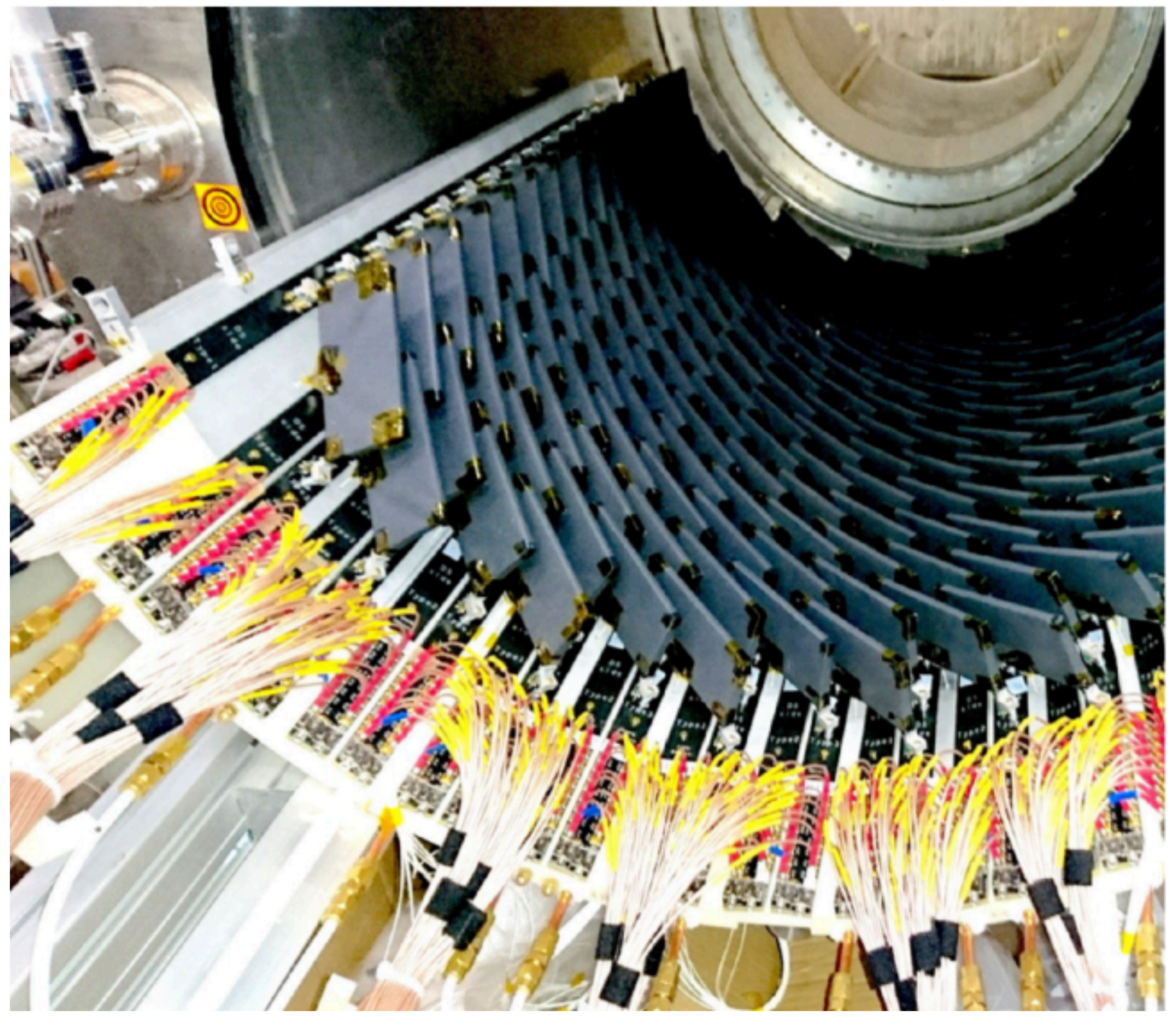
MEG II at PSI



by H. Nishiguchi @13th ICFA seminar

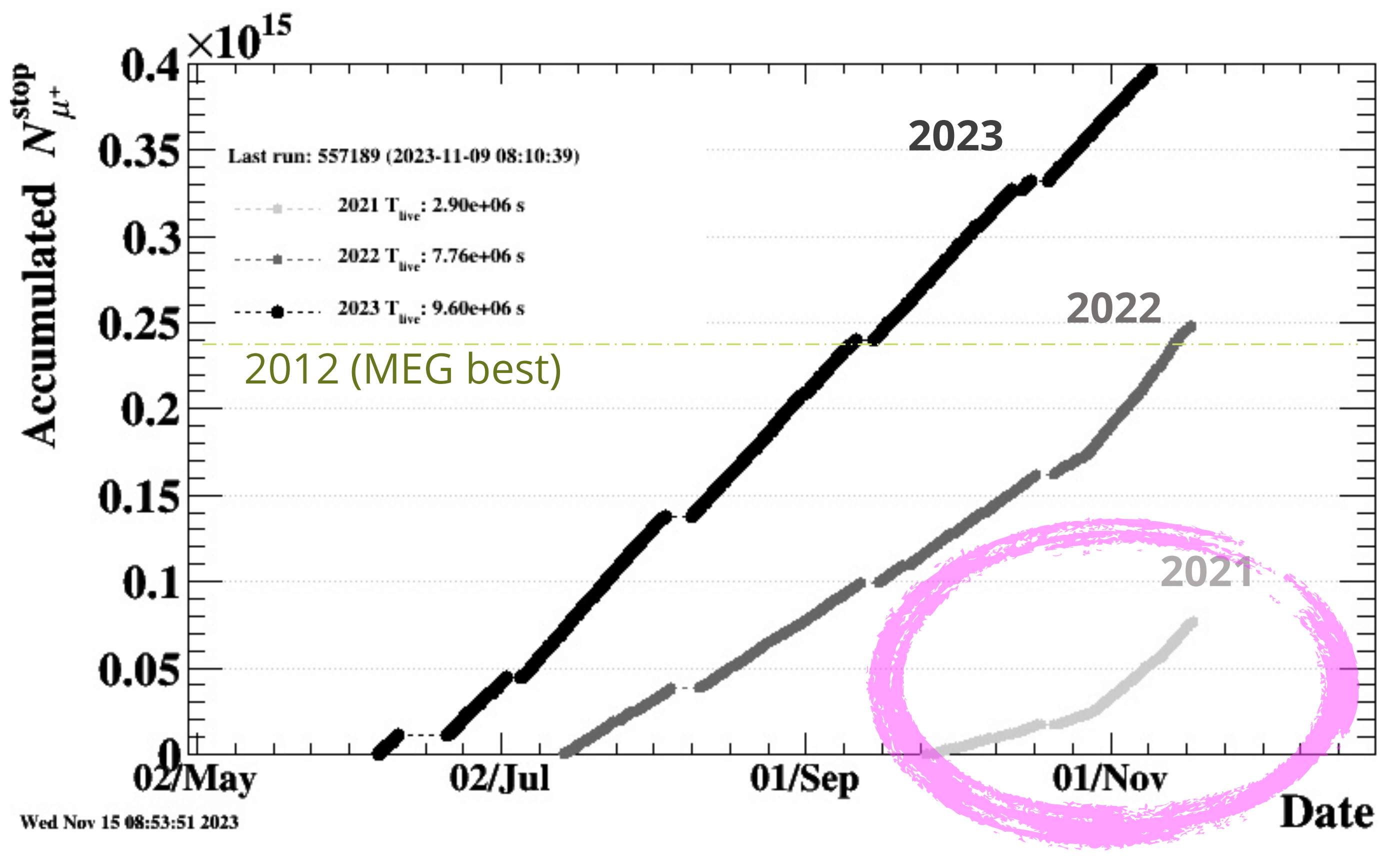




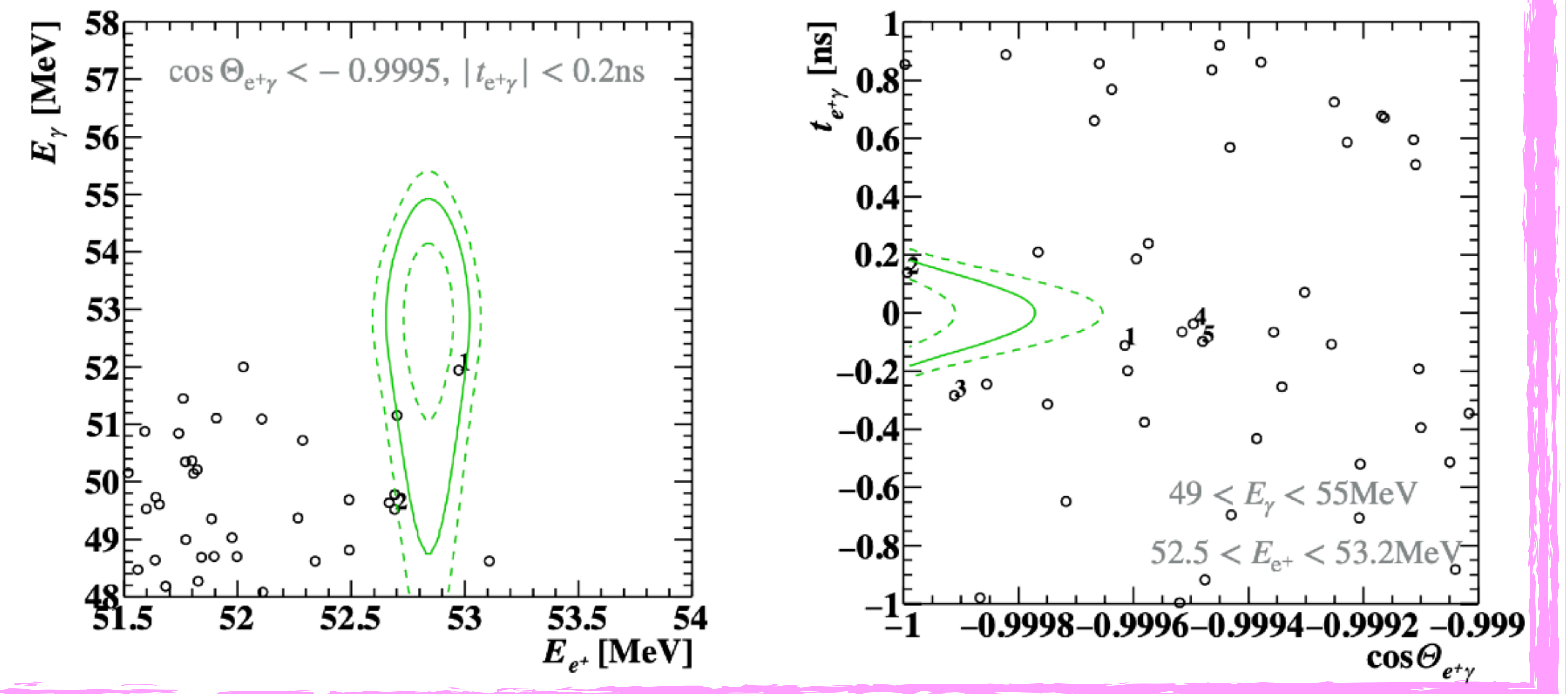


Latest Update — MEG II, First Result —

- MEG II is running from 2021
- The 1st result have been published just last month !



Unblinded 2021 Data

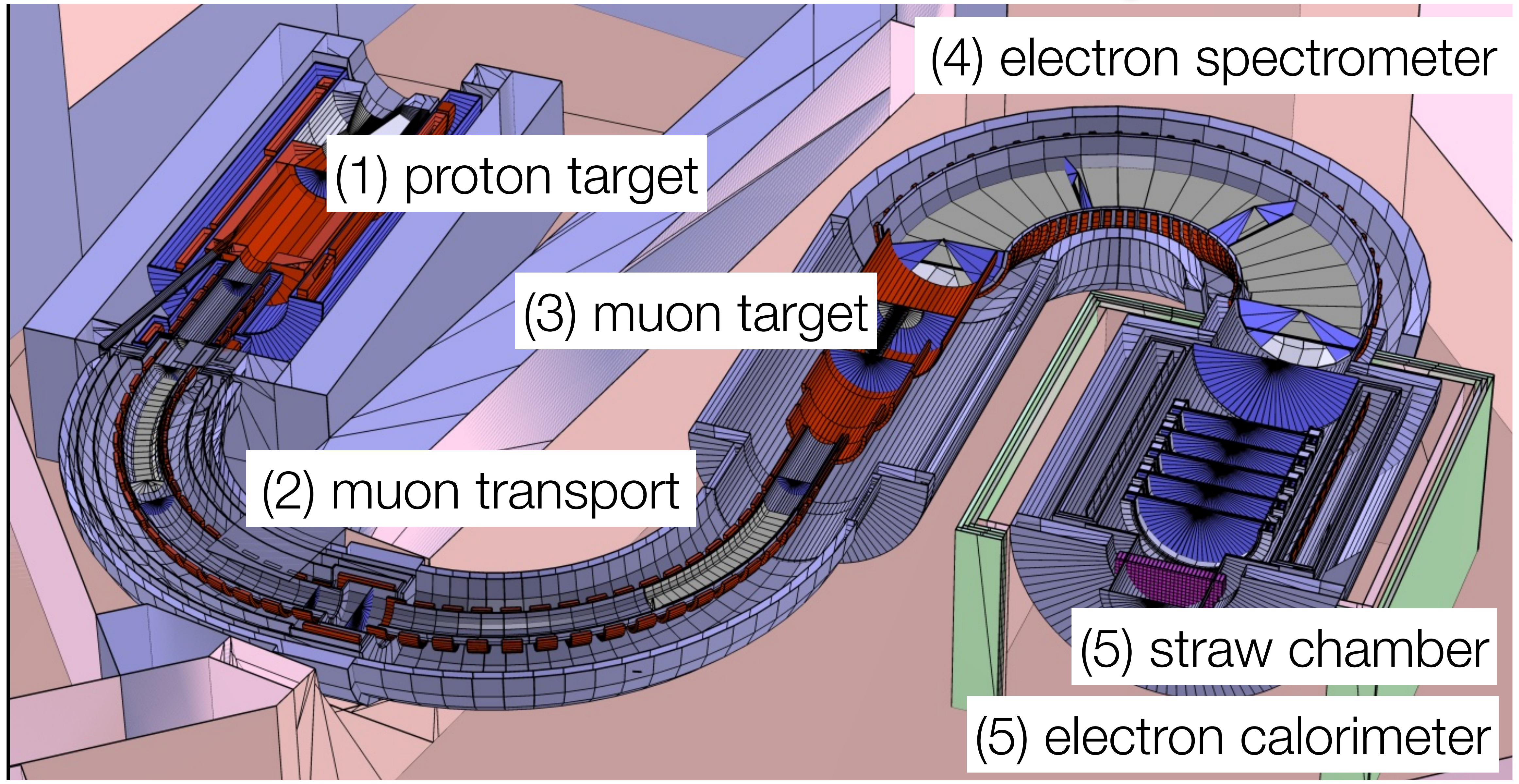


- Only 7 weeks of physics run in 2021 = Almost equivalent to MEG data
- No excess of events over the expected background is observed
  - Upper Limit (90CL), $\mathcal{B}(\mu^+ \to e^+\gamma) < 7.5 \times 10^{-13}$, *c.f.* MEG result : $< 4.2 \times 10^{-13}$
  - **Combined (MEG II 2021 + MEG): $\mathcal{B}(\mu^+ \to e^+\gamma) < 3.1 \times 10^{-13}$ (90% C.L.)**

The most stringent limit to date !

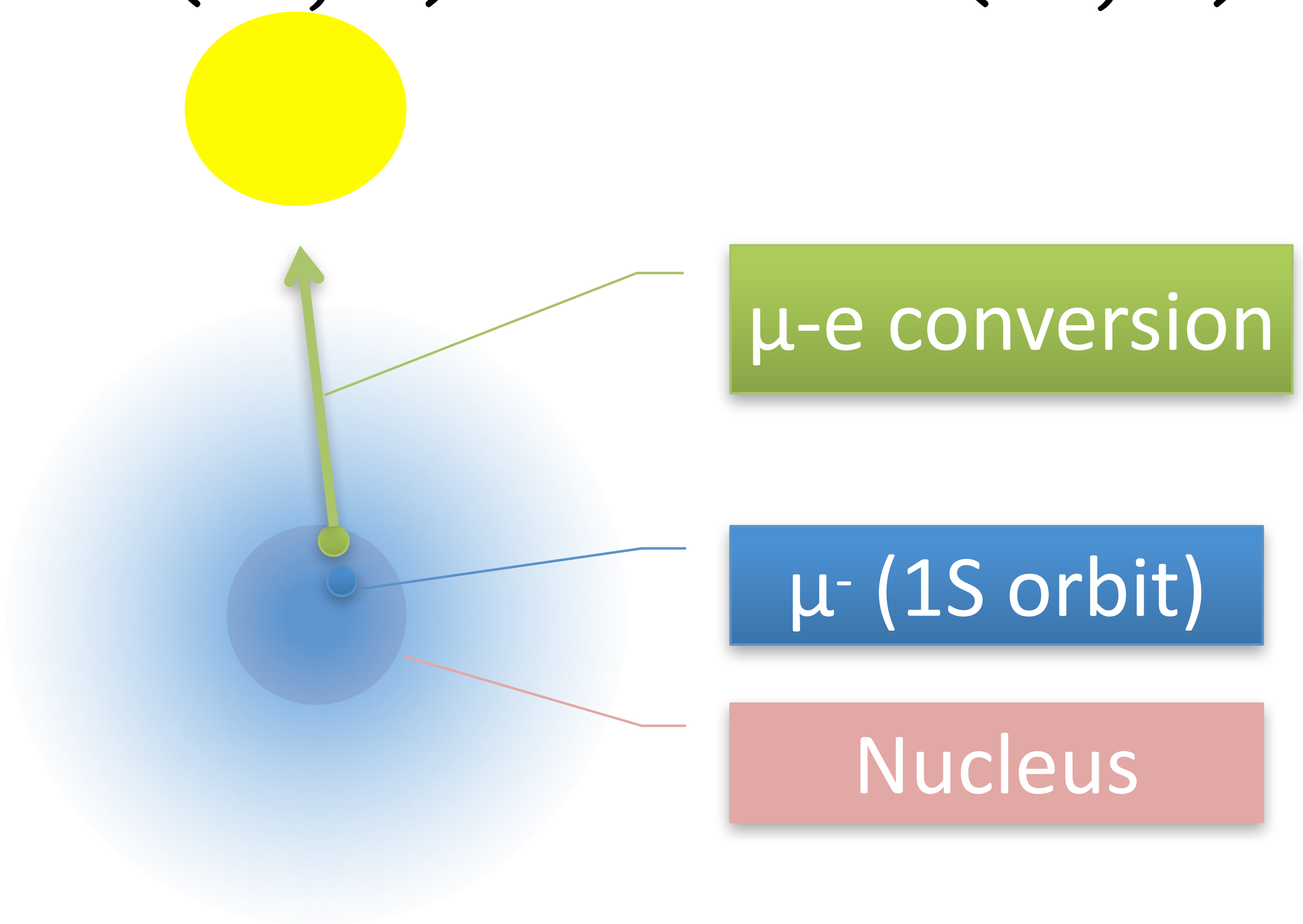
COMET

μ-e conversion



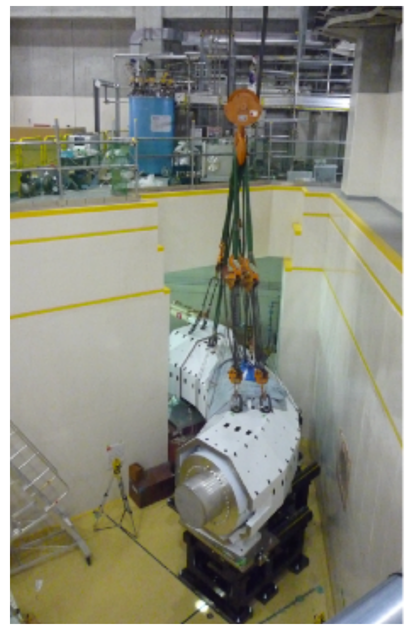
- High intensity pulsed muon beam (10^{11}/sec)
- Large solid angle curve solenoidal electron spectrometer
  - Experimental sensitivity: BR = 10^{-17}
    - 100,000 times better than current limits
- Energy scale comparable to LHC

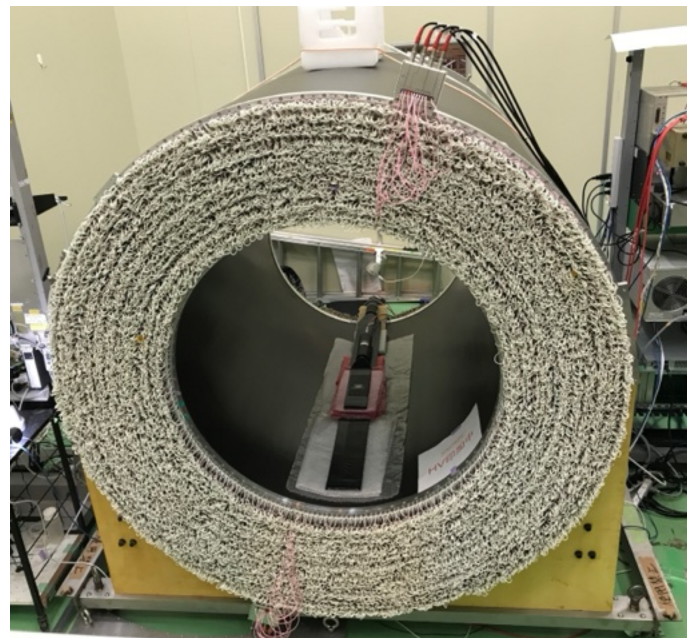
$$\mu^- + N(A,Z) \rightarrow e^- + N(A,Z)$$



Immediate Outlook (3) — Mu2e / COMET / Mu3e —

- **Preparations for 3 experiments (Mu2e, COMET, Mu3e) are in the final stage**



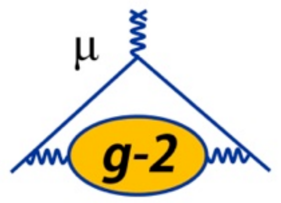



	JFY2023	JFY2024	JFY2025	JFY2026	JFY2027
Detector for mu-e Search			★ Ready		
Detector for beam measurement			★ Ready		
Beam line construction		Magnet Installation	Shield★		
Engineering & Physics Runs			Eng	Physics Run	

- **Two detectors, for physics and BG, Ongoing and will be ready in 2025**
- **Beam-line commissioning w/ low-intensity proton beam, completed**
- **Pion Capture and Detector Solenoids, will be installed in 2026**
- **Engineering/Physics Runs are expected to start in 2025-2026, after radiation shield construction which leaves uncertainty in schedule.**

Fermilab | U.S. DEPARTMENT OF ENERGY | Office of Science

Muon g-2 Experiment and SM



Esra Barlas-Yucel
on behalf of the Muon g-2 Collaboration

Lepton Photon 2023
Melbourne
20 July 2023

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

FERMILAB-SLIDES-23-172-PPD

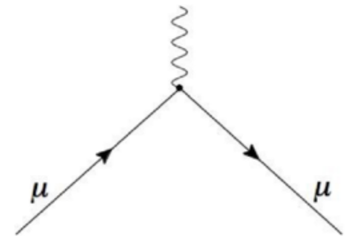
Muon Magnetic Moment and Defining the Anomaly

Magnetic Moment of Muon

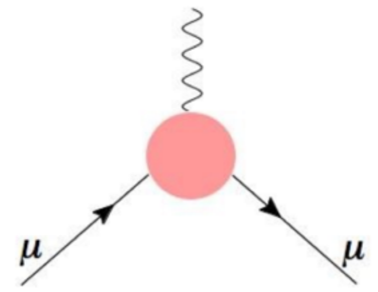
$$\vec{\mu} = g_\mu \frac{e}{2m}\vec{s}$$

g: Proportionality constant between spin and magnetic moment

Dirac: g=2



Quantum effects : g>2



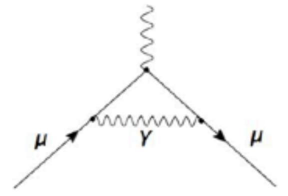
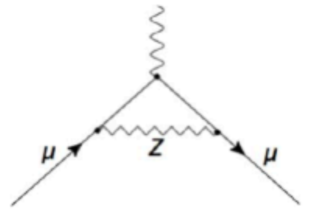
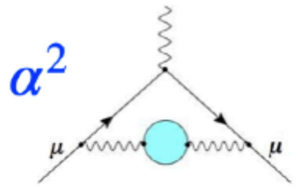
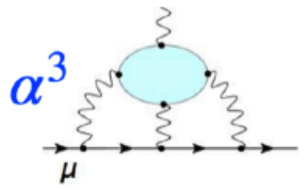
Anomalous Magnetic Moment of Muon

$$a_\mu = \frac{g_\mu - 2}{2}, \qquad \vec{\mu} = (1 + a_\mu)\frac{e}{m}\vec{s}$$

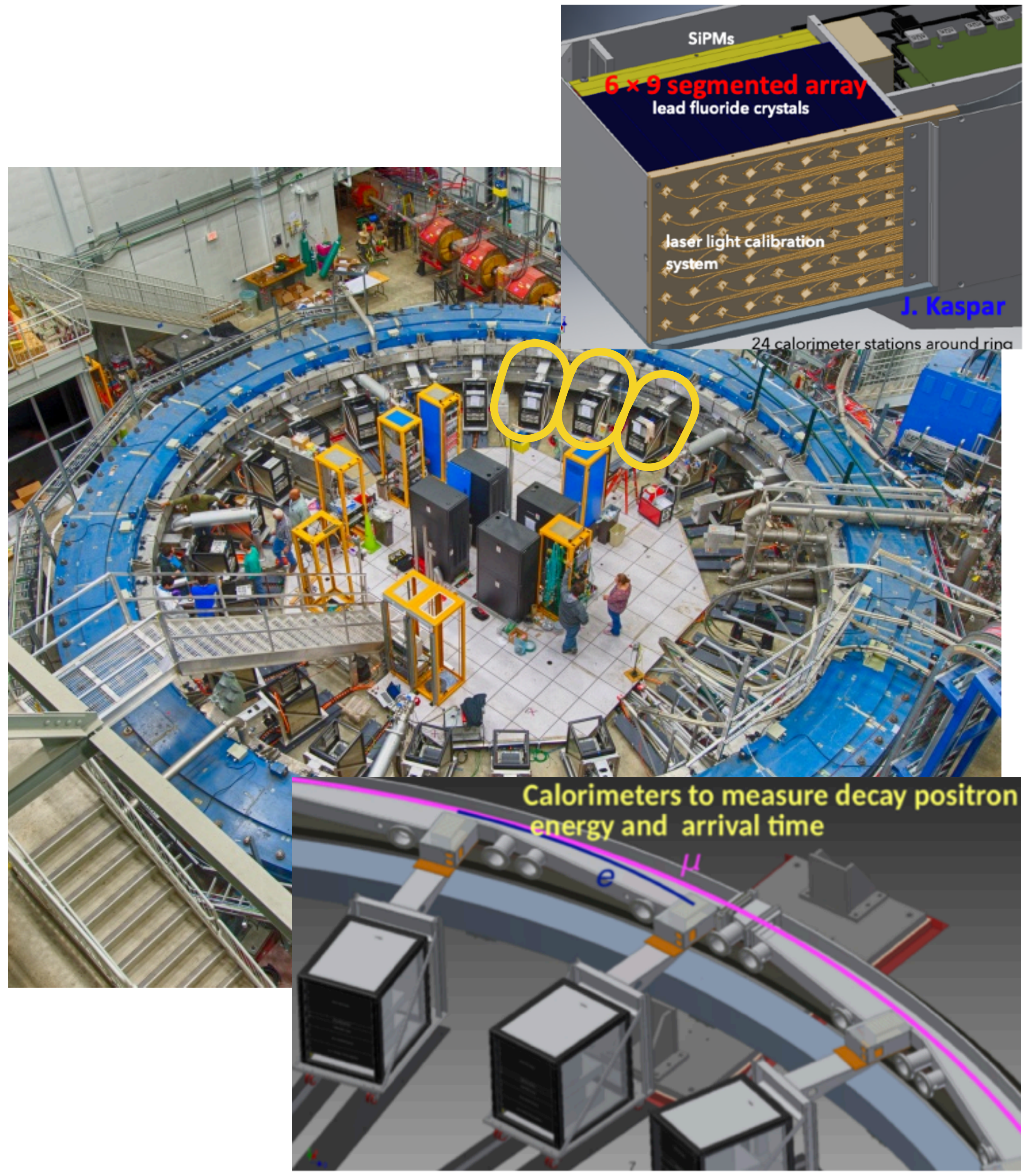
Shows how much g differs fractionally from 2!

Measuring this anomaly could tell us if there are new particles or even forces that contribute to a_μ

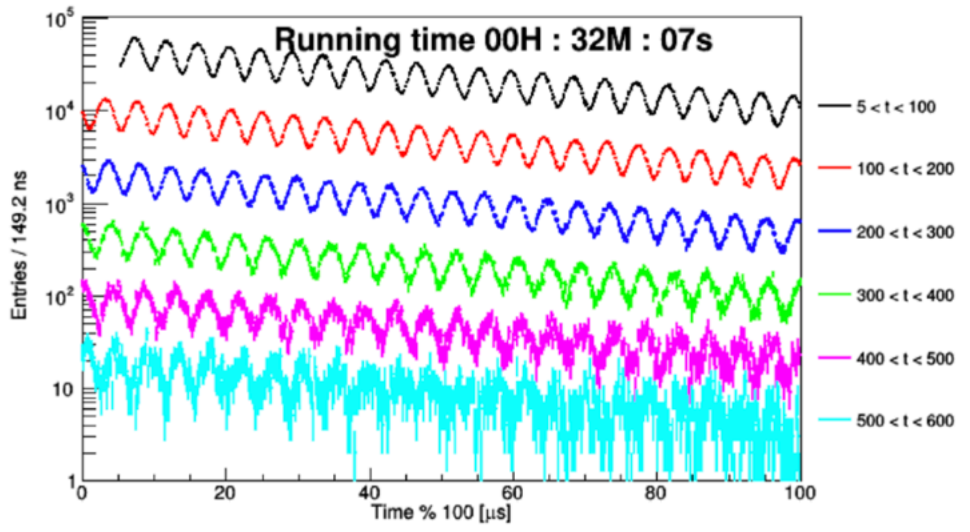
$$a_\mu = a_\mu(QED) + a_\mu(EW) + a_\mu(hadronic)$$

QED		+…	(5 loops)	$116\,584\,718.9\,(1) \times 10^{-11}$	0.001 ppm
EW		+…	x	$153.6\,(1.0) \times 10^{-11}$	0.01 ppm
HVP	α^2 	+…	(NNLO)	$6845\,(40) \times 10^{-11}$ [0.6%]	0.34 ppm
HLbL	α^3 	+…	(NLO)	$92\,(18) \times 10^{-11}$ [20%]	0.15 ppm

Detectors : Calorimeters

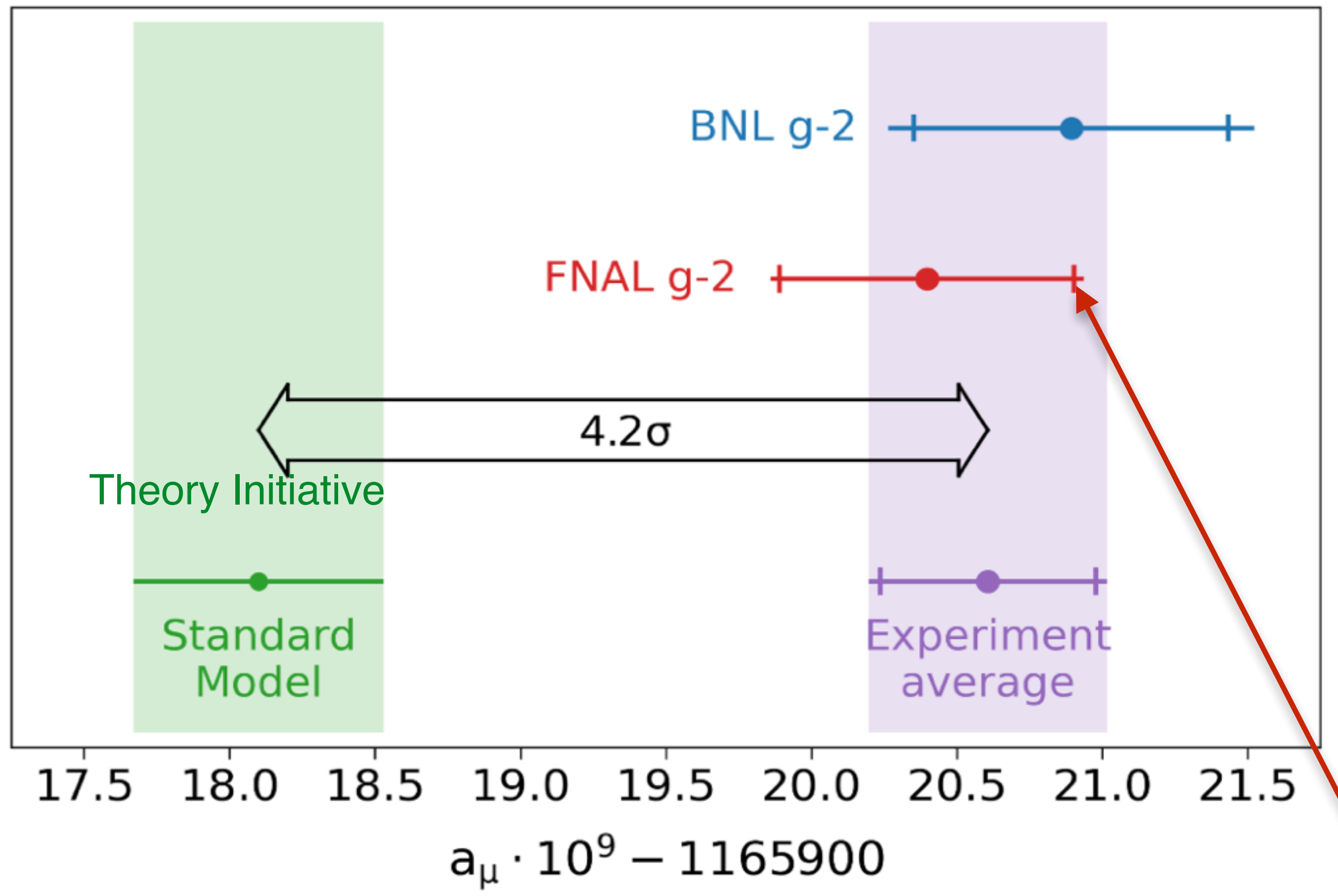


- **Calorimeters**
  - 24 segmented PbF_2 crystal calorimeters stationed around the ring
  - Detects energy and arrival time of e^+ decayed from muons: $\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$



$$N(t) = N_0 e^{-t/\tau}[1 + A\cos(\omega_a t + \phi)]$$

$$a_\mu = \left(\frac{g_e}{2}\right)\left(\frac{\omega_a}{\langle\omega_p\rangle}\right)\left(\frac{\mu_p}{\mu_e}\right)\left(\frac{m_\mu}{m_e}\right)$$



FNAL Run-1

New result

Phys. Rev. Lett. 131, 161802

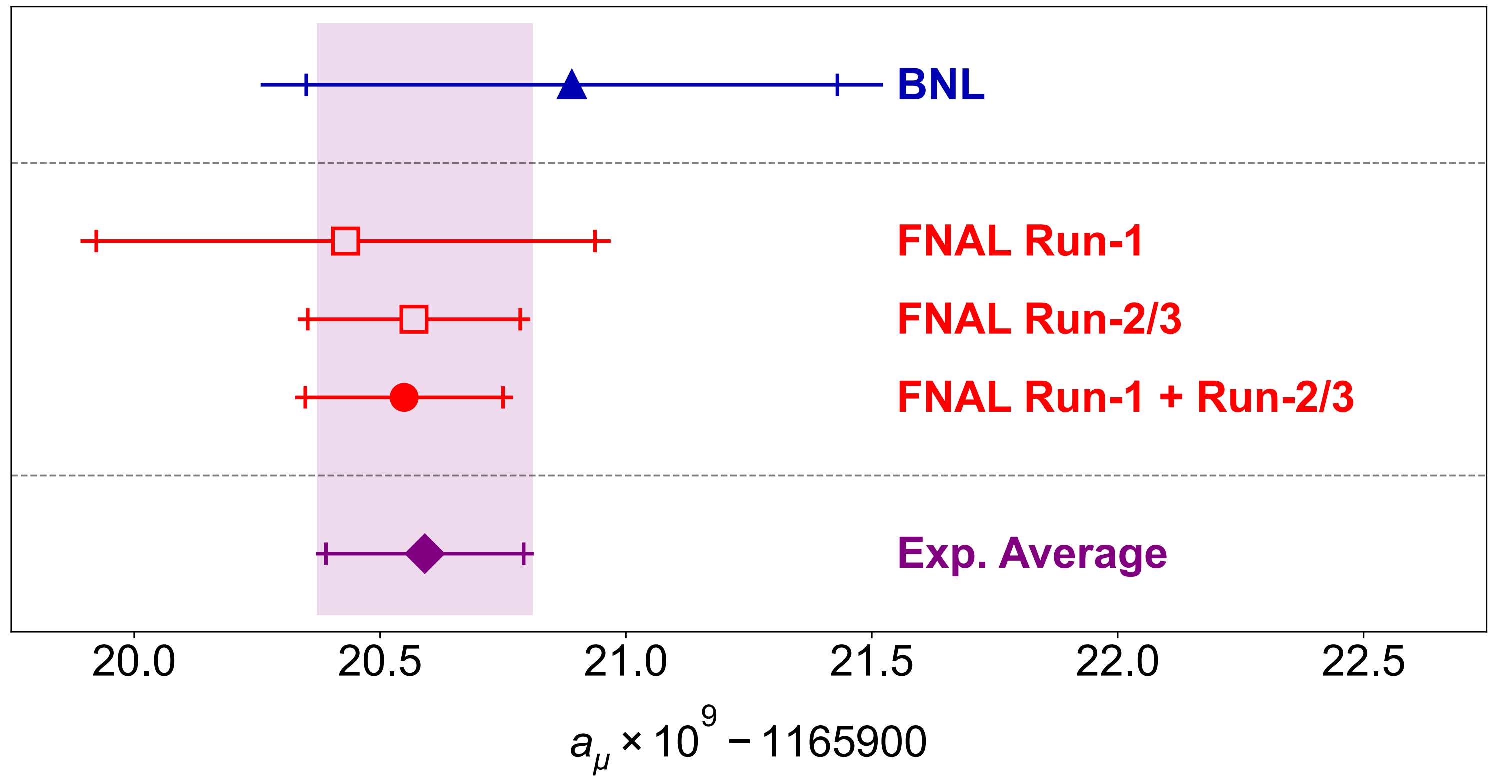
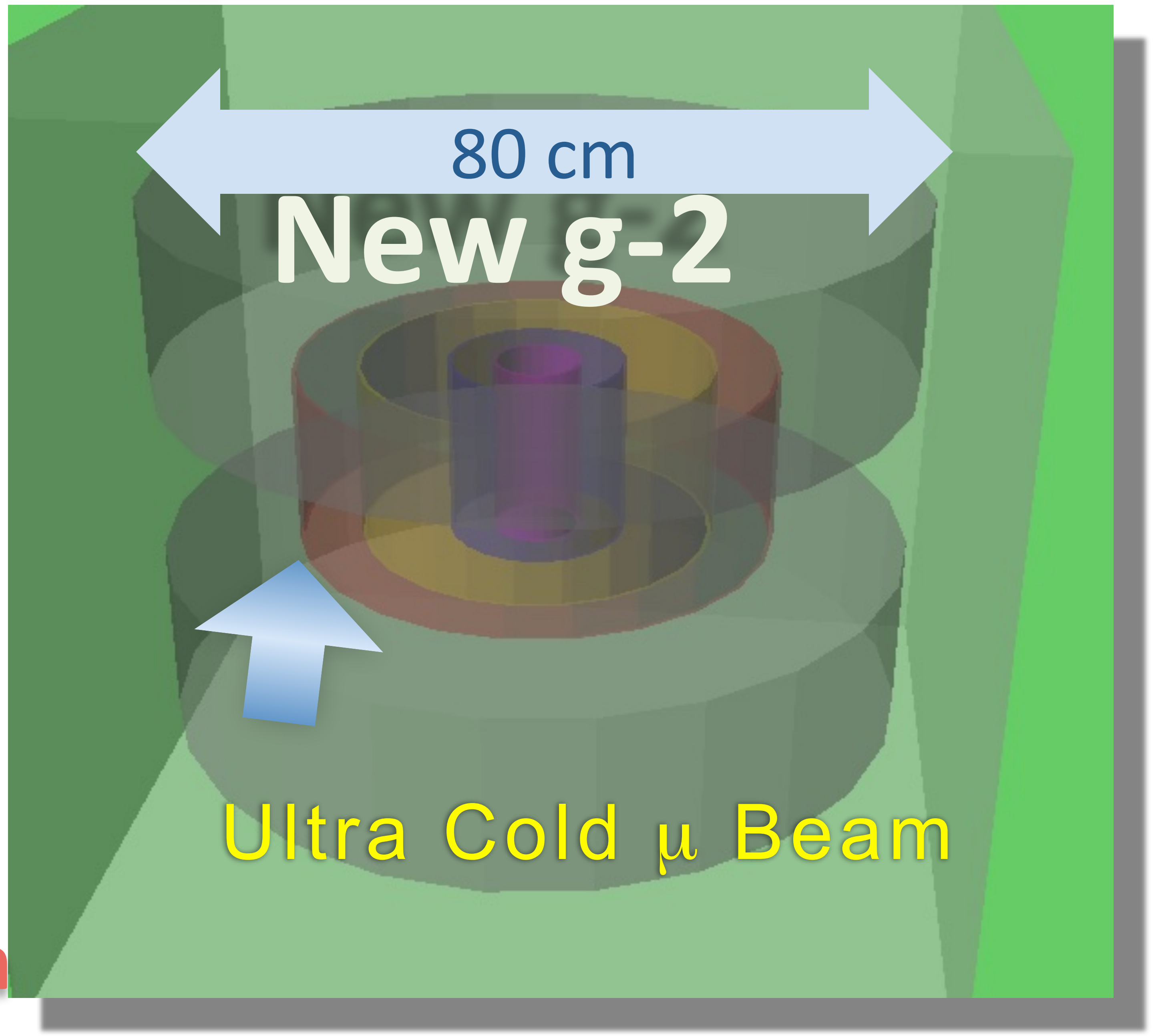
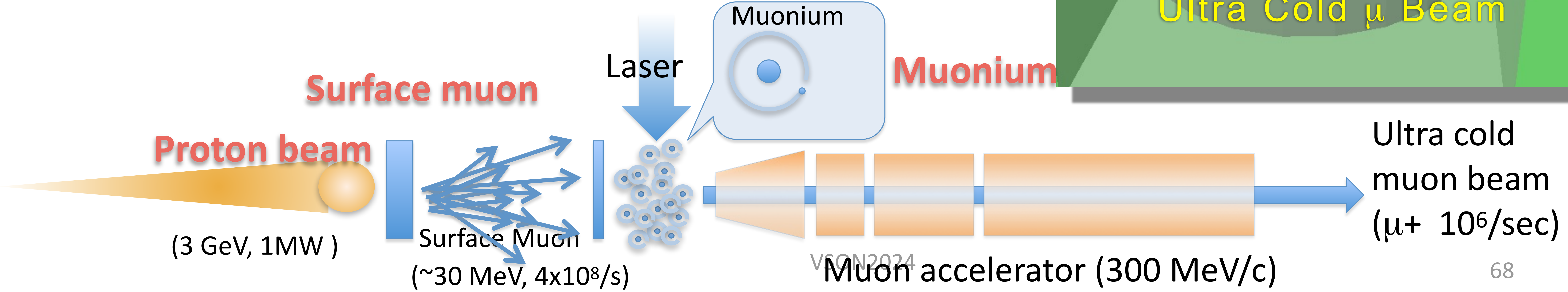


FIG. 3. Experimental values of a_μ from BNL E821 [8], our Run-1 result [1], this measurement, the combined Fermilab result, and the new experimental average. The inner tick marks indicate the statistical contribution to the total uncertainties.

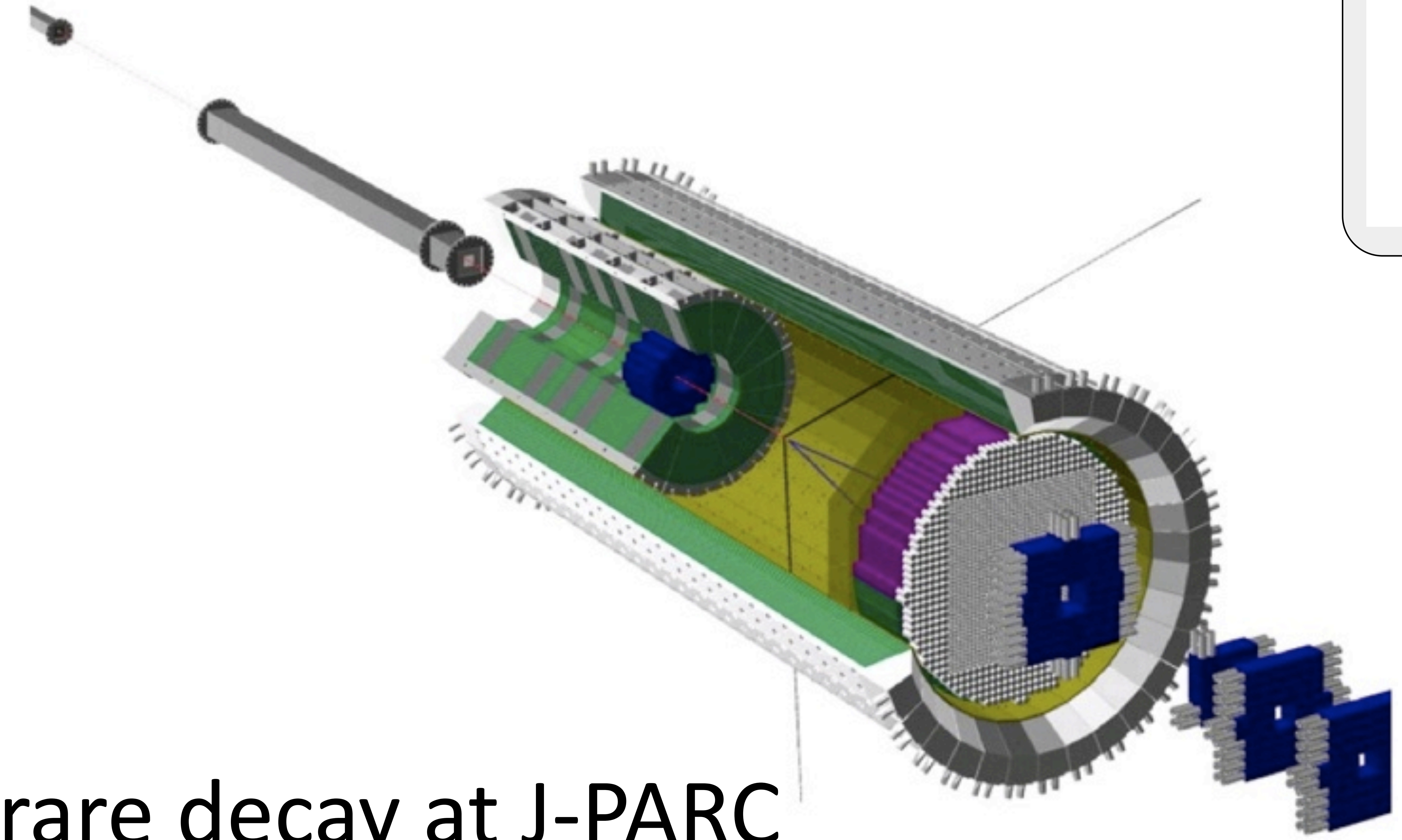
J-PARC Muon g-2 experiment.



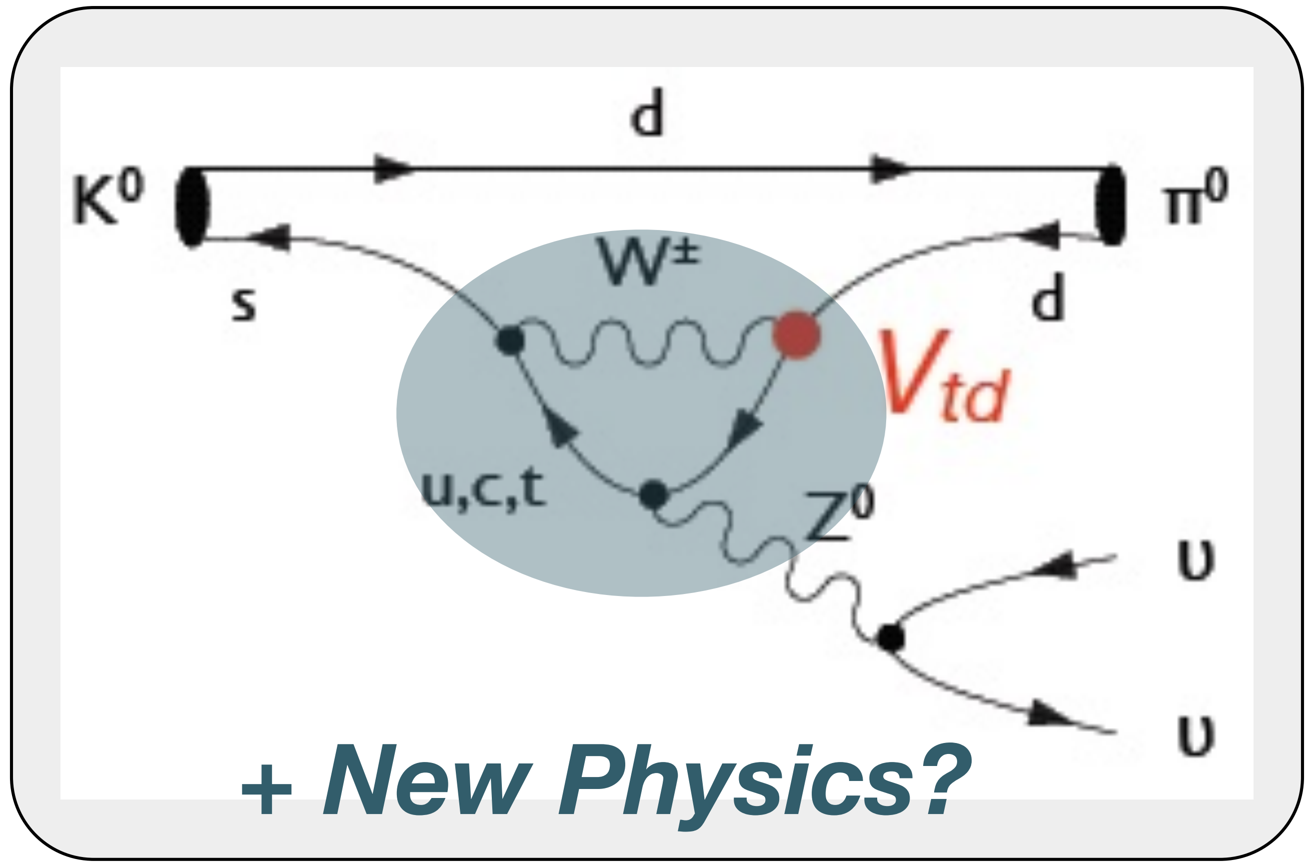
- New technology improves both statistical and systematic errors
  - Use ultra-slow muon sources
  - Storage rings about 1/20th of conventional ones
  - Ultra-precise electromagnets based on MRI technology



Other targets

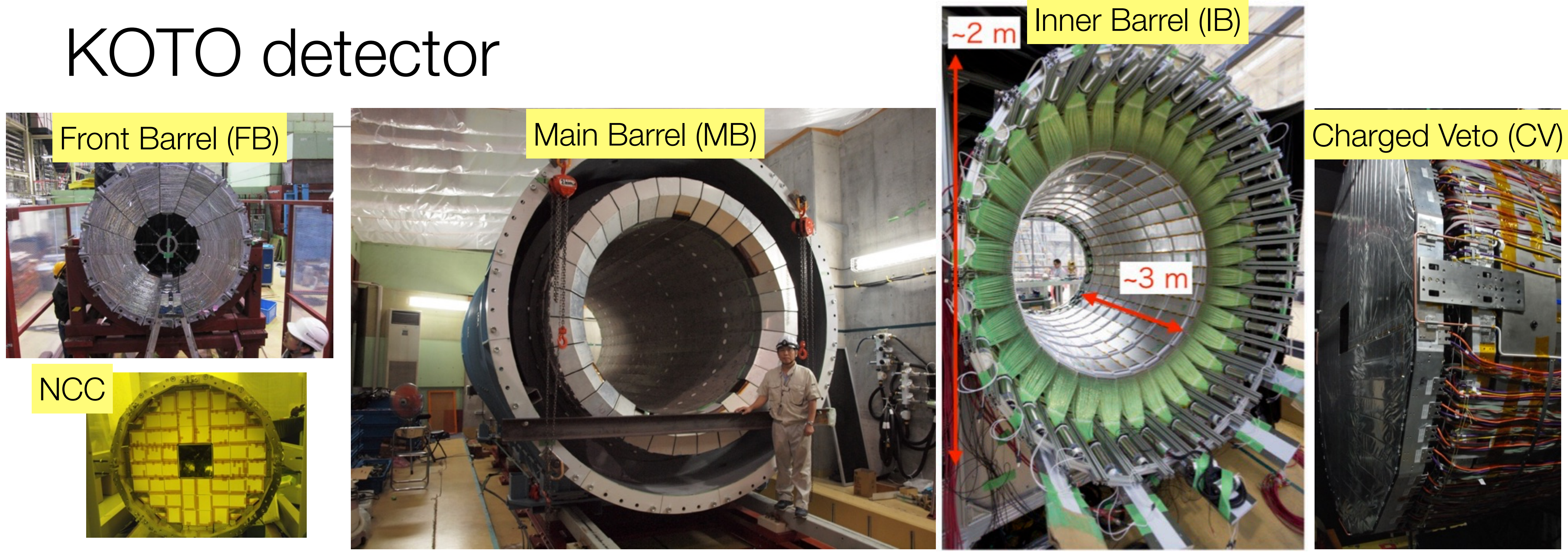


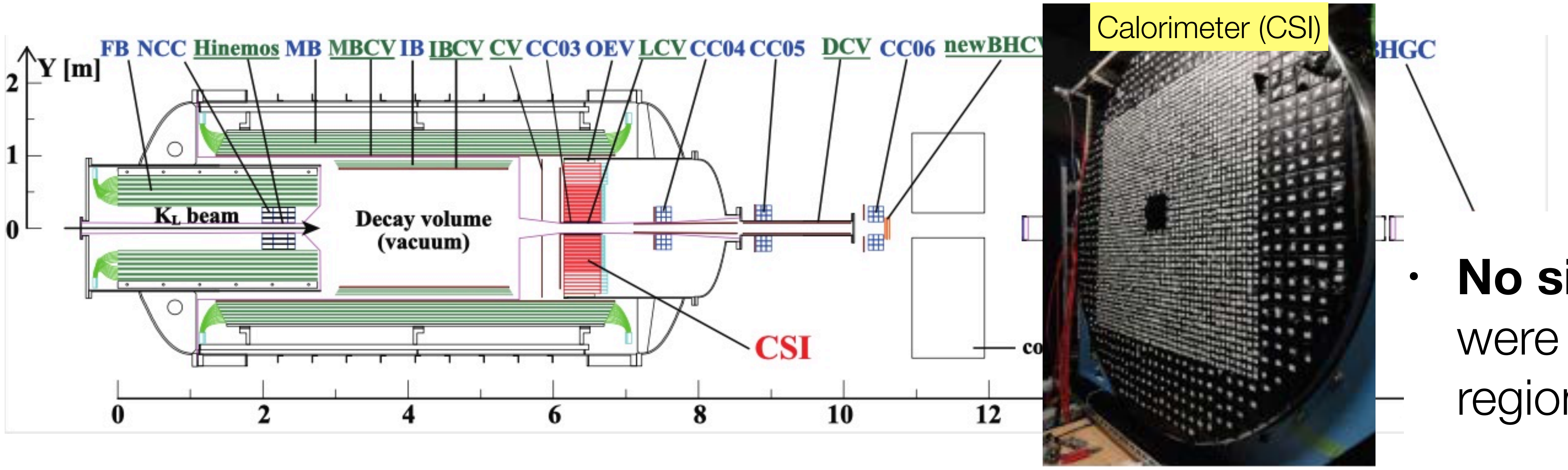
Standard Model

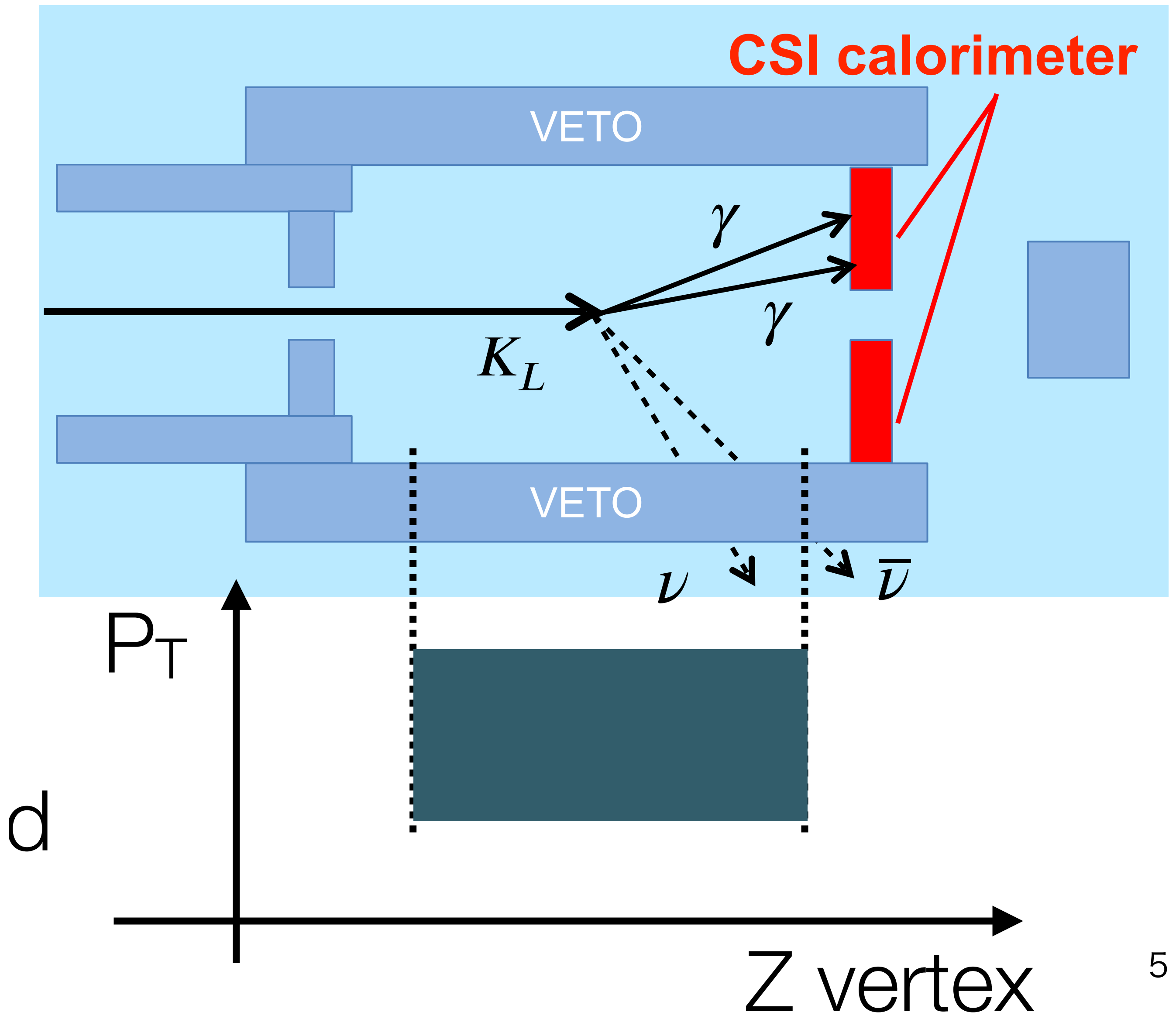


K rare decay at J-PARC

KOTO detector





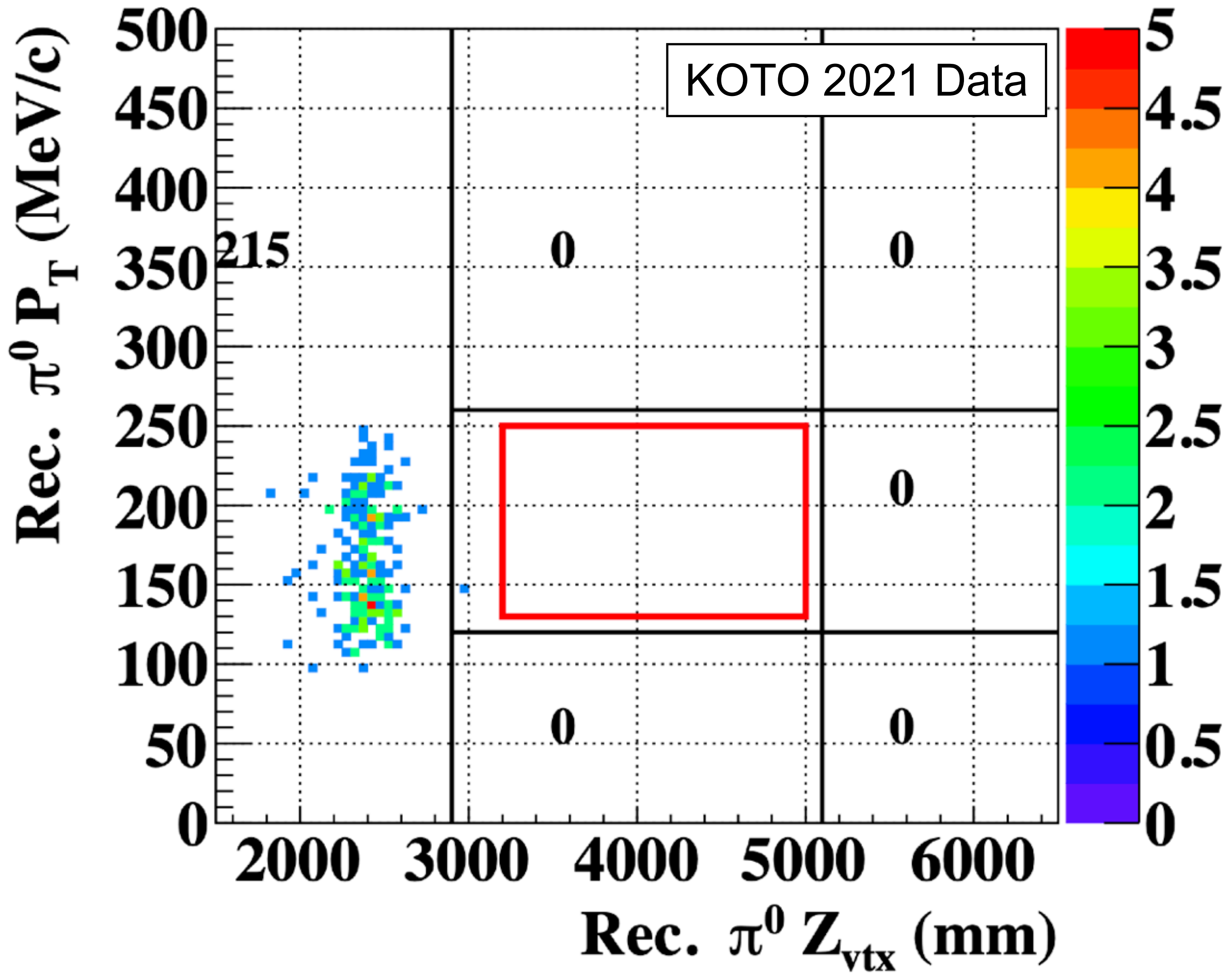


- **No signal candidates** were observed in the signal region.
- Set the upper limit to be

  $BR(K_L \rightarrow \pi^0 \nu\nu) < 2.0 \times 10^{-9}$

  at 90% confidence level.

  - Corresponding to SES×2.3 based on Poisson statistics.



by T. Nomura @37th J-PARC PAC

CERN NA62: Search for $K^+ \to \pi^+ \nu\nu$

Dark boson searches at CERN's North Area

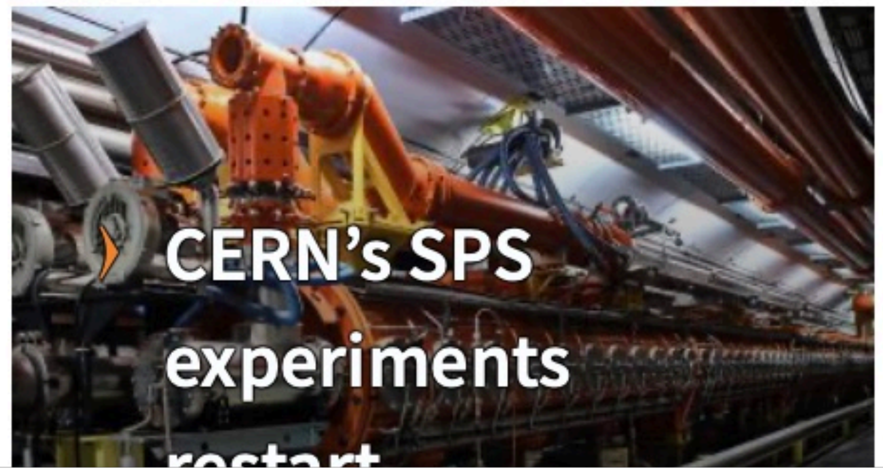
With their latest dark-matter searches, both the NA62 and NA64 experiments start probing several well motivated light dark-matter models

21 AUGUST, 2023 | By Kristiane Bernhard-Novotny

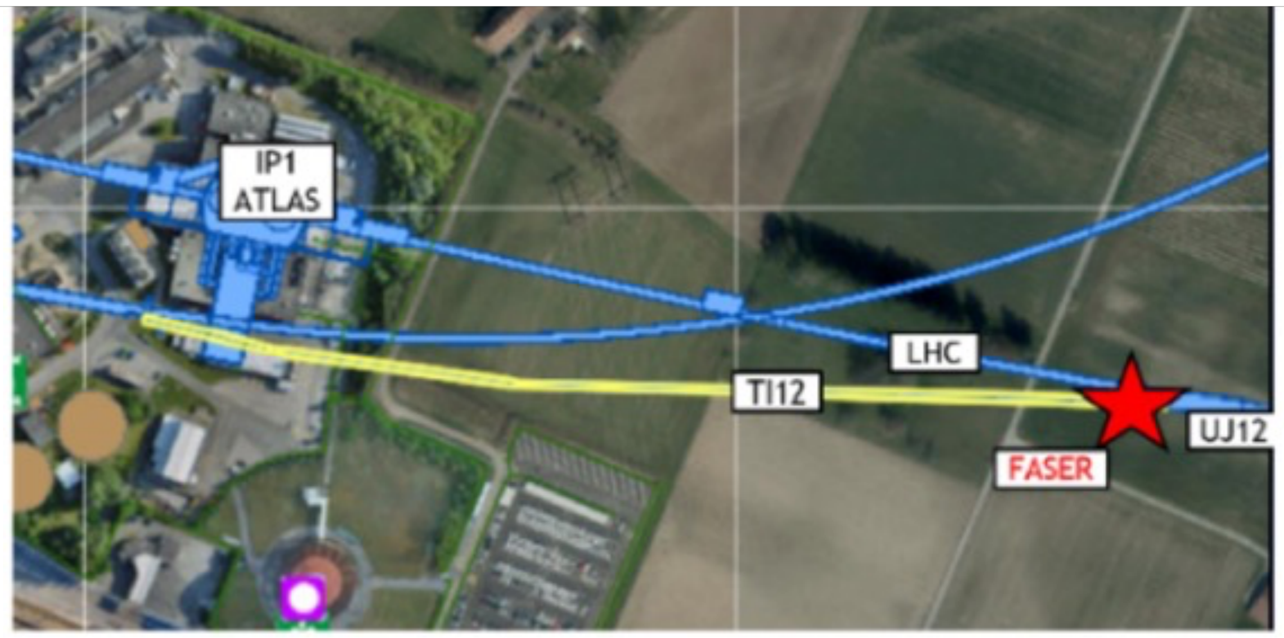
The NA62 (left) and NA64 (right) experiments at CERN's North Area.

Located at CERN's North Area and receiving beams from the Super Proton Synchrotron (SPS), the NA64 and NA62 experiments search for dark matter, complementing searches at the LHC, as they cover a different energy range. Both experiments recently published new results.

Related Articles

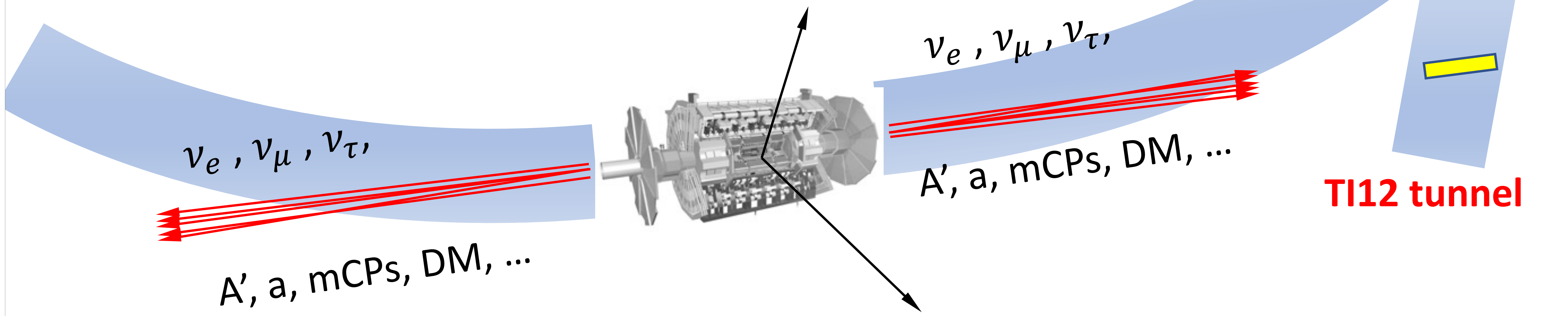


FASER experiment



FASER is a new forward experiment of LHC, located 480 m downstream from the ATLAS IP.
Successfully started data taking in Run 3 from July 2022 for:

- Search for new weakly-coupled particles in the MeV-GeV range
  - proposed to CERN in 2018, approved by CERN in 2019
- Study of all flavors of neutrinos at the TeV-energy frontier
  - proposed to CERN in 2019, approved by CERN in 2020

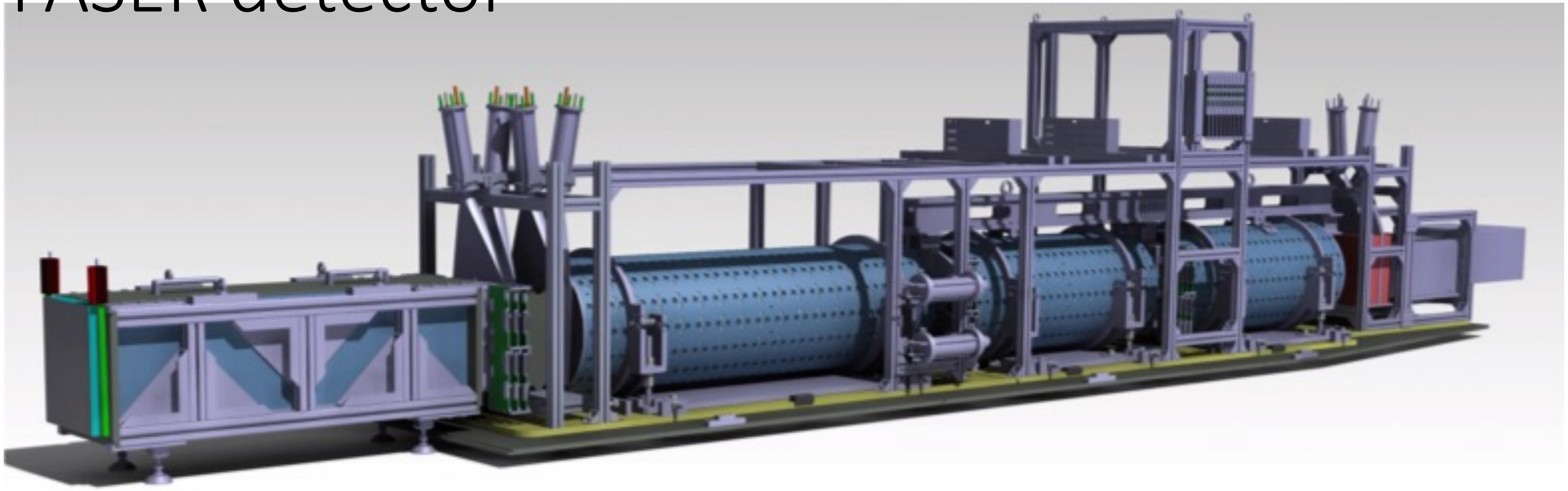


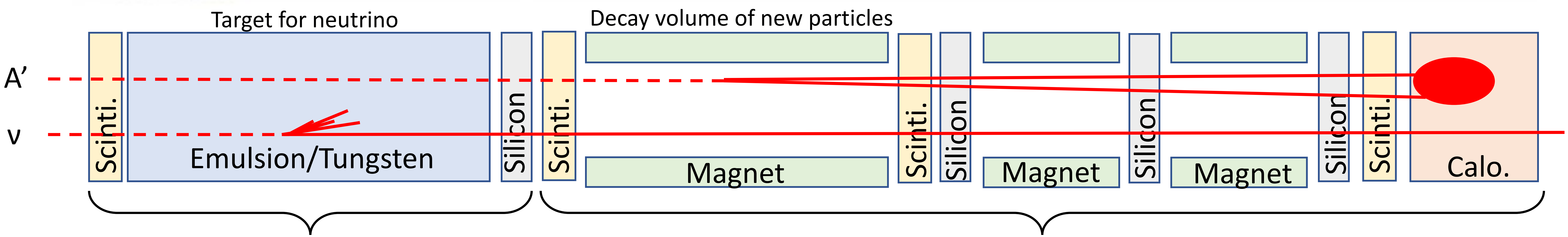
Favorable location, except that refurbishment is needed to be an experimental site.

- Background from collision point is only high-energy muon at about 1 /cm^2/sec, thanks to ~100-m rock
- Radiation level from LHC is quite low, around 4×10^{-3} Gy/year (= 4×10^7 *1*-MeV neutron/cm^2/year)

by H. Otono @ Kyoto seminar 2023

FASER detector





For neutrino physics:
Installation completed 2022 March

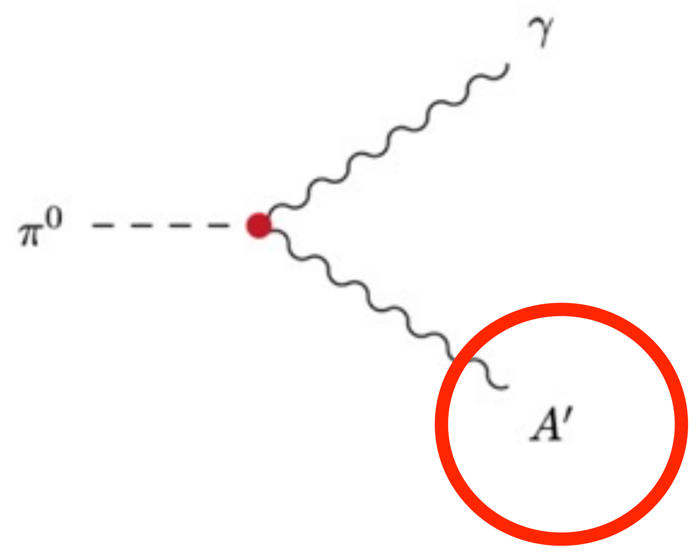
For new particle search:
Installation completed 2021 March

12

by H. Otono @ Kyoto seminar 2023

Motivated by dark matter

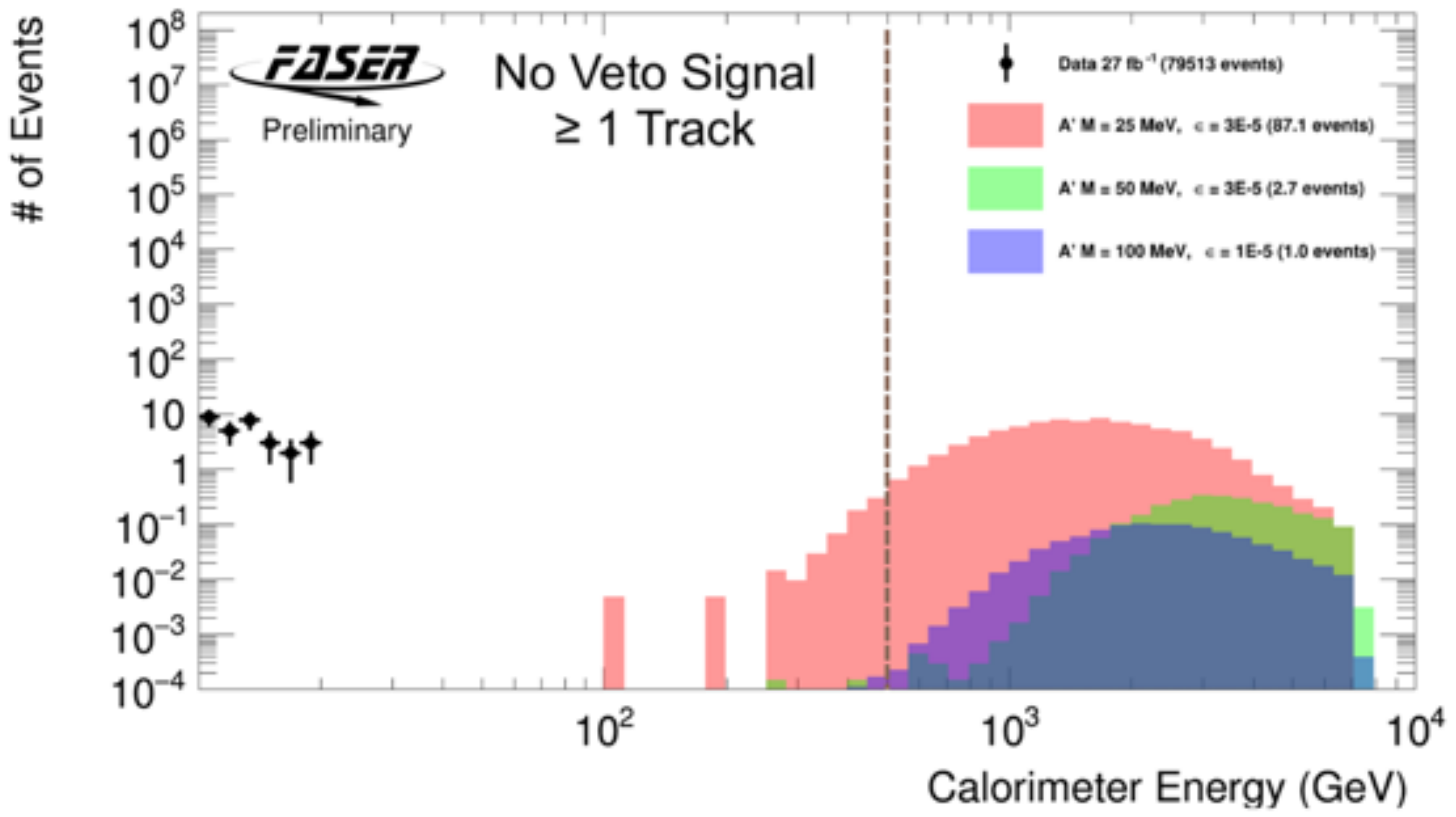
- Example is a dark photon (A') – vector portal to dark sector
- Could be produced very rarely in decay of a π^0
- Could be long-lived due to small coupling constant

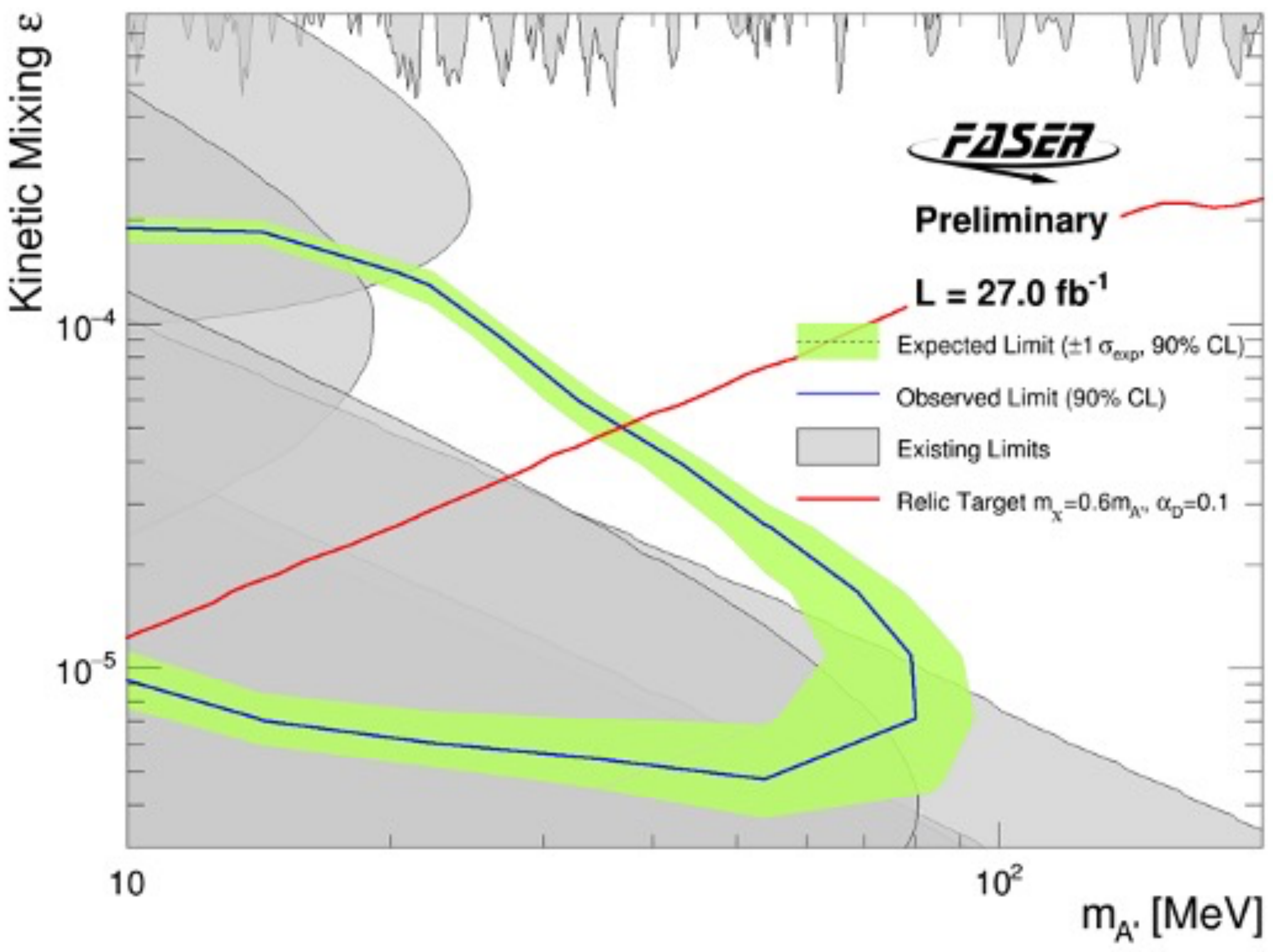


Source	Systematic Uncertainty	Typical Effect on Signal Yield
Theory, Statistics and Luminosity		
A' cross section	$\frac{0.15 + (E_{A'}/4\,\mathrm{TeV})^3}{1 + (E_{A'}/4\,\mathrm{TeV})^3}$	15-45%
Luminosity	2.2%	2.2%
MC statistics	$\sqrt{\sum W^2}$	1-2%
Tracking		
Momentum scale	5%	< 0.5%
Momentum resolution	5%	< 0.5%
1-track efficiency	3%	3%
2-track efficiency	15%	15%
Calorimetry		
Energy scale	6%	< 1%

No events seen in unblinded signal region

- Total background: **0.0020±0.0024 evts**,



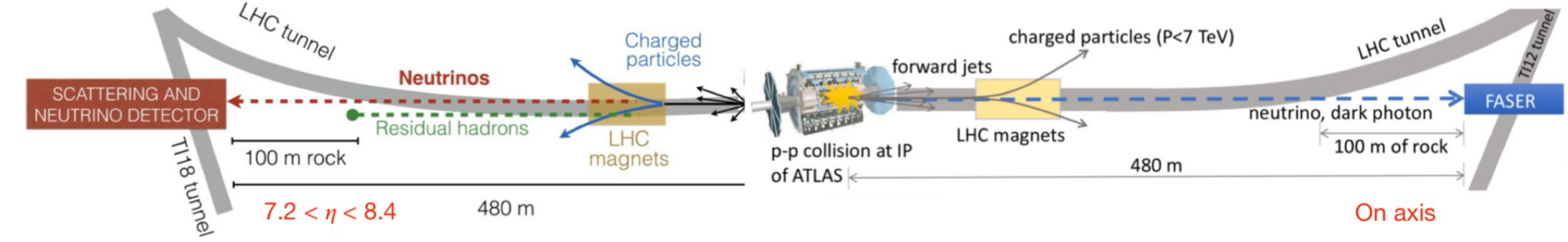


28

by H. Otono @ Kyoto seminar 2023

The birth of Collider Neutrinos (at the LHC)

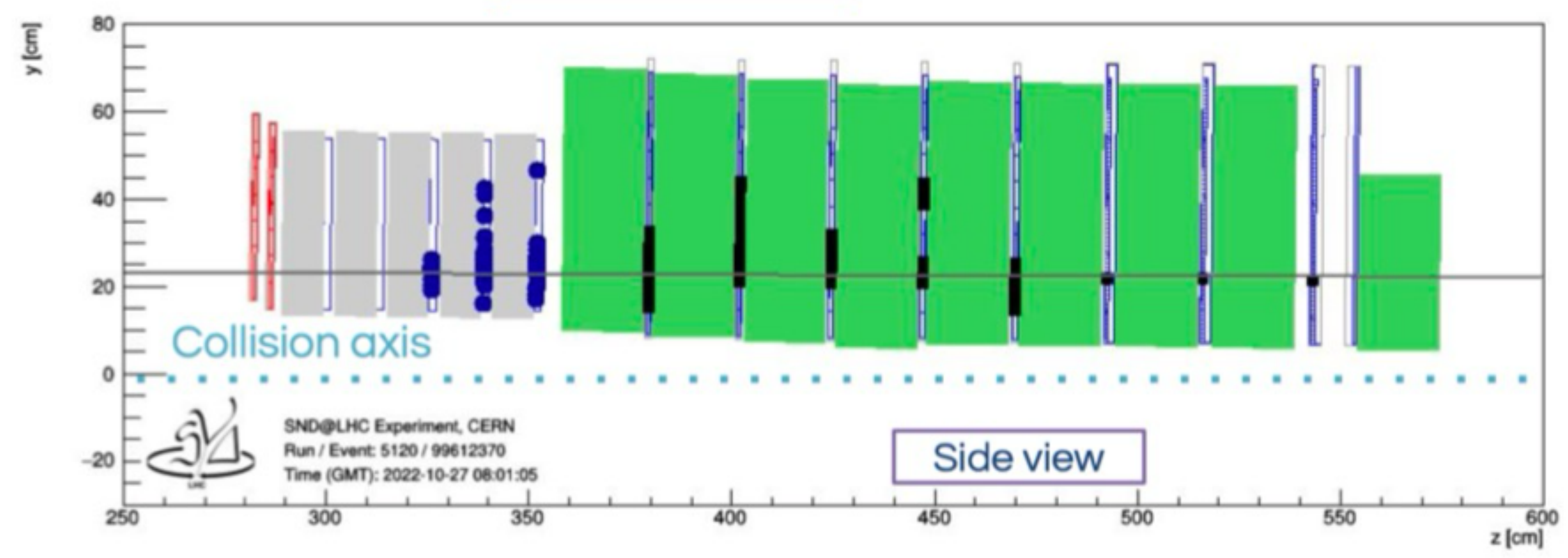
Ettore Zaffaroni — Brian Petersen — 19

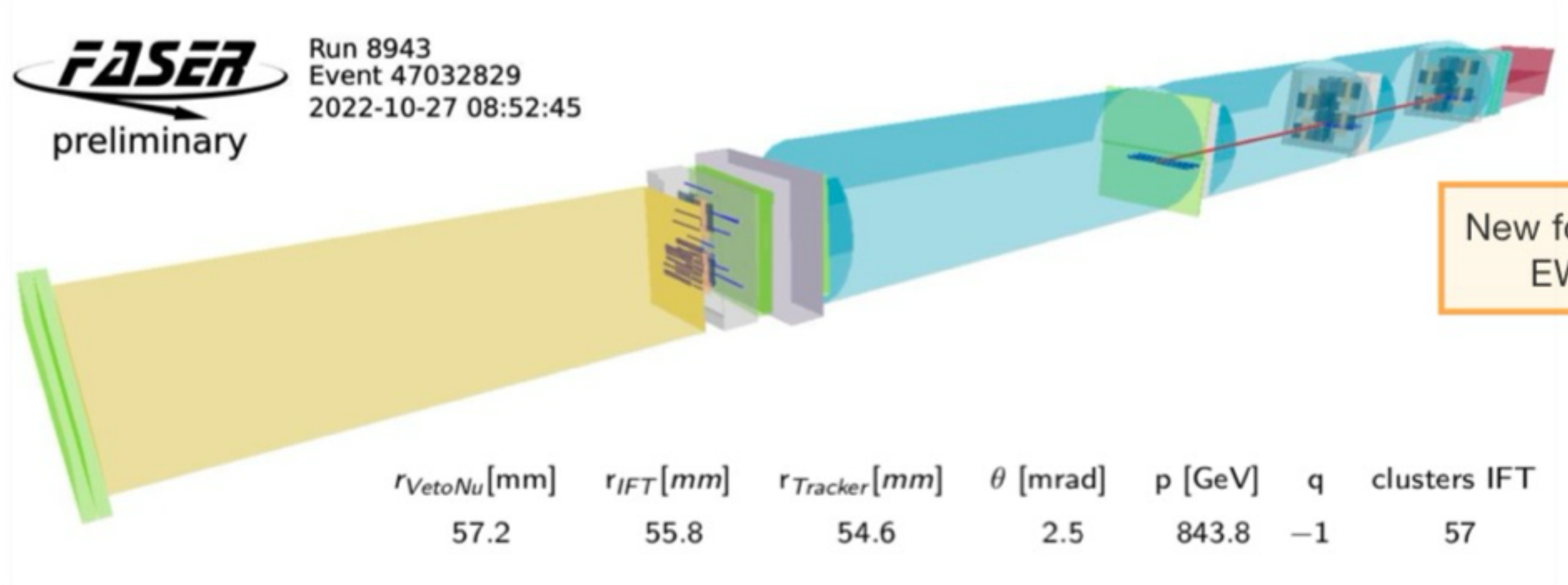


SND — New for Moriond EW 2023

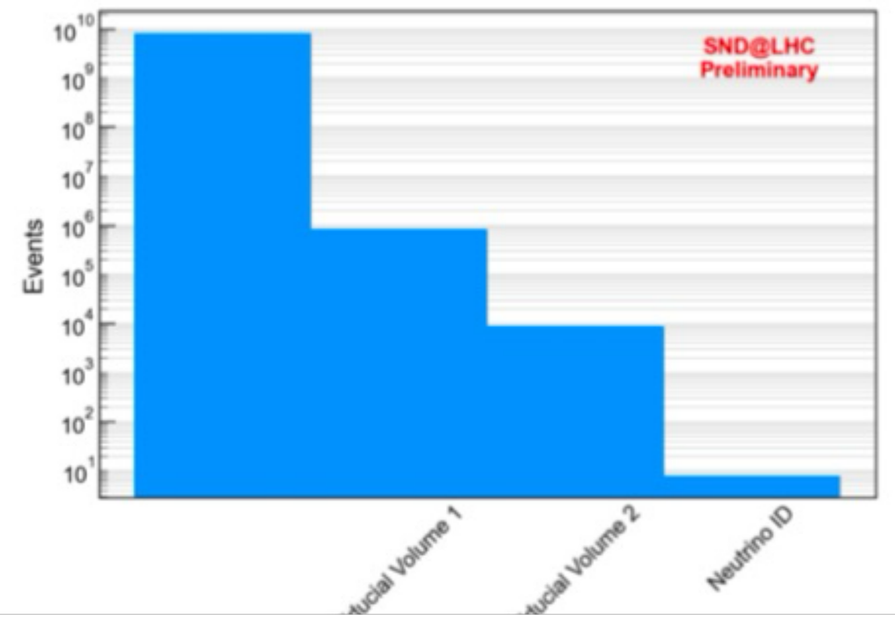
First results from SciFi/Silicon tracking devices

Faser-ν





New for Moriond EW 2023

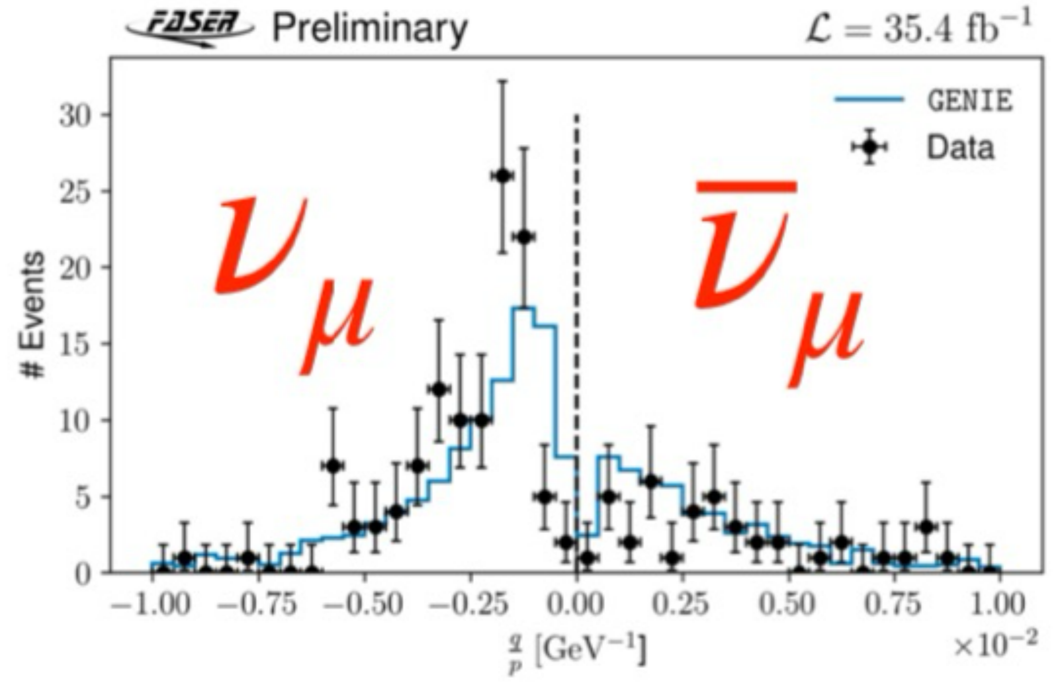


5 events expected and 8 observed (0.2 background)

Approximately 5σ observation!

150 events expected and 153 observed (0.2 background!!)

16σ observation!



by H. Otono @ Kyoto seminar 2023

3. Cosmic Frontier

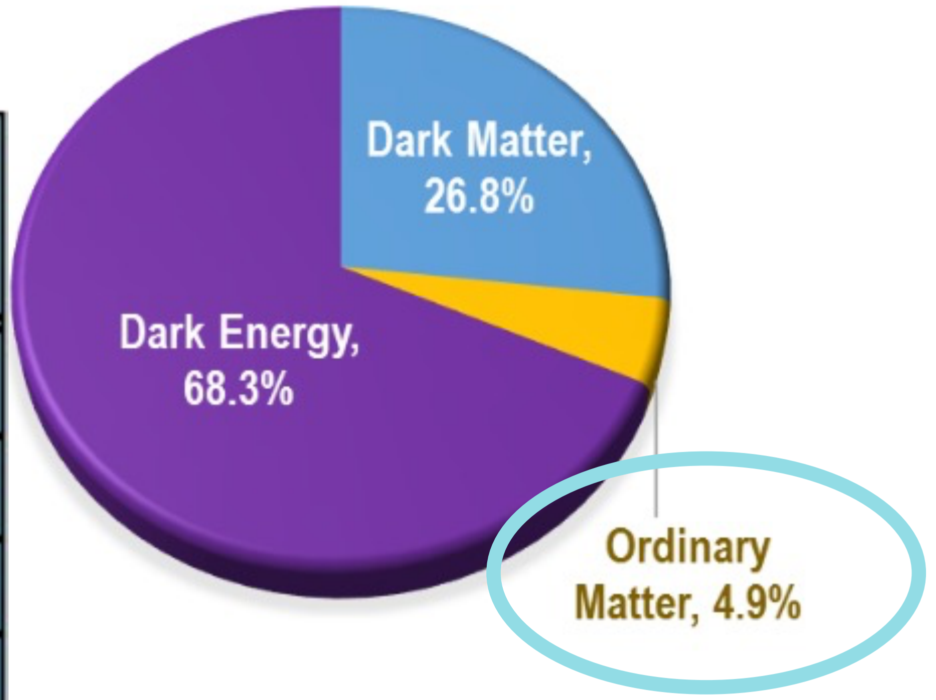
by H. Murayama @ 13th ICFA seminar

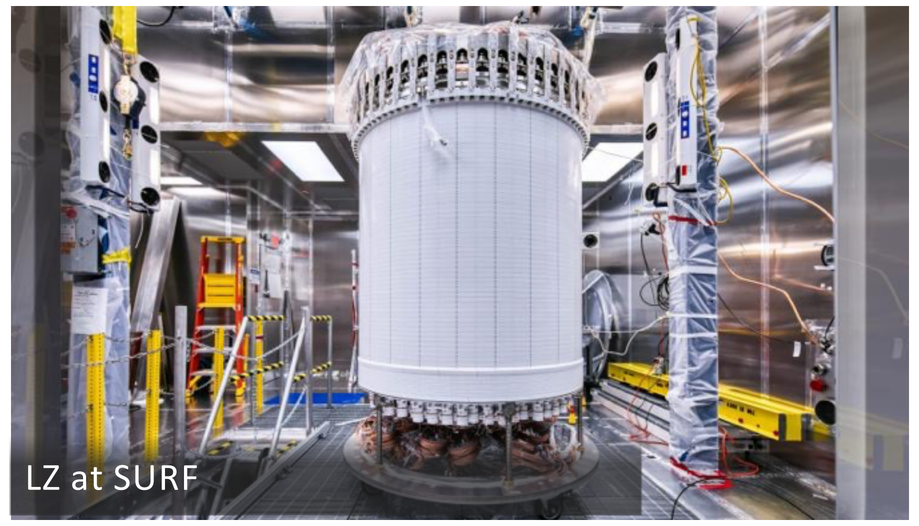
Dark Energy

Cosmic Frontier Experiments

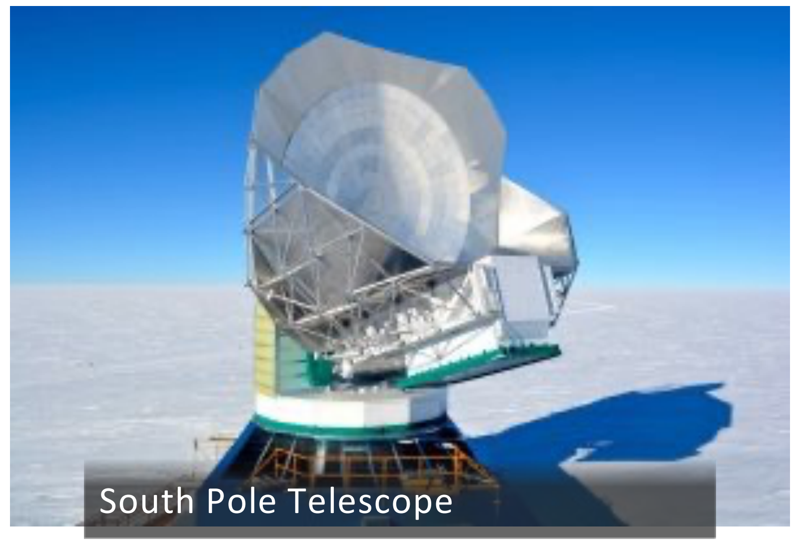
- **Cosmic Frontier experiments** address four of five science drivers
- They use naturally occurring sources to determine the fundamental nature of matter, energy, space and time.

	Energy Frontier	Intensity Frontier	Cosmic Frontier
Higgs Boson	●		
Neutrino Mass		●	●
Dark Matter	●	●	●
Cosmic Acceleration			●
Explore the Unknown	●	●	●

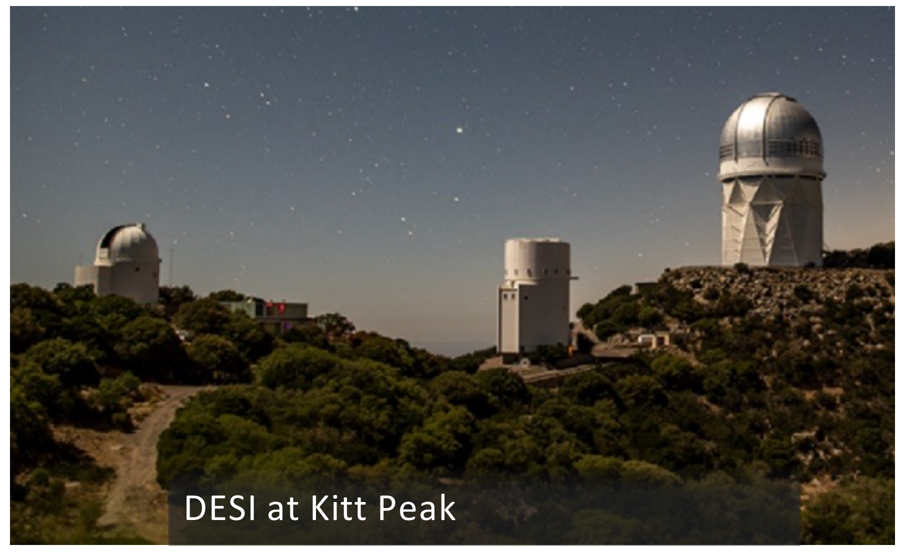



LZ at SURF


Legacy Survey of Space and Time at Vera Rubin Observatory


South Pole Telescope

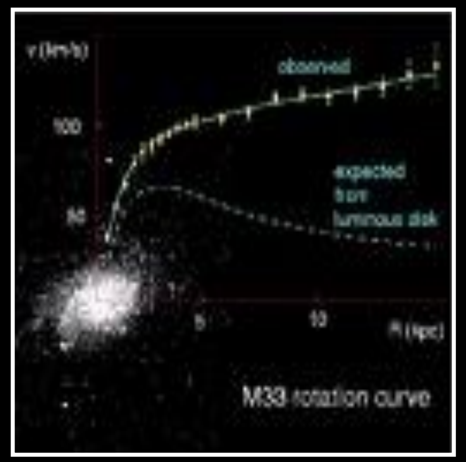

AMS at ISS


DESI at Kitt Peak

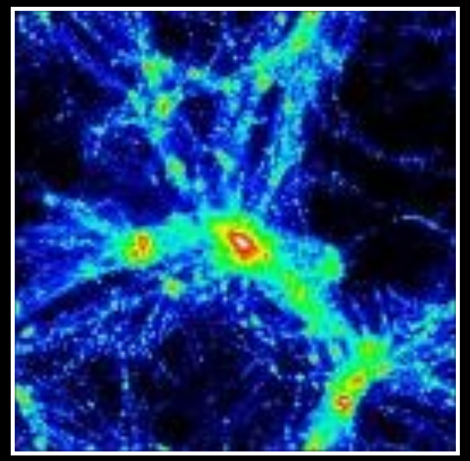
- Partnerships w/NSF (PHY, AST, OPP) NASA (AST, ISS, CLPS) are essential

Evidence of Dark Matter

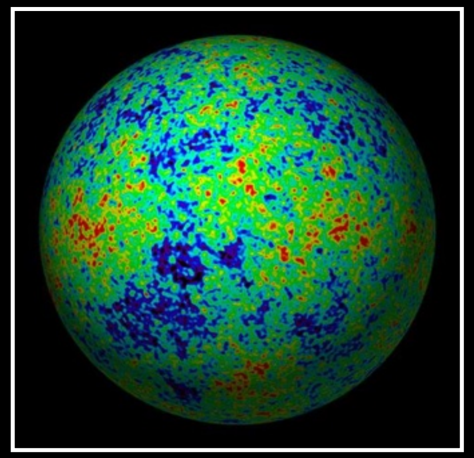
OBSERVATIONS



- Rotation Curves



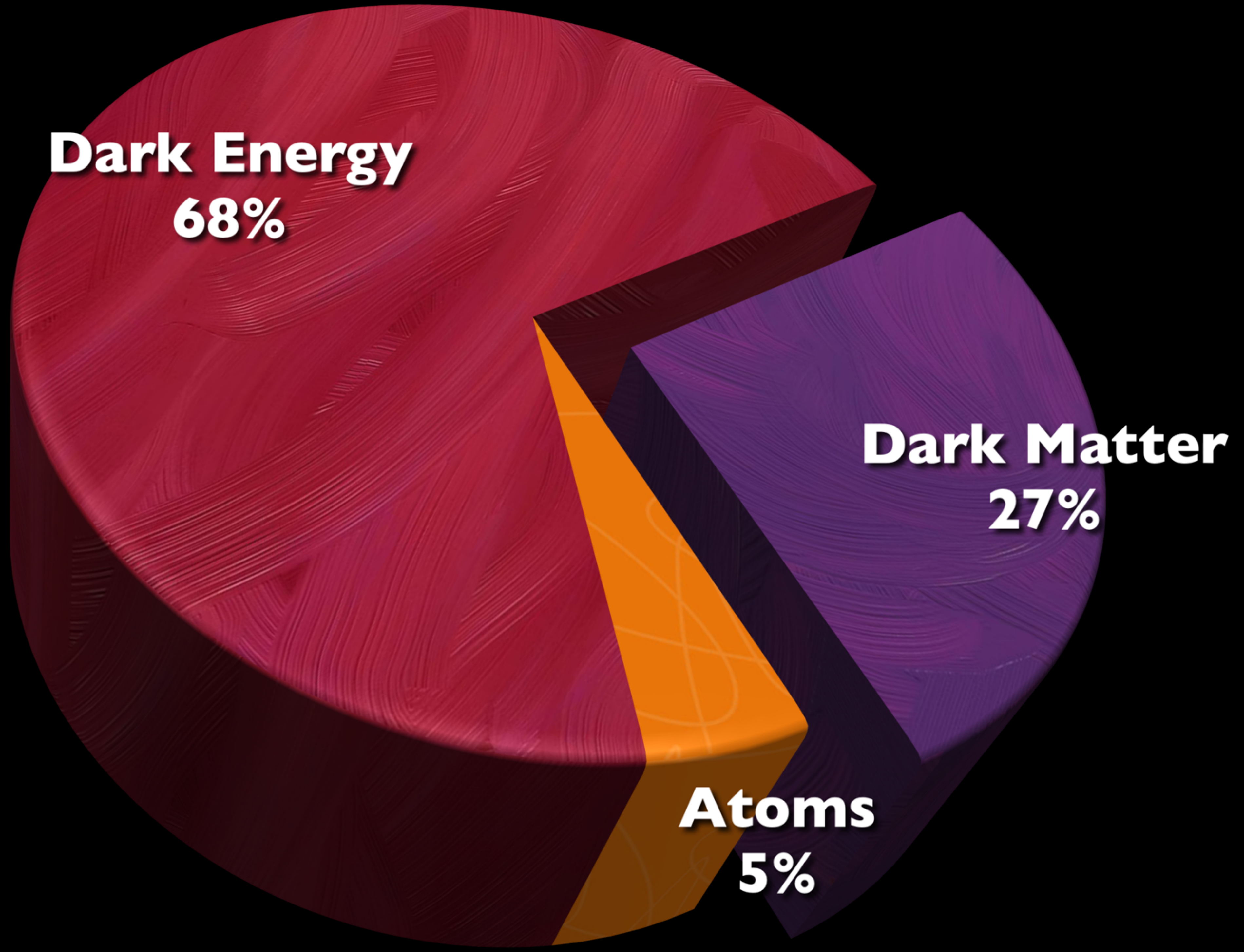
- Clusters of galaxies



- CMB

- Type Ia Supernovae

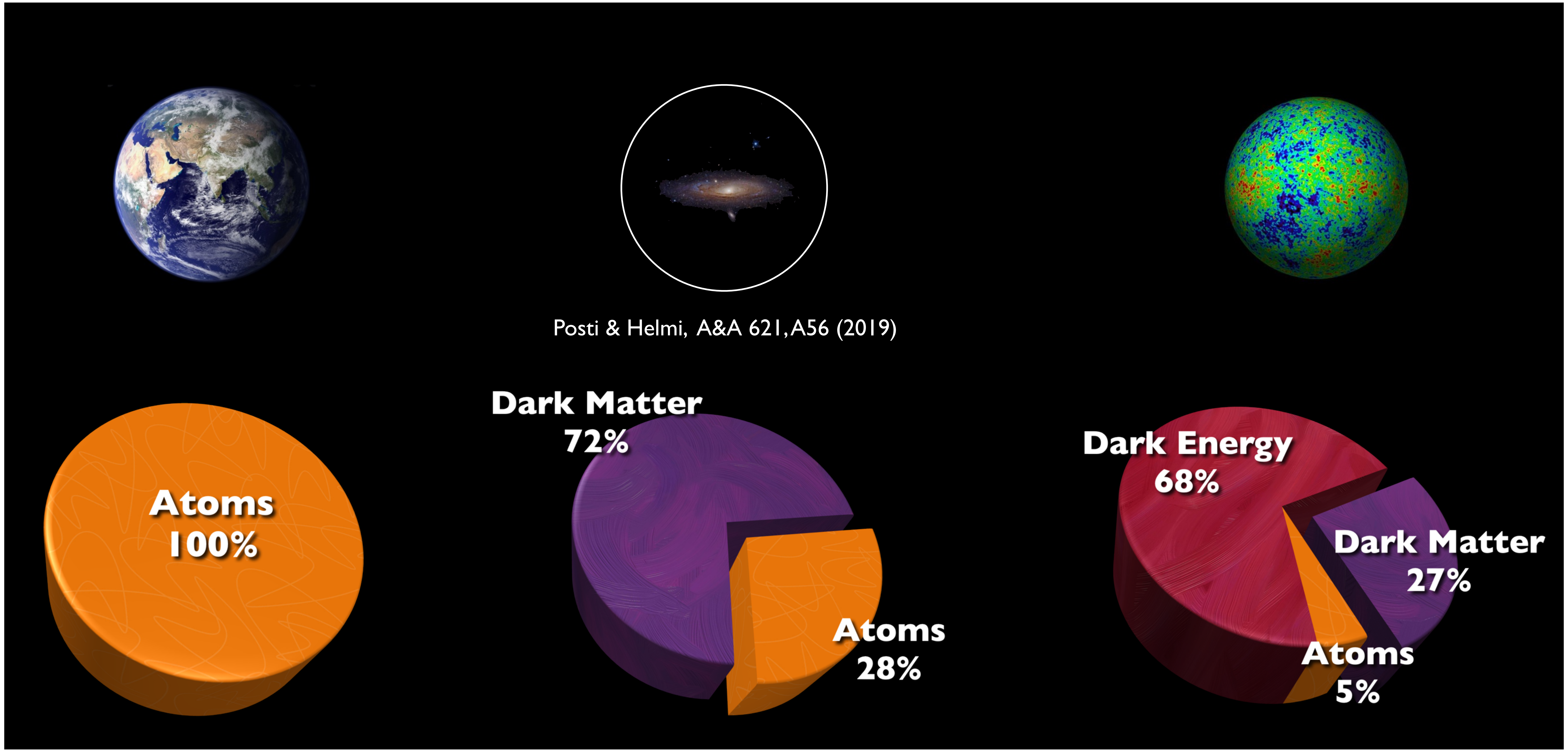
…



[statement valid *now*, and on *very large scales*]

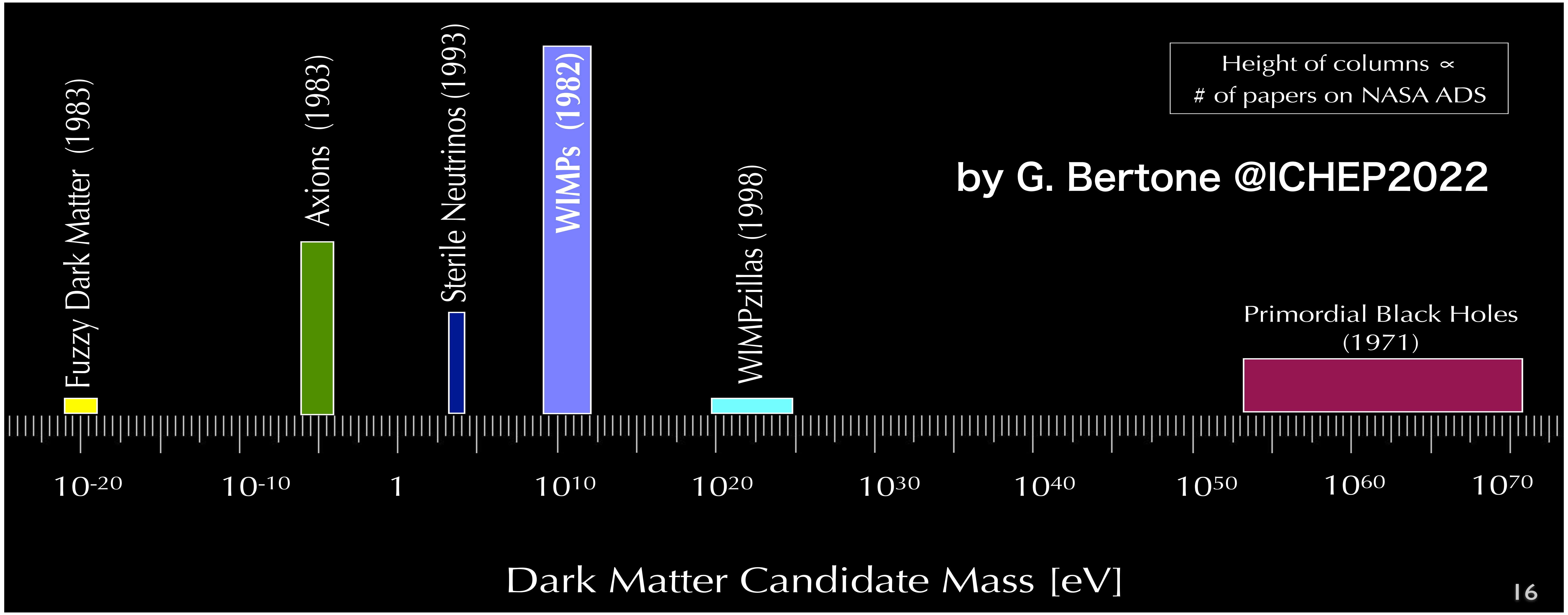
by G. Bertone @ICHEP2022

Where are the dark matters?



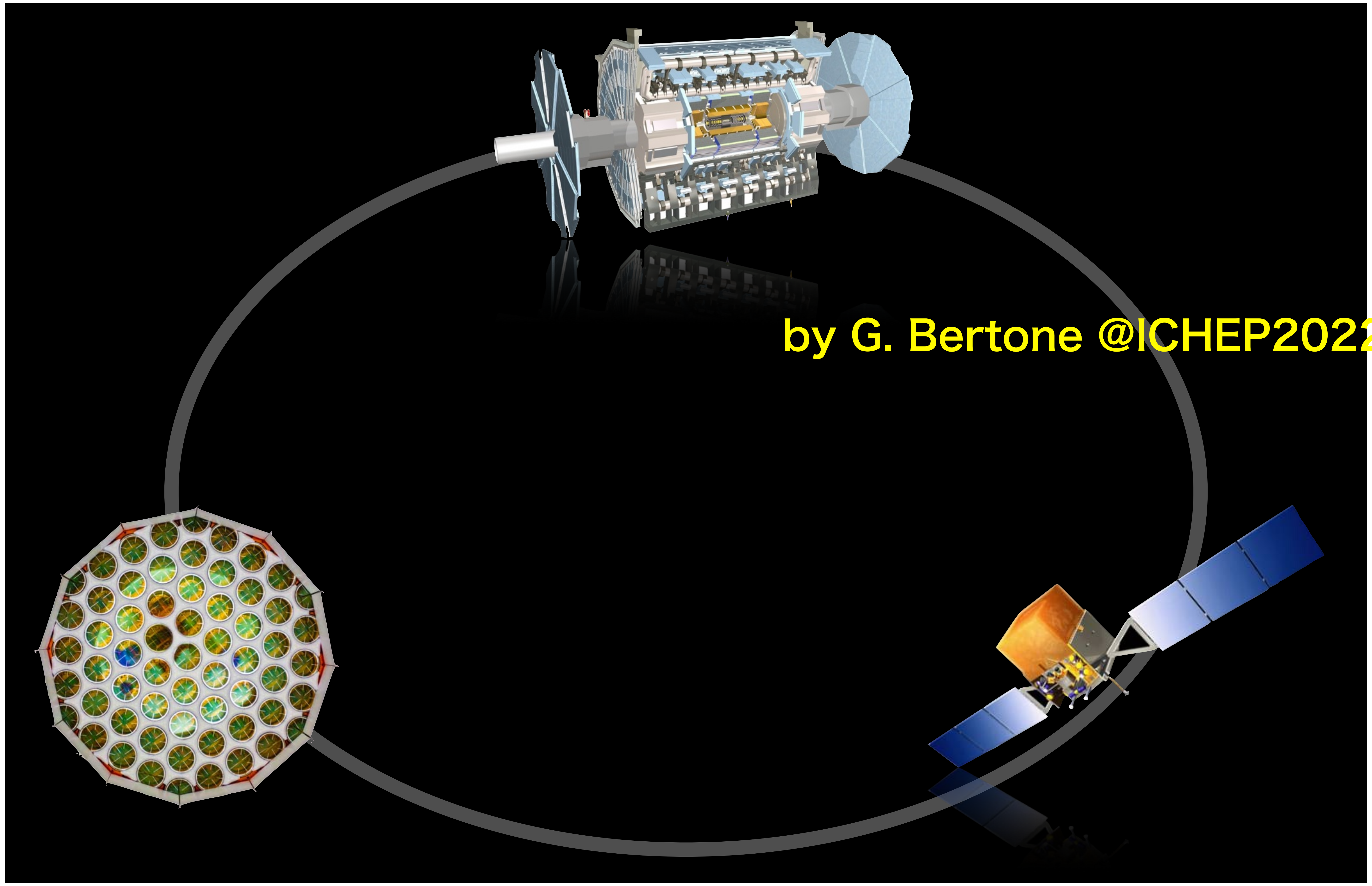
by G. Bertone @ICHEP2022

What are the dark matters?



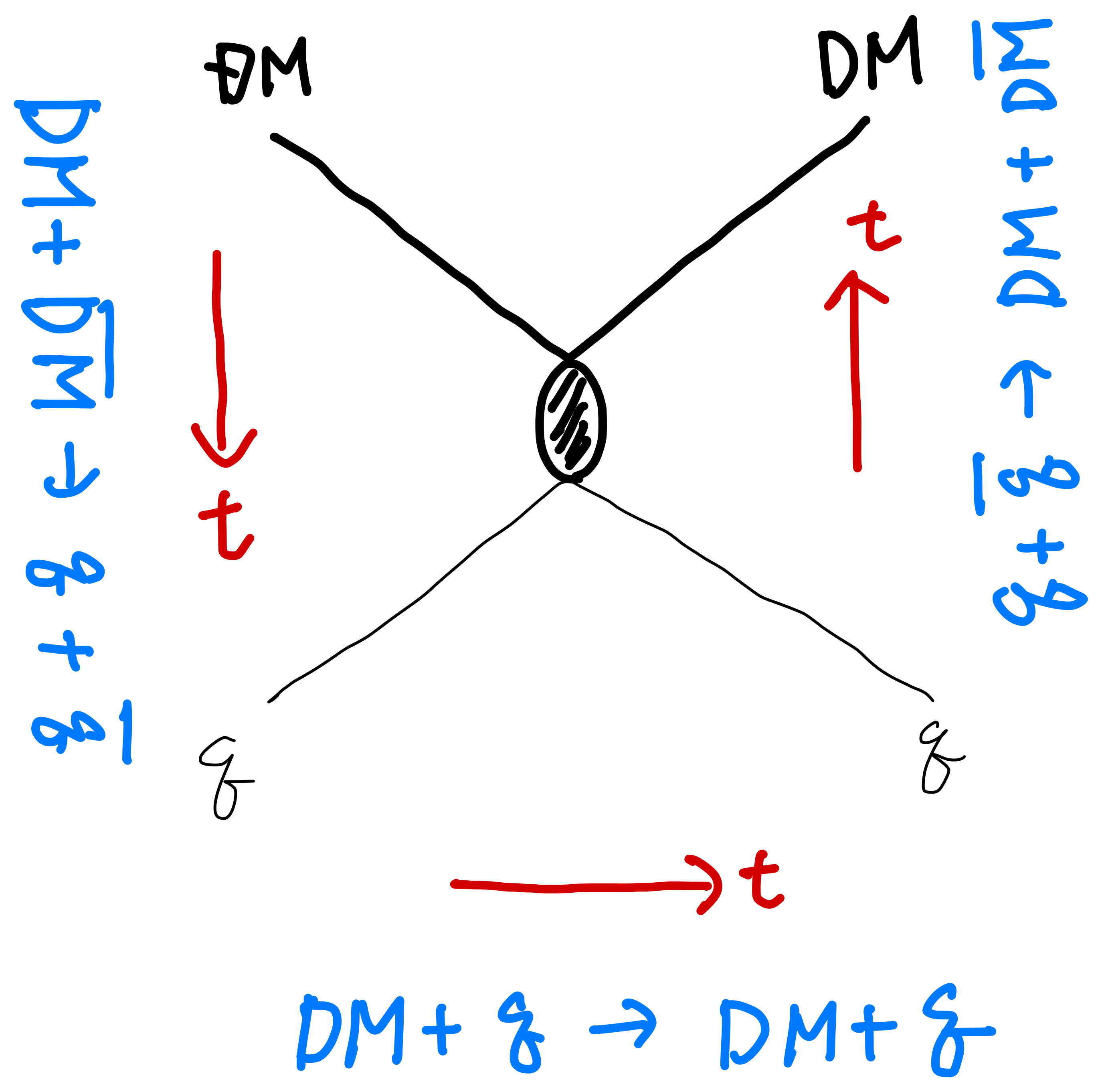
- Primordial Black Holes
- Weakly Interacting Massive Particles（WIMP)
- Sterile Neutrinos
- Axions
- others

How to find dark matters



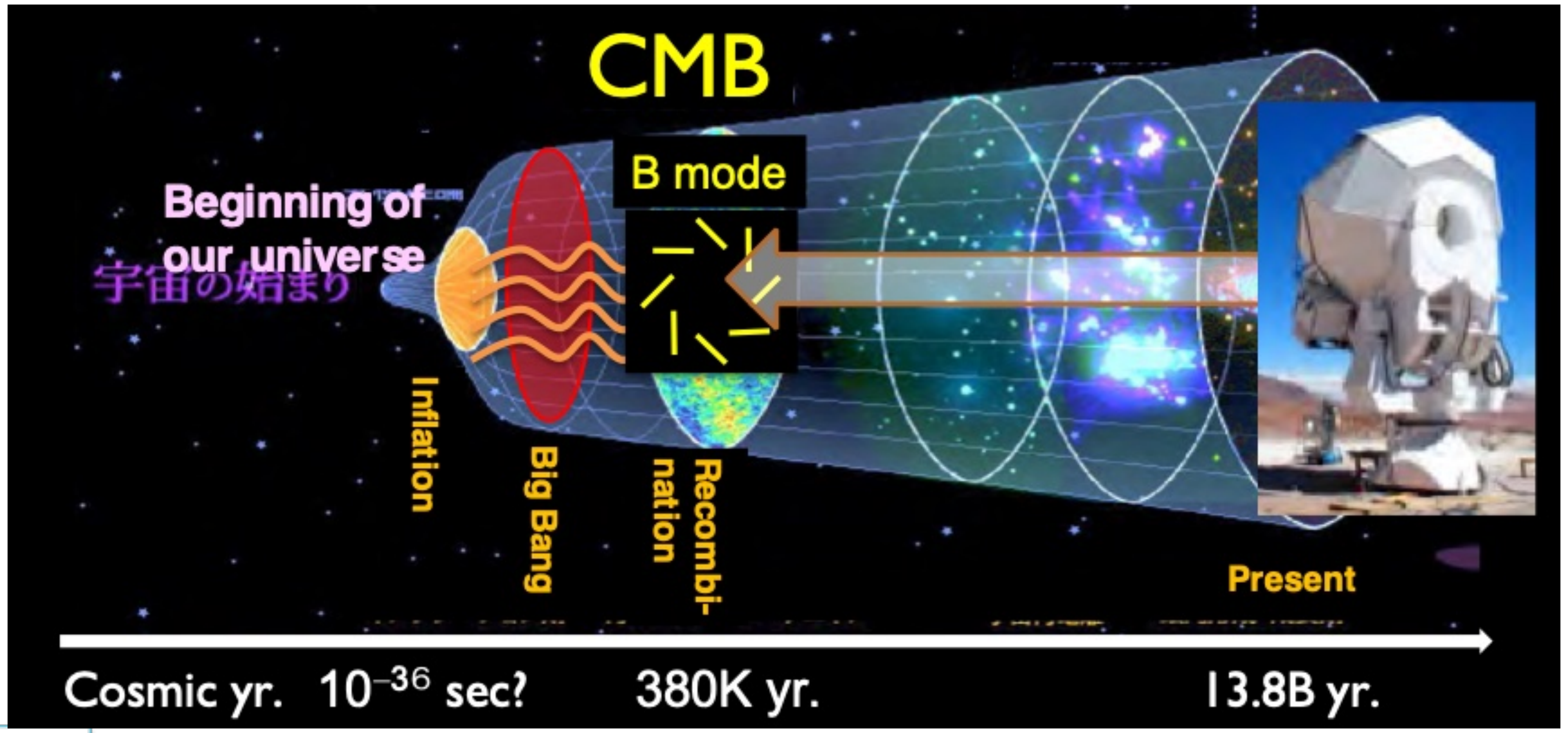
- produce them by accelerators
- look for them by underground experiments
- search for their annihilation signal by satellite and observatory

How to find dark matters

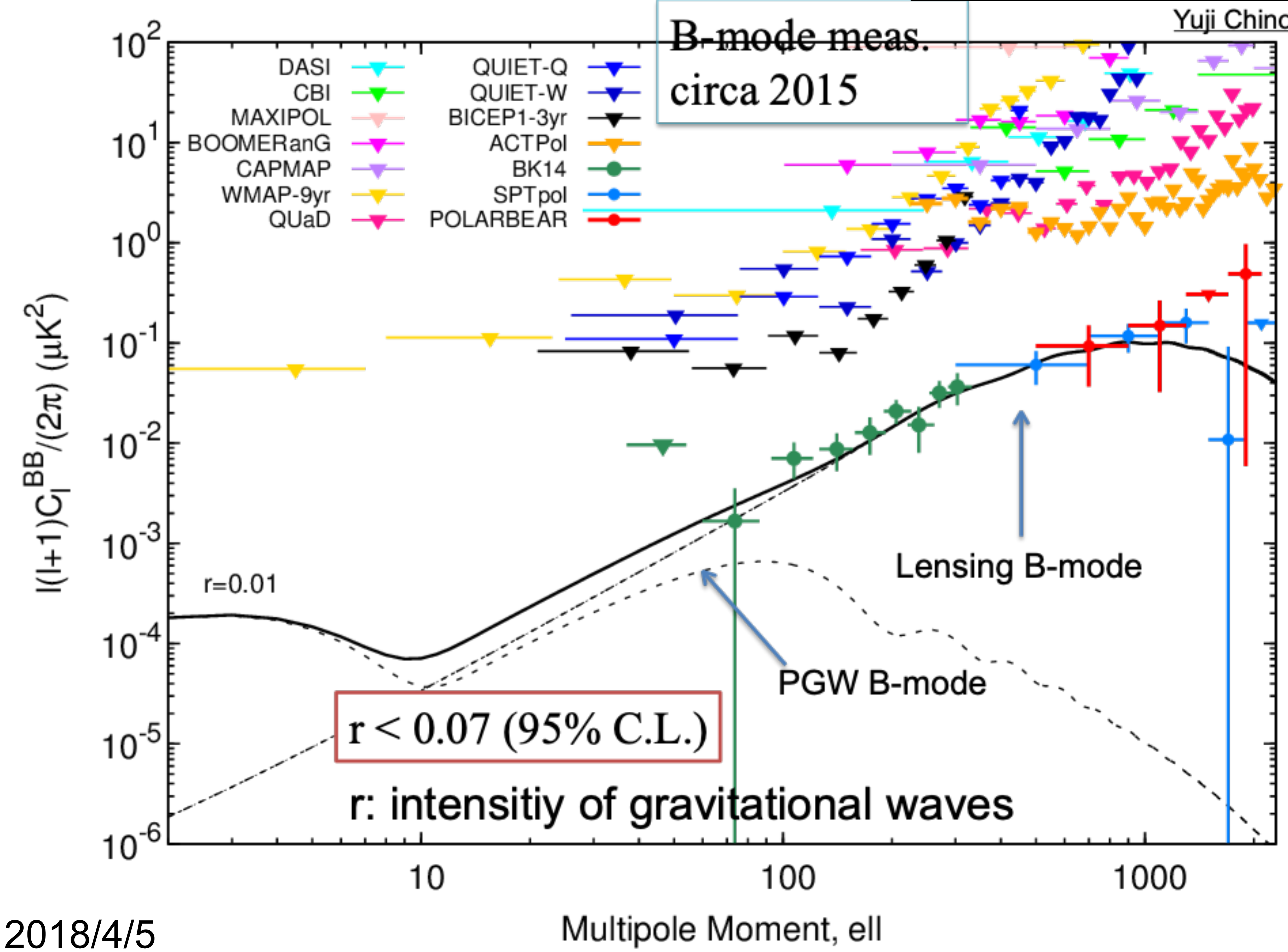


- produce them by accelerators
- look for them by underground experiments
- search for their annihilation signal by satellite and observatory

CMB



Yuji Chinone



It may be an interesting dark-horse.

Message to you

- There are many types of high energy experiments with various phases.
  - Large-scale international collaboration to small (medium?) size collaboration
  - Often long term projects with different phases
    - Ideas are generated
    - Construction phase
    - Initial data commissioning
    - Stable data taking
    - Analysis phase
    - Upgrade phase

- Please consider
  1. What type of physics are you most interested in?
  2. What kind of experiences would you like to havt?
  3. What problem will you want to tackle?
  4. Enjoy the experiment with your friends.

Trust your own senses as a scientist!

Summary of High Energy Experiments

I did not cover
- neutrino experiments
- future projects
- Specific Cosmic Frontier experiments
- new types of experiments using quantum technology

Bias towards experiments involving the Japanese HEP community