Quantum Observables for Collider Physics 2026

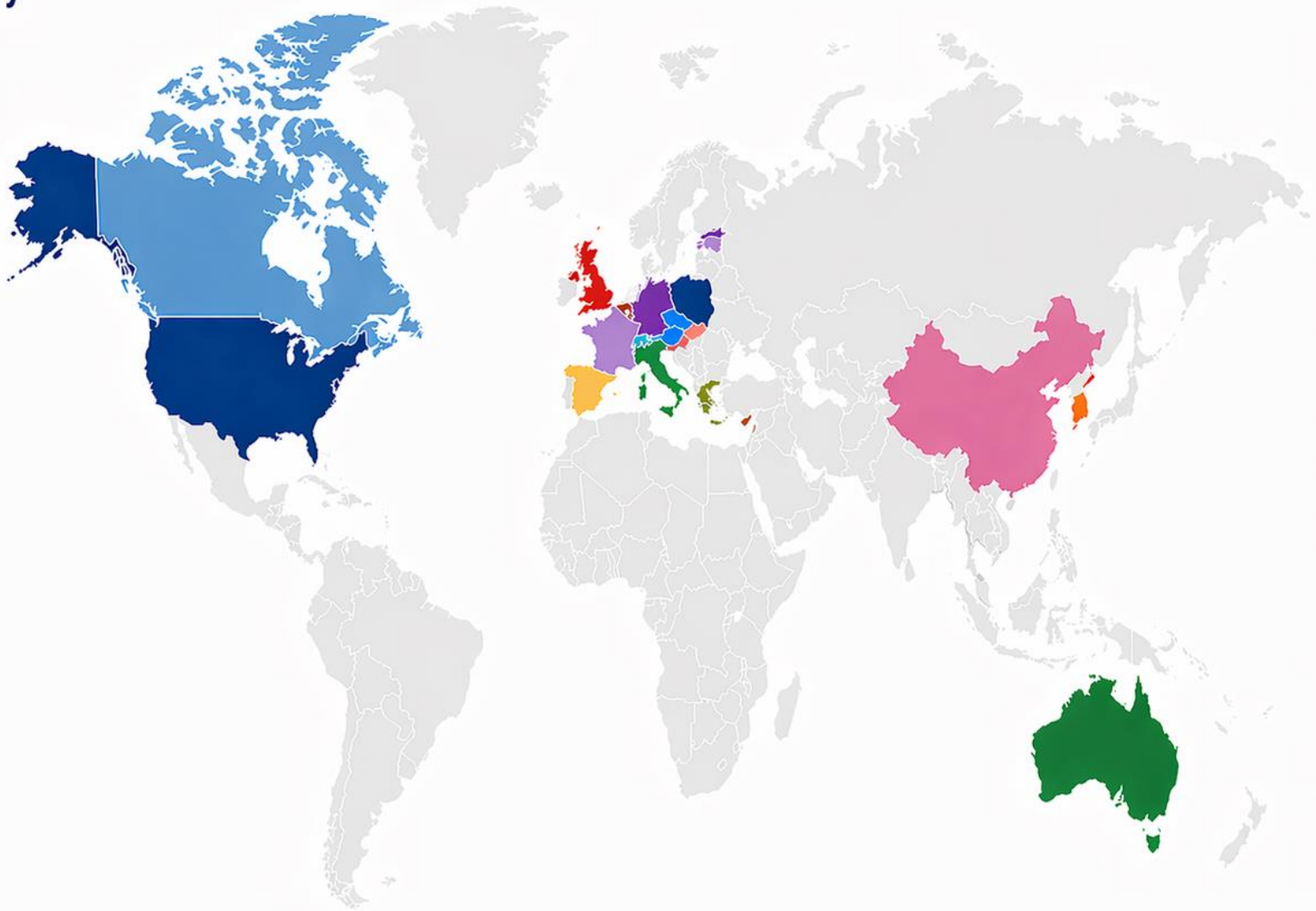
Image © CERN

Correlations and entanglement

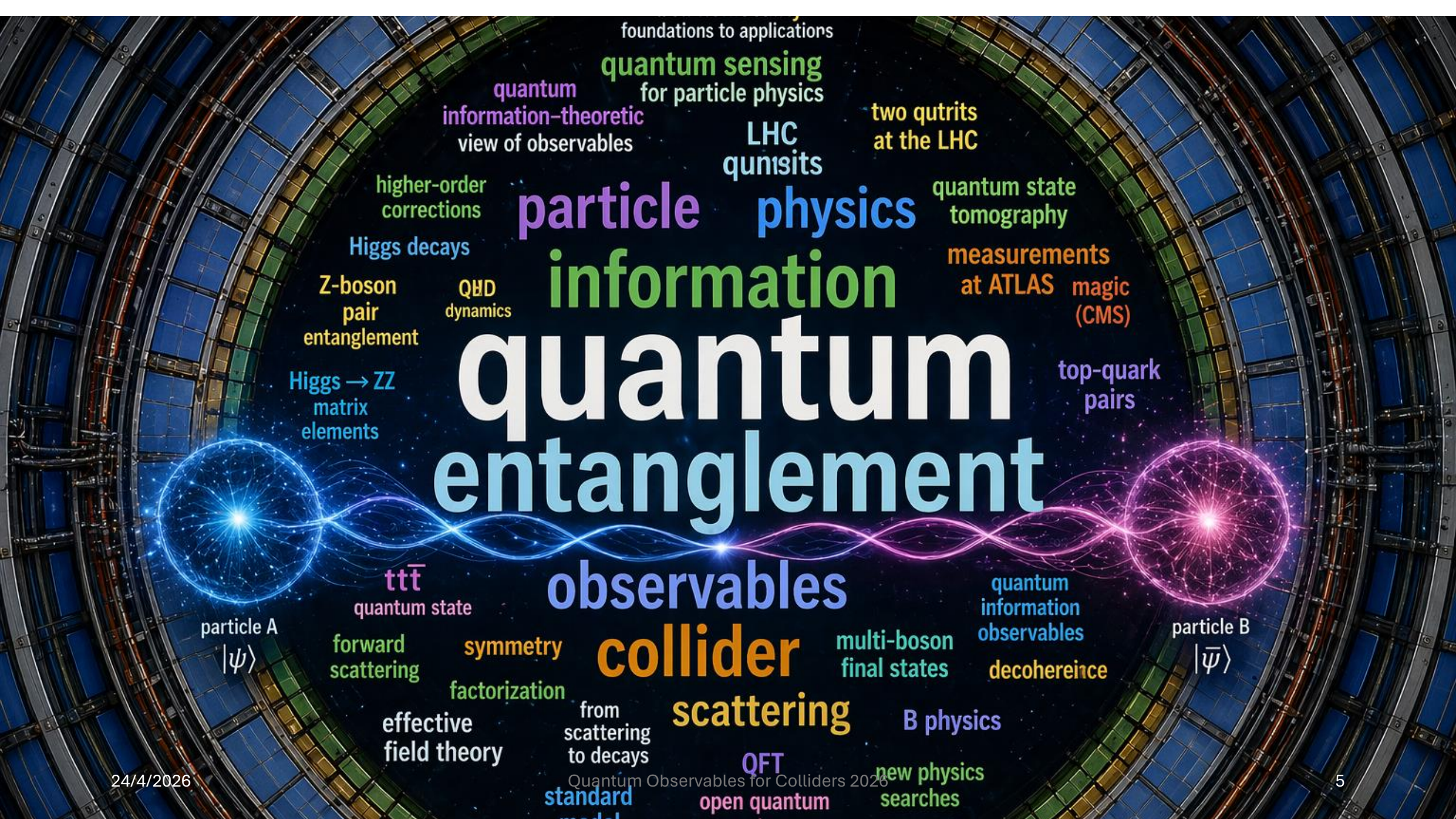
Participants by Country

(Total = 100)

United States	28
United Kingdom	11
South Korea	9
Germany	9
Italy	8
Switzerland	7
Spain	6
Poland	5
China	4
Belgium	3
Australia	2
France	1
Austria	1
Cyprus	1
Czechia	1
Estonia	1
Slovakia	1
Canada	1
Greece	1
TOTAL	**100**



Caveat...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quantum sensing
for particle physics
quantum
information–theoretic
view of observables
LHC
qunıits
two qutrits
at the LHC
higher-order
corrections
particle physics
quantum state
tomography
Higgs decays
information
measurements
at ATLAS
magic
(CMS)
Z-boson
pair
entanglement
QHD
dynamics
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Higgs → ZZ
matrix
elements
top-quark
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forward
scattering
symmetry
collider
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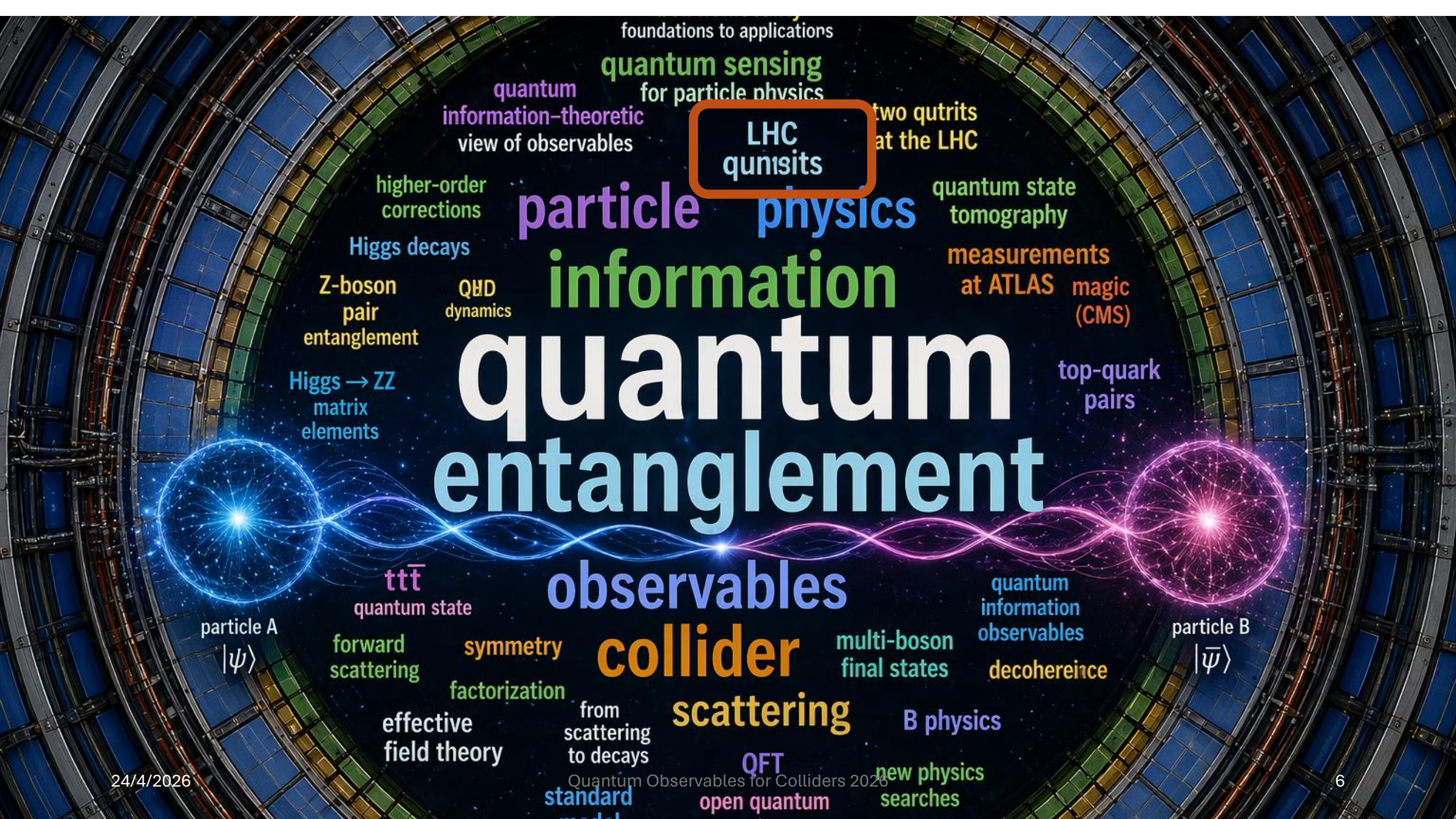
field theory
from
scattering
to decays
B physics
QFT
new physics
searches
standard
open quantum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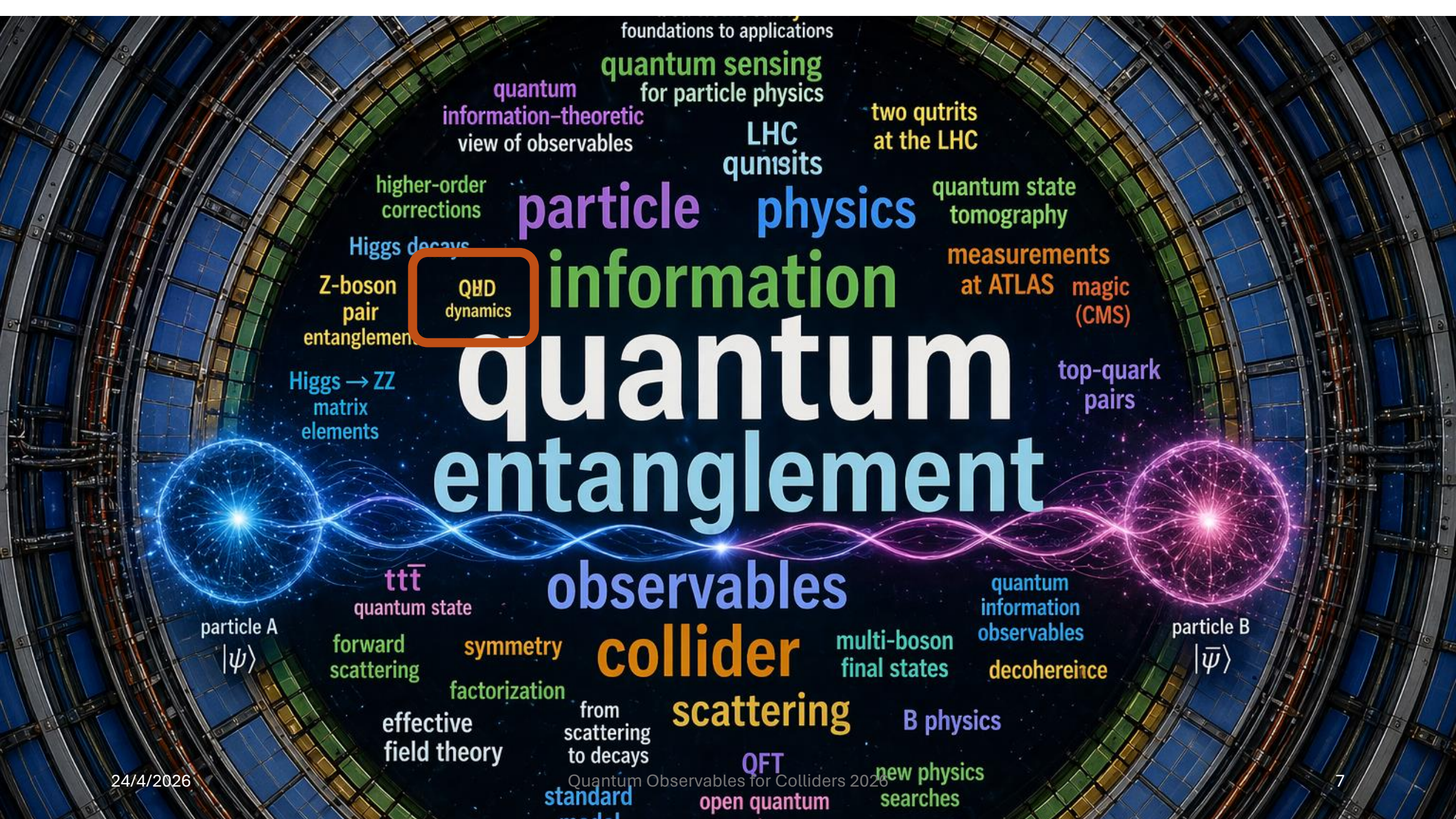
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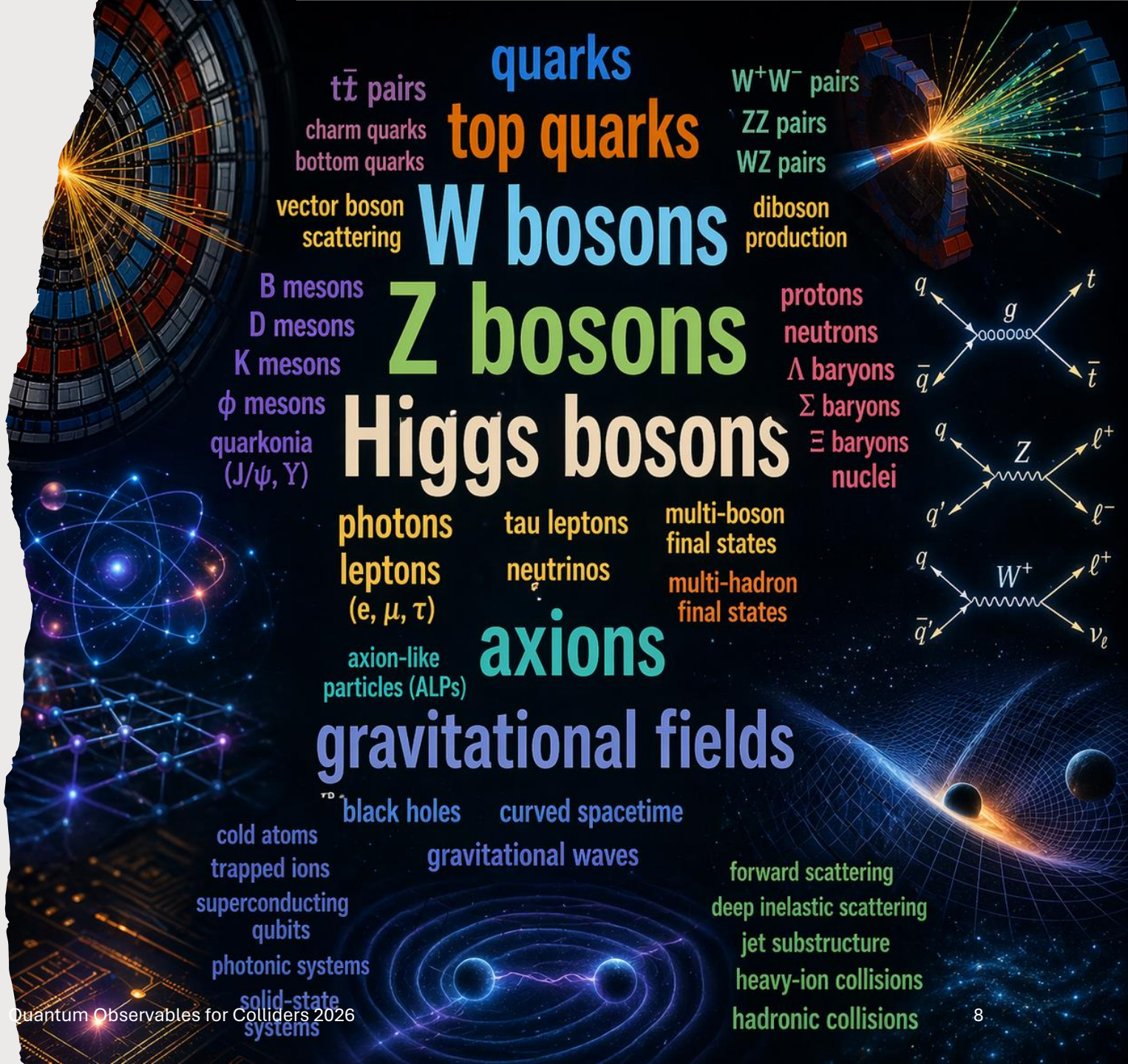
Quantum, quantum everywhere…



Flavour

Meson pair system

4 × 4 flavor density matrix:

$$\rho = \frac{a}{4}\left(\mathbb{1}_4 + b_i^{\mathcal{A}}\,\sigma_i \otimes \mathbb{1}_2 + b_i^{\mathcal{B}}\,\mathbb{1}_2 \otimes \sigma_i + C_{ij}\,\sigma_i \otimes \sigma_j\right)$$

Flavor correlation matrix

Observables:

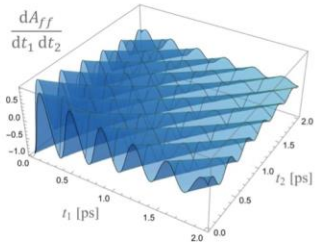
$$\frac{\mathrm{d}^2 N_{\mathrm{tot}}}{\mathrm{d}t_1 \mathrm{d}t_2} = N_0\, e^{-\Gamma(t_1+t_2)}\left(\mathrm{ch}_{t_1}\mathrm{ch}_{t_2} - \mathrm{ch}_{t_1}\mathrm{sh}_{t_2}\, b_x^{\mathcal{A}} - \mathrm{sh}_{t_1}\mathrm{ch}_{t_2}\, b_x^{\mathcal{B}} + \mathrm{sh}_{t_1}\mathrm{sh}_{t_2} C_{xx}\right)$$

$$\frac{\mathrm{d}^2 A_{ff}}{\mathrm{d}t_1 \mathrm{d}t_2} = N_0\, e^{-\Gamma(t_1+t_2)}\left(\mathrm{s}_{t_1}\mathrm{s}_{t_2} C_{yy} - \mathrm{c}_{t_1}\mathrm{s}_{t_2} C_{zy} - \mathrm{s}_{t_1}\mathrm{c}_{t_2} C_{yz} + \mathrm{c}_{t_1}\mathrm{c}_{t_2} C_{zz}\right)$$

$$\frac{\mathrm{d}^2 A_f^{\mathcal{A}}}{\mathrm{d}t_1 \mathrm{d}t_2} = N_0\, e^{-\Gamma(t_1+t_2)}\left(\mathrm{ch}_{t_2}(\mathrm{c}_{t_1}\, b_z^{\mathcal{A}} - \mathrm{s}_{t_1}\, b_y^{\mathcal{A}}) - \mathrm{sh}_{t_2}(\mathrm{c}_{t_1} C_{zx} - \mathrm{s}_{t_1} C_{yx})\right)$$

$$\frac{\mathrm{d}^2 A_f^{\mathcal{B}}}{\mathrm{d}t_1 \mathrm{d}t_2} = N_0\, e^{-\Gamma(t_1+t_2)}\left(\mathrm{ch}_{t_1}(\mathrm{c}_{t_2}\, b_z^{\mathcal{B}} - \mathrm{s}_{t_2}\, b_y^{\mathcal{B}}) - \mathrm{sh}_{t_1}(\mathrm{c}_{t_2} C_{xz} - \mathrm{s}_{t_2} C_{xy})\right)$$

$$\mathrm{c}/\mathrm{s}_t = \cos/\sin(\Delta m t)$$
$$\mathrm{ch}/\mathrm{sh}_t = \cosh/\sinh(\Delta\Gamma t/2)$$



Quantum state tomography

Arthur Wu

See also Sagar Hazra, Beatrix Hiesmayr

CP violation from Quantum state tomography

Decay	BR ($\times 10^{-2}$)	Asymmetry
$D^0 \to \pi^0\pi^0$	0.0826 ± 0.0025	$A_{CP}(\pi^0\pi^0) = 0.000 \pm 0.006$
$D^0 \to \pi^+\pi^-$	0.1453 ± 0.0024	$A_{CP}(\pi^+\pi^-) = 0.0013 \pm 0.0014$
$D^0 \to K_S^0 K_S^0$	0.0141 ± 0.0005	$A_{CP}(K_S^0 K_S^0) = -0.011 \pm 0.019$
$D^0 \to K^+K^-$	0.408 ± 0.006	$A_{CP}(K^+K^-) = (4 \pm 5) \times 10^{-4}$
$D^0 \to \pi^0 K_S^0$	1.240 ± 0.022	$A_{CP}(\pi^0 K_S^0) = -0.0020 \pm 0.0017$
$D^0 \to \pi^+K^-$	3.945 ± 0.03	$A_{CP}(\pi^+K^-) = 0.002 \pm 0.005$
$D^0 \to \pi^-K^+$	0.0150 ± 0.0007	$A_{CP}(\pi^-K^+) = -0.009 \pm 0.014$
$D^0 \to K_S^0\eta$	0.434 ± 0.016	$A_{CP}(K_S^0\eta) = 0.005 \pm 0.005$
$D^0 \to \eta\eta$	0.211 ± 0.019	–

Emidio Gabrielli

$$|i\rangle = \frac{1}{\sqrt{2}}\left[\left|K^0\right\rangle\left|\overline{K}^0\right\rangle - \left|\overline{K}^0\right\rangle\left|K^0\right\rangle\right]$$

$\zeta_{0\bar{0}} = (-0.5$

$\zeta_{SL} = (0.1 \pm$

$\gamma = (1.3 \pm 9.4_{stat} \pm 4.2_{syst})\times 10^{-22}$ GeV

$\Re\omega = \left(-2.3^{+1.9}_{-1.5 stat} \pm 0.6_{syst}\right)\times 10^{-4}$

$\Im\omega = (-4.1^{+2.8}_{-2.6 stat} \pm 0.9_{syst})\times 10^{-4}$

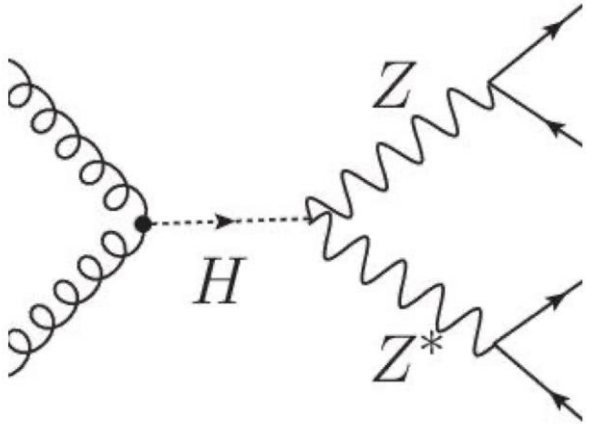
$|\omega| = (4.7 \pm 2.9_{stat} \pm 1.0_{syst})\times 10^{-4}$

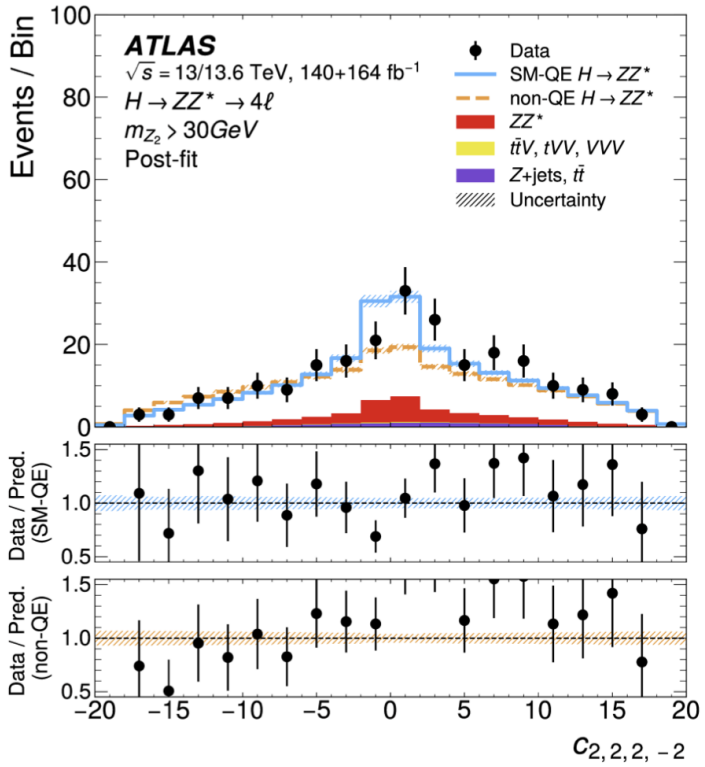
$\phi_\omega = -2.1 \pm 0.2_{stat} \pm 0.1_{syst}$ rad

Limits on decoherence

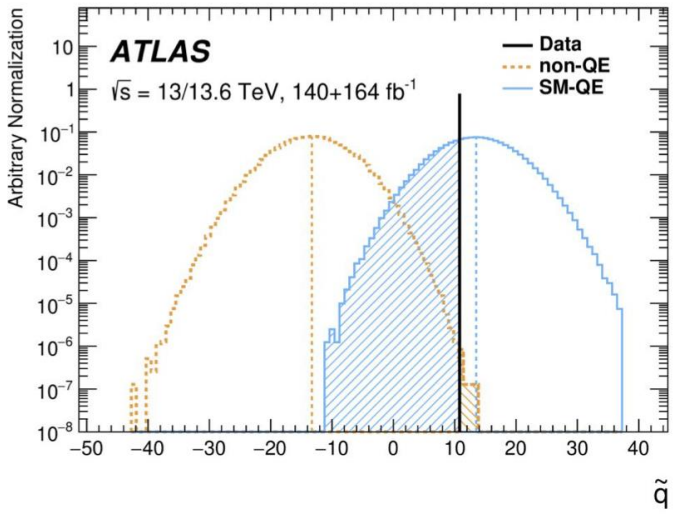
Antonio Di Domenico

New experimental results - LHC

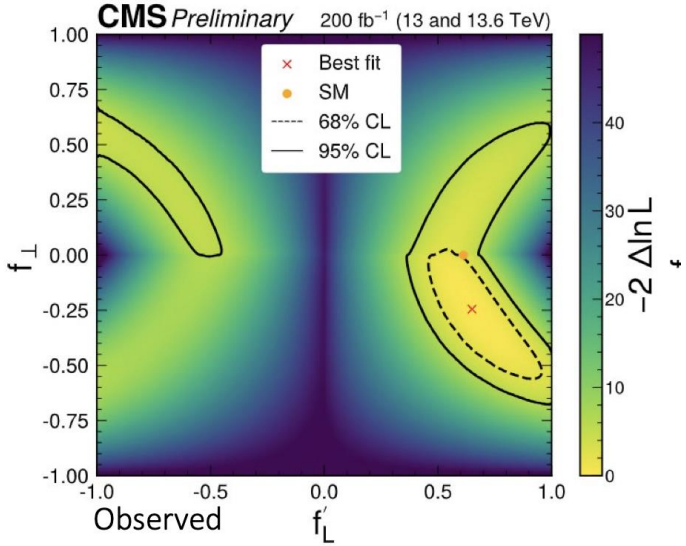




Observed (expected) significance for c222-2: **4.7σ (4.9σ)**



Tairan Xu



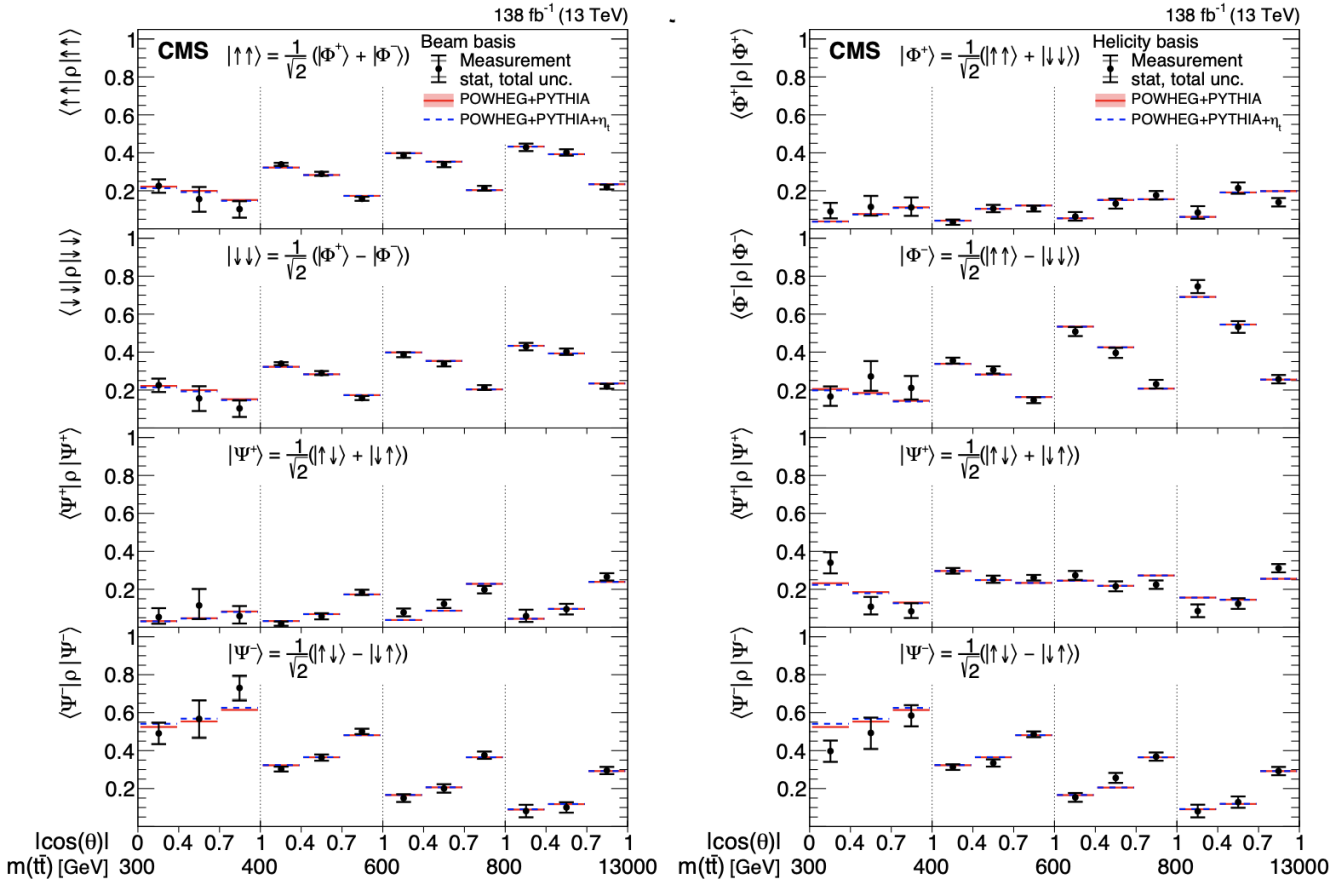
$$f_L = f_L'(1 - f_\perp)$$

Jeffrey Davis

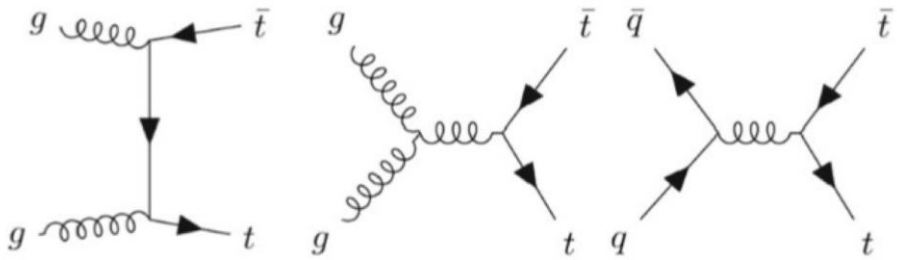
See also caveats from Alberto Navarro, Giovanni Pelliccioli

Spin in Tops

$$\rho = \frac{1}{4}(\mathbb{1}_4 + \sum P_i \sigma_i \otimes \mathbb{1}_2 + \sum \bar{P}_j \mathbb{1}_2 \otimes \sigma_j + \sum C_{ij} \sigma_i \otimes \sigma_j)$$

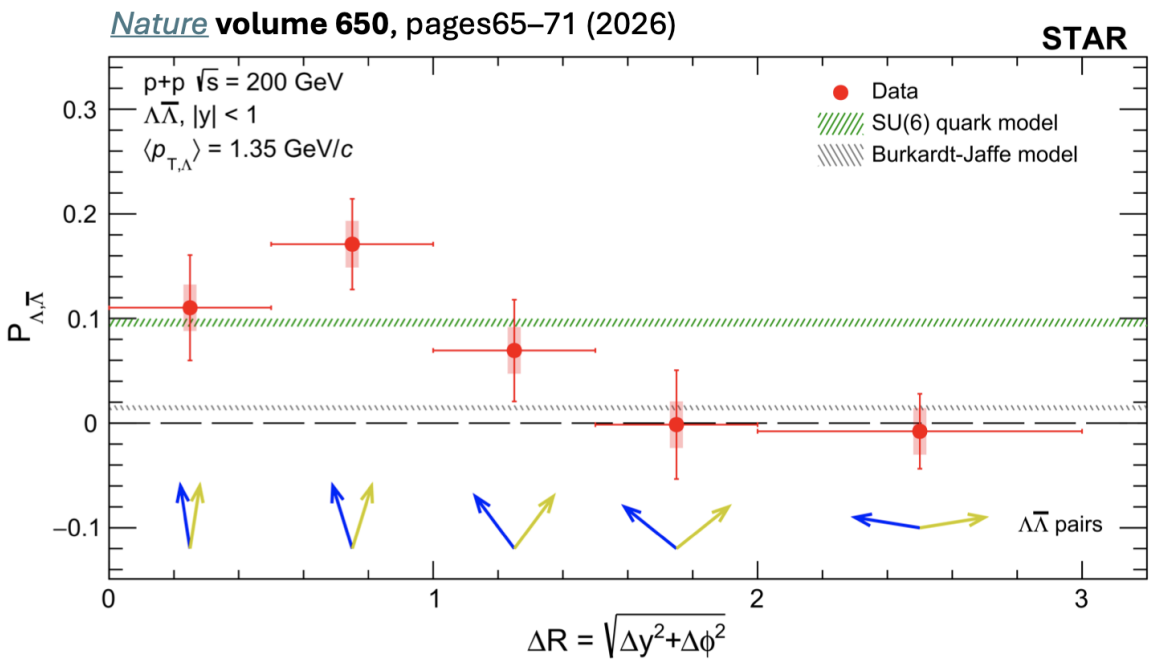


Otto Hindrichs

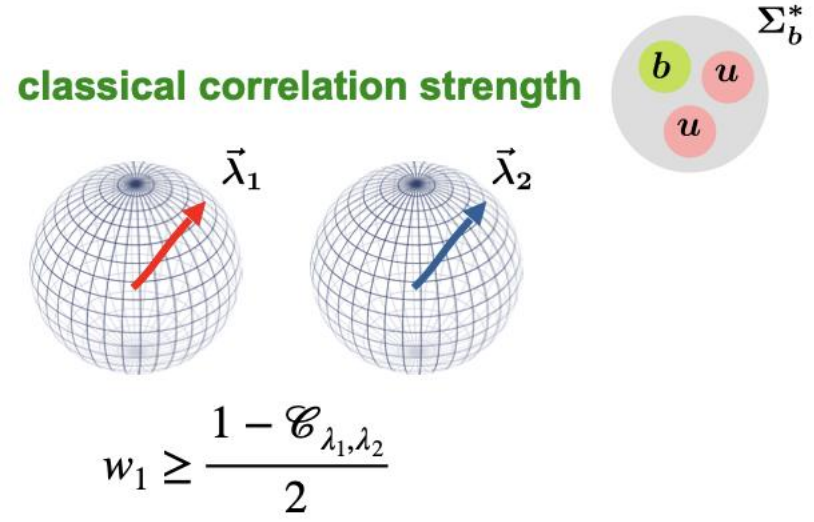


See also Dong Woo Kang, Fiona Jolly

Spin in hadrons



Kong Tu

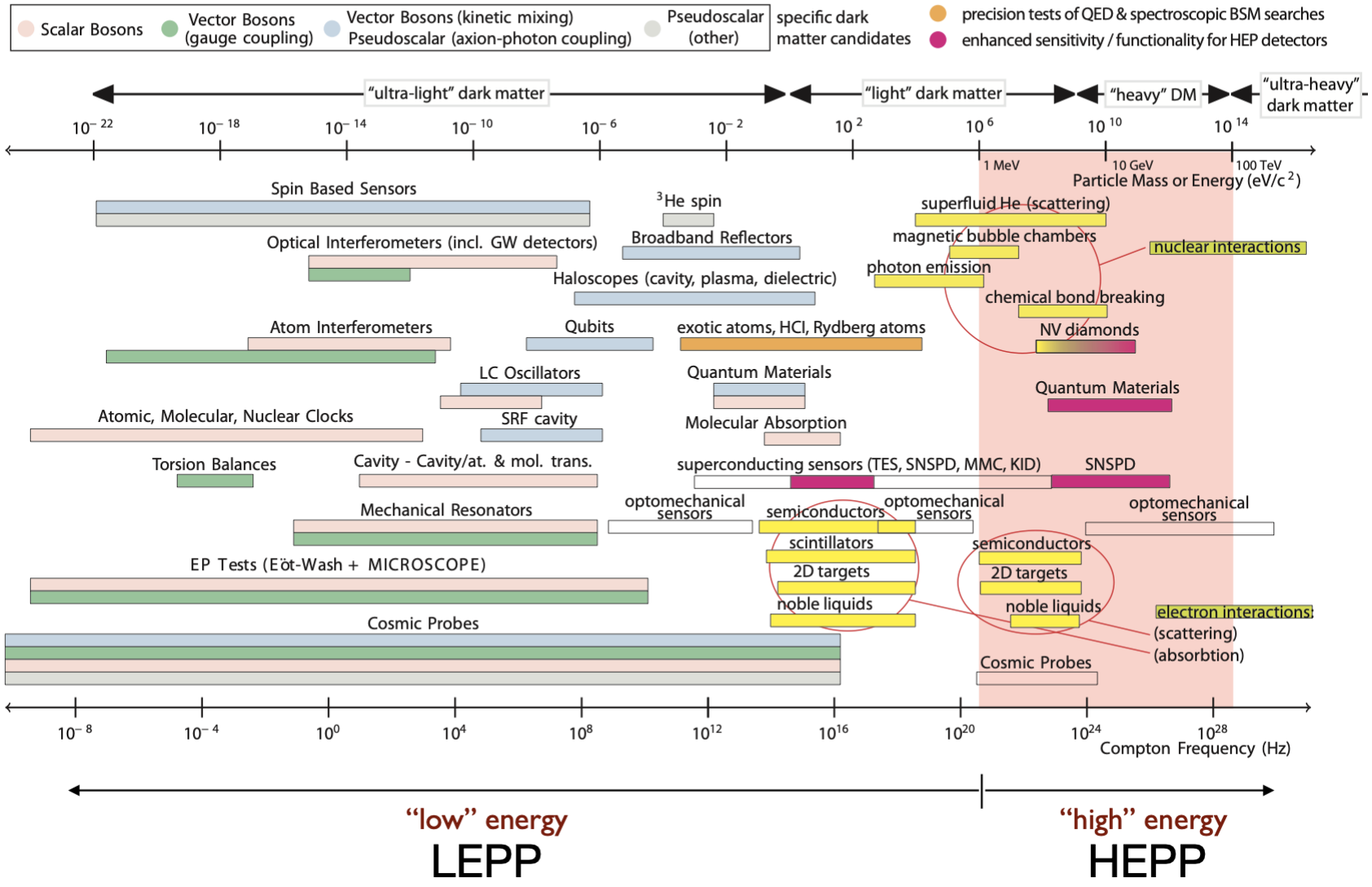


Rebecca von Kuk

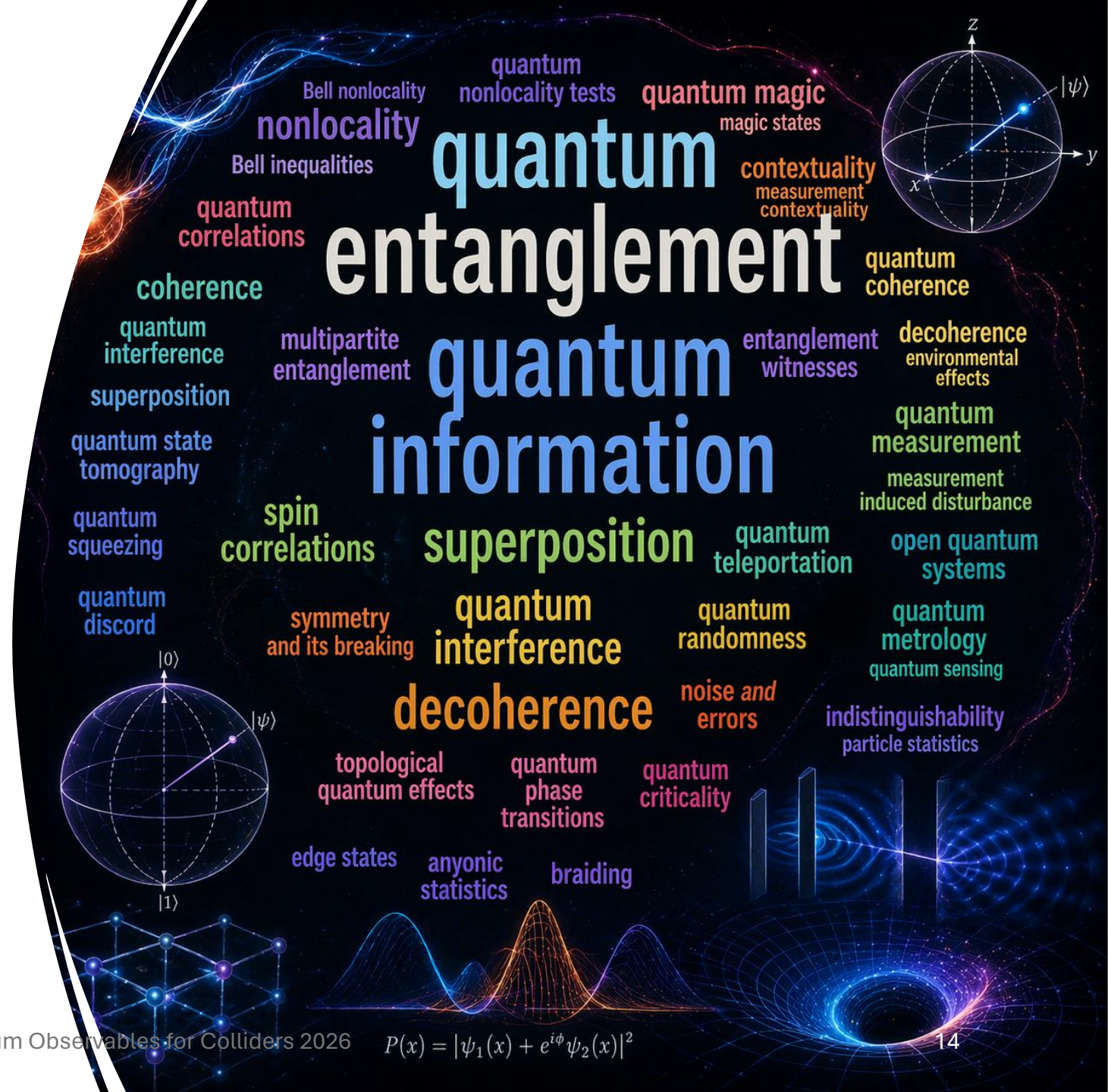
See also Enrico Speranza

"Quantum" is everywhere

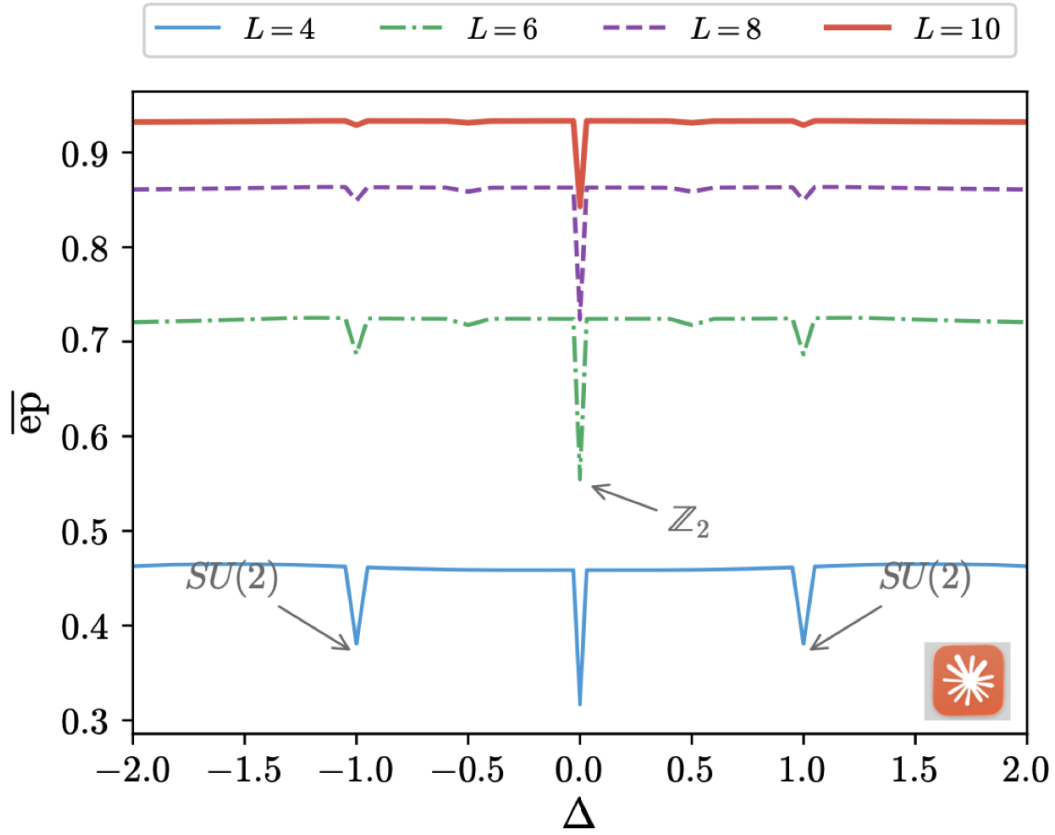
Landscape: quantum sensing applied to an extremely wide range of DM searches



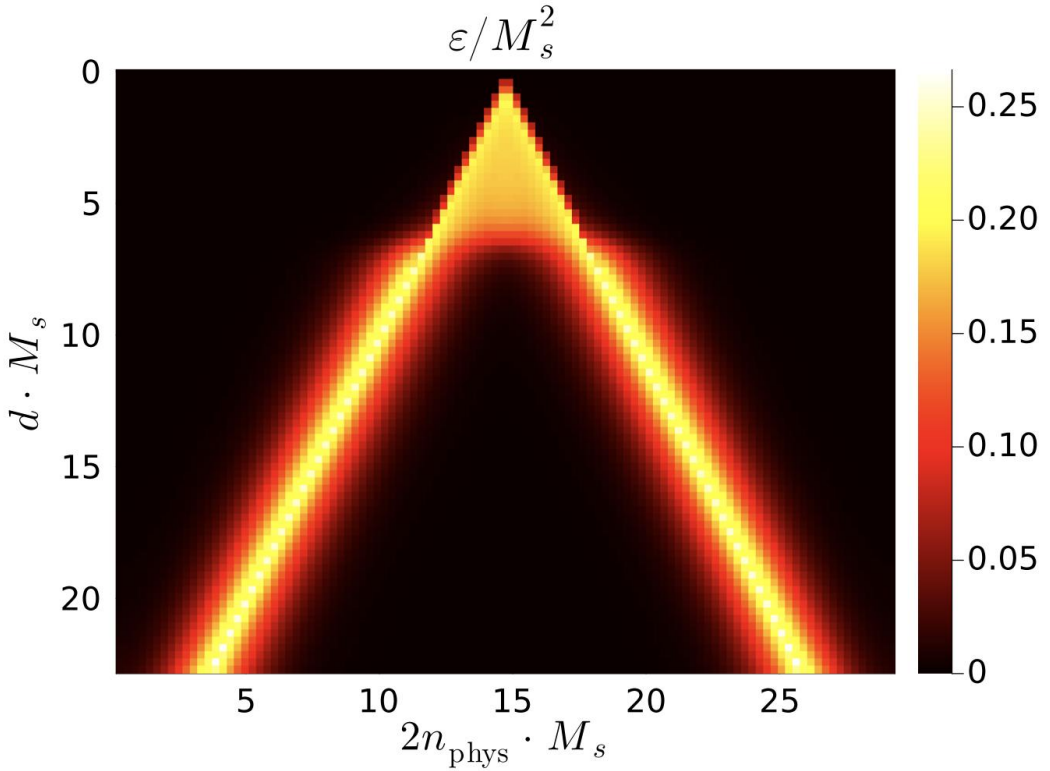
A wide variety of quantum phenomena



Understanding sources



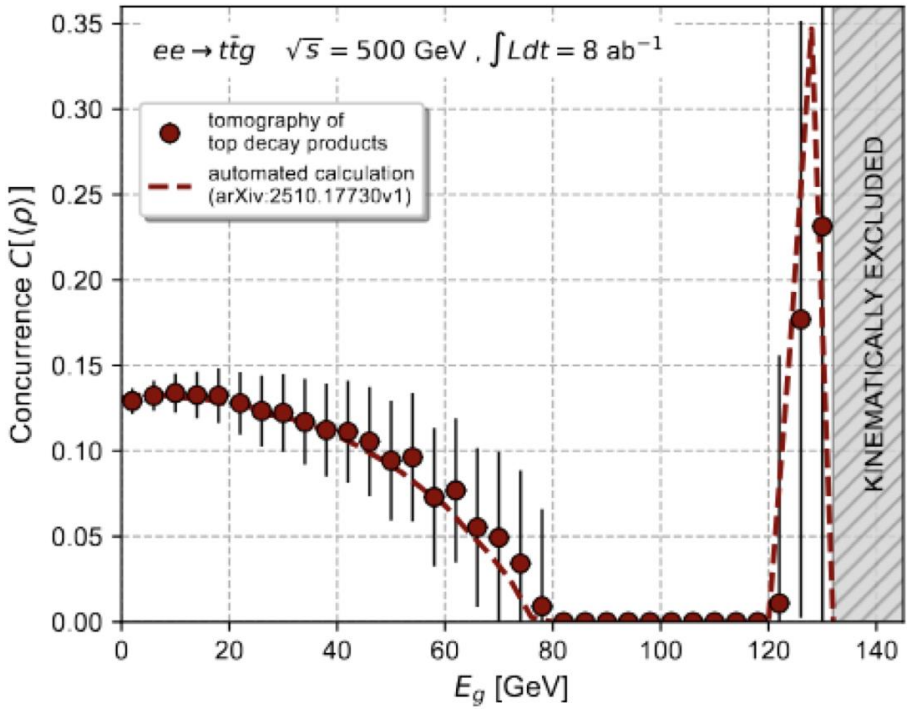
Ian Low



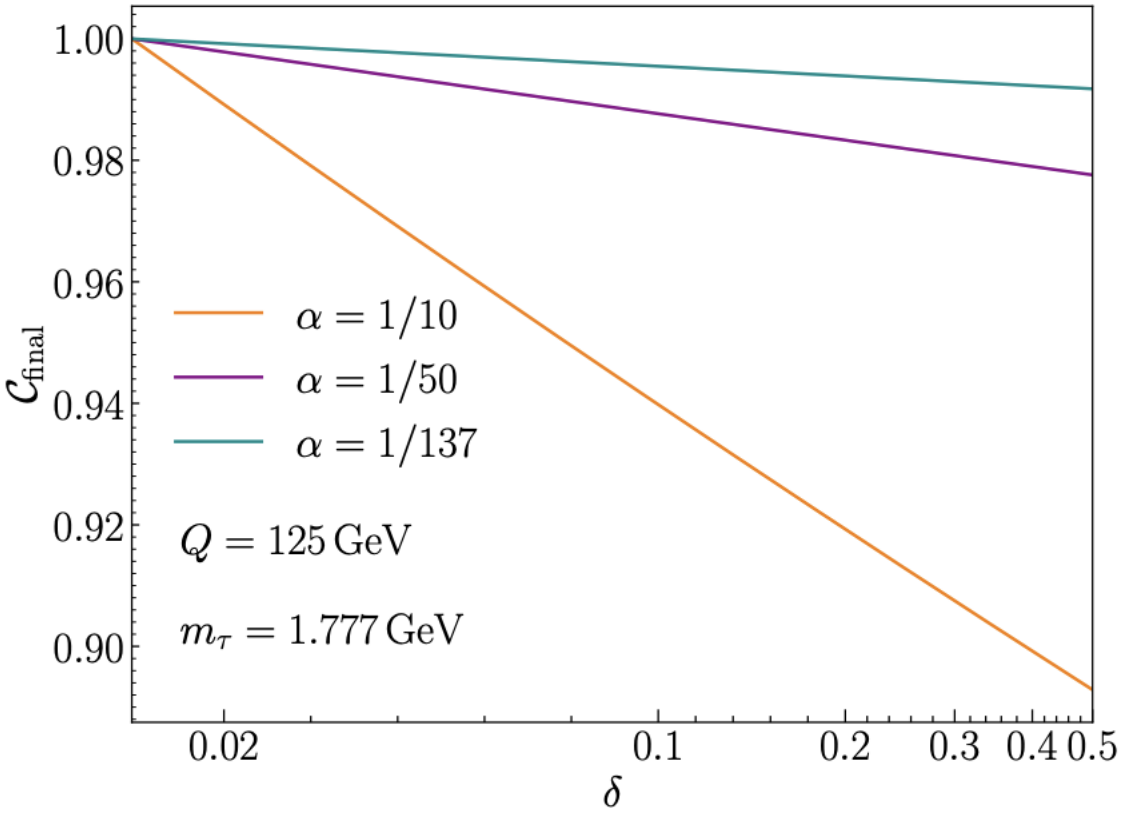
Dmitri Kharzeev

See also Thomas Richardson

Decohering



Marcel Vos



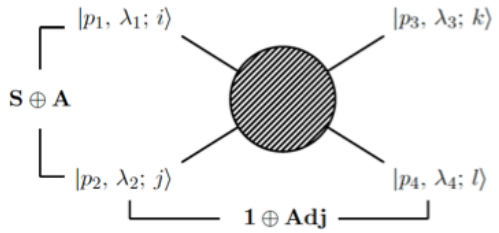
Liantao Wang

$$\mathcal{C}_{\mathrm{final}} \leq \mathcal{C}(0) \left(\frac{Q\delta}{m}\right)^{-\frac{\alpha}{\pi}}$$

See also Rafa Aoude

Symmetries and Quantum Computation

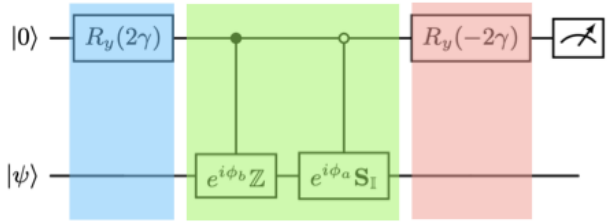
$$\mathcal{M}^{(t)} = \mathcal{M}(s,\Omega)\mathbf{S}_{\mathbb{I}} + \mathcal{M}_W(s,\Omega)\mathbf{S}_W ,$$

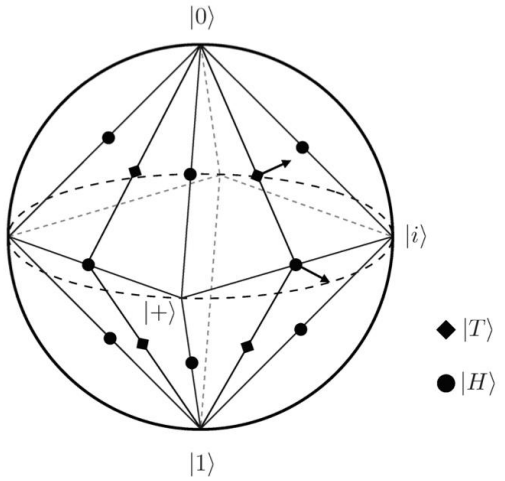


Navin McGinnis

$$\mathcal{M} = a\,\mathbf{S}_{\mathbb{I}} + b\,\mathbb{Z}$$

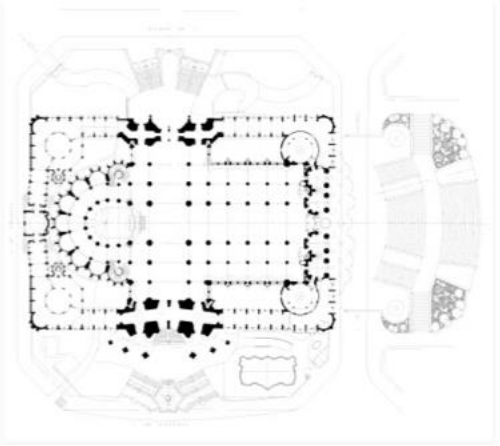
Linear Combination of Unitaries





Zhewei Yin

Guiding principles…



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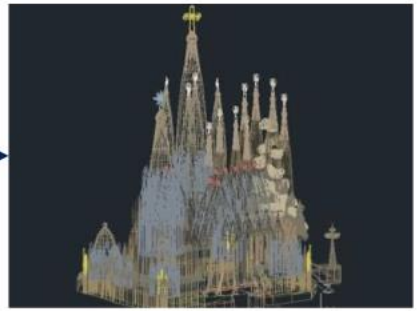
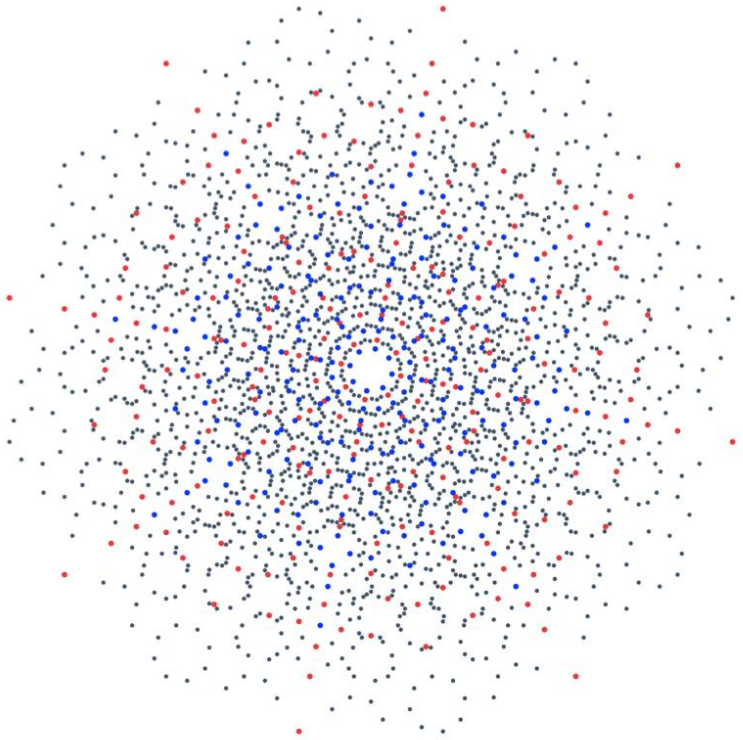
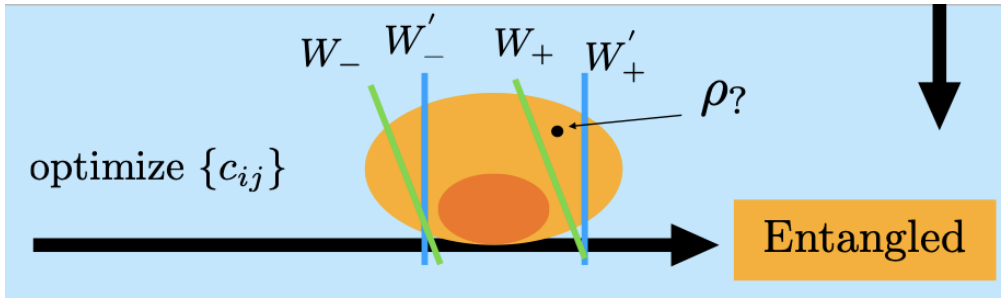


Alba Cervera Lierta

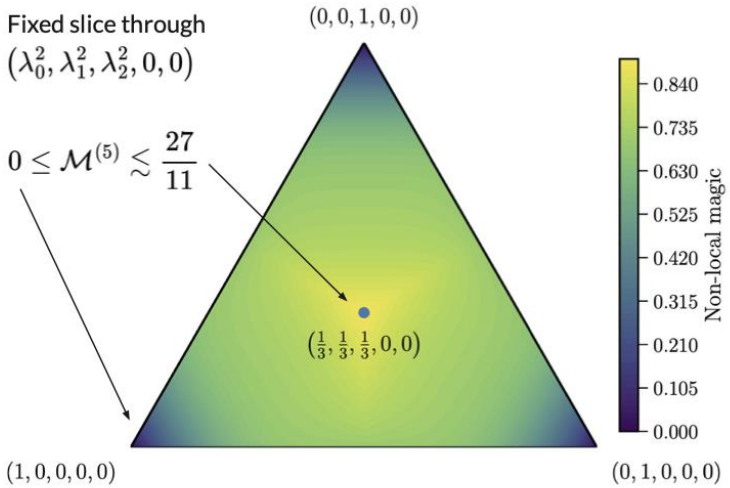
Carlos Wagner, Kamila Kowalska, Ian Low, Spencer Chang



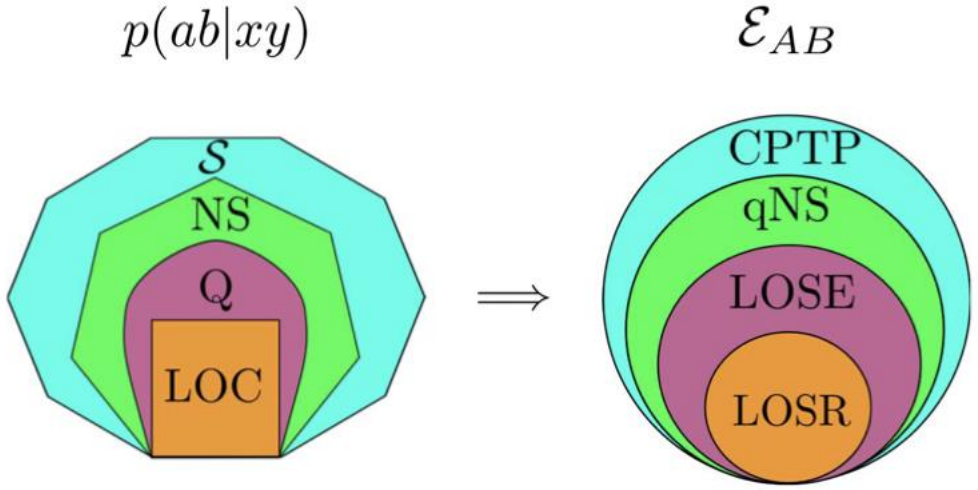
Kazuki Sakurai



Joonwoo Bae

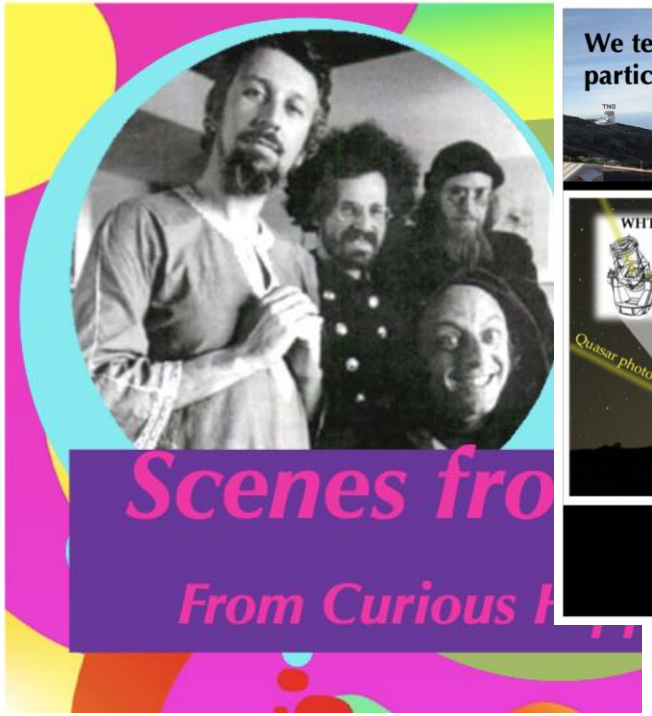


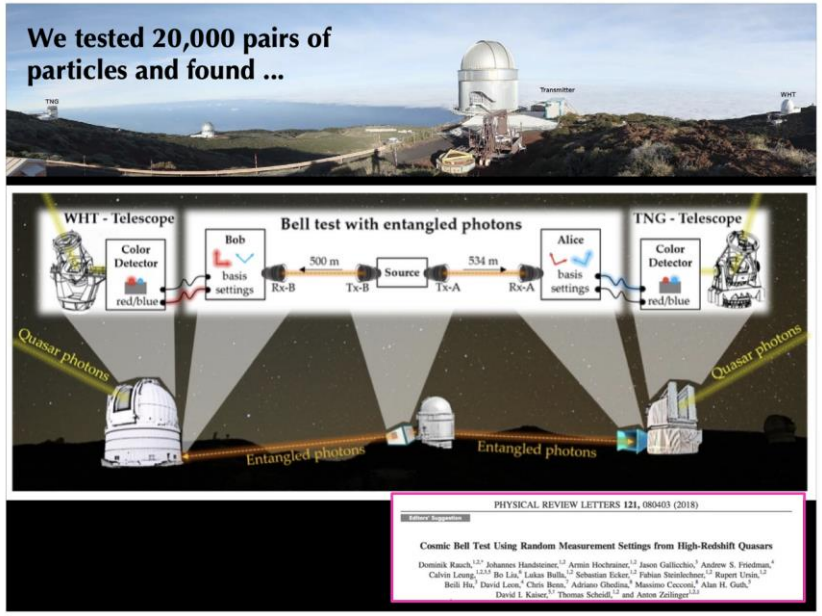
Giorgio Busoni



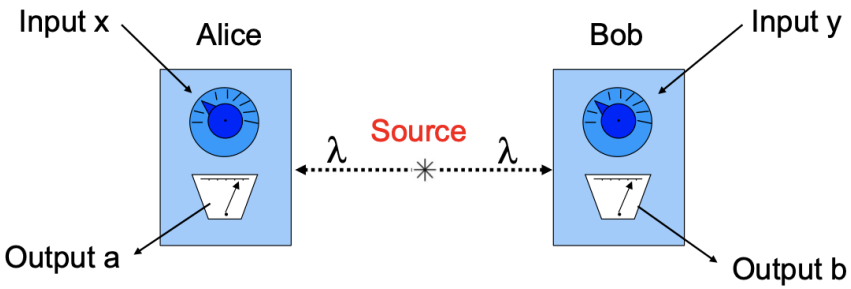
Albert Rico

See also Chris White, Zhewei Yin



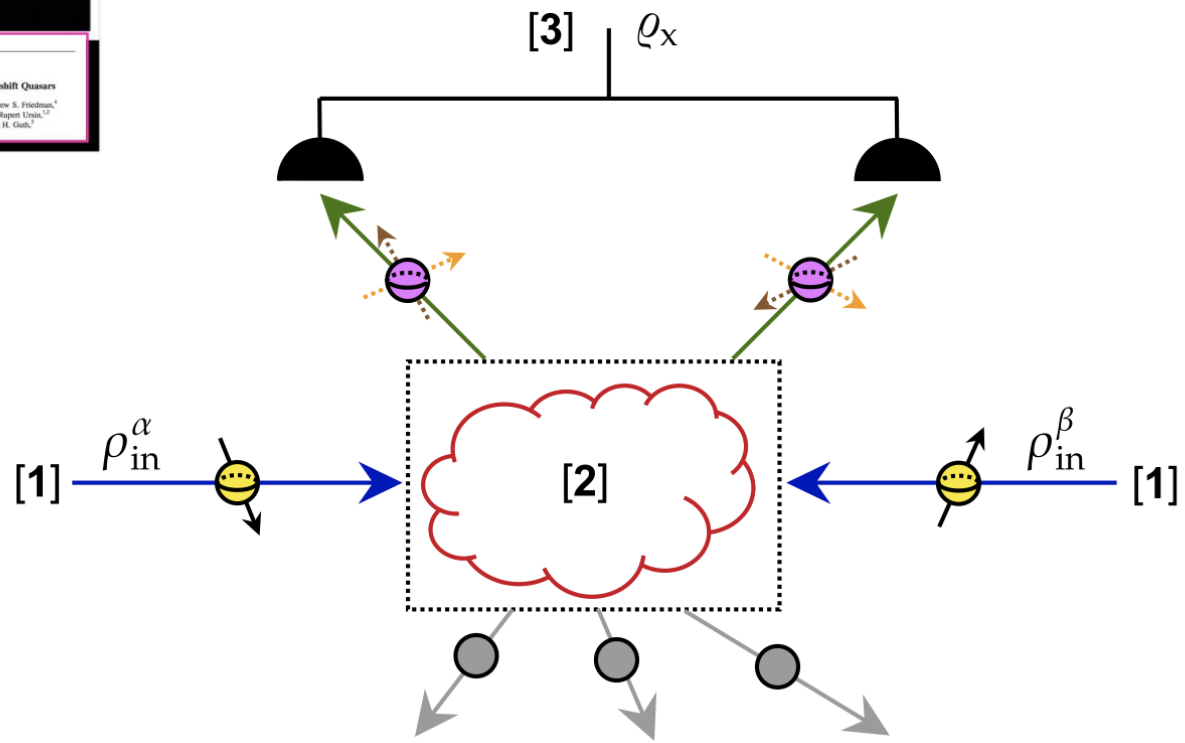


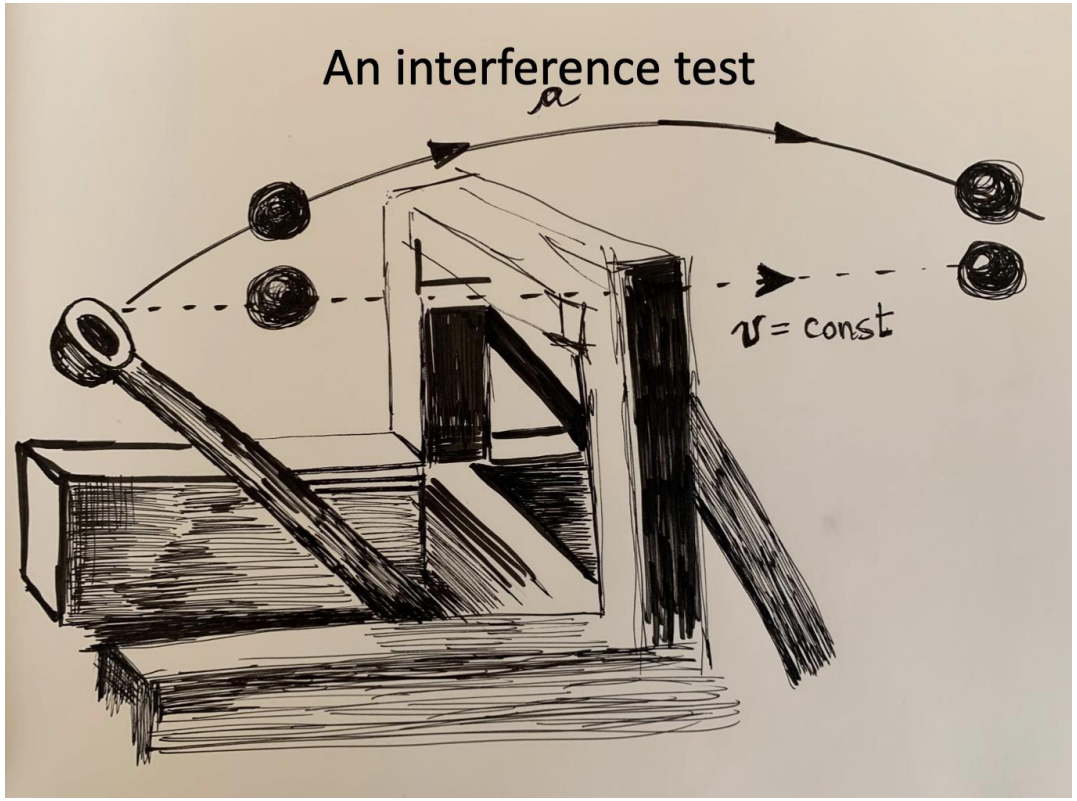
David Kaiser



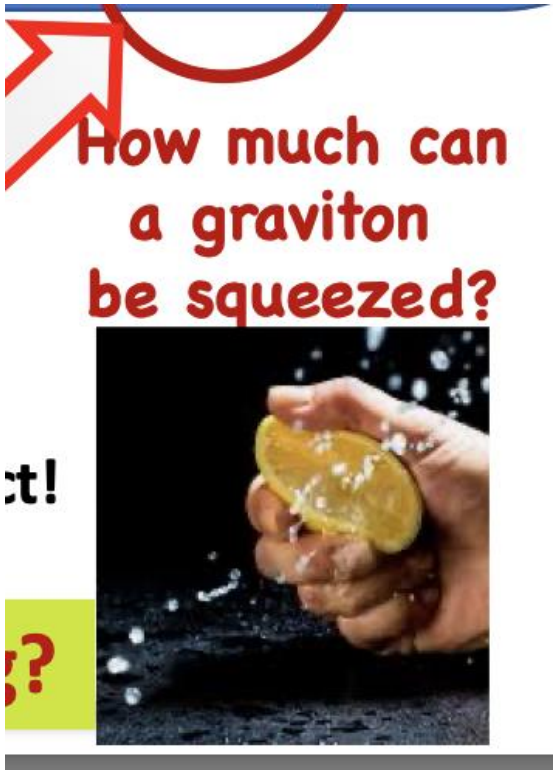
Nicolas Brunner

Pawel Horodecki

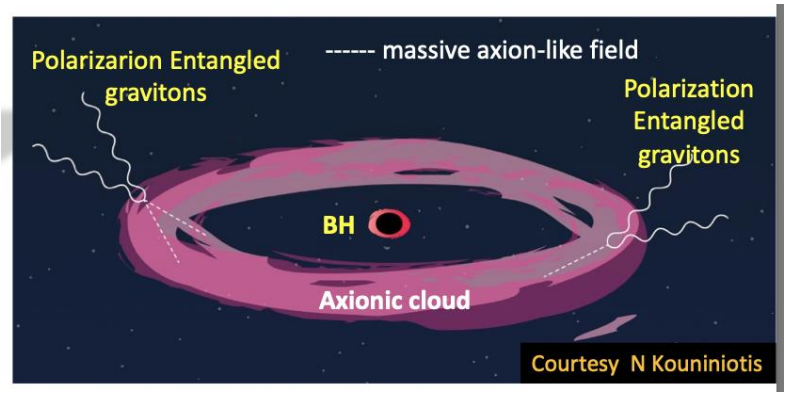


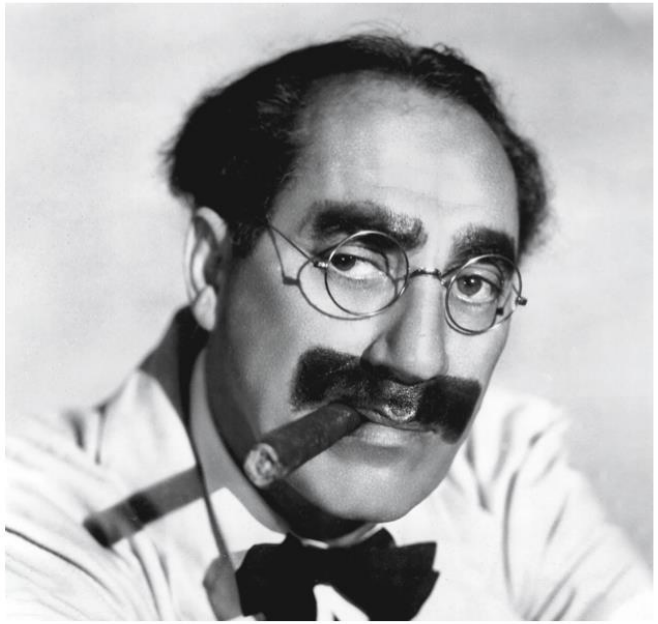


Vlatko Vedral



Nikos Mavromatos





Those are my assumptions, and if you don't like them… well I have others

Juan Antonio Aguilar Saavedra

See also Claude Duhr, Fabio Cerutti

Tao Han

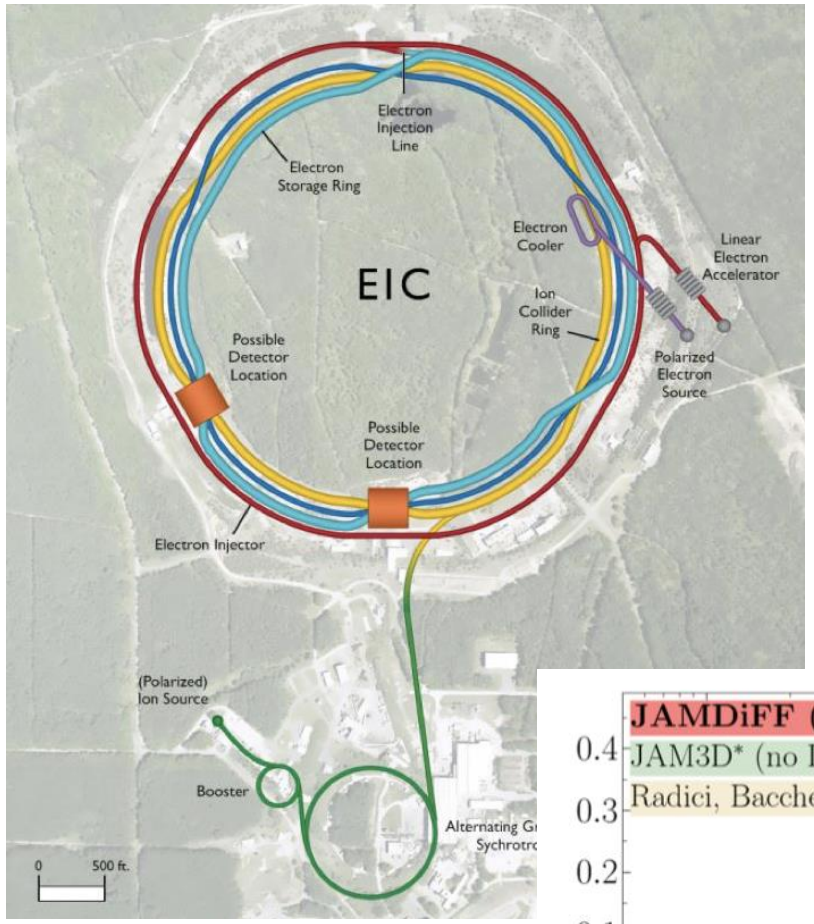
Control beam polarizations (60%-80%?)

Highly successful programs:

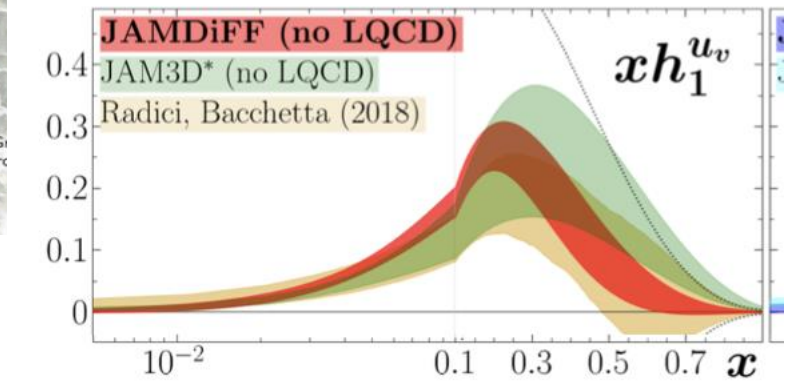
LEP1, LEP2, SLC, SuperKEKB, BEPC II, DAΦNE …

Next HEP collider: the Higgs factory

FCC-ee, CEPC, ILC, LCF …



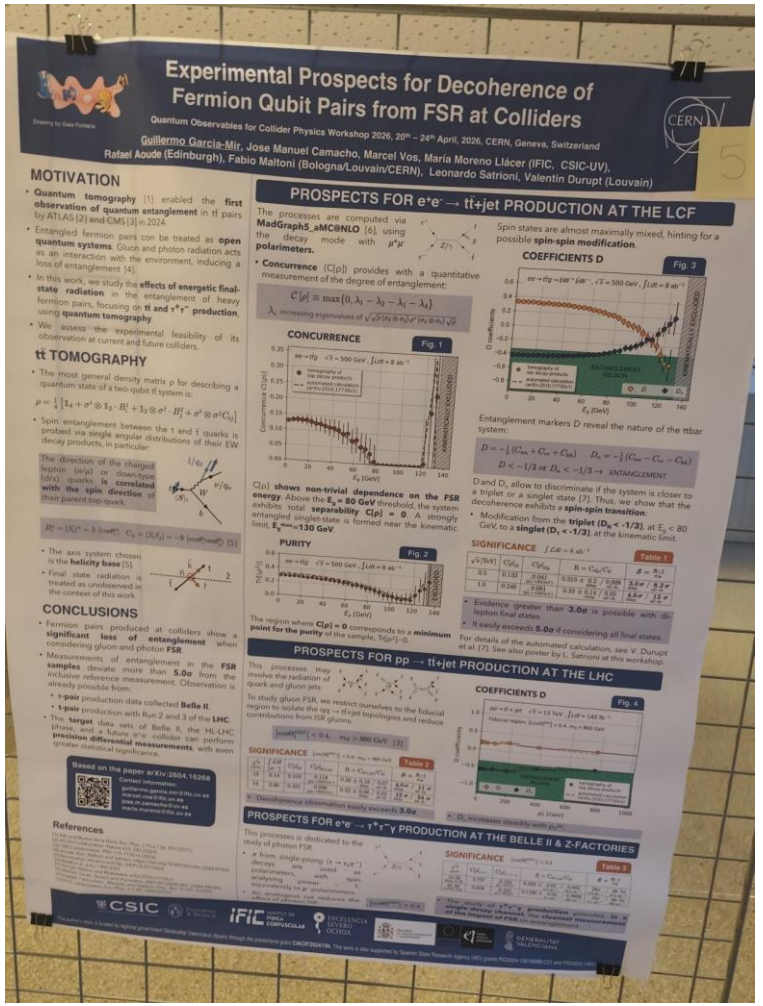
Kun Cheng,
Yoshitaka Hatta



$$e^+e^- \to f\bar{f}$$

19 superb posters by:

Guillermo García Mir, Jose Manuel Camacho, Marcel Vos, Maria Moreno Llacer
Leonardo Satrioni
Olimpia Miniati
Anindita Bera, Beatrix Hiesmayr, Dariusz Chruściński,
Joonwoo Bae, 지헌 성
Sung Won Yun, Joonwoo Bae
Masanori Tanaka
Ivo Young
Sokratis Trifinopoulos, Spencer Chang, Thomas Driscoll
Enzo Ghilardi Nogueira, Felipe Recio Busquier
Alan Herrera
Mira Varma
Avalon Roberts
Laurel Carpenter
Ondrej Penc
Rojalin Padhan
Andy Jung, Andrew Wildridge, Angelo Arisi, Giulia Negro, Jack Li, Juan Duarte, Juan Jose Mejia Alvarez, Santosh Bhandari
Seong Youl Choi, Dong Woo Kang, Jae Sik Lee, Chan Beom Park
Radoslaw Grabarczyk
Danilo Fucci



Guillermo García Mir

“I disagree with you”

“Let’s talk over coffee”

“People are paying attention”

- **AI generated** poster for workshop next year
- Date to be confirmed
- Venue - Chicago