Baryon Asymmetry

Baryon Asymmetry

Place

Location: The Hong Kong University of Science and Technology
Address: Hong Kong, China

Files

Edit files

Date: **28 Jun 19:30 - 21:30**

Description

Discussion Leader: Pasquale Di Bari (University of Southampton, United Kingdom)

Timetable | Contribution List

Wed 28/06

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19:00

Electroweak Baryogenesis — *Thomas KONSTANDIN*
The Hong Kong University of Science and Technology 19:30 - 19:45

20:00

Unifying Inflation with the Axion, Dark Matter, Baryogenesis and the Seesaw Mechanism — *Carlos TAMARIT*

Baryogenesis from Right-Handed Neutrino Oscillations — *Takehiko ASAKA*
The Hong Kong University of Science and Technology 20:10 - 20:25

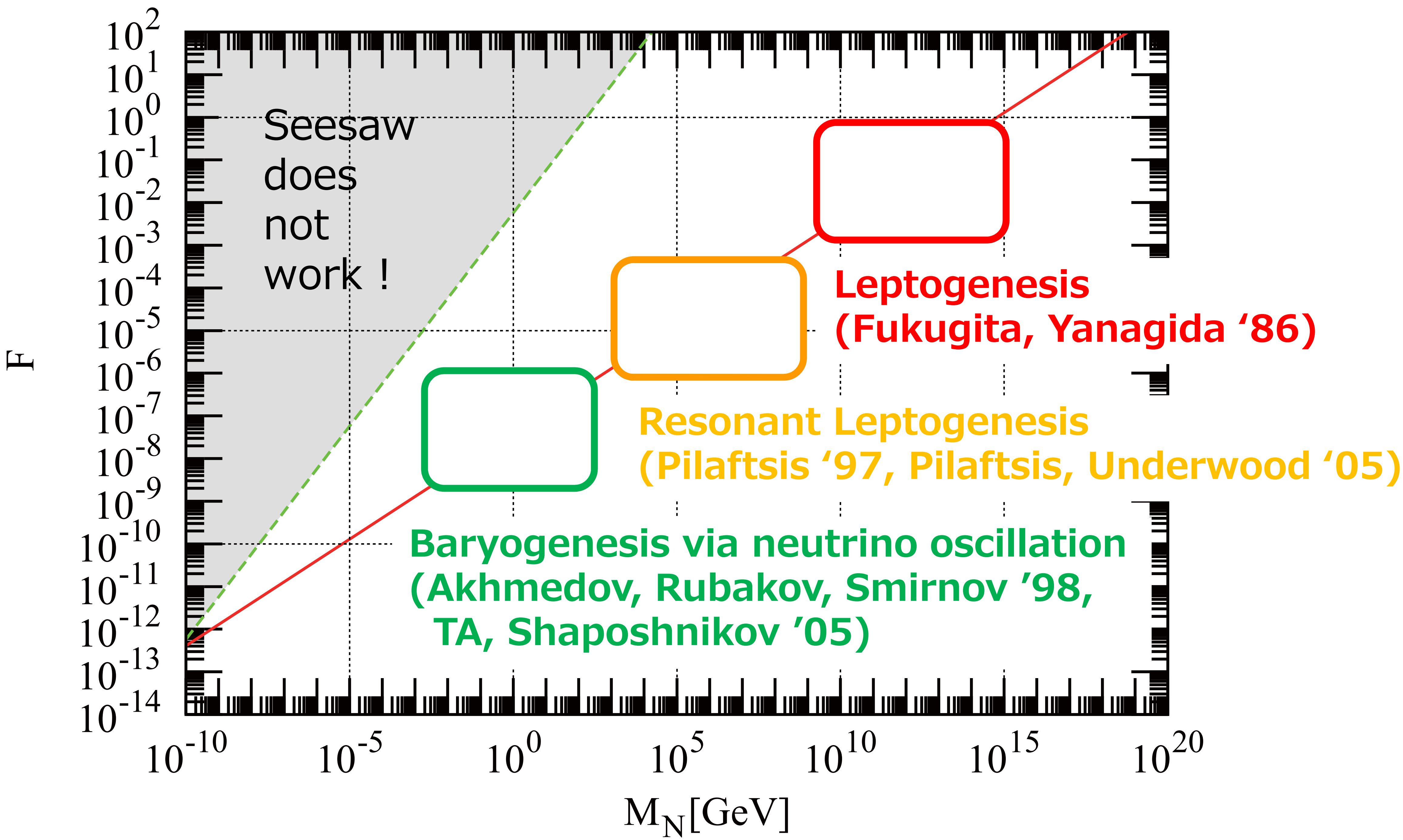
Leptogenesis from Realistic Models — *Chee Sheng FONG*
The Hong Kong University of Science and Technology 20:30 - 20:45

21:00

Models on the Origin of Ordinary and Dark Matter — *Peihong GU*
The Hong Kong University of Science and Technology 20:50 - 21:05

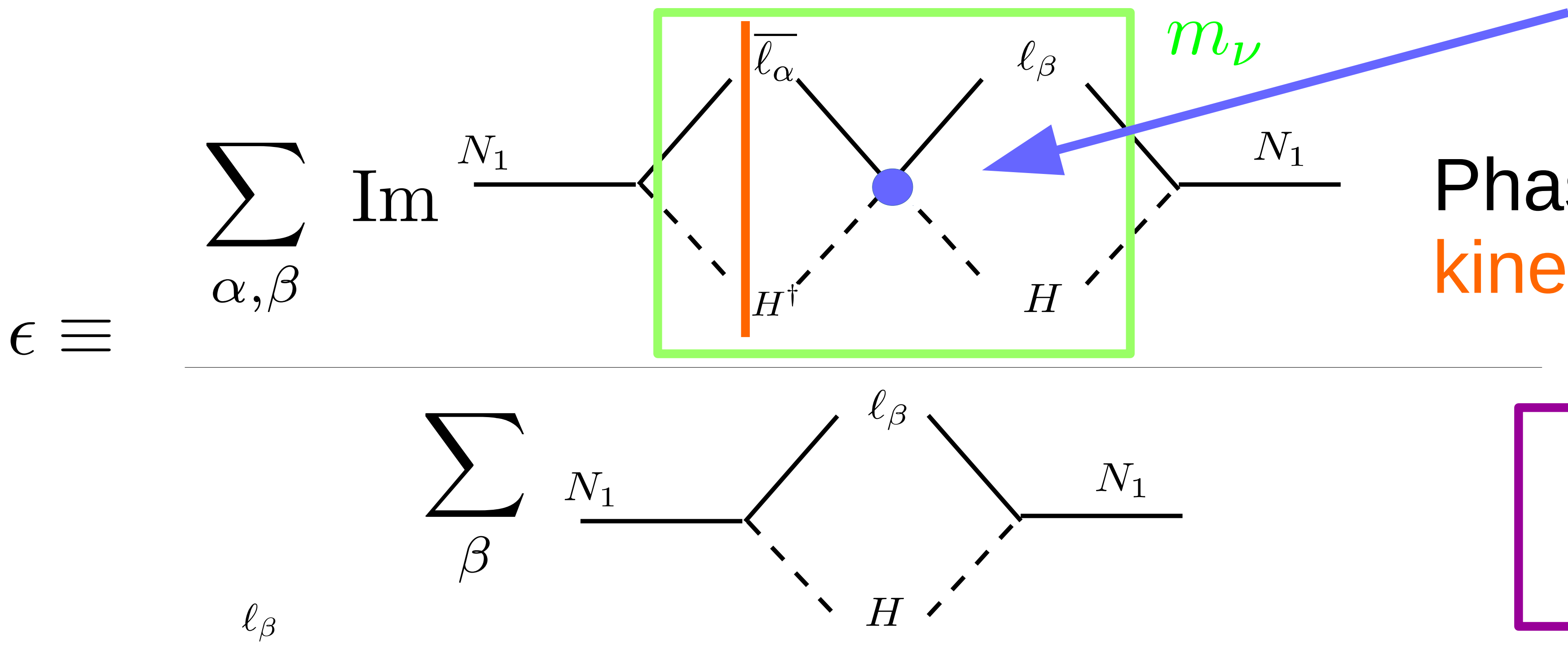
Yukawa coupling and Majorana mass

Explain baryon asymmetry of the universe too!



Restrictions from neutrino masses

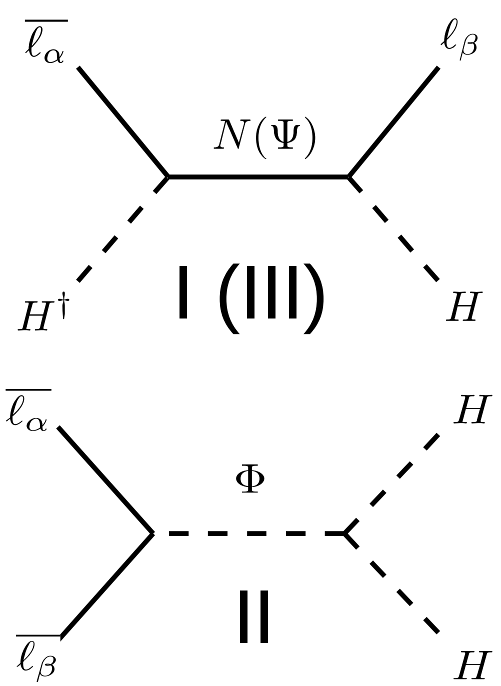
- CP violation is tied to neutrino mass scale



Heavier states

Phases from
kinematic & couplings

$$|\epsilon| \sim \frac{1}{16\pi} \frac{m_\nu M_1}{v^2}$$



$$|\epsilon| \gtrsim 10^{-7} \implies M_1 \gtrsim 3 \times 10^9 \left(\frac{0.05\,\mathrm{eV}}{m_\nu} \right) \mathrm{GeV}$$

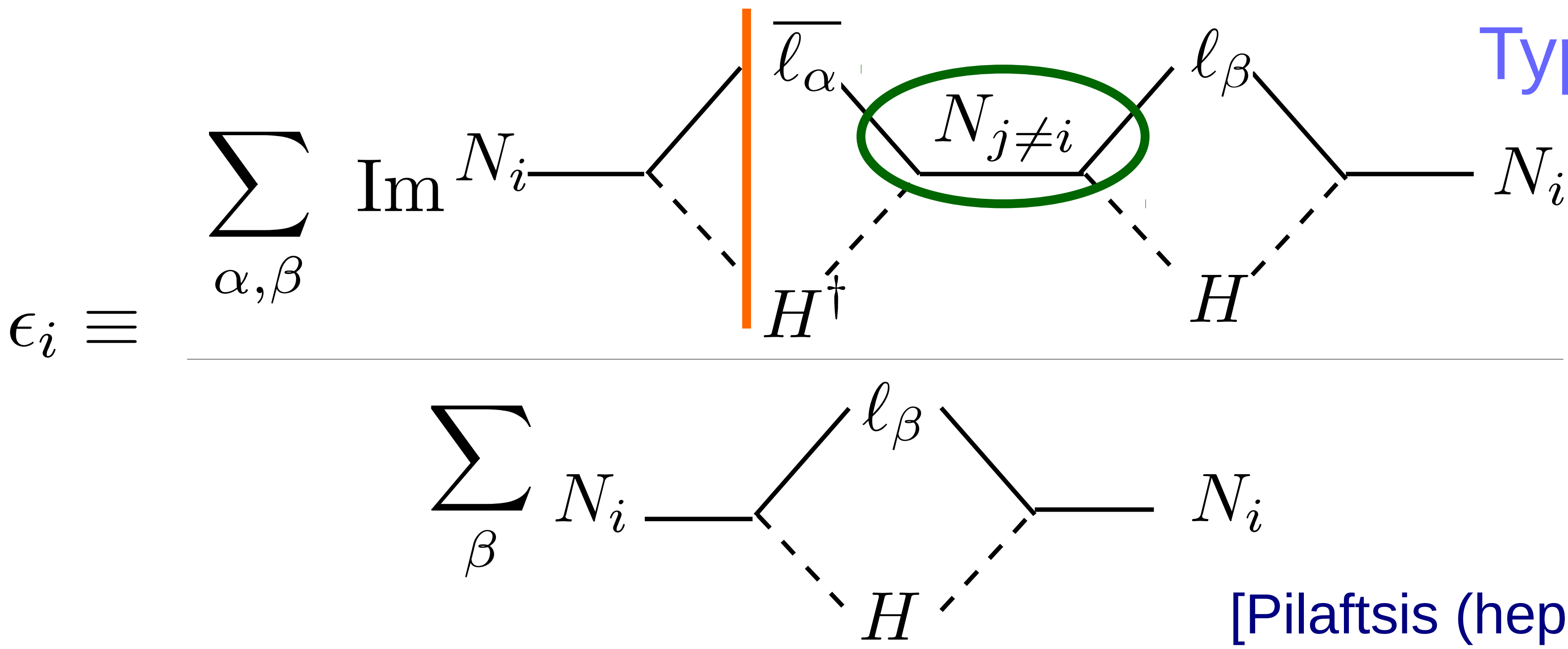
[Davidson & Ibarra (hep-ph/0202239)]

Caveats

$M_i \sim M_j$

- "Heavier states" not much heavier → ***resonant enhancement***

Type I seesaw



[Pilaftsis (hep-ph/9707235)]

$$\epsilon_i \sim \frac{1}{16\pi}\frac{m_\nu M_i}{v^2} \times \sum_j \sin(\phi_i - \phi_j)\frac{(M_i^2 - M_j^2)M_j^2}{(M_i^2 - M_j^2)^2 + M_i^2\Gamma_j^2}$$

Can go as low as possible i.e. $M_i > 132\,\mathrm{GeV}$ (more later)

Doesn't apply on those which rely on different physical mechanisms...

Resonant leptogenesis

[Pilaftsis (hep-ph/9707235)] [Pilaftsis & Underwood (hep-ph/0309342)]

- The right-handed neutrinos are quasi-degenerate to enhance the CP violation from self energy corrections
- Can be probed at LHC & CLFV [Bray, Lee & Pilaftsis (hep-ph/0702294)]
- Quasi-degeneracy $M_2 - M_1 = \mu \ll M_{1,2} \approx M$ due to
  - Approximate family symmetry (ok)
  - Soft SUSY breaking terms (ok)
  - Approximate lepton number (*difficult*)

[Grossman et al. (hep-ph/0307081)]
[D' Ambrosio et al. (hep-ph/0308031)]
[Review (hep-ph/1107.5312)]

Difficult because mass degeneracy is tied to CP violation!

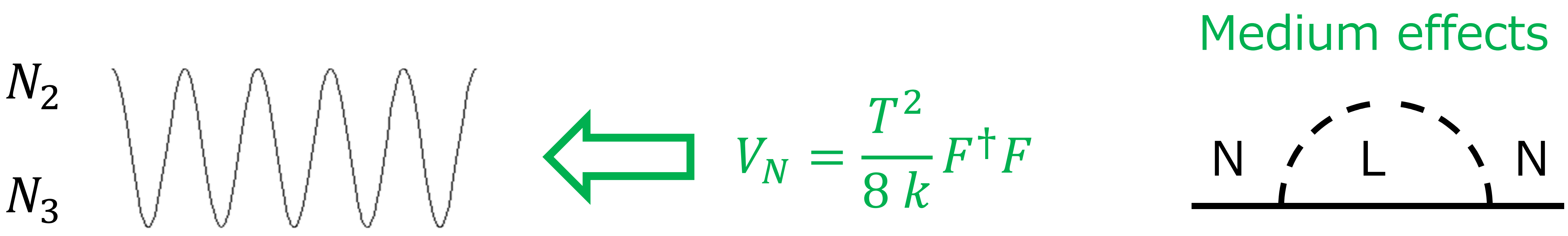
$$M_2 - M_1 = \mu \qquad\qquad |\epsilon| \propto \mu$$

Baryogenesis via neutrino oscillation

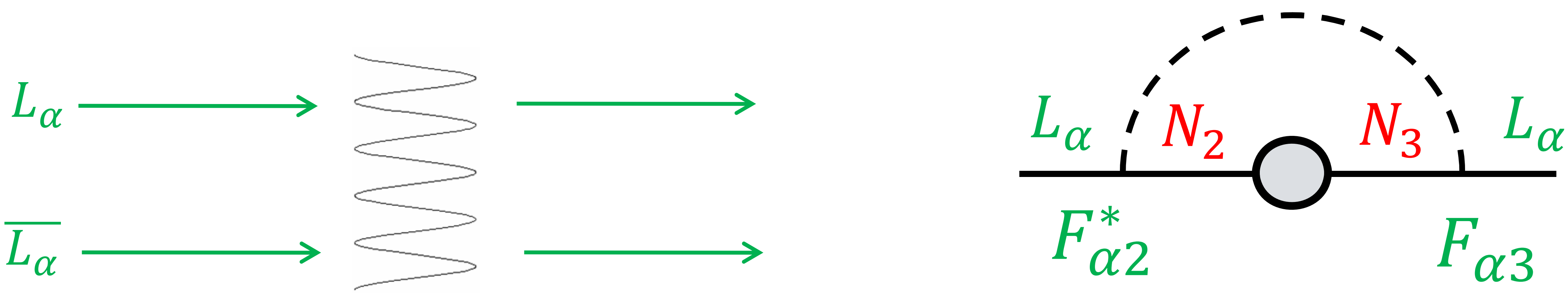
- **Oscillation of RH neutrinos can be a source of BAU**

  Akhmedov, Rubakov, Smirnov ('98) / TA, Shaposhnikov ('05)

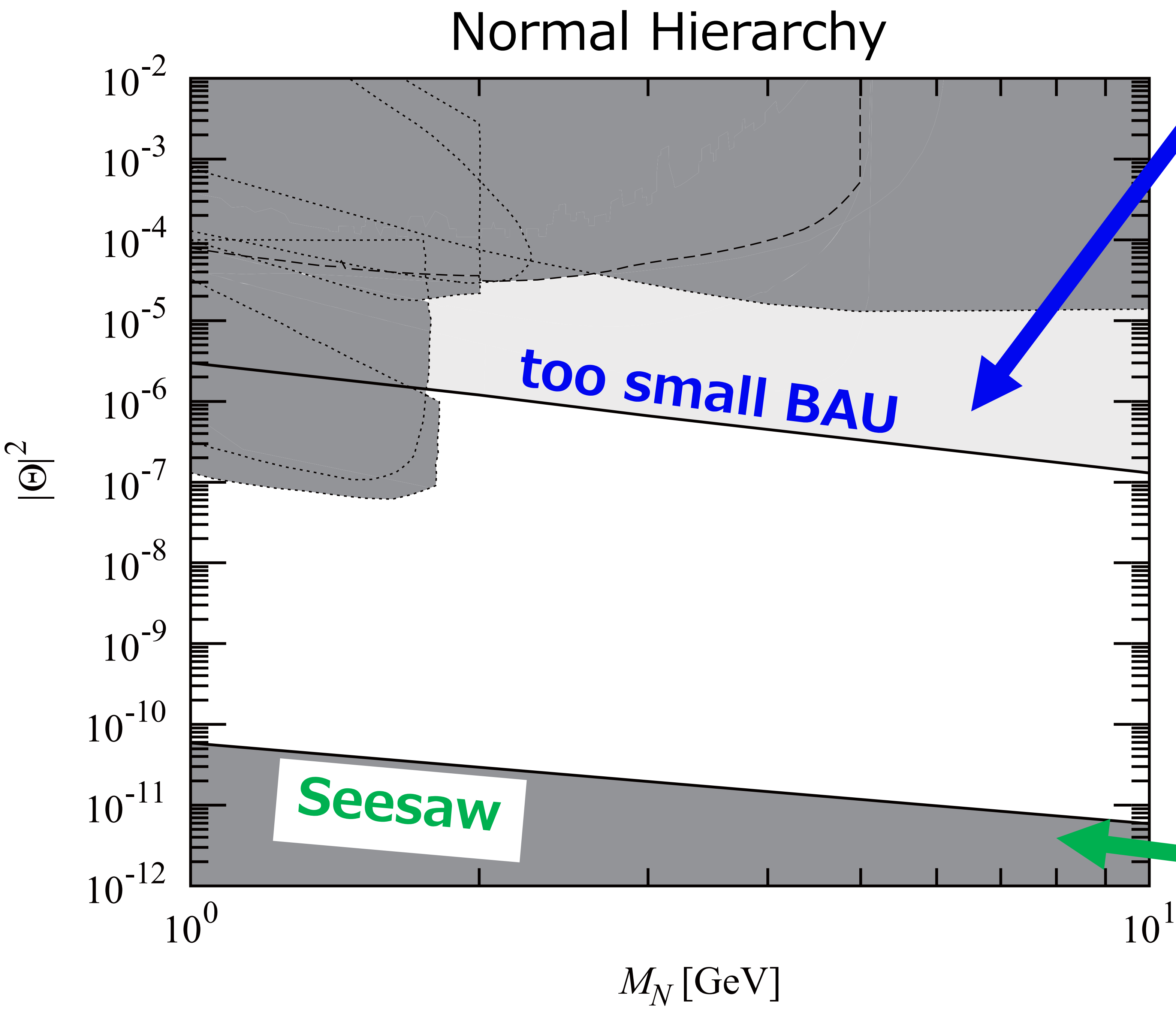
  - Oscillation starts at $T_{osc} \simeq (M_0\, M_N\, \Delta M)^{1/3}$



  - Asymmetries are generated since evolution rates of L_α and $\overline{L_\alpha}$ are different due to CPV



Baryogenesis region



Bound from BAU

to avoid strong washout

Canetti, Shaposhnikov ’10 [arXiv:1006.0133]

Drewes, Garbrecht, Gueter, Klaric ’16 [arXiv:1609.09069]

TA, Eijima, Ishida, Minogawa, Yoshii ’17 [to appear]

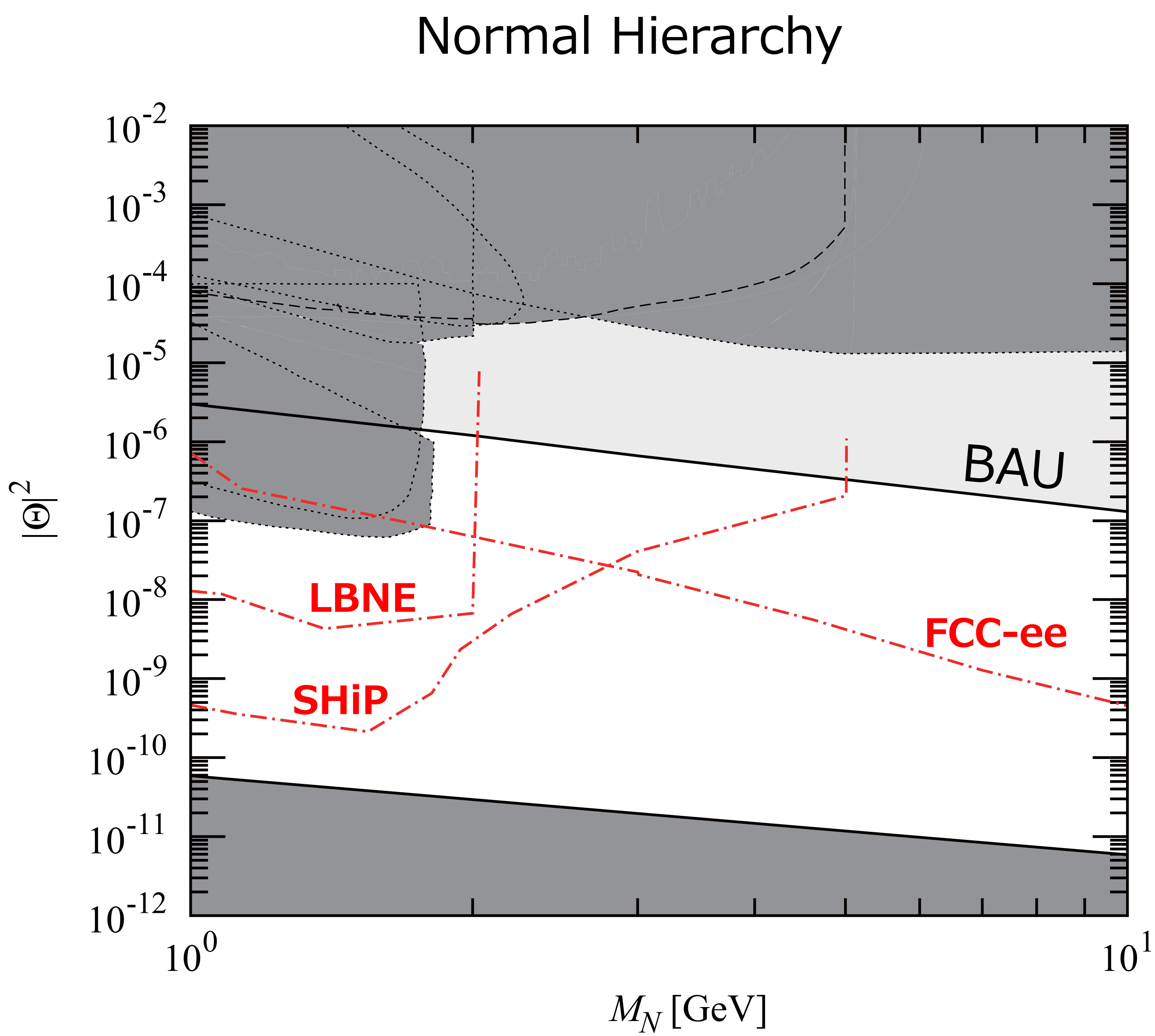
See also a poster #16 by Juraj Klaric

Bound from Seesaw

to explain neutrino masses

$$|\Theta|^2 > \frac{\Sigma m_i}{2\, M_N}$$

Sensitivities by future searches



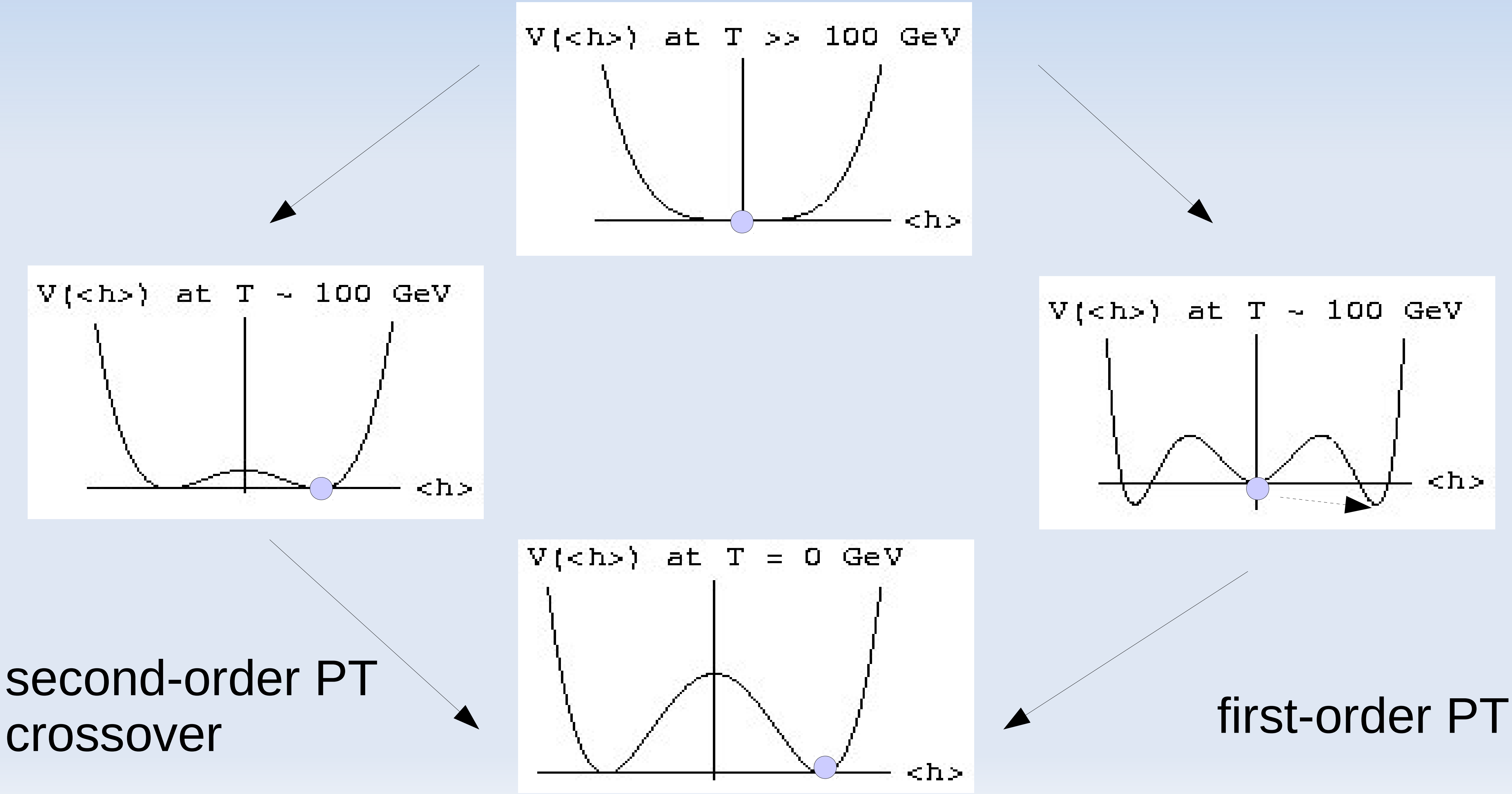
Sensitivity for $|\Theta_\mu|^2$

- LBNE (DUNE)
  N decay inside near detector
  Adams et al '13 [arXiv:1307.7335]
- SHiP
  beam dump exp.
  Anelli et al '13 [arXiv:1504.04956]
- FCC-ee at Z-pole
  displaced vertex of N decay
  Blondel, Graverini, Serra, Shaposhnikov (FCC-ee study team) '14 [arXiv:1411.5230]

eq

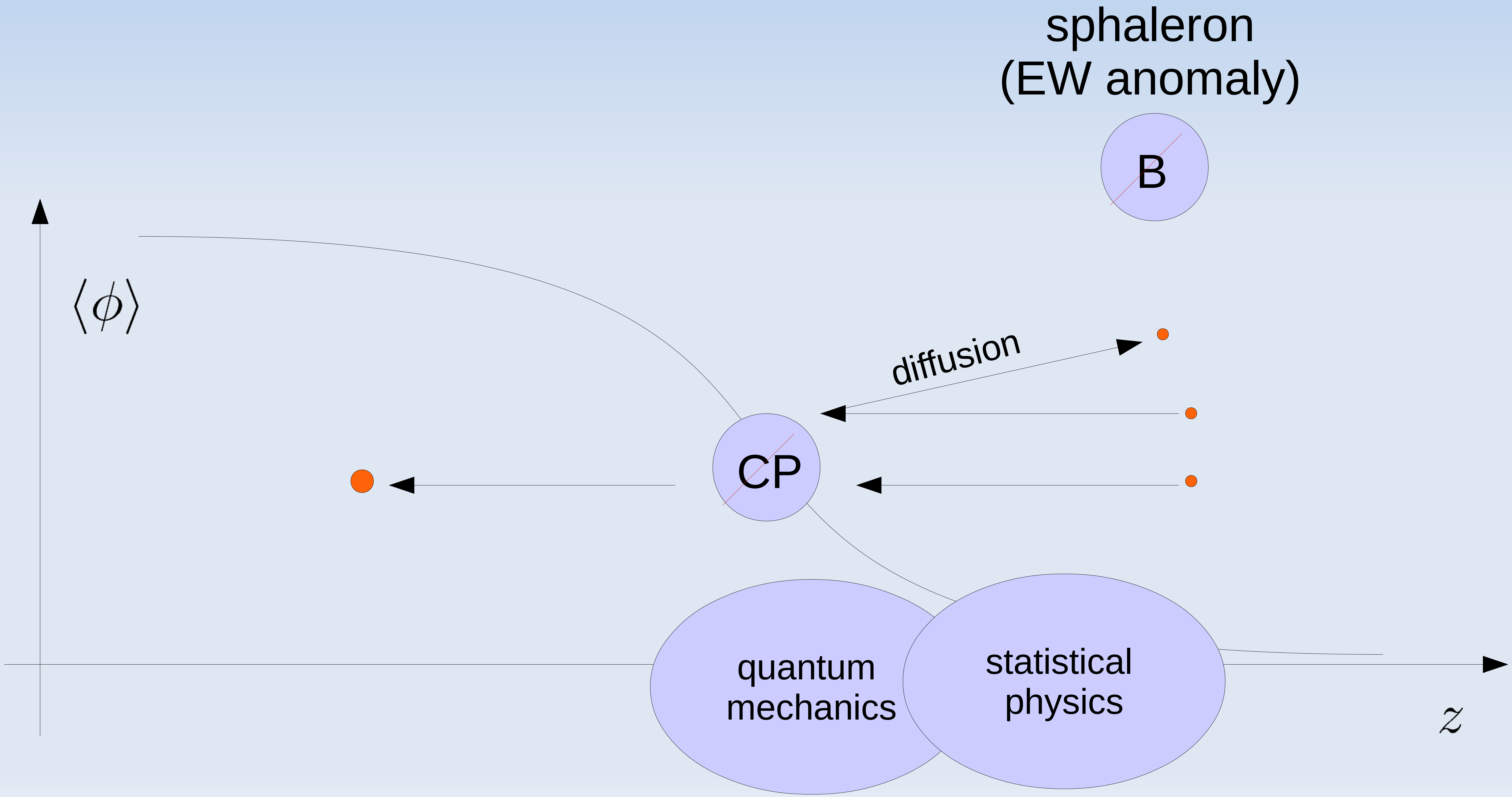
First-order phase transition

The free energy (as a function of the Higgs vev) decides the nature of the phase transition:



What are the challenges?

[Kuzmin, Rubakov, Shaposhnikov '85]
[Cohen, Kaplan, Nelson '93]



Pre LHC EWBG

Before LHC, the main focus was on supersymmetric models.

~~eq~~ Strong first-order electroweak phase transition from light stops $m_{\tilde{t}} \lesssim m_t$

NMSSM *[Menon, Morrisey, Wagner '04]*
[Huber, TK, Prokopec, Schmidt '06]

U'(1) MSSM *[Kang, Langacker, Li, Liu '04]*

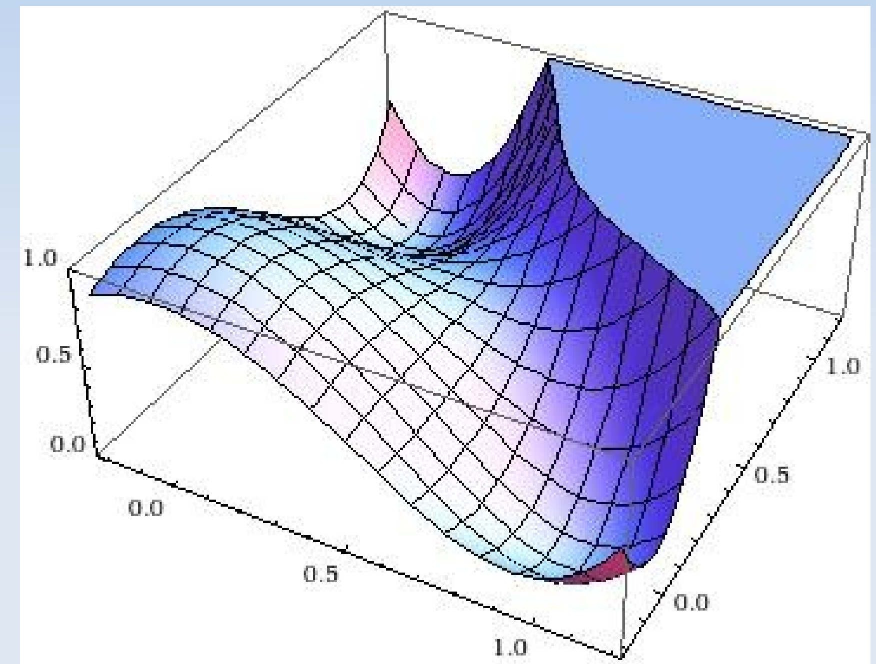
~~CP~~ CP violation
From the chargino sector

$$m_{\chi^{\pm}} < 200\,\mathrm{GeV}$$

problematic, also because of EDMs

EWBG in the LHC era

After LHC run II, the focus in EWBG is more on minimal models:



~~eq~~ Strong first-order electroweak phase transition from extended scalar sector

Two Higgs doublet model

~~CP~~ CP violation from the Higgs sector

Singlet extension with a low cutoff

~~CP~~ CP violation from the dim-5 top-singlet operators

new dof
low cutoff
in principle testable

Composite Higgs models

The Higgs could be a Pseudo-Goldstone boson of a broken global symmetry

QCD:
$$\frac{SU(2)_L \times SU(2)_R}{SU(2)_V} \to 3\pi$$

The broken symmetry will determine the light degrees of freedom and their quantum numbers

$$\frac{SO(5)}{SO(4)} \to H$$

but also

$$\frac{SO(6)}{SO(5)} \to H + S \qquad \frac{SO(6)}{SO(4) \times SO(2)} \to 2H$$

[Kaplan, Georgi '84]

Ingredients

Two ingredients of baryogenesis are missing in the Standard Model. These are provided in models that have an additional singlet in the low energy effective description

~~eq~~

Strong first-order electroweak phase transition

$$V(s,h)$$

~~CP~~

CP violation from dimension-five operators

$$\mathcal{L} \ni y_t \bar{\psi}_Q H \psi_t + \frac{\tilde{y}_t}{f} S \bar{\psi}_Q H \psi_t + h.c.$$

$$\Im(y_t \tilde{y}_t^*) \neq 0$$

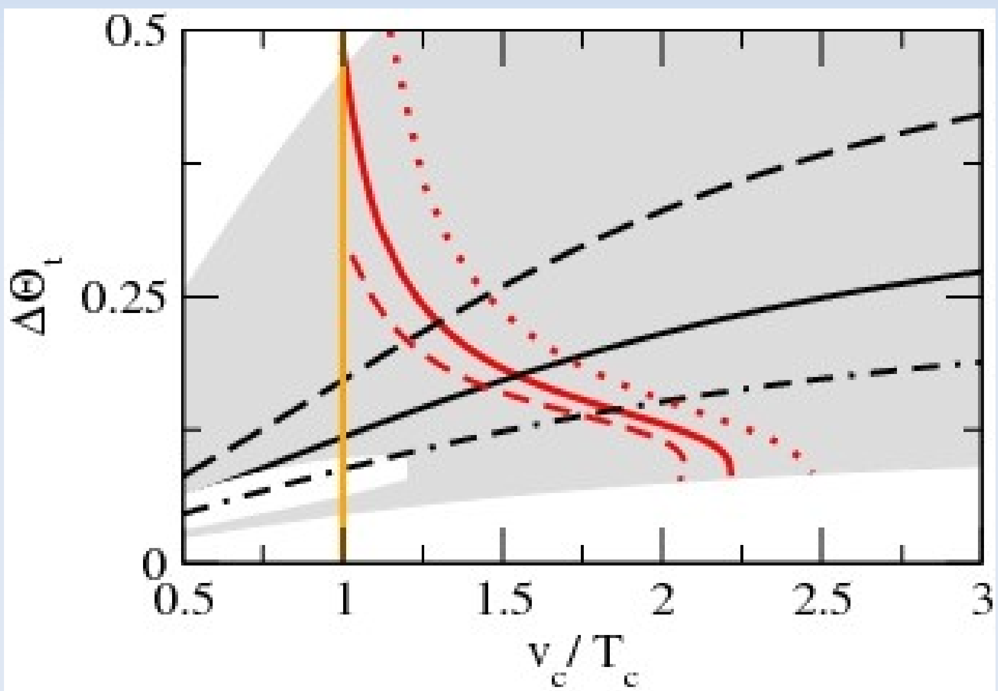
Baryogenesis

$$\Delta\theta_t \simeq \frac{\Im(y_t \tilde{y}_t^*)}{y_t y_t^*}\frac{\Delta s}{f}$$

$$\Delta\theta_t \gtrsim 0.15$$

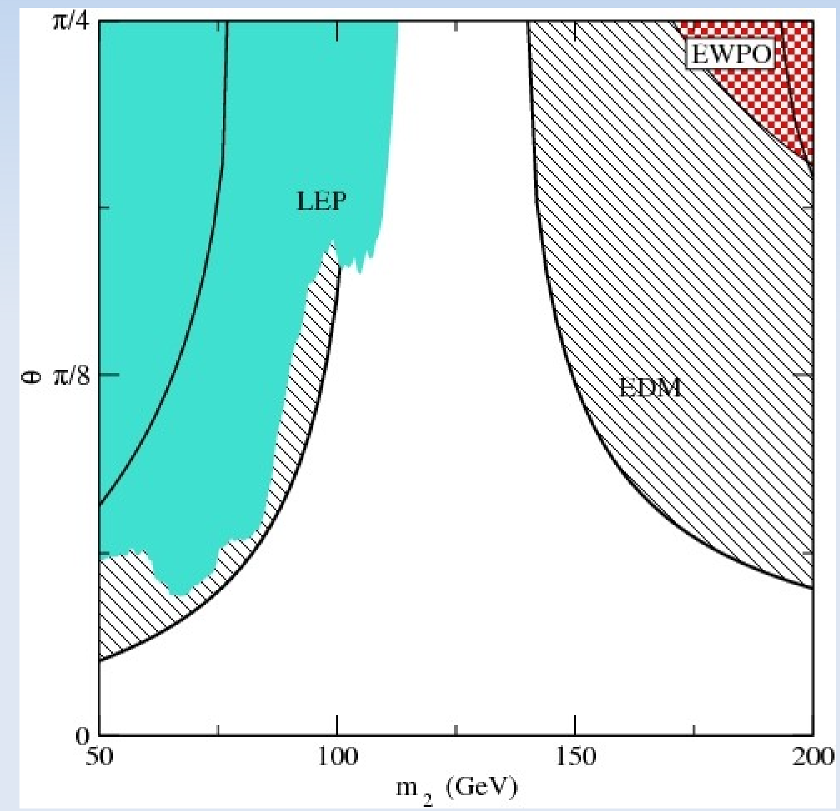
$$m_s = 130\,\mathrm{GeV}$$
$$m_h = 120\,\mathrm{GeV}$$

strength of
CP violation



strength of the phase transition

Higgs-singlet mixing ~
CP violation



singlet mass

[Espinosa, Gripaios, TK, Riva '11]

CPV is mostly present during the phase transition and does not require sizable mixing the broken phase → nightmare scenario

Dark Matter

Place

Location: The Hong Kong University of Science and Technology
Address: Hong Kong, China

Files

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Date: **29 Jun 09:00 - 12:35**

Description

Discussion Leader: Jianglai Liu (Shanghai Jiao Tong University, China)

Timetable | Contribution List

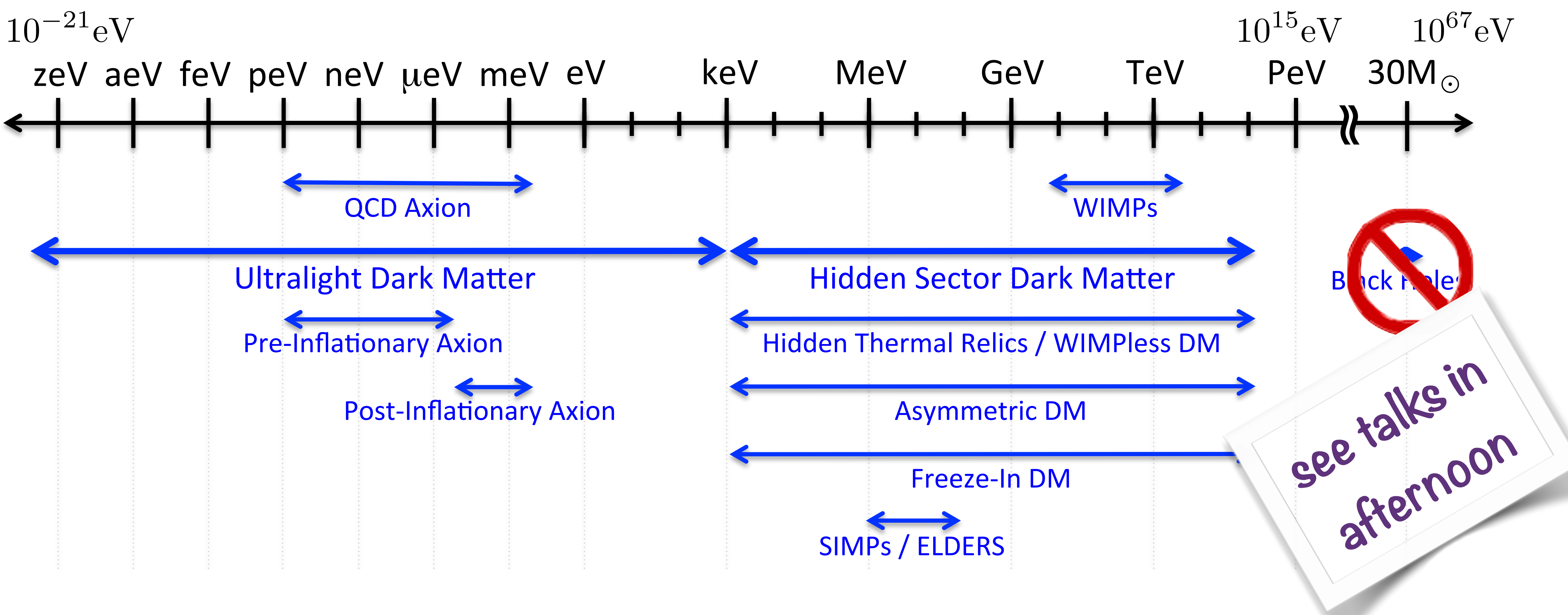
Thu 29/06

Print | Full screen | Filter

09:00	**Particle Theories of Dark Matter**	*Patrick FOX*	*The Hong Kong University of Science and Technology*	09:00 - 09:25
	Dark Matter Direct Detection Experiment	*Wolfgang RAU*	*The Hong Kong University of Science and Technology*	09:30 - 09:55
10:00	**Dark Matter Searches in Space**	*Jin CHANG*	*The Hong Kong University of Science and Technology*	10:00 - 10:25
	Experimental Searches of Axions	*Yannis SEMERTZIDIS*	*The Hong Kong University of Science and Technology*	10:50 - 11:15
11:00	**Dark Matter Searches in Colliders**	*Ning ZHOU*	*The Hong Kong University of Science and Technology*	11:20 - 11:45
	Recent Results from the XENON1T Experiment	*Shingo KAZAMA*	*The Hong Kong University of Science and Technology*	11:50 - 12:05
12:00	**Diversity Problem of Galaxies and Self-Interacting Dark Matter**	*Hai-Bo YU*	*The Hong Kong University of Science and Technology*	12:10 - 12:25

Fox (USA)

Particle theories

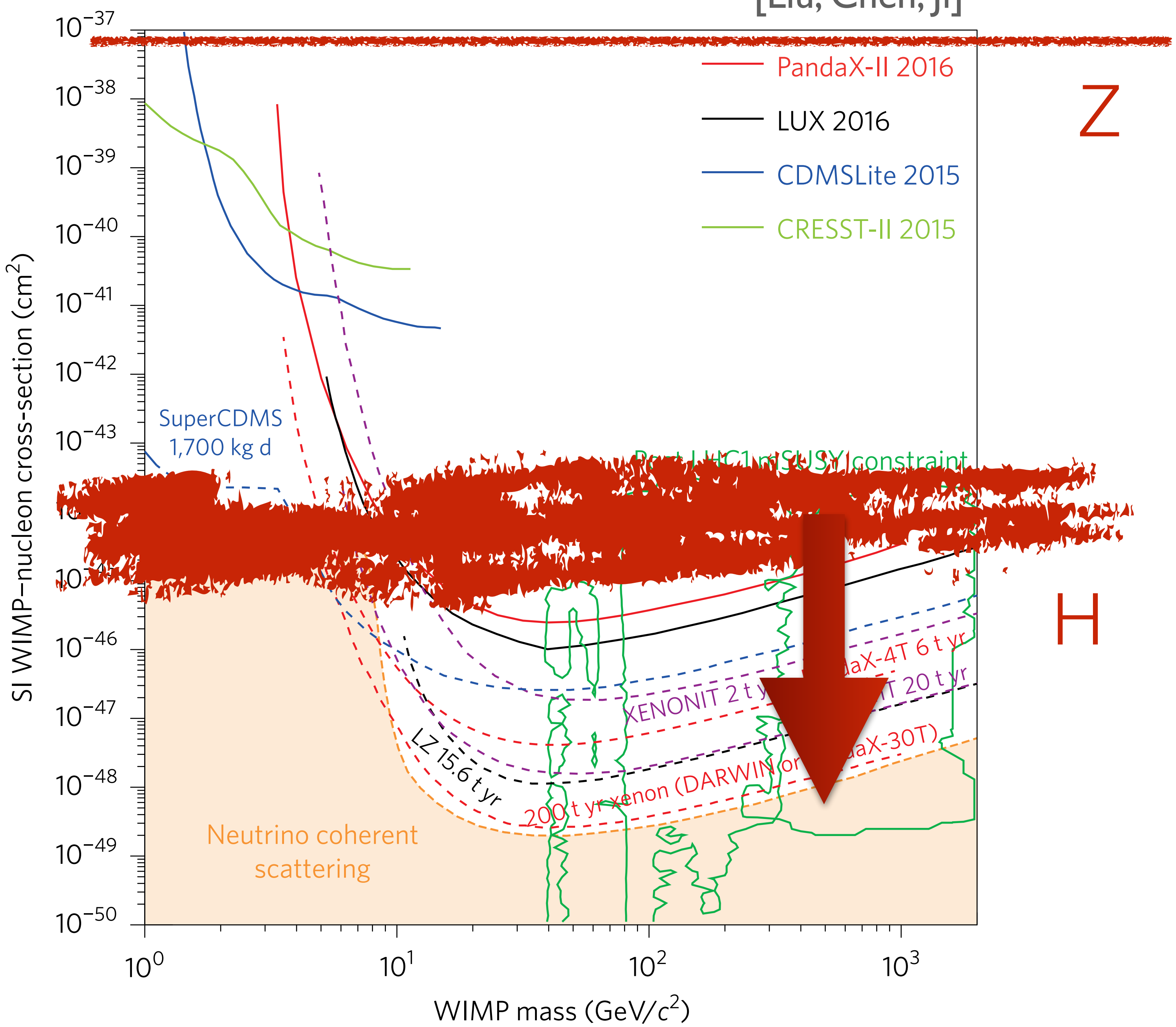


[Feng-US Cosmic Visions White papers]

WIMP

- DM interacts through weak (or weak scale) couplings
- Lee-Weinberg and Unitarity constrain mass range
  - ~1 GeV —~10 TeV
- Usually consider a thermal relic

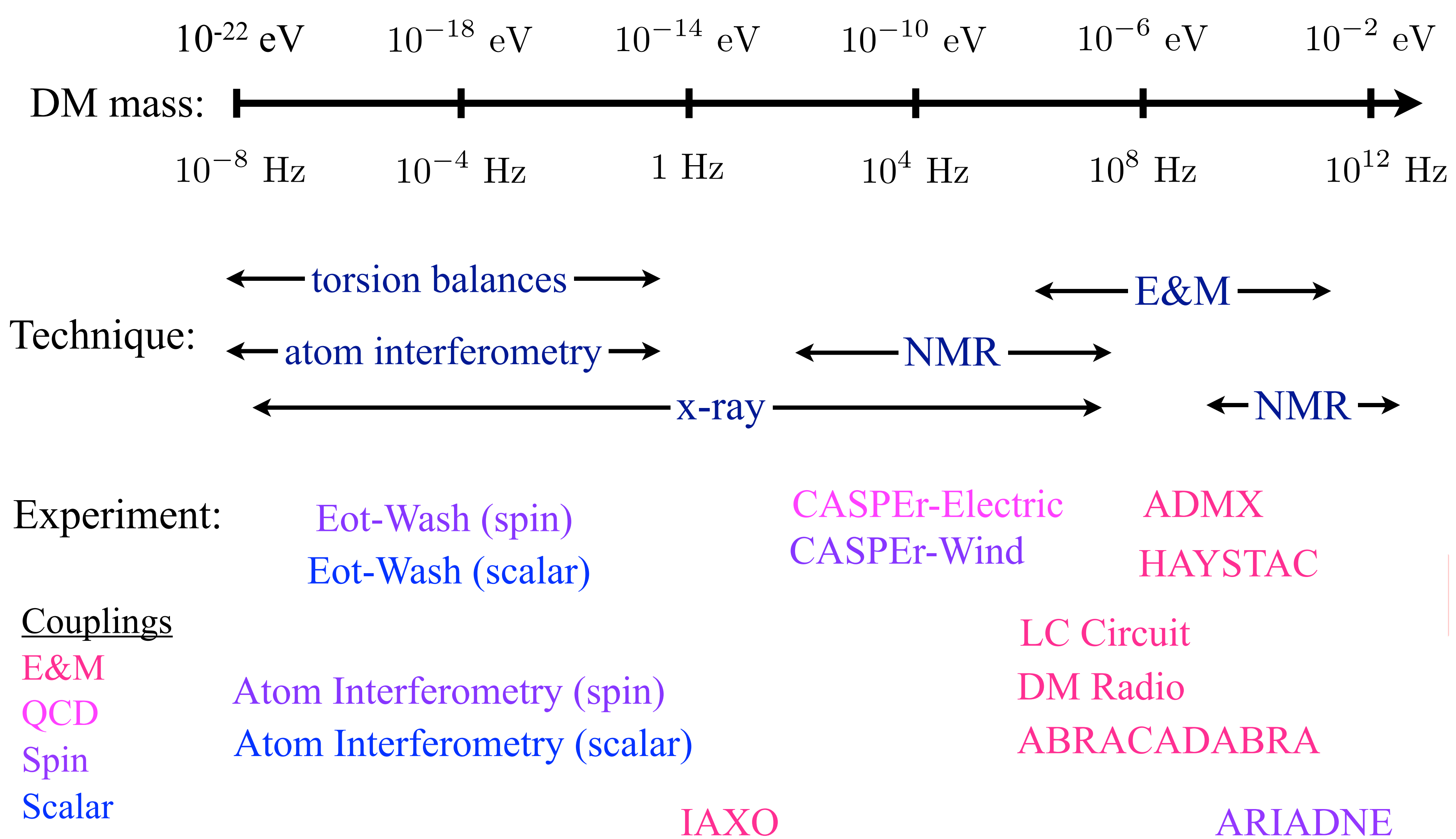
[Liu, Chen, Ji]



Fox (USA)

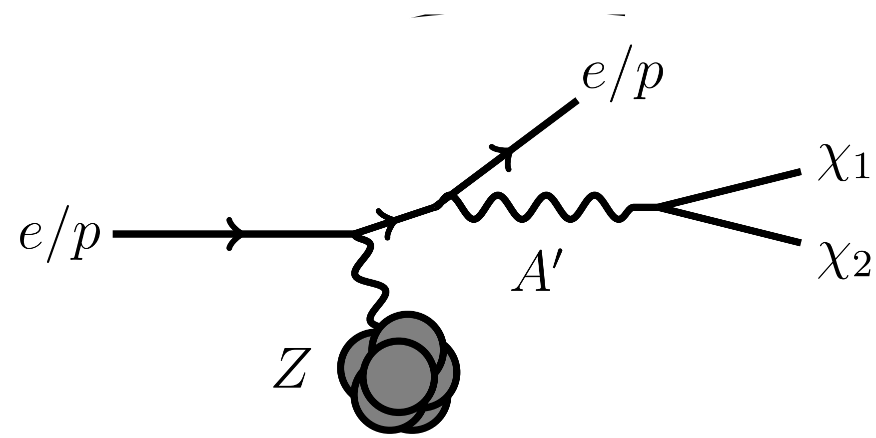
sub-keV DM

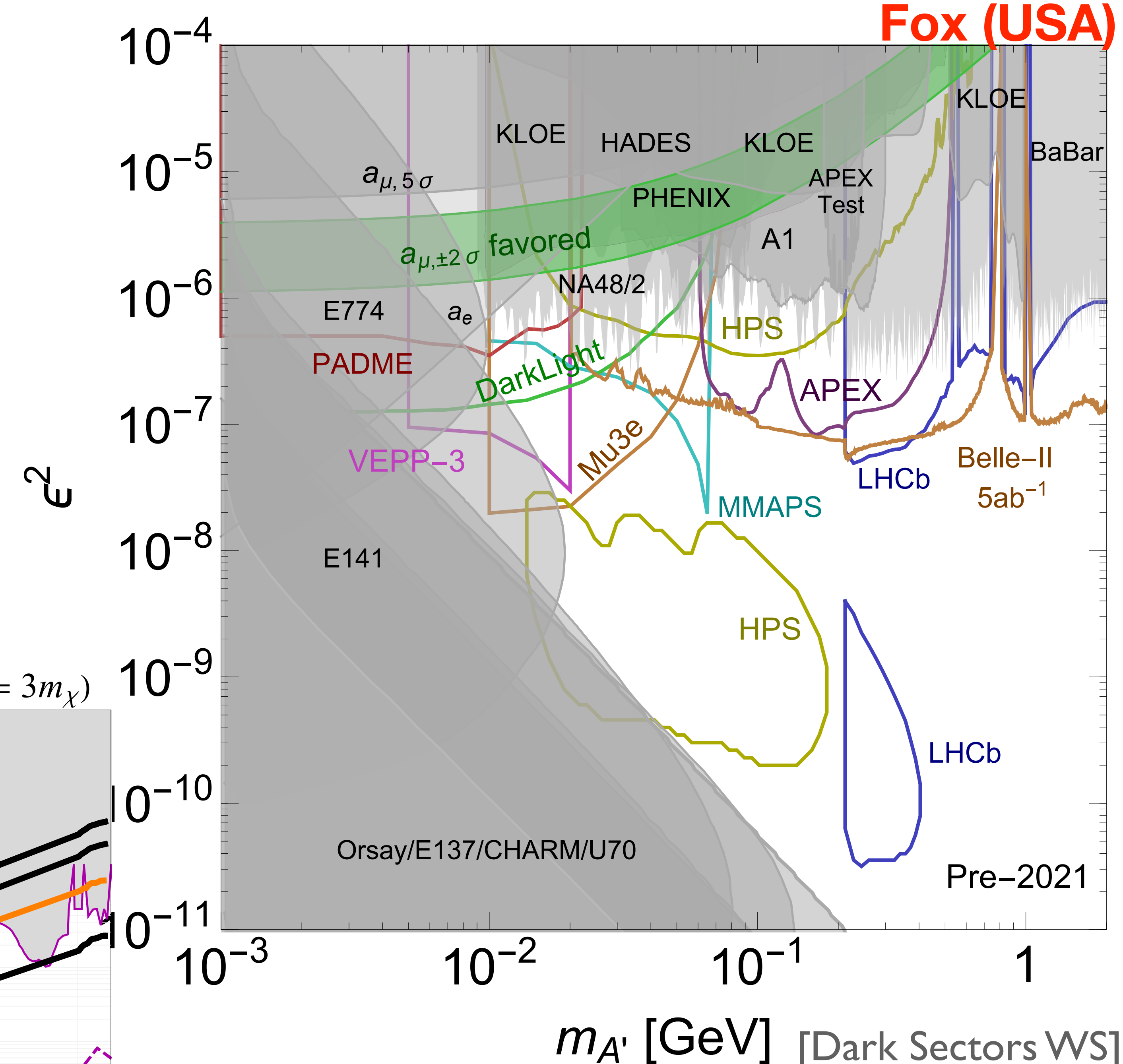
- Very light DM is bosonic
- Heavier than $10^{-22}\,\mathrm{eV}$
- More appropriately thought of as semiclassical wave, large n
- Or, absorption of DM, linear coupling to matter

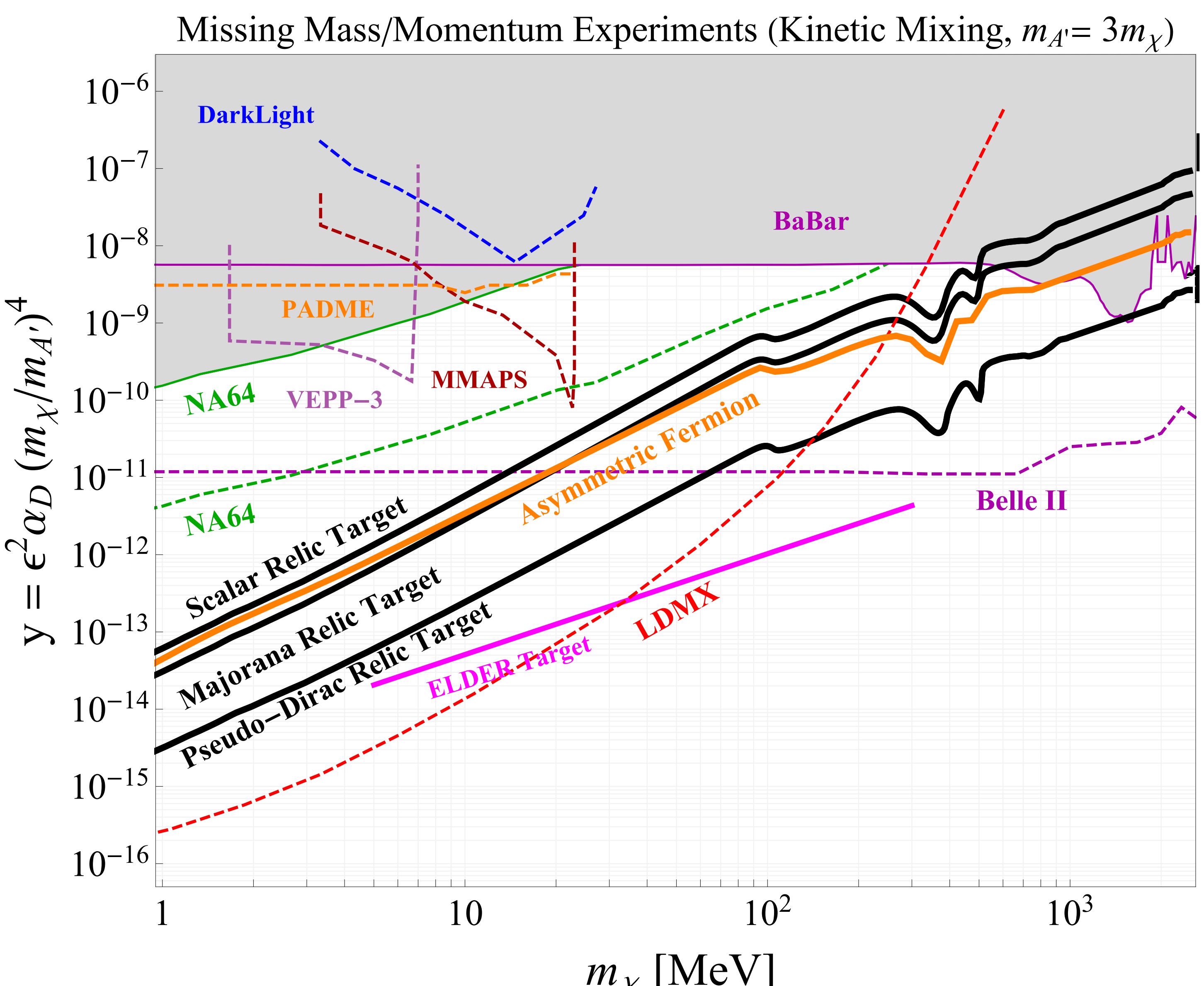


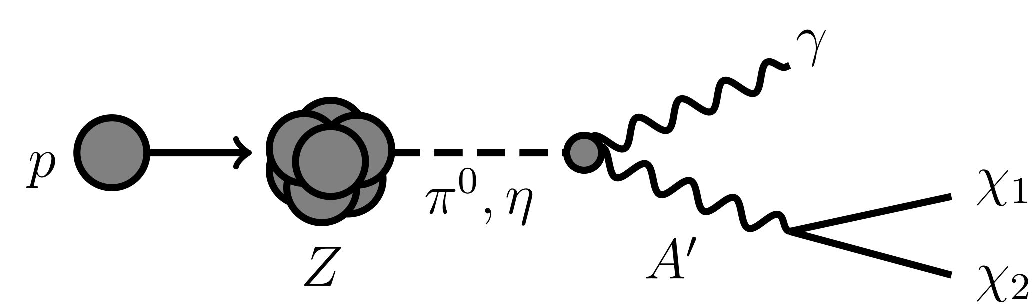
[US Cosmic Visions White papers]

Fox (USA)


e/p
e/p
A′
χ1
χ2
Z

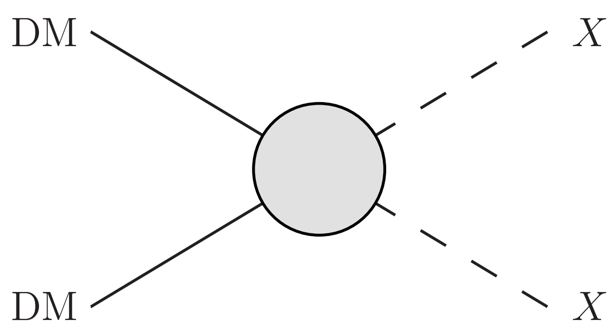

KLOE
HADES
KLOE
BaBar
KLOE
aμ,5σ
PHENIX
APEX Test
aμ,±2σ favored
A1
NA48/2
E774
ae
HPS
PADME
DarkLight
APEX
VEPP−3
Mu3e
LHCb
Belle−II 5ab−1
MMAPS
E141
HPS
LHCb
Orsay/E137/CHARM/U70
Pre−2021
ε2
mA′ [GeV]
[Dark Sectors WS]

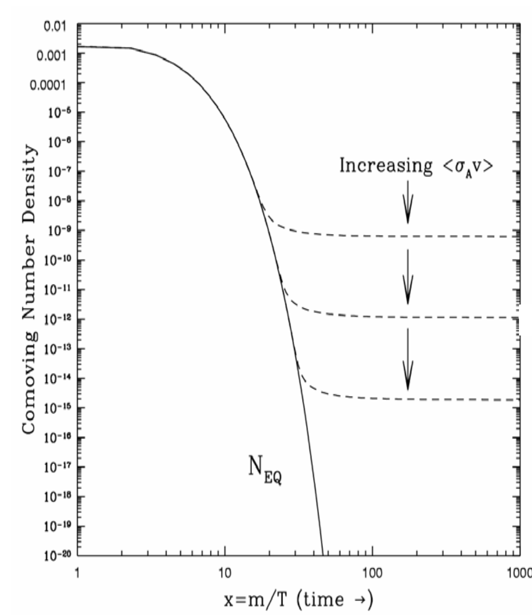

Missing Mass/Momentum Experiments (Kinetic Mixing, mA′= 3mχ)
DarkLight
BaBar
PADME
MMAPS
NA64
VEPP−3
NA64
Belle II
Asymmetric Fermion
Scalar Relic Target
Majorana Relic Target
Pseudo−Dirac Relic Target
ELDER Target
LDMX
y = ε2αD (mχ/mA′)4
mχ [MeV]

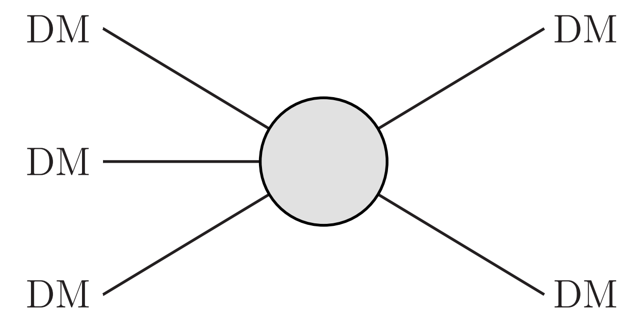

p
Z
π0, η
A′
γ
χ1
χ2

Hidden sector DM—thermal relics

Leads to interesting changes in cosmology



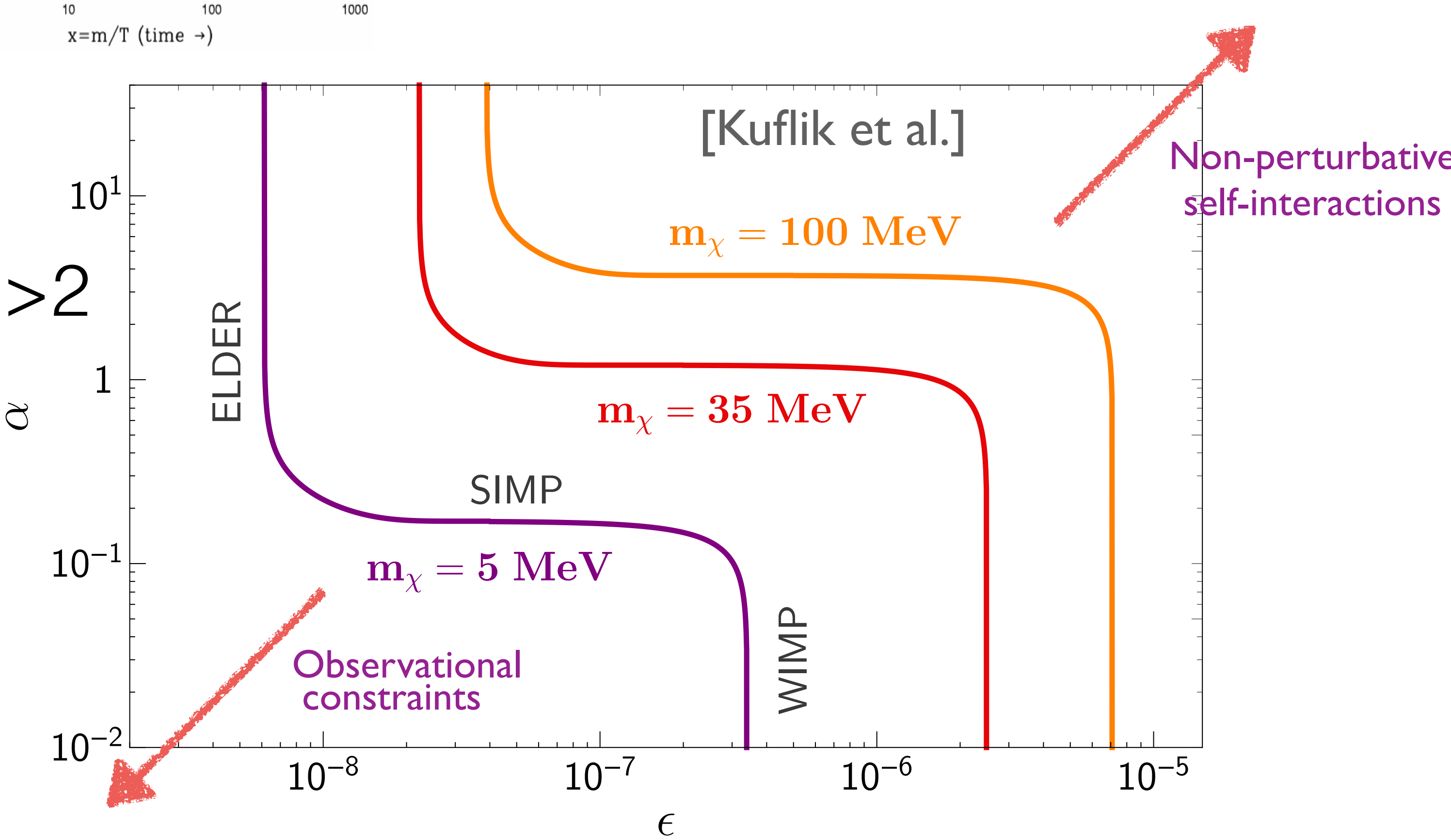




cannibalization

WIMPless-miracle
(1-100 MeV scale)
SIMP-miracle
ELDER…
all smoothly connected
in parameter space

3->2



DM-SM elastic scatter

Fox (USA)

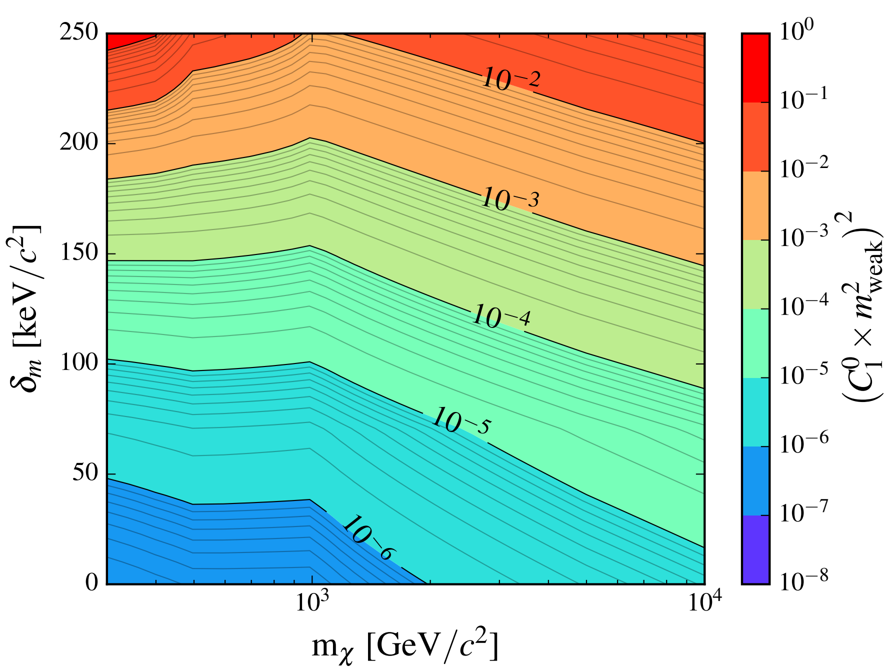
Crossing the Inelastic Frontier—Xenon100

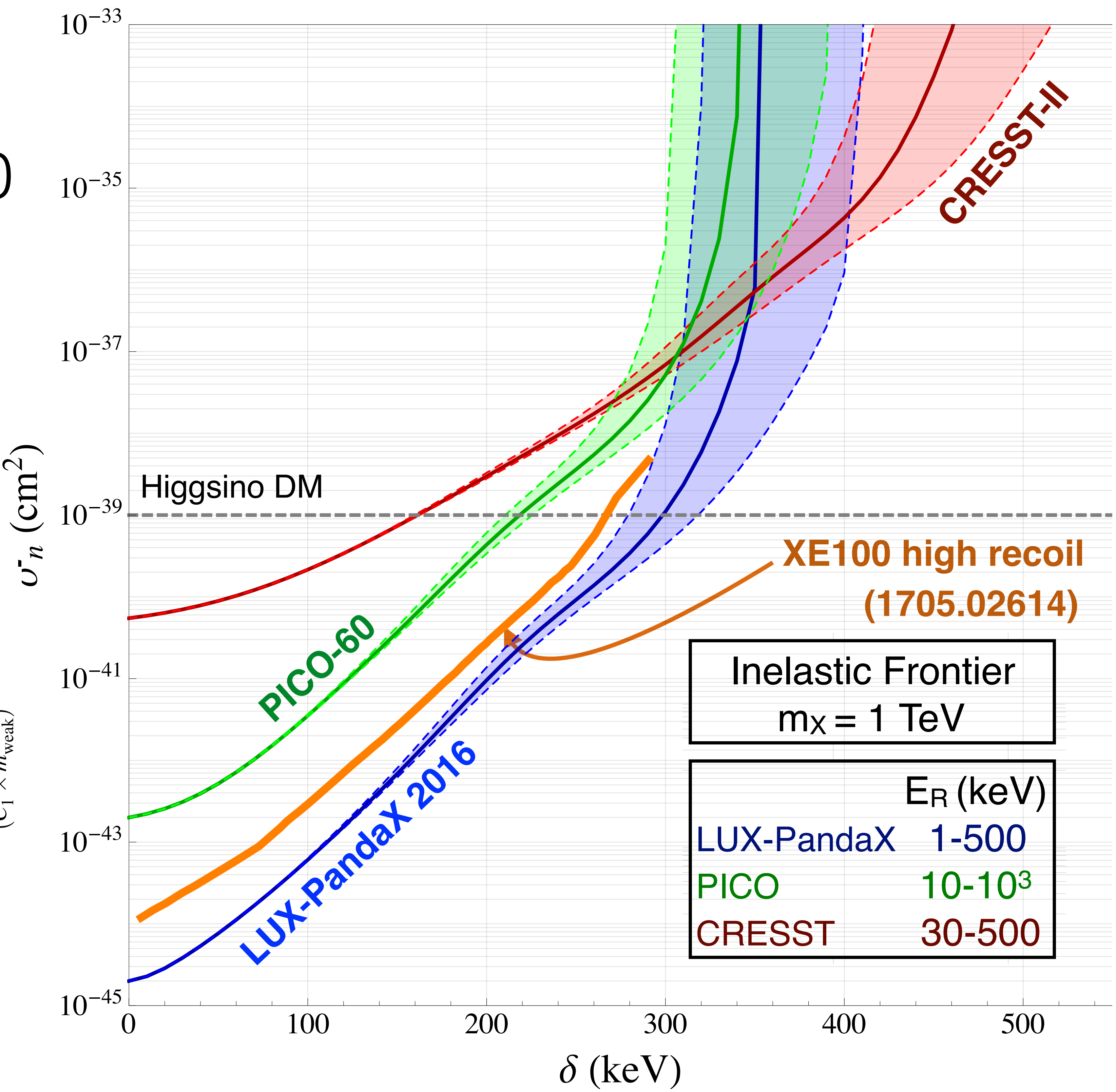
Reanalysis

7.6 ton-days, Xe100

6.6-240 keVnr

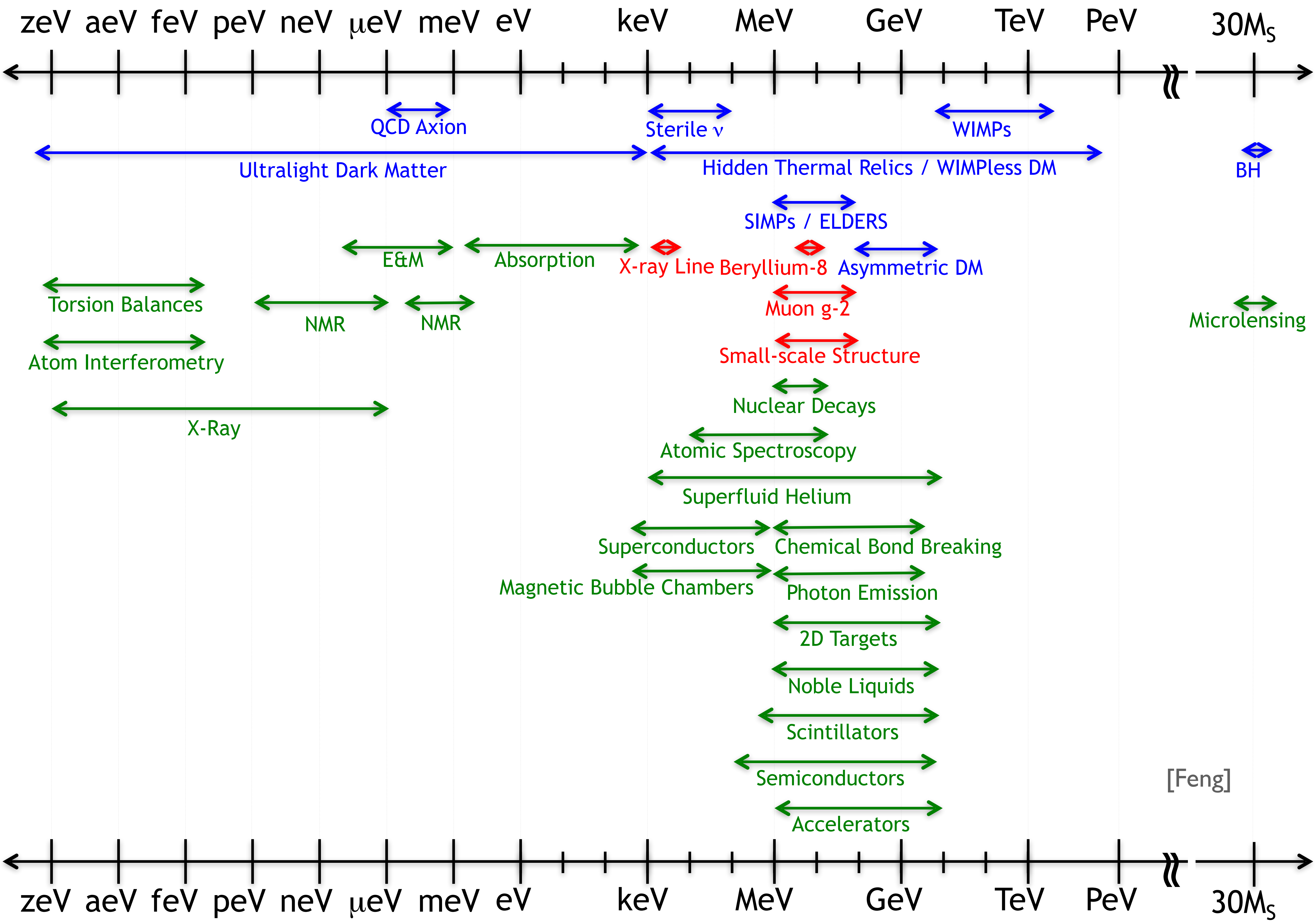
Inelastic analysis



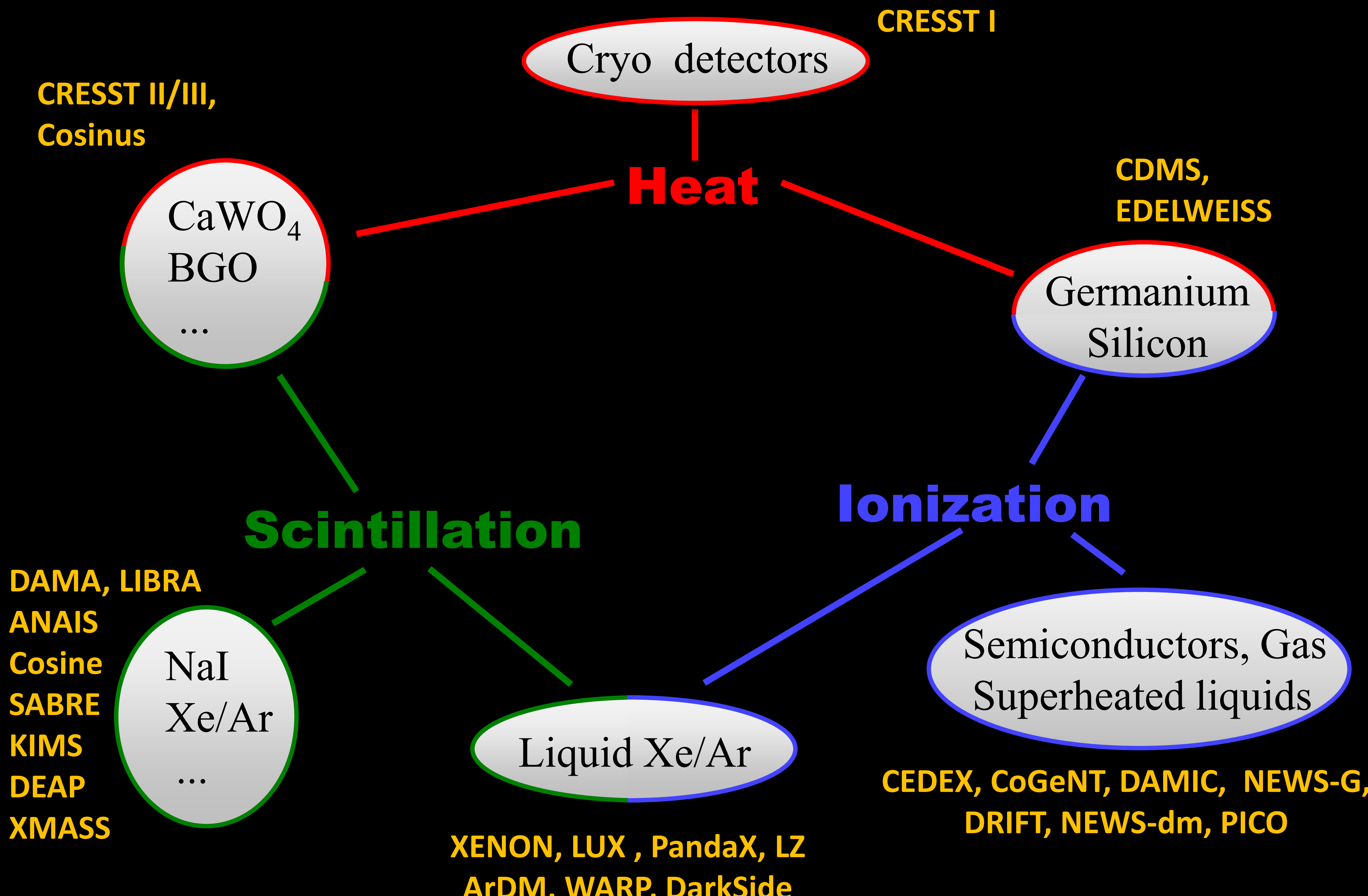


Dark Sector Candidates, Anomalies, and Search Techniques

Fox (USA)

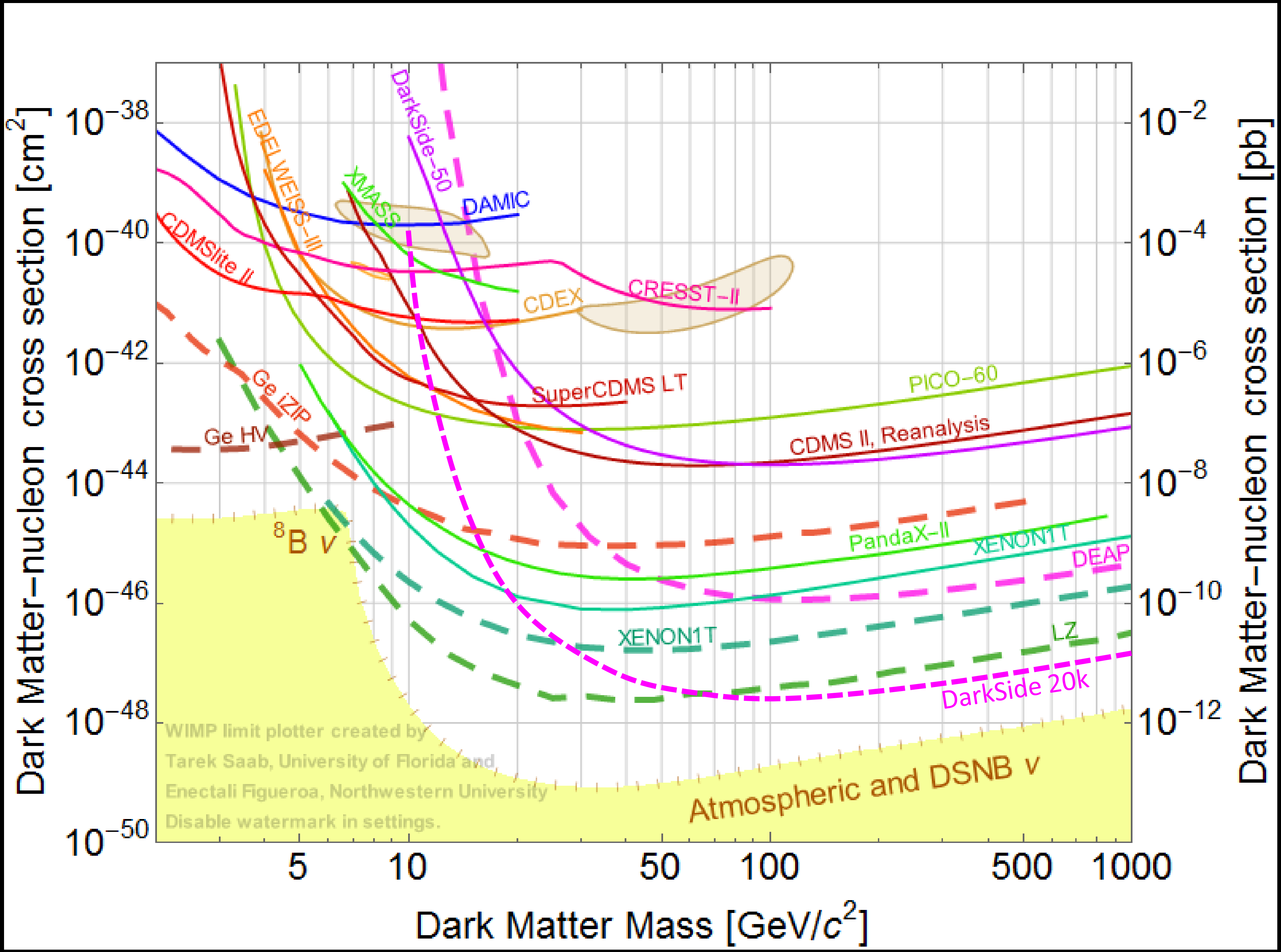


Direct Detection Triangle



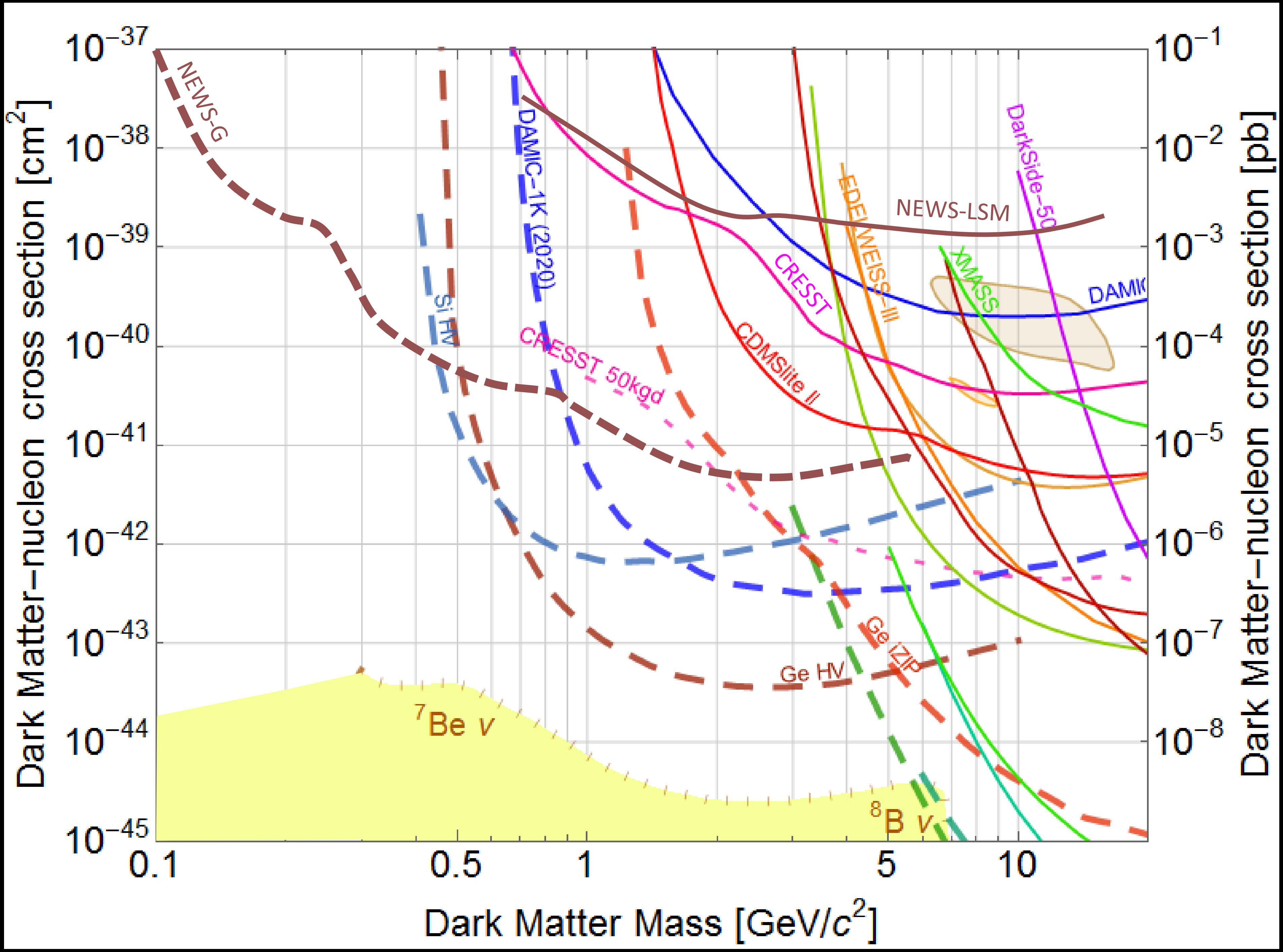
Rau

Results and Projections

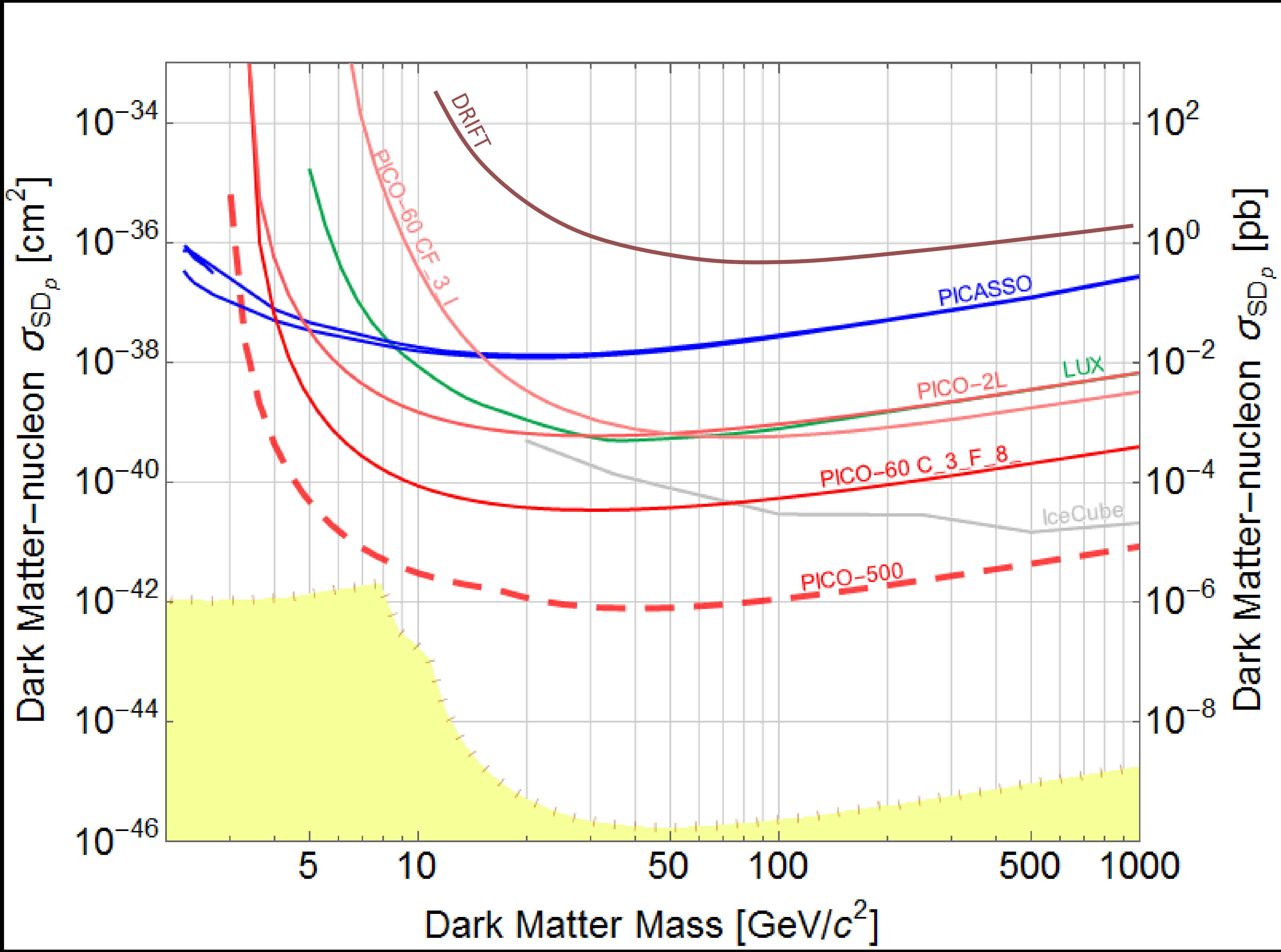


Rau

Results and Projections

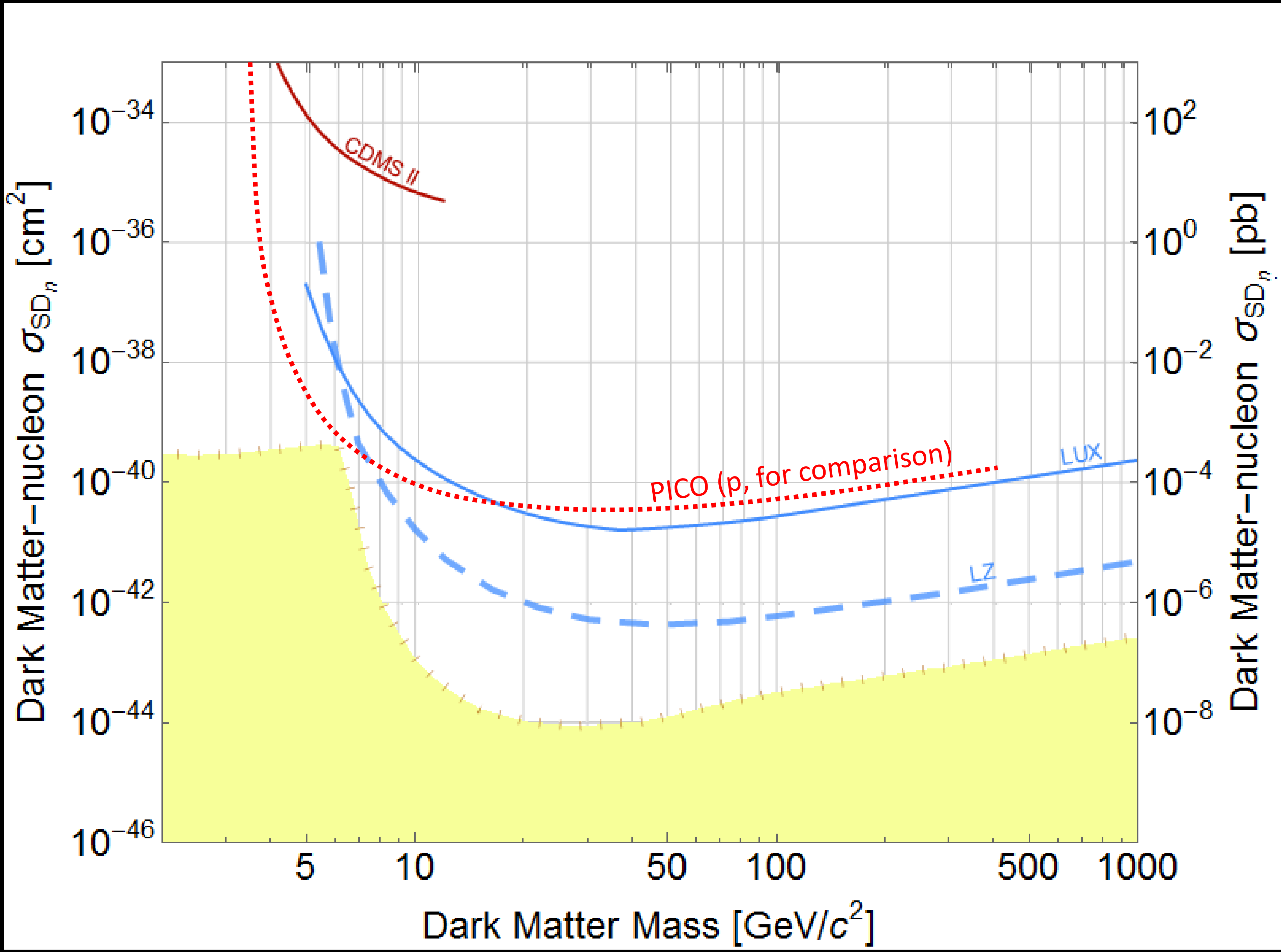


Results and Projections



Rau

Results and Projections



After LHC

Physics After LHC

Place

Location: The Hong Kong University of Science and Technology
Address: Hong Kong, China

Files

Edit files

Date: **28 Jun 11:00 - 14:30**

Description

Discussion Leader: Michelangelo Mangano (CERN, Switzerland)

Wed 28/06

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11:00	**The Unique Role of Future High-Energy pp Colliders** *The Hong Kong University of Science and Technology*	*Andrea WULZER* 11:05 - 11:25
	The Unique Role of Future High-Energy ee Colliders *The Hong Kong University of Science and Technology*	*Tao HAN* 11:30 - 11:50
12:00	**The Technology Landscape of Future Accelerators** *The Hong Kong University of Science and Technology*	*Lyn EVANS* 11:55 - 12:20
13:00	**Detectors for Future Collider Experiments** *The Hong Kong University of Science and Technology*	*Lucie LINSSEN* 12:55 - 13:15
	Searches for Unconventional Signatures at Future Accelerators *The Hong Kong University of Science and Technology*	*David CURTIN* 13:20 - 13:40
14:00	**Future Experiments to Complement High-E Colliders in the Search and Study of BSM** *The Hong Kong University of Science and Technology*	*Eder IZAGUIRRE* 13:45 - 14:05

Ideology

HEP before the LHC

HEP before the F.C.

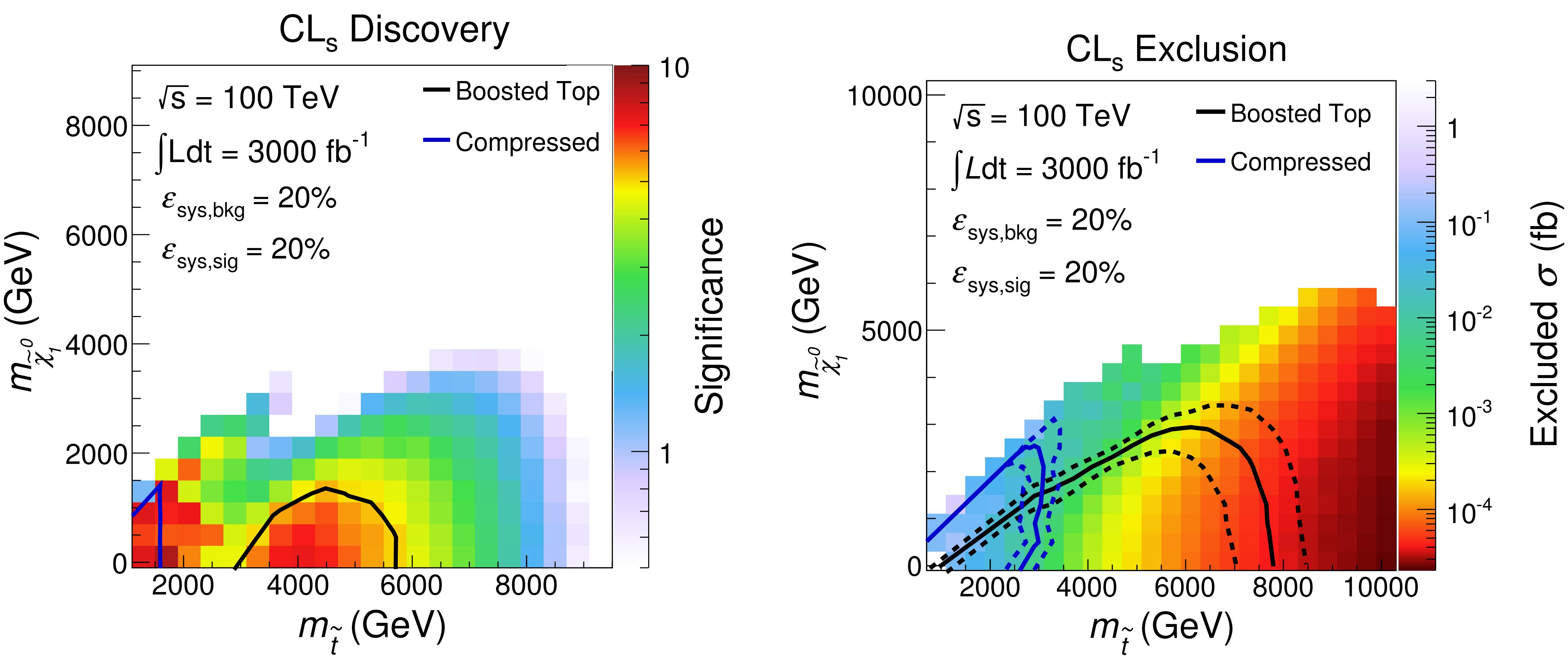
Particle physics is not **validation** anymore, rather it is **exploration of unknown territories** *

* Not necessarily a bad thing. Columbus left for his trip just because he had no idea of where he was going !!

Naturalness

Stop to top + Neutralino:

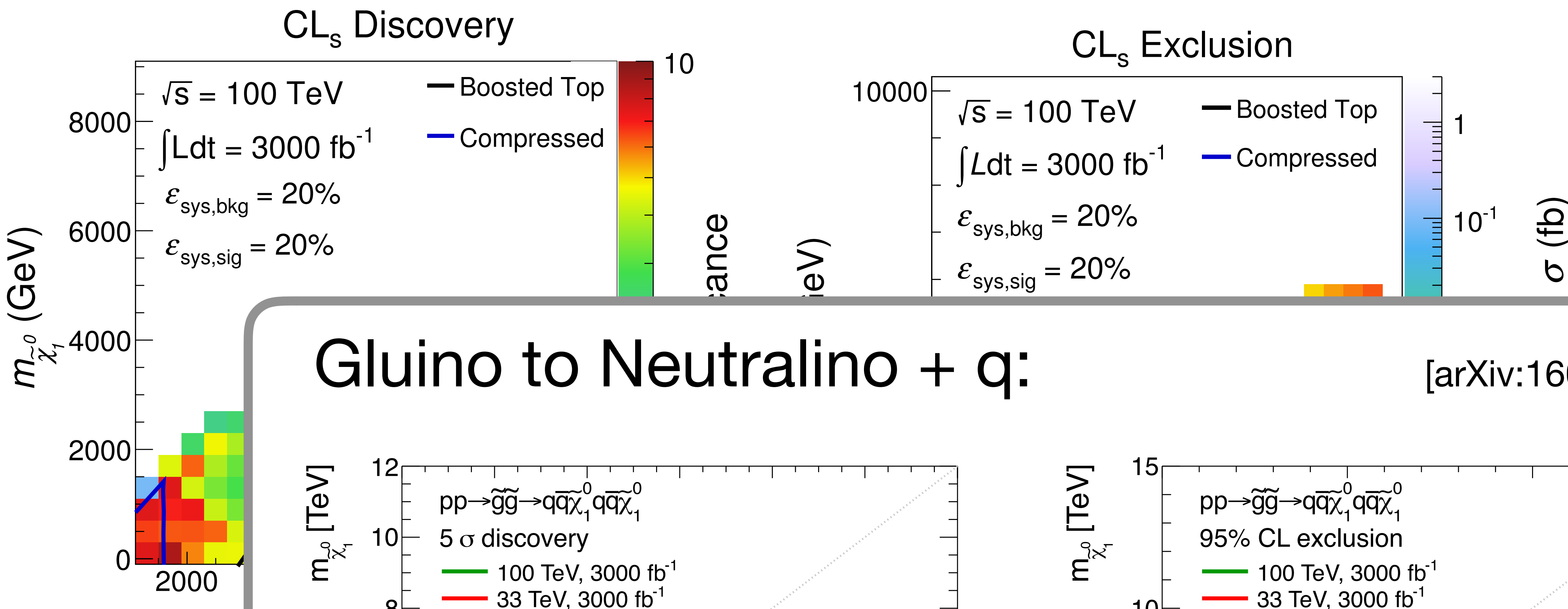
[arXiv:1406.4512]



Naturalness

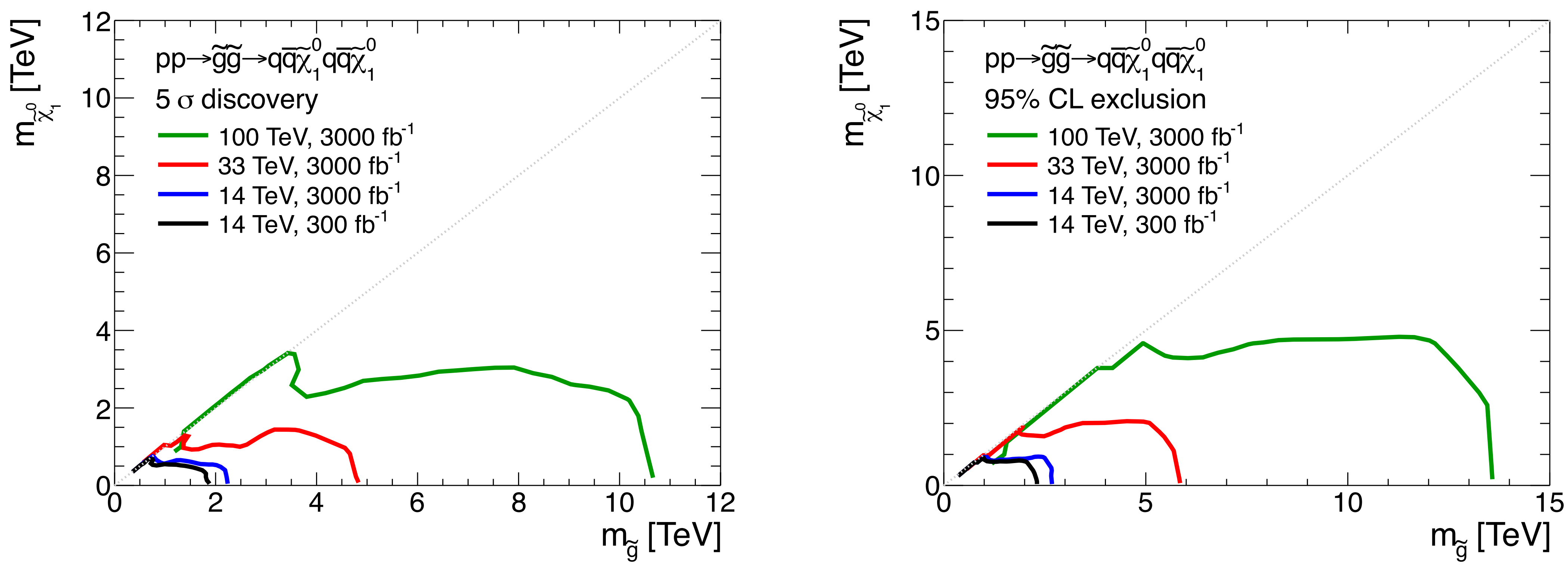
Stop to top + Neutralino:

[arXiv:1406.4512]



Gluino to Neutralino + q:

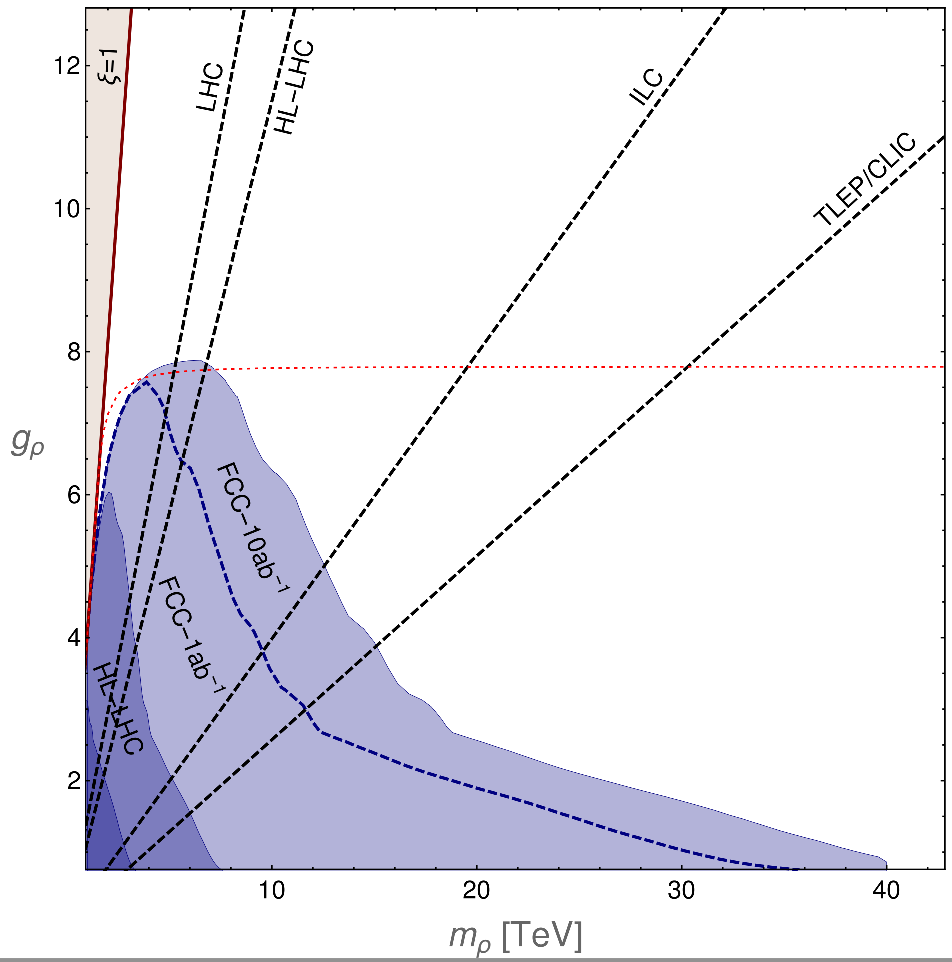
[arXiv:1606.00947]

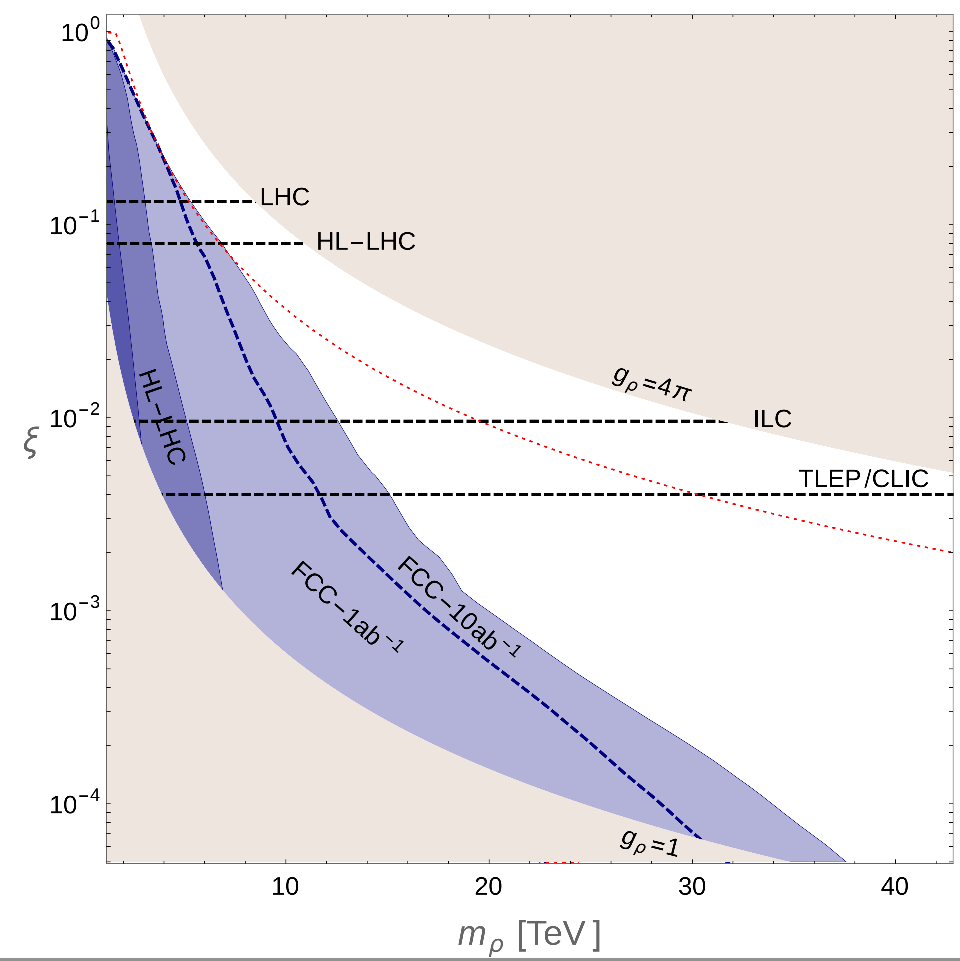


Naturalness

Spin-1 CH resonances (or V'):

[arXiv:1502.01701]

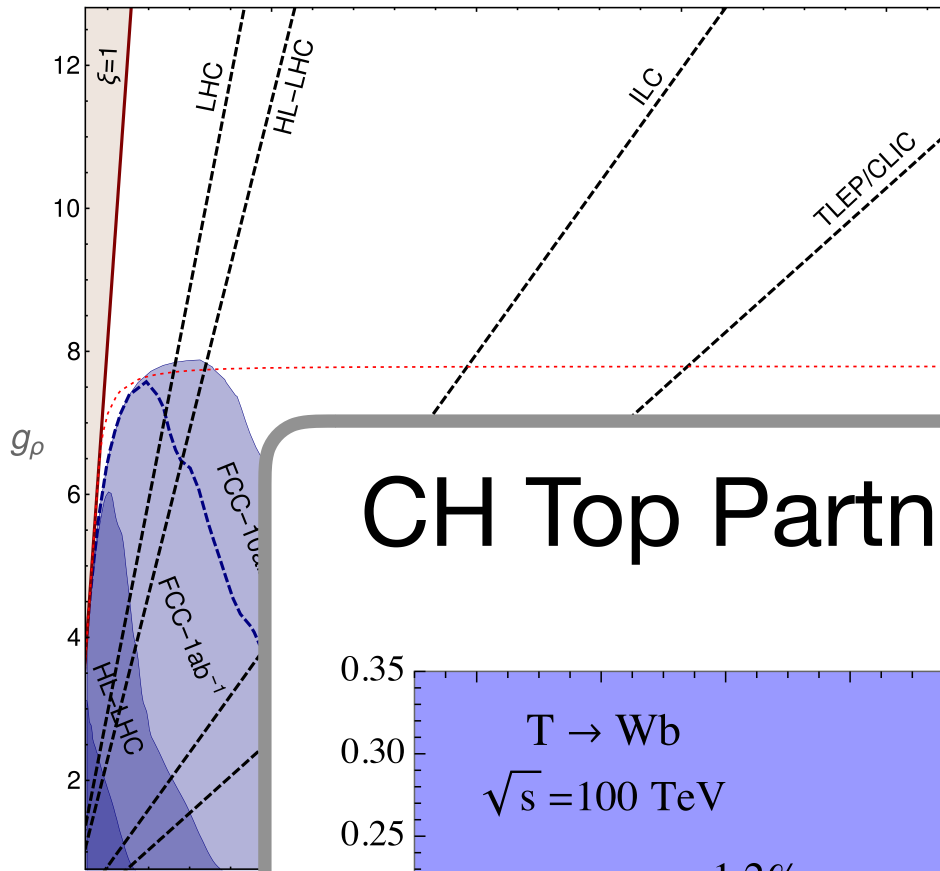


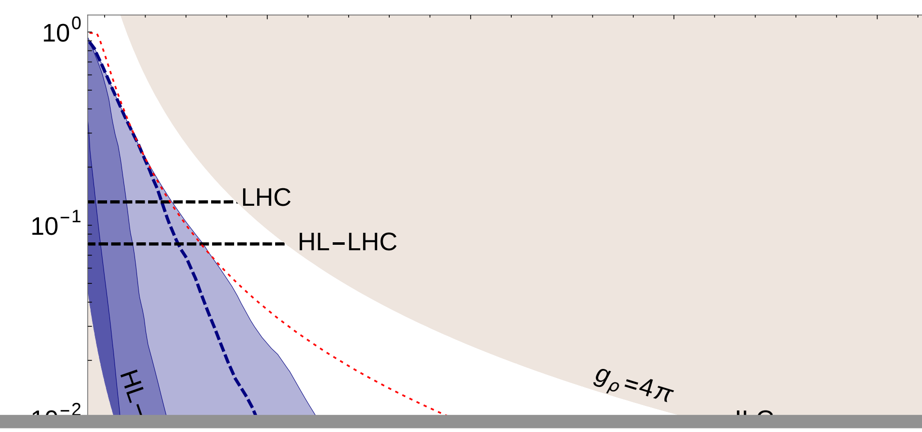


Naturalness

Spin-1 CH resonances (or V’):

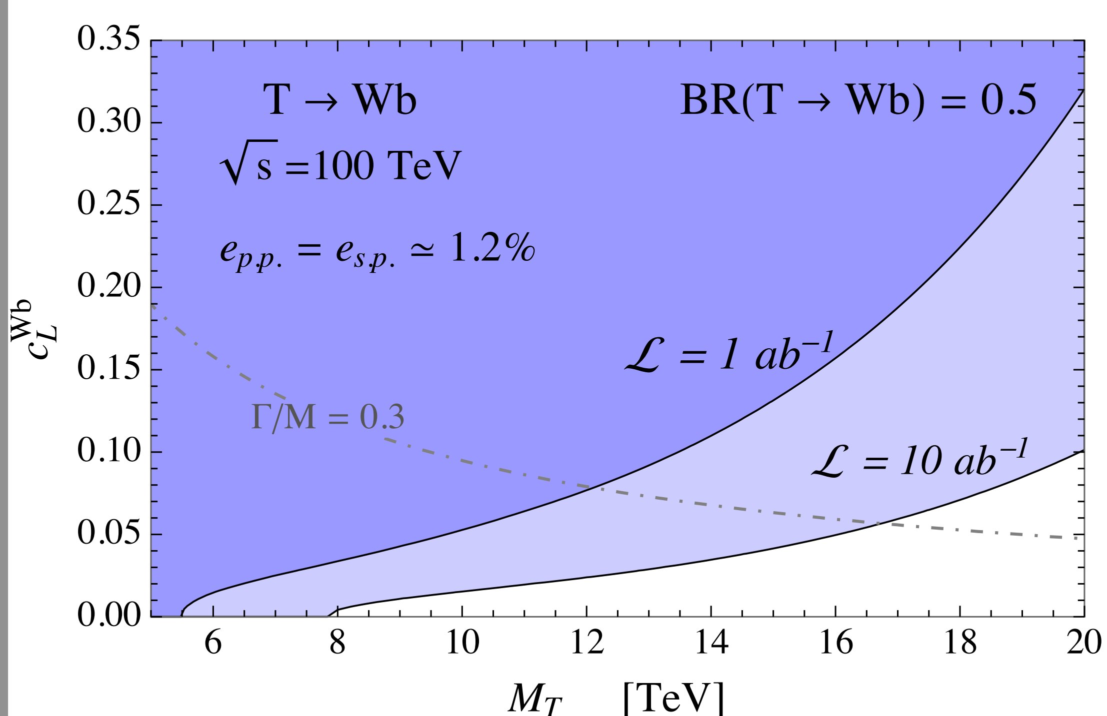
[arXiv:1502.01701]

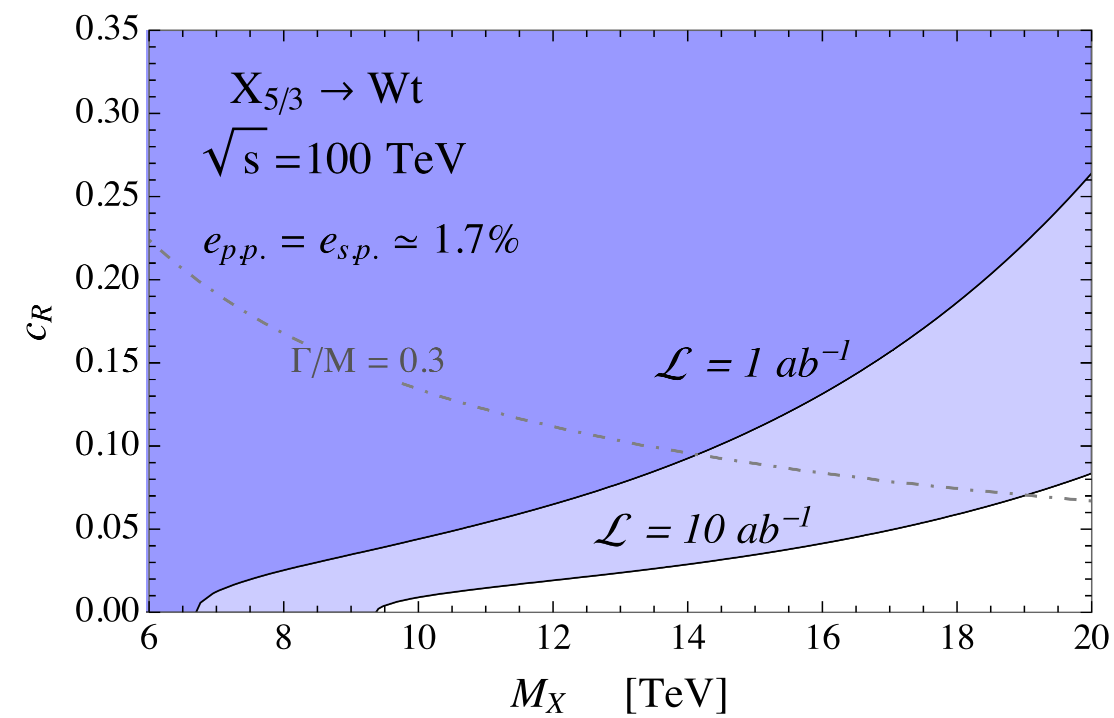




CH Top Partners:

[arXiv:1409.0100]



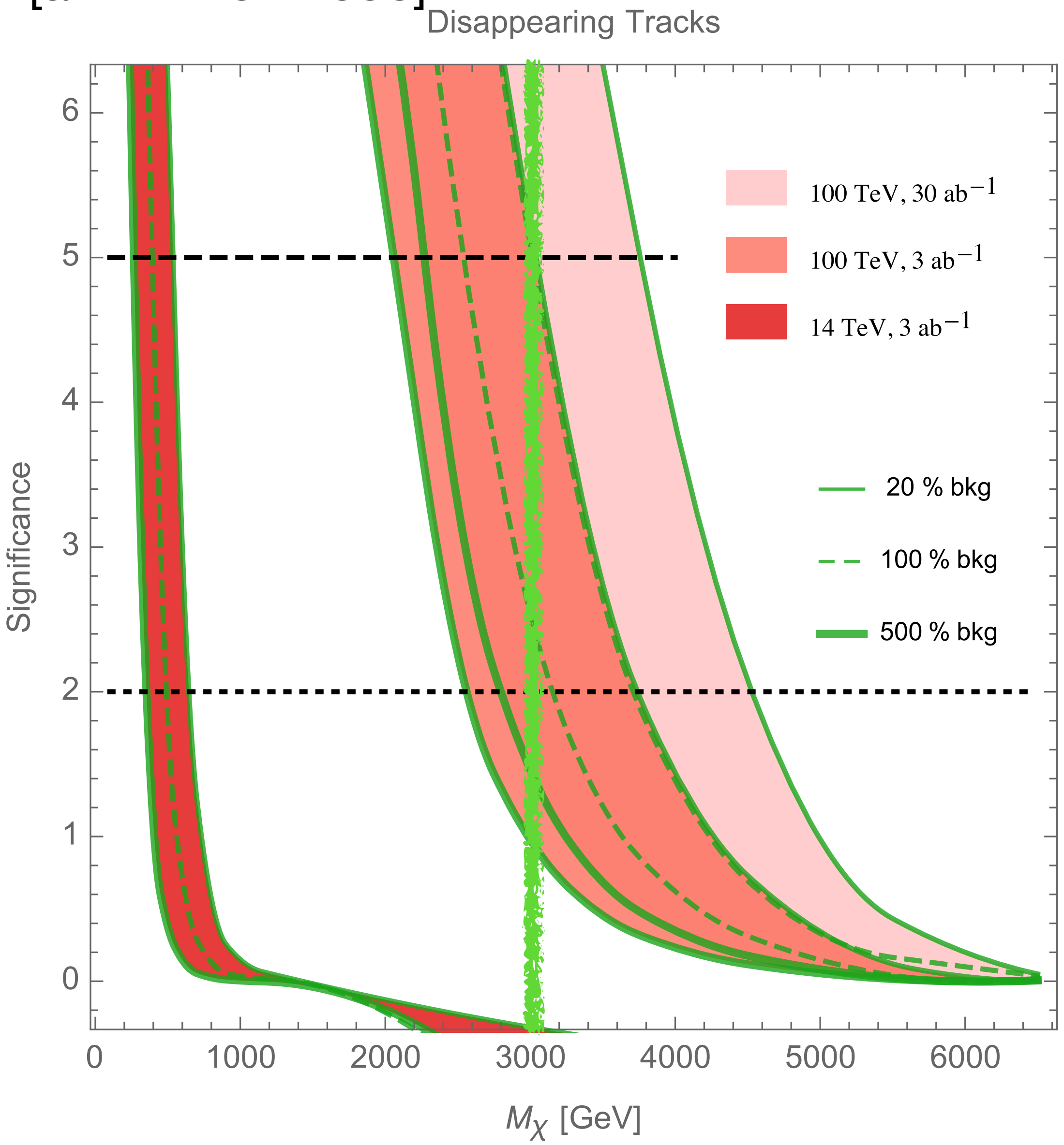


Dark Matter

100 TeV can probe WIMP DM unaccessible to current and future Direct Detection

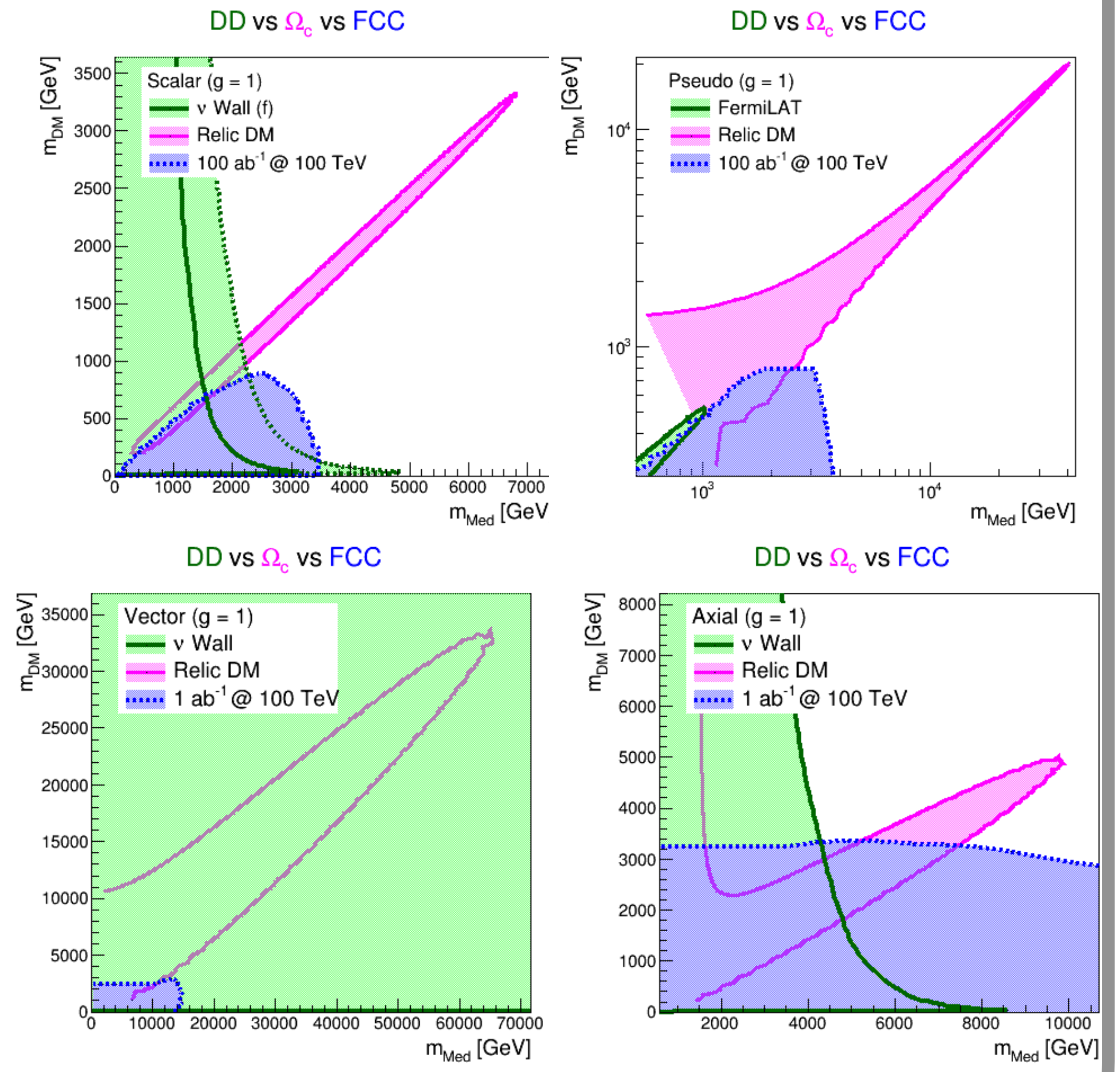
Wino DM. (disappearing tracks:)

[arXiv:1407.7058]



Crossing neutrino wall:

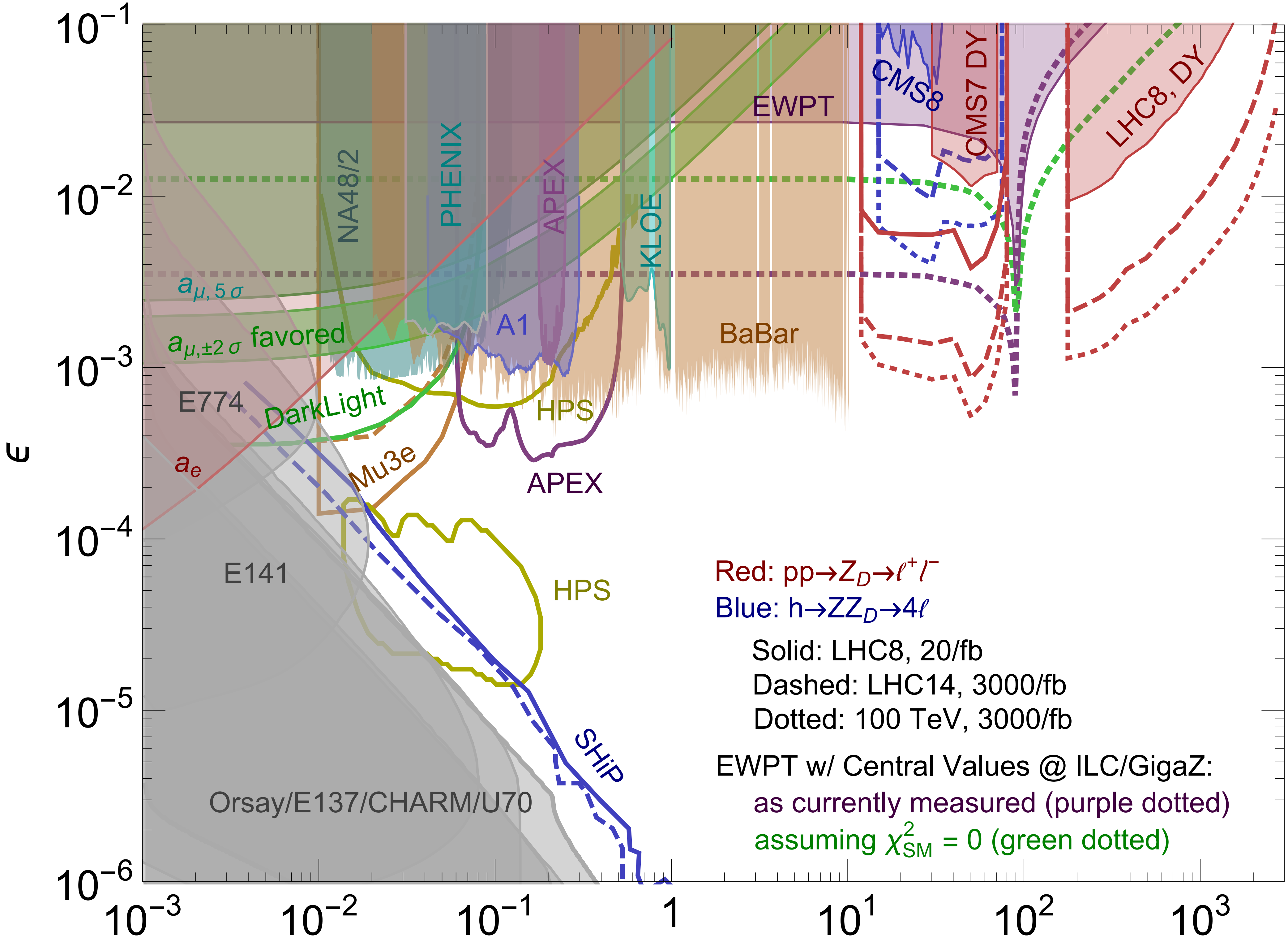
[arXiv:1606.00947]



Intensity/Accuracy Frontier @ 100 TeV

Huge “low-mass” rate allows to produce Dark Sec. part. ...

Dark photon:
[arXiv:1412.0018]

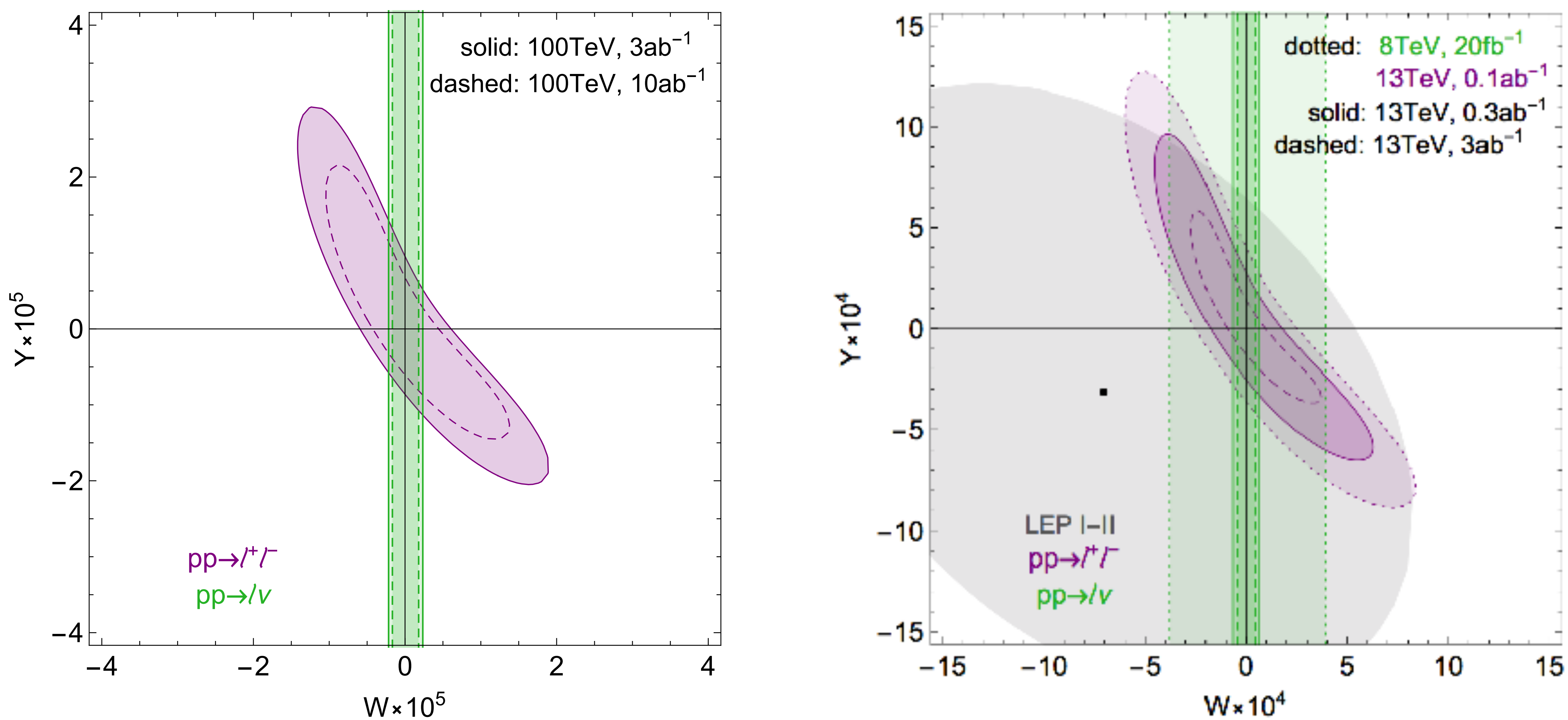


Energy **and** Accuracy Frontier @ 100 TeV

Enhanced indirect NP effects in high mass tails

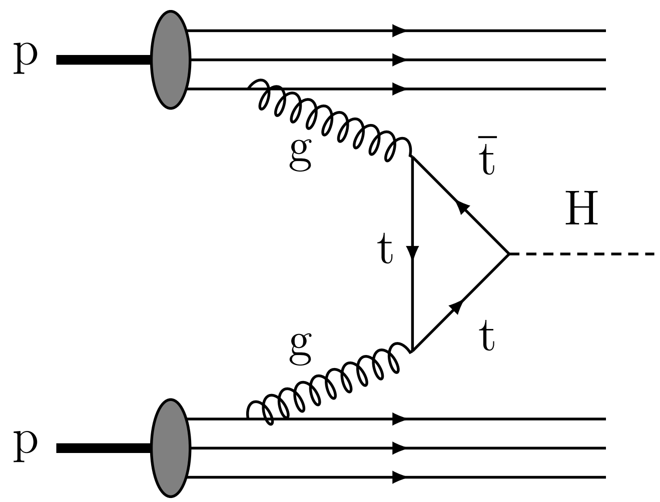
No need of extreme accuracy for indirect NP probe

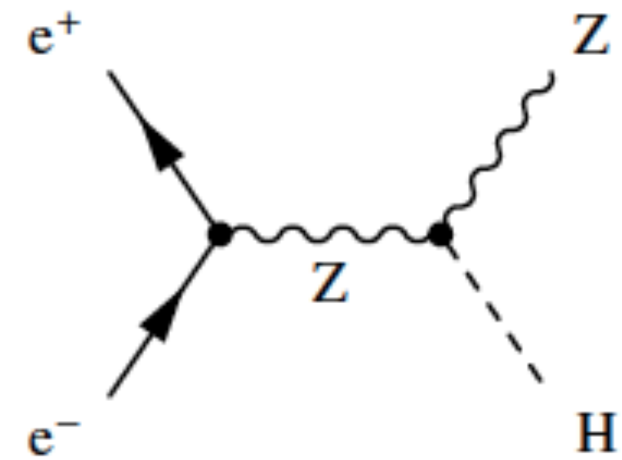
EWPT @ hadron colliders: (W and Y oblique par.s) [arXiv:1609.08157]



pp collisions / e^+e^- collisions

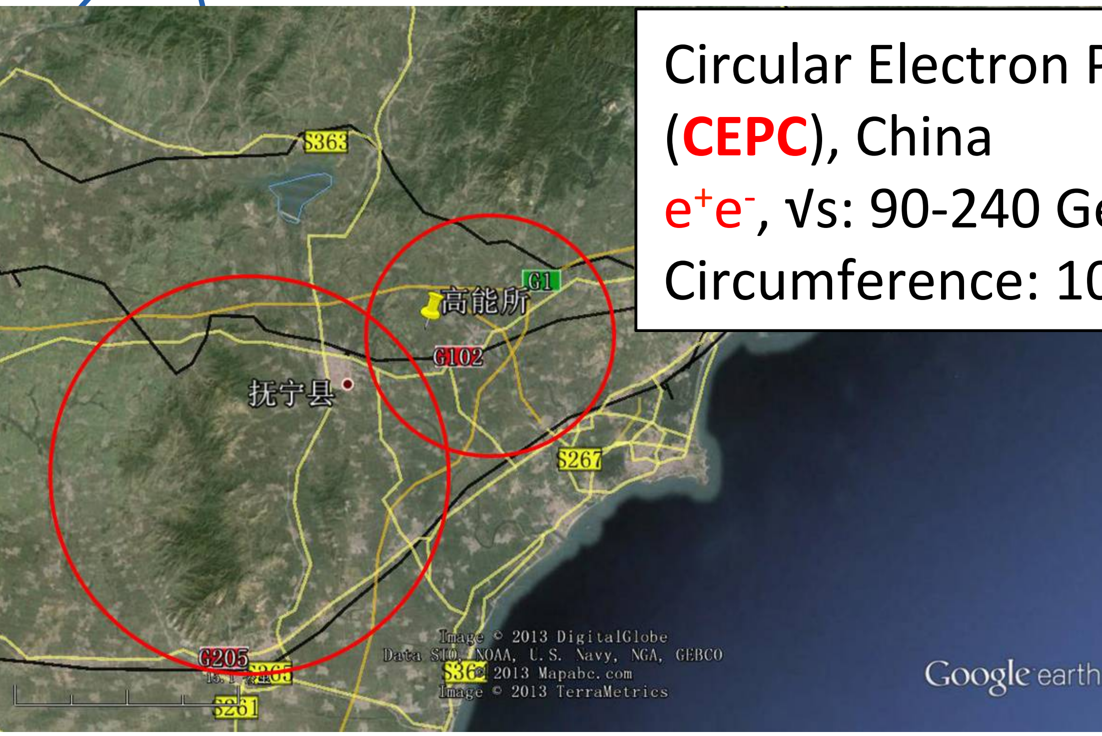
to tackle the open questions in particle physics



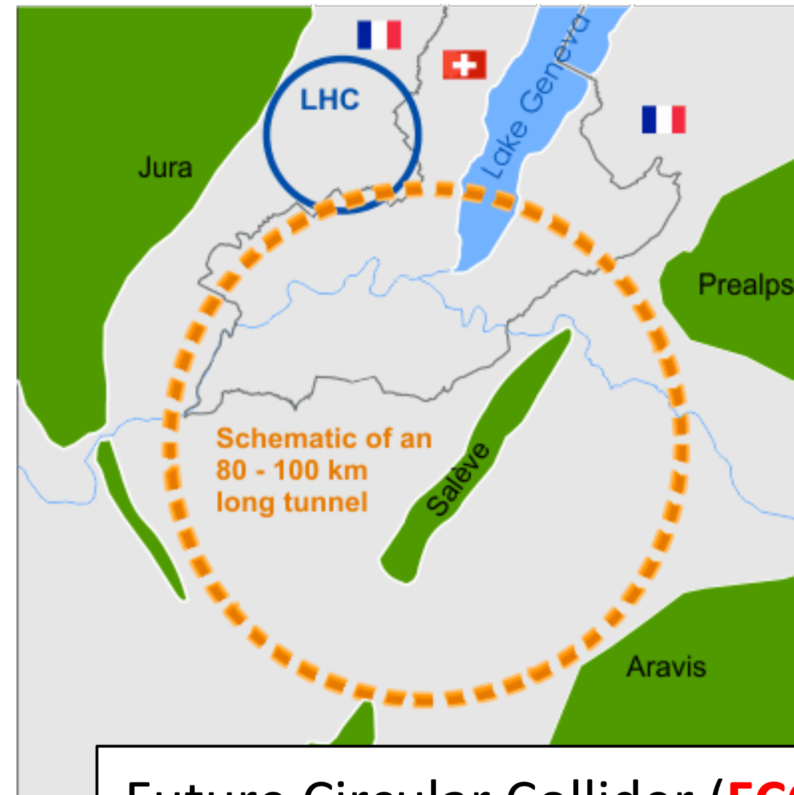


p-p collisions	e^+e^- collisions
Proton is compound object → Initial state unknown → Limits achievable precision	**e^+/e^- are point-like** → Initial state well defined (√s / opt: polarisation) → High-precision measurements
High rates of QCD backgrounds → Complex triggering schemes → High levels of radiation	**Cleaner experimental environment** → Less / no need for triggers → Lower radiation levels
High cross-sections for **colored-states**	Superior sensitivity for **electro-weak states**
Very high-energy **circular** pp colliders feasible	High energies (>≈350 GeV) require **linear** collider

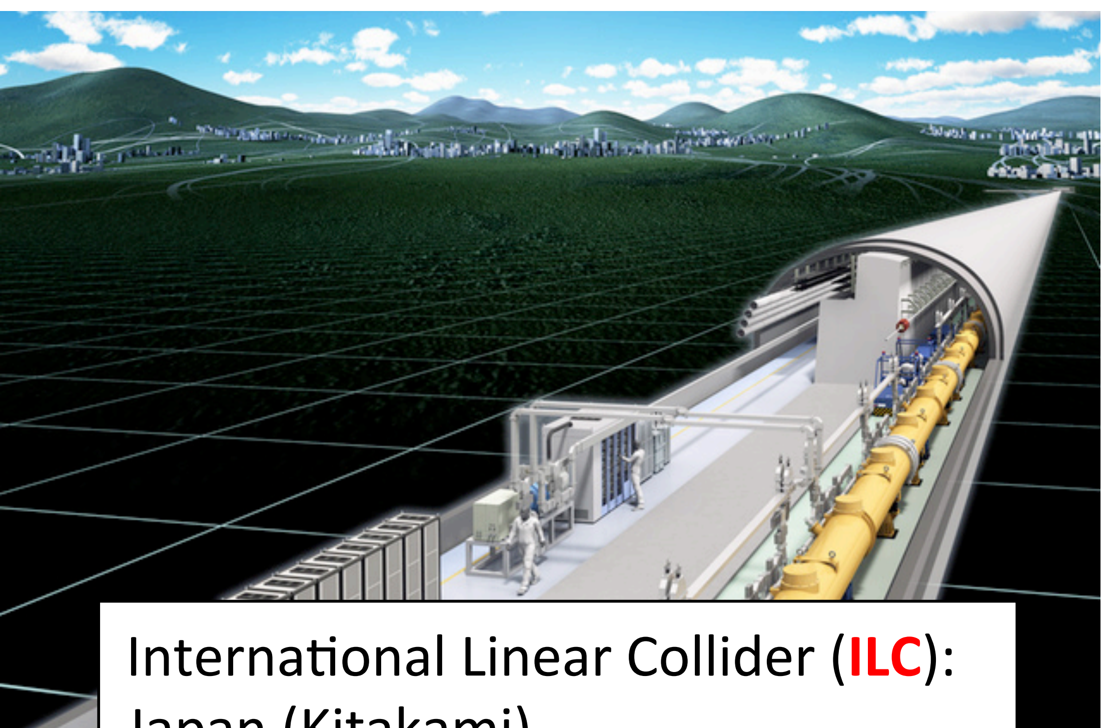
studies of high-energy e^+e^- colliders



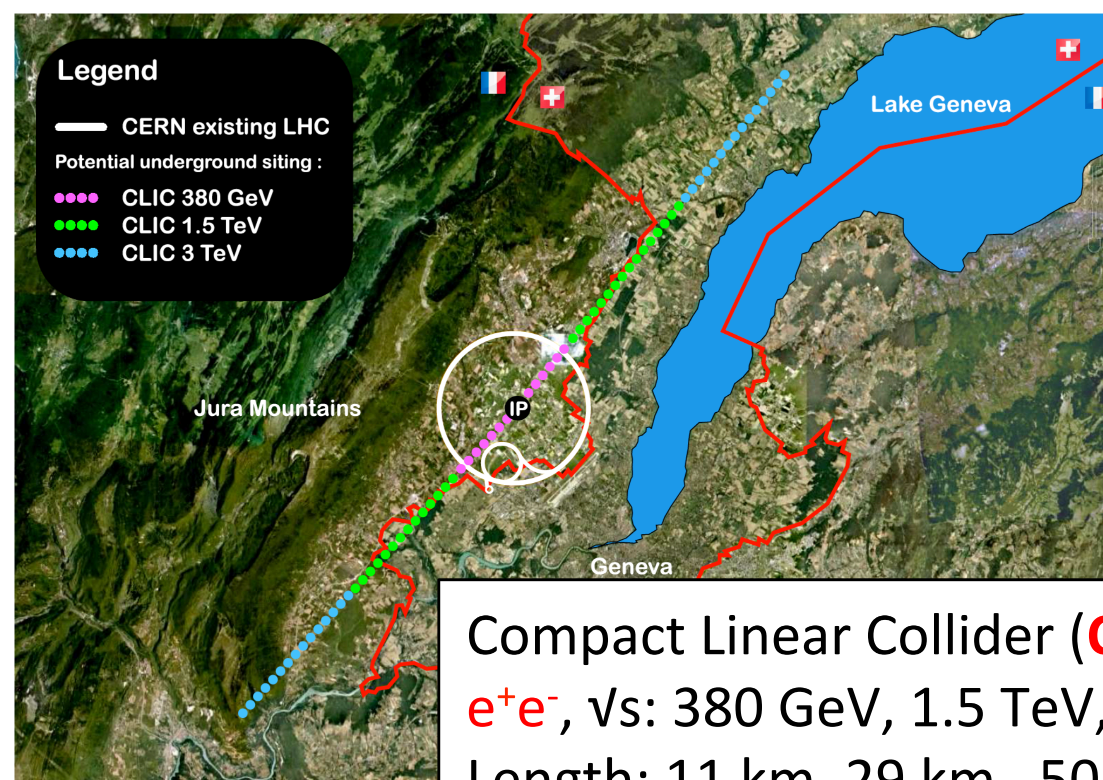
Circular Electron Positron Collider (**CEPC**), China
e^+e^-, √s: 90-240 GeV; SPPC pp,
Circumference: 100 km



Future Circular Collider (**FCC-ee**): CERN
e^+e^-, √s: 90 - 350 GeV; FCC-hh pp
Circumference: 97.75 km

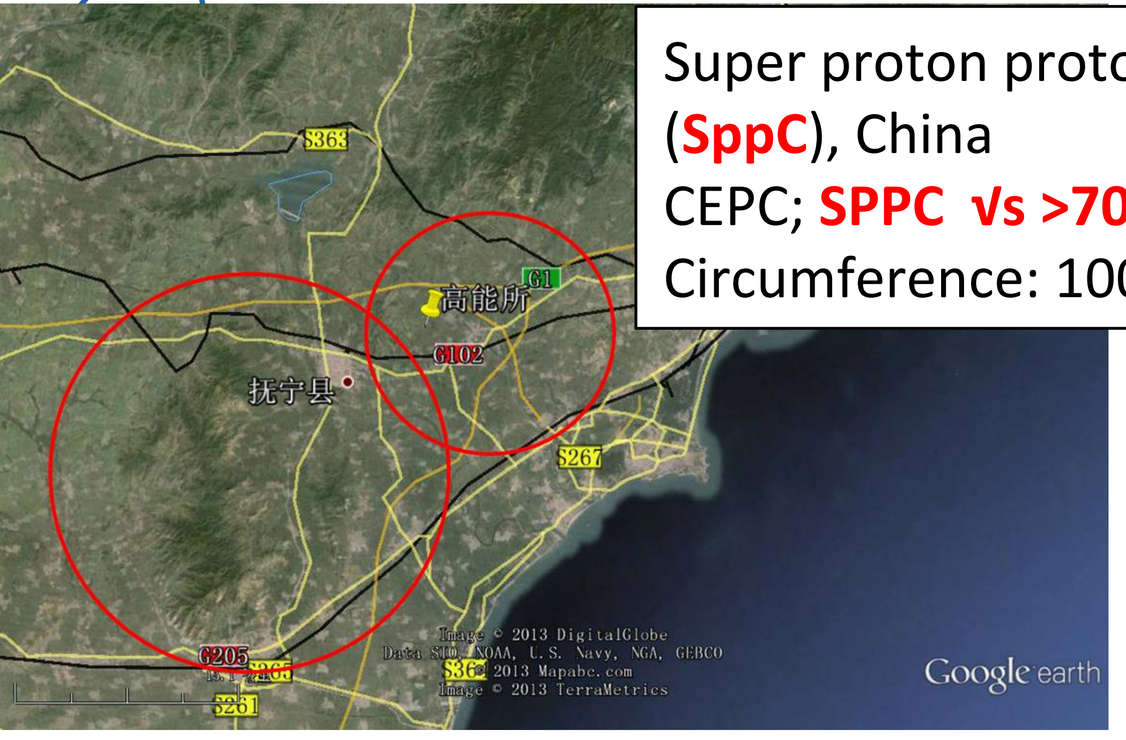


International Linear Collider (**ILC**): Japan (Kitakami)
e^+e^-, √s: 250 – 500 GeV (1 TeV)
Length: 17 km, 31 km (50 km)

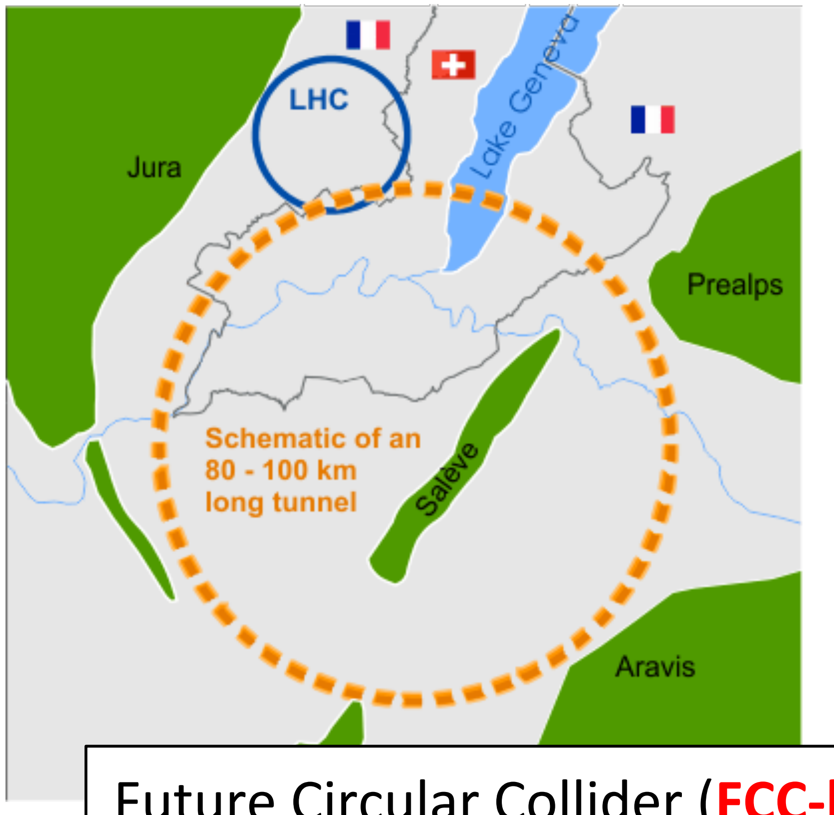


Compact Linear Collider (**CLIC**): CERN
e^+e^-, √s: 380 GeV, 1.5 TeV, 3 TeV
Length: 11 km, 29 km , 50 km

studies of high-energy pp colliders



Super proton proton Collider (**SppC**), China
CEPC; **SPPC √s >70 TeV**
Circumference: 100 km



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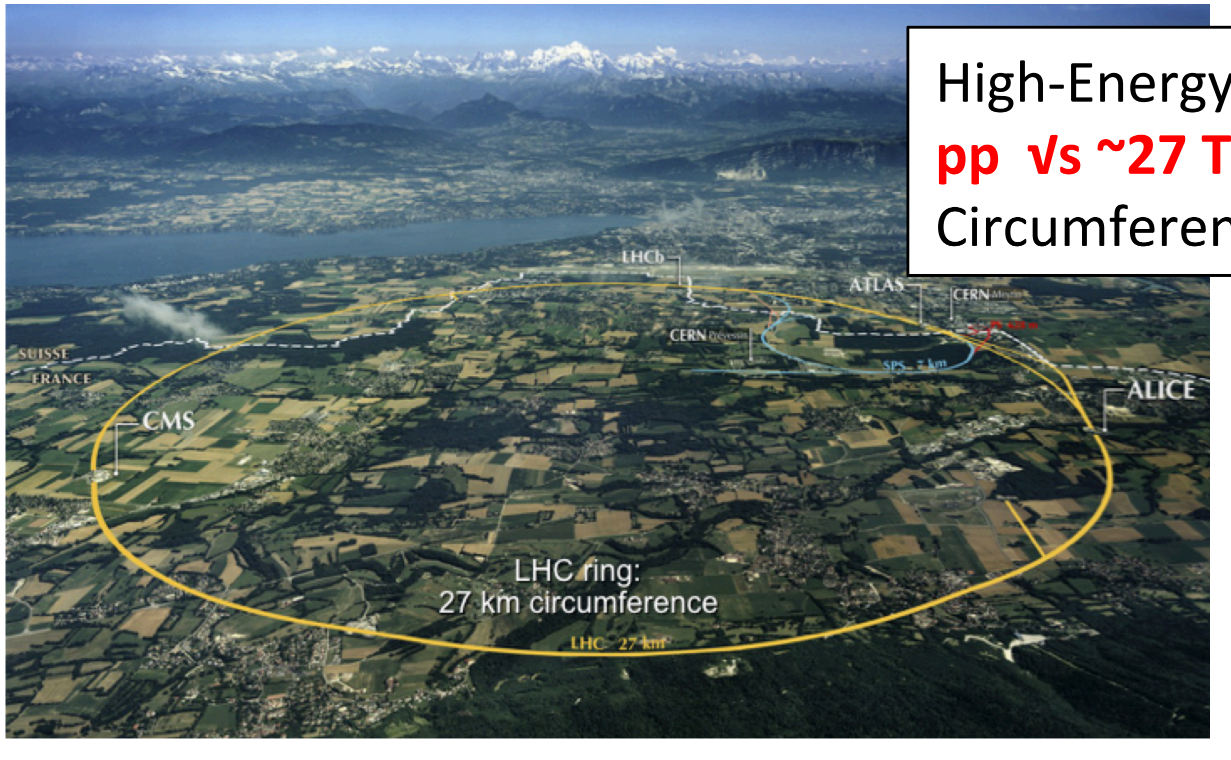
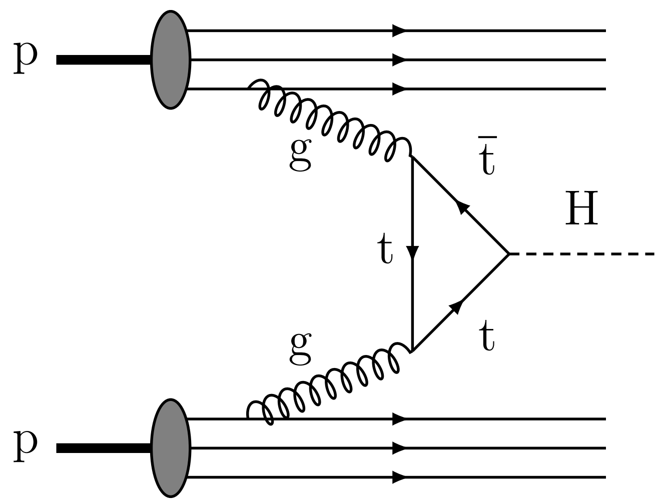
FCC-ee; **FCC-hh √s ~100 TeV**
Circumference: 97.75 km

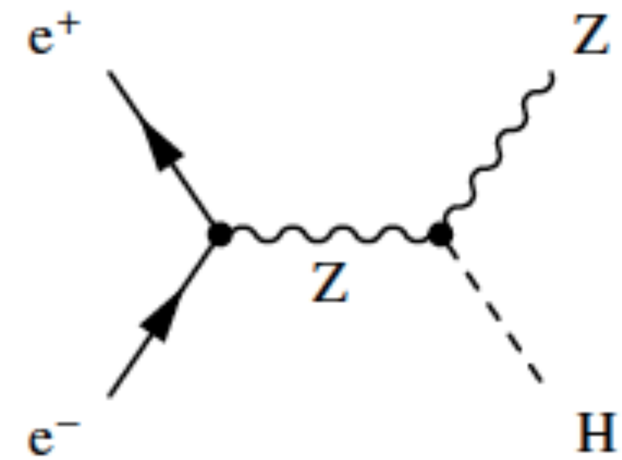


High-Energy LHC (**HE-LHC**): CERN
pp √s ~27 TeV
Circumference: 27 km

pp collisions / e^+e^- collisions

to tackle the open questions in particle physics





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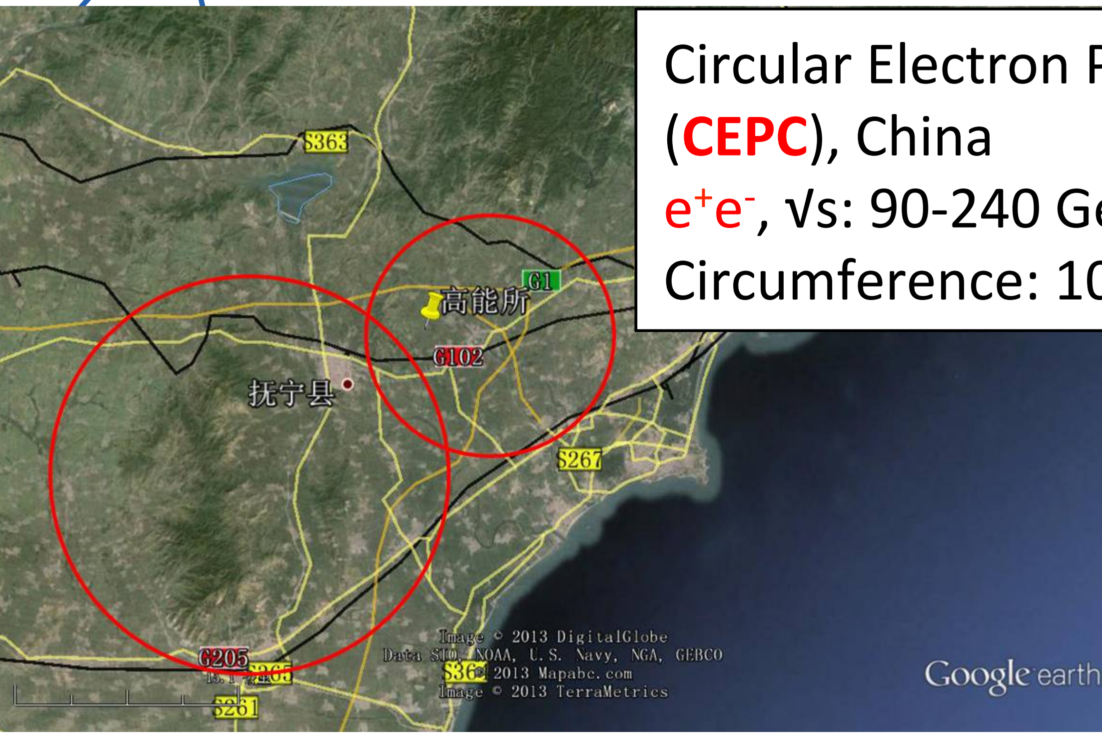

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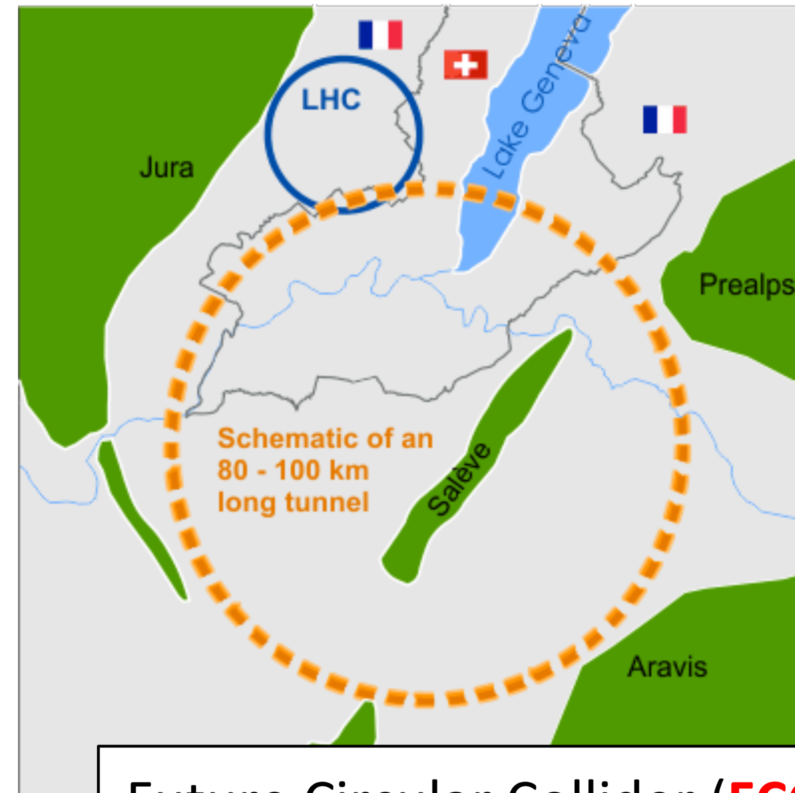

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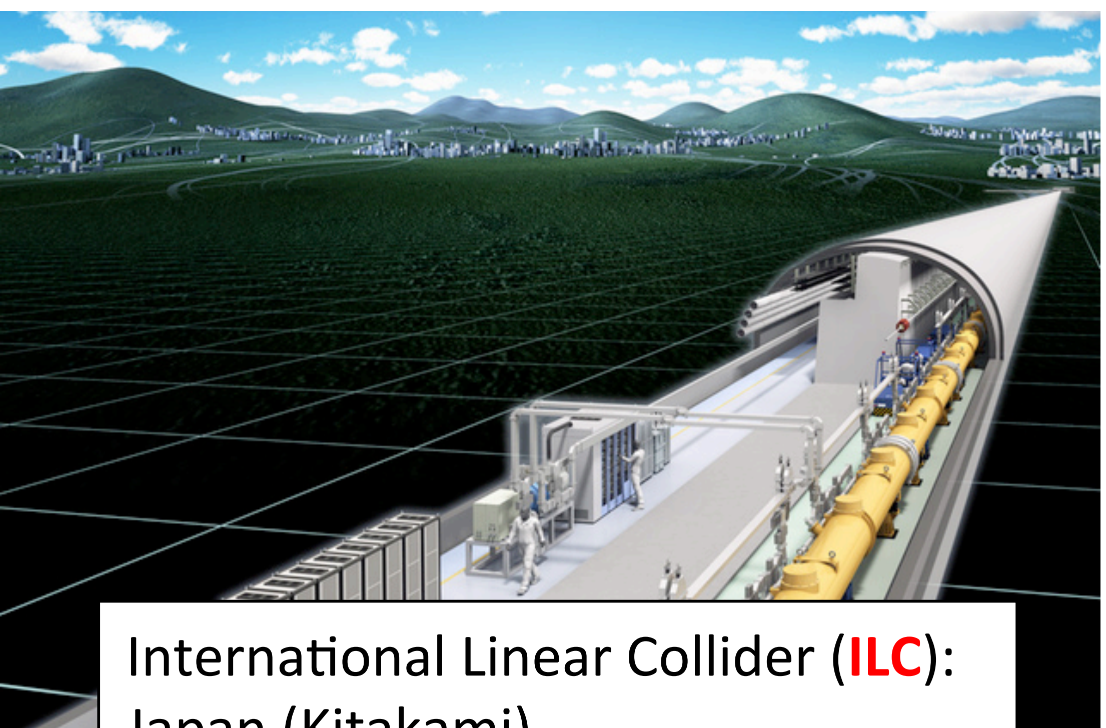

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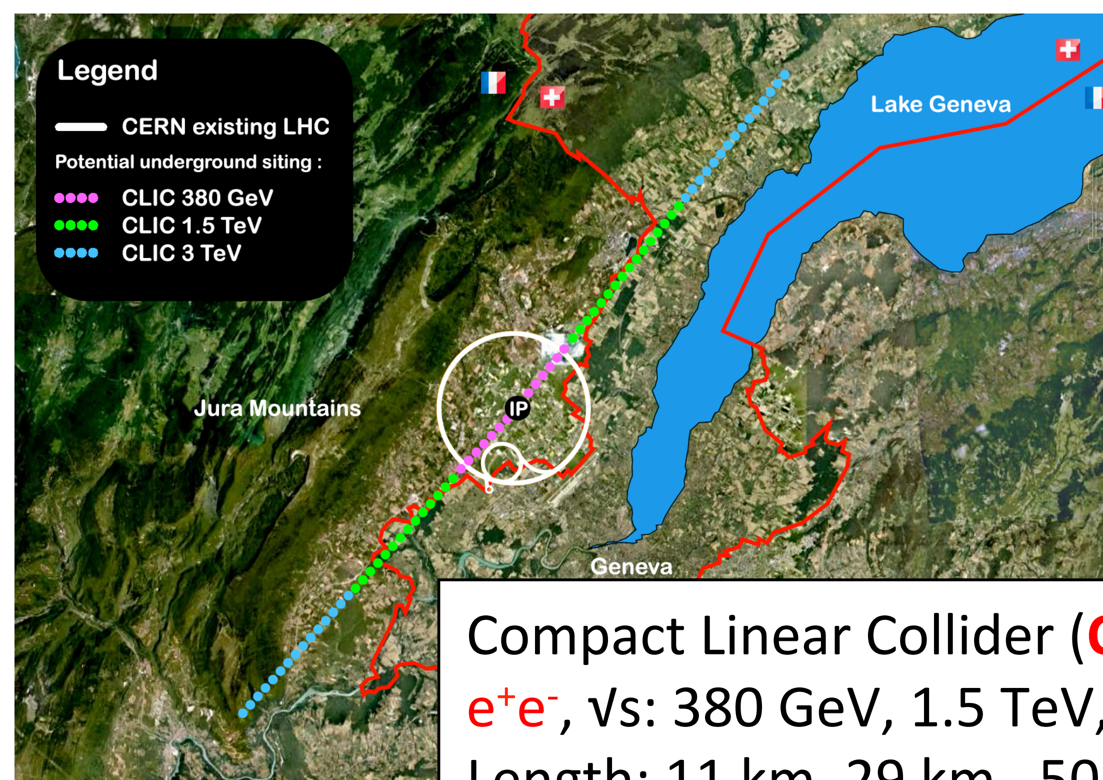

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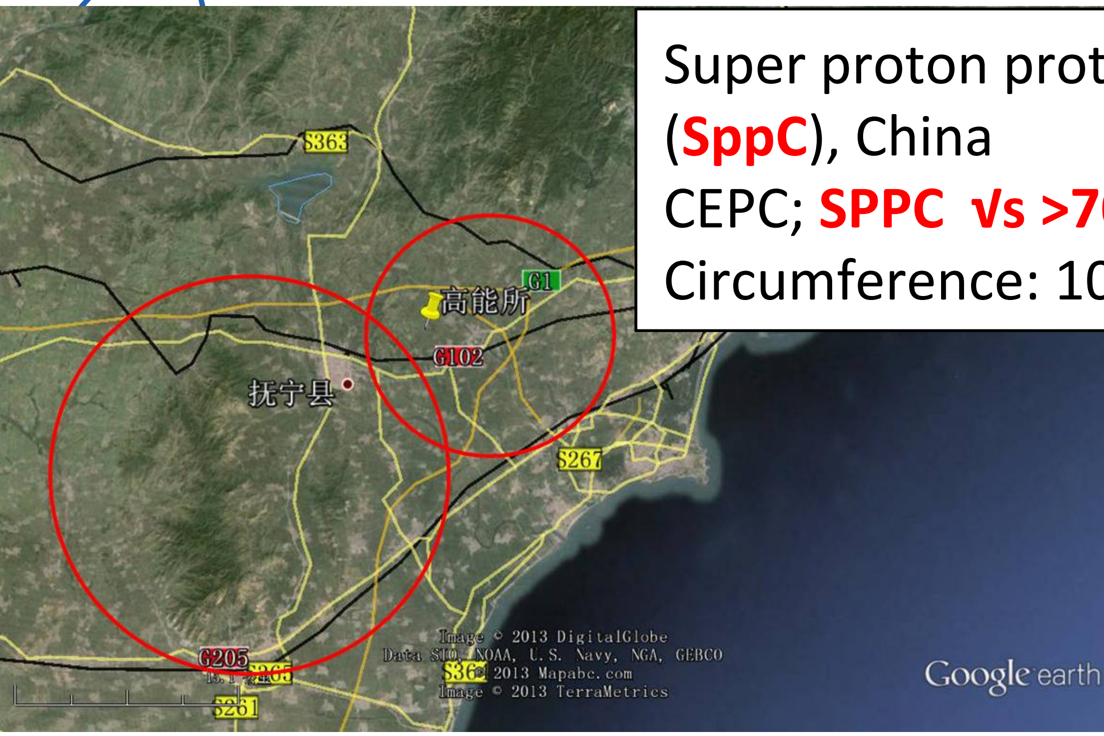
studies of high-energy pp colliders



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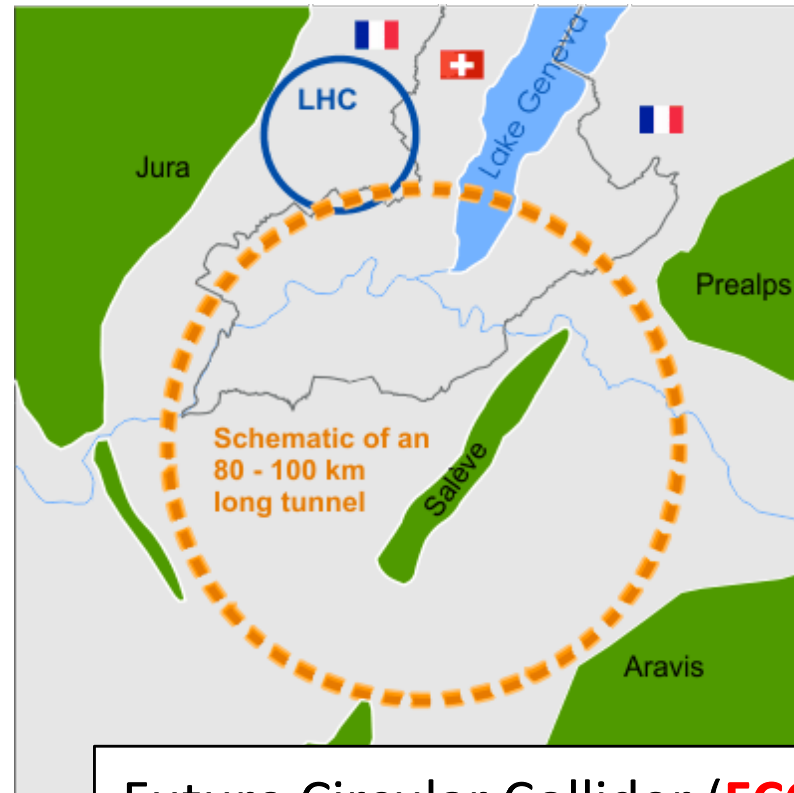

Future Circular Collider (**FCC-hh**): CERN
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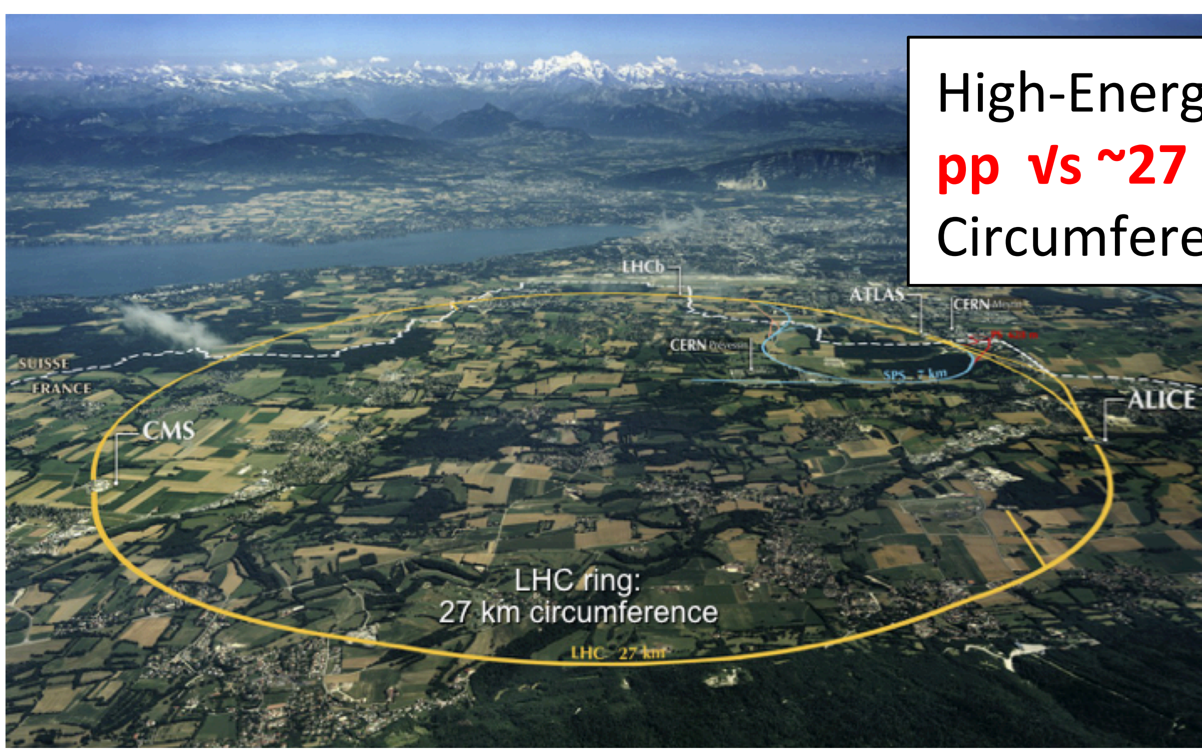
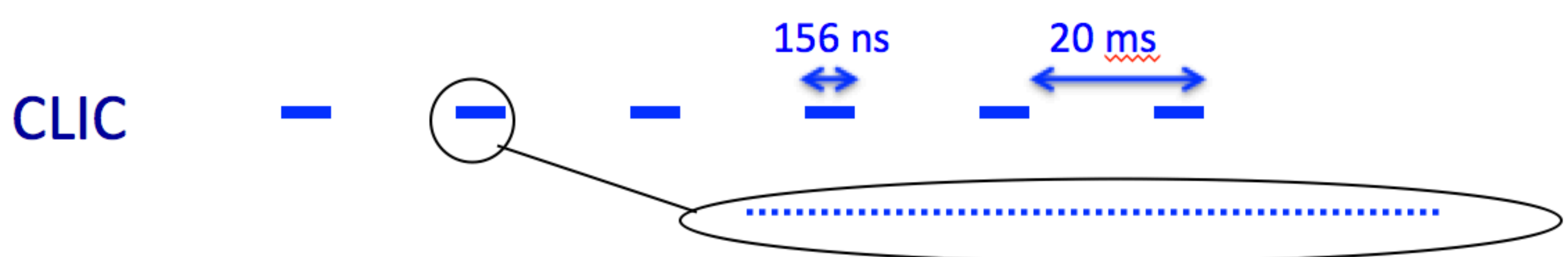


High-Energy LHC (**HE-LHC**): CERN
pp √s ~27 TeV
Circumference: 27 km

linear e^+e^- accelerator parameters

Parameter	ILC		CLIC		
	250 GeV (next stage)	**500 GeV**	**380 GeV**	**1.5 TeV**	**3 TeV**
Luminosity $\mathscr{L}$ ($10^{34}cm^{-2}sec^{-1}$)	**1.5**	**1.8**	**1.5**	**3.7**	**5.9**
$\mathscr{L}$ above 99% of √s ($10^{34}cm^{-2}sec^{-1}$)	**1.3**	**1.0**	**0.9**	**1.4**	**2.0**
Accelerator gradient (MV/m)	31.5	31.5	72	72/100	72/100
Site length (km)	~17	31	11.4	29	50
Repetition frequency (Hz)	10	5	50	50	50
Bunch separation (ns)	554	554	0.5	0.5	0.5
Number of bunches per train	1312	1312	352	312	312
Beam size at IP σ_x/σ_y (nm)	**729/7.7**	**474/5.9**	**150/2.9**	**~60/1.5**	**~40/1**
Beam size at IP σ_z (μm)	**300**	**300**	**70**	**44**	**44**



1 train = 312 bunches, 0.5 ns apart

- not to scale -

circular e+e- collider parameters

FCC-ee parameters:

parameter	Z	W	H (ZH)	ttbar
√s [GeV]	**91**	**160**	**240**	**350**
Beam current [mA]	1400	147	29	6.4
Number of bunches	**71000**	**7500**	**740**	**62**
Bunch intensity [10^{11}]	0.4	0.4	0.8	2.1
Bunch spacing [ns]	2.5 / 5.0	40	400	5000
SR energy loss / turn [GeV]	0.036	0.34	1.71	7.72
Total RF voltage [GV]	0.25	0.8	3.0	9.5
Long. damping time [turns]	1280	235	70	23
Bunch length with SR & BS [mm]	4.1	2.3	2.2	2.9
Luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	**130**	**16**	**5**	**1.4**

Note on CEPC:

- pre-CDR 2015, 54 km ring
- CDR expected in 2017, 100 km ring ➔ parameters @ H (HZ), W, Z under study *(see next slide)*

FCC-hh, HE-LHC, HL-LHC, LHC parameters

parameter	FCC-hh (New tunnel)		HE-LHC (LHC tunnel)	HL-LHC (LHC tunnel)	LHC (LHC tunnel)
√s [TeV]	**100**		**27**	**14**	**14**
Dipole field [T]	16		16	8.33	8.33
Circumference [km]	**97.75**		26.7	26.7	26.7
Beam current [A]	0.5		1.12	1.12	0.58
Bunch intensity [10^{11}]	1	1 (0.2)	2.2 (0.44)	2.2	1.15
Bunch spacing [ns]	25	25 (5)	25 (5)	25	25
Synchr. rad. power / ring [kW]	2400		101	7.3	3.6
SR power / length [W/m/ap.]	28.4		4.6	0.33	0.17
Long. emit. damping time [h]	0.54		1.8	12.9	12.9
Peak luminosity [10^{34} cm^{-2}s^{-1}]	**5**	30	25	**5**	1
events/bunch crossing	170	**~1000** (200)	~800 (160)	135	27

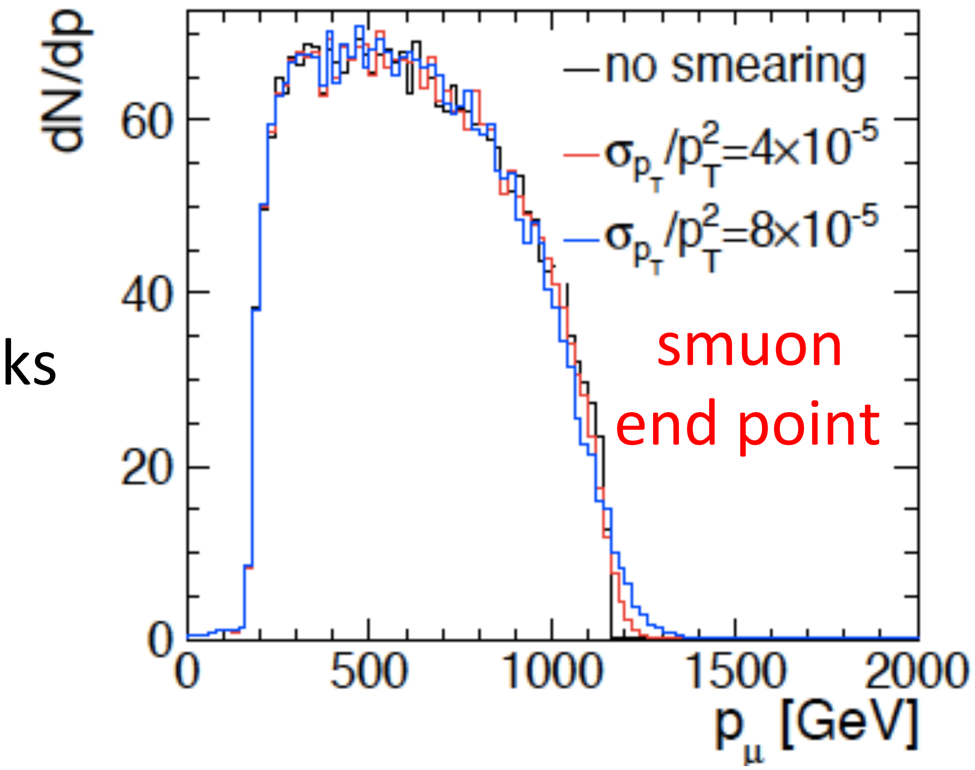
e^+e^- detector requirements (from physics)

★ **momentum resolution:**

e.g, ZH with Z➔μμ, Smuon endpoint

$$\sigma_{p_T}/p_T^2 \sim 2\times 10^{-5}\ \mathrm{GeV}^{-1}$$

for high p_T tracks

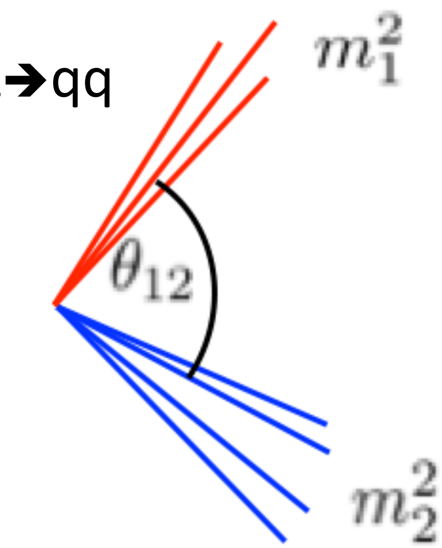


★ **jet energy resolution:**

e.g. W/Z/H di-jet mass separation, ZH with Z➔qq

$$\frac{\sigma_E}{E} \sim 3.5-5\ \%$$

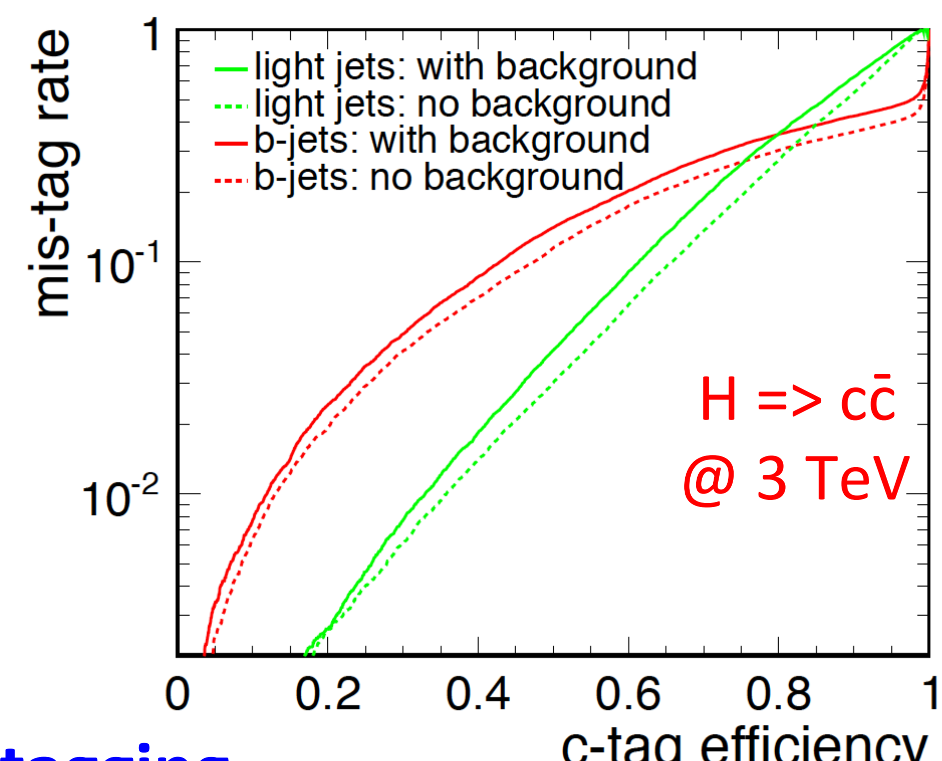
(for high-E jets, light quarks)



★ **impact parameter resolution:**

e.g. c/b-tagging, Higgs BR

$$\sigma_{r\phi} = 5 \oplus 15/(p[\mathrm{GeV}]\sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}$$



★ **angular coverage, very forward electron/photon tagging**

+ requirements from CLIC experimental conditions

calorimetry and PFA

Jet energy resolution + background suppression for optimal detector design

=> => fine-grained calorimetry + Particle Flow Analysis (PFA)

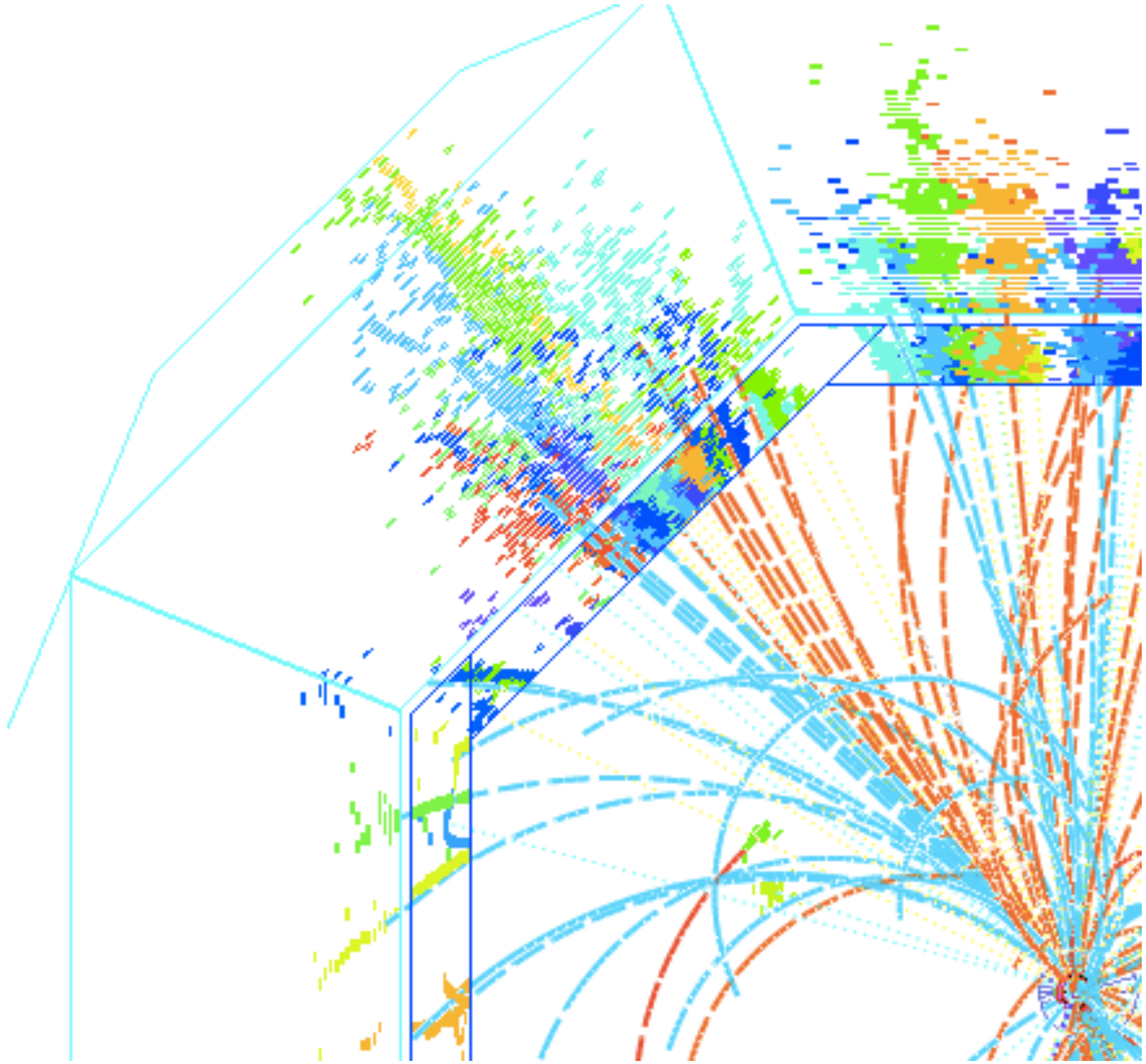
What is PFA?

Typical jet composition:
- 60% charged particles
- 30% photons
- 10% neutral hadrons

↓

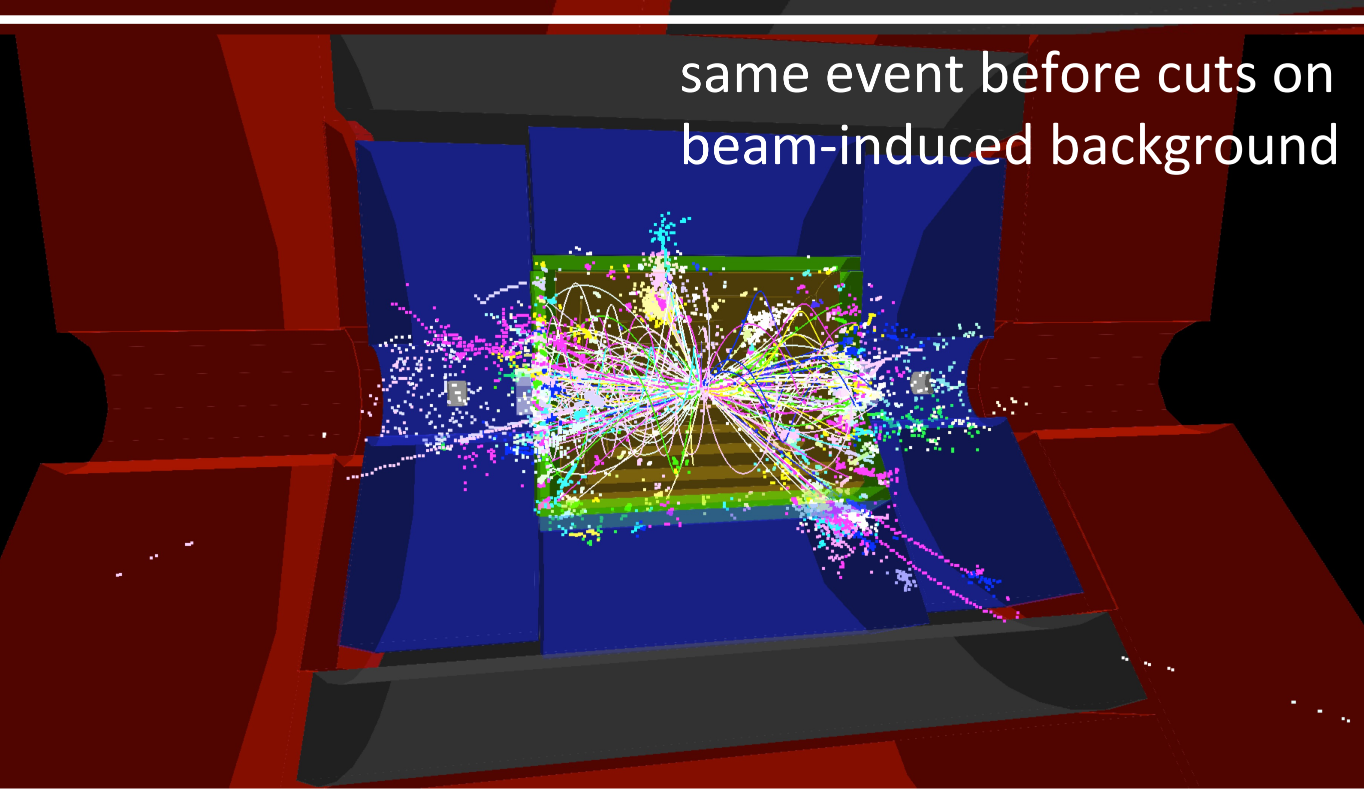
Always use the best info you have:
- 60% => tracker 🙂 🙂
- 30% => ECAL 🙂
- 10% => HCAL 🙁

Hardware + software !



$e^+e^- \rightarrow t\bar{t}H \rightarrow WbW\bar{b}H \rightarrow q\bar{q}b\ \tau\nu\bar{b}\ b\bar{b}$

CLIC 1.4 TeV



same event before cuts on beam-induced background

Highly granular calorimetry + precise hit timing

↓

Very effective in suppressing backgrounds for fully reconstructed particles

↓

General trend for **e^+e^-** and **pp** options (e.g. CMS endcap calorimetry for HL-LHC)

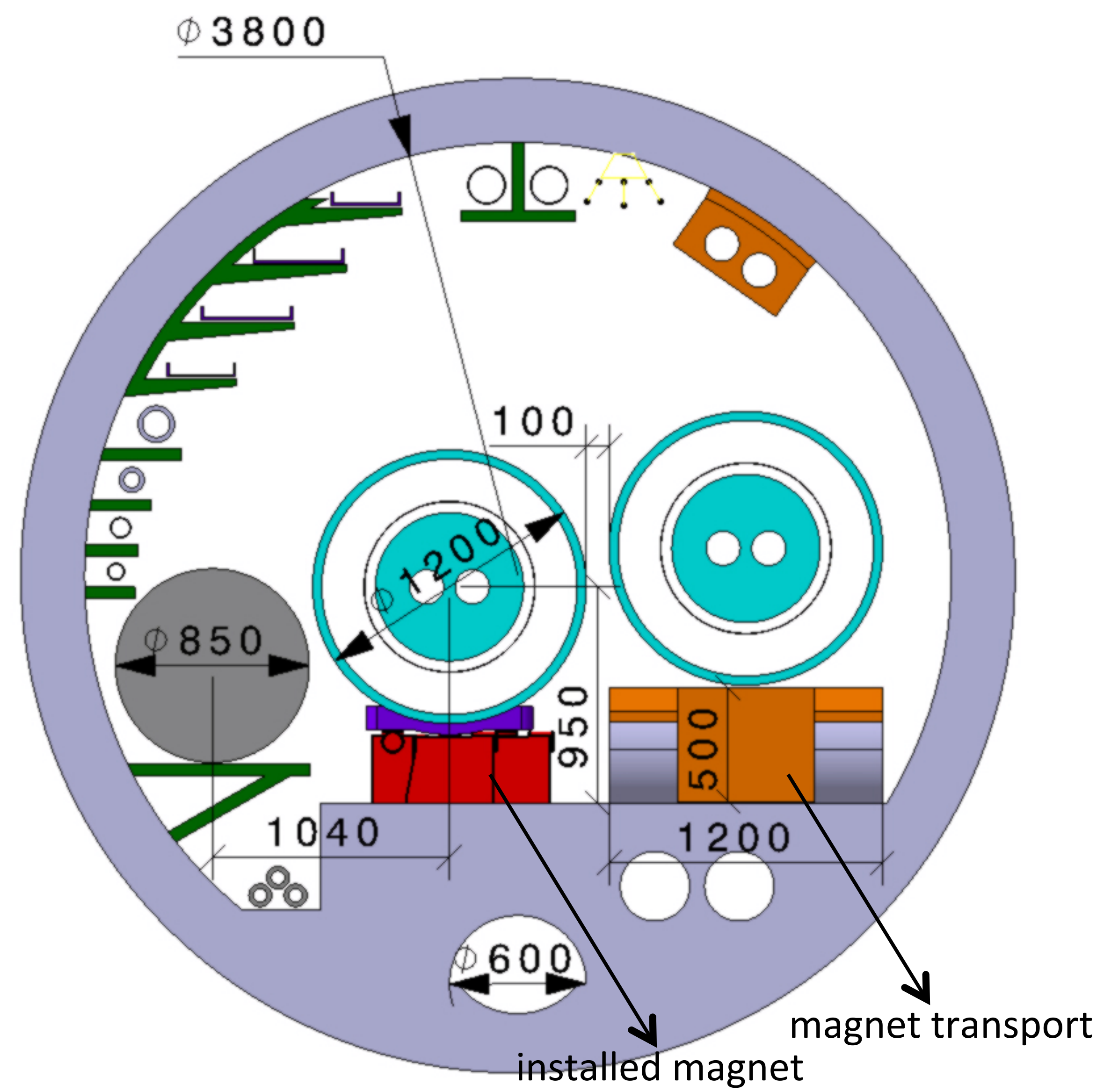
HE-LHC

Use the FCC-hh magnet technology for a proton-proton collider in the LHC tunnel

- **$\sqrt{s}$=27 TeV** (=14 TeV * 16 T / 8.33 T)
- **Luminosity 4 times higher than HL-LHC** ($1/E^2$)
- Constraint on external diameter of magnet cryostat, 1.2 m, for LHC tunnel compatibility

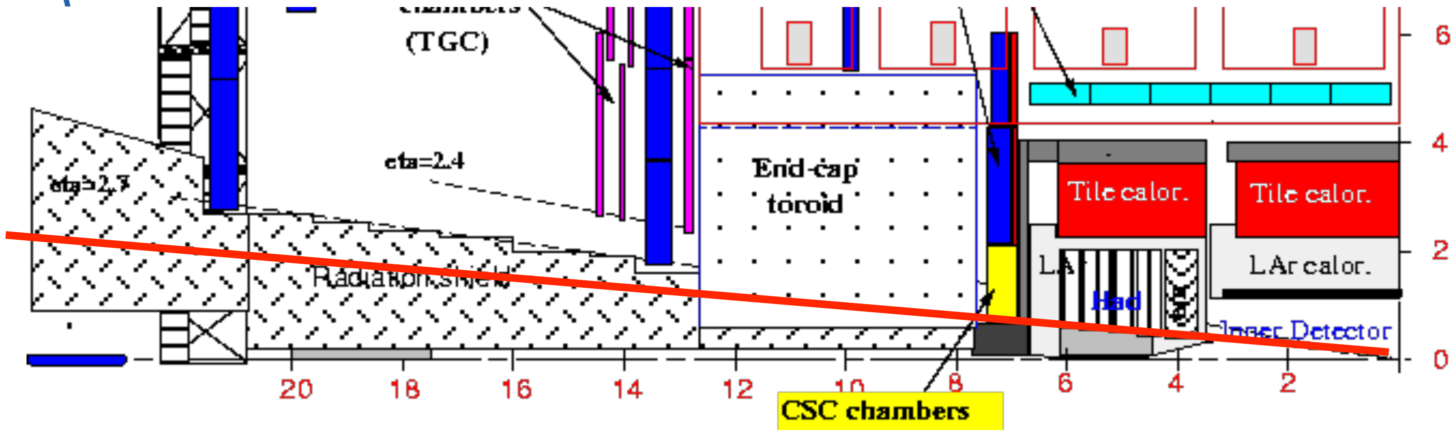
Key ingredients:

- FCC-hh magnet technology
- FCC-hh vacuum system
- HL-LHC crab waist scheme
- HL-LHC electron lens
- HL-LHC/LIU beam parameters (25 ns bunch structure, 5 ns option)



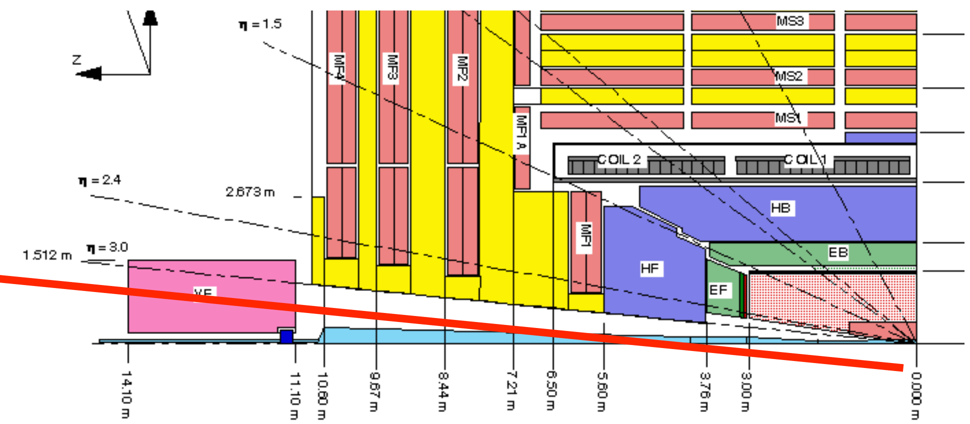
comparision ATLAS, CMS, FCC-hh

2.7



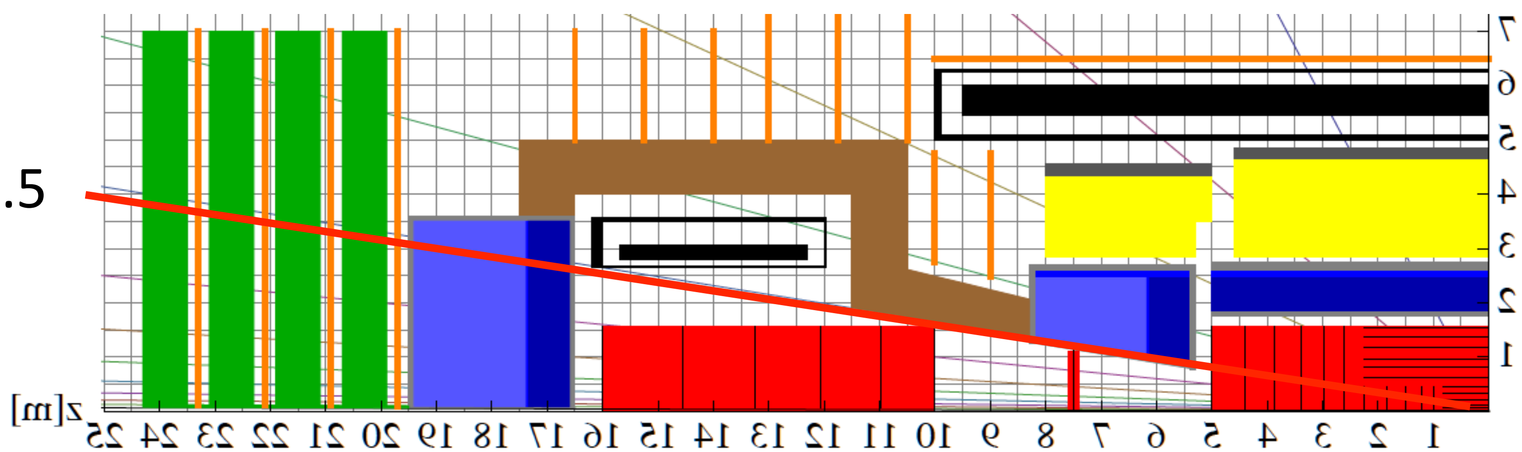
ATLAS

3.0



CMS

2.5



FCC-hh
(cavern length of 70 m required)

Compared to ATLAS / CMS, the forward calorimeters are moved far out in order to reduce radiation load and increase granularity.

→ A large shielding (brown) needed to stop neutrons from escaping to cavern and muon syst.