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Exploration of Hidden Sector (HS)

(open session of the 6th SHiP collaboration meeting)

Physics motivation: Standard Model is great but it is not a complete theory

Experimental facts of BSM physics

- *Neutrino masses & oscillations*
- *The nature of non-baryonic Dark Matter*
- *Excess of matter over antimatter in the Universe*
- *Inflation of the Universe*

Theoretical shortcomings

Gap between Fermi and Planck scales, Dark Energy, connection to gravity, resolution of the strong CP problem, the naturalness of the Higgs mass, the pattern of masses and mixings in the quark and lepton sectors, …

No clear guidance at the scale of New Physics and on its coupling strength to the SM particles !

Scale of NP: See-saw generation of neutrino masses

Most elegant way to incorporate non-zero neutrino mass to the SM Lagrangian is given by the see-saw formula:

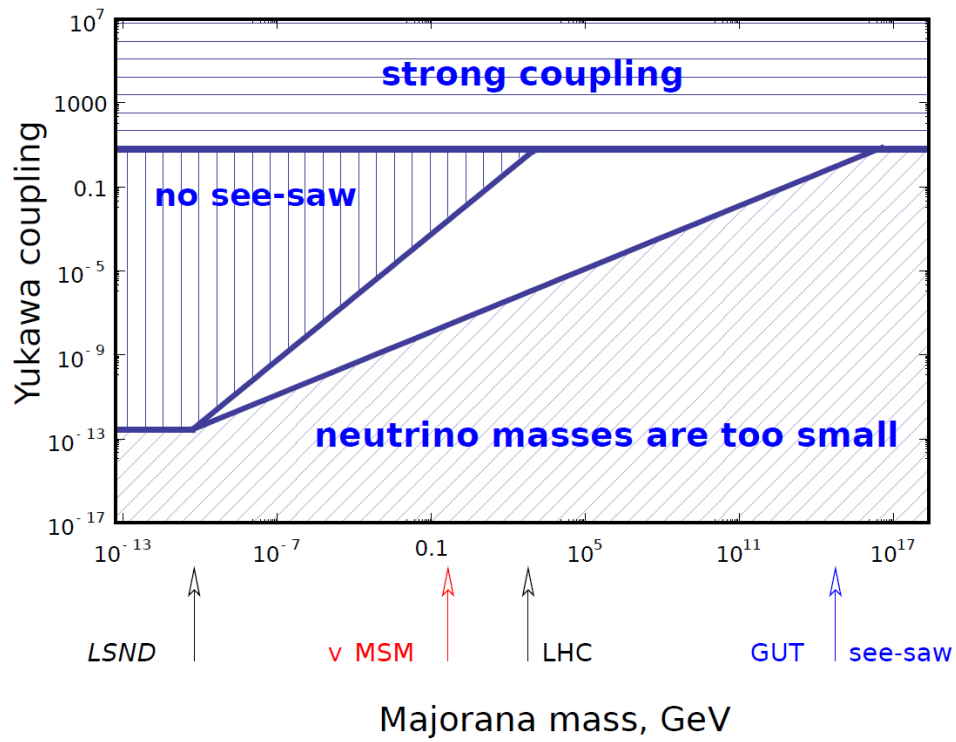
$$m_\nu = \frac{m_D^2}{M}$$

where $m_D \sim Y_{I\alpha} < \phi >$ *- typical value of the Dirac mass term*

Example:

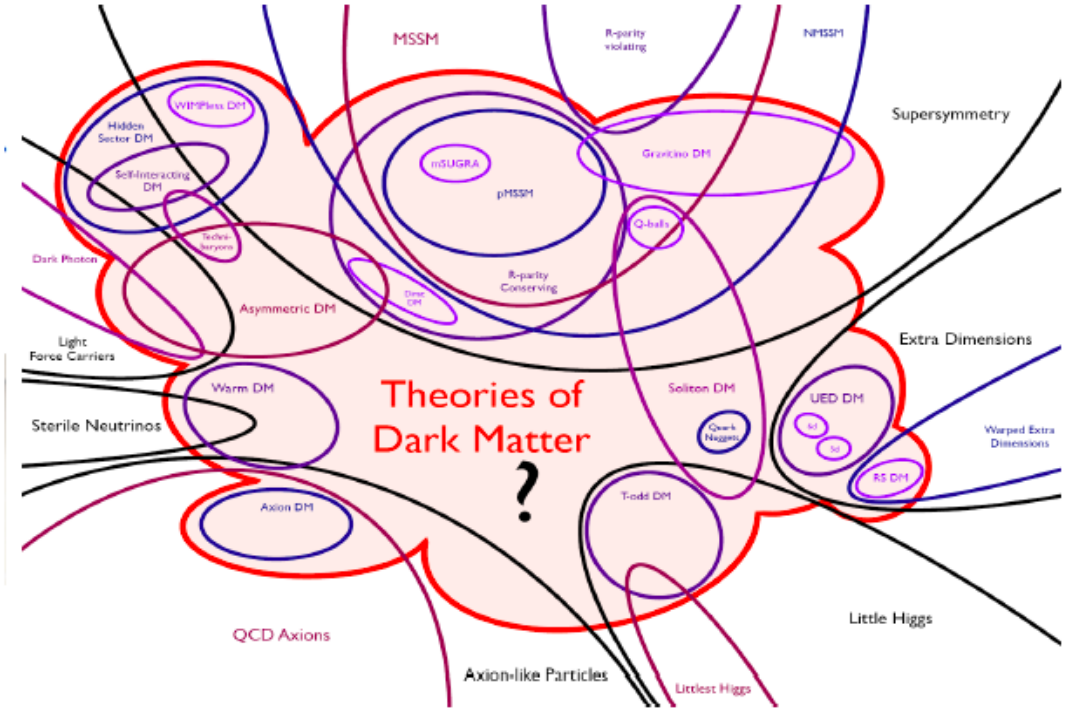
For M ~ 1 GeV and m_ν *~ 0.05 eV it results in* m_D *~ 10 keV and Yukawa coupling ~* 10^{-7}

Smallness of the neutrino mass hints either on very large M or very small $Y_{I\alpha}$



Scale of NP: Dark Matter

The energy scale(s) of new physics



T. Tait, DM@LHC '14

The prediction for the mass scale of Dark Matter spans from 10^{-22} eV (ALPs) to 10^{20} GeV (Wimpzillas, Q-balls)

BSM theories with a new energy scale

(which may also contain "light" particles)

GUT → *(SM particles)* — *~ 10^{16} GeV*

SUSY → *(sgoldstinos from SUSY breaking, with couplings ~1/F)* — *?*

Composite Higgs → *(Higgs)* — *?*

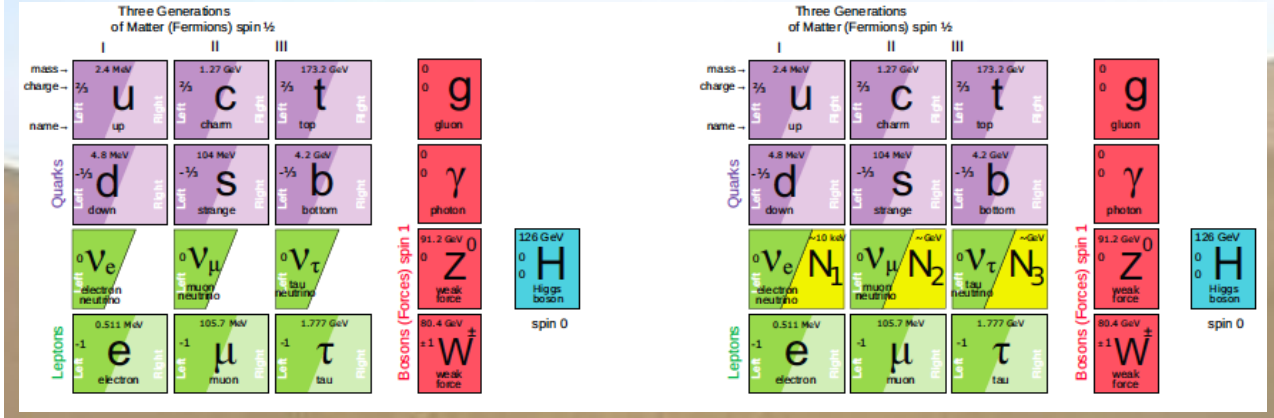
Large extra dimensions → *(Branons)* — *?*

Peccei-Quinn symmetry → *(Axions)* — *10^9-10^{12} GeV*

Models with Hidden Sector → *(Various messengers: dark photons, scalars, ALPs)* — *?*

So, there is always a good reason to increase the energy (even $\sqrt{s}$ > 14 TeV) and intensity, even if the scale of NP happens to be inaccessible directly. LHC is also one of the best machines at the Intensity Frontier !

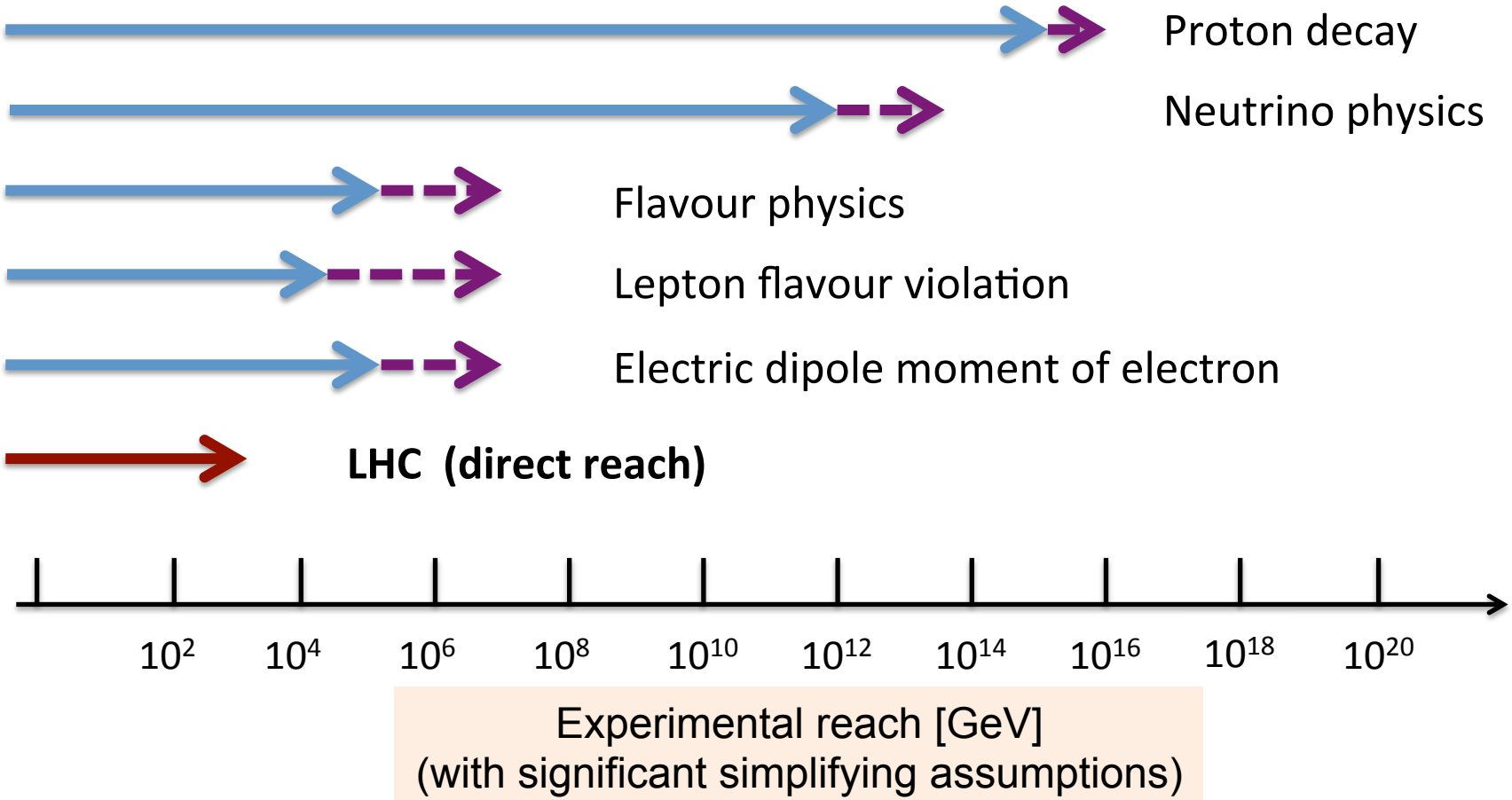
BSM theories with no NP between Fermi and Planck scales



N_1 → Dark Matter
$N_{2,3}$ → Neutrino masses and BAU

νMSM (T.Asaka, M.Shaposhnikov PL B620 (2005) 17) explains all experimental evidences of the BSM physics at once by adding 3 Heavy Neutral Leptons (HNL): N_1, N_2 and N_3

Experimental constraints on the scale of NP



The scale of NP is well above direct reach in the BSM models with not suppressed couplings

Search for Hidden Sector (HS)

$$L = L_{SM} + L_{mediator} + L_{HS}$$

Visible Sector

Mediators or portals to the HS:
vector, scalar, axial, neutrino

Hidden Sector

Naturally accommodates Dark Matter
(may have very complicated structure)

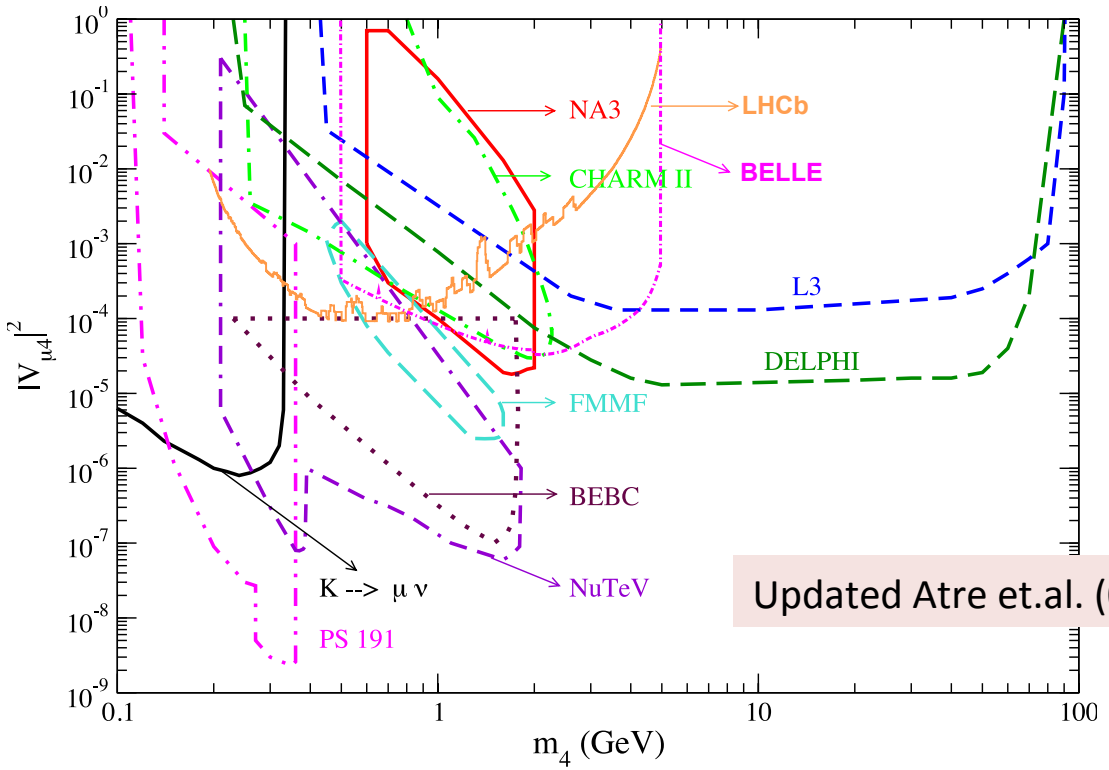
- ✓ *HS production and decay rates are strongly suppressed relative to SM*
  - *Production branching ratios O(10^{-10})*
  - *Long-lived objects*
  - *Travel unperturbed through ordinary matter*

Models	Final states
HNL, SUSY neutralino	$l^+\pi^-$, l^+K^-, $l^+\rho^-$ $\rho^+ \rightarrow \pi^+\pi^0$
Vector, scalar, axion portals, SUSY sgoldstino	l^+l^-
HNL, SUSY neutralino, axino	$l^+l^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0\pi^0$

Full reconstruction and PID are essential to minimize model dependence

Experimental challenge is background suppression
→ requires O(0.01) carefully estimated

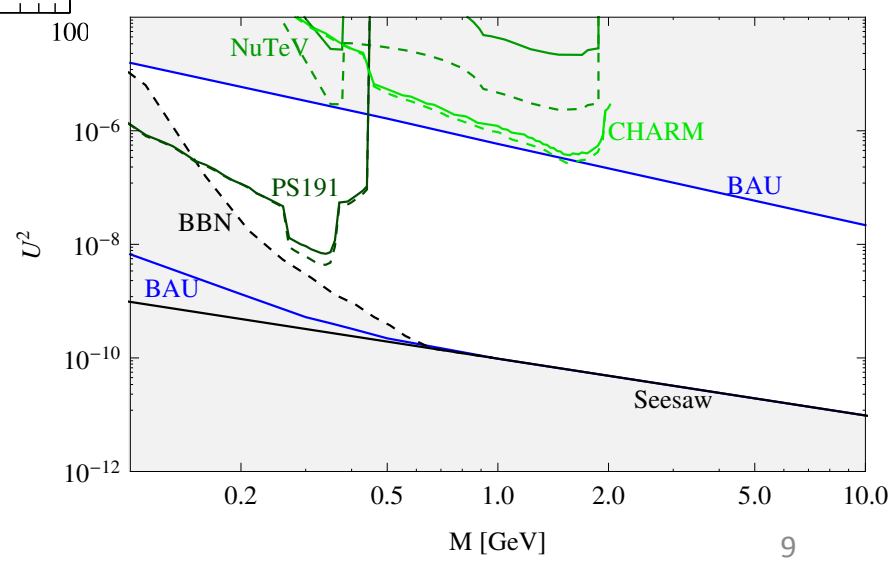
Experimental and cosmological constraints on HNLs



Updated Atre et.al. (0901.3589)

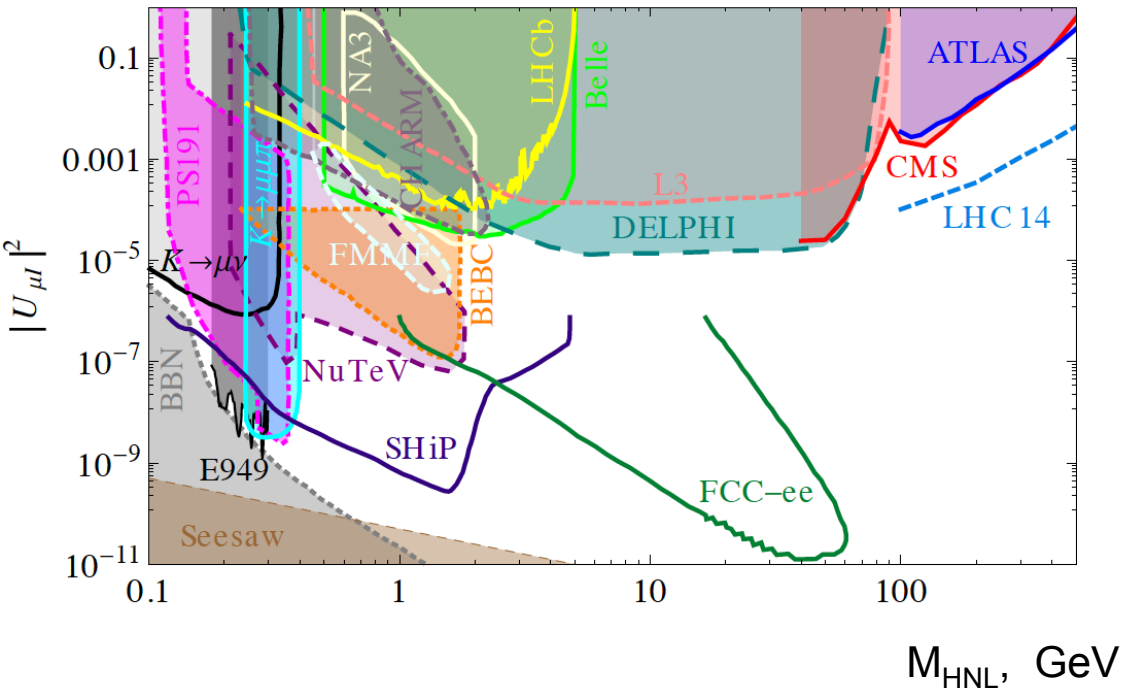
- ✓ *Coupling to active neutrinos $U^2 = U_e^2+U_\mu^2+U_\tau^2$ ($V_{\mu 4}^2 = U_\mu^2$)*
- ✓ *Stringent constraints on light HNLs below kaon mass*
- ✓ *The mass range above charm is relatively poor explored*

- ✓ ***Recent progress in cosmology***
- ✓ *The upper bound is model dependent (shown for νMSM). The lower bound is an ultimate seesaw limit*



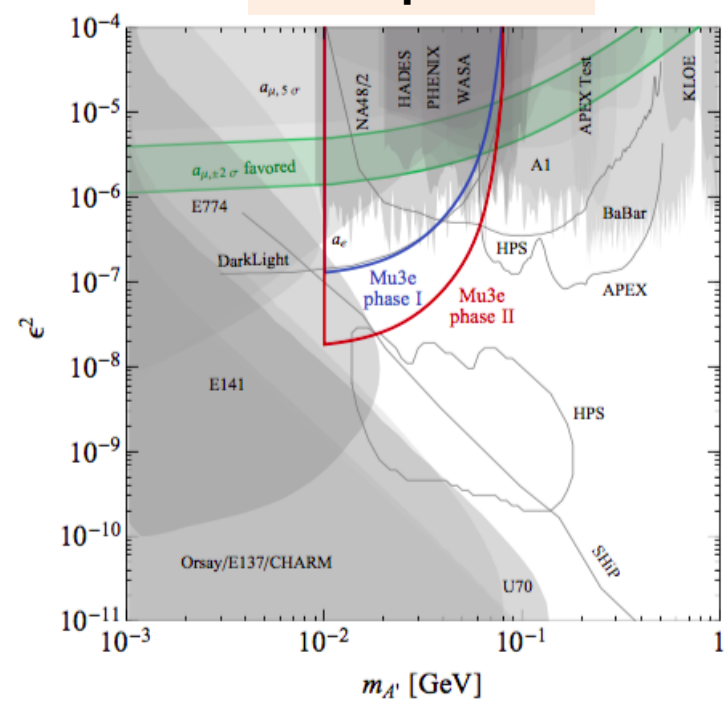
Hidden Sector experimental constraints in future

HNL



- ✓ $M_{HNL} < M_b$ LHCb, BelleII
  SHiP will have much better sensitivity
- ✓ $M_b < M_{HNL} < M_Z$ FCC in ee mode
- ✓ $M_{HNL} > M_Z$ Prerogative of ATLAS/CMS @ HL LHC

Dark photon



- ✓ SHiP will have unique sensitivity for "heavy" dark photons
- ✓ HPS is expected to cover new range of ε^2 in a couple of years

Agenda of Today

Covers searches for Hidden Sector in a wide interval of masses and couplings

11:30	[24] Introduction	GOLUTVIN, Andrei	
11:45	[25] HNLs and Dark Matter	BOIARSKYI, Oleksii	
13:30	[8] Hidden sector searches using displaced decays in ATLAS	MERMOD, Philippe	$M > M_Z$
13:55	[9] Hidden Sector searches in the CMS experiment	SHCHUTSKA, Lesya TITOV, Maxim	
14:20	[10] Searches for heavy neutrinos, long lived particles, etc, at LHCb	DETTORI, Francesco	$M_b < M < M_\pi$
14:45	[11] Constraining the Dark Sector at Belle (2)	GOLOB, Bostjan	
15:10	[34] Search for Hidden Sector at BaBar	CHAUVEAU, Jacques	
15:35	Coffee		
16:00	[12] Results and prospects from NA48 and NA62	GOUDZOVSKI, Evgueni	$M < M_\pi$
16:25	[13] The Heavy Photon Search experiment at Jefferson Lab	GUIDAL, Michel	
16:50	[14] P348: search for new physics in missing energy events	GNINENKO, Sergei	
17:15	[15] Search for dark photon in positron annihilations at Frascati: the PADME proposal	KOZHUHAROV, Venelin	
17:40	[16] SHiP sensitivities for Hidden Sector	GRAVERINI, Elena	