Future Beamdump/Fixed-Target Experiments

Heiko Lacker, HU Berlin

KET-KAT-KHuK-Strategie-Workshop (Bonn, 3./4.5.2018)

KET–KAT–KhuK Workshop: The future of Non-Collider Physics (27./28.04.2017)

P2-Experiment @ MESA: ***Precision measurement of weak mixing angle***

BDX @ MESA*:* ***Search for light dark matter (LDM)***

NA62++: ***rare kaon decays & Detection of long-lived, very weakly-interacting particles****.*

KLEVER: $K_L \to \pi^0 \nu \nu$

SHiP*:* ***LDM dark photons and scalars, ALPs, low-mass SUSY, sterile neutrinos, neutrino-DIS***

COMPASS*:* ***Further development of program w/ myons & improved kaon and antiproton beams***

Many thanks to A. Denig, F. Maas, R. Wanke, J. Jäckel, J. Friedrich, S. Paul

After Higgs-boson discovery: Where to search for BSM ?

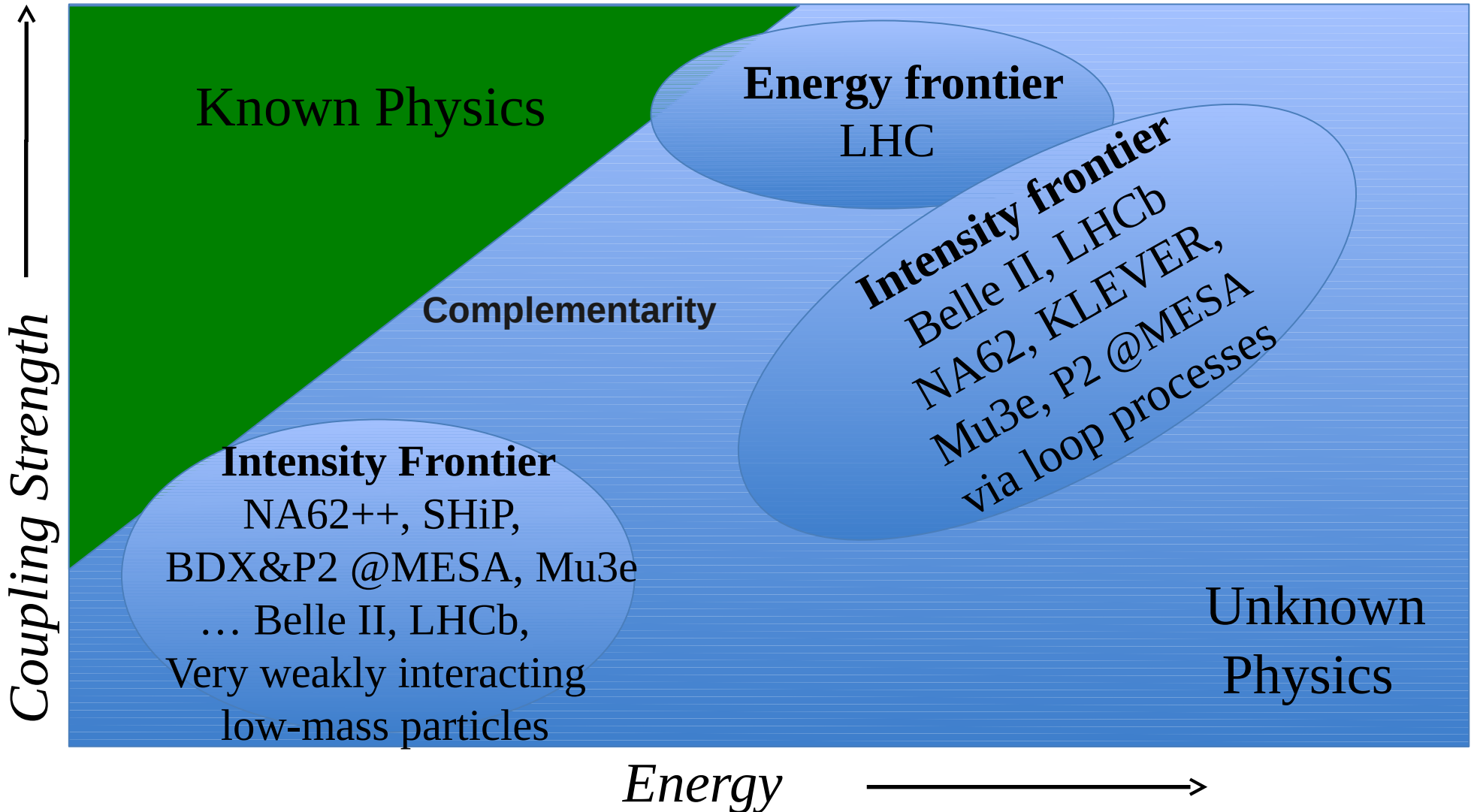
Origin of neutrino masses ?

Origin of matter-antimatter asymmetry?

Nature of dark matter?

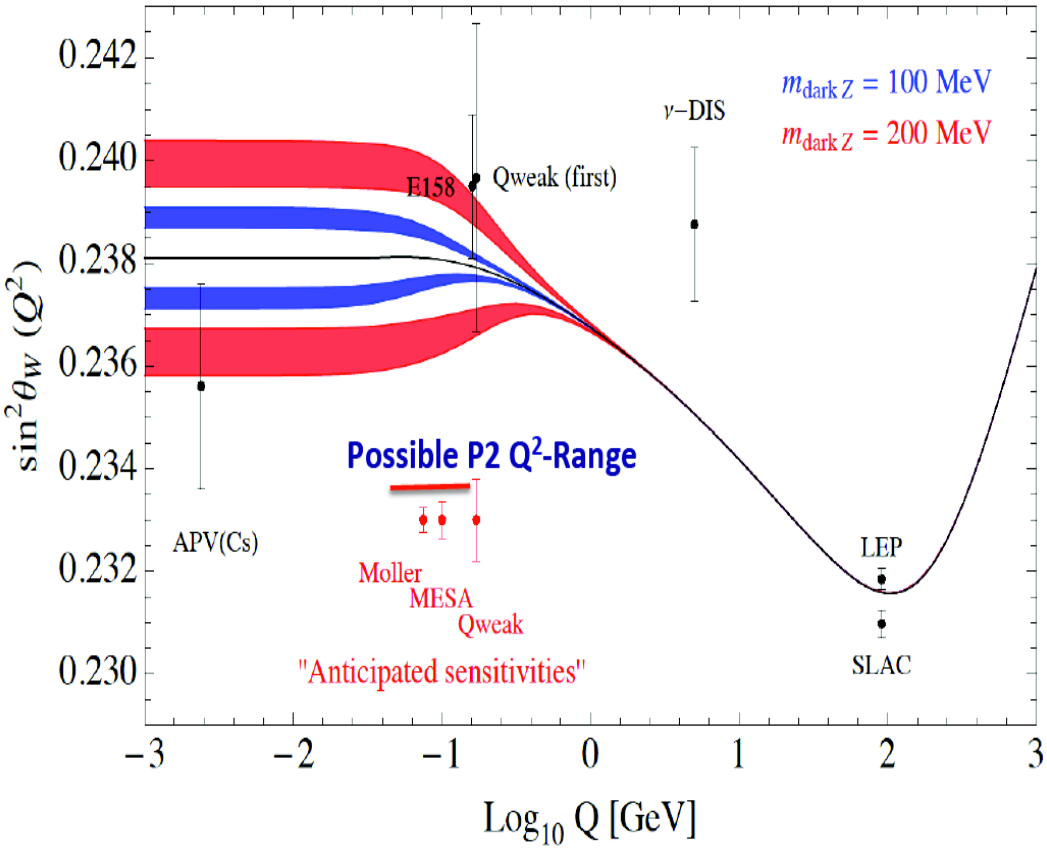
...

Simplistic and incomplete scetch



P2 @ MESA (Mainz Energy recovering Superconducting Accelerator)

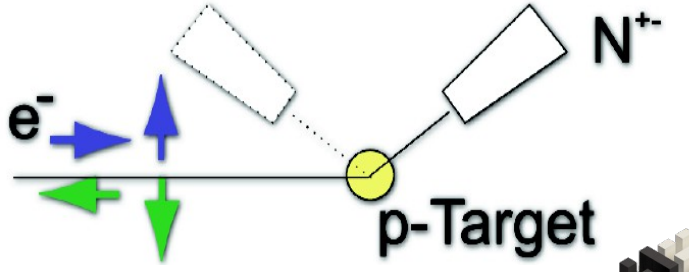
Measurement of $\sin^2\theta_W$ at small Q^2 with LEP precision (10^{-3}) via PV ep scattering (weak charge of proton)

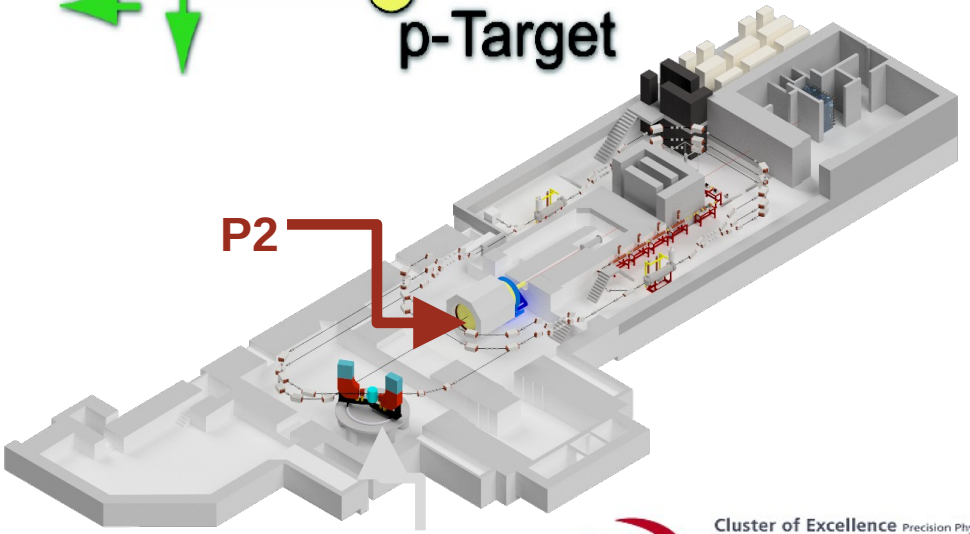


Weak Charge Of Proton: Qweak (Jlab), P2 (MESA)

Weak Charge Of Electron: MOELLER (JLAB)

Weak Charge Of Quarks: SOLID (PVDIS) (JLAB)





→ **Sensitivity to dark photons/Z, Z', (RPV) SUSY, contact interactions (49 TeV), ...**

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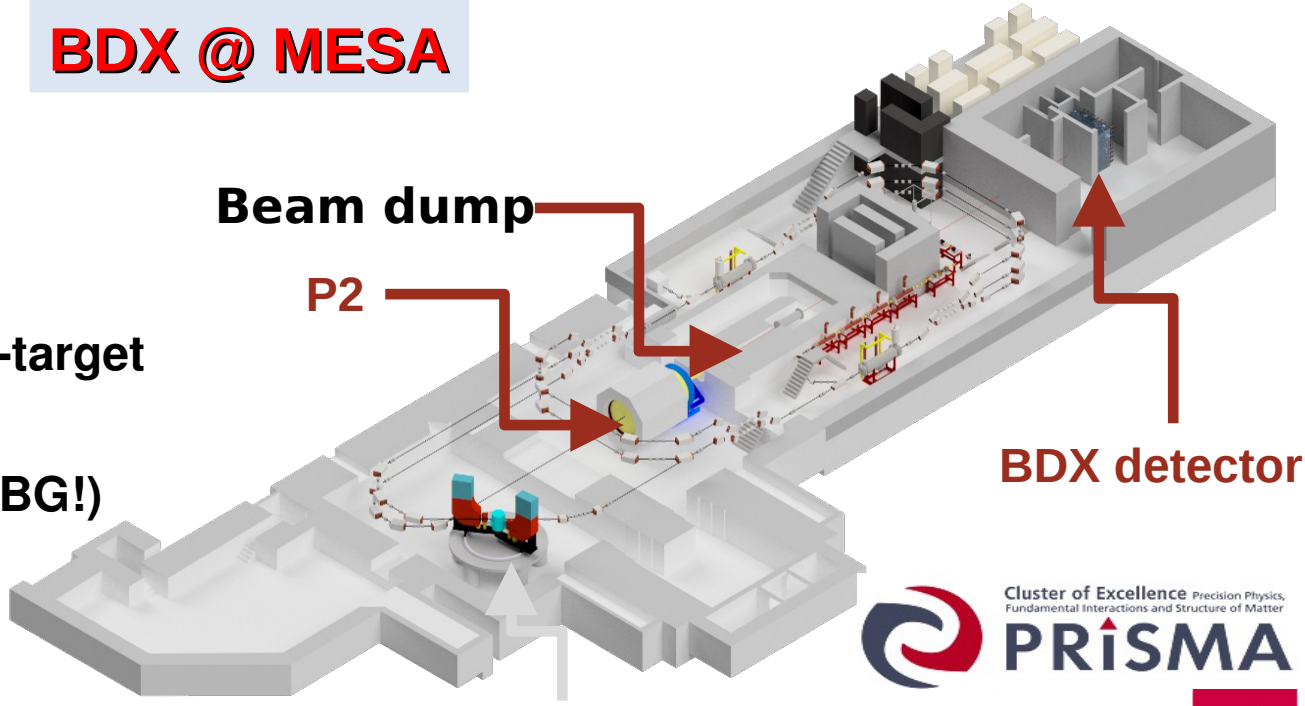
JG|U

BDX @ MESA

- **Extracted beam mode: 2021**
  E_{beam}: 147 to 155 MeV
  I_{beam}: 150 µA
- **P2-Experiment: $3 \cdot 10^{22}$ EOT on H-target**
- **P2 beamdump ideally suited for parasitic dark sector exp. (no ν BG!)**



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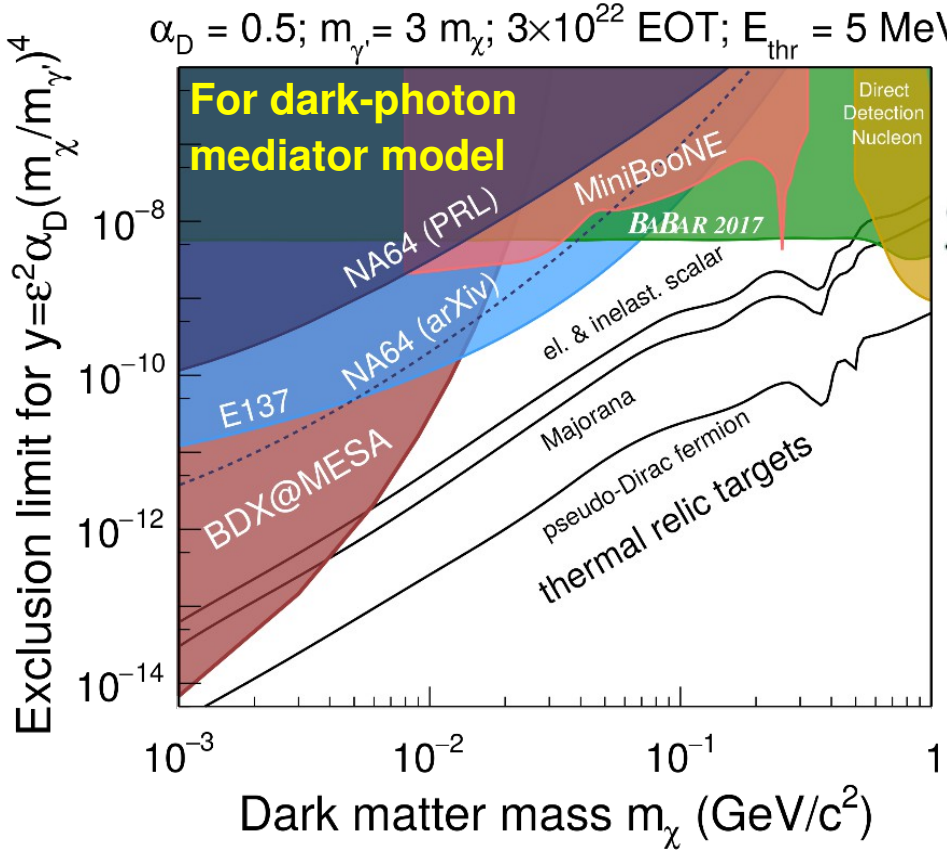
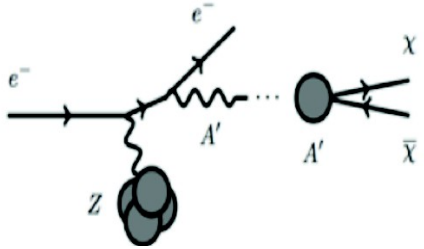
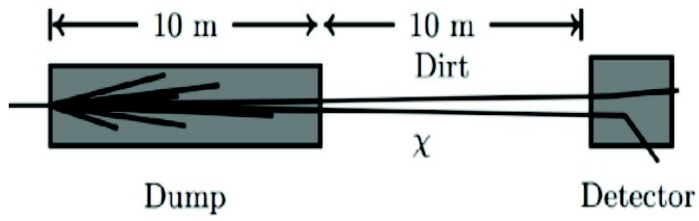
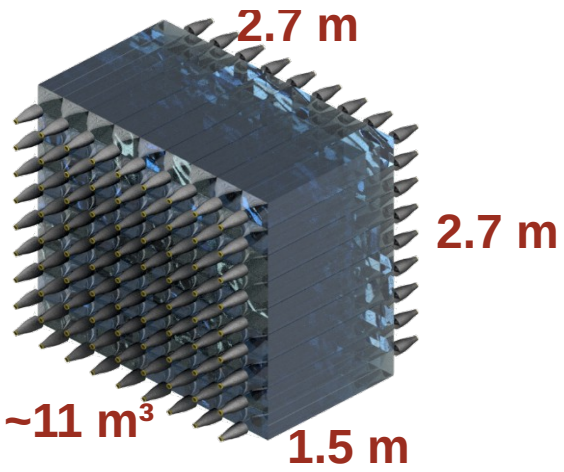


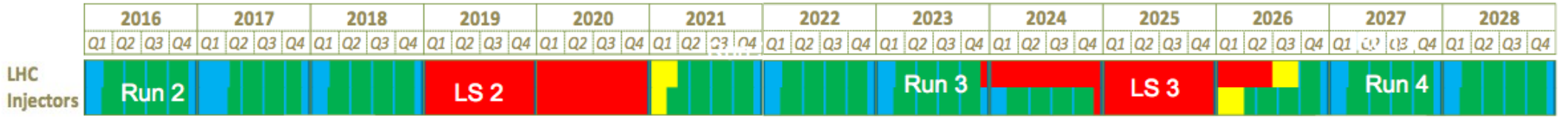




First BDX detector design
81 lead glass blocks
11 m³ active volume
5“ photomultipliers



NA62++ during Run 3



NA62: Data taking and analysis → **NA62++** → **KLEVER (?)**

$K^+ \to \pi^+ \nu\bar{\nu}$

$K_L \to \pi^0 \nu\bar{\nu}$

Rare K decays (1 year)

Mainz: HCal & Myon veto system

Hodoscope for charged particles

L1/L2 PC farm

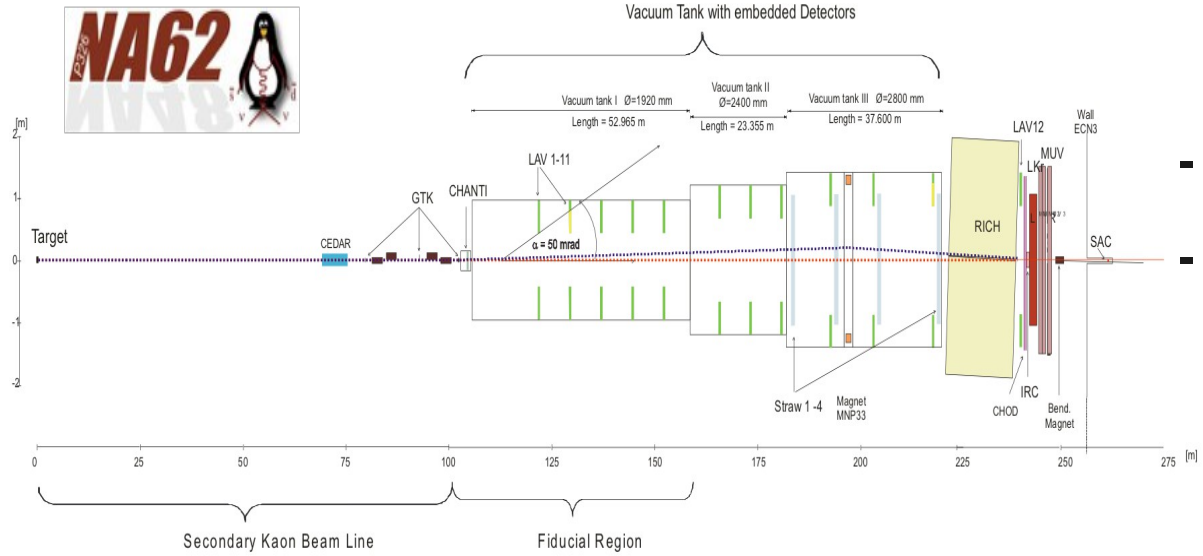
Data Analysis

"Beamdump mode"
(1 year, 10^{18} POT):

sterile ν, dark photons, ALPs, …
(„Mini-SHiP")

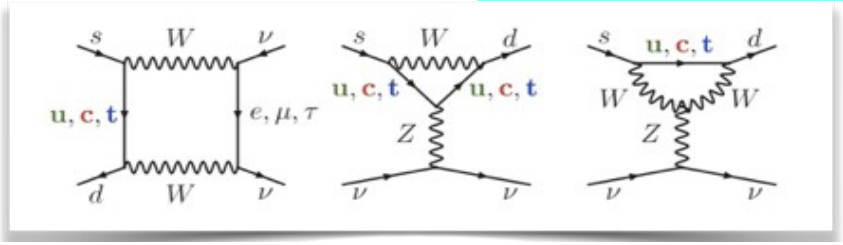
"Beamdump mode":
close (TAX) collimator

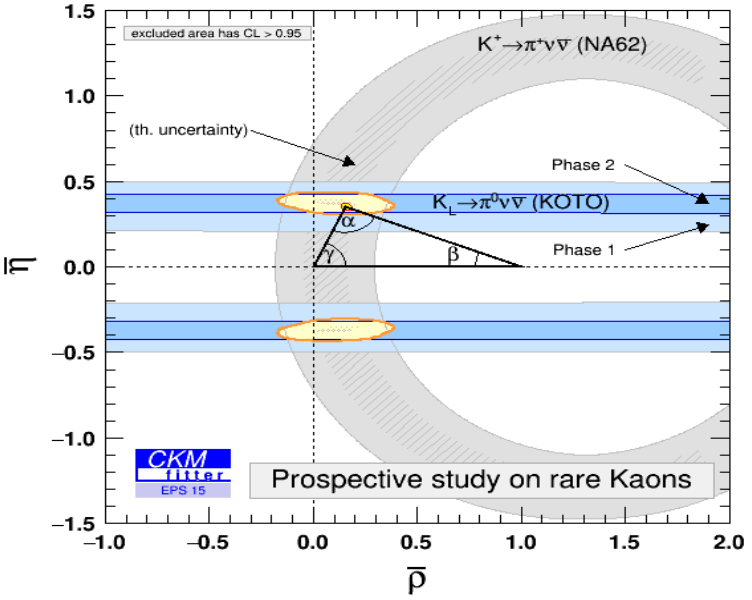
Lengths of dedicated periods depend on $K^+ \to \pi^+ \nu\bar{\nu}$ status by end of 2021



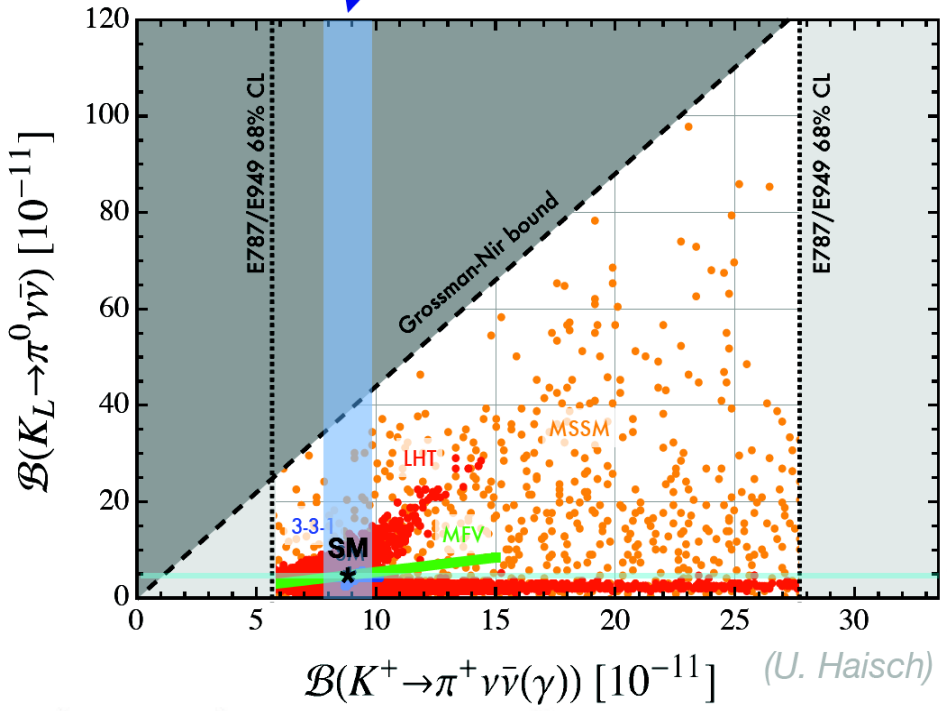
- Veto upstream of decay volume
- Preshower-detector in front of ECal for ALP → γγ
  (Interest of Mainz → Synergy w/ SHiP)

KLEVER: $K_L \to \pi^0 \nu\bar{\nu}$



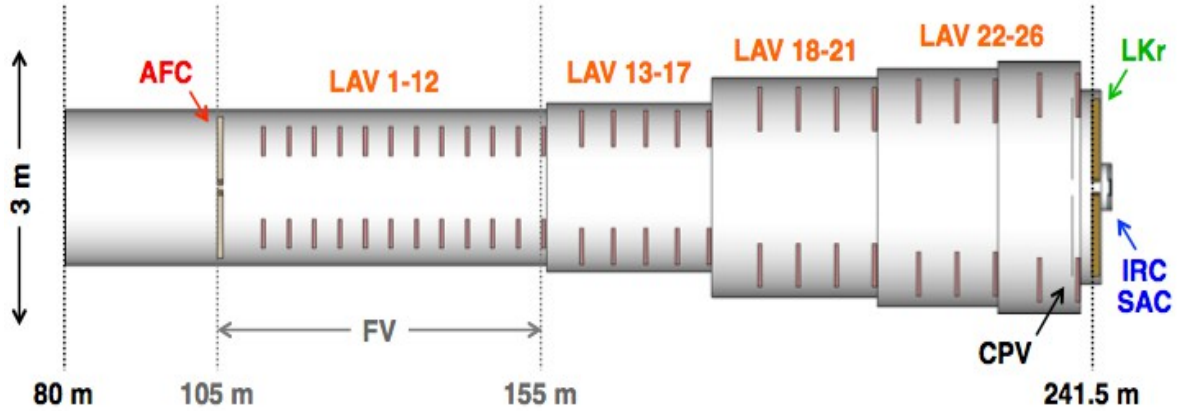


NA62 sensitivity



KLEVER sensitivity

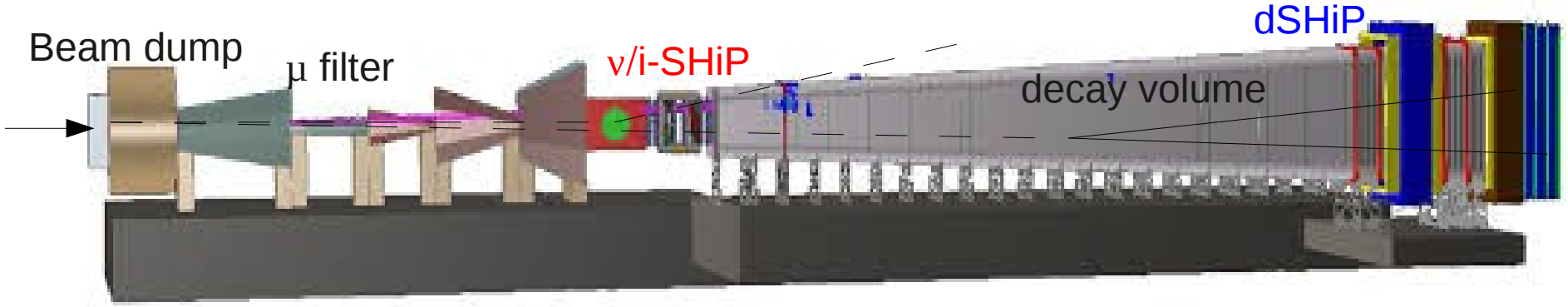
(U. Haisch)



- **Goal: 100 SM evts, S/B~1**
- **ECal from NA62, New Veto**
- **Feasibility: not yet completely shown, but substantial progress**
- **Costs: O(40) MEuro**
- **Germany: Mainz interested**
- **Planned time schedule:**
  2018: EoI → ESPP → SPSC approval → TDR: 2020 → Installation until 2026
- **Competitor: KOTO @ JPARC**
  Expect SM sensitivity in 2021
  No proposal yet to go for 100 SM evts

Search for Hidden Particles (SHiP) @ an SPS Beam Dump Facility (BDF)

- **CERN: "Experiment under study" (Greybook); own Budget; in Midterm Planning**
- **Collaboration since 12/2014, 52 institutes, 16 countr., 267 memb. (Germany: ~8%)**



ν/i-SHiP: indirect LDM detection; ν DIS

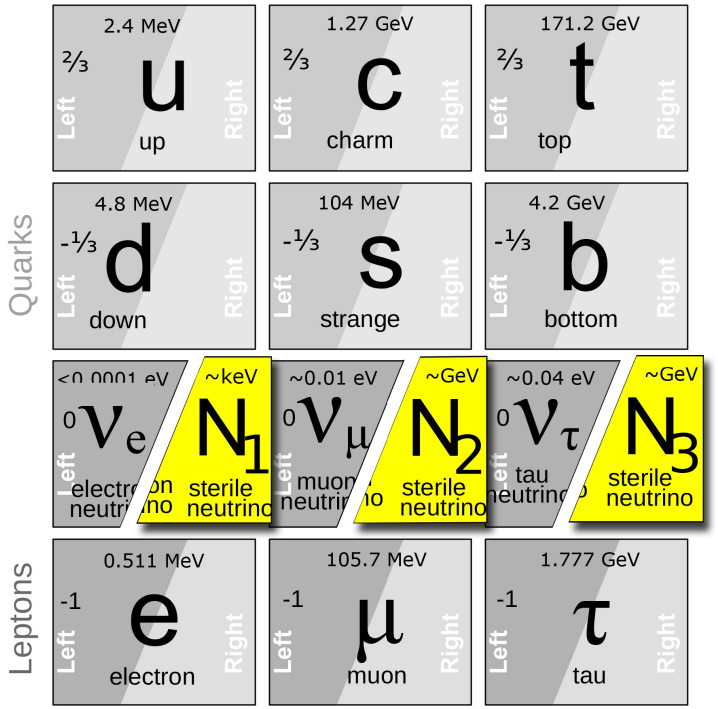
d-SHiP: direct detection of Majorana ν, dark photons/scalars, ALPs, low-mass SUSY

Surrounding BG Tagger (Berlin, Mainz), Tracker (Hamburg, Jülich), Pointing ECAL (Mainz)

Measurement of μ & charm production in SHiP-like target in 2018 (Bonn, Hamburg)

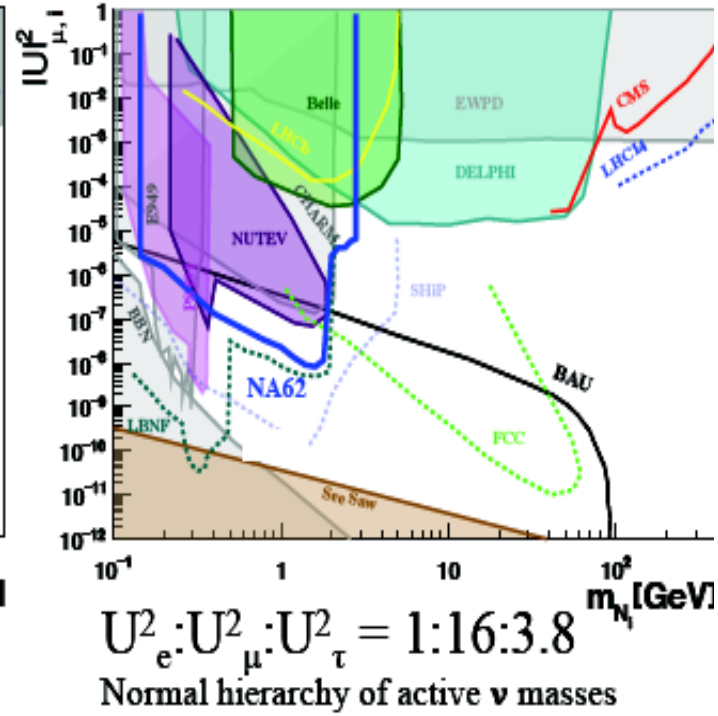
- **Full sim.: no significant BG for searches with d-SHiP in 5 years ($2 \cdot 10^{20}$ POT)**
- **2018-2021: Detector Prototyping → 2019: Comprehensive Design Study report → ESPP → SPSC Approval 2020 → Start Det. Constr. 2021 → Data Taking 2026**
- **Tech. Prop. 04/2015: 135 MCHF (BDF)+59 MCHF (SHiP detector) →to be updated**
- **BDF can host other experiments, e.g.: LFV $\tau \rightarrow 3\mu$ ($<10^{-10}$) (independent groups interested)**

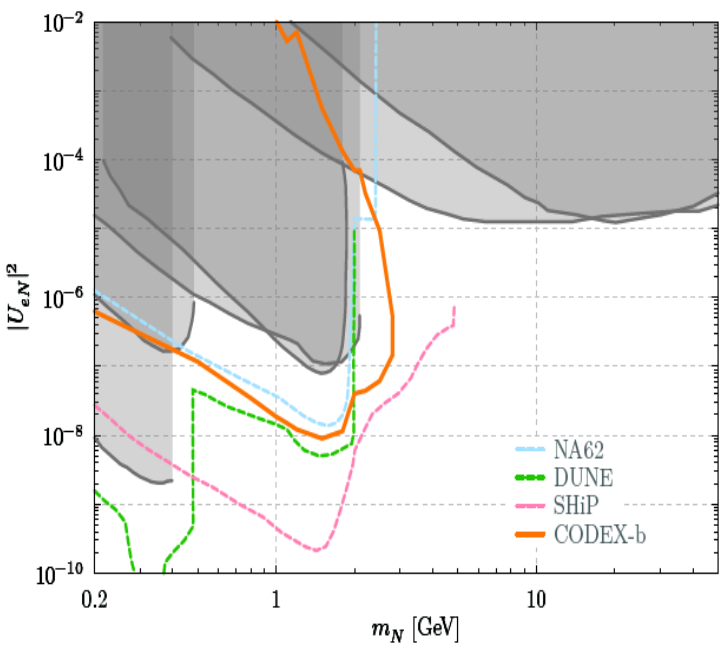
Right-handed Majorana neutrinos below electroweak scale

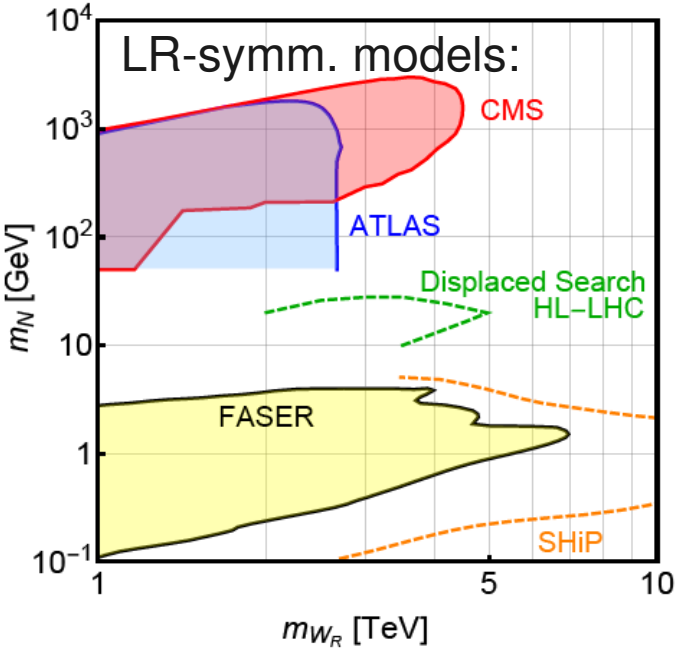


ν masses & BAU: $N_{2,3}$ above ~0.1 GeV
warm DM: N_1~O(keV)
} νMSM

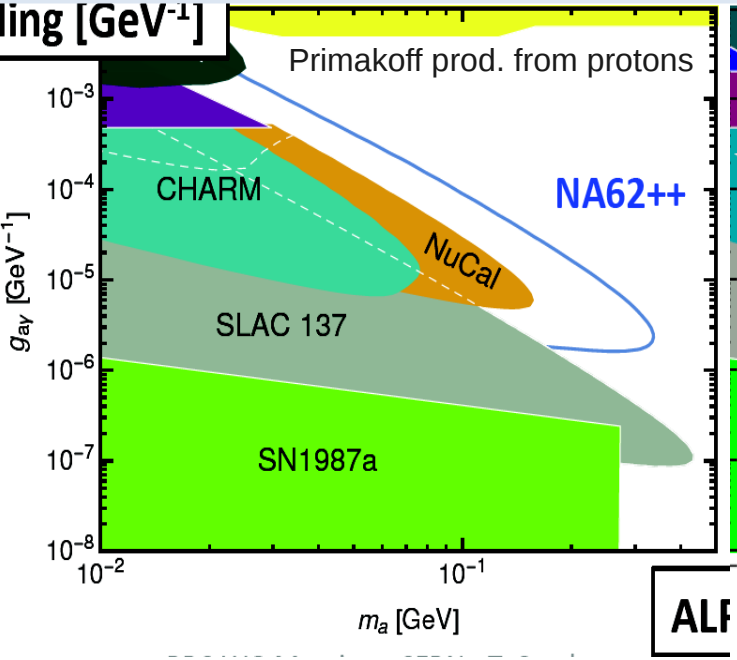
- NA62++ improves existing limits
- < 0.5 GeV: DUNE best sensitivity
- $0.5 < m_N < M_b$:
  d-SHiP improves by 1-2 order, approaches seesaw limit,
  has higher sens. than ideas for new HL-LHC detectors:
  CODEX-b, FASER, and MATHUSLA* (sens. not yet clear)

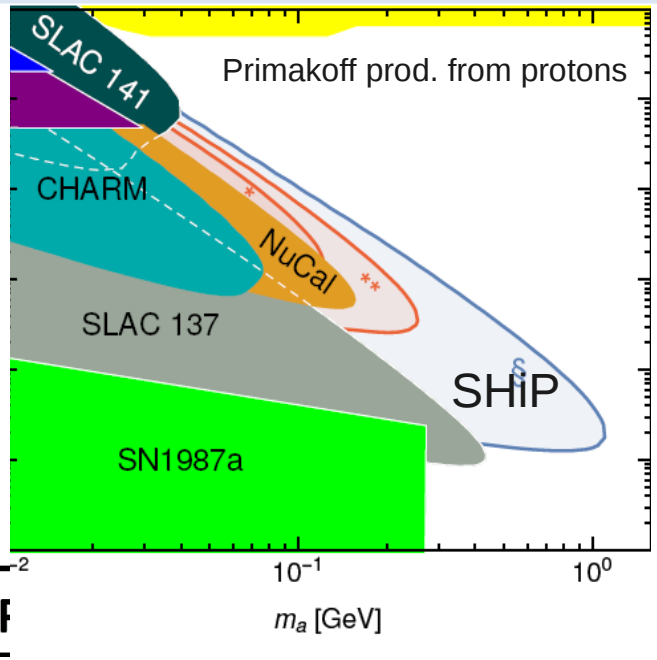


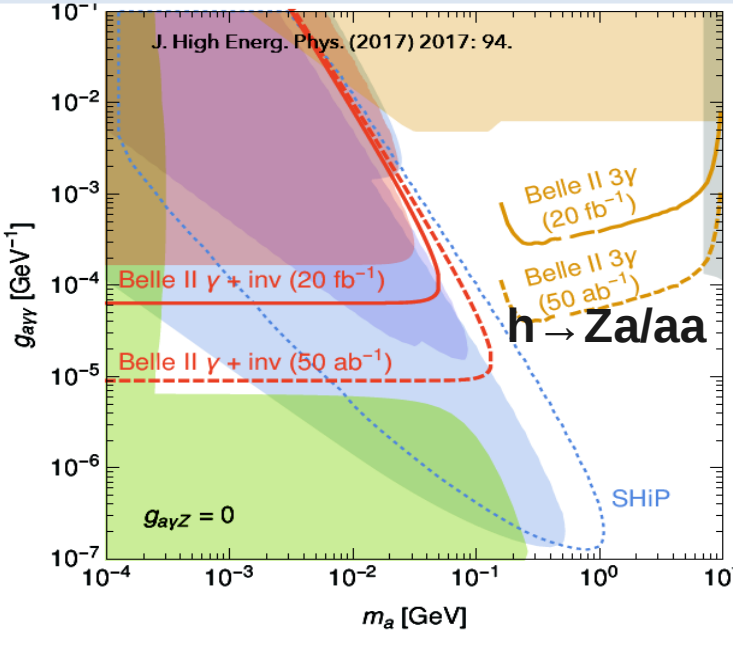




Search sensitivity for axion-like particles (ALPs)







a → γγ: - Distinction from dark scalar/photon

	NA62++	SHiP
$g_{a\gamma\gamma}$	> 1.5·10^{-6}	> 10^{-7}
m_a	< 0.3 GeV	< 1 GeV

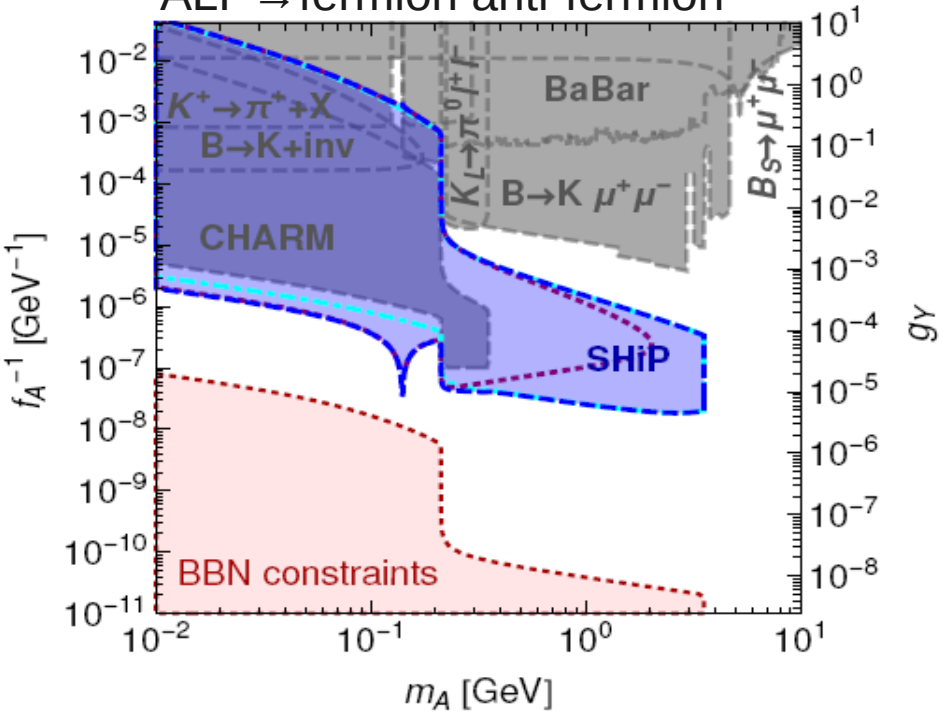
- NA62++/d-SHiP complementary to Belle II probing e.g. h → Za/aa parameter range

a → ff: - NA62++ sensitivity for scalar (next slide)

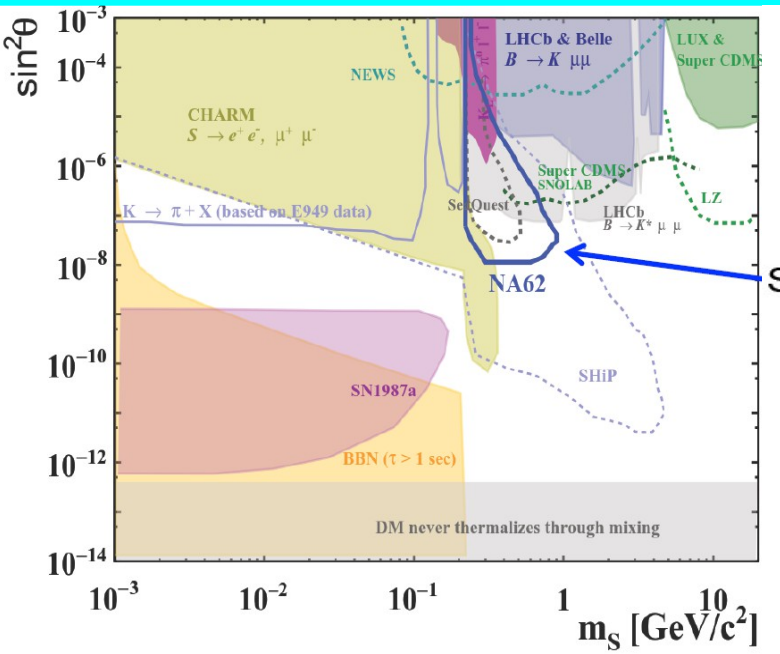
- d-SHiP: probes light DM mediator range (in extended Higgs sector)

improves towards BBN constraints

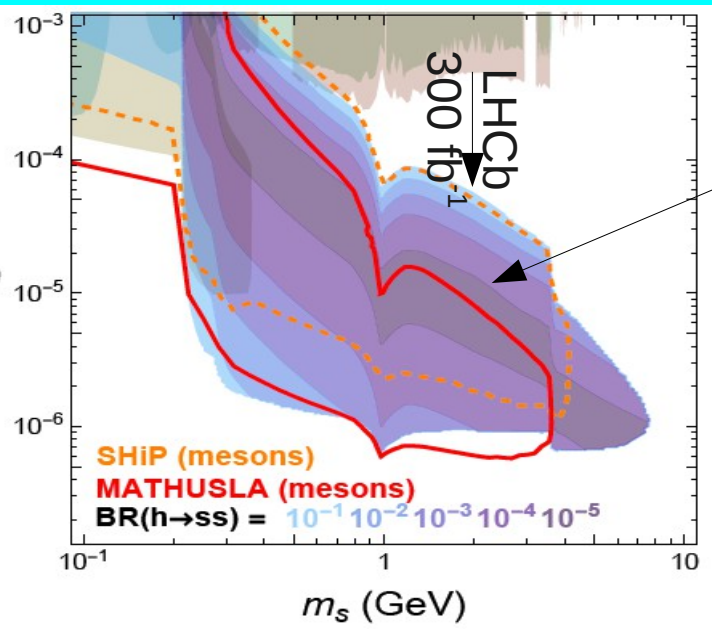
ALP → fermion anti-fermion



Scalar DM mediator (→visible) mixing with Higgs (sinθ)



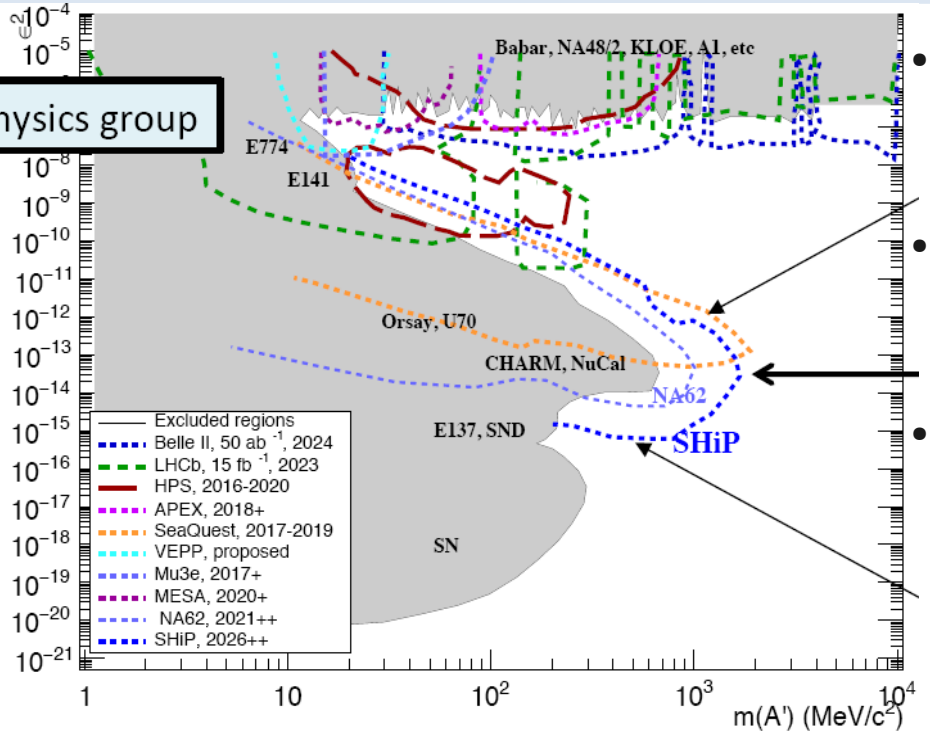
Sin θ



- NA62++ improves current constraints
- range relevant for scalar as LDM med. (Higgs → invisible @ HL-LHC)
- MATHUSLA more sensitive in sinθ, d-SHiP in mass

Dark photon A' → SM particles

PBC BSM physics group



- Production: meson decays (e.g. $\pi^0 \to \gamma A'$) or proton bremsstrahlung
- NA62++ improves current constraints, large overlap w/ other future expts.
- d-SHiP improves in mass and 10-50 in ε^2

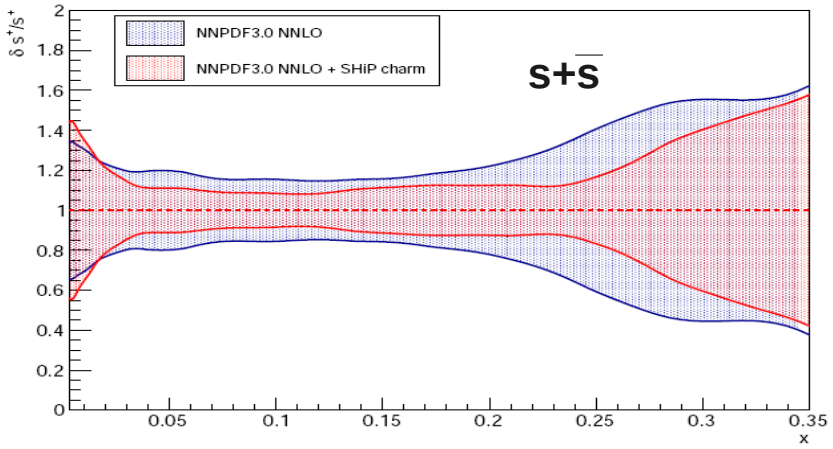
Neutrino physics with ν/i-SHiP

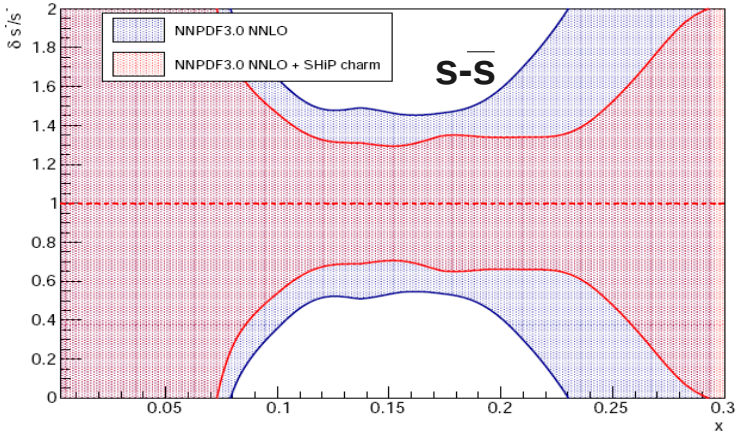
CHORUS: 7 ν_τ DONUT: 4 ν_τ ν/i-SHiP prospects: 6700 ν_τ 3400 $\bar{\nu}_\tau$

$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\left((y^2x + \frac{m_\tau^2 y}{2E_\nu M})F_1 + \left[(1-\frac{m_\tau^2}{4E_\nu^2}) - (1+\frac{Mx}{2E_\nu})\right]F_2 \right.$$
$$\left. \pm \left[xy(1-\frac{y}{2}) - \frac{m_\tau^2 y}{4E_\nu M}\right]F_3 + \frac{m_\tau^2(m_\tau^2+Q^2)}{4E_\nu^2 M^2 x}F_4 - \frac{m_\tau^2}{E_\nu M}F_5\right), \quad \text{LO: } F_4 = 0,\ F_5 = \frac{F_2}{2x}$$

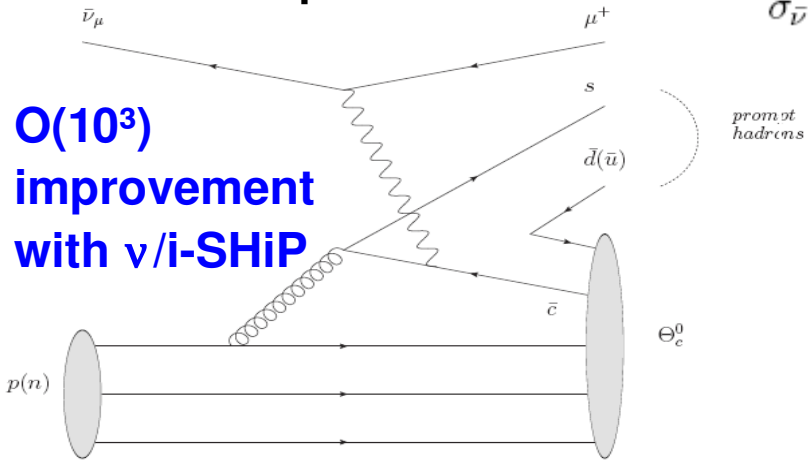
Limit on μ(ν_τ) ~ O(10^{-7}) μ_B

$\overset{(-)}{\nu}_{e,\mu}$: **O(10^5) charm production events**





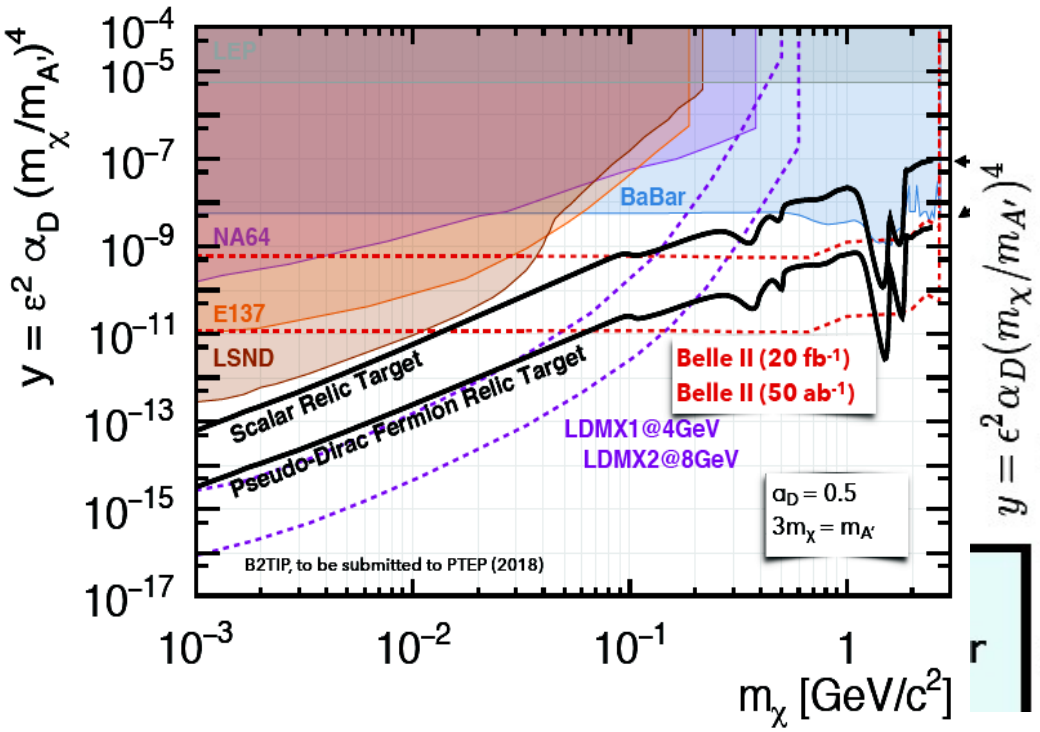
Charmed Pentaquark CHORUS limit: $\frac{\sigma_{\Theta_c^0}}{\sigma_{\bar{\nu}}} < 0.039$

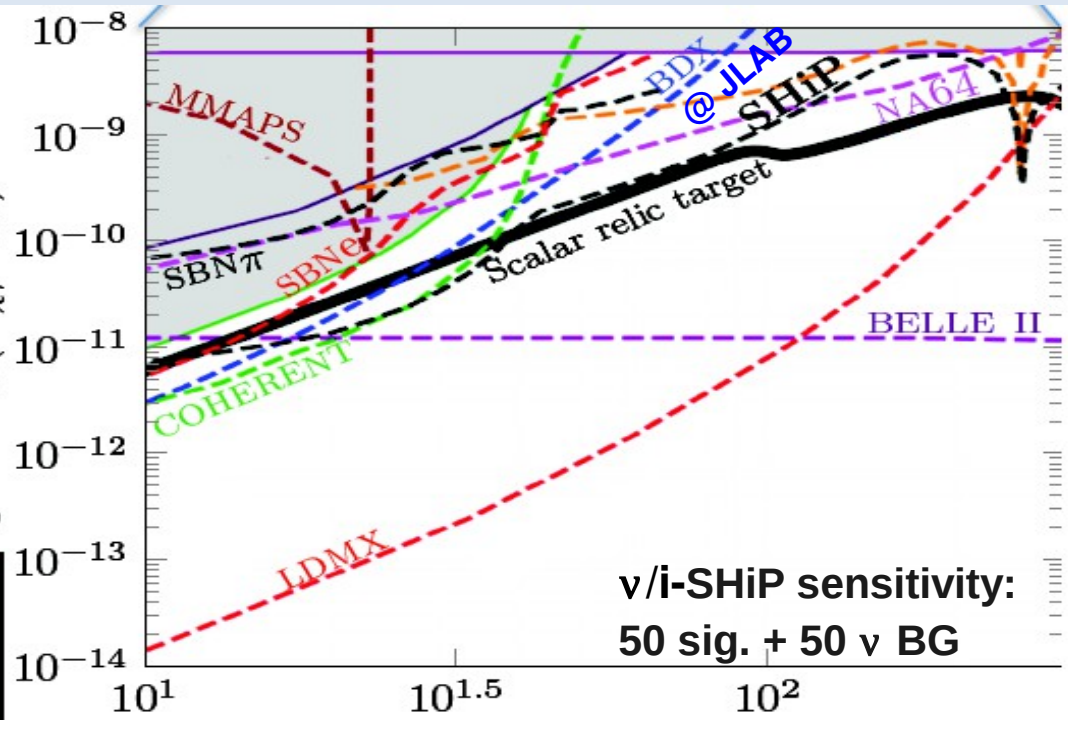


O(10^3) improvement with ν/i-SHiP

- **α_s determination from DIS**
- **Test of NuTeV anomaly**
- **$|V_{cd}|$ from dimuon DIS events**

Light Dark Matter sensitivity (via dark photon mediator A' → invisible)



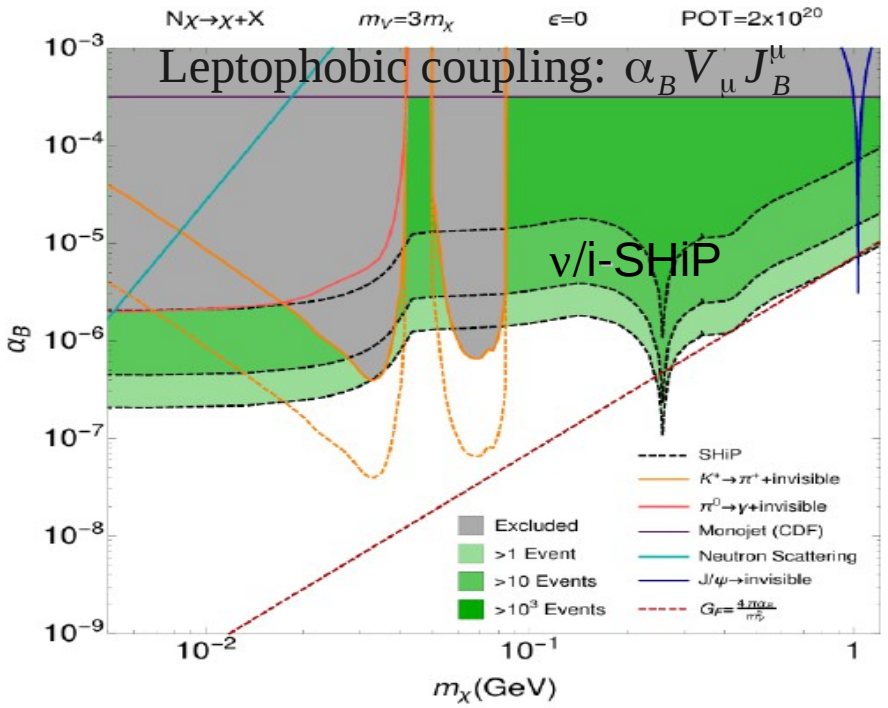


Missing-Mass technique:

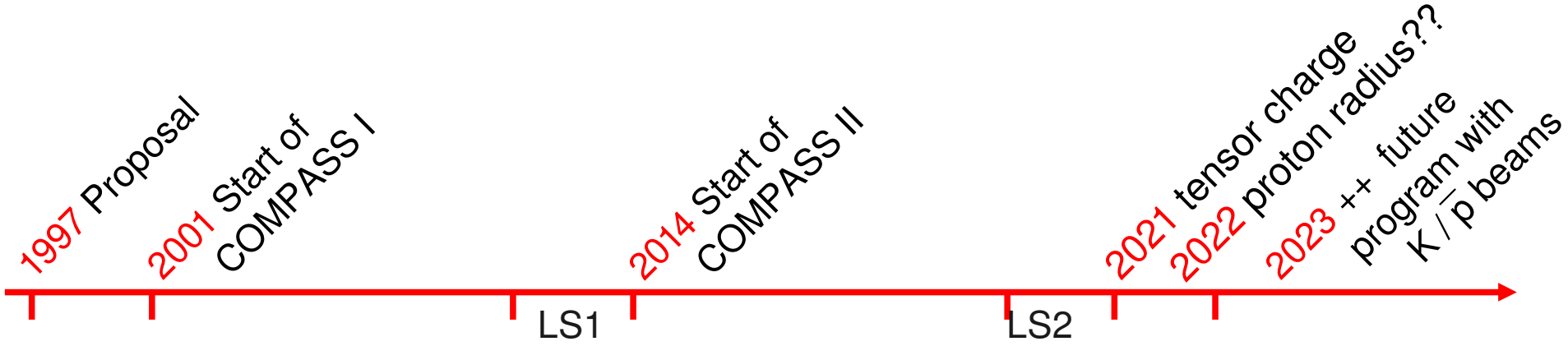
- **Belle II, mono-γ trigger:** m_χ **>O(100 MeV)**
- **LDMX (status unknown to us):** m_χ **<O(100 MeV)**

LDM scattering (complementary):

- **ν/i-SHiP: 20<m_χ< 300 MeV, probing scalar relic density**
  BG can be suppressed w/ bunched beam
- **BDX @ MESA:** m_χ **< 5 MeV**
- **Proton beamdumps in particular well suited for leptophobic coupling**



COMPASS @ CERN (beamline M2)

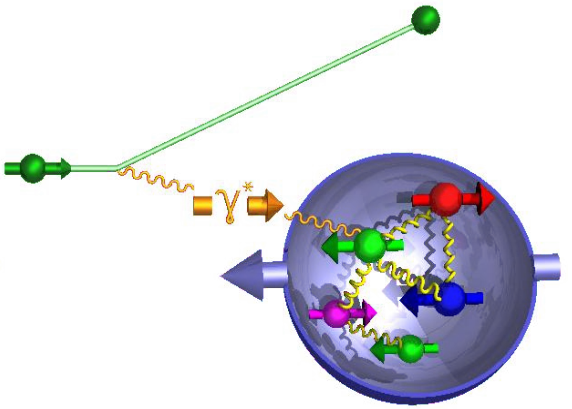


Partons in nucleus

hard polarised Muon Scattering,
hard exclusive and Drell-Yan Processes

Spectroscopy of Hadron resonances

soft High-energy Scattering of Pions and Protons

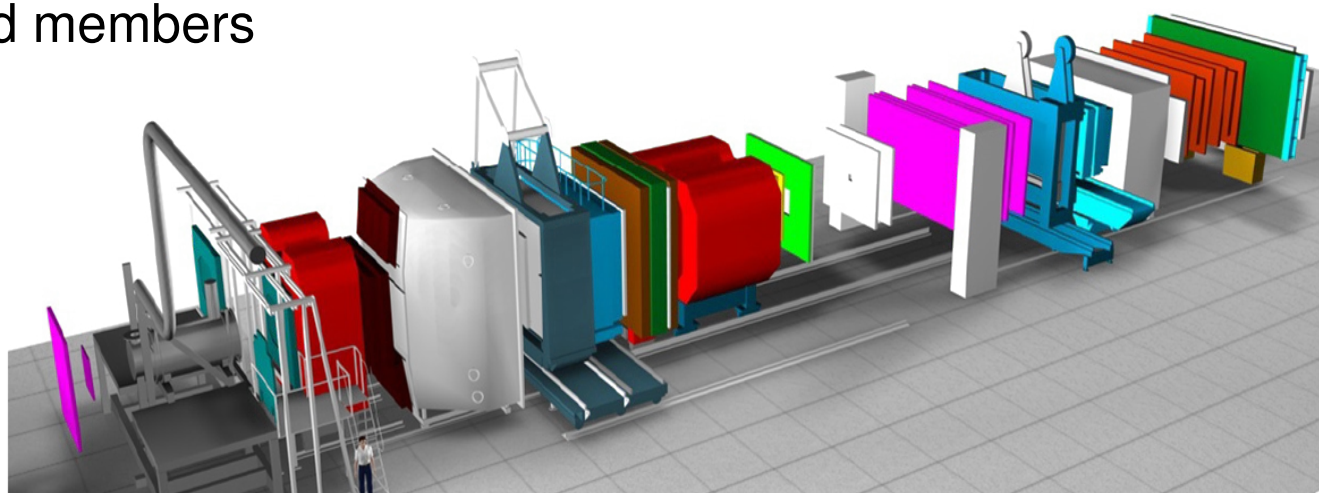


~230 scientists, 23 Institutes worldwide

Since 2015, additional associated members

Bonn, Freiburg, Mainz, München
(at least until 2021/22)

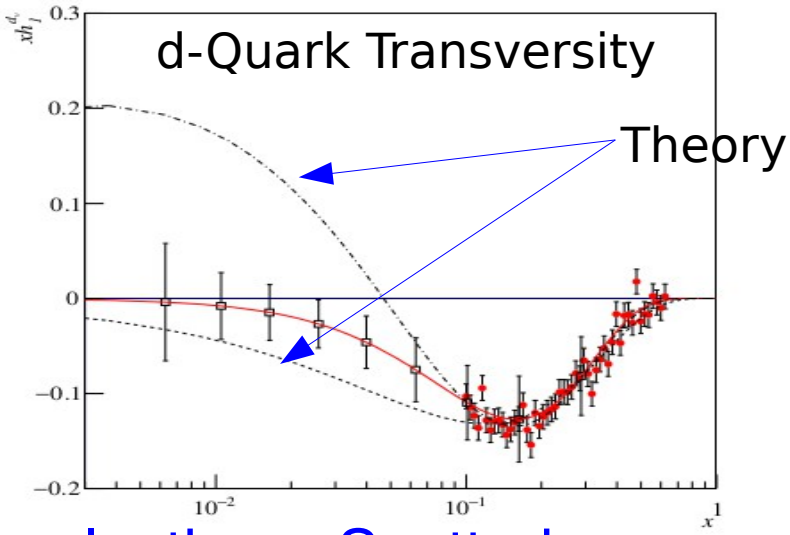
BMBF application 2018-21: 4 M€



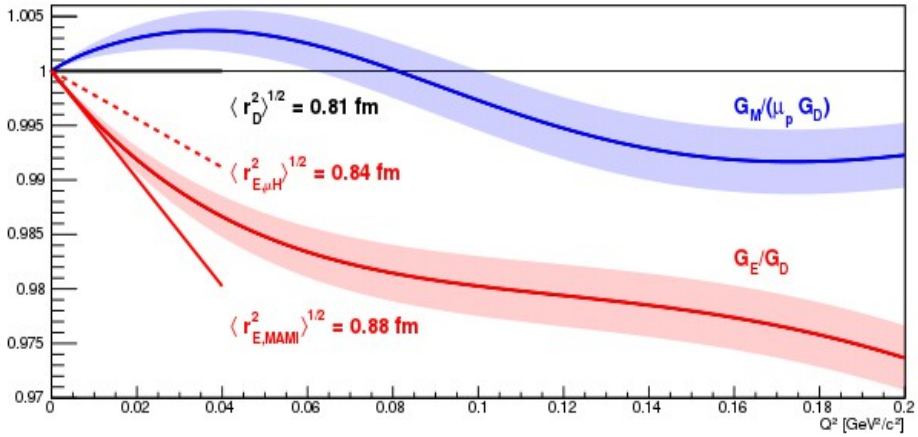
COMPASS Plans

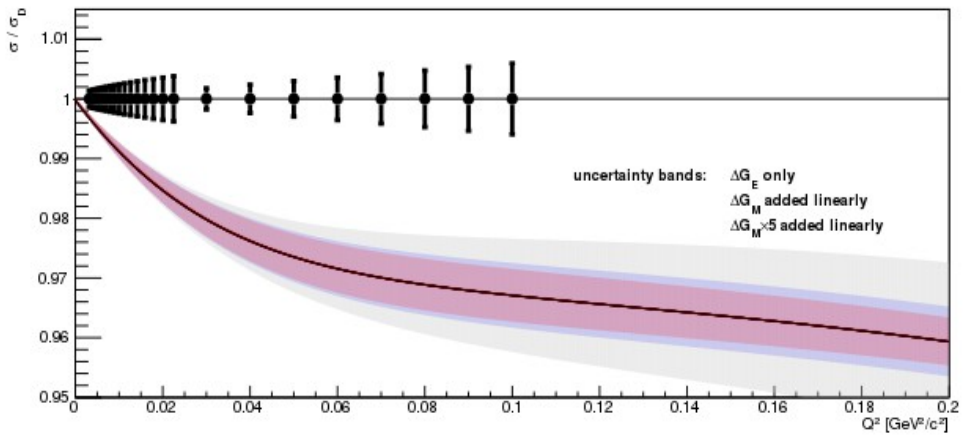
2021-2022

Physics with Myon Beam



- Tensor charge of Nucleon
  - (Integral über Transversity)
  - Recommandation of SPSC
- Proton radius in high-energy elastic μp Scattering
  - smaller systematics than in e/low-energy μ scattering
  - $\Delta r_E \leq 0.01$ fm
  - H target (active Target TPC)
  - Test measurements: feasilibity demonstrated
  - Approval process via ESPP





COMPASS Plans

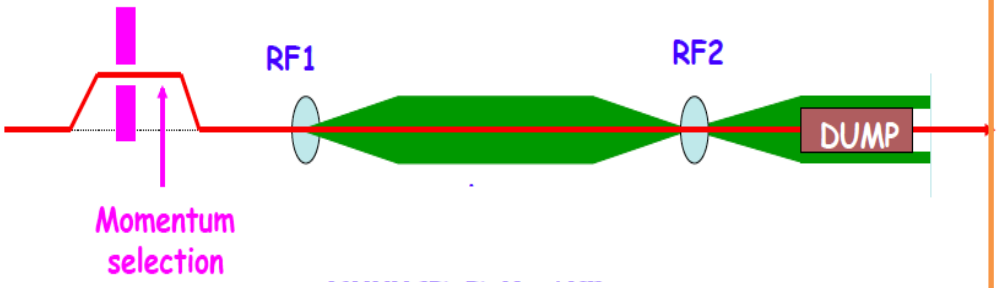
2023-202x Long-term plans (requires beamline changes)

Physics with RF separated Kaons and Antiprotons:

- Intensity: Kaon: 30-50 x increase, $\bar{p}$: FAIR light

- Spectroscopy
- Drell-Yan

- Letter of Intent 2017 - Proposal 2018



DY with antiprotons: **- Additional constraints on proton PDFs**

DY with kaons: **- kaon PDFs (not well known up to now)**
- π-K difference → gluon PDF

Spectroscopy w/ kaons: **- high-mass resonances with strangeness**

"low-energy" Antiprotons from secondary hadron beam (15 GeV):
"Preparation" for PANDA (w/ 1/40 luminosity)

KET–KAT–KhuK Workshop: The future of Non-Collider Physics (27./28.04.2017)

Aus der Abschlusserklärung:

*Die **Präzisionsmessung des schwachen Mischungswinkels** bei niedrigen Energien mit dem **P2-Experiment am MESA-Beschleuniger** als empfindlicher Test des Standardmodells sollte realisiert werden.*

*Zur **Suche nach leichter dunkler Materie** wäre die Nutzung der hohen Intensität des Elektronbeschleunigers **MESA durch das BDX-Experiment** sehr wünschenswert.*

*Das **NA62**-Experiment bietet eine weltweit einmalige Sensitivität für **seltene Kaon-Zerfälle** und für den **Nachweis langlebiger, schwach wechselwirkender Teilchen**. Die Fortführung und ein Ausbau sind sehr wünschenswert.*

*Das vorgeschlagene **SHiP**-Experiment am Protonbeschleuniger CERN-SPS hat weltweit einzigartige Sensitivität und ein **breites Physikprogramm (z.B. leichte dunkle Materie, dunkle Photonen, axion-ähnliche Teilchen, sterile Neutrinos)**. Eine sichtbare deutsche Beteiligung an SHiP wäre sehr wünschenswert.*

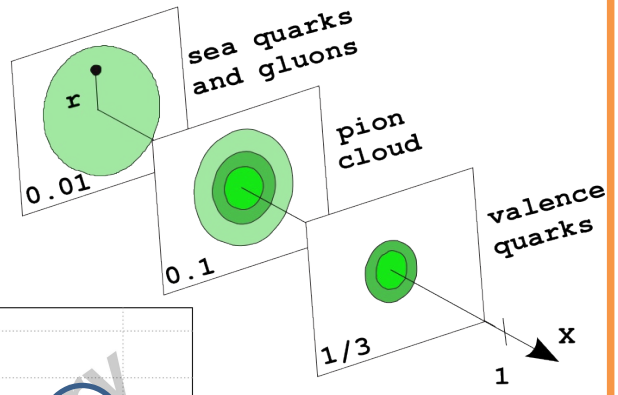
*Eine Weiterentwicklung des **COMPASS**-Messprogramms mit **Myonstrahlen und den vorgeschlagenen, verbesserten Kaon-und Antiprotonstrahlen** wäre sehr wünschenswert.*

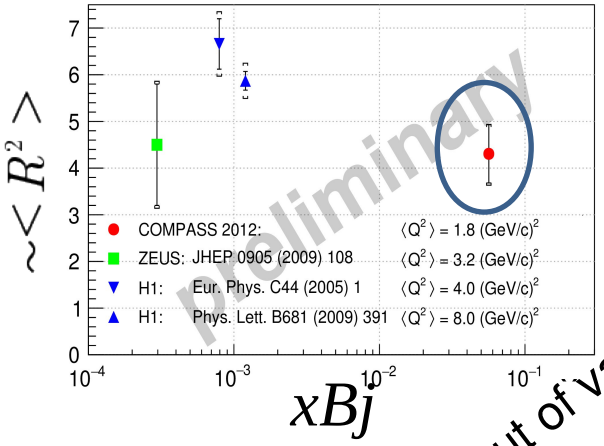
*Das **Mu3e**-Experiment nutzt einen Myonstrahl am PSI für die Suche nach Zerfällen, die die **Leptonfamilienzahl** verletzen. Der vorgeschlagene Bau eines neuen hochintensiven Myonstrahls (**HiMB**) am PSI wäre sehr wünschenswert, um das volle Potenzial des Mu3e Detektors auszunutzen.*

BACKUP

COMPASS 2015-2018 – three Highlights

Tomography of Nucleon via DVCS



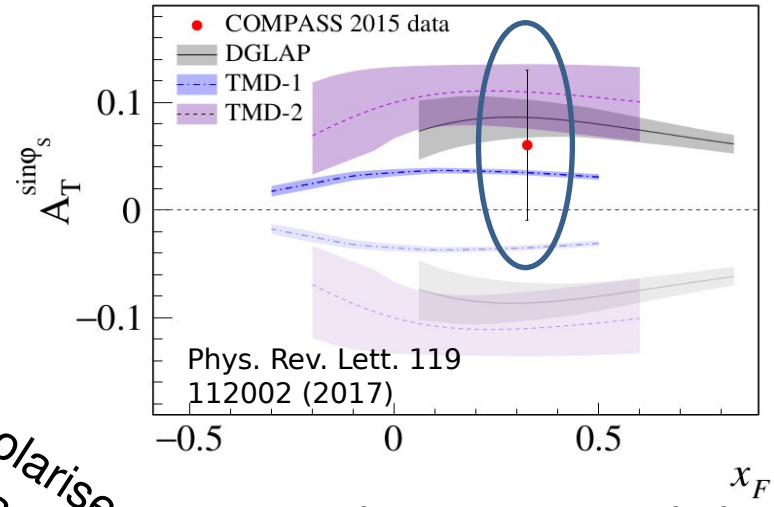


Compact nucleus out of valence quarks
First data @ x=0.1

Understanding poles,
Interference etc:

PHASE Initiative

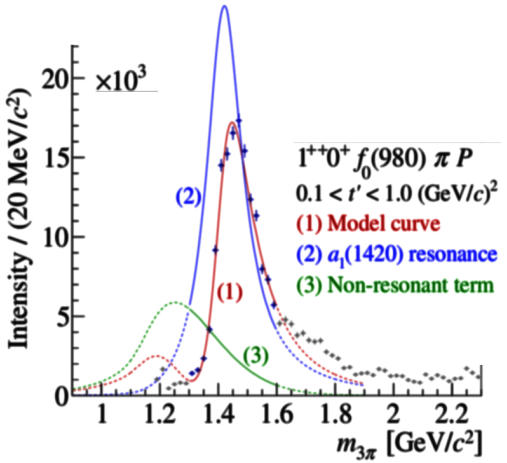
QCD: Universality of Drell-Yan and SIDIS (NLO corrections)



First polarised Drell-Yan Sivers Asymmetry:
Sign change towards SIDIS favoured as predicted by NLO QCD

Goal 2018: 4 x statistics
→ ½ unc.

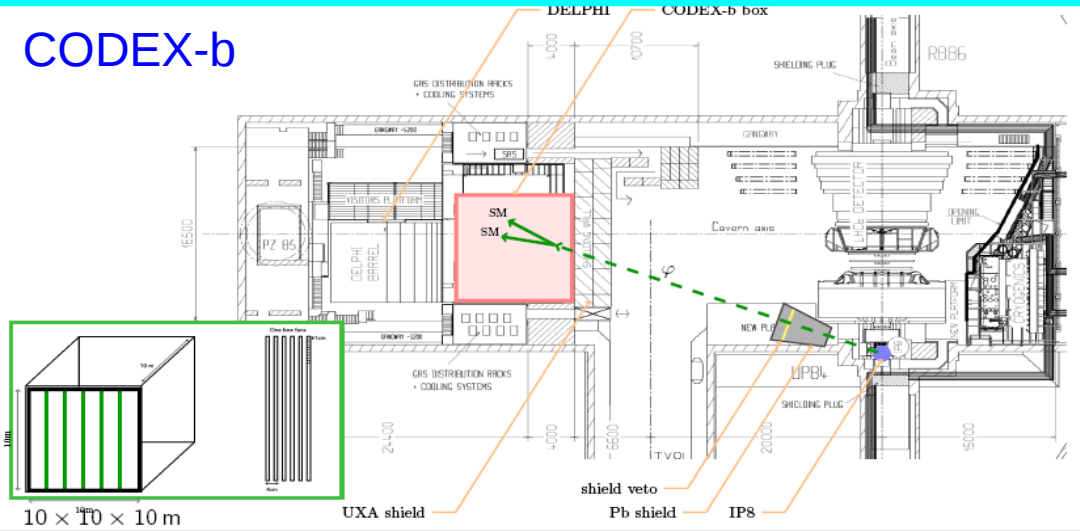
Meson Spectroscopy



new Resonance a1(1420) - new Analysis methods

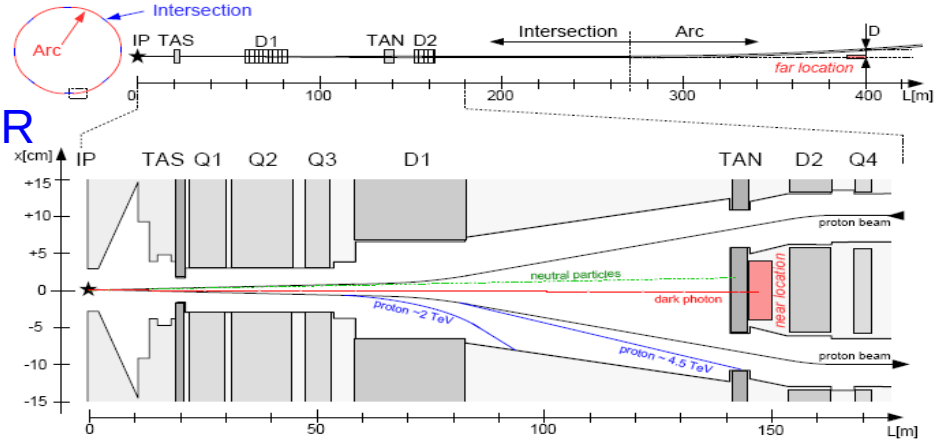
New detector ideas for HL-LHC: CODEX-b, FASER, MATHUSLA

CODEX-b



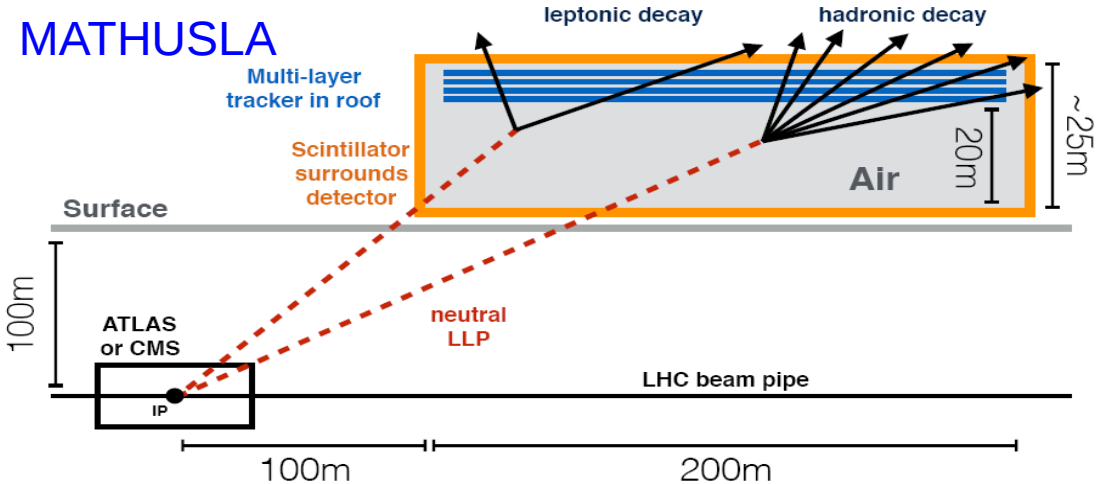
- Discussed in the context of LHCb upgrade
- No full detector simulation; zero BG assumed
- (Veto) efficiencies?
- No collaboration yet

FASER



- few 100 m in forward direction from a LHC experiment
- No full detector simulation; zero BG assumed
- (Veto) efficiencies?
- No collaboration yet

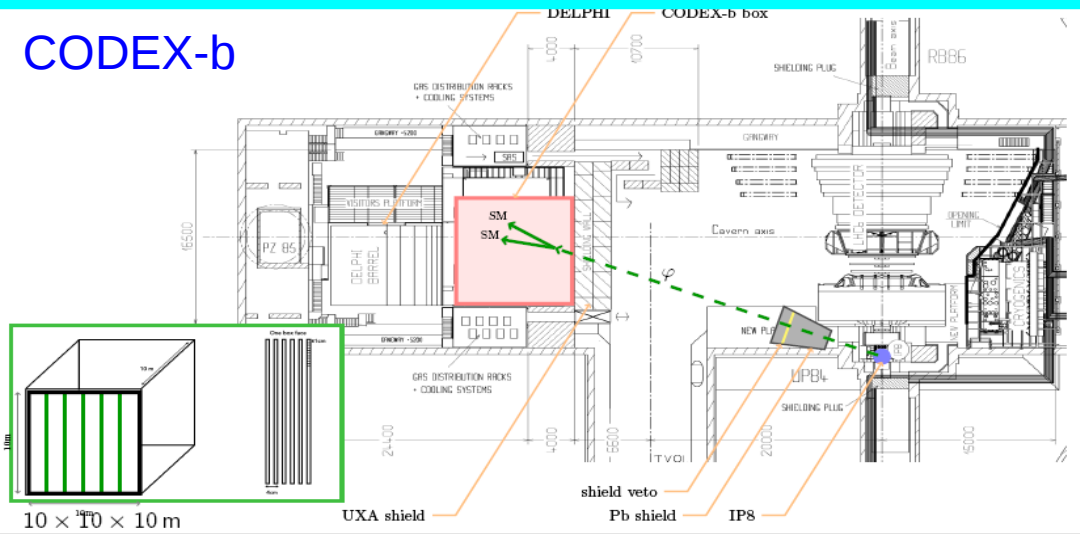
MATHUSLA

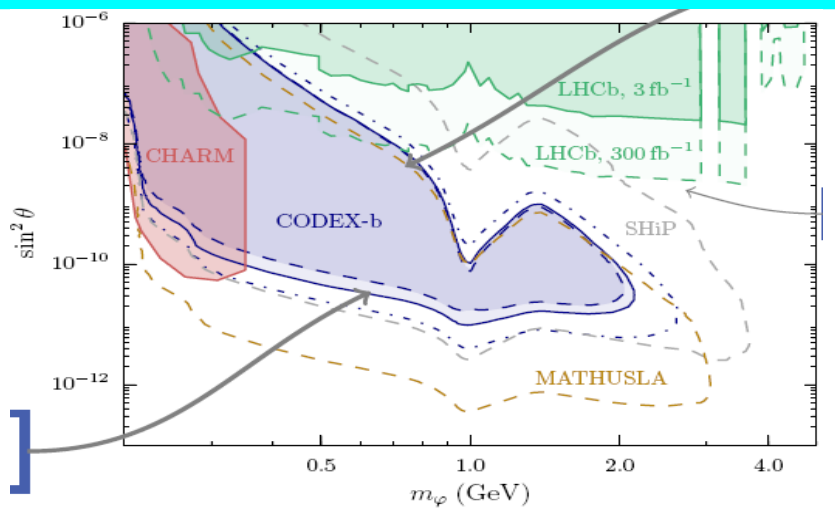


- Letter of intent planned for 2018
- No full detector simulation; zero BG assumed
- (Veto) efficiencies?
- Unofficial cost estimate: O(50 MUSD)

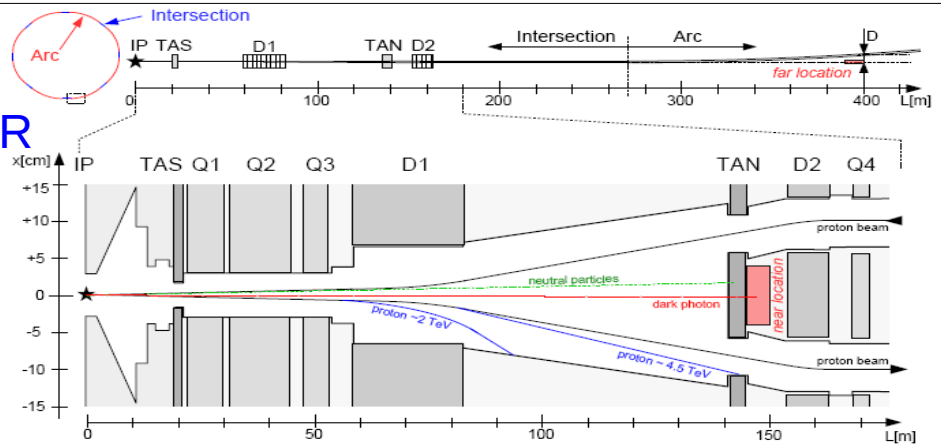
New detector ideas for HL-LHC: CODEX-b, FASER, MATHUSLA

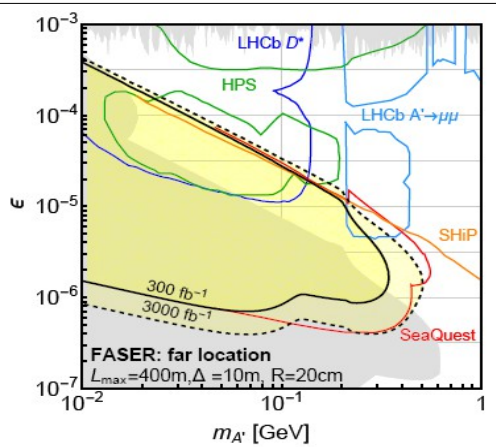
CODEX-b

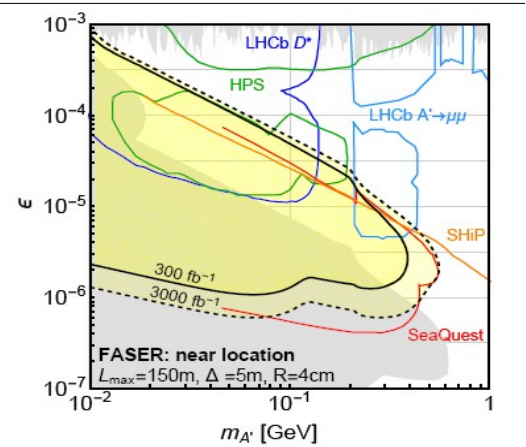




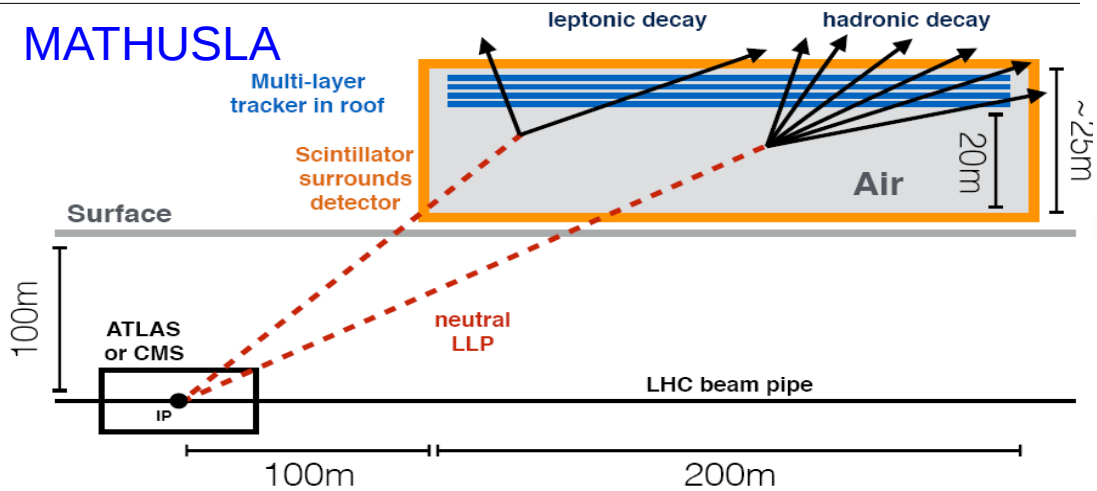
FASER

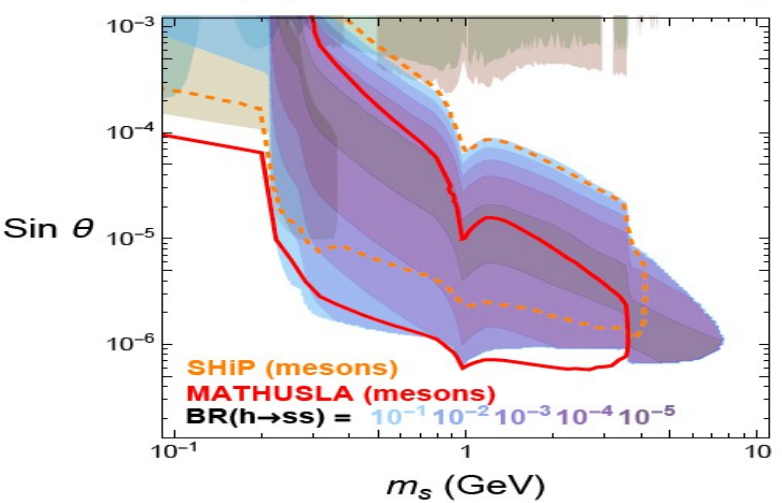




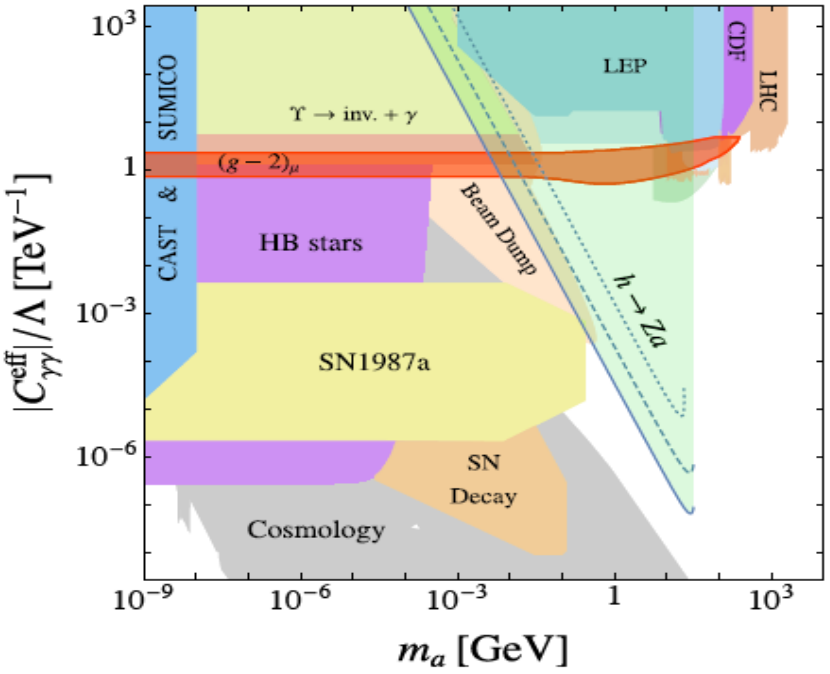


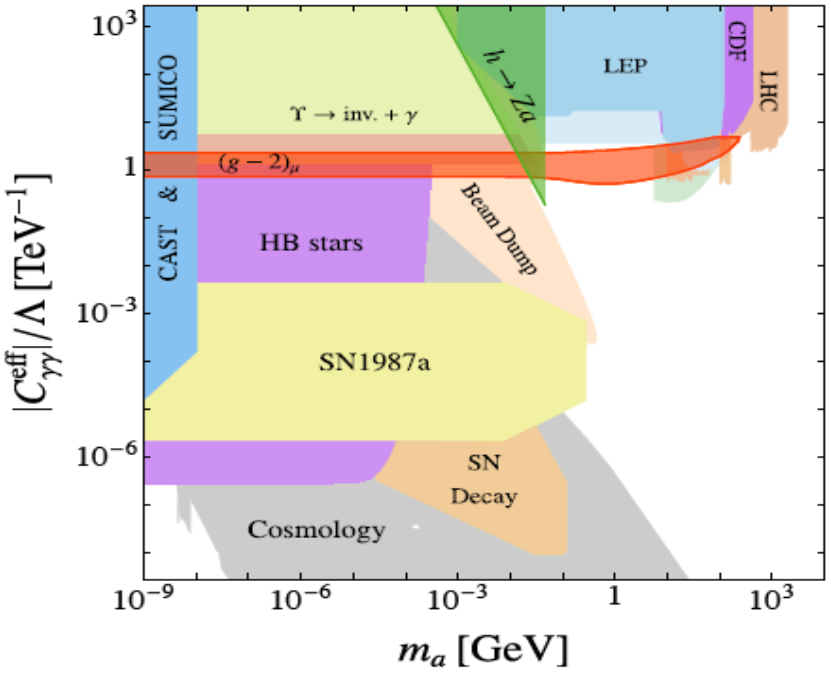
MATHUSLA

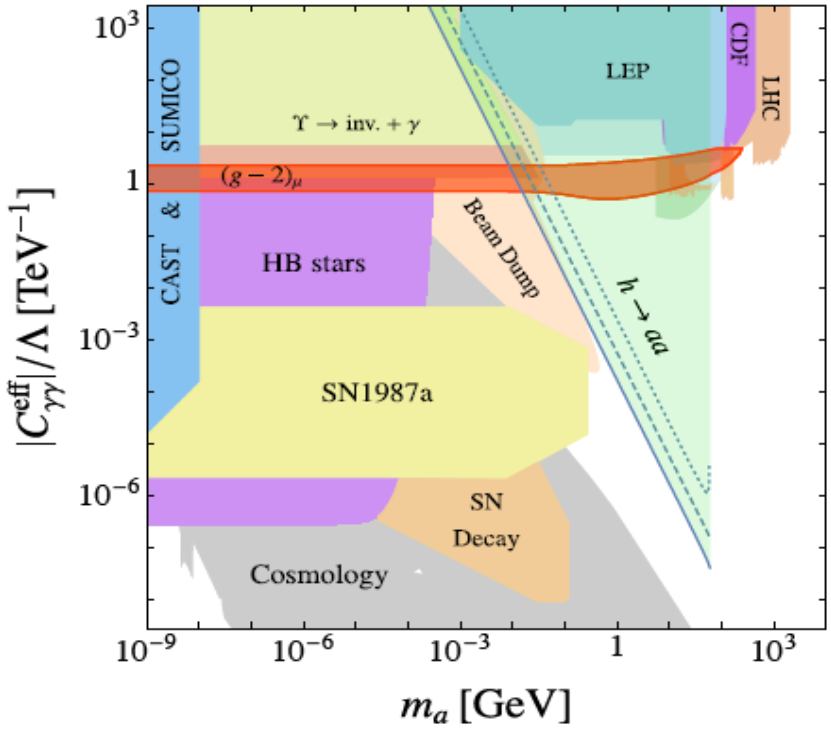


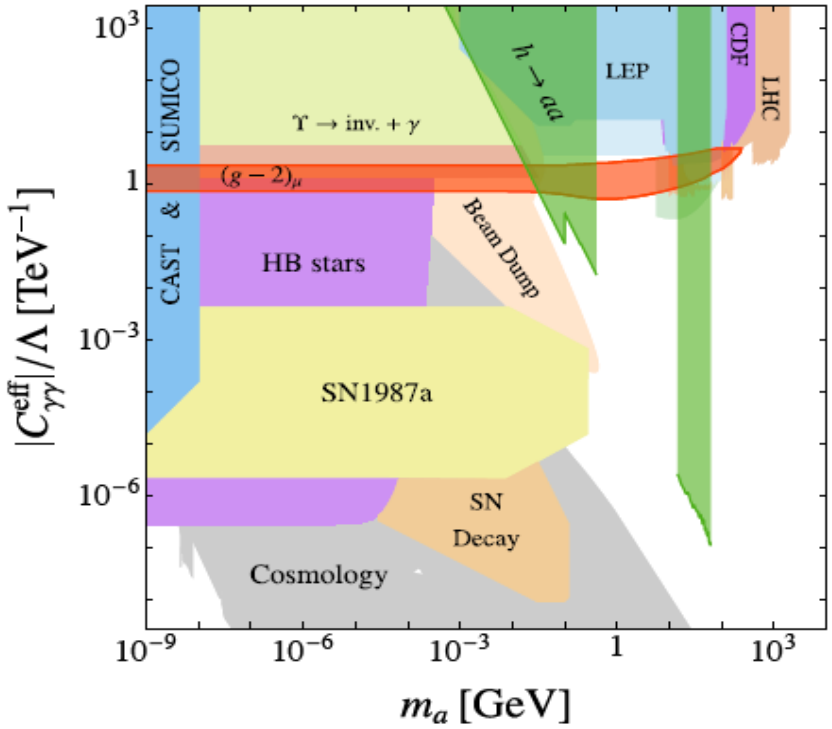


Search sensitivity for axion-like particles (ALPs)

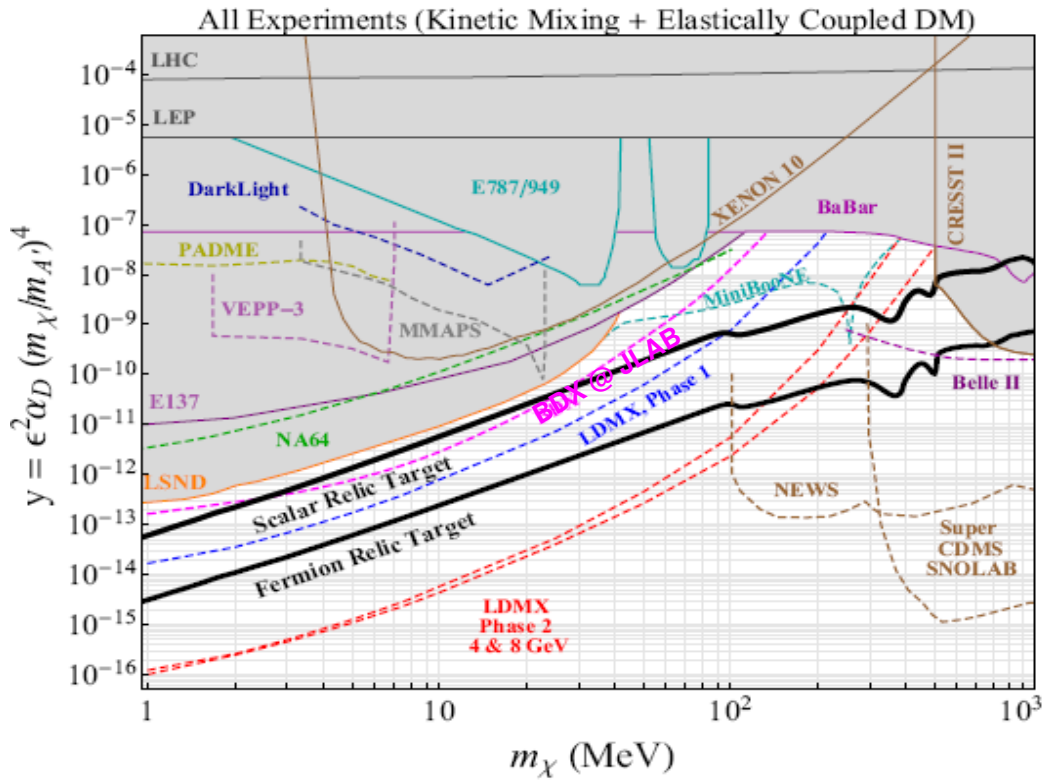


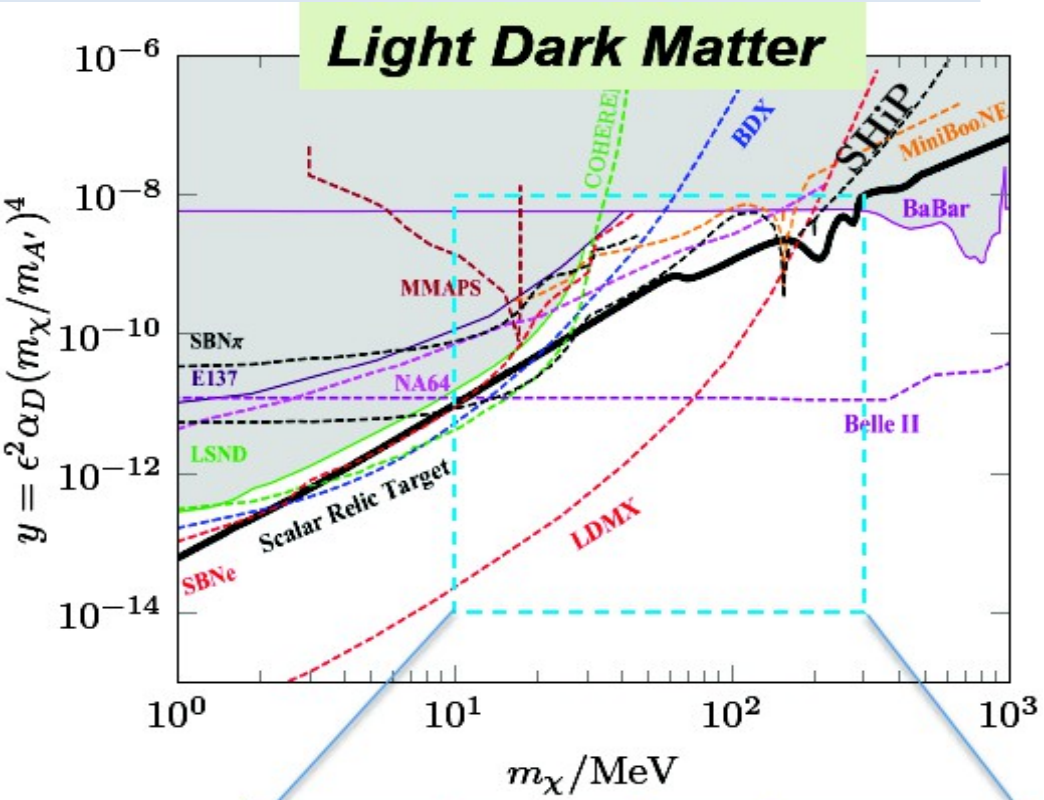


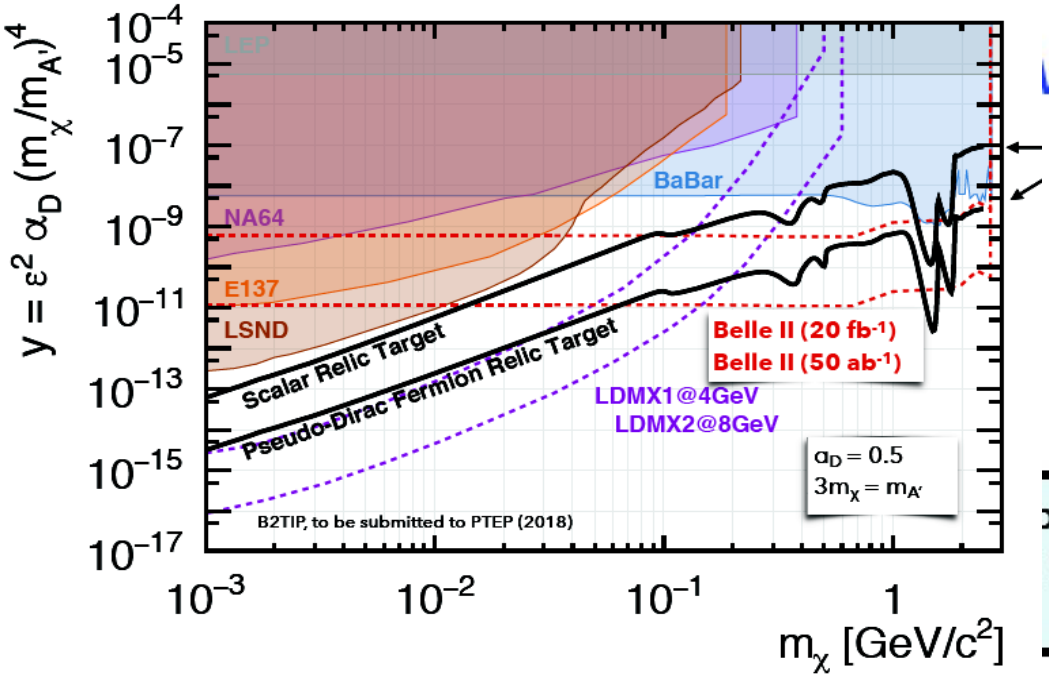


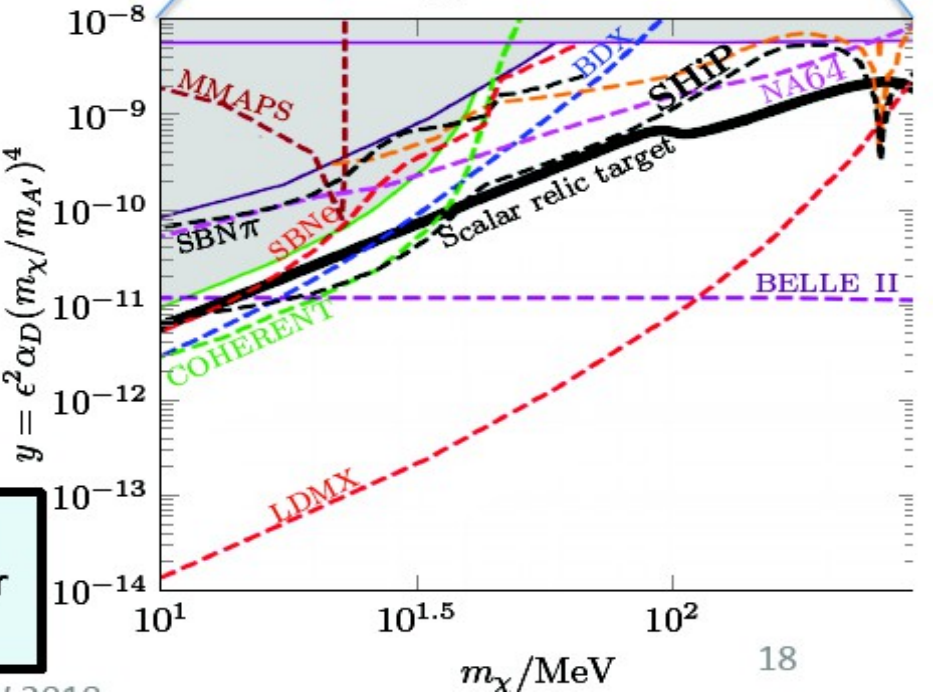


Light Dark Matter sensitivity (dark photon mediator A' → invisible)









osmic Matter