Session Summary
Neutrino, GW, Dark Matter, Dark Sector, Flavor and CPV

European Strategy Update

INFN-Pisa, June 10, 2019

Francesco Forti,
INFN and University, Pisa

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Disclaimer and topics

- Lots of material, it is the summary of the summaries
  - No way to get in any detail (also because of limited knowledge)
  - Try to list interesting directions
- Three sessions:
  - Neutrino (accelerator and not accelerator), gravitational waves
  - Dark matter and dark session
  - Flavour physics and CP violation
- Comments on instrumentation and computing session
- https://cafpe.ugr.es/eppsu2019/

Neutrino Physics

(accelerator and non-accelerator)

summary of the session

NOTE: including Gravitational Waves

Conveners: Stan Bentvelsen, Marco Zito

Big questions

What is the origin of the neutrino masses ? And of the leptonic mixing ?

What is the optimal strategy towards a complete set of measurements of neutrino oscillation parameters and towards a precision global fit of the PMNS matrix ?

Is the existing experimental program (reactor, SBL) sufficient to confirm or exclude the existence of sterile neutrino states with masses in the eV/c^2 range ?

How to search for heavy neutral leptons with present and future facilities ?

Is gravity described by the Einstein theory of general relativity?

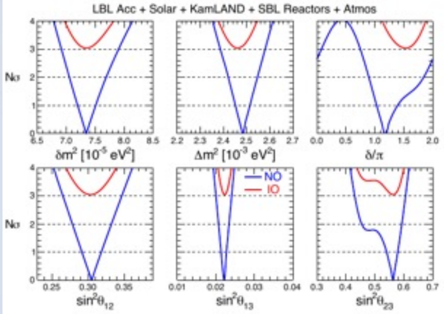
How do gravitational waves help to understand Dark Sector of the universe?

What is the proton-proton cross section at ultra-high energies?

How can cosmic neutrino's help to pin-down their properties - oscillations and mass hierarchy?

Study of neutrino properties

Today : few % precision on most of the parameters



Oscillation parameter		Best-fit (NO)	(IO)	"1σ" error
Δm^2	$/10^{-3}$ eV^2	2.49	2.47	1.3 %
δm^2	$/10^{-5}$ eV^2	7.34	7.34	2.2 %
$\sin^2\theta_{13}$	$/10^{-2}$	2.23	2.24	3.0 %
$\sin^2\theta_{12}$	$/10^{-1}$	3.04	3.03	4.4 %
$\sin^2\theta_{23}$		0.56	0.56	~ 5 %

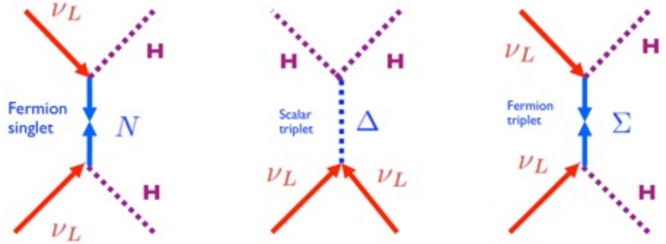
E. Lisi Granada 2019

But there are still major unknowns : Dirac or Majorana, CP violation phase δ, mass ordering and θ_{23} octant, absolute mass

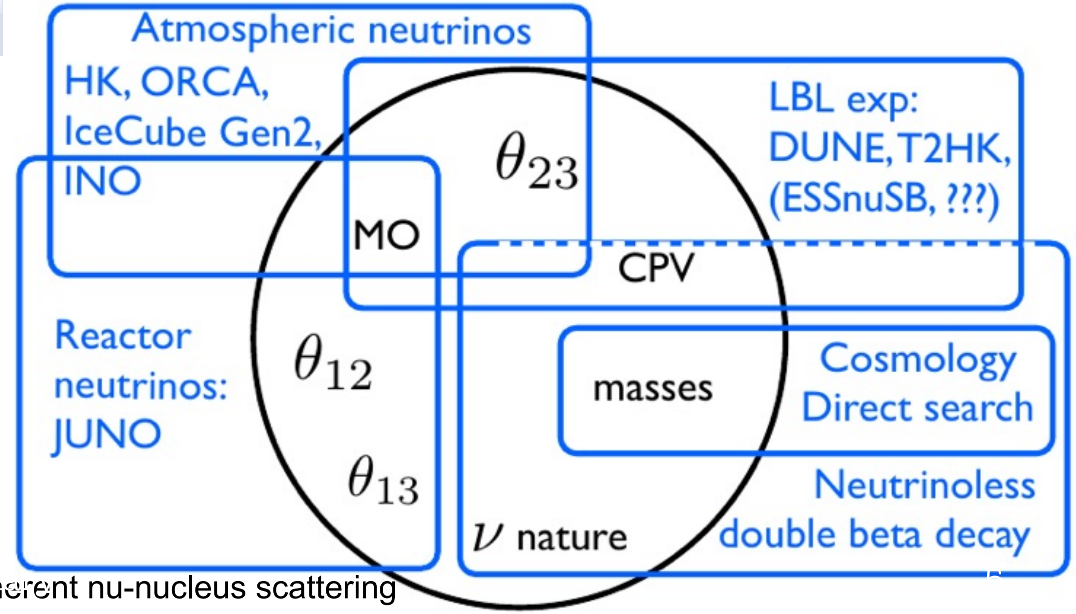
- Masses and oscillations
- Dirac or Majorana
- CP Violation
- New states

Neutrino as a window to new physics

- The minimal extension is to have new elementary neutral fermions
- Neutrinos could have new interactions



A very diverse experimental approach

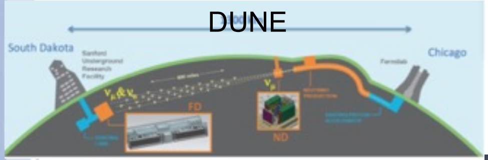


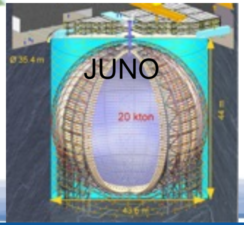
S. Pascoli Granada 2019

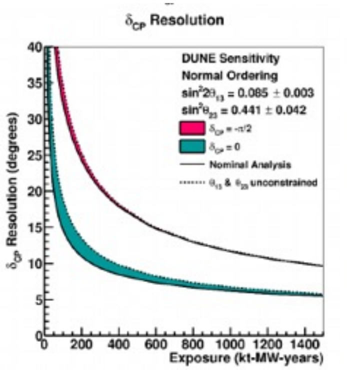
Coherent nu-nucleus scattering

New long baseline projects

- Golden physics case for LBL: CP violation in PMNS would be a new source since 1964 discovery, possible link with leptogenesis, CP and MO linked to model building
- Since 2013 progress in the field had been faster than “rapid” convincing a growing community (>2000 worlwide) of physicists and the funding agencies to invest in these experiments
- Major players : DUNE, Hyper-Kamiokande, JUNO, ORCA

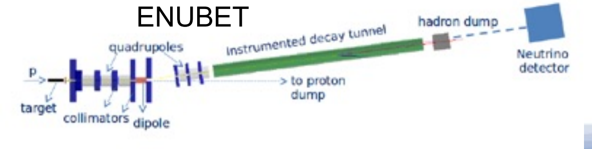


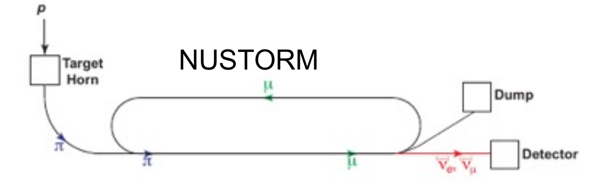




Precision program in Europe

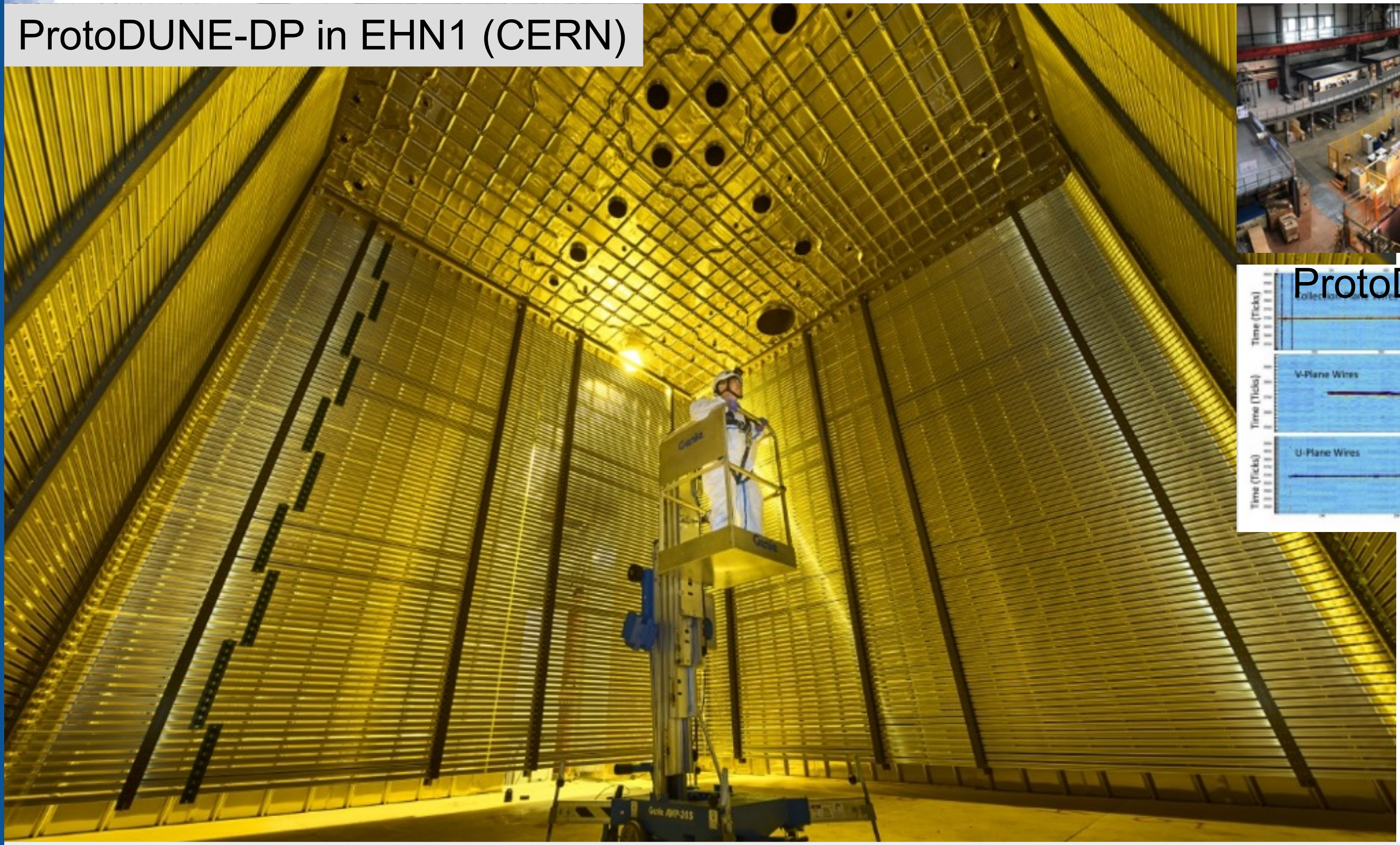
- Squeezing every bit of information out of the future experiments requires a complementary program (special rôle for Europe) to
  - Measure hadroproduction for the neutrino flux prediction (NA61)
  - Understand the neutrino-nucleus cross-section at the % level, both theoretically and with new facilities (Enubet, Nustorm)
  - Collaboration to be developed with nuclear physicists
- Next-to-next generation facilities (ESSnuSB, …) are also under study

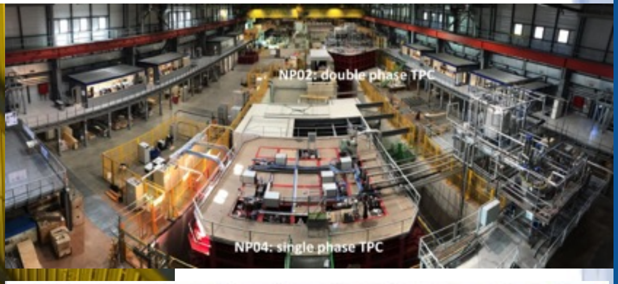




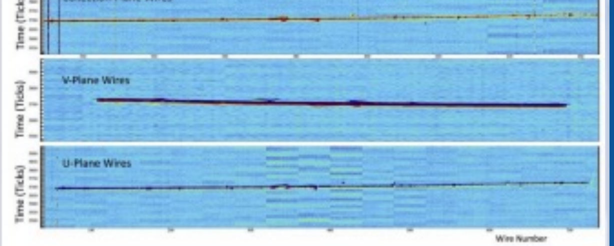
The CERN Neutrino Platform

ProtoDUNE-DP in EHN1 (CERN)





ProtoDUNE-SP beam event



- Demonstration of membrane cryostats for LAr TPC
- ProtoDUNE-SP exposed to the SPS beam in 2018 and fully validated (purity, S/N, HV)
- ProtoDUNE-DP to be tested this summer
- Also T2K ND Upgrade, ENUBET, BabyMIND...

A game changer for the field worlwide !

Measuring the neutrino masses

- Future cosmology missions (Euclid, DESI …) target the neutrino mass detection ! (only parameter in common between particle physics and cosmology)
- Neutrinoless double beta decay : key to determine the neutrino nature. IO covered with the next generation of experiments (strong program in Europe: LEGEND, CUPID, NEXT ...)
- Single beta decay : KATRIN taking data. New exp. methods (Project8, ECHo) under development.

Are there sterile neutrinos ?

- Motivated by long standing anomalies (LSND, MiniBoone, Gallium, reactor anomaly)
- No successful model and strong tension with other results (MINOS+, IceCube)
- A very rich program developing with SBL reactor neutrino experiments (Prospect, Solid, Stereo, Neutrino4, DANSS, NEOS). The results are ambiguous.
- Fermilab SBN three detectors program (SBND, MicroBoone, Icarus). 2020 results from MicroBoone
- We will know a lot more in the next couple of years

Hunting new states (HNL)

- New neutrino states (Heavy Neutral Leptons) possibly related to neutrino masses and baryon asymmetry
- Their masses could be anywhere between eV and GUT scales !
- Very active area : searches based on LBL near detectors, beam dump, colliders, « symbiotic » expt.
- Unique sensitivity at low masses for the beam dump facility

Cosmic neutrinos

- Cosmic neutrinos are complementary to accelerator-based experiments : mass ordering with KM3NeT/ORCA and IceCube/PINGU.
- But also neutrino properties and interactions, tau neutrino, PMNS unitarity...

UHE Cosmic Rays

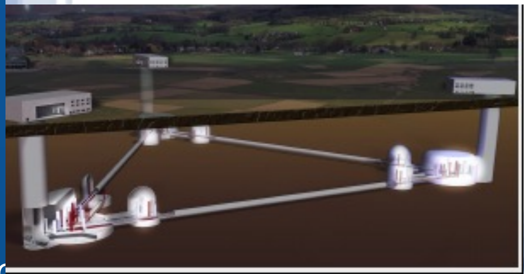
- Flux suppression observed at ~10^{20} eV
- Dipole distribution observed above 8 EeV : extragalactic origin
- Most models of UHECR from exotic sources are ruled out (monopoles, cosmic strings…)
- Proton-proton cross-sections
- The first EeV-neutrino should be 'just around the corner'

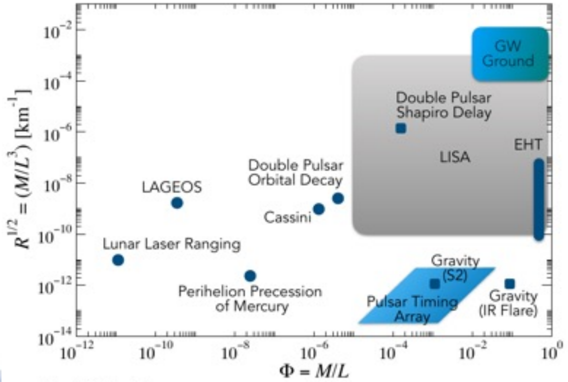
Multimessengers

- Multimessenger : combining information from photons, neutrinos, CR, GW.
- Recent highlights : Neutron star merger (GW+photon), Blazar (neutrino's +photon)
- Many physics topics : dark matter searches, expansion history of the Universe, Lorentz symmetry, ...

Gravitational waves

- Gravitational waves open a new field of research
  - Testing General Relativity in extreme conditions
  - Probing Black hole as Dark Matter
  - Equation of state in neutron stars
  - Serendipity : exotic objects, new fields and phenomena
- Einstein Telescope : 3rd generation of interferometers. Ultimate facility to probe the entire universe in the 1-100 Hz frequency range
- ET has put on the table a request for CERN to help with
  - Underground infrastructure, cryogenics
  - Vacuum, material and surface science
  - Electronics and data acquisition, computing





Credit: Nico Yunes

Neutrino session take-away message

- Neutrino oscillations, mass ordering, CPV phase:
  - Ongoing program DUNE, Hyper-Kamiokande, JUNO, ORCA
  - Need cutting-edge detectors and % precision on the flux and cross-sections: NA61, Neutrino Platform. New facilities under study.
  - Long term future for high precision LBL measurements with new techniques.
- Neutrino masses
  - Absolute mass is still unknown (m<~0.1 eV!). Laboratory (Katrin) and cosmology missions ongoing.
  - Dirac or a Majorana fermion ? Neutrinoless double beta decay searches
  - The neutrino mass might require new neutral fermions with masses between eV and GUT scale (!)
    - Clarify eV scale anomalies (SBL program at FNAL, reactor neutrino experiments)
    - Search for new states at the GeV-EW scale (beam dump and colliders)
- Astroparticle physics
  - Gravitational waves and multimessenger physics open up a new window on the Universe. Very strong physics case.
  - There is a very high impact on the field of particle physics (and fundamental interactions) (eg dark matter, neutrinos, general relativity, …)
  - There is clearly an opportunity for the particle physics community and laboratories to expand their involvement in this program

Dark Matter - Dark Sector Summary

Shoji Asai and Marcela Carena

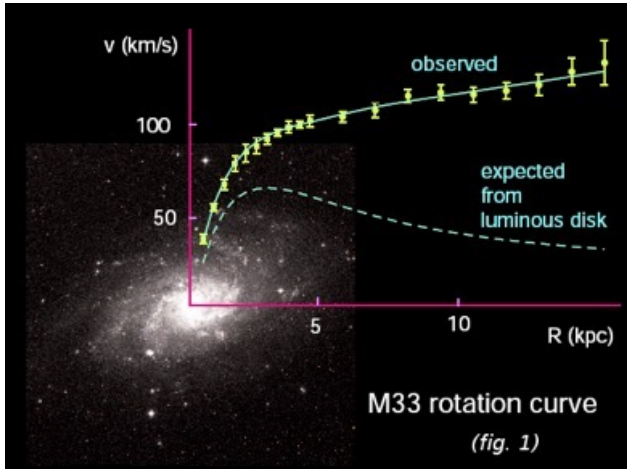
on behalf of the Dark Matter–Dark Sector Group

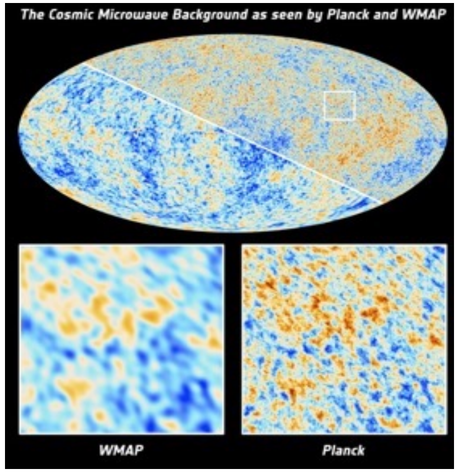
B.Dobrich, J.Jaeckel , G.Krnjaic , K.Petridis and K Zurek

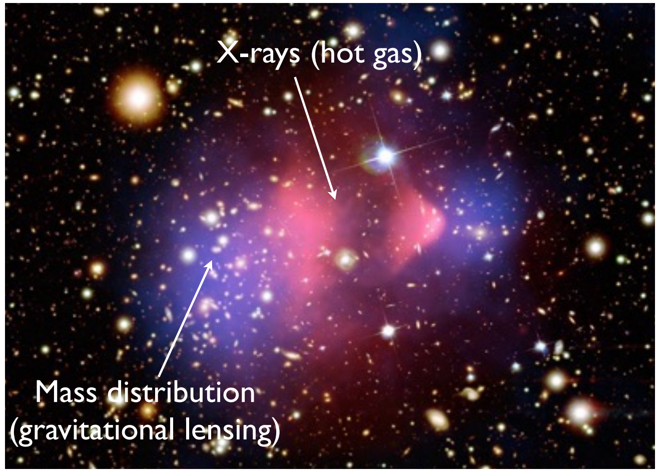
Dark Matter/Dark Sector Introductory talk

[H. Murayama]

- Dark Matter exists, awaiting for discovery







Big Questions

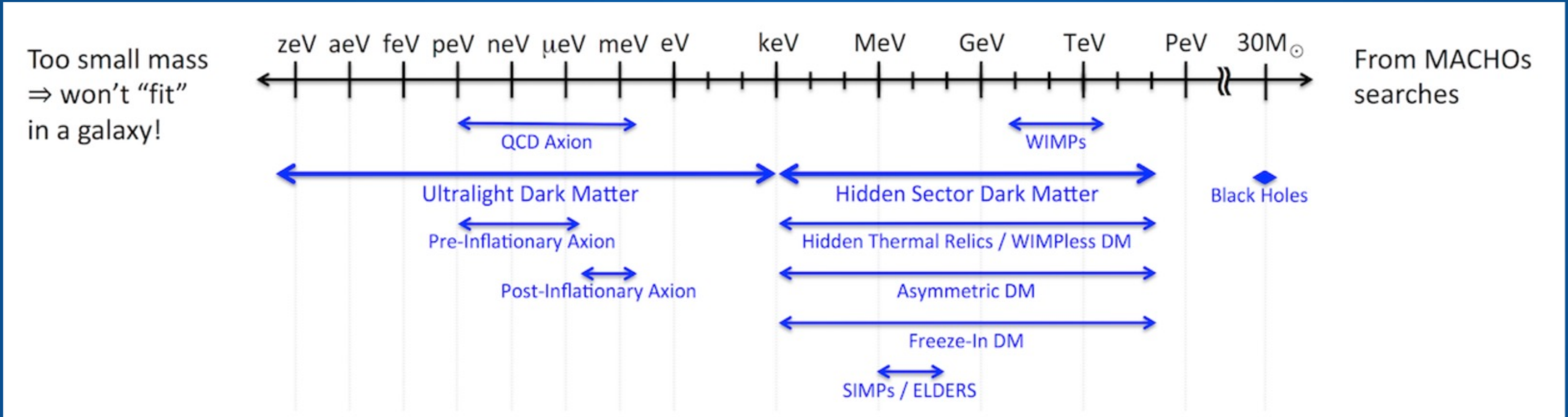
1) How do we search for DM, depending on its properties?
   What are the main differences between light Hidden Sector DM and WIMPs?
   How broad is the parameter space for the QCD axion?

2) What are the most promising experimental programs, approved or proposed, to probe the different DM possibilities in a compelling manner?

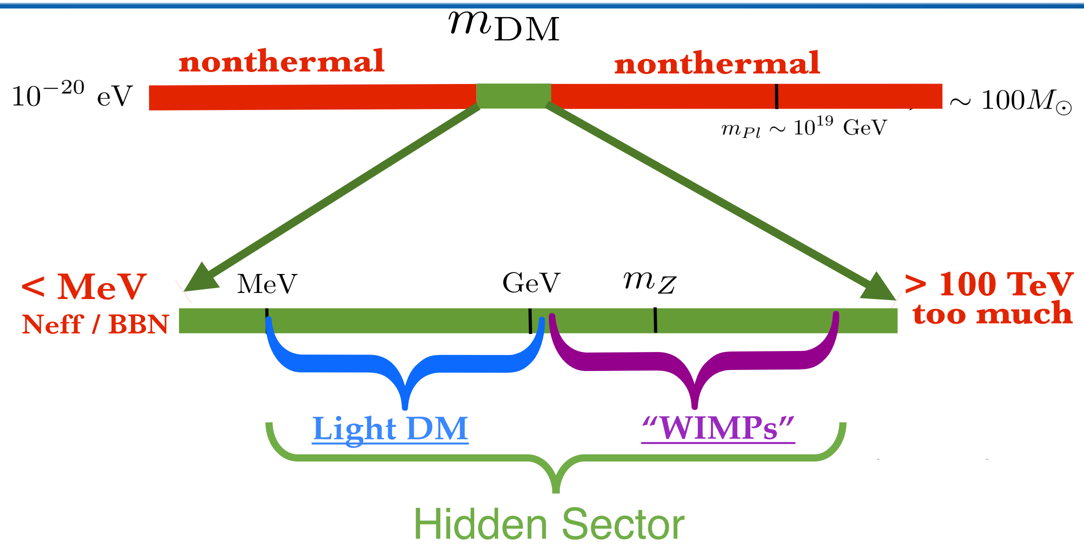
3) How to compare results of different experiments in a more model-independent way?

4) How will direct and indirect DM Detection experiments inform/guide accelerator searches and vice-versa?

Very little clues on mass scale

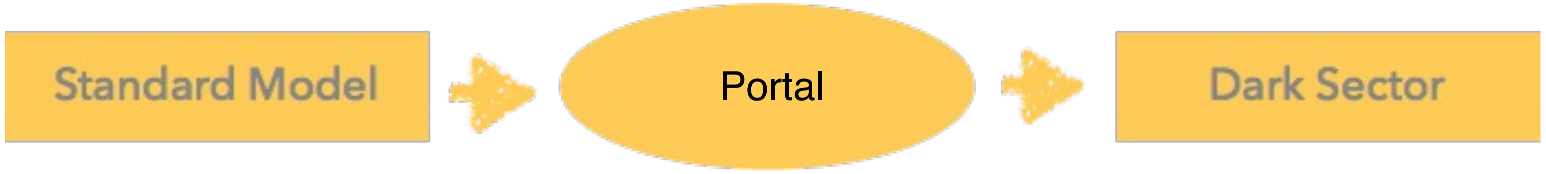


Thermal Equilibrium in early Universe narrows the viable mass range



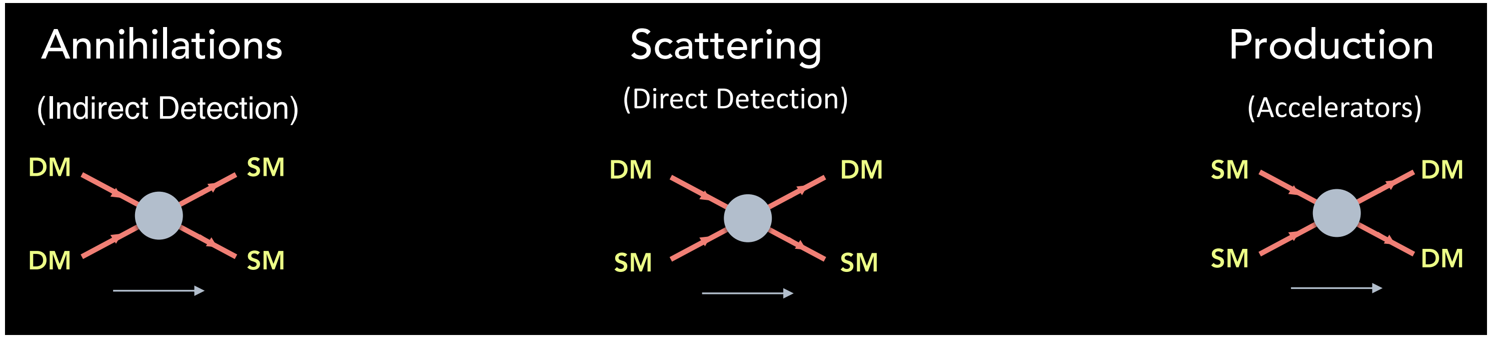
Dark Sectors

What is meant by a dark sector ?
A Hidden sector, with Dark matter, that talks to us through a Portal



Interesting, distinctive phenomenology
- Long-Lived Particles
- Feebly interacting particles (FIP's)

Portal can be the Higgs boson itself or New Messenger/s



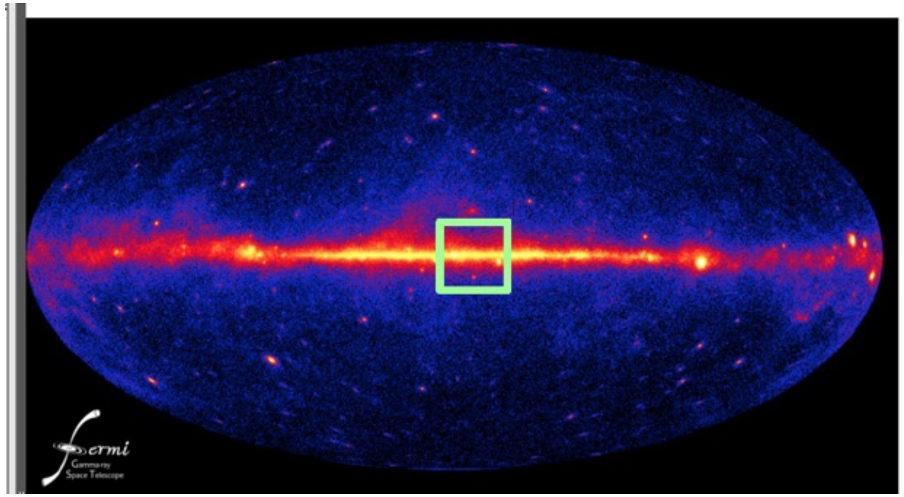
M. Lisanti's Talk

Indirect detection

No conclusive signals from indirect DM searches so far

But, slow and steady progress being made on indirect searches in many fronts

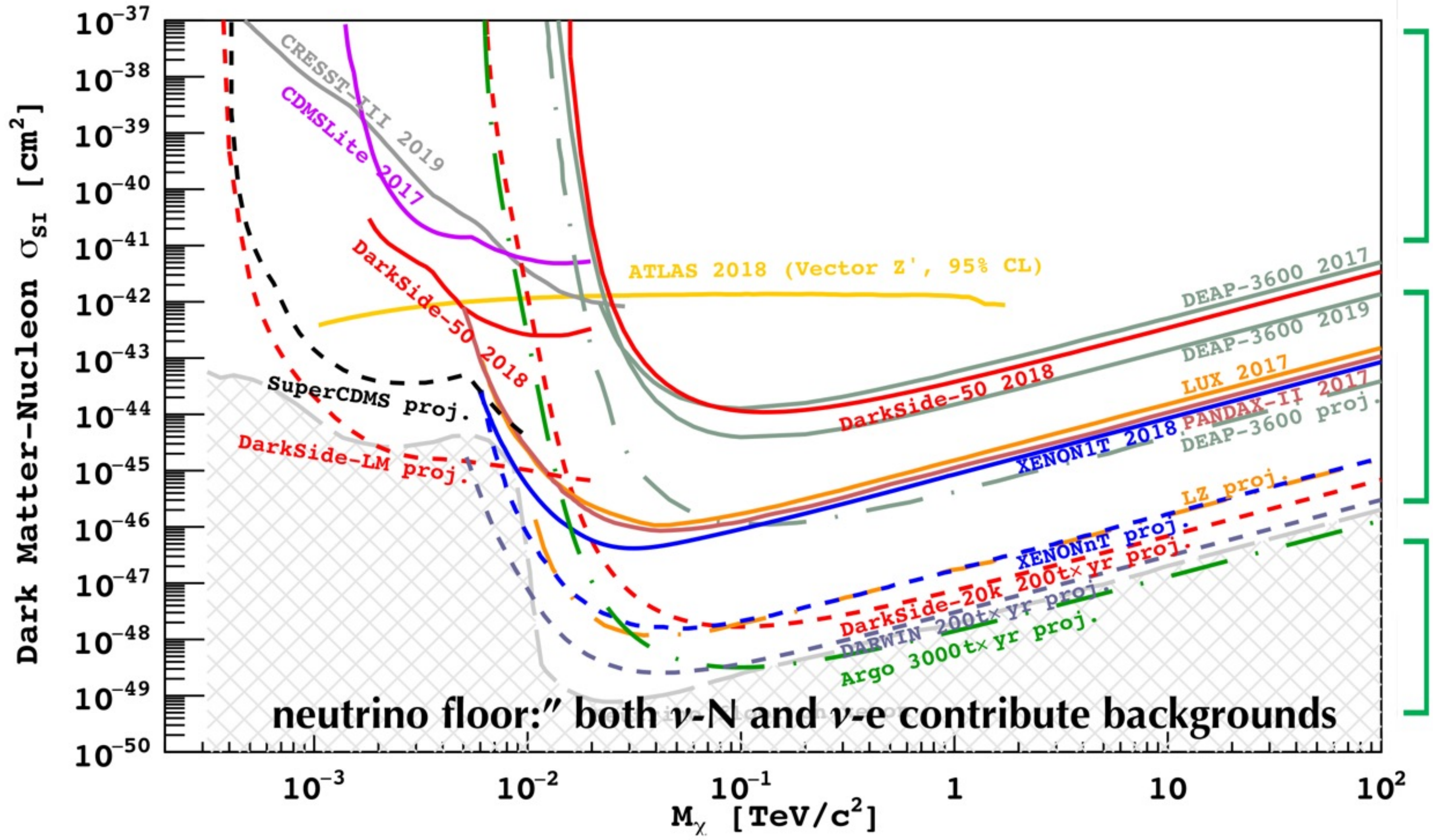
- Diffuse gamma rays, e.g Galactic Center GeV Excess
- 3.5 keV “Sterile Neutrino decay”
- Antiproton excess from cosmic rays
- Neutrinos from DM annihilation in the Sun



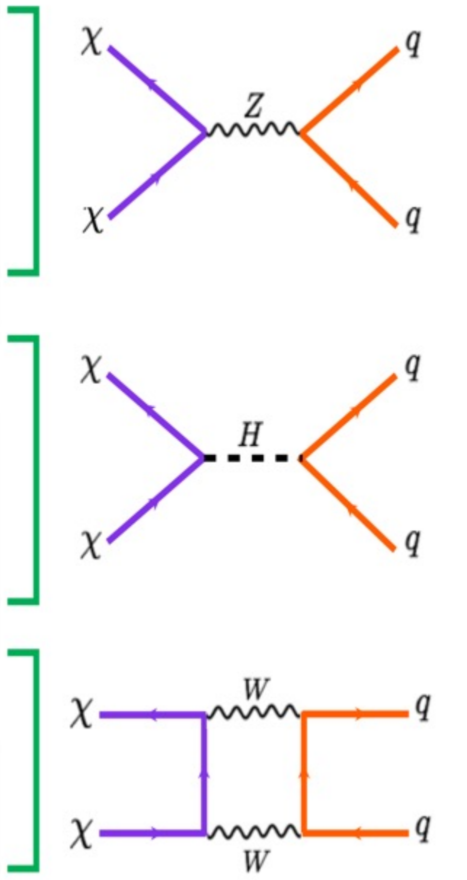
It is possible that in the future it will be a convincing signal from one or more indirect DM searches

This will have large impact on Direct Detection and Accelerator based DM searches

WIMP Direct Detection Searches



Primary Weak Interactions



Marching down to the Neutrino Floor

J. Monroe's talk

WIMP Standard Candles

- Still a viable solution for Thermal DM (e.g. in many SUSY extensions/ regions)
- Being broadly probed by Direct and Indirect detection as well as Collider experiments

Pure Wino DM

- Thermal abundance requires Wino mass of about 2.9 TeV
- DD: just above the neutrino floor.
  Ballpark of DarkSide 20k-200t-yr,
  DARWIN 200t-yr and Argo 3000t—yr.
- ID: Wino only constitutes all the DM for density profiles not generically produced in simulations of Milky Way-like galaxies
- @ Hadron Colliders: Disappearing tracks
- @Lepton Colliders: Reach close to kinematic limit plus
  precision measurements extended reach

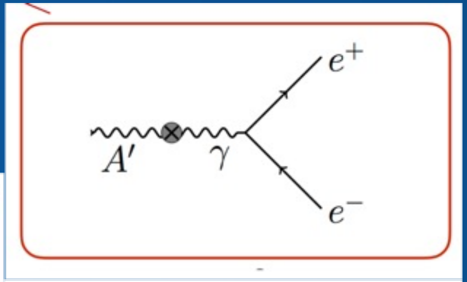
Pure Higgsino DM

- Thermal abundance requires Higgsino mass of about 1.1 TeV
- DD: Suppressed. Deep in neutrino floor region
- ID: Bounds strongly dependent on halo morphology.
- @ Hadron Colliders: Disappearing tracks
- @Lepton Colliders: Reach close to kinematic limit plus
  precision measurements extended reach

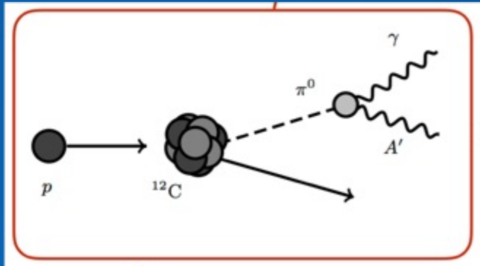
Accelerator-based searches

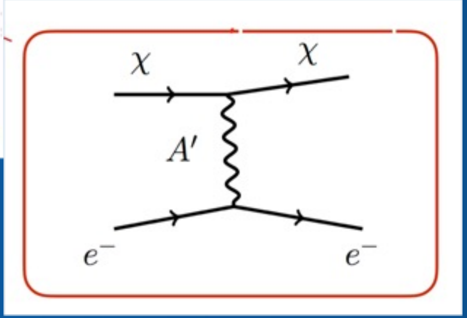
- Dark photons/scalars to SM particles
  - Dark portals at beam dumps (NA62++, SHIP)
  - Dark portals at fixed target (NA64++, LDMX) – missed energy
- Heavy neutral leptons
  - Neutrino masses ?
- Invisible dark photon decays
  - Several techniques also at colliders

LLP DECAY

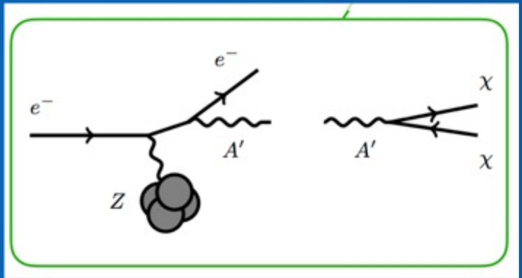


Beam DUMP

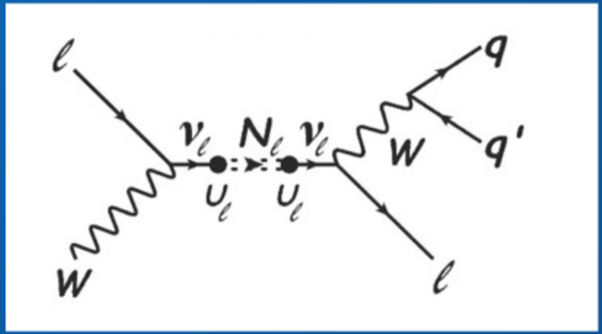




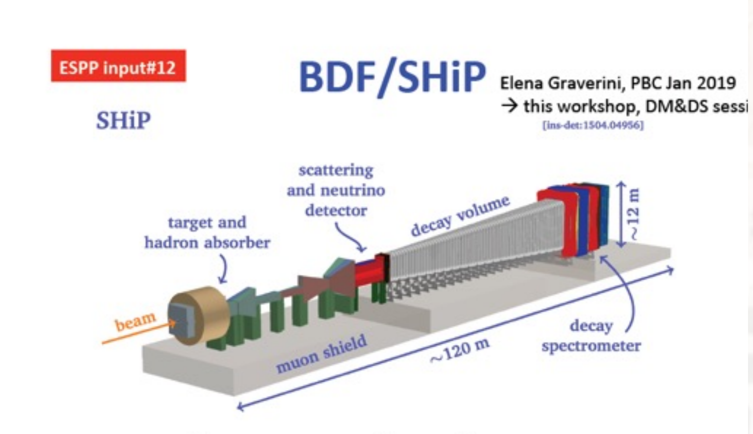
DM Scatters in detector

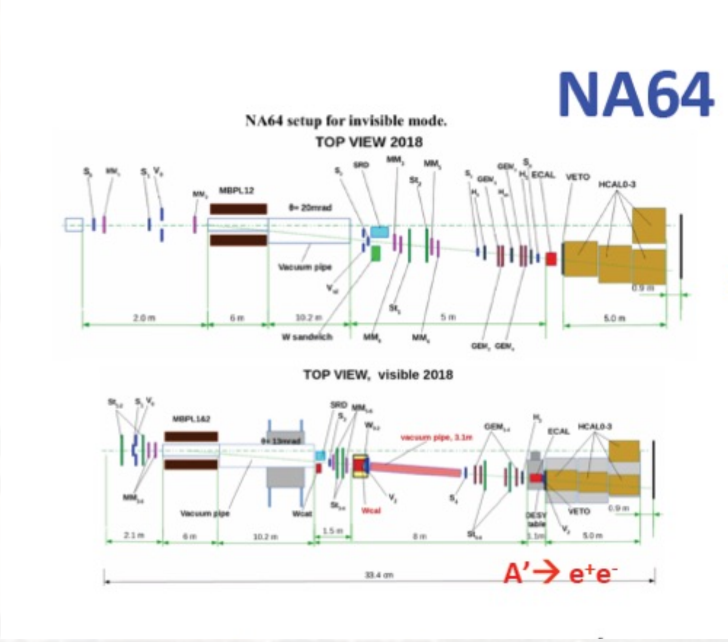


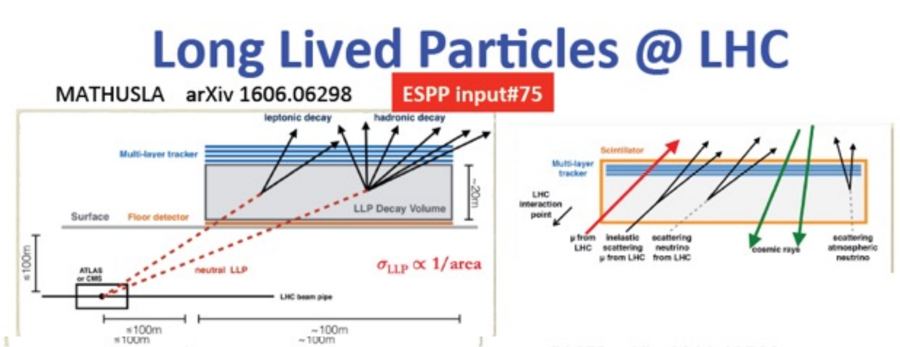
Invisible decay

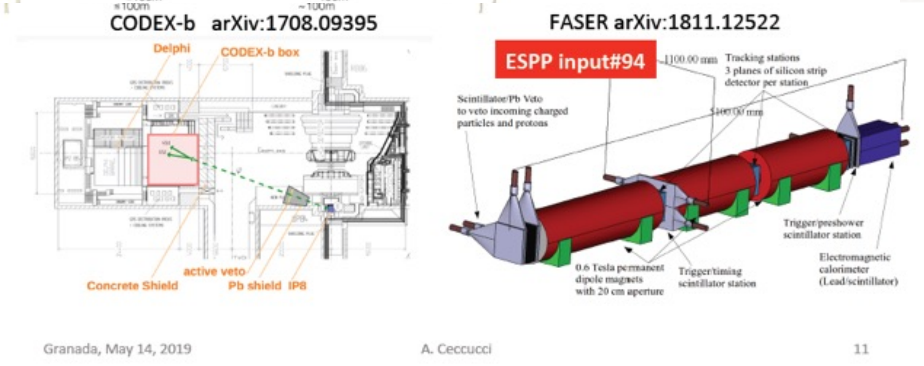


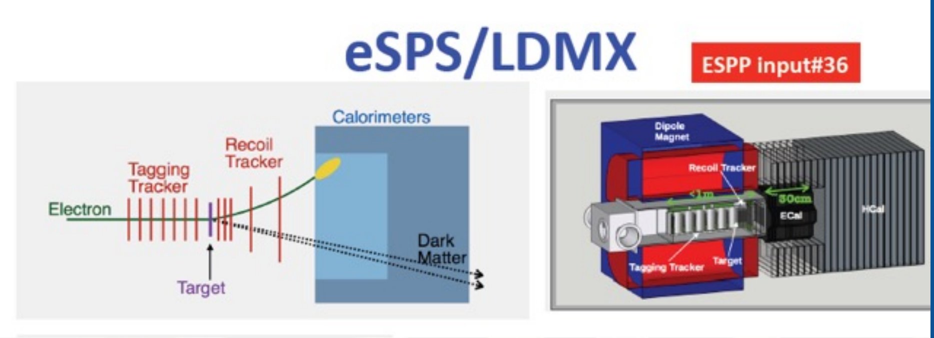
Dark sector possible experiments









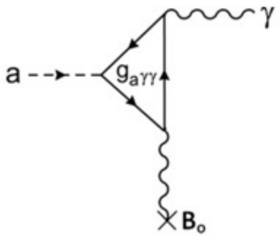


Axions/ALPs

- QCD Axions as DM ?
  - Search for axion-photon couplingq

QCD axion
- Solves Strong CP problem
- Natural Dark Matter candidate

Important target for experimental searches

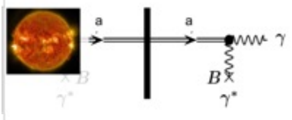


Many Beyond the Standard Model scenarios contain
- Axion-like particles
- General light dark sector particles

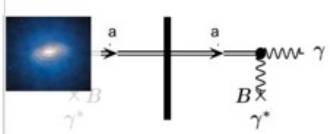
Probe wider parameter regions including different scenarios

Motivates a variety of non-accelerator experiments

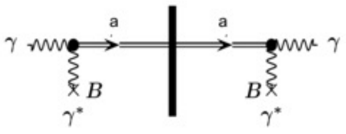
Mature Key Tec



Helioscopes
- Build on success of CAST hosted by CERN
- Proposed BabyIAXO, leads to IAXO, with large discovery potential



Haloscopes
- ADMX (US) is leading the field
- In Europe, MadMax is new key player
- Smaller efforts developing new techniques



Light-shining-through-walls
- ALPS II is well underway
- STAX is a new idea RF based
- JURA is long term plan

Lindner and Irastorza's talks

Comments from discussion

Need for better coordination

- Consensus emerged on the need for more coordination between accelerator based, direct detection and indirect detection dark sector searches, for common interpretation of results.
- This will also be of fundamental importance to validate, through different channels, a possible dark matter discovery.
- To address this issue, it was recommended to make profitable use of the initiative of APPEC on the EuCAPT Astroparticle Theory Centre.
- This offers a strong opportunity to collaborate with working groups such as the LHC DM and Physics Beyond Colliders and the many recognized dark sector experiments using different approaches

Need for technology support and exchange between communities

- Technology challenges are shared between and beyond the communities engaged in dark matter searches.
- CERN and other large European National labs has relevant expertise and infrastructure for most/many of the big challenges, including vacuum over large volume, cryogenics, photosensors, liquid argon detectors, design and operation of complex experiments, software and data processing.
- Expanded support for dark matter research at CERN would stimulate knowledge transfer, increase coordination and synergies between experiments, and add guidance and coherence to the overall program.

Dark sector session take away message

- Change of paradigm:
  - OLD: a good BSM theory may provide an explanation for DM
  - NEW: understanding DM may provide a clue to BSM theory
- Enormous range of possibilities
  - Use all available experimental techniques
  - Complementarity of different approaches
  - Evaluate correlated impact of different measurements

- Dark Matter exists, awaiting for discovery
- In general, Dark Sector may exist, too
- Very little clue on mass scales now
- WIMP still main paradigm, reach ν floor
- Many new ideas on lighter dark matter
- Colliders, beam dump, underground, cosmic rays, cavity, new technologies
- Vibrant area and need more data!

Summary of the flavor session

Antonio Zoccoli and Belen Gavela

Flavor Physics → BSM

- EW Hierarchy… driven by the top in SM
- Strong CP problem
- Origin of weak CP and matter-antimatter asymmetry
- Flavour puzzle (quarks, charged leptons, neutrinos)

Flavour is the usual graveyard of BSM electroweak theories

1) The light sector (u,d,s + e, μ)

Three "clear" cases calling for diversity in the short/mid-term:

1. EDMs [d_e, d_n, d_N,.]	Strong CP EW CP	new: Storage rings
2. $\mu \to e$ processes	1 → 2 Gen Lep. Mix.	Intense μ beams
3. Rare K decays	1 → 2 Gen. Quark Mix.	Intense K beams

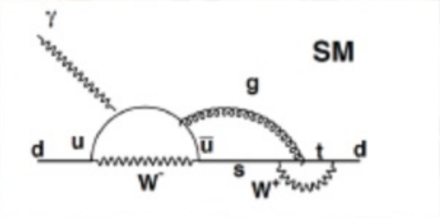
- Outstanding physics goals (fundamental & unique) Difficult experiments, but on a small scale

EDM

Electric dipole moments (EDM) are counterpart to magnetic dipole moments

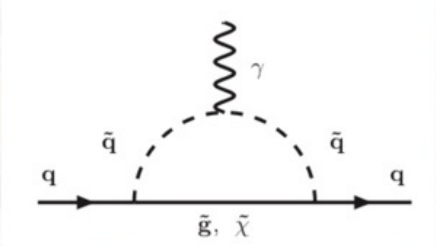
$$\mathcal{L}_{Pauli} = -\kappa \frac{\mu_B}{2} \overline{\Psi} \sigma^{\mu\nu} \Psi F_{\mu\nu} \longrightarrow \mathcal{L}_{EDM} = -i \frac{d}{2} \overline{\Psi} \boxed{\gamma^5} \sigma^{\mu\nu} \Psi F_{\mu\nu}$$

EDMs are optimal BSM windows:



SM: multiloop suppressed

$d_n^{SM} \approx 10^{-31}$ e cm



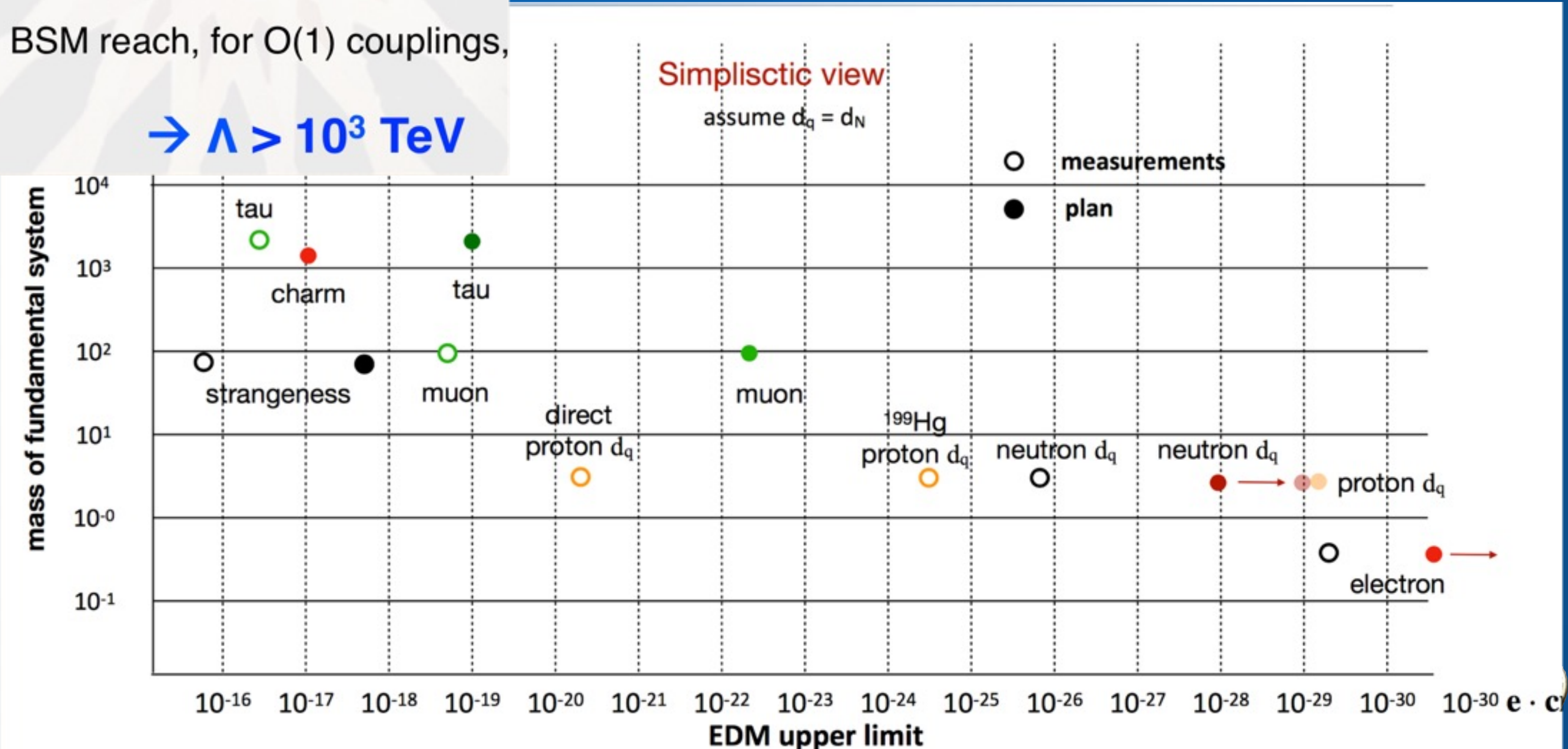
BSM: typically 1 loop

* Hadron EDMs: strong CP and EW CP

* Lepton EDMs: EW CP

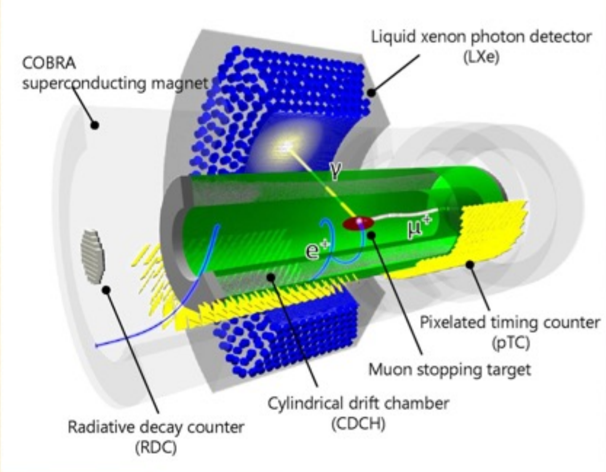
BSM reach, for O(1) couplings,

→ $\Lambda > 10^3$ TeV

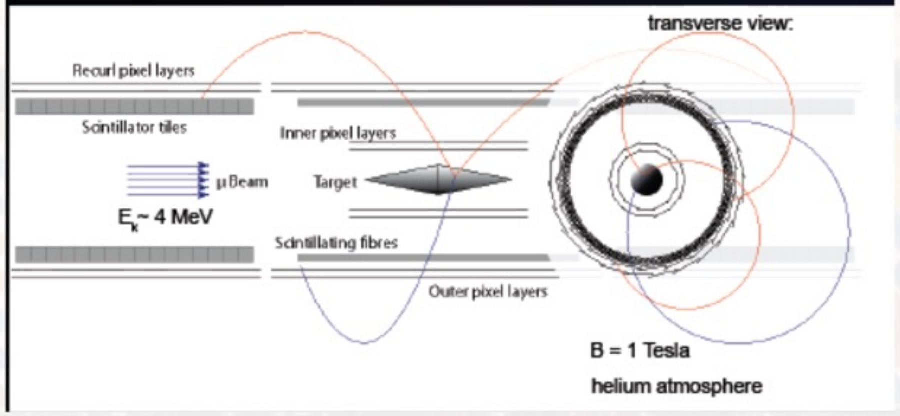


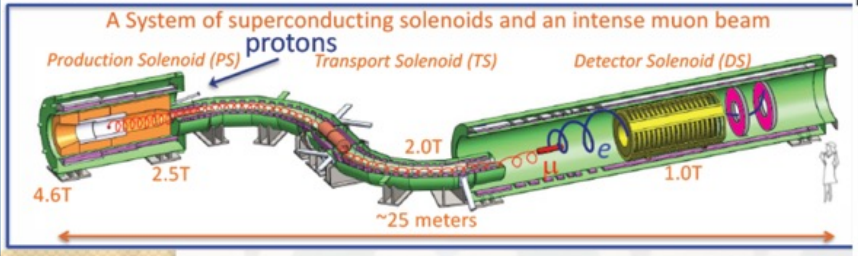
μ - e experiments

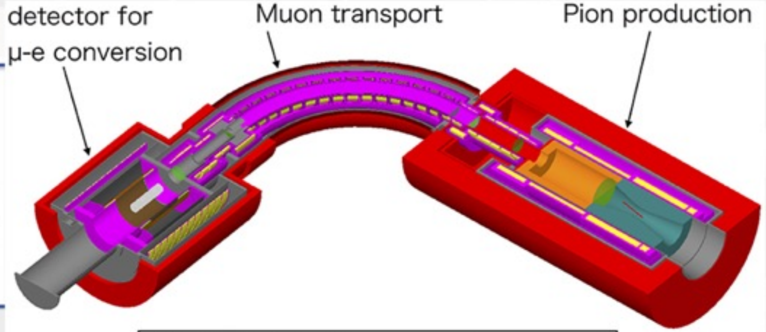
MEG @ PSI



Mu3e side and transverse view







COMET Phase-I Layout

MU2E @ FERMILAB

European Strategy

μ - e

$$\mathscr{L}_{eff} = \mathscr{L}_{SM} + \sum_{d>4} \frac{C^{(d)} O_d}{\Lambda^{d-4}}$$

	$\lvert C_a \rvert$ [$\Lambda = 1$ TeV]	Λ (TeV) [$\lvert C_a \rvert = 1$]	CLFV

BSM reach for O(1) couplings → Λ > 10^4 TeV

Probing amazingly high scales

Muon g-2 Experiments

Muon g-2 (E989) at Fermilab

- aim at 0.14 ppm (x4 improvem
- data more than E821@ BNL ha accumulated.
- new results in summer ?

J-PARC g-2/edm (Contributio

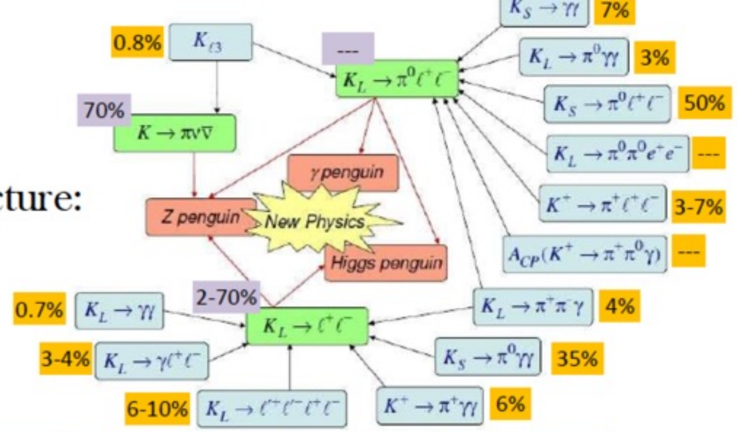
- new technique : slow muons fr laser ionization of muonium.
- aim at 0.45 ppm
- different systematics

MUonE@CERN (Contribution

- proposal on elastic μ-e scatterir beamline to measure hadronic c

Rare K

The full picture:



Decay	Γ_{SD}/Γ	Theory err.	SM BR $\times 10^{-11}$	Exp BR $\times 10^{-11}$
$K_L \to \mu^+\mu^-$	40%	20%	681 ± 32	684 ± 11
$K_L \to \pi^0 e^+ e^-$	40%	10%	35 ± 10	< 28 @90%CL
$K_L \to \pi^0 \mu^+ \mu^-$	30%	15%	14 ± 3	< 38 @90%CL
$K^+ \to \pi^+ \nu\nu$	90%	3.6%	9.3 ± 0.8	17 ± 12
$K_L \to \pi^0 \nu\nu$	>99%	1.5%	3.7 ± 0.7	< 240 @90%CL

- Kaon decays have great potential to contribute in unique, complementary, self-contained ways to the understanding of flavor
- Forbidden/LFV decay searches can probe unreachable mass scales, will mostly come as byproducts
- Ultra-rare K decays are the most-promising driving goal in the field: experiments are hard and different shots must be taken at them
- After fully exploiting the existing p machines (CERN SPS, J-PARC) with suitable sharing to fixed-target intensity frontier experiments, a very intense (MW) slowly-extracted proton machine would allow ultimate NP searches

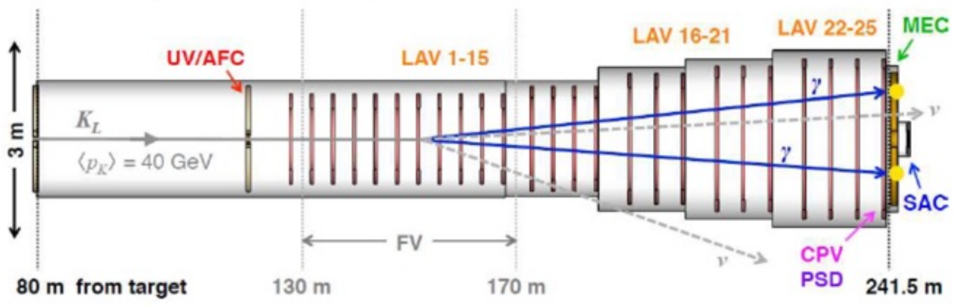
K → πνν possible future

KOTO Step-2 @ J-PARC

Now using 50% of protons
Increase to 100kW

Extension of Hadron Experimental Facility: considered among JP priority projects (not yet approved nor funded), O(140) M$:
2 new targets, 4 new lines

KLEVER @ CERN



2) The heavy sector (b, c, t + τ + h)

Bright near-term future [~ 10 yrs] with LHCb (I) & Belle-II

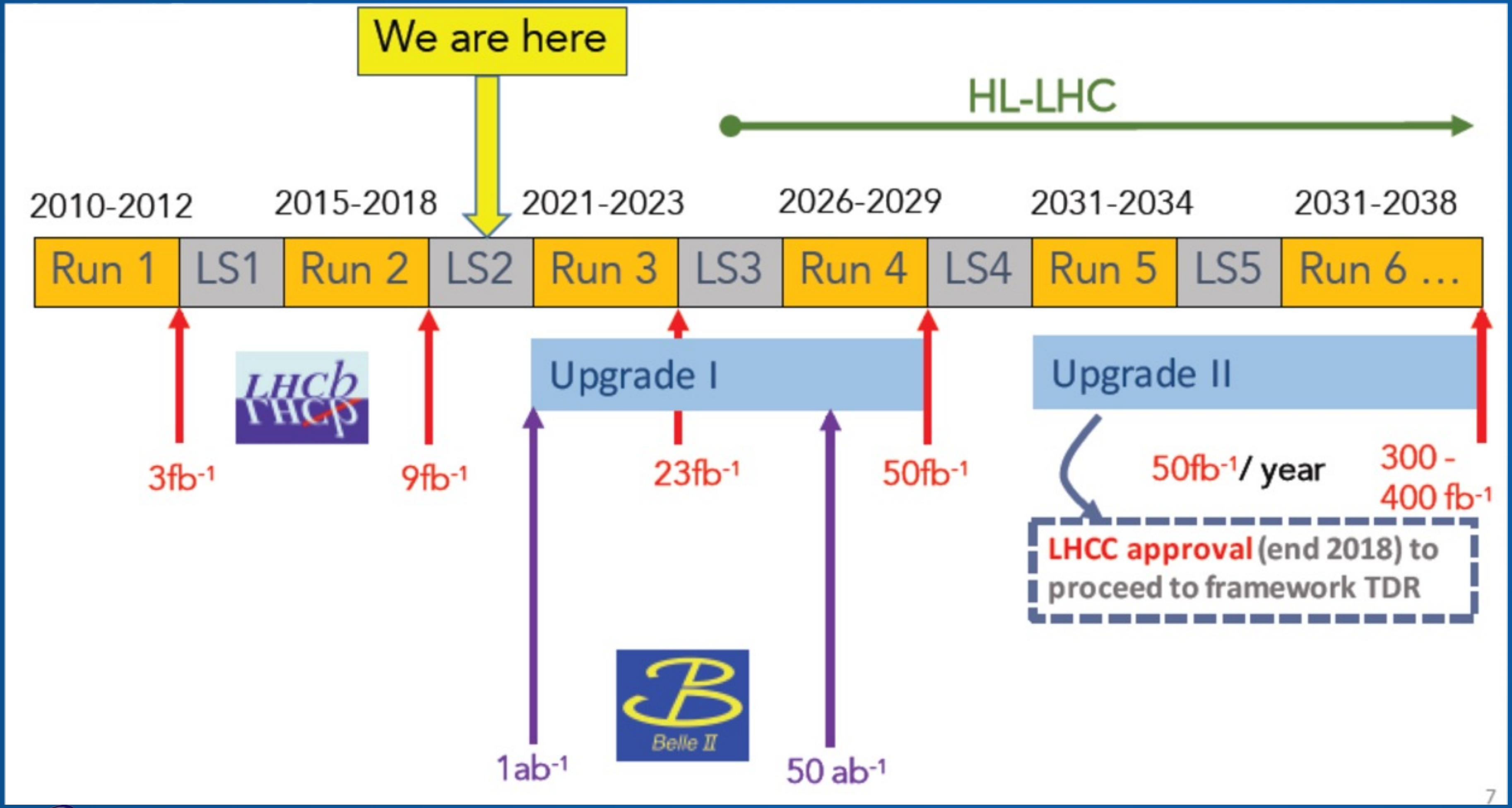
This is likely to be the most exciting frontier of particle physics in the next years, with large discovery potential (wide parameter range still to be explored)

Further “enriched”:

➔ lattice will keep pace with experimental precision

➔ present anomalies

Rich flavor program



Belle II+1= Belle III

Just started within Belle II

Goal: x5 increase in peak luminosity

- ❑ Doable from a machine perspective ?
- ❑ Detectors issues running at 4 10^{36} cm^{-2} s^{-1}
- ❑ Physics case

Under study, more before the end of 2019

Z^0 factories

Goal: $10^{11} - 10^{12}$ Z^0 (CEPC)
5. 10^{12} Z^0 (FCCee)
$BR(Z^0 \to b\bar{b}) = 15\%$

ILD-like detector + charged hadron PID.

FCC-pp a dedicated experiment (à la LHCb)

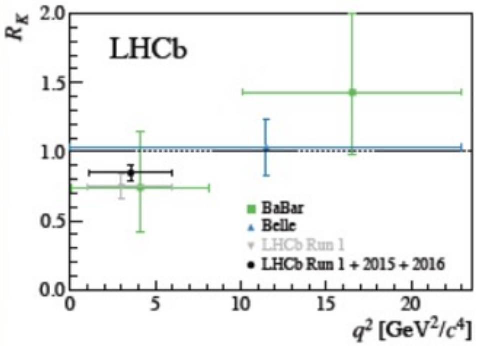
e^+e^- Super Charm-Tau Factories:
SCT (BINP, Novosibirsk) and STCF/HIEPA (China)
E: 2 to 6 GeV
Peak Luminosity (> 4 GeV) 10^{35} cm^{-2} s^{-1}

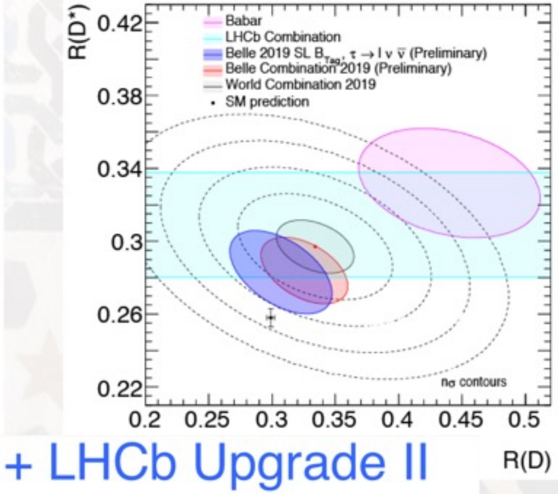
B anomalies…..

Two examples:

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} \stackrel{\text{SM}}{\cong} 1.0$$

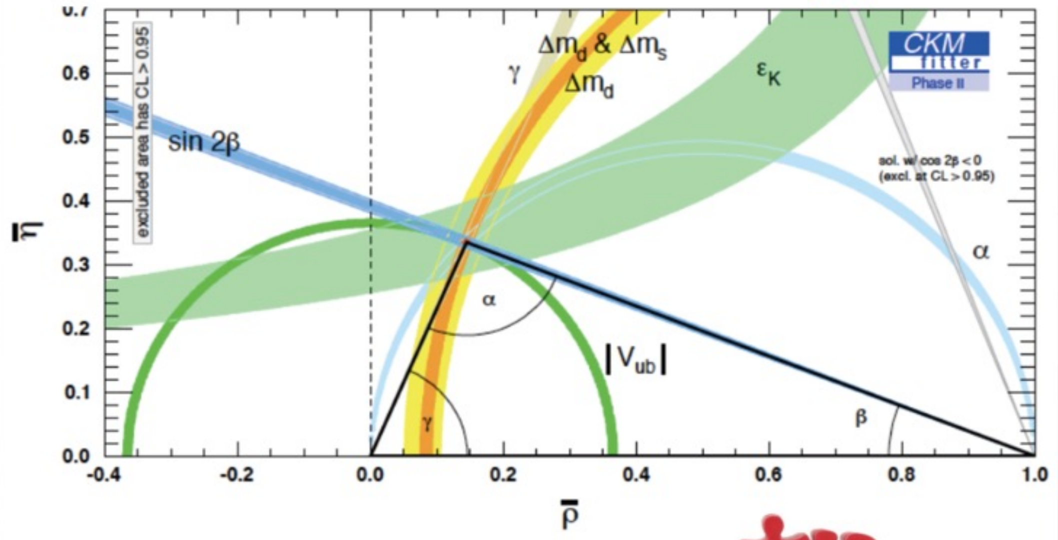
$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)} \quad (\ell = e, \mu)$$





Moriond EW 2019

End of HL-LHC: Belle II + LHCb Upgrade II



Inconsistencies among measurements ?

CPV in charm

Experimentally:
$$A_{raw} = \frac{N(D^0 \to f) - N(\bar{D}^0 \to f)}{N(D^0 \to f) + N(\bar{D}^0 \to f)} = A_{CP} + A_D(\pi_s^+/\mu) + A_P(D^{*+}/D^0_{\text{from } B})$$

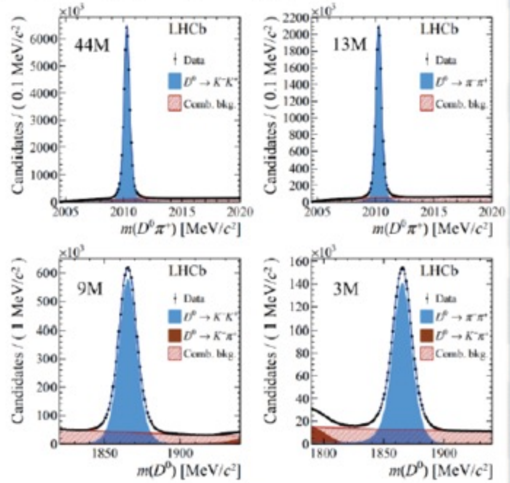
$D^0 \to$KK or ππ
charge symmetric
$$\Delta A_{CP} = A_{raw}(KK) - A_{raw}(\pi\pi) \cong A_{CP}(KK) - A_{CP}(\pi\pi)$$

Kinematical reweighting ⇒ production and detection asymmetries cancel

π tag

μ tag

ΔA_{CP}=(-0.154±0.029)%
Observation of CP violation at 5.3 σ



Run2 dataset (6 fb^{-1})
arXiv:1903.08726
ESPP Granada May 2019

BSM EFT analysis, for O(1) couplings

e.g. B – $\bar{\text{B}}$ mixing → Λ > 10^2-10^3 TeV
(if MFV: > TeV)

τ physics topics

Searches for Lepton Flavor Violation in tau decays:

- clean & effective search for “natural” NP processes extremely suppressed in SM
- upper limits are effective constraints on NP models

Lepton Universality tests:

- EW precision tests
- effective constraints on NP models

Many topics where τ is a decay product (H, Z, W, B etc.) (→ EW group)

τ physics plans of relevant fa

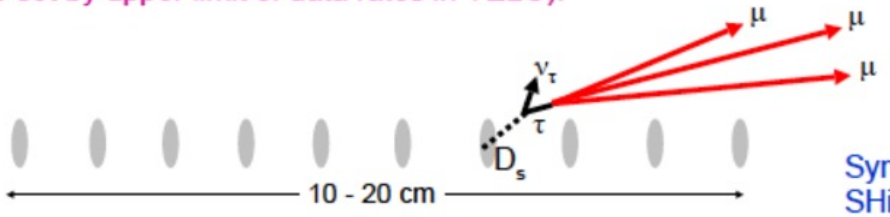
Present with many LFV studies:

- Belle-II
- LHC: (LHCb, ATLAS, CMS)

Possible future facilities:

- HL-LHC, HE-LHC many improvements
- Super Charm Tau Factories
- TauFV [@ SHIP beam line]:

Instead, design dedicated experiment upstream of SHiP, with thin, distributed targets, to bleed off ~2% of the beam intended for SHiP → 2 mm of tungsten (this value also set by upper limit of data rates in VELO).



Synergetic with SHiP operation !

2) The heavy sector (b, c, t + τ + h)

Bright near-term future [~ 10 yrs] :

- LHCb (I) & Belle-II

Clear mid-term future [~ 10-20 yrs] with an interesting case:

- LHCb-II [@ HL-LHC] and Belle-III (?): ultimate precision on “all- visible” B and D decay modes [$B_{s,d} \rightarrow \mu\mu$, R_{K,K^*}, CKM, charm CPV, ...]

possibly complemented by specific initiatives such as:

- TauFV [@ SHIP beam line]: $\tau \rightarrow 3\mu$ @ 10^{-10}, outstanding goal , competitiveness with Belle-II to be clarified
- STC @ Novosibirsk or HIEPA [competitiveness after Belle-II less clear...]

2) The heavy sector (b, c + τ)

A strong case for the long-term future [> 20 yrs]:

Flavor physics @ FCC-ee [running at the Z-pole , with 5×10^{12} Z's !]

Unique potential on b and τ decays with missing energy, from $Z \to bb, \tau\tau$

Just one example: $B \to K^*\tau\tau$: ~1000 SM events @ FCC-ee vs. ~10 @ Belle-II

And of course FCC-ee would allow major improvements on EWPO & Higgs

→ ideal set-up to optimize indirect NP searches

Higgs and flavor

We know:
We have evidence that the Higgs gives mass to the 3rd generation fermions (and gauge bosons).

We do not know:

- Many additional couplings!

light generations,
self-coupling,
flavor violating couplings

- Are (some of the) couplings CP violating?
- Higgs rare/exotic decays?
- Higgs width
- Are there new Higgs bosons?

Many open questions are in the realm of flavor and CPV physics

How can we learn more?

First two generations; down quark 3^{dr} generation

Meson mixing (Bs);
Rare B decays experiments

Higgs flavor violation

up type and lepton 3^{dr} generation

Higgs rare processes
$t \to c$, $t \to u$
$\tau \to \mu$, $\tau \to e$

High energy machines

Higgs & gauge boson CP violation

High energy machines
&
e^+e^- machines

CPV in Higgs-gauge boson couplings

CPV in Higgs-fermion couplings

CPV in triple-gauge boson couplings

Electron EDM experiments

Flavor session take away message

- Flavor physics crucial for BSM search:
  - Outstanding BSM scale reach à $\Lambda > 10^2 - 10^5$ TeV, especially for lepton flavor violation and universality.
  - Complementarity of low-energy, HE frontier and feebly interacting searches
- Many possibility in small, medium, large scale facilities
  - Precision EDM, g-2
  - e+e- colliders: B-factories, tau-charm factories
  - Several dedicated experiments
  - Vibrant upgrade program for the near and mid-term future
- Flavour is also a major legacy of LHC:
  - Many results from all experiments
  - Charged hadron PID is mandatory for a full physics program.
  - Essential that HE future experiments follow this same path
- Important to have experiments in very different environments (pp and e+e-), and with PID
- In the longer term: Z-factory is a fantastic tool for Flavor Physics

Instrumentation and Computing Session
Xinchou Lou, Brigitte Vachon

Instrumentation:

(a) What **areas of instrumentation R&D** should be supported, and how, in order to meet the needs of future experimental programs?

(b) How to preserve knowledge, technical expertise and train the future generation of experts in detector R&D?

Computing:

(a) How should **HEP computing evolve** in order to support future scientific programs and their specific needs?

(b) What **R&D activities** must be supported, and how, in order to enable this computing evolution?

Instr/Comp General comments

- Detector/computing R&D needs strong support.
- Maintain/develop proper mixture of activities related to “now, next, horizon” (yes, even for computing)
- General opinion that R&D should not be centralized exclusively in large-scale facilities and/or in major labs.
- Current R&D collaborations (eg. RDx, AIDA2020, CALICE,etc.) seen to be effective models of collaboration.
- Need support to strengthen R&D consortia - and establish new ones - while preserving expertise and working relationships
- Provide opportunities to build on, and benefit from, synergies with non-HEP and industry
  - (e.g. through technology-centered R&D platforms across disciplines providing)

Human factor

- Training: Students/postdocs often lack basic knowledge (computing skills and instrumentation).
  - University courses are often insufficiently oriented towards these technical aspects.
- Career recognition/opportunities: Instrumentation and Software & Computing activities need to be recognized as fundamental to research activities and bearing a large impact on the final physics results.
- Special considerations in computing: Teams working on S&C need to be well-rounded, including physicists and developers.


THE FUN BEGINS...
DIRT
ROAD
AHEAD
WHERE THE
PAVEMENT ENDS