CNRS Helmholtz Dark Matter Lab (DMLab)

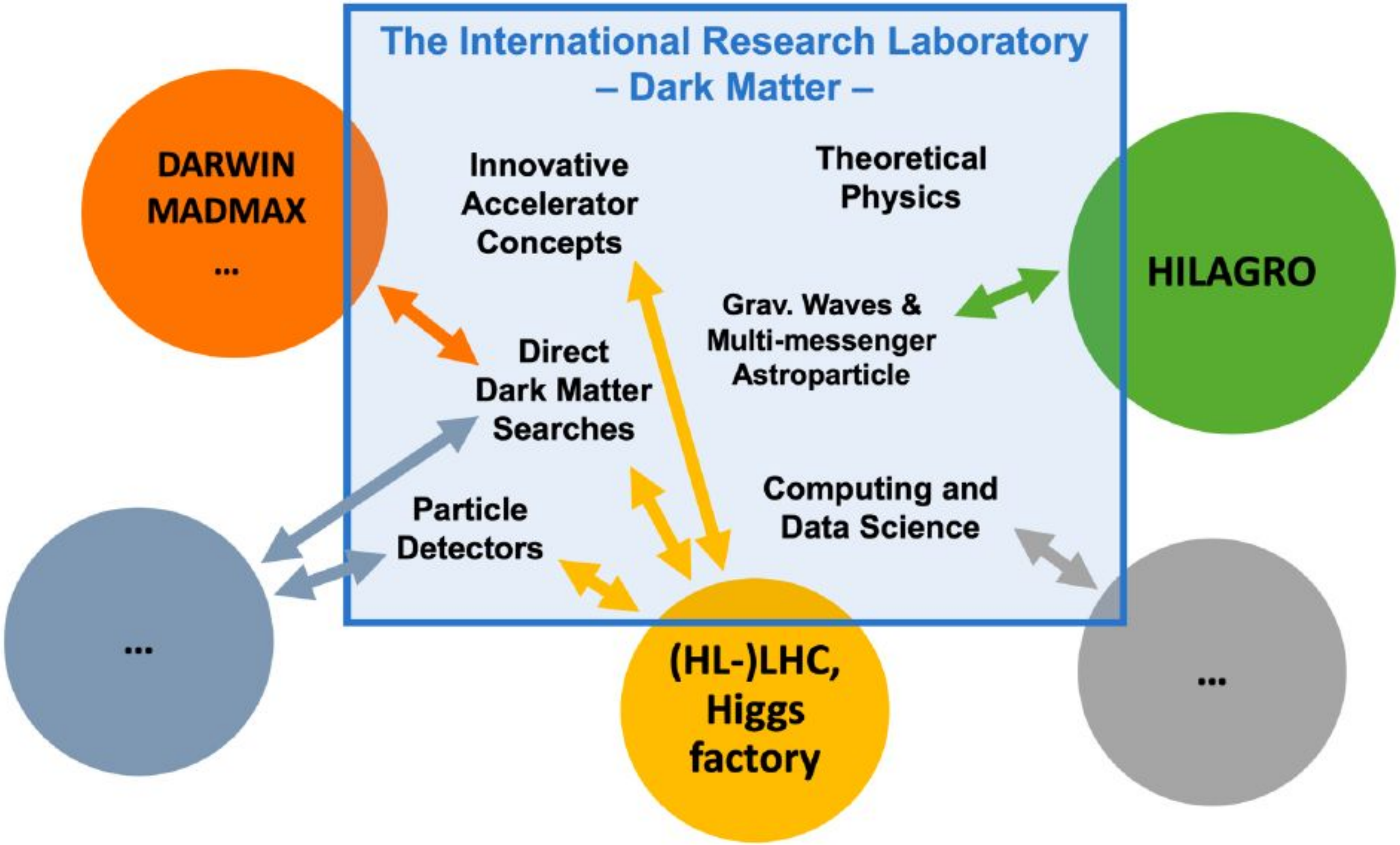
Thomas Schoerner (DESY) and Dirk Zerwas (DMLab and IJCLab)

PPPS
April 8, 2024

Scientific Topics of DMLab

Organised around the central theme dark matter

Historical salespitch



IRL tasks:

- develop new ideas
- across topic boundaries
- glued by dark matter

Formally

- **long term visits to DESY, KIT and GSI** (sabbaticals/expatriation=change of lab, 1y minimum)
- **working visits** (typically 1-2 weeks)
- workshops broad and narrow
- common work
- try for common funds

The DMLab Projects

Projects

Projects:

- **living system: starting/merging/ending**

2024

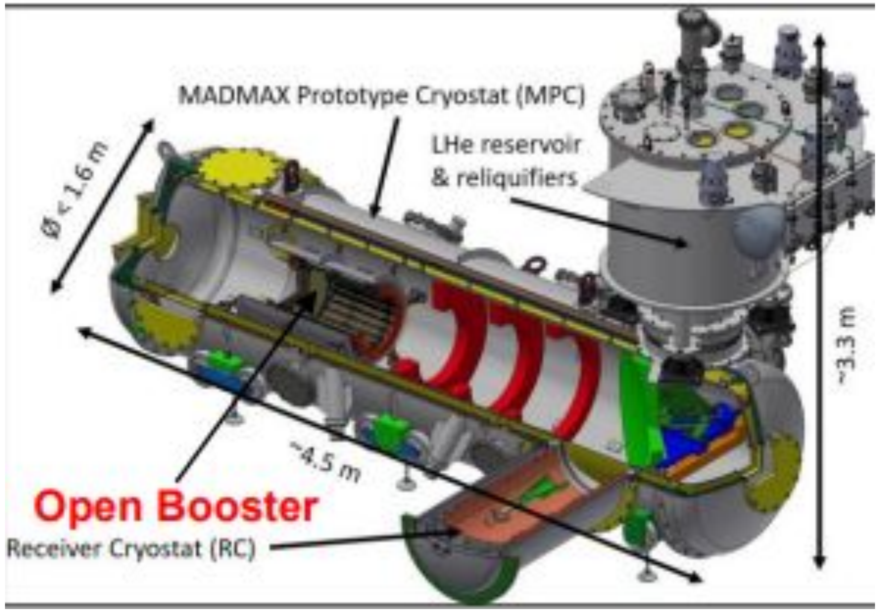
- Annual workshop Paris Oct 17-18
- working visits to:
  - KIT
  - GSI
  - DESY
- Common funds:
  - ANR-DFG projects submitted
  - **success CALO5D**

Topic	Project	PI France	PI Germany
Direct Searches	Darwin	Julien Masbou (Subatech)	Klaus Eitel (KIT)
	MadMax	Fabrice Hubaut (CPPM)	Axel Lindner (DESY)
GW and MM Astroparticles			
Accelerators	Laser-plasma acceleration of Electrons	Nicolas Delerue (IJCLab)	TBN
	Laser-plasma acceleration of Hadrons	Medhi Tarisien (LP2i)	Vincent Bagnoud (GSI)
Computing and ML	?Precision and ML?	David Rousseau (IJCLab)	Margarete Mühlleitner (KIT)
	High Precision for Dark Matter	Fawzi Boudjema (LAPTH)	Peter Marquard (DESY)
Particle Detectors	Tracking Detectors	Marc Winter (IJCLab)	Ingrid-Maria Gregor (DESY)
	CBM-MVD	Auguste Besson (IPHC)	Michael Deveaux (GSI)
	Calorimeters	Roman Poeschl (IJCLab)	Katja Krueger (DESY)
	Germanium Detectors	Gilbert Duchene (IPHC)	Juergen Gerl (GSI)
Theory	Dark Matter, Gravity, Cosmology	Adam Falkowski (IJCLab)	Geraldine Servant (DESY)
	Dark Photons	Juergen Brunner (CPPM)	Peter Marquard (DESY)
	DM Gravity Cosmology	Daniele Steer (APC)	Thomas Konstandin (DESY)
	Probing Strongly Interacting BSM	Giacomo Cacciapaglia (IP2I)	Christophe Grojean (DESY)
	Strangeness in Nuclear Matter	Joerg Aichelin (Subatech)	Elena Bratkovskaya (GSI)
		Luc Darme (IP2I)	Felix Kahlhöfer

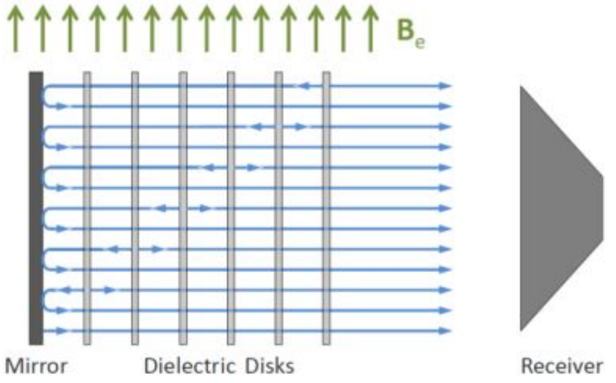
MADMAX

PIs: Fabrice Hubaut and Axel Lindner

CPPM Marseille, DESY, UHH



$$P_{sig} = 10^{-22}\ \mathrm{W} \times \left(\frac{\beta^2}{50000}\right) \times \left(\frac{B_e}{10\ \mathrm{T}}\right)^2 \times \left(\frac{A}{1\ \mathrm{m}^2}\right) \times C_{a\gamma}^2$$

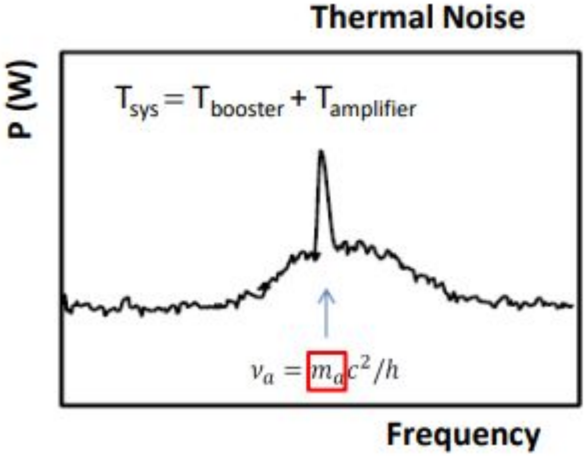


Axions:

- **solution to strong CP problem in QCD**
- **Postulate as CDM candidate**
- **needs masses of ~30μeV**
- **WISP candidate**

Axion detection

- Magnetized Disc and Mirror Axion experiment (MADMAX)
- Axion → ***π*** → ɣ + ɣ
- Primakov effect: magnetic field = ɣ, Axion+B-field → ɣ
- deBroglie wavelength: ~m
- coherent wave at experiment scale
- E-field oscillations discontinuous at surface
- Discs and mirror
- Resonance detection



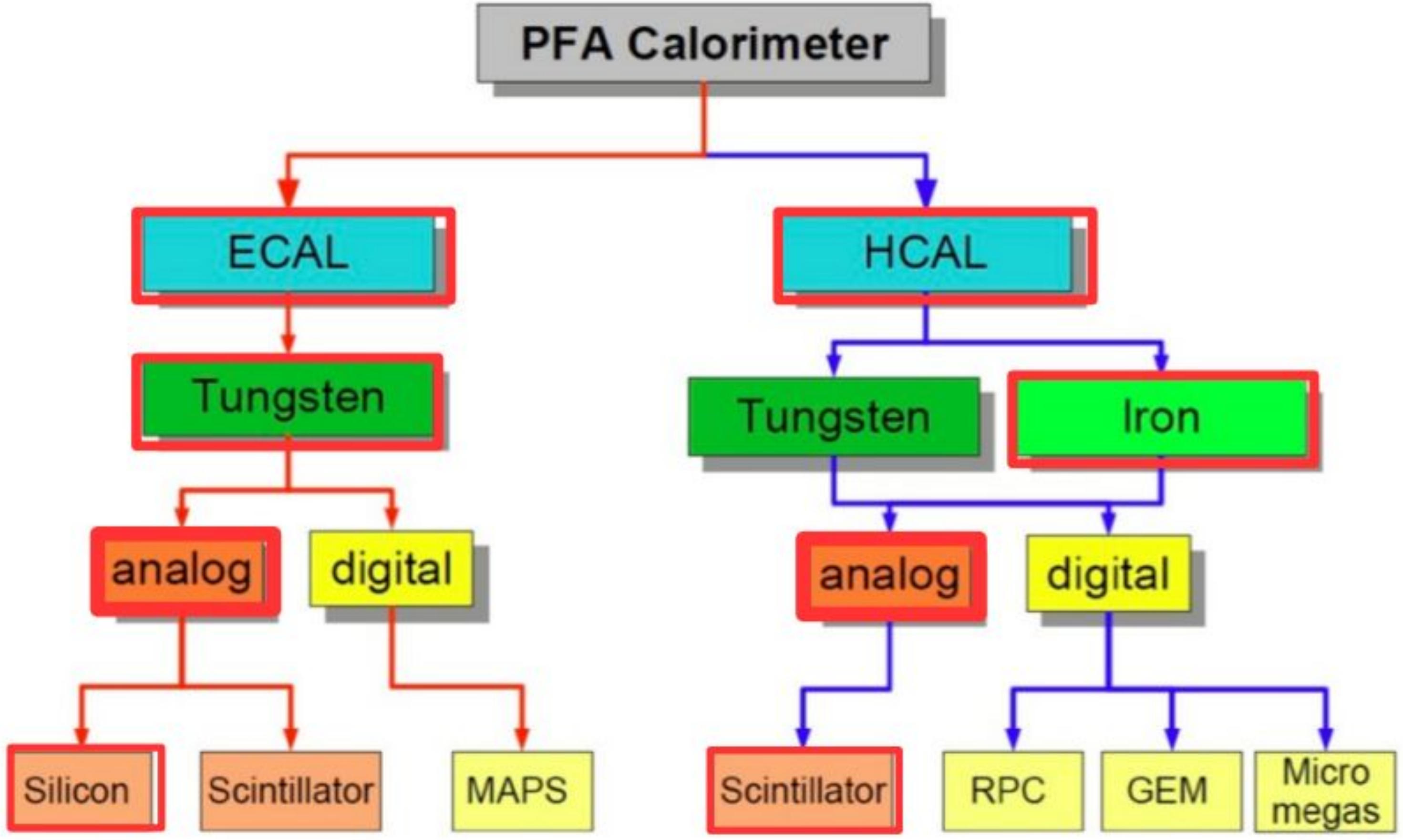
French contribution:

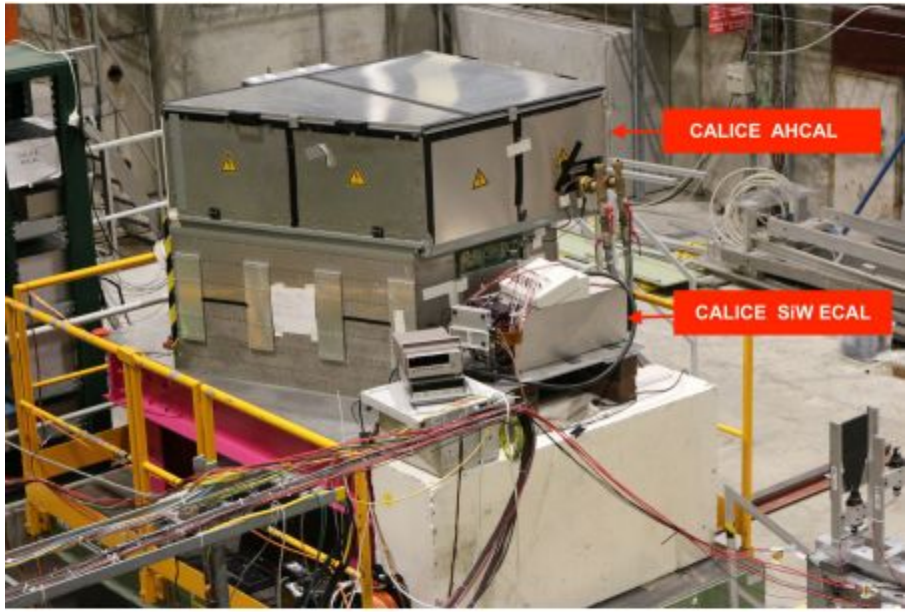
- **precise positioning of discs**
- **visiting thesis student**

PIs: Roman Poeschl and Katja Krueger

CALICE: Highly Granular Calorimetry for a Higgs factory

IJCLab, DESY, KIT, LLR and Valencia





France

Germany

Goals:

- Synchronous running
- Exchange on interfaces

SiW ECAL

Breaking down the structure

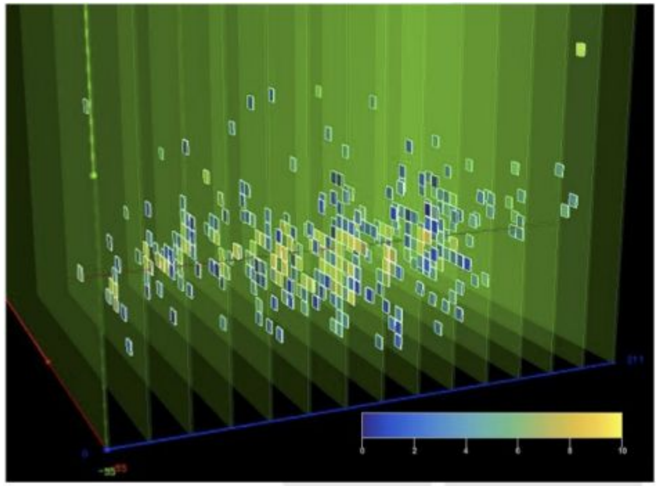
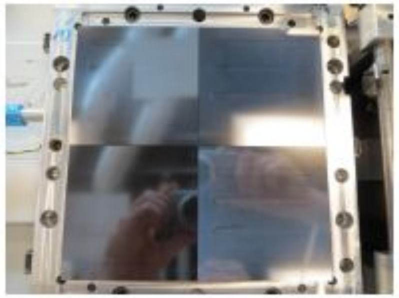


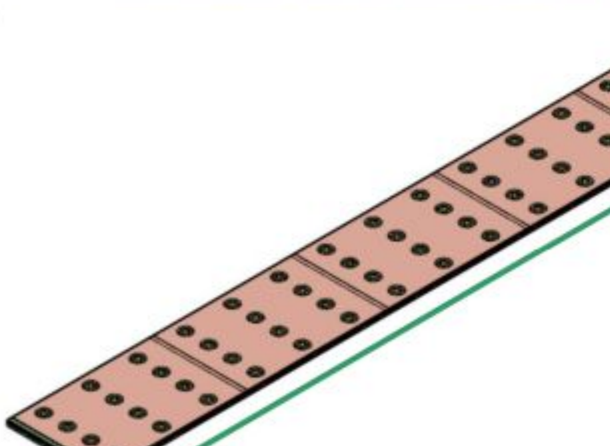
Fig. SiWECAL Electron 40 GeV

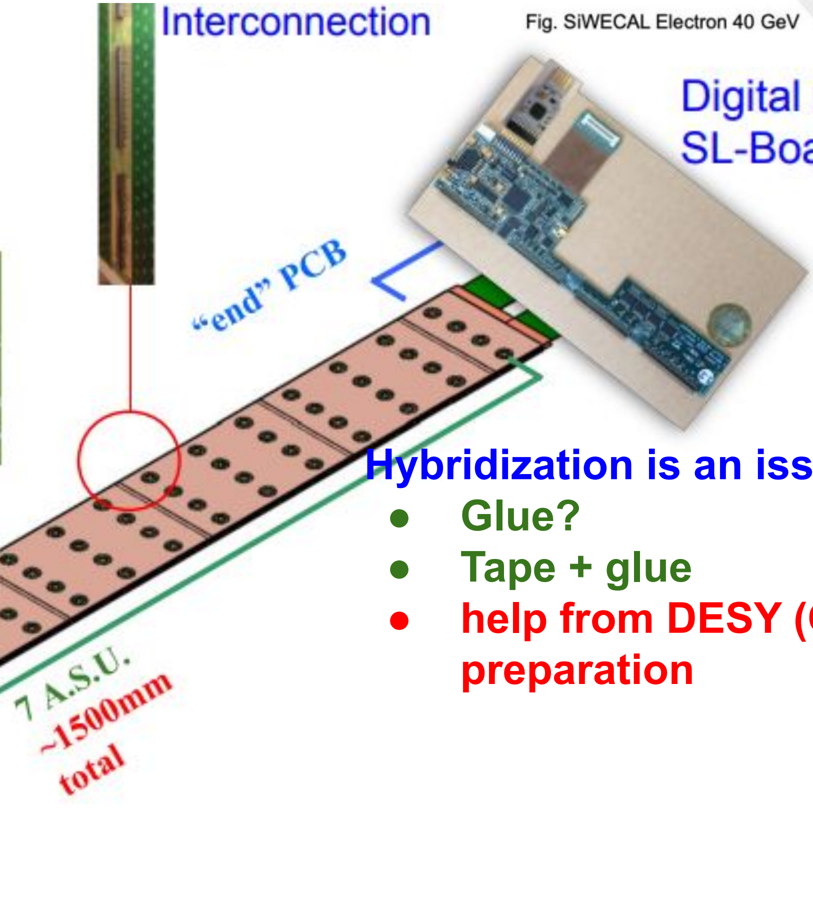
ASIC+PCB+SiWafer
=ASU
Size 18x18 cm^2

ASIC SKIROC2(a)
Wire Bonded or
In BGA package

SiWafers
glued
onto PCB
Pixel size
5.5x5.5 mm^2





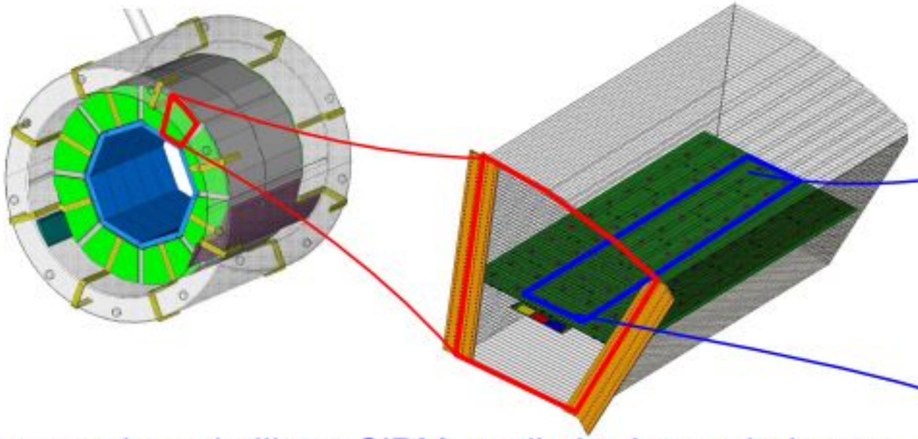


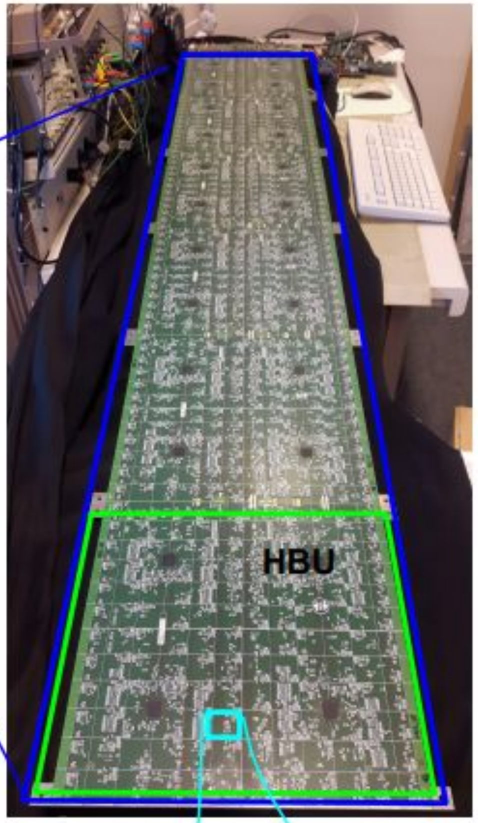
Hybridization is an issue:

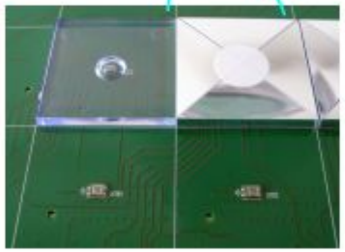
- Glue?
- Tape + glue
- help from DESY (Ole Bach) on tape preparation

AHCAL

Structure





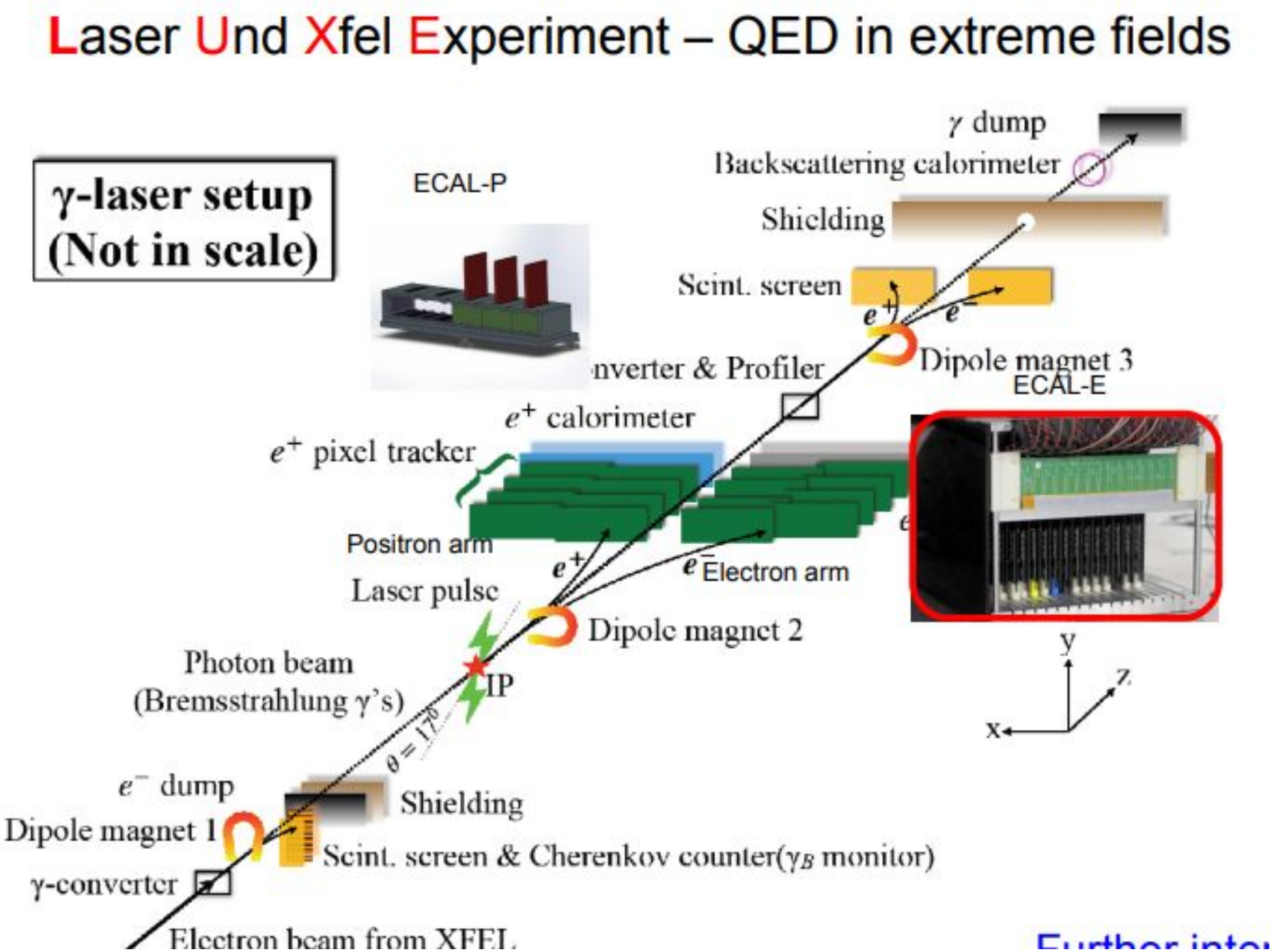


- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles optimised for uniformity
- **fully integrated design**
  - front-end electronics, readout
  - voltage supply, LED system for calibration
  - no cooling within active layers -> **power pulsing**
- **scalable** to full detector (~8 million channels)
- geometry inspired by ILD, similar to SiD and CLICdp
- HCAL Base Unit: 36*36 cm2, 144 tiles, 4 SPIROC2E ASICs
  - slabs of 6 HBUs, up to 3 slabs per layer

Calorimetry

CALO5D:

- Use of ps timing (not the same as in LHC)
- integration in PFlow
- Application in Higgs physics
- Derive consequences on CALO design:
  - 1 precise measurement
  - N less precise measurements
  - power consumption (PA) and its consequences
  - benefit of gain



Lohengrin at ELSA in Bonn?

Discussions with Matthias Hamer and Klaus Desch

SUSPECT3 and SUSYHIT

KIT, L2C, LUPM

PIs: David Rousseau and Margarete Muehlleitner

Introduction

A brief history:

- 1997 GDR Supersymmetry (Pierre Binetruy)
  - Working group MSSM
- 1997-2002 Definition of phenomenological MSSM (pMSSM)
  - sfermions: 1st and 2nd generation universality
  - No new sources of FCNC and CP violation
- 1999 Publication MSSM report: arXiv:hep-ph/9901246 (406 citations)
- 2002 Publication of Spectrum Calculator SuSpect: Comput.Phys.Commun.176:426-455,2007
  - Abdelhak Djouadi, Jean-Loic Kneur, Gilbert Moultaka
  - pMSSM (of the MSSM WG +3 parameters), mSUGRA, mGMSB,….
- 2003 Susy Les Houches Accord (SLHA): JHEP 0407:036,2004
  - Interoperability of Spectrum, Decay and Cross section calculators
- 2012 Discovery a R=+1 particle: h
- 2013 Relic density MSSM with SuSpect2: Phys. Rev. D 89, 055017 (2014)
- 2013 Start on major rewrite in C++ (SuSpect3)
- 2015 Relic density NMSSM with SFitter: Phys. Rev. D 93, 015011 (2016)

Calculating a SUSY Spectrum

Not a one shot effort: iterations

Calculating a Supersymmetric Spectrum

GUT scale ~10^{16}GeV

$m^2_{H_d}$, $m^2_{H_u}$, sign(μ)

$A_b,\ A_\tau$, A_t

Ae, Aμ, Ad, As, Au, Ac

M_1, M_2, M_3

$m_{\tilde{e}_L}$, $m_{\tilde{\mu}_L}$, $m_{\tilde{\tau}_L}$, $m_{\tilde{e}_R}$, $m_{\tilde{\mu}_R}$, $m_{\tilde{\tau}_R}$

$m_{\tilde{q}1_L}$, $m_{\tilde{q}2_L}$, $m_{\tilde{q}3_L}$, $m_{\tilde{u}_R}$, $m_{\tilde{c}_R}$, $m_{\tilde{t}_R}$

$m_{\tilde{d}_R}$, $m_{\tilde{s}_R}$, $m_{\tilde{b}_R}$

RGE

RGE

Derived:

EWSB scale ~10^3GeV

$m^2_A(Q),\ \mu$

RGE

Z scale ~10^2GeV

$\tan\beta$

Boundary conditions:

- High scale: SUSY breaking masses
- EWSB scale: μ, m^2A(EWSB)
- Z scale: tanβ

Numerical solution of coupled RGE:

- High Scale to Low Scale in N steps

Ensure EWSB

- Iteration at EWSB scale

Radiative corrections EWSB scale:

- Higgs Potential
- Higgs and SUSY running masses to pole masses

Radiative corrections Z scale:

- Corrections to SM couplings (yukawa, W, Z

Major rewrite C++

From Fortran to C++

C++ Inheritance: Models and EWSB

Models:

- Base for initialization
- Generic bottom up running NEW
- Generic models as function of the number of scales (up to 5)
- Generic models implement the algorithm:
  - RGE running
  - Calculating rad corrs at the right scale
  - Calculating pole masses
- Specific models implement boundary conditions (set the SUSY breaking parameters)
- Minimal models inherit from larger models of the same type

EWSB

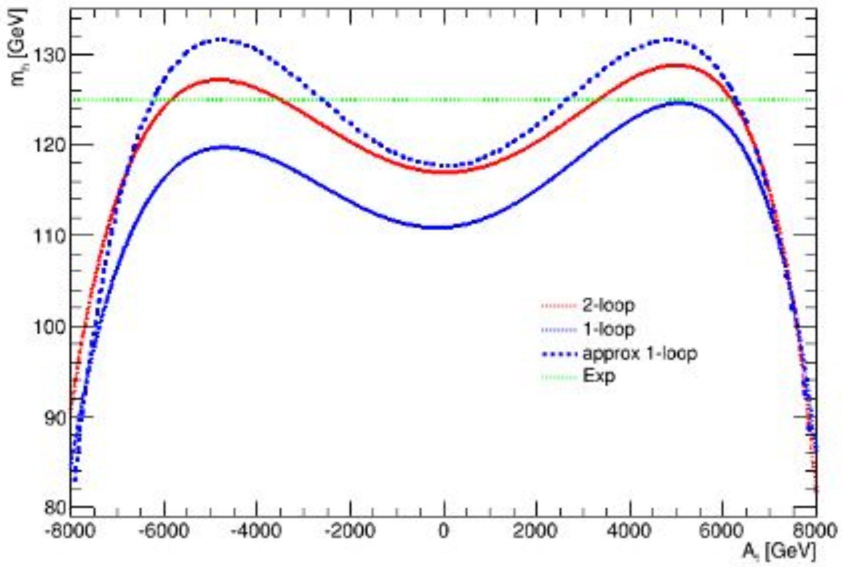
- Base for initialization
- 3 classes EWSBclassic → Base
  - Algorithm specific part
  - m^2H_u m^2H_d
  - μ, mA^2(EWSB) (BC at 3 scales)
  - μ, mA
- 1 class EWSBmh → Base
  - mh NEW
- EWSBclassic+EWSBmh
  - Alg developed for 1 EWSB variant, worked for all 3
  - Difficulty: diamond inheritance (virtual solved the problem)

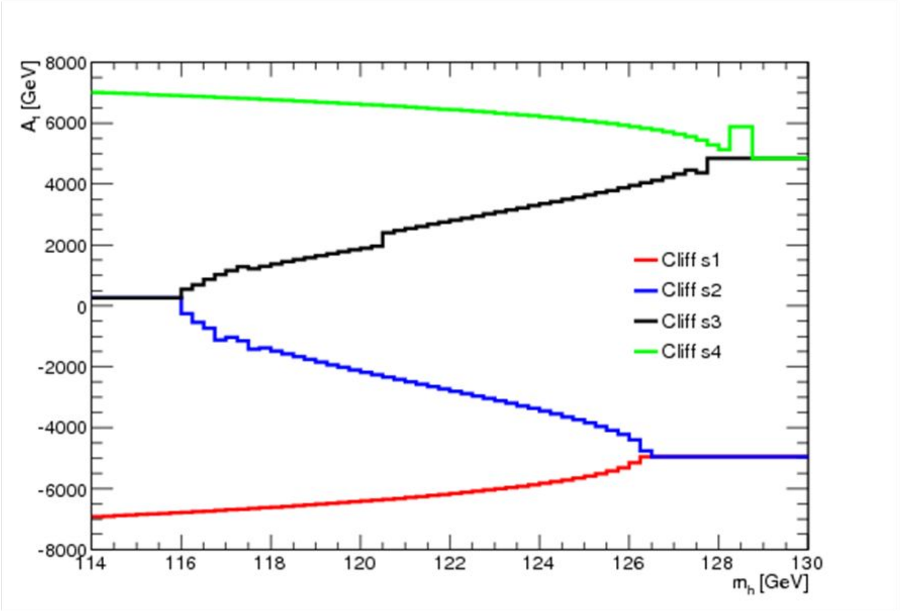
Examples:

- Base → 2scales →LowScaleMSSM
- Base → 4scales → GMSB →mGMSB
- Base → 4scales → AMSB →mAMSB
- ….

Higgs mass prediction or input parameter?

Inversion problem: trilinear coupling from Higgs mass





FixedPoint problem:

$$C_{FP}(A_t) = -\frac{1}{C_3}[C_2 A_t^2 + C_1 A_t + C_0 + (R_2 A_t^2 + R_1 A_t + R_0)\sqrt{a_s A_t^2 + b_s A_t + c_s}],$$

Eur. Phys. J. C (2022) 82:657

Inversion works: from $m_h(A_t)$ to $A_t(m_h)$

SUSYHIT2

From the Sparticle to the decay: SUSYHit upgrade in the works

Availability:

- v3.1.1
- http://suspect.in2p3.fr
- wget http://suspect.in2p3.fr/tar/suspect3.tar.gz
- tar xvfz suspect3.tar.gz
- ./configure
- make
- suspect3 –d examples/mSUGRA.in

SUSY-HIT1

- 100% Fortran
- Input files: SLHA*, susyhit.in, hdecay.in
- Communication between suspect2 and SDECAY/HDECAY: SLHA spectrum file

SUSY-HIT2:

- Upgrade to hdecay v6.61
- Move to SuSpect3 (C++)
- Communication SuSpect3 - SDECAY/HDECAY in memory (more efficient for large parameter scans)
- C++ calling Fortran

C++ inheritage:

- Object SLHA4suspect: SLHA memory implementation of SLHA (limited to BLOCKS)
- Object SLHA4susyhit: inherits from SLHA4suspect and adds BLOCK DCINFO and DECAY of SLHA

Code maintance:

- Implemented CI tests for example files

Testing:

- Intrinsic comparisons: communication via file versus memory
- Change comparisons: SUSYHIT v1 versus SUSYHIT v2

Availability: Soon

* SLHA: SUSY Les Houches Accord format

```
#          PDG            Width
DECAY   1000021     4.51015016E+00   # gluino decays
#           BR          NDA      ID1       ID2
     2.11421275E-02    2     1000001        -1   # BR(~g -> ~d_L  db)
     2.11421275E-02    2    -1000001         1   # BR(~g -> ~d_L* d )
     5.06628143E-02    2     2000001        -1   # BR(~g -> ~d_R  db)
     5.06628143E-02    2    -2000001         1   # BR(~g -> ~d_R* d )
     2.73930365E-02    2     1000002        -2   # BR(~g -> ~u_L  ub)
     2.73930365E-02    2    -1000002         2   # BR(~g -> ~u_L* u )
     5.02331604E-02    2     2000002        -2   # BR(~g -> ~u_R  ub)
     5.02331604E-02    2    -2000002         2   # BR(~g -> ~u_R* u )
     2.11421275E-02    2     1000003        -3   # BR(~g -> ~s_L  sb)
     2.11421275E-02    2    -1000003         3   # BR(~g -> ~s_L* s )
     5.06628143E-02    2     2000003        -3   # BR(~g -> ~s_R  sb)
     5.06628143E-02    2    -2000003         3   # BR(~g -> ~s_R* s )
     2.73930365E-02    2     1000004        -4   # BR(~g -> ~c_L  cb)
```

Dark Matter, Gravity and Cosmology

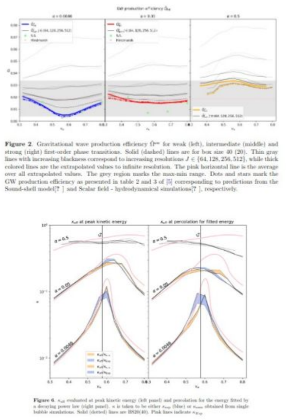
Project in French/German collaboration:

In preparation / preliminary

Towards gravitational waves from strong phase transitions with the Higgsless simulations

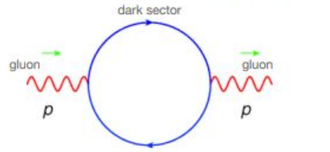
Chiara Caprini,[a,b] Ryusuke Jinno,[c] Thomas Konstandin,[d] Alberto Roper Pol,[a] Henrique Rubira,[c] Isak Stomberg[d]

We use a new hydrodynamic simulation scheme to study GW power spectra generated to during a first-order phase transition. We provide condensed information on the spectra as function of the wall velocity, latent heat, PT duration ...

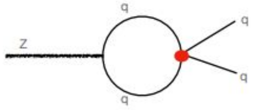


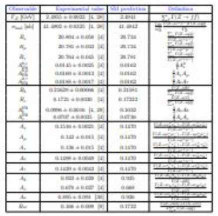
Project: Precision constraints on strongly interacting dark particles

Adam Falkowski <-> Guilherme Guedes



$2g_s^{-2}M_W^2 Z \;=\; \Pi''_{GG}(0)$ $\qquad O_{GG} \;=\; (D_\rho G^A_{\mu\nu})^2/2g_s^2$



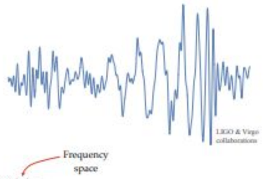


- It is conceivable that dark sectors particles with only strong interactions and no electroweak interactions exist
- They would contribute to the so-called Z parameter (analogue of electroweak S,T parameters) corresponding to a specific dimension-6 operator in SMEFT
- This operators is equivalent to a linear combination of 4-quark operators in the Warsaw basis
- Goal: map out precise constraints on the Z parameter from electroweak precision measurements at LEP

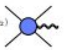
PIs:
Geraldine Servant and Adam Falkowski
Thomas Konstandin and Daniele Steer
Christophe Grojean and Giacomo Cacciapaglia

Project: Gravitational waves in modified gravity

Panagiotis Marinellis <-> Massimiliano Riva



$$\text{waveform}(\omega) = \frac{1}{\text{distance}}\int d^4q_1 d^4q_2\, \delta(p_1\cdot q_1)\delta(p_2\cdot q_2)\delta^4(k-q_1-q_2)\, e^{ib\cdot(q_1-q_2)}$$



Cristofoli, Gonzo, Kosower & DOC

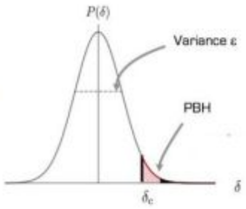
- It's the golden age of gravitational wave astronomy
- On-shell amplitude techniques have pushed forward precision calculations of waveforms emitted in black hole/neutron star collisions, in GR and EFT extension thereof
- Less explored are the application in scalar-tensor theories where gravity is coupled to a cosmologically light scalar
- Using on-shell amplitude techniques simplifies calculation of both gravitational waves and scalar waves for Schwarzschild and Kerr black holes

Project: Gravitational waves from primordial black holes

DMLab project

Mathias Pierre and Simon Cléry

- Large perturbations of curvature can be generated in some models of inflation, studied to generate Primordial Black Holes (PBH)
- Scalar (curvature) perturbations can source second order Gravitational Waves (GWs) spectrum



$$h''_{ij} + 2\mathcal{H}h'_{ij} - \partial_k\partial^k h_{ij} = \mathcal{P}^{ab}{}_{ij}\{T_{ab}\} \approx \mathcal{P}^{ab}{}_{ij}\{\partial_a\delta\varphi\partial_b\delta\varphi\} \;\Rightarrow\; \mathcal{P}_h \propto \mathcal{P}^2_{\delta\varphi} \text{ with } \mathcal{P}_{\delta\varphi} \sim \mathcal{P}_{\mathcal{R}} \text{ (curvature spectrum)}$$

- Look at the production of GWs induced by large perturbations of curvatures generated during inflation, related to the formation of PBH
- Study the effect of Non-Gaussianities and the consequences of non-linear dynamics for the GWs spectrum and its anisotropy

Outlook

- Can SILH be systematically extended to include DM?
- Systematic study of baryo-genesis, DM-genesis and GW production.
- Exotic phenomenology of composite states: exotic decays, LLP, light composite scalars...
- Synergy between current and future experiments.

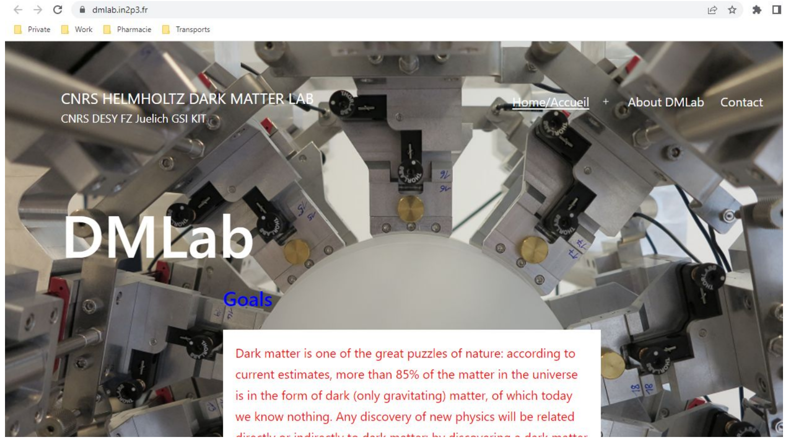
Institutions

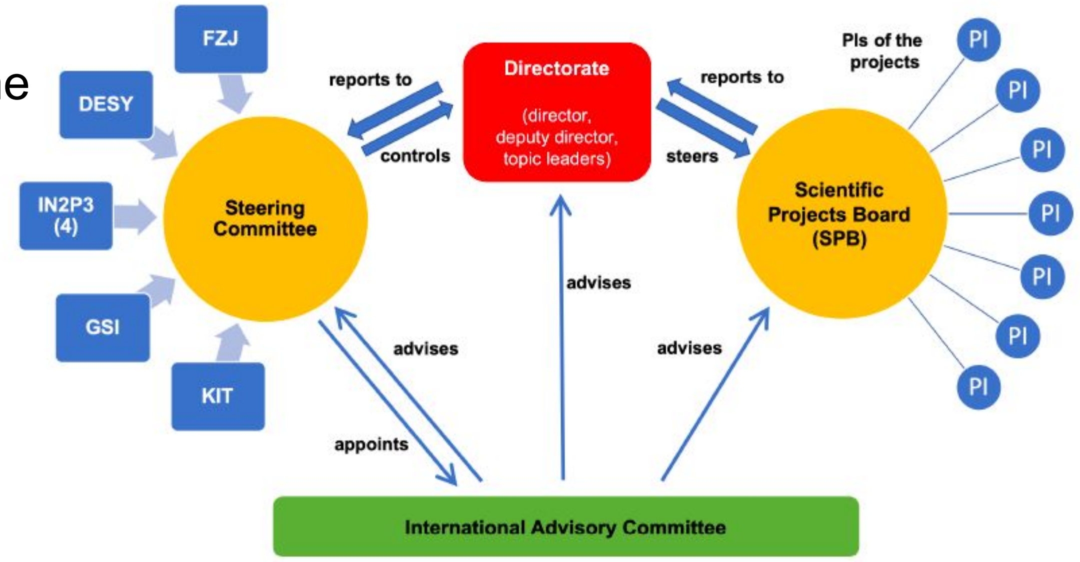
Governance

- Directorate (Director and CoDirector)
  - Dirk Zerwas (CNRS) and Thomas Schoerner (DESY)
- Steering Committee
- Scientific Projects Board
- International Advisory Committee

Name	Institution	Function
Reynald Pain / Berrie Giebels	IN2P3	Director
Patrice Verdier (co-chair)	IN2P3	
Vincent Poireau	IN2P3	
Laurent Vacavant	IN2P3	
Beate Heinemann	DESY	Director of particle physics
Hans Ströher (co-chair)	FZ Jülich	Director of IKP2
Yvonne Leifels	GSI	Deputy research director
Marc Weber	KIT	Head of division V

- Website
- Mailing list dmlab-general:
  - contact Thomas or Dirk
  - or mail to: sympa@desy.de
  - subject: subscribe dmlab-general Firstname Name





DMLAB

Formal Information

DMLab creation

- created formally on Jan 1, 2023 (dictionary need: French/German lab/institute, IN2P3(institut)/faculty or department)
- MoU last signature May 17, 2023 (evidence for new physics :)

Starting up:

- Direct searches
- Detector development
- Theory and Phenomenology
- Machine Learning
- Advanced Accelerator concepts (plasma)
- Astroparticles and Gravitational Waves

DMLab future:

  - Open lab: pitch your idea to Thomas and Dirk