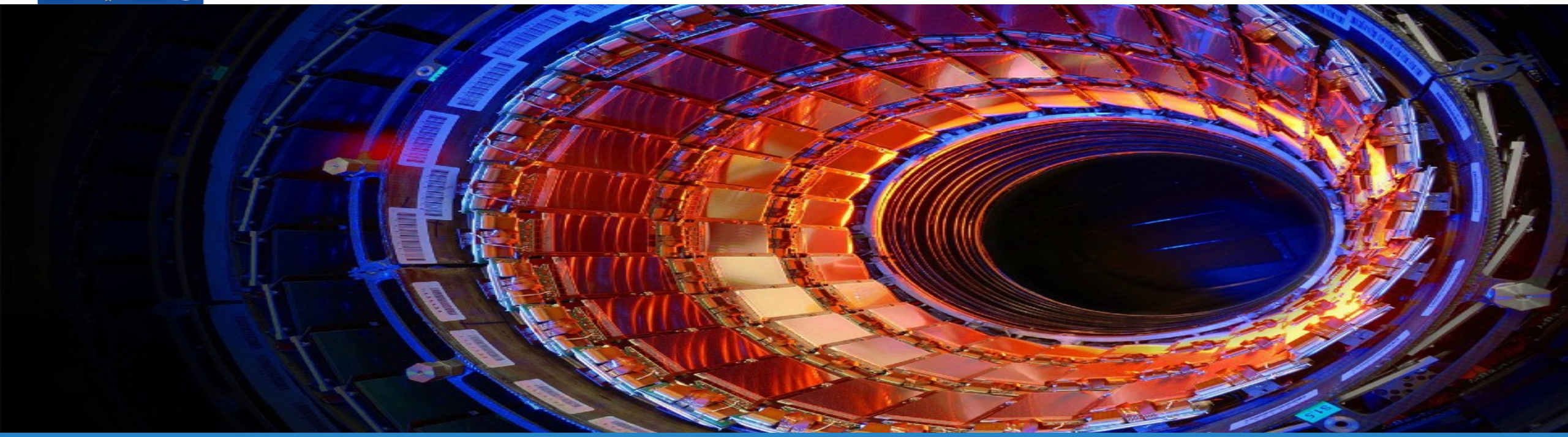


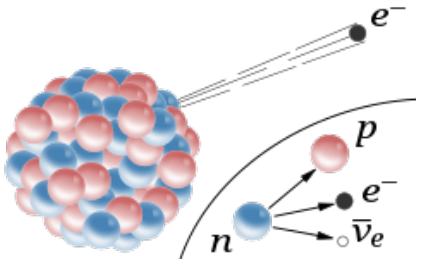
# WP21 — JRA3 PrecisionSM: "*Hadron Physics for Precision Tests of the Standard Model*"

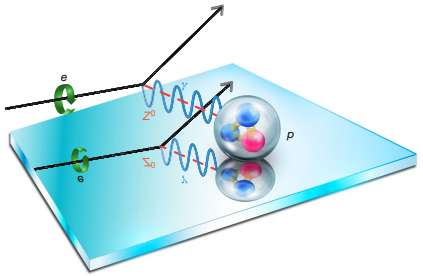
Spokespersons: M. Gorshteyn (JGU Mainz), A. Kupsc (Uppsala University)

***This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093***

# WP21 / JRA3 — Hadron Physics for Precision Tests of the Standard Model
## Goal: combine theory and experiment for precision tests SM & BSM

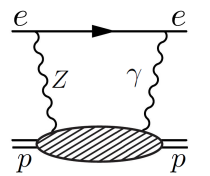
### Precise SM parameters in the weak sector

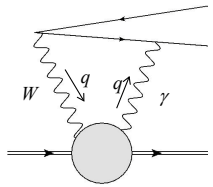


Beta decay: $V_{ud}$, $V_{us}$ & CKM unitarity: $3\sigma$ deficit PDG2020
Exp. (CERN, TRIUMF, ANL, Notre Dame, TAMU, LANL, NIST, ILL, Mainz, SNS, Munich, NIST, ESS, J-PARC, …)

$\sin^2\hat{\theta}_W(0)$ from PVES: agreement w. SM; Improved precision in near future (MESA, JLab)

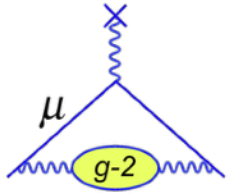



Common ingredient: electroweak boxes
Depend on hadronic structure
Dominate the theory uncertainty

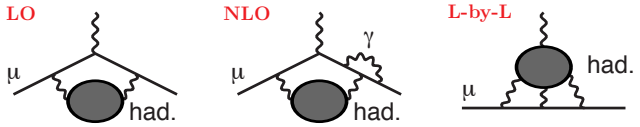
Combine
Lattice QCD + Dispersion Theory + Exp.
(DUNE, T2HK, Mainz, JLab)

### Test of SM radiative corrections



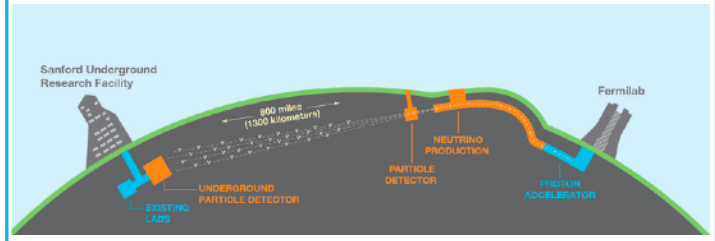

$a_\mu^{\rm SM} = 116\,591\,810\,(43) \times 10^{-11}$
$a_\mu^{\rm BNL} = 116\,592\,089\,(63) \times 10^{-11}$
Discrepancy $\sim 3.7\sigma$

Exp. (FNAL, JPARC): reduce error by 4
Theory: hadronic contributions




Combine & Coordinate
LQCD + EFT + Dispersion Theory + Exp.
(CERN, Mainz, JLab, BES III, Belle II…)

### Neutrino masses and mixing
### At the intensity frontier




$$P_{\nu_i \to \nu_j} \sim \sin^2(2\theta_{ij}) \sin^2\left[1.27 \frac{\Delta m^2_{ij}}{\mathrm{eV}^2} \frac{L[\mathrm{km}]}{E[\mathrm{GeV}]}\right]$$

Goals: masses, mass hierarchy, CPV, p decay, sterile $\nu$, …

Main uncertainty: neutrino energy
Reconstructed from neutrino-nucleus
Interactions in the near detector

Combine Theory and exp. data on
$\gamma N \to \pi N, eN \to e'\pi N, \ldots$ to predict
$\nu N \to \ell \pi N, \nu N \to \nu \pi N, \ldots$

# Overview

1. Hadronic Effects in Precision Tests of the weak sector of the Standard Model

   1.1 Electroweak MAID: Partial Wave Analysis of Weak $\pi, \eta, \eta', K$ Production (Mainz, Valencia, Fermilab)

   1.2 New $\nu\pi$ Monte Carlo Event Simulator based on WeakMAID for Short Baseline $\nu$ Experiments (Mainz, Valencia, Fermilab)

   1.3 EW Box Corrections for Extraction of the Weak Mixing Angle from PVES and $V_{ud}$ from Beta decays (Mainz, UMass, Bonn)

2. Hadronic Effects in Precision Tests of the electromagnetic sector of the Standard Model: Muon g-2

   2.1 Hadronic Vacuum Polarization from spacelike and timelike processes
   (Uppsala, INFN-Pisa, Mainz, UL, USlaski, BINP, LAL UPS)

   2.2 Hadronic Light-by-Light Scattering Contribution to $(g-2)_\mu$
   (Lund, Giessen, Mainz, Bern, Barcelona, Marseille, Bucarest, LPHNE, UBO, Uppsala, Prague, FZJ, Orsay)

# JRA3: — Publications

## 3 articles on radiative corrections to β-decays


[1] X . Feng, M. Gorchtein, L. Jin , C.Y. Seng, "*First-principles calculation of electroweak box diagrams from lattice QCD*", Phys. Rev. Lett. 124 (2020) 19, 192002;

[2] C.Y. Seng, X. Feng, M. Gorchtein, L. Jin, U.-G. Meissner, "*New method for calculating electromagnetic effects in semileptonic beta-decays of mesons*", arXiv:2009.00459 [hep-lat];

[3] C.Y. Seng, X . Feng, M. Gorchtein, L. Jin , "*Joint lattice QCD-dispersion theory analysis confirms the quark-mixing top-row unitarity deficit*", Phys. Rev. D101 (2020) 11, 111301;


## 3 articles on extraction of Weak Mixing Angle from PVES and on related observables


[4] J. Erler, M. Gorchtein, O. Koshchii, C.-Y. Seng, H. Spiesberger, "*Reduced uncertainty of the axial γZ-box correction to the proton's weak charge*", Phys. Rev. D 100 (2019) 5, 053007

[5] O. Koshchii et al, "*Weak charge and weak radius of C-12*", Phys. Rev. C 102, 022501 (2020);

[6] A. Esser et al, "*Beam normal single spin asymmetry in elastic electron scattering off Si-28 and Zr-90*", *Phys.Lett.B* 808 (2020) 135664;


## 2 articles on muon g-2


[7] T. Aoyama, et al., "*The anomalous magnetic moment of the muon in the Standard Model*", [arXiv:2006.04822];

[8] P. Banerjee, et al. "*Theory for muon-electron scattering @ 10 ppm: A report of the MUonE theory initiative*", Eur. Phys. J. C 80, no.6, 591 (2020), [arXiv:2004.13663]

# JRA3: Task 1 — Summary of results

Developed a novel method for evaluating the EW box corrections: Dispersion Theory + Lattice QCD

- [1] $\gamma W$-box for $\pi\ell 3$ decay: direct lattice calculation + DR —> uncertainty reduction by a factor 3 (previously ChPT)
- [2] Foundations for an improved analysis of RC to $K\ell 3$ decays w. LQCD and improved precision of $V_{us}$ laid out
- [3] Neutron decay: $\gamma W$-box on the nucleon from LQCD on pion + phenomenology input confirms previous results and CKM unitarity deficit now established [PDG 2020] $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9985(3)_{V_{ud}}(4)_{V_{us}}$

- [4] Updated calculation of the $\gamma Z$-box correction to the proton weak charge: theory uncertainties of the future P2@MESA experiment firmly under control
- [5] Feasibility study for a simultaneous sub-% measurement of weak charge and weak radius of C-12 with P2@MESA
- [6] Experimental and theoretical study of the Z-dependence of a related observable in polarized e-scattering, beam-normal spin (Mott) asymmetry on Si-28 and Zr-90 — important systematic uncertainty for PVES in view of exp. programs on precision tests of SM and neutron skins

# JRA3: Task 1 — Deliverables and Milestones

**Task 1.1** (Weak MAID) - originally planned Deliverable D21.1 and Milestone MS37 for m18

- Activity started, new collaboration formed (Mainz-Valencia) additionally to existing Mainz-Tusla-Zagreb (MAID)
- Due to COVID-19 the completion of the task is delayed as the dedicated position could not be filled
- Interaction with partners at Fermilab (an extended visit to FNAL planned) was severely impaired
- Position dedicated to this task filled starting from Nov. 1 2020 — updated plan for submitting the deliverable is Month 24 ($\geq$1 publication of the theoretical model of Weak MAID, new WeakMAID website)
- PhD student in U. Valencia will join the project (Task 1.2 and/or 1.1)
- Impact on progress in Task 1.2 (MS39: MC simulator for $\nu\pi$ production - m48) should not be affected

**Main goals of Task 1.3 achieved prior to the plan** (Deliverable D21.3 - m48)

— PDG included our new RC analysis in the 2020 review of the top-row CKM unitarity

**New results**:

$\gamma W$-box for $\pi\ell 3$, $K\ell 3$ w. LQCD + ChPT + DR — expands the impact of our JRA

Planned PVES experiment on C-12 at MESA based on our work — will impact extraction of $\sin\hat{\theta}_W(0)$ and assessment of isospin symmetry breaking effects in nuclear beta decays

**Bottomline Task 1: Delay of D21.1 caused by COVID-19 (~6m) is compensated by other achieved results and does not endanger the success of this part of the project**

# JRA3: Task 2 — Summary of Results & Deliverables and Milestones

2 reports published —define the state-of-the-art of the theory for the respective experiment

[7] White paper by the Muon g-2 Theory Initiative —> E989 experiment at Fermilab (to be unblinded this year)
[8] Report by the MUonE Theory Initiative (D21.2 - m24)

Position dedicated to feasibility study for MUonE (INFN-Pisa) could not be filled — postponed

Activity towards the creation of the e+e- database (D21.4, MS40 - m48) started:

A community composed of more than 30 world-wide experts (theory + experiment) working in the field of low-energy e+e- physics has met at a dedicated virtual workshop on database structure June 3, 2020 (MS38 - m24).

A mailing list and a collaboration indico page was set up

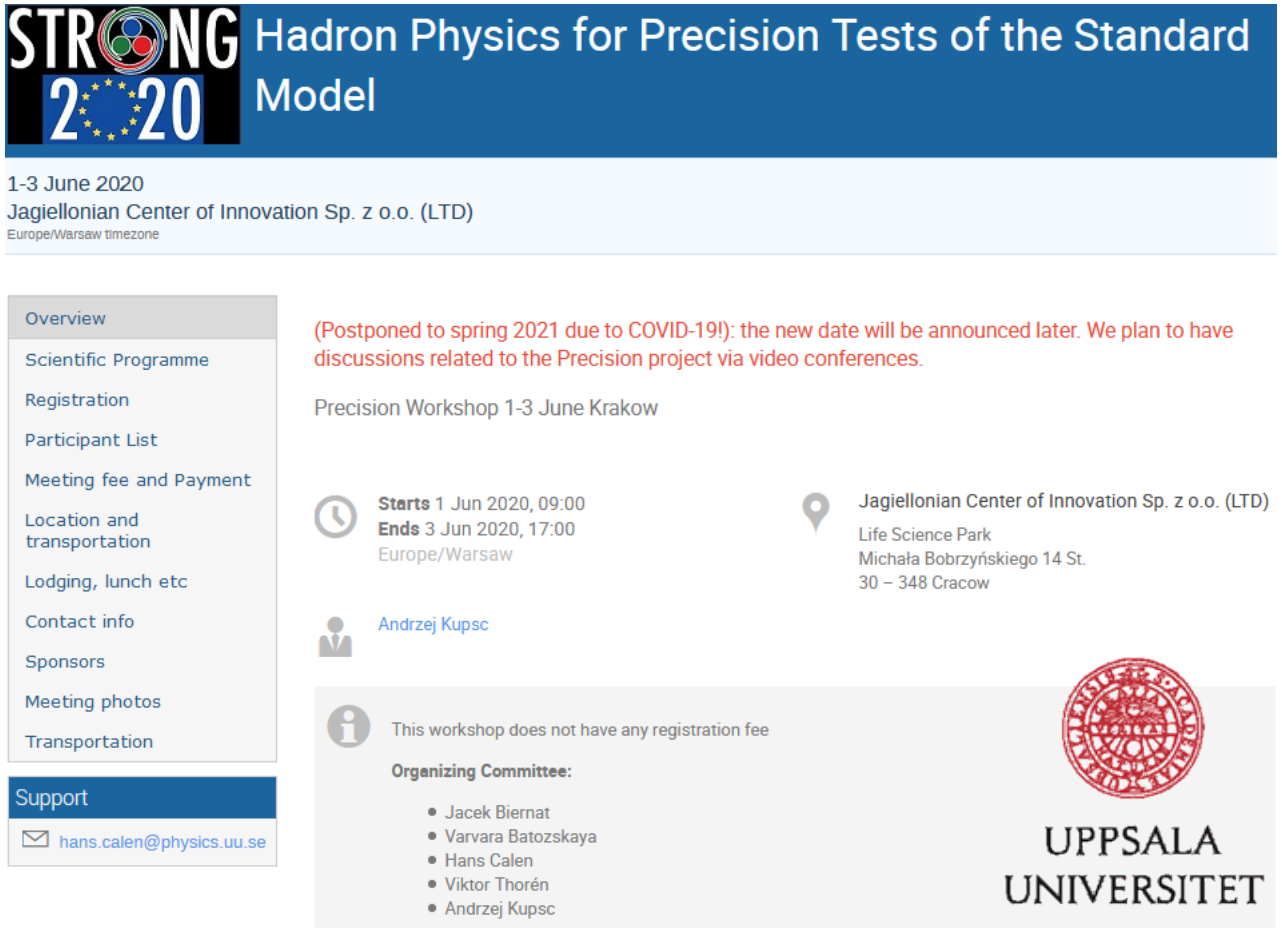
Test web page with basic functionalities developed; the approach for the construction of the database with e+e- data retrieved by HEPDATA identified

Collaboration Meeting planned for Mid-November

# JRA3: Task 2 — Summary of Results & Deliverables and Milestones

Meeting on data base for low-energy hadronic cross sections in e+e- collisions
June 3rd (zoom)

Agenda
- Introduction PrecisionSM/STRONG2020 - Andrzej Kupsc
- DataBase project goal - Graziano Venanzoni
- DataBase project status/options - Alberto Lusiani
- HEPData - Graeme Watt
- Example from KLOE - Stefan Mueller
- Contact with experiments - Simon Eidelman
- Discussion/conclusions/next steps




**Bottomline Task 2:**
**Steady progress on the projects proceeds according to or ahead of the plan; only mildly affected by the COVID-19 emergency**

# JRA3: Use of Resources

Use of financial resources

Uppsala: 4k/60k — travel + workshop organization (prepayment for cancelled workshop in Krakow)
INFN Pisa: 0/56k (position not filled as of now)
JGU Mainz: 1 person-month salary /96k (exact figures will be known Nov. 30, 2020)

**2.2 Use of human resources**

*[Indicate the human effort involved in the WP during the reporting period.]*

| **Beneficiary number** | **Organization legal name** *(in italics the Research Units)* | **Short name** | **Human effort from Annex I** *(person-months for 18 months)* | **Actual human effort in the reporting period** *(person-months)* |
|---|---|---|---|---|
| 9 | *Johannes Gutenberg-Universitat Mainz* | JGU MAINZ | 8,60 | 1 |
| 30 | *Istituto Nazionale di Fisica Nucleare* | INFN | 5,25 | 3 |
| 41 | *Uppsala Universitet* | UU | 0 | 0 |

# Summary

D21.1 and MS37 delayed due to COVID by ~6 months

D21.2 and a good part D21.3 achieved before schedule

Activity towards MS40 and D21.4 on track

Scientific Highlights:

- White paper by the Muon g-2 Theory Initiative — Sets the state-of-the-art awaiting the exp. results from FNAL
- Theory report on spacelike HVP for MUonE experiment published
- Radiative corrections to beta decay — CKM unitarity deficit is now firmly established and included in PDG2020
- Radiative corrections to PVES — precision extraction of the weak mixing angle from experiments @ MESA is warranted