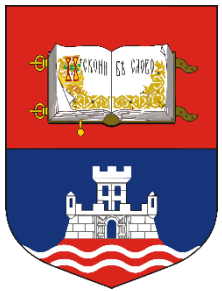
# SERBIAN HEP ACCTIVITIES WITH FUTURE COLLIDERS

Higgs factories are the highest-priority future initiatives
of the European (and global) Particle Physics community
ESPPU2020




# Serbian institutes @ FC

Vinca Institute of Nuclear Sciences

National Institute of the Republic of Serbia

Institute of Physics

National Institute
of the Republic of Serbia

## Current MoU based collaborations

@ CERN

CLIC (2012 - ) TL I. Bozovic

FCCee (2023 - ) TL M. Pandurovic

Outside CERN

ILC (2005 - ) TL I. Bozovic

CEPC (2016 - ) TL I. Bozovic

## MoU based collaborations @ CERN/recognized by CERN

MICE Muon Ionization Cooling Experiment (2015 – 2017 )
TL D. Maletic

Faculty of Physics,
University of Belgrade

FCCee (*plan to join*)
TL V. Milosevic

# Vinca @ FC (past – update since 2012)

## Core research: Forward region instrumentation at LCs


- 2 EU projects: FP7 AIDA, HORIZON2020 E-JADE
- 2 PhD theses at ILC related to very forward instrumentation
- FCAL R&D Collaboration
- 4 FCAL Collaboration papers:

  Eur.Phys.J. C79 (2019) no.7, 579,
  Eur.Phys.J. C 78 (2018) 2, 135,
  JINST 10 (2015) 05, P05009,
  JINST 5 (2010) P12002

### Roles & expertise:

- Elected chair of the Board of Institutes of the FCAL Collaboration (2013-2015)
- Member of the ICFA appointed Linear Collider Collaboration LCC Conference Group (2015-2019)
- LoC LCWS2014, Belgrade
- LoC of 4 FCAL Collaboration Workshops in Belgrade (2008, 2011, 2014, 2017)

# Vinca @ FC

**Core research: Higgs studies (couplings, CPV), MDI and integrated luminosity**

The Team:
Ivanka Bozovic TL,
post-docs: Goran Kacarevic, Ivan Smiljanic, Gordana Dumbelovic
PhD students: Natasa Vukasinovic (completed PhD), Ivana Vidakovic
External (FSUKG): Mirko Radulovic (PA), Jasna Stevanovic (PA)

Completed:
- 3 PhD theses at CLIC

Ongoing:
- PhD thesis (CEPC)
- Grant No. 7699827 by the Science Fund on studies at future Higgs factories (~200 kEUR)

Current roles & expertise:

- (2024) ECFA Experts Groups:
  - Higgs/top/EW: ZH angular observables & CP
  - Precision: Luminosity
- (2021 - ) Higgs physics convener at ILC/ILD
- (2021 - ) ILC IDT detector & physics WG Publication and Speakers Bureau – chair
- (2024 - ) ILC/ILD Publication and Speakers Bureau – chair
- (2024 - ) LC Vision Coordination Group

## Higgs physics at LC

6 completed analyses

1. Higgs to EW: $g_{HZZ}$ at 350 GeV, 1.4 TeV and 3 TeV CLIC
2. Higgs rare decays: $g_{H\mu\mu}$ at 1.4 TeV CLIC
3. Higgs rare decays: $g_{H\gamma\gamma}$ at 3 TeV CLIC
4. CP violation in HZZ vertex in VBF at 1 TeV ILC

*CLICdp Collaboration, Higgs physics at the CLIC electron–positron linear collider, Eur.Phys.J. C77 (2017) 7, 475, IF 4.1*

*N. Vukasinovic, I.Bozovic et al.(8 authors), Measurement of the H to ZZ branching fraction at a 350 GeV and 3 TeV CLIC, Phys. Rev. D Vol. 105, 092008 (2022), IF 5.0*

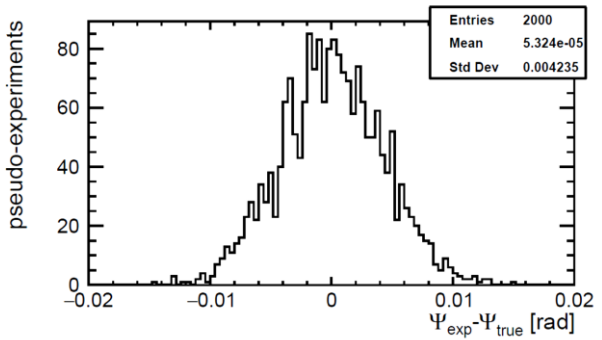
*G. Milutinović-Dumbelović, I. Božović-Jelisavčić et al. (8 authors), Physics potential for the measurement of σ(Hνν̄)×BR(H→μ+μ−) at the 1.4 TeV CLIC collider, Eur.Phys.J. C75 (2015) 11, 515, IF 4.1*

*G. Kacarevic, I.Bozovic et al. (8 authors), Measurement of the Higgs boson branching ratio BR(H→γγ) at a 3 TeV CLIC, Phys. Rev. D 105, 092009 (2022) IF 5.0*

*N.Vukasinovic, I.Bozovic et al. (4 authors), Probing CPV mixing in the Higgs sector in VBF at 1 TeV ILC, Phys. Rev. D 110, 032011 (2024), IF 5.0*

- (4) is the first CPV estimate in VBF at an $e^+e^-$ collider
- (1) and (4) are input to the ECFA Higgs/to/EW Group for the EPPSU 2025

- $\Delta\psi_{CP}$= (3.8±0.4) mrad at 68% CL
  - CPV factor $f_{CP}$=1.44 ·$10^{-5}$



# Vinca at CEPC and LC


## MDI and integrated luminosity

### CEPC

1. CEPC CDR study on precision of $\mathcal{L}_{\text{int}}$
2. Systematics in $\mathcal{L}_{\text{int}}$ measurement
3. Metrology for the $\mathcal{L}_{\text{int}}$ measurement at the Z-pole

*CEPC Conceptual Design Report: Volume 2 - Physics & Detector, CEPC Study Group, (Machine detector interface and luminosity detectors, I. Bozovic Jelisavcic, S. Hou and H. Zhu (ed.)), Nov 23, 2018. 424 pp., IHEP-CEPC-DR-2018-02, IHEP-EP-2018-01, IHEP-TH-2018-01, e-Print: arXiv:1811.10545 [hep-ex],*

*Ivan Smiljanic, Ivanka Bozovic Jelisavcic, et al. (6 authors), Systematic uncertainties in integrated luminosity measurement at CEPC, JINST 17 P09014, (2022)*

*Ivan Smiljanic, Ivanka Bozovic Jelisavcic, et al. (5 authors), Uncertainties from metrology in the integrated luminosity measurement with the updated design of a detector at CEPC, Progress of Theoretical and Experimental Physics, ptae141 (2024), IF 8.6*

### LC

4. Instrumentation of the very forward region at ILC/ILD
5. Systematics in $\mathcal{L}_{\text{int}}$ measurement ILC & CLIC
6. Metrology for the $\mathcal{L}_{\text{int}}$ measurement at all ILC energies

*I. Bozovic Jelisavcic et al. (5 authors), Luminosity measurement at ILC, JINST 8 (2013) P08012*

*S. Lukic, I. Bozovic Jelisavcic et al. (4 authors), Correction of beam-beam effects in luminosity measurement in the forward region at CLIC, JINST 8 (2013) P05008*

*Ivan Smiljanic, Ivanka Bozovic Jelisavcic, et al. (5 authors), Metrology requirements for the integrated luminosity measurement using small-angle Bhabha scattering at ILC, submitted to Progress of Theoretical and Experimental Physics, IF 8.6*

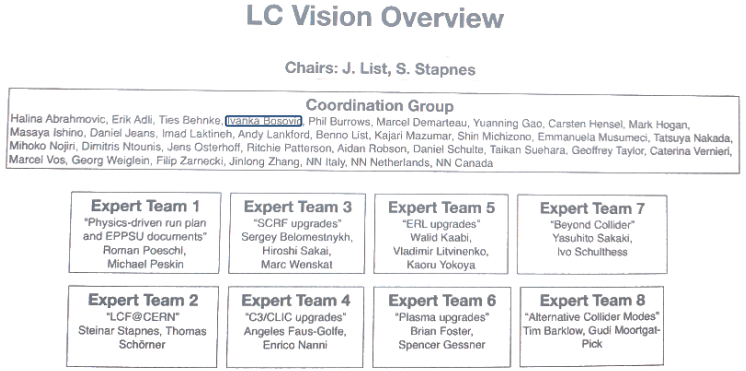
- (1) CEPC CDR
- (3) and (6) are input to the ECFA Precision Group for the ESPPU 2025

# Vinca @ FC

**A Linear Collider Facility in Japan, at CERN or whereever**

- offers
  - the **full Higgs/top/EW e+e- physics program** from 91 to (at least) 1000 GeV with polarised beams
  - and a rich program of **other collision modes and beyond-collider / R&D opportunities**
- can be built
  - at CERN:
    - ~within the CERN budget (ref CLIC PIP), leaving resources for scientific diversity and investment in R&D / demonstrators
    - **early:** industrialised SCRF production & expertise in other labs minimizes interference with HL-LHC
  - in Japan: **even earlier** if we could overcome political obstacles for funding…
- can be **upgraded** with same - or **advanced accelerator technology** (CLIC, C3, Plasma, ERL, …)
- leaves time to decide on target energy and best technology for exploring the energy frontier based on
  - scientific progress from HL-LHC *and* Higgs Factory
  - technology development

**Vinca is a part of LC global initiative – LC Vision**

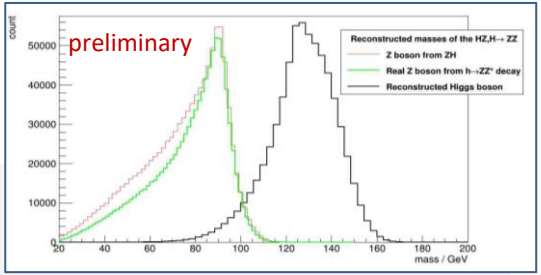



Preparing 'strong contribution' to EPPSU

- Joint LC Vision Document (physics from 90 GeV to multi-TeV)
- LCF@CERN

# Vinca @ FCCee

The Team:
Mila Pandurovic TL,
post-docs: Slobodan Milutinovic,
PhD students: Nemanja Savic, Dimitrije Rajcic




- Recently joined in 2023
- 4 FTE
- Institutional funding
- Planned application for a grant by the Science Fund of the Republic of Serbia

- Higgs physics studies
  - HZZ, HWW, Z,W mass reconstruction in multi-jet final state
  - W/Z separation
  - Reconstruction of multi-jet final states
  - BSM physics in prospect

# Summary on Vinca at FC

- Vinca is the largest Serbian institute with diverse HEP activity (LHC,HL-LHC, FC)
- No particular FC funding except through competitions for (inter)national grants
- Simulation studies (even for detector R&D) are minimizing costs of research
- Other Serbian institutes are involved in these activities in cooperation with Vinca - Faculty of Science from the University of Kragujevac (FSUKG) is sharing the grant from the Science Fond
- Total of 12 FTEs @FC (2 PI, 2 senior scientist, 2 junior scientists, 4 PhD students + 2 senior scientist from FSUKG)


- Strong interest in linear colliders realized at CERN or not – physics case for operation at higher (than 240/250 GeV) energies is evident
- Circular ($e^+e^-$) Higgs factory will be also supported in China and/or at CERN – MoU on cooperation with IHEP Beijing on CEPC (2016, renewed 2023)

# IPB @ FC

The Team:
Dimitrije Maletic TL,
post-docs: Dejan Jokovic, Mihailo Savic

## MICE: Muon cooling for MC (or a neutrino factory)

- Belgrade team made significant contribution to MICE collaboration by working on:
  - physics analysis of Energy loss in MICE absorbers
  - software development - especially work on Event Display for MICE experiment,
  - computing operations by working on Monte Carlo grid production for MICE experiment and
  - Data taking shifts at MICE experiment.

- Belgrade team was awarded funds, for the period of 24 months starting from November 2015, for Transnational Access to the Ionisation Cooling Test Facility at RAL (ICTF@STFC) within EuCARD-2 work package 8, which is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453, to travel and short stay at RAL.

- After Brexit in june 2016, MICE collaboration was informed by RAL that it needs to finish all it's activities using ISIS till the end of summer 2017.

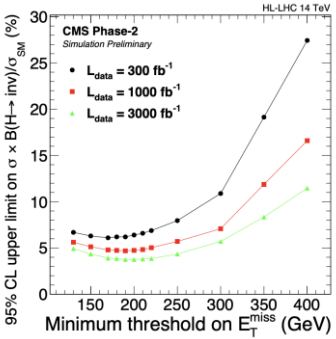
- Conducted **unprecedented single particle measurement of particle trajectories in an accelerator lattice**
- MICE has made **first observation of ionization cooling**
- Results published in various publications, and most important are:
  1) **Nature** in 2020, Demonstration of cooling by the Muon Ionization Cooling Experiment
  2) **Nature Physics** in 2024, Transverse emittance reduction in muon beams by ionization cooling

# FF @ FC

The Team (*to be built*):
Vukasin Milosevic TL

- **Returning to the Faculty of Physics (UB) as a research associate (past associations: Imperial, IHEP Beijing, CERN):**
  - **Planning to join the FCC physics studies focusing on the Higgs boson**
  - **The idea is to involve new students in these efforts as well through master and summer student projects**

- Past studies: Study of prospects for the HL-LHC phase from the perspective of H->invisible searches:
  - Similar approach as the mainline analysis strategy focusing on the VBF topology
  - Published as part of the Report on the Physics at the HL-LHC, and Perspectives for the HE-LHC
  - Relaxing the dijet mass and $E_{T,miss}$ selection requirements to test the sensitivity
  - Obtaining B(H→inv.) as a function of these variables
  - Main conclusions: We can't simply rely only on larger data samples – **specialized triggers!**



## SUMMARY

- Serbian HEP community is involved in the most relevant future Higgs factory projects on the market (the most mature ones: LC, CEPC and FCCee)
- Total of 15 FTEs (3 PI, 5 senior scientist, 3 junior scientists, 4 PhD student) from 3 institutes in Serbia
- No particular FC funding except through competitions for (inter)national grants - 4 grants including 2 EU
- Visibility and prominent roles of Serbian community members in collaborations gathered around future Higgs factory projects

- Strong interest in linear colliders due complementarity to circular $e^+e^-$ colliders and their unique capability to reach TeV scale in interactions of fundamental particles
- Circular ($e^+e^-$) Higgs factory will be also supported in China and/or at CERN

Drawing by F. Simon