Vinca in CMS

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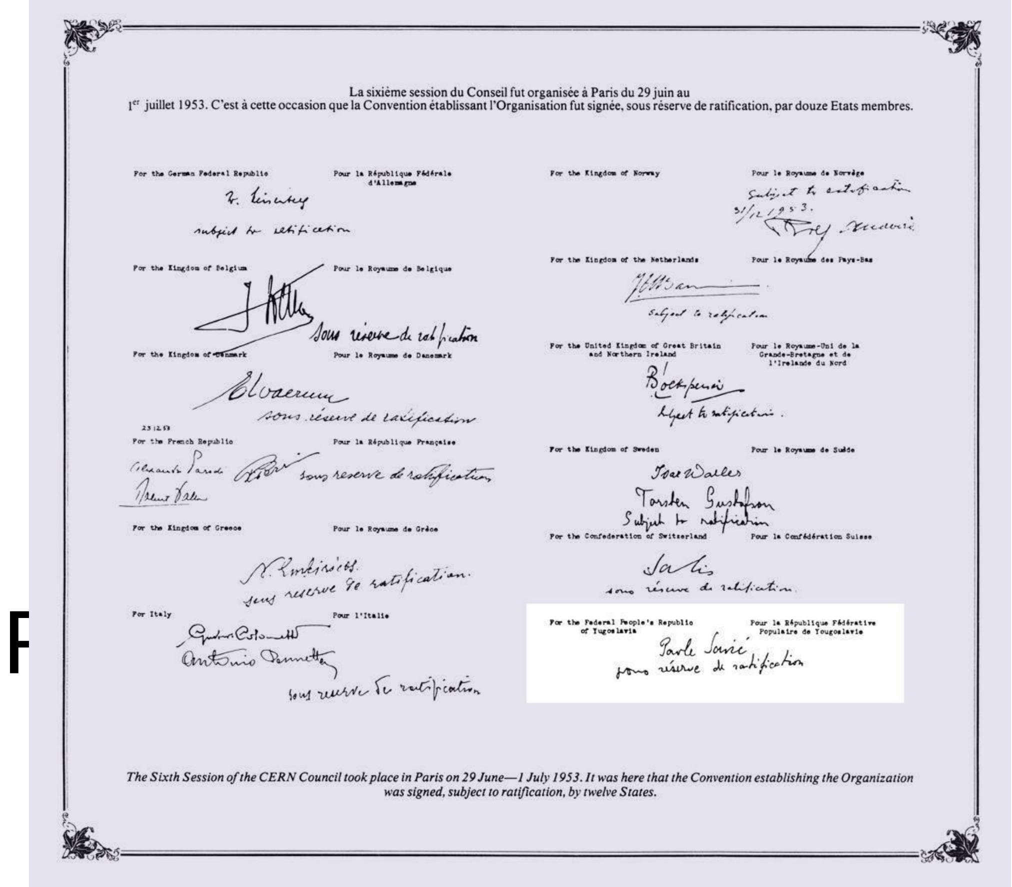
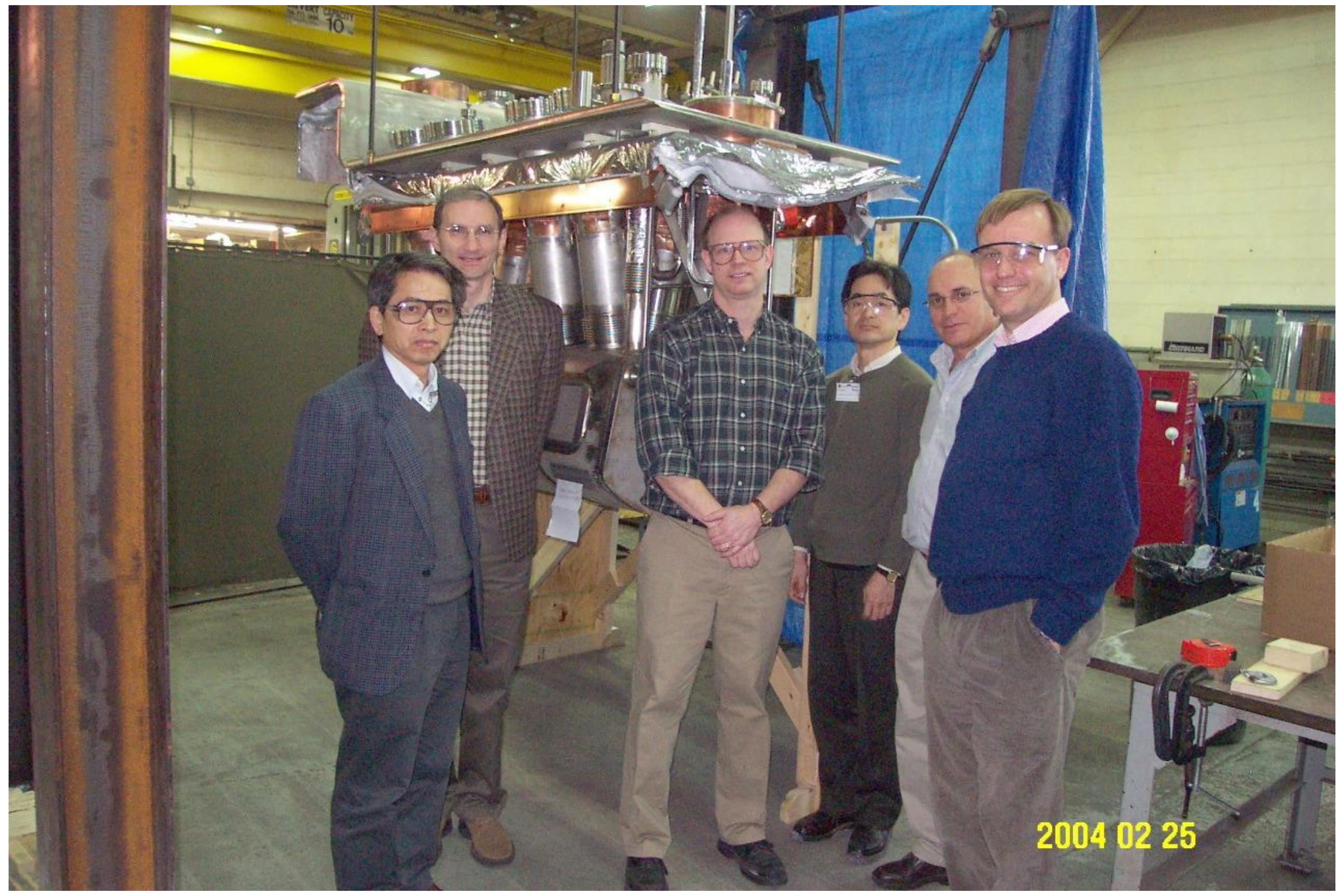
RECFA visit, Belgrade, 29.11.2024

Vinca’s History in CERN

- Founded in 1948 by Prof. Pavle Savic, one of twelve **CERN** founding fathers (1953)
- Many exemplary Vinca’s contributions to CERN
- Throughout decades Vinca physicists and engineers made contributions to CER and accelerators
    - Outstanding example is **Dr. Ranko Ostojic** (Vinca, then CERN) – one of the **fathers** of the **LHC** accelerator



Akira Yamamoto (KEK), **Ranko Ostojic** (CERN), Ed Bonnema (Meyer Tool), Norihito Ohuchi (KEK), Joseph Rasson (LBNL), and Jim Strait (Fermilab)



- LHC experiments
    - CMS (this presentation)
    - ATLAS (2008-2013): TL I. Bozovic, CERN-DELPHI-THESES-209 1999 - CERN-THESIS-2016-430
- Growth and development of Vinca HEP and CMS was stifled for a while.
- Due to support of our FA (NITRA), Vinca HEP not only survived, but is livelier and stronger than ever in the last 20 years as I will try to convince you in this presentation.

History - Vinca in CMS since 2001

- VINCA group is in CMS since 2001, originally participating in ECAL Project
- FA signed 2 MoU’s with Ministry of Republic of Serbia for CMS 2001 “Construction”, 2007 “Maintenance and Operations”
- **Since 2022** there are 2 Serbian groups in CMS, with researchers in **two institutions,** committed to sign **two PhaseII MoUs.**
  - **VINCA Institute of Nuclear Sciences, (VINS)** -> **Phase II** Upgrade Level-1 Trigger
  - Faculty of Physics, University of Belgrade (FP) -> Phase II Upgrade ECAL Barrel
- Two groups have de-facto developed **different** research interests and goals over a course of last 5 years.
- In this presentation will cover activities of Vinca Group

Vinca Institute of Nuclear Science (VINS) Full Membership Group in CMS

Personnel - 6 physicists, 2 engineers, 2 MS candidates

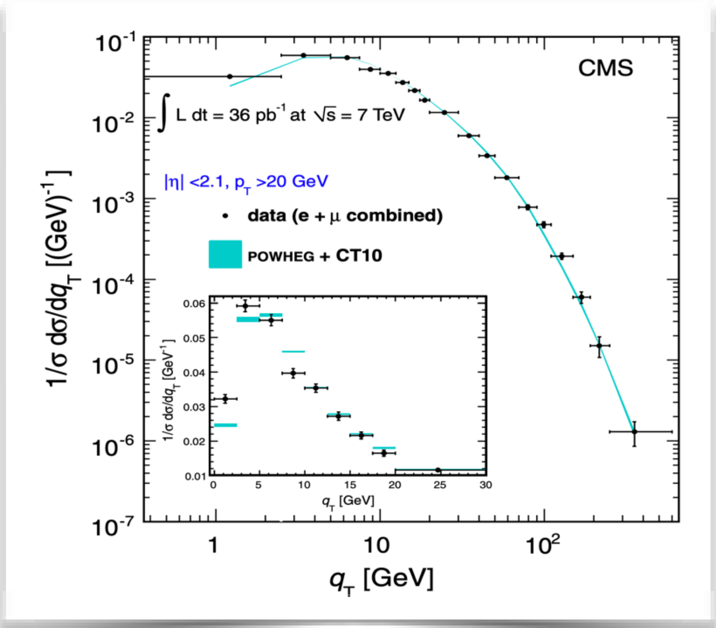
- VINS researchers in CMS consist of 6 physicists, 3 electrical engineer.
  - Luka Terzic, MS candidate, Belgrade University
  - Aleksandar Petos, MS candidate, Belgrade University
  - Ana Jelisijevic. MS EE, Belgrade University external
  - Dragan Pleskonjic, Magister of Computer Science, Zagreb University
  - Laslo Nadderd, PhD physics, Belgrade University.
  - Milos Djordjevic, PhD physics, Belgrade University
  - Milan Stojanovic, PhD physics, Belgrade University
  - Damir Devetak , PhD physics, Belgrade University
  - Jovan Milosevic, PhD physics, Heidelberg University - Deputy TL
  - Vladimir Rekovic, PhD physics, University of New Mexico - Team Leader

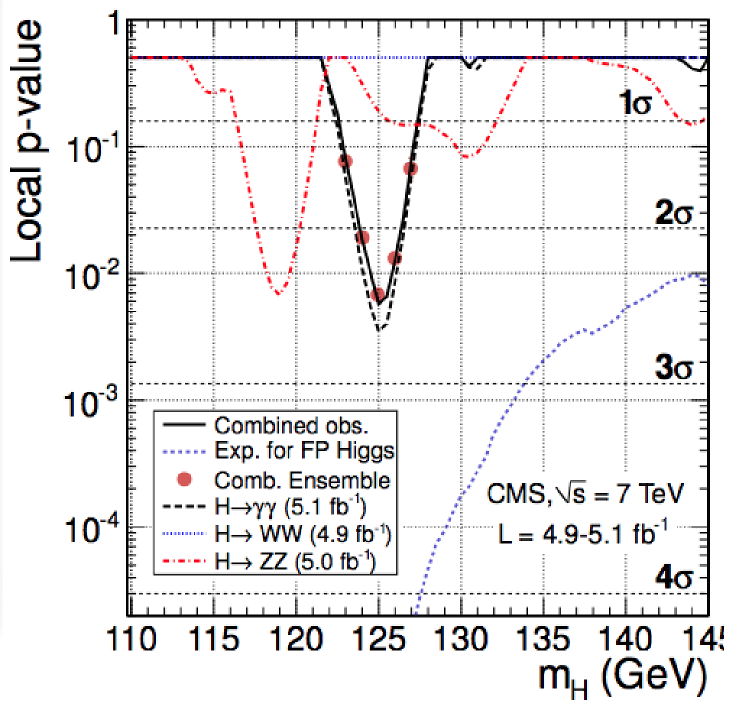
- Expertise in HEP Physics with longstanding experience in International collaborations at CERN, JINR, China, Fermilab
  Most of **physicists active members of CMS over 10-15 years** .

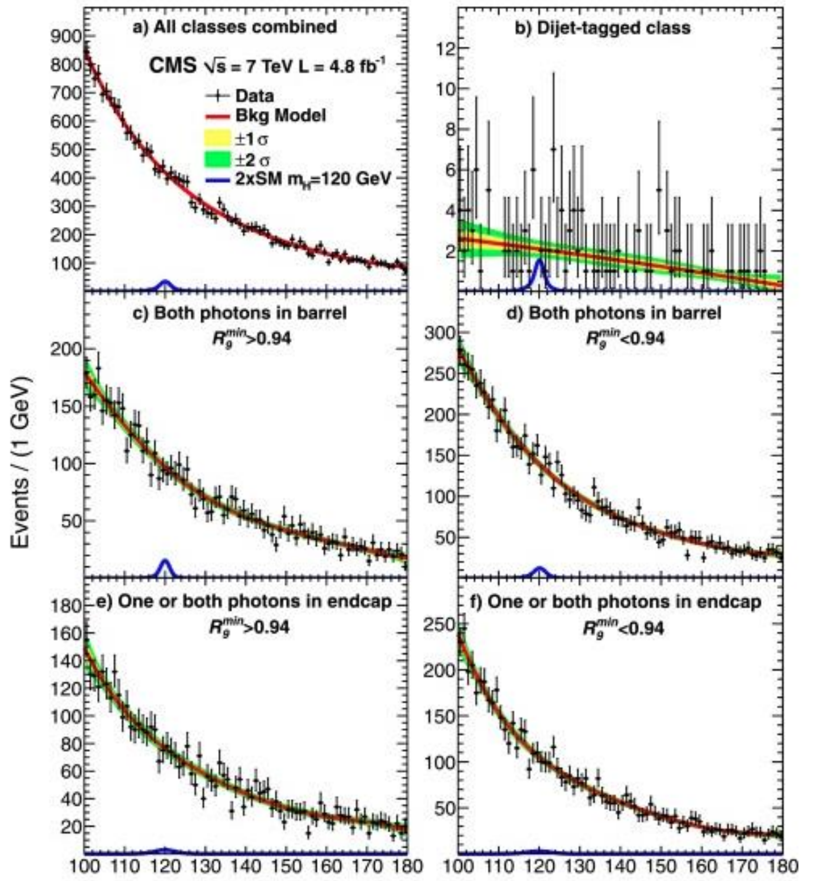
- Working connections with the School of Electrical Engineering University of Belgrade, working on Phase-II Upgrade.

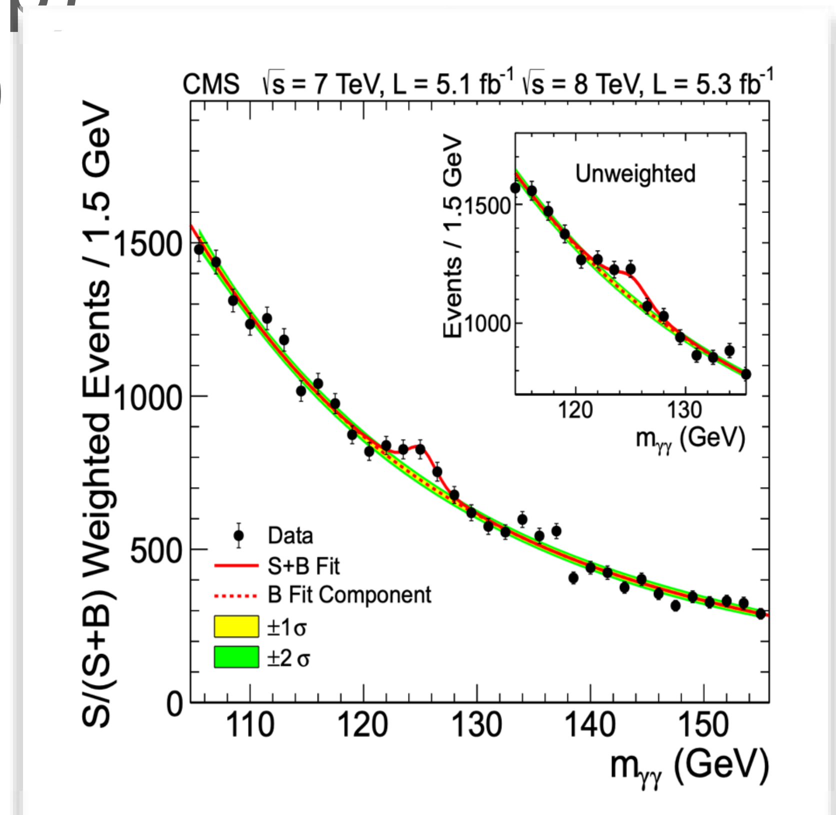
Selected publications in pp collisions (Higgs discovery, EWK, B-Phys , Particle Flow, Trigger)

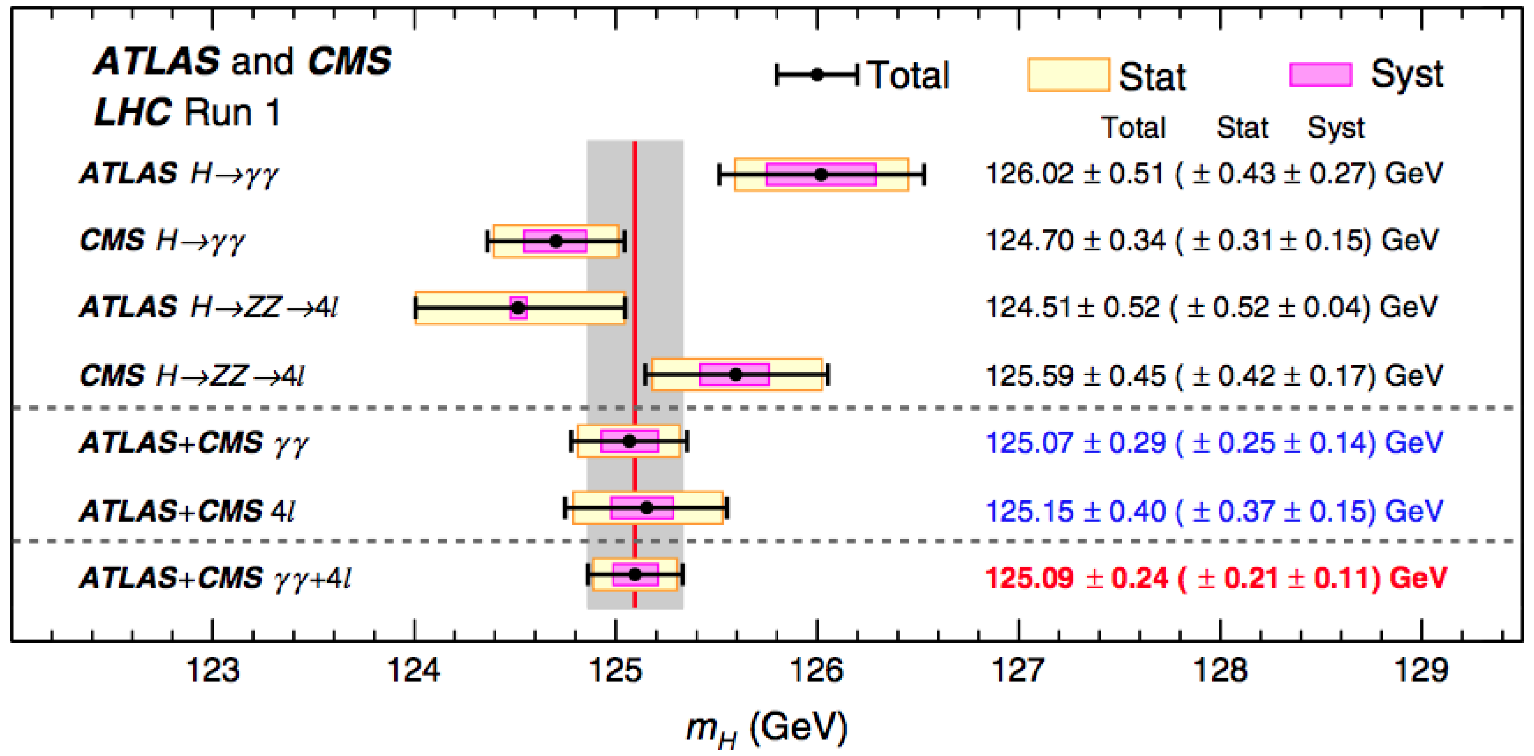
- Phys. Rev. D 85 (2012) 032002 (Diff Zee cross section)
- JHEP 09 (2012) 111 (Fermiophobic Higgs)
- Phys. Lett. B (2012) 710:3 (Search for Higg γγ 7 TeV)
- Phys. Lett. B 726 (2013) 587 (Higgs to Zgamma@7 TeV)
- Phys. Lett. B (2012) 716:30 (Observation of a new boson)
- Eur. Phys. J. C 74(2014) 3076 (Observation of Higgs γγ & prop)
- Phys. Rev. Lett. 114, (2015) 191803 (Combined Meas. Higgs)
- JHEP 08 (2018) 066 (tt + Higgs in the multilepton state)
- Phys. Rev. Lett. 120, 231801 (2018) (tt+Higgs combined)
- JHEP 06 (2018) 102 (BSM single t + Higgs FCNC@13 TeV)
- JINST 14 (2019)P07004 (MET performance @ 13 TeV)
- JINST 15 (2020) P09018 (Pileup mitigation @ 13 TeV)
- JINST 12 (2017) P10003 (Particle Flow and GED at CMS)

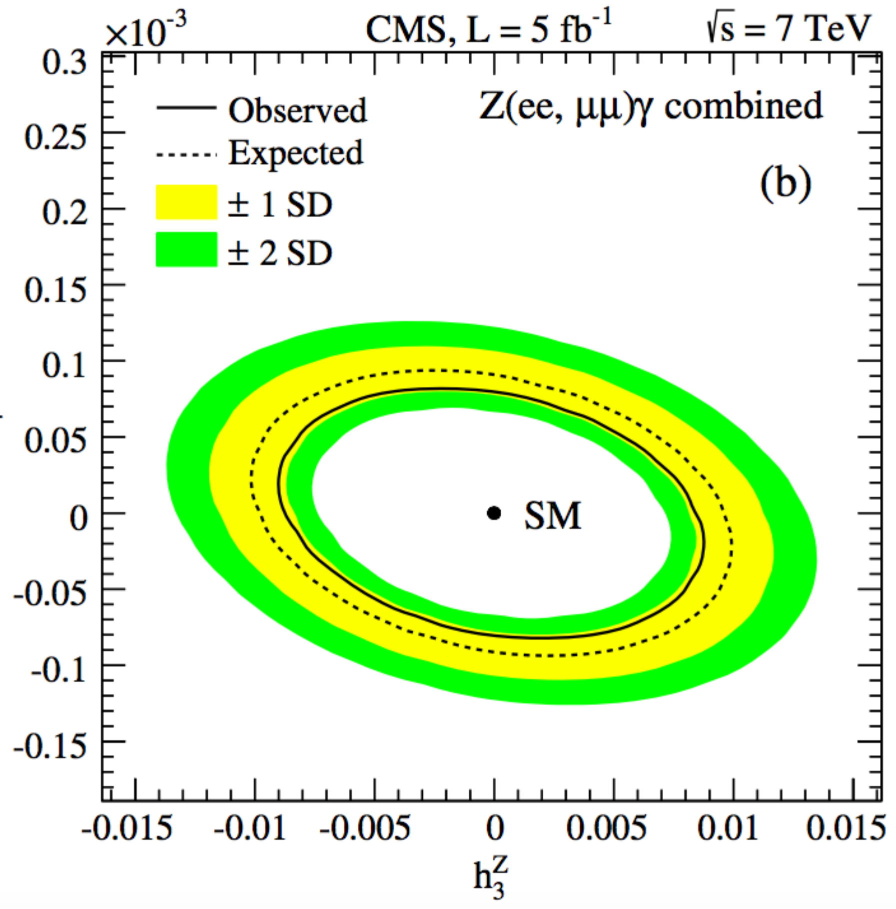


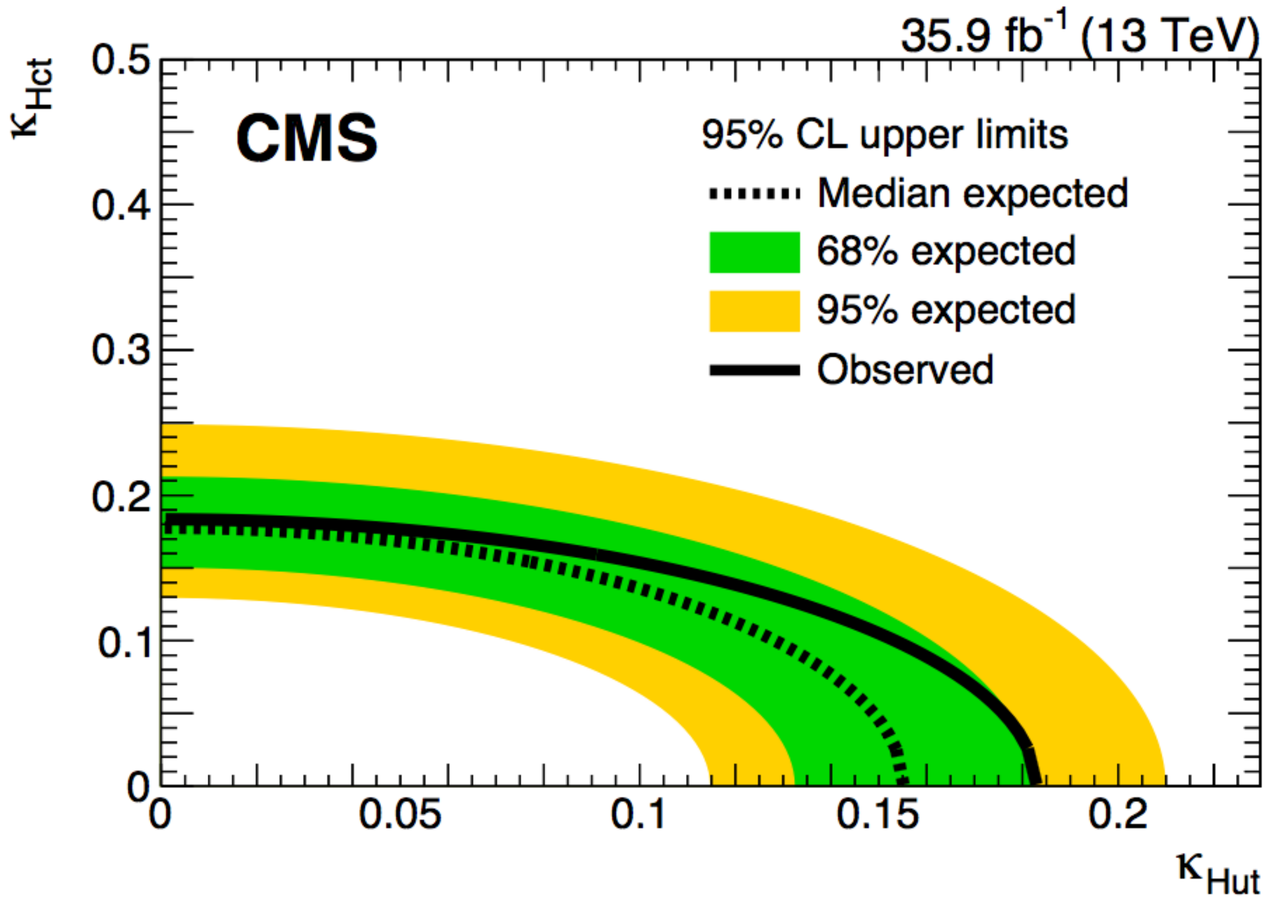


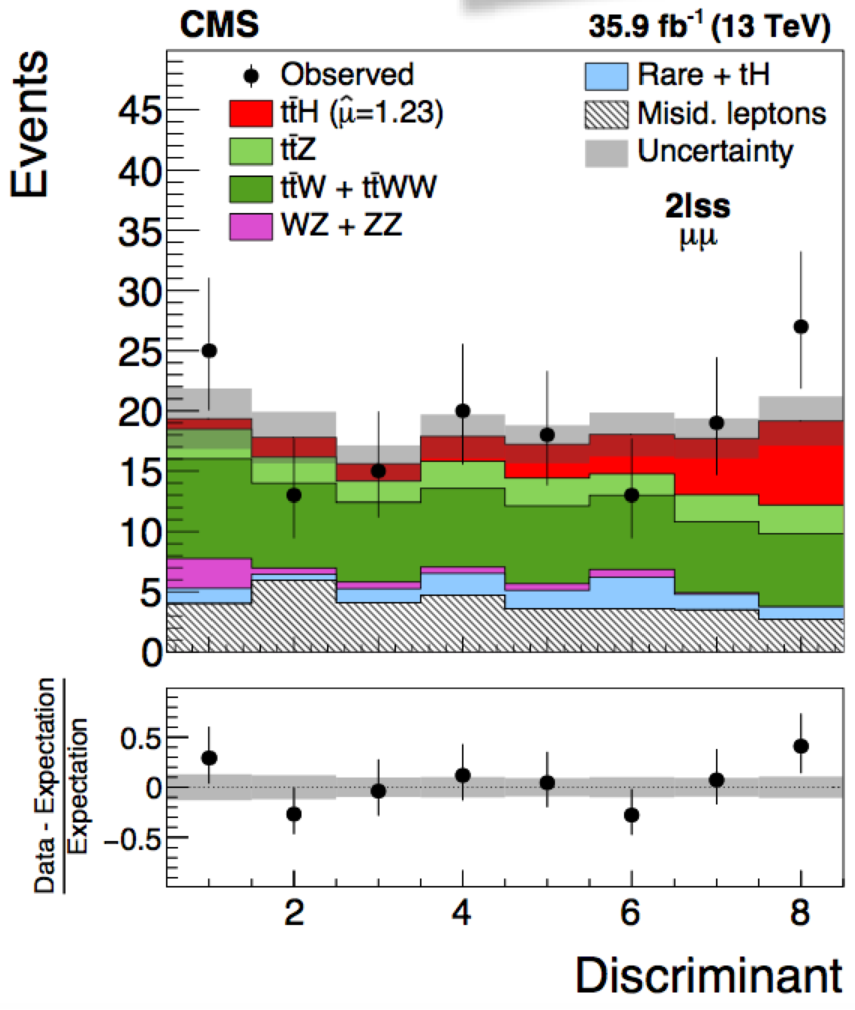


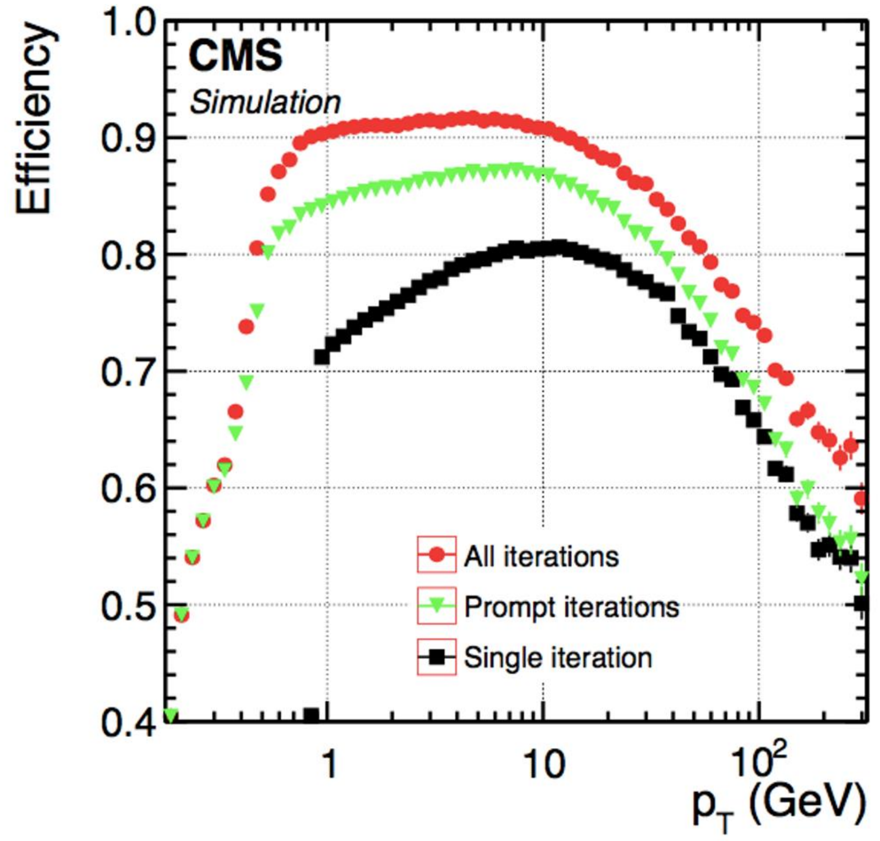


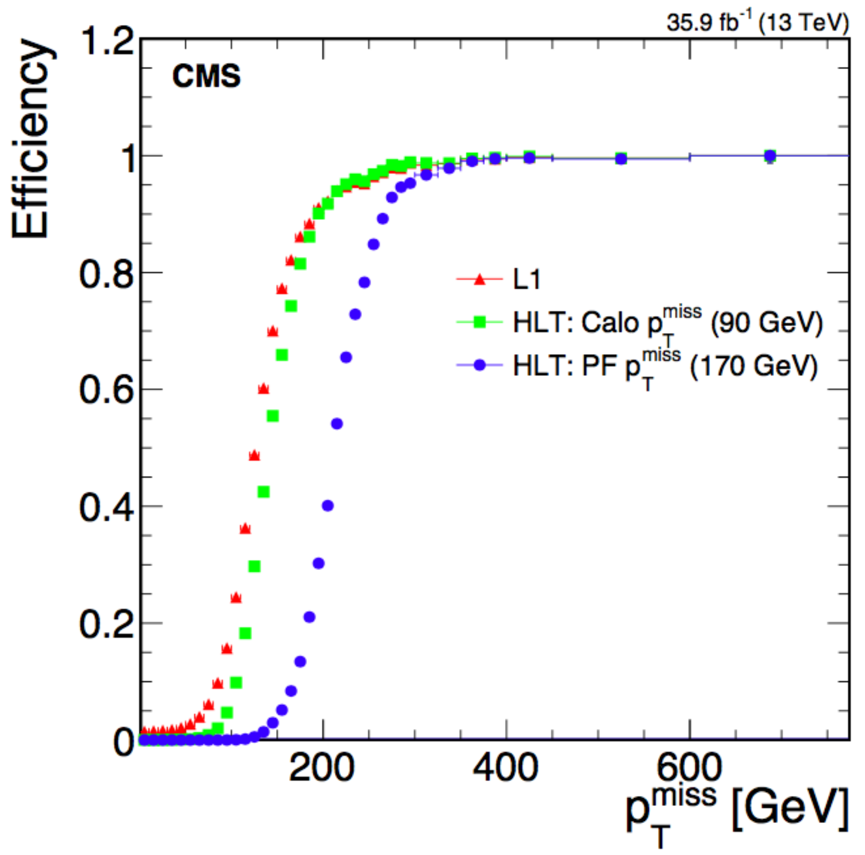






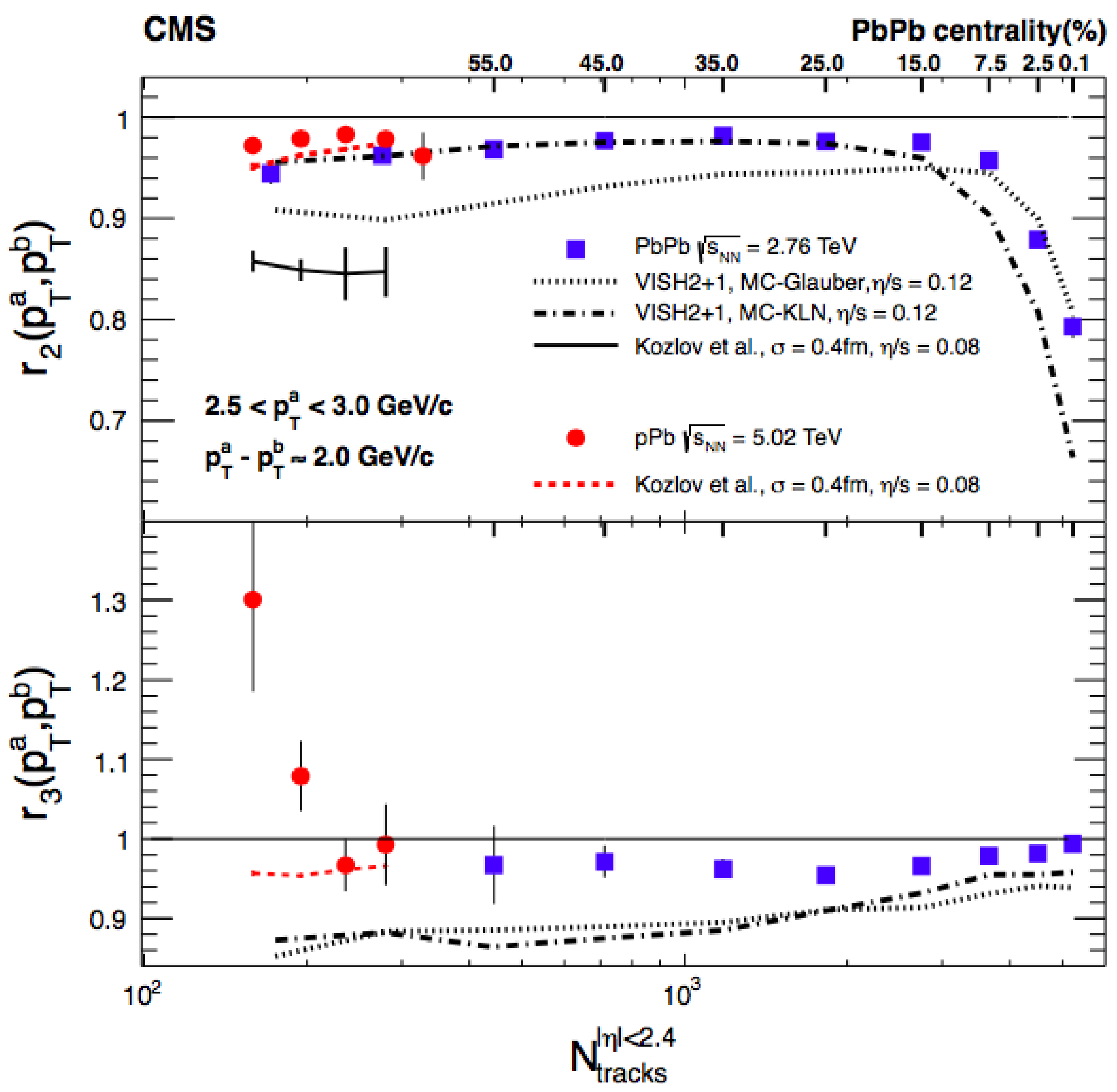




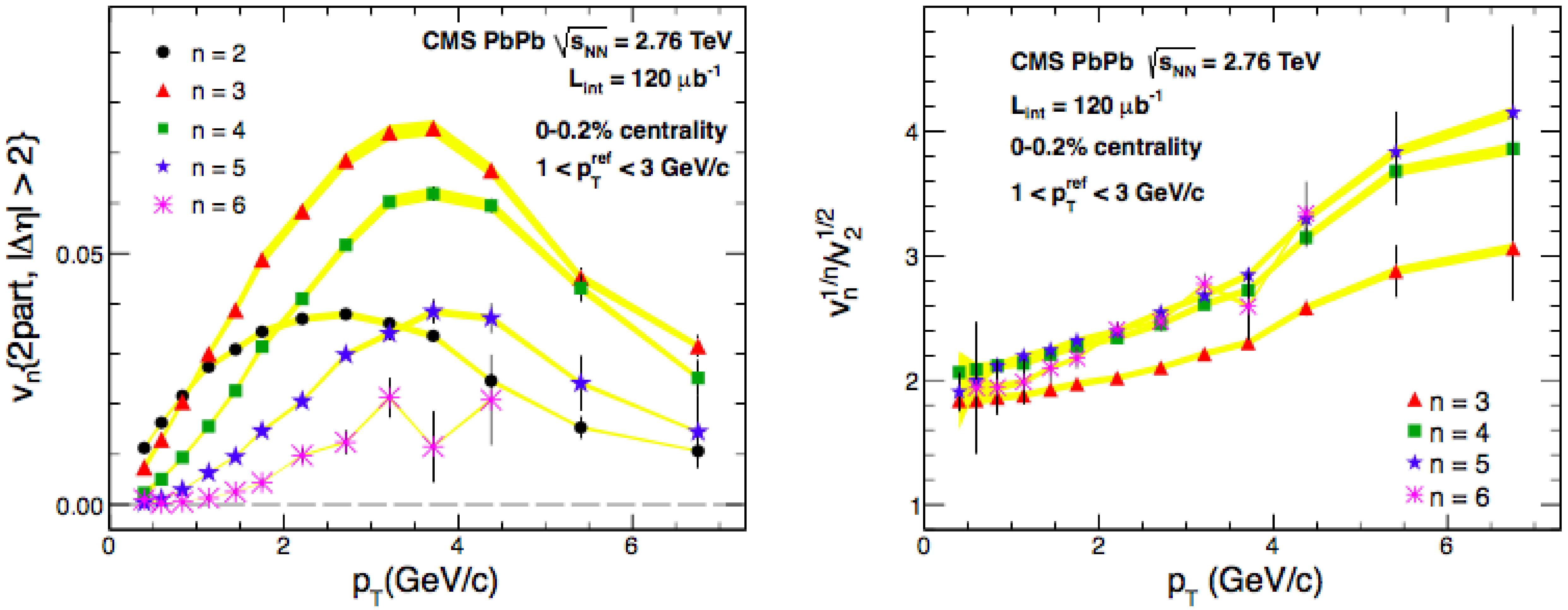


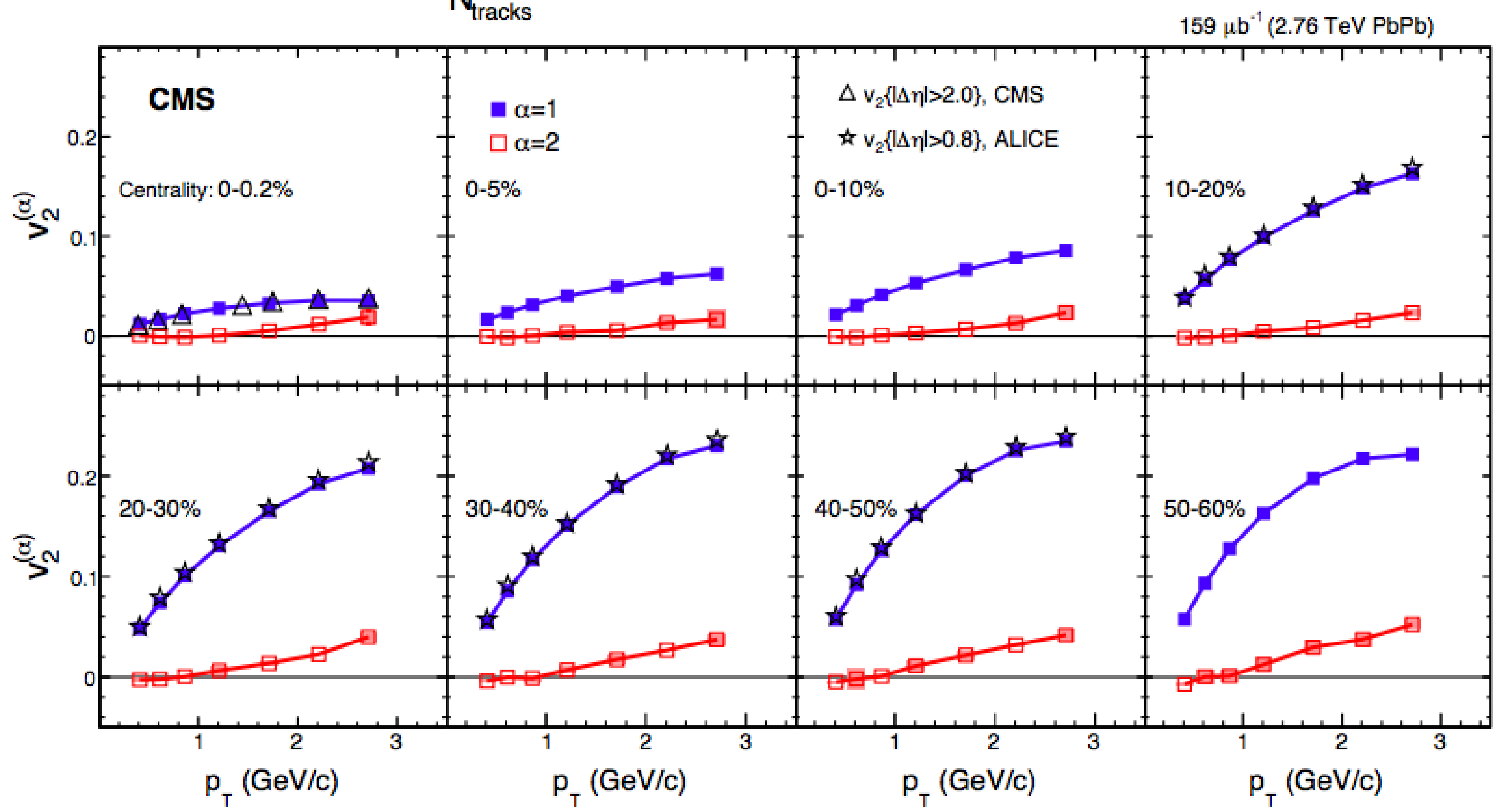
Vinca in CMS Heavy Ion

Factorization Breaking
Phys.Rev.**C**92(2015)034911

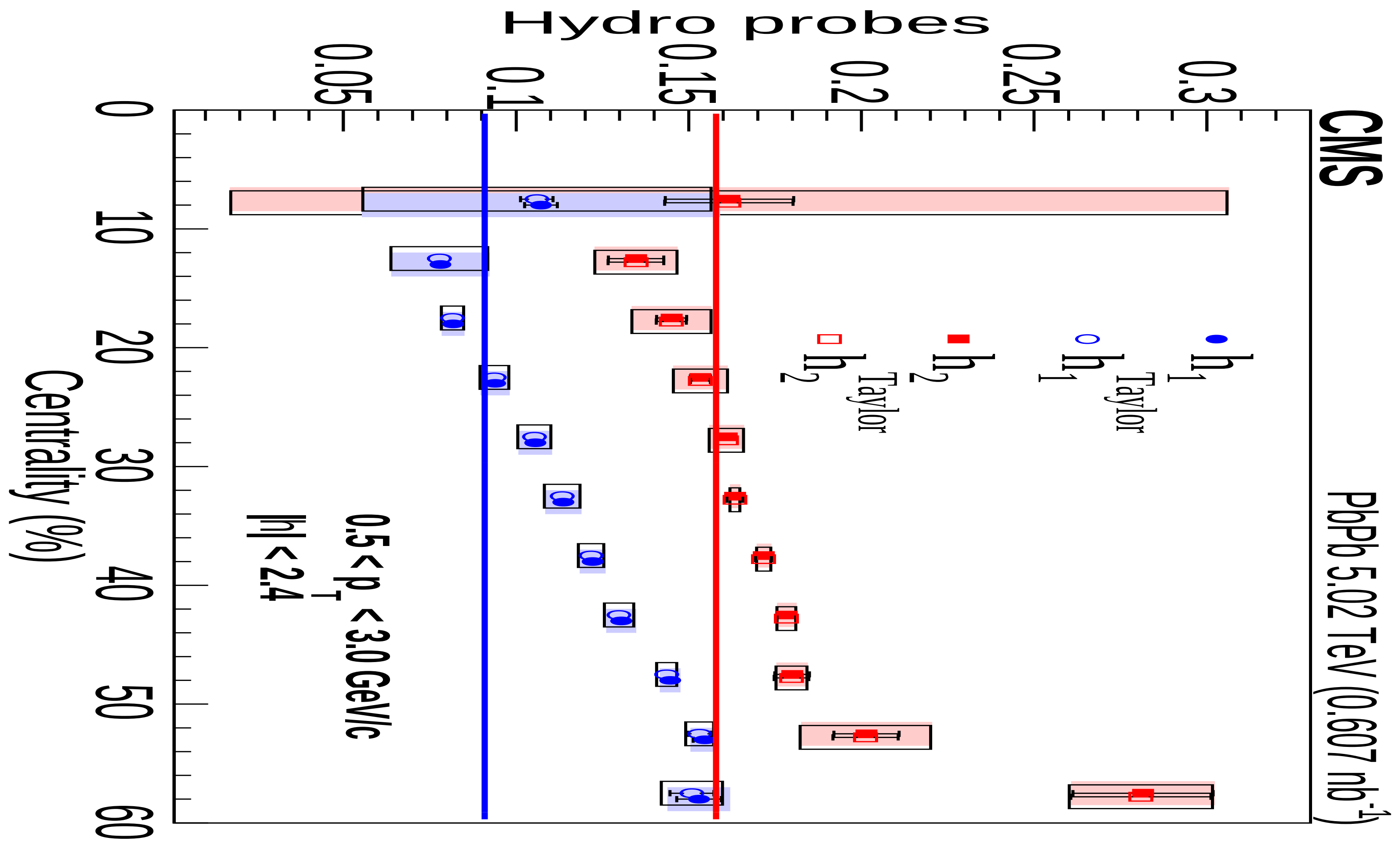


Flow in ultra central collisions
JHEP 02 (2014) 088





Principal component analysis
Phys. Rev. **C** 96 (2017) 064902



Higher order moments in v_2
JHEP 02 (2024) 106

VINS at CMS Positions of Responsibilities

- Aprovals/Preaprovals of Analysis - 10
  - EWK-10-010, HIG-12-002, HIG-13-001
  - HIN-12-011, HIN-14-012, HIN-15-010, HIN-18-001, HIN-21-003, HIN-21-010
  - PRF-14-001
- Contact persons or Pdf authors of Analysis- 10
  - HIG-12-002, HIG-12-009, HIG-12-013
  - HIN-12-001, HIN-14-012, HIN-15-010, HIN-18-001, HIN-21-003, HIN-21-010
  - Phase II Upgrade Level-1 Trigger TDR CERN-LHCC-2020-004
- Over 70 international conferences (over 30 major)
- Experimental Physics responsibilities (EPR) fulfilled
  - Level-1 Trigger, HLT, Statistics Committee, Conference Committee

- L2/L3 coordination - 7
  - L2 @ TSG - Trigger Performance Group
  - L2 @ TSG - Steam Group
  - L2 @ Level-1 Trigger - Offline Software Group
  - L3 @ TSG - Offline Trigger Performance Group
  - L3 @ TSG - JetMET Trigger
  - L3 @ Level-1 Trigger - Phase2 Upgrade Menu Group
  - L3 @ HF/Spectra PING in HIN PAG
- Analyis Review Committee (ARC) members - 17
  - B2G-17-003, B2G-16-018, EXO-16-038, EXO-16-052, FTR-18-007, HIG-24-013
    HIN-14-008, HIN-15-014, HIN-17-009, HIN-18-004, HIN-18-010, HIN-18-008, HIN-19-004, HIN-23-007
    HIN-19-007, HIN-20-001, HIN-21-003, HIN-21-013
    HIN-21-014, HIN-24-018
- ARC chair – 8
  - HIN-15-009, HIN-16-007, HIN-16-010, HIN-16-019, HIN-18-015, HIN-19-002, HIN-20-003, HIN-24-001

VINS – Awards and Achievements

The Compact Muon Solenoid Collaboration
confers on
Vladimir Rekovic
Vinca Institute of Nuclear Sciences - University of Belgrade
a
CMS 2020 Award
For
his excellent coordination, crucial contributions, and exceptional commitment to the offline software of the Level-1 Trigger Project

The Collaboration Board Chairperson
(Harrison B. Prosper)

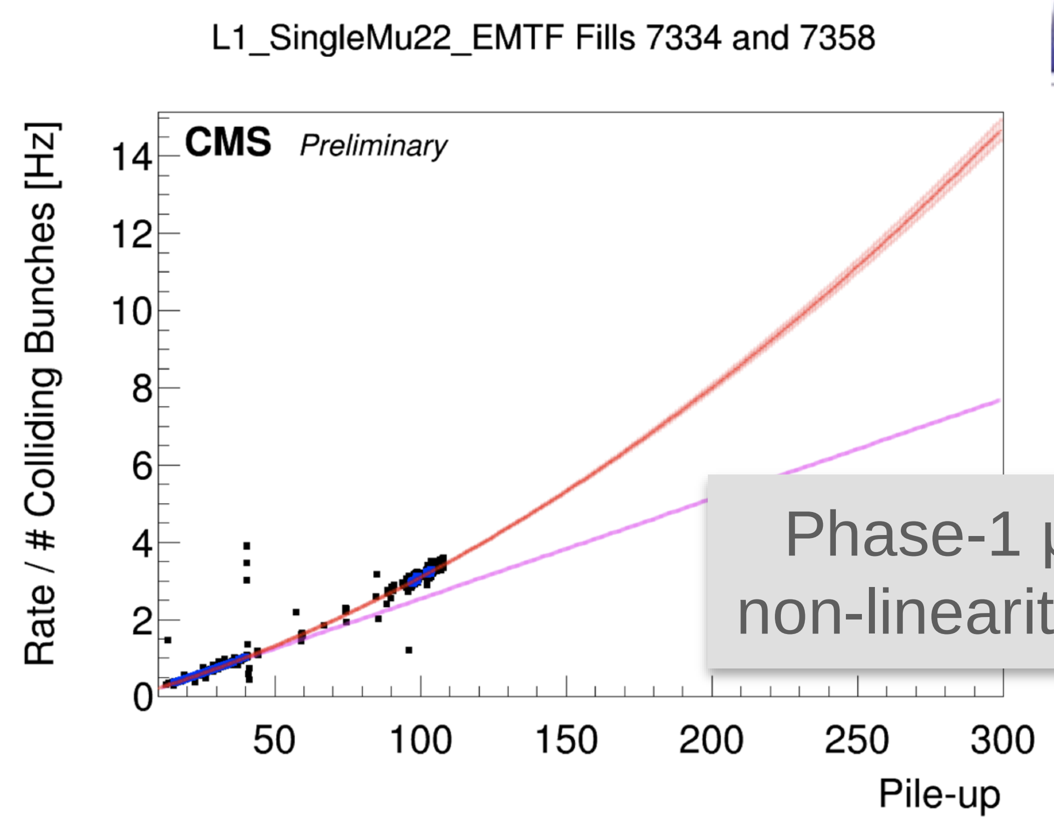
The Experiment Spokesperson
(Luca Malgeri)

February 1st, 2021

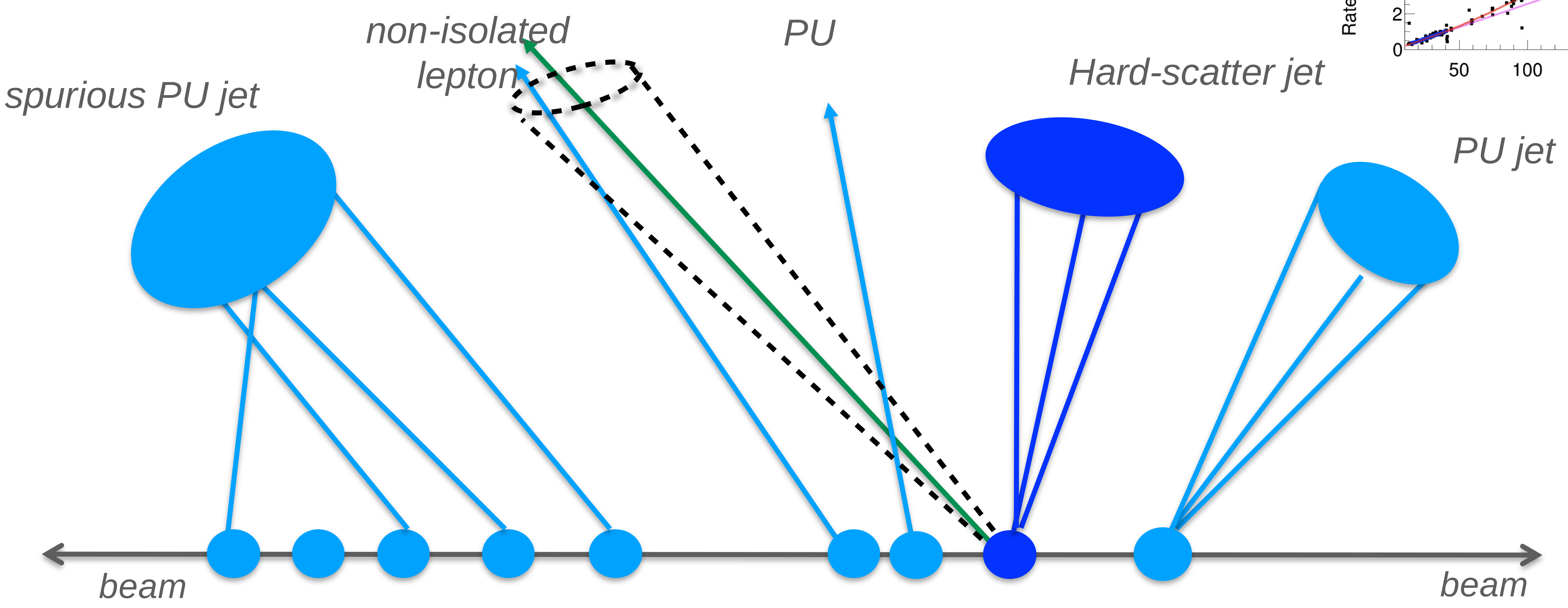
- V.R. – CMS Award 2020
- Jovan Milosevic 2024 – Outstanding Researcher of Republic of Serbia (top 10%)
- V.R. – successful proposal and design of Serbian Tier-1 WLCG center
  - designated Scientific Director

HI-LHC Main challenge - effects of PU

- **Pile up (PU) – many inelastic proton-proton collisions in (small) interaction region of crossing beams**



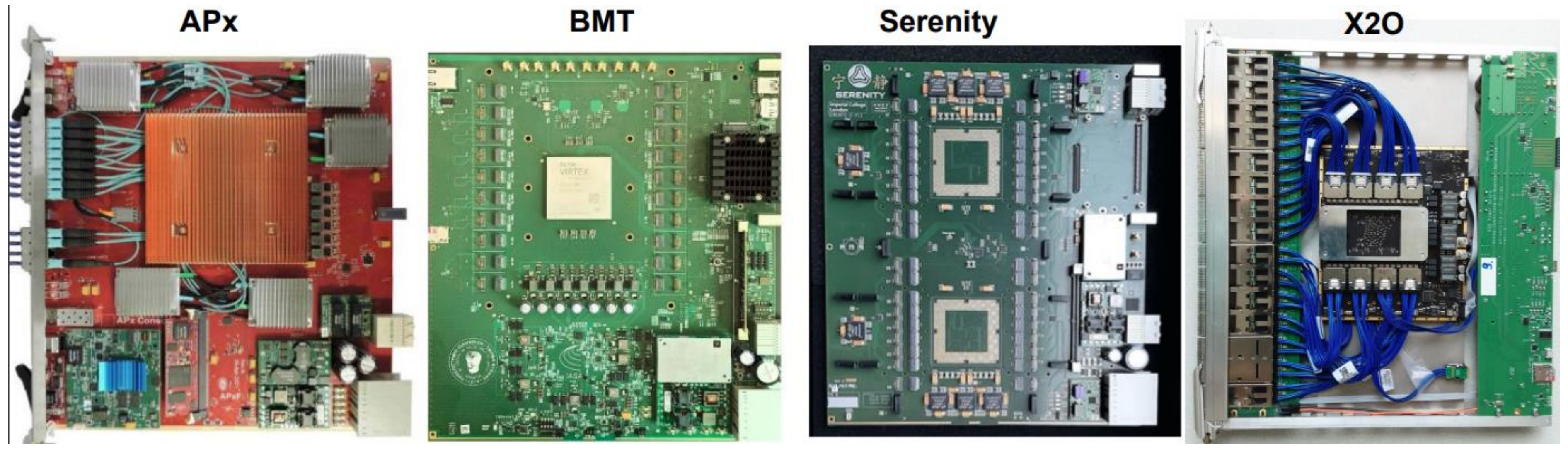
Phase-1 μ trigger non-linearity with PU



- **Approach to solving problem: Use of tracking to identify a primary vertex and associate reconstructed objects.**
- **Objective**: exclude from relevant quantities charged particles not associated with hard interaction.
  —> build time-of-flight detector to assign time tag to particle signatures
  —> use tracking in the trigger and higher detector granularity

VINS in CMS Phase-II L1T Upgrade

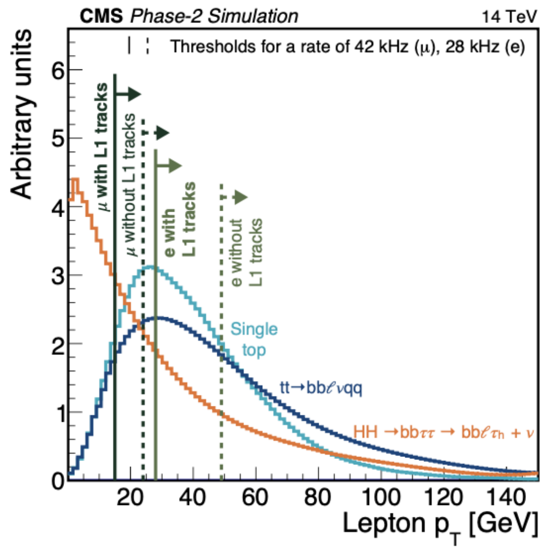
- **Exploit high detector granularity and modern powerful FPGAs, effectively moving the HLT into Level-1 .**

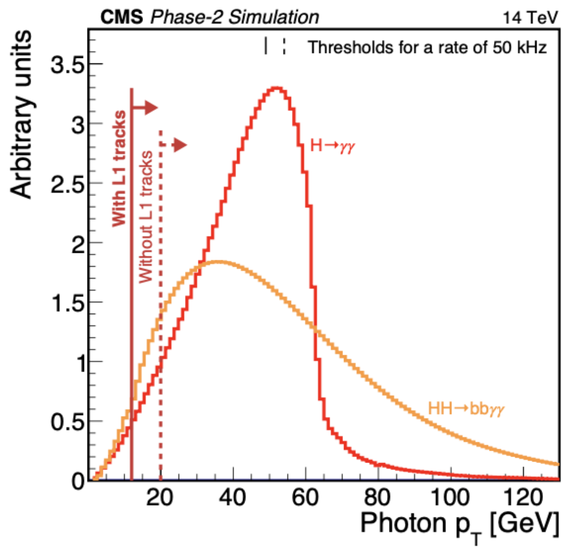


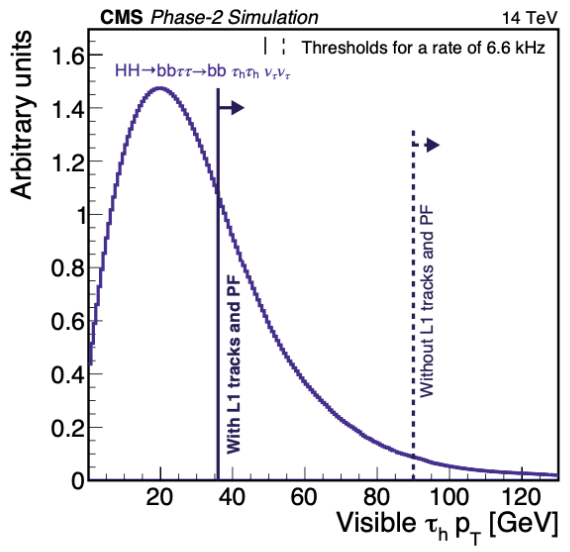
- **Retained object thresholds of Run1/2, made possible with use of Level-1 Tracker tracks in GMT, GCT, GTT, Correlator**

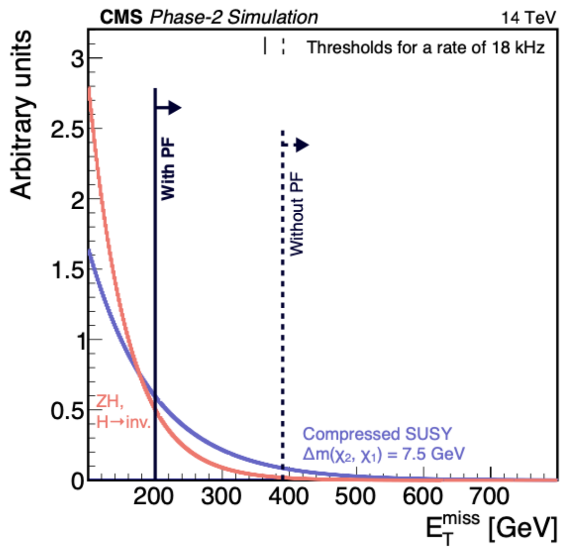
L1 Trigger seeds	Offline Threshold(s) at 90% or 95% (50%) [GeV]	Rate $\langle PU \rangle = 200$ [kHz]	Additional Requirement(s) [cm, GeV]	Objects plateau efficiency [%]
Single/Double/Triple Lepton (electron, muon) seeds				
Single TkMuon	22	12	$\|\eta\| < 2.4$	95
Double TkMuon	15,7	1	$\|\eta\| < 2.4$, $\Delta z < 1$	95
Triple TkMuon	5,3,3	16	$\|\eta\| < 2.4$, $\Delta z < 1$	95
Single TkElectron	36	24	$\|\eta\| < 2.4$	93
Single TkIsoElectron	28	28	$\|\eta\| < 2.4$	93
TkIsoElectron-StaEG	22, 12	36	$\|\eta\| < 2.4$	93, 99
Double TkElectron	25, 12	4	$\|\eta\| < 2.4$	93
Single StaEG	51	25	$\|\eta\| < 2.4$	99
Double StaEG	37,24	5	$\|\eta\| < 2.4$	99
Photon seeds				
Single TkIsoPhoton	36	43	$\|\eta\| < 2.4$	97
Double TkIsoPhoton	22, 12	50	$\|\eta\| < 2.4$	97
Taus seeds				
Single CaloTau	150(119)	21	$\|\eta\| < 2.1$	99
Double CaloTau	90,90(69,69)	25	$\|\eta\| < 2.1$, $\Delta R > 0.5$	99
Double PuppiTau	52,52(36,36)	7	$\|\eta\| < 2.1$, $\Delta R > 0.5$	90
Hadronic seeds (jets,H_T)				
Single PuppiJet	180	70	$\|\eta\| < 2.4$	100
Double PuppiJet	112,112	71	$\|\eta\| < 2.4$, $\Delta\eta < 1.6$	100
PuppiH_T	450(377)	11	jets: $\|\eta\| < 2.4$, $p_T > 30$	100
QuadPuppiJets-PuppiH_T	70,55,40,40,400(328)	9	jets: $\|\eta\| < 2.4$, $p_T > 30$	100,100
E_T^{miss} seeds				
PuppiE_T^{miss}	200(128)	18		100
Cross Lepton seeds				
TkMuon-TkIsoElectron	7,20	1	$\|\eta\| < 2.4$, $\Delta z < 1$	95, 93
TkMuon-TkElectron	7,23	3	$\|\eta\| < 2.4$, $\Delta z < 1$	95, 93
TkElectron-TkMuon	10,20	1	$\|\eta\| < 2.4$, $\Delta z < 1$	93, 95
TkMuon-DoubleTkElectron	6,17,17	0.1	$\|\eta\| < 2.4$, $\Delta z < 1$	95, 93
DoubleTkMuon-TkElectron	5,5,9	4	$\|\eta\| < 2.4$, $\Delta z < 1$	95, 93
PuppiTau-TkMuon	36(27),18	2	$\|\eta\| < 2.1$, $\Delta z < 1$	90, 95
TkIsoElectron-PuppiTau	22,39(29)	13	$\|\eta\| < 2.1$, $\Delta z < 1$ $\Delta R > 0.3$	93, 90

L1 Trigger seeds	Offline Threshold(s) at 90% or 95% (50%) [GeV]	Rate $\langle PU \rangle = 200$ [kHz]	Additional Requirement(s) [cm, GeV]	Objects plateau efficiency [%]
Cross Hadronic-Lepton seeds				
TkMuon-PuppiH_T	6,320(250)	4	$\|\eta\| < 2.4$, $\Delta z < 1$	95,100
TkMuon-DoublePuppiJet	12,40,40	10	$\|\eta\| < 2.4$, $\Delta R_{j\mu} < 0.4$, $\Delta\eta_{jj} < 1.6$, $\Delta z < 1$	95,100
TkMuon-PuppiJet-PuppiE_T^{miss}	3,100,120(55)	14	$\|\eta\| < 1.5$, $\|\eta\| < 2.4$, $\Delta z < 1$	95,100, 100
DoubleTkMuon-PuppiJet-PuppiE_T^{miss}	3,3,60,130(64)	4	$\|\eta\| < 2.4$, $\Delta z < 1$	95,100, 100
DoubleTkMuon-PuppiH_T	3,3,300(231)	2	$\|\eta\| < 2.4$, $\Delta z < 1$	95,100
DoubleTkElectron-PuppiH_T	10,10,400(328)	0.9	$\|\eta\| < 2.4$, $\Delta z < 1$	93,100
TkIsoElectron-PuppiH_T	26,190(124)	9	$\|\eta\| < 2.4$, $\Delta z < 1$	93,100
TkElectron-PuppiJet	28,40	34	$\|\eta\| < 2.1$, $\|\eta\| < 2.4$, $\Delta R > 0.3$, $\Delta z < 1$	93,100
PuppiTau-PuppiE_T^{miss}	55(38),190(118)	4	$\|\eta\| < 2.1$	90,100
VBF seeds				
Double PuppiJets	160,35	40	$\|\eta\| < 5$, $m_{jj} > 620$	100
B-physics seeds				
Double TkMuon	2,2	12	$\|\eta\| < 1.5$, $\Delta R < 1.4$, $q1 * q2 < 0$, $\Delta z < 1$	95
Double TkMuon	4,4	21	$\|\eta\| < 2.4$, $\Delta R < 1.2$ $q1 * q2 < 0$, $\Delta z < 1$	95
Double TkMuon	4.5,4	10	$\|\eta\| < 2.0, 7 < m_{\mu\mu} < 18$, $q1 * q2 < 0$, $\Delta z < 1$	95
Triple TkMuon	5,3,2	7	$0 < m_{\mu 5 \mu 3, q1*q2<0} < 9$ $\|\eta\| < 2.4$, $\Delta z < 1$	95
Triple TkMuon	5,3,2.5	6	$5 < m_{\mu 5 \mu 2.5, q1*q2<0} < 17$ $\|\eta\| < 2.4$, $\Delta z < 1$	95
Rate for above Trigger seeds				346
Total Level-1 Menu Rate (+30%)				**450**







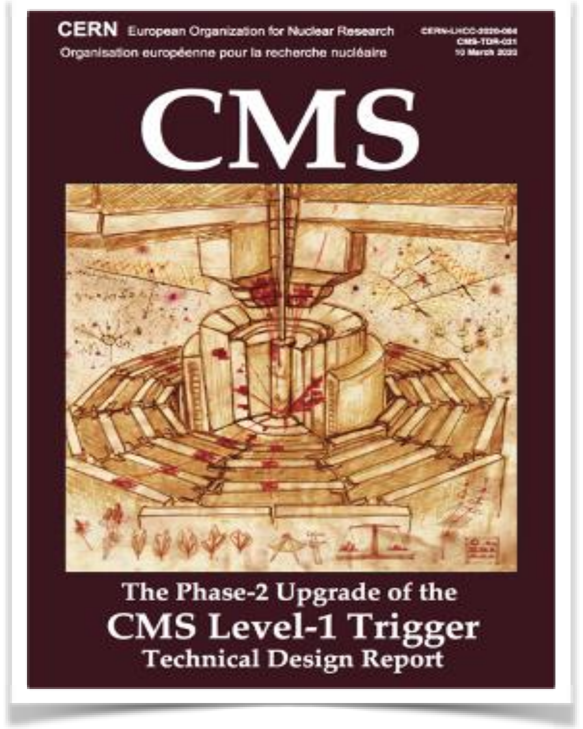


Contribution: Physics Menu

- **Co-Coordination and creation of physics Trigger Menu covering Run 2 physics with over 40 trigger paths**

Target rate Rate below 350 Hz met !

VINS in CMS Phase-II L1T Upgrade



Contribution: Extended Physics Menu

- **Proposed to extend Run-2 Physics trigger menu and explored New Physics reach with**

  - novel trigger strategies

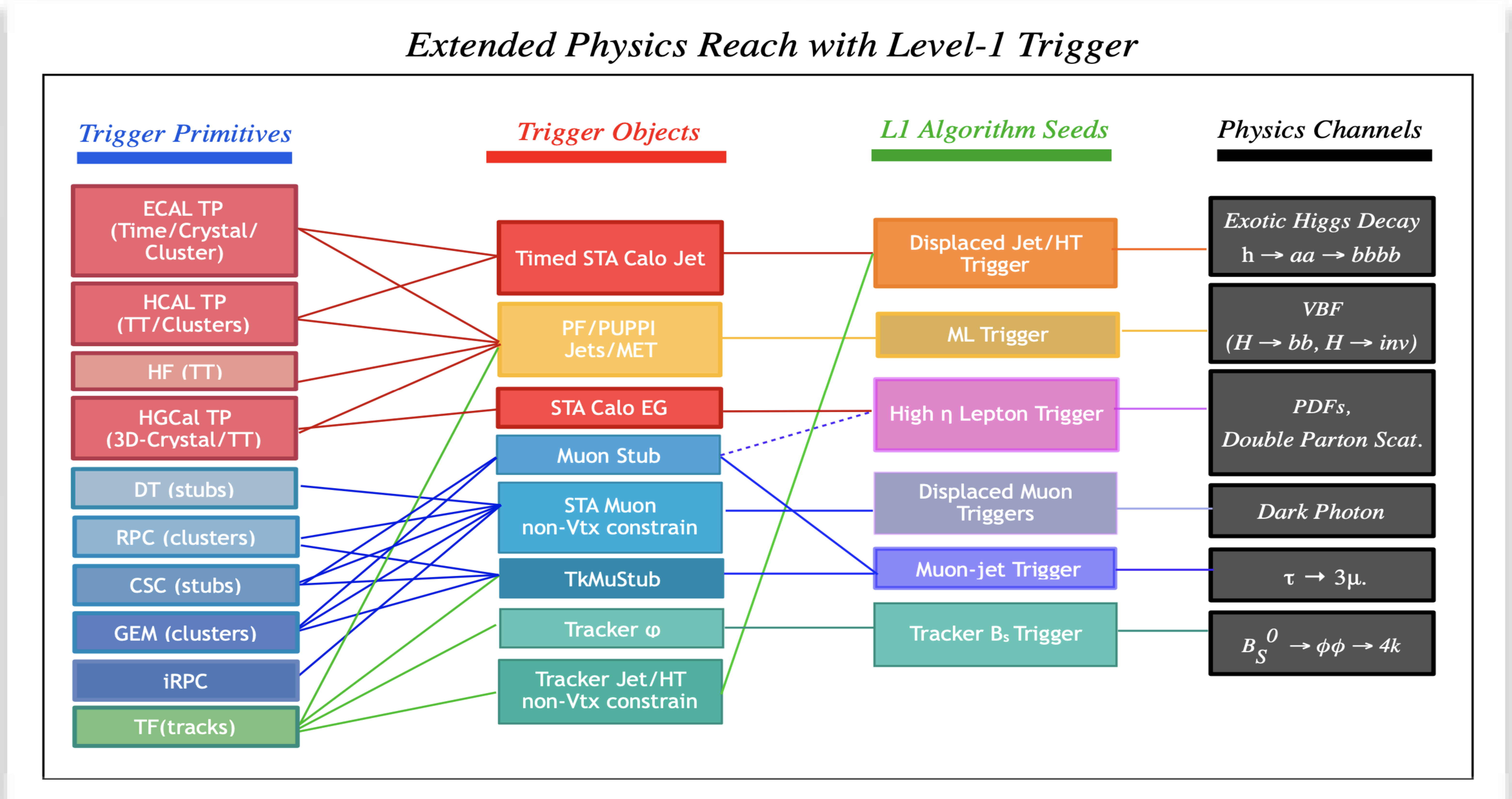
  - never possible before

  - exploiting new features

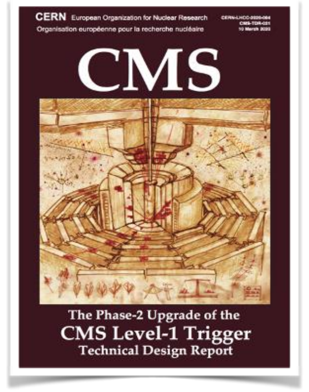
  - significantly enlarging

  physics reach potential

  - Exotic Higgs,
  - Vector Boson Fusion,
  - Double Parton Scattering,
  - Lepton Flavor Violation
  - B-physics



VINS in CMS Phase-II L1T Upgrade

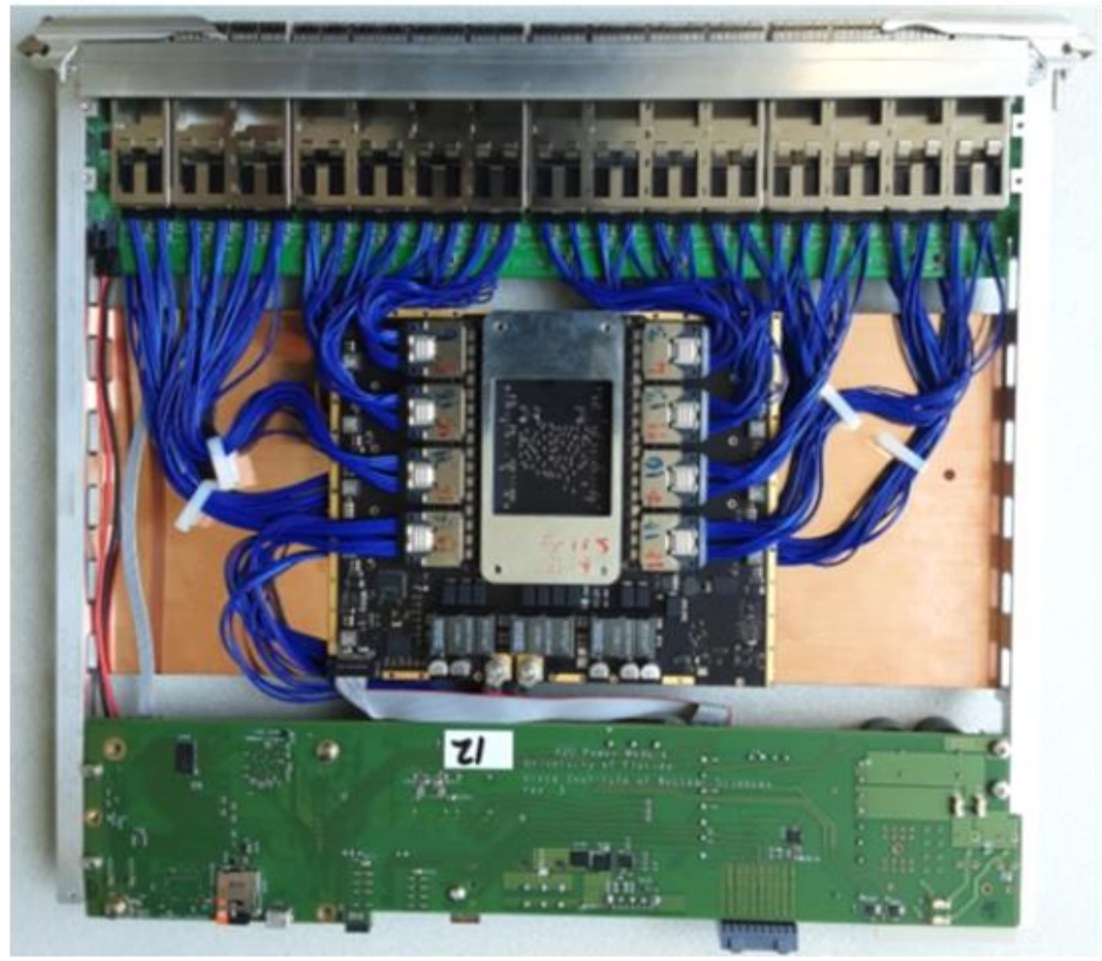


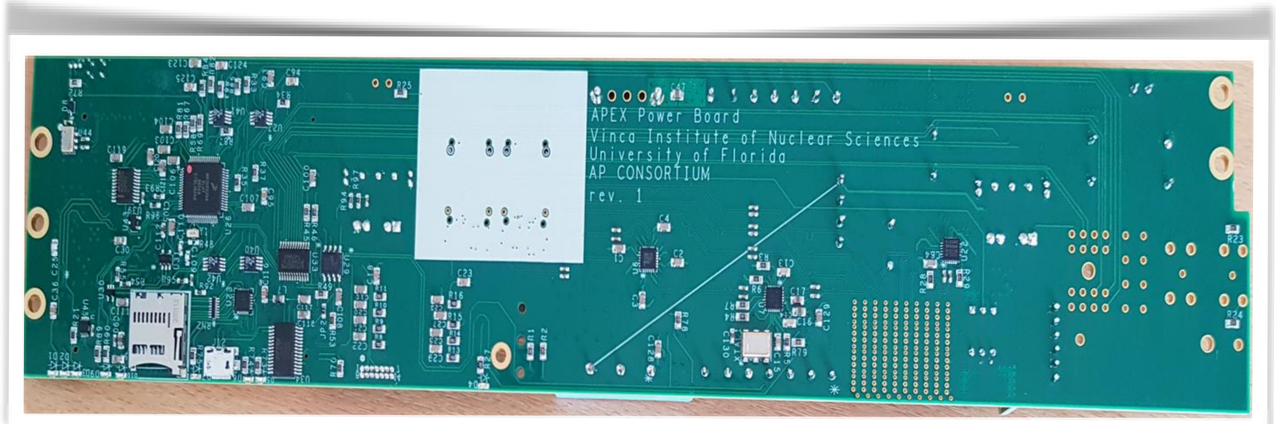
Contribution: Hardware and Object Roconstruction

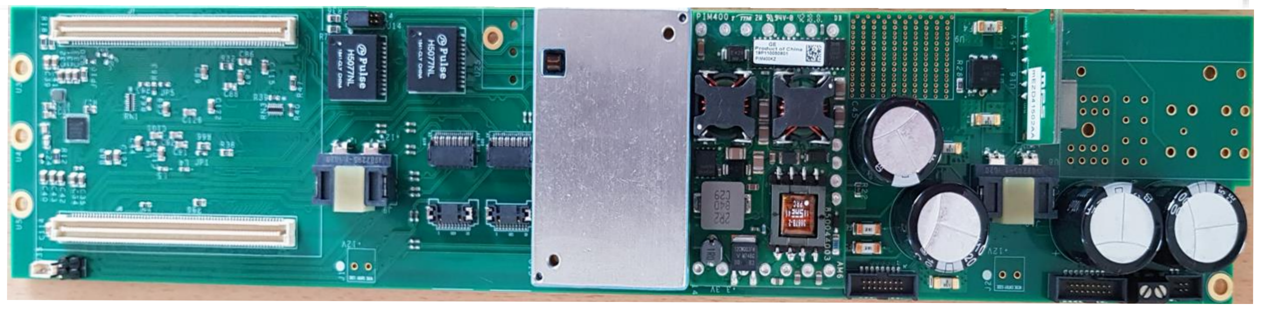
Table 7.2: List of institutions expressing interest in participation in the Phase-2 upgrade of the L1 trigger.

Tag	Institution name
Vienna	Institut fur Hochenergiephysik,Wien, Austria
Beijing	Institute of High Energy Physics, Beijing, China
Cyprus	University of Cyprus, Nicosia, Cyprus
Tallinn	National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
LLR	Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France
NKUA	National and Kapodistrian University of Athens, Athens, Greece
NTUA	National Technical University of Athens, Athens, Greece
Ioannina	University of Ioannina, Ioannina, Greece
SINP	Saha Institute of Nuclear Physics, HBNI, Kolkata, India
TIFR	Tata Institute of Fundamental Research-B, Mumbai, India
Belgrade Vinca	Vinca Institute of Nuclear Sciences
CIEMAT	Centro de Investigaciones Energeticas Medioambientales y Tecnologicas, Madrid, Spain
Oviedo	Universidad de Oviedo, Oviedo, Spain
CERN	CERN, European Organization for Nuclear Research, Geneva, Switzerland
Zurich	Universität Zürich, Zurich, Switzerland
Bristol	University of Bristol, Bristol, United Kingdom
RAL	Rutherford Appleton Laboratory, Didcot, United Kingdom
Imperial	College Imperial College, London, United Kingdom
FNAL	Fermi National Accelerator Laboratory, Batavia, USA
Colorado	University of Colorado at Boulder, Boulder, USA
MIT	Massachusetts Institute of Technology, Cambridge, USA
UIC	University of Illinois at Chicago, Chicago, USA
Davis	University of California, Davis, Davis, USA
Florida	University of Florida, Gainesville, USA
Rice	Rice University, Houston, USA
UCLA	University of California, Los Angeles, USA
UCSD	University of California, San Diego, USA
Wisconsin	University of Wisconsin - Madison, Madison, USA
Princeton	Princeton University, Princeton, USA

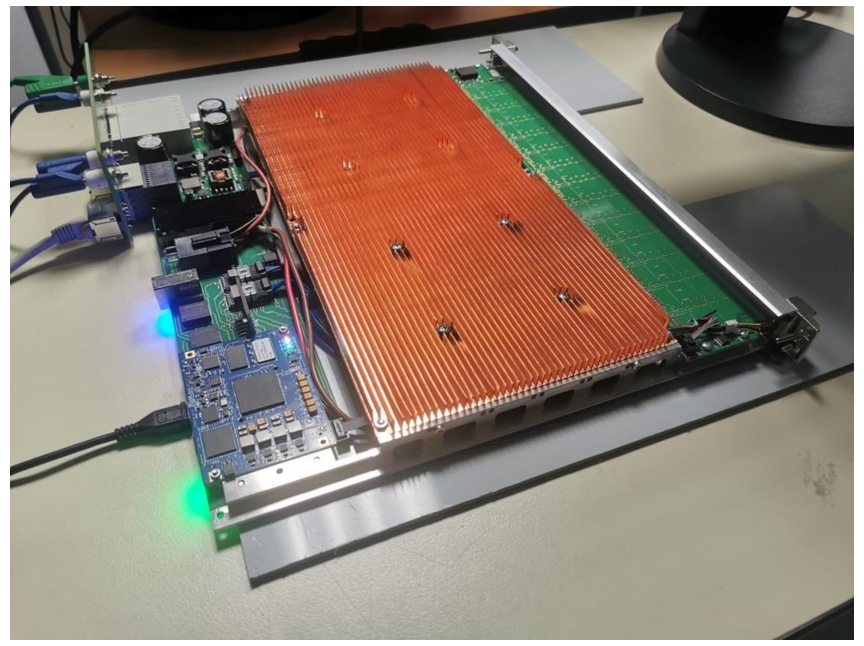
- **VINS contribution L1 Trigger detector development:**
- Pledge for **R&D** of **Muon Trigger** hardware (EndCap and Global Muon)
  - Prototyped **X2O Trigger boards** Power Module
    - Designed and assembled **in Serbia**
    - Part of slice test at b-904
  - X2O Consortium: Florida, UCLA, **Vinca|**





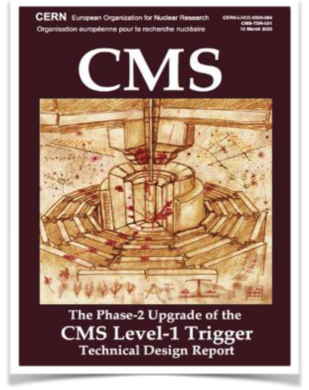


- Power Module designed by VINS and prototypes produced in Belgrade
- Vinca test stand at CERN
  - Testing CERN L1T Standard Protocol
  - Developing firmware and emulation for reconstruction



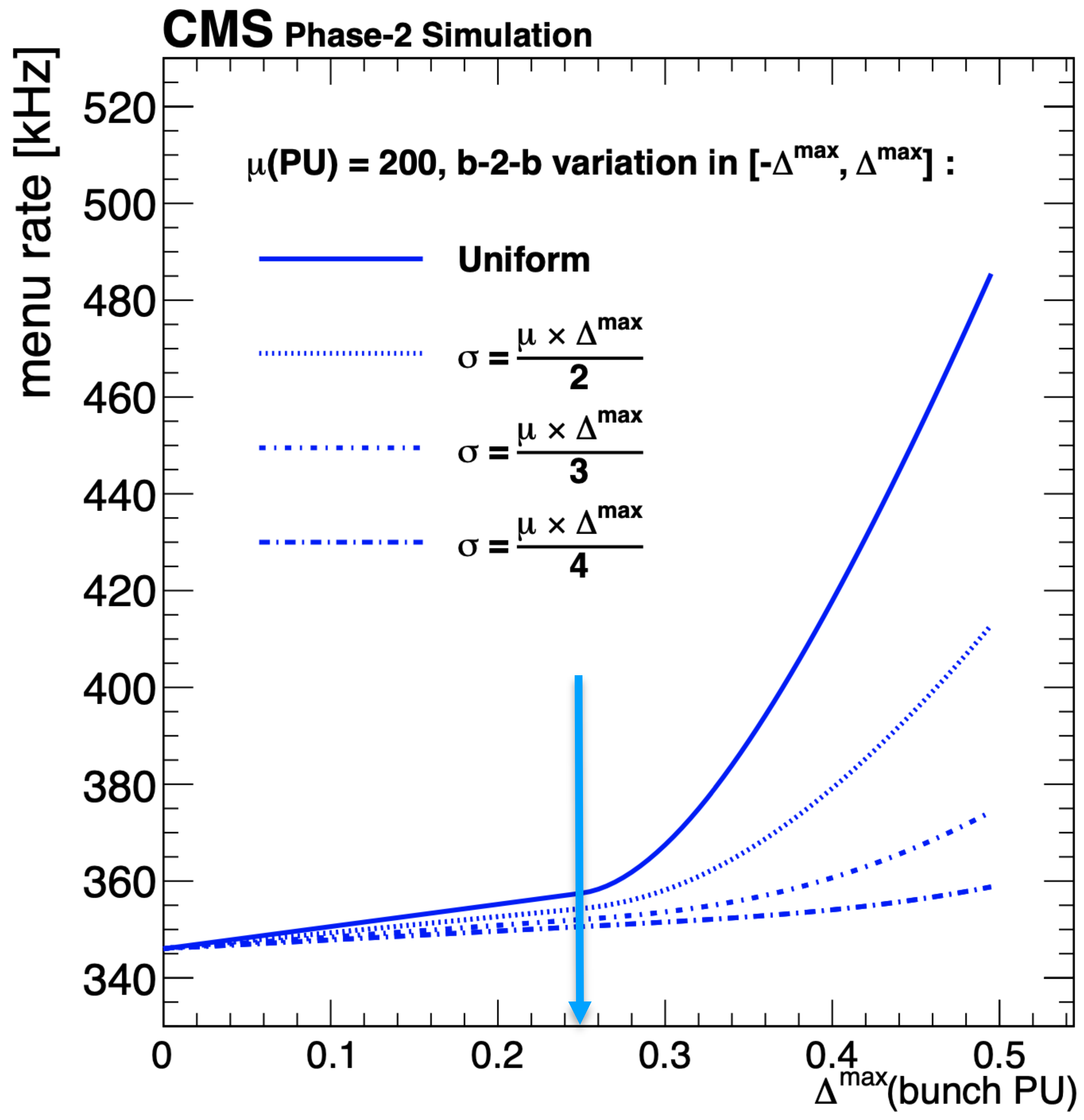
VINS in CMS Phase-II L1T Upgrade

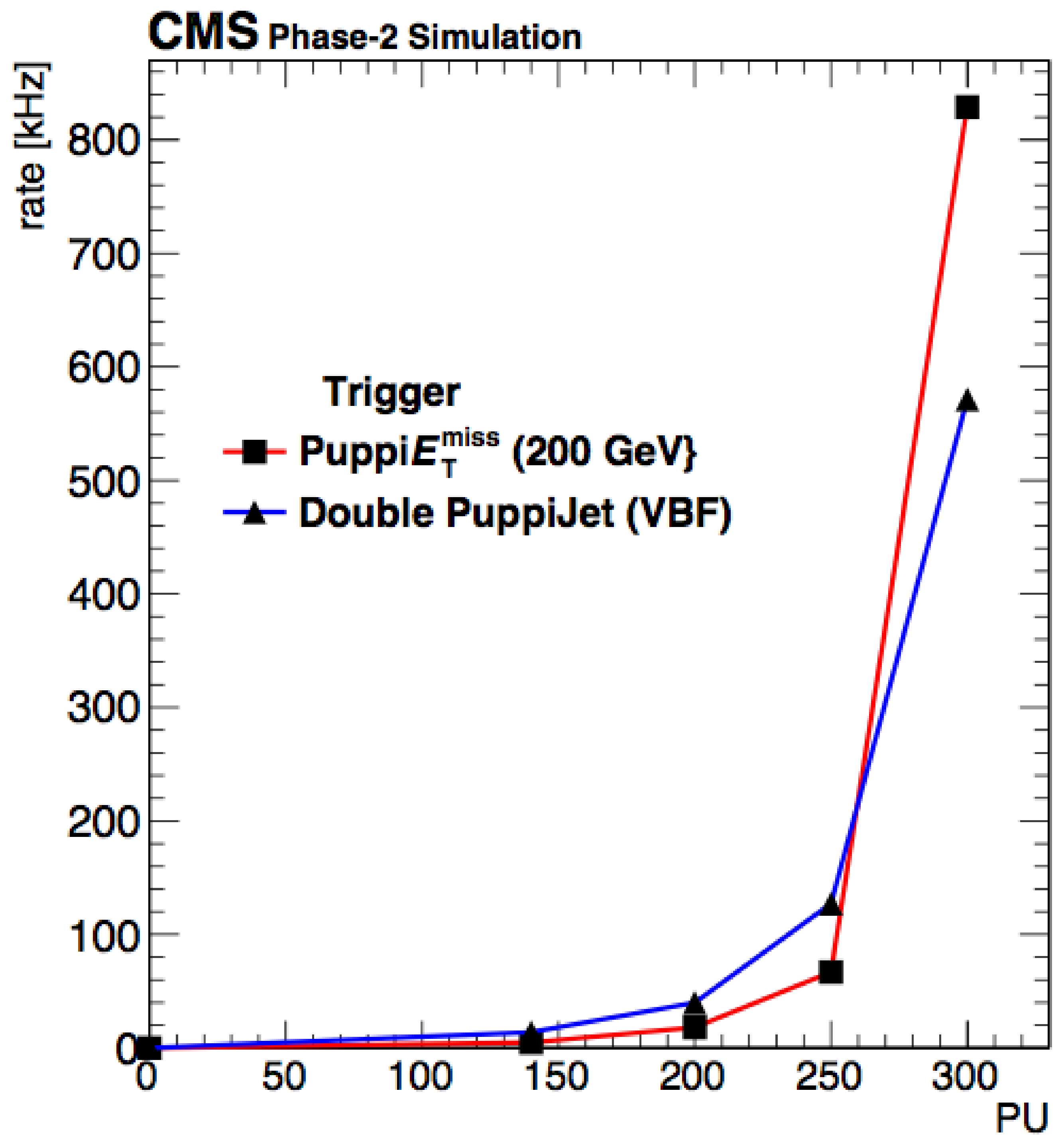
Contribution: Study of rate stability with bunch HL-LHC variations



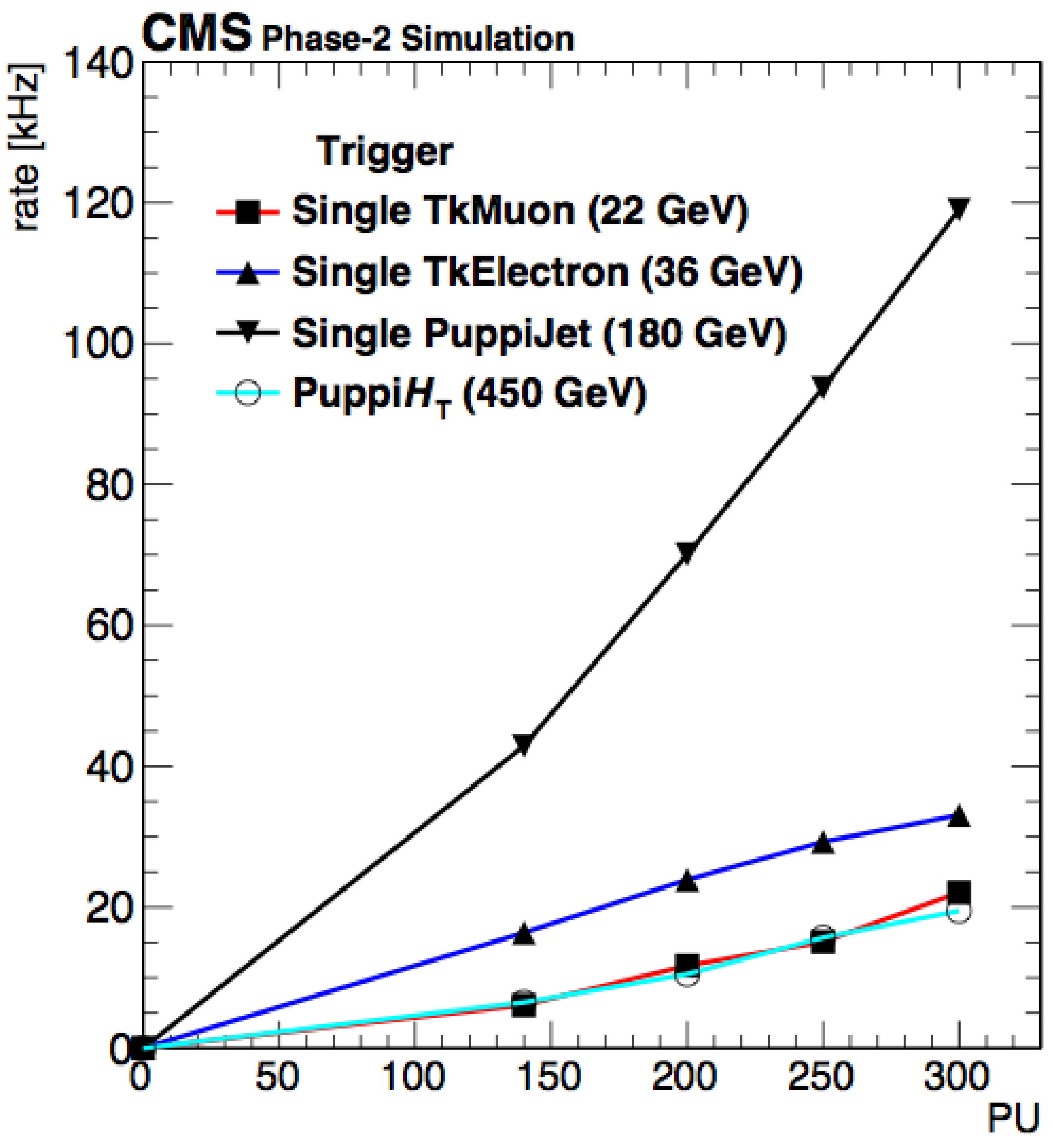
- L1 trigger rate of 347 kHz at <PU> = 200 is
  - **stable** (up to 10%) with PU bunch-to-bunch variations of up to 25%
  - **unstable** quickly for the case of the more drastic bunch-to-bunch PU variations (eg. uniform)

Nonlinear rate triggers





Linear rate triggers



VINS in CMS Phase-II L1T Upgrade

Contribution: Developed alternative MET triggers for extreme PU

MET triggers are extremely important because some BSM physics only accessible via these triggers

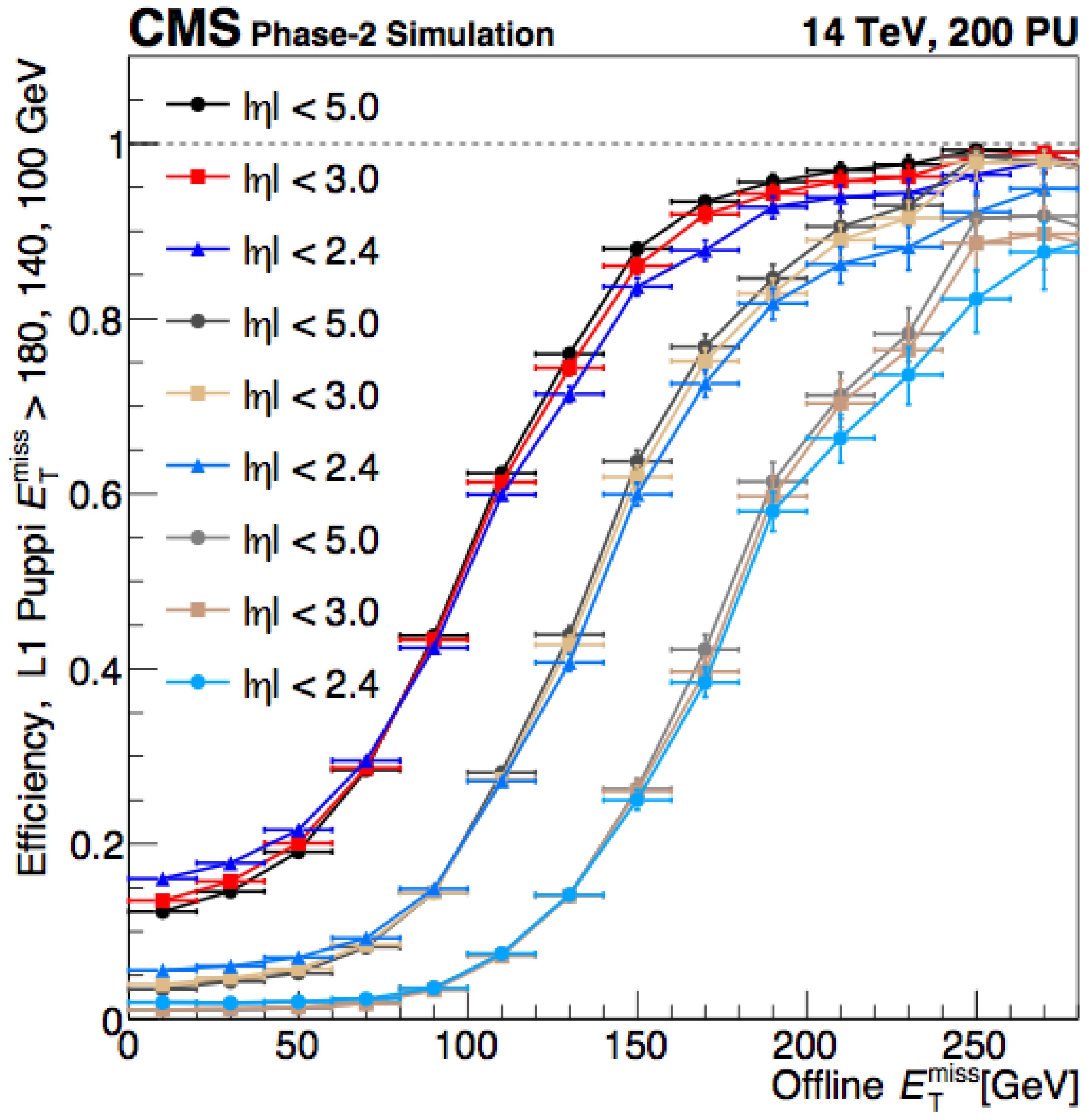
- Problem at high rate: standard PuppiMET trigger rate explodes, 67 kHz @ PU 250, 830 kHz @ PU 300

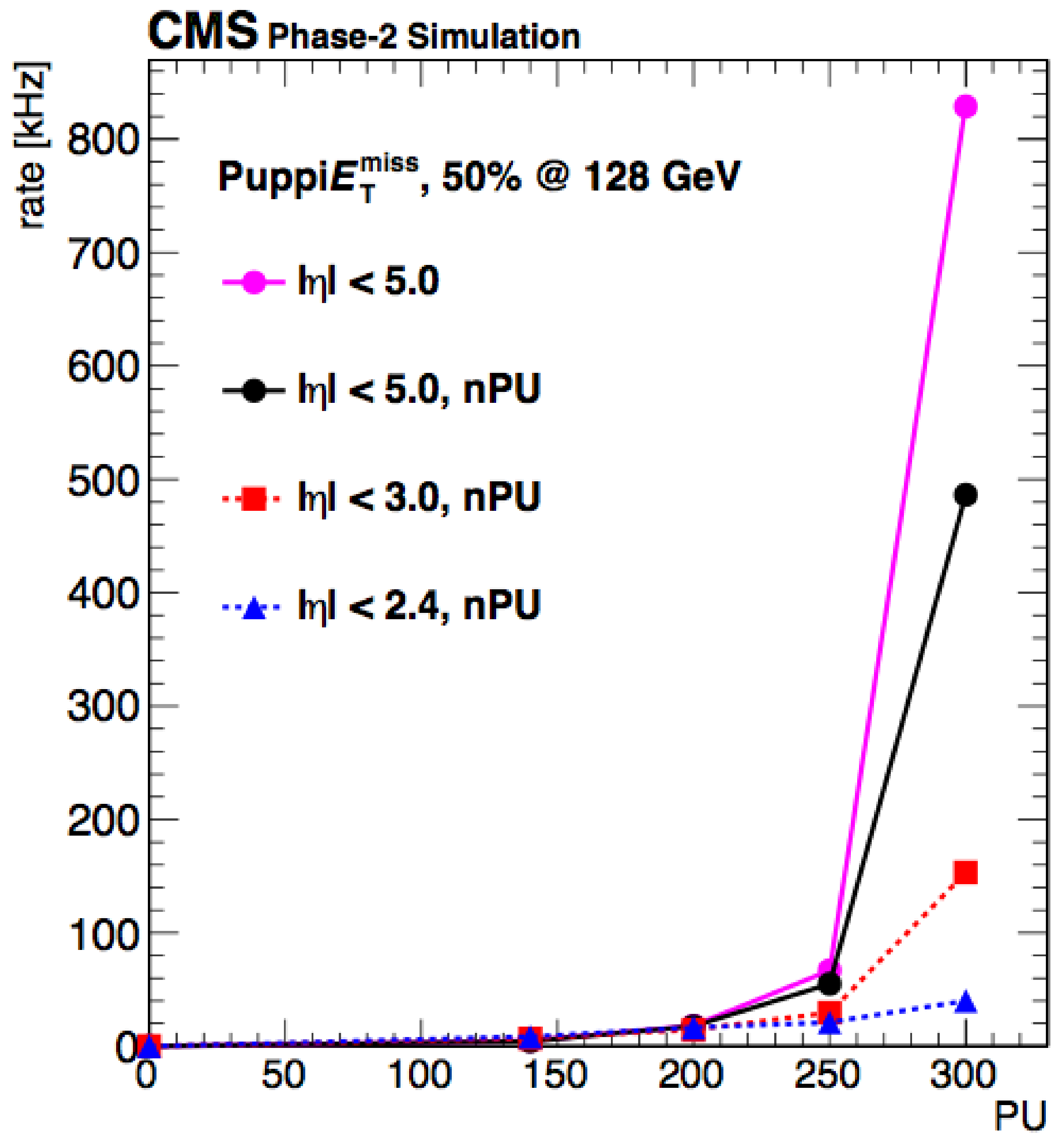
VINS invented an improved PUPPI MET reconstruction algorithm for PU (250, 300) while preserving efficiency

- Use event PU estimate as input to Puppi reconstruction, which can be done from # vertices (GTT)

$$
\begin{aligned}
w_i &= \frac{1}{1+e^{-x_{\text{tot}}}} \\
x_{\text{tot}} &= x_\alpha + x_{p_T} - x_{\text{PU}} \\
x_\alpha &= \min(\max(c_\alpha \cdot (\alpha - \alpha^0), -x_\alpha^{\max}), +x_\alpha^{\max}) \\
x_{p_T} &= c_{p_T} \cdot (p_T - p_T^0) \\
x_{\text{PU}} &= \log(N_{\text{PU}}/200) + c_0.
\end{aligned}
$$

- Can further control rate if restricting in η in case of extreme PU

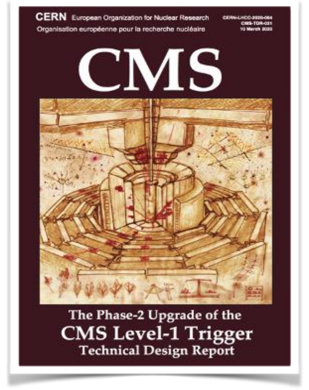




VINS in CMS Phase-II L1T Upgrade

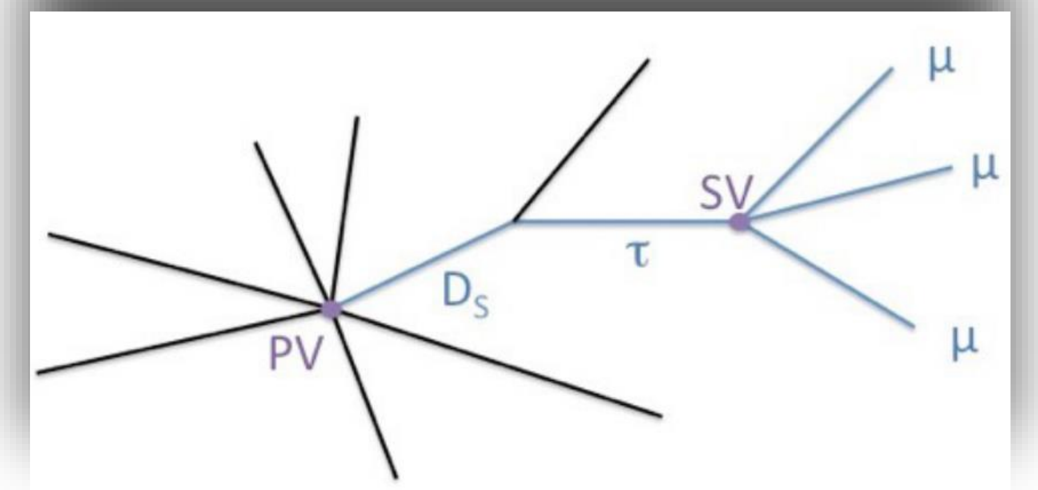
Contribution: Developed trigger for discovery of Lepton Flavour Violation.

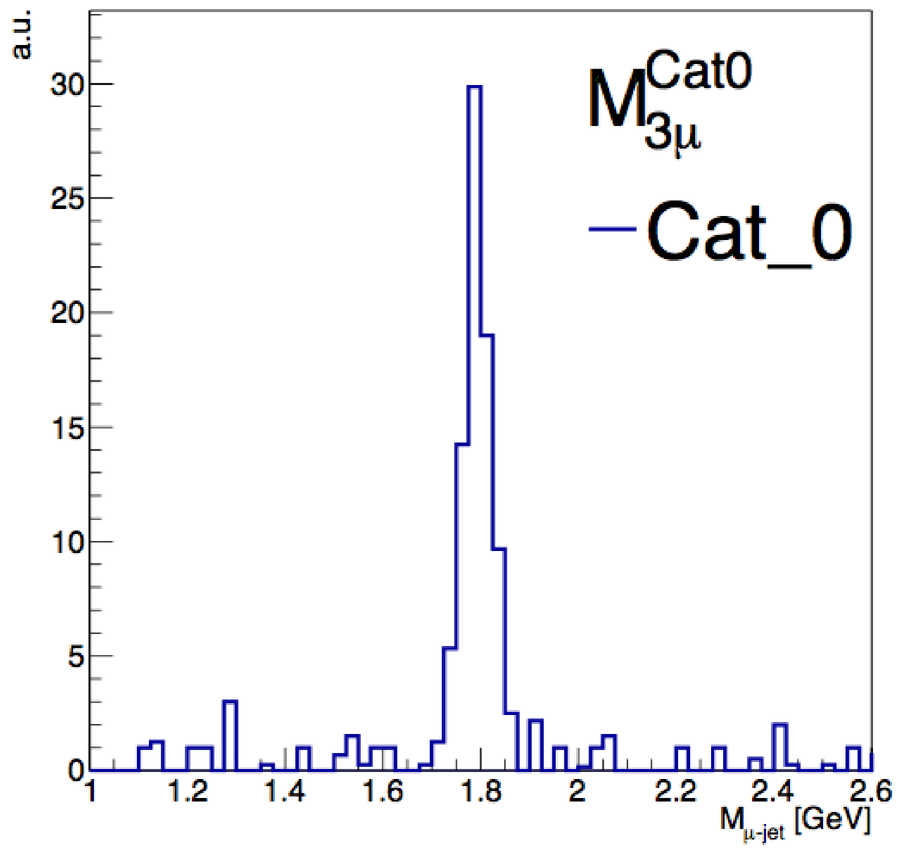
LFV: Tau-> 3μ with L1 Muon Jets (3 tracks, 2 tracks +1 stub, 2 stubs +1 track)

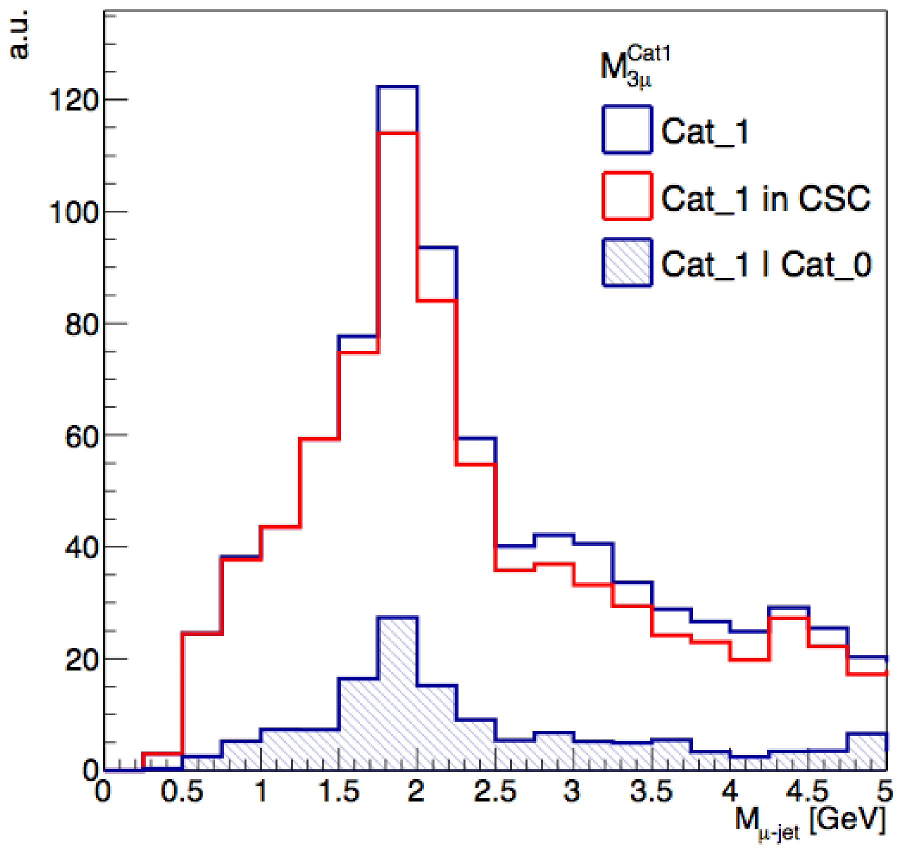


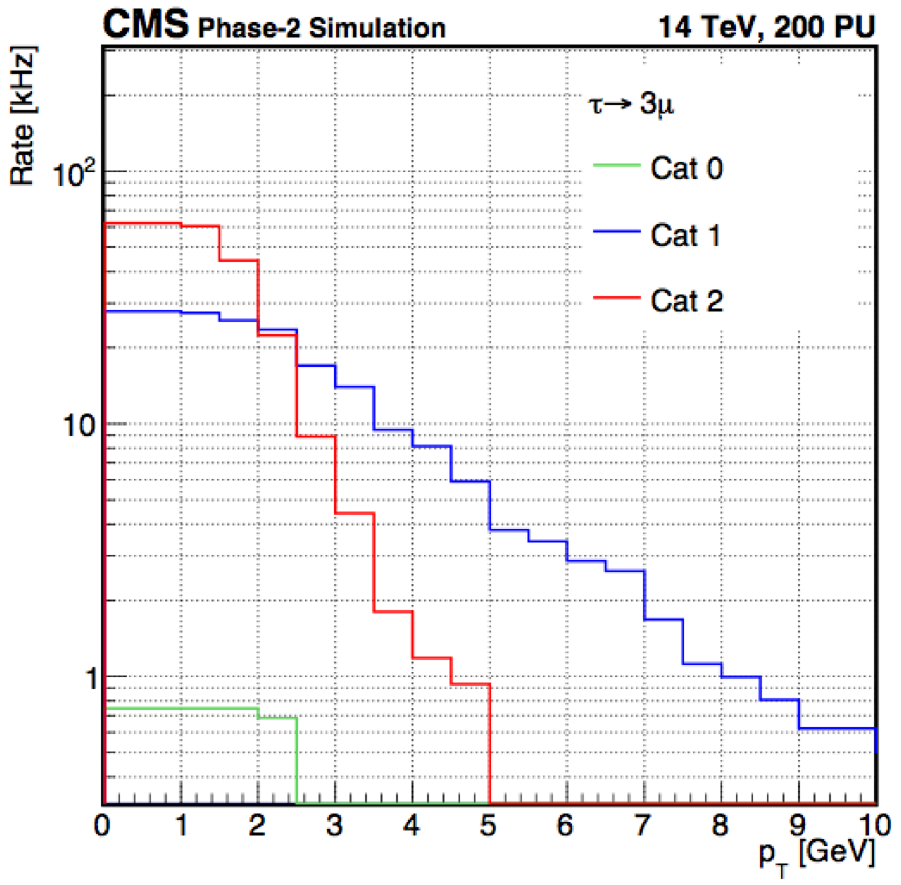
- Presence of L1T Tracker Tracks allows for a more precise pT reconstruction

  => low mass resonances decaying to charged particles can be reconstructed in L1T with an acceptable rate









LFV: Tau-> 3μ with L1 Muon Jets in GMT, predominantly in the EndCap

- L1 Muon Jets (2 stubs +1 track)
- Very challenging due to large background
  - Develop new algorithms
  - Need to deploy machine learning

Algorithm to run on X2O board

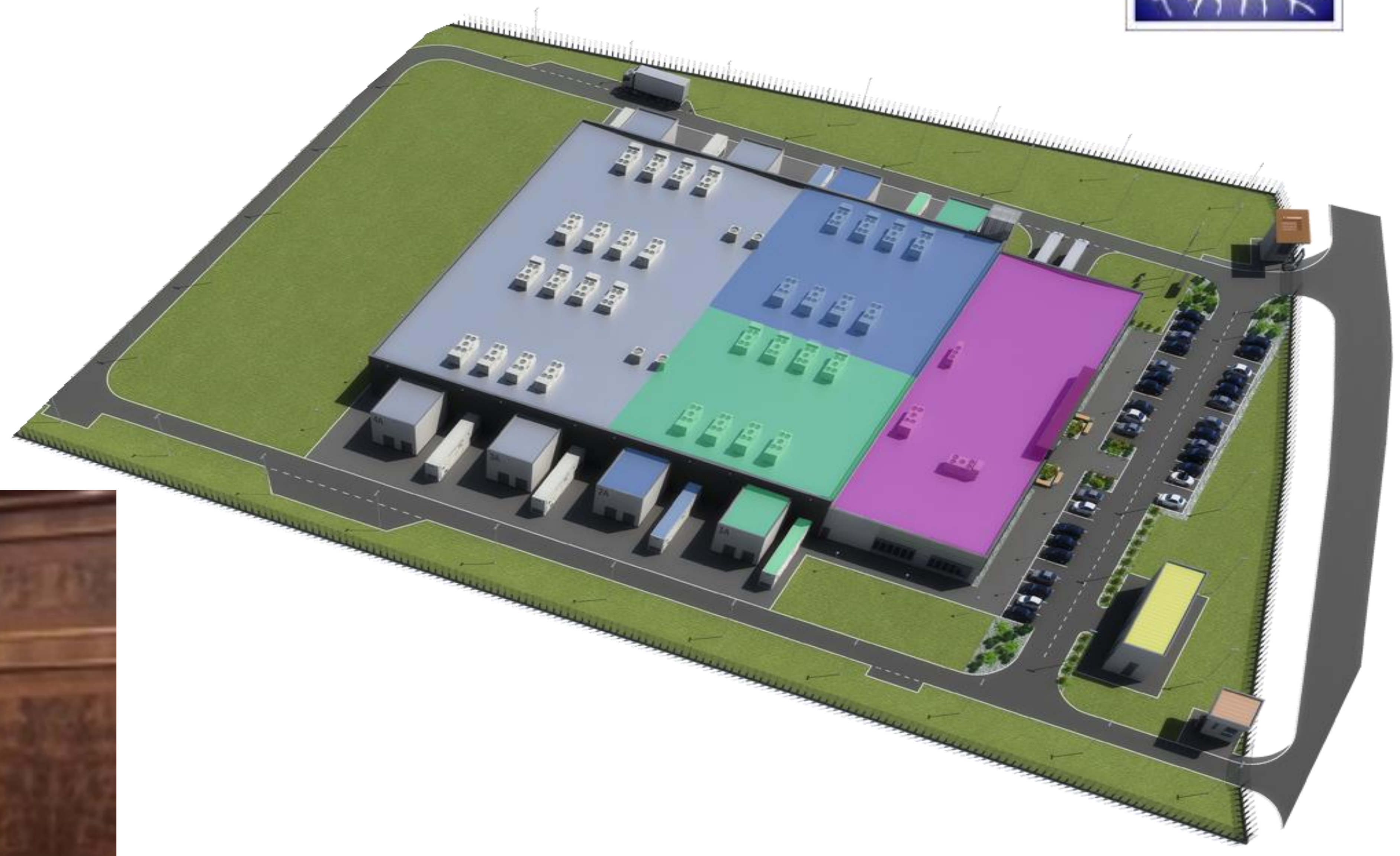
VINS Computing

- VINS group has over 15(20) years in R&D of core software for HEP experiments (GEANT simulation of CDF detector on Tevatron, CMS detector on LHC)
- Broad expertise in development of the CMS Computing
  - CMS SW Upper Management
- CMS L1T and HLT : Legacy, Phase-1 Upgrade, Phase-2 Upgrade
  - Design of computing framework (menu, data streams, physics object reconstruction)
  - Design of CMS Offline Computing (Data Formats , Event Content, Emulation workflows, data and MC processing, Offline CMSSW optimization and profiling)

December 2023 – Serbia & CERN sign MoU for Computing

Serbia joins the Worldwide LHC Computing Grid

On 9 December, CERN and Serbia signed a Memorandum of Understanding (MoU) at the Serbian State Data Centre. The centre will become a Tier1 member of the Worldwide LHC Computing Grid (WLCG), the highest level of collaboration within the Grid

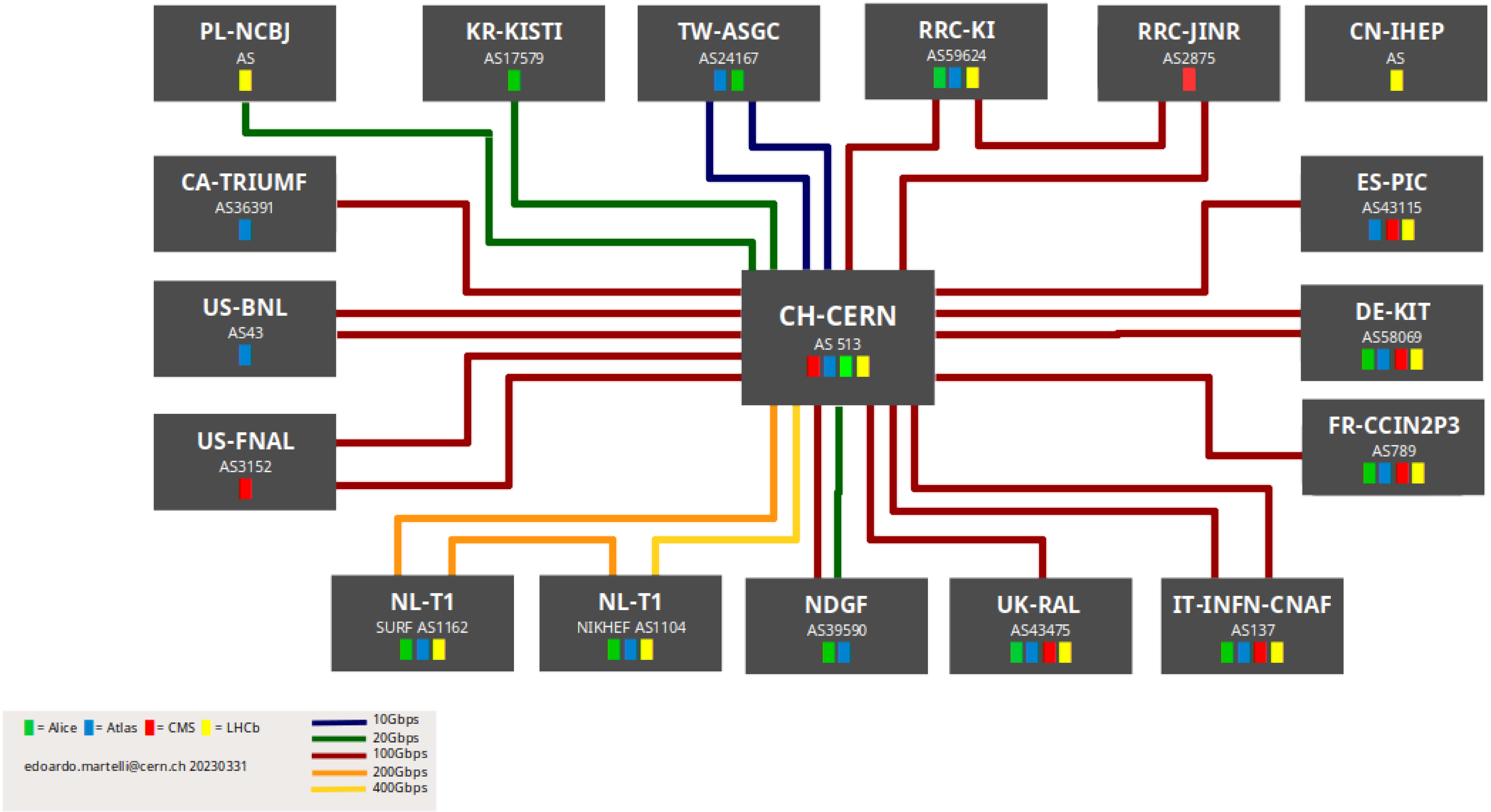


From left to right: Enrica Porcari, Head of CERN's IT department, Jelena Begović, Serbian Minister of Science, Technological Development and Innovation, and Mihailo Jovanović, Serbian Minister of Information and Telecommunications. (Image: Serbian Ministry of Information and Telecommunications)

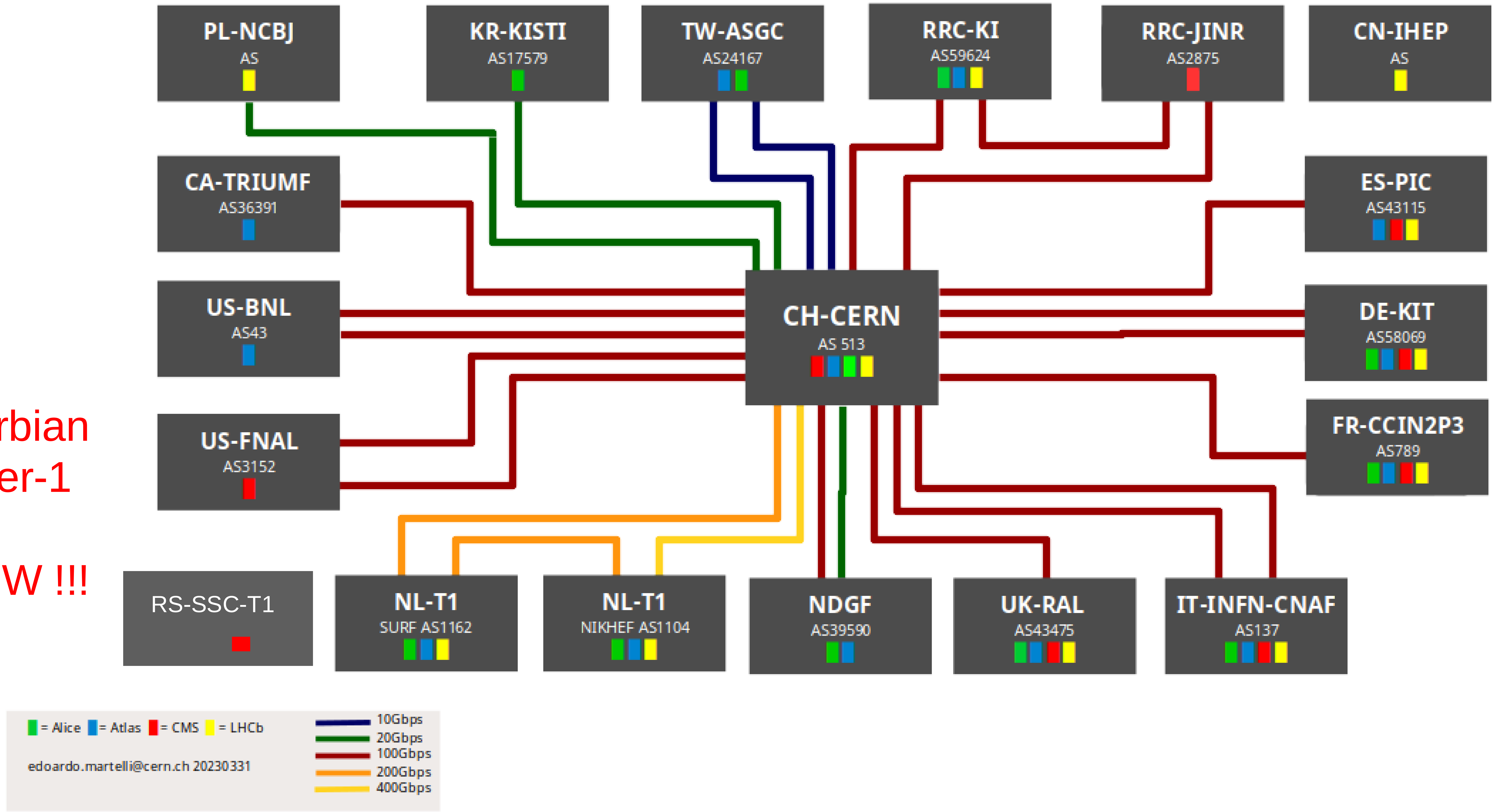
SSC-T1 (Serbian Scientific Computing – Tier1)

- SSC-T1
  - Become average-size CMS Tier-1 providing Compute, Storage, Custodial services
    - Currently there are 7 CMS Tier-1 : KIT, PIC, IN2P3, CNAF, RAL, FNAL, JINR
    - Serbian T1 pledge is to provide 10-15% of CMS T1's capacity
      - 170 kHS23, 15 PB disk storage, 30 PB tape storage
- Strategic goal of SSC-T1 is to enlarge the scientific ecosystem in Serbia in the field of HEP and strengthening of its collaboration with CERN.
    - This is a game-changer for Serbian HEP and Scientific Computing
- Using HEP as a primer will introduce new major opportunities in scientific/technological field of high-throughput and high-data-volume computing in Serbia.
  - *Together with scientists at CNAF (Italy) Vinca submitted a Proposal for Serbia-Italy research and innovation project for the period 2024-2026, Title "Low Power Platforms for Scientific Computing"*

LHCOPN LHC Optical Private Network - Topology



LHCOPN LHC Optical Private Network - Topology

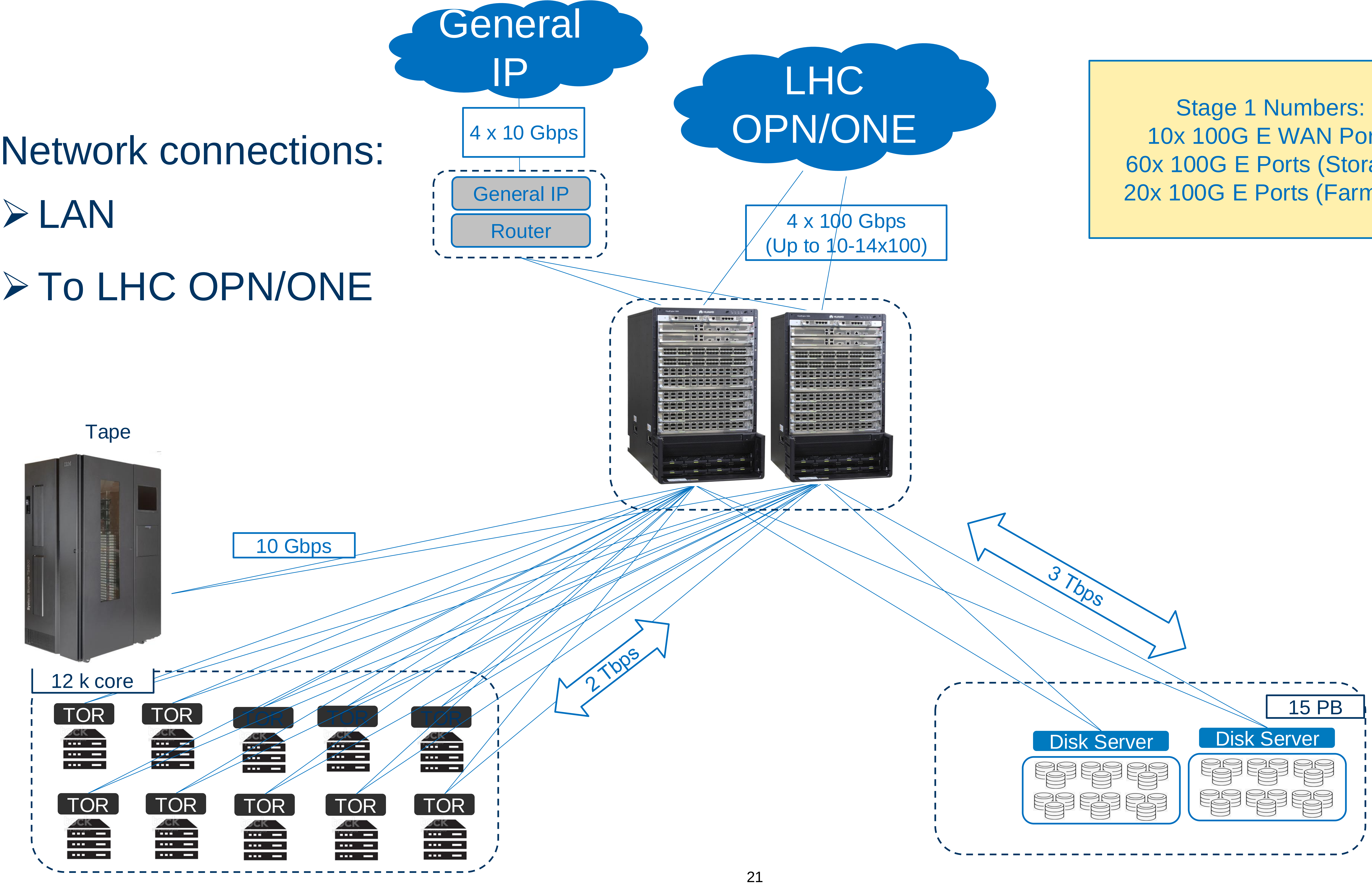


Serbian Tier-1

NEW !!!

Network connections:

- LAN
- To LHC OPN/ONE



Stage 1 Numbers:
10x 100G E WAN Ports
60x 100G E Ports (Storage)
20x 100G E Ports (Farming)

Status of Serbian Tier-1 – High Level Design

- **High Level Design document presented and green-lighted by the CMS Computing Resource Board**

High Level Design of Serbian Scientific Computing Tier-1 (SSC-T1) Center

Purpose, Project Description, Design with Scientific Guidelines, Organization, Roadmap

Vladimir Rekovic for Serbian Tier-1
13. 09. 2024.

Table of contents:

Abstract

The Project of the deployment and the exploitation of the Worldwide LHC Computing Grid in the Republic of Serbia to support high energy physics experiments CMS at CERN assumes establishing of a Tier-1 computing center. The center will be hosted by the State Data Center in Kragujevac, Serbia. In this document the case argument for creation of an advanced scientific computing facility is presented and a design of the SSC-T1 center is described. The future extensions of the center are discussed in scope of a development of broader scientific community as well.

- **Currently in the process of finalizing the hardware specifications with the Technical team and soon preparing tenders for procurement.**

High Level Design of Serbian Scientific Computing Tier-1 (SSC-T1) Center

Vladimir Rekovic for Serbian Tier-1

13.09.2024

Contents

Conclusions

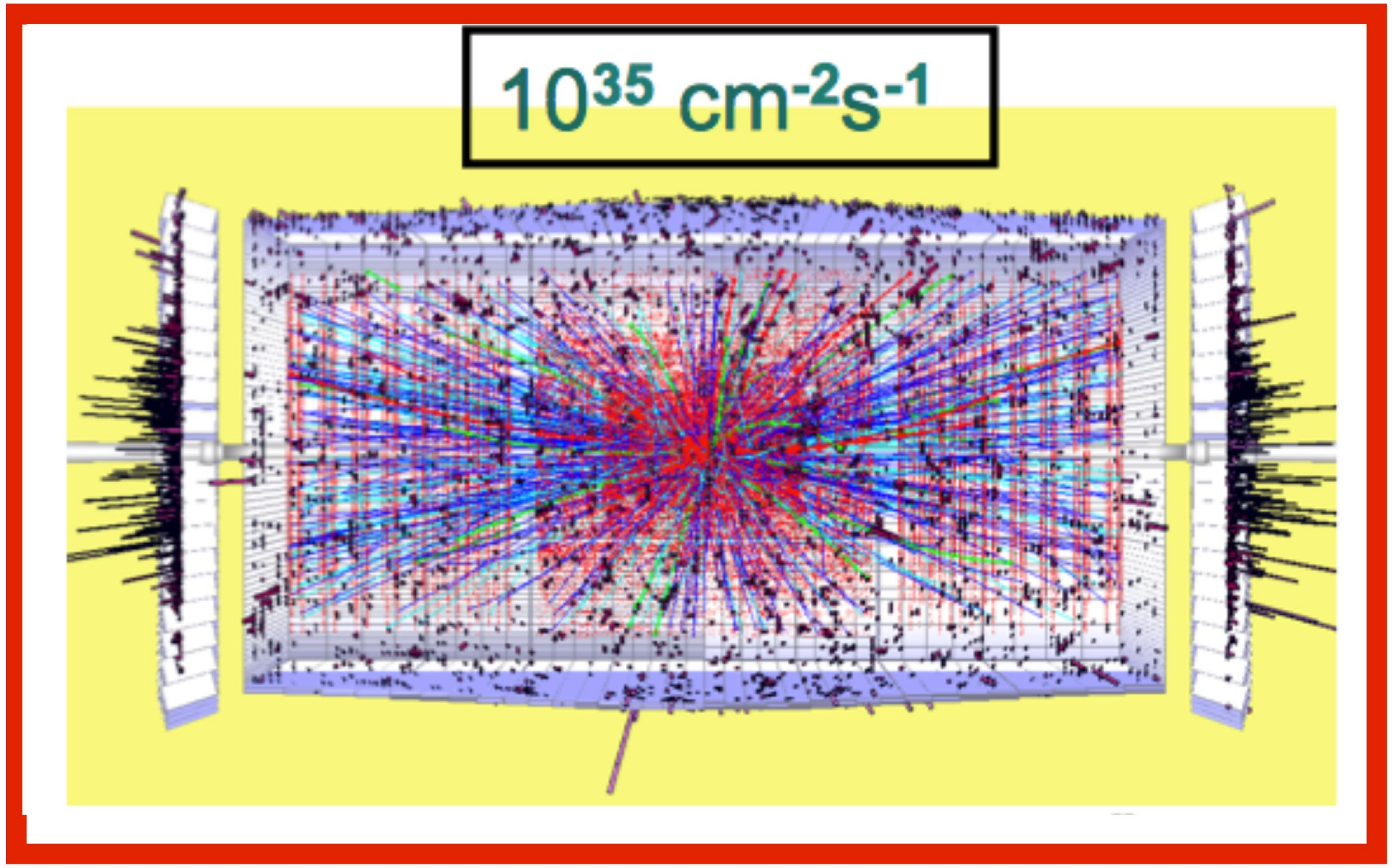
- Vinca has a long history at CERN and CMS
  - Currently total of 10 researchers (physicists and engineer and EE MS students)
- Active in physics analysis (Heavy Ion, Higgs, Lepton Flavor Violation)
- Since a few years ago intensive effort on detector development (Level-1 Trigger Phase-II Upgrade)
- Extensive experience and expertise in Offline and Core CMS Software and Comp.
  - Intensifying computing expertise, submitting grant proposals
- After a long time Vinca CMS Group is now a renewed with its proper organization.
- VINS is an active group with major contributions and innovations to the CMS experiment, contributing to Vinca retaking it leading position in Serbian HEP activity, receiving international recognition.
  - Authors of numerous major CMS analysis, Detector TDR, ARC Chairs, ARC members, CMS Award,
  - VINS is responsible for maintenance, and operations of CMS detector in Run-3 of LHC.
- VINS Group is actively participating in the Upgrade of CMS detector and looking forward to HL-LHC era.

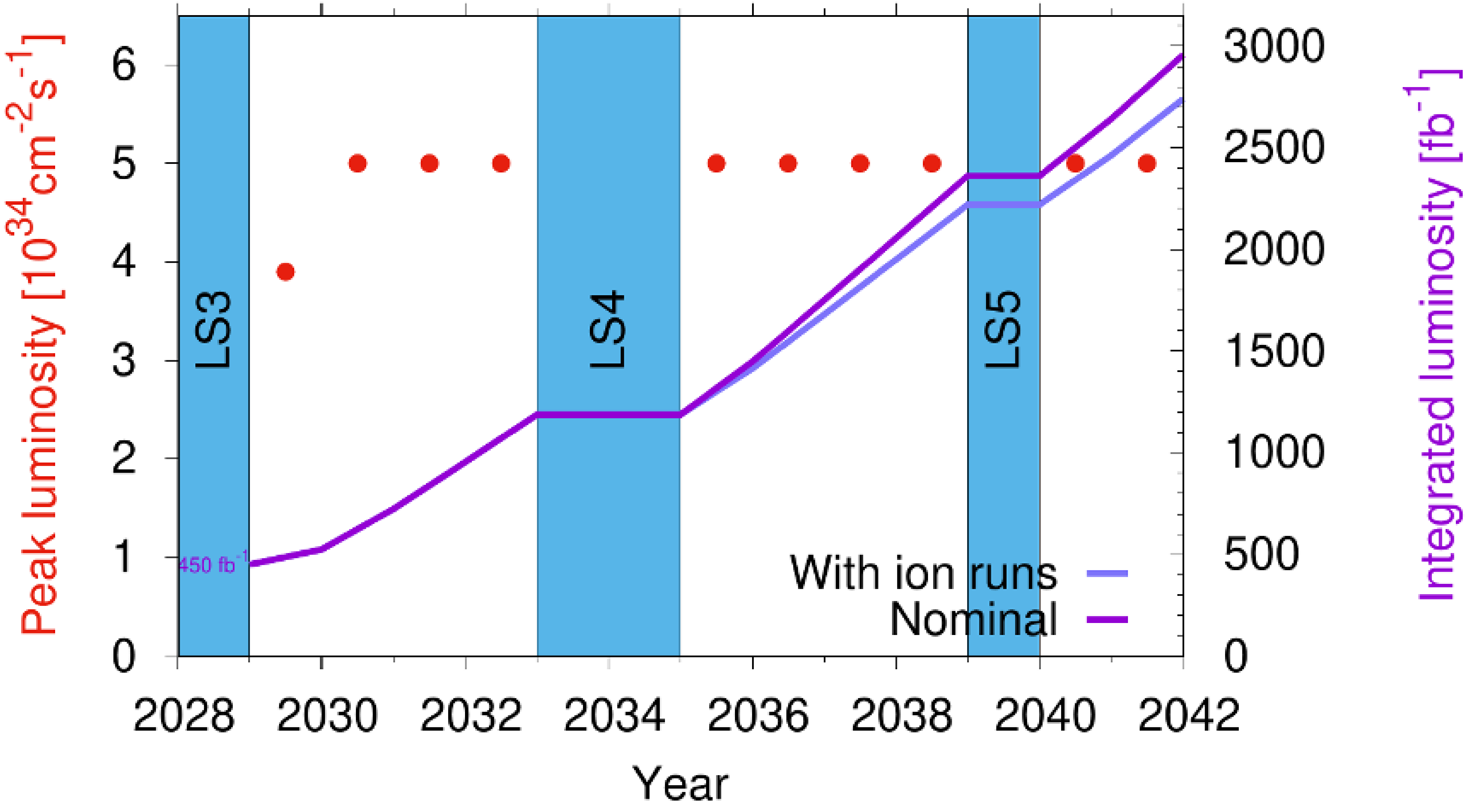
BACK-UP

HL-LHC

The Phase II (HL-LHC) project established in 2010, is already more than half-way through:

- Inst. Luminosity up to 7.5e34 (updated projection for Integrated 4000 fb-1)
- Energy: 14 TeV or more (discussion ongoing on availability of the machine)
- Filling schemes considered: similar to previous experience (8b4e, 48b etc.)

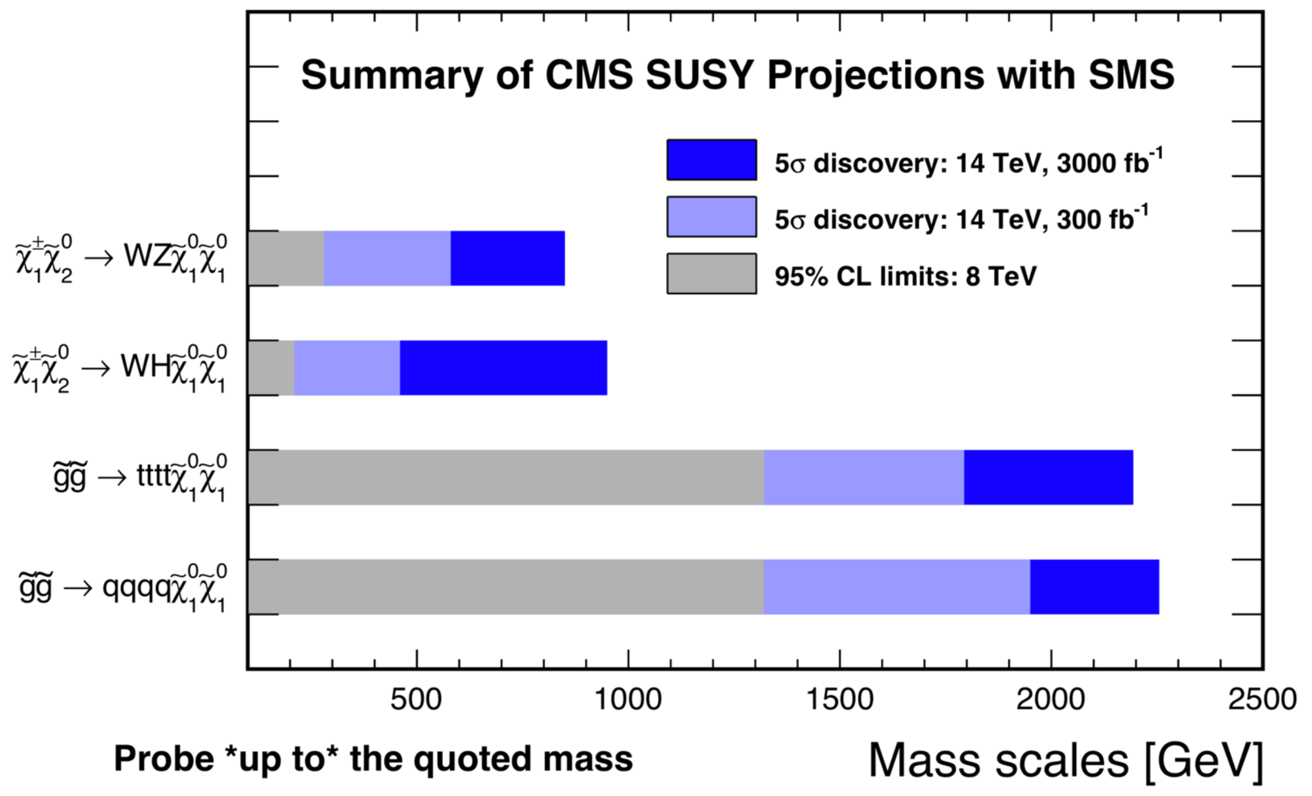




p-p collisions in HL-LHC

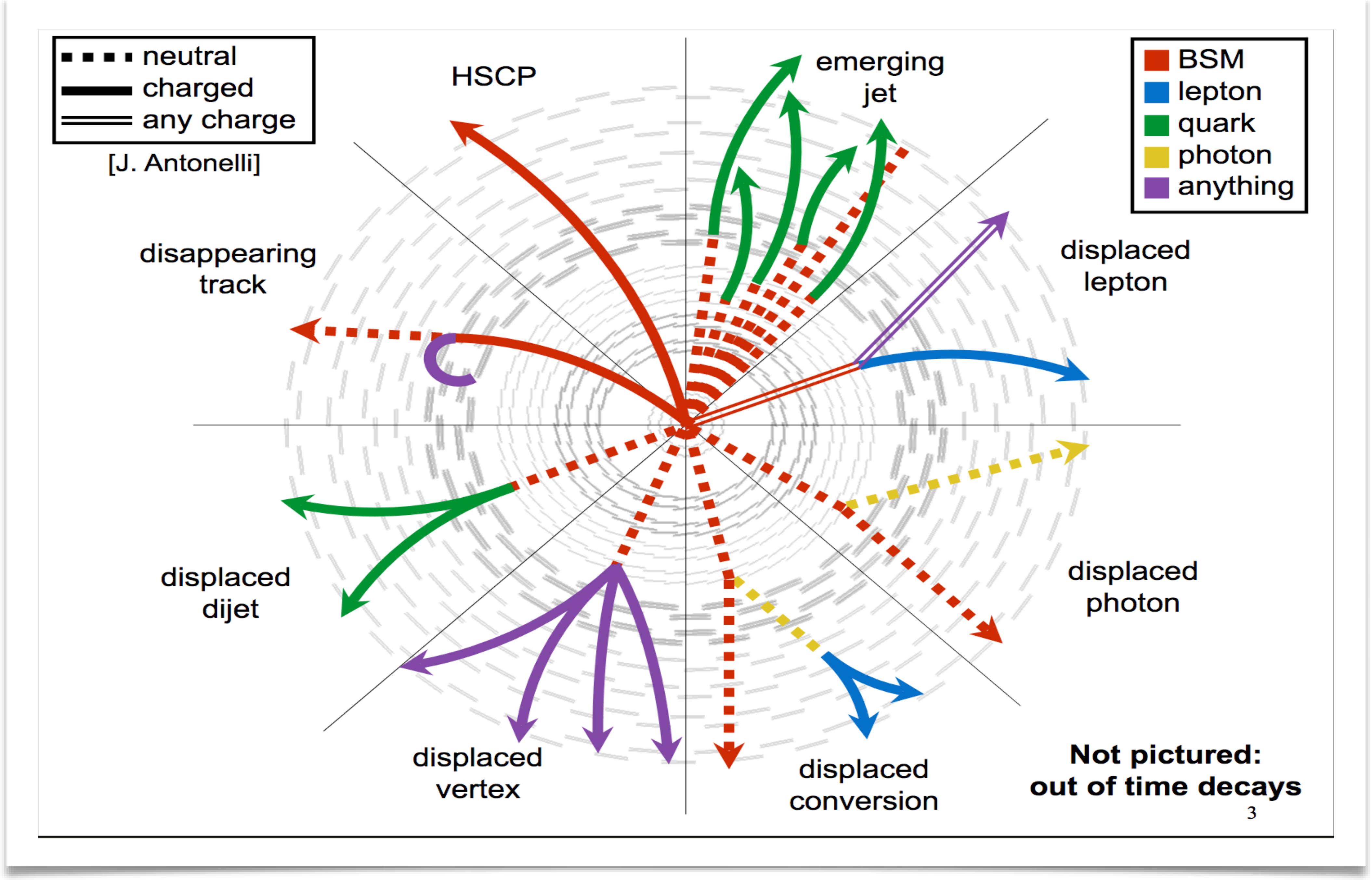
- Interaction region with Gaussian spread 45 mm along beam axis
- Average number of collisions : <μ> 200
  - Average interaction density: 1.8 collisions/mm

Reasons for HL-LHC



Significantly extend the physics program with HL-LHC 10x data of LHC

- SM Precision measurement: Higgs, PDFs, QCD,
- New Physics: DM, SUSY, BSM, extra dim.



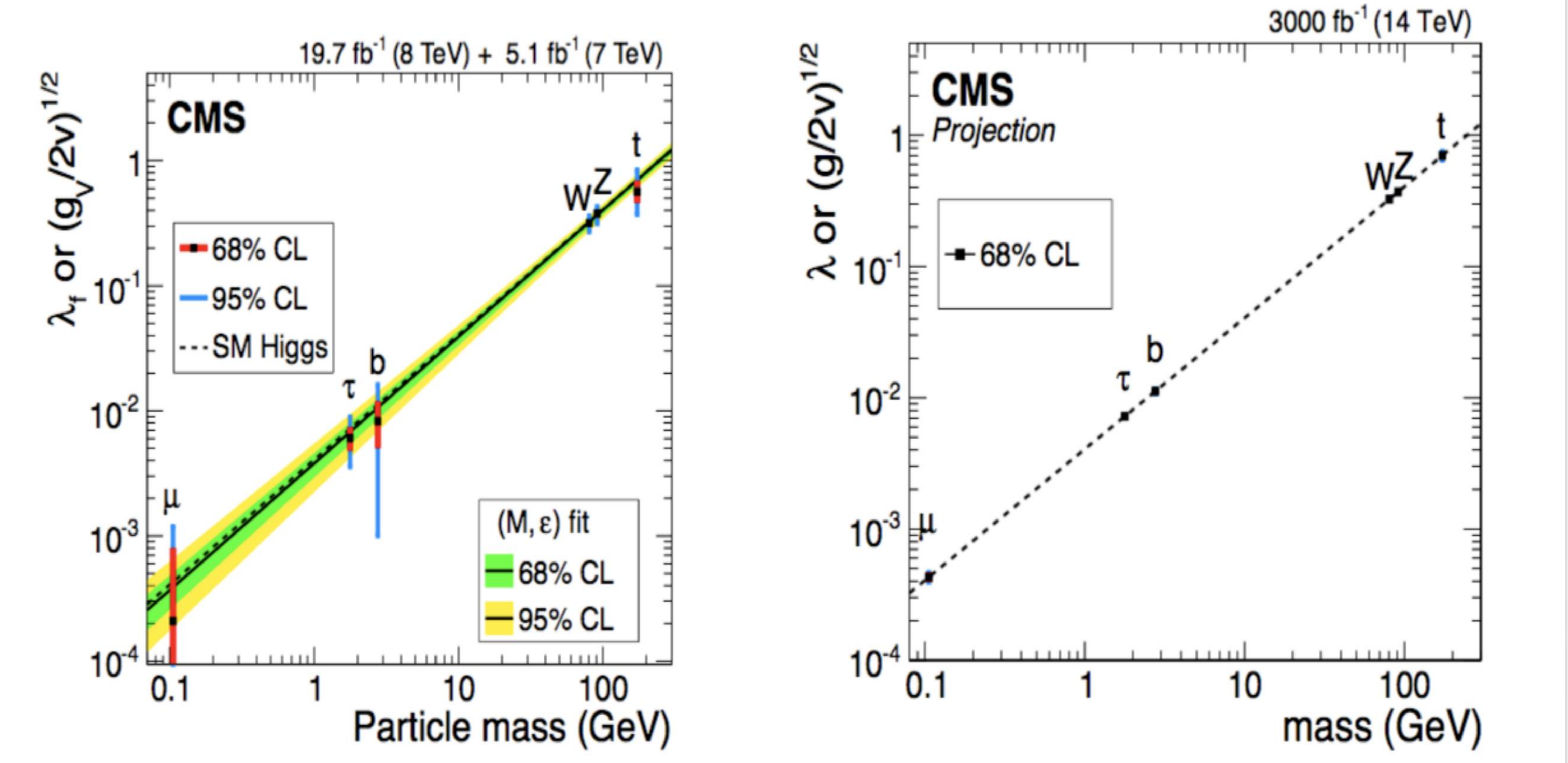


Figure 1.10: Observed and projected precision on Higgs boson couplings as a function of boson or fermion masses.

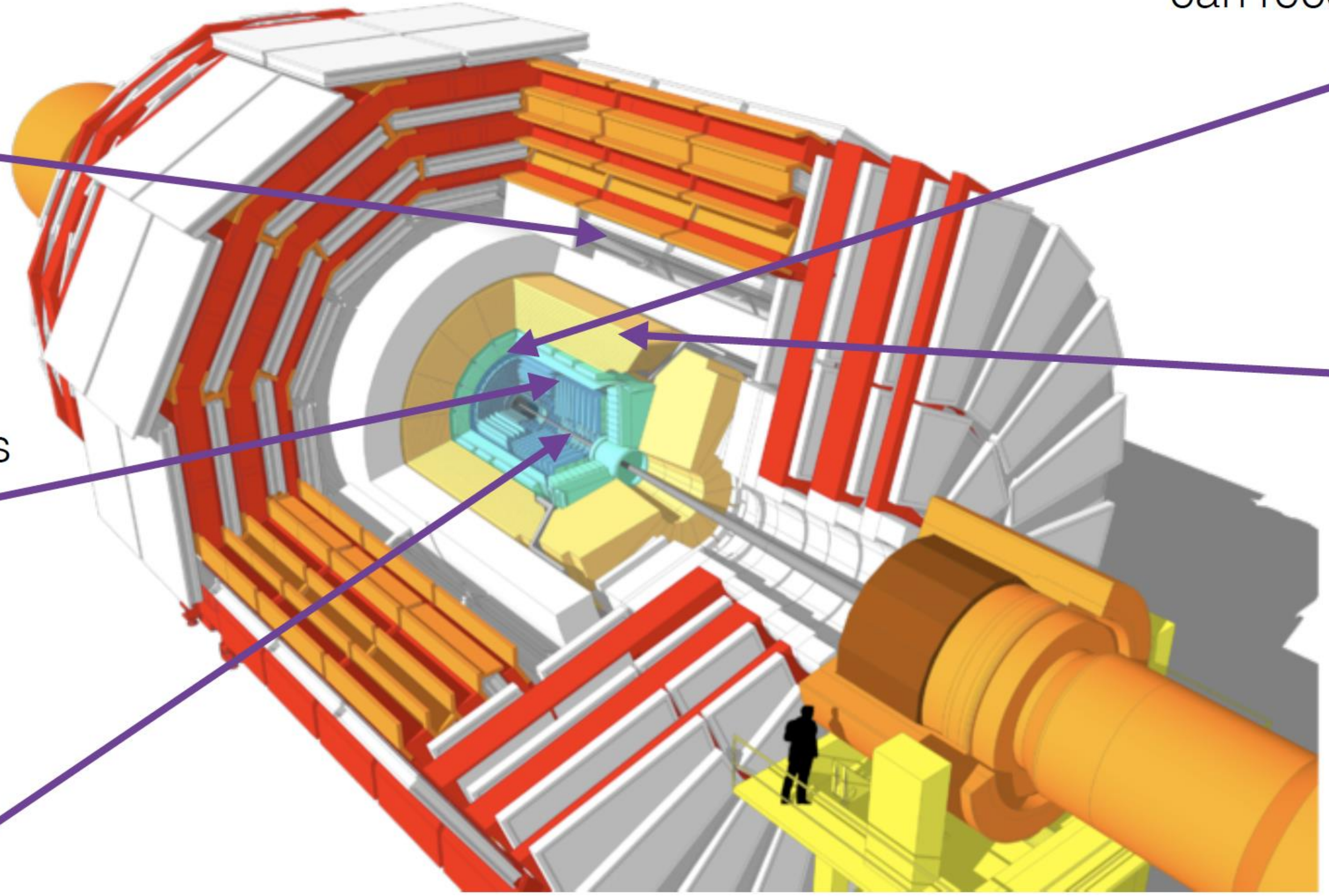
Major challenge for tracking detectors in HL-LHC CMS

- Efficiently reconstruct charged particles from primary interactions
  - Correctly assign them to production vertices -> Need upgraded detectors for Phase-2.

Phase-2 upgrade for the CMS detector

Improved muon coverage and trigger
increased RPC coverage (1.5 < |η| < 2.4)
new electronics
CMS-TDR-016

New endcap calorimeters
high granularity
can reconstruct showers in 3D
CMS-TDR-019



New precision timing detector
Timing resolution of 30-40 ps for MIPs
full coverage of |η| < 3.0
CMS-TDR-020

Updates to calorimeter and trigger
higher granularity
electronics for trigger
CMS-TDR-015

L1: CMS-TDR-021
DAQ/HLT: CMS-TDR-022

New inner tracker
all silicon tracker
4 layers of pixels
5 layers of strips
coverage to |η| < 4
CMS-TDR-014

Beam Radiation Instrumentation and Luminosity Detectors
CMS-TDR-023

Upgrade to trigger and DAQ
L1 rate increased to 750 kHz
High Level trigger rate to 7.5 kHz
Track information at L1

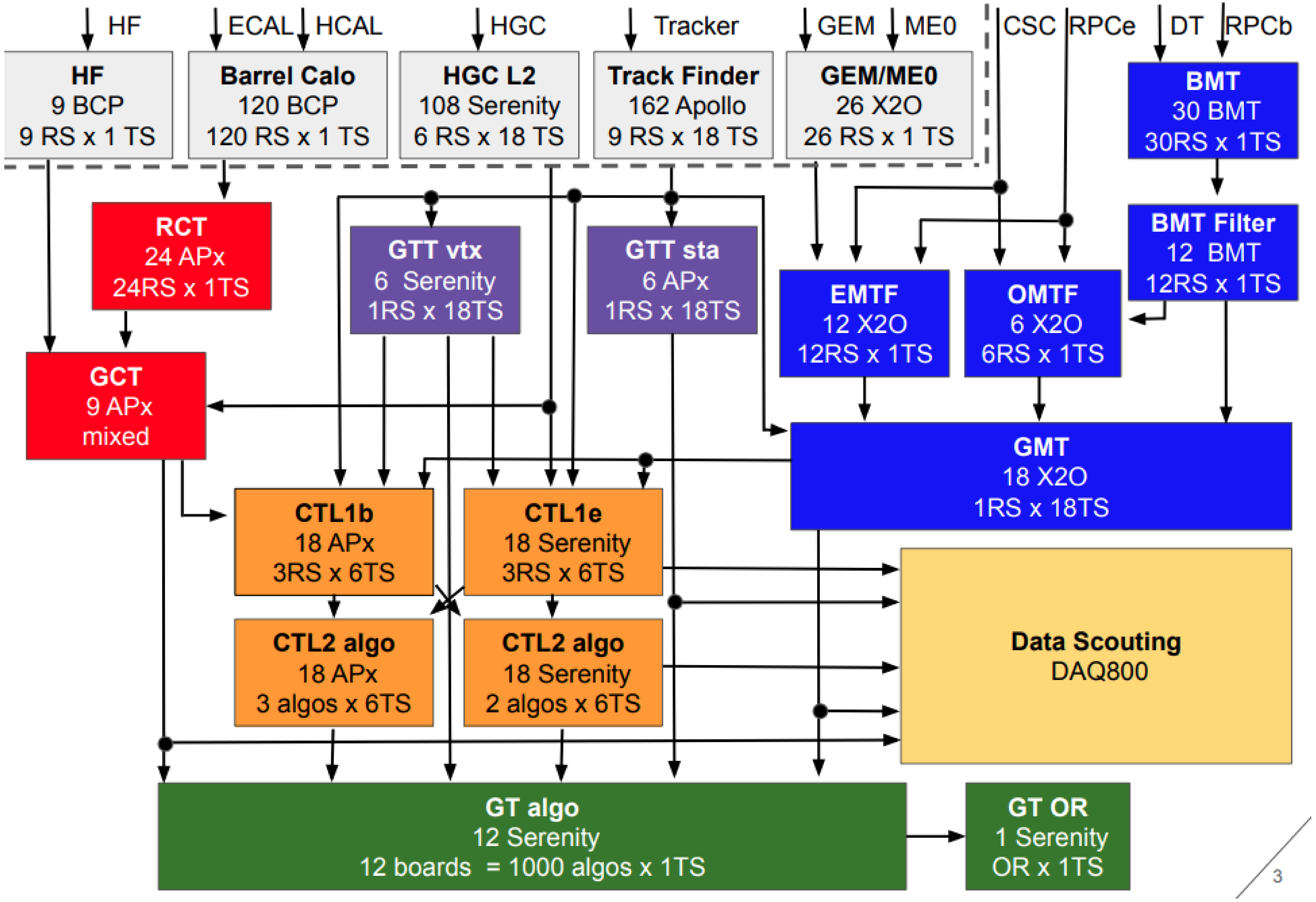
High Luminosity LHC

Increase in data rate and volume

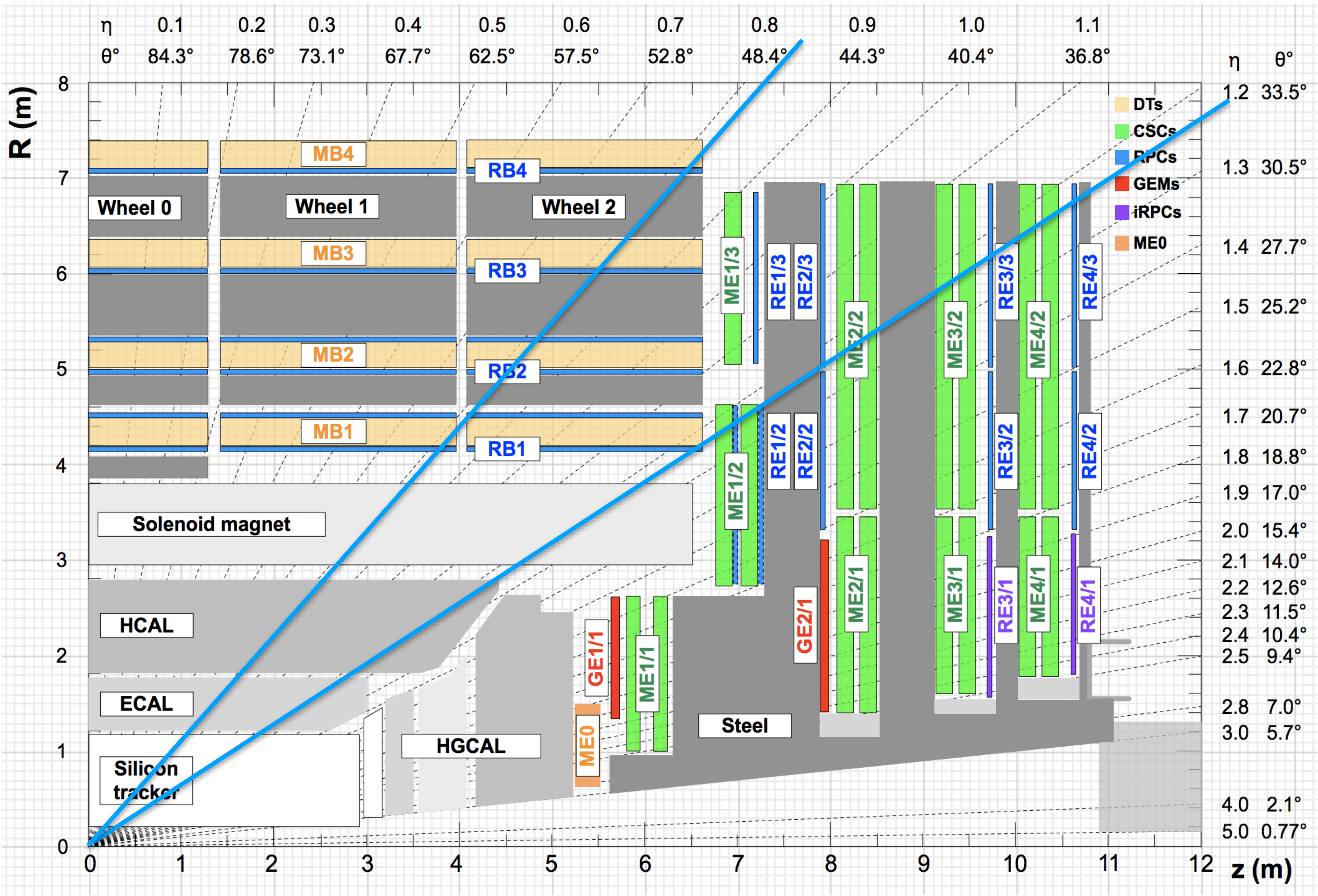
- **CMS detector needed upgrade (Phase-2). Level-1 Trigger as well.**
  - **Higher resolution in upgraded detectors (at L1) HGCal, ECAL, more muon chamber, introduced L1 Tracker**
  - **Larger event size, but increased available latency with new electronics**

CMS detector	LHC Run-2	HL-LHC Phase-2	
Peak ⟨PU⟩	60	140	200
L1 accept rate (maximum)	100 kHz	500 kHz	750 kHz
Event Size	2.0 MB [a]	5.7 MB [b]	7.4 MB
Event Network throughput	1.6 Tb/s	23 Tb/s	44 Tb/s
Event Network buffer (60 seconds)	12 TB	171 TB	333 TB
HLT accept rate	1 kHz	5 kHz	7.5 kHz
HLT computing power [c]	0.5 MHS06	4.5 MHS06	9.2 MHS06
Storage throughput	2.5 GB/s	31 GB/s	61 GB/s
Storage capacity needed (1 day)	0.2 PB	2.7 PB	5.3 PB

Use of 4 flavors of Boards in Phase-II Trigger

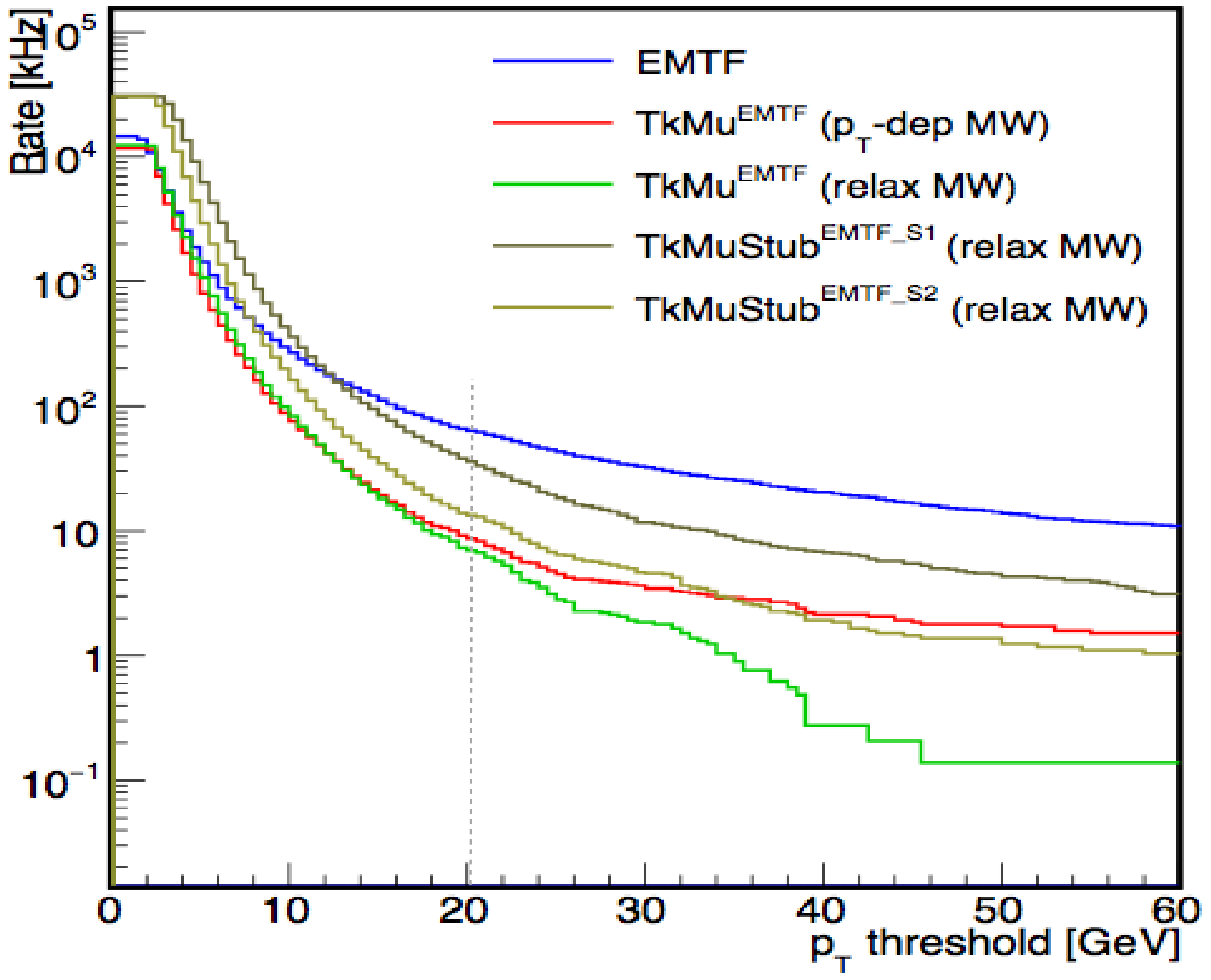


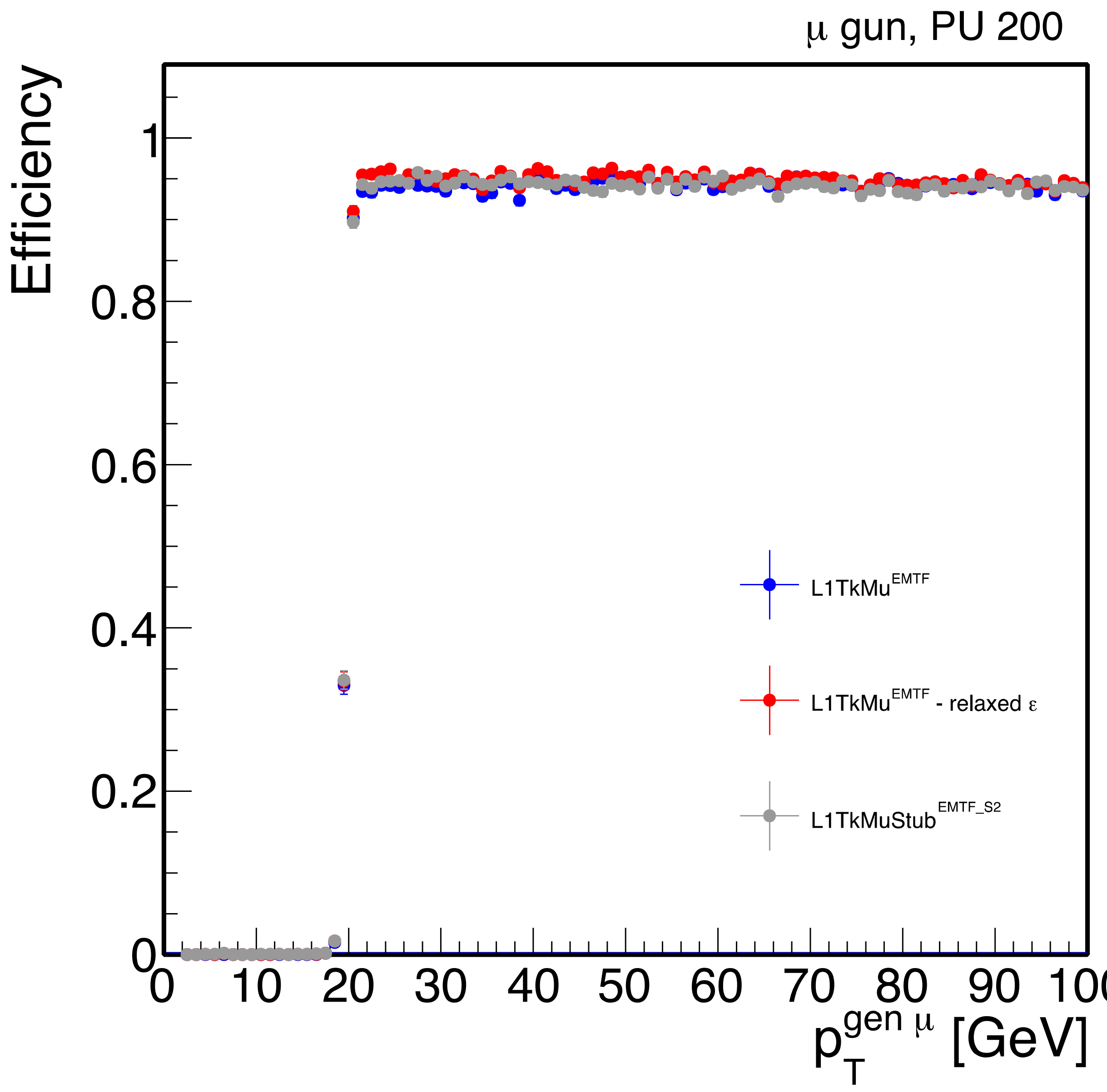
Phase-II Muon Level-1 Trigger in the EndCap

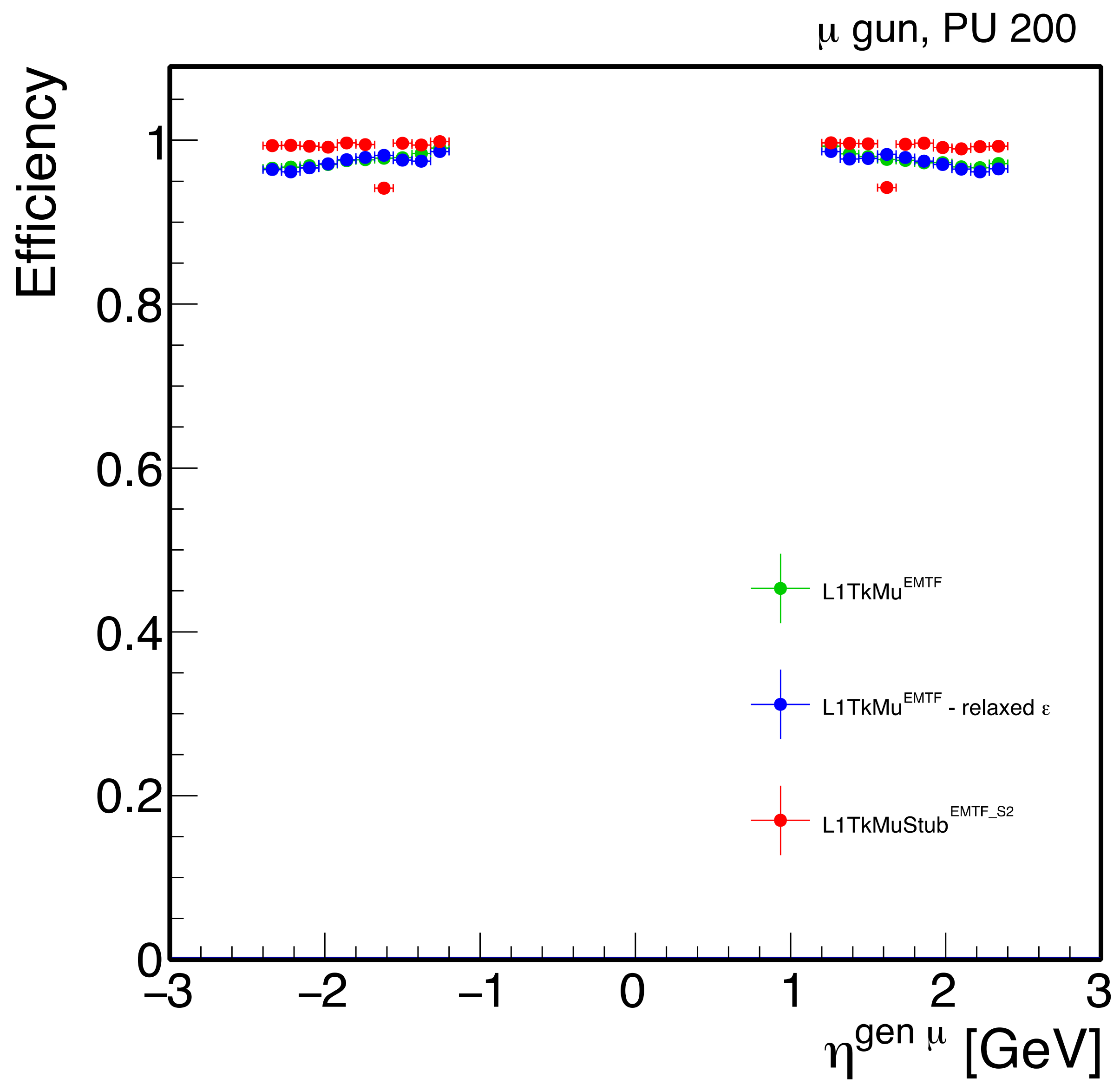


VINS Developed Tracker Track + μ Stub trigger

- 10 x reduced rate of standalone EndCap μ trigger







FARMING (CPU)

Serbia Tier-1

- 11.5 k cores (23 k threads, 170 kHS06)
- 5/6 racks with CPU with TOR switches
- 180 CPUs with 64 cores @ ~280 W

- Options 5 racks, per rack:
  - 36 U
  - 10 kW CPU
  - 5 kW cooling
- Options 6 racks, per rack:
  - 30 U
  - 8.4 kW CPU
  - 4.2 kW cooling

Management: In the Top of the Rack (TOR) architecture, each cabinet can be considered as an independent management entity. Servers and switches can be upgraded by cabinet while the traffic forwarding of other cabinets is not affected and impact on services is minimized.

Configuration options
with HUAWEI TOR Switches

TOR SWITCH

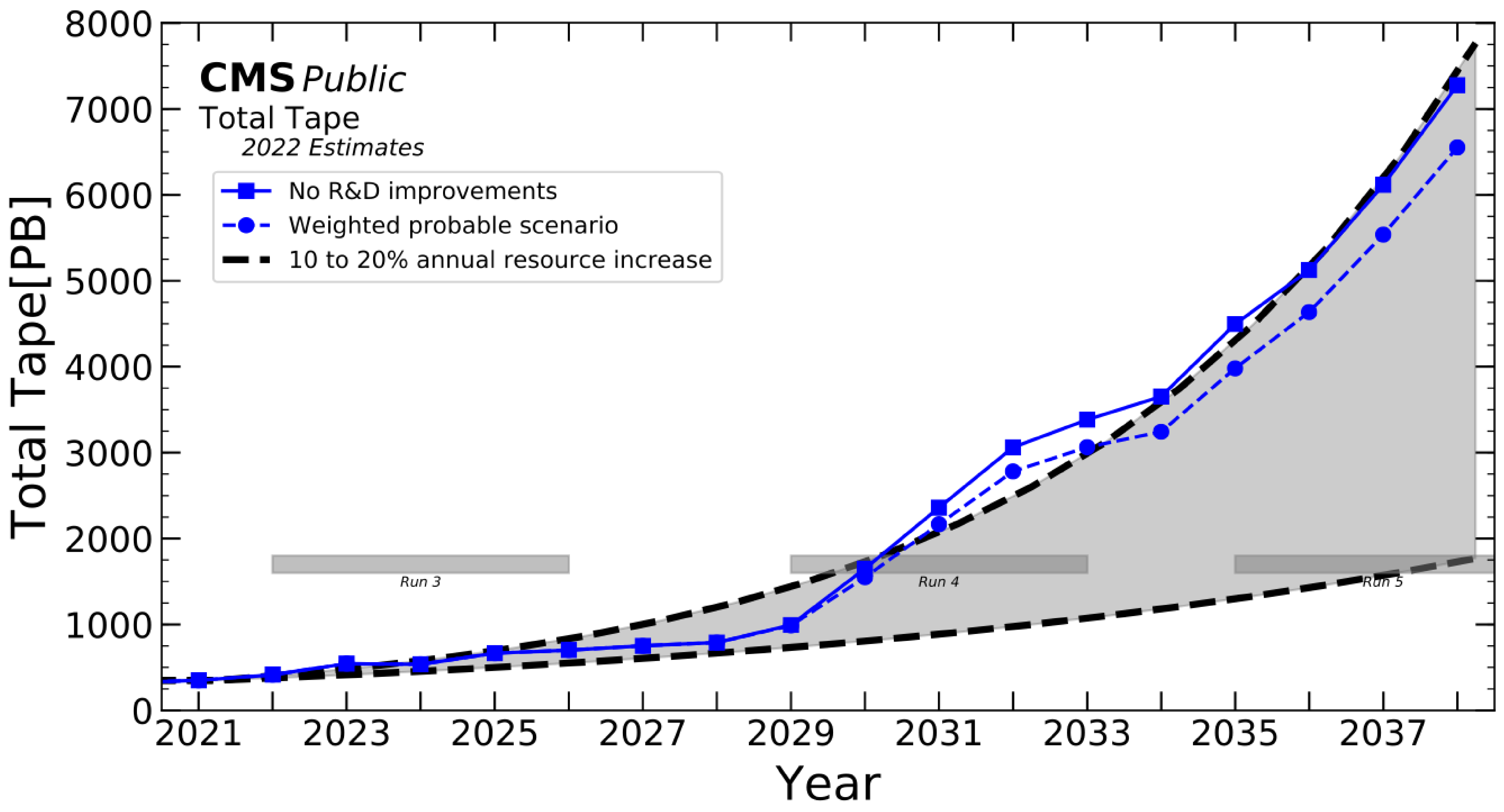
- in a server cabinet (1/2U)
- Huawei CE5800, CE6800 series .

TOR SW Huawei CloudEngine 6863

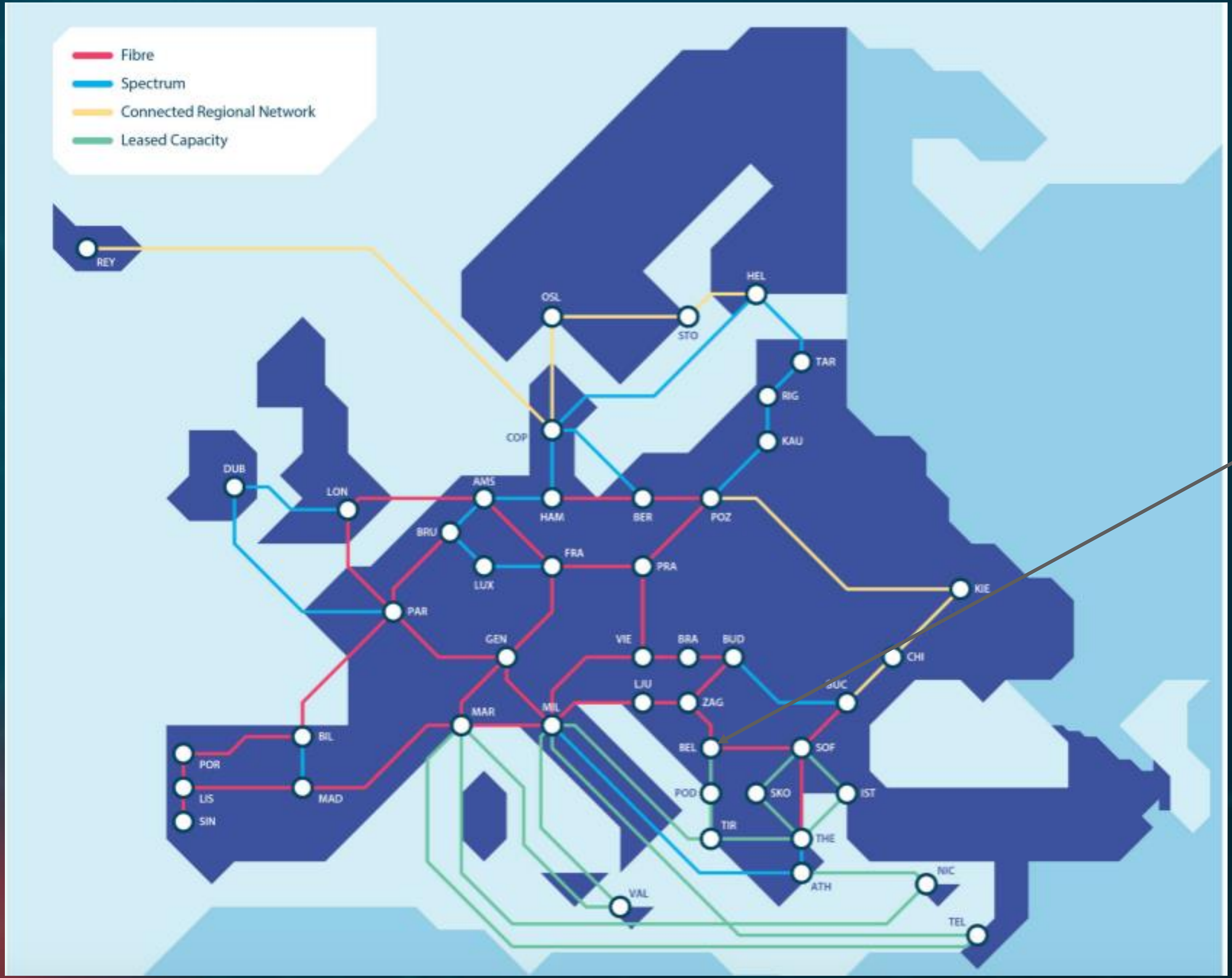
- Uplink: 6 x 40/100 GE QSFP28
- Downlink: 48 x 10/25 GE SFP28

Need for R&D in (HL-) LHC computing

- Simple doubling of T1 resources would not suffice
- SSC-T1 would like to contribute in scientific R&D to provide improvements. Potential areas
  - Computing
    - CMSSW
    - ROOT
    - Alternative processors
  - Disc-Storage
    - CEPH for HEP storage
- VERY IMPORTANT aspect of the design is to create a platform so that scientist and students can contribute



Serbia NETWORK connectivIty



Serbia well integrated in GEANT.

- collaboration of European National Research ar Education Networks (NRENs)
- Academic Network of Serbia (AMRES)

Connection to CERN good.

- Belgrade and DC connected to CERN via DarkFiber

LHC-OPN (1 or few x 100 G GEANT via DarkFiber)

LHC-ONE (State TC, via DarkFiber Amsterdam,CERN

State of the Art computing Data Center in Serbia

- CMS Tier-1 In Serbia
- Providing services satisfying conditions
  - Availability
  - Reliability
  - Maintainability
  - Connectivity