# ADVANCED CALCULUS for FUNDAMENTAL INTERACTIONS

**one-day Scientific Flash-mob del Gruppo Teorico**

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*Galileo Galilei*
University of Padova - Italy

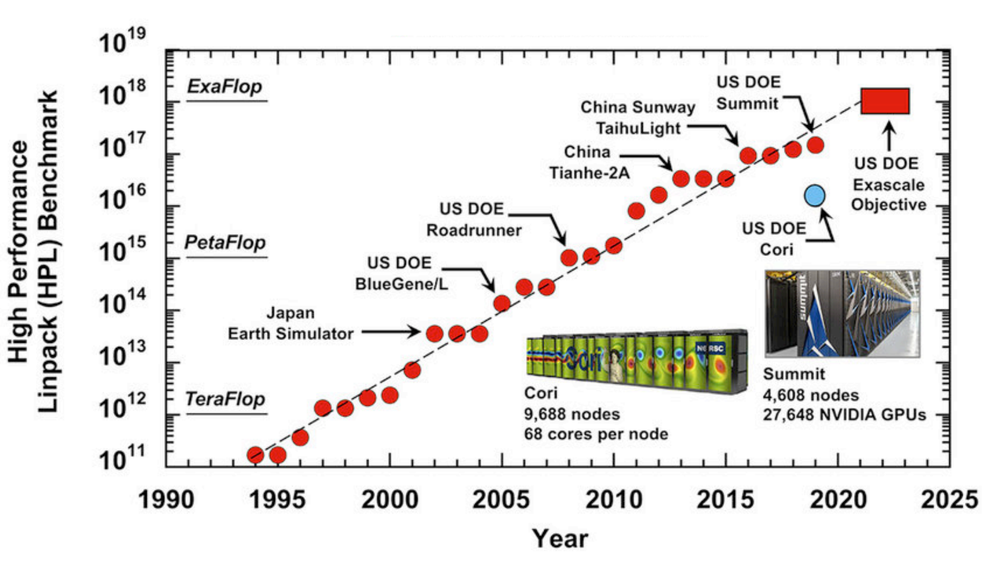
Istituto Nazionale di Fisica Nucleare

# Motivations

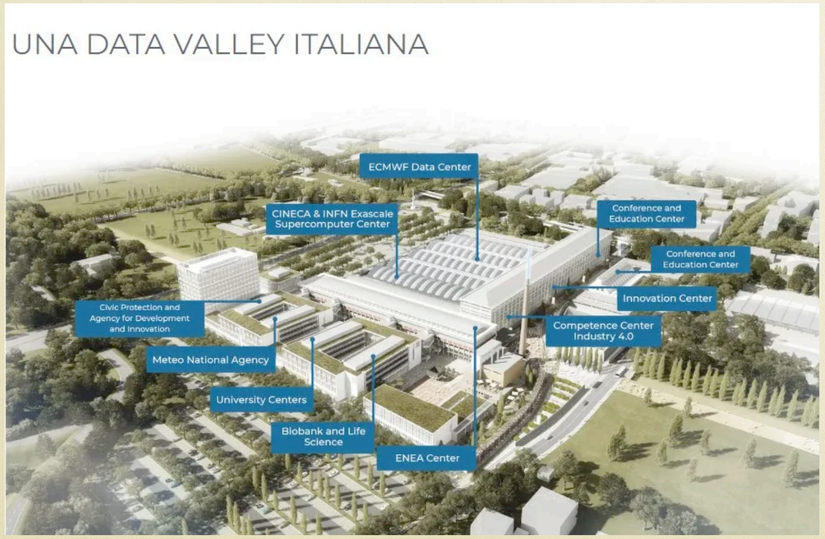
- Three reasons that triggered this meeting
  - A PNRR initiative
  - An INFN initiative
  - An interdisciplinary activity

# PNRR e SuperCalcolo Exascale : 1,000,000,000,000,000,000 Flops

- Advancement of HPC developments




- Tecnopolo *Cineca* a Bologna




- Centro Nazionale HPC, BD e QC


Leonardo at Cineca [video link]

# CN1.HPC.Spoke2 / Fundamental Research & Space Economy

- Spoke2 & Work Packages
  - WP1. Theoretical Physics
  - WP2. Experimental Particle Physics
  - WP3. Experimental Astro-Particle Physics
  - WP4. Boosting the Computational Performances
  - WP5. Architectural Support

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- **Spoke2 & Work Packages**
  - **WP1. Theoretical Physics**

a. Development of algorithms, codes and computational strategies for the simulation of physical theories and models, towards pre-Exascale and Exascale architectures.
b. Theoretical research projects in domains already using HPC solutions, such as:
    i. lattice field theory (flavour physics, QCD phase diagrams, hadronic physics, interactions beyond the Standard Model, machine learning in quantum field theories, electromagnetic effects in hadronic processes);
    ii. collider physics phenomenology;
    iii. gravitational waves, cosmology and astroparticle physics (neutron-star physics, primordial universe, dark matter and energy, neutrino physics);
    iv. nuclear physics;
    v. physics of complex systems (fluid dynamics, disordered systems, quantitative biology);
    vi. condensed matter in low dimensional systems;
    vii. quantum systems (entanglement, quantum simulations, quantum information).

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# Usecase HPC.spoke2.WP1 /ADVANCED CALCULUS FOR PRECISION PHYSICS

**Nodes: UNIBO - UNICAL - UNIMIB - UNIPD**

N. Bartolo, R. Gröber, M. Liguori, F, Maltoni, P. Mastrolia, M. K. Mandal, C. Oleari, A. Papa, T. Peraro, A. Raccanelli, E. Re, E. Salvioni, M. Zanetti

- **Five research directions:**

- **1. Models & Diagrams**
- **2. Amplitudes & Integrals**
- **3. Cross Sections & Events**
- **4. Physics at Colliders**
- **5. Beyond Colliders**

The software developed in this research program will have a major impact on Collider Phenomenology, as well as on Cosmology and Mathematics.

- Standard Model Physics
- Beyond Standard Model Physics
- Parton Distributions Functions
- Higgs boson and Heavy Particles Physics
- Effective Field Theories for Quantum and Classical Physics
- Scattering Amplitudes
- Physics of the Universe and Gravitational Waves Physics
- Computational Algebraic Geometry

# Iniziativa Specifica INFN /AMPLITUDES

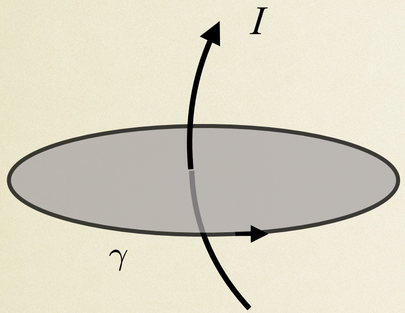
| **Sezioni** | *Bologna* | *LNF* | *Napoli* | *Padova* | *Roma* | *Torino* |
|---|---|---|---|---|---|---|
| **Responsabili** | T. Peraro | V. Del Duca (P.I.) | F. Tramontano | P. Mastrolia | R. Bonciani | S. Badger |

| **Partecipanti** | *Staff* | *Postdoc* | *PhD* |
|---|---|---|---|
| **Nazionali** | 10 | 4 | 3 |
| **Locali** | P. Mastrolia, R. Groeber, P. Paradisi, M. Passera, M. K. Mandal | - | G. Brunello, G. E. Crisanti |

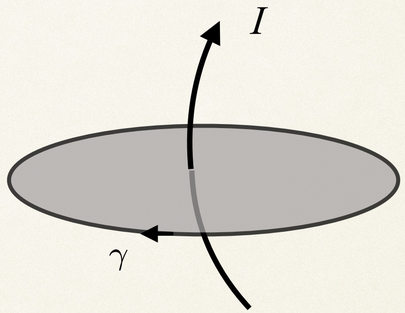
| **Temi di Ricerca** | *Analytic Structure of On-Shell Amplitudes* | *Computational Methods for Multiscale Amplitudes* | *Applications to High-Energy Particle Physics* | *Applications to Gravitational Waves Physics* |
|---|---|---|---|---|
| **Progetti e Attività** | • High Energy Behaviour<br>• Multi-collinear Factorisation<br>• **Mathematical Structures** | • **Integral Relations**<br>• **Differential Equations**<br>• **Intersection Numbers** | • Subtraction Methods<br>• Two-loop five-particle Processes<br>• **Top-quark Precision Physics**<br>• **Higgs-boson Precision Physics**<br>• **EFT and On-Shell Methods** | • **Binary Systems and Radiation**<br>• **Post-Newtonian Corrections**<br>• **Post-Minkowsian Corrections** |

[in grassetto sono indicate le attività a cui collabora la sez. Padova]

# Ampere's Law: *Stokes, Riemann, de Rham, Morse and Feynman*




$$\oint_\gamma \mathbf{B} \cdot d\vec{\ell} = \mu_0 I$$

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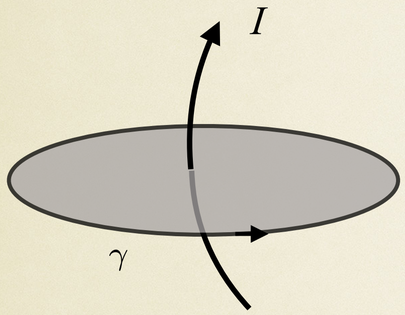


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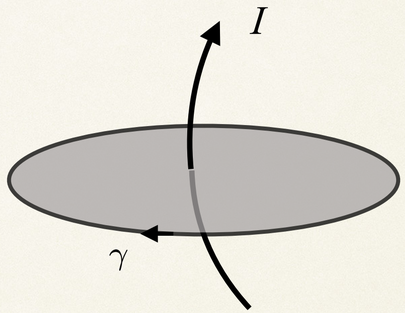


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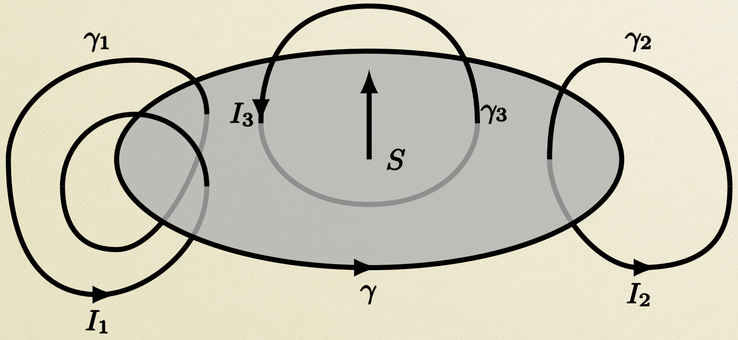



- **Integral decomposition by geometry**

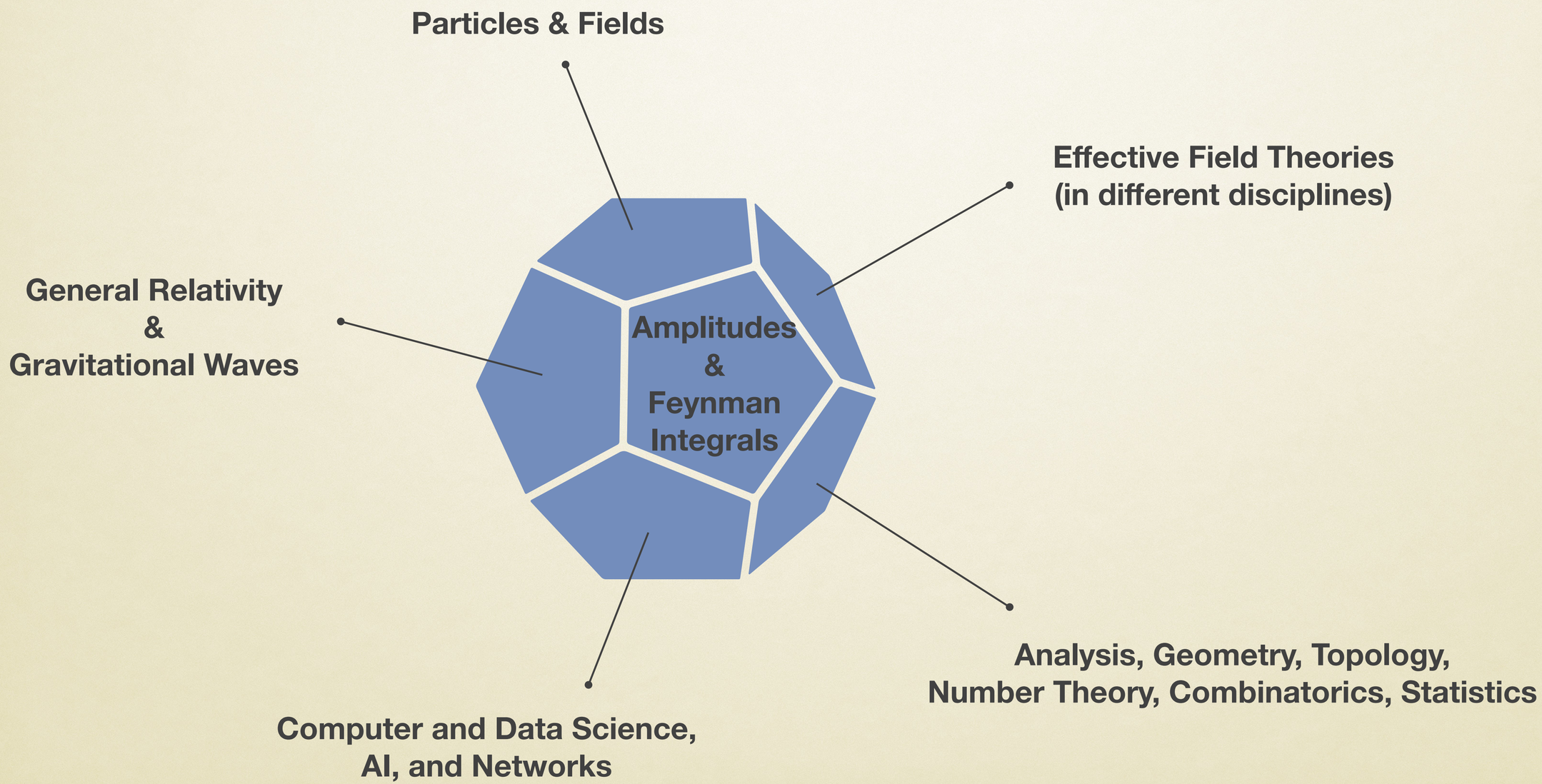
$$\oint_\gamma \mathbf{B} \cdot d\vec{\ell} = \mu_0 \sum_k (\pm n_k) I_k \qquad n_k = \mathrm{Link}(\gamma_k, \gamma)$$

Master Contributions

Gauss' Linking Number

$\mathrm{Link}(\gamma_1, \gamma) = +2$, $\mathrm{Link}(\gamma_2, \gamma) = -1$, and $\mathrm{Link}(\gamma_3, \gamma) = 0$

# Scattering Amplitudes: interdisciplinary toolbox



# ~~Conclusion~~ Beginning

- Novel methods and algorithms, new ideas and novel technology will help the investigation of Nature at its most extreme and critical conditions, at all scales.
- Numerical, Analytic, and Symbolic Calculus is ubiquitous.
- Physics as Applied Geometry: the legacy of Galileo.

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Let's enjoy the day:
*thank you all for contributing to it!*