Theory and Phenomenology

Alberto Lerda

CSN4

U.P.O. “A. Avogadro” and INFN (Torino/Alessandria)

Laboratori Nazionali di Frascati, October 5, 2012

Summary

- **Structure and organization of CSN4**
- **Research activity in CSN4**
    - Topics and a few scientific highlights
- **The GGI in Florence**
- **Computing, training and other activities**

Structure and organization of CSN4

CSN4

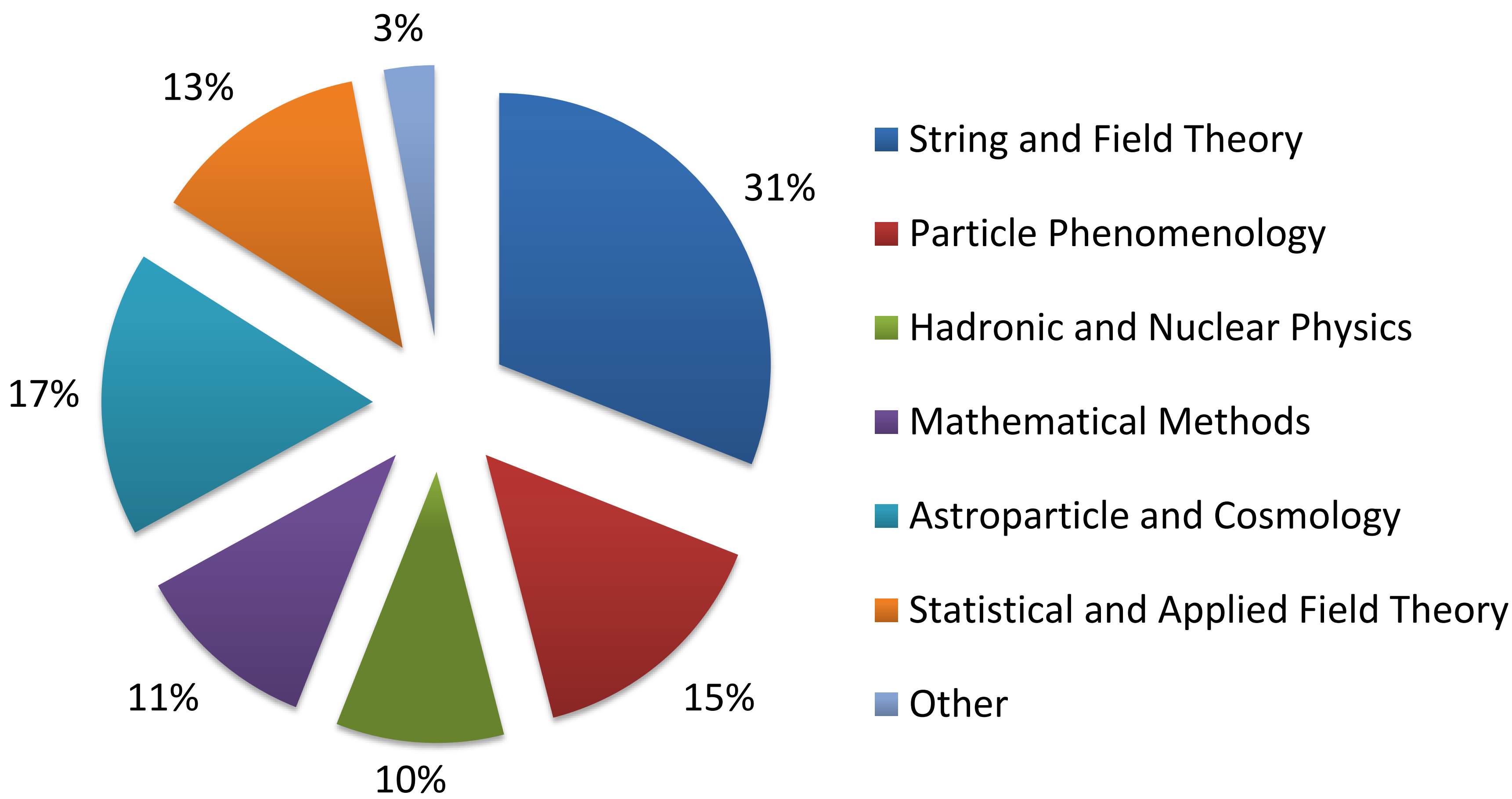
- The research activity is organized in six sectors
  (each of them supervised by two internal referees):

  1. **String and Field Theory**
  2. **Particle Phenomenology**
  3. **Hadronic and Nuclear Physics**
  4. **Mathematical Methods**
  5. **Astroparticle Physics and Cosmology**
  6. **Statistical and Applied Field Theory**

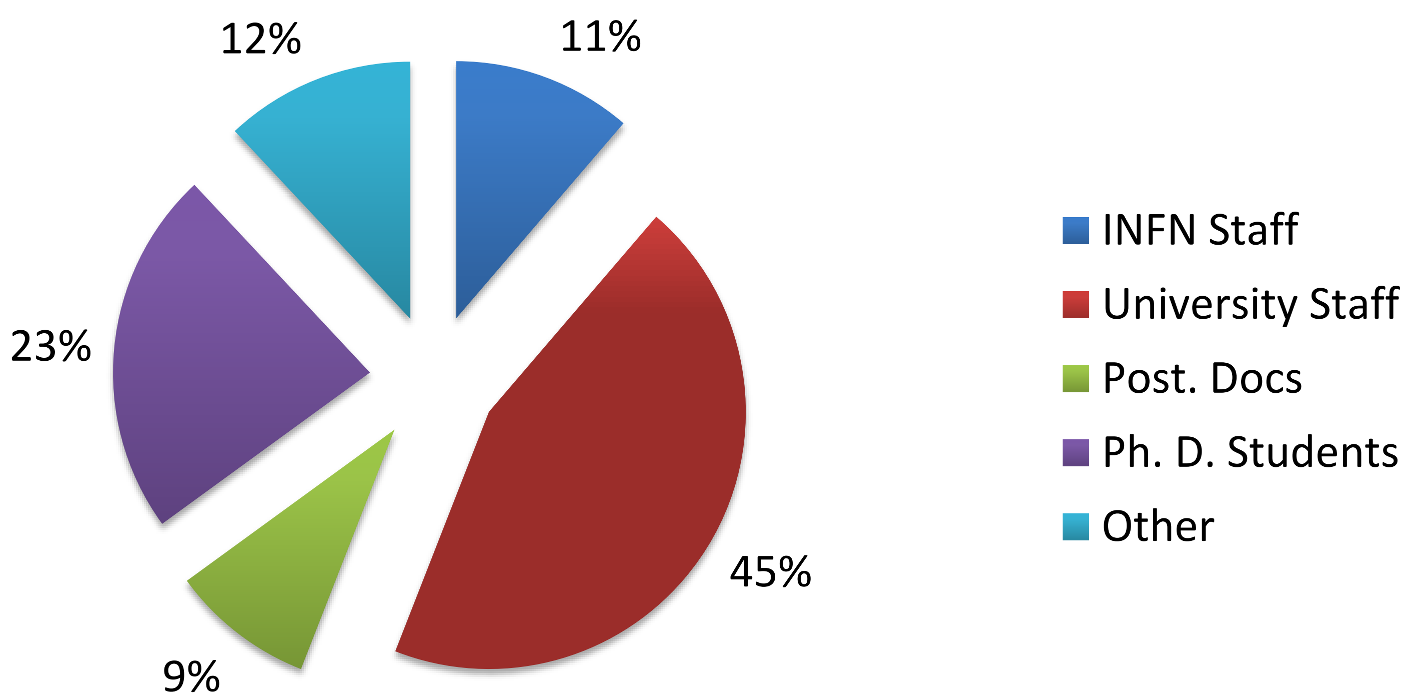
with a complete coverage of the main topics and research subjects

FTE in CSN4

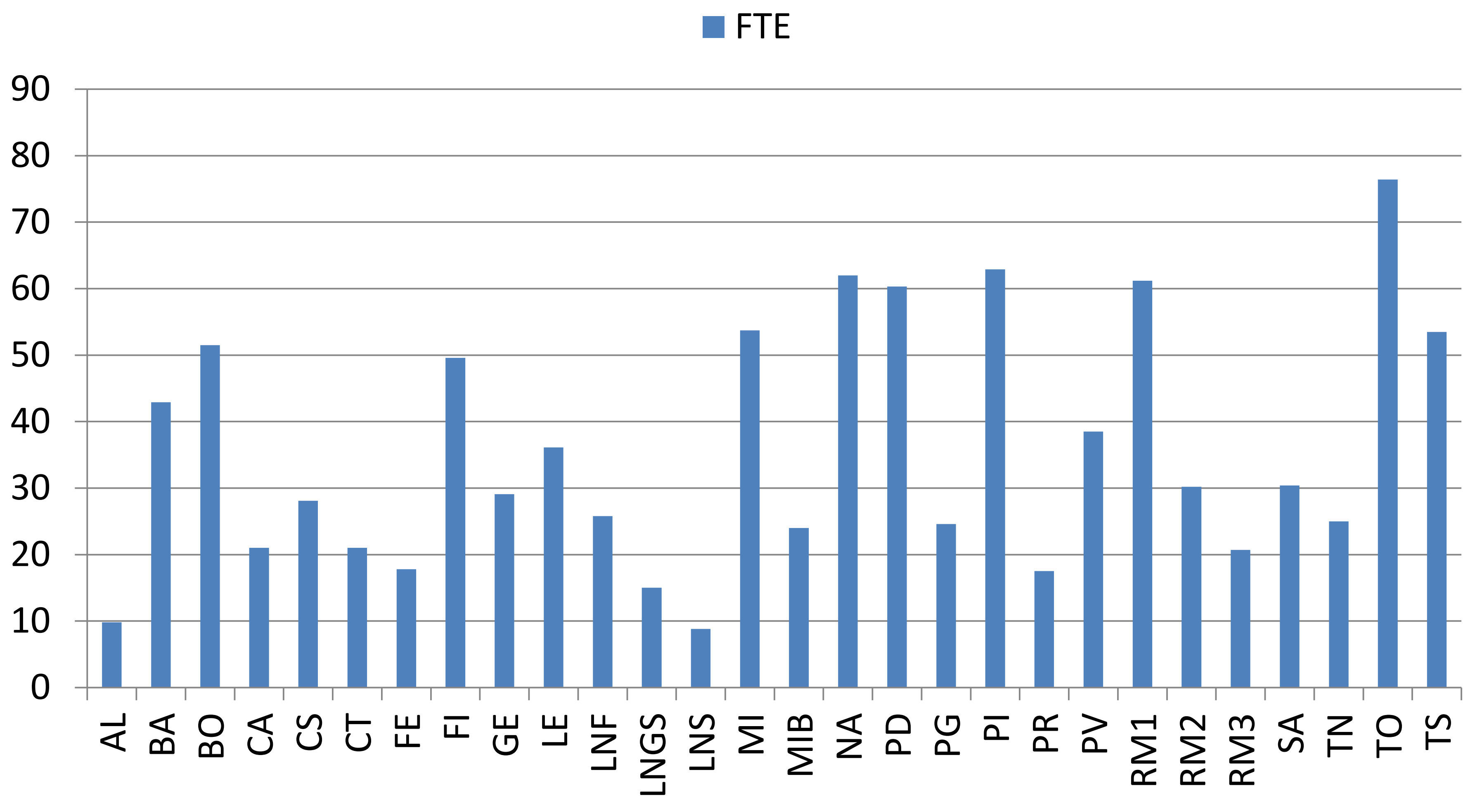
- In 2011/2012 the CSN4 activities involved slightly more than **1000 physicists**, corresponding to **973 FTE**, distributed as follows:



Distribution of FTE in CSN4 among categories



Distribution of FTE among the INFN sections



Research activity in CSN4

CSN4 Research

- The CSN4 activity is developed in close connection with the academic world and other scientific institutions, both in Italy and abroad
- The research activity is currently organized in **50 groups**, called "**Iniziative Specifiche**" (IS) whose distribution in the six sectors is

CSN4 Sector	Number of IS
String and Field Theory	12
Particle Phenomenology	11
Hadronic and Nuclear Physics	9
Mathematical Methods	6
Astroparticle and Cosmology	5
Statistical and Applied Field Theory	7

Publications (2011)

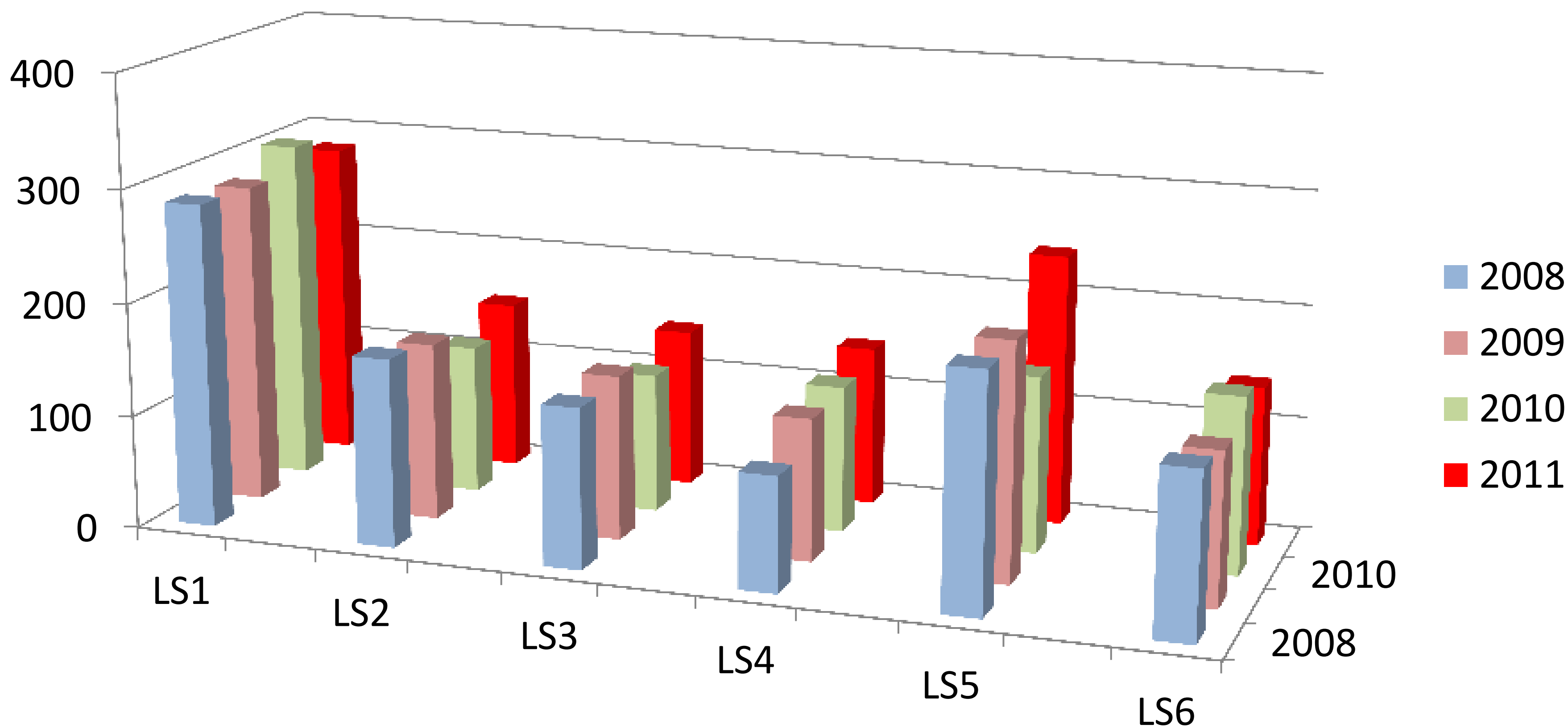
- In 2011 the CSN4 physicists published **1112 papers (+101)** on refereed scientific journals

- The distribution of published papers among the six sectors is

CSN4 Sector	FTE (2011)	% FTE	Papers	Papers/FTE
String and Field Theory	304.1	31.2	313.5	1.03
Particle Phenomenology	143.4	14.8	137.6	0.96
Hadronic and Nuclear Physics	92.9	9.6	128.6	1.38
Mathematical Methods	110.3	11.3	142.5	1.29
Astroparticle and Cosmology	163.8	16.8	218.1	1.33
Statistical and Applied Field Theory	124	12.7	150.7	1.22
Other	34.5	3.6	19	
Total	**973**	**100**	**1112 (+101)**	

- The high-level productivity of CSN4 obtained in the previous years has been confirmed also in 2011.

Number of publications (2008 – 2011)



- Total number of papers (2008-2011) : **4587** **(1112 in 2011)**
- Total number of ISI citations (2008-2011) : **31983** **(3857 in 2011)**

Int'l Collaborations

International collaborations are strongly supported and the INFN agreements with ITEP, JINR, IHEP (Russia), MEC (Spain), MIT (US), ICTP and ECT* (Italy) are intensively used by CSN4 members.

Which are the countries we mainly publish with?

Country	% (2011)	% (2010)	% (2009)
USA	25	27	25
SPAIN	21	18	17
GERMANY	20	18	19
UK	18	9	16
FRANCE	17	19	18
SWITZERLAND	11	9	10
RUSSIA	9	9	9
JAPAN	6	4	7
CHINA	5	5	--

Research Topics and Scientific Highlights

(only very few due to lack of time and of competence)

CSN4 Research Lines

1. **String and Field Theory (31%)**
   - String theory, D-branes, M-theory, F-theory, Supergravity, AdS/CFT, Quantum Gravity, Non-perturbative Effects, Lattice Gauge Theories, Confinement
2. **Particle Phenomenology (15%)**
   - Standard Model and Beyond (Susy breaking, Extra dimensions), Higgs, QCD at Colliders (MC simulations,…), (Heavy) Flavor Physics, AdS/CFT and QCD
3. **Hadronic and Nuclear Physics (10%)**
   - Nuclear Structures, Heavy Ion Collisions, Confined Hadronic Matter, Quark Gluon Plasma, Spin Physics
4. **Mathematical Methods (11%)**
   - General Relativity, Quantum Theory (foundations, chaos,…), Integrable models
5. **Astroparticle and Cosmology (17%)**
   - Neutrino physics, Dark Matter, Dark Energy, Gravitational Waves, Cosmological Models, Nuclear Astrophysics
6. **Statistical and Applied Field Theory (13%)**
   - Spin Glasses, Complex Systems, Non-equilibrium Physics, Applications (Condensed Matter, Nanostructures, Turbolence, Biology,…)

Particle Physics in one slide
(almost...)

$$\mathcal{L}_{sm} = -\frac{1}{2}\,\mathrm{tr}\,F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\Psi$$
$$+|D_\mu h|^2 - V(h)$$
$$+\,\Psi_i\,\lambda^{ij}\,\Psi_i\,h + \mathrm{c.c.}$$
$$+\,N_i M^{ij} N_j$$
$$+\cdots$$

Particle Physics in one slide

(almost...)

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$$+\cdots$$

The gauge sector

Particle Physics in one slide
(almost...)

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$$+\cdots$$

The EWSB sector

Particle Physics in one slide

(almost...)

$$\mathcal{L}_{sm} = -\frac{1}{2}\,\mathrm{tr}\,F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\Psi$$

$$+|D_\mu h|^2 - V(h)$$

$$+\,\Psi_i\,\lambda^{ij}\,\Psi_i\,h + \mathrm{c.c.}$$

$$+\,N_i M^{ij} N_j$$

$$+\cdots$$

The flavour sector

Particle Physics in one slide

(almost...)

$$\mathcal{L}_{sm} = -\frac{1}{2}\,\mathrm{tr}\,F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\Psi$$

$$+|D_\mu h|^2 - V(h)$$

$$+\,\Psi_i\,\lambda^{ij}\,\Psi_i\,h + \mathrm{c.c.}$$

$$+\,N_i M^{ij} N_j$$

$$+\cdots$$

The neutrino mass sector

Particle Physics in one slide
(almost...)

$$\mathcal{L}_{sm} = -\frac{1}{2}\,\mathrm{tr}\,F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\Psi$$
$$+|D_\mu h|^2 - V(h)$$
$$+\Psi_i\,\lambda^{ij}\,\Psi_j\,h + \mathrm{c.c.}$$
$$+N_i M^{ij} N_j$$
$$+\cdots$$

Very many things ...

The gauge sector

$$\mathcal{L}_{sm} = -\frac{1}{2}\,\mathrm{tr}\,F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\Psi + \cdots$$

In CSN4 there is an intense on-going activity in QCD:

Perturbative QCD at colliders and PDF:

quark and gluon distribution functions in the proton (essential ingredients for the theoretical predictions of all LHC cross sections). A fitting code (NNPDF) developed also by members of the CSN4 is now employed by all experimental collaborations.

NLO and NNLO amplitudes:

twistors, unitarity methods, numerical methods,... These are used in many of the predictions for the Higgs related observables at LHC (soft-gluon resummation at NNLO for total cross-section and transverse momentum distribution,...).

QCD scattering amplitudes:

all-order structure of (infrared and collinear) singularities of QCD scattering amplitudes, both at finite orders and including the resummation of soft-gluon effects.

The EWSB sector

$$\mathcal{L}_{sm} = \cdots + |D_\mu h|^2 - V(h) + \cdots$$

The LHC results have triggered an intense activity also in CSN4:

<u>Properties of the discovered «Higgs» boson</u>:

J^{PC}, production cross sections, branching fractions, SM Higgs vs not-SM Higgs...

<u>Search for signals of New Physics</u>:

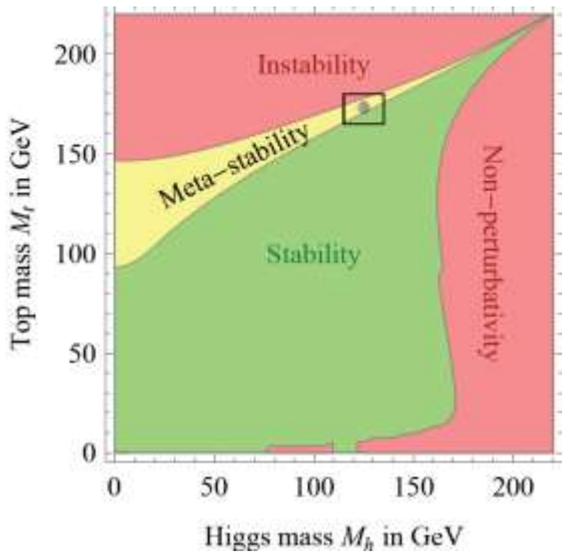
SUSY particles, Extra-dimensions,...

<u>Naturalness of the «Higgs» boson</u>

FT problem, ...

<u>Origin of the ew scale and stability of the SM vacuum:</u>

The observed M_h is close to the minimum value for absolute stability of the SM vacuum



NNLO calculations (performed by a group including several physicists from the CSN4) indicate that **absolute stability of the Higgs potential seems to be excluded at the 98% C.L**. if the Higgs mass is under 126 GeV. What does this mean?

The Flavour Sector

$$\mathcal{L}_{sm} = \cdots + \Psi_i \lambda^{ij} \Psi_j h + \text{c.c.} + \cdots$$

In CSN4 there is a traditional actvity in various directions of FP:

FlaviaNET and UTFit collaborations

<u>Search for New Physics through understanding of the Flavour Sector</u>:

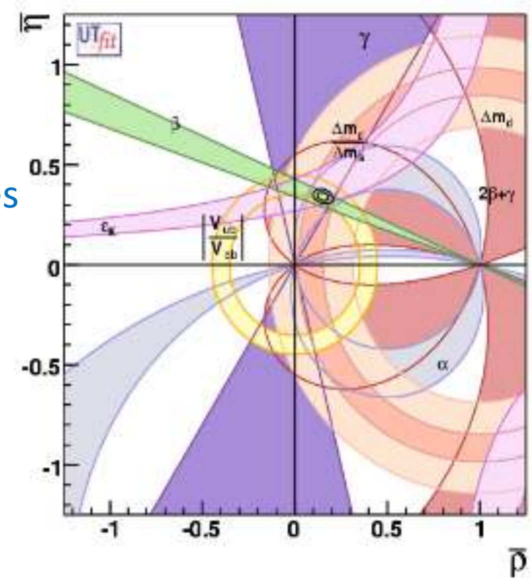
- CP violation in non-leptonic decays
- (g-2) for the muon
- h → ϒ ϒ excess

<u>Lattice Gauge Theories:</u>

- Non-perturbative calculations of correlators from first principles
- ...

<u>Analysis of the CKM matrix elements</u>

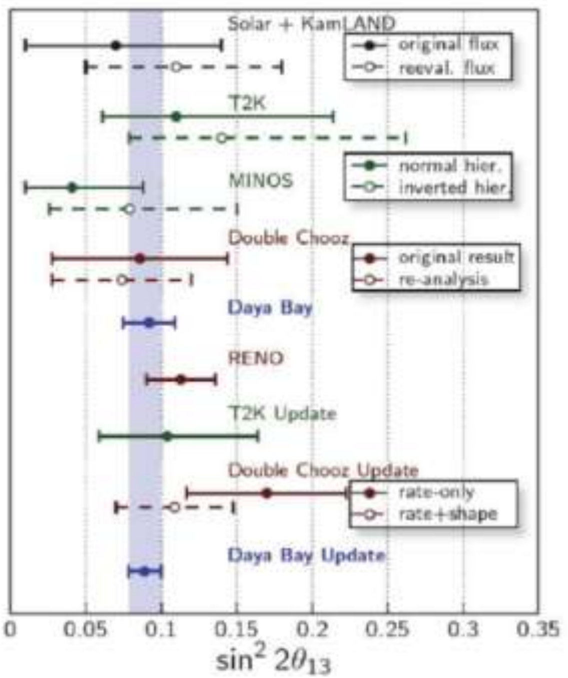
- Unitarity Triangle Analysis
- ...



The neutrino mass sector

$$\mathcal{L}_{sm} = \cdots + N_i M^{ij} N_j + \cdots$$

Several interesting and open questions are investgated in CSN4:



<u>Neutrino properties</u>:

- Dirac or Majorana?
- Neutrino mass hierarchy
- Number of neutrino families
- ...

<u>Neutrino oscillations:</u>

Indication of a non-zero Θ_{13} obtained by **a group of CSN4 researchers** with a global analysis of all available data including those from the T2K and MINOS longbaseline accelerator experiments.

This analysis has been recently updated by including also high-precision measurements of Θ_{13} at the short-baseline reactor experiments Daya Bay and RENO, confirming the previous indications.

The rest

$$\mathcal{L}_{sm} = \cdots + \cdots$$

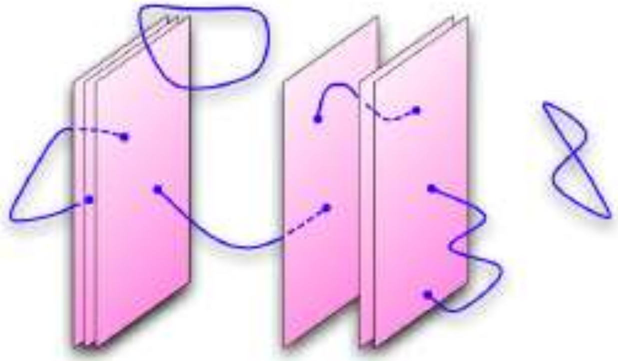
Very many (and very interesting) things

- Dark Matter – Dark Energy
- Supersymmetric particles
- Extra – dimensions
- Non-perturbative effects
- …

- **GRAVITY**

All these issues are actively investigated by various groups in CSN4

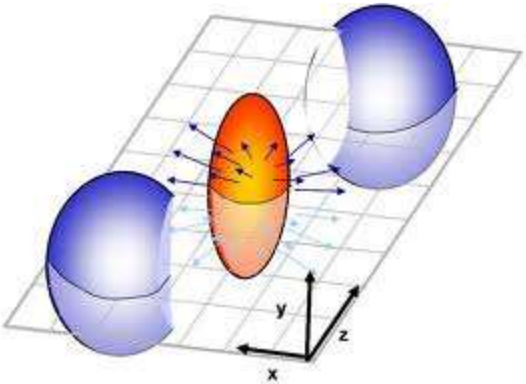
More formal research



- **String theory** and **D-brane** physics
- (Super)gravity
- (Supersymmetric) Field Theories
- AdS/CFT correspondence: **holography**
  - a new way to look at gauge theories (gauge/gravity correspondence)
  - applications to QCD, hydrodynamics, condensed matter systems
- New methods and techniques to compute **amplitudes**
  - Even if formal, these methods have been very inspiring and **are useful** for practical calculations directly relevant for LHC
- Problems in **quantum gravity**
  - Black Hole entropy
  - ...

Hadron and Nuclear Physics

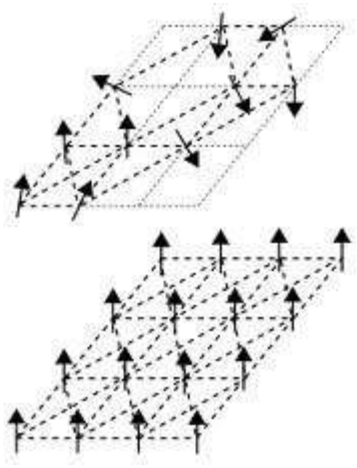
- **Heavy Ion collisions at LHC (ALICE) and RHIC**
  - Small x physics and saturation
  - Jet physics (quenching, multiplicity, energy loss, shear viscosity…)
  - Heavy flavour emission and suppression



- **Hadron Matter and QCD-like models**
- **Quark Gluon Plasma**
- **Hadron fragmentation**
- **Nuclear structure and reactions**

Applied Field Theory

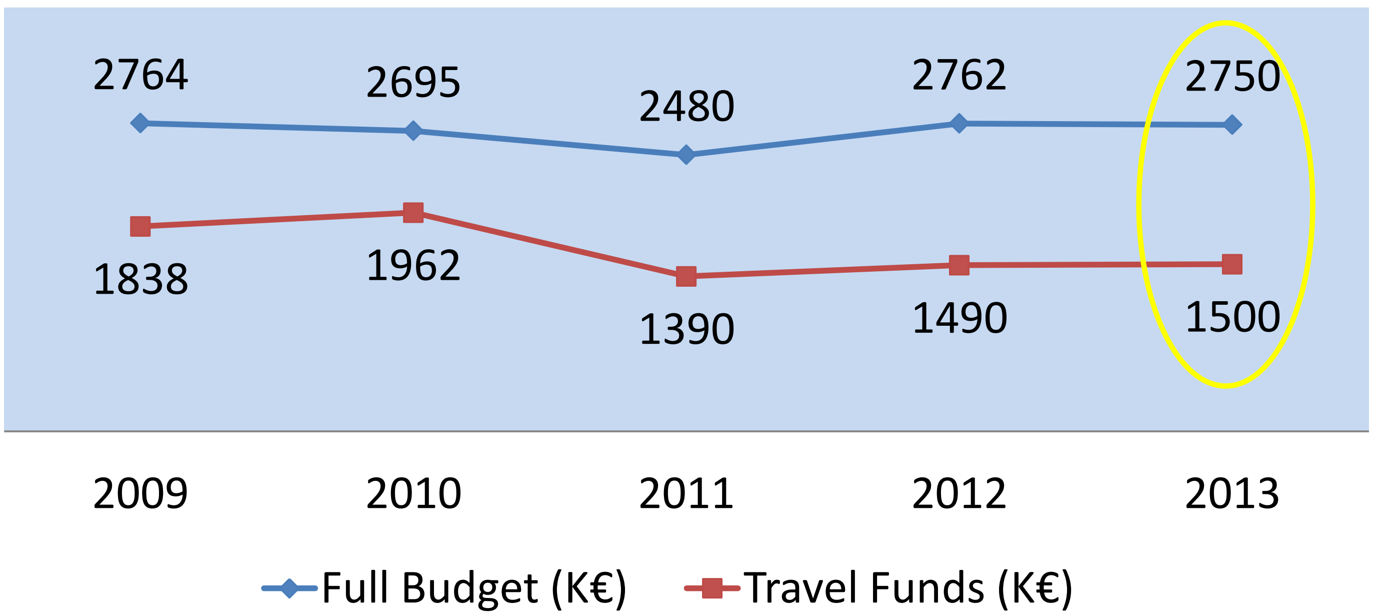
- **Non-Perturbative QFT applied to statistical systems:**
    - Quantum Hall Effect and Superconductivity
    - Strongly correlated electron systems, BEC
    - Non-equilibrium statistical mechanics



- **Turbolence, Disordered Systems**
- **Spin Glasses and Complexity**
- **Quantitative biophysics:**
    - Protein folding, Genetic functions and regulation, Properties of DNA Structure functions and duality
- **Nanostructures, Syncrotron radiation**
- **Strongly correlated electron systems**

CSN4 Budget

- The CSN4 budget is represented in the following (the numbers **do not** include inflation effects)



- The travel funds are the essential part of the budget for the theoretical activities!!

	2009	2010	2011	2012	2013
% of travel funds	66.5%	72.8%	56.0%	53.9%	54.5%

Summary

- Very large spectrum of research subjects (much broader than those of INFN)
- Leadership in several fields
- Continuing high-level activity in String and Field Theory, Nuclear Theory and Statistical Physics
- **Increasing phenomenological activity** related to LHC experiments
- **Increasing interest in astroparticle** and cosmology

- Unfortunately the number of INFN and University staff is **rapidly decreasing** and the average age is **steadily increasing**

The GGI in Florence

The Galileo Galilei Institute (GGI)

The Galileo Galilei Institute for Theoretical Physics in Arcetri (GGI), an initiative of CSN4 since 2005, has achieved an impressive record of high-level activities and by now is counted among the leading international institutes for the organization of long-term workshops.

The Galileo Institute, funded by INFN and sponsored by INFN and the University of Florence, is located in Arcetri, near the house where Galileo spent periods of his life and died in 1642, in a building owned by the University of Florence.

In the period 2006 – 2012 there have been 18 extended workshops

Subject	# of workshops
String Theory and Quantum Field Theory	6
Standard Model (and beyond) Phenomenology	5
Astroparticle Physics and Dark Matter	4
Statistical Physics and Complex Systems	3

The average number of participants per workshop is 85. Among these, about 25% are Italians.
With 3 workshops every year, this means about **250 visitors** per year (plus the participants to the conferences and schools).

GGI Workshops

- **Just finished** :

  New Frontiers In Lattice Gauge Theories

- **Future Workshops**

  10-2012 Understanding the TeV Scale Through LHC Data, Dark Matter And Other Experiments

  03-2013 Higher Spins, Strings and duality

  05-2013 Beyond the Standard Model After the First Run of LHC

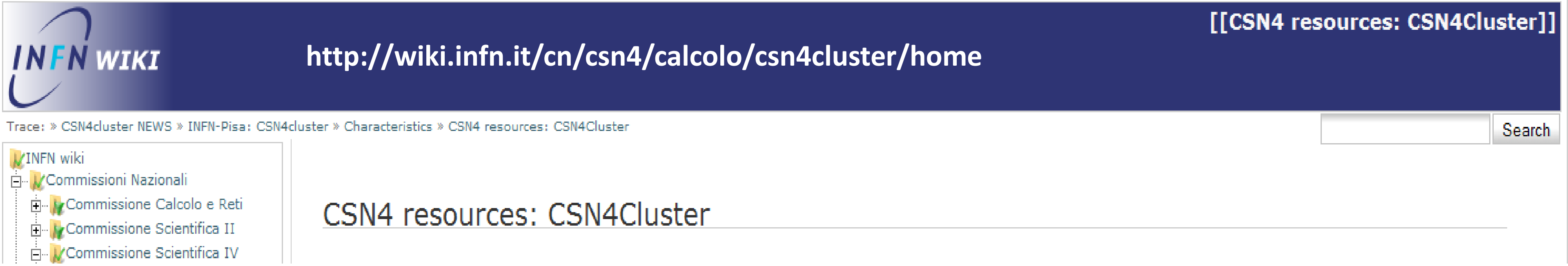
  08-2013 Geometry of Strings and Fields

Other activities like **schools, focus-weeks, satellite conferences,…** are planned

Computing, training and other activities

Computing: the CSN4cluster in Pisa

- In early 2010 the CSN4 promoted a new project named **"CSN4cluster“**, aiming at providing a centralized facility for parallel and serial computations reserved for the theoretical physics community.
- The installation has been finalized in the summer of 2010 at the site of the **INFN Section of Pisa** and the technical management is provided by the local staff of the “Settore Calcolo Scientifico di Sezione”
- This service is provided for the **period 2010-2012**, but the cluster is planned to remain operational **even after year 2012**.
- The CSN4 is considering the possibility of upgrade or hardware expansions.



Computing: the CSN4cluster in Pisa

News from the CSN4Cluster web-site:
http://wiki.infn.it/cn/csn4/calcolo/csn4cluster/home

May-2012	Added a new Computing Element (gridce4.pi.infn.it) supporting the new middleware EMI-1
Dec-2011	The cluster has a single partition for parallel jobs (1024 cores). Serial jobs are used to fill the unused job slots
Sep-2011	Second CSN4cluster and parallel computing on the grid tutorial
14-Apr-2011	CSN4cluster inauguration
Apr-2011	First CSN4cluster tutorial
Dec-2010	Parallel partition is up and running
Dec-2010	Cluster partitioned: 64 nodes for serial jobs, 63 nodes for parallel jobs
Oct-2010	The cluster is officially working for serial jobs
Jul-2010	The cluster is under testing for serial Serial Jobs

Training

- The CSN4 devotes continuous attention and substantial resources to training young researchers during their undergraduate, graduate, and post-doctoral studies :

	CSN4	INFN (total)	CSN4/INFN
Laurea	**137**	311	**44%**
Laurea Magistralis	**143**	367	**39%**
Ph.D.	**75**	174	**43%**

- Ph.D. students and post-docs amount to **1/3** of the whole CSN4 FTE!

- Since 2005, the CSN4 awards the “Sergio Fubini Prize” to the best three doctoral thesis of the year (most of the winners are post-docs abroad). In 2011 the Fubin prize was awarded to Ph.D. theses on:
    - Supersymmetry Breaking in Grand Unified Theories
    - Applications of Perturbation Theory in Black Hole Physics
    - The Three-Dimensional Gauge Glass Model.

CSN4 @ LHC

- In 2010 a new joint effort between the ATLAS and CMS collaborations on one side and the theory community on the other side was announced and a new LHC-wide working group has been created
- The aim of this group is to produce agreements on cross sections, branching ratios and pseudo-observables relevant to SM and MSSM Higgs bosons, which will facilitate comparison and combination of results.
- This group was active through 2011 and recently, in spring 2012, it has been restructured with the addition of new subgroups on the Higgs properties and BSM theoretical issues.

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

Higgs cross sections at 7, 8 and 14 TeV

Numbers are always the most updated ones.

- Recommended values on SM Higgs XS at 7 TeV NEW
- Recommended values on SM Higgs XS at 8 TeV NEW
- Recommended values on SM Higgs XS at 14 TeV
- Recommended values on SM Higgs XS at 14/33 TeV for European Strategy studies 2012 NEW
- Recommended values on SM Higgs BR NEW
- Recommended values on XS and BR for Higgs in the Fourth Generation Model at 7 TeV
- Recommended values on BR for Fermiophobic Model
- MSSM neutral Higgs: XS scans of the m_A-tanβ plane in the mhmax scenario

Latest plots

- You can find more figures at our gallery here. NEW
- For BSM plots, please look at each XS and BR TWiki page linked above.
- You can also find useful figures for talks/lectures at European Strategy page.

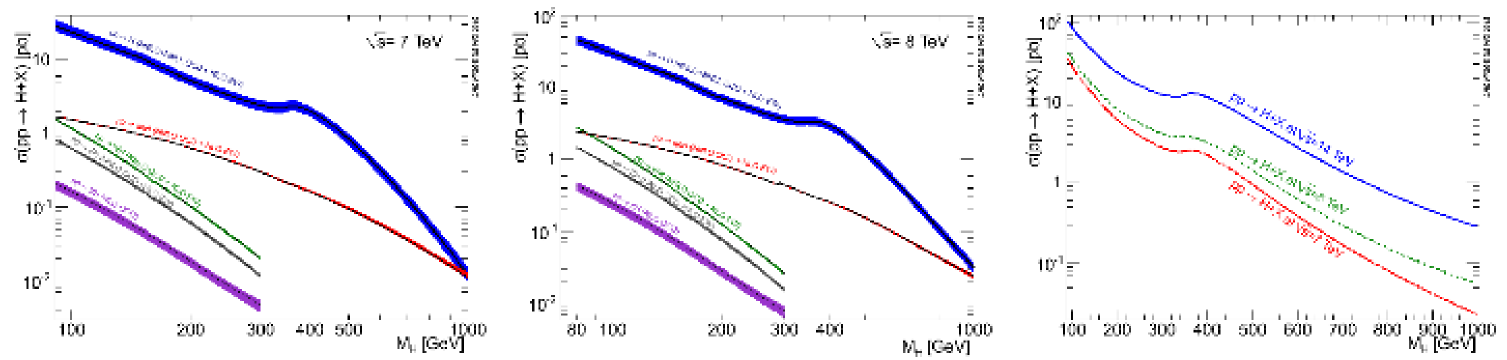


Figure 1: Standard Model Higgs boson production cross sections at Ecm = 7 and 8 TeV. Transition for VBF at M_H=300 GeV at 8 TeV is due to change from ZWA to complex-pole-scheme. Right hand plot shows the total cross sections for Ecm = 7, 8 and 14 TeV.

Organization

- The mandate of the current overall and subgroup contacts are until March 31, 2014.
- Click here for organization 2010-2011.

Overall Contacts

ATLAS	CMS	THEORY	
Reisaburo Tanaka (LAL)	Chiara Mariotti (Torino)	Sven Heinemeyer (IFCA)	Giampiero Passarino (Torino)

Subgroup Contacts and Link for Subgroup Wiki

- We are organized in 11 subgroups, with 1-2 experimental contacts from each ATLAS and CMS and 2-4 theoretical contacts for each subgroup.

Group	Higgs decay	ATLAS	CMS	THEORY			
1. ggF	$\gamma\gamma, WW^*, ZZ^*$	Biagio di Micco (Roma Tre)	Yanyan Gao (FNAL)	Daniel de Florian (Buenos Aires)	Kirill Melnikov (Johns Hopkins)	Frank Petriello (Northwestern)	
2. VBF	$\tau\tau, \gamma\gamma, WW^*, ZZ^*$	Daniela Rebuzzi (Pavia)	Pietro Govoni (CERN)	Ansgar Denner (Würzburg)	Carlo Oleari (Milano-Bicocca)		
3. WH/ZH	***bb***	Giacinto Piacquadio (CERN)	Jim Olsen (Princeton) Andrea Rizzi (Pisa)	Stefan Dittmaier (Freiburg)	Giancarlo Ferrera (Milano)		
4. ttH	***bb***	Chris Potter (Oregon)	Jim Olsen (Princeton) Andrea Rizzi (Pisa)	Laura Reina (Florida)	Michael Spira (PSI)		
5. Light Mass Higgs	***all***	Michael Dührssen (CERN) Markus Schumacher (Freiburg)	André Tinoco Mendes (LIP) Marco Zanetti (MIT)	Ansgar Denner (Würzburg)	Massimiliano Grazzini (Zurich)	Georg Weiglein (DESY)	
6.MSSM	***Neutral Charged***	Trevor Vickey (Witwatersrand) Martin Flechl (Freiburg)	Monica Vazquez Acosta (IC) Sami Lehti (Helsinki)	Robert Harlander (Wuppertal)	Michael Krämer (Aachen)	Pietro Slavich (LPTHE Paris)	Michael Spira (PSI)
7.Heavy Higgs and BSM		Sara Diglio (Melbourne) Krisztian Peters (CERN)	Sara Bolognesi (Johns Hopkins) Mario Kadastik (NICPB Estonia)	Christophe Grojean (CERN)	Heather Logan (Carleton)		
8. Branching ratios		Daniela Rebuzzi (Pavia)	Ivica Puljak (Split)	Sven Heinemeyer (IFCA)	Alexander Mück (Aachen)		
9. Jets		Bruce Mellado (Wisconsin)	Daniele Del Re (Roma 1)	Gavin Salam (CERN)	Frank Tackmann (DESY)		
10. NLO MC				Stefano Frixione (CERN)	Frank Krauss (Durham)	Fabio Maltoni (Louvain)	Paolo Nason (Milano-Bicocca)
11. PDF		Joey Huston (Michigan State)		Stefano Forte (Milano)	Robert Thorne (UCL)		

Conclusions

- The **CSN4** represents a fundamental organism for the development and coordination of Theoretical Physics in Italy.

- The spectrum of the CSN4 activities is **much wider** than those of strict interest for INFN.

- This has been possible also thanks to the close relationships between **INFN** and the **academic world**, which have to be maintained and possibly strengthened in the future. This intertwining between INFN and Universities (and other research institutions) has led to **results of very high quality**.

- The **CSN4,** even if financially “light” in comparison with the other CSN’s, is **scientifically very heavy !**