INFN  Scientific Committees
CNS

1  Experimental subnuclear Physics
2  Astroparticle, neutrino, gravity
3  Experimental Nuclear Physics
4  Theoretical Physics
5  Technological and interdisciplinar research
# FTE and funds of the CSN

<table>
<thead>
<tr>
<th></th>
<th>FTE</th>
<th>FUNDS</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSN 1</td>
<td>660</td>
<td>40.3</td>
<td></td>
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<tr>
<td>CSN 2</td>
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<td>CSN 3</td>
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<td>CSN 4</td>
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<tr>
<td>CSN 5</td>
<td>527</td>
<td>7.2</td>
<td></td>
</tr>
</tbody>
</table>
20 Sezioni ➔ 586 Researchers ➔ 465 FTE

38% from Universities

Post doc 106 59 PhD 83 Undergraduates

In 2002 156 Papers 231 Conference TALKS

\[\begin{array}{l}
\text{RESEARCHERS} & \text{FTE} \\
1994 & 350 \\
1995 & 400 \\
1996 & 450 \\
1997 & 500 \\
1998 & 550 \\
1999 & 600 \\
2000 & 650 \\
2001 & 700 \\
2002 & 750 \\
2003 & 800 \\
2004 & 850 \\
\end{array}\]

\[\begin{array}{l}
\text{EXPERIMENTS} \\
1994 & 90 \\
1995 & 80 \\
1996 & 70 \\
1997 & 60 \\
1998 & 50 \\
1999 & 40 \\
2000 & 30 \\
2001 & 20 \\
2002 & 10 \\
2003 & 0 \\
2004 & 0 \\
\end{array}\]
The experimental INFN activity in Fundamental Nuclear Physics follows four main research lines (NuPECC, December 1997):

- **Quark and Hadron Dynamics**
  
  9 experiments (5 with e.m. probes, 4 with hadron beams);
  106 FTE researchers, 26.2% of experimental budget;

- **Phase Transition of Nuclear Matter**
  
  6 experiments (4 with Relativistic or Ultra-relativistic Ions, 2 with Intermediate Energy Ions);
  181 FTE researchers, 39.5% of experimental budget;

- **Nuclear Structure and Dynamics**
  
  9 experiments (2 on Nuclear Spectroscopy, 7 on Nuclear Dynamics);
  131 FTE researchers, 25.6% of experimental budget;

- **Nuclear Astrophysics and Interdisciplinary Research**
  
  5 experiments (3 on Nuclear Astrophysics);
  48 FTE, 8.6% of experimental budget.
2004 Resources division

<table>
<thead>
<tr>
<th>Line 1</th>
<th>Line 2</th>
<th>Line 3</th>
<th>Line 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTE %</td>
<td>Funds %</td>
<td>FTE %</td>
<td>Funds %</td>
</tr>
</tbody>
</table>

- Line 1: FTE 25%, Funds 25%
- Line 2: FTE 35%, Funds 40%
- Line 3: FTE 25%, Funds 25%
- Line 4: FTE 15%, Funds 10%
QUARK AND HADRON DYNAMICS

Electromagnetic probes 1

JNAF ➔ 6 GeV e⁻ beam

AIACE 10 FTE ➔ CLAS Spectrometer ➔ N* resonances, spin structure functions, GPD, Multiquarks hadrons, GDH......

ELETTRO 4 FTE ➔ High Resolution Spectrometer ➔ spin structure functions, GDH, hypernuclear production......

MAMI B-C ➔ photons 800 to 1500 MeV

CTT 4 FTE ➔ Magnetic dipole moment of nucleon resonances ω meson photoproduction at threshold, meson production to measure radiative coupling of N* ......
QUARK AND HADRON DYNAMICS

Electromagnetic probes 2

**ESR, NSLS** ➞ Compton back-scattered polarized photons 200-1670 MeV

**GRAAL 13 FTE** ➞ Polarized target, $4\pi$ detector ➞ vector mesons
   production, $N^*$physics, Polarised HD target

**HERA** ➞ 27.5 GeV polarized e$^-$ DIS on polarised internal gas target

**HERMES 26 FTE** ➞ Internal polarized target, large acceptance
   spectromete, EN calorimeter ➞ spin physics,
   GPD, Transversity, Nuclear medium effects
Contributi hardware LNF
HERMES: Spin structure of the nucleon through the DIS of 27.5 GeV longitudinally polarised electrons on (unpolarised, longitudinally and transversely polarised) internal gas targets at DESY.

Inclusive, semi-inclusive & exclusive spin dependent DIS are simultaneously measured in a forward spectrometer.

- TDR of Recoil Detector for exclusive processes (DVCS)
- First data taking with transverse polarised target for transversity measurements

Measurement of the DVCS Beam Spin asymmetry on D.

First measurement of the DVCS Beam Charge asym. E. Chiavassa

First measurement of attenuation ratio of fast $\pi^\pm$, $K^\pm$ and $p,\bar{p}$ on Kr respect to D.

Quark helicity distributions

First measurement of the attenuation ratio of fast $\pi^\pm$, $K^\pm$ and $p,\bar{p}$ on Kr respect to D.
**The recoil detector**

**Actual situation:**
exclusive events are identified by "missing mass".
Resolution to be improved.

**Near future:**
complete event reconstruction by recoil particle detection.
Physics goals:
Understand the nature of the strong interactions in nucleons and nuclei in terms of fundamental constituents and QCD

Research groups involved: INFN, Frascati and Genoa units & University of Genoa
total of 9 staff scientists/professors + 5 postdocs

Laboratory: Jefferson Lab (USA), Hall B (CLAS collaboration)
Beams: CW $e^-$, $\gamma$ up to 6 GeV
Targets: LH$_2$, LD$_2$, He$_3$, C, Fe, etc. + polarized NH$_3$, ND$_3$
AIACE physicists are also involved in important collaboration committees (conferences, papers, etc.) + one PAC member from INFN

Journal publications september 2002 - september 2003: 16 (6 under italian leadership)
Talks at conferences september 2002 - september 2003 : 21 (12 invited + 9 contributed)

Highlights from physics results

Surprising scaling properties observed analysing the higher moments of the $F_2$ structure function (sensitive to the valence region)

Possible evidence for pentaquark baryons in photoproduction off proton and nuclei

Deuteron target

$\gamma d \rightarrow p K^+ K^- (n)$ in CLAS

Accepted by PRL hep-ex/0307018

Proton target

$\gamma p \rightarrow K^+ K^- \pi^+ (n)$ in CLAS
cos$\theta_{K^+} < 0.6$
cos$\theta_{\pi^+} > 0.8$

Proton signal prominent when angular cuts applied
Analysis in progress on other channels and data sets
$\rightarrow$ new proposal to be submitted to Jlab PAC

Submitted to PRL hep-ex/0311046

Recent interpretation in terms of a constituent quark form factor
$\rightarrow$ possible evidence for extended objects inside the proton from the dynamics

\[ \frac{N_s}{N_b} = 71.7/163.6 \]

in 2\(\sigma\) interval

Fit Gauss+P4

\[ \text{Chi2} = 1.4 \]

\[ M = 1526 \pm 2(\text{stat}) \pm 2(\text{sys}) \text{ MeV} \]

\[ \sigma = 7.5 \pm 2.4(\text{stat}) \text{ MeV} \]

Reconstructed \(K^0\)

Released September 2003
Quark and Hadron Dynamics

36 participating institutes
INFN – ISS, Bari

2001-2002 Contributions to Hall A upgrade

• Septum magnets ➔ Forward angle Phisics ➔ Hypernuclear spectroscopy, GDH Low Q², parity exp.
• RICH Detector ➔ Unambiguous K identification ➔ Strangeness physics

2002

Exp. 94-107: High Resolution 1p Shell Hypernuclear Spectroscopy in the Valence Quark Region

Exp. 97-110: The GDH Sumrule and the Spin Structure of ³He and Neutron Using Near Real Photons

Ring generated by a 7 GeV/c π (CERN PS Test beam, Nov 2000).

The RICH Installed in Hall A

Septum magnets

$^9$Be(e,e’K)$^9$Li

Expected results: doublets
Graal Apparatus

NOT IN SCALE
The new data analysis shows
• suppression of $S_{31}(1620)$
• evidence of the $P_{13}(1720)$
  (confirmed by Ron Crawford analysis in fixed-$t$ disp. rel.)
• possible evidence of a third $S_{11}$ resonance
Risultati Graal: $\sigma_{\text{tot}}(2\pi^\circ)$

**Oset Calculation**
(Nucl. Phys A600,(1996),413)

a) $\gamma p \rightarrow D_{13}(1520) \rightarrow \Delta \pi$
b) $\gamma p \rightarrow P_{33}(1232) \rightarrow \Delta \pi$
c) $\gamma p \rightarrow P_{11}(1440) \rightarrow \Delta \pi$

**Laget Calculation**

1. $\gamma p \rightarrow P_{11}(1440) \rightarrow \Delta \pi$
2. $\gamma p \rightarrow D_{13}(1520), D_{13}(1700) \rightarrow \Delta \pi$
3. $\gamma p \rightarrow P_{11}(1440), P_{11}(1710) \rightarrow \sigma p$
4. $\gamma p \rightarrow \sigma p$
**QUARK and HADRON DYNAMICS**

*Hadron probes*

**LNF  DAFNE** ➔ K beam from Φ decay

**SIDDARTHA  7 FTE** ➔ H, N, D targets; CCD soft X detector
  ➔ anti-K nucleon scattering lengths, chiral perturbation theory test

**FINUDA  25 FTE** ➔ various nuclei targets; large acceptance
  π detector ➔ Λ–hypernuclei spectroscopy

**JINR** ➔ low energy π beam

**DUBTO  6 FTE** ➔ ⁴He target, self-shunted streamer chamber

**GSI** ➔ antiproton Beam

**PANDA  11 FTE** ➔ Hypernuclei, Charmonium in nuclei….
An ~ eV kaonic hydrogen precision measurement
First measurement of kaonic deuterium

Measuring the KN scattering lengths with the precision of a few percent will drastically change the present status of low-energy KN phenomenology and also provide a clear assessment of the SU(3) chiral effective Lagrangian approach to low energy hadron interactions.

1. Breakthrough in the low-energy KN phenomenology;
2. Threshold amplitude in QCD: Chiral 2003 (Bonn); Hadatom03 (Trento)
3. Determination of the KN sigma terms, which give the degree of chiral symmetry breaking;
4. Determination of the strangeness content of the nucleon from the KN sigma terms.
Kaonic Hydrogen
October-December 2002, 60 pb⁻¹

The best measurement performed on Kaonic Hydrogen up to now

Recent Theory:
Kaiser, Siegel, Weise 1995
Oller, Meißner 2001
Ivanov, Troitskaya et al, 2003
SIDDHARTA setup: 3D-view

Beam pipe

SDDs (216 cm² for $\phi_{pipe} = 5$ cm)

Kaon monitor

Cryogenic target cell
SIDDHARTA Kaonic hydrogen simulated spectrum

Precision on shift ~ 1 eV

S/B = 5/1

60 pb⁻¹

Counts/30 eV

X-ray energy (keV)
Quark and Hadron Dynamics

Study of $\Lambda$-hypernuclei production and decay at the Frascati $\Phi$-factory DA$\Phi$NE

Main physics items:

- high resolution spectroscopy ($\sim$ 700 KeV FWHM) of $\Lambda$ -hypernuclei
- search for neutron-rich $\Lambda$ -hypernuclei ($^6_\Lambda H$, $^7_\Lambda H$, ...)
- $\Lambda$ lifetime in nuclei
- branching ratios for mesonic and non-mesonic decay of $\Lambda$ -hypernuclei (both proton and neutron stimulated emission)
- systematic, good statistics survey over the full $A$ mass range

Reaction production: $K^-_{stop} + ^AX_Z \rightarrow ^AX_Z + \pi^-$

using the low energy $K^+$ ($\sim$16 MeV) from the ($K^+K^-$) decay ($\sim$ 49%) of the $\Phi$ -meson

Advantage of this approach:

- thin targets ($\sim$100 mg/cm$^2$) reduced straggling on the energy loss possibility of tagging with the associated, back-to-back $K^+$

Apparatus features:

- large acceptance detector: $\sim$2$\pi$ sr for both the $\pi^-$ from the production reaction and the decay products
Hypernucleus $^{27}$Al

$\pi^-$ (~ 246 MeV/c)  
$p$ (~ 457 MeV/c)
4) Expected physics results from present run

differentiated targets: $2 \times ^6Li + 1 \times ^7Li + 3 \times ^{12}C + 1 \times ^{27}Al + 1 \times ^{51}V$

integrated luminosity: 250 pb$^{-1}$

$^6Li$

- source of $\Lambda ^4He$ and $\Lambda ^5He$ ($^6Li$ unstable), expected yields $10^5 - 10^6$
- study of the decay of light hypernuclei ($\sim$ never examined)

\[
\Lambda ^5He \rightarrow ^3He + n + p \\
\Lambda ^5He \rightarrow ^3He + n + n \\
\Lambda ^6He \rightarrow ^4He + n + n \\
\Lambda ^4He \rightarrow d + d \\
\Lambda ^4He \rightarrow ^3He + p \\
\Lambda ^4He \rightarrow ^3H + n + \pi^-
\]

$\Delta I = \frac{1}{2}$ still valid???

$^7Li$

- comparison with the $^6Li$; available data of poor quality
- more than $10^5$ events in the excitation spectrum
4) Expected physics results from present run (cont’d)

$^{12}C$
- reference target for spectroscopy and weak decay studies
- expected over $10^5$ events in the excitation spectrum
- search for weakly excited states, $\leq 10^{-5}/K_{\text{stop}}$
  (present limit $10^{-4}/K_{\text{stop}}$)
- weak decays:
  $\Gamma_p \sim 2\%$
  $\Gamma_n \sim 3\%$
  $\Gamma_{pn} \sim 5\%$
  $\Gamma_{pn} \sim 10\%$
  $\Gamma_{\pi} \sim 3\%$

$^{27}Al$
- never studied before
- measurement of the capture rate in the medium hypernuclei
- excitation spectrum with $> 10^5$ events, useful for weak decay studies

$^{51}V$
- no measurements available with K- at rest, useful for weak decay studies
- important to assess the capture rate for medium and heavy hypernuclei ($>10^5$ events in the excitation spectrum)
5) Perspectives for next data taking runs

Following the results of the present run, the choice for the next target set will be done

- medium/heavy targets
- few light targets

- survey of excitation spectra (cont’d)
- weak decay parameters ($\Gamma_p$, $\Gamma_n$, $\Gamma_{2N}$, …) measurements
- study of new effects ($\bar{K}$ nuclear bound states)
Ge array for hypernuclei

- solid state micro-tracker
- thickness ~ 3 cm
- capillar (2D) or pixel (3D) detector
- high rate Ge detector
Italian Involvement

Presently the Italian group interested in the project are:

- Frascati LNF (6 ric. 2.5 fte);
- Torino INFN dip. Fisica Sper. Univ. e Politecnico (8 ric. 2.4 fte);
- Torino INFN dip. Fisica Gen. Univ. e Univ. Piemonte orient. (7 ric. 1.6 fte);
- Genova INFN e Univ. (2 ric. 0.5 fte);
- Trieste INFN e Univ. (4 ric. 1 fte);
- Pavia INFN e Univ. (7 ric. 2.3 fte);
- Catania LNS (3 ric. 1.5 fte);
- Milano INFN e Univ. (2 ric. 0.5 fte);
- Ferrara INFN e Univ. (2 ric. 0.2 fte);
Antiproton Physics Program

Charmonium (c¯c) spectroscopy: precision measurements of mass, width, decay branches of all charmonium states, especially for extracting information on the quark confinement.

Search for gluonic excitations (charmed hybrids, glueballs) in the charmonium mass range (3 – 5 GeV/c²).

Search for modifications of meson properties in the nuclear medium, and their possible relationship to the partial restoration of chiral symmetry for light quarks.

Precision γ-ray spectroscopy of single and double hypernuclei for extracting information on their structure and on the hyperon-nucleon and hyperon-hyperon interaction.

Inverted DVCS to measure quarks and gluons dynamic in hadronic matter proton Form-factors at large Q² up to 25 GeV²/c⁴ D(s)-Physics BR and decay dalitz plots CP-Violation in the D/Λ sector
HADRONIC MATTER PHASE TRANSITION
UltraRelativistic heavy ions

CERN SPS ➔ Pb 158 A GeV, In 170 A GeV
IPER 9.7 FTE ➔ In target; 2 µ spectrometer + Vertex detector (Na50,Na60) ➔ J/Ψ production, open charm…

NA57 3.7 FTE ➔ silicon pixel and microstrip tracking system
➤ strange baryons and anti-baryons production,

CERN LHC ➔ Pb \( E_{\text{CM}} = 2.7 \text{ TeV} \) A
ALICE 128 FTE ➔ General purpose heavy ion experiment
➤ QGP formation and characterization
NA60

Muon Spectrometer (NA50)

Interaction Counter

Target box

2.5 T dipole magnet

Beam Tracker (Si $\mu$-strip)

vertex tracker

pBe

$\sigma_\omega \sim 25$ MeV

$\sigma_\phi \sim 30$ MeV

$\sigma_{J/\psi} @ B_{\text{max}} \sim 55$ MeV

Silicon Pixel Detectors

ZDC Quartz Blade

Interaction Counter

Target box

2.5 T dipole magnet

Beam Tracker (Si $\mu$-strip)

vertex tracker

pBe

$\sigma_\omega \sim 25$ MeV

$\sigma_\phi \sim 30$ MeV

$\sigma_{J/\psi} @ B_{\text{max}} \sim 55$ MeV

Silicon Pixel Detectors

ZDC Quartz Blade
• Fall 2003: 38 days of In beam @ $5 \times 10^7$ / burst
• Complete set-up (with pixel telescope, 16 planes, 96 chips, 786000 channels !)
• Good quality data
• Now analyzing

Opposite sign dimuon $p_T$ vs mass spectrum (muon spectrometer only)

Centrality estimate through ZDC and pixel multiplicity
ALICE: experimental layout

ITS: layers of Si pixel, Si drift and Si strip detectors
TPC: main tracking system
TOF: multigap RPC
PHOS: high granularity E.M. Calorimeter
HMPID: RICH detector for high momentum PID
Muon arm: 5 tracking stations + trigger chambers
ZDC: forward calorimeters
PMD: photon multiplicity detector

Central part covers / |<0.9
Muon arm: 2-9° (2.5< <4)
ZDCs located at ~115m from the IP
PMD: 1.8< <2.6

HMPID: Bari
ITS: Alessandria, Bari, Bologna, Catania, LNL, Torino, Padova, Roma, Salerno
MU: Alessandria, Cagliari, Torino
TOF: Bologna, Salerno
ZDC: Alessandria, Cagliari, Torino
The ALICE Inner Tracking System

- 6 Layers, three technologies (keep occupancy ~constant ~2% for max mult)
  - Silicon Pixels (0.2 m², 9.8 Mchannels)
  - Silicon Drift (1.3 m², 133 kchannels)
  - Double-sided Strip Strip (4.9 m², 2.6 Mchannels)

Major technological challenge!
DOUBLE STACK OF 0.5 mm GLASS

Edge of active area

Resistive layer (cathode)

Resistive layer (anode)

Resistive layer (cathode)

Resistive layer (anode)

Resistive layer (cathode)

Resistive layer (anode)

cathode pick up pad

anode pick up pad

cathode pick up pad

5 gaps

5 gaps

resistive plate chambers

**Time - Of - Flight**

for $\pi$, $K$, $p$ PID

$\pi$, $K$ for $p < 2$ GeV/c

$p$ for $p < 4$ GeV/c

- $0.9 < \eta < 0.9$

full size TOF module

Typical time spectrum

![Graph showing time spectrum](image)

**STRIP 10 H.V. +- 6 kV**

$\sigma = 53$ ps minus $30$ ps jitter

of timing scintillator = $44$ ps

Entries/50 ps

Time with respect to timing scintillators [ps]

5.12.03

E. Chiavassa

37
The MRPC

ALICE TOF
(INFN Bologna-Salerno)

- 1638 MRPCs
- 160000 readout pads
- 140 m² active detector

<table>
<thead>
<tr>
<th>Efficiency (%)</th>
<th>Time Resolution (ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>80</td>
<td>4</td>
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<tr>
<td>70</td>
<td>80</td>
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<td>60</td>
<td>100</td>
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<td>50</td>
<td>95</td>
</tr>
<tr>
<td>40</td>
<td>100</td>
</tr>
<tr>
<td>30</td>
<td>110</td>
</tr>
</tbody>
</table>

Readout pads ~10 cm²
High Momentum Particle Identification

The HMPID module in STAR

7 modules, each ~1.5 x 1.5 m²

RICH

charged particle

container

C_{6}F_{14} radiator

quartz window

collection electrode

pad cathode covered with CsI film

MWPC

frontend electronics

pions

kaons

protons

STAR data

p > 1 GeV
Quarkonia Production

**µ⁺ µ⁻ channel**

**e⁺e⁻ channel**

background from B and D under control

ϒ mass resolution
Event Geometry: ALICE ZDC Calorimeters

**Aim:** determination of the impact parameter of the collision by measuring the energy carried by the spectator nucleons

**Where:** hadronic calorimeters at ~ 116 m from IP
e.m. calorimeter at ~ 8 m from IP

*Central events selected with both:*
- Energy in hadronic calorimeters $< E_0$
- Energy in e.m. calorimeter $> E_1$

<table>
<thead>
<tr>
<th>Proton ZDC (ZP)</th>
<th>Neutron ZDC (ZN)</th>
<th>EM ZDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions (cm³)</td>
<td>12x21x150</td>
<td>7x7x100</td>
</tr>
<tr>
<td>Absorber</td>
<td>brass</td>
<td>W-alloy</td>
</tr>
<tr>
<td>Fibre angle wrt LHC axis</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>Fibre Ø (µm)</td>
<td>550</td>
<td>365</td>
</tr>
</tbody>
</table>
### Phase Transition in Nuclear Matter

#### Italian contribution to ALICE

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inner Tracking System</strong></td>
<td>6 silicon detector layers based on 3 different technologies to cope with local particle densities</td>
</tr>
<tr>
<td>- SPD</td>
<td>Silicon Pixel Detectors (BA, CT, LNL, PD, RM1, SA) 0.20 m², 9.83·10⁶ channels</td>
</tr>
<tr>
<td>- SDD</td>
<td>Silicon Drift Detectors (AL, BO, TO, TS) 1.31 m², 0.13·10⁶ channels</td>
</tr>
<tr>
<td>- SSD</td>
<td>double-side Silicon Strip Detectors (TS) 4.92 m², 2.61·10⁶ channels</td>
</tr>
<tr>
<td><strong>Time Of Flight</strong></td>
<td>multi-gap RPC (BO, SA)</td>
</tr>
</tbody>
</table>
| - | P<2.5 GeV/c  
barrel length 750 cm, internal radius 370 cm, sensitive pads 3.5x2.5 cm²  
overall time TOF resolution 120 ps, ε ~ 95% |
| - **High Momentum Particle IDentification (BA)** | 7 modules proximity focusing CsI RICH 10 m²  
PID range: 1 < p < 3 GeV/c p K, 2 < p < 5 GeV/c p |
| **Di-muon spectrometer** | 3 tracking stations (CA)  
4 RPC trigger planes (AL, TO) 144 m², 0.21·10⁵ channels |
| **Zero Degree Calorimeters (AL, CA, TO)** | 4 quartz-fiber calorimeters to detect spectator p and n @ 115 m from the interaction point  
2 e.m. ZDC to improve the centrality trigger |
| **ALICE GRID** | core GRID functionalities ready (Alice Installation Kit, Bookkeeping System / Data Catalogue, Data Manager, Queue Manager, FARM Monitoring)  
Italy (TO, CT, CA, BO), France, Germany, Netherlands, USA in action for PPR production now  
tests ongoing with UK, India, Mexico, Russia |

5.12.03  
E. Chiavassa
NUCLEAR MATTER PHASE TRANSITION

Relativistic Heavy Ions

GSI ➔ heavy ions 1 GeV A

HADES 5 FTE ➔ High acceptance dilepton spectrometer
Partial chiral symmetry restoration

Intermediate energy Heavy Ions

GSI SIS2 5 FTE ➔ Dynamics of the multifragmentation

LNS CS EXCYT ISOSPIN 29 FTE ➔ Isospin Effects in EOS
Main features:
Total solid angle $\Delta \Omega / 4\pi = 94\%$, Threshold $< 0.3$ MeV/A for H.I.
Experimental Method
$\Delta$E-E: ISOTOPE identification ($Z < 10$)
CHARGE identification (H.I.)
E-TOF: VELOCITY - MASS
PULSE SHAPE in CsI(Tl) for $Z < 4$

THE CHIMERA DETECTOR
Installed at LNS-Catania

The IDEA

1192 $\Delta$E-E-TOF
Si-CsI(Tl)
Telescopes

30°

TARGET

BEAM

1°

1 m

The REALITY

1998/2000 - REVERSE 688 telescopes
2002/2003 - CHIMERA configuration

Chimera project

5.12.03

E. Chiavassa
Present and next future experimental programs with CHIMERA

ISOSPIN EFFECTS ON CLUSTER FORMATION

THERMODYNAMICS OF EXCITED NUCLEAR SYSTEMS

NONEQUILIBRIUM EMISSIONS IN SEMIPERIPHERAL REACTIONS

TWO BODY DISSIPATION IN NUCLEUS - NUCLEUS COLLISIONS

LIMITING EXCITATION ENERGY OF NUCLEAR MATTER

NUCLEAR TRANSPARENCY AT FERMI ENERGIES

ISOSPIN DEPENDENCE OF NUCLEAR EOS
NUCLEAR STRUCTURE and REACTION DYNAMICS
Low energy H.I.

**LNL**
- **EDEN** 5 FTE ➤ Properties of fission and evaporation channels
- **EXOTIC** 11 FTE ➤ Properties of rare isotopes
- **PRISMA** 10 FTE ➤ Nuclear structure from Heavy Ions Interaction
- **MISSIVE** 4 FTE ➤ Study of multiphonon excitation
- **N2P** 10 FTE ➤ Neutron production from Heavy Ions
- **NUCLEX** 28 FTE ➤ Dynamics and Thermodynamics of the reactions

**LNS**
- **MAGNEX** 15 FTE ➤ Neutron rich light nuclei spectroscopy

**LNL** **GSI**
- **GAMMA** 44 FTE ➤ Nuclear structure from $\gamma$ spectroscopy

**LMU**
- **TRARE** 4 FTE ➤ Few Nucleon transfer reactions
Main elements

- Position sensitive start detector;
- vertically focusing quadrupole;
- bending magnet;
- focal plane detector measuring ion direction, energy, charge and mass.

The start detector

PSD based on microchannel plate technology

The Focal Plane Detector

The FPD is under construction at GANIL. A prototype has already been realized and tested with Tandem beams at LNS

Main parameters of MAGNEX

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum magnetic rigidity</td>
<td>1.8 Tm</td>
</tr>
<tr>
<td>Solid angle</td>
<td>51 msr</td>
</tr>
<tr>
<td>Momentum acceptance</td>
<td>± 10 % max</td>
</tr>
<tr>
<td>Momentum resolution</td>
<td>1 / 5400</td>
</tr>
<tr>
<td>Mass resolution</td>
<td>1 / 2000</td>
</tr>
<tr>
<td>Subject</td>
<td>Beam</td>
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<tr>
<td>Dynamic polarization of the core</td>
<td><strong>Tandem</strong></td>
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<tr>
<td>Spin-orbit far from the stability</td>
<td><strong>EXCYT</strong></td>
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<td>Single particle structure in (^9)Li</td>
<td><strong>EXCYT</strong></td>
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<td>s and p isonances in the (^9)Li+n system</td>
<td><strong>EXCYT</strong></td>
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<td>Single and double charge exchange far from</td>
<td><strong>Tandem</strong></td>
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<td>the stability</td>
<td><strong>quasi-stabili</strong></td>
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<td>Charge exchange at intermediate energy far</td>
<td><strong>CS</strong></td>
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<td>from the stability</td>
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<td>Isovectorial monopole giant resonance</td>
<td><strong>CS</strong></td>
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<tr>
<td>Single particle structure in the continuum</td>
<td><strong>CS</strong></td>
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</tbody>
</table>

5.12.03
E. Chiavassa
48
GOAL: coincident experimental information on

- Critical partitioning of the system, fluctuations
- Calorimetric excitation energy
- Isotopic temperature
- Space-time proximity of the decay products
- Heat capacity
- Compressibility coefficient?
- Asymmetry term of the Equation of State?

- 23 FTE Researchers
- MEASUREMENTS at LNS and LNL with GARFIELD and FIASCO apparatus
Improvements of the apparatus:
• A, Z identification up to $\vartheta \approx 90^o$
• Digital electronics for pulse-shape discrimination
Cross section and spectra for neutron producing reactions induced by charged particles and light heavy ions are required between 20 and hundreds AMeV in several fields. In particular, (p,xn) and (d,xn) reactions are needed for the design of future RIB facilities as SPES@LNL. Measurements will be performed at LNL and other European Facilities by using a newly designed Proton Recoil Telescope.
Study of the production cross section for rare nuclear species by using deep inelastic collisions induced by U and Pt beams on Pb, U, Pt, Th targets at 10-25 AMeV. Reaction product will be collected using the Superconductive Solenoid BigSol at the Cyclotron Institute of the Texas A&M University. A neutron calorimeter is under construction to study Delayed Neutron emission.
Activities with stable beams:

**LNL:** GASP and PRISMA+EUROBALL Clover
   - Nuclei far from stability, high spin states and super-hyper deformation
   - Neutron rich nuclei via deep inelastic and multinucleon transfer
   - Isospin symmetry and pairing

Activities with radioactive beams:

**GSI:** RISING array (Euroball Cluster+BaF$_2$ detectors), use of Rel. Coulex
   - Collective motion and pygmy resonance in n-rich nuclei
   - Shell structure and exotic shapes

R&D project:

**AGATA (A GAmma Tracking Array):** is the new array of segmented HPGe detectors and Digital electronics

58 researchers (43 FTE) from I.N.F.N. sections of Fi, Ge, LNL, Mi, Na, Pd, Pg collaboration with 40 European institutions
Rare ISotope INvestigation at GSI

15 Euroball Clusters \(-\varepsilon (1.3 \text{ MeV}) \sim 2\%\)
8 BaF\(_2\) for high energy \(-\varepsilon (10 \text{ MeV}) \sim 1\%\)

First beams in summer 2003
Radioactive beams from fragmentation at relativistic energies 100-400 MeV/u

Some experiments approved by the PAC:

- Pigmy Resonance in \(^{68}\text{Ni}\)
- Structure of \(N \sim Z\) \(^{102}\text{Sn}\) and \(^{94}\text{Rh}\)
- Test for shell closure at \(Z \sim 50\) \(N\) \sim 82 by knock-out reactions with \(^{132}\text{Sn}\)
- Coulomb excitation in \(^{132}\text{Xe}\)

26 EUROBALL Clovers
Efficiency \sim 3\% \(\Theta \sim 104-156^\circ\); Peak/Total \sim 50\%
FWHM \sim 10 \text{ KeV} \text{ for } E_\gamma = 1.33 \text{ MeV} \text{ at } v/c \sim 10\%

Campaign starts in fall 2003 use of multiple particle transfer reactions to study moderately n-rich nuclei
Agata is the design of a new array for γ–rays using the tracking technique

180 segmented encapsulated HPGe
60 triple capsule cryostats

Radius ~ 17-26 cm
Solid Angle Coverage ~ 77%
6780 Digital Electronic Ch.

Efficiency ~ 40% (M=1) and 25% (M=30)
Peak/Total ~ 65% (M=1) and 50% (M=30)

First test on γ tracking

$^{56}\text{Fe} \ (240 \text{ MeV}) + ^{208}\text{Pb} \Rightarrow ^{56}\text{Fe}^* \ (\beta=0.08) + \gamma$
$^{56}\text{Fe}^* \text{ detected by phobos} \ (\Delta\theta = 2.6^\circ)$

γ measured by MARS detector - 25 Segments

The Doppler broadening has been drastically reduced
NUCLEAR ASTROPHYSICS and INTERDISCIPLINARY RESEARCHES

<table>
<thead>
<tr>
<th>Location</th>
<th>Institute</th>
<th>FTE</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNGS</td>
<td>LUNA</td>
<td>12</td>
<td>Cross section measurements at very low energy</td>
</tr>
<tr>
<td>LNS</td>
<td>ASFIN</td>
<td>11</td>
<td>Cross section measurements with indirect methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Measurements with EXCYT beams</td>
</tr>
<tr>
<td>BOCHUM</td>
<td>ERNA</td>
<td>4</td>
<td>$\alpha$ radioactive capture on C</td>
</tr>
<tr>
<td>CERN</td>
<td>nTOF</td>
<td>10</td>
<td>Neutron cross section measurements</td>
</tr>
<tr>
<td></td>
<td>ATHENA</td>
<td>12</td>
<td>Antihydrogen production</td>
</tr>
</tbody>
</table>
Accelerator facilities @ LNGS:

LUNA2 (400 kV)

Voltage Range: 50 - 400 kV
Output Current: 1 mA 75% H
(@ 400 kV)
25% H₂

: 500 mA 4He
Absolute Energy error ±300 eV
Beam energy spread: <100 eV
Long term stability (1 h): 5 eV
Terminal Voltage ripple: 5 Vpp Ge detector

LUNA1 (50 kV)

Voltage Range: 1 - 50 kV
Output Current: 1 mA
Beam energy spread: 20 eV
Long term stability (8 h): 10⁻⁴
Terminal Voltage ripple: 5 10⁻⁵
...some results obtained in 2002

gamma spectrum of $^{14}\text{N}(p,\gamma)^{15}\text{O}$ at 140 keV
(the lowest energy measured)

$S(E)$ factor ($R/DC \rightarrow 0$ transition) in $^{14}\text{N}(p,\gamma)^{15}\text{O}$

results of Schroeder et al.
The Trojan Horse Method can give hints on the bare astrophysical S(E)-factor and the electron screening effect, for many reactions of astrophysical interest:

\[
\begin{align*}
A + x & \rightarrow C + c \\
A + a & \rightarrow C + c + b \\
\end{align*}
\]

\[
\begin{align*}
\text{nLi} & + \text{d} \rightarrow \alpha + \alpha \\
\text{nLi} + \text{He} & \rightarrow \alpha + \alpha + \text{p} \\
\text{nLi} & + \text{He} \rightarrow \alpha + \alpha + \text{n} \\
\end{align*}
\]

**Direct Measurements**

<table>
<thead>
<tr>
<th>( U_e ) (adiab)</th>
<th>( U_e ) (THM) ( ^6\text{Li} + \text{d} )</th>
<th>( U_e ) (THM) ( ^7\text{Li} + \text{p} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>186 eV</td>
<td>340 ± 50 eV</td>
<td>330 ± 40 eV</td>
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</tbody>
</table>
Astrophysical factor
\[ \sigma(E) = S(E) E^{-1} \exp(-2\pi\eta) \]

Enhancement factor
\[ \frac{\sigma_s(E)}{\sigma_b(E)} = \exp(\pi\eta U_e/E) \]

electron screening effect

LUNA

3He(d,p)4He

Screened
\( U_e = 219 \) eV

Adiabatic limit:
\( U_e \sim 119 \) eV

Gamow

ASFIN

\( ^7Li + p \rightarrow \alpha + \alpha \)

Direct Measurements

\( U_e^{(adiab)} \quad U_e^{(THM)} \quad ^7Li+p \)

186 eV  
330 ± 40 eV
**BIG BANG at LNS**

- **Homogenous Big-Bang**: elements up to Lithium only produced in primordial nucleosynthesis
- **Inhomogenous Big-Bang**: much wider set of primordially born elements (up to carbon at least).

In this scenario the reaction path for nucleosynthesis is

\[
^1\text{H}(n,\gamma)^2\text{H}(n,\gamma)^3\text{H}(d,n)^4\text{He}(t,\gamma)^7\text{Li}(n,\gamma)^{8}\text{Li}(\alpha,n)^{11}\text{B}(n,\gamma)^{12}\text{B}(\beta\nu)^{12}\text{C}.
\]

\[^8\text{Li} \text{ half-life} = 840 \text{ msec} \quad \text{chain bottleneck}\]

**Test of \(^8\text{Li} \text{ production and of the specifically designed beam line}**

**\(^7\text{Li} \text{ peak @ channel 1926}**

**\(^8\text{Li} \text{ peak}**

**Channel 2567**

**\(^7\text{Li} \text{ tail}**

**ToF \approx 33 \text{ nsec (calculated)}**

**ToF \approx 32 \text{ nsec (experimental)}**

**The experiment is ready to run with the first \(^8\text{Li} \text{ beam from Excyt}**

5.12.03

E. Chiavassa
Measurements of neutron Cross-Sections for Astrophysics and ADS

- \((n,\gamma)\) cross-sections relevant for Stellar Nucleosynthesis (production of heavy elements in \textit{s-process});
- \((n,\gamma)\) and \((n,f)\) cross-sections for long lived fission fragments and actinides relevant to Accelerator Driven Systems (transmutation of nuclear waste and energy production).

Capture measurements (AstroΦ and ADS)  
Fission measurements (ADS)
Antihydrogen Production and Spectroscopy

ATHENA COLLABORATION
INFN Genova, INFN Pavia, Università di Genova, Università di Pavia, Università di Brescia, University of Aarhus, CERN, University of Rio de Janeiro, University of Wales Swansea, University of Tokyo, University of Zurich

ATHENA (AnTiHydrogEN Apparatus) @ CERN
Opening Angle between two 511 keV photons (seen from charged particle vertex)

Mixing with cold positrons

131 ± 22 events

Mixing with hot positrons

New Results

• ~1 MILLION OF ANTI-ATOMS WERE PRODUCED (in 2002)
• High initial rate production (peak rate > 300 Hz)
• Time modulation of antihydrogen formation
• Temperature dependence of the production
• Other aspects: plasma modes and diagnostics, interaction dynamics, antihydrogen angular emission,…

Announcement

M. Amoretti et al.,

• Conservative estimate:
>50000 Cold Antihydrogen Atoms
2004 Funds in percentage assigned to the experiments
Conclusions and Outlooks

A lot of data produced with electromagnetic probes in different LABS

- HERMES will take data until 2007
- Experimentation at MAMI
- Polarization target at GRAAL
- Strong participation to JNAF experimentation. CEBAF upgrading??
- More data with improved apparatus and beams
Conclusions and Outlooks

**LNF**
- FINUDA is taking data
- SIDDARTHA will complete with a new apparatus the studies on kaonic hydrogen

**STRONG INTEREST IN ANTIPROTON PHYSICS**

**PANDA DETECTOR**

**CERN**
- Na 60 took data on In In interaction

**ALICE** strong Italian participation to subdetectors construction, analysis and computing (Grid)
Conclusions and Outlooks

Reaction dynamics and Nuclear Phase transition
LNS
Dynamics and Thermodynamics of nucler matter (NUCLEX)
ISOSPIN dependence of EOS with CHIMERA and MEDEA
CHIMERA completed
MAGNEX ready in the 2004
First EXCYT radioactive beam 2004

LNL EXOTIC EDEN

GAMMA spectroscopy experiments
LNL $\gamma$ detectros + PRISMA with stable beams
GSI RISING $\gamma$ detectors + Ba F$_2$ with fast radioactive beams
R&D Segmented $\gamma$ detector AGATA

Neutron production reaction
LNL and TAMU
Conclusions and Outlooks

ATHENA produced more than 1 M of cold anti hydrogen atoms

nTOF facility measures neutron cross sections of ADS and Astrophysical interest

Nuclear Cross section of Astrophysical interest measured at LNGS (LUNA) and with indirect methods

More data of astrophysical interest with improved apparatus, LUNA and EXCYT beams