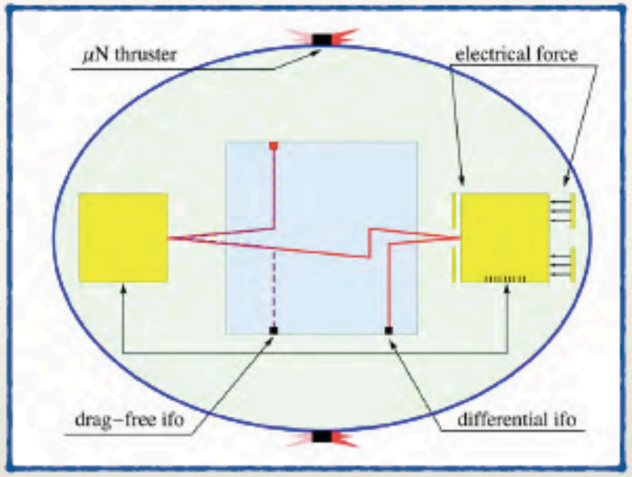
Giornate del Piano Triennale, Catania, 3-4 Dicembre 2015

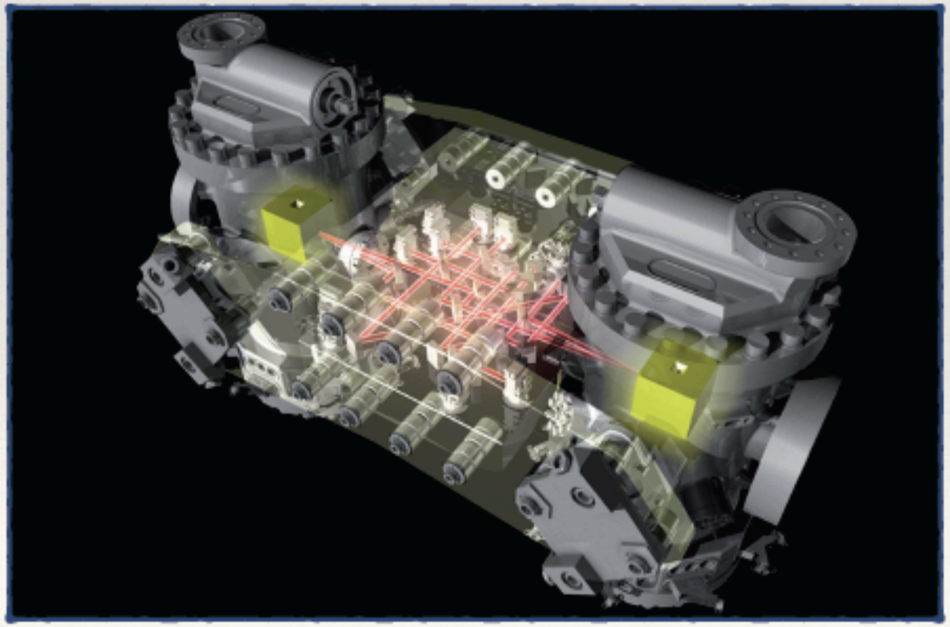
DOVE SIAMO
e
DOVE ANDIAMO

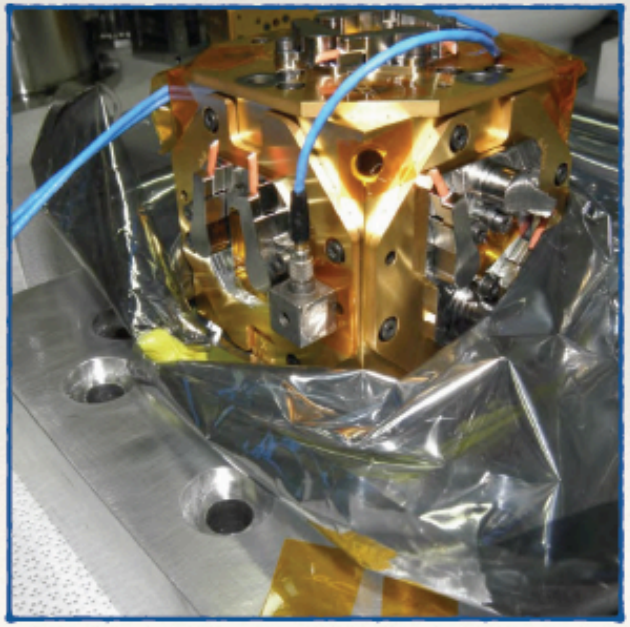
Antonio Masiero
INFN e Univ. of Padova

LISA-PF

- Goal: **validate the concept of "no-touch" satellite**
- Two Au-Pt masses in the same satellite
    - One free falling, the second one controlled by low-frequency electrostatic system
    - Launch in **Dec. 2, 2015 at 5.15 GMT**

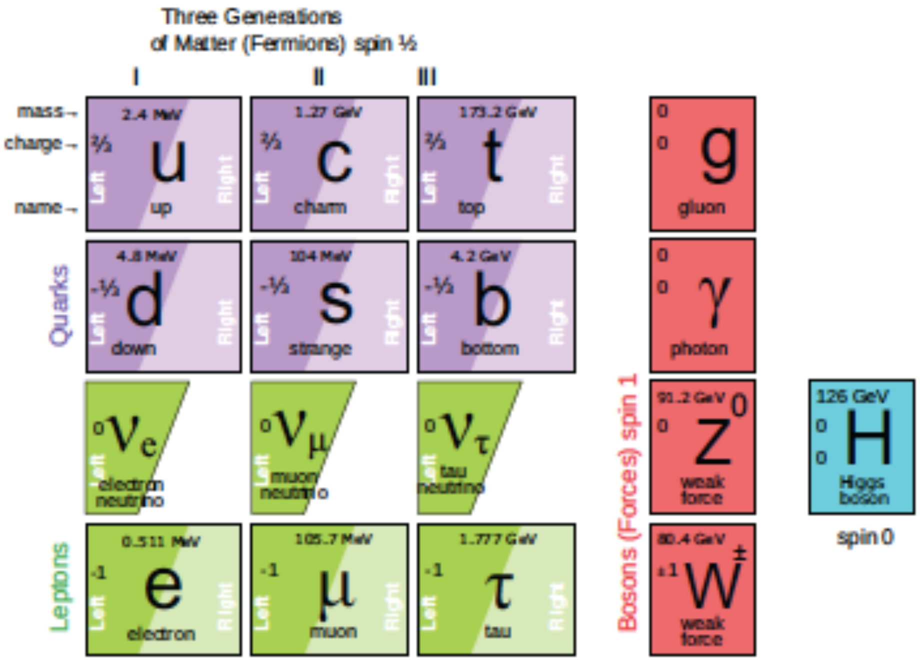


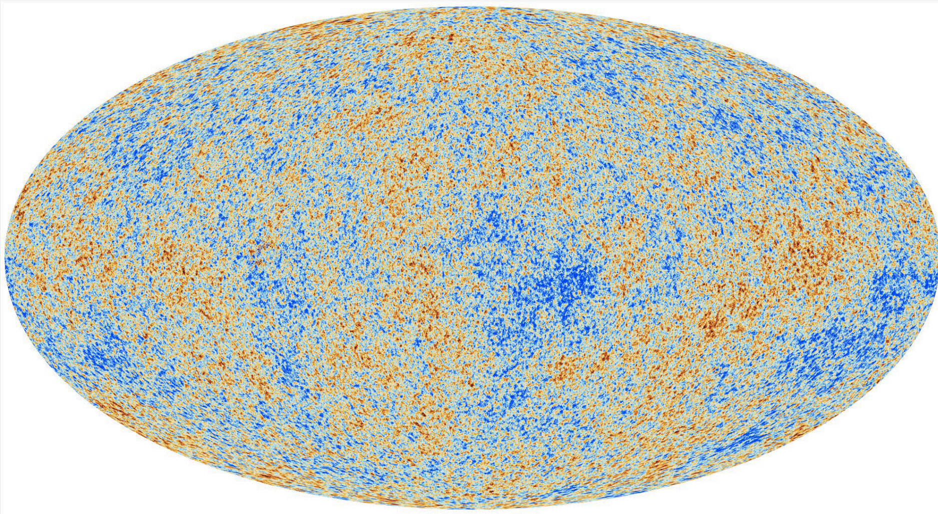




2013: the thiumph of the **STANDARD**

- **PARTICLE STANDARD MODEL**
- **COSMOLOGY STANDARD MODEL**





ΛCDM + “SIMPLE” INFLATION

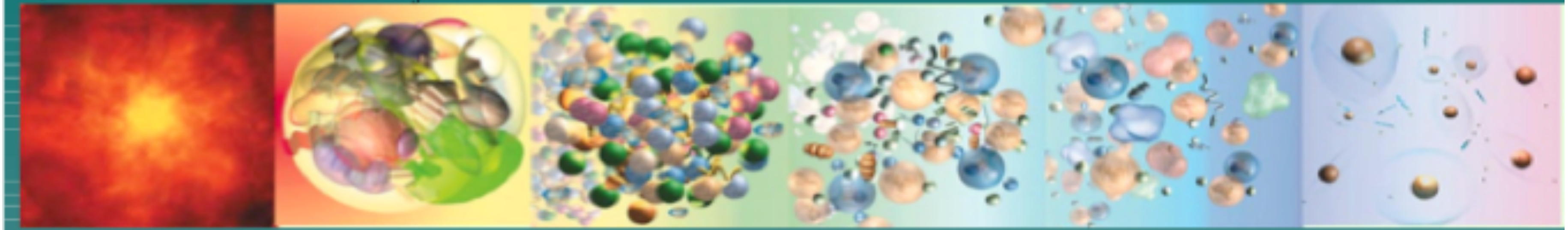
$\Omega_\Lambda = 0.686 \pm 0.020$

$\Omega_m = 0.314 \pm 0.020$

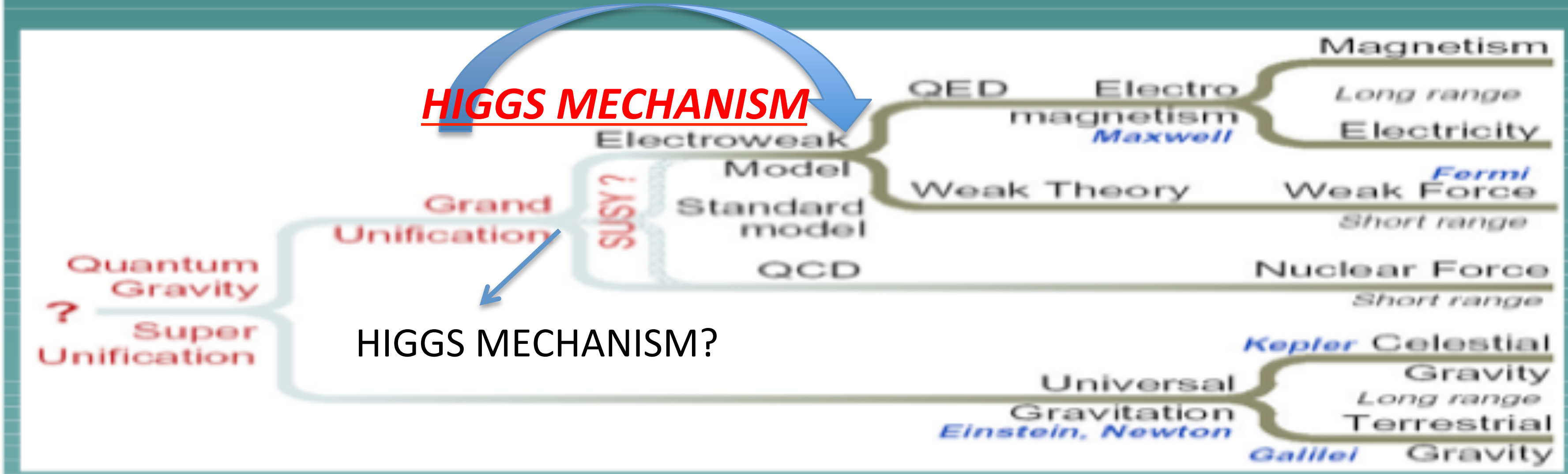
$\Omega_b h^2 = 0.02207 \pm 0.00033$

$h = 0.674 \pm 0.014$

Big Bang	Quark-Gluon Plasma		Protoni e neutroni	Protoni e Nuclei leggeri	Atomi →Galassie →Molecole→DNA
Gravità	*Nucleare forte*	*Nucleare debole*			



10^{-43} sec **10^{-35} m** **10^{19} GeV**	**10^{-32} sec** **10^{-32} m** **10^{16} GeV**	**10^{-10} sec** **10^{-18} m** **10^{2} GeV**	**10^{-4} sec** **10^{-16} m** **1 GeV**	**100 sec** **10^{-15} m** **1 Mev**	**300KY → 15GY** **10^{-10} m** **10 eV**
???	LHC	LEP			Astronomia→



HIGGS MECHANISM

Electroweak Model

QED

Electro magnetism

Maxwell

Magnetism

Long range

Electricity

Weak Theory

Fermi

Weak Force

Short range

SUSY ?

Standard model

Grand Unification

QCD

Nuclear Force

Short range

Quantum Gravity

?

Super Unification

HIGGS MECHANISM?

Kepler Celestial Gravity

Long range

Universal Gravitation

Einstein, Newton

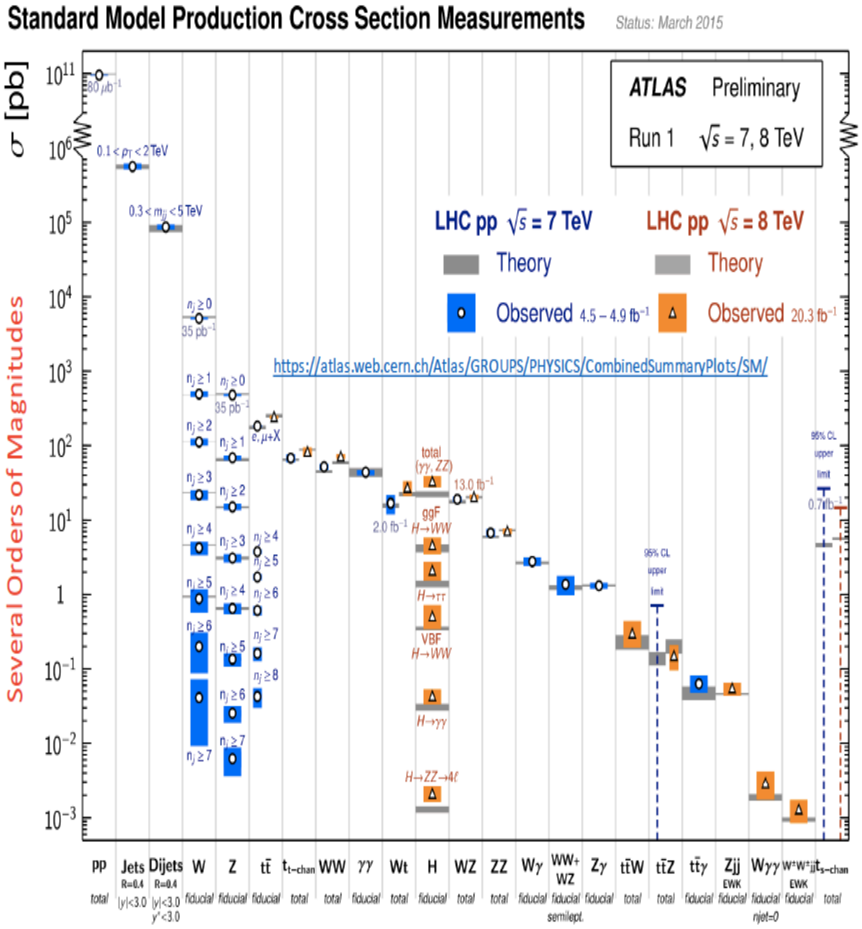
Terrestrial

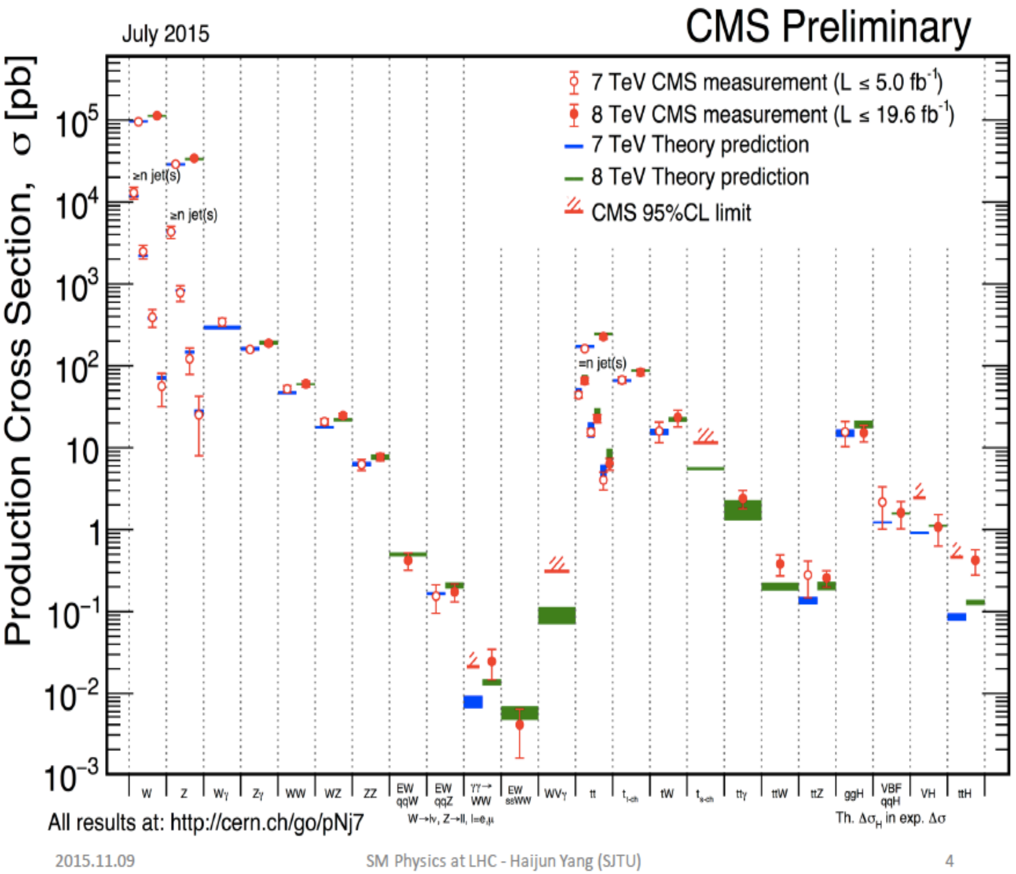
Galilei Gravity

Theories:

STRINGS? **RELATIVISTIC/QUANTUM** **CLASSICAL**

NEW ERA IN PRECISION HIGGS PHYSICS



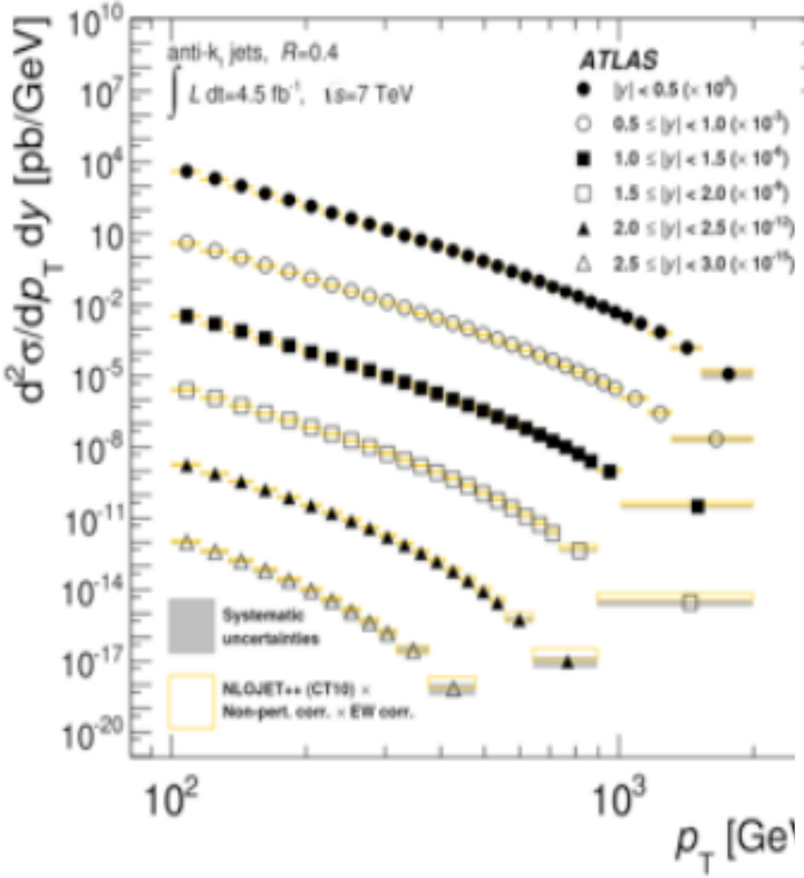


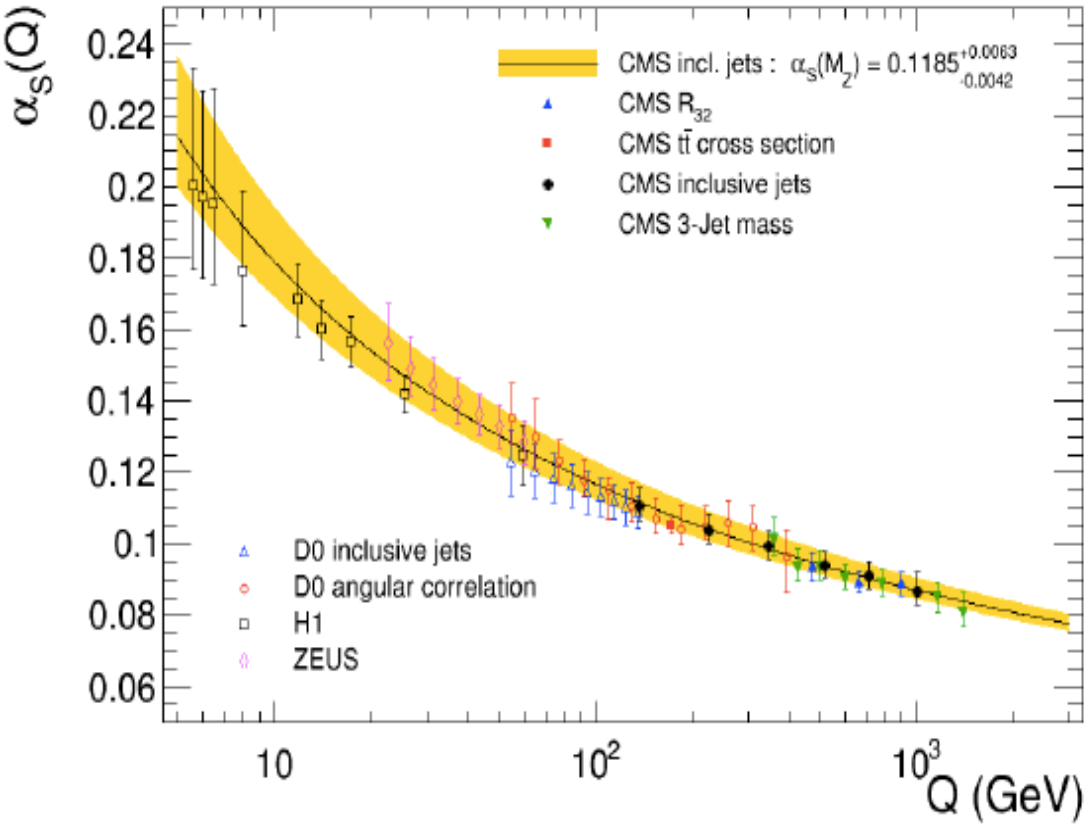
2015.11.09 SM Physics at LHC - Haijun Yang (SJTU) 4

- **State-of-the-art calculation NNLO, NLO EW**
- **NNNLO Higgs cross sections**
- **NNLO kinematic contributions**

Notevoli contributi INFN

Sinergia teorici-sperimentali





- QCD predictions successful over many orders of magnitude
- **α_s runs beyond the TeV scale**: into a GUT?
- Consistent with world average

J. Ellis, LP 2015

INFN

The Standard Model from LHC to future colliders

a contribution to the Workshop “What Next” of INFN

Editors: S. Forte
A. Nisati
G. Passarino
R. Tenchini

Cosa ci resta da imparare sul Modello Standard da LHC e da futuri acceleratori

- **Higgs boson couplings to bosons and fermions**: precisions ≤ 10% attainable with 300 fb^{-1} ;

  precisions 2% - 5% in the High Luminosity phase

  uncertainties O(1%) at ILC and <1% at FCC-ee

- **Higgs total width**: too narrow (~4 MeV) to be measured at LHC – at HL-LHC try using the interference of a specific mode with the continuum; at ILC/FCC-ee through HZ

- **Higgs boson rare production and rare decay modes**: HH production important → related to Higgs self-couplings → need full HL-LHC phase

Units are %

Coupling $\sqrt{s}$ (TeV)→ L (fb^{-1}) →	LHC 14 3000(1 expt)	CepC 0.24 5000	FCC-ee 0.24 +0.35 13000	ILC 0.25+0.5 6000	CLIC 0.38+1.4+3 4000	FCC-hh 100 40000
K_W	2-5	1.2	0.19	0.4	0.9	
K_Z	2-4	0.26	0.15	0.3	0.8	
K_g	3-5	1.5	0.8	1.0	1.2	
K_γ	2-5	4.7	1.5	3.4	3.2	< 1
K_μ	~8	8.6	6.2	9.2	5.6	~ 2
K_c	--	1.7	0.7	1.2	1.1	
K_τ	2-5	1.4	0.5	0.9	1.5	
K_b	4-7	1.3	0.4	0.7	0.9	
$K_{Z\gamma}$	10-12	n.a.	n.a.	n.a.	n.a.	
Γ_h	n.a.	2.8	1%	1.8	3.4	
BR_{invis}	<10	<0.28	<0.19%	<0.29	<1%	
K_t	7-10	--	13% ind. tt scan	6.3	<4	~ 1 ?
K_{HH}	?	35% from K_Z model-dep	20% from K_Z model-dep	27	11	5-10

Few preliminary estimates available
SppC : similar reach

from K_γ/K_Z, using K_Z from FCC-ee

rare decays → pp competitive/better

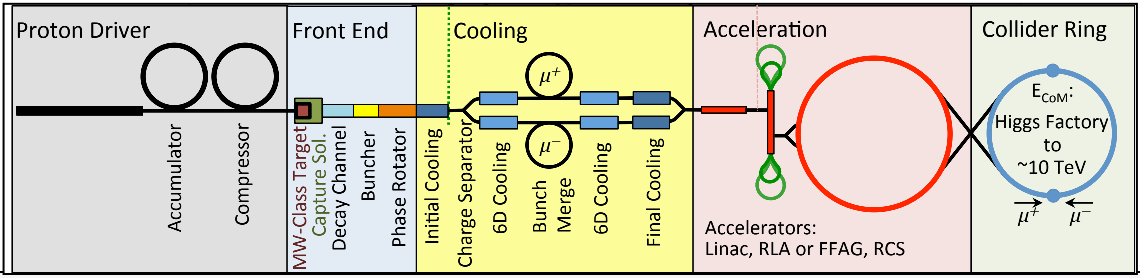
from ttH/ttZ, using ttZ and H BR from FCC-ee

- ☐ LHC: ~20% today → ~ 10% by 2023 (14 TeV, 300 fb^{-1}) → ~ 5% HL-LHC
- ☐ HL-LHC: -- first direct observation of couplings to 2nd generation (H→ μμ)
  -- model-independent ratios of couplings to 2-5%
- ☐ Best precision (few 0.1%) at FCC-ee (luminosity !), except for heavy states (ttH and HH) where high energy needed → linear colliders, high-E pp colliders
- ☐ Complementarity/synergies between ee and pp

F. Gianotti, EPS '15

Theory uncertainties (presently few percent e.g. on BR) need to be improved to match expected superb experimental precision

Muon colliders



Synergies with neutrino factories

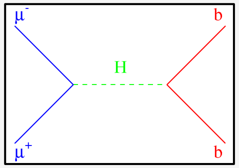
F. Gianotti, EPS '15

Main advantage compared to e^+e^- colliders: $m_\mu \sim 200\ m_e$

→ negligible SR → can reach multi-TeV with (compact !) circular colliders: 300 m ring for $\sqrt{s}$ = 125 GeV, 4.5 km for $\sqrt{s}$ = 3 TeV

→ negligible beamstrahlung → much smaller E spread

→ $\sigma(\mu\mu \to H) \sim 20$ pb (s-channel resonant production) → H factory



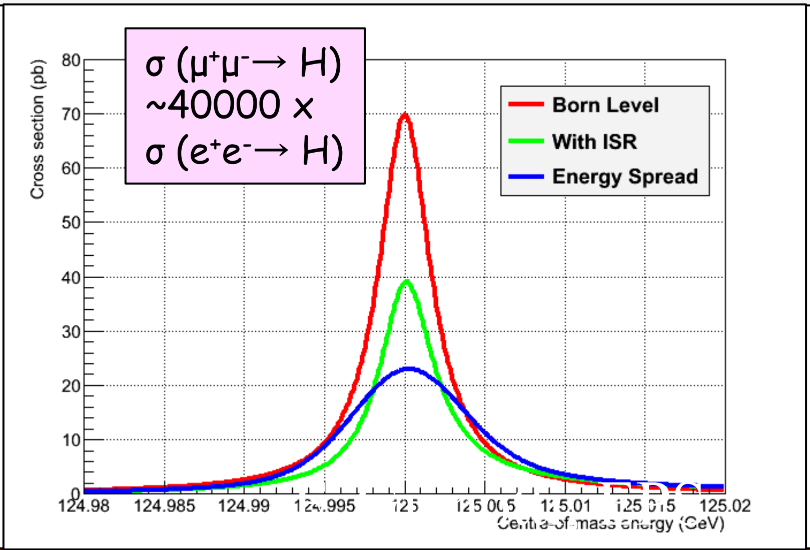
Main challenge: produce high-intensity, low E-spread beams:

☐ $m_\mu \sim 200\ m_e$ → SR damping does not work → novel cooling methods (dE/dx based) needed to reach beam energy spread of ~ $3\text{x}10^{-5}$ (for precise line shape studies) and high L

☐ $\tau_\mu \sim 2.2\ \mu s$ → production, collection, cooling, acceleration, collisions within ~ ms

Beam spread of ~ $3\text{x}10^{-5}$ would allow Γ_H measurement from line shape to 5% (0.2 MeV) → resolve (possible) resonances

However, with currently projected L (~10^{32}): ~ 20000 H/year → not competitive with e^+e^- colliders for coupling measurements (except Hμμ ~ 1%)

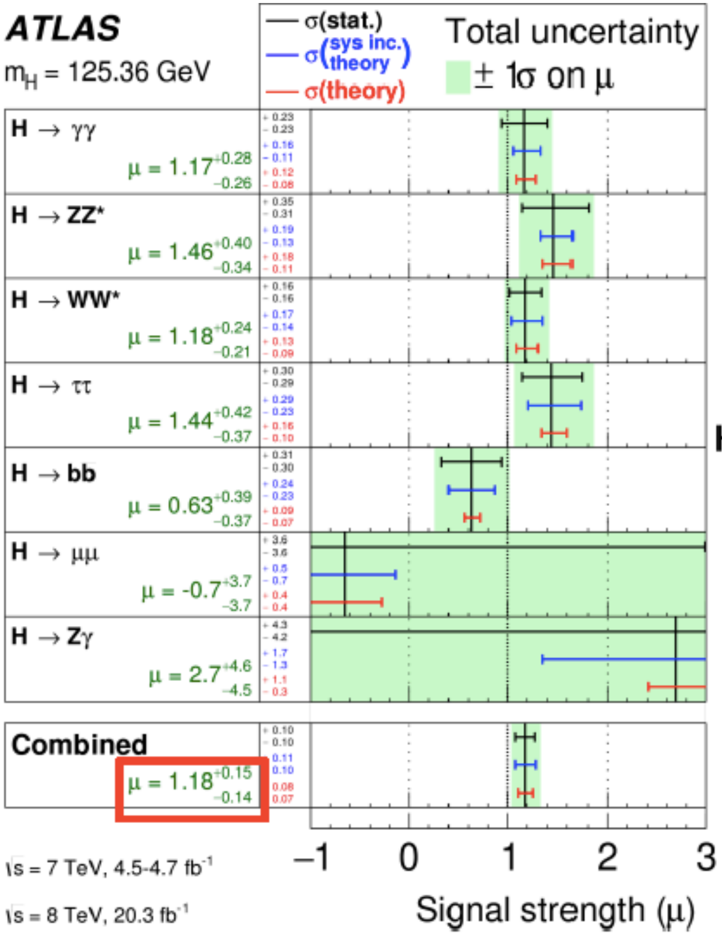


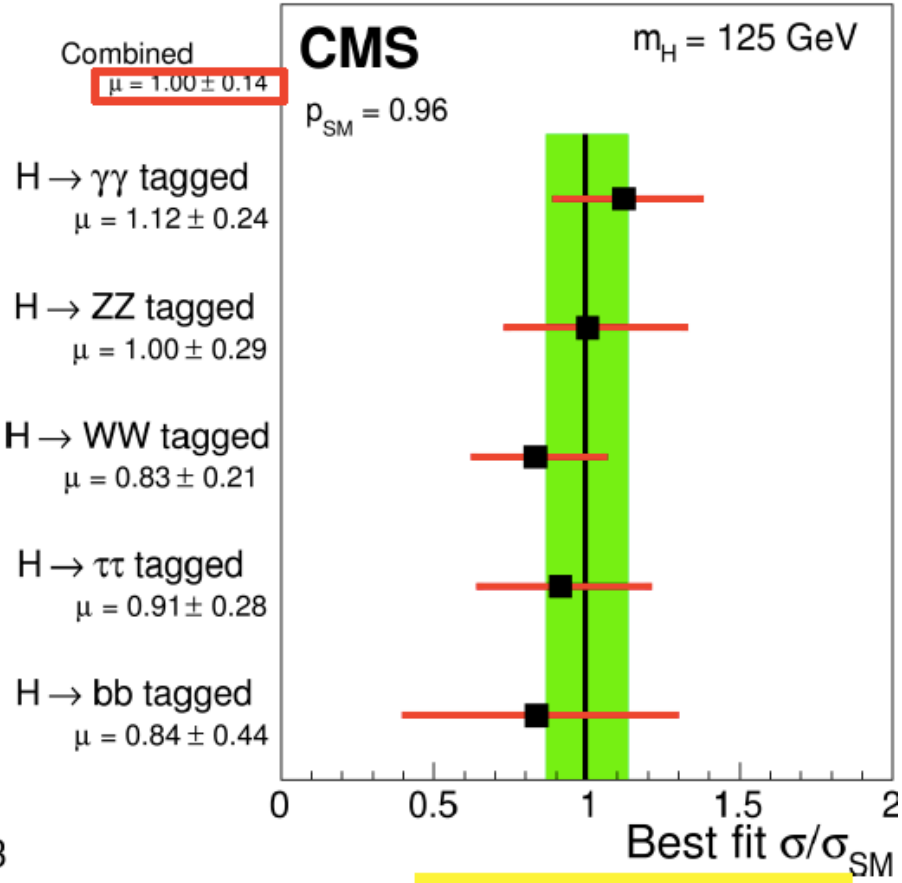
$\sigma(\mu^+\mu^- \to H)$ ~40000 x $\sigma(e^+e^- \to H)$

More R&D needed to demonstrated feasibility, in particular cooling:

linear systems (MICE at RAL), rings (recently re-ignited by C.Rubbi

Higgs Signal Strengths





EPJC 75 (2015) 212

Globally the SM is OK @ 10% level

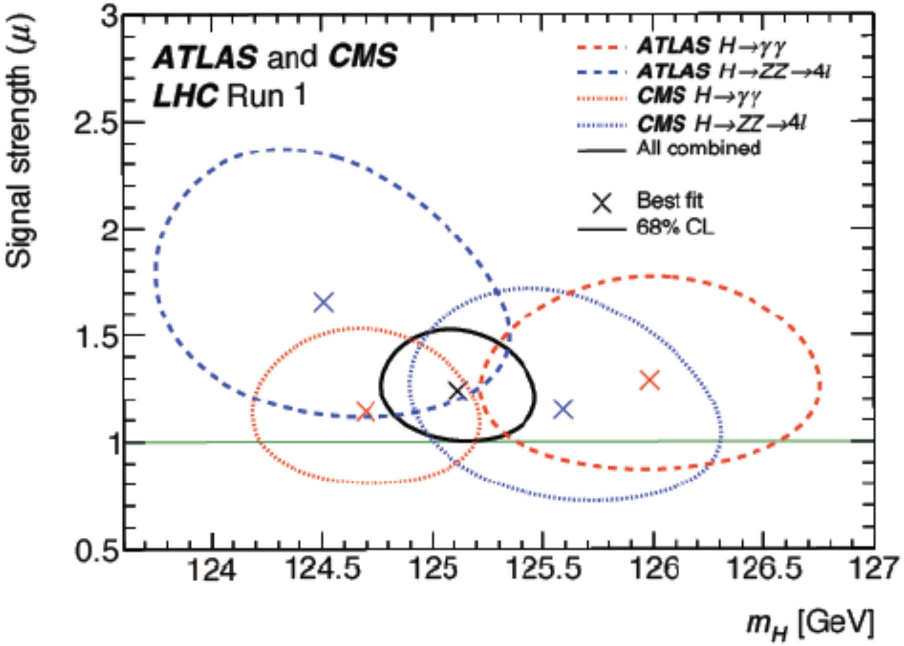
Cosa ci resta da imparare sul Modello Standard da LHC e da futuri acceleratori protone-protone e/o elettrone-positrone

- **Top quark mass**: at hadron colliders present precision ~0.5%, difficult even in the future to go below ~0.5 GeV uncertainty; to do better → go to lepton colliders, ILC or FCC-ee

- **Top quark properties**: precise measurements of top decays → tWb vertex; measurement of top-Higgs Yukawa coupling through ttH → 10% precision at HL-LHC with 3 ab^{-1}; 4% precision with 1 ab^{-1} at a lepton collider with c.m. energy 1 TeV

Higgs Mass measurements

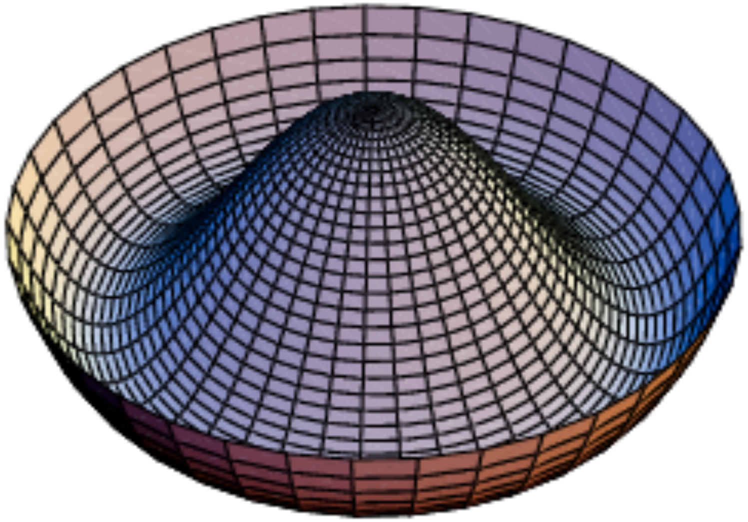
ATLAS + CMS ZZ* and γγ final states

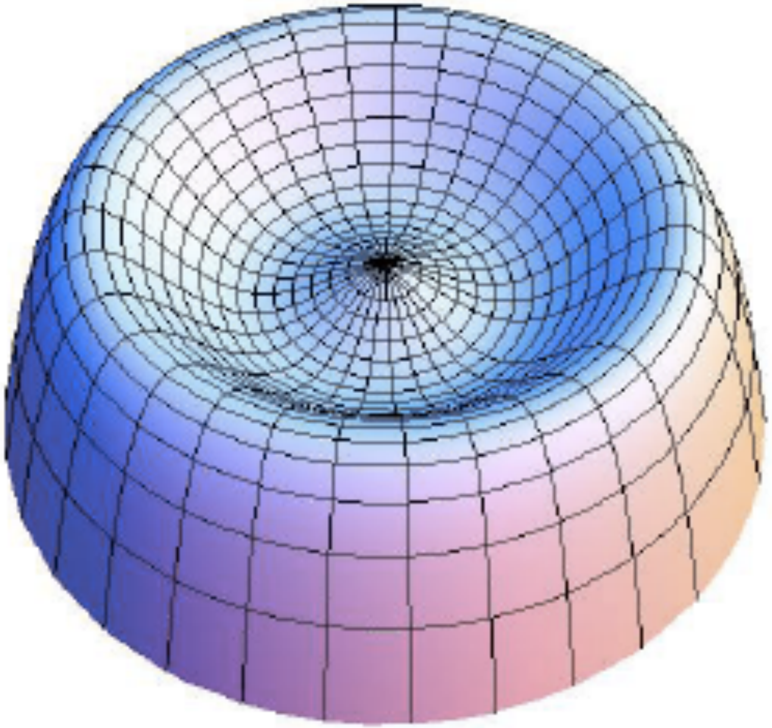


$125.09 \pm 0.21\,(\text{stat}) \pm 0.11\,(\text{syst})$

The values of the **TOP and HIGGS masses** are crucial to establish the stability of the **ELECTROWEAK VACUUM**

STABILITY ⟷ **INSTABILITY**

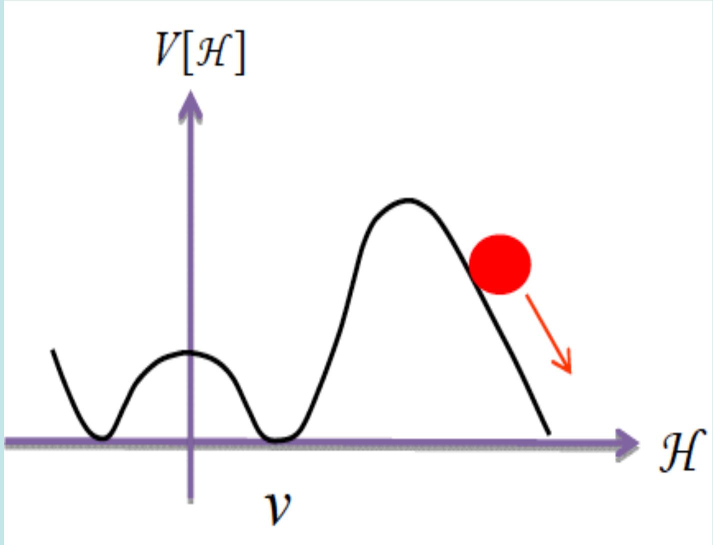




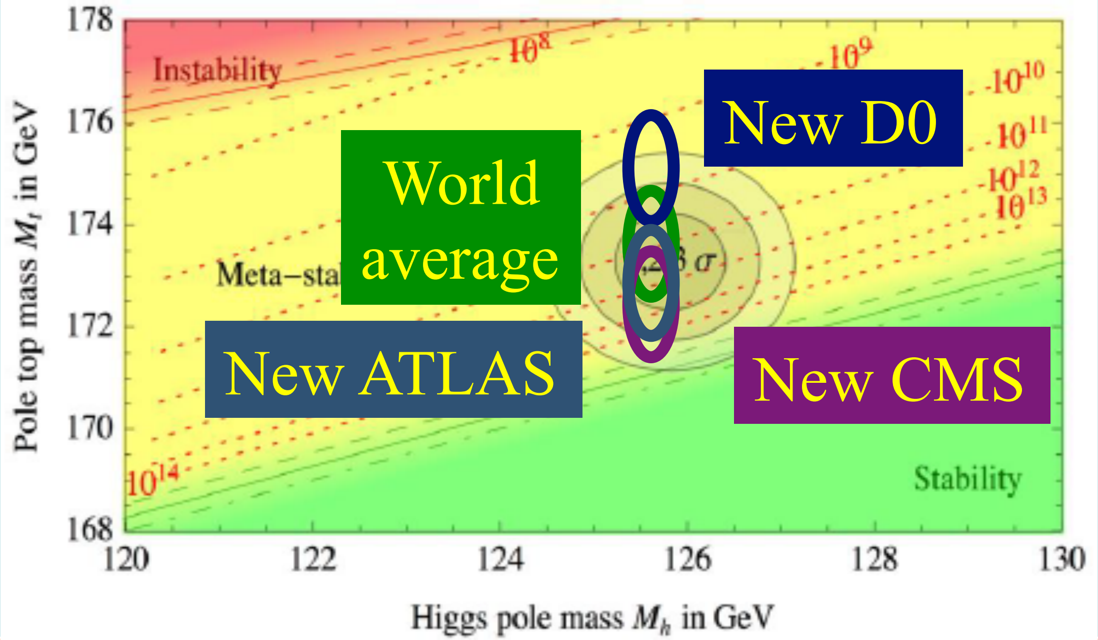
ON THE IMPORTANCE OF PRECISELY MEASURING HIGGS and TOP MASSES

Vacuum Instability in the Standard Model

- Very sensitive to m_t as well as M_H



J. Ellis, LP 2015



Buttazzo, Degrassi, Giardino, Giudice, Sala, Salvio & Strumia, arXiv:1307.3536

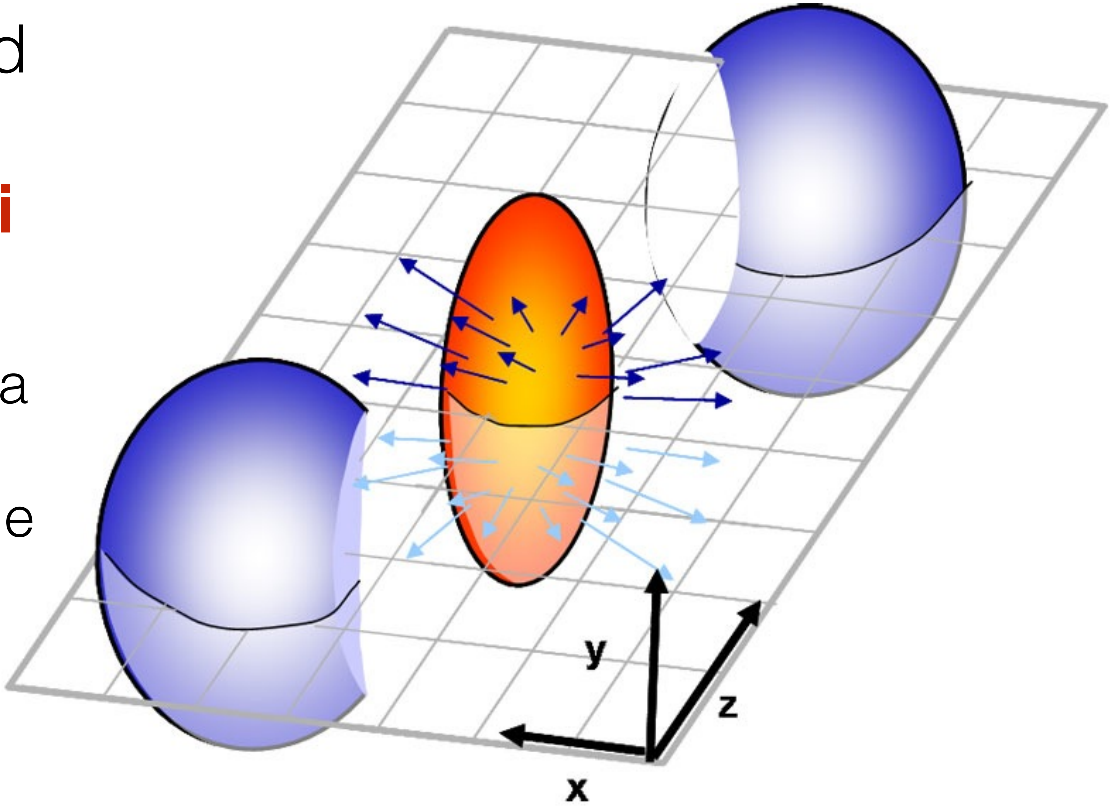
- Instability scale:

$$\log_{10}\frac{\Lambda_I}{\text{GeV}} = 11.3 + 1.0\left(\frac{M_h}{\text{GeV}} - 125.66\right) - 1.2\left(\frac{M_t}{\text{GeV}} - 173.10\right) + 0.4\,\frac{\alpha_3(M_Z) - 0.1184}{0.0007}$$

$m_t = 173.3 \pm 1.0$ GeV ➔ $\log_{10}(\Lambda/\text{GeV}) = 11.1 \pm 1.3$

Fenomeni collettivi

la materia creata in collisioni di ioni pesanti ad alta energia **può essere descritta tramite modelli idrodinamici**



- fase partonica calda e densa in rapida espansione
- si sviluppano flussi collettivi e il sistema si raffredda
- transizione di fase (adronizzazione) quando è raggiunta la T_{critica}

che comporta

- dipendenza della forma degli spettri in p_{T} dalla massa della particella
- <u>caratteristica anisotropia azimutale (anisotropia spaziale iniziale)</u>

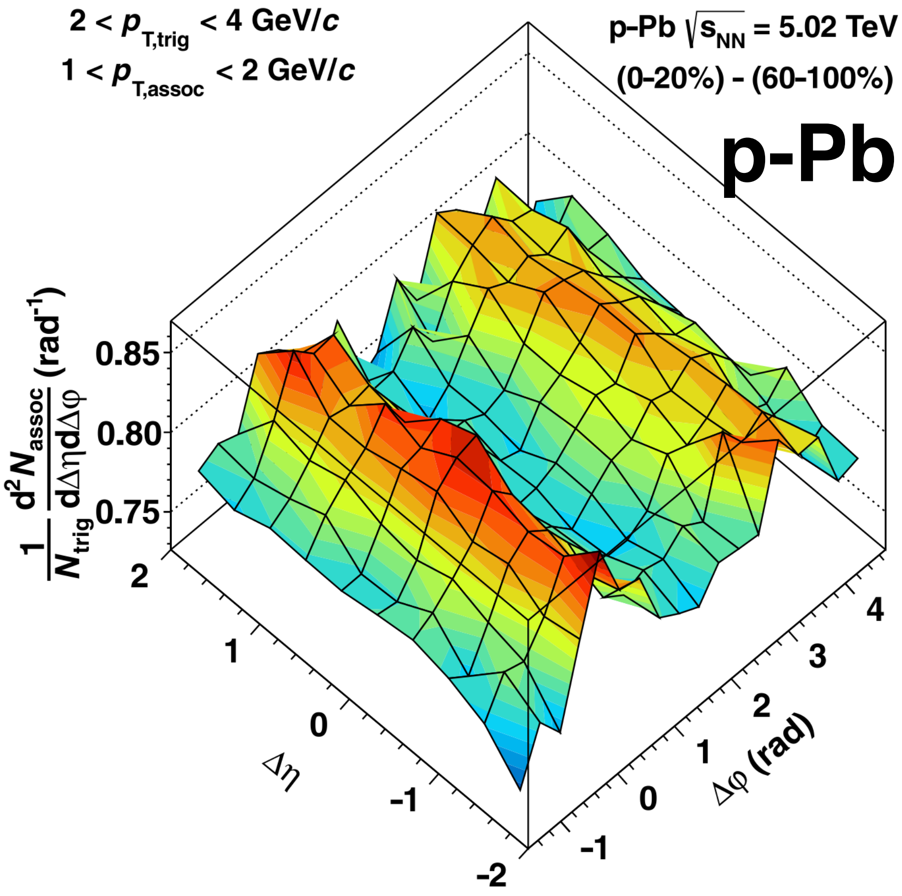
esistono effetti simili anche in piccoli sistemi ?

Il "double ridge"

l'osservazione del ridge in p-Pb ha stimolato **ulteriori idee**

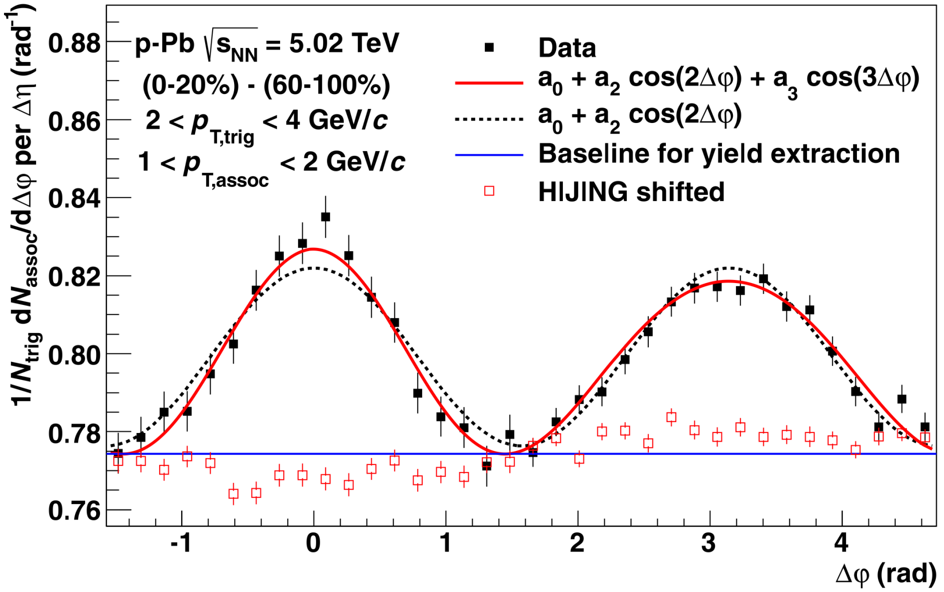
<u>rimozione del contributo da jet:</u> sottrazione degli eventi a bassa molteplicità

rivelata la presenza di una struttura **"double ridge"**



sembra un effetto collettivo

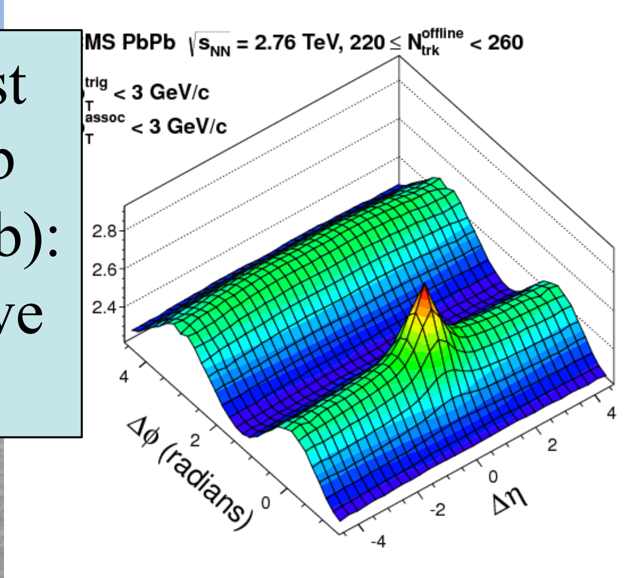
espansione di Fourier in **Δφ**: v_2, v_3, ...



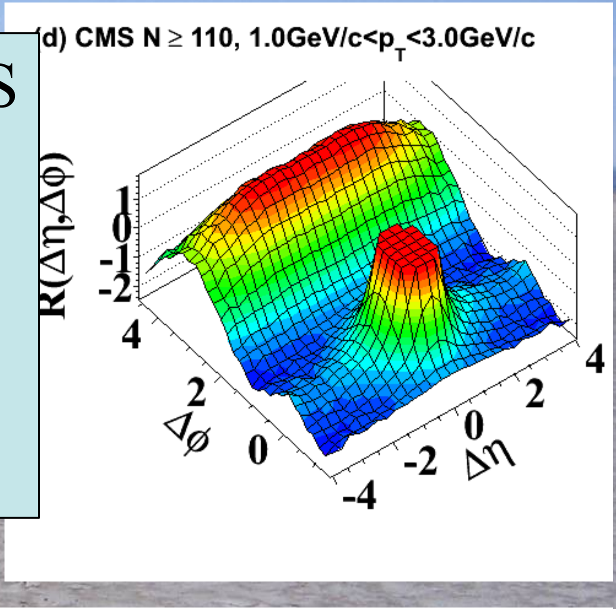
ALICE, PLB 719 (2013) 29

“Ridge”: Collective Effect in pp?!

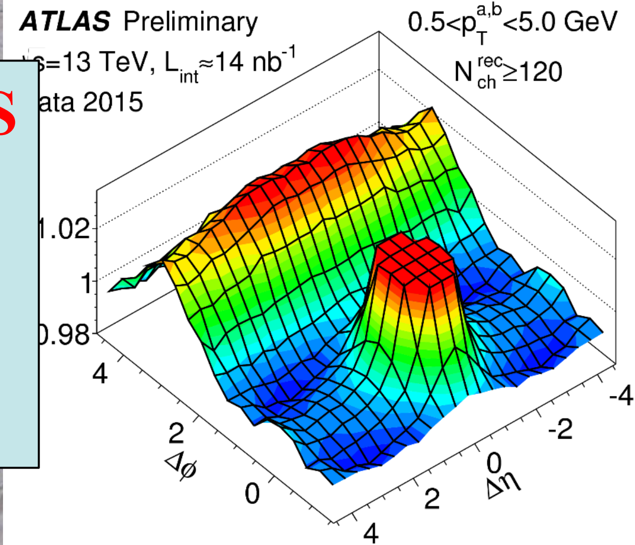
Seen first in Pb-Pb (later p-Pb): “collective effect”



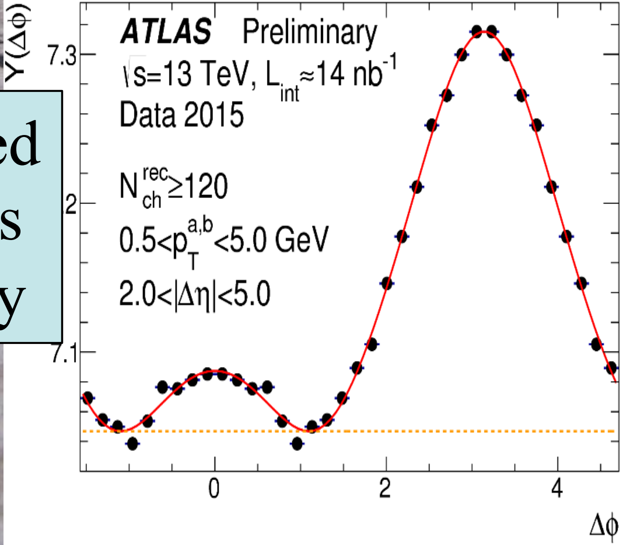
Then by CMS in high-multiplicity pp events: **BIG SURPRISE!**



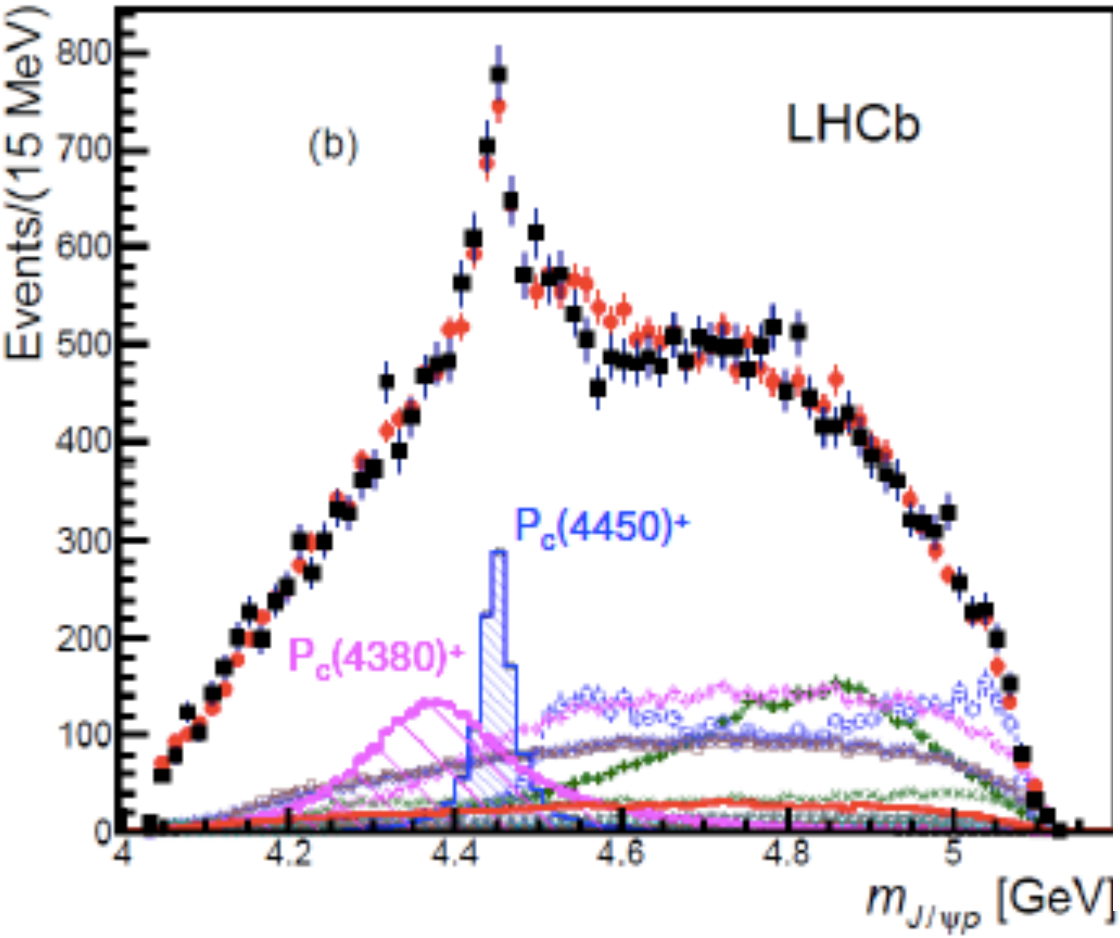
Now by ATLAS in high-multiplicity pp events at 13 TeV

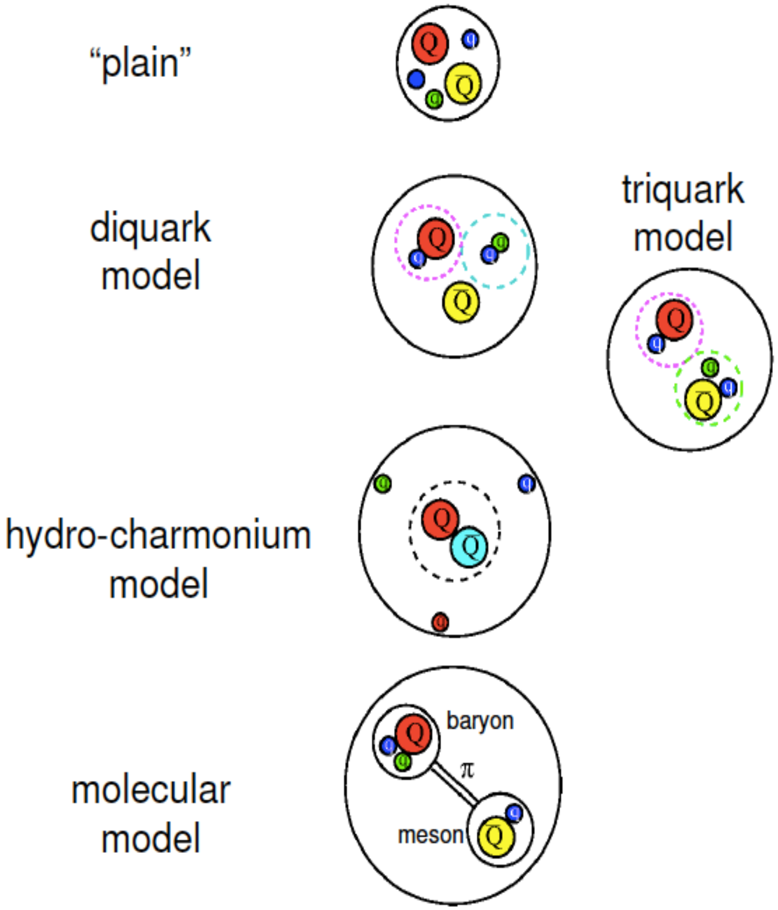


Detailed studies on way



PENTAQUARK





“plain”

diquark model

triquark model

hydro-charmonium model

molecular model

2005: Maiani, Polosa, Piccinini, Riquer → TETRAQUARK (heavy quark pair+light quark pair)

Z^+ : Belle (2007), LHCb (2014) charm-anticharm + light quark pair

Pentaquark: charm-anricharm + proton (3 light quarks)

THE FLAVOUR PROBLEMS

FERMION MASSES

What is the rationale hiding behind the spectrum of fermion masses and mixing angles (our "**Balmer lines**" problem)

→ **LACK OF A FLAVOUR "THEORY"**

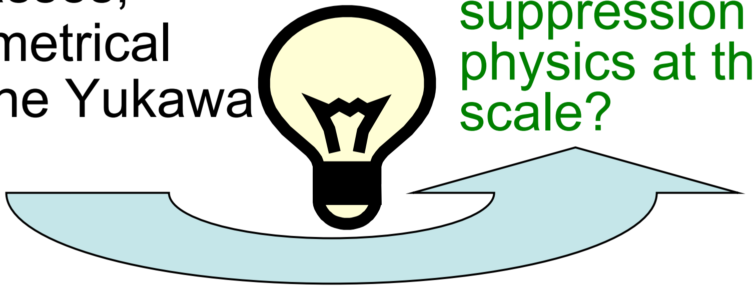
(new flavour – horizontal symmetry, radiatively induced lighter fermion masses, dynamical or geometrical determination of the Yukawa couplings, …?)

FCNC

Flavour changing neutral current (FCNC) processes are suppressed.

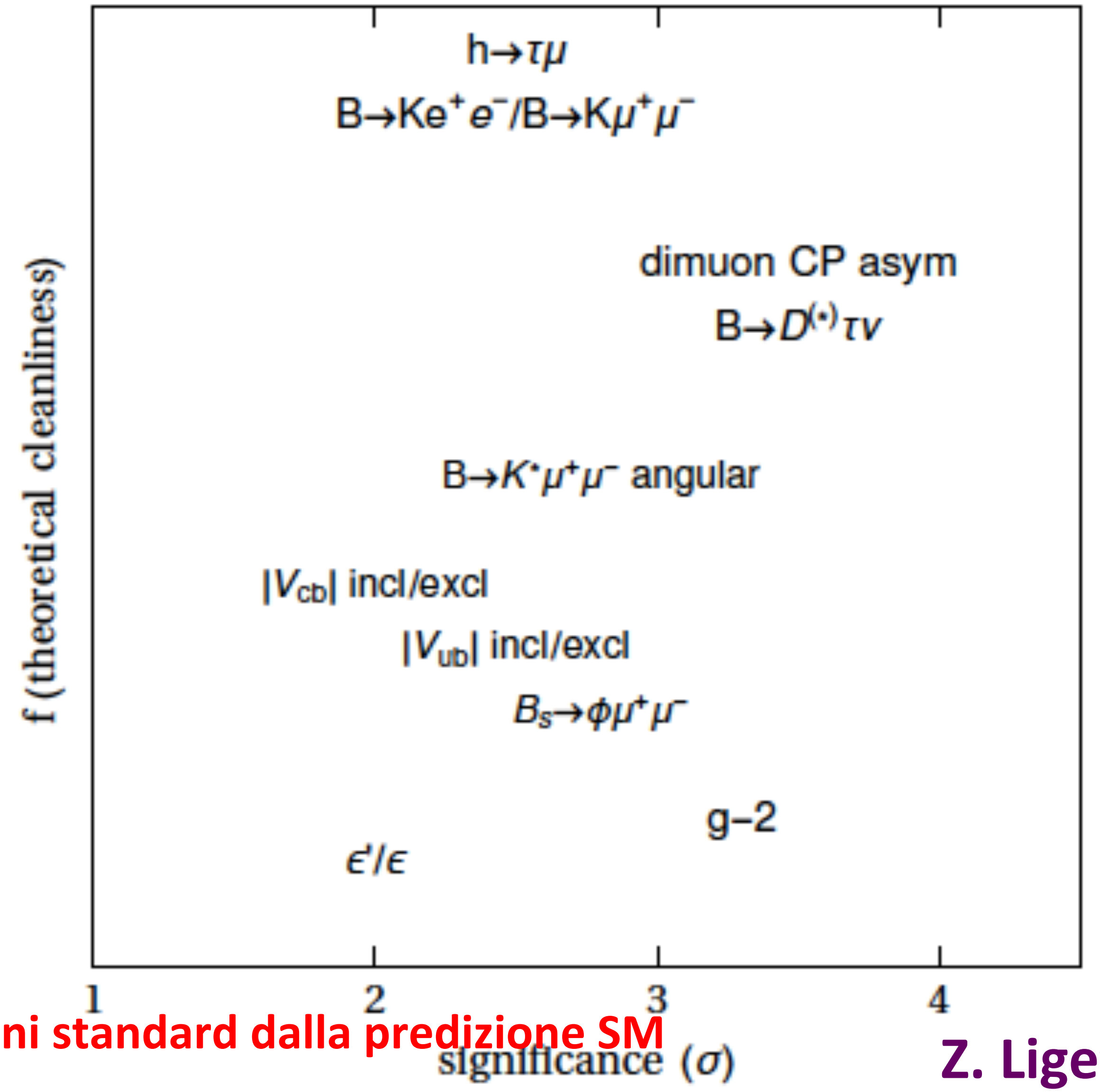
In the SM two nice mechanisms are at work: the **GIM mechanism** and the structure of the **CKM mixing matrix.**

How to cope with such delicate suppression if the there is new physics at the electroweak scale?



Non manca qualche indicazione di deviazione dalle predizioni del SM (fisiologico?)

Quanto e' affidabile
il conto
teorico della
predizione
SM



Quante deviazioni standard dalla predizione SM

Z. Ligeti, LP 2015

Puzzling deviations: $R(D^{(*)}) = BR(\bar{B} \to D^{(*)}\tau\bar{\nu})/BR(\bar{B} \to D^{(*)}l\bar{\nu})$

New HFAG average of $R(D^*)$ and $R(D)$:

HFAG averages:

$R(D^*) = 0.322 \pm 0.018 \pm 0.012$

$R(D) = 0.391 \pm 0.041 \pm 0.028$

Correlation $(D,D^*) = -0.29$

SM predictions:

$R(D^*) = 0.252 \pm 0.003$

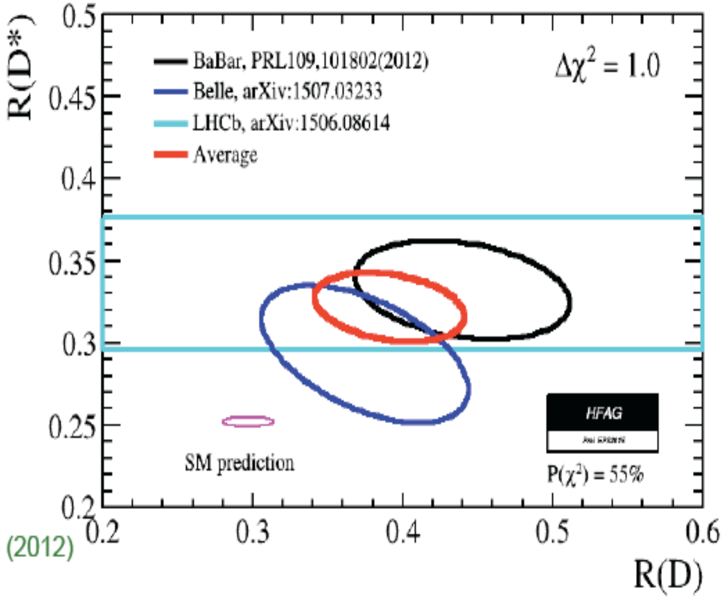
PRD 85 (2012) 094025

$R(D) = 0.300 \pm 0.010$

FNAL/MILC, arXiv:1503.07237

H. Na at al., arXiv:1505.03925

S. Fajfer et al., PRD 85, 094025 (2012)



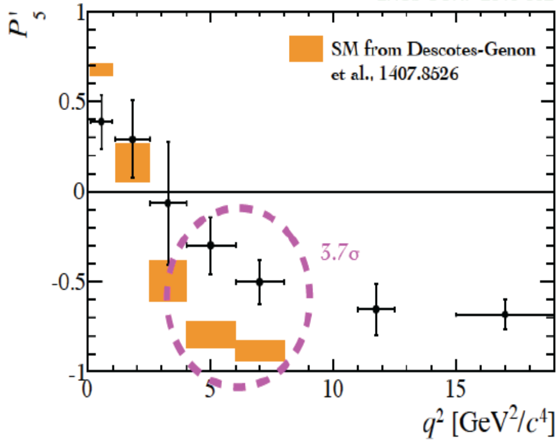
Difference with SM predictions at 3.9 σ level.

G. Lanfranchi, LP 2015

Puzzling deviations: P'_5 in $B^0 \to K^{*0}\mu^+\mu^-$

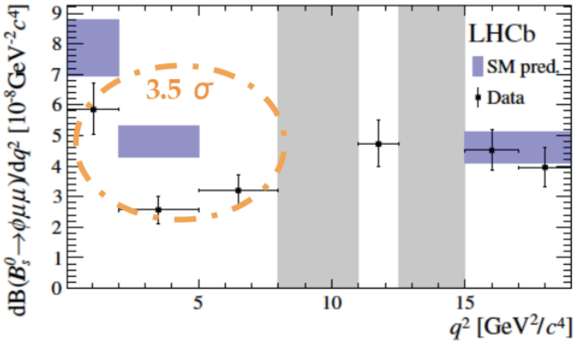
Recently confirmed by LHCb with the full Run I dataset (3 fb^{-1})

LHCb-CONF-2015-002



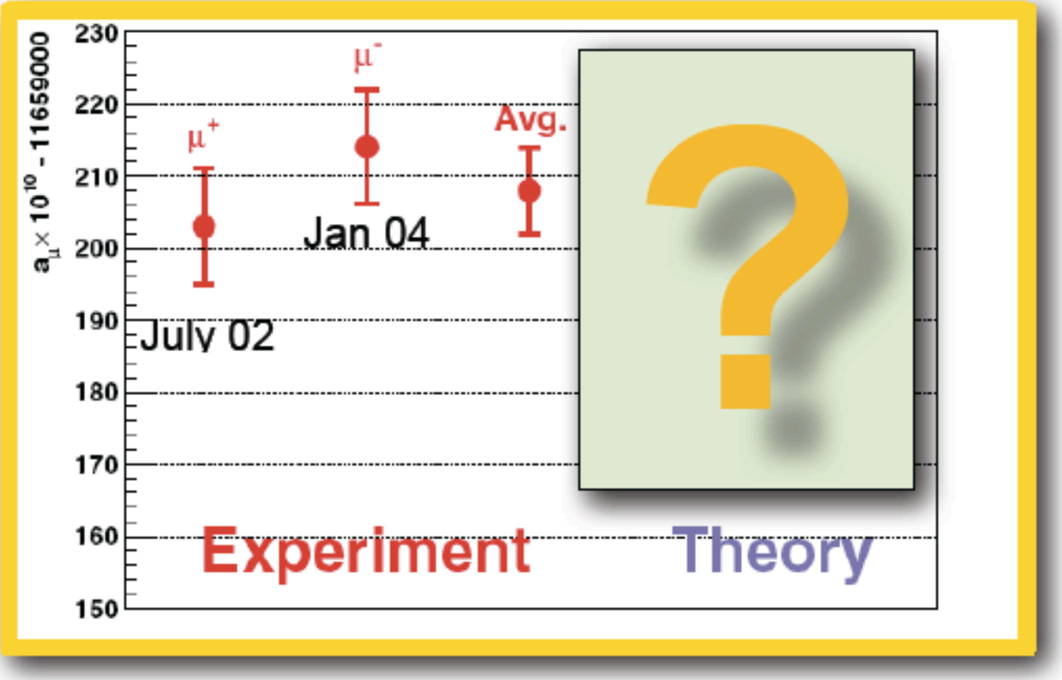
..and recently also in the differential BR of $B^0_s \to \phi\mu^+\mu^-$ with full Run I dataset (3 fb^{-1})

LHCb, arXiv:1506.08777, submitted to JHEP



SM predictions based on W. Altmannshofer and D. Straub, arXiv:1411.3161
A. Bharucha, D. Straub, R. Zwicky: arXiv:1503.05534

The muon g-2: the experimental result



- Today: $a_\mu^{EXP} = (116592089 \pm 54_{stat} \pm 33_{sys}) \times 10^{-11}$ [0.5ppm].
- Future: new muon g-2 experiments at:
  - Fermilab E989: aiming at ± 16×10^{-11}, ie 0.14ppm. Beam expected in 2017. First result expected in 2018 with a precision comparable to that of BNL E821.
  - J-PARC proposal: aiming at 2019 Phase 1 start with 0.4ppm.
- Are theorists ready for this (amazing) precision? No(t yet)

The muon g-2: SM vs. Experiment

Adding up all SM contributions we get the following theory predictions and comparisons with the measured g-2 value:

$a_\mu^{\mathrm{EXP}} = 116592091\ (63) \times 10^{-11}$

E821 – Final Report: PRD73 (2006) 072 with latest value of $\lambda=\mu_\mu/\mu_p$ from CODATA'10

$a_\mu^{\mathrm{SM}} \times 10^{11}$	$\Delta a_\mu = a_\mu^{\mathrm{EXP}} - a_\mu^{\mathrm{SM}}$	σ
$116\,591\,795\ (56)$	$296\ (86) \times 10^{-11}$	3.5 [1]
$116\,591\,815\ (57)$	$276\ (85) \times 10^{-11}$	3.2 [2]
$116\,591\,841\ (58)$	$250\ (86) \times 10^{-11}$	2.9 [3]

with the very recent "conservative" hadronic light-by-light $a_\mu^{\mathrm{HNLO}}(\mathrm{lbl})$ = 102 (39) x 10^{-11} of F. Jegerlehner arXiv:1511.04473, and the hadronic leading-order of:

[1] Jegerlehner, arXiv:1511.04473 (includes BaBar, KLOE10-12 & BESIII 2π)
[2] Davier et al, EPJ C71 (2011) 1515 (includes BaBar & KLOE10 2π)
[3] Hagiwara et al, JPG38 (2011) 085003 (includes BaBar & KLOE10 2π)

Muon g-2 @FNAL
(>13 FTE)

- **Sept 2014 – May 2015**

– Reassembly of the storage ring with cryogenic system; fully operational

- **June 2015**

– Start of cooling

- **July-August 2015**

– **CD2/3 received**

- **September 2015**

– Magnet cooled, ON (5300 A, 1.45T)

– 8 months needed for shimming

READY FOR BEAM APRIL 2017

INFN contribution:

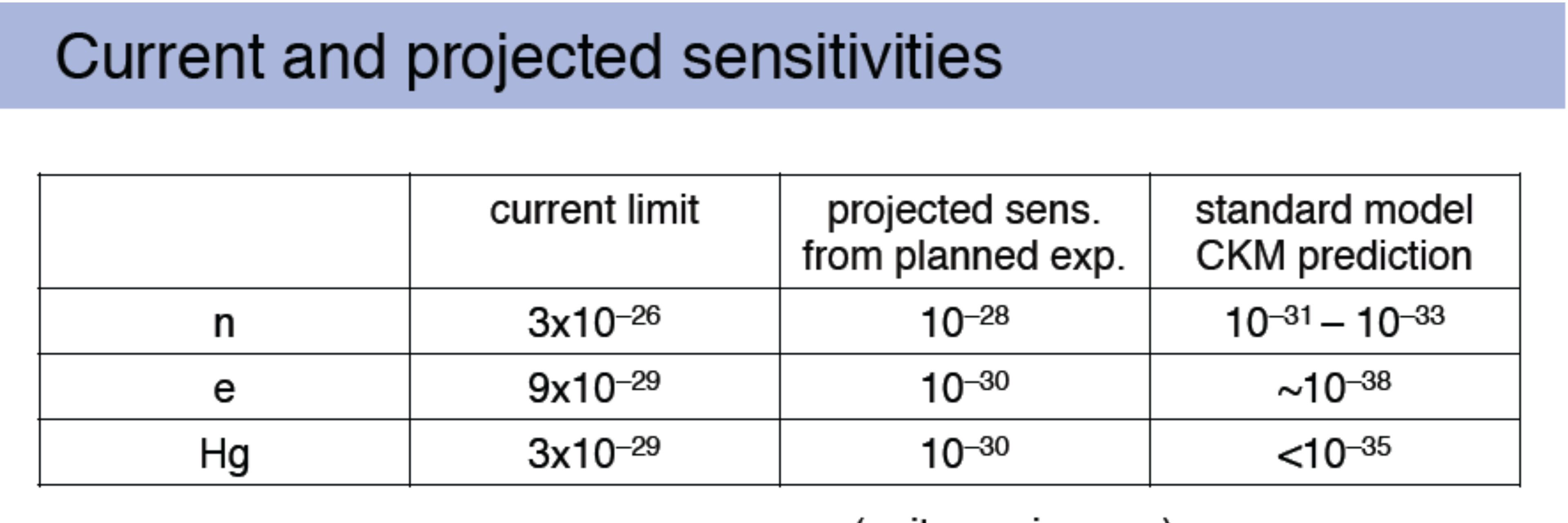
Laser monitoring system for calorimeter calibration

Gain stability 10^{-4} per hour

RISE EU-grant MUSE **with Mu2e** starting Jan 2016

THE EDM CHALLENGE

FOR **ANY** **NEW PHYSICS AT THE TEV SCALE** WITH **NEW SOURCES OF CP VIOLATION** → NEED FOR **FINE-TUNING** TO PASS THE EDM TESTS OR SOME **DYNAMICS TO SUPPRESS THE CPV** IN FLAVOR CONSERVING EDMS

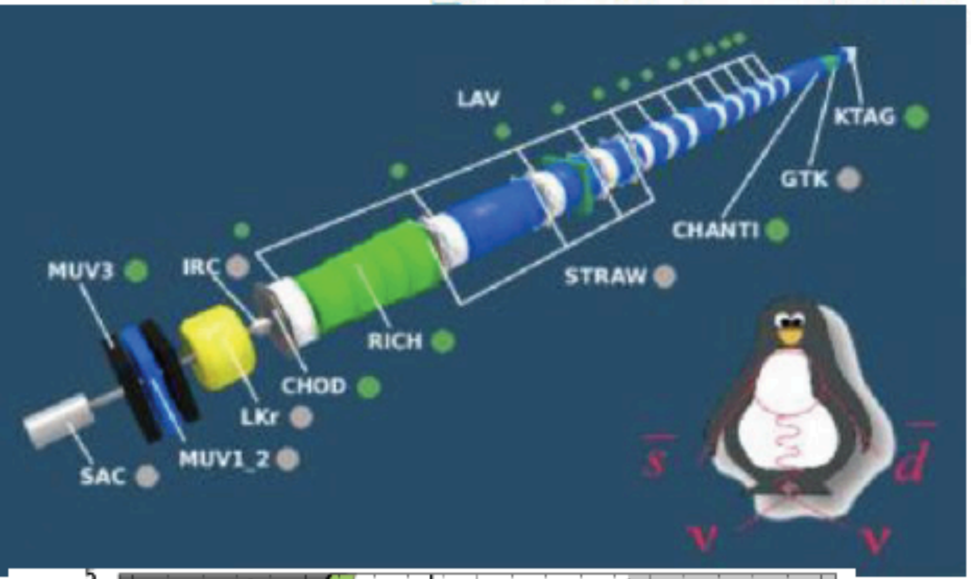


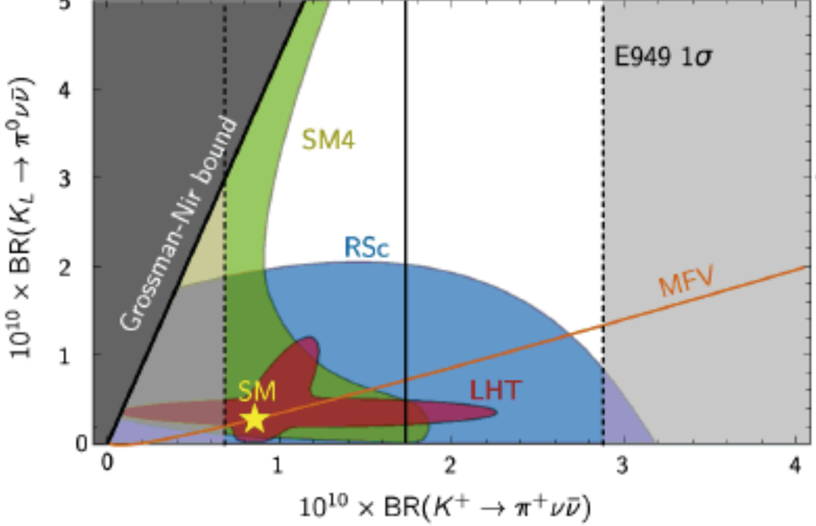
Current and projected sensitivities

	current limit	projected sens. from planned exp.	standard model CKM prediction
n	$3\mathrm{x}10^{-26}$	10^{-28}	$10^{-31} - 10^{-33}$
e	$9\mathrm{x}10^{-29}$	10^{-30}	$\sim 10^{-38}$
Hg	$3\mathrm{x}10^{-29}$	10^{-30}	$< 10^{-35}$

Kaon Physics: NA62
(44 FTE)

☐ $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ is a compelling measurement EVEN IN THE LHC RUN II ERA !!!





Motivations for New Analysis

1. NA62 in progress: 10% measurement of $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ in 2018.
2. Stress CKM uncertainties in $Br\left(K^+ \rightarrow \pi^+ \nu\bar{\nu}\right)$, $Br\left(K_L \rightarrow \pi^0 \nu\bar{\nu}\right)$
3. Point out correlation between $\boxed{K^+ \rightarrow \pi^+ \nu\bar{\nu},\ B_s \rightarrow \mu^+\mu^- \text{ and } \gamma}$
   (NA62) (LHCb+CMS) (LHCb)
4. Update correlation between $\boxed{K^+ \rightarrow \pi^+ \nu\bar{\nu},\ K_L \rightarrow \pi^0 \nu\bar{\nu} \text{ and } \beta}$
5. Use most recent lattice input for CKM
6. Provide the present best value in SM

Basically no CKM uncertainties

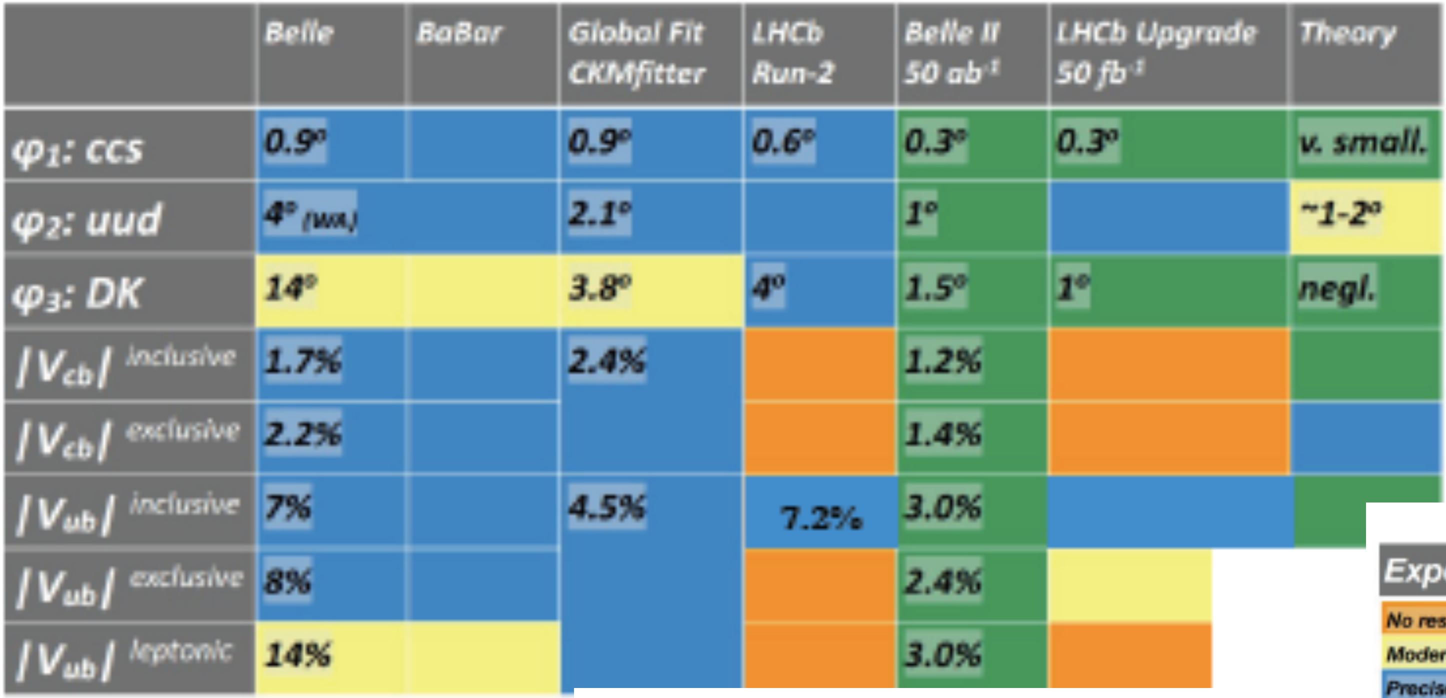
(Buchalla, AJB, 94)
(AJB, Fleischer, 00)

Taking data with all detector completed
40% nominal beam intensity

Expected ~ 100 events/ 3 years full intensity

BELLE2 @ SuperKEKB:

data taking starting with full detector in 2018 → expected 50 ab^{-1} by 2025

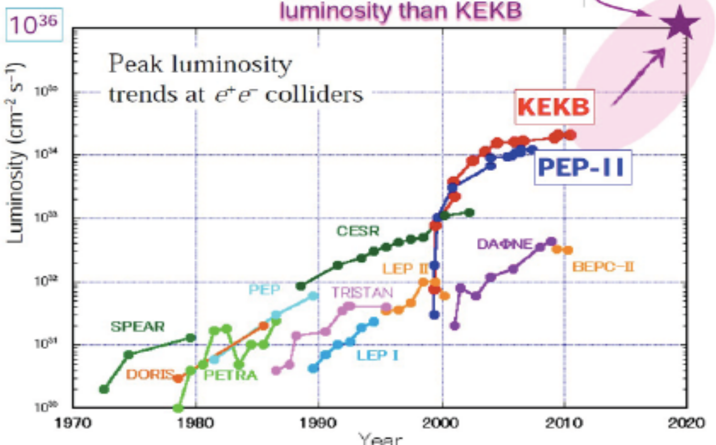


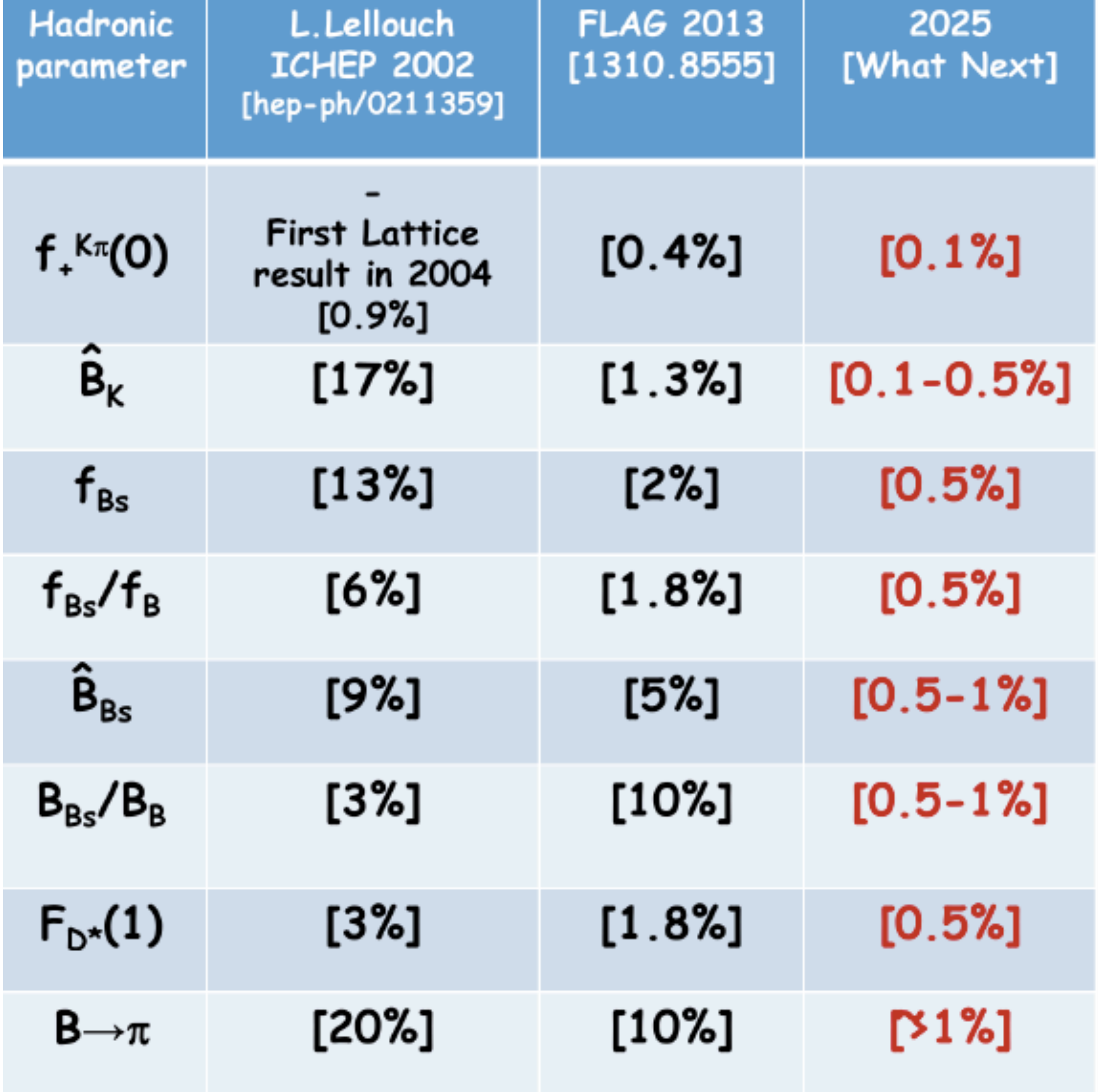
	Belle	BaBar	Global Fit CKMfitter	LHCb Run-2	Belle II 50 ab^{-1}	LHCb Upgrade 50 fb^{-1}	Theory
φ_1: ccs	0.9°		0.9°	0.6°	0.3°	0.3°	v. small.
φ_2: uud	4° (WA)		2.1°		1°		~1-2°
φ_3: DK	14°		3.8°	4°	1.5°	1°	negl.
$\lvert V_{cb}\rvert$ inclusive	1.7%		2.4%		1.2%		
$\lvert V_{cb}\rvert$ exclusive	2.2%				1.4%		
$\lvert V_{ub}\rvert$ inclusive	7%		4.5%	7.2%	3.0%		
$\lvert V_{ub}\rvert$ exclusive	8%				2.4%		
$\lvert V_{ub}\rvert$ leptonic	14%				3.0%		

Experiment	Theory
🟧 No result	
🟨 Moderate precision	🟨 Moderate precision
🟦 Precise	🟦 Clean / LQCD
🟩 Very Precise	🟩 Clean

SuperKEKB is the intensity frontier

40x higher instantaneous luminosity than KEKB



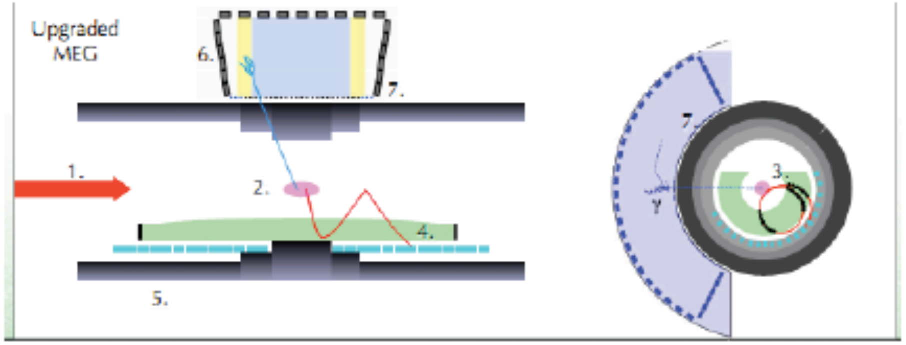


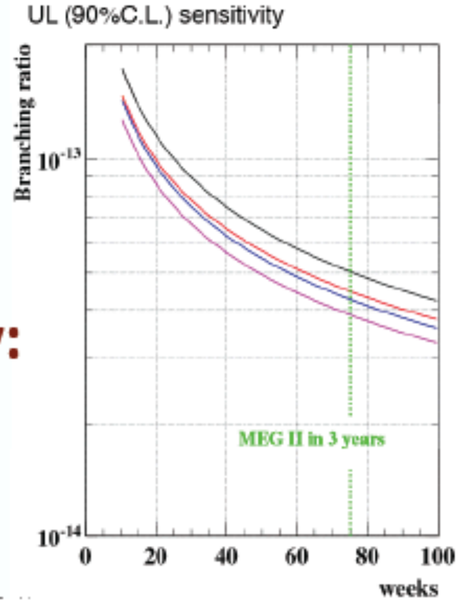
Hadronic parameter	L.Lellouch ICHEP 2002 [hep-ph/0211359]	FLAG 2013 [1310.8555]	2025 [What Next]
$f_+^{K\pi}(0)$	- First Lattice result in 2004 [0.9%]	[0.4%]	[0.1%]
$\hat{B}_K$	[17%]	[1.3%]	[0.1-0.5%]
f_{Bs}	[13%]	[2%]	[0.5%]
f_{Bs}/f_B	[6%]	[1.8%]	[0.5%]
$\hat{B}_{Bs}$	[9%]	[5%]	[0.5-1%]
B_{Bs}/B_B	[3%]	[10%]	[0.5-1%]
$F_{D^*}(1)$	[3%]	[1.8%]	[0.5%]
$B \to \pi$	[20%]	[10%]	[>1%]

C. Bozzi per il GdL Flavour di What Next

C. Tarantino
LTS1
Elba 2014

MEG2 @ PSI
(17 FTE)

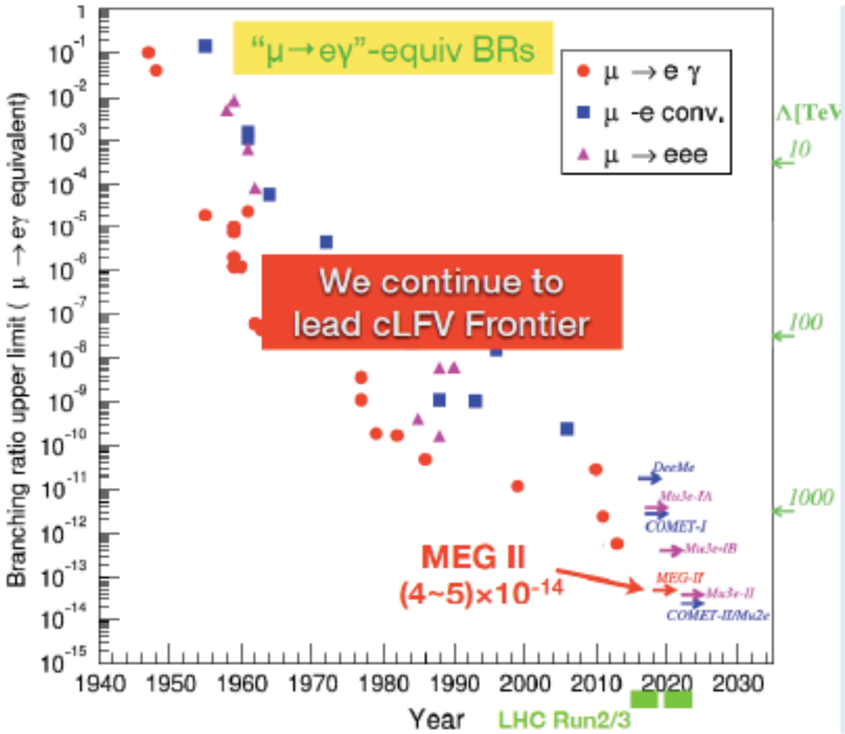




INFN responsability:

Tracking chamber,
timing counters,
active target

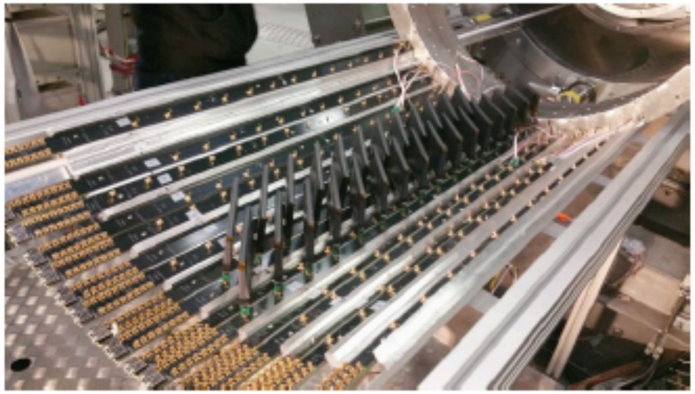
READY FOR BEAM DELAYED FALL 2016



We continue to lead cLFV Frontier

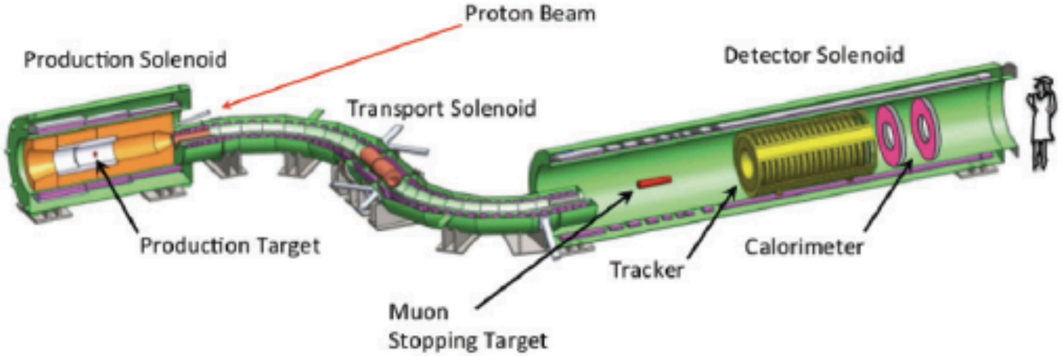
MEG II
$(4\sim5)\times10^{-14}$

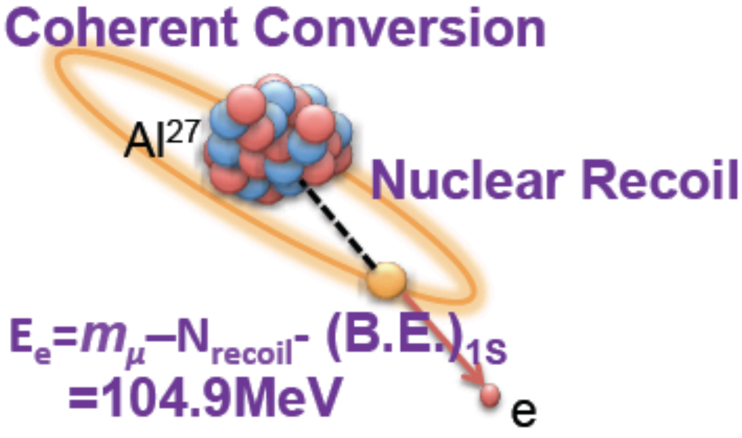
New Timing Counter installed Oct 2015



New Drift Chamber construction late by 5-6 months ➔ STARTED NOW

Mu2e @ FNAL
(>17 FTE)





$E_e = m_\mu - N_{recoil} - (B.E.)_{1S}$
$= 104.9 MeV$

Fermilab *Today*

INFN contribution:
Electromagnetic calorimeter

Jan 2015
From the Italian laboratory INFN-Genoa (ASG) came the completed prototype of one coil module for the s-shaped Mu2e transport solenoid.

Aug 2015
Prototype of Mu2e solenoid passes tests with flying colors

CD3 expected summer 2016

➔ START CONSTRUCTION

Strong sinergy with g-2

RISE EU-grant MUSE
with g-2 starting Jan 2016

DAΦNE Timeline

In the first six months of 2013 ***DAΦNE*** *faced a long shutdown intended mainly for installing the KLOE detector upgrade and exploited also to consolidate the accelerator complex*

At the end of 2014, DAFNE started a systematic period of data-delivery to the experiment

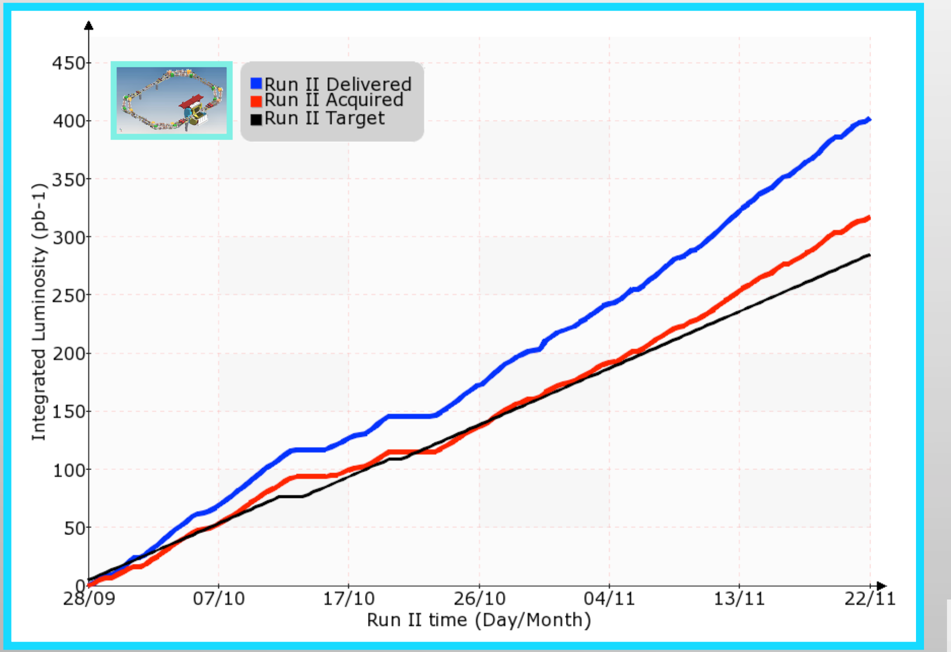
In this framework the collider was expected to deliver:

1 fb^{-1}	*(15 Nov 2014 – 15 Jul 2015)*	***RUN I***
1.5 fb^{-1}	*(28 Sept 2015 – 20 Jul 2016)*	***RUN II***

Since first months in 2015 the machine achieved good performances in terms of peak and integrated luminosity

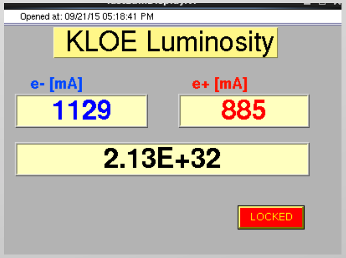
DAΦNE and KLOE-2 mission aims at collecting at least 5 fb^{-1} by the end of 2017

Ongoing Run II



***Peak Luminosity** measured so far is:*

- *40% higher than in 2005*
- *a factor 2 lower than the best achieved during the Crab-Waist test run*



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KLOE Luminosity

e- [mA]: 1129

e+ [mA]: 885

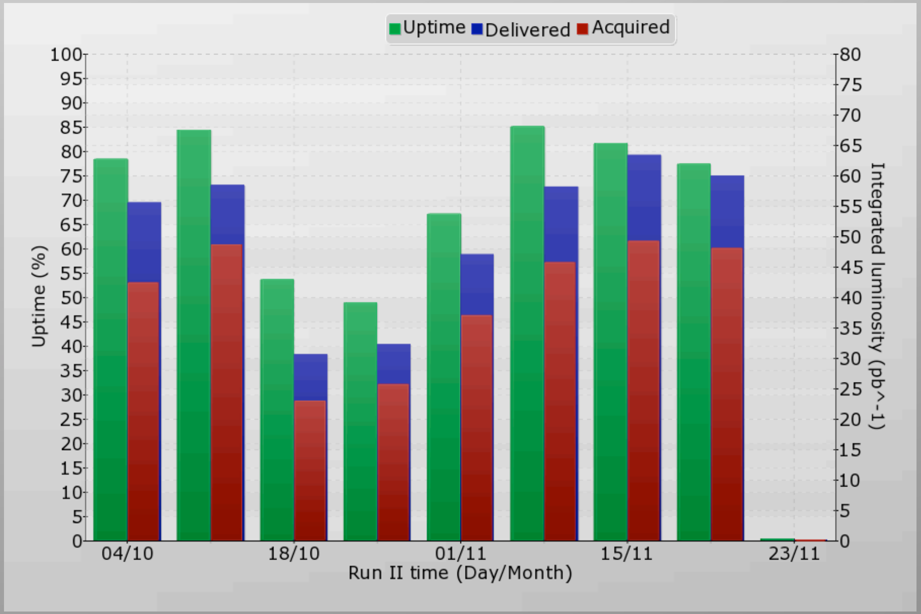
2.13E+32

LOCKED

During run II DAΦNE is expected to deliver 1.5 fb^{-1} to the KLOE-2 experiment

By now:

- Delivered and acquired Integrated Luminosity overtakes the scheduled values
- 70% Uptime by now



Conclusions

DAΦNE performances:

- *operation is more stable and reproducible*
- *peak and integrated luminosity are growing*
- *background is compatible with an efficient data-taking*

There are many ideas to further improve the present achievements

The KLOE-2 RUN I has been completed delivering

$\int L \sim 1\ fb^{-1}$ *according to the milestone*

DAFNE is now expected to deliver by the end of July 2016 at least

$\int L \sim 1.5\ fb^{-1}$

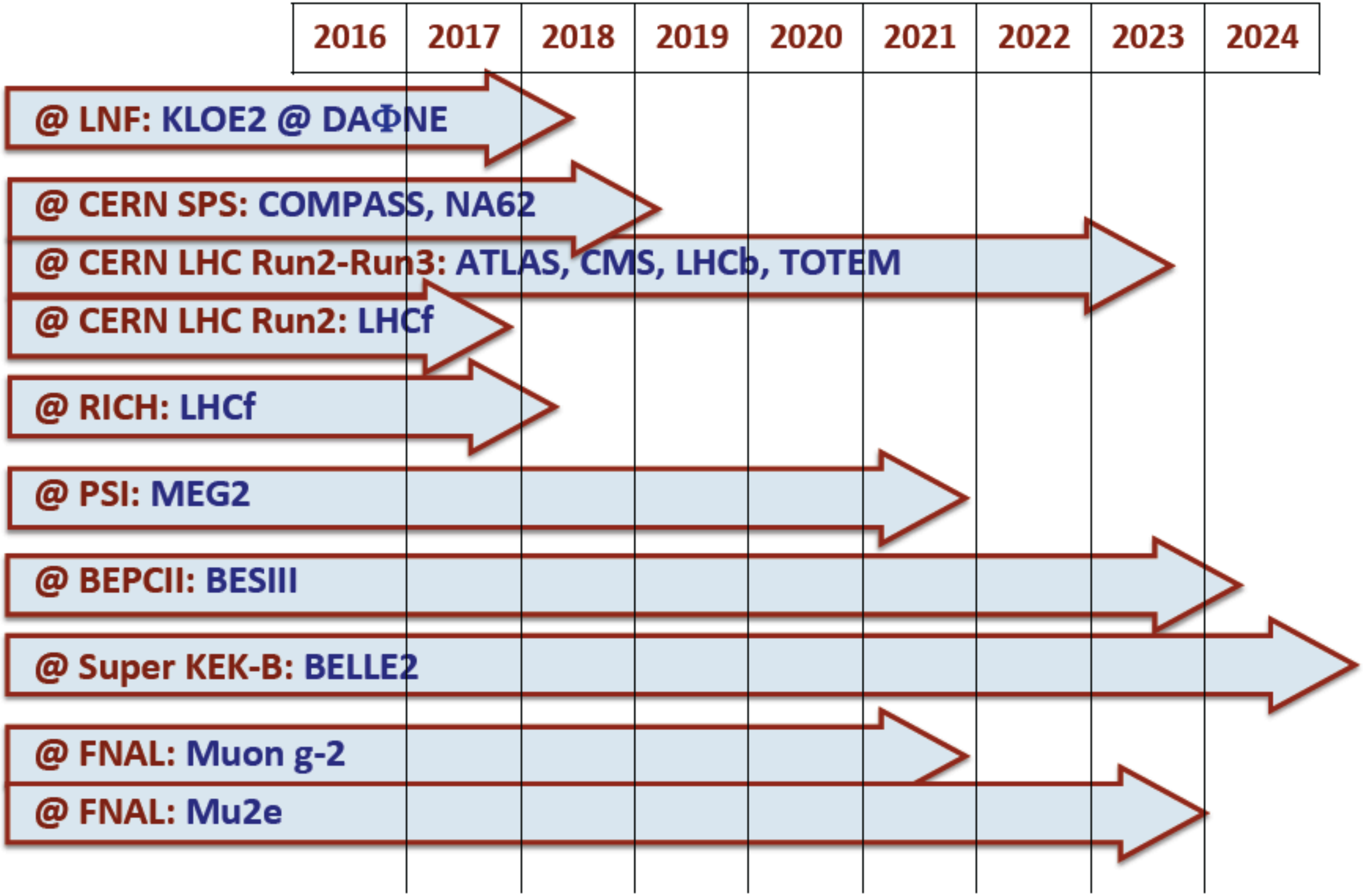
Uptime and reliability of the DAΦNE subsystems are improving. Several interventions have been planned to maintain and hopefully ameliorate the present uptime compatibly with the available resources

Dark Matter at accelerators

GdL di What Next sulla Materia Oscura Battaglieri, Fornengo, Ianni, Mazziotta, Polesello, Ullio

- Principalmente due attività di R&D presso i LNF (PADME) e JLAB (BDX)
  - Attività intecommissioni: esperimento PADME presentato (e approvato) in CSN1, esperimento BDX presentato (e approvato) in CSN3
  - PADME@LNF
    - *Ricerca del DARK PHOTON in* $e^+e^- \rightarrow \gamma$ + energia mancante
    - R&D sulla macchina per garantire energia e intensità necessarie (+250 MeV)
    - Recupero di ~600 cristalli di BGO da L3 per il rivelatore
    - 18 mesi per costruzione e commissioning dell'esperimento
  - BDX@JLAB
    - *Ricerca di LIGHT DARK MATTER in* $e^- \rightarrow \chi$ anti$-\chi$
    - Presentazione delproposal al PAC del JLab a Giugno 2015
    - *Recupero di ~1000 cristalli di BaBar per il rivelatore*
    - *Interesse da parte di altri laboratori per esperimenti tipo BDX: SLAC, Mainz, Cornell*
  - Preparazione di un PRIN (Light Dark matter search in electron beam-dump experiments) con USS,CT, UGE, ULE, LNF, URM1, URM2
  - Workshop: PADME Kickoff meeting (LNF), LDMA2015 (Camogli), Challanges in Dark Sector (LNF)
  - Workshop a SLAC 28-30 Aprile2015 per rilanciare il laboratorio sulla fisica del DARK SECTOR con intento simile a Snowmass

Complete data taking plans with approved detectors



2016 2017 2018 2019 2020 2021 2022 2023 2024

@ LNF: KLOE2 @ DAΦNE

@ CERN SPS: COMPASS, NA62

@ CERN LHC Run2-Run3: ATLAS, CMS, LHCb, TOTEM

@ CERN LHC Run2: LHCf

@ RICH: LHCf

@ PSI: MEG2

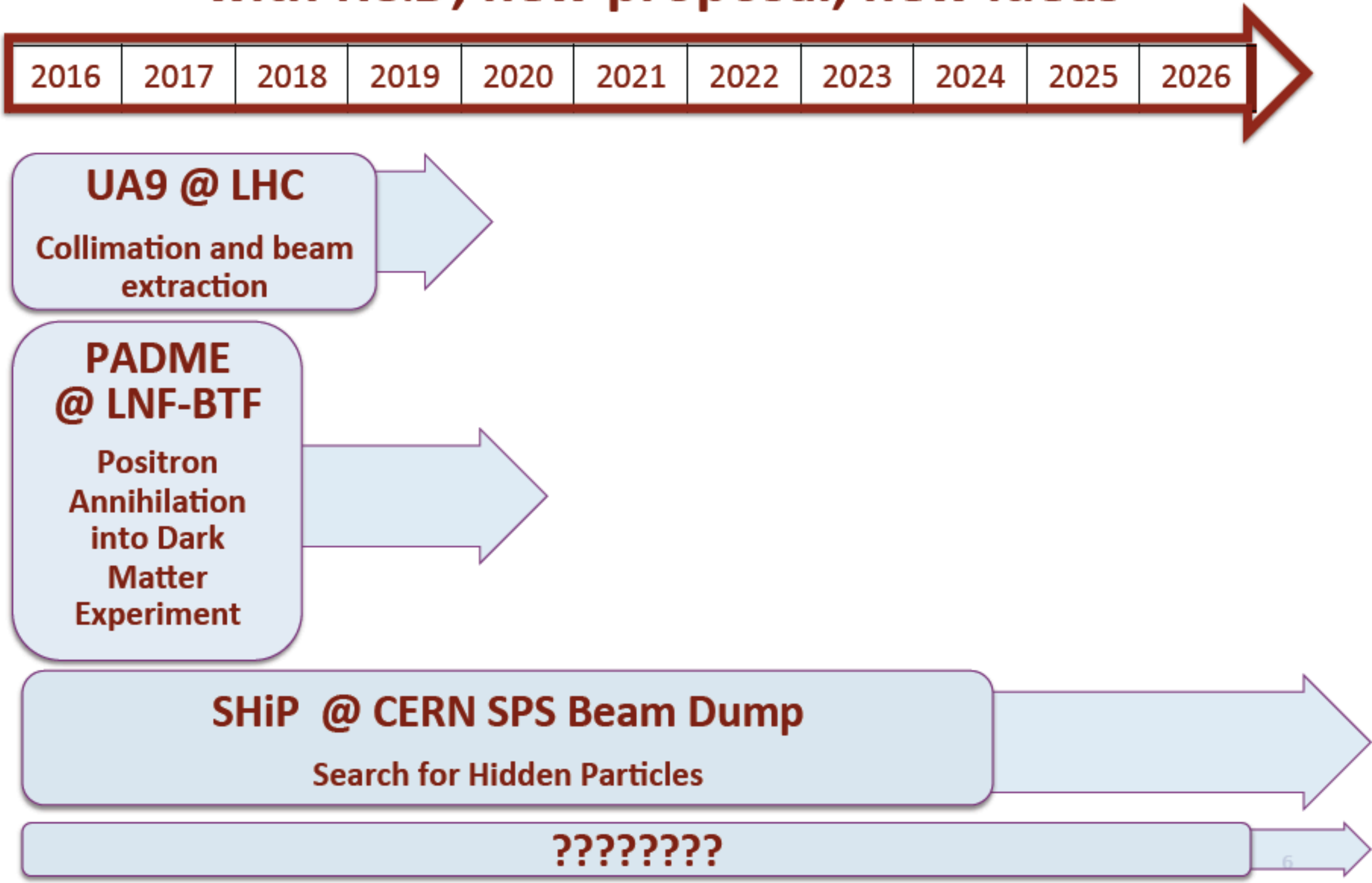
@ BEPCII: BESIII

@ Super KEK-B: BELLE2

@ FNAL: Muon g-2

@ FNAL: Mu2e

Towards future plans with R&D, new proposal, new ideas



2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026

UA9 @ LHC

Collimation and beam extraction

PADME @ LNF-BTF

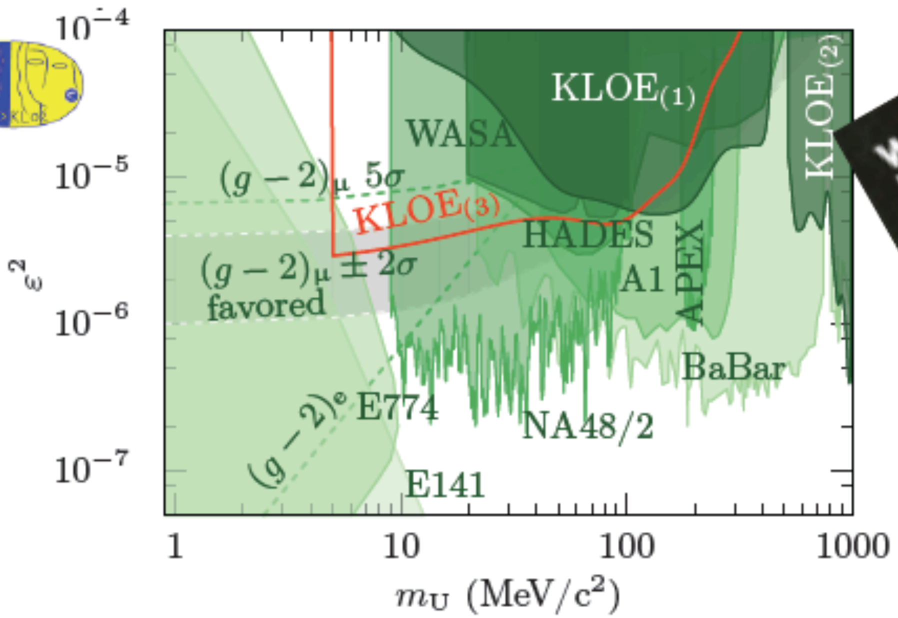
Positron Annihilation into Dark Matter Experiment

SHiP @ CERN SPS Beam Dump

Search for Hidden Particles

????????

U boson search @ LNF: present & future



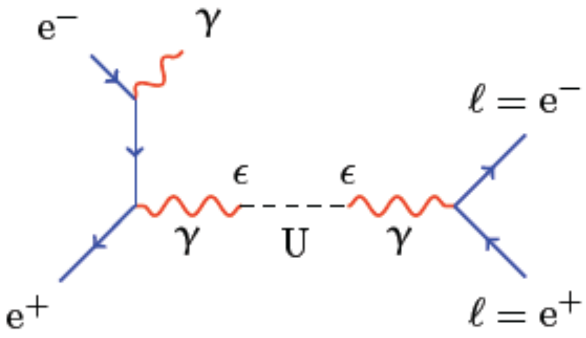
arXiv:1509.00740 [hep-ex] accepted by PLB

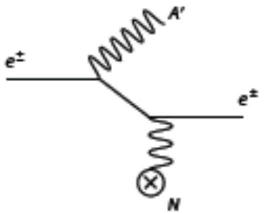
PADME

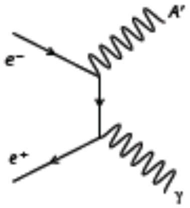
Positron Annihilation into Dark Matter Experiment

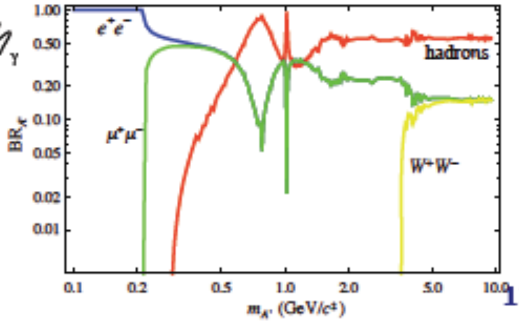
Annihilation, invisible decays

$e^+e^- \rightarrow \gamma\ (E_{miss})$







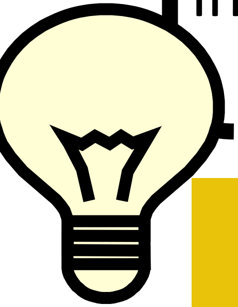


N. Pastrone

The Energy Scale from the "Observational" New Physics

neutrino masses
dark matter
baryogenesis
inflation

NO NEED FOR THE NP SCALE TO BE CLOSE TO THE ELW. SCALE



The Energy Scale from the "Theoretical" New Physics

★ ★ ★ **Stabilization of the electroweak symmetry breaking at M_W calls for an ULTRAVIOLET COMPLETION of the SM already at the TeV scale** **+**

★ **CORRECT GRAND UNIFICATION "CALLS" FOR NEW PARTICLES AT THE ELW. SCALE**

Towards future accelerators: HL-LHC the highest priority

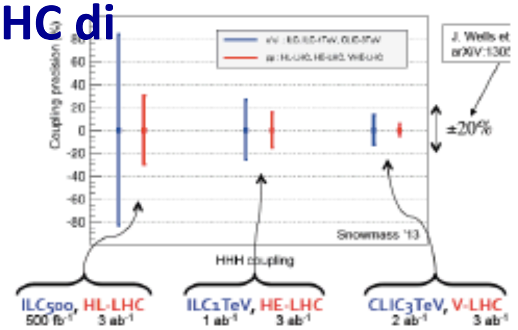
2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026

ATLAS and CMS (LHCb?) upgrades for HL-LHC

R&D for future detectors RD_FASE2

RD50, RD51, RD53

via libera ai TDR di Fase2 per HL_LHC di ATLAS/CMS!



R&D for future trigger, DAQ, computing

R&D for future accelerators:

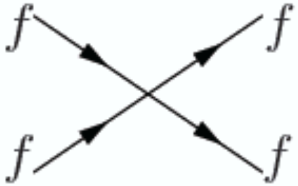
EIC, ILC/CLIC, CEPC, FCC, Muon Collider,…..

No-Lose Theorems

A. Wulzer per il GdL BSM di What Next con Polesello, Rahatlou, Romanino

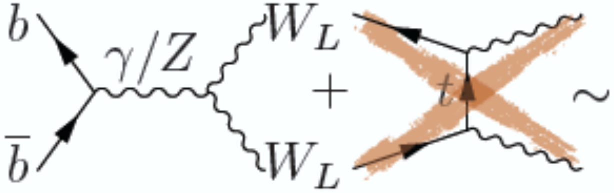
A number of **guaranteed** discoveries in the history of HEP

Beyond the Fermi Theory:



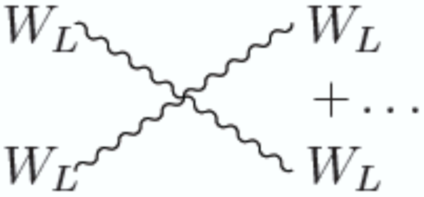
$$\sim G_F E^2 \simeq E^2/v^2 < 16\pi^2 \Longrightarrow m_W < 4\pi v$$

Beyond the Bottom Quark:



$$\sim g_W^2 E^2/m_W^2 < 16\pi^2 \Longrightarrow m_t < 4\pi v$$

Beyond the (Higgsless) EW Theory:



$$\sim g_W^2 E^2/m_W^2 < 16\pi^2 \Longrightarrow m_H < 4\pi v$$

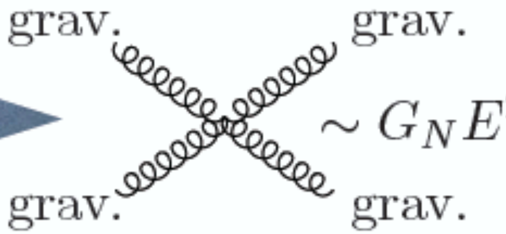
Each (secretly) due to d=6 non-renormalizable operators, signalling nearby new physics.

No-Lose Theorems

A. Wulzer per il GdL BSM di What Next con Polesello, Rahatlou, Romanino

Only one d>4 is left after Higgs discovery …

$$\frac{1}{G_N}\sqrt{g}R \longrightarrow$$



$$\sim G_N E^2 \simeq E^2/{M_{\mathrm{P}}}^2 < 16\pi^2 \longrightarrow \Lambda_{\mathrm{SM}} \lesssim M_{\mathrm{P}}$$

… the last, impractical, No-Lose Theorem is Q.G. at M_{P} !

We do have exp. evidences of BSM, but none necessarily pointing to light/strongly-coupled enough new physics:

“No guaranteed discoveries” $=$ “post-Higgs depression”

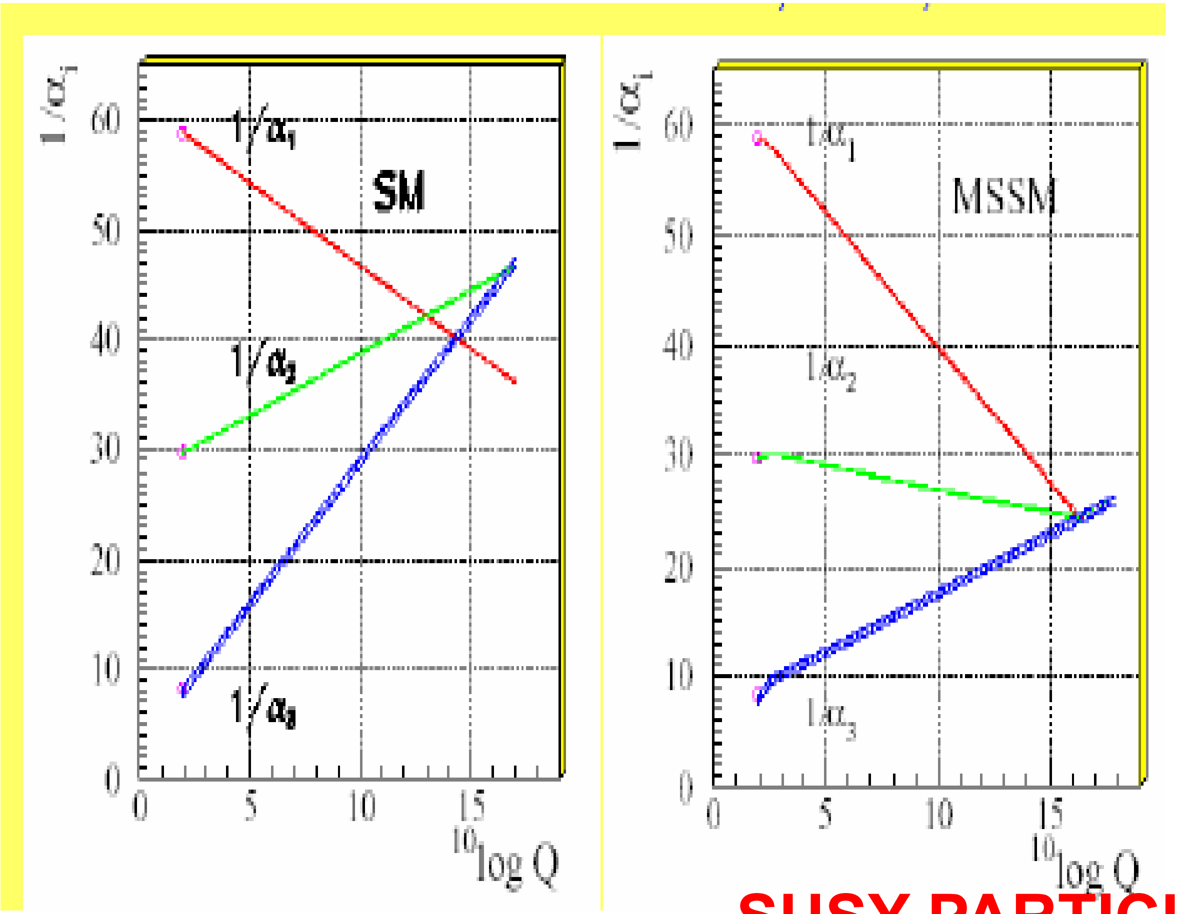
However, one **d<4** comes with the Higgs discovery:

$$\frac{m_H^2}{2}H^\dagger H \longrightarrow$$

The **Naturalness Problem:**

Why $m_H \ll \Lambda_{\mathrm{SM}}$?

LOW-ENERGY SUSY AND UNIFICATION



Input

$\alpha^{-1}(M_Z) = 128.978 \pm 0.027$

$\sin^2\theta_{\overline{MS}} = 0.23146 \pm 0.00017$

$\alpha_s(M_Z) = 0.1184 \pm 0.0031$

Output

$M_{SUSY} = 10^{3.4 \pm 0.9 \pm 0.4}$ GeV

$M_{GUT} = 10^{15.8 \pm 0.3 \pm 0.1}$ GeV

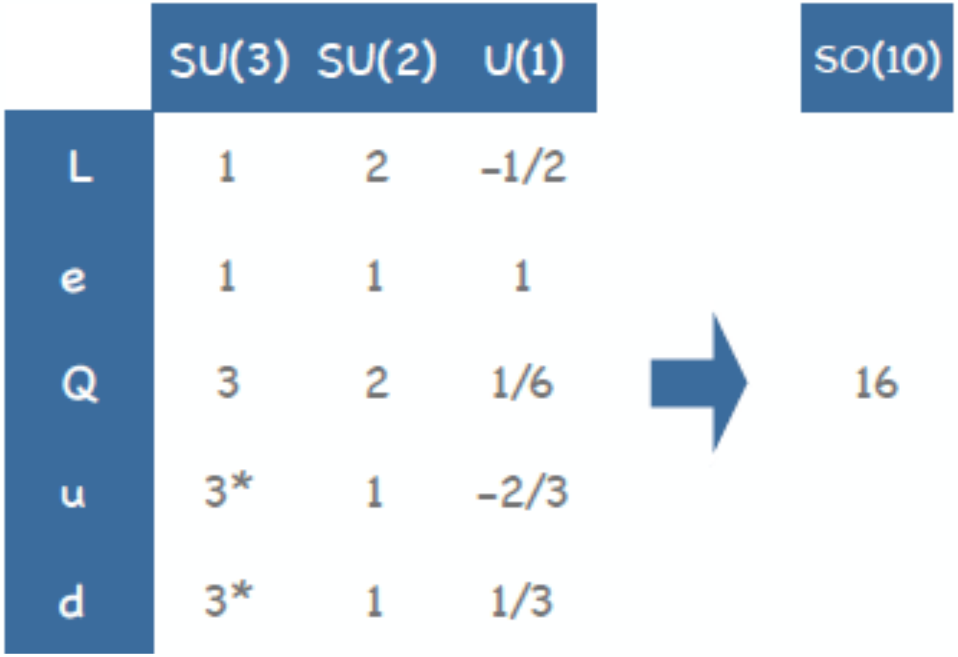
$\alpha^{-1}_{GUT} = 26.3 \pm 1.9 \pm 1.0$

SUSY PARTICLES AT THE TEV SCALE !

THE “COMPREHENSION” OF THE ELECTROWEAK SCALE

$$V = \mu^2 |H|^2 + \lambda |H|^4$$ $\mu \sim 10^2$ GeV

- $M = O(10^{16}$ GeV$)$



	SU(3)	SU(2)	U(1)	SO(10)
L	1	2	-1/2	16
e	1	1	1	
Q	3	2	1/6	
u	3*	1	-2/3	
d	3*	1	1/3	

$$m_H^2 \sim -2\mu^2 + \frac{g^2}{(4\pi)^2} M^2$$

ONLY FOR SCALARS; SM FERMIONS AND GAUGE BOSON MASSES ARE PROTECTED BY THE SU(2) × U(1) SYMMETRY !

To comprehend (i.e. stabilize) the elw. scale need NEW PHYSICS (NP) to be operative at a scale $m_{NP} \ll M$

Romanino

Naturalness or Un-naturalness?

- **New SYMMETRY** giving rise to a cut-off at

$$m_{NP} \ll M$$

Low-energy **SuperSymmetry**

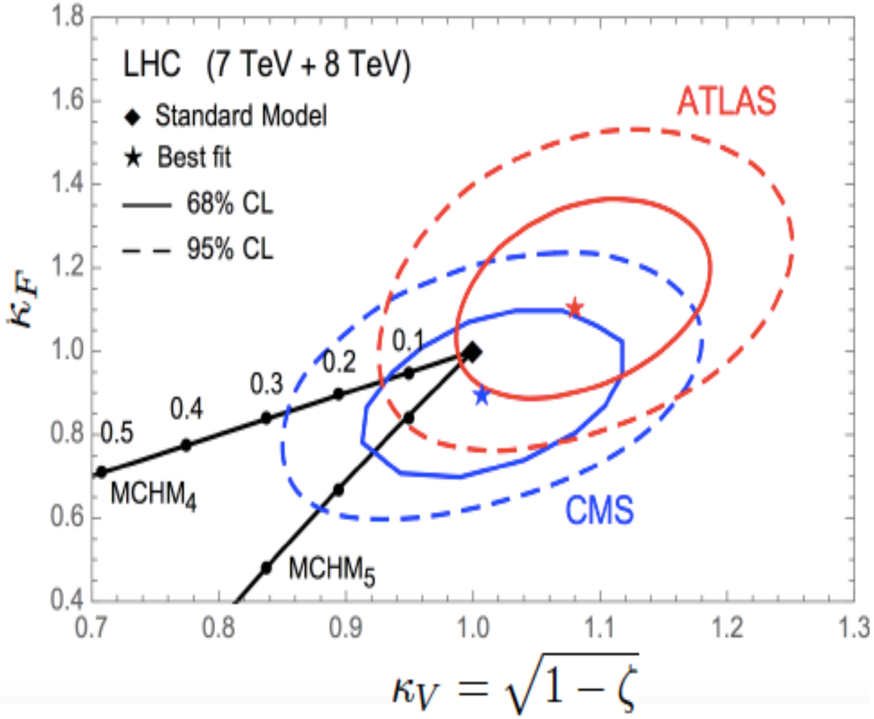
- **Space-time modification (extra-dim., warped space)**

- **COMPOSITE HIGGS** : the Higgs is a pseudo-Goldstone boson (pion-like) → new interaction getting strong at $m_{NP} \ll M$

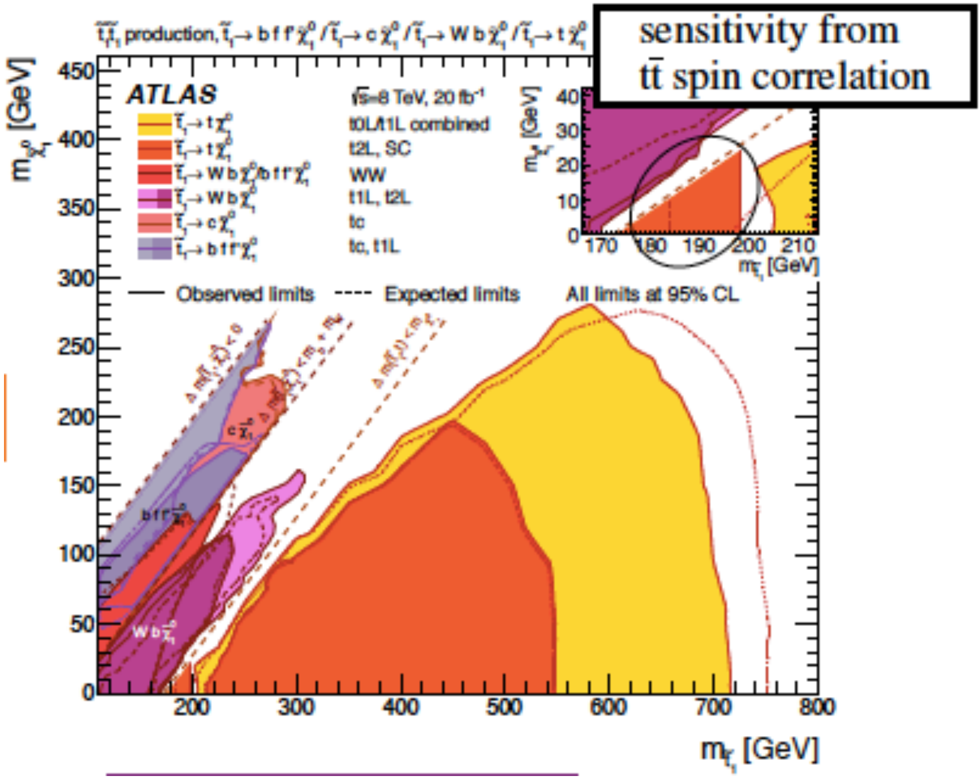
- **The scale at which the electroweak symmetry is spontaneously broken by <H> results from COSMOLOGICAL EVOLUTION**

- **H is a fundamental (elementary) particle → we live in a universe where the fine-tuning at M arises (anthropic solution, multiverse, Landscape of string theory)**

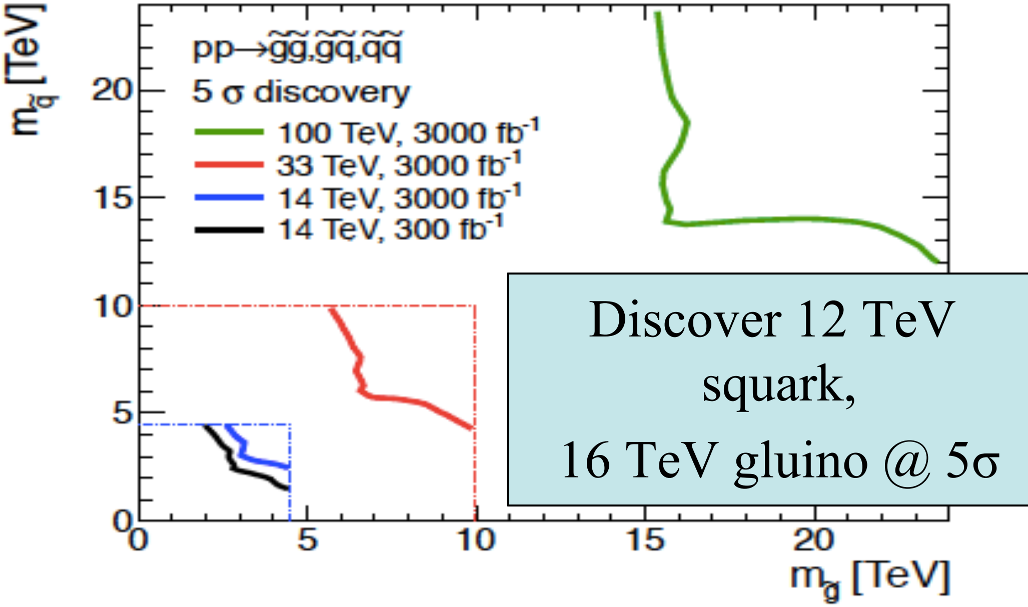
Il bosone di Higgs e' una particella elementare o un oggetto composto – ad es. da nuovi tipi di quark – come lo e' il pione?



Current bound $\zeta < 0.12$ → already some tuning on the **composite** models to look like SM



sensitivity from
$t\bar{t}$ spin correlation



Discover 12 TeV squark,
16 TeV gluino @ 5σ

The Energy Scale from the "Observational" New Physics

neutrino masses

dark matter

baryogenesis

inflation

NO NEED FOR THE NP SCALE TO BE CLOSE TO THE ELW. SCALE

Going beyond the SM:
the NEUTRINO MASS

A. GIULIANI, SAC APPEC

Cosmology, **single** and **double β decay** measure different combinations of the neutrino mass eigenvalues, constraining the **neutrino mass scale**

In a standard three active neutrino scenario:

$$\Sigma \equiv \sum_{i=1}^{3} M_i$$

cosmology
simple sum
pure kinematical effect

$$\langle M_\beta \rangle \equiv \left(\sum_{i=1}^{3} M_i^2 \, |U_{ei}|^2 \right)^{1/2}$$

β decay
incoherent sum
real neutrino

$$\langle M_{\beta\beta} \rangle \equiv \left| \sum_{i=1}^{3} M_i \, |U_{ei}|^2 \, e^{i\alpha_i} \right|$$

double β decay
coherent sum
virtual neutrino
Majorana phases

La massa dei neutrini, portale della Fisica oltre il Modello Standard

It is often said that ν masses are physics beyond the SM

Massless ν's?

- no ν_R
- L conserved

But ν_R can well exist and we really have no reason to expect that B and L are exactly conserved

Small ν masses?

- ν_R very heavy
- L not exactly cons.

How to guarantee a massless neutrino?

1) ν_R does not exist

→ No Dirac mass

$$\bar{\nu}_L\nu_R + \bar{\nu}_R\nu_L$$

and

2) Lepton Number is conserved

→ No Majorana mass

$$\nu^T_R\,\nu_R \text{ or } \nu^T_L\,\nu_L$$

Guido Altarelli, in occasione dell' incontro a Pisa nel 2013 per i 100 anni dalla nascita di **Bruno Pontecorvo**

See-Saw Mechanism

Minkowski; Glashow; Yanagida;
Gell-Mann, Ramond , Slansky;
Mohapatra, Senjanovic…..

$M\nu^T{}_R\nu_R$ allowed by SU(2)xU(1)

Large Majorana mass M (as large as the cut-off)

$m_D\overline{\nu}_L\nu_R$

Dirac mass m_D from Higgs doublet(s)

$$\begin{array}{c|cc} & \nu_L & \nu_R \\ \hline \nu_L & 0 & m_D \\ \nu_R & m_D & M \end{array}$$

$M >> m_D$

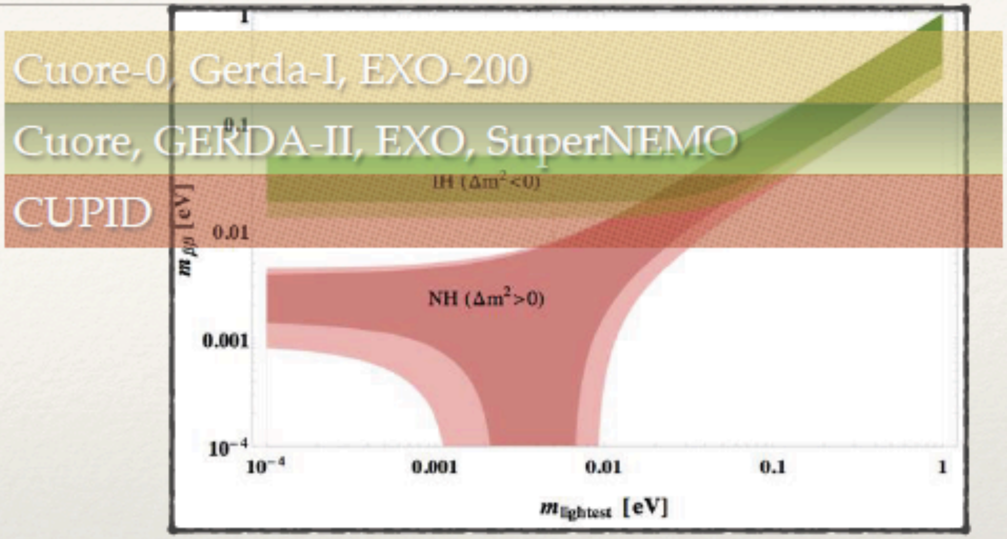
Eigenvalues

$$|\nu_{light}| = \frac{m_D{}^2}{M} \quad , \quad \nu_{heavy} = M$$

G. Altarelli

0νββ strategy

- **What next CUORE and GERDA-II ?**
  - CUORE is ***background limited:*** simple mass scaling is useless and probably also very difficult to do
  - **GERDA** has lower background.
    - However: can we increase to ton scale ?
    - Not easily. Very expensive, and probably US based.

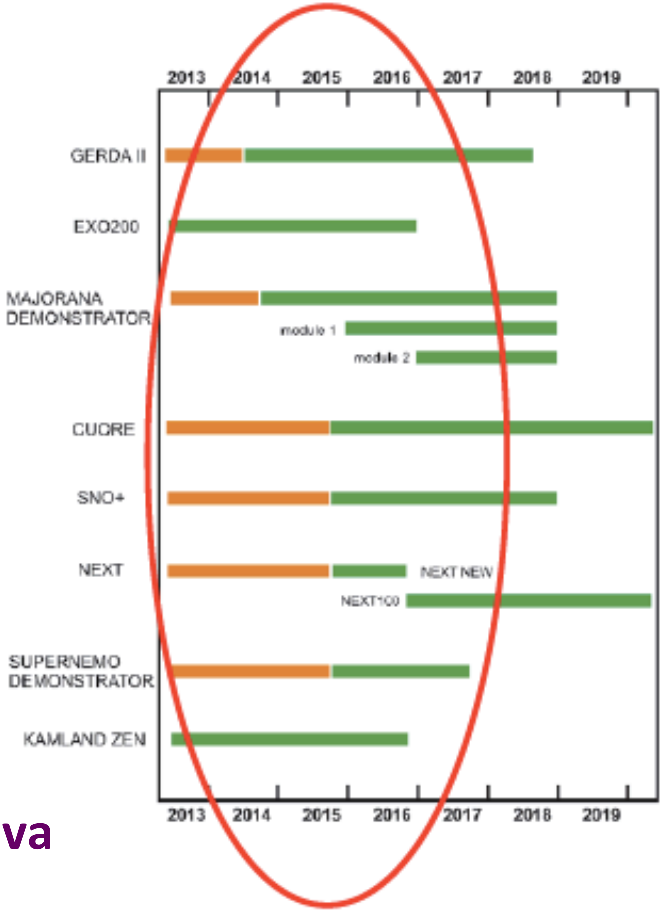


- **GOAL:** *seek for a zero background experiment* at **ton scale** to **explore inverse hierarchy region**
  - if g_a is not a show stopper
  - if direct hierarchy is not discovered first or ν mass is not measured by EUCLID first

- **Answer: CUPID R&D**

Doppio beta

What Next ha intercettato (e valorizzato) un trend che domina solo da pochi anni in questo settore:



Obiettivo (2001-2015): fare una misura di neutrinoless double beta decay (0νββ) piu' precisa di quella di Heidelberg-Moscow; possibilmente, con una tecnica che abbia un **evidente punto di forza** e ampi **margini di miglioramento**

Germanio: risoluzione, radiopurezza, arrichimento
Tellurio (bolometri): risoluzione, radiopurezza, abbondanza isotopica naturale
Tracking (SuperNemo, Next): reiezione del background
Scintillatori (Kamland-Zen, SNO+): massa

GdL What Next Brofferio, Giunti, Lisi, Spurio, Terranova

Oggi, con GERDA-FASE I, CUORE-0, EXO e KAMLAND-ZEN **funzionanti** e **in presa dati**, **l'obiettivo é più ambizioso**: fare una misura con una tecnica scalabile ai O(10) meV. Questo nuovo goal tende a far convergere le forze su item cruciali un tempo trascurati, impone di ridurre la dispersione delle risorse e la duplicazione delle infrastrutture.

Zero background

Oggi:

Bulk screening dei materiali (soprattutto spettroscopia gamma)

Surface screening (soprattutto spettroscopia alpha)

Protocolli di installazione definiti dall'esperienza passata

Al momento abbiamo solo tecniche "precauzionali". Il background budget lo si scopre all'inizio della presa data (e le sorprese non mancano – v. ^{42}K in Gerda ☺)

Domani:

Infrastrutture condivise (0νββ, Dark Matter, ν solari) per il bulk screening

Surface screening e permeazione del Radon

Aree di stoccaggio sotterranee di materiali strategici

Dopo-domani:

Bulk e surface screening con rivelatori simili a quelli che oggi usiamo per gli esperimenti veri e propri

Material production e cristal growth all'interno delle strutture INFN

Le scale dei nuovi esperimenti Dark Matter e 0νββ di fatto impongono un cambio di strategia che ricorda quanto e' avvenuto in passato per i detector di LEP, CDF, Babar e gli esperimenti LHC. **La qualita' delle infrastrutture per la fisica degli eventi rari deve essere all'altezza dei nuovi standard.**

E' certamente la richiesta più pressante emersa dal processo What Next dalla comunità della fisica underground

Germanio

LSGe (Large Scale Germanium) activities

Bolometri

Te, enrichment
Cherenkov e discr. α

Bolometri scintillanti

Scintillatori

Borexino con ^{136}Xe

GERDA e Majorana molto probabilmente evolveranno in un esperimento a grande scala (>250 kg) che combini il meglio delle loro tecnologie

Attivita' diversificate che stanno confluendo in uno schema coerente (CUORE-IHE→CUPID)

Difficile da conciliare al momento con il physics plan di Borexino-SOX

Cosa ha fatto (e può fare) What Next per loro?

- Mettere in rilievo le sinergie con la Dark Matter dal punto di vista delle infrastrutture e delle facilities di sviluppo
- Mantenere viva l'attenzione sugli sviluppi non convenzionali (soprattutto sui rivelatori traccianti: negative ion TPC, scintillatori) [una situazione analoga alla DM direzionale…]

- NUMEN @ LNS
  - We are presently in what is so-called «phase two»:
    - Experimental campaign on nuclei of interest for neutrino-less double beta decay

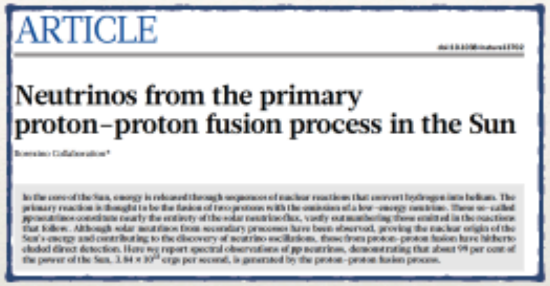
		2016				2017				2018			
Reaction	**Energy (MeV/u)**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
^{116}Sn (^{18}O,^{18}Ne) ^{116}Cd	15-30	🟥	🟥										
^{116}Cd (^{20}Ne,^{20}O) ^{116}Sn	15-25			🟦	🟦								
^{130}Te (^{20}Ne,^{20}O) ^{130}Xe	15-25			⬜	⬜	🟩	🟩			⬜	⬜		
^{76}Ge (^{20}Ne,^{20}O) ^{76}Se	15-25			⬜	⬜	⬜	⬜	🟪	🟪				
^{76}Se (^{18}O,^{18}Ne) ^{76}Ge	15-30			⬜	⬜			⬜	⬜	🟦	🟦		
^{106}Cd(^{18}O,^{18}Ne) ^{106}Pd	15-30			⬜	⬜							🟧	🟧

    - R&D activity to adapt the spectrometer Magnex to the new kinematical configuration (tracking system and focal plane detectors) – partly financed by CNS3, partly by CSN5 with the SICILIA grant

Short Term Activity

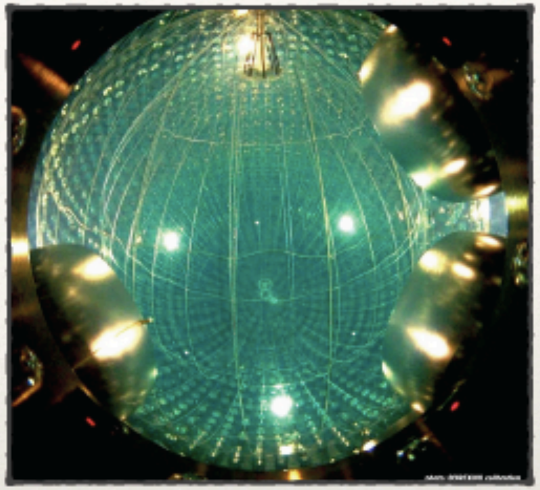
Recent results: BOREXino (@LNGS)

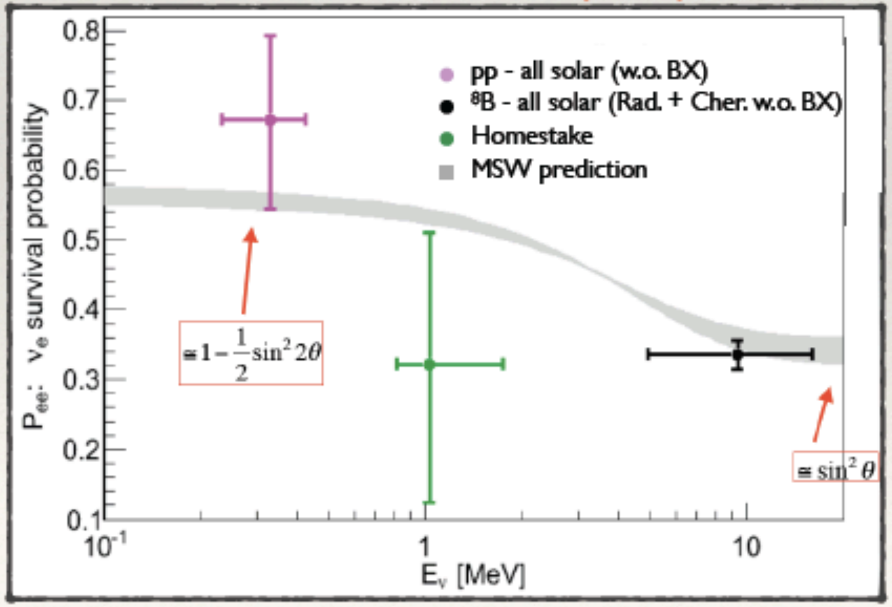
- **A liquid scintillator** detector for solar and geo-neutrinos
  - ~ 20 years of collaboration on a very successful project
  - Three more years approved
  - **SOX + attempt to constrain CNO**



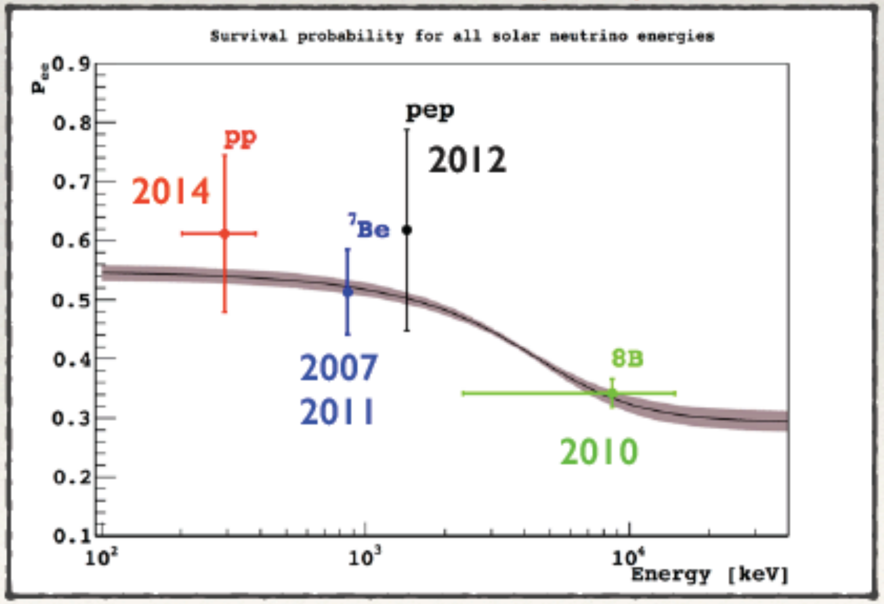
ARTICLE

Neutrinos from the primary proton–proton fusion process in the Sun





Before Borexino (2006)

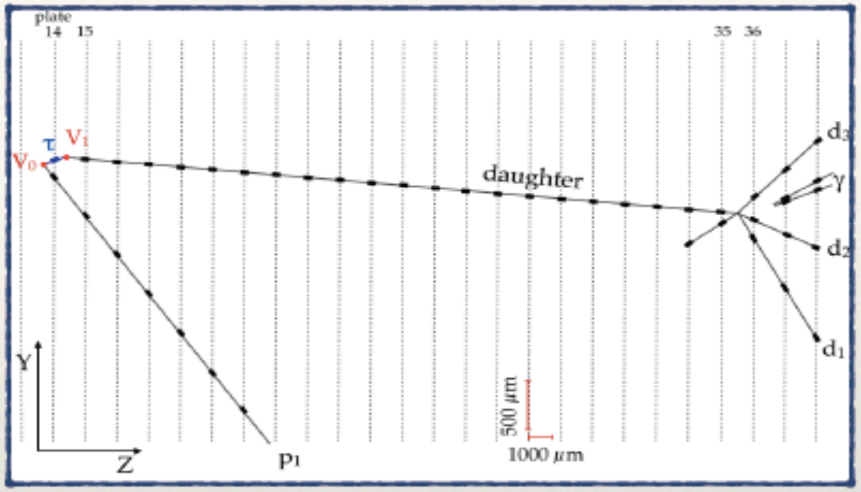


After Borexino (2015)

Recent results: Opera (@LNGS)

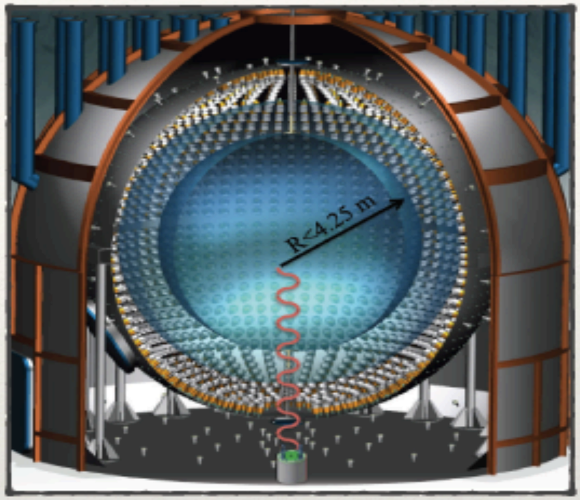
- The **Opera** experiment is over
  - **5 candidates,** sufficient to claim *discovery* at **5 σ of ν_τ appearance**
  - Limits on sterile neutrinos and results on charm production
    - Possibly, direct measurement of oscillation parameters in appearance mode

The fifth candidate



Near future: sterile Neutrinos with SOX

- A nice re-use of BOREXino detector
  - Search for sterile neutrinos by means of an artificial anti-neutrino
    - Most funds from 2 ERC projects (INFN and CEA)
  - **^{144}Ce anti-neutrino source** made in Russia
    - **Delivery: expected Dec. 2016**



LUNA MV ai LNGS

3.5 MV accelerator mainly devoted to:

Helium-Burning (in stars: ~100 T_6, ~10^5 gr/cm^3)

$^{12}C(\alpha,g)^{16}O$ the most important reaction of nuclear astrophysics: production of the elements heavier than A=16, star evolution from He burning to the explosive phase (core collapse and thermonuclear SN) and ratio C/O

Sources of the neutrons responsible for the S-process: 50% of the elements beyond Iron

$^{13}C(\alpha,n)^{16}O$: isotopes with A≥90 during AGB phase of low mass stars

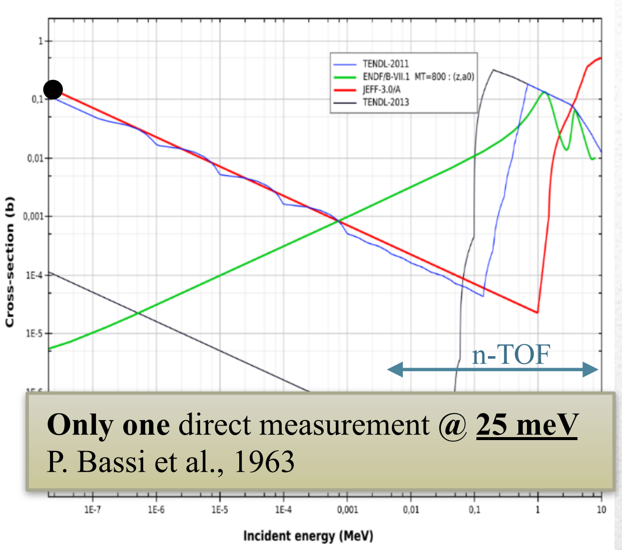
$^{22}Ne(\alpha,n)^{25}Mg$: isotopes with A<90 during He and C burning in massive stars

Carbon-Burning (~500 T_6, ~$3\cdot10^6$ gr/cm^3)

$^{12}C(^{12}C,\alpha)^{20}Ne$, $^{12}C(^{12}C,p)^{23}Na$

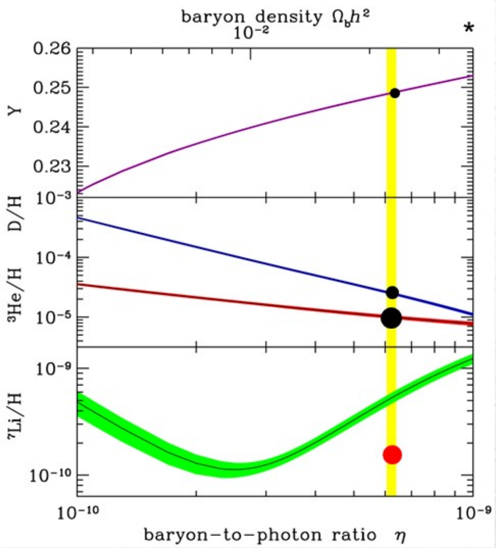
+ (α,g) on ^3He, ^{14}N, ^{15}N, ^{18}O……

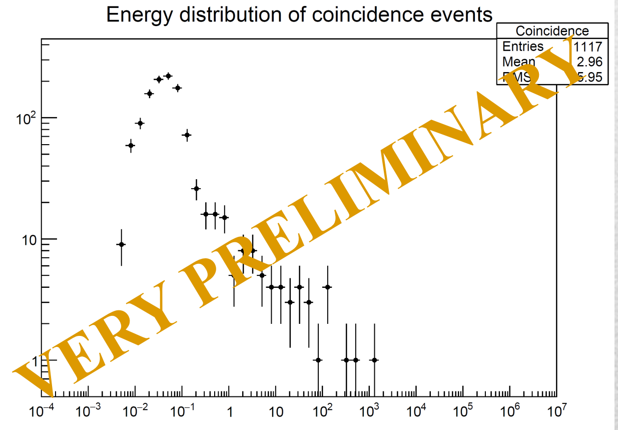
C. Broggini per la Collab. LUNA



Only one direct measurement @ **25 meV**
P. Bassi et al., 1963

- Measurement of ^{7}Be(n,α) cross section for the cosmological Li problem

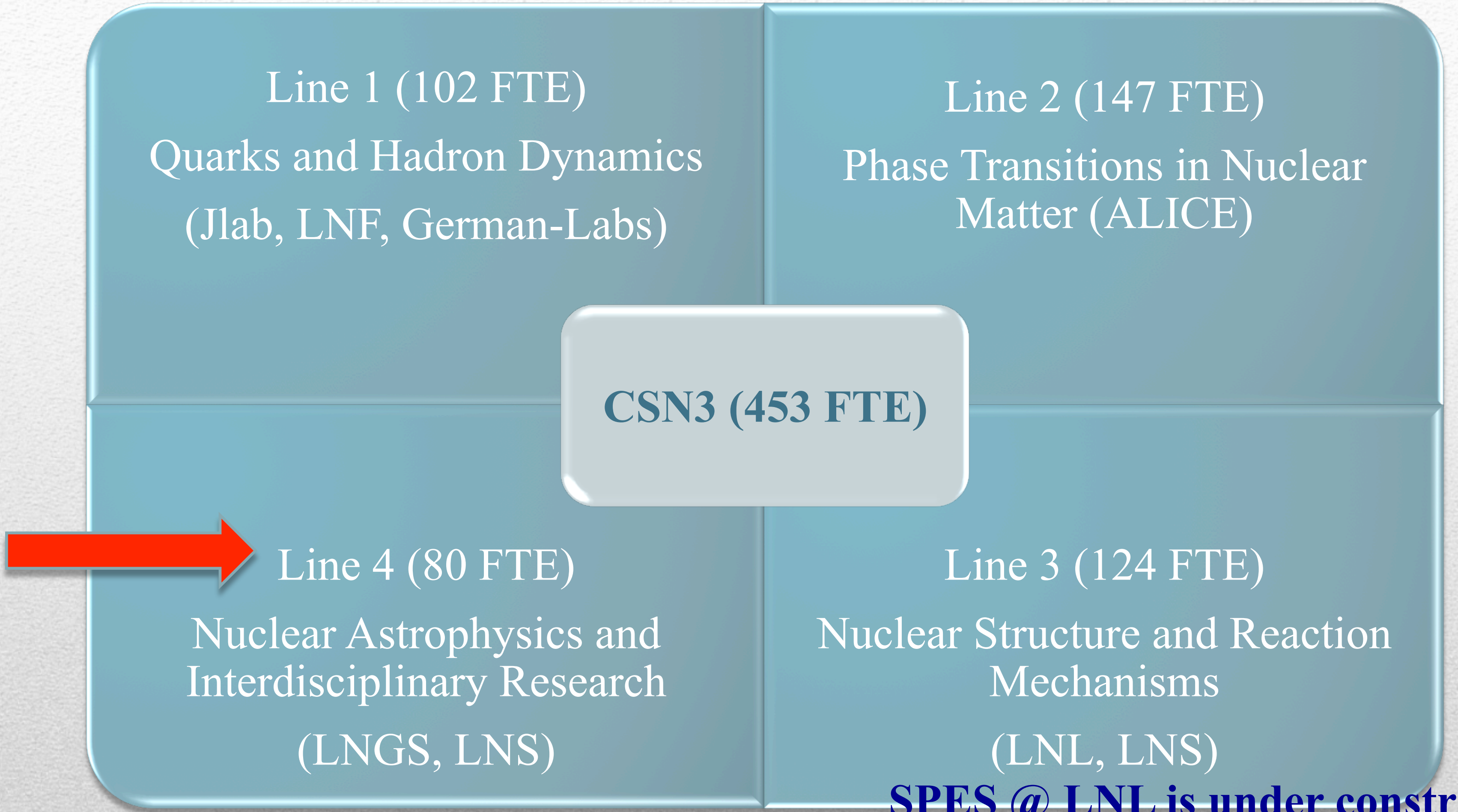




- Approximately 95% of primordial ^{7}Li is produced from the electron capture decay of ^{7}Be ($T_{1/2}$=53.2 d).
- ^{7}Be is destroyed via (n,p) and (p,x), (d,x), (3He,x), … (n,α) reactions
- The (n, α) reaction produces two α-particles emitted back-to-back with several MeV energy (Q-value=19 MeV)

n_TOF

M. Taiuti, CVI 2015



Line 1 (102 FTE)

Quarks and Hadron Dynamics

(Jlab, LNF, German-Labs)

Line 2 (147 FTE)

Phase Transitions in Nuclear Matter (ALICE)

CSN3 (453 FTE)

Line 4 (80 FTE)

Nuclear Astrophysics and Interdisciplinary Research

(LNGS, LNS)

Line 3 (124 FTE)

Nuclear Structure and Reaction Mechanisms

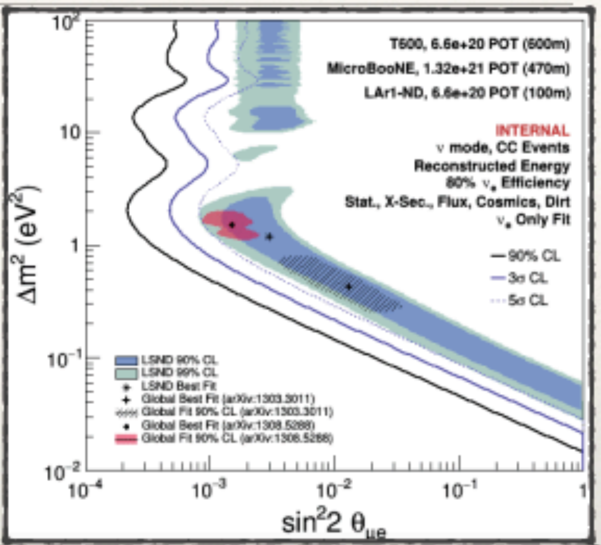
(LNL, LNS)

Research Lines

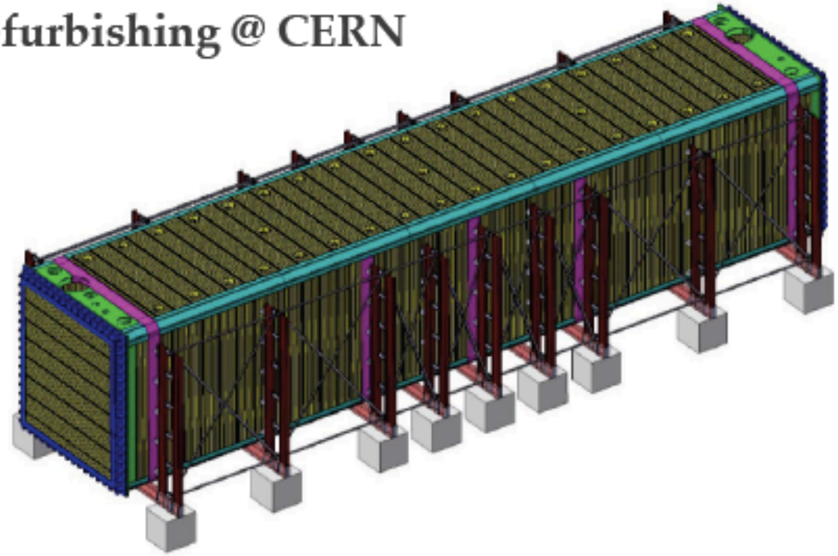
SPES @ LNL is under construction and, being SPIRAL2 delayed at leas till 2020 due to budget problems, it has the great opportunity to lead the research in the RI. The first beam is foreseen in 2018.

Sterile Neutrinos: Icarus-SBL

- One of 3 detectors in the SBL ν program @ FNAL
  - 5 M€ investment for Icarus refurbishing at CERN
  - New electronics (CSN2, 2.2 M€)
  - A first step toward DUNE (to be discussed in the future)



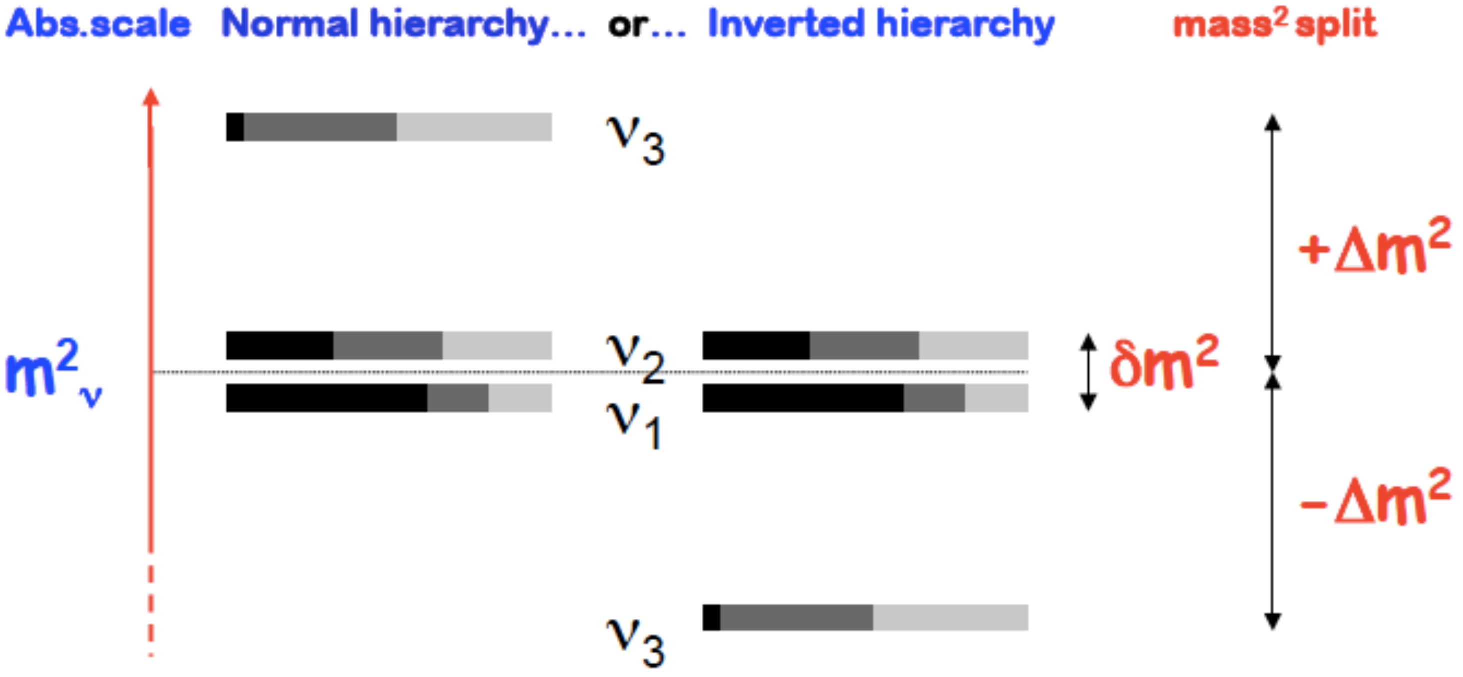
Refurbishing @ CERN



Current 3ν picture in just one slide (with 1-digit accuracy)

Flavors = e μ τ

LISI, 2014



Terra Cognita:

$\delta m^2 \sim 8 \times 10^{-5}$ eV²
$\Delta m^2 \sim 2 \times 10^{-3}$ eV²
$\sin^2\theta_{12} \sim 0.3$
$\sin^2\theta_{23} \sim 0.5$
$\sin^2\theta_{13} \sim 0.02$

Terra Incognita:

δ (CP)
sign(Δm^2)
octant(θ_{23})
absolute mass scale
Dirac/Majorana nature

Neutrino oscillations: global view

- Long term projects (world wide): **JUNO**, **HK (T2HK)**, **DUNE**
  - Likely, nothing else in the next 15 years (except PINGU & ORCA for mass hierarchy)

- **Does it make sense to contribute to all three ?**
  - *Yes, in principle. Physics programs are diverse, rich, and complementary.*
    - **JUNO** is based on technology and know-how developed by INFN for Borexino
    - **HK (T2HK):** Water Cherenkov has proven to be extremely successful and still can be
    - **DUNE** is the natural evolution of liquid Argon technology, mostly developed at Gran Sasso

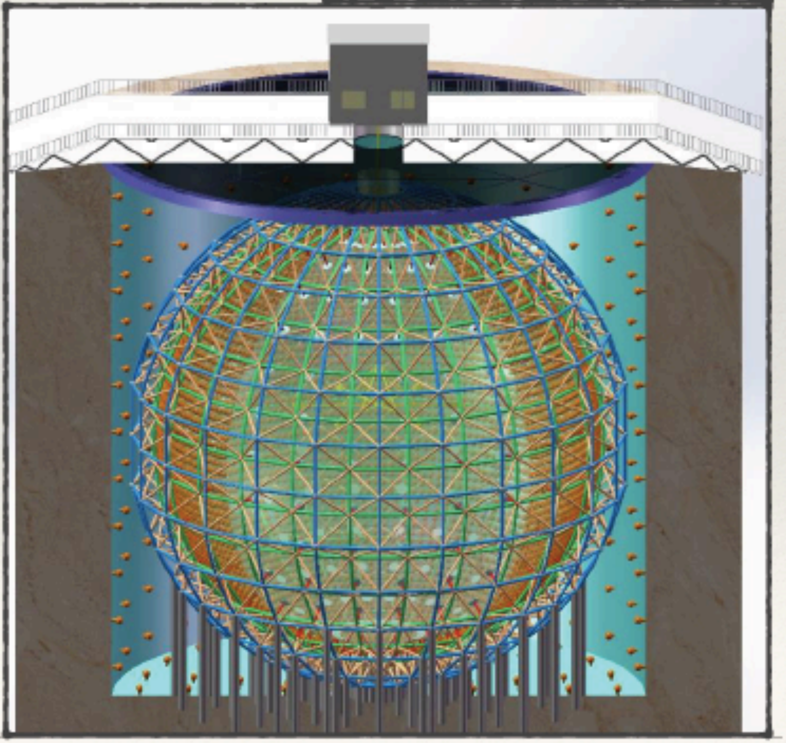
- **Can we do it ?**
  - Probably not, at least with relevant contributions
    - **Not enough people.** An INFN community issue, not just CSN2
    - **Not enough resources.** Connected to previous point.

The near future: JUNO

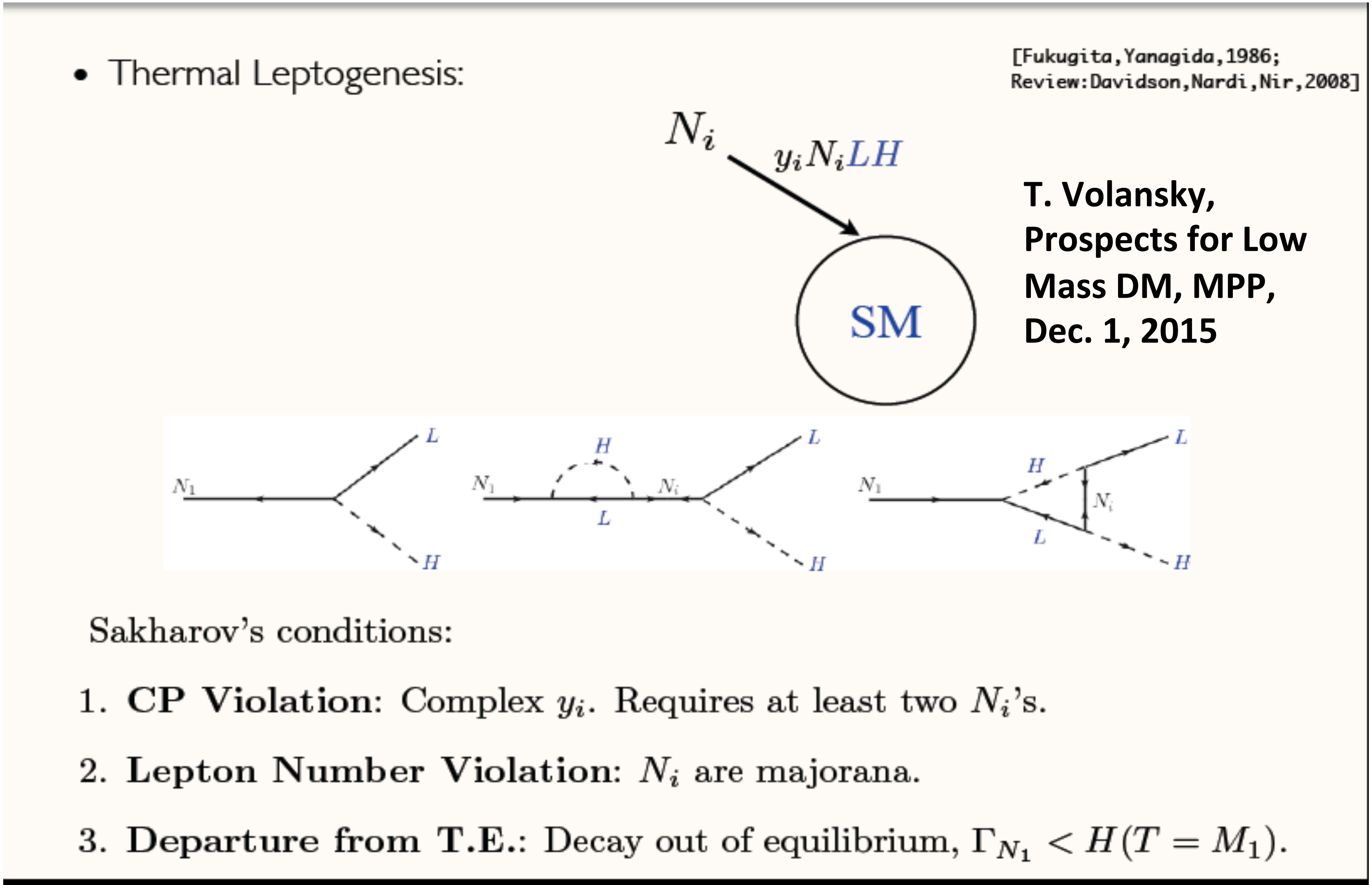
- **Main goals:**
  - **Precision measurement of oscillation parameters** SAFE
  - **Determination of mass hierarchy** Challenge!
- Data taking foreseen for **2020** **(TDR done)**
  - **INFN Tasks:**
    - **Distillation plant prototype (funded 2015)**
    - Distillation plant construction (to be defined)
    - **Electronics (initial fundings 2016)**
    - Veto tracker re-using Opera material
- **The INFN group is growing**
  - **50** people, 22 F.T.E. (13 technologists)
  - **30% more than 2014**

JUNO Conceptual Design Report

August 27, 2015



Linking neutrino masses, matter-antimatter-asymmetry and DM



- Thermal Leptogenesis:

[Fukugita,Yanagida,1986;
Review:Davidson,Nardi,Nir,2008]

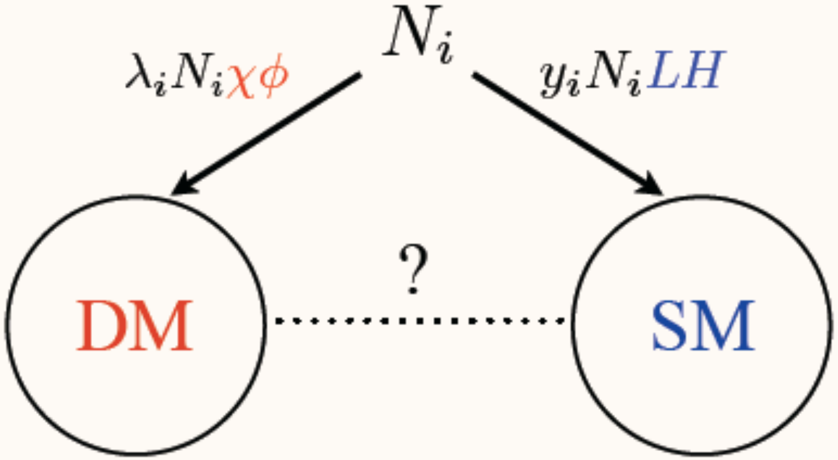
T. Volansky, Prospects for Low Mass DM, MPP, Dec. 1, 2015

Sakharov's conditions:

1. **CP Violation**: Complex y_i. Requires at least two N_i's.
2. **Lepton Number Violation**: N_i are majorana.
3. **Departure from T.E.**: Decay out of equilibrium, $\Gamma_{N_1} < H(T = M_1)$.

- Simple scenario: 2-sector leptogenesis.

[Falkowski,Ruderman,TV, 2011]



N_i

$\lambda_i N_i \chi \phi$

$y_i N_i L H$

DM

?

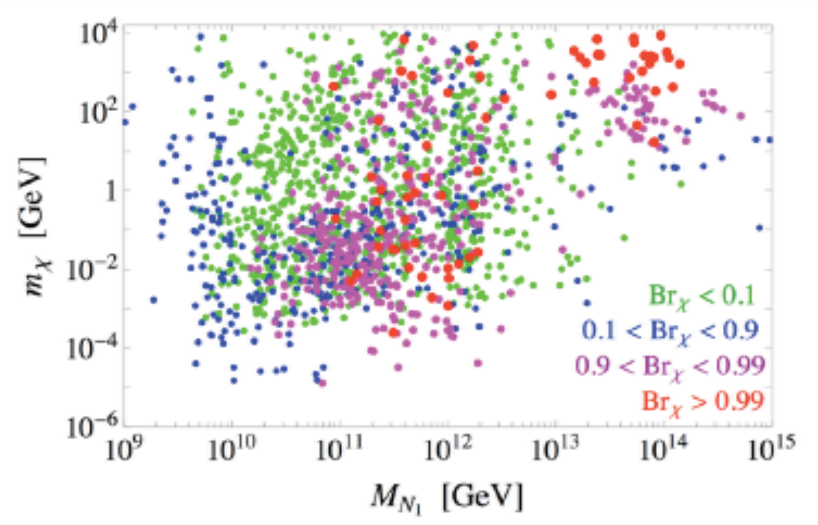
SM

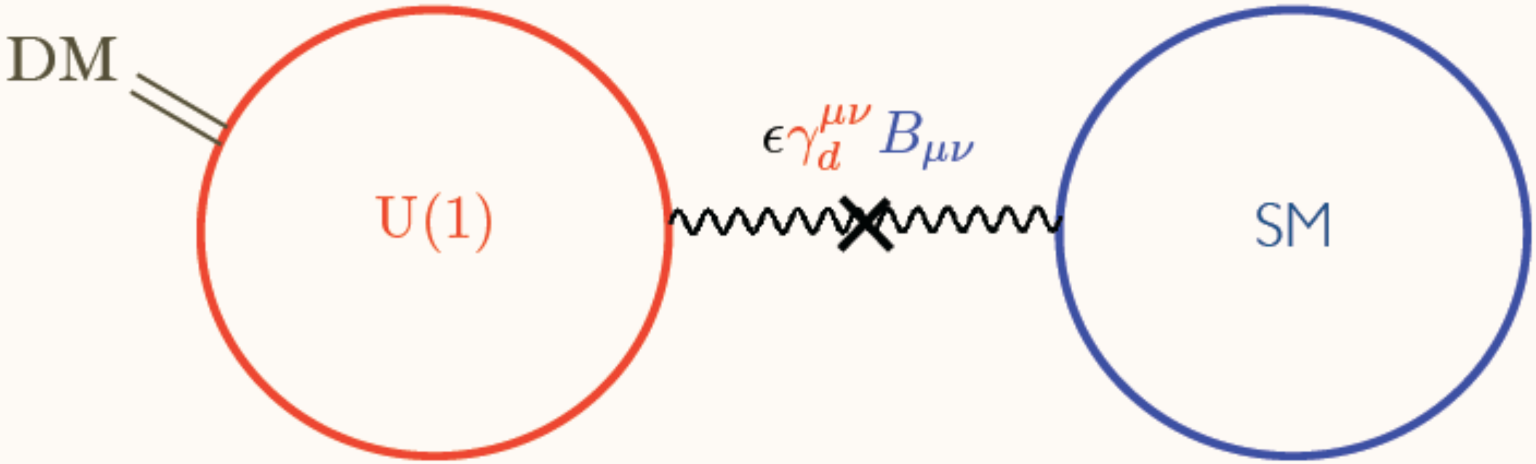
T. Volansky

- The number densities in the two sectors depend on the ratio of branching fractions and washout effects.

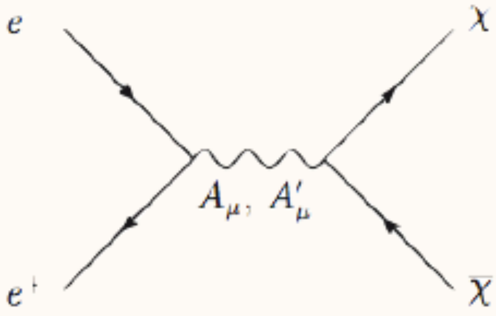
Wide range of DM masses:

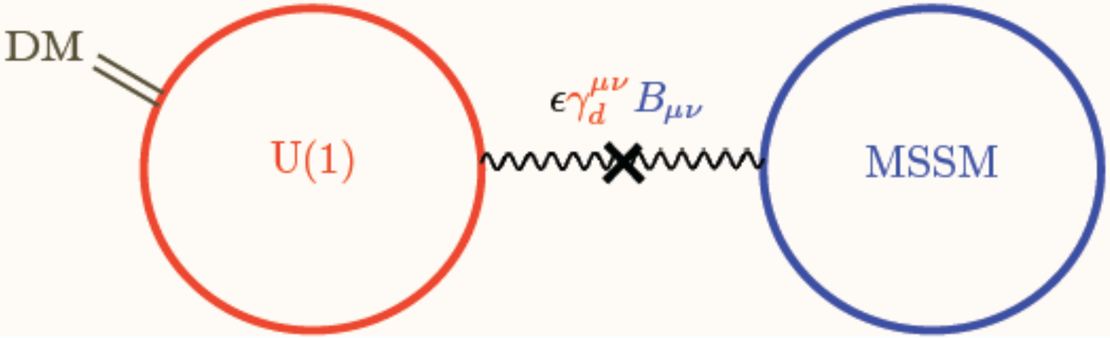
keV - 100 TeV

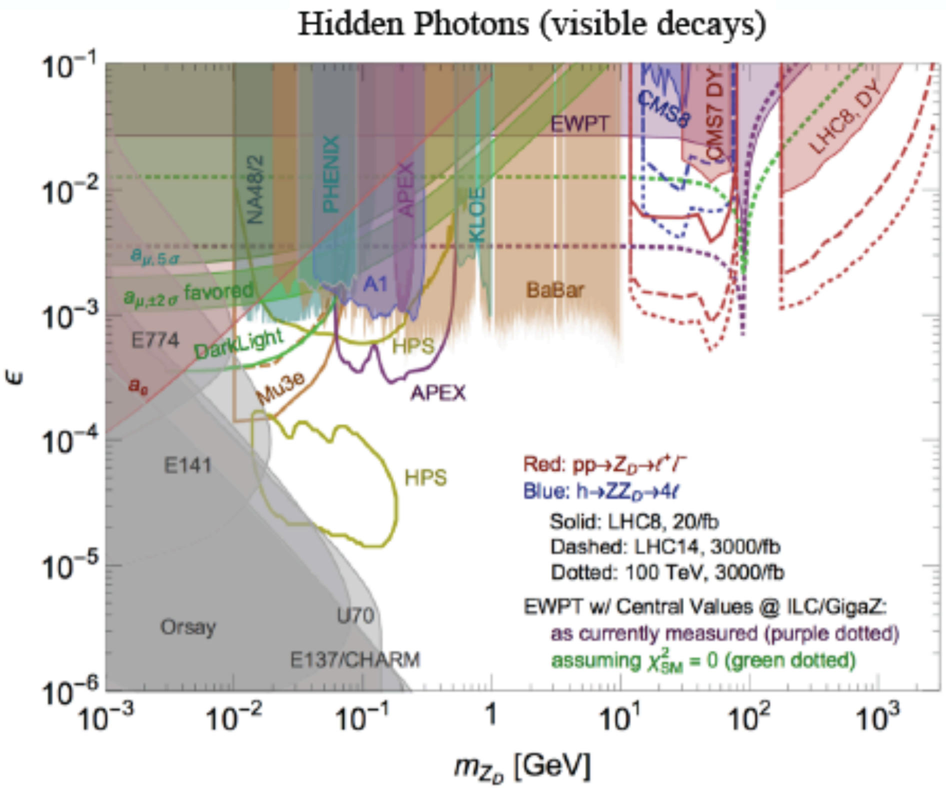




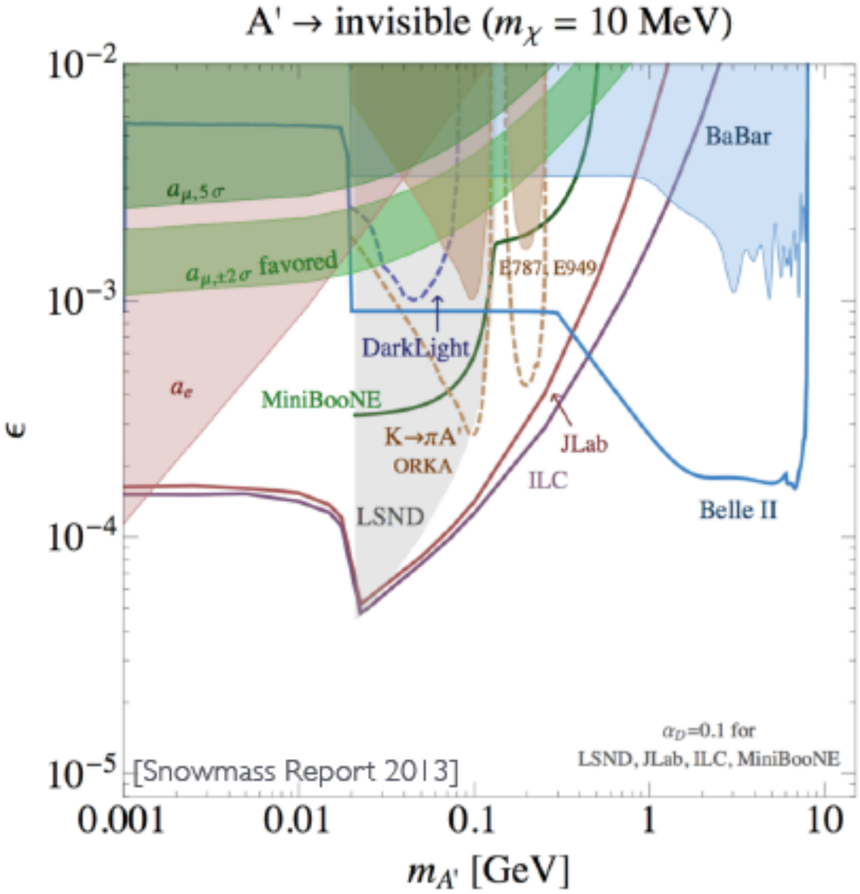
- DM is charged under a new massive U(1) (hidden photon).
- Hidden photon mixes with the SM hypercharge.
- Thermal history of the hidden sector depends on **ε** and mass of hidden photon.





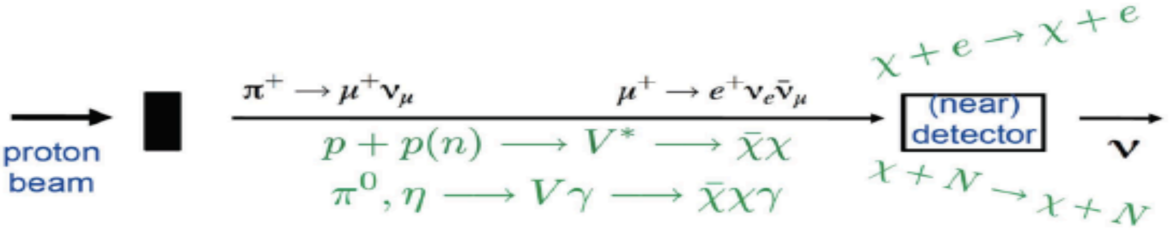


[Curtin, Essig, Gori, Shelton, 2014]



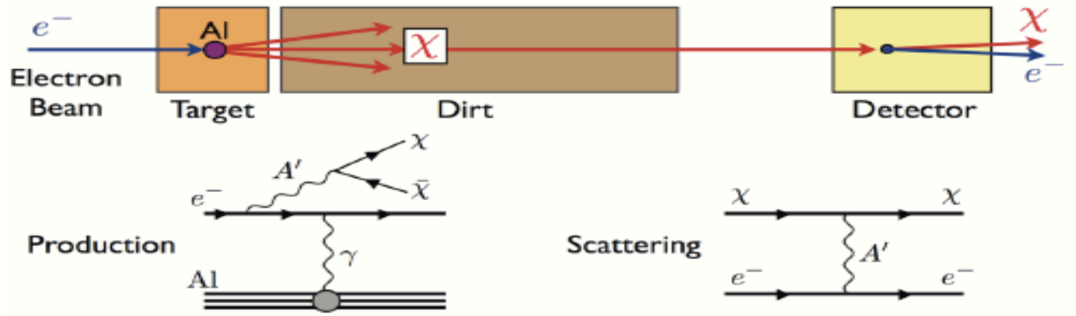
[Snowmass Report 2013]

Neutrino Experiments



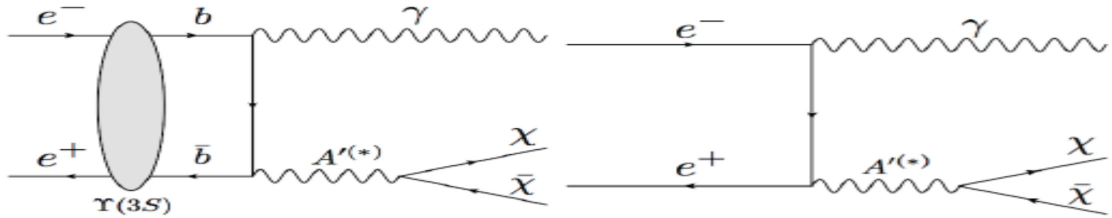
[MiniBooNE + Batell, deNiverville, McKeen, Pospelov, Ritz 2012]

Electron Beam-dumps

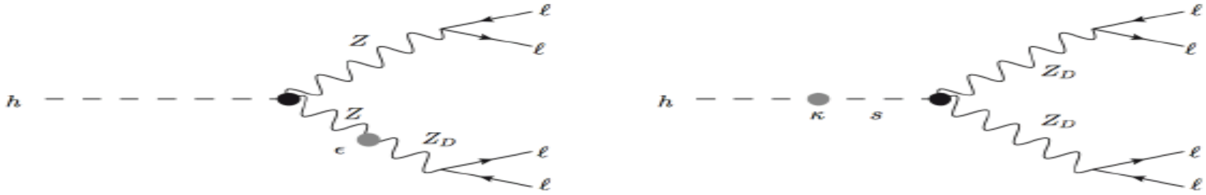


Low-E Colliders

[Bird et al. 2004; McElrath 2005; Fayel 20105; Dreiner et al. 2009;
Borodatchenkova et al. 2006; Reece, Wang 2009; Essig., Mardon, Papucci, TV, Zhong, 201

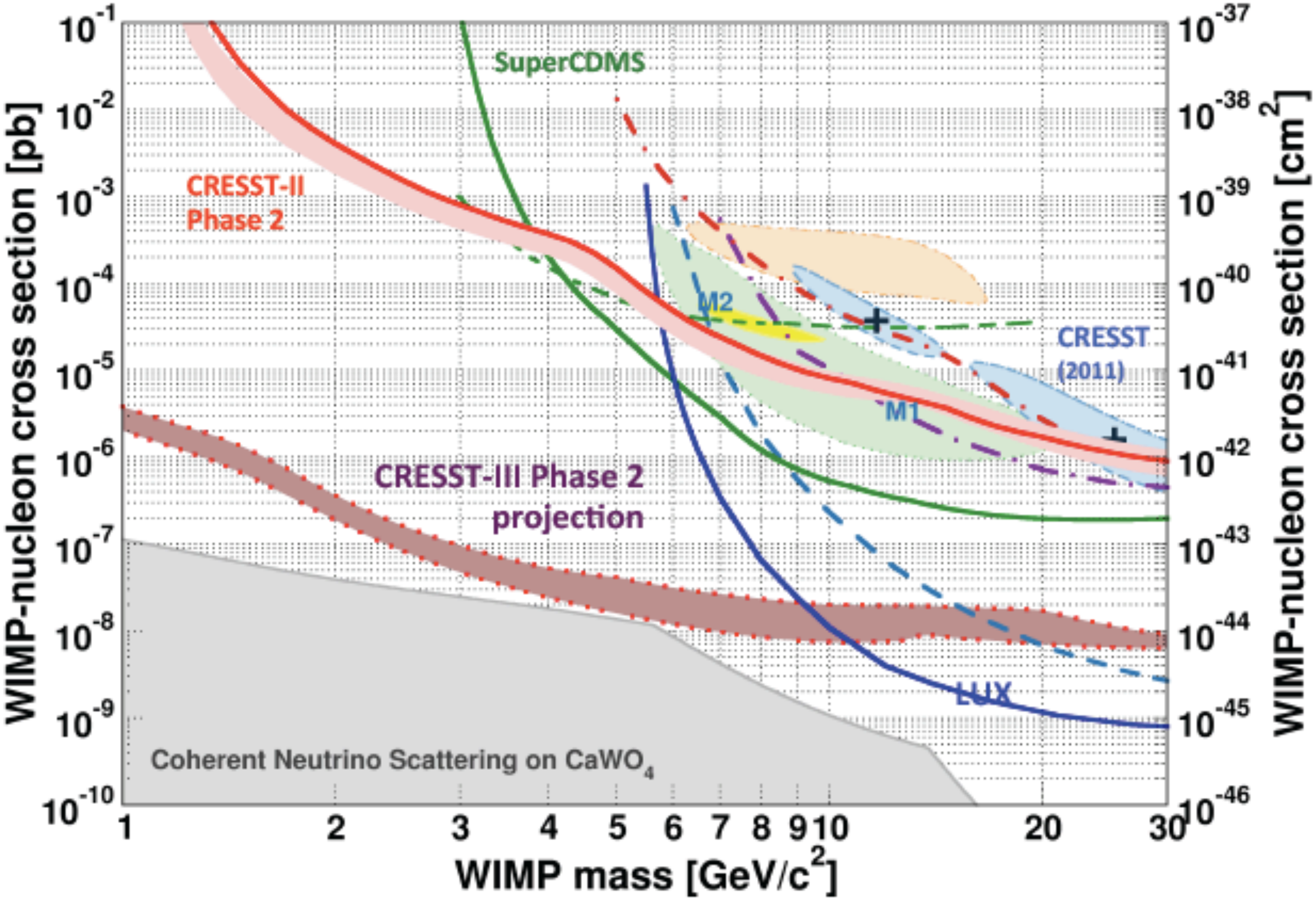


High-E Colliders



[Curtin, Essig, Gori, Shelton, 201

CRESST-III Phase 2



100 x 24g detectors of improved quality operated for 2 year ≈ 1000 kg-days (net)

Search for Axion – QUAX / AXIOMA Experiments

Exploit the axion-electron coupling

$$L_{ae} = \frac{C_e}{2f_a} \Psi_e \gamma^{\mu} \gamma_5 \Psi_e \, \partial_{\mu} a$$

Ce ≤ 10-13Gev-1

$$H_a = -\vec{S} \cdot \left[\frac{g_p}{m_e} \nabla a \right]$$

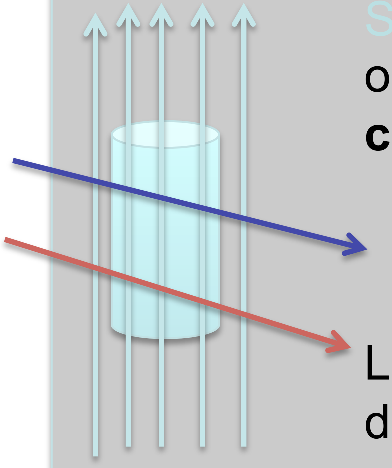
(only DFSZ axion)

Axion wind equivalent to magnetic field

$$B_E = \frac{2g_p}{e} \frac{g_a}{g_J} \nabla_z a$$

$$B_{Ef} \approx \left(\frac{m_a}{10^{-4} eV} \right) 9.4 \times 10^{-23} T$$

Detection using EPR magnetometry



Static external field

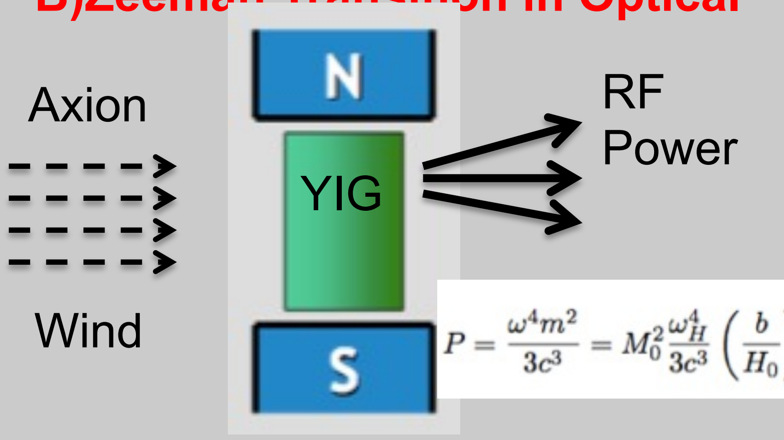
on **paramagnetic crystal sample**

Modulated RF field

Low frequency detection of **induced magnetization**

-A) **Excess Noise in Magnetized Crystal**

- **B)Zeeman Transition in Optical**



$$P = \frac{\omega^4 m^2}{3c^3} = M_0^2 \frac{\omega_H^4}{3c^3} \left(\frac{b}{H_0} \right)^2 Q^2$$

For both schemes **annual modulation expected**

ELECTRON – AXION interaction through SPIN

J.M. Martín, J. Leon, R. Barbieri, I.V. Kolokolov, G. Raffelt , F. Wilczek

$$L = \overline{\psi}(x)\,(i\hbar\ \not{\partial}_x - mc)\,\psi(x) - a(x)\overline{\psi}(x)\,(g_s + i g_p \gamma_5)\,\psi(x) \tag{1}$$

$$B_E = \frac{2g_p}{e}\frac{g_a}{g_J}\nabla_z a$$

Effective magnetic field for cosmological axion

$$B_{Ef} \approx \left(\frac{m_a}{10^{-4}\,eV}\right) 9.4\times 10^{-23}\,T$$

DETECTION TECHNIQUES :

Electron Spin Resonance Magnetometry with Paramagnetic Materials

Optical Spectroscopy in Paramagnetic Crystals

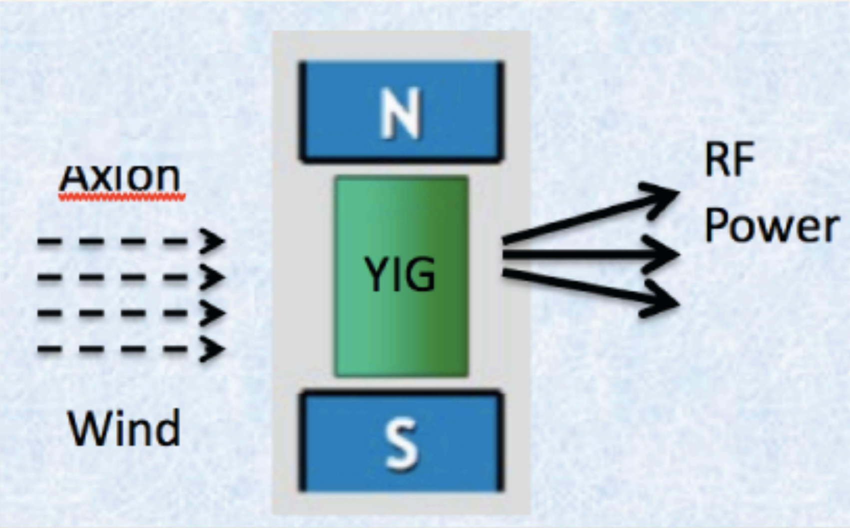
Search for Axion – QUAX / AXIOMA Experiments

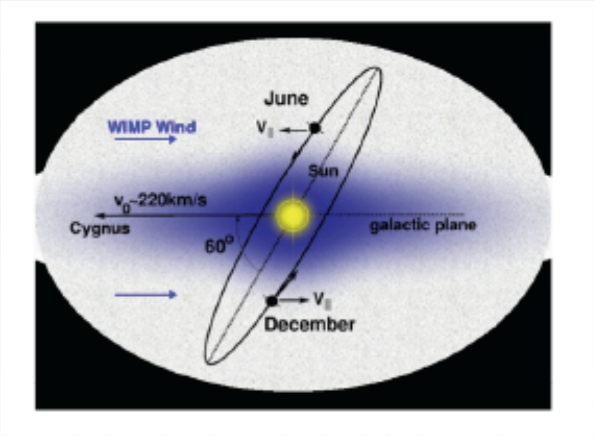
GdL What Next Fisica Fondamentale

Calarco, Carugno, Pascazio, Testera

QUAX: search for axions

- **Main idea:**
  - Use axion spin coupling
  - The axion field may act as an effective magnetic field on electron spin
  - It may induce ferromagnetic transitions in magnetised sample and emit μ-waves
  - R&D is in progress 2015-2016
    - Noise budget unknown
    - Collaboration with INRIM
    - Magnet uniformity and stability: a challenge
    - Group: PD, LNL, TO





Directionality between axion wind and spin

A) Multimessenger astronomy, B) neutrino properties, C) dark side of the Universe and CMB

- A) **Photon**, **cosmic ray**, **neutrino** , **gravitational** astronomies (some in their maturity, some in their youth, some just baby or even still to be born
- B) **neutrino mass** and its relation to the global symmetry of the SM, **Lepton number** (Dirac vs. Majorana natur of the neutrinos); measuring the full neutrino mass parameters (neutrino mass hierarchy, CP violation)
- C) **Dark Matter**; **Dark Energy** and **their role in the evolution of the Universe** (primordial inflation, elw. Phase transition, quark-hadron phase transition, nucleosynthesis, matter-antimatter cosmic asymmetry)

Cosmic radiation: aerial view

GdL What Next Radiazione Cosmica

Aloisio, Bertucci, Busso, De Angelis, Sapienza, Vissani

Charged

Pamela
AMS-02
Dampe
Gamma-400

Herd ? AMS-03 ?

Auger (Prime)
LHAASO

Photons

Fermi
Magic
CTA
LHAASO

Cosmic radiation

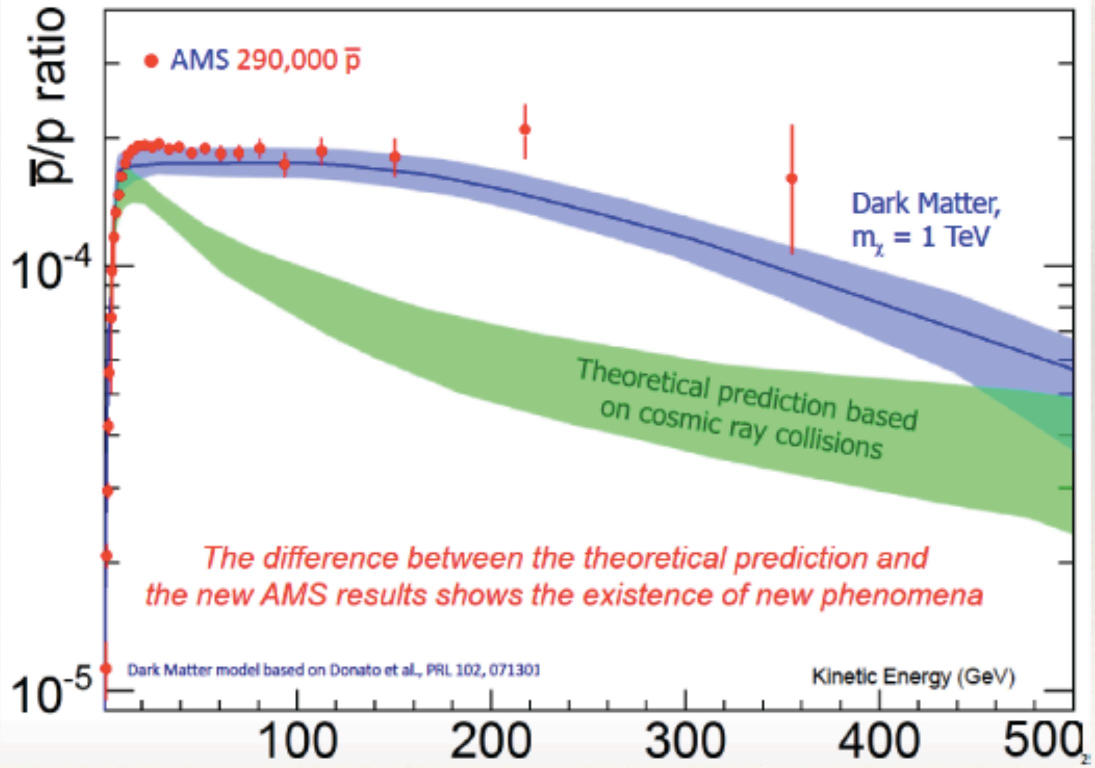
Neutrinos

Borexino
LVD
Km3Net

Running
Under construction
Future planning
Closing

AMS-02 (2)

- Anti-protons
  - Clear deviation from current propagation and diffusion models
  - Dark matter a suggestive possibility, but astrophysical explanations are possible



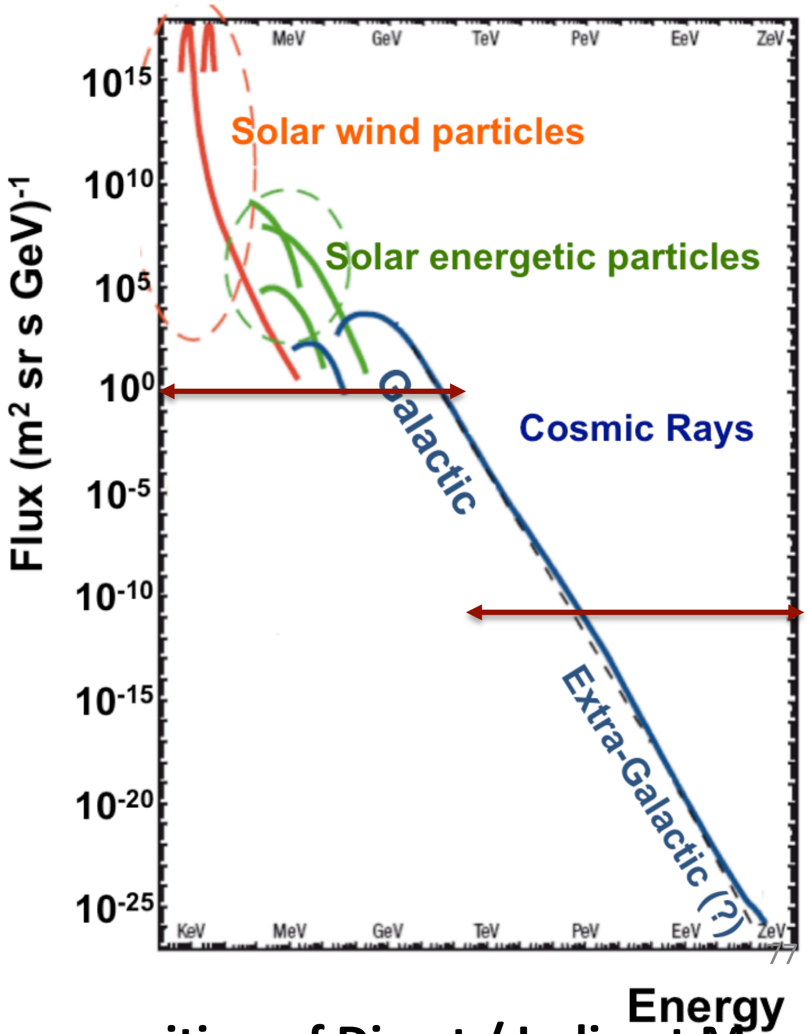
The difference between the theoretical prediction and the new AMS results shows the existence of new phenomena

The Cosmic Ray spectrum

GdL What Next Radiazione Cosmica

Aloisio, Bertucci, Busso, De Angelis, Sapienza, Vissani

Direct Measurements in space



Indirect Measurements on ground

(future also in space?)

WN ?   superposition of Direct / Indirect Measurements composition and statistics at high energy

Direct CR measurements

GdL WN Rad. Cosmica

- Direct CR measurements: in the last 5 years with PAMELA and AMS have entered a new era of precision and unknown is being probed: unexpected spectral features, positrons sources, anti-protons challenging our understanding of interstellar medium….

  TeV has been reached

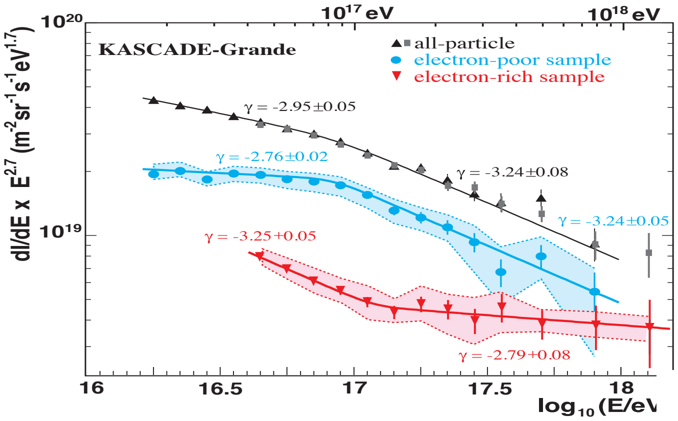
- CALET, DAMPE (Launch in 2 weeks), ISS-CREAM will provide more precise measurements in the multi-TeV energies.

- The next challenge will be to extend direct measurements to the knee with the same level of accuracy. Opportunities are around the corner (e.g. China space program & HERD) but should be caught on the fly!

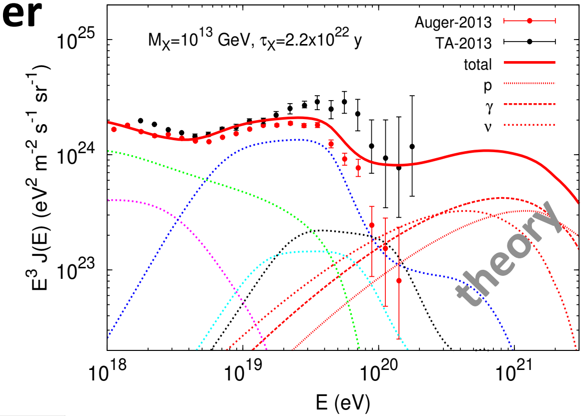
- Let's not forget the unknown: to advance in rare anti-matter channels measurements R&D is needed.

High Energy Cosmic Rays – the science cases

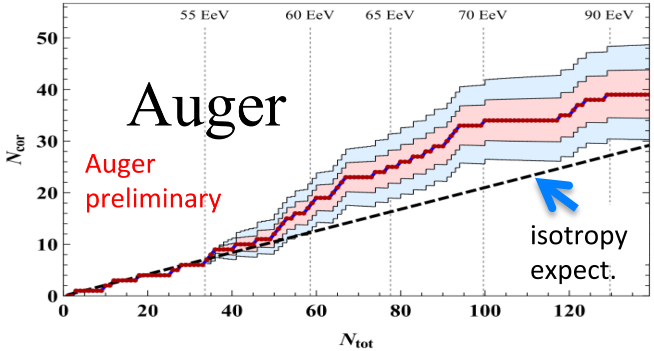
Transition Galactic-Extragalactic CR



New physics at the highest energies $E>10^{20}$ eV, super heavy dark matter

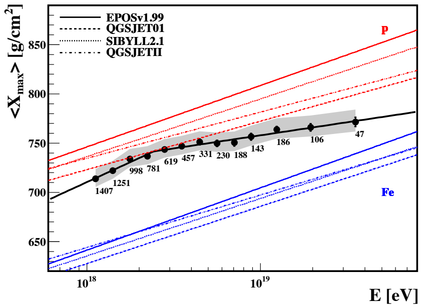


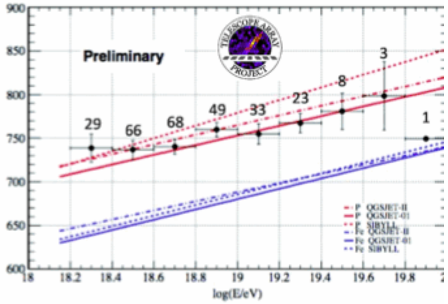
CR astronomy

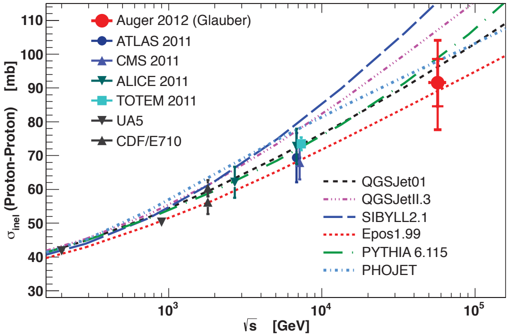


GdL WN Rad. Cosmica

UHECR chemical composition, hadronic cross sections at $\sqrt{s}\approx10^2$ TeV







NEUTRINI DI ALTA ENERGIA

GdL WN Rad. Cosmica

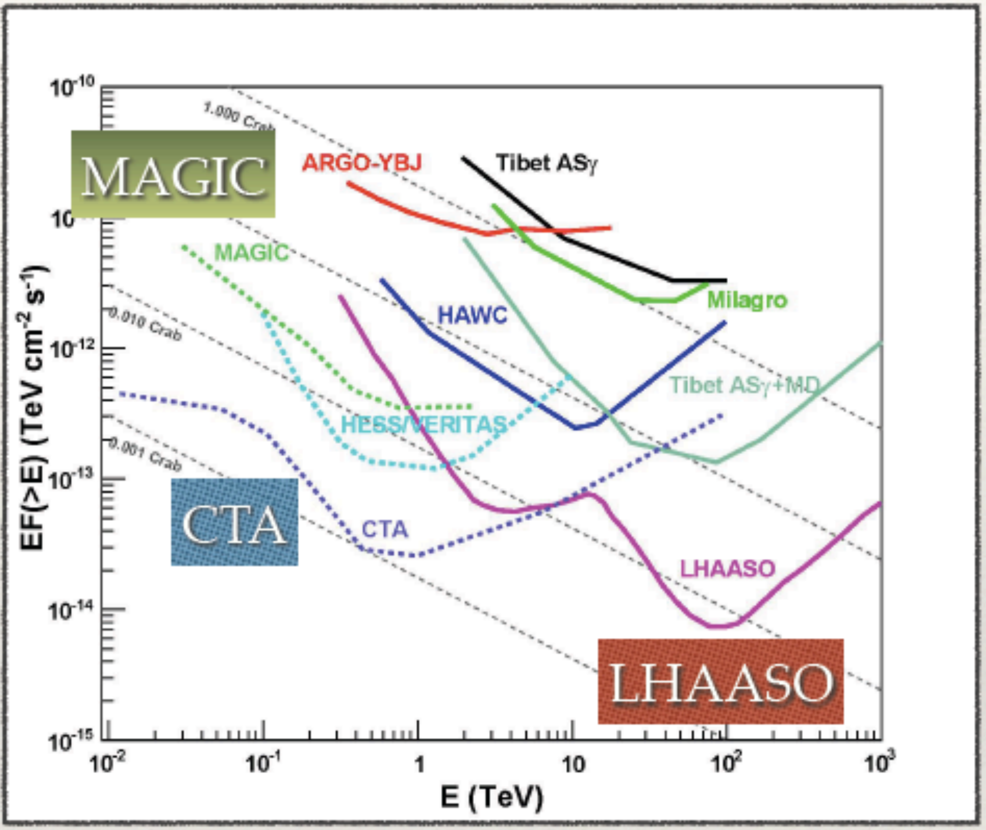
- Le osservazioni di IceCube costituiscono uno dei risultati più interessanti di fisica degli ultimi anni e segnano l'inizio della astronomia di neutrini di alta energia

- La significatività del segnale è di 6.5σ. Le prime misure di spettro, distribuzione angolare e composizione di flavor sono in accordo con l'ipotesi che neutrini cosmici siano stati visti

- Le domande cruciali a cui bisogna rispondere includono:
  - *Qual'è il contributo relativo di sorgenti galattiche ed extragalattiche?*
  - *È possibile individuare (alcune) sorgenti di raggi cosmici?*
  - *Come osservare eventi dovuti a neutrini tau o a risonanza di Glashow?*
  - *Quanto vale in flusso di neutrini prompt atmosferici?*

H.E. γs from ground detectors

- **MAGIC**
  - **Running,** recently improved trigger, threshold down to 35 GeV
  - INFN support till beginning of CTA
- **CTA**
  - Pointing observatory 100 GeV - 100 TeV
  - Coordination with INAF
  - INFN scope: trigger, electronics for LT
  - Building on MAGIC experience: **Canary Islands site approved besides Chile !**
- **LHAASO**
  - **Large FoV and duty cycle.** More sensitivity above 10 TeV and knee CR physics too
  - Complementary with CTA with better sensitivity at high energy and transient detection capability
  - Scope: physics, simulations, analysis: **building on ARGO experience**



The future of gamma astrophysics

- Rich panorama of γ experiments at (V)HE proposed for the future.
  - **MeV Region**: Present technology allows ~easily to design a satellite 1-2 orders of magnitude better than COMPTEL. Useful also for fundamental physics (backgrounds to DM). 4 projects designed for 2020+, converge?
  - **GeV region**: keep Fermi in orbit as long as possbile (2028?), then need for a successor of Fermi. Best DM studies till m ~ 100 GeV.
  - **TeV region** (with extension down to 50 GeV and up to 200 TeV): CTA will lead the field. Will outperform present gamma detectors (HESS, MAGIC, VERITAS) not before 2020.
  - **PeV region**: Northern EAS projects approved (HAWC already running); are producing and will produce good science – probably HAWC will be the leader till 2020. Need to converge to a Southern PeV EAS project to study PeVatrons and new sources in the Galactic Centre (at least 3 proposals).
- **Multimessenger** astrophysics can help our understanding of cosmic accelerators, of physics under extreme environments and of fundamental particle physics.

A. De Angelis

- Bridging direct space measurement with large ground based detectors

- **Goal 1:** **CRs around and above the knee 10^{12} - 10^{18} eV**
  - Understanding knee origin and disentangle galactic and possible extragalactic components
  - Composition around the knee is not understood completely, spectral index Z dependent
    - Simple diffusion models are challenged by data, and anisotropies are important

- **Goal 2:** **photons 10^{11} - 10^{15} eV**
    - Better or complementary to CTA for transients, GRB, all sky surveys, diffuse signal
    - Searching for PeVatrons (hot topic after PeV neutrino discovery)

Overall, **in the next few years the APPEC agencies will need to take a decision on**

a) **the construction of the phase 1.5 of KM3Net,**

b) **a major investment as a contribution to a neutrino long baseline program in US or Japan,**

c) **a European-led dark matter multi-ton experiment**

d) **a ton-scale neutrino mass detector (double beta decay technique)**

e) **a major contribution on ground and/or space to the cosmology program probing the param. of inflation.**

Hunting for
GRAVITATIONAL WAVES:
DISCOVERY AND ASTRONOMY

2nd generation detectors:
Advanced Virgo, Advanced LIGO

GOAL:

sensitivity 10x better →

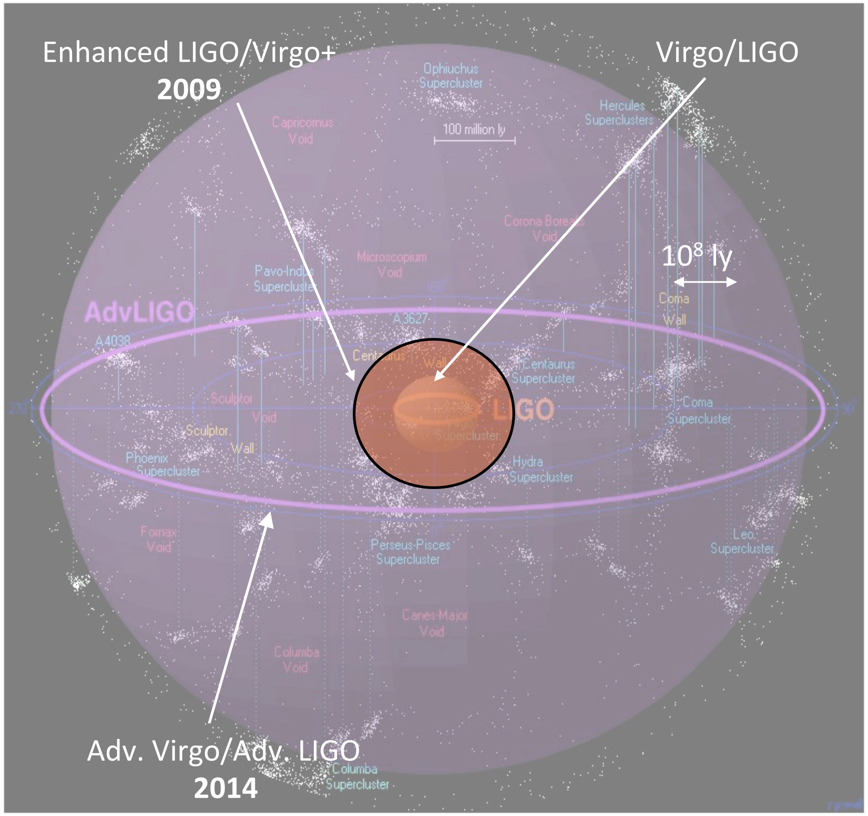
look 10x further →

Detection rate 1000x larger

NS-NS detectable as far as 300 Mpc

BH-BH detectable at cosmological distances

10s to 100s of events/year expected!



Credit: R.Powell, B.Berger

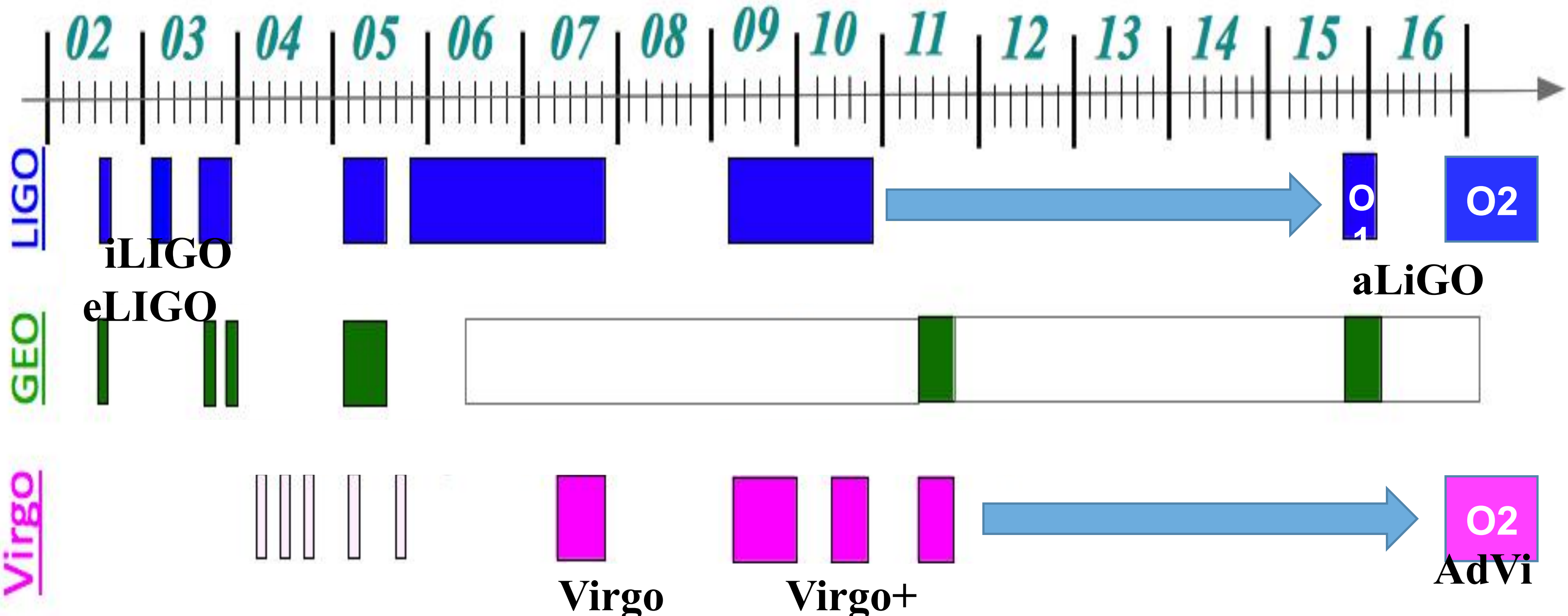
WORLDWIDE NETWORK OF GW DETECTORS

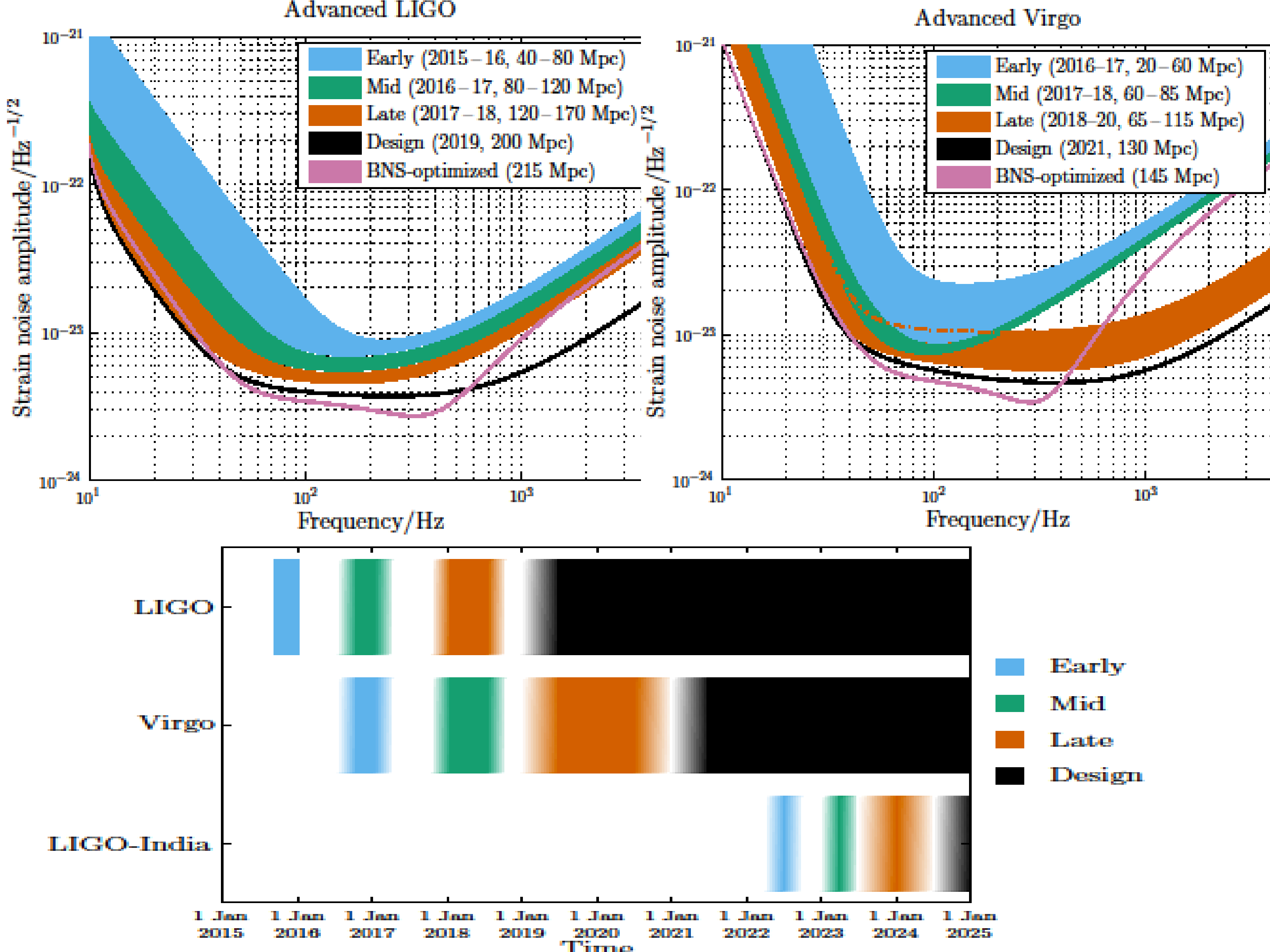
ADVANCED LIGO (aLIGO)

- ✓ Project funded: April 2008
- ✓ Project start: 2010
- ✓ Funding: >205 M$
- ✓ Installation completed: June 2014
- ✓ First science run: O1 Aug 2015

ADVANCED VIRGO (AdV)

- ✓ Project funded: Dec 2009
- ✓ Project start: 2012
- ✓ Funding: 23 M€
- ✓ Installation completed: early 2016
- ✓ First science run: O2 ~Sep 2016

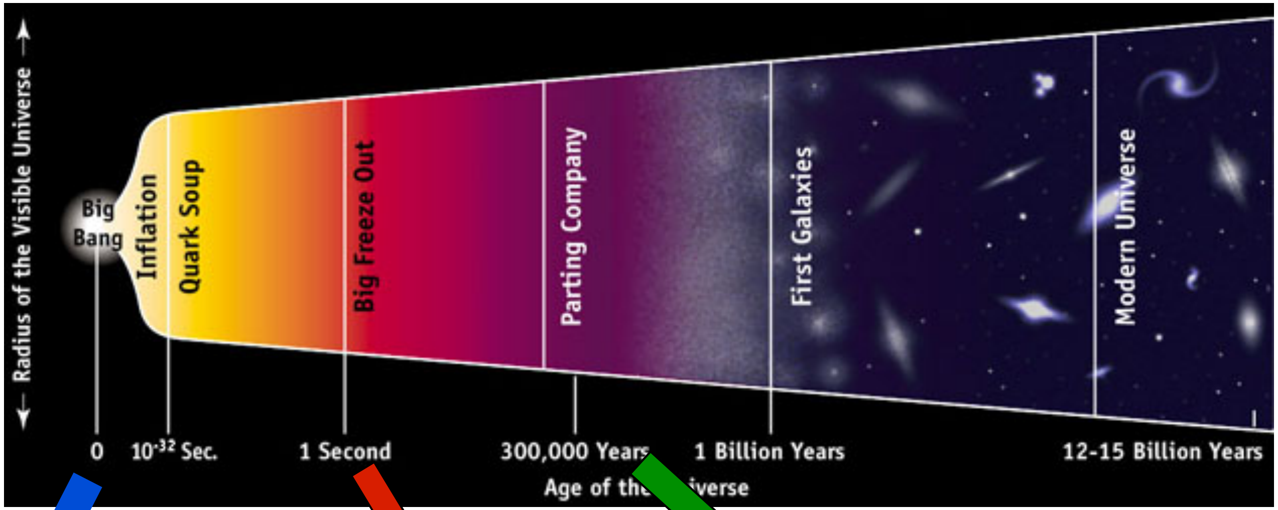



Advanced LIGO
Early (2015 – 16, 40 – 80 Mpc)
Mid (2016 – 17, 80 – 120 Mpc)
Late (2017 – 18, 120 – 170 Mpc)
Design (2019, 200 Mpc)
BNS-optimized (215 Mpc)
Strain noise amplitude /Hz$^{-1/2}$
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{1}
10^{2}
10^{3}
Frequency/Hz
Advanced Virgo
Early (2016–17, 20 – 60 Mpc)
Mid (2017–18, 60 – 85 Mpc)
Late (2018–20, 65 – 115 Mpc)
Design (2021, 130 Mpc)
BNS-optimized (145 Mpc)
Strain noise amplitude /Hz$^{-1/2}$
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{1}
10^{2}
10^{3}
Frequency/Hz
LIGO
Virgo
LIGO-India
Early
Mid
Late
Design
1 Jan 2015
1 Jan 2016
1 Jan 2017
1 Jan 2018
1 Jan 2019
1 Jan 2020
1 Jan 2021
1 Jan 2022
1 Jan 2023
1 Jan 2024
1 Jan 2025
Time

Interferometria atomica?

- La componente non-balistica che si sta affacciando è il mondo degli interferometri atomici
- Tecnologia interessante, performante per costruire gravimetri, ma il loro utilizzo per realizzare in GW detectors è tutto da dimostrare
- Design Study proposal in H2020
  - Componente italiana assente
- Inseriti in EGWII
  - Framework opportuno per la definizione del loro potenziale ruolo in GW

Relic Stochastic Background

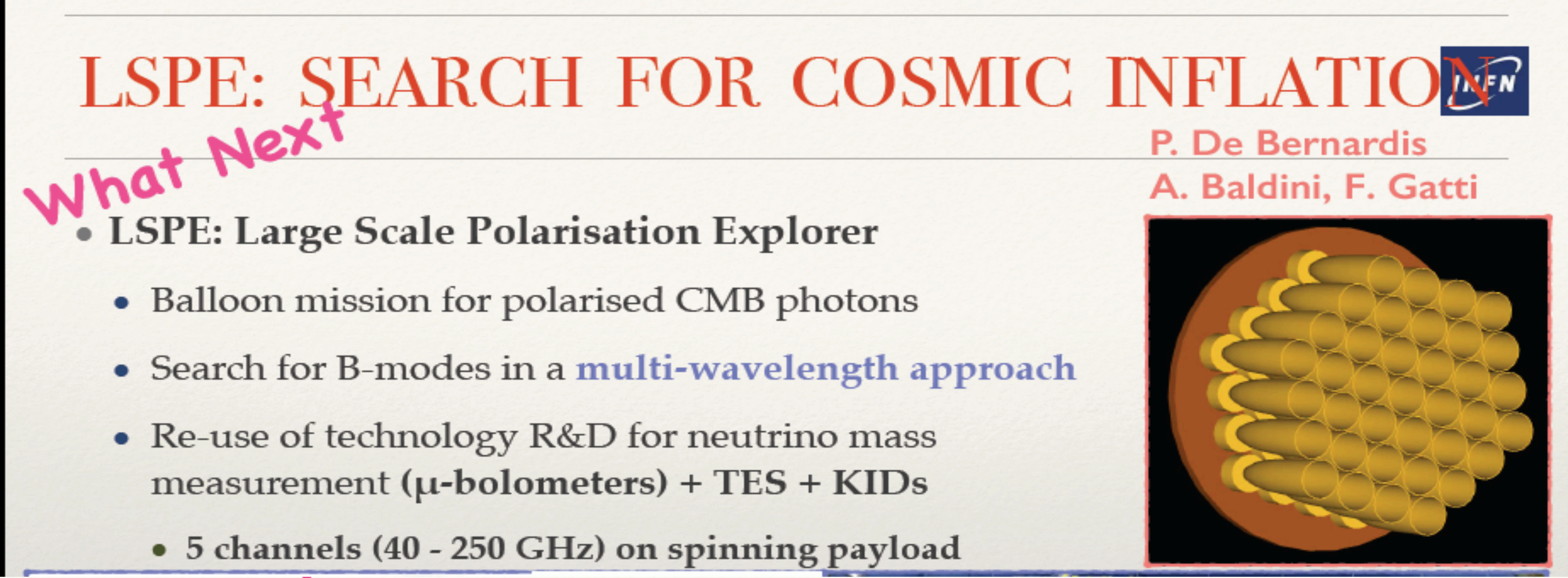


Relic gravitons

Relic neutrinos

CMBR

- Imprinting of the early expansion of the universe
- Correlation of at least two detectors needed



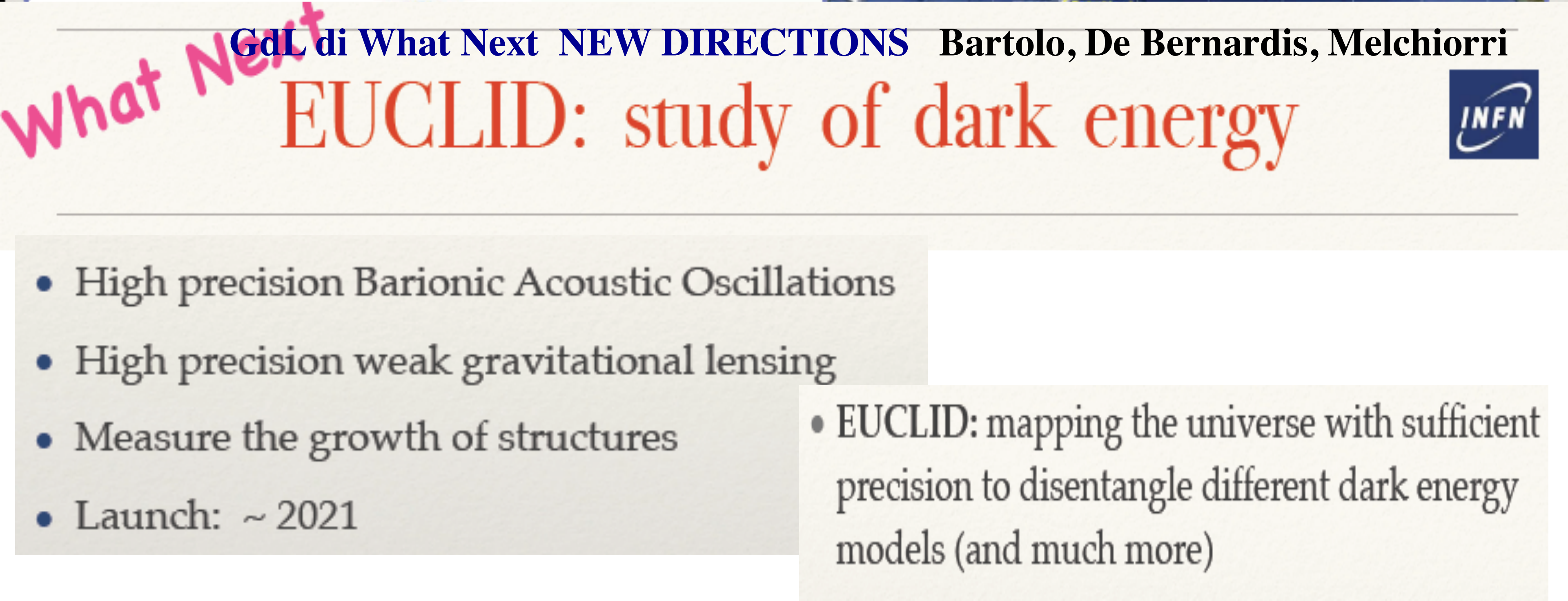
What Next

LSPE: SEARCH FOR COSMIC INFLATION

P. De Bernardis
A. Baldini, F. Gatti

- **LSPE: Large Scale Polarisation Explorer**
  - Balloon mission for polarised CMB photons
  - Search for B-modes in a **multi-wavelength approach**
  - Re-use of technology R&D for neutrino mass measurement **(μ-bolometers) + TES + KIDs**
    - **5 channels (40 - 250 GHz) on spinning payload**

GdL di What Next NEW DIRECTIONS Bartolo, De Bernardis, Melchiorri



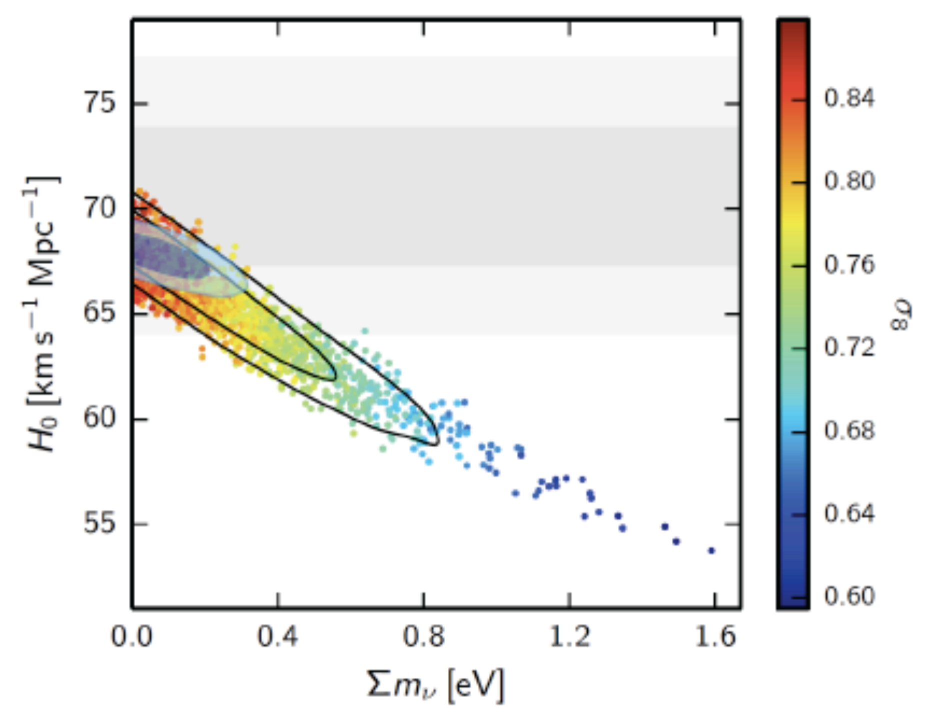
What Next

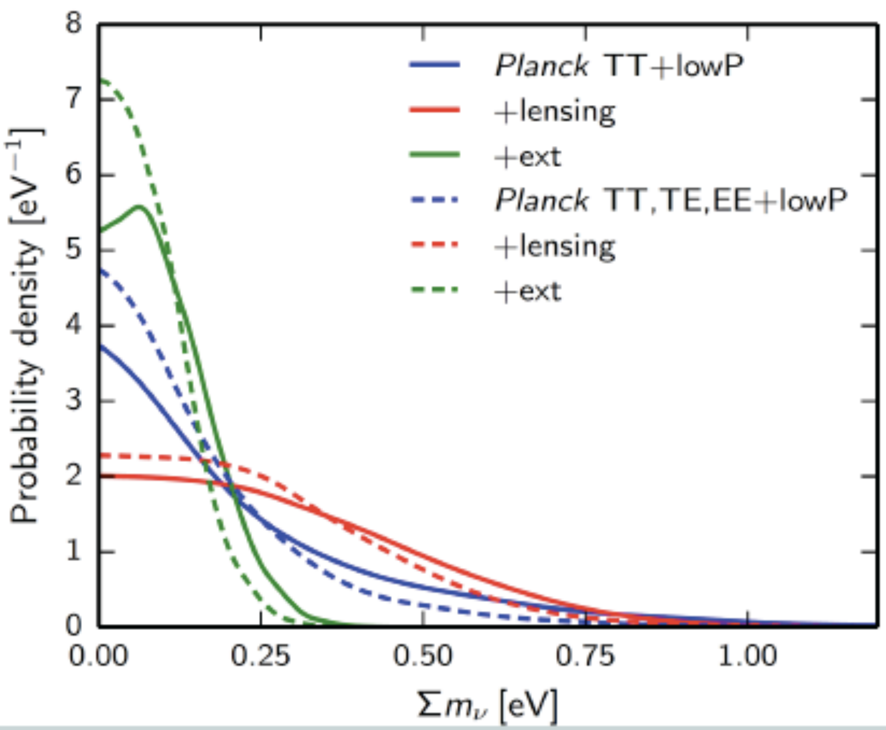
EUCLID: study of dark energy

- High precision Barionic Acoustic Oscillations
- High precision weak gravitational lensing
- Measure the growth of structures
- Launch: ~ 2021

- EUCLID: mapping the universe with sufficient precision to disentangle different dark energy models (and much more)

Planck constraints on neutrino masses



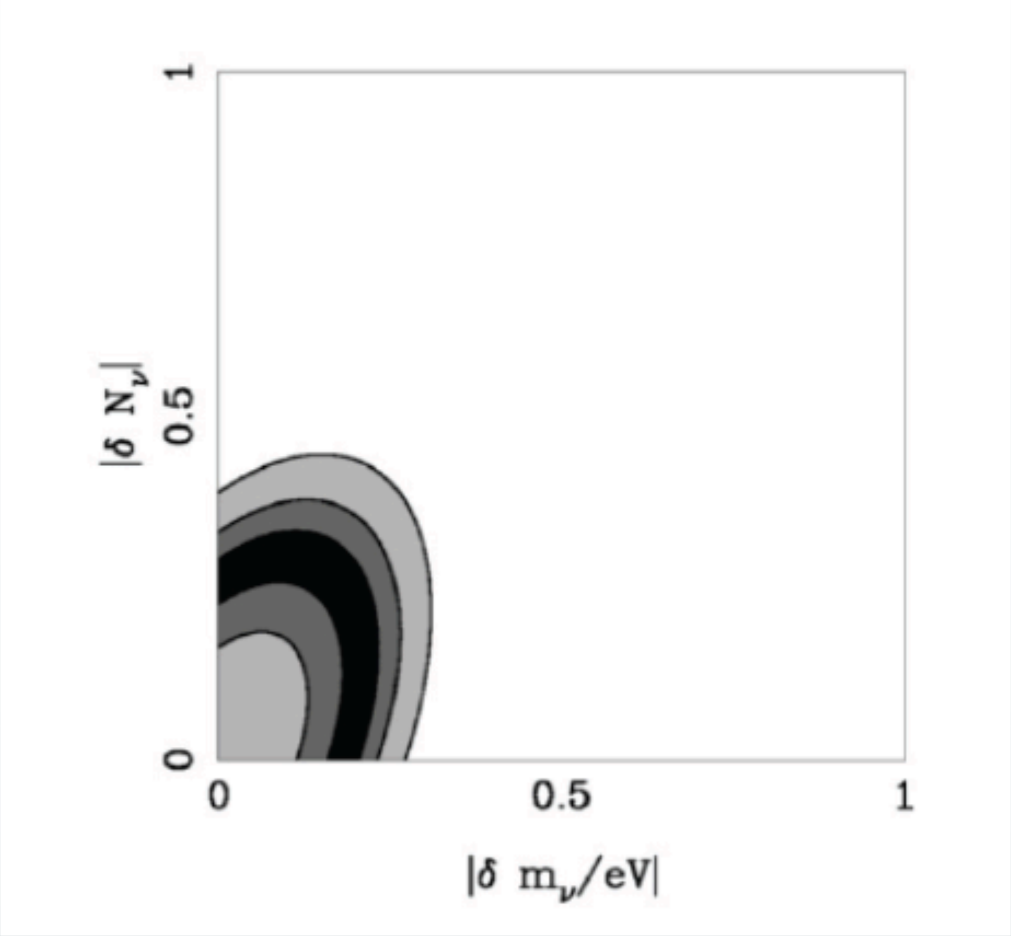


Bartolo per il GdL
New Directions

$\Sigma m_\nu < 0.23$ eV (95% CL)

$N_{eff} = 3.15 \pm 0.23$

Example: Euclid and neutrino physics



Planck+Euclid
(Kitching et al.2008)

Bartolo per il GdL
New Directions

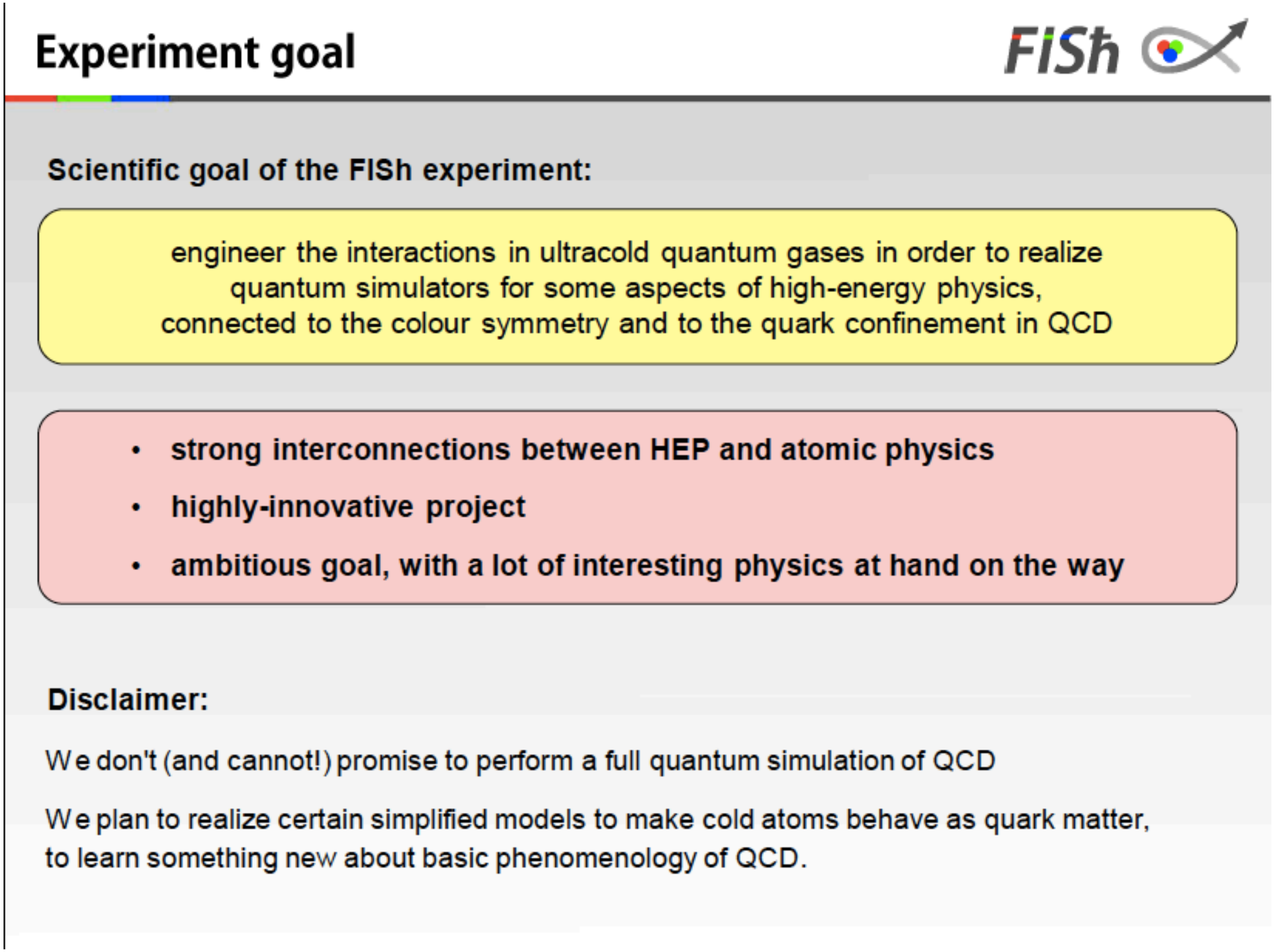
Δm_ν~0.03 eV & ΔN_ν~0.08

GdL di What Next Nuove Tecnologie CALABRETTA, Alberto FACCO, Massimo FERRARIO, Valter Bonvicini, Gaetano MARON, Marco PAGANONI, Ezio PREVITALI, Marco RIPANI

Detectors are our eyes

- We, as a field, need to maintain and develop detector expertise. Today's detector marvels are not automatically reproducible by the next generation. Three essential elements:
  - Training: organizing and stimulating participation in instrumentation schools
  - Experimenting: encouraging young experimentalists to do hands-on detector work especially in smaller, shorter scale experiments and R&D
  - Rewarding: giving proper recognition of excellence in instrumentation development in careers at universities and research institutions.

INFN ai suoi “confini” in What Next



Experiment goal

FISħ

Scientific goal of the FISh experiment:

engineer the interactions in ultracold quantum gases in order to realize quantum simulators for some aspects of high-energy physics, connected to the colour symmetry and to the quark confinement in QCD

- **strong interconnections between HEP and atomic physics**
- **highly-innovative project**
- **ambitious goal, with a lot of interesting physics at hand on the way**

Disclaimer:

We don't (and cannot!) promise to perform a full quantum simulation of QCD

We plan to realize certain simplified models to make cold atoms behave as quark matter, to learn something new about basic phenomenology of QCD.

INFN ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

FRASCATI PHYSICS SERIES

INFN Commissione Scientifica Nazionale 1 (CSN1)

What Next: White Paper of CSN1

Proposal for a long term strategy for accelerator based experiments

Bonvicini 2015

Editors
F. Bedeschi, R. Tenchini, J. Walsh

M. Ferrario, F. Forti, D. Lucchesi, G. Punzi.

Completely new acceleration techniques, are unlikely to become capable to produce the high luminosity electron/positron beams needed for HEP on the time scale of 20 years from now, so for next two decades, machines will need to be based on more conventional technologies like the one foreseen for HL-LHC.

Nevertheless a tremendous effort is ongoing towards the development plasma wake fields accelerators or muon based collider and a wider range of options will be likely available on a longer time scale.

In particular the EuPRAXIA project will bridge the gap between successful proof-of-principle experiments (today) and a reliable technology with many applications (end of the 2020's).

Experiment goal

Scientific goal of the FISh experiment:

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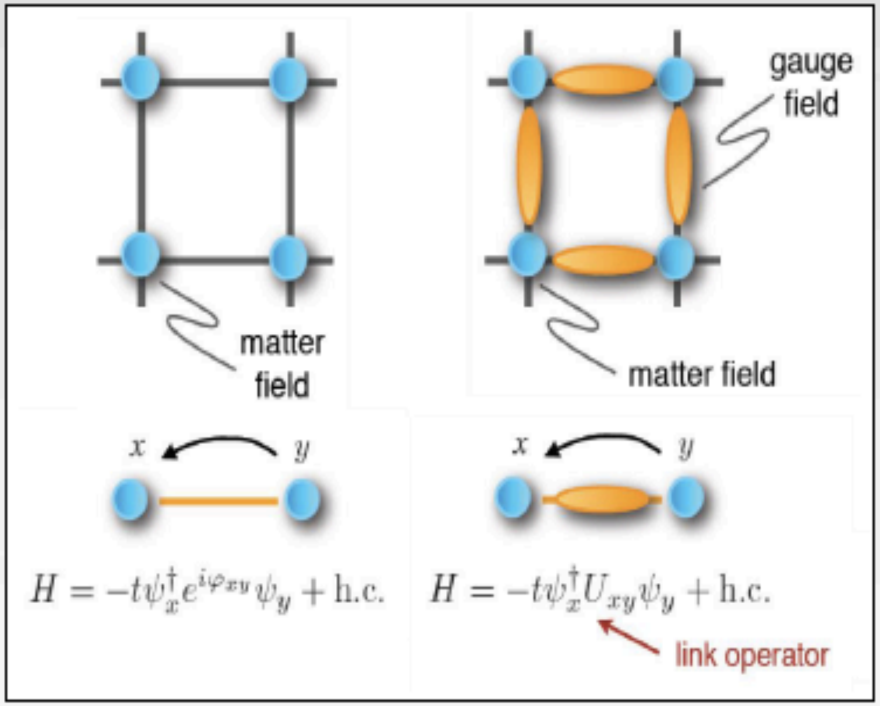
Quantum simulation of fermionic matter coupled to gauge fields

Recent proposals for the implementation of gauge fields and gauge theories
in Yb atoms with laser-assisted tunnelling and/or structured optical lattices

- Realization of abelian and non-abelian gauge fields with ultracold atoms
- Dynamical gauge fields (simple instances of lattice gauge theories)

Theory collaboration: P. Zoller (Innsbruck)



$$H = -t\psi_x^\dagger e^{i\varphi_{xy}}\psi_y + \mathrm{h.c.}$$

$$H = -t\psi_x^\dagger U_{xy}\psi_y + \mathrm{h.c.}$$

Artificial gauge potentials for neutral atoms
J. Dalibard et al., Rev. Mod. Phys. **83**, 1523 (2011).

Atomic Quantum Simulation of U(N) and SU(N) Non-Abelian Lattice Gauge Theories
D. Banerjee et al., PRL **110**, 125303 (2013)

Galileo Galilei Institute: esperimento di successo

The Galileo Galilei Institute for Theoretical Phys
Arcetri, Florence

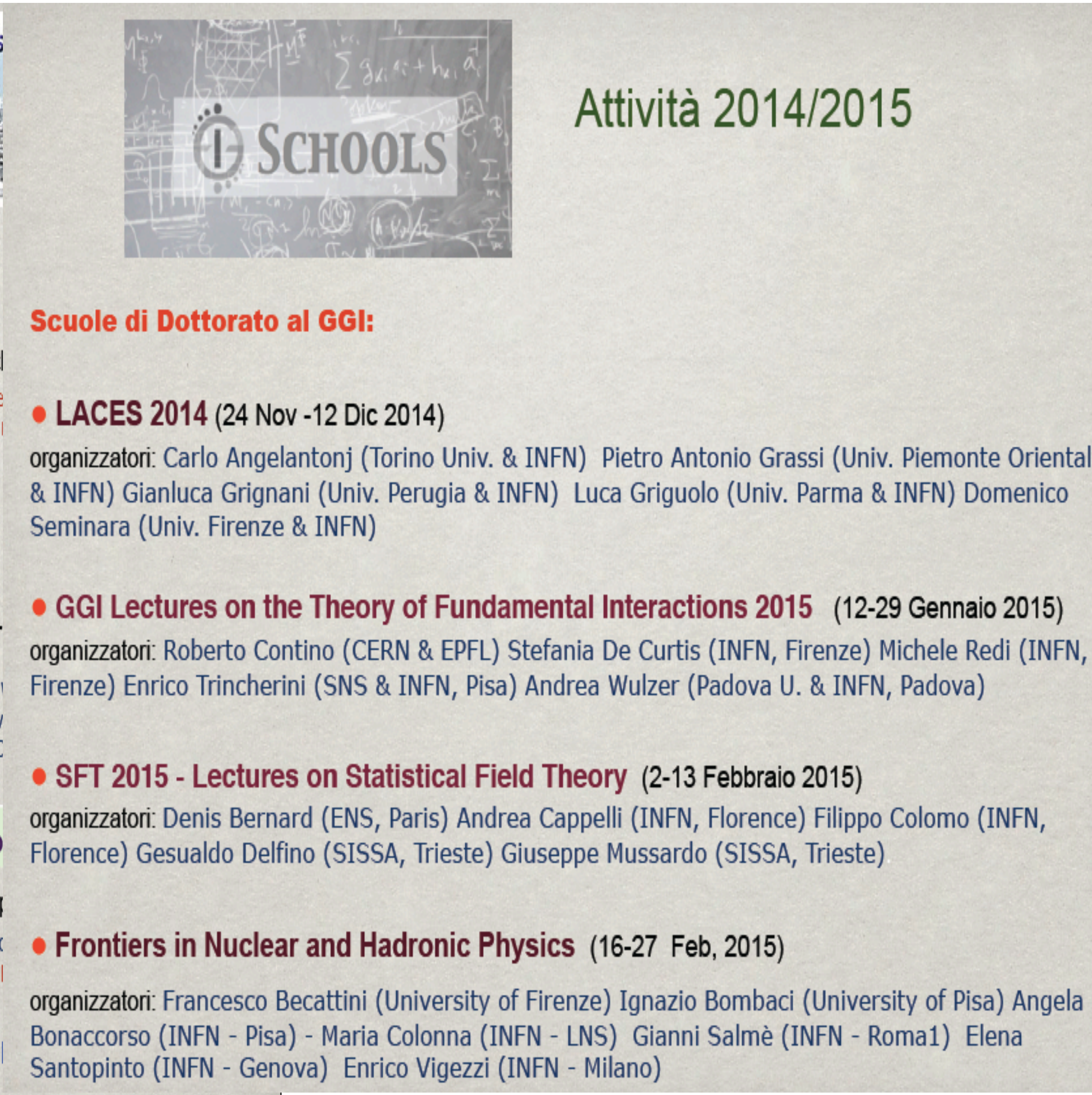
Attività 2014

3 Workshops (with Training Weeks and Conferences):

- **The Structure and Signals of Neutron Stars, from Birth to Death** (Marc
organized by: Fiorella Burgio (INFN sez. Catania) Alessandro Drago (University of Fe
(Southampton University) Brian Metzger (Columbia University) Pierre Pizzochero (U
Watts (API Amsterdam)+LOC Daniele Dominici
(Conference: March 24-28, 2014)
73 participants (20% italian)

- **Advances in Nonequilibrium Statistical Mechanics: large deviations
correlations, extreme value statistics, anomalous transport and long-r**
(May 5 - July 4, 2014), organized by: Joel Lebowitz (Rutgers, State University of Ne
(Università di Firenze, Italy) Satya Majumdar (Université de Paris Sud, France), Dav
Institute of Science, Israel) Stefano Ruffo (Università di Firenze, Italy) +LOC Lapo C
(Training Week: May 12-16, 2014 --- Conference: May 26-30, 2014)
127 Participants (18% italian) + 6 students (per-diem GGI funding for yo

- **Prospects and Precision at the Large Hadron Collider at 14 TeV** (Sep
organized by: Daniel de Florian (University of Buenos Aires) Sven Moch (University
Zeuthen), Guido Montagna (University of Pavia and INFN, Pavia) Fulvio Piccinini (IN
Colferai
(Training week: September 29 - October 3, 2014 --- Conference: Septem
CMS-ATLAS-TH Meeting: October 20-21, 2014)
107 participants (40% italian) + 7 students (per-diem GGI funding for young researchers)



Attività 2014/2015

Scuole di Dottorato al GGI:

- **LACES 2014** (24 Nov -12 Dic 2014)
organizzatori: Carlo Angelantonj (Torino Univ. & INFN) Pietro Antonio Grassi (Univ. Piemonte Oriental
& INFN) Gianluca Grignani (Univ. Perugia & INFN) Luca Griguolo (Univ. Parma & INFN) Domenico Seminara (Univ. Firenze & INFN)

- **GGI Lectures on the Theory of Fundamental Interactions 2015** (12-29 Gennaio 2015)
organizzatori: Roberto Contino (CERN & EPFL) Stefania De Curtis (INFN, Firenze) Michele Redi (INFN, Firenze) Enrico Trincherini (SNS & INFN, Pisa) Andrea Wulzer (Padova U. & INFN, Padova)

- **SFT 2015 - Lectures on Statistical Field Theory** (2-13 Febbraio 2015)
organizzatori: Denis Bernard (ENS, Paris) Andrea Cappelli (INFN, Florence) Filippo Colomo (INFN, Florence) Gesualdo Delfino (SISSA, Trieste) Giuseppe Mussardo (SISSA, Trieste)

- **Frontiers in Nuclear and Hadronic Physics** (16-27 Feb, 2015)
organizzatori: Francesco Becattini (University of Firenze) Ignazio Bombaci (University of Pisa) Angela Bonaccorso (INFN - Pisa) - Maria Colonna (INFN - LNS) Gianni Salmè (INFN - Roma1) Elena Santopinto (INFN - Genova) Enrico Vigezzi (INFN - Milano)

THE COMMUNICATIONS OFFICE AT INFN

CRUCIALE
per noi


LA STAMPA.it SCIENZA

Archivio storico CERCA OPINIONI POLITICA ESTERI CRONACHE COSTUME ECONOMIA ARTE FOTOGRAFIA BENESSERE CUCINA MODA MOTORI

NEWS
3/3/2010 - IL SUCCESSO DEL TEST ITALIANO "BOREXINO"

La grande fornace al centro della Terra

stampa invia più letti

Osservati per la prima volta i flussi di geoneutrini

BARBARA GALLAVOTTI

La Terra ha un cuore caldo. Un calore che smuove i continenti, semina distruzione con i terremoti ed esplode nelle eruzioni vulcaniche, ma che può assumere la forma gentile del geotermico. Un calore misterioso, perché conosciamo meno le viscere del nostro pianeta di quelle di una stella.

Dalle profondità della Terra giungono in realtà messaggi rivelatori, ma la natura li ha scritti usando come lettere le più inafferrabili delle particelle: gli anti-neutrini, che come i neutrini hanno la proprietà di attraversare masse di roccia restando pressoché invisibili. A svelarli e leggerli per la prima volta è stato «Borexino», un esperimento allestito del Gran Sasso dell'Istituto Nazionale di Fisica Nucleare. Lo studio, appena reso noto, prome una nuova stagione nel viaggio alla scoperta del pianeta.


la Repubblica

Riuscito l'esperimento che fa scontrare
dopo molti tentativi falliti a un passo da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INFN Istituto Nazionale di Fisica Nucleare

Una comunità di ricercatori che vogliono scoprire i meccanismi dell'Universo, i perché del tutto. Inventano e sviluppano tecnologie innovative, realizzano misure tra le più precise che l'umanità possa fare.

EUROPA LEADER MONDIALE DELLE PARTICELLE

L'Europa si conferma all'avanguardia nel campo della fisica delle particelle in particolare grazie a un modello di ricerca in cui le università e le comunità scientifiche...

5 X mille
Guarda al tuo futuro! Investi nella ricerca scientifica INFN
C.F. 84001850589

LINEE DI RICERCA
1 fisica delle PARTICELLE
2 fisica delle ASTROPARTICELLE
3 fisica NUCLEARE
4 fisica TEORICA
5 ricerca TECNOLOGICA

::: L'INFN NEL MONDO ::: ::: OPPORTUNITA' DI LAVORO ::: ::: UFFICIO COMUNICAZIONE ::: ::: RASSEGNA STAMPA ::: ::: COMUNICATI ::: ::: NEWS :::

Conferenze
02-06-2013: CS - 1 rst European Advanced Accelerator Workshop
[Conferenze]
02-06-2013: FI - INPC2013 (International Nuclear Physics Conference)
[Conferenze]
05-06-2013: LNS - Modelli predittivi degli effetti

Seminari
06-06-2013: LNF - Le molecole chirali: un caso di rottura spontanea di simmetria ?
[Seminari] 24 aprile 2013 00:00:00 GMT+02:00
Speaker: Giovanni Jona-Lasinio (La Sapienza Univ.) Abstract: Hund osservo' nel 1927 che la meccanica quantistica proibisce ...
06-06-2013: LNF - Le molecole chirali: un caso

Eventi
10-10-2013: LNGS - Scienza e Metodo 2013 - Un confronto con scienziati e filosofi sui metodi della Scienza
[Eventi] 16 maggio 2013 00:00:00 GMT+02:00
Scienza e Metodo 2013 - Un confronto con scienziati e filosofi sui metodi della Scienza 10-11 ottobre 2013 Da qualche ...

asimmetrie.it
LHC Italia
ScienzaPerTutti
TRASPARENZA E MERITO

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Woods: "Il sesso può ...
tutti i blog dei giornalisti
LA STAMPA
Abbonamenti al giornale


INFN

NEWSLETTER 15
Italian National Institute for Nuclear Physics

SEPTEMBER 2015

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INFN - COMMUNICATIONS OFFICE

ews
invernale e riprenderà attorno alla fine di febb

much depends on the next 5 years …

- **LHC14** (high energy: ATLAS, CMS; flavor: LHCb; quark-hadron phase transition: ALICE)
- **Flavor**: NA62; upgraded MEG, Mu-e; BELLEII; EDMs; g-2
- **DM** 1-ton exps. → $10^{-10} – 10^{-11}$ pb
- **Neutrinoless double β** → ν mass degenerate region; enter IH region
- **SBN** → sterile ν ?
- **Gravitational waves** → discovery
- **DE**: BOSS →DESI; DES → LSST
- **CMB**: final PLANCK; B-modes of the polariz.+ black-body spectrum : EU exps. QUBIC, LSPE, QIJOTE + many others on ground and balloons in US, Japan

The importance of being SMALL

My recommendation: beware the temptation of going ONLY for LARGE enterprises

The protective shield of large, Big Science: too big to fail!

Richness of small, “unorthodox” projects based more on clever ideas than on muscular, managerial strength!

problemi di equilibrio (dinamico, non statico) …

- Grande attivita’. Problema: trovare un punto di equilibrio tra i) convergenza su obiettivi in cui l’ente abbia una “massa” critica che garantisca alto impatto e visibilita’ per l’INFN e ii) spazio a nuove idee, nuovi interessi, aperture interdisciplinari etc.
- Equilibrio tra fisica “balistica” e “non balistica”
- Equilibrio tra “grandi” e “piccoli” progetti

analogia tra fine XIX sec. e inizio XXI sec.

fine '800: fine della ricerca **fondamentale** in fisica (meccanica+termodinamica+ elettromagnetismo chiudono il cerchio)

→ applicazioni o approfondimenti di quanto si sa

dove sono I nostri "**indizi**" tipo effetto fotoelettrico o catastrofe UV della radiazione di corpo nero:

massa neutrini, DM, DE, asimmetria materia-antimateria, inflazione, g-2 muone, crisi dell'informazione nei buchi neri, .. → questi sono known **Un**known;

oppure saranno **Un**known **Un**known….

- E' un momento eccitante, largo ai giovani (o per lo meno alle giovani idee…)