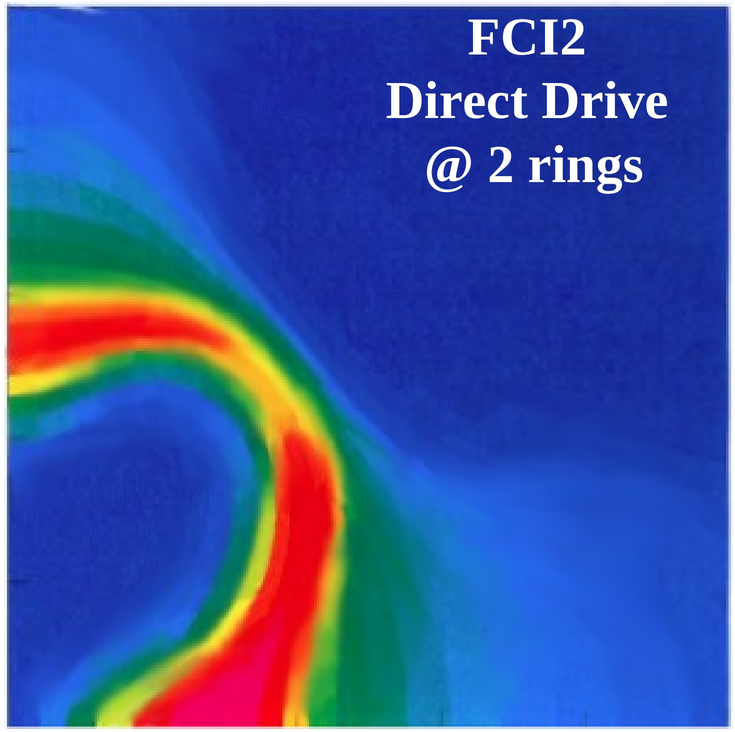
Towards Direct-Drive Shock-Ignition on the Laser Megajoule.

Density at stagnation



Radius (µm)

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France

10th DDFIW
May, 27th, 30th, 2012
Praha

Goals of Direct-Drive fusion program for LMJ.

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- Direct Drive fusion program for LMJ is developed to help / reinforce Indirect Drive Fusion program for the LMJ => studying basic fusion physics in a more simple scheme (without hohlraums).

- Direct-Drive fusion program for LMJ could interest international community for Inertial Fusion Energy (IFE) programs => HiPER project.

- Direct-Drive fusion on LMJ is one component of the Simulation Program.

Direct-Drive Shock-Ignition is the most hopeful concept for fusion on LMJ.

The full Laser MégaJoule is a hybrid Direct-Drive/Indirect-Drive facility.

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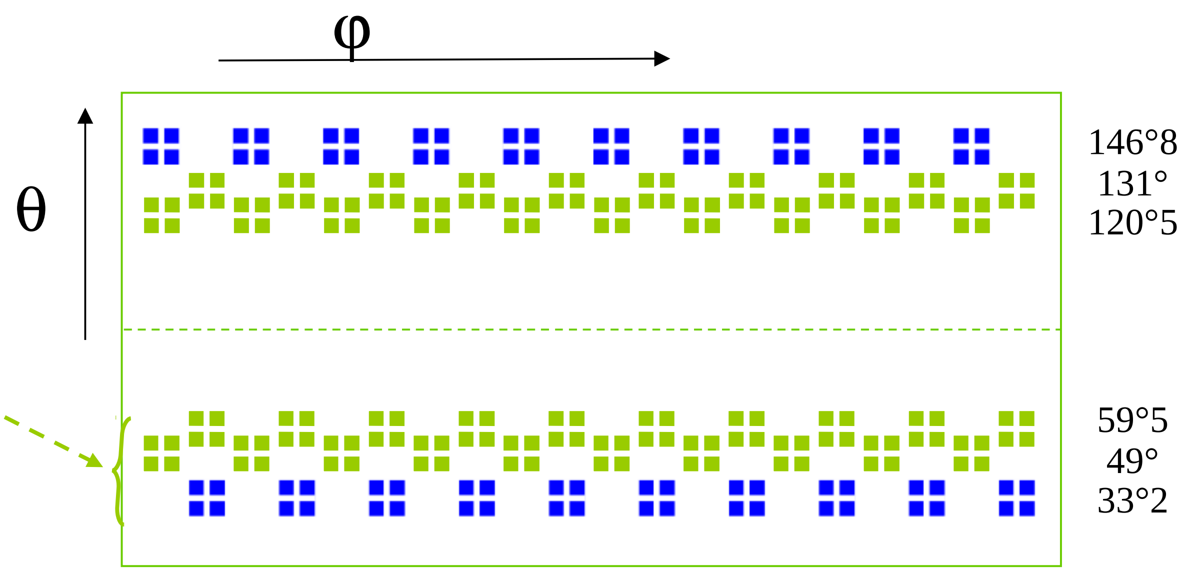
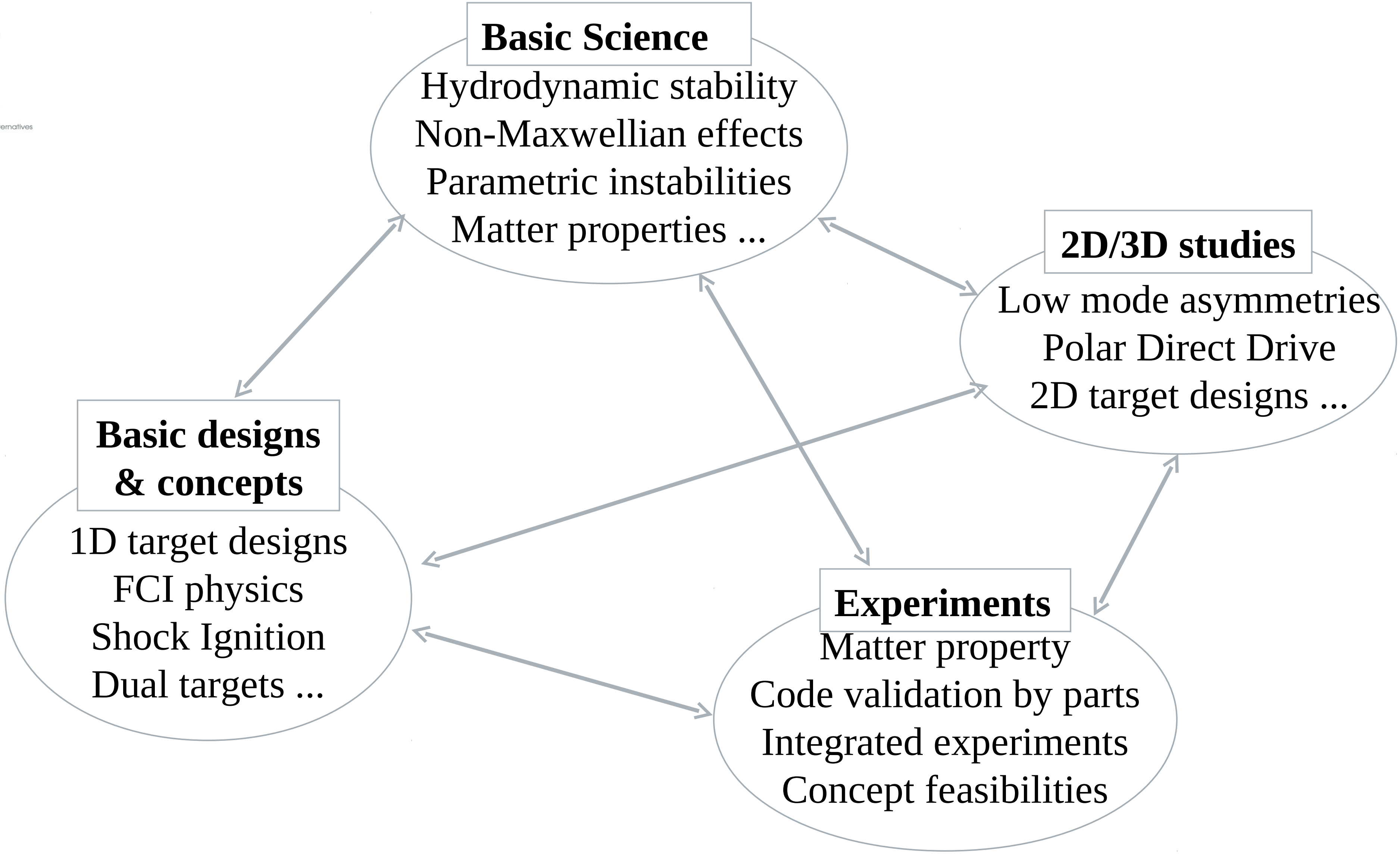
- **Fuel assembly should be done with cones at 49° & 59° (thanks to the 59°, above the Schmitt's angle).**
  - E_{max} ~1.2 MJ
  - P_{max} = 400 TW

- **Shock ignition should be done with the 33° cone.**
  - E_{max} = 0.6 MJ
  - P_{max} = 200 TW



LMJ appears to be a good candidate for Direct-Drive Shock Ignition.

Strategy for Direct-Drive on LMJ focuses on four main axis.

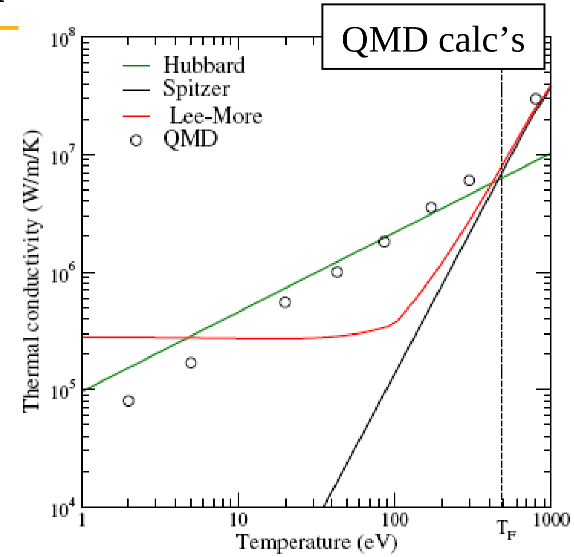


Basic science concerns a large variety of topics.

- Thermal conductivity in strongly coupled and degenerate regime is addressed.

=> **Hubbard-Spitzer model is the best suited for DT at stagnation.**

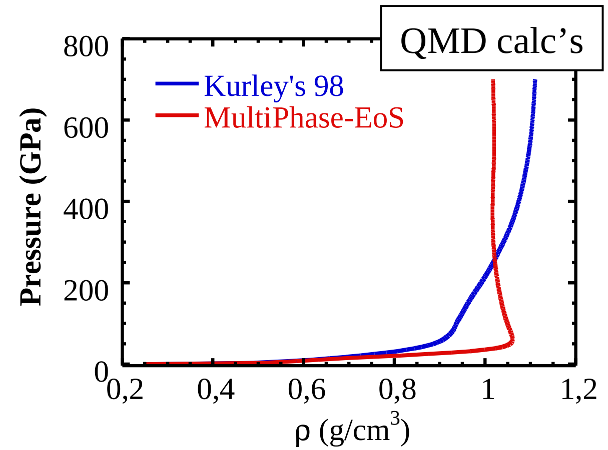
V. Recoules *et al*, Phys. Rev. Letter (2009).



- A new DT Multi-phase EoS is proposed in strongly coupled and degenerate regimes.

=> **Laser pulse has to be modified to compensate shock mistiming and entropy during implosion.**

L. Caillabet *et al*, Phys. Rev. Letter (2010).



- Magnetic RTI/RMI w/wo self-generated magnetic fields is addressed
=> **See the Levy's talk (PhD).**

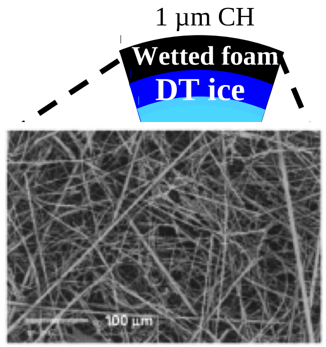
Basic science concerns a large variety of topics.

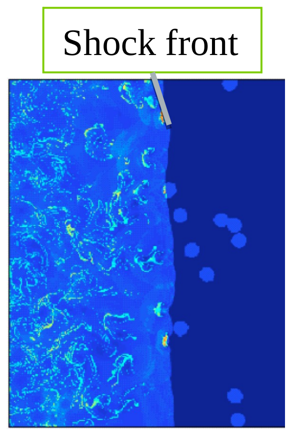
- Polarized DT fuel improves the fusion process. => **see the Temporal's talk**.

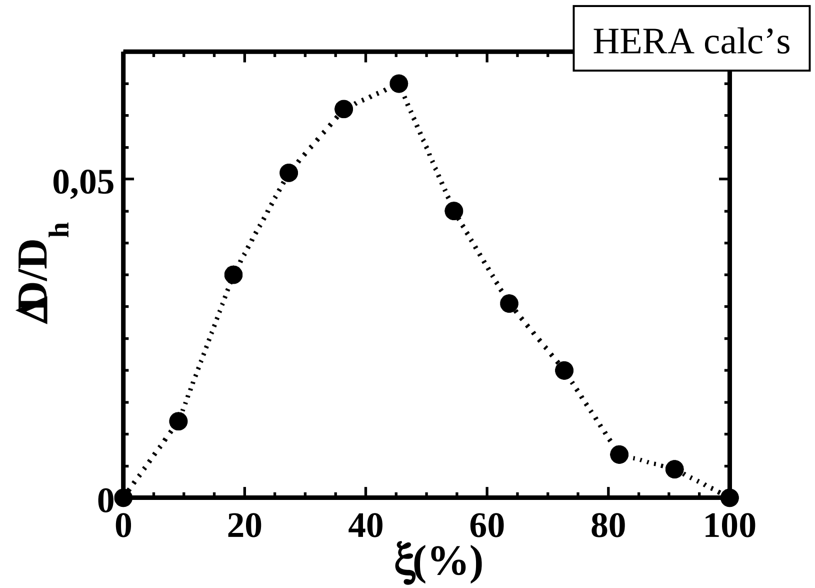
- Shock propagation in wetted foams is altered.

=> **The shock velocity is significantly increased with foam heterogeneities**.

Elbaz D. *et al*, Shock Waves, submitted (2012)
Elbaz D. *et al*, Phys.Plasmas, (2010)
Piron R. *et al*, Eur.J Mech. B Fluid, (2009)
Philippe F. *et al*, Laser&Part.Beams (2004)



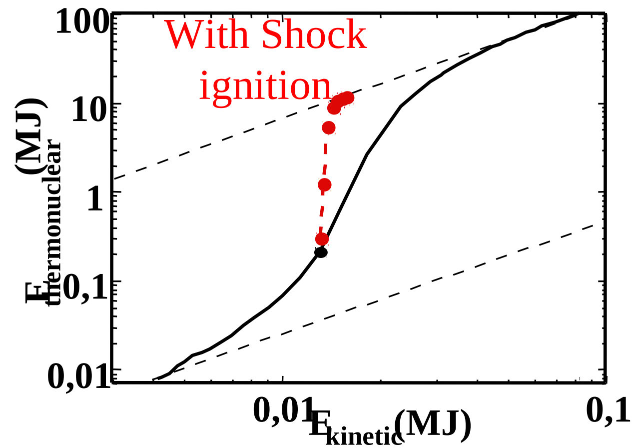




Basic designs and concepts focus on Shock Ignition.

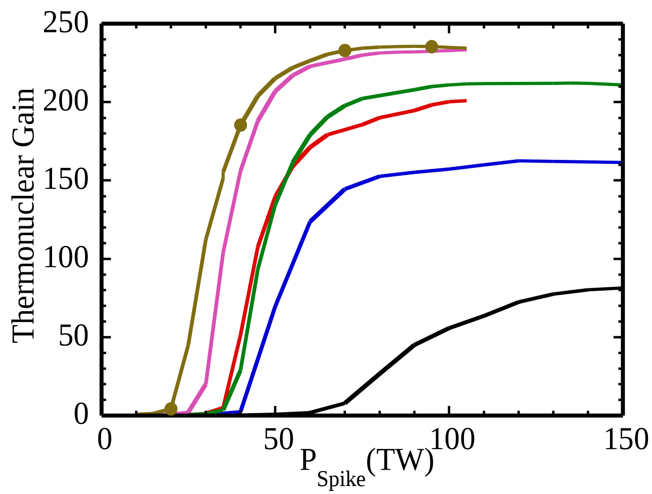
- DD marginally igniting target @ high implosion velocity can be shock ignited.

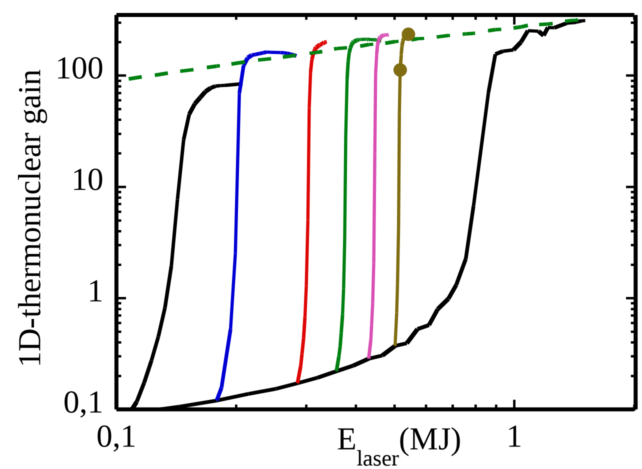
=> **Shock ignition allows to displace the self-ignition threshold towards lower kinetic energies.**



- HiPER-like design for Shock Ignition are studied.

=> **SI is easier close to the threshold.**

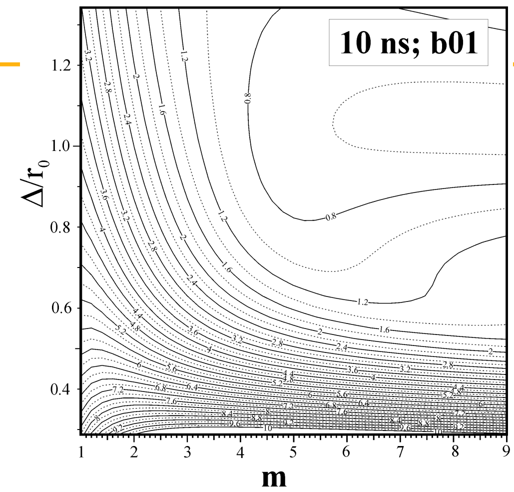




- New DD designs are being done. => **See the talk of V. Brandon (PostDoc).**

B. Canaud *et al*, New J. Phys. (2010).

2D/3D studies stay focus on LMJ geometry.



- Illumination and absorption uniformity is addressed for the LMJ.

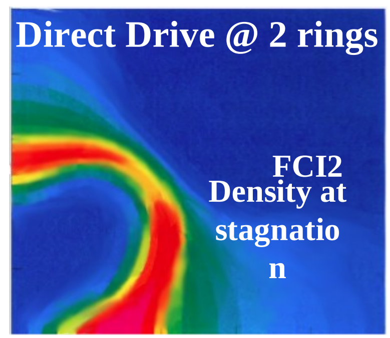
=> **Full LMJ is a hybrid Direct/Indirect Drive facility.**

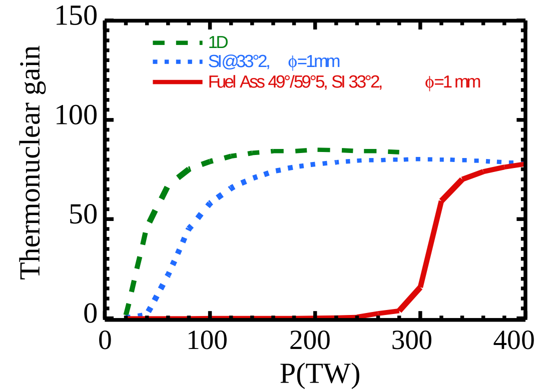
Canaud B *et al*, Nucl. Fusion, (2007)
Temporal M. *et al*, Eur. Phys. J. D (2009)
Temporal M. *et al*, Plasmas Phys. (2009)
Temporal M. *et al*, Plasmas Phys. (2010)

- Full 2D FCI2 calculations of DD-SI on LMJ are done for a HiPER like target.

⇒ **The key issue is the fuel assembly uniformity.**

Canaud B *et al*, Laser & Part. Beams (2012).



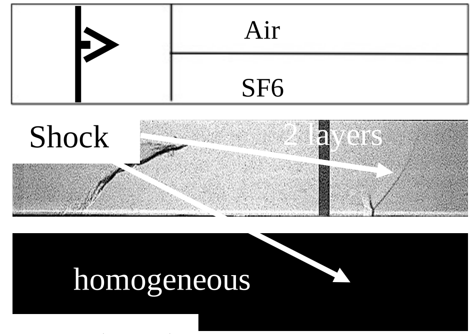


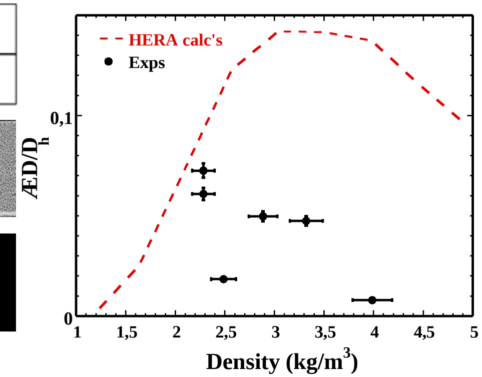
- Uniformity calculations are investigated by means of hydrodynamics calc's => **See the Laffite's talk**.

Experiments cover the whole previous axis.

- Shock velocity increase measurements in heterogeneous medium.

⇒ **First experimental evidence of shock velocity increase due to heterogeneities.**





Elbaz D. *et al*, Phys.Rev. E (2012)

- Fuel assembly integrated experiments.

⇒ **Integrated implosion exp's are used to validate our FCI2 code and LMJ predictions.** Canaud B. *et al*, PPCF (2007)

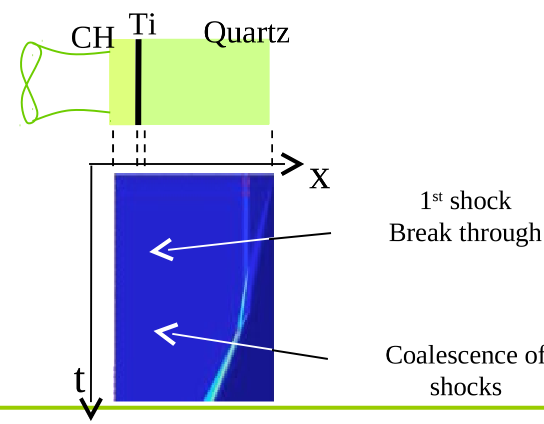
Low adiabat Omega implosion of cryo D_2 sphere

	Exp's	2D
E_{abs} (kJ)	13±2	14.2
Bang time (ns)	3,18±0.05	3,2
Burn time (ns)	0,34±0.02	0,18
Yn	6 10^9	1,25 10^{11}
ρr (kg/m²)	0,7 ± 0.2	0,8
Ti (keV)	2,5 ± 0.3	1,9

- Basic shock ignition experiments.

⇒ **The exp's have demonstrated the feasibility to launch a strong shock in preshocked plasma.**

	t (ns)	D_{shock}	t (ns)	D_{shock}
1st choc	2,05±0,05	25 km/s	2,05	25 km/s
Coalescence	2,8±0,1	30 km/s	2,6	32 km/s



Baton S. *et al*, Phys.Rev. Lett. (2012)

During the previous DDFIW, a schedule of key issues was proposed.

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Summary of the 9th DDFIW Direct-Drive Session (CEA-DIF)

	Planar exp's	Integrated exp's	Scaling laws:	PDD
LULI	SI @ 1ω		Pulse shaping @ 3ω Δ of contrast, delay, ...	
ORION			Preplasma: short pulse 2nd Shock: long @ 3ω	long pulse @ 3ω
OMEGA		2011, Cryo DT, RPP, FA+SI with 60 Beams. I_{spike}<10^{15} W/cm^2		

FA: Fuel Assembly
SI: Shock Ignition

Our job is to support the achievement of ICF on LMJ.

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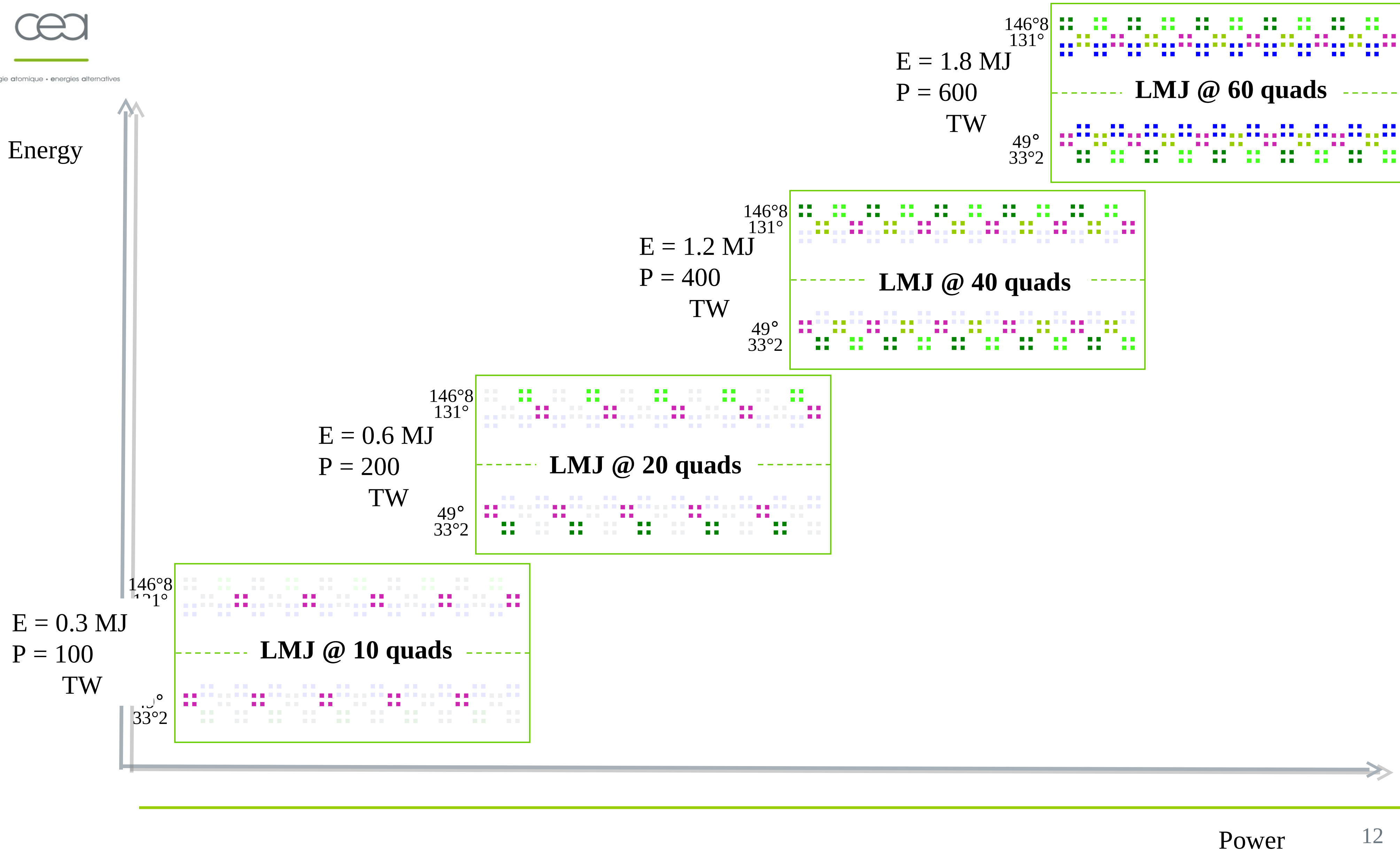
That means that we have to

- propose DD experiments at each step of LMJ completion,
- support neutron diagnostic developments,
- improve and validate our code and prediction capabilities.

⇒ This implies to carry on previous studies:
basic science, target designs and concepts, 2D/3D studies and experimental plan.

The LMJ could be used step by step.



Basic science has still large number of field to be investigated.

(B. Canaud, M. Temporal, S. Laffite, & R. Ramis)

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- The influence of thermal conductivity in strongly coupled and degenerate regime on ICF designs has to be addressed.

⇒ **This requires specific hydrodynamics calc's.**

- Kinetic effects in corona should have implications in laser-target coupling efficiency.

⇒ **This needs electronic VFP codes.**

- Kinetic effects in hot spot must be considered in the context of NIF implosions.

⇒ **This should be addressed with ionic VFP codes.**

- Fusion products characterization is necessary for target experimental chamber and diagnostic damages. Neutron and gamma spectra are done, not suprathermal particles.

⇒ **This should modify the target design.**

- LPI must be considered, especially two-plasmons decay.

⇒ **This should require non-paraxial codes.**

Basic design and concepts must be investigated to optimize the thermonuclear gain. (R. Ramis, B. Canaud, M. Temporal, & S. Laffite)

- 1D target designs have to be chosen on the "catalogue" done by Brandon.

⇒ **This requires a "figure of merit" or specific criteria: "one target for one effect".**

- Alternative designs should be studied.

⇒ **This needs a brainstorming on "design zoology" (dual target, greenhouse targets, cylindrical target, ...).**

- Magneto-ICF is an alternative for IFE.

⇒ **What can be envisaged on LMJ?**

- Other.

⇒ **What else?**

2D/3D studies are on going for the next years.

(M. Temporal, S. Laffite, R. Ramis & B. Canaud)

- Polar direct drive is considered in the first steps of LMJ completion.

⇒ **An optimized PDD will be determined for LMJ in a two steps approach.**

- A first PDD optimization is done for the foot a the laser pulse.

⇒ **The direct illumination is optimized.**

- The second PDD optimization concerns the drive.

⇒ **Absorption and 3D ray-tracing must be taken into account.**

- Dynamic PDD and zooming could be considered.

⇒ **This will assume a good flexibility of the LMJ.**

- 2D calc’s are used to validate the solution.

⇒ **This will be done with hydrodynamics codes.**

- A LMJ shot will be simulated in 3D geometry.

⇒ **This will be done with the 3D MULTI code.**

Experiments must be used to check/understand/validate each step of the Direct Drive program for LMJ. (S. Laffite, M. Temporal, R. Ramis & B. Canaud)

- Physical models have to be checked and improved by dedicated exp's

⇒ **Specific exp's will be defined (including the choice of the facility).**

- Target design should require specific issues (following NIF experimental plan).

⇒ **Shock timing, implosion velocity measur's, areal density, ionic temp, and isotropy of the implosion are the key parameters.**

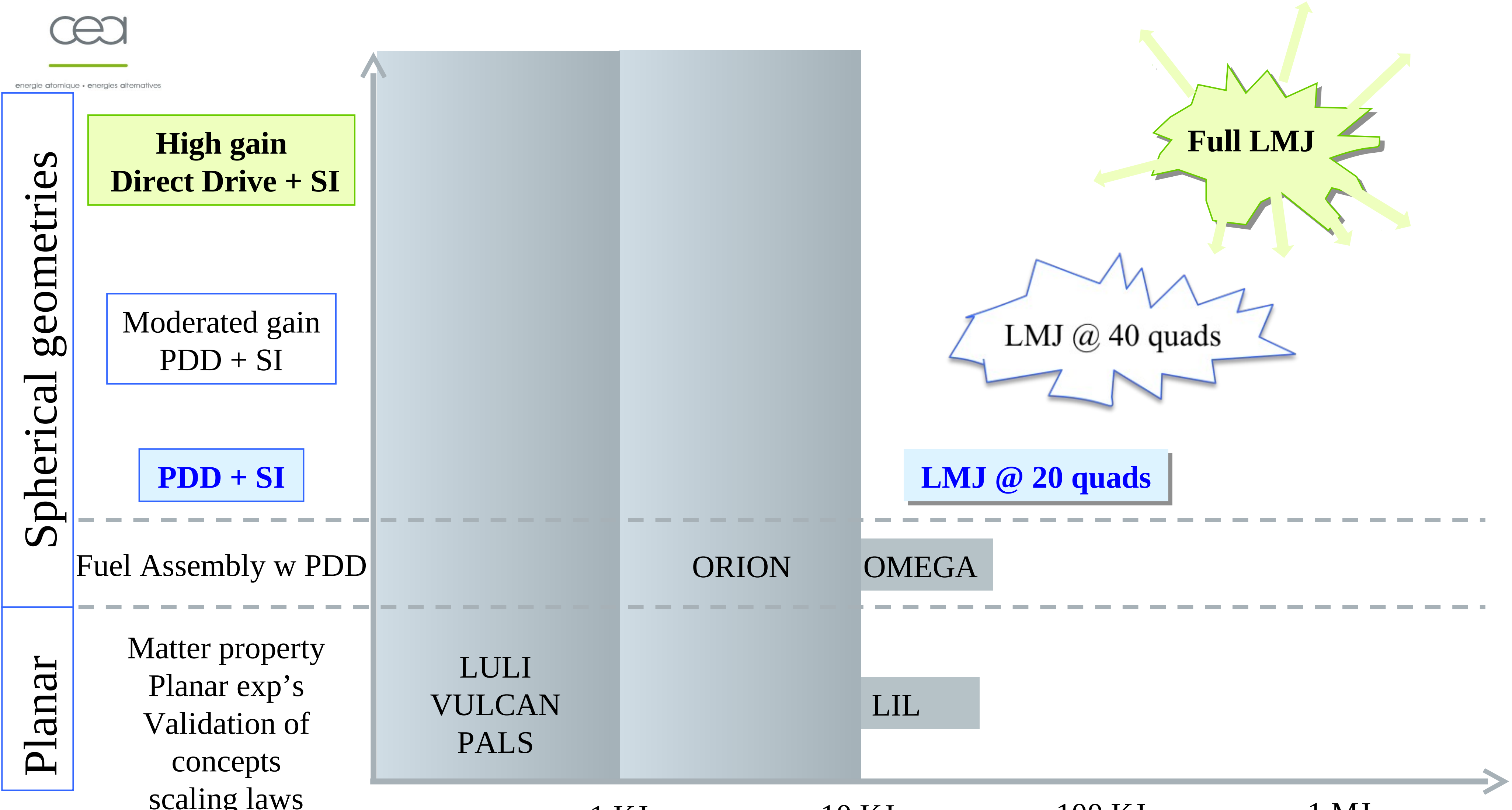
- The concept of PDD must be validated experimentally.

⇒ **The preparation of the LMJ's first steps should be done on ORION.**

- Dynamic PDD and zooming would be done at the late time.

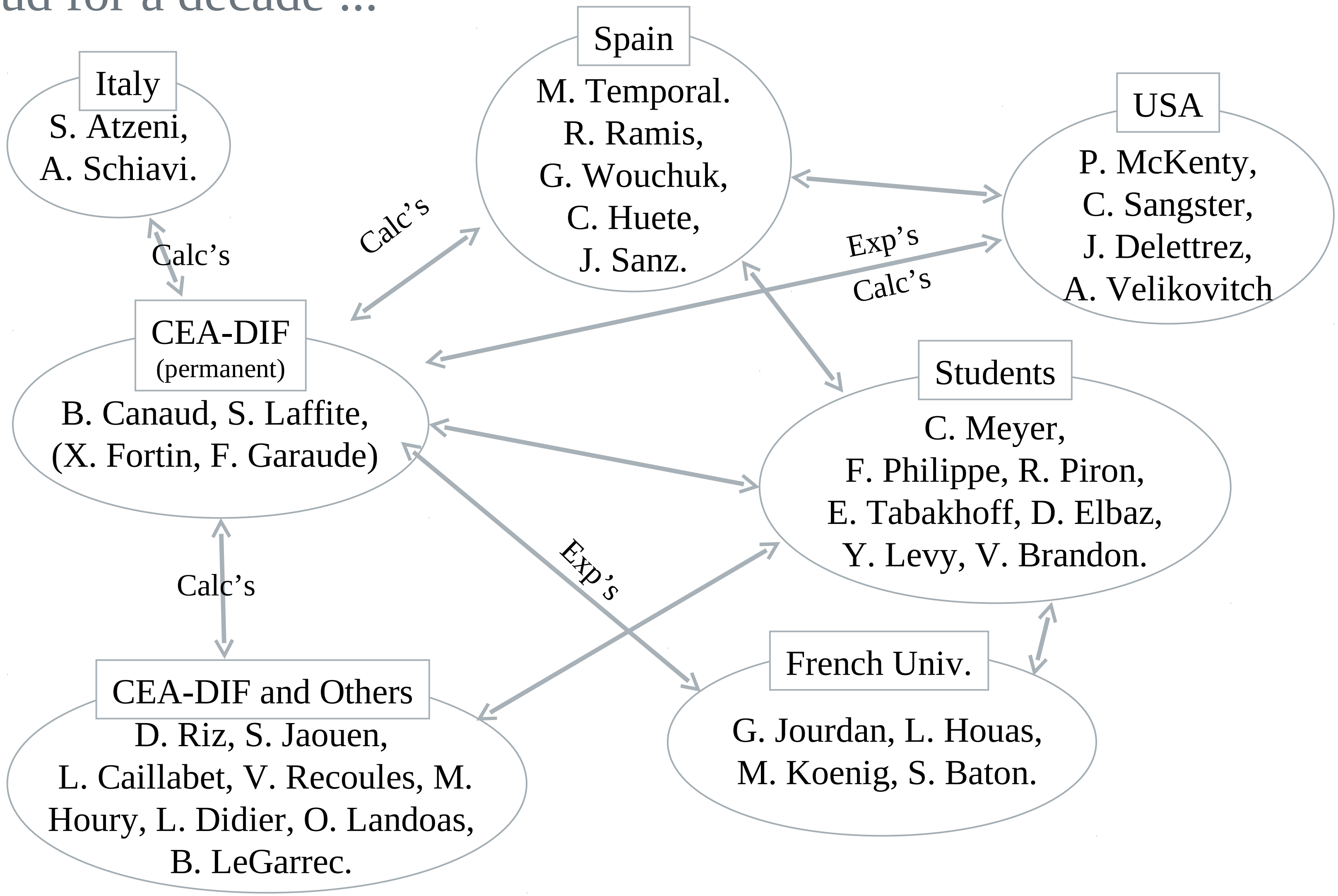
⇒ **This step requires at least the LMJ @ 40 quads.**

A multifacilities / multiapproaches is necessary to prepare DD-SI on LMJ.



The preparation of the LMJ's Direct Drive Shock Ignition experimental program requires the best of ourselves over the next decade to achieve thermonuclear fusion and high gain.

We have been collaborating with many people/Labs/Countries in a DD cloud for a decade ...



... and we are determined to open collaborations with new labs/people.