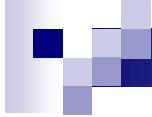


# XFEL - ILC ( $\sqrt{s}=250\text{-}500$ )

*Présenté par O. Napolý*

Réunion IN2P3/IRFU  
Orsay, 4 mai 2012



## Plan de l'exposé

- L'option Collisionneur Circulaire
- Paramètres ILC250 'Light Higgs Factory'
- Aspects Accélérateur Linéaire
  - Performance accélérateur
  - Coût
  - Calendrier de construction
  - Industrialisation
  - Gouvernance

$$\text{Luminosité : } 1 \text{ nb}^{-1}\text{s}^{-1} = 10^{33} \text{ cm}^{-2}\text{s}^{-1}$$

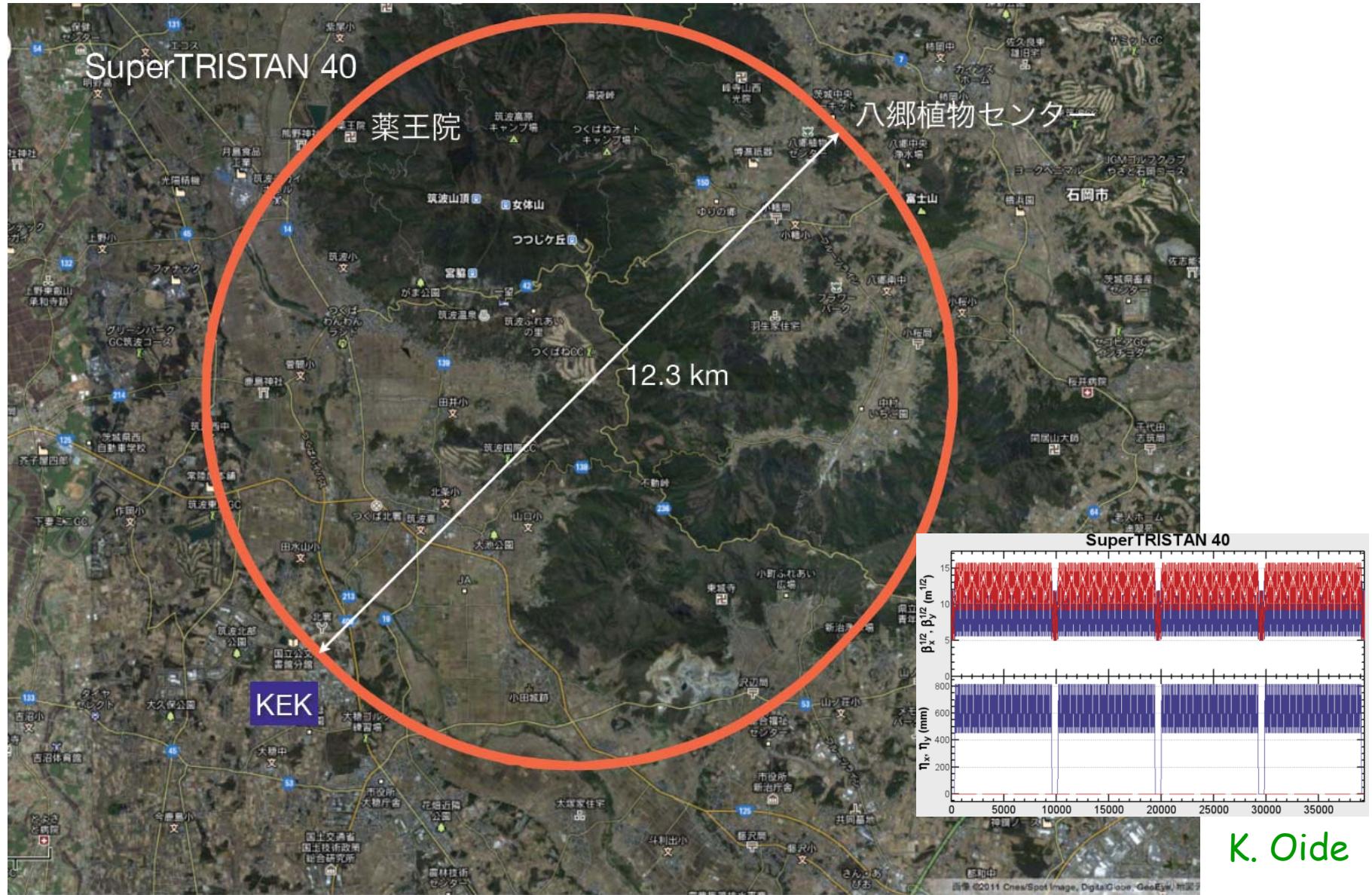
$$\text{Luminosité intégrée : } 1 \text{ an} \times 10^{34} \text{ cm}^{-2}\text{s}^{-1} = 100 \pi \text{ fb}^{-1}$$



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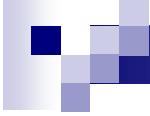
# Usine à Higgs: SuperTristan (e.g. 40 km)



# Usine à Higgs $\sqrt{s} = 240$ GeV: LEP3 vs. SuperTristan

	TRISTAN	KEKB	LEP2	LEP3	DLEP	SuperTRISTAN		
						40	60	
Beam Energy	32	8 / 3.5	105	120	120	120	120	GeV
Circumference	3	3	27	27	53	40	60	km
Beam Current / beam	7	1400 / 1700	4	7.2	14.4	8.6	8.6	mA
Bunches / beam	2	1600	4	3	60	12	18	
$\beta^* x / y$	2000 / 40	1200 / 6	1500 / 65	150 / 1.2	200 / 2	80 / 2.5	80 / 2.5	mm
Emittances x / y		18 / 0.1	48 / 0.25	20 / 0.15	5 / 0.05	23.3 / 0.09	24.6 / 0.09	nm
Bunch length	10	6	3	3	1.5	3	3	mm
Beam-beam parameters	0.02 0.025	0.05 0.09	0.025 0.065	0.126 0.13	0.1 0.1	0.05 0.156	0.045 0.155	
Radiation loss / turn	300	4 / 2	2750	6900	3470	3420	2150	MV
RF Voltage	400	10 / 5	3640	9000	4600	5000	3300	MV
RF frequency	508	509	352	1300	1300	1300	1300	MHz
Total SR Power	4.2	5.6 / 3.4	22	100	100	59	37	MW
Luminosity / IP	0.04	21	0.13	13	16	10	10	/nb/s

K. Oide



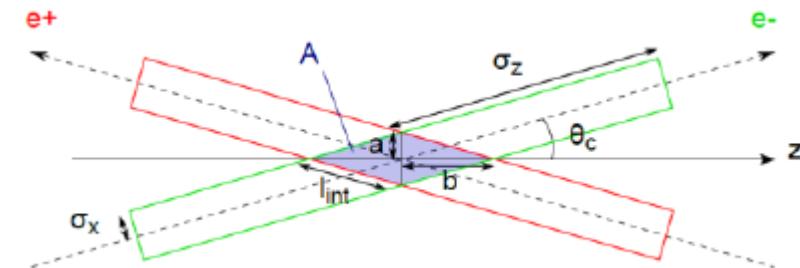
# Usine à Higgs: LEP3, SuperTristan

Principaux défis de R&D, dans le périmètre Irfu-IN2P3:

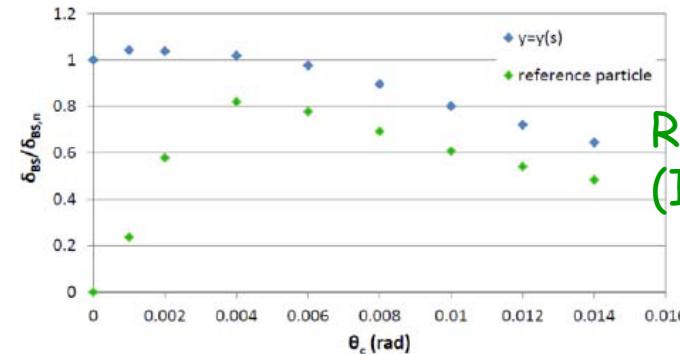
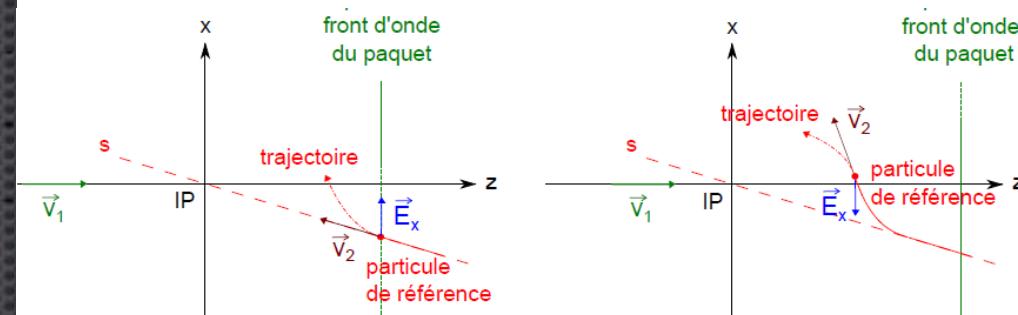
- Cryomodules 15-20 MV/m CW  
e.g.  $E_{acc}(LEP3) = 2,5 \times E_{acc}(LEP200) \sim 18 \text{ MV/m}$ ,  
 $P_{cryo}(LEP3) = 6 \times P_{cryo}(LEP200) \sim 30 \text{ MW}$
- Injecteurs 'LIL3'
- L'option Anneau de Stockage ne peut pas s'étendre à 500 GeV:  
« Thank you for the information.  
The beamstrahlung issue of the nano beam has been pointed out  
by Kaoru and Valery. It is indeed very severe for  $ECM > 240 \text{ GeV}$ ,  
enough to kill such a scheme for higher energies.  
Regards,  
Katsunobu »

# SuperTristan à 500 GeV

	SuperTRISTAN 80-Nano	
Beam Energy	250	GeV
Circumference	80	km
Beam Current / beam	1.4	mA
Bunches / beam	2	
$\beta^* x / y$	34 / 0.26	mm
Emittances x / y	3.4 / 0.013	nm
Bunch length	1.9	mm
Beam-beam parameters	0.018 0.140	
Radiation loss / turn	32450	MV
RF Voltage	34700	MV
RF frequency	1300	MHz
Total SR Power	90	MW
Luminosity / IP	20	/nb/s



Pour les hautes énergie de faisceaux, limitation due au 'Beamstrahlung' :  
**même la trajectoire centrale est déviée dans une collision à angle (nanobeam).**



R. Versteegen  
(IPAC 2011)

Figure 4: Beamstrahlung parameter as a function of  $\theta_c$  for ILC nominal beam parameters,  $\delta_{BS,n} = 2.1\%$ .

# SuperTristan à $\sqrt{s}=500$ GeV

## Common Features

- For reducing synchrotron radiation
  - Large circumference
  - small number of bunches compared with B Factories
- Bunch collision frequency ranges 5kHz to ~150kHz compared with 13kHz in ILC
- Luminosity similar to ILC
- → Luminosity by one bunch collision comparable to ILC
- → Beamstrahlung similar to ILC

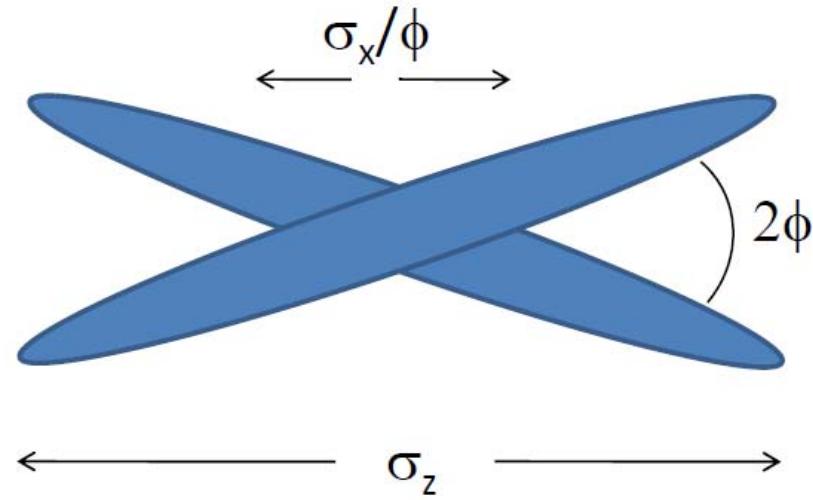
# SuperTristan à $\sqrt{s}=500$ GeV

## Interaction Length

- In the case of head-on collision, the orbit length in the on-coming beam is effectively  $\min(\sigma_z, \beta_y)$
- In the nanobeam scheme, choose  $\beta_y \ll \sigma_z$ . The interaction length is  $\sim \min(\beta_y, \sigma_x/\phi)$  ( $\phi = \text{half crossing angle}$ )
- Combining these, define

$$l_{eff} \equiv \min (\sigma_z, \sigma_x/\phi, \beta_y)$$

- As crude approximation,  $l_{eff}$  can be used instead of  $\sigma_z$  in the formulas of Luminosity, tune-shift, energy loss, number of photons.
- Note: better to eliminate  $\beta_y$  for beamstrahlung because the beamstrahlung is insensitive to the vertical beam size. But OK because we consider here only the case of  $\beta_y$  close to either one of others.



# SuperTristan à $\sqrt{s}=500$ GeV

## Conclusions

- The luminosity scaling of ring colliders at beamstahlung limit is established.
- The ring colliders (in particular for  $E_{cm}=400$  and 500GeV) are scientifically impossible because of the energy spread due to the beamstrahlung, under the constraints that the luminosity and power consumption are comparable to those of ILC.  
The only way to solve is
  - Huge ring
  - Extremely small vertical emittance
- The machine for  $E_{cm}=240$ GeV is at the border of feasibility. It is not a trivial machine. It requires serious studies of lattice design with very large momentum aperture or very small vertical emittance.

# SuperTristan à $\sqrt{s}=500$ GeV

Restriction on the energy and luminosity of  $e^+e^-$  storage rings due to beamstrahlung

V. I. Telnov<sup>1,\*</sup>

<sup>1</sup>Budker Institute of Nuclear Physics SB RAS, 630090, Novosibirsk, Russia

Novosibirsk State University, 630090, Novosibirsk, Russia

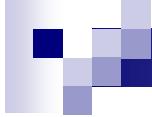
(Dated: 29 March 2012)

It was recently suggested that a  $120\times 120$  GeV  $e^+e^-$  storage ring for the study of a  $125\text{ GeV}/c^2$  Higgs boson could be built more simply and cheaply than a linear collider. It was also argued that the “crab waist” collision scheme would allow a storage ring to surpass a linear collider in luminosity up to  $2E_0 = 500$  GeV. We demonstrate that particle loss due to beamstrahlung (synchrotron radiation in beam collisions) reduces beam lifetime at the proposed storage rings to nearly zero. Reasonable beam lifetime can be achieved only at the price of a considerable reduction in luminosity. At  $2E_0 = 240$  GeV, the luminosity may still be sufficient; however, at  $2E_0 = 400\text{--}500$  GeV, the luminosity would be a factor 15–25 smaller than desired.

TABLE II. Realistically achievable luminosities and other beam parameters for the projects listed in Table I at synchrotron-radiation power  $P = 100$  MW. Only the parameters that differ from those in Table I are shown.

	LEP	LEP3	DLEP	STR1	STR2	STR3 cr-w	STR4 cr-w	STR5 cr-w	STR6 cr-w
$2E_0$ , GeV	209	240	240	240	240	240	400	400	500
Circumference, km	27	27	53	40	60	40	40	60	80
Bunches/beam	$\sim 2$	$\sim 7$	70	24	53	240	36	45	31
$N$ , $10^{11}$	33	5.9	2.35	3.9	4.	0.4	0.34	0.6	0.65
$\sigma_z$ , mm	8.1	8.1	5.7	6.9	6.9	3.4	6.7	7.8	9.6
$\sigma_y$ , $\mu\text{m}$	1.4	1.1	0.53	0.78	0.78	0.19	0.27	0.36	0.35
$\mathcal{L}$ , $10^{34}\text{ cm}^{-2}\text{s}^{-1}$	0.47	0.31	0.89	0.55	0.83	1.1	0.12	0.16	0.087

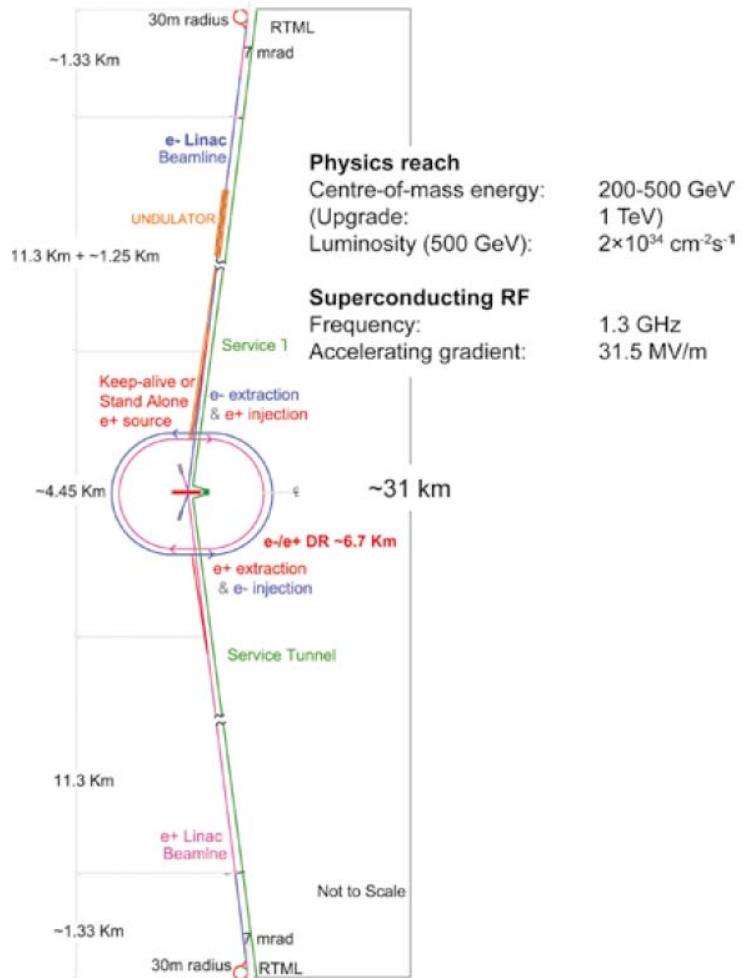
V. Telnov



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# Collisionneurs e+e- : ILC à $\sqrt{s}=250-1000$ GeV



Luminosité intégrée  
200 fb<sup>-1</sup>/an @ 250 GeV

IP and General Parameters		TF = Traveling Focus						<i>L Upgrade</i>		<i>E<sub>cm</sub> Upgrade</i>			
		<i>E<sub>cm</sub></i> GeV	200	230	250	350	500	500	1000	1000	<i>A<sub>1</sub></i>	<i>B<sub>1b</sub></i>	
Centre-of-mass energy	<i>E<sub>cm</sub></i> GeV												
Beam energy	<i>E<sub>beam</sub></i> GeV	100	115	125	175	250	500	500	500	500	500	500	
Lorentz factor	$\gamma$	####	####	####	####	####	####	####	####	9,78E+05	9,78E+05		
Collision rate	<i>f<sub>rep</sub></i> Hz		5	5	5	5	5	5	4	4	4	4	
Electron linac rate	<i>f<sub>linac</sub></i> Hz	10	10	10	5	5	5	5	4	4	4	4	
Number of bunches	<i>n<sub>b</sub></i>	1312	1312	1312	1312	1312	2625	2450	2450				
Electron bunch population	<i>N<sub>e</sub></i> $\times 10^{10}$	2,0	2,0	2,0	2,0	2,0	2,0	2,0	1,74	1,74			
Positron bunch population	<i>N<sub>p</sub></i> $\times 10^{10}$	2,0	2,0	2,0	2,0	2,0	2,0	2,0	1,74	1,74			
Bunch separation	$\Delta t_b$ ns	554	554	554	554	554	366	366	366				
Bunch separation $\times f_{RF}$	$\Delta t_b f_{RF}$	720	720	720	720	720	476	476	476				
Pulse current	<i>I<sub>beam</sub></i> mA	5,8	5,8	5,8	5,79	8,75	7,6	7,6	7,6				
RMS bunch length	$\sigma_z$ nm	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,250	0,225			
Electron RMS energy spread	$\Delta p/p$ %	0,206	0,194	0,190	0,158	0,124	0,124	0,124	0,083	0,085			
Positron RMS energy spread	$\Delta p/p$ %	0,190	0,165	0,152	0,100	0,070	0,070	0,070	0,043	0,047			
Electron polarisation	<i>P<sub>e</sub></i> %	80	80	80	80	80	80	80	80	80			
Positron polarisation	<i>P<sub>p</sub></i> %	31	31	30	30	30	30	30	20	20			
Horizontal emittance	$\gamma \sigma_x$ $\mu\text{m}$	10	10	10	10	10	10	10	10	10			
Vertical emittance	$\gamma \sigma_y$ nm	35	35	35	35	35	35	35	30	30			
IP horizontal beta function	$\beta_x$ * mm	16,0	14,0	13,0	16,0	11,0	11,0	11,0	22,6	11,0			
IP vertical beta function (no TF)	$\beta_y$ * mm	0,34	0,38	0,41	0,34	0,48	0,48	0,48	0,25	0,23			
IP RMS horizontal beam size	$\sigma_x$ * mm	904	789	729	684	474	474	474	481	335			
IP RMS vertical beam size (no TF)	$\sigma_y$ * mm	7,8	7,7	7,7	5,9	5,9	5,9	5,9	2,8	2,7			
analytical estimates		Horizontal disruption parameter	<i>D<sub>x</sub></i>	0,2	0,2	0,3	0,2	0,3	0,3	0,1	0,2		
		Vertical disruption parameter	<i>D<sub>y</sub></i>	24,3	24,5	24,5	24,3	24,6	24,6	18,7	25,1		
		Horizontal enhancement factor	<i>H<sub>Dx</sub></i>	1,0	1,1	1,1	1,0	1,1	1,1	1,0	1,0		
		Vertical enhancement factor	<i>H<sub>Dy</sub></i>	4,5	5,0	5,4	4,5	6,1	6,1	3,5	4,1		
		Total enhancement factor	<i>H<sub>D</sub></i>	1,7	1,8	1,8	1,7	2,0	2,0	1,5	1,6		
		Geometric luminosity	<i>L<sub>geom</sub></i> $\times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$	0,30	0,34	0,37	0,52	0,75	1,50	1,77	2,64		
		Luminosity	<i>L</i> $\times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$	0,50	0,61	0,68	0,88	1,47	2,94	2,71	4,32		
		Average beamstrahlung parameter	<i>Y<sub>av</sub></i>	0,013	0,017	0,020	0,030	0,062	0,062	0,127	0,203		
		Maximum beamstrahlung parameter	<i>Y<sub>max</sub></i>	0,031	0,041	0,048	0,072	0,146	0,146	0,305	0,483		
		Average number of photons / particle	<i>n<sub>y</sub></i>	0,95	1,08	1,16	1,23	1,72	1,72	1,43	1,97		
		Average energy loss	$\delta E_{BS}$ %	0,51	0,75	0,93	1,42	3,65	3,65	5,33	10,20		
		Luminosity	<i>L</i> $\times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$	0,498	0,607	0,681	0,878	1,50	3,00	3,23	4,31		
		Coherent waist shift	$\Delta W_y$ $\mu\text{m}$	250	250	250	250	250	250	190	190		
		Luminosity (inc. waist shift)	<i>L</i> $\times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$	0,56	0,67	0,75	1,0	1,8	3,6	3,6	4,9		
		Fraction of luminosity in top 1%	<i>L<sub>0,01</sub></i> / <i>L</i>	91,3%	88,6%	87,1%	77,4%	58,3%	58,3%	59,2%	44,5%		
		Average energy loss	$\delta E_{BS}$ %	0,65%	0,83%	0,97%	1,9%	4,5%	4,5%	5,6%	10,5%		
		Number of pairs per bunch crossing	<i>N<sub>pairs</sub></i> $\times 10^3$	44,7	55,6	62,4	93,6	139,0	139,0	200,5	382,6		

# Collisionneurs e+e- : ILC à $\sqrt{s}=500\text{-}1000$ GeV

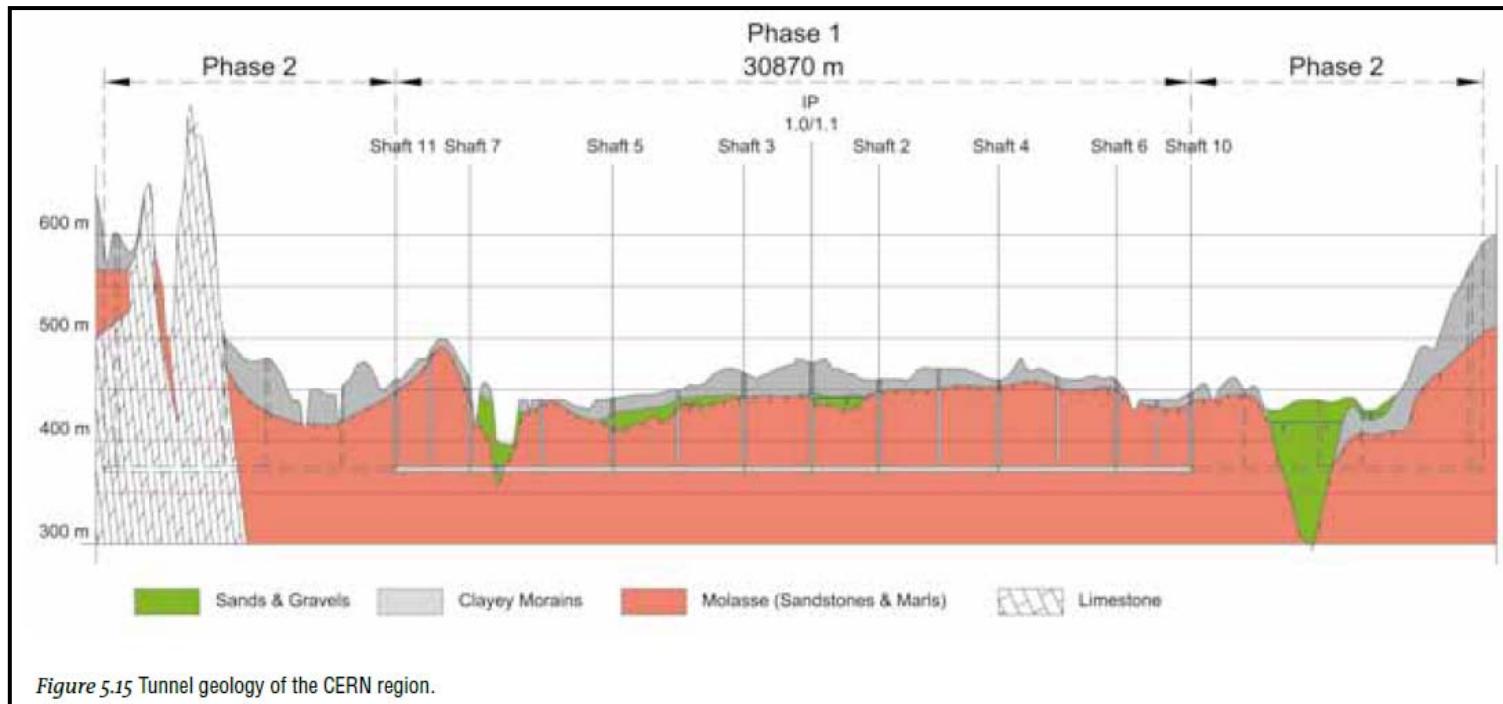
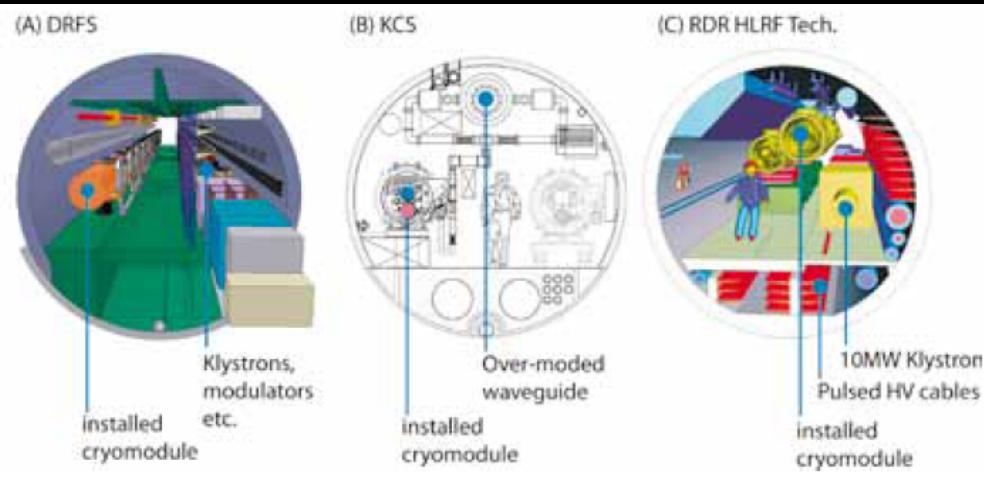


Figure 5.15 Tunnel geology of the CERN region.

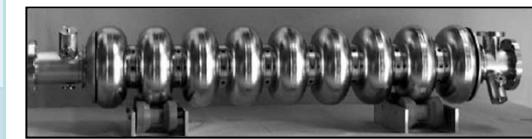
Figure 4.2 Single-tunnel solutions for the main linacs: (a) distributed radiofrequency sources, where many small modular 800-kilowatt klystrons, modulators and associated power supplies are all installed in the tunnel; (b) klystron cluster system, where no active RF is installed in the tunnel, and the RF power is brought to the accelerator via long high-power over-moded waveguide system; and (c) the solution adopted for the European X-ray Free Electron Laser (ILC backup solution), where the 10-MW klystrons are installed in the tunnel, but driven by surface-located modulators connected via many high-voltage pulsed cables.





# SCRF-ML Technology Required

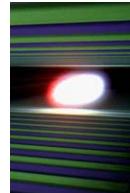
	ILC 500	XFEL
RDR Parameters	Value	
C.M. Energy	500 GeV	17.5 GeV
Peak luminosity	$2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$	-
Beam Rep. rate	5 Hz	10 Hz
Pulse time duration	1 ms	1 ms
Beam current	9 mA (in pulse)	1 mA
Av. field gradient	<b>31.5 MV/m</b>	<b>23.6 MV/m</b>
# 9-cell cavity	<b>15,873</b>	<b>808</b>
# cryomodule	<b>1,832</b>	<b>101</b>
# RF units	<b>560</b>	<b>25</b>



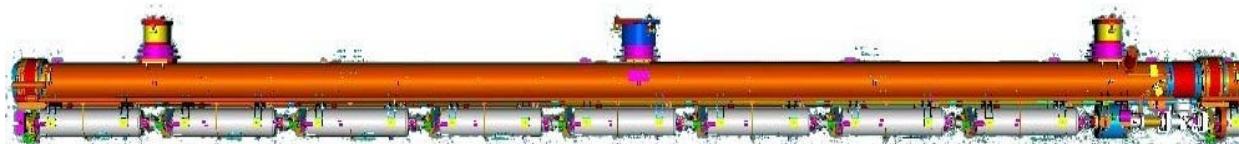
~20 × XFEL

~18 × XFEL

# Accelerator Complex: Back to the 17.5 GeV Start -up Version



**100 accelerator  
modules**

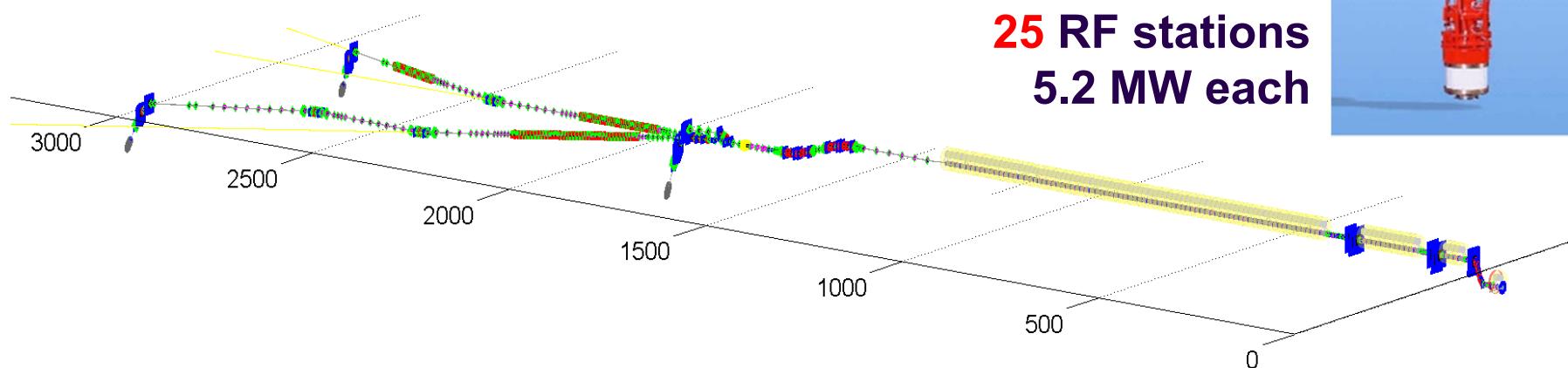


**800 accelerating cavities**



**1.3 GHz / 23.6 MV/m**

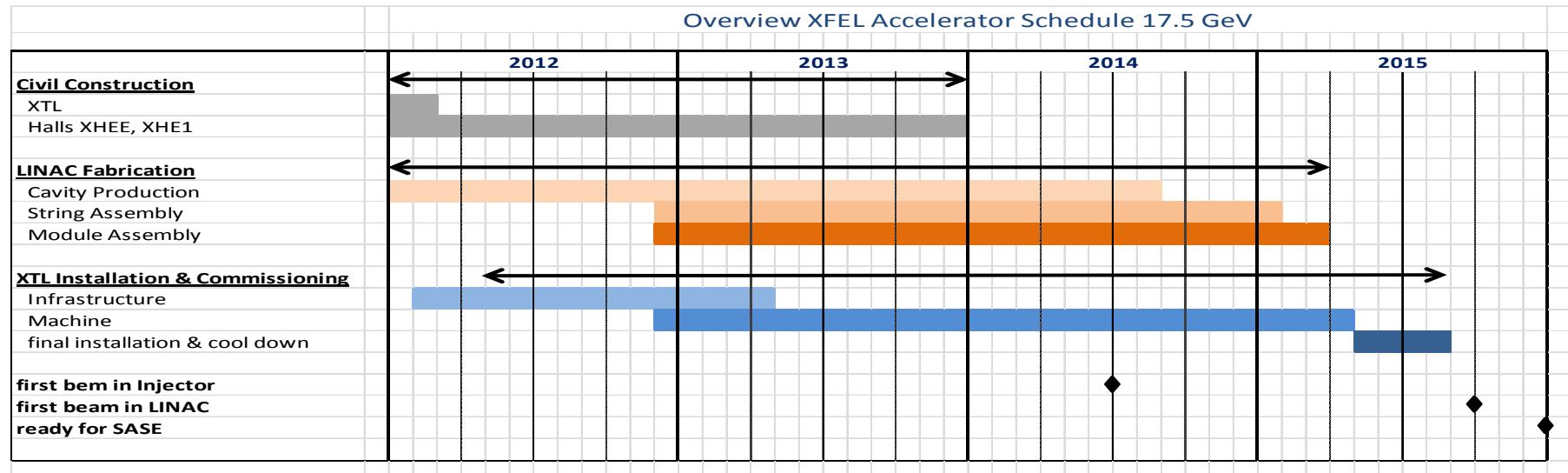
**25 RF stations  
5.2 MW each**

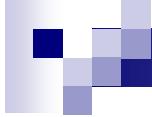




## Scheduling

- Tremendous progress of construction, infrastructure planning and ramp up of accelerator component fabrication
- Working hard to finish installation in time for
  - start of injector commissioning mid 2014
  - start of linac commissioning mid 2015
  - observe first SASE by end of 2015





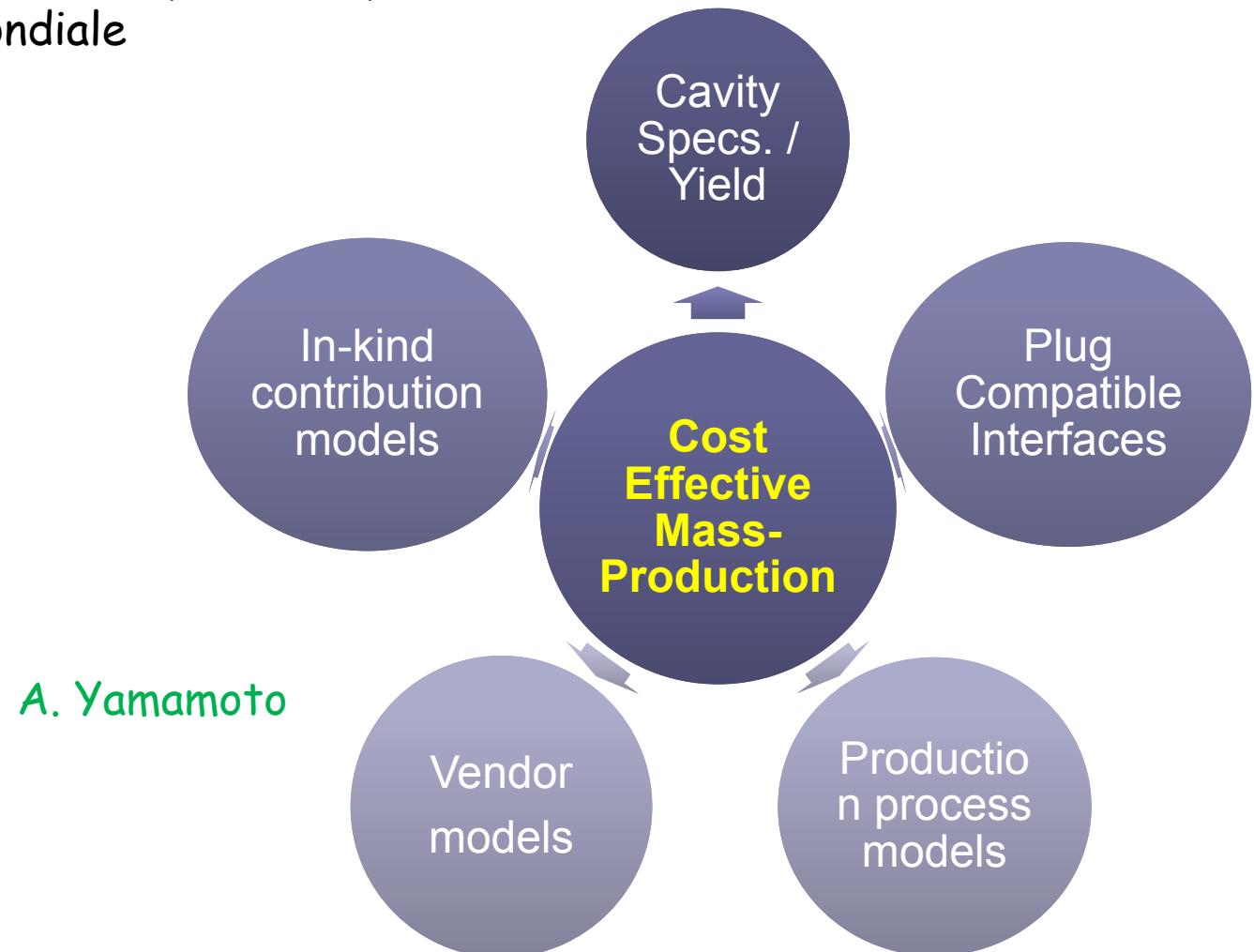
# Plan de l'exposé

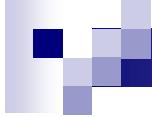
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# Collisionneurs e+e- : ILC

Principaux problèmes:

- Taux de réussite à l'acceptation des cavités 35 MV/m
- Organisation de la production à grande échelle sur 3 régions
- Coûts des cryomodules (~XFEL/2)
- Gouvernance mondiale





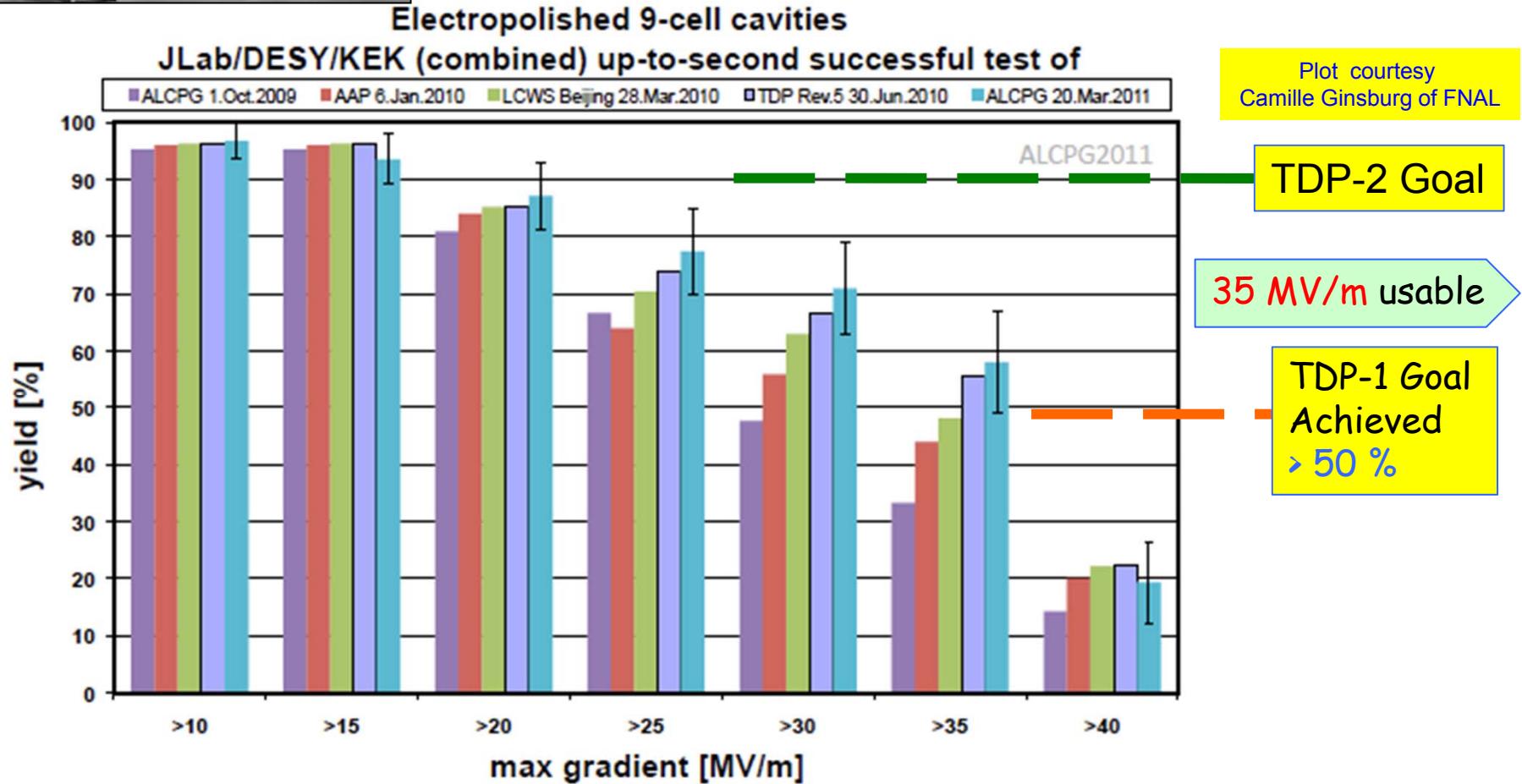
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# Collisionneurs e+e- : ILC



## Global ILC Cavity Gradient Yield



Principaux défis de R&D, dans le périmètre Irfu-IN2P3:

- Electropolissage vertical et tests RF
- Cavités hauts gradients: développements multicouches, inspection optique

# Collisionneurs e+e- : ILC



81 % Yield at 35 MV/m achieved at JLab

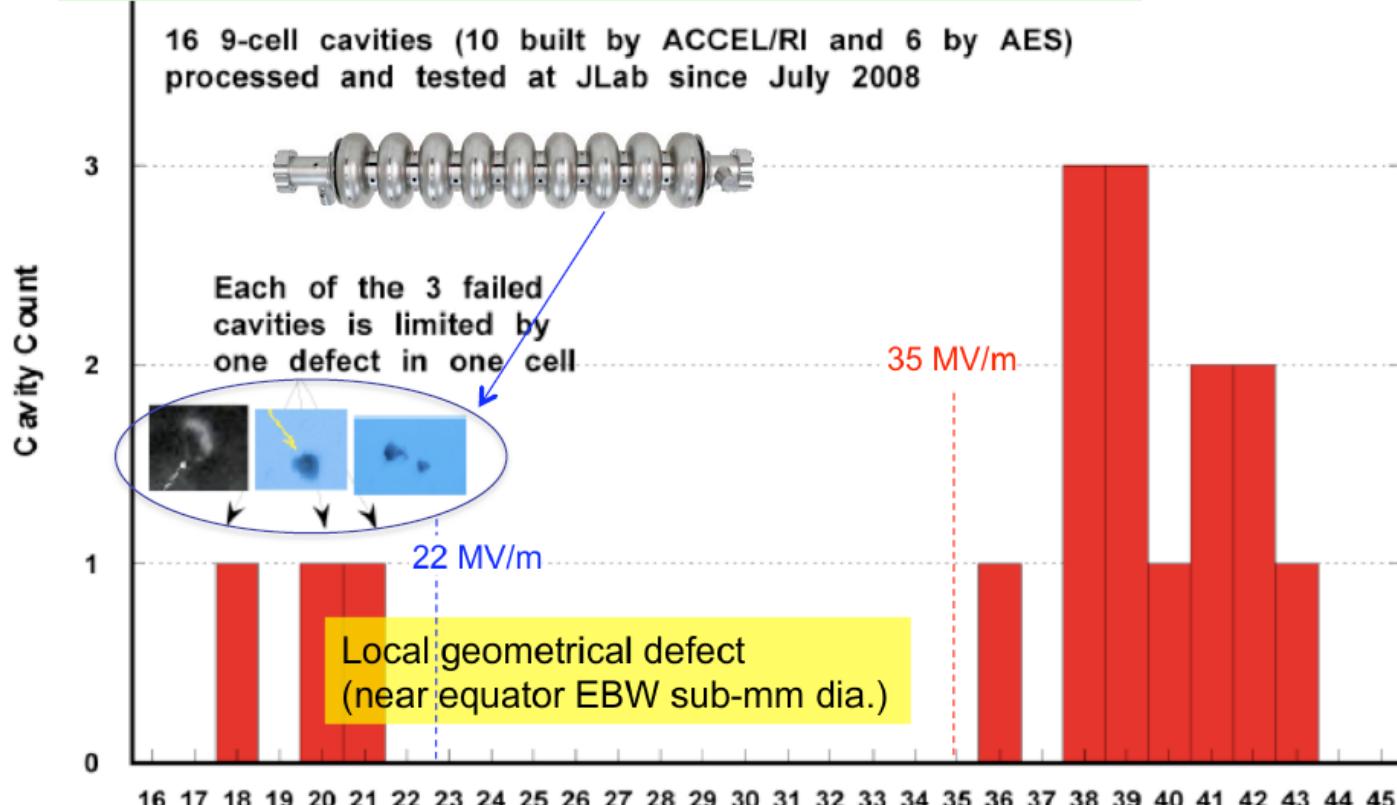
R. Geng

Main Issue, now: Quench Limit ~20 MV/m

Gradient Scatter (up to 2nd-pass proc.)

16 recent data from cavities built by ACCEL/RI and AES

RLGeng19oct10



# Collisionneurs e+e- : ILC



90 % Yield at 35 MV/m achieved with  
one vendor and JLab Process/Test

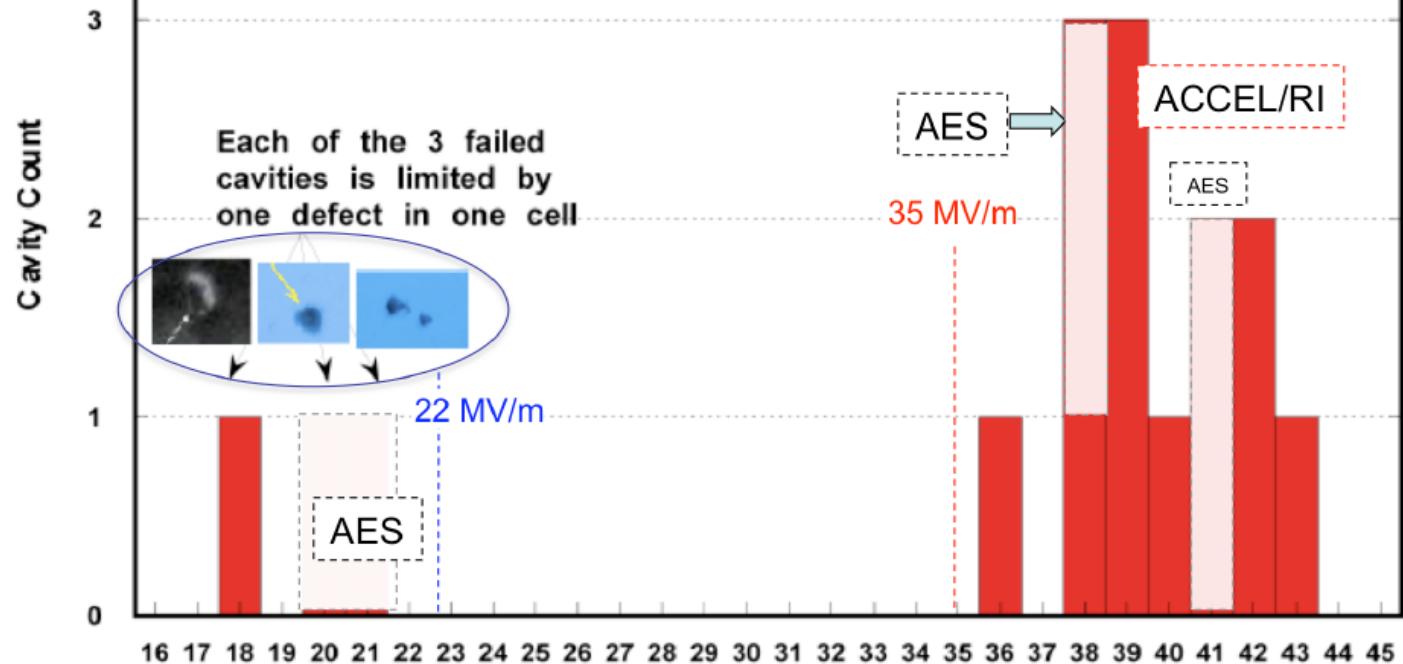
R. Geng

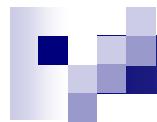
Gradient Scatter (up to 2nd-pass proc.)

RLGeng19oct10

9/10 A CCEL/RI cavity exceeded 35 MV/m

16 9-cell cavities (10 built by ACCEL/RI and 6 by AES)  
processed and tested at JLab since July 2008



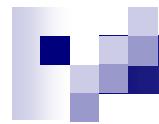


## Collisionneurs $e^+e^-$ : ILC



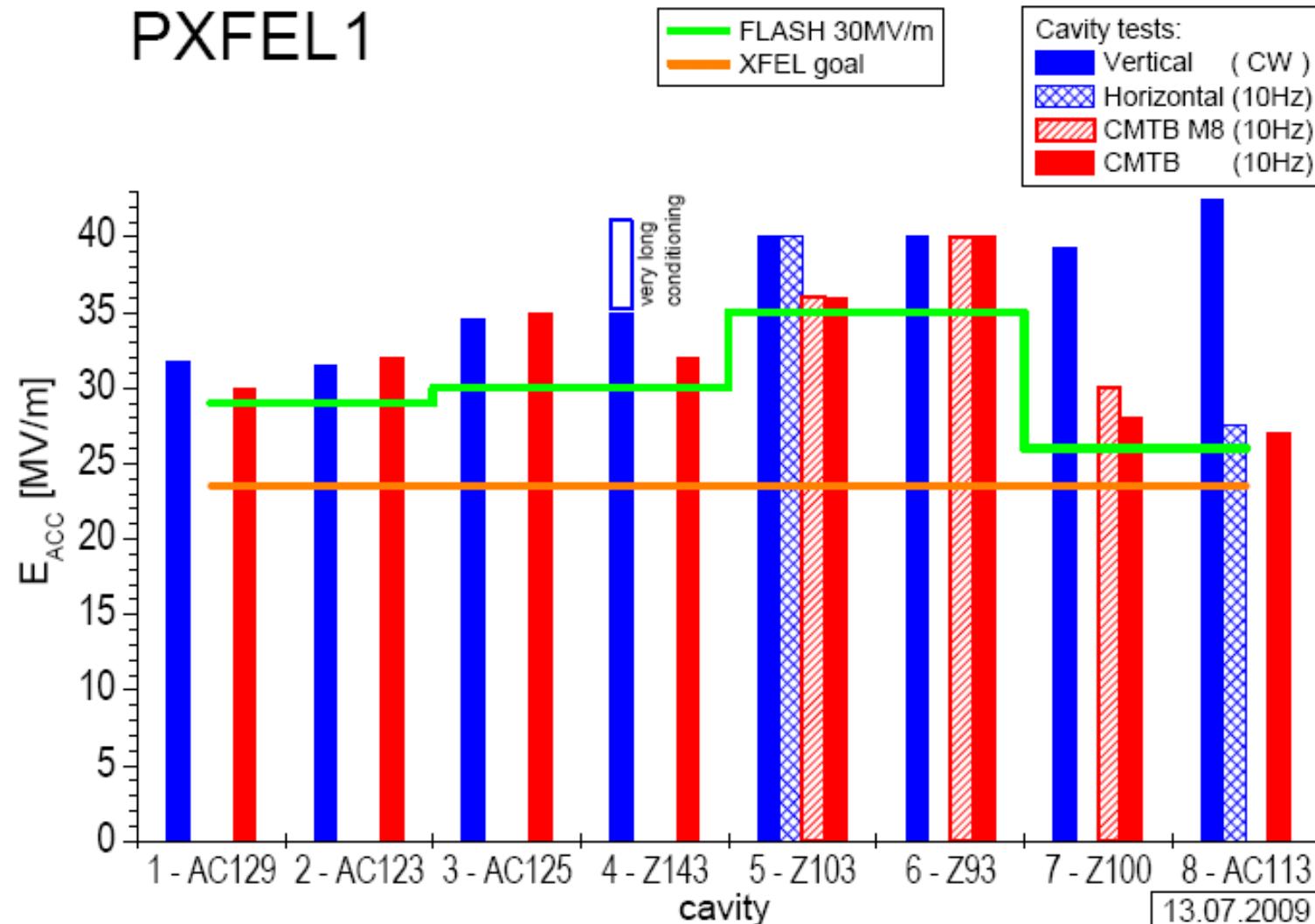
### Progress in the 3<sup>rd</sup> batch production at MHI (No. 12 ~ 22) processed at KEK

Test Date	Name of cavity	Process Cycle	E-max [MV/m]	Q0 at E-max	Q0 at 35 MV/m	Project
2010/11/11	MHI-12	1 <sup>st</sup>	37.5	5.4E9	7E9	Q. B. / Injector
2010/12/18		2 <sup>nd</sup>	40.7	6.18E9	1E10	
2010/11/25	MHI-13	1 <sup>st</sup>	36.2	7.5E9	9E9	Q. B. / Injector
2010/12/22		2 <sup>nd</sup>	32.2	8.75E9	---	
Plan in 2011	MHI-14	1 <sup>st</sup> , 2 <sup>nd</sup> , ...				STF2, CM1
	MHI-15	1 <sup>st</sup> , 2 <sup>nd</sup> , ...				STF2, CM1
		...	...			
	MHI-22	1 <sup>st</sup> , 2 <sup>nd</sup> , ...				STF2, CM1



# Module du Linac FLASH: $\langle E_{acc} \rangle = 30 \text{ MV/m}$

## PXFEL1

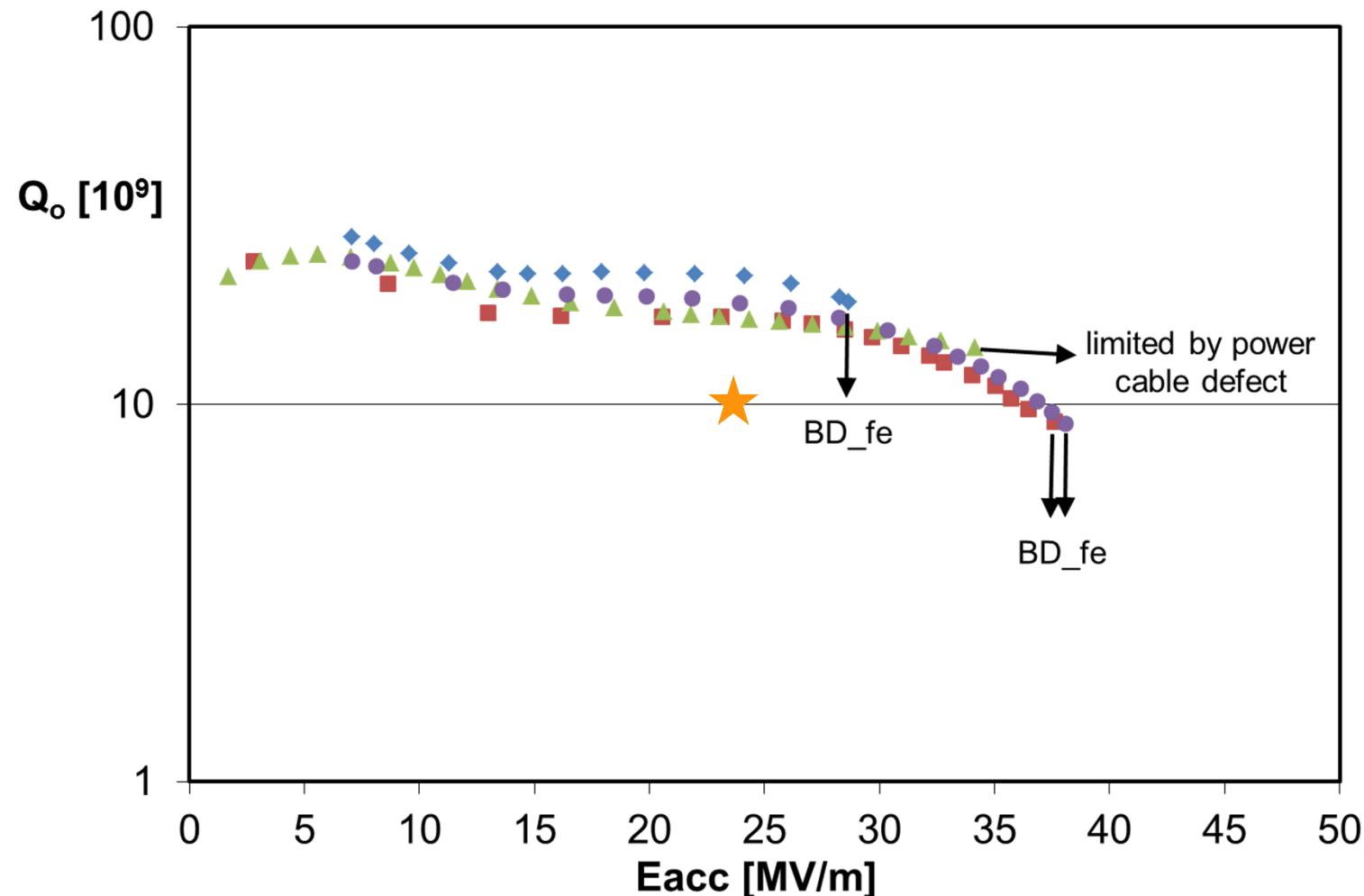


1. First XFEL prototype module (PXFEL1) = 10th Module from DESY
2. Based on a cryostat fabricated in China / IHEP Beijing
3. Seventh module installed in FLASH accelerator  $\Rightarrow$  1 GeV energy.

13.07.2009

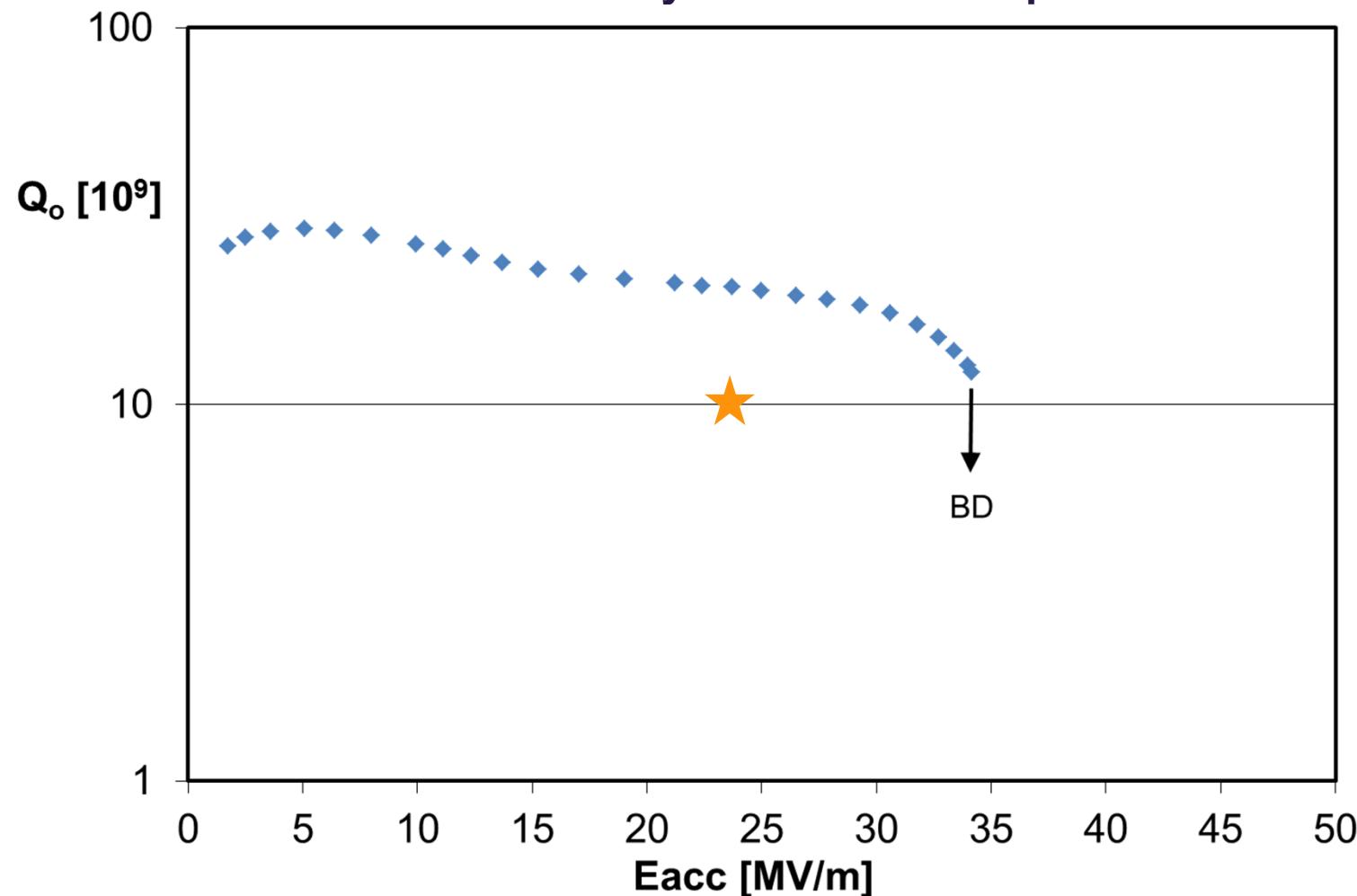
# Status of Reference Cavities: Research Instr.

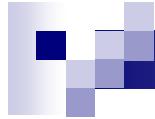
■ Acceptance test done with all four RI reference cavities  $E_{acc} > 28 \text{ MV/m}!$



## Status of Reference Cavities: EZ

- First cavity vertical acceptance test successful
- Three cavities ready for vertical acceptance test





## Mes Conclusions

- Aspects Accélérateurs Linéaires
  - Performance accélérateur

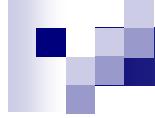
La production de cavités à 35 MV/m est (en passe d'être) maîtrisée au niveau européen (mondial).

Il est possible d'assurer le transfert de ces performances sur l'accélérateur, à condition de ne pas faire de compromis sur :

- ⇒ Qualité, propreté, méthodes :
- ⇒ Coupleurs de puissance !!
- ⇒ Intégration en salle blanche !! et hors salle blanche (chocs !)

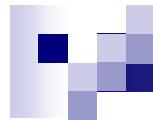
Deux leviers :

- 1) XFEL
- 2) R&D ciblée sur la contamination



## Plan de l'exposé

- L'option Collisionneur Circulaire
- Paramètres ILC250 'Light Higgs Factory'
- Aspects Accélérateurs Linéaires
  - Performance accélérateur
  - **Coût**
  - Calendrier de construction
  - Industrialisation
  - Gouvernance



# Industrialisation SCRF Linac

## Coût Matière du Niobium

Données CEA, DESY

Projet	Matière	Marque	Date	Quantité	Coût	Coût / kg	Commentaires
SPIRAL2	Nb	TOKYO DENKAI	2007	? kg	? €	273,4 €	Nb pour les 12 cavités SPIRAL2
IFMIF	Nb	TOKYO DENKAI	07/04/2009	220,3 kg	85 349,55 €	387,42 €	Nb pour les 2 protos IFMIF-EVEDA
IFMIF	Nb	Plansee	02/03/2009	267,304 kg	109 864,71 €	411,01 €	Nb pour les 2 protos IFMIF-EVEDA (devis non acheté)
IFMIF	Nb	TOKYO DENKAI	04/11/2009	6,3 kg	3 029,31 €	480,84 €	Nb supplémentaire pour les cavités
Spiral 2	Nb	TOKYO DENKAI	12/11/2009	9,3 kg	4 856,17 €	522,17 €	Nb supplémentaire pour Spiral2 (acheté en Yen)
XFEL	Nb	TOKYO DENKAI, ...	~2010	~24 000 kg	? €	475 €	Trois fournisseurs: Tokyo-Denkai, Plannsee and Ning-Xia pour 800 cavités
EuCARD	Nb	?	2011	125 kg	72 125,00 €	577,00 €	Cavité SPL beta=1, hors taxe d'import
IFMIF	Nb-Ti	BFI	17/03/2011	0,53 kg	901,50 €	1 700,94 €	Disque pour SAF IFMIF (devis non acheté)
IFMIF	Nb-Ti	BFI	23/03/2011	4,7 kg	3 719,00 €	791,28 €	Couronne pour SAF IFMIF
IFMIF	Nb-Ti	Marphil (Wah Shang)	05/04/2011	4,7 kg	5 170,00 €	1 100,00 €	Couronne pour SAF IFMIF (devis non acheté)

1 cavité XFEL :

18 tôles 265\*265\*2,8 mm,  
(800 € par tôle)

soit 30,33 kg matière brute  
soit ~24 kg sans les chutes

Données DESY

En ajoutant les extrémités en NbTi, le coût est de 22 k€ par cavité, pour environ 25 kg de matière.

Pas d'effet d'échelle !?



# Industrialisation SCRF Linac



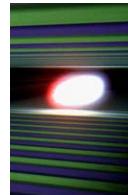
## XFEL cavities

XFEL (2013)	unit	yield	count	cost
Material	17.9	1	560	10,000
Cavity fabricatio				
Surface prep.	89.3	1	560	50,000
Tank+shield				
Total	107.1			60,000 kEUR

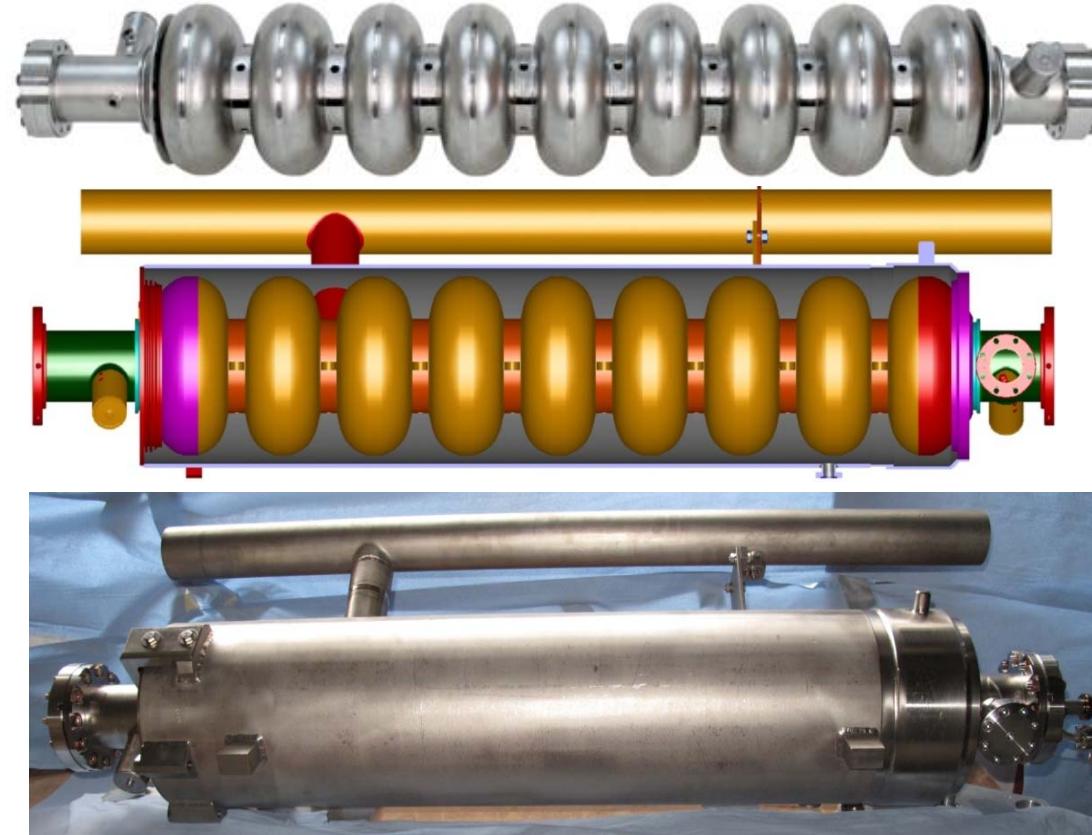
approximate best knowledge

- 2 vendors - 280 cavities each
- ILC number (scaled to 2013) ~42 k€ (factor 2.5)
- Production ratio =  $20,000 \div 280 \sim 70$

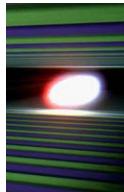
Nick Walker



## Cavities - Large Series Production



- Worldwide approx. 300 9-cell cavities were produced over the last 15 years.
- **The European XFEL requires 800 cavities at a production rate of up to 8 cavities per week and 1 module per week.**
- Acceptance testing is a challenge by itself and requires a large infrastructure.

**European  
XFEL**

# Niobium / Cavities



- Eddy current scanning of XFEL niobium sheets at DESY



- Equipment for tactile 3D dimension measurement



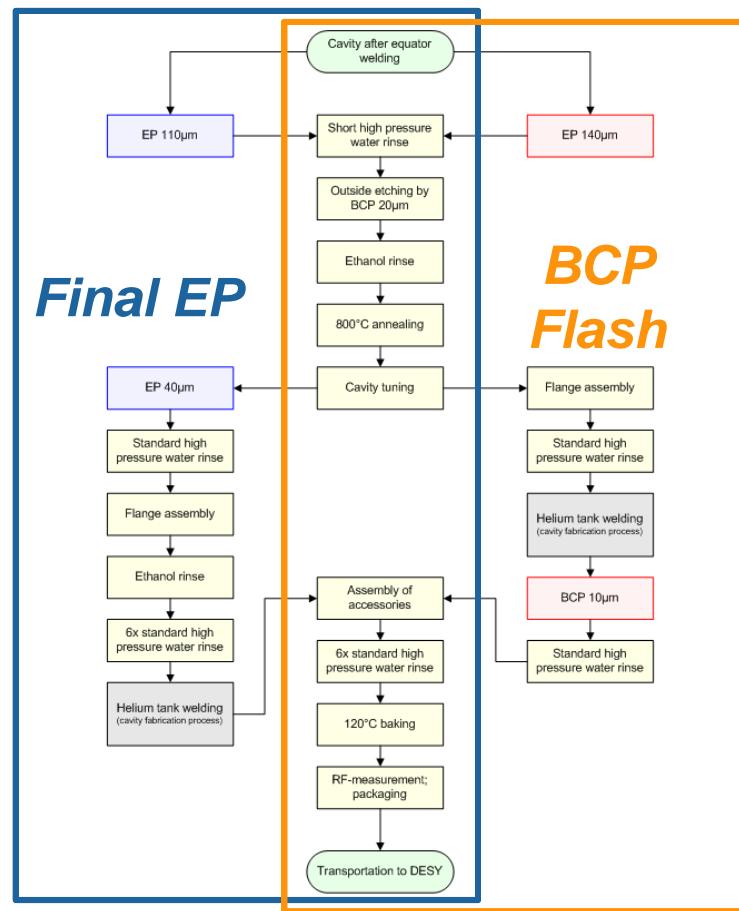
Equipment for sheets marking

- More than 6,000 niobium sheets arrived, the next 2,000 to come soon.
- In average 40% of all niobium incl. tubes etc. delivered to cavities vendors (status 3/2012).
- Material for remaining 160 cavities contracted.
- Reference cavities from both companies arrived and currently tested.
- Commissioning of infrastructure at cavity vendors is next.
- First cavities expected for summer 2012.

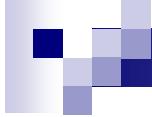


# Cavities – Preparation & Reference Cavities

- Two schemes for the final surface treatment:
  - Final EP at Research Instr.
  - BCP Flash at Zanon Inc.



- At each company
  - 4 dedicated Cav's for set-up of infrastructure
  - 4 dedicated Cav's for qualification of infrastructure
- Close supervision of
  - infrastructure set-up, processes, procedures and handling
  - by DESY + INFN Milano
- Specification w/o performance guarantee, thus:
  - the risk of unexpected low gradient or field emission is with DESY
  - responsibility for re-treatment at DESY



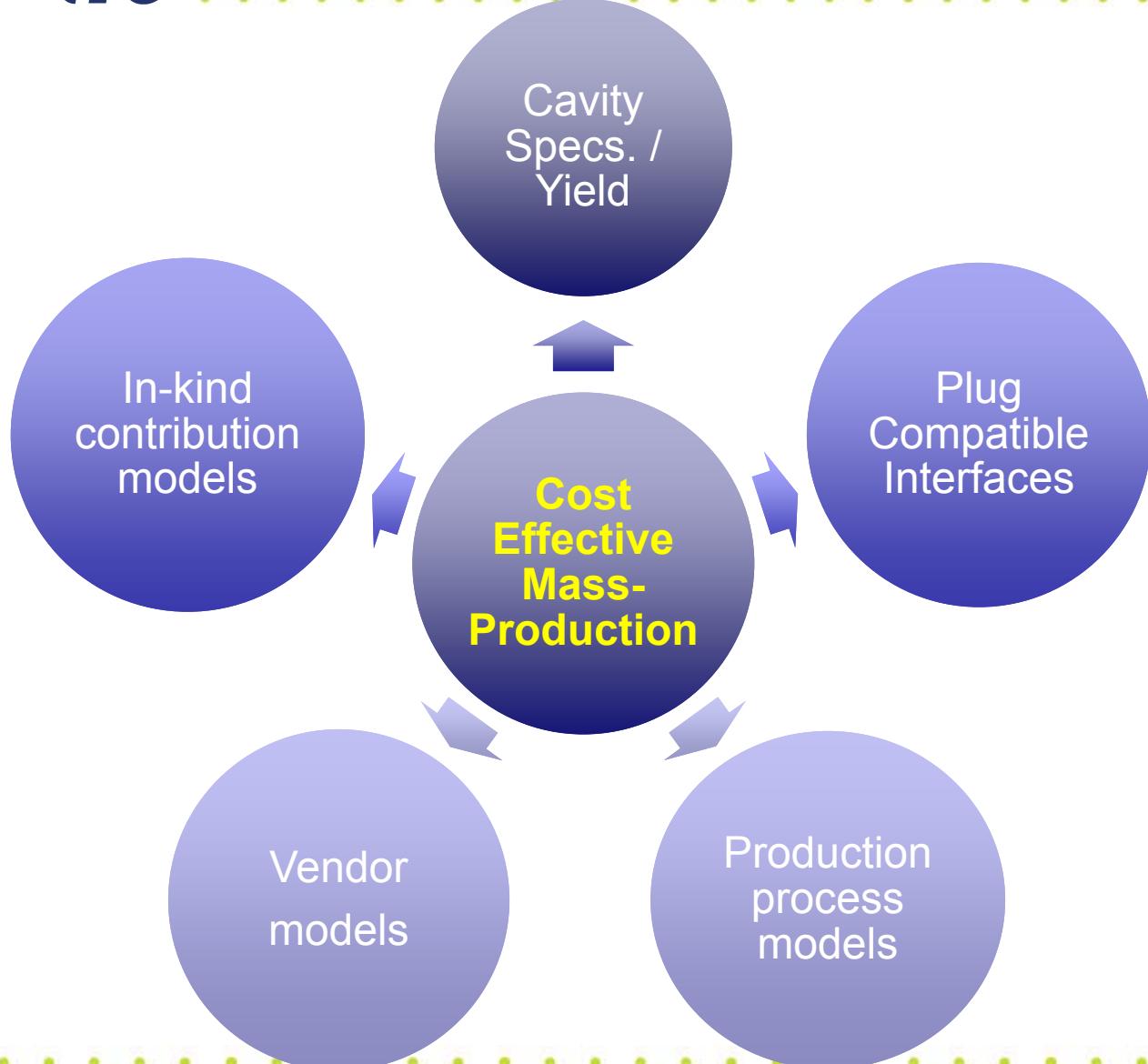
# Industrialisation SCRF Linac

Cavités XFEL : marché 2010 captif !

1. DESY ne connaît que 2 fournisseurs qualifiés : RI et EZ
2. DESY annonce vouloir 2 chaînes de production (moins de risque)
  - 2 tranches fermes de 280
  - 1 tranche optionnelle de 80 cavités pour un total de 640 cavités (80 cryomodules)
3. Les cavités sont des contributions en nature de l'Allemagne (50%) et de l'Italie (50%).

On doit pouvoir faire mieux pour organiser un marché compétitif.

# SCRF Cost Effective Production



Emphasize global approach  
(Multiple region mass-production)

- Critically important TDP2 activity
- Learn from XFEL experience
  - 5% ILC
- Develop realistic models on which to base cost estimate
  - With industry

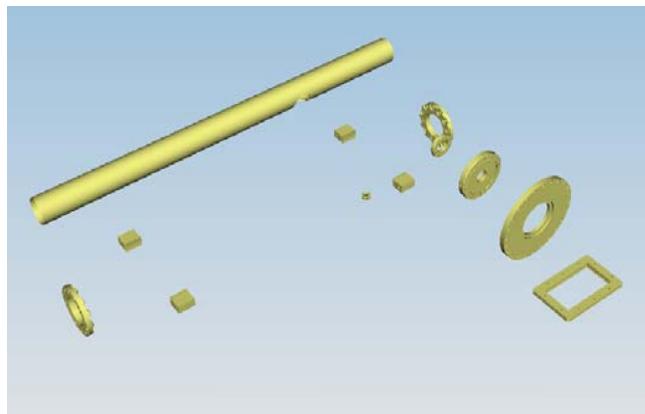
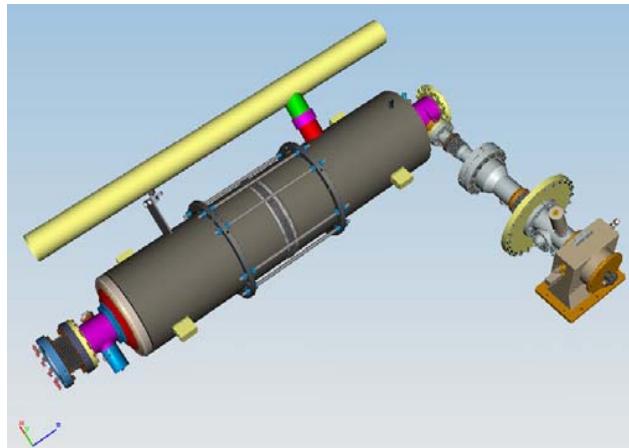


# Plug-compatibility

## under Construction Phases

- R&D Phase
  - Creative work for further improvement with keeping replaceable condition,
  - Global cooperation and share for advanced technology
- More generally, under Construction Phase
  - Best effort to define universal envelope / interfaces with plug compatibility,
  - Keep adequate competition with multiple-suppliers, to aid in cost reduction, while allowing variants within a common envelope,
  - Prepare for multiple organizations, with differing constraints, to be able to contribute to the ILC collaboration, and
  - Maintain intellectual interest from each contributor,
    - Encourage regional / national centers for integration and test

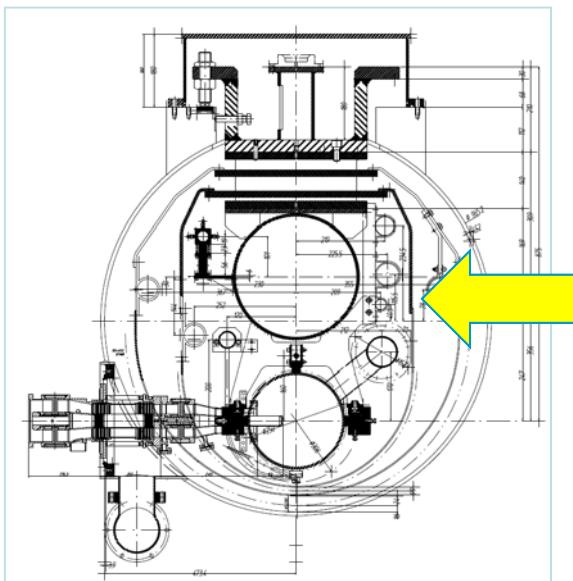
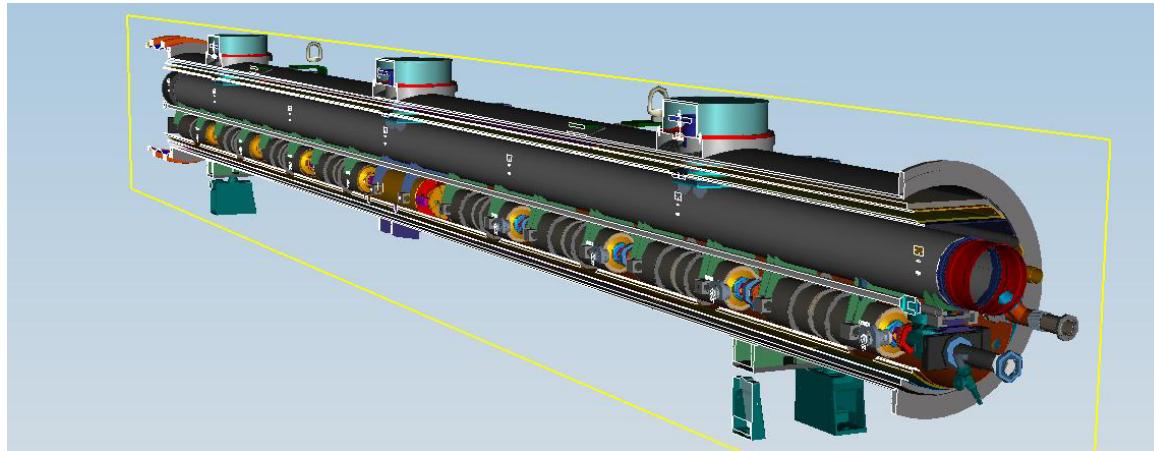
# Plug-compatible Conditions



Item	Can be flexible	Plug-comp.
Cavity shape	TeV/LL/ RE	
Length		Fixed
Beam pipe flange		Fixed
Suspension pitch		Fixed
Tuner	Blade/Jack	
Coupler flange (warm end)		Fixed
Coupler pitch		fixed
He –in-line joint		TBD

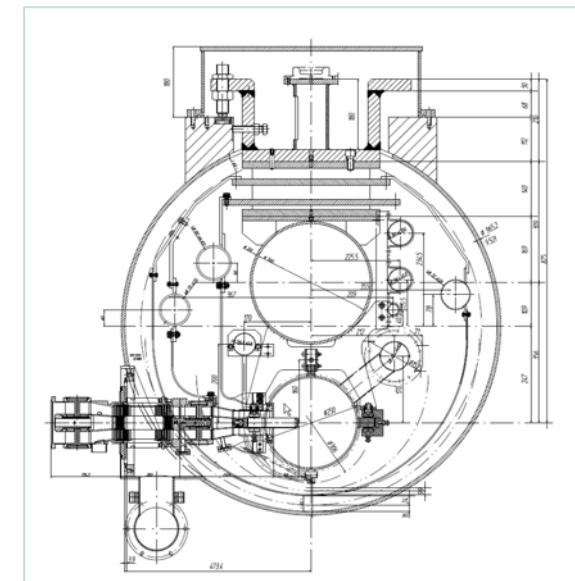
Plug-compatible interface nearly established

# Cryomodule Plug-compatibility

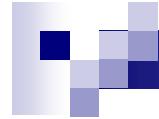


Vacuum vessel  
 $= \phi 965.2\text{mm}$

**Two shield model**



**One shield model**



# Collisionneurs e+e- : ILC à $\sqrt{s}=250$ GeV

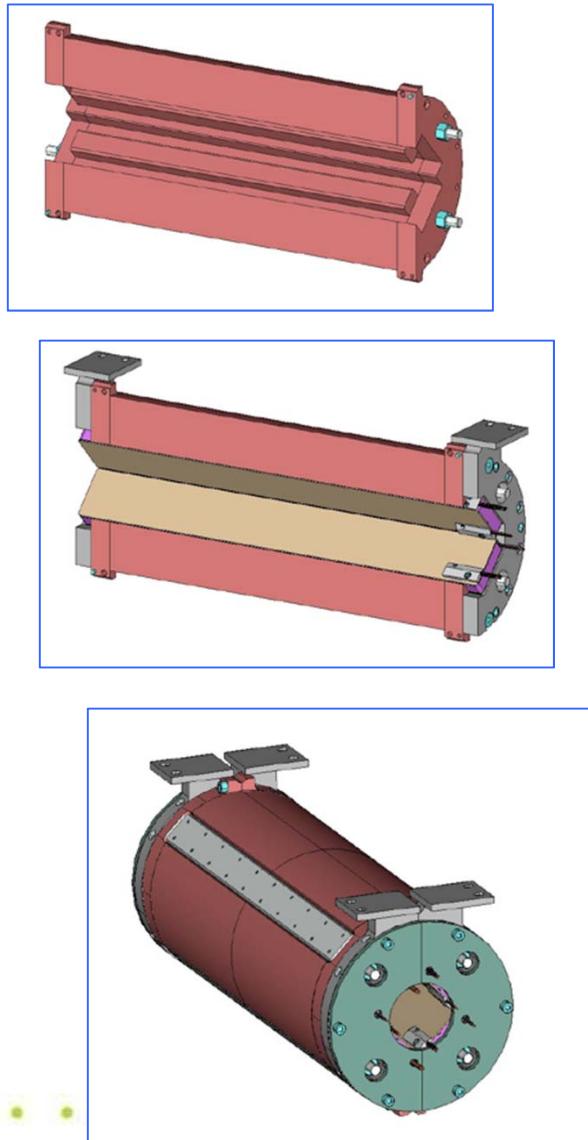
## Réduction des coûts de fabrication

Principaux défis de R&D, dans le périmètre Irfu-IN2P3:

- S'associer aux études d'industrialisation menées par DESY et le CERN
- Ouvrir la compétition sur la production de cavités ILC
- Maîtriser/réduire les coûts de production des coupleurs et cryomodules XFEL
  - Brasage de coupleurs
  - Blindages magnétiques
  - Manteaux de superisolation
  - Simplification des procédures (quadrupole froid, visserie propre)
  - Etc..



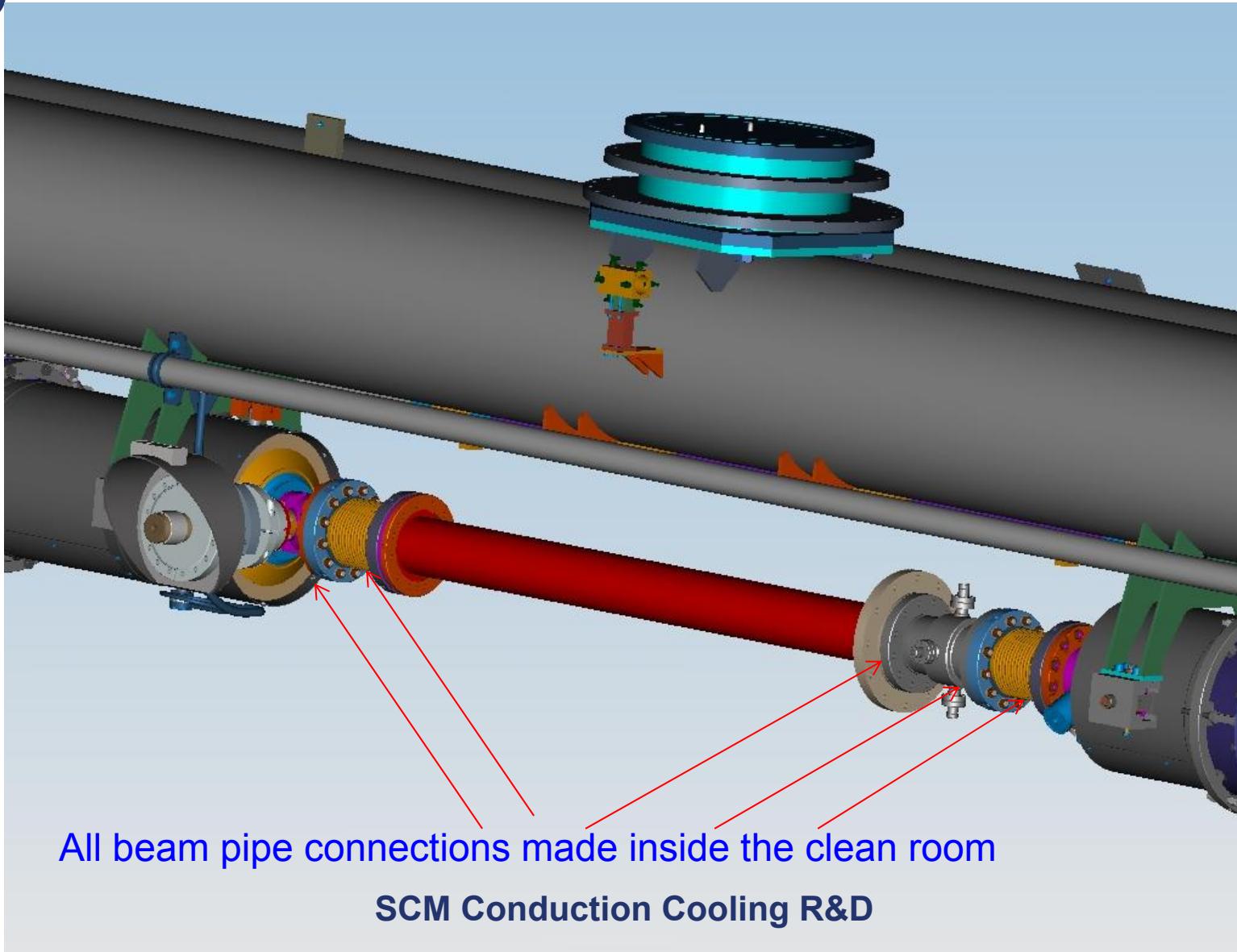
# Assembly of Split Quadrupole



A, Yamamoto, 110909

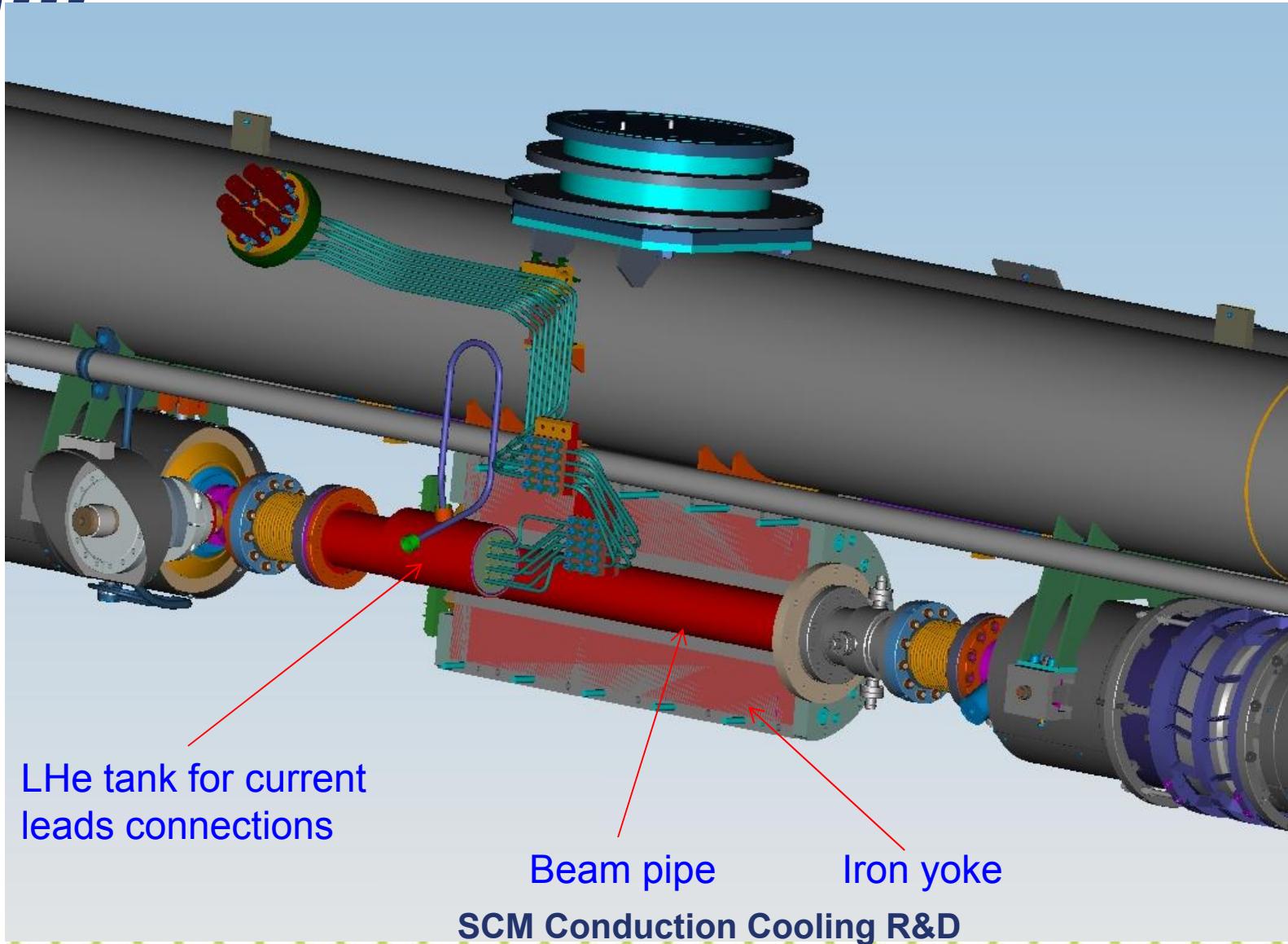
SCM Conduction Cooling R&D

# Cryomodule Before Quadrupole Installation

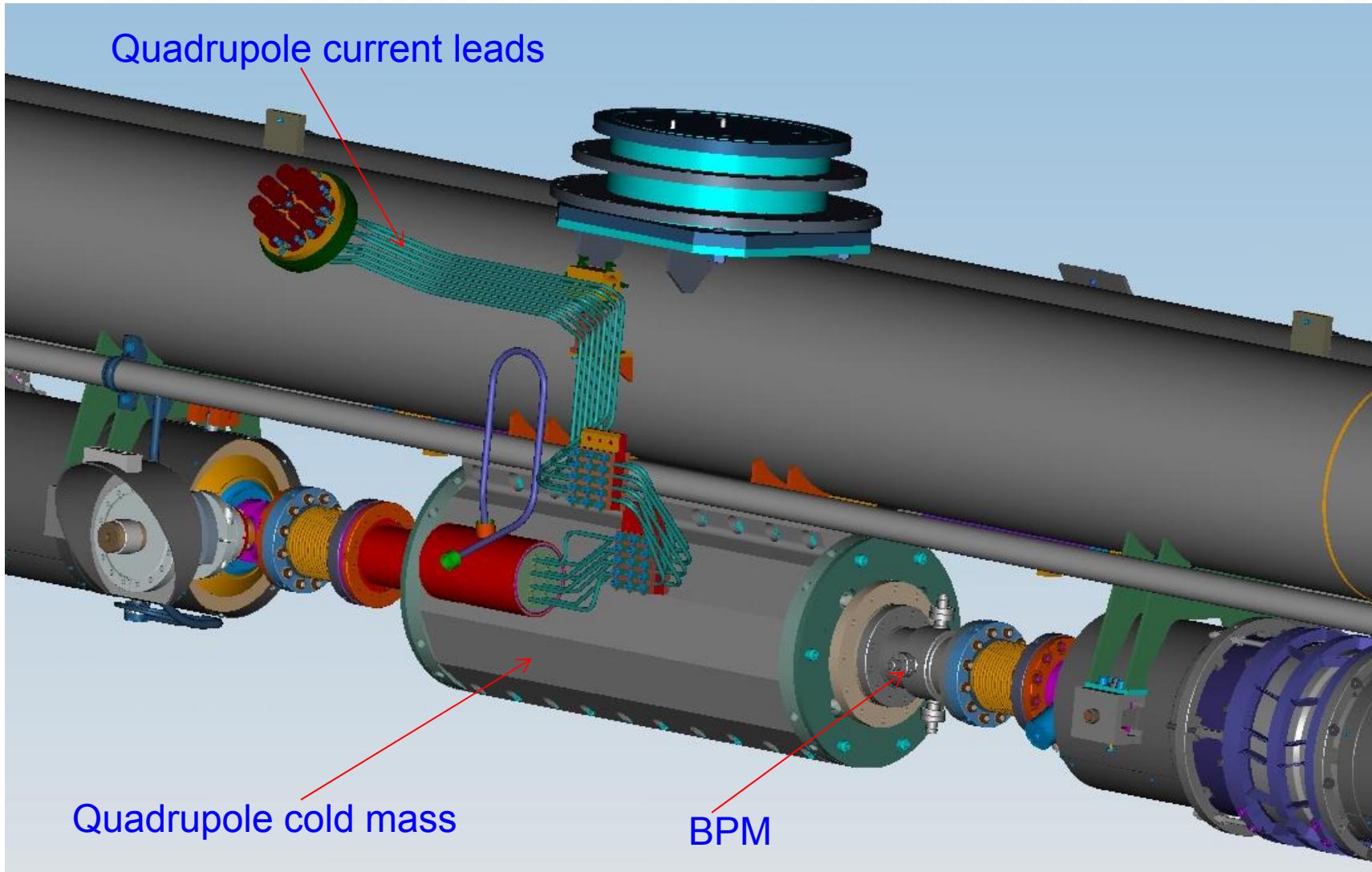




# Quadrupole Cross-Section



# Quadrupole Inside Cryomodule



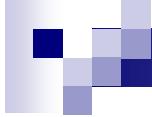
SCM Conduction Cooling R&D

# Déploiement des accélérateurs RF Supra en Europe

SCRF Accelerators / Europe [29+5+11+4+9]										
Name	Particles	# cavities		Type	Material	Gradient	Mode	T	Status	Location
HERA	electrons, positrons	16	500 MHz	$\beta=1$ elliptical 4-cell	Nb	4.0 MV/m	CW	4.2 K	de-commissioned	DESY
LEP200	electrons, positrons	16 272	352 MHz	$\beta=1$ elliptical 4-cell	Nb Nb/Cu	5 MV/m 7 MV/m	CW	4.5 K	de-commissioned	CERN
LISA	electrons	4	500 MHz	$\beta=1$ elliptical 4-cell	Nb	6 MV/m	pulsed	4.2 K	de-commissioned	LN Frascati
MACSE	electrons	5	1.5 GHz	$\beta=1$ elliptical 5-cell	Nb	10 MV/m	CW	1.8 K	de-commissioned	CEA-Saclay
Tandem PA	ions	16 34	81 MHz 135 MHz	$\beta=0.085$ helix $\lambda/2$ $\beta=0.085$ helix $\lambda$	Nb	2.2 MV/m	CW	4.2 K	de-commissioned	CEA-Saclay
ALICE	electrons	2	1.3 GHz	$\beta=1$ elliptical 9-cell $\beta=1$ elliptical 9-cell	Nb	3.5 MV/m 13.5 MV/m	pulsed	2 K	operation	Daresbury
ALPI	ions	2 12 50 58	80 MHz 80 MHz 160 MHz 160 MHz	$\beta=0.0255$ RFQ $\beta=0.055$ QW $\beta=0.13$ QW $\beta=0.13$ QW	Nb Nb Pb/Cu Nb/Cu	2.3 MV/m 4 MV/m 2.7 MV/m 4.8 MV/m	CW	4.5 K	operation de-commissioned	LN Legnaro
DIAMOND	electrons	2	500 MHz	$\beta=1$ elliptical 1-cell	Nb	6.5 MV/m	CW	4.5 K	operation	Oxford
ELBE	electrons	1 4	1.3 GHz	$\beta=1$ elliptical 3½-cell $\beta=1$ elliptical 9-cell	Nb	8 MV/m 9 MV/m	CW	2 K	operation	HZDR
ELETTRA	electrons	1	1.5 GHz	$\beta=1$ elliptical 2-cell	Nb	5 MV/m	CW	4.5 K	operation	Trieste
FLASH	electrons	56 4	1.3 GHz 3.9 GHz	$\beta=1$ elliptical 9-cell	Nb	20-30 MV/m 14.5 MV/m	pulsed	2 K	operation	DESY
ISOLDE	ions	12 20	101 MHz	$\beta=0.063$ QW $\beta=0.103$ QW	Nb/Cu	6 MV/m	CW	4.5 K	operation	CERN
LHC	protons, ions	16	400 MHz	$\beta=1$ elliptical 1-cell	Nb/Cu	6 MV/m	CW	4.5 K	operation	CERN
S-DALINAC	electrons	1 1 10	3 GHz	$\beta=0.85$ elliptical 2-cell $\beta=1$ elliptical 5-cell $\beta=1$ elliptical 20-cell	Nb	5 MV/m 5 MV/m 5 MV/m	CW	2 K	operation	Darmstadt
SLS	electrons	1	1.5 GHz	$\beta=1$ elliptical 2-cell	Nb	5 MV/m	CW	4.5 K	operation	PSI
SOLEIL	electrons	4	352 MHz	$\beta=1$ elliptical 1-cell	Nb/Cu	6 MV/m	CW	4.2 K	operation	SOLEIL
BERLinPro	electrons	1 3 3	1.3 GHz	$\beta=1$ elliptical 1½-cell $\beta=1$ elliptical 2-cell $\beta=1$ elliptical 7-cell	Nb	20 MV/m 18 MV/m	CW	2 K	construction	HZB
E-XFEL	electrons	808 8	1.3 GHz 3.9 GHz	$\beta=1$ elliptical 9-cell	Nb	24 MV/m 15 MV/m	pulsed	2 K	construction	Hamburg
IFMIF-EVEDA	D+	8	175 MHz	$\beta=0.094$ HW	Nb	4.5 MV/m	CW	4.5 K	construction	Rokkasho
SPIRAL2	D+, ions A/Q = 3	12 14	88 MHz	$\beta=0.07$ QW $\beta=0.12$ QW	Nb	6.5 MV/m 6.5 MV/m	CW	4.2 K	construction	GANIL
ESS	protons	28 64 112	352 MHz 704 MHz 704 MHz	$\beta=0.5$ double spoke $\beta=0.7$ elliptical 5-cell $\beta=0.9$ elliptical 5-cell	Nb	8 MV/m 15.5 MV/m 18.2 MV/m	pulsed	4.5 K	design	Lund
EURISOL Driver	protons, deutons, H-, $^3\text{He}2+$	16 56 36 45 40 24	176 MHz 176 MHz 352 MHz 704 MHz 704 MHz 704 MHz	$\beta=0.09$ HW $\beta=0.15$ HW $\beta=0.3$ triple spoke $\beta=0.47$ elliptical 5-cell $\beta=0.65$ elliptical 5-cell $\beta=0.76$ elliptical 5-cell	Nb	4.7 MV/m 5.2 MV/m 5.8 MV/m 12 MV/m 15 MV/m 18 MV/m	CW	2 K	design	-
EURISOL PA	ions, A/Q from 2 to 8	15 27 80 154	88 MHz 88 MHz 176 MHz 264 MHz	$\beta=0.065$ QWR $\beta=0.14$ QWR $\beta=0.27$ HWR $\beta=0.39$ single-spoke	Nb	?	CW	4 K	design	-
ILC 500	electrons, positrons	16 900	1.3 GHz	$\beta=1$ elliptical 9-cell	Nb	35 MV/m	pulsed	2 K	design	-
LUNEX5	electrons	16	1.3 GHz	$\beta=1$ elliptical 9-cell	Nb	25 MV/m	pulsed	2 K	design	SOLEIL
LHeC ERL	electrons	944	721 MHz	$\beta=1$ elliptical 5-cell	Nb	20 MV/m	CW	2 K	design	CERN
MYRRHA	protons	8 48 34 60	176MHz 352 MHz 704 MHz 704 MHz	CH DTL $\beta=0.35$ single spoke $\beta=0.47$ elliptical 5-cell $\beta=0.65$ elliptical 5-cell	Nb	4 MV/m 6 MV/m 8 MV/m 11 MV/m	CW	2 K	design	SCK Mol
POLFEL	electrons	?	1.3 GHz	$\beta=1$ elliptical 9-cell	Nb	25 MV/m	pulsed	1.8 K	design	-
SPL	protons, H-	60 192	704 MHz	$\beta=0.65$ elliptical 5-cell $\beta=1$ elliptical 5-cell	Nb	19 MV/m 25 MV/m	pulsed	?	design	CERN
TRASCO	protons		704 MHz		Nb		pulsed		design	-

Table en cours de consolidation pour TTC/EuCARD:

- 5 accélérateurs démantelés
- 11 acc. en opération
- 4 acc. en construction
- 9 acc. en projet



# Plan de l'exposé

- L'option Collisionneur Circulaire
- Paramètres ILC250 'Light Higgs Factory'
- Aspects Accélérateurs Linéaires
  - Performance accélérateur
  - Coût
  - Calendrier de construction
  - Industrialisation
  - Gouvernance

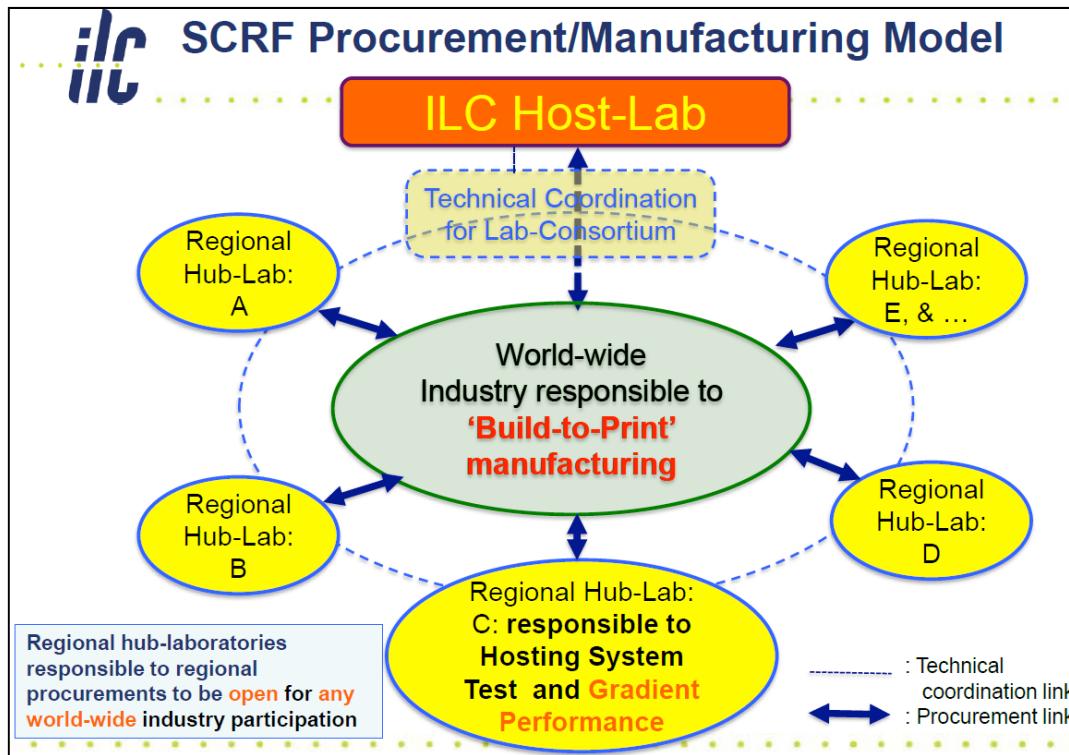


# How we may learn from E-XFEL Experience

- Multiple vendors contribute to the manufacturing w/ a typical fraction of one fifth to one half ,
  - A model: RI and Zanon for E-XFEL manufacturing
- Multiple laboratories host the integration and test
  - A model: Saclay for E-XFEL cryomodule assembly and DESY for cavity/cryomodule tests,
  - Multiple hub-laboratories may be adequate for the ILC
- In case, construction period assumed to be
  - twice (or more) of the XFEL construction (5 ~ 6 year for ILC),
  - Production rate can be reduced to be a half
    - Factor: 20 to 10,
  - If four hub-laboratories host and share the work, production/test rate becomes
    - Factor : $10 / 4 = 2.5$
    - →  $2.5 \times$  XFEL production rate may be considered

# Collisionneurs e+e- : ILC

Organisation de la production à grande échelle sur 3 régions



## A. Yamamoto

Pour ILC 500 GeV avec ~2000 cryomodules: le but est d'atteindre une cadence de production de 2 cryomodules/semaine/5 hubs → 6 ans de construction

Pour XFEL avec 100 cryomodules : 1 cr. / semaine  
Les infrastructures sont compatibles avec une cadence de 2 cr. / semaine

## Principaux défis de R&D, dans le périmètre Irfu-IN2P3:

- Assurer un rôle de 'Hub' (ou 'Tier 1') sur les infrastructures construites pour XFEL au LAL-Orsay et Irfu-Saclay
- Soutien aux industriels français : Thales, ALSYOM, SDMS, Aperam, Jehier, etc... et européens, RI, Zanon, BNG, Plansee, Heraeus, VAC.



# Collisionneurs e+e- : ILC à $\sqrt{s}=250-1000$ GeV

Durée de la production des cryomodules  
à grande échelle sur 3 régions

	Nbre de Centres	Cadence / semaine	Nbre de semaines	Nbre de jours	Durée < tps montée
XFEL	1	1 CM	100	500	3 ans
ILC 250	3	2 CM	1000 ÷ 6	830	4-5 ans
ILC 500	4	2,5 CM	2000 ÷ 10	1 000	6 ans
ILC 500	5	2 CM	2000 ÷ 10	1 000	6 ans

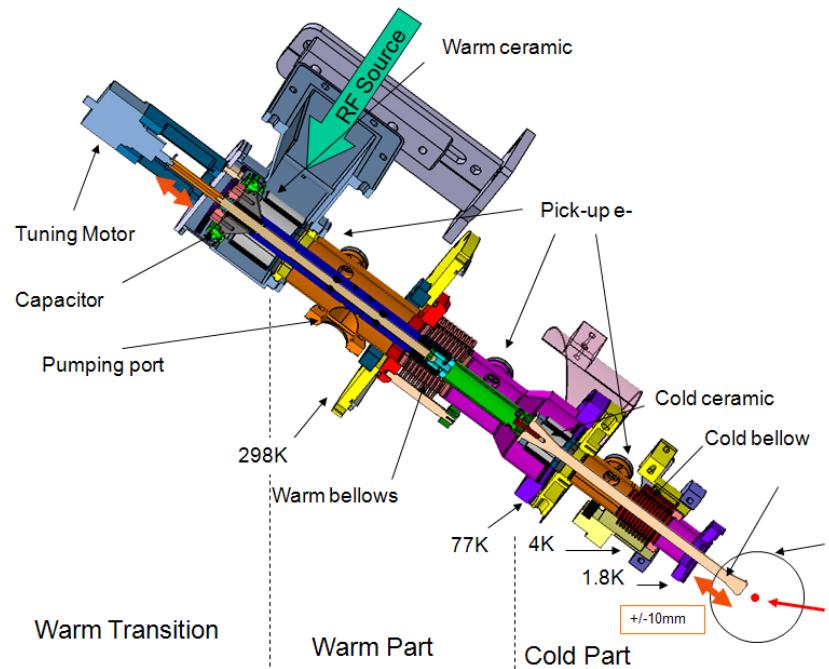
# Collisionneurs e<sup>+</sup>e<sup>-</sup> : ILC

## Outils de Production XFEL @ LAL-Orsay



800 coupleurs de puissance

- Fourniture
- Conditionnement RF (0.5 MW, 500 µs)



# Collisionneurs e+e- : ILC

## Outils de Production XFEL @ Irfu

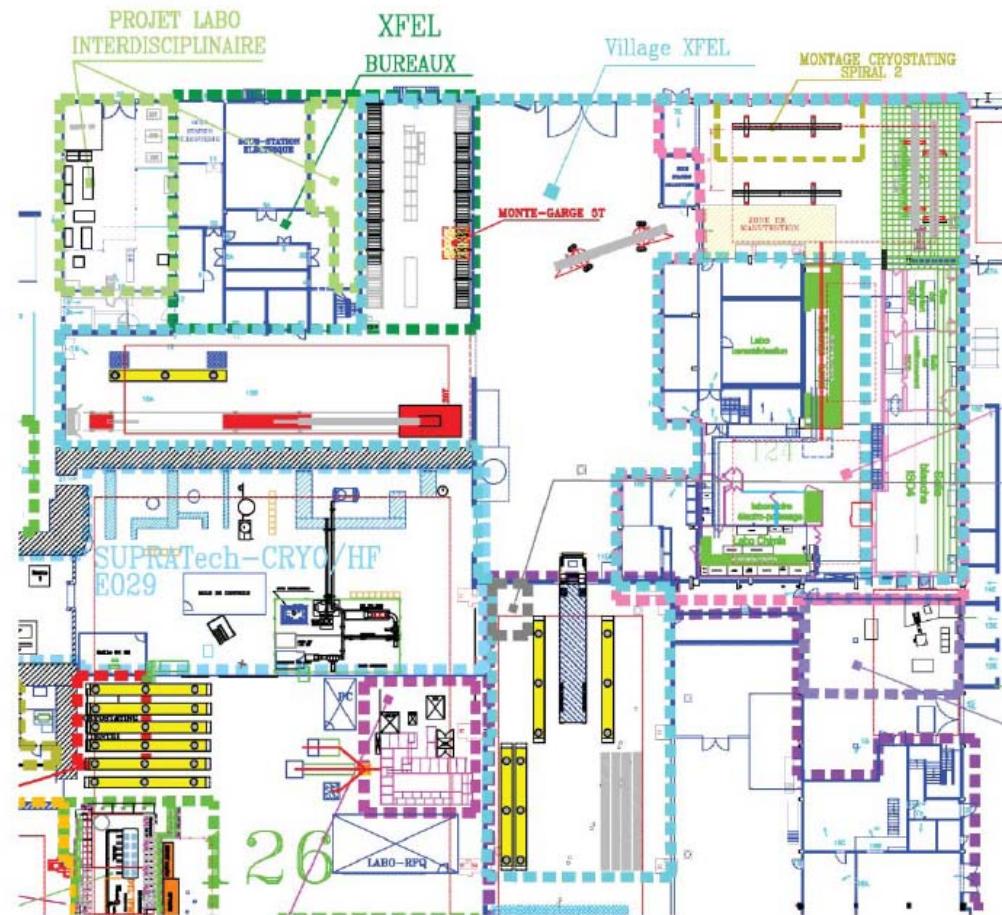
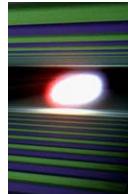
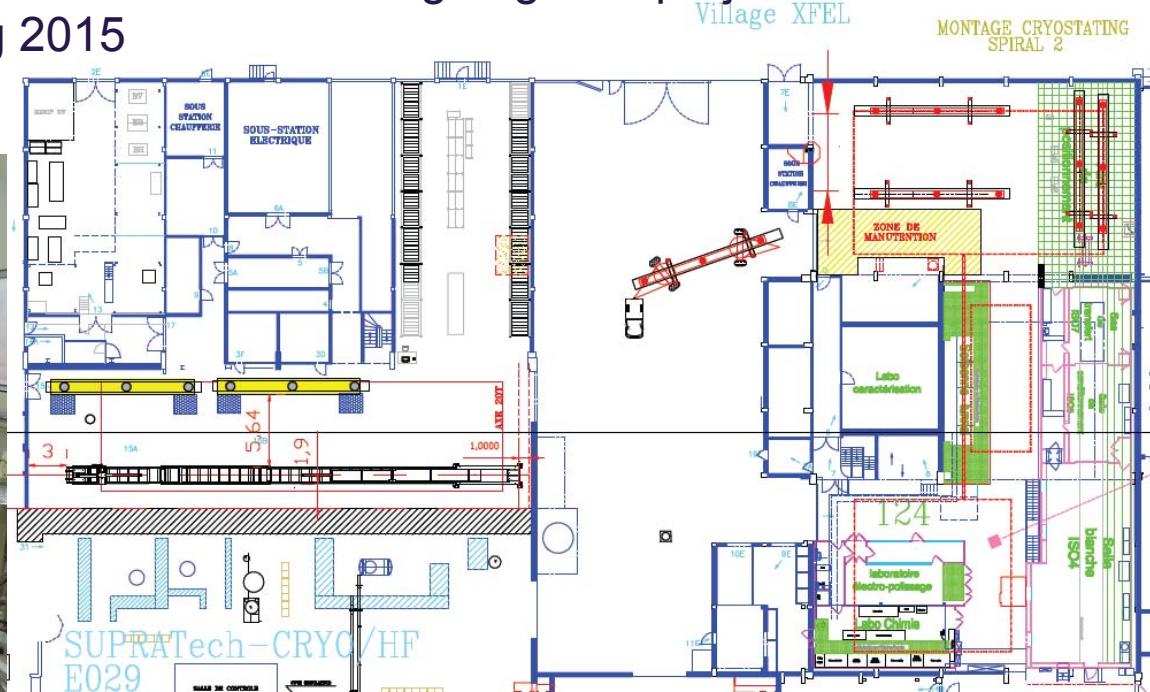


Figure 3-2 : Plateau technique des stations de montages.

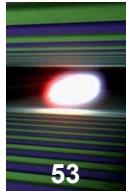
# Saclay Infrastructure for String and Module Assembly



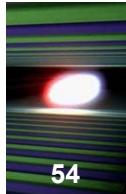
- Publicity and call for candidatures last summer
- Restricted CFT based on cryomodule assembly specifications
- Selection of industrial contractor finished; contracts to be placed now
- Pre-series assembly of three modules in 2012
- First series assembly scheduled for end of 2012
- Exact start date still under discussion but according to global project schedule module #100 expected for spring 2015



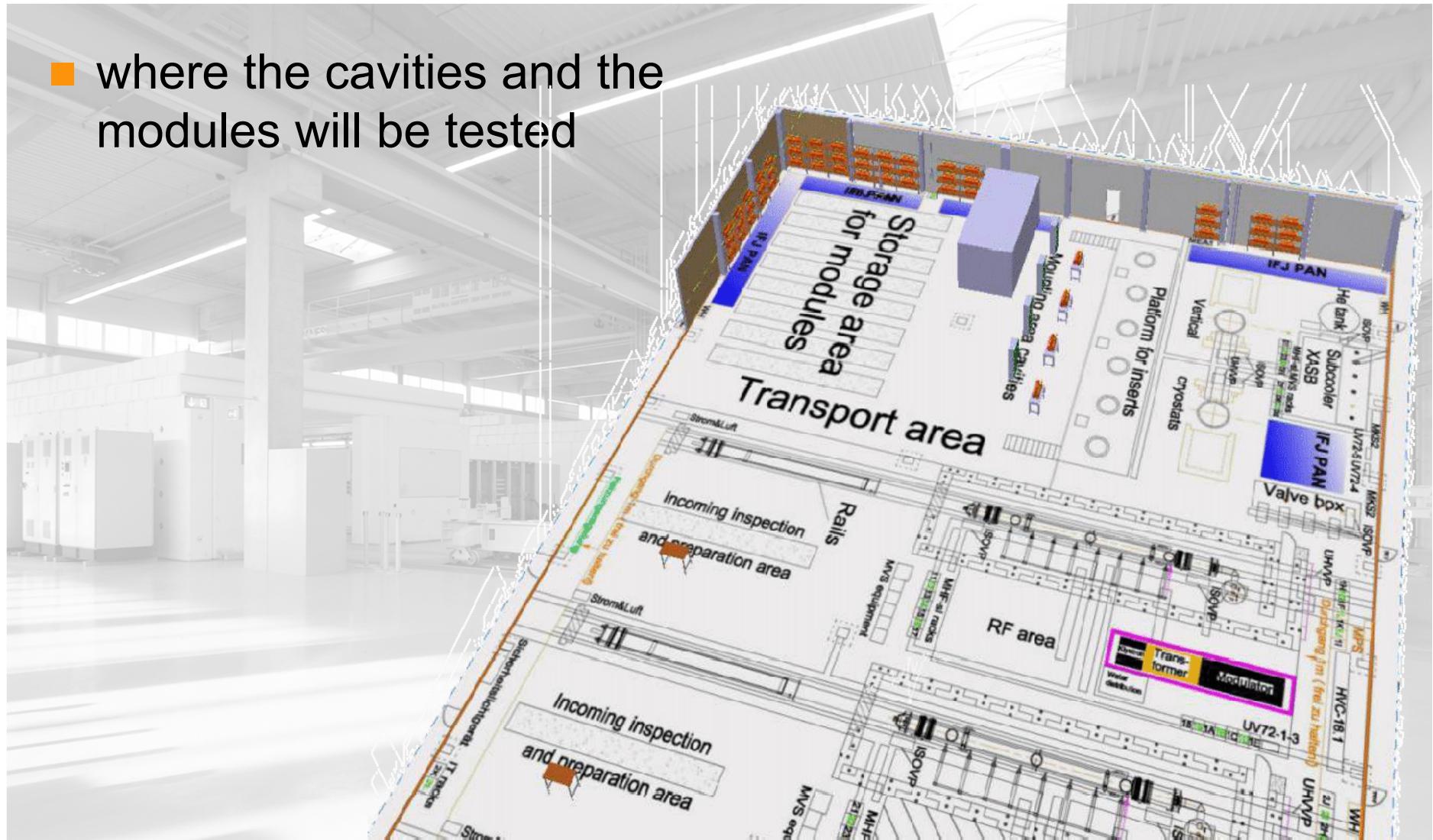
# WP10: Accelerator Module Test Facility (AMTF)



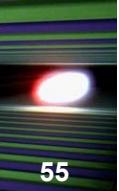
# WP10: Accelerator Module Test Facility (AMTF)



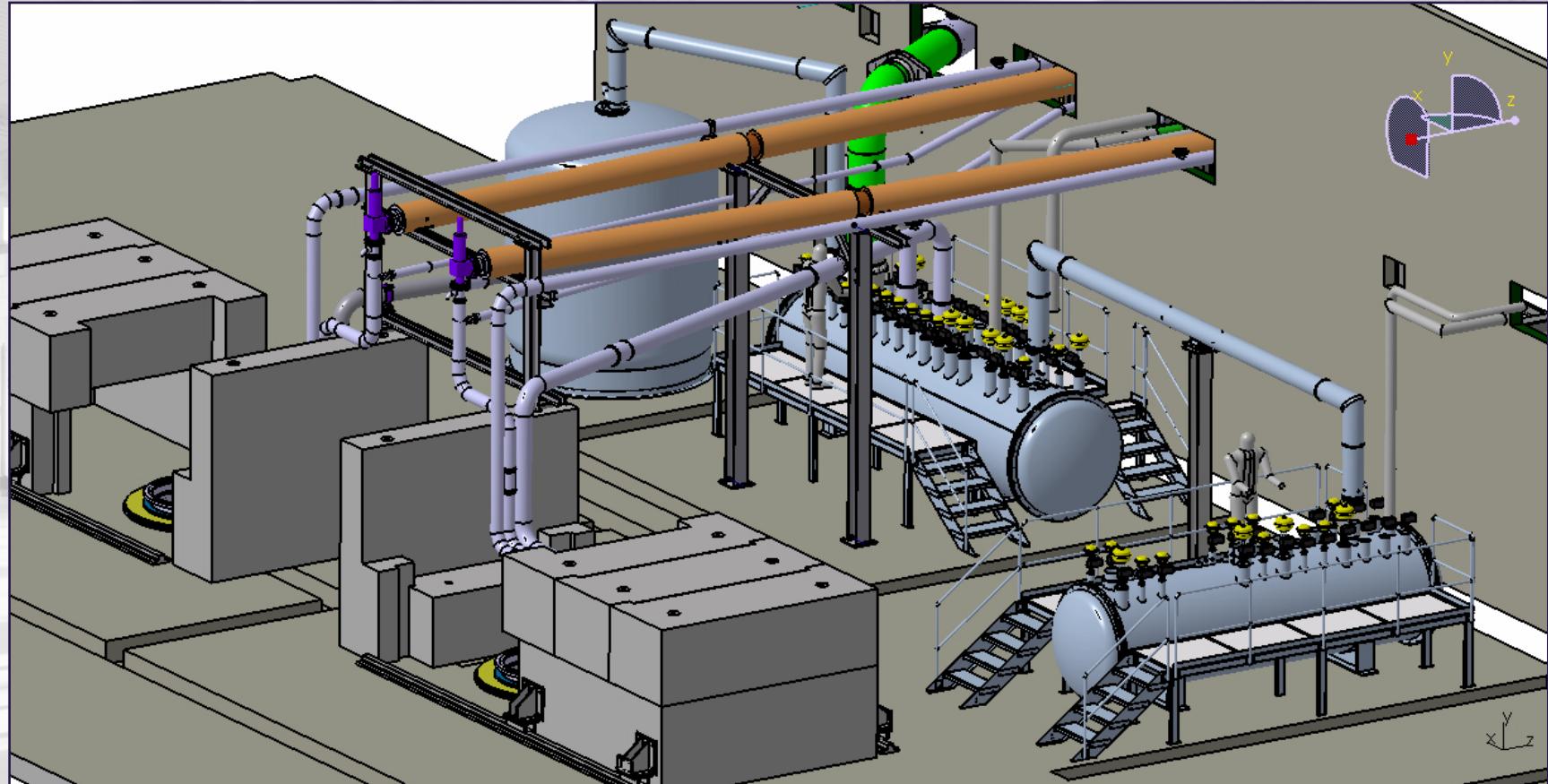
- where the cavities and the modules will be tested



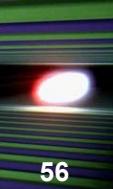
# WP10: Subtask: Cavity Testing



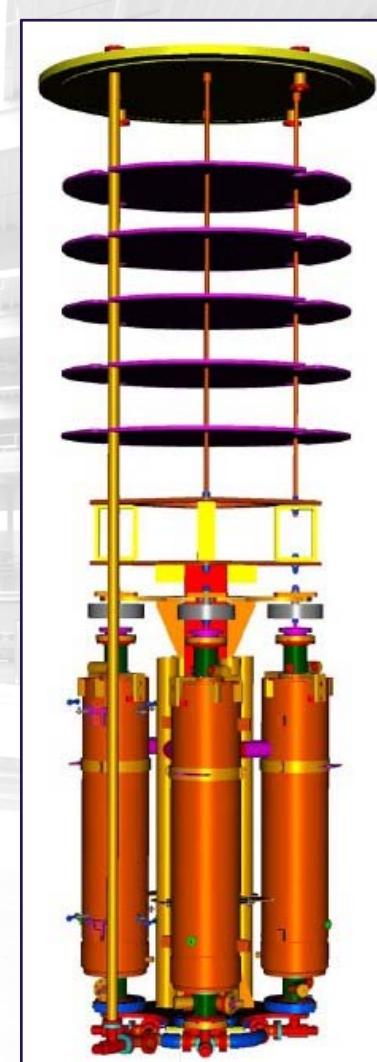
- the two cavity test stands in the AMTF hall



# WP10: Subtask: Cavity Testing

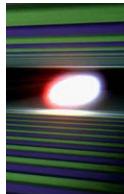


- first vertical cavity test stand
  - fully operational at September 14<sup>th</sup>
- second vertical cavity test stand
  - fully operational at November 9<sup>th</sup>
- implications
  - first cavity tests need to be performed in Hall 3
  - the setup of second test stand parallel to operation of the first is a technical and organizational challenge





Electron Accelerator Status

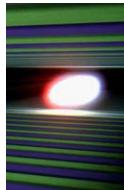


# European XFEL RI Infrastructure





Electron Accelerator Status



# European XFEL Zanon Infrastructure



**European  
XFEL**

# Cold Mass and Vacuum Vessel

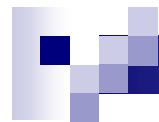


Institute of High Energy Physics  
Chinese Academy of Sciences



- 58 plus 25 cryostats and vacuum vessels ordered; fabrication on-going; sub-components ready for assembly.
- Production schedule uncritical. First units will arrive very soon (5/2012); storage at DESY and CEA foreseen.
- Remaining 20 cryostats: Call for tender (by DESY) prepared.





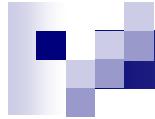
# Collisionneurs e+e- : ILC à $\sqrt{s}=250$ GeV

## Infrastructure de Production Industrielle

Les infrastructures de production existent en Europe et sont adaptables ou adaptées à un doublement des cadences de production.

XFEL	cavités	coupleurs	1/3 cryomodules	klystrons	intégration
Thales		X		X	
RI	X	X			
Zanon	X		X		
ALSYOM					X
BNG					
SDMS					

Problème de capacité industrielle européenne pour un facteur 10.



## Mes Conclusions

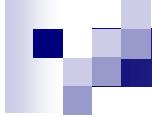
- Aspects Accélérateurs Linéaires
  - Calendrier

Les infrastructures des labos européens sont compatibles avec un doublement des cadences de production.

Le renfort technique et intellectuel du CERN sera évidemment bénéfique (avec un grand B).

Les infrastructures des industries européens sont une assise très forte mais doivent être complétées par d'autres intervenants.

Ces infrastructures sont inexistantes, au mieux en cours de constitution, en Amérique et en Asie.



## Plan de l'exposé

- L'option Collisionneur Circulaire
- Paramètres ILC250 'Light Higgs Factory'
- Aspects Accélérateurs Linéaires
  - Performance accélérateur
  - Coût
  - Calendrier de construction
  - Industrialisation
  - Gouvernance



# Preparing for ILC SCRF Industrialization

- Learn from previous efforts and on-going programs:
  - **Study of the TESLA project (1990's)**
    - Assuming to manage ~ 20,000 cavities
  - **R&D progress in past 10 years**
    - Varied industrialization efforts
  - **On-going Industrialization for the E-XFEL Project**
- Develop Industrialization Model
  - Need to adapt various governance models and in kind contribution models from multiple regions, countries, and laboratories,
  - Make our own effort to seek for the best cost-effective production technology and approach
    - An example: A pilot-plant effort at KEK
  - Communicate with industry and laboratories to seek for cost-effective manufacturing and quality control



# An Industrialization Model

- **Industry-based Cavity Production**
  - Manufactured by companies,
    - shared fraction of (10%~) 20 % ~ 100 %
  - According to ‘**build-to-print specification**’ , satisfying
    - Minimum acceptance criteria and inspections, such as mechanical, surface, pressure, leak-tight, RF characteristics, so on,
    - Specific process such as EBW, EP, heat-treatment,
  - **Delivery from industry to laboratories with no inspection for the gradient performance**
- **Laboratory-based Cavity Performance Test**
  - Collaborating laboratories **responsible for the cavity gradient performance**,
    - Multiple laboratories' collaboration are natural.
    - Delivery from laboratory to (host) laboratory with performance tested/guaranteed,



# Industrialization Models

Production Models and Production Rate of SCRF Cavities					
Project	Total numbers of Cavities	Fraction Of Production Sharing	# of Cavity production	Production period (years)	Production Rate: (Cavities/day/vendor) (at 250 work-days/yr)
SNS	~ 110 (including +20%)	100 %		3	0.15
XFEL	~600	100 % 50 %		~ 2.5	0.8 ~ 1 0.4 ~ 0.5
ILC	~ 16,000 (including +10%)	100 % 50 % 20 % 10 %	16,000 8,000 3,200 1,600	6 (= 2 x 3)*	~ 11 ~ 5.5 ~ 2 ~ 1

\*Assumption : ILC full production-rate period to be twice of production time of XFEL



# Numbers of processes trade-off in a case study of 1/6 production model:

	Fabrication of Dumb-bell with EBW	Fabrication of End group EBW	Assemble 9-cell Cavity With EBW	Number of machines and processes required	
				EB Welding	Electro- polishing
Case1 R&D phase	1 seam / welding cycle (3 hrs/3 cycle)	1 seam / welding cycle (11 hrs / 11 cycle)	one 2(4,8)- cell / welding cycle (9 hrs/9 cycle)	12	6
Case3 Mass Production Study	8 dumb-bell / welding cycle (6.5/8 hrs/3 cycle)	8 end group / welding cycle (46.7/8 hrs/11 cycle)	one 9-cell / 2 welding cycle (4.7 hrs / 2 cycle)	5 Possible → 4	6

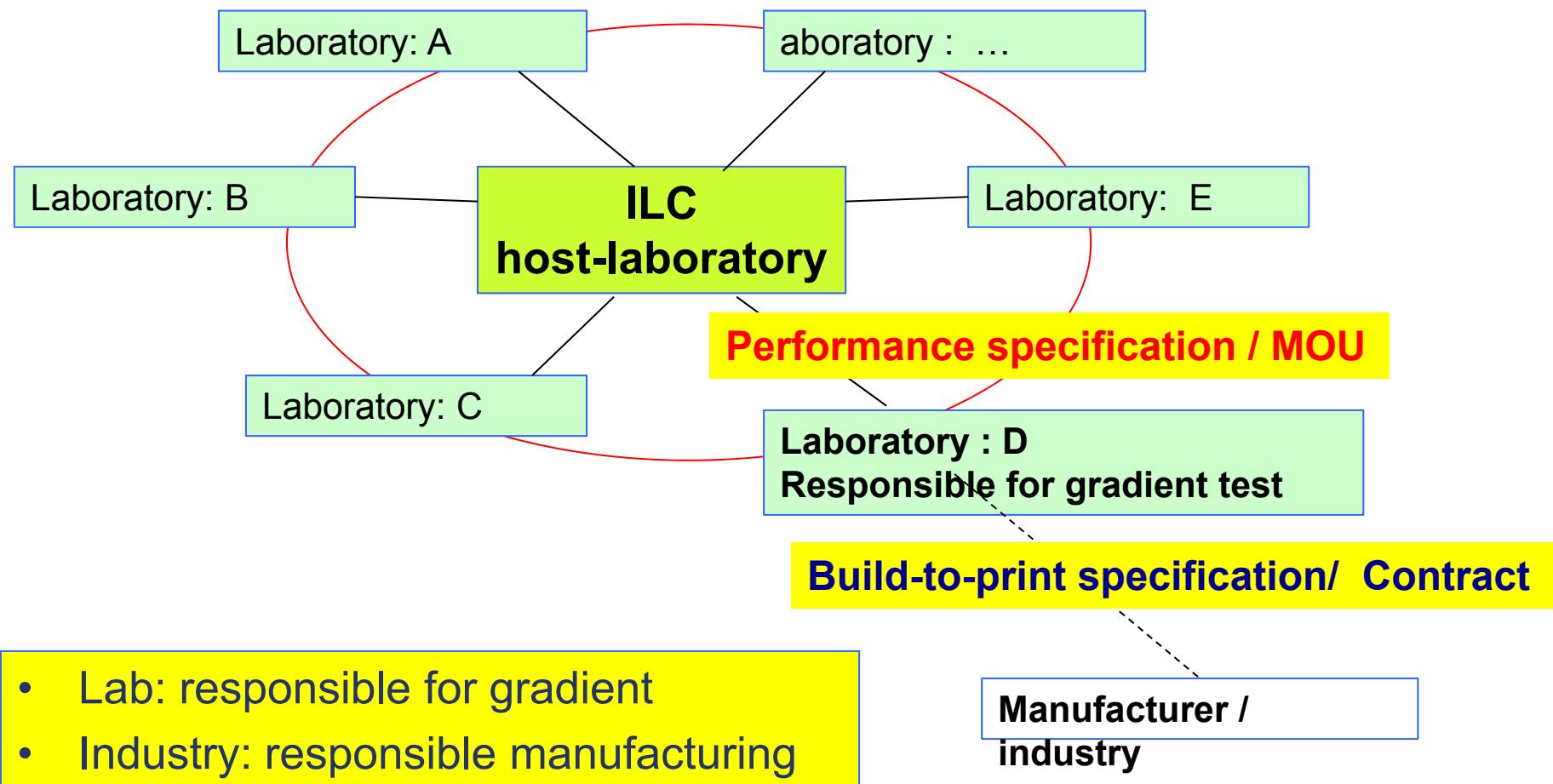


# Possible Models of Industrialization

Possible work sharing	Commercially supplied, relying on market	Region/ Laboratory responsible	Notes, constraint
# of participants	1: possible , $\geq 2$ : desired	$\geq 2$ : most likely	
<b>Cavity:</b>			
Nb and raw material	Yes		
Main cell, He-Jacke	Yes with care		High Pressure Code
End-group, HOM etc.	Yes		
Input Coupler, Tuner	Yes		
Surface Process	Yes /Possible	Yes/Possible	
Integration		<b>Most Likely</b>	High Pressure Code
Cavity Perform.. Test		<b>Most Likely</b>	<b>Lab should be responsible</b>
<b>Cryomodule:</b>			
Vacuum vessel	Yes		
C.M. component	Yes with care		High P. code
<b>Cavity-CM Assembly</b>		<b><math>\geq 2</math>: Most likely 1: special case</b>	
<b>Cryomodule test</b>		<b>Most likely</b>	<b>Lab should be responsible</b>



# An Industrialization Model and Responsibility





# Next Step for Preparing Industrialization

- Plan for 2010-2011:
  - Extend our own effort for industrialization at laboratories,
  - Prepare for “ILC Cavity/cryomodule Specification” and
  - Expect responses/advices from cavity/cryomodule vendors
- Boundary conditions:
  - **Plug-compatible and build-to-print specification**
    - Including design parameter, interfaces, manufacturing process,
    - Requirement on quality control, and minimum acceptance criteria
  - **Possible mass-production model**
    - Scale of production: **4,000 ~ 8,000** (25 ~ 50 %, for example)
      - Possible industrial collaboration (grouping etc.. )
    - Scale of production period: **2 + 5~6 years**
      - Set-up + main production period, assuming  $\geq 2 \times$  EXFEL period



# Updated Plan for Visiting Vendor

No.	Date	Company	Meeting Place	Technical subject	Notes
1	2/8	Hitachi	Tokyo	Cavity & Cryomodule	
2	2/8	Toshiba	Yokohana	Cavity & Cryomodule	
3	2/9	MHI	Kobe	Cavity & Cryomodule	
4	2/9	Tokyo Denkai	Tokyo	Nb, NbTi Material	
5	2/18	NingXia, OTIC	NingXia	Nb, NbTi, Ti Material	
6	3/3	Zanon	INFN, Milano	Cavity & Cryomodule	
7	3/4	RI	Koeln	Cavity & Cryomodule	
12	4/27	Plansee	via Munchen	Nb, NB-Ti Material	
8	3/14, (4/8)	AES	NY, Long Island	Cavitu & Cryomodule	Re-Tele-conf
9	3/15, (4/7)	Niowave	Lansing	Cavity & Cryomodule	Re-visit
10	4/6	PAVAC	Vancouver	Cavity & Cryomodule	
11	4/25	Wah-Chang	Via Portland	Nb, Nb-Ti material	

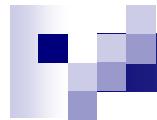
GDE members: PMs, and RDs / Cost-experts / Experts from Lab (shared regionally)

# Industrialisation SCRF Linac



## Summary – 1/3

- Technical base in laboratory responsibility:
  - 35 MV/m in 9-cell cavity (in vertical test)
  - 31.5 MV/m on average, w/ spread  $\leq +/- 20\%$  in accelerator operation
- Performance specification for tests
  - Applied for MOU/contract between ILC host-lab and hub-laboratories (contributing laboratories)
- Build-to-print specification for manufacturing
  - Plug-compatible design specification, with specific acceptance criteria



# Industrialisation SCRF Linac



## Summary – 2/3

- An industrial model
  - Multiple vendors to manufacture components
    - A model: RI and Zanon for E-XFEL manufacturing
  - Multiple laboratories to host the integration and test
    - A model: Saclay for E-XFEL cryomodule assembly and DESY for cavity/cryomodule tests,
    - Multiple hub-laboratories may be required for the ILC
  - Construction period assumed to be twice to the XFEL construction,
    - → a few times XFEL production rate.

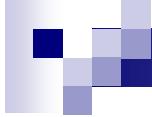
# Collisionneurs e+e- : ILC

Organisation de la production à grande échelle sur 3 régions

- **Industry to**
  - be responsible for ‘built-to-print’ manufacturing with minimum acceptance criteria
  - No regional constrain for material / sub-component, such as Nb, specific components
- **Regional hub-laboratories to**
  - be responsible to coordinate cooperation/consortium with other laboratories,
  - be responsible with **performance of SCRF cryomodule**
  - host and operate cold, performance test facility, and may host cavity-string/cryomodule assembly facility and work on it through contract.
  - procure specific sub-components for cavity and cryomodule hardware

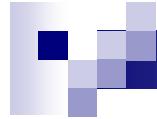
A. Yamamoto

**Modèle XFEL** d'industrialisation de la production des coupleurs (LAL-Orsay) et de l'intégration des cryomodules (Irfu-Saclay):  
→ Maîtrise du processus industriel  
→ Pérennité des infrastructures (conditionnement, salle blanche, alignement, etc...)



## Plan de l'exposé

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## Plan de l'exposé

- Aspects Accélérateurs Linéaires
  - Gouvernance

Vous avez la parole !