Jefferson Lab
Hydrogen Workshop

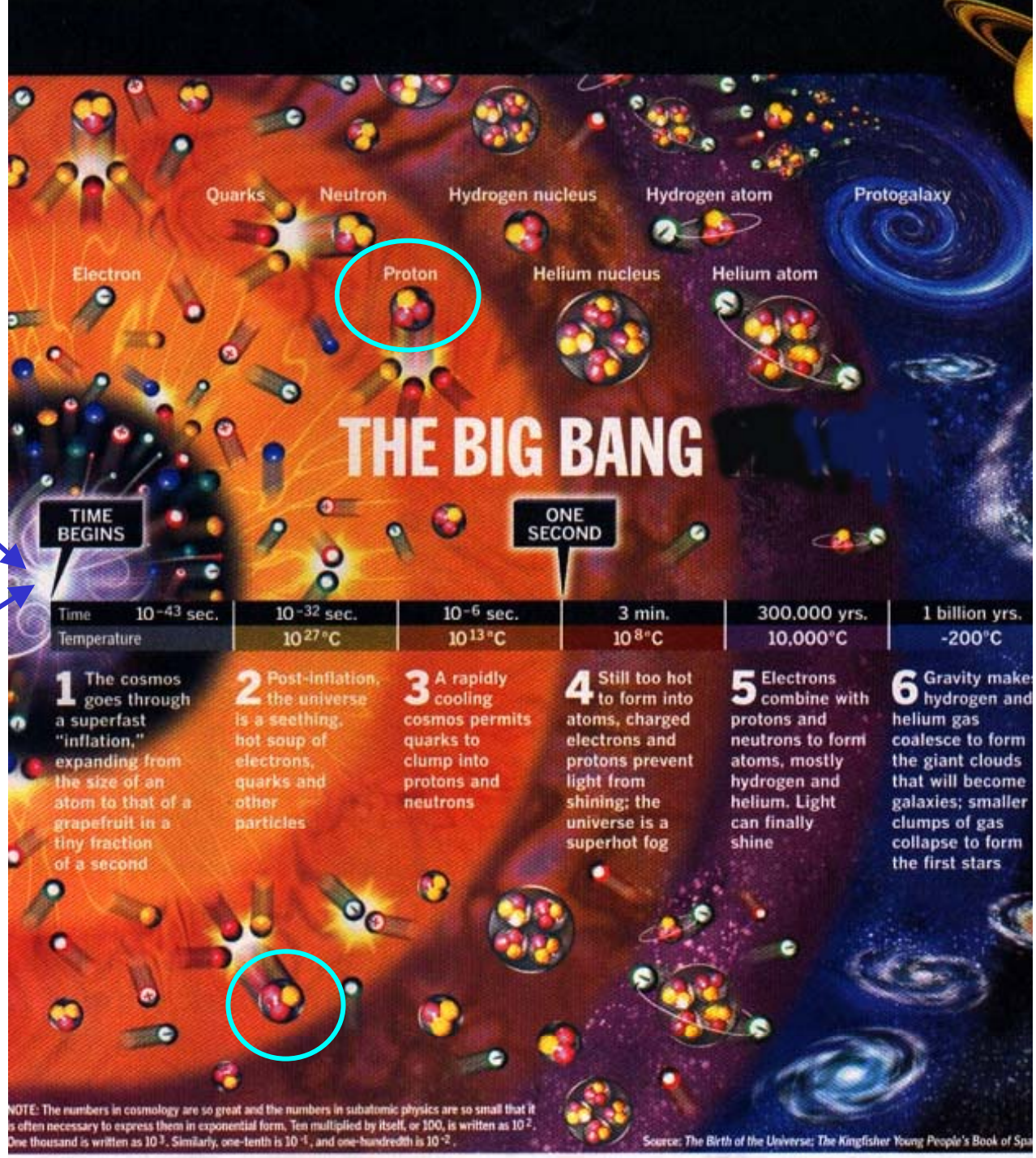
Summary Talk

Hasan Padamsee, Cornell University

Start with a few remarks about Hydrogen History

We all know where all the H came from in the first place !

Underlying very simple symmetric reality???!



But, on earth the gas was first
discovered more recently by one

Theophrastus Bombastus von Hohenheim

Changed his name to Paracelsus (1493-1541)

Paracelsus isolated a new "spirit" liberated by reacting metals with acids.

Renaissance)

Already acid treatment of metals found to release hydrogen

"Alchemy is to make neither gold nor silver; it is to make the sciences supreme and to direct them against disease."

Ah! A true scientist
Thinking of important practical applications

(1733-1804))

Cavendish continued to study Paracelsus' "flammable air"

When trying to weigh the flammable air, he ran into a puzzle. A bag full of flammable air weighed less than when the bag was empty. Could the flammable air have negative weight?

Cavendish was too good a physicist to accept the idea of negative weight,
Remember he was the first to measure G

From Archimedes principle, he figured out that the density of gas was less than density of air, like cork in water

Cavendish was able to fill a silk balloon with H and watch it rise
Future Application : Transportation !

Lavoisier Extracted Hydrogen from Water by Passing Steam through hot iron tube

(1743-1794)

French Revolution

One of the very same techniques that we talked about at this workshop to liberate Hydrogen

Lavoisier wanted to show that water is not an element as thought from antiquity

He identified H as an element and gave the name Hydrogen - to generate from water

What a far thinker !

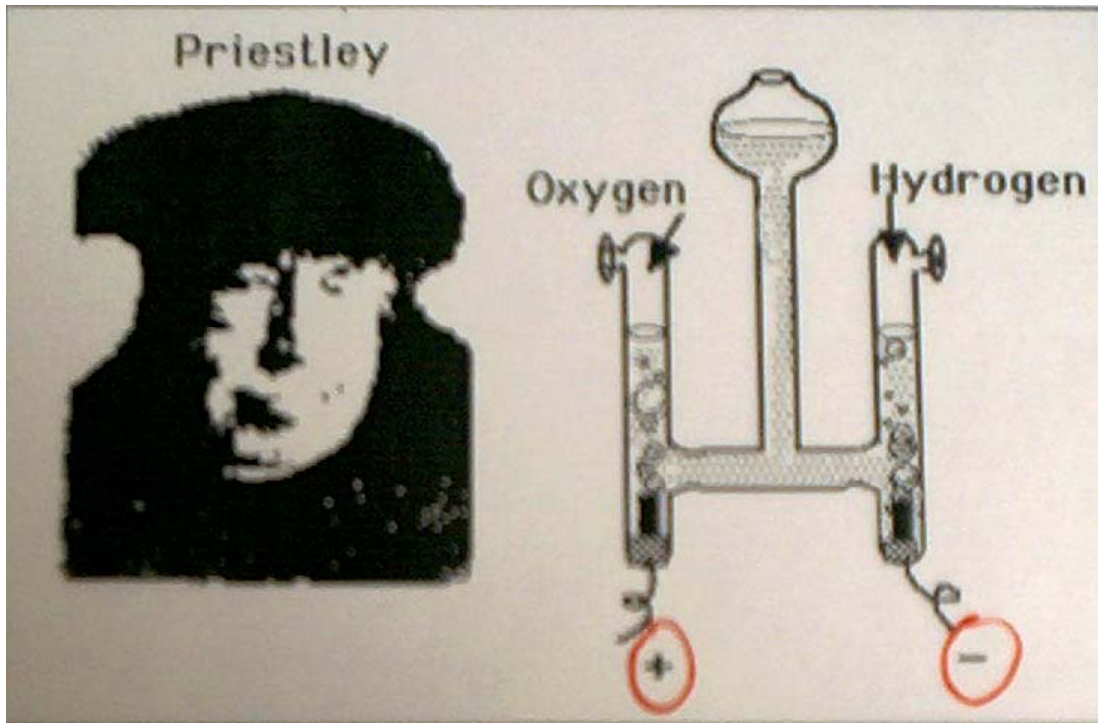
- *"Nothing gives us the certainty that substances which we now believe to be simple are actually simple…this stuff presents today merely the limits of analytical chemistry, it cannot be further decomposed with our present knowledge and devices…"* *Lavoisier*

Poor guy !

Lagrange mourned:

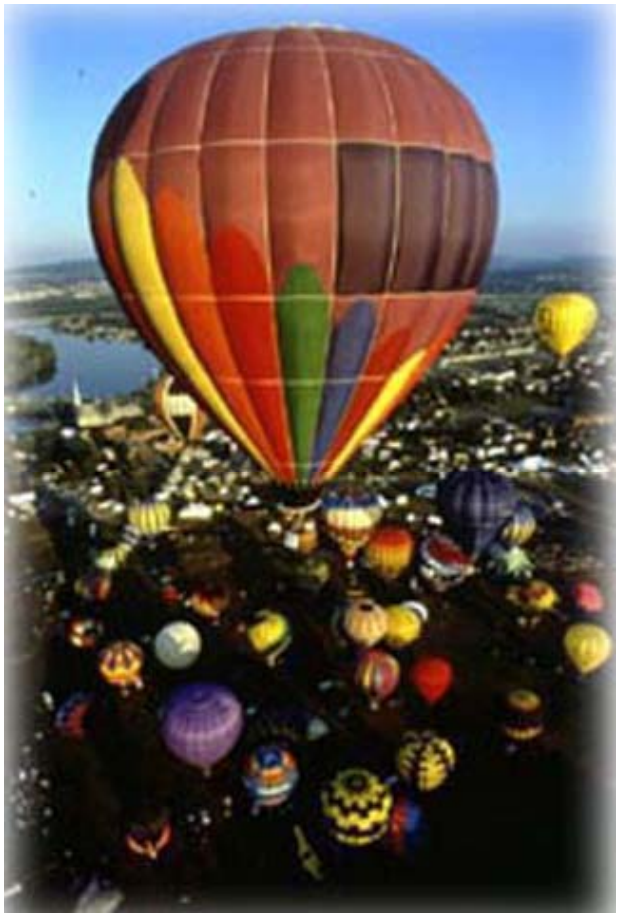
"A moment was all that was necessary to strike off his head, and probably a hundred years will not be sufficient to produce another like it"

- Priestley decomposed Water With Electricity to generate Hydrogen
- The first electrolysis



(1733-1804))

Hydrogen Applications



A century before the Wright brothers historic flight at Kitty Hawk.

Italian poet Vincenzo Monti wrote:

"Never has Nature, subject to the order of its laws suffered such offense from the power of chemistry."

1937

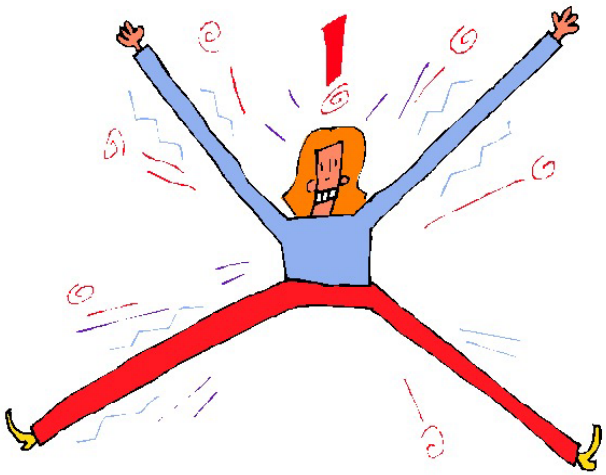
MAY

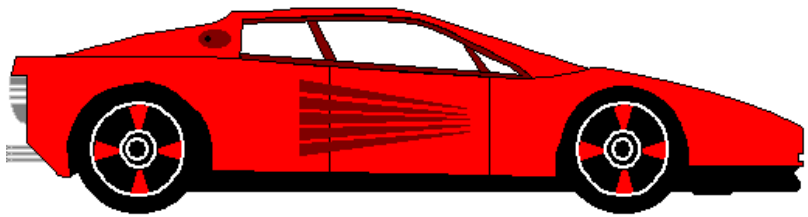
Su	Mo	Tu	We	Th	Fr	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

Hindenburg blows up

The hydrogen-filled Hindenburg, a tragic fireworks display over Lakehurst.

Now we have the H-fuel cell !





I am sure you noticed how This community was divided into two basic grouns

Those who wish to capitalize on the rich diversity of Hydrogen behavior

Accelerator builders - who want to avoid hydrogen like the plague

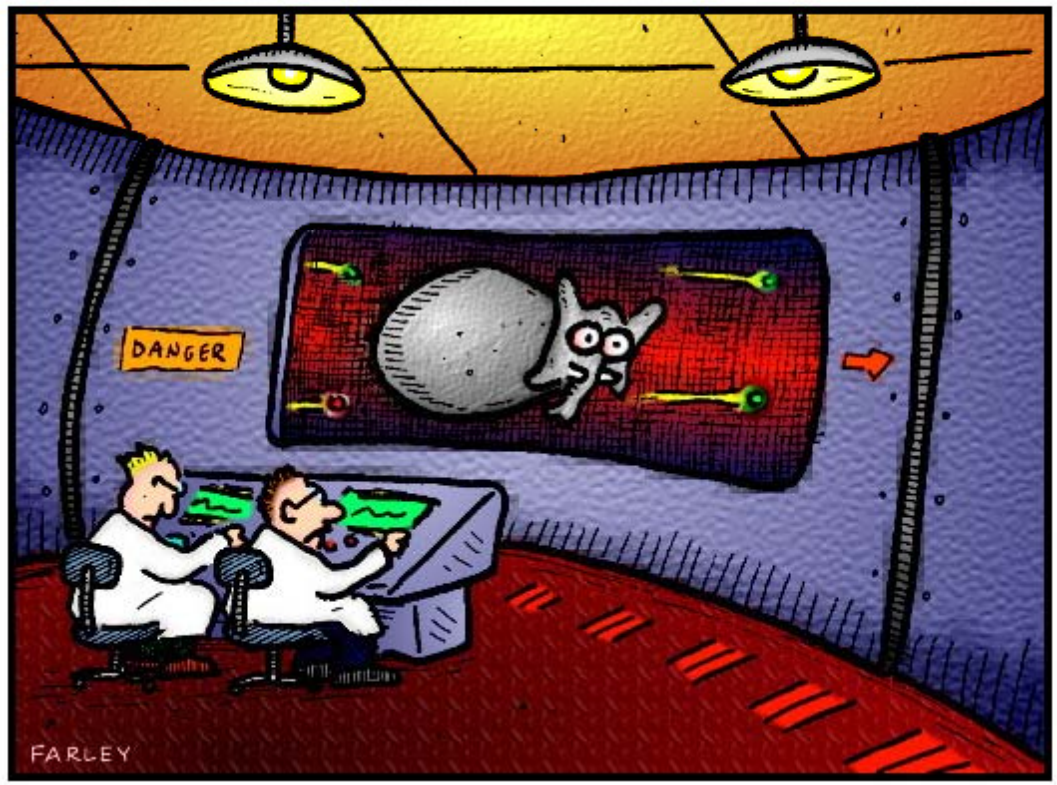
But we both have something in common

Big Dreams !!

H Electronics,
H Electro-Optics
H driven cars by 2010!
H on demand
H economy !

DOCTOR FUN

2006 - 2015



Deep within the atomic supercollider, the search continues for the elusive elephantino.

H in Semiconductors
Applications in Electronics, OptoElectronics

Surprising rich variety of phenomena

H makes donor states and acceptor states

How about making a PN junction?

Fabricate visible LEDs

H passivates unwanted defects by binding to defects

H improves minority carrier lifetime

H passsivation for solar cells

Makes multicrystal Si behave more like single crystal Si

By populating the grain boundaries?

H passivates dangling bonds in Si

H can neutralize donors and acceptors

Hydrogen for Transportion

Why H instead of gasoline?
Air pollution from fossil fuels,
CO_2 emission, greenhouse effect...

H is cleaner fuel
Advances in fuel cell technology
H fuel cells now exist
Even fuel cell powered vehicles exist

Generate electricity from H
To drive electric motor
more efficient than internal combustion engine?

Generation of H

Gasoline has 14 wt % H, Methanol 13%, Methane 25%

….quite a lot !

Distribution system already exists for gasoline

Pollution problems: less?

How to change gasoline, methane directly to H?

- on board reforming

Catalytic steam

$CH_4 + H_2O \rightarrow CO + H$

Oxidation

$CH_4 + O_2 \rightarrow CO + H$

Challenge; Need to clean up H after forming (S, CO)

Electrolysis…..like Priestley

Steam + Reagent (Ca Br) - high temperature….like Lavoisier

Large Scale H Generation for the Economy

50 million tons of H per year made now,
mostly for NH_4 fertilizer
Also for hydrogenated oil, to increase energy output

Need large energy sources to produce H for the future
E.g. 240 GW of electricity needed to displace all gasoline and diesel

World oil production will peak in 5- 10 years
Think about nuclear energy as alternate
Uranium runs out in 50 years

Big Challenge:
Need new infrastructure for H distribution

How to store the H? And in a reversible way

New storage cells for automobile, Target 8 wt % (is that fair?)
Could be lower for special uses, mass transportation?

For comparision, keep in mind
Natural gas, Methane 25 %
Gasoline 14 %

Are GM/DOE setting unrealistic goals?
Is there a fox in the chicken coop?

Many types of materials under investigation
Metal hydrides, PdH 1%, Ti H - 4%

Sodium-Aluminum Hydrides , Ti doping 4 - 5 % - reversible
Lithium hydride - 8%, but not as easily engineered for reversibility

Sodium-Boro-Hydride
Zeolite at 77K
Nanosize powders….few %

Metal organic materials ZnO + benzene

Milled graphite 8%
Activated carbon 2%

Cut up Carbon nano-tubes, doped with T-V-Al some studies 4 %, others 5 - 8%

How to Release the stored H and other challenges

NaAlH - Just add water
(Or vodka)

Heat

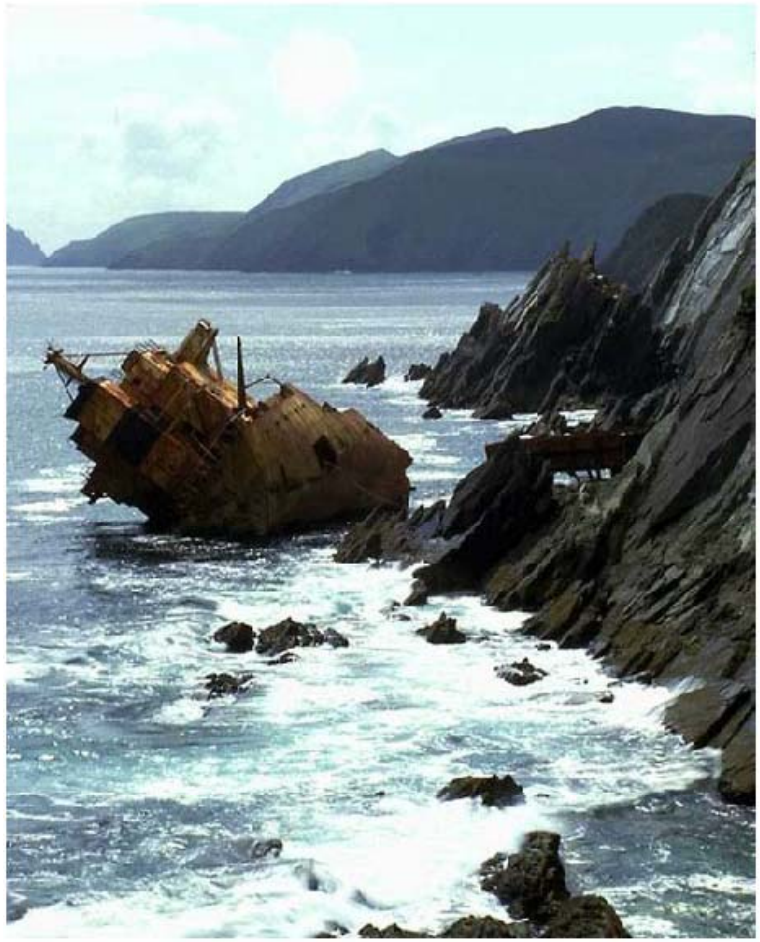
Must deal with recycling the byproduct

How many cycles of storage and release - 500?

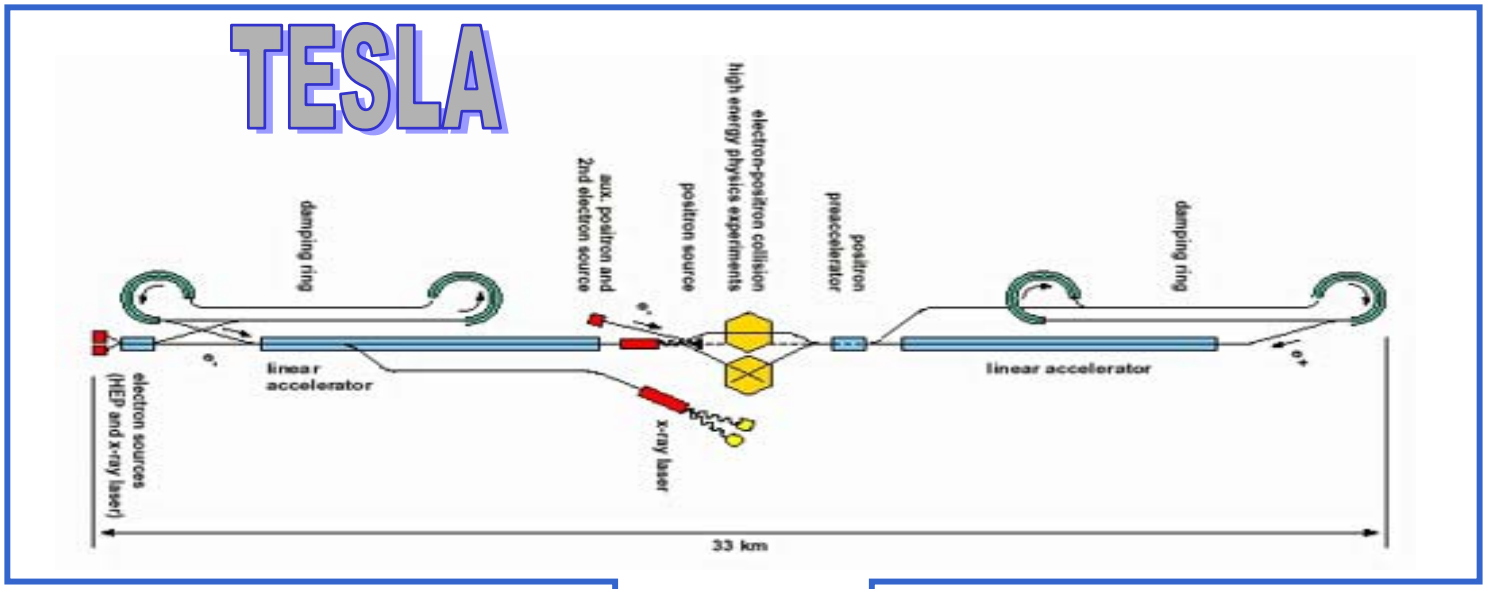
Lots of Studies to Improve Basic Understanding

How and where is H stored?
Mechanisms of H intake and release
Dynamics of H in semiconductors
Vibration spectra, modes
Use muonium as an isotope of H
Basic physics: H provides magnetic couplings,
Yield exotic forms of magnetic behavior and phase transitions

Turn to H as the Trouble-Maker

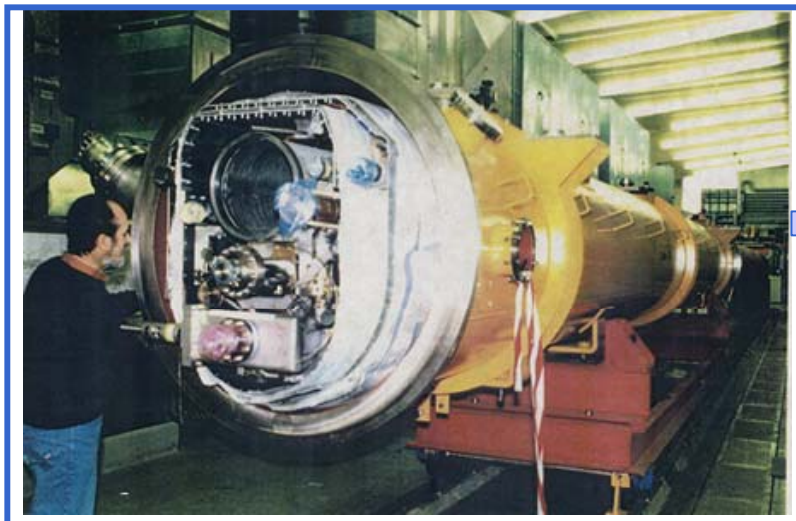


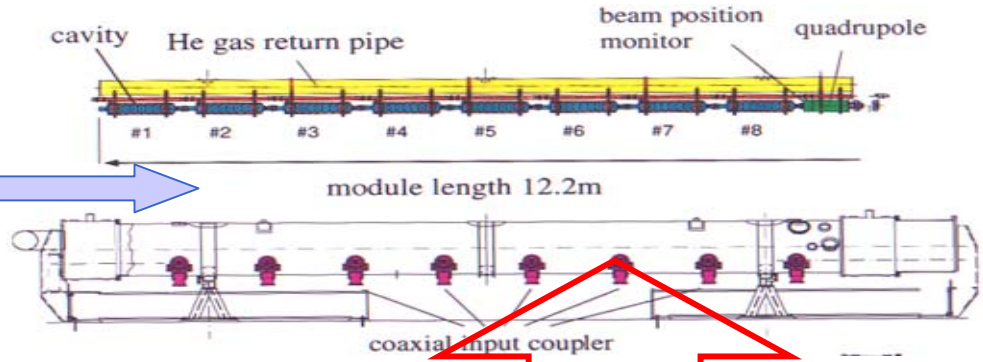
Need to be careful about such mechanisms for Large Systems

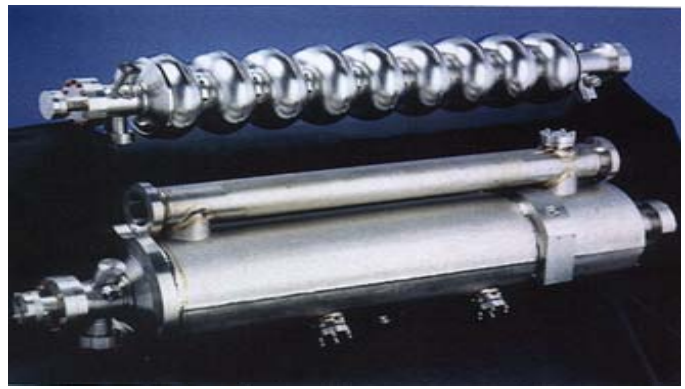

TESLA
damping ring
aux. positron and 2nd electron source
positron source
electron-positron collision high energy physics experiments
positron preaccelerator
damping ring
linear accelerator
linear accelerator
electron sources (HEP and x-ray laser)
x-ray laser
33 km

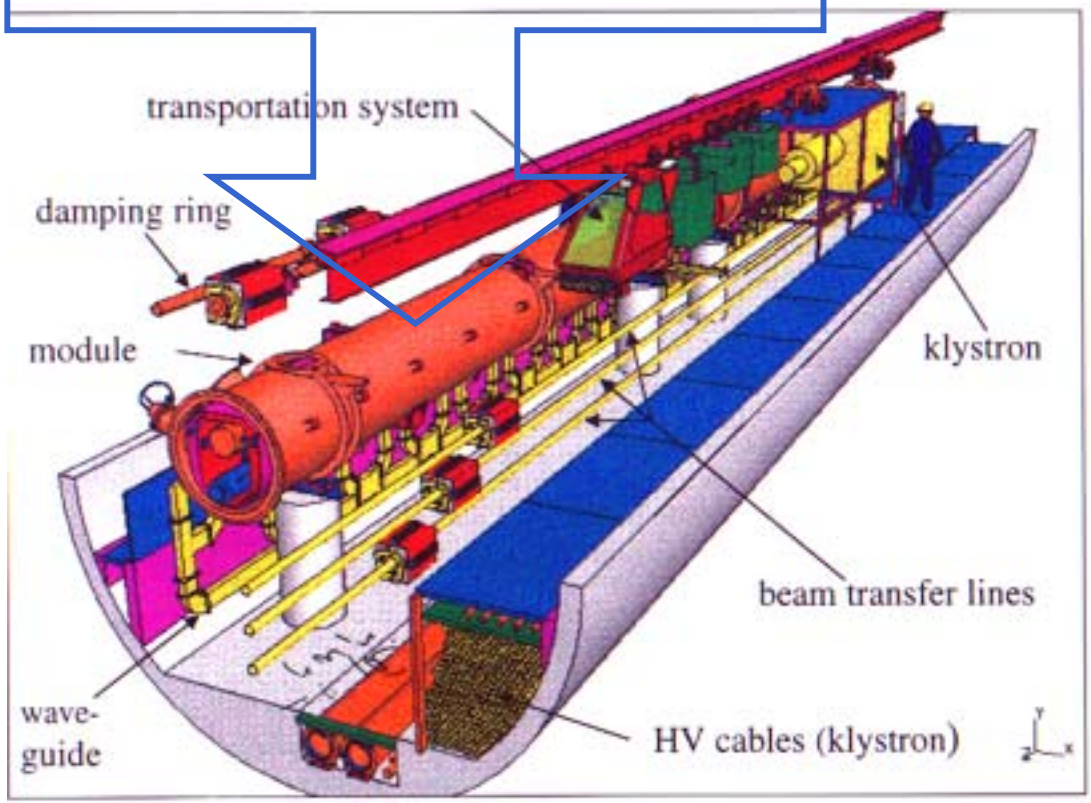
33 km


HAMBURG
NEUMÜNSTER





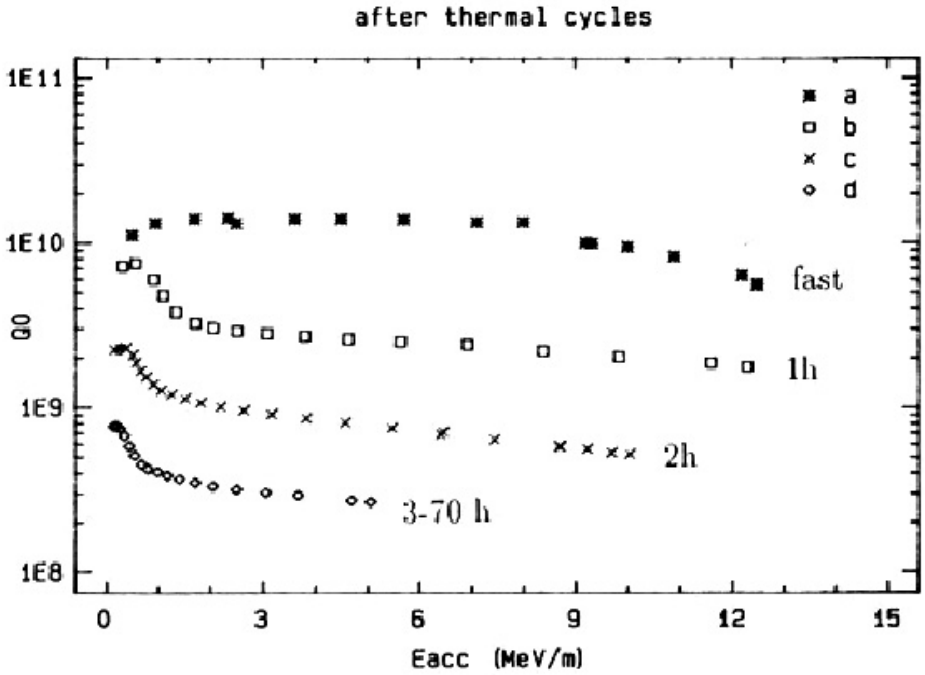




TESLA Cryomodule in Tunnel

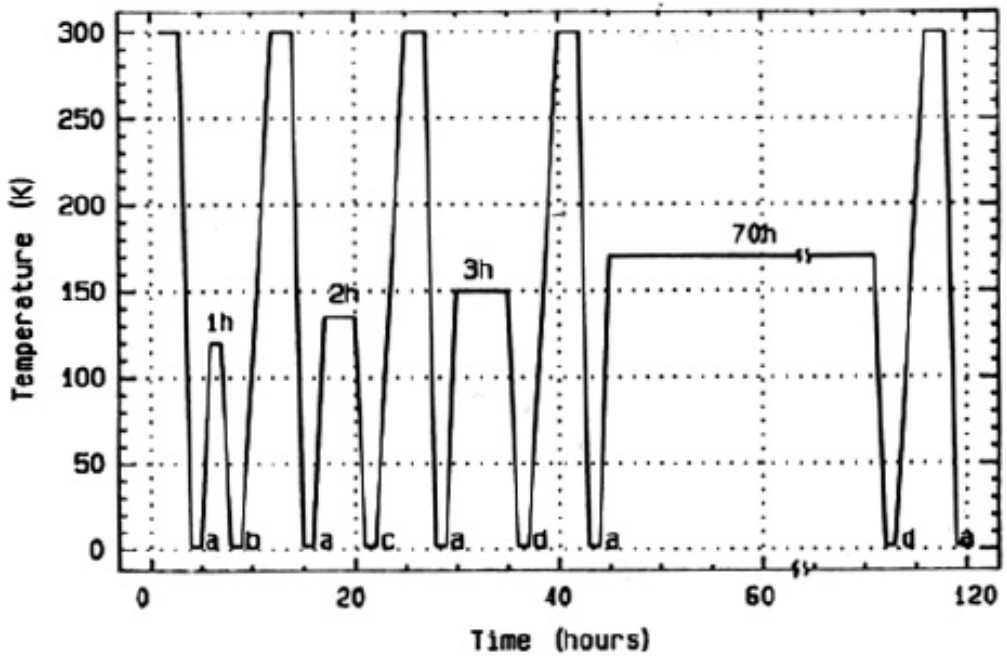
Nb Cavities: H generated by

Etching, grinding,
Electrolysis, Electropolishing



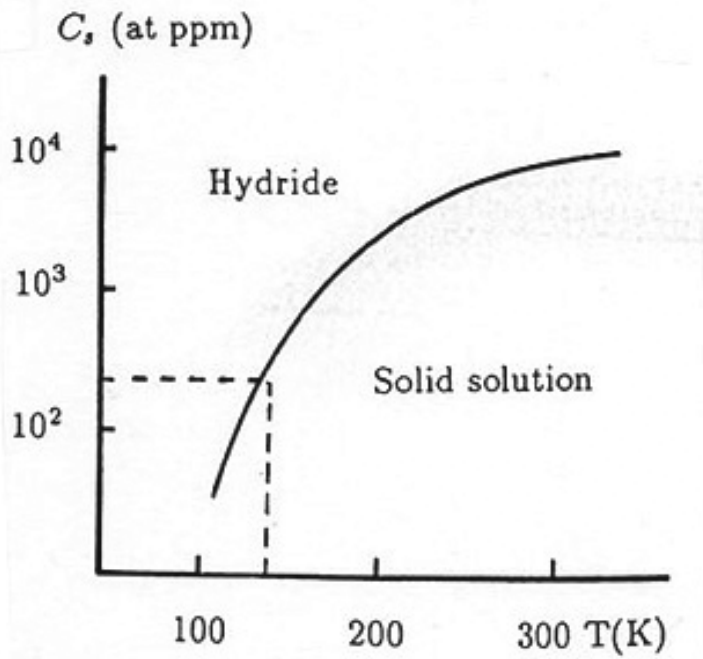
on the 1.5 GHz Cavity

Q-Virus



At room temperature the required conc. to form hydride phases is very high,

Below 150 K
the required concentration drops to 100 at ppm.

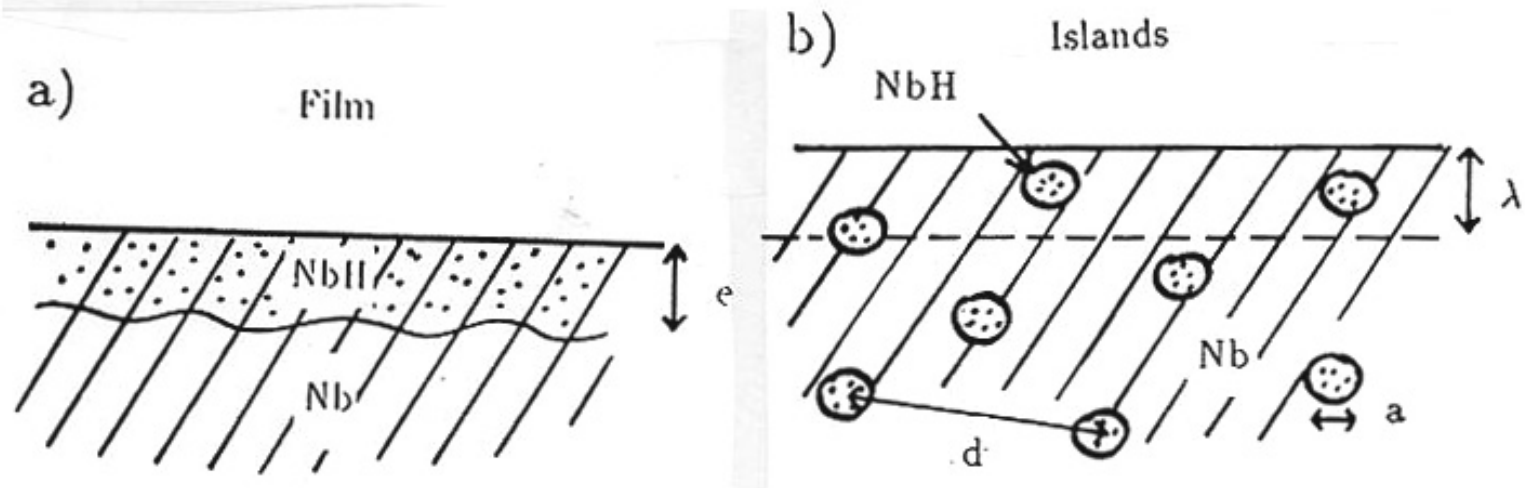


Mechanism and Explanation of Symptons

At room temperature H moves freely,
there is some evidence of surface enrichment

When a cavity is cooled the dissolved hydrogen precipitates as a hydride phase that has high rf loss
Tc of hydride = 2.8 K, Hc = 60 Oersted

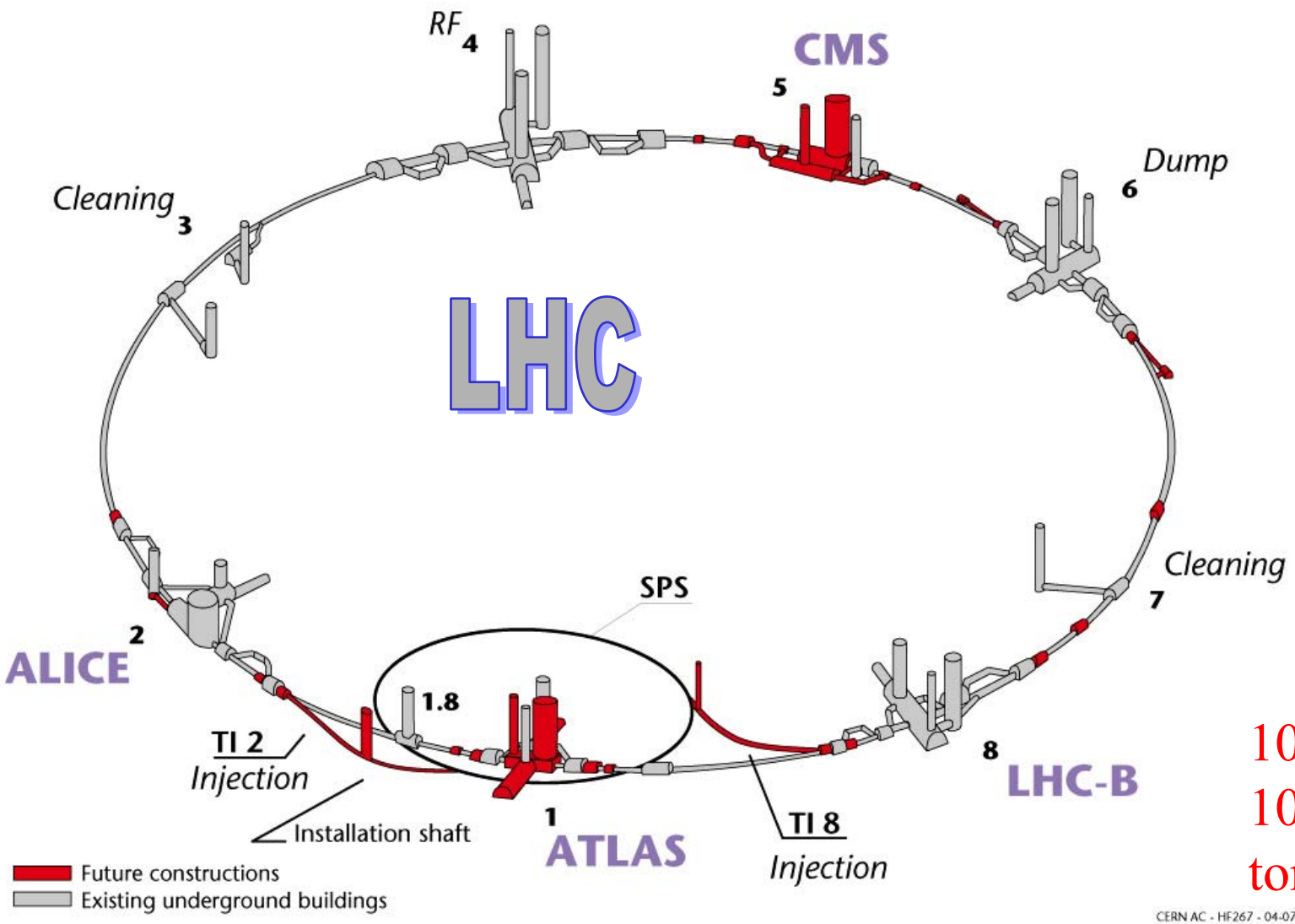
This explains shape of Q vs E curves of Q-disease cavities



H Removed by heating to 700 - 800 heating in vacuum

H Troubles in Large Vacuum Systems

Layout of the LEP tunnel including future LHC infrastructures.



10^{-10}

10^{-12}

torr

H Troubles in Vacuum Systems

One of the main problems of vacuum systems
Get the H out of stainless steel by baking
H loosely bonded to various components of stainless steel alloy

H Desorbed by presence of beam In several ways
Need to keep overall pressure low to decrease number of interactions

- Coulomb scattering, messes up beam quality
- Particle loss, beam loss
- Reduces beam lifetime
- eg10^{-10} beam gas lifetime 1000 hours

Beam ionizes residual gas
Ion bombardment of vac chamber
Raises gas density in vacuum chamber

Ion induced pressure instability, limits current

Creation of ions, accompaned by electrons,
Electrons hit chamber, create secondary electrons, timing causes resonant production
Dense electron cloud around beam, deteriorate beam quality
SR hits vacuum wall -> Photon induced desorption

More H troubles in Cold Systems

Gas condensed on cold walls, loosely bound

Can warm up to restore good conditions,
but beam time lost
Use good surface preparation techniques

Pump like crazy…km of pumps
Ion pumps,
Introduce non-evaporable getter pumps

30 - 90% H is dominant residual gas…
but not so bad for beam

Concluding Conclusions

With intense demands for copious hydrogen on the one hand
And strong need for hydrogen elimination on the other

Accompanied by innovative research on the problems
Hand in hand with basic research
The prognosis for the future can only be exciting...