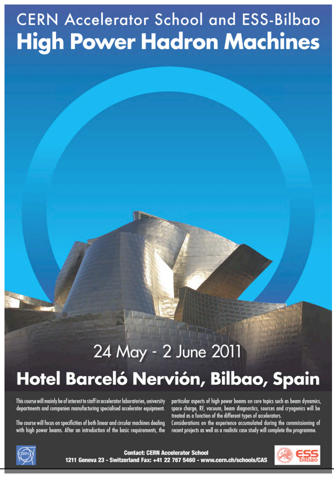
New Target Concepts



Outline

- Why new concepts?
- High-Power targetry for future neutrino facilities
- From ideas to facilities

Further info:
http://cern.ch/efthymio/Wiki Pages/targetry.aspx

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Why New Concepts?

- In accelerators, targets are used as particle converters
  - transform a beam of a known (and easy to produce) particle type to another one
  - Examples:
    - p+A ⟶ p, p-bar, $\pi^{\pm}$, $K^{\pm}$ — secondary beams
    - p+A ⟶ $\pi^{\pm}$, ($K^{\pm}$) ⟶ $\mu^{\pm}$,ν — neutrino (super)beams
    - p+A ⟶ $\pi^{\pm}$ ⟶ $\mu^{\pm}$ ⟶ ν_e,ν_μ — μ-collider
    - p(or ion) +A ⟶ ions(A,Z) — fragmented ions or RIB
- The key factor here is FLUX
  - we tend to study more and more rare physics effects
  - we want to use and make physics with tertiary beams, ν,μ
  - The gain in a collider is quadratic to the source strength (target)
  - Capture and cooling to arrive to small interaction area is important too
- High flux ➔ High-power : MW, or MMW of beam power onto the target

High-Power Targetry

- Impinging beam power – protons : 0.7 - 1 – 2 – 4 MW
  - Present stations
    - 300-400 kW (CNGS, NUMI), 1.6 MW (JPARC in the near future)

- Options for materials
  - Solid targets ?
  - Liquid metal targets ?
  - Hybrid solutions: fluidized powder target?

- Options for beams
  - DC (or CW) beams
  - Pulsed beams

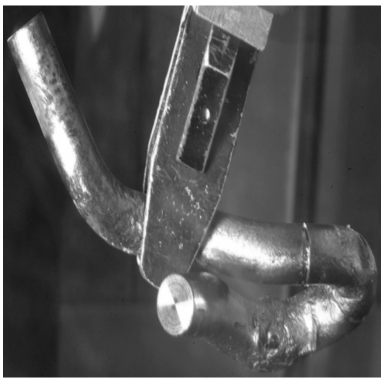
  - Pulsed beams are mandatory for HEP applications (ν-beams), but will also become mandatory for material science experiments from spallation sources (n TOF is an important tool)

High-Power Targetry

- Going to the (M)MW range is not trivial

- The energy deposited by the proton beam can cause major damage to the target material
  - excessive heat
  - structural failures

- ~20% of the proton beam power is deposited into the target material
  - → 0.8 MW for a 4MW proton beam as prposed in the neutrino factory !



Ta-rod after irradiation with 6E18 protons in 2.4 us pulses of 3E13 at ISOLDE – Courtesy: J. Lettry

- **Exercises:**
  - Estimate the temperature increase in a W, Ta, Carbon rod hit by a 4MW beam pulse of 50Hz rep rate, 8 GeV, focused to an area of 0.1 cm^2

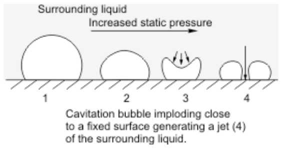
  - What is the resulting tensile stress?

High-Power Targetry

- Issues to consider
  - Thermal management (heat removal)
    - Target melting
    - Target vaporization
  - Radiation damage
    - Change of material properties
    - Lifetime dose against radiation damage (embirlement, cracking,..) of most solids materials is **10^{22} protons/cm^2**
      - 5-14 days in a Neutrino Factory
      - 9-28 days in a Super beam

      } **Exercise** : verify these numbers based on info on Slide ##
  - Thermal shock
    - Beam induced pressure waves

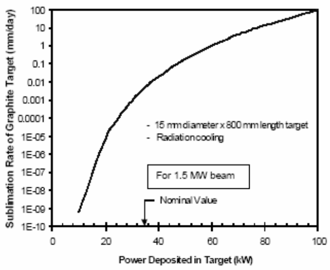
***Cavitation** – wikipedia* = is the formation of empty cavities in a liquid by high forces and the immediate implosion of them.

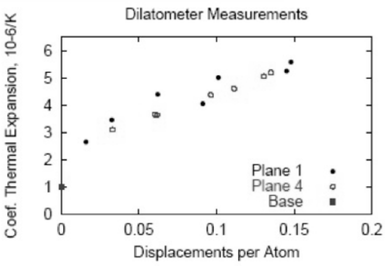


High-Power Targetry

Thermal management

- A carbon target in vacuum sublimates away in 1-day at 4 MW
  - **Sublimation** – wikipedia = refers to the process of transition of a substance from the solid phase to the gas phase without passing through an intermediate liquid phase.
- Mitigation options:
  - Use He atmosphere/cooling?
  - ..but change of properties due to radiation?
- **Exercise:**
  - What is the equilibrium temperature for a carbon target of 1-cm diameter as a function of the beam power assuming only radiative cooling?



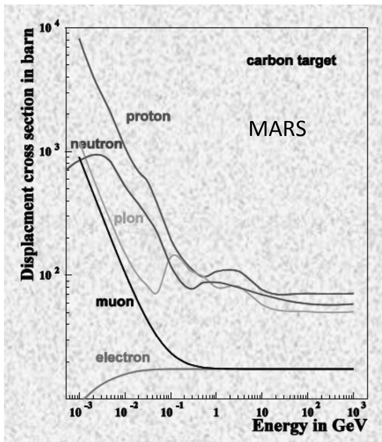


Courtesy: H.Kirk, N.Simos, et al.

High-Power Targetry

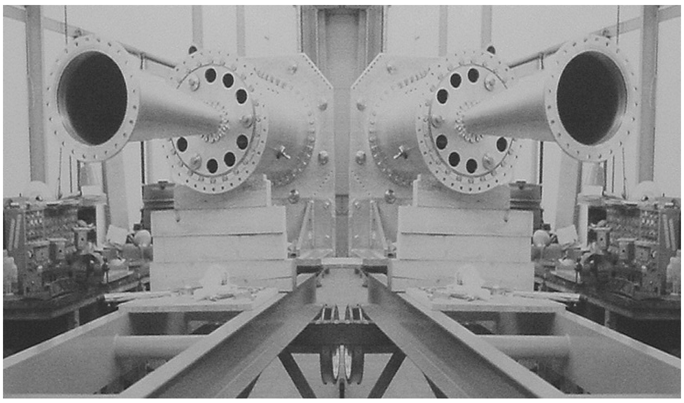
Radiation damage

Courtesy: N.Mokhov – 4th HPTWorkshop, Malmoe 2011



- Radiation damage to materials (change of their crystalline structure, deterioration of their physical properties) is usually analyzed as a function of displacements per atom (DPA)s
  - **DPA** = f(beam parameters, particle type, material type, environment (T, P, …))
  - Typical culprits: low energy (~10 MeV) neutrons – Z^2 dependence of slow particles, He-gas production by high-energy beams
- DPA calculation is now included in all particle simumaiton codes: FLUKA, MARS
- Caution:
  - DPAs cannot be measured (today)
  - The DPA concept is developed and lots of data exist to characterize material resistance on nuclear industry – full body irradiation; not easy to extrapolate for beams where the beam impact is on a small volume of the material

New Target Concepts



FOR NEUTRINO HUNTING

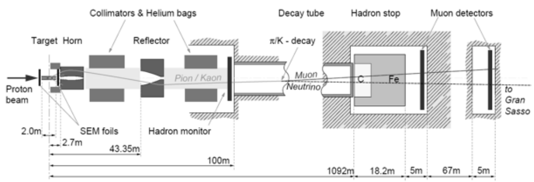
High-Power Targetry – New Concepts

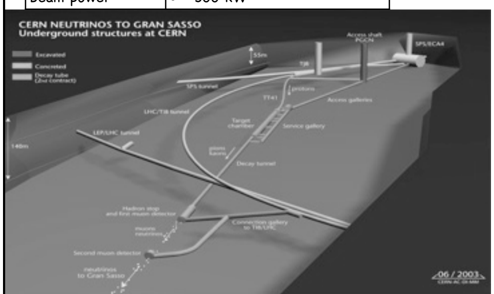
- Future Neutrino Projects
  - From conventional to Super beams
  - The ultimate facilities : Neutrino Factory – Mon collider
  - Unique facility in Europe/CERN : Beta-beams
- Mitigation path for High-Power Targets:
  - Single solid target can barely survive ~1 MW of beam power
  - For going beyond the 1 MW, the target must be replaceable
    - Moving solid targets
    - Liquid targets
    - Fluidized powder targets
    - Granular targets - pebble bed
- Don't forget the beam dump !!!
  - For a high-power installation the corresponding beam dump must be envisaged
    - Typical target length is ~2λp – quite some beam power still to deposit in the beam dump – Exercize: can you calculate it?
    - The beam dump must also be able to asborb the full beam power, at least for the accident case
    - If a beam must be generated after the target like the case of a Neutrino Factory, the beam dump must not intercept the secondary particles → the primary beam must hit at an angle the target

High-Power Targetry – CNGS

- **CNGS is a sub-MW class facility**
  - 350kW operation, target design up to 750kW)

Proton beam parameters	
Energy	400 GeV/c
Cycle length	• 6 seconds • 2 extractions/cycle, 50ms apart
Extraction	• 2.4×10^{13} protons • 10.5 μs long pulse
Beam power	• 500 kW



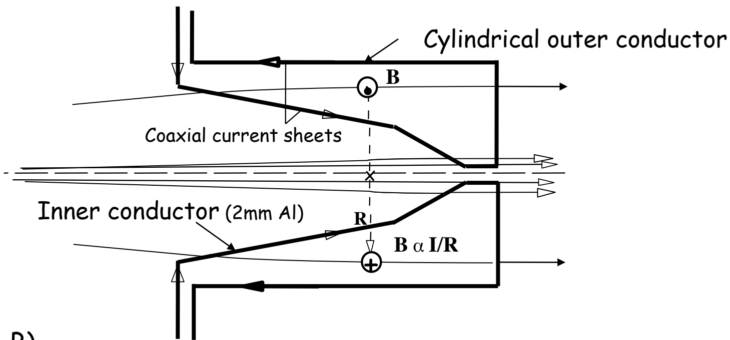


Approved program:
- 4.5×10^{19} protons/year – 5 year program
- ~3.5×10^{11} ν_μ/year at Grand Sasso
- ~3000 CC ν_μ interactions/kt/year at the experiment
- ~2÷3 ν_τ interactions detected/year (OPERA)

Parenthesis – Magnetic Horns

Parenthesis – Magnetic Horns

- **Horns**: focusing element downstream the primary target to capture the charged secondaries (**π**,signle-sign) and focus them towards the experiment where they decay producing **μ**, and then **ν**
- **Pros:** uniform field, focusing on all planes, can be combined to make final beam optics
- **Cons:** high-current, pulsed, radiation and thermal load in the inner conductor, end window



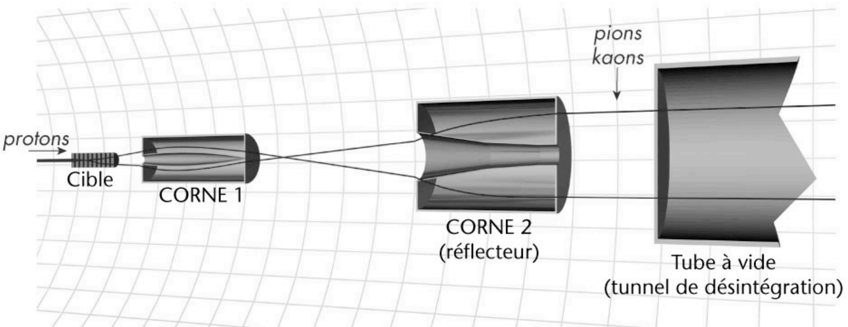
$F = q\,(v \wedge B)$

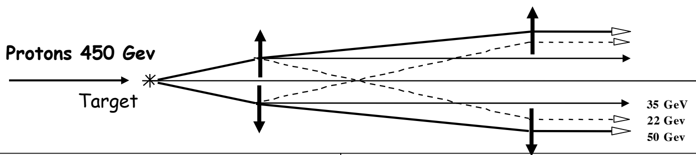
$B = \mu_0 I / 2 \pi R$ CNGS → I=150 kA, R =15.4 mm B = 1.95 Tesla

Parenthesis – Magnetic Horns

Conventional ν-beam optics (CNGS)

- Conventional → Super Beam = difference is **beam power (and rep rate!)**

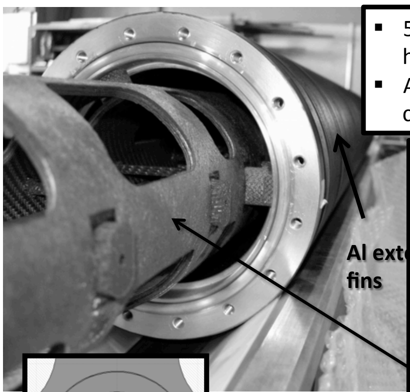


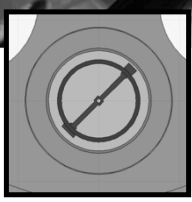


Flux amplification factor in detector (> 10)

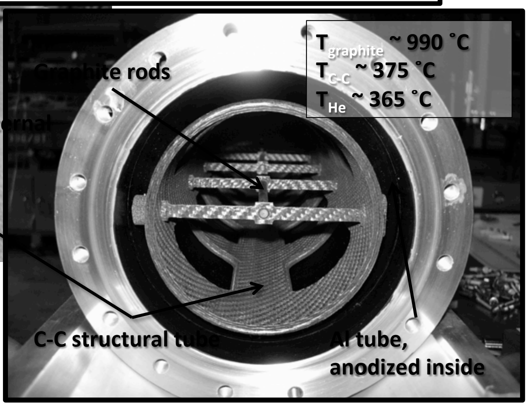
High-Power Targetry – CNGS

- 5 units (1 active + 4 in-situ spare) are hosted in a target magazine
- An additional spare magazine is available in case of complete target failure

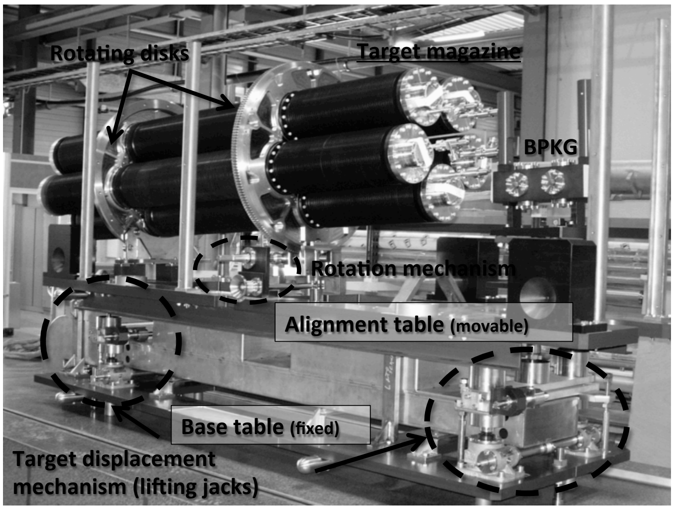




Implementation in FLUKA

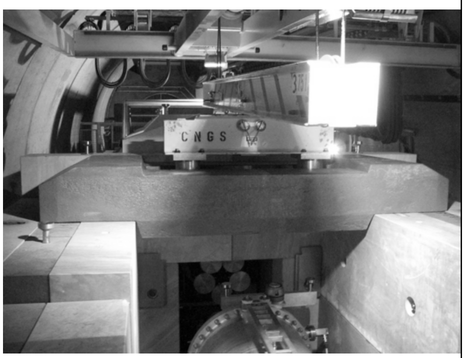


High-Power Targetry – CNGS



High-Power Targetry – CNGS Target Station

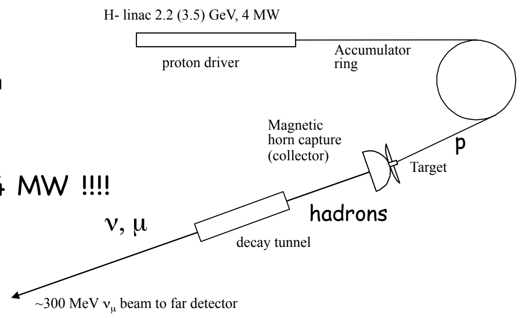
- Optimized shielding
  - Marble – iron – concrete
  - Remote handling

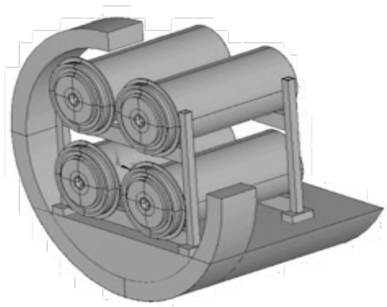


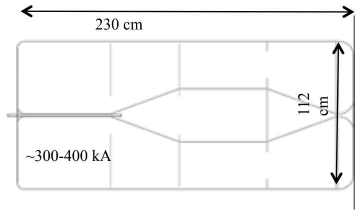
- Remote station for radiation survey in the target chamber

New Target Concepts - ν-Super Beams

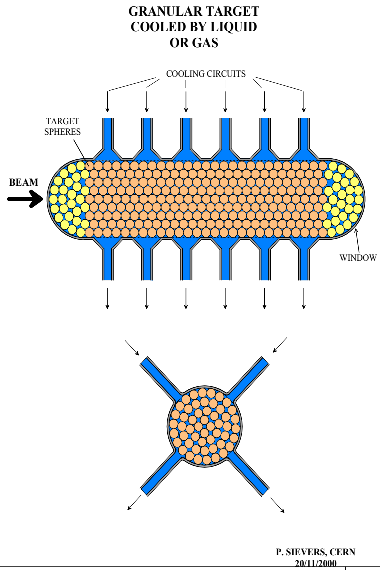
- Proton beam
  - 4.5 GeV; 4 MW
  - 50Hz rep rate – 12.5 Hz/horn
  - Pulse duration : 5.2μs
  - Beam width : 4 mm
- Genius idea: 4 × 1 MW = 4 MW !!!!







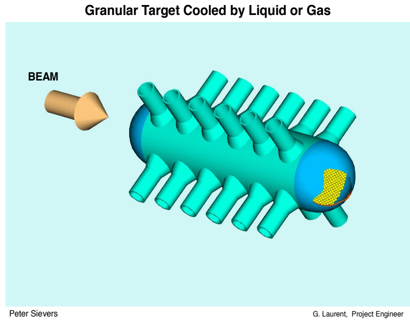
New Target Concepts - Granular target



If the solid target is going to break – why not break it before?

- No stress transmission between the beads
- ...but no heat as well!

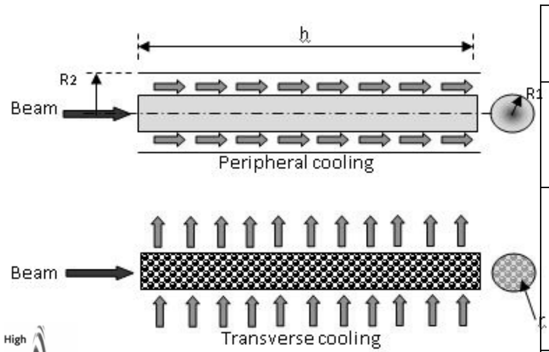
Granular Target Cooled by Liquid or Gas



- Volume of Tantalum beads, d~2mm
- Cooled by liquid or gas

New Target Concepts - ν-Super Beams

Example Comparison (h=0.78m, R_1=12mm, R_2=25mm, r=1.5mm, Q=1.5e9W/m^3, k=200W/mK)



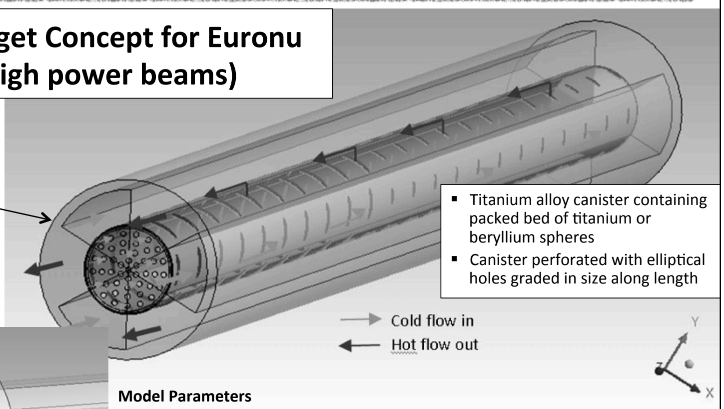
Target→	Solid Target	Packed Bed Sphere
Radial temperature difference (Thermal stress)	$3R1^2Q/16k$ =202.5K	$QR1^2/6k$ =3K
Inertial Stress	Significant (stress waves due to rapid heating and stress oscillation due to off centre beam)	Small (stress waves small due to fast expansion time, off centre beam not a problem due to segmentation)
Surface area for heat exchange	$2\pi R1h=0.058m^2$	$\pi R1^2h/$ $(4/3\ \pi r^3)$* $4\ \pi r^2=0.71m^2$
Flow area	$\pi(R2^2-R1^2)$ = 1.5e-3m^2	R1h/2 =4.68e-3m^2

Courtesy: C. Densham et al, RAL

New Target Concepts - ν-Super Beams

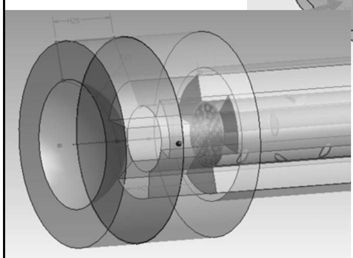
Packed Bed Target Concept for Euronu (or other high power beams)

Packed bed canister in parallel flow configuration



- Titanium alloy canister containing packed bed of titanium or beryllium spheres
- Canister perforated with elliptical holes graded in size along length

Packed bed target front end



Model Parameters
Proton Beam Energy = 4.5GeV
Beam sigma = 4mm
Packed Bed radius = 12mm
Packed Bed Length = 780mm
Packed Bed sphere diameter = 3mm
Packed Bed sphere material : Beryllium or Titanium
Coolant = Helium at 10 bar pressure

Courtesy: C. Densham et al, RAL

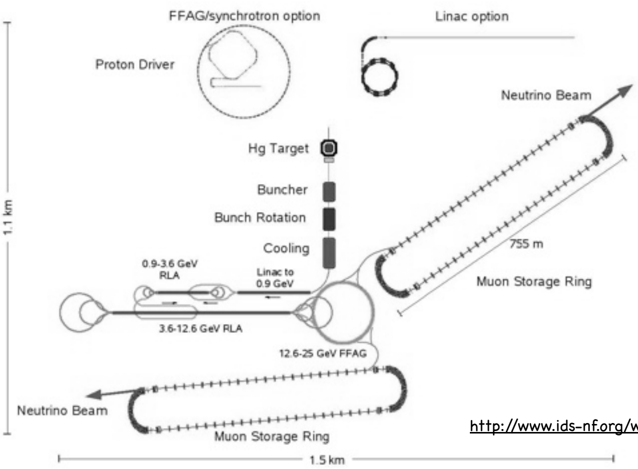
New Target Concepts - ν-Super Beams

- Packed bed target – issues to consider
  - Cooling efficiency – He flow
  - Interface with Horn(s)
  - Upstream /downstream target windows

  - Realistic test with beam?
    - HiRadMat Facility @ CERN !!!

New Target Concepts - ν-Factory

p+ C (int) → $\mu^{\pm}$ (capture, accelerate, store, decay) → ν_{μ}, ν_e

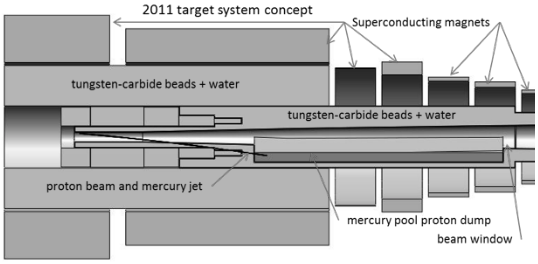


http://www.ids-nf.org/wiki

ν-Factory Target Station

- Desire ≈ 10^{14} μ/s from ≈ 10^{15} p/s (≈ 4 MW proton beam).
  - Highest rate μ^+ beam to date: PSI μE4 with ≈ 10^{9} μ/s from ≈ 10^{16} p/s at 600 MeV.
- Low-energy π's collected from side of long, thin cylindrical target.
- Collects both signs of π's and μ's,
  - Shorter data runs (with magnetic detector).
- Solenoid coils can be some distance from proton beam.
- ≳ 4-year life against radiation damage at 4 MW.
- Liquid mercury jet target replaced every pulse.
- Proton beam readily tilted with respect to magnetic axis.
  - Beam dump (mercury pool) out of the way of secondary π's and μ's.

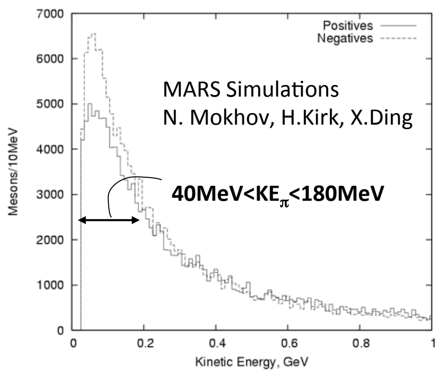
Present Target Concept

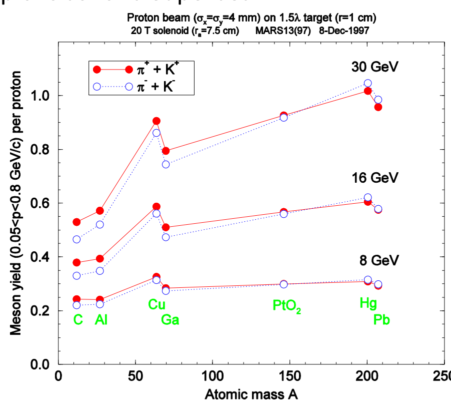


Shielding of the superconducting magnets from radiation is a major issue.
Magnet stored energy ~ 4 GJ!

New Target Concepts - ν-Factory

- **Why Hg?**
  - Only pions with 40 < KE_π < 180 MeV are useful for later RF bunching/ acceleration of their decay muons.
- Hg better than graphite in producing low-energy pions
  - graphite is better for higher energy pions as for a Superbeam

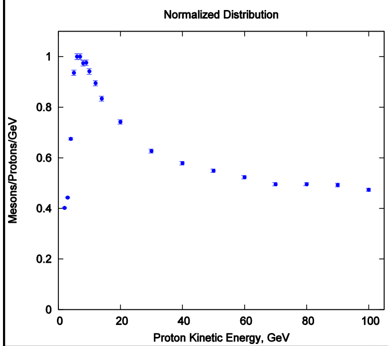




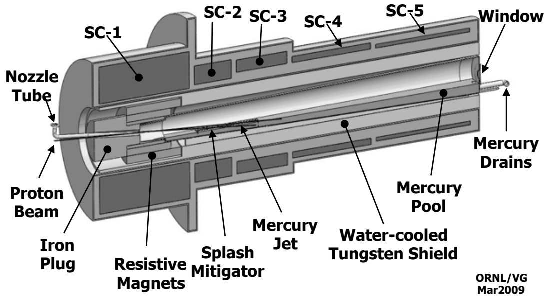
New Target Concepts - ν-Factory

Optimization studies

- Energy : E~8GeV
- Beam-jet x-sing angle
  - Beam below jet
  - Beam-jet angle ~27mrad



Neutrino Factory Study 2 Target Concept

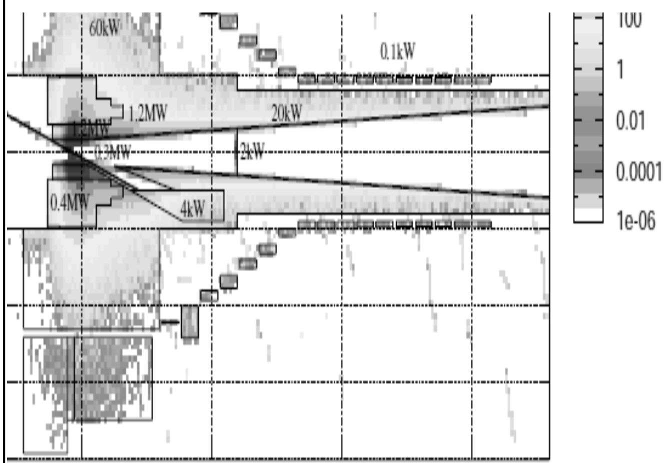


NF capture via solenoids

- Both sign pions → muons
- Avoid disadvantages of horns
- Radiation is the major issue

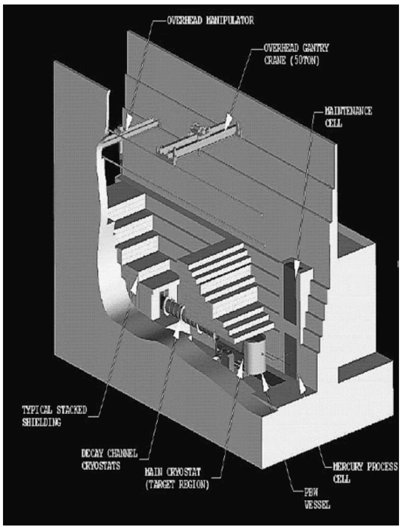
New Target Concepts - ν-Factory

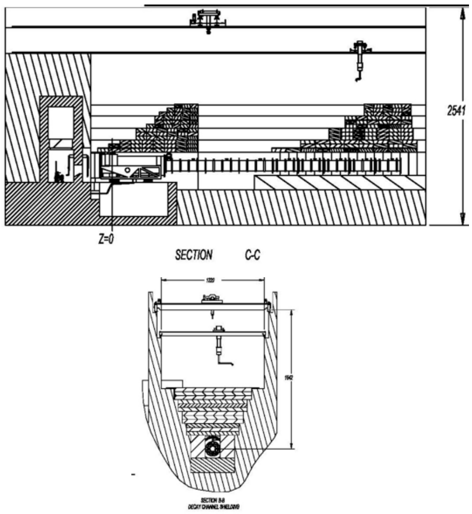
FLUKA Simulation – *Courtesy : J.Back*



- ~2.4 MW must be dissipated in the shield.
- Some 800 kW flows out of the target system into the downstream beam-transport elements.
- Total energy deposition in the target magnet string is ~ 1 kW @ 4k.
- Peak energy deposition is about 0.03 mW/g.

ν-Factory Target Station



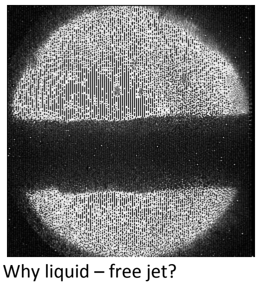


ν-Factory Target Baseline

- Liquid target (Hg) option as baseline for a(M)MW target station

Statue : A. Calder Parit 1937

Mercury fountain, Funtació Juan Miró, Barcelona - Spain



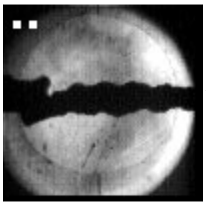
- Free jet technique pioneered at CERN and BNL
- Video: **MERIT Experiment**
  - 14 GeV proton beam
  - 1.3 1013 protons.pulse
  - 5T B-field

- Why liquid – free jet?
  - Free jet avoids using an upstream beam window
  - Radiaition damage to the target not an issue
  - V=20m/s replaces the target for 50Hz operation
    - Each proton pulse sees a new target !
  - Passive cooling by removing the liquid

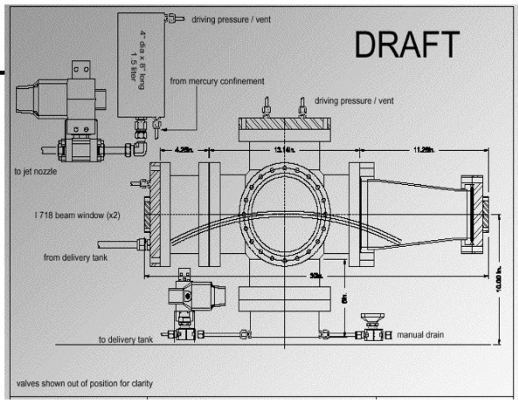
  But:
  - Handling a radioactive chemically dangerous liquid not trivial

- Note: contained liquid target (like in spallation sources) not an interesting option due to the need of beam windows

Hg Jet test a BNL E-951



Protons

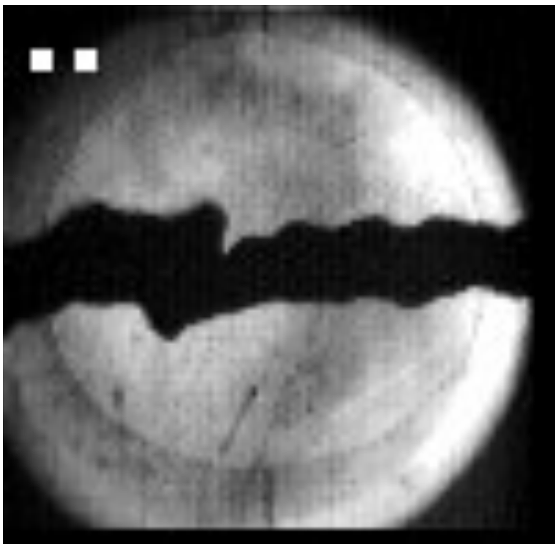


P-bunch: 2.7×10^{12} ppb
100 ns
t_o = ~ 0.45 ms
Hg- jet : diameter 1.2 cm
jet-velocity 2.5 m/s
perp. velocity ~ 5 m/s

Proton beam on mercury Jet

Recorded at 4kHz
Replay at 20 Hz

1 cm



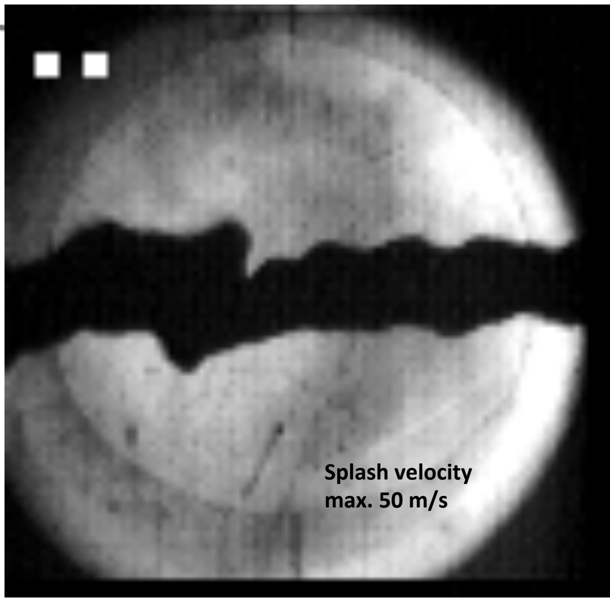
BNL AGS
Proton beam

Hg jet
v=2 m/s

Proton beam on mercury Jet

Recorded at 4kHz
Replay at 20 Hz

1 cm



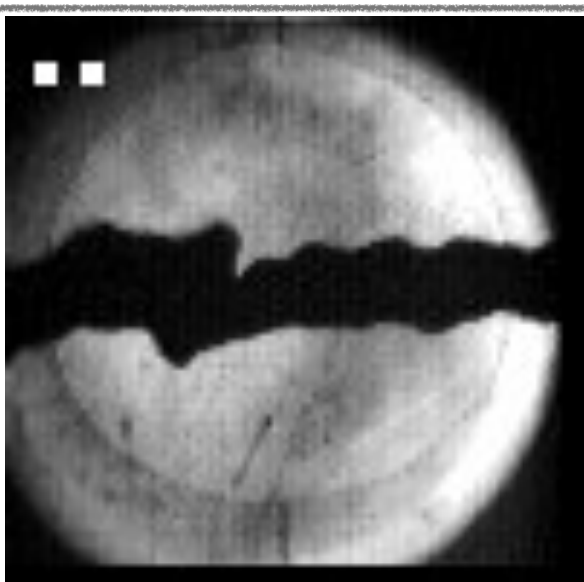
BNL AGS Proton beam

Hg jet v=2 m/s

I. Efthymiopouls - CERN | May 31, 2011 | 31

Proton beam on mercury Jet

1 cm



BNL AGS Proton beam

Hg jet v=2 m/s

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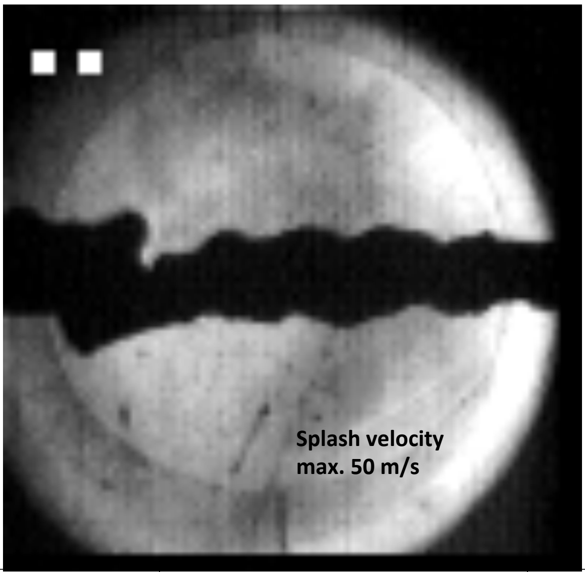
Proton beam on mercury Jet

1 cm

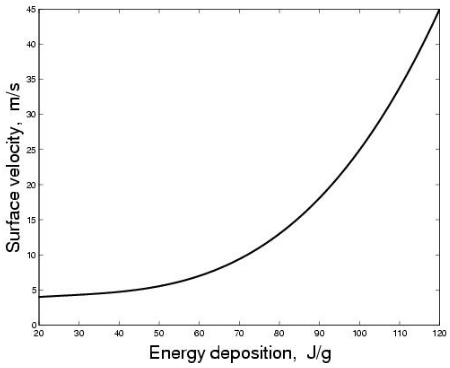


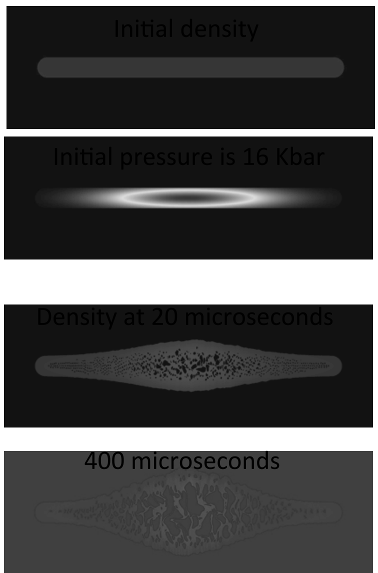
BNL AGS
Proton beam

Hg jet
v=2 m/s

Simulation : beam induced shocks

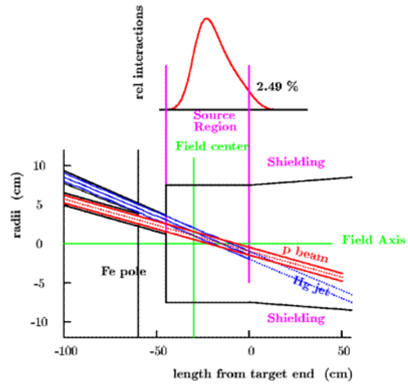
Frontier code,
R.Samulyak et al.

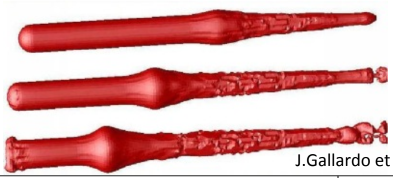




Magneto-hydro-dynamics (MHD)

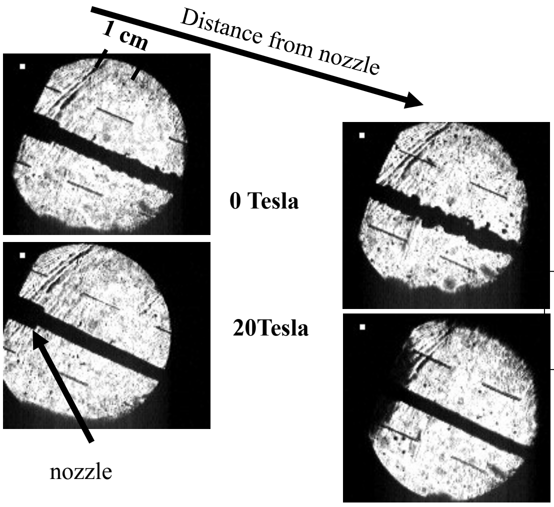
- 20-T solenoid DC-field for sec. particle capture
- Moving mercury target sees dB/dt
- Farady's law → eddy currents induced
- Magnetic field acts back on current and mercury jet
- Forces: repulsive, deflecting, quadrupole deformation, …

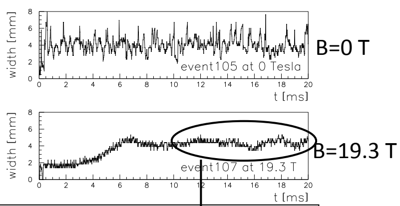




J.Gallardo et al., PAC01, p.627

Previous experimental results





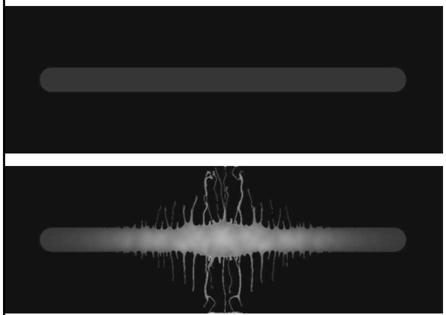
Jet smoothing

(damping of Rayleigh surface instability)

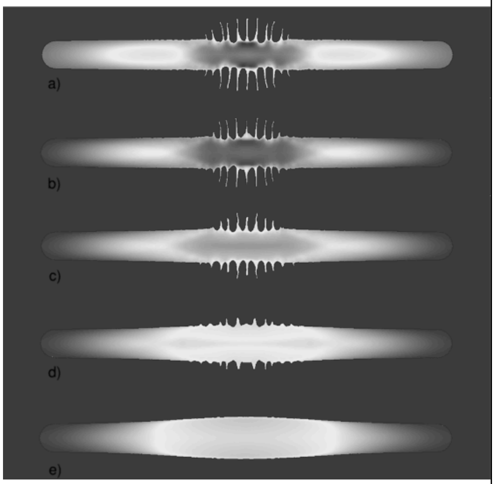
15 m/s mercury jet injected into 20 T field.

MHD Stabilization

Frontier code, R.Samulyak et al.



- Simulation of the mercury jet – proton pulse interaction during 100 microseconds, B = 0
- damping of the explosion induced by the proton beam

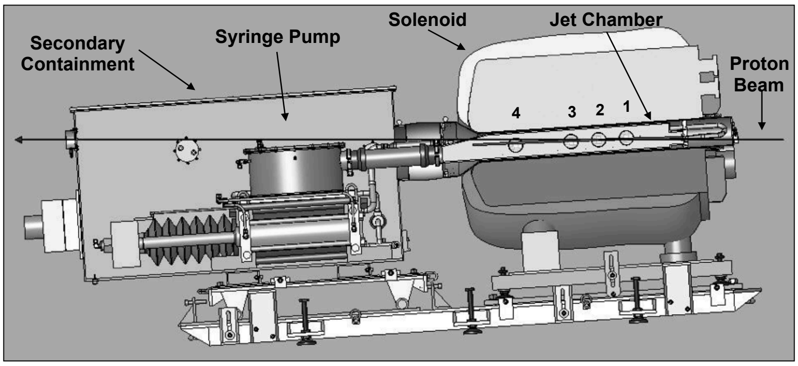


a) B = 0 b) B = 2T c) B = 4T
d) B = 6T e) B = 10T

The MERIT Experiment

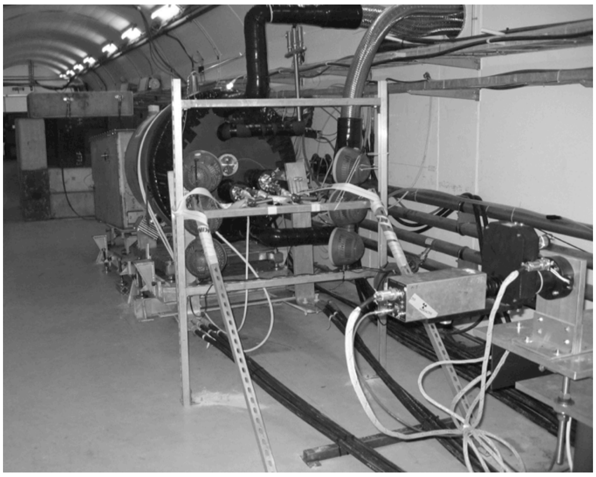
Proof-of-principle demonstration of a mercury jet target at 20 m/s in a strong magnetic field, with proton bunches of intensity equivalent to a 4 MW beam.

- Most data collected with jet velocity of 15 m/s.

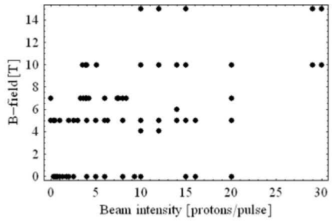


- The experiment was specially designed to avoid opening the primary container (Hg-wet volume) at CERN
  - 180deg bend in the Hg-delivery piping system upstream; likely cause of deterioration in the quality of the Hg-jet

The MERIT Experiment



- 3.310^{13} protons
- 15 T field
- **115kJ** of beam power



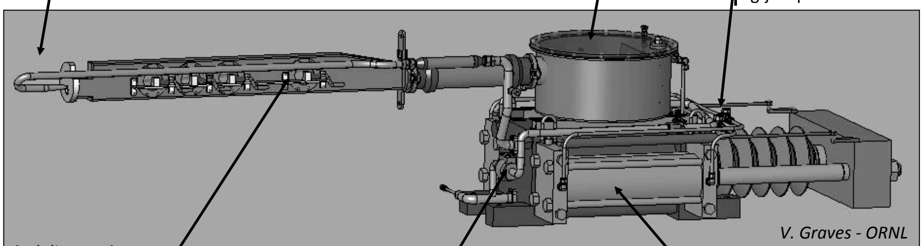
MERIT – Experimental setup

- Hg-delivery system

1” pipe to transport mercury to nozzle at upstream end of primary vessel

Reservoir; collects the mercury returning at the end of the injection/jet

Local electronics ; Hg-jet speed control



Optical diagnostics mounted on the outside of the primary vessel

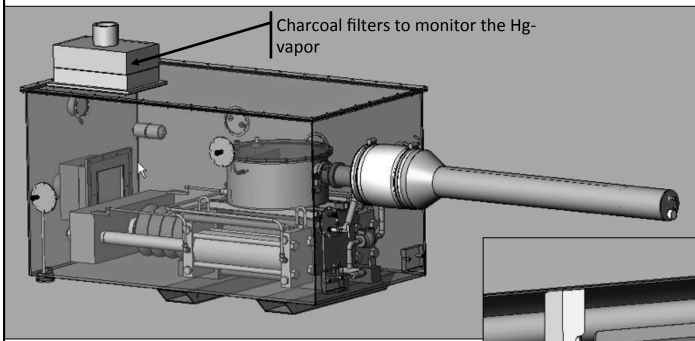
Pressure monitor of Hg-supply pipe during pulsing

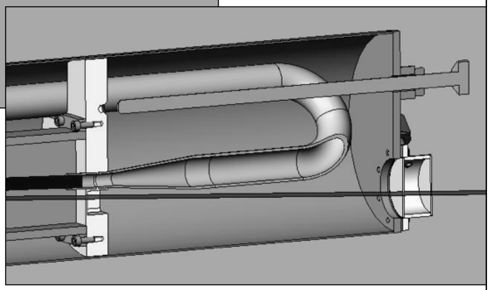
Syringe system; can produce a Hg-jet for 15s (~23lt)

System parameters:
- Piston velocity : 3.0 cm/s
- Hg jet duration of 12s ;
- Drive cylinders: 15-cm diam, 45 lt/min, 2.1 MPa

MERIT – Experimental setup

- Hg-delivery system



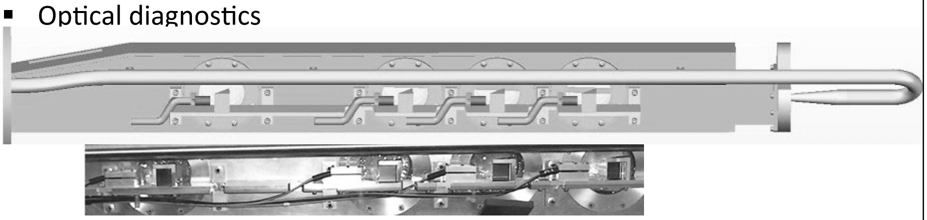


V. Graves - ORNL

- Double container (primary and secondary) for safety requirements
- Upstream window; Ti6AlV4, double pressurized wall to detect failure

MERIT – Experimental setup

- Optical diagnostics

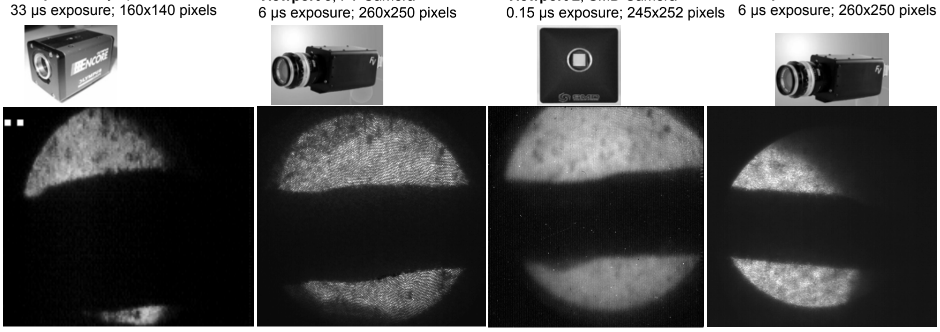


Viewport 4, Olympus
33 μs exposure; 160x140 pixels

Viewport 3, FV Camera
6 μs exposure; 260x250 pixels

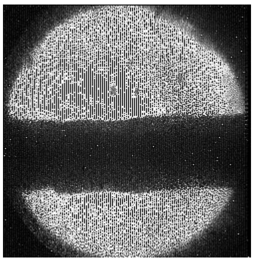
Viewport 2, SMD Camera
0.15 μs exposure; 245x252 pixels

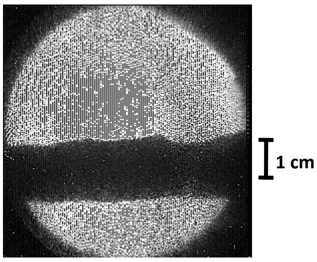
Viewport 1, FV Camera
6 μs exposure; 260x250 pixels

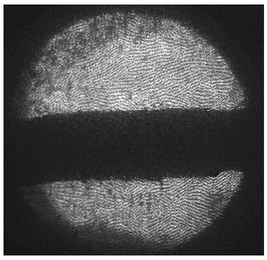


Nov. 11, 2007, Shot # 17020, 8 bunches, $6x10^{12}$ protons, 7 Tesla, 15 m/s jet

The MERIT Experiment







Run 103
- **14 GeV/c**
- **$1.6*10^{13}$ protons/pulse**
- **B-field 5 T**

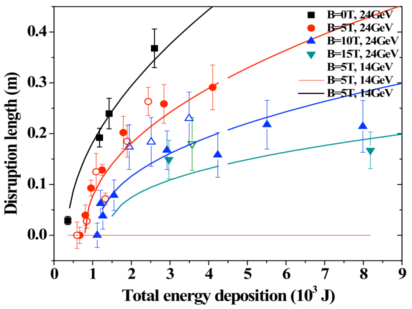
Run 119
- **14 GeV/c**
- **$1.6*10^{13}$ protons/pulse**
- **B-field 5 T**

Run 214
- **14 GeV/c**
- **$1.2*10^{13}$ protons/pulse**
- **B-field 10 T**

- **Images were recorded at 2000 frames/second.**
- **Play-back is about 400 times slower.**
- **Splash velocities up to 60 m/s observed.**

I. Efthymiopouls - CERN | May 31, 2011 | 43

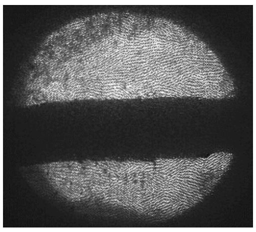
The MERIT Experiment



Key results #1

- Hg-jet disruption mitigated by magnetic field
- 20 m/s jet operation allows up to **70Hz** operation with beam

Hg-jet - beam impact
4×10^{12} protons, 10T field

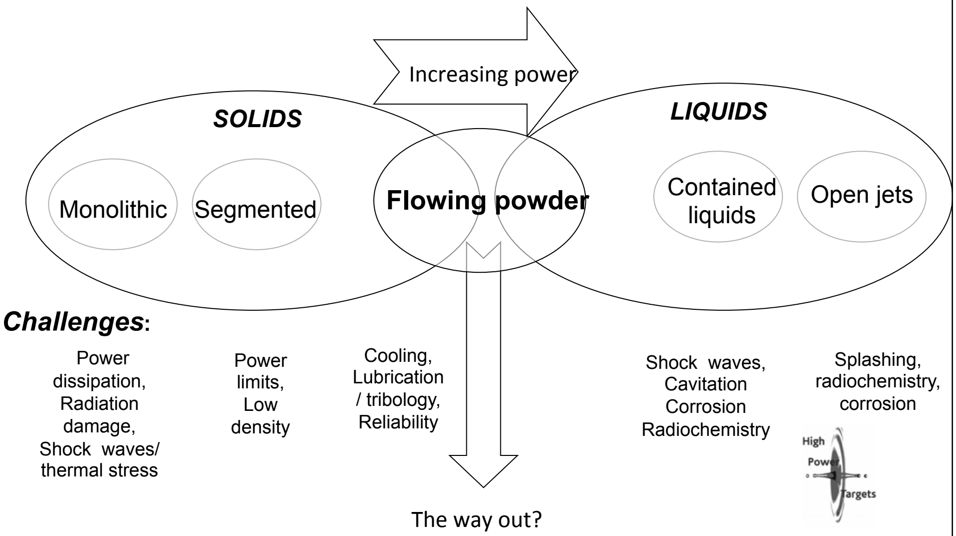


Key results #2

- Disruption threshold: **$>4 \times 10^{12}$ protons@14 GeV, 10T field**
  - **115kJ** pulse containment demonstrated
  - **8 MW** capability demonstrated

I. Efthymiopouls - CERN | May 31, 2011 | 44

New Target Concepts – ν-Factory



Courtesy: C. Densham et al, RAL

New Target Concepts – ν-Factory

- Flowing power target – an attractive alternative
- Shock waves
  - Material is already broken – intrinsically damage proof
  - No cavitation, splashing or jets as for liquids
  - high power densities can be absorbed without material damage
  - Shock waves constrained within material grains, c.f. sand bags used to absorb impact of bullets
- Heat transfer
  - High heat transfer both within bulk material and with pipe walls - so the bed can dissipate high energy densities, high total power, and multiple beam pulses
- Quasi-liquid
  - Target material continually reformed
  - Can be pumped away, cooled externally & re-circulated
  - Material easily replenished
- Other
  - Can exclude moving parts from beam interaction area
  - Low eddy currents i.e. low interaction with NF solenoid field
  - Fluidised beds/jets are a mature technology
  - Most issues of concern can be tested off-line -> test programme

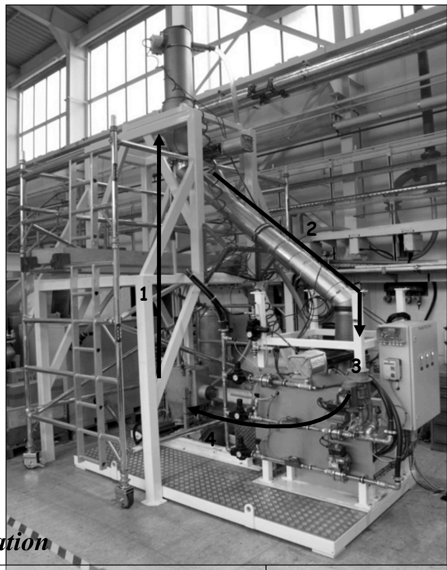
New Target Concepts – ν-Factory

- Flowing power – R&D issues to consider
- Is a dense material such as tungsten powder flowable?
- Is it fluidisable (it is much heavier than any material studied in the literature)?
- Is it possible to generate a useful fluidised powder geometry?
- Is it possible to convey it
  - in the dense phase?
  - in the lean phase?
- What solid fraction is it possible to achieve?
  (a typical loading fraction of 90% w/w solid to air ratio is not good enough!)
- How does a dense powder jet behave?

- Difficult to model bulk powder behaviour analytically
- Physical test programme underway:
  - Test bed at RAL
  - Test with beam (MERIT like) in HiRadMat @ CERN

New Target Concepts – ν-Factory

- Flowing powder – test stand at RAL
- Powder
  - Rig contains 100 kg Tungsten
  - Particle size < 250 microns
- Total ~10,000 kg powder conveyed so far
  - > 100 ejection cycles
  - Equivalent to 20 mins continuous operation
- Batch mode
  - Test out individual handling processes before moving to a continuous flow loop

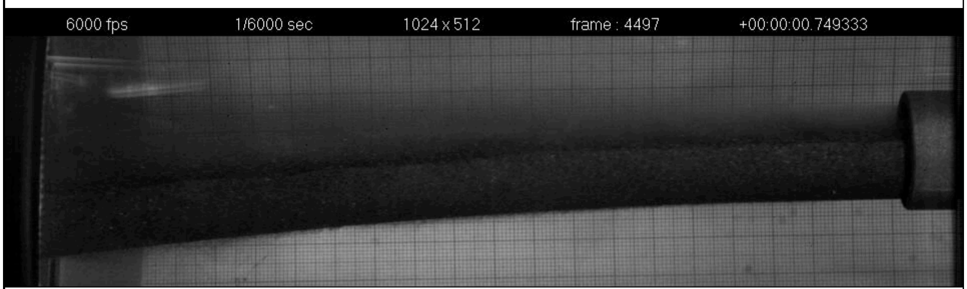


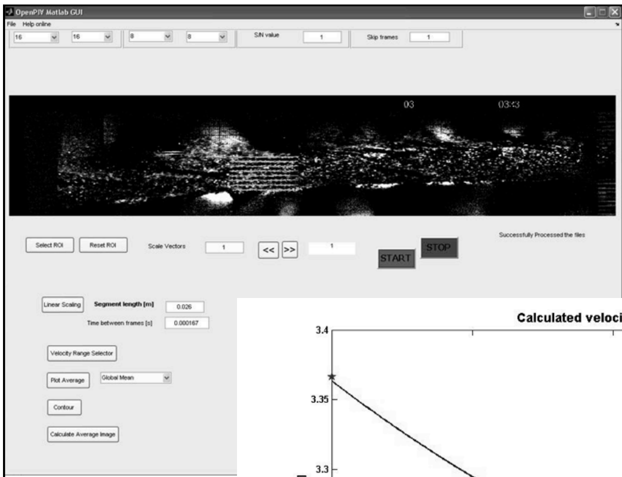
1. ***Suction / Lift***
2. ***Load Hopper***
3. ***Pressurise Hopper***
4. ***Powder Ejection and Observation***

Open Jet

Open Jet

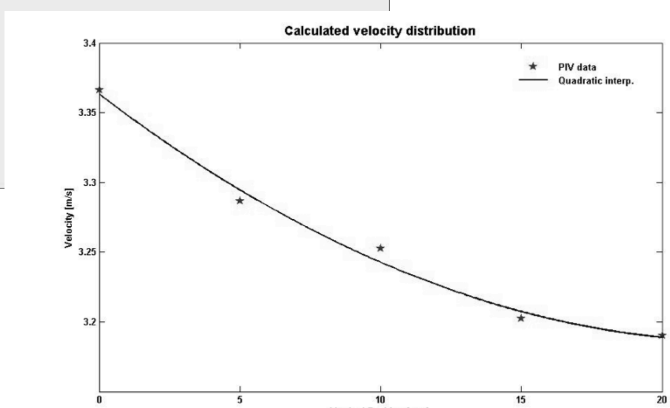
Driving pressure = 2 bar
Jet velocity = 3.7 m/s
Material fraction ~ 42%





Particle Image Velocimetry

velocity distribution required to determine bulk density

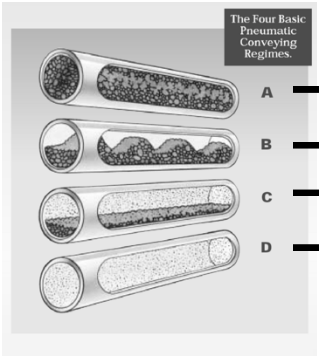


Pneumatic Conveying Regimes

Low Velocity

Increasing Driver Pressure

High Velocity



A. Solid Dense Phase

- Pipeline full of material, 50% v/v
- Low velocity
- Not yet achieved in our rig – further work

B. Discontinuous Dense Phase

- Pipeline almost full of material
- Unstable "plug flow"
- Intermediate velocity

C. Continuous Dense Phase

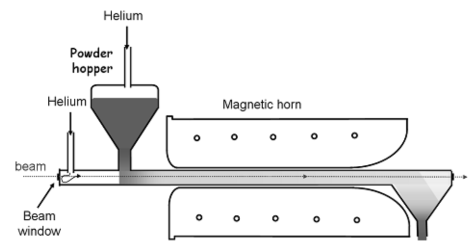
- Pipeline part full of material
- Stable continuous flow
- Intermediate velocity

D. Lean Phase

- Low fraction of solid material
- High velocity = erosion!
- Used in vacuum recirculation line

A Flowing Powder Superbeam Target?

- Potential powder target materials
  - Tungsten (W), ρ_{solid}19.3 g/cc
  - Titanium? (Ti), ρ_{solid}4.5 g/cc
  - Nickel (Ni), ρ_{solid}8.9 g/cc
  - Titanium Oxide (TiO_2), ρ_{solid}4.2 g/cc



Schematic layout of a flowing powder superbeam target

New Target Concepts – ν-Factory

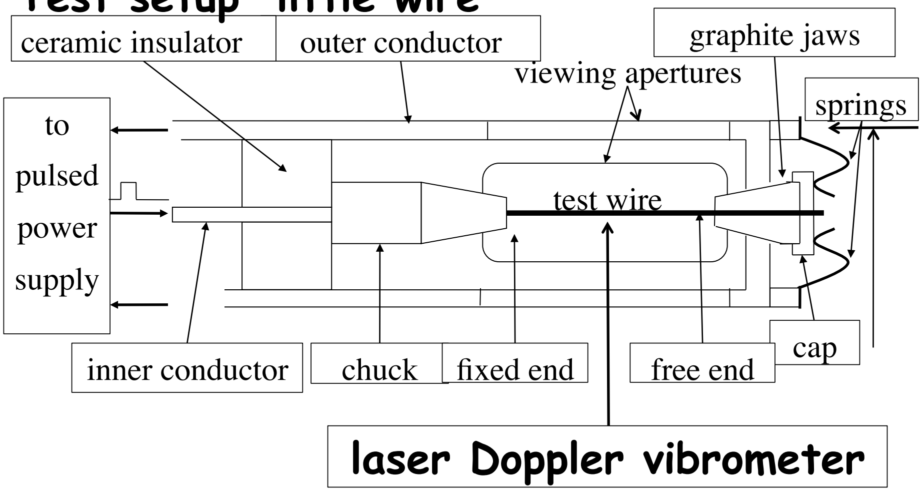
- Liquids or flowing powder have shown to work, however for a final solution important drawbacks must be overpassed
- Have we said the final word on solid targets?

- R&D at RAL continues pursuing the idea of a movable solid target system
  - Initial thoughts were to use many solid targets with radiation cooling.
  - A solid target is a relatively simple and well tried solution with minimum problems of radiation contamination compared to liquid or powder targets.

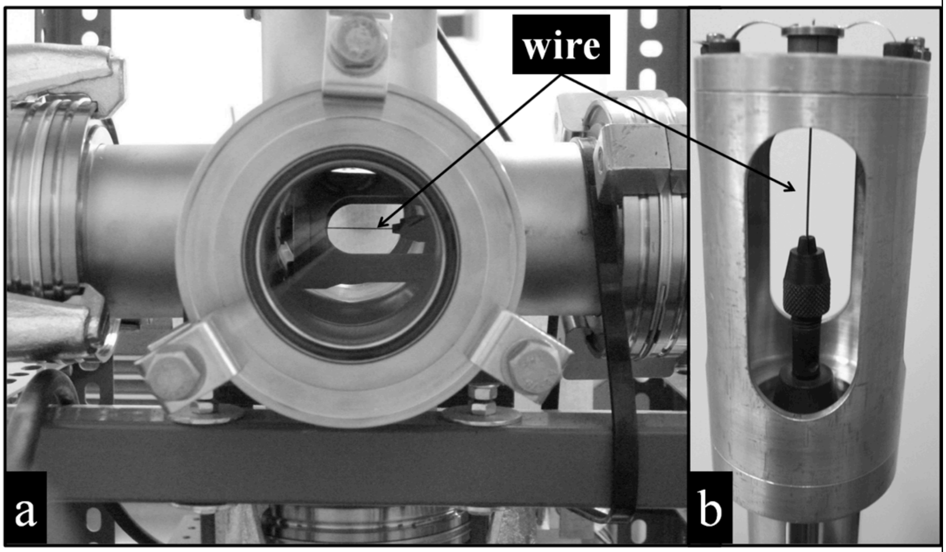
  Issues to consider:
  - To move target bars into the beam at 50 Hz (one every 20 ms) is difficult.
  - The target needs to be ~2 cm diameter to reduce the temperature and the stress., but the larger diameter reduces the pion yield.
  - And above all the thermal shock must be managed!

New Target Concepts – ν-Factory

Test setup "little wire"

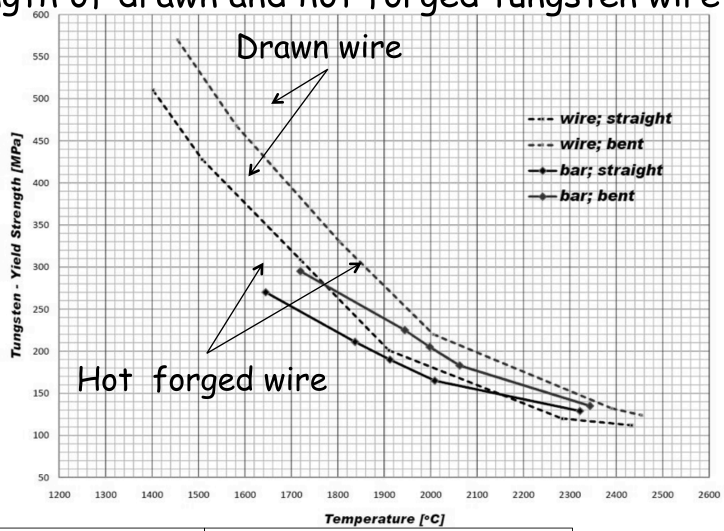


Solid Wire Test Setup @ RAL

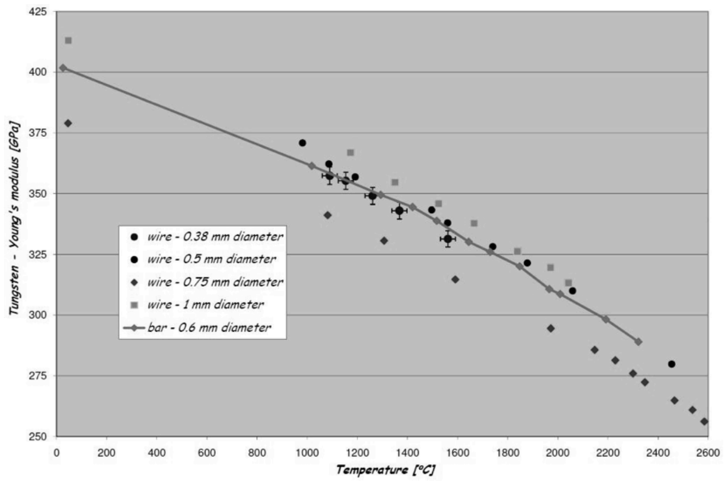


Solid Wire Test Setup @ RAL

- Strength of drawn and hot forged tungsten wire



Solid Wire Test Setup @ RAL

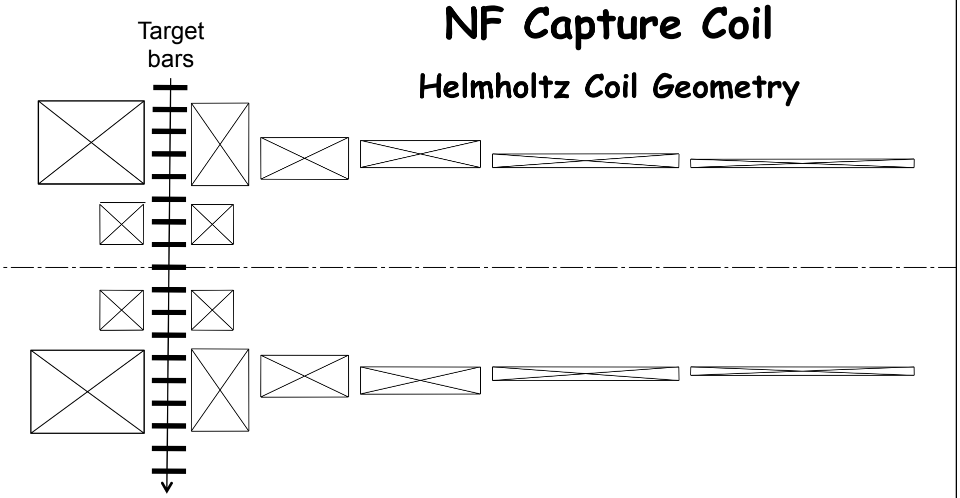


Measured Young's modulus versus temperature for various wire diameters. The 0.6 mm diameter wire is hot forged and centreless ground.

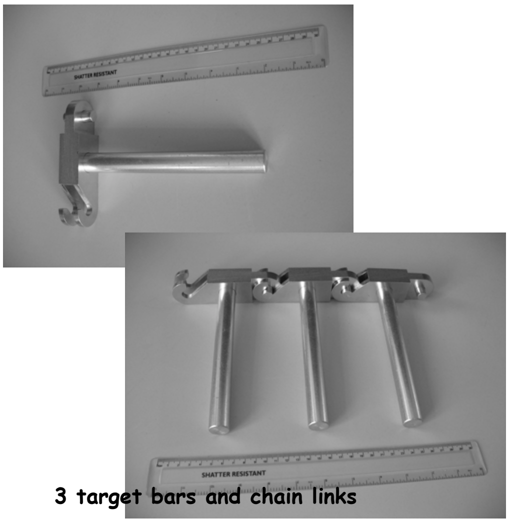
New Target Concepts – ν-Factory

NF Capture Coil

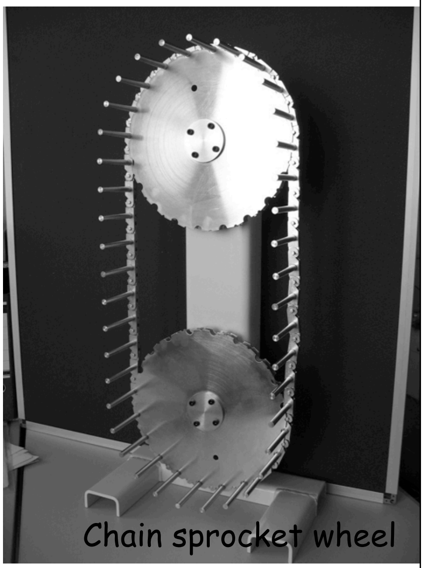
Helmholtz Coil Geometry



Full sized model of a target bar and chain link in mild steel



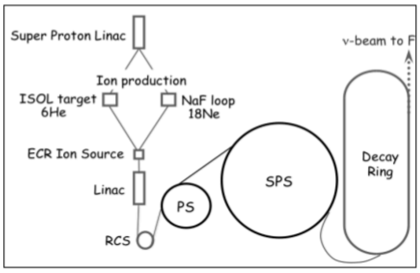
3 target bars and chain links



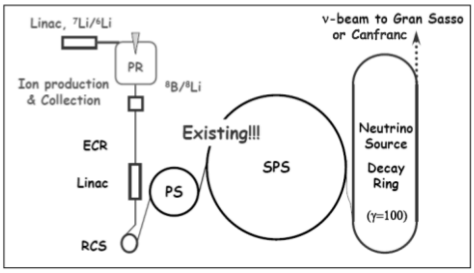
Chain sprocket wheel

New Concepts - Beta-Beams

Detector @ Frejus (130 km)



Detector @ Canfranc/Gran Sasso (~ 700 km)



Courtesy: E. Wildner, EUROnu

- Beta Beams: acceleration of beta active isotopes
- Unique facility for CERN:
  - Reuse of CERN existing accelerators and infrastructure ⇒ cost reduction
  - Known technologies
  - Ion Production: ISOL technique, ion production ring, molten salt loop
- Synergies with Super beam to Frejus for enhanced physics reach

β-beam: isotope production

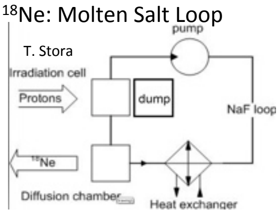
Courtesy: E. Wildner, EUROnu

Type	Accelerator	Beam	I_{beam} mA	E_{beam} MeV	P_{beam} kW	Target	Isotope	Flux s^{-1}	Ok?
ISOL & n-converter	SPL	p	0.1	$2\ 10^{3}$	200	W/BeO	6He	$5\ 10^{13}$	
ISOL & n-converter	Saraf/GANIL	d	15	40	600	C/BeO	6He	$5\ 10^{13}$	
ISOL	Linac 4	p	6	160	700	19F Molten NaF loop	18Ne	$1\ 10^{13}$	
ISOL	Cyclo/Linac	p	10	70	700	19F Molten NaF loop	18Ne	$2\ 10^{13}$	
ISOL	LinacX1	3He	> 170	21	3600	MgO 80 cm disk	18Ne	$2\ 10^{13}$	
P-Ring	LinacX2	7Li	0.160	25	4	d	8Li	$?1\ 10^{14}$	
P-Ring	LinacX2	6Li	0.160	25	4	3He	8B	$?1\ 10^{14}$	

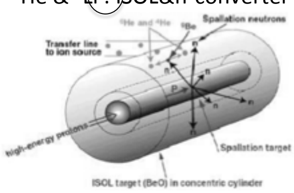
Experimentally OK
On paper may be OK
Not OK yet

Baseline option (^{6}He and ^{18}Ne). ^{18}Ne production experiments in 2011.
^{8}Li can be produced in sufficient quantities with ISOL & n-converter

^{18}Ne: Molten Salt Loop

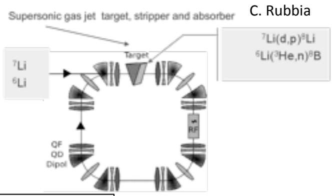


^{6}He & ^{8}Li : ISOL&n-converter



^{8}B & ^{8}Li : Production Ring

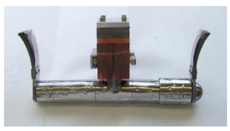
C. Rubbia

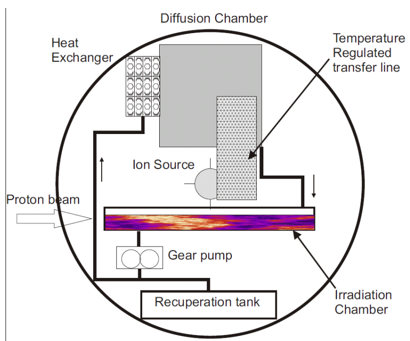


New Target Concepts – β-Beam

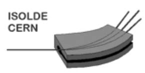
- Test of a molten Pb/Bi target loop at CERN ISOLDE for Beta Beams
- ISOLDE facility offer a possibility to test a Molten Pb/Bi target

Static Pb/BI target used at ISOLDE

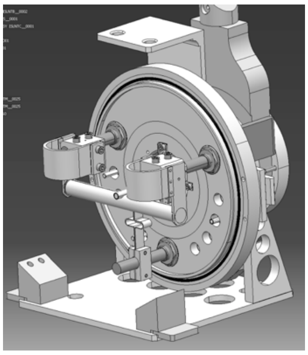


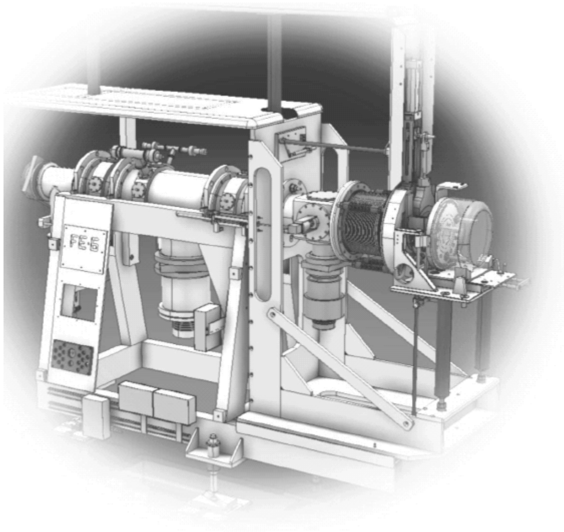


Loop compatible with present Fron End



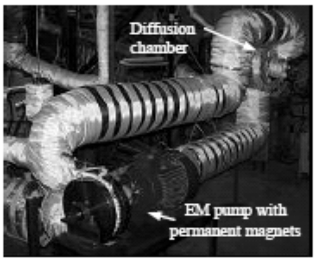
ISOLDE target layout

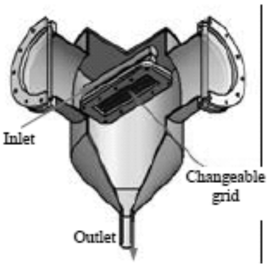


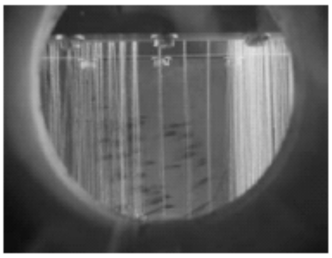


Diffusion chamber for Pb/Bi

Experimental program at IPUL (Institute of Physics of the university of Latvia) has shown the feasibility of a molten Pb/Bi « shower » to accomodate a 100 kW 1GeV incoming proton beam

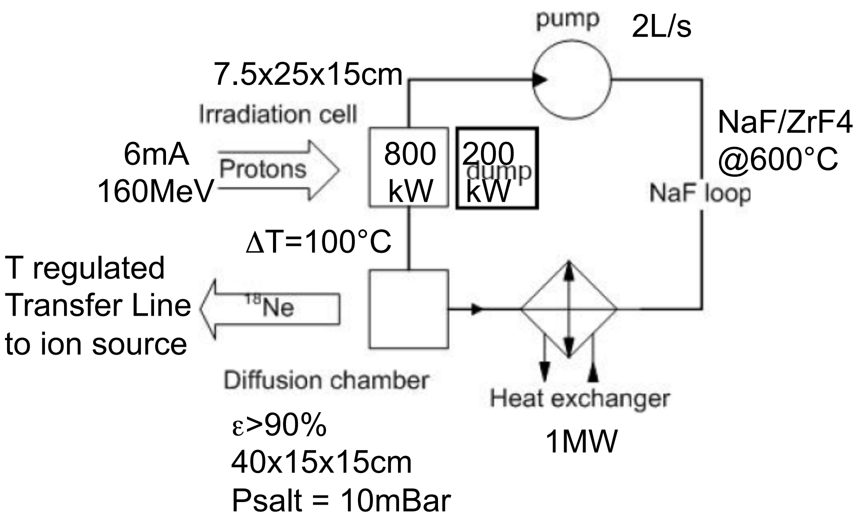






Liquid-metal loop setup at IPUL: Final Report EURISOL DS, 2009 (E. Noah et al.)

^{18}Ne production target 10^{13}/s



Scientific Scope

HiRadMat High-Radiation to Materials

- Facility to study the impact of intense pulsed beams on materials
  - Thermal management (heating)
    - material damage even below melting point
    - material vaporization (extreme conditions)
  - Radiation damage to materials – change of properties
  - Thermal shock - beam induced pressure waves
- Uses an LHC-type (25ns) beam extracted from SPS
  - 440 GeV/c proton beam, 3.4MJ maximum pulse energy, avariable spot size
  - Ion beams can be used as well: 173.5 GeV/n Pb^{82+}
- Foreseen clients : LHC collimators, machine components (dumps, windows, vacuum pipe coatings), material studies (bulk, superconductors(!)), high-power targets

Examples –
Past experiments → potential clients

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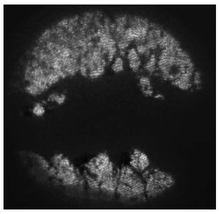
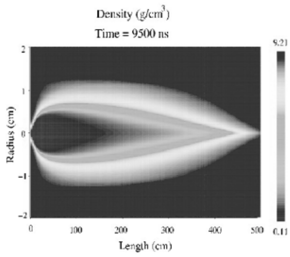
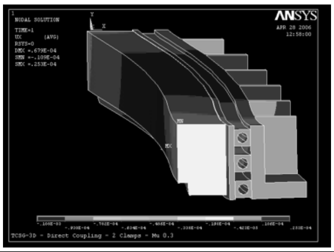
Targetry: High-intensity beam on a solid target (Ta) *Courtesy: J. Lettry, CERN*



MERIT experiment: High-intensity beam on a liquid Hg-target





LHC collimator: Displacement analysis – 500kW load case for 10s Loss rate $4x10^{11}$ p/s (Beam Lifetime 12min)

Courtesy: R.Assmann, CERN

Material studies: High-intensity beam on a bulck material – plasma formation *Courtesy: N.Tahir, GSI*

The facility

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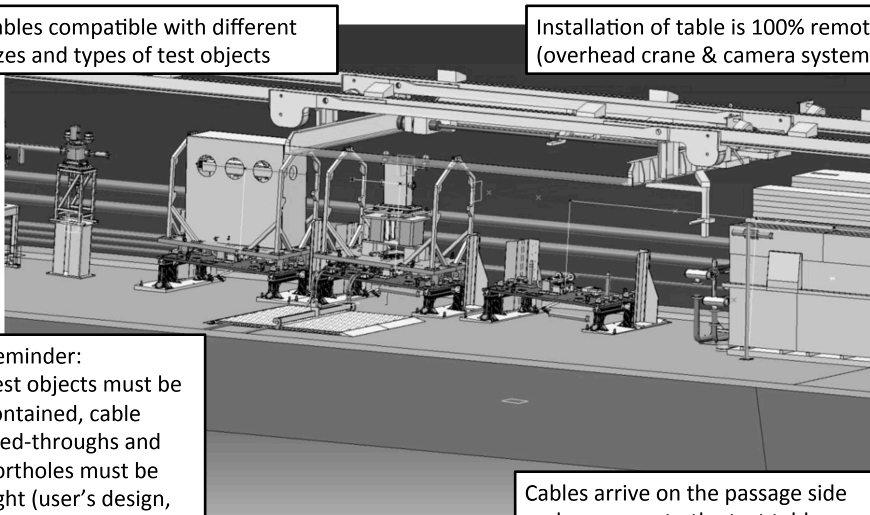
Tables compatible with different sizes and types of test objects

Installation of table is 100% remote (overhead crane & camera system)



Reminder:
Test objects must be contained, cable feed-throughs and portholes must be tight (user's design, with CERN approval)

Cables arrive on the passage side and pass over to the test tables

The facility

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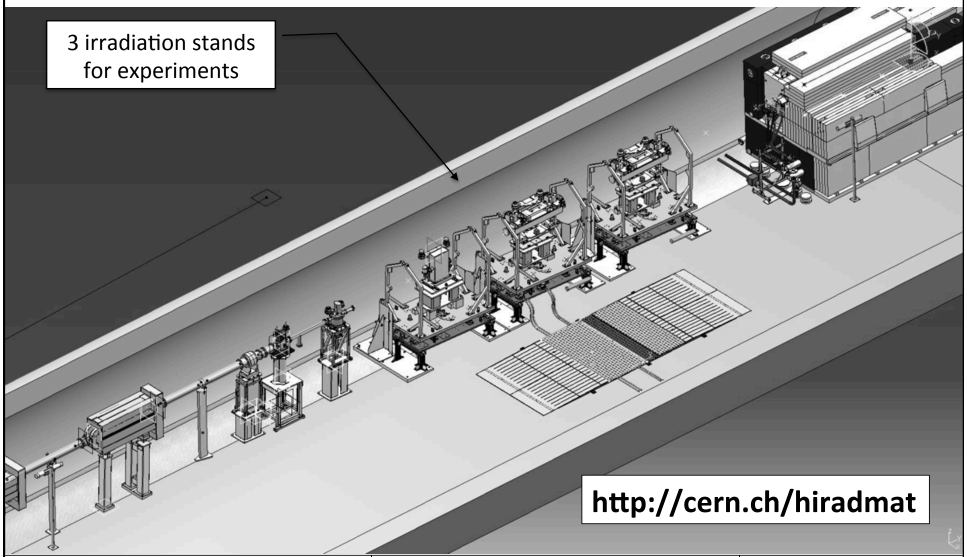

Experimental test LHC collimator (example)

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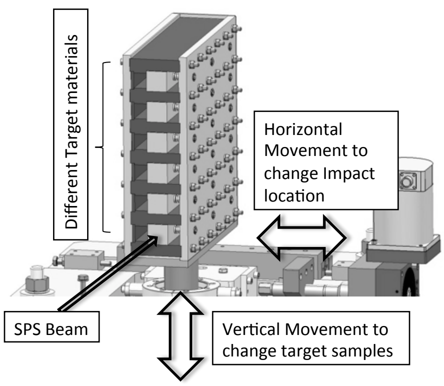
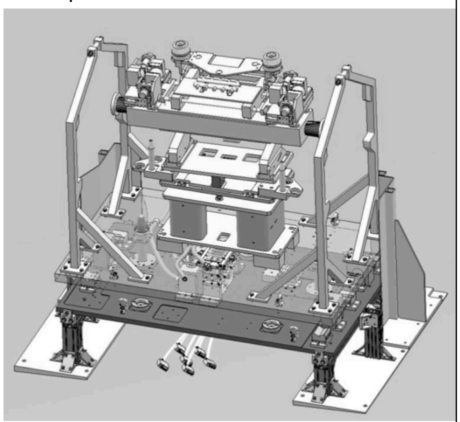
Sample holder for material or targetry tests



Example installatin of an LHC collimator



Further reading

- Reference publications
- Web pages with info

Summary

- High-power Targetry is an important ingredient and main forus of R&D for the future facilities, ν-physics in particular
- Substantial R&D and innovative ideas are required to pass from the present operational facilities of sub-MW range to the dreamed (M)MW ones
- I tried to give an overview on the ideas and options, if interested for more or you have questions don't hesitate to contact me
- Talking on (M)MW is easy – doing and operating a production facility at this range is extreemely challenging
  - Mega-Watts should be treated with respect!

Many thanks to colleagues who helped preparing this presentation:
- T. Stora, K.McDonnald, A. Fabic, N.Simos, C. Densham & the RAL colleagues

Thank You !!!