Introduction to the Proposed TT2A target Experiment

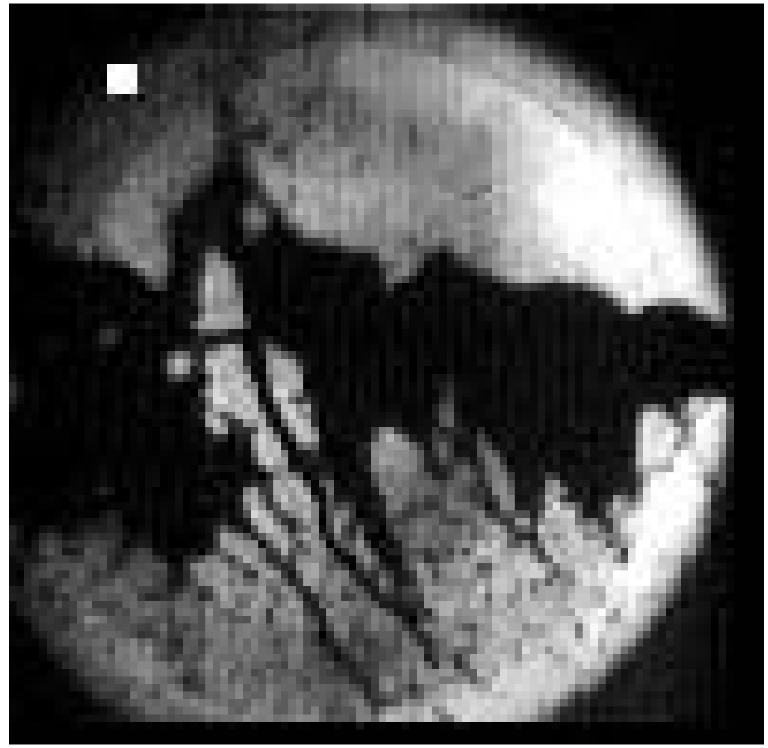
A.Fabich, CERN

24.May 2004

Meeting: ENG Target and Collector

Contents

- Intro, basic idea
- Subsystems
  - solenoid
  - Jet chamber
  - Power
  - Cooling
  - Safety
  - Diagnostics
- Budget
- Time schedule
- Conclusion



http://nfwgtarget.web.cern.ch
http://proj-hiptarget.web.cern.ch/

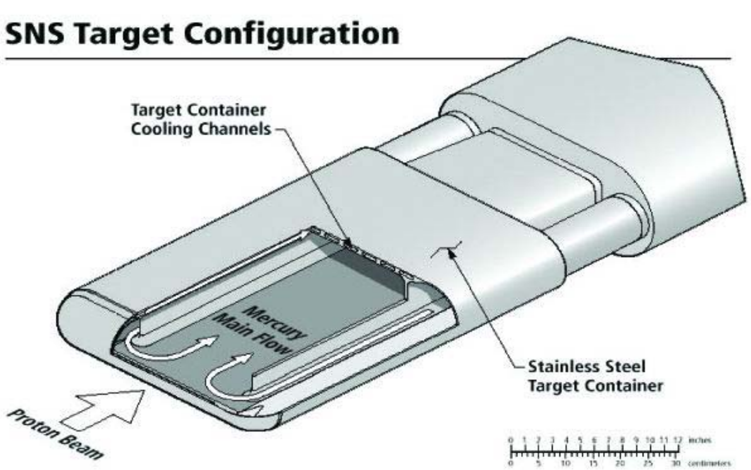
Primary Target Configuration

Contained

SNS, ESS, MegaPie, …

Hot issues:
- cavitation
- corrosion
- beam window

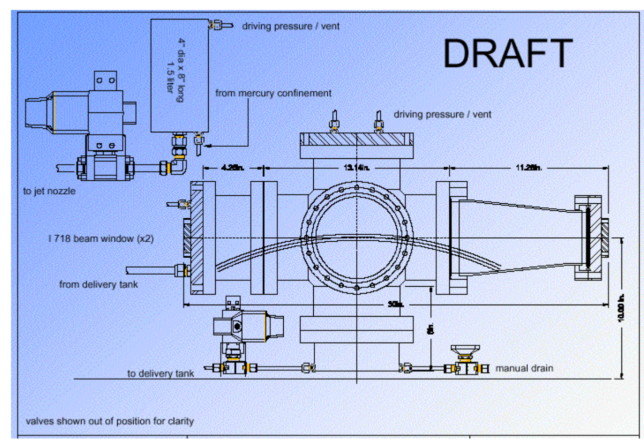
R&D at Oakridge (US),
Juelich (D), Villigen (CH), …



Free Surface

ν-factory, …

Hot issues:
- violent explosion
- mechanical challenge
- Less experience



Liquid Targets with free surface

• jet	avoid beam window
• Mercury	increased meson yield for high-Z materials
• v~20 m/s	Replace target at 50 Hz
• D= 1-2 cm	Optimized for re-absorption of mesons

??? What is the impact on the jet by

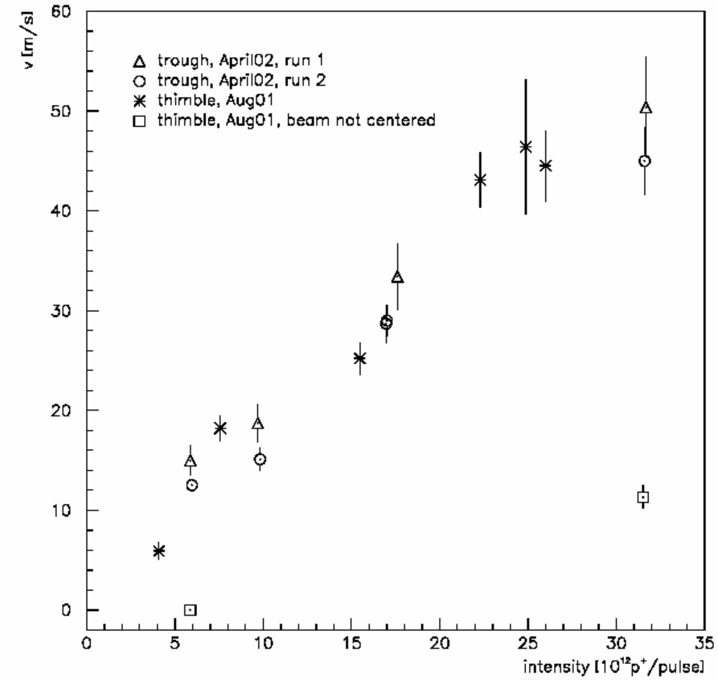
- 4 MW proton beam
- 20 T solenoidal field

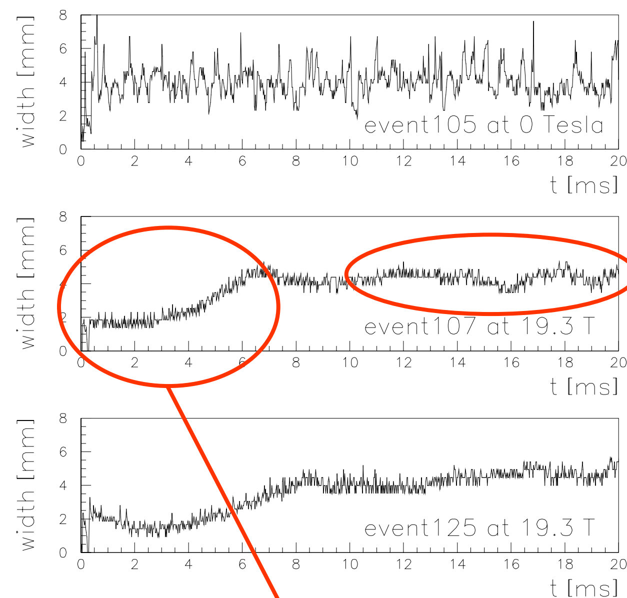
Experimental results

Achieved at CERN/BNL/GHMFL

MHD

Proton induced shocks





Jet smoothing

Tip shaping

Towards a nominal target

- LOI (Nov03) and proposal (May04) submitted to INTC
  - http://cdsweb.cern.ch/search.py?p=intc-2004-016

- perform a proof-of-principle test
  - NOMINAL LIQUID TARGET

    for a 4 MW proton beam
  - in solenoid for secondary particle capture
  - single pulse experiment

  COMBINE PREVIOUS TEST SERIES

- Observation of combined effect of proton induced shocks and MHD
  - BNL&ISOLDE: proton induced shocks
  - CERN at GHMFL: MHD

  one order off nominal parameters
  no observation of combined effects of proton induced shocks and MHD

	ISOLDE	GHMFL	BNL	TT2A	NuFact
p+/pulse	$3\ 10^{13}$	----	$0.4\ 10^{13}$	$2.5\ 10^{13}$	$3\ 10^{13}$
B [T]	---	20	---	15	20
Hg target	static	15 m/s jet	2 m/s jet	20 m/s/ jet	20 m/s jet

Collaboration

- Participating Institutes
  - Rutherford Appleton Laboratory
  - CERN
  - Oak Ridge National Laboratory
  - KEK
  - Brookhaven National Laboratory
  - Princeton University
  - …

Where?

- Machine dependent
  - provide nominal beam
- Site dependence
  - Suitable for installation
  - Safety issues

Experiment Site Considerations

- Nufact Study 2 Beam Parameters:
  - 16 TP (10^{12} Protons) per bunch 24 GeV, 1 MW Scenario
  - 32 TP per bunch (x2 rep rate) 24 GeV, 4 MW Scenario

BNL capabilities

4 TP per bunch E951 experience

6 to 8 TP foreseen (with bunch merging)

No multi-bunch single turn extraction (g-2 rebuild)

CERN capabilities

5 TP per bunch normal operation

7 TP multi-bunches foreseen (for CNGS)

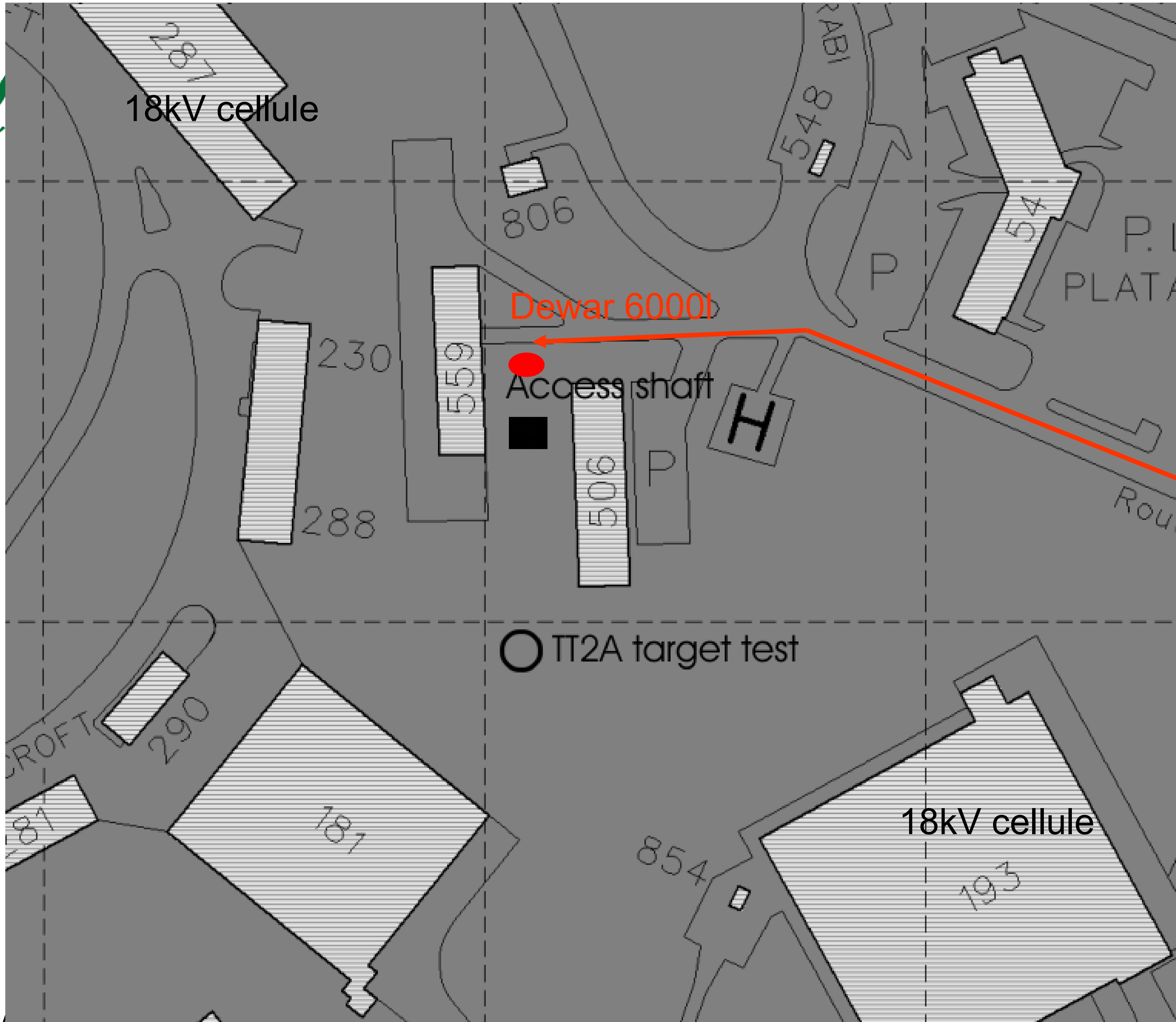
Multi-bunch single turn extraction available

4 bunch flexible fill of PS from booster available → Pump-Probe capability

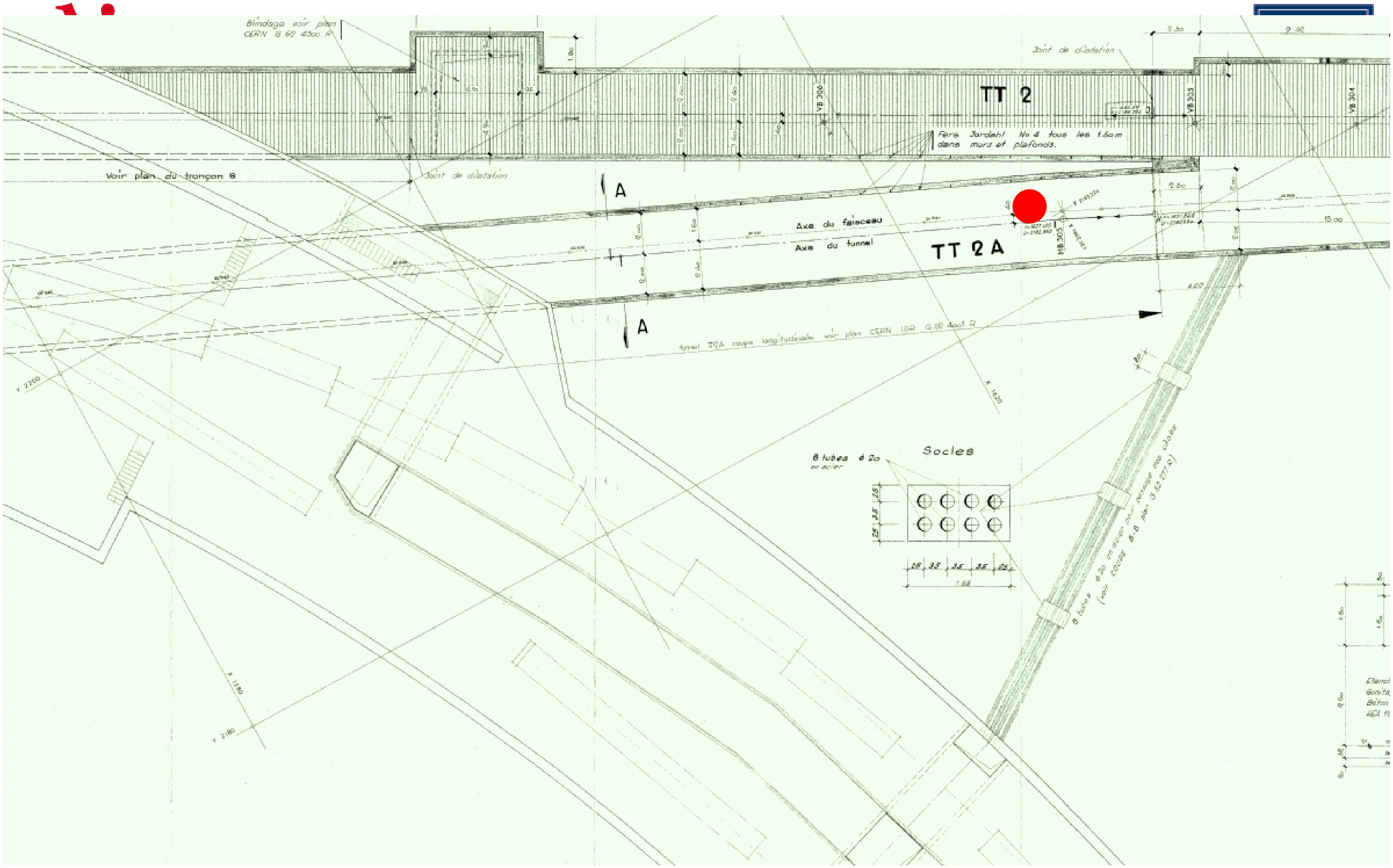
Alternatives

- Placed just upstream of TT2A in TT2
  - Already ventilated
  - Interference with SPS running on access
  - Longer distance to surface
    - esp. difficult for LN2 supply
- ISOLDE: no space
- BNL: single turn extraction not installed (~2MChF for modification)

- Preffered solution: TT2A
  - All studies have been done towards an implementation in TT2A



Access route for LN2 delivery

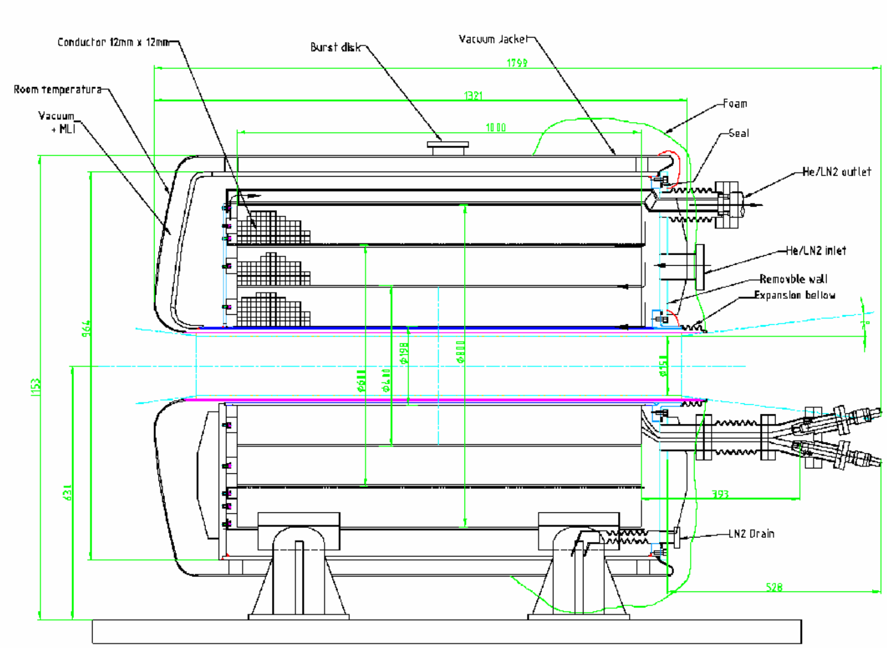

TT 2
TT 2 A
Axe du faisceau
Axe du tunnel
Voir plan du tronçon 8
Joint de dilatation
Fers Jordahl No 4 tous les 1.50 m
dans murs et plafonds.
A
A
Socles
8 tubes ⌀ 20
en acier
VB 306
VB 305
VB 304
HB 305

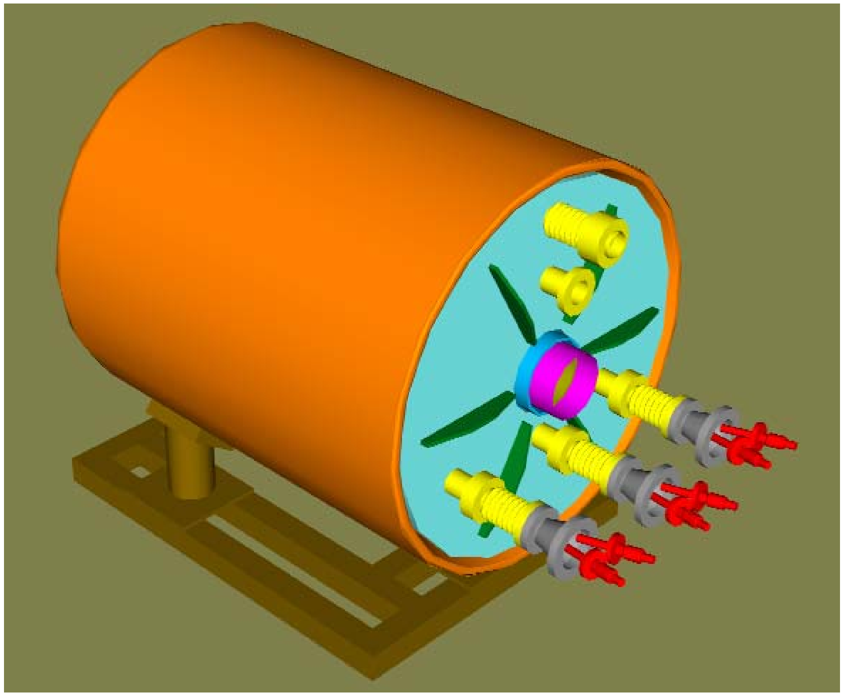
Sub-systems

- Solenoid
- LN2 circuit
- Power
- Jet chamber
- Mercury circuit
- Diagnostics
- PS beam

SAFETY
BUDGET
TIME SCHEDULE

High Field Pulsed Solenoid

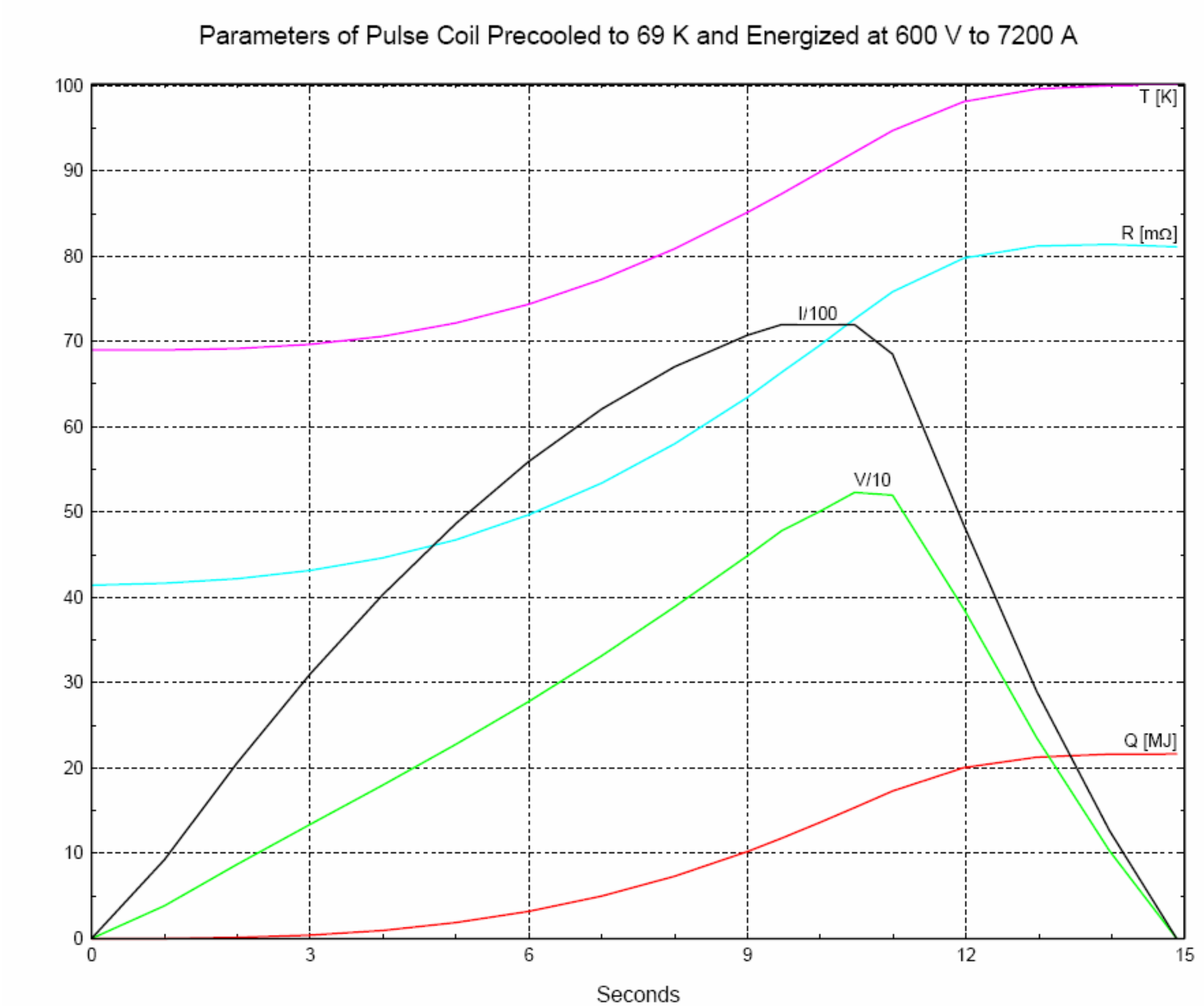




- 70º K Operation
- 15 T with 4.5 MW Pulsed Power
- 15 cm warm bore
- 1 m long beam pipe

Peter Titus, MIT

Power cycle



Bob Weggel's 10-14 analysis of the LN2 magnet operation

- 650 V
- 7kA peak
- 22 MJ deposited
- ΔT=30 K

Power supply

Item	investment kChF	man-months
BATTERY solution		
purchase batteries	90	
power supply 50 kW	100	3
Charge/switch system	80 ??? (R&D needed)	
Cabling	25	
Commissioning + safety		4
TOTAL batteries	300	7
RENTAL ALICE TYPE		
transport		3
feasibility + commissioning		3
rental fee	0?	
cables	75	
TOTAL rental	75	6
PURCHASE ALICE TYPE		
purchase Alice type	350	
installation	10	
Feasibility + contract + commissioning		9
cabling	75	
TOTAL purchase	440	9

1. Batteries
   waste management? Reuse for trucks?
2. Rent power supply type ALICE/LHCb
   LHCb excluded
   ALICE unlikely
3. Purchase power supply ALICE/LHCb
   - resell? To BNL/JPARC/CERN

All three possibilities are technically possible!

Installation:

- ISR tunnel
- access to TT2A through gallery
- no activation of material

Power Supply

Contact person/credits: Carlos DE ALMEIDA MARTINS, AB/PO

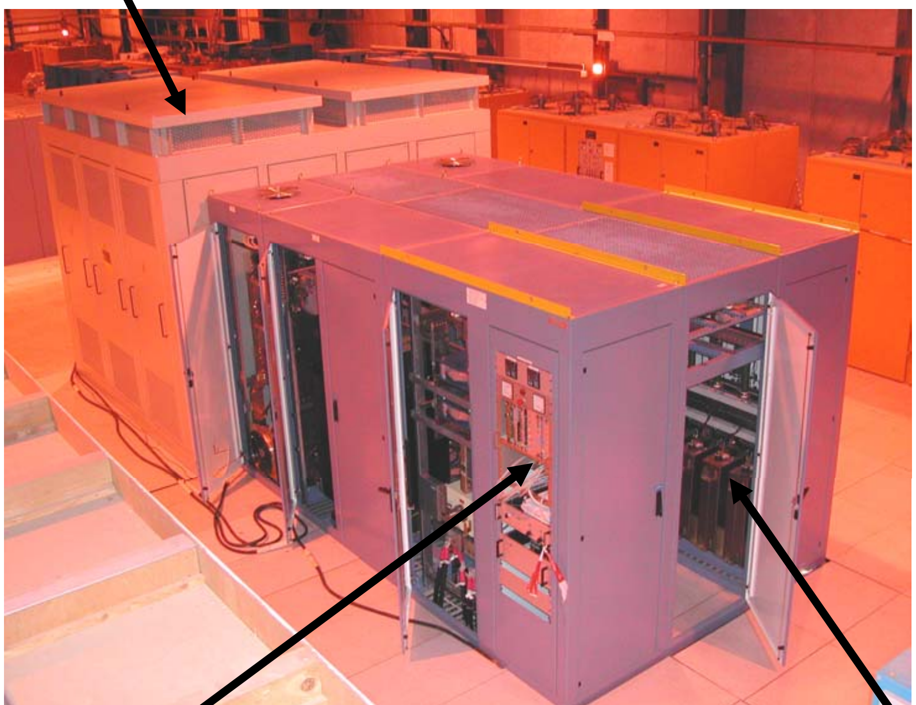
Concentrates on evaluating a solution “available” at CERN:

power supply Alice/LHCb

- 950 V, 6000 A
- size: ~10 m x 4 m x 3m, 40 tons
- installed in six pieces
- transformer (TRASFOR, IT), EDMS 315101 (http://edms.cern.ch)
- converter (Schneider Elec., FR), EDMS 311284
- price/piece: 400 kChF (transformer 100 kChf + converter 300 kChF)

Main characteristics of power converter type ALICE/LHCb, rated 950V, 6500A

2 x Power transformers in parallel, housed in the same cubicle



High precision current control electronics

2 x rectifier bridges in parallel

Total DC output ratings:
6500Adc, 950Vdc, 6.7 MW

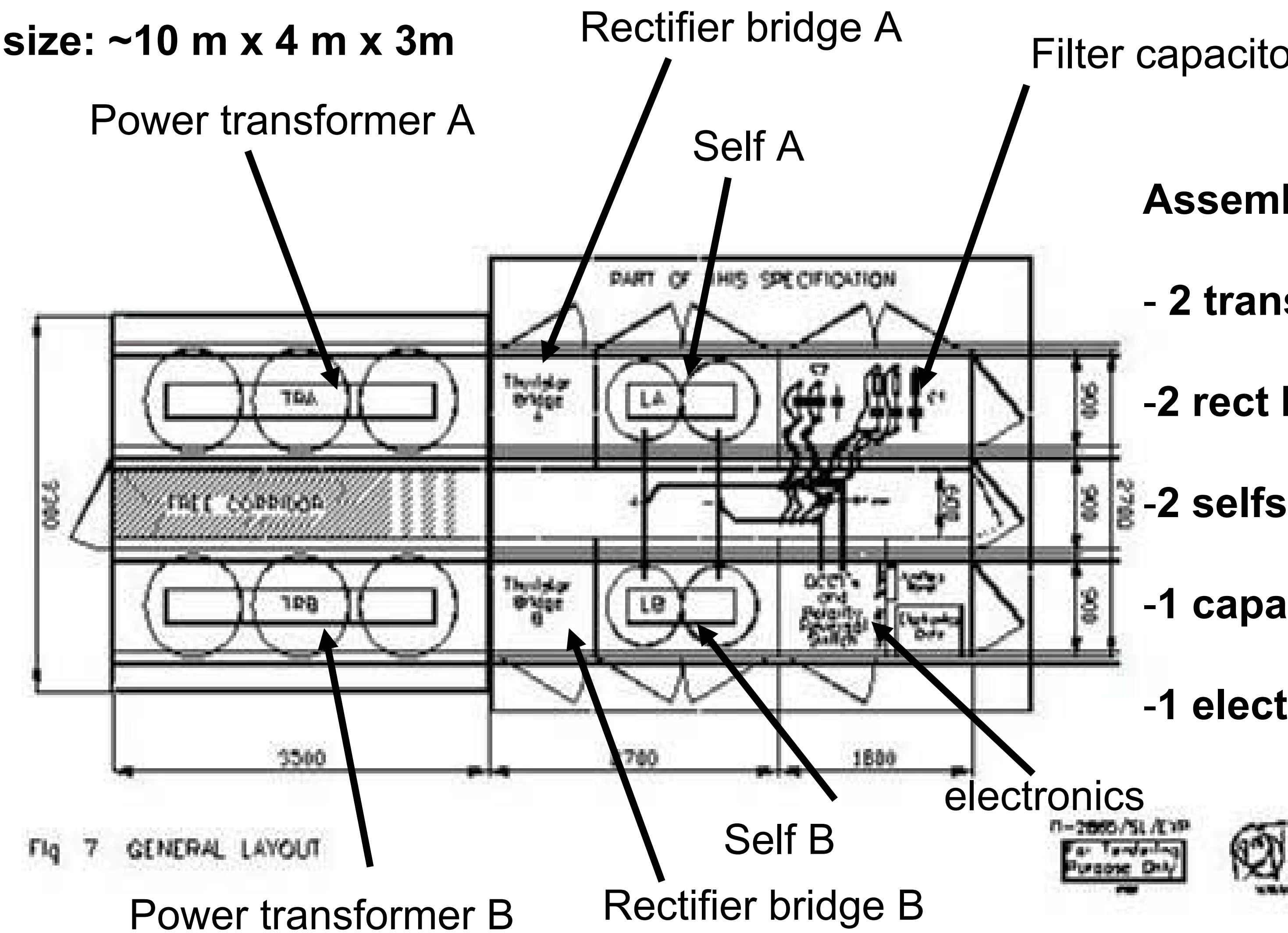
AC input ratings (per rectifier bridge):
2858Arms, 900Vac (at no load), 4.5 MVA

Each power transformer ratings
Primary side: 154Arms, 18kVac
Secondary side: 3080Arms, 900Vac
Nominal power: 4.8 MVA

Other
- Air forced cooling;
- Fed by two18 kV lines

Power Converter Type Alice/LHCb

size: ~10 m x 4 m x 3m



Assembled in 8 parts:

- **2 transformers (13 ton each);**
- **2 rect bridges: (~ 0.6 ton each);**
- **2 selfs (~4 ton each);**
- **1 capacitor bank (< 1 ton);**
- **1 electronic rack (< 1 ton);**

Main technical details still to be verified

-***Best solution for connecting to a 18kV cell (CERN TS-EL group)***
- one available cell at building 269;
- one available cell at building 193 (AD);
- two used cells at building 287 (A7) – check for the possibility of joining a new one temporarily ?;

- check for other solutions, if any

-***Location of the power converter (CERN AB/PO group)***
- One solution, ***still need to be verified!!!!***
In the ISR gallery,
availability of the space?? (today used for storage of material);
the capacity of the existing crane?
- check for other solutions, if any

-***Cabling paths for the power lines (CERN TS/EL group)***

Cryogenics

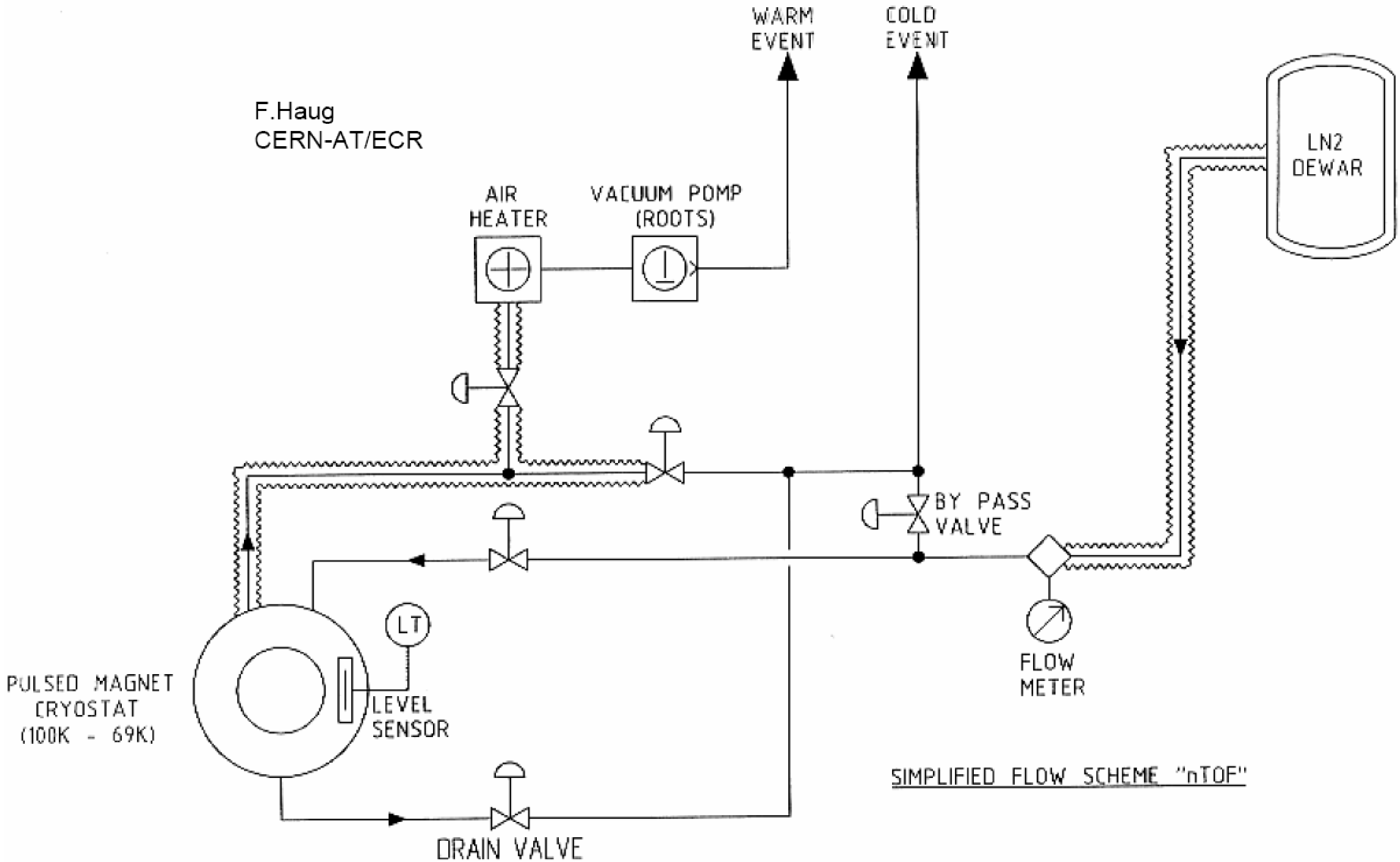
Solution studied towards TT2A and “permanent” LN2 supply (fixed dewar)

Responsibility in US: solenoid, controls, DVB

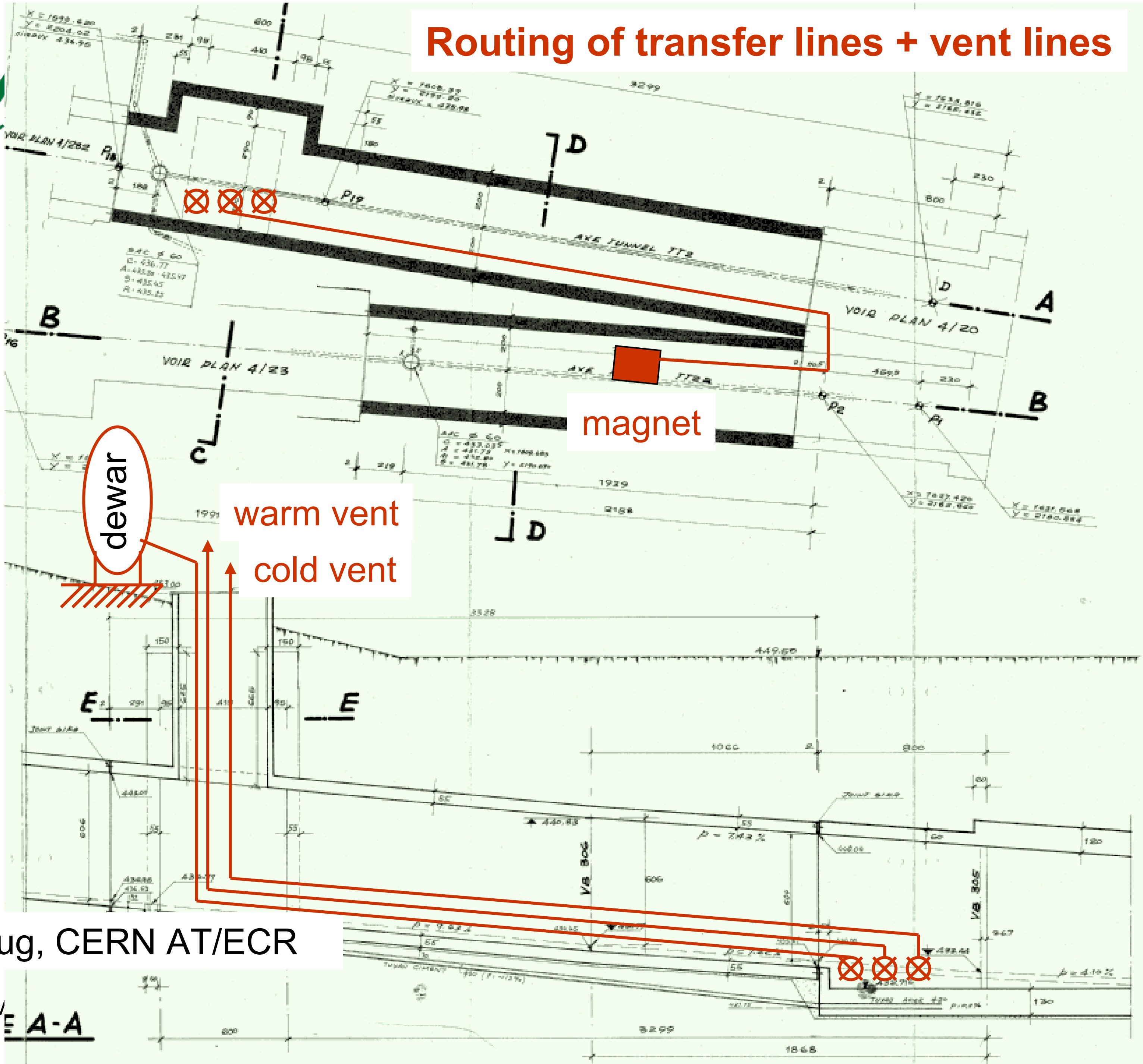
– Schematic flow chart
– List of recuperated material
  - 6000 l dewar
  - Cryogenic lines (bat 180: 4x25 m simple, 2x50 m shielded)
  - Heater
  - Vacuum pump ROOT

- Manpower: 1.5 FTE*years
- 100 kChF (for small parts)

Flowchart


WARM EVENT
COLD EVENT
F.Haug
CERN-AT/ECR
LN2 DEWAR
AIR HEATER
VACUUM POMP (ROOTS)
BY PASS VALVE
LT
PULSED MAGNET CRYOSTAT (100K - 69K)
LEVEL SENSOR
FLOW METER
SIMPLIFIED FLOW SCHEME "nTOF"
DRAIN VALVE

Routing of transfer lines + vent lines



About 60 m from target place to surface

F.Haug, CERN AT/ECR

TT2A preliminary equipment proposal

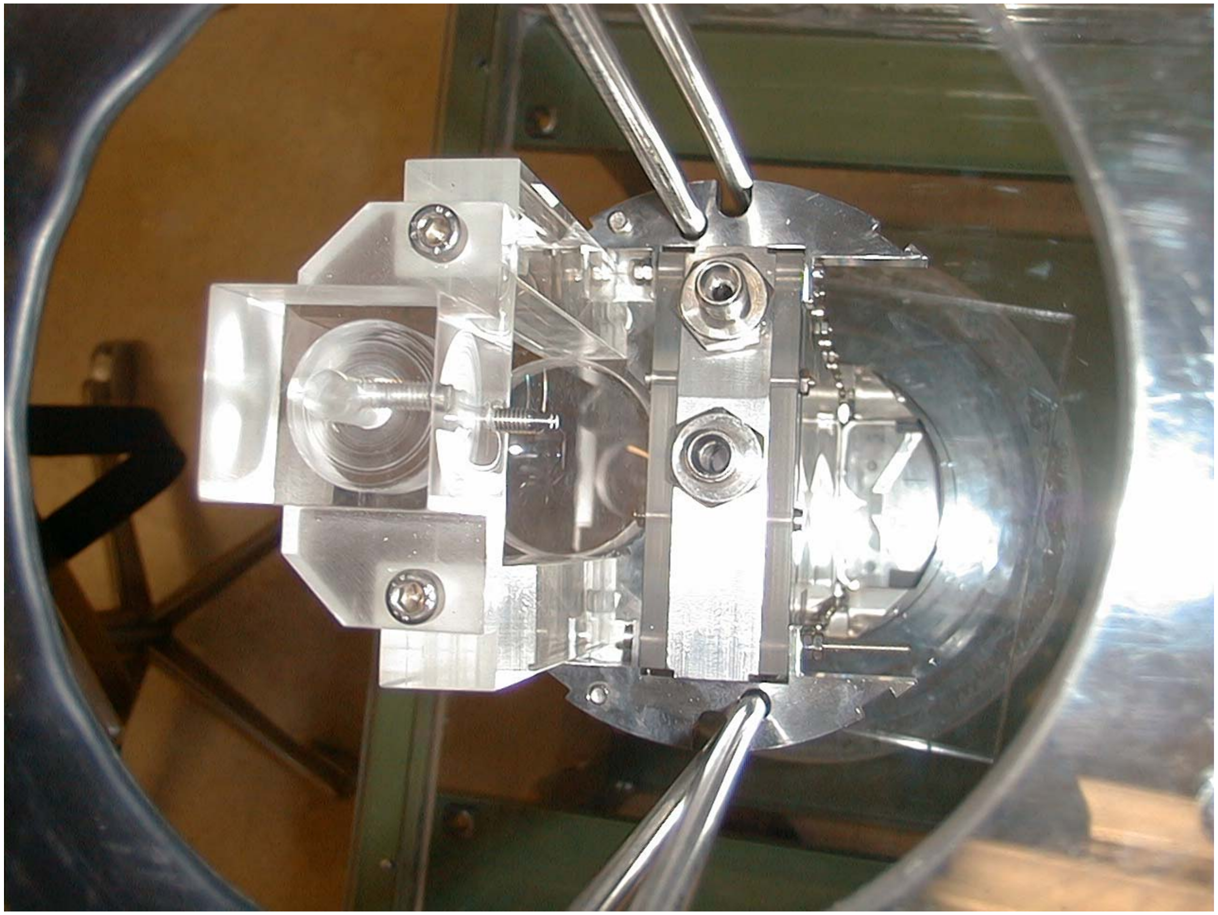
- **Process control and instrumentation**
- 1) UNICOS (Schneider) ?, ABB ?, LabView ?
- - control from distance
- - proposed is ISR building 230 or 288 from which
- 2) Instrumentation in conformity with CERN standards
- **Equipment to be cooled**
- 1) Pulsed magnet
- **Proximity equipment**
- 1) DVB valve box -feed valve with level control
- -by-pass valve of TFL before recooling
- -drain valve
- -pumping line valve
- -valve for nitrogen gas out
- -temp sensors
- -flow meter

US

- 2) vacuum pump for insulation vacuum of magnet
- 3) vacuum pump for reducing pressure in bath
- 4) heat exchanger or el. heater
- **Intermediate Infrastructure**
- 1) transfer line for cooling and filling
- 2) exhaust for cold nitrogen gas during cooling and filling
- 3) pump line (warm)
- **External Infra**
- 1) LN2 reservoir next to vertical shaft

CERN

Jet Chamber



CERN at GHMFL, 2002

Materials

in contact with liquid mercury

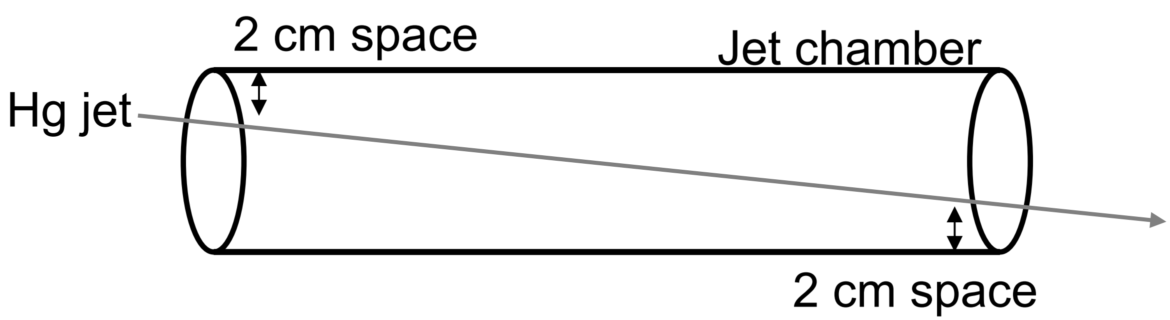
- Stainless Steel (316LN)
- Makrolon (LEXAN),
  - no visible darkening after exposure to ~40 pulses
- quartz glass
- EPDM (seal rings)
  - radiation hard to our needs

In magnetic field and in radiation environment

Jet

- Bore, 1m long, 15 cm diameter
  - Jet offset from entrance to exit given by

Intended inclination:	100 mrad →	10 cm
Jet diameter		1 cm
(Gravity)		2.5 cm (v_{jet}=15 m/s)



bore contains:
- outer confinement
- frame of jet chamber
- fixation of jet chamber
- Hg return path?
- tolerances

It is not impossible, but one has to keep in mind, that the place inside the bore is one more time very tight.

Mercury pump system

Rotary pump

system currently developed at Princeton

ElectroMagnetic

- No moving parts in contact with target liquid
- No seals

highly reliable

Problems?

- High slip → high power consumption
- Heating of the liquid by Ohm losses

→ CRITICAL

Can we reach the desired flow rate? (1cm jet, 1l/s, 20 m/s)

Existing applications

of EM pumps

- Aluminium production
- Testing Pb-Be loops
  - MegaPie
  - ADS
  - spallation source
- Sodium circuit in nuclear facilities
- MegaPie
- LiSoR:
- LiSoR like facility at JAERI / KEK
- ORNL: SNS test facilities
- …

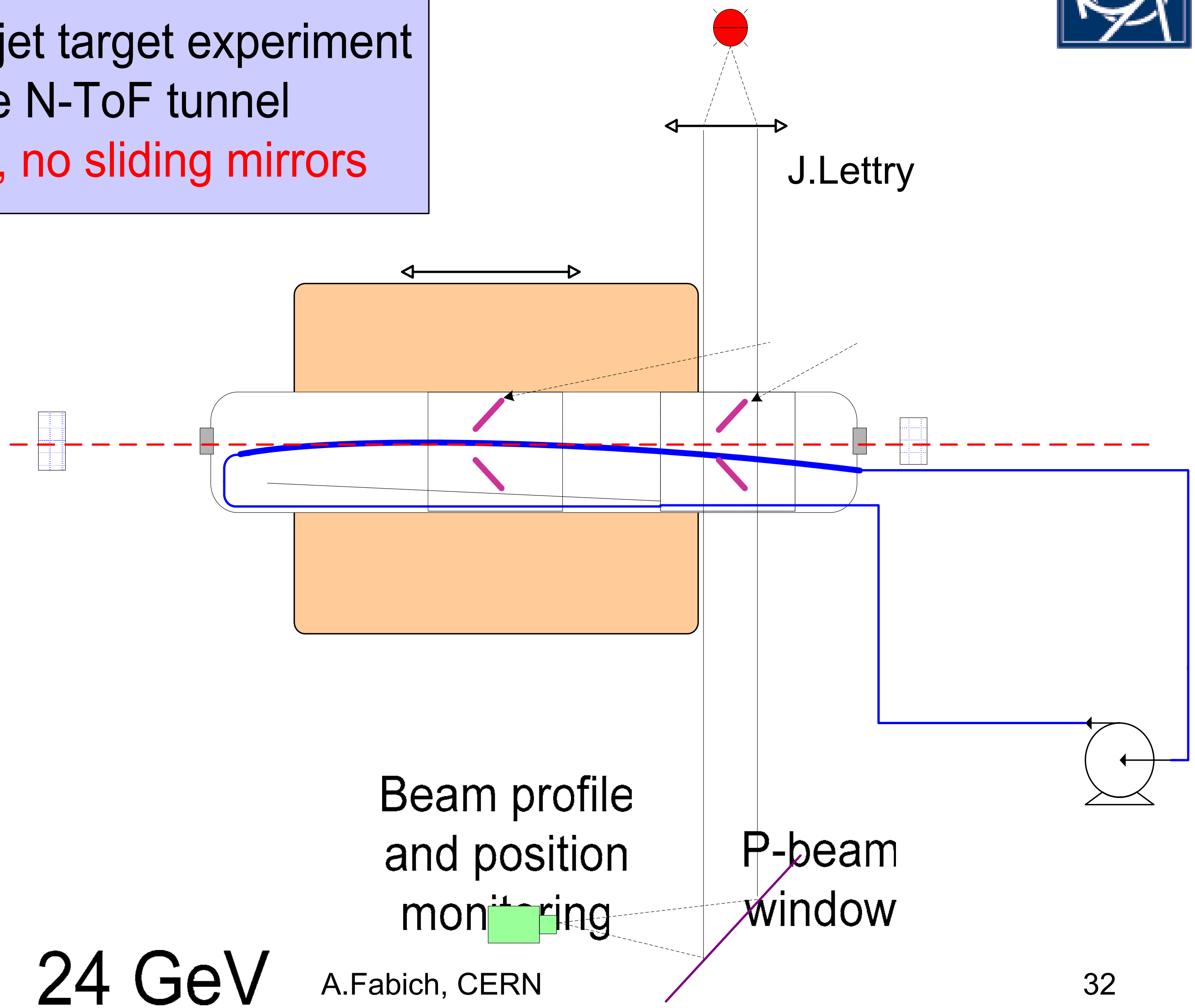
Mercury Recuperation

1) Through the bore
   - Needs space inside the bore

2) Loop closed outside the coil
   - Safes space inside the bore
   - But needs braking the Hg loop on disassembling

Nufact Hg-jet target experiment in the N-ToF tunnel

classical, no sliding mirrors



24 GeV

proton beam

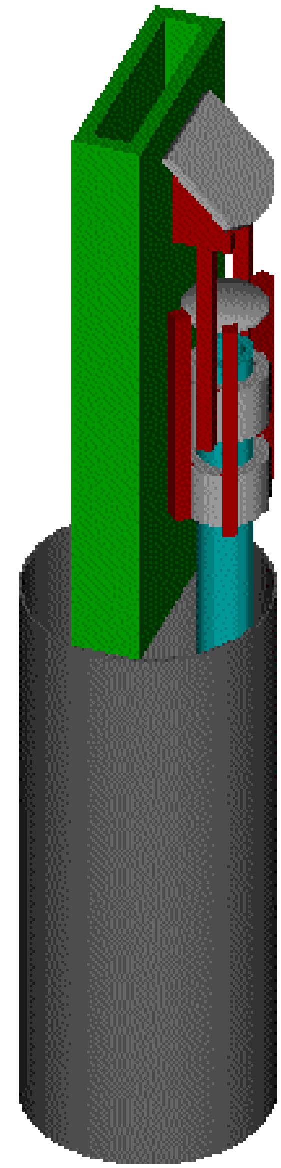
Diagnostics

- Optical System
  - Direct observation of jet behavior
- Particle detector
  - Interaction efficiency

- Primary Proton
  - Beam intensity
  - Beam position
- Magnetic field

Optical read-out

- Achieve maximum observation area
  - Restricted by bore size
  - Outside jet chamber
    - Sensible mirrors separated from Hg jet
    - avoid unwanted mercury in the light path
- Light path
  - Source: laser, a few mW
  - Inserted via glass fiber
  - Optical lens to get large parallel beam
  - Deflected transverse the Hg jet by mirror
  - Second mirror guides light towards camera



From GHMFL: we can fit the optical system in this very small space
From ISOLDE/BNL: we can record at a distance of at least 15m

OPTICAL READ-OUT is BLIND in case of a perfect jet!

Jet Chamber (top view)

- Basic principle for all designs:

✓ inner chamber for jet

Connected by

Straight nozzle

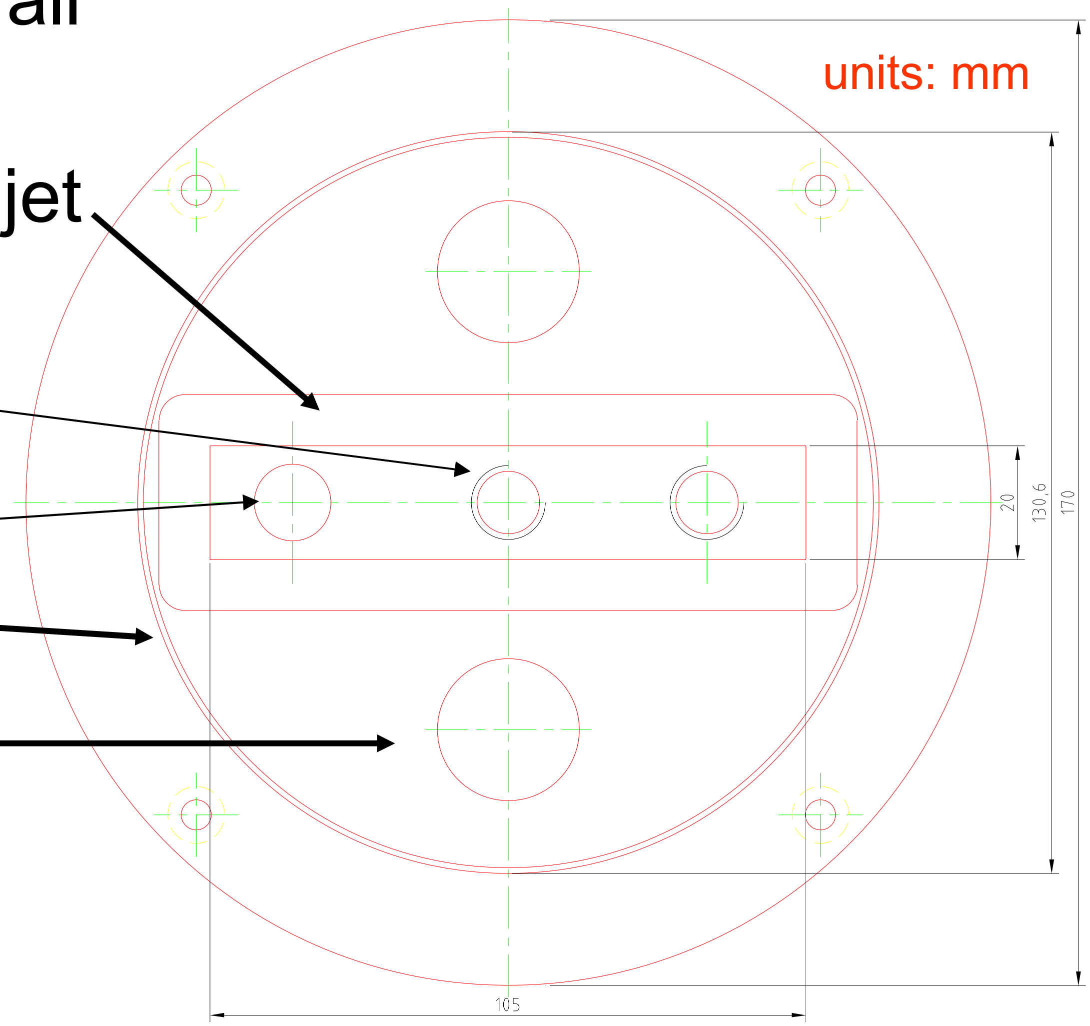
Tilted nozzle

Return pipe

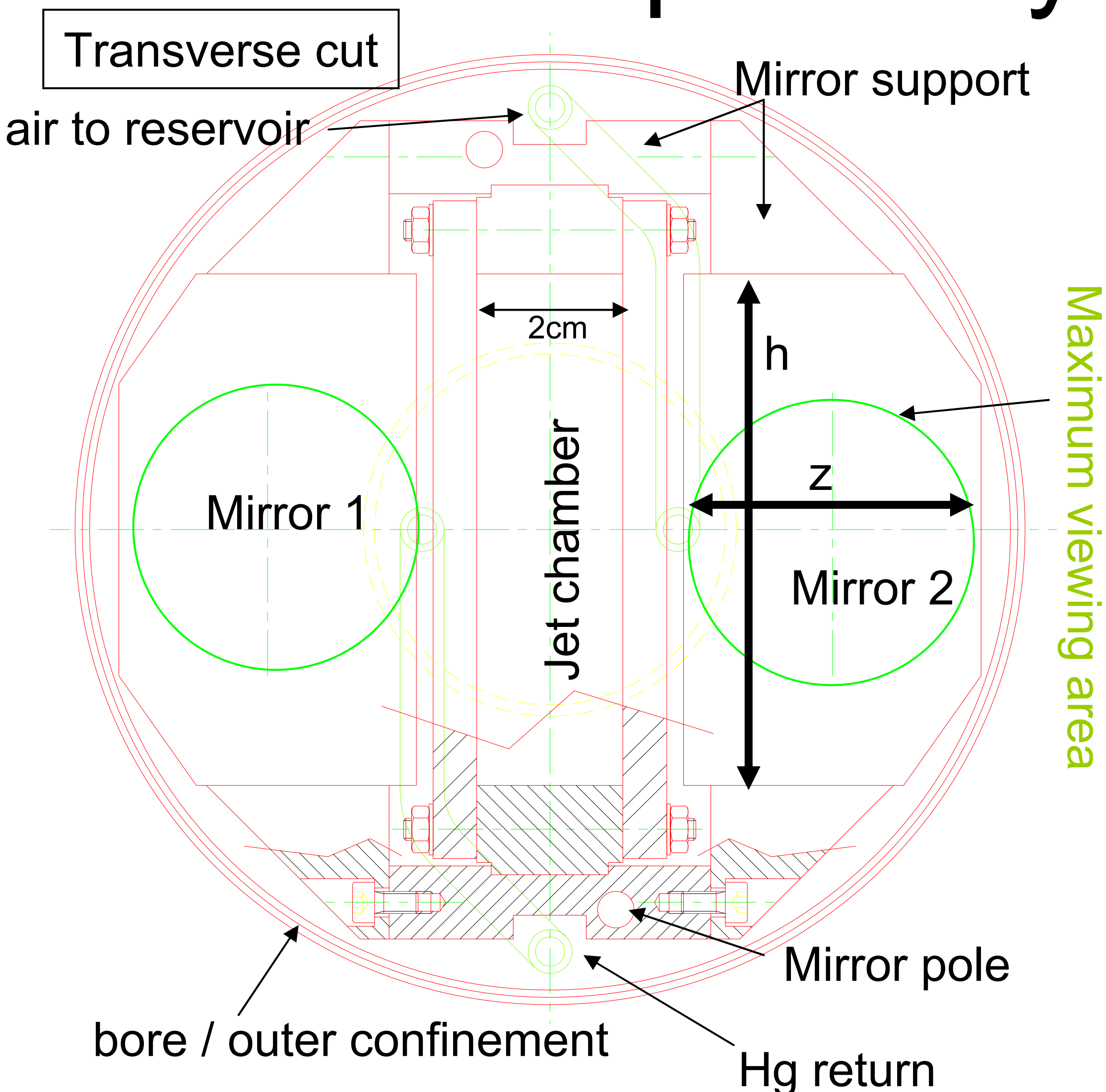
✓ outer inox tube

✓ Optical ligth path

+ mirror(s)



Optical System



Bore of magnet 13 cm contains:

- jet chamber
  - steel frame
  - Makrolon plates
- mirror system
  - support (adjustable in height) around jet chamber
  - 2 mirrors
- mercury recuperation system

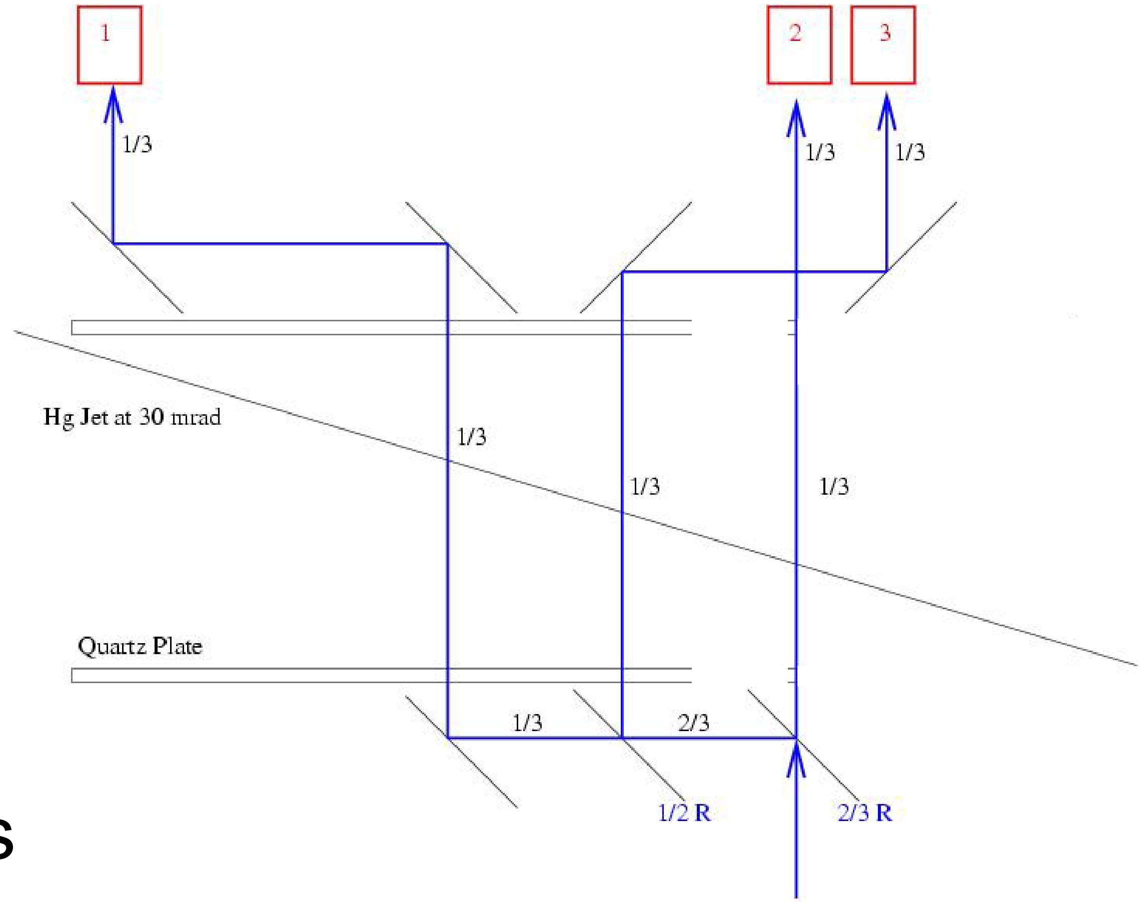
The maximum observation along jet is defined by magnet bore minus the width of the jet chamber (minus some safety margins)

- Total area given by h and z

SAFETY MARGINS ~ 1mm

flexibility!

Multi-Camera system



- One light source
- Several cameras
- Light is guided by (semi-) mirrors

Pulse list

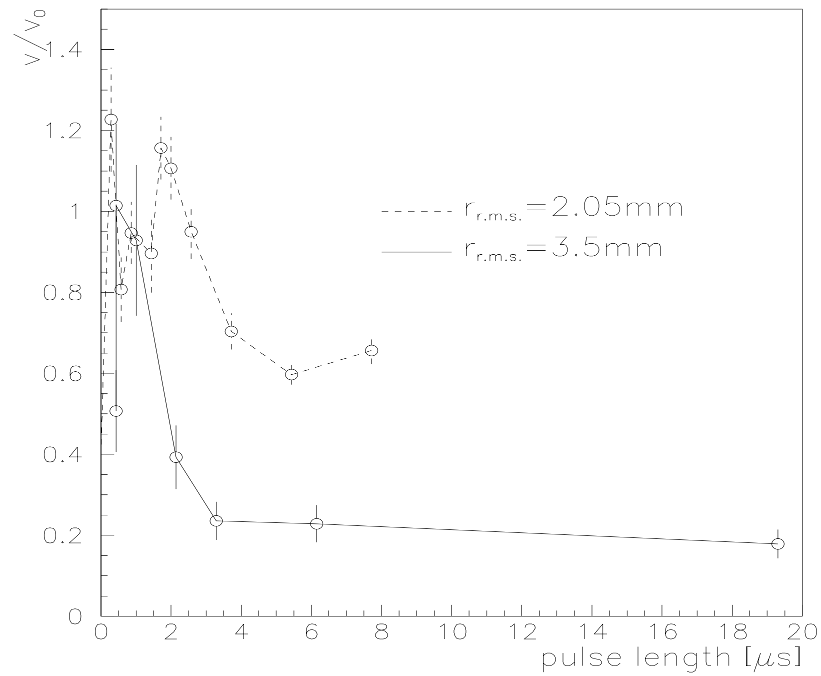
- parameters to vary:
  - Magnetic field (0-15, 3 T)
  - Pulse intensity (1-20, 4 TP)
  - Pulse length (0.5-20, 0.5 μs)
  - ~~Spot size~~
  - Beam position (±5, 1 mm)

- Total number of pulses on target (no tuning): <100

- Needs ~3 weeks of beam time

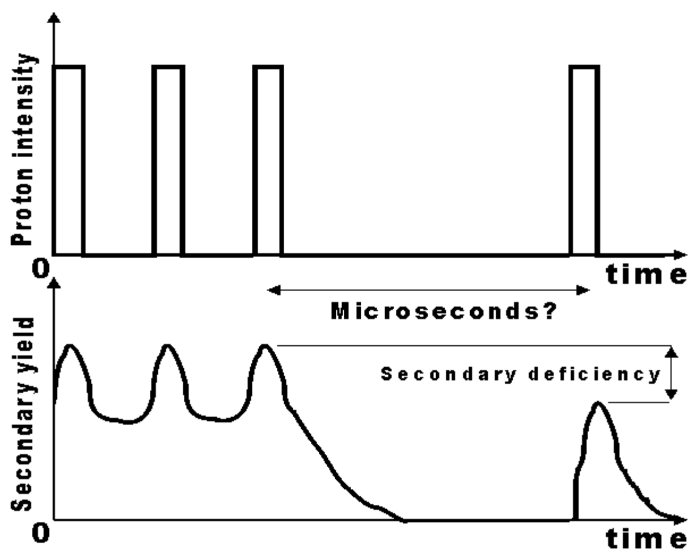
Cavitation in Liquid targets

- Cavitation was already "observed" at ISOLDE
  - Unfortunately only indirect observation by splash velocity
  - No observation of sec.particle yield
- Does it reduce the secondary particle yield?
  - Most probable not an issue for American design, but for facilities using "long" pulses



PS beam

- momentum p = 20 GeV/c
  due to compatibility with nToF and kicker
- 4 bunches within 8 PS buckets at our digression
- t_{pulse}= 0.5-2 microseconds
- t_{bunch}=50ns full length, peak-to-peak 250 ns
- spot size at target: ~1 mm r.m.s.



Pump-Probe method
for cavitation studies

Interaction Efficiency

- measure interaction efficiency either by
  - Radiation monitors
  - Disappearance of primaries
    - Pick-up monitor downstream of target
  - Appearance of secondaries
    - total particle yield within
    - Partly coverage of solid production angle sufficient
    - Off-axis
    - Detector
      - Simple, e.g. scintillator
      - radiation hard or installed far

Safety

- Mercury (activated)
  - Currently heavy e-mail conversation with SC/RP
- Radiation
  - Beam dump downstream of Hg target?
- LN2 cooling
  - Circuit safety
  - Study on ODH
- High magnetic field

- “Waste” managament
  - Mercury given to ORNL
  - Solenoid back to US/Japan
  - Power supply?
  - Contaminated jet loop?

Mercury

- Ventilation requested by SC/RP
- Double confinement
  - Outer one not gas tight
  - Not to be broken outside …
- Dedicated Hg laboratory
  - Equipped with safety material (mask, aspirator, gloves, …)
  - In TT2A itself?
- Mercury waste stream
  - Minimize mercury quantity
  - To be defined/proven in advance
    - ~~Distillation: minimize waste stream~~
    - ~~Solidification: demanded by Swiss authorities~~
    - ~~ultimate repository: provided by – " –~~

→ Disposal at ORNL

- Minimize number of pulses (<100)

Residual Contact Dose Rate Isotope Production

- Assumptions as input for MARS/MCNP:
- 200 pulses
- 16 x 10^{12} protons/pulse average
- 30 days running
- 24 GeV proton beam
- 1 cm diameter – 30cm long Hg target

- Then the contact radiation on magnet exterior will be:
- After 1 hr 400 μSv/hr
- After 1 day 200 μSv/hr
- After 1 week 130 μSv/hr
- After 1 month 50 μSv/hr
- After 1 year 10 μSv/hr

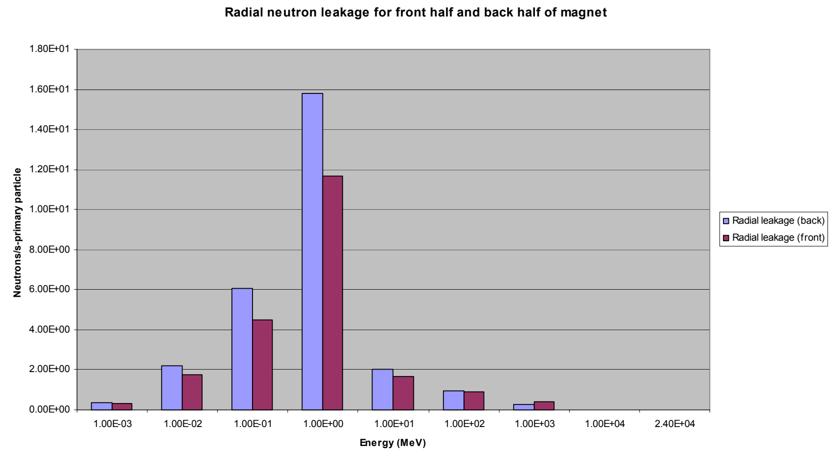
Neutron Production

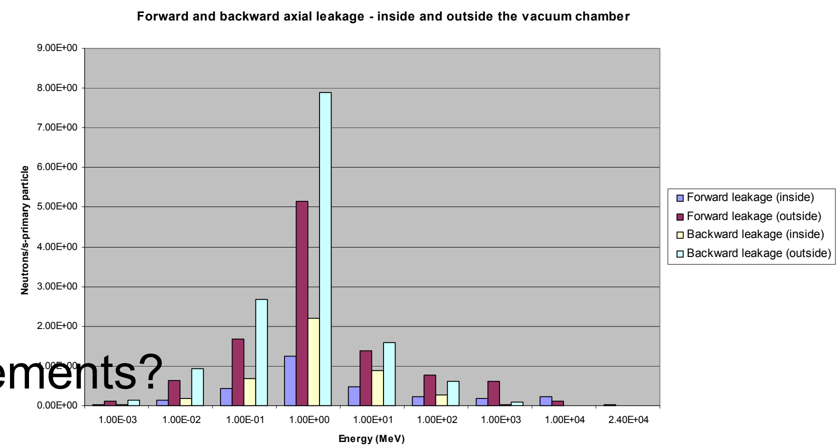
- Neutron flux escaping radially at r=0.6 m
- Is 10^{-3} n/cm^2 for each incoming proton.

- Neutron flux escaping forward is
- 1.2 x 10^{-3} n/cm^2 for each incoming proton.

- Neutron flux escaping backwards is
- 1.6 x 10^{-3} n/cm^2 for each incoming proton.

- What is the impact on already installed elements?





End of Exposure- 1 Month delay

Elements	Curies
hg	0.00043070
au	0.00034510
te	0.00028140
ir	0.00027650
ag	0.00026910
in	0.00023670
sn	0.00023540
eu	0.00018110
rh	0.00018070
i	0.00014630
xe	0.00014040
gd	0.00012370
pd	0.00012230
cs	0.00012100
w	0.00011980

- Total 4.3 x 10^{-3} Curies

- Important contributing Isotopes
- (up to 1% of activation levels)

Hg 203	4.3 x 10^{-4} Curies
Au 195	3.1 x 10^{-4} Curies
Te 121	2.3 x 10^{-4} Curies
Ir 188, 189	9.6 (17) x 10^{-5} Curies
Ag 105	2.0 x 10^{-4} Curies
In 113	2.3 x 10^{-4} Curies
Sn 113	2.3 x 10^{-4} Curies
Eu 146, 147	5.7 (6.5) x 10^{-5} Curies
Rh 103	1.3 x 10^{-4} Curies
I 125	1.4 x 10^{-4} Curies
Xe 127	1.4 x 10^{-4} Curies

End of Exposure- 1 Year delay

- Elements Curies
- au 0.00011470
- ag 0.00004882
- cd 0.00004671
- in 0.00004633
- sn 0.00004630
- ta 0.00001930
- gd 0.00001678
- lu 0.00001345
- os 0.00001287
- ce 0.00001223
- rh 0.00001145
- pm 0.00001097
- w 0.00001089
- sm 0.00001046
- hf 0.00000957

- Total 4.9×10^{-4} Curies

- Important contributing Isotopes
- (up to 1% of activation levels)
- Au 195 1.1×10^{-4} Curies
- Ag 109 4.7×10^{-5} Curies
- Cd 109 4.7×10^{-5} Curies
- In 113 4.6×10^{-5} Curies
- Sn 113 4.6×10^{-5} Curies
- Ta 179 1.9×10^{-5} Curies
- Gd 151, 153 7.4×10^{-6} Curies 8.1×10^{-6} Curies
- Lu 172, 173 5.3×10^{-6} Curies 8.1×10^{-6} Curies
- Os 185 1.3×10^{-5} Curies
- Ce 139 1.2×10^{-5} Curies
- Pm 143 9.3×10^{-6} Curies
- Sm 145 1.0×10^{-5} Curies
- W 181 1.1×10^{-5} Curies

Budget

kChF

• Solenoid	1183
• Power Supply	611
• Cryogenic System	390
• Hg Jet System	169
• Beam Diagostics	98
• Support Services	234

TOTAL 2700 kChF

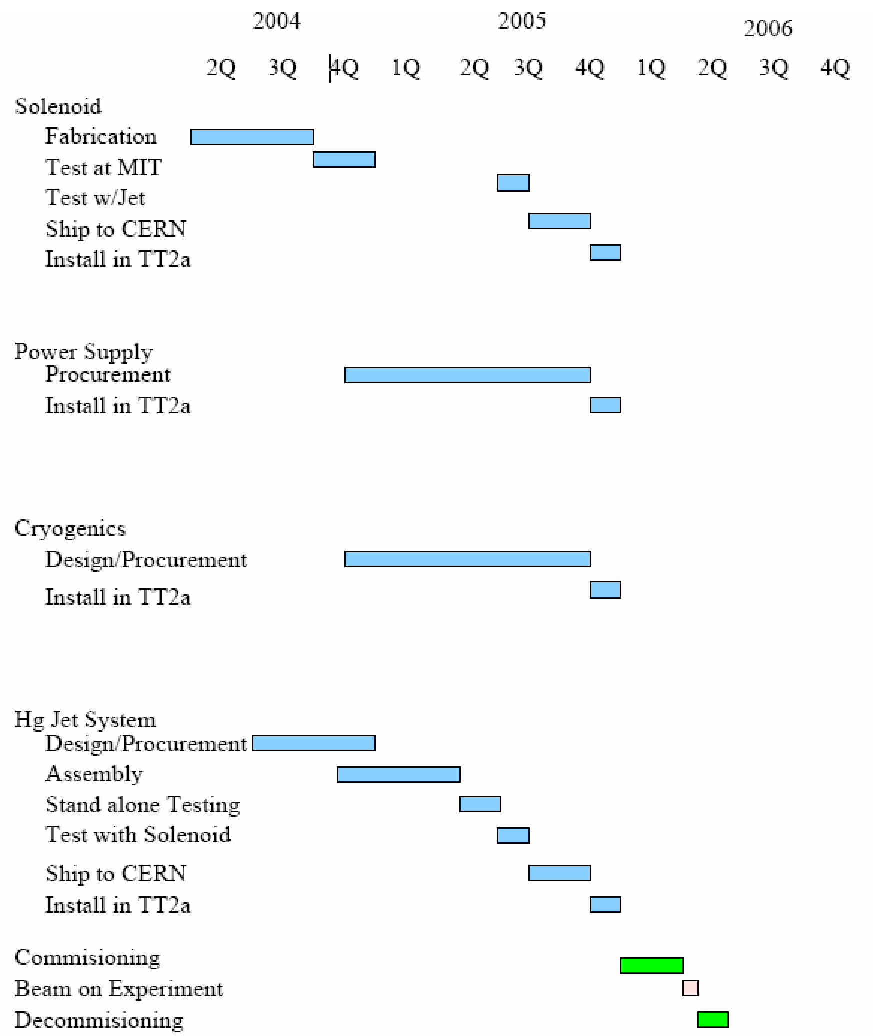
Including manpower: 1 man*month=10kChF

Beam Time

- at PS start-up 2006
  - Allows maximum installation time (year 2005)
  - Dedicated mode on nToF line preferred
- PS beam time
  - Given by number of pulses
  - One pulse every 30 minutes (LN2 cooling)
  - 2-3 weeks of PS beam time

Time schedule

- 2003
  - Autumn LOI
- 2004
  - March detailed study at CERN
  - Spring solenoid constr. launched
  - Spring proposal to INTC
- 2005
  - January solenoid delivered to MIT
  - April solenoid test finished
  - June solenoid shipped to CERN
  - September test at CERN
- 2006 April final run at PS start-up



Conclusion

- Approval by INTC needed
- Run quasi-continuous, 1cm, 20 m/s mercury jet including a stable optical observation
- solve RP issues

- The largest impact of our efforts on the accelerator community would be the acceptance of the concept of a free liquid jet target in a high-field solenoid for use in >2 MW proton beams
- Step-by-step R&D on liquid jet targets has been very successful, but is not sufficient.
- needed proof-of-principle test of a liquid jet + magnet + beam
- with an outstanding near-term opportunity at CERN.

- Special thanks to:
  F.Haug, C. De Almeida Martins, T.Otto