CMMS

TRIUMF Centre for

Molecular & Materials Science

8 Year Plan 2007-2015

Jess H. Brewer - 6 Dec. 2006

Proposal:

Design Study for a **Surface Muon Source**

in the present **Proton Hall** (2010-2015)

Recapitulating the Obvious:

- A Five-Year Plan should include the following categories:
  - **Maintenance & Operation** of existing facilities and programs.
  - **Construction & Commissioning** of finished engineering designs.
  - **Engineering Design** of thoroughly evaluated new concepts.
  - **Concept Evaluation**: Comparison of scientific potential, technical feasibility and probable cost of competing proposals.

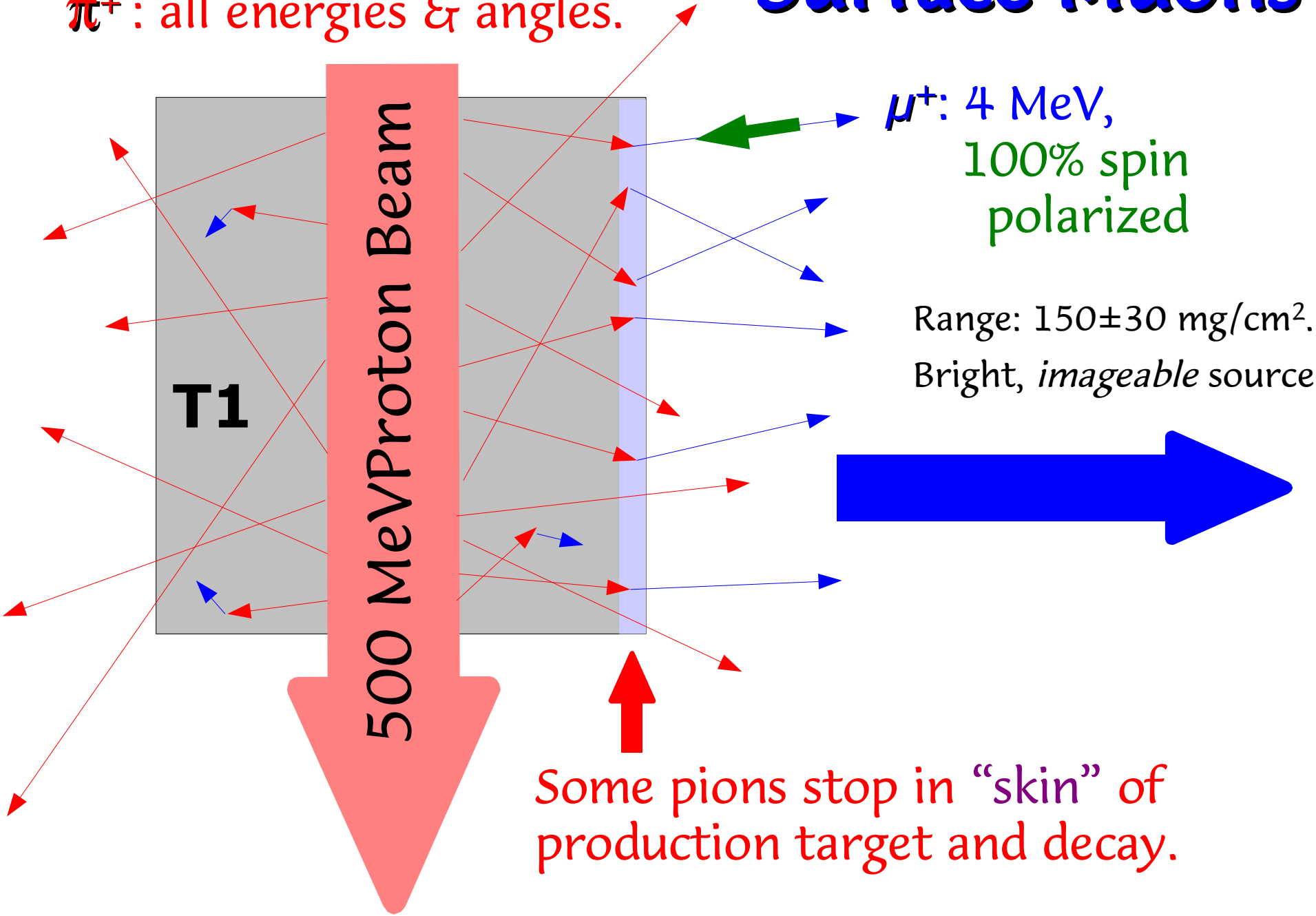
- Guiding Principles:
  - Do what you're good at.
  - Go for the Gold. 

What We're Good At

- **Making Muons** - *e.g.*
  - **Surface μ^+ beam** invented by U. Arizona group at LBL but developed at TRIUMF. Now ubiquitous and indispensable at all muon facilities.
  - **Ultra low energy μ^+ beam** invented at TRIUMF but developed at PSI because of rates. Now world's most oversubscribed muon channel.
- **Using Muons** - *e.g.*
  - **Spin Rotators** developed & perfected at TRIUMF.
  - **RF-μSR spin echo** first achieved at TRIUMF.

Surface Muons

π^+ : all energies & angles.



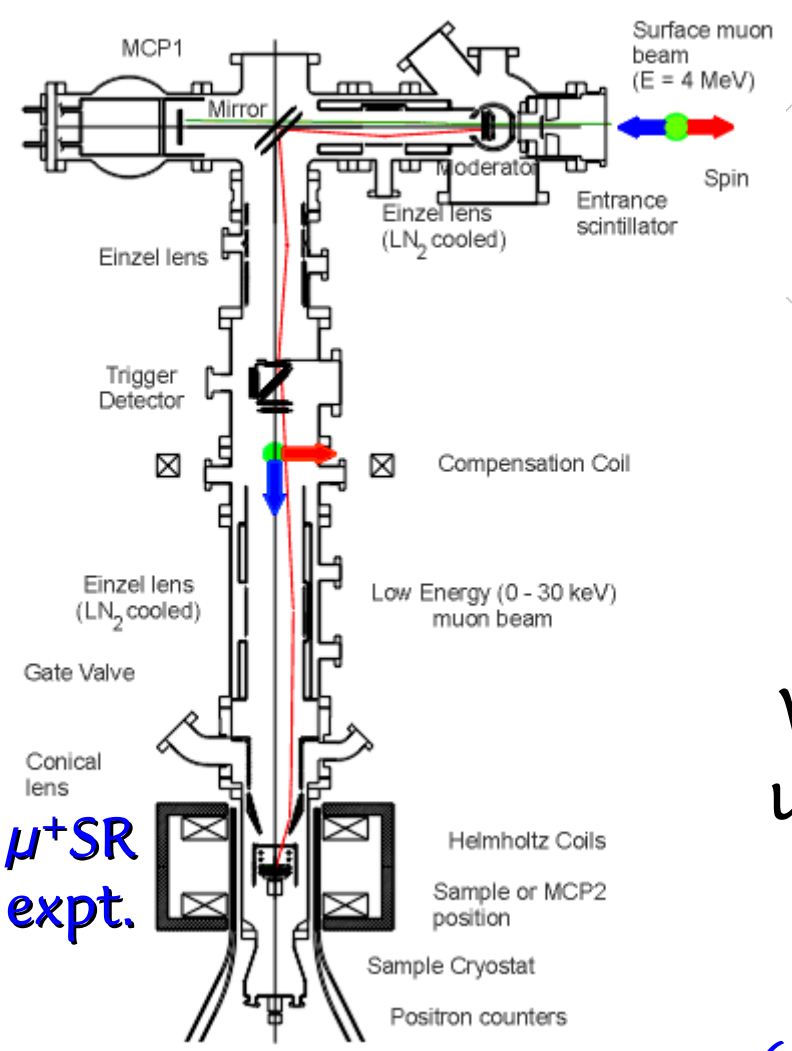
μ^+: 4 MeV,
100% spin
polarized

Range: 150±30 mg/cm^2.

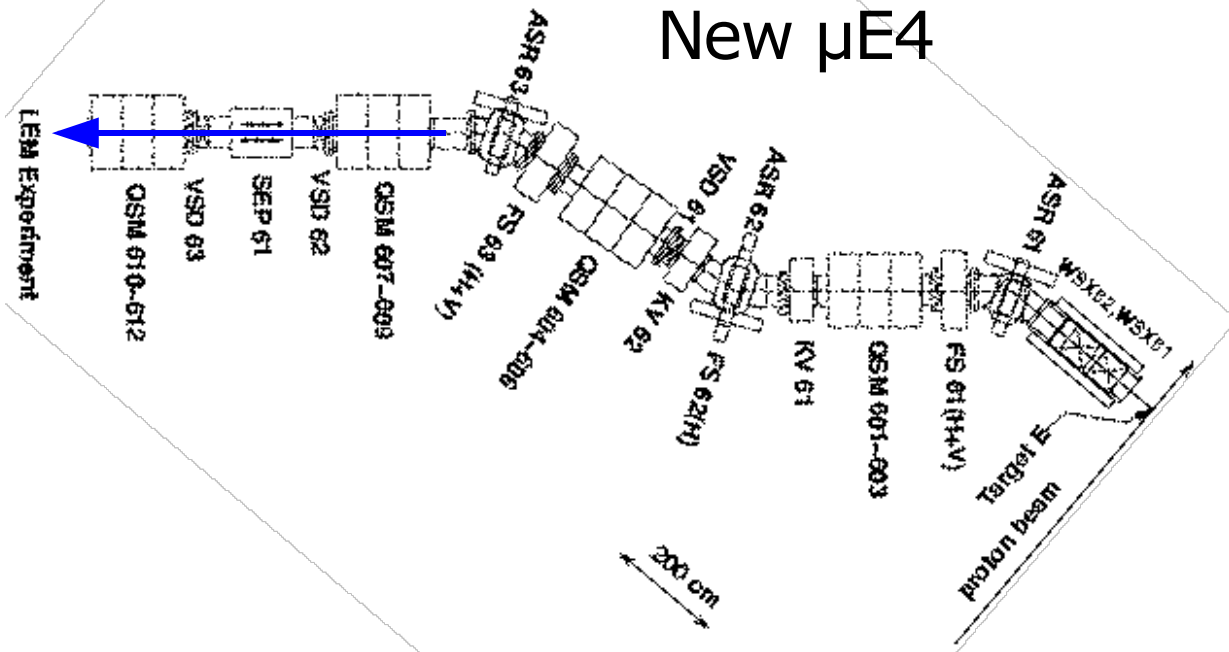
Bright, *imageable* source.

Some pions stop in "skin" of production target and decay.

The PSI Apparatus for Low Energy μSR



μ^+SR expt.



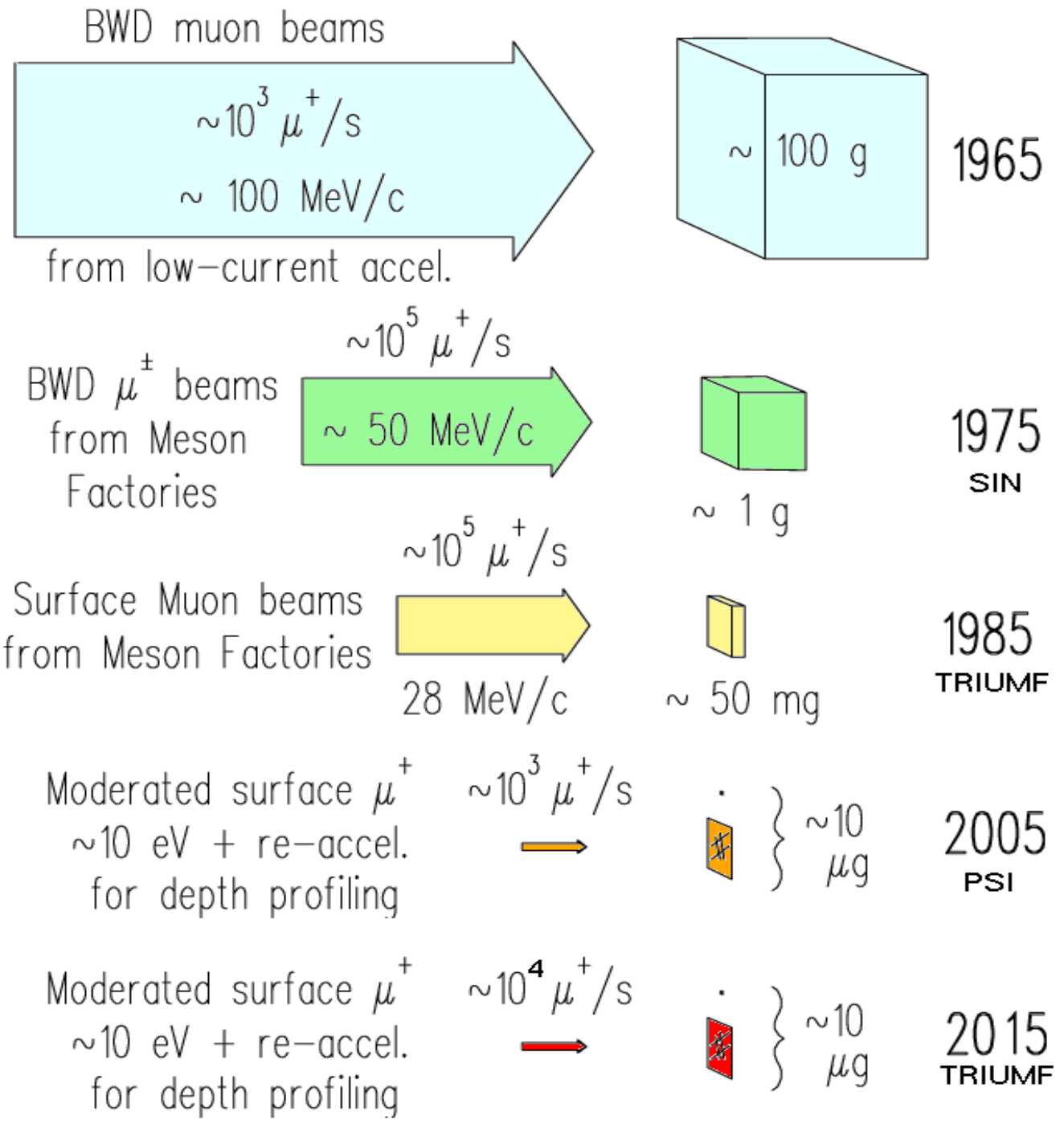
World's only operating ultra-Low Energy Muon beam facility at PSI:

~10^3 μ^+/sec

(*vs.* TRIUMF's ^{8}Li β-NMR)

History of μ^+ stopping luminosity:

Enabling μ^+SR

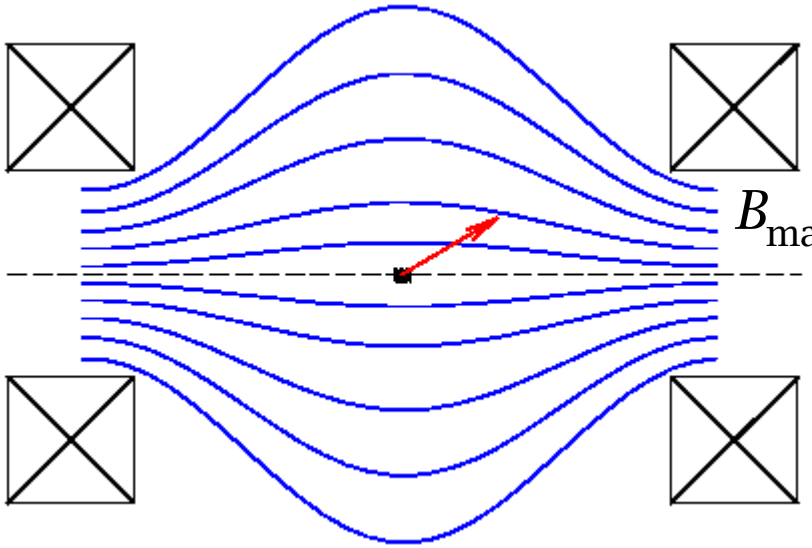


One possible design:

Leaky Magnetic Bottle

Place production target in a field between two rad-hard coils (proton beam into page).

$B_0 \sim 0.2$ T

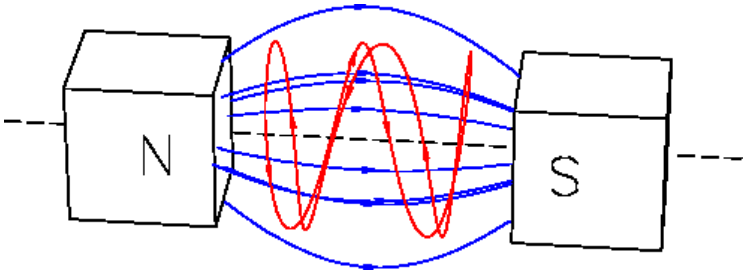


$B_{max} \sim 0.6$ T

$\theta_{crit} \sim 35^o \Rightarrow \Omega_{escape} \sim 1.5$ sr

Reflection criterion:

$$\left|\frac{v_{0\parallel}}{v_{0\perp}}\right| = |\cot\theta_0| < \sqrt{\frac{B_{max} - B_0}{B_0}}$$



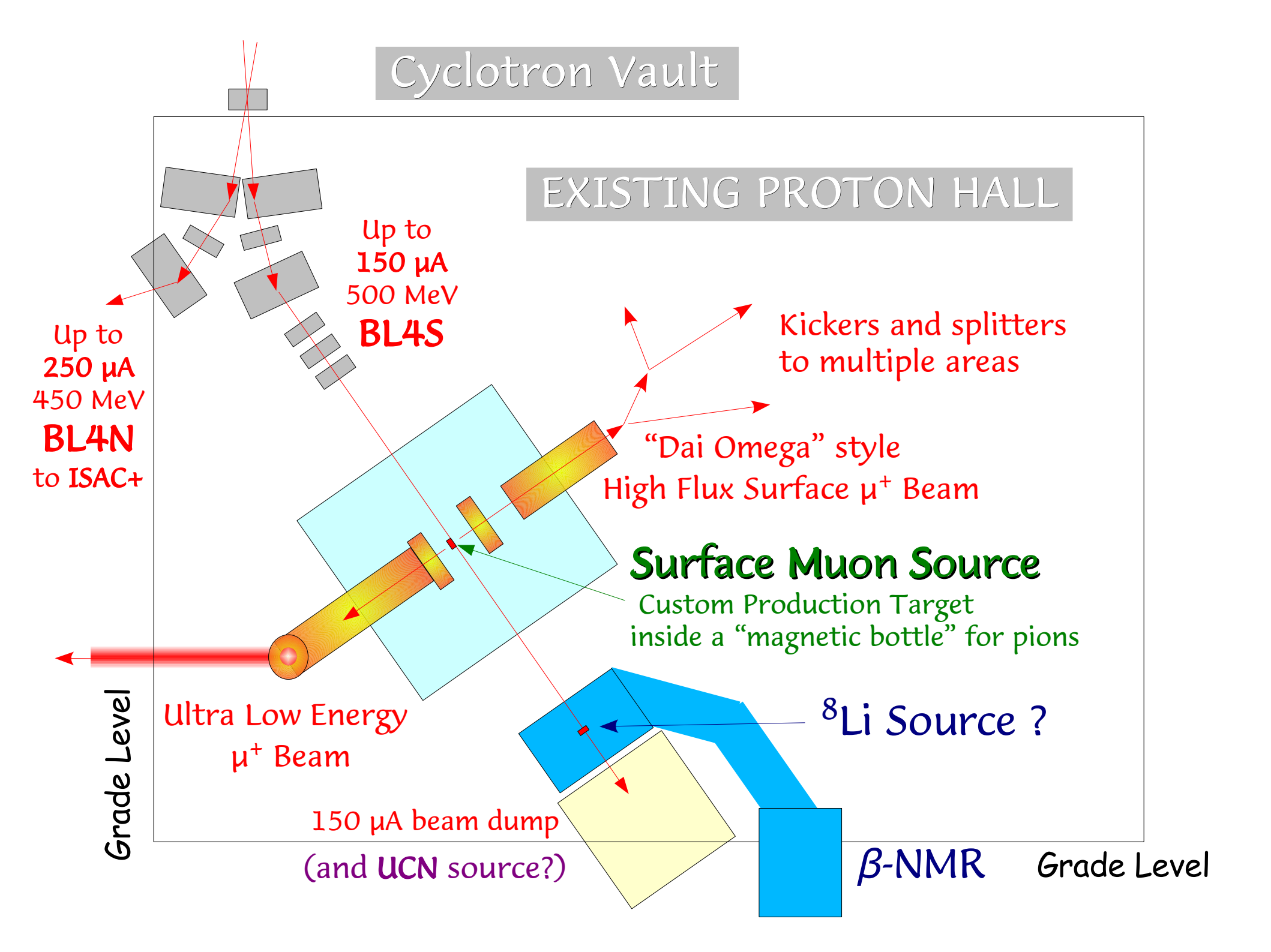
Low energy **pions** **return** to skin of production target (textured to make every surface both an entrance and an exit surface).

Surface **muons** **escape** if $\theta_0 < \theta_{crit}$ (equivalent to an **acceptance** of 1/4 of entire 2π solid angle).

Compare $\Omega \approx 50$ msr for typical surface muon channel: factor of

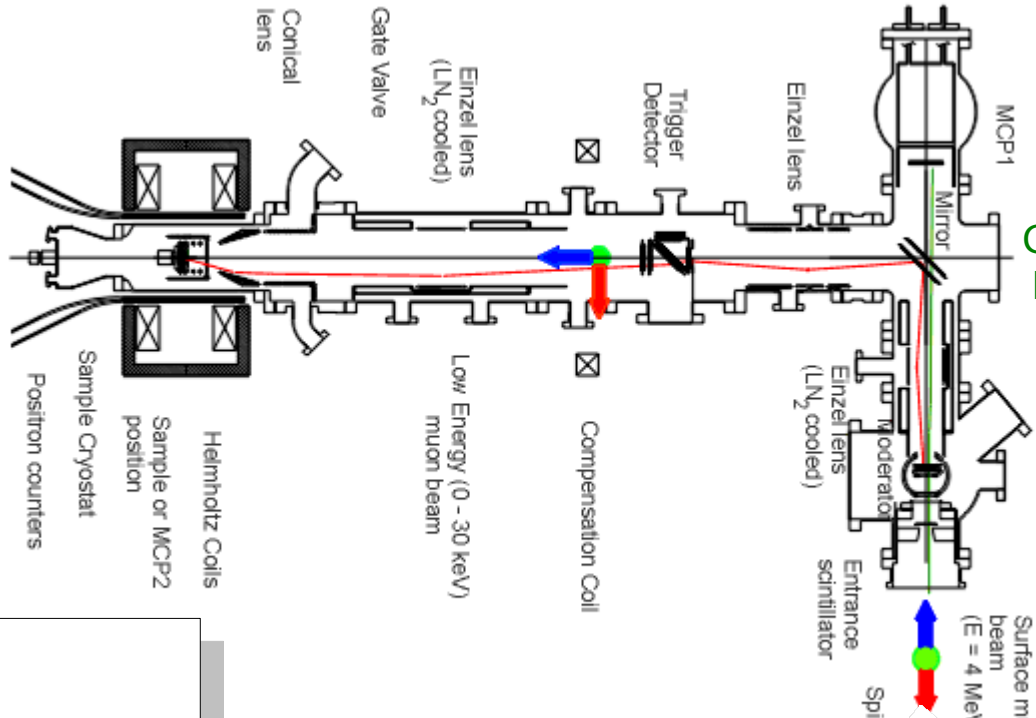
30

from solid angle alone.


Cyclotron Vault
EXISTING PROTON HALL
Up to
150 μA
500 MeV
BL4S
Up to
250 μA
450 MeV
BL4N
to ISAC+
Kickers and splitters
to multiple areas
"Dai Omega" style
High Flux Surface μ+ Beam
Surface Muon Source
Custom Production Target
inside a "magnetic bottle" for pions
Ultra Low Energy
μ+ Beam
8Li Source ?
150 μA beam dump
(and UCN source?)
β-NMR
Grade Level
Grade Level

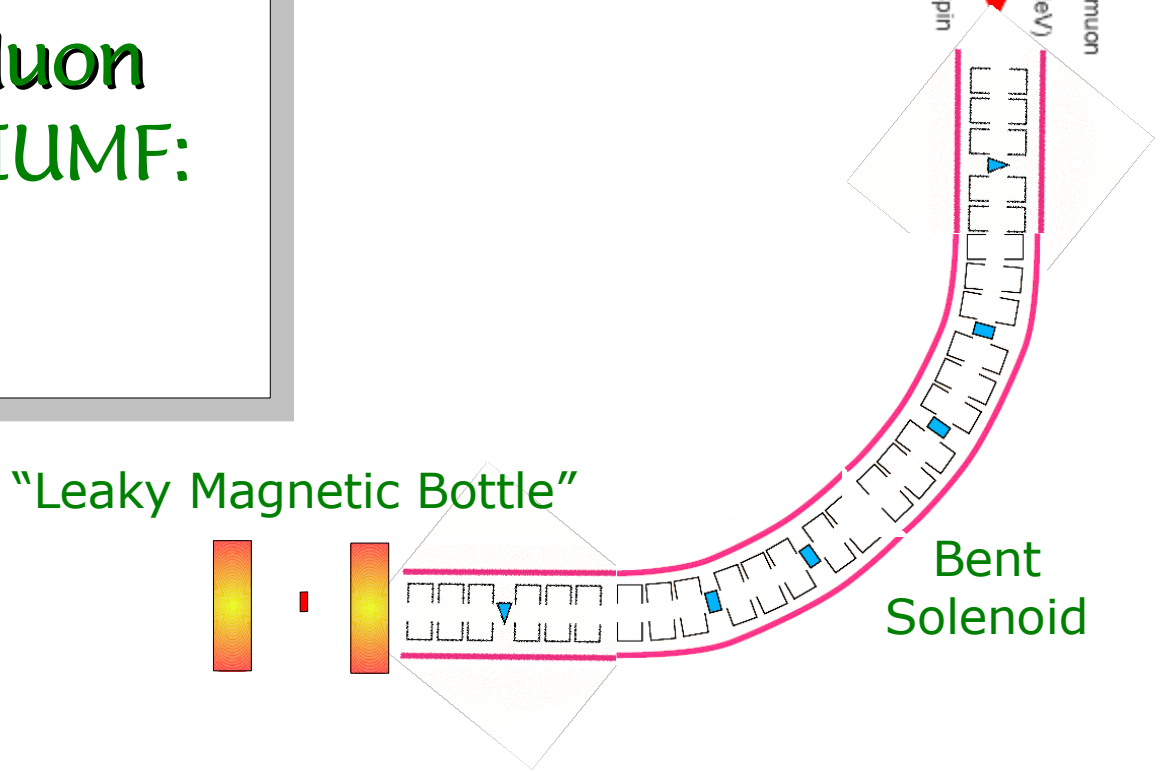
OR . . . re-accelerate
to ~ 500 keV and

focus on **very** small spot.



Proposed
ultra-**Low Energy Muon**
beam facility at TRIUMF:

~10^4 μ^+/sec



New Science Opportunities

- Simply increasing Low Energy Muon intensity from 10^3 to 10^4 μ^+/s is a huge step for LE-μSR.
- Combined with β-NMR, probe thin films, multilayers, magnetic nanostructures, ...
- Muonium in gases; hydrogen isotope chemistry.
- Re-accelerate LEM to ~ 1 MeV $\Rightarrow$ parallel beam can be focused onto μm-sized spot:

"Scanning μSR Microscope"?

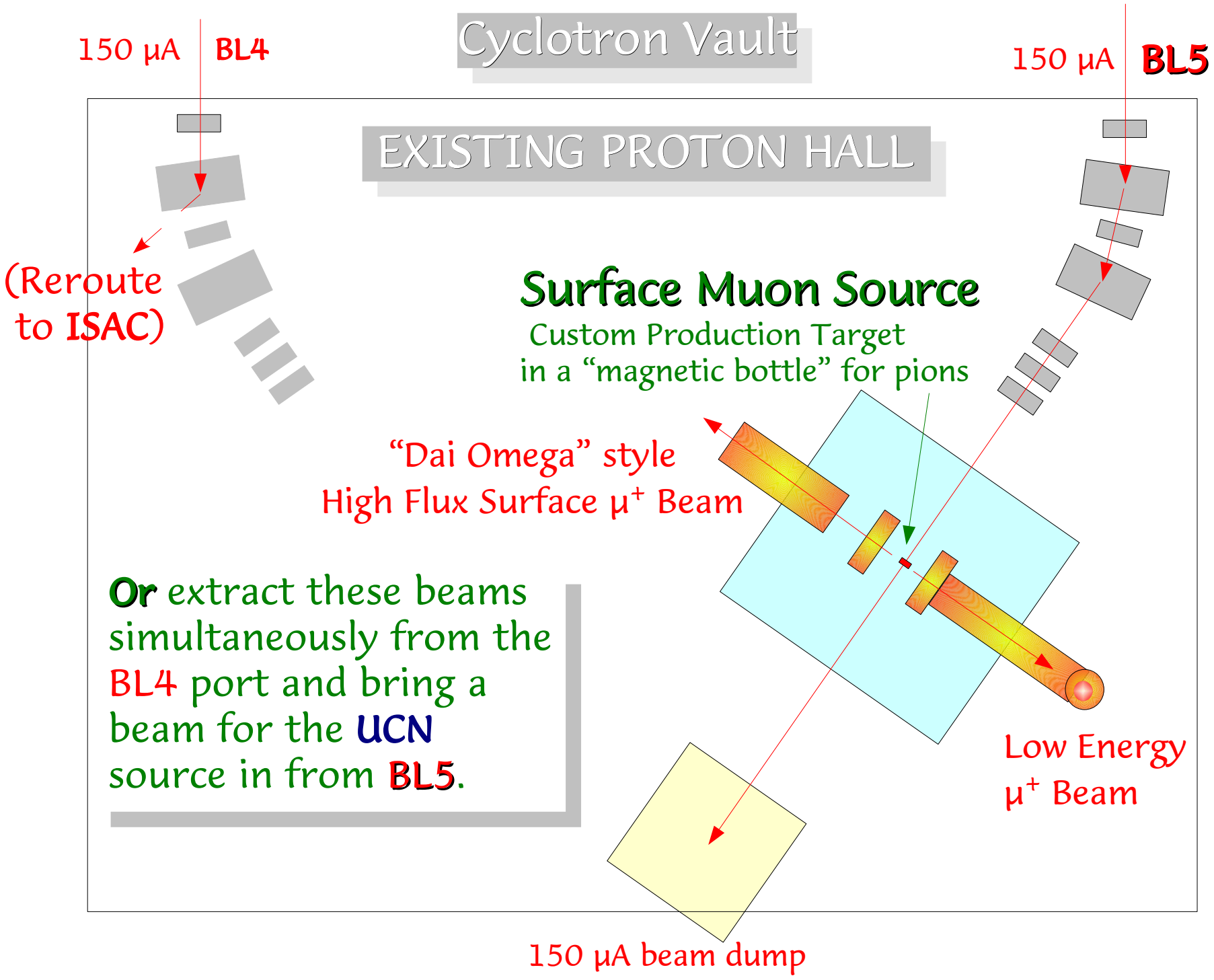
Schedule & "Bare Minimum" Costs

- Working Backward:
  - 2015: Start Construction
  - 2014: Finalize details
  - 2013: Next 5YP firm
  - 2012: Converge
  - 2011: Choose winners
  - 2010: Develop designs
  - 2008: Recruit people

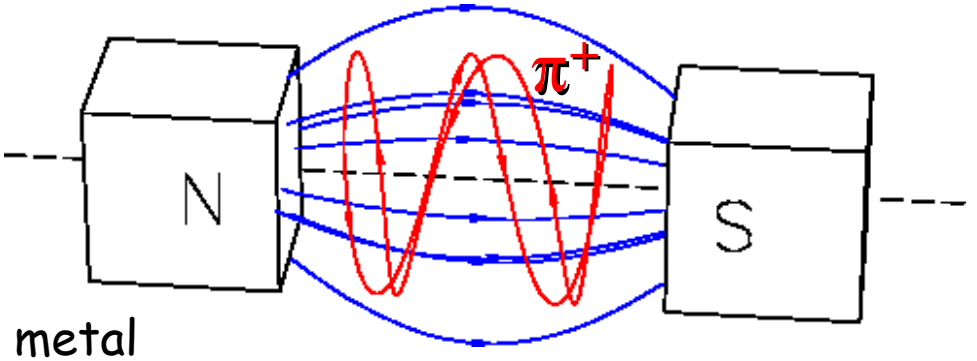
- People Costs:
  - Beam Optician $75K/y
  - Engineer $75K/y
  - Technician $50K/y
- Other Costs:
  - Prototypes $300K
  - Test Expts $200K
- TOTAL $ **1.5 M** (2010-15)

The End

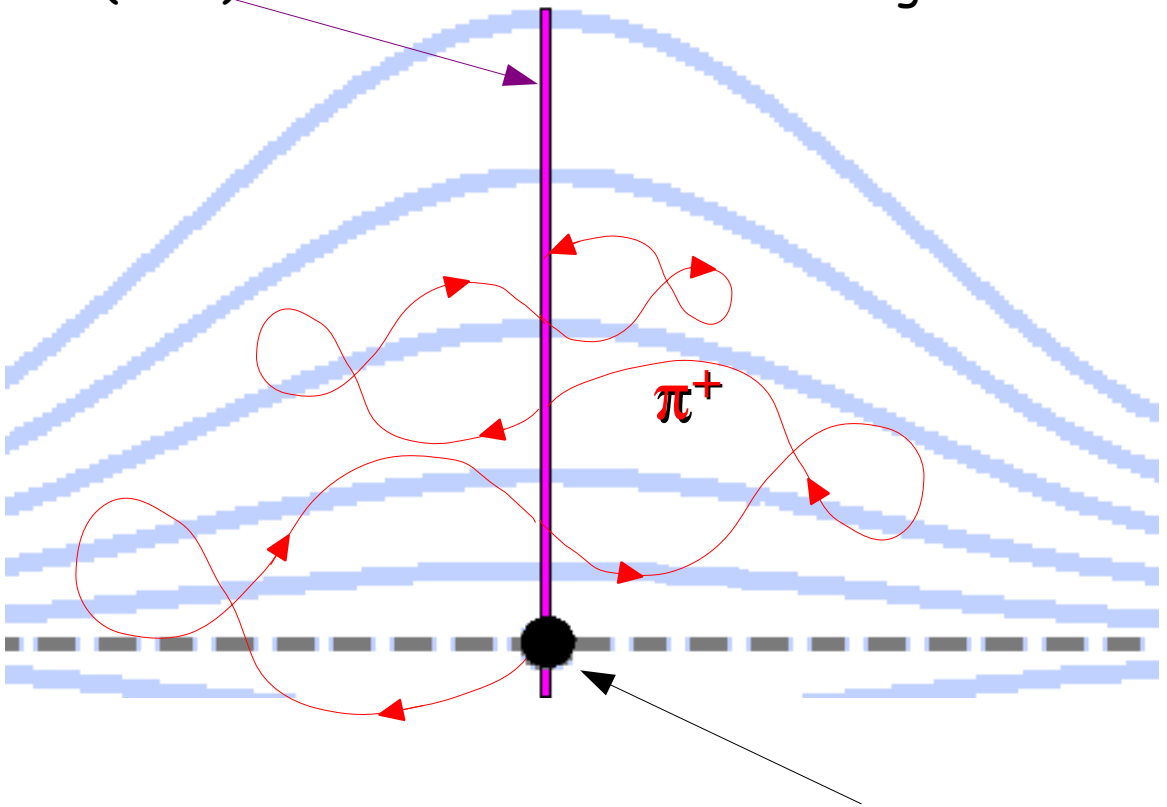
"Appendices" follow . . .


150 μA
BL4
Cyclotron Vault
150 μA
BL5
EXISTING PROTON HALL
(Reroute to ISAC)
Surface Muon Source
Custom Production Target
in a "magnetic bottle" for pions
"Dai Omega" style
High Flux Surface μ+ Beam
Or extract these beams simultaneously from the BL4 port and bring a beam for the UCN source in from BL5.
Low Energy
μ+ Beam
150 μA beam dump

Details of Production Target:
Magnetic Bottle for π^+



Production target thermally coupled to thin metal disk ("fin") viewed here "edge on".



Low energy **pions** **return** to "fin" of production target (every surface is both an entrance and an exit surface). At each pass, the pion loses energy and is **scattered**.

The π^+ spectrum is almost flat near zero energy, so each pass through the "fin" is another chance to stop within the "muon skin". But at each pass, a fraction f of the pions "leak out of the bottle". Thus the "surface enhancement factor" relative to a plain target is

$$\varepsilon = \sum_{n=0}^{\infty} (1-f)^n = 1/f$$

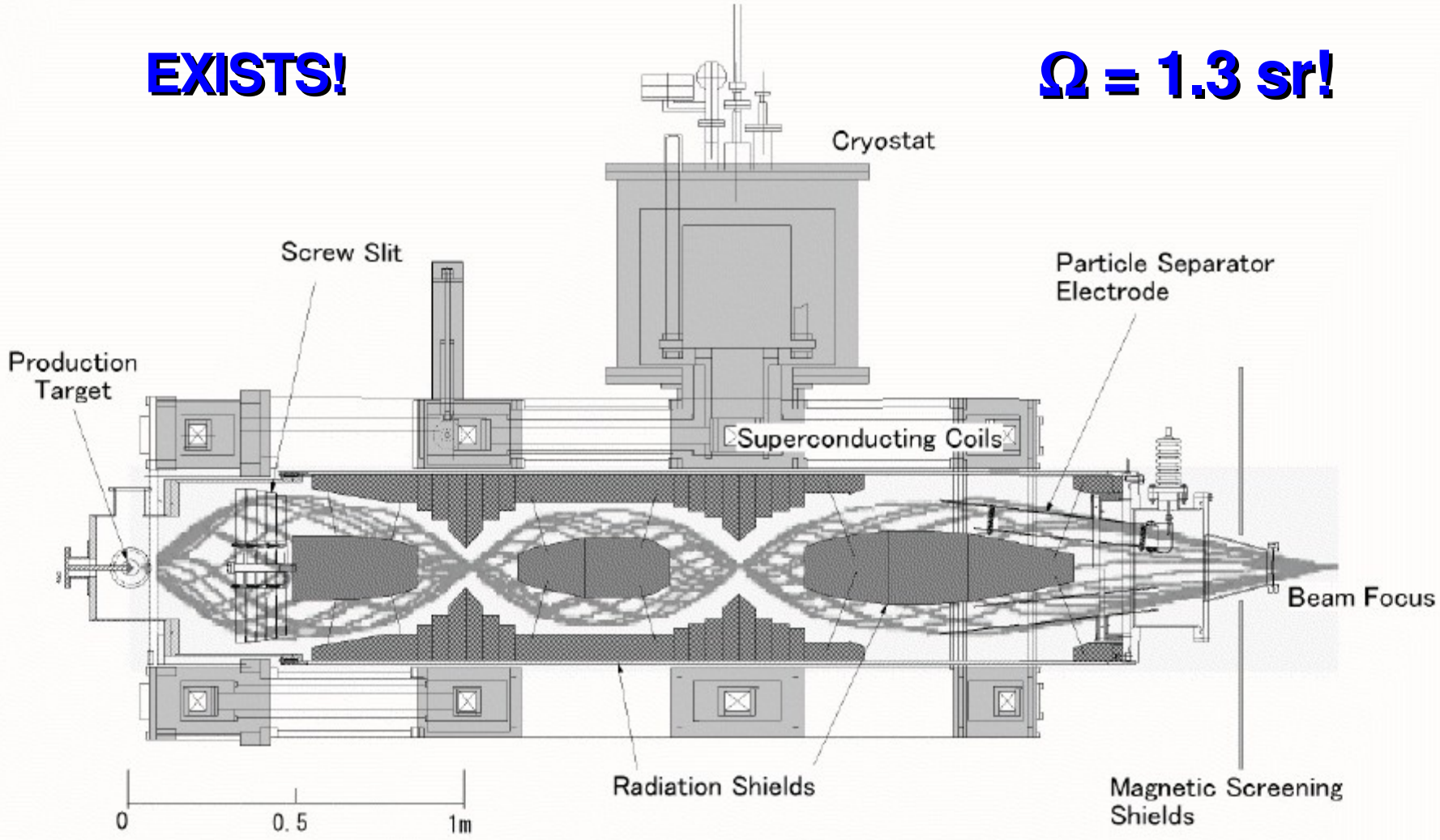
For $f = 1.5/2\pi$,

$$\varepsilon \approx 4.2$$

Large Solid Angle Axial Focusing Superconducting Surface Muon Channel, Dai Omega

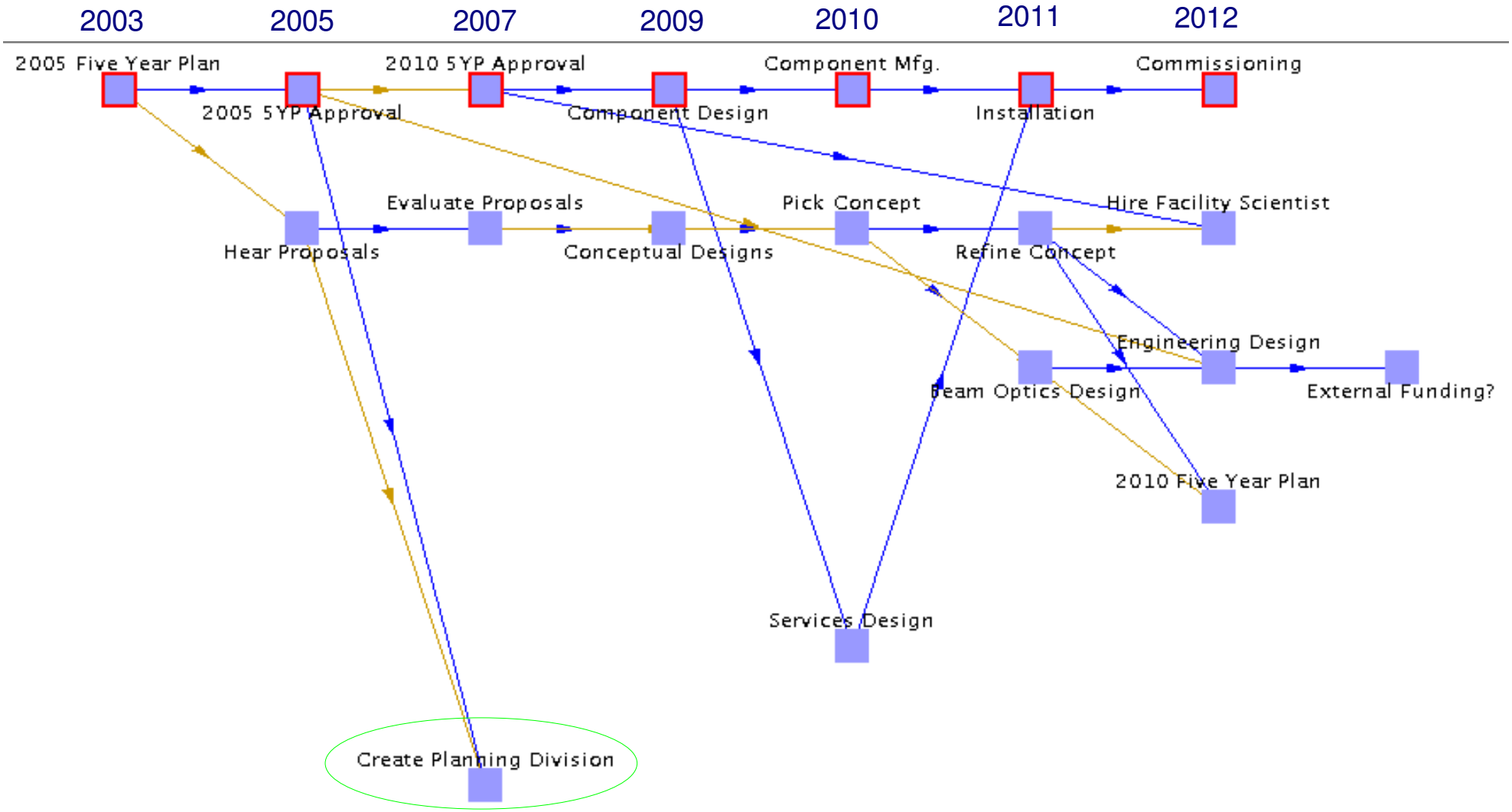
EXISTS!

Ω = 1.3 sr!

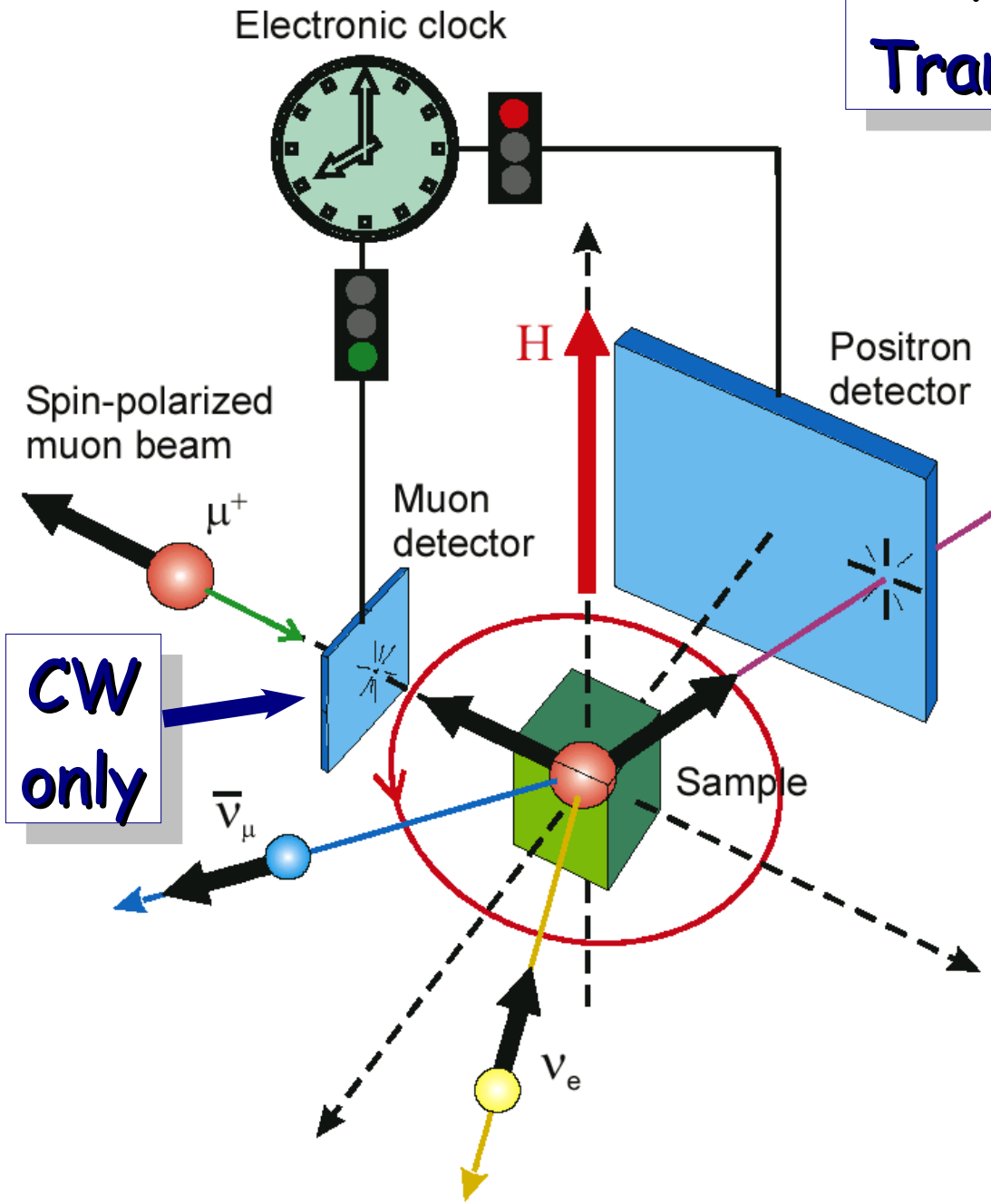


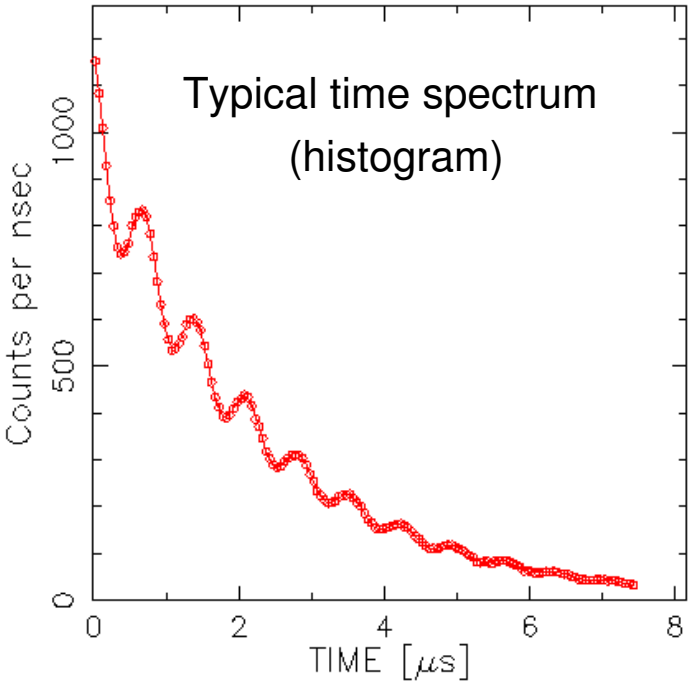
(ADD 5 YEARS)

Proton → Muon Hall: Critical Path



High Time Resolution Transverse Field (TF)-μSR





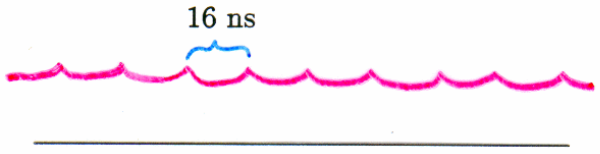
CW (PSI & TRIUMF) *vs.* Pulsed (ISIS, J-PARC) Muon Facilities

Time resolution of CW-μSR *two orders of magnitude* better!

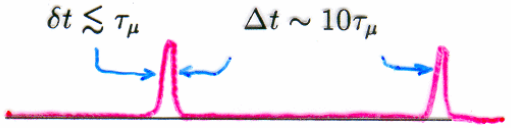
- **Time Structure:**

Most "standard" muon experiments (as performed at TRIUMF or PSI) require *CW* beam. However, other time structures can be very useful:

– *CW Beam:*

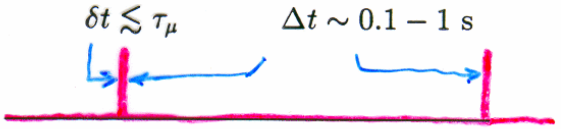


– *Bunched Beam:*



1. Rare decays & capture (low backgrounds).
2. Pulsed TD-$\mu\mathcal{SR}$ (if δt is small).

– *Pulsed Beam:*



1. Laser excitation of short-lived species.
2. More efficient RF-$\mu\mathcal{SR}$ (like NMR).

$A_p \equiv$ "ADVANTAGE FACTOR" for PULSED MUONS (OVER CW MUONS)

$$A_p = \log\left(\frac{N_i}{N_f}\right)$$

NUMBER OF SYNCHRONIZED "INPUTS" (μ, RF, Laser, ...)

NUMBER OF CORRELATED "OUTPUTS" (e, n, γ, fragments, recoil, ...)

"Themes" in μSR

Muonium as light Hydrogen

(Mu = μ^+e^-) (H = p^+e^-)

- **Mu vs. H atom Chemistry:**
  - gases, liquids & solids
  - Best test of reaction rate theories.
  - Study "unobservable" H atom rxns.
  - Discover new radical species.
- **Mu vs. H in Semiconductors:**
  - Until recently, μ^+SR → **only** data on metastable H states in semiconductors!

The Muon as a Probe

- **Probing Magnetism:** unequalled sensitivity
  - Local fields: electronic structure; ordering
  - Dynamics: electronic, nuclear spins
- **Probing Superconductivity:** (esp. HT$_c$SC)
  - Coexistence of SC & Magnetism
  - Magnetic Penetration Depth
  - Coherence Length

- **Quantum Diffusion:** μ^+ in metals (compare H^+); Mu in nonmetals (compare H).

AFTERWORD
Town Meeting 2002

- Ideally, a 5-Year Plan should include the following categories:
  - Maintenance & Operation of existing facilities and programs.
  - Construction & Commissioning of completed engineering designs.
  - Engineering Design of new facilities chosen by thorough evaluations.
  - Concept Evaluation: Comparison of scientific potential, technical feasibility and probable cost of competing proposals for new facilities.
- Traditionally the final category has been relegated to semi-democratic processes such as TUG AGMs, Town Meetings and the prior efforts of self-organized groups of Users. While new initiatives must always have "grass roots" origins, these partisan efforts must evaluated and compared much more thoroughly than is possible in a year or two before each 5-Year Plan. A step is missing.
- I therefore proposed (in 2002) that TRIUMF create a standing LRPC to fulfill this role. This body would receive proposals asynchronously and review them full time, thus alleviating the "Communication Bottleneck" .
- 2005 : Communication Task Group recommends creative use of Web-based tools (databases, interactive forms, *wikis etc.*) to facilitate User INPUT.