Modulator Overview

System Design vs. Tunnel Topologies

Snowmass Workshop

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Ray Larsen for the SLAC ILC Group

Outline

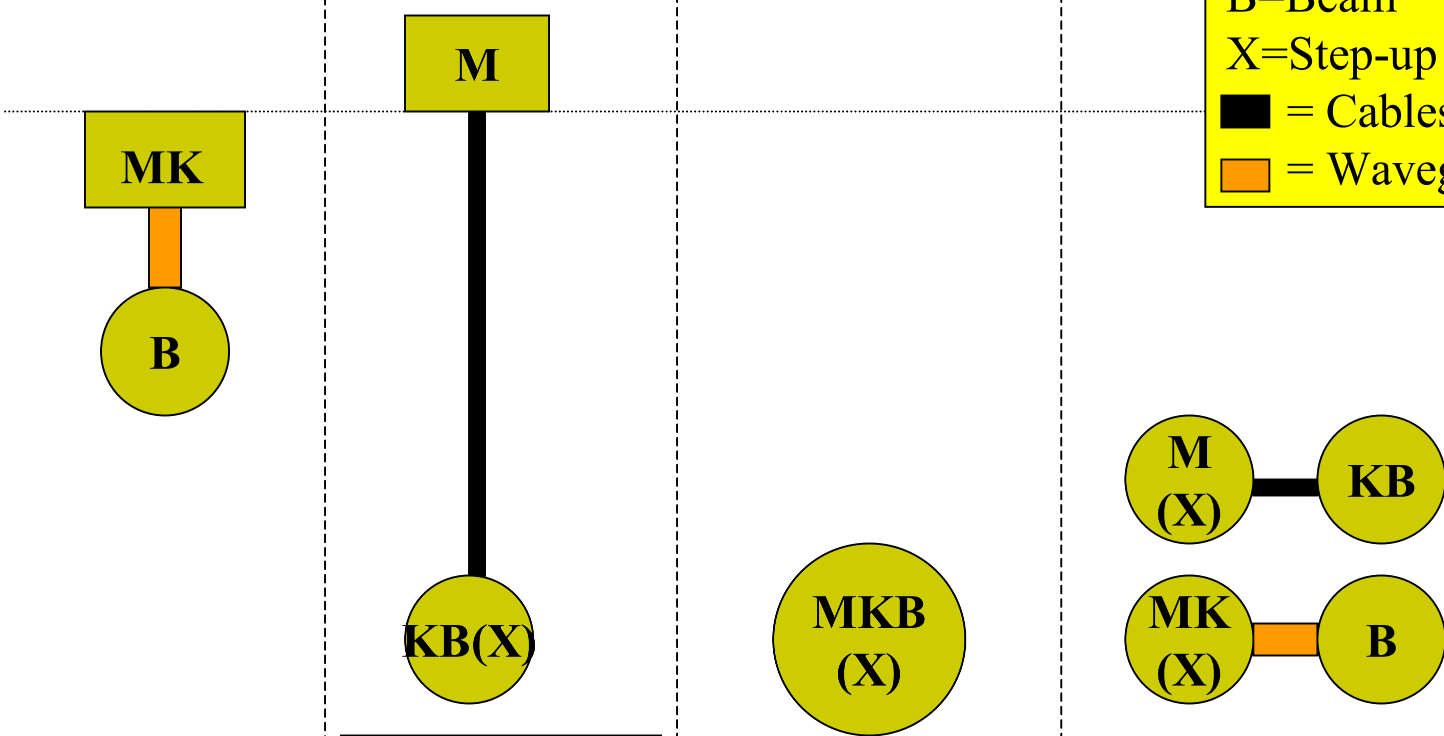
- I. Modulator Options vs. Topologies
- II. Preliminary Cost Estimates
- III. Single Tunnel Challenges, Possible Solutions
- IV. Conclusions

TESLA Modulator Works So Why R&D?

- Still many unknowns about modulator performance, maintainability, final tunnel topology choices, availability, cost optimization.
- Possible improvements:
  - Reduce total footprint, weight, cost
  - Reduce bulk, cost of cable plant in tunnel
  - Eliminate step-up transformer, oil in tunnel
  - Eliminate modulator oil
  - Improve energy efficiency
  - Reduce installation, servicing time
  - Improve maintenance safety

I. Options vs. Tunnel Topol

M=Modulator
K=Klystron
B=Beam
X=Step-up Xfmr
= Cables
= Waveguide



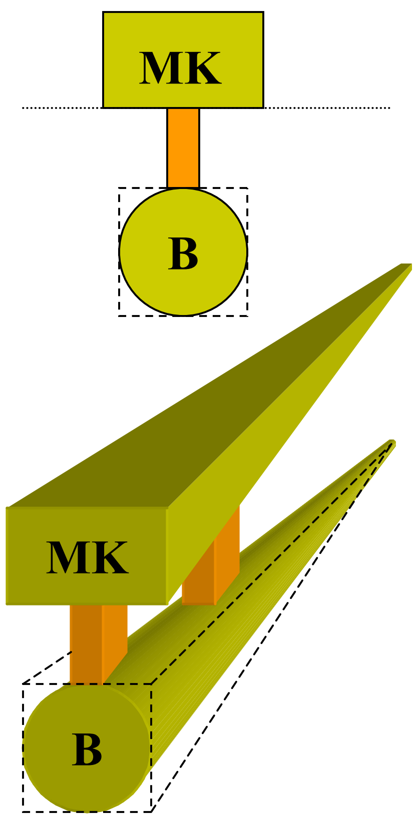
1. SLAC: Gallery + Shallow Tunnel

2. TESLA: Spaced Surface Huts + Deep Tunnel

3. Single Tunnel Deep or Shallow

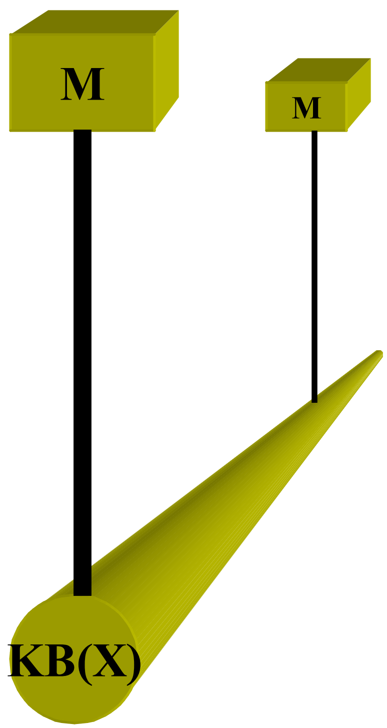
4. Dual Deep Tunnels

1. Surface Gallery + Shallow Tunnel



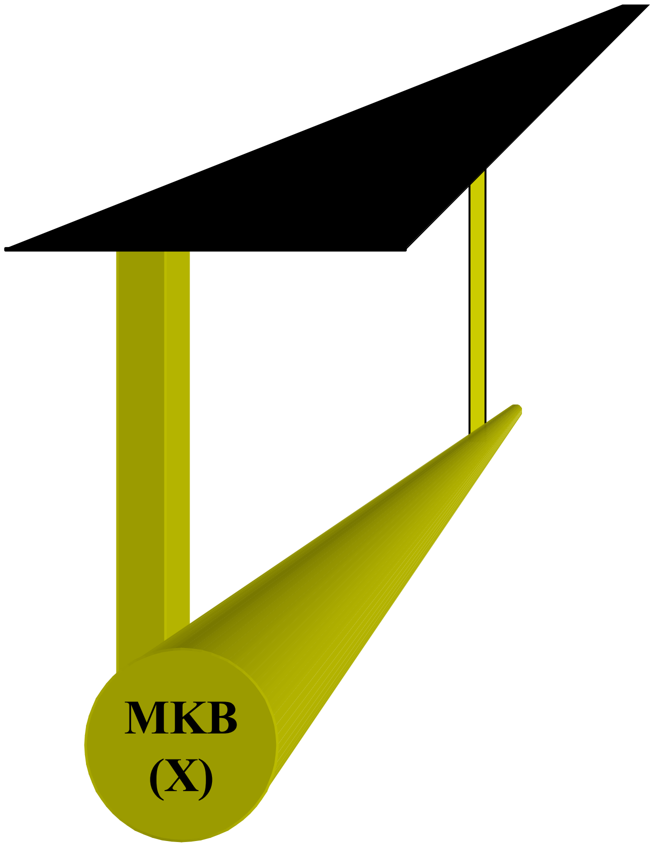
- Shallow tunnel
- Bored or rectangular cut and cover
- ~10 m deep waveguide feed penetrations every 40m (~1000 total)
- M-K co-located on surface for easy access
- n/N redundancy for energy overhead in case of failure

2. Spaced Surface Huts + Deep Tunnel



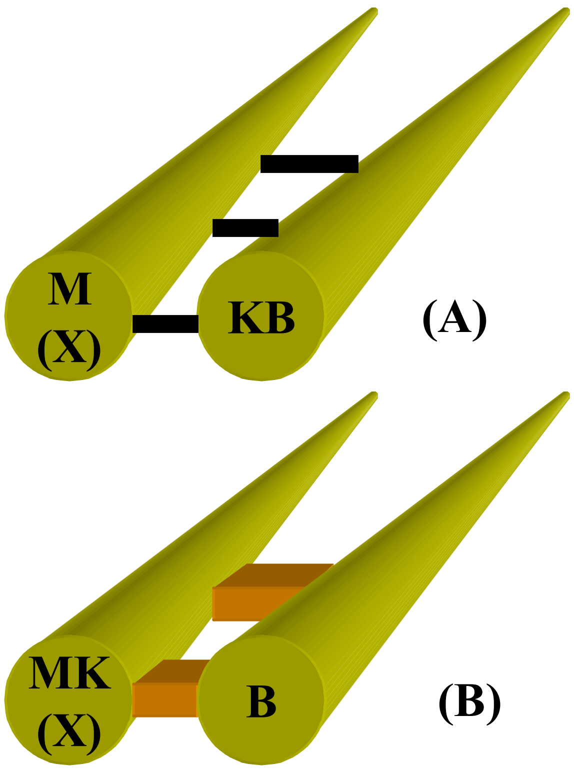
- Modulator cluster in huts service up to 2.5 Km sector
- Klystrons in beam tunnel
- Cables HV or LV + X
- Modulators easily accessible, klystrons and Xfmr not

3. Single Tunnel Deep or Shallow



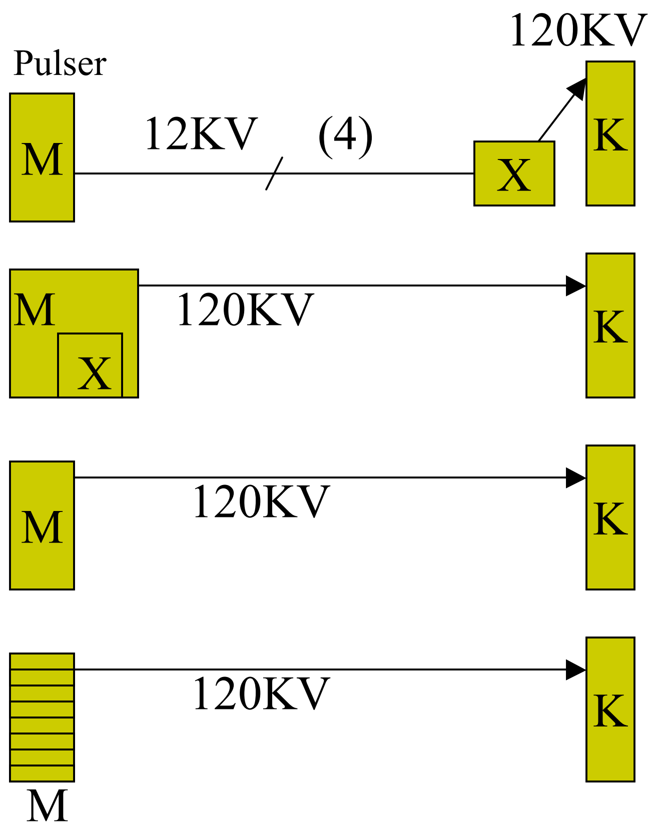
- Modulators & Klystrons co-located in beam tunnel
- Access Penetrations every *n* Km
- All electronics in beam tunnel
- Shield electronics from neutron, gamma flux

4. *Dual Deep Tunnels*



- Modulators and/or klystrons accessible via 2nd tunnel
- Access every *n* Km
- Lateral penetrations every ~40 m for short WG or cable feeds
- *Fig. A:* Klystrons inaccessible in beam tunnel – LV/HV Cable feed
- *Fig. B:* Klystrons accessible co-located in service tunnel – Waveguide Feed

Modulator Candidates



1. TESLA Model: 12 KV pulsed DC source w/ 4 long LV cables, 1:10 Step-up near klystron,
2. SNS Model: Pulsed HF DC-DC Converter produces 120 kV output pulses on 1 cable
3. DTI Model: Pulsed direct HV IGBT switch produces 120 KV directly, transformerless, 1 cable
4. Marx Model: Pulsed 12 KV IGBT stack produces 120 kV directly, transformerless, 1cable

Status

- TESLA Design:
  - Multiple units (~10) working with 5MW CW tubes.
  - Latest units produced commercially.
  - Fermilab upgrading, building 2-3 more units for SMTF
  - Development of redundant switch, other upgrades in progress.
  - See S. Choroba & H. Pfeffer presentations this meeting.

Status

- SNS Design (LANL)
  - Units in full production
  - ~15 units installed and started commissioning
  - Units drive single or multiple klystrons depending on load Z matching
  - Unit being installed at SLAC for L-Band test facility and evaluation
  - Design optimization under study for ILC
  - See W. Reass presentation at this meeting.

Status

- Direct Switch (DTI Design)
  - DTI Corporation is building first unit on DoE SBIR Phase 2
  - Company has built similar products commercially
  - Due for delivery FY06
  - Will be evaluated on test stand at SLAC FY06
  - See J. Casey presentation this meeting.

Status

- Marx Design (SLAC)
  - Design in process.
  - Earlier design effort for 500 kV unit demonstrated 18 kV test cell successfully
  - First 12 kV cell for 120 kV full prototype (120 kV, 140 A) now under test
  - Full unit under aimed for completion & testing on klystron mid FY 06
  - 3 companies recently awarded SBIR Phase I's for Marx design & commercialization
  - See G. Leyh presentation this meeting

Modulators vs. Tunnel Topology

TOPOLOGY / LINAC / MODULATOR	I. MK – B	II. M – KB(T)	III. MKB	IV. (A) M – KB (B) MK – B
1. TESLA Model	**SLAC topology. MXK coupled in Gallery . Short WGs to Beamline. Cables short. All components accessible. Highest Availability.**	**TESLA design. M in Huts, long LV cables to T,K. MTTR, Availability of transformer, cables, Klystrons Compromised.**	**Radiation protection needed! All components in deep tunnel. Short cables, WG MTTR all components compromised. Large bulk, non-modular design, oil makes difficult or impractical. Lowest Availability.**	**A ~ TESLA w/short cables. B ~ SLAC w/ short WG. All components in 2nd tunnel accessible. Availability same as (2) in (A), closer to (1) in (B)**
2. SNS Model	**Modulator footprint comparable to TESLA**	**HV cable plant less bulky, costly. K protection needs study**	**Same comments. Radiation protection.**	**Same Comments**
3. Direct Switch	**Transformer-less design, smaller footprint than 1, 2.**	**Same comments as (2). More protection issues for switch, cap failures as well as klystron arcs.**	**Smaller footprint would make easier to install, maintain. Oil in tunnel still an issue. Radiation protection.**	**Smaller footprint would make 2-tunnel more practical. Oil in tunnel still an issue.**
4. Marx Stack	**Smaller footprint than all other designs. Unique redundant stack gives highest unit MTTR, Availability. Oil-less design.**	**HV cable plant less bulky, costly. K protection needs study. See R. Cassel Paper this meeting.**	**Modular design makes topology more feasible. Small light modules can be replaced by machine without human access. Radiation protection studies needed.**	**Marx adapts to either topology easier than others. (B) preferred for highest Availability, no radiation issues.**
Topology Availability Ranking	**1**	**3**	**4**	**(A) = 3.5 (B)=2**

Availability Rankings

1. Near-surface building w/ all RF accessible
2. Twin tunnel with all RF components accessible. Penalty for more difficult deep tunnel access.
3. Single deep tunnel with huts for modulators. Penalty for inaccessible cable plant, transformer, klystron.
4. Single deep tunnel with all components inside

   However, may be greatly improved with modular design (see later in this talk).

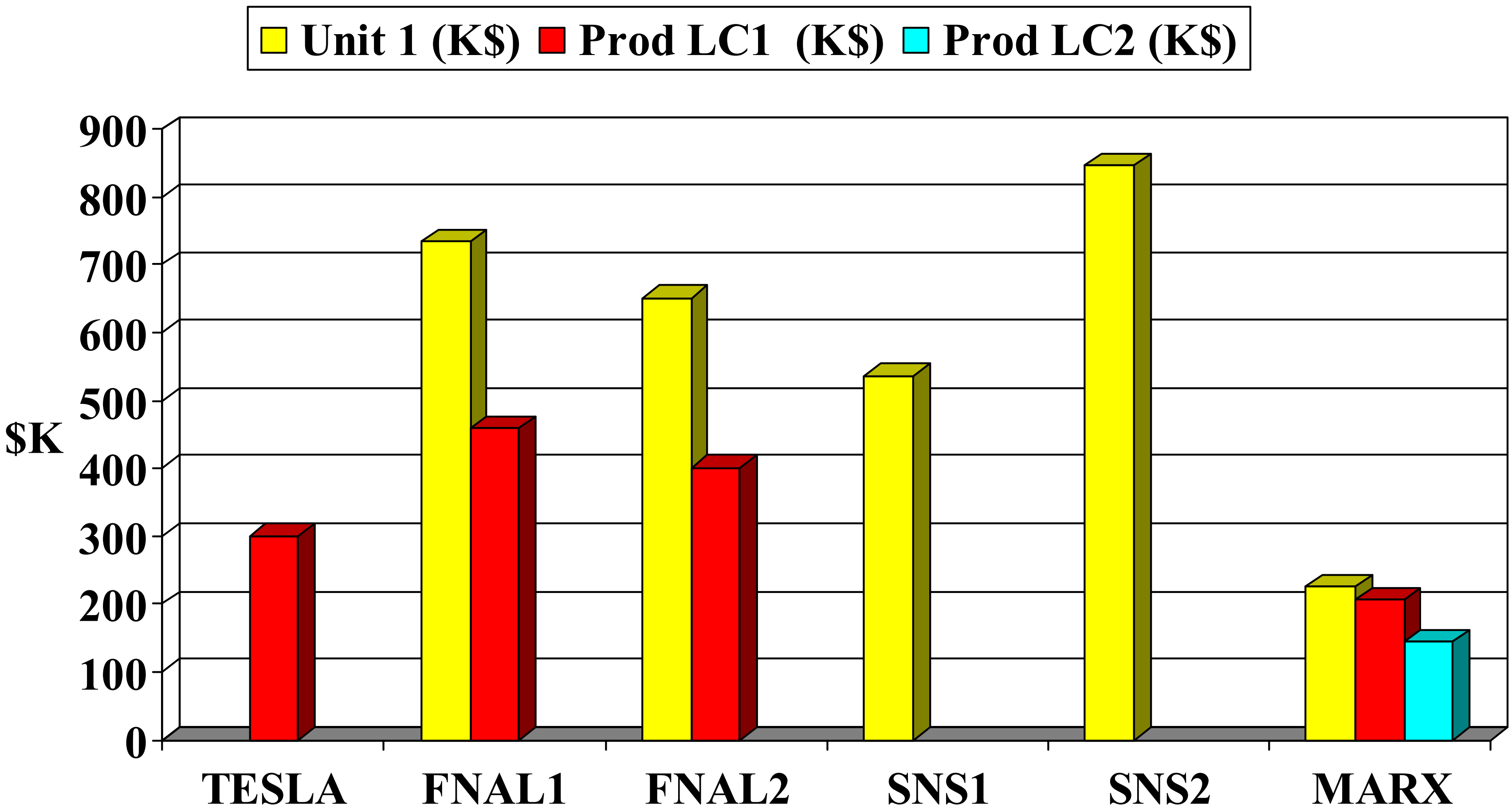
Modulators vs.Topologies Summary

- Any modulator design will work in any topology provided that:
  - A. Transmission of 120 KV on single cable over 2.5 Km feasible, reliable
  - B. Klystron can be protected in any configuration
    - See R. Cassel presentation this session
- Factors which may dictate final choices are sizes of tunnels vs. footprints, access for repair, overall system availability, overall system cost.

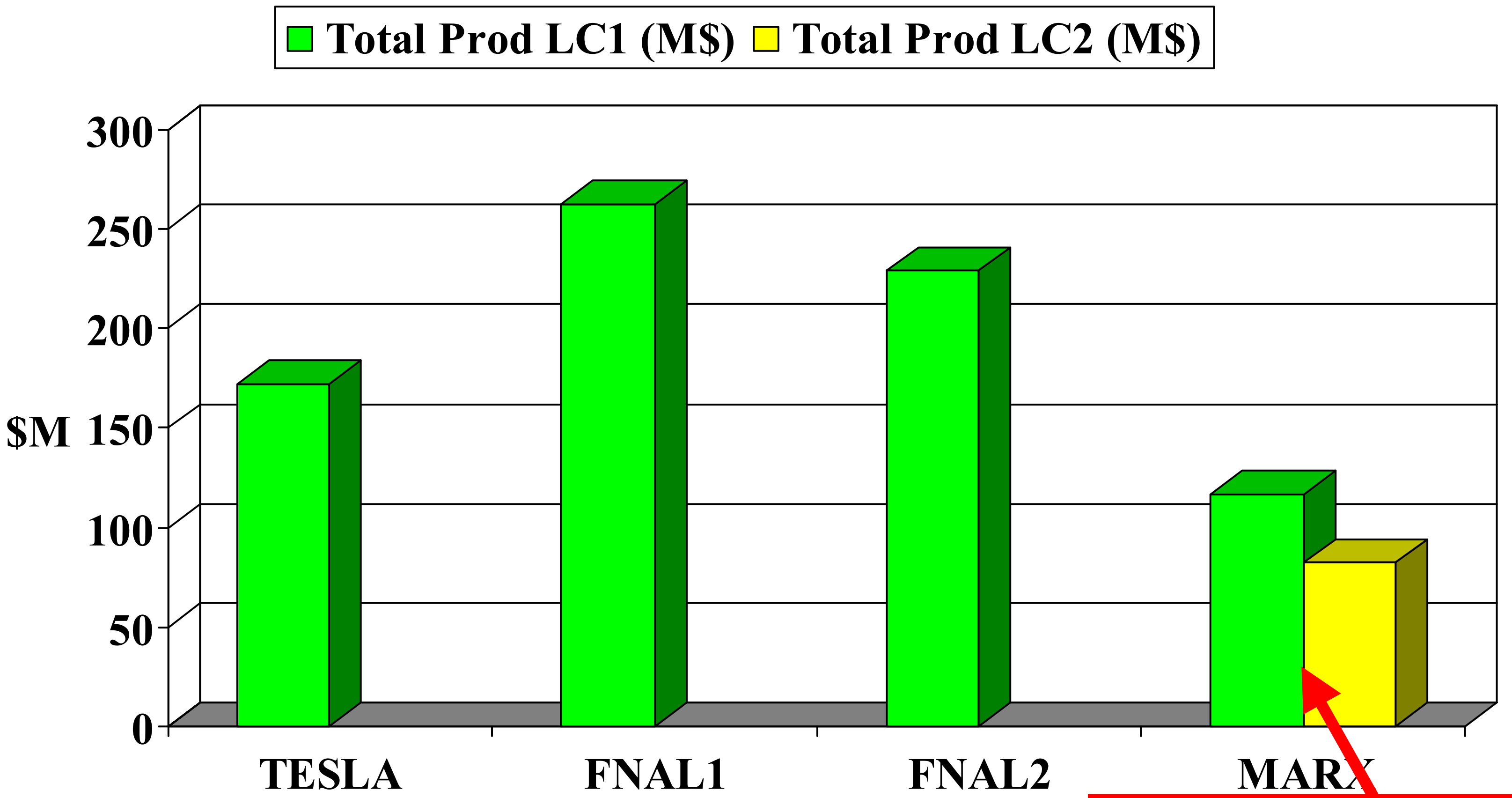
II. Preliminary Cost Estimates

- TESLA Model
  - Production cost from industry
    - Source: S. Choroba quoted in Pfeffer/Wolff 10/14/2004
- FNAL Model
  - Current design unit, production estimates
  - Upgraded model unit, production estimates
    - Source: Pfeffer/Wolff 10/14/2004
- SNS Model
  - Original 1-unit cost est.
    - Source: W. Reass, LANL
  - Updated & upgraded new build (4 units) 1- unit cost est.
    - Source: D. Anderson, SNS
- MARX Model
  - Prototype bottom-up costs
    - Source: Unit 1 estimate by G. Leyh, SLAC; Production est. by R. Larsen

Modulator 1 Unit vs. Unit Avg. Production Cost 572 Units



Total Production Cost 572 Modulators



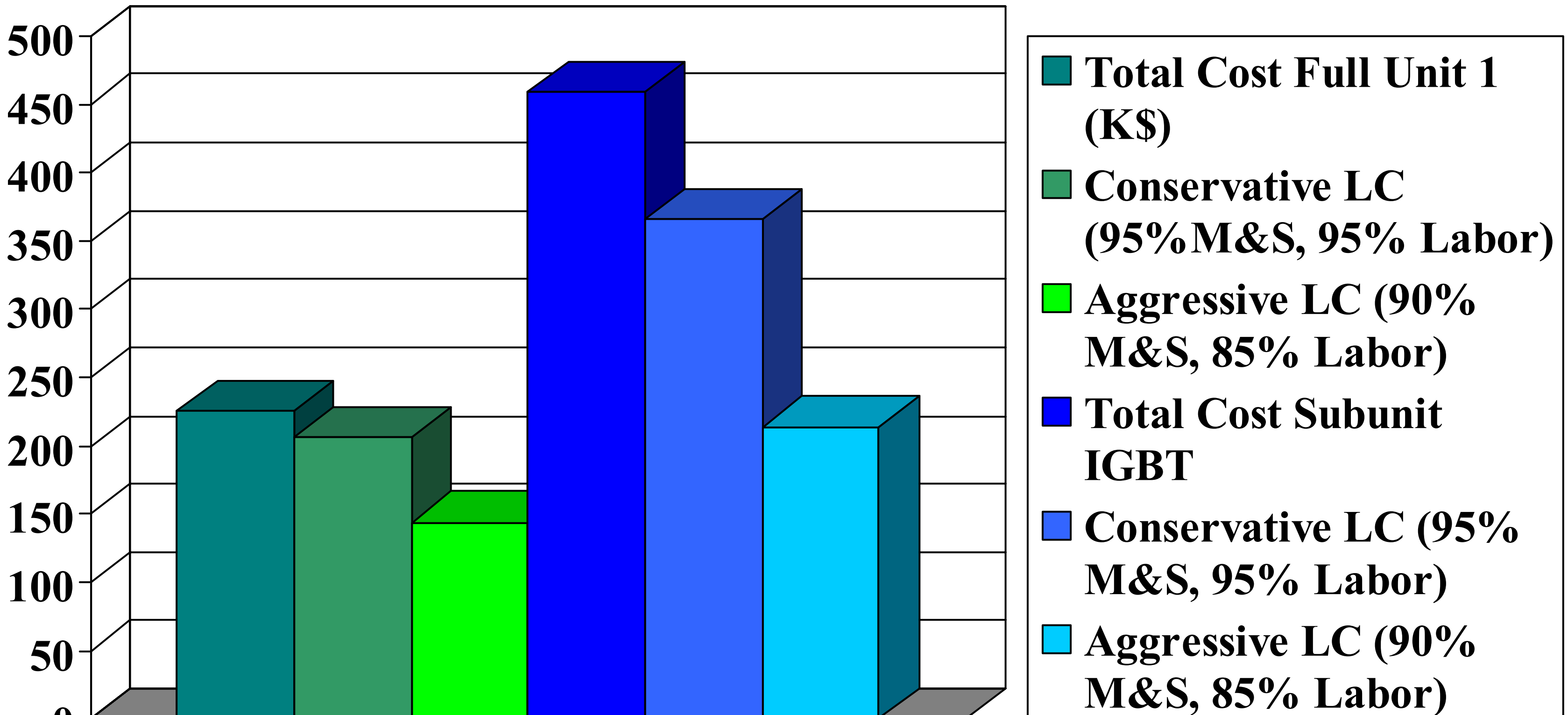
Cable Plant Costs Not Included

Learning Curves 1&2
Incl. 20%ED&I, 15% Profit

Refined Learning Curve Estimates

- Method:
  - Separate component parts that are very different and run separate learning curves.
  - Derive a weighted final average LC.
- Example:
  - Half of Marx M&S is due to one component, the IGBT sub-subunit, a circuit board which numbers 160 per modulator, or 91,520.
  - Using 160 as batch, learning curve has many more doublings and gets to lower average (over).

Average Cost 572 Units (K$)
Average Cost 91520 IGBT Subunits ($)



Includes 20% Mfgr ED&I, 15% Profit

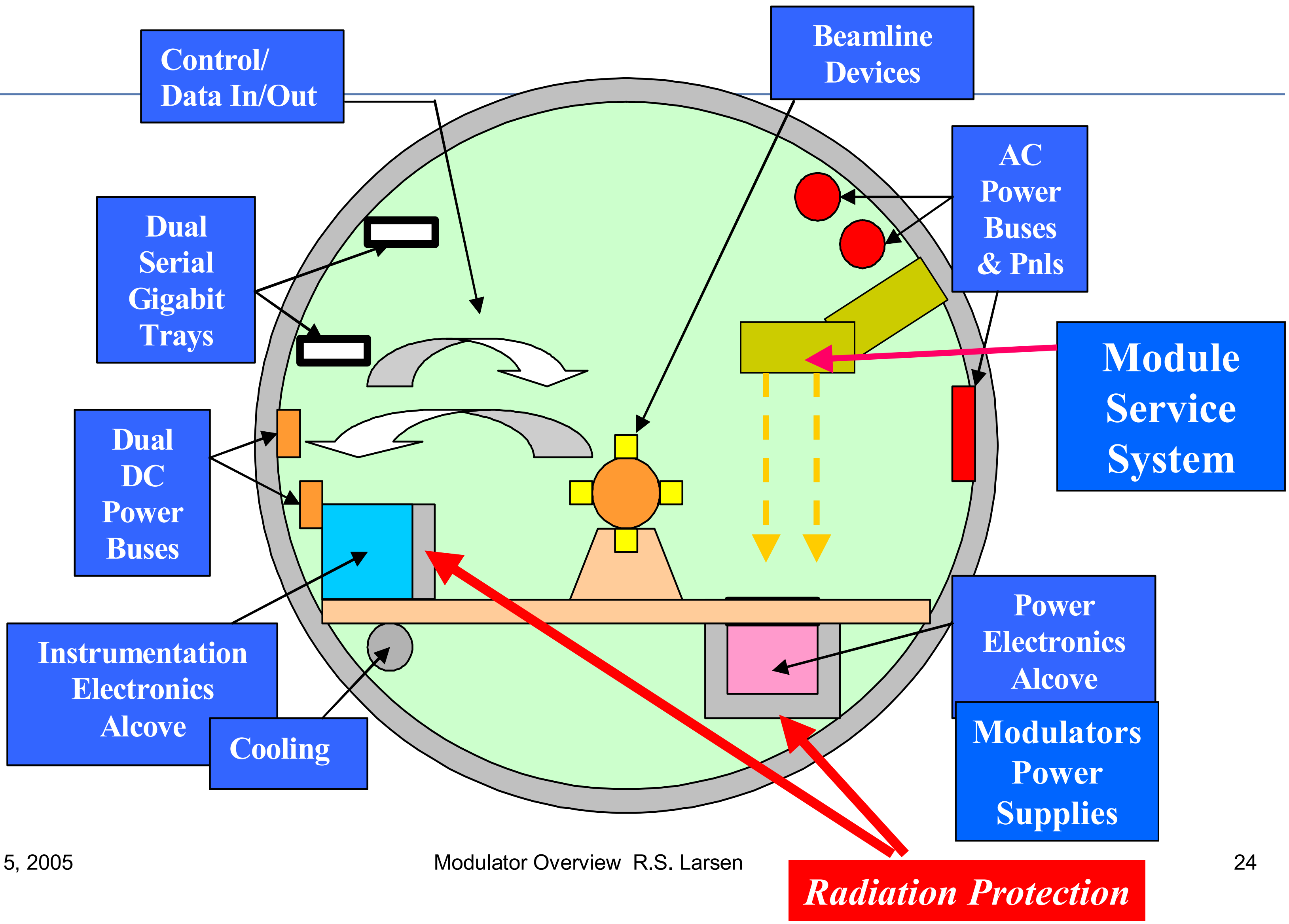
Preliminary Cost Summary

- Estimated Unit 1 and 572 unit average production costs based on partial data available are ~ \$6-700K, \$3-400K respectively, except for Marx.
- Marx bottom-up estimates give \$225K unit 1 cost & \$144-\$209K production average for Aggressive & Conservative Learning Curves.
- Designs of TESLA-FNAL, SNS are mature and unit costs known quite well.
- MARX design, costs estimated from actual circuits under construction, are immature but prototype design indicates savings potential of ~40-50%.
- This and other factors taken together justify continued R&D.

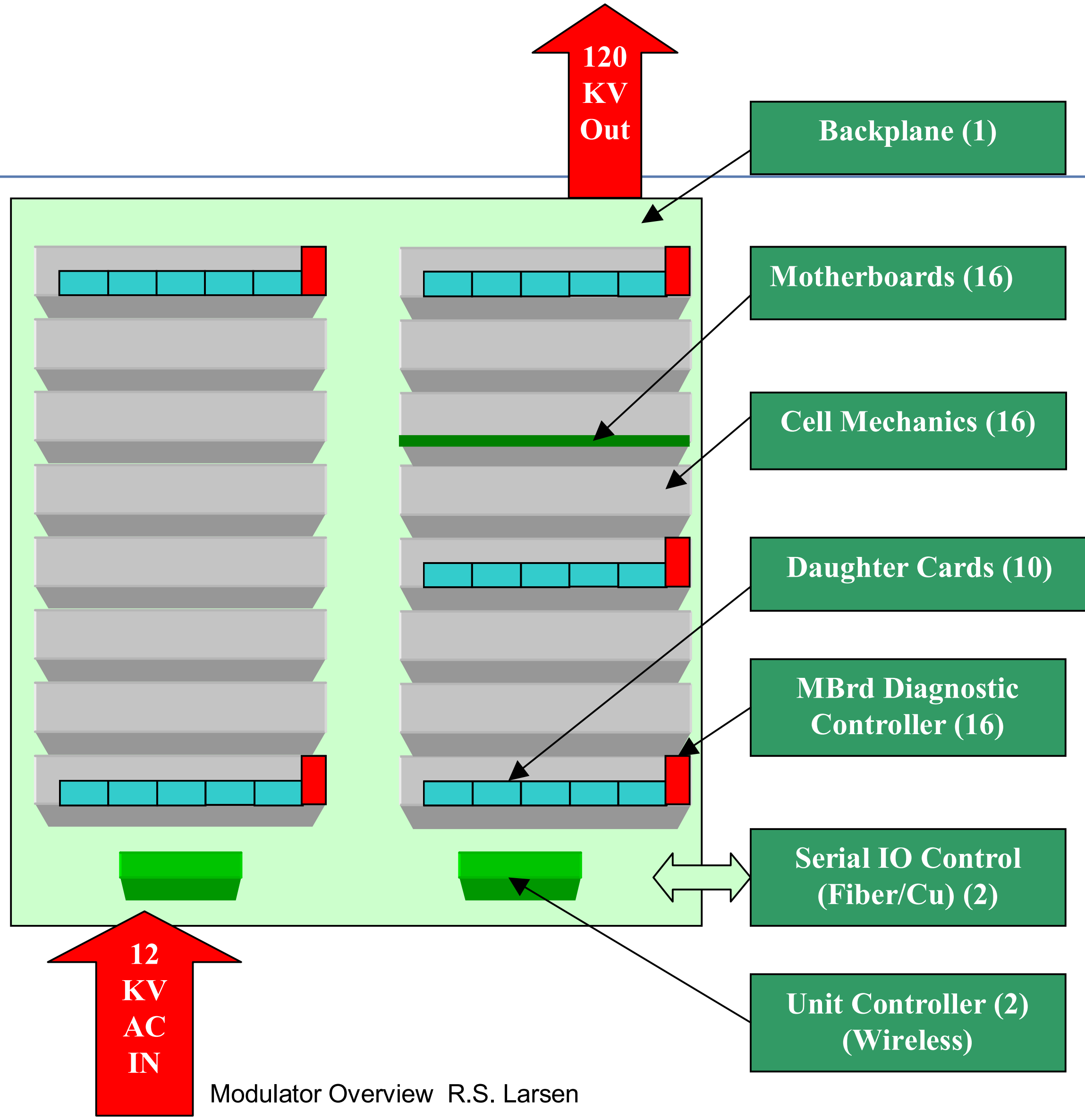
III. Single Tunnel Challenges, Possible Solutions

- Large cost pressure toward single tunnel design.
- Least desirable topology from electronics protection, all-system serviceability viewpoint.
- If becomes reality, how do we prevent overall machine Availability disaster?
- Four High Availability (HA) design principles:
  1. *Modular HA design for <u>all</u> power systems, instrumentation*
  2. *Radiation protection vs. γ's, n's for all electronics*
  3. *Robotic Module Service System (RMSS) replaces failing/ failed modules without machine interruption, human access.*
  4. *Intelligent Diagnostics analyzes faults, manages RMSS*

Module Replacement Concept



HA Modulator Architecture



Robotic Module Service System (RMSS)

- Modulators, power supplies, instrumentation designed with easily replaceable modules, n/N redundancy for high MTBF.
- Divide machine into service sectors with human-accessible module depot every *n* km
- Robotic track units receive instructions by wireless from Maintenance Control
  - Immediate response
  - Day shift personnel restock bins & returns broken modules to shops
  - Higher Availability
  - Improved personnel safety by avoiding hostile tunnel environment
- *RMSS highly advantageous in any tunnel topology.*

Conclusions

- Modulators vs. Topologies
  - All modulator designs adaptable to any tunnel topology assuming single 120 KV cable works.
  - Klystron protection needs more work, demonstration for all designs
  - Single tunnel poses design, radiation protection, availability issues for all electronics subsystems.
  - *Recommend R&D on single HV cable, klystron protection for all designs.*
  - *Recommend R&D on electronics radiation hazards, solutions (starting).*
- Costs
  - All costs should be considered Preliminary
  - TESLA production cost estimates are $300-400K/unit.
  - MARX estimates promise ~40-50% lower but still in development.
  - *Recommend collaboration develop standard cost models, rules.*

Conclusions 2

- Maintenance & Availability
  - High Availability favors modular designs accessible by person or robotics during machine operation.
  - *Recommend HA design analysis of all electronics systems*
- Single Tunnel Electronics Issues
  - Possible solution to achieve overall high Availability is Robotic Module Service System - RMSS
  - Concept cannot work without modular equipment design.
  - Important to set design rules early, adopt modular standards
  - RMSS mandatory for single tunnel but could streamline operations & reduce maintenance costs for *all* topologies.
  - *Recommend modular HA standard platform for all tunnel electronics.*
  - *Recommend collaboration R&D effort on RMSS concept.*

Acknowledgment

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