..projections of proton decay experience...

from IMB thru Super K

...and onto MegaTonne

...ideally at Frejus?

L. R. Sulak

CPPM Marseille and Boston University

physics motivation…some quotes from theorists

unification theories severely constrained...nucleon decay around corner
neutrino oscillations exist $\Rightarrow$ proton decay

synergism with superbeams, neutrino factories — Mauro Mezzett
search for CP violation in leptons, if mixing angle θ_{13} big enough
sign of Δm^2, using matter interference if sufficient L/E

state of the art…extrapolating IMB and SK to MegaTonne with ~ no backgroun

"proposed sites"...potential competition…no known $(100m)^3$ excavation

WIPP, Homestake, San Jacinto, etc...with beams from BNL or FNAL

Frejus, with eventual beams from CERN — Jacques Bouche
depth?…only mass, timing & pixels count...photoelectrons second order
S-K continues, Hyper-K later? with Japanese Superbeam to both

potential detector technologies...

water Cherenkov…affordable big mass…especially below π threshold
balanced scintillation & Cherenkov light, water or oil-based medium
new photodetectors…e.g. pm's half the price of SK? — Pierre Bourgeois

liquid argon…feasible at this scale?

some quotes from theorists,

Murayama, 2003:

- Baryon Number Violation is naturally expected at some level even without grand unification
- Supersymmetry connects proton decay to Planck-scale physics
- Proton decay suppression may well be due to the same reason why electron is light
- Models suggest rates at “interesting” levels

Babu, Pati, Wilczek:

SO(10) models have many more fields at the GUT-scale

Typically worse than SU(5)

Just above the current limit $\tau\,(\,p \rightarrow K^{+}\,\nu\,) < 10^{34}$ yrs *review of the past success...*

comments on ring-imaging Cherenkov detectors

project prematurely terminated along with SSC

Dumand '76 -

...an opportunity seized by Antares

vorld's largest calorimeters

IMB '81-	10 kilotons = $(20m)^3$	salt mine, Ohio
Kamiokande '83-	3 kilotons	heavy metal mine, Japar
Super-K '96-	50 kilotons = $(40m)^3$	a 2nd site at Kamioka

ttle to say about the other experiments or the era...
.g. SNO, Soudan…too small (1 kT) or not totally active (iron absorber)

MB III (1983)

2000 - 8 inch pms and light collectors

dry suit diver/physicist

uper-K (1996)

half way up first filling

inner detector -

11,000 20 inch pms

outer detector (not visible)

a reconfigured IMB III

2,000 – 8 inch pms +

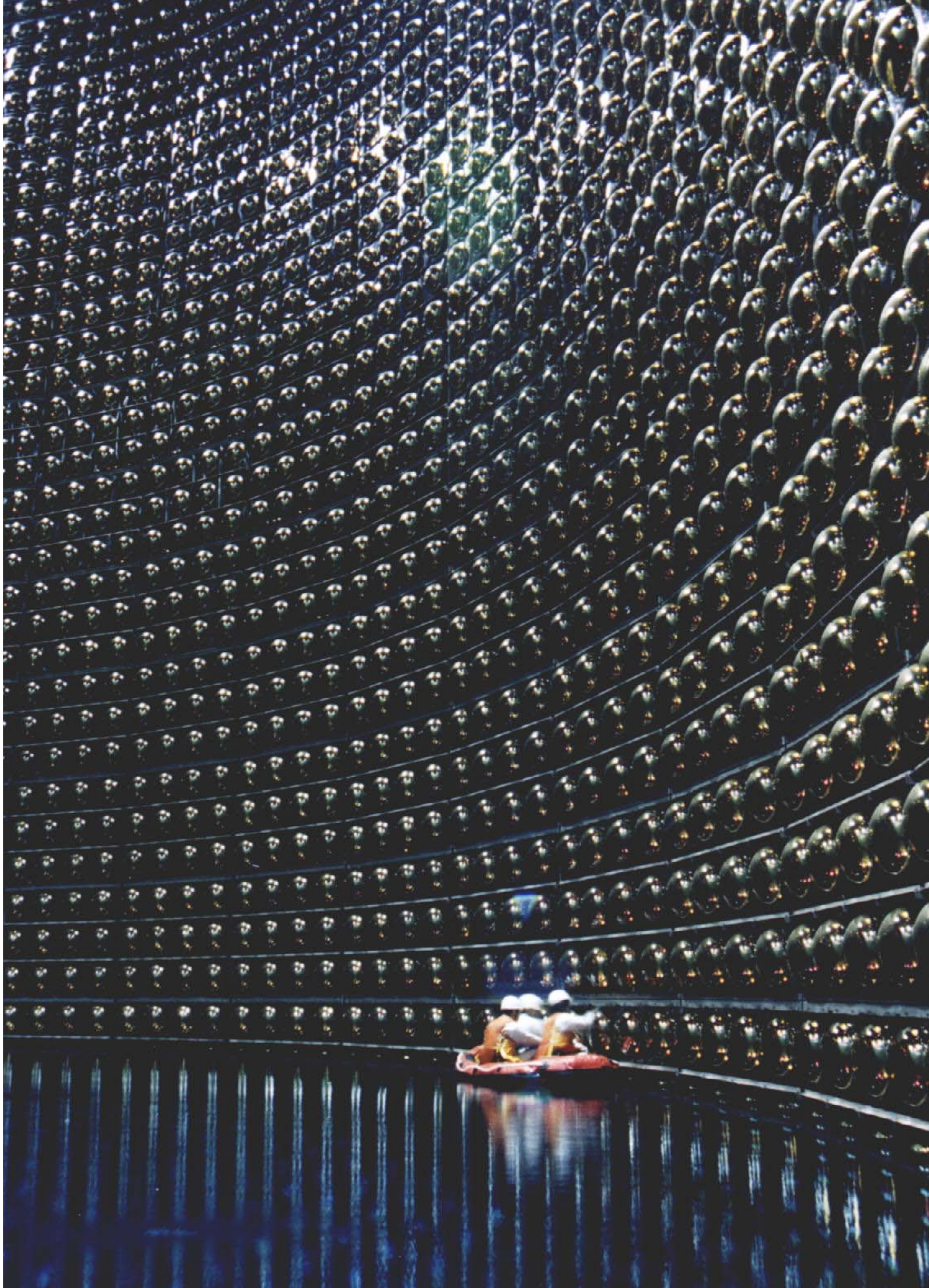
wavelength shifting light

collectors

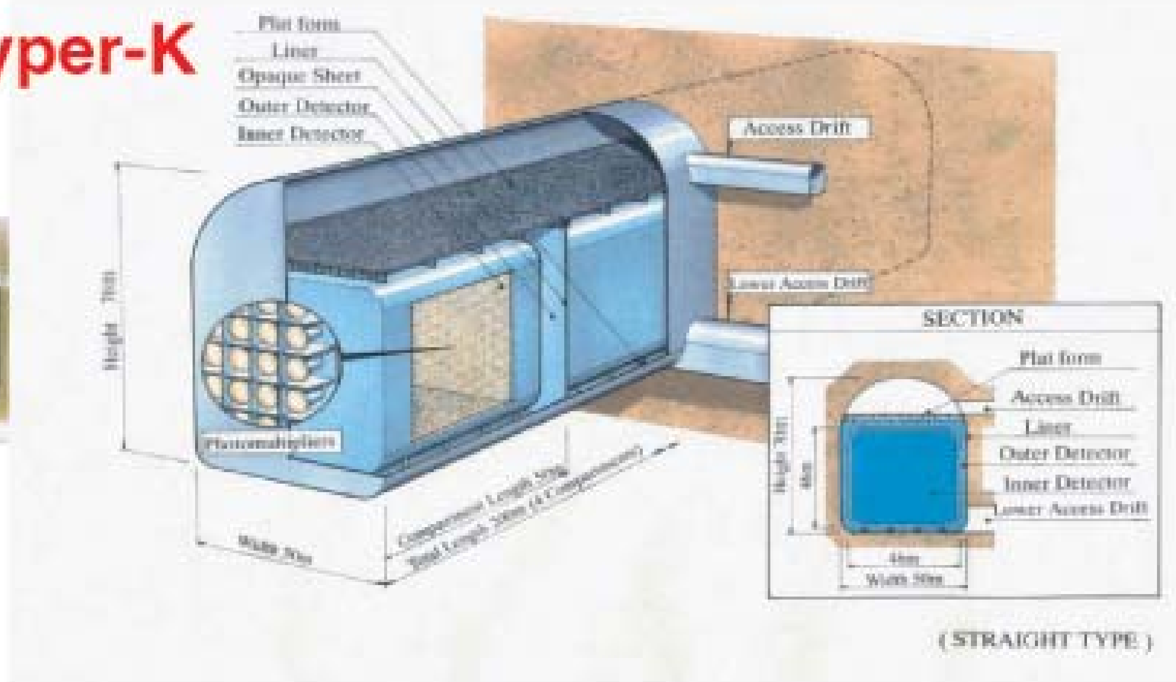
~$100 M = ~1/3 pms + DAQ

~1/3 excavation

~1/3 tank *et al.*



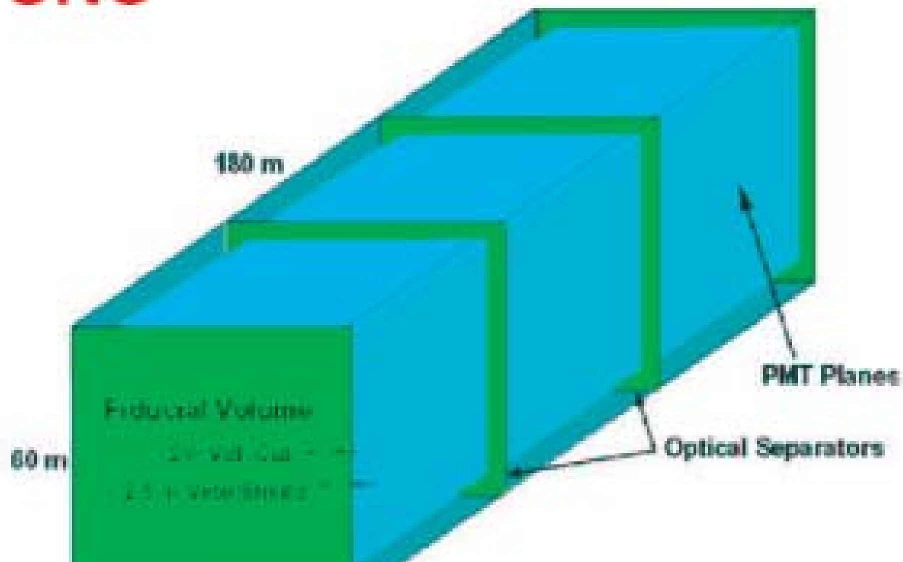
Hyper-K



SK

two proposed future large water detectors...

UNO



what is a 50% volume scale up of Super-K cavity?

~12 Atlas stories…60m high = 200 kT of water…need a few such caverns at depth

…Europe well experienced

A summary of water detectors: where are we? where going?

Proton Decay Search at Super-K I and II

Current State...size, then livetime are everything

IMB: best lifetime limits for most of ~ 40 modes…takes time, 10 years
blackened spherical volume, surface detectors (22 m/side)
most economical: minimum # pms, water cheapest medium
reverse osmosis water attenuation length ~ 100 m
scales as volume/surface until 100m characterize dimension

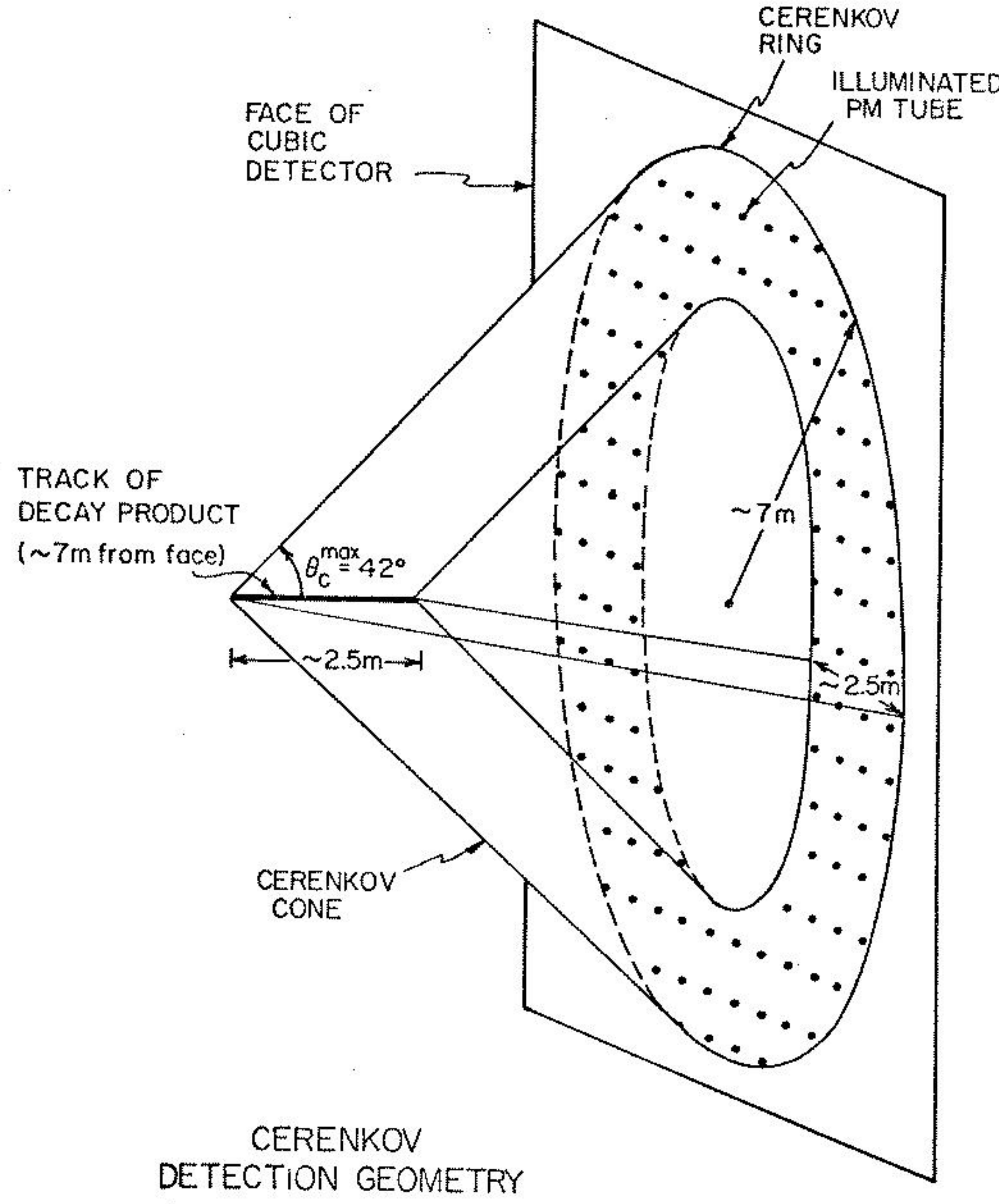
Super-K: 3.5 yr × 22 kT ≅ 80 kT-yr
biggest water-filled cavern, 40 m high, 40 m diameter
could probably go to 60 m × 60 m in a nearby location
$p \rightarrow e^+ \pi^o \quad \geq 7 \times 10^{33}$, background ~ 0.2 events
$p \rightarrow \nu K^+ \quad \geq 1.6 \times 10^{33}$, background ~ 2.2 events

K2K: study of ν interactions in water in near detector
with new cuts for SK…eventually be ≥ 5 times more restrictive?
appears to be no background for 10 yr × 0.5 MegaTon fiducial

IMB (‘81-’90), Kamiokande (‘83-’96), Super-K: ≥ 10 year livetime realistic

...a charged particle track

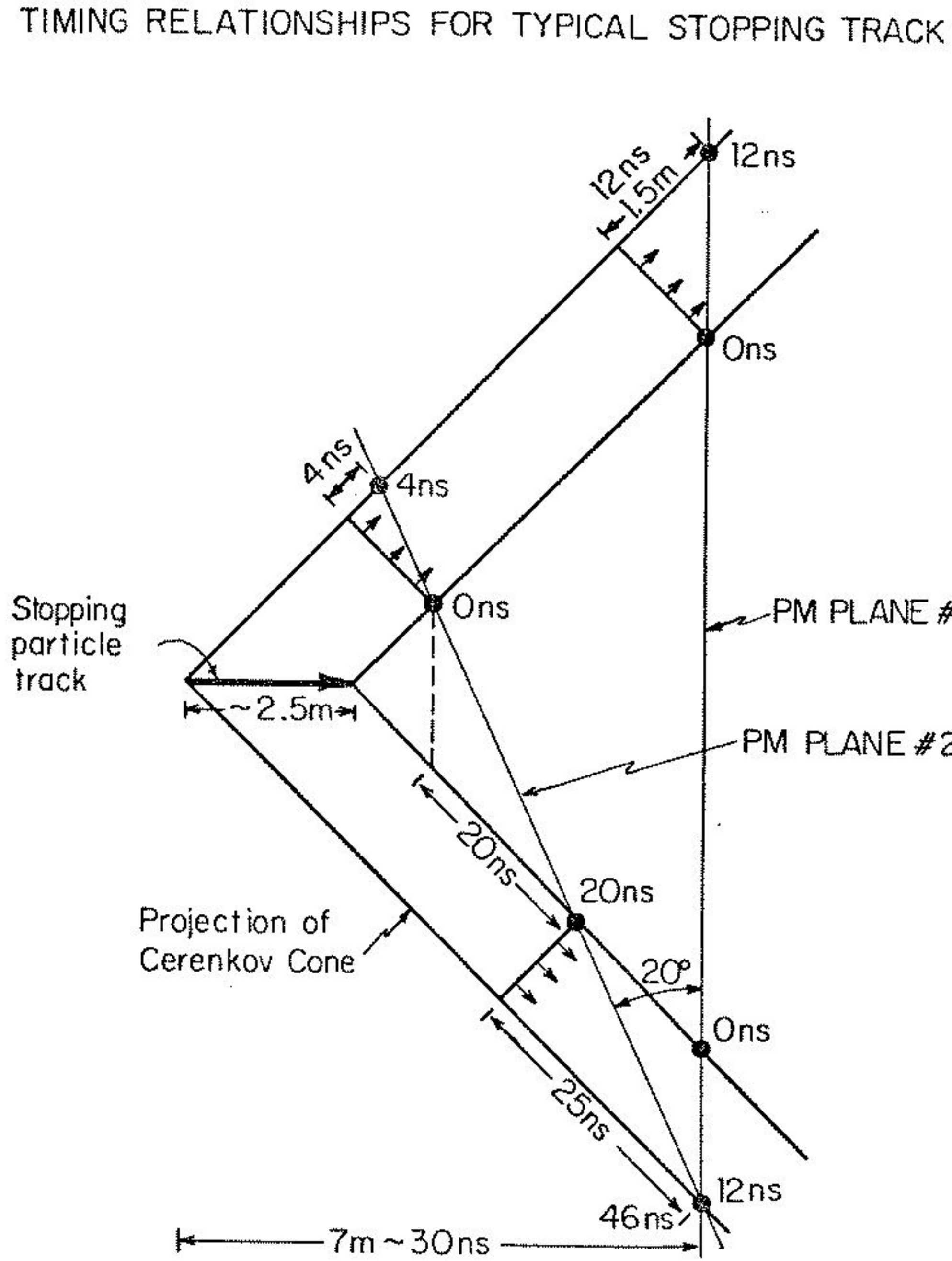
what does it look like?



"Neutrino '79, Bergen" LRS

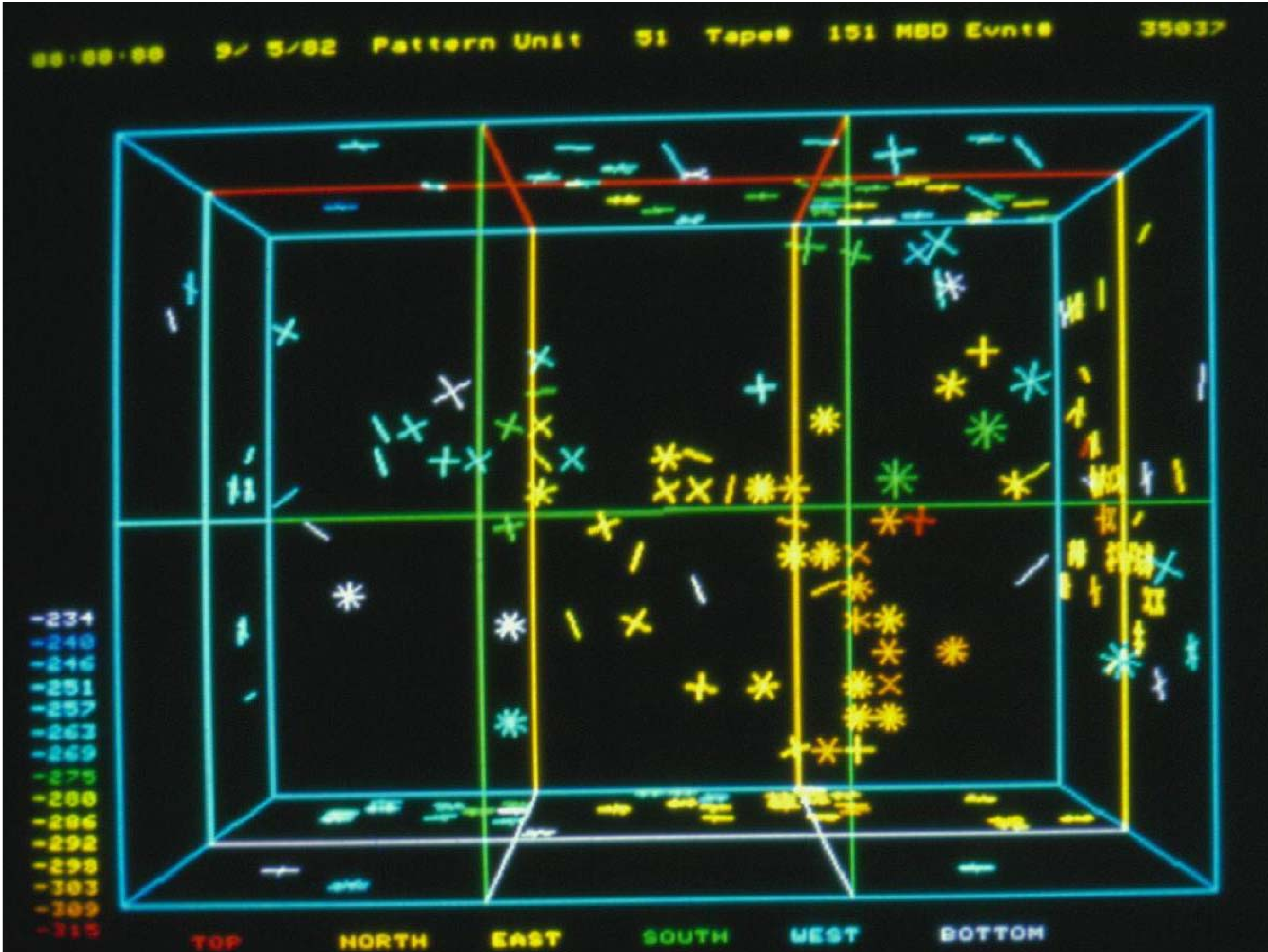
...why is timing so important?

Cherenkov light is directional



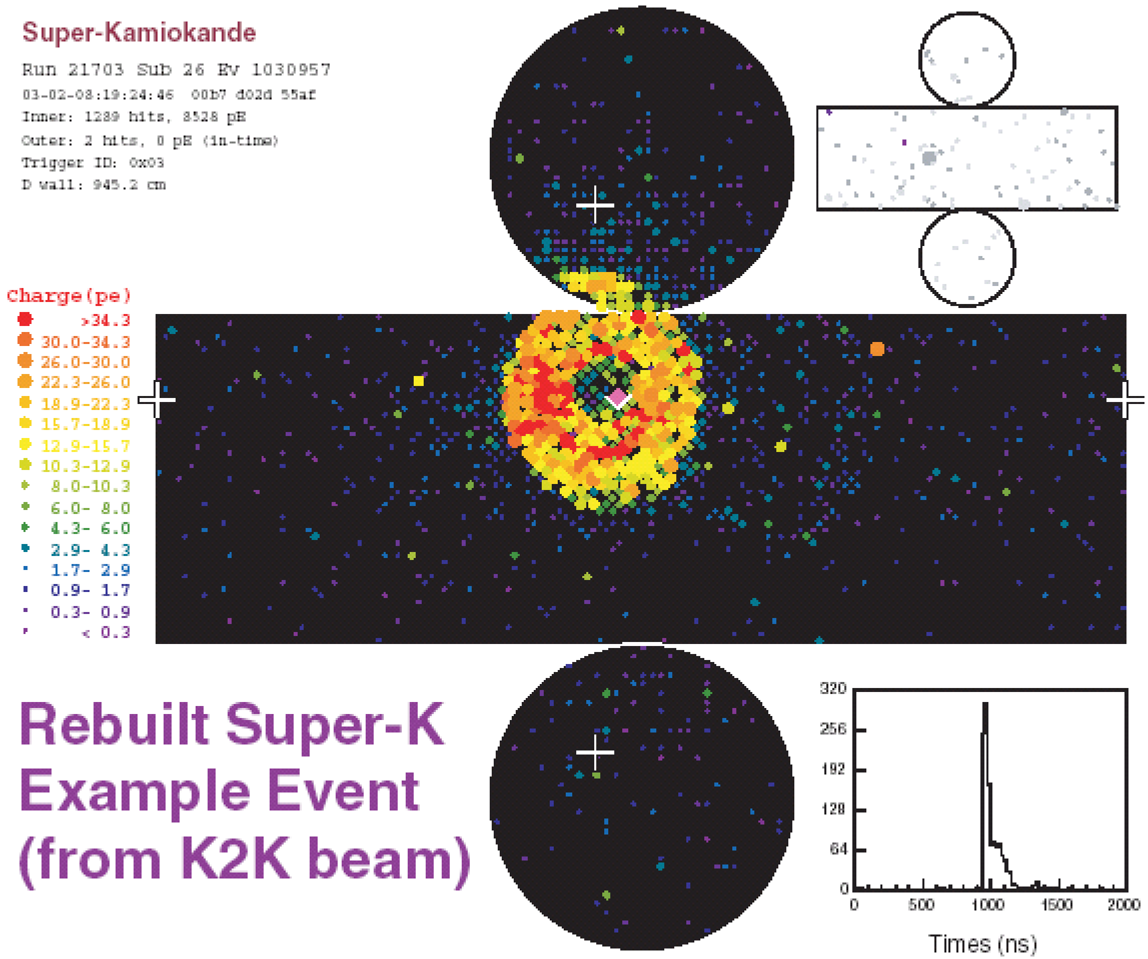
“Neutrino ’79, Bergen ,” LRS

MB: best proton decay candidate...pm code = timing in color, 1 pe/slas



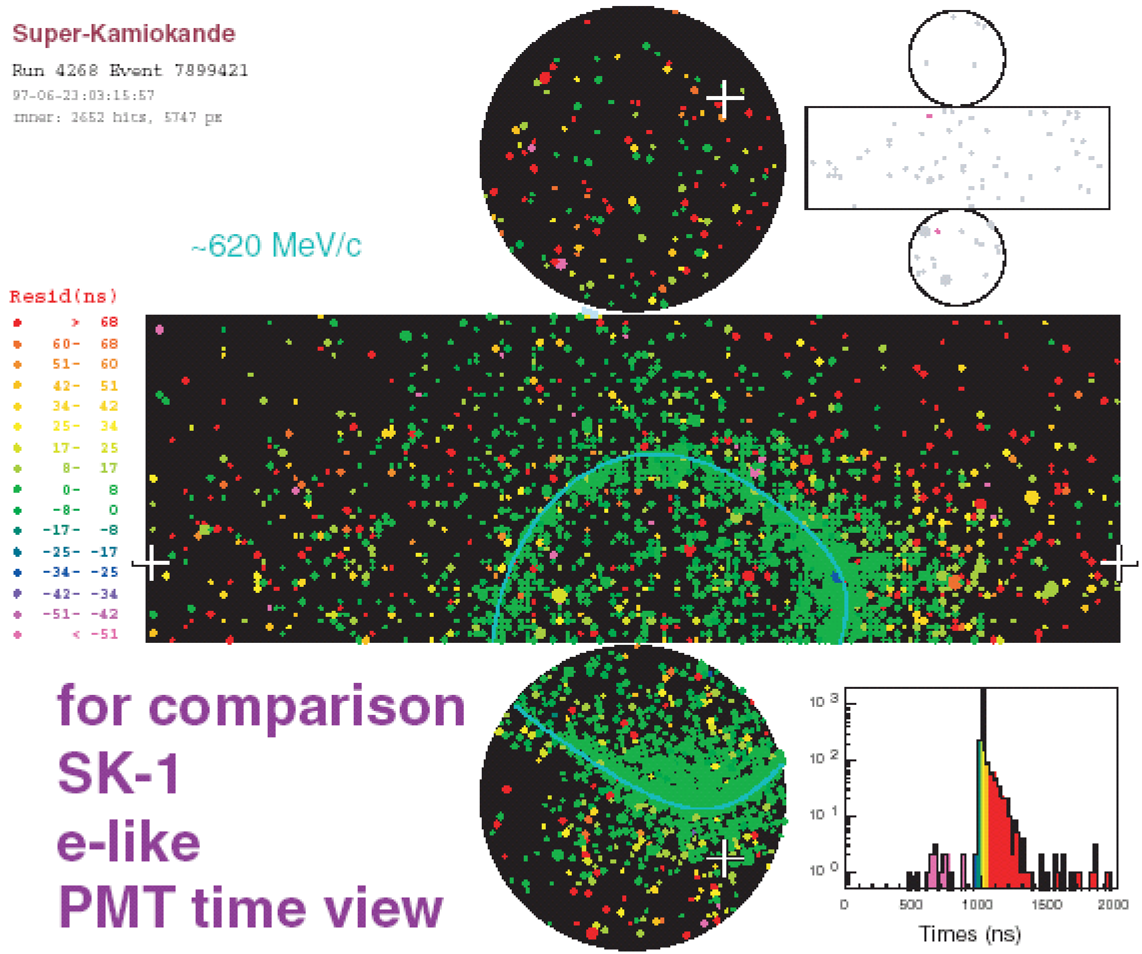
SK II (2003): muon-neutrino event

...in time with beam pulse from KEK accelerator 300 km away



...sharp ring edges characteristic of a muon track

typical electron track...fuzzy at edges



Proton Decay Search at Super-K II

Near Term Program:

through September 2005 operate with 1/2 pms
- no deterioration of sensitivity for proton decay
  - SK designed for MeV solar neutrinos…overkill for pdk

complete comparison of atmospheric ν background to proton decay
- with events in near water detector of K2K
- linear gain in limits for "no background" modes
  - …square root otherwise

develop improved cuts and reconstruction for Hyper-K…detector
- invaluable guide to designing post Super-K detector
  - define size of detector by level of background
  - set technology
  - optimize cost

Future of Kamioka Lab

Medium Term Goal: Continuation

end 2005 and ~2012

proton decay search with original pm density

(probably put in gadolinium salt to enhance supernova signal)

≥ 2007 JHF 1

superbeam for neutrino oscillation studies

Long Term Goal: New Megaton Detector Hyper-K

need significant increase of sensitivity, × 10-20

sensitivity = fiducial mass × detection efficiency

what mode to focus on?

K^+ detection could drive technology

Caveat: no Hyper-K start unless

some indication of proton decay, or

θ_{13} big enough

Some Post Super-Kamiokande detector ideas

which detector technology?

0.5 - 2 MT water Cherenkov

Titanic - a sunken, water and pm-filled tanker — Y. Suzuki -

detector with balanced scintillator / Cherenkov oil — Svoboda

liquid argon LANNDD — Cline

Which Detector Technology? water underground

water Cherenkov - lowest cost per megaton

underground

Super-K 50 kT total, 22 kT fiducial

…due to 2 m veto + 2 m fiducial cut

scale-up volume of Super-K × 2 to 100 T…rock supportable at new site

...repeat array of 5 ~ double Super-K tanks

maximum cavern size sets ultimate limit…what is possible at Frejus?

excellent for oscillations at neutrino energies below π production

do not want to confuse with ν_μ , ν_e conversion

only solution for massive, economical far detector at 2000-4000 km?

for sign of neutrino mass difference

virtual proposals

Hyper-K, probably for JHF 2, ≥ 2012, with 4MW superbeam

UNO

Which detector technology: sunken water tank?

water Cherenkov - lowest cost per megaton

undersea

submerged vessel sunk and anchored on bottom

e.g. used liquid natural gas tanker

no excavation

avoid dominant construction time and cost

outfit at surface; fill with osmosis water; raise to surface for maintenance

moveable from source for oscillation studies

but, >100m depth...must use pressure-tolerant enclosures

(no bioluminescence, sea currents movement

…*e.g.* for advocates of MegaTon nestled inside Antares)

“Supersymmetry...

as generated so many thousands of papers it must be correct’

Shelly Glashow

new detector technology for ν K^+ ?

What if SUSY discovered at LHC ? Focus detector on ν K^+ ?
What if Super-K gets a candidate for ν K^+ ?
fill with dilute scintillator to gain a factor of 4 in rate, 16 in signal?

2 options to boost sensitivity for $p \rightarrow \nu K^+$

1) replace with high light yield scintillator oil, *e.g.* Kamland, or
2) balanced doping of oil or water: *e.g.* LSND / Miniboone
   - a) isotropic scintillator light
     - gives calorimetry and timing signature of K^+
   - b) but dilute so that Cherenkov signal not overwhelmed
     - preserves ring-imaging and directionality

ν K^+ detection efficiency increases 10% $\rightarrow$ 40%
potential problem: μ/e discrimination degraded? Now under study

technical information to come from Miniboone
e. g. electron *vs.* π^o discrimination

MegaTon project: $1B/MT of oil? No, use "gin & tonic" in water

Super-K Lifetime limits...

$p \to e^+\pi^0$

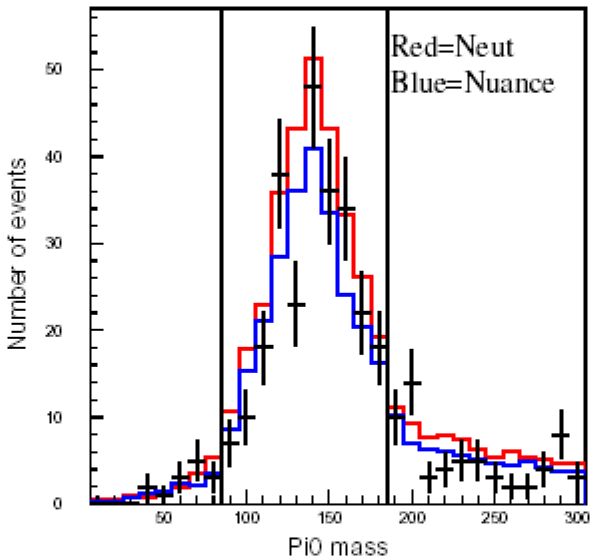
Summary of cuts

- 2 or 3 rings
- All rings e-like
- 85 MeV $< m_\pi <$ 185 MeV
  - Applied only to 3-ring events
- 0 decay electrons
- 800 MeV $< m_p <$ 1050 MeV
- $P_p <$ 250 MeV

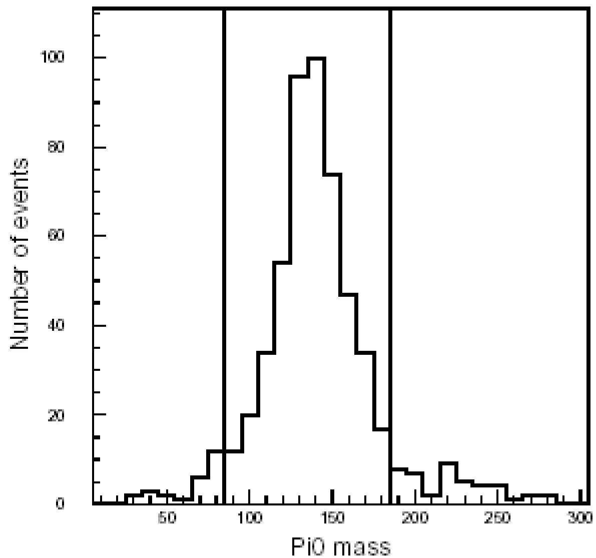
preliminary results, from Scott Clark

Reconstructed π^0 mass, SK-I

For 3-ring events, reconstruct the π^0 mass for the 2 rings coming closest to 135 MeV. This must be between 85 MeV and 185 MeV



Atmospheric data & MC



$e^+\pi^0$ MC

Two 100 year simulations...

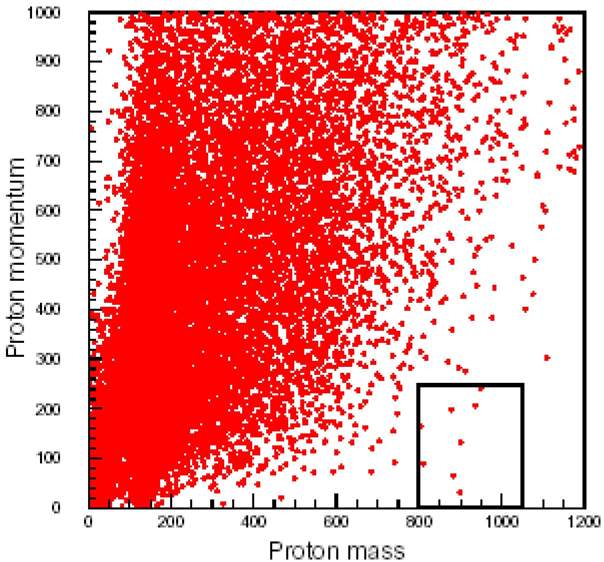
Proton mass & momentum, SK-I

Require: $800\ \text{MeV} < m_p < 1050\ \text{MeV}$

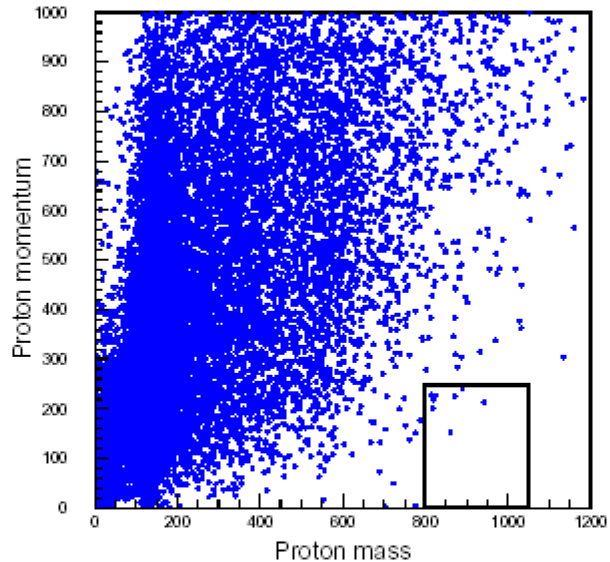
$p_p < 250\ \text{MeV}$

8 BG events (0.3 in 1489 days)

9 BG events (0.4 in 1489 days)



Atmospheric Neut MC



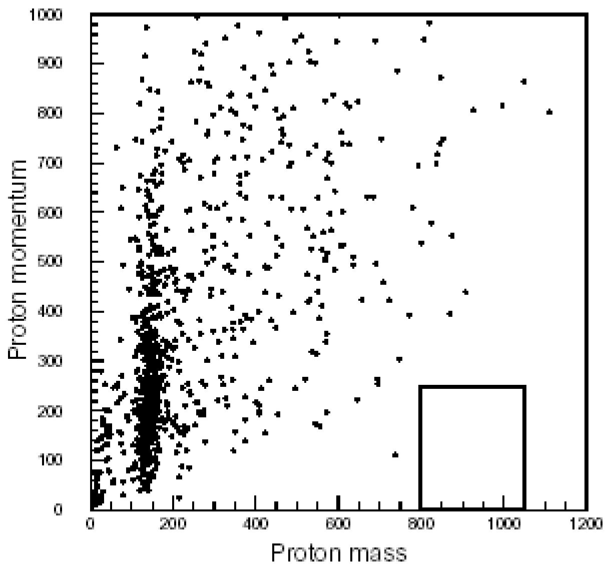
Atmospheric Nuance MC

Proton mass & momentum, SK-I

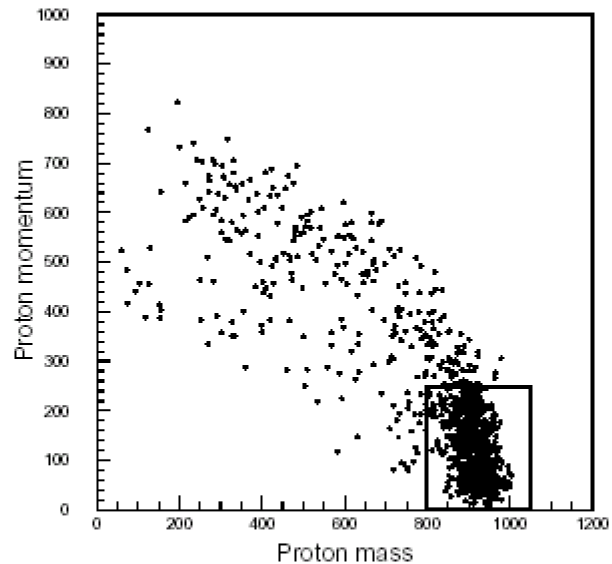
Require: 800 MeV < m_p < 1050 MeV

p_p < 250 MeV

0 candidates



Atmospheric Data



$e^+\pi^0$ MC

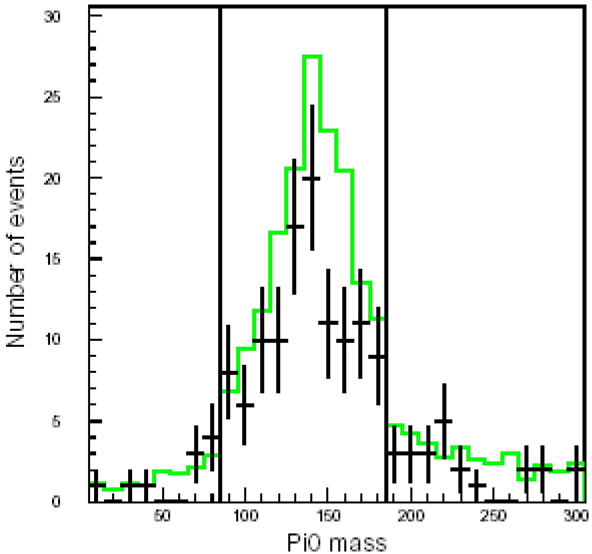
Summary: SK-I

- 1489 days of data
  - 0 candidates
  - 0.3-0.4 expected background
- Detection efficiency 40.9%
  - 18.6% 2-ring, 22.3% 3-ring
- $\tau/B >$ **5.4 x 10^{33} years** at 90% confidence

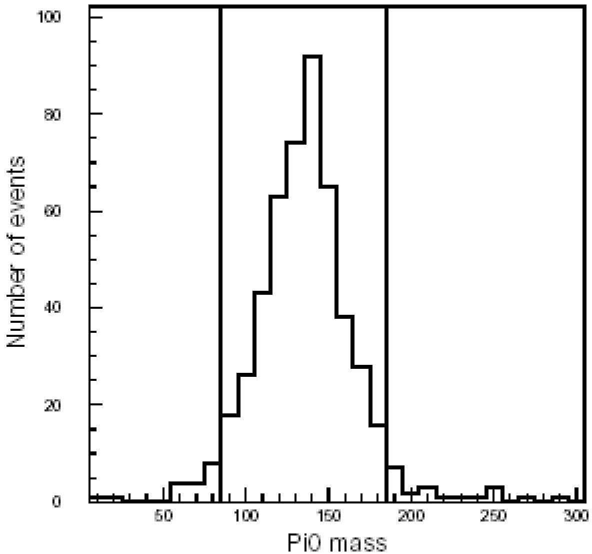
preliminary results, from Scott Clark

Reconstructed π^0 mass, SK-II

For 3-ring events, reconstruct the π^0 mass for the 2 rings coming closest to 135 MeV. This must be between 85 MeV and 185 MeV.



Atmospheric data & MC



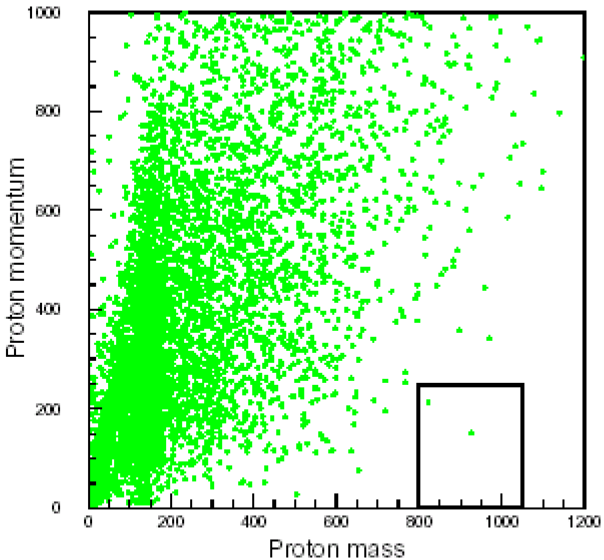
$e^+\pi^0$ MC

Proton mass & momentum, SK-II

Require: 800 MeV $< m_p <$ 1050 MeV

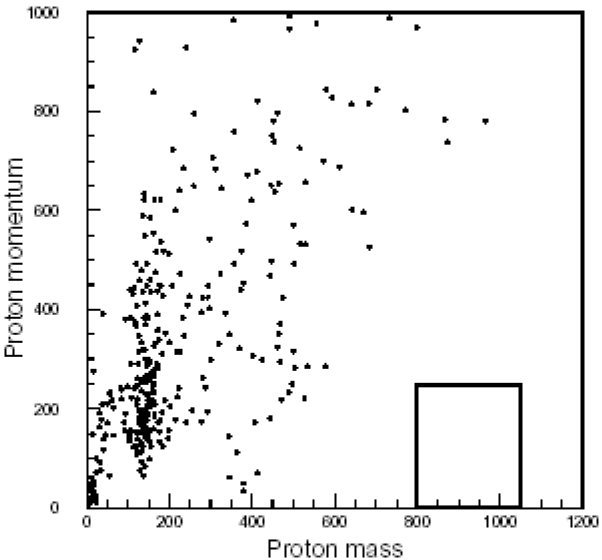
$p_p <$ 250 MeV

2 BG events = 0.1 in 421 days



Atmospheric MC

0 candidates



Atmospheric Data

Conclusions

- A analysis (neglecting systematic uncertainties for now) for $p \to e^+\pi^0$ on SK-I and SK-II has been done.
- No candidate events are observed in either the SK-I or the SK-II data.
- Limits are placed on the partial lifetime at 90% confidence:
  - From SK-I: $\tau/B > 5.4 \times 10^{33}$ years
  - From SK-II: $\tau/B > 1.5 \times 10^{33}$ years
  - Combined limit: **$\tau/B > 6.9 \times 10^{33}$ years**

preliminary results, from Scott Clark

Super-K Lifetime limits...

$p \to \mu^+\pi^0$

Summary of cuts

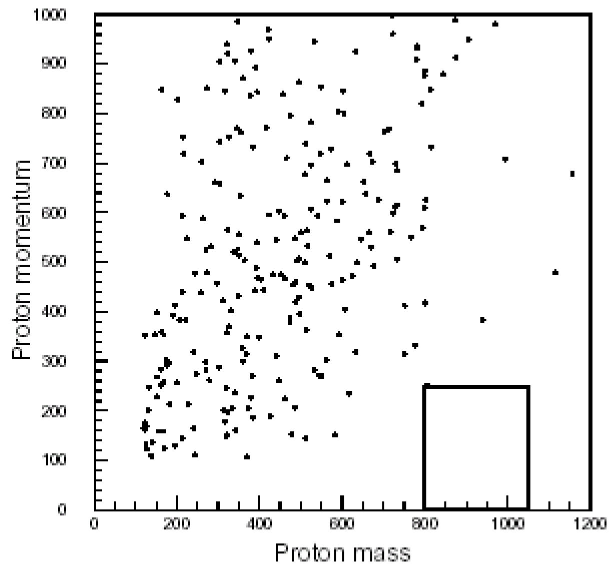
- 2 or 3 rings
- 1 ring m-like, all others e-like
- 85 MeV < m_π < 185 MeV
  - Applied only to 3-ring events
- 1 decay electron
- 800 MeV < m_p < 1050 MeV
- P_p < 250 MeV

Proton mass & momentum, SK-I

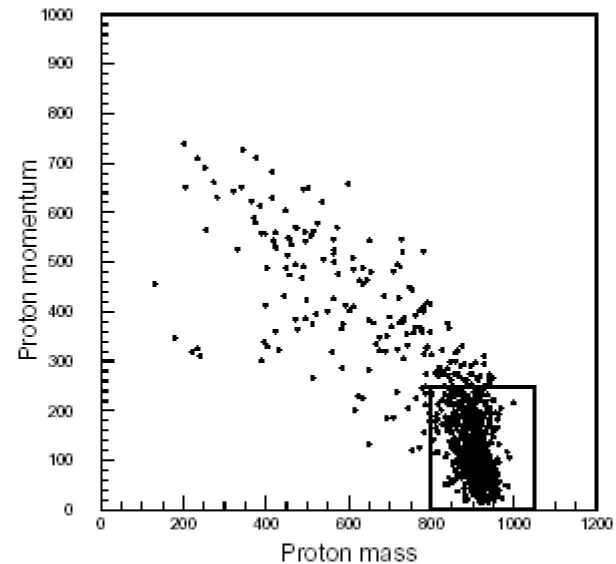
Require: 800 MeV < m_p < 1050 MeV

p_p < 250 MeV

0 candidates



Atmospheric Data



$\mu^+\pi^0$ MC

Final Conclusions

p-->$(e/\mu)^+\pi^0$ limits for SK-I and SK-II are found.

No candidate events are observed in either the SK-I or the SK-II data.

Limits are placed on the partial lifetime at 90% confidence:

- $e^+\pi^0$ Combined limit: **τ/B > 6.9 x 10^{33} years**
- $\mu^+\pi^0$ Combined limit: **τ/B > 5.4 x 10^{33} years**

preliminary results, from Scott Clark

Super-K lifetime limits...

$$p \rightarrow K^{+} \nu$$

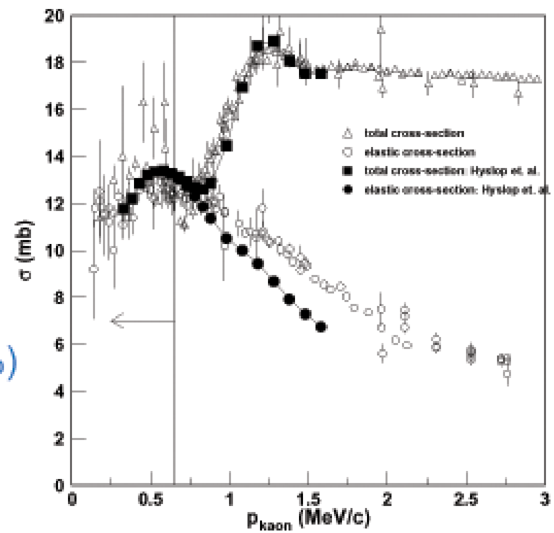
Favored SUSY decay mode

Note: Also $p \rightarrow \pi^{+} \nu$ in some circumstances (Strassler and Babu, see also Goto and Nihei).
Also $\mu^{+} K^{0}$, Babu, Pati & Wilczek

Momentum of K^{+} is 340 MeV/c: below Č-threshold

Nuclear Interaction:
cross section is small
scattering is elastic

⇒ K^{+} escapes nucleus
and decays at rest (90%)



Branching ratios:

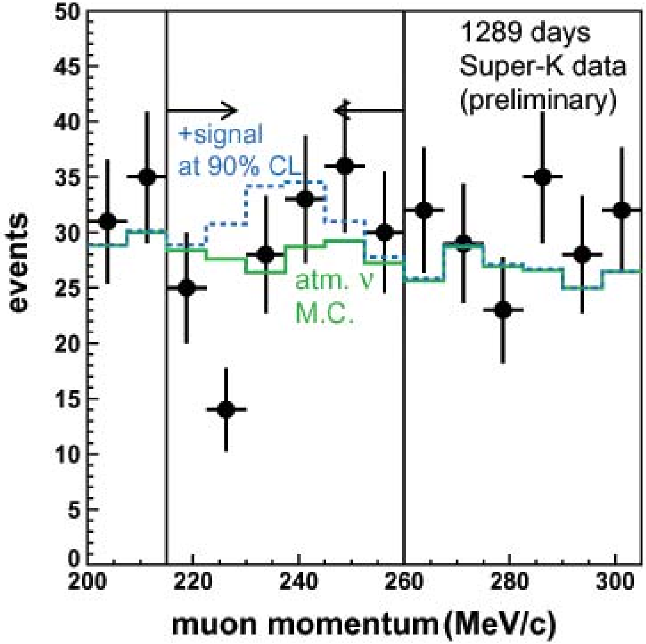
	$K^{+} \rightarrow \mu^{+} \nu_{\mu}$	65%
	$K^{+} \rightarrow \pi^{+} \pi^{0}$	21%

From Ed Kearns

Super-K lifetime limits...

$K^+ \rightarrow \mu^+$(236 MeV/c) ν **search**

1 μ-like ring
1 decay electron
215 < p_μ < 260 MeV/c
B.R. x efficiency = 33%



from joint fit to background + signal:

τ/B($p \rightarrow \nu K^+$) > 4.4 x 10^{32} yr

Super-K lifetime limits...

Gamma Tag for $p \to \nu K^+$

Nuclear Shell Model:
$^{16}O\ (p_{3/2}) \to {}^{15}N^* +$ proton hole
de-excites by 6.3 MeV gamma

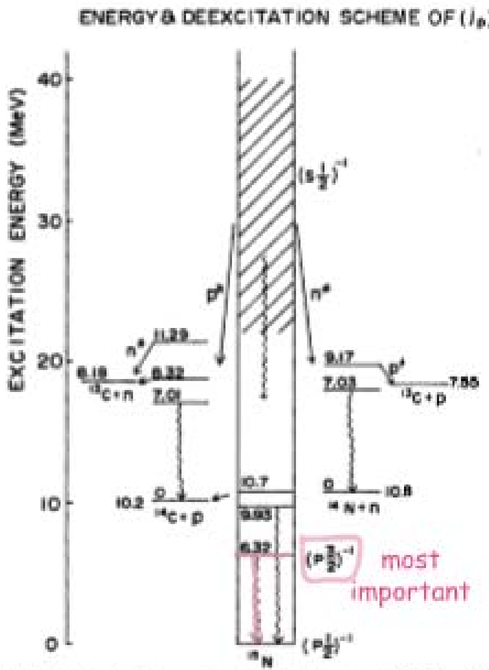
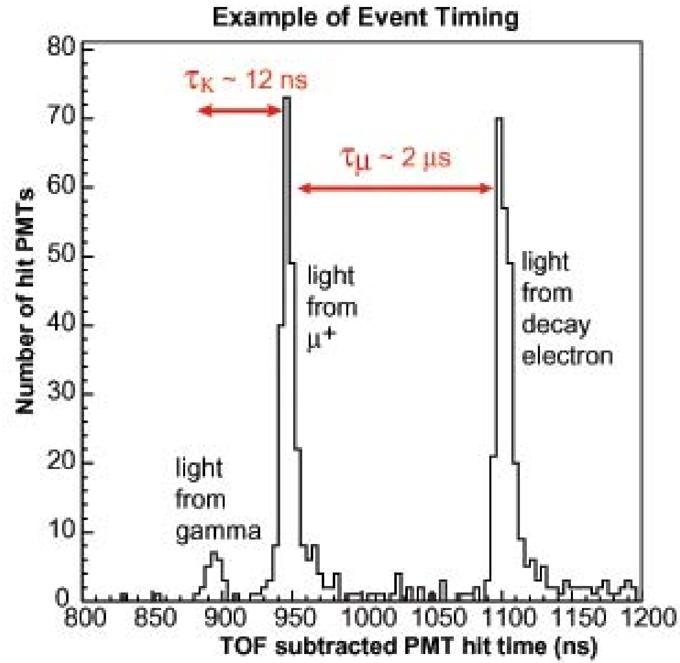


FIG. 2. Level scheme of proton-hole states in ^{15}N and their deexcitation modes. Energies are given in units of MeV. p^* and n^* are the protons and neutrons emitted from the continuum (unbound) region, respectively.

H.Ejiri Phys. Rev. C48 (1993) 1442

Coincidence signature:
proton decay to K^+n accompanied by prompt γ
K^+ is below Cherenkov threshold: no light
followed by K^+ decay to $\mu^+\nu$ ~12 ns later
followed by muon decay to electron ~ 2 ms later

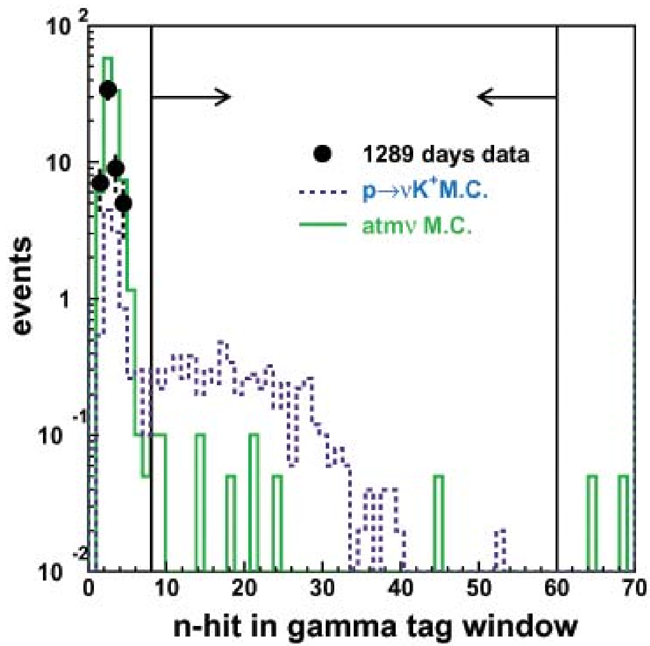


Super-K Lifetime limits...

$K^+ \rightarrow \mu^+$(236 MeV/c) ν search with gamma tag

count PMT hits
in 12-ns sliding window
preceding light from muon

B.R. x efficiency = 8.8%



0 events detected, background = 0.5 events:

τ/B($p \rightarrow \nu K^+$) > 10 x 10^{32} yr

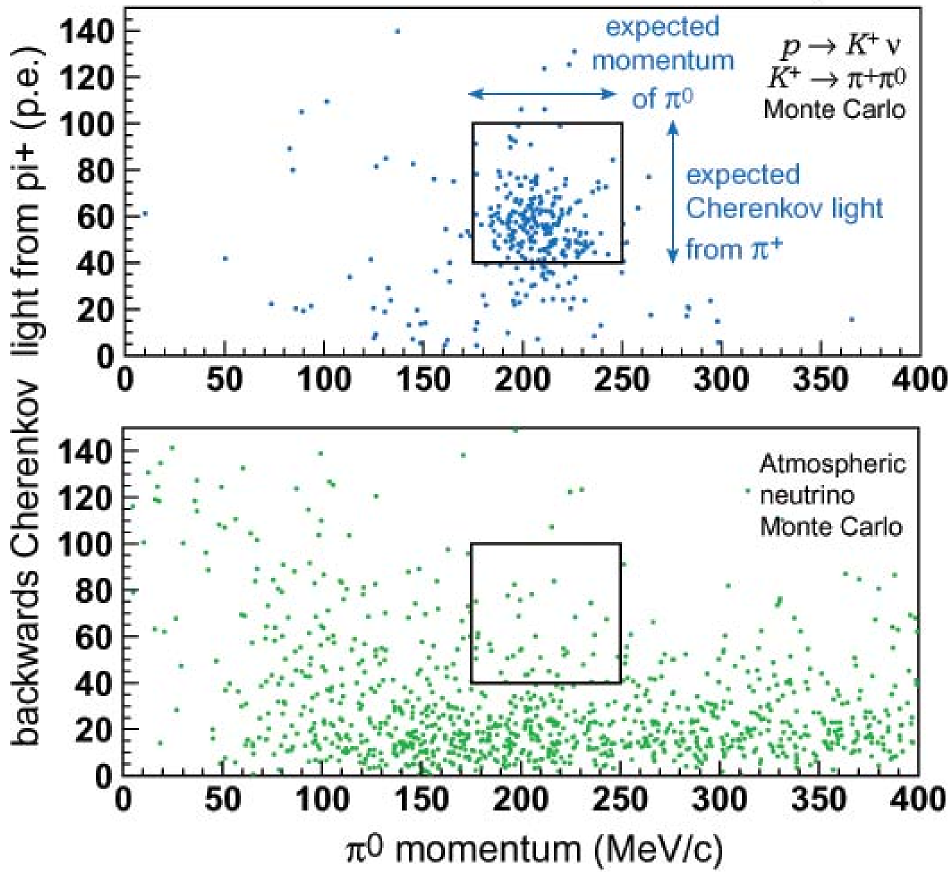
Super-K lifetime limits...

$K^+ \to \pi^+ \pi^0$ search

momentum of π^+ is only 205 MeV/c:
barely above Cherenkov threshold

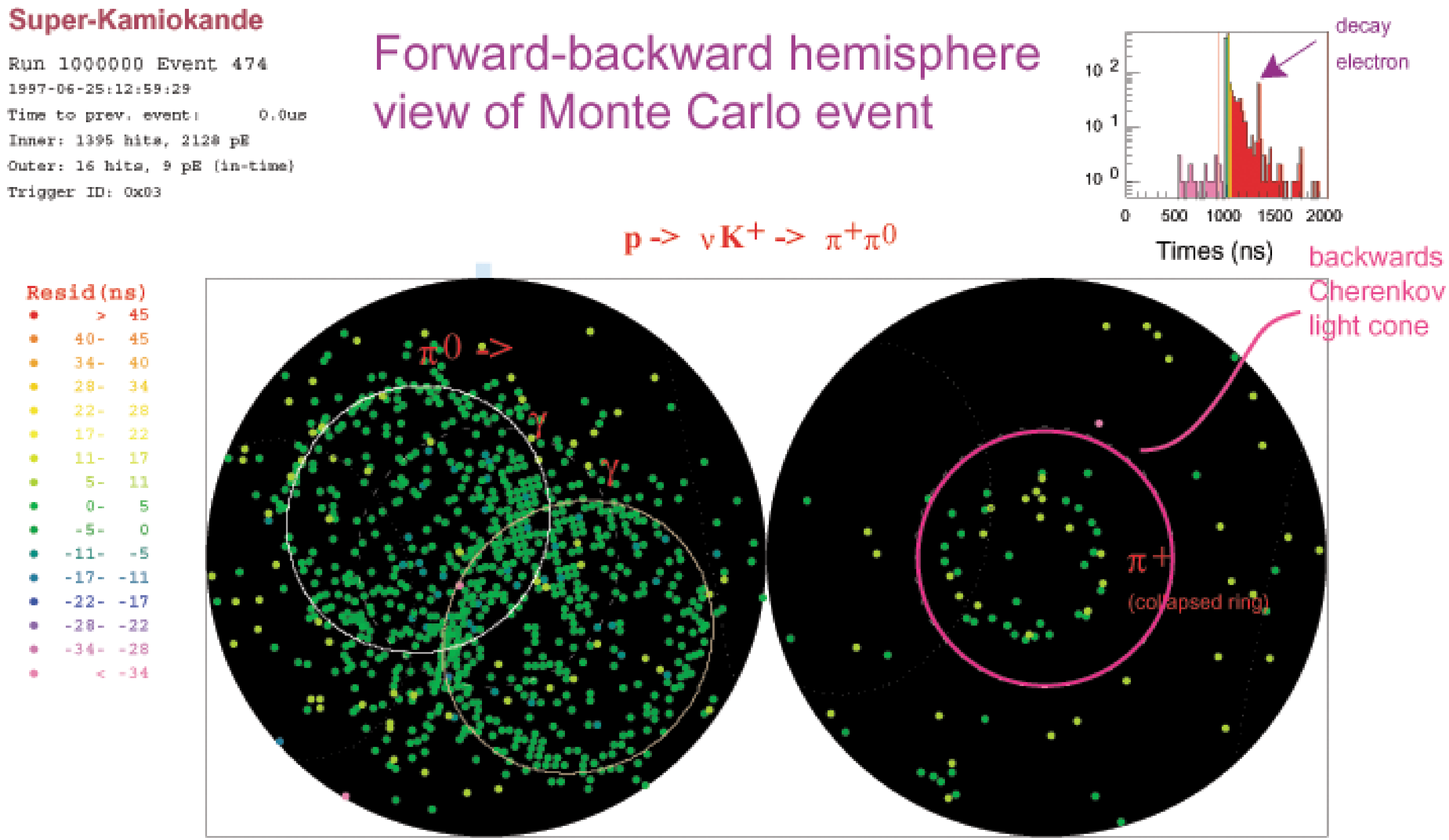
require 1 decay electron, π^0 mass

BR x efficiency = 6.8%



background estimate
~2.3 events/100 kt·yr

Forward-backward hemisphere view of Monte Carlo event



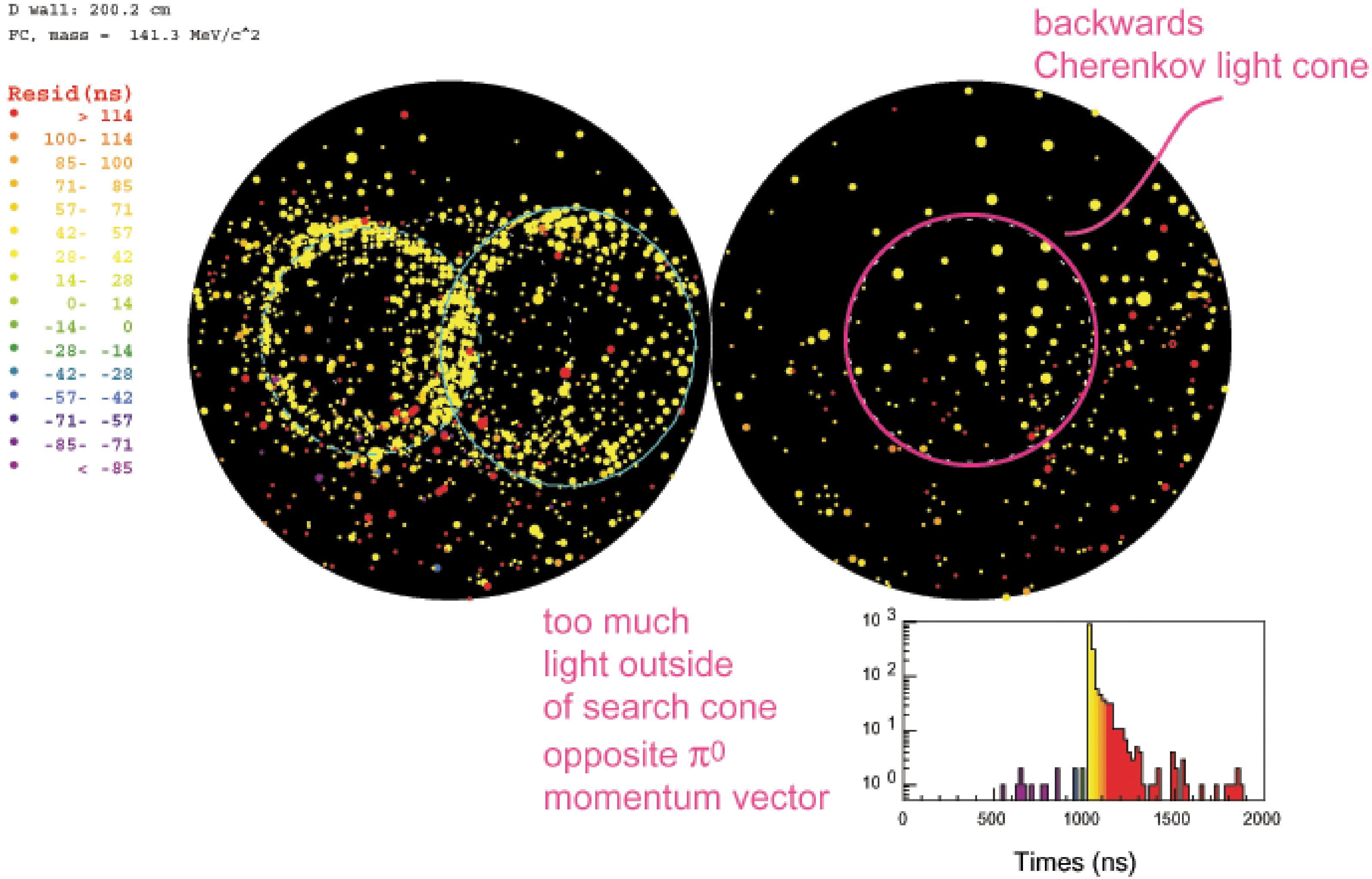
(only hits in time window drawn)

expect only small
amount of light
outside backwards cone

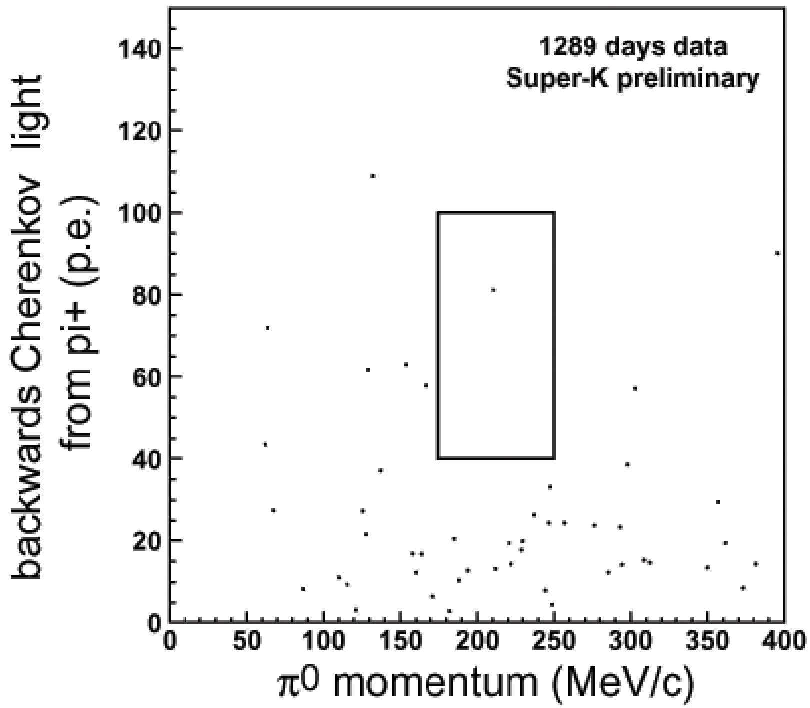
Forward-backward hemisphere view of PMT hits as seen from reconstructed vertex

Super-Kamiokande

Run 7944 Sub 203 Ev 27128713
99-10-12:23:00:23
Inner: 1572 hits, 2794 pE
Outer: 3 hits, 3 pE (in-time)
Trigger ID: 0x07
D wall: 200.2 cm
FC, mass = 141.3 MeV/c^2



Super-K Data: $p \to K^+ \nu$
$K^+ \to \pi^+ \pi^0$



result for 79.3 kt·yr (Super-K preliminary):

- 1 candidates
- 6.8% efficiency
- 1.7 events background

$\tau/B\ (p \to K^+ \nu) > 5.9 \times 10^{32}$ yr (90% C.L.)

For final limit: combine all three results (they are independent)

Summary of Super-K Limits

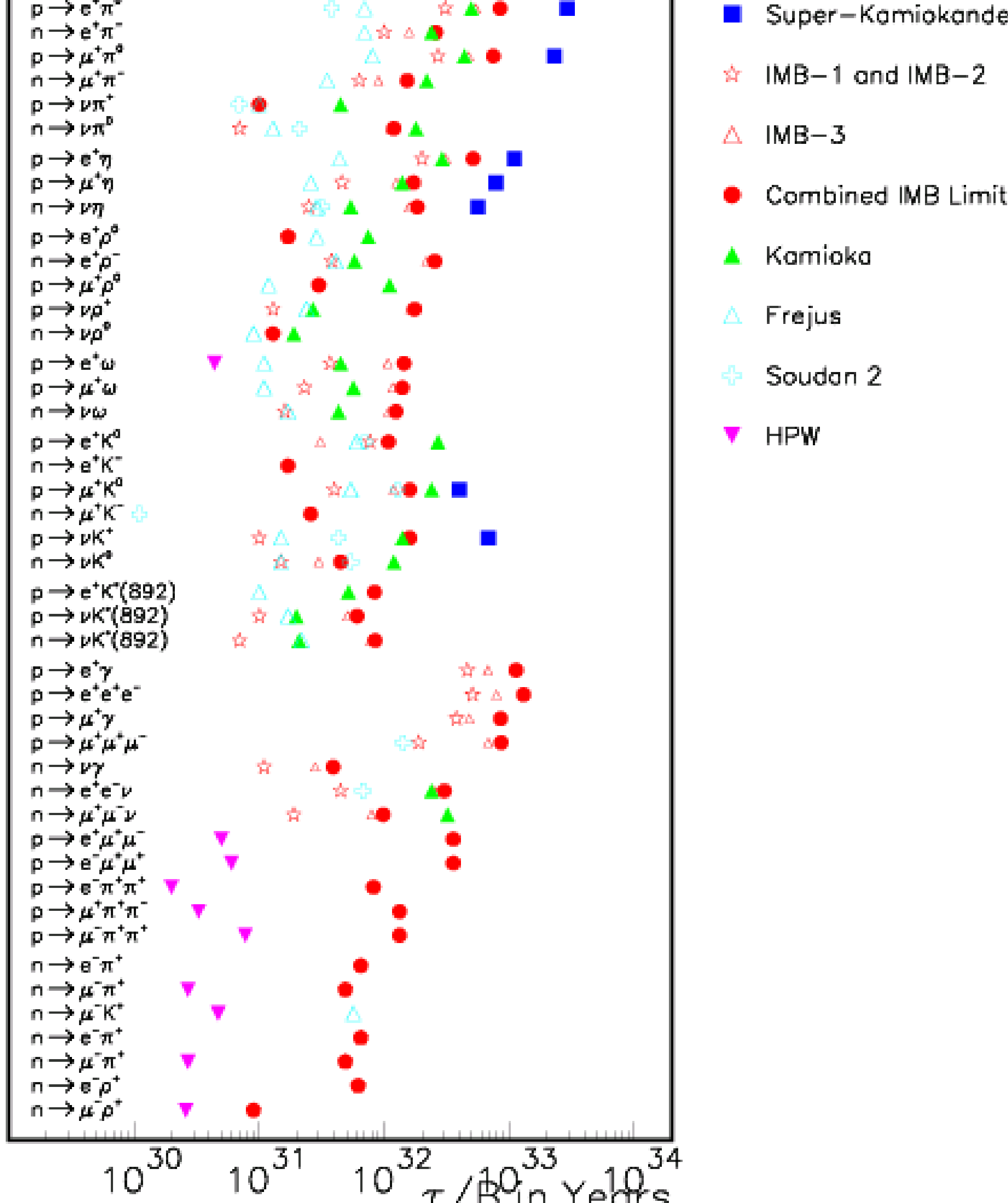
mode	exposure (kt• yr)	εB_m (%)	observed event	B.G.	τ/B limit (10^{32} yrs)
$p \rightarrow e^+ + \pi^0$	79	43	0	0.2	50
$p \rightarrow \mu^+ + \pi^0$	79	32	0	0.4	37
$p \rightarrow e^+ + \eta$	45	17	0	0.3	11
$p \rightarrow \mu^+ + \eta$	45	12	0	0	7.8
$n \rightarrow \bar{\nu} + \eta$	45	21	5	9	5.6
$p \rightarrow e^+ + \rho$	61	6.8	0	0.6	6.1
$p \rightarrow e^+ + \omega$	61	3.3	0	0.3	2.9
$p \rightarrow e^+ + \gamma$	70	71	0	0.1	73
$p \rightarrow \mu^+ + \gamma$	70	60	0	0.2	61
$p \rightarrow \bar{\nu} + K^+$	79				16
$K^+ \rightarrow \nu\mu^+$ (spectrum)		33	--	--	4.4
prompt $\gamma + \mu^+$		8.8	0	0.5	10
$K^+ \rightarrow \pi^+\pi^0$		6.8	1	1.7	5.9
$n \rightarrow \bar{\nu} + K^0$	79				3.0
$K^0 \rightarrow \pi^0\pi^0$		9.6	25	33.8	3.2
$K^0 \rightarrow \pi^+\pi^-$		4.6	10	6.7	1.1
$p \rightarrow e^+ + K^0$	70				5.4
$K^0 \rightarrow \pi^0\pi^0$		11.8	1	1.4	8.8
$K^0 \rightarrow \pi^+\pi^-$					
2-ring		6.2	6	1.0	1.5
3-ring		1.4	0	0.2	1.4
$p \rightarrow \mu^+ + K^0$	70				10
$K^0 \rightarrow \pi^0\pi^0$		6.1	0	1.1	6.2
$K^0 \rightarrow \pi^+\pi^-$					
2-ring		5.3	0	1.5	5.4
3-ring		2.8	1	0.2	1.8

ucleon Lifetime Limits

IMB: 45 decay modes

mass is everything,

EGATON is needed



Detector Technology: Liquid Argon

liquid argon time projection chamber - Icarus

everything charged visible...3 x 3 x 0.6 mm^3 pixels

300T half-module studied at surface…now in Gran Sasso

1.5 m drift, 1.8 ms lifetime (vs. 30 ms needed for scaling up to pdk)

2 x 1200T = 3 kT originally proposed for Gran Sasso

safety a consideration

evaluation *in situ* underway see muon decay pix

reconstruction of stopping muons and decay:

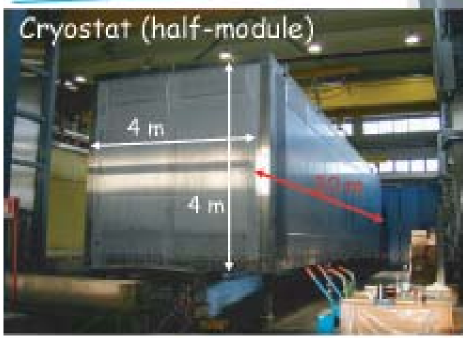
vertices of end of muon and beginning of e

dE/dx vs. range for stopping muons

cross-check with multiple scattering

ICARUS Experiment at Gran Sasso

A. Eridato
NOON 2003



~100 evts/yr/600t from atmospheric ν
~280 CC ν_τ in 3 kt, CNGS beam (5 yr)

Liquid Argon TPC

- mm resolution
- 300 t module tested on surface
- 600 t module to be installed underground this year
- final proposed size 3 kt

(relatively small mass but...)

Fine grained reconstruction of neutrino interactions (atmospheric or CNGS beam)

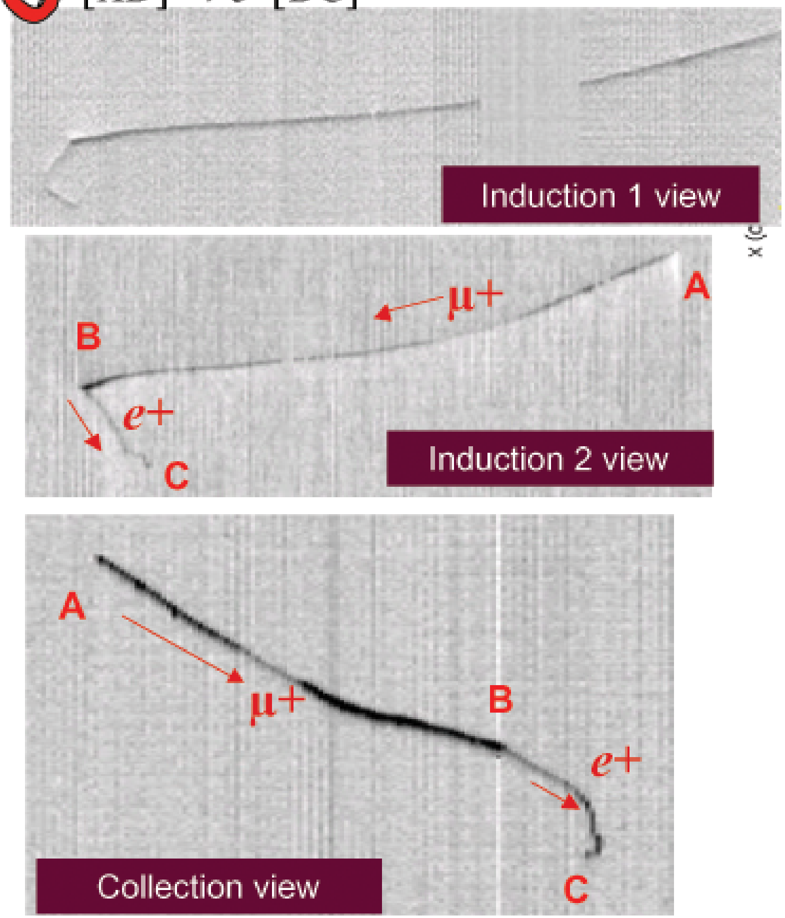
will detailed events reveal anything new?
Liquid Argon TPC in near site of beams may provide valuable exclusive cross section data

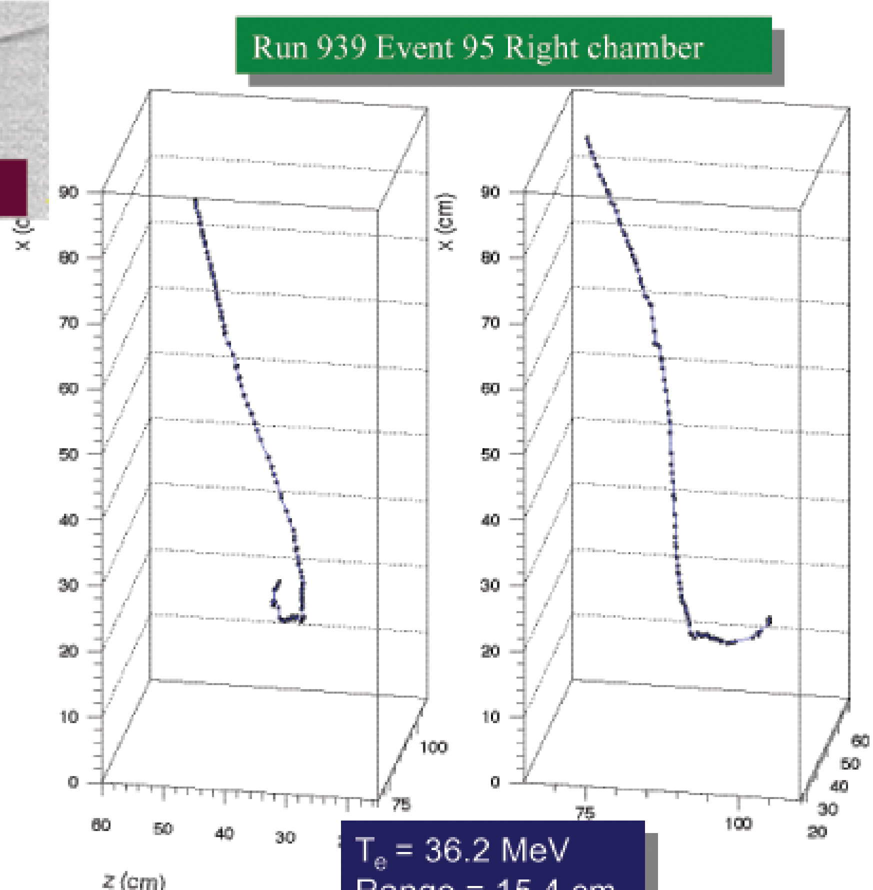
Charge

3D reconstruction of a stopping muon

$\mu^{+}[AB] \rightarrow e^{+}[BC]$

(Reconstruction is automatic)





T_e = 36.2 MeV
Range = 15.4 cm

Detector Technology: Liquid Argon

scale up Icarus to LANNDD 70 kT for K^+ detector

~ factor 6 higher efficiency than water for K^+

…so cavern could be smaller *if only want to concentrate on* K^+

⇒ 420 kT effective mass of water (8 x Super-K total)

but efficiency for $e^+ \pi^o$ and many other modes same as with water

liquid argon would need × 6 bigger cavity for a broad search of pdk

cost: $200 M for the 70kT of liquid argon alone (420 kT too expensive?)

proposed sites: Frejus and WIPP in New Mexico

LLANNDD

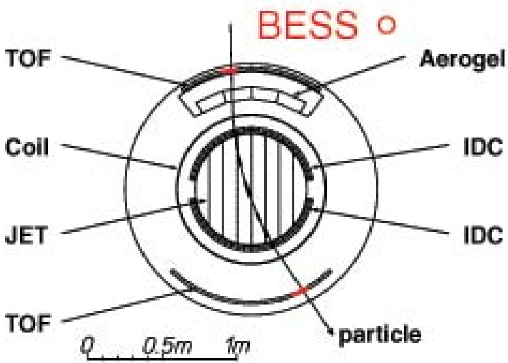
Large Liquid Argon Neutrino

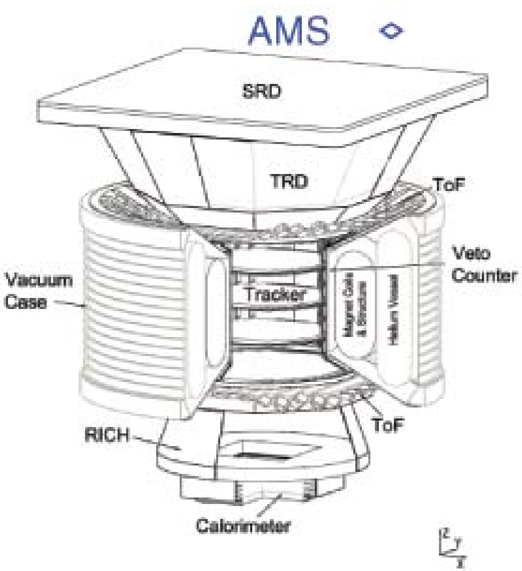
and

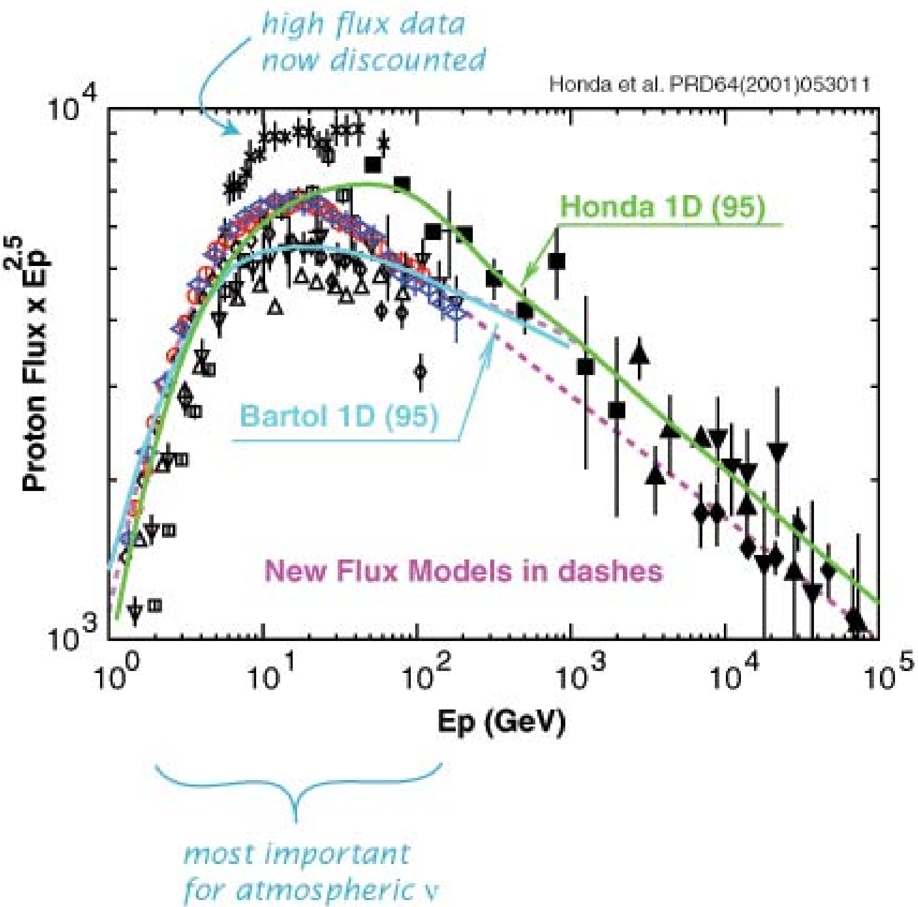
Nucleon Decay Detector

70 kT magnetized

New Precise Data on Primary Cosmic Ray Flux







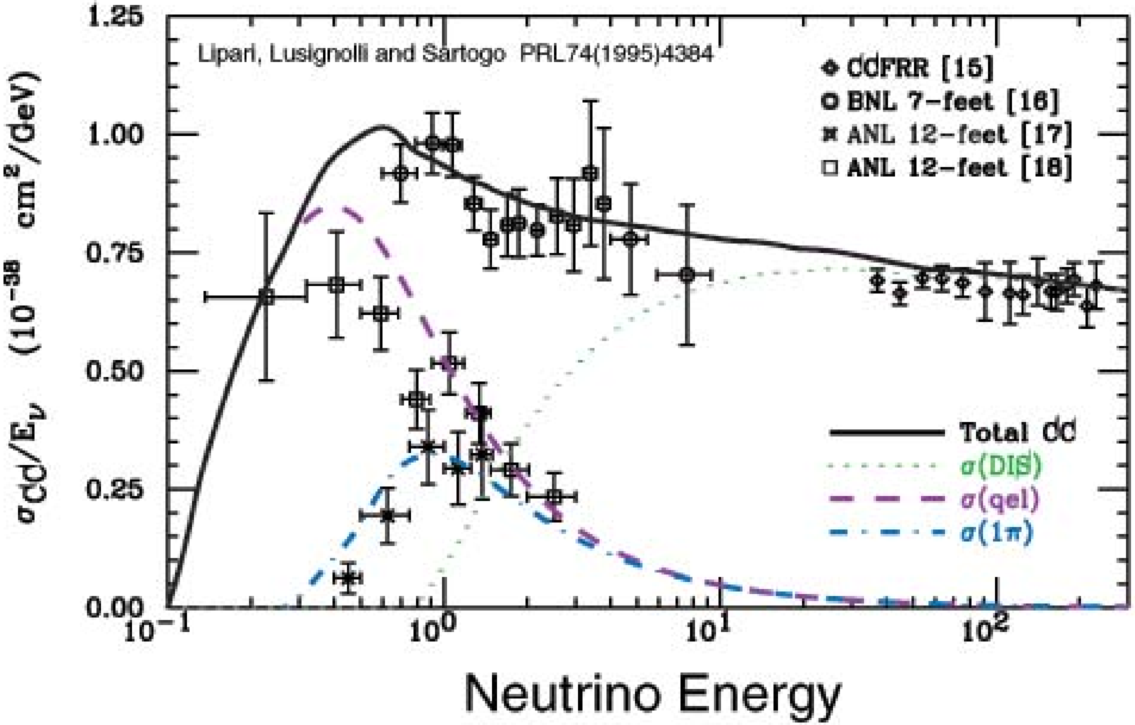
Note: Honda and Bartol neutrino fluxes generally agreed with each other (despite primary flux difference) due to different hadronic models.

From Ed Kearns

Neutrino Cross Sections

Long baseline near detector data (K2K) influence atm ν Monte Carlo:

M_A(QE) = 1.11 GeV M_A(1p) = 1.21 GeV
K2K oscillation analysis insensitive
atmospheric neutrino analysis under study



Quasi-Elastic
$\nu_\mu N \rightarrow \mu^- N'$
V-A
Llewellyn-Smith 1972

Single Pion
$\nu_\mu N \rightarrow \mu^- N' \pi$
resonance production
Rein & Seghal 1981

Coherent Pion (not shown)
$\nu_\mu\ {}^{16}O \rightarrow \mu^- X \pi$
Marteau et al.

Deep Inelastic Scattering
$\nu_\mu N \rightarrow \mu^- N'$ *hadrons*
GRV94 parton distribution
with Bodek 2001

Nuclear Effects
Fermi motion
Pauli blocking
Nuclear rescattering

From Ed Kearns

meanwhile in America?

Two Neutrino/Astro Physics Planning Processes

merican Physical Society Neutrino Study…soon to be public   Freedman & Kayse

set priorities for experiments: astro, reactor, solar & atmospheric, etc.

highest long term: massive detector for pdk + oscillations, highest

highest medium term: NOVA, off-axis neutrino oscillations

double beta decay @ 100 kg level

SF Initiative: A "Deep Engineering and Science Underground Laboratory"   Sadoule

8 potential sites: Anderson, Henderson, Homestake, Icicle Creek,
Kimburton, San Jacinto, Soudan, WIPP

3 solicitations for proposals:

1) site independent physics justification and requirements, funded 10 days ago

2) site specific proposals, due 28/2/05, 3-5 to be chosen ~7/05

likely at least one massive & one deep (geo- and bio- want more)

3) full proposals due 2/06... Goal: funding in '09 presidential budget

staged, $1-1.5 B expected for detector + proton driver + superbeam

likely will include possibility of international site for massive detector beside geography,

why so many facilities?

for Megaton...

the bigger the better.

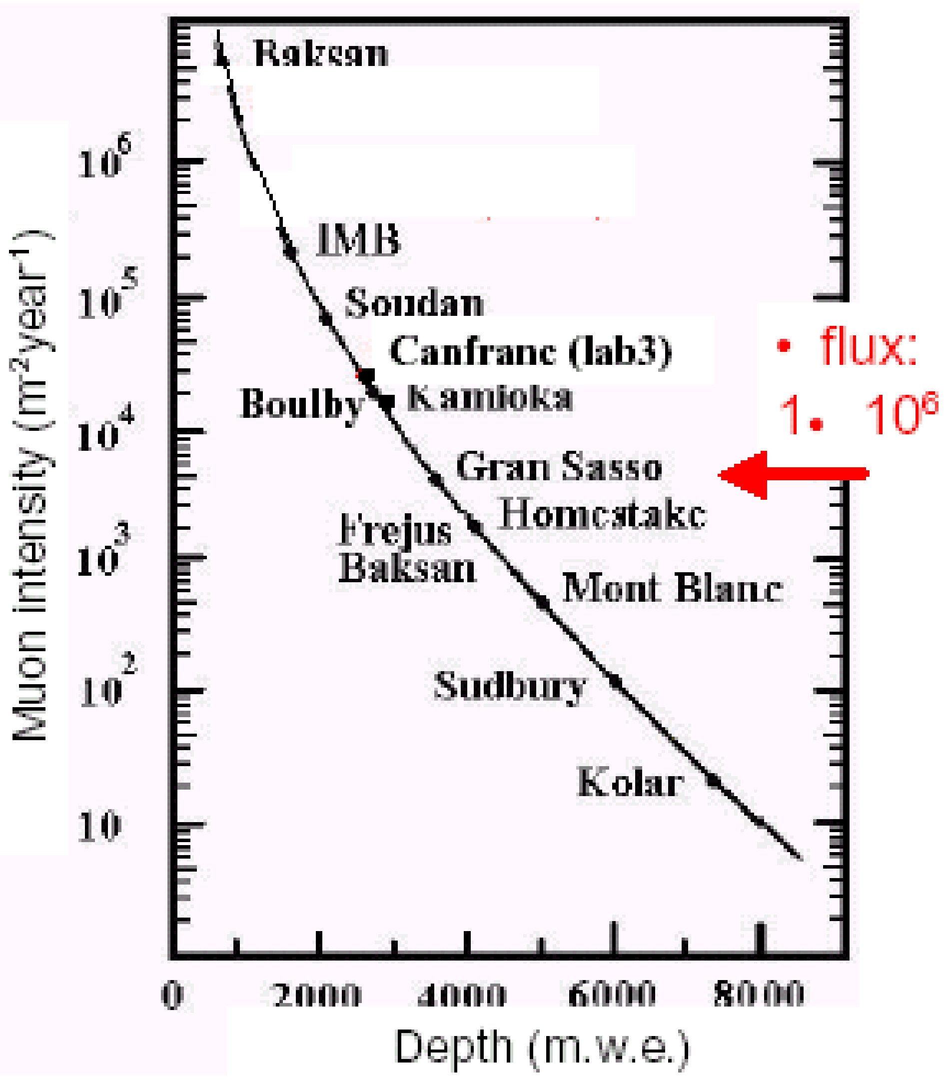
for solar and

background sensitive exp'ts

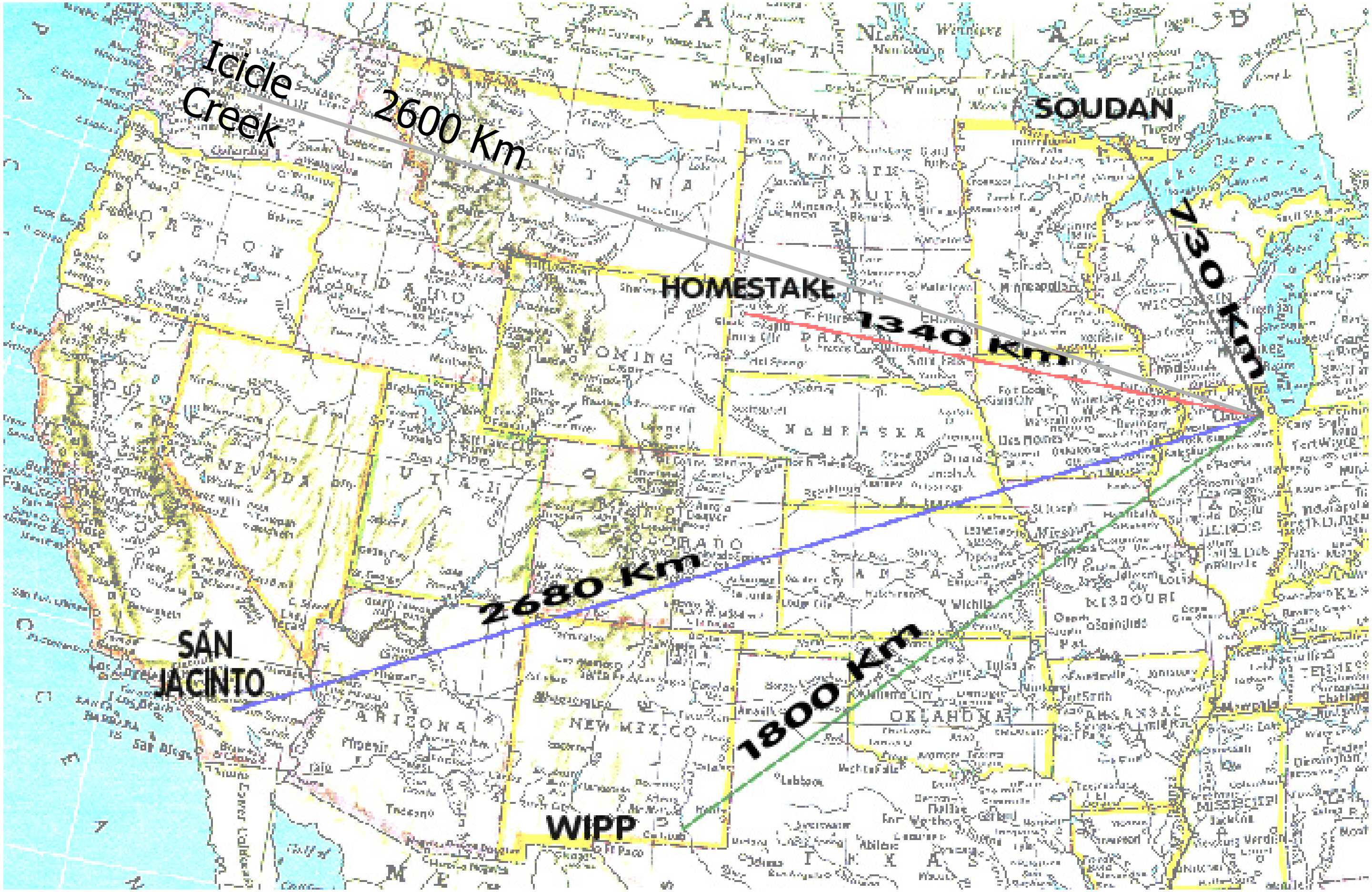
the deeper, the better

e.g. impossible for IMB

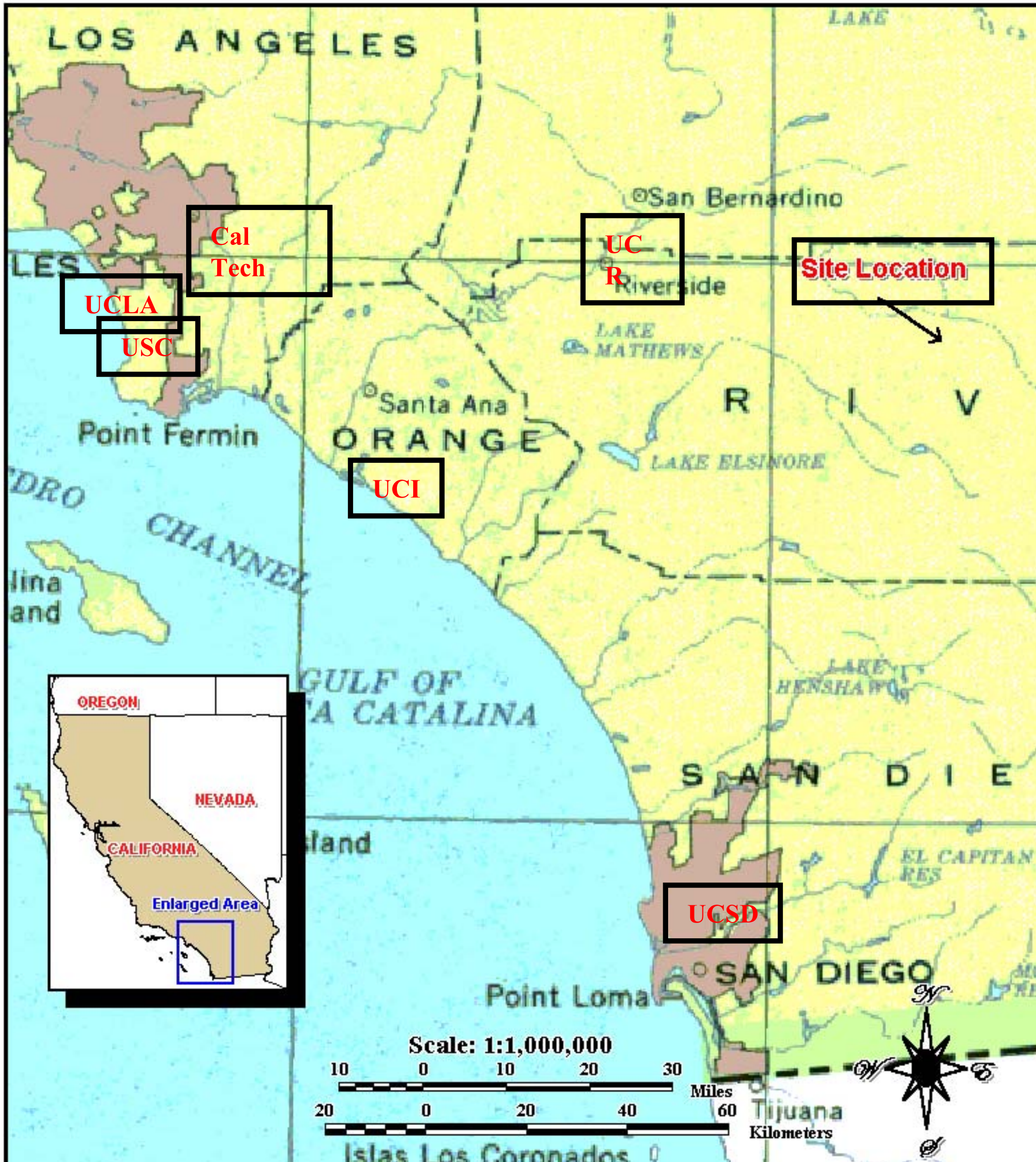
consider SNO-Lab at Sudbury



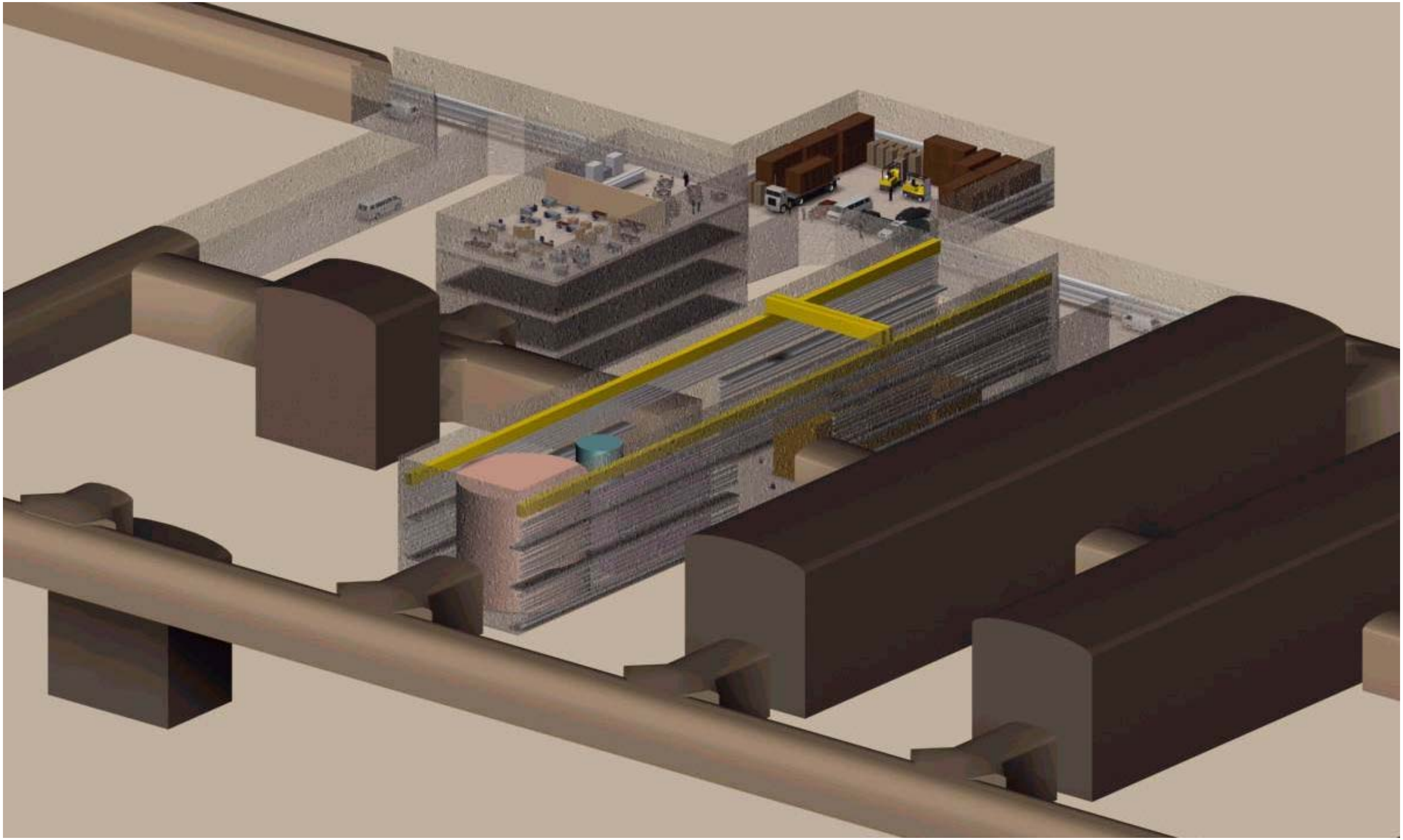
Possible long baseline proposals in US...



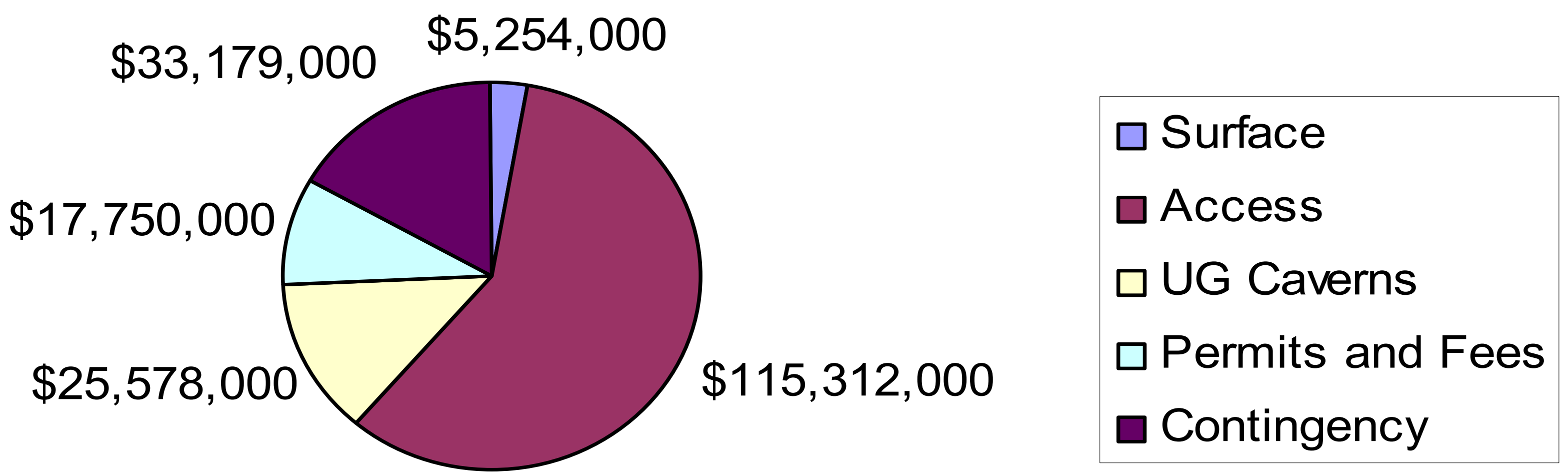
San Jacinto, California proposal...



Underground Laboratory Complex



Sample Cost Breakdown
(8,000 feet overburden)



Estimated total cost $200 million

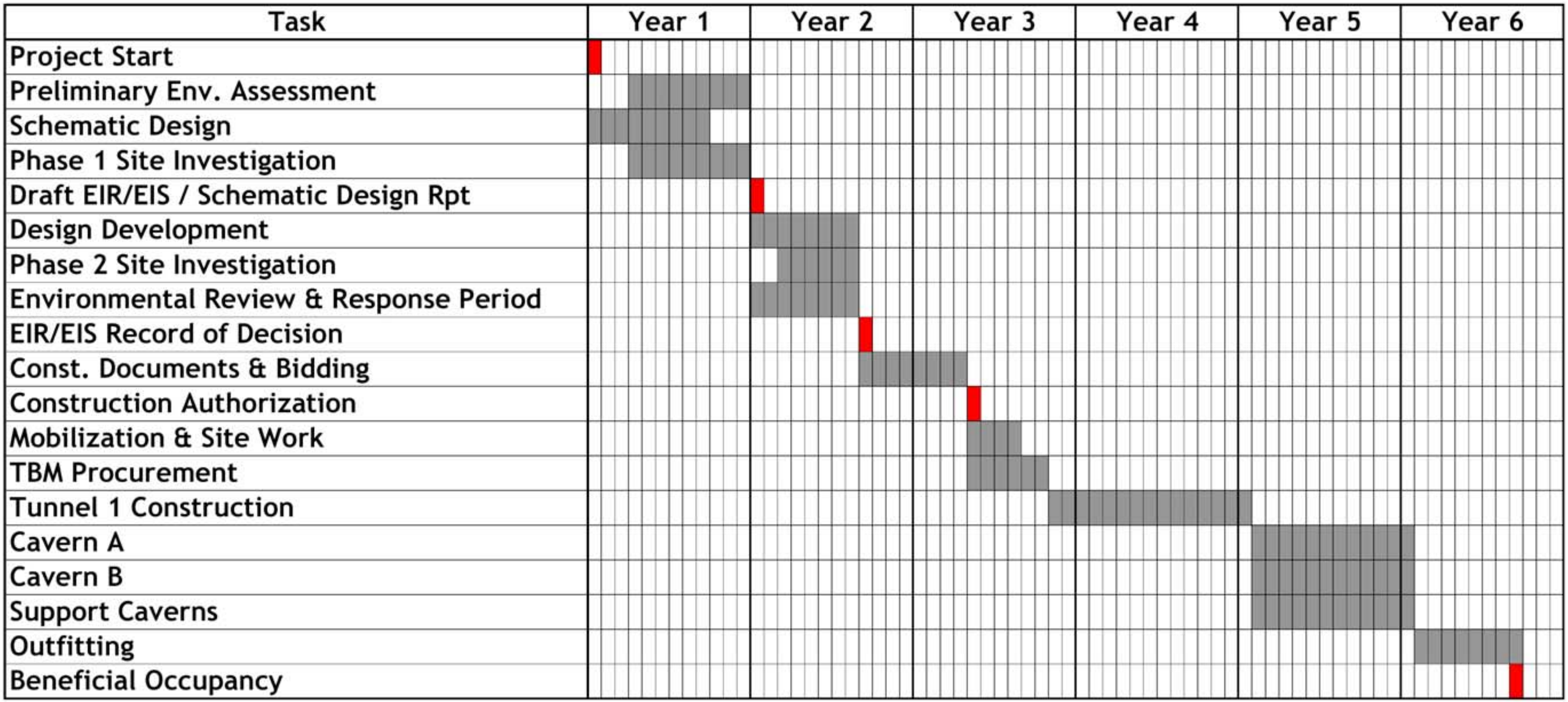
Estimated Operating Costs

WBS 1-Fees	$100,000
WBS 2-Utility Costs	$2,604,000
WBS 3-Maintenance	$560,000
WBS 4-Equipment & Transportation	$225,000
WBS 5-Staff	$1,080,000
WBS 6- Programs	$160,000
WBS 7-Outside Costs & Subcontracts	$638,000
Total	**$5,367,000**

*

San Jacinto proposal…

Project Schedule



San Jacinto proposal...

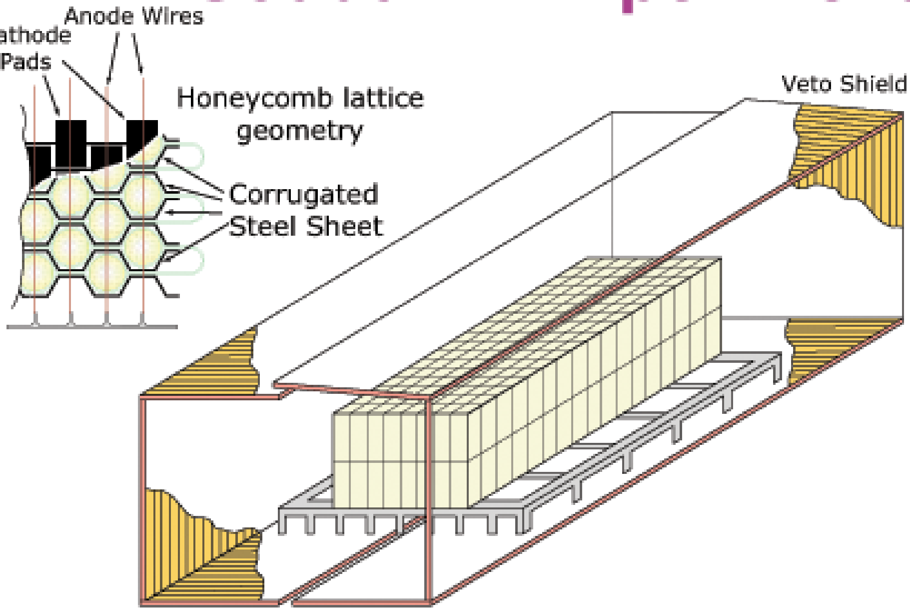
California funding for detailed engineer costing...

		1 Tun	2 Tun	1 Tun	2 Tun	1 Tun	2 Tun
1	**Land Acquisition, Easements & Usage Fee**	**$0**	**$0**	**$0**	**$0**	**$0**	
1.1.	Surface Land Costs						
1.2.	Underground Rights Costs						
1.3.	Road Easements						
1.4.	Utility Easements						
1.5.	Public/Private Road Fees						
2	**Surface**	**$5,254,356**	**$5,254,356**	**$5,254,356**	**$5,254,356**	**$5,254,356**	**$5,254,3**
2.1	Access roads	$29,356	$29,356	$29,356	$29,356	$29,356	$29,3
2.2	Surface Infrastructure						
2.2.1	Electrical and substation	$105,000	$105,000	$105,000	$105,000	$105,000	$105,0
2.2.3	Water	$50,000	$50,000	$50,000	$50,000	$50,000	$50,0
2.2.4	Sewer	$50,000	$50,000	$50,000	$50,000	$50,000	$50,0
2.2.5	Communications	$100,000	$100,000	$100,000	$100,000	$100,000	$100,0
2.3	Buildings						
2.3.1	Building 1-Visitor's Center & Administration	$2,550,000	$2,550,000	$2,550,000	$2,550,000	$2,550,000	$2,550,0
2.3.3	Building 3-Warehouse & Assembly	$1,350,000	$1,350,000	$1,350,000	$1,350,000	$1,350,000	$1,350,0
2.3.4	Building 4-Laboratories	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,000	$1,020,0
3	**Underground Access**	**$115,312,744**	**$162,217,558**	**$118,421,321**	**$172,773,234**	**$115,272,839**	**$166,605,4**
3.1	Portal(s)						
3.1.1	Access tunnel portal	$3,252,000	$4,407,000	$3,252,000	$4,407,000	$3,252,000	$4,407,0
3.2	Tunnel(s)						
3.2.1	Access Tunnel	$56,413,837	$51,127,005	$58,732,214	$53,228,114	$56,413,837	$51,127,0
3.2.2	Egress Tunnel	$0	$51,461,023	$0	$53,228,114	$0	$51,461,0
3.2.3	Cross Cuts or Turnouts	$1,950,000	$1,950,000	$1,950,000	$2,100,000	$1,950,000	$1,950,0
3.2.4	Mechanical	$44,404,290	$47,835,290	$45,194,490	$49,921,490	$44,404,290	$47,835,2
3.2.5	Electrical	$4,451,275	$0	$4,451,275	$4,451,275	$4,451,275	$4,451,2
3.2.6	Fire Protection	$3,830,400	$3,830,400	$3,830,400	$3,830,400	$3,830,400	$3,830,4
3.3	Surface haulage	$1,010,942	$1,606,840	$1,010,942	$1,606,840	$971,037	$1,543,4
4	**Underground Facilities**	**$25,578,546**	**$25,578,546**	**$30,453,600**	**$30,453,600**	**$16,987,289**	**$16,987,2**
4.1	Caverns						
4.1.1	Common Area Cavern	$1,506,221	$1,506,221	$1,506,221	$1,506,221	$1,506,221	$1,506,2
4.1.2	Utility Cavern	$853,444	$853,444	$853,444	$853,444	$853,444	$853,4
4.1.3	Experimental Cavern A	$4,190,846	$4,190,846	$4,190,846	$4,190,846	$2,109,741	$2,109,7
4.1.4	Experimental Cavern B	$4,989,999	$4,989,999	$4,989,999	$4,989,999	$0	
4.1.5	Experimental Cavern C	$0	$0	$4,190,846	$4,190,846	$0	
4.1.7	Refuge Cavern	$156,320	$156,320	$156,320	$156,320	$156,320	$156,3
4.1.8	Sump	$156,320	$156,320	$156,320	$156,320	$156,320	$156,3
4.2	Tunnels						
4.2.1	Main Street Tunnel	$1,074,918	$1,074,918	$1,330,156	$1,330,156	$819,680	$819,6
4.2.2	Connecting Tunnels	$2,177,548	$2,177,548	$2,504,253	$2,504,253	$1,074,918	$1,074,9
4.3	Underground Infrastructure						
4.3.1	Groundwater Drainage	$500,000	$500,000	$500,000	$500,000	$500,000	$500,0
4.3.2	Mechanical	$2,717,033	$2,717,033	$2,717,033	$2,717,033	$2,717,033	$2,717,0
4.3.3	Electrical	$632,100	$632,100	$632,100	$632,100	$632,100	$632,1
4.3.4	Fire protection	$1,213,038	$1,213,038	$1,213,038	$1,213,038	$1,213,038	$1,213,0
4.3.5	Security	$0	$0	$0	$0	$0	
4.3.6	Assembly Areas	$116,880	$116,880	$116,880	$116,880	$116,880	$116,8
4.3.7	Steel & concrete structures	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,0
4.4	Surface Haulage	$293,880	$293,880	$396,145	$396,145	$131,595	$131,5
5	**Permits, Fees and Professional Services**	**$17,750,811**	**$23,370,946**	**$18,707,410**	**$25,219,856**	**$16,716,625**	**$22,867,2**
5.1	Professional Services						
5.1.1	Site Investigation	$2,432,552	$3,202,729	$2,563,643	$3,456,101	$2,290,828	$3,133,7
5.1.2	Schematic Design	$1,185,165	$1,560,404	$1,249,034	$1,683,850	$1,116,116	$1,526,7
5.1.3	Design Development	$1,925,893	$2,535,656	$2,029,681	$2,736,255	$1,813,688	$2,481,0
5.1.4	Construction Documents	$3,407,350	$4,486,161	$3,590,973	$4,841,067	$3,208,833	$4,389,4
5.1.5	Construction Engineering Services	$5,481,389	$7,216,867	$5,776,783	$7,787,804	$5,162,036	$7,061,3
5.1.6	Site Characterization During Construction	$740,728	$975,252	$780,646	$1,052,406	$697,572	$954,2
5.1.7	Environmental Studies	$740,728	$975,252	$780,646	$1,052,406	$697,572	$954,2
5.1.8	Cultural Studies	$207,404	$273,071	$218,581	$294,674	$195,320	$267,1
5.1.9	Public Affairs	$148,146	$195,050	$156,129	$210,481	$139,514	$190,8
5.2	In-House Services, Permits, Owner's Rep.	$1,481,456	$1,950,505	$1,561,293	$2,104,812	$1,395,145	$1,908,4
6	**Environmental Mitigation**	**$2,000,000**	**$2,000,000**	**$2,000,000**	**$2,000,000**	**$2,000,000**	**$2,000,0**
6.1	Environmental Mitigation	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,0
	Subtotal	**$165,896,458**	**$218,421,406**	**$174,836,687**	**$235,701,046**	**$156,231,109**	**$213,714,3**
	Contingency 20%	$33,179,292	$43,684,281	$34,967,337	$47,140,209	$31,246,222	$42,742,8
	Total	**$199,075,749**	**$262,105,687**	**$209,804,025**	**$282,841,255**	**$187,477,331**	**$256,457,2**

Proton Decay Detector at Soudan

- Water Cerenkov detector
- Believe key to progress is improved photodetectors
- Solid state photodetectors address two significant problems of PMT's: pressure limitation and radioactivity of glass
- Also yield unclear advantage in greater pixelation
- Goal is ~\$1/cm^2 with 70% QE (CMOS process)
- Conceptual design is vertical cylinder 50 m in diameter with heights up to 100 m (~0.2 MT)
- Multiple volumes provide required mass

Soudan 2 Experiment

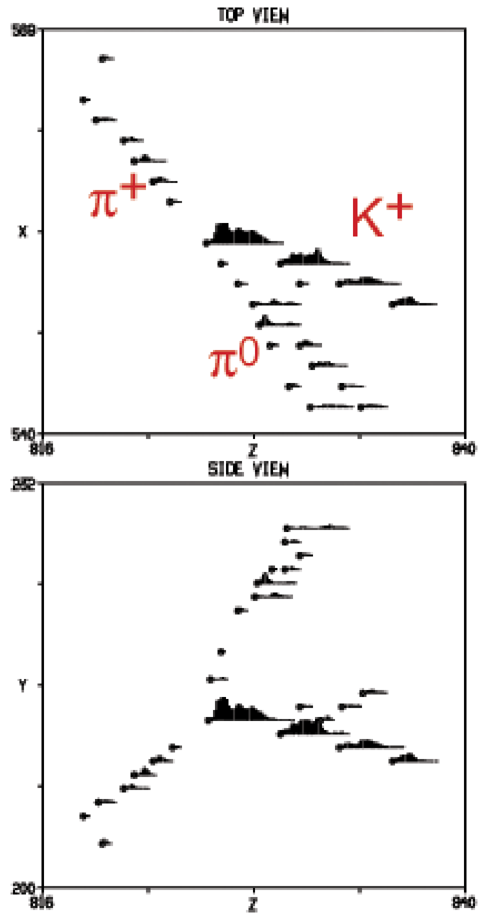


tracking iron tracking calorimeter

Soudan Mine (Minnesota), 2100 m.w.e., 770 ton (fiducial)
1 cm spatial resolution with dE/dx sampling

suitable for: non-relativistic particles (K^+)
high final state multiplicities

however: greater intranuclear scattering than water
smaller in size due to cost and complexity

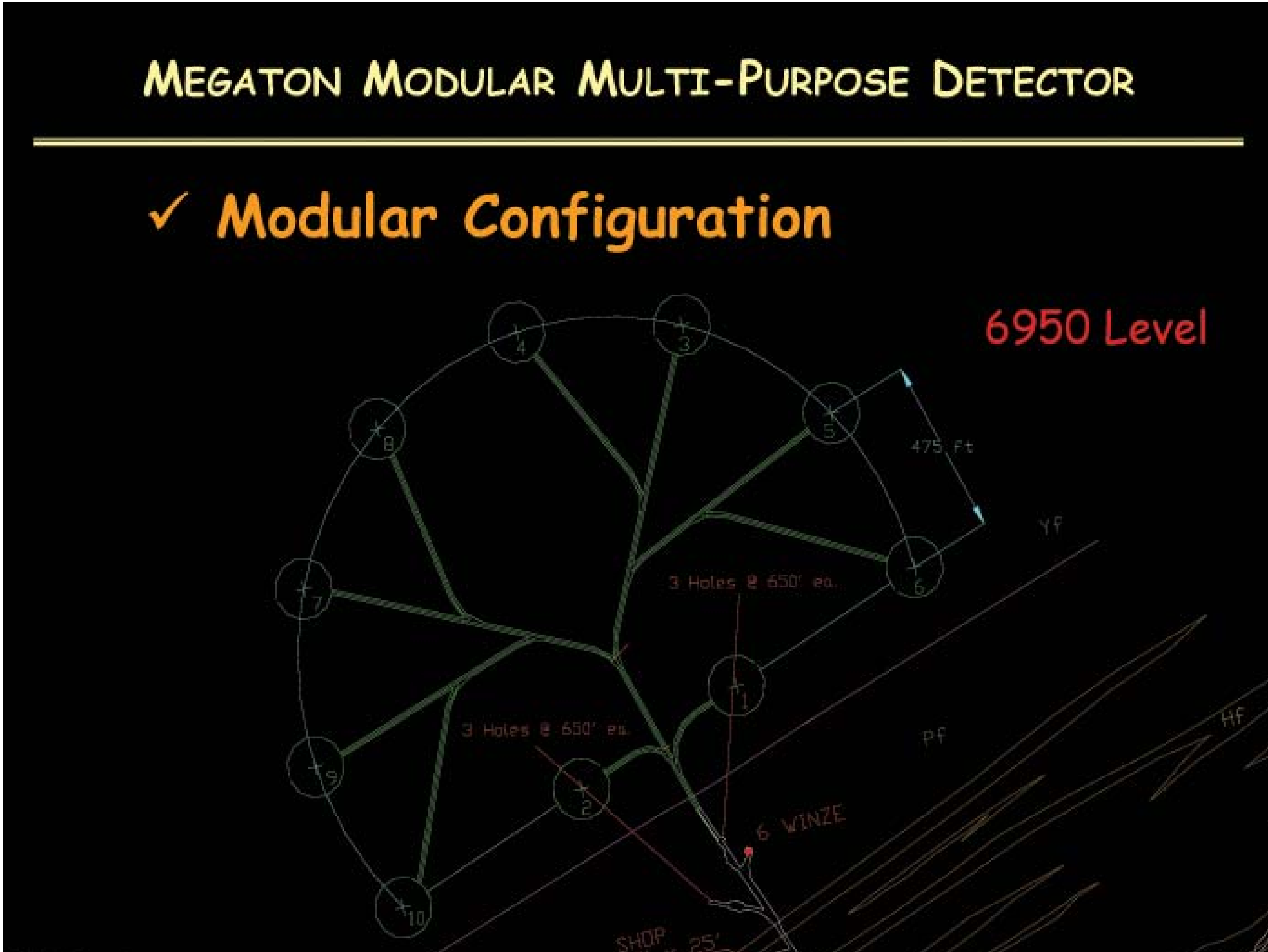


Soudan 2 proton decay M.C.

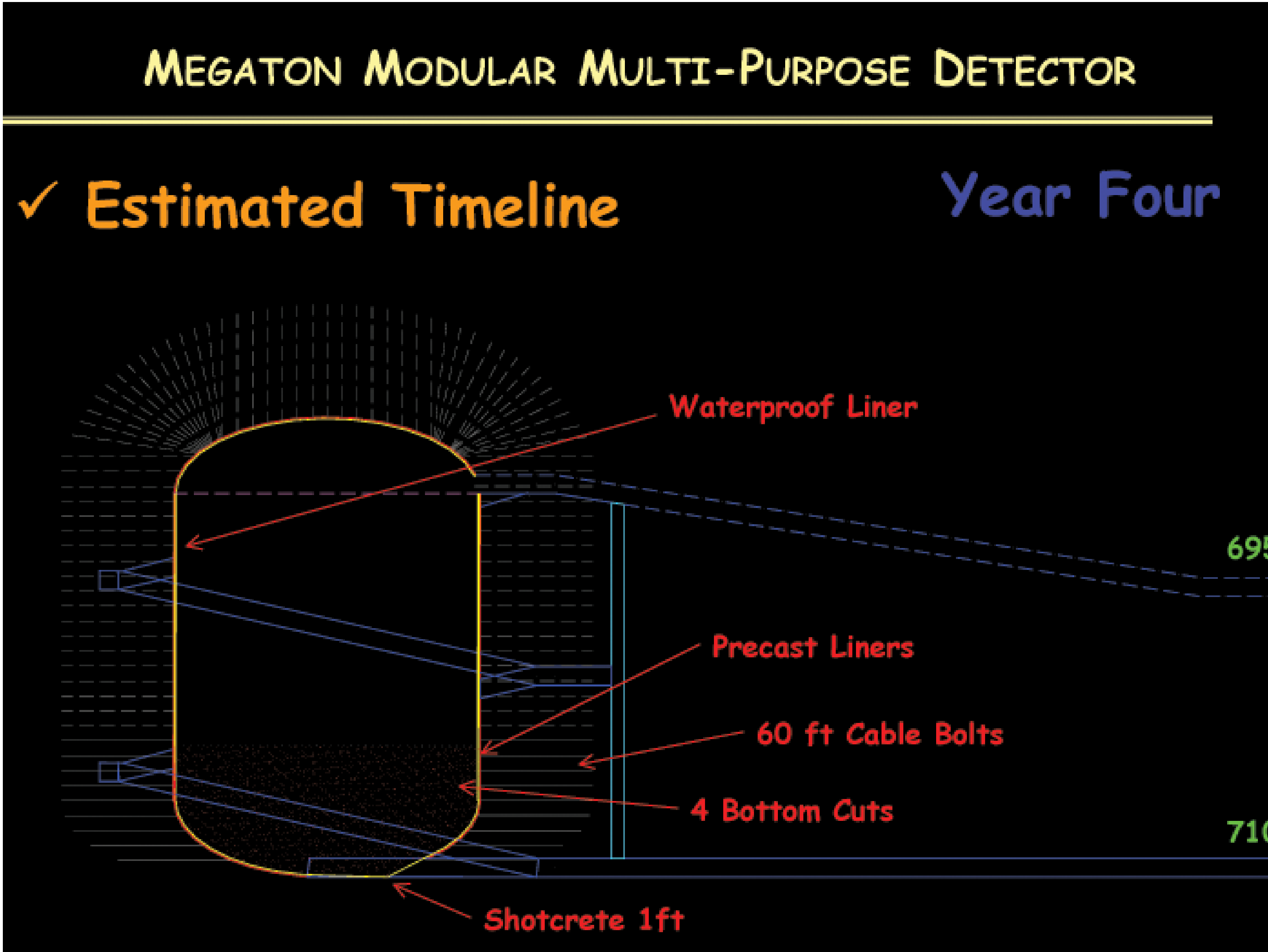
Proton Decay Detector at Soudan

- Build Phase 1 detector 50 m diameter, 50 m high (2 Super-K's) at 700 m depth
- Use Phase 1 detector to develop techniques, software etc.
- Use Phase 1 detector to do physics in coincidence with beam (depth not a problem)
- Extend lab to 2,500 m (8,200 feet)
- Build 5 Phase 2 Detectors at 1,500 to 2,500 m

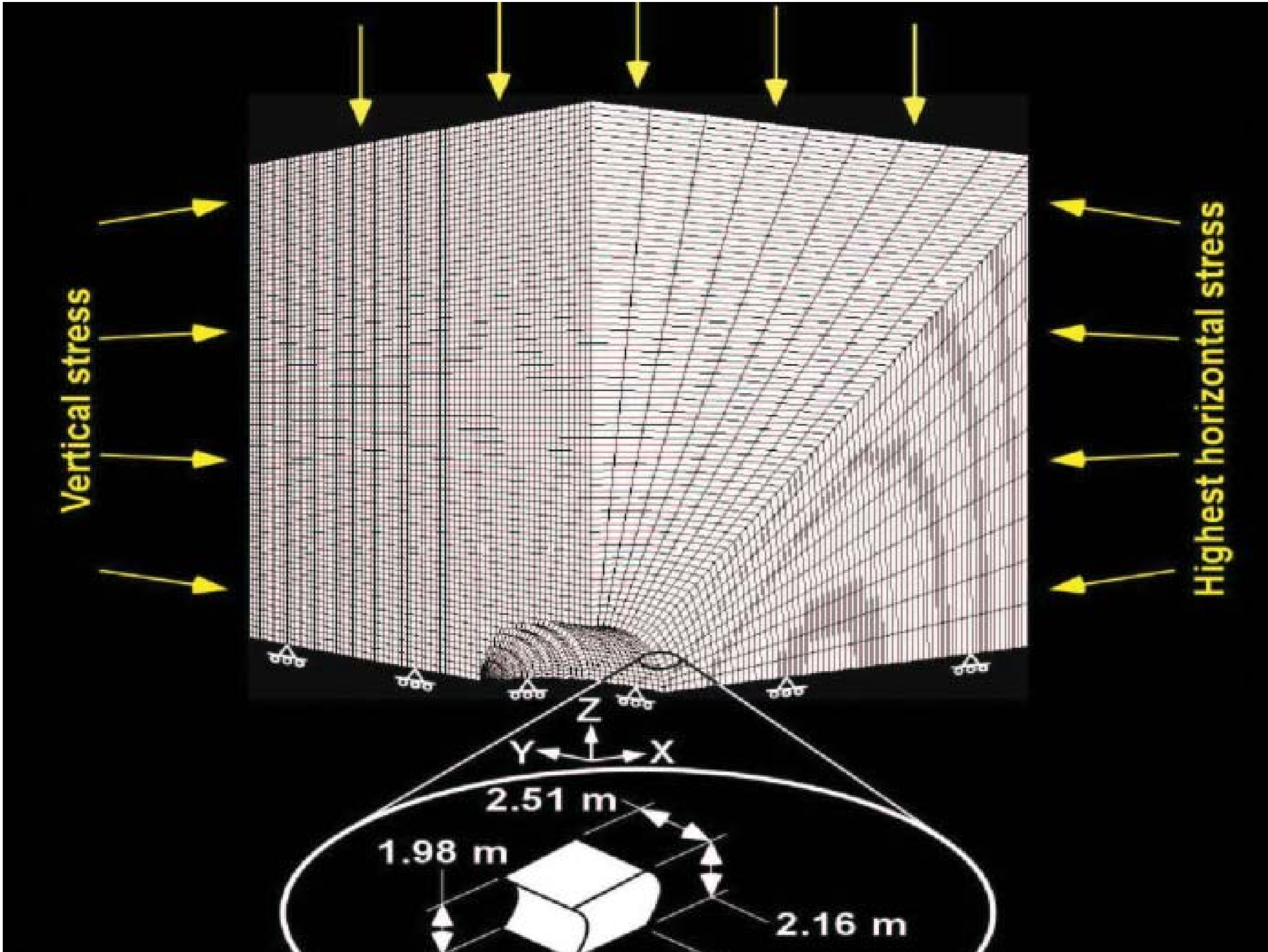
Homestake proposal…10 – 100 kT Super-K tanks…



Homestake proposal…100 kT Super-K tank…



Homestake proposal...detail geological engineering in deep site ...



Homestake proposal...

MEGATON MODULAR MULTI-PURPOSE DETECTOR

✓ Estimated Excavation Costs ($MM)

# Of Chambers	1	3
⇨ Labor & Benefits	$ 5.51	$ 10.94
⇨ Mining & Construction		
★ Equipment Operation	$ 1.30	$ 3.89
★ Supplies	$ 4.51	$ 13.35
★ Precast Concrete Liner	$ 3.25	$ 9.75
⇨ Other (Outside Contractor)	$ 0.12	$ 0.37
⇨ 15% Contingency	$ 2.20	$ 5.74
TOTAL	$ 16.89	$ 44.04

Homestake proposal...

Features of the Design:

1) Module dimensions 50 m diameter x 50 m high
- 100 kilotons water

2) Parallel construction of modules – one "crew" can build
3 modules in parallel- completion in 4-5 years

3) Multiple crews can work at same time – , 2 crews can
build 600 kilotons of detector in 4-5 years.

4) Concrete liner in each module provides strength and
stability, smooth surface for water tight plastic inner liner,
surface for photomultiplier installation guides.

5) Low construction cost

conclusion...

physics motivation strong for PDK search

unification theories severely constrained

synergism with neutrino superbeams, ν factories

preparatory work in progress

K2K (data now finished) and other precision studies of ν interactions coming

detailed understanding of cross sections and neutrino background, especially from neutrino-induced single pion modes

vigorous r & d for detector options…phototubes, liquid argon at Gran Sasso

if S-K gets one candidate for PDK, first put scintillator in Super-K? then make big water detector?

if SUSY, found at LHC, make detector dedicated to K^+ ?

next generation detector

build water Cherenkov to largest size limited by atmospheric ν background consistent with geology

why CPPM? why build Megaton at Frejus?

potential CERN neutrino beam
2 hours from infrastructure of CERN, as well as
    12 HEP labs of CEA/CNRS, INFN, and CH with couple of hours
        CPPM one of closest in France

For low energy neutrino beam...water detector most economical, ideal L/E
    CPPM experience: extensive water Cherenkov : Antares, Km^3
        high numbers of pm's, optimizing electronics, underwater cabling, etc.

Limiting investment: the cavern dominates
    in size, in cost ...moving from 20 m, to 40 m, to 60 m
        Italy: drilling tunnels...a national pastime
            long Gran Sasso experience
        France: world renown for grand civil engineering challenges
            ...highest bridge, biggest caverns for LHC

CERN: 150 M € / year available for new initiatives starting '09?

EU framework projects...MegaTonne a unique, continent wide project
    ~20 year program, 1 – 1.5 B €, should involve most of Europe