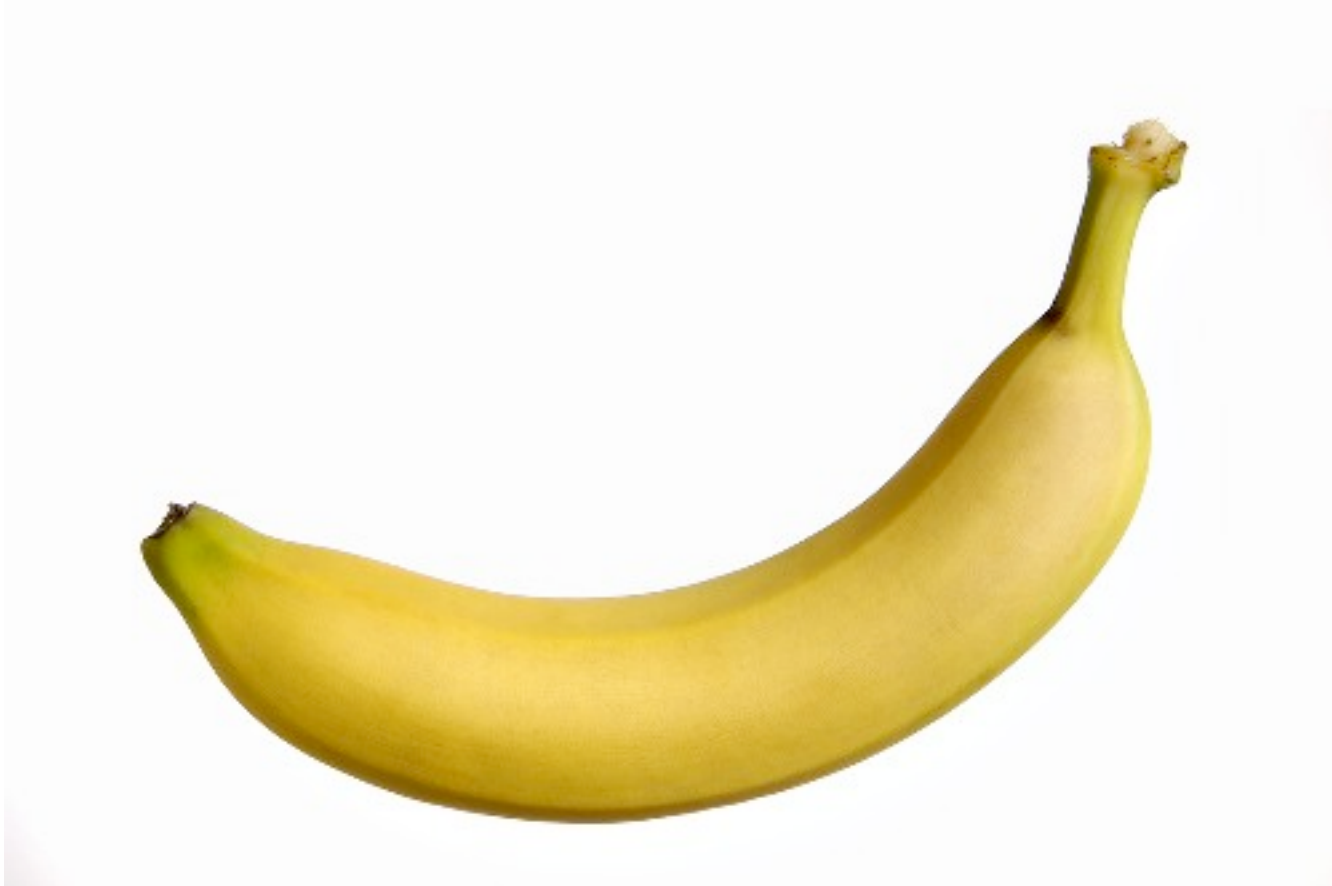
Test beams for neutrinos and rare processes

Transformative Hadron Beamlines Workshop
20140721 David Jaffe/BNL



BROOKHAVEN NATIONAL LABORATORY

Applications

1. ν_e appearance:
   - signal: $\nu_e N \longrightarrow e^- X$
   - background: $\nu_\mu N \longrightarrow \nu_\mu \pi^0 X$
2. proton decay:
   1. signal: $p \longrightarrow K^+ \bar{\nu}$
   2. background: $K_{\mathrm{L}}^0 X \longrightarrow K^+ X'$
3. $K^+ \longrightarrow \pi^+ \nu \bar{\nu}$ in a stopped K+ beam
   1. low energy K+ beam

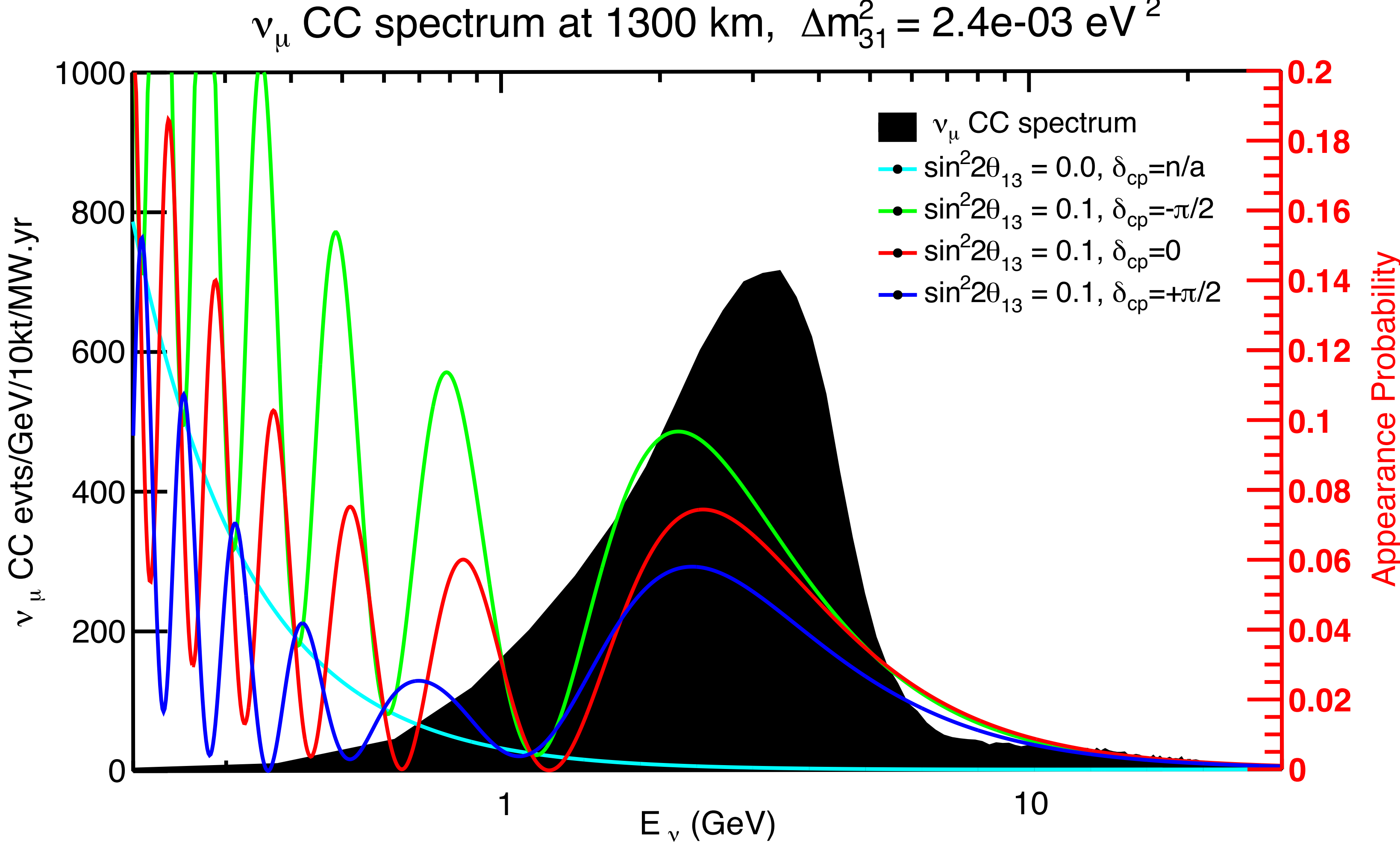
Applications

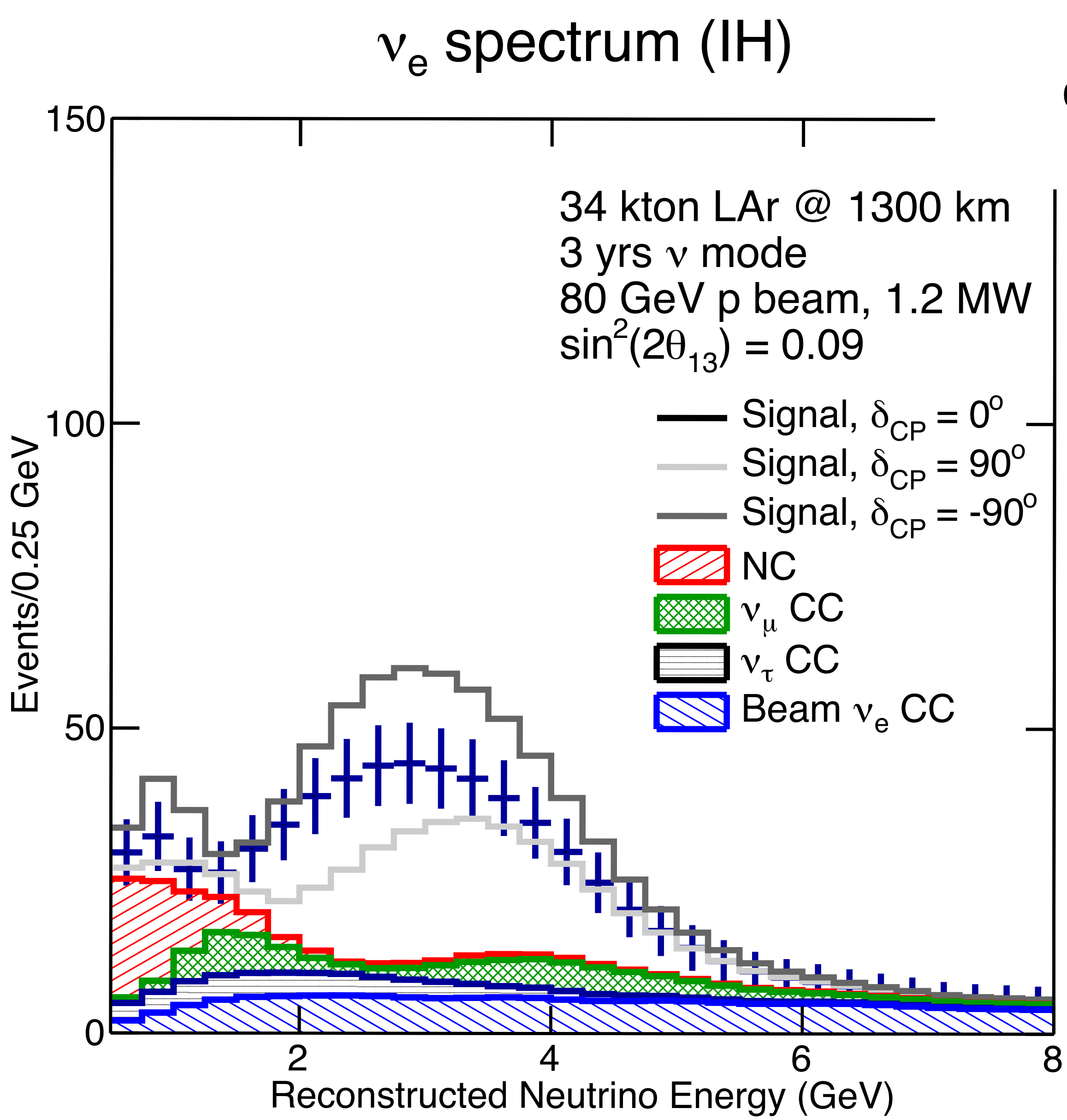
1. ν_e appearance:
    - signal: $\nu_e N \longrightarrow e^- X$
    - background: $\nu_\mu N \longrightarrow \nu_\mu \pi^0 X$
2. proton decay:
    1. signal: $p \longrightarrow K^+ \bar{\nu}$
    2. background: $K^0_{\mathrm{L}} X \longrightarrow K^+ X'$
3. $K^+ \longrightarrow \pi^+ \nu \bar{\nu}$ in a stopped K+ beam
    1. low energy K+ beam

P5: NO

ν_e appearance energy range

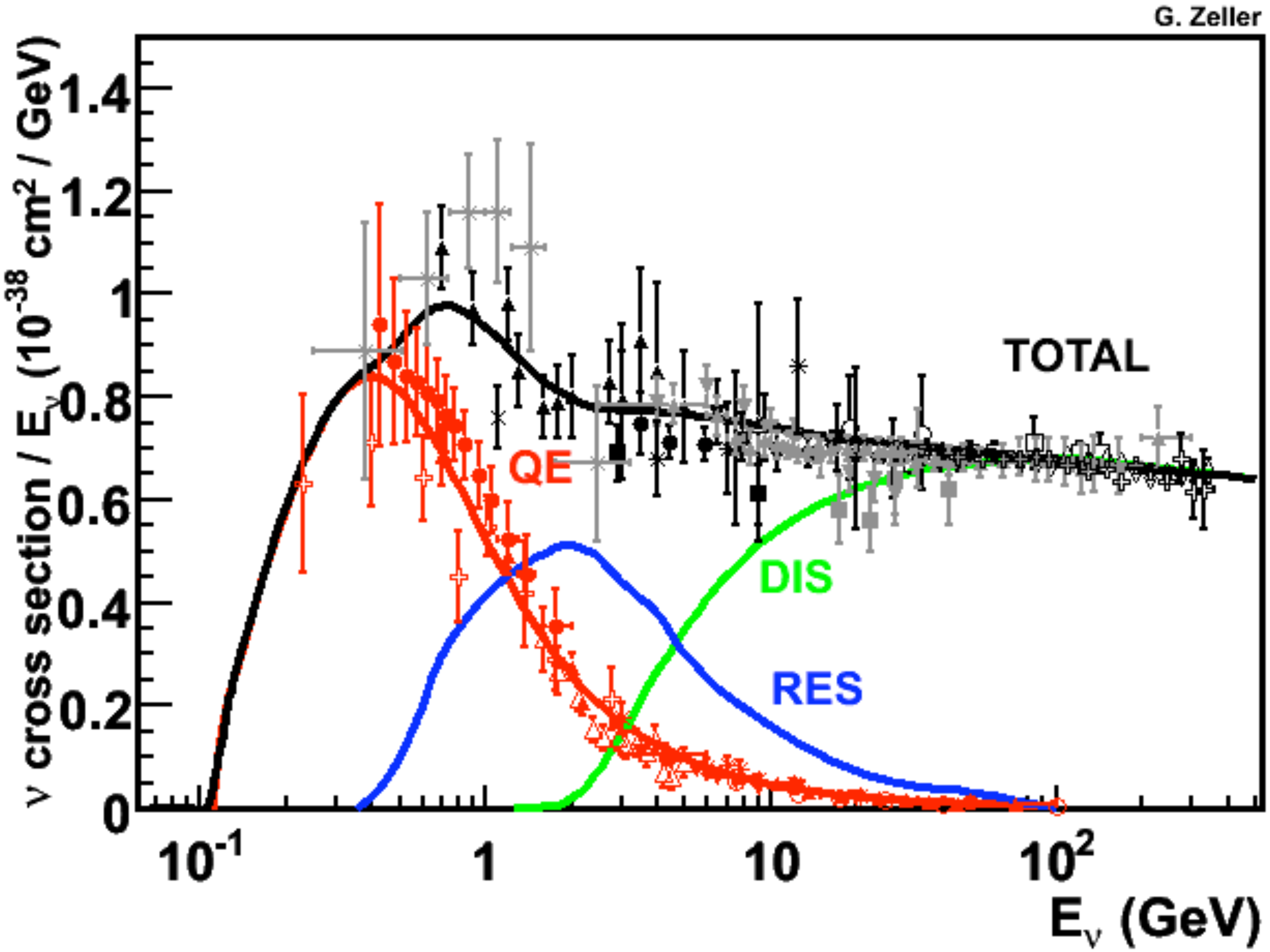
LBNE ν_μ beam energy ==>





<== LBNE ν_e signal and background

arXiv:1307.7335



- LBNE: 0.5< $E(\nu_e)$ <10 GeV
- microBooNE: 0.1< $E(\nu_e)$ <2GeV
- Need a source of signal ($e^{\pm}$) and background ($\pi^0, \gamma, \pi^{\pm}$, etc.) in energy range ~0.1 to 10 GeV

proton decay: K+ energy range

1. Signal is single K+
    1. Free proton decay: p(K)=337 MeV/c
    2. Bound proton decay in Ar,C: 100<p(K)<500MeV/c (arXiv:0811:1892, arXiv:hep-ph.0511230)
2. One background is $K^0_{\mathrm{L}} X \rightarrow K^+ X'$

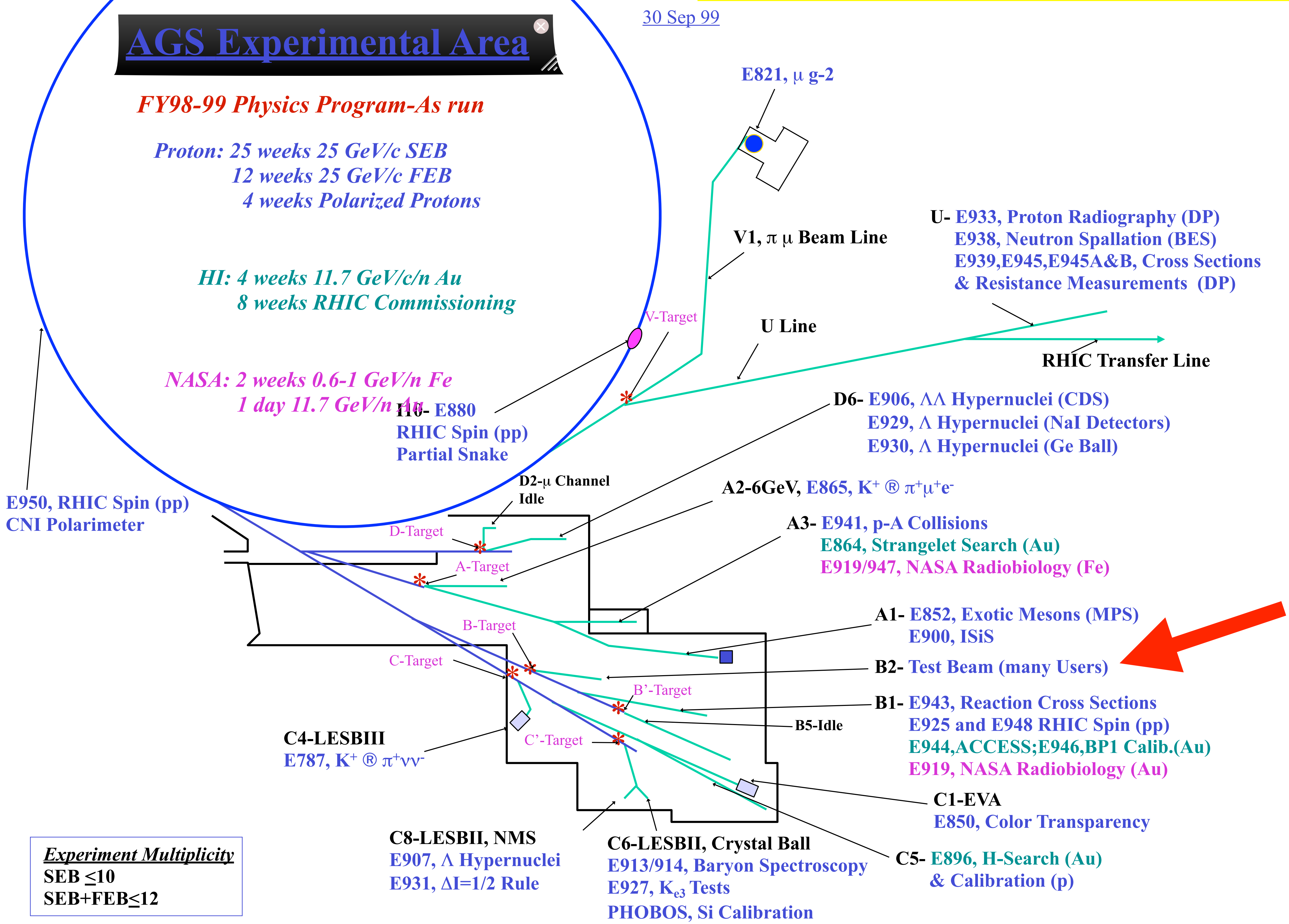
Stopped K+ beam for rare K+ decays

1. Relevant K+ momentum range
   1. ORKA: 550<p(K+)<600 MeV/c
   2. E787/E949: 700<p(K+)<790 MeV/c
2. Prototyping enabled with a low p(K+) beam:
   1. Active target
   2. K+ beam degradation
   3. K+ beam instrumentation

Summary, test beam desiderata and proposal

1. particles, energy range:
    1. $e^{\pm}$ $\pi^0, \gamma, \pi^{\pm}$ 0.1 < E < 10 GeV
    2. K: 100 < p < 800 MeV/c
2. Requirements on test beam:
    1. Charged particle momentum selection
    2. Particle identification (TOF, Cerenkov,dE/dx)
    3. Tagged/enriched kaon beam
3. Proposals
    1. Proposal-1: Reproduction of AGS B2 test beam
    2. Proposal-2: Low energy K+ beam
    3. Proposal-3: Tagged neutral kaon beam

The AGS in the good old days



Phil Pile

Test Beam – *B2*

Parameters:

Maximum Momentum: < 9 GeV/c

Length: 40 meters

$\delta\Omega$: 0.5 msr

$\delta p/p$: 5 % fwhm

$\delta p\delta\Omega$: 2.6 msr–%

Beam Optics:

- **Corrected to first order**

Collimators:

1. **Vertical Intensity Collimator – Adjustable**
2. **Horizontal Momentum Collimator – Adjustable**

Target:

- **10 cm Beryllium, air cooled**
- **Normally intercepts 10% of the B–line proton beam**

Production Angle: 6 deg

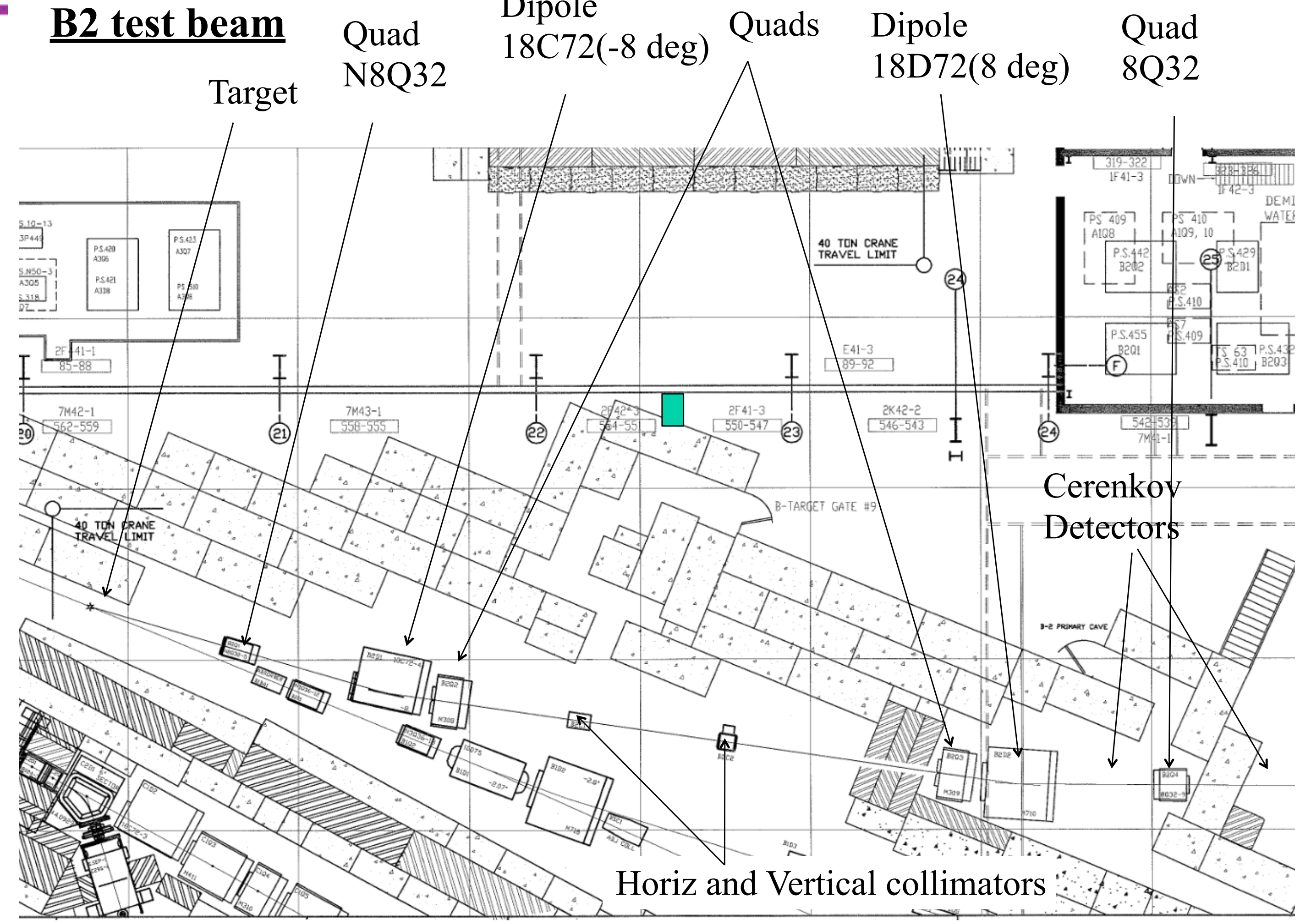
Flux (particles / 10^{13} protons): @ 4 GeV/c

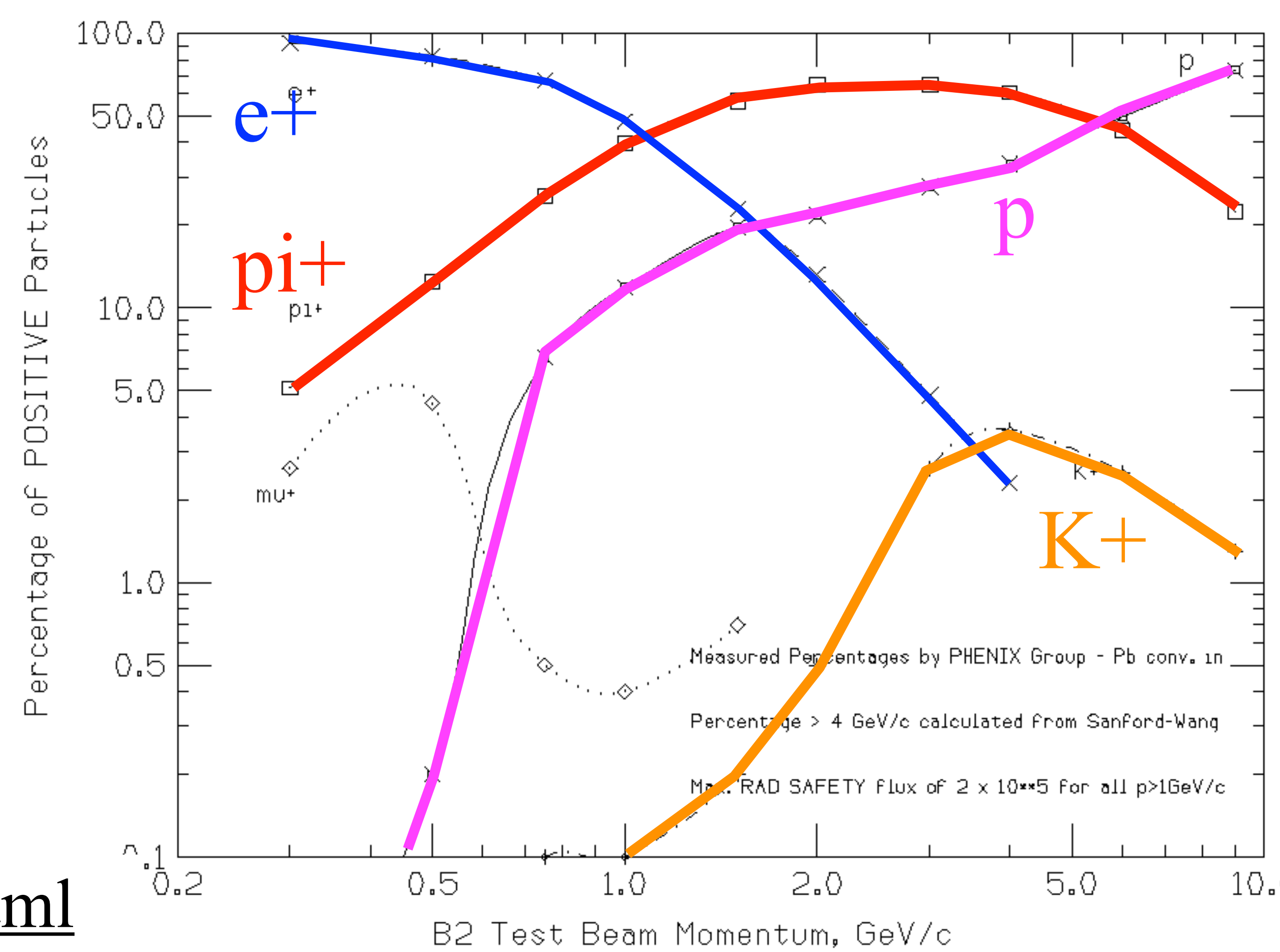
- **π^+ = 1.2×10^7 π^- = $.9 \times 10^7$**
- **p = 8.5×10^6 p = 9.5×10^4**
- **K^+ = 3.4×10^5 K^- = 1.2×10^5**
- **e^+ = 1×10^5 e^- = 1×10^6**
- **Limited to < 2×10^5 due to radiation safety issues**

Present Use:

General Purpose Test Beam – Available to All

beam size(1-9GeV/c): 7mm(H) x 2mm(V)





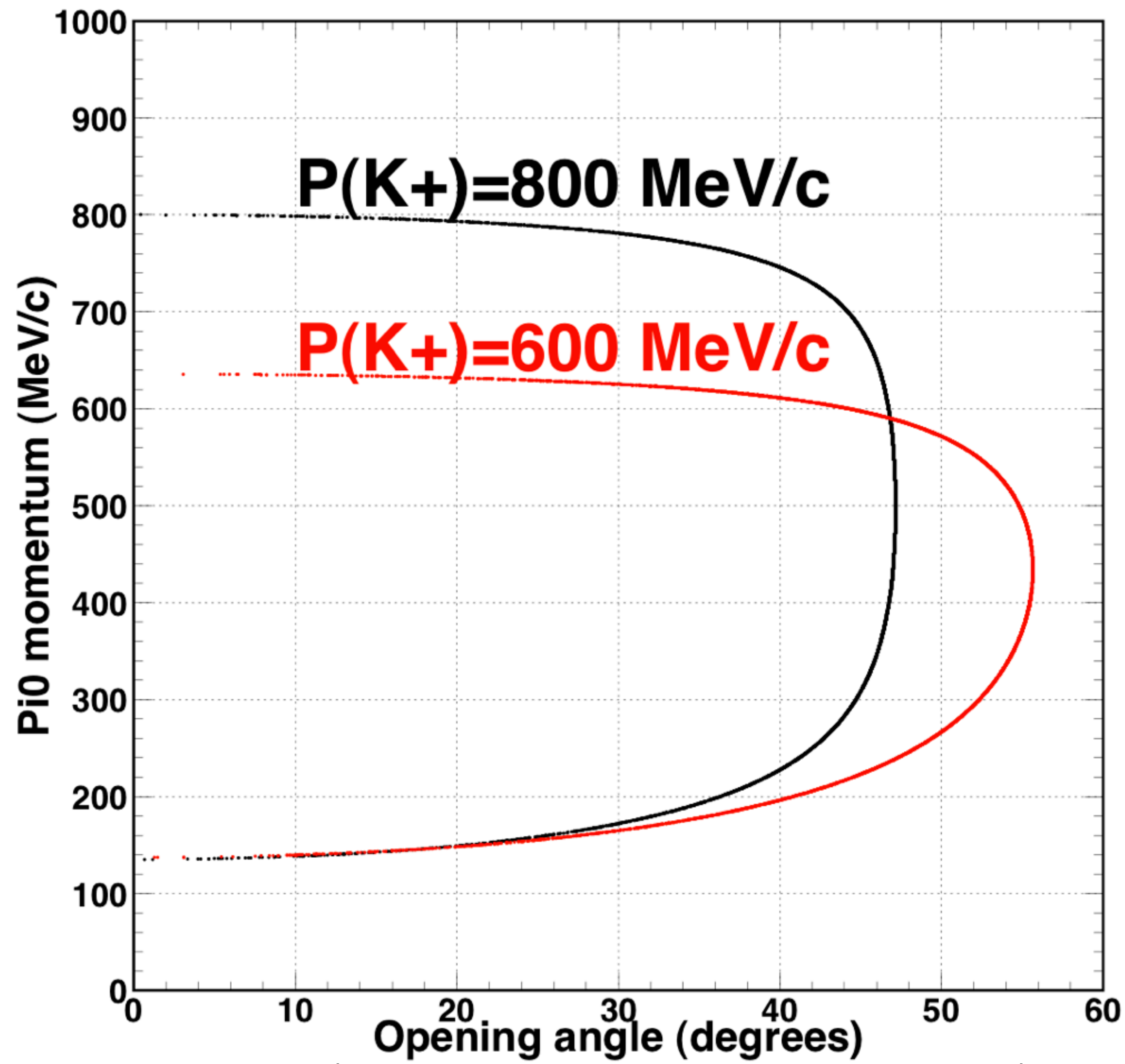
source: http://www.c-ad.bnl.gov/esfd/B2.html

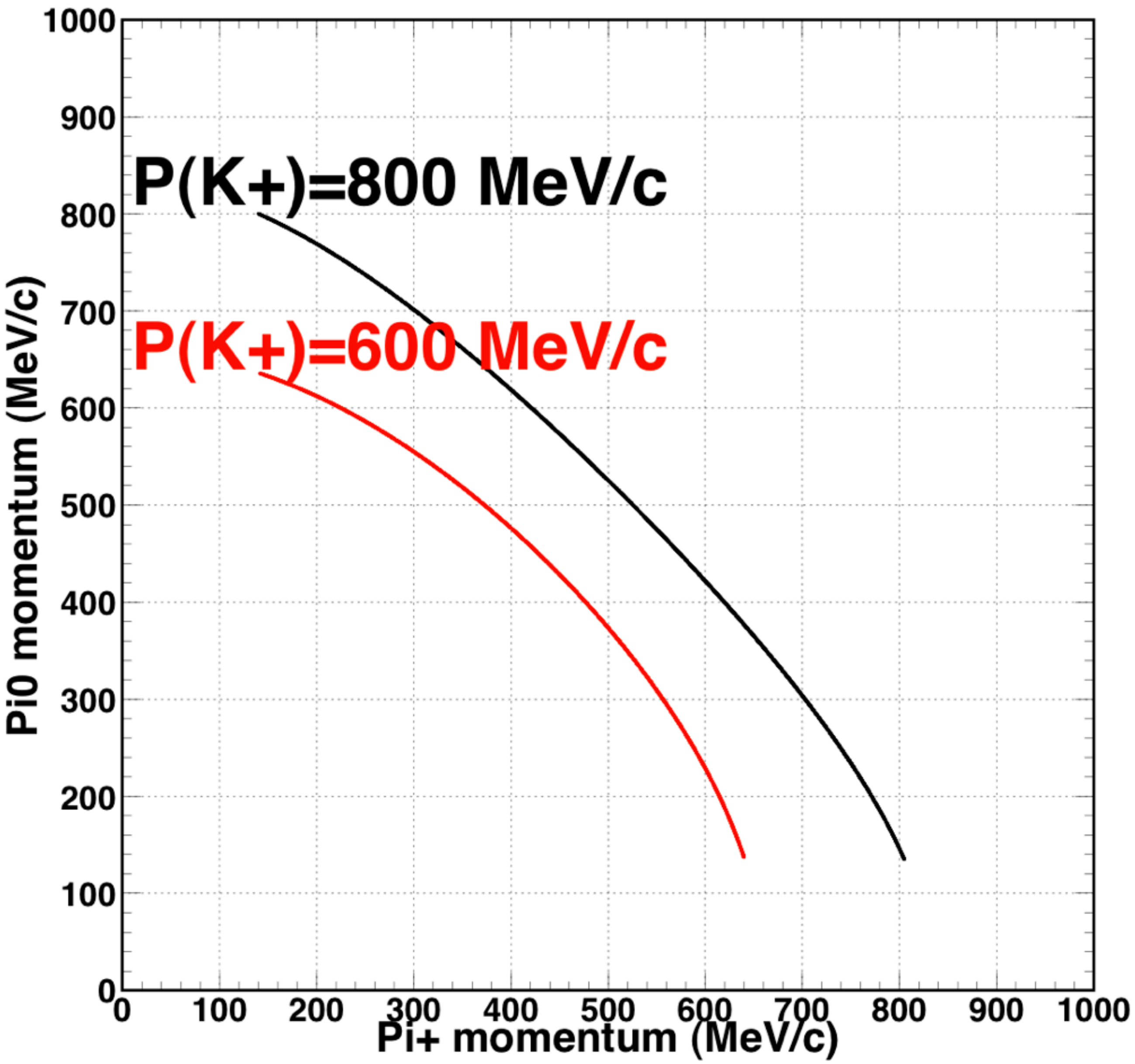
Utility of low momentum (<1GeV/c) K+ beam

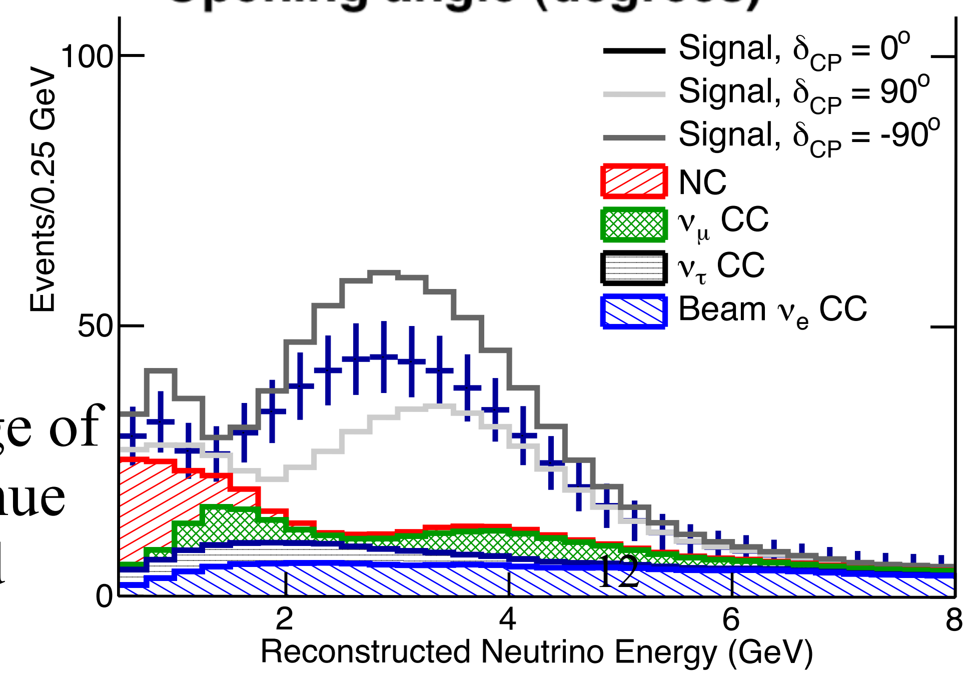
1. Directly address detection efficiency of K+ from proton decay in Liquid Argon TPC (LAr), Liquid Scintillator (LS) or Water-based Liquid Scintillator (WbLS) detectors
2. The "electronic bubble chamber" nature of a LAr detector offers the following potential capabilities
   - Stopped $K^+ \to \pi^+\pi^0$ (BR=21%) gives a monoenergetic 205 MeV/c pi0 beam
   - $K^+ \to \pi^+\pi^0$ decay-in-flight can provide tagged pi0 beams in a wider momentum range

K+ decays as pi0 beam

In LAr detector, the pi0 momentum can be determined from the pi+ range and (π^+, π^0) opening angle







Covers pi0 energy range of interest of nue background

Low energy K+ beam

1. Long and successful history of Low Energy Separated Beams (LESB) at BNL
2. An example, taken from a 1972 technical note, is shown on the next page.
3. Key parameters of interest:
    1. K+ per incident proton-on-target
    2. pi+/K+ ratio
    3. Estimated $K^+ \to \pi^+\pi^0$ decays in the detector
4. More modern LESB could likely have much better performance than the example from 1972

Low energy K+ beam properties

P(K+) MeV/c	600	800
$K^+/10^{12}$ POT	8K	40K
π/K	20	7
K+ range(LAr) cm	64	96
K+ range(H20) cm	90	134
K+ range(LS) cm	103	154
Decay rate(10cm)	2.3%	1.7%
Decay rate(100cm)	20.6%	15.9%
$K^+ \to \pi^+\pi^0/10^{12}$ POT (10cm)	38	140
$K^+ \to \pi^+\pi^0/10^{12}$ POT (100cm)	340	1314

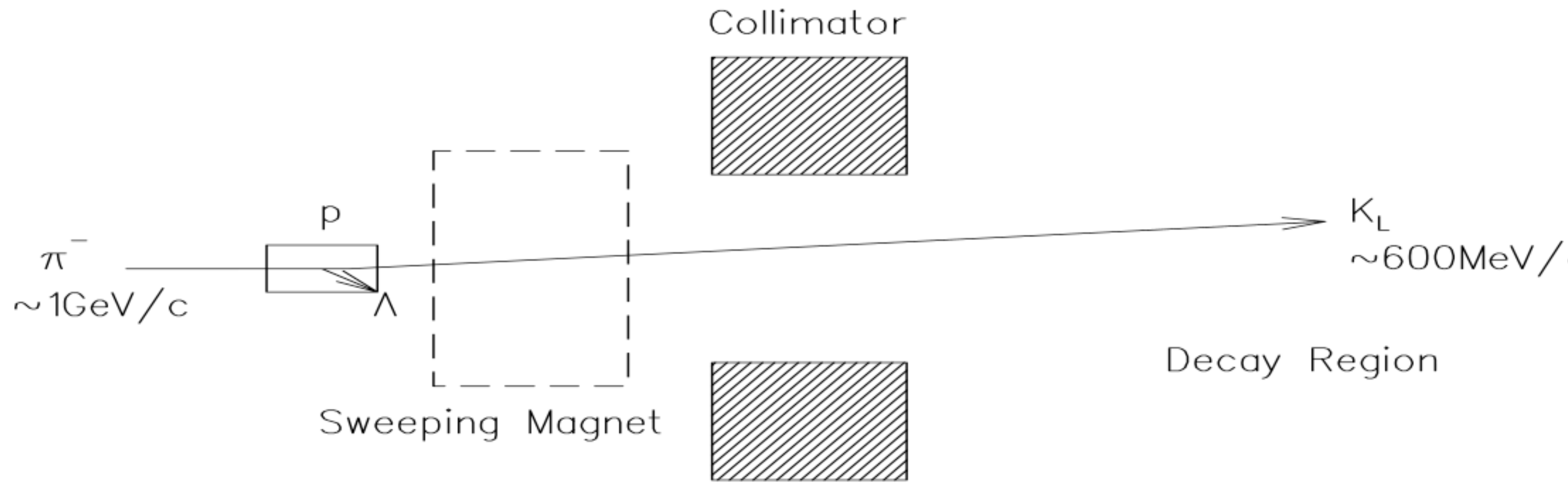
15m from target

Other properties:
K-/K+ ~ 1/3.
pbar/K+ ~ 1/40.
~1% momentum RMS

Significant number of decays to pi+,pi0

Source: "Some observed properties of the low energy separated beam", A.S.Carroll et al., EP&S Division Tech.Note#54, Nov.1,1972.

Tertiary K0L beam



1. utilize $\pi^- p \rightarrow K^0\Lambda$ (0.5-0.9 mb cross-section or about 0.3-0.9% of total cross-section) to produce tagged KL beam
   1. Prior use: $\sim 2\ K^0_L/\mathrm{spill}$ in LH2 bubble chamber for ~1GeV pi- beam at $10^7\pi^-/\mathrm{spill}$ on hydrogen target (Engler et al, PRD18 (1978) 3061.)
   2. Estimated rate of ~6e-4 KL/pi- for nuclear target (A.Konaka, TRIUMF)
2. requires magnet to remove un-interacted beam, charged secondaries
3. Bunched pi- beam enables time-of-flight measurement to measure K0L momentum and separate from gammas, neutrons
4. Energy of tagged K0L covers proton decay background range

Summary

1. ``Standard'' test beam
   1. Duplicates some of FNAL test beam capability
   2. Duty factor @ BNL affected by RHIC, but not neutrino running
   3. $6M FY05 guesstimate (Phil Pile)
2. Low energy K+ beam:
   1. Provides relatively copious and pure K+ beams <1GeV unavailable in ``standard'' test beam
   2. Enables "pi0 beam" for LAr detector
3. Tertiary K0L beam
   1. Would allow direct measurement of K0L decays and interactions in LAr, water, LS detectors

Thanks to Milind Diwan, Phil Pile and Jim Stewart for their assistance in preparing this presentation.

For comparison: FNAL test beam facility

1. 1 bunch/11.2microsec with 4.2s spill every 60 seconds
2. Secondary beam
   1. 8-32 GeV/c : pi+,pi-
   2. 10k-300k particles/spill
   3. beam spot size 1x1 cm2
3. Tertiary beam (8 GeV secondary pion beam)
   1. 200 - 1000 MeV/c
   2. beam spot: 10cm diameter
   3. >10 pi+-; >1 p,mu+-,e+-; >0.1K+- per spill
   4. dp/p <=5%

Source: Technical Scope of Work for LArIAT, Feb. 28, 2013