ORKA, The Golden Kaon Experiment: Precision Measurement of $K^+ \to \pi^+ \nu \bar{\nu}$

(Orcinus orca), Life of Sea blogspot

The ORKA Collaboration

Arizona State University USA, Brookhaven National Laboratory USA, Fermi National Accelerator Laboratory USA, Institute for Nuclear Research Russia, Joint Institute of Nuclear Research Dubna Russia, Istituto Nazionale di Fisica Nucleare Napoli Italy, Istituto Nazionale di Fisica Nucleare Pisa Italy, TRIUMF Vancouver British Columbia, Canada, University of British Columbia, Vancouver Canada, University of Texas at Austin, USA, University of Illinois, Urbana USA, University of Northern British Columbia Prince George Canada, Universidad Autonoma de San Luis Potosi Mexico, Universidad Nacional Autonoma de Mexico,Tsinghua University Beijing China

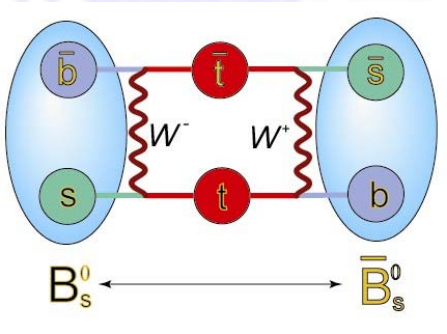
US High Energy Physics should be pursuing:

"Opportunities for paradigm changing scientific advances"

Paraphrased from Persis Drell's Key-Note Remarks at the Intensity Frontier Workshop December 2011

There is now an elite set of rare-decay opportunities that can deeply challenge the Flavor Problem

Why don't we see the *Terascale Physics we expect* affecting the flavor physics we study today??



The Most Promising Paradigm Changing Modes in Quark Flavor Physics

	$\nu\bar{\nu}$	$\ell^+\ell^-$	γ
$b \to s$	$B \to X_s \nu\bar{\nu}$	$B \to X_s \ell^+\ell^-$	$B \to X_s \gamma$
$(\sim \lambda^2)$	$B \to K^* \nu\bar{\nu}$	$B \to K^* \ell^+\ell^-$	$B \to K^* \gamma$
	$B \to K \nu\bar{\nu}$	$B \to K \ell^+\ell^-$	$B \to K \gamma$
		$B_s \to \mu^+\mu^-$	
$b \to d$	$B \to X_d \nu\bar{\nu}$	$B \to X_d \ell^+\ell^-$	$B \to X_d \gamma$
$(\sim \lambda^3)$		$B_d \to \mu^+\mu^-$	
$s \to d$	$K_L \to \pi^0 \nu\bar{\nu}$	$K_L \to \pi^0 \ell^+\ell^-$	
$(\sim \lambda^5)$	$K^+ \to \pi^+ \nu\bar{\nu}$	$K_L \to \ell^+\ell^-$	

Table 1: (Incomplete) list of theoretically interesting and experimentally promising rare semileptonic and radiative B and K decays. The approximate CKM suppression within the SM is indicated in the leftmost column in terms of the Wolfenstein parameter λ.

Straub, CKM 2010 workshop (arXiv:1012.3893v2)

Buras et al "DNA"grades for Flavor models

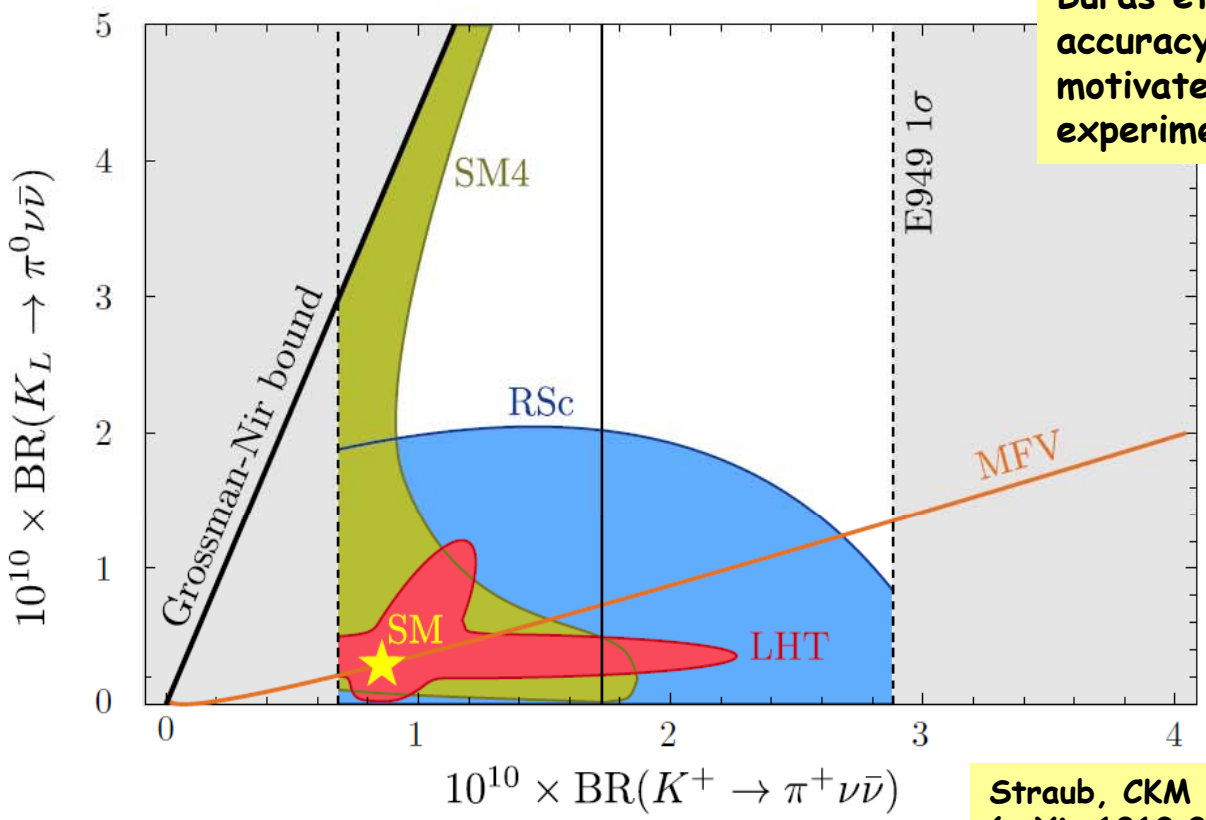
	LHT	RSc	4G	2HDM	RHMFV
$D^0 - \bar{D}^0$ (CPV)	★★★	★★★	★★	★★	
ϵ_K	★★	★★★	★★	★★	★★
$S_{\psi\phi}$	★★★	★★★	★★★	★★★	★★★
$S_{\phi K_S}$	★	★	★★		
$A_{\rm CP}(B \to X_s\gamma)$	★		★		
$A_{7,8}(K^*\mu^+\mu^-)$	★★	★	★★		
$B_s \to \mu^+\mu^-$	★	★	★★★	★★★	★★
$K^+ \to \pi^+\nu\bar{\nu}$	★★★	★★★	★★★		★★
$K_L \to \pi^0\nu\bar{\nu}$	★★★	★★★	★★★		★★
$\mu \to e\gamma$	★★★	★★★	★★★		
$\tau \to \mu\gamma$	★★★	★★★	★★★		
$\mu + N \to e + N$	★★★	★★★	★★★		
d_n	★	★★★	★	★★★	
d_e	★	★★★	★	★★★	
$(g-2)_\mu$	★	★★	★		

Table 3. "DNA" of flavour physics effects for the most interesting observables in a selection of non-SUSY models. ★★★ signals large NP effects, ★★ moderate to small NP effects and ★ implies that the given model does not predict visible NP effects in that observable. Empty spaces reflect my present ignorance about the given entry.

A. Buras, arXiv:1012.1447v2

Rare processes sensitive to new physics… Warped Extra Dimensions as a Theory of Flavor??

Buras et al. SM accuracy of <5%, motivates 1000-event experiments

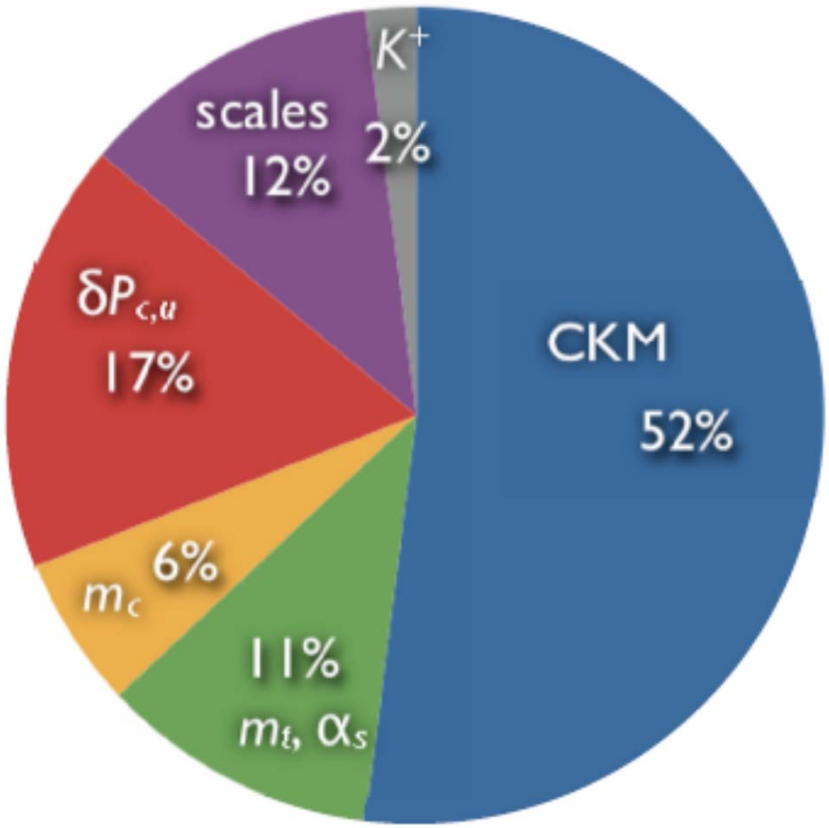


Straub, CKM 2010 workshop (arXiv:1012.3893v2)

Figure 1: Correlation between the branching ratios of $K_L \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$ in MFV and three concrete NP models. The gray area is ruled out experimentally or model-independently by the GN bound. The SM point is marked by a star.

Summary of SM Theory Uncertainties

CKM parameter uncertainties dominate the error budget today.



With foreseeable improvements, expect total SM theory error ≤6%.

A. Kronfeld

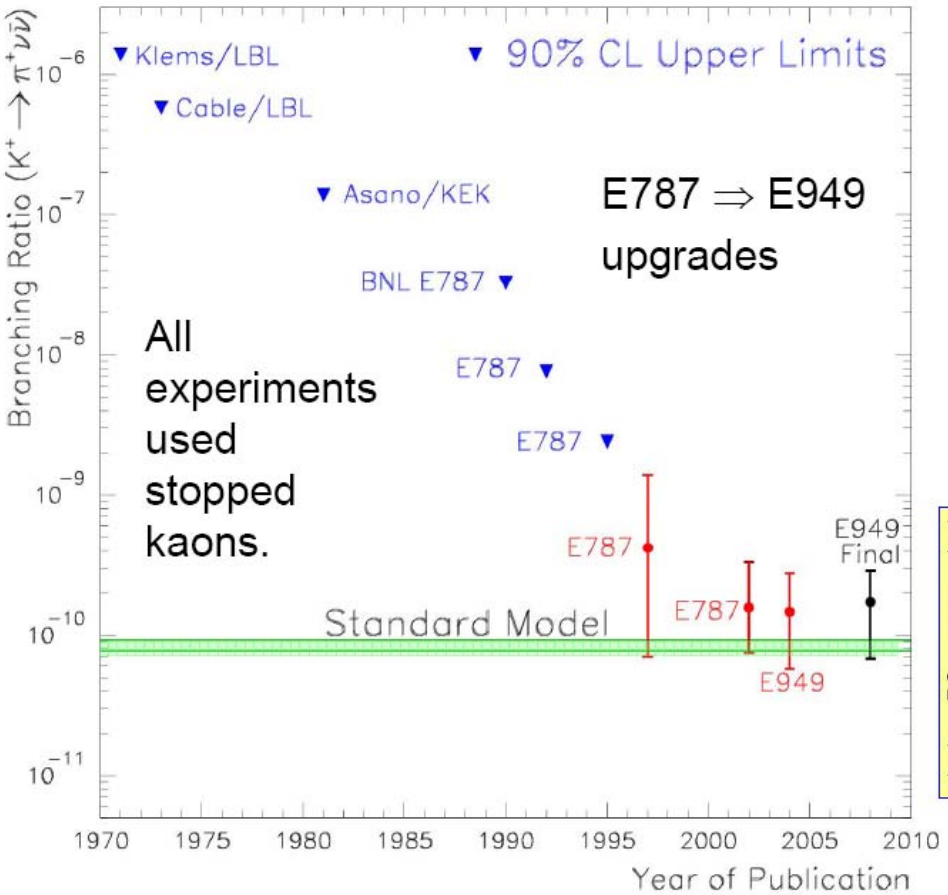
Unmatched by any other FCNC process (K or B).

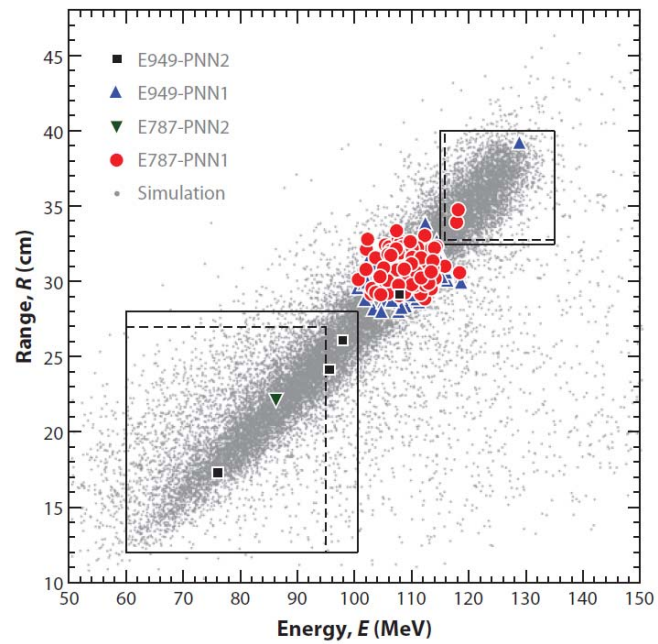
30% deviation from the SM would be a 5σ signal of NP

SM theory error for $K_L^0 \to \pi^0 \nu\bar{\nu}$ mode exceeds that for $K^+ \to \pi^+ \nu\bar{\nu}$.

U. Haisch, arXiv:0707.3098

$K^+ \to \pi^+ \nu\bar{\nu}$ History





E787/E949 Final: 7 events observed

$B(K^+ \to \pi^+ \nu\bar{\nu}) = 1.73^{+1.15}_{-1.05} x10^{-10}$

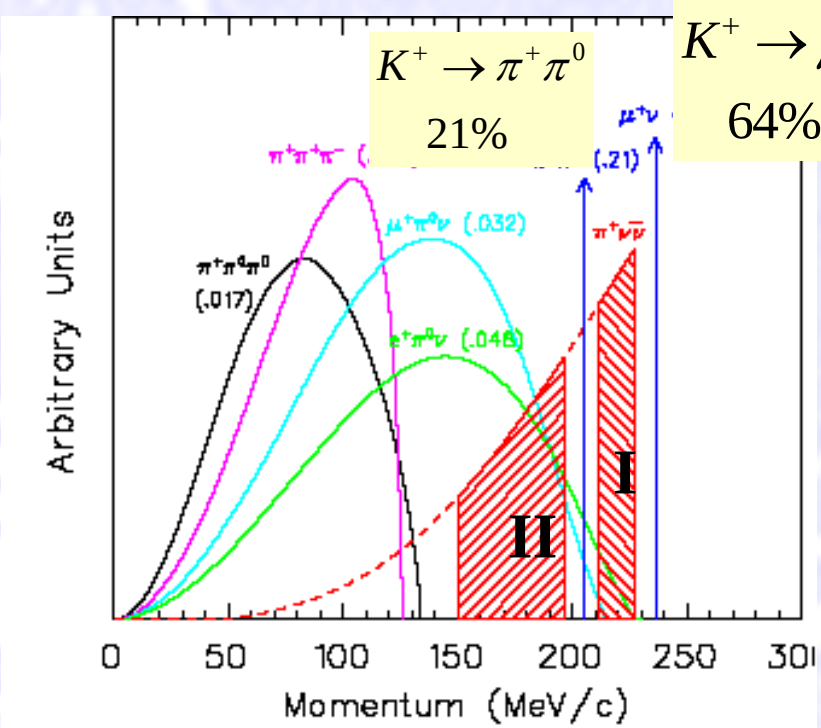
Standard Model:

$B(K^+ \to \pi^+ \nu\bar{\nu}) =$ (0.78+-0.09) $x10^{-10}$

Special Features of Measuring

$$K^+ \to \pi^+ \nu \bar{\nu}$$

Experimentally weak signature with background processes exceeding signal by >10^{10}



Determine everything possible about the K^+ and π^+

* π^+ / μ^+ particle ID better than 10^6 (π^+ - μ^+ - e^+)

Eliminate events with extra charged particles or ***photons***

* π^0 inefficiency < 10^{-6}

Suppress backgrounds well below the expected signal (S/N~10)

* Predict backgrounds *from data*: dual independent cuts
* Use "Blind analysis" techniques
* Test predictions with outside-the-signal-region measurements

Evaluate candidate events with S/N function

The BNL E787/E949 stopped kaon technique

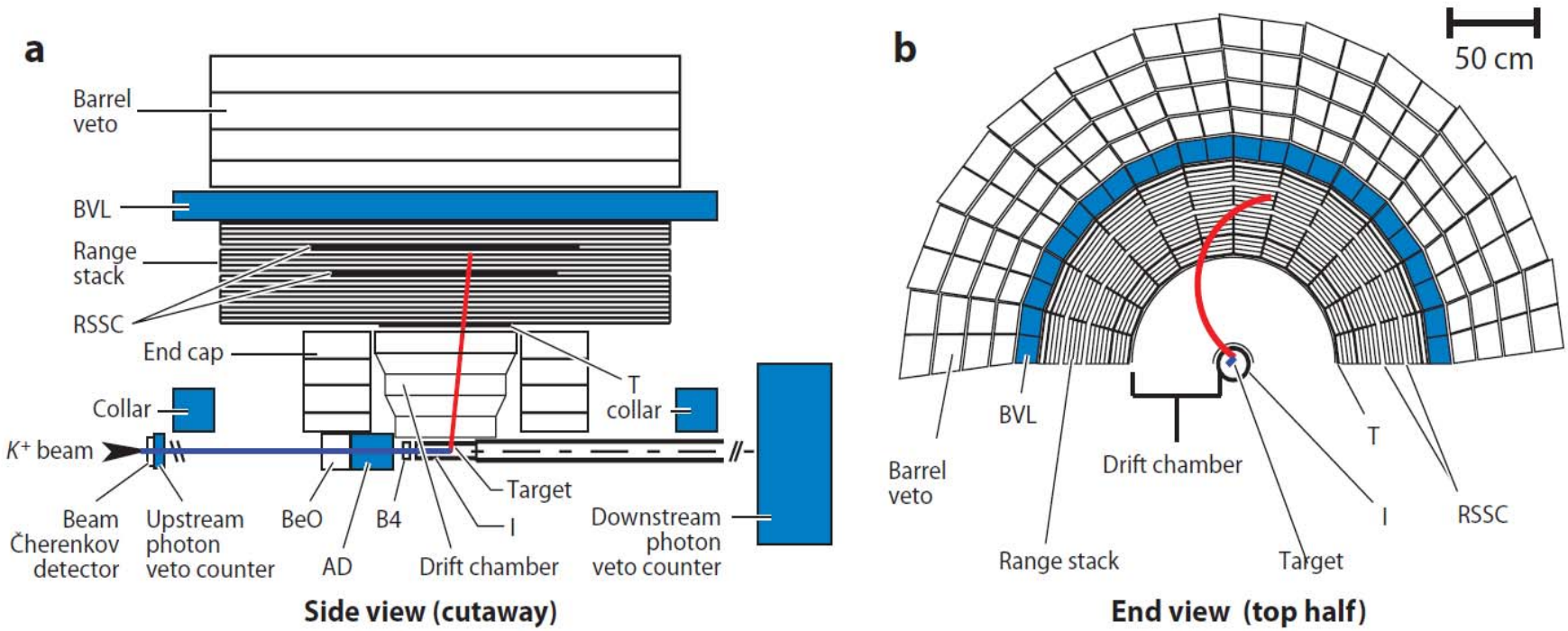
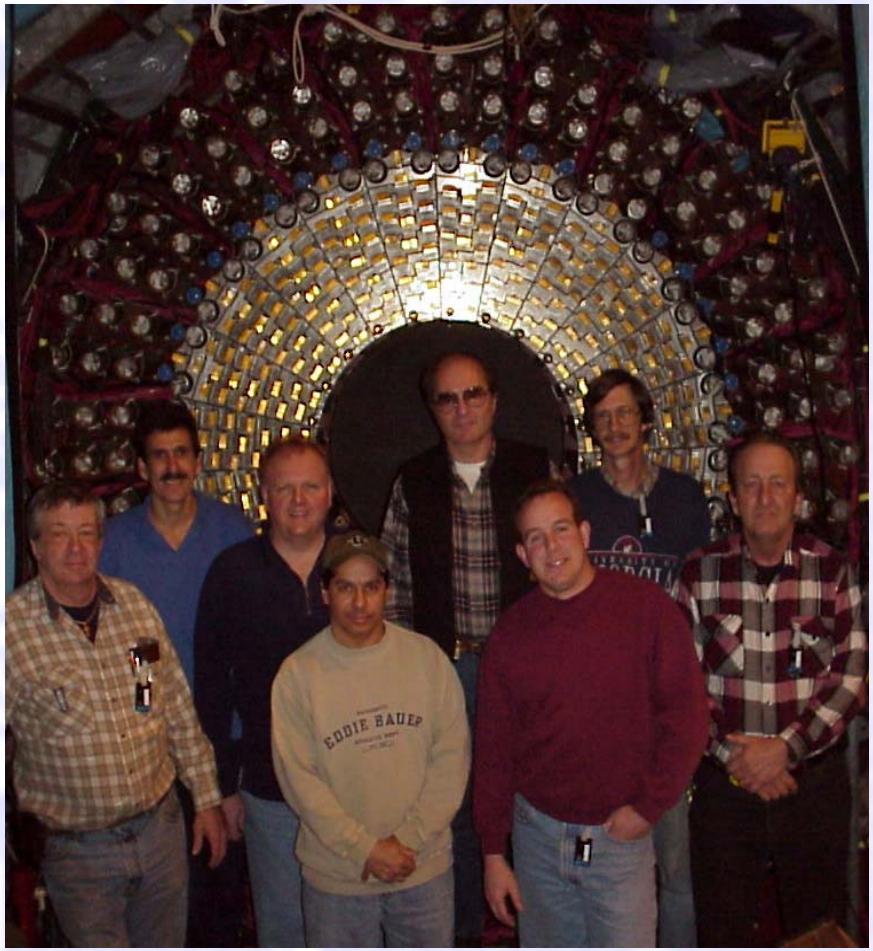


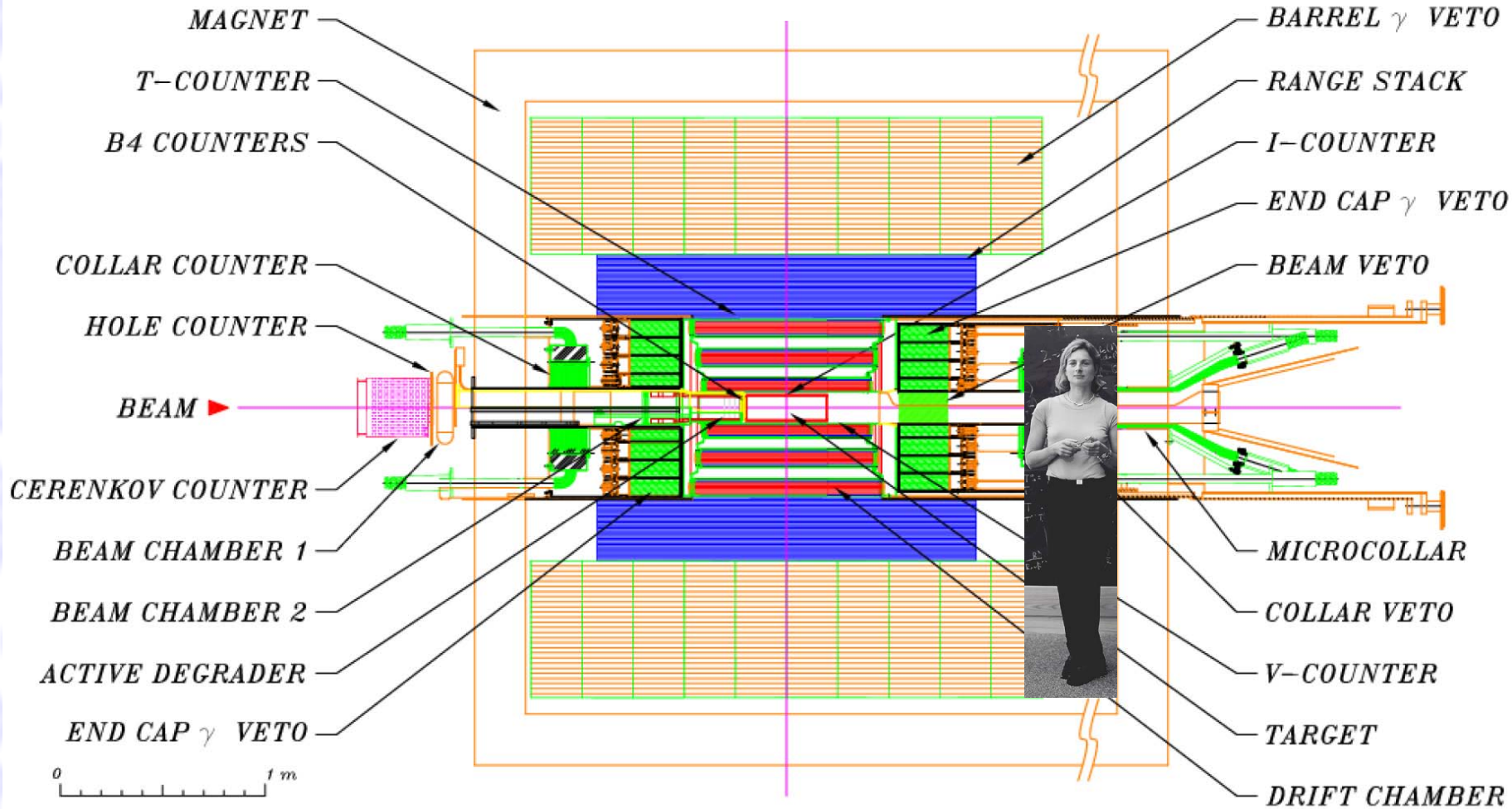
Figure 1

Elevation side view and end view schematic of the BNL E787 and E949 technique. (*a*) The 700-MeV/*c* K^+ beam enters from the left. (*b*) The stopped K^+ decays in the stopping target, and the subsequent decay π^+ track is momentum-analyzed by the tracker. The decay π^+ then stops in the range stack, where its range and energy are measured. The range stack STRAW chamber (RSSC) measures the position of the putative charged pion with the range stack. The barrel veto liner (BVL) is an upgrade of photon veto performance in E949 and E787. Abbreviations: AD, active degrader; DPV, UPV.

The Range Stack measures the π^+ energy, range, and progeny. BNL implementation based on 1980's technology…Ripe for upgrade.



Evolution to 4th Generation Detector

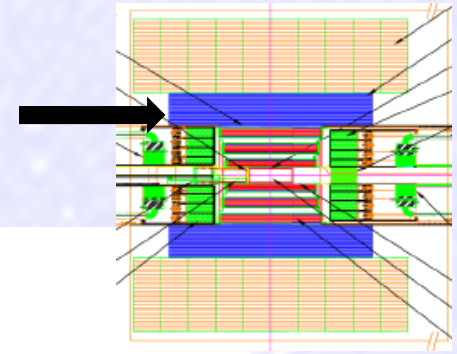


ORKA Detector Improvements

Incremental increases in signal acceptance based largely on E787/E949 measurements.

Component	Acceptance factor
$\pi \to \mu \to e$	2.24 ± 0.07
Deadtimeless DAQ	1.35
Larger solid angle	1.38
1.25-T B field	1.12 ± 0.05
Range stack segmentation	1.12 ± 0.06
Photon veto	$1.65^{+0.39}_{-0.18}$
Improved target	1.06 ± 0.06
Macro-efficiency	1.11 ± 0.07
Delayed coincidence	1.11 ± 0.05
Product (R_{acc})	$11.28^{+3.25}_{-2.22}$

Additional acceptance gains expected from trigger improvements.



$\pi \rightarrow \mu \rightarrow e$ Acceptance Factors

1. Identify range stack counter where π^+ stops
2. Detect $\pi \rightarrow \mu$ decay in stopping counter
3. Detect $\mu \rightarrow e$ in stopping counter and neighboring counters

Quantity	Acceptance	Range
π decay	0.8734	(3,105) ns
μ decay	0.9450	(0.1,10) μs
μ escape	0.98	
e^+ detection	0.97 ± 0.03	
Product	0.78 ± 0.02	
E949 acceptance	0.35	
Improvement factor	2.24 ± 0.07	

Detector Improvements and $\pi \to \mu \to e$ Acceptance

1. Eliminate 4x multiplexing of range stack (RS) waveform digitizers used in E949.
   - Reduced loss due to accidentals
2. E949 RS: 19 layers (1.9cm thick), 24 azimuthal sectors.
   ORKA RS: 30 layers (0.95cm thick), 48 sectors.
   - Reduced accidental veto loss (μ^+ and e^+)
   - Improved discrimination of π and μ
3. Increased RS scintillator light yield by higher QE photodetectors and/or better optical coupling.
   - Improved μ identification
4. Deadtime-less DAQ and trigger: $\pi \to \mu \to e$ acceptance improvements; rudimentary $\pi \to \mu$ identification was an essential component of the $K^+ \to \pi^+ \nu \bar{\nu}$ trigger in E787/E949.

Livetime and Delayed-Coincidence Acceptance

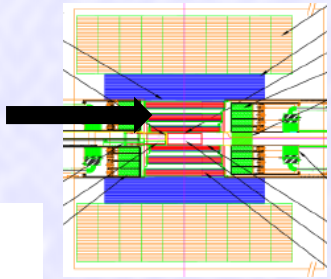
Livetime	
E949 livetime	0.74
ORKA estimate	1.00
Acceptance increase	1.35

Macro-efficiency	
E949 average	0.76
E949 best week	0.84
MiniBooNE (FY08)	0.85
ORKA estimate	0.85 ± 0.05
Acceptance increase	1.11 ± 0.07

E949 required a delayed coincidence of 2 ns between the stopped kaon and the outgoing pion to suppress prompt backgrounds.

Delayed coincidence	
E949 acceptance	0.763
ORKA estimate	0.851 ± 0.035
Acceptance increase	1.11 ± 0.05

Improved Momentum and Range Resolution and Increased Solid Angle

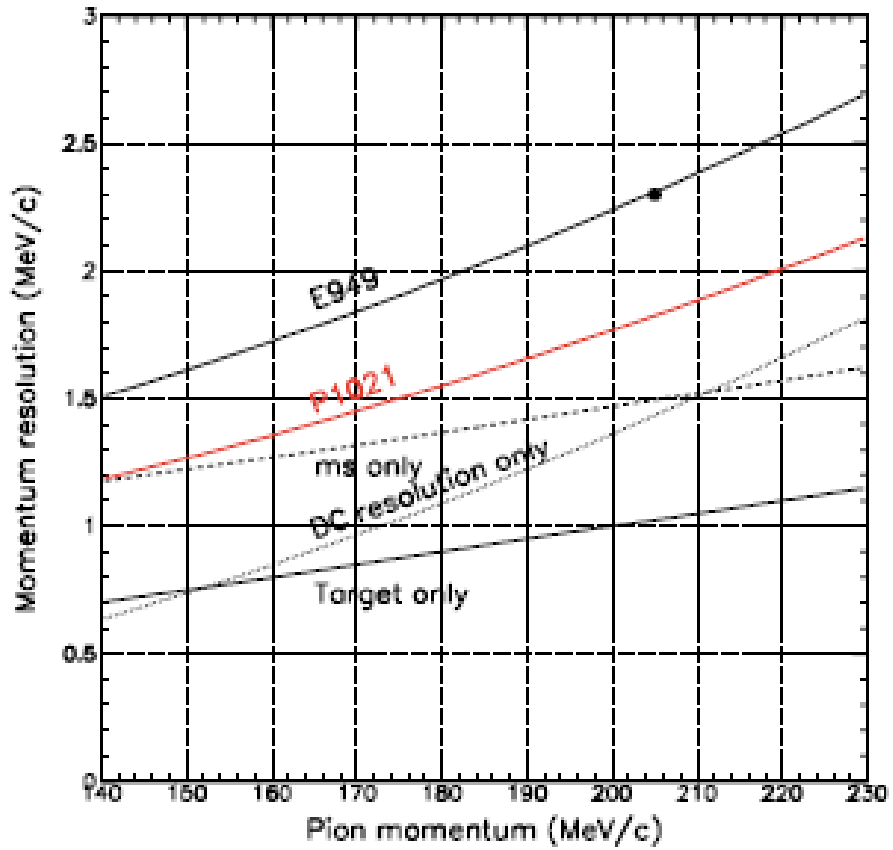


ORKA /E949 momentum resolution
Acceptance increase

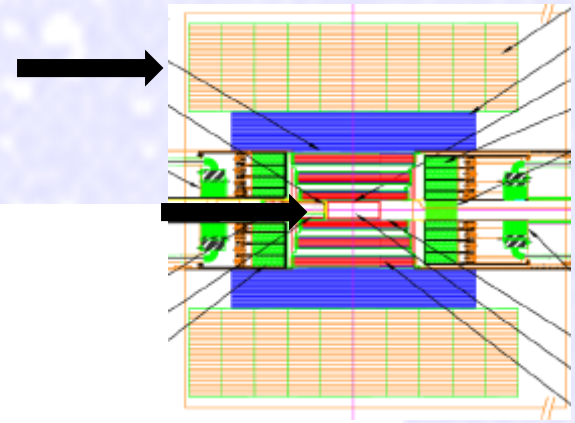
ORKA /E949 range resolution
Acceptance increase

E949/E787 energy resolution
Acceptance increase

	Solid ang
	Drift chamber
E949	50.8
ORKA	84.7
Acceptance increase	1.38



Photon Veto and Target Improvements



Photon veto	
E949	17.3 radiation lengths
ORKA	23.0 radiation lengths
Acceptance increase	$1.65^{+0.39}_{-0.18}$

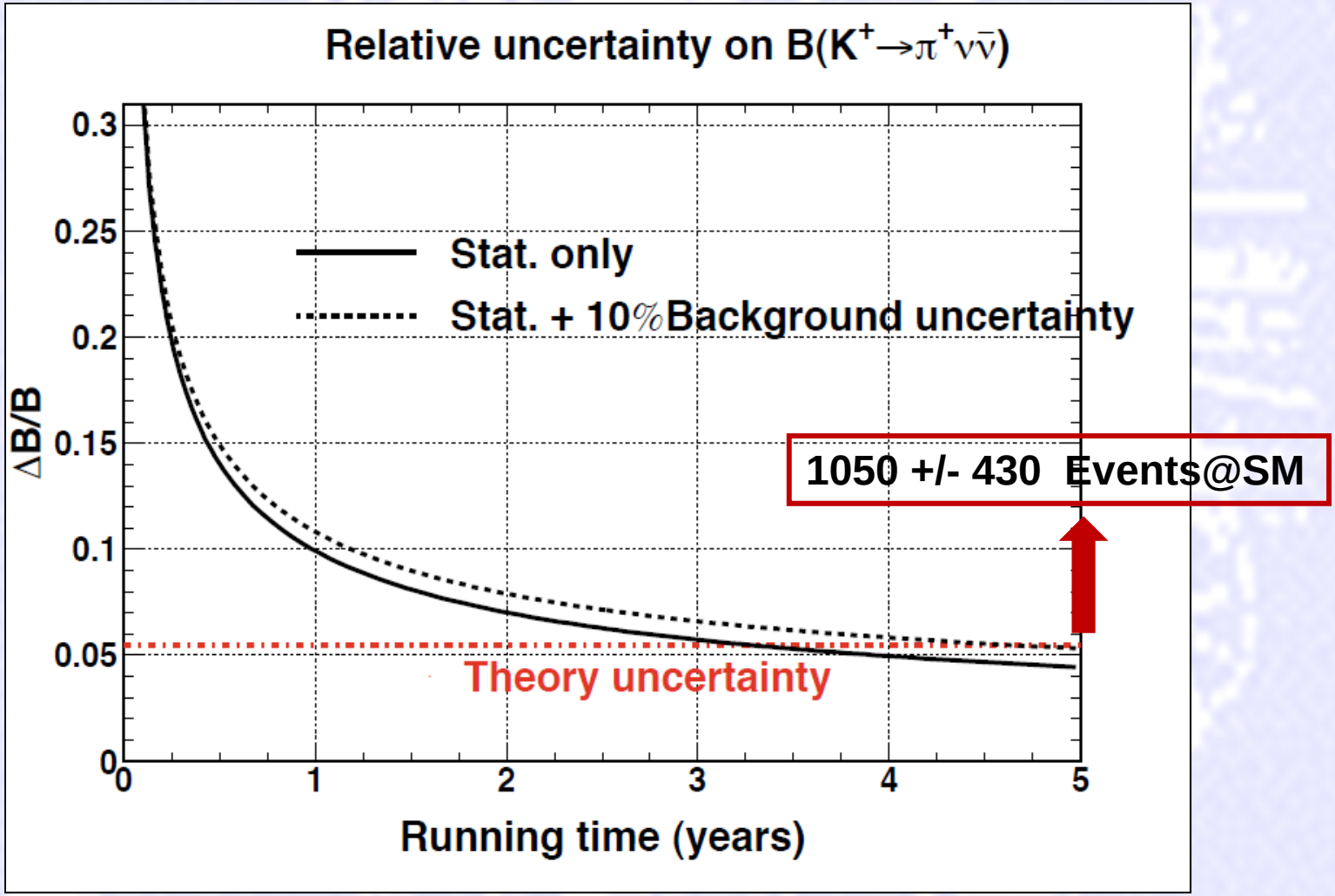
Estimated increase taken from simulated KOPIO PV performance. KOPIO simulation was adjusted to agree with E949 PV efficiency.

Target	
E949	3.1 m long, single-end readout
ORKA	1.0 m long, double-end readout
Acceptance increase	1.06 ± 0.06

Comparison of ORKA and BNL E949

	E949	**ORKA**
P_p (GeV/c)	21.5	95
Duty Factor (%)	41	44
P_K (MeV/c)	710	600
Fraction of kaons that stop in target (%)	21	54
Average rate of stopping kaons/s (10^6)	0.69	4.78
Accidental loss (%)	23	28
Events/yr (SM)	**1.3**	**210**

ORKA Sensitivity *vs.* Time



$K \rightarrow \pi \nu \bar{\nu}$…
Past, Present, Future

Facility (Experiment)	Proton Power	Kaon Decay/stop rate	Kaon Properties	$K \rightarrow \pi \nu \bar{\nu}$ Sensitivity
BNL AGS (E787/E949):	50kW	1×10^6 K^+/sec	Pure stopped K^+ source	7 events (charged)
CERN (NA62):	20kW	10×10^6 K^+/sec	Un-separated 1- GHz $K^+/\pi^+/p^+$ beam	80 events (charged)
Fermilab: (ORKA):	75kW	9×10^6 K^+/sec	Pure stopped K^+ source	1000 events (charged)
Project-X $K^+ \rightarrow \pi \nu \bar{\nu}$	1500 kW	100×10^6 K^+/sec	Pure stopped K^+ source	>1000 events (charged)
JPARC (KOTO):	<300 kW	$<0.5 \times 10^6$ K_L/sec	Pencil beam	1 event (neutral)
Project-X $K_L \rightarrow \pi \nu \bar{\nu}$	1500kW	50×10^6 K_L/sec	Pencil beam & Precision TOF	1000 events (neutral)

How?

How Much??

Proton Source: Main Injector

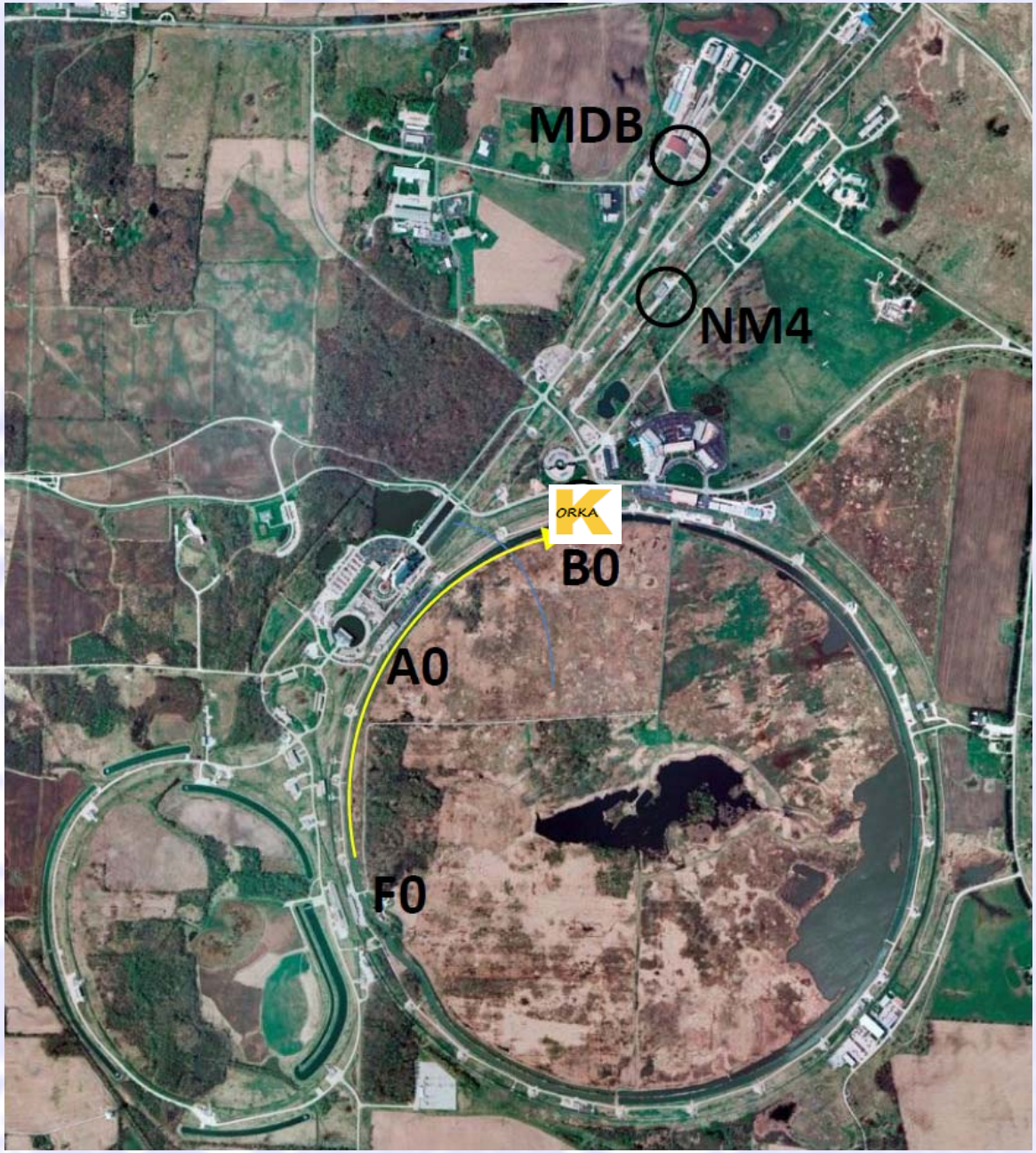
Table 4.1: Relationship between beam energy, cycle time, flattop, duty factor, and beam power with a 4800 A (rms) magnet power bus constraint. The proposed operating proton beam energy of 95 GeV is highlighted with bold face.

E_{beam}[GeV]	T_{cycle} [s]	t_{flattop}	Duty Factor [%]	P_{ave}[kW]	P_{max}[kW]
120	15	2.5	16	62	377
120	20	3.3	16	46	283
120	25	4.1	16	38	232
120	30	4.9	16	31	189
100	10	3.5	35	77	222
100	15	5.0	33	52	154
100	20	6.5	33	39	118
100	25	8.1	32	31	96
95	**10**	**4.4**	**44**	**74**	**166**
95	15	6.3	42	49	116
95	20	8.3	41	37	89
95	25	10.1	40	29	73
90	10	5.9	59	70	118
90	15	8.3	56	46	83
90	20	10.8	54	33	61
90	25	13.3	53	28	52

Sites considered:

- B0:
  - -Rad hard transport, requires A0 to B0 line.
  - -Resident magnet & cryo
  - -Infrastructure

- Sea-Quest/NM4/MDB:
  - -Existing beam transport, but not rad-hard.
  - -Infrastructure at NM4 but no cryo.



B0 Assets for ORKA

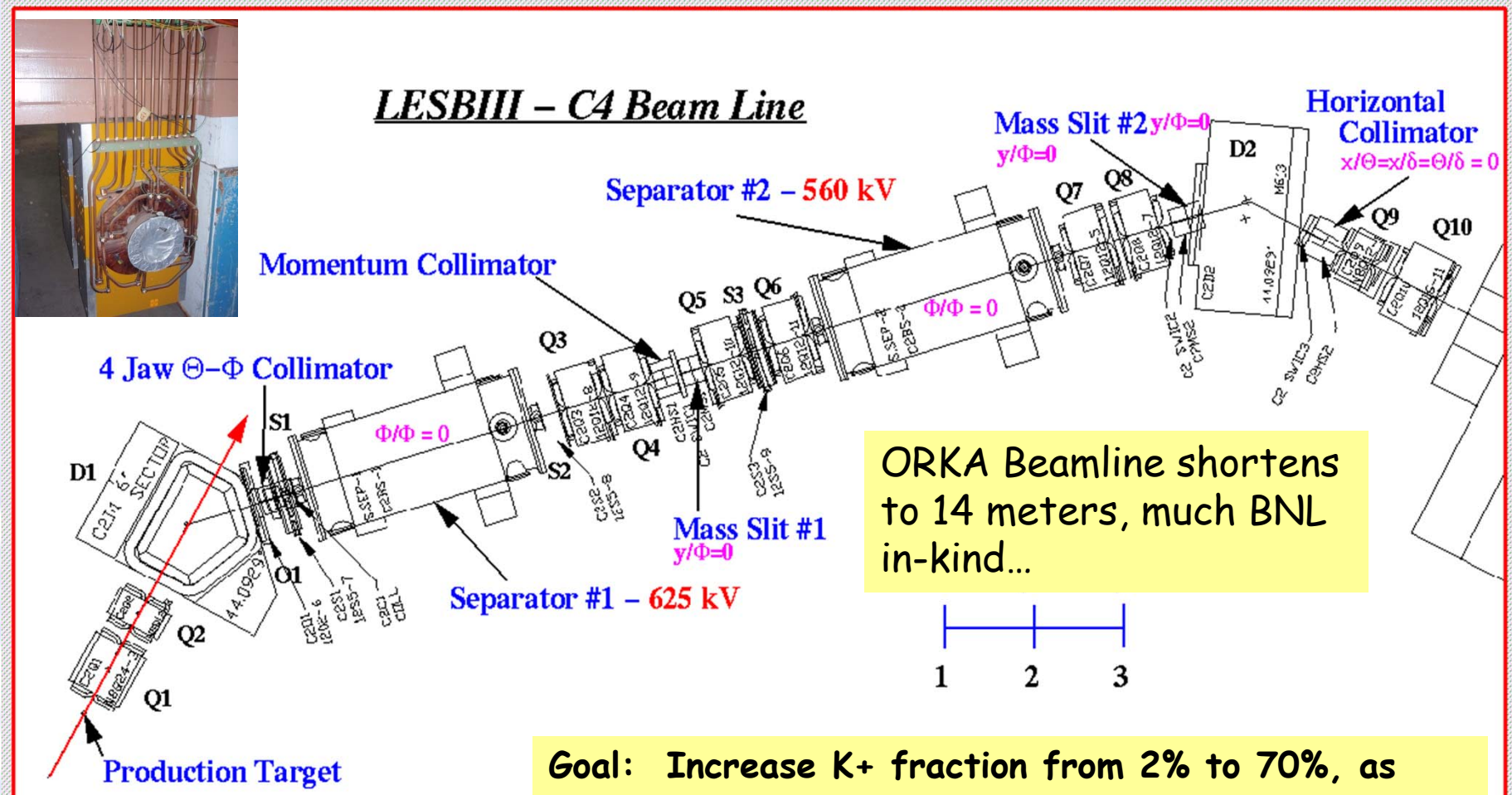
- Siting ORKA in the B0 collision hall requires no civil construction. Shielding that can manifestly support loss of a Main Injector pulse exists in the Tevatron tunnel. Sustained full losses must be studied.

- Existing Solenoid, yoke, cryo, and magnet systems.

- Infrastructure. Experiment would live in the collision hall, but some access to assembly hall infrastructure would be desirable. Cable bridge from assembly hall to collission hall is not required.

- Beam-line from A0 to B0 built from Main-Ring magnets must be built. Possible common cause with the Proton Wakefield initiative that is interested in an experiment with Main Injector beam driving the low-beta quad system now at B0.

K^+ Beamline: Focus a low energy separated charged beam on a stopping target. Measure kaon decays at rest!



ORKA Beamline shortens to 14 meters, much BNL in-kind…

Goal: Increase K+ fraction from 2% to 70%, as quickly as possible! Slow kaons are rapidly decaying.

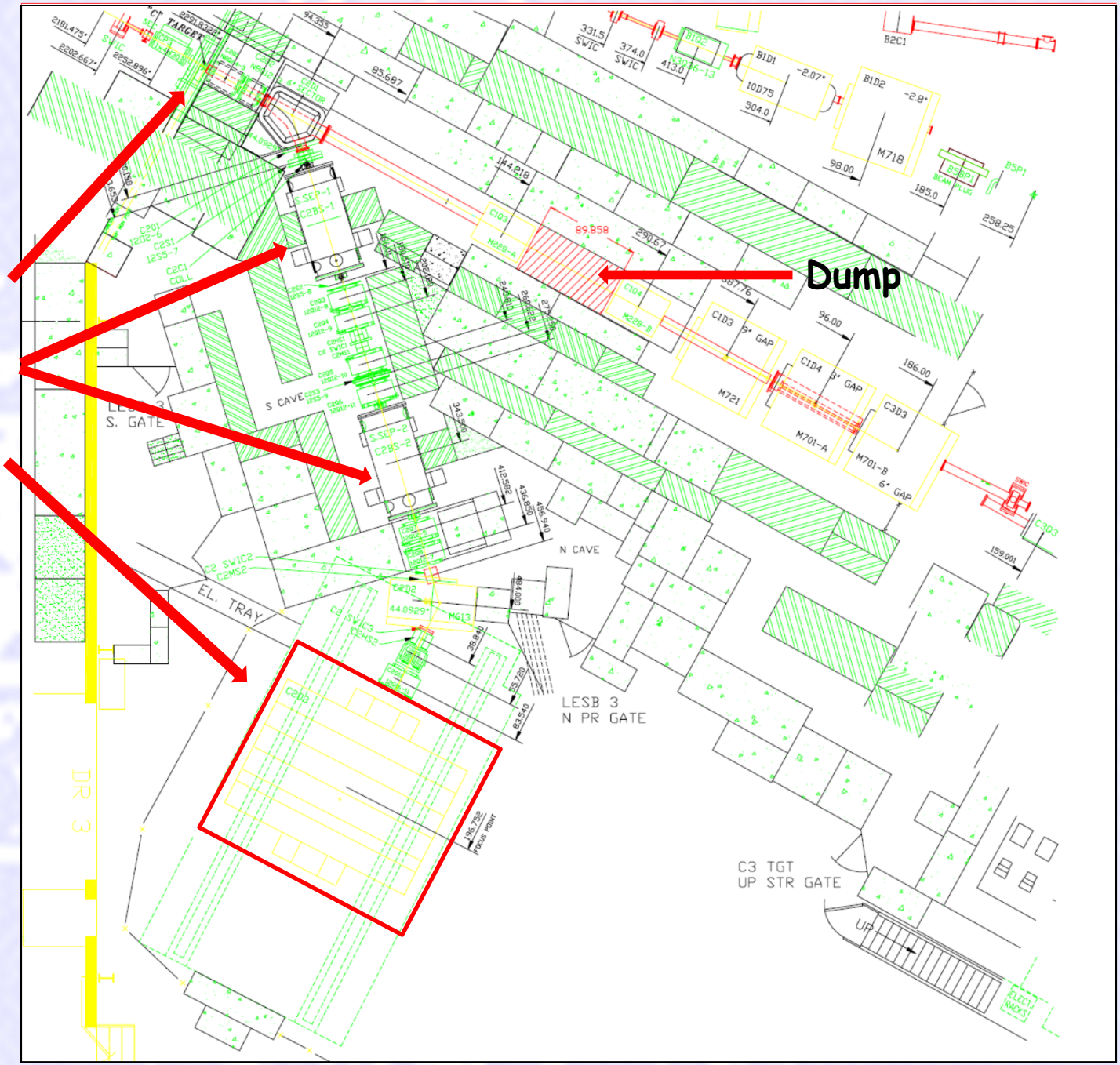
Siting of the E949 experiment at the BNL AGS operated at 50 kW

Target

ExB separators

Detector

Dump



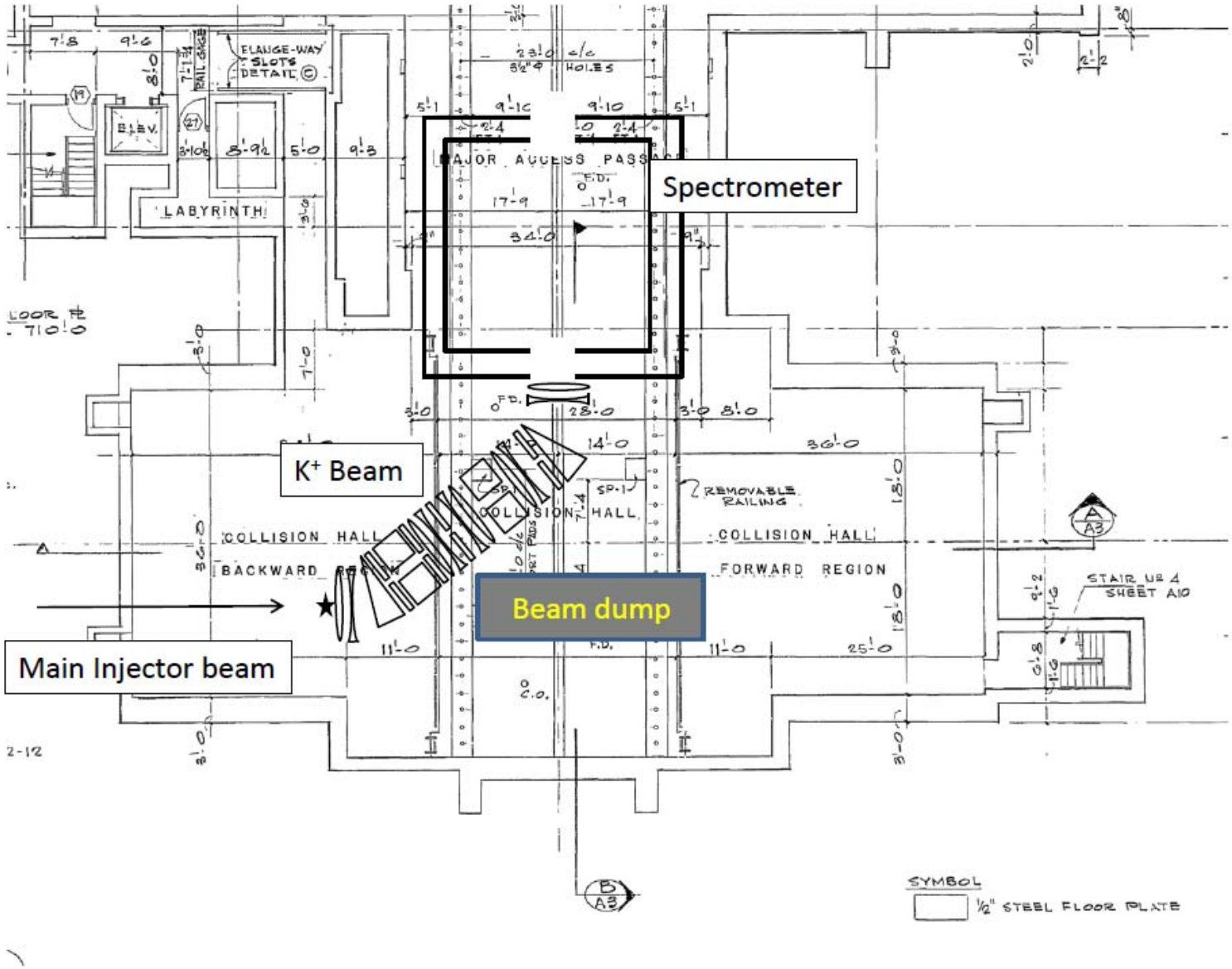
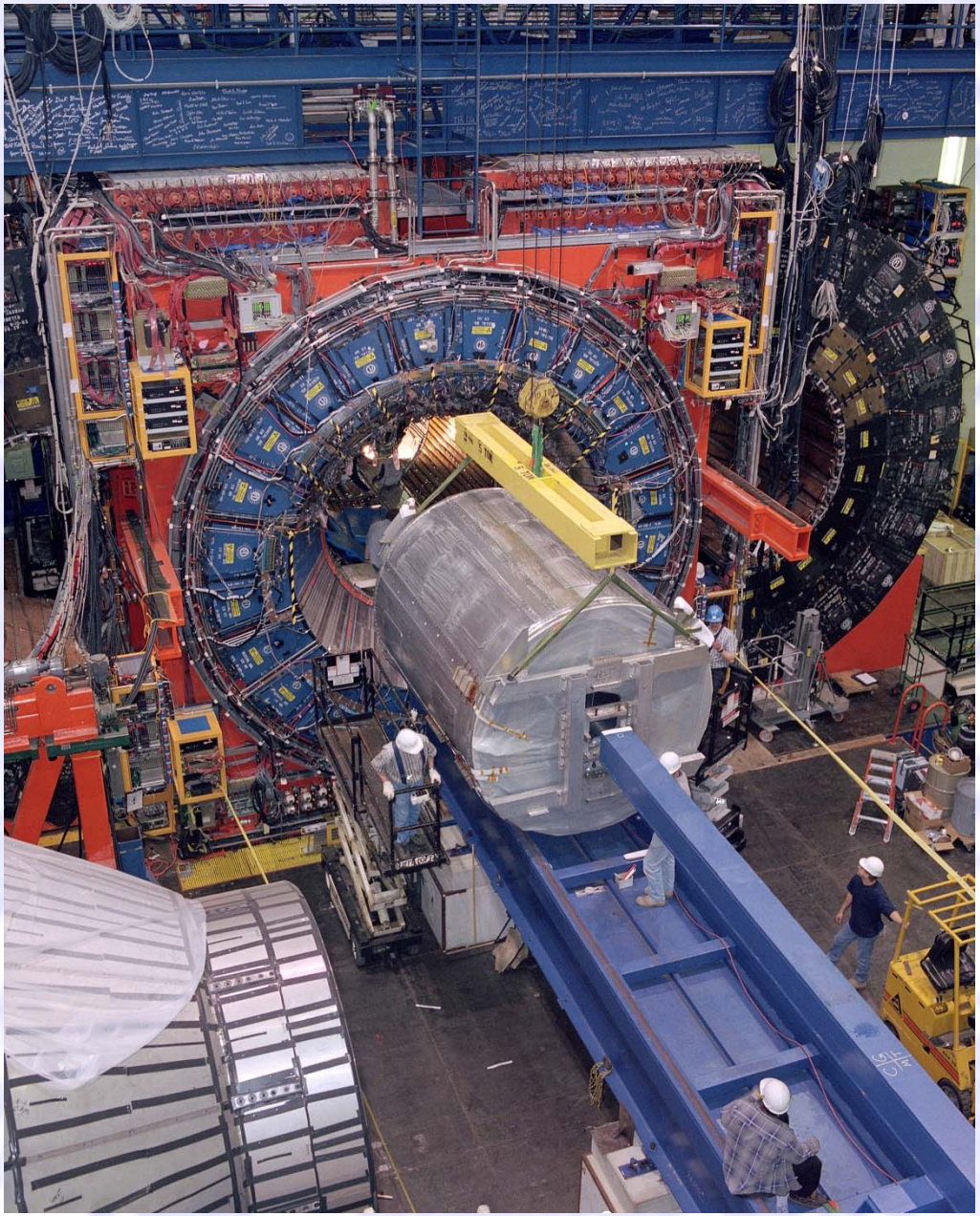
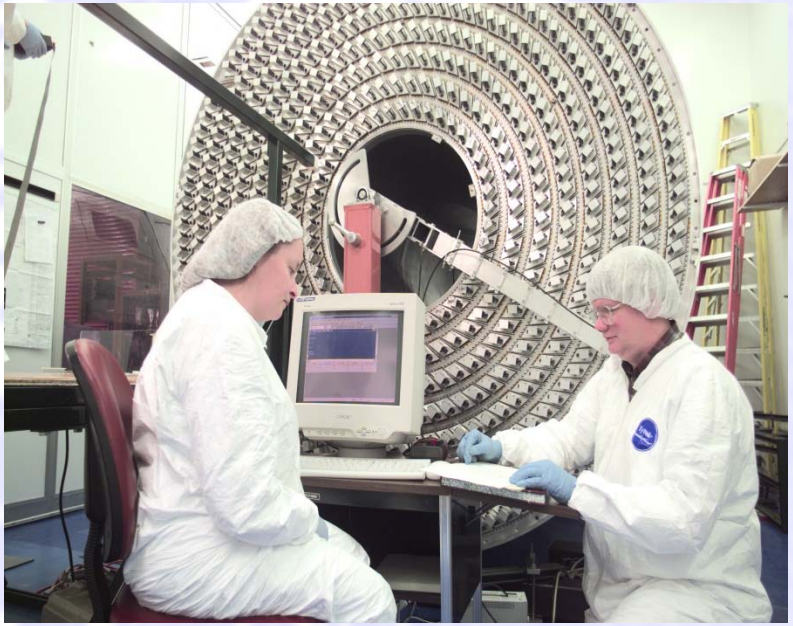


Figure 5.3: Illustration of the ORKA beam line and detector sited within the B0 collision hall.

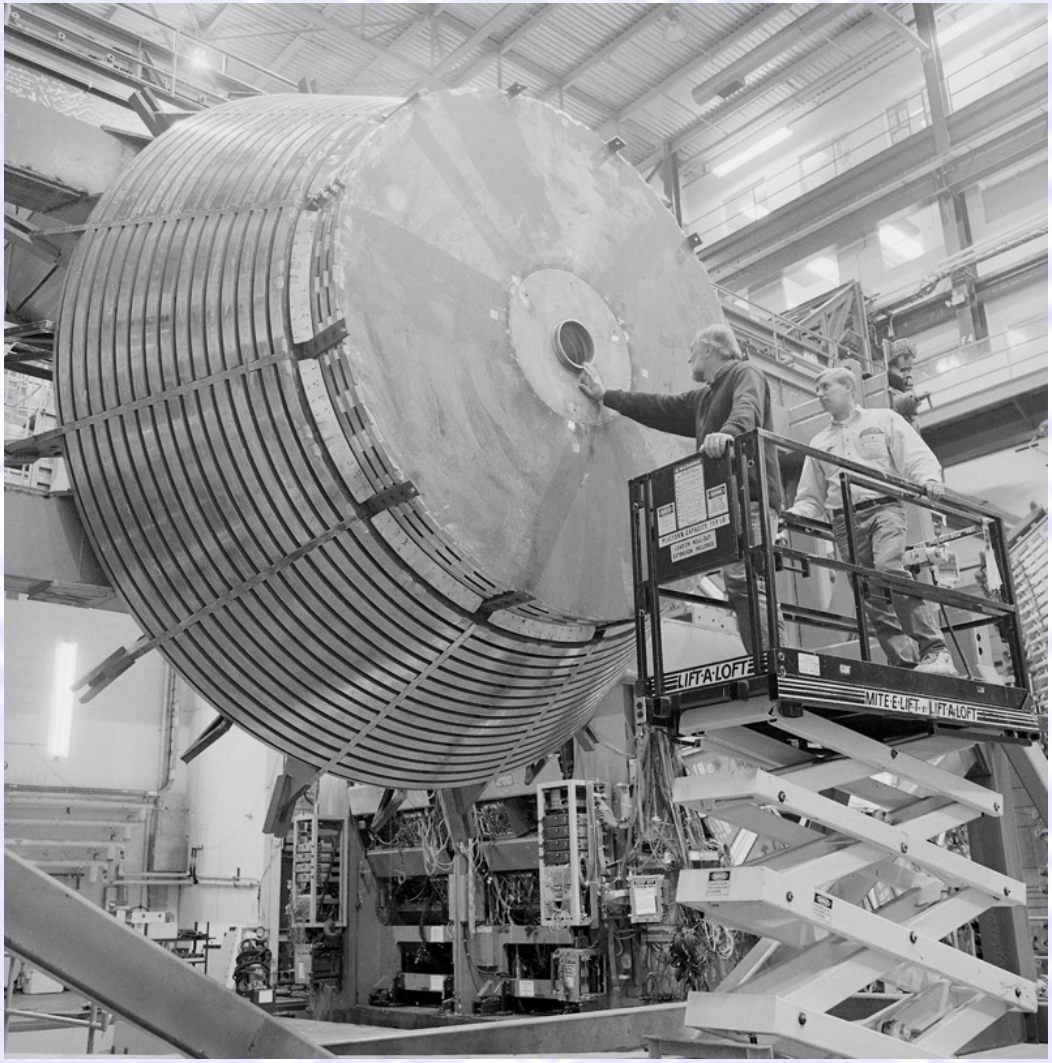


The ORKA new detector payload replaces the CDF tracker volume.



One Plug Must be modified to Transport kaon beam to the center of the CDF solenoid

Some Plug plates will be retained to Carry Magnetic Flux



Estimated Cost

Table 10.2: Estimated project cost. All costs in FY10 $k.

WBS element		Description	Total Cost	60% conting.	Total w/cont.
1.0		**TPC**	**$33M**	**$20M**	**$53M**
1.1		**Accelerator and Beams**	**7,510**	**4,490**	**12,000**
	1.1.1	A0 to B0 transport*	2,200	1,300	3,500
	1.1.2	Target and Dump	940	560	1,500
	1.1.3	Kaon Beam	4,370	2,630	7,000
1.2		**Detector**	**22,390**	**13,430**	**35,820**
	1.2.1	Spectrometer Magnet	500	300	800
	1.2.2	Beam and Target	600	360	960
	1.2.3	Drift Chamber	1,900	1,140	3,040
	1.2.4	Range Stack	2,500	1,500	4,000
	1.2.5	Photon Veto	3,000	1,800	4,800
	1.2.6	Electronics	4,000	2,400	6,400
	1.2.7	Trigger and DAQ	2,000	1,200	3,200
	1.2.8	Software and Computing†	2,000	1,200	3,200
	1.2.9	Installation and Integration	5,890	3,530	9,420
1.3		**Project Management**	**2,740**	**1,640**	**4,380**
1.4		**OPC**	**700**	**420**	**1,120**
	1.4.1	R&D	300	180	480
	1.4.2	Commissioning	400	240	640

* Candidate for off-project Accelerator Improvement Project (AIP) funding.
† Included here although there is no uniform practice to do so.

Plausible Schedule

Table 11.1: Our projected timescale for major milestones and activities. Dates refer to calendar year, not fiscal year.

Milestone/Activity	Time Period
Stage One Approval	Winter 2012
DOE Approval of Mission Need (CD-0)	Fall 2012
Beam/Detector Design	2012–2013
Approve Cost Range (CD-1)	early 2013
Baseline Review/CD-2	End of 2013
Start Construction (CD-3)	Spring 2014
Begin Installation	mid-2015
First Beam/Beam Tests	End of 2015
Complete Installation	Mid-2016
First Data (Start Operations/CD-4)	End of 2016

What about the Competition?

- The CERN NA62 experiment:

- Evolution of existing assets, new in-flight technique, strong group.

- Sensitivity goal: ~40 events/year.

- Development run in summer 2012 with SPS beam. First production run in 2014, only coincident with LHC ops, shares beam with CNGS.

- The JPARC KOTO experiment :

- KEK & FNAL/KTeV detector assets moved to JPARC, strong group.

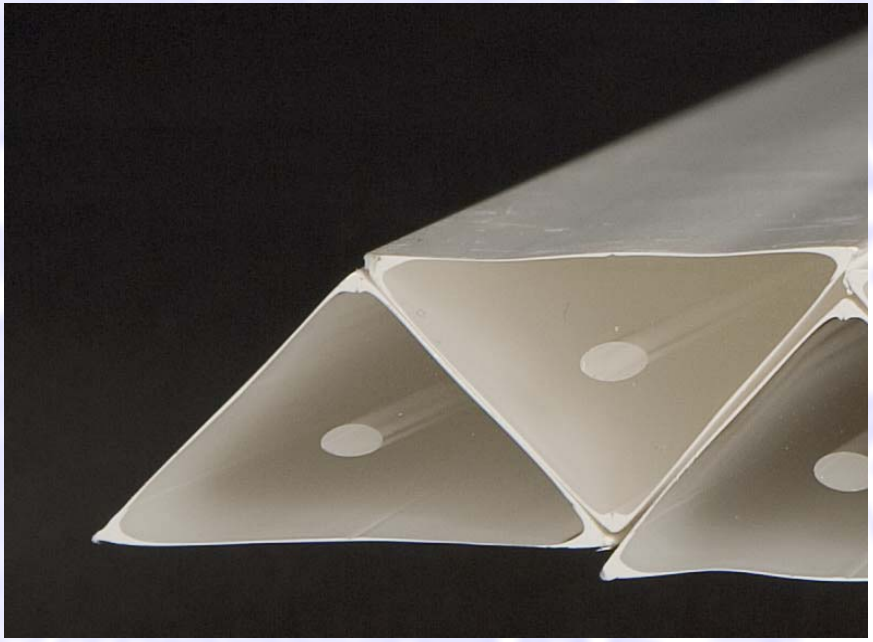
- Sensitivity goal: ~ 3 events S, S/N ~ 1 by 2018, shares beam with T2K.

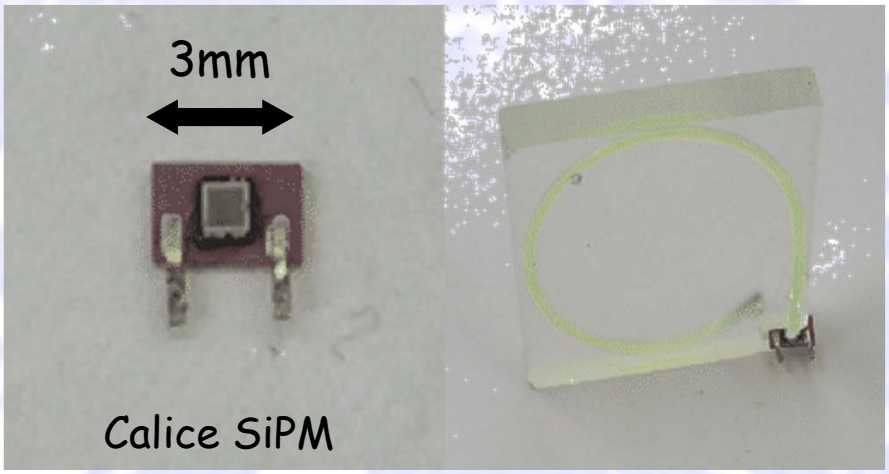
- No scheme for precision measurement.

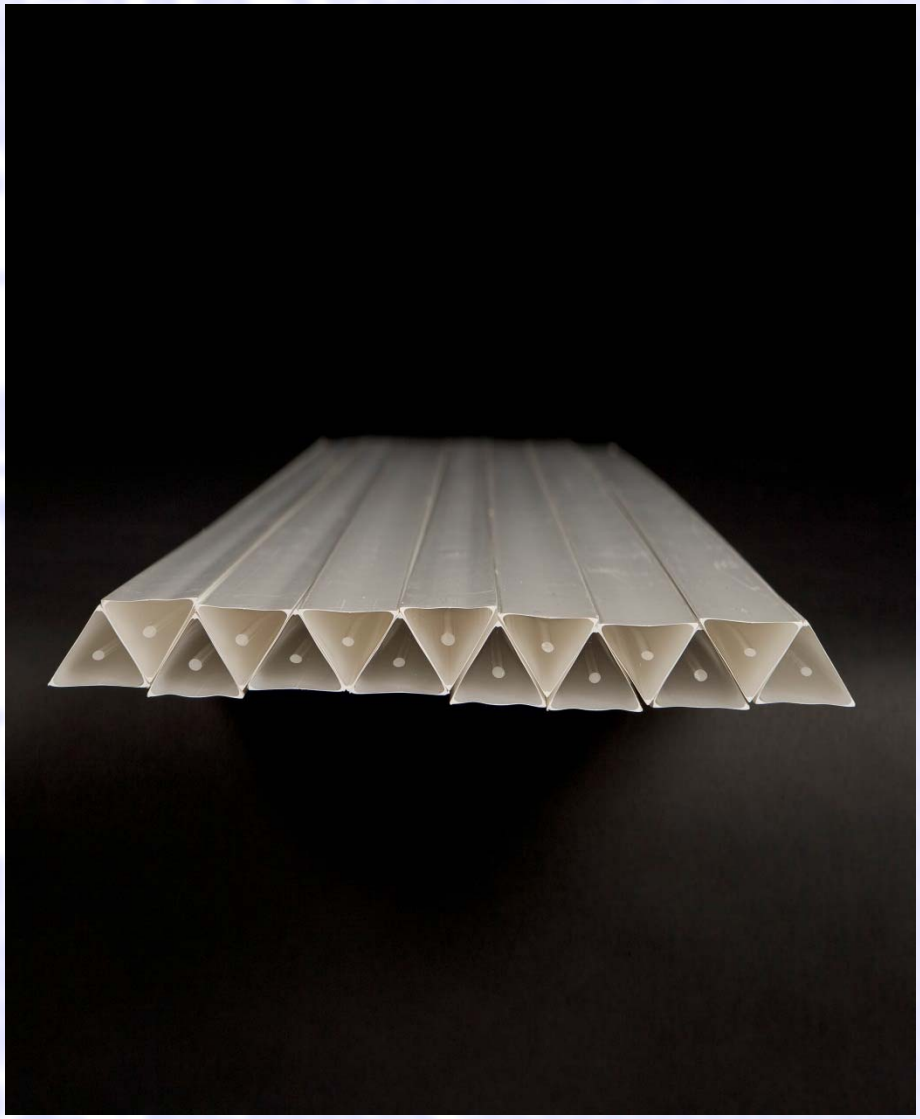
Detector R&D that can lower cost and increase performance

- **D:** Geiger Avalanche Mode (SiPMs, MPPCs) devices for scintillator readout of stopping target, range-stack, photo veto.
- **D:** Extruded scintillator for the stopping target and range stack.
- **D:** Fully streaming DAQ.
- **R:** High efficiency photon veto technology, synergy with Project X.

Development required for more precise extrusion and compact photon readout…



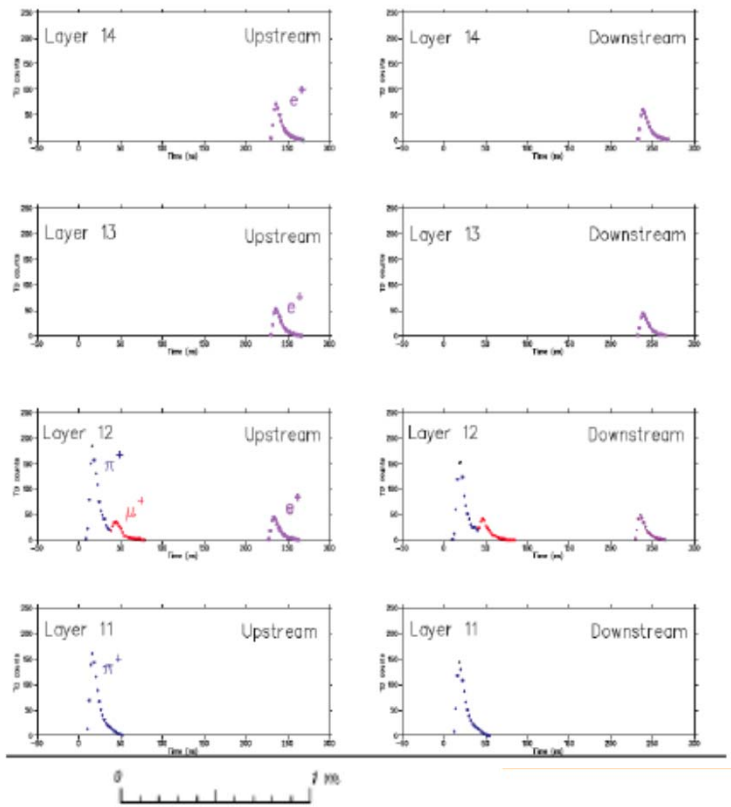


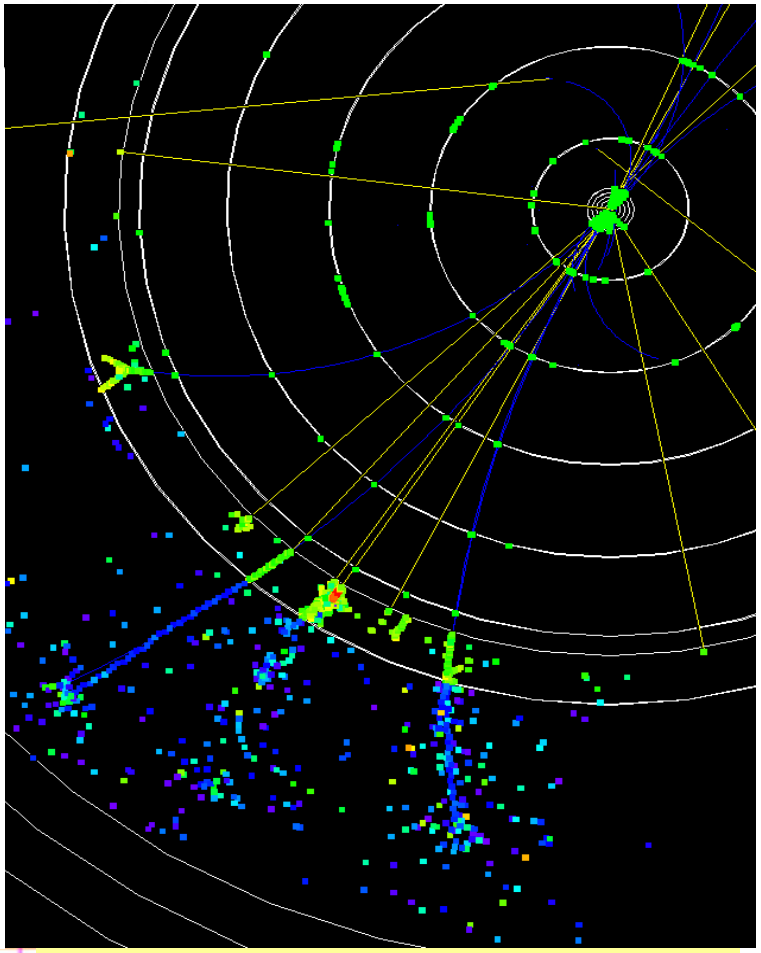


ORKA Range Stack

Use existing (CDF or CLEO) solenoid

$\pi \rightarrow \mu \rightarrow e$ detection in E949





SiD fine grained calorimetery

David E. Jaffe (BNL) FNAL PAC Meeting Nov. 13, 2009 6 / 34

The Relationship of ORKA to Project-X

- While the relevant accelerator R&D is adequately supported, the Project-X schedule is not clear.

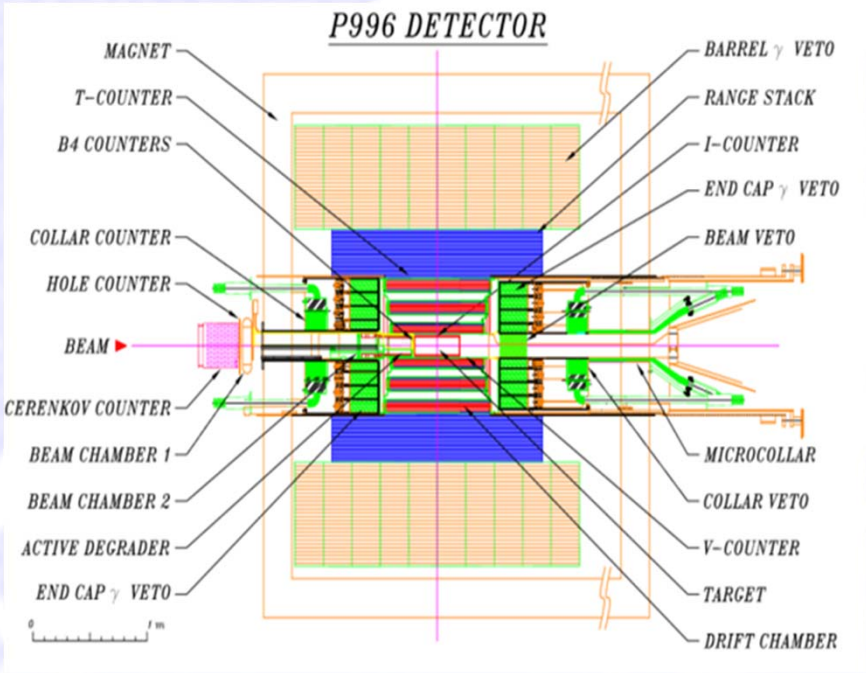
- ORKA is a Project-X demonstrator experiment that will come to full fruition with Project-X beam. ORKA can be directly ported to the rare-decay campus as a candidate Day-1 experiment.

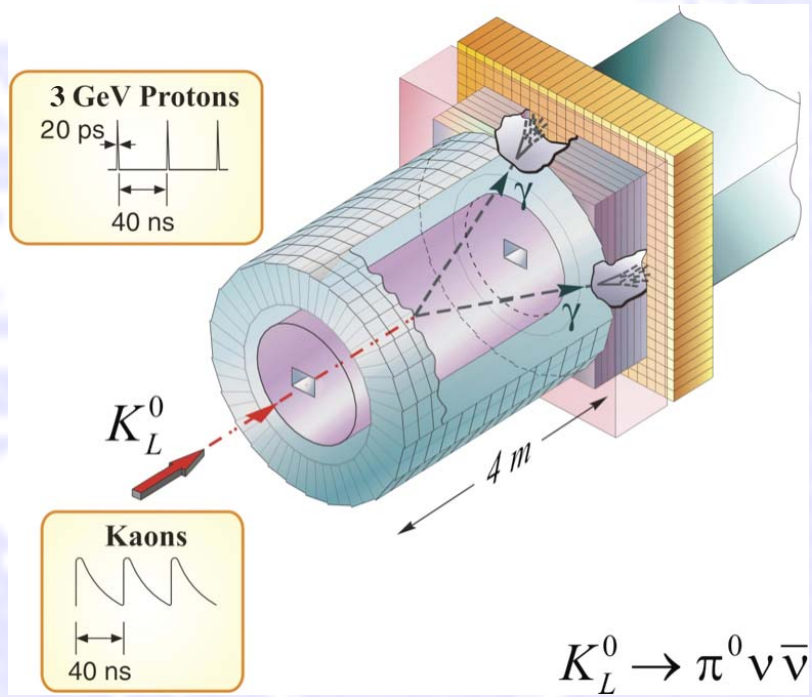
- The most important element of the Project-X research program is people. The promise of the ORKA research program has and will attract the best of the community. In parallel with ORKA, this community will develop the experimental techniques necessary to fully exploit the quark flavor physics potential of Project-X.

Project X Day-1 program goals: Definitive Measurement of $K \to \pi \nu \bar{\nu}$

In the Project-X era the Fermilab ORKA experiment would precisely measure the rate and form-factor of $K^+ \to \pi \nu \bar{\nu}$.

The Project-X era presents an opportunity to measure the holy grail of kaon physics with precision: $K_L \to \pi \nu \bar{\nu}$.





Evolution of the CDF/B0 Infrastructure

- 2012-2015: Stabilize ORKA infrastructure, collider-technology exhibit.
- Environment to communicate evolution from energy to intensity frontier to public, community, policy makers, investors.
- Project-X demonstrator experiment and proton-plasma wakefield experiment associated with IARC.

A Strategy Forward in a Constrained World

- Evaluate critical issues for siting at B0:
  - Beam-line elements for transport from A0 to B0.
  - Shielding analysis of the B0 siting solution.

- Continue development of the collider technology visitor exhibit with consideration of ORKA infrastructure.

- Develop an Accelerator Improvement Plan to transport beam from A0 to B0; coordinate with plasma-wakefield experiment.

- Work with DOE and Fermilab on identifying and supporting relevant detector R&D that can benefit ORKA in the near term.

Given the uncertainty of funding, we ask the PAC to comment and make its recommendations separately under assumptions of
(1) no budgetary issues and
(2) if the Fermilab budget is severely constrained over the next four years.

Charge Q1:
Is the science in the proposal interesting and/or compelling?

Charge Q2:
Is the technique proposed appropriate for, and likely to be capable of reaching the physics goals of the experiment?

Charge Q3:
What is the competition for reaching the physics goals of the proposed experiment? Does the proposed experiment have particular advantages or disadvantages relative to the competition?

Charge Q4:
What is needed to make such an experiment successful?

A Strategy for Revival of US Based Experiments in Quark Flavor Physics

- FNAL ORKA experiment scope is $50M (FY10,TPC). No new accelerator infrastructure or civil construction is required, reuse of existing facilities, relatively low technical risk. Construction start of 2014 plausible, data taking by 2017, 2017-2022 program.

- **2012-2022:** Community engages in critical R&D and design work for $K_L \to \pi^0 \nu \bar{\nu}$, $K_L \to \pi^0 ee$, and many other promising opportunities enabled with a high intensity proton accelerator complex.

- **2022+:** Onset of the Project-X era. ORKA@Project-X is a Day-1 experiment refining the $K^+ \to \pi^+ \nu \bar{\nu}$ rate measurement and a precision attack on the form-factor, followed by a series of definitive experiments at the frontier of quark flavor physics.

Spare Slides

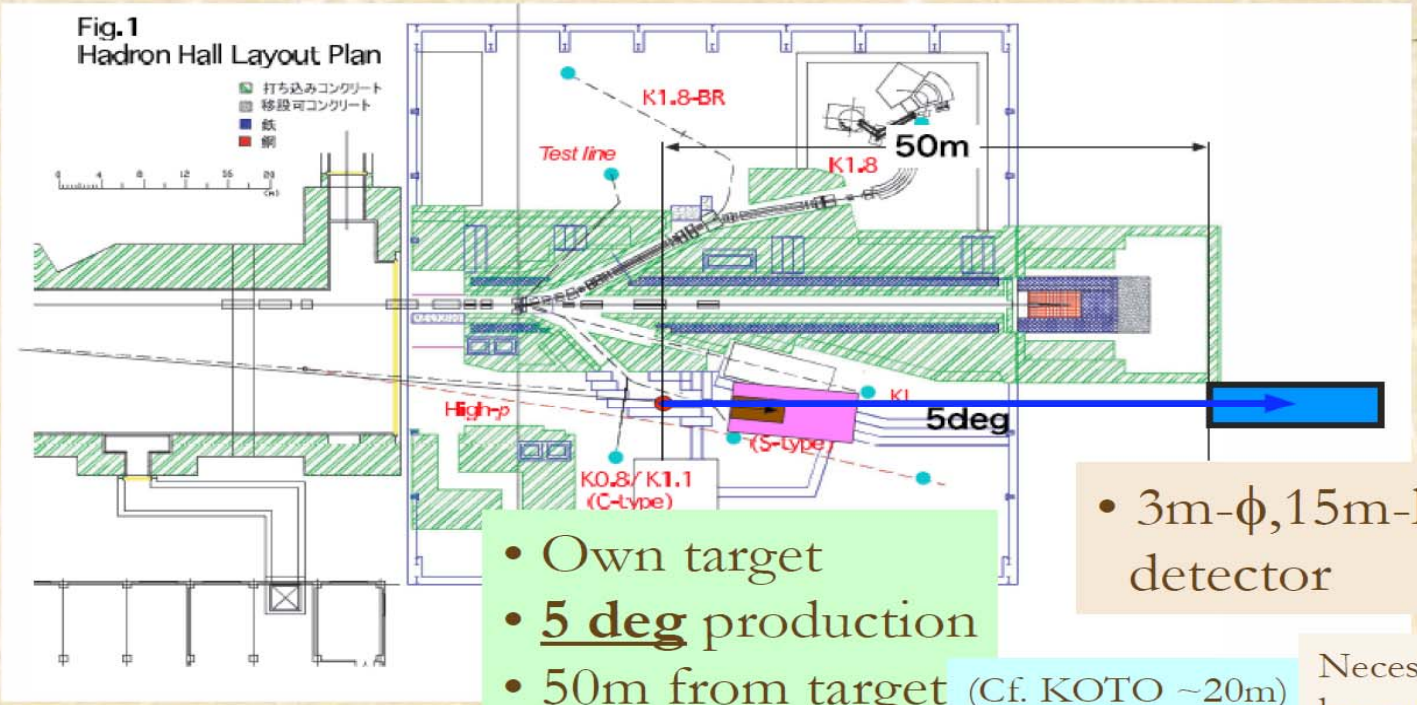
ORKA, The Golden Kaon Experiment: Precision Measurement of $K^+ \to \pi^+ \nu \bar{\nu}$

Wikipedia:
Orcinus orca are regarded as apex predators, lacking natural predators and preying on even large sharks.
Orcinus orca are highly social; some populations are composed of matrilineal family groups which are the most stable of any animal species.[5] Their sophisticated hunting techniques and vocal behaviors, which are often specific to a particular group and passed across generations, have been described as manifestations of culture.

(Orcinus orca), Life of Sea blogspot

Long Term Vision* in Asia: KOTO

"Step 2" described in the E14 proposal (2006)



- Own target
- **5 deg** production
- 50m from target (Cf. KOTO ~20m)

- 3m-ϕ,15m-long detector

Necessary to consider hyperon BG in Step2

- intensity 3×10^{14} ppp (450kW !!!)
- 3 snowmass years run

➔133 SM events (S/N~5)

23 October 2011 HUA WS on the future of the Hadron Hall, T. Nomura (KEK) 18

*Beyond current and approved experiments

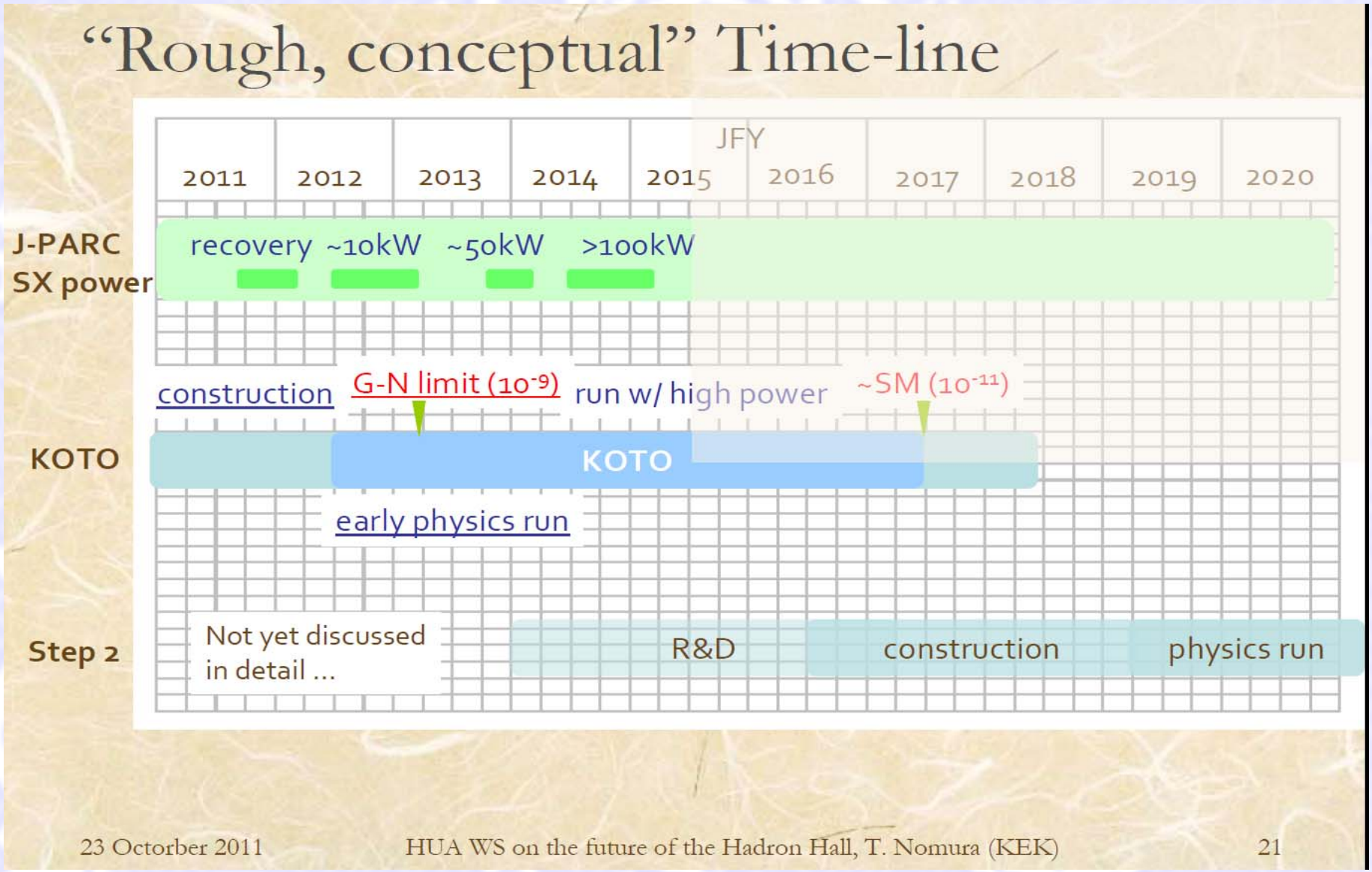
Slow Extracted Beam: The Standard Tool to Drive Ultra Rare Decay Experiments

- Techniques developed in the late 1960's to "slow spill" beam from a synchrotron.
- Technique operates at the edge of stability---Betatron oscillations are induced which interact with material in the beam (wire septum) to eject particles from the storage ring beam phase space.
- Technique limited by septum heating & damage, beam losses, and space charge induced instabilities. Works better at higher energies where the beam-power/charge ratio is more favorable.
- Performance milestones:

  Tevatron 800 GeV beam: 64 kW of SEB in 1997
  BNL AGS 21 GeV beam: 65 kW of SEB in 2001

- JPARC Goal: >300 kW of SEB, 30 kW goal in near future.

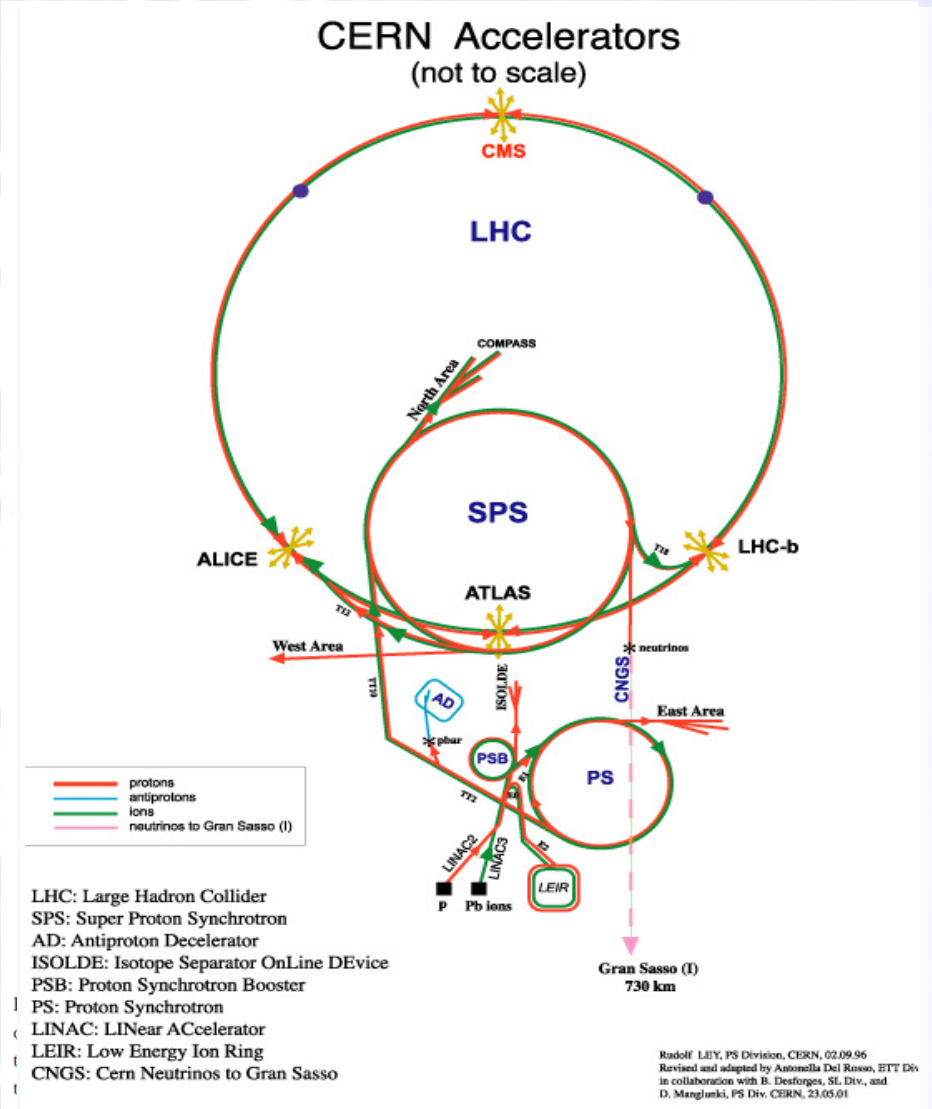
Long Term Vision* in Asia: KOTO



*Beyond current and approved experiments

Long Term Vision in Europe for High Sensitivity Experiments

- **2001:** CERN study outlined the evolution of higher power, high energy techniques, possibly implemented with the PS or SPS
- **2005-2007:** Landmark study:
  "Flavour in the LHC era"
- **2008-2009:** Recognition of SPS upgrades for the LHC program: Can benefit beam power & duty factor for the SPS SEB program.
- ESS & SPL duty factor too low for high rate experiments



The Project-X Research Program

- ***Neutrino oscillation experiments***
- A high-power proton source with proton energies between 8 and 120 GeV would produce intense neutrino beams directed toward near detectors on the Fermilab site and massive detectors at distant underground laboratories.

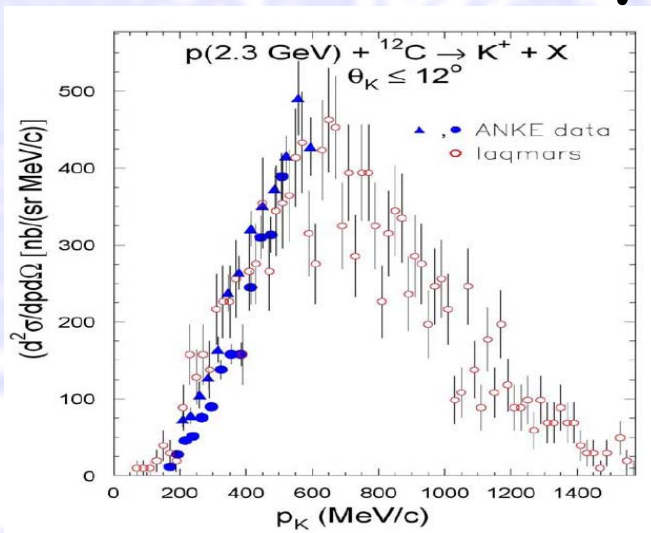
- ***Kaon, muon, nuclei & neutron precision experiments***
- These could include world leading experiments searching for muon-to-electron conversion, nuclear and neutron electron dipole moments (edms), precision measurement of neutron properties and world-leading precision measurements of ultra-rare kaon decays.

- ***Platform for evolution to a Neutrino Factory and Muon Collider***
- Neutrino Factory and Muon-Collider concepts depend critically on developing high intensity proton source technologies.

- ***Nuclear Energy Applications***
- Accelerator, spallation, target and transmutation technology demonstration which could investigate and develop accelerator technologies important to the design of future nuclear waste transmutation systems and future thorium fuel-cycle power systems.

Detailed Discussion: Project X website

BNL E949 and Project-X kaon momentum spectra and sensitivity comparisons



x140 average rate of stopping kaons with respect to BNL E949, x11 the average stopping rate of ORKA.

	Beam Energy T_p	Protons/second (avg) on [target (λ_I)]	p(K^+) (MeV/c)	Stopping K^+/second	K^+/π^+ Production Ratio
BNL AGS (E949)	21 GeV	12×10^{12} on [0.7 λ_I Pt.]	700-730	0.7×10^6 K^+/sec	1:24
Project-X/ K^+ expt	3.0 GeV	1/2 x 6000×10^{12} on [1.0 λ_I C]	450-570	98×10^6 K^+/sec	1:80

Table 1: Compares the measured rate of stopping K^+ in the BNL-E949 experiment with full LAQGSM/MARS thick-target simulations for Project-X charged kaon yield with ½ of the 1 ma 3.0 GeV proton beam.

Project-X kaon physics white paper

Project-X High-Intensity Campus

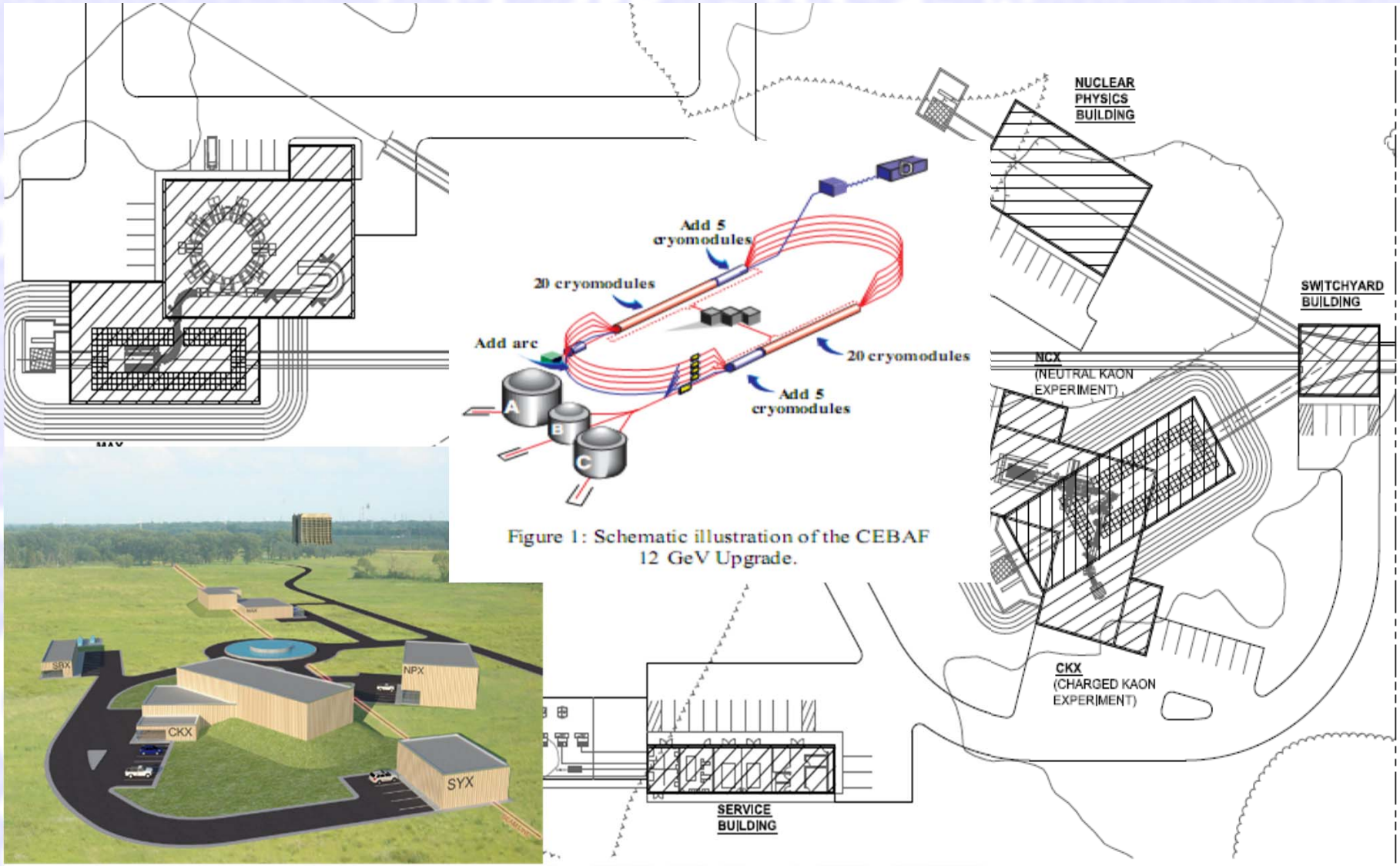


Figure 1: Schematic illustration of the CEBAF 12 GeV Upgrade.

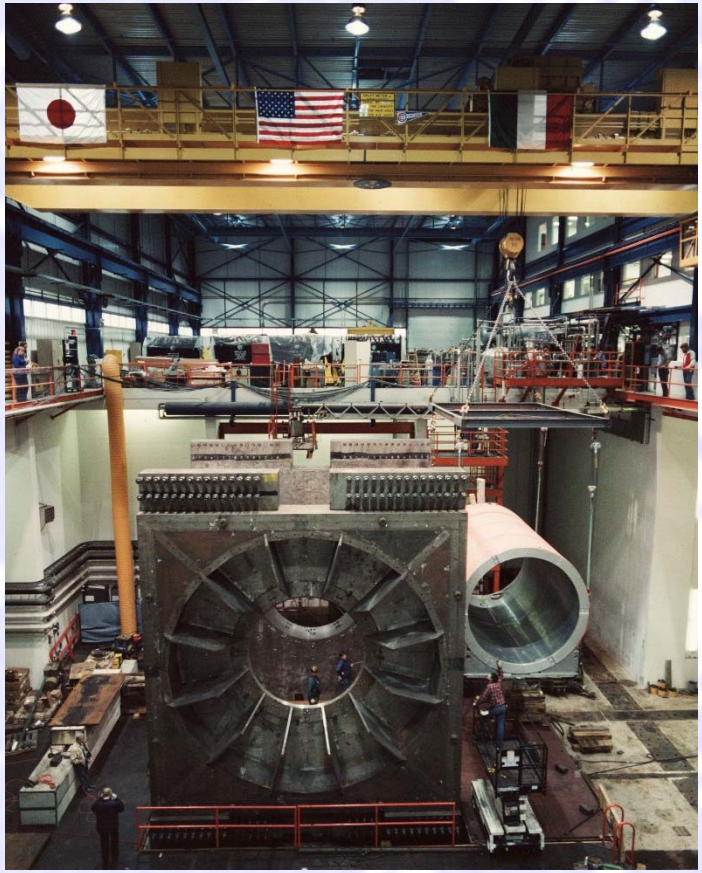
Footprint of charged and neutral detectors motivated by BNL-E949, KOPIO and JPARC

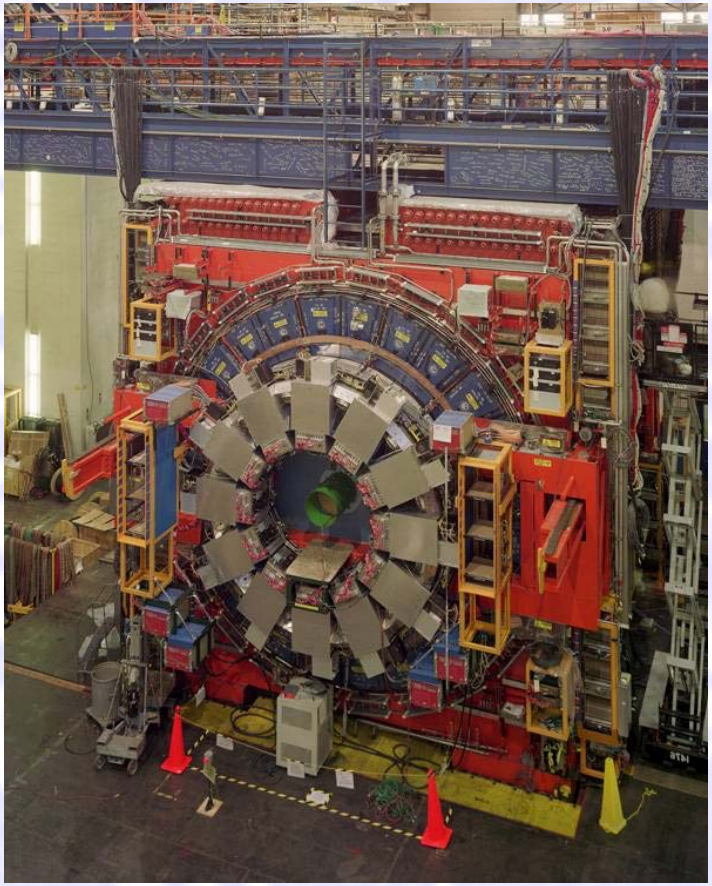
Project-X kaon physics white paper

Project-X R&D Challenges to the Community

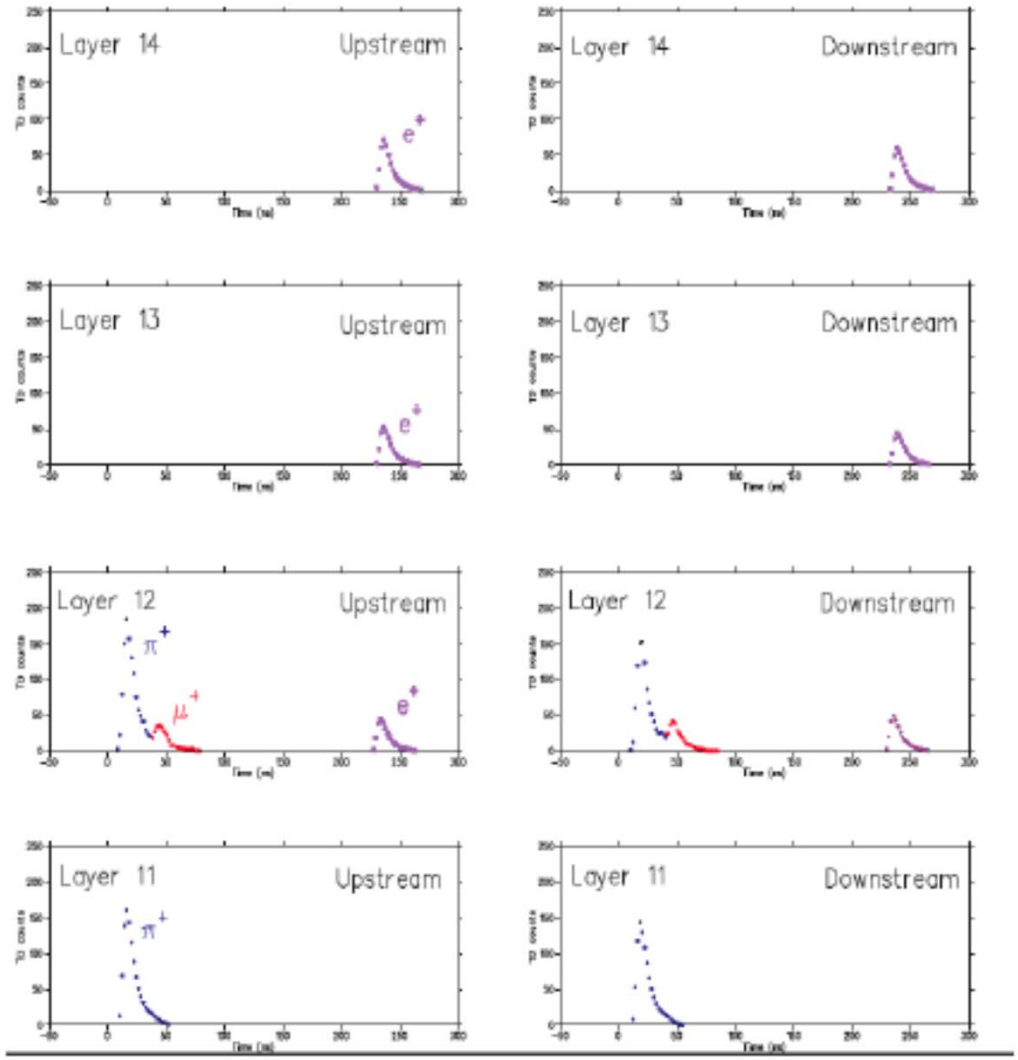
- High-rate, ultra-low-mass tracking
- Fine grained fast scintillator technology in high B-fields, in vacuum
- High-rate, ultra-high- efficiency photon tagging (10 MeV – 100 GeV)
- Breakthrough TOF *system* performance (<20psec)
- Design and build the perfect EM calorimeter:
  High rate, breakthrough -TOF, γ-pointing, fine grained particle-flow
- Fully streaming "triggerless" DAQ technologies:
  GHz front-ends to Peta-Byte data stores.

CDF detector, then and now…





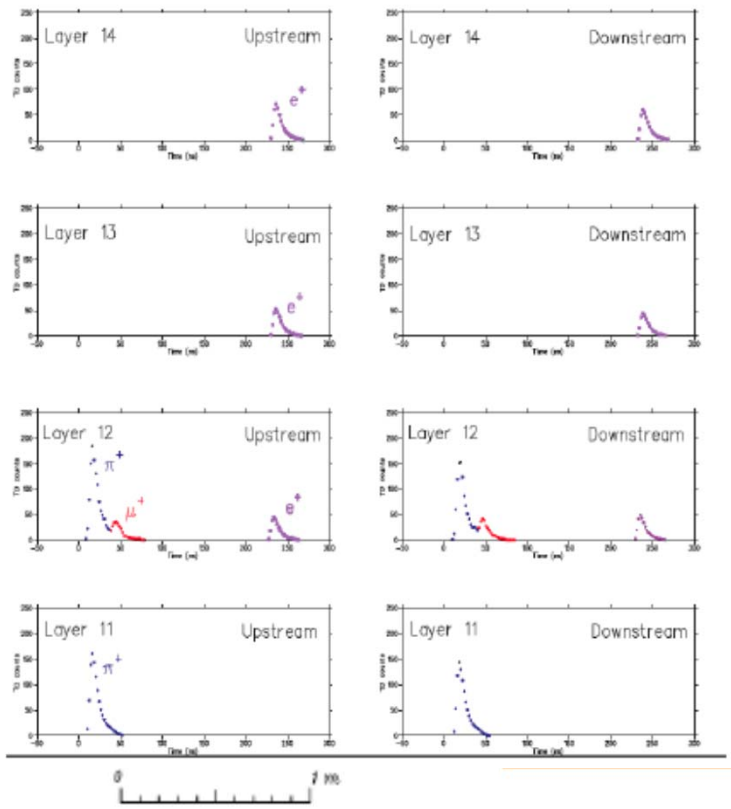
$\pi \rightarrow \mu \rightarrow e$ detection in E949

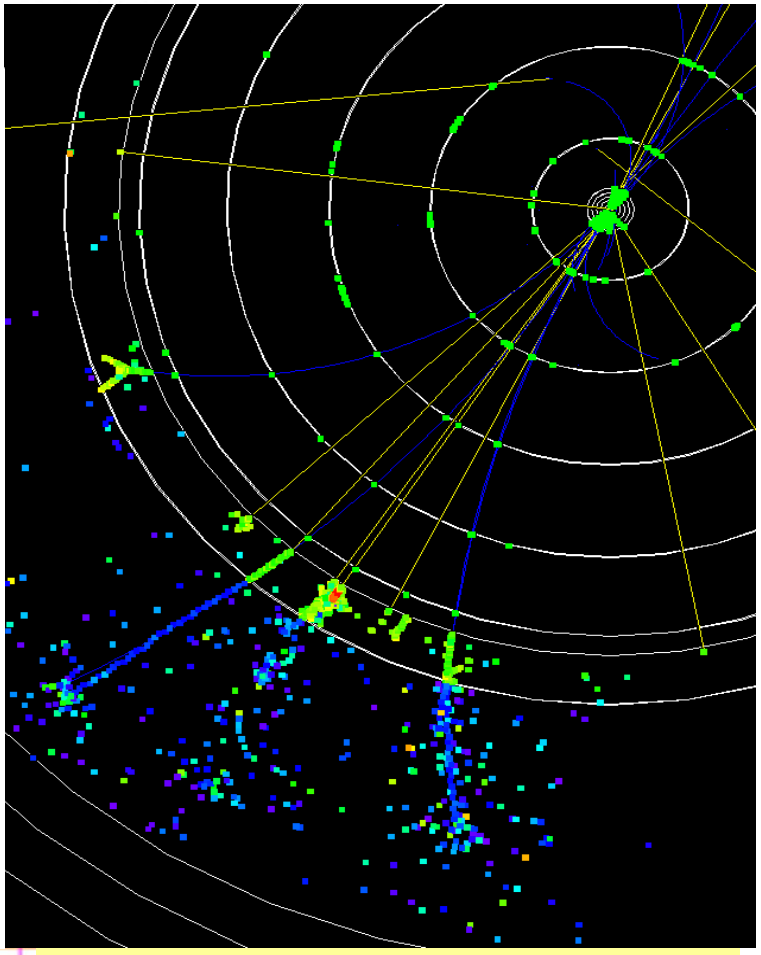


ORKA Range Stack

Use existing (CDF or CLEO) solenoid

$\pi \rightarrow \mu \rightarrow e$ detection in E949

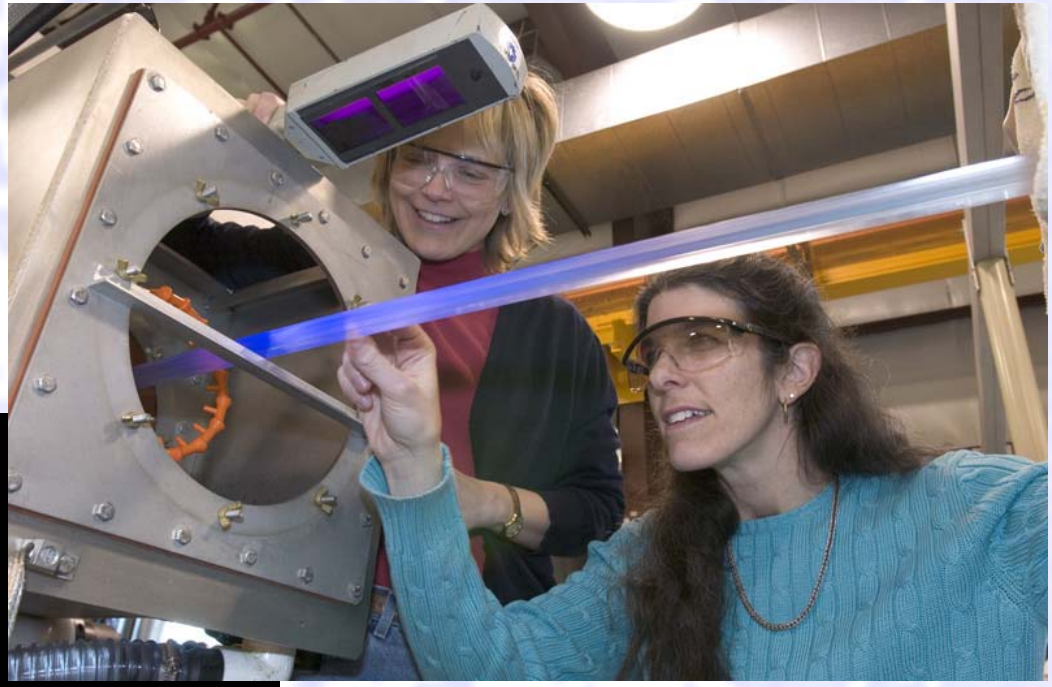


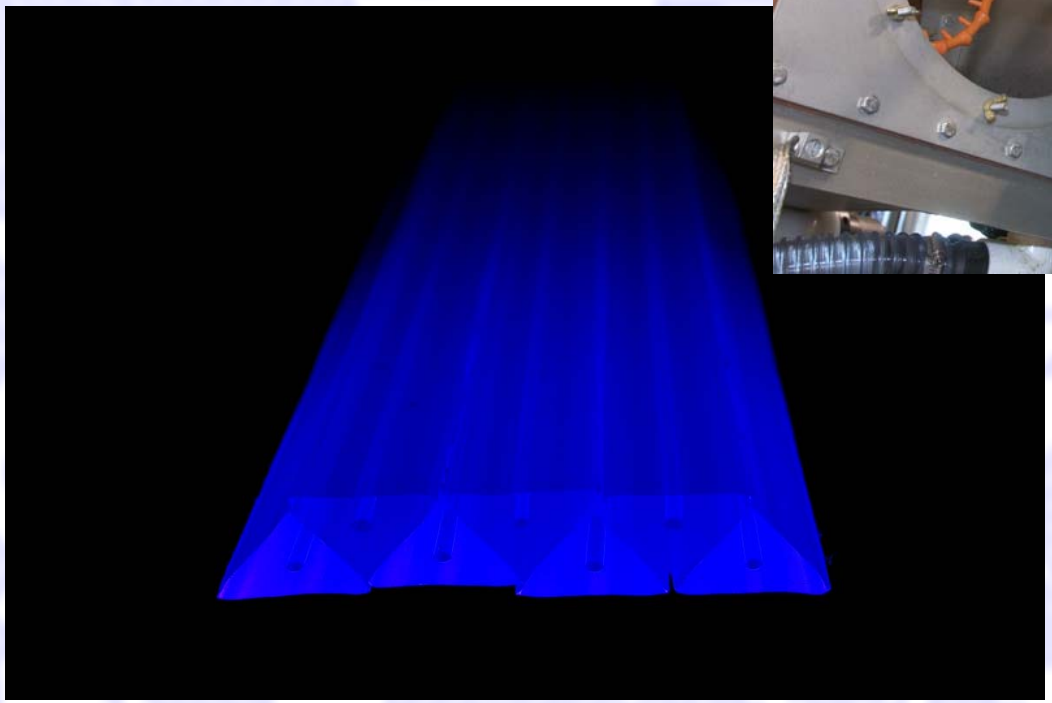


SiD fine grained calorimetery

David E. Jaffe (BNL) FNAL PAC Meeting Nov. 13, 2009 6 / 34

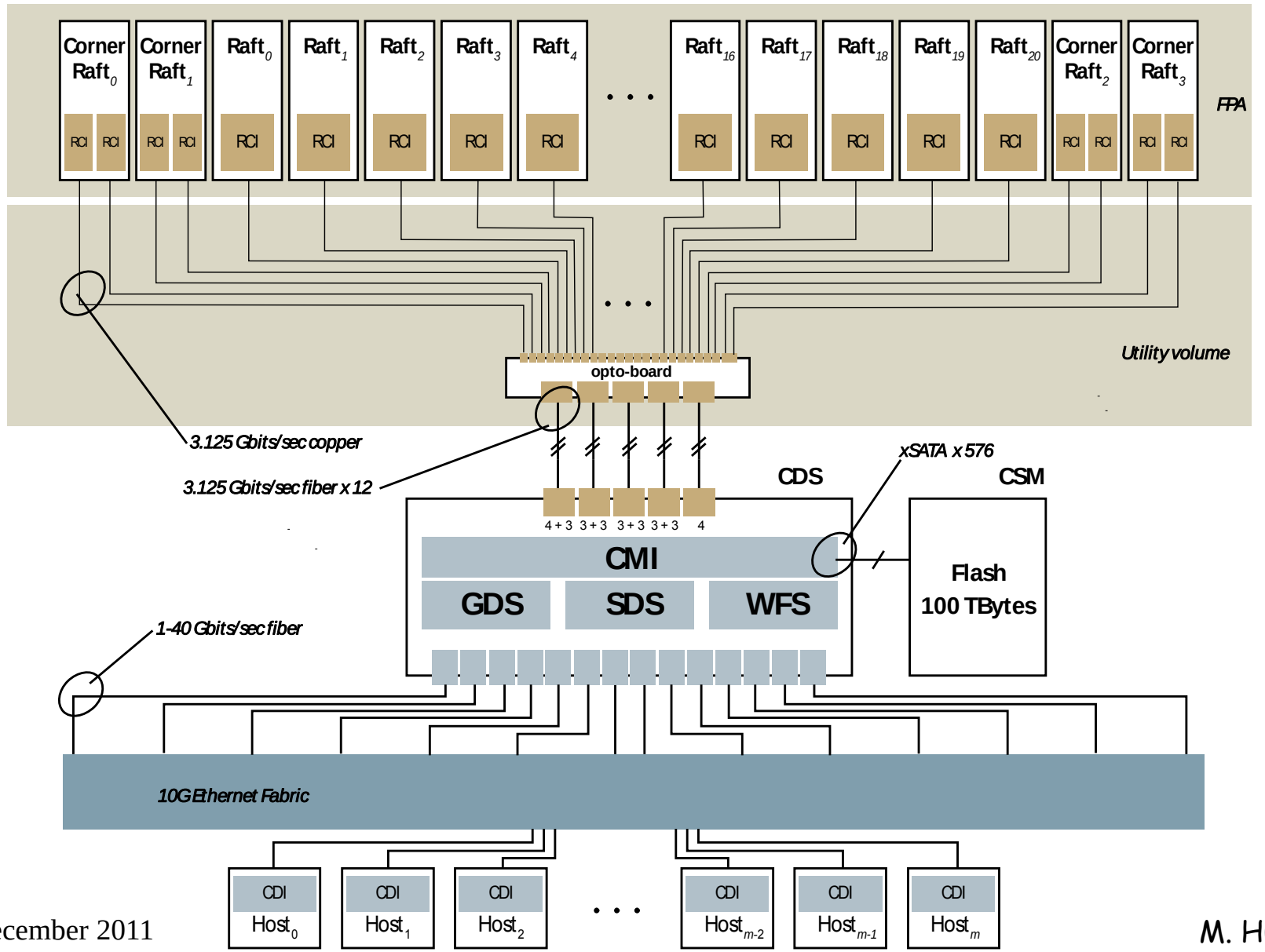
Extruded Scintillator technologies can lower costs…



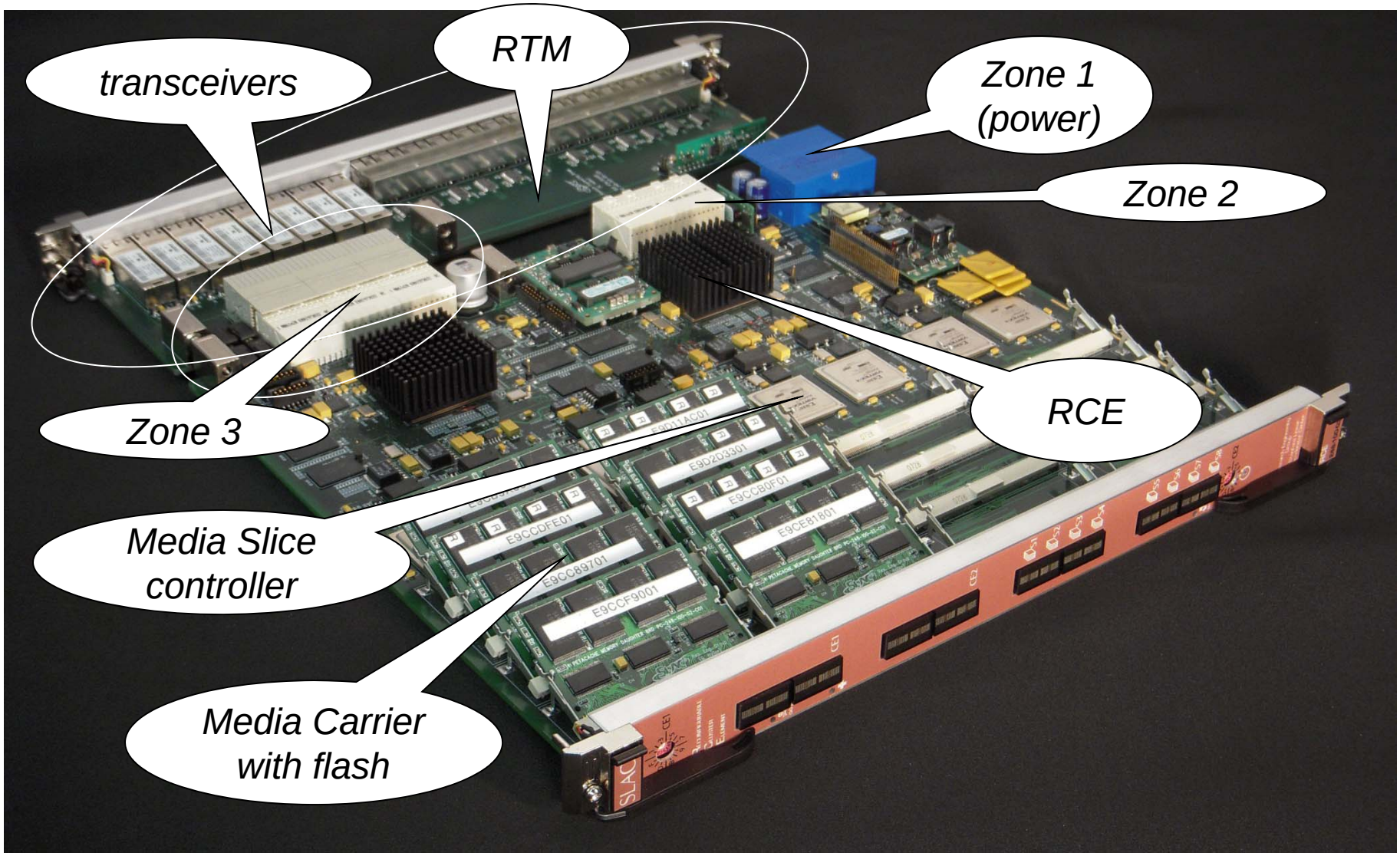


Minerva Scintillator

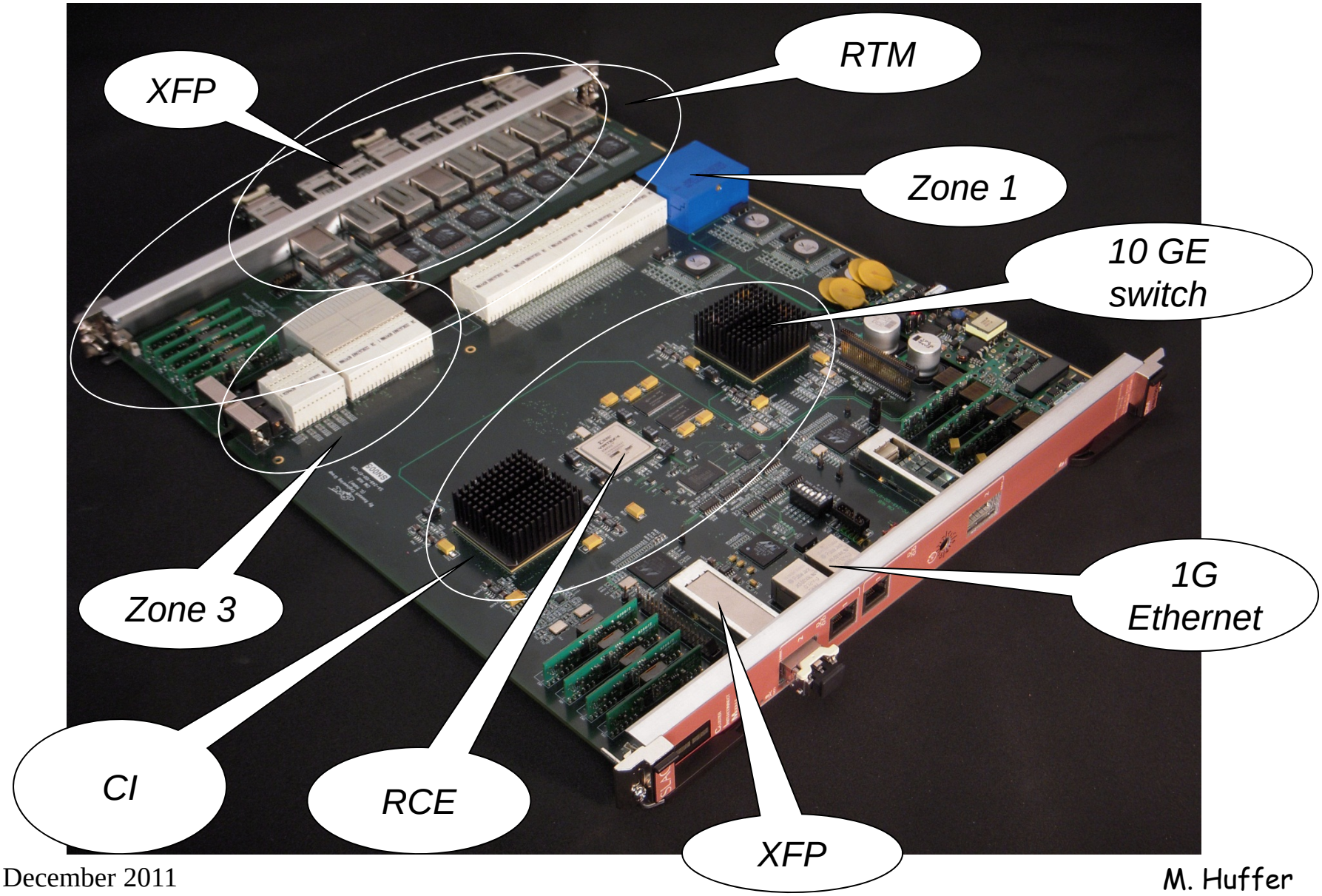
Block Diagram of the LSST DAQ System



RCE board + RTM

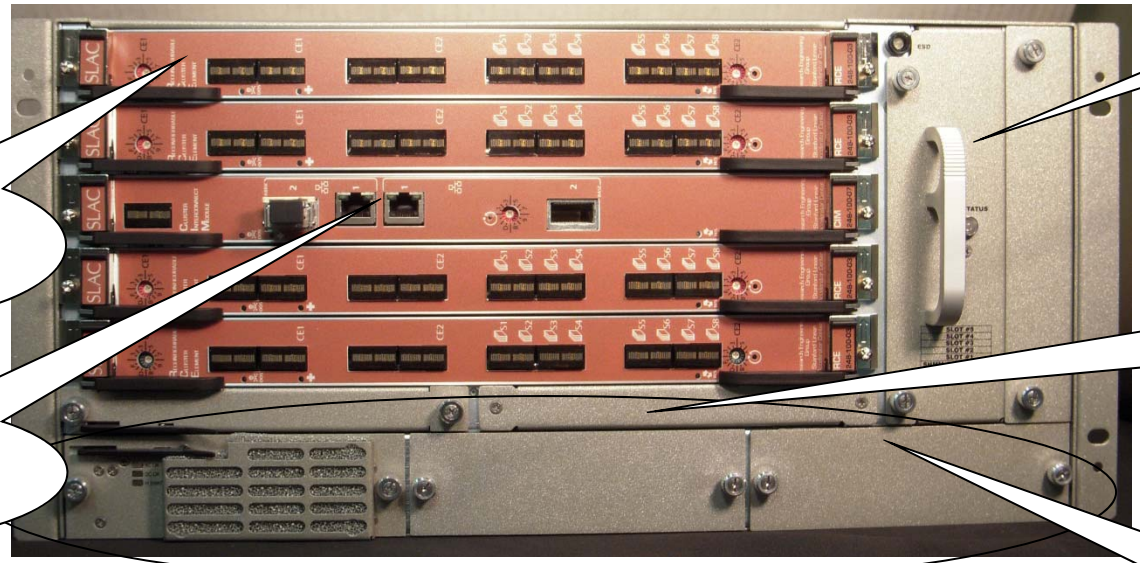


CI board + RTM



Typical (5 slot) shelf

Front



fans

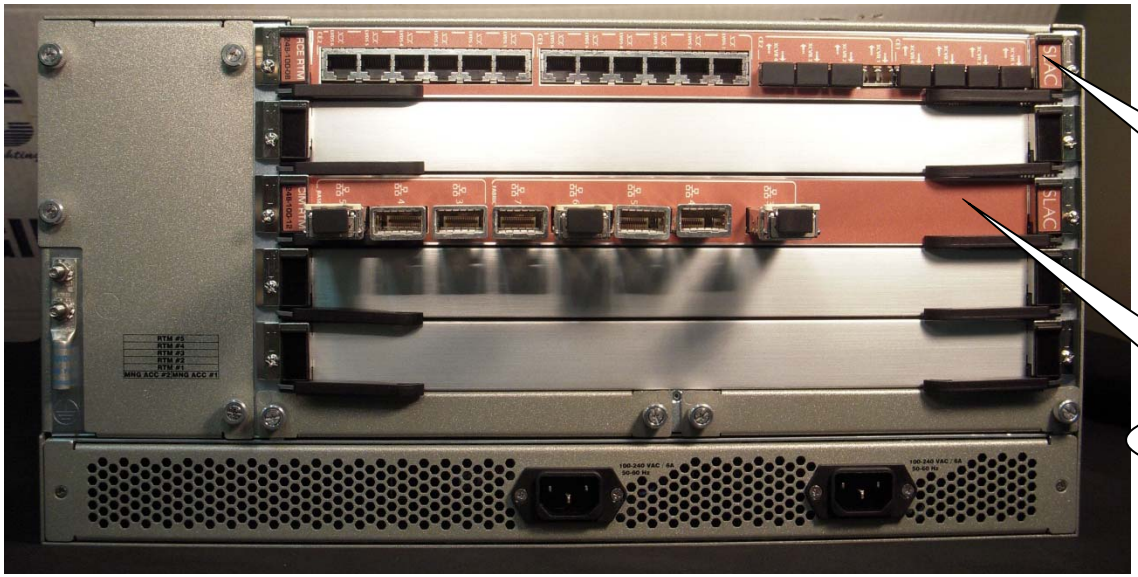
front board

Shelf manager

front board

Power supplies

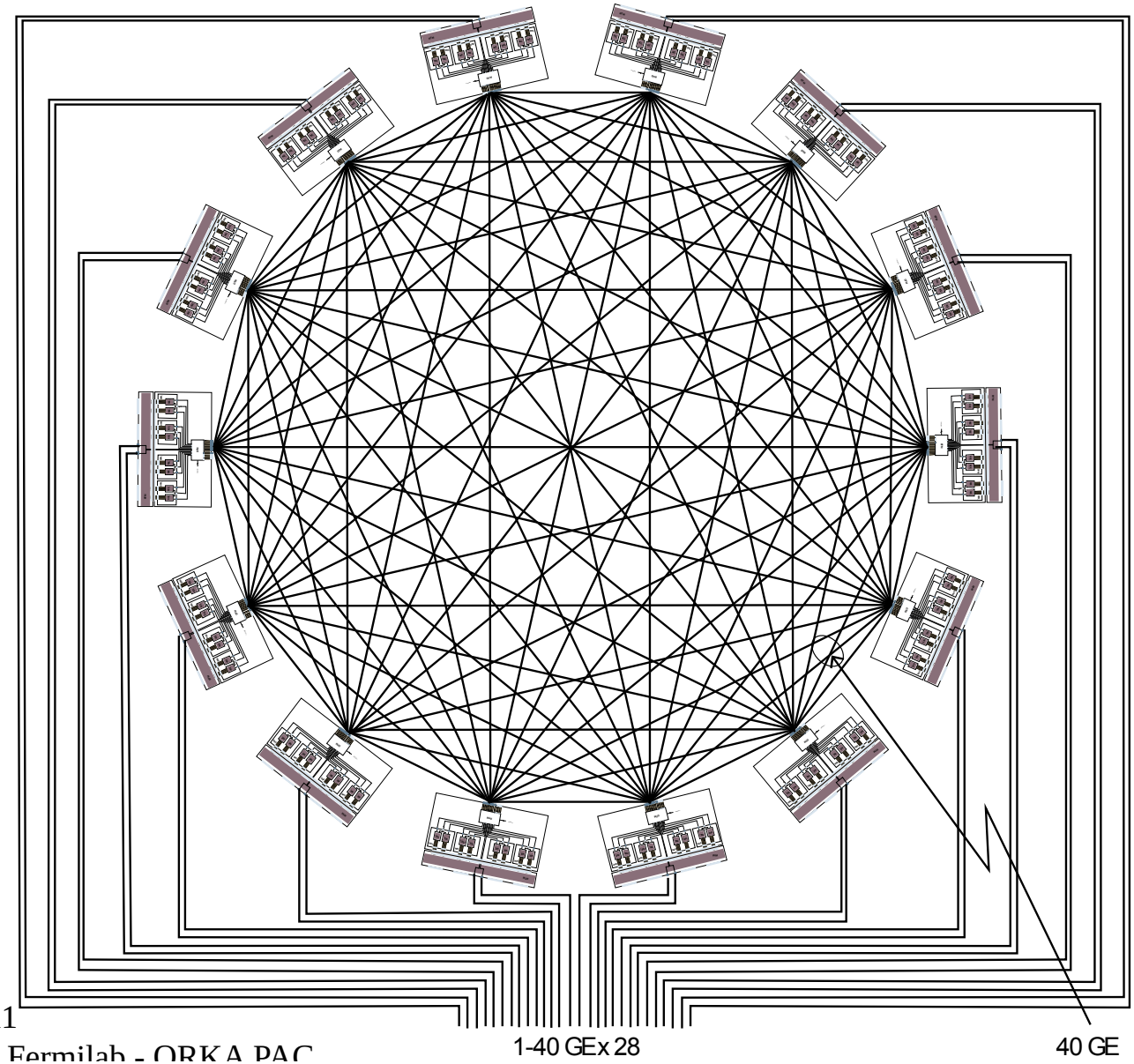
Back



RTM

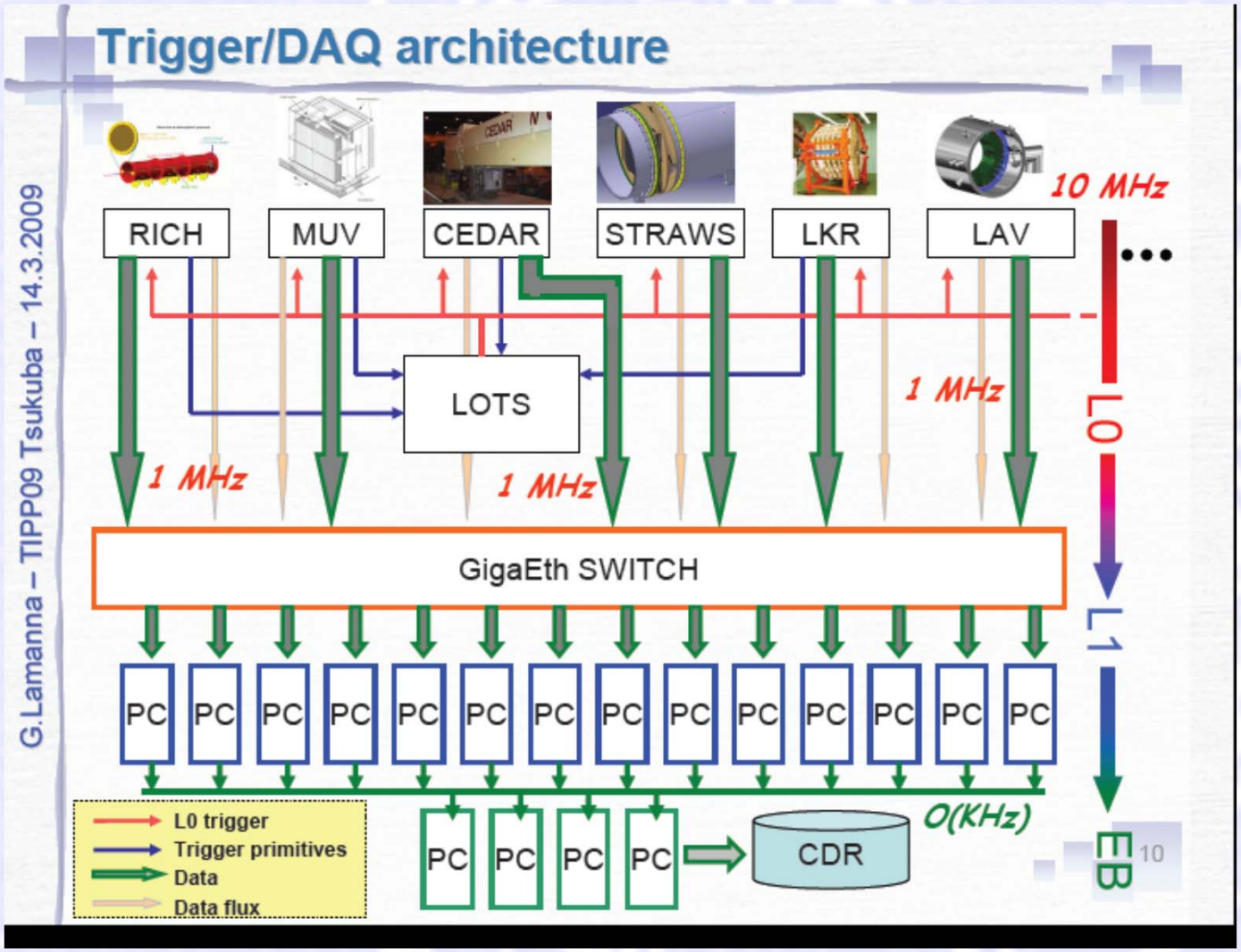
RTM

Ethernet topology in a 14-slot shelf…

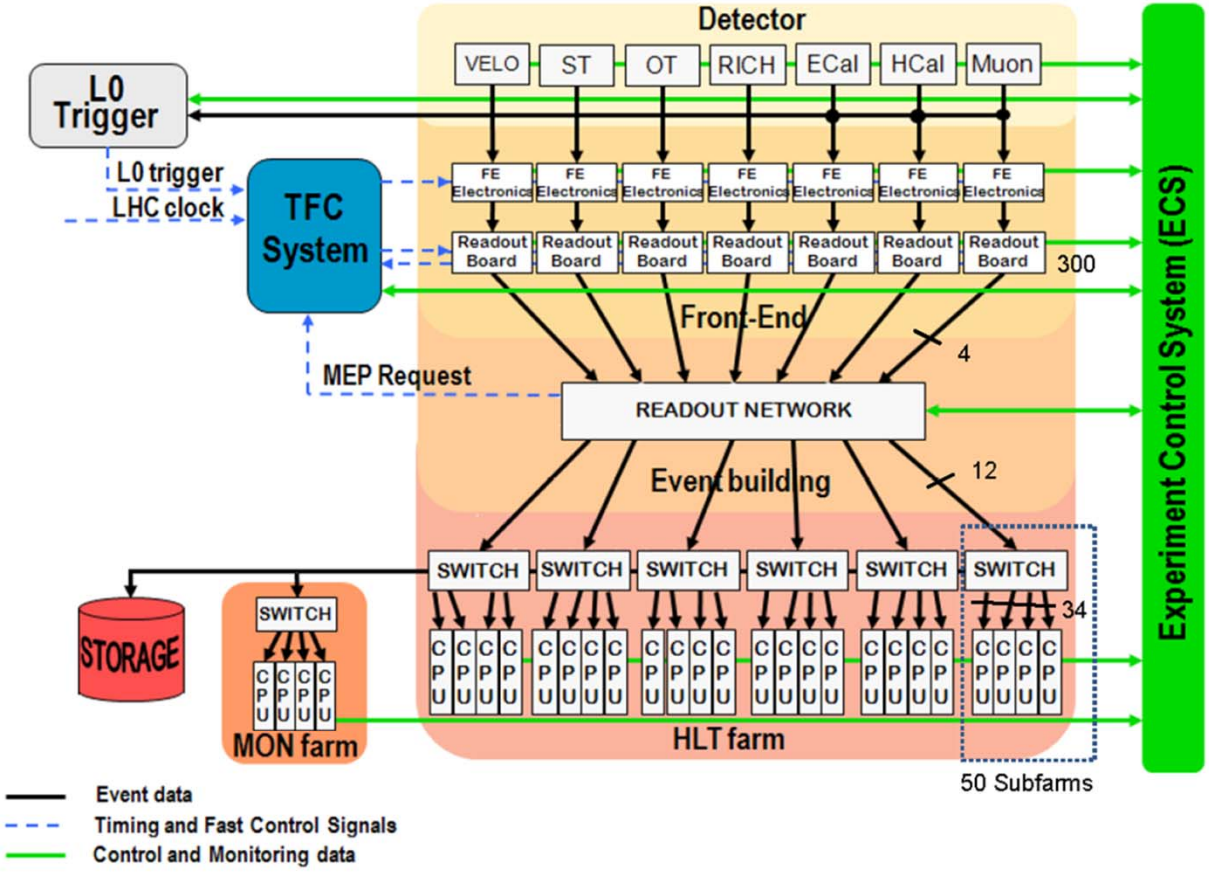


M. Huffer

NA62 near-Streaming DAQ



LHCb Streaming DAQ upgrade



Mu2e Streaming DAQ

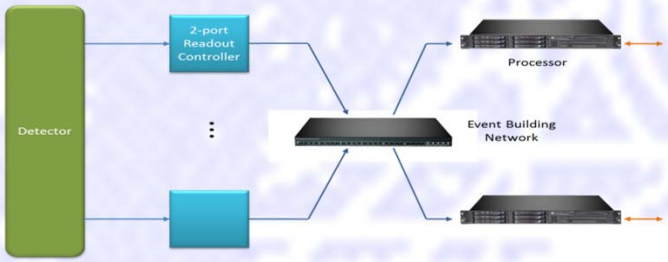


Figure 2a

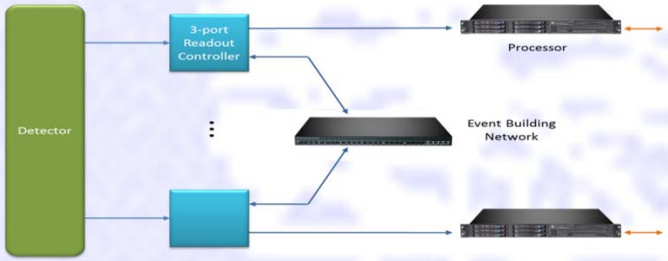


Figure 2b

In a switch based DAQ, the Readout Controller (ROC) collects data from the front-end systems and sends it through the Event Building (EVB) network to a Processor Farm. The typical ROC is a two-port device. Dataflow through the network is mostly unidirectional (Figure 2a) and final event assembly is done in the processors. Mu2e will use a three-port ROC. In this architecture the event building is done entirely in the ROCs and full events are then forwarded to the processors (Figure 2b). This has two advantages;

1) the EVB network connections are handled by an FPGA and can run at a full 10 Gbps wire speed (not usually possible with a processor running a software IP stack). Bidirectional data flow reduces the number of switch ports required.
2) the FPGA in the ROC has access to the fully assembled events, and can serve as a trigger pre-processor in addition to its function as readout controller and event builder. This offloads the farm and provides several TeraOps of supplementary processing power.

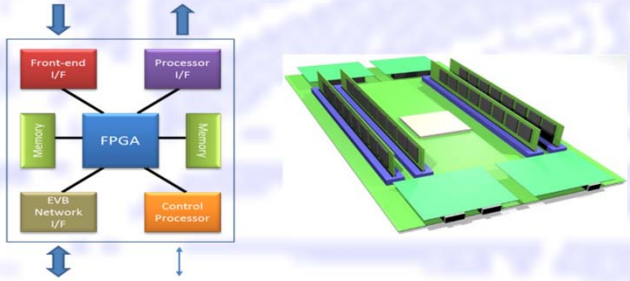


Figure 3

The Readout Controller I/O (Figure 3) is modular to support multiple applications. For Mu2e, the front-end interface is a 12-channel parallel optical receiver, and the EVB network interface is dual channel 10Gbps Ethernet (SFP+).

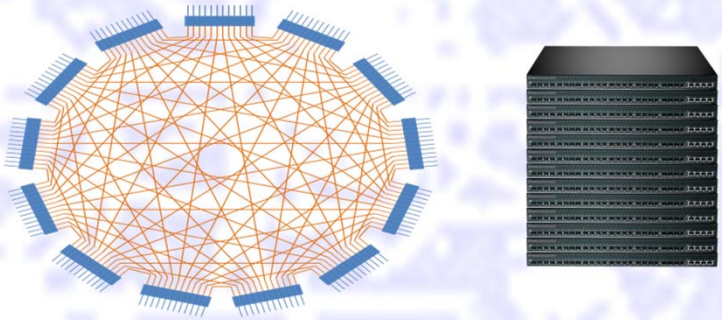
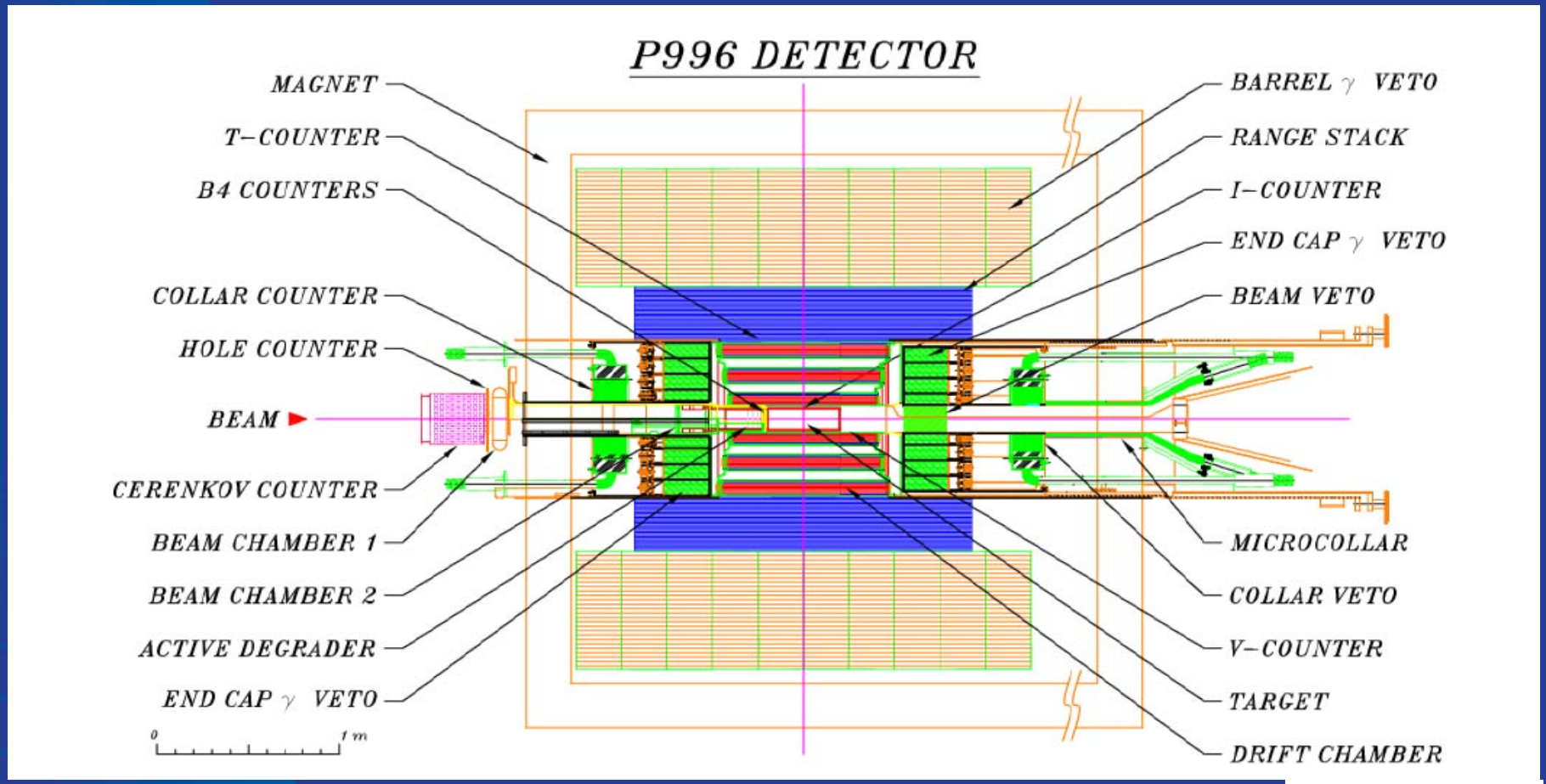


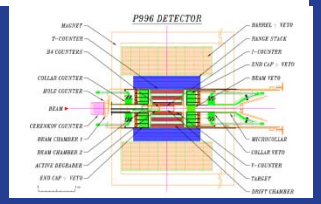
Figure 4

Figure 4 shows a 156 port EVB network using thirteen 24 port Ethernet switches. Each switch port is 10Gbps, for a total bandwidth capacity of 150 GBytes/sec. Interswitch connections are "direct attach" SFP+ copper cables. External connections are copper or optical depending on distance.

Present and Future of $K^+ \to \pi^+ \nu\bar{\nu}$



- Project-X experiment based on E787/E949 success:



Active fiber target

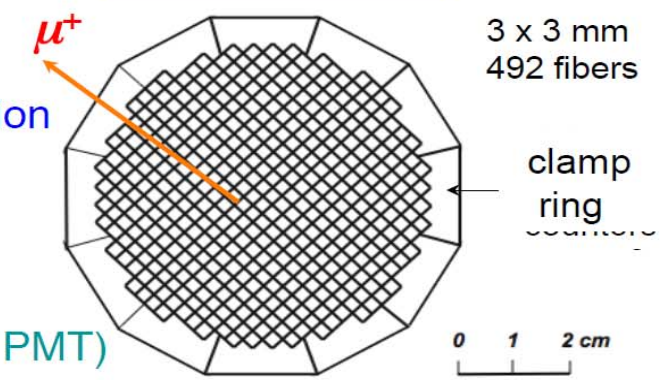
1. Finer segmentation for
   - Higher μ^+ tracking resolution
   - Higher K^+ stop point resolution
   - Better $K\pi 2$ background suppression

   (E246 : 256 fibers with 5 x5 mm^2)

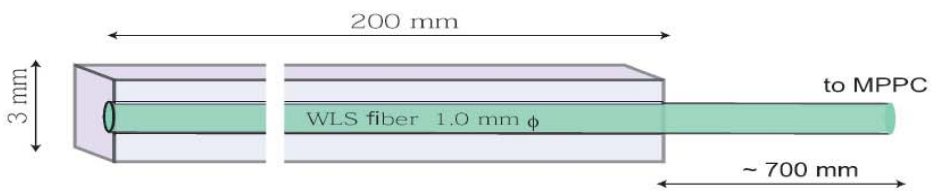
2. Compact and light system
   - By using MPPCs

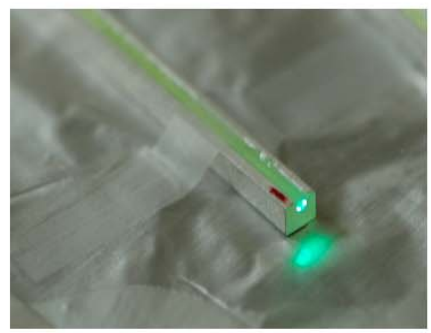
   (E246 : each fiber was read by a1/2" PMT)

Cross section



One element





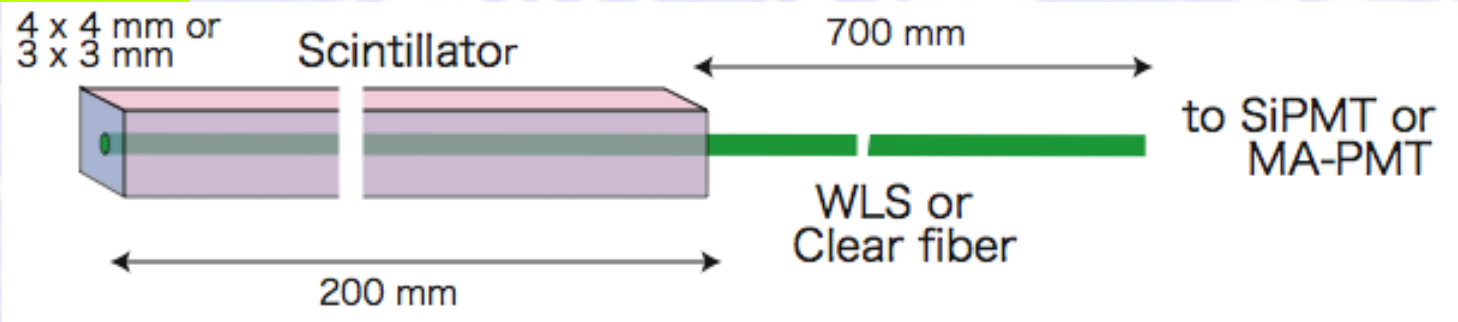
- MPPC direct readout test at KEK (2008)
- Radiation damage test of MPPC with 130 MeV/c π^+ (2008)

Detector preparation
(2) Active fiber target

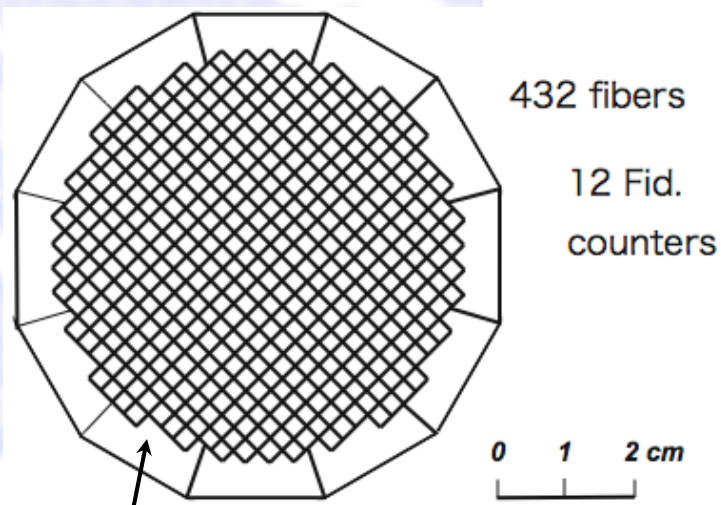
Current baseline design

c.f. E246 Ring counte
PSI FAST target

One element



Cross section



Timing counters

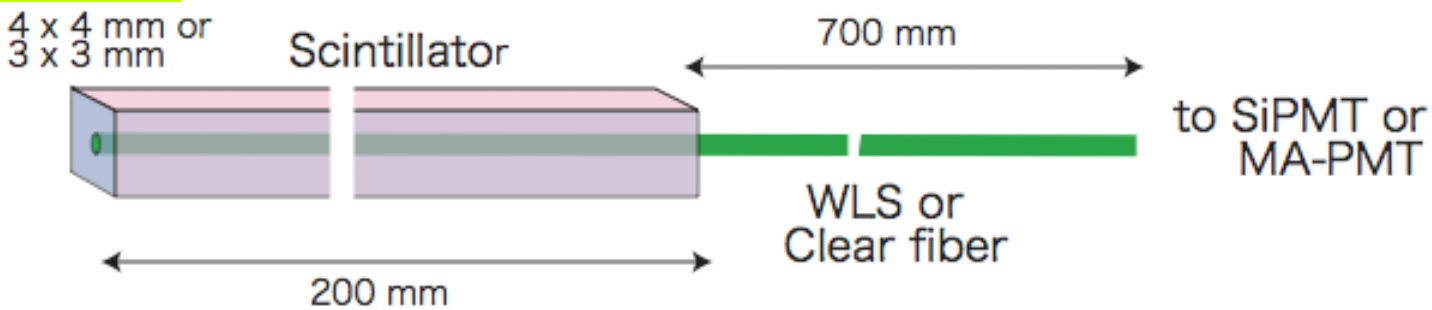
- Light guide :
  Bicron 692 WLS or
  Kuraray Y11 WLS or
  Clear optical fiber
- Readout:
  SiPMT (HPK MPPC) or
  MA-PMT
- Beam test using 100 MeV/c pions at TRIUMF in this year

Detector preparation
(2) Active fiber target

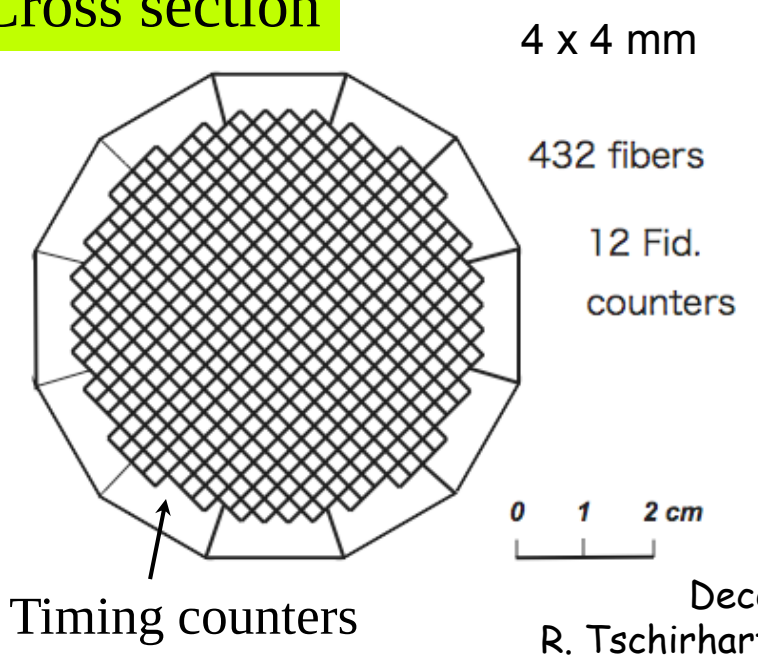
Current baseline design

c.f. E246 Ring counters
PSI FAST target

One element



Cross section



- Light guide :
  Bicron 692 WLS or
  Kuraray Y11 WLS or
  Clear optical fiber
- Readout:
  SiPMT (HPK MPPC) or
  MA-PMT
- Beam test using 100 MeV/*c* pions at TRIUMF in this year

Sensitivity Frontier of Kaon Physics Today

- CERN NA62: 100×10^{-12} measurement sensitivity of $K^+ \to e^+\nu$
- Fermilab KTeV: 20×10^{-12} measurement sensitivity of $K_L \to \mu\mu ee$
- Fermilab KTeV: 20×10^{-12} search sensitivity for $K_L \to \pi\mu e$, $\pi\pi\mu e$
- BNL E949: 20×10^{-12} measurement sensitivity of $K^+ \to \pi^+\nu\bar{\nu}$
- BNL E871: 1×10^{-12} measurement sensitivity of $K_L \to e^+e^-$
- BNL E871: 1×10^{-12} search sensitivity for $K_L \to \mu e$

Probing new physics above a 10 TeV scale with 20-50 kW of protons.

Next goal: 1000-event $\pi\nu\bar{\nu}$ **experiments...10^{-14} sensitivity.**