

# Quark Flavor Physics

## Working Group Report

Argonne IF Workshop  
April 27, 2013

Co-conveners: Joel Butler, Zoltan Ligeti, Jack Ritchie

# Outline

- Preliminaries
  - Some History
- Reaching Beyond the TeV Mass Scale
- Facilities and Experiments
  - Kaons
  - B's
  - Charm
- The Message for Snowmass

# Quark Flavor Physics Working Group

<http://www.snowmass2013.org/tiki-index.php?page=Quark+Flavor+Physics>

Quark Flavor Physics, for the purposes of this Intensity Frontier subgroup, refers to experimental and theoretical studies of processes involving strange, charm, or bottom quarks, which are promising directions to discover the existence of new physics at high mass scales.

The co-conveners have set up four **Task Forces**:

**Kaons** (Vincenzo Cirigliano, Steve Kettell)

**Charm** (Roy Briere, Alexey Petrov)

**B-physics** (Alan Schwartz, Tomasz Skwarnicki, Jure Zupan)

**Lattice QCD** (Norman Christ, Steve Sharpe, Ruth Van de Water)

## Parallel sessions at this meeting:

- Each Task Force organized a session
- A Joint session with Charged Leptons (theory and facilities overlap)
- Two discussion sessions

# Some History

- Quark flavor experiments were critical in the evolution of the Standard Model
  - Absence of  $K_L \rightarrow \mu\mu$  (aka GIM suppression) predicted charm
  - $\Delta m_K$  ( $K^0$ - $\bar{K}^0$  mixing) allowed Gaillard and Lee to predict the charm mass
  - Discovery of CP violation ( $K_L \rightarrow \pi\pi$ ) led KM to propose 3<sup>rd</sup> generation
  - Large  $\Delta m_B$  ( $B^0$ - $\bar{B}^0$  mixing) foretold the high mass of the top quark
- The U.S. HEP quark-flavor program was very successful.
  - CESR/CLEO led in B-physics for nearly two decades
  - BNL rare K decay experiments (1990's) set benchmarks not surpassed yet
  - *BABAR* at SLAC (along with Belle at KEK) made precision measurements of CP violation in agreement with the KM model (plus numerous other achievements)

# More History

- Yet, the U.S. HEP program has almost abandoned quark-flavor physics as an activity.
  - B-physics in hadronic interactions (BTeV) was not pursued at Fermilab
    - Now underway in LHCb at CERN
  - A precision measurement of  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  (CKM proposal) was not pursued at Fermilab
    - Now underway in NA62 at CERN
  - RSVP (including KOPIO for  $K_L \rightarrow \pi^0 \nu \bar{\nu}$ ) was abandoned (BNL).
    - Now underway in the KOTO experiment at JPARC in Japan
  - An upgrade of the PEP-II B-factory to high luminosity was not pursued at SLAC.
    - Now in progress with SUPERKEKB at KEK in Japan
- Where should the U.S. go from here?

# First Principle of Flavor Physics

$$\Delta E \Delta t \geq \frac{\hbar}{2}$$



Heavy particles, that cannot be produced directly, affect low energy processes.

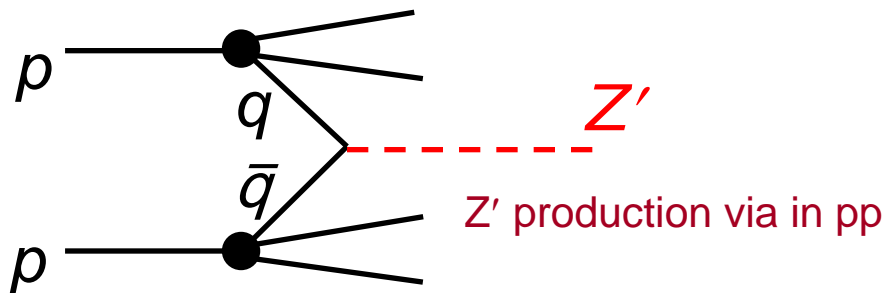
Classic example: beta decay

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8M_W^2}$$



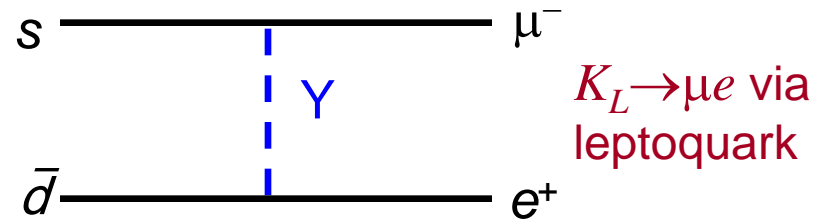
W boson of mass  $\sim 100$  GeV  
if  $g \approx e$

Direct Production



$$M_{\text{NP}} \approx E_{\text{parton}}^{\text{CM}} \approx 1 \text{ TeV for LHC}$$

Rare Decays



$$M_{\text{NP}} \approx 200 \text{ TeV} \left( \frac{10^{-12}}{\sqrt[4]{B}} \right)$$

# New Physics Flavor Problem

New Physics is constrained by  
flavor physics observables.  
E.g. mixing and CP violation.

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{C_{\text{NP}}}{\Lambda^2} O_{ij}$$

$\Delta F = 2$ operator	Bounds on $\Lambda$ [TeV] ( $C = 1$ )		Bounds on $C$ ( $\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L \gamma^\mu d_L)^2$	$9.8 \times 10^2$	$1.6 \times 10^4$	$9.0 \times 10^{-7}$	$3.4 \times 10^{-9}$	$\Delta m_K; \epsilon_K$
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	$1.8 \times 10^4$	$3.2 \times 10^5$	$6.9 \times 10^{-9}$	$2.6 \times 10^{-11}$	$\Delta m_K; \epsilon_K$
$(\bar{c}_L \gamma^\mu u_L)^2$	$1.2 \times 10^3$	$2.9 \times 10^3$	$5.6 \times 10^{-7}$	$1.0 \times 10^{-7}$	$\Delta m_D;  q/p , \phi_D$
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	$6.2 \times 10^3$	$1.5 \times 10^4$	$5.7 \times 10^{-8}$	$1.1 \times 10^{-8}$	$\Delta m_D;  q/p , \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	$5.1 \times 10^2$	$9.3 \times 10^2$	$3.3 \times 10^{-6}$	$1.0 \times 10^{-6}$	$\Delta m_{B_d}; S_{\psi K_S}$
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$(\bar{b}_L \gamma^\mu s_L)^2$	$1.1 \times 10^2$	$2.2 \times 10^2$	$7.6 \times 10^{-5}$	$1.7 \times 10^{-5}$	$\Delta m_{B_s}; S_{\psi \phi}$
$(\bar{b}_R s_L)(\bar{b}_L s_R)$	$3.7 \times 10^2$	$7.4 \times 10^2$	$1.3 \times 10^{-5}$	$3.0 \times 10^{-6}$	$\Delta m_{B_s}; S_{\psi \phi}$

From the Report of the Heavy Quarks working group, Fundamental Physics at the Intensity Frontier (2012), arXiv:1205.2671

If there is New Physics at the 1 TeV scale, its flavor structure is unnatural.

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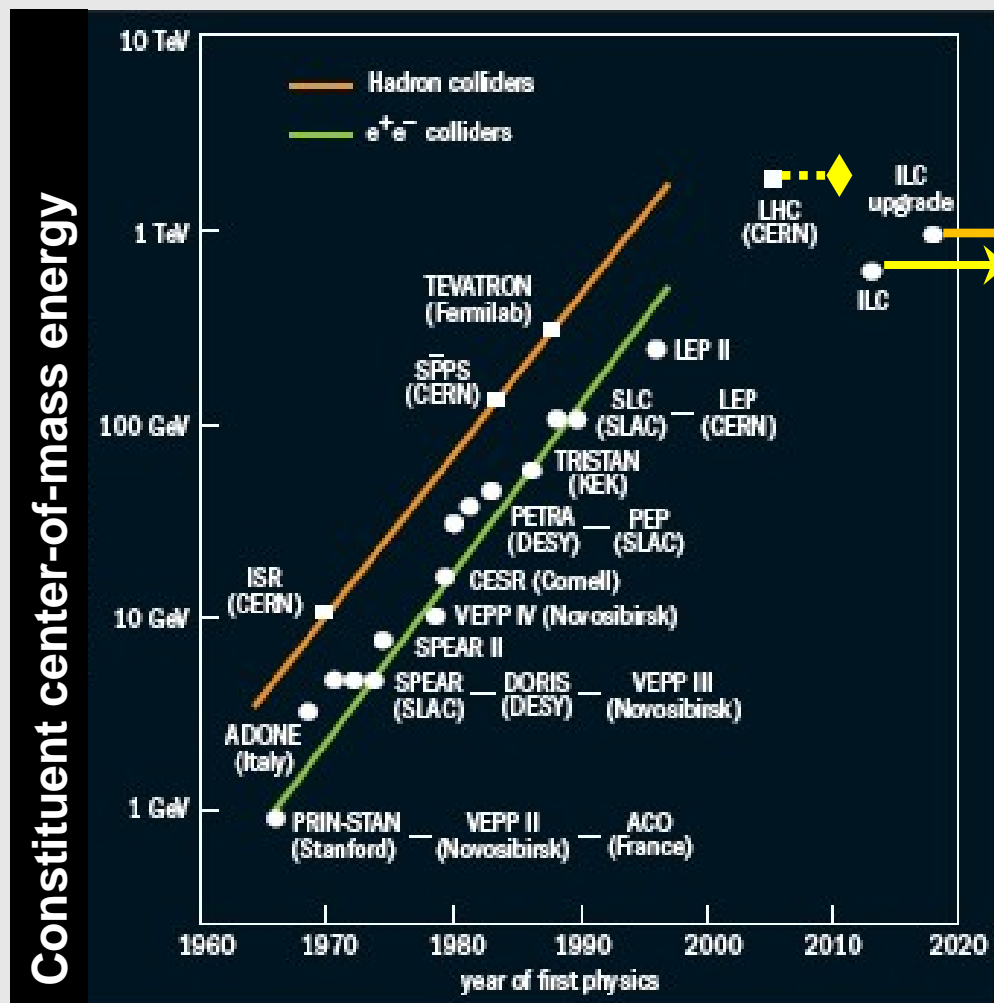
For New Physics with a “generic” flavor structure, the mass scale must be very high.

From the Report of the Heavy Quarks working group, Fundamental Physics at the Intensity Frontier (2012), arXiv:1205.2671

If there is New Physics at the 1 TeV scale, its flavor structure is unnatural.

# Physics Beyond the 1 TeV Scale ?

Within the reach of flavor physics



From L. Chatterjee, SciDAQ Review, Spring 2006

# Quark Flavor in the LHC Era

## New Physics found at LHC

⇒ New particles with unknown flavor- and CP-violating couplings

Precision flavor-physics expts will be needed sort out the flavor- and CP-violating couplings of the NP.

## New Physics NOT found at LHC

Precision flavor-physics expts will be needed since they are sensitive to NP at mass scales beyond the LHC.

Precision quark-flavor experiments (and lepton-flavor too) are essential.

A healthy U.S. HEP program will include a vigorous flavor-physics component (like Europe and Asia).

# The Experimental Quark Flavor Program

## Kaons

- KLOE-2
- NA62
- TREK
- KOTO
- ORKA
- Project X experiments

## B-physics

- Belle II
- LHCb + Upgrade
- ATLAS/CMS

## Charm

- Belle II
- LHCb
- ATLAS/CMS
- BESIII
- Panda
- Future  $\tau/c$  factories

There is not time to discuss everything in this talk.

# The Experimental Quark Flavor Program

## Kaons

- KLOE-2
- NA62
- TREK
- KOTO

- ORKA
- Project X experiments

Proposed  
in U.S.

## B-physics

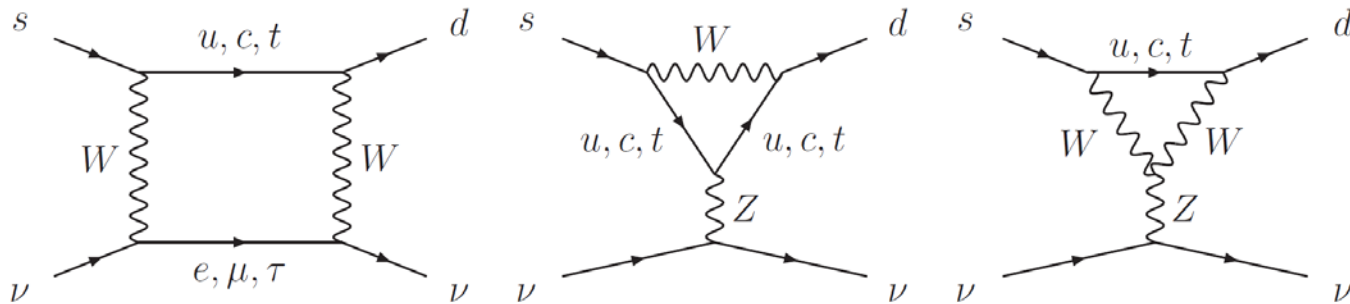
- Belle II
- LHCb + Upgrade
- ATLAS/CMS

## Charm

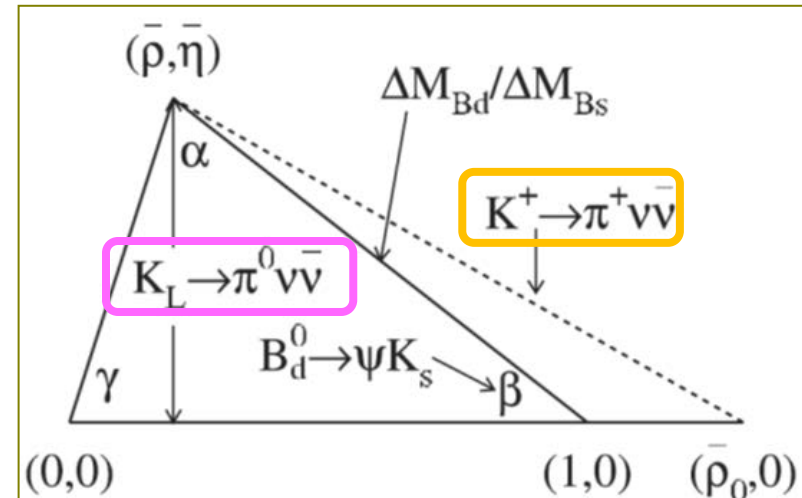
- Belle II
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# $K \rightarrow \pi \nu \bar{\nu}$ in the Standard Model



- A single effective operator  
 $(\bar{s}_L \gamma^\mu d_L)(\bar{\nu}_L \gamma_\mu \nu_L)$
- Dominated by top quark
- Hadronic matrix element shared with  $K \rightarrow \pi e \nu$
- Standard Model predictions precise

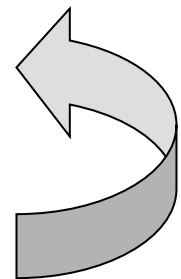


$$B(K^+ \rightarrow \pi^+ \nu \bar{\nu})_{\text{SM}} = (7.8 \pm 0.8) \times 10^{-11}$$

$$B(K_L^0 \rightarrow \pi^0 \nu \bar{\nu})_{\text{SM}} = (2.4 \pm 0.4) \times 10^{-11}$$

Brod, Gorbahn, and Stamou, PR D **83**, 034030(2011)

$$\begin{aligned} \pm 10\% &\Rightarrow \pm 5\% \\ \pm 16\% &\Rightarrow \pm 11\% \end{aligned}$$

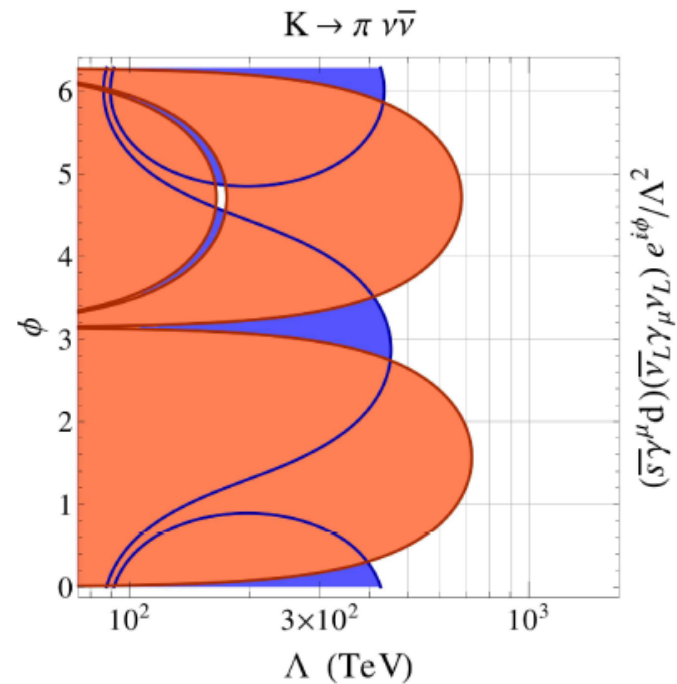
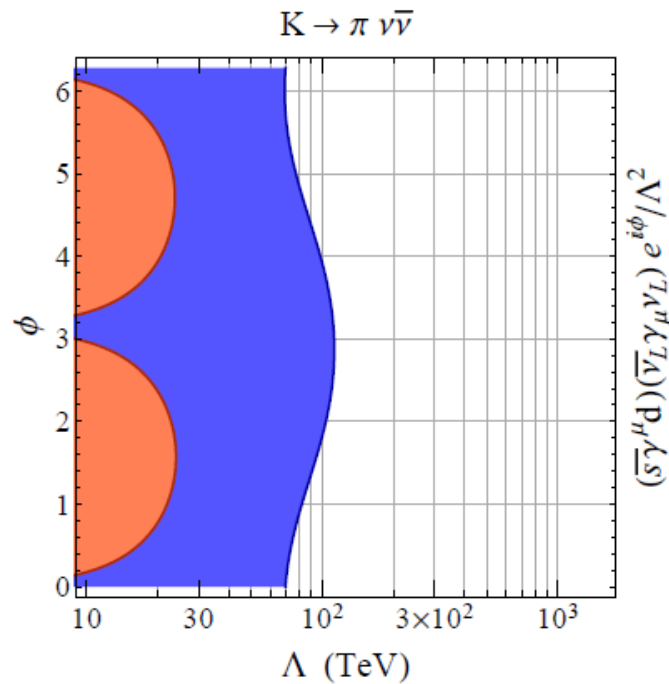


- Largest uncertainty from CKM elements (which will improve)
- Remains clean in New Physics models

$$(\overline{s}\gamma^\mu d)(\overline{\nu}_L\gamma_\mu\nu_L) e^{i\phi}/\Lambda^2$$

current situation

assuming 5% measurements of both modes

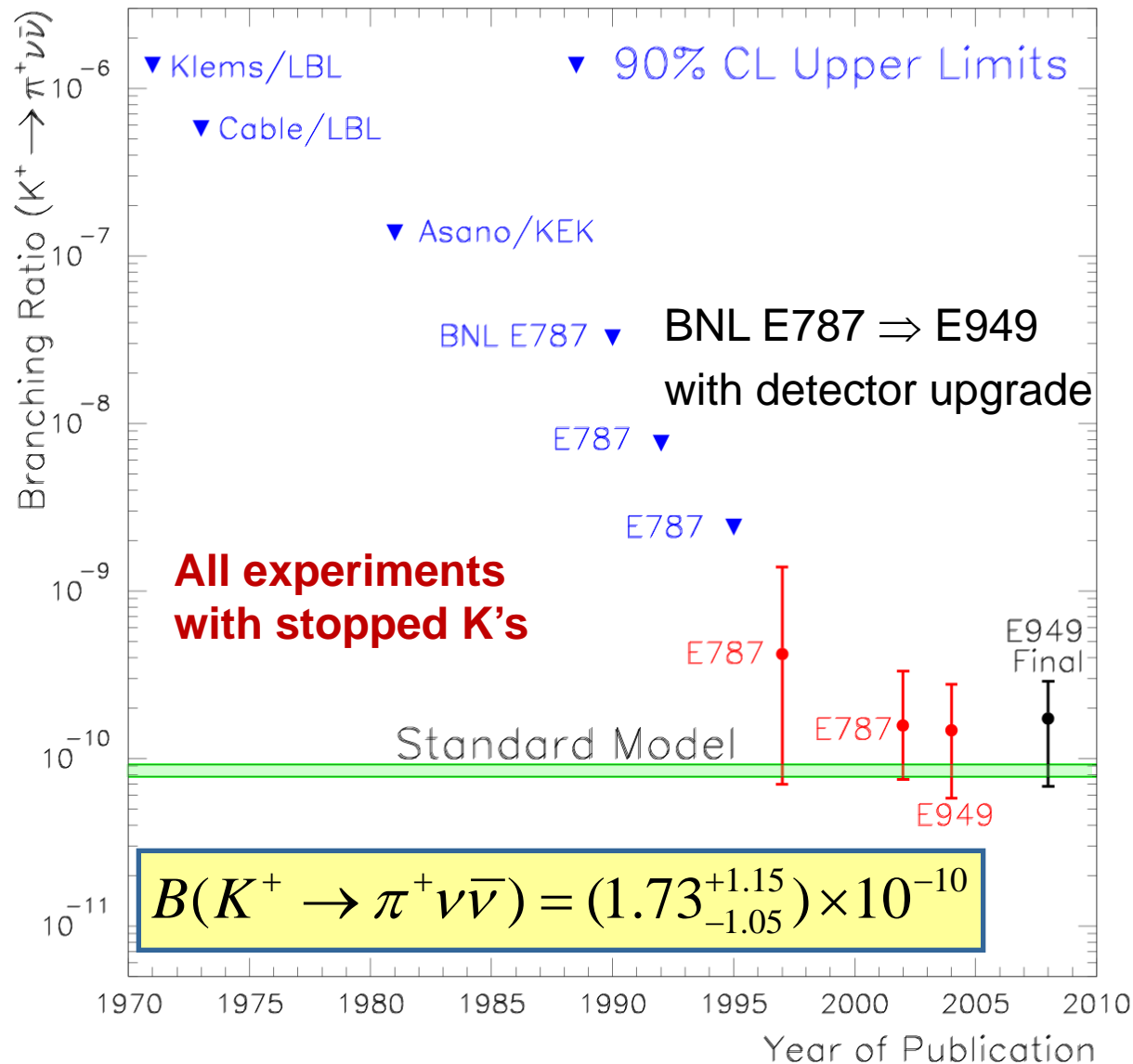


- ▶  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  already constrains scales of  $\sim 100$  TeV
- ▶  $K_L \rightarrow \pi^0 \nu \bar{\nu}$  bound still above the Grossman-Nir bound  
→ no additional constraint

- ▶  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  and  $K_L \rightarrow \pi^0 \nu \bar{\nu}$  give complementary information
- ▶ scales of order 700 TeV are probed

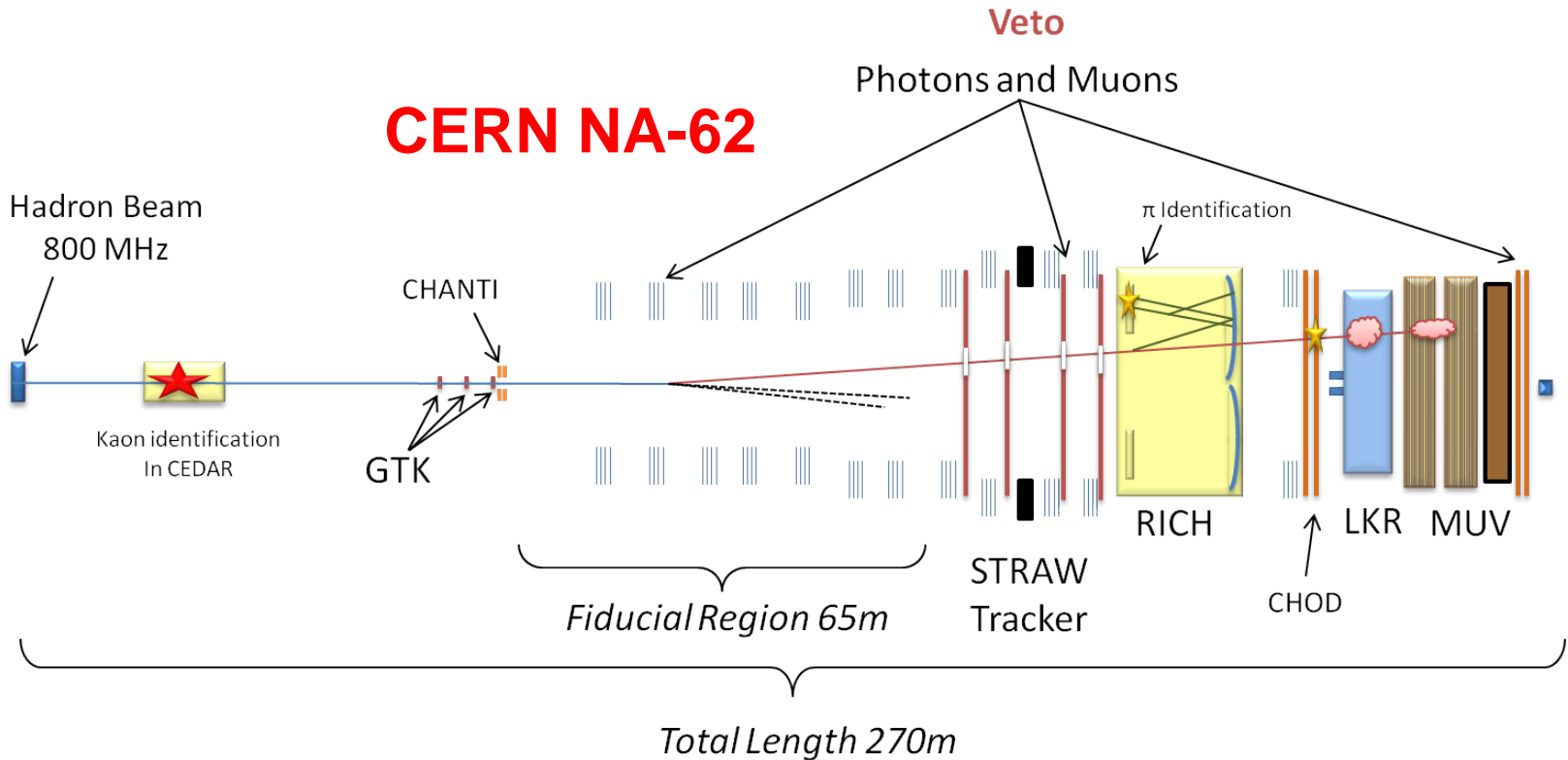
Slide from Wolfgang Altmannshofer's talk

# $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ History



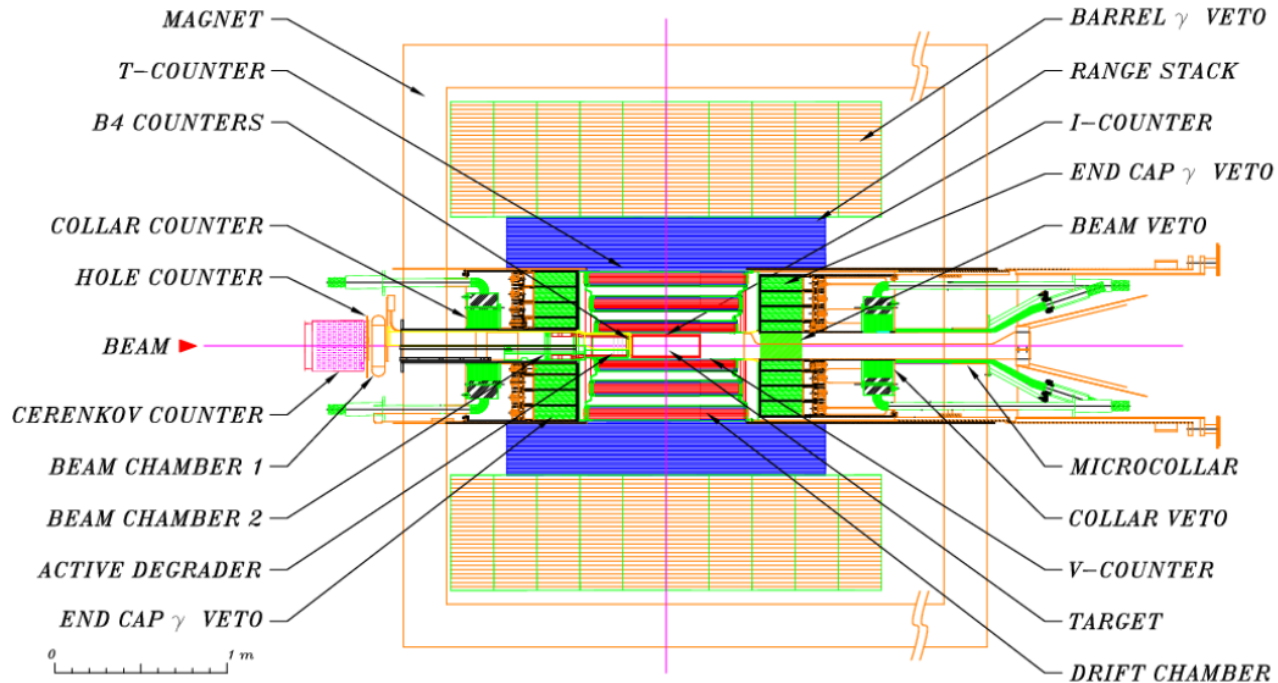
BNL E787/949  
observed a  
total of 7 signal  
events.

# $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at CERN



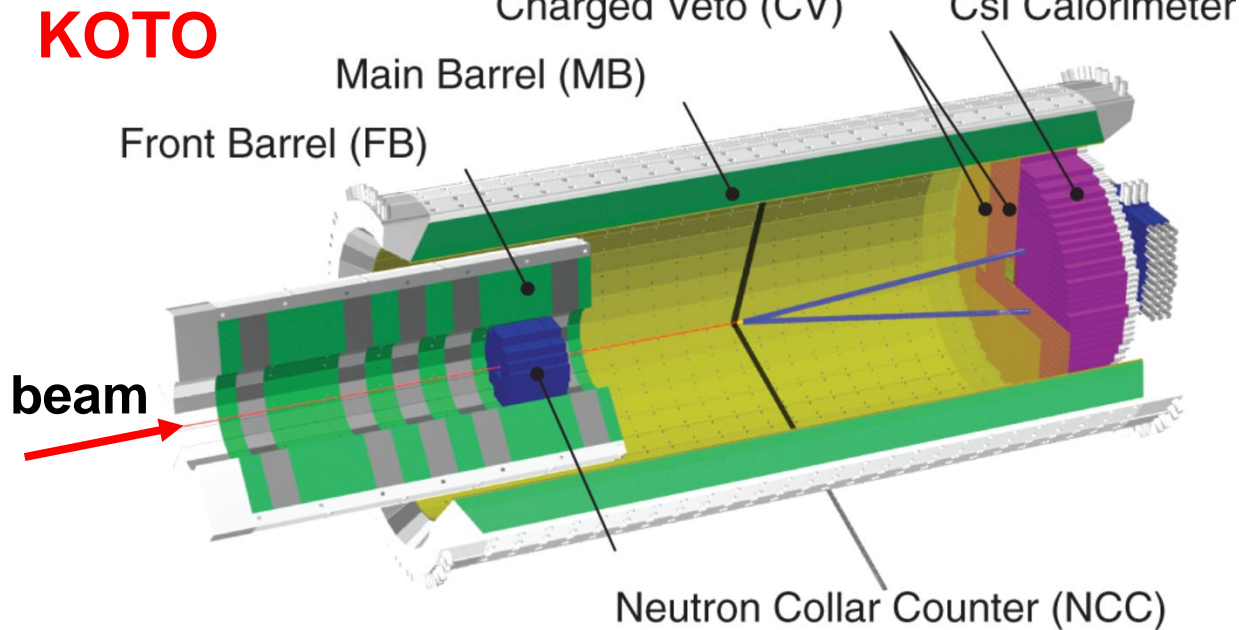
- Evolution of long-established program (NA31, NA48)
- First attempt for this mode with decays-in-flight
- Un-separated charged beam (75 GeV)  $\Rightarrow$  ambitious “gigatracker” in beam to measure incoming  $K^+$ ; straw tracking in vacuum for  $\pi^+$
- Goal to collect  $\approx 50$  events/yr at SM level
- First data in 2014

# $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at Fermilab



- Will employ the proven technique (stopped K) from BNL E787/949, with beam, detector, and data acquisition improvements
  - Goal to collect 1000 events,  $\sim 200$  events per year (error  $\cong$  theory)
  - Does not require better background rejection than E949
- Will utilize existing facilities and infrastructure at FNAL (Main Injector protons, B0/CDF Hall, CDF superconducting solenoid)

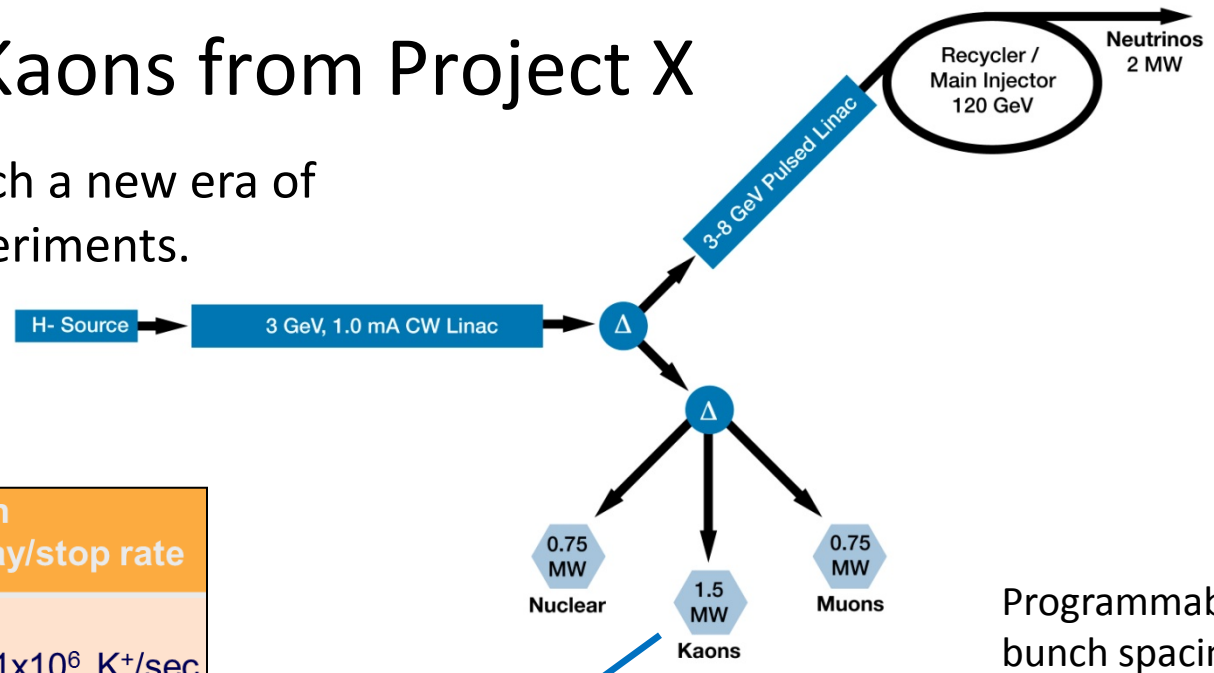
# $K_L \rightarrow \pi^0 \nu \bar{\nu}$ at J-PARC



- “Pencil beam”, search for  $\pi^0 \rightarrow \gamma\gamma$  with  $p_T$  beyond max  $p_T$  of other modes
- Evacuated detector volume to suppress beam  $n$  interactions
- Hermetic photon veto system, augmented with CsI from FNAL KTeV
- Builds on KEK E391a experience  $B(K_L^0 \rightarrow \pi^0 \nu \bar{\nu}) < 6.7 \times 10^{-8}$  (90% C.L.)
  - KOTO has higher intensity ( $\times 40$ ), cleaner beam ( $n/K_L \times 0.3$ )
- First Physics run 2013; Phase 1 goal – 3.5 events at SM BF ( $\sim 2017$ ); Phase 2 goal – beamline/detector upgrade to reach 100 SM events

# Kaons from Project X

Project X will launch a new era of high-intensity experiments.



Facility (Experiment)	Proton Power	Kaon Decay/stop rate
BNL AGS (E787/E949):	50kW	$1 \times 10^6$ K <sup>+</sup> /sec
CERN (NA62):	20kW	$10 \times 10^6$ K <sup>+</sup> /sec
Fermilab: (ORKA):	75kW	$15 \times 10^6$ K <sup>+</sup> /sec
Project-X K <sup>+</sup> → π ν ν	1500 kW	$100 \times 10^6$ K <sup>+</sup> /sec
JPARC (KOTO):	<300 kW	< $0.5 \times 10^6$ K <sub>L</sub> /sec
Project-X K <sub>L</sub> → π ν ν	1500kW	$50 \times 10^6$ K <sub>L</sub> /sec

3 GeV protons ( $\sim 3 \times 10^{15} \text{ s}^{-1}$ )



Good extinction between bunches.

20 MHz structure  
40 ps bunch width

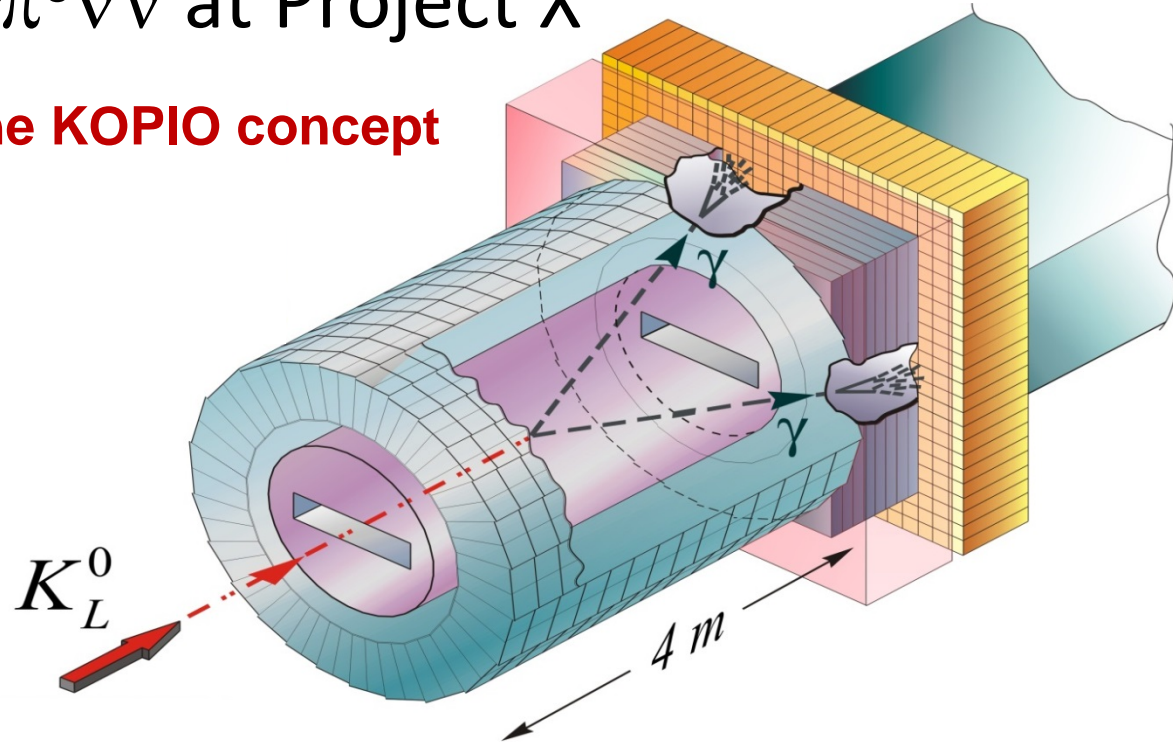
Simultaneous neutrino, muon, kaon, and nuclear physics experiments with unprecedented fluxes.

From R. Tschirhart

# $K_L \rightarrow \pi^0 \nu \bar{\nu}$ at Project X

**Based on the KOPIO concept**

- Project-X beam energy is well-suited
- CW-linac time structure supports time-of-flight measurement
  - Provides kinematic info for background rejection
- High intensity from Project-X allows small beam (like KOTO)
  - 2-dimn constraint provides additional background rejection
- Reconstruct  $\pi^0 \rightarrow \gamma\gamma$  with a pointing calorimeter
- $4\pi$  photon and charged particle vetos
- Provides opportunity for a high statistics ( $\sim 1000$  event) measurement



# Kaon Projections

## a few K observables

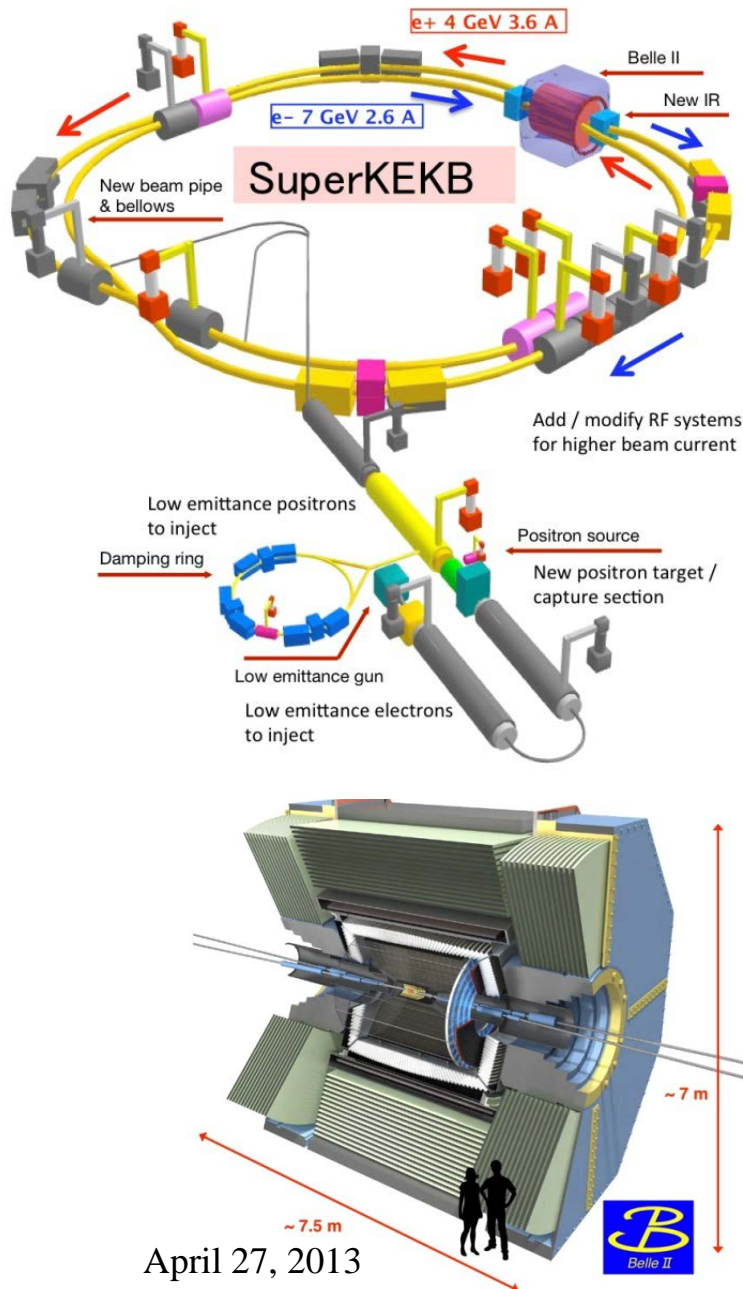
Observable	SM Theory	Current Expt.	Future Experiments
$\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$	$7.8 \times 10^{-11}$	$1.73_{-1.05}^{+1.15} \times 10^{-10}$	$\sim 10\%$ measurement from NA62 $\sim 5\%$ measurement from ORKA $\sim 2\%$ with Project X
$\mathcal{B}(K_L^0 \rightarrow \pi^0 \nu \bar{\nu})$	$2.43 \times 10^{-11}$	$< 2.6 \times 10^{-8}$	1 <sup>st</sup> observation from KOTO $\sim 5\%$ measurement with Project X
$\mathcal{B}(K_L^0 \rightarrow \pi^0 e^+ e^-)_{SD}$	$1.4 \times 10^{-11}$	$< 2.8 \times 10^{-10}$	$\sim 10\%$ measurement with Project X
$\mathcal{B}(K_L^0 \rightarrow \pi^0 \mu^+ \mu^-)_{SD}$	$3.5 \times 10^{-11}$	$< 3.8 \times 10^{-10}$	$\sim 10\%$ measurement with Project X
$ P_T $ in $K^+ \rightarrow \pi^0 \mu^+ \nu$	$\sim 10^{-7}$	$< 0.0050$	$< 0.0003$ from TREK $< 0.0001$ with Project X
$R_K = \Gamma(K_{e2})/\Gamma(K_{\mu2})$	$2.477 \times 10^{-5}$	$(2.488 \pm 0.080) \times 10^{-5}$	$\pm 0.054 \times 10^{-5}$ from TREK $\pm 0.025 \times 10^{-5}$ with Project X
$\mathcal{B}(K_L^0 \rightarrow \mu^\pm e^\mp)$	$< 10^{-25}$	$< 4.7 \times 10^{-12}$	$< 2 \times 10^{-13}$ with Project X

From the Report of the Heavy Quarks working group, Fundamental Physics at the Intensity Frontier (2012), arXiv:1205.2671

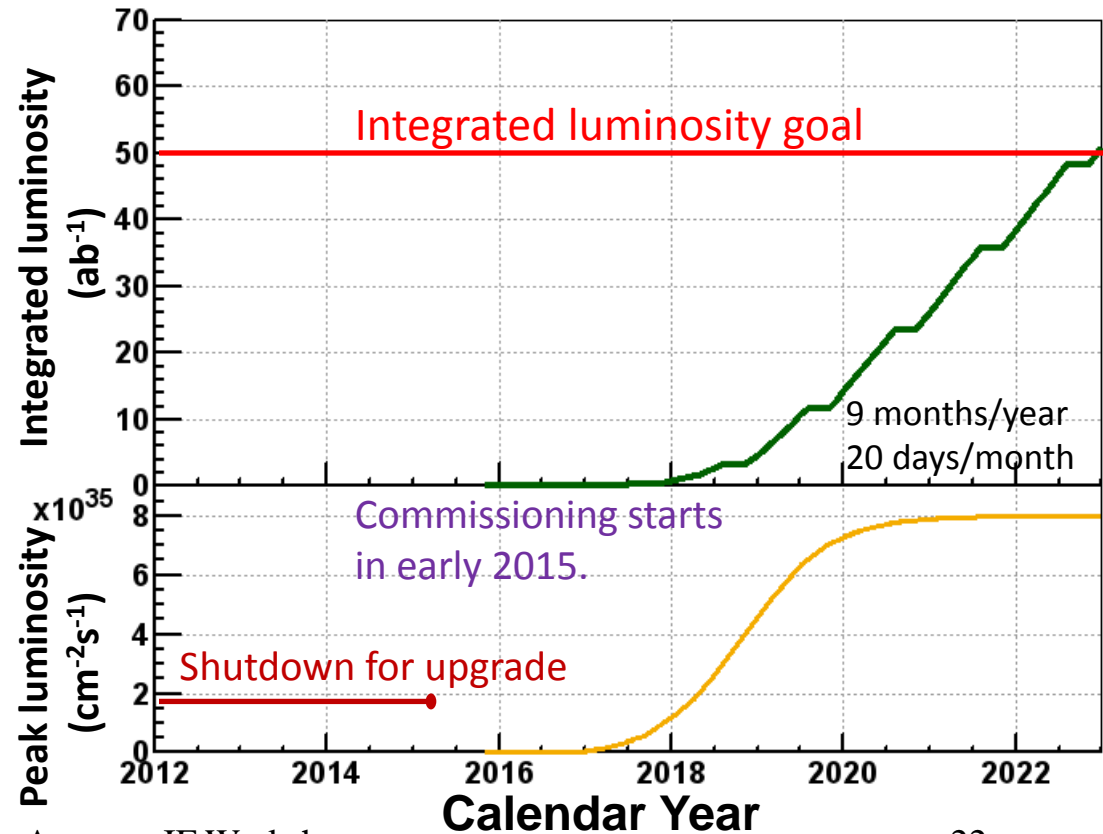
# SuperKEKB and Belle II

Major upgrades of the Japanese B-factory and detector are in progress.

- Peak  $L \rightarrow 8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$  ( $\sim 40 \times \text{KEKB}$ )
- Integrated  $L \rightarrow 50 \text{ ab}^{-1}$  by end of 2022 ( $\sim 5 \times 10^{10} \text{ B}\bar{\text{B}}$  pairs)



April 27, 2013



Argonne IF Workshop

# Projections for Belle II

a few B observables

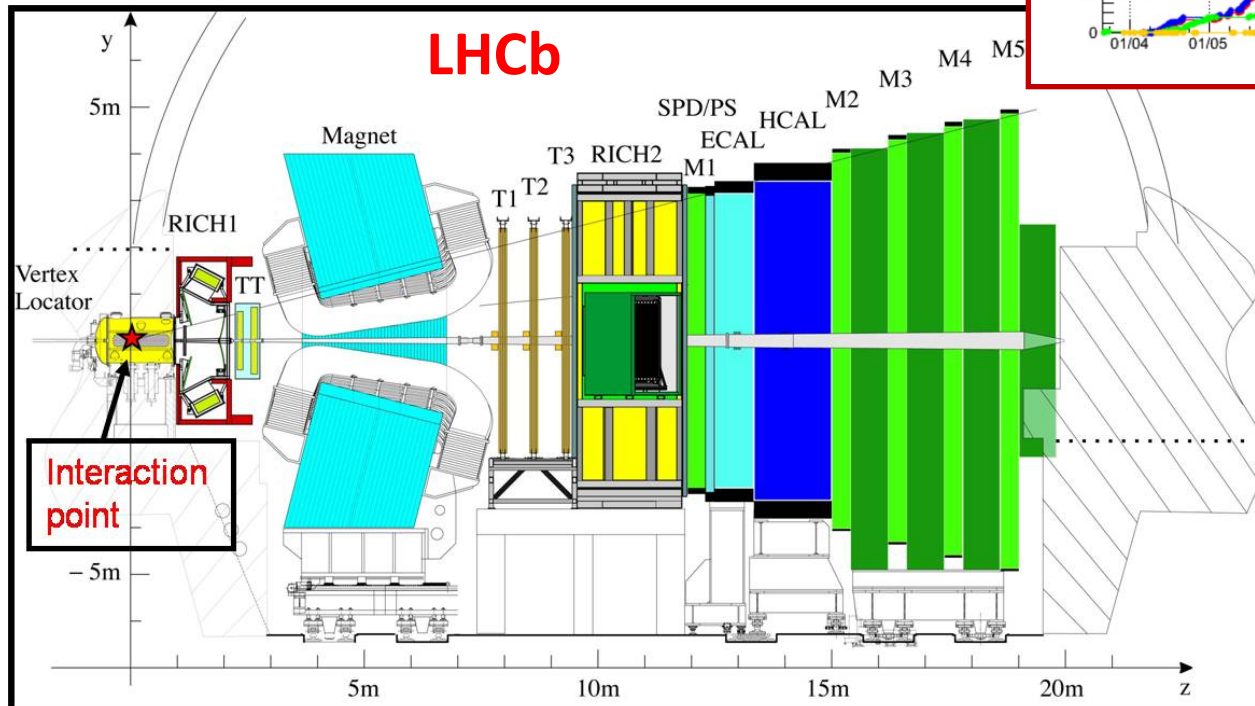
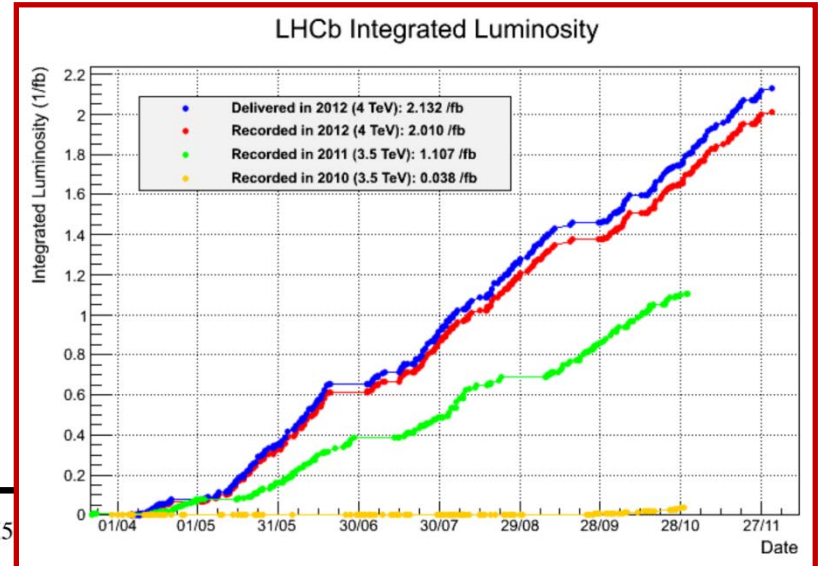
assumes 50 ab<sup>-1</sup>

Observable	SM Theory	Current Expt.	Super Flavor Factories
$S(B \rightarrow \phi K^0)$	0.68	$0.56 \pm 0.17$	$\pm 0.03$
$S(B \rightarrow \eta' K^0)$	0.68	$0.59 \pm 0.07$	$\pm 0.02$
$\gamma$ from $B \rightarrow DK$		$\pm 11^\circ$	$\pm 1.5^\circ$
$A_{\text{SL}}$	$-5 \times 10^{-4}$	$-0.0049 \pm 0.0038$	$\pm 0.001$
$S(B \rightarrow K_S \pi^0 \gamma)$	$< 0.05$	$-0.15 \pm 0.20$	$\pm 0.03$
$S(B \rightarrow \rho \gamma)$	$< 0.05$	$-0.83 \pm 0.65$	$\pm 0.15$
$A_{\text{CP}}(B \rightarrow X_{s+d} \gamma)$	$< 0.005$	$0.06 \pm 0.06$	$\pm 0.02$
$\mathcal{B}(B \rightarrow \tau \nu)$	$1.1 \times 10^{-4}$	$(1.64 \pm 0.34) \times 10^{-4}$	$\pm 0.05 \times 10^{-4}$
$\mathcal{B}(B \rightarrow \mu \nu)$	$4.7 \times 10^{-7}$	$< 1.0 \times 10^{-6}$	$\pm 0.2 \times 10^{-7}$
$\mathcal{B}(B \rightarrow X_s \gamma)$	$3.15 \times 10^{-4}$	$(3.55 \pm 0.26) \times 10^{-4}$	$\pm 0.13 \times 10^{-4}$
$\mathcal{B}(B \rightarrow X_s \ell^+ \ell^-)$	$1.6 \times 10^{-6}$	$(3.66 \pm 0.77) \times 10^{-6}$	$\pm 0.10 \times 10^{-6}$
$\mathcal{B}(B \rightarrow K \nu \bar{\nu})$	$3.6 \times 10^{-6}$	$< 1.3 \times 10^{-5}$	$\pm 1 \times 10^{-6}$
$A_{\text{FB}}(B \rightarrow K^* \ell^+ \ell^-)_{q^2 < 4.3 \text{ GeV}^2}$	-0.09	$0.27 \pm 0.14$	$\pm 0.04$

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# LHCb Upgrade

- $3 \text{ fb}^{-1}$  recorded so far at 7-8 TeV
- 5-7  $\text{fb}^{-1}$  expected at 13 TeV by 2018
- $50 \text{ fb}^{-1}$  long-term goal requires upgrade
- Major upgrade planned for installation during the 2018 LHC shutdown



- Replacement or upgrade of most detector systems.
- Trigger change to readout at 40 MHz, then software filter.
- Then  $5 \text{ fb}^{-1}/\text{yr}$

# LHCb Projections

**Needs update**

Observable	Precision as of 2011	LHCb (5 fb <sup>-1</sup> )	Upgrade (50 fb <sup>-1</sup> )
$\phi_s(B_s \rightarrow J/\psi\phi)$	0.16	0.019	0.006
$S(B_s \rightarrow \phi\phi)$	—	0.08	0.02
$S(B_s \rightarrow K^{*0}\bar{K}^{*0})$	—	0.07	0.02
$\beta(B^0 \rightarrow J/\psi K^0)$	1°	0.5°	0.2°
$S(B^0 \rightarrow \phi K_S^0)$	0.17	0.15	0.03
$\gamma(B \rightarrow D^{(*)}K^{(*)})$	$\sim 20^\circ$	$\sim 4^\circ$	0.9°
$\gamma(B \rightarrow D_s K)$	—	$\sim 7^\circ$	1.5°
$B(B_s \rightarrow \mu^+\mu^-)$	—	30%	8%
$B(B^0 \rightarrow \mu^+\mu^-)/B(B_s \rightarrow \mu^+\mu^-)$	—	—	$\sim 35\%$
$S(B_s \rightarrow \phi\gamma)$	—	0.07	0.02
$A^{\Delta\Gamma_s}(B_s \rightarrow \phi\gamma)$	—	0.14	0.03
$A_T^2(B^0 \rightarrow K^{*0}\mu^+\mu^-)$	—	0.14	0.04
$s_0 A_{FB}(B^0 \rightarrow K^{*0}\mu^+\mu^-)$	—	4%	1%

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# Charm in B-physics Experiments

Charm production exceeds B production at LHC and in  $e^+e^-$  at the  $Y(4S)$ .  
⇒ LHCb and Belle II will have unprecedented charm data samples.

- Rich program of charm studies “for free”
- Belle II and LHCb will make large improvements on mixing, CPV tests, rare decays, ...

E.g., improvements in charm mixing measurements.

Observable	Current Expt.	LHCb (5 fb <sup>-1</sup> )	Super Flavor Factories (50 ab <sup>-1</sup> )	LHCb Upgrade (50 fb <sup>-1</sup> )
$x$	$(0.63 \pm 0.20)\%$	$\pm 0.06\%$	$\pm 0.02\%$	$\pm 0.02\%$
$y$	$(0.75 \pm 0.12)\%$	$\pm 0.03\%$	$\pm 0.01\%$	$\pm 0.01\%$
$y_{CP}$	$(1.11 \pm 0.22)\%$	$\pm 0.02\%$	$\pm 0.03\%$	$\pm 0.01\%$
$ q/p $	$0.91 \pm 0.17$	$\pm 0.085$	$\pm 0.03$	$\pm 0.03$
$\arg(q/p)$	$(-10.2 \pm 9.2)^\circ$	$\pm 4.4^\circ$	$\pm 1.4^\circ$	$\pm 2.0^\circ$

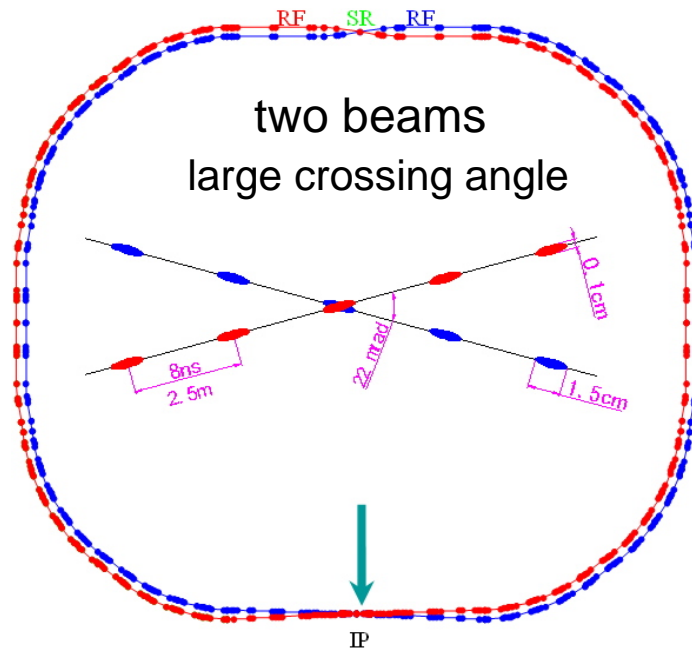
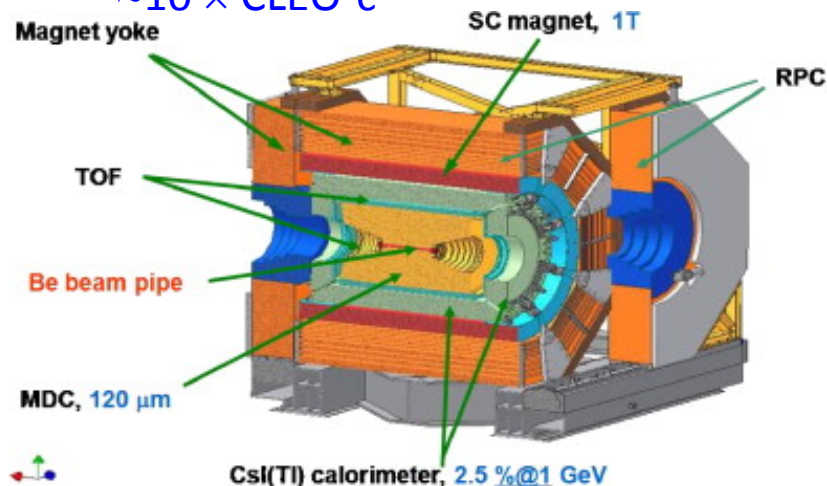
From the Report of the Heavy Quarks working group, Fundamental Physics at the Intensity Frontier (2012), arXiv:1205.2671

# Charm in Tau/Charm Factories

- BES-III underway at BEPCII (Beijing)

- Peak lumi =  $0.65 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

- $\sim 10 \times \text{CLEO-c}$



- Broad program: charmonium spectroscopy, charm physics, ...
  - $\psi(3770) \rightarrow D\bar{D}$  provides pair in entangled quantum state (tagging, mixing)
- Expected to run for about 10 years
- Other tau/charm factories under development/discussion
  - BNP Super  $c/\tau$  Factory (Novosibirsk); Italy post-SuperB cancellation; Turkey
- Complementary approach  $\bar{p}p \rightarrow c\bar{c}$  in Panda at FAIR (GSI, Darmstadt)
  - Operational  $\sim 2017$

# The Role of Theory / Lattice QCD

- Theory is an essential part of the quark-flavor program, including Lattice QCD which provides nonperturbative QCD calculations of key parameters.
  - Data stimulates theoretical work, and new theory ideas identify useful new observables.
- The case for quark-flavor experiments does not depend on future theory progress, but theoretical progress will strengthen the program by increasing the set of observables that can be used to search for new physics (e.g., “golden modes”).
- Lattice calculations of many basic parameters (e.g., meson decay constants ( $f_K/f_\pi$ ), semi-leptonic form factors ( $f^+(0)$  in  $K_{l3}$ ), bag parameter  $B_K$ ), have reached the 1% level.
- Lattice is beginning to address more difficult problems that will be extremely important for flavor physics. E.g., hadronic contribution to muon g-2, long-distance contribution to  $K_L \rightarrow \pi^0 e^+ e^-$ ,  $D \rightarrow \pi\pi$ ,  $D \rightarrow KK$ ,  $D\bar{D}$  mixing, form factors for  $B \rightarrow K l^+ l^-$  and  $B \rightarrow \pi l^+ l^-$ , ...

# Tentative Outline for QFP Report

**Any outline is tentative before actual writing has been done.**

## 1 Quark Flavor Physics at the Intensity Frontier

- 1.1 Executive Summary . . . . .
- 1.2 Quark Flavor as a Tool for Discovery . . . . .
- 1.3 Update of the Heavy Quarks Report . . . . .
- 1.4 Elements of a Quark Flavor Physics Program . . . . .
  - 1.4.1 Kaons . . . . .
  - 1.4.2 B-physics . . . . .
  - 1.4.3 Charm . . . . .
  - 1.4.4 The Role of Theory . . . . .
  - 1.4.5 Lattice QCD . . . . .
- 1.5 Future Facilities and Experiments for Quark Flavor Facilities . . . .
- 1.6 A U.S. Plan for Quark Flavor Physics . . . . .
  - 1.6.1 Opportunities in the Remainder of This Decade . . . . .
  - 1.6.2 Opportunities in the Next Decade . . . . .
  - 1.6.3 Conclusion . . . . .

# Message for Snowmass

- Flavor physics probes far above the TeV scale.
  - A necessary complement to LHC if new physics is found there.
  - Probes above the reach of LHC and other foreseeable machines.
- Existing facilities at Fermilab can support unparalleled rare K decay experiments (ORKA, and potentially others).
  - A cost effective way to mount quark-flavor experiments in **this** decade with significant potential to uncover new physics.
  - This opportunity is not open-ended (the world won't wait).
- Project X can open a new regime of sensitivity for rare K decay experiments in the next decade.
  - An order of magnitude beyond other kaon sources in the world.
- B-physics and charm physics will be led by non-U.S. programs for the foreseeable future.
  - These programs will do great physics! The U.S. should be actively involved in these experiments (Belle II and LHCb).