

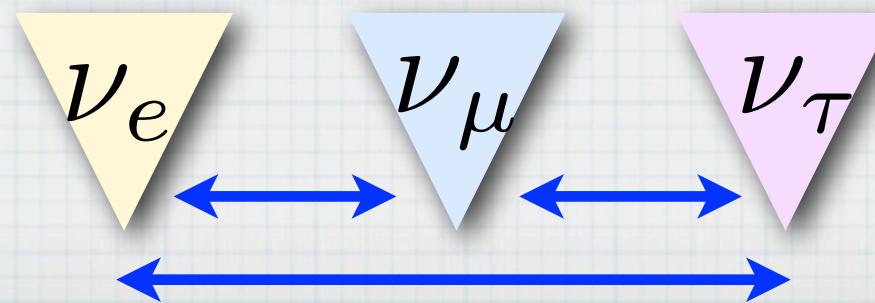
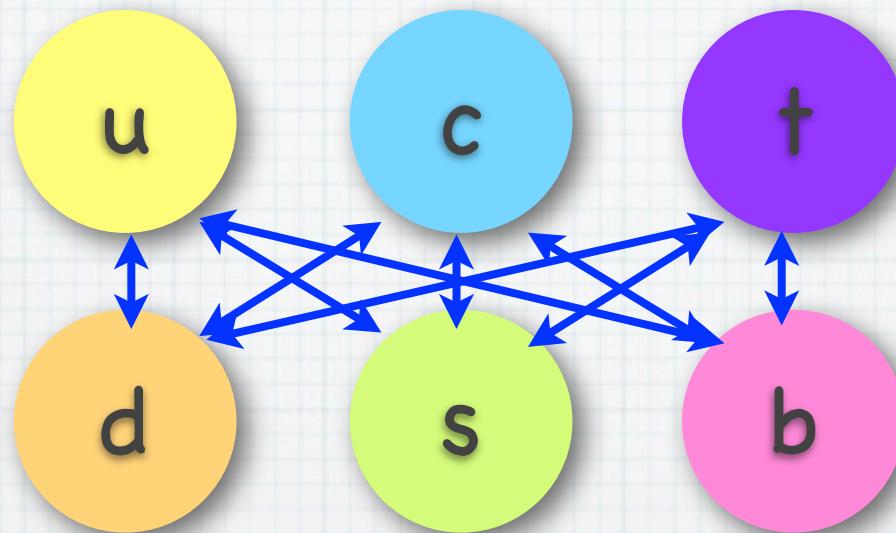
# Future Facilities II: Future of Flavor Physics

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Taku Yamanaka  
Osaka University

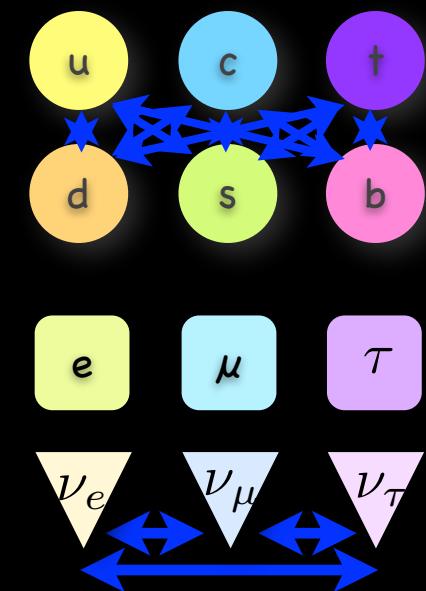
2013-06-27  
Lepton Photon 2013 @San Francisco

# Flavors in Standard Model



# New Physics Beyond the Standard Model

- \* CP violation in universe?
- \* dark matter?
- \* neutrino mass?
- \* why 3 generations?
- \* ...



# New Physics Beyond the Standard Model

- \*  $\Delta E \times \Delta t \sim h$
- \* Look for
  - \* reactions prohibited by SM
  - \* deviations from SM
- \* High sensitivity experiments at high intensity facilities

# New Physics Probe: B-mesons

# B-factories

- \* BABAR and Belle
  - \* Established CP violation in SM
  - \* Measured CKM matrix parameters, ...
- \* LHCb
  - \*  $D^0$  mixing,  $\gamma$ , ...
- \* CDF
  - \*  $B_s$  mixing

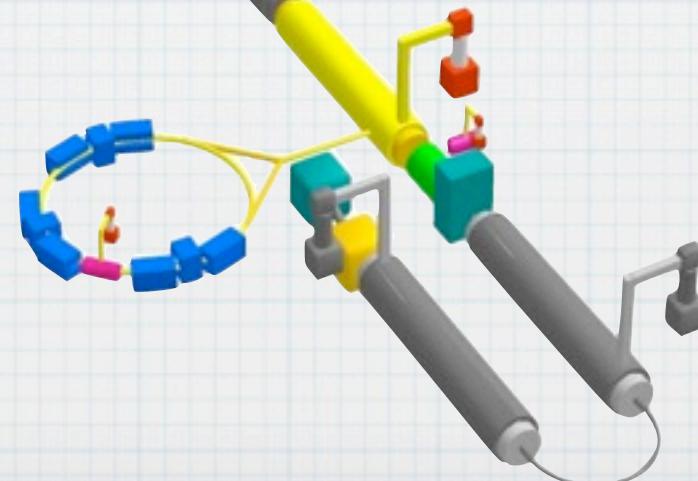
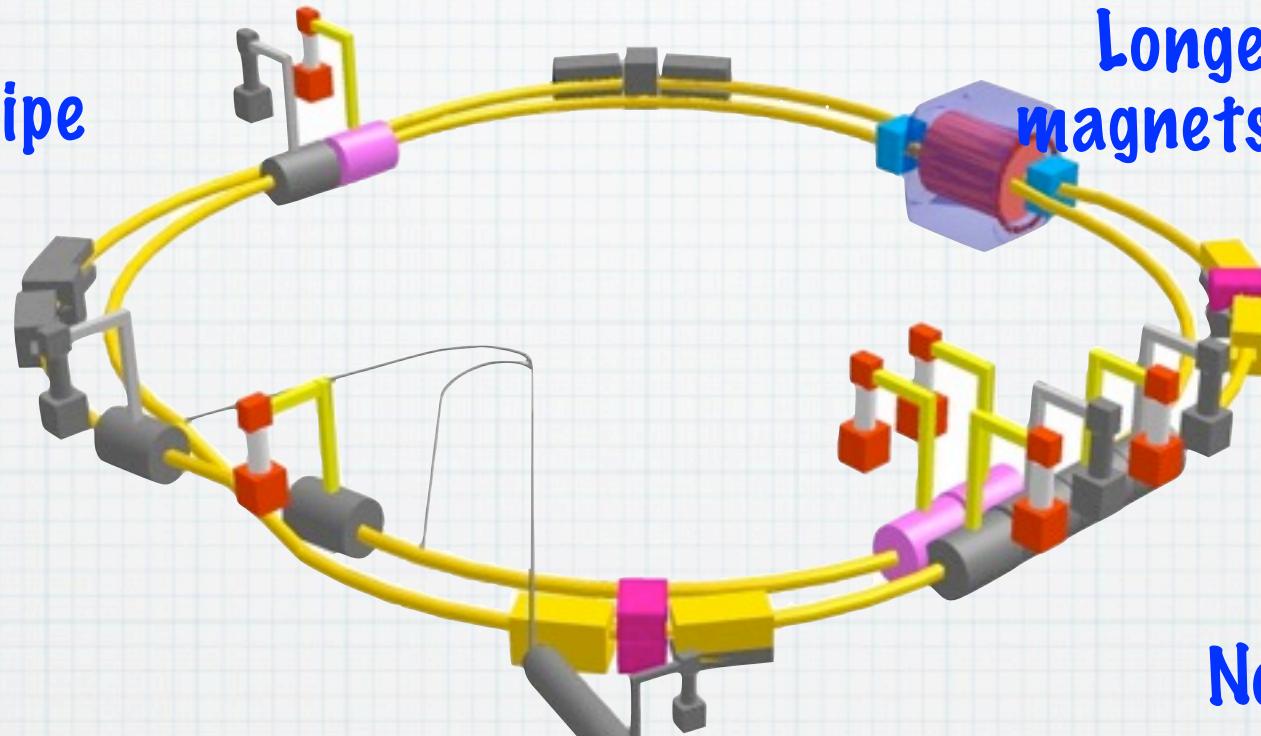
# SuperKEKB

New beam pipe

Longer bending  
magnets for 4GeV  $e^+$

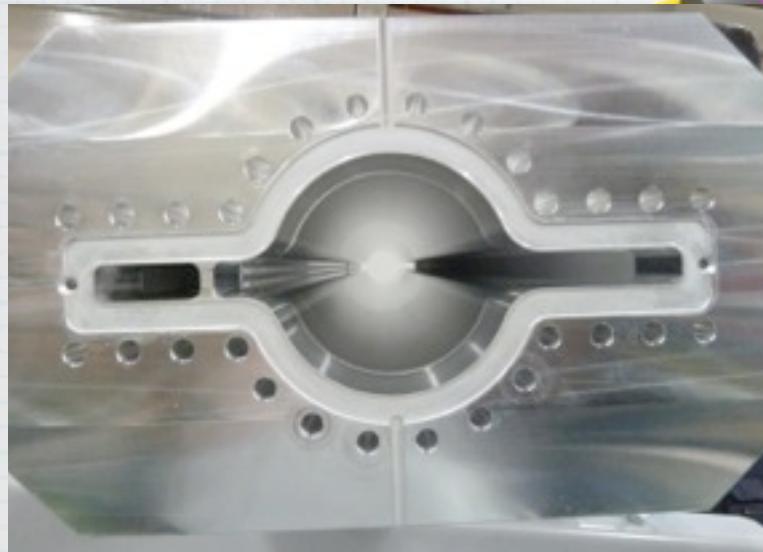
New RF

New damping ring

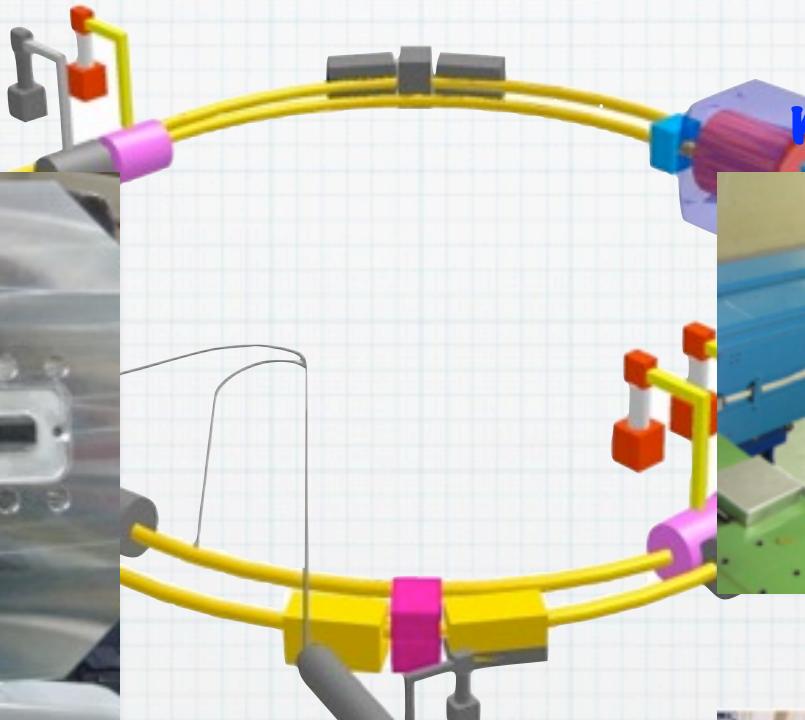


# SuperKEKB

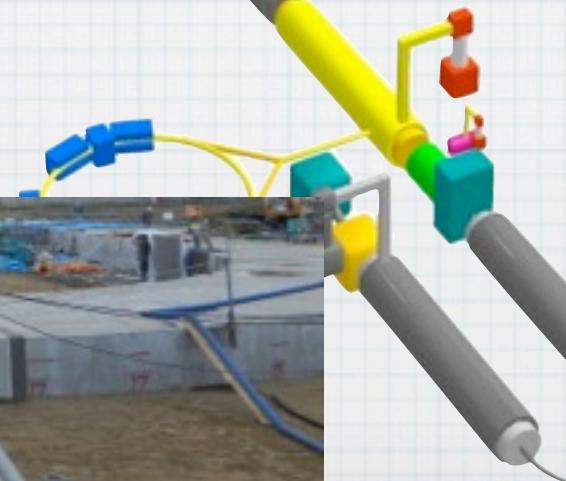
New beam pipe



Longer bending  
magnets for 4GeV e<sup>+</sup>



New damping ring

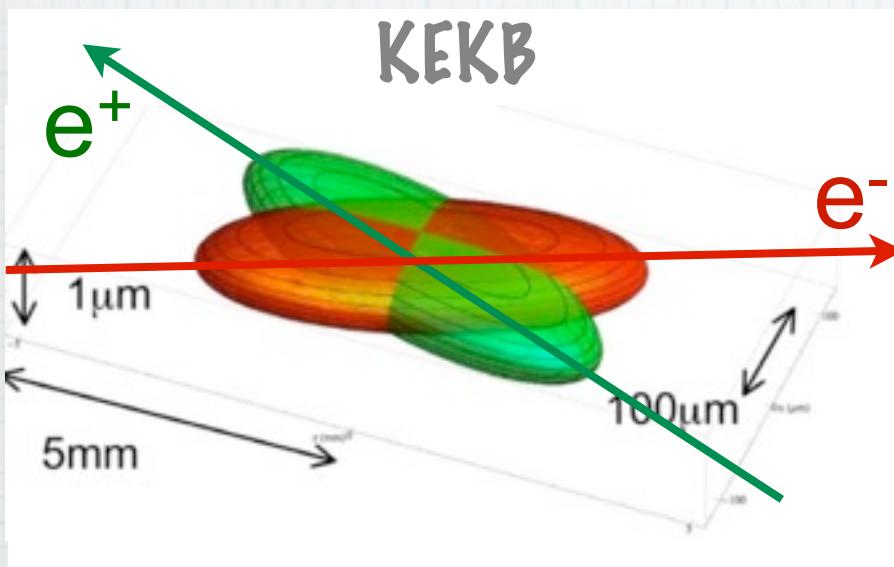


New RF



# SuperKEKB Interaction Region

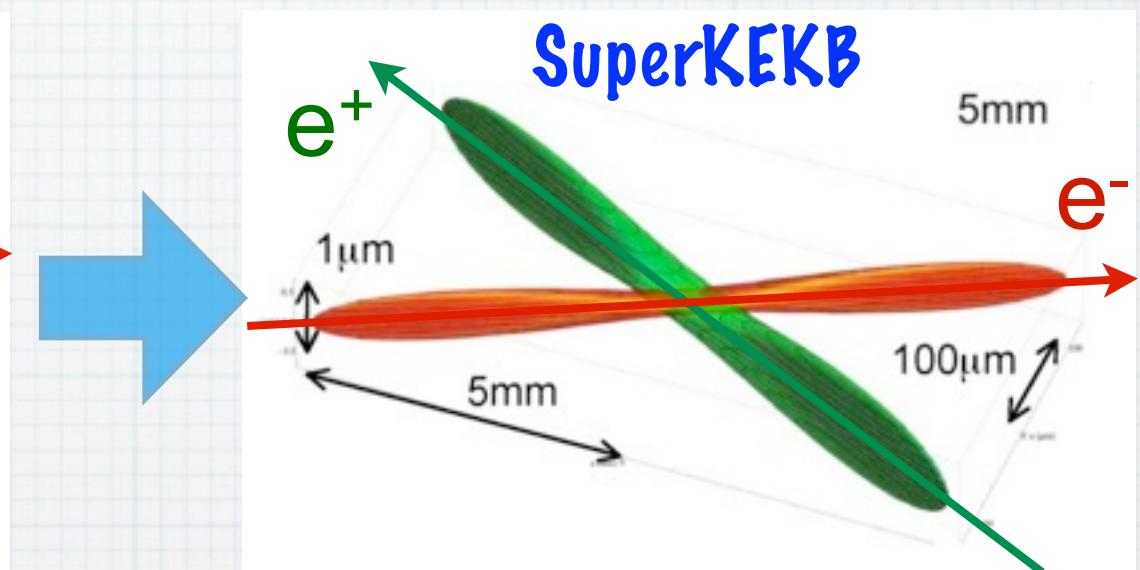
- \* Nano-Beam (for SuperB)



$100\mu\text{m} \times 2\mu\text{m}$

\* I:  $1.6\text{A} \times 1.2\text{A}$

\*  $L(\text{/cm}^2\text{s})$ :  $2.1 \times 10^{34}$

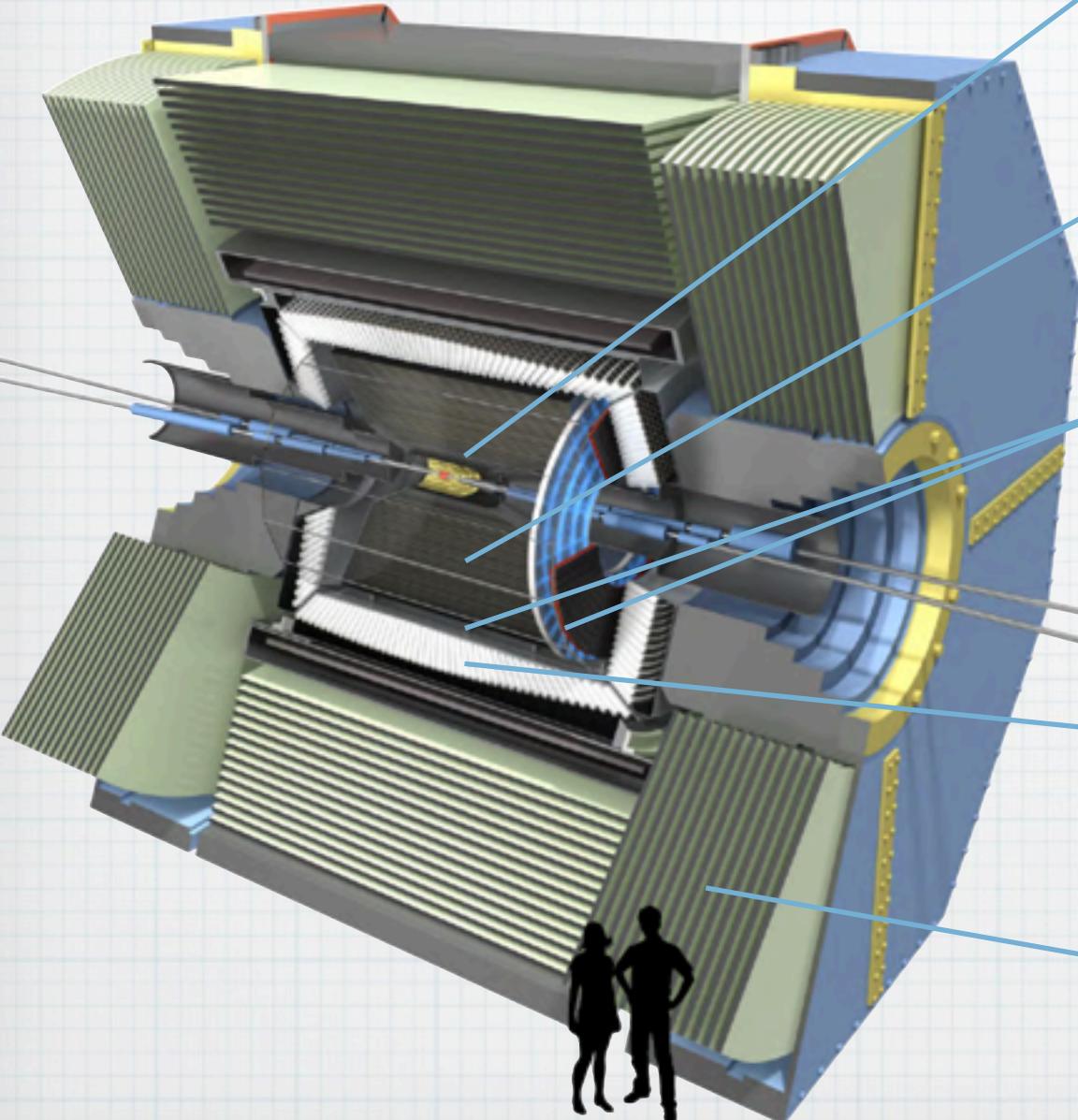


$10\mu\text{m} \times 0.06\mu\text{m}$

$3.6\text{A} \times 2.6\text{A}$

$80 \times 10^{34}$

# Belle II Detector

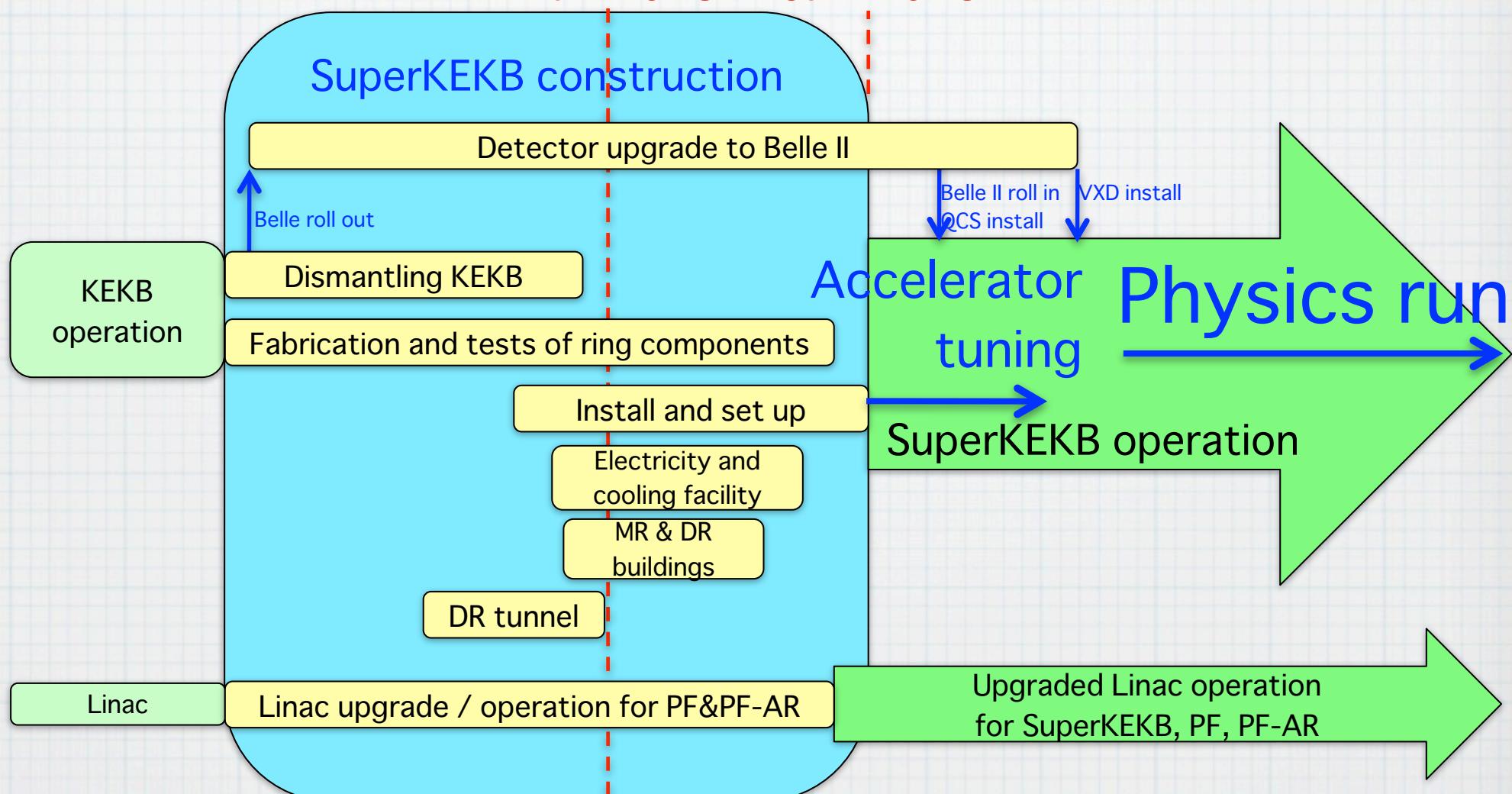


- \* Vertex Detector  
pixel + strip  $\rightarrow 20\mu\text{m}$
- \* Smaller cell drift chamber
- \* Time of Propagation counter and aerogel RICH for better K/ $\pi$
- \* EM calorimeter:  
waveform readout
- \* Replace endcap KL,  $\mu$  detector

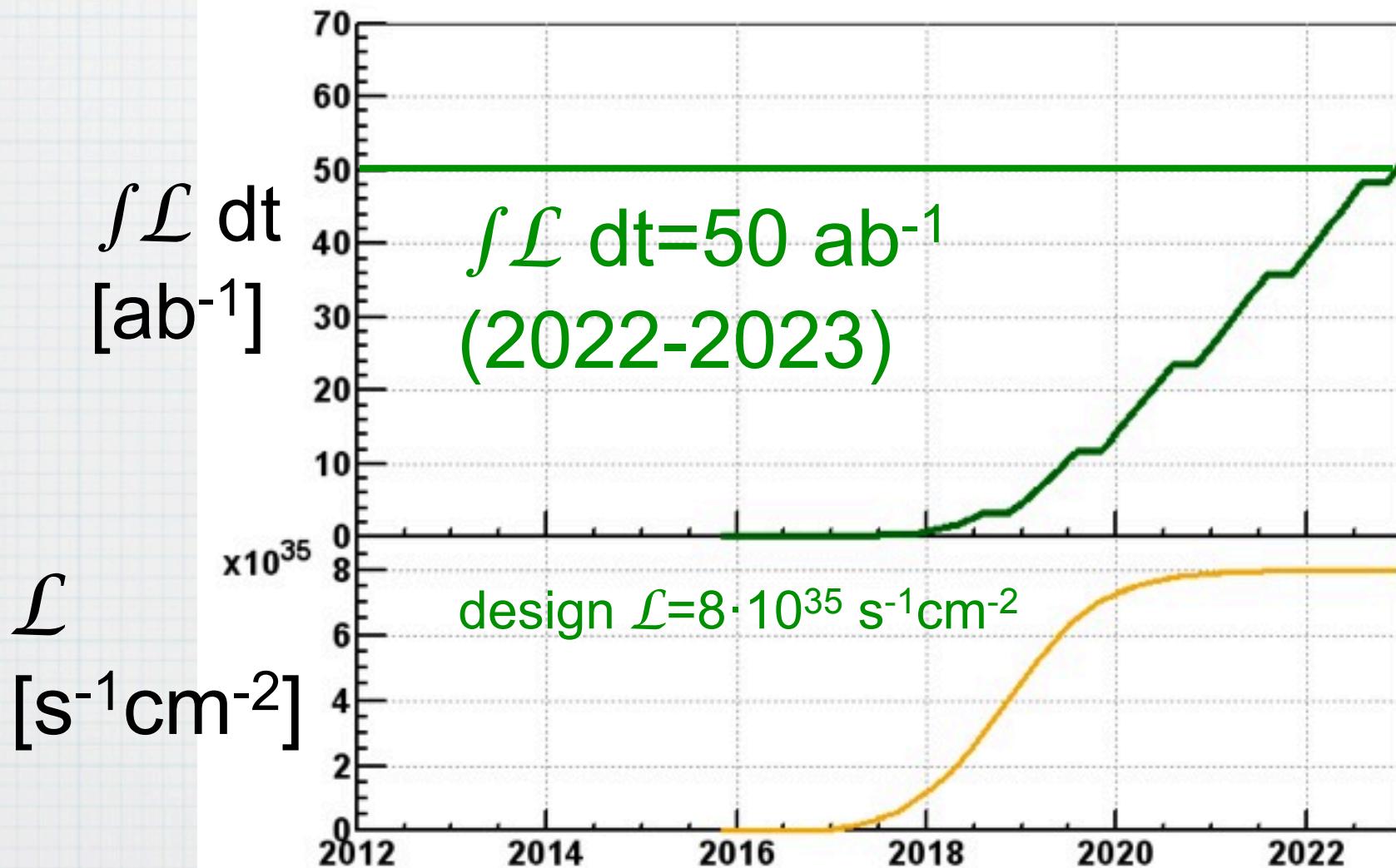
# Belle II Schedule

Calendar	2010	2011	2012	2013	2014	2015	2016	2017	...
Japan FY	2010	2011	2012	2013	2014	2015	2016	2017	..

Mar. 2013      Jan. 2015



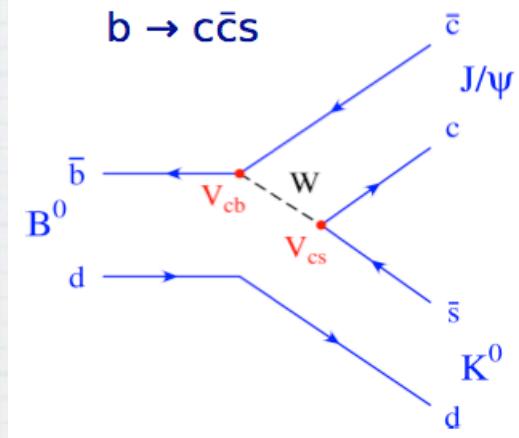
# SuperKEKB Luminosity



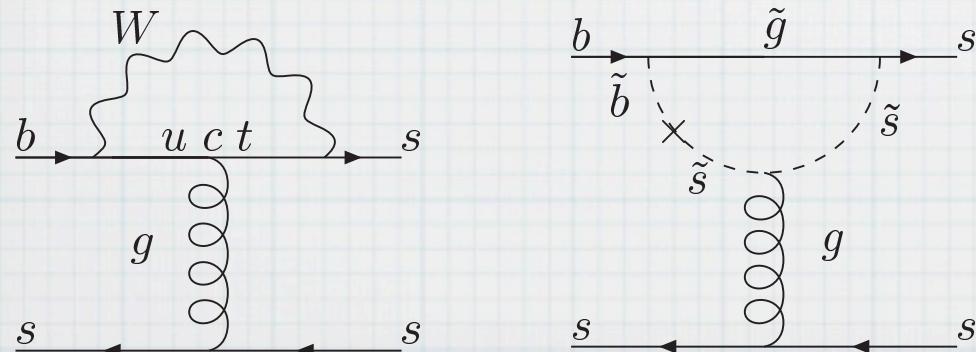
# Belle II Physics

$b \rightarrow s\bar{s}s$

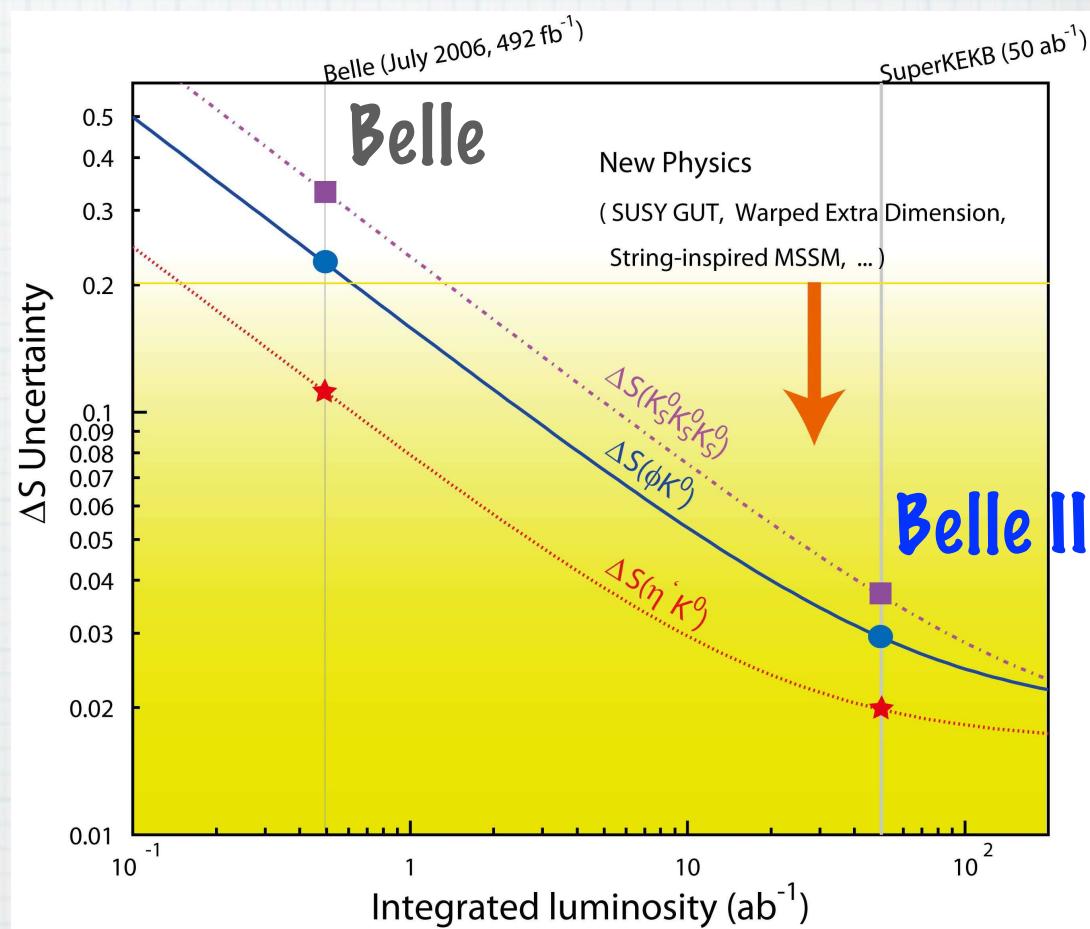
$$B \rightarrow J/\psi K_s$$



$$B \rightarrow \phi K_s$$

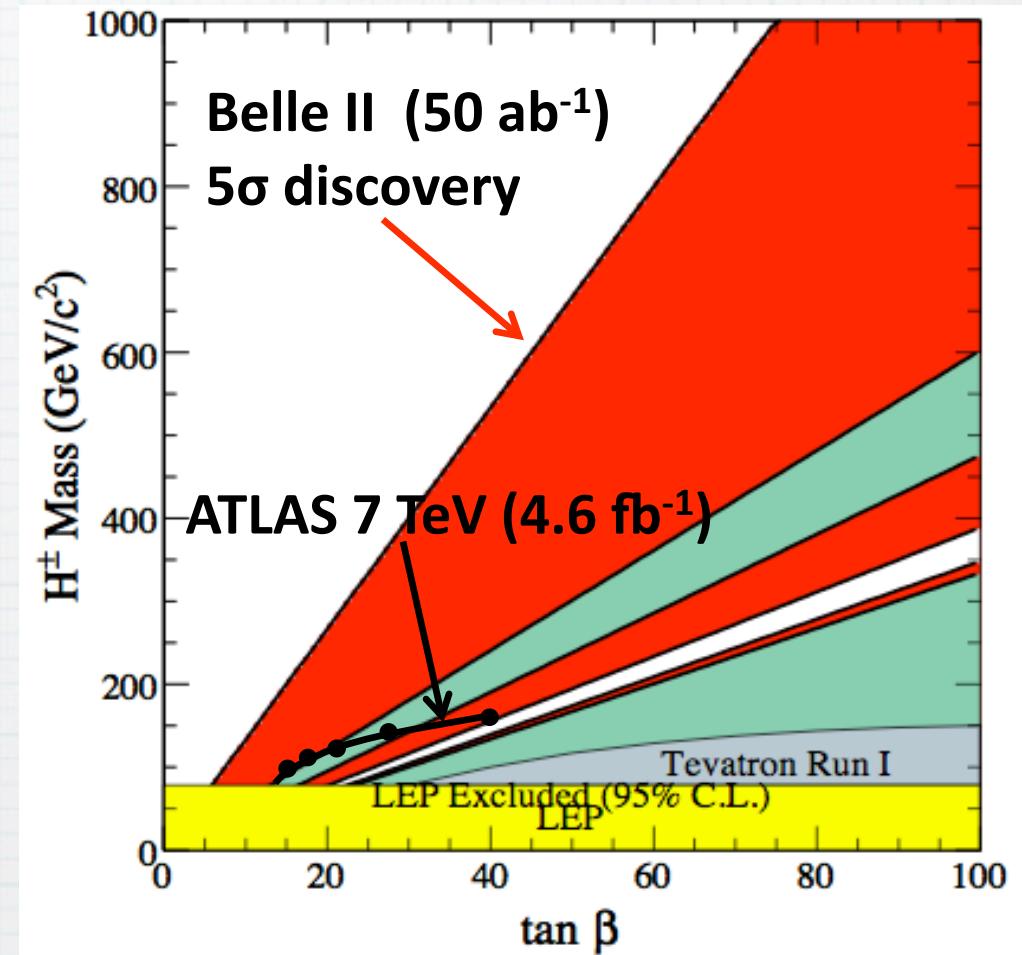
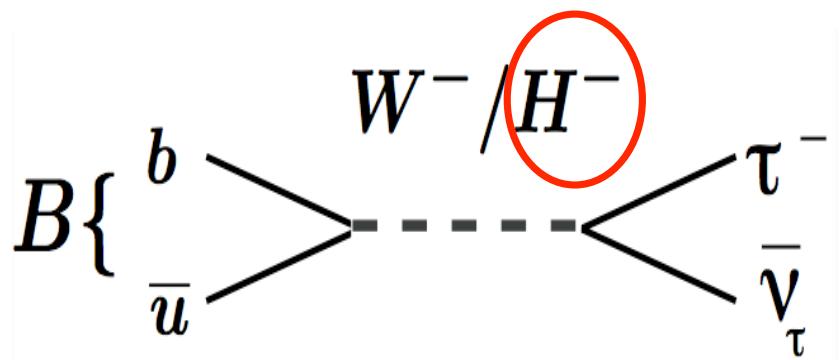


$$\Delta S = \sin 2\phi_1^{\phi K_s} - \sin 2\phi_1^{J/\psi K_s}$$



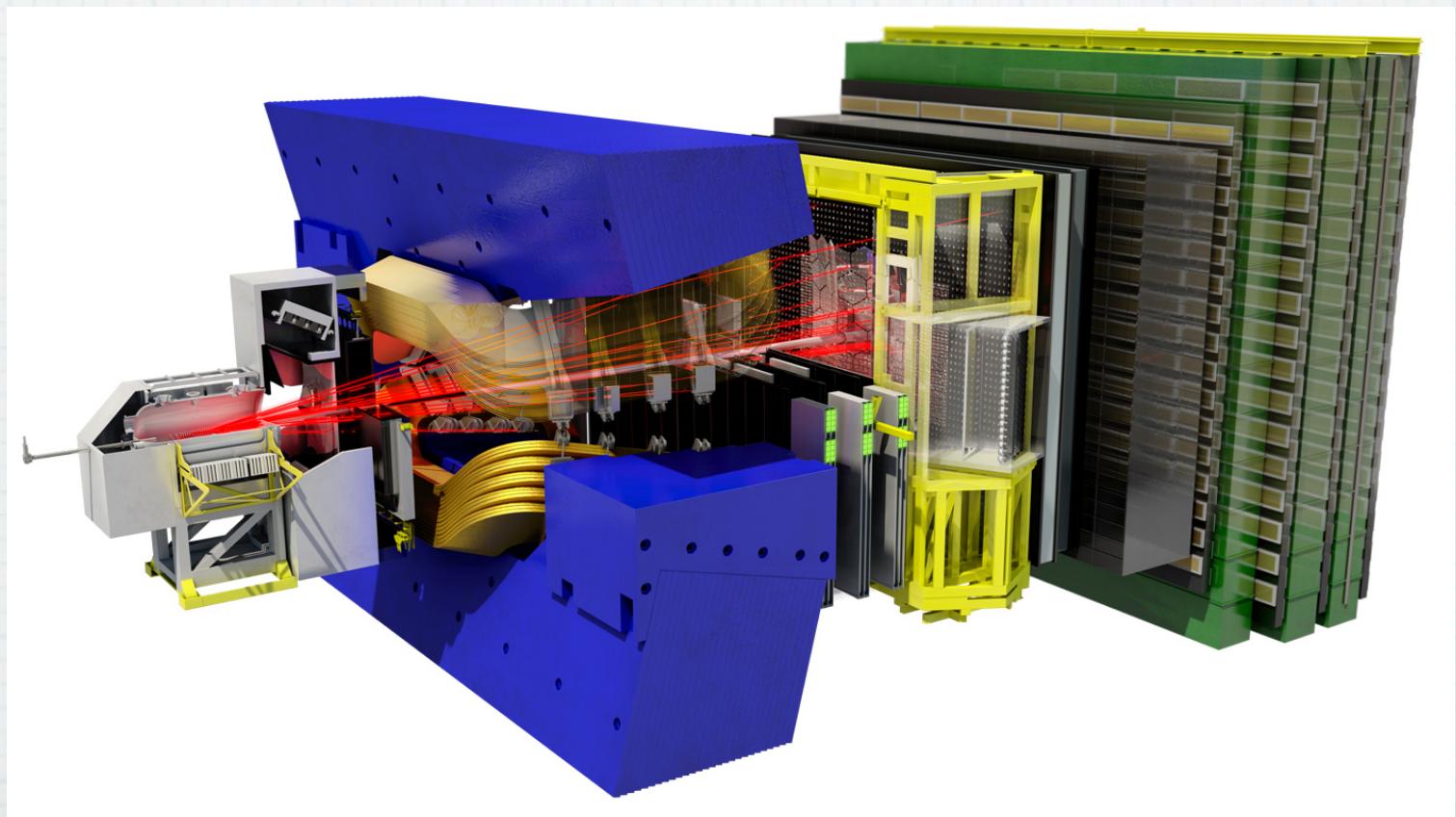
# Belle II Physics

## Charged Higgs



# LHCb Upgrade

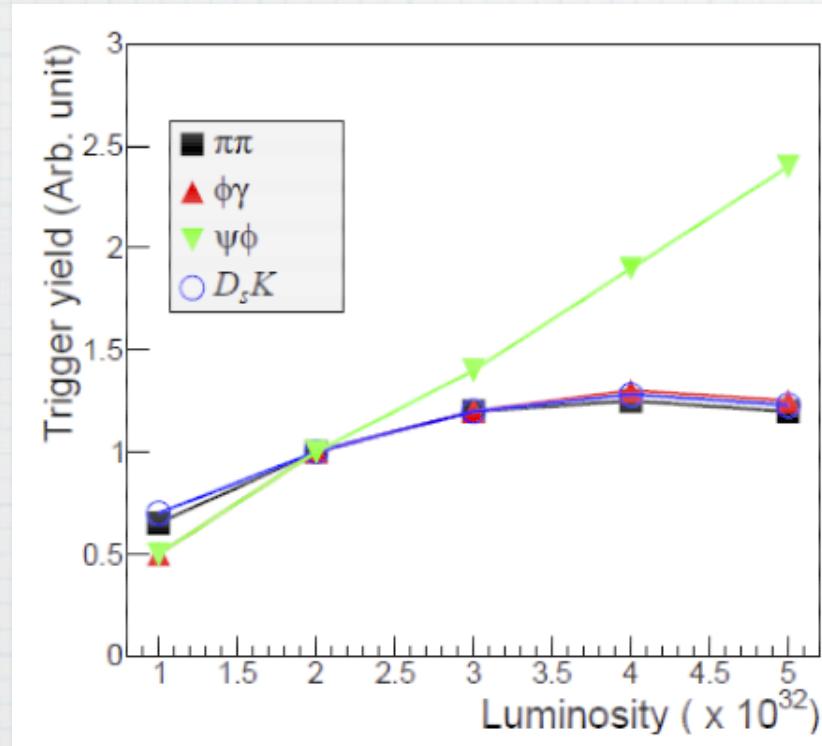
- \* Luminosity
- \* Now:  $4 \times 10^{32}$  → 2018~:  $10 \sim 20 \times 10^{32}$



# LHCb DAQ Upgrade

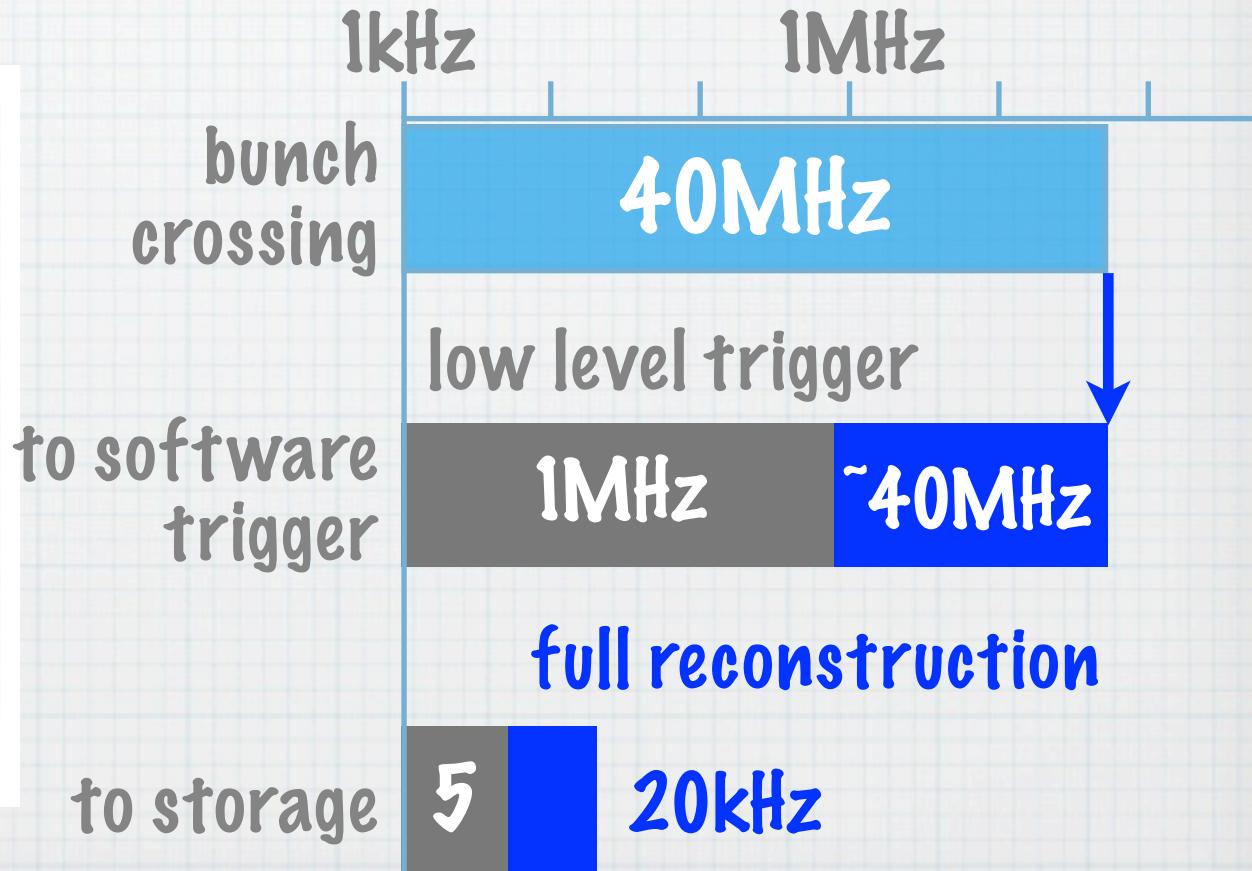
- \* Now

- \* Limited by readout



- \* Upgrade

- \* Read all, software trig



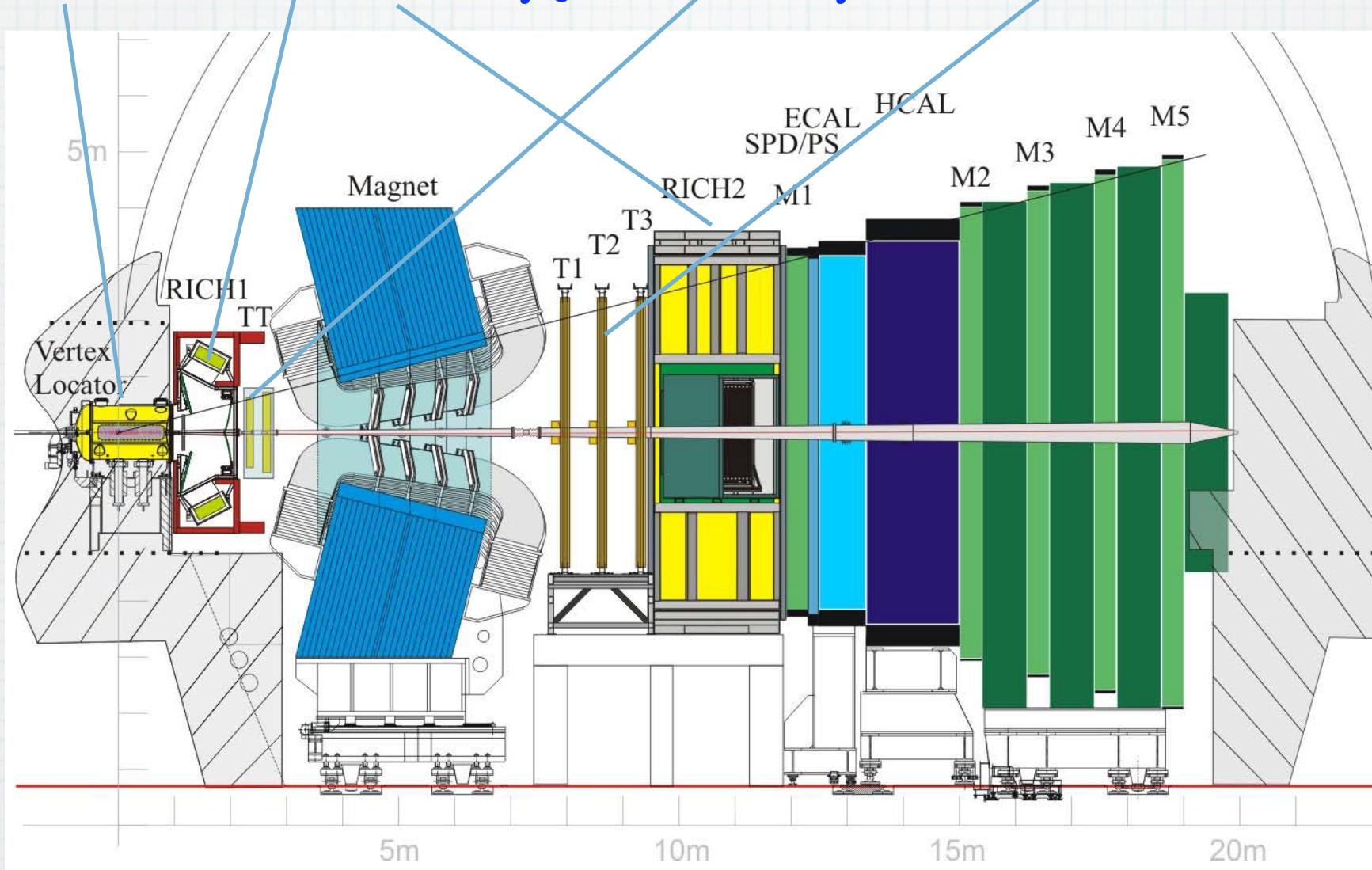
# LHCb Detector Upgrade

**Vertex Locator:**  
pixel or thin strip

**RICH1: remove**  
**RICH2: upgrade**

**Silicon Tracker:**  
replace all

**Outer Tracker:**  
straw tubes?



and all the readout electronics

# LHCb Upgrade Schedule

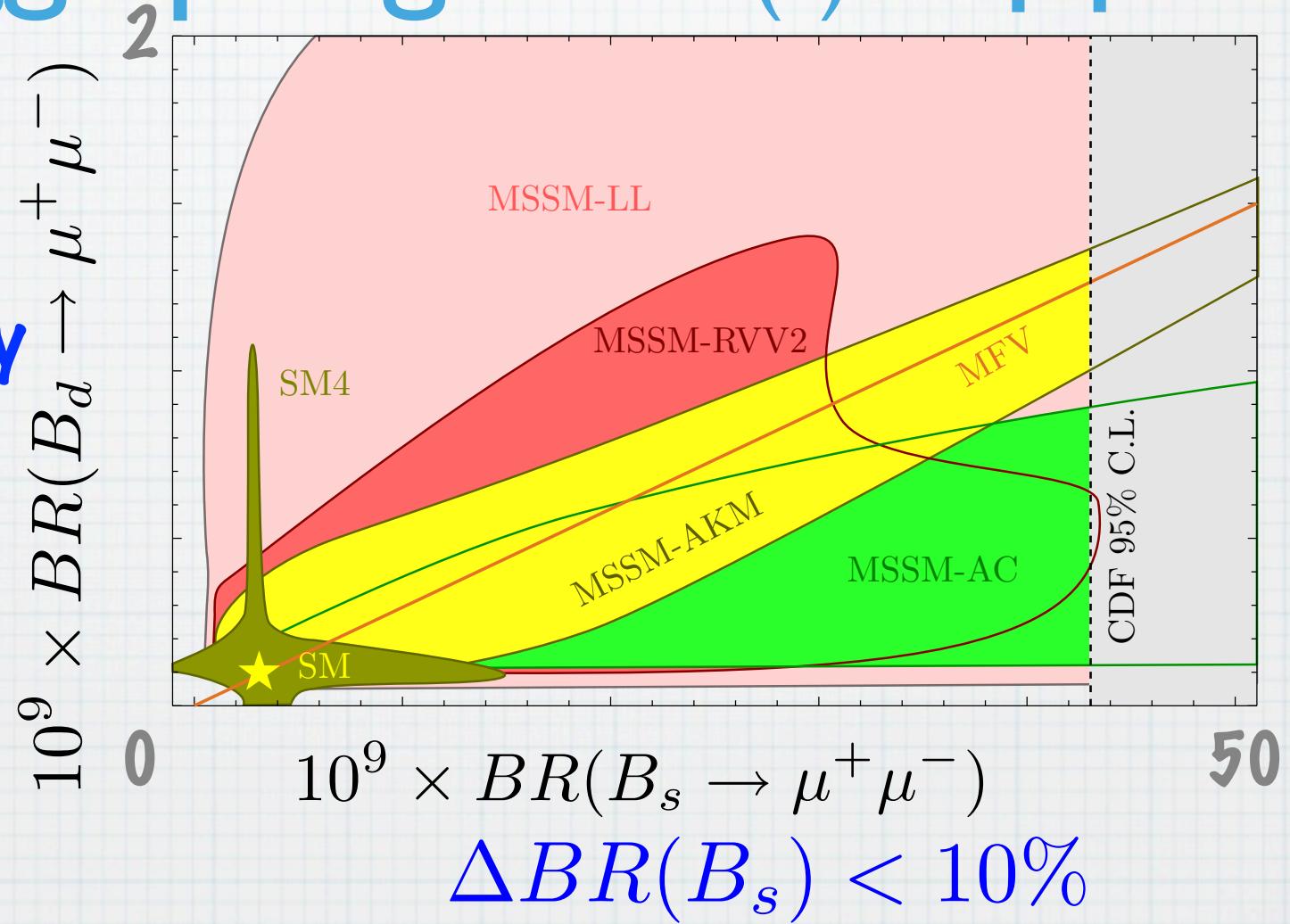


- \* 10/fb w/ LHCb before 2018
- \* UPGRADE
- \* 5/fb per year  $\times$  10years = 50/fb

# LHCb Upgrade Physics

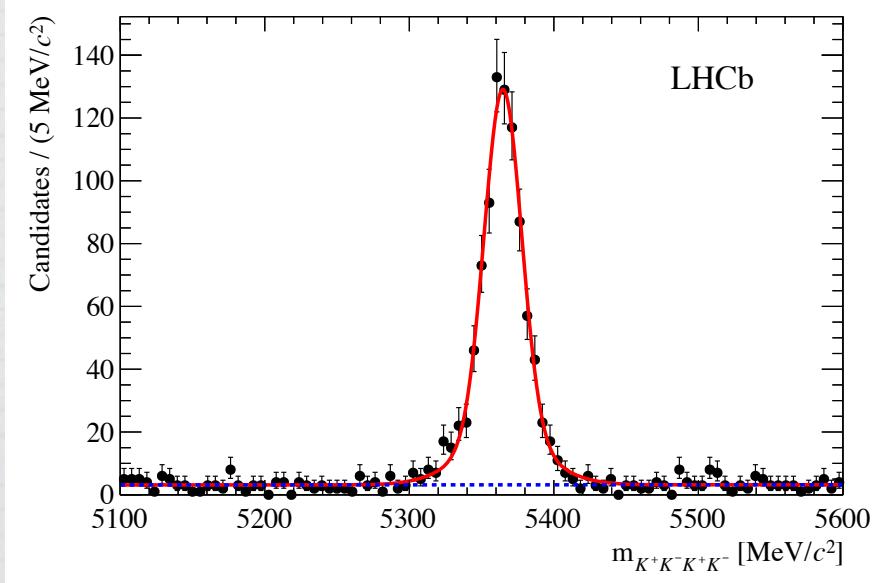
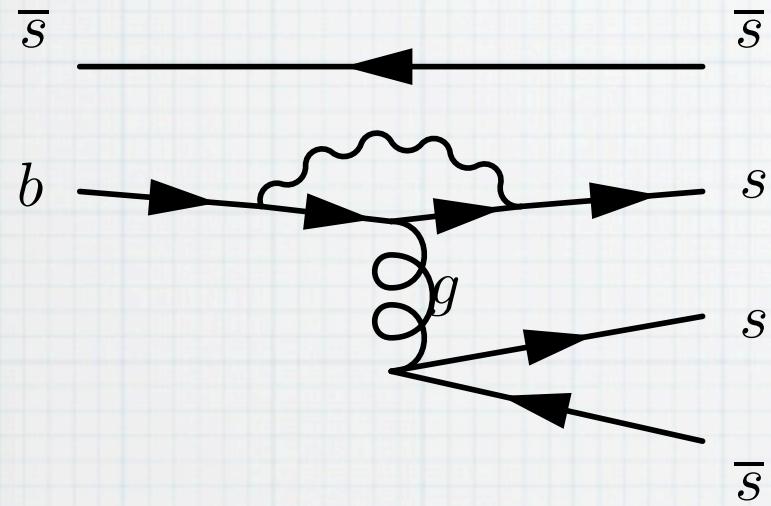
## Higgs penguin $B_{(s)} \rightarrow \mu\mu$

$B_d$  sensitivity  
→ SM rate



# LHCb Upgrade Physics

## $B_s \rightarrow \Phi\Phi$



- \*  $S(B_s \rightarrow \Phi\Phi)$  error
- \* 100%@ 1/fb
- \* 3%@LHCb upgrade (50/fb)
- \* ~2% theoretical error

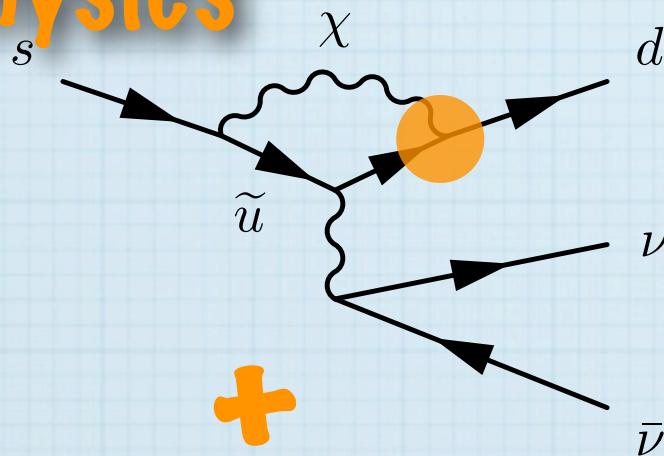
# New Physics Probe: Kaons

# Probes:

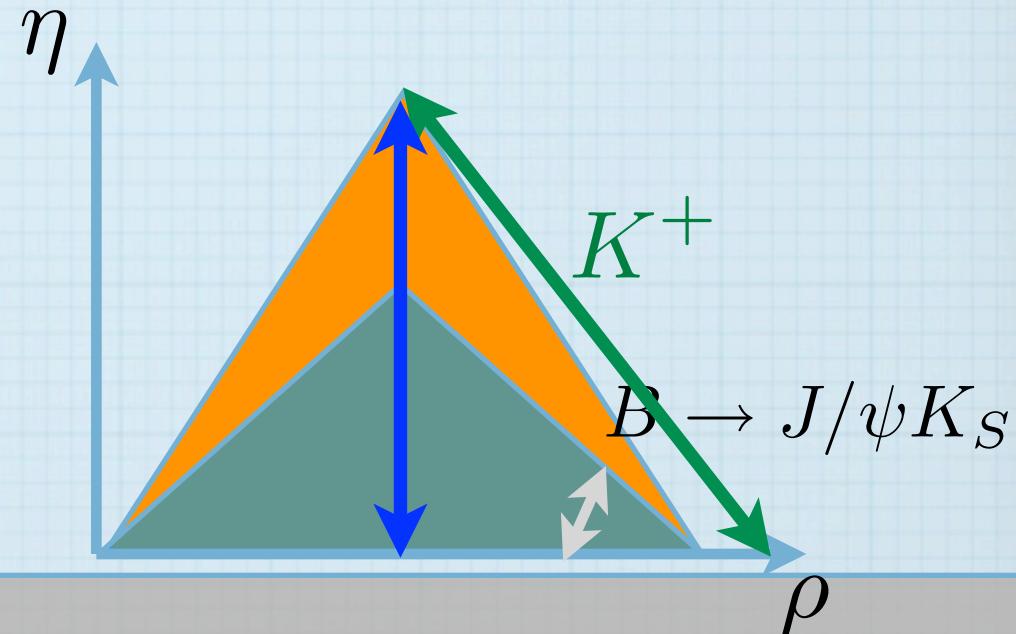
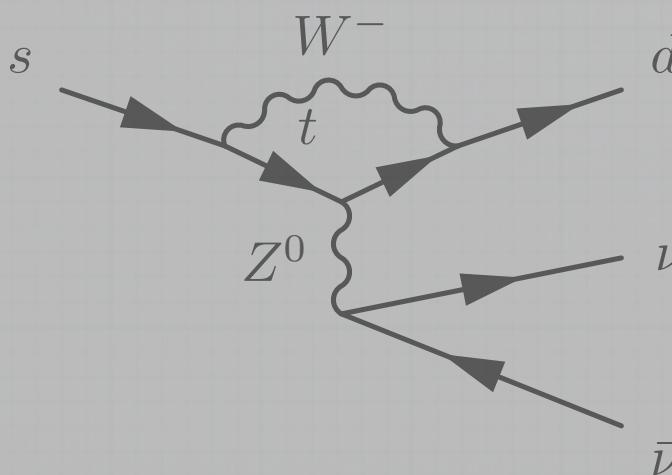
$$K_L \rightarrow \pi^0 \nu \bar{\nu}$$

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

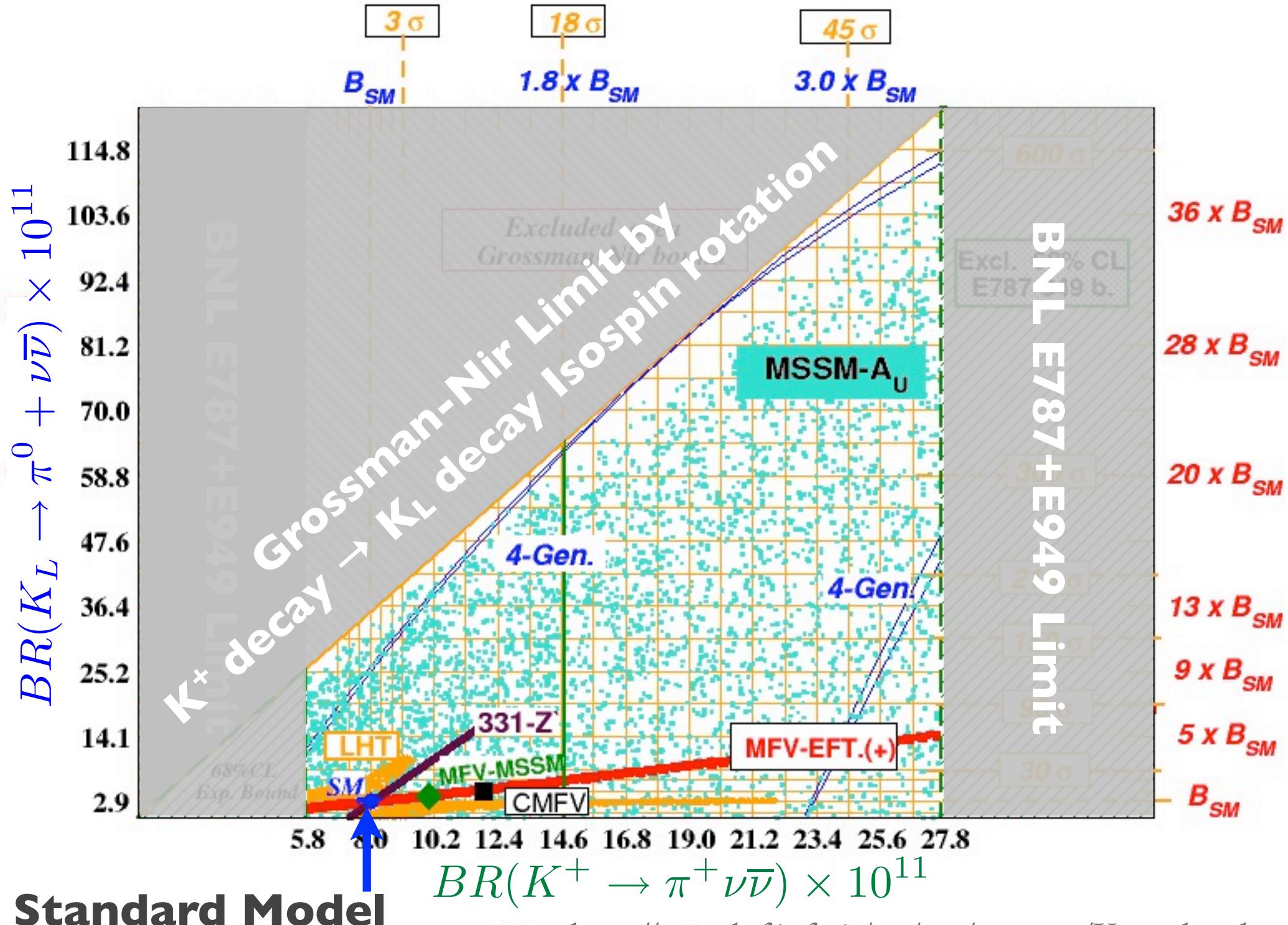
New Physics

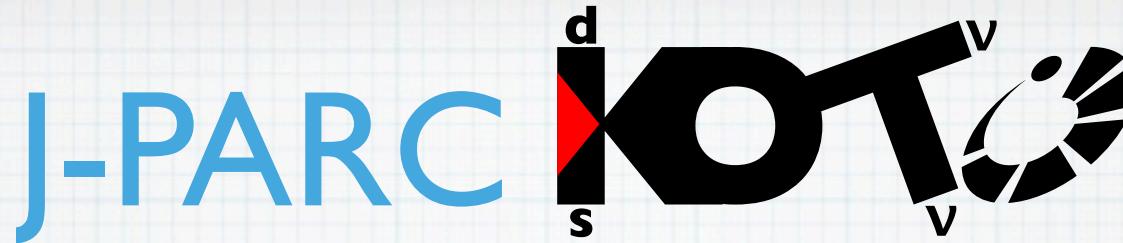


Standard Model



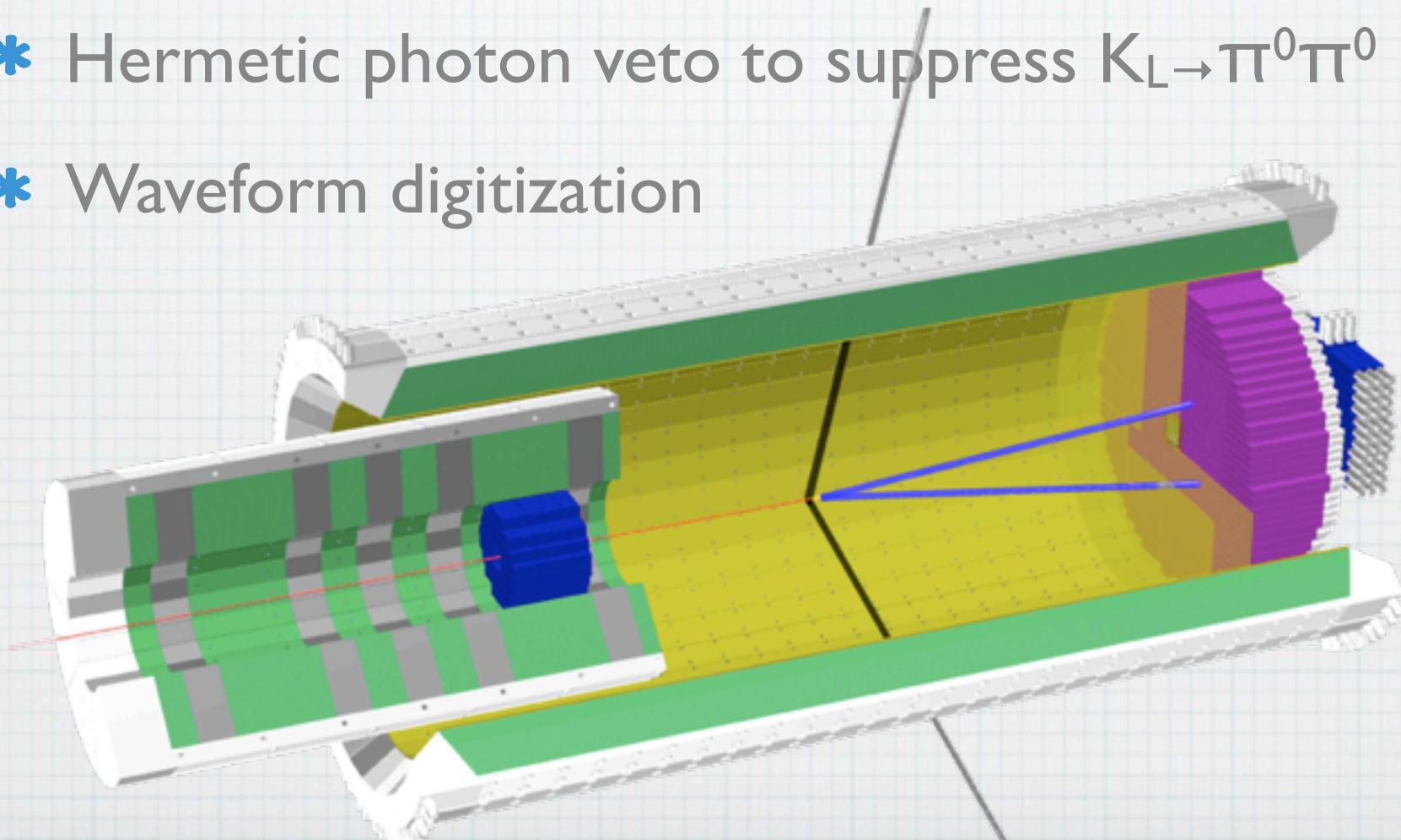
- \* SM background is
- \* small ( $\text{BR}(K_L) \sim 3\text{E-}11$ )
- \* well known ( $K_L \sim 2\%$   
theo. error)





$$K_L \rightarrow \pi^0 \nu \bar{\nu}$$

- \* CsI calorimeter from KTeV
- \* Hermetic photon veto to suppress  $K_L \rightarrow \pi^0 \pi^0$
- \* Waveform digitization





# Schedule and Sensitivity

- \* Engineering runs w/ full detector
- \* 2012 Dec, 2013 Jan, March
- \* May 2013: Physics Run! ... till the accident
- \* 2014: hope to cross the GN limit
- \* 3-sigma New Physics if  $BR > 8E-11$  by 2018

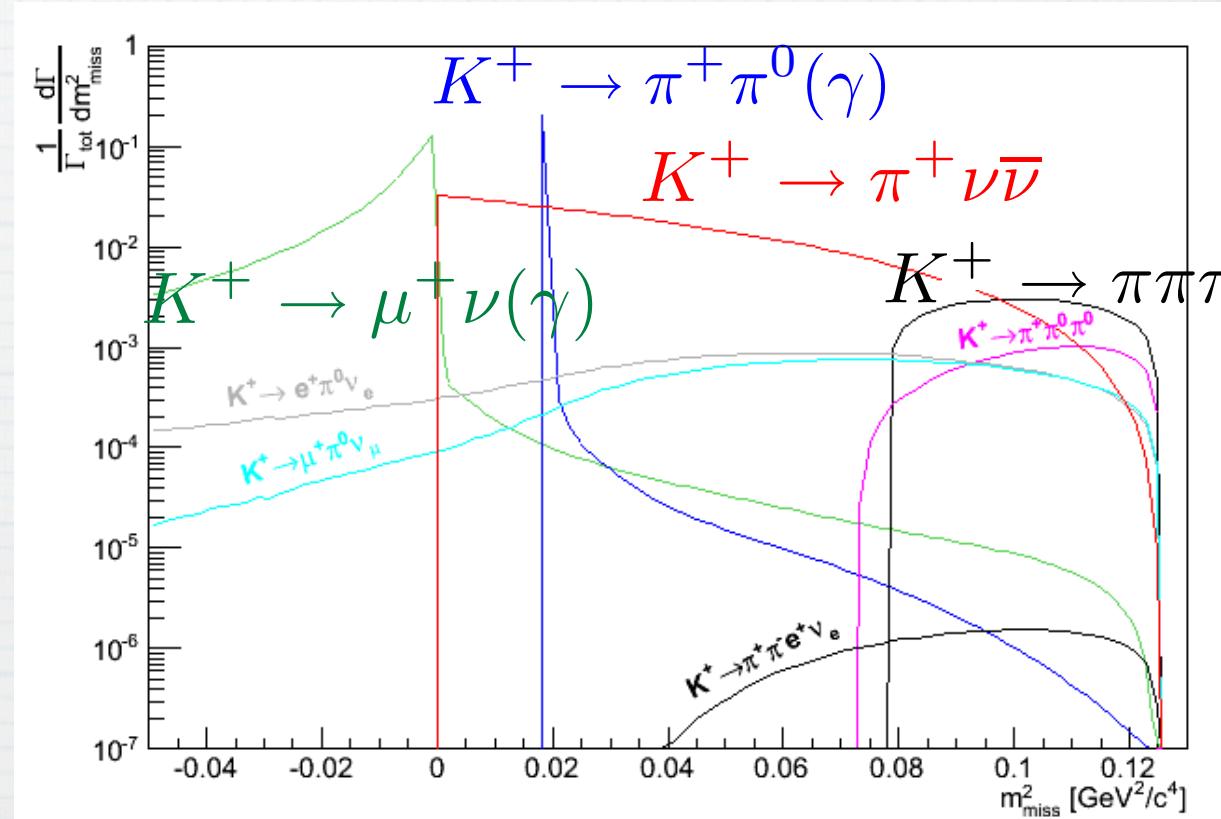
# CERN NA62



- \* Decay in flight



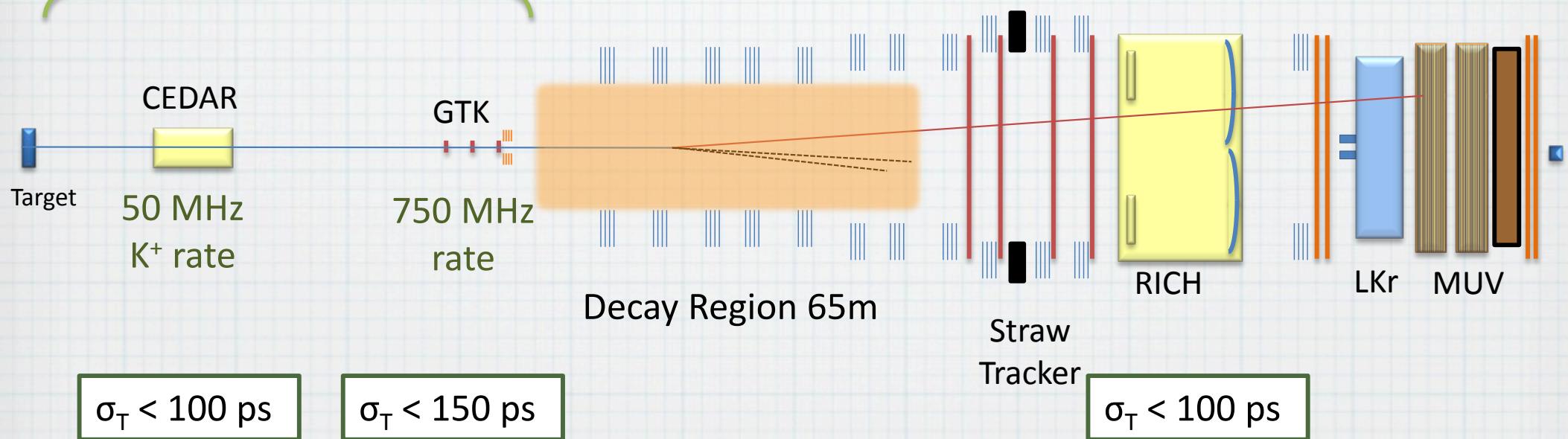
- \* Missing mass
- \* Good tracking
- \* Particle ID
- \* Photon Veto to suppress  
 $K^+ \rightarrow \pi^+ \pi^0$



# CERN NA62

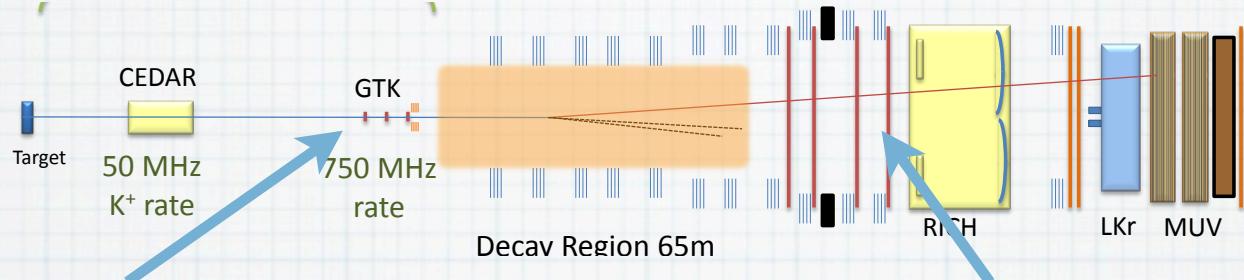
750 MHz primary  
Hadron beam at 75GeV/c  
6% are Kaons

7-10 MHz of Muon Rate  
in the Detectors



$4.5 \cdot 10^{12} K^+ \text{ decays/ year in fiducial region}$

# CERN NA62 trackers

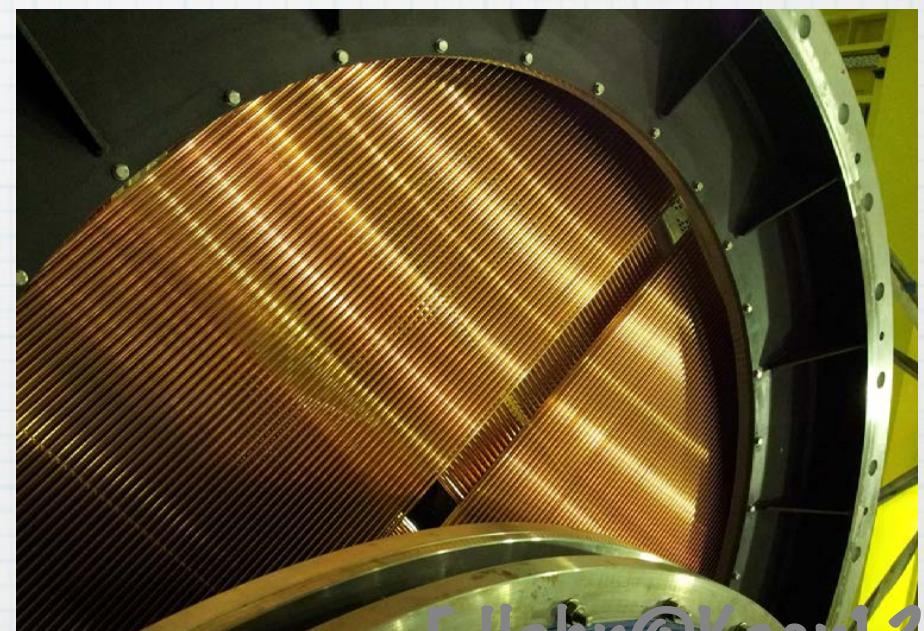
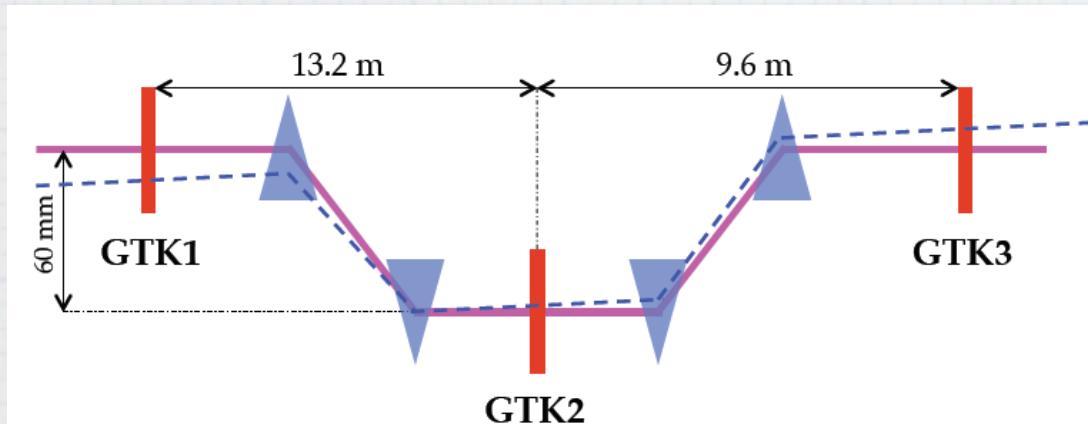


- \* For K<sup>+</sup>

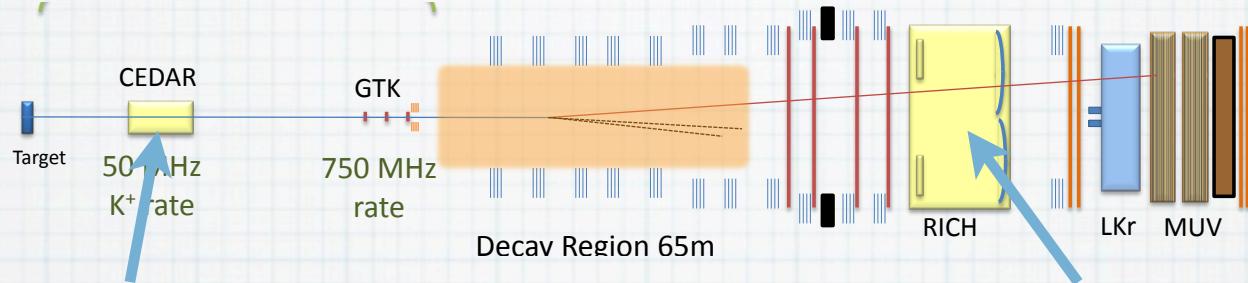
- \* 300μm pixels
- \* Δθ ~ 0.016mrad
- \* Δt ~ 200ps

- \* For π<sup>+</sup>

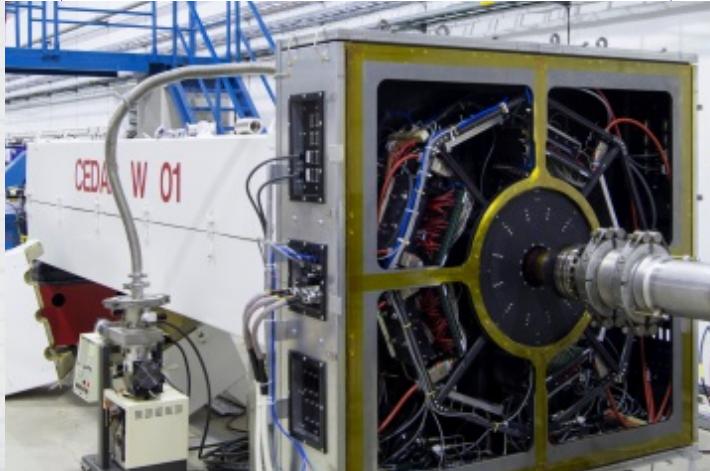
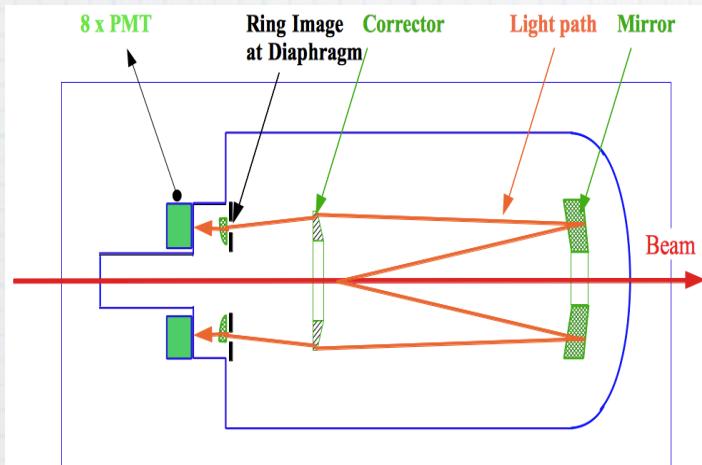
- \* straw tracker
- \* Δx~140μm



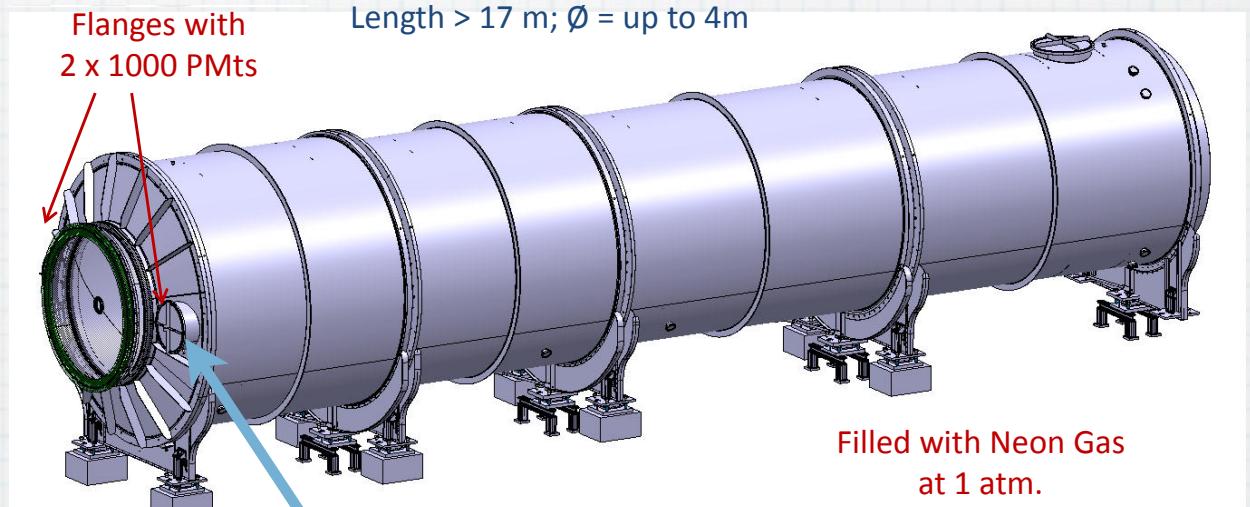
# CERN NA62 PID



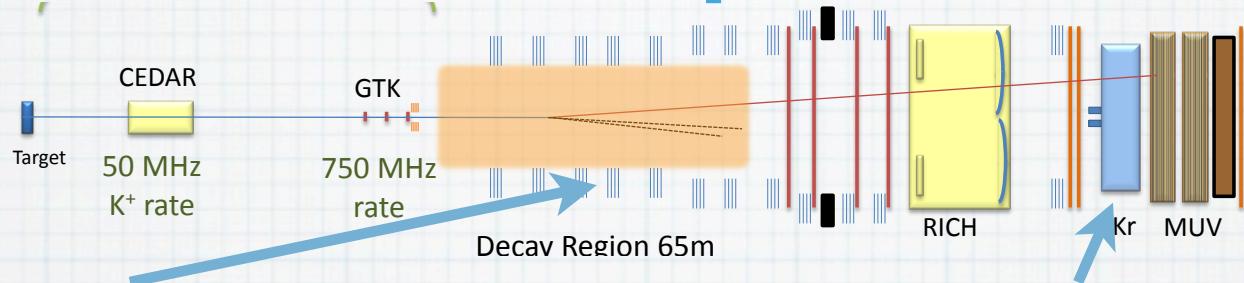
\* For K<sup>+</sup>



\* For π<sup>+</sup>



# CERN NA62 photon veto



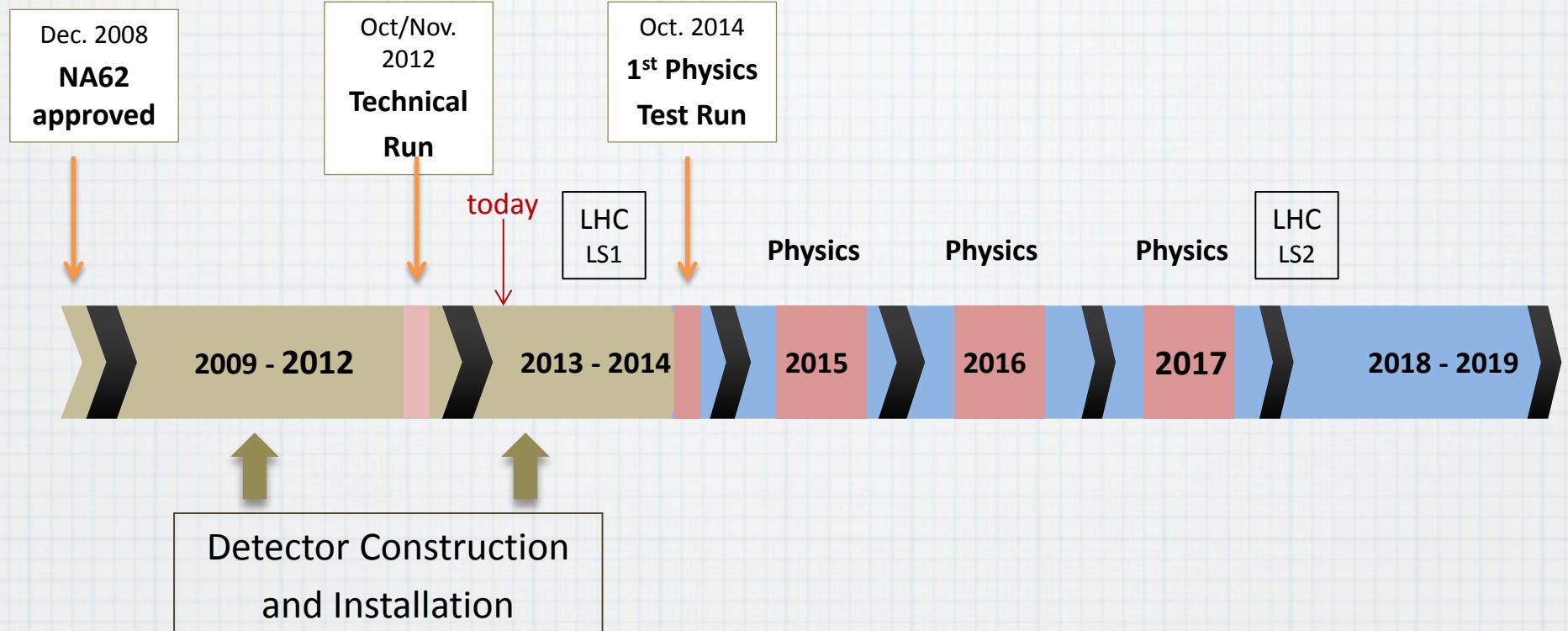
- \* large angle photons
- \* leadglass from OPAL



- \* small angle photons
- \* NA48 LKr cal.



# CERN NA62 Schedule and Sensitivity

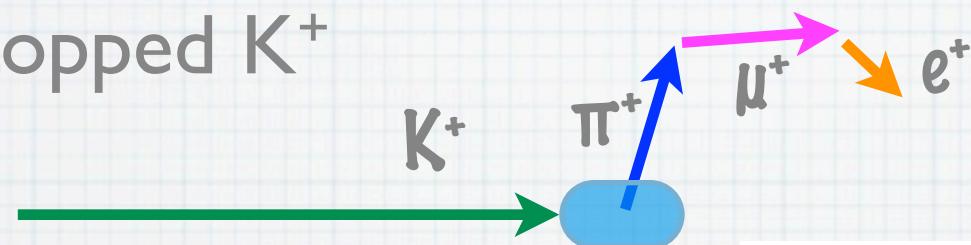


- \* 45 SM events/year
- \* background <10 events

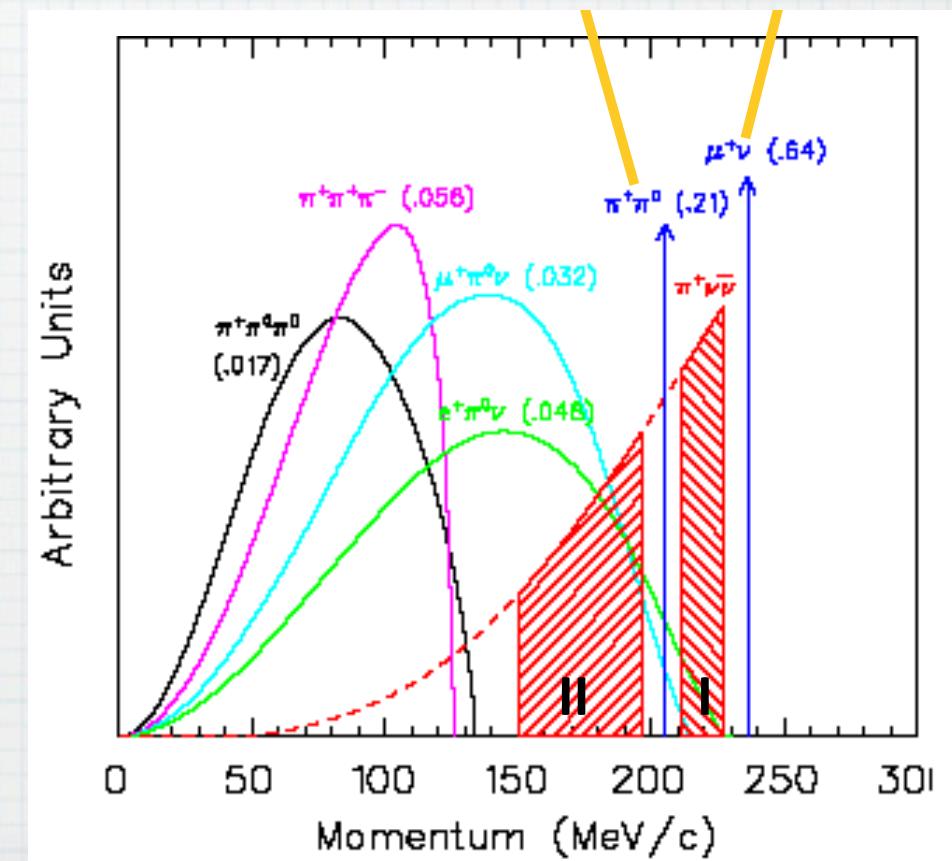
# Fermilab ORKA



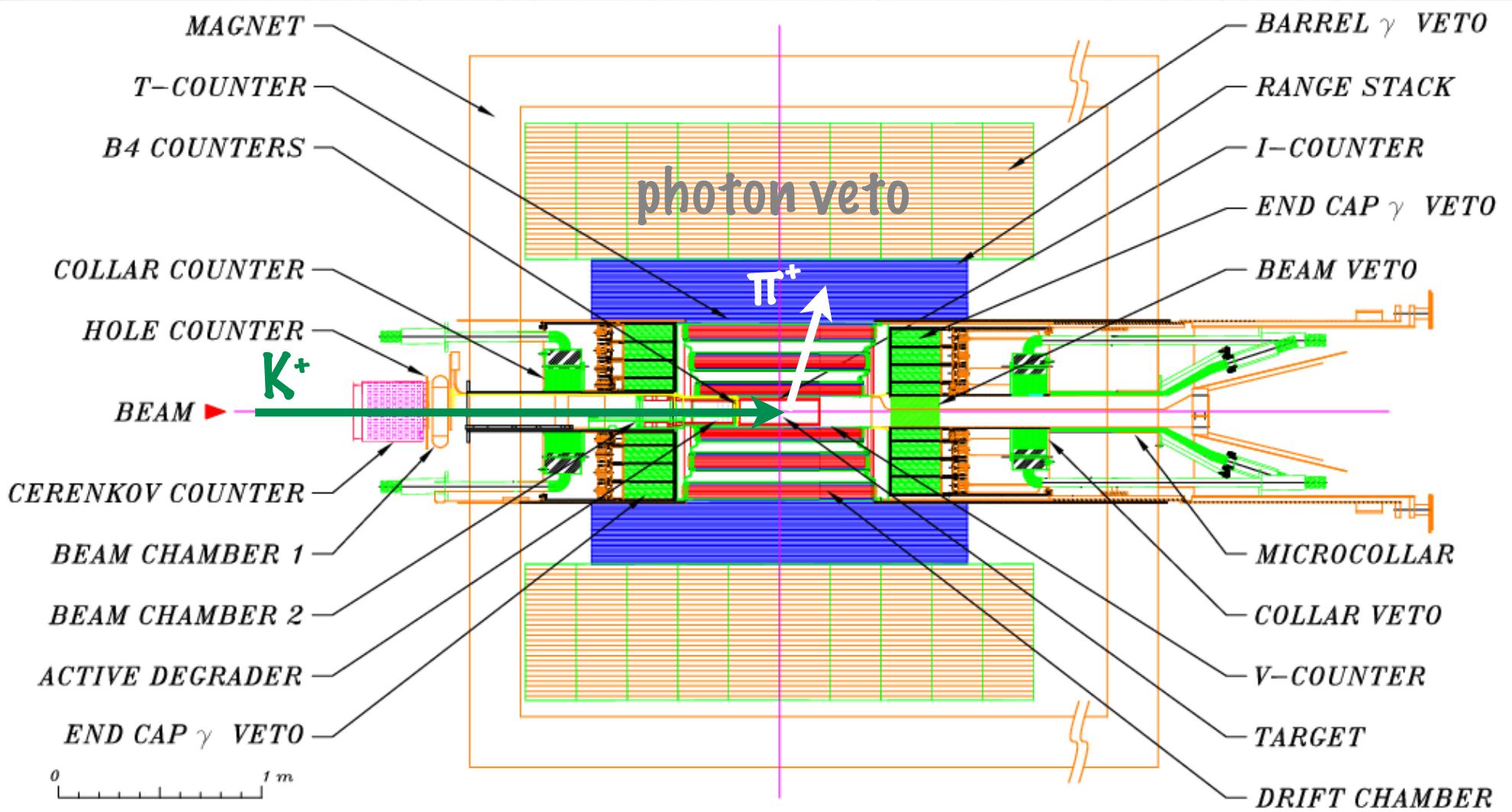
- \* Stopped  $K^+$



- \*  $\pi^+$  momentum
- \* Independent PID via range, E, decay chain
- \* hermetic photon veto
- \* Established technique (BNL 787/949)

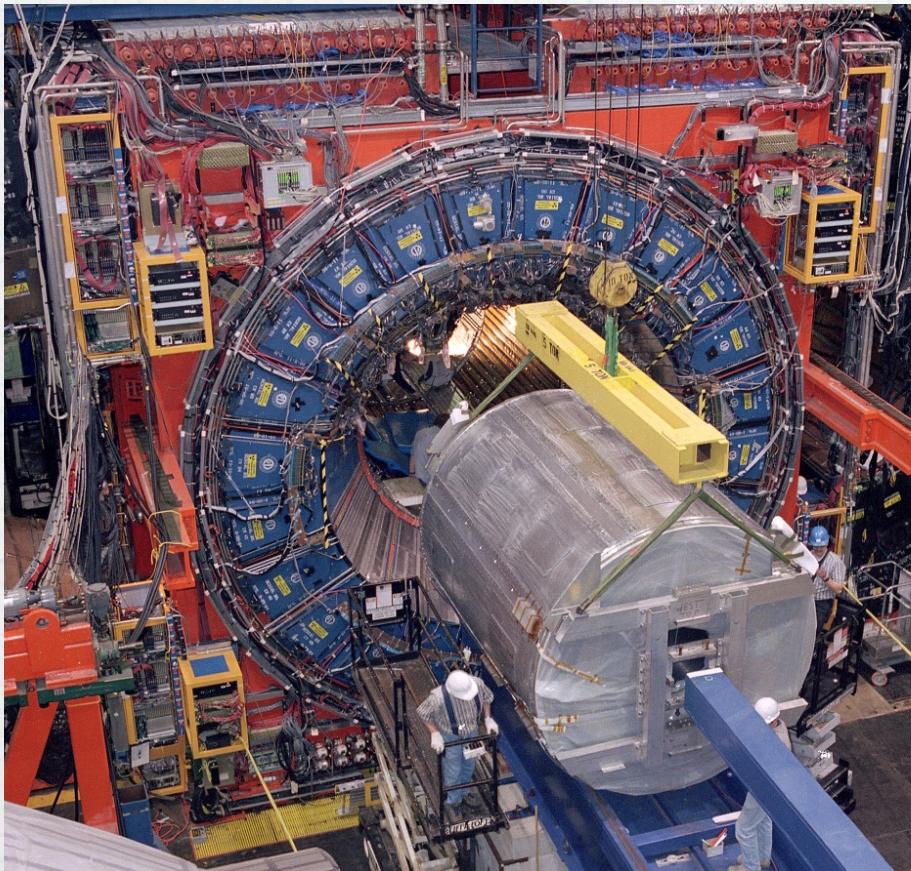


# Fermilab ORKA Detector

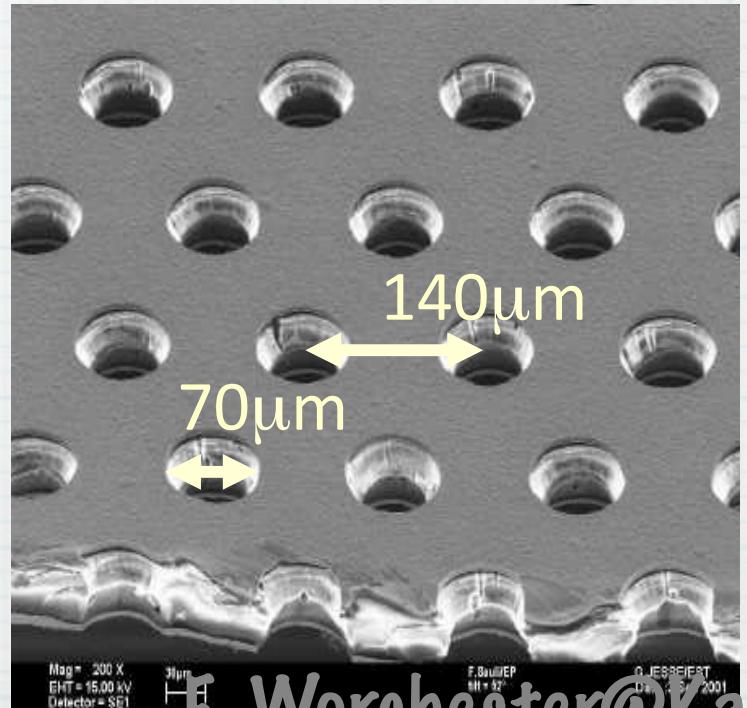


# Fermilab ORKA Detector

- \* Hall and solenoid magnet were built



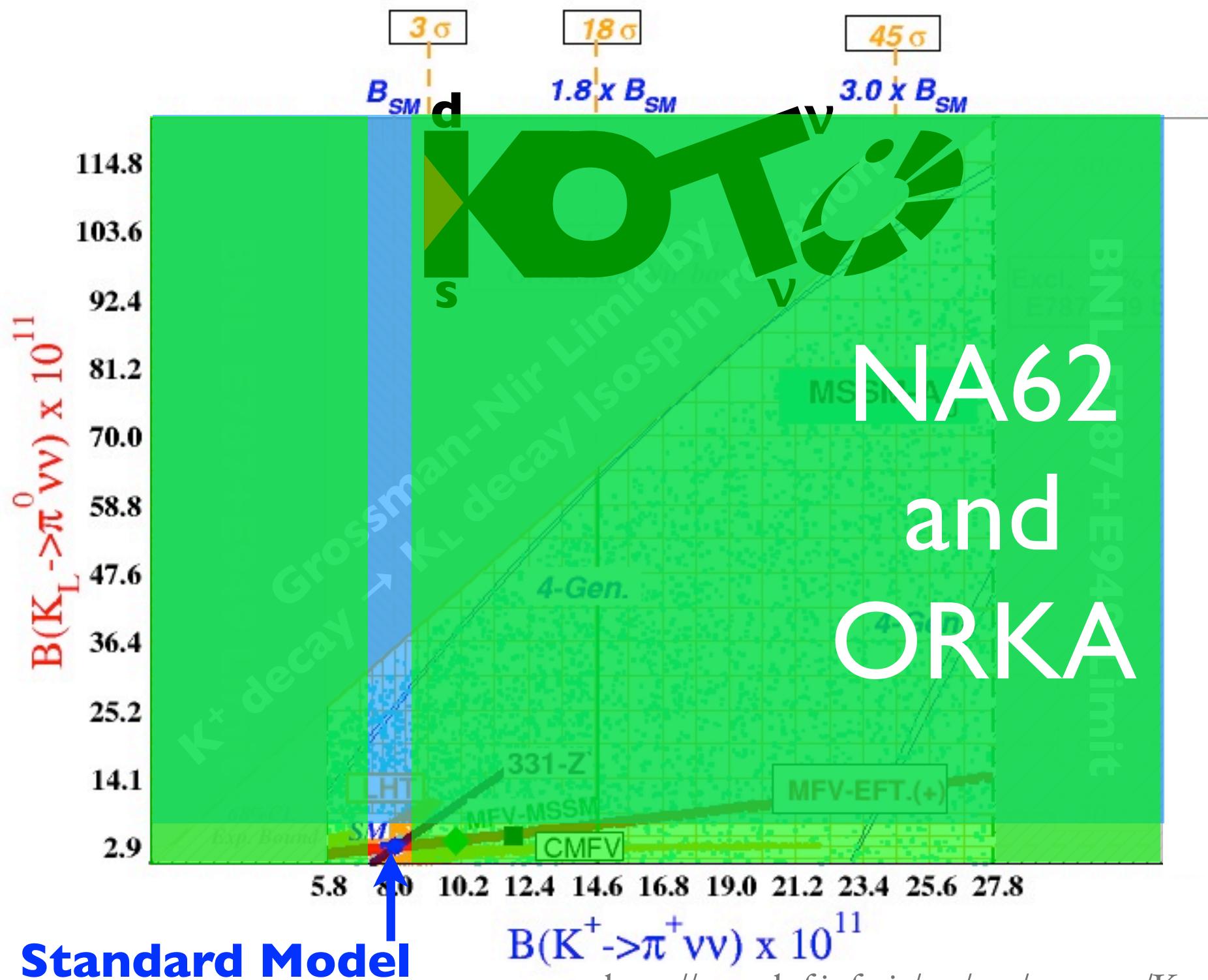
- \* Detector R&D
  - \* leadglass+scint. cal
  - \* GEM tracker



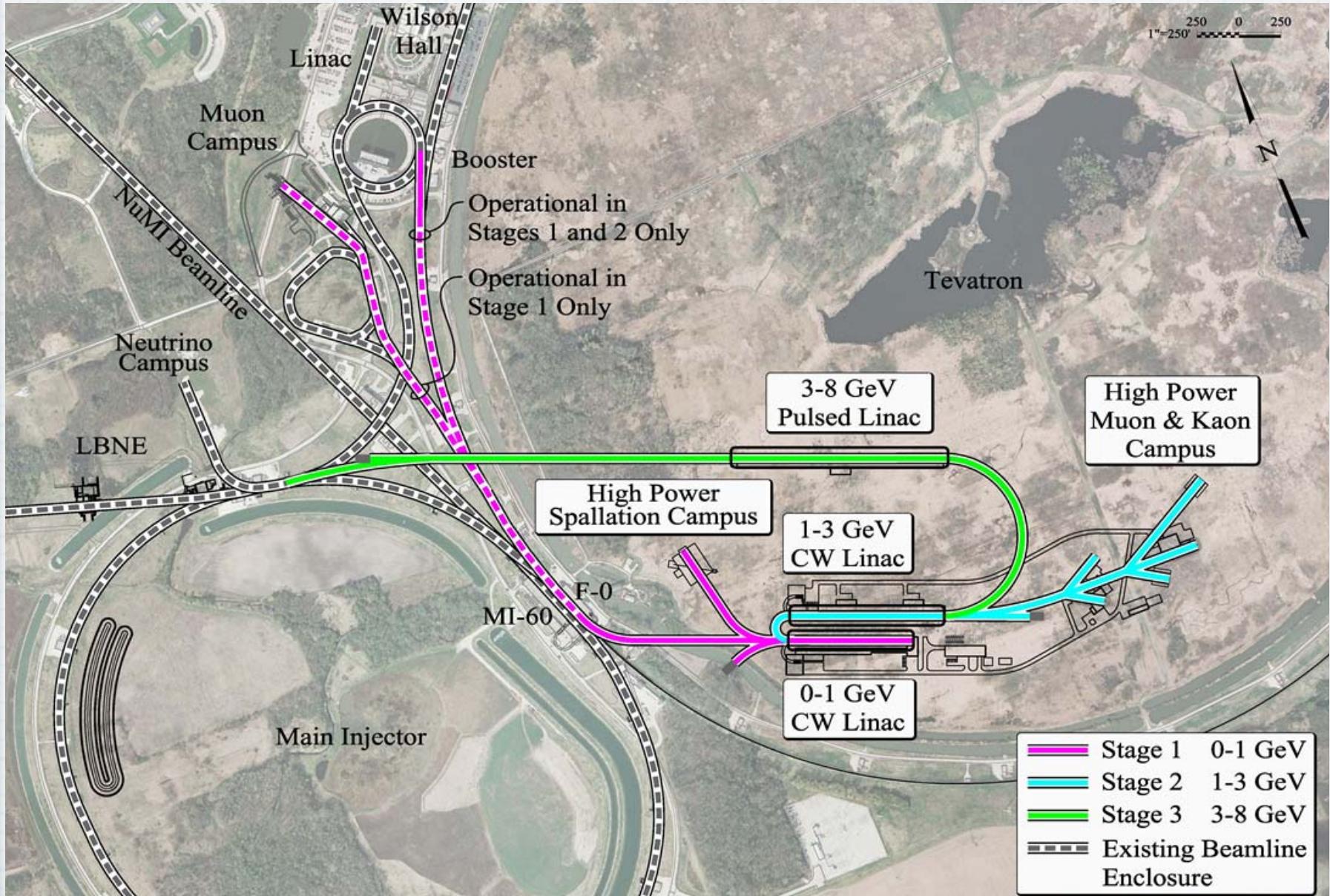
# Fermilab ORKA

## Sensitivity

- \* 210 SM events/year with Main Injector
- \* K beam: x10 E949
- \* acceptance: x11 E949
- \* 1000 events / 5 years  $\rightarrow \Delta BR \sim 5\%$
- \* Stage I Approval
- \* Detector R&D and preparing for next step

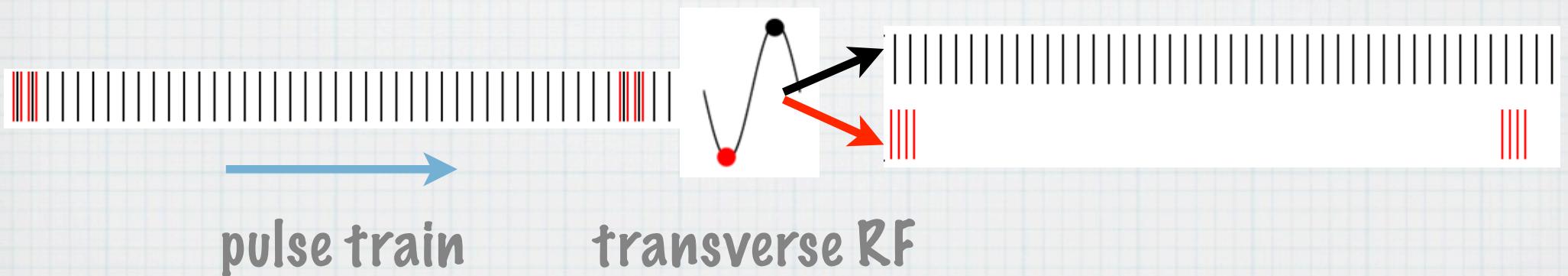


# Fermilab Project X



# Fermilab Project X

- \* High intensity protons for
  - \* neutrinos, K, muons, neutrons
- \* Instead of slow extraction, just accelerate and split



# Project X Stage I



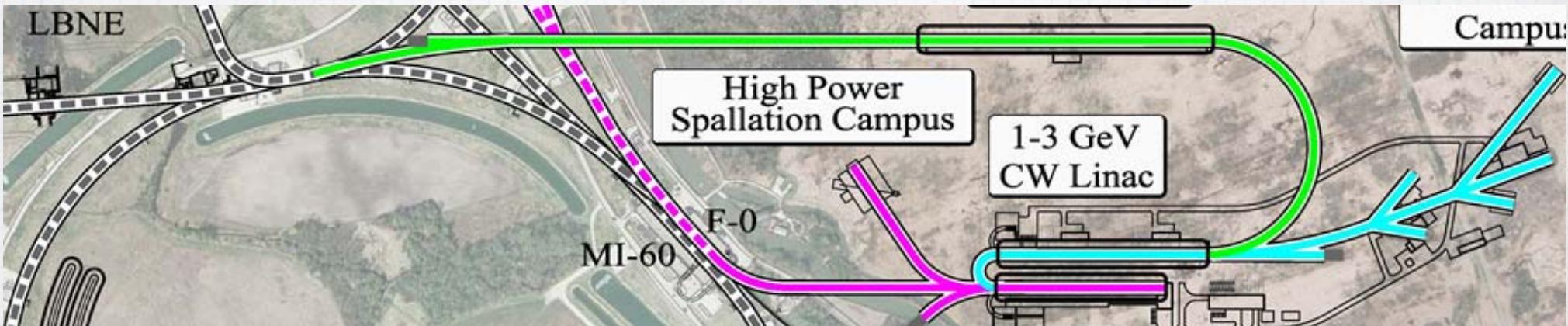
- \* 0-1 GeV continuous wave Linac: atomic EDM
- \*  $\rightarrow$  8 GeV Booster
- \* 130kW short-baseline  $\nu$
- \* speed up ORKA (1000 SM events)
- \*  $\rightarrow$  120 GeV Main Injector: 515~1200kW long-baseline  $\nu$  (LBNE)

# Project X Stage 2



- \* 1-3GeV CW Linac
- \* 1000 SM  $K_L \rightarrow \pi^0 \nu \bar{\nu}$  events
- \* +1000 kW for 3rd phase of Mu2e
- \* → 1200 kW LBNE

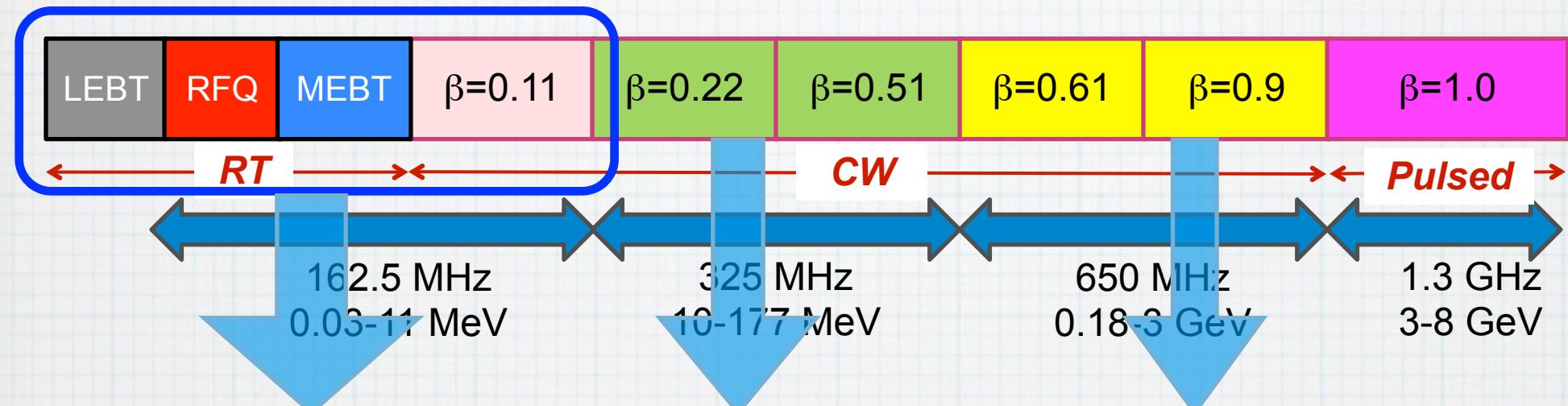
# Project X Stage 3



- \* 3-8GeV Pulsed Linac
- \* 180 kW 8 GeV (x10 of booster)
- \* 2450 kW 60-120 GeV Main Injector
- \* + K,  $\mu$ , n, ...

# Project X R&D

ANL, BNL, Cornell, Fermilab, PNNL, SLAC,...



- \* Project X can start construction before 2020

# New Physics Probe: charged leptons

# Charged Lepton Factories

- \* Belle II, LHCb Upgrade =  $\tau$  factories
  - \* lepton flavor violation in  $\tau$  decays
- \* J-PARC, Fermilab, Project X =  $\mu$  factories
  - \*  $\mu \rightarrow e$  conversion
  - \*  $\mu$  g-2
  - \*  $\mu$  EDM
- \* ➤ Friday: “Charged Lepton Physics” by S. Mihara

# Summary

## \* Belle II

$|V_{cb}|, |V_{ub}|, S(B_d \rightarrow K^*\gamma), A_{CP}(b \rightarrow s\gamma),$   
 $B \rightarrow \tau\nu, B \rightarrow \mu\nu, B \rightarrow K\nu\bar{\nu}, \phi_D, \dots$

## \* LHCb

$\gamma, S(B_d \rightarrow \psi K, \phi K), S(B_s \rightarrow \psi\phi, \phi\phi, \phi\gamma),$   
 $B_s \rightarrow \mu^+ \mu^-, B_d \rightarrow \mu^+ \mu^-, A_{FB}(B \rightarrow K^* \mu^+ \mu^-), \dots$

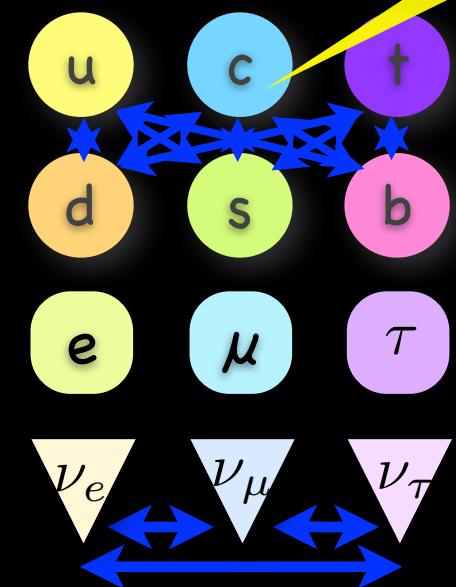
## \* KOTO, Project X

$K_L \rightarrow \pi^0 \nu\bar{\nu}$

## \* NA62, ORKA

$K^+ \rightarrow \pi^+ \nu\bar{\nu}$  + many rare decays

# New physics beyond standard model



- \* Many thanks to
  - \* Yutaka Ushiroda, Tatsuya Nakada
  - \* NA62 and ORKA Collaborations