Augusto Ceccucci/CERN

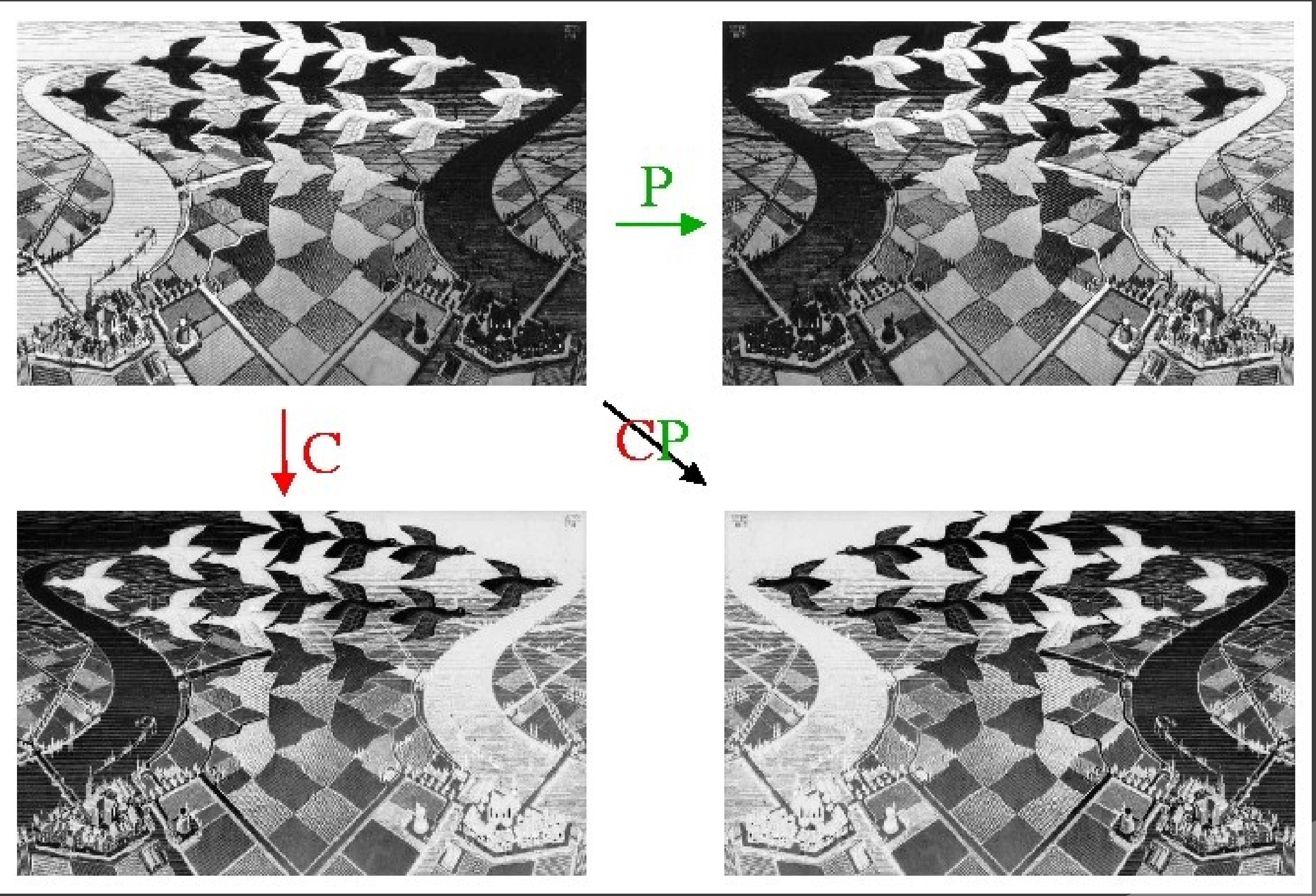
STATUS OF CP-VIOLATION SEARCHES IN HADRONIC SECTOR

GLA2011, 5-10 June, 2011, Jyväskylä, Finland

Contents

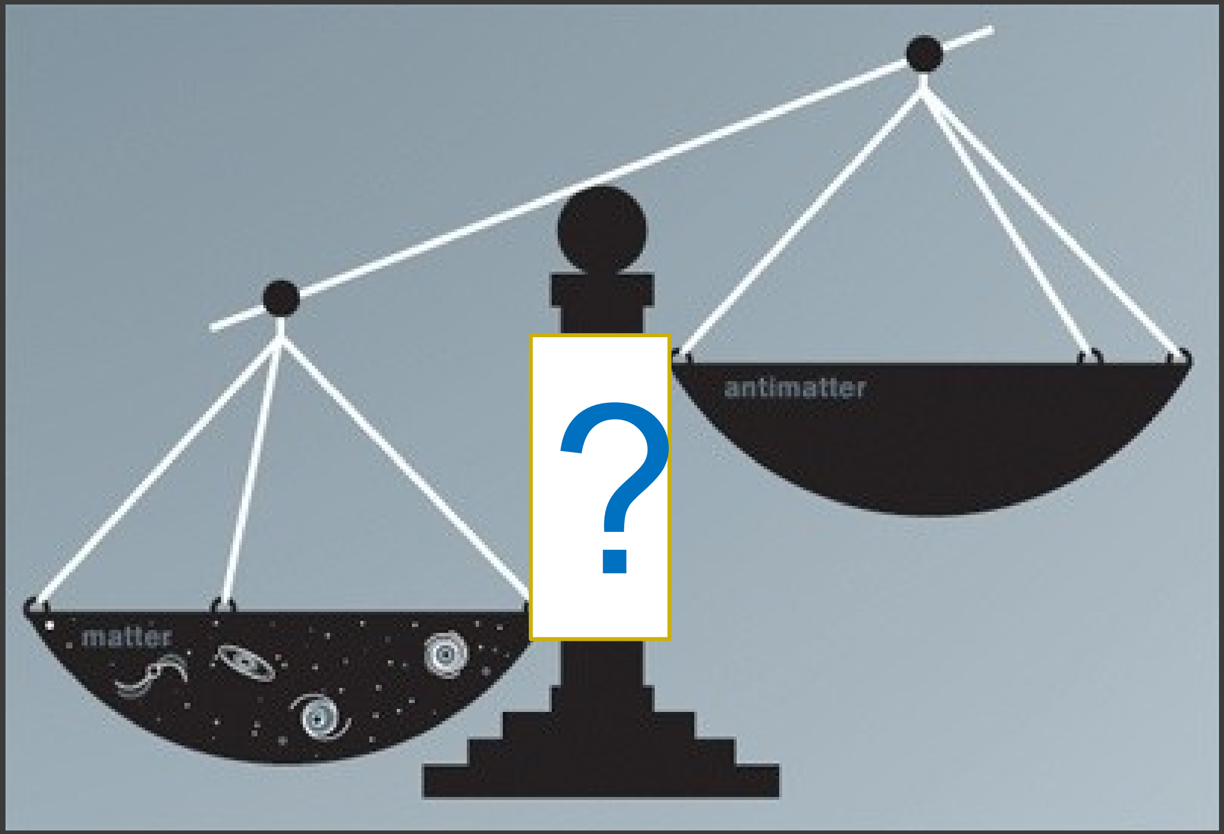
- Why CP-Violation is essential
- CP-Violation in the "Standard Model", quark mixing and decay
- Experimental State of the Art
  - K & B mesons
- Status of new experiments and future projects

CP-Violation



Da Gino Isidori:
http://scienzapertutti.lnf.infn.it/P1/schedaCP.html

Baryon Asymmetry of the Universe (BAU)



$n_{quark} - n_{antiquark} / n_{quark}$ (Proto Universe) $\sim n_{Baryon} / n_{photon}$ (Today)$\sim$**5×10^{-10}**

Sakharov Conditions for BAU

Andrei Sakharov (1967)

To allow the development of an asymmetry between matter and anti-matter

1. Violation of Baryonic Number

2. Thermodynamic Non-equilibrium

3. Violation of C & CP

Origin of BAU: Baryogenesis or Leptogenesis?

CP-Violation and Flavour Physics in the Era of the LHC

- Many open questions are associated with flavour and CP-Violation
- Why are three generations (if there are three)?
- What determines the hierarchy of the quark masses?
- What determines the pattern of the quark mixing?
- What determines the non-zero neutrino mass and mixing?

- **Flavour Problem:**
  - **Many reasons to expect New Physics (NP) at $\Lambda \sim 1$ TeV**
  - **Naïve Flavour bounds $\Lambda > 10^4$ TeV**

  → the full theory must have a non-trivial flavour structure

Types of CP-Violation

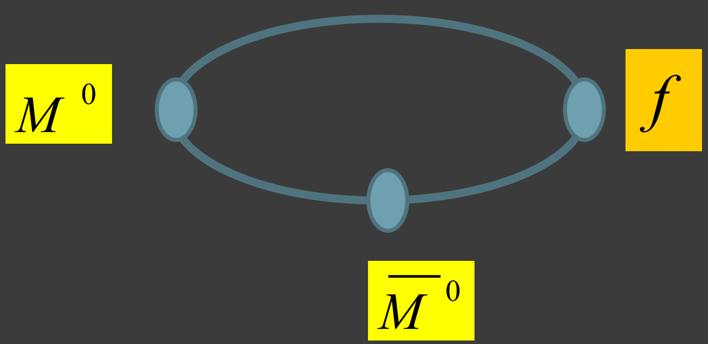
$$|M_L\rangle \propto p|M^0\rangle + q|\overline{M}^0\rangle$$
$$|M_H\rangle \propto p|M^0\rangle - q|\overline{M}^0\rangle$$

$\Delta F = 2$

$$A_f = \langle f|H|M\rangle, \quad \overline{A}_f = \langle f|H|\overline{M}\rangle$$
$$A_{\bar{f}} = \langle \bar{f}|H|M\rangle, \quad \overline{A}_{\bar{f}} = \langle \bar{f}|H|\overline{M}\rangle$$

$\Delta F = 1$

1. CP Violation in mixing $|q/p| \neq 1$ (indirect)
2. CP Violation in decays $|\overline{A}_{\bar{f}} / A_f| \neq 1$ (direct)
3. CP Violation in the interference



$$\mathrm{Im}\,\lambda_f \neq 0$$

$$\lambda_f \equiv \frac{q}{p}\frac{\overline{A}_f}{A_f}$$

Cabibbo-Kobayashi-Maskawa (CKM) Quark Mixing

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

With 3 generations CP violation is naturally introduced by an irreducible complex phase in the quark mixing matrix (Komayashi & Maskawa, 1973)

Kobayashi and Maskawa shared ½ of the 2008 Nobel Prize in Physics " for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature".

$\lvert V_{ud}\rvert = 0.97425 \pm 0.00022$	$0^+ \to 0^+$ super-allowed nuclear β decays
$\lvert V_{us}\rvert = 0.2252 \pm 0.0009$	Kaon semi-leptonic and leptonic decays
$\lvert V_{cd}\rvert = 0.230 \pm 0.011$	$2\mu/1\mu$ ratio in neutrino/antineutrino interactions
$\lvert V_{cs}\rvert = 1.023 \pm 0.036$	Average of semi-leptonic D and leptonic D_s decays
$\lvert V_{cb}\rvert = (40.6 \pm 1.3) \times 10^{-3}$	Combination of exclusive and inclusive B decays
$\lvert V_{ub}\rvert = (3.89 \pm 0.44) \times 10^{-3}$	Comb. of exclusive and inclusive charmless B decays*
$\lvert V_{tb}\rvert = 0.88 \pm 0.07$	Single top-quark production cross-section

V_{td} & V_{ts} accessible from FCNC processes (loops)

*But tension inclusive and exclusive determinations (see later)

Hierarchical Structure

$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Wolfenstein parameterization

From Global fit (PDG review, 2010):

Imposing SM constraint (3 generation unitarity):

λ= 0.2253 ± 0.0007   A = 0.808 $^{+0.022}_{-0.015}$

ρ = 0.132 $^{+0.022}_{-0.014}$ η = 0.341 ± 0.013

CP-Violation in Kaons

- Neutral Kaon Mixing (ππ, semi-leptonic)

$$|\varepsilon| = \frac{G_F^2 f_K^2 m_K m_W^2}{12\sqrt{2}\pi^2 \Delta m_K} \hat{B}_K \{\eta_1 S(x_c)\,\mathrm{Im}\left(V_{cs}V_{cd}^*\right)^2 + \eta_2 S(x_t)\,\mathrm{Im}\left(V_{ts}V_{td}^*\right)^2 + 2\eta_3 S(x_c, x_t)\,\mathrm{Im}\left(V_{cs}V_{cd}^* V_{ts}V_{td}^*\right)\}$$

$$|\varepsilon| = (2.233 \pm 0.015) \times 10^{-3}$$

- Neutral Kaon Decays into ππ

PDG Average

$$\mathrm{Re}\,\frac{\varepsilon'}{\varepsilon} \propto \mathrm{Im}(V_{td}V_{ts}^*)$$

$$\mathrm{Re}\,\frac{\varepsilon'}{\varepsilon} = (1.67 \pm 0.23) \times 10^{-3}$$

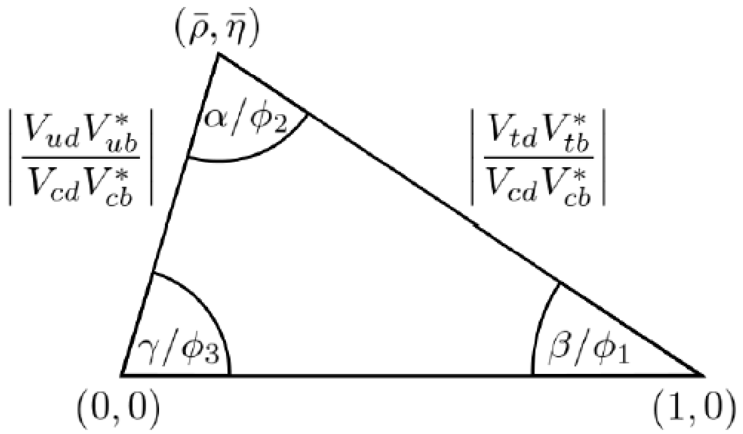
$$\Gamma(K^0 \to \pi^+\pi^-) \neq \Gamma(\overline{K}^0 \to \pi^+\pi^-)$$

Direct CP-Violation

Decisive Experiments: NA48 & KTeV

One (of the six) Unitarity Relations

$$V_{td}V_{tb}^* + V_{cd}V_{cb}^* + V_{ud}V_{ub}^* = 0$$



$$\beta = \phi_1 = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

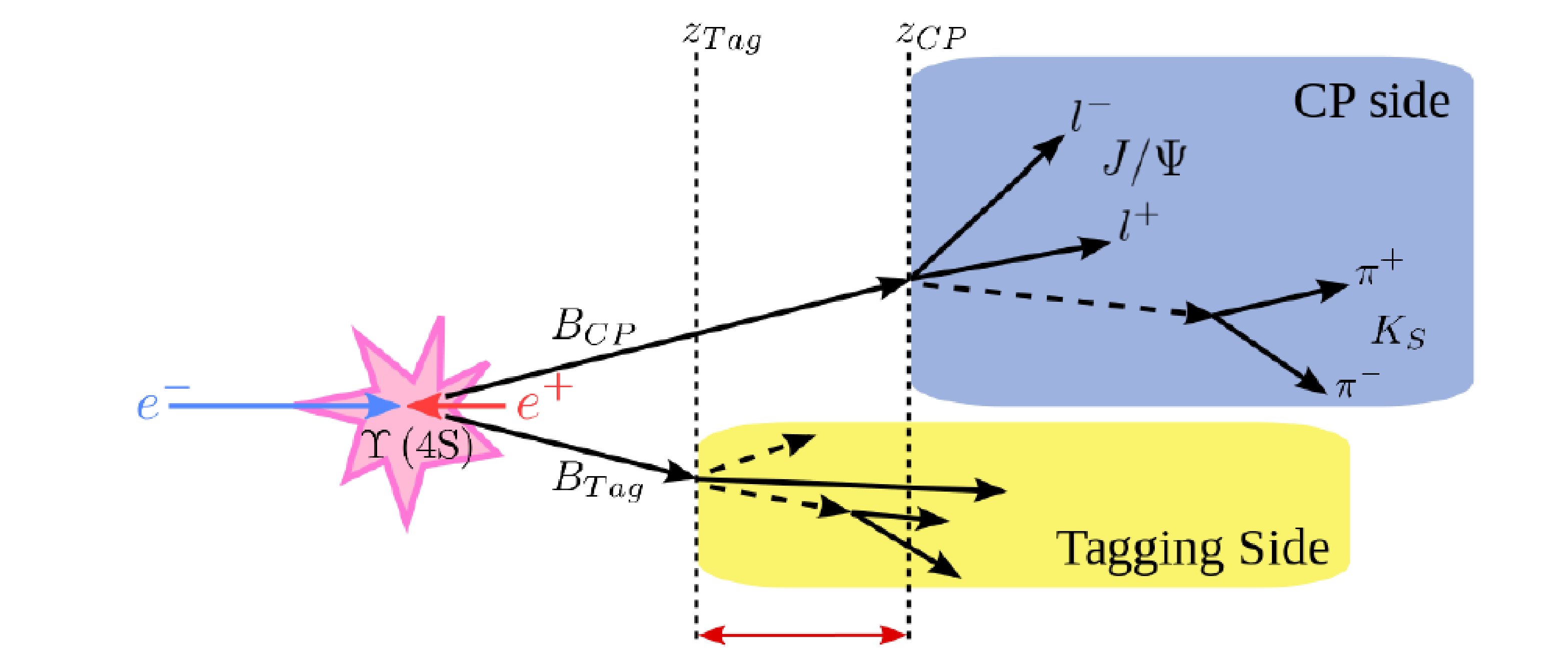
$$\alpha = \phi_2 = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\gamma = \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

Constraints (examples)

Process	CKM and other factors	Constraint
$b \to u$ / $b \to c$	$\lvert V_{ub}\rvert^2 / \lvert V_{cb}\rvert^2$	$\rho^2 + \eta^2$
Δm_{Bd}	$\lvert V_{td}\rvert^2 \ (f_{Bd}B_{Bd})^2$	$(1-\rho)^2 + \eta^2$
$\Delta m_{Bd} / \Delta m_{Bs}$	$\lvert V_{td} / V_{ts}\rvert^2 \ (f_{Bd}B_{Bd} / f_{Bs}B_{Bs})^2$	$(1-\rho)^2 + \eta^2$
ε_K	(see before)	$\eta(1-\rho)$
$B(K^0_L \to \pi^0 \nu \nu)$	$\lvert Im(V_{td} V^*_{ts})\rvert^2$	η^2

Time dependent CP-Asymmetry



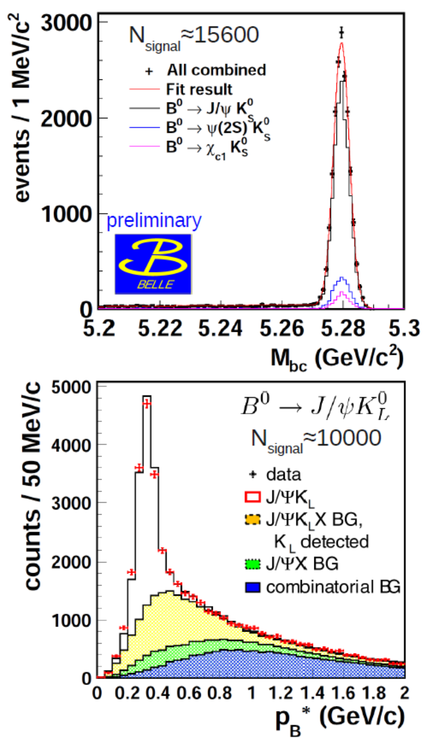
Courtesy by Markus Roehrken $\Delta z = \beta\gamma c \Delta t, \quad \langle|\Delta z|\rangle \approx 200\,\mu m$

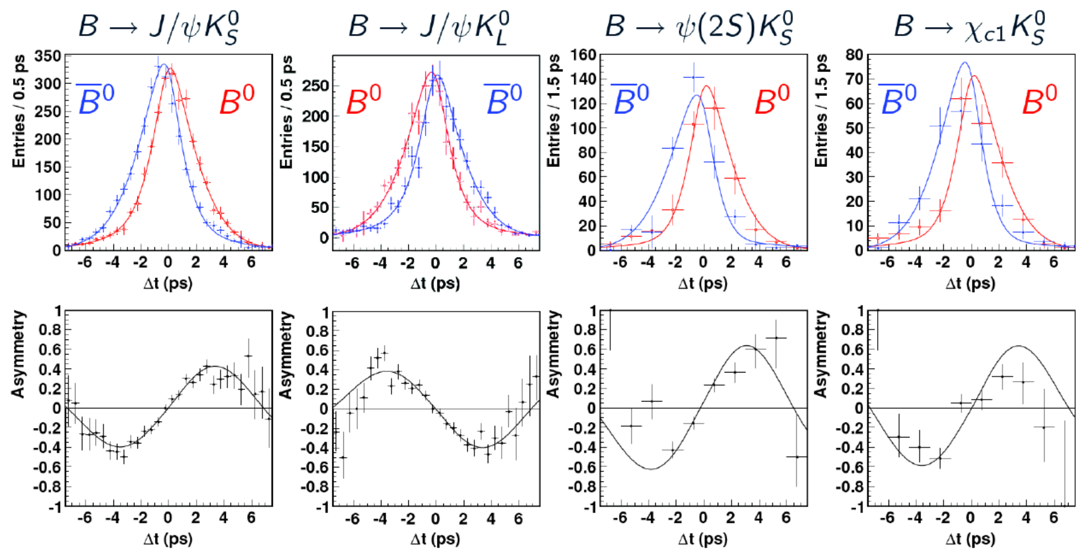
$$A_{CP} = \frac{\Gamma(\overline{M}^0 \to f) - \Gamma(M^0 \to f)}{\Gamma(\overline{M}^0 \to f) + \Gamma(M^0 \to f)} = \sin(2\Psi)\sin(\Delta m t)$$

For $f = \bar{f}$

Most recent determination of $\sin(2\phi_1)=\sin(2\beta)$: Belle

Belle's update on full dataset (preliminary):





Belle with 772×10⁶ BB:

$$\mathcal{A} = 0.007 \pm 0.016\,(\mathrm{stat}) \pm 0.013\,(\mathrm{syst})$$

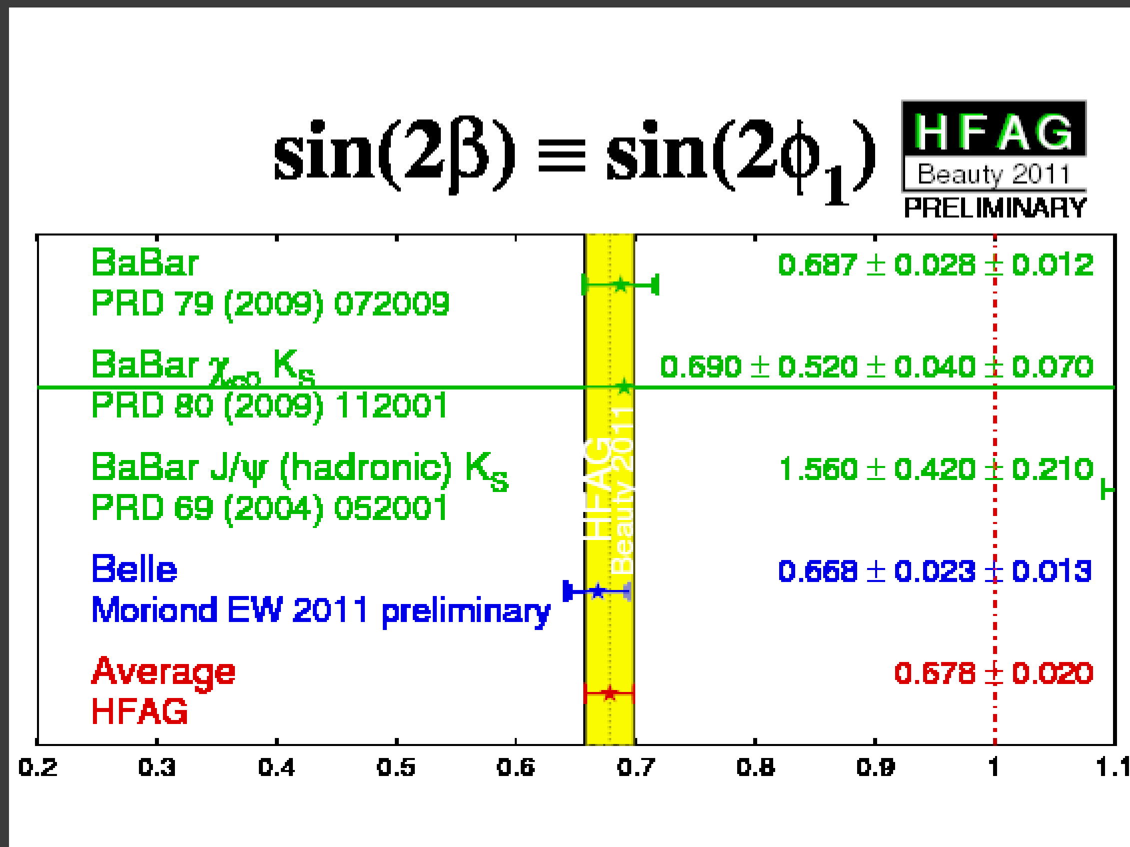
$$\sin(2\phi_1) = 0.668 \pm 0.023 \quad \pm 0.013$$

preliminary

Current world's most precise measurement of Φ_1

Courtesy by Markus Roehrken, Beauty 2011

Time-Dependent CP-Asymmetry in b→c c s

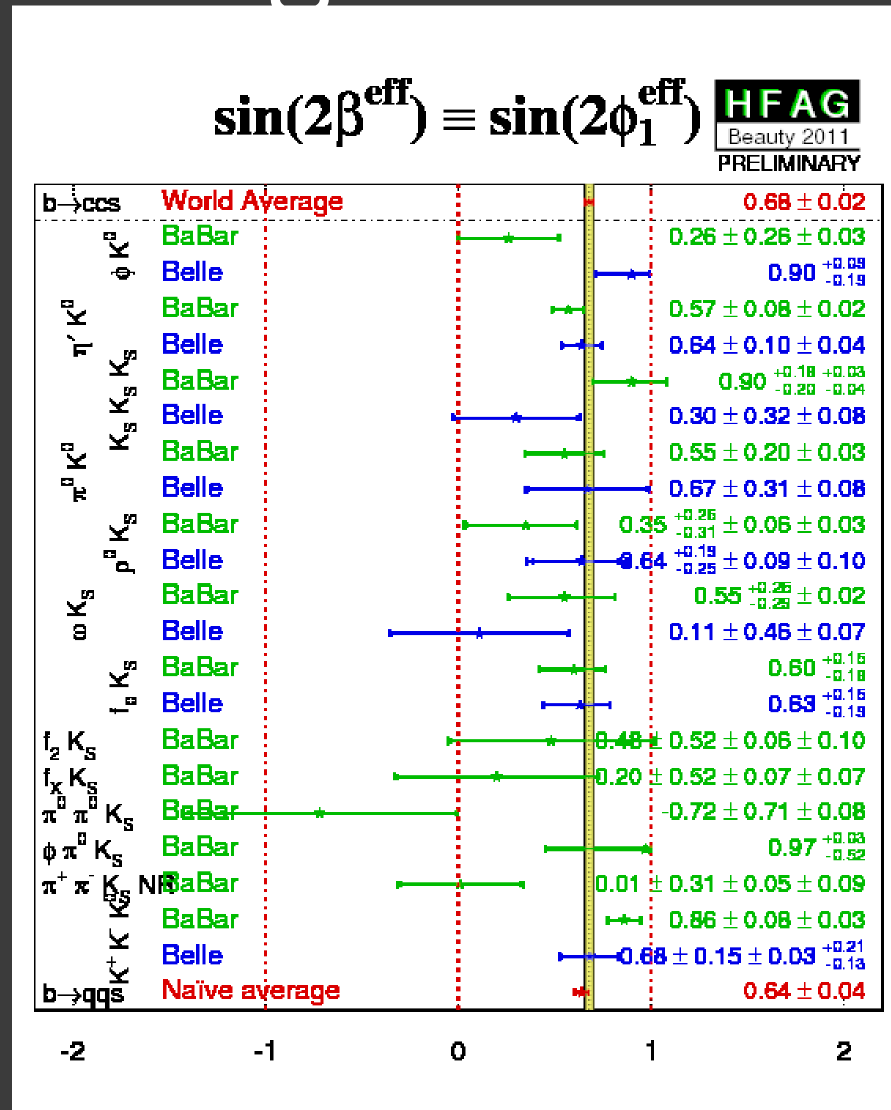


Sin2β^eff from "Penguins"

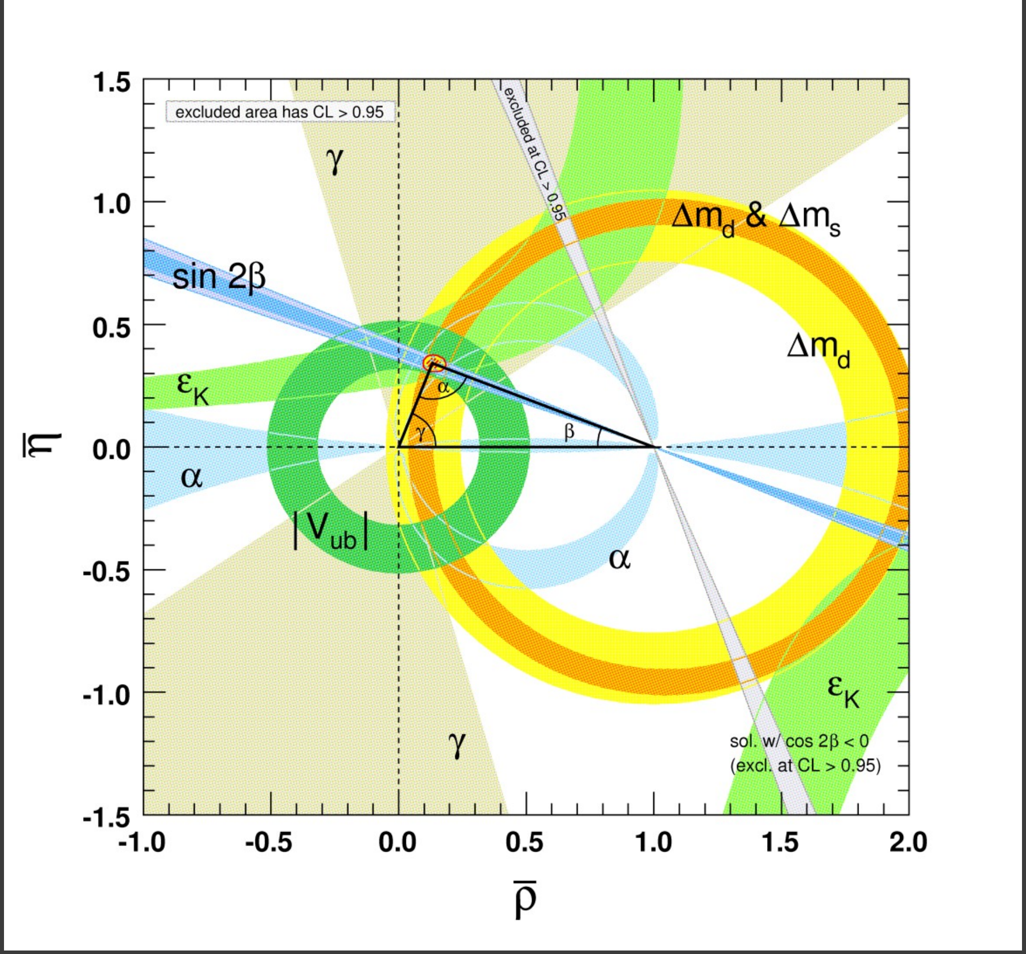
Determinations of sin2β from modes other than charmonium can be affected by New Physics Contributions via Penguin (loop) diagrams

Naïve average (use with extreme caution!) consistent to the b→ cc s determination

Δ = 0.04 ± 0.04



Constraints on the rho eta plane



PDG 2010

The unique measure of CP-Violation in the SM is the area of the Unitarity Triangle (Jarlskog invariant J)

$$J = (2.91^{+0.19}_{-0.11}) \times 10^{-5}$$

Masiero's glass: New Physics generically entails new Sources of CP-violation

- The stringent limits from FCNC are a threat to New Physics Searches

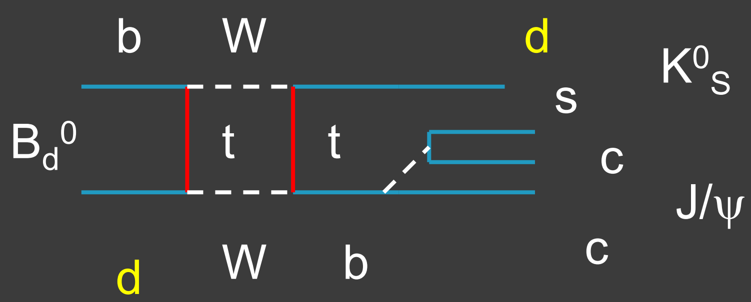
Half Empty Glass…

- Departure from the SM predictions → Possible hints of New Physics

….Half Full !

Are there any "hints" of deviation from the CKM description of quark mixing?

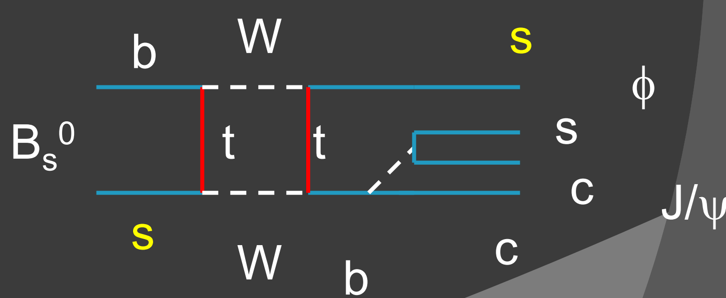
Time dependent CP-Asymmetries in B_s



$V_{td}V^*_{td} \sim e^{i2\beta}$

Large CP asymmetry in SM ($\beta=\phi_1$)

$V_{ts}\,V^*_{ts} \sim \text{real}$



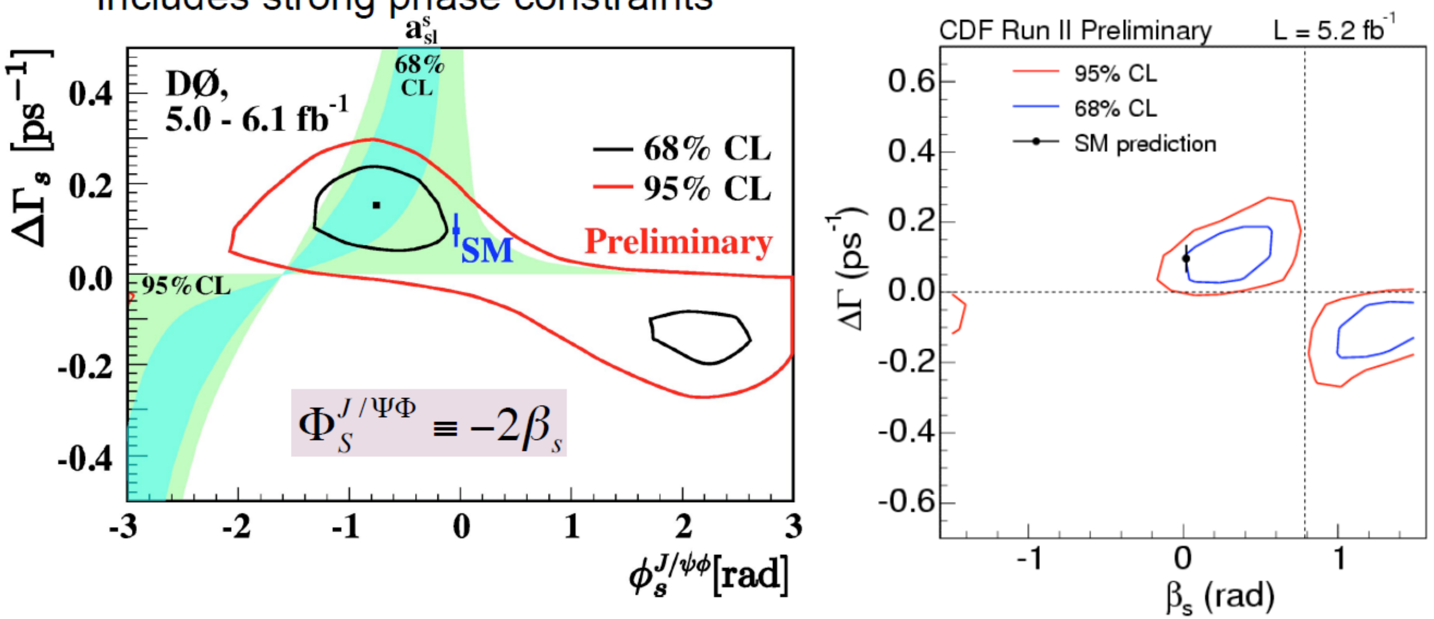
Very small CP asymmetry expected in SM

CP-Asymmetry in $B_s \rightarrow J/\psi\ \phi$

D0: 6.1 fb^{-1} of data

Includes strong phase constraints

CDF: 5.2 fb^{-1} of data

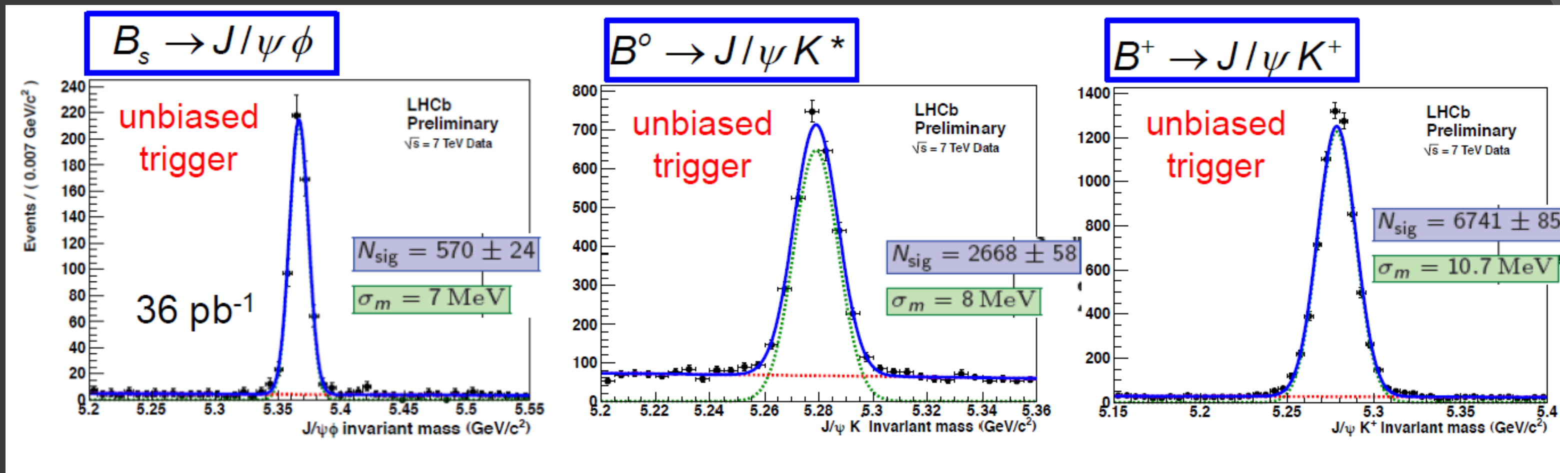


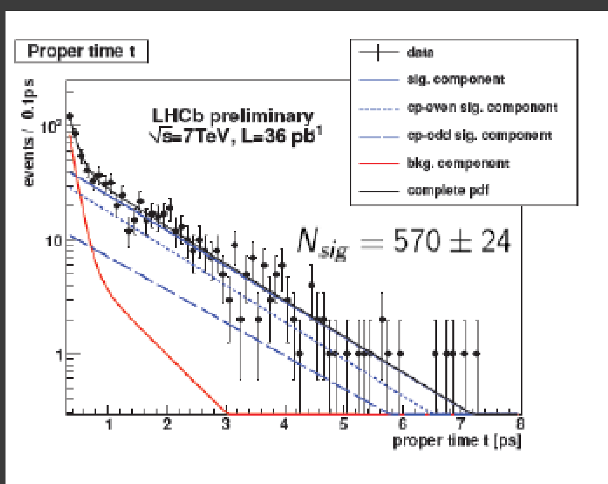
D0: 1.1σ deviation

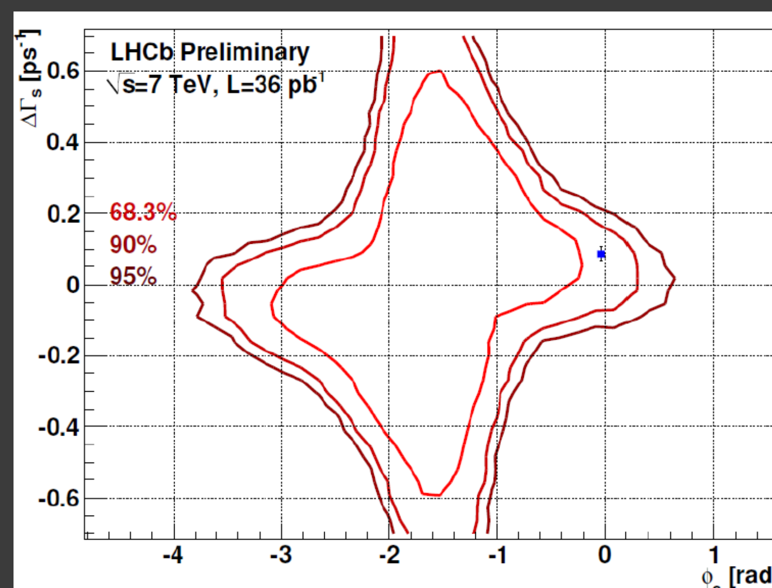
CDF: 0.8σ

Presented by Julia Thom-Levy @ Moriond EW 2011

New Strong Contender: LHCb@LHC



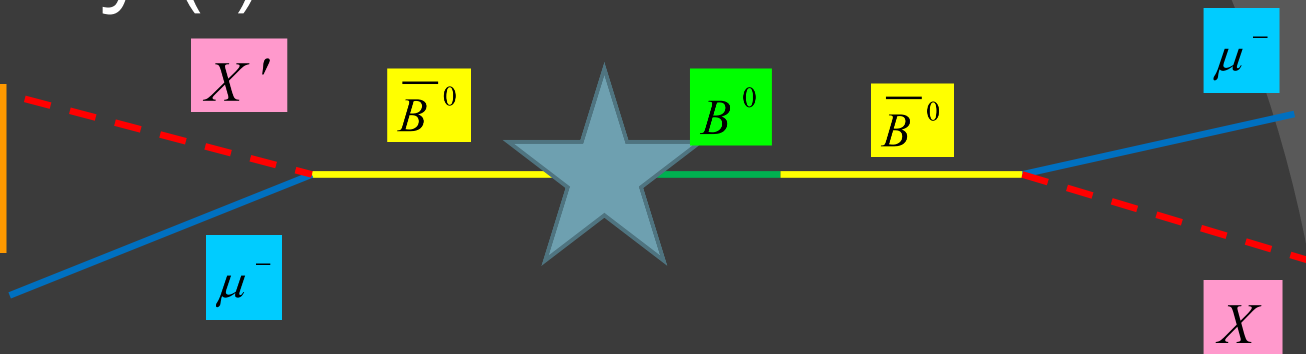




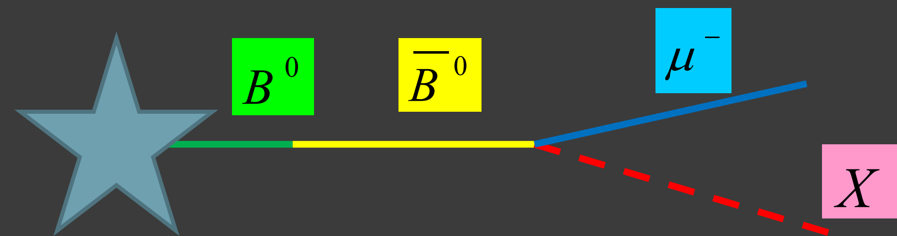
$\phi_s \in [\,-2.7,\ -0.5]$ rad at 68% CL
$\phi_s \in [\,-3.5,\ 0.2\,]$ rad at 95% CL

CP–Violating muon charge Asymmetry (I)

$$A_{sl}^{b} = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$



$$a_{sl}^{b} = \frac{n_b^{+} - n_b^{-}}{n_b^{+} + n_b^{-}}$$



$$a_{sl}^{b} \equiv \frac{\Gamma(\overline{B} \to B \to \mu^{+} X) - \Gamma(B \to \overline{B} \to \mu^{-} X)}{\Gamma(\overline{B} \to B \to \mu^{+} X) + \Gamma(B \to \overline{B} \to \mu^{-} X)} = A_{sl}^{b}$$

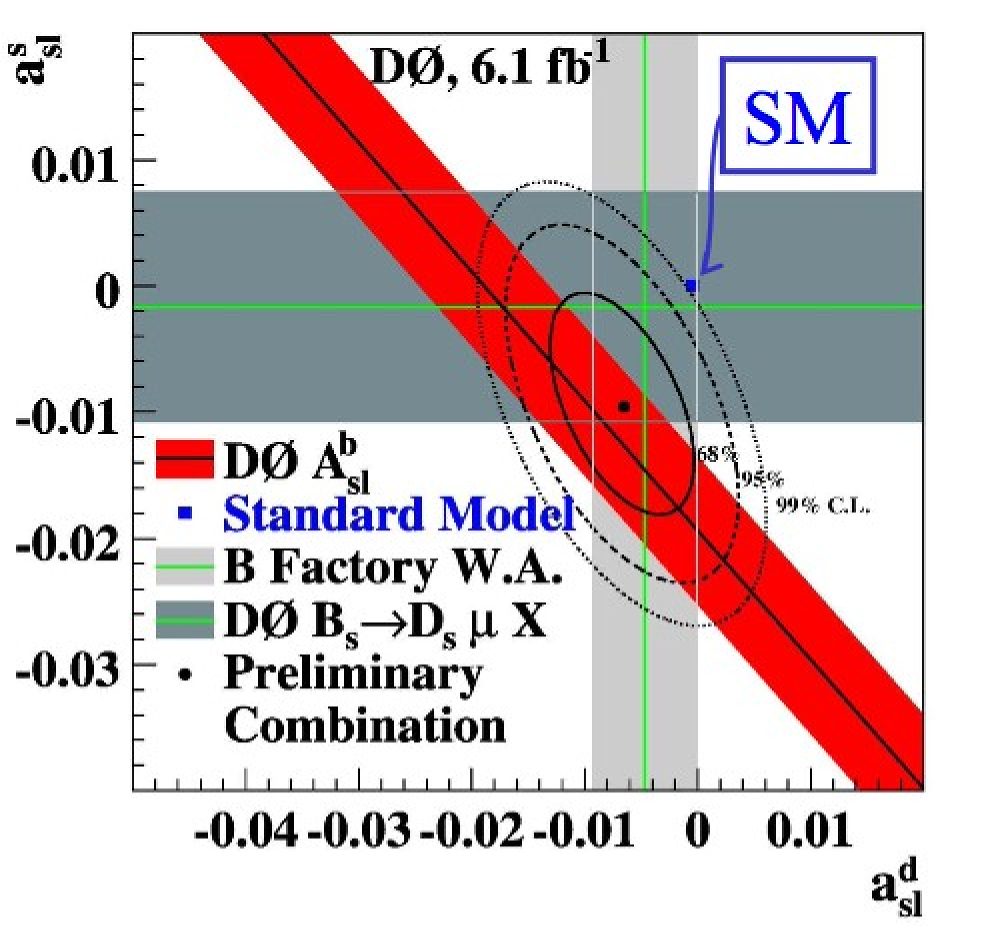
In SM ~0

$$A^{b}_{sl} = [\,-0.957 \pm 0.251\ (\text{stat.}) \pm 0.146\ (\text{syst.})\,]\ \%$$

Two independent methods
To measure the asymmetry

D0: PRL, 081801 (2010)

CP–Violating muon charge asymmetry (II)



V_{ub} "tension"

- Charmless b decays → first evidence of mixing between first and third generation (Argus & CLEO, 1990)
- As we saw, V_{ub} is an important constraint to the CKM fits
- In addition, it's value is needed to fix the SM expectation for $B(B^+ \to \tau^+ \nu)$ which, beyond SM, is sensitive to contributions coming from charged Higgs exchanges
- Big effort to bring theoretical errors under control
- Big experimental effort to reduce background (Full reconstruction methods etc.)
- There is a persisting tension between the exclusive and inclusive determinations

V_{ub} "tension"

As summarized by Guido Altarelli at FPCP 2011

V_{ub}incl = 4.35±0.18±0.23

V_{ub}excl = 3.25±0.12±0.28

Bernlocher

V_{ub}incl- V_{ub}excl = 1.10 ±0.42

2.6 σ

I think that this "tension" is due to the fact that over the last 30 years hundreds of theory papers have been devoted to the determination of Vub: each author claiming that his work led to a decrease of the theor. error

$B^+ \to \tau^+ \nu$

In the SM it measures the combination $f_b|V_{ub}|$

$$B(B \to \ell \nu) = \frac{G_F m_B}{8\pi} m_\ell^2 \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 \left|V_{ub}\right|^2 \tau_B$$

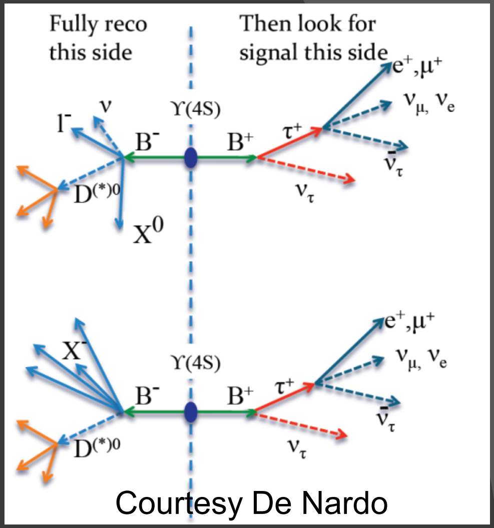
Using V_{ub} as external input, the decay can be used to determine the B meson decay constant f_B and compare it to the lattice QCD value

(e.g. f_B= 190 ±13MeV (HPQCD collaboration arXiv:0902.1815v2)

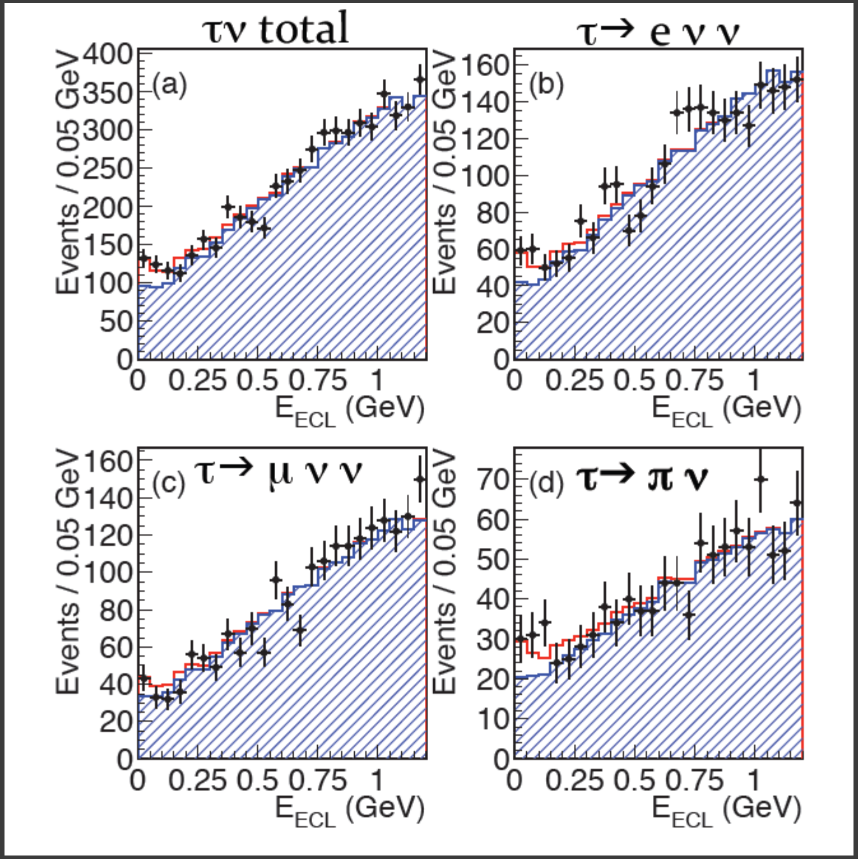
Helicity suppressed in the SM, sensitive to Charged Higgs mass in SM extensions

B Factories: $B^+ \to \tau^+ \nu$

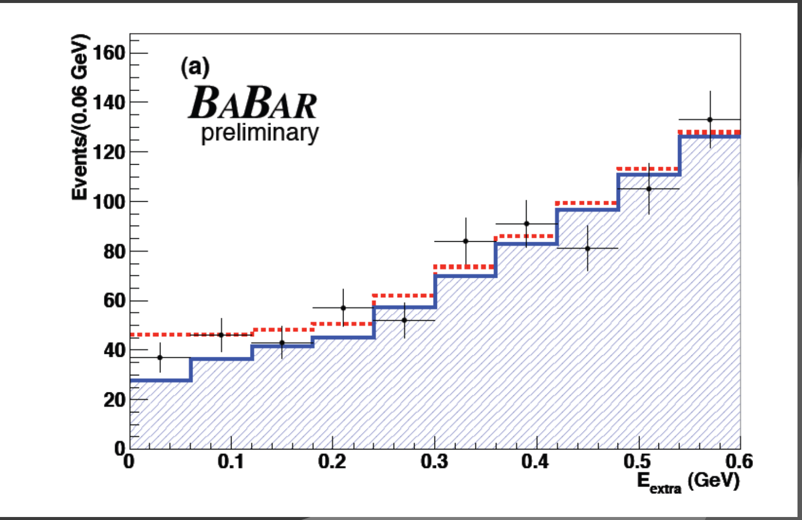
No kinematic constraints, **many neutrinos!**



Belle Semi Leptonic tags PRD 82 071101 R (2010)

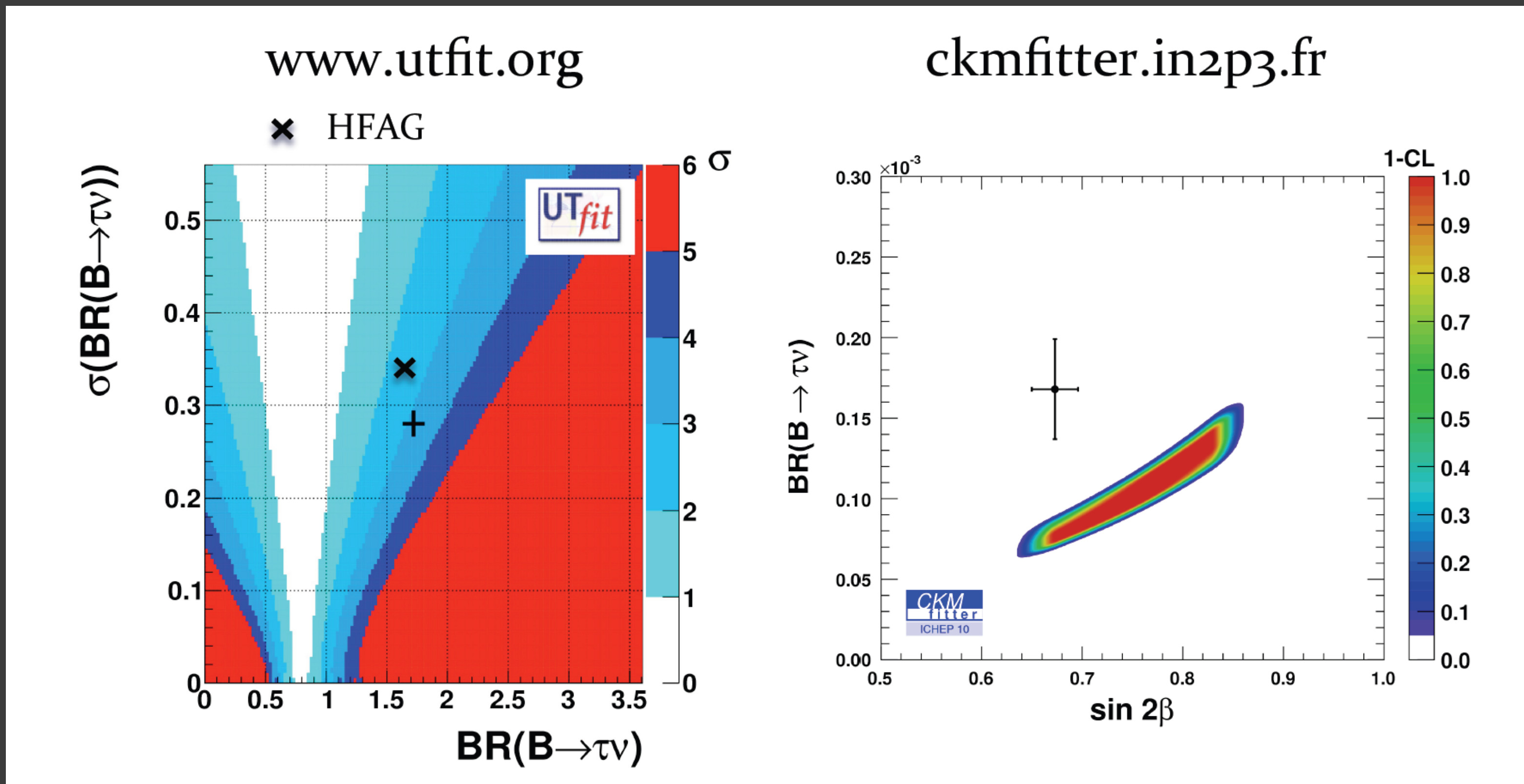


Babar Hadronic tags (arXiv:1008.0104 (2010)



HFAG Average: $B(B^+ \to \tau^+ \nu) = (1.64 \pm 0.34) \times 10^{-4}$

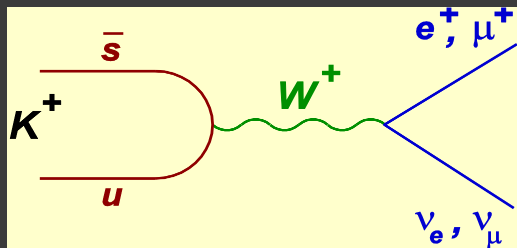
$B^+ \to \tau^+ \nu$ and CKM fits



As shown by G. De Nardo at FPCP 2011

Similarly: $R_K = K_{e2}/K_{\mu 2}$

SM

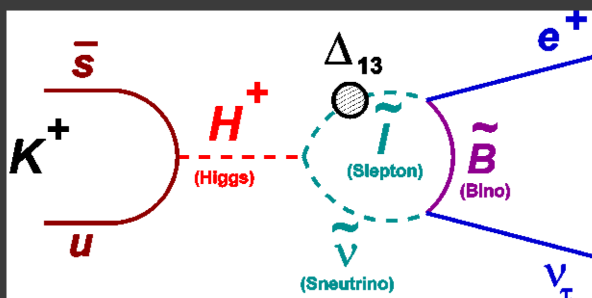


$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \cdot (1 + \delta R_K^{\text{rad.corr.}})$$

$R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$

Cirigliano & Rosell PRL 99 (2007) 231801

BSM, LFV



e.g. Masiero, Paradisi Petronzio
PRD 74 (2006) 011701,
JHEP 0811 (2008) 042

$$R_K^{LFV} \approx R_K^{SM} \left[1 + \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{M_e^2}\right) |\Delta_{13}|^2 \tan^6 \beta \right]$$

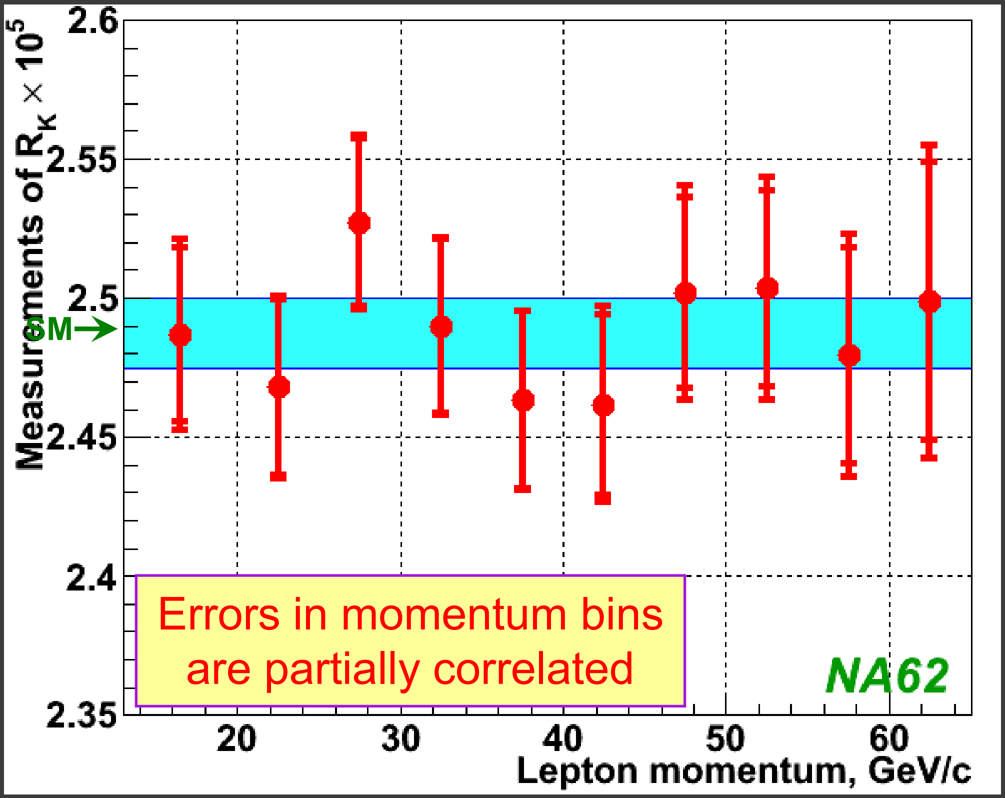
Example:
($\Delta_{13} = 5 \times 10^{-4}$, $\tan\beta = 40$, $M_H = 500$ GeV/c^2)
$R_K^{MSSM} = R_K^{SM}(1+0.013)$.

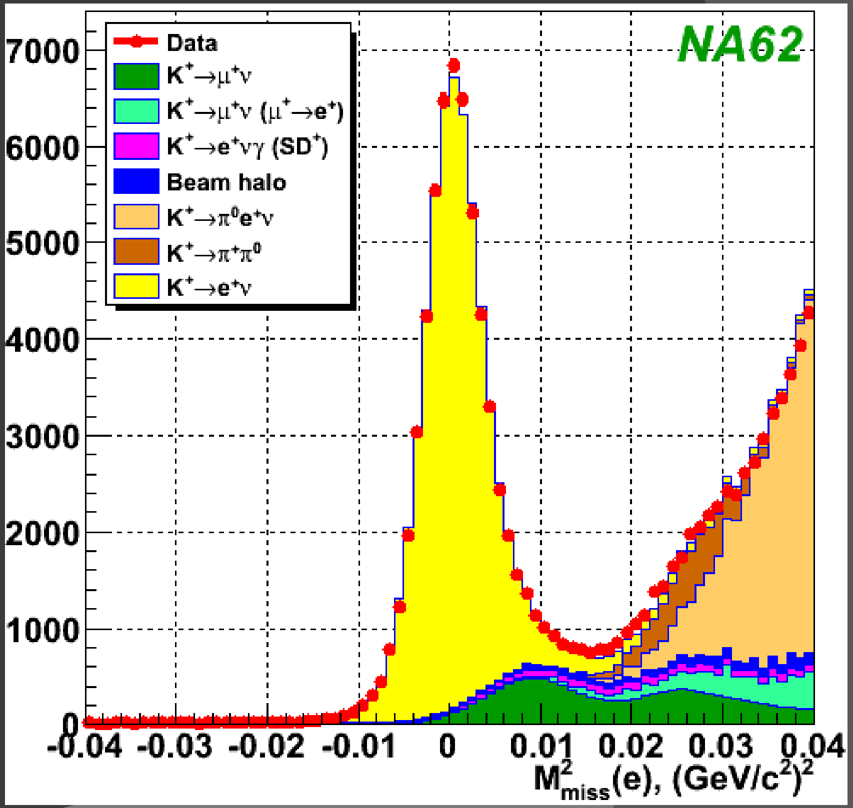
NA62: 40% 2007 data set

$R_K = (2.487 \pm 0.011_{stat} \pm 0.007_{syst}) \times 10^{-5}$

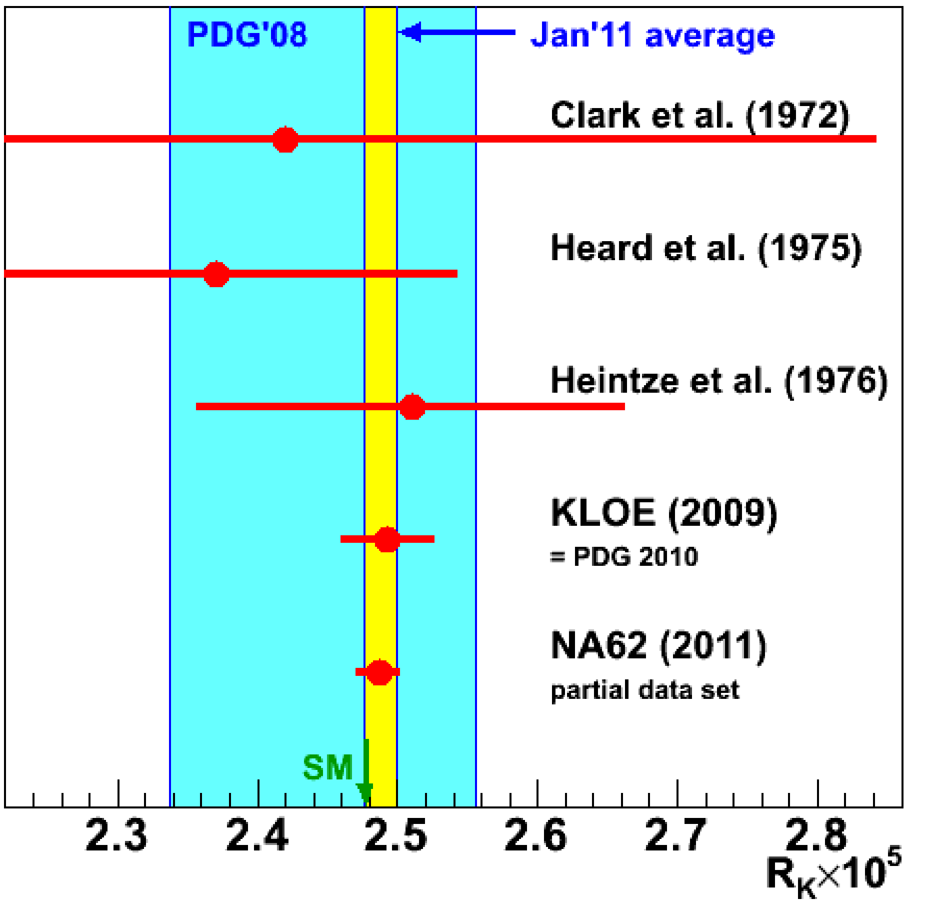
$R_K = (2.487 \pm 0.013) \times 10^{-5}$

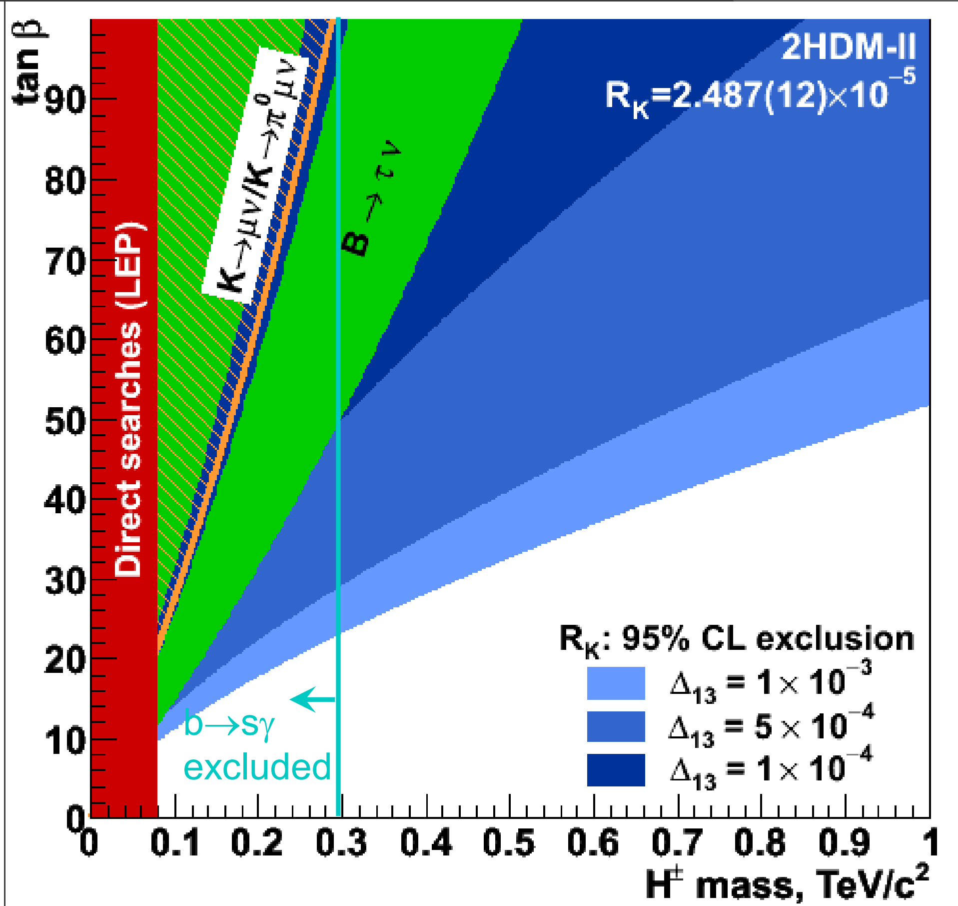
CERN-PH-EP-2011-004,
arXiv:1101.4805,
PLB B698 (2011) 105





R_K world average





World average	$\delta R_K \times 10^5$	Precision
PDG 2008	2.447±0.109	4.5%
Today	2.487±0.012	0.5%

Other limits on 2HDM-II:
PRD 82 (2010) 073012.

SM with 4 generations:
JHEP 1007 (2010) 006.

A. Buras list of Flavour Superstars

Superstars of 2011 – 2015
(Flavour Physics)

$S_{\psi\varphi}$

$\not{C}\not{P}$ in $B_s^0 - \bar{B}_s^0$

$(B_s \to \varphi\varphi)$

$B_s \to \mu^+\mu^-$

$(B_d \to \mu^+\mu^-)$

$(B^+ \to \tau^+\nu_\tau)$

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

$(K_L \to \pi^0\nu\bar{\nu})$

$(B_d \to K^*\mu^+\mu^-)$

γ
from Tree Level Decays

$\mu \to e\gamma$

$\tau \to \mu\gamma$

$\tau \to e\gamma$

$\mu \to 3e$

$\tau \to 3$ leptons

ε'/ε *)

(Lattice)

EDM´s

$(g\text{-}2)_\mu$

*) Direct $\not{C}\not{P}$ in $K_L \to \pi\pi$

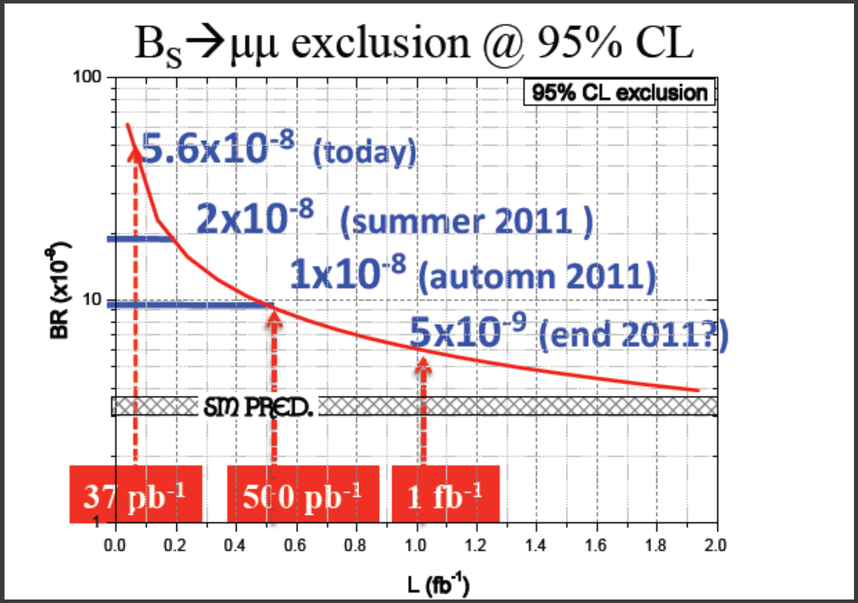
$B_{d,s}^0 \rightarrow \mu^+\mu^-$

- Exploratory decay sensitive to non-standard Higgs(es)

$$(c_{S,P}^{MSSM})^2 \propto \left(\frac{m_b m_\mu \tan^3\beta}{M_A^2}\right)^2$$

- Clean signature at hadronic colliders

LHCb Projection



		@ 90% CL	@ 95% CL
LHCb	Observed (expected) 37 pb^{-1}	< 12 (14) $x10^{-9}$	< 15 (18) $x10^{-9}$
CDF	World best, 2 fb^{-1} PRL 100 101802 (2008)	< 15 $x10^{-9}$	< 18 $x10^{-9}$
CDF	Preliminary, 3.7 fb^{-1} Note 9892	< 7.6 $x10^{-9}$	< 9.1 x 10^{-9}

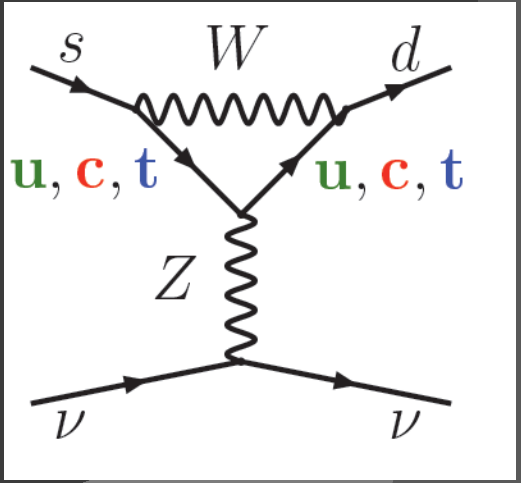
G. Lanfranchi, La Thuile 2011

Ultra-rare K Decays

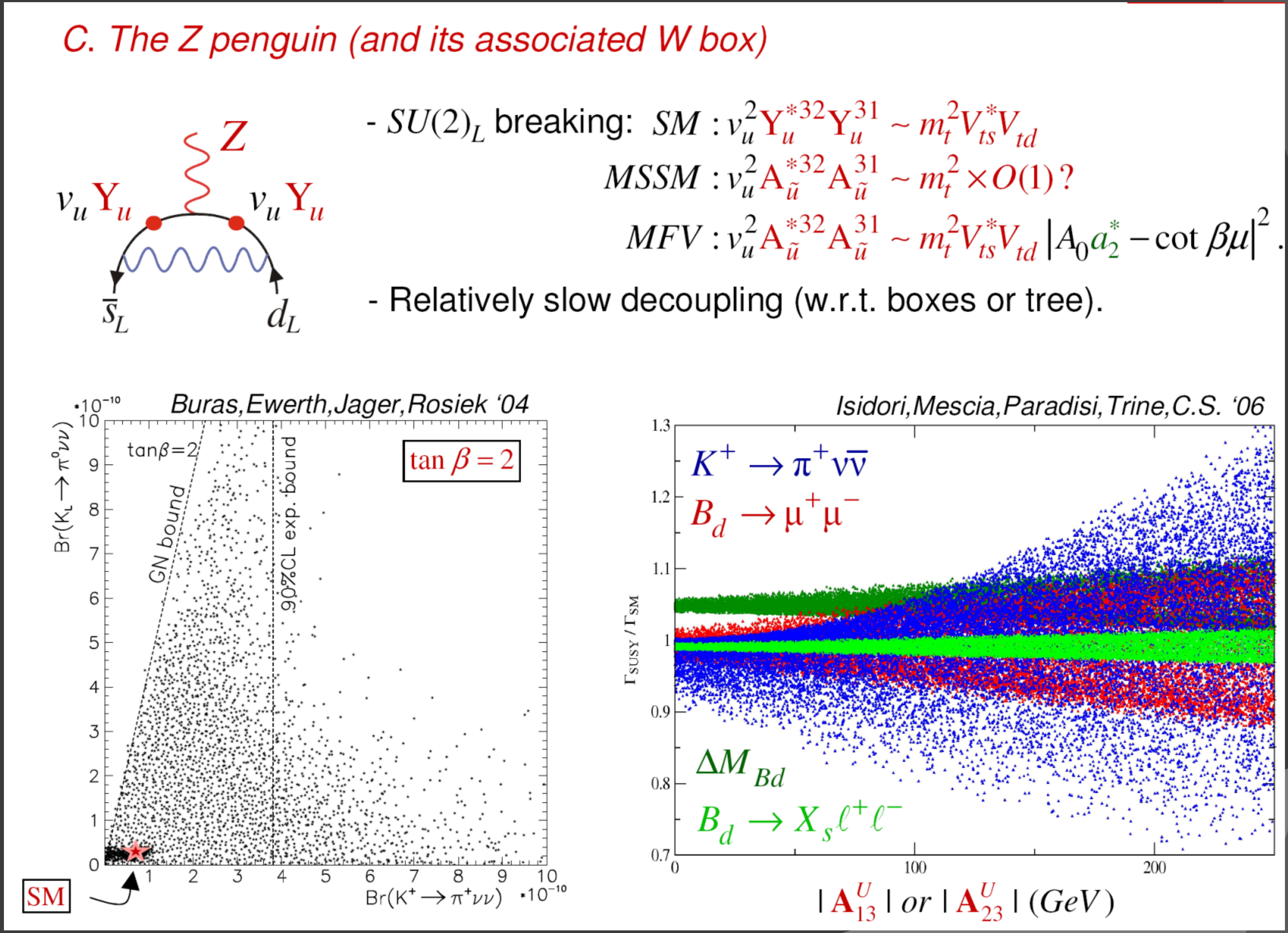
Decay	Branching Ratio $(\times 10^{10})$ Theory (SM)	Experiment
$K^+ \to \pi^+ \nu \bar{\nu} (\gamma)$	0.85 ± 0.07 [1]	$1.73^{+1.15}_{-1.05}$ [2]
$K_L^0 \to \pi^0 \nu \bar{\nu}$	0.26 ± 0.04 [3]	< 260 $(90\%$ CL $)$ [4]

[1] J.Brod, M.Gorbahn, PRD78, arXiv:0805.4119
[2] AGS-E787/E949 PRL101, arXiv:0808.2459
[3] M. Gorbahn
[4] KEK-E391a arXiv:0911.4789v1

- New experiments under construction:
  - KOTO JPARC: $K^0_L \to \pi^0 \nu \nu$
  - NA62 CERN: $K^+ \to \pi^+ \nu \nu$



Kaon Rare Decays and NP



(courtesy by Christopher Smith)

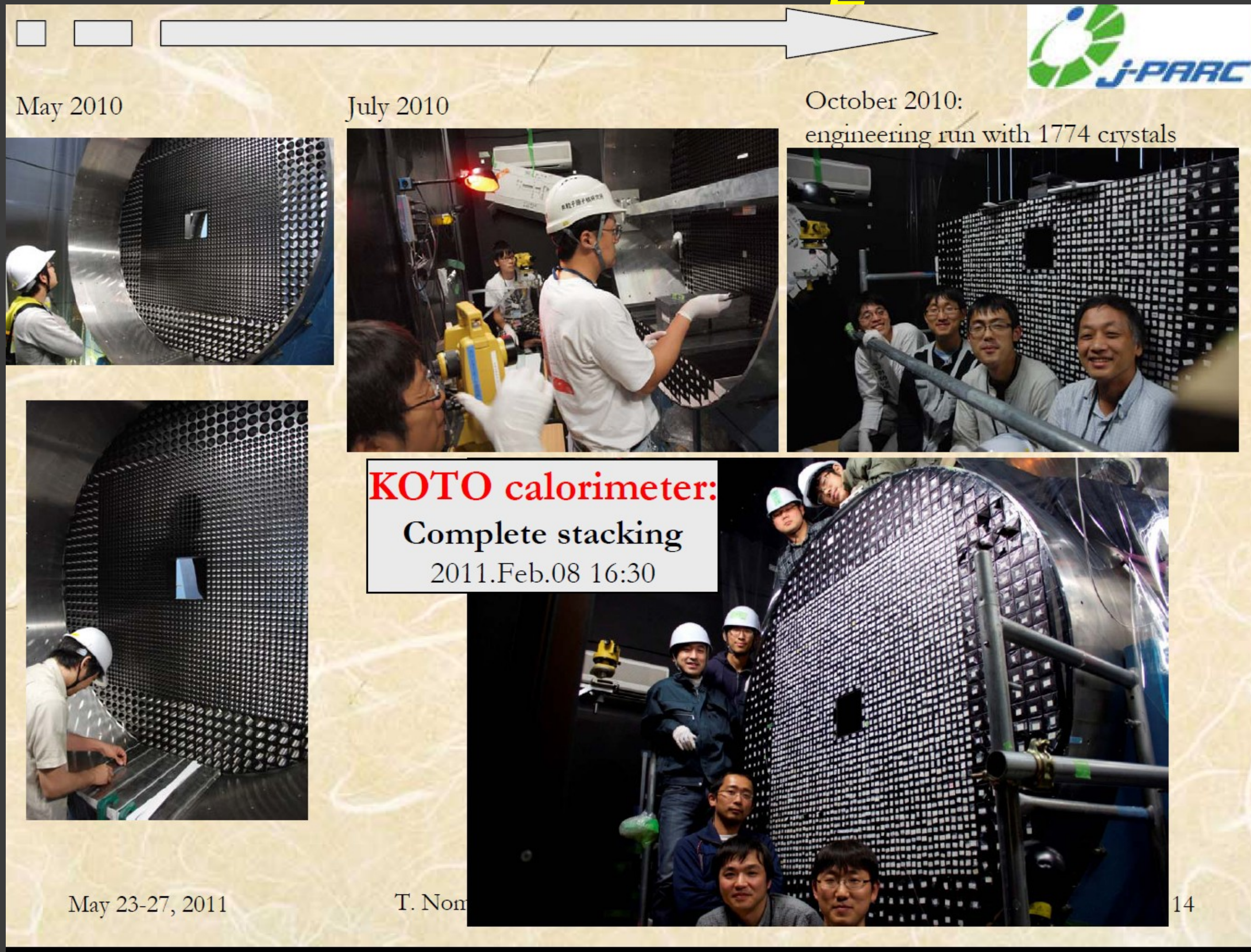
JPARC Flavour Programme

- $K^0_L \to \pi^0 \nu \nu$ (KOTO)

$$B(K_L \to \pi^0 \nu\nu) = \kappa_L \left(\frac{\mathrm{Im}(V_{ts}^* V_{td})}{\lambda^5} X_t \right)^2$$
$$= (2.43^{+0.40}_{-0.37} \pm 0.06) \times 10^{-11}$$

- T-Violation Search in $K^+ \to \pi^0 \mu^+ \nu$
  μ transverse polarization (TREK):
  aim to $\delta(P_T)$(stat)~10^{-4}, $\delta(P_T)$(syst)~10^{-4}

KOTO Experiment $K^0_L \to \pi^0 \nu\nu$



Courtesy of Tadashi Nomura (FPCP 2011)

KOTO Sensitivity and timeline

Note: As is considered before the earthquake. Will be updated.

- Goal: ~3 SM events / 3 years
  with S/N ratio ~ 2

  *** assuming design MR power ~270kW

COMPLETED
- 2009 Beamline survey

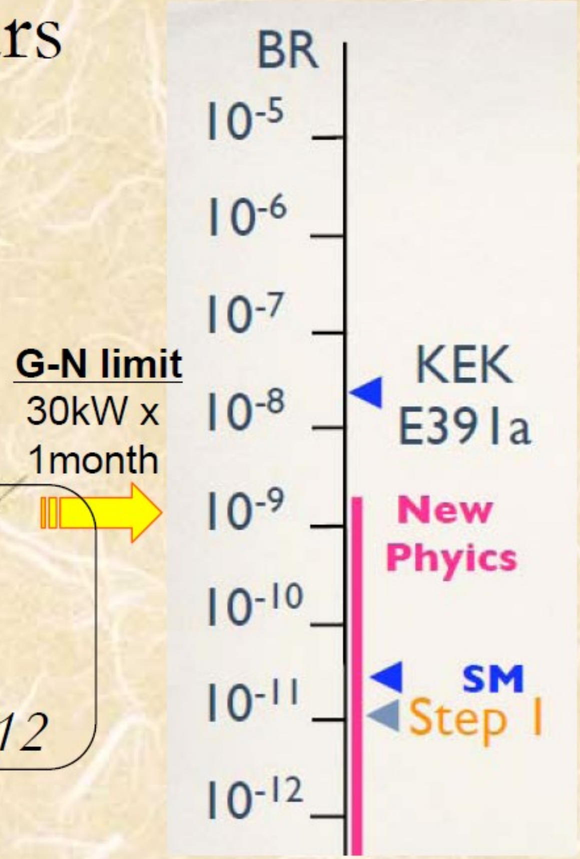
PARTIALLLY
- 2010 Calorimeter engineering

- 2011 Full engineering and
  Start physics run

  ➔ *1st milestone:*
  Grossman-Nir limit *by summer 2012*

~1YEAR DELAY ?
UNDER DISCUSSION

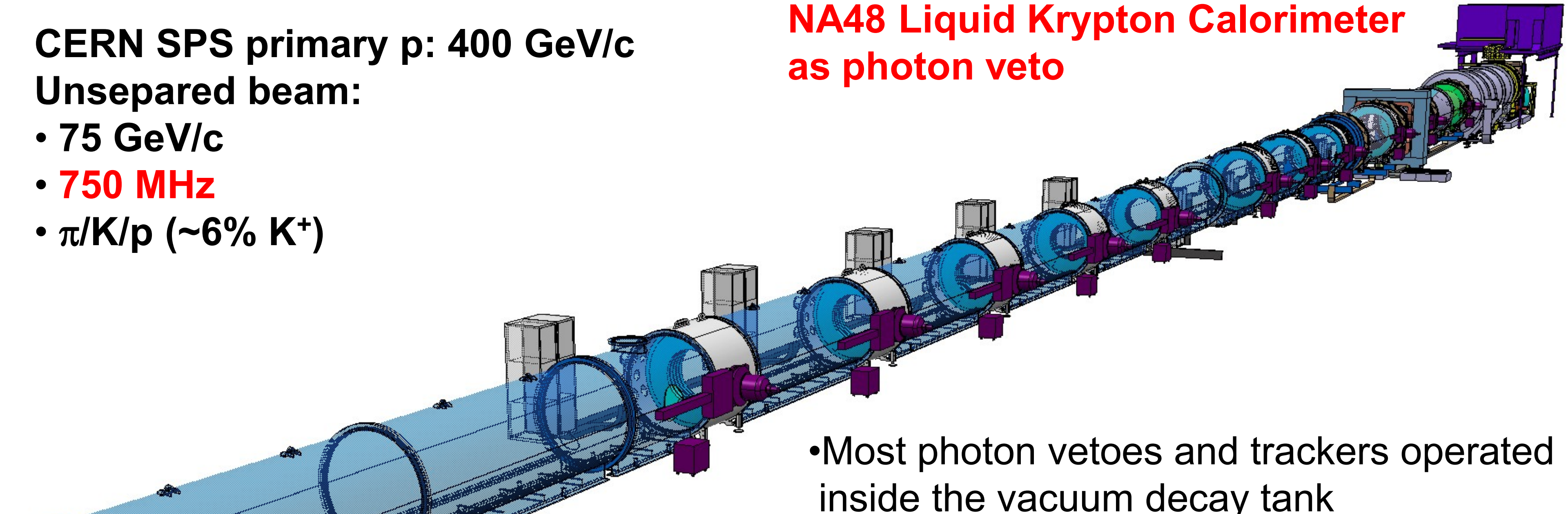
- Next step depends on scenario
  of accelerator's power upgrade.



NA62 EXPERIMENT: $K^+ \to \pi^+ \nu \nu$
K^+ DECAYS IN FLIGHT

CERN SPS primary p: 400 GeV/c
Unsepared beam:
- **75 GeV/c**
- **750 MHz**
- **π/K/p (~6% K^+)**

NA48 Liquid Krypton Calorimeter as photon veto



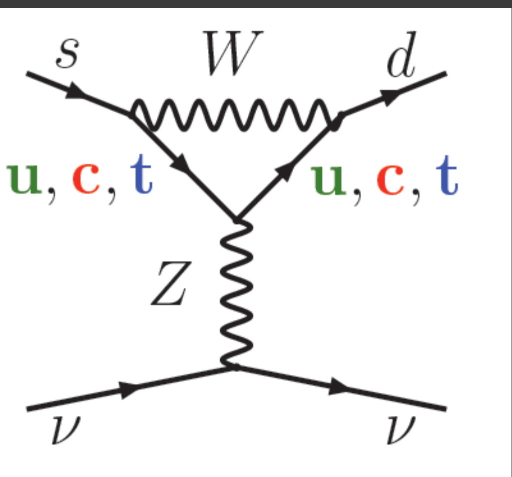
- Most photon vetoes and trackers operated inside the vacuum decay tank
- 17 m long RICH for π/μ separation
- High resolution Hermetic detector
- ~100 ps time resolution to correlate the beam K^+ to the decay π^+

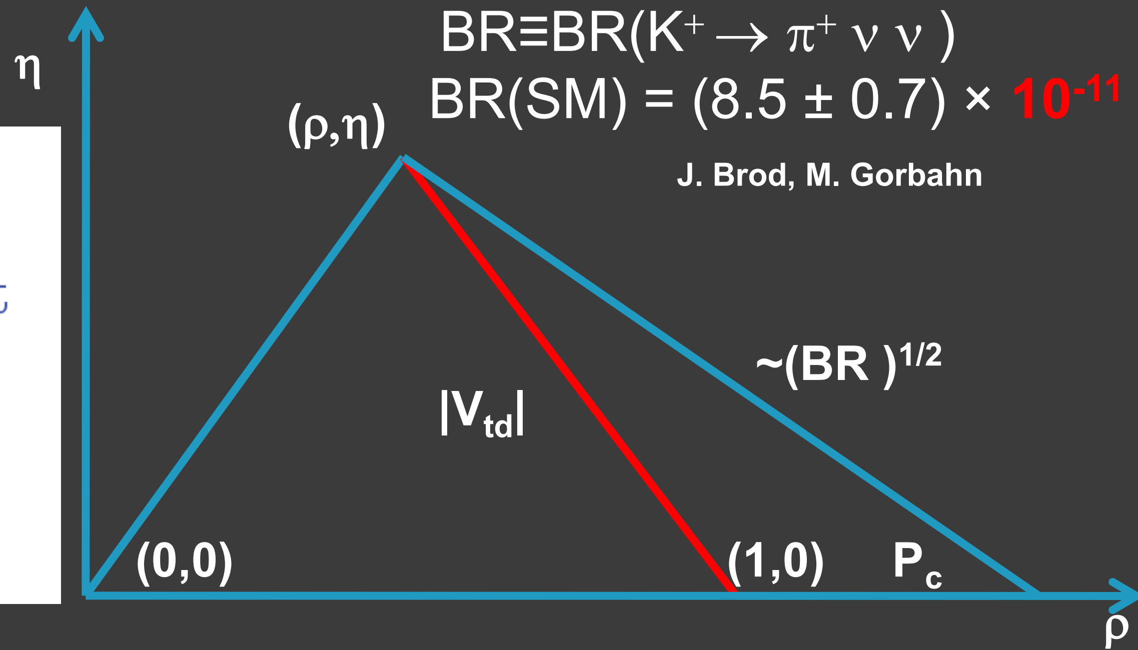
$K^+ \to \pi^+ \nu \bar{\nu}$ in SM

BR≡BR($K^+ \to \pi^+ \nu \bar{\nu}$)

BR(SM) = (8.5 ± 0.7) × 10^{-11}

J. Brod, M. Gorbahn



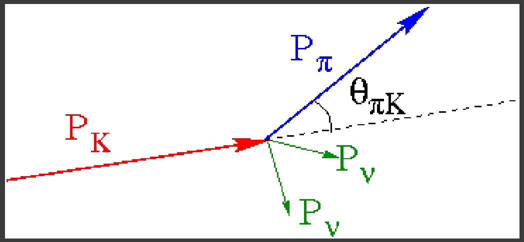


$$\delta |V_{td}| / |V_{td}| \approx 0.4\, \delta P_c/P_c \oplus 0.7\, \delta BR/BR \oplus \delta |V_{cb}| / |V_{cb}|$$

~2 % (mostly δ m_c) 62 % BNL 3 %

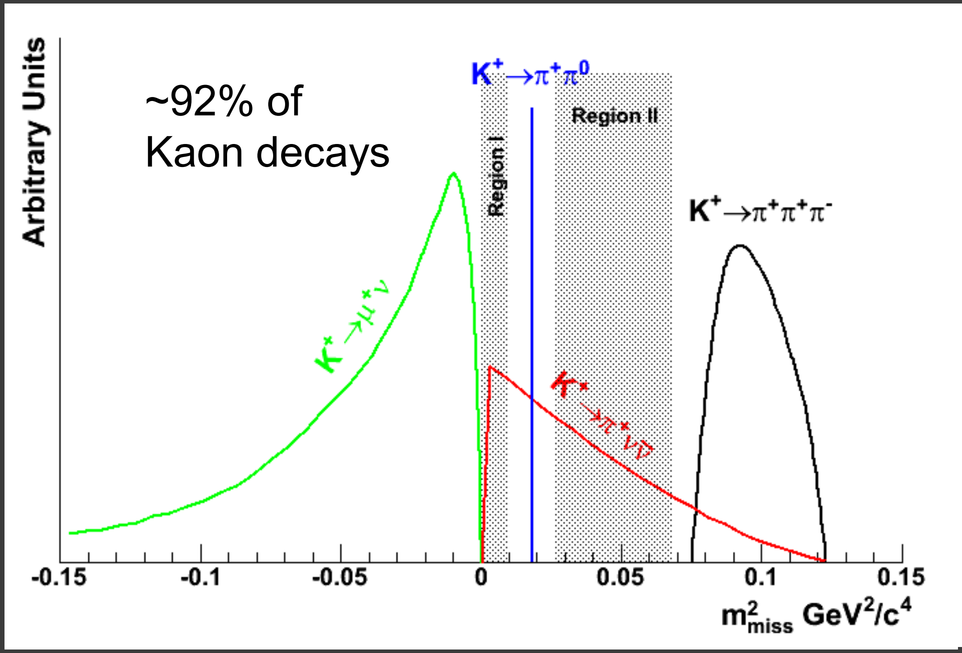
7% aim of NA62 (2y)

NA62 Technique: Decay in Flight

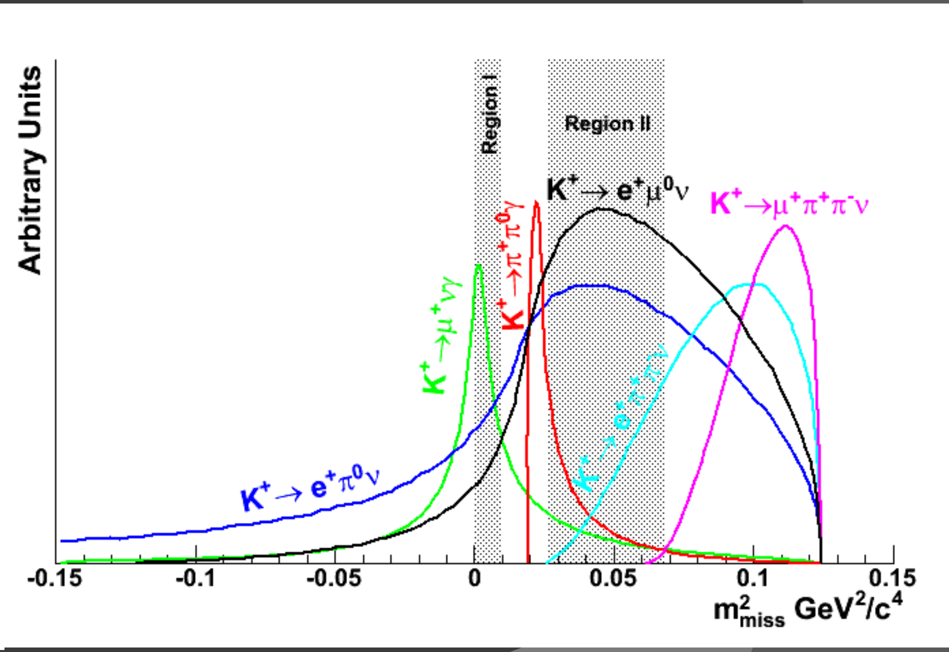


$$m^2_{miss} = (\tilde{p}_K - \tilde{p}_\pi)^2$$

Kinematically Constraint Decays

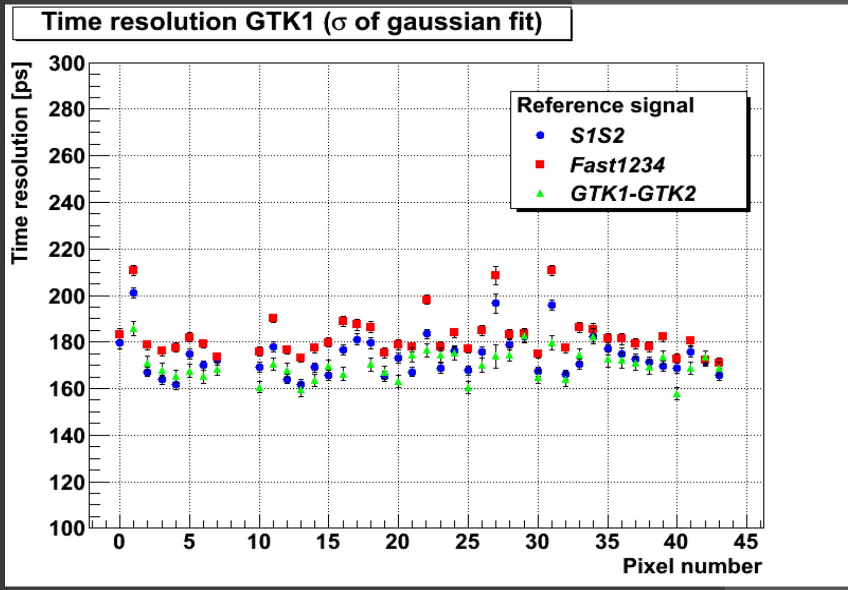


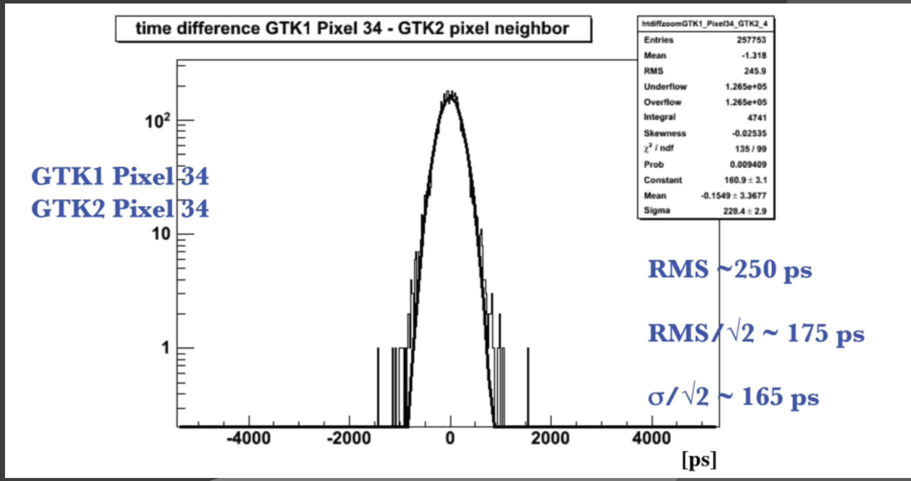
Unconstraint Decays



NA62 Gigatracker: Test Beam Results

- Albeit only 6% of the incoming particles are kaons, all of them (~ 1 GHz) have to be tracked
- Material budget ~0.5% X_0 per station
- Time resolution < 200 ps / station
- Silicon micro-pixels with ultra-fast ASIC front end with DLL TDC
- Prototypes beam tested at CERN PS

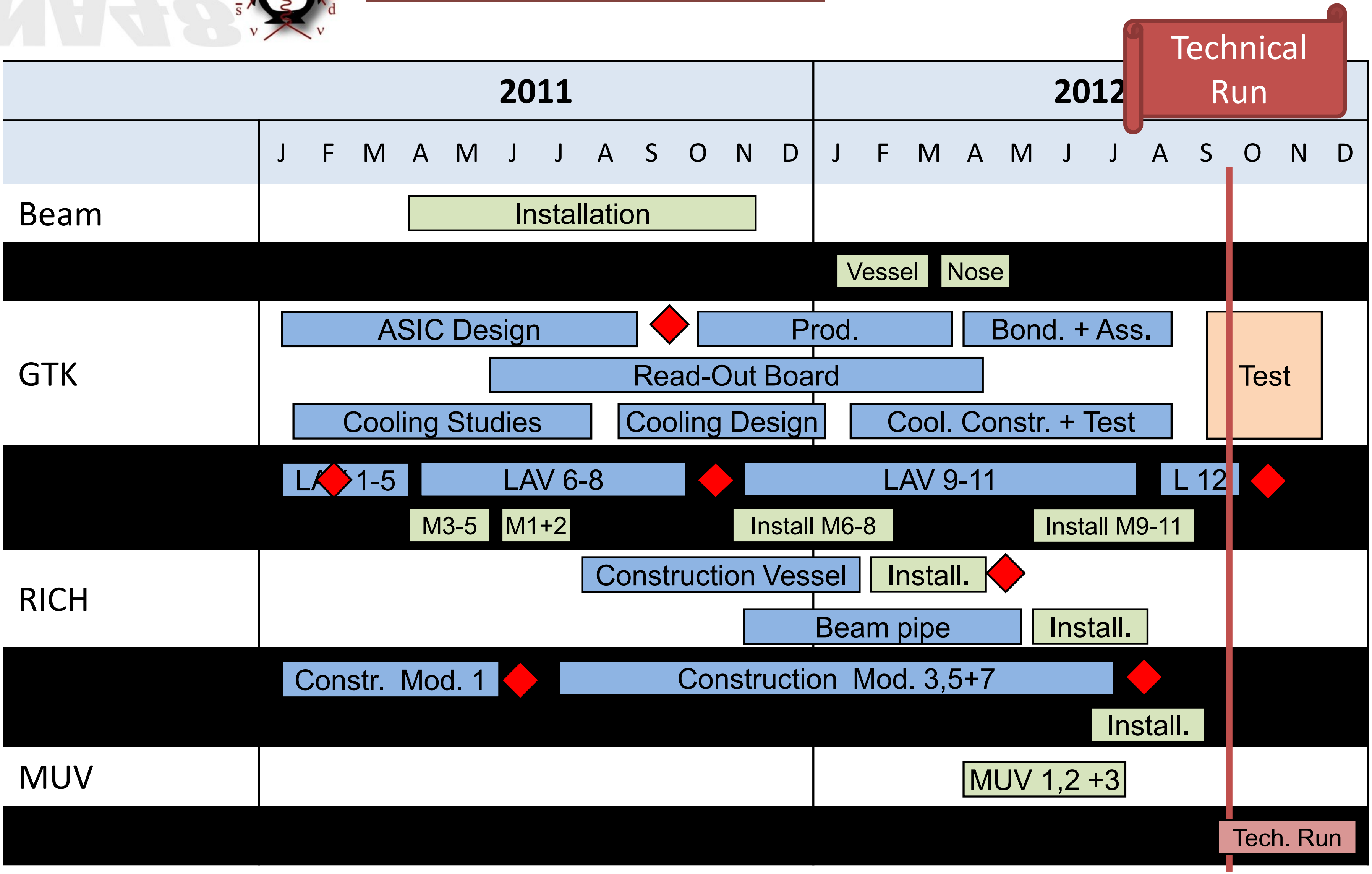




NA62 Sensitivity

Decay Mode	Events
Signal: $K^+ \to \pi^+ \nu\nu$ *[flux = 4.8×10^{12} decay/year]*	55 *evt/year*
$K^+ \to \pi^+\pi^0$ $[\eta_{\pi0} = 2\times10^{-8}\ (3.5\times10^{-8})\ ]$	4.3% (7.5%)
$K^+ \to \mu^+\nu$	2.2%
$K^+ \to e^+\pi^+\pi^-\nu$	≤3%
Other 3 – track decays	≤1.5%
$K^+ \to \pi^+\pi^0\gamma$	~2%
$K^+ \to \mu^+\nu\gamma$	~0.7%
$K^+ \to e^+(\mu^+)\ \pi^0\nu$, others	negligible
Expected background	≤13.5% (≤17%)

NA62 Schedule



Construction

Installation

Milestones

Note: not all milestones are shown on this planning

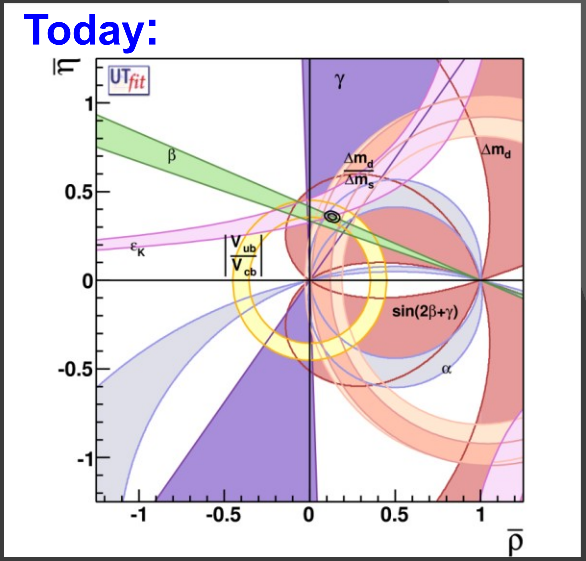
Future Projects

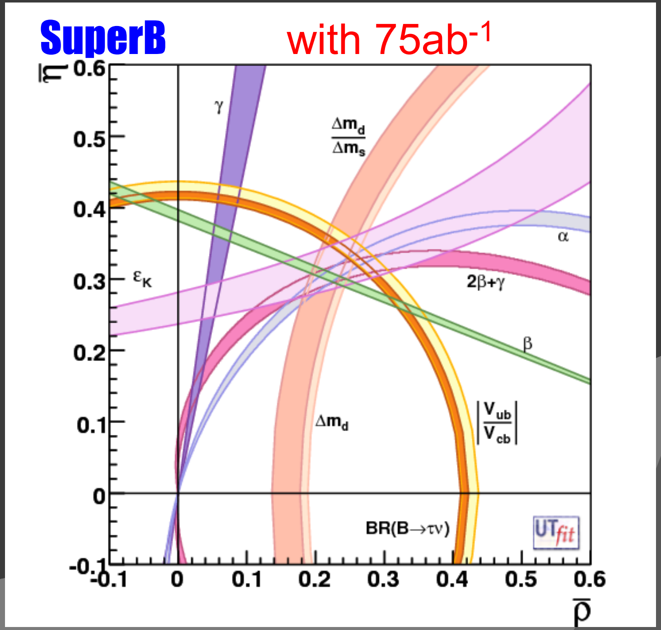
- e^+e^- Super-Flavour Factories
  - Italian SuperB
  - Japanese KEK/Belle II
- LHCb Upgrade
- Fermilab Project X (cf. S. Holmes)

SuperB Motivation

SuperB measures the sides and angles of the Unitarity Triangle (UT)

- Many measurements constrain the sides and angles of the UT: the SM predicts that all measurements “intersect” at apex of the triangle
- When NP is present, the measurements do not yield a unique apex, but you need the high precision of a Super Flavour Factory.



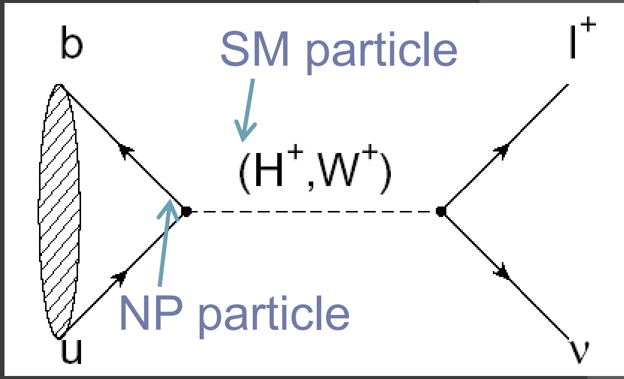


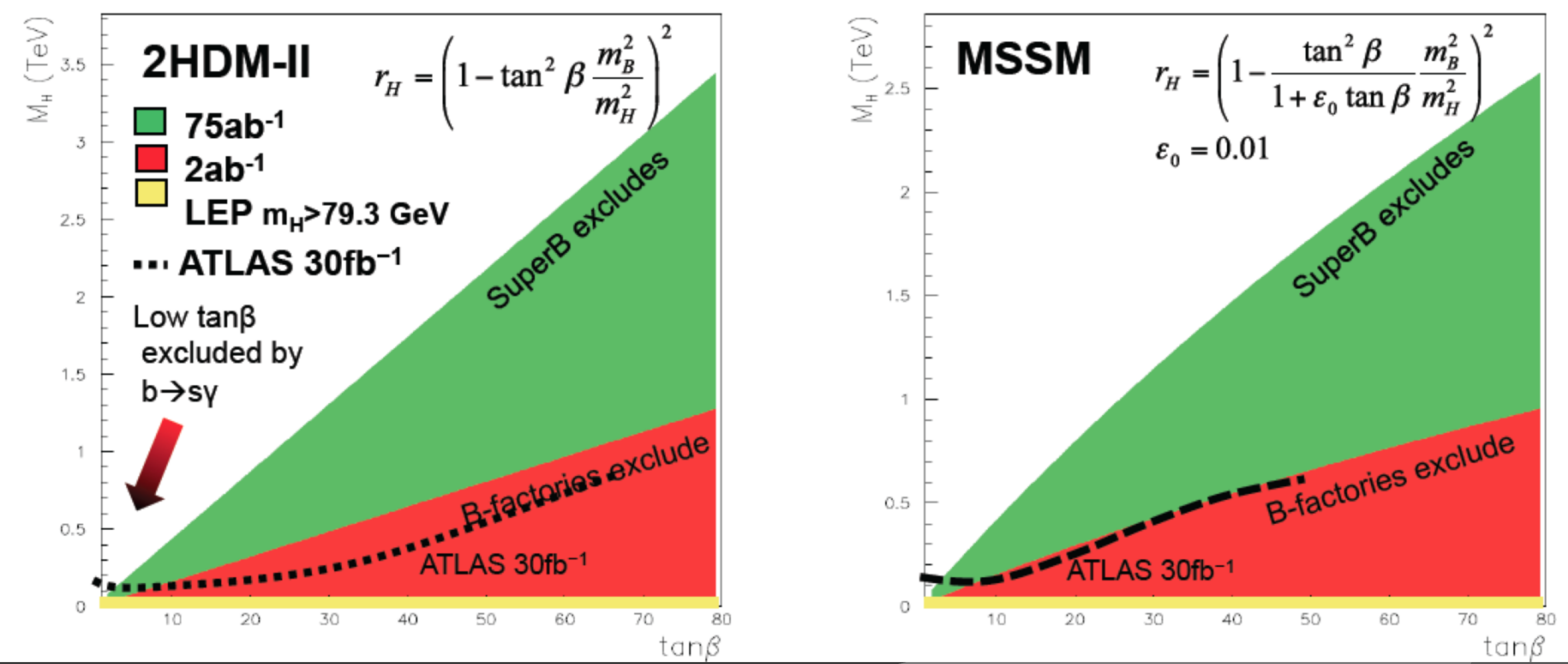
Adapted from M. Giorgi

$B_{u,d}$ physics: Rare Decays

- Example: $B^{\pm} \to \tau^{\pm}\nu$
  - Rate modified by presence of H^+

$$r_H = \frac{\mathcal{B}_{SM+NP}}{\mathcal{B}_{SM}}$$



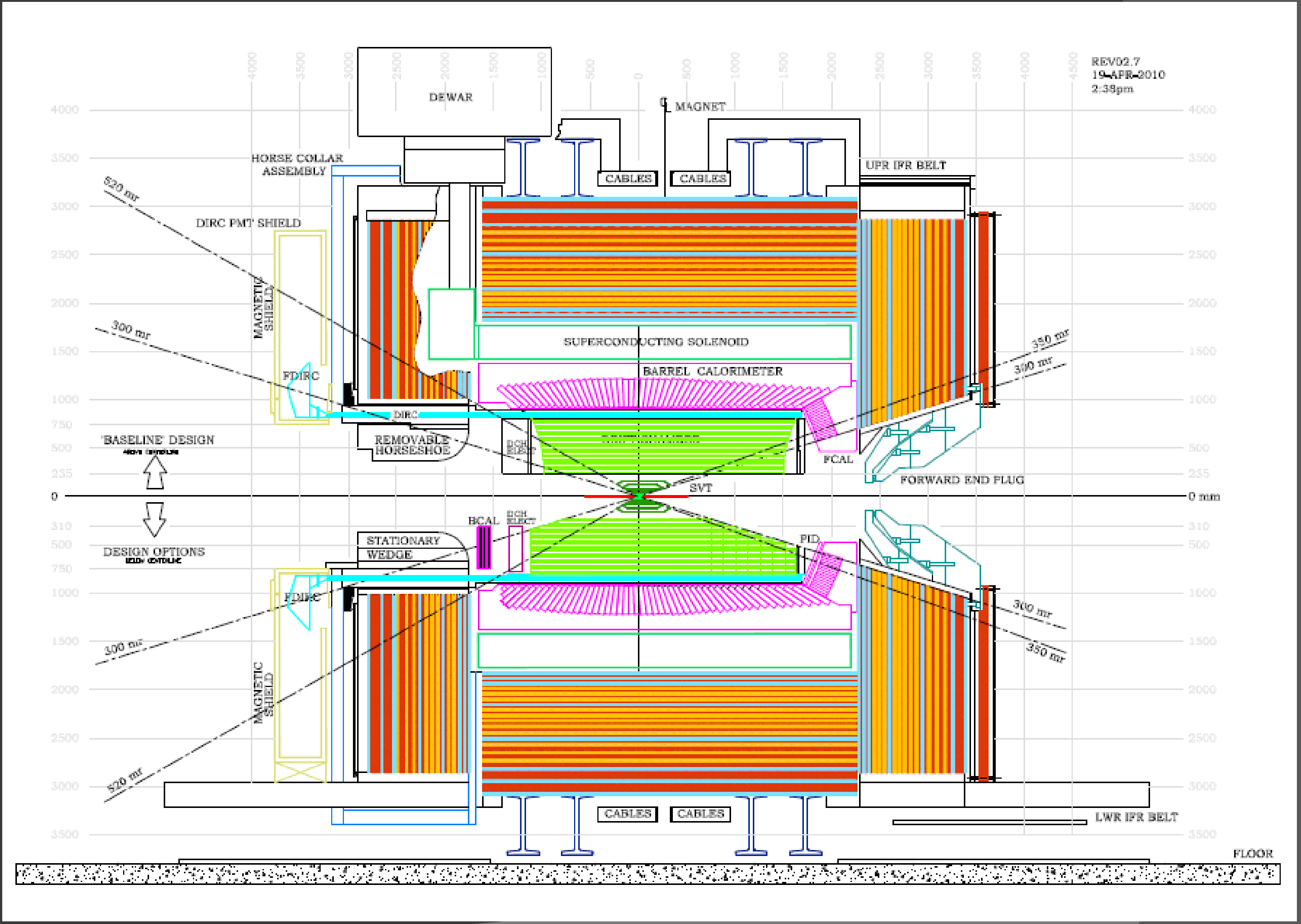


Future Super B Factories

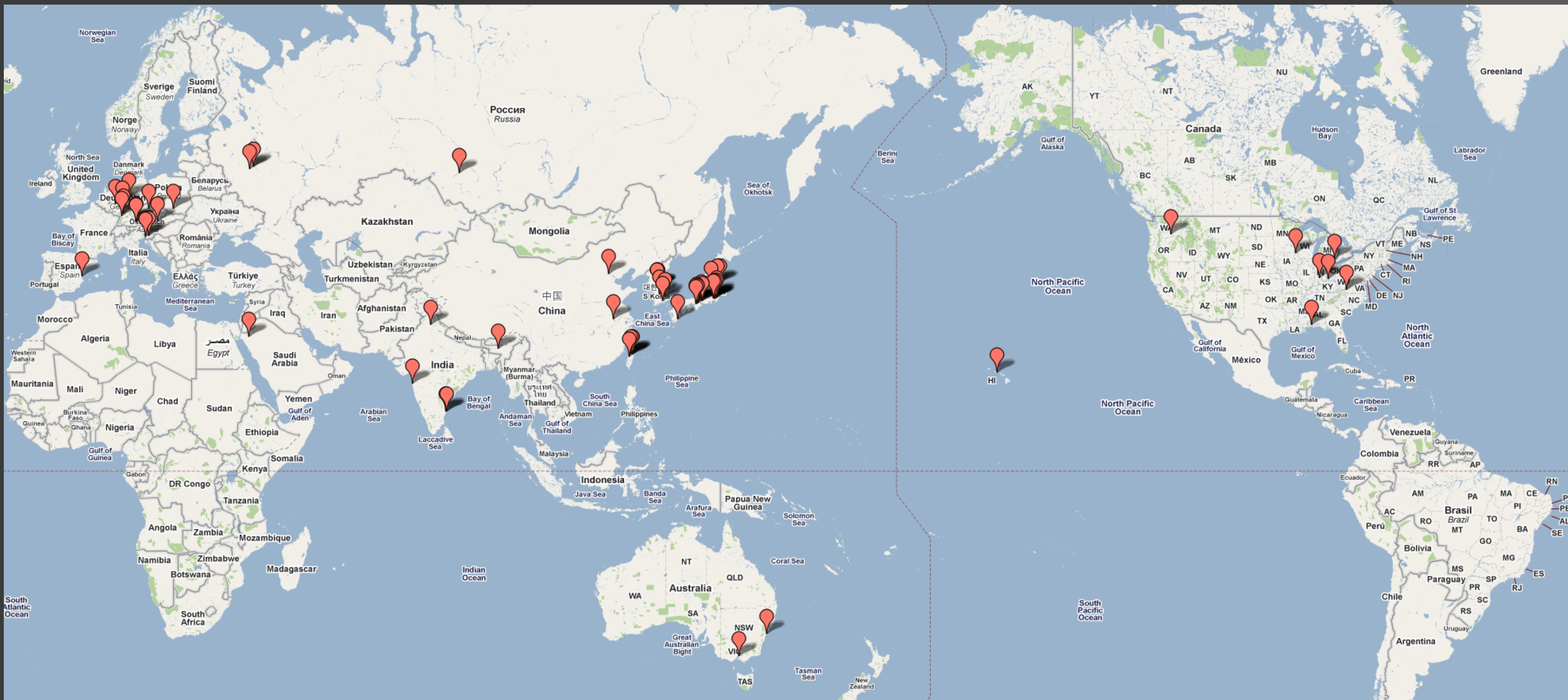
	SuperB	Super KEKB
Peak Luminosity	$>10^{36}$	0.8×10^{36}
Integrated Luminosity	75 ab^{-1}	50 ab^{-1}
Site	Green Field	KEKB Laboratory
Collisions	mid 2016	2015
Polarization	80% electron beam	No
Low energy running	10^{35} @ charm threshold	No
Approval status	Approved	Approved

Courtesy of Marcello Giorgi

SuperB Detector (with options)



Belle II Collaboration



15 countries, ~60 institutions

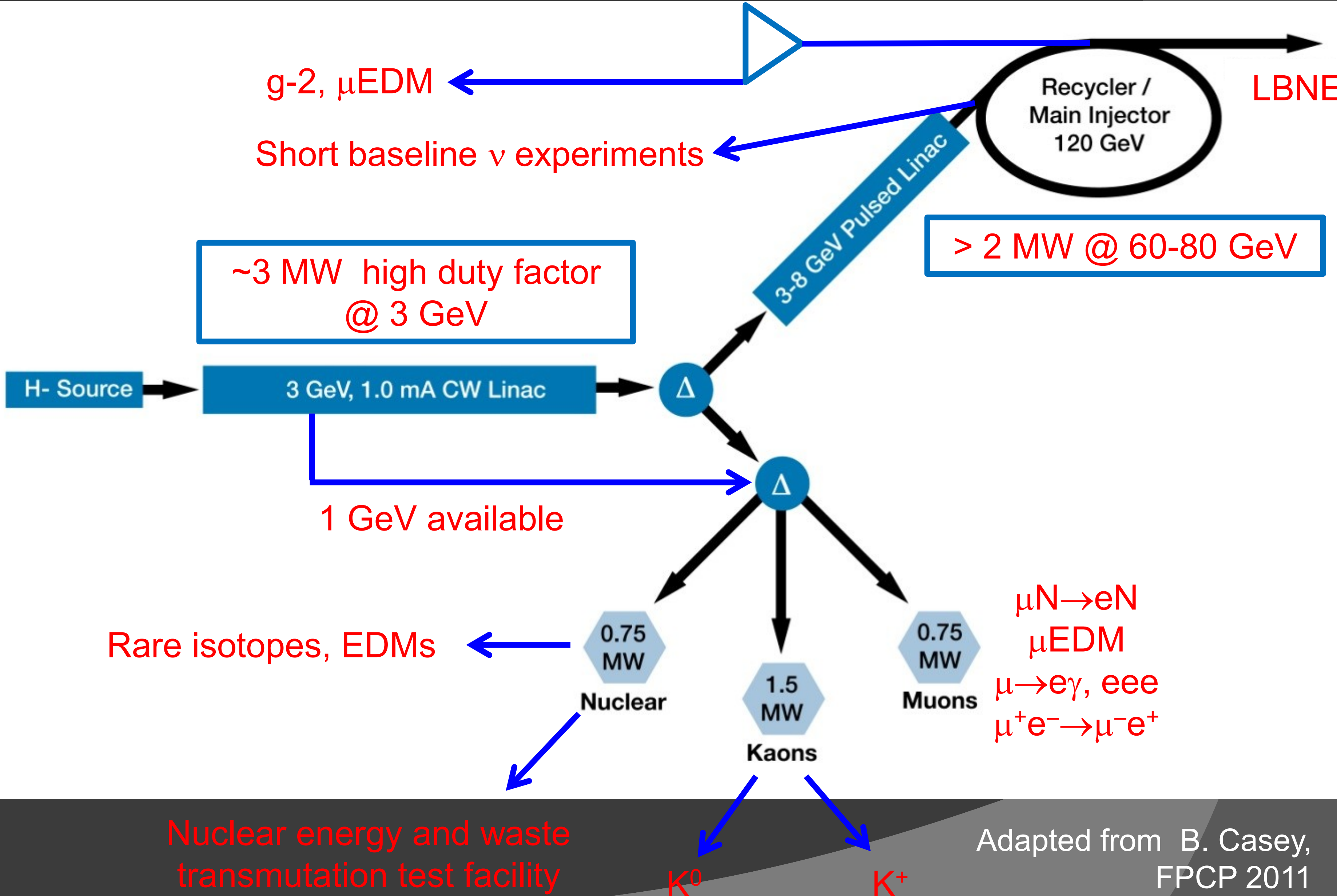
~400 collaborators

Courtesy of Peter Križan

LHCb Upgrade (Letter of Intent)

- CERN/LHCC 2011-001, March 2011
- LHCb expects to accumulate 5 fb^{-1} in the years up to 2017
- Then plans to upgrade to collet 5 fb^{-1} per year
- Not limited by LHC luminosity
- Main Motivations:
  - Precise measurement of the B_s oscillation phase
  - Analysis of $B \rightarrow V V$ decays
  - ~1 deg determination of gamma angle
  - Make precision measurement of $B_s \rightarrow \mu^+ \mu^-$ and extend to $B_d \rightarrow \mu^+ \mu^-$
  - Exploit the NP sensitivity of the full kinematic distribution in $B_d \rightarrow K^{0*} \mu^+ \mu^-$

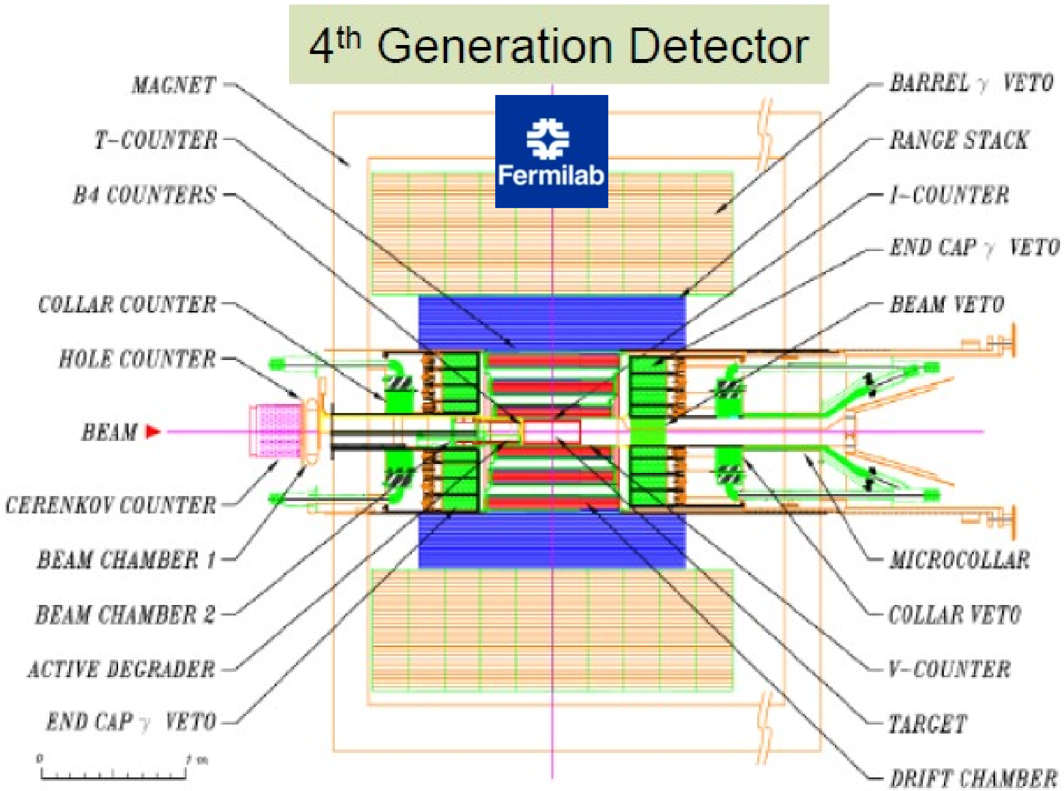
Fermilab Intensity Frontier: Project X



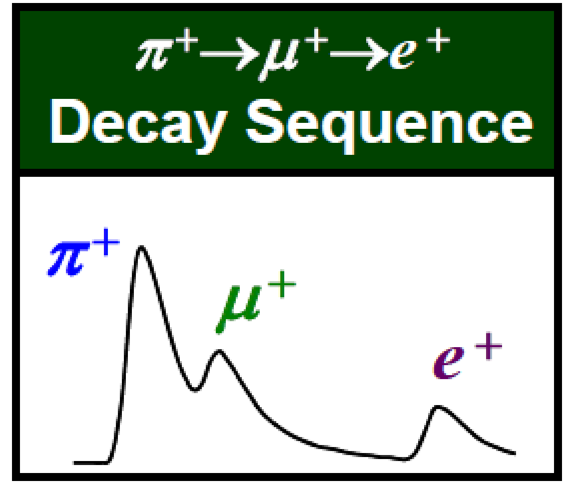
Adapted from B. Casey, FPCP 2011

$K^+ \to \pi^+ \nu\nu$

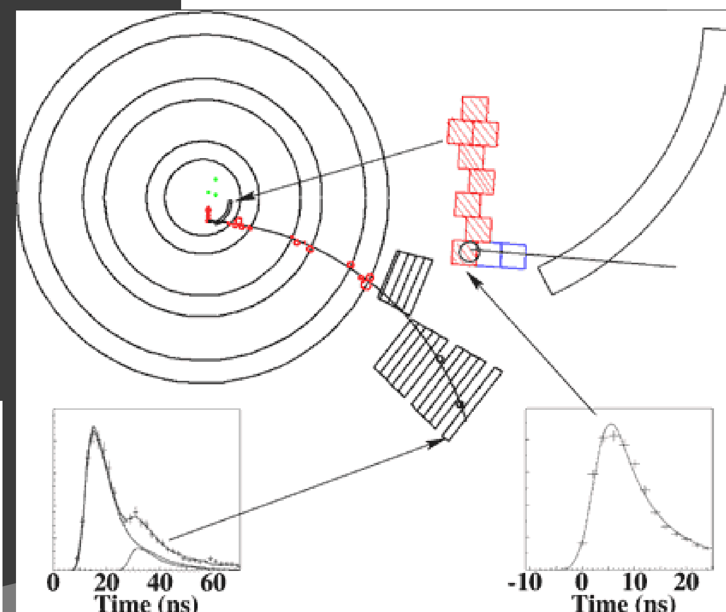
1st 2nd 3rd generation at BNL
= 7 event data sample



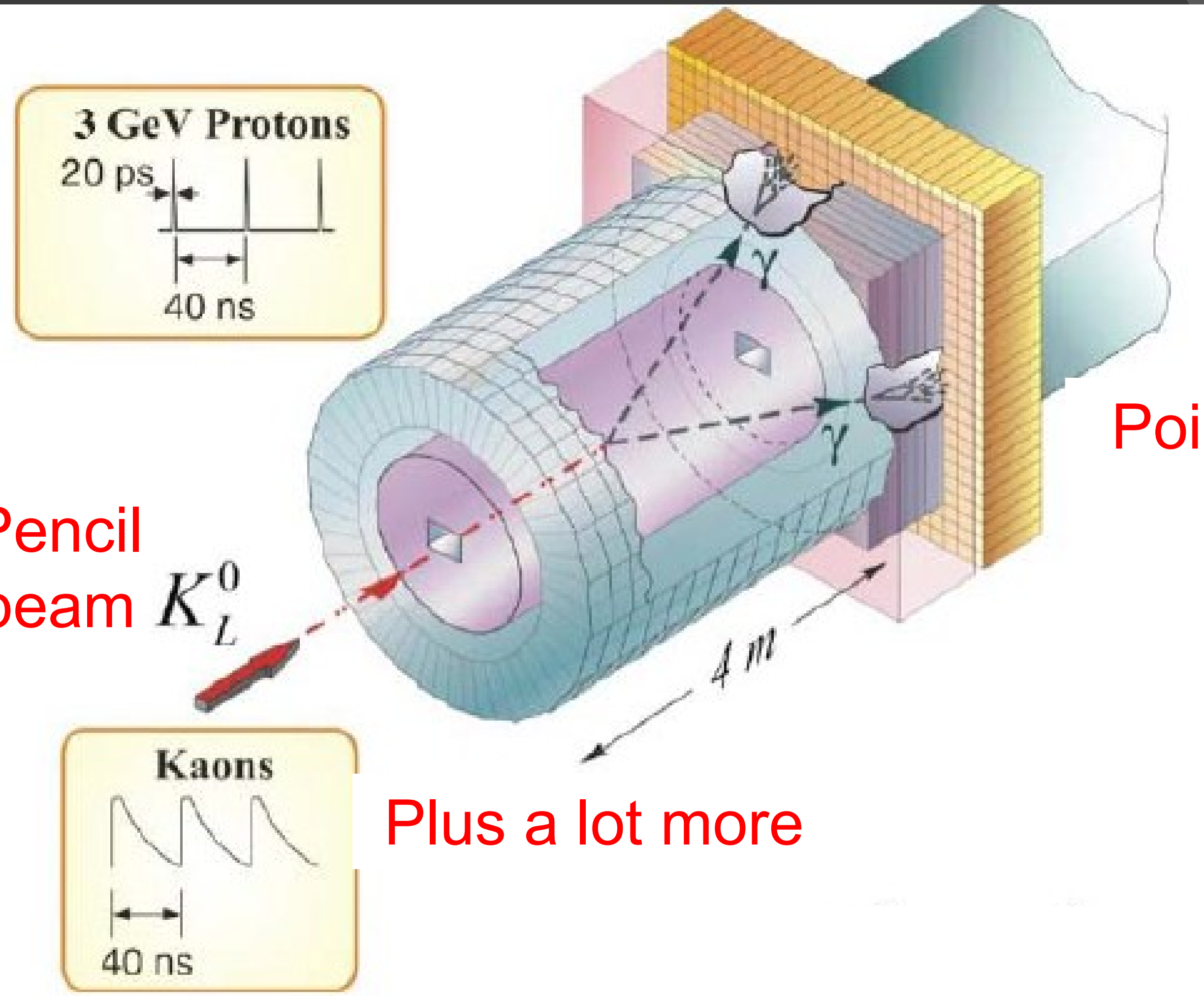
Can get hundreds of evts per year starting with beam from Main Injector and continuing with Project X



BNL E787 event display



Pico-bunches



Pencil beam

Pointing

Plus a lot more

200 evt/yr possible with Project X

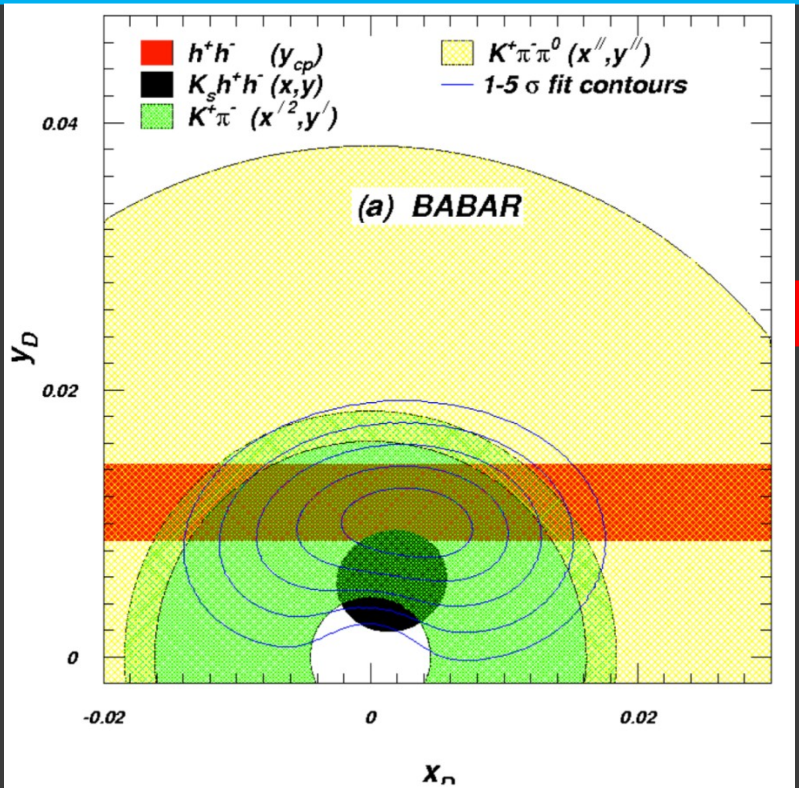
$K^0 \rightarrow \pi^0 \nu\nu$

Summary

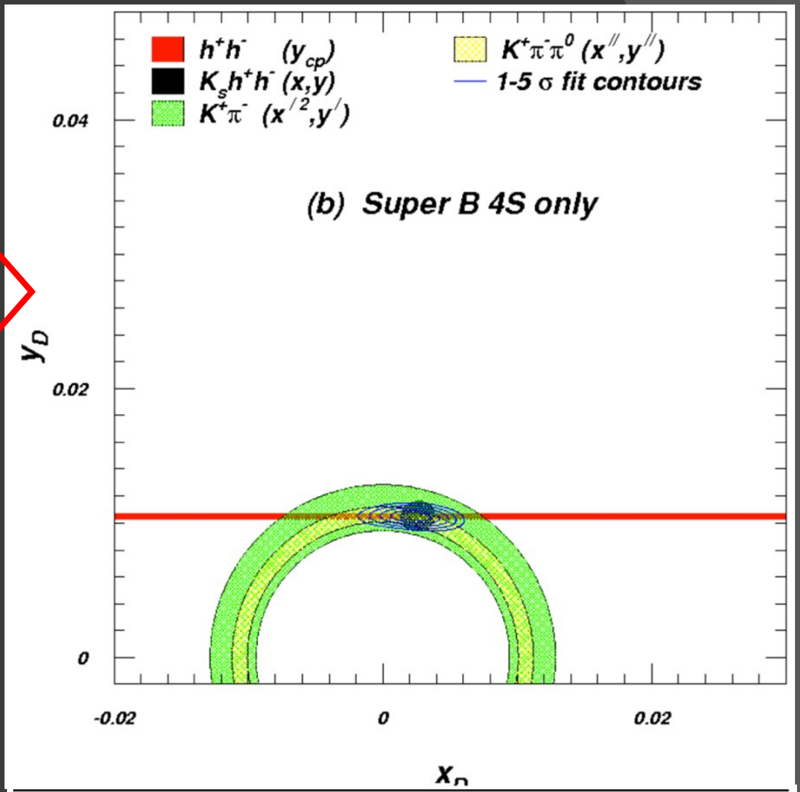
- There is a strong programme to continue the search for CP-Violation and New Physics beyond the Standard Model in the hadronic sector (quarks)
- So far all manifestations of CP violation are consistent with "just" one complex phase in the CKM quark mixing matrix
- New experiments are being constructed and several future projects have been approved or evaluated
- Evidence of CP-Violation in the neutrino sector is eagerly awaited…

Spares

Sensitivity projections with 75 ab^{-1} at $\Upsilon(4S)$



Fit	$x \times 10^3$	$y \times 10^3$	$\delta^\circ_{K^+\pi^-}$	$\delta^\circ_{K^+\pi^-\pi^0}$
(a)	$3.01^{+3.12}_{-3.39}$	$10.10^{+1.69}_{-1.72}$	$41.3^{+22.0}_{-24.0}$	43.8 ± 26.4
Stat.	(2.76)	(1.36)	(18.8)	(22.4)



Fit	$x \times 10^3$	$y \times 10^3$	$\delta^\circ_{K^+\pi^-}$	$\delta^\circ_{K^+\pi^-\pi^0}$
(b)	$xxx^{+0.72}_{-0.75}$	$xxx \pm 0.19$	$xxx^{+3.7}_{-3.4}$	$xxx^{+4.6}_{-4.5}$
Stat.	(0.18)	(0.11)	(1.3)	(2.9)

Uncertainties shrink:

$x_D \rightarrow x_D/4$; $y_D \rightarrow y_D/10$

Precision in x_D is limited by Dalitz plot model.

KEKB/Belle status: official statement

„As is now well known, Japan suffered a terrible earthquake and tsunami on March 11, which has caused tremendous damage, especially in the Tohoku area. Fortunately, all KEK personnel and users are safe and accounted for.

The injection linac did suffer significant but manageable damage, and repairs are underway. The damage to the KEKB main rings appears to be less serious, though non-negligible. No serious damage has been reported so far at Belle. Further investigation is necessary.

We would like to convey our deep appreciation to everyone for your generous expressions of concern and encouragement.“

As reported by Peter Krizan at the SuperB workshop, May 2011

Other Kaon measurements

$K^+ \rightarrow \pi^0 \mu^+ \nu$ (Transverse Polarization -T violation)

$K^+ \rightarrow e^+ \nu / K^+ \rightarrow \mu^+ \nu$ (Universality, LFV, Pseudoscalars...)

$K^+ \rightarrow \mu^+ \nu_H$ (Heavy neutrinos)

$K_L^0 \rightarrow \pi^0 ee / \pi^0 \mu\mu$ (CP Violation)

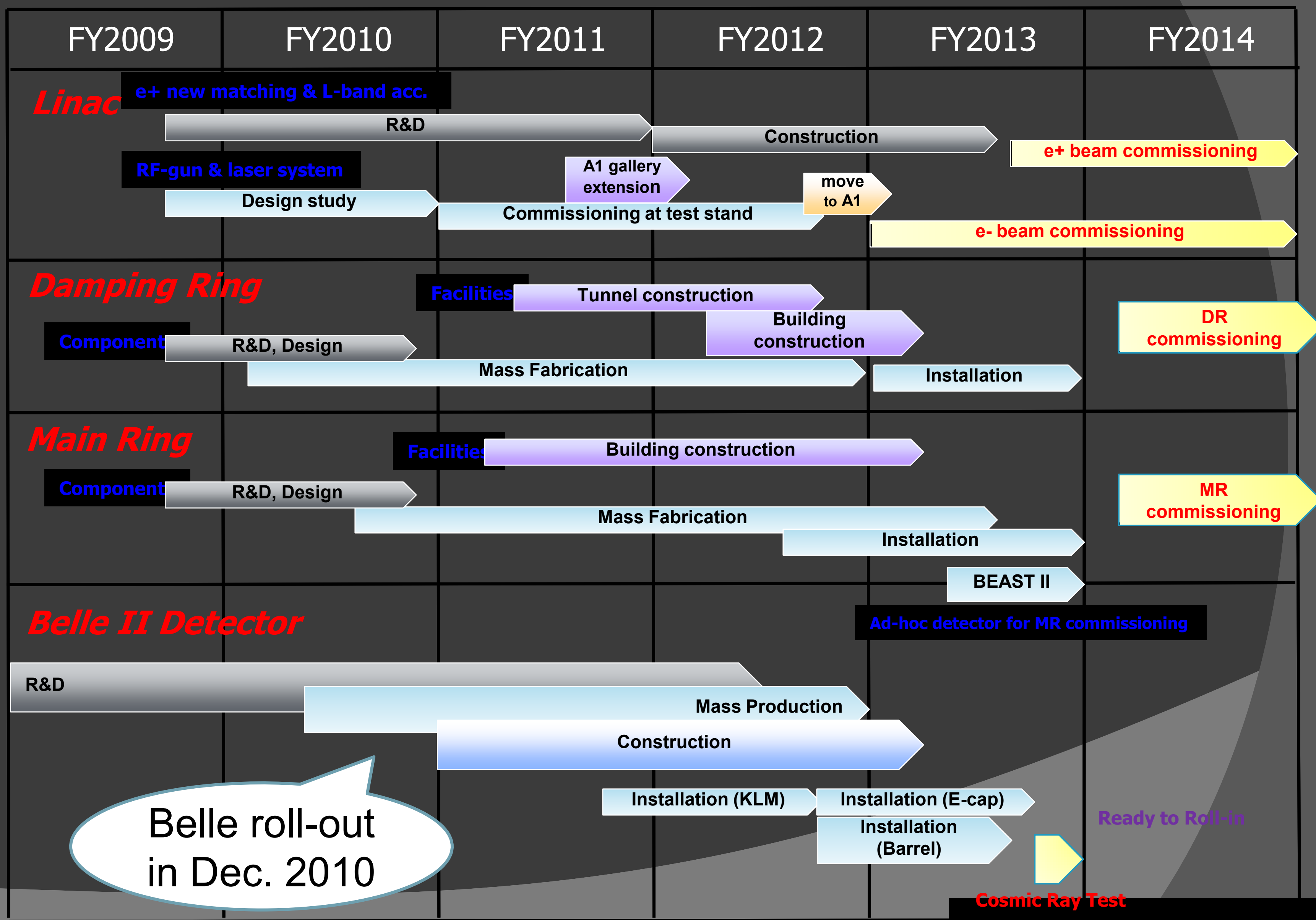
$K_L^0, K^+ \rightarrow LFV \quad e.g. \quad K_L^0 \rightarrow \mu e$

K^0 Interferometry (Plank scale physics)

$K \rightarrow \pi l \nu$ ... (Universality, Chiral PT)

Enormous data sets + multipurpose detectors = lots of physics

SuperKEKB/Belle II



Neutral Meson Mixing

CP violation in decay is defined by

|A $_f$ /A f | = 1 .

In charged meson decays, where mixing effects are absent, this is the only possible source of *CP asymmetries:*

A

f± ≡ Γ(M− → f−) − Γ(M+ → f+)

Γ(*M− → f−) + Γ(M+ → f+)*

=

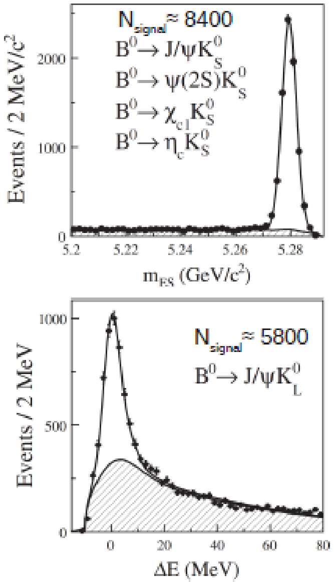
|Af−/Af+|2 − 1

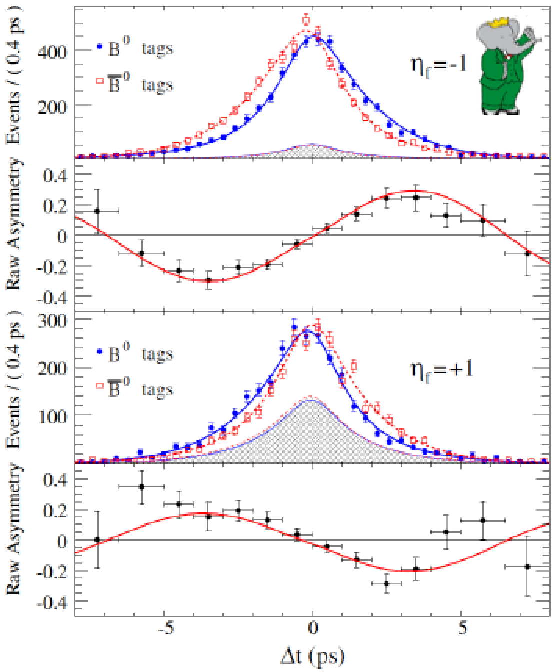
|Af−/Af+|2 + 1

.

Measurement of Φ_1/β

BaBar's last update on full dataset:





BaBar with 465×10⁶ BB:

PRD 79, 072009 (2009)

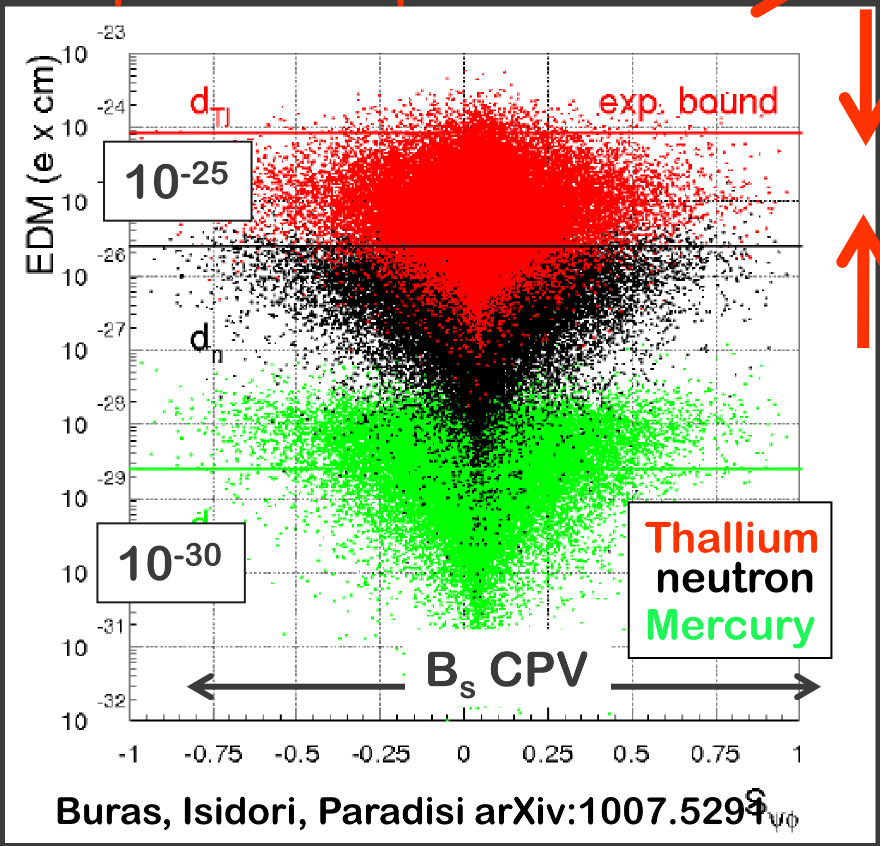
$$\mathcal{A} = -0.024 \pm 0.020\,(\text{stat}) \pm 0.016\,(\text{syst})$$

$$\sin(2\phi_1) = 0.687 \pm 0.028 \pm 0.012$$

EDMs

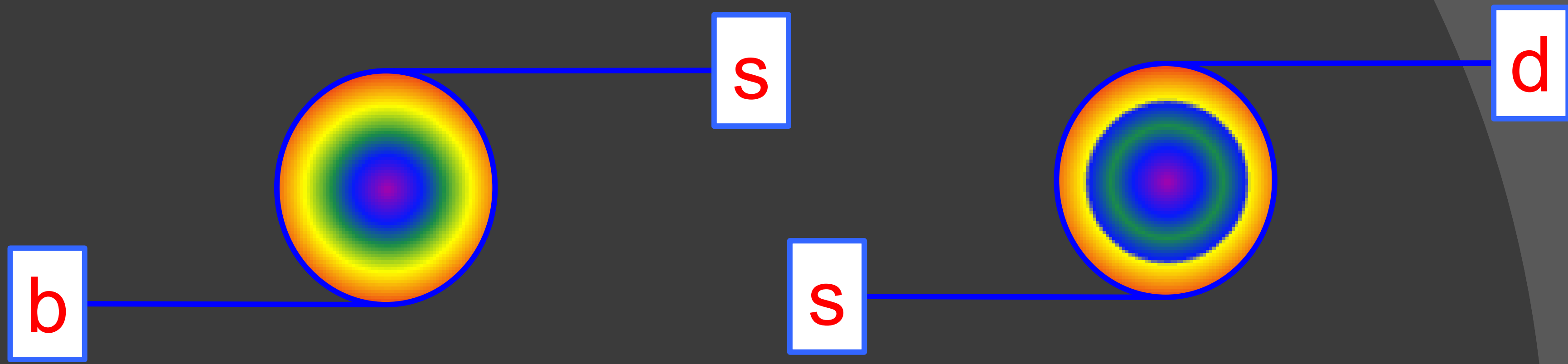
MFV + 1 new phase + Bs CPV = EDM

Large B_s CPV shrinks available parameter space



Buras, Isidori, Paradisi arXiv:1007.5291

Same motivation for FCNC B and K programs



Difference is the size of the SM 'background'

B mesons: $V_{ts} \approx \lambda^2$ or $V_{td} \approx \lambda^3$ or $V_{ub} \approx \lambda^3$

Kaons: $V_{ts}^* V_{td} \approx \lambda^5$

$b \to s\gamma : 3 \times 10^{-4}$ $\quad K^+ \to \pi^+ \nu \bar{\nu} : 7.8 \times 10^{-11}$

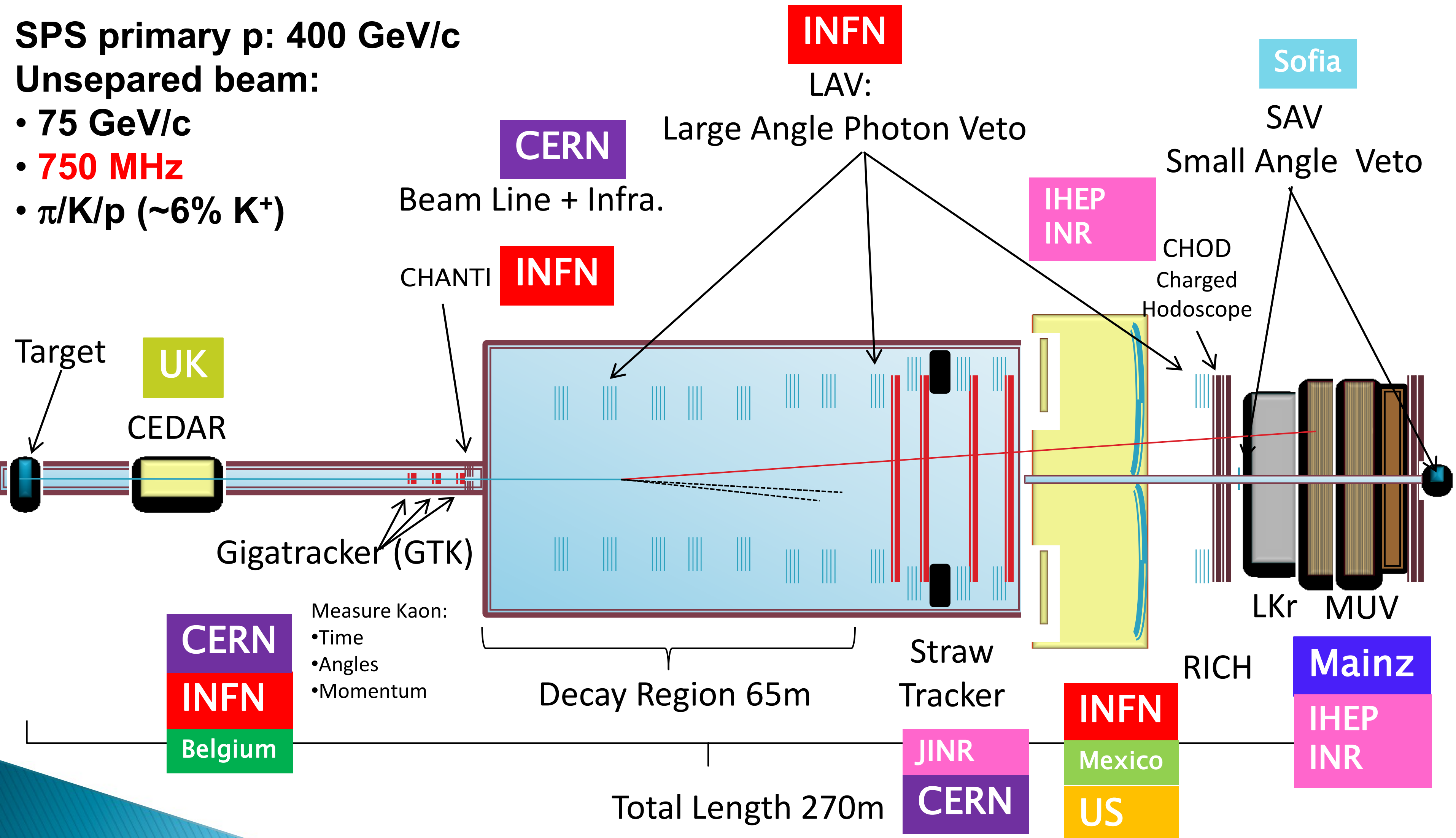
$B_s \to \mu\mu : 3 \times 10^{-9}$ $\quad K^0 \to \pi^0 \nu \bar{\nu} : 2.4 \times 10^{-11}$

Generic couplings: Kaons win, flavor specific: need both

NA62 Beam & Detectors

SPS primary p: 400 GeV/c
Unseparated beam:

- **75 GeV/c**
- **750 MHz**
- **π/K/p (~6% K^+)**



B physics @Υ(4S)

Variety of measurements for any observable

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
[redacted]		
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi\,\pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
α $(B\to\pi\pi)$	$\sim 16°$	3°
α $(B\to\rho\rho)$	$\sim 7°$	1–2° (∗)
[redacted]		
α (combined)	$\sim 6°$	1–2° (∗)
[redacted]		
$S(\omega K_S^0)$	0.17	0.03 (∗)
$S(f_0 K_S^0)$	0.12	0.02 (∗)
$\lvert V_{cb}\rvert$ (exclusive)	4% (∗)	1.0% (∗)
[redacted]		
$\lvert V_{ub}\rvert$ (exclusive)	8% (∗)	3.0% (∗)
[redacted]		

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab
[redacted]		
$\mathcal{B}(B\to\rho\gamma)$	15%	3% (†)
$\mathcal{B}(B\to\omega\gamma)$	30%	5%
[redacted]		
$A_{CP}(B\to\rho\gamma)$	~ 0.20	0.05
[redacted]		

Possible also at LHCb

Similar precision at LHCb

Example of « SuperB specifics »

[redacted]

physics (polarized beams)

Process	Sensitivity
$\mathcal{B}(\tau \to e\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \ell K_S^0)$	2×10^{-10}

Charm at Y(4S) and threshold

Mode	Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$D^0 \to K_S^0\pi^+\pi^-$	x_D^2	$1\text{–}2 \times 10^{-4}$	3×10^{-5}
	y_D	$2\text{–}3 \times 10^{-3}$	5×10^{-4}
	x_D	$2\text{–}3 \times 10^{-3}$	5×10^{-4}
Average	y_D	$1\text{–}2 \times 10^{-3}$	3×10^{-4}
	x_D	$2\text{–}3 \times 10^{-3}$	5×10^{-4}
$D^0 \to K^+\pi^-$	x'^2	*To be evaluated at LHCb*	3×10^{-5}
	y'		7×10^{-4}
$D^0 \to K^+K^-$	y_{CP}		5×10^{-4}
$D^0 \to K_S^0\pi^+\pi^-$	x		4.9×10^{-4}
	y		3.5×10^{-4}
	$\lvert q/p \rvert$		3×10^{-2}
	ϕ		2°

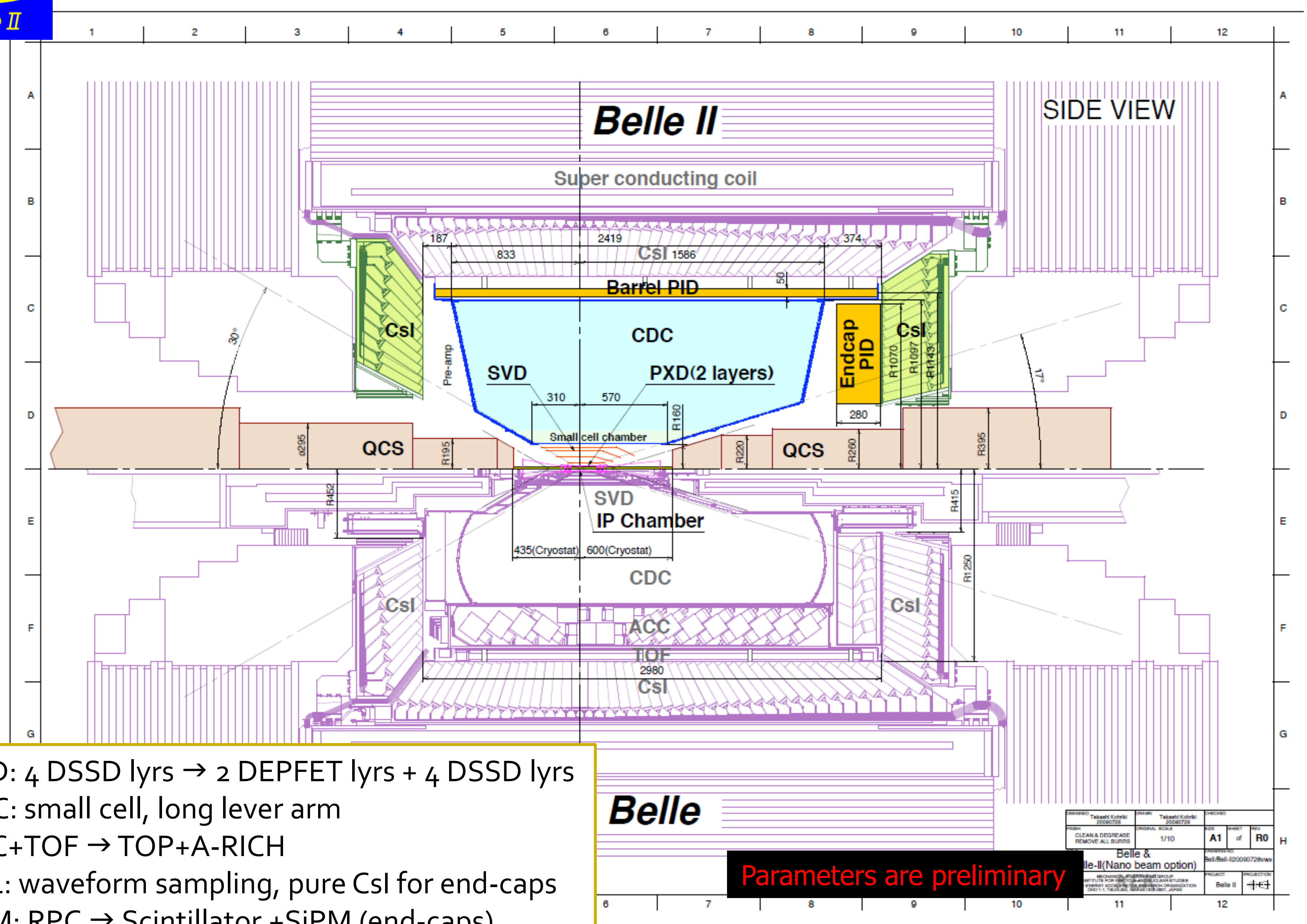
B$_s$ at Y(5S)

Observable	Error with 1 ab^{-1}	Error with 30 ab^{-1}
A_{SL}^s	0.006	0.004
$\lvert V_{td}/V_{ts} \rvert$	0.08	0.017

Channel	Sensitivity
$D^0 \to \pi^0 e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K_S^0 e^+e^-$, $D^0 \to K_S^0\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0 e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K_S^0 e^\pm\mu^\mp$	3×10^{-8}

Bs : Definitively better at LHCb

Belle II in comparison with Belle



SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

Parameters are preliminary