INTRODUCTION

Augusto Ceccucci / CERN

NA62 Collaboration Meeting

September 1 – 5, Ferrara, Italy

FERRARA: A CITY OF ARTS AND SCIENCES

- Nicolaus Copernicus was a Renaissance mathematician and astronomer who formulated a model of the universe that placed the Sun rather than the Earth at its center.

In 1503, Copernicus attended the University of Ferrara, where he prepared to take the canon law exam. After passing the test on his first attempt, he hurried back home to Poland, where he resumed his position as canon and rejoined his uncle at a nearby Episcopal residence (source biography.com)

FERRARA: A CITY OF ARTS AND SCIENCES

- **Alfonso II d'Este**
  (22 November 1533 – 27 October 1597) was Duke of Ferrara from 1559 to 1597. He raised the glory of Ferrara to its highest point, and was the patron of Torquato Tasso, Giovanni Battista Guarini and Cesare Cremonini — favouring the arts and sciences, as the princes of his house had always done….(source Wikipedia)

NA62 GOAL

- We aim to measure precisely

$$Br(K^+ \to \pi^+ \nu\bar{\nu})$$

exploiting a novel in-flight technique based on:

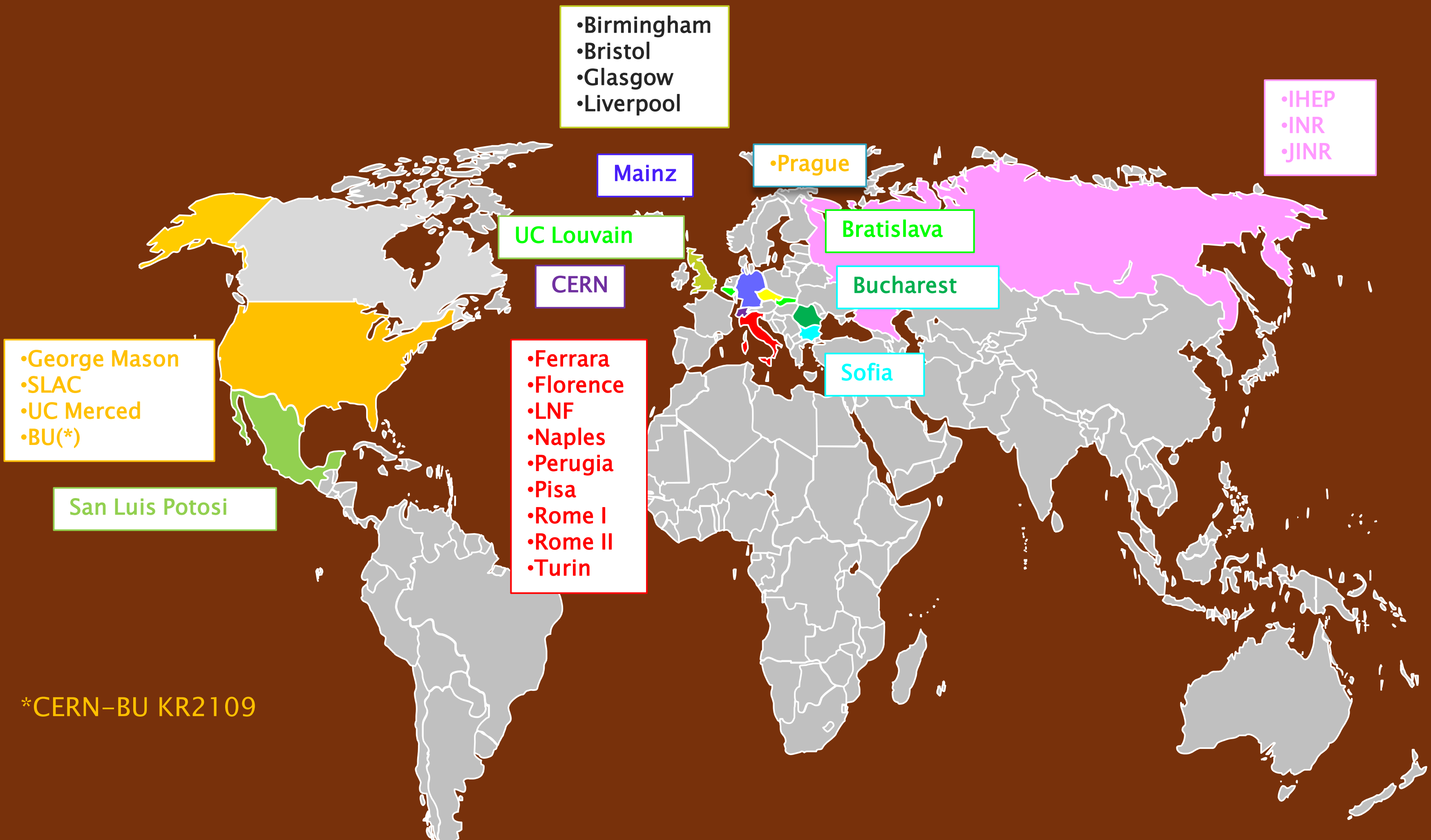
- Calorimetry to veto extra particles
- Very light trackers to reconstruct the K^+ and the π^+ momenta
- Full particle identification

State of the art:

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]
$K_L^0 \to \pi^0 \nu\bar{\nu}$	0.27 ± 0.04 [3]	< 260 (90% CL) [4]
$B_s^0 \to \mu^+\mu^-$	32.3 ± 2.7 [5]	29 ± 7 [6]

[1] J. Brod, M. Gorbahn, PRD78, arXiv:0805.4119
[2] AGS-E787/E949 PRL101, arXiv:0808.2459
[3] M. Gorbahn arXiv:0909.2221
[4] KEK-E391a, arXiv:0911.4789v1
[5] A.J. Buras et al., EPJ C72, arXiv:1208.0934
[6]MS PAS BPH-13-007; LHCb-CONF-2013-012

The NA62 Collaboration

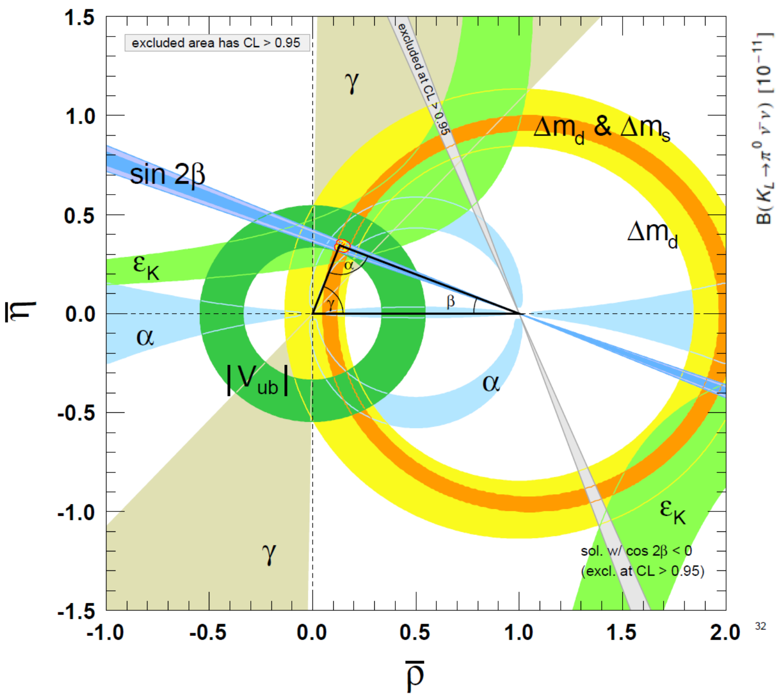


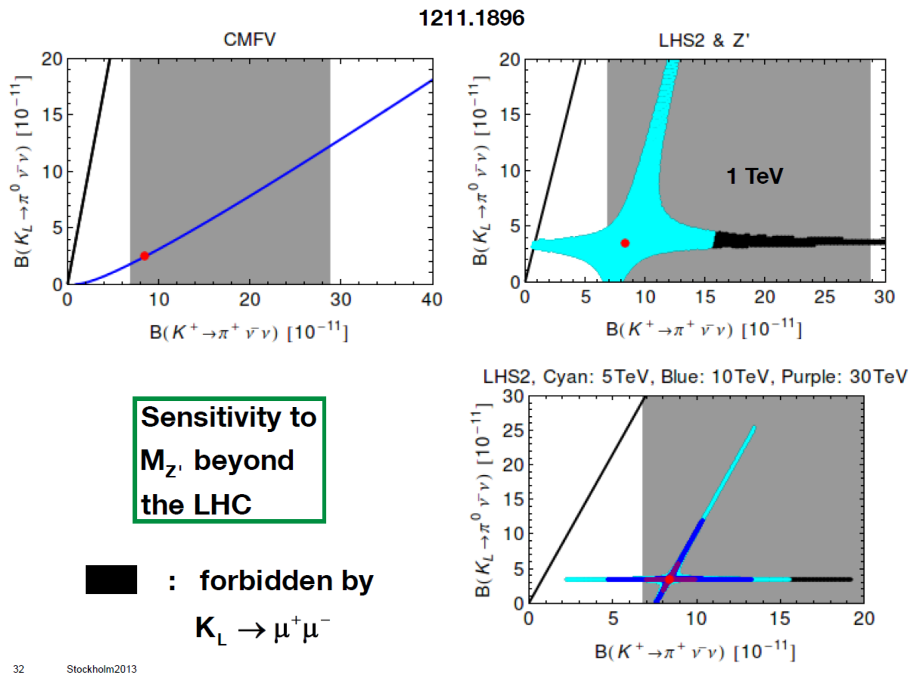
*CERN-BU KR2109

28 Institutes, 206 Collaborators

NA62 “NO-LOSE” THEOREM

Measure precisely SM parameters or discover New Physics



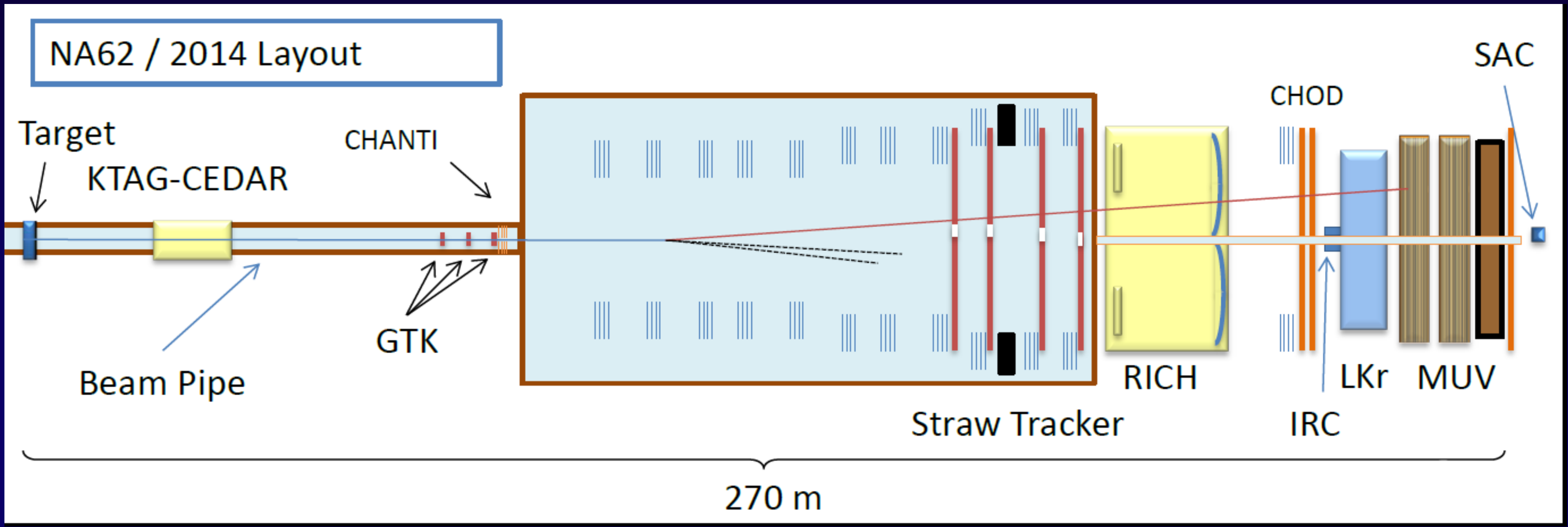


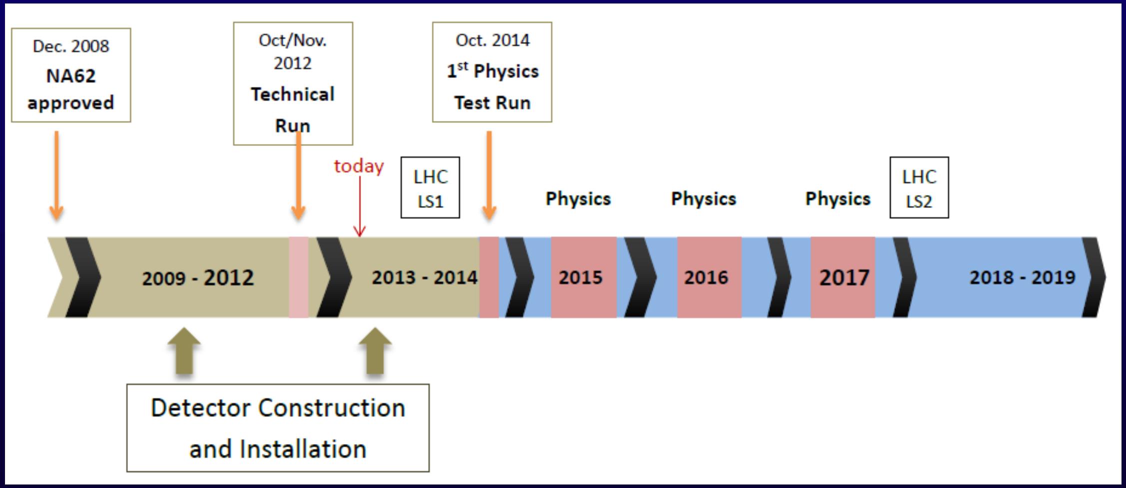
Standard Model

New Physics

Part of a Strong Flavour program worlwide which includes LHCb and BELLEII

NA62 Layout

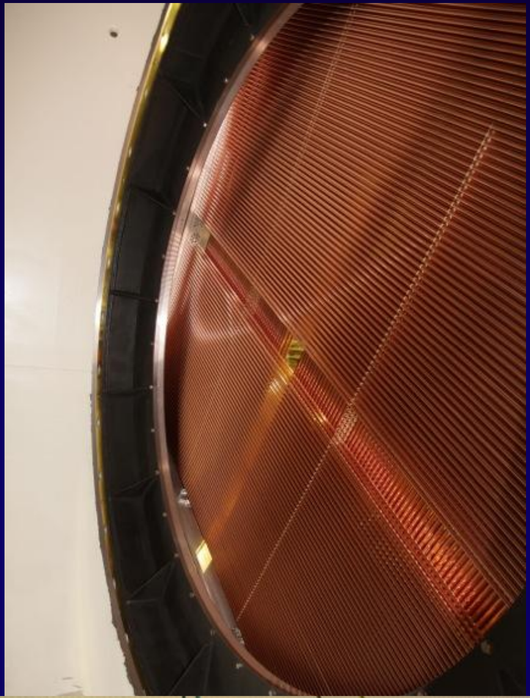


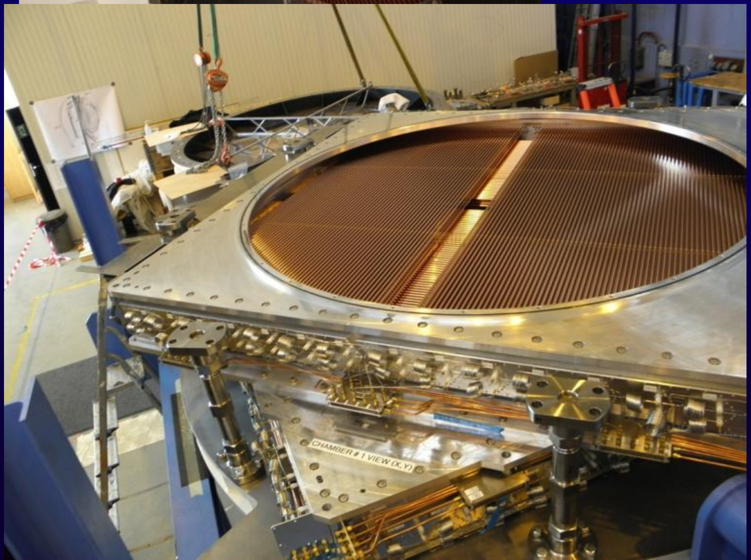


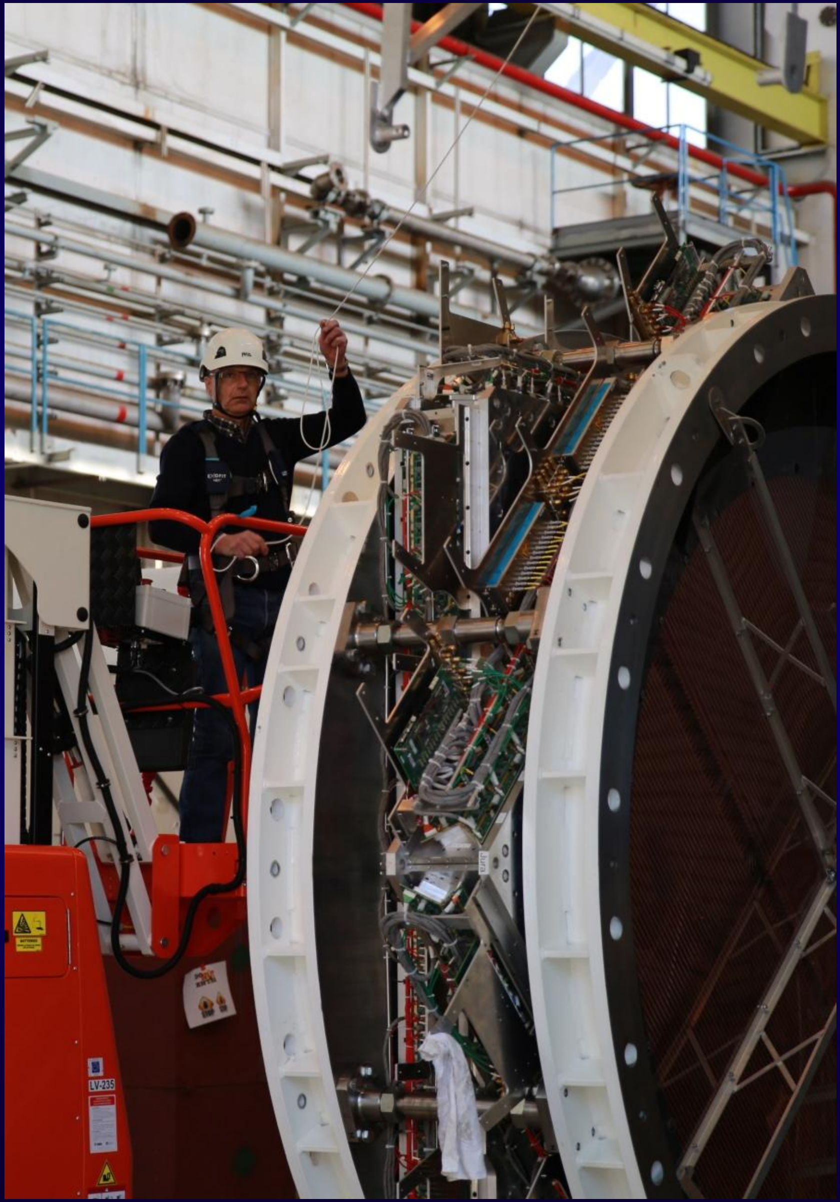
~10^{12} / s protons from SPS (400 GeV/c) on Be target (~1 λ)

750 MHz secondary beam:
- Positive
- Kaon fraction ~6%
- Δ p/p ~ 1%

NA62 STRAW TRACKER

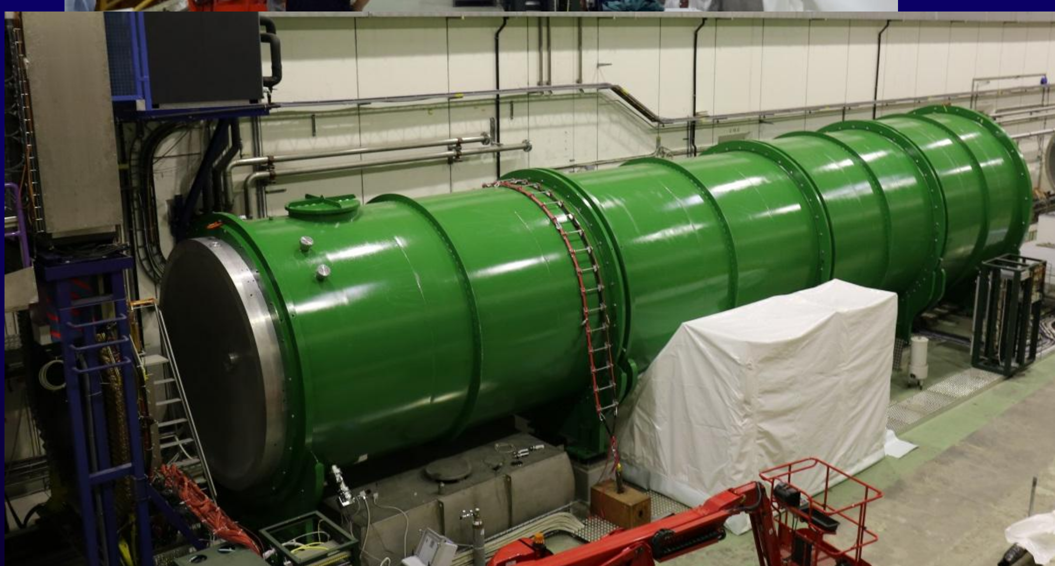




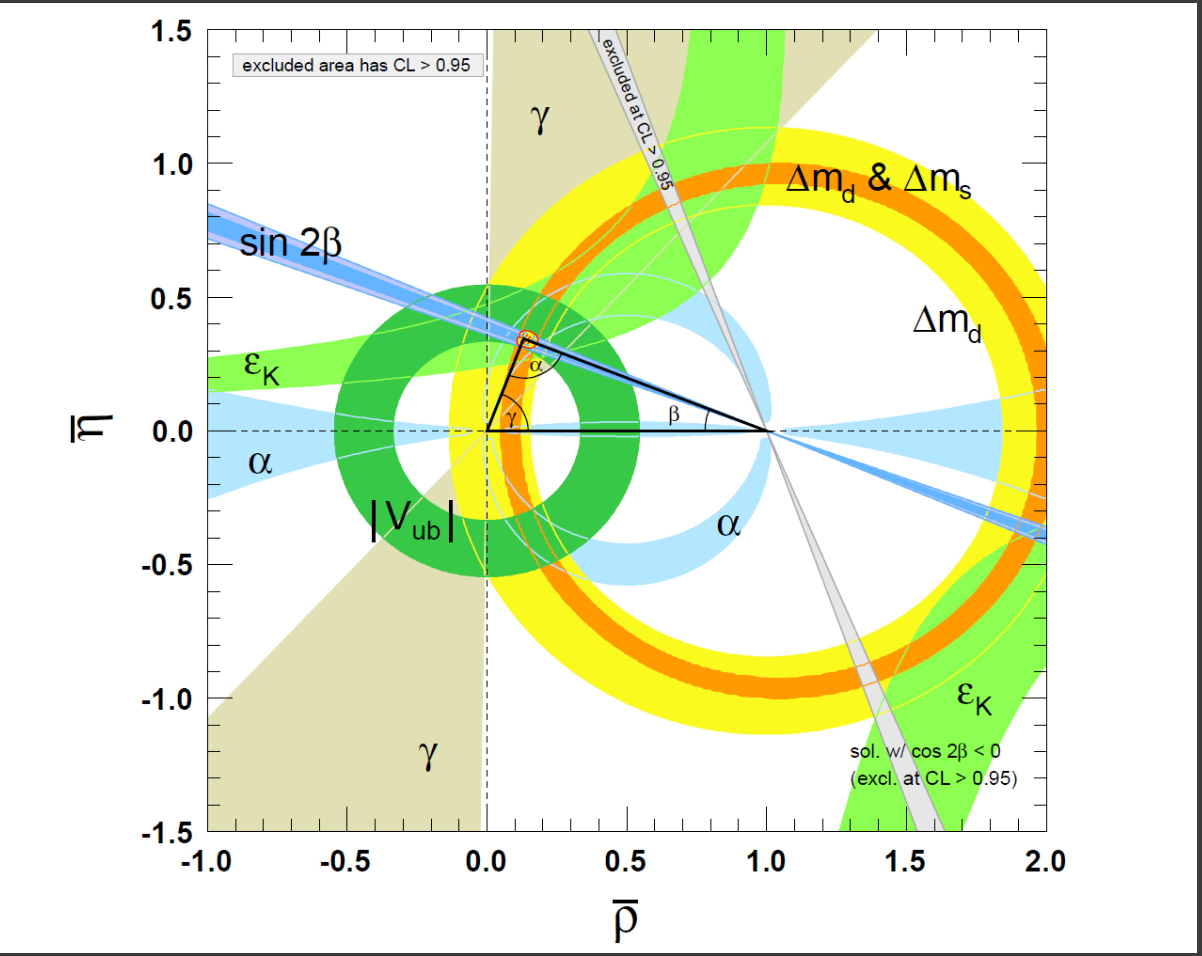


NA62 LAV

NA62 RICH



SM and CKM matrix



PDG 2014

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

$$J = (2.96^{+0.20}_{-0.16}) \times 10^{-5}$$

UNITARITY TRIANGLE FOR KAONS

- When the bd UT is used, the variables extracted from kaons are affected by an apparent parametric uncertainty due to V_{cb}
- The six UTs are all born equal (they have the same measure of CP-violation, the Jarlskog invariant J_{CP})

- K_{e3}, BR($K^+ \rightarrow \pi^+ \nu\nu$) and BR($K^0{}_L \rightarrow \pi^0 \nu\nu$) (or ε, ε'/ε) completely determine the ds UT triangle w/o V_{cb} or V_{ub} (S. Kettell et al., 2002)
- A remarkable feature is that in the ds UT

  $$J_{CP} = 5.6 * \mathrm{sqrt(BRK0)} \text{ !!!}$$

  This is a determination which is basically free from theoretical error (down to 1-2%)

- It is to be compared with the current J_{CP} determination from the bd UT fit where the error ranges from 3% to 7% depending on the treatment of the errors

UNITARITY TRIANGLES (UT)

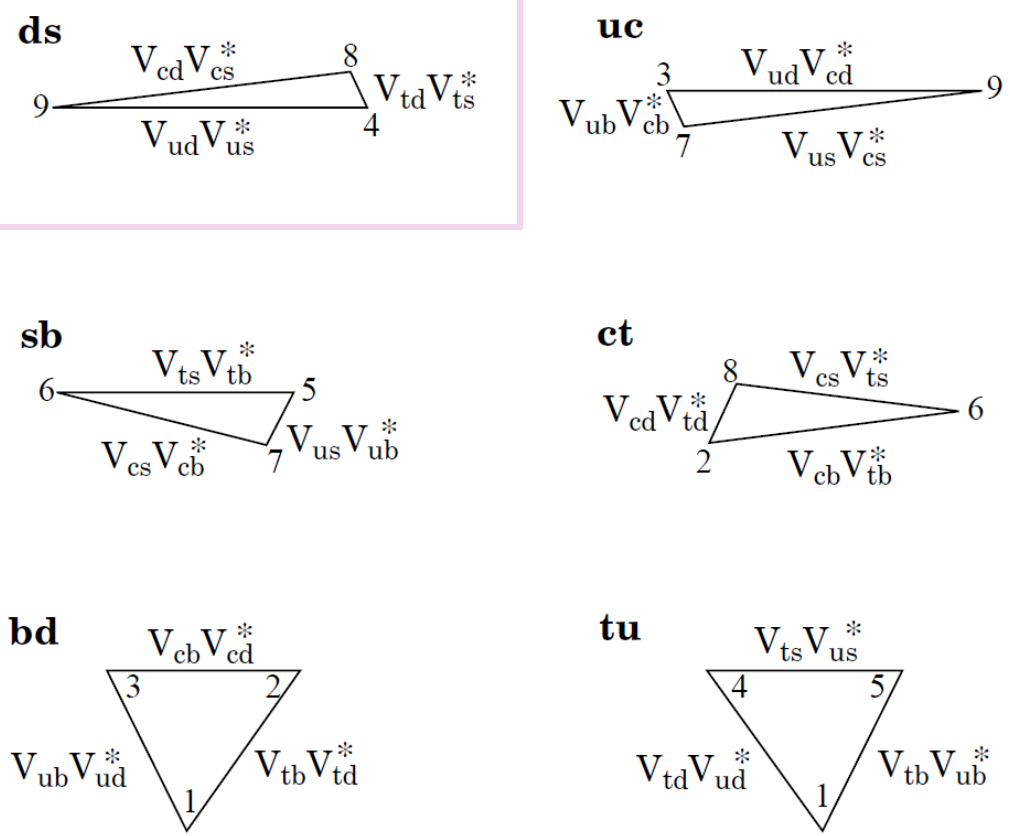


FIG. 1. *The unitarity triangles for three quark generations, as presented in Ref. [9]. The triangles are labeled by the pair of rows or columns whose orthogonality is represented. The angles as numbered are:* $1 \equiv \alpha$; $2 \equiv \beta$; $3 \equiv \pi - (\alpha + \beta)$ *(conventionally called* γ *if closure of the triangle is not assumed);* $4 \equiv \beta + \epsilon - \epsilon'$; $5 \equiv \pi - (\alpha + \beta + \epsilon - \epsilon')$; $6 \equiv \epsilon$; $7 \equiv \alpha + \beta - \epsilon'$; $8 \equiv \pi - (\beta + \epsilon)$; $9 \equiv \epsilon'$. *In all cases, the arrows on the complex vectors are oriented counterclockwise, indicating the experimental positivity of* J.

From R.F. Lebed, PRD 55, 348, hep-ph/9607305

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

- Why it is so special:

1. Apart from a small admixture (ε_K~2.229 10^{-3}), K^0_L is a CP eigenstate. Neglecting the CP-even state we can write:

$$< \pi^0 \nu\bar{\nu} | A | K^0 > \sim V_{td} V_{ts}^* X(x_t) + P_c(X) V_{cd} V_{cs}^*$$
$$< \pi^0 \nu\bar{\nu} | A | \bar{K}^0 > \sim V_{td}^* V_{ts} X(x_t) + P_c(X) V_{cd}^* V_{cs}$$

$$| K_L^0 > \sim \frac{K^0 - \bar{K}^0}{\sqrt{2}}$$

2. In taking the difference, the charm part (which is almost real) drops off and only the imaginary part of the top contribution remains!

$$< \pi^0 \nu\bar{\nu} | A | K_L^0 > \sim \mathrm{Im} V_{td} V_{ts}^* X(x_t)$$

3. The main experimental background ($K^0_L \to \pi^0\pi^0$) is heavily suppressed by CP conservation !
4. The very long life time of the K^0_L makes the interesting partial width "measurable" (Br~O(10^{-11}))

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

Formulas from A.J. Buras et al. RMP 80, 2008

$$Br(K_L^0 \to \pi^0 \nu\bar{\nu}) = \kappa_L \times \left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2$$

$$\kappa_L = (2.231 \pm 0.013) \times 10^{-10} \left[\frac{\lambda}{0.225} \right]^8$$

Numerical example:

$$\lambda_i = V_{id} V_{is}^*$$

$$\lambda = \frac{|V_{us}|}{\sqrt{|V_{ud}|^2 + |V_{us}|^2}}$$

$$\mathrm{Im} V_{td} V_{ts}^* = \sin \beta_K \, |V_{td} V_{ts}^*| \sim 1.29 \times 10^{-4}$$

$$X(x_t) \sim 1.44$$

$$Br(K_L^0 \to \pi^0 \nu\bar{\nu}) \sim 2.3 \times 10^{-11}$$

$Br(K^+ \to \pi^+ \nu\bar{\nu})$

$$Br(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+ \left(1 + \Delta_{EM}\right) \times$$

$$\left[\left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2 + \left(\frac{\mathrm{Re}\,\lambda_c}{\lambda} P_c(X) + \frac{\mathrm{Re}\,\lambda_t}{\lambda^5} \right)^2 \right]$$

$$\kappa_+ = (5.173 \pm 0.025) \times 10^{-11} \left[\frac{\lambda}{0.225} \right]^8$$

$$\lambda = \frac{|V_{us}|}{\sqrt{|V_{ud}|^2 + |V_{us}|^2}}$$

$$\kappa_+ = r_{K^+} \cdot \frac{3\alpha^2 Br(K^+ \to \pi^0 e^+ \nu)}{2\pi^2 \sin^4 \theta_W} \cdot \lambda^8$$

$$\lambda_i = V_{id} V_{is}^{\;*}$$

Formulas from A.J. Buras et al. RMP 80, 2008

$Br(K^+ \to \pi^+ \nu\bar{\nu})$ (MY NUMEROLOGY)

$$Br(K^+ \to \pi^+ \nu\bar{\nu}) \propto 1.56\times 10^{-4} \times$$

$$\left[|V_{td}V_{ts}^*|^2 \, X(x_t)^2 + 2\lambda^5 P_c(X)\,|V_{td}V_{ts}^*|\,X(x_t)\cos\beta_K + \lambda^{10}P_c(X)^2 \right] \approx$$

$$[\quad 4.40 \quad + \quad 3.68 \quad + \quad 0.87 \quad] \times 10^{-11} =$$

$$8.95\times 10^{-11}$$

$$\cos\beta_K = \cos\beta - \beta_s \approx 0.94$$

$$|V_{td}V_{ts}^*| \sim 3.69\times 10^{-4} \quad \text{(PDG 2014)}$$

$$X(x_t) \sim 1.44 \quad \text{(Buras et al.)}$$

$$P_c(X) = 0.41 \pm 0.05 \quad \text{(Buras et al.)}$$

The charm- top-quark interference term is comparatively large

For this set of values the m_c parametric uncertainty is:
$\delta Br/Br \sim 0.68\ \delta P_c/P_c$

CHARM CONTRIBUTION PARAMETRIC SENSITIVITY

$$\frac{\sigma\left(|V_{td}|\right)}{|V_{td}|} = \pm 0.41\,\frac{\sigma\left(P_c(X)\right)}{P_c(X)}\,,$$

$$\frac{\sigma\left(\sin 2\beta\right)}{\sin 2\beta} = \pm 0.34\,\frac{\sigma\left(P_c(X)\right)}{P_c(X)}\,,$$

$$\frac{\sigma\left(\gamma\right)}{\gamma} = \pm 0.83\,\frac{\sigma\left(P_c(X)\right)}{P_c(X)}\,,$$

Thanks to the NNLO calculation (Buras, Gorbahn, Haisch, Nierste, 2006) the charm scale error is now negligible.
The main charm uncertainty now comes from the charm mass

Effects of light quarks loops were computed by Mescia and Smith (2005)

Two loop EW corrections were computed by Brod, Gorbahn and Stamou (2011)

NA62 START UP

SPS: October 2014

schedule issue date: 14-Aug-2014 Version: 2.3

		Mon 29 Sep	Tue 30 Sep	Wed 1 Oct	Thu 2 Oct	Fri 3 Oct	Sat 4 Oct	Sun 5 Oct	Mon 6 Oct	Tue 7 Oct	Wed 8 Oct	Thu 9 Oct	Fri 10 Oct	Sat 11 Oct	Sun 12 Oct	Mon 13 Oct	Tue 14 Oct	Wed 15 Oct	Thu 16 Oct	Fri 17 Oct	Sat 18 Oct	Sun 19 Oct	Mon 20 Oct	Tue 21 Oct	Wed 22 Oct	Thu 23 Oct	Fri 24 Oct	Sat 25 Oct	Sun 26 Oct	Mon 27 Oct	Tue 28 Oct	Wed 29 Oct	Thu 30 Oct	Fri 31 Oct	Sat 1 Nov	Sun 2 Nov
Week		40							41							42							43							44						
Machine											7h 19h							7h 19h							7h 19h							UA9 MD TS 7h 8h 7h 16h				
North Area	T2 - H2				NA Setup				CMS Si/GE D. Lazic							CMS Upgrade 1 D. Lazic							CMS Upgrade 2 D. Lazic							NA61 (SHINE) Z. Fodor						
	T2 - H4				NA Setup				LHCf Y. Itow										CMS EE aging D. Lazic											CMS ECAL R&D D. Lazic						
	T4 - H6A				NA Setup				CERF M. Silari							RD42 H. Kagan							ATLAS ITK/NSW S. Vlachos													
	T4 - H6B				NA Setup				CERF M. Silari							ALICE ITS P. Martinengo							RD50 M. Moll							Arachnid F. Wilson						
	T4 - H8				NA Setup				LHCb H. Schindler H8A							TOTEM(+UA9) M. Bozzo H8C							LHCb H. Schindler H8A													
	T4 - K12				NA Setup				NA62 A. Ceccucci																											
	T6 - M2				NA Setup				NA58 (COMPASS) F. Kunne																											

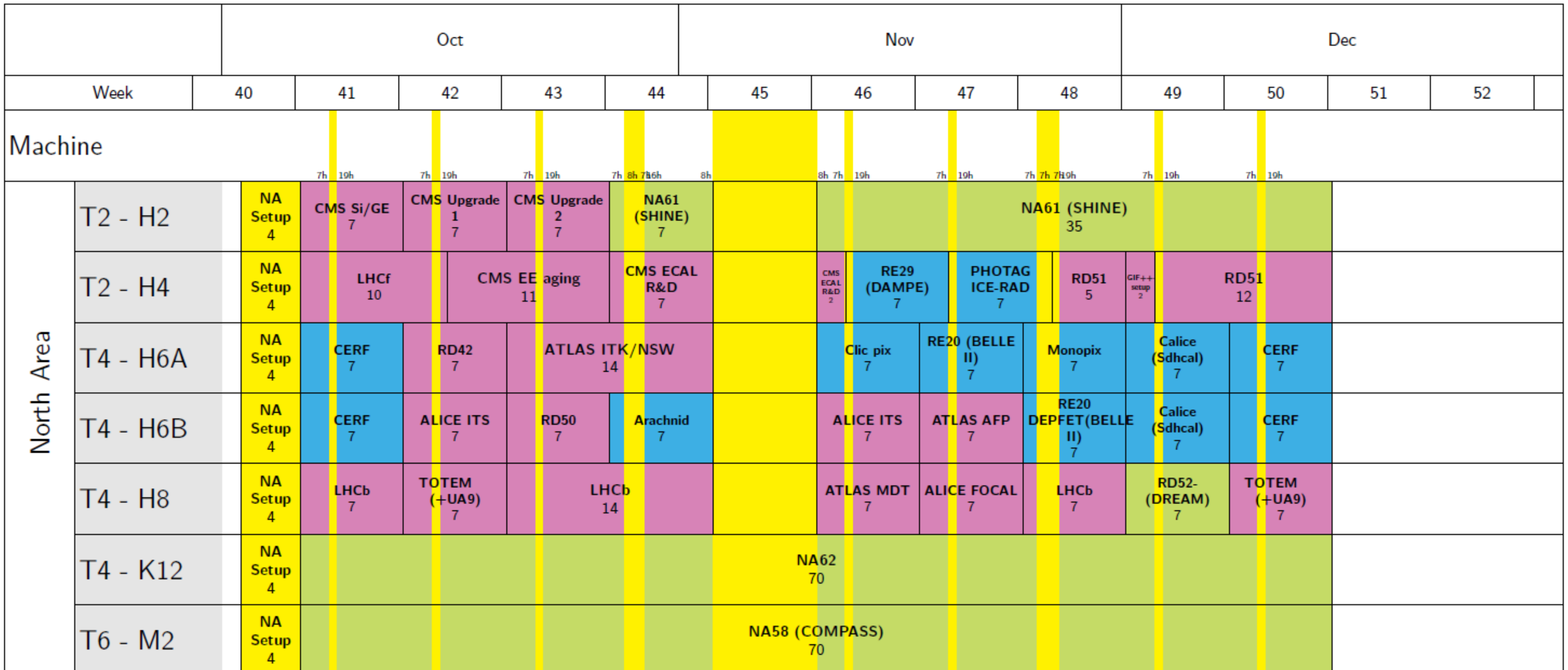
For further information contact the PS/SPS-Coordinator. Email: Sps.Coordinator@cern.ch, Tel: +41 76 487 3845.

The latest version of the schedule are available here: http://sps-schedule.web.cern.ch/sps-schedule/
This schedule in synchronized with injector schedule v1.6
No access to EHN1 experimental areas 22-25 of September for access system tests.
2 extractions with a 4.8s flat top per supercyle.
No beam during Technical Stops (TS) and Machine Developments (MD)
in H8 UA9 runs parasitically to Totem, ATLAS MDT parasitically to LHC-b.

NA62: BEAM TIME 2014

SPS user schedule for 2014

schedule issue date: 14-Aug-2014 Version: 2.3 LHC Exp. PS/SPS Exp. INT Exp. Other Exp.



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in H8 UA9 runs parasitically to Totem, ATLAS MDT parasitically to LHC-b.

ARGON IONS IN SPS: NOT FOR NA62

Dear Colleagues,

there will be a 6 week SPS run with Ar ions for the NA61 experiment early 2015. The exact dates will be finalised in october 2014.

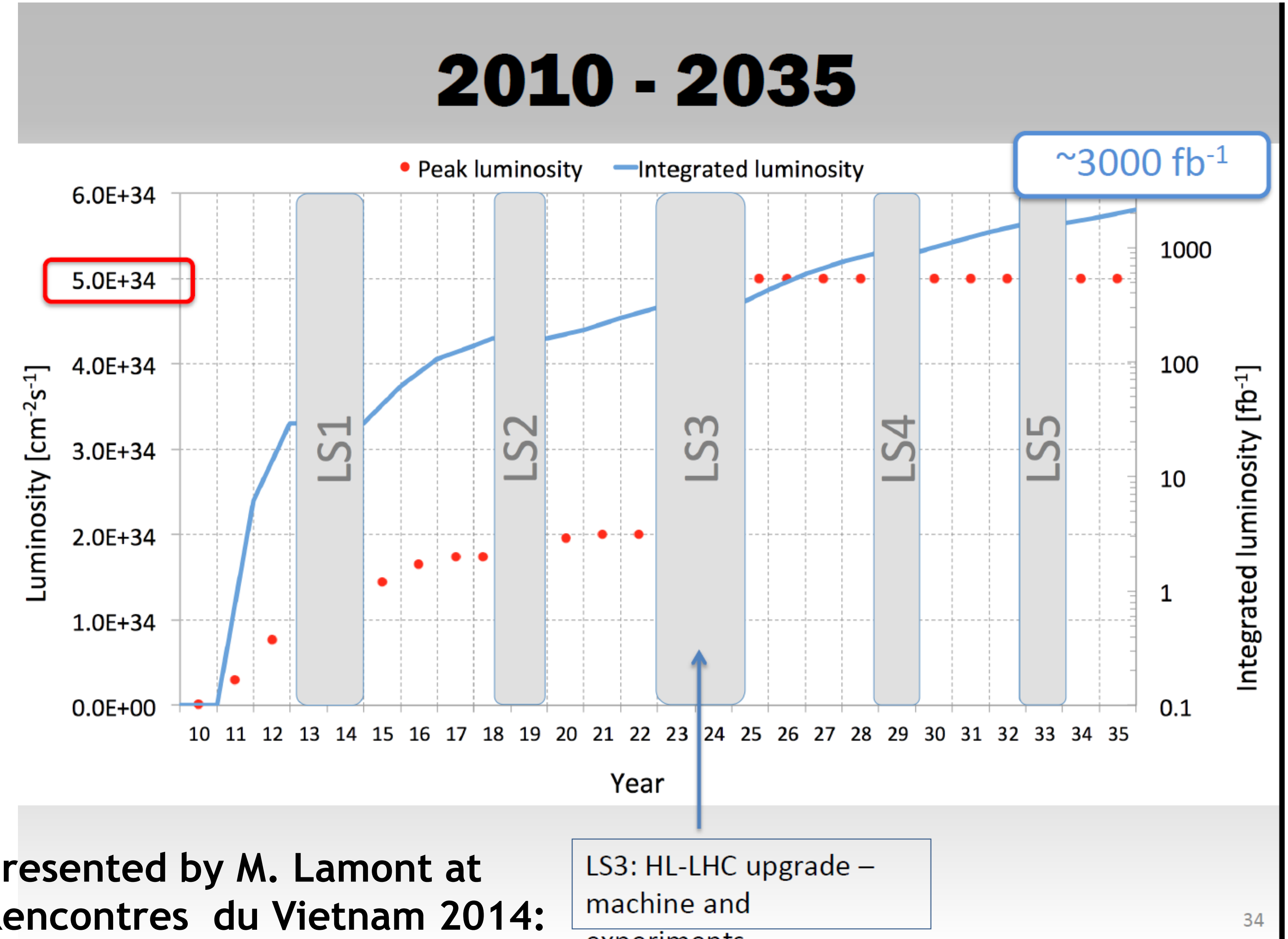
The momenta which will be available during this run are 13A GeV/c, 19A GeV/c, 30A GeV/c, 40A GeV/c, 75A GeV/c, 150A GeV/c. Ar ions can be made available for test-beams in the H4 and/or H8 beam lines, according to interest of the user community.

Please let me know you beam time request for these 2 beam lines for the Ar run by filling the attached beam time request form and returning it to me by September 15th 2014.

Best regards,

Henric Wilkens

LHC FUTURE RUNNING

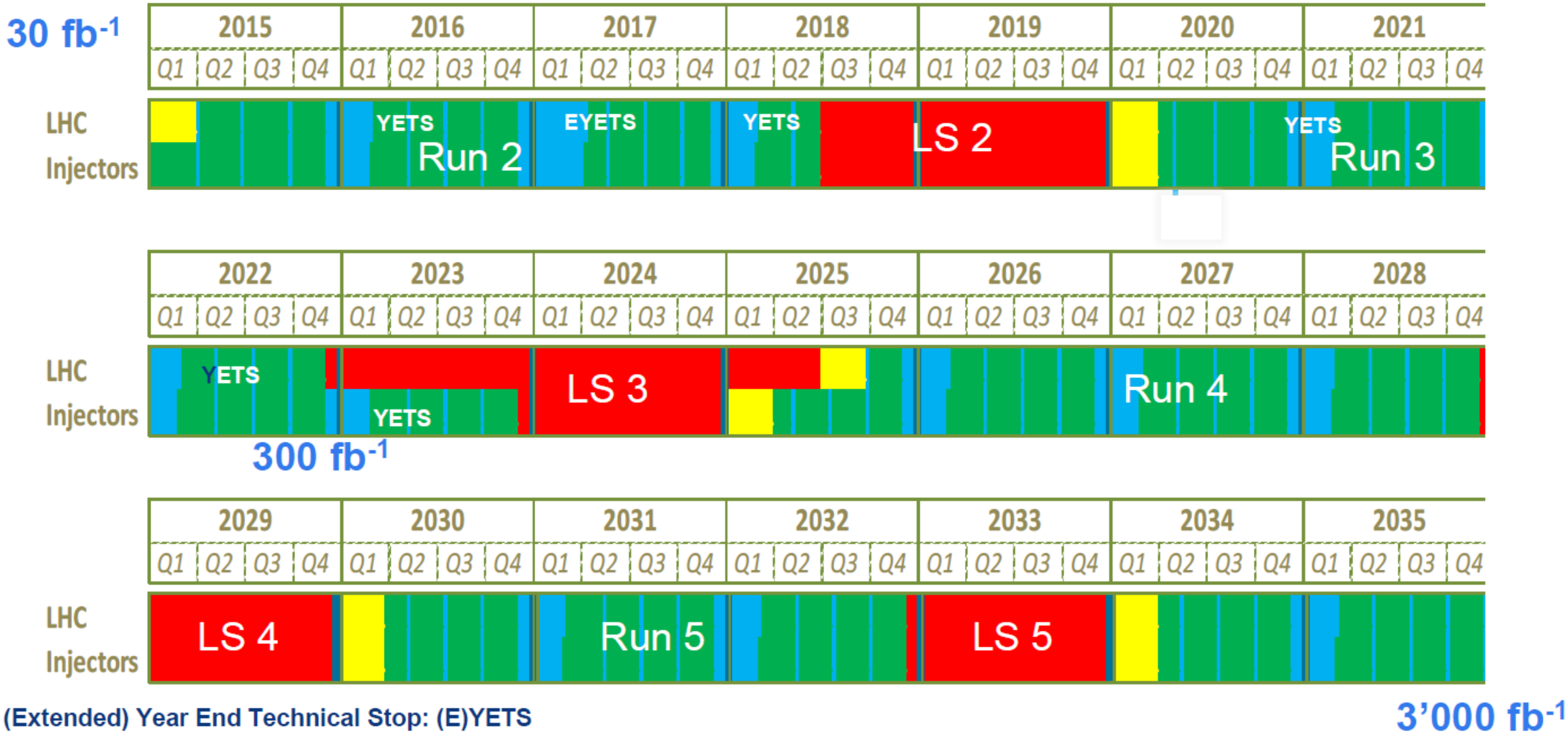


Presented by M. Lamont at Rencontres du Vietnam 2014: Physics at LHC and beyond

LHC schedule beyond LS1

LS2 starting in 2018 (July) => 18 months + 3 months BC
LS3 LHC: starting in 2023 => 30 months + 3 months BC
Injectors: in 2024 => 13 months + 3 months BC

- Physics
- Shutdown
- Beam commissioning
- Technical stop



Availability of the LHC injectors (R. Heuer, March 2014 Council)

For how long should we take data ?

Naive projection: $S = S\_SM$; $S\_EQ = S/(1+B/S)$

$\delta BR/BR\ (\%) = sqrt(S\_EQ)/S\_EQ$

Running until	B/S	δBR/BR (%)
LS2	1/10 3/10 1/1	6.1 6.6 8.2
LS3	1/10 3/10 1/1	4.1 4.4 5.5
LS4	1/10 3/10 1/1	3.5 3.7 4.6

It depends crucially on the level and knowledge of the backgrounds

To match the ~5% theory error requires to run until LS3

Implications for operation and maintenance

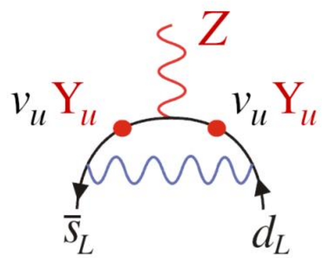
DISCUSSION/SPARE MATERIAL

NA62 Sensitivity

Decay	evt/year
$K^+ \to \pi^+ \nu\nu$ [SM] (flux 4.5×10^{12})	45
$K^+ \to \pi^+ \pi^0$	5
$K^+ \to \mu^+ \nu$	1
$K^+ \to \pi^+ \pi^+ \pi^-$	< 1
$K^+ \to \pi^+ \pi^- e^+ \nu$ + other 3 tracks decays	< 1
$K^+ \to \pi^+ \pi^0 \gamma$(IB)	1.5
$K^+ \to \mu^+ \nu \gamma$(IB)	0.5
$K^+ \to \pi^0 e^+ (\mu^+) \nu$, others	negligible
Total background	< 10

Kaon Rare Decays and BSM

C. The Z penguin (and its associated W box)

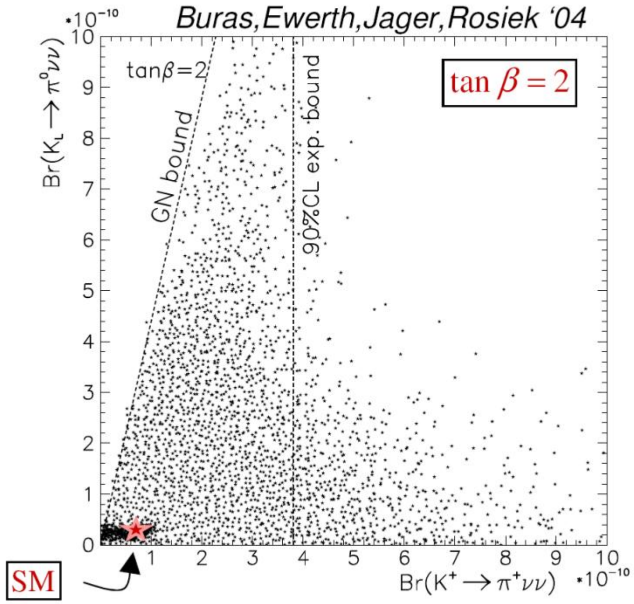


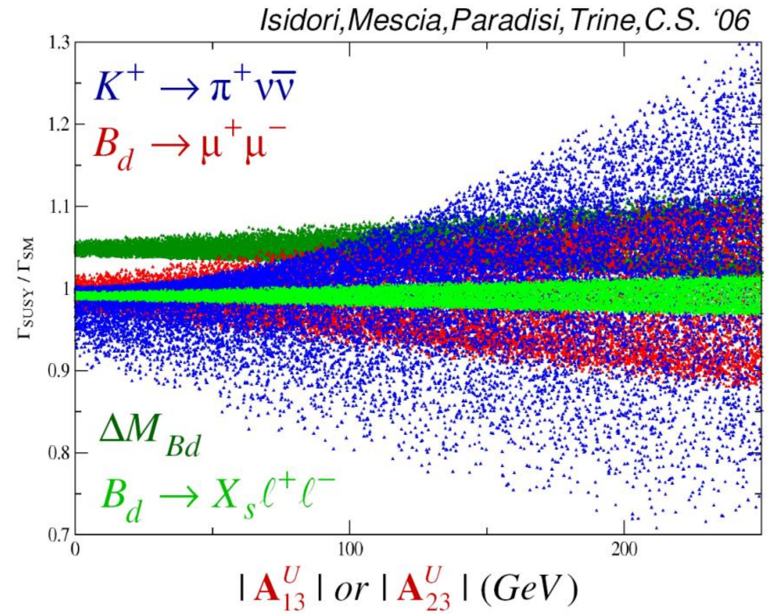
- $SU(2)_L$ breaking: $SM: v_u^2 Y_u^{*32} Y_u^{31} \sim m_t^2 V_{ts}^* V_{td}$

$$MSSM: v_u^2 A_{\tilde{u}}^{*32} A_{\tilde{u}}^{31} \sim m_t^2 \times O(1)?$$

$$MFV: v_u^2 A_{\tilde{u}}^{*32} A_{\tilde{u}}^{31} \sim m_t^2 V_{ts}^* V_{td} \left| A_0 a_2^* - \cot\beta\mu \right|^2.$$

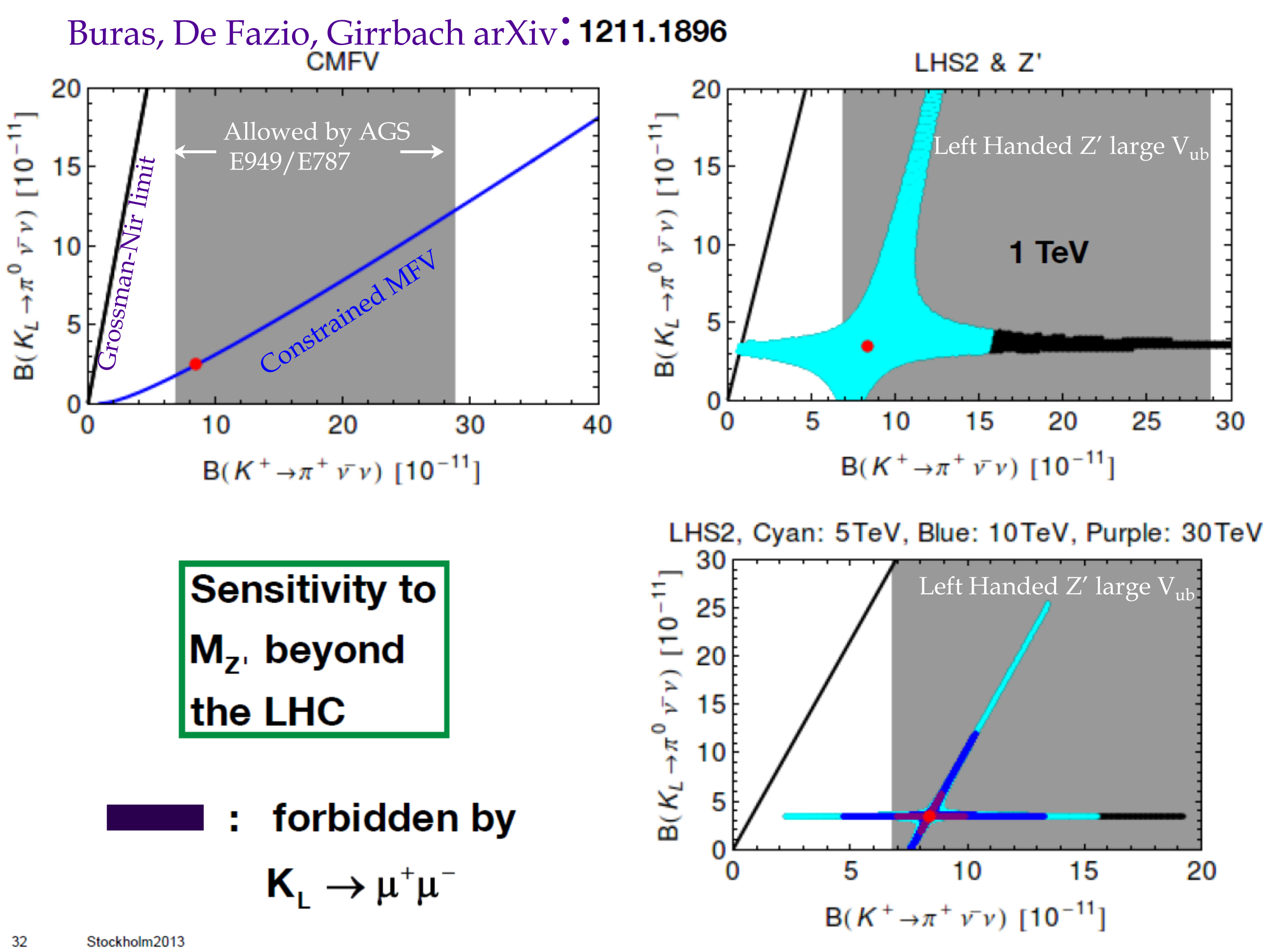
- Relatively slow decoupling (w.r.t. boxes or tree).





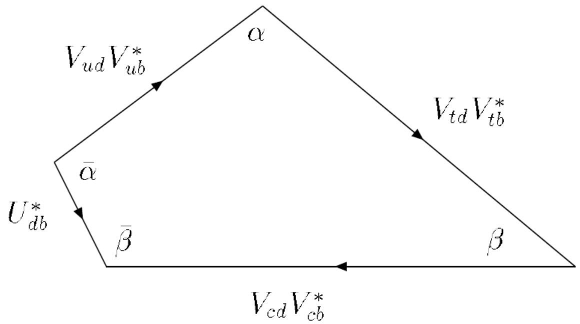
(courtesy by Christopher Smith)

Example: Rare *K* decay sensitivity to flavor violating *Z'*



Sensitivity beyond direct searches

THE UNITARITY QUADRANGLES



The three elements which are most relevant to our study are

$$\begin{aligned} U_{ds} &= V_{ud}^* V_{us} + V_{cd}^* V_{cs} + V_{td}^* V_{ts}, \\ U_{db} &= V_{ud}^* V_{ub} + V_{cd}^* V_{cb} + V_{td}^* V_{tb}, \\ U_{sb} &= V_{us}^* V_{ub} + V_{cs}^* V_{cb} + V_{ts}^* V_{tb}. \end{aligned} \tag{3.7}$$

The fact that, in contrast to the Standard Model, the various U_{pq} do not necessarily vanish, allows FCNC at tree level. This may substantially modify the predictions for CP asymmetries.

From: Grossman, Nir and Rattazzi hep-ph/970123

A NICE INTERPLAY BETWEEN KAONS AND BEES IN THE SM

$$\frac{\Gamma(K_L^0 \to \pi^0 \nu \overline{\nu})}{\Gamma(K_S^0 \to \pi^0 \nu \overline{\nu})} = \tan(\beta - \beta_s)^2$$

$$\frac{\Gamma(K_L^0 \to \pi^0 \nu \overline{\nu})}{\Gamma(K^+ \to \pi^+ \nu \overline{\nu})} = r_{is} \sin(\beta - \beta_s)^2$$

Sensitivity BSM

$$A_{SM} + A_{NP} = K_{SM} \frac{\alpha_W}{4\pi} \frac{F_{CKM}}{M_W^2} + K_{NP} L \frac{F_{NP}}{\Lambda^2}$$

Operator	Bounds on Λ in TeV ($c_{\rm NP}=1$) Re	Im	Bounds on $c_{\rm NP}$ ($\Lambda = 1$ TeV) Re	Im	Observables
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p \rvert_D$, ϕ_D
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	
$(\bar{b}_L \gamma^\mu d_L)^2$	6.6×10^2	9.3×10^2	2.3×10^{-6}	1.1×10^{-6}	Δm_{B_d}; $\sin(2\beta)$ from $B_d \to \psi K$
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	2.5×10^3	3.6×10^3	3.9×10^{-7}	1.9×10^{-7}	
$(\bar{b}_L \gamma^\mu s_L)^2$	1.4×10^2	2.5×10^2	5.0×10^{-5}	1.7×10^{-5}	Δm_{B_s}; $\sin(\phi_s)$ from $B_s \to \psi\phi$
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	4.8×10^2	8.3×10^2	8.8×10^{-6}	2.9×10^{-6}	

Isidori and Teubert, arXiv:1402.2844