Rio de Janeiro, June 2011

See Standard Model's Beauty from Far-Away -- like Helen on the Towers of Troy

Ikaros Bigi (Notre Dame du Lac)

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But the Achaeans elected another hero –
Odysseus
known for his thinking and ideas,
not just for his physical strength!

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They built the Trojan Horse,took Troy & their prize – Helen, daughter of Zeus!

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- to find the new dynamics we cannot study only high p_T processes – we need `low energies' with precision!

One challenge:

- Achaeans knew that beauty existed in the form of Helen –

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another lesson from German literature:
"A young man sees Helen in any young woman!"
Remember this warning, young experimenters!

Memorial for Nicola Cabibbo – Pioneer of Our View of Weak Forces

Cabibbo should have made it with KM!

mass eigenstat. ≠ interaction eigenstat.

➢ unitary $V_{CKM} = T_{U,L}\, T_{D,L}^{*}$ due to weak universality

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$$\Sigma_{j=1}^{j=3}\, V^*(ij)V(jk) = 0, \quad i \neq k$$

➥ triangle relations in the complex plane

➥ 6 triangles have equal areas

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CP asym depend on angles

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weak universality to interpret CP asym

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Outline

I. Cabibbo-Kobayashi-Maskawa Matrix (& 5 more … & more)

II. Future Campaigns

III. Rosetta Stone for Understanding Flavour Dynamics

IV. Conclusions

I. Cabibbo-Kobayashi-Maskawa Matrix (& 5 more … & more)

the emerging pattern:

- $|V(us)| = \lambda = \sin\theta_{Cabibbo}$
- $\tau(B) \sim 1$ psec $\Longrightarrow$ $|V(cb)| \sim O(\lambda^2)$ `long' lifetime
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- Menelaos found out:
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only true beauty does it!

- Wolfenstein representation

$$V_{CKM}= \begin{pmatrix} 1-\lambda^2 & \lambda & A\lambda^3(\rho-i\eta+\eta\lambda^2/2) \\ -\lambda & 1-\lambda^2/2-i\eta A^2\lambda^4 & A\lambda^2(1+\eta\lambda^2) \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

- I can see the hidden `Helen' on the towers

- 3 classes of 2 triangles
  - $\lambda + \lambda + \lambda^5$

sd triangle: $V^*_{ud}V_{us} + V^*_{cd}V_{cs} + V^*_{td}V_{ts} = \delta_{sd} = 0$

cu triangle: $V^*_{ud}V_{cd} + V^*_{us}V_{cs} + V^*_{ub}V_{cb} = \delta_{cu} = 0$

  - $\lambda^2 + \lambda^2 + \lambda^4$

bs triangle: $V^*_{us}V_{ub} + V^*_{cs}V_{cb} + V^*_{ts}V_{tb} = \delta_{bs} = 0$

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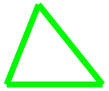


bd triangle: $V^*_{ub}V_{ud} + V^*_{cb}V_{cd} + V^*_{tb}V_{td} = \delta_{bd} = 0$

tu triangle: $V^*_{ud}V_{td} + V^*_{us}V_{ts} + V^*_{ub}V_{tb} = \delta_{tu} = 0$

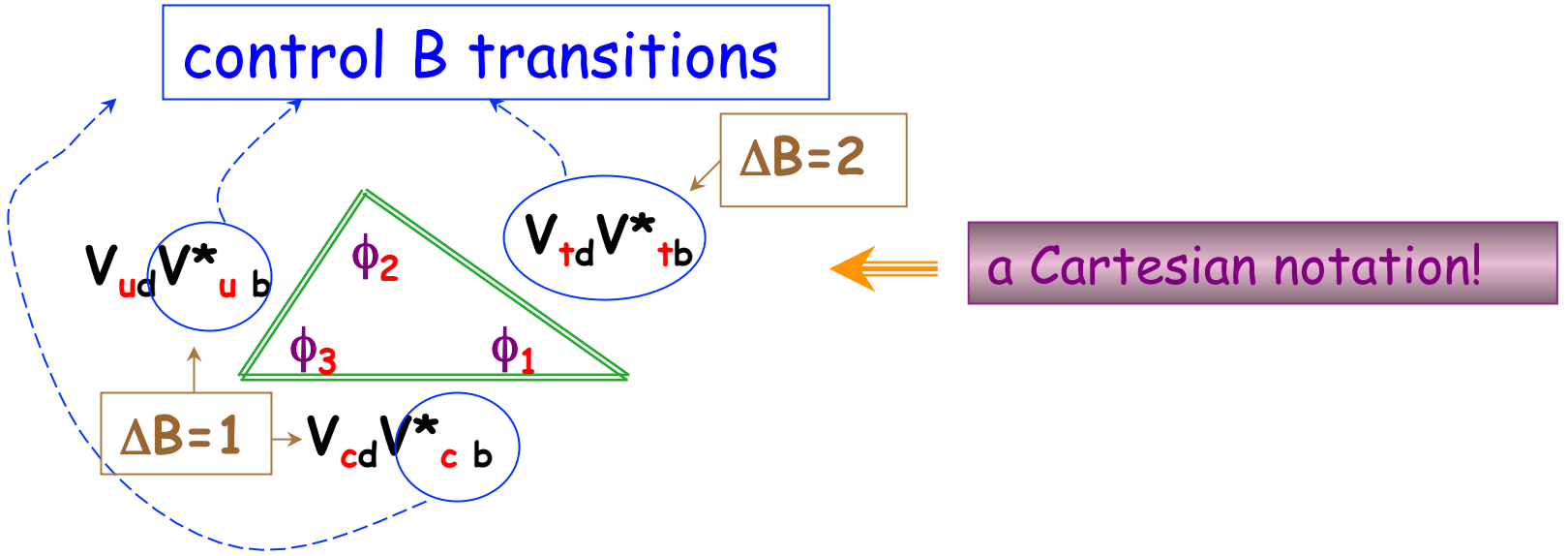
all six triangles have equal area!

"The" CKM (= Cabibbo-Kobayashi-Maskawa) Triangle

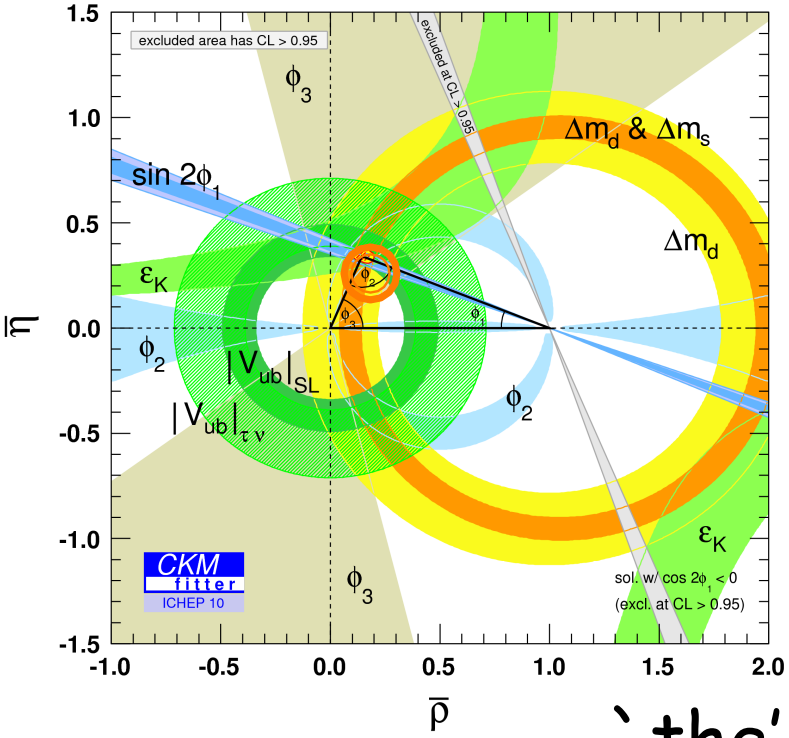
bd triangle: $V^*_{ub}V_{ud} + V^*_{cb}V_{cd} + V^*_{tb}V_{td} = \delta_{bd} = 0$ B

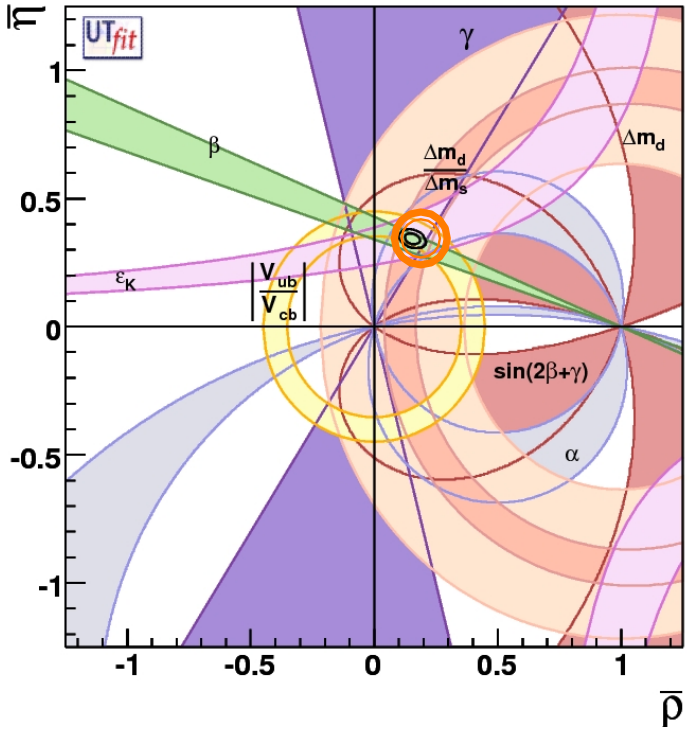
$\lambda^3 + \lambda^3 + \lambda^3$

- all 3 sides of comparable length
- all their angles are naturally large



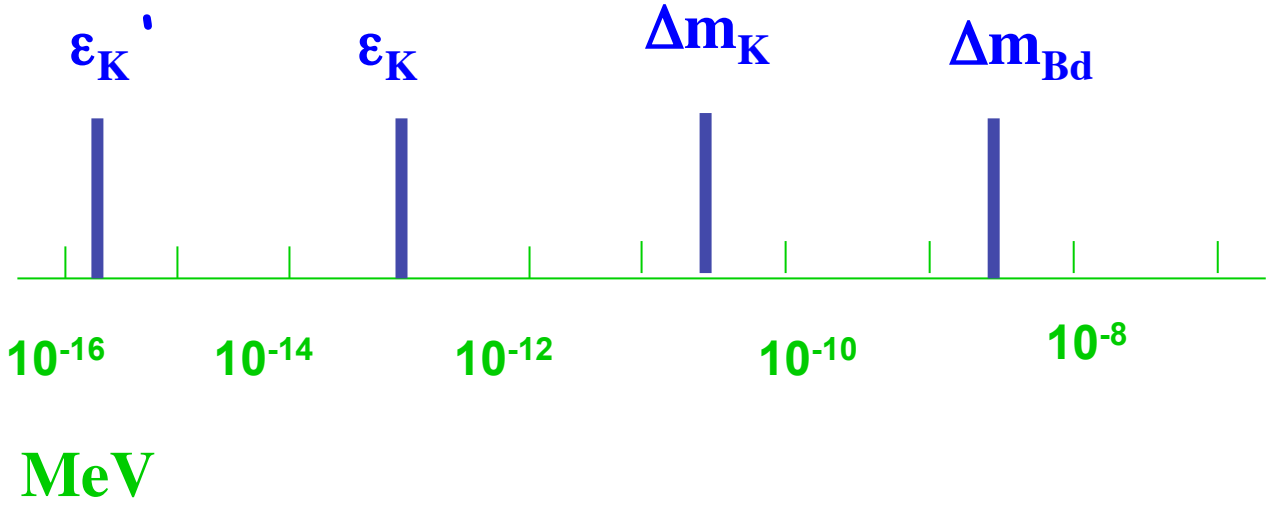
I (1) Status of Cabibbo-Kobayashi-Maskawa Matrix



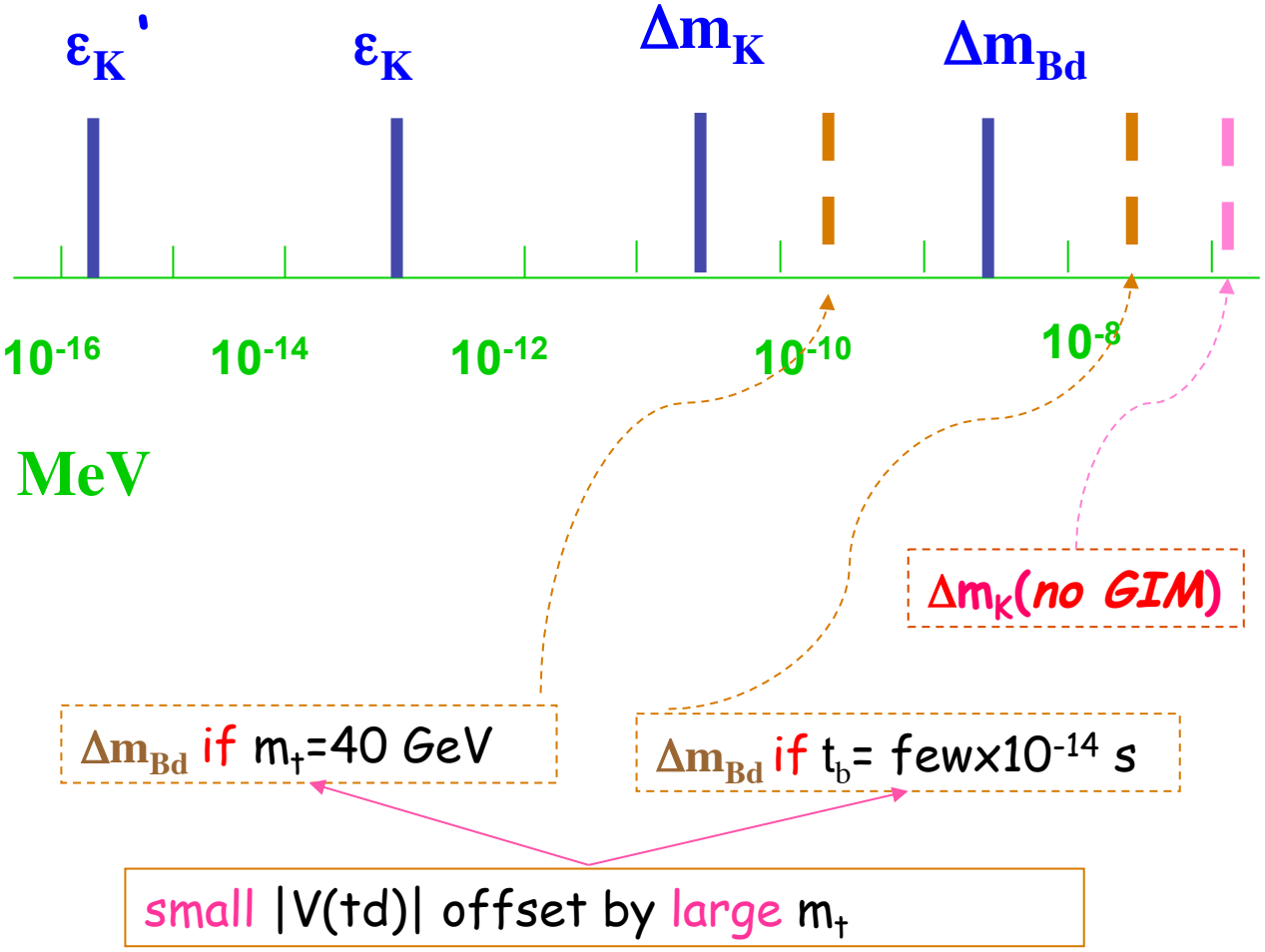


`the' CKM Triangle

fitting observables close to single triangle a `miracle'



reproduced observables spanning several orders of magnitude



reproduced observables spanning several orders of magnitude accommodated with parameter choices

|V(us)|~ 0.22,

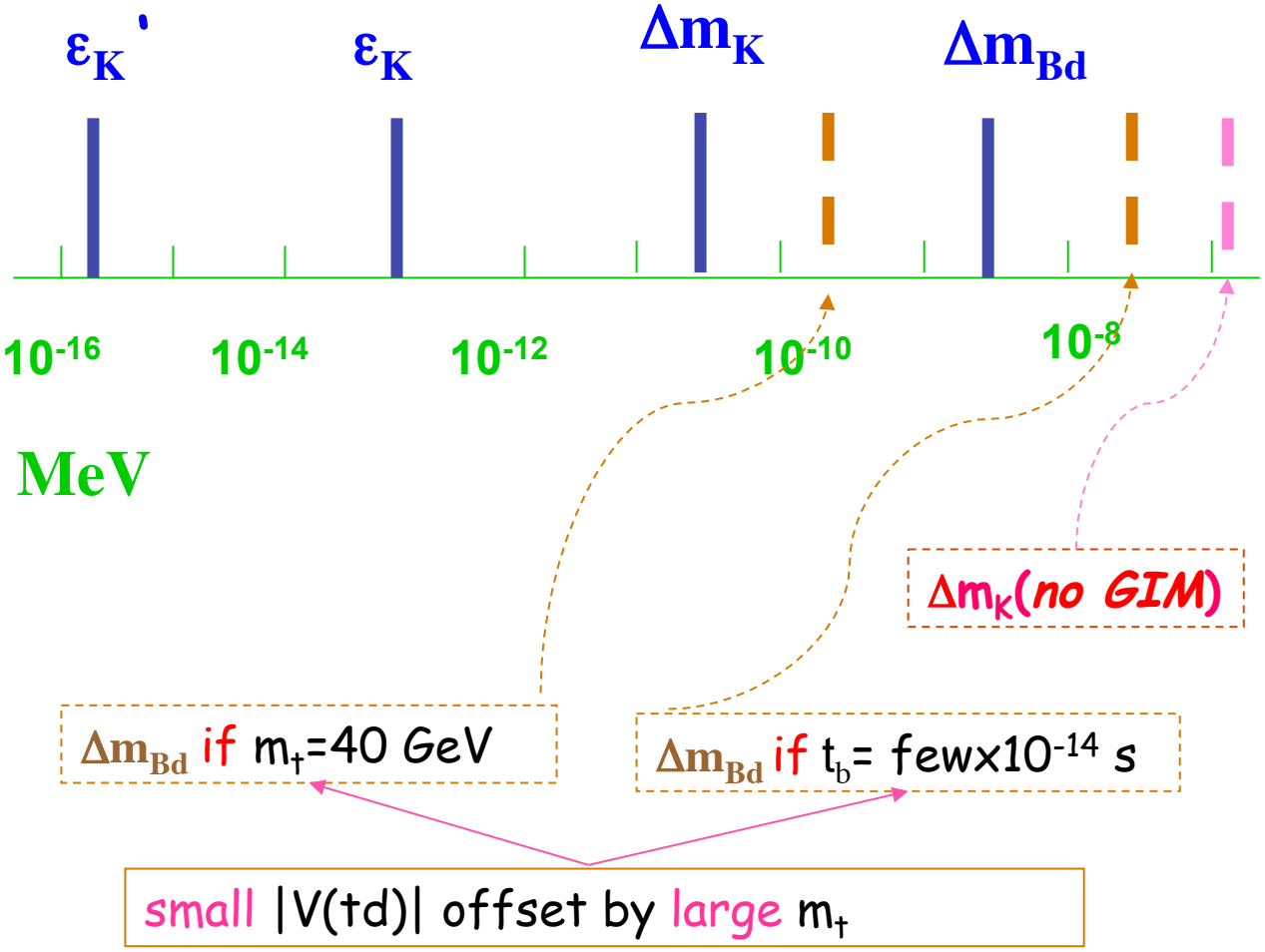
|V(ts)|~0.04

|V(td)|~ 0.004

m_u~5 MeV, m_d ~10 MeV

m_s~0.15 GeV,m_c~1.2 GeV

m_b~4.6GeV,m_t~175 GeV,



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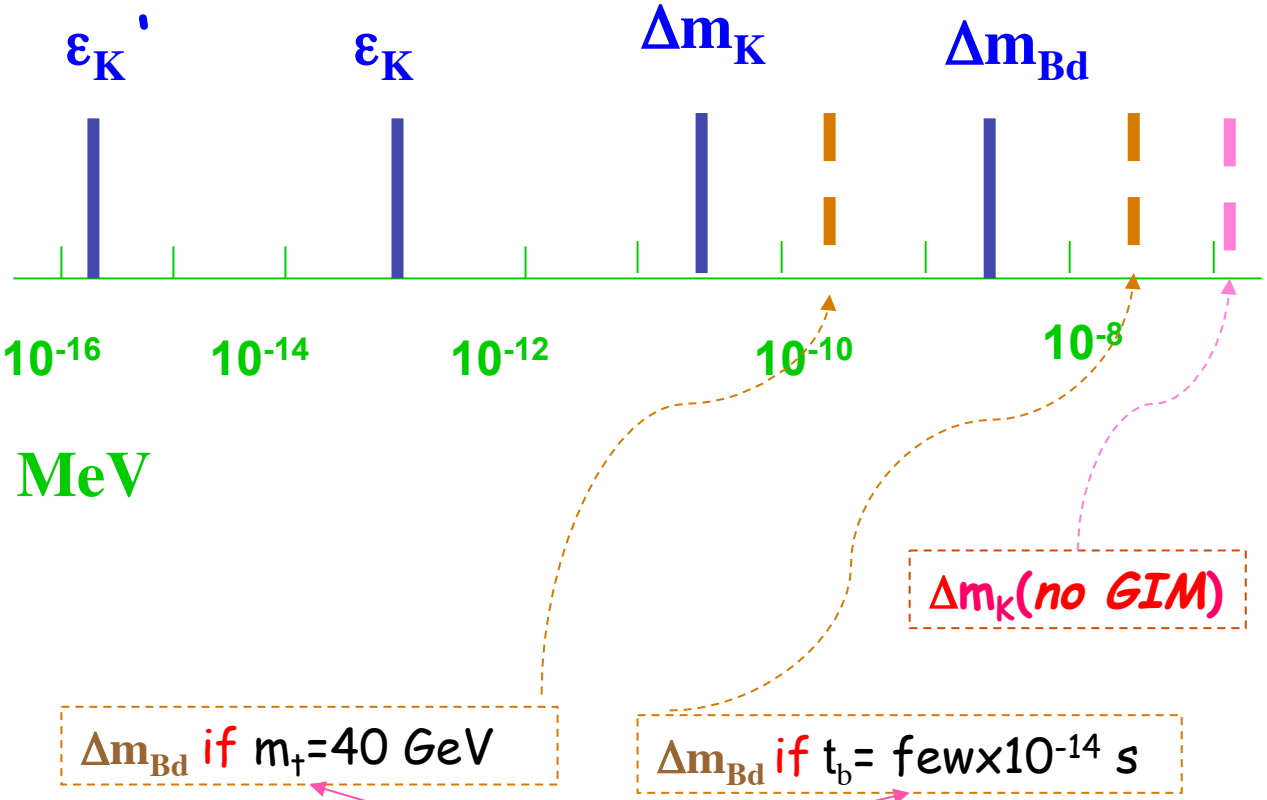
There could easily have been inconsistencies!



weak universality crucial!

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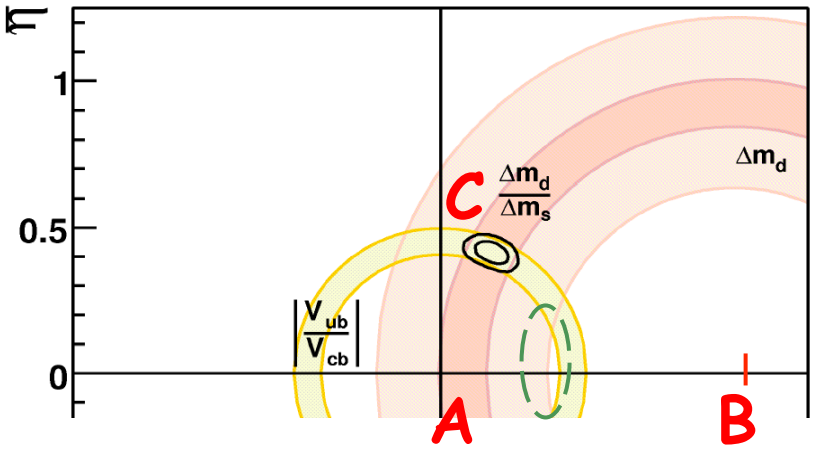
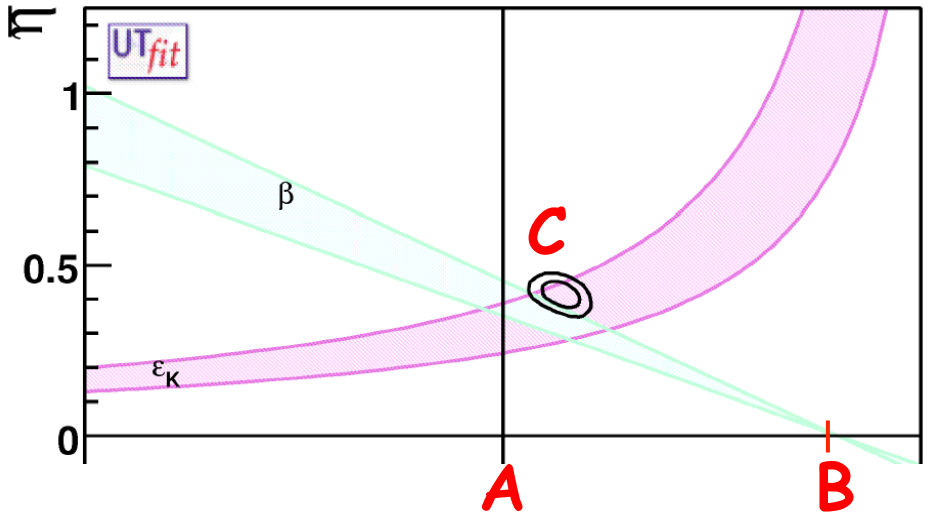
Impact of measurement of B_s - $\bar{B}_s$ oscillations





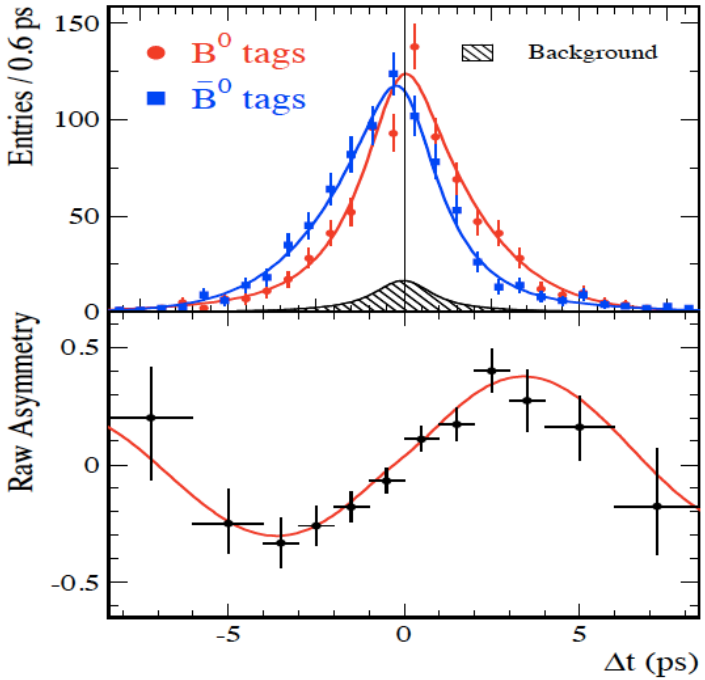
Another triumph for CKM theory:

CP insensitive observables (|V(ub)|, ΔM_s) imply ~~CP~~

qualitatively as well as quantitatively!

Angles in CKM triangle are indeed large:

- $\sin 2\phi_1 = S(B_d \rightarrow J/\psi\, K_S) = 0.658 \pm 0.024$



- $\sin 2\phi_2 \sim S(B_d \rightarrow \pi^+ \pi^-) = -0.61 \pm 0.08$

Resume:

☑ indirect & direct CPV established in K_L & B_d decays (close for $B^{\pm} \to K^{\pm}\rho^0$) & given by CKM at least as the leading source

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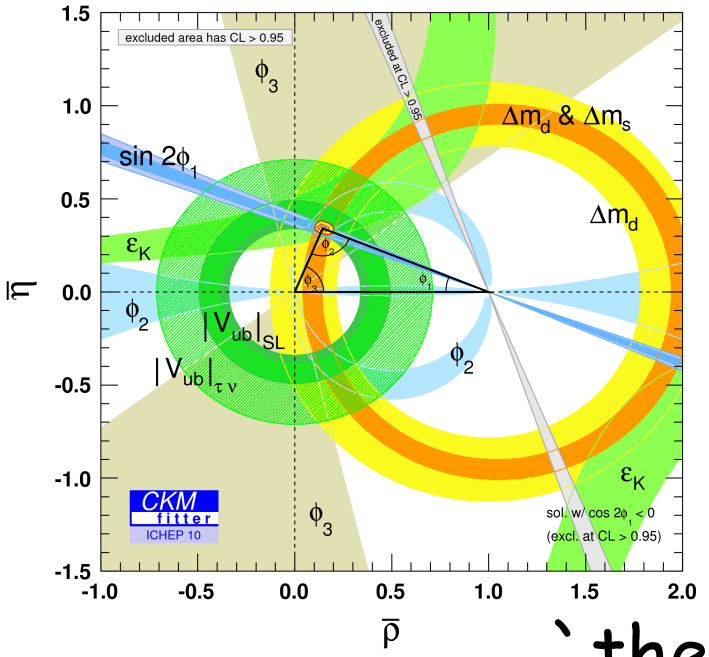
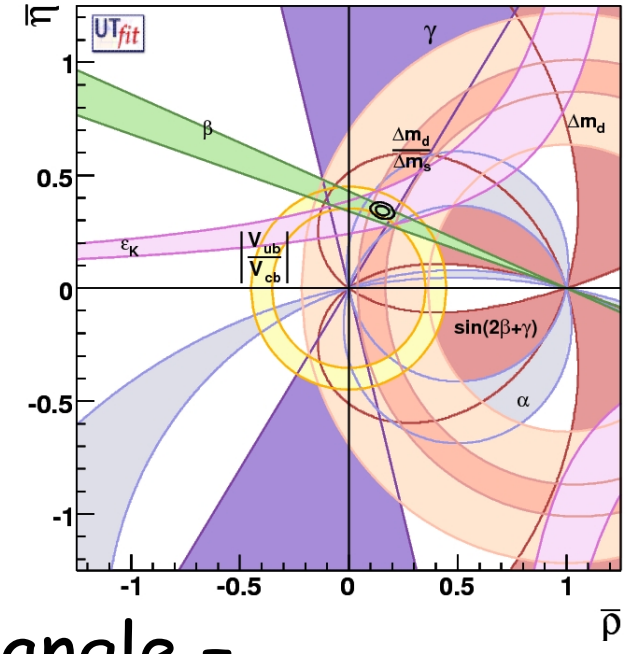
☑ New Dynamics with CPV has to exist in our Universe

I (2) Cabibbo-Kobayashi-Maskawa Matrix as Cathedral





`the' CKM Triangle –
Cathedral of Fundamental Science

Ikaros Bigi: "SM's Beauty = Helen"

about ~ 1500 HEP worked on the construction of the Cabibbo-Kobayashi-Maskawa Triangle -- but not all on the same level!

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Averages of b-hadron, c-hadron, and τ-lepton Properties

Heavy Flavor Averaging Group (HFAG):

arXiv: 1010.1589 [hep-ex]
lists 601 references

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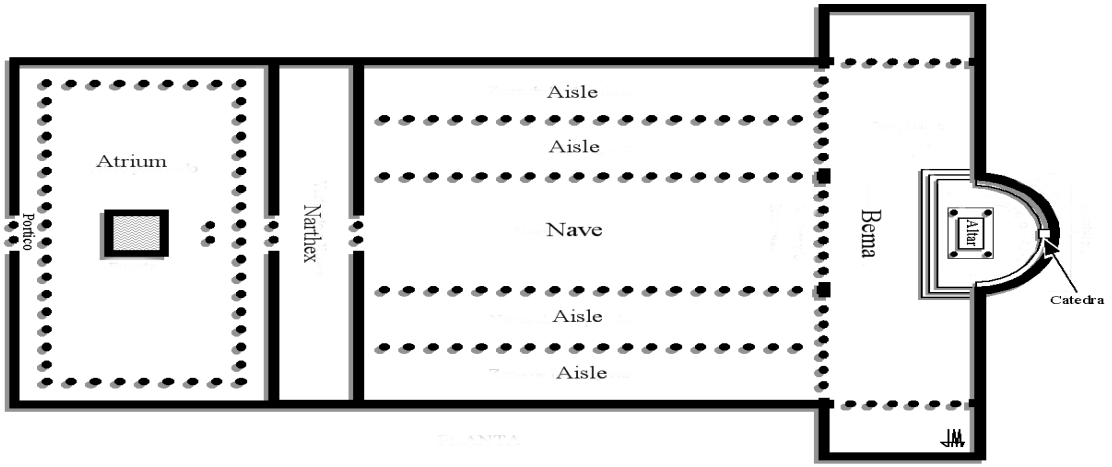
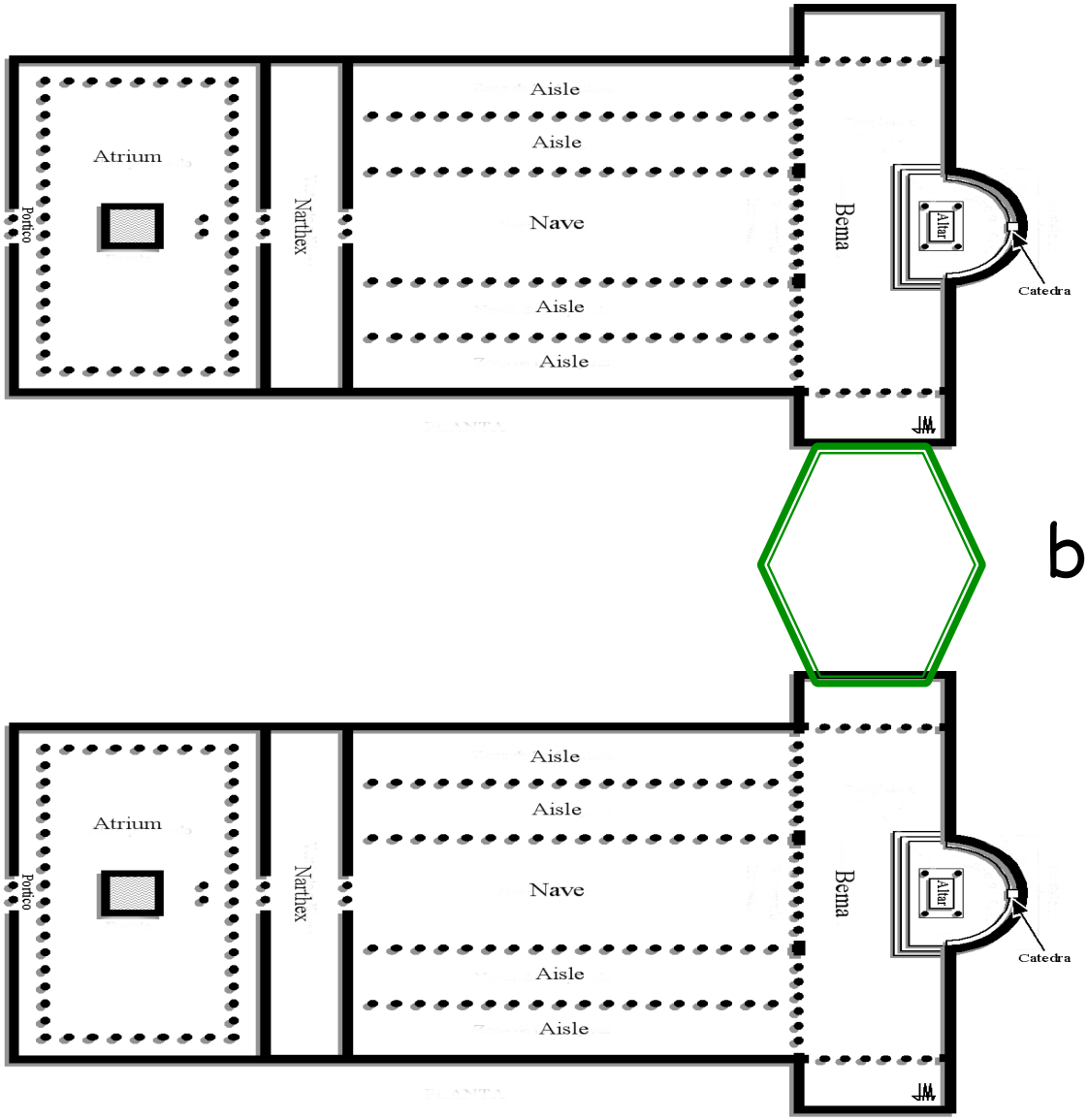
References

[1] N. Cabibbo, Phys. Rev. Lett. **10**, 531–533 (1963).

[2] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652–657 (1973).


Aisle
Aisle
Atrium
Narthex
Portico
Nave
Bema
Altar
Catedra
Aisle
Aisle

Barbarians

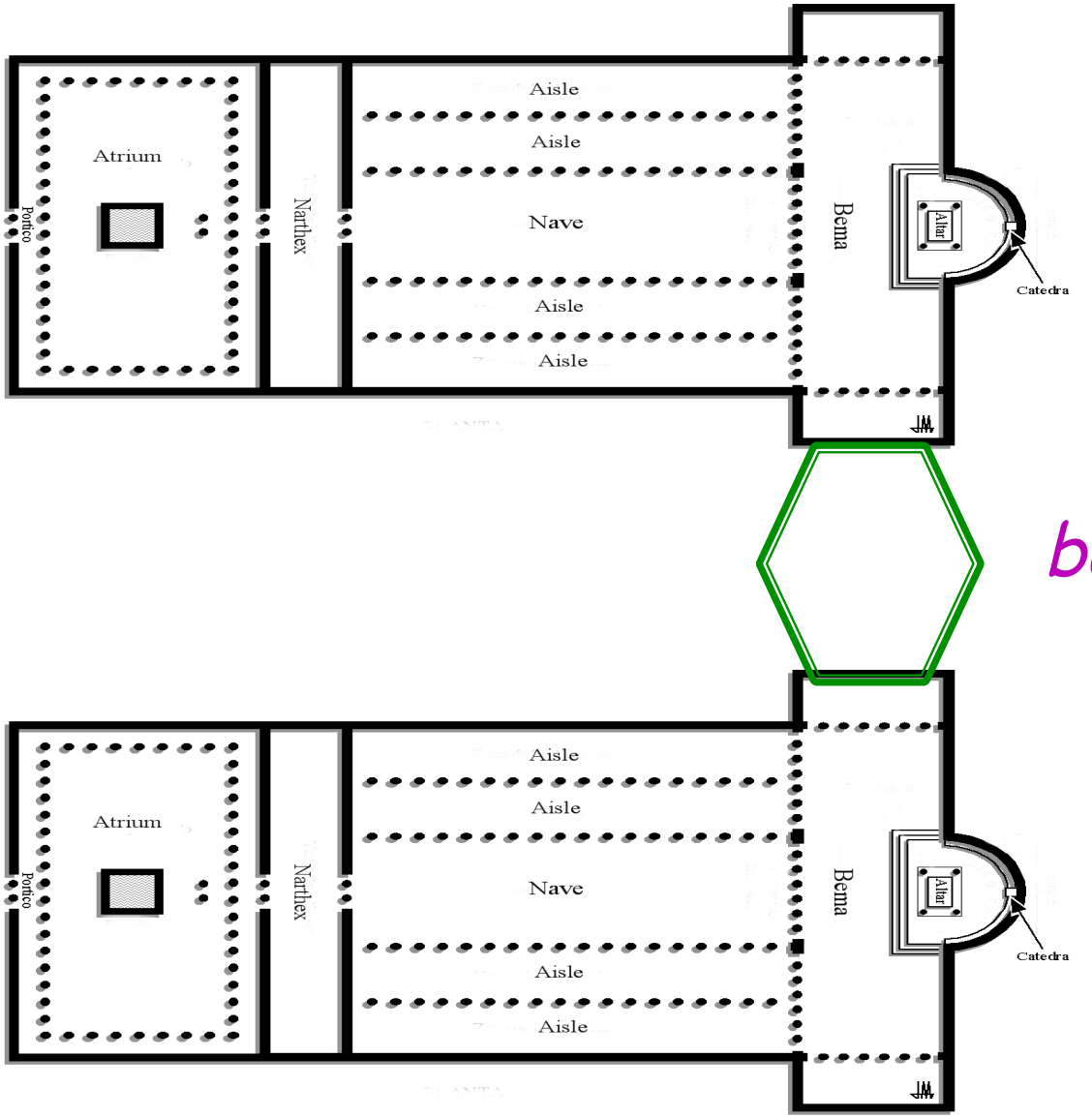


baptistery

Romans

Ikaros Bigi: "SM's Beauty = Helen"

Barbarians



baptistery

Romans

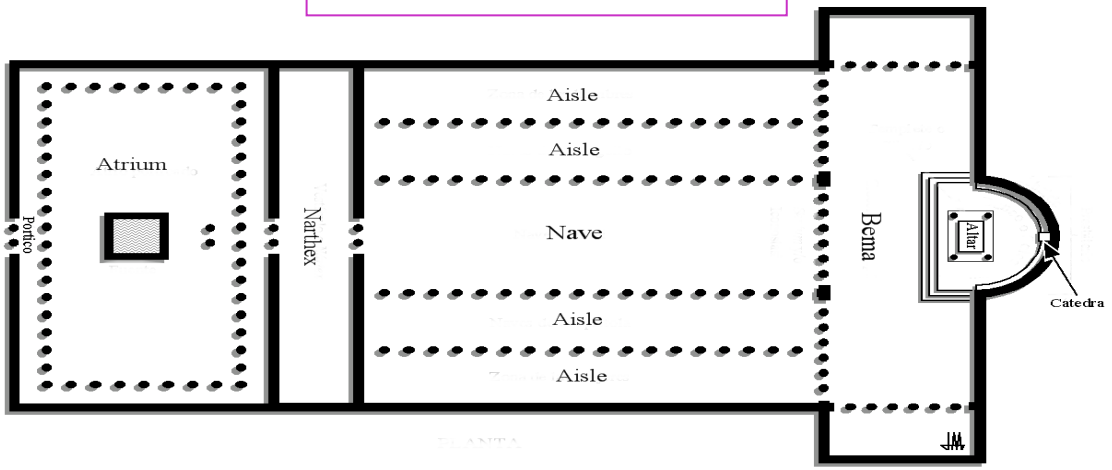
Trier (Germany)

Quarks mix. matrix

Leptons mix. matrix

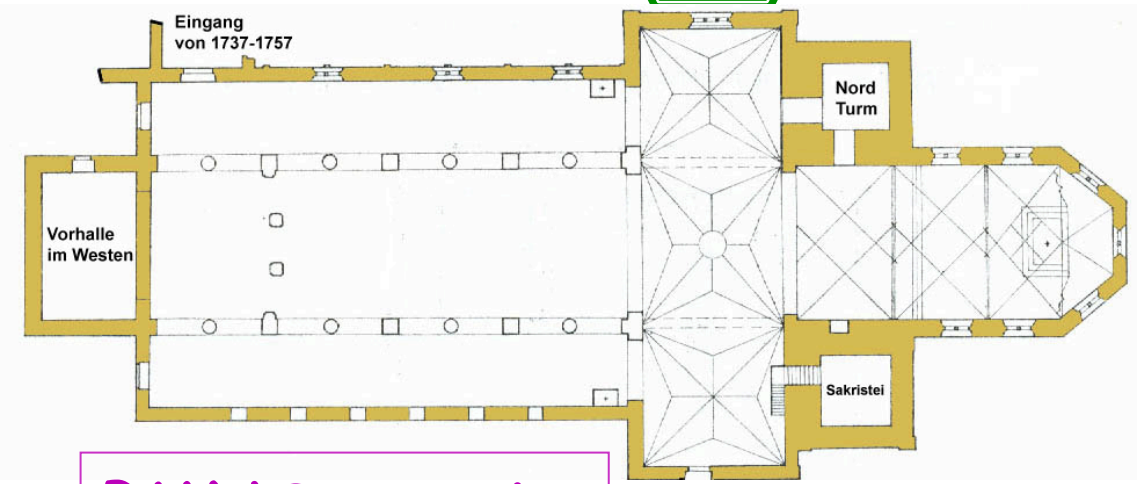
CKM matrix

quarks



theory

leptons

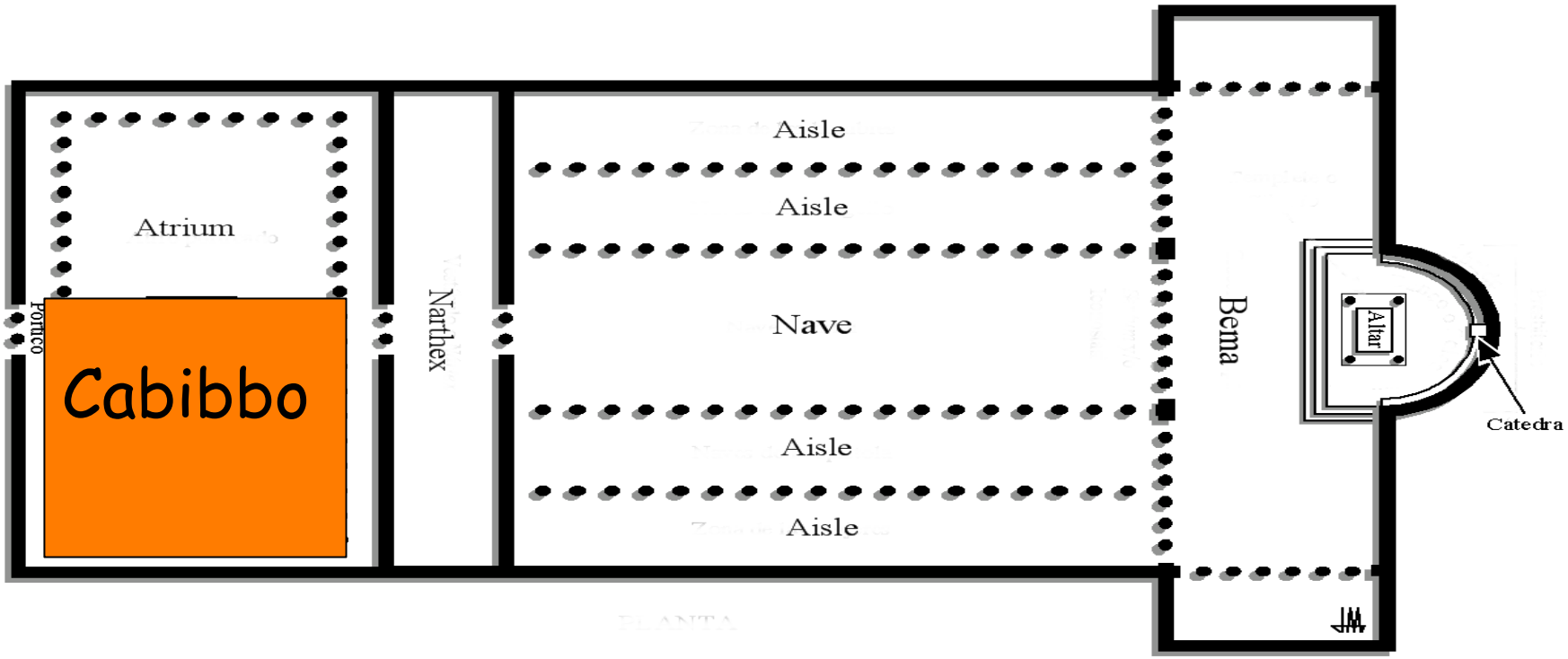


PMNS matrix

Cathedral of Flavour Dynamics has begun

SM = $SU(3)_C$ x $SU(2)_L xU(1)$ + CKM + PMNS

`only' thing | not greatest thing | accidental miracle



have reached

atrium

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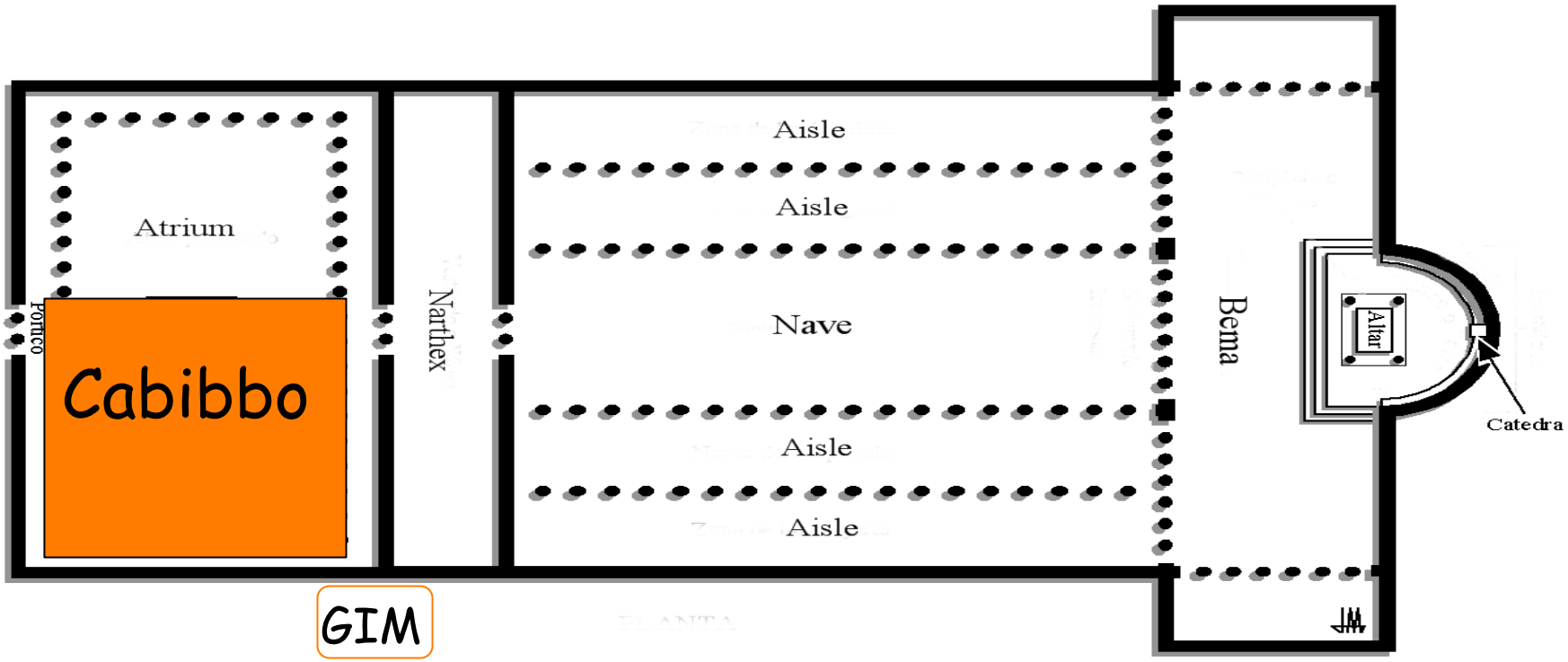

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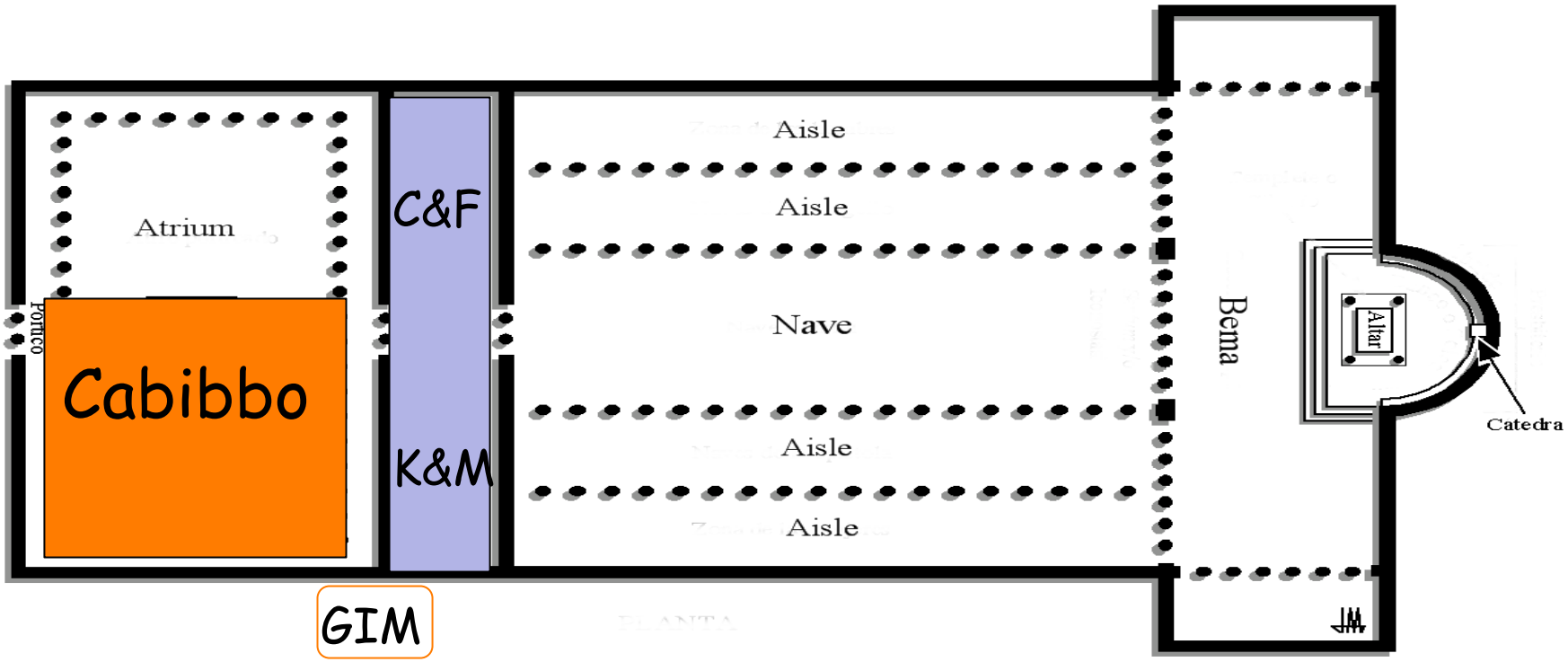

have reached

atrium & vestibule

Cathedral of Flavour Dynamics has begun

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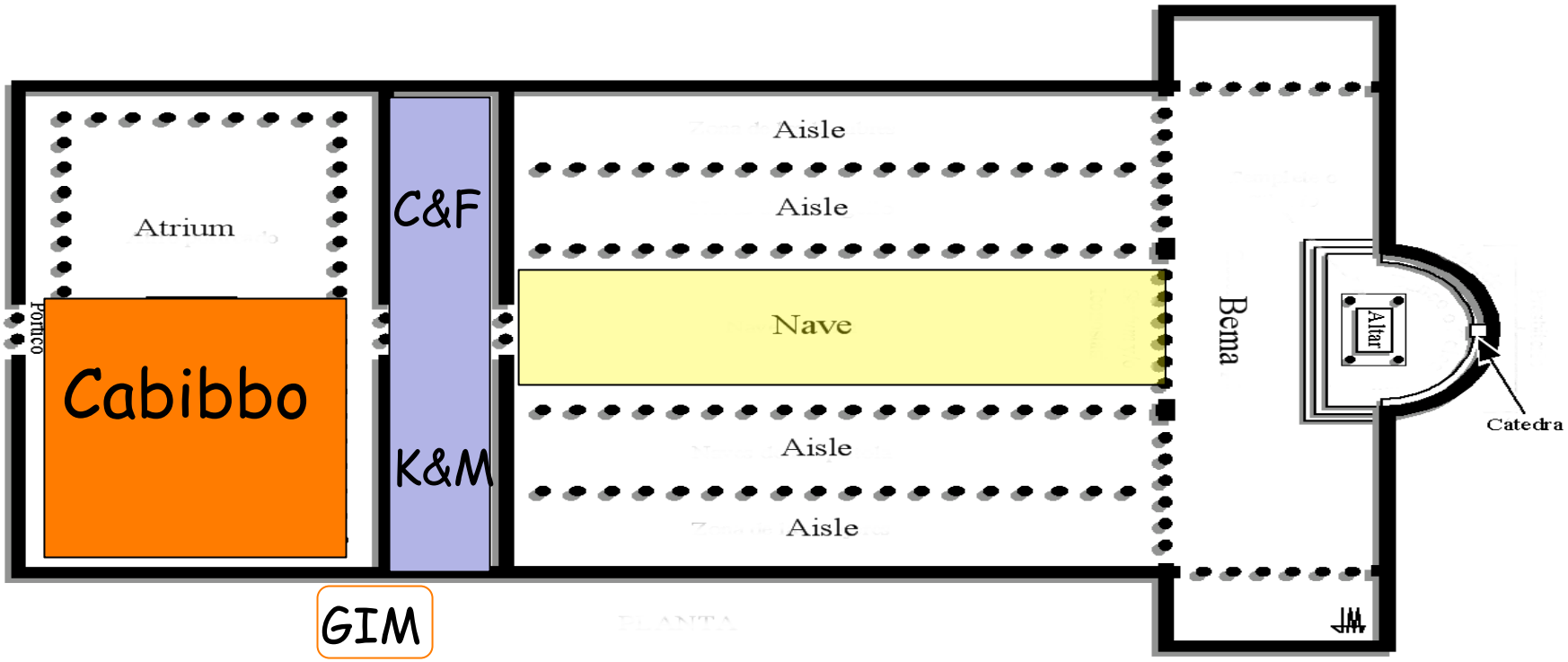

have reached

atrium & vestibule & idea of central nave ...

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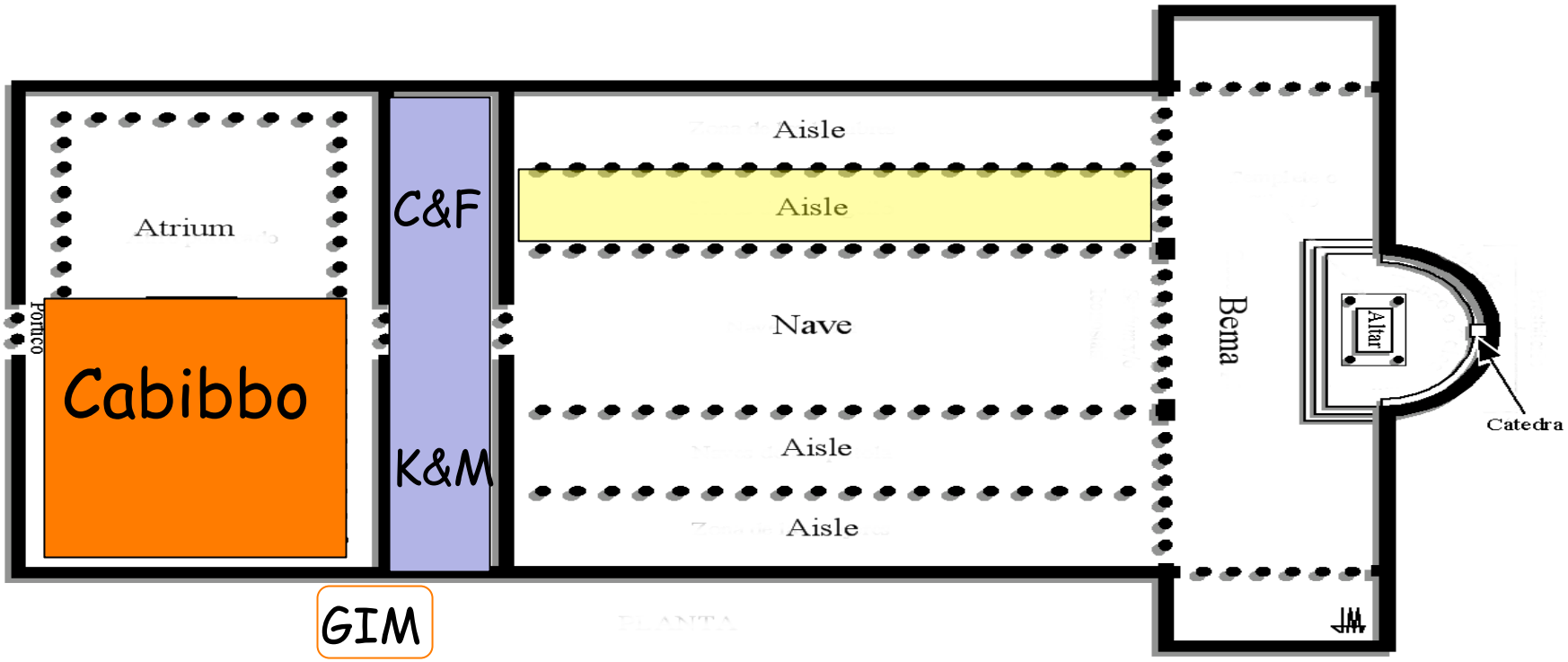

have reached

aisle ?

atrium & vestibule & idea of ~~central nave~~ ...

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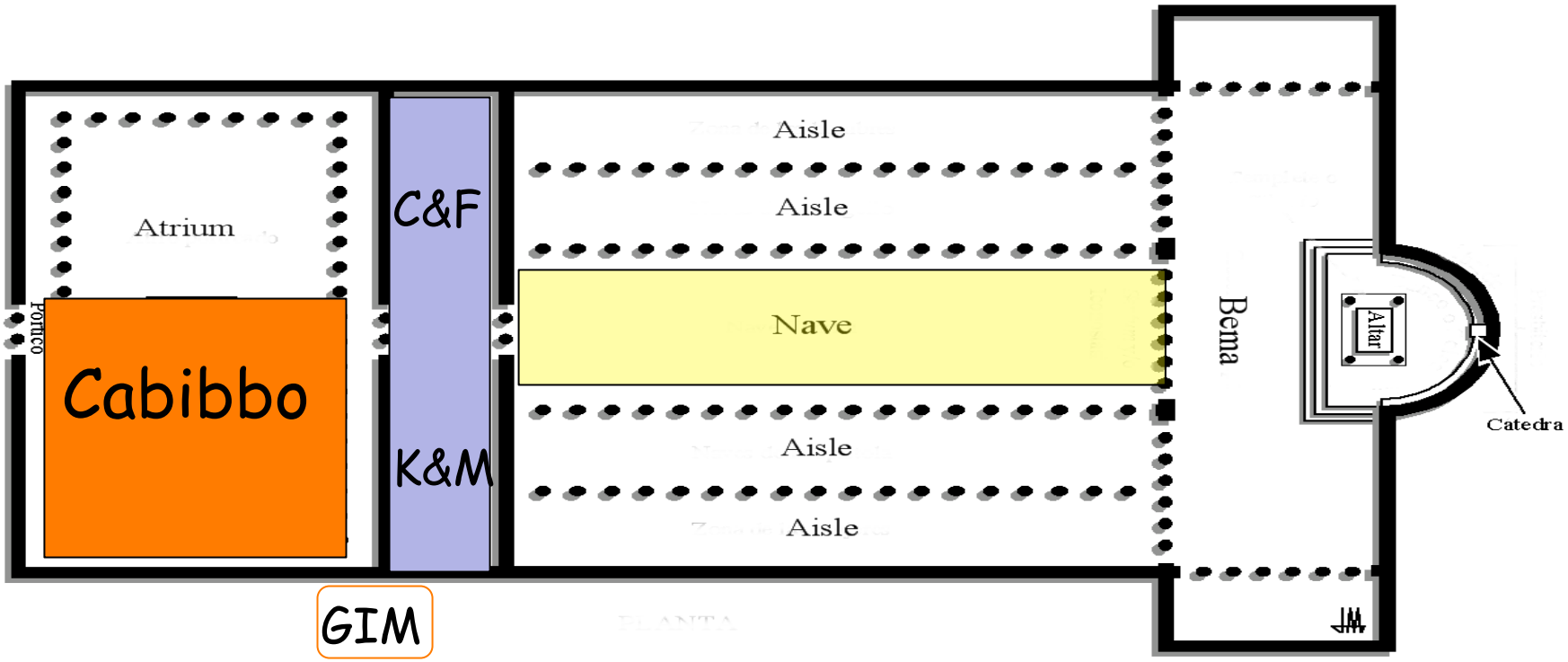

have reached

atrium & vestibule & idea of central nave …, but not more

I (3) Six Triangles of CKM Theory

- $\lambda + \lambda + \lambda^5$

sd triangle: $V^*_{ud}V_{us} + V^*_{cd}V_{cs} + V^*_{td}V_{ts} = \delta_{sd} = 0$

cu triangle: $V^*_{ud}V_{cd} + V^*_{us}V_{cs} + V^*_{ub}V_{cb} = \delta_{cu} = 0$

- $\lambda^2 + \lambda^2 + \lambda^4$

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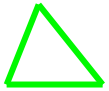
- $\lambda^3 + \lambda^3 + \lambda^3$



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all six triangles have equal area!

I (3) Six Triangles of CKM Theory

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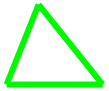

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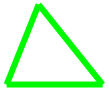

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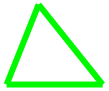

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I(4) Plan of Future Campaigns

- CPV in neutrino oscill. & charged leptons — here not
- EDM leptons and hadrons — discuss it
- Beauty decays
- Charm decays
- Strange decays
- Top quarks productions (& decays)

II. Future Campaigns

II (1) Principles of strategies

- Minimal Flavour Violation (MFV)
  - simple computable scheme,
    no `good' principle behind (yet)
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  - *If* data on $B_s \to J/\psi\,\phi$, $J/\psi\, f_0(980)$, $\phi\phi$ yield CPV less than 4 % -- I eat my hat!

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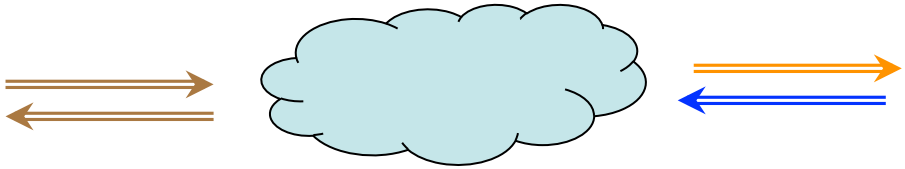
- keep in mind Electric Dipole Moments (= EDM) searches!

Lagrangian $\rightleftharpoons$ $\rightleftharpoons$ Observables

Lagrangian  Observables

theoretical technology !

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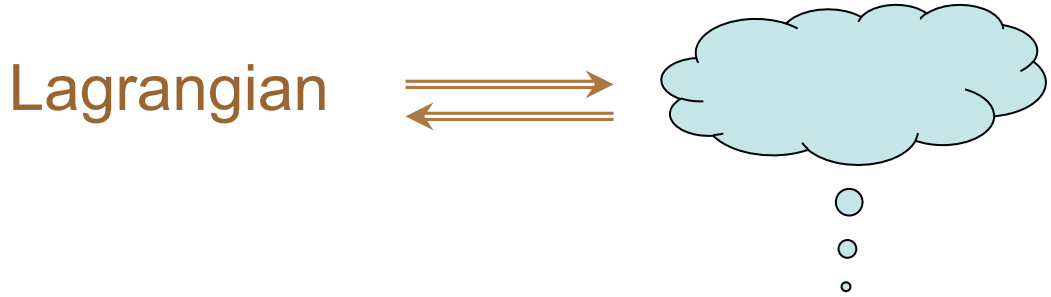

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➢ established CP asym. in K^0 & B_d decays are basically for 2-body final states – except $K_L \to \pi^+\pi^- e^+ e^-$

➢ analyses of 3- & 4-body final states require more start-up work … but once it is done

- ❖ with the theoretical progress on soft QCD
- ❖ they yield more info on the presence of ND &
- ❖ their features!

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single path to heaven - asymmetries in the Dalitz plot

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➫ some theoretical guidance!

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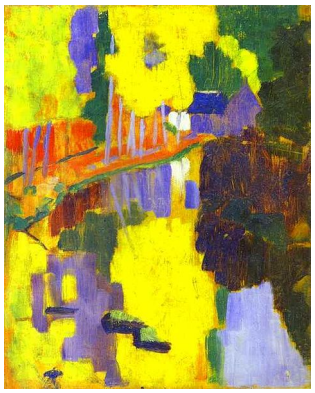
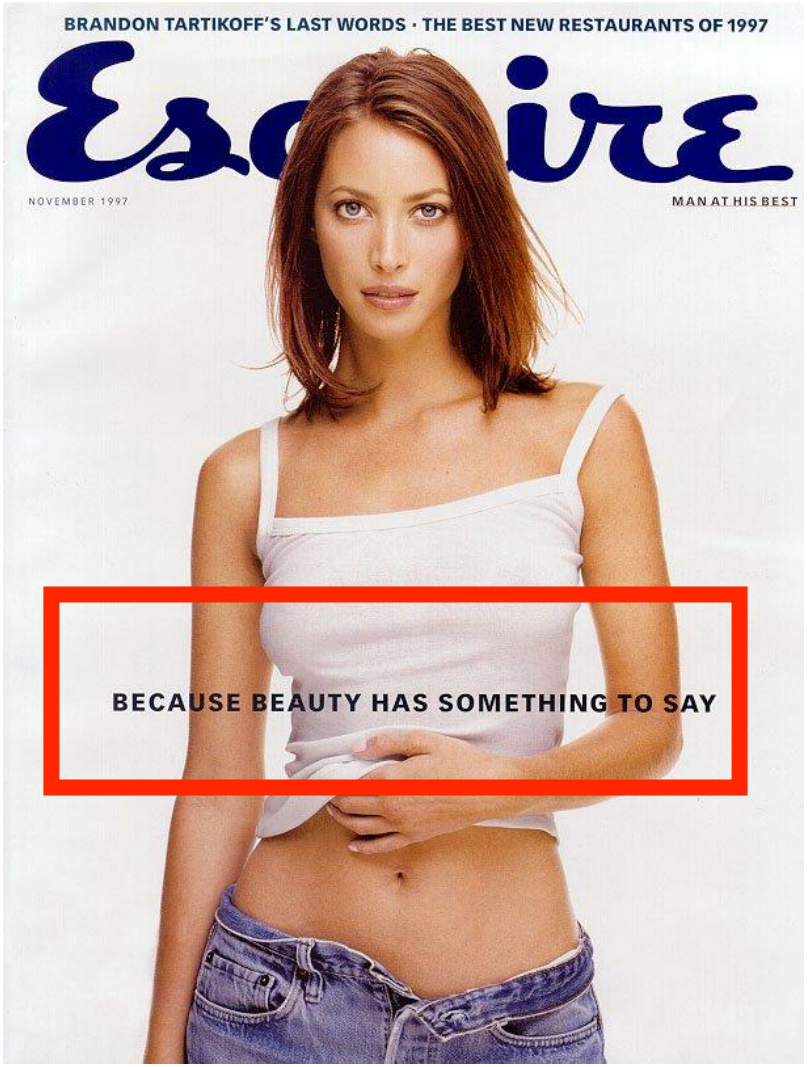


II (2) $B_{(s)}$ Decays



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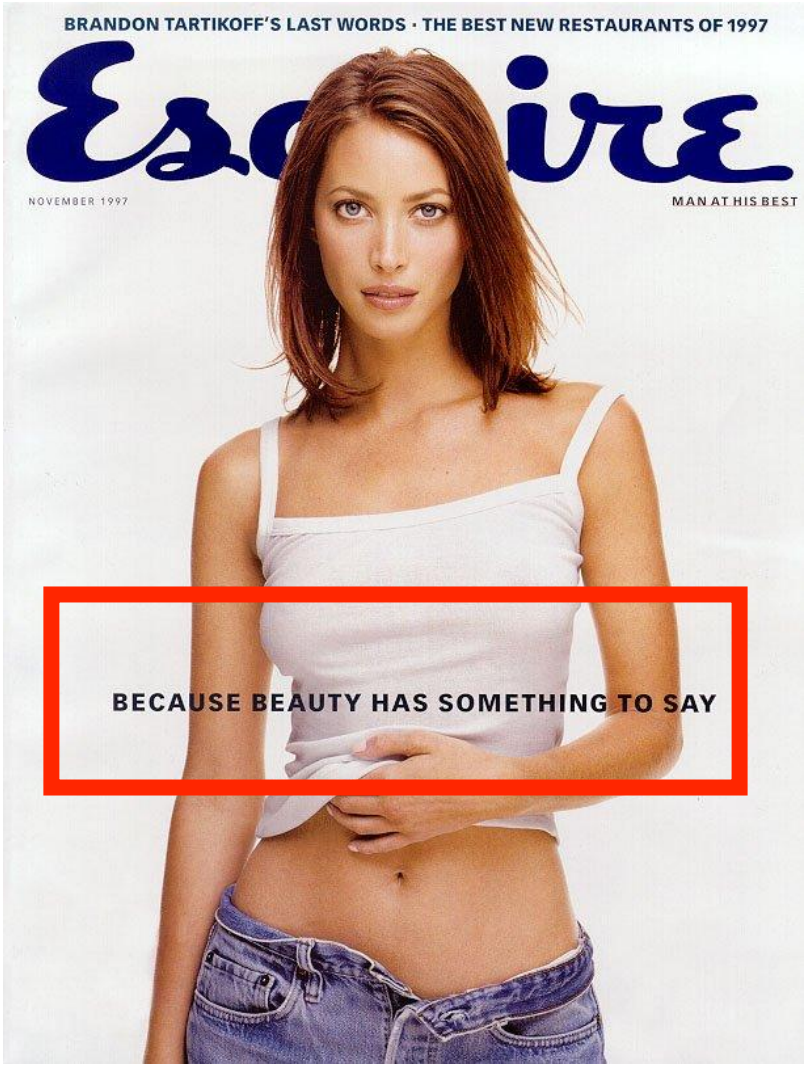

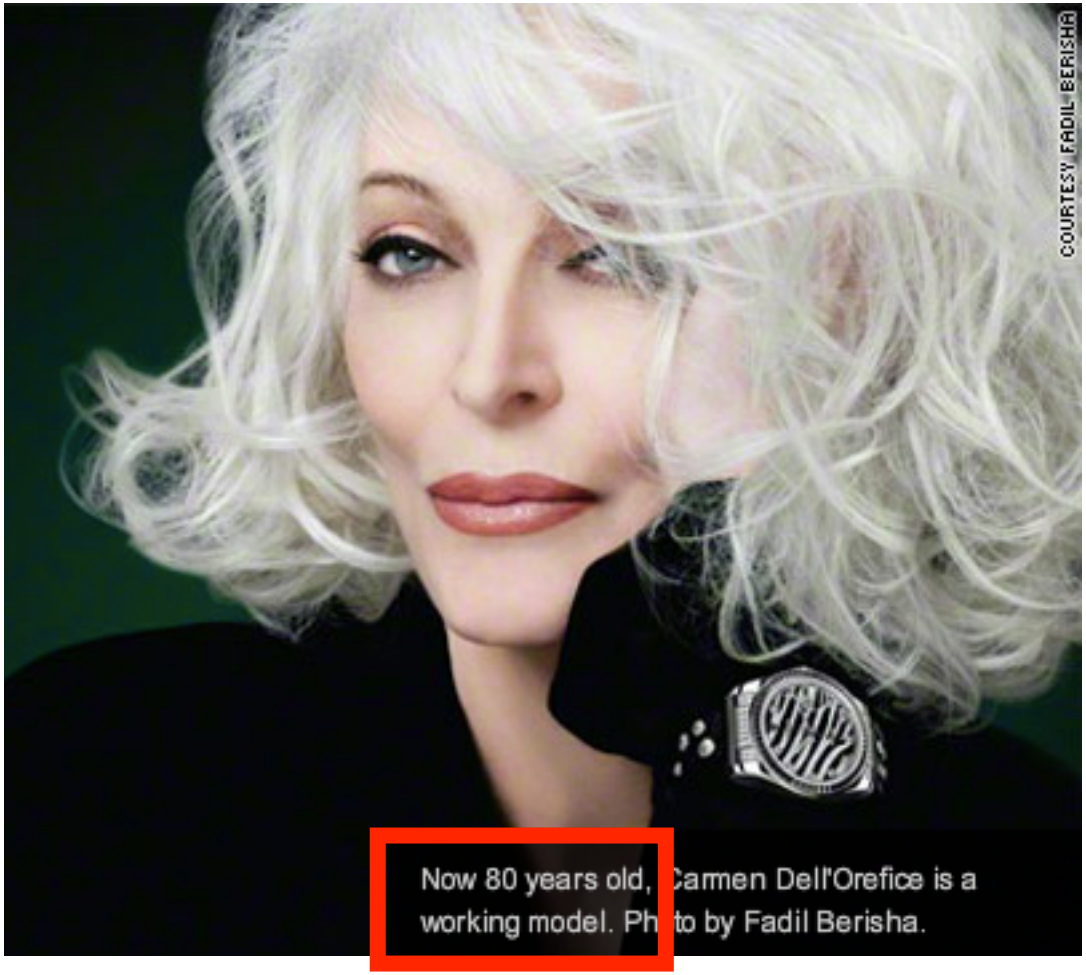

[paraphase of Franz Kafka]

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II (2a) B_s Decays

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- ND – while only secondary source of CPV in other B decays – could be leading source here!
- When the presence of ND has established here, you want to find its features – CPV ~ S x P or V x A etc.

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  - I had not understood D0's claim of 3.2σ above SM prediction for $a_{SL}(B_s)$
  - till June 30:

$a_{SL}(B_s)|_{WA}=(-0.85\pm0.58)\times10^{-2}$ vs. $a_{SL}(B_s)|_{WA}=(0.206\pm0.057)\times10^{-4}$

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- CPV in B_s oscillat. should satisfy Bell & Steinberger…
- while $a_{SL}(B_s)$ is independent of time, $\overline{B}_s \to l^+X$ vs. $B_s \to l^-X$ depend on time evolution given by $\Delta M_s/\Gamma_s$ & $\Delta\Gamma_s/\Gamma_s$

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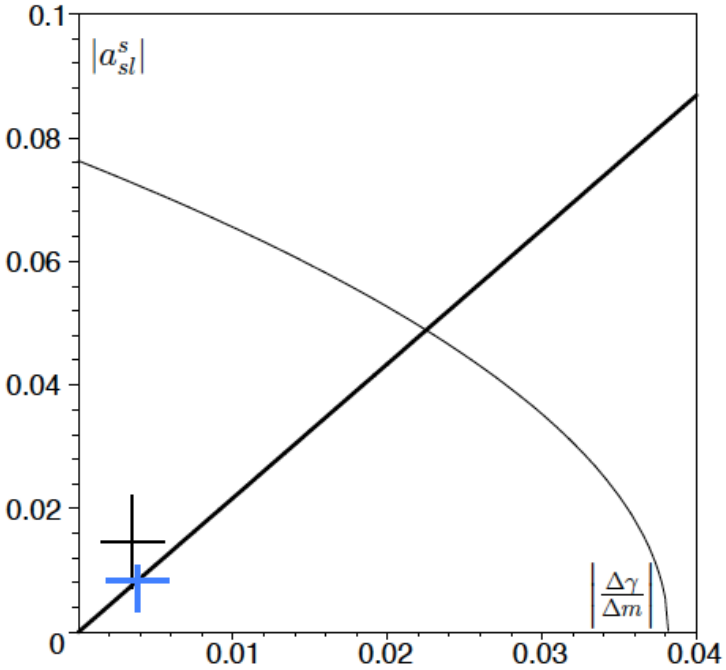

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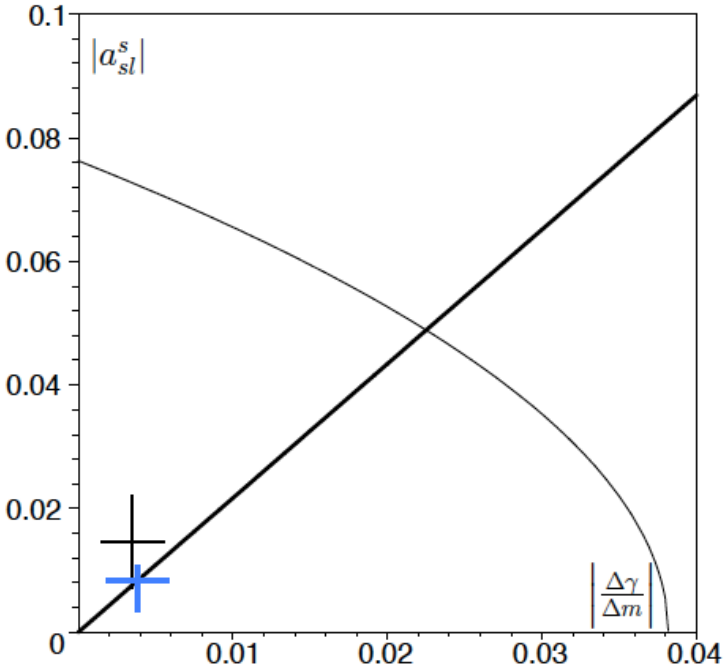

  - I am still surprised even with NP - $|a_{SL}(B_s)|_{ND} < 0.5 \times 10^{-2}$
  - I like to see $\Delta\Gamma$ from D0

II (2b) B Decays

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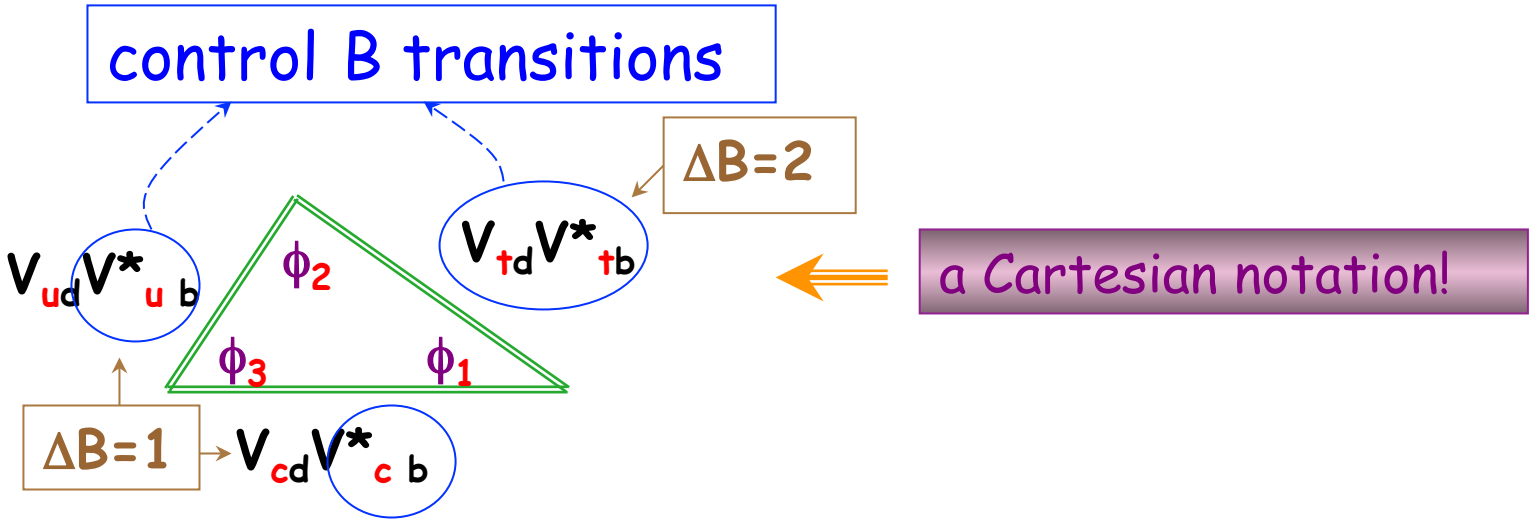

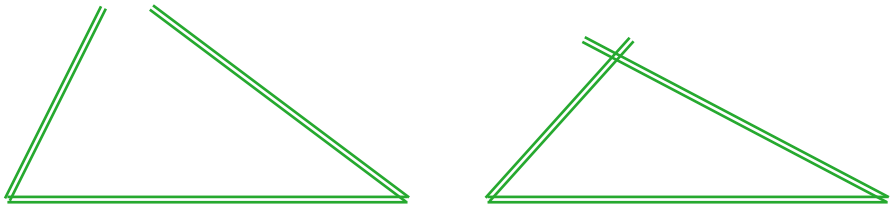

$\varepsilon_K \neq \varepsilon_K$?

II (3) D Decays

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II (3a) Uniqueness of Charm

SM:

- FCNC greatly suppressed
- even more so for *up*-type quarks

NP:

- FCNC might be less suppressed for *up*-type quarks

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D^0 oscillations at an observable rate! ← new situation!

$x_D = (0.59 \pm 0.20)\%$, $y_D = (0.83 \pm 0.13)\%$

- could be due `merely' to SM dynamics --
  - still a great discovery & must know } 'Nobel' goal
  - x_D vs. y_D irrespective of theory } Guy W.
- yet might also contain sizable contributions from NP

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- important validation of (presumably small) time dep. ~~CP~~
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- SM `background' much smaller for FCNC of *Up*-type quarks
  - ➥ cleaner (not larger) signal:

$$\left[\frac{\text{NP signal}}{\text{theor.SM noise}}\right]_{\text{Up-type}} > \left[\frac{\text{NP signal}}{\text{theor.SM noise}}\right]_{\text{Down-type}}$$

Down-type dynamics ≠ Up-type dynamics

Up-type quarks: u c t

Charm only Up-type quark allowing full range of probes for New Physics

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Previously no CP asymmetries seen so far down to the 1% level

☞ indirect asymmetries they are ~ $(x_D$ or $y_D)\ (t/\tau_D)\sin\phi_{weak}$;

- with $x_D, y_D \leq 0.01$ a signal would hardly have been credible

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- yet now it is getting interesting!

➥ $A^{SM}_{CP}(t) < 10^{-4}$ vs. $A^{NP}_{CP}(t) < 10^{-2}$

- recent CDF data have reached:

$A_{\text{indir CP}}(\pi^+\pi^-/K^+K^-) = (-0.01 \pm 0.06 \pm 0.05)\% < 0.14\%$ (95% CL)

- systematic limitations?

more consistency checks for D → 3P, 4P?

The `Dark Horse'

SL: $D^0 \to l^- \nu K^+$ vs. $D^0 \to l^+ \nu K^-$

$a_{SL} \sim \text{Min}[\Delta\Gamma/\Delta M, \Delta M/\Delta\Gamma] \sin\phi_{NP}$, $\Delta\Gamma/\Delta M \sim O(1)$

- $a_{SL} \sim 0.1$ conceivable (even few x 0.1)

i.e. relatively few wrong-sign leptons, yet with a large asymmetry!

The `Dark Horse'

SL: $D^0 \to l^- \nu K^+$ vs. $D^0 \to l^+ \nu K^-$

$a_{SL} \sim \text{Min}[\Delta\Gamma/\Delta M, \Delta M/\Delta\Gamma] \sin\phi_{NP}$, $\Delta\Gamma/\Delta M \sim O(1)$

- $a_{SL} \sim 0.1$ conceivable (even few x 0.1)

i.e. relatively few wrong-sign leptons, yet with a large asymmetry!

vs.

- $a_{SL}(K_L) = 3.3 \times 10^{-3}$ with $\Delta\Gamma/\Delta M \sim O(1)$ & $\sin\phi_{CKM,eff} << 1$
- $a_{SL}(B_d) \sim 4 \times 10^{-4}$ with $\Delta\Gamma/\Delta M \sim O(\text{few} \times 10^{-3})$
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$a_{SL}(D^0)$ probably cannot be measured by LHCb, yet

$|p/q| \sim |1 - a_{SL}/2|$ affects NL ~~CP~~ observables

II (4) K Decays

- sd triangle: $V^*_{ud}V_{us} + V^*_{cd}V_{cs} + V^*_{td}V_{ts} = \delta_{sd} = 0$ K

$$\lambda + \lambda + \lambda^5$$

$BR(K_L \to \pi^0\nu\nu)|_{CKM} = (8.4 \pm 1.0) \times 10^{-11}$ vs.

$BR(K^+ \to \pi^+\nu\nu)|_{CKM} = (2.7 \pm 0.4) \times 10^{-11}$

- $Pol_\perp(\mu)$ in $K^+ \to \mu^+\nu\pi^0$ $Pol_\perp = (-1.7 \pm 2.5) \times 10^{-3}$

interference of $W^\pm$ - $H^\pm$ exchange

II (5) Top Quark Dynamics

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- top (with $m_t \sim 175$ GeV) can open window to ND

- top productions with CPV!

- $p\bar{p} \to t\bar{t}\,X$
  - CDF found FB_t larger than predicted by SM; while data show $FB_t \sim -FB_{\bar{t}}$, they do not have sensitivity for realistic models of CPV
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  - `future': $pp \to t_L\bar{t}_L X$ vs. $pp \to t_R\bar{t}_R X$

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- Measuring FB & Charge asymmetries can show the presence of ND …, but CPV can tell us more features!

III. Rosetta Stone for Understanding Flavour Dynamics

Kandinsky as a seer in paintings from 1920's

"Composition VIII" 1923
triangles of different shapes

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Kandinsky did not understand that triangles have same area – after all he is *not* a theorist!

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are they triangles, quadrangle, ???

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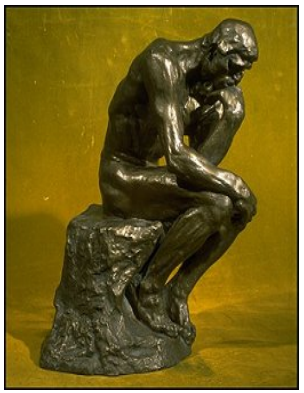
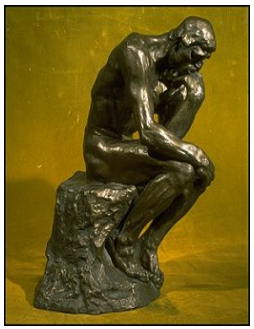
Theorists – inspired by an artist?



"thinkers"

Ikaros Bigi: "The Achaeans outside Troy"



"thinkers"

Schlaeft ein Lied in allen Dingen,
Die da traeumen fort und fort,
Und die Welt hebt an zu singen,
Findst Du nur das Zauberwort.

There sleeps a song in all things
That dream on and on,
And the world will start to sing,
If only you find the magic word.

J. v. Eichendorff

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(a la Randall-Sundrum model)

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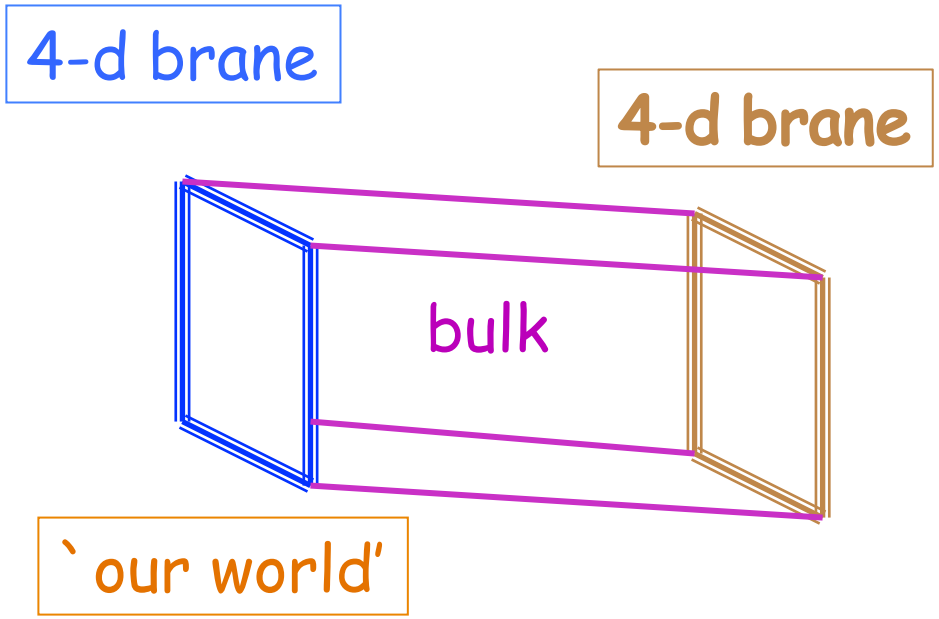

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    - they often followed `herd instinct' …
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➢ a second (& ...) source of CP dynamics is `typically' down an order of magnitude (or more).

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Remember – water is where the action is!

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